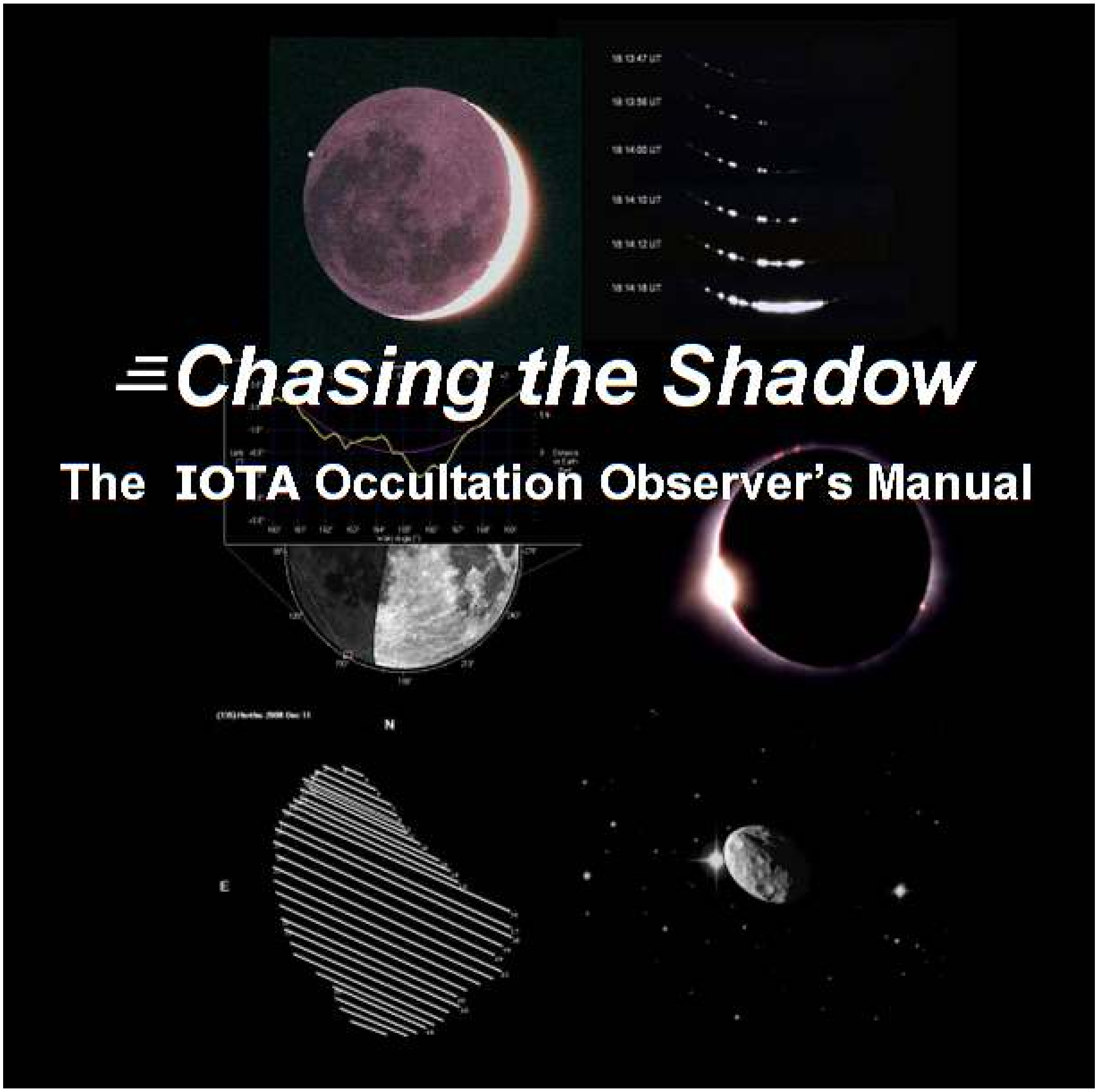

Chasing the Shadow

The IOTA Occultation Observer's Manual

The Complete Guide to Observing Lunar, Grazing and Asteroid Occultations

Published by the International Occultation Timing Association

Richard Nugent, Editor

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The IOTA Occultation Observer's Manual is available to download from:
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Downloading of this publication and making a hardcopy for one's self is encouraged to promote the observation of occultation phenomenon.

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Cover Images:

Total occultation of star about to occur by crescent Moon's dark side near position angle 65°	Baily's Beads during total Solar Eclipse of February 26, 1998. Mosaic of 6 video frames covering a 33 second time interval
Lunar limb profile – Watts angle 164°	Diamond ring effect during total Solar Eclipse
Asteroid profile of 135 Hertha from occultation Dec 11, 2008. Scotty Degenhardt obtained 14 of the 23 chords with his remote video stations	Asteroid about to pass in front of a star

Preface

An occultation (pronounced "Occ-kull-tay-shun") occurs when the Moon, asteroid or other planetary body eclipses a star momentarily blocking its light. Occultation observations have been used for hundreds of years by sailors to determine time and their position at sea. Modern occultation observations are routinely used to refine the orbit of the Moon, analyze the positions of stars and the coordinate system they represent, detect new stellar companions, pinpoint the position of X-ray and radio sources, determine the size and shape of lunar mountains, determine stellar diameters, and the recent hot area of determining the size and shape of asteroids in our solar system. In 1985, Pluto's atmosphere was discovered by the occultation technique. In March 1977, the occultation of a bright star by the planet Uranus resulted in the discovery of its ring system. This ring system might actually have been seen indirectly by the discoverer of Uranus, William Herschel, as he noticed faint stars dim as the planet passed close by.

Occultation observations are fun to observe. There is perhaps nothing more exciting than watching a star vanish and return from behind a lunar mountain, or to see the star disappear for several seconds as an asteroid passes in front of it. Anyone with a small telescope, tape recorder or camcorder and shortwave radio can make valuable scientific observations to help determine the size and shape of asteroids and to aid in new discoveries about these mysterious objects, including some of the elusive small moons that orbit them.

This observer's manual is the first comprehensive book of its kind to assist beginning observers get started in occultation observations. This manual also shows advanced observers the latest in video and GPS time insertion techniques. It is a *How To* guide in observing total and grazing occultations of the moon, asteroid occultations and solar eclipses. Whether you are an observer with a small telescope or an experienced observer with a video system, this book will show you how to set up your equipment, predict, observe, record, report and analyze occultation observations whether you are at a fixed site or have mobile capabilities.

The International Occultation Timing Association (IOTA) and its worldwide sister organizations (Europe, United Kingdom, Australia/New Zealand, Japan, S. Asia/India, Mexico, Latin America, South Africa) are here to assist you. We have online Internet discussion groups and observers are in contact with each other nearly every day planning for the next occultation expedition or sharing ideas on new equipment, software and new techniques. IOTA and several of its members have web pages loaded with occultation information and methods, tips, software, predictions and results of observations. The Internet has simplified occultation observations with predictions and results now online. Equipment advances (especially video) along with accurate star and asteroid positions have resulted in an explosion of occultation observations in the past ten years. Whereas between 1978 and 1998 less than 20 successful asteroid occultationswere observed each year, now there are over 150-200 successful asteroid events observed worldwide annually by numerous teams of observers.

The novice occultation observer will find the basics of occultations including how to observe and to record them accurately using simple, inexpensive equipment. Advanced observers will find video methods of recording occultations. This includes the use of the GPS satellites along with video time inserters that can allow frame by frame analysis of observations providing timings accurate to a few hundredths of a second !

The latest method for obtaining multiple chords on asteroid events comes from remote unattended video stations. See Chapter 10, and Scotty Degenhardt's 14 remote video stations used to determine the size and shape of the asteroid 135 Hertha on page 139.

The potential for new discoveries continues with every new occultation observation. Astronomers, both professional and amateur, are encouraged to get involved in this exciting field and on several online occultation discussion groups to see what events are to occur in their area. Information on how to get involved with IOTA and contact information is given in Appendix A, along with the many IOTA organizations worldwide.

Please join us.

Richard Nugent
Editor, IOTA Occultation Observer's Manual
Executive Secretary
International Occultation Timing Association

Acknowledgments

A project on occultations such as this is the product of decades of effort and work by the hundreds of worldwide occultation observers, expedition leaders, software originators, and many others. Without the dedicated efforts of these individuals, the modern occultation program would simply not exist. Dr. David Dunham is the founder and only President of IOTA/USA, leading the way in the occultation program in North America for over 46 years. Many pioneers have carved out the methods and techniques of occultation observing including: Hal Povenmire, Paul Maley, Dr. Wayne Warren Jr., Robert Sandy, Richard Wilds, Tom Campbell, Dr. Tom van Flandern, Steve Preston, Walter Morgan, Walt Robinson, Don Stockbauer (USA), Dr. David Herald (Australia) Edwin Goffin, Jean Meeus, Hans Bode, Eberherd Riedel (Europe), Gordon Taylor (UK), Dr. Mitsuru Soma, Dr. Isao Sato (Japan) and numerous others.

Special thanks are due to the contributors Dr. David Dunham, Dr. Joan Dunham, Paul Maley, Guy Nason, Walt "Rob" Robinson, Arvind Paranjype, Dr. Roger Venable, Dr. Wayne Warren, Jr., James W. Young and Trudy E. Bell who submitted material in their field of expertise included in the chapters in this book. Thanks is due to all of these individuals and the thousands of observers who for the past 50 years have traveled worldwide and braved the elements with numerous equipment and other hardships to make solar eclipse and occultation observations. Lydia Lousteaux, assistant editor, proofread the entire book and made numerous suggestions and changes including the rewriting of whole paragraphs. As Editor in Chief and contributing author of the *IOTA Occultation Observer's Manual*, I take full responsibility for the layout, content and accuracy of the information presented. Nevertheless, in a project of this size some errors may have gone undetected. Please direct any errors or corrections to me at RNugent@wt.net. Good luck in your occultation observing!

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1 Introduction to Occultations

In astronomy, an occultation occurs when the Moon, asteroid or other planetary body eclipses a star temporarily blocking its light. The celestial object passing in front of the more distant one is referred to as the *occulting body*. For practical purposes, an occultation is a celestial event in which a larger body covers up a distant object. Compare this to an eclipse, where the bodies are generally nearly equal in angular diameter, and a transit, where a much smaller body passes in front of a large object, such as transits of the Sun by Mercury and Venus. During an occultation the occulting body blocks the light of the more distant celestial object. As an example, when an airplane flies directly between an observer on the Earth's surface and the Sun, its shadow passes right over the observer blocking the Sun's light momentarily. The airplane has *occulted* the Sun. Now move the observer just 100 meters away, and the airplane's shadow would miss the observer entirely. If the observer had arrived 30 seconds later to that position he or she would not see the occultation of the Sun by the airplane, and have a miss at that location due to being late.

Occultations are both time and position dependant. The occultation observer must be at the right place at the right time to be in the occulting body's shadow. The most common occultation events are *total occultations* by the Moon in which the Moon passes in front of a star, an asteroid, planet or other object (see Figure 1.1).

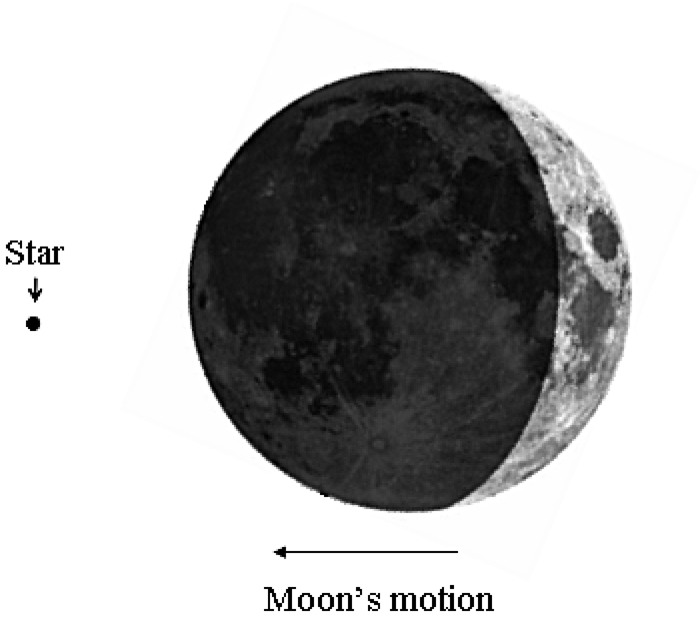

Figure 1.1 Total occultation geometry of a star by the Moon as seen from Earth.

A *grazing occultation* occurs when the Moon's edge appear to just barely glide by the star on a tangent as it moves in its orbit around Earth, (see Figure 1.2). As the Moon drifts by the tangent line, the star momentarily disappears and reappears from behind lunar mountain peaks and valleys on the Moon's limb (edge). The *graze line*, also known as the limit line (See Figure 5.1, Chapter 5), is a line on the Earth that projects the limb of the Moon from the direction of the star. Grazing occultation observations, when made by a team of observers perpendicular to the graze line, are scientifically useful to help determine the shape of the Moon's limb. Grazing occultations and their use are described in Chapter 5.

Asteroid occultations occur when an asteroid passes directly in front of a star causing the star to disappear for some interval of time usually from several seconds to one minute or more. An instantaneous drop in the light level of the star of the merged object (star + asteroid) can be observed. This fading is caused by the asteroid's own light replacing the light of the brighter star. If the asteroid is too faint to be seen then the star vanishes completely for the duration of time that the asteroid is in front of it. Asteroid occultation events provide a unique opportunity for ground based observers to directly determine the sizes and shapes of these mysterious objects. Asteroid events are described in detail in Chapter 6.

Occultations have been used since the invention of the telescope to determine the lunar position, time and the observer's position at sea. They have recently been used to measure stellar diameters, to discover unseen stellar companions and to measure the diameter of the Sun.

Many people who make occultation observations have mobile capabilities, since occultation events are location dependent. However, for any particular location on Earth there are quite a few occultation events that occur each year; thus any permanent observatory can be outfitted with relatively inexpensive equipment to collect potentially valuable data. An observer's geographic position and ability to time an occultation event accurately can be more important than the equipment used.

The purpose of the *IOTA Occultation Observer's Manual* is to educate observers on the techniques of occultations and equipment, and to provide advanced techniques for the more experienced observer. Toward this purpose, Section 1.2 contains a brief history of the International Occultation Timing Association, (IOTA), its goals and objectives, plus discovery opportunities from occultation observations, Chapter 2 discusses observing occultation fundamentals and equipment, Chapter 3 covers total occultation observations, Chapter 4 covers predictions of occultations plus solar and lunar eclipses. Chapter 5 covers lunar grazing occultations by the Moon; Chapter 6 covers asteroid occultations; Chapter 7 covers determining your ground position accurately; Chapter 8 discusses occultation timing techniques; Chapter 9 covers weather considerations including how to prepare yourself and your equipment for weather extremes; Chapter 10 covers advanced observing techniques and remote video stations; Chapter 11 covers solar eclipses and the solar diameter and Chapter 12 covers the modern history of occultation observations. The appendices contain web resources, information on how to contact IOTA, an extensive list of references, report forms, example graze profiles, short wave time signal frequencies around the world, a glossary, equipment suppliers and useful tips.

1.1 Scientific Uses of Occultations

The news media frequently carries articles about discoveries made with advanced equipment found at major observatories and space probes. In this day of enormous radio telescopes, Space Shuttle missions, the Hubble Space Telescope, the Chandra X-Ray telescope, the Space Infrared Telescope Facility (now known as the Lyman Spizter Observatory) and planetary space probe missions, is a visual or video occultation timing with WWV time signals, and a small telescope of scientific value? *The answer is a resounding YES*. Occultation timings are one area where interested amateurs can and do make valuable contributions.

The geometry of an occultation is the major reason why valuable observations can be made with simple equipment. The location (geodetic coordinates) of an amateur telescope can be determined to the same accuracy as that of a professional observatory. This is quite easy with low cost GPS receivers, internet and computer programs or United States Geological Survey (USGS) topographic maps with methods presented in Chapter 7. Referring to Figure 1.2, consider two observers **A** and **B** at nearby sites close to the northern limit of a lunar occultation. Observer **B** is placed such that the star just misses the Moon from his observing station, and the other observer **A** sees just one short event. Observer **B** who experiences the miss, although he may not realize it, has actually made a valuable observation. Most observers who have a miss are disappointed, however the results from the two stations **A** and **B** pin down the location of the Moon's edge to within their ground separation. Note that only the observer experiencing a miss who is closest to an observer who sees events has a valuable observation. If many observers along a line see a miss, all but one of them has good reason to be unhappy. In this example, the location of the observer who saw the miss is far more important than the equipment used to make the observation.

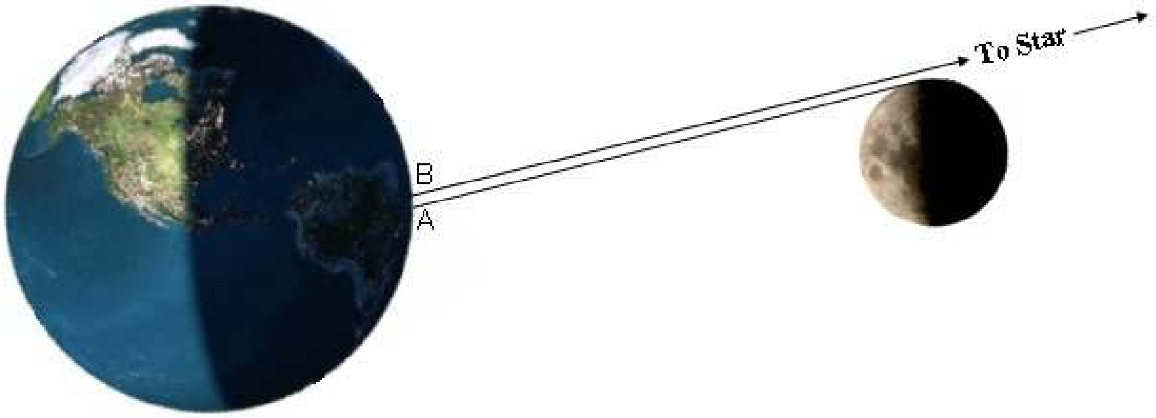

Figure 1.2. The observer at **A** sees the star just graze the Moon passing in and out of lunar mountain peaks. Observer at **B**, 100 meters north of **A**, has no occultation. This observer **B** has a miss. Diagram not to scale. Earth image © 2006 The Living Earth/Earth Imaging.

Occultation timings are used to refine our knowledge of the Moon's motion and shape. Predicting the motion of the Moon from past observations has always been one of the toughest problems celestial mechanics has had to face. Many famous names in astronomy have been associated with predicting the Moon's motion. The most recent attempts before the contemporary studies were those of Dirk Brouwer and Chester Watts in the 1930's and 40's. Since that time new information has become available – ephemeris time, atomic time, Watts charts, new International Astronomical Union (IAU) astronomical constants, and ephemeris corrections by Dr. W. J. Eckert, to name a few. Improvements in our knowledge about the Moon's motion had an influence on many other branches of astronomy as well. Occultation observations and an improved lunar ephemeris have been used to determine the location of the celestial equator and the zero-point of right ascension (equinox). These are important corrections to the coordinate system used for stellar reference. Lunar occultation data were given the highest weight for the determination of the FK4, FK5 and FK6 (Fundamental Catalogues) stellar reference frame. The analysis of occultation data gathered over a period of many years has allowed astronomers to refine our knowledge of the motion of the Earth, the precession of the north pole and the secular motion of the obliquity of the ecliptic (tilt of the Earth's axis to the equator). Since 1969, lunar orbital parameters have been accurately determined from laser ranging to the retro-reflector arrays placed on the Moon by Apollo astronauts and a Soviet spacecraft. Occultation and solar eclipse observations made before 1969 are used to study the long term motion of the Moon. The longer baseline of these observations still gives occultation data an advantage for measuring the Moon's secular deceleration in ecliptic longitude. This deceleration is caused by an exchange of angular momentum between the rotation of the Earth and the lunar orbit via oceanic tides amounting to 23" (23 seconds of arc) per century^2. Recent studies indicate that the tidal deceleration should be about 28" per century^2. The difference, an acceleration of 5" per century squared, may be caused by a changing gravitational constant, according to some cosmological theories. Other studies indicate that the difference is smaller and possibly negligible.

Occultation data can accurately relate the lunar motion to the stellar reference frame, and the data have proven extremely useful for refining the latter. Lunar occultations have been analyzed to derive average stellar proper motions, and from these the Oort parameters (Oort's Constants) of galactic rotation have been determined.

The analysis of occultation observations for astrometric purposes (determination of orbital and stellar positional parameters) is limited by our knowledge of the lunar limb profile as seen from the Earth. The profile changes with our different viewing angles of the Moon, called librations, as the Moon moves in its not quite circular orbit inclined to the ecliptic plane. Nearly all possible profiles were charted in an ambitious program to carefully measure hundreds of Earth-based lunar photographs led by Chester B. Watts at the U. S. Naval Observatory (USNO) a half century ago. This resulted in a series of 1800 charts representing the lunar limb profiles known as the Watts charts. The accuracy of an individual limb correction looked up in Watts charts is about 0.2". Since it takes about half a second for the Moon to move this distance, timings of occultations made visually to a precision of 0.2 sec are still quite useful. Although the Clementine and Lunar Orbiters obtained high-resolution photographs of most of the lunar surface, they did not have the positional accuracy and Earth-based perspective needed to derive limb profiles that would have been an improvement over the Watts data. And due to the Moon's very irregular gravity field, which is caused by mascons (mass concentrations), and because the orbiters could not be tracked on the Moon’s far side, their positions at any time could be recovered only to an accuracy of about 700 meters.

Updated lunar limb profiles have been derived from occultation timings which are being carried out by observers all over the world. These improvements are needed for better analysis of occultation data for the astrometric purposes described above. Better profile data obtained when the Moon is within a degree of the ecliptic also allows accurate analysis of total and annular solar eclipse timings, which are in turn used to determine small variations of the Sun's diameter. Grazing occultations by the Moon give the most accurate resolution of the profile. They are very important for solar eclipse studies because the lunar profile is similar in the lunar polar regions at each eclipse, but always different in the lunar equatorial areas. (See Chapter 11, Section 11.3 for more on IOTA’s Solar eclipse research).

Occultation observations have also resulted in the discovery of hundreds of double stars. During a total occultation by the Moon, if a star gradually disappears, as opposed to an instantaneous disappearance, this is evidence of a very close binary star. The gradual disappearance is due to one of the stars of the system vanishing behind the Moon followed by the other.

For resolving double stars, occultations fill the observational gap between direct visual and spectroscopic observations.* Visual observers can take advantage of the circular geometry during a grazing occultation to resolve separations as small as 0.02". Compare this to the 0.8" telescopic naked eye limit (this figure depends on wavelength, telescope objective diameter) separation of a close visual double star under the best seeing conditions. Some spectroscopic binaries have been resolved during occultations, and many new doubles, even bright ones, have been discovered. During grazes of bright stars, visual observers should be able to distinguish between light diffraction effects and multiple star step events. Diffraction effects cause gradual disappearances and reappearances while double and multiple stars produce step events. Video and high speed photometric recordings of total occultations give better resolution to 0.02" allowing the angular diameters of some of the larger stars to be measured.

Scientifically useful information may be gathered from occultation observations made with relatively simple equipment by amateur astronomers. When the apparent diameter of an occulting body is smaller than the body occulted, the term *transit* is used. Examples include *shadow transits* (regular transits occur, they are harder to observe) of the Galilean satellites of Jupiter when their shadows land on the cloud tops of the planet, and transits of Mercury and the rare transits of Venus across the Sun. (The most recent Venus transit occurred on June 8, 2004, the first since 1882; the next one is June 6, 2012). Transits are now becoming an

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*Speckle interferometry is now used to measure binary systems having separations in the range only previously detectable during occultations, but occultation observations are still necessary to discover new close pairs, since speckle interferometry can only be carried out for a limited number of stars.

important part of extrasolar planet research. Photometric (brightness change) observations of an extrasolar planet as it transits across its parent star provides information on the planet's actual size, orbital parameters and the parent star's mass.

The main purpose for observing occultations by asteroids, comets and other solar system bodies is to obtain an accurate size and shape of the occulting body. The sizes and shapes of asteroids and comets have proved to be very small. The asteroid 1 Ceres, for example has an angular extent of just 0.8", while most of the other asteroids are 0.1" and smaller. The Hubble Space Telescope has a spatial resolution of 0.0455"/pixel with its Wide Field and Planetary Camera thus making only a few dozen asteroid sizes measurable. The technique of infrared bolometry on the Infrared Astronomical Satellite (IRAS) gave mean diameters of hundreds of asteroids however the errors exceeded 10% or more. There have been several close encounters of asteroids and comets by spacecraft, namely Halley's Comet by Giotto, 951 Gaspra and 243 Ida by the Galileo spacecraft in route to Jupiter, 253 Mathilde and 433 Eros by the Near Earth Asteroid Rendezvous (NEAR) mission. With more than 300,000 known asteroids and comets (and the list growing by several thousand each month), spacecraft are far too expensive to make journeys to more than just a few of these objects feasible.

An asteroid occultation provides more than just an accurate size and shape of the asteroid. An astrometric position of the asteroid can be extracted from the occultation of well observed events. Currently, positional accuracy derived from well observed asteroid events are in the range of 100-200 µsec (±0.0002"). With 3-5 observations, a position accurate to ±0.003" can be derived. For single chord observations, the error is set at the apparent diameter of the asteroid. It is interesting to note at this precision, relativistic bending of light by the Sun is quite significant at a 90 degree solar elongation. Single chord observations have the highest inherent uncertainty with no corroborative observations. But a great majority of single chord events are reported and virtually all multi-chord events are reported. The Minor Planet Center (MPC) has allocated observatory code 244 for positions derived from asteroid occultations.

Occultations have more applications than determining the Moon's motion, lunar limb profiles, asteroid profiles, astrometric and galactic parameters. Occultations of stars by Saturn's largest moon Titan have yielded critical information on some of the properties of Titan's atmosphere. This information was put to use as the Huygens probe from the Cassini mission to Saturn (launched in 1997) descended to Titan's surface in January 2005. In March, 1977, an occultation of a bright star by the planet Uranus led to the discovery of its system of rings. Before and after the occultation of Uranus a series of short disappearances occurred. Almost immediately these disappearances were determined to be a set of rings, and their characteristics and distances from Uranus were easily deduced from the occultation observations. The great English astronomer, William Hershel, who discovered the planet Uranus, reported that some faint stars faded as Uranus moved right by them. This was perhaps the first visual observation (although not known at the time) of the effect of the Uranus ring system occulting these stars.

Occultations by the Moon have been used to pinpoint the location of extragalactic radio sources. Unlike the light from a star which is a pinpoint on the celestial sphere, radio waves cover a larger area of the sky, thus making it difficult to identify optical counterparts precisely. An occultation by the Moon cuts off the radio waves, allowing astronomers to match the optical counterpart.

Another great discovery from the occultation technique was the detection of an atmosphere of Pluto in June 1985 and confirmed in 1988. From analysis of this occultation event and other data, the main component of Pluto's atmosphere was determined to be methane (CH_4) with an estimated surface pressure of 10 millibars. Compare this to the pressure on Earth's surface of 1,000 millibars.

Hopefully, the above discussion has convinced potential observers that occultations are not only exciting, enjoyable and striking to observe, but that when timed and reduced carefully can provide much valuable scientific information. For observers who are interested in gathering this valuable data the remainder of this manual provides the information necessary to successfully predict when occultations will occur and will prepare you to observe occultation events, extract their timings and also includes information on how to send the data to IOTA astronomers for final reduction or to reduce and analyze them yourself.

1.2 The International Occultation Timing Association, IOTA

The International Occultation Timing Association, (IOTA) is the primary organization for occultation predictions, the reducing of data acquired and the publication of results. IOTA members are engaged in a wide variety of activities related to observing, data collection, computing, instrumentation, etc. Members of the organization provide different services, such as computing predictions for regional and independent observers, coordinating local expeditions, predicting asteroid occultations, collecting graze reports, maintaining lists of double stars that have been occulted, etc. Grazing occultation expedition leaders collect data on grazes and submit observer's reports to regional coordinators. The primary source for information about IOTA and upcoming occultations is the official IOTA website: http://www.lunar-occultations.com/iota/iotandx.htm.

IOTA is based in the USA and its sister organization, IOTA/ES is the European Section carrying occultation research in Europe. Another major occultation center is the Royal Astronomical Society of New Zealand (RASNZ), Occultation Section. The RASNZ promotes and encourages occultation observing in New Zealand, Australia and the South Pacific. A new IOTA region, the Southwest Asian Section (IOTA/SWAsia) was formed at the time of this publication in India headed by Arvind Paranjype as President. Occultation observers are scattered all over the world and with the widely available access to the Internet, assistance in predictions, observing, timing and instrumentation techniques are just a few clicks away.

IOTA was unofficially started in 1962 by David Dunham, when he made the first prediction of a grazing occultation of 5 Tau that was successfully observed by another observer (Leonard

Kalish) near Castaic Junction, California. IOTA was officially organized in 1975 (intentionally delayed by Dr. David Dunham due to the paperwork and other requirements) and incorporated as a non-profit 501(c) corporation in 1983 by IOTA Vice President Paul Maley in Texas. IOTA's non profit status allows its members in certain situations to deduct their IOTA travel related expenses since occultation work sometimes involves extensive travel. Since that time IOTA has recruited observers from around the world and has begun publishing the *Occultation Newsletter,* the official publication of IOTA. *Occultation Newsletter,* which began publishing in July 1974*,* contains results of occultation and eclipse observations, observing techniques and research articles on all aspects of occultations. *Occultation Newsletter* articles are indexed on the internet on the Astrophysics Data System (ADS) website along with all the major professional astronomy journals such as the *Astronomical Journal* (AJ), *Astrophysical Journal* (ApJ) and *Publications of the Astronomical Society of the Pacific* (PASP). *Occultation Newsletter* is published four times per year and is available by subscription from IOTA, see Appendix A for details.

IOTA also maintains a website in North America for announcing major occultation events of stars by the Moon, asteroid events and other articles of general interest located at http://www.lunar-occultations.com/iota/iotandx.htm. IOTA/ES is linked from the North American site; its web address is http://www.iota-es.de/.

The Royal Astronomical Society of New Zealand's Occultation Section maintains a web site here: http://occsec.wellington.net.nz/.

The Dutch Occultation Association is located here: http://www.doa-site.nl/

These and other important IOTA web addresses are also found in Appendix K. Many other excellent personal occultation web sites are maintained by IOTA members and these can also be found in Appendix K, *Useful Web addresses*.

1.3 The International Lunar Occultation Centre (ILOC) 1923-2009

The International Lunar Occultation Centre (ILOC) up until September 2008 was the worldwide clearing house organization located in Tokyo, Japan and collected and maintained data from lunar occultation observations from all over the world. The ILOC officially ceased operations in March 2009 due to funding cuts. Each year the ILOC received thousands of occultation reports. The ILOC also issued predictions for use in making occultation observations and provides other data for a variety of researchers and research institutions.

The International Lunar Occultation Center was founded by the International Astronomical Union in the United States in 1923 as an organization dedicated to collecting and maintaining occultation observational data from all over the world. ILOC was later entrusted to the Royal Greenwich Observatory before being moved again in 1981 to the Japanese Hydrographical Office, which by then had established itself as a leader in performing occultation observations. In 1992, the work of providing predictions of lunar occultations was taken over from the US Naval Observatory by the same organization.

The work of observing occultations is performed with the assistance of more than 1,000 observers working worldwide in the United States, Europe, Australia and more than thirty other nations. The regional coordinators that now collect lunar occultation observations are listed in Appendix F, *Report Forms and How to Report Observations*.

1.4 Occultation Firsts

Some 'firsts' in the field of occultation observing including IOTA members are:

The first reported observation of an asteroid occultation was made on February 19, 1958 by P. Bjorklund and S. Muller, in Malmo, Sweden of Copenhagen, Denmark. They timed a 7.2 second occultation of an 8.2 mag star in the constellation Orion by the asteroid 3 Juno.

The first 'true' grazing occultation was observed by D Koch in Danzig (now Gdansk, Poland). It was a northern-limit graze of Aldebaran, observed on 1794 Mar 7, at around 19h 24m UT. Koch observed 5 events. A disappearance “D” a reappearance “R” 10 secs later, D after another 4 or 5 secs, then a rapid R and D sequence. Koch then watched for about 30 secs before taking his eye away from the scope to write down what he saw. When he looked back, the star had reappeared. Koch clearly understood that the events were caused by valleys on the edge of the moon.

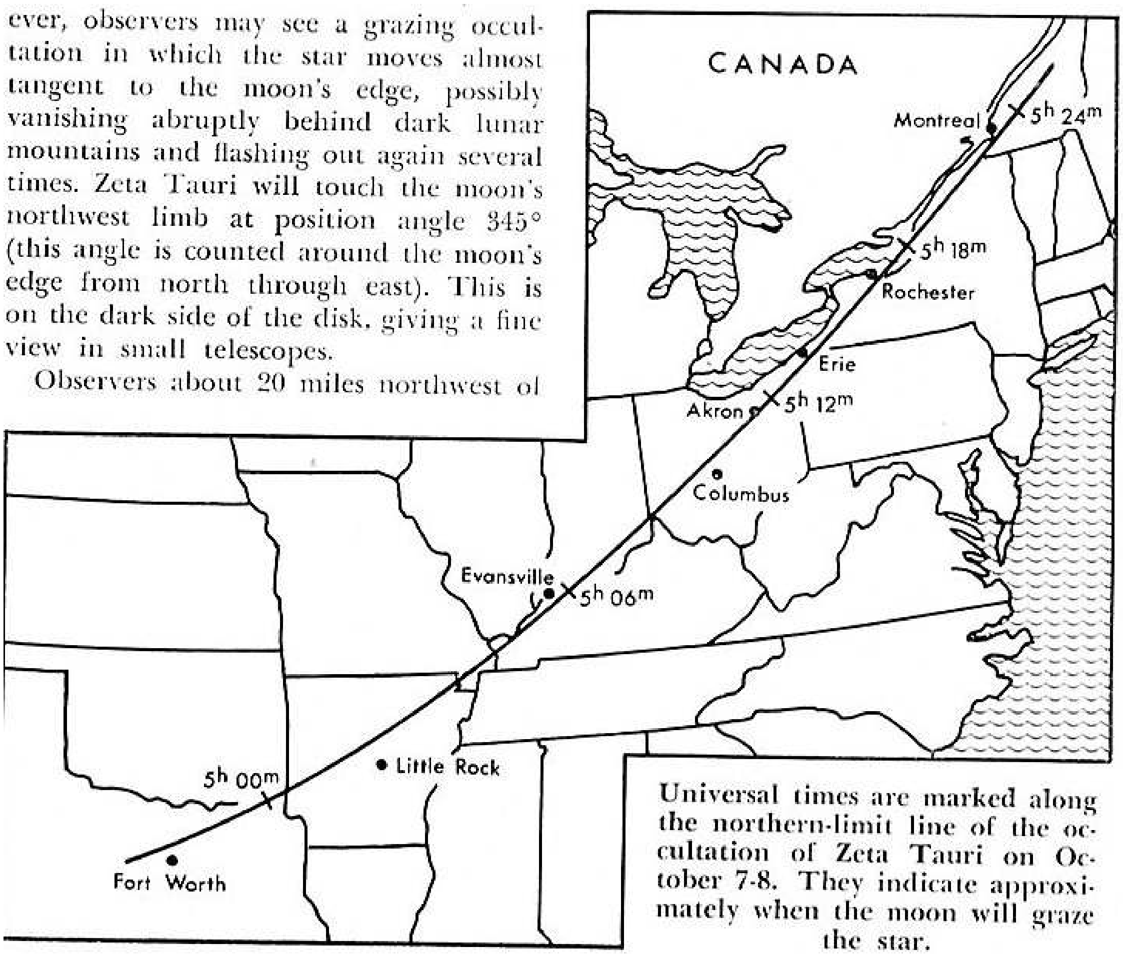
On November 20, 1959, Jean Meeus computed and observed a graze of the star λ Geminorium from Kessel - Io, Belgium. This was the first predicted and observed grazing occultation by the Moon. Although his data were not of high quality compared to today's standards, they did show that techniques were available to make such predictions.

The first predicted grazing occultation observation in the United States was made on September 18, 1962. David Dunham made predictions of the graze of 5 Tau, $m = 4.3$. His predictions showed the graze path about 40 miles north of Los Angeles. Dunham, then in Berkeley, California, could not travel to see this one but he did notify several observers. One of them, Leonard Kalish, traveled from his home in Los Angeles to the path just north of Castaic Junction and saw several disappearances and reappearances of the star. This was Dunham’s first successful graze prediction and as far as we know, the first time ever that someone had traveled to an occultation limit and observed a graze.

The first organized grazing occultation expedition was on September 9, 1963 of a dark-limb graze near Davis, California. During this graze, Dunham had recruited several observers from the Sacramento Valley Astronomical Society. Four observing stations were set up. One observer, Art Leonard, had only a one second occultation at his location and was quite impressed realizing that, if the Moon were a perfect sphere, that implied that he was very close to the northern limit!

Dunham was set up south of Leonard and called out three disappearances and three reappearances using WWV* recorded on a tape.

For the graze on October 8, 1963 of ζ Tauri, Dunham had published the prediction in the October, 1963 *Sky and Telescope* magazine. It is shown below as Figure 1.3. It is interesting to note that in 1963, *Sky and Telescope* had been publishing the yearly occultation supplement for standard stations for five years but this was the first map published of a grazing occultation suggesting that these events be observed. It was observed near Ft. Worth, Texas, Cincinnati, Ohio and Columbus, Ohio and became the first published account of a grazing occultation in *Sky and Telescope*, December 1963, page 369. Tom Van Flandern at the US Naval Observatory saw and analyzed these results and was amazed to find more than 0.8 km error in the current combination of star position, lunar ephemeris and lunar limb data. That sparked USNO's interest in occultations, especially grazes and van Flandern began working with Dunham to facilitate the prediction process and obtain more graze observations.



ever, observers may see a grazing occultation in which the star moves almost tangent to the moon's edge, possibly vanishing abruptly behind dark lunar mountains and flashing out again several times. Zeta Tauri will touch the moon's northwest limb at position angle 345° (this angle is counted around the moon's edge from north through east). This is on the dark side of the disk, giving a fine view in small telescopes.

Observers about 20 miles northwest of

Universal times are marked along the northern-limit line of the occultation of Zeta Tauri on October 7-8. They indicate approximately when the moon will graze the star.

Figure 1.3 First predicted grazing occultation map. Courtesy David Dunham, © 1963 Sky & Telescope, used by permission.

One of the observers on this October 8, 1963 graze event of ζ Tauri was Hal Povenmire of Florida, who has successfully to date led and observed more than 500 grazing occultation expeditions.

* WWV is the call letters for the shortwave radio station from Ft. Collins Colorado that broadcasts continuous time signals at 2.5, 5, 10, 15 and 20 MHz.

On December 4, 1970 the graze of ι Capricorni was observed in Central Florida and a total of 235 timings were made making it the most successful grazing occultation expedition ever.

The first successful asteroid occultation profile made by a team of observers was on January 24, 1975 when 9 observers in New England observed the asteroid 433 Eros occult the $m = 3.6$ star κ Geminorum. The resulting size of Eros determined from that series of observations was 14.8 km x 6.9 km.

The first successful video observation of a total occultation by the Moon was made by Susumu Hosoi of Japan. He video recorded the occultation of the bright star Aldebaran in 1979.

The first photograph of an asteroid occultation was made by Paul Maley on December 11, 1979. In a time exposure using a 1000mm focal length lens at *f /16*, Maley recorded on film a 27 second occultation of the star SAO 80950 by the asteroid 9 Metis.

In June 1980, a TV station cameraman in New Orleans video recorded a graze of the star Regulus. He had only one disappearance and one reappearance. On May 10, 1981 Alan Fiala of the US Naval Observatory video recorded 14 events (7 disappearances and 7 reappearances) of δ Cancri near Conowingo Dam, Maryland. Fiala had the most timings of anyone in that 20 station expedition. This was also the first time that multiple events were video-recorded during a grazing occultation expedition.

On May 29, 1983 IOTA President David Dunham, IOTA Vice-President Paul Maley and Hal Povenmire organized expeditions in Texas and Florida to observe the asteroid 2 Pallas occult the $m = 4.8$ star 1 Vulpeculae which resulted in a record 131 timings.

The first video observations of an asteroid occultation were made on November 22, 1982 by Peter Manly. He taped 93 Minerva occulting the $m = 7.8$ star SAO 76017. Also using intensified video to record this event were J. Vedere, Pierre Laques and Lecacheaux at Pic Du Midi Observatory, France.

The first remote video station set up to observe an asteroid occultation was on September 7, 2001 near Orland, California. David Dunham placed an unattended video camera pointed toward a star to be occulted by the asteroid 9 Metis. The star was SAO 78349, $m = 6.0$. Dunham set up a camcorder with 50mm lens and image intensifier on a tripod and pointed it to the area of sky the target star would drift into during the occultation. He then drove some 23 miles south on Interstate 5 and video taped the event with a telescope. After returning to the remote station, he saw the battery had died, *but just after the occultation!* IOTA astronomer Steve Preston video taped this event from Redding, CA and had step events caused by the star's duplicity. Each video station produced chords, and the analysis showed Metis to be elongated in shape 240 x 122 km. The target star was in fact a double star and analysis of the tapes by Dr. Frank Anet found the star components to be separated by 0.040″ in position angle 343°. Further details appear in *Sky and Telescope*, March 2002, page 97.

On December 31, 2003, 15 year-old Beth Turner of The Woodlands, Texas (near Houston) became the youngest person to video record an asteroid occultation. From the driveway of her home she obtained one of five chords that determined the size and shape of 208 Lacrimosa (41 km x 48 km). Beth used a Celestron-8 telescope and a Supercircuits PC-164C camera. She used this event as her Science Fair Project in 2004 and was the Grand Award winner at the 45th annual Science and Engineering Fair in Houston, Texas which covers 16 surrounding Counties and is one of the largest Science Fairs in the United States.

On December 11, 2008, Scotty Degenhardt obtained 14 chords of the asteroid occultation 135 Hertha over Oklahoma using *14 remote video stations*. Eight other chords were obtained to map this asteroid. Hertha's profile appears on the front cover of this book and on page 139.

More about the history of occultations can be found in Chapter 12, Half a Century of Occultations.

1.5 IOTA Goals and Objectives

The principal goals and objectives of the International Occultation Timing Association are:

1. To promote scientific research and discovery using occultation related methods
2. To conduct research at the local, regional and international level and to publish results of studies in popular and scientific journals
3. To stimulate public awareness of phenomena such as eclipses and occultations
4. To improve lunar profile data through timing of grazing and total occultations
5. To determine shapes and sizes of minor planets and comets through timing of occultations of stars by these objects
6. To conduct research into improving lunar diameter measurements through timing of simultaneous observations of a grazing occultation at both northern and southern limits
7. To conduct research into determining changes in the polar diameter of the sun through total and annular solar eclipse studies of Baily's Beads
8. To search for hidden companions of stars during grazing occultation and asteroid occultation events and to use the latter to measure the angular diameters of some stars
9. To search for natural satellites of minor planets using occultation methods
10. To conduct research into Earth crossing and very distant (i.e., Kuiper Belt Objects) asteroids through occultation methods

11. To engage in new types of complementary research

12. To engage in expeditions and return with useful pertinent scientific data

13. To promote occultation science through presentations, electronic and printed media

14. To improve methods of data recording and reduction

15. To work with and support efforts of the professional astronomical community toward furthering aims related to eclipse and occultation research

16. To develop hardware and software necessary for predictions and analysis

17. To disseminate forecasts of upcoming events and document results

18. To recognize and acknowledge efforts and accomplishments of members

19. To seek funding for research tools and support in order to further the immediate processing of accumulated data

Since the star positions are now more accurate than the mapped lunar profile, all grazes and well timed total occultations can be used for the purpose of updating the lunar limb profile. Occultations can no longer compete with lunar laser ranging for lunar ephemeris determination although the older observations have some value for this (especially determination of ΔT). Before the Hipparcos stellar data became available in 1997, the polar diameter determination of the Moon by nearly simultaneous observation of grazes at opposite limits was an important goal of IOTA.

1.5.1 Double Stars

Hundreds of double stars have been discovered by the occultation technique. This important field of IOTA still requires the monitoring of stars for possible duplicity. Although resolving a double (binary) star system may not be possible with some current tiny angular separations, such binary star candidates are still monitored. Their angular separations change, and in many cases widen over the duration of their orbits, allowing for new discoveries.

1.5.2 Satellites of Asteroids

Discovery potential is thriving in the field of asteroid occultations. The most interesting aspect is the possibility of detecting a natural satellite in orbit around an asteroid or perhaps the determination that an asteroid might in fact be a binary object. Both are within the reach of the amateur astronomer. The existence of asteroidal satellites was first predicted in the early 20th century. They have only been directly photographed by the largest Earth-bound telescopes and interplanetary spacecraft. Occultation observers with video systems may observe an occultation of a body as small as 3 - 5 km in diameter.

1.6 Relativistic Effects

From Einstein's theory of General Relativity, the path of starlight will bend slightly when passing/grazing near a massive body. For the Sun, relativity predicts a deflection angle of 1.75″. At the Sun's limb the observable deflection would be half this amount or 0.875″. A deflection angle of 1.61 ± 0.30″ was first measured during the solar eclipse on May 29, 1919 from Sobral, Brazil on an expedition led by Arthur S. Eddington. Closer agreement to within 1% has been found with the bending of radiation of radio sources (such as quasars) when measured with radio telescopes. The question is will starlight be bent significantly as it grazes by the Moon during a total or grazing occultation ?

Since occultation observations are used to refine the inertial system of celestial coordinates, astronomers need to know the absolute positions of the stars unaffected by the relativistic bending of light. Using the mass of the Moon as 7.3483×10^{25} gm, relativity predicts the deflection angle as 0.000013″ at the limb, which is far too small to measure with current occultation equipment and techniques. See Appendix O for an illustration of this effect.

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2 Observing Prerequisites

In order to observe occultations or eclipses of any type an observer must exhibit some fundamental skills. It is not necessary to be a computer genius or mechanical or electrical wizard, yet it is important to have basic knowledge of the sky. Having financial resources for equipment and travel is important. The minimum investment in equipment may be in the order of \$300-\$700, consisting of rudimentary tools such as a small telescope, tape and/or digital recorder and a short wave receiver. This estimate does not include a personal computer.

More important is the ability to learn about the sky, what to look for, how to find it, who to consult for help, how to collect and record data plus the ability to work as a team player and to follow simple instructions.

2.1 Skills

To enable the quick setup of mounts requiring polar alignment, it is of primary importance to be able to recognize the North or South Celestial Pole (NCP or SCP) in order to find directions without a map, compass or GPS. For asteroid occultations, it is necessary to be able to manually find stars down to $m = +12.0$ using a technique known as *star hopping*. This is the use of different levels of star charts to find progressively fainter and fainter stars until the *target star* is located.

Using a GO TO telescope automates the method of locating a difficult to find star thus providing a number of factors working together. When experiencing a mostly cloudy sky in the hours preceding an event, it is not necessarily a fact that at occultation time the event will be a “wash out”. Having manual skills at finding stars, the telescope can be pointed close to, if not right at, the correct place assuming even a rough polar alignment has been attained using a level, compass, inclinometer and/or setting circles.

Another basic necessity is having access to use the Internet to check prediction updates and download star charts.

2.2 Resources

IOTA and IOTA/ES convene annually at separate meetings in the USA and Europe. Members are notified by email of meeting locations and through postings on the main IOTA web page (Appendix A, Appendix M).

IOTA is a volunteer, nonprofit organization and has no property or assets. While IOTA does provide software, reference material online, predictions of scientific events and advice, it does not supply funds, pay salaries or provide equipment to its members. IOTA observers use their own computers, telescopes, video equipment, etc. and pay their own travel expenses, as well as commit their own time and effort to the organization.

2.2.1 Expenses

In the USA, IOTA is a nonprofit organization under provisions of the federal tax code. As such, certain expenses may be tax deductible, though you should consult an accountant to ascertain which are legitimate. Expenses such as meals, gas, video tape, hotel, rental car and airfare which are reasonable and pertain only to the expedition are generally allowable. This may also include attending IOTA's annual meeting. For example, if one is planning to observe an event on October 4, expenses incurred to arrive at the location by October 3 should be allowable. Legitimate expenses from October 3 through October 5 should be included. It is assumed that October 5 is the reasonable date of return, assuming the event occurred on the night of October 4. Expenses on dates before or after that would clearly not be reasonable and therefore illegitimate. Expenses for others who are not part of the expedition or entertainment are clearly not legitimate. Any person who deducts any expenses as part of charitable contributions is personally responsible for accounting for and justifying those expenses in the event of a tax audit. Consult your tax consultant for current legitimate, deductible expenses.

To keep track of expenses, save all receipts and keep a log. A report form and more detailed instructions are available from IOTA at the link:
http://www.lunar-occultations.com/iota/iotatax.htm.

2.3 Personal Considerations and Behavior

Observing occultations may involve traveling long distances in the middle of the night, depending on the distance of the event from the observer's home. This could mean essentially being away from family for hours or a few days at a time (worst case – solar eclipses, annual meetings). It also may mean waking up at odd hours if the observation is to be attempted from home or nearby. This can cause disruption in family life, depending on the level of understanding that exists in a household. One should balance the need and desire to observe and contribute a measure of scientific data with those of your household. Astronomy is a great hobby but is usually a solitary activity. This can be a detriment to relationships and it is recommended that the observer use every bit of good will and understanding to strike a balance within one's family before committing to occultation observing.

Sometimes an observer is focused on only one thing: to contribute data at whatever the cost. It is important to realize that one's safety and peace of mind are the important considerations in the collection of these data. One must also consider other people (colleagues, service providers) and avoid degrading relationships for the sake of *being right*. IOTA is a group brought together by common interests and members work together as a team in order to achieve success.

Individualism flourishes because observers are generally on their own in the field operating under no supervision. This dictates that IOTA members approach an expedition with professionalism and a working together attitude toward law enforcement. It is not uncommon for an observer to be approached by a passerby or law enforcement official, even at a critical time (perhaps within a minute or two) before an occultation and have to endure headlights shining directly on the observer. This is where it helps to have a prepared handout that the onlooker can be given to minimize the downtime experienced at that crucial moment, or even better, a companion to handle the situation while the observer continues working.

Avoid confrontations with law enforcement officials. One approach is to go to a local police station on the day of the event and obtain a business card from someone in authority there. If you are confronted you can provide proof that you attempted to notify the sheriff or police official in advance.

Observers must refrain from trespassing on private property. Asking permission is usually quite productive. Many rural homeowners are more than happy to assist IOTA members who are looking for a dark sky site. Always be professional and respectful of the property and feelings of others. If you feel you lack the appropriate social behavior to interact professionally with the general public, bring along a companion who has these communication skills.

Do not leave a mess. Always be respectful where you drive and always leave your observing site clean and free of litter. Assess the mood of the landowner whose property you want to use. If the landowner is not receptive to your presence don't press the issue and find another location. Your objective is to find a site and build good will in the process but not through provocation or intimidation.

Once given permission never attempt to take advantage of a situation. This includes such things as digging up bushes or cutting down a tree because it blocks your view. If you are offered a place to stay overnight decline the offer for safety reasons. It is best to leave as soon as the observation is done. Sleeping in a rental car or your own car is not uncommon and should be considered to avoid overtiring yourself before or after a long drive. If you find that you must rest in a car do so only in a designated rest area or parking area. Never just pull over onto the side of the road to rest as that could be dangerous and/or illegal.

Dogs and other animals may present a nuisance or even a hazard. If you feel unsafe, abandon the site. Never knowingly expose yourself or others with you to any risk to personal safety. Choose your traveling companion wisely making sure it is someone who is able to withstand the rigors of the trip. Sharing expenses is reasonable and should be mutually agreed upon beforehand.

When in foreign countries you could be asked for money in order to set up at a location or share in local customs such as drinking tea. Negotiating is acceptable, but think twice before refusing since it could create an undesirable cultural backlash. If you do not speak the local language take along a companion who does.

If someone loans you their equipment, you are responsible for it while it is in your care and if damaged, you are responsible for the repairs. Show professionalism in returning the equipment at the mutually agreed time and in the same condition as when given to you.

2.4 What if Something Goes Wrong?

Planning and execution of occultation expeditions can be fun. But what happens if your plan is altered by unforeseen events? This can happen especially if you travel by air. Always allow enough time in your travel plans in case of flight delays or weather cancellations, etc., and have a backup plan ready. Plan ahead when traveling by land for road closures and/or traffic backups which could prevent you from getting to your destination. Take detailed maps, a gazetteer and GPS in order to provide the most options in planning an alternate route if necessary.

If you have a cell phone be sure it works and that there are cell connections in the area. If you have car trouble be alert and careful if you accept a ride from strangers.

In a situation in which you may be forced into a making a choice between leaving without your equipment or collecting your equipment at great risk to yourself or others, remember your personal safety is more important than material possessions.

2.5 Observing Post-requisites

Once an observer has experienced an occultation, we hope they will continue to observe on request. Any ideas on improvements are welcome and we hope that each observer will be an advocate for IOTA in helping to stimulate and promote the research aspects of our field. IOTA's quarterly publication *Occultation Newsletter* is always looking for submissions on occultation projects and we encourage observers to contribute their thoughts and studies. Observers are also invited to attend IOTA's annual meeting and present topics of interest (Appendix M).

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3 Types of Occultation Projects

3.1 Total Occultations

A total occultation of a star by the Moon is the most common type of event. These events are visible everywhere on Earth on every clear night except when the Moon is in the new phase. Since stellar angular diameters are usually well below 0.01", their disappearances and reappearances are instantaneous allowing accurate timings to be made. Larger giant stars can cause a gradual disappearance. For a total occultation observation to be visible with a useful observation/timing made the Moon should be high enough above the horizon without obscurations while the sky is still dark and the target star being occulted must be plainly visible.

As the Moon moves in its orbit, it comes between observers on the Earth and the stars in its apparent path. Properly placed observers can see the Moon obscure or occult these stars. Figure 3.1 illustrates a total lunar occultation event. At a given instant a star in the Moon's path casts a shadow of the Moon on the Earth. This shadow moves across the Earth as the Moon moves in its orbit. Observers on the advancing edge of the Moon's shadow, such as at point **A** in the eastern US, would see the star disappear, and an observer on the trailing limb at point **B** in the southwest US would see the star reappear. An observer north or south of the path of the Moon's shadow, such as at **C** in Canada, and **D** in Mexico will see no occultation, or a close approach of the star to the Moon (a close miss or appulse).

The path of the star relative to the Moon for Observer **A** is shown by the chord “A” in Figure 3.2. The star follows a chord behind the lunar disk during the occultation. An observer inside the shadow would not see the star until the Moon's shadow had completely passed over him. An observer at the center of the Moon's shadow will see the star disappear for about one hour.

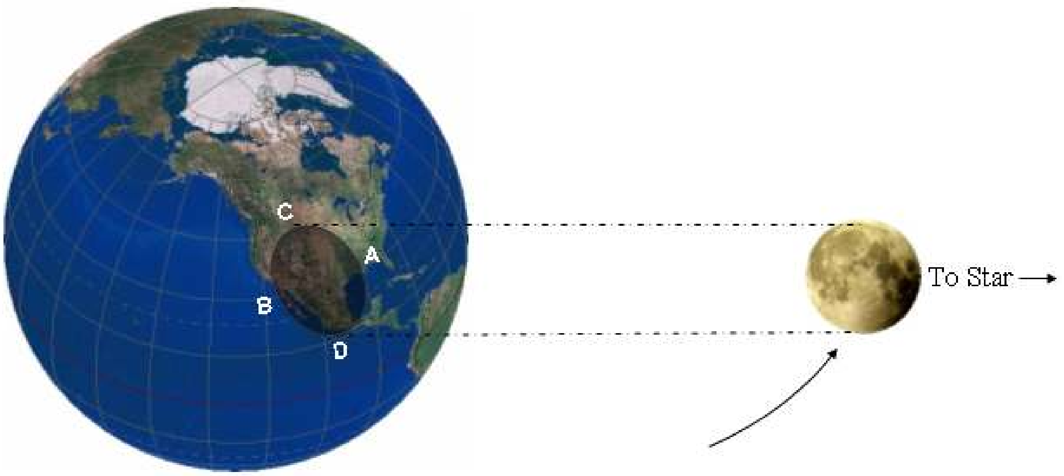

Figure 3.1. A total occultation about to occur for observer at **A**. Observer at **B** sees a reappearance. Observers at points **C** and **D** are just outside the north and south limits and would have no occultation. Earth image taken from Snap! 3D atlas. Used with permission, courtesy of Topics Entertainment.

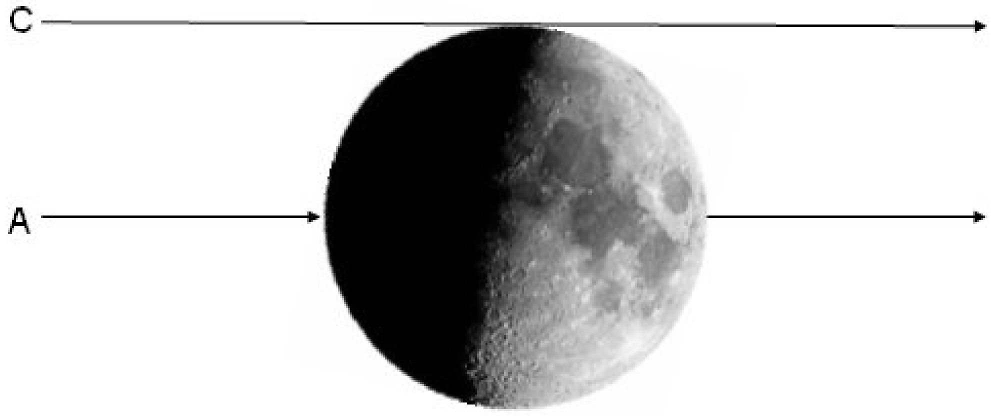

Figure 3.2. Path of star behind Moon. Chord **A** is the path a star would appear to take as for an observer at point -A- from Figure 3.1. Observer at point **C** from Figure 3.1 would have no occultation, this is called a miss.

Whether or not a particular star is occulted by the Moon depends on the Moon passing between the star and the observer at a specific point on the Earth. Only those stars that lie within the Moon's path (± 5° of the ecliptic) will be occulted. Not all occultations can be observed. The star must be brighter than 11th magnitude or it will appear to merge with the Moon's limb rather than to distinctively disappear or reappear. During the waxing Moon the leading (east) limb will be dark while the trailing (west) limb will be sunlit. Reappearances will occur on the bright limb and only stars of approximately magnitude 3.5 or brighter will be observable. The situation is reversed for the waning Moon. During this period the leading limb is sunlit and we will see only disappearances of stars approximately magnitude 3.5 or brighter. Observations of daytime events are usually impossible for stars fainter than magnitude 3.0-3.5. The brightness of the Moon is also an important factor. The closer the Moon is to being full the more the glare around it creates problems for the observer. Weather is also important since even on a clear night the atmospheric clarity may be too poor for successful observations of fainter events.

3.2 Methodology

Someone who has never observed an occultation before will be surprised by how small and pale a star can look next to the brightly sunlit Moon. As mentioned earlier total occultations of stars can be seen from anywhere on Earth. Mobility is not as necessary as compared to grazing occultations (Chapter 5) and asteroid occultations (Chapter 6). A telescope, short wave receiver, tape recorder (or video system) and observer's geographic latitude, longitude and elevation are necessary. The observer should possess a working knowledge of telescopes and the effects of the local temperature variations (including humidity effects) on a telescope at night plus have an accurate method to record data.

3.2.1 Equipment

Total occultations of stars fainter than 9th-magnitude require good atmospheric transparency, good equipment and observing experience. Events with brighter stars can be quite easy and do not require as much from the observer or the equipment. The easiest occultation events to observe are dark limb (non-sunlit portion of the Moon) disappearances. Fainter stars and reappearances require more skill. For a dark limb disappearance the star can be found well before the event, and tracked as the Moon's limb approaches. If the Moon is not more than one-half sunlit, such as a crescent or half Moon, the dark limb will be visible from Earthshine making the observation even easier.

The observer will need a telescope, a source of time information, and a means of recording the timings. Observers attempting their first occultation may not have much equipment and may be somewhat hesitant to invest money or time in buying or making it. Most observers are limited to what they have, to what is available from their school or club or to what they can afford. Observations can be made with simple equipment which may limit the observer to a small number of events. There may be difficulties in using simple equipment. A seemingly minor inconvenience can turn into a major problem if it spoils observing during the moments leading up to the occultation. Several considerations when selecting equipment will be discussed in this section. The perfect equipment varies from observer to observer and even from event to event depending on the circumstances.

Under good conditions, occultations of 4th-magnitude stars can be observed without optical aid during a total lunar eclipse in a dark sky away from city lights (such events are very rare), or during lunar crescent phases with binoculars, if they are steadily held on a tripod or supported firmly in some way. However, a telescope is necessary to observe nearly all occultations. Timing information can be from radio station WWV or other shortwave broadcast time signals, a watch synchronized to an accurate time source or GPS time. Note that the time provided by most local telephone companies in North America is not accurate enough for occultation work. This is due to the wide range of signal processing delays from the time the signal is sent to the time it is received by the caller. Chapter 8 gives more information on timing methods for occultations.

3.2.2 The Telescope

The telescope is the most important piece of equipment used in observing occultations. There are occasional spectacular events observable with binoculars, but they are uncommon. For those who are planning to buy or make a telescope, or who have the choice of several instruments, here are some things to consider.

The best telescope for an event is one large enough for the event to be seen and yet is easy for the observer to use. Portability is paramount, and the observer must be able to manage the telescope and its assembly alone in the dark. Such a telescope may be fine for deep sky and certain types of astrophotography work or in a permanently mounted observatory, but is overkill for occultation work.

Some telescopes are more prone to problems from the scattered light of the Moon. The Moon is a bright light in the sky and when in a gibbous phase its glare becomes a serious problem. Large f-ratio refractors, *f* /12 or *f* /15 are recommended for observing under these conditions, as are instruments of simple design with a minimum of mirrors and lenses. A high f-ratio telescope has a smaller field of view (FOV), so less lunar light is collected within the instrument. Some telescopes are better protected than others of the same size and type with a better designed system of baffles to keep light from being scattered inside the telescope tube. Schmidt-Cassegrain telescopes (SCT's) such as Meade and Celestron generally have long focal lengths that make up for their multiple reflections. For a given aperture, they are the most compact telescope type, an important consideration for portability and ease of setting up. Reflectors, especially those with Dobsonian mounts, are the least expensive per inch of aperture. Their increased aperture can compensate for their generally lower f-ratio. With a lower f-ratio telescope a high power eyepiece should be used to decrease the field of view. Although most cost effective, they are bulky and can be difficult to transport and set up.

An inexpensive telescope mount is frequently a less sturdy mount with less reliable slow motion controls. If the observer is not using a motorized clock drive he may find himself continually frustrated. Just as an event is about to occur the Moon and star drift out of the field and by the time he has them back in view the event is over. This problem is the most discouraging of all to a beginning observer. The weather can be gorgeous, the star easily visible, and the event lost because the telescope does not track well. The best telescope mount is a sturdy one with no wobble, whose motion, either in right ascension and declination, or in altitude and azimuth, is smooth, positive and easy to use. A clock drive is convenient, but is not necessary if adjustments can be made smoothly. If a telescope must be used that is stiff or hard to adjust, use an eyepiece that gives a wide field of view, and close to the event set the star (or lunar limb for reappearances) at one edge of the observing field so that it will drift to the other side. This may take some practice with the telescope to see the direction of drift across the field of view. Wobbly mounts can be made sturdier with braces or by the addition of weights hanging from the middle of the mount. If permanent structural changes cannot be made, as in the case of a borrowed instrument, the braces can be attached with masking tape or string. A good mount can be very expensive but a poor mount can make a telescope of good optical quality almost worthless.

The possible discomfort caused by using a particular instrument should also be considered. Some problems are obvious but may not be thought of in time. The observer should be alert to avoid any situation where the observing position is uncomfortable. Continued discomfort while observing not only affects accuracy but may convince the observer that this is not an experience worth repeating. This is especially the case during a grazing occultation where the observer must monitor events continuously for five or more minutes. In this case it is extremely important to assume a comfortable position before the start of the events and to maintain that position throughout the observing period. It is especially wise to practice ahead of time looking through the telescope at the same altitude/azimuth that the Moon will have during the time of occultation event. This way comfort and other problems can be identified and corrected before the occultation event. Examples might include: will you need an observing chair and a star diagonal to simplify the observing angle of your neck? Will you need gloves, and can you use the telescope's controls and operate your recording equipment with them on? Will you require mosquito repellant? Will there be any glare from a nearby streetlight, neighboring home or passing cars at the time of the occultation? A dew shield placed over the end of the telescope will help reduce or eliminate extraneous light. These are just a sample of issues that can come up when making an occultation observation. Even experienced observers will do a dry run in the days before an event to check out equipment, batteries, viewing angles and any obstructions that might occur with the telescope and all equipment attached. For example, if you plan to video tape a total occultation when the Moon is at a high altitude, you should check that your attached video system will not hit anything (such as the table the telescope is on or the hood of a car) as the telescope tracks the star when the time of the event approaches. When using video systems, proper balance of the telescope and all attached equipment is critical. Having extra weight might cause the motor drive to be strained and it may not track the target star properly.

With the wide availability of image intensifying eyepieces, should you buy this device for occultation work? For video recording faint asteroid occultations you'll need all the light gathering power you can get to reach fainter stars. An intensifier such as the Collins I^3 piece, (See Appendix D) is a great accessory. For total lunar occultations, including grazing events an image intensifying eyepiece *should not* be used. This is because the intensifier will wash out the star with the tremendous increase in brightness of the Earthshine from the Moon.

If a telescope is going to be used to observe grazing occultations, it should be readily transportable. The definition of transportable depends on the situation. There are 24-inch trailer mounted telescopes that can go anywhere their owners can drive. The observer who wants to chase grazes frequently should be able to set up the observing equipment without assistance *in the dark*. Telescopes that require more than one person to assemble, or that are complicated and hard to set up, won't be used as often as those that do not require so much effort. Small telescopes are also advantageous for car pooling and for traveling on airplanes.

Further information on telescope selection can be obtained from local astronomy clubs, planetariums, colleges or University astronomy departments and other observers. *Sky and Telescope* and *Astronomy* magazines publish a guide to buying a first telescope. They also have this information on their web sites (Appendix K). It is useful to attend a star party organized by a local group in order to see different telescopes and to talk to observers about their preferences and experiences.

3.2.3 Short Wave Receivers

The method of timing an occultation event is by shortwave time signal broadcasts or from GPS satellites. In the USA, The National Institute of Standards and Technology in Ft. Collins, Colorado broadcasts continuous time signals at frequencies of 2500, 5000, 10000, 15000 and 20000 kHz. In Canada, CHU broadcasts at frequencies of 3330, 7850 and 14670 kHz. See Appendix J for more information on these time signal frequencies and their broadcast format.

Generally in the USA, WWV is best heard at 5000, 10000 or 15000 kHz. To improve signal reception it is advisable not to set up near power lines, as their strong magnetic fields can distort the shortwave signals sometimes making them impossible to discern. When choosing an observing site, check for power lines and the strength of the WWV signal before setting up your telescope and other equipment.

A good shortwave radio is one with digital tuning. See Figure 3.3. Stations can be identified by their actual frequency readout on a small LCD screen compared to the awkward manual tuning with conventional older tuning radios. These radios (which typically cost between $50-$100) can also have pre-set stations programmed for one-touch recall which becomes useful if you accidentally bump your radio or hit the tuning button.

Figure 3.3 Digital Tuning shortwave radio set to WWV 10 MHz. Radio is Grundig model YB 300PE and is a compact 5.5" x 3.5" x 1".

The older Radio Shack “Timekubes” used for many years by occultation observers are no longer made. Radio Shack and other companies sell digital shortwave radios for a reasonable cost. Sometimes local astronomy club members (especially experienced occultation observers) have extra shortwave radios that may be loaned out. Sometimes, a radio that cannot quite get a good signal can be improved by grounding it, or by adding a 50-foot antenna (see Chapter 8, Section 19) and by changing out the batteries.

Time signals from GPS satellites are now being used for occultation timing by direct insertion and overlay onto the video tape. For detailed information about occultation timing techniques, including GPS time insertion see Chapter 8. For a list of sources for purchasing shortwave radios see Appendix D.

3.2.4 Recorders

To effectively make a scientific observation, the occultation observation is recorded in real time using a simple cassette or digital recorder. Motor driven cassette recorders are subject to speed variations with temperature extremes or low battery power, a problem even mini-cassette recorders suffer. For these reasons digital voice recorders are preferred. See Chapter 8, Section 8.6 for more details on these types of recorders.

If you are going to video tape an event it is still a good idea to have a cassette or digital recorder as a backup in case the video system fails. A perfectly working video/camcorder setup may sometimes fail for the least expected reasons, such as low battery level, forgetting to bring video tape, cables missing, adapters missing, non-functioning, etc. Pre-identifying an equipment problem in the daytime makes for a faster fix at night.

3.2.5 Equipment Check List

1. Telescope
    a. Optical tube
    b. Mount, equatorial head for equatorially mounted telescope
    c. Tripod or pedestal, legs, bolts for the legs
    d. Tools for assembly (Allen wrench, pliers)
    e. Power inverter and battery or auto jumper cable
    f. Finder scope (for asteroid occultations)
    g. Eyepieces

2. Tape Recorder or Digital Voice Recorder
    a. Fresh batteries
    b. Tape cassette (preferably not one with unreduced data)
    c. External microphone (especially for cold weather observing)

3. Video recorder/camcorder
    a. Charged battery
    b. Blank video tape (use tape without unreduced data)
    c. Cables and adapters

4. Time Signal Receiver

   - a. New batteries
   - b. Antenna wire, copper, 20 meters

5. Other Items
   - a. Red flashlight, with new batteries
   - b. Mosquito repellant
   - c. Digital watch that displays seconds
   - d. First aid kit
   - e. Standard broadcast radio
   - f. Money for snacks, food, tolls, gasoline, etc. (grazes and asteroid events)
   - g. Battery powered hair dryer for removing dew on telescope optics
   - h. Drinking water and snacks

6. Cold Weather Necessities (See Chapter 9)
   - a. String to hang tape recorder inside jacket
   - b. Heavy boots
   - c. Gloves, sweater and hat
   - d. Foot warmers, hand warmers (electric socks, for example)
   - e. Hot soup, hot coffee, and/or hot chocolate in unbreakable thermos
   - f. Extra blanket

Several of the above items are weather dependent and are not necessary in all climates.

3.3 How to Observe a Total Occultation

Now assume you will attempt to observe a total occultation by the dark limb of the Moon tonight. Predictions of a total occultation will include parameters to locate the star on the Moon's limb. These parameters are called cusp angle and position angle. See Figure 3.4 and 3.5:

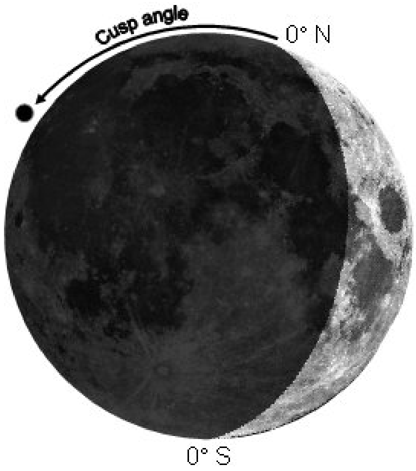

Figure 3.4 Cusp Angle. The cusp is the point on the Moon where the terminator meets the sunlit point, thus there is a North and South cusp. Cusp angles are measured from the North or South Cusp. A negative cusp angle indicates the star will be occulted on the sunlit limb. Cusp angles range from -90° to +90°.

Test your shortwave radio before you set up to confirm a good signal. Power lines can cause problems with signal reception. Verify this by walking around with your radio tuned to station WWV. Check for obstructions that might block visibility of the Moon at the time of the event keeping in mind that celestial objects move westward at the rate of 15°/hour as the Earth rotates, in addition to the Moon's own eastward orbital motion with respect to the stars.

Have your telescope set up and pointed on the target star at least 30 minutes to an hour prior to the time of the event. You will notice that the Moon is moving closer to the star as time progresses. If you don't have a predicted time for the event, a good rule of thumb is that it moves its own diameter in one hour, and it is always moving eastward with respect to the target star.

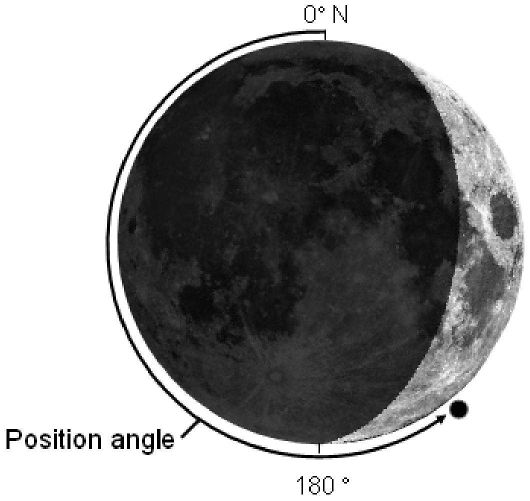

Figure 3.5 Position angle. The position angle is measured from the Celestial North Pole eastward and ranges from 0° - 360°.

Thirty minutes before the event, record (this could also be a video system) your name, date, time, a brief description of telescope equipment, eyepiece power, approximate location (nearby intersection is adequate) and the identifying catalog number of the star being occulted. This information will be used for the report and entered into a computer later. Turn off your recorder after this brief announcement is made to save battery power.

A few minutes before the event turn on your recorder and radio and watch the star. The recorder and radio should be close you and the telescope so your voice can be heard clearly. When starting the recorder, let it begin about 15-20 seconds before the top of the minute so as to have the voice announcement on WWV identifying the start of this next minute. Keep your eyes moving around the field of view of the eyepiece to avoid blank stares. Blank stares can cause the eyes to see illusions and the star intermittently dim, vanish and come back again.

When the star disappears, call out "D" (for disappearance) or "Gone" or "In" as soon as you can. These one syllable words minimize the time spent on projecting your verbal sound into the recorder and simplify the time reductions later. There will be a delay when you actually see the star disappear vs. when you call it out into the recorder. This delay is called reaction time or personal equation. Techniques for measuring and estimating reaction time are given in Chapter 4, Section 4.1, #11 and Chapter 8, Section 8.2. Allow the recorder and radio to continue until 10 seconds past the top of the next minute after the event.

As an example assume the occultation is predicted to occur over your home at 2:18:24 Universal Time (UT) on July 21, 2006 and you are in the US Central time zone. Converted to US Central Daylight Savings time, this is 9:18:24 PM (or 9h 18m 24 sec) on the evening of July 20, 2006, as midnight marks the beginning of the next day over Greenwich, England where UT originates. Times are read as follows: 9:18:24 means 9:18 PM and 24 seconds. The format is hh:mm:ss, hh = hour (0-24), mm= minute (1-60) and ss = seconds (1-60).

Knowing how to convert from UT to your time zone is important to prevent you from missing the event since you may have thought it was the night before or after it actually occurred.

The timeline for this observation is as follows:

1. <u>In the days before the event:</u> Test your telescope, radio and recorder. Place your telescope at the approximate angles of where the Moon will be at the time of the event and check for any comfort issues while viewing. A chair or stool may be required. Determine the geographic coordinates of the observing site either by GPS receiver, internet or road atlas computer programs to an accuracy of at least 30 meters (1"). Determination of this position can also be made after the occultation.

2. <u>During the day of the event</u>: Check the weather forecast and have any item needed for your recorder (new batteries, video tape, necessary cables or adapters, etc.).

3. <u>Two hours prior to the event:</u> (Around 7 PM in this example) Set up your telescope, polar align if necessary and confirm the tracking motor is working. If you are using a dobsonian or other non motor driven telescope, make any adjustments to the bearings and teflon pads and slow motion controls to ensure their smooth operation. Check WWV reception. US observers use the best signal from 5000, 10000 or 15000 kHz.

4. <u>Thirty minutes prior to the event:</u> (8:50 PM) Use the recorder and state your name, date, time, a brief description of telescope equipment, eyepiece power, approximate location (nearby intersection is adequate), weather conditions, and the identifying catalog number of the star being occulted and magnitude. Turn off your recorder after this brief announcement is made to save battery power.

5. <u>Five minutes prior to the event:</u> (9:13 PM) start your radio.

6. <u>Three minutes prior to the event:</u> (9:15:45 PM) start your recorder. Watch the target star as the Moon’s dark limb seems to press up against it. At the moment of disappearance, call out “D” into the recorder. Tip: Mention any type of problem into the recorder after the event that might aid in the reduction of the tape. For example, if you knew you had

a longer reaction time that what you may have practiced, or if you were surprised by the event, or there was a disturbance (barking dog, interference from on coming car headlights, etc.) mention this onto the recording. All of this information can be used to help pin down the reaction time and the actual disappearance time.

7. Record a minimum of at least ten seconds past the top of the next minute marker.

8. <u>One minute after the event:</u> (9:19:24) Turn off your recorder. You have now completed a total occultation observation.

9. Reduce and extract the times from your tape and send them to the regional coordinator and use the report forms from Appendix F or use the programs *Occult*/*Low* which take your observational data and convert it directly into the proper email format. If you need assistance with this, contact your local coordinator.

3.4 Reducing the Observation (quick overview)

Extracting the time of the occultation observation requires that you determine the exact time the event occurred. Detailed methods of timing including stopwatch, cassette recorder and video reduction methods are presented in Chapter 8 *Timing Strategies for Occultations*. The time can be extracted by first noting which second after the WWV minute tone marker the event occurred and then by repeated playback of the tape to refine to within 0.3 – 0.5 second the time of the occultation.

After the occultation, replay the tape back and count the number of seconds into the minute when the event occurred. Write this down. In the above example if you called out “D” somewhere between 9:18:24 PM and 9:18:25 PM, then it is now a matter to estimate when during the 24th second you called out “D”. Was it at the beginning of the second? Near to the middle of the 24th second? Or was it closer to the end of the 24th second nearing the 25th second?

Play the tape back several times and for each playback listen carefully when you said “D” to the nearest tenth of a second (0.10 sec). Imagine each second is divided into 10 parts, 0 – 9, and estimate when you shouted “D”. Write each estimate down. Do this for at least 5-6 tries. Then average the results. For example, if you played the tape back five times and your estimates of when you called out “D” were:

First playback:	0.6
Second playback:	0.7
Third playback:	0.7
Fourth playback:	0.6
Fifth playback:	0.5

Then the average of these is 0.62, so your preliminary time when you called out “D” into the recorder was 9h 18m 24.62 sec or 9:18:24.6 PM CDT rounded off. See Chapter 8, Section 8.11 for more information on accurate timing.

The next step is to estimate your reaction time and subtract it from the above result to derive the *actual time* of the occultation. Estimating reaction time (or your personal equation) is an individual approximation. Personal notes recorded after the event can assist the observer in reconstructing individual reaction time. If you were very confident that you shouted “D” immediately after you saw the disappearance, then your reaction time could be close to 0.2 or 0.3 second. If you were slightly surprised by the star’s disappearance behind the Moon’s limb, before calling out “D”, then your reaction time could be 0.4 sec or more. Methods for determining raw times from observations and reaction time and personal equation are found in Chapter 8.

Once you have established what your reaction time was for the occultation, write it down and subtract it from your uncorrected time of the observation. Assume your reaction time was 0.4 second:

Raw time of event from recorder playback:	9:18:24.62 PM CDT, July 20, 2006
Reaction Time:	–0.40 sec
Actual time of occultation	9:18:24.22 PM CDT, July 20, 2006
Rounded to nearest 0.1 sec	9:18:24.20 PM CDT, July 20, 2006
Time be reported	2:18:24.2 UT July 21, 2006

In the above example, the time was rounded to the nearest 0.1 sec for reporting purposes. The time was also converted to Universal Time (UT) by adding 5 hours to the local time (add 6 hours for Central Standard Time, CST). Additional reduction methods for visually recorded observations and video observations are presented in Chapter 8.

How accurate is your final time? This depends on several factors. The transparency of the sky, the seeing conditions, if the telescope was in thermal equilibrium with the outside air temperature, the presence of dew or frost on the telescope’s corrector plate (SCT’s only), was the mount shaking due to wind or a wobbly mount, were you in a blank stare at the time of the event, were you observing through trees, were there any interruptions near occultation time, etc. Generally, visual times are accurate to 0.5 second, which is the minimum desired accuracy needed for scientific use.

3.5 Sending in Your Observations (quick overview)

The time of your occultation observation should be sent in to the regional coordinator. A special Excel file format should be used and is described in detail in Appendix F. If part of a combined team effort you may be requested to also send your observations to a local IOTA coordinator.

3.6 Double Stars

In the course of observing a total lunar occultation there may be an event that does not have an instantaneous disappearance. If the disappearance is gradual or happens in "steps", this might be an indication of a double star being occulted. During the occultation of a double star first one star will be covered up by the Moon followed by the next component. Thus there will be a drop in brightness as the first star is occulted followed by the complete drop off in brightness as the second star is occulted. Depending upon the position angle of the components, the duration of the brightness drop could be less than 0.1 second or longer. Double stars with angular separations down to 0.02" have been discovered by the occultation technique. The prediction of an occultation event will usually have a code next to the star to indicate it is a known or suspected double.

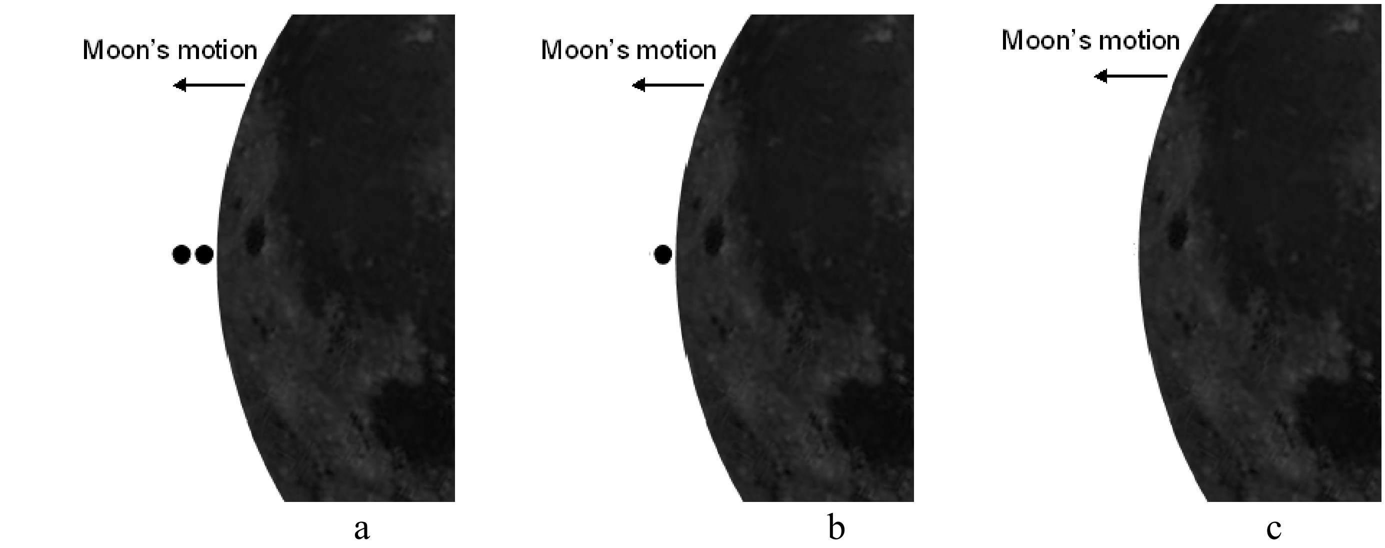

Figure 3.6 Double star geometry during an occultation. As the Moon approaches the double star (a), it first covers up one component (b) and then the second component (c). Diagrams not to scale.

If the star being occulted is a known double star expect to see step events in the disappearance. Call out the "D" as you would normally do so into the recorder and note the estimated duration until the star completely vanishes immediately following the event. If videotaping the event, later analysis of individual frames will show the step events as they occur over several 0.03 sec duration frames. (American VCR's and camcorders, both digital and analog, generally record at 30 frames/second). A video record of the occultation of a double star cannot necessarily derive the separation or position angle of the pair, but the observation can be used by professional astronomers with high resolution speckle interferometers to further study the pair.

3.7 Safety Considerations

Normally, total occultations can be observed from your backyard. Sometimes, because of special circumstances, you may have to travel to observe a particularly bright star occultation that misses your location (or in the event of a graze). If you travel to a remote site it is recommended that you first obtain permission from the landowner for setting up equipment. If possible notify the local law enforcement agency to let them know you are in the area and will be conducting scientific data collecting, especially if it is in a public area (such as a roadside park). Contacting local law enforcement is not practical when traveling for an asteroid occultation expedition. The key element is to **always** be aware aware of your surroundings. More about safety considerations can be found in Chapter 6 Section 6.10.

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4 Predictions

General Overview

This chapter describes how to generate predictions of total occultations by the Moon at any location, occultations by asteroids, solar and lunar eclipses, transits of Mercury and Venus and how to report these observations.

The prediction of occultations used to be a complex process involving the calculation of the precise positions of the Moon, the target star and other solar system objects with respect to the Earth. This required computers with the ability to produce detailed maps showing the projected positions on the Earth's surface of the Moon and asteroids with respect to the target star being occulted. With the arrival of personal computers and software for astronomical purposes, the process of predicting occultations has been greatly simplified so that anyone with a personal computer can produce accurate predictions for the observer's individual locations. The following software packages are widely used for predicting occultations: *Occult* written by David Herald and the Lunar Occultation Workbench *Low* written by Eric Limburg. Both are written to run in Windows format and require only minimal processor speed and memory.

Planetarium software programs such as *The Sky*, *SkyMap*, *Megastar*, etc. simulate the star field and position of the Moon for an occultation event but lack the output format and high accuracy necessary to predict occultations and eclipses.

The predictions for grazing occultations are more involved than can be covered here. Predictions for these important events are covered in Chapter 5, *Lunar Grazing Occultations*.

4.1 Lunar Occultation Workbench (*Low*)

Low is a powerful occultation freeware program in two editions: Lite and Professional. The Professional edition includes over 476,000 stars from Guide Star Catalog 1.1 (GSC) in the Zodiacal region. The Lite edition has an 80,000+ star database and computes and displays all aspects of total and grazing occultations. Both editions can handle the large lunar limb databases called Watts and MoonLimb which are add ons. A complete description of *Low* 3.1 and its history are referenced in the *Occultation Newsletter*, Volume 8, Number 4; January 2002. *Low* was written by Eric Limburg.

Some of *Low*'s capabilities include:

1) Input of observer information, including level of expertise.

2) Telescope specs: type, size, focal length, eyepiece info, filters used, type of mounting.

3) Station information, latitude, longitude, altitude, geodetic datum, local horizon and elevation. The local horizon option allows an observer to define in intervals of 10° of azimuth, the altitude at which the observer has a clear view of the sky. There is an option that filters out occultations occurring below the local horizon.

4) Allows input of timing methods used for the observation: visual, video, stopwatch, eye and ear, photoelectric, CCD drift scan, etc.

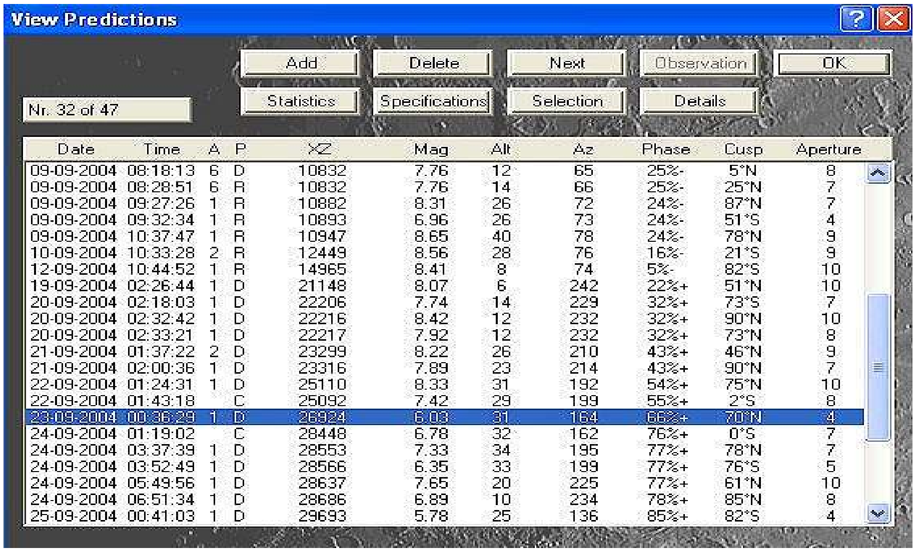
5) Prediction of occultations for tonight and for any time period past or future with a wide range of controlling parameters. Parameters include star magnitude limits for individual telescope's limiting magnitude, a lunar eclipse occultation option and dark/bright lunar limb star magnitude limits. *Low* also allows the local horizon to be set on or off.

6) Computation of Moon and Sun ephemeris in right ascension (RA) and declination (DEC) coordinates.

7) Predictions are listed in an easy to read format showing the date and time of the predicted occultation to the nearest second, star magnitude, altitude, azimuth, Moon phase, cusp angle, Watts angle and position angles. See Figure 4.1.

8) Details for each prediction: time, star information such as RA and DEC, accuracy of prediction in seconds, type of occultation (disappearance, reappearance), Moon details and all associated angles including librations, relative motion, etc. These parameters are defined below following Figure 4.1.

9) A screen shot of sample total occultation predictions is shown as Figure 4.1:



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Date	Time	A	P	XZ	Mag	Alt	Az	Phase	Cusp	Aperture
09-09-2004	08:18:13	6	D	10832	7.76	12	65	25%-	5°N	8
09-09-2004	08:28:51	6	R	10832	7.76	14	66	25%-	25°N	7
09-09-2004	09:27:26	1	R	10882	8.31	26	72	24%-	87°N	7
09-09-2004	09:32:34	1	R	10893	6.96	26	73	24%-	51°S	4
09-09-2004	10:37:47	1	R	10947	8.65	40	78	24%-	78°N	9
10-09-2004	10:33:28	2	R	12449	8.56	28	76	16%-	21°S	9
12-09-2004	10:44:52	1	R	14965	8.41	8	74	5%-	82°S	10
19-09-2004	02:26:44	1	D	21148	8.07	6	242	22%+	51°N	10
20-09-2004	02:18:03	1	D	22206	7.74	14	229	32%+	73°S	7
20-09-2004	02:32:42	1	D	22216	8.42	12	232	32%+	90°N	10
20-09-2004	02:33:21	1	D	22217	7.92	12	232	32%+	73°N	8
21-09-2004	01:37:22	2	D	23299	8.22	26	210	43%+	46°N	9
21-09-2004	02:00:36	1	D	23316	7.89	23	214	43%+	90°N	7
22-09-2004	01:24:31	1	D	25110	8.33	31	192	54%+	75°N	10
22-09-2004	01:43:18		C	25092	7.42	29	199	55%+	2°S	8
23-09-2004	00:36:29	1	D	26924	6.03	31	164	66%+	70°N	4
24-09-2004	01:19:02		C	28448	6.78	32	162	76%+	0°S	7
24-09-2004	03:37:39	1	D	28553	7.33	34	195	77%+	78°N	7
24-09-2004	03:52:49	1	D	28566	6.35	33	199	77%+	76°S	5
24-09-2004	05:49:56	1	D	28637	7.65	20	225	77%+	61°N	10
24-09-2004	06:51:34	1	D	28686	6.89	10	234	78%+	85°N	8
25-09-2004	00:41:03	1	D	29693	5.78	25	136	85%+	82°S	4

Figure 4.1 *Low* View Predictions window for total occultations.

Explanation of columns in Figure 4.1 above:

Date
Date of event in day-month-year format. The date highlighted is September 23, 2004.

Time
UT time of event to the nearest second.

A
Accuracy of the prediction in seconds.

P
Phenomena or type of event, D = Disappearance, R = Reappearance, C = conjunction or miss

XZ
XZ catalog number of star. The XZ catalog is a star catalog of over 58,000 stars in the ecliptic zone of the sky where lunar occultations occur

Mag
Magnitude of star being occulted

Alt
Altitude of Moon at time of event

Az
Azimuth of Moon at time of event

Phase
Moon's sunlit illumination (phase) as a percentage at time of event. 0% = New Moon, 50% = half Moon, 100% = Full Moon. "+" after the phase means the Moon is between new and full (waxing), "–" means the Moon is between full and new (waning)

Cusp
Cusp angle of star at time of event. Angle in degrees around the dark limb away from the terminator, N = angle from north cusp, S = angle from south cusp. Cusp angle range is 0 - 90°.

Aperture
Minimum aperture telescope in centimeters (cm) to view the event. Determining factors: observer's experience, altitude of the Moon and Sun, magnitude of star, Moon phase, cusp angle, dark limb or bright limb event.

10) *Low* also shows a Moonview illustration of the event depicting the lunar phase and and earthshine. Also shown is the location of the star at the point of disappearance and reappearance overlaid on the background star field. A single column table of required data, angles, and times is also shown. See Figure 4.2. The Moonview feature demonstrates where to find the target star in regard to the lunar terrain emphasizing how to spot a reappearance. Reappearances are more difficult to time due to their

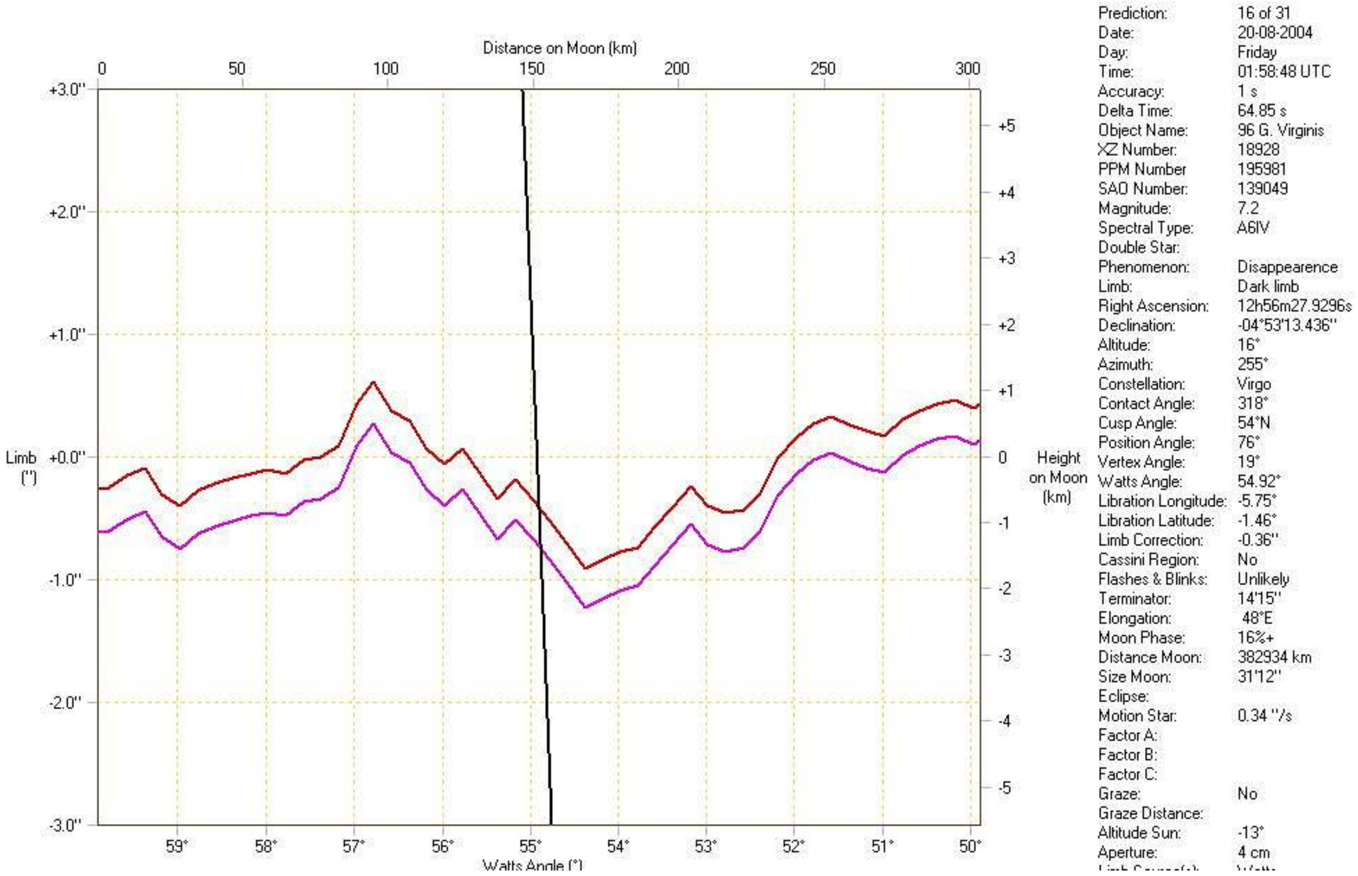
surprise re-emergence from behind the Moon.

Prediction:	16 of 31
Date:	20-08-2004
Day:	Friday
Time:	01:58:48 UTC
Accuracy:	1 s
Delta Time:	64.85 s
Object Name:	96 G. Virginis
XZ Number:	18928
PPM Number	195981
SAO Number:	139049
Magnitude:	7.2
Spectral Type:	A6IV
Double Star:	
Phenomenon:	Disappearence
Limb:	Dark limb
Right Ascension:	12h56m27.9296s
Declination:	-04°53'13.436''
Altitude:	16°
Azimuth:	255°
Constellation:	Virgo
Contact Angle:	318°
Cusp Angle:	54°N
Position Angle:	76°
Vertex Angle:	19°
Watts Angle:	54.92°
Libration Longitude:	-5.75°
Libration Latitude:	-1.46°
Limb Correction:	-0.36''
Cassini Region:	No
Flashes & Blinks:	Unlikely
Terminator:	14'15''
Elongation:	48°E
Moon Phase:	16%+
Distance Moon:	382934 km
Size Moon:	31'12''
Eclipse:	
Motion Star:	0.34 ''/s
Factor A:	
Factor B:	
Factor C:	
Graze:	No
Graze Distance:	
Altitude Sun:	-13°
Aperture:	4 cm

Figure 4.2 Sample Moonview output from *Low*. North is at the top. The star will be occulted at an angle 54° away from the North cusp. Information is tabulated for each predicted event in the right column.

The lunar limb profile can be displayed at the position on the Moon where the occultation event occurs. This is a zoomed in portion of the lunar limb (Figure 4.3) to show the mountains and valleys the star will pass during the occultation to enable planning grazing occultation expeditions using information from the Watts and MoonLimb databases. The Watts Angle (WA) is defined as the angle between the lunar North Pole and the occulted object at the moment of occultation. It is measured in an eastward direction and expressed in degrees and ranges from 0° to 360°. Chester B. Watts of the US Naval Observatory pioneered the measurements of the lunar limb profiles in the 1950's and published his now famous Watts charts in 1963.

A sample screen of the Lunar Limb profile is shown below as Figure 4.3.



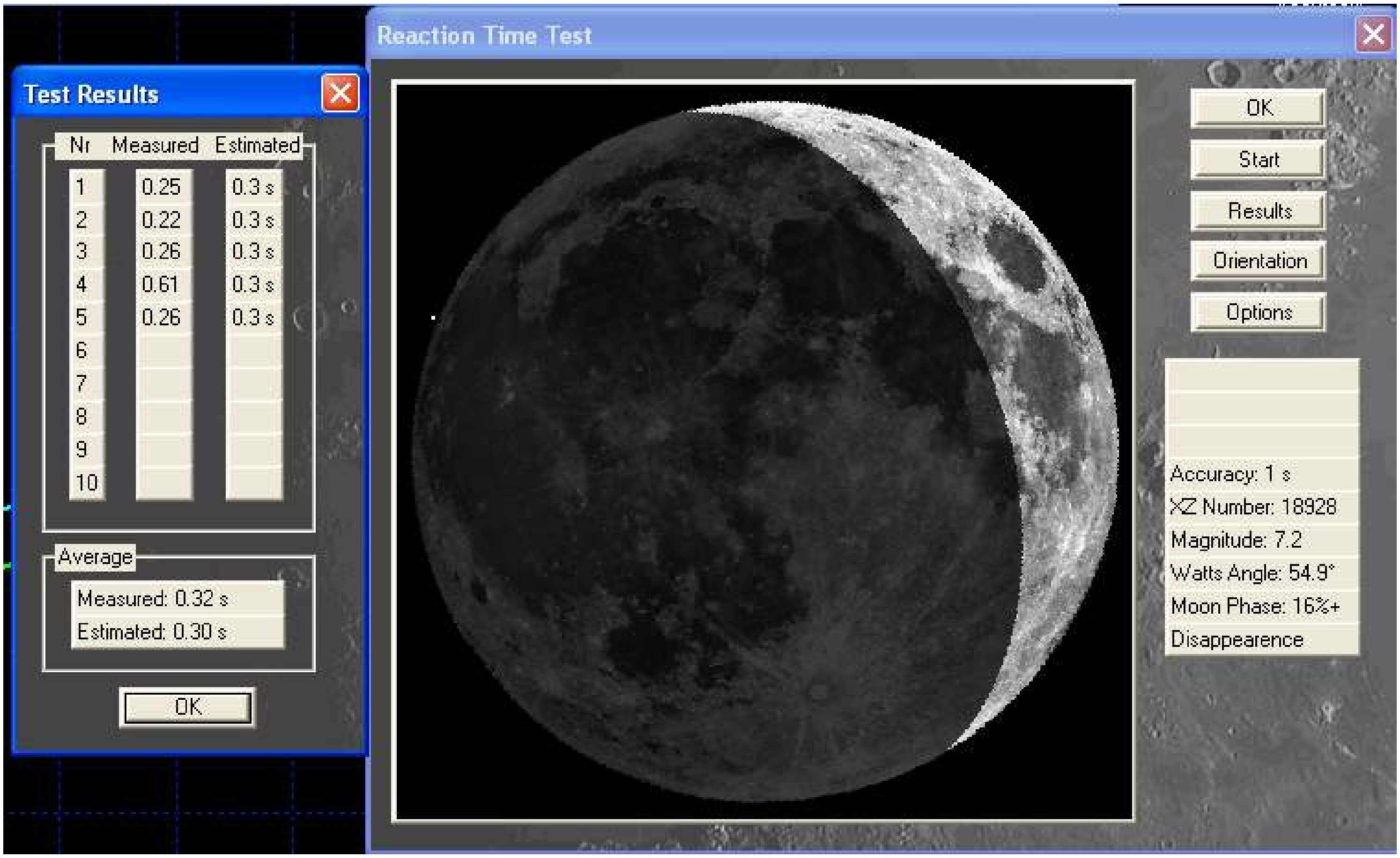
Prediction:	16 of 31
Date:	20-08-2004
Day:	Friday
Time:	01:58:48 UTC
Accuracy:	1 s
Delta Time:	64.85 s
Object Name:	96 G. Virginis
XZ Number:	18928
PPM Number	195981
SAO Number:	139049
Magnitude:	7.2
Spectral Type:	A6IV
Double Star:	
Phenomenon:	Disappearence
Limb:	Dark limb
Right Ascension:	12h56m27.9296s
Declination:	-04°53'13.436"
Altitude:	16°
Azimuth:	255°
Constellation:	Virgo
Contact Angle:	318°
Cusp Angle:	54°N
Position Angle:	76°
Vertex Angle:	19°
Watts Angle:	54.92°
Libration Longitude:	-5.75°
Libration Latitude:	-1.46°
Limb Correction:	-0.36"
Cassini Region:	No
Flashes & Blinks:	Unlikely
Terminator:	14'15"
Elongation:	48°E
Moon Phase:	16%+
Distance Moon:	382934 km
Size Moon:	31'12"
Eclipse:	
Motion Star:	0.34 "/s
Factor A:	
Factor B:	
Factor C:	
Graze:	No
Graze Distance:	
Altitude Sun:	-13°
Aperture:	4 cm

Figure 4.3 *Low* screen shot of limb profile for Watts angle 54.92°. The vertical line is the path the target star will follow as it is occulted by this portion of the limb. The vertical scale here at limb = 0.0″ represents the mean limb of a perfectly spherical Moon. The actual limb profile shown is the data from numerous grazing and total occultation observations. The upper line is the limb profile from the MoonLimb data, the lower line shows the Watts data.

The various screens in *Low* can be tiled on your computer screen allowing simultaneous viewing of all the information regarding a particular event including the Moonview.

11) *Low* also includes a reaction time simulator to test one's personal (reaction time) equation. From the ***View*** function on the toolbar, select ***Reaction Time Test***. An image of the Moon and star in the case of a disappearance will appear. (See Figure 4.4). Press ***Start*** in the Reaction Time Test window and notice the star begins flickering simulating actual seeing conditions. As soon as the star disappears the user presses the left mouse button and the user's reaction time is displayed in a table. Reaction times are displayed in the Test Results window.

12) Using this reaction time test users can estimate individual reaction time. This test is a useful training tool in preparation for an actual occultation.



Nr	Measured	Estimated
1	0.25	0.3 s
2	0.22	0.3 s
3	0.26	0.3 s
4	0.61	0.3 s
5	0.26	0.3 s
6		
7		
8		
9		
10		

Average
Measured: 0.32 s
Estimated: 0.30 s

Accuracy: 1 s
XZ Number: 18928
Magnitude: 7.2
Watts Angle: 54.9°
Moon Phase: 16%+
Disappearence

Figure 4.4 Reaction Time Test option using *Low*. The user will click when the star disappears and the results will be tabulated. Results are displayed in Test Results window. In this test event No. 4 was the slowest at 0.61 sec. The average was 0.32 sec for the five attempts.

13) *Low* has the ability to import and export selected prediction data. A tab character in the export file separates the fields to be imported and organized in columns in spreadsheet programs such as Excel. Observation data is reported in a standard format and the exported file may be sent by email either to your regional coordinator.

14) *Low* has the ability to print custom reports for predictions, grazes, and observations and also allows printing of up to four Lunar limb profiles in black and white or color. The Moonview diagrams may only be printed using the Print Screen Function from the User's own PC.

15) Access *Low's* help function by pressing F1. In addition, the user can select the ***Help*** function on the toolbar to access 160 entries for specific information.

How to obtain Lunar Occultation Workbench Software:

The program can be obtained in two different ways:
1) From the Dutch Occultation Association Home page: http://www.doa-site.nl

2) By CD-ROM, $10.00 including postage. The professional edition includes both the complete Watts and MoonLimb databases. One may also acquire a Zip Drive for $20.00 including postage. Please make your international money order or Eurocheck payable to:

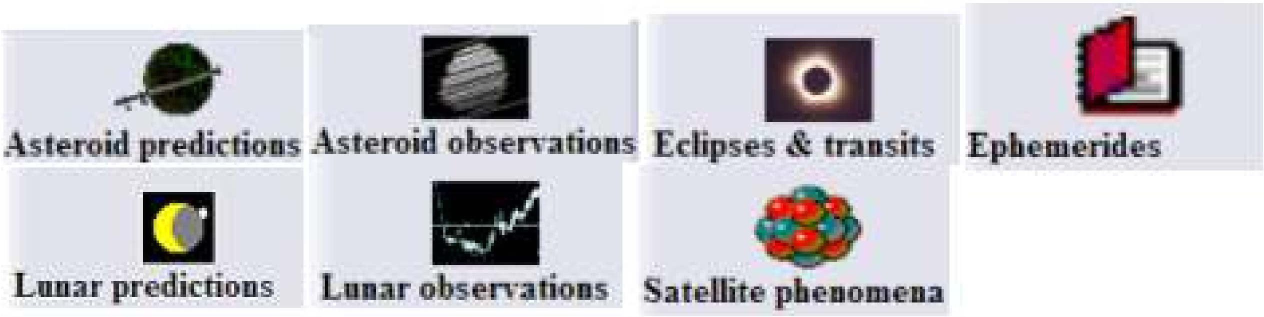
Dutch Occultation Association,
Boerenweg 32
NL 5944 EK Arcen
The Netherlands
or e-mail for more information: info@doa-site.nl

4.2 OCCULT

Occult is issued as a freeware program distributed by IOTA, with the aim of encouraging observations of occultation phenomena. *Occult* was written by David Herald of Australia.

The program has six distinct modules:

1) Asteroidal and Planet Occultations
2) Baily's Beads
3) Eclipses and Transits
4) Ephemerides; Mutual events
5) Lunar occultations – Prediction and Observations
6) Satellite Phenomena



Click on a selected module and follow the on screen instructions.
As related to occultation predictions, *Occult4* has been updated as of November 2007 and is a complete rewrite:

1) The method of handling ΔT (pronounced *delta T*) has been modified. ΔT is an increment of time added to Universal Time to give Terrestrial Dynamical Time (TDT). See Chapter 8, Section 8.16 for more about ΔT.

2) Improved functionality and tools for prediction and analysis of Lunar and asteroid occultations.

3) Greater accuracy, through revision of the code, and use of improved data sources (DE413 planetary ephemeris, Chebychev polynomial series for many moons of Jupiter and Uranus)

4) Incorporation of all reported occultation observations from 1623 to 2008 with options to analyze and display the lunar profile for grazing occultations.

5) Direct linking with **GoogleEarth** for drawing occultation and eclipse paths and direct linking with **GoogleSky** for viewing star fields.

6) Animations for several phenomena, lunar occultations, eclipses of planetary satellites, Baily's Beads during solar eclipses.

Both *Occult* and *Low* perform equally well with similar accuracy. The interface on *Occult* is easy to navigate through the use of drop down menus. *Low* has some extra features not found in *Occult* such as the simulator module. In *Occult*, all information can be entered into one popup box. With *Low*, the information has to be entered into separate boxes – one for observer's information, one for telescope information and one for site information. *Occult* allows the choice to set up a global information box on an observer, telescope and coordinates, which are set up as defaults within the other modules: Ephemeris, Asteroidal, Baily's Beads, and Eclipses and Transits.

4.2.1 Sample Total occultation output generated by Occult (partial listing):

```
Occultation Predictions for Bonner_Springs in May 2004
E.Long. - 94 53 35.5   Lat.  39  3 28.6   Alt. 250m.   T.dia 204mm.   dMag 2.0

      day  Time   P   Star  Sp  Mag    % Elon Sun  Moon   CA   PA  VA  WA Libration   A   B   RV   Cct    R.A.        Dec
 y  m  d  h  m  s      No  D       V  ill     Alt Alt Az   o    o   o   o   L    B   m/o m/o "/sec   o  h  m   s    o  m  s
04 05 23  0 50 47 d    1067cK2  7.1   12+  41    6 44 272  61N  62   1  56 -3.8 -5.7 +1.8-0.1 .294  +42  7  1 12.6  27  9 14
      1067 is double :   8.0  8.0   0.100"   90.0
04 05 23  1 43 10 r    1067cK2  7.1   13+  42  -3 34 279 -34N 327 267 320 -3.9 -5.6 -0.3-2.9 .317 +137  7  1 12.6  27  9 14
      1067 is double :   8.0  8.0   0.100"   90.0
04 05 23  1 59 23 d X 97145      9.7   13+  42  -5 31 281  75N  76  17  69 -3.9 -5.6 +0.8-0.9 .388  +29  7  3 24.6  26 58 35
04 05 23  2 15 24 d   79007 A2  9.3   13+  42  -8 28 283  41S 141  83 134 -4.0 -5.6 -0.3-2.5 .369  -36  7  3 33.7  26 41 38
04 05 23  2 15 57 d    1075 G0  8.5   13+  42  -8 28 283  60N  62   4  55 -4.0 -5.6 +1.0-0.5 .334  +43  7  3 51.3  27  0  6
04 05 23  2 18 28 D   79022 K0  8.0   13+  42  -9 28 283  80S 101  43  94 -4.0 -5.6 +0.3-1.5 .458   +3  7  4  3  26 49 57
04 05 23  2 41 48 d X 97342     11.4   13+  42      23 286  30S 151  95 145 -4.0 -5.6 -0.7-2.8 .325  -47  7  4 17.3  26 37  4
04 05 23  2 46 58 d X 97379      9.5   13+  42      22 287  30S 152  95 145 -4.0 -5.6 -0.7-2.8 .321  -48  7  4 27.8  26 36 26
```

Total Occultation Prediction Format:
The predictions commence with a header identifying the site. The predicted information is as follows:

DAY

The day of the event in "y m d" (year month day) format. There is a quirk in the system that may place the first or last day of the month in the wrong month. The program selects events by the time of the geocentric conjunction of the star and moon, however an occultation may occur up to 1.5 hours within this time causing events falling within 1.5 hours of the end or beginning of a month to be listed in an adjacent month. Such occurrences are obvious when they occur.

TIME
Universal time, in hours, mins and secs

P
The type of event
D- disappearance
d - star less than 1 mag brighter than predicted visibility limit for disappearances

R- reappearance
r - star less than 1 mag brighter than predicted visibility limit for reappearances
Gr- grazing occultation at site. At mid-occultation, or closest approach, the star is less than 4" from the limb of the moon
gr- Graze with star less than 1 mag brighter than predicted visibility limit

STAR NO

The star identification number, with the catalogue indicated as follows:
nnnn- zc catalogue no.
nnnnn- or **nnnnnn**- Smithsonian Astrophysical Observatory (SAO) catalogue number
xnnnnn- xz94 catalogue no.
gnnnnnnnn- the Hubble Guide Star Catalogue number (note that this continues through the double star and spectral type fields.)
nnnn- catalogue no. in another catalogue (with the initial letter of the catalogue file name leading)

D

The double star code. The following definitions apply:
a- listed by Aiken or Burnham
b- close double, with third star nearby with separate xz entry
c- listed by Innes, Couteau, or other visual observers
d- primary of double, secondary has separate XZ entry
e- secondary of double, primary has separate XZ entry
f- following component
g- a or c with second star either m, j, u or v, with a third star referred to second star
h- triple: j or u or v, and m
i - o, - with secondary either j, u, or v (third star's data referred to secondary)
j- one-line spectroscopic binary, separation probably < 0.01"
k- u or v, but duplicity doubtful
l- triple: j or u, and v; or all v; or all j
m- mean position of close pair
n- north component orbital elements available
p- preceding component
q- triple; j or u or v, and o
r- triple; o and o
s- south component
t- triple, v, and a or c; or all a and/or c
u- separation < 0.01" (usually a double-line spectroscopic binary)
v- separation > 0.01" but not visual (occultation, interferometric or speckle component)
w- triple; j or u, and a or c
x- probably a close double, but not certain
y- triple; k or x, and a or c
z- triple; o, and a or c or v or x or l
$- g except m rather than a or c for 1-2 stars
Note: visual observers will usually not notice the duplicity of stars with codes j or u.

SP

The star's spectral type

MAG

The star's magnitude, v (visual magnitude).

%ILL

The percent illumination of the moon. If followed by a **+**, values are for a waxing moon; **-** for a waning moon and **e** for illumination during a lunar eclipse

ELON

The elongation of the moon from the sun, in degrees. New moon = 0°; first quarter = 90°; full Moon 180°, etc.

SUNALT

The altitude of the sun in degrees, greater than -12 deg. A negative value indicates the Sun is below the horizon.

MOON ALT

The altitude (degrees) of the moon in reference to the horizon (horizon = 0º, zenith = 90º)

MOON AZ

The azimuth (degrees) of the moon in reference to the cardinal points on the earth's surface (North = 0º, East = 90º, South = 180º, West = 270º)

CA

Cusp Angle - The angle of the event around the limb of the moon, measured from the nearest cusp. Negative values a indicate bright limb event. The cusps are usually n (north) or s (south), but near full moon can be e (east) or w (west). If a lunar eclipse is in progress, CA given is the % distance from the center of the umbra to the edge (that is, center = 0, edge of umbra = 100) and is followed by a **u**. Values up to 103% are possible.

Dark limb	Northern cusp to +90º W	Positive number with "N" measured counterclockwise from northern cusp (e.g. 43N)
Dark limb	Southern cusp to +90º W	Positive number with "S" measured clockwise from southern cusp (e.g 43S)
Bright limb	Northern cusp to -90º E	Negative number with "N" measured clockwise from northern cusp (e.g. –43N)
Bright limb	Southern cusp to -90º W	Negative number with "S" measured counterclockwise from southern cusp (e.g. –43S)

PA

Position angle - The angle of the event around the limb of the moon, measured from celestial north. The angular convention used is north being 0º and moving counterclockwise to 360º as seen from the naked eye view.

VA

Vertex Angle - the angle of the event around the limb of the moon measured counterclockwise from the vertex of the lunar limb – i.e. the point on the limb highest from the horizon. Angle is measured from 0º to 360º. Angles less than 180º are on the left limb of the moon, and angles more than 180º are on the right limb of the moon, as seen be the naked eye.

WA

Watts Angle - The angle of the event around the limb of the moon, measured eastward from the moon's North Pole. Essential for reappearance, as it locates the event with reference to lunar features. To use, mark a map of the moon around the circumference at 10 deg intervals, starting at the North Pole. Mare Crisium is at about 300 deg. This provides the Watts Angle scale.

LIBRATION L

The libration of the moon in longitude, as seen from the site at the time of the event. The range of longitude libration is ± 7.59º

LIBRATION B

The libration of the moon in latitude. The longitude and latitude librations are the selenographic coordinates on the

Moon's surface through which a line from the Moon's center to the prediction site on the Earth passes. The range of latitude libration is ± 6°.83°

A
Coefficient for correcting the prediction for changes in site location. The units are seconds of time per minute of arc. The correction to the prediction for a change in site, in seconds of time, is found by multiplying **A** by the change in site longitude (in minutes of arc, positive to the East) from the prediction site. See Example below in Section 4.4.1.

B
Same as for **A**, but for changes in latitude (positive to the north).

RV (or photoelectric observations
Radial Velocity - the radial rate of motion of the star relative to the lunar limb, in milli-arc secs per second.

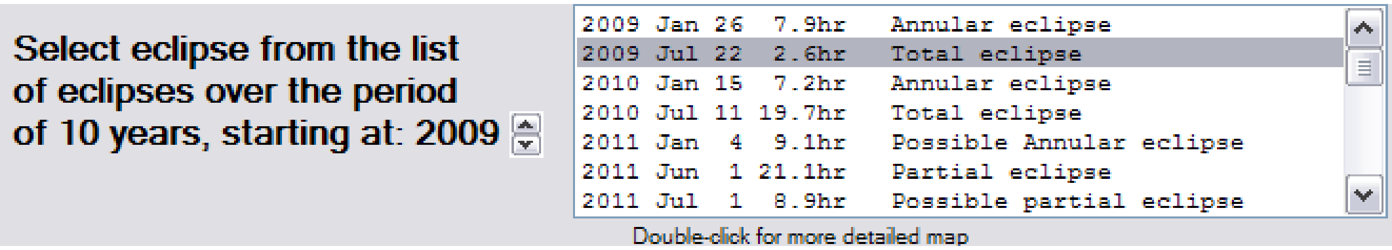
CCT for photoelectric observations
Contact Angle - the difference between the normal to the lunar limb and the direction of lunar motion. Values range between -180 and +180 - with values greater than 90 being reappearances, and positive values to the north, negative to the south.

RA
The apparent RA of the star

DEC
The apparent DEC of the star

4.2.2 Eclipses and Transits

Occult's Eclipses and Transits module provides predictions for solar and lunar eclipses and transits of Mercury and Venus. The user simply keys in a year and to obtain a list of eclipse and transit events. By double clicking on a particular event from the list, a world map is displayed showing the path limits for solar eclipses along with Moon/Earth shadow geometry for lunar eclipses and Earth facing orientations for transits. The program provides a tabular listing of UT times for the start and end aspect of each event. Sample screen for a solar eclipse are shown in Figures 4.6.



Select eclipse from the list of eclipses over the period of 10 years, starting at: 2009

```
2009 Jan 26  7.9hr   Annular eclipse
2009 Jul 22  2.6hr   Total eclipse
2010 Jan 15  7.2hr   Annular eclipse
2010 Jul 11 19.7hr   Total eclipse
2011 Jan  4  9.1hr   Possible Annular eclipse
2011 Jun  1 21.1hr   Partial eclipse
2011 Jul  1  8.9hr   Possible partial eclipse
```

Figure 4.5. *Occult* Eclipses prediction window. Double click on the highlighted event (July 22, 2009 eclipse) to display a world map. See Figure 4.6 for map.

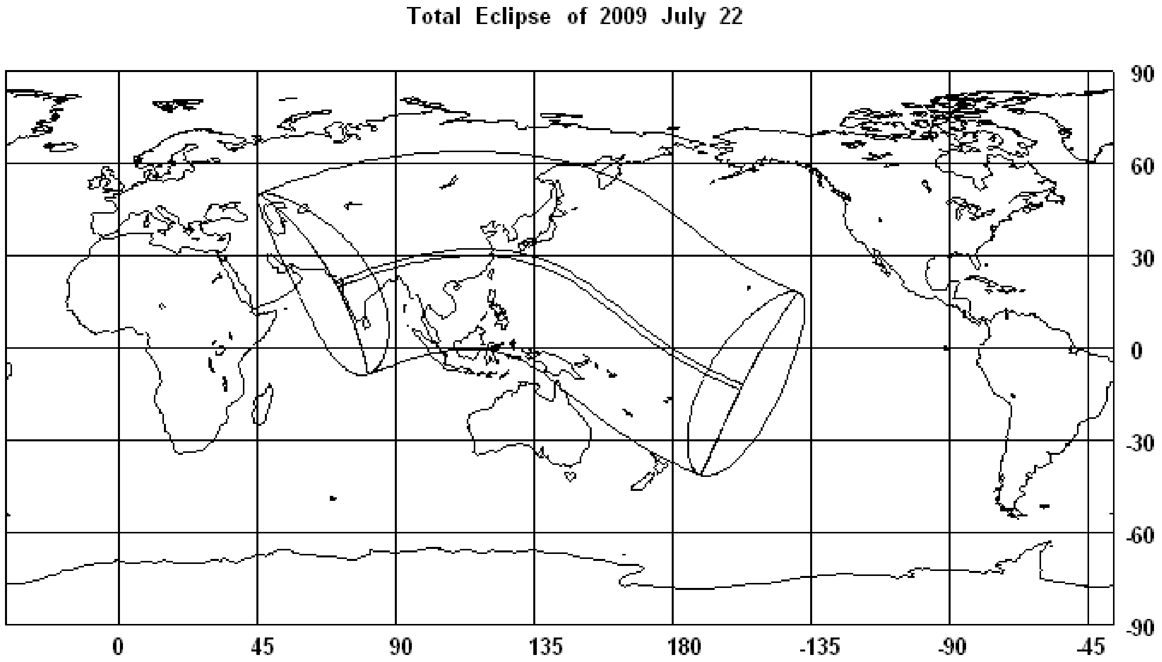
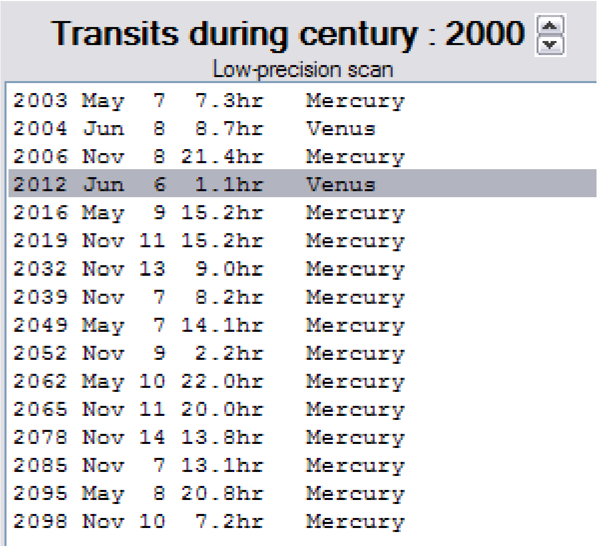


Figure 4.6. Global map projection of eclipse from July 22, 2009. The path of totality from India through China into the south Pacific Ocean is shown. The area where partial phases are visible are shown north and south of totality.

Occult displays detailed maps for eclipses by zooming in on a particular latitude/longitude box. North, south and center path limit predictions may be displayed for individual and multi sites in an easy to read tabular format. Occult predicts eclipses from 2000 BC to 9999AD.

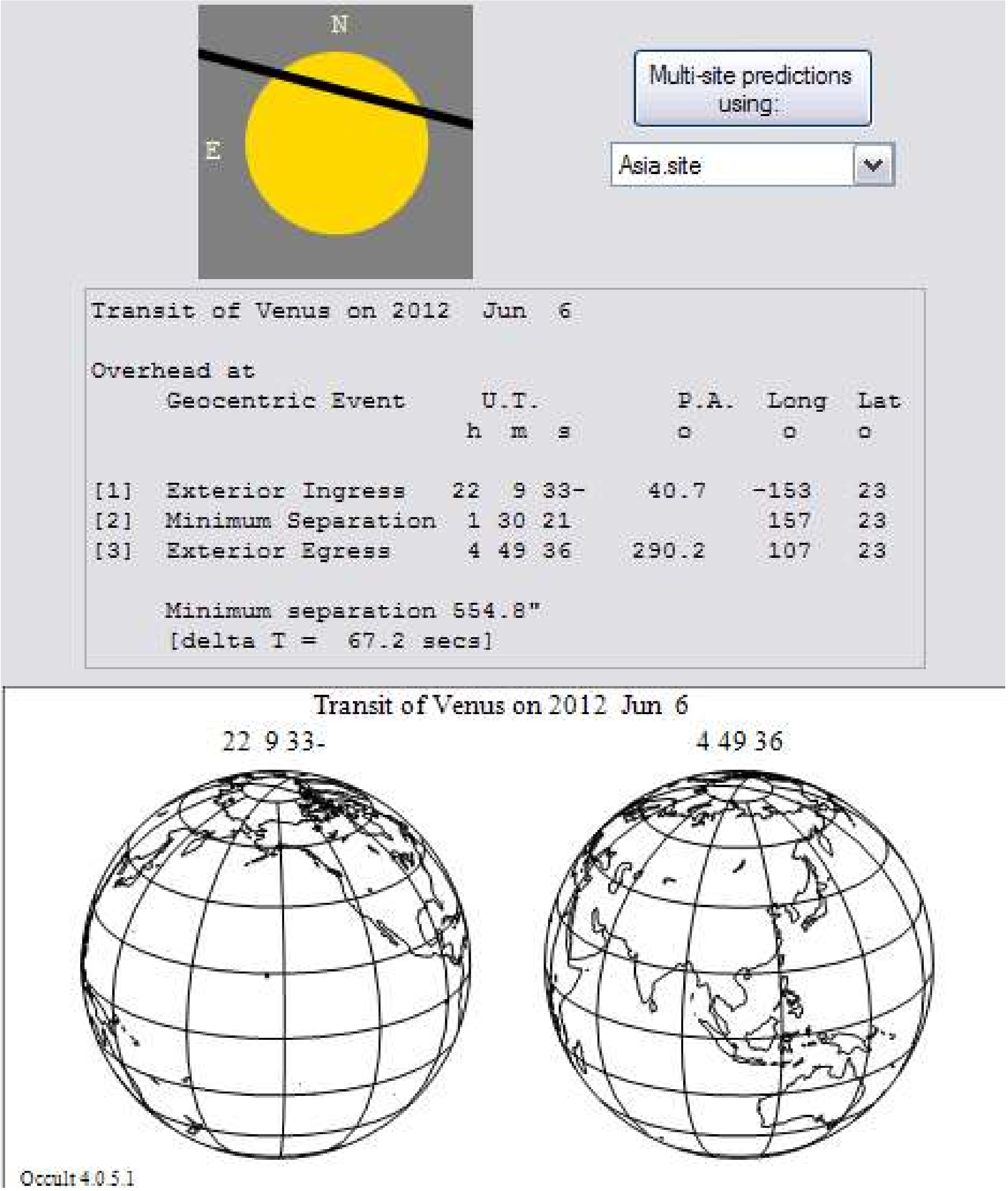
Occult displays the circumstances and contact times for a lunar eclipse. Figure 4.7. shows the Moon's motion through the Earth's shadow along with tabular times of 1st through 7th contact. Also shown for each contact time is the orientation of the Earth as seen from the Moon.



```
2003 May   7  7.3hr   Mercury
2004 Jun   8  8.7hr   Venus
2006 Nov   8 21.4hr   Mercury
2012 Jun   6  1.1hr   Venus
2016 May   9 15.2hr   Mercury
2019 Nov  11 15.2hr   Mercury
2032 Nov  13  9.0hr   Mercury
2039 Nov   7  8.2hr   Mercury
2049 May   7 14.1hr   Mercury
2052 Nov   9  2.2hr   Mercury
2062 May  10 22.0hr   Mercury
2065 Nov  11 20.0hr   Mercury
2078 Nov  14 13.8hr   Mercury
2085 Nov   7 13.1hr   Mercury
2095 May   8 20.8hr   Mercury
2098 Nov  10  7.2hr   Mercury
```

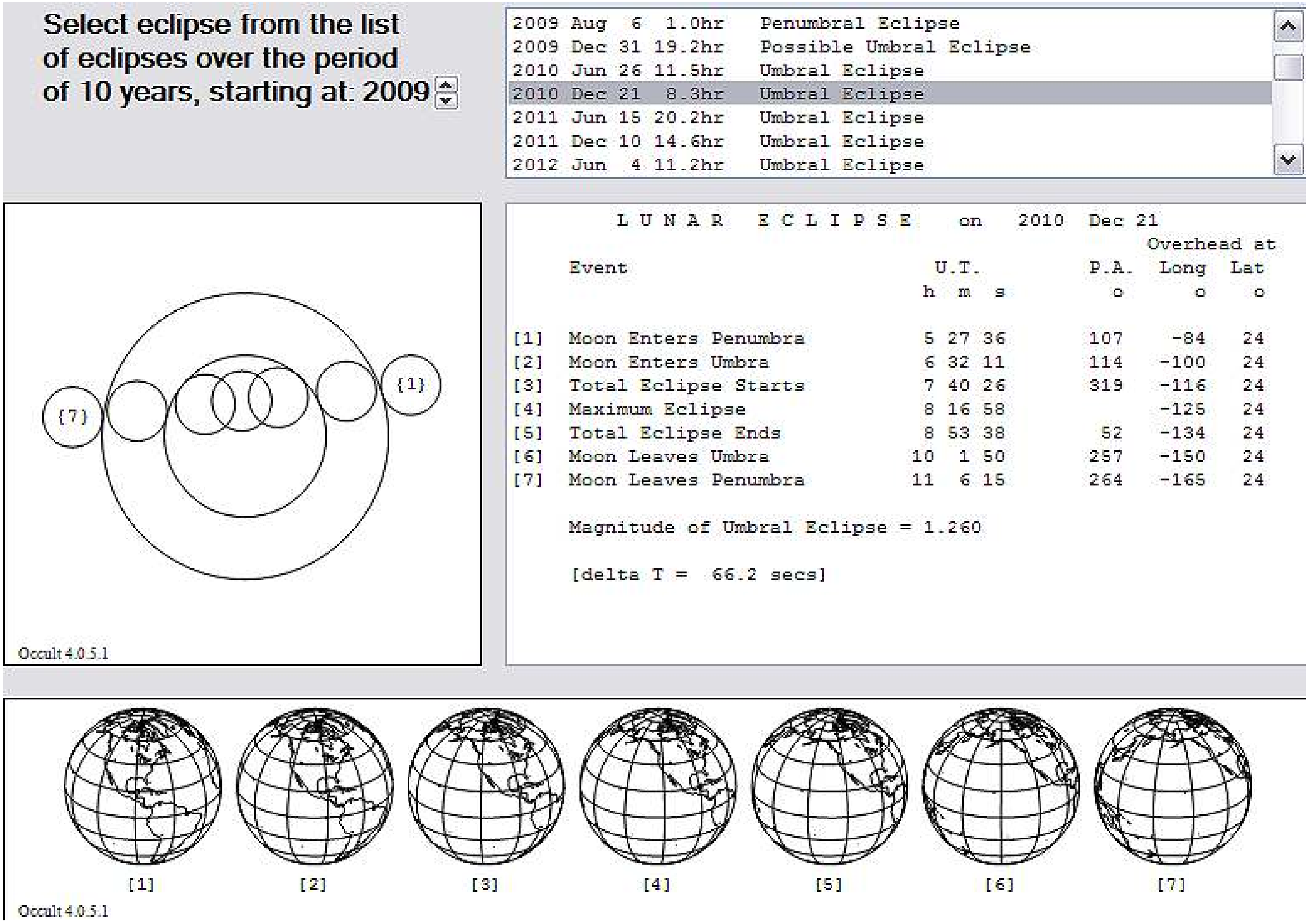
Figure 4.6a Occult Transits window. Transits are listed for the century selected.

By double clicking on a transit event, an Earth view is shown along with the planet's path across the Sun’s disk (Figure 4.6b).



```
Transit of Venus on 2012  Jun  6

Overhead at
     Geocentric Event      U.T.          P.A.  Long   Lat
                         h  m  s          o      o     o

[1]  Exterior Ingress   22  9 33-    40.7   -153   23
[2]  Minimum Separation  1 30 21            157    23
[3]  Exterior Egress     4 49 36   290.2    107    23

     Minimum separation 554.8"
     [delta T =  67.2 secs]
```

Figure 4.6b. Venus transit for June 6, 2012. Orientation of Earth is shown at the start and end of transit. Diagram above the Earth views shows a line and direction that Venus will take as it transits the Sun’s disk.



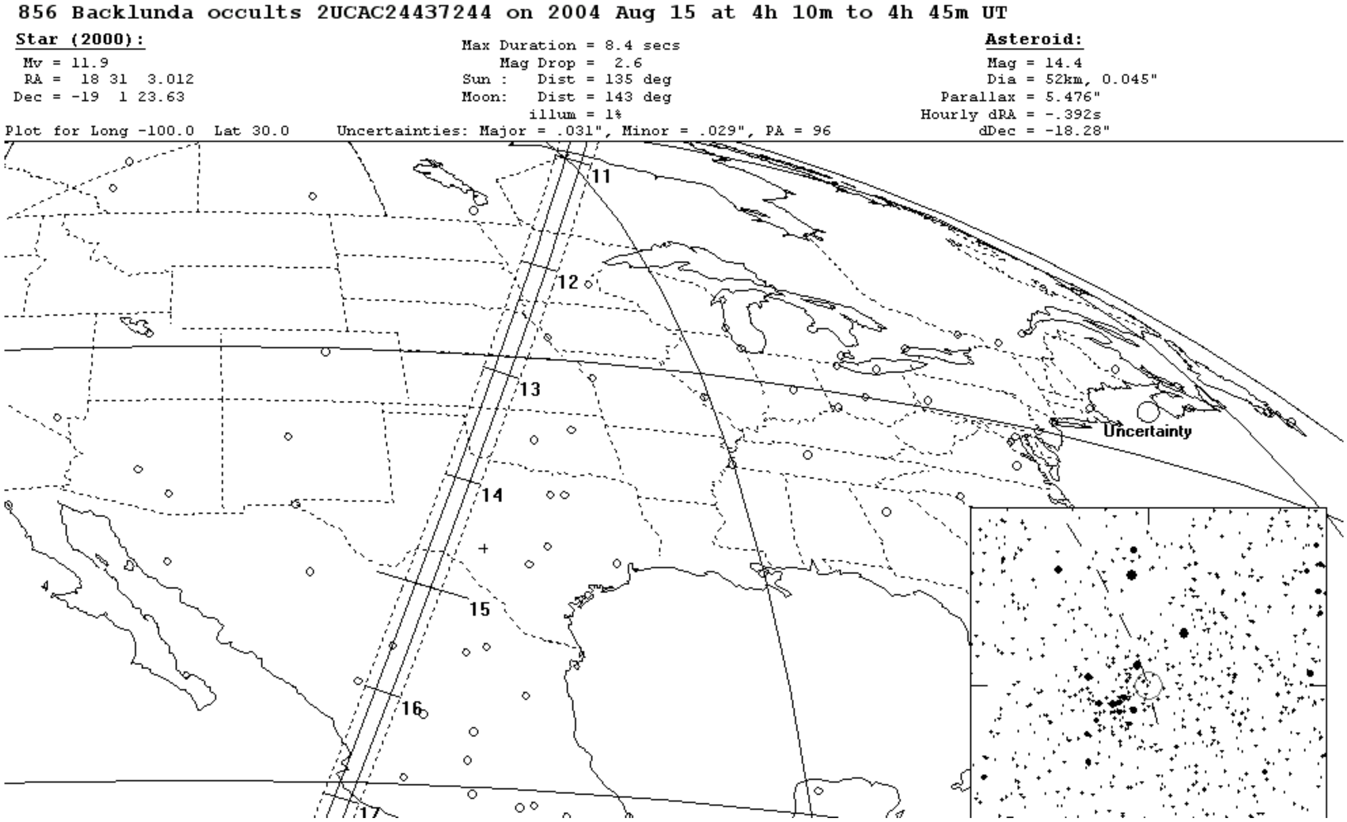
```
2009 Aug  6  1.0hr   Penumbral Eclipse
2009 Dec 31 19.2hr   Possible Umbral Eclipse
2010 Jun 26 11.5hr   Umbral Eclipse
2010 Dec 21  8.3hr   Umbral Eclipse
2011 Jun 15 20.2hr   Umbral Eclipse
2011 Dec 10 14.6hr   Umbral Eclipse
2012 Jun  4 11.2hr   Umbral Eclipse
```

```
         L U N A R   E C L I P S E   on   2010  Dec 21
                                                  Overhead at
     Event                          U.T.        P.A.  Long  Lat
                                   h  m  s        o      o    o

[1]  Moon Enters Penumbra          5 27 36       107    -84   24
[2]  Moon Enters Umbra             6 32 11       114   -100   24
[3]  Total Eclipse Starts          7 40 26       319   -116   24
[4]  Maximum Eclipse               8 16 58             -125   24
[5]  Total Eclipse Ends            8 53 38        52   -134   24
[6]  Moon Leaves Umbra            10  1 50       257   -150   24
[7]  Moon Leaves Penumbra         11  6 15       264   -165   24

     Magnitude of Umbral Eclipse = 1.260

     [delta T =  66.2 secs]
```

Figure 4.7. Lunar eclipse contact times. Earth orientations for each contact time and Moon's motion through Earth's shadow are displayed.

4.2.3 Asteroid Event Predictions

Occult's module on Asteroid and Planet Occultations provides detailed predictions for asteroid and planetary occultations of stars. The user may search for occultations for a particular asteroid or a whole list of asteroids using the Tycho-2, PPM (Position and Proper Motion Catalog), UCAC2 or Goffin star catalog data. With the predicted occultations, each event is displayed in a global format as viewed from the asteroid.



```
856 Backlunda occults 2UCAC24437244 on 2004 Aug 15 at 4h 10m to 4h 45m UT
Star (2000):                         Max Duration = 8.4 secs                        Asteroid:
 Mv = 11.9                              Mag Drop =  2.6                              Mag = 14.4
 RA =  18 31  3.012                  Sun :   Dist = 135 deg                          Dia = 52km, 0.045"
Dec = -19  1 23.63                   Moon:   Dist = 143 deg                     Parallax = 5.476"
                                             illum = 1%                       Hourly dRA = -.392s
Plot for Long -100.0  Lat 30.0     Uncertainties: Major = .031", Minor = .029", PA = 96      dDec = -18.28"
```

Figure 4.8. *Occult* prediction for the asteroid occultation of 856 Backlunda on August 15, 2004. The map projection shows the orientation of the Earth from the asteroid. Details are shown in the tabular section at the top of the chart.

In the prediction of star 2UCAC24437244 in Figure 4.8, the asteroid's shadow will pass over the Earth's surface from 4h 10m to 4h 45m UT, for a total duration of 35 minutes. Each minute across the USA is shown as tick marks ranging from 4h 11m to 4h 15m, which are the predicted times when the asteroid's shadow will pass over that area. For example, the asteroid's shadow moving southward across the USA will pass over the Kansas/Oklahoma border near 4h 13m 20sec, (Figure 4.8a below) and pass from Texas into Mexico near 4h 14m 40sec. An observer can estimate the time of the occultation by interpolating and thus plan accordingly for a particular location.

A 2° x 2° star chart of the target star region is shown on the maps with North up and East to the left.

The asteroid's predicted shadow path and size is indicated by the dark parallel lines on the map that contain the minute by minute tick marks. The dashed lines just outside the predicted shadow lines represent the margin of error in the prediction, called the 1-sigma uncertainty. This means that there is a 68% chance the asteroid's shadow path will shift anywhere in between these dashed lines. Detailed tabular lists for each asteroid occultation event prediction and path maps are located on IOTA's asteroid occultation website, http://www.asteroidoccultation.com. This website is maintained and constantly updated by IOTA astronomer Steve Preston.

In Figure 4.8 tabular quantities are defined as follows:

Star (2000):
M_v
Visual magnitude of the target star being occulted.

RA
Right Ascension of the target star in the J2000 equator and equinox.

Dec
Declination of the target star in the J2000 equator and equinox.

Max Duration
The maximum predicted duration of the occultation in seconds. This is based upon a predetermined estimate of the asteroid's size usually from non-occultation methods. Many surprises have occurred from observations of occultations so this number should only be considered an estimate.

Mag Drop
The drop in brightness during the occultation in units of magnitudes. Before the occultation, when the asteroid and star have merged in the telescope field of view, and can no longer be distinguished as 2 objects, they will have a combined brightness. During the occultation, the star is now covered up by the star, and thus only the light visible is from the asteroid. The drop in brightness is the magnitude drop. The larger the Mag Drop the easier it is to see the occultation, Mag Drops lower than 0.5 are difficult to see visually, however with a video recording and the use of the software program *LiMovie* (See Chapter 8, Section 8.13.1) Mag Drops of 0.10 have been detected.

Sun
Angular distance of the Sun from the target star in degrees

Moon
Angular distance of the Moon from the target star in degrees. The further away the Moon is from the target star makes for an easier to see occultation.

Illum
Sunlit illumination of the Moon expressed as a percentage. 0% = New Moon, 100% = Full Moon

Asteroid
Mag
Magnitude of the asteroid

Dia
Estimated diameter of the asteroid in kilometers followed by its angular diameter in arc seconds. This is only an estimate obtained from non-occultation methods.

Parallax
The parallax of the asteroid from the change in observer's position from the Earth's rotation

Hourly dRA
The asteroid's hourly change in the Right Ascension direction expressed in seconds of time

dDec
The asteroid’s hourly change in the Declination direction expressed in seconds of arc

Plot
Center longitude and latitude of the plot

Uncertainties Major, Minor

The specified uncertainty in the relative position of the star and asteroid.

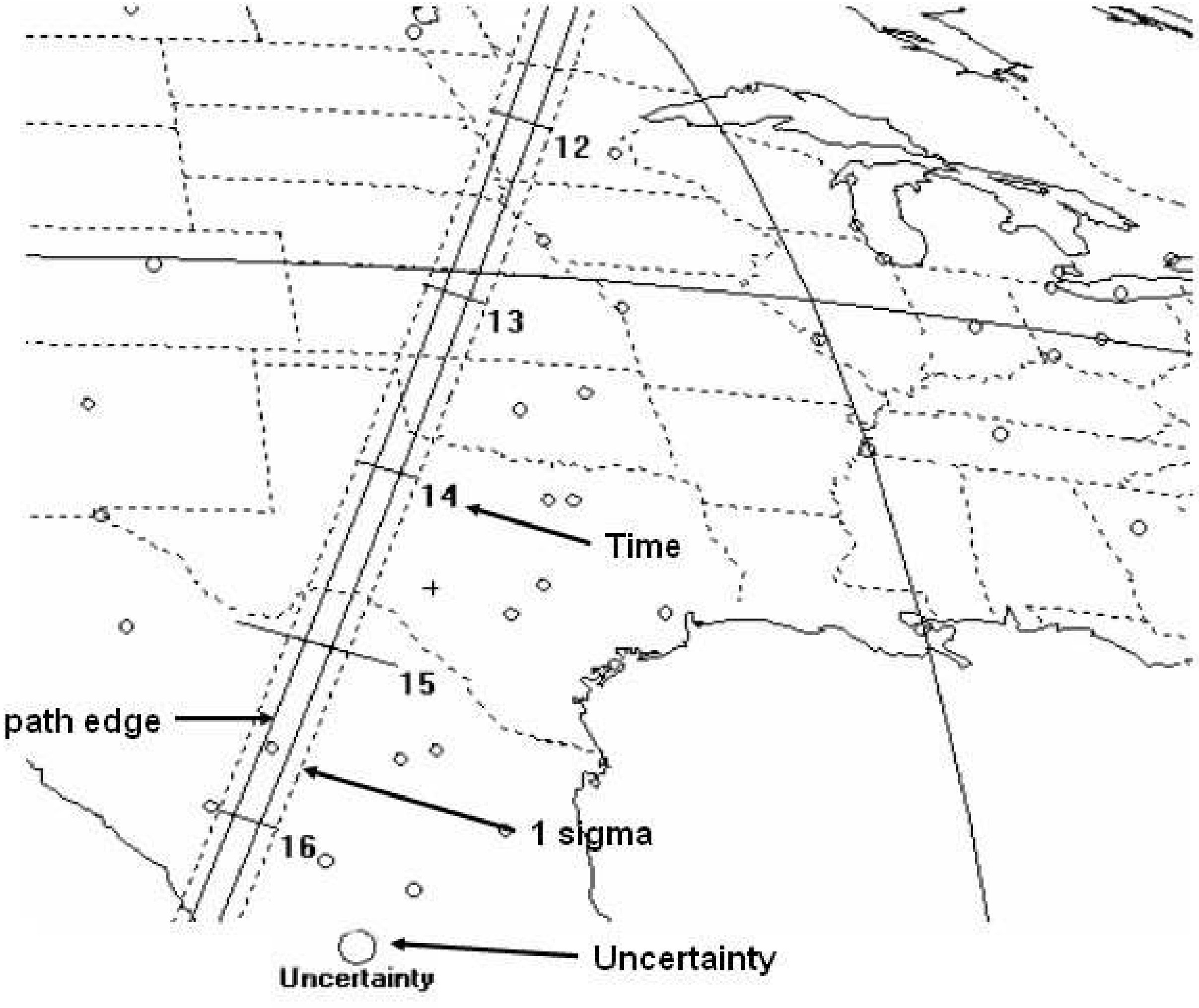


Figure 4.8a. Shadow path description. Enlargement of prediction from Figure 4.8.

In Figure 4.8a the path of the asteroid occultation is displayed with solid parallel lines showing the edges of the asteroid's shadow as it travels across the Earth. *Occult* plots the path and assumes that the asteroid's shape is circular. If the occulted star is not at the zenith, the width of the shadow path is greater than the width of the asteroid thus the actual ground path of the asteroid is a projected path. This concept is illustrated in Figure 5.17 in Chapter 5, *Lunar Grazing Occultations*. The width of the asteroid's projected shadow is determined by the altitude of the star at the time of the event.

The dashed lines on either side of the path lines indicate the effect of a 1-sigma shift in the edge of the path. As mentioned above, in theory, there is a 68% probability the actual path of the asteroid's shadow will fall somewhere between the 1-sigma lines. The uncertainty ellipse is also plotted somewhere on the path plot and shows the full orientation of the 1-sigma uncertainty in the path prediction. One may estimate the location of 2-sigma lines. Given the distance from the path edge to the nearest 1-sigma line as a distance of 1-sigma, the associated 2-sigma line would be located at a distance of 2 x 1-sigma from the path edge. In theory the actual path of the occultation should be located within the 2-sigma lines with a probability of 95%.

Occult shows the time of the occultation along the path by plotting cross lines and labeling them with the time in UT (Universal Time). The time marked on the path is the predicted central time for an event. If the predicted duration of the event is 20 seconds, the event should start 10 seconds before the marked time and end 10 seconds after the marked time.

The small circles on the plots show the location of major cities and towns.

4.2.4 Ephemerides and Mutual Events

Occult's Ephemerides and Mutual events module provides detailed predictions for the following solar system events:

1. Positions, elongations, illuminations, apparent magnitudes and distances of the Sun, planets, comets and satellites in intervals of 1 day to 366 days for any year
2. Positions and an ephemeris of an object from orbital elements
3. Graphics of the planets and their positions including animations of planetary moons
4. Detailed planetary moon ephemeredes including distance from parent planet and position angles
5. Moon phases: perigee and apogee
6. Central meridians for Mars, Jupiter and Saturn
7. Diary of astronomical phenomena
8. Detailed predictions for mutual conjunctions of planets
9. Rise and set times of the major planets
10. Moonrise and Moonset, plus altitude of any object
11. Calendar for any year -9000 BC to +9999 AD
12. Julian Day No, Sidereal time, solar transit times, ecliptic
13. JD ⇔ Date, angle conversions, precession from any dates -9000 to +9999, Earth orientation
14. Draws star charts, magnitude calculator
15. Datum conversions local ⇒ WGS84, plus Geoid heights Mean Sea Level (MSL) TO WGS84

Use of these functions is as easy as a mouse click and following the on screen instructions. The user may save the data to a file or print for easy reference.

4.2.5 Record and Reduce

Occult allows users to record and reduce lunar occultation observations in the standard new Excel format and submit them by email. It will also guide the user to prepare asteroid occultations and allow users to view and analyze graze reports.

4.2.6 Baily's Beads

This application, which is part of the Eclipses and Transits module allows the user to simulate Baily's Beads for a selected solar eclipse and identify them compared to the lunar limb profile. This part of the program is for advanced users involved in IOTA's long term solar radius studies. See Chapter 11, Section 11.3 for more about IOTA's solar eclipse research.

4.2.7 How to obtain Occult Software

The program can be obtained three different ways:
1) browser via http://www.lunar-occultations.com/iota/occult4.htm
2) through FTP software (e.g. WS_FTP) - username: your email address; password: anonymous
3) CD-ROM at a cost of $5. International postal rates will apply outside of the US. Contact Walt Robinson, 515 W. Kump, Bonner Springs KS, 66012. Email for further information: webmaster@lunar-occultations.com

Added notes: For those interested in *Occult* who are located in Australia, please contact David Herald at dherald@bigpond.net.au for quicker delivery service. Mailings from the USA to overseas addresses usually take 1-3 weeks.

Included on the CD-ROM version are the PPM, Goffin and Tycho-2 catalogs for the Asteroidal Module.

4.2.8 How to Obtain Predictions Only

You may request total occultation predictions either by email or regular mail. Please provide your longitude, latitude and telescope diameter to Walt Robinson, 515 W. Kump, Bonner Springs KS, 66012 USA. Email webmaster@lunar-occultations.com. Response time usually takes 3-5 days. Predictions by email are sent in a zip format package, along with other pertinent information. Predictions sent via US Postal Service are in tabular format. You may be referred to an IOTA prediction specialist in your area.

4.3 Royal Astronomical Society of Canada Observer's Handbook

The Observer's Handbook is a 300+ page guide published annually since 1907 by The Royal Astronomical Society of Canada (RASC). Through its long tradition and the expertise of more than 40 contributors, the Observer's Handbook has come to be regarded as the standard North American reference for sky data. Each year under the section "Occultations By The Moon" the handbook has predictions for total occultations for the 18 Standard Stations in the US and Canada, Halifax (Ha), Montreal (Mo), Toronto (To), Winnepeg (Wi), Edmunton (Ed), Vancouver (Va), Massachusetts (Ma), Washington, D.C. (Wa), Chicago (Ch), Miami (Mi), Atlanta (At), Austin (Au), Kansas City (Ka), Denver (De), New Mexico/Arizona (NM), Los

Angeles (LA), Northern California (NC), and Honolulu (Ho). The Standard Stations are shown in Figure 4.9.

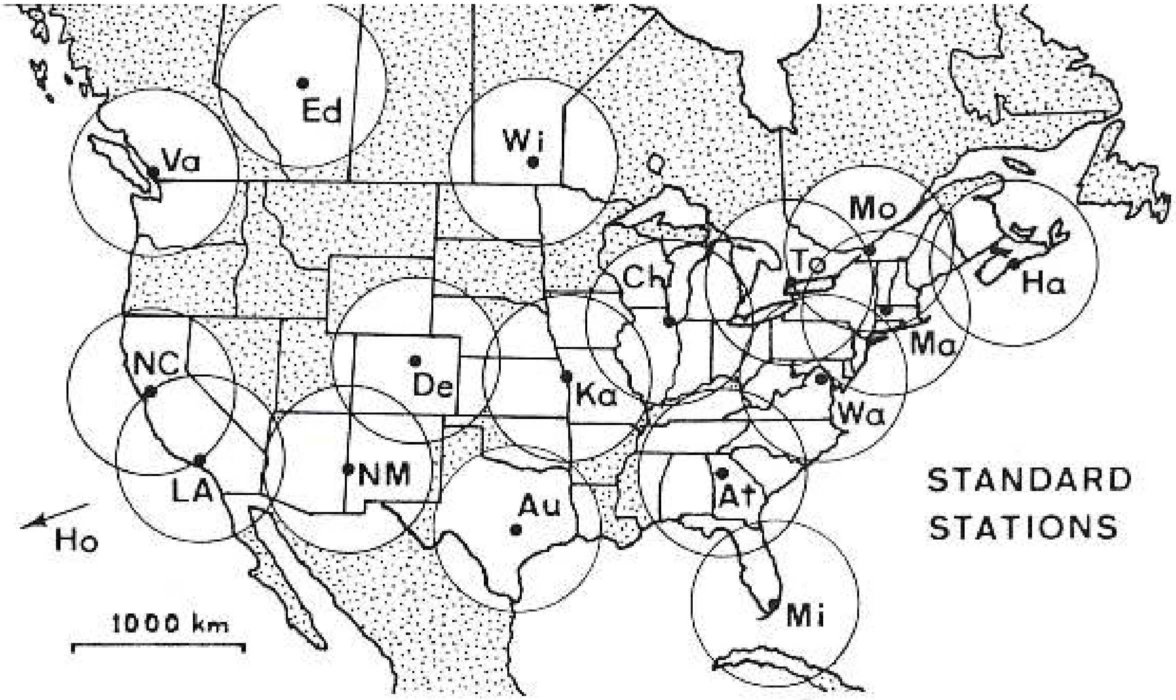


Figure 4.9 North American Standard Stations for occultation predictions by the Moon. Figure Courtesy the Observer's Handbook 2006 Edition, page 153, Royal Astronomical Society of Canada with permission. See also http://www.rasc.ca/publications.htm.

Predictions are limited to stars of magnitude 5.0 and brighter. To compute an event for your city choose the city closest to you. Occultation times will require adjustment for sites outside the listed cities. To do this, use the coefficients ***A*** and ***B*** that are provided for each occultation event in the Standard Station tables using the formula:

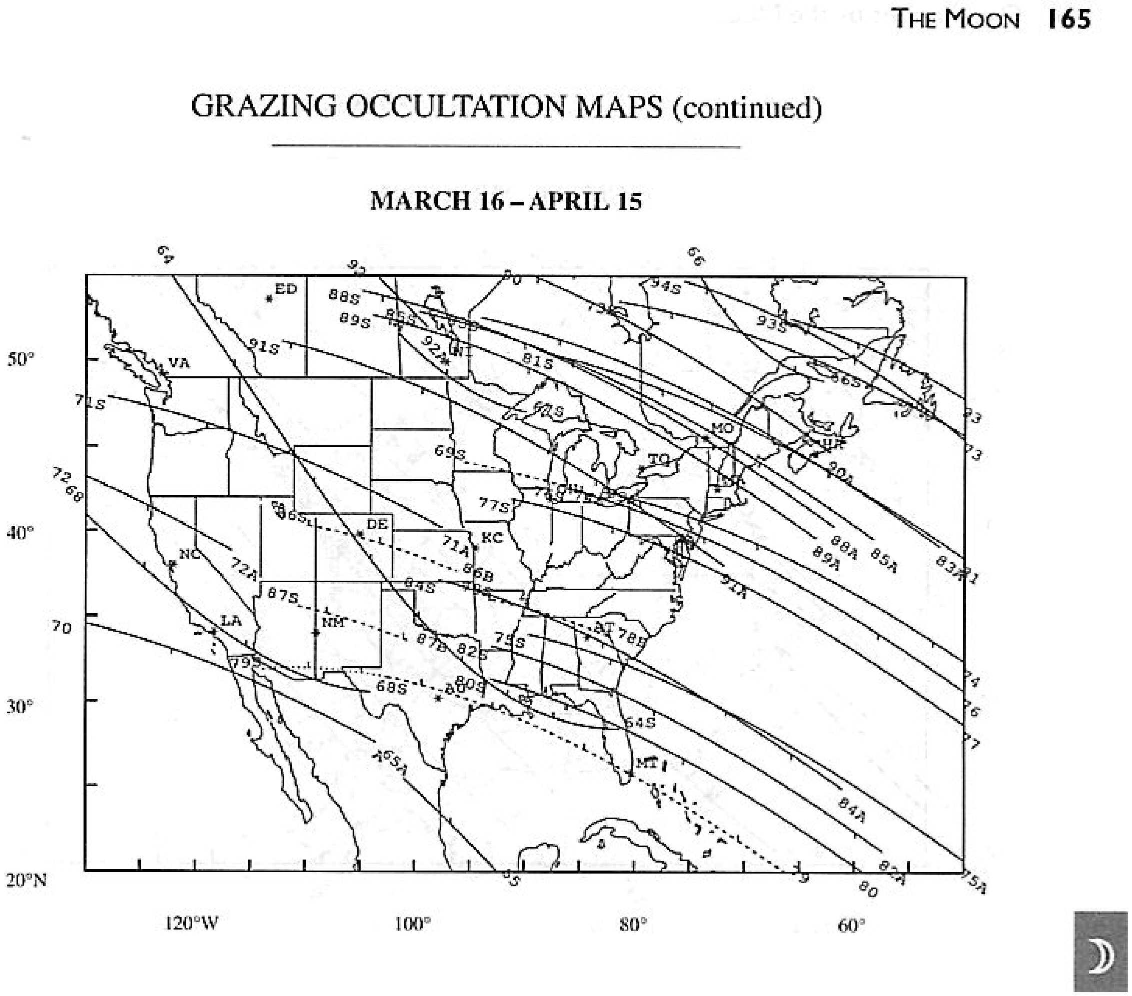
$$\text{UT of event} = \text{UT of event at Standard Station} + \boldsymbol{A}(\text{Lo} - \text{Lo}^*) + \boldsymbol{B}(\text{La} - \text{La}^*), \quad 4\text{-}1$$

where:

Lo*, La* are the longitude and latitude of the Standard Station, in degrees,
Lo, La are the longitude and latitude of the observer, also expressed in degrees,
A and ***B*** are expressed in minutes of time per degree.

Longitude is measured *west* of Greenwich and is assumed to be positive (which is opposite convention used by IAU, *Occult* and *Low* software).

The Handbook also provides a list of favorable grazing occultations. Grazes and path maps are shown for star magnitudes 7.0 and brighter. If the Moon is less than 40% sunlit, maps are shown for stars down to magnitude 7.5. Due to the high number of grazes, the Handbook provides up to one map per month to avoid confusion due to extensive overlapping of the graze paths. A sample graze chart is shown as Figure 4.10 below. A full explanation of the maps and how to read them is provided in the Handbook. The Handbook can be ordered from astronomy clubs or directly from the RASC at http://www.rasc.ca.



THE MOON 165

GRAZING OCCULTATION MAPS (continued)

MARCH 16 – APRIL 15

Figure 4.10. Sample graze chart from the RASC Observer's Handbook. Grazes/tracts are identified by number and a tabular list for each graze is given in the Handbook. Data given for each graze includes date, USNO star number, star's visual magnitude, percent of sunlit Moon, UT of the West end of the track, and longitude and latitude of the West end of the track. Figure courtesy the Observer's Handbook, published by the Royal Astronomical Society of Canada. Reprinted with permission from the Royal Astronomical Society of Canada. See also http://www.rasc.ca/publications.htm.

4.4 Standard Station Predictions – IOTA Website

It is impractical to list predictions for every location and/or observer on the IOTA website. When generating predictions for multiple cities, coordinates may not be close to your particular observing site. Occult uses a multi-city data file which generates predictions for 300+ North American Cities. By selecting a city near you and using formula 4-1, you can compute accurate prediction times for your particular observing site. If you have difficulty computing a prediction using formula 4-1, contact webmaster@lunar-occultations.org for predictions. A listing of the North American cities can be found on the IOTA website at: http://www.lunar-occultations.com/iota/nadat.htm.

4.4.1 Standard Station Predictions and Your Location

When a major occultation event is about to occur predictions are usually placed online at the main IOTA website under the heading, ***Time Critical Events*** for many North American Cities. The format for these multi-city predictions is the same as the format used by *Occult*, with the addition of the ***A*** and ***B*** factor. When the prediction shows the time of the event for your city (or one nearby) a general formula can be used to determine a more precise time of the event for your site.

After selecting the closest major North American city from the selections, use the **A** and **B** column to correct for your local time. Using Blon = base longitude, and Blat = base latitude, and where Lon is your station longitude and Lat is your station latitude, the corrected time is:

$$\text{Local Station Time} = \text{Base Station Time} + \boldsymbol{A}(\text{Blon}-\text{Lon}) + \boldsymbol{B}(\text{Blat}-\text{Lat}) \qquad 4\text{-}2$$

Where Blon, Lon, Blat, Lat are in decimal degrees.
The value sign (+ or –) of the number is important. For stations located East or South of the base station your time will be later than the base station. For stations located West or North of the base station, your time will be earlier than the base station.

An example of how to use the ***A, B*** factor constants to determine your site time:

Date taken from *Occult* predictions: 05/23/04 (see sample output listed from Section 4.2.1) Star ZC 1075. Predicted Time shown from Bonner Springs, KS (the standard station) *Occult* predictions = 2:15:57 UT.

Using the Standard Station of Bonner Springs, KS at 94.89319º West and 39.05794º North, an observer in Blue Springs, Missouri (approximately 40 miles away) wishes to determine the disappearance time at his site. The site location coordinates are 94.34508º West and 39.02783º North.

From the table above of *Occult* predictions, coefficients ***A*** = +1.0 min, ***B*** = -0.5 min.
Thus we have from the above formula:

$$\text{Local Station Time} = \text{Standard Station Time} + 1.0 \text{ min } (0.54811) + -0.5 \text{ min } (0.03011)$$

or

$$\text{Local Station Time} = + 0.54811 \text{ min} + (-0.015055 \text{ min}) = +0.533055 \text{ min}$$

Convert +0.533055 min = +31.98 seconds (rounded to +32 sec) and add this time to the Standard Station time at Bonner Springs, KA:

Local Station Time = 2:15:57 UT + 32sec = 2:16:29 UT at Blue Springs.

Note since the site in question is EAST of the Base Station in Bonner Springs, the Blue Springs disappearance time will be later.

4.5 Training and Simulation

The first time an observer witnesses an occultation, such is the amazement that the observer may forget to actually time it! Although the observer can only gain proficiency through experience, there are several ways he or she can practice without the use of a telescope and at the same time define his or her personal equation. Personal equation (or reaction time) must not be confused with accuracy. Reaction time is that fraction of a second between when the event is seen and when it is marked. Those using a video camera with date/time overlays have zero reaction time, while those using stopwatches for visual observations will have a reaction time difference to subtract from the raw time. Numerous factors come into play when considering reaction time: age, health, weather, and/or distractions.

A study was done in Japan on average individual reaction times. Dr. Mitsuru Soma, who was Director of the International Lunar Occultation Center discusses visual timing accuracies:

“Three occultation observers at Shimosato station of Japanese Hydrographic Department made experiments in 1980 imitating an occultation observation of a 7th magnitude star at the dark limb of a 8 or 9 day old Moon through a 30cm reflector, with the following results:

Table 4.1 Personal equations of actual occultations measured by an oscillograph

	Voice recorded Event				Key-tapping Event			
	Event Type	**N**	**M/sec**	**standard deviation**	**Event Type**	**N**	**M/sec**	**standard deviation**
Observer A	D	20	0.36	0.03	D	18	0.32	0.03
	R	18	0.36	0.04	R	19	0.32	0.05
Observer B	D	18	0.34	0.05	R	18	0.33	0.04
	R	20	0.31	0.03	R	18	0.30	0.03
Observer C	D	19	0.33	0.04	D	20	0.30	0.04
	R	19	0.32	0.05	R	20	0.31	0.04

where Event Type D = Disappearance, R = Reappearance, **N** = number of experiments, **M** = mean value. Times were also obtained by hearing the recorded tapes with an accuracy of 0.1sec or 0.05sec, and the differences calculated hearing the tape minus the time from the oscillograph.

Therefore if one can estimate personal equations appropriately, achieving a 0.3 second precision is not very difficult.”

4.5.1 Simulation Software

Currently on the IOTA website there are two simulation programs which can be used for practice and determining personal equation. *Low* (Lunar Occultation Workbench) as previously mentioned, has a simulation module included with the basic software package. *Occult* has no simulation program.

The first simulation program on the IOTA website written by Gary Goodman is here: http://www.lunar-occultations.com/iota/react.bas. It is written in DOS basic, and will run under any of the Windows operating systems with some considerations. The referenced page is actually the DOS program code, requiring the user to save the program to the PC hard drive and employ BASIC and QBASIC to run the program. BASIC and QBASIC can be downloaded free from Microsoft's website. Go to Microsoft Product Support, do a search on the keyword ***OLDDOS.EXE***. Scroll down to the bottom of the page under ***Other Folder*** download it and extract it to your hard drive. Only the basic executable file and related help file are required. Delete all other files extracted in the package. Place these saved files in the Windows/Command folder and restart your computer.

Asteroid Occultation Program Simulator (AOPS), by Doug Kniffen, can be downloaded from the IOTA website at http://www.lunar-occultations.com/iota/aops.htm. AOPS was originally written for asteroid occultations but is well suited for total occultations. It is a DOS EXE file that will run well under any version of Windows. The events it displays are actually dimmings and brightenings of the star but they are abrupt enough to get a good idea of one's reaction time by following the on-screen instructions. The AOPS simulator is recommendable for those not familiar with DOS programs.

For more detailed discussion about personal equation and methods of estimating it, see Chapter 8 Section 8.2.

4.6 Results and Reporting Observations

4.6.1 IOTA Website Publications

Published articles and observation logs for significant events appear on the IOTA website: http://www.lunar-occultations.com/iota/. There are also archives available on the IOTA website located near the bottom of the page with links to other sites.

4.6.2 Reporting Your Lunar Occultation Observations

Lunar occultation reports are sent by email to your regional coordinator listed in Appendix F. Your regional coordinator is determined by where your observation was made (North America, Europe, Australia, etc.). Both *Occult* and *Low* have options for sending the data electronically. Refer to the help file within each program. Paper submission of reports is no longer accepted. If you cannot send your report by email using the new Excel file format, contact an IOTA member in your area that has email/internet capability.

Report forms and detailed instructions are covered in Appendix F, *Report Forms and How to Report Observations*.

4.6.3 Asteroid Occultation Reporting and Results

For assistance in reporting your successful observation of asteroid occultations, see Appendix F.2. Again, electronic reporting of observations is required.

North American results of asteroid occultation events can be found on several websites:

http://www.asteroidoccultation.com/observations/NA/ - North America results

http://weblore.com/richard/Asteroid_Profiles.htm - Texas results page

Results of events worldwide:

http://www.asteroidoccultation.com/observations - This website has links to asteroid occultations results from Australia and New Zealand, Europe, Japan and North America.

References for Chapter 4

Gupta, R., ed., *Observer's Handbook 2006*, Royal Astronomical Society of Canada, University of Toronto Press, 2006, pp. 153, 165

Limburg, Eric, *Occultation Newsletter*, Volume 8, Number 4; January 2002.

Lunar Occultation Workbench version 3.1, *LOW* 3.1, Eric Limburg, Dutch Occultation Association, http://www.doa-site.nl.

OCCULT, version 4, David Herald, http://www.lunar-occultations.com/iota/occult4.htm November 2007.

5 Lunar Grazing Occultations

NOTE: If you are new to grazing occultations read Sections 5.1 – 5.4 and 5.11 – 5.14. Sections 5.5-5.10 are important for those leading grazing occultation expeditions.

5.1 Introduction

A lunar grazing occultation (called grazing occultations or grazes) is a special type of eclipse in which the Moon *grazes* by the star. The star would thus appear to skim by the Moon's northern or southern limb. The visible effect would reveal the star passing in and out from behind the lunar mountains and valleys, (disappearing and reappearing). Grazes are only visible only from a narrow band on the Earth's surface. The series of disappearances and reappearances from behind the lunar mountains will last a fraction of a second to a minute or longer. This blinking is caused by the lunar topography and is dependent upon the alignment of the observer, the Moon's limb, and the star. An exaggerated view of the lunar limb is shown in Chapter 11 Figure 11.4.

Both the Moon's northern and southern limbs project tracks on the Earth's surface where the graze may be visible. These lines are shown in Figure 5.1. These are the north and south limits of the occultation.

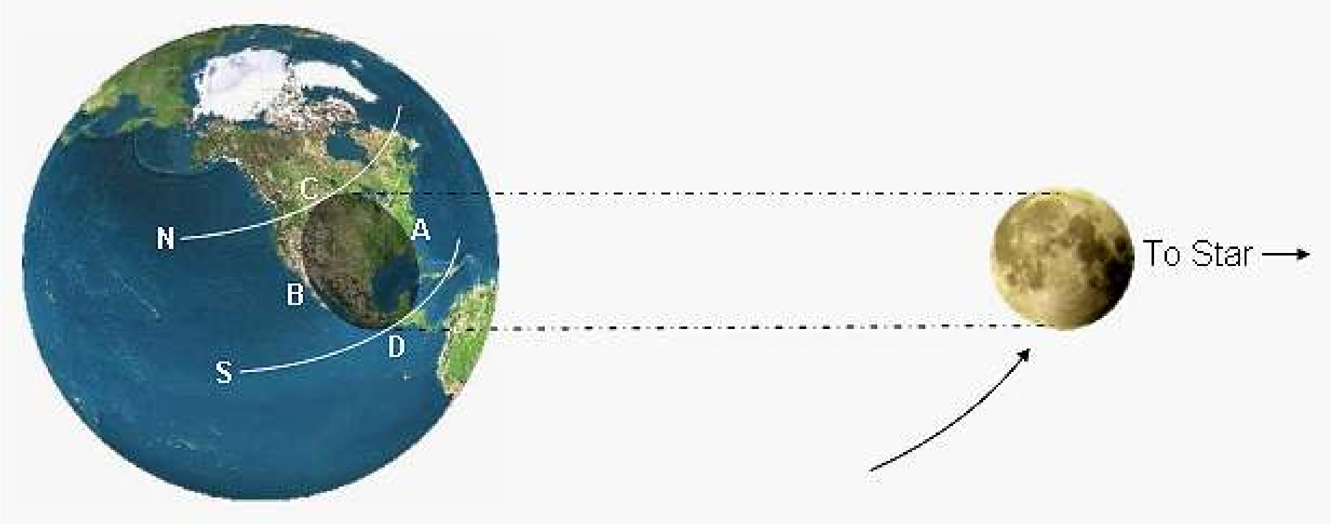


Figure 5.1. Grazing occultation limit lines. The lines *N* and *S* represent the grazing limits of the occultation. Observers stationed along these lines will see a grazing occultation. *N* and *S* are called the north and south limit lines. Earth image © 2006 The Living Earth/Earth Imaging.

The occultation path in Figure 5.1 contains two curves marked with N and S that define the northern and southern limits of visibility of the occultation. These are called the graze lines, also known as the *limit lines*. An observer situated near one of these curves such as at *C* or *D*, will see the star eclipsed (occulted) by the Moon for only a few tenths of a second to a few minutes. The star appears to move along a line tangent to the lunar disk, as shown by the limit lines N and S. The edge of the Moon is not smooth and the observer may see multiple events (a disappearance or reappearance is called an event) as the star disappears and reappears from the mountains and valleys at the Moon's limb. For every grazing occultation there will be two graze regions centered on the predicted northern and southern limit lines *N* and *S*. Due to various factors such as the variations in the topography of the lunar limb and the altitude of the Moon above the horizon, the band on the Earth's surface may vary from several hundred meters to 8 km depending on whether the graze occurs at the Moon's northern or southern limb. The widths of these graze paths are directly related to the heights of the mountains in the Moon's polar regions. A star can produce two grazes 180° apart along the Moon's limb, one at the north limit *N* and one at the south limit *S*. Thus one graze will be on the Moon's sunlit (bright) limb and the other graze along the dark limb (except during total lunar eclipses when both north and south limits are dark limb events). Only the brightest stars can be seen against the Moon's bright limb, so only for those stars is it possible for both the northern and southern grazes to be observed simultaneously. If a total lunar eclipse is in progress, grazes of stars of fainter magnitudes may be observable.

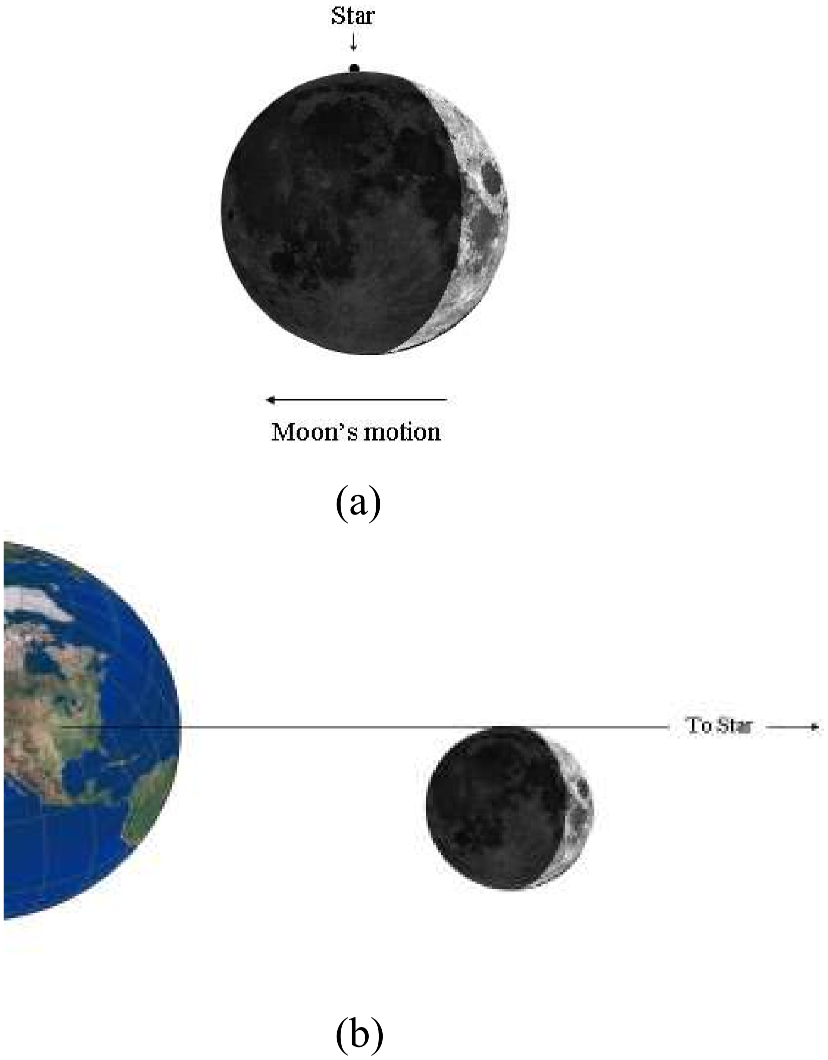


Figure 5.2 Grazing occultation geometry. In order for a graze to occur, the observer , Moon's limb, and star must be in alignment as in (b) above. The observer would see the star appear to drift by the Moon's north limb as depicted in (a). Earth image taken from Snap! 3D atlas. Used with permission, courtesy of Topics Entertainment.

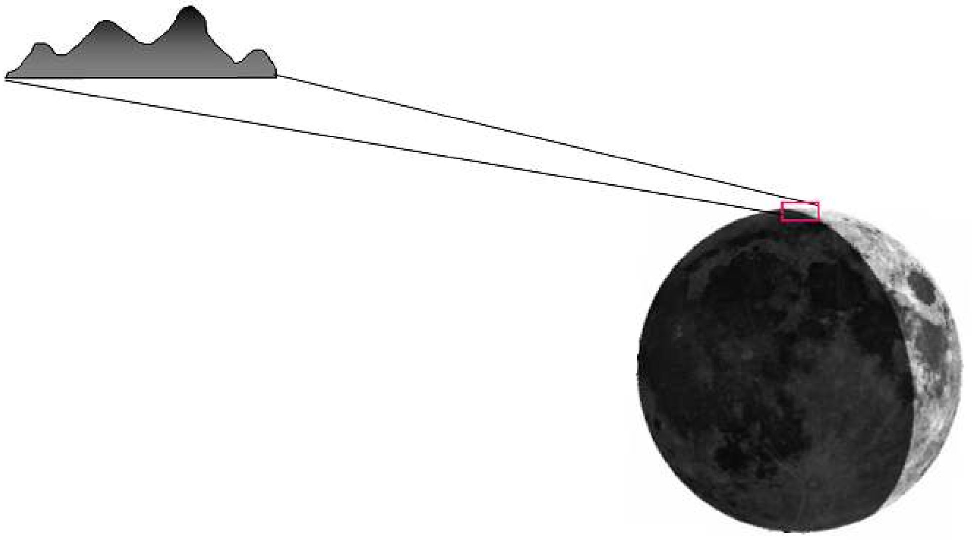


Figure 5.3 View of lunar limb near the Moon’s north pole. The lunar limb consists of craters, mountains and valleys. The south lunar limb has higher mountain peaks than the north limb. Diagram not to scale.

The importance of the lunar limb was studied in detail by Chester B. Watts in his work in the 1940’s and 50’s. The project was started by Dr. Watts in 1946 at the United States Naval Observatory (USNO) in Washington, D.C. The purpose of this project was to produce the most detailed map of the lunar limb to date and to create a precise datum from which to reference the topography. Watts published over 1,800 charts of the lunar limb and determined the limb profiles within 30° of the Moon’s north and south poles. These charts are called *The Marginal Zone of the Moon*. One of the major reasons for observing grazing occultations is to continuously refine the Watts charts, which were published in 1963 and have been computerized. Further refinements in the charts were developed from artificial satellite observations and have made the foundation of the modern occultation program consisting of total occultations and grazes possible. Per Watts convention, the *Watts angle* is measured positive eastward around the lunar limb starting at the Moon’s north pole where the Watts angle is 0°. The Watts angle ranges from 0° to 360°.

Lunar features on the far side of the Moon just beyond the lunar north and south poles are sometimes presented in profile at the Moon's edge during certain latitude orientations. As a result of Cassini's third law these regions are never fully illuminated by the Sun when they are at the lunar limb. Watts' survey of the marginal zone of the Moon being based on photographs taken from the surface of the Earth was not able to map these regions, which we call "Cassini" regions.

5.2 Scientific Value of Grazes

One of the most frequently asked questions by both the amateur and professional astronomer is, “What is the importance of observing grazes?” While grazes are interesting to watch it would be a waste of time if they did not have scientific value. In addition to the scientific benefits and uses of occultation observations mentioned in Chapter 1, grazing occultations have other scientific applications, including:

1. Refinement of the Moon's motion and position in ecliptic latitude. In order to determine the exact position of the Moon, its distance and ecliptic longitude must be known. The Moon's distance has been accurately determined from placement of laser reflectors on the lunar surface by the Apollo astronauts. Two full 18.6 year saros cycles revealed precise distance data (± 5 cm) frequently used today.

2. The Moon is not perfectly spherical and is somewhat flat at the poles in the regions called the "Cassini Third Law Areas." A Cassini region is a sector of surface as seen from the Earth never fully illuminated by the Sun. There are frequent grazes in these areas providing important limb data. With careful observations of grazes it is possible to resolve systematic errors in the Watts lunar limb profile charts. These charts are the most complete set of corrections we have of the marginal zone of the Moon at the present time. Under ideal conditions profile heights of less than fifty feet can be resolved.

3. Grazes have been extremely effective in the discovery of new binary star systems and studying known systems in detail. Binary systems under 0.1" separation cannot be resolved visually, but grazes cover the range between the visual and the spectroscopic range. Under ideal conditions with just a camcorder, a resolution of 0.02 arc/second has been achieved. Hundreds of new binary systems have been found as a result of graze observations.

4. Another benefit of knowing the size, shape and position of the Moon during a graze is determining the position of the star being occulted. Through a total or grazing occultation the positions of radio sources, X-ray sources, infrared and other objects that radiate non-visible wavelengths can be accurately determined. Scientists can perform some of this work in the daytime and even in cloudy weather using radio telescopes.

5. Stellar diameters can be accurately measured with moderate sized amateur equipment during total and grazing occultations. Hundreds of stellar diameters have been measured using the occultation technique. This direct method of measuring stellar diameters complements stellar sizes from astrophysical theories.

6. With more data available, astronomers can begin to determine an accurate system of stellar coordinates within the zodiacal region (The zodiac region is the path in the sky followed by the Sun). This can be used to improve the reference system for stellar proper motions (apparent angular rate of motion a star has across the celestial sphere). Proper motions are of prime importance to accurately compute the mass and rotation of the galaxy.

7. The Earth's rotation rate can be monitored through very precise reductions of total and

grazing occultation data. It is well known that the Earth's rotation rate is slowing down but the exact rate is difficult to measure. Occultation data helps determine the value of ΔT in the equations of motion.

8. Dimming phenomena: Giant and supergiant stars will have a brief dimming effect during an occultation due to their large angular diameter. While this can be seen during a total (single) occultation observation, a grazing occultation provides multiple dimmings to confirm the effect. The dimming effect can also be interpreted as a close double star; thus the grazing occultation offers more than one chance to see the effect. The slope of lunar mountains increases the dimming effect.

9. Accurate lunar limb profiles are used to predict the Baily's Bead phenomenon during solar eclipses. This in turn is being used by IOTA in its long term study of measuring possible solar radius variations. See Chapter 11, *Solar Eclipses and the Solar Diameter*.

10. One extremely important function of the grazing occultation field is to provide a training ground for young visual observers. Many of the leaders in the field of occultations got much of their visual work experience through the American Association of Variable Star Observers (AAVSO), Association of Lunar and Planetary Observers (ALPO), Project Moonwatch and similar organizations.

5.2.1 What to Expect When Observing a Graze

There are four basic phenomena observed during a graze. These include the disappearance (D), reappearance (R), blink (B), and flash (F). A blink occurs when a star disappears and then reappears in less than one second. A flash occurs when the star reappears and then disappears for less than one second. Sometimes other phenomena are experienced. This is where the star disappears or reappears over a period of time that is noticeable to the eye. In one example, a competent observer noted dimming phenomena during a favorable graze of the red supergiant star Antares that lasted a full ten seconds. This particular type of dimming is due to the extremely large angular diameter of these red supergiant stars.

5.3 The Lunar Limb Profile

Lunar mountains and valleys can be seen with small telescopes along the edge of the Moon. These features of the lunar profile affect occultation events. A total occultation disappearance can occur several seconds earlier than predicted if it occurs at the top of a high lunar mountain. Of course, the multiple phenomena seen during a graze are entirely dependent on the lunar profile. Accurate predictions, especially of grazes, demand that the profile be taken into account. In general, the Moon keeps one face pointed toward the Earth, but in practice, the profile changes as the Moon moves in its orbit and as seen from different places on the Earth's surface. The profile depends on the rotation of the Moon which is described by three laws of celestial mechanics that were postulated and observationally confirmed by the Italian astronomer Giovanni Cassini:

1. The Moon rotates uniformly on an fixed axis. The period of rotation being equal to its period of revolution around the Earth.

2. The lunar equator is inclined to the ecliptic by a constant angle of approximately 1° 32′.

3. The plane of the Earth's apparent orbit (seen from the Moon), the ecliptic plane, and the lunar equatorial plane intersect in a line with the ecliptic always in the middle.

The lunar profile depends on the apparent orientation of the Moon as described by the librations, which are the selenographic coordinates of the place on the lunar surface pierced by a line connecting the Earth-based observer and the center of the Moon. The latitude libration is the latitude of this point on the Moon's surface, while the longitude libration is its longitude. The mean longitude libration of the Moon is 6° 9′, due primarily to the non uniform motion of the Moon in its roughly elliptical orbit around the Earth. The mean latitude libration is 5° 9′ due primarily to the Moon's motion north and south of the ecliptic while its rotation axis remains near the ecliptic pole.

5.4 Observing Grazes

Observing grazing occultations requires the observers to be stationed on the ground perpendicular to the Moon’s motion such that the lunar limb is projected onto them. Figure 5.4 shows this geometry and Figure 5.5 shows how observers would set up on the ground path of the predicted projection area. This area is known as the graze path.

Graze observers use the same equipment and the same methods to observe and time the events as described in Chapter 3, Sections 3.3 and 3.4. Prior to attempting a grazing occultation the observer should review these Sections and practice beforehand. Experienced observers and observers with video equipment can record the graze using the techniques described in Chapter 6, Section 6.5 except for the CCD drift scan method which is inapplicable to grazes. Advanced observing and timing methods are presented in Chapter 8, *Timing Strategies for Occultations* Sections 8.10 – 8.13 and Chapter 10, *Unattended Video Stations*.

Figure 5.4. The lunar mountains and valleys are projected onto the Earth’s surface. Diagram not to scale.

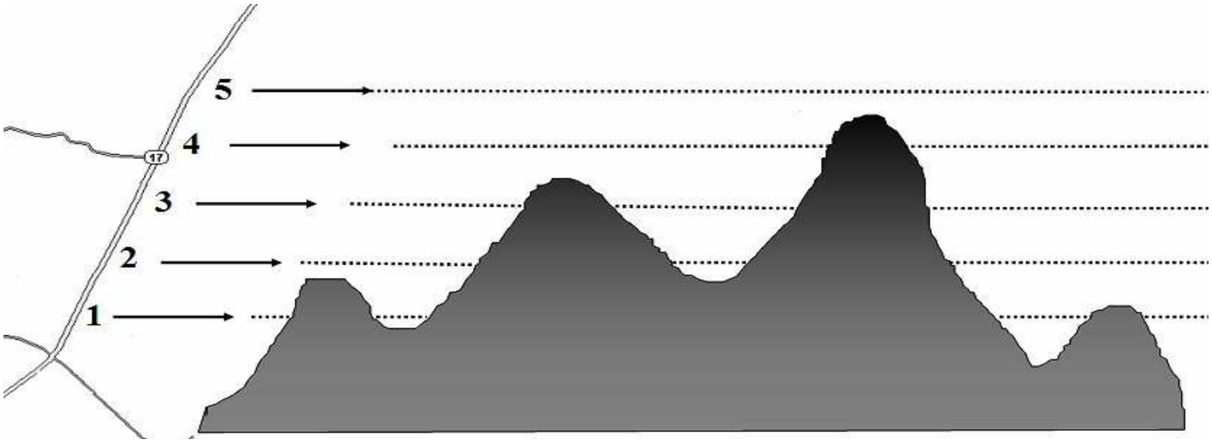


Figure 5.5. Positioning of 5 observers. The graze observers would set up their telescopes at stations 1-5 to get unique coverage of the lunar limb profile.

From Figure 5.5, observers at stations 1-5 will have different timings as the Moon's limb passes over them:

Station 1: This observer has the most events, three disappearances and three reappearances.

Station 2: Two disappearances and two reappearances.

Station 3: Two disappearances and two reappearances. Even though this station has the same number of events as Station #2, they will be at different times as indicated by the slope of the mountains.

Station 4: One disappearance and one reappearance. This observer only sees the events due to the tall mountain peak.

Station 5: No events. This observer's position on the ground is such that there is a miss. This miss observation is valuable data as it places a limit to the height of the tall mountain peak seen by the observer at Station 4.

A good knowledge of the limit line (graze line) is a must for any grazing occultation expedition and is the responsibility of the graze leader. The detailed procedure for organizing a grazing occultation expedition is given in Section 5.11. The basic procedure for a successful grazing occultation expedition is as follows:

1. Examine and plot the limit line on a computer generated atlas or USGS topographic map. The limit line is determined from predictions and the predicted limit line coordinates assume the Moon is a perfect sphere. The limit line actually has a slight arc to it, but for plotting on a 7.5′ topographic map straight lines are adequate since the deviation from an arc is negligible for prediction purposes.

2. Make corrections to the limit line for elevation (Sections 5.5, 5.6)

3. Coordinate with potential observers at least 2 or 3 weeks ahead of time.

4. On graze night, station observers perpendicular to the limit line to provide the maximum amount of coverage of the limb profile. Depending on the limb profile observers could be spread out across a 300 meter span or even up to 3 or 4 km. Obtain precise latitude/longitude coordinates of each observer (See Chapter 7).

5. Observe the graze with the same equipment as you would a total occultation or asteroid occultation (telescope, WWV receiver, video or cassette recorder).

6. Report timings within 24 hours to the graze team leader.

7. Team Leader: send results to the regional coordinator (See Appendix F, *Report Forms and How to Report Observations*) using the preferred email format and keep a paper copy for your files.

Grazes and asteroid occultations are a team effort and require the cooperative efforts of many observers in order to determine the lunar limb profile.

5.5 Elevation Correction

This Section and Sections 5.6- 5.10 are specific for graze expedition team leaders. New grazing occultation observers may desire to skip to Section 5.11.

On a perfect Earth with no deviations from a perfect sphere, (See the "N" and "S" arcs on Earth's surface from Figure 5.1 at the beginning of this chapter) the limit lines projected on the ground by a perfectly smooth Moon would not require any corrections for elevation and variations in topography. Due to the Earth's wide variations in elevation a correction is usually made when plotting a limit line on a map or computer screen map. The discussion of elevation correction and associated limit shift are presented early on in this chapter to familiarize the reader with the physical effects of plotting the limit line when preparing for an actual grazing occultation expedition. Elevation corrections are directly related to the observer's elevation above sea level. The correction amount d can range from zero to 3 or 4 times the observer's elevation for a low altitude Moon during a graze. Elevation corrections are usually made only for elevations above 200 meters (620 feet).

The elevation correction is also known as the TAN Z correction in predictions and is illustrated by comparing Figure 5.6a to Figure 5.6b below. These two figures have North to the left, South to the right, and East/West perpendicular into the paper.

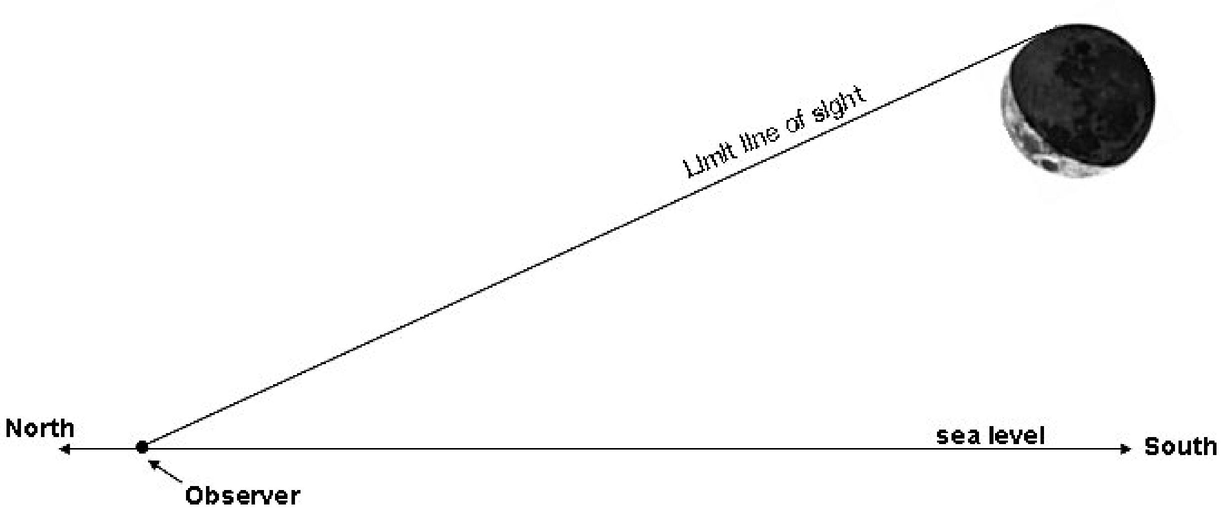


Figure 5.6a. No elevation correction for observer. On a perfect Earth with no deviations in elevation or topography the Moon's limb would project onto the ground at sea level across the graze path. The position of the observer is then uncorrected for elevation.

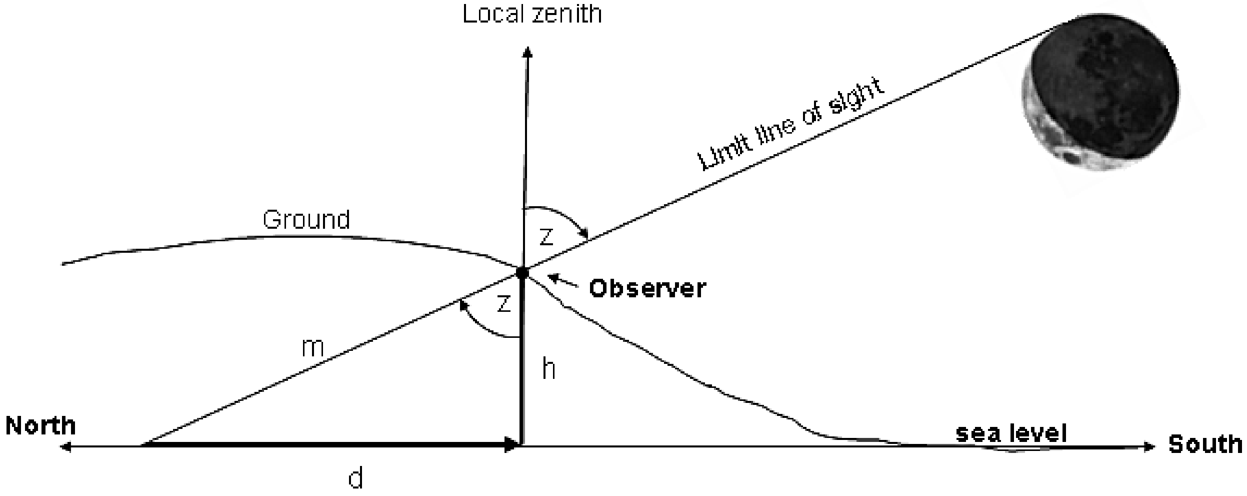


Figure 5.6b. Elevation corrected observer. The observer is at the point marked with an elevation above sea level of **h; z** is the zenith distance and is the angle measured from the local zenith to the line of sight to the Moon's limb. The quantity **d** is the elevation correction to be applied in the direction of the Moon's azimuth. The triangle with the sides **m**, **d**, and **h** and angle **z** allows the elevation correction to be calculated.

Figure 5.6b demonstrates that when set up well above sea level, the observer will set up further south (further north for observers in the southern hemisphere) by the distance d as compared to the observer in Figure 5.6a. In Figure 5.6b above the triangle defined by the sides m, d, h is identified as follows:

h = elevation (altitude) of observer in feet or meters
m = line of sight distance to the Moon from the fictitious ground (at sea level) to the observer at elevation h
z = zenith distance (angle) of the star being occulted
d = correction to limit line applied in the direction of the Moon's azimuth

thus

$$\tan z = \frac{d}{h} \qquad 5\text{-}1$$

or

$$d = h \tan z \qquad 5\text{-}2$$

The elevation h is determined from topographic maps (www.topozone.com or sometimes GPS receivers*). From the graze predictions the quantity z is given to compute the elevation correction d. If one does not have the zenith distance z, it can be computed easily in one of two ways. First, note the target star's altitude a at the time of central graze. This quantity is available from the graze predictions or many of the planetarium programs for desktop PC's with a few mouse clicks. Subtract this corrected altitude from 90° to obtain the zenith distance z. For zenith distances of 0° the elevation correction equals 0.

The second method for obtaining the zenith distance requires a scientific calculator with trig functions or a computer using the formula:

$$\cos z = \sin \delta \sin \phi + \cos \delta \cos h \cos \phi \qquad 5\text{-}3$$

where

δ = graze star's declination (or Moon's declination)
ϕ = observer's latitude
h = local hour angle of the Moon at the time of central graze

The hour angle h is the angle measured from the observer's meridian to the hour circle of the Moon. It is the time interval it takes for the Moon to go from the local meridian to the location when the graze occurs or vice versa and is related to the sidereal time, ST = h + RA, with RA = right ascension coordinate. The hour angle is usually given in hours, minutes and seconds and will be in the same units as the other variables (degrees or radians) for use in formula 5.3.

For grazes north of +31° latitude the elevation correction d is always southward unless the elevation is below sea level. This is because +31° is the highest northern latitude in which the Moon can reach the local zenith. Latitudes south of +31° will have the Moon on the southern half of the local celestial sphere as shown in Figures 5.6a and 5.6b. Elevation corrections are vector quantities and the directions in which they are applied is as important as their measure. To apply the elevation correction to plot the shifted limit line see Section 5.6 below.

5.6 How to Apply the Limit Line Correction

This Section and Sections 5.7-5.10 are specific for graze expedition team leaders. Beginning graze occultation observers may desire to skip to Section 5.11.

---

*GPS receivers provide elevations; however the elevation correction to the limit line is usually done long in advance of the graze, usually before the graze leader makes a field trip to the observing site.

Once the elevation correction *d* has been obtained from Section 5.5 for a graze the limit line will be shifted by the perpendicular amount *X* in the direction of the Moon's azimuth. Next plot the shifted line on the map you intend on using to station the observers for the graze.

Figure 5.7 shows the effect of the elevation correction. The sea level limit line is drawn using two points generated by the predictions. The elevation corrected line is then drawn further south by the amount *X* which is computed as follows:

In Figure 5.7 below,

d = elevation correction (feet or meters)
X = shift to correct limit line
angle VAH = G = Moon's azimuth at time of graze
angle VAI = F = azimuth of sea level limit line

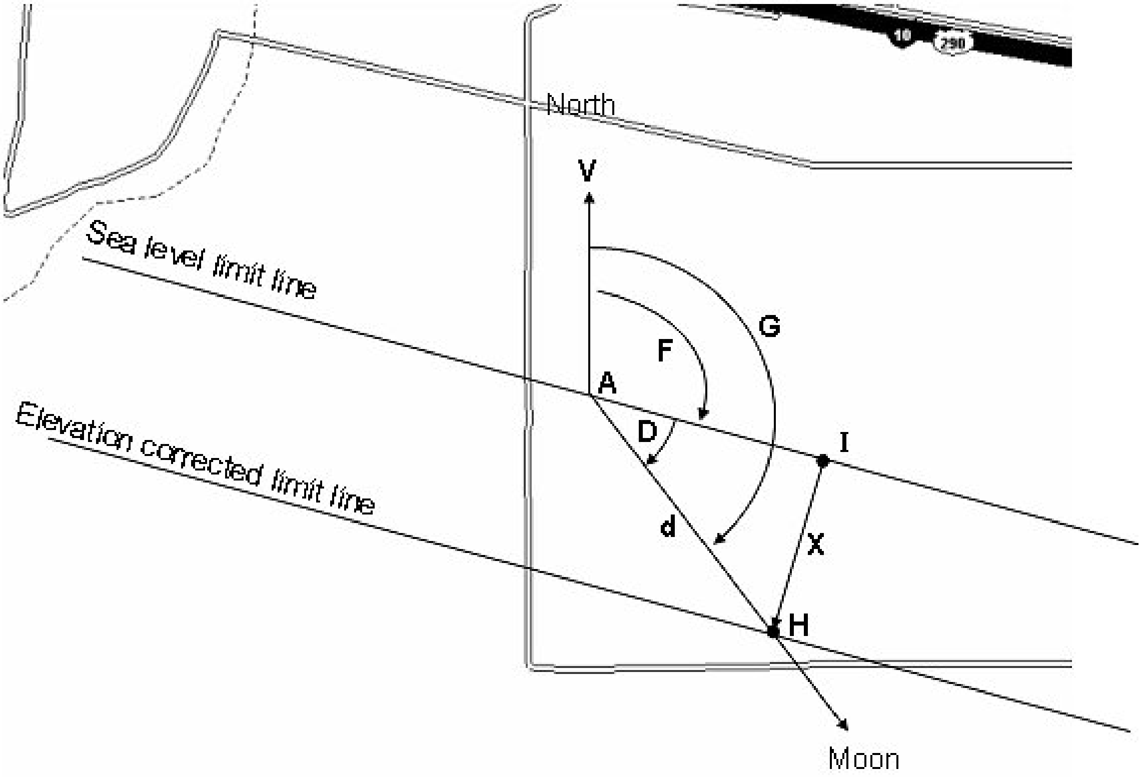


Figure 5.7 Limit line shift. The sea level limit line is the projection of the Moon's limb on a perfect uniform smooth Earth. The elevation corrected limit line is shifted by the amount *X* in the direction of the Moon's azimuth AH and is parallel to the sea level limit line. Background map from Microsoft *Streets and Trips*. Microsoft product screen shot reprinted with permission from Microsoft Corporation.

From Figure 5.7, subtract angles G – F = D, and then

$$\sin D = \frac{X}{d} \qquad 5\text{-}4$$

or

$$X = d \sin \mathsf{D}$$

$$X = h \tan z \sin \mathsf{D} \qquad 5\text{-}5$$

If the elevation h is in meters, X will also be in meters. The azimuth angle F of the sea level limit line can sometimes be computed from GPS receivers by plotting two longitude points centered at the intended graze observing site. In GPS terminology the angle F is known as the bearing angle.

The angle F is found below the lunar limb profile plot on *Grazereg** predictions. See Figure 5.8 below shown as line 5 under the plot "HEADING = 79.75 DEG". The occultation programs *Low* and *Occult* do not currently provide the azimuth of the limit line.

For users using *Low* or *Occult* a method to compute the angle F is as follows: In Figure 5.7b below, the sea level limit line is one side of a right triangle with sides *AI*, *AB* and *BI*.

This triangle is a spherical triangle since its sides are on the Earth's curved surface. For practical purposes we will assume its sides to be short enough to approximate a plane triangle so that we can use elementary trigonometry to compute the angle F.

The point *A* has the coordinates of (LAT, LONG $_{\text{WEST}}$) and the point *I* has the coordinates (LAT, LONG $_{\text{EAST}}$). The angle at point *A* is a right angle (90º) and the angle denoted by F is the unknown angle to be calculated. Clearly F = angle VAB + *b* or 90º + *b*. The angle *b* is found by

$$\tan b = \frac{BI}{AB} \qquad 5\text{-}6$$

The side *BI* is equal to the difference in latitudes of points *A* and *I* (denoted $\Delta\phi$), and the side *AB* is equal to the difference in longitudes of points *A* and *B* (denoted $\Delta\lambda$), thus

$$\tan b = \frac{\Delta\phi}{\Delta\lambda \cos \phi} \qquad 5\text{-}7$$

thus

$$b = \tan^{-1} \frac{\Delta\phi}{\Delta\lambda \cos \phi} \qquad 5\text{-}8$$

The quantity cos ϕ is applied as a correction to compensate for the different distances between identical longitude meridians on Earth due to higher latitudes. Choose ϕ as the latitude half-way between the points selected.

**Grazereg* is a computer program that predicts grazes and provides tabular data.

We can now calculate F = 90º + *b*. *A* and *B* are any two well spaced points 10 km apart from the detailed graze predictions found below in Table 5.2 or Figure 5.10. Graze predictions provide longitudes and latitudes for numerous points along the limit line.

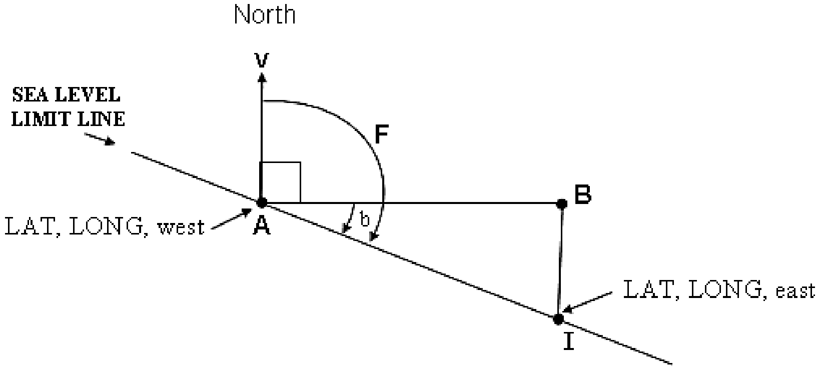


Figure 5.7b. Computing the azimuth F of the sea level limit line. F = 90 + b. A right triangle is formed from the sides AB, BI and AI.

Elevation Correction Example: For an observer's elevation of 322.5 m (1,000 feet) above sea level and a Moon's zenith distance of 41°, Moon's azimuth of 153° and a sea level limit line azimuth of 106°, the limit line correction is computed using equation 5.5 above:

$$X = 322.5 \tan(41°) \sin(153° - 106°)$$

$$X = 322.5\,(0.869)\,(\sin 47°)$$

$$X = 322.5\,(0.869)\,(0.731) = 205 \text{ meters}$$

The limit line would be plotted 205 meters further south parallel to the sea level limit line. Caution: Large differences in elevation across a 10 km mile stretch of the limit line plotted on a map will affect the correction/shift. Expedition leaders will prepare the correction/shift for each graze team site.

5.7 Grazing Occultation Predictions

Detailed occultation predictions and lunar profiles are distributed to IOTA members by volunteers known as Computors, who prepare the predictions from one of the computer programs *Occult*, *Lunar Occultation Workbench* (*Low*), *Grazereg* and/or the *Automated Computer Limb Profile Prediction Program* (*ACLPPP*). Interested observers can make their own predictions using these same freeware programs. Summary predictions of stars in North America to magnitude 7.5 are found in the yearly publication *Observer's Handbook*, published by the Royal Astronomical Society of Canada (www.rasc.ca). See also Chapter 4, Section 4.3 for more information. In addition, *Sky and Telescope's* February issue each year provides graze paths for North America and Europe for some of the brighter stars and highlights important planned expeditions.

Prior to 1993, data for predictions were provided by the United States Naval Observatory. Since 1994, data has been taken from modern star catalogues such as Tycho-2, Hipparcos, PPM, UCAC2 and the Moon's dynamical parameters from updated lunar ephemeredes and modern theories of the Moon's motion. The predictions use the most up to date lunar limb database. This constantly revised database is made from the Watts charts and has been updated with the many thousands of grazing occultation data observations since 1963.

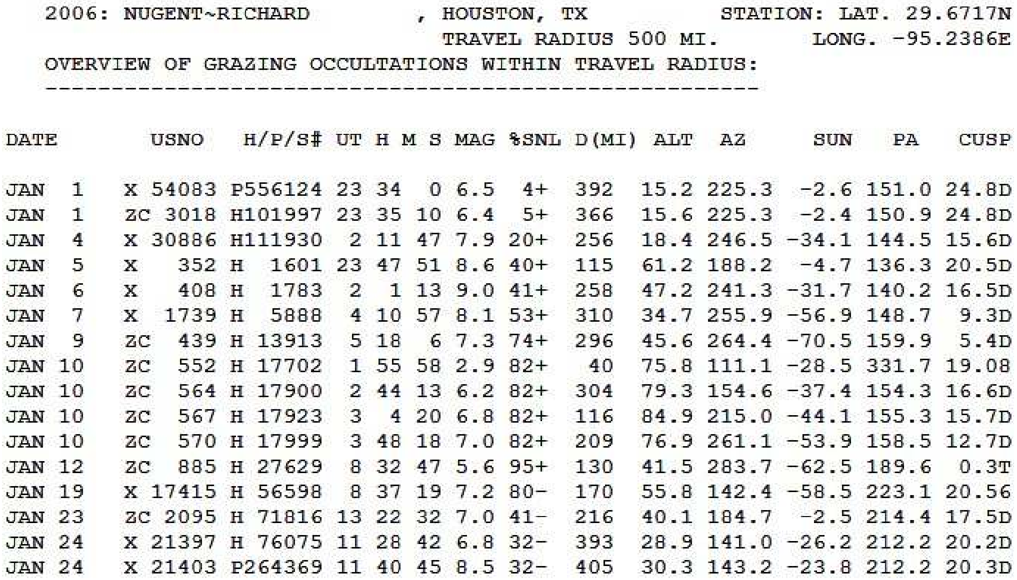
Persons interested in observing grazing occultations can request a list of grazes from a Computor that will occur within a specified radius of their homes. The Computor will send (usually by email) the list of predictions and the detailed circumstances of each graze. Interested graze observers can contact an IOTA member in their areas to locate a Computor.

Predictions from Computors are in tabular form (Table 5.1, 5.2). Profile plots are derived from the *Grazereg* program (Figure 5.8), the programs *Low* (Figure 5.9) or *Occult* (Figure 5.14).

These predictions give the data for northern or southern limit grazes within a travel radius the observer has selected. The grazes are rated based on the expected ease or difficulty of observation with additional information provided about the Moon and star. Each observer is provided with a summary page listing all predicted events (one line per event) for the time period requested. The profile predictions prepared from the Watts charts of the marginal zone of the Moon give the observer an indication of the distance from each side of the limit line where multiple events will be seen.

5.7.1 Overview of Predictions

Tables 5.1, 5.2 and Figure 5.8 show sample predictions, detailed graze data and the Moon limb profile using the *Grazereg* program written by Dr. Eberhard Riedel of the IOTA European Section. (IOTA-ES).



```
   2006: NUGENT~RICHARD        , HOUSTON, TX         STATION: LAT. 29.6717N
                                 TRAVEL RADIUS 500 MI.       LONG. -95.2386E
   OVERVIEW OF GRAZING OCCULTATIONS WITHIN TRAVEL RADIUS:
   ------------------------------------------------------

DATE        USNO    H/P/S# UT H  M  S MAG %SNL D(MI) ALT   AZ      SUN    PA   CUSP

JAN  1    X 54083 P556124 23 34  0 6.5  4+   392  15.2 225.3  -2.6 151.0 24.8D
JAN  1    ZC 3018 H101997 23 35 10 6.4  5+   366  15.6 225.3  -2.4 150.9 24.8D
JAN  4    X 30886 H111930  2 11 47 7.9 20+   256  18.4 246.5 -34.1 144.5 15.6D
JAN  5    X   352 H  1601 23 47 51 8.6 40+   115  61.2 188.2  -4.7 136.3 20.5D
JAN  6    X   408 H  1783  2  1 13 9.0 41+   258  47.2 241.3 -31.7 140.2 16.5D
JAN  7    X  1739 H  5888  4 10 57 8.1 53+   310  34.7 255.9 -56.9 148.7  9.3D
JAN  9    ZC  439 H 13913  5 18  6 7.3 74+   296  45.6 264.4 -70.5 159.9  5.4D
JAN 10    ZC  552 H 17702  1 55 58 2.9 82+    40  75.8 111.1 -28.5 331.7 19.08
JAN 10    ZC  564 H 17900  2 44 13 6.2 82+   304  79.3 154.6 -37.4 154.3 16.6D
JAN 10    ZC  567 H 17923  3  4 20 6.8 82+   116  84.9 215.0 -44.1 155.3 15.7D
JAN 10    ZC  570 H 17999  3 48 18 7.0 82+   209  76.9 261.1 -53.9 158.5 12.7D
JAN 12    ZC  885 H 27629  8 32 47 5.6 95+   130  41.5 283.7 -62.5 189.6  0.3T
JAN 19    X 17415 H 56598  8 37 19 7.2 80-   170  55.8 142.4 -58.5 223.1 20.56
JAN 23    ZC 2095 H 71816 13 22 32 7.0 41-   216  40.1 184.7  -2.5 214.4 17.5D
JAN 24    X 21397 H 76075 11 28 42 6.8 32-   393  28.9 141.0 -26.2 212.2 20.2D
JAN 24    X 21403 P264369 11 40 45 8.5 32-   405  30.3 143.2 -23.8 212.2 20.3D
```

Table 5.1. Sample graze prediction for an observer in Houston, Texas. This is only a partial list of grazes generated.

Table 5.1 is a convenient list of all grazes within the specified radius of the observer's station coordinates (upper right hand side of Table) giving basic information for each graze. By examining this table, the graze observer can decide which grazes would be attempted. For example, the Jan 1st graze of ZC 3018 occurs at 5:35 pm local Houston time (which is December 31st the evening before) with the Moon's altitude of just 15.6 degrees. The Sun is only 2.4 degrees below the horizon (see column SUN), thus bright twilight exists. Even with the relatively bright 6.4 magnitude star this graze is highly unfavorable due to the twilight interference.

The Jan 24th graze of USNO 21397 is more favorable. It occurs at 5:28AM approximately 2 hours before sunrise in a dark sky with a magnitude +6.8 star. The star will be at a cusp angle of 20 degrees. The Moon is 32% illuminated (waning crescent) 28.9 degrees above the horizon at the time of central graze. This graze is listed as 393 miles from the observer's base station so if the observer wasn't planning a trip in the direction of the graze, the long travel time must be considered in planning to observe this event.

In Table 5.1, the columns are identified as:

Date: Date of graze

USNO: United States Naval Observatory reference no. or Zodiacal Catalog (ZC) star number

H/P/S#: The letters H, P or S in front of the number refer to the star catalog, H=Hipparcos, P=Position and Proper Motion catalog, S =SAO catalog

UT H M S: Universal time of central graze in hours minutes and seconds

MAG: visual magnitude of the star

%SNL: percent of the Moon that is sunlit and is also an indication of the phase of the Moon. A '+' after this number refers to a waxing Moon (phase between new and full) and a '-' after this number refers to a waning Moon (phase between full and new)

D(MI): perpendicular distance in miles of the graze line from the observers specified site coordinates

ALT: altitude in degrees of the star at central graze. Altitude varies from 0 - 90°

AZ: azimuth in degrees of the star at central graze. Azimuth range is 0 - 360°

SUN: altitude of the Sun in degrees at central graze. Negative signs specify the Sun is below the horizon.

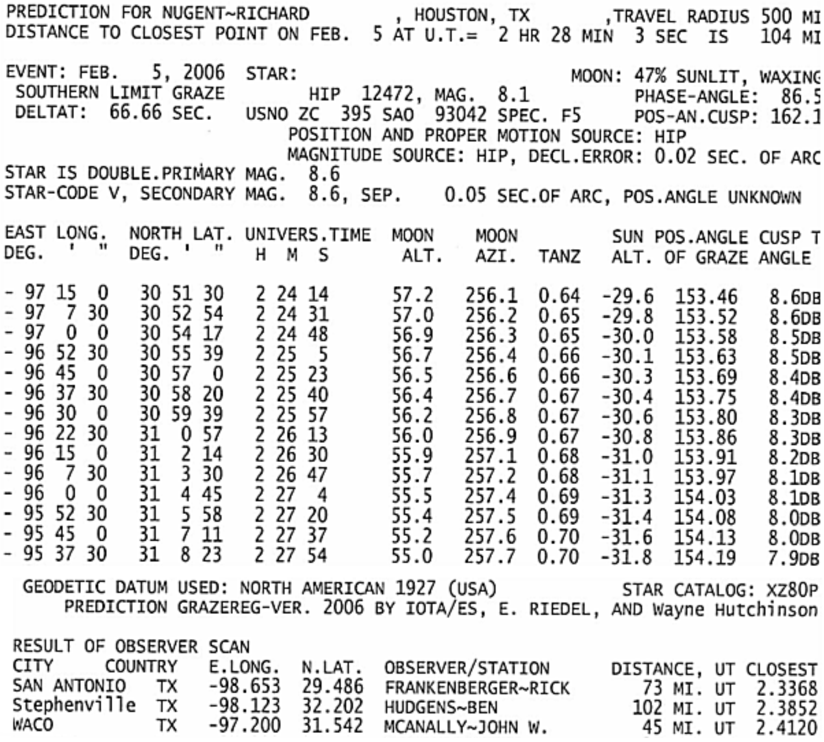
PA: position angle of the star on the Moon's limb. Range is 0 - 360°

CUSP: cusp angle of the star at central graze. This is the angle measured from the terminator to the star. 'D' refers to dark limb graze, 'T' refers to a graze less than 1 degree from the terminator and 'B' refers to a graze on the bright, sunlit limb.

5.7.2 Column Data

In Table 5.2, detailed graze predictions are given for the graze of the star HIP 12472 (which is also known a ZC 395 and SAO 93042) on February 5, 2006 in regular intervals of longitude. The columns are identified as:

EAST LONG	Longitude in degrees, minutes, and seconds of the sea level limit line. Negative (-) longitudes are westward, positive (+) longitudes are measured eastward.
NORTH LAT	Latitude where the predicted sea level limit line crosses in degrees, minutes and seconds.
UNIVERSAL TIME	The Universal Time of central graze seen from the longitude and latitude. **HMS** (hours, minutes and seconds) is the time
MOON ALT	Altitude of the star being occulted. Range is from 0 - 90º. Atmospheric refraction is not considered in the calculation of altitude.
MOON AZI	Azimuth of star being occulted. Range is from 0 - 360º. Azimuth is measured positive eastward from due north and is identical to compass angle with respect to true north.
TAN Z	This is the tangent of the zenith distance described in Section 5.5 above and is used for the elevation correction.
SUN ALT	Altitude of the Sun in degrees at central graze. It is negative when the Sun is below the horizon and positive when the Sun is above. Atmospheric refraction is not taken into account. Refraction is typically 0.5 degrees.
POS ANGLE OF GRAZE	The position angle of central graze in decimal degrees measured eastward around the Moon's limb from the north (See Figure 3.5 Chapter 3).
CUSP ANGLE	Angle measured in degrees from the Moon's terminator closest to the star. (See Figure 3.4 Chapter 3) A negative number indicates the point of central graze is on the sunlit limb, a positive number is on the dark limb.



```
PREDICTION FOR NUGENT~RICHARD        , HOUSTON, TX       ,TRAVEL RADIUS 500 MI
DISTANCE TO CLOSEST POINT ON FEB.  5 AT U.T.=  2 HR 28 MIN  3 SEC  IS   104 MI

EVENT: FEB.   5, 2006  STAR:                              MOON: 47% SUNLIT, WAXING
 SOUTHERN LIMIT GRAZE        HIP  12472, MAG.  8.1             PHASE-ANGLE:  86.5
 DELTAT:  66.66 SEC.   USNO ZC  395 SAO  93042 SPEC. F5        POS-AN.CUSP: 162.1
                           POSITION AND PROPER MOTION SOURCE: HIP
                           MAGNITUDE SOURCE: HIP, DECL.ERROR: 0.02 SEC. OF ARC
STAR IS DOUBLE.PRIMARY MAG.  8.6
STAR-CODE V, SECONDARY MAG.  8.6, SEP.    0.05 SEC.OF ARC, POS.ANGLE UNKNOWN

EAST LONG.  NORTH LAT. UNIVERS.TIME  MOON    MOON          SUN POS.ANGLE CUSP T
DEG.  '  "  DEG.  '  "   H  M  S      ALT.    AZI.  TANZ   ALT. OF GRAZE ANGLE

- 97 15  0   30 51 30   2 24 14       57.2   256.1  0.64  -29.6  153.46    8.6DB
- 97  7 30   30 52 54   2 24 31       57.0   256.2  0.65  -29.8  153.52    8.6DB
- 97  0  0   30 54 17   2 24 48       56.9   256.3  0.65  -30.0  153.58    8.5DB
- 96 52 30   30 55 39   2 25  5       56.7   256.4  0.66  -30.1  153.63    8.5DB
- 96 45  0   30 57  0   2 25 23       56.5   256.6  0.66  -30.3  153.69    8.4DB
- 96 37 30   30 58 20   2 25 40       56.4   256.7  0.67  -30.4  153.75    8.4DB
- 96 30  0   30 59 39   2 25 57       56.2   256.8  0.67  -30.6  153.80    8.3DB
- 96 22 30   31  0 57   2 26 13       56.0   256.9  0.67  -30.8  153.86    8.3DB
- 96 15  0   31  2 14   2 26 30       55.9   257.1  0.68  -31.0  153.91    8.2DB
- 96  7 30   31  3 30   2 26 47       55.7   257.2  0.68  -31.1  153.97    8.1DB
- 96  0  0   31  4 45   2 27  4       55.5   257.4  0.69  -31.3  154.03    8.1DB
- 95 52 30   31  5 58   2 27 20       55.4   257.5  0.69  -31.4  154.08    8.0DB
- 95 45  0   31  7 11   2 27 37       55.2   257.6  0.70  -31.6  154.13    8.0DB
- 95 37 30   31  8 23   2 27 54       55.0   257.7  0.70  -31.8  154.19    7.9DB
  GEODETIC DATUM USED: NORTH AMERICAN 1927 (USA)            STAR CATALOG: XZ80P
      PREDICTION GRAZEREG-VER. 2006 BY IOTA/ES, E. RIEDEL, AND Wayne Hutchinson

 RESULT OF OBSERVER SCAN
 CITY      COUNTRY   E.LONG.  N.LAT.  OBSERVER/STATION        DISTANCE, UT CLOSEST
 SAN ANTONIO   TX    -98.653  29.486  FRANKENBERGER~RICK         73 MI. UT  2.3368
 Stephenville  TX    -98.123  32.202  HUDGENS~BEN               102 MI. UT  2.3852
 WACO          TX    -97.200  31.542  MCANALLY~JOHN W.           45 MI. UT  2.4120
```

Table 5.2. Detailed graze data from the *Grazereg* program. See text for explanation.

Following the columns of data in Table 5.2 are statements indicating the version of the prediction program used, the geodetic datum used, the prediction data source, and the name of the Computor who ran the program. The last information given is a result of the observer scan indicating all other observers have been selected to receive these predictions. In the scan the observer's specified travel radius are given in miles after their name. An asterisk following the radius denotes those who expect to organize expeditions more often than join expeditions set up by others. The time of closest approach of the graze to that specific observer is in hours and decimals of an hour.

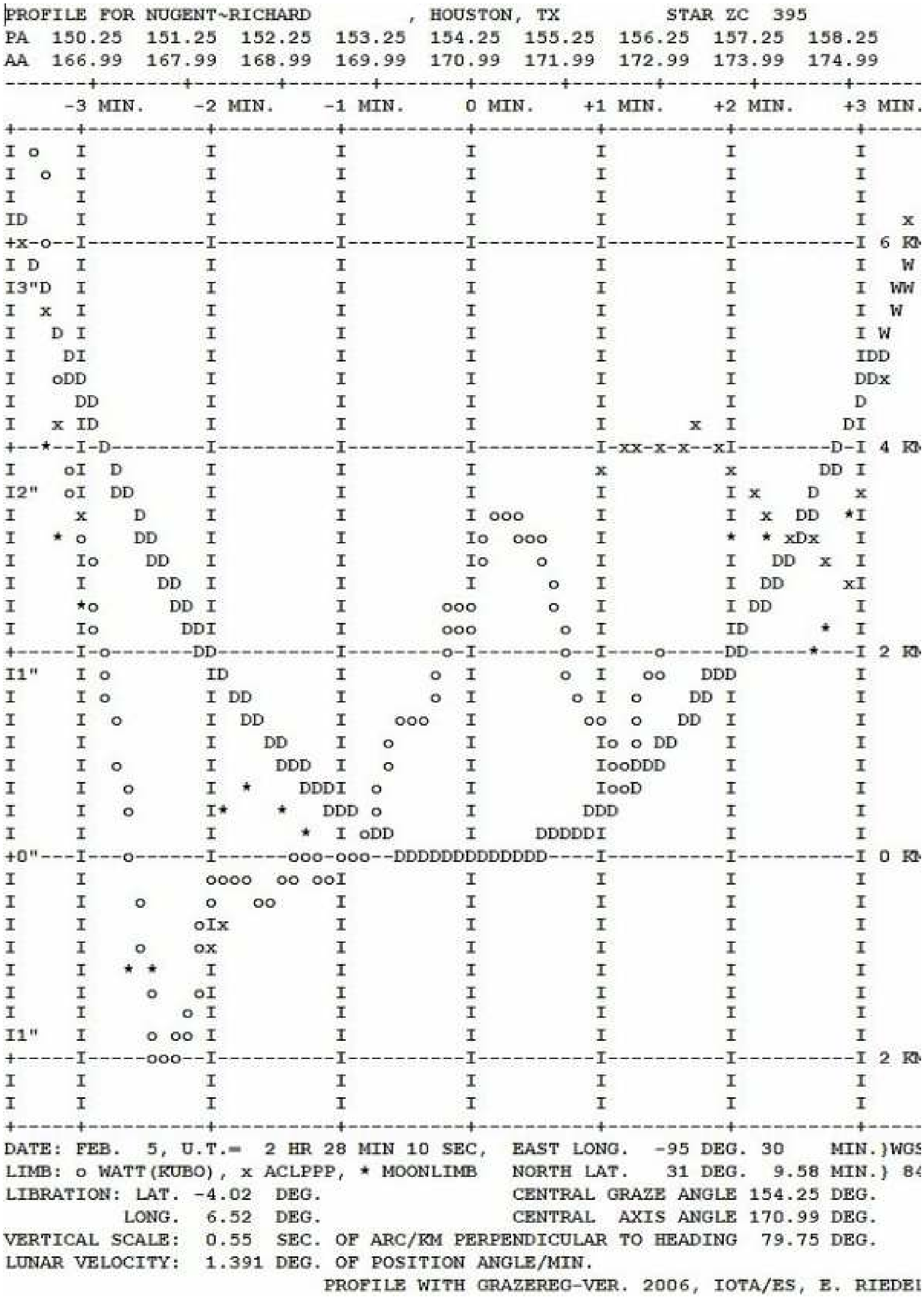
5.7.3 Limb Profile Predictions

Graze observers are provided with computer generated profiles of the Moon’s limb at the time of the grazing occultation. The lunar limb profile for the graze of ZC 395 is shown as Figure 5.8. The data used to compute the profile is derived from the Watts Marginal Zone of the Moon with additional corrections determined from occultation observations. These profiles are only a prediction of what the observer might see. They are used by observers to determine where the best region is in the occultation path for observing. The profiles are for the point on the limit line closest to the observer. The Watts angle of central graze, position angle of the graze, and cusp angle are all shifted from the longitude and latitude printed on the profile to the longitude and latitude of the closest point on the limit line. The central graze time for the intended observation area should be obtained from the limit predictions in Table 5.2.

The plot looks busy with the various letters, numbers and asterisks but upon careful examination it is simple to understand. Figure 5.8 is an enlargement of the lunar limb profile with a 3 minute window surrounding the time of central graze. In the plot the smooth curve pointed downward using the letter “**D**” shows a view of the southern limb assuming a perfectly smooth mean Moon (a northern limb graze would have the smooth curve pointed upward). The second jagged curve represents the predicted limb profile from Watts chart data using the character (**o**), *ACLPPP* (**x**) and *MoonLimb* (*****) along with previous graze observations.

The vertical scales on the left and right show the range of the Moon’s limb in arc seconds notated on the left and kilometers notated on the right side with the zero point (0.0″ and 0 km) as the mean uncorrected limb. Other heading information includes the position angle (PA) of the limb shown in one degree intervals, date and time of the graze, along with the longitude and latitude of central graze, libration angles, vertical scale, central graze angle which can be read off from the top of the plot at the “0” minute mark, and lunar velocity.

Notice the valley near the time of central graze extending below the mean limb (pointed up) of +3 km (2″). A mountain is present in the lower left of the plot (pointed down) with a height of 2 km. Since these two features are projected onto the Earth’s surface during a graze, placing observers in a range covering 3 km north and 2 km south of the predicted limit line after applying the elevation correction should give sufficient coverage of the profile.



```
PROFILE FOR NUGENT~RICHARD        , HOUSTON, TX         STAR ZC  395
PA  150.25  151.25  152.25  153.25  154.25  155.25  156.25  157.25  158.25
AA  166.99  167.99  168.99  169.99  170.99  171.99  172.99  173.99  174.99
-------+-------+-------+-------+-------+-------+-------+-------+-------+------
     -3 MIN.    -2 MIN.    -1 MIN.     0 MIN.    +1 MIN.    +2 MIN.    +3 MIN.
+-----+----------+----------+----------+----------+----------+----------+-----
I o   I          I          I          I          I          I          I
I  o  I          I          I          I          I          I          I
I     I          I          I          I          I          I          I
ID    I          I          I          I          I          I          I   x
+x-o--I----------I----------I----------I----------I----------I----------I 6 K
I D   I          I          I          I          I          I          I   W
I3"D  I          I          I          I          I          I          I  WW
I  x  I          I          I          I          I          I          I  W
I   D I          I          I          I          I          I          I W
I    DI          I          I          I          I          I          IDD
I   oDD          I          I          I          I          I          DDx
I     DD         I          I          I          I          I          D
I   x ID         I          I          I          I       x  I         DI
+--*--I-D--------I----------I----------I----------I-xx-x-x--xI--------D-I 4 K
I    oI  D       I          I          I          x          x       DD I
I2"  oI  DD      I          I          I          I          I x    D   x
I     x    D     I          I          I ooo      I          I  x  DD  *I
I   * o    DD    I          I          Io  ooo    I          *  * xDx   I
I     Io    DD   I          I          Io    o    I          I   DD  x  I
I     I      DD  I          I          I      o   I          I  DD     xI
I     *o      DD I          I        ooo      o   I          I DD       I
I     Io        DDI          I        ooo       o  I          ID      *  I
+-----I-o-------DD----------I--------o-I-------o--I----o-----DD-----*---I 2 K
I1"   I o        ID         I       o  I       o  I   oo   DDD          I
I     I o        I DD       I       o  I        o I  o    DD I          I
I     I  o       I  DD      I    ooo   I         oo  o   DD  I          I
I     I          I    DD    I   o      I          Io o DD    I          I
I     I  o       I     DDD  I   o      I          IooDDD     I          I
I     I   o      I  *    DDDI  o       I          IooD       I          I
I     I   o      I*    *   DDD o       I         DDD         I          I
I     I          I       *  I oDD      I     DDDDDI          I          I
+0"---I---o------I------ooo-ooo--DDDDDDDDDDDDD----I----------I----------I 0 K
I     I          oooo  oo ooI          I          I          I          I
I     I    o     o   oo     I          I          I          I          I
I     I         oIx         I          I          I          I          I
I     I    o    ox          I          I          I          I          I
I     I   * *    I          I          I          I          I          I
I     I     o   oI          I          I          I          I          I
I     I        o I          I          I          I          I          I
I1"   I     o oo I          I          I          I          I          I
+-----I-----ooo--I----------I----------I----------I----------I----------I 2 K
I     I          I          I          I          I          I          I
I     I          I          I          I          I          I          I
+-----+----------+----------+----------+----------+----------+----------+-----
DATE: FEB.  5, U.T.=  2 HR 28 MIN 10 SEC,  EAST LONG.  -95 DEG. 30    MIN.)WGS
LIMB: o WATT(KUBO), x ACLPPP, * MOONLIMB   NORTH LAT.   31 DEG.  9.58 MIN.) 84
LIBRATION: LAT. -4.02  DEG.                CENTRAL GRAZE ANGLE 154.25 DEG.
          LONG.  6.52  DEG.                CENTRAL  AXIS ANGLE 170.99 DEG.
VERTICAL SCALE:  0.55  SEC. OF ARC/KM PERPENDICULAR TO HEADING  79.75 DEG.
LUNAR VELOCITY:  1.391 DEG. OF POSITION ANGLE/MIN.
                           PROFILE WITH GRAZEREG-VER. 2006, IOTA/ES, E. RIEDE
```

Figure 5.8 *Grazereg* Lunar limb profile prediction for graze of ZC 395 on February 5, 2006

A detailed description of the information found in Figure 5.8 is given below.

PROFILE HEADING DATA:

LINES 1-2 The values on the scale are printed in one-degree intervals from the Watts angle of central graze.

LINE 3 This is the time from central graze in one-minute intervals -3 min to +3 min. Vertical bars are generated for each minute through the plot, with the one for central graze so labeled. Negative numbers indicate minutes before central graze, and positive numbers minutes after central graze.

PROFILE PLOT:

Horizontal bars are drawn across the plot at regular intervals to help in scaling the distance from the predicted limit. The vertical scale on the right is the number of miles or kilometers from the limit, while the scale on the left is seconds of arc from the limit. A negative value is south of the limit and a positive value is north of the limit. Values are labeled for both north and south of the limit.

The actual profile data are a series of letters, numbers, and asterisks that can look busy and bewildering. Some observers have found that drawing smooth curves through the points with a red pen for the limb and for the predicted profile help in understanding the plot.There are at least two curves represented on each plot, and sometimes more. Each plot has a curve for the smooth mean limb of the Moon, and a more jagged plot for the predicted profile. In addition, the terminator may appear on the plot, if it is near the central graze. If the star is double, and both components will graze, the profile for the secondary (and tertiary) component will also be provided.

Codes for limbs and terminators:

D dark limb of the Moon

B bright limb of the Moon

T terminator

W "worst" terminator, where two-mile (3-km) high lunar mountain peaks can be sunlit. Areas enclosed by W's will usually be sunlit at the south limb, where high mountains are common, and will usually be dark at the relatively smooth north limb

Codes for the profile points:

* good limb correction, typically accurate to 0.15"

1 fair limb correction, accurate to 0.3"

2 meaningless limb correction, either exreme librations or in the Cassini region

3 good limb correction from previously observed graze data, accurate to 0.4"

4 poor limb correction from previously observed graze data, accurate to 1.0" most of the Cassini regions have been crudely "mapped" with previously observed grazes, so 3's and 4's usually dominate the profile when a graze occurs in these regions

5 good limb correction with an empirical correction applied ± 0.5"

6 fair limb correction with an empirical correction applied (1.0 ± 0.5")

7 meaningless limb correction with an empirical correction applied (2.0 ± 0.5")

P shifted limb of the primary component of a multiple star (when the star is not at the position used for the limb predictions, which is often the case when a center-of-light, or mean position, is used)

S	shifted limb of the secondary component of a multiple star
R	shifted limb of the tertiary component of a multiple star

When drawing curves through the plotted points, the following groups should be connected together. A different color pen for each group makes the profile more readable.

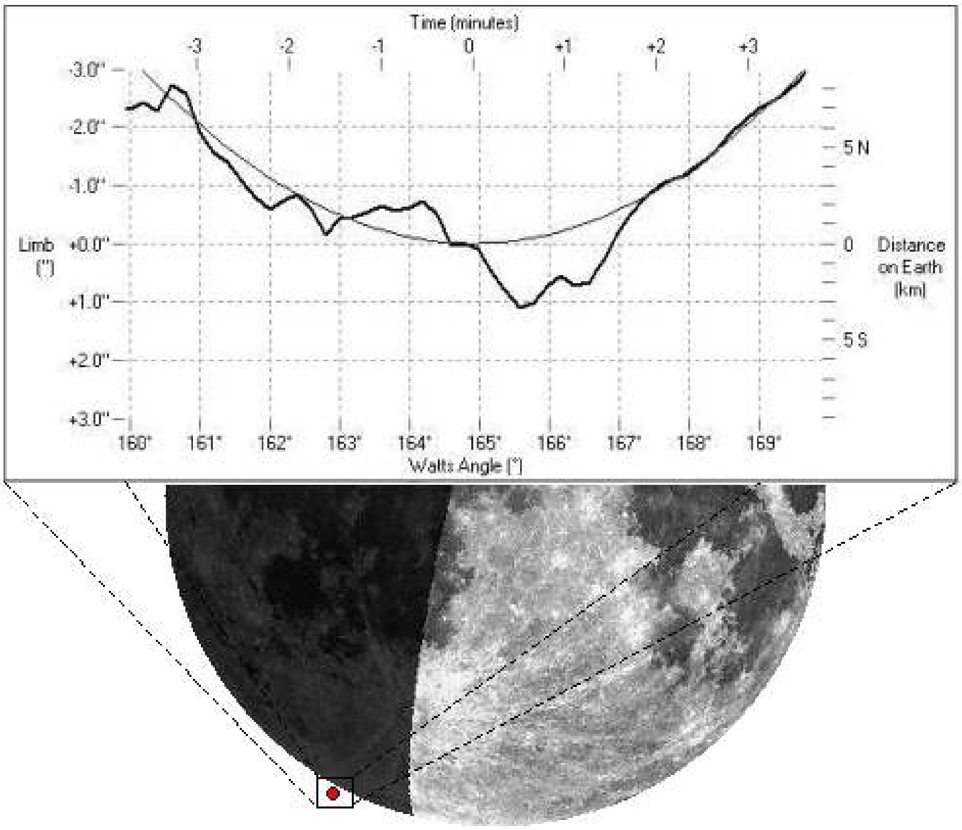
B AND T	enclose bright area of the Moon
D	encloses dark mean limb
W	encloses area where sunlit peaks may exist and cause observing difficulties ("worst" terminator)
*,1-7	the predicted limb for mean star position
P	the predicted limb for a primary star not at the mean star position
S	the predicted limb for a secondary component
R	the predicted limb for a tertiary component

At the bottom of the profile plot are lines of additional information.

LINE 1	The date, time and latitude libration, longitude of the graze is given.
LINE 2	Limb data source, plotted symbols, “o” = Watts, “x” = ACLPPP, “*” = MOONLIMB And latitude of central graze
LINE 3	Latitude libration in degrees, central graze position angle
LINE 4	Longitude libration, central axis angle
LINE 5	Vertical profile scale in seconds of arc per kilometer, heading: azimuth of sea level limit line in degrees. This heading is the angle “F” in the calculation above in Section 5.6.
LINE 6	Lunar velocity in deg/min. This is how fast the Moon is moving in position angle at the Time of central graze.

5.7.4 Using *Lunar Occultation Workbench* for Predictions of Grazes

The *Lunar Occultation Workbench* (*Low*) is a freeware program with excellent graphics, tabular data, and limb profile data for generating predictions for grazing occultations. Some of *Low'*s capabilities for predicting total occultations were discussed in Chapter 4, *Predictions*. Once the user enters basic information about the observing location (latitude/longitude/elevation, telescope and observing methods), the program *Low* will generate grazing occultation predictions based on a wide range of parameters such as the distance from observer's home site, star magnitude, minimum Moon altitude, local horizon obstructions, Sun altitude, etc. *Low* provides all the data needed for plotting limit lines. A sample prediction is shown as Figure 5.9 for the star SAO 189348 on October 20, 2007.

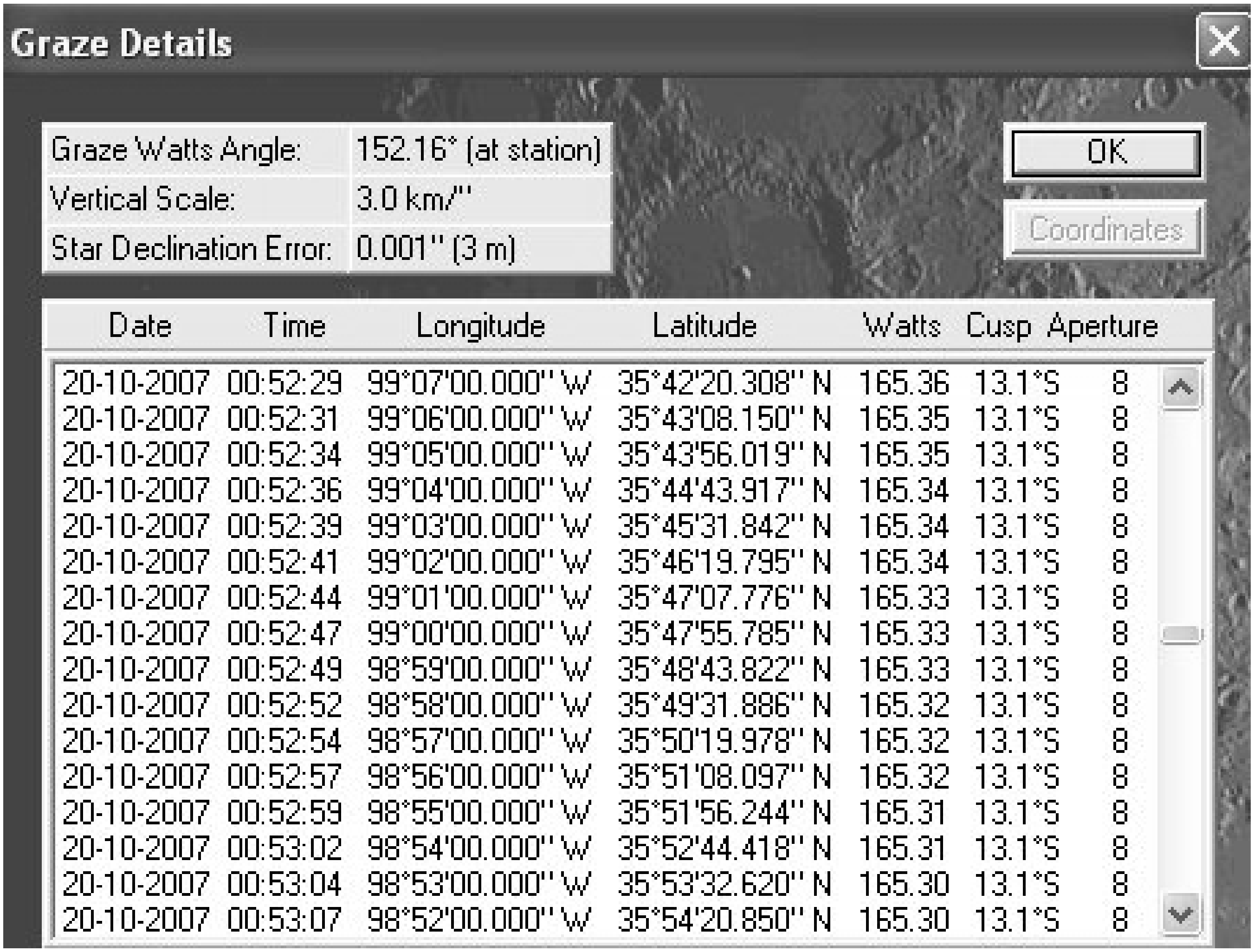


Prediction:	1 of 2
Date:	20-10-2007
Day:	Saturday
Time:	00:54:29 UTC
Accuracy:	
Delta Time:	65.59 s
Object Name:	
XZ Number:	28487
PPM Number	271211
SAO Number:	189348
Magnitude:	7.6
Spectral Type:	K1III
Double Star:	
Phenomenon:	Disappearence
Limb:	Dark limb
Right Ascension:	20h30m05.9932s
Declination:	-22°49'13.049"
Altitude:	30°
Azimuth:	176°
Constellation:	Capricornus
Contact Angle:	79°
Cusp Angle:	14°S
Position Angle:	151°
Vertex Angle:	155°
Watts Angle:	164.05°
Libration Longitude:	-7.51°
Libration Latitude:	+4.31°
Limb Correction:	+0.00"
Cassini Region:	Yes
Flashes & Blinks:	Unlikely
Terminator:	3'07"
Elongation:	98°E
Moon Phase:	57%+
Distance Moon:	386069 km
Size Moon:	30'57"
Eclipse:	
Motion Star:	0.01 "/s
Factor A:	
Factor B:	
Factor C:	
Graze:	Yes
Graze Distance:	0 km SE
Altitude Sun:	-14°
Aperture:	8 cm

Figure 5.9 *Low* grazing occultation prediction for the star SAO 189348 on October 20, 2007. A lunar limb profile box is shown for the area of the graze. The target star has a 14 degree cusp angle from the southern limb.

The *Low* prediction includes a wealth of tabular data along the right side of the graph providing day of week, time, star numbers from several catalogs, altitude, azimuth of the star at time of graze, along with the various position/cusp/libration angles and graze distance from observer's home site. The box is an enlargement where the star will graze the lunar limb and shows the smooth mean limb and the Watts data (wavy line). Vertical scales left and right show the range of the Moon's limb in arc seconds (″) and km as projected on Earth. The Watts angle is labeled along the bottom axis.

Tabular data for plotting the limit is also provided in another window. For the above graze of SAO 189348, a portion of the Graze Details window is shown as Figure 5.10.



Graze Watts Angle:	152.16° (at station)
Vertical Scale:	3.0 km/"
Star Declination Error:	0.001" (3 m)

Date	Time	Longitude	Latitude	Watts	Cusp	Aperture
20-10-2007	00:52:29	99°07'00.000" W	35°42'20.308" N	165.36	13.1°S	8
20-10-2007	00:52:31	99°06'00.000" W	35°43'08.150" N	165.35	13.1°S	8
20-10-2007	00:52:34	99°05'00.000" W	35°43'56.019" N	165.35	13.1°S	8
20-10-2007	00:52:36	99°04'00.000" W	35°44'43.917" N	165.34	13.1°S	8
20-10-2007	00:52:39	99°03'00.000" W	35°45'31.842" N	165.34	13.1°S	8
20-10-2007	00:52:41	99°02'00.000" W	35°46'19.795" N	165.34	13.1°S	8
20-10-2007	00:52:44	99°01'00.000" W	35°47'07.776" N	165.33	13.1°S	8
20-10-2007	00:52:47	99°00'00.000" W	35°47'55.785" N	165.33	13.1°S	8
20-10-2007	00:52:49	98°59'00.000" W	35°48'43.822" N	165.33	13.1°S	8
20-10-2007	00:52:52	98°58'00.000" W	35°49'31.886" N	165.32	13.1°S	8
20-10-2007	00:52:54	98°57'00.000" W	35°50'19.978" N	165.32	13.1°S	8
20-10-2007	00:52:57	98°56'00.000" W	35°51'08.097" N	165.32	13.1°S	8
20-10-2007	00:52:59	98°55'00.000" W	35°51'56.244" N	165.31	13.1°S	8
20-10-2007	00:53:02	98°54'00.000" W	35°52'44.418" N	165.31	13.1°S	8
20-10-2007	00:53:04	98°53'00.000" W	35°53'32.620" N	165.30	13.1°S	8
20-10-2007	00:53:07	98°52'00.000" W	35°54'20.850" N	165.30	13.1°S	8

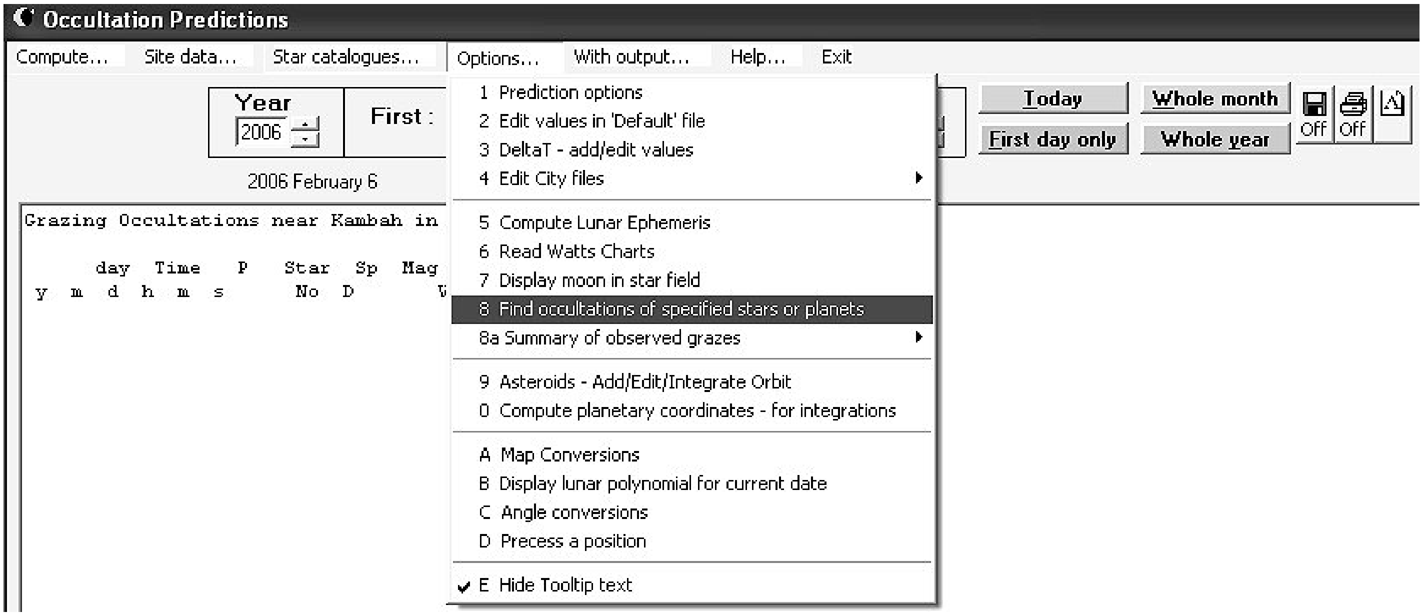
Figure 5.10 *Low* graze details. The columns define the position of the sea level limit line at approximately two-second intervals during the graze of SAO 189348 for October 20, 2007. Sixteen limit line points are shown, although over 400 points were generated for this prediction.

To plot the sea level limit line on a map, select two of the longitudes (spaced approximately 10 km apart) with their corresponding latitudes and draw a straight line between them. As an approximation for distance on Earth's surface in mid-northern latitudes, you can use 1 minute of arc in longitude = 0.7 mile = 1.1 km. So a longitude difference of 9 arc minutes ~ 10 km. Graze lines are actually arcs on the Earth's surface, but for short distances of less than 16 km a straight line will not deviate significantly from the true arc. *Low* provides ground coordinates of the central graze limit line listed at intervals of approximately 1 arc minute in longitude, along with the Watts angle and cusp angle of the star. The last column in Figure 5.10 is the estimated minimum recommended telescope aperture in centimeters (cm) needed to see the graze. Many factors including altitude, sky transparency and seeing, will determine which minimum size telescope is needed. A numerical example of plotting an elevation corrected limit line is shown in Section 5.8.

5.7.5 Using *Occult* for Predictions of Grazes

The computer program *Occult* written by David Herald of Australia is the most comprehensive software package available to date for predicting lunar and asteroid occultations, solar and lunar eclipses, Baily's Beads during eclipses, recording observations, drawing maps and limb profiles, applying corrections and generating tabular data for all events, etc. This section will briefly describe *Occult's* module for predicting grazing occultations using the star SAO 189348 on October 20, 2007 for observers in Oklahoma.

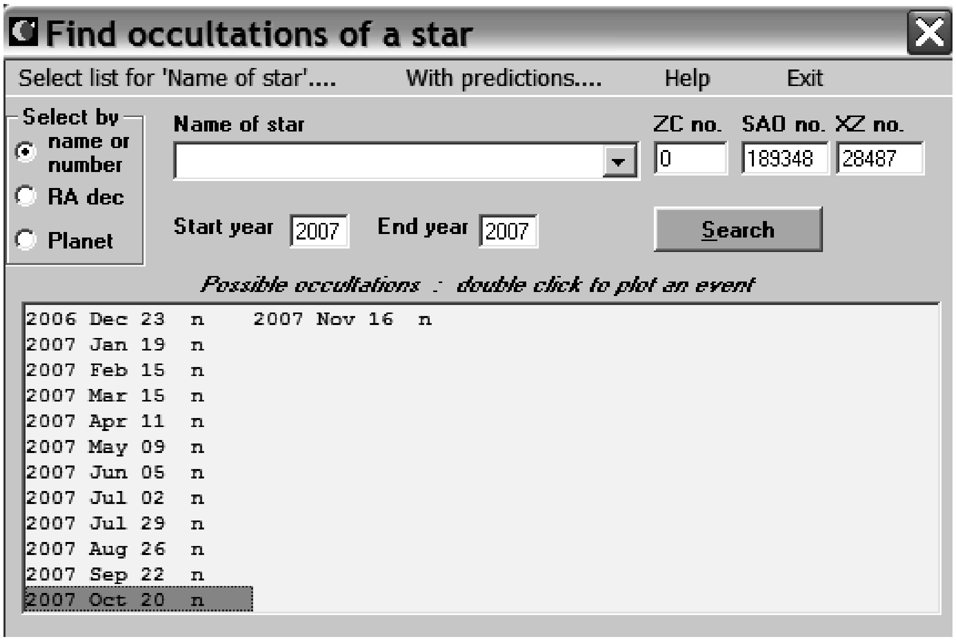
Occult can predict grazes of single stars or for all stars for any time period at specified distances from specified sites. For this example we will use the single star prediction option. Once the user selects the Lunar Occultation Module the window from Figure 5.11 appears. After editing the observer site under SITE DATA the user will go to the drop down menu "Options" and choose **8 Find occultations of specified stars or planets**.



```
Grazing Occultations near Kambah in

     day  Time    P   Star  Sp  Mag
 y  m  d  h  m  s      No  D      V
```

Figure 5.11. Occult Lunar Occultation prediction main window. Option #8 to find a specified star or planet for an occultation has been highlighted.

This window (Find Occultations of a Star, see Figure 5.12) allows the user to select a particular star from one of three catalogs ZC, SAO or XZ. Enter a catalog number in any of the catalog fields and the remaining fields will automatically be displayed. Since this is a graze prediction only for a single star the minimum time period *Occult* searches for the calculation of visible grazes is one year. Enter a Start year and End year and click on Search. The result of the search for SAO 189348 is a tabular list of dates from 2006 Dec 23 to 2007 Nov 16 shown in Figure 5.12.



● name or number
○ RA dec
○ Planet

ZC no. 0
SAO no. 189348
XZ no. 28487

Start year 2007
End year 2007

Possible occultations : double click to plot an event

```
2006 Dec 23  n    2007 Nov 16  n
2007 Jan 19  n
2007 Feb 15  n
2007 Mar 15  n
2007 Apr 11  n
2007 May 09  n
2007 Jun 05  n
2007 Jul 02  n
2007 Jul 29  n
2007 Aug 26  n
2007 Sep 22  n
2007 Oct 20  n
```

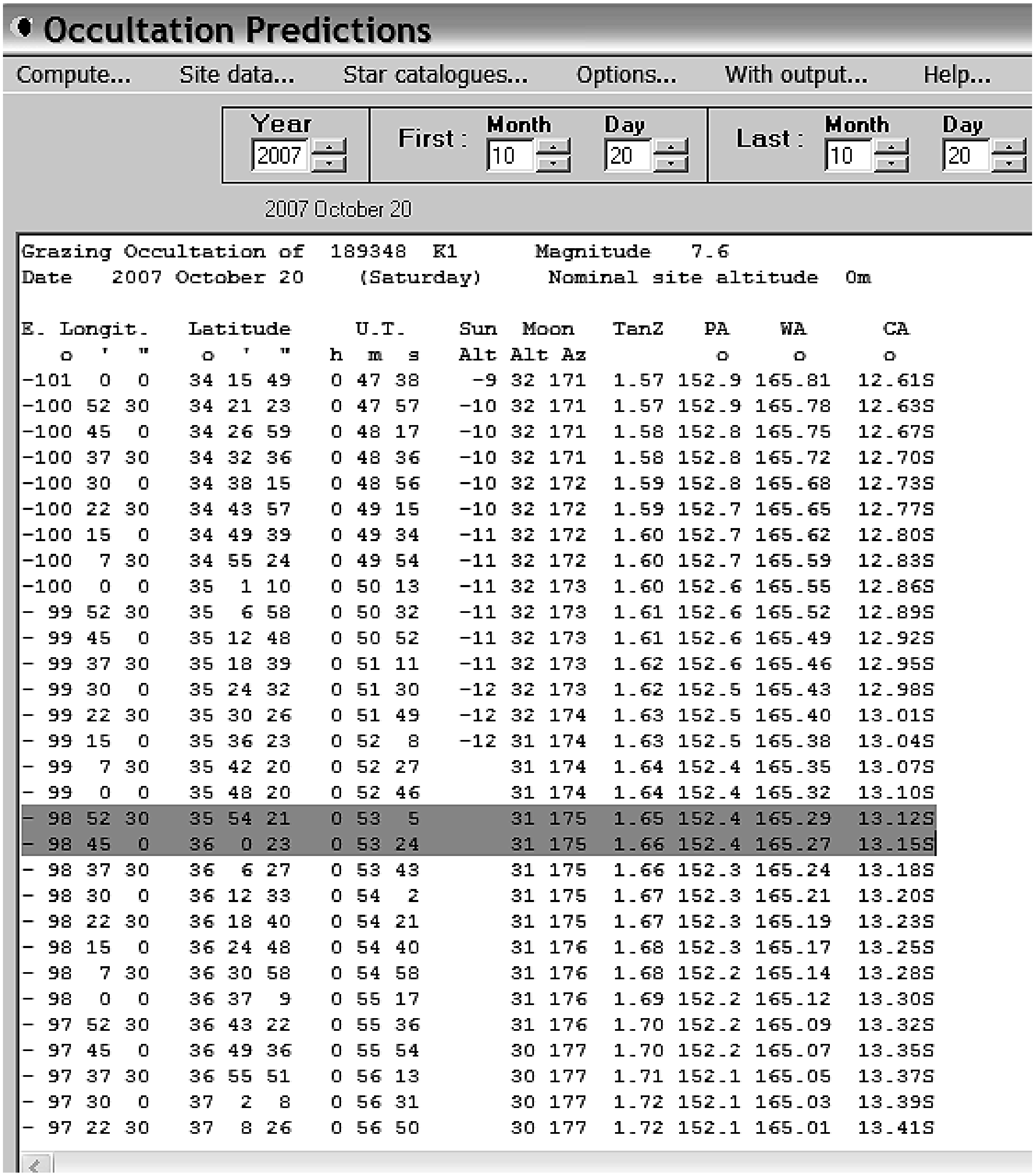
Figure 5.12. The user specifies a particular catalogued star for the year and a list of grazes is produced.

Next, the user double clicks on the graze dated 2007 Oct 20 and a map displays the Moon's north and south limit lines for the graze. Figure 5.13 shows only a portion of the southern limit line.

Figure 5.13. USA map showing south limit line of the graze of SAO 189348 on October 20, 2007.

Figure 5.13 shows the south limit line of the Moon's shadow crossing the central USA over Texas, Oklahoma and Missouri. The graze will simultaneously occur on the Moon's north limb across northern Canada. It is a dark limb graze on the south limb, hence it will be a bright limb graze on the north limb as previously explained in Section 5.1.

Occult then generates tabular data for the graze in the increments of longitude specified by the user (See Table 5.3). This listing of longitudes and latitudes is used to plot the sea level limit lines on detailed maps and can be copied for use in other programs. The highlighted lines in Table 5.3 are used to plot the example elevation corrected limit line in Figure 5.15.



```
Grazing Occultation of  189348  K1      Magnitude   7.6
Date   2007 October 20    (Saturday)     Nominal site altitude  0m

E. Longit.    Latitude      U.T.     Sun  Moon   TanZ   PA    WA      CA
   o  '  "     o  '  "   h  m  s   Alt Alt Az           o     o       o
-101  0  0    34 15 49   0 47 38    -9 32 171  1.57 152.9 165.81  12.61S
-100 52 30    34 21 23   0 47 57   -10 32 171  1.57 152.9 165.78  12.63S
-100 45  0    34 26 59   0 48 17   -10 32 171  1.58 152.8 165.75  12.67S
-100 37 30    34 32 36   0 48 36   -10 32 171  1.58 152.8 165.72  12.70S
-100 30  0    34 38 15   0 48 56   -10 32 172  1.59 152.8 165.68  12.73S
-100 22 30    34 43 57   0 49 15   -10 32 172  1.59 152.7 165.65  12.77S
-100 15  0    34 49 39   0 49 34   -11 32 172  1.60 152.7 165.62  12.80S
-100  7 30    34 55 24   0 49 54   -11 32 172  1.60 152.7 165.59  12.83S
-100  0  0    35  1 10   0 50 13   -11 32 173  1.60 152.6 165.55  12.86S
- 99 52 30    35  6 58   0 50 32   -11 32 173  1.61 152.6 165.52  12.89S
- 99 45  0    35 12 48   0 50 52   -11 32 173  1.61 152.6 165.49  12.92S
- 99 37 30    35 18 39   0 51 11   -11 32 173  1.62 152.6 165.46  12.95S
- 99 30  0    35 24 32   0 51 30   -12 32 173  1.62 152.5 165.43  12.98S
- 99 22 30    35 30 26   0 51 49   -12 32 174  1.63 152.5 165.40  13.01S
- 99 15  0    35 36 23   0 52  8   -12 31 174  1.63 152.5 165.38  13.04S
- 99  7 30    35 42 20   0 52 27       31 174  1.64 152.4 165.35  13.07S
- 99  0  0    35 48 20   0 52 46       31 174  1.64 152.4 165.32  13.10S
- 98 52 30    35 54 21   0 53  5       31 175  1.65 152.4 165.29  13.12S
- 98 45  0    36  0 23   0 53 24       31 175  1.66 152.4 165.27  13.15S
- 98 37 30    36  6 27   0 53 43       31 175  1.66 152.3 165.24  13.18S
- 98 30  0    36 12 33   0 54  2       31 175  1.67 152.3 165.21  13.20S
- 98 22 30    36 18 40   0 54 21       31 175  1.67 152.3 165.19  13.23S
- 98 15  0    36 24 48   0 54 40       31 176  1.68 152.3 165.17  13.25S
- 98  7 30    36 30 58   0 54 58       31 176  1.68 152.2 165.14  13.28S
- 98  0  0    36 37  9   0 55 17       31 176  1.69 152.2 165.12  13.30S
- 97 52 30    36 43 22   0 55 36       31 176  1.70 152.2 165.09  13.32S
- 97 45  0    36 49 36   0 55 54       30 177  1.70 152.2 165.07  13.35S
- 97 37 30    36 55 51   0 56 13       30 177  1.71 152.1 165.05  13.37S
- 97 30  0    37  2  8   0 56 31       30 177  1.72 152.1 165.03  13.39S
- 97 22 30    37  8 26   0 56 50       30 177  1.72 152.1 165.01  13.41S
```

Table 5.3 *Occult* detailed graze prediction for the SAO 189348 graze on October 20, 2007. The longitude/latitude points represent the sea level limit line for plotting on a map. These points are used in Figure 5.15 for the elevation corrected limit line plot.

5.7.6 Reading *Occult's* Lunar Limb Profile Plot

Occult draws a limb profile of the Moon at the time and position angle of central graze nearest the observer's site. Figure 5.14 is a detailed plot of the lunar limb profile drawn by *Occult* for the graze of SAO 189348 on October 20, 2007. This profile is a projection of the Moon's curved limb onto a flat plane.

Dots depicting the mean lunar limb are plotted as a bowl shaped curve starting from the upper left corner above the –14 km mark coming down to the 0 km horizontal line at the center of the plot then on to the upper right corner above the -14 km mark. This is the limb of a perfect spherical Moon. The vertical scales on the left and right are in kilometers centered on the mean limb at the point 0 km. The Watts data is the wiggly continuous line starting on the upper left near the –10 km mark and across the entire plot dropping down to below the 0 km horizontal scale line and ending at the upper right above the -14 km mark. This is the limb profile one should expect when planning a graze expedition. The dots scattered near the Watts data line are the observations from previous grazes. These data points should be given more influence as to the actual limb of the Moon. Notice the similarity in the profile plots from *Grazreg*, *Low* and *Occult* of the same region for the same graze. The *Grazereg* profile (Figure 5.8) is somewhat squeezed in the horizontal direction due to the width of the paper. Both *Occult* and *Low* have the option of displaying the Watts limb data, the *ACLPPP* data and or the *MoonLimb* data. In addition, data derived from observations can also be plotted.

The horizontal line just below the center of the plot from –4m to +4m is the time in minutes from the point of central graze. These minute marks indicate the time with respect to central graze (0m) before (-) and after (+) when the Moon's limb profile will be passing in front of the star for the observer at the longitude specified on the plot. In this case the longitude is -99° 00' 00".

This is a southern limit limb profile, so the mountain peaks indicated by Watts data and data points from observations are facing downward. Northern limit profiles have the mountain peaks facing upward.

Having graze observations drawn on the limb profile is also important for planning future graze expeditions. When significant bright stars undergo a series of grazes (such as the Pleiades passages), their observations should be reduced as soon as possible so that the next set of graze expeditions can use the corrected limb data and any derived limit shifts for their own observer station planning. This is due to the fact that the Watts data is not necessarily accurate everywhere around the limb. The Watts data was obtained by close examination of photographs whereas graze observations generally provide updates and corrections to this data.

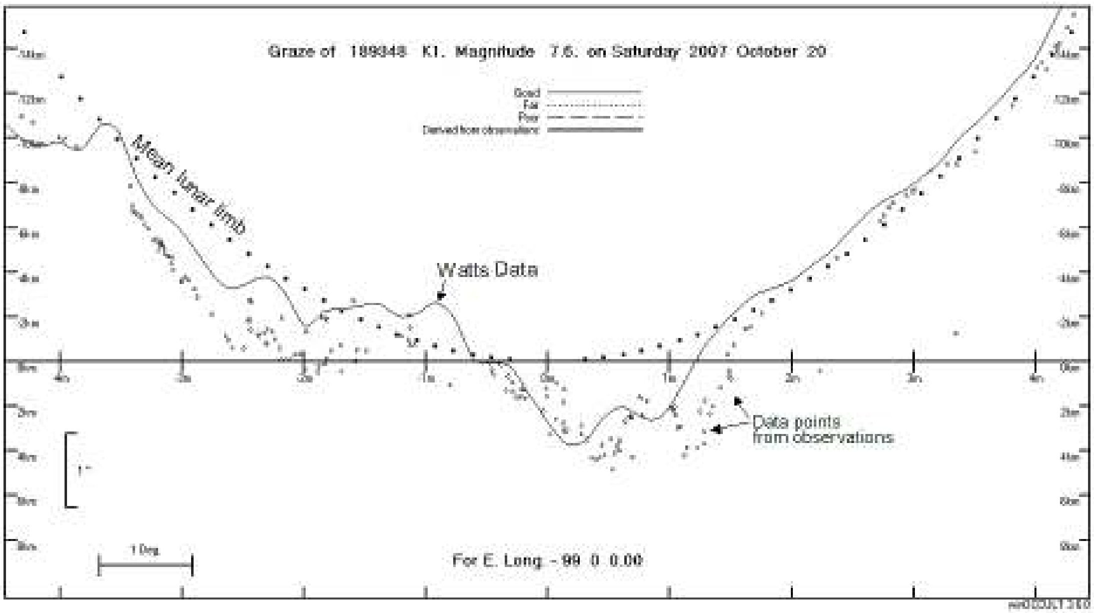


Figure 5.14. *Occult* chart of lunar limb profile for the graze of SAO 189348 on October 20, 2007. The smooth wiggly line from left to right is the Watts data. The mean lunar limb is depicted by the solid dots and the open dots scattered near the Watts data line represent data obtained from graze observations.

5.7.7 How to Station Observers for a Graze

The limb profile plot from *Occult* in Figure 5.14 is used in planning the stations for the graze. With the data points derived from observations (the open circles scattered near the Watts data) the graze team leader can clearly see where other observers have actually had D's and R's with respect to the actual limb profile. The data points show a 4 km high mountain between the 0m and +1m mark (Remember this is a southern limit limb profile so the mountain peaks are facing downward). Another mountain peak of 3 km height lies near the –2m mark.

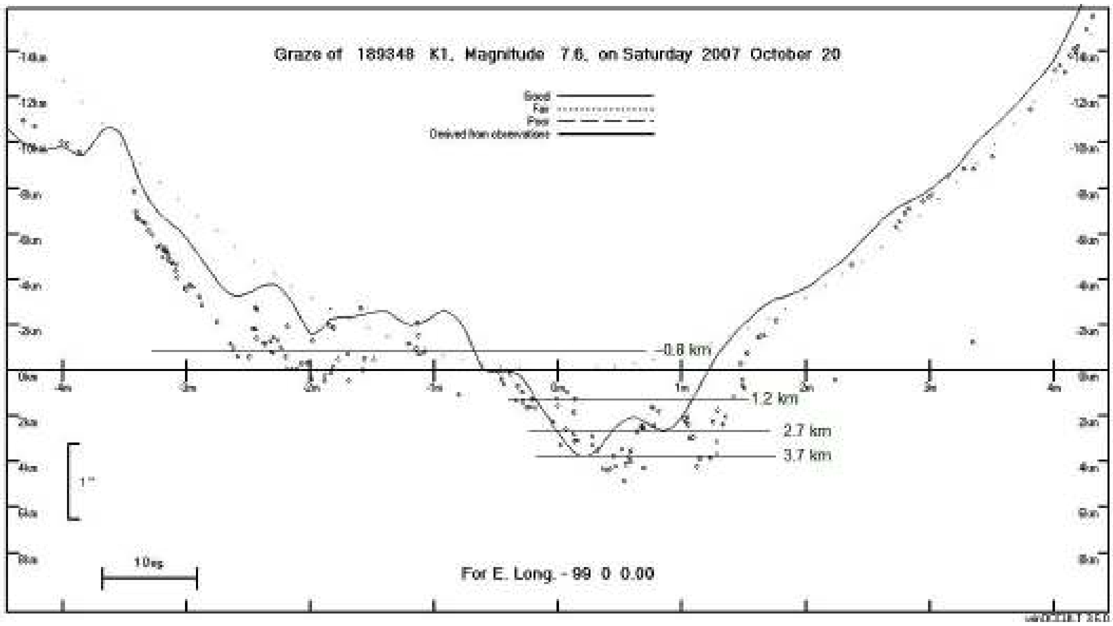


Figure 5.14a. Identical chart as in Figure 5.14. The four lines added at -0.8km, 1.2km, 2.7 km and 3.7 km are preferred locations for a 4 station expedition.

To determine where to station observers refer to Figure 5.14a which is the same limb profile as Figure 5.14. With more influence of the open circle data points from observations rather than the Watts data line a four station expedition is chosen as follows:

1) Station located at -0.8 km inside the mean limit line providing coverage for the mountain peaks at 2 minutes before central graze (–2m mark).

2) Stations located at +1.2 km, +2.2 km and +3.7 km outside the mean limit line. These three stations provide coverage of the profile's terrain between the 0 km and +4 km height.

3) No stations are placed between the +4 km and +6 km position for the risk of having a miss. Similarly no stations are placed between the –2 km and –4 km zones. These zones would likely be a long total occultation 6-7 minutes as the limb profile drifted over them. With more observers, they could be placed in these zones.

With the placement of the stations chosen with respect to the Moon's mean limb, it's now time to plot them on a map.

5.8 How to Plot Graze Path Limit Lines

Unlike asteroid occultations where observers can be spread out across the country to collect observations grazes generally require observer teams to be at the same location in a fairly straight line perpendicular to the limit line. This simplifies expedition planning. However graze teams can be placed along the limit line at different parts of the country and the results from different expeditions can be combined.

Limit lines can easily be plotted on computer generated atlas maps (such as Microsoft's *Streets and Trips*) by simply plotting a set of longitude and latitude points spaced 5-10 km apart from Table 5.2, Table 5.3 or Figure 5.10 over the area(s) where the graze is expected to be observed. Recall earlier it was stated that limit lines are actually arcs on the Earth's surface. For prediction purposes short distances of 10 km or less can be plotted as straight line and the deviation from a true arc is negligible.

When using a topographic map to plot a limit line the observer should examine a map of the state or region using the predictions to determine an approximate location where the graze might be observed. One or two alternative locations might be selected in case bad weather or other circumstances prevent observation at the first location. Computer drawn maps should cover two or more regions for the same reason.

Use this procedure to plot the sea level limit line and the elevation corrected limit line. We will continue to use the example of the graze of SAO 189348 on October 20, 2007.

1. Find two longitude points 10 to 20 km apart from the predictions. Estimate 1 minute of arc in longitude = 0.7 mile = 1.1 km. Look for a 7-8 arc minute difference in longitudes for picking points. In Table 5.3 the highlighted points are used.

2. Use the corresponding latitudes and plot these two points.

3. Have the computer plot (or draw) a straight line between the two points.

4. This straight line is the sea level limit line. See Figure 5.15.

5. If you are unable to get two longitude points on a single topographic map two adjacent maps can be taped together. Computer map software programs don't have this problem.

6. Determine the elevation of the sea level limit line on Highway 270/281 from the map. Using longitude –98° 45′, latitude 36° 0′ (a point at the sea level limit along Highway 270/281) www.topozone.com shows the elevation as 1,850 ft (596.7m)

7. From Table 5.3 at the longitude point –98° 52′ 30″, TAN Z = 1.65. The corresponding elevation shift d = TAN Z (596.7m) = 984.8m in the direction of the Moon's azimuth. Using the procedure from Section 5.6 the shift amount X = 767 m (0.767 km) south (parallel) of the sea level limit line.

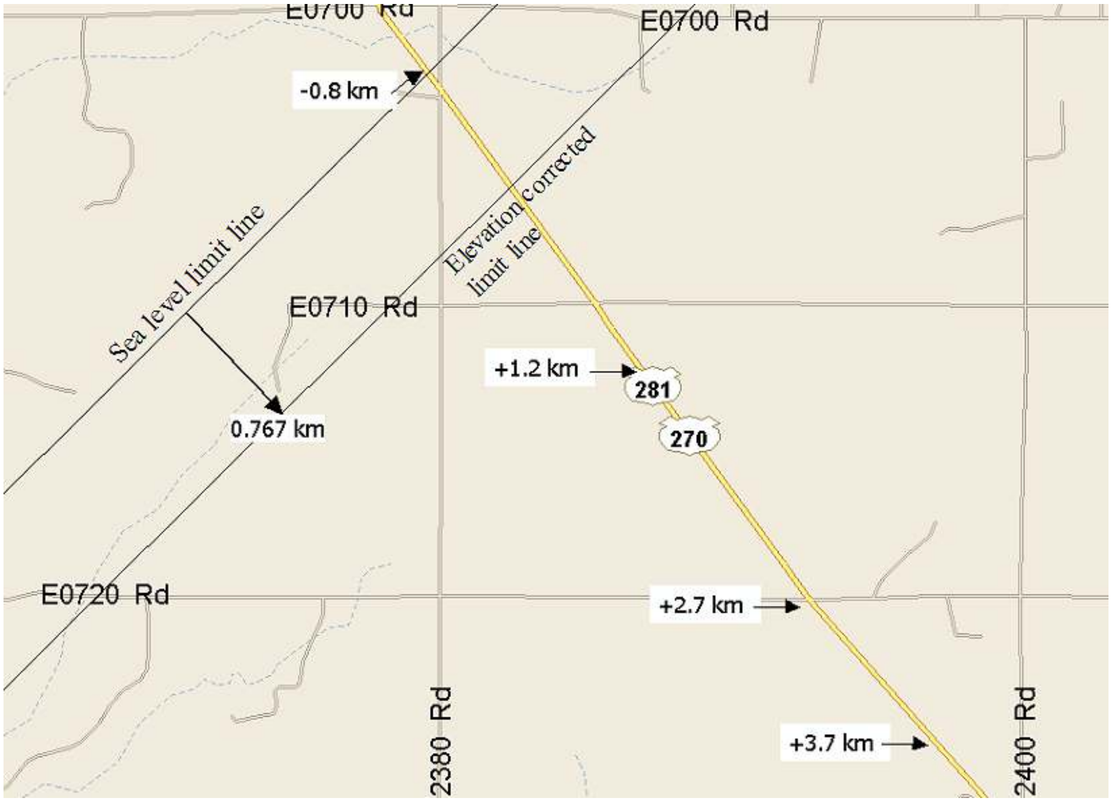


Figure 5.15. Sea level limit line and elevation corrected limit plot on Microsoft's *Streets and Trips*. The user plotted two pairs of longitude/latitude points and connected the line to get the sea level limit line. The elevation corrected line was computed from the method from Section 5.6. Observer stations are marked by –0.8km, +1.2km, +2.7km and +3.7km with respect to the elevation corrected limit line. Microsoft product screen shot reprinted with permission from Microsoft Corporation.

For determining the azimuth of the sea level limit line from a topographic map, use a protractor to determine the angle F from Figure 5.7 or use the mathematical technique from equations 5-6 and 5-8 and Figure 5.7b. Follow the procedure for calculating the shift *X*. With *X* calculated, re-plot the limit line shifted by this amount south for positive elevations, north for negative elevations. As mentioned earlier some GPS receivers can calculate the angle F, the bearing.

8. With the shift *X* calculated, plot the corrected limit line on the map. This line will be the elevation corrected limit line as shown 0.767 km southeast from the sea level limit line. This line is where the Moon's mean limb (Figures 5.8, 5.9 and 5.14) will fall on Earth during the graze.

Figure 5.15 illustrates the sea level limit line drawn using Microsoft's *Streets and Trips*. The user picked two points from the graze details table (Table 5.3), plotted by the program. The user then drew a line connecting the points and enlarged the scale. Microsofts's *Streets and Trips* has the convenient feature called *Measure Distance* whereas the user draws a line perpendicular to the limit line with the mouse and it displays the distance the cursor has traveled as the mouse moves. So it's an easy task to stop the mouse at 0.767 km for the elevation corrected limit line.

5.8.1 Plotting and Locating Observer Graze Stations

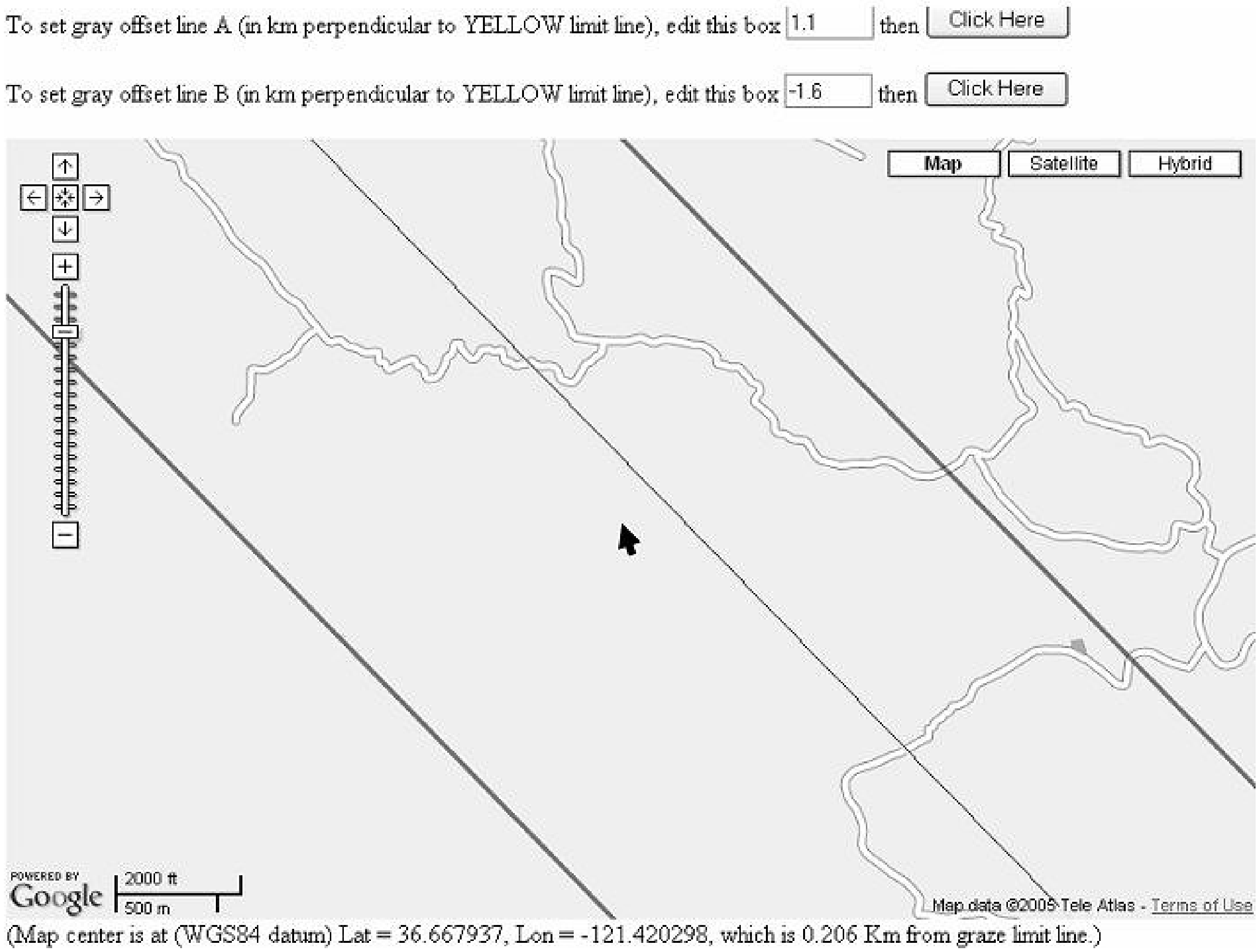
It was previously determined from the lunar limb profile for this graze that a four station expedition would consist of locations at –0.8km, +1.2 km, +2.7 km and +3.7 km perpendicular to the elevation corrected limit line.

Using Microsoft's *Streets and Trips*, it's a simple matter to use the *Measure Distance* function and plot the four stations. The –0.8 km station is just inside the sea level limit line (also shown in the limb profile Figure 5.14a). As a convenience for the graze team leader all four stations were placed along Highway 270/281. The Moon's azimuth for this graze is 174° thus the observers will be pointing their telescopes in a nearly due south direction and should be set up on the west side of Highway 270/281 facing away from traffic.

If plotting these stations on a topographic map, measure the shift perpendicular to the sea level limit line using the quantity *X*. Determine the scale factors (millimeters per km) and draw the line. Plot the four stations the same way.

5.8.2 Google Map Plots

The popular Internet search engine Google has added an interactive map feature to its website www.earth.google.com. IOTA members have used it to plot limit lines for grazes and asteroid occultations. Google maps resolution varies from the entire country view to 1 inch = 200 ft on a typical computer monitor screen. These maps also feature options favorable for IOTA applications such as limit line plotting, one-click lat/long coordinates and one-click perpendicular distances. See Figure 5.16 for a sample screen shot of its application for the graze of ZC 1251 on May 3, 2006 over California. These interactive features were originally added to Google Maps by Geoff Hitchcox of New Zealand. Hitchcox is also the inventor of a GPS video time inserter used by many occultation observers. Its webpage in given in Appendix D, Equipment Suppliers. IOTA astronomer Derek Breit maintains updated Google maps, star charts, and pre-point lists for important grazes and asteroid events worldwide. See Appendix K for the web address. Remember the limit lines plotted for the Google Maps are not corrected for elevation.


To set gray offset line A (in km perpendicular to YELLOW limit line), edit this box 1.1 then Click Here

To set gray offset line B (in km perpendicular to YELLOW limit line), edit this box -1.6 then Click Here

(Map center is at (WGS84 datum) Lat = 36.667937, Lon = -121.420298, which is 0.206 Km from graze limit line.)

Figure 5.16. Screen shot of Google Earth Maps for the graze of ZC 1251 on May 3, 2006. The center coordinates of the map are given at the bottom and the cursor was clicked at its location to display the 0.206 km distance perpendicular to the center line.

5.9 Graze Profile Use

The limb profiles are used to select the region of the graze path where observers should be concentrated. Once the graze path has been plotted, the observers can be placed north and/or south of the predicted limit where the tracks across the profile indicate that multiple events should be seen. For any location within a few miles of the predicted limit the star will appear to move in a horizontal line across the profile chart.

The limb profile chart from Figure 5.14 shows that from –3.5 m of central graze to +1.5 m indicates most of the Moon's features are south of the dotted mean limit line. The Watts data line shows a mountain peak situated at the +0.2m mark at 4 km in height. The data derived from observations line shows the same mountain peak at the +0.5 m mark and what appears to be a second peak near the +1m 15 sec mark. Between +2 min and +4 min, the Watts profile and observations profile lines are in good agreement. From –1m to –3m marks, the observational data is shifted south approximately 2km or about 0.5 arc second from the Watts data.

Not all limb profiles have Watts data or observational data points in good agreement. The placement of observers by the graze team leader is generally a judgment call based upon the Watts profile, the profile from recent observations and the number of observers that show up to observe the graze.

5.10 Finding the Time of Central Graze

Once the sites have been selected, the next step is to determine the time of the earliest event as seen from the sites. The UT of central graze is determined by interpolating the times given in the predictions between the longitudes of the two plotted points on the map. The limb profile charts (Figures 5.8, 5.9 and 5.14) have tick marks from -4m to +4m. These are the predicted times with respect to central graze when the star will be at that point on the limb profile.

To determine the time central graze for the organized stations, use the longitude from the graze site and find two adjacent longitudes from the graze details Table 5.3. Each longitude will have a corresponding UT for the time of central graze. For example, in the map of the graze site (Figure 5.15), the corrected limit line crosses Highway 270/281 at longitude -98.761°. From Table 5.3, we have the following data adjacent to the graze site and the corresponding UT of central graze:

E. Long	Latitude	UT		
°	°	h	m	s
-98.875	35.0583	0	53	05
-98.761	*--- graze site ---*			
-98.750	36.0064	0	53	24

The graze site is located just about 9/10 way eastward between the table longitudes. Thus to find the time of central graze calculate the UT between the two times shown. The difference in time between the two table longitudes is 19 seconds. Nine-tenths of this is 17 seconds. Adding 17 seconds to the time at longitude –98.875° gets the time of central graze at Highway 270/281 of 0h 53m 22sec UT.

From the limb profile the earliest event might occur at –2.5 min from central graze or 0h 50m 52sec UT. Observers should be ready to time events about at least a minute or two before the expected time of the first event. Unexpected shifts (prediction errors) can cause events to occur early. A minimum observing window from the limb profile from Figure 5.14a should be from -3.5 to +2.5 corresponding to 0h 49min 52 sec to 0h 55min 52 sec.

In the case of a known double star where there is a possibility of observing the secondary, two lunar profiles will be provided on the profile chart, one for each component. Observers can use the profiles to position themselves to observe grazing phenomena of either or both components. In general, the expedition leader should station most observers in the zone where multiple events can be seen for the component whose profile is deepest into the lunar shadow. Then most observers should see some complete disappearances of the star, which are usually easier to observe than the partial drop in light when one of the two stars disappears. However, if the difference in component magnitude of the double star is 1.5 or greater, it is best to position observers based on the profile of the brighter component.

Often the two stars will be so close together that observers will not be able to tell that the star is double until the graze begins. Due to the grazing geometry, the step events sometimes seen during total occultations of double stars may be very prolonged. A resolution of 0.05" is obtainable from a graze of a double star observed visually along flat lunar surfaces. This is nearly equivalent to the resolutions obtained in photoelectric work with total occultations. Video observations of double stars can resolve 0.02" separations with favorable geometry. Many close double stars have been discovered during grazing occultations. However, gradual or fading events seen during grazes are more often due to grazing enhancement of Fresnel diffraction at the Moon's limb rather than to stellar duplicity, which is more noticeable by events occurring in distinct steps.

5.11 Organizing Grazing Occultation Expeditions

Section 5.4 briefly outlined the basic procedure for organizing a grazing occultation expedition. More details are presented here along with some safety tips. Remember, safety is the most important concern. If you are in a situation where your safety is at risk, where for example an irate homeowner threatens or intimidates you, it is advisable to pack up your equipment and leave. It is best not to take the offensive position even if your right and even if you are on a public road. Your safety is more important than the occultation no matter how far you traveled to get there. Bear in mind there will always be more grazes.

Unlike asteroid occultations where multiple observers can be situated across the country or even across oceans, grazing occultations are most successfully observed when a group of people meets at a prearranged site and set up a chain of observers across the graze path. Someone must obtain the graze predictions, select the best site, notify other observers, and assign observing locations before the graze. Afterward, someone must verify the lat/long of each of the observing sites, report the locations, and collect and report the observations. The graze organizer obviously bears the burden of the work. This section is intended to detail the steps involved in organizing a successful graze. A single observer at one location can observe a chord across the graze. These data are useful especially if they can be combined with other chords obtained by observers to the east or west during the same graze. However, the resolution obtained by having a line of well-spaced observers, even if only a few, across the predicted graze path is much better and worth the time it takes to set up such an event. Observer safety should be the top priority of all expedition leaders. The articles discussing expedition safety (*Occultation Newsletter*, 6, No. 11, 1993 March, pp. 284-286) are required reading for all IOTA graze expedition leaders. Additional tips on safety are described in Section 6.10 in the *Asteroid Occultation* chapter of this book.

5.11.1 Preparation

The time and effort needed for organizing a graze will vary depending on the number and experience of the people expected to observe. As a general rule the more people who want to observe the more elaborate the preparations must be. The graze organizer will need to select the sites, notify the observers, often help the observers find equipment and transportation and teach the new observers what to do.

5.11.2 Site Selection

The graze organizer should first obtain predictions of the grazing occultations for the local area. These are available to members of IOTA. Predictions for the brightest events are published in *Sky and Telescope* and the yearly *Observer's Handbook* of the Royal Astronomical Society of Canada for the areas those publications cover. Graze organizers will usually want the predictions distributed by IOTA or generate their own from freeware programs such as *Low* and *Occult*.

Predictions can be used to determine approximately where grazes might be observed. Any computer drawn map or map of the state map of the general area that gives latitude and longitude can be used for predicting where grazes can be observed.

The predicted graze limit line at sea level can be plotted on computer drawn and other types of maps directly from the predictions. The plotting of limit lines and correcting them for elevation when necessary are discussed in Section 5.6 above.

The region of expected events can be determined from the predicted profile, as discussed in Section 5.7.5. This region is the area near the predicted limit where observers should be stationed. It could be anywhere from 300 meters to and sometimes several kilometers in length. The observing sites should be selected to fall within this suggested range. It should be stressed that the suggested range and the profile are indications of what is going to happen. Taking into account the accuracies in the predicted stellar and lunar positions, as well as the lunar profile, means that the exact location having the most events cannot be precisely predicted. All locations within the suggested observing range will have approximately the same chance of seeing multiple events with locations near to the limit line having slightly less chance.

Things to consider when selecting sites are the ability to see the Moon at the time of graze from the site, accessibility of the site to observers, lighting, parking, traffic (if the site is a road), what permission is needed if the site is located on private property and whether public authorities will need to be notified if the site is public property. It is advisable to notify local authorities such as the sheriff's office or the office of the local police force especially for expeditions with three or more sites. The observers will need reference points to locate their stations. Some graze team leaders plant wooden stakes in the ground with numbers and assign observers to specific numbered sites. After the graze they are asked to return the wooden stakes to the graze leader provided an accurate geocentric position is obtained for the sites.

Observers will want to be able to move their equipment in order to find the best observing locations for grazes when the Moon’s altitude is low. It may not be possible to determine the effects of local obstacles such as houses, trees, and hills until actually arriving at the graze location to observe. A pre-site survey by the graze organizer is helpful and can help avoid surprises.

If the observing sites chosen are along a road, observers with cars will need places to park completely out of the traffic. The shoulder may be sufficient but smaller country lanes and county roads may not have them. If the road is heavily traveled by trucks the observers will need to be well away from the road to avoid problems from equipment vibration and associated traffic noise.

Railway tracks and railway rights of way are not public property. They are the property of the railroad. And don’t forget to use common sense: **NEVER, NEVER set up your equipment on the railroad tracks !** As a practical matter, even if the observers will not be in the right of way but only nearby, it might be wise to contact the rail line to determine if there are any trains scheduled near the time of the graze. Passing trains will drown out D and R voice call outs and the WWV time signals into tape recorders.

Public parks may be closed after sunset. If accessible they are often very good sites due to lack of lighting and traffic. Avoid locations near water especially if the dew point is predicted to be reached by graze time.

The organizer should inspect the sites before the graze to check their suitability or to mark the locations selected for the sites. If the selected observing location is devoid of landmarks the observers are not going to find their stations unless they are marked. This can be done with marked or numbered stakes pounded into the ground, cards tied (not nailed, that is not always legal) to utility poles. Water-soluble spray paint or chalk can be used to write station numbers on the side of the road.

5.11.3 Observer Notification And Preparation

It is advisable to contact potential graze observers at least 2-3 weeks before the graze. Remember occultations wait for no one. Notification of observers can be as simple as by email, through a local astronomy club newsletter or through graze notices sent to anyone who has expressed an interest or by telephone. The notification should state when and where the graze will occur, a meeting time and place, a telephone number to call for notice of weather cancellation, and a list of equipment they will need for observing. The organizer will want to know who is interested in observing a particular graze to help in planning the observations.

5.12 Expedition Results and Reporting

The expedition leader will collect the observed times or the unreduced observation tape from all observers. Accurate geodetic coordinates for all successful stations must be determined (see *Site Position Determination* Chapter 7), and the expedition leader must take charge of that task as well. See Appendix F, *Report Forms and How to Report Observations* for information on how to prepare the final expedition report.

5.13 Other Tips for Making a Successful Graze Expedition

Roads: Selected roads should be somewhat perpendicular to the graze path. Country roads are better than city roads due to less interference by passing cars and trucks. When setting up on roads set up stations so observers will be aiming their telescopes away from traffic.

Marking of Observing Stations: Wooden stakes can be hammered into the ground off the side of a road and numbered with a magic marker. Heavy white paper, cardboard or reflective tape can also be attached and numbered to the stakes for easy identification. The road may be marked with spray paint at the intervals needed for station layout. As the team leader marks each station with wooden stakes or paint, GPS position readings can be taken.

Layout of Observing Stations: The lunar limb profile will determine the span of the observers to obtain the most data. Along the Moon's south limb the mountains are much higher than the north limb. The observers should be spread out more for these southern limit grazes. The Moon's altitude above the horizon will also introduce a projection effect on the Earth's surface. When the Moon is at lower altitudes stations should be spread out further compared to higher Moon altitudes. (See Figure 5.17).

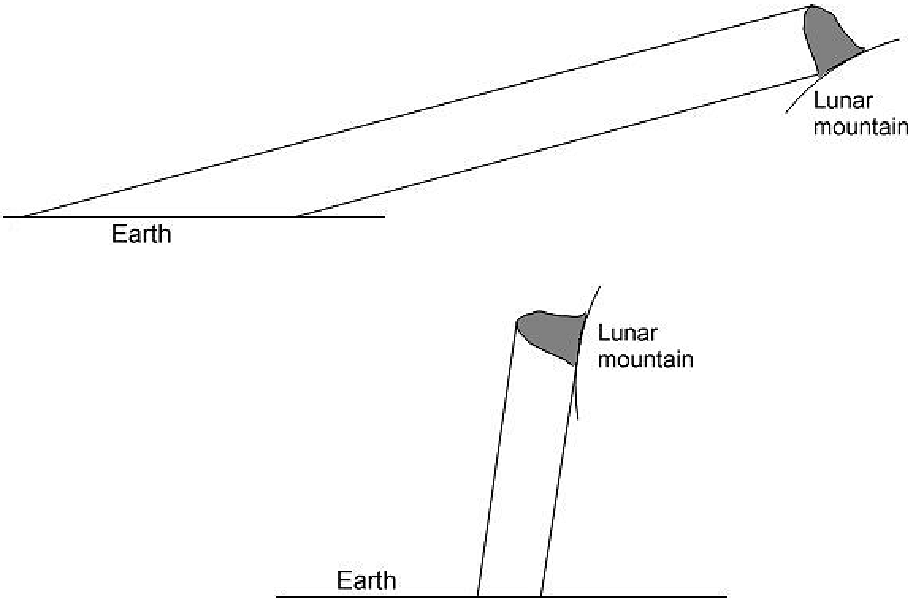


Figure 5.17. Effect of the Moon's altitude on the projected lunar limb profile. The length of the lunar profile on the Earth's surface is wider at low Moon altitudes than at higher altitudes.

Power Lines: Power lines cause interference and static with the WWV radio time signals. When choosing a site walk around with your radio tuned to WWV and determine where you can set up safely and still get a good WWV signal. Notify all observers of the best WWV frequency. If your WWV reception is poor choose another site. This is where a pre-site survey by the graze team leader can solve these problems ahead of time.

Meeting Place: Meeting spots can be at a nearby landmark, parking lot or one of the graze stations. Go over the plan with the observers and assign the stations. A single page handout with the central graze time, cusp angle (from which terminator) and desired observing window should be printed out. Have some blanks on this info sheet where the observer can write down his latitude and longitude, station no. and any other notes. Late arriving observers should be set up closer to the limit line rather than further away so they can at least get some data.

Temperature: Cold weather observations require telescope optics to cool down to reach equilibrium with the outside air temperature. Telescope optics in thermal harmony with the outside air will give better images and less flicker effects. Observers should plan to arrive early. A typical cool down time for a Schmidt-Cassegrain telescope is one hour.

Dew Formation: Observers should have a battery powered hair dryer to keep dew off the optics. While waiting for a graze, a cover for the eyepiece is useful to keep it free of dew formation.

Placement of Observers: The most experienced observers (and/or observers with video) should be placed at the stations expected to give the most multiple events. An inexperienced observer can be placed in between two experienced observers or can be placed *into the Moon* (closer in the direction of the center of the Moon) where they will get longer duration events.

After the Graze: Have the observers meet up again at the team leader's site or nearby site in town. Observers should turn it their tapes or take them home and reduce them. Stress to the observers they need to reduce their times and email them to the leader within 48 hours. This way, memory retention is better for any particular circumstances that might have affected the observations. Video observations should have their tapes WWV time inserted for accurate report times to within 0.03 second. See Appendix H, *Where to Send Observation Reports* to get your tapes time inserted.

Extra Useful Equipment:

1. Cell phones for emergencies or when an observer needs assistance. Cell phones should not be used to transmit WWV time signals to other observers due to their signal processing delays (see Chapter 8, Section 8.8.4)

2. Low Cost hand held CB radios. Cost: $30 - $50 pair. A CB radio can transmit WWV time signals to an observer without a radio.

3. Bug spray. Annoying mosquitoes can ruin an observation.

4. Extra batteries, second short wave radio, pen and writing pad. Fold out chair. Red flashlight and white flashlight.

5. Backup power source and a means of connecting it to your telescope/video/radio.

6. Backup recording method. An extra cassette recorder or digital voice recorder can record the observation in case a video system fails.

7. Good road atlas for finding the graze meeting site.

8. Drinking water, money for food, snacks. Hunger can tempt observers to go to a nearby convenience store leaving their equipment. Never do this as your equipment is at risk. If you make a mess at your site, clean it up. Leave it exactly as you found it.

9. Warm clothing and gloves for cold weather grazes. More about this and how to protect your batteries during cold weather in found in Chapter 9, *Cold Weather Observing*.

10. Contact lens solution and case. Contact lens wearers may prefer removing their lenses and wear glasses. Be sure to have your glasses handy to see clearly after removing your contacts.

11. Allen wrenches and tools needed to adjust your telescope and finder scope.

12. Observing chair for maintaining a comfortable position while observing the graze.

5.13.1 Reasons for Failure

When driving a car people continue to make mistakes and have accidents. These accidents are not due to new kinds of problems but to the same kinds of mistakes that are repeated. The same holds true for occultation observing. The following list will indicate the most common reasons of observational failure.

1. Incorrect conversion of the UT date and hour. Failure to get to the site or get equipment set up in time. Be sure that your equipment is set up and tested at least thirty minutes before central graze time.

2. Using batteries that are not new.

3. Poor reception of WWV. This may be due to a poor receiver, or more likely due to the wrong frequency chosen, bad ionospheric conditions or setting up too close to high voltage power lines.

4. Tape recorder not checked. Tape recorder running out of tape, batteries weak, volume not correct, microphone not turned on. Microphone turned toward traffic and not toward observer or WWV.

5. Improper handling of human or police interference during the graze.

6. Observer couldn't see star because of dirty optics, dew or bad collimation.

7. Observing the wrong star.

8. Mirror not to temperature. It is important in cold climates to allow the telescope to cool down for at least one hour prior to the event.

9. Failure to prepare for mosquitoes and other insects.

Remember that observing occultations is done at night. Practice ahead of time at your home *in the dark* to verify that you can find your tape recorder and radio, turn them on and be at a comfortable viewing angle while observing the graze.

5.14 Approximate Reduction And Shift Determination

The expedition leader should make an approximate reduction of the observations by plotting the observed timings made by each observer on the predicted profile. This allows an estimate to be made of the shift of the graze shadow from its nominal or predicted position. The graze shift is the correction the predicted shadow of the Moon would need to be moved on the ground to match the actual shadow observed during the graze. Its scale is in seconds of arc subtended at the Moon's mean distance and is the vertical scale on the right side of computer predicted profiles. The shift may be thought of as the residual of the observations for the entire expedition and is used to notify future expedition organizers of stars with poorly determined positions and to identify poor quality Watts limb correction data (which are used to generate profile plots). These procedures are used to plot graze observations on the predicted profile in order to determine this shift. Plotting the expedition's data is the best way to verify that all stations of a graze agree with one another. Plots can also reveal large unpredicted mountains or valleys on the lunar limb that should be added to the data set used in predicting profiles.

Plotting the observations on the predicted profile is very much like the process of determining predicted event times described in Section 5.7 above.

For computing the correction of a graze profile to that of the actual observing location, see Appendix E.

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6 Asteroid Occultations

Asteroids (minor planets) range in size from many meters to hundreds of kilometers in diameter. They are located in general between the orbits of Mars and Jupiter within the so-called asteroid belt and are believed to have originated from planetesimals 4.6 billion years ago. Perhaps more than one million such bodies reside in the belt and only half a dozen are larger than 300km across. Of interest to inhabitants of Earth are the special groups of asteroids whose orbits cross that of our planet's orbit with the potential of a catastrophic collision. This is still another reason why the study of asteroid occultations is of such interest.

As the Earth and these objects move in their orbits, geometric alignments occur where the Earth, minor planet and a star (called the 'target star') will line up. For a brief interval of time a shadow from the star's light is created by the minor planet covering the star and is projected on Earth. When this happens, an 'eclipse' or occultation occurs along some portion of the Earth's surface whose path width is directly related to the size of the asteroid. If an observer is located inside the limits of the ground track he will observe a brief dimming of the target star during the occultation ranging from perhaps a fraction of a magnitude to as much as 8 or 10 magnitudes depending on the brightness difference between asteroid and target star. Such an occultation can last from a fraction of a second to as long as a minute or more. The length of occultation is related by the angular speed differences between that of the Earth and the asteroid. A typical occultation lasts seven seconds. Detecting a small drop of 0.5 magnitude or less may be difficult to impossible depending on atmospheric transparency and seeing stability at your site. The geometry of an asteroid occultation is shown as Figure 6.1 below.

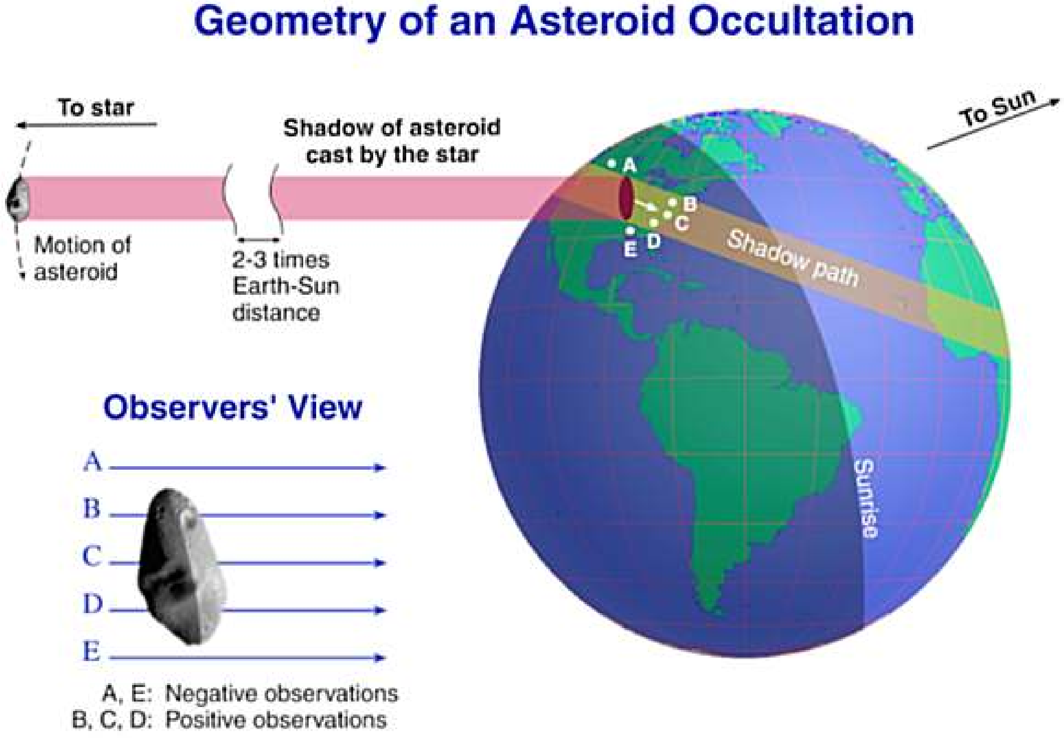


Figure 6.1. Geometry of an asteroid occultation. The asteroid eclipses the star and its shadow is projected onto the Earth's surface. Observers B,C, D on Earth see the asteroid block "occult" the star for several seconds while observers A and E are out side the shadow path and do not observe it. This lack of seeing the event is termed a miss.

From Figure 6.1, observers at B, C and D have *positive* observations, meaning they do have an occultation since they are within the asteroids shadow path on the ground. The observers at A and E have *negative* observations, meaning they do not see an occultation since they were outside the shadow path limit. Negative observations are just as important as positive ones since they place limits on the size of the asteroid and provide confirmation of the reliability of the prediction. Asteroids are numbered and generally named. For example, 25 Phocaea is the 25th discovered asteroid and its formal name is ‘Phocaea’. The smaller bodies with much higher number designators are often not named.

6.1 Scientific Value

An asteroid occultation offers a fabulous opportunity for an amateur astronomer to determine a number of things based on an accurate timing of the occultation. The timing is composed of two key events: the disappearance and the reappearance. The combination of the two is termed a ‘chord’. Each event can occur instantaneously or in steps or slowly (meaning over a fraction of a second or longer). Accuracy is generally needed to within 0.2 second or better. This precision timing is easily achieved using video where 0.03 second accuracy can normally be accomplished (See Chapter 8, Section 10). A successful observation will also provide information on the accuracy of the prediction which in turn will be highly useful in evaluating the quality of the prediction measurements and the data reduction technique. Details of the appearance of the event such as how long it took for the star to drop or restore in brightness may offer insight as to whether the star might have a hidden companion and perhaps even reveal the dimensions of that newly discovered star. The length of occultation will provide data on the shape and size of the asteroid especially if coupled with data recorded by other observers located at independent observing stations perpendicular to the ground track.

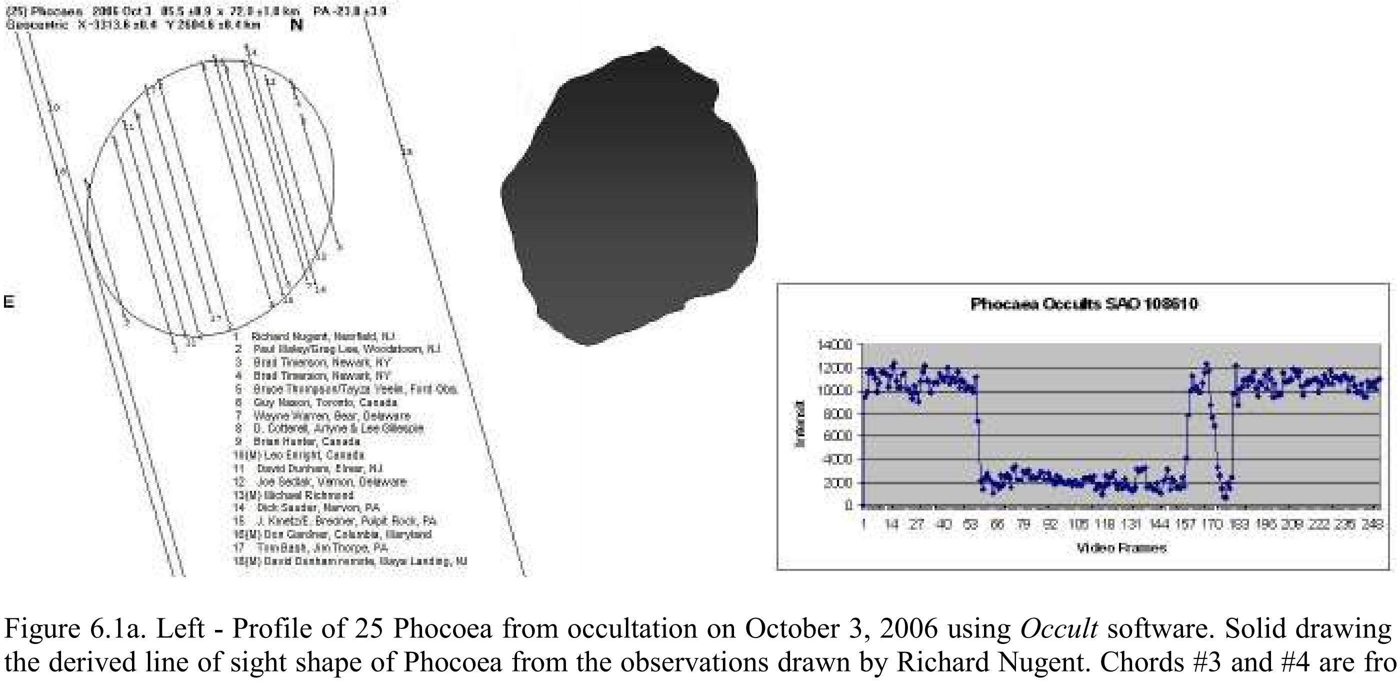


Figure 6.1a. Left - Profile of 25 Phocoea from occultation on October 3, 2006 using *Occult* software. Solid drawing is the derived line of sight shape of Phocoea from the observations drawn by Richard Nugent. Chords #3 and #4 are from Brad Timerson’s video and show a valley or depression on the northwest side of the asteroid. Right-Limovie light curve shows Brad Timerson’s double event from chord’s # 3 (3.4 second occultation) and #4 (0.30 second occultation).

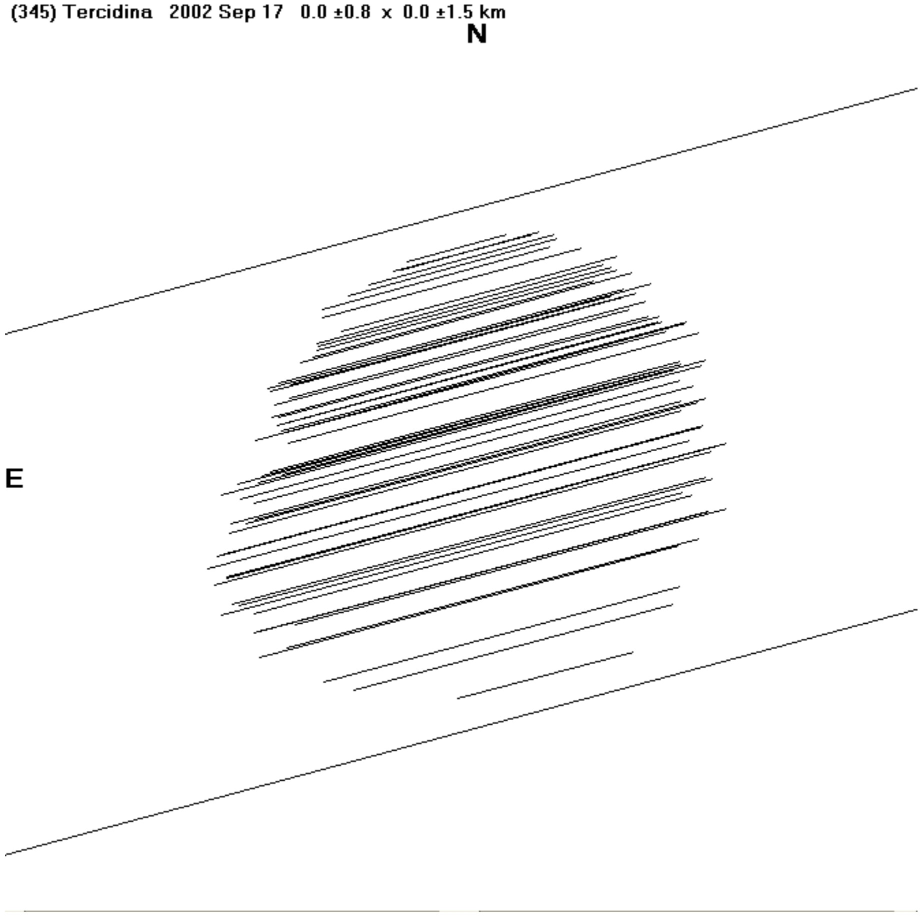


Figure 6.2 Profile of 345 Tercidina from *Occult* software. This occultation was recorded by over 70 observers in Europe on September 17, 2002 (although the number of chords shown here is a subset of that). Observations of these events show the irregular size/shape of asteroids, and the difference in timings due to human error and other factors. Each line represents an observation from a single observer. Tercidina's estimated size was derived as 107.6 km X 89.8 km.

In Figures 6.1a and 6.2, the asteroid's derived shape is strictly line of sight and instantaneous for that moment in time when the occultation took place in its rotational phase. If the occultation had occurred earlier or later, a different shape would be revealed. Hence the resulting shape is two-dimensional. Additional occultations of the same asteroid are required in order to reveal more about the three dimensional morphology.

Even a lone observation might be enough to determine the minimum size of an asteroid. Figure 6.2 illustrates how a large group of observers (each contributing a unique chord) can determine the accurate size and shape of an asteroid, which is otherwise not attainable except by space probe missions.

6.2 Asteroid Satellites

Amateur astronomers played an important role in the early detection and identification of the existence of asteroid satellites. The first reported evidence of an asteroid satellite was made as a result of an observed 0.5 second duration drop in brightness of the 3.6 magnitude star Gamma Ceti during the occultation by the asteroid 6 Hebe in March 1977. It was observed by Paul Maley with a 5 inch (12.6cm) refracting telescope and the account documented in *Occultation Newsletter* (See Volume 11, page 116, July 1977). The visual observation occurred at Victoria, Texas some 1600km north of where the primary occultation was definitely observed at Mexico City. The Victoria observation was reported before the Mexico data was received. Since the predicted time of occultation had a significant error, there was no way the Victoria observer could have known the results of any observations elsewhere. Both times of observations of the Hebe occultation and the reported secondary occurred very close together. Because there were no other sightings, this possible asteroid moon could not be confirmed. See Figure 12.2, in Chapter 12.

A suspected event was observed of 129 Antigone occulting an $m = +6.4$ star on October 12, 1974. Veteran grazing occultation team leader Hal Povenmire planned on observing a graze that night of a star from Cooper City, Florida so he set up his equipment early for the asteroid event (See Figure 12.1 Chapter 12). Povenmire observed a 0.7 sec occultation of the star at the predicted time of the event and sent his report in to the US Naval Observatory, the Smithsonian Astrophysical Observatory and the Royal Greenwich Observatory in England. Povenmire thought this short occultation was caused by the asteroid grazing by the star. Later astrometric updates had showed that the asteroid's shadow passed well south of Povenmire in Guatemala and Belize. For this reason the observation was not taken too seriously although Gordon Taylor of the HM Nautical Almanac's Royal Greenwich Observatory notified Povenmire about a southward shift of the predicted path. Other observers that attempted this event were clouded out hence there is no confirmation of what Povenmire saw. After the Hebe occultation, the word was out and observers began to look at asteroid occultations in a new light. However, the credibility of IOTA observers (amateurs especially) was looked at with skepticism since the tools in their possession were not good enough to enable a confirmation.

In the 1980's other secondary occultations were reported, both visual and photoelectric but none could be confirmed. This was before the era of video, though even as of 2007, confirmation of an asteroid satellite has yet to occur. It was clear that the standards IOTA observers needed to conform to were those involving rigorous self examination and care to ensure that personal judgment and human errors were minimized. Regardless of this, the prediction accuracy enabling observers to be alerted and deployed were poor since path prediction errors were on the order of hundreds of miles.

It was not until 1993 that skepticism about the existence of asteroid satellites vanished. At that time, the Galileo spacecraft discovered Dactyl, the first asteroid satellite to be confirmed in orbit around the known asteroid 243 Ida. On November 1, 1998 the first asteroid satellite found from Earth was discovered by Merline et al. (see *Nature* vol. 401, pp. 565-568) The moon, called Petit Prince, having a diameter of about 13km in diameter, was discovered orbiting minor planet 45 Eugenia.

The latest box score on newly discovered asteroid satellites can be found at:
http://www.johnstonsarchive.net/astro/asteroidmoons.html

Beginning in 2000, better astrometry was available consisting of improved positions of both stars and better data on minor planets which resulted in a greater degree of reliability in predictions and also a greater number of observations by IOTA members. Soon the number of predicted asteroid occultations expanded as smaller and smaller minor planets were added to IOTA's prediction database. As of 2007 more than 1000 asteroid occultations have been observed.

Finding an asteroid satellite through direct telescopic observation is not a trivial task since a find may come only as a byproduct of attempting to observe the occultation of the minor planet itself. IOTA undertakes observation of minor planet occultations with a strategy to first define information on the asteroid size and shape. The odds of discovering a satellite are theoretically increased by placing a large group of observers at closely spaced strategic intervals across the occultation path since the probability of a single observer finding one is rather low.

Because an occultation is directly proportional to the size of the body doing the occulting, satellites are expected to produce short lived occultations—on the order of one second or less. Hence spotting one visually is rather difficult but not impossible. In Figure 6.3, the geometry of a possible asteroidal moon is shown crossing the United States along with the parent asteroid. Thus an observer outside the predicted path of the asteroidal event may make an important discovery if a brief occultation is recorded.

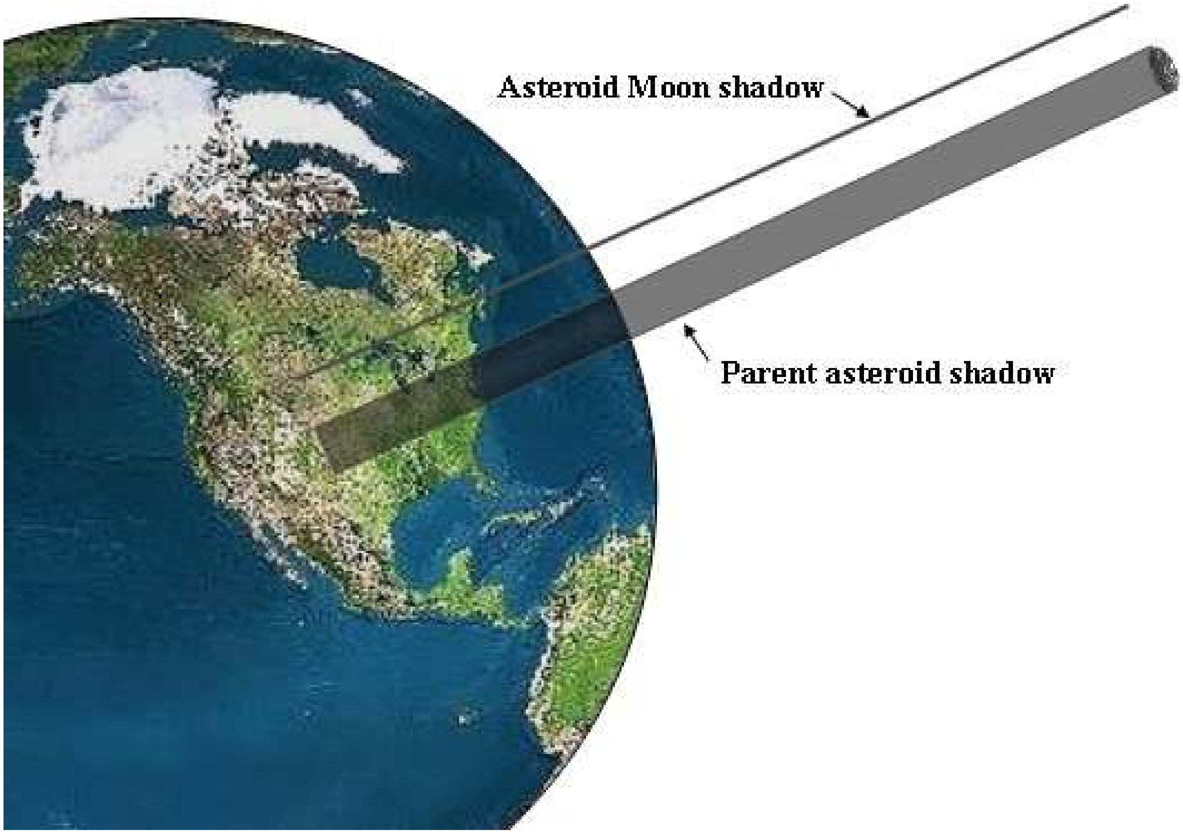


Figure 6.3. Geometry of an asteroid moon shadow. The large shadow is that of the parent asteroid crossing the Earth. The smaller asteroid moon's shadow moves across Earth along with that of the parent asteroid. Asteroidal moon occultations would be of short duration-less than one second. Diagram not to scale. Earth image taken from Snap! 3D atlas, used with permission, courtesy of Topics Entertainment.

Only a small group of satellites have been identified to date. The satellites found up to 2006 appear to lie in orbits within 1,000 miles (1600km) of the parent; some are associated with tiny asteroids and located at relatively close distances from them, essentially binary asteroids. The theory of celestial mechanics has demonstrated that an asteroid satellite can maintain a stable orbit around the parent asteroid up to a distance of 10 times the size of the parent. Thus an observer lying anywhere within 10 diameters of the predicted ground path should be watching for possible satellite occultations. If an asteroid occultation is predicted to occur within 1600km, IOTA's recommendation is to monitor the occultation preferably using a video camera whose sensitivity will enable detection and recording of the occultation. Direct visual observation can be used but this does not offer a permanent record of the event. Visual observations are subject to reaction time errors plus memory recollecting problems. Having a permanent video and corresponding timing record that can be replayed for an audience and for proper analysis is the best methodology. The observing window for an asteroid occultation should be a minimum of 4 minutes centered on the predicted time of the event for the observer's location (i.e. 2 minutes on either side of the predicted event time).

6.3 Equipment Needed

6.3.1 Visual Observation and Timing

The following is a minimum set of equipment that IOTA recommends. Other combinations of equipment are permitted provided they exceed the minimum. Telescope aperture is based on the magnitude of the target star and the assumption that the observer will encounter a dark sky background at the site. Higher elevation sites are more likely to offer darker conditions but could offer more turbulence, such as those found near mountain chains.

a. Telescope aperture as related to the magnitude of the target star:

Target Star Magnitude	Minimum equipment
+5 or brighter	7x50 binoculars firmly mounted on a tripod or other mount.
+5 to +8	4 inch telescope on motor driven mount
+8 and fainter	8 inch telescope on motor driven mount

b. Time signal receiver with new batteries (portable)
c. Tape recorder with new batteries (portable)
d. Quartz watch (digital suggested)
e. Red flashlight
f. Star charts or software program able to lot stars down to at least *m* = +12

6.3.2 Video Observation and Timing

Video and image intensifier equipment is explained in more detail in Chapter 8 Section 10. A sensitive video camera will gain you at least one or two magnitudes, while use of an image intensifier may provide an additional 2 to 4 magnitudes.

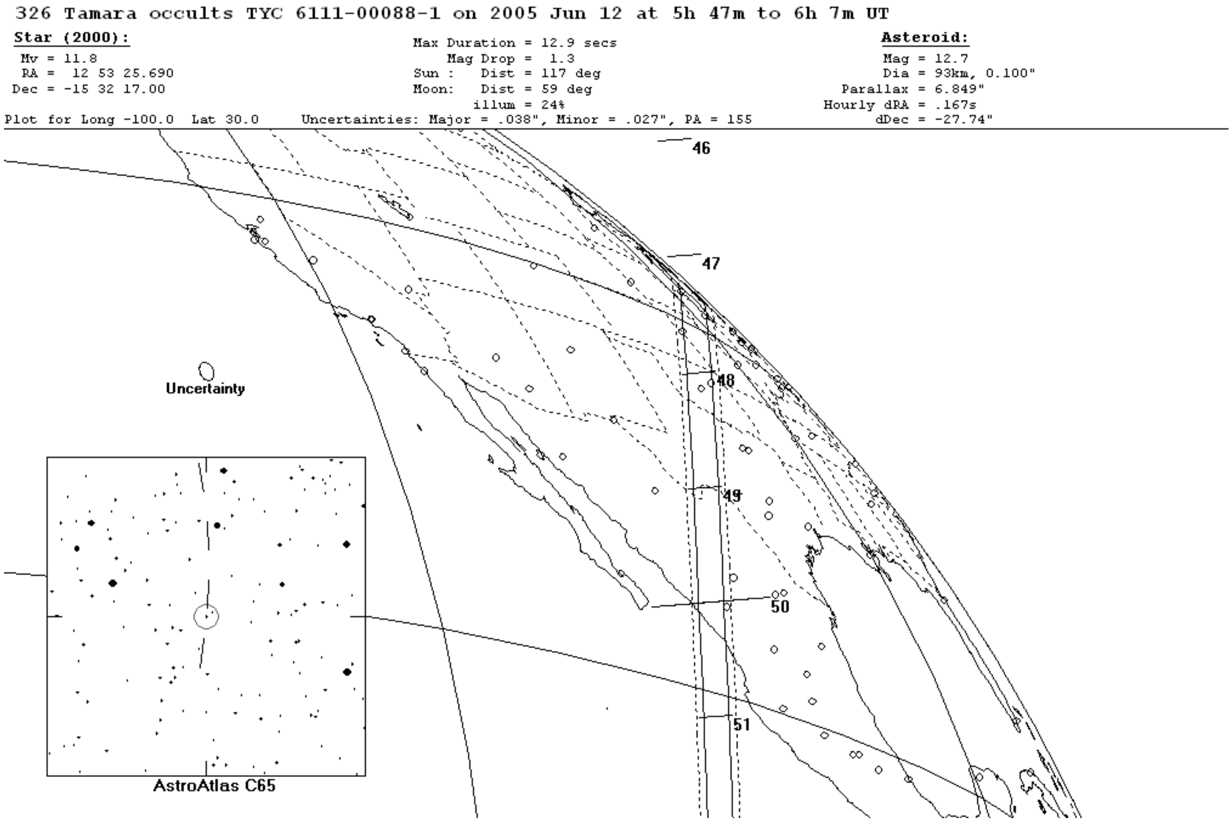
6.4 Methodology

Stars undergoing occultations typically exhibit magnitudes between +9 and +12.5. Occultations of naked eye stars rarely occur. It is rare for an occultation to cross an observatory with a fixed telescope, statistically it will happen once maybe twice per year, therefore mobility is the key for success. Having access to an automobile, personal computer (PC), the Internet, a telescope, short wave receiver, GPS receiver etc. are normally necessary. In addition the observer should possess at least a working knowledge of telescopes, effects of the local temperature, humidity, clouds, air pollution on a telescope at night, how to navigate around the sky, good planning and contingency expectation skills, accurate data recording and reporting and communications with others.

6.4.1 Analyzing the Event Before You Try It

Examine the predictions from the IOTA site: http://www.asteroidoccultation.com on a regular basis and plan ahead for an event. Never wait until the last minute.

A map of a sample prediction is shown below:



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326 Tamara occults TYC 6111-00088-1 on 2005 Jun 12 at 5h 47m to 6h 7m UT
Star (2000):                         Max Duration = 12.9 secs                  Asteroid:
 Mv = 11.8                               Mag Drop =  1.3                       Mag = 12.7
 RA =  12 53 25.690                  Sun :   Dist = 117 deg                    Dia = 93km, 0.100"
Dec = -15 32 17.00                   Moon:   Dist = 59 deg                Parallax = 6.849"
                                             illum = 24%              Hourly dRA = .167s
Plot for Long -100.0  Lat 30.0    Uncertainties: Major = .038", Minor = .027", PA = 155     dDec = -27.74"
```

Figure 6.4. Map of the asteroid occultation by the asteroid 326 Tamara from *Occult* software. The solid lines 93 km wide from Oklahoma through Texas into Mexico is the predicted path of the asteroid's shadow. The dashed lines parallel to the path just outside of the solid lines indicate the 1-sigma error margin, this is where the shadow could shift.

Figure 6.4, a prediction from David Herald's *Occult* program, shows a view of the Earth as seen from the asteroid at the time of occultation. For a detailed explanation of the terms and meanings of the map quantities and symbols, see Chapter 4 Section 4.2.3, Asteroid Event Predictions.

Study the information carefully and review the following before making a decision to either observe it or travel to observe an asteroid event:

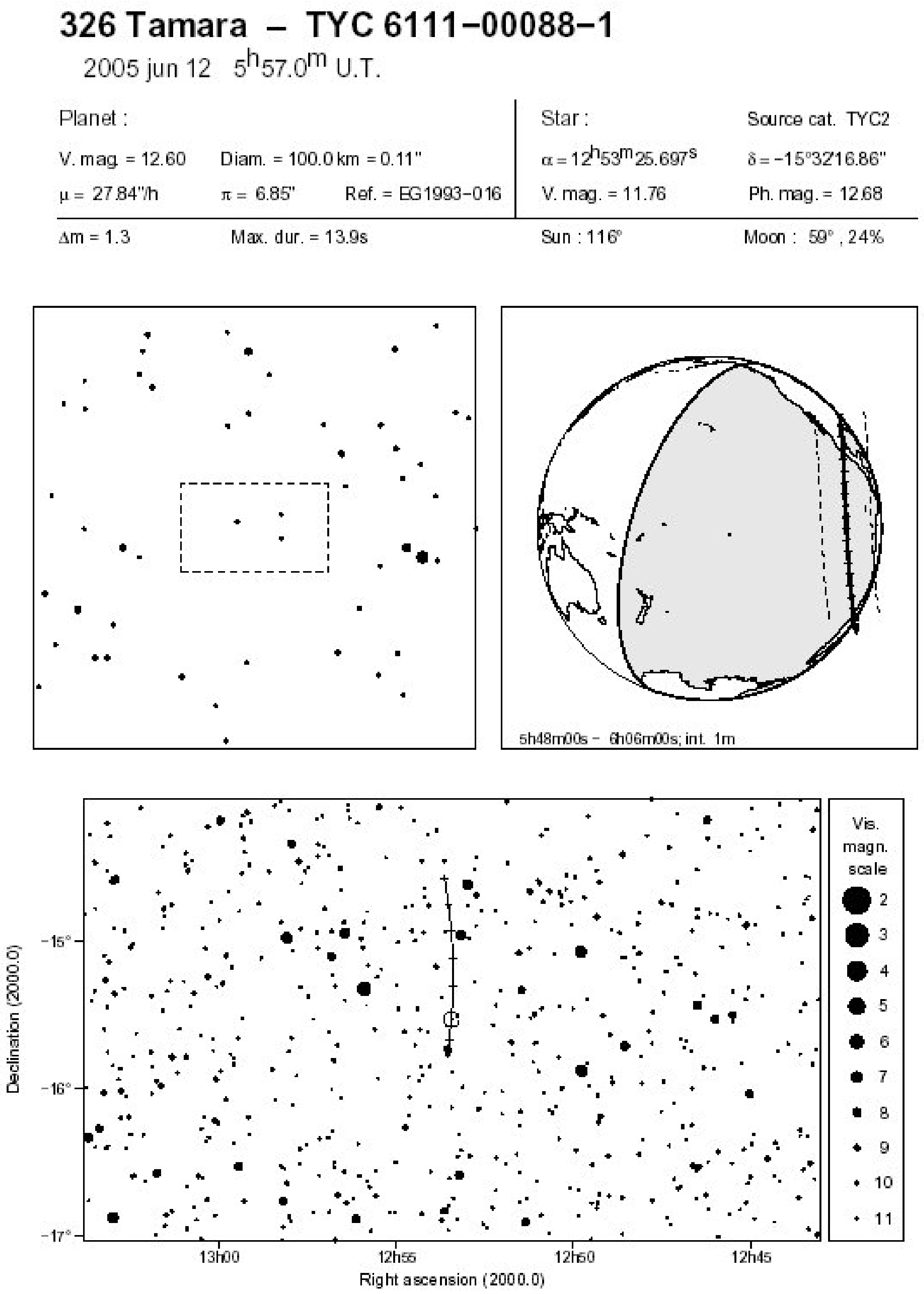
a. altitude of the Sun to avoid twilight. If the event doesn't pass this test, stop.
b. expected magnitude drop (Mag Drop on heading of chart) to assure you can detect it with the equipment you have
c. elevation and azimuth of star to assure you can see it
d. distance of the target star from the Moon, and the phase of the Moon
e. magnitude of the star to assure that your equipment can detect it
f. date and time of event to be sure you can support it
g. distance from your location to be sure you can reach it
h. check the prediction site all the way up to the day before the event for updates
i. expected error in major axis of the prediction to assure that you understand the likelihood of seeing or missing the event (See Section 6.6.2)

6.4.2 What to Expect When You Make the Observation

Note: You do not need to be able to see the asteroid to make the observation, you only need to see the target star! If you are able to see the asteroid, that's fine, you can watch it as it approaches the target star. An asteroid looks just like a star. Regardless of the magnification you attempt to use, it will still appear just like a point of light. If your telescope is large enough you may be able to see the asteroid approaching the star slowly until perhaps 15 minutes before the event when its light merges with the light of the target star. It is desirable to keep at least two other reference stars in the field of view in order to detect variations in the target star that result from Earth's atmospheric seeing. A focal reducer lens (see Figure 6.7 below) is very useful in this case.

The telescope should have motorized tracking so you can concentrate completely on the observation without worrying about having to manually track the star. The aperture of the telescope should be covered with a dew shield to prevent stray light (such as passing car headlights) from entering or dew from forming. Finding the target star can take quite a bit of time. In the case of a GO TO telescope, it should not be used except when skies are known to be free of clouds, as these telescopes require specific alignment stars usually located across a wide area of the sky.

Use adequate charts to find the target star. A useful set of charts is Wil Tirion's *Sky Atlas 2000.0* or *Pocket Sky Atlas* both published by Sky Publishing Corp. These charts are available at discounts from used book suppliers on the Internet. Although the limiting magnitude of the



326 Tamara – TYC 6111-00088-1

2005 jun 12 $5^h57.0^m$ U.T.

Planet :			Star :	Source cat. TYC2
V. mag. = 12.60	Diam. = 100.0 km = 0.11"		$\alpha = 12^h53^m25.697^s$	$\delta = -15°32'16.86"$
μ = 27.84"/h	π = 6.85"	Ref. = EG1993-016	V. mag. = 11.76	Ph. mag. = 12.68
Δm = 1.3	Max. dur. = 13.9s		Sun : 116°	Moon : 59° , 24%

Figure 6.5. Edwin Goffin's condensed prediction of the 326 Tamara event for June 12, 2005. The bottom detailed chart (3 x 5 degrees) represents the portion of the larger field of view in the chart at the left center of the page bordered by the dashed line box. See Figure 6.6 for this 3 x 5 degree field drawn in on *Sky Atlas 2000.0*.

Sky Atlas 2000.0 charts is $m = +8.5$, the large fold out page format allows you to find the target star area by identifying bright stars nearby. The *Pocket Sky Atlas* has a limiting magnitude of $m = +7.6$ and its adjacent pages cover typically 40° x 55° of the sky. This makes it easy to navigate to the 3° x 5° field needed to find the target star. Then, most any planetarium program can print a detailed chart to say 11th or 12th magnitude to help you identify the target star. Figure 6.5 shows the Goffin prediction (from Edwin Goffin's website in Belgium) and the associated 3° x 5° finder chart.

The prediction web site (http://www.asteroidoccultation.com) usually has five levels of charts. The fainter the star, the more time it generally takes to locate it with certainty. **Always allow a two hour set up time before the time of occultation**. It is crucial to allow plenty of time to setup and find the target star. Many occultation observations have been lost due to observers saying, "I couldn't find the target star in time…" Don't fall victim to this, always allow at least one hour after equipment setup to find the target star.

For the 326 Tamara event from Figure 6.4 and Figure 6.5, a section of Wil Tirion's *Sky Atlas 2000.0* is shown below as Figure 6.6. By drawing the 3° x 5° box on the chart near right ascension = 13h and declination = -16°, this makes it easier to navigate to locate the target star field by star hopping.

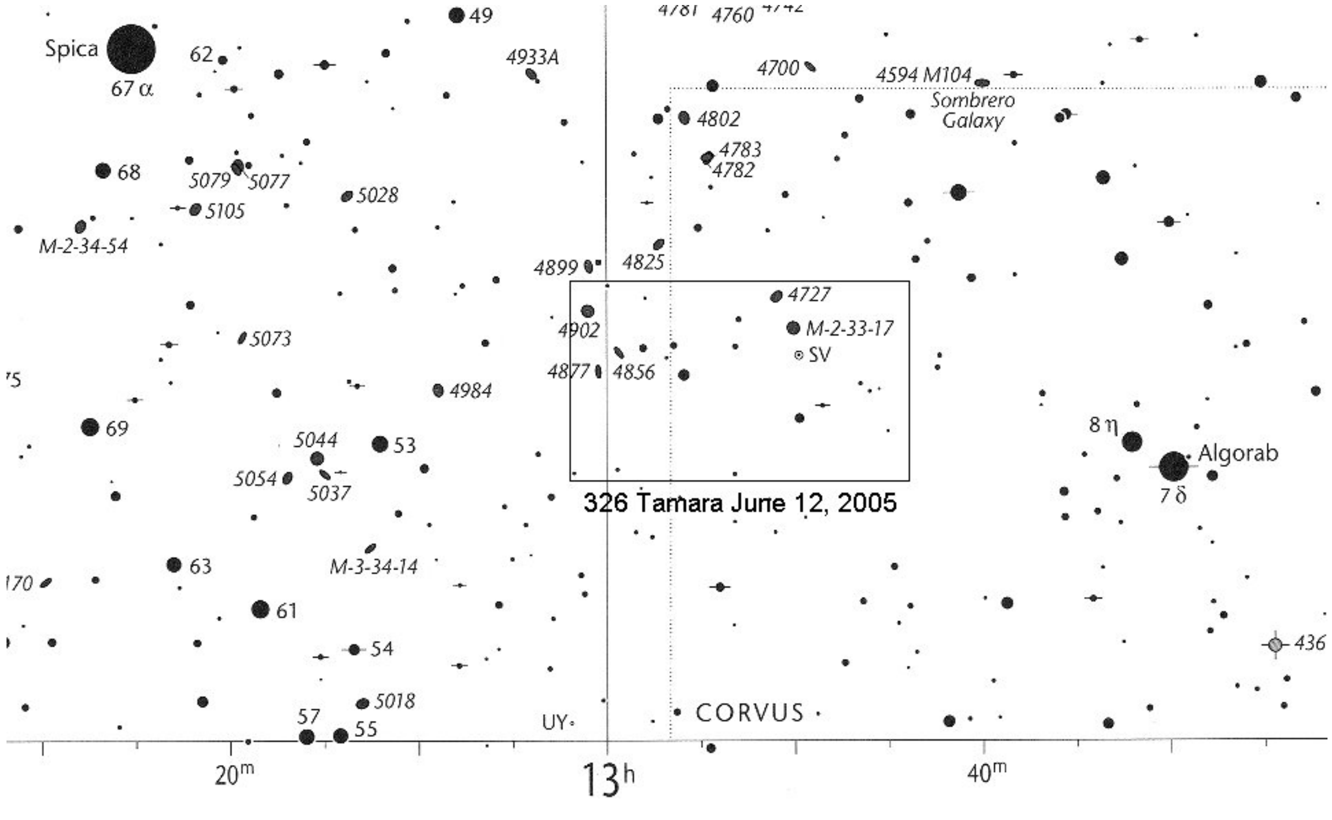


Figure 6.6. Portion of Chart 14 of Wil Tirion's *Sky Atlas 2000.0* showing the region for the 326 Tamara occultation. Drawing a 3° x 5° box as shown on this large full page chart greatly aids in finding the target star area fast. *Sky Atlas 2000.0* © Sky Publishing Corp.

During the observing window (the time period ± 3 minutes from central occultation time), expect to see one disappearance (D) and one reappearance (R) as the star is occulted and then returns back to its normal brightness. Depending on your method of timing you should also watch for a secondary occultation caused by a satellite. If this were to occur it would likely be a short blink. Thus using a video recording setup is far superior to the human eye in detecting and recording the event accurately without the reaction time. If you clearly have seen the occultation, continue observing until the end of the observing window.

The D and R usually are instantaneous. Sometimes either event could occur in step-wise fashion lasting a fraction of a second. If the observer is close to the edge of the actual occultation path, a 'grazing occultation' might be seen where an episode of short duration light variation occurs within the time span of one or two seconds. Step-wise dimmings may also be caused by Fresnel diffraction effects.

The observer must anticipate many things:

- altitude and azimuth of the star at occultation time must be in the clear (no trees or structures blocking the view)
- checking out all equipment before leaving home for the site
- all equipment should be battery powered and batteries should be fully charged
- assure clear reception of time signals
- carry a cell phone or other reliable means of communication
- assure an accurate ability to determine the site location through GPS or geodetic maps and be able to relocate the site after the fact if necessary
- the observation site must be safely located above all other factors
- the site should be located on a flat, quiet, dark location away from transmission lines and power lines since these cause short wave reception problems
- bring backups of all key equipment components in case of failure
- effect of low temperatures on equipment and the observer
- anticipate location of the Moon and twilight relative to the event
- practice finding the target star in the days before the event if at all possible
- carry the proper star charts and be able to positively identify the target star by approaching it through identification with other stars in the vicinity. Often similar asterisms can confuse the proper identification for inexperienced observers.
- Be aware that seeing can effect the detection and recording of the target star as well as confirmation that an occultation has even taken place
- Shallow magnitude drops are possible and should be anticipated
- Step events may be observed signifying possible duplicity in the target star
- It is never necessary to see the asteroid but depending on the telescope, the observer may monitor the approach until the two images merge
- Protect telescope from condensation, animals, poor mounting surfaces such as soft gravel
- If setting up telescope on hood of a car, check tires to make sure they don't have slow leaks as this could shift the telescope while waiting for the occultation
- Being careful never to set up on private property without the owner's permission
- Never leave the observation site until the precise location has been recorded
- Make a commitment to the organizer to take a certain observation line and stick with it

The observation should commence from at least two minutes before the time of predicted occultation at the latitude/longitude of the site and extend the same amount of time after. The observer must not be distracted and must be able to monitor and record data continuously during this critical period. Portable video systems are currently the most expedient and reliable method of data recording.

Abandoning an assigned site on a whim is not recommended since it will leave a valued portion of the ground track vacant and could result in a duplicate observation elsewhere. However, there may be a rarely unanticipated situation where moving to another unplanned and off assigned location at the last moment may be required such as the onset of fog or clouds. For the occultation of 54 Alexandra in central Texas On May 17, 2005, Richard Nugent had to relocate from his assigned station by 12 km to find some trees to block the 30 mph sustained winds. 54 Alexandra's profile is shown in Figure 6.14.

If a star field is low in elevation, expect that even the presence of thin high scattered clouds could wipe out the event. Poor seeing at low elevations coupled with the fact that one is looking through a denser atmosphere than in a field at high elevation may also be detrimental.

Clouds can often scare away even experienced observers. However, weather can be quite changeable and more often than not, clouds have broken or dissipated at unpredicted times. An apparently hopeless sky condition at 6PM may turn into a great observing night at 10PM. Of course the reverse can also occur too. Don't give up too soon. Using internet resources to watch the infrared images from weather satellites can be a help in establishing weather patterns. One well known website, www.weather.com, offers hourly cloud forecasts. Eventually it comes down to one observer making the final decision to attempt the event.

6.4.3 Example Timeline

The following is detailed information that you can use to train yourself and others in organizing for an asteroid occultation. The letter "O" signifies "Occultation".

<u>O-7 days to O-1 day</u>: Locating the target star ahead of time is invaluable and can save the day. PRACTICE! If you are training others, finding the star before occultation night will be an investment in success. There are many times when clouds are near the star on occultation night and locating may consume lots of time. If you have already spotted it on preceding nights, you may short cut the process considerably compared to another observer who is totally unfamiliar with the star field. The star might also be situated in an area of the sky devoid of other reference stars or it could be in a very rich area with confusing star patterns. Other factors such as proximity to the moon or twilight makes early detection very important.

<u>O-1 day</u>: Determine where you plan to observe. If observing from your house, notify the local coordinator so we will know that that part of the occultation path is covered. Send either GPS

coordinates or an address. If you plan to be mobile, notify the coordinator so you can be assigned a site area.

O-2 hours: you should be set up at your chosen site by this time. Polar align your mount and be sure your clock drive is working. If using a Schmidt-Cassegrain watch out for dew formation and use a ‘dew zapper’ or portable hair dryer to lessen this possibility. Be sure you have the following: at least 2 eyepieces (wide field), bug spray, right angle finder, red flashlight, binoculars, copies of the star chart, tape recorder with fresh batteries and tape rewound to the beginning, short wave radio source of time signals. This latter item is the key to precision timing.

O-30 minutes: find the target star and observe from a comfortable position either sitting or standing that will not cramp your neck. Be sure your hands are free as possible.

O-20 minutes: For a visual timing: test your voice and the radio and recorder to be sure the time signals and your voice evenly record. Play it back to verify. If one is drowned out, reposition and repeat the test until you get it right. Be prepared to comment on passage of clouds, distractions, seeing changes, stability of the target star, etc. during your 10 minute observation window. Be quick about it and be aware to quickly call out when the star disappears and reappears. Use either "D" and "R" or "out" and "back" to mark those events. Call out your reaction time if you can estimate it after you have seen the occultation. For example, if you think you were late in timing the D, try to estimate the delay by counting to yourself “one thousand one” which should take about one second. There is always a “personal equation” of error by a visual observer which must be accounted for immediately before you forget. If you are using video, start recording 4-5 minutes before central occultation time.

O-2 minutes: Begin continuous observing. Start radio and recorder. If the radio fades in and out, another person at your site could assist in helping get the signals back. While it is best to keep both hands free, if using a tape recorder hold it in one hand close to your mouth and use the other hand to adjust the telescope focus. The focus must always be kept sharp!

O+2 minutes: End the observation. Turn off radio and recorder.

6.5 Techniques

Several proven techniques are recommended to be suitable for data recording and collection. The best methods for producing the most accurate data are those which minimize the resultant timing error of the event. A comprehensive discussion on timing methods for asteroid occultations may be found in Chapter 8, *Timing Strategies for Occultations*.

6.5.1 Visual

This is the least costly from a hardware perspective but offers the most chance of error. It involves the observer looking through a telescope and watching as the target star undergoes the occultation. The observer must watch the star constantly without interruption and will use his/her voice to record onto a portable cassette tape or voice recorder along with short wave radio time signals. Beware of staring continuously at the target star as your eyes can play tricks on you as the star can fade and change colors. Keep your eyes moving every 15 seconds or so to avoid blank stares. Without a time signal source, the data may or may not be useful. In a general sense, timing the length of occultation without knowing the precise UT of the D and R offer some data. Observers located north or south of your position may have obtained accurate time references of their data and so, even just the length of your occultation can be used to interpolate between adjacent stations.

All visual observers have reaction times, which must be accounted for. This can best be done by estimation realizing that more experienced observers may develop quicker reaction times after having seen a couple of occultations and a typical error in a novice observer might be a full second or even longer, or perhaps less depending on his/her acuity. An experienced observer's reaction time is usually 0.3 seconds. Testing reaction time indoors may be done by using a projected or video taped star field where the observer handles a stopwatch and tape recorder along with time signals. Methods of estimating reaction time are found in Chapter 8, Section 8.2, *Estimating Personal Equation* and Chapter 4, Section 4.5.1.

A tendency to blink or turn away from the eyepiece perhaps due to fatigue, insects or other factors is common, hence one should verbally annotate into the tape recorder when the observation is interrupted.

It is most important for the observer to minimize the distractions. Having the telescope well aligned and tracking means the observer can concentrate fully on looking into the eyepiece. Be careful in a humid environment to watch for dew formation. Avoid the gap between the eye and the eyepiece, which could trap air in the small space and encourage condensation. Having a battery powered hair dryer handy is a good tactic.

Use several eyepieces, right-angle finder and a right angle eyepiece for the main telescope. A visual observer who is more comfortable at the eyepiece will likely obtain better data.

6.5.2 Video

Video is by far the best method to date for eliminating the human reaction factor in capturing time sensitive data and using inexpensive off the shelf equipment. A video camera is currently the best method of occultation recording. (See Appendix D, *Equipment Suppliers*). Such cameras will eventually develop 'dead pixels' which will exhibit star like characteristics in the same portion of the field. Stars can be distinguished from dead pixels as they move through the field while the dead pixels do not move. The cameras are lightweight and usually require no counterweights even on telescopes as small as 4 inches (10cm) in diameter. The most common cameras used by IOTA observers are the Supercircuits PC-164C and PC-180XS low light cameras (0.0003 lux), and the Watec 902H and 902H Ultimate cameras (0.00015 lux).

For stars brighter than +7, it is even possible to use a small portable tracking mount or tripod with camera attached to a telephoto lens and set up a *remote station at a additional location* (See Chapter 10, *Unattended Video Stations*), then go to your primary, fully equipped site, returning later to pick up the remote station gear and data tape. A camcorder with a night vision setting may also be used for the same purpose. Test your camcorder system a few days before the event to be certain it can record the target star.

If available, use a focal length that results in at least two or three reference stars visible in the same field. A focal reducer lens such as an f/3.3 or f/6.3 provided by Meade or Celestron expands the field of view noticeably. This can make locating the star (and keeping it in the field if polar alignment is not optimized) much easier. The use of a focal reducer increases the ability of your video system to detect fainter stars. This principle is demonstrated in Figure 6.7. Here the left frame shows a video chip FOV with no focal reducer and the star's light is spread over a 3x3 or a 4x4 pixel array. This limits the amount of light striking each pixel. On the right frame a focal reducer is used and now the star's light is only spread over a 2x2 pixel array. The same amount of starlight hits the whole chip and thus each pixel in the 2x2 array receives more light and appears brighter. This increases the faintest magnitude limit. Experience has shown that using an f/3.3 focal reducer on a Schmidt-Cassegrain compared to its $f/10$ factory ratio increases the sensitivity by at least one magnitude on video.

6.5.3 Locating the Target Star Using Video

To locate the target star in the video field follow this procedure:

1. Locate the target star visually in the center of the eyepiece field using star charts such as *Sky Atlas 2000.0*, *Pocket Sky Atlas* and detailed planetarium program custom charts. Make sure the telescope is tracking the star. See Figures 6.5 and 6.6.

2. Carefully remove the eyepiece/star diagonal assembly.

3. Install focal reducer/video camera/adapters, attach all cables and turn video monitor/camcorder on. Be sure during this process that the removal/installation of hardware does not cause the mount/telescope to move.

4. Focus the field of view using the monitor by turning the focus knob. It is useful to already know how many turns of the focus knob it takes clockwise or counter-clockwise to achieve focus for the star and your particular setup. Have this written down somewhere for rapid focus. For example, if it takes 3¾ turns clockwise of the focus knob to reach focus from visual to video, write this down on a piece of paper and tape it to the telescope so you can see it. See Figure 6.7b.

5. Since you are very close to or at the target star, use the detailed star charts to center the target star in the video field.

6. Understand the field of view of your video camera and have this field marked on your detailed star charts. This makes it easier to determine where your field of view is. Also keep in mind the inverted and/or mirrored FOV with your particular telescope system.

7. Once you have acquired the target star in the field, with say 30 minutes to spare before the occultation, you may want to turn off your camcorder and the power to the camera. This will conserve battery power. You should recheck the position of the target star at least every five minutes to make sure it's in the field of view of the camcorder, making small adjustments to as needed. This will also help you see the direction and amount of drift that your telescope has, if any. If the tracking is drifting in a preferential direction you should 'lead' the field and position the star so that it will drift into the center after some period of time knowing the drift rate as you are able to watch it. To prevent large drifts with time, look through the finder to remember key reference stars, so that when you manually adjust the telescope for drift, you can minimize the time and number of such operations.

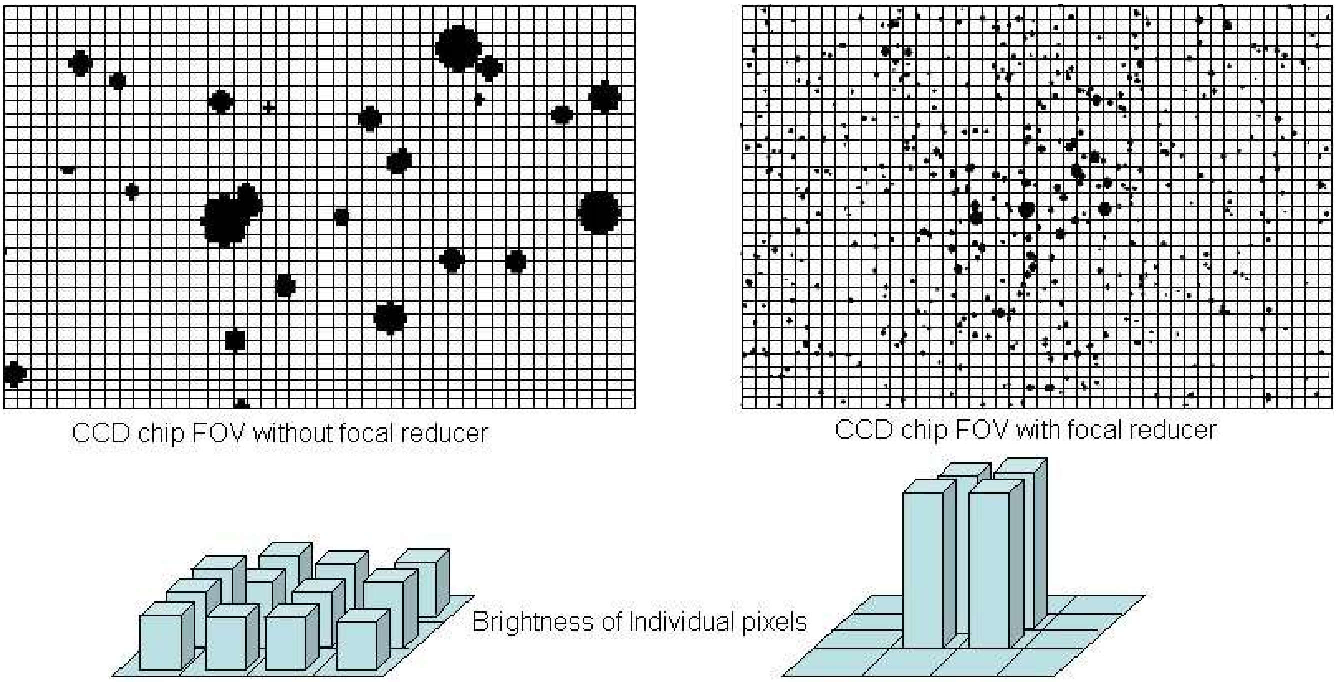


Figure 6.7. Effect of a focal reducer on the pixel brightness on a video camera chip. The left CCD frame shows a smaller field of view and hence the starlight is spread over many pixels (lower frame). The right CCD frame used a focal reducer creating a larger FOV allowing starlight to fall on fewer pixels resulting in brighter star images.

Figure 6.7b. Reminder note on telescope base to achieve rapid focus

The camera must be battery or DC powered and the telescope mount driven from a car or other portable battery. If the camera does not have built in audio you must arrange for the time signal receiver to transmit either directly into the camcorder (if you are using one as a substitute VCR) or generate audio signals that can be monitored and recorded by a lapel microphone attached to the AUDIO IN plug of the camcorder. You should also run a test to ensure both video and audio record at proper levels.

Batteries used for camcorders and video cameras can generally operate for one or more hours with on/off usage during one or even more occultation sessions without fear of running down. Always keep spare batteries just in case.

6.5.4 Remote Video at Unattended Video Site(s)

This method utilizes the video or image intensified video technique with the sole exception that a single observer prepares and sets up two (or more) stations with full sets of equipment which may or may not be identical. One station will be unattended during the occultation. The idea here is to maximize the opportunity for acquiring chords at well spaced distances especially when there is significant uncertainty in the prediction accuracy. Stations can be set up where the distance between them is to be determined by the path error and also the distance to which you can conveniently travel. For example, if the path error is +/-1 full path width, one might consider a site just outside the predicted south predicted limit and one just outside the north predicted limit. This assumes no other observers are in attendance. See Figure 6.8.

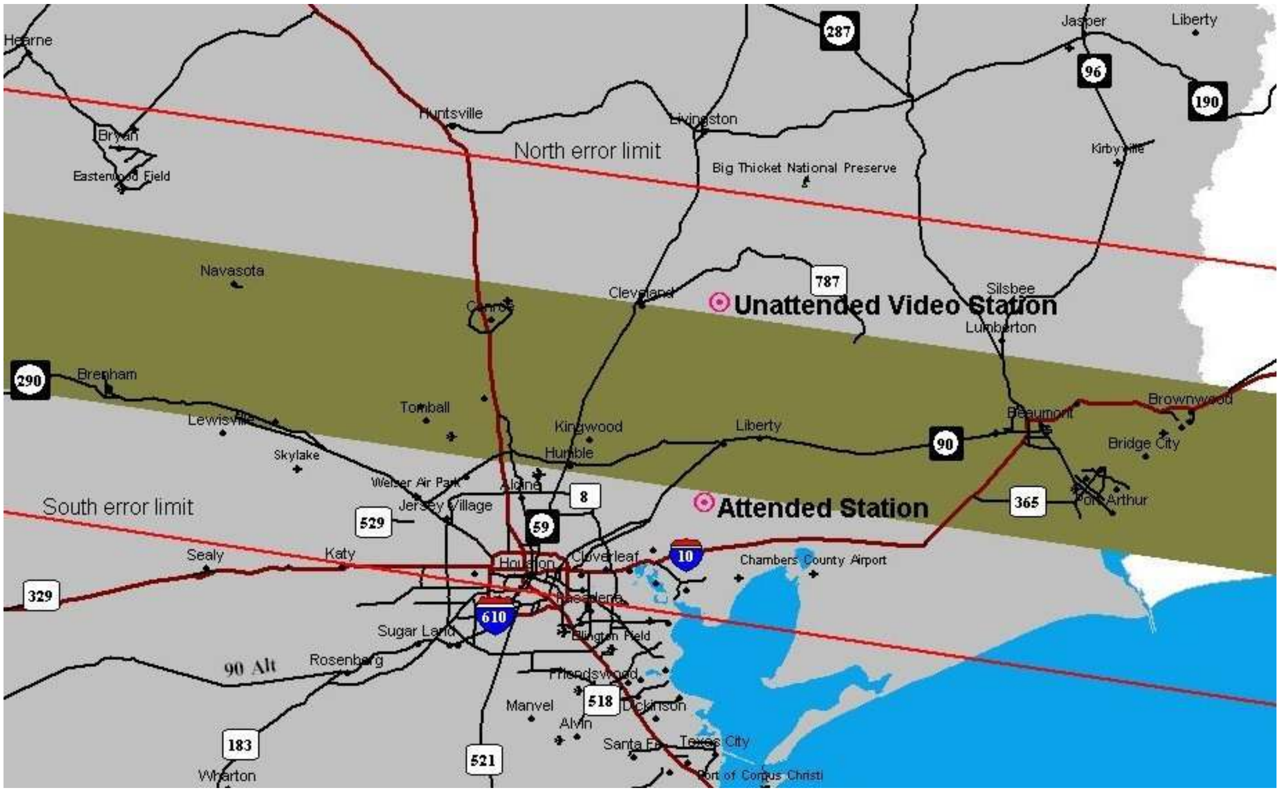


Figure 6.8. Location of Unattended video station at North path limit and attended station at South limit.

The strategy also requires that the observer have enough time to set up one set of equipment at a safe dark site where it can later be retrieved hours later without risk. This site will run by itself, record data and must have enough battery power to operate past the time of the occultation for all system components. The observer needs to drive to the second location and have enough time to get the equipment set up there before the event occurs.

If the star is bright enough, the camera system might be set up on just a tripod eliminating the need for a tracking mount with a telephoto (e.g. 135mm) lens preset so that the star will actually drift into the field of view at just the right time. The lens used should depend on sky darkness and clarity. Fainter stars can also be recorded this way with telephoto lenses pointed at the target area ready for the time of the event. This remote video station method is routinely used by IOTA astronomers Roger Venable and David Dunham. Setting up such a site is not without its risks especially when there is high humidity. A site left alone without dew removal capability will likely fail. Always check the prediction of ambient temperature and dew point. If there is a 3 degree or less spread between them prior to or during occultation time, you can expect dew to form.

If the observer has a companion that wants to participate at a remote site, then appropriate instructions should be provided to ensure that the companion verifies that all equipment at the site are operating correctly through the time of the observing window. Cell phones can prove extremely valuable in this scenario. The most common problems might be with short wave time signal reception, dewing of optics, battery levels or tracking. For contingencies, there should always be extra batteries and a method to remove dew. One desperate method for dew removal for Schmidt-Cassegrain telescopes at a mobile site is to divert the hot air from the dashboard of an automobile heater turned on full blast through a narrow, but long flexible ductwork from a clothes dryer. The flexible ductwork can be attached to the dashboard with duct tape. For a more detailed account of remote video stations see Chapter 10, *Unattended Video Stations*.

6.5.5 Image Intensified Video

An electronic image intensifier is a device that amplifies the input light from the telescope before reaching the video camera. It is attached to the prime focus of the telescope with the video camera mounted directly behind it. If a focal reducer lens is employed, that lens is attached first, followed by the intensifier and then the video camera. At least one intensifier (Collins I^3) has an accessory eyepiece allowing focus to be achieved before placing the video camera in the optical path. Though this intensifier can operate for a hundred hours from a 3V lithium battery, the observer should keep a spare battery handy and turn off the intensifier when not in use. See Figure 6.9.

Figure 6.9. PC-164C camera attached to Collins I^3 Image intensifier. The Collins I^3 piece is attached to a f3.3 focal reducer at the back of the telescope. The Collins I^3 is powered by a 3V lithium battery with its holder attached to the bottom of the Collins tube.

The intensifier may be damaged by prolonged exposure to bright sources. Depending on the aperture of the telescope, a ‘bright’ star might be $m = +6$. If the target is a bright object, there is no need for an intensifier. One must take care when using an intensifier close to twilight.

Sky background can also impact the resultant image and potentially damage the intensifier tube itself. A burn spot may appear which will not change position when the field is changed. This signifies that damage has occurred. Adding an intensifier to the optics may shrink the field even further; hence accurate polar alignment and being certain that you have the target in the field become even more critical. If a burn spot is present, be sure not to allow the target to drift over the spot.

Adding the intensifier increases the moment arm of the telescope but probably will not require counter weighting. Smaller telescopes such as the 4" Meade 2045D (Figures 6.9, 8.6) may have a tripod mount that is too short to accommodate this moment arm. However, even on a larger scope one must exercise care that the extended optics will not bump the telescope mount as it is moved either during the initial location of the target star or during the tracking process for the occultation. The additional weight of an intensifier may require additional support to maintain the telescope balance for proper tracking.

Always choose a telescope whose mounting does not require re-pointing as the target crosses the meridian. A fork mount is generally the favored design. If a target star is located 85 degrees above the east after you have first located it and it is predicted to be occulted when 85 degrees above the west, for example, one must ensure that the telescope will track without repositioning during that time. Scopes on German equatorial mounts will bump up against the mount and force a repositioning. With the amount of time needed to manually find high altitude events, this is an important issue to consider.

6.5.6 CCD Camera Drift Scan

The CCD drift scan technique is a method of using CCD cameras for occultation recording. Since CCD cameras do not have the 30 frames/sec exposure rate that video systems have, an alternate method to record asteroid occultations is the drift scan method which is described in detail in Chapter 8 Section 8.9. In this method the motor drive of the telescope is turned off while the CCD camera is making a time exposure. The field of view is allowed to trail across the CCD chip. As the occultation occurs, a dimming in the target star is apparent (see Figure 6.10 below) and the exposure is stopped a few minutes later. The UT start and end times of the exposure must be known, and the times of the event are measured graphically as can be seen from Figure 6.10. A numerical example of the CCD drift scan technique is presented in Chapter 8, Section 8.9.2.

6.5.7 Photography

The occultation may be photographed with a time exposure, though this technique is not recommended for accurate timing data. The resultant gap in the trail of an unguided time exposure will reveal the occultation if the magnitude drop is steep enough. If the start and end time of the exposure are accurately timed, one may use a print of the trailed image to interpolate the D and R times. Unlike the CCD drift scan method described above, the precision will perhaps be accurate to at best one second depending on the duration of exposure and focal length used. This method is discouraged except as a medium for the simple recording of the event.

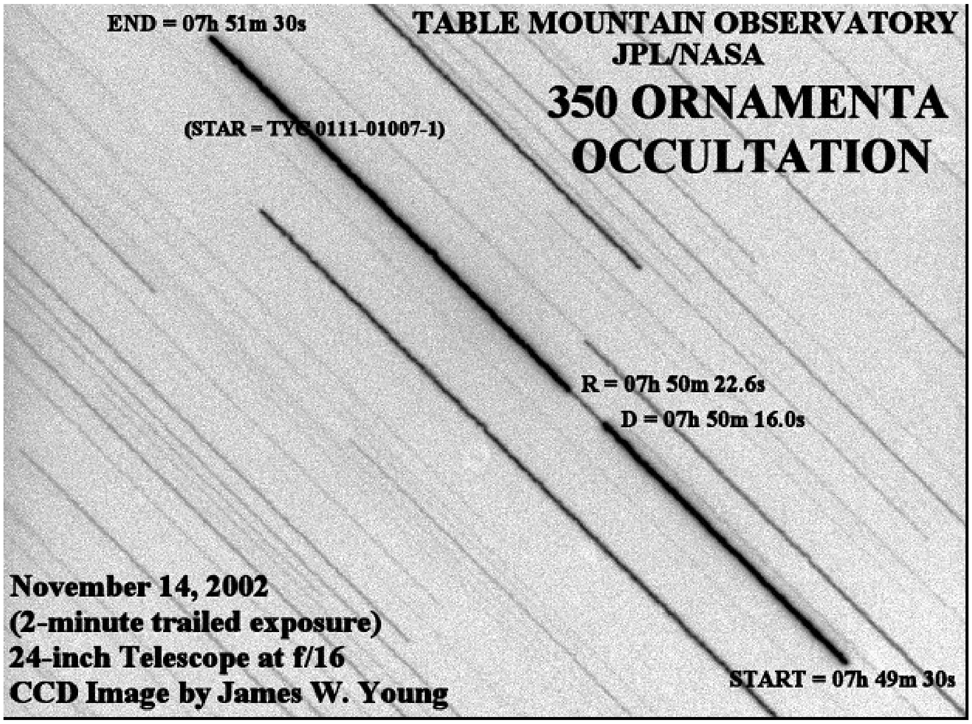


Figure 6.10. CCD drift scan (negative image) of the 350 Ornamenta occultation on November 14, 2002. Image courtesy James W. Young.

6.6 Predictions

Predicting asteroid occultations is a challenging task and it is these forecasts that must be relied on in order to successfully execute an observation. A detailed account of the asteroid occultation prediction parameters is presented in Chapter 4, Section 4.2.3.

6.6.1 Overview of the Prediction Process

To observe an asteroid occultation you must be located in the right place at the right time. When an asteroid occults a star for an observer on the Earth, it cuts off the light from the star and thus casts a “shadow” on the Earth (Figure 6.1 & Figure. 6.3). As the asteroid moves across the sky, the asteroid’s shadow moves across the Earth – this is the asteroid occultation “shadow path” or the “path of the occultation”. It is a phenomena identical to a total solar eclipse, except the asteroid’s shadow is much smaller than that of the Moon on the Earth’s surface. Computing the path for an asteroid occultation is a challenging task because very small errors in the position of either the asteroid or the star can translate to a significant shift in the path of the occultation. Although we have seen many improvements in the accuracy of asteroid and star astrometry in recent years, we still have significant uncertainty in our prediction of the path of asteroid occultations. Because of this uncertainty, we refer to our asteroid occultation path information as a “prediction” or “predicted path”. If we observe an event and thereby determine the actual location of the asteroid’s shadow, we then know the “actual path”. For the vast majority of events, the difference between the actual path and the predicted path is likely to be more than a quarter of the path’s width.

IOTA employs a two step process to improve the accuracy of path predictions: search and update. The first step is to perform a search for possibly interesting asteroid occultation events. In the spring of each year, Edwin Goffin (IOTA European Section in Belgium) utilizes his database of asteroid orbits and star catalogs to search for asteroid occultations that would occur in the following calendar year. He then reviews these asteroid occultation events, both computationally and manually, to reject events where the asteroid is too small, the duration of the event is too short, and other criteria of the occultation. He then publishes path predictions for worldwide asteroid occultation events for the following year which typically include over a thousand events. This list of events (also known as Goffin’s events) is the starting point for IOTA’s efforts. In addition to Goffin’s events, other IOTA members perform searches finding additional events during the year. IOTA will add some of these events to the list of events for observers. See Appendix K for Goffin’s FTP website for downloading asteroid events.

Because Goffin computes his predictions in the spring, many events will occur more than a year after he publishes his predictions. To improve the accuracy of the path predictions for observers, IOTA computes updated path predictions closer to the time of the event. These updated path predictions, also called “updates”, are typically more accurate that the initial path predictions because they can include recent astrometry of the asteroid and sometimes recent data on the star. Updated accurate positions of the asteroids comes from the US Naval Observatory (USNO) in Flagstaff, Arizona and the Table Mountain Observatory (TMO) operated by the Jet Propulsion Laboratory, Pasadena, California.

Since the uncertainty in initial path predictions is often much more than the width of the path, these updates are crucial to our goal of gathering as many successful observations as possible. Until recently IOTA only computed updates for the most promising events. Recently, IOTA has computed updates for a larger percentage of worldwide events. Based upon the latest astrometry, updates are computed and posted approximately one month prior to an event. Also note updates are sometimes produced for new events that are not listed on the event summaries posted at the main IOTA website. “New” events are sometimes discovered relatively near the time of the event and these events are not always added to the summary lists. In the case of an important new event, it is usually posted on the IOTA E-group listserver.

6.6.2 Using the Updates

Predicted path and uncertainties are the key elements of the update because these are the only elements of the path prediction that change from Goffin’s initial computation. The location of the star and other circumstances of the event essentially remain unchanged from the initial prediction. Updates provide path information in two forms: maps and latitude/longitude coordinates. Updates provide a global map of the path and one or more maps showing a more enlarged view of the path. The maps provide a general idea of the location of the predicted path, a general idea of the time of the event at a particular location along the path, and some indication of the uncertainty in the predicted path. This same information is provided in more detail via a text based web page, which includes lat/long coordinates of the shadow path center, limits and 1 sigma limits. The maps provide a good general view but the text based documentation provides more accuracy.

IOTA astronomers use the program *Occult* to produce the basic path plots. The maps (See Figure 6.4) have a text legend at the top that provide the key circumstances of the event. The event time in the first line of the plot legend is the time for the mid-point of the event and is almost certainly NOT the time of the event at your location. The time at the top of the plot is UT followed by a time interval to show the length of time that the asteroid's shadow path is on the Earth. The actual plot of the path on the Earth's surface depicts the path from the perspective as viewed from the asteroid. When plotting a picture of the Earth's, *Occult* shows the sunlit areas with vertical lines, twilight areas with dashed lines, The predicted occultation path is shown with parallel lines. The path lines primarily identify the width of the path. One minute tick markers are plotted along the path lines with labels for each 5 minute marker.

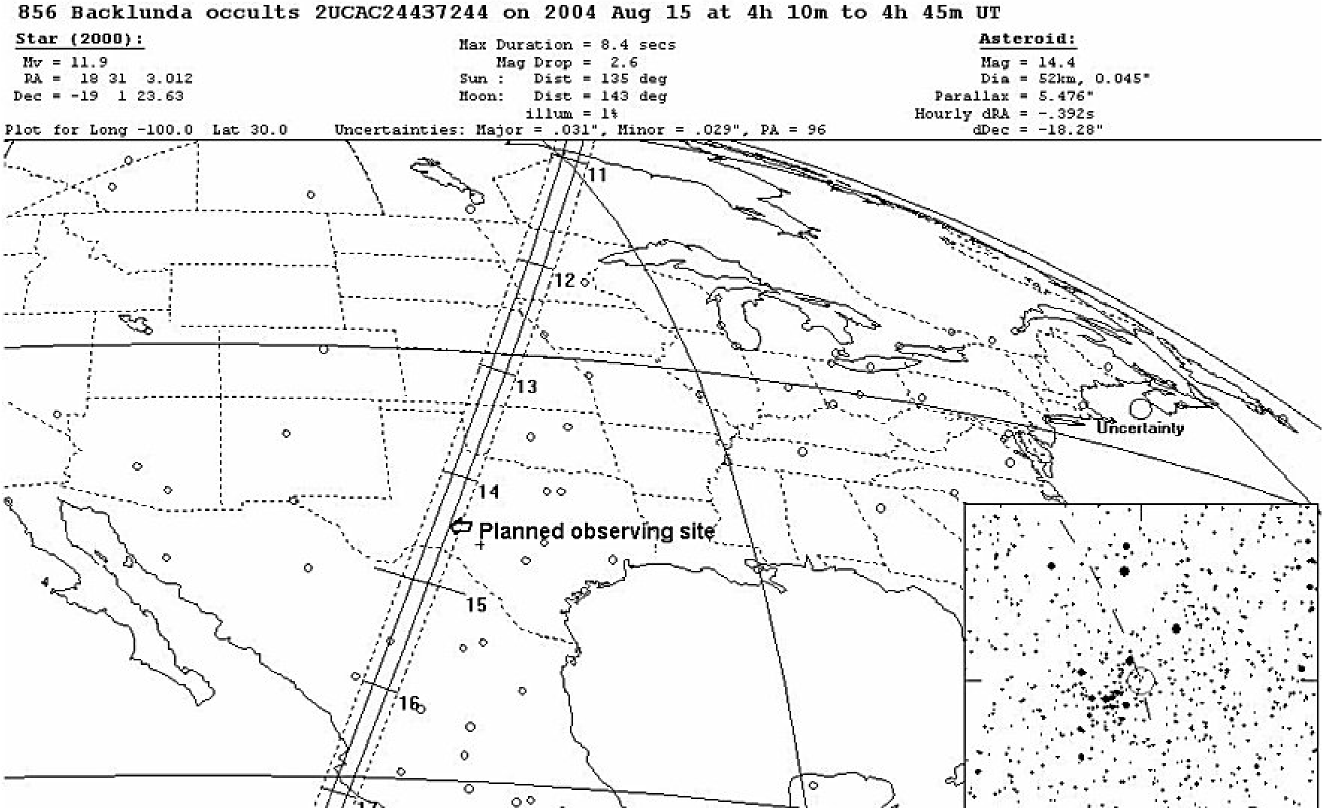
Occult also plots a finder chart for the star. The field of this chart is two degrees square, centered on the occulted star. Tick marks assist identification in crowded fields and a dashed line shows the motion of the asteroid as it approaches the star. Updates usually include an uncertainty ellipse on each plot and this ellipse is described more completely below. See Chapter 4, Section 4.2.3 for detailed description of asteroid occultation *Occult* map parameters. The asteroid occultation website http://www.asteroidoccultation.com is maintained and updated by IOTA astronomer Steve Preston as new data about asteroid positions is available.

When planning to observe an event observers should determine the time of the event from the text document for the event. The timeline marked on the path plot maps can used for a general idea of the time at a location. To determine the time of an event for a specific location follow these steps:

1. On a path map, find a point along the predicted path that corresponds to your planned observing location. A line drawn from this corresponding point on the path to your location should be perpendicular to the direction of the path. Note the approximate latitude and longitude (or event time) of this point along the center of the path. See Figure 6.11 below.

2. On the prediction website for each event, click on "**Detailed Info**". This displays a text document providing a listing of the latitude and longitude coordinates for the path center and occultation whether over land or water.

3. Locate in the latitude/longitude table where the latitude/longitude of the center of the path is nearest to the corresponding point for your planned observing location. Note that the latitude/longitude table gives the time (UT) of the center of the event for each location along the path (each line in the table). Now determine the approximate time for your location from



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856 Backlunda occults 2UCAC24437244 on 2004 Aug 15 at 4h 10m to 4h 45m UT
Star (2000):                          Max Duration = 8.4 secs              Asteroid:
 Mv = 11.9                               Mag Drop =  2.6                   Mag = 14.4
 RA =  18 31  3.012                   Sun :   Dist = 135 deg               Dia = 52km, 0.045"
Dec = -19  1 23.63                    Moon:   Dist = 143 deg          Parallax = 5.476"
                                               illum = 1%            Hourly dRA = -.392s
Plot for Long -100.0  Lat 30.0    Uncertainties: Major = .031", Minor = .029", PA = 96     dDec = -18.28"
```

Figure 6.11. Determining your observing position from prediction updates. The pointed arrow corresponds to an event time near 4h 14m 30sec UT in central Texas. Prediction from *Occult* software asteroid module.

the path locations near your corresponding point. Note that this table also gives the star's altitude and other circumstances of the event. Be sure to apply the time correction from UT; e.g. in the USA, for Central Standard Time, subtract 6 hours, 5 hours for Central Daylight Time. It is easy to make a mistake and mark down the wrong day/time if you are not careful.

For some updates, also included is measure of the path certainty called **Rank**. The event **Rank** is a measure of the likelihood of observing an event. Currently, the **Rank** equals the probability of at least one successful observation by a team of two observers where the two observers are positioned 3/4-path width apart perpendicular to the center of the path along the asteroid's motion. This probability is a function of the size of the asteroid in the sky (in arc seconds), the uncertainty in the position of the asteroid, and the uncertainty in the position of the star. Note that due to rounding, the event **Rank** can be 100%, but in reality there is always a chance of no success.

6.7 Organizing Expeditions

Coordinating observers for maximum coverage depends on the number and location of available observers. Deployment of mobile observers is important to complement fixed sites from which observers are unable to move their equipment. Since video records are more accurate than visual, ideally it is desirable to place video stations at equally spaced intervals alternating with visual observers.

The average occultation is observed by one to three observers, therefore it is not always possible to cover the path effectively. Spectacular asteroid events can bring in dozens of observers.

Single Observer

One person has the most flexibility in covering an occultation. If the observer can reach the occultation path, set up as close to the predicted center as possible. If the occultation is quite far from the observer the odds of seeing the occultation will be poor, yet detection of an asteroid satellite might be possible. The observer may then set up in any convenient location and make the effort. In that case one might expect the best (a brief occultation) but prepare for the worst (not seeing any change in the brightness of the target star).

Two to Five Observers

Depending on the number of observers, an ideal group strategy is to blanket the predicted path to plus or minus the predicted error with alternating video and visual observing stations. If only two to five observers join the effort, it is mandatory to coordinate observers to avoid duplication of data and to position them equally along a perpendicular to the ground track covering the center outward in both directions. If the path width is e.g. 150km, observers might be set up at the center and 50km in each direction (3 observers).

Fifteen or More Observers

With a larger observer base, a 150km path width can be approached in a number of ways. Ten observers can be placed at 15km intervals across the track with remaining observers positioned as outliers at 15km intervals to account for errors.

The biggest problem in such observations is the onset of weather. To account for this IOTA has developed one strategy that consists of cutting the path into parallel lines along the track. The number of lines is proportional to the number of observers. Each observer is assigned a fixed line and only that line. For urban observers, it is helpful to lay out the lines on a map and then poll candidate observers in advance to establish the latitude/longitude of each observer's home or preferred observing location. A composite map of observer locations can then be built. Each time a new occultation expedition is mounted and new sets of lines are drawn, the observer inventory can then be assessed on the computer map and mobile observers used to fill in the gaps.

Employing a GPS receiver with the coordinates of the predicted center, a given observer e.g. is assigned a line 20km north of center. Two pairs of coordinates for the centerline are entered into the observer's GPS unit. The first set is perhaps 1 degree west of the planned set up point, and the second set 1 degree east along path and in the opposite direction. These two points define a line parallel to the occultation path 20 km north of center allowing the observer to be independently mobile and set up anywhere without further coordination. The observer can travel virtually anywhere along this 20km "off course" line simply by monitoring the GPS display and maintaining this 20km off course distance from the center of the path and pick an observing site. Many times the observer will encounter the unexpected: weather, lights, bad roads, other people, trees and other obstructions in the direction of the occultation. By using this method, the observer can travel across a broad geographic span and relocate as necessary without altering the overall plan. If GPS receivers are not available, the organizer must provide maps with the same flexibility and resolution in determining site locations. The use of GPS receivers for this "off course" type of navigation is illustrated in Chapter 7, Figure 7.4.

Having one or more observers at the same site is a waste of resources and should never occur especially if both observers are capable of independently observing and recording the event. This is extremely important. Often social interactions (such as a star party) may dictate that a group observe together, and IOTA stresses that safety is the number one consideration. The only time when we do recommend that two or more observers monitor the star at the same place is when there are novice observers who have never seen an asteroid occultation and are reluctant to undertake independent observation. In this case using the event as a training effort can be quite important for future occultation efforts.

6.7.1 The Organizer/Coordinator

There should always be a single organizer or coordinator who assigns sites and distributes observers based on:

ability to travel,
size of telescope,
whether they have a recording capability such as video, photometry, etc.,
overall need for coverage,
all mandatory equipment including time signal reference,
safety considerations including having to avoid hazardous areas such as waste dumps, high crime areas, recently flooded areas, etc.

The organizer should be good at delegating responsibility especially if the observer corps grows to unmanageable levels. Providing educational talks to prospective clubs or groups where one or more observers might be recruited is important especially in the case of high priority asteroid occultations (e.g. a naked eye star being occulted close to a major metropolitan area).

The organizer should also be sensitive to the interests (or lack of) in prospective telescope owners. Often e.g. a planetary observer may be interested only in that discipline and no amount of persuasion may get that person to participate in an asteroid occultation. It is important to attend to new observers and maintain the level of interest of others who may have sporadically participated in the past. One challenge can be to try to get armchair observers out of the house and into the field.

Communication using email and phone is important as well as recruiting large numbers of observers in advance and keeping them interested in the upcoming event. This takes a great deal of networking, attention to detail and planning. Giving a talk a month in advance of the event and expecting 30 or 40 persons to be present without any intervening one on one discussion is not likely to produce great results. It is extremely important to pay attention to the needs of inexperienced observers. One cardinal rule for organizers: there are no dumb questions. At times observers may be afraid to ask a question in the presence of others. The organizer must often ask questions such as:

Have you ever observed an occultation before? What were the results? Did you ever make a mistake during an occultation? Do you know how to recover if your radio fails in the field? Can you find a 10th magnitude star on your own? Do you know how to use star charts? Will you travel 50 miles by yourself to a place you have never seen and set up in the middle of nowhere for 3 or 4 hours?" and be respectful of the responses.

For expeditions where guest observers have traveled a long way to get to the area, these individuals should be given priority for the best sites since clearly they have probably spent the most money, time and resources to get there.

6.8 Training and Simulation

A new observer should not be thrown into the field without having experienced one occultation as a training experience with someone else. The one exception to this rule is when a very experienced observer (though not with asteroid occultations) uses an automatic recording system such as video. Often new observers have no idea what to expect. A good way to introduce them to the asteroid occultation phenomenon is to play a videotape of an event in front of an astronomy club meeting or novice observer meeting. A role playing demonstration performed in front of the same group where a demonstration of typical equipment is brought in and an occultation simulated can also be beneficial. Another method is to bring a prospective observer to an actual occultation to watch how it's done in real time. Another variation is for an observer to borrow an occultation video to play at leisure in his/her home for independent self style training. Many asteroid occultation videos are now on the internet for demonstration and practice.

It is especially important for the observer to conduct self training in order to practice for the inevitable contingency. It is quite common for a piece of equipment to fail in the field even with proper preparation and checking. Even experienced observers have trouble locating the star field or having to manually adjust the telescope if the motor drive power source fails or the polar alignment is severely misaligned. Often it is not practical to bring backups of everything (such as 2 telescopes) and so one must anticipate a backup plan if e.g. the tape recorder fails or motorized drive stops running.

6.9 Results of Asteroid Occultations

The following are examples of publications of results of IOTA occultation expeditions that have made their way into the professional literature. Results of other expeditions can be found in *Occultation Newsletter*, the official publication of IOTA and *Sky and Telescope* magazine.

Dunham, D.W. et al. *"The Size and Shape of (2) Pallas from the 1983 Occultation of 1 Vulpeculae by Pallas"*, Astronomical Journal: 99, 1636-1662, May 2000.

Dunham, D.W. et al. *"Results from the occultation of 14 Piscium by 51 Nemausa"*, Astronomical Journal 89: 1755-1758, 1984.

Povenmire, H., Bookamer, R., "*The Feb 16, 2001 Asteroid 83 Beatrix Occultation*", Meteoritics and Planetary Science, 36, No. 9, Supplement, 2001

Sada, P., Nugent., R., Maley, P., Frankenberger, R., Preston, S., Dunham, D., Pesnel, W.Dean., *Occultation of π Arietis by Asteroid (828) Lindemannia on November 10, 2002,* Occultation Newsletter, Volume 9, Number 4, page 9, September 2002.

"The Probable Detection of a Moon of Asteroid 98 Ianthe", Venable, Roger, *Occultation Newsletter*, International Occultation Timing Association (IOTA) (ISSN 0737-6766), Vol. 11, No. 2, p.8 April 2004

6.10 Safety Considerations

Being safe is more important than getting data. This includes driving to a site at a reasonable speed, planning to meet colleagues or being at the site at a time that is practical and without endangering the observer or others. Choosing a safe observing site for oneself and or colleagues is equally important. Avoid sites with obvious problems such as a location close to major roads where oncoming traffic will be visible or where road vibrations will affect the telescope. This is an indication you are in the wrong place!

If setting up along a road shoulder (in the absence of any other viable alternative), always ensure your vehicle is pulled completely off the road. Let others know where you will be before leaving home. Informing local law enforcement is also useful since they may be even able to help recommend a good site! Never transport unsupervised children or animals. Try to bring a companion who can help with security aspects such as examining the site for holes, ant hills, sharp objects, wet areas, proximity to drop-offs, etc. If in a remote area be sure to have enough water and food and if you require medicine, don't forget to bring it with you. Consider having an easy to understand handout that could be given to someone such as an irate property owner or law enforcement officer in case you have such an encounter close to occultation time. An example handout is shown in Appendix L.

Carry proper identification and the minimum amount of money necessary for a trip. Ensure the car is properly loaded, tire pressure adequate, gas tank full, etc. If clouds threaten it is always tempting to try to outrun them. In this case having a companion to navigate to ensure you will end up where you need to be is quite an advantage.

6.11 Negative Observations

The observer should approach an asteroid prediction with a clear view of the world. Predictions are often accurate but sometimes do not meet expectations. Making the effort and having everything proceed smoothly only to ultimately observe that no occultation occurred at your site can be a little disappointing. But in fact this information can be of great value to IOTA and supplement knowledge on where the path did or did not go. A positive attitude can go a long way toward stimulating young people and non-occultation observers alike to becoming interested in this discipline of astronomy that offers the opportunity for amateurs to contribute useful data with off the shelf equipment.

Experiencing a **miss**, where no occultation is observed can be disappointing, but this information is quite important in terms of establishing an upper limit on prediction quality and in assessing whether the zone occupied by the observer at a fixed distance from the asteroid has been scanned for a satellite. A **miss** observation can establish the limits to the size of the asteroid and is of great value to the effort. In this context a **miss** observation does not refer to observers that are clouded out and missed the event due to weather conditions. In Figure 6.2 of the occultation by 345 Tercidina, the upper and lower most chords were observers that had misses. **These miss observations put size limitations on the asteroid.**

6.12 Reporting Observations

All observers should keep their own observing log. This log should be printed clearly with date and time of event, equipment used, problems encountered. It is a valuable record of the events that happened along with important notes, times, errors and other subtle notes that would be impossible to recall later on. For occultations, the audio/video tape records should be reduced quickly, preferably within 24 hours after the occultation and key information (disappearance, reappearance times, reaction times if applicable, site latitude/longitude recorded in degrees, minutes, seconds and hundredths of a second if possible; altitude is not really a factor) extracted while it is fresh. Tapes should be filed away for later reference if required.

6.12.1 Report Form

The official IOTA asteroid occultation report form for North American Observers is a user friendly Excel form. It is located at:

http://www.asteroidoccultation.com/observations/Forms/AsteroidReportForms.html

It should be filled out within 72 hours after the event. Regardless of the result, the observation should be reported to IOTA through the official asteroid report email address: reports@asteroidoccultation.com and to the event coordinator. Report even NEGATIVE observations which are very important for confirming astrometry as well as determining path shifts and perhaps even other observer's sightings. The format for email reporting is included in Appendix F. See also Appendix H of where to send these report forms after you make an asteroid occultation observation. Reports for asteroid occultations in Europe, Australia/New Zealand, Japan should be sent to the coordinators specified in Appendix H, *Where to Send Observation Reports*.

6.13 Asteroid Occultation Profiles and Analysis

Several asteroid profiles are shown as follows. As of the publication date of this book, over 1,000 asteroid occultations have been recorded with the amount growing by 140-160 each year. In *Sky and Telescope* magazine several times per year, the brighter more favorable asteroid events are shown and charted worldwide along with general information on how to observe and report the observations.

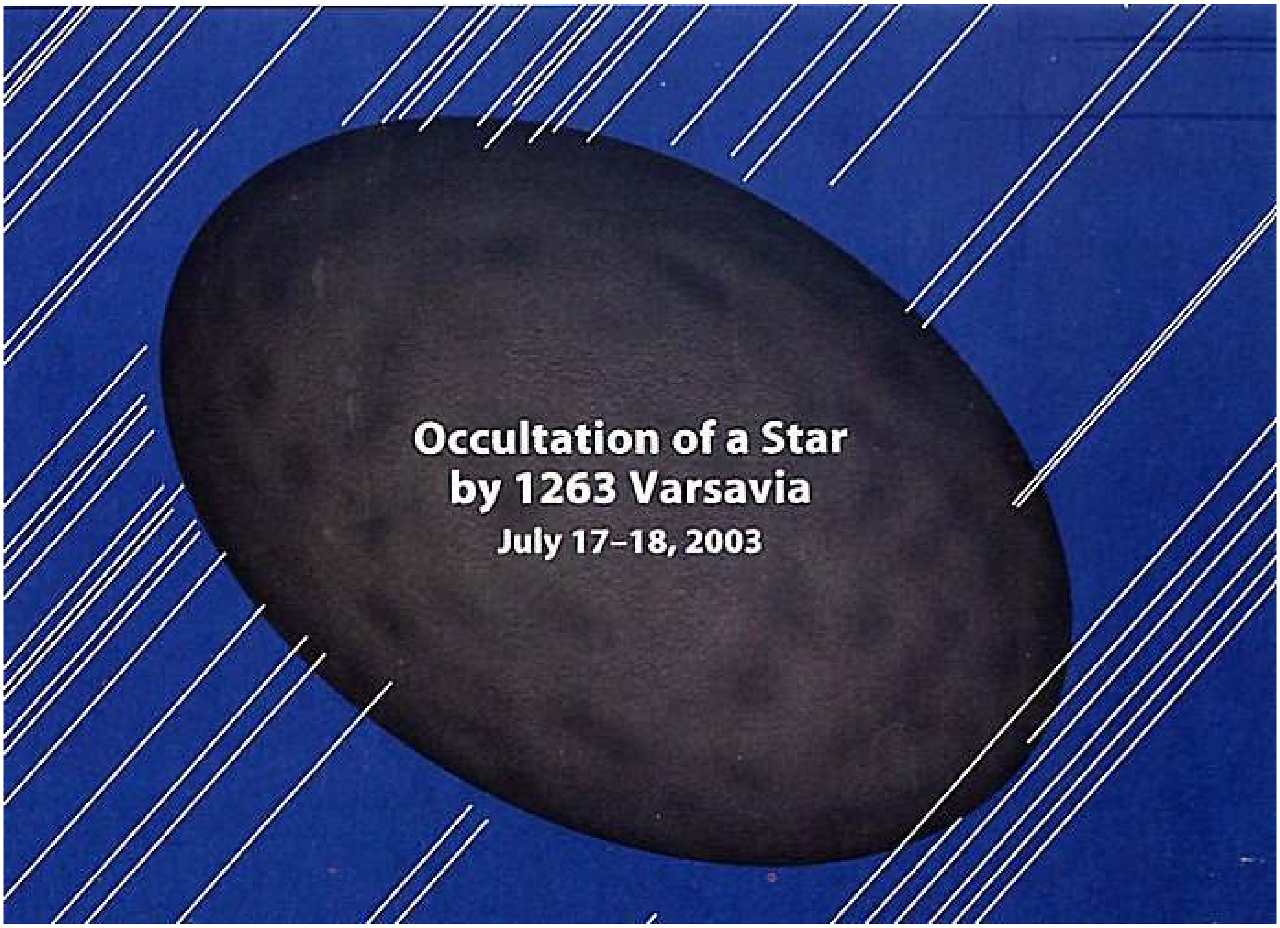

Figure 6.11. Profile of 1263 Varsavia. Courtesy David Dunham, © 2004 Sky & Telescope, used by permission. Varsavia's size was derived to be 53.9 km x 36.2 km

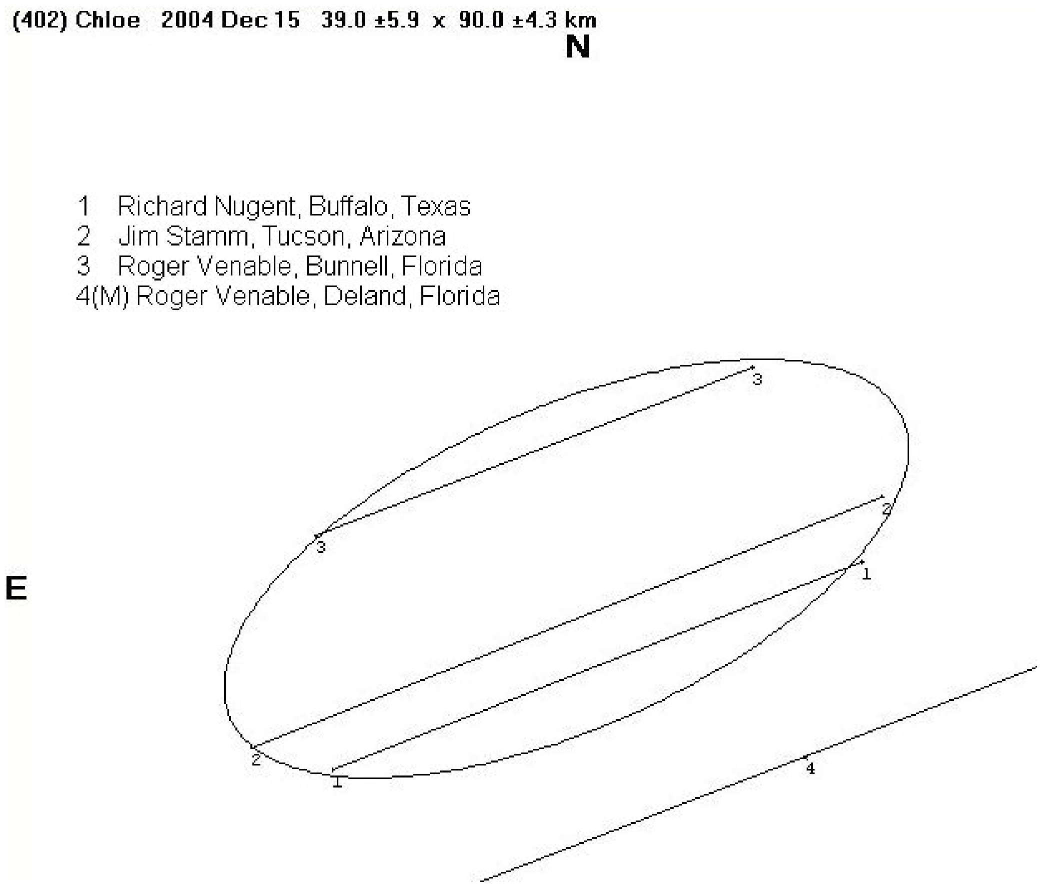

Figure 6.12. Profile of 402 Chloe, December 15, 2004 from *Occult* software. Shape appears to be elongated by a 2:1 ratio.

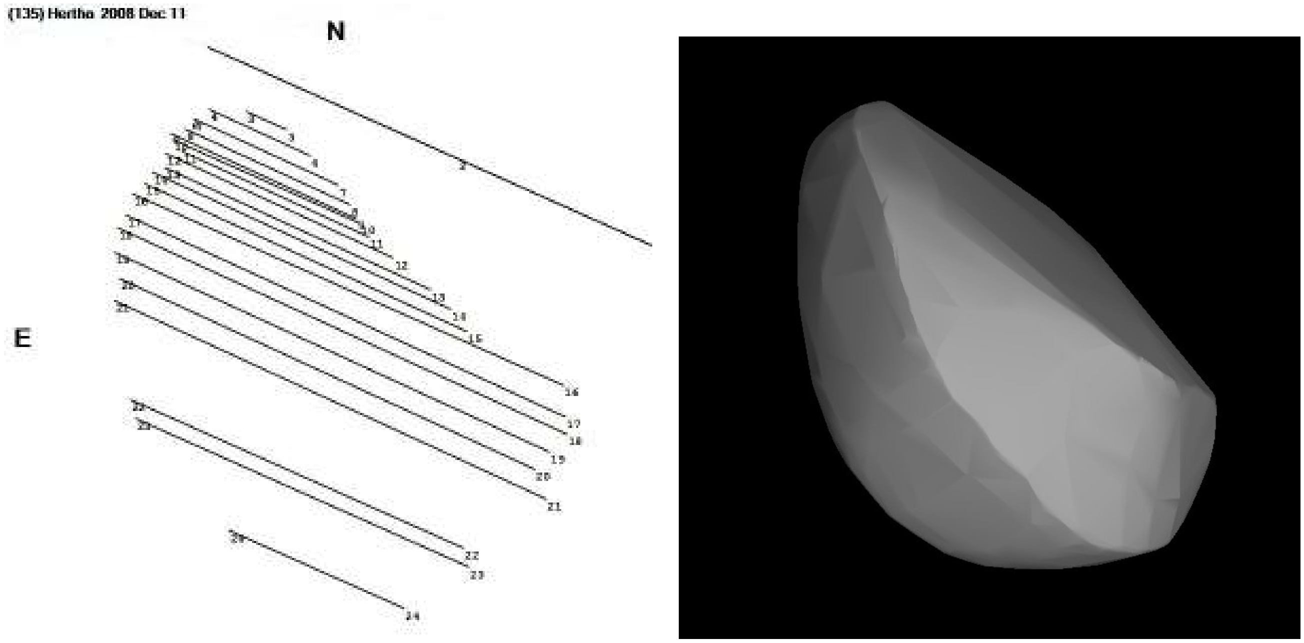

Figure 6.12a. Left: Profile of 135 Hertha, December 11, 2008. Chords 4, 7-9, 11-15 and 17-21 were obtained by Scotty Degenhardt with his 14 remote video stations. Hertha's size is 75 km x 94 km. Right: Model from radar observations oriented to same viewing angle as during the time of the occultation.

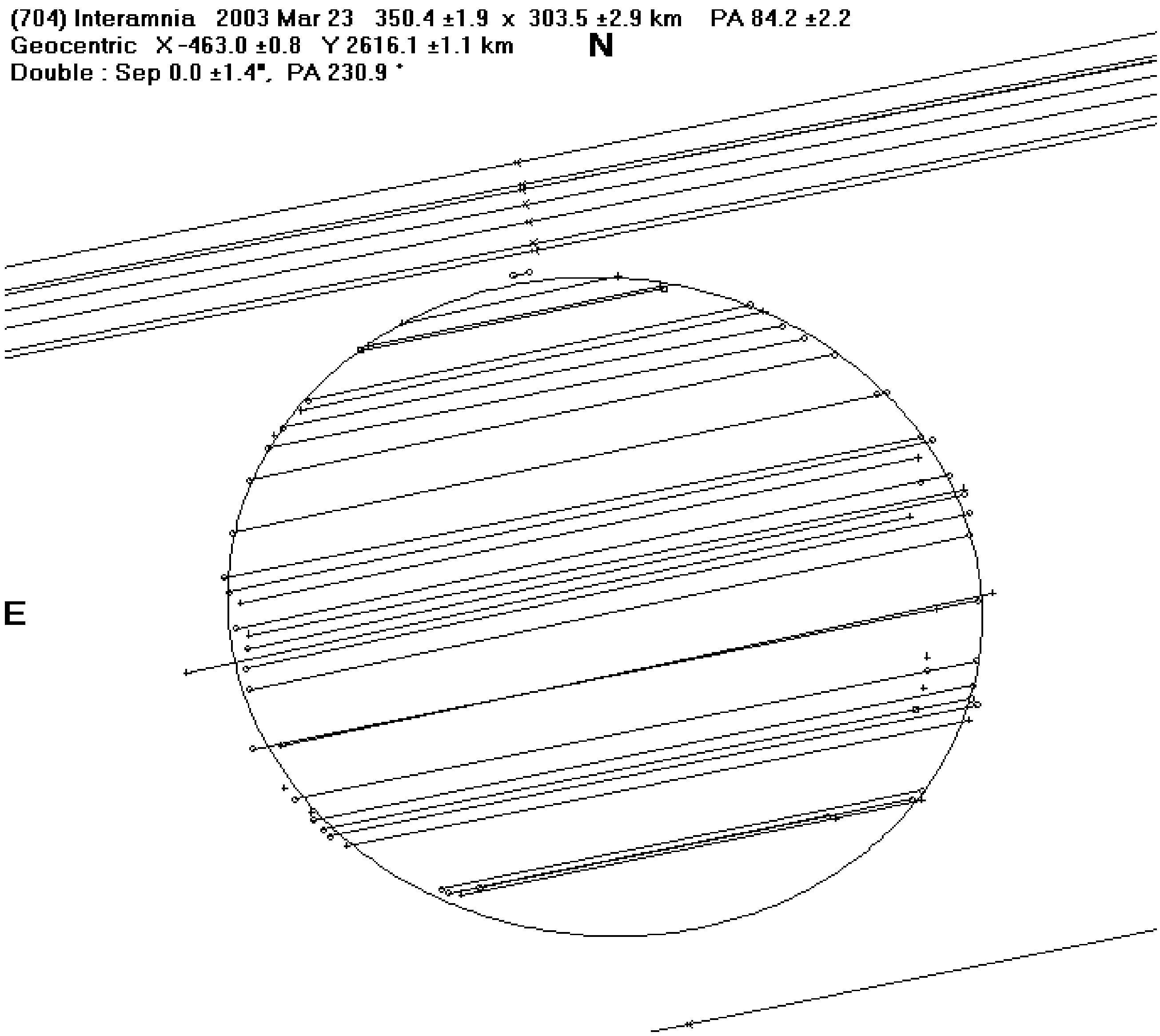

Figure 6.13. Profile of 704 Interamnia from March 23, 2003. This occultation was recorded by 54 observers in Hawaii and Japan, demonstrating international cooperation in observing occultations. Proile generated from *Occult* software.

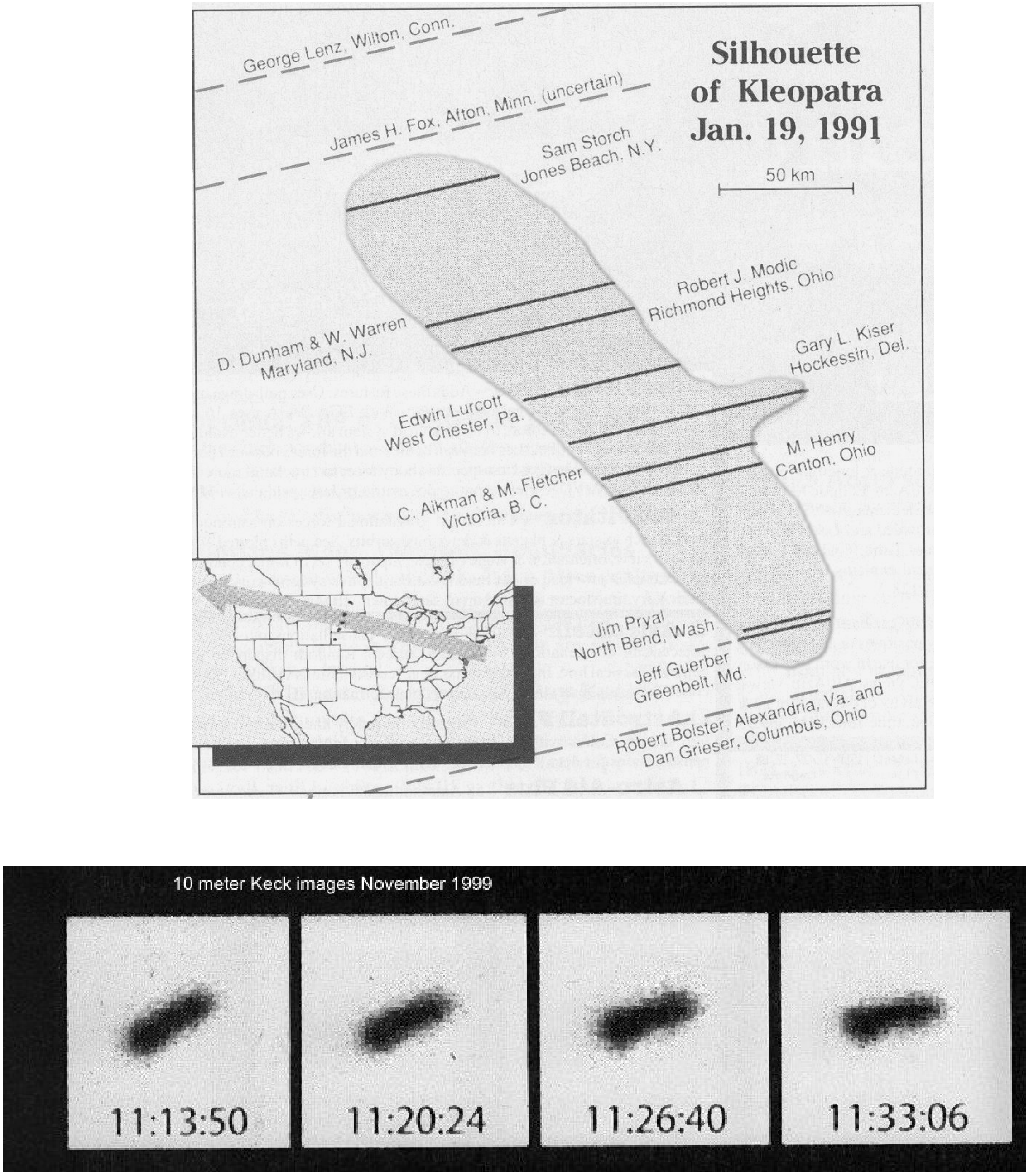

Figure 6.14. Profile of 216 Kleopatra from January 19, 1991 occultation (above) and direct photos by the 10-meter Keck telescope 8 ½ years later on November, 1999 (below). Kleopatra's line of sight size came to 264 km x 60 km at the time of the occultation. Courtesy David Dunham, © 1992 Sky & Telescope, used by permission.

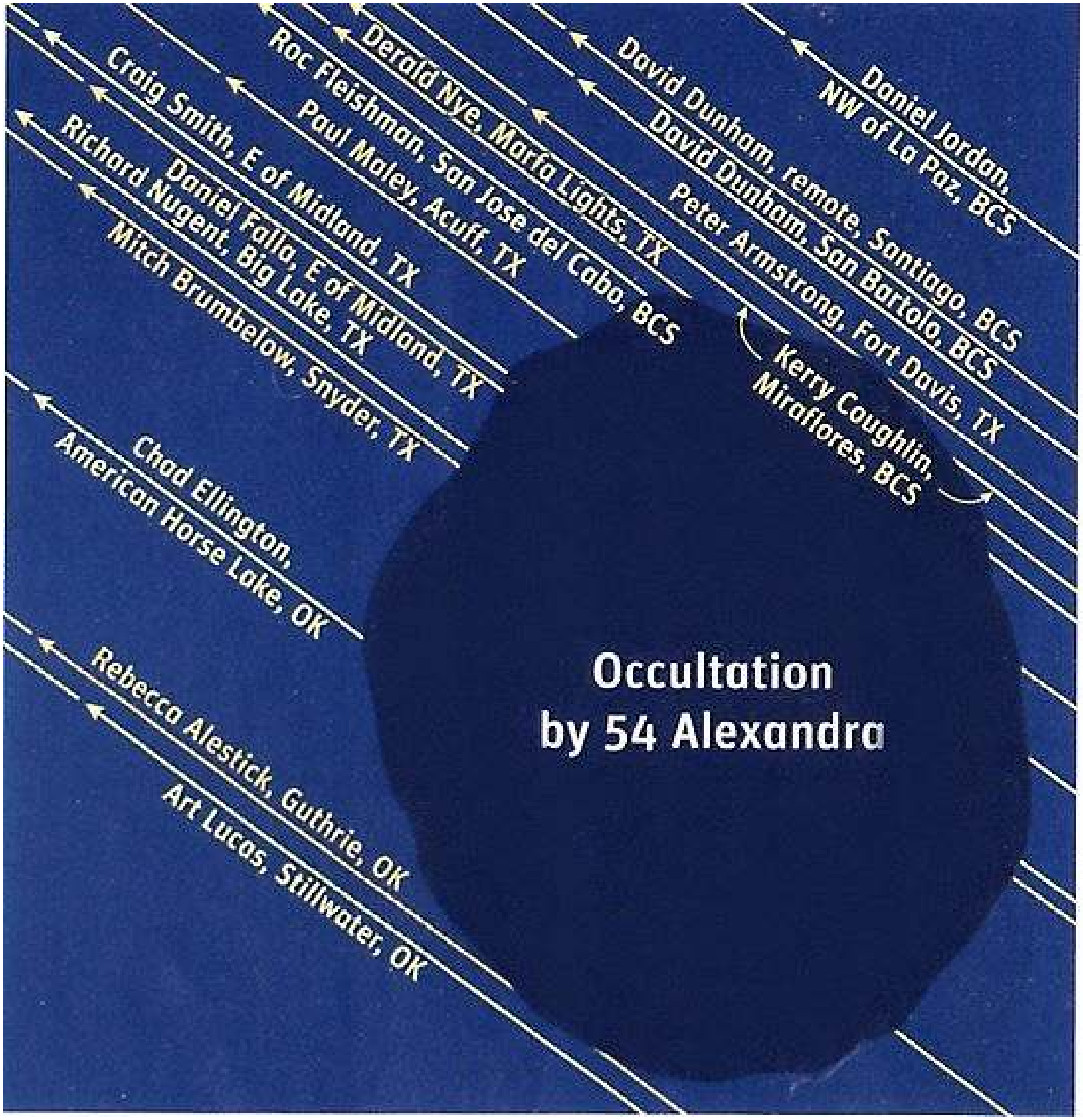

Figure 6.15. Profile of 54 Alexandra from May 17, 2005. Two very important north and south limit chords here are from Peter Armstrong, Texas and Rebecca Alestick, OK. Both were at the Alexandra's extreme edges while Mitch Brumbelow and Richard Nugent's chords were 63 seconds each in duration near to the center of the path. Alexandra's size was derived as 160.3 km x 134.8 km. Courtesy David Dunham, © 2006 Sky & Telescope, used by permission.

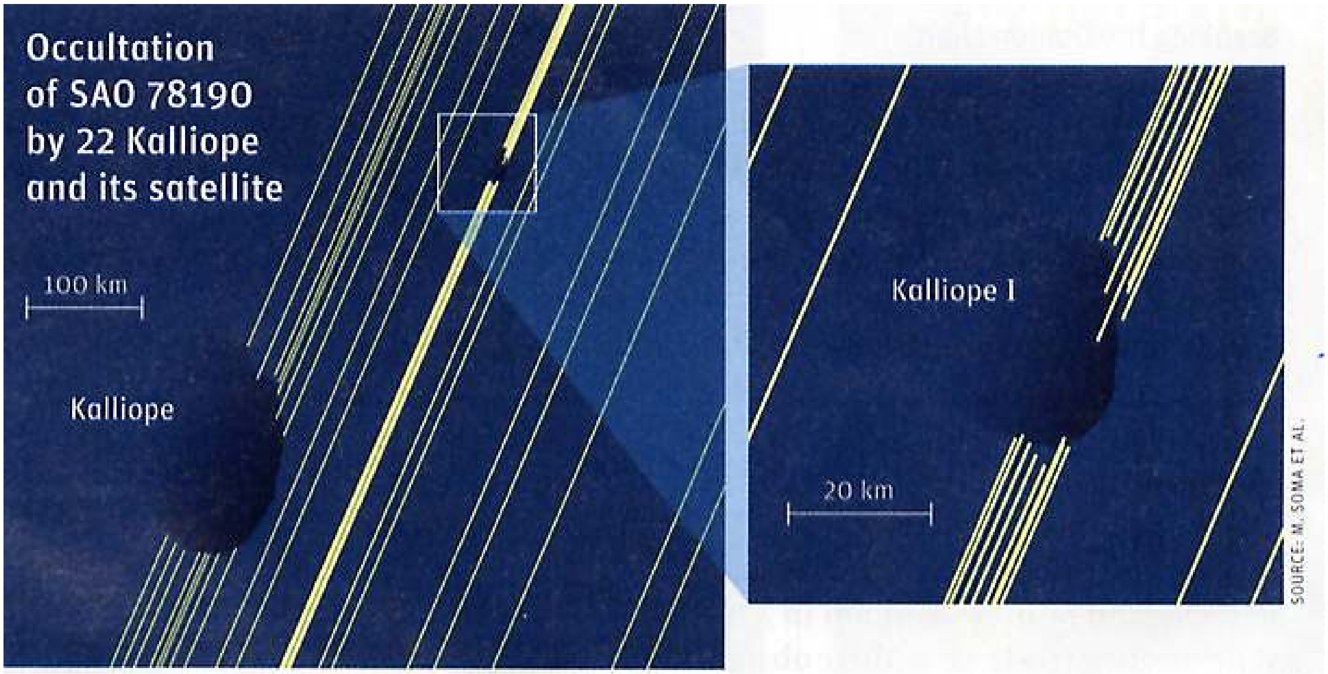

Figure 6.16. Profile of 22 Kalliope and its satellite from occultation of a 9th magnitude star on November 7, 2006. This is the first occultation observation of a previously known asteroid satellite. Courtesy David Dunham, © 2007 Sky & Telescope, used by permission.

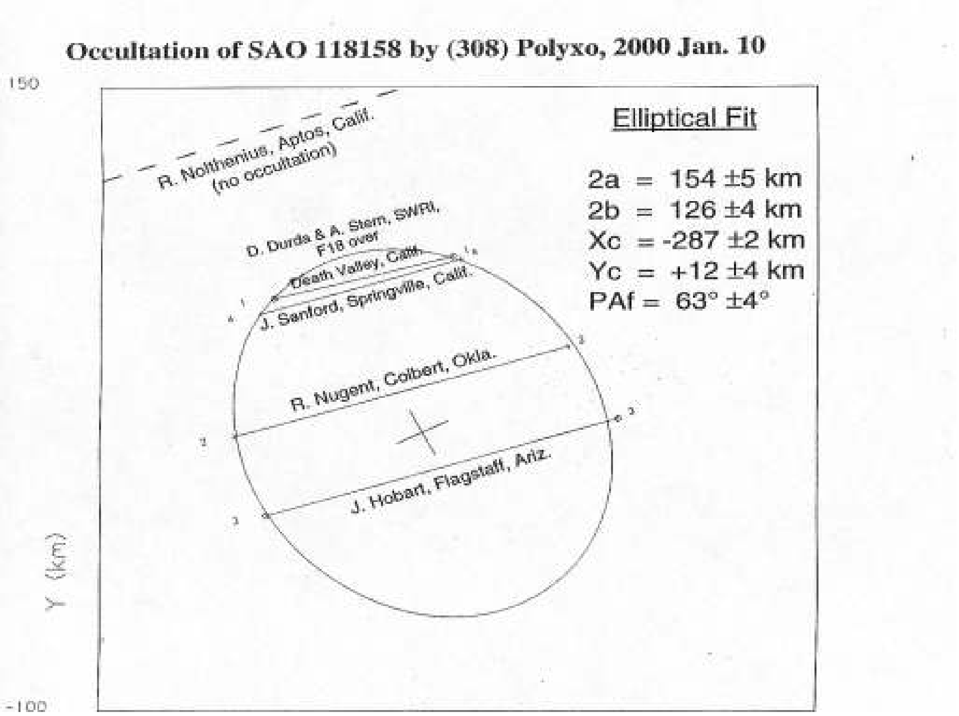

Figure 6.16. Profile of 308 Polyxo, January 10, 2000. This occultation was the first to be observed and timed from an aircraft, namely an F-18 Air Force jet over Death Valley California. Profile courtesy David Dunham.

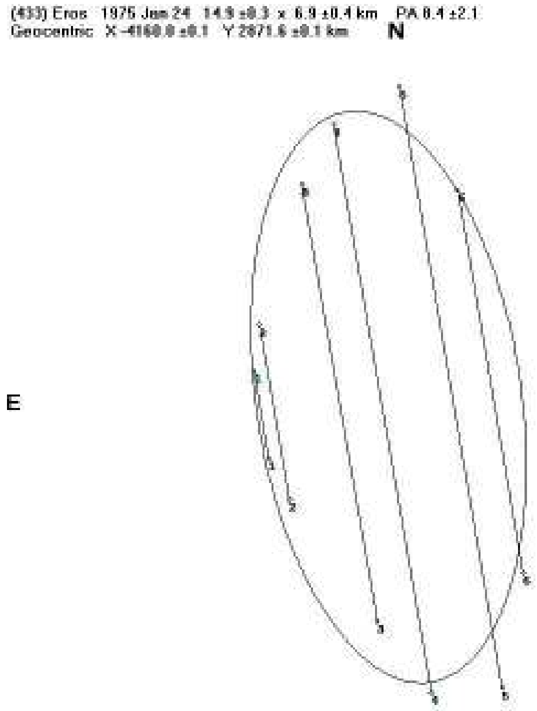

Figure 6.17. Profile of 433 Eros, the first asteroid observed by a team of observers in the United States on January 24, 1975. Eros' size came to 14.9 km x 6.9 km. Profile generated from *Occult* software.

References for Chapter 6

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Sada, P., Nugent., R., Maley, P., Frankenberger, R., Preston, S., Dunham, D., Pesnel, W.Dean., *Occultation of π Arietis by Asteroid (828) Lindemannia on November 10, 2002,* Occultation Newsletter, Volume 9, Number 4, page 9, September 2002.

7 Site Position Determination

7.1 Accuracy Requirements

The precision needed for ground positions for occultation work is:

Total Occultations	± 0.5" (±15 meters)
Grazing Occultations	± 0.3" (±10 meters)
Asteroid Occultations	± 3" (±100 meters)
Solar Eclipses	± 0.5" (±15 meters)
Elevations	± 15 meters

An immediate question new occultation observers might ask is with low cost hand held Global Positioning System (GPS) receivers on the market why do we need a chapter on site position determination? GPS receivers are now built into wrist watches, cell phones and even personal data assistants (PDA's). The reality is that low cost (under $150) GPS receivers are capable of providing positions accurate to 0.2" (with WAAS*) and they are widely available. The reality is not all observers will have these receivers, wrist watches, cell phones, PDA's and as discussed below, GPS receivers fail due to a number of reasons. Furthermore GPS elevations are not recommended for total or grazing occultation work due to their low precision so alternative methods must be used. This chapter informs the occultation observer on how to obtain their ground position (latitude, longitude and elevation) from GPS receivers, the internet, road atlas software programs, topographic maps or the Gazetteers.

The determination of ground position is of prime importance when observing occultations. An observer's precise geodetic (ground based) coordinates are as important, and at times even more important, than the accuracy of the occultation timings made from that position. The coordinates of the observer should be determined to at least the nearest 0.5" in latitude and longitude (approximately 15 meters) and the height above sea level (elevation) to the nearest 50 feet or about 15 meters. The coordinates of the observer's location (station) must be geodetic coordinates (coordinates with respect to the center of the Earth), measured with respect to a datum (an internationally recognized regional surveying system), and not astronomical or measured by astronomical observations.

The most common way of measuring a position is by using a GPS receiver. If one is not available a topographic map can be used. If adequate maps are not available the position can be determined from a road atlas, computer map program or the internet, however some internet based coordinates are only accurate to a few arc seconds, hence they will *only be* useful for asteroid occultation observations and *are not* of sufficient accuracy for lunar grazing occultation or total occultation studies. Determination of coordinate without a GPS receiver sufficient for asteroid occultations is described below in Sections 7.4 and 7.5.

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* WAAS: Wide Area Augmentation System. See Section 7.3.3.

Instructions on accurate position determination from United States Geological Survey (USGS) topographic maps are given below in Section 7.7. An observer who finds the instructions hard to follow should not hesitate to seek assistance. Experienced observers in the same area should be willing to assist as they understand the necessity for accuracy in coordinate determination.

In reality, positions using USGS topographic maps (7.5 miles square) are no longer used due to the widespread use of GPS receivers. The method is included here for completeness. Even though you plan to use your GPS receiver it is a good idea to identify your position using nearby street corners, landmarks and other natural or manmade features in case your GPS receiver stops working, your GPS batteries fail or you are unable to acquire a signal. These backup precautions are typical in the field of occultations since failures are usually unexpected.

For occultation work, it is advisable to obtain elevation data from topographic maps including the low resolution maps found on the internet at www.topozone.com rather than those from GPS receivers.

7.1.1 Definition

A geodetic position is one measured in three coordinates: latitude, longitude and height above sea level (elevation or altitude) in a regional coordinate frame called a datum. A datum is determined by surveys of relative measurements to other points on the Earth. The science of measuring the shape of the Earth and of measuring the relative locations of parts of the Earth's surface is geodesy. Surfaces, called datums, are simply reference models of the Earth’s shape. They are fit to the Earth in an attempt to approximate its shape, and coordinates are measured with respect to these datums. When coordinates measured on different datums are to be combined each is corrected to a single global standard in an attempt to adjust for the known datum errors, which have been determined primarily from precise observations of artificial satellites. Coordinates measured in other systems, such as those determined by astronomical observations, cannot be so combined, as their errors with respect to other coordinate systems are not known. Only geodetic coordinates can be used in reducing occultation observations.

Geodetic maps will give its datum usually in the margin of the map sheet. Examples of datums are the Tokyo Datum, the European (or Potsdam) datum, and the 1927 and 1983 North American datums. GPS receivers generally use the WGS84 datum. The majority of observers will be able to use GPS receivers or geodetic survey maps to find their observing station coordinates, the familiar latitude, longitude and elevation.

When using your GPS receiver check it against a topographic map to make sure it is on the same datum as the map. Most GPS receivers have an option to adjust to the desired datum. For the majority of applications, use your GPS unit with the WGS84 datum. Use of a different datum may result in discrepancies.

7.2 Determination of Elevation from USGS Topographic Maps

Although GPS receivers provide elevations they are not always reliable. To find the elevation of your observing site on topographic maps use its contours. Contours are the wavy lines on the map showing the elevation profile and the contour intervals generally range from 5' to 40'. A few points to remember: closed contours are at higher elevations than nearby labeled ones, and individual contours are usually in intervals of anywhere from 5'-50' between each other. Normal contours can be as low as 1' difference in elevation. When estimating your elevation, you must interpolate between contours. Elevation accuracy for IOTA applications should be better than ± 50 feet (± 15 meters).

FOR EXAMPLE: assume your site is at a position **A** on the hairpin road as shown to the right of center in the map in Figure 7.1 below. Note it is halfway between two contours. On the left of position **A**, note the bold contour labeled 5200. In this particular map, the contours are specified at 40' intervals. Keeping in mind that elevations increase toward closed contours, and decrease away from closed contours, there are 3 contours between **A** and the 5200 contour. Thus the contours from the 5200 moving left to right would correspond to elevations of 5160', 5120' and 5080'. To the right of **A** is another contour, its elevation would be 5040'. Since **A** is just about halfway between the 5080 and 5040 contours, its elevation would be 5060'.

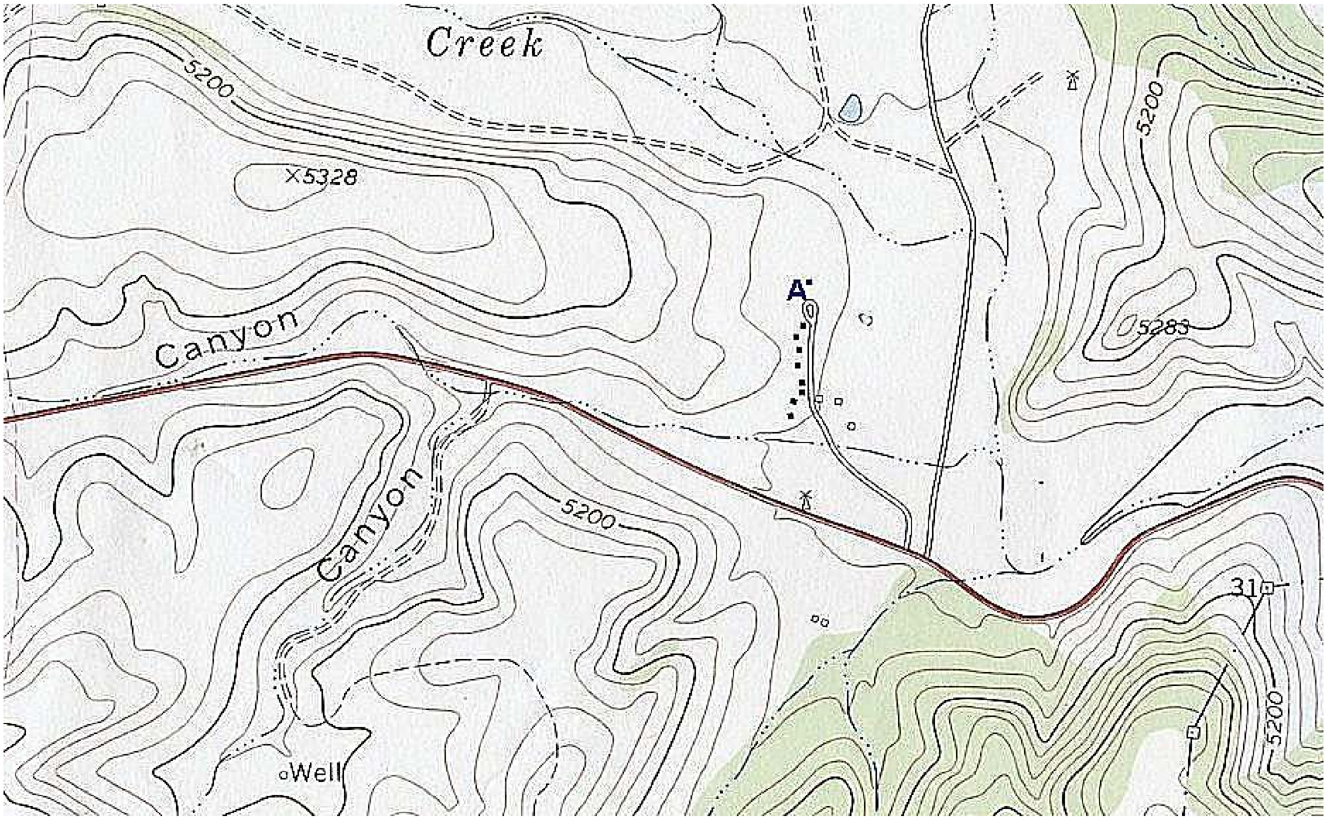


Figure 7.1. USGS topographic map showing elevation contours. The contour interval is 40' as specified on the actual map. The elevation of the position marked by **A** is 5060' being halfway between the 5080 and 5040 contours. See text for explanation.

Why is the elevation factor necessary for occultation work? As can be seen from the Figure 7.2 it is important to have the elevation to fully comprehend the occultation observation. Observers with nearly the same position can have different results due to the elevation difference.

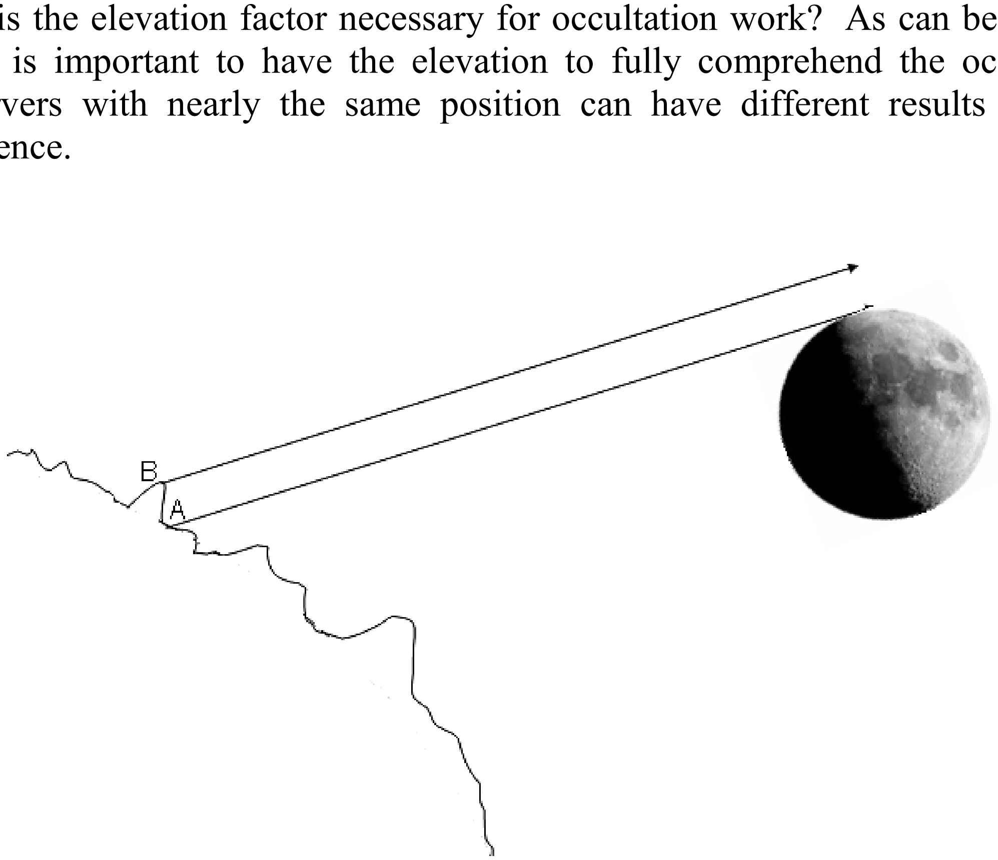


Figure 7.2. Use of elevations in occultation observations. The observer at -B- is at a higher elevation than the observer at -A-, thus he will have a slightly different view of the occultation. Diagram not to scale.

7.3 Coordinate Determination Using the Global Positioning System (GPS)

The Global Positioning System (GPS) was designed and implemented by the United States government in 1978 originally for military purposes as it became necessary for knowing accurate positions of the nuclear arsenal in US warships and submarines. The current GPS constellation consists of 28 satellites in orbits of altitudes of about 12,000 miles above the earth's surface at orbital inclinations of 55° and is operated by the US Government, which is solely responsible for its accuracy and maintenance. Several additional satellites are in reserve to be launched on an "as needed" basis. The system is subject to changes which could affect the accuracy and performance of all GPS equipment.

With the widespread use of GPS receivers, the USGS topographic maps generally are no longer used for the determination of geodetic coordinates for occultation purposes. At any given point on the Earth's surface at any given time, five or more satellites are usually above the horizon and visible to a GPS receiver. It is rare not to have the signals from at least three satellites visible for signal acquisition by a GPS receiver.

If during an asteroid occultation expedition your GPS receiver cannot acquire a signal or the batteries fail and you are pressed for time, estimate your position with respect to a nearby intersection or landmark. Write this information down. You can determine your position later from a road atlas or computer program or the internet.

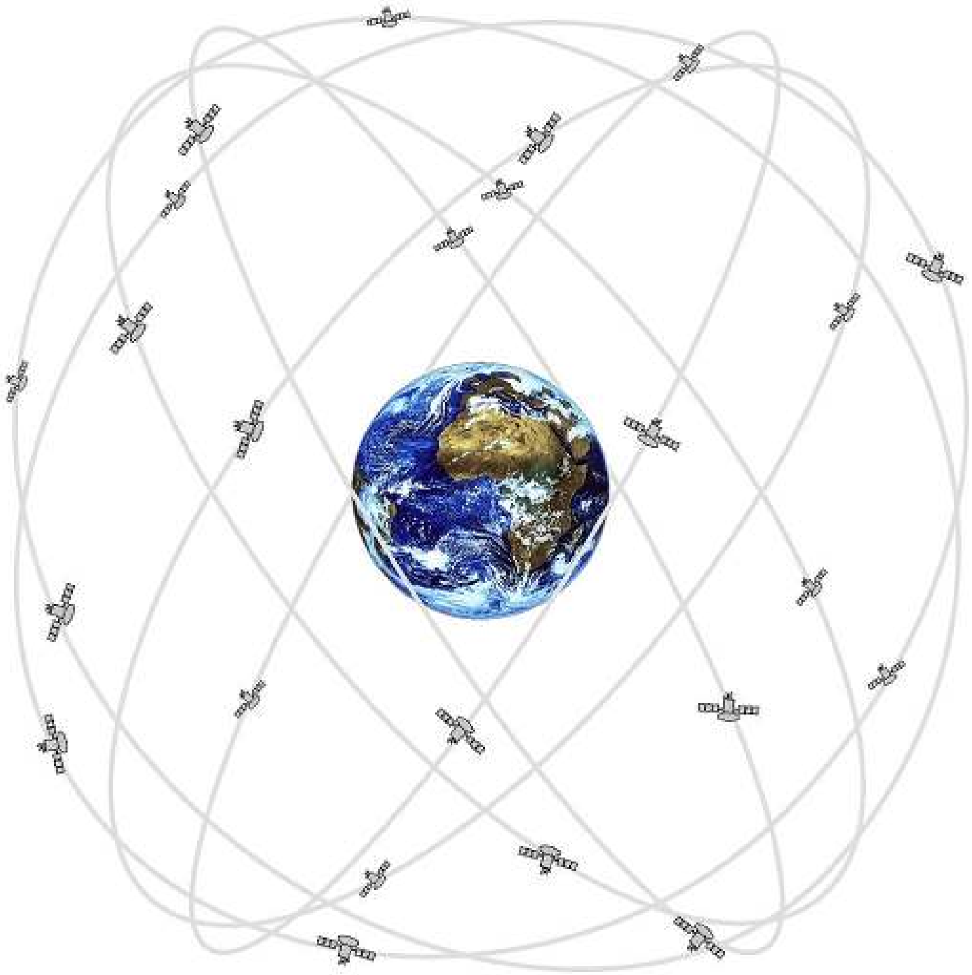


Figure 7.3 GPS Satellites and their orbits. Diagram courtesy Michael Wobner, www.kowoma.de.

NOTE: Test and initialize your GPS receiver before setting out to observe an occultation. Using them before this initialization procedure could give erroneous position data and cause major problems for the user. Be sure to test your GPS receiver with known positions from an accurate topographic map or other accurate source.

7.3.1 How GPS Receivers Work

The basis of the GPS system is *trilateration*, similar to triangulation, except no angles are involved. For those interested in how GPS receivers process signals and provide accurate ground coordinates a simplified description is given below. This section is added for information purposes only and is not required for occultation work.

1) The GPS receiver measures the distance to the satellite by calculating the travel time of the radio signal. GPS satellites have high precision atomic clocks on board. GPS satellites transmit at two distinct carrier frequencies. L1, at 1575.42 Mhz, transmits a status message and a pseudo random code (PRC) for timing. L1 is the frequency used by civilian receivers. The PRC is a complicated code which is unique for each satellite that prevents GPS receivers

from accidentally picking up another signal from other sources and from accidentally picking up another satellite's signal.

L2, at 1227.60 Mhz, is used for the more precise Military pseudo random code. This Department of Defense (DoD) exclusive PRC is encrypted and only Military receivers with the encryption key can receive the signals.

2) To measure travel time the receiver needs to know exactly where the satellite is at any time. GPS satellites are in high orbits above the Earth's dragging atmosphere and thus simple theory of celestial mechanics governs their orbits making their position a relatively simple calculation.

The orbit of each satellite is constantly monitored by the DoD. Very precise radar is used to check each satellite's exact position, altitude and velocity. These measurements check for ephemeris errors caused by the gravitational forces due to the Sun, Moon and radiation pressure from the Sun. These errors are very slight but are measured to obtain the highest precision in the satellite's position. Once the satellite's position is accurately known it is transmitted back up to the satellite. The satellite then uses this new updated information in broadcasting its timing and position signals to receivers on the ground.

GPS receivers have an almanac programmed into their internal memory allowing for computation of where each satellite is at any time. Once a satellite is acquired the receiver updates this almanac in real time with the new updated ephemeris transmitted directly from the satellite.

Travel time is computed by the receiver by comparing how late the satellites PRC appears compared to the receiver's code, thus allowing us to calculate how long it took for the signal to reach it. Once the distance and position of at least three satellites are known, the GPS receiver can calculate the position where all these distances cross at the same point. This point is the location or ground position. It is constantly updated including the use of additional satellites and their signals into the receiver.

3) The received signal from the satellites doesn't come through the Earth's atmosphere without noticeable effects. The ionosphere (50 - 500 km altitude) consists of a high concentration of free electrons and ions produced by the ionizing action of solar X-ray and other ultraviolet radiation. These high energy particles disturb the propagation of radio and GPS signals by reflecting or refracting and attenuating them. Errors introduced by the ionosphere can be modeled mathematically however it is still a significant portion of the total error in the GPS system.

The troposphere is the lowest layer of the atmosphere, being from sea level to 18 km altitude. It is here where our weather comes from. Despite the enormous activity in this layer very little interference occurs to the GPS signals hence the error introduced is marginal.

7.3.2 GPS Errors

Much of the delay caused by a signal's trip through our atmosphere can be predicted. Mathematical models of the atmosphere take into account the charged particles in the ionosphere and the varying gaseous content of the troposphere. In addition the satellites constantly transmit updates to the basic ionospheric model. A GPS receiver must factor in the angle each signal is taking as it enters the atmosphere because that angle determines how much atmosphere the GPS signal must pass through on its way to the receiver.

In addition to the complications caused by the GPS signal traveling through the Earth's ionosphere and troposphere, it can bounce off local obstructions on or near the ground before it gets to the receivers. This is called *multipath error*, and is similar to the ghosting effect seen on televisions. Good GPS receivers use sophisticated signal rejection algorithms to minimize this problem.

Prior to May 1, 2000, the signals from these satellites were scrambled intentionally by the US government to avoid non US military from obtaining rapid accurate positions. This intentional degradation of the GPS signals was known as *selective availability*, or *SA*. The *SA* was turned off by following a Presidential Order signed in the early part of 2000. Prior to the *SA* being turned off accurate positions were obtainable using a method known as *differential corrections* (see Maley et. al. 1997). Positions determined by GPS units without applying the differential correction technique yielded coordinates accurate to only 100 meters, which was unacceptable for IOTA applications.

The method of differential corrections required a minimum of two receivers. One receiver, called the reference receiver is stationary at a known benchmark and the others are roving. If the receivers are fairly close to each other (within a few hundred kilometers) the signals reaching both of them will have traveled through the same slice of atmosphere. The signals will have virtually identical errors. That's the idea behind differential GPS. We have one receiver measure the timing errors and then providing correction information to the other receivers that are roving. That way virtually all errors can be eliminated from the system even with the Selective Availability error that the DoD puts in on purpose.

The reference station receives the same GPS signals as the roving receiver but instead of working like a normal GPS receiver it attacks the equations backwards. Instead of using timing signals to calculate its position it uses its known position to calculate timings. It computes what the travel time of the GPS signals should be and compares it with what they actually are. The difference is an ‘error correction’ factor. The receiver then transmits this error information to the roving receiver so it can use it to correct its measurements.

Since the reference receiver has no way of knowing which of the many available satellites a roving receiver might be using to calculate its position, the reference receiver quickly runs through all the visible satellites and computes each of their errors. Then it encodes this information into a standard format and transmits it to the roving receivers. The roving receivers obtain the complete list of errors and apply the corrections for the particular satellites they're using. The transmission of data from the stationary receiver to the roving receiver need not be done in real time since these differential corrections can be applied later.

With the *SA* function now disabled, the differential corrections technique is no longer needed.

A brief summary of the errors introduced from using GPS units are grouped into the following classes:

1) Ephemeris Data Errors in the transmitted location of the satellite. Ephemeris errors result when the GPS signal does not transmit the correct satellite location.

2) Satellite Clock Errors in the transmitted clock. Fundamental to GPS is the one way ranging that ultimately depends on satellite clock predictability. This is no longer a major issue since the *SA* was terminated on May 1, 2000.

3) Ionosphere 50 km to 1,000 km. Errors in the corrections of pseudo range caused by ionospheric effects. Because of free electrons in the ionosphere, GPS signals do not travel at the vacuum speed of light as they travel through this region. The modulation on the signal is *delayed* in proportion to the number of free electrons encountered and is also (to first order) proportional to the inverse of the carrier frequency squared ($1/f^2$). The phase of the radio frequency carrier is *advanced* by the same amount because of these effects. The ionosphere is usually reasonably well behaved and stable in the temperate zones; near the equator or magnetic poles it can fluctuate considerably.

4) Troposphere Sea level to 8 km at the Earth's poles, up to 18 km near the tropics. Errors in the corrections of pseudo range are caused by tropospheric effects. Another deviation from the vacuum speed of light is caused by the troposphere. Variations in temperature, pressure and humidity all contribute to variations in the speed of light of radio waves. Both the code and carrier will have the same delays.

5) Multipath is the error caused by reflected signals entering the front end of the receiver and masking the real correlation peak. These effects tend to be more pronounced in a static receiver near large reflecting surfaces where 15 meters in or more in ranging error can be found in extreme cases. Monitor or reference stations require special care to avoid unacceptable errors. The first line of defense is to use the combination of antenna cut off angles and antenna location that minimizes this problem.

6) Receiver Errors in the receiver's measurement of range caused by thermal noise, software accuracy, and inter-channel biases. Initially most GPS commercial receivers were sequential in that one or two tracking channels shared the burden of locking on to four or more satellites.

With modem chip technology it is common to place three or more tracking channels on a single inexpensive chip. As the size and cost have shrunk, techniques have improved and 12 channel receivers are common. Most modem receivers use reconstructed carrier to assist the code tracking loops, producing a precision of better than 0.3 m.

With the *SA* function turned off virtually any GPS receiver can give geodetic coordinates accurate enough for any IOTA application, usually to 15 meters or better every time. The GPS receiver will usually acquire the minimum 4 satellites within a few minutes time and then provide an accurate position. By allowing the unit to remain on for at least 10 minutes before utilizing a reading the upper atmospheric fluctuations in the Earth's ionosphere are averaged to provide a stable accurate position. The Earth's upper atmosphere sometimes has marginal effects on the signal coming from the satellites.

7.3.3 Using GPS receivers

These low cost receivers (many models under $150) have a multitude of functions including the storing of *waypoints* (a particular latitude/longitude position) into memory for future reference. It is advisable to store your final site position in the unit's memory (and record it on paper) as soon as possible so the time can be spent on acquiring the target star and calibrating any telescope/video equipment. Moderately priced units such as the Garmin etrex Venture model, or the Magellan Meridian model can project a line between two waypoints and show your current position and perpendicular distance from this line. This feature is known as **Off Course** distance and on some model units it is called **Cross Track Error, XTE,** or **X-Track**. This feature is especially useful for positioning oneself for asteroid occultations and solar eclipses. **Off Course** refers to the perpendicular distance from a projected line specified by two waypoints.

When planning to observe an asteroid occultation in coordination with others, observers should be spread out as much as possible to cover the path plus error limits. If assigned the position at 20 km north, after programming the required two waypoints near you, stop your vehicle when the GPS receiver displays **Off Course**: 20 km. Most of the time you would not be exactly at the 20 km position but nearby where you could find a suitable place to set up your telescope and equipment, usually within 1 km. An example screen of the GPS unit Garmin etrex Venture model is shown in Figure 7.4.

Elevations are also available from GPS units. Generally they are not as accurate as the latitude/longitude positions. It is suggested that observers use the USGS topographic maps (now available on-line at www.topozone.com) in conjunction with the GPS reading of elevation.

The Wide Area Augmentation System (WAAS), developed by the Federal Aviation Administration allows many newer GPS receivers to produce accurate positions typically approaching ± 3 meters. At the current time this additional precision is not needed for IOTA applications, but may be necessary for future work.

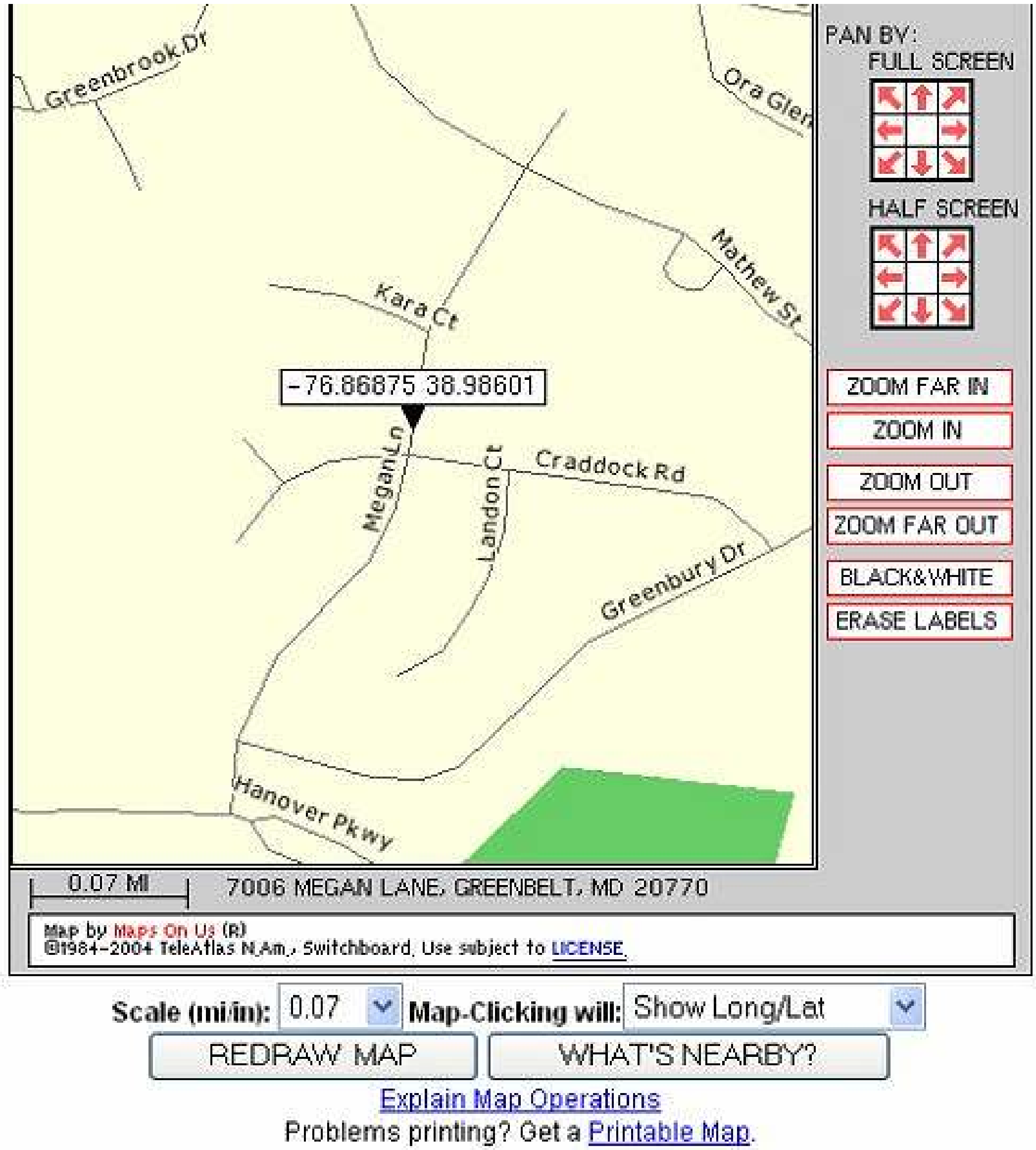
A **B**

Figure 7.4. The GPS screen **A** shows a reference line (left to right) which is the center of the predicted shadow path of the asteroid 522 Helga. The triangular marker shows the observers position as 47.1 km "Off Course" (north) of the center line. The screen **B** shows the observer positioned 78.7 miles "Off Course" (north) of the center of the path for the occultation by the asteroid 559 Nanon. GPS is Garmin etrex Venture model, copyright Garmin International.

7.4 Coordinate Determination Using the Internet

When a GPS receiver or USGS topographic map is not available for an asteroid occultation observation, one can use the internet to get a low precision geodetic position determination. To do this, identify your observing site with respect to the nearest road/highway intersection. Measure the distance in either feet (if a short enough distance) or in tenths of a mile using your car odometer. Log on to www.MapsOnUs.com and follow the on-screen directions to display a map of your occultation observing site. When this map appears use the drop down menu to select "Lat/Long". Click on the spot where you were stationed for your observation by estimating this position from your car odometer reading and/or estimate in feet. A box will appear with the coordinates in decimal latitude/longitude displayed to five decimal places. Due to possible error in placement of your cursor the true accuracy of the point will be no more than to 2-3 arc seconds (200-300 feet) which is adequate for an asteroid occultation event but unacceptable for total/grazing occultation data reduction.

Figure 7.5 shows a screen shot of this program and how it is used.



-76.86875 38.98601

7006 MEGAN LANE, GREENBELT, MD 20770

Map by Maps On Us (R)
©1984-2004 TeleAtlas N.Am., Switchboard. Use subject to LICENSE.

Scale (mi/in): 0.07 Map-Clicking will: Show Long/Lat

Problems printing? Get a Printable Map.

Figure 7.5. Sample screen of www.MapsOnUs.com web page showing latitude and longitude of a selected point. The Latitude and Longitude reading is returned in decimal format accurate to approximately 2-3 arc seconds.

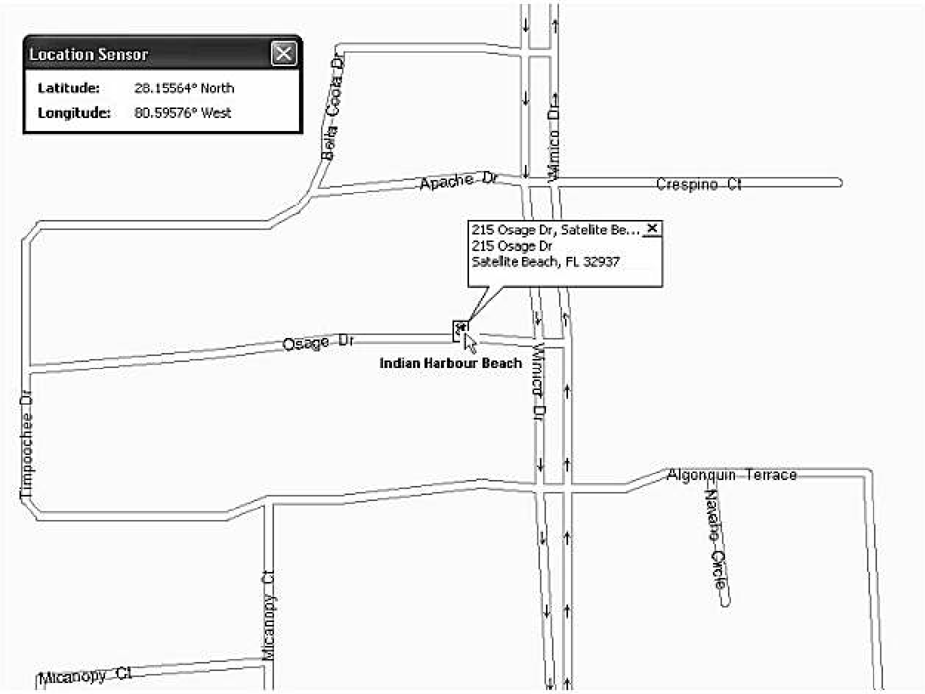
Another widely available Internet program to determine coordinates is Google Earth Maps (www.earth.google.com). The popular internet search engine Google has added an interactive map feature to their website. Google maps resolution varies from the entire country view to a zoom of one inch = 200 ft on a typical computer monitor screen. Thus users can approximate their position to usually 100 ft. In addition to options favorable for IOTA applications, Google Earth Maps displays one-click latitude and longitude coordinates and one-click perpendicular distances. See Figure 5.16 in Chapter 5, *Lunar Grazing Occultations* for a sample screens shot of its application.

Caution: Internet programs such as mentioned here are updated frequently. Their availability is not guaranteed when it comes time to use them. Observers should check for their availability before using them for occultation work, as features may be assessed a fee and/or changed regularly.

Some Internet websites such as MapsOnUs.com, Topozone.com, etc. require registration and or fees ranging from $50 - $150/year. Unless you are an armchair astronomer this is not recommended since a GPS receiver can be purchased for $100 to give accurate coordinates which is the cost of a one year fee.

7.5 Coordinate Determination Using Software Programs

Another method of determining ground position is by computer using one of the many road atlas software programs widely available. This method displays the position of the site by moving the computer's mouse directly over the location. These programs also feature various levels of zoom so locating your position to a 1-3 arc seconds is common. In addition, these maps provide driving and travel directions when planning an occultation expedition. One such widely available program is Microsoft's *Streets and Trips* which retails for about $30. A sample screen shot is shown as Figure 7.6a. *Streets and Trips* has a location sensor option which displays the current latitude/longitude of the cursor in a separate window. This position is accurate to 1" corresponding to approximately 100 ft.



Location Sensor

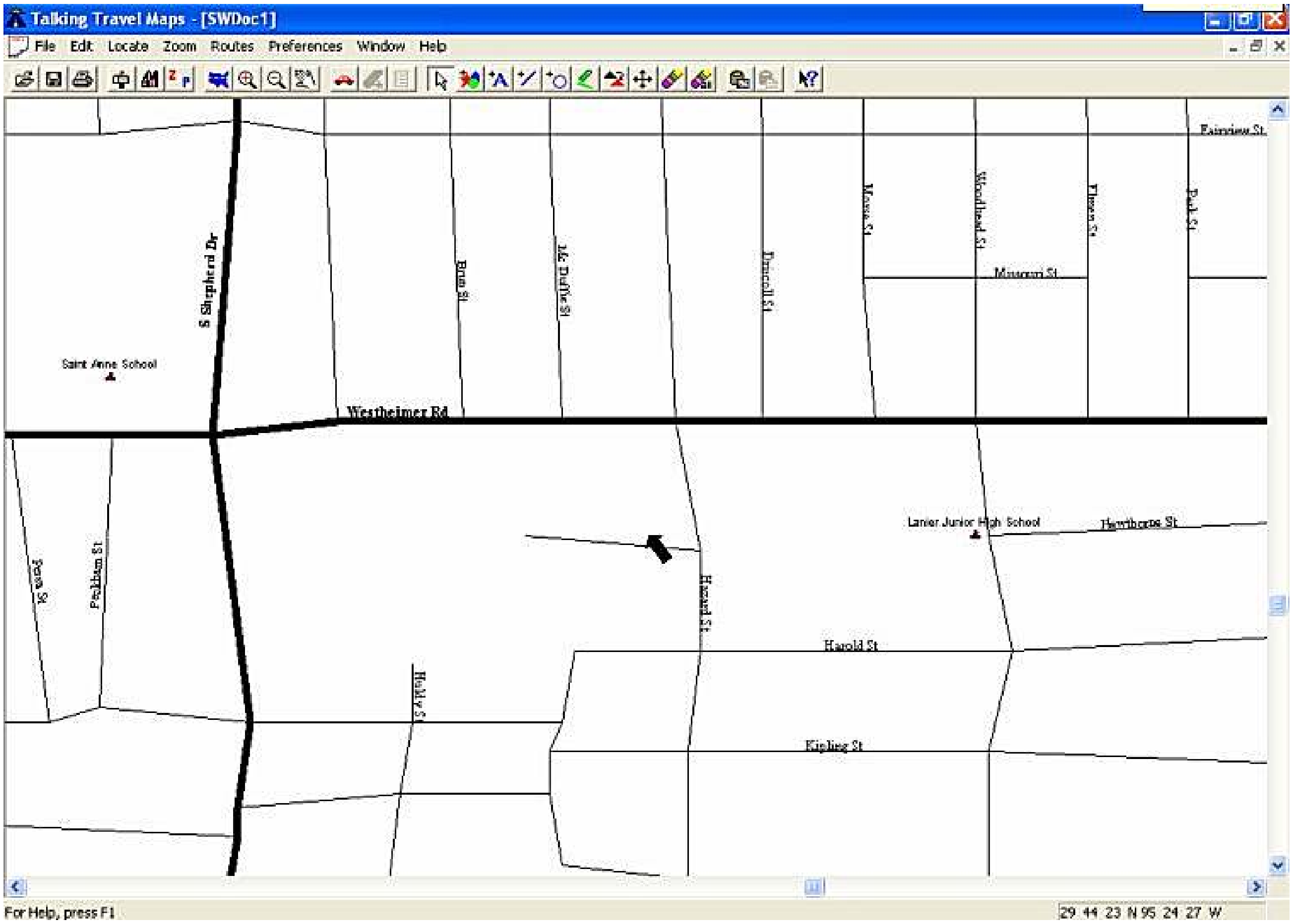
Latitude: 28.15564° North

Longitude: 80.59576° West

215 Osage Dr, Satelite Be...
215 Osage Dr
Satellite Beach, FL 32937

Figure 7.6a. Screen shot of Microsoft's *Street and Trips*. The location sensor window displays the latitude and longitude of the cursor. Microsoft product screen shot reprinted with permission from Microsoft Corporation.

Another program widely available on CD-ROM is Cosmi Corporation's *Street Maps and Talking Travel Maps USA* (See www.cosmi.com). This low cost software program can be acquired for under $10 from Office Depot. For the IOTA user this program features a constantly changing readout of latitude and longitude wherever the computer's cursor is displayed and is accurate to 1" (100 feet), which is adequate for asteroid occultations but not accurate enough for grazing and total occultation positions. See a sample of a coordinate determination in the sample screen in Figure 7.6b.



For Help, press F1

29 44 23 N 95 24 27 W

Figure 7.6b. Sample screen of map software program showing latitude and longitude in lower right corner corresponding to position of cursor. From *Talking Travel Maps*, www.cosmi.com.

This atlas program will also draw a rectangle defined by four latitude/longitude points for mapping the path of an asteroid occultation. This feature is simplified by entering the latitude/longitude points in a window which are then plotted on a map by the program using a symbol. With four positions plotted for an asteroid occultation path it's a simple matter to connect these four points to create a rectangle/region of predicted visibility for the asteroid event. This screen (See Figure 7.7) can be copied in any image format and emailed or uploaded to a web page to broadcast the asteroid's ground path to potential observers. This makes it easier to recruit observers based upon their location or mobility.

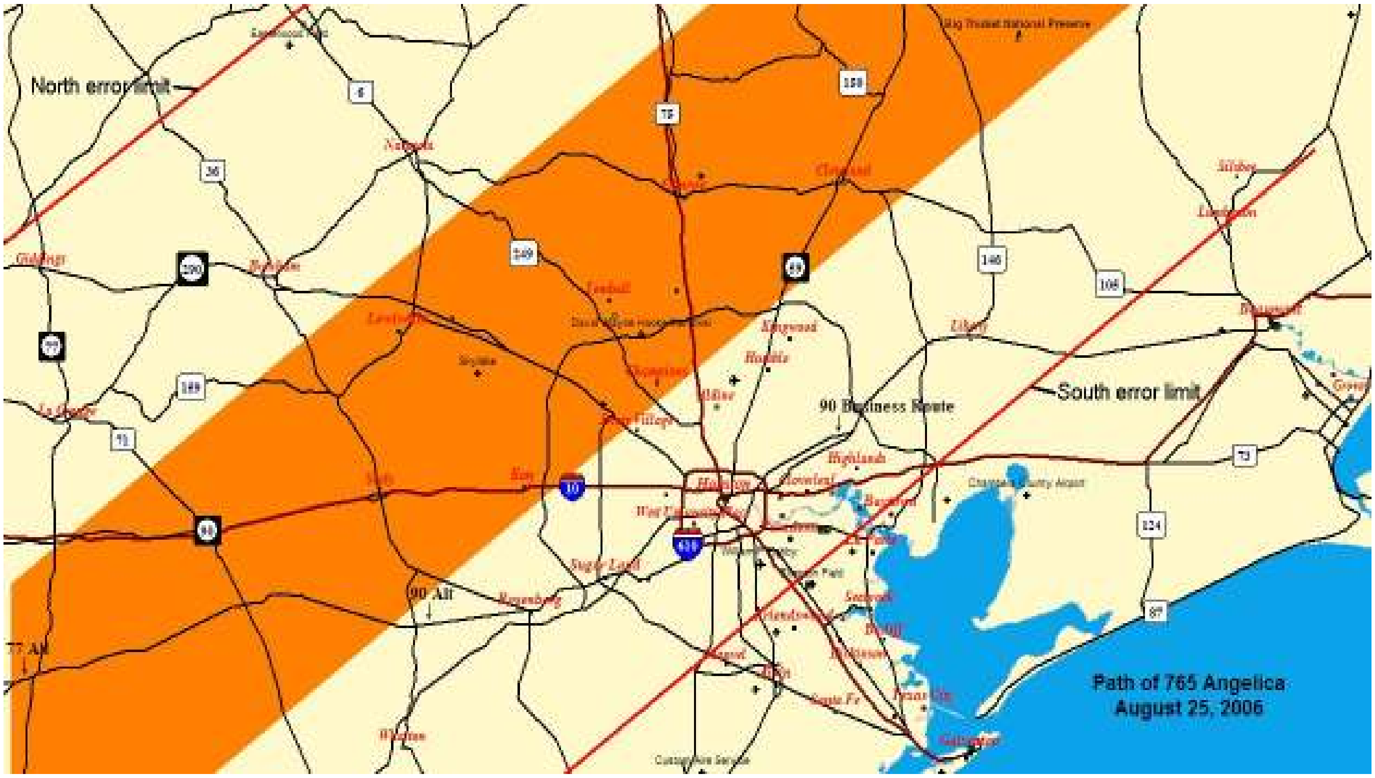


Figure 7.7. Sample screen of *Talking Travel Maps* showing the asteroid occultation map region drawing capability. The path center for the occultation by 765 Angelica is north of Houston, Texas with the south error limit line going through Baytown and La Porte and the north error limit north of Giddings, Texas. From *Talking Travel Maps*, www.cosmi.com.

Though it's not a necessary feature for IOTA applications, this program has the capability to speak to the user an address/address range by clicking the mouse on an area of the screen. If unsure about a software program's ability to provide latitude and longitude coordinates, check the company's web site.

Although the wide use of the internet offers constantly changing new and updated programs with more and more features for land navigation and position determination, it is wise to have a simple program on one's computer such as *Talking Travel Maps* or *Streets and Trips*. One may not always be able to link to the internet when traveling or when some other situation arises making it impossible to get internet access. A program loaded on one's computer is always there and ready to use. The same may be said in reference to paper bound maps and atlases, as they are always "up and running".

7.6 Elevation Determination using the Internet

To estimate the elevation of your observing site, logon to www.topozone.com and follow the instructions to bring up the low precision USGS topographic map. The map area being sought may be identified by entering in the place name, or latitude and longitude coordinates. Estimate the elevation by reading of the contours with the known latitude and longitude position. An example map from this web site is shown below of the area as the example is shown as Figure 7.8.

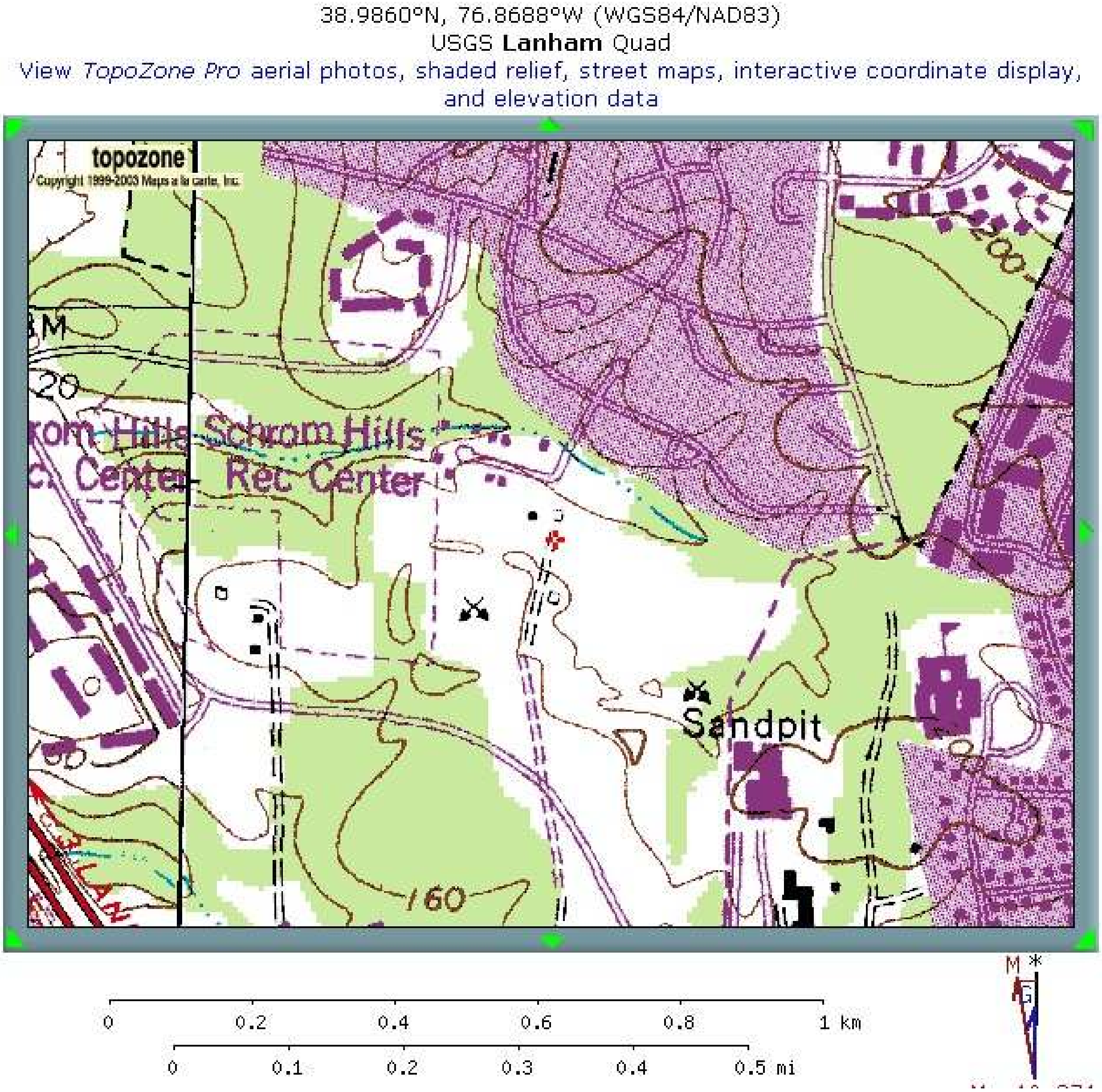


Figure 7.8. Topozone.com portion of USGS Map. Note the position of the cross at the center. See text for method to determine its elevation.

In Figure 7.8, the estimated elevation of an observer located at the position marked by the cross at the center is 180'. This is estimated by noting its position very close to the contours marked 200 and 160. In this map the contour intervals are 20'.

7.7 Determining Position from USGS 1:24,000 scale Topographic Maps

At stated earlier, geodetic coordinates are generally no longer derived from topographic maps. This method with its examples is included here for completeness only.

7.7.1 Locating your observing site on the map

Map Accuracy

As applied to the USGS 7.5-minute quadrangle topographic map, the horizontal accuracy standard requires that the positions of 90 percent of all points tested must be accurate within 1/50th of an inch (0.05 centimeters) on the map. At 1:24,000 scale, 1/50th of an inch is 40 feet (12.2 meters). The vertical accuracy standard requires that the elevation of 90 percent of all points tested must be correct within half of the contour interval. On a map with a contour interval of ten feet, the map must correctly show 90 percent of all points tested within 5 feet (1.5 meters) of the actual elevation.

With a view to the utmost economy and expedition in producing maps that fulfill not only the broad needs for standard or principal maps, but also the reasonable particular needs of individual agencies, the Federal Government has defined the following standards of accuracy for published maps:

1. Horizontal accuracy. For maps on publication scales larger than 1:20,000, not more than ten percent of the points tested shall be in error by more than 1/30 inch measured on the publication scale; for maps on publication scales of 1:20,000 or smaller 1/50 inch is required. These limits of accuracy shall apply to positions of well defined points only. Well defined points are those that are easily visible or recoverable on the ground such as: monuments or markers, bench marks, property boundary monuments, intersections of roads and railroads, corners of large buildings or structures or center points of small buildings. In general, what is well-defined will also be determined by what can be plotted on the scale of the map within 1/100 inch. While the intersection of two roads or property lines meeting at right angles would come within a sensible interpretation, identification of the intersection of such lines meeting at an acute angle would not be practical within 1/100 inch. Similarly, features not identifiable upon the ground within close limits are not to be considered as test points within the limits quoted even though their positions may be scaled closely upon the map. This class would include timber lines and soil boundaries.

2. Vertical accuracy. As applied to contour maps on all publication scales, shall be such that not more than ten percent of the elevations tested shall be in error by more than one-half the contour interval. In checking elevations taken from the map the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale.

3. Published maps meeting these accuracy requirements shall note this fact in their legends at the bottom of the map as follows: “This map complies with National Map Accuracy Standards.”

4. Published maps whose errors exceed the accuracy requirements will omit from their legends all mention of standard accuracy.

It is important to verify the accuracy of a map for site position determination.

The first step in coordinate determination is to find features near the observing site whose locations can be accurately determined from a map. Best are manmade features such as road intersections, railroad crossings, and buildings. Buildings on U. S. Geological Survey maps are not usually as accurately placed as roads, driveways, or railroads. Natural features such as rivers, hills, etc. are not generally useful as they are too large and subject to change from year to year. Creeks in deep gullies are usually quite stable and well defined. The observing site should then be measured relative to those features. Measurements made from roads or intersections should be made from the center of the road or intersection. The widths of roads and sizes and sometimes positions of buildings are not as accurate as other features on the maps, since they are often given a standard size on the map regardless of their true dimensions. This will also mean when choosing an observing site, opting for one near an identifiable object is preferable to one on a featureless plain. There are times when this is not possible and observers find that the only choice is a road with no features for several miles. In that case the observers may need to measure all the positions from a feature several or more miles distant. The standard car odometer which reads to 0.1 mile is not accurate enough but one that reads to 0.01 mile or 0.01 km can be used if two or more sets of careful readings are made. Some roads are bordered by equally spaced telephone poles or power line poles, or may have survey markers. In some jurisdictions, all telephone and power line poles are numbered and local authorities or public service companies can provide coordinates for them.

Measurements can be made for relatively short distances (less than 100 meters or 300 feet) by pacing if the observer has measured the length of his pace. A 100-foot tape measure can also be used but this can be tiresome for distances over a few hundred feet. There are devices made to measure distances that count the turns of a wheel of known diameter. These are available at many hardware stores. These are fine for distances to several thousand feet provided the terrain being measured is *flat*. A rolling terrain will result in a longer distance since you are measuring all the curves in the surface as opposed to a straight line distance. Longer distances are better done with car odometers. Precision odometers for automobiles can be purchased from taxi supply companies or companies that supply equipment for rally enthusiasts. The wide spread use of low cost GPS receiver units have virtually eliminated their use.

The next step is to locate the observing site on the largest scale, most recent available map of the area. High resolution USGS Maps are available on CD-ROMS but are very costly. Maps are also sold by specialty bookstores, hiking supply shops, and other sporting goods stores. Often they are available in public libraries or libraries of college and university geology departments. In addition to the survey maps from national survey offices, sometimes local government bodies may independently survey their localities on the national datum. It is sometimes necessary to consult engineering diagrams for housing developments built since the most recent map. Advance prints of updated maps can sometimes be obtained from map publishers. The longitudes and latitudes of points on a map are determined by measuring distances from map fiducial marks in millimeters or inches and converting those measurements to angular measure using the map scale. The scale should be determined by measuring adjacent fiducial marks. On USGS 1:24,000 scale maps they are 150" apart. The elevation is interpolated from the contour heights plotted on the map. The observing site can be plotted on the map and measured directly or its offset from a known feature converted to angular measure and applied as a correction to the coordinates of the known feature. The first is probably the technique used most often when the observer owns the map, the second when the map is borrowed. There are techniques that can be used to make the chore of position measurement easier. Some observers may find that a magnifying glass, especially one on a stand with illumination will make the job easier. Transparent scales may also help.

If you have no previous experience with determining accurate geographical coordinates from maps you may want to contact an IOTA member in your area who may have already done this work. Check the IOTA Listserver discussion group (see Appendix K) for experienced observers.

7.7.2 Numerical Example

To determine the latitude and longitude position of a site on the USGS map, use the following procedure:

1. Place a small dot on the map marking your site. Draw a circle around the dot so as not to lose its position with all of the other symbols on a typical map. If using a borrowed map, place a clear transparency over the map and attach securely with paper clips.

2. Using the scale at the bottom of the map and using a (preferably transparent) millimeter ruler measure the distance in millimeters (mm) for 1,000 feet. Most maps will show 12.5mm per 1,000 ft. however the printing scale may vary from one map to the next.

3. There are four crosshair (+) marks placed symmetrically from the center of the map, lined up with the coordinates plotted on the perimeter of the map. For example at the lower left corner of the *Spring Quadrangle Map* covering a 7.5 square mile area north of Houston, Texas, the lower left corner coordinates are latitude 30° 00', longitude: 95° 30'. The next latitude plotted approximately 1/3 of the map's height north is 2' 30", thus this latitude is 30° 2' 30". One-third eastward in longitude along the map's bottom is the coordinate 27' 30", thus this longitude is 95° 27' 30".

Drawing an east-west line with a long ruler from the latitude marker 30° 2' 30" on the left side to the same latitude marker on the right side, the line will intersect 2 of the cross hairs +. Draw another line north-south from the longitude point 95° 27'30" at the bottom of the map to the same longitude point at the top of the map and the line will intersect two cross hairs ("+"). Draw one more set of lines at the locations of the other latitude/longitude marked points will give you a map separated into nine sectors. See Figure 7.9a.

4. Now measure the ***(x,y)*** distance of your site (denoted by a small dot) from the nearest corner of the sector in which it is located. In the example of the enlarged portion of Figure 7.9b below, the (***x,y***) position of the site is ***x*** = 52 mm, ***y*** = 15.5 mm.

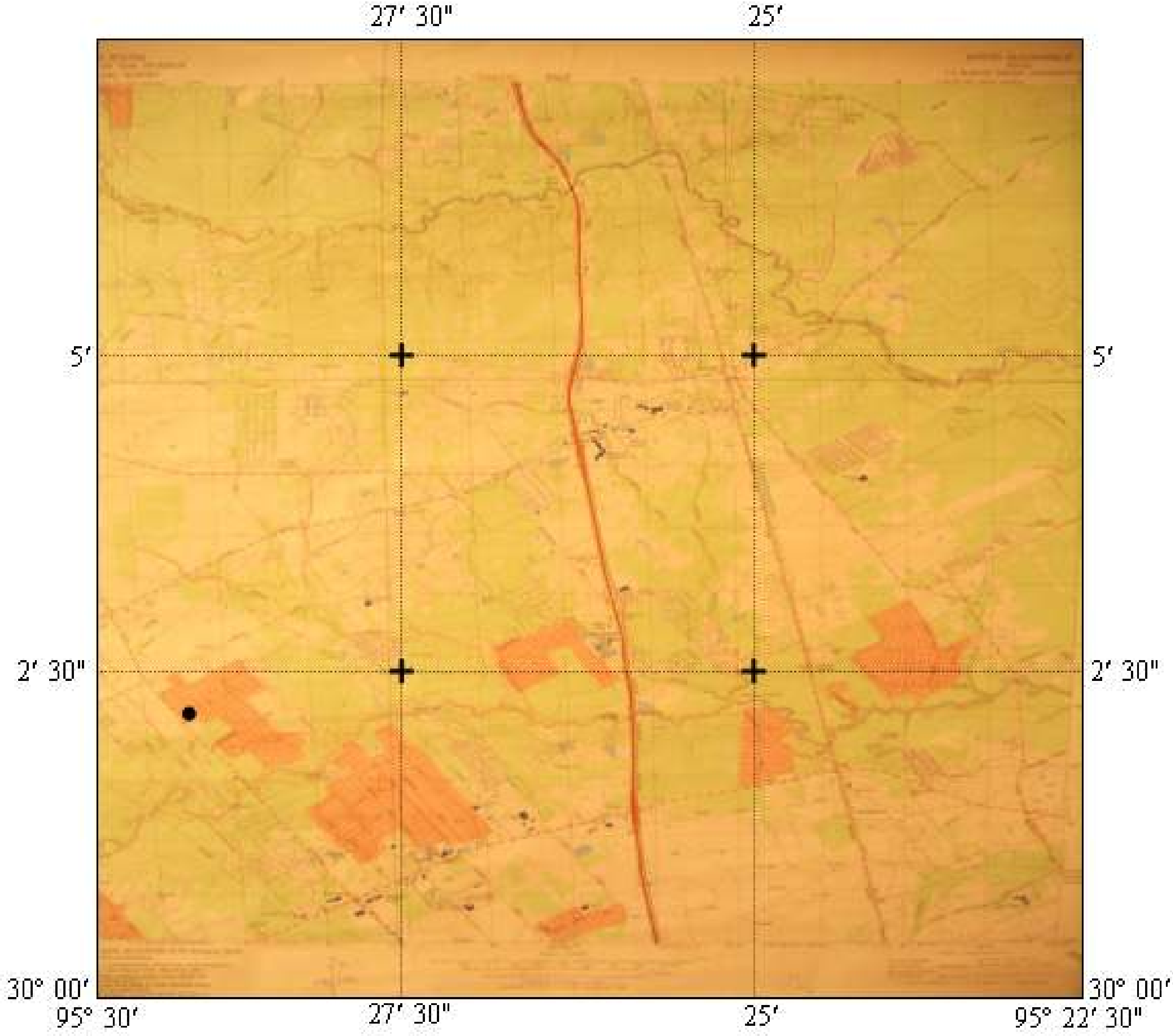


Figure 7.9a. USGS Quadrangle topographic map with + symbols and dotted lines added for clarity. Typical sizes for these maps is 23 x 27 inches.

5. Convert these (x,y) values to feet using the scale factor from Step 2.

   x in feet = 52 mm (1,000 feet/12.5 mm) = 4,160 feet

   y in feet = 15.5 mm (1,000 feet/12.5 mm) = 1,240 feet

6. Convert these (x,y) values from feet to arc seconds:

   1 arc minute on Earth's surface = 6,080 feet in latitude,

1 arc minute for longitude = 6,080 feet cos ϕ, where ϕ is the latitude of the site and *cos* is the trigonometric function cosine. The quantity cos ϕ is applied as a correction to compensate

for the different distances between identical longitude meridians on Earth due to higher latitudes.

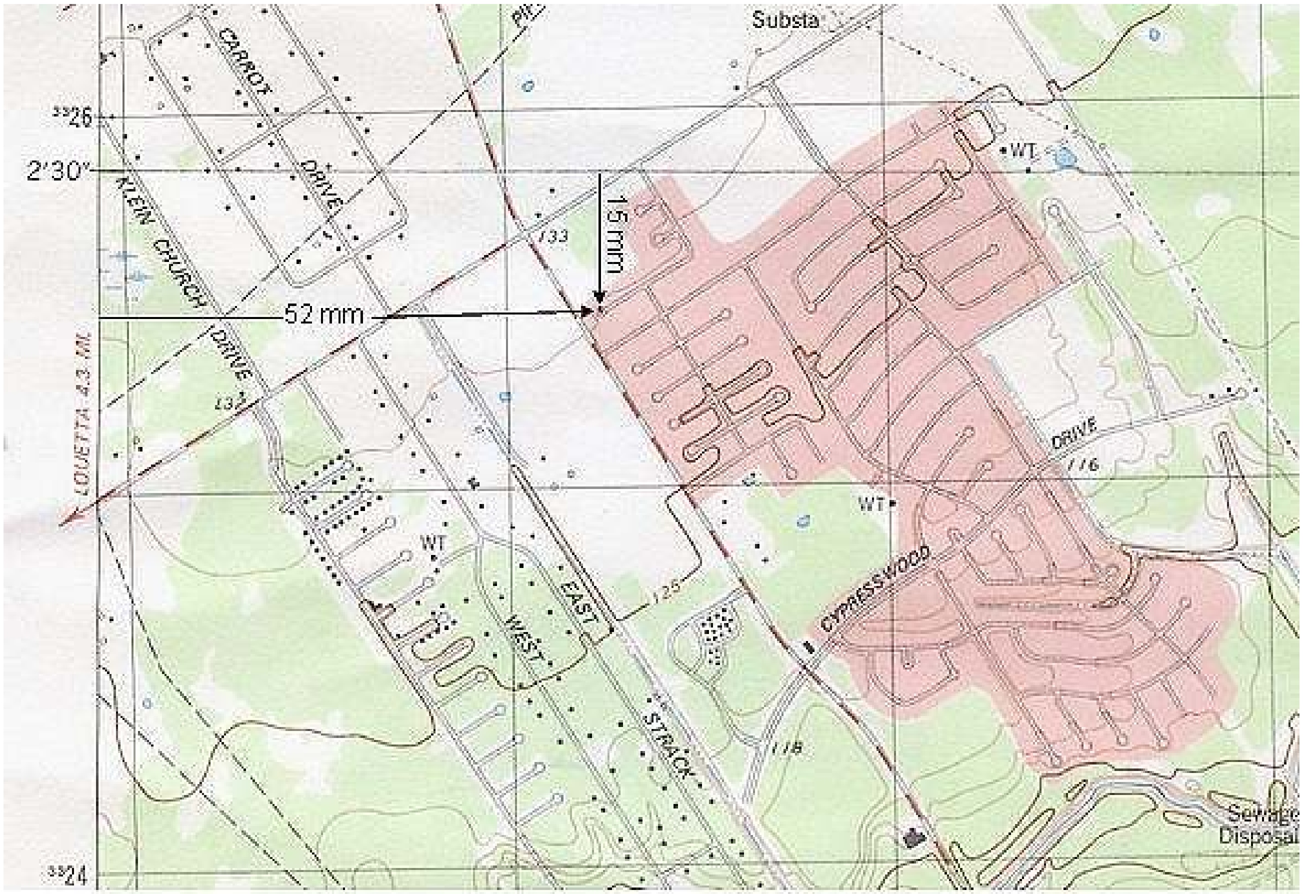


Figure 7.9b. Enlargement of section from map in Figure 7.9a. The measured position of the dot identified by the arrows is $x = 52\text{mm}$, $y = 15.5\text{mm}$

Thus,

$$x \text{ in arc seconds} = 60\{4{,}160/6{,}080 \cos(30.0386^\circ)\} = 47.42''$$

$$y \text{ in arc seconds} = 60\,(1{,}240/6{,}080) = 12.23''$$

7. Apply the (x,y) offsets of your site from the map coordinates of the measured sector:

latitude of site = 30° 2' 30" – 12.23" = 30° 2' 17.8" (rounded to nearest tenth of arc second)

longitude of site = 95° 30' 00" – 47.42" = 95° 29' 12.6" (rounded to nearest tenth of arc second)

Thus your observing site coordinates are 30° 2' 17.8" North latitude and 95° 29' 12.6" West longitude which will be the reported coordinates on your submitted form.

7.8 Approximate Coordinate and Elevation Determination using the Atlas & Gazetteer Maps

The widely popular Atlas & Gazetteer maps are available at many sporting good stores, travel stops and office supply stores. Each atlas covers an individual state in its entirety with these exceptions: Connecticut/Rhode Island, Maryland/Delaware, Northern California, and Southern & Central California. The DeLorme series of Atlas & Gazetteer (www.delorme.com) maps combine some of the detail of a US Geological Survey topographic map with the convenient packaging of a conventional road atlas.

The map scale varies from State to State and ranges from 1.0 miles/inch in the case of Rhode Island) to 6.3 miles/inch for Texas. This precision is not accurate enough for lunar occultation or grazing occultation work but is acceptable for asteroid occultation positions. Detail commonly includes back roads, dirt roads, many County Roads, trails and some elevation contours. Tick marks at one arc minute intervals are labeled on three sides of each page, with labels every ten arc minutes. Contour intervals range from 60' for Alabama to 200' for Texas. A position from the smaller scale Texas map can be determined to a precision of about 10"-15", or 500 meters (0.5km), and with the larger scaled Florida/Northern California maps to 5"-8" (0.2 km).

The Atlas & Gazetteer maps are inexpensive and their average cost is around $20 per state. They also make excellent planning maps for grazing occultations expeditions since they have many County roads plotted (See Figure 7.10). To estimate your position use the latitude/longitude grid that is marked at the corners and count the tick marks which are at one arc minute intervals. To obtain the measurement in arc seconds, measure the tick marks estimate to a millimeter. In Figure 7.10, the position of the city Altair, north of center is estimated as Latitude = 29° 34′ 30" North, Longitude = 96° 27′ 20" West. This estimate, considering the scale of the map is probably accurate to ± 5-10 arc seconds. This is adequate for the foreseeable future for asteroid occultation observations however it is not nearly sufficient for total lunar and grazing occultation work.

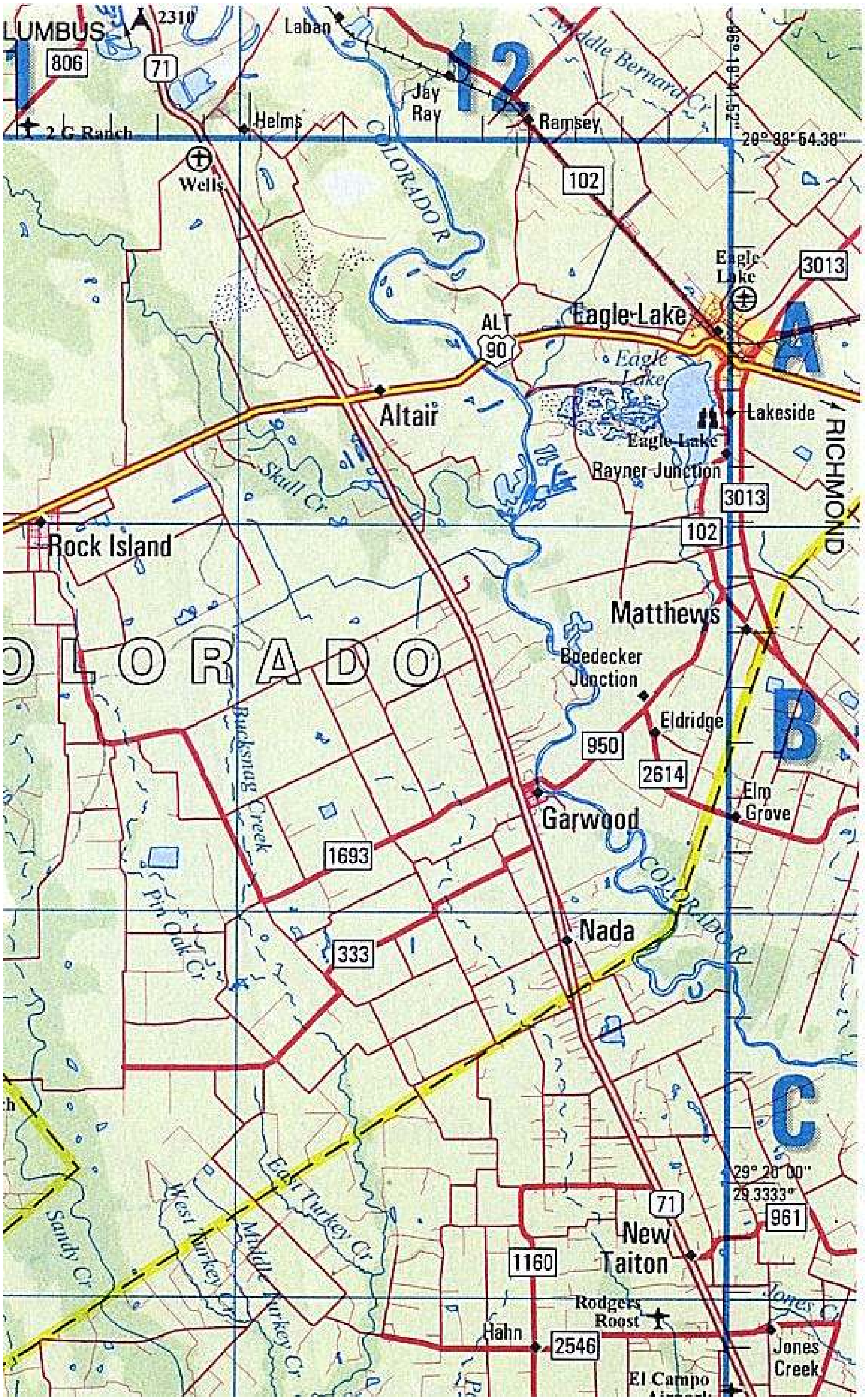


Figure 7.10 Example of Atlas and Gazetteer Map – Texas. The coordinates of Altair, Texas (north of center) is read as Latitude = 29° 34′ 30" North, Longitude = 96° 27′ 20" West. Map from DeLorme’s Texas Atlas & Gazetteer ™ Copyright © Delorme, Yarmouth, Maine.

References for Chapter 7

Dunham, D., Dunham, J., Warren, Jr., W., *IOTA Observer's Manual*, Draft version July, 1994.

Maley, P.D. Palmer, J.L., Nugent, R., Rosenzweig, P., Naranjo, O., "Determining Locations of Unknown Sites for Astronomical Purposes", *Publications of the Astronomical Society of the Pacific* 109, June 1997, pp. 719-724.

www.MapsOnUs.com, webpage providing lat/long positions

Streets and Trips, CD-ROM, Microsoft Corp, www.microsoft.com, 2004.

Talking Travel Maps USA, CD-ROM, Cosmi Corporation, www.cosmi.com, 2003

Texas Atlas and Gazetteer, Fifth Edition, DeLorme, ISBN – 0-89933-320-9, www.delorme.com, 2006.

www.topozone.com, webpage providing elevations from scanned USGS Topographic maps.

8 Timing Strategies for Occultations

A summary of the occultation timing methods discussed in this chapter are listed below:

Method Used	Recommended	Accuracy	Personal Equation
Stopwatch	No	0.2 sec	Yes
Eye and ear	No	0.2 – 0.6	No
Recording Assistant	No	0.5 – 1.0	Yes
Internet/Computer	No	0.1 – 1.0	No
Tape Recorder	Yes	0.2 – 0.3	Yes
CCD Drift Scan	Yes	0.2 – 0.5	No
Video	Yes	0.1	No
Time Inserted Video	Yes	0.03	No

Table 8.1. Historical and modern methods to time occultation events.

This chapter describes the various methods (including historical methods) used to time occultation events. Novice occultation observers please see Sections 8.1 to 8.8. Advanced observers with the appropriate equipment may wish to advance to Sections 8.9 to 8.13. Sections 8.14 through 8.20 are important for all observers who desire to understand more about the timing processes and their sources.

In occultation observations the observer is required to measure a precise time at which the event took place and to time the duration of the event, if applicable. Astronomical observations are time sensitive. Transient phenomenon such as eclipses, transits and occultation observations are all location sensitive. The final results of these observations depend on the accuracy of the measured time and geographical coordinates of the location from where the observations took place. But, as it is said: Time waits for no one and those making observations of occultations should pay a great deal of thought of how they are going to time the event accurately.

Over the years, the observation of a large number of grazing occultations and large increase in the number of total occultations observed annually have led to improvements in our knowledge of the orbital motion of the Moon and of systematic errors in the fundamental stellar coordinate system. While these advances could not have been achieved without the help of amateur observations of total lunar occultations, the value of continuing visual observations of total occultations will diminish unless the accuracy of the timings is kept to a level consistent with the accuracy of the lunar theories and stellar positions. The required timing accuracy is attainable by all amateurs with up to date equipment and requires only a modest amount of practice and cost. Such accurate timing methods are similarly required for the exciting field of asteroid occultations, to help determine profiles of their size and shape.

For grazing occultations by the Moon, timings accurate to 0.5 sec remain adequate for all foreseeable astronomical applications, which is easily attainable. The accuracy needed for useful observations of total occultations varies with the accuracy to which each star's position is known but for most purposes should be 0.2 sec. For asteroid occultations, a timing accuracy of 0.2 sec or better is preferred. Video observations can push this limit to 0.03 sec. To reach this accuracy the observer must have working knowledge of the inaccuracies in the timing equipment and methods used. This chapter discusses the different timing techniques the observer might use and how to determine the errors of each. In reality, most mobile observers no longer use stopwatches for raw observations, nor the eye and ear and photoelectric methods, but prefer to use tape recorders, digital audio recorders, and/or video, along with shortwave (SW) radios as the prime timing techniques. The sections and examples using stopwatches are included here for completeness, and provide good practice for estimating ones own personal equation.

Occultation event times (disappearance and reappearance, referred to as D or R) can be obtained by listening to time signals on a shortwave radio. No matter where on Earth you may be located, there are radio stations transmitting time signals that most any shortwave radio can receive. These stations transmit short beep sounds for most every second and at the top of each minute a long beep is transmitted. Periodically these stations also make voice announcements of the time and information about the station. In the United States, radio station WWV (WWVH in Hawaii) broadcasts continuously at frequencies of 2.5, 5, 10, 15 and 20 MHz. A list of radio stations broadcasting time signals is given in Appendix J.

8.1 Stopwatch Method

(As stated earlier, stopwatches are generally no longer used). Any visual timing technique will require a correction to the raw times known as personal equation or reaction time. In visually timing the event* (D or R) your brain will transmit a signal to your fingers to start the stopwatch the moment your eyes convey that the target star has become dim or has vanished, this takes less than a second. With some practice you can bring this response to between 0.2 and 0.3 seconds. This delay is called reaction time or personal equation.

Using the stopwatch method the observer starts the watch as quickly as possible after the event is seen and stops it at some known moment (such as the 1st second after the top of the minute marker) while listening to time signals from a shortwave radio tuned to radio station WWV or similar station. (Appendix J has details and transmission formats for select stations around the world that broadcast time signals). Some observers prefer to reverse the procedure and start the stopwatch to time signals stopping it when the event is seen. The most important element for achieving the required accuracy is determining the reliability of the stopwatch and estimating the observer's reaction time. No amount of care can be too great in checking and evaluating a stopwatch. Every stopwatch has different and peculiar problems. Mechanical (wind up) stopwatches may have problems from their mechanisms, may delay or jump slightly at the moment they are started, may require a few sweeps of the second hand before their rates become regular or constant, may have different rates when held horizontally or vertically, or

---

* The event for timing purposes in this chapter refers to timing of the disappearance, reappearance, and or both.

may change rate when not fully wound. For these reasons, the use of mechanical stopwatches is not recommended. Electronic ones are also not free from problems, and may change their rates when their batteries are low. Both mechanical and electronic watches may have different rates when cold.

The best policy would seem to be to assume that every stopwatch needs corrections and to determine as many of these corrections as possible while at the telescope so that actual observing conditions are present. Also, since stopwatches may change as they age, they should be tested frequently. The best procedure is the take data to determine stopwatch errors at each observing session.

Personal equation, or reaction time, is probably more difficult to estimate with the stopwatch timing method than with any other. Here, the personal equation has two parts, one when starting the watch and the other when stopping it. If the stopwatch being used does not have a lap timer function (allowing multiple stop-start times to be saved in the watch's memory), you may need two stopwatches to record a D and R. Experiments have shown that even the most alert and experienced observer will require at least 0.2sec to start (or stop) the stopwatch when observing an occultation. Delays under good conditions average around 0.3sec. Clearly, the actual delay is different for every occultation. Observations made with stopwatches must be corrected for this delay when they are reduced. The observer is always in a better position to estimate the delay for each event than anyone else. which may just assume an average of 0.3sec when no other information is available. The correction is always in the sense that the real occultation time is before the time read from the stopwatch. The determination of the occultation time is given by the expression:

Actual time of event = Raw observed time − Reaction time

The actual time equals the raw time minus the reaction time (also known as personal equation). Either the actual time or the raw time may be reported as the observed time as long as it is made clear which is being reported. An estimate of the personal equation should always accompany the reported observation time whether the time has been corrected for it or not.

8.1.1 Stopwatch Errors

Stopwatches are not perfect timing devices and do suffer from propagation errors. To estimate a stopwatch error compare its time against WWV time signals. Start the watch at the top of any given minute. Let the watch run for 10 minutes. When 10 minutes has elapsed on WWV stop the watch at the top of the 10th minute tone. Does the watch show precisely 10 minutes? If it is less or more than 10 minutes, this difference is the watch error over the 10 minute time interval. This error can be divided by 10 to get the error for one minute and your times will have to reflect this correction.

Example: The stopwatch is 2 seconds late in the 10 minute test from above. Thus at the end of 10 minutes on WWV, the watch reads 10:02. The 2 second error is for the full 10 minutes and thus the error for each minute is 2 sec/10 min = 0.2 seconds per minute. Thus a 0.2 second correction needs to be subtracted for each minute (in addition to the correction for the previous minute) to synchronize it with WWV. This means that after the 1st minute, the watch is off by 0.2 sec, at the end of the 2nd minute the error is 0.4 sec, and so on, since the error is accumulative.

As an example, assume you observed a graze of a star that lasted 6 minutes. And further assume that you observed a series of disappearance and reappearance events that were 1 minute apart (this does not happen in reality, D's and R's can occur at any interval) using the lap timer function with the start time of the observing run at 3:23:00 (read 3 hours, 23 minutes and 0 seconds), with the hypothetical 1st event at 3:24:00.

Your raw event times would be:

3:23:00 - Start observing

D at 3:24:00

R at 3:25:00

D at 3:26:00

R at 3:27:00

D at 3:28:00

R at 3:29:00

Apply the 0.2 sec correction for the 1st minute, 0.4 sec for the 2nd minute, 0.6 sec for the 3rd minute and so on.

Corrected times are thus:

D 3:23:59.8 sec

R 3:24:59.6 sec

D 3:25:59.4 sec

R 3:26:59.2 sec

D 3:27:59.0 sec

R 3:28:58.8 sec

8.2 Estimating Personal Equation

How can the personal equation be estimated? Some methods for testing your personal equation are presented in this chapter. Generally, an occultation event will surprise an observer more than a test, resulting in a slightly greater personal equation. Even the most alert and experienced observers will take at least 0.2 sec to react to time a visual occultation.

The actual delay differs for every occultation, sometimes reaching one second or more for difficult events when it takes a finite time to be certain the event has happened. The observer is in the best position to estimate his or her delay. Many observers are not familiar with personal equations or give unrealistic values when reporting their timings. Observers should test themselves to learn what their reaction times are likely to be. The best tests are those that simulate the suddenness of an occultation, and which give a means of measuring how quick the observer reacted.

Comparing a stopwatch with time signals will not introduce any further personal equation but in practice it usually does. With time signals there should be no delay in stopping or starting the stopwatch on the 1st second after the minute marker because one can anticipate the moment rather well from the audio seconds tones/pulses. In any case, the best course to follow in is to read the tenths of a second on the running stopwatch while listening to the time signals before stopping it (this is called Gordon Taylor's Method). Employing the Gordon Taylor Method removes the reaction time delay of starting or stopping the watch to the time signals from the timing and leaves only the reaction delay of the observer to the event as the personal equation. This is easier to do with an analog (difficult to find nowadays) than a digital watch because it is easier to mark or see when the second beats occur as the second hand sweeps around the face of the watch, rather than to read the numbers as they change. There are digital watches that have a moving dot sweeping across the bottom of the watch once per second. Digital watches with this type of analog display are the only digital watches that can be used with Gordon Taylor's method. Some observers might find timing easier by starting the stopwatch at the occultation event and stopping at the next top of the minute time signal tone. Other observers prefer the alternate method starting the stopwatch at the top of the minute time signal tone and stopping at the occultation event.

For a stopwatch personal equation (including a digital stopwatch) may be estimated as follows: North American and Canadian observers can run a personalized test by using the Canadian CHU time signals (3.330, 7.850 or 14.670 MHz). CHU time signals do not broadcast pulses nor voice commands for seconds 51 to 59 for each minute. The “0” ZERO second (top of each minute) has a tone followed by pulses for each second. The broadcast format is as follows:

Seconds	Signal*
0	0.5 second tone
1-28	0.3 second tones

29	No tone, silent
30-50	0.3 second tones
51-59	No tones

*The 1st minute of each hour commences with a one second tone, followed by nine seconds of silence and then the normal pattern of 0.3 second tones for each second.

When listening to the last 10 seconds of each minute (which are silent) it is difficult to anticipate the exact moment when the next minute will begin. Use the following procedure:

1. Start your watch when you first hear the top of the minute signal tone.
2. Stop your watch at a known second (say the 15th second).
3. If you fail to anticipate the 15th second for stopping the watch try again.
4. Read the watch.
5. For this example it should read slightly less than 15 seconds (say 14.7 sec).
6. Subtract 15.0 sec – 14.7 sec = 0.3 sec.
7. 0.3 sec is your personal equation or reaction time.

Do this experiment several times to see if your reaction time decreases for each successive test.

This method allows you to determine your reaction time by timing the start of the minute marker as you would not quite know when an occultation would occur but you would be alert and ready to anticipate the occurrence. Total lunar occultations can be predicted to usually ± 2 seconds, and asteroid occultations to ± 6 seconds, so the anticipated moment is known well.

Another realistic test involves a flashlight positioned on a table, a tape recorder and a shortwave radio. A minimum of two people are required for this test, one to create the occultation and at least one observer. The experiment must be done at night or in a darkened room so that the observers can see the light but not what the assistant is doing. Start by covering up the end of the flashlight with dark tape with a small hole to simulate a star. While the tape recorder is recording the time signals the assistant hits a stiff piece of cardboard down on the table in front of the light cutting off the light to the observers and creating a sound which is recorded by the tape recorder. The observers time the event, and then the times they determine using the method of their choice are compared with the actual time from the tape recorder. Using the stopwatch technique, if there is no stopwatch error, the observed time will always be later than the actual time and the difference will be the reaction time, or personal equation, of the observer. This test can be made even more realistic with the use of a very small light such as an LED or laser pointer, projected on a wall and observing it with actual telescopes. Care must be taken never to look directly at a laser pointer as irreversible damage to the eyes may occur.

Whereas estimating or eliminating personal equation is one problem, estimating the accuracy of the timing by occultation observers is a different issue. Many observers confuse the two. Personal equation and accuracy are somewhat related in that when the personal equation is large, the estimated probable error will usually be correspondingly large. Accuracy should be thought of as the estimated probable error of the observed time of occultation *after* application of the personal equation correction. If the observer believes he may have been as much as half a second late in starting the stopwatch then the correction of 0.5 sec is an estimate of the personal equation, not the accuracy. The accuracy is the uncertainty of the personal equation estimate combined with any other uncertainties that may affect the observed time. For example the observer estimates he started his stopwatch about 0.5 sec late but 0.3 sec is the estimate of the accuracy. The accuracy is preceded by the symbol ±, and it means that the reported time is likely to be within the range of values by that amount. For example a measurement is quoted as 15 ± 3. This means that the actual value of the measurement could be as low as 12 (15–3) and as high as 18 (15+3).

After an observer gains experience with estimating reaction times, a general rule of thumb is that the accuracy value is half the personal equation estimate. Reaction times are essentially eliminated by the eye and ear timing method, but the timing accuracy must still be estimated.

There are several factors that will affect personal equation with a stopwatch or even cassette/digital voice recorder timings. Conditions such as cloudiness, haze, changing sky transparency, seeing, telescope tube currents, passing headlights from cars, loose animals etc. will all affect the observer's raw time.

8.3 Timing a Single Occultation Event

An example of starting a watch to record an event and stopping it at the top of the next minute marker is as follows: An observer starts the watch at the time the star undergoes the disappearance. Comparing the watch to time signal tones, he sees that the WWV seconds tones occur on the face of the watch systematically at 0.8 sec. This means that for every seconds tone that occurs for the remainder of that minute, the seconds time on the stopwatch will display 0.8 sec. The watch is then stopped at the next minute signal which is easily anticipated. Since the observer knows that the fraction will be at 0.8 sec, there is no pressure to stop the watch at the exact minute beat. The observer only needs to count how many whole seconds have transpired since the watch was started at the event. In this example, assume the time signal announcement alerts the observer that the watch was stopped at 4:36:00 UT. The watch reads 47.8 sec and the observer knows the seconds pulses were at 0.8 sec. The next top of the minute tone was 47.8 seconds after the observer commenced timing thus his raw time for the event is 47.8 sec prior to 4:36:00 or 4:35:12.2sec UT. The observer's reaction time was 0.3 sec when starting the watch. After some thought, the observer decides that his personal equation was slightly higher at 0.4sec thus this reaction time is subtracted from the raw time (4:35:12.2sec - 0.4sec) giving a corrected time of 4:35:11.8sec for the timing of the disappearance.

What if the observer had started the watch at the top of the minute marker tone and then stopped it at the occultation event? The observer then starts the watch as accurately as possible on the tone that marks 4:34:00. In the following seconds he compares the running watch to the time signals noticing that the time signals are occurring at 0.2sec on his watch. This means that the stopwatch was started slightly early at 4h 33m 59.8sec. The observer stops the watch to the event and reads the time from the watch as 1m 12.4sec. This corrected time added to the time of 4h 33m 59.8sec when he started his watch gives him a raw time for the event of 4h 35m 12.2sec UT. Again, with a personal equation of 0.4 sec, his corrected time of observation would be 4h 35m 11.8sec. This example also demonstrates one of the problems of starting the watch to a time signal and stopping it to the event. If the observer had waited until the 35th minute to start his stopwatch he may not have had enough time in the 11sec before the event happened to determine his error in starting the watch and could miss the event entirely.

These two examples demonstrate the use of stopwatches for *single* occultation events. For *multiple* occultation events (lunar grazes) this technique cannot be used.

Another factor that will affect your occultation timing is the WWV radio signal. This signal sometimes has to travel several thousand miles before reaching you creating a delay from the time the signal was sent to the time it was received by your shortwave radio. This usually has no noticeable effect on an observers occultation times. See Section 8.17 for a complete explanation along with an example calculation.

8.4 Timing an Asteroid Occultation

Let us consider, an example, that you are going to observe an occultation of a star by an asteroid and you have identified the target star, i.e. the star which is predicted to be occulted by the asteroid. To time this event with a stopwatch requires a lap timer. You are observing the target star through the eyepiece of the telescope when the star all of a sudden becomes very faint or disappears from the field of view and after a few seconds it reappears.

The duration of time in which the star disappears or becomes very faint is what is required to be timed along with the Universal Time (UT) of both the D and R. These times, when combined with those of other observers, will give an estimate on the physical size and shape of the asteroid.

This simple observation should be carefully planned. In this example you are going to record the event visually using a digital stopwatch with lap timer. Any disturbance may make the difference between successfully timing the event or losing it completely. Make sure that your telescope shows stars at least one magnitude fainter than that of the target star. Verify that there is no possibility of reflected light entering your telescope. Avoid setting up to close to any highway or road with passing motor vehicles. Stray light can be minimized with the use of a dew shield.

It is very important to remain calm. As the time of event approaches your heart beat will likely increase possibly causing you to be nervous and/or make some mistakes. It is also very important that you are in a comfortable observing position to observe the event. If your eyepiece is at an awkward position then it may cause additional strains on you and will likely affect your ability to make the observation and estimate your reaction time.

If your telescope has a clock drive, this will maintain the target star in the field of view without you having to constantly move the telescope by hand. It will keep the star in the center of the field without having you to frequently readjust the telescope. If your scope is mounted on a polar aligned equatorial mount then you will have to adjust only one axis to keep the star in the center of the field. If you are using a non equatorial mount, such as a dobsonion type mount, then you will have to adjust both the axes simultaneously to maintain sight of the target star. For observers contemplating on doing many asteroid occultations, it makes sense to upgrade to a clock driven telescope setup.

When observing visually it is advisable to do these observations in pairs in order to have someone assisting you. Besides helping with security, as event time approaches your colleague can perform very useful functions such as holding a sheet of cardboard to protect you from unwanted light, to hand you over your stopwatch that you accidentally dropped, adjust the shortwave radio, etc.

8.4.1 Accuracy of Your Observations

In visually timing the event your brain will transmit a signal to your fingers to start the stopwatch the moment your eyes convey that the target star has become dim or vanished. If your fingers received the signal 0.3 seconds later to start the stopwatch following the disappearance, and also 0.3 seconds later to halt the stopwatch after the reappearance, then the duration of the occultation event will be more accurate than the determined D and R times.

However, it is easier to start the stopwatch then to stop it. Since you are already looking at the star the disappearance is perceived quickly but it might take extra time for your eyes and brain to register that the star has reappeared. With enough practice you can find out your personal equation. An asteroid occultation simulator program called “AOPS”, that runs on Windows is available from the main IOTA web page at the URL:

http://www.lunar-occultations.com/iota/aops.htm ….Asteroid occultation program simulator

AOPS will display a random star field on the screen with the target star at the center. When the target star dims, the user presses any key and when the target star regains its original brightness, the user again hits any key. Each time you press any keys the reaction time is displayed on the screen for you to see. With practice the user’s reaction time can be reduced.

8.4.2 Best Stopwatches for Timing Occultations

You can calculate the duration of the event with a simple stopwatch that has a lap timer. The lap timer function lets you record more than one event’s duration. You get the stopwatch running by pressing the start button. Then by pressing the lap button you can record multiple durations with respect to the original start time. Each time you press the lap time function button, a new time is saved on the display allowing you to directly read off the display how much time has elapsed since the original start time. This function is useful for asteroid occultation events and may also be used for grazing occultation events by the Moon when multiple events are expected. A stopwatch that can record up to 10 laps is of course more expensive than a simple stopwatch but it is well worth the investment. Nowadays, most LCD watches have lap timers as part of their many functions and usually cost less than $40.

8.4.3 Calculating the Duration and Times of Disappearance and Reappearance

With the star in the field have the stopwatch ready in your hand. Be alert and be attentive. The moment you see the target star disappear or drop in brightness from the field start the stopwatch. Press the lap button when the target star reappears. Listen to time beeps on the shortwave radio and stop the stopwatch at the top of the next minute. By now, you must have realized that to get the time of the event all you have to do is to subtract the time shown on the stopwatch from the time at which you stopped it.

For example, supposed you stopped the stopwatch at 22:41:00 LST (LST being your local standard time) and the time that was shown on the stopwatch was 00:00:37.65 then the disappearance event took place at the local standard time at which the stopwatch was stopped minus the time shown by the stopwatch:

Disappearance time = D = 22:41:00 – 00:00:37.65 = 22:40:22.35 (LST)

You must then add or subtract your reaction time (already known) from this raw time to get the true disappearance time. The Lap time will give you the duration of the event. Assuming the Lap timer shows 7.50 seconds, add this Lap time to the disappearance time to get the reappearance time:

Reappearance time = R = Disappearance time + Lap time = 22:40:22.35 + 7.50sec

= 22.40:29.85 (LST)

Now subtract your personal equation (reaction time) to give the actual times of D and R. Assuming a pre-determined reaction time of 0.3 sec,

Reported D = 22:40:22.35 – 0.3 sec = 22:40:23.05 (LST)

Reported R = 22:40:29.85 – 0.3 sec = 22:40:29.55 (LST)

Duration of event = 7.50 seconds.

These are the times you would report to the IOTA coordinator, along with other basic information such as your reaction time, telescope used, magnification, site position, etc.

Since different watches will have a different sequence of buttons to push to start the watch and lap timers, it is highly advisable to practice several times before the day of the event *in the dark* to work out any bugs in this timing process. Learning the technique ahead of time can save the observer from panicking during an actual asteroid occultation.

It is useful to have a portable cassette tape or digital voice recorder running close to you and voice record all your observations and conversations. Keep the recorder going as long as it is needed. This will be useful later.

8.5 Tape/Voice Recorder Method

Using the tape/voice recorder method, the observer records time signals and an audible (usually voice) signal during the occultation. This has the advantage of multiple playback to extract the D and R times of the occultation. The observer calls out the event (D for disappearance, R for reappearance, or "IN", "OUT", "GONE", "BACK", etc.) presses a buzzer or uses a mechanical clicker or toy cricket to create the audible signal. (If using some sort of clicker or other device to create a sound on the recorder for a grazing occultation, understand how to distinguish between disappearance and reappearance events). The tape is subsequently replayed to determine the second and fraction of a second when the event occurred. Many observers who use this method praise it highly, because of the confidence it gives them in the time they determine for their events. The tape can be replayed as many times as necessary to eliminate any uncertainty in the timing. This method is also very useful if several events are predicted to occur within a few minutes, such as during a grazing occultation or multiple events over a very short interval. This has the advantage over using a stopwatch (even with a lap timer) for recording multiple events.

One issue with recording multiple D and R events is that there could be multiple reaction times which must be taken into account. For a grazing occultation, the observer should mention any pertinent comments immediately after making a D or R announcement into the recorder to help identify or estimate the reaction time when playing back the tape. Comments such as "Was at least one second late in seeing the D", or "Was uncertain if it was a D or a seeing effect", etc. Keep your remarks short and to the point since you really don't know when the next D or R event will occur.

8.6 Tape Recorder or Digital Voice Recorder?

Digital voice recorders have come way down in price recently (many cost less than $40) and are comparable in cost than micro cassette and/or tape recorders. Digital voice recorders lack moving parts for the recording process so there is no variation in playback speed when analyzing the timing data. The playback speed is virtually constant and is barely affected by temperature variations as compared to tape/micro cassette recorders. Figure 8.1 shows us that digital voice recorders are just as compact as the micro cassette recorders. When seeking to purchase one, a typical digital voice recorder will advertise a long time period for data/voice storage such as six hours, which may be misleading. Many such recorders have two (or more) different modes for recording and playback. It is advisable to record using the highest quality SP (Standard Play) mode as opposed to the LP (Long Play) mode. The difference in voice and playback quality is far greater in SP mode vs. LP mode. In SP mode, the total recording time for the unit's memory will be shorter but of higher quality than in the LP mode (30 minutes vs. 90 minutes for example). Even though occultation events will rarely last more than 7-8 minutes always use the highest quality mode when recording them. A higher quality voice recording will simplify the timing reduction process and allow you to hear your call outs for events clearly. Digital voice recorders can have the audio transferred to a computer with low cost hardware devices or cables for further analysis.

Digital voice recorders are just as inexpensive as micro cassette recorders, plus their batteries last longer on these units. These recorders use built in flash memories and may be affected by magnetic fields. When using these devices, keep them away from ATM cards and credit cards to avoid damaging the data stored in the memory.

Tape recorders have all of the problems associated with using electronic devices for timing events. When outdoors, tape recorders may misbehave when cold, the speed may vary and it may be difficult to hear the time signal or observer or both, high humidity/moisture may affect the tapes, etc. Also, voice or mechanical buzzer reaction time uncertainties, while perfectly acceptable for grazing occultation timings, may not be good enough for total occultation timings. A good practice is to carry a micro cassette recorder as a backup and to use it simultaneously along with the digital recorder. Whether you plan to use a micro cassette or digital voice recorder keep it in a pocket for warmth during cold weather. By using a good primary recorder backup observations will rarely if ever be lost because of recording instrument malfunction. These recorders also make great backups for video systems.

Figure 8.1. Micro-cassette recorder (left) and digital voice recorder (right). Digital voice recorders are not affected significantly by temperature variations and have no moving parts.

Tape recorders may be negatively affected with speed variations when used for timings. They should be tested prior to making the occultation observation by comparing a recorded WWV playback to actual WWV radio transmissions. If you record WWV on the tape for two minutes and then play it back compared to WWV live, you can tell by listening if there is noticeable difference in the second pulses between the two sources. If there is a tape playback speed variation you should not use a stopwatch for analyzing the timings since there is virtually no way to calibrate two unequal devices. If the tape speed varied the time signals on the tape will vary as well but will be consistent.

The times from tape recorder timings should be reduced first by counting the seconds from a minute tone to the event occurrence and then to the tenth of a second between two seconds ticks at which the event occurred can be determined. It might be easier to use a stopwatch to count the number of seconds from a minute tone to the event instead of counting manually, but the watch should not be used to determine the seconds and tenths of a second from a minute tone. If the seconds beats cannot be heard well enough to count on the tape it might be necessary to use a stopwatch started at a minute tone (assuming that it can be heard) to count the seconds to the event. If necessary the tape speed can be determined by measuring the duration between minute beats on the tape and the time corrected for the speed. Observers may want to leave the recorder running when they are using other timing techniques such as the stopwatch method just as a backup in case anything goes wrong. If the recorder microphone is close to the stopwatch and there is not too much background noise it can pick up the click of the watch being started.

If you notice any special circumstances that will affect your voicing of the occultation events note them in the recorder as they happen. As stated earlier, be careful not to talk too much as one or more events can still occur and you might compromise them. It is then advisable to reduce your timings as soon as possible (preferably right away) to avoid forgetting anything that might have affected the final resulting timings.

Observers will find that it pays to practice using the recorder including the pressing of the proper buttons in the dark and determination of timings from the recorder before trying to observe using that method. The practice is also a test of the recorder so that the observer can see if it works well enough to use for timing. Microcassette and digital voice recorders can be purchased at electronics stores including Best Buy, Circuit City, Office Depot, Wal-Mart, etc. See Appendix D, *Equipment Suppliers* for more information.

8.7 Eye and Ear Method

Using this method the observer listens carefully to the seconds beats of the time signals, observes the occultation and mentally estimates the fraction of a second at which the event occurred. It is not easy to estimate fractions of a second although it is possible to become better with practice. The whole seconds are obtained by counting or with the aid of a stopwatch or tape recorder. Experiments have shown that the method is feasible and if used by a trained and alert observer it can be accurate as any other visual method. The method has the advantage that the least equipment is needed the observations can be recorded in final form rapidly and personal equation is virtually eliminated. Before the invention of stopwatches and chronometers the eye and ear method was the only procedure available for making timings. It required that the observer have a well developed audio memory. Observers interested in this method should try testing themselves to see if they have a knack for this method. Many observers feel that they can only estimate fractions of a second accurately if it falls close to a whole second. Experience and practice usually remedy the problem. The time should be estimated in tenths, not quarter seconds, half seconds, etc. A point that will be obvious upon reflection is that when counting the seconds, the seconds tones will be zero, not one.

The eye and ear method is not recommended unless all of your equipment fails and you have no other way to record the occultation.

8.8 Alternate Methods for Limited Equipment

This section describes several timing methods that have been used by individual observers without the customary equipment such as a shortwave receiver and/or tape recorder. These are not the only methods used since occultation observers are creative and have employed many clever techniques. Consider creating your own technique that has the merit to accomplish the goal of accurate timing. *Use of these methods is discouraged except in the case of a last minute emergency.*

8.8.1 AM Radio as a Time Standard

If one or more individual observers at site **A** have no receivers for shortwave time signals but do have AM or FM radios, then another person at site **B** can record shortwave time signals and the AM or FM station simultaneously. It is then possible to reduce the timing data from site **A** using the two recordings since certain key points in the AM/FM broadcast can be precisely determined by using the simultaneous recording.

8.8.2 Recording Assistant

If time signals and willing assistant is available but recording equipment is not, then the assistant can record the times as D and R events are called out. Obviously, this requires very careful attention on the part of the assistant who must keep constant guard on the time signals or wristwatch. The assistant can record off his or her watch the times of events and immediately compare the watch to WWV. This method is *not advisable except as a last resort* since there are numerous types of errors than can be introduced into the timings. Errors such as not being able to keep up with the observer's call outs or not being able to read the handwriting for events in rapid succession are common.

8.8.3 US Naval Observatory Master Clock

The United States Naval Observatory (USNO) maintains a Master Clock telephone line that provides continuous voice time services. Use these numbers to *PRACTICE* occultations and timings. They should not be used for actual occultation timings that are intended on being submitted for analysis and data reduction purposes. The phone numbers are:

Time Voice Announcer Washington, DC: 202-762-1401, 202-762-1069

Time voice Announcer Colorado Springs, CO: 719-567-6742 (These numbers give 50 seconds of time announcements per call)

Digital Time for MODEMS, which operate at 1200 baud, 8N1 only:

From Washington, DC:	202-762-1594
From Colorado Springs, CO:	719-567-6743

In Canada time signals are available from the National Research Council in Ottawa. Within Canada call 800-363-5409, outside Canada call 613-745-1576.

These telephone numbers broadcast the voice announcements for only up to one minute. This alone poses problems for the occultation observer, who needs continuous time signals for 5-7 minutes for grazes and asteroid events. And what would you do if you called this number and got a busy signal?

8.8.4 WWV Voice Announcements

WWV : 303-499-7111 WWVH: 808-335-4363

With these phone numbers there is no assurance that the signal has not been sent via a geosynchronous communications satellite, adding more than 50,000 miles to the trip and a delay of 0.25 sec to the time. These calls are automatically cut off after approximately three minutes.

Although telephone time announcements are sufficient for most civilian applications they should not be used for occultation work except for practicing. This is due to signal processing delays over the telephone networks amounting to a few tenths of a second, since some telephone connections are routed through satellites and several ground based stations before you hear them. The same is true for time acquired from the Internet since they are subject to a multitude of processing delays through multiple servers before reaching your computer. Delays approaching 1.0 second or more are not uncommon. DO NOT USE THE INTERNET FOR TIMING!! The use of cellular telephones can add more processing delays to the actual time heard.

8.8.5 GPS Time

The GPS system as a source of time has the following advantages:

- Extremely good accuracy and traceability,

- Available reliably anywhere in the world, 24 hours per day,

- Provides positional information,

- Expected to be stable for many decades to come.

Global Positioning System (GPS) receivers generally provide accurate time. GPS time is automatically synchronized to UT on a daily basis to within 0.000001 second (1 microsecond). The US Naval Observatory maintains that in recent years the accuracy of GPS time does not deviate by more than a few hundred nanoseconds (1 nanosecond = 10^{-9} second = 0.000000001 second = 1 billionth second).

The Global Positioning System (GPS) maintains extremely accurate system clocks and communicates this to all receivers. GPS receivers internally keep time better than 300 nanoseconds and the time output at the 1 pps (pulse per second) dedicated time port is typically better than 1 microsecond. (Note: the LCD display on consumer handheld receivers sometimes does not show the correct time, see below). Excellent background information on the GPS system can be found in Appendix K, *Useful Web Addresses*.

A note of caution using handheld GPS receivers. It has been reported by users in the USA, New Zealand and Australia that the LCD time display on most, if not all, handheld GPS receivers can be late by as much as 1 or 2 seconds. This can be readily shown by comparing the LCD display on a handheld GPS receiver with a source of known accurate time such as WWV or *true* GPS time. Such comparisons show that the LCD time display on most handheld receivers is typically late by between a few tenths of a second and as much as two seconds. This delay is caused by the sequencing and relative priorities of the computing tasks performed by the microprocessor in the unit which gives highest priority to computing position and velocity. The time discrepancy for any one receiver is not necessarily constant but may vary with the internal computing workload of the device, e.g. the number of satellites tracked at the time. In some models it has been shown to depend on the power mode (power save, or full power). Therefore regrettably, the LCD display on a standard handheld GPS receiver should not automatically be accepted as being correct.

Even with the LCD reading the correct UT, the high internal precision cannot be extracted easily for most GPS receivers since they have only readouts to the whole second on their displays. Receivers lack the ability to record these times along with your voice for recording occultation events and GPS receivers do not have stopwatch capabilities either. There is some good news for GPS users: A GPS time inserter is available to overlay GPS time on your video recording in real time during an occultation. This technique and equipment is described in Section 8.13 below.

8.8.6 WWV, WWVH and other Long Wave Alarm Clocks

Oregon Scientific (see Appendix D) sells several WWV driven travel alarm clocks, Models # RM932A, RM323A for about $25. The time displayed on this clock is WWV. It allows the setting of an alarm to go off at a preset time. The time displayed on this clock is WWV time and is checked and updated several times per day. Since the displayed time can be off from true WWV time due to the daily updates, the observer is encouraged to have the clock remain off until say 30 minutes before the occultation. Then the batteries can be installed forcing the unit to acquire WWV. The user can then set the clock to go off at the minute in which the occultation is predicted to occur. This alarm clock does not have audible tones for each second and it displays whole seconds only.

For only a few dollars more, a digital tuning shortwave radio can be purchased hence this alarm clock radio is not recommended for actual timings. However this clock may be used to verify the timing when initializing GPS time insertion.

8.9 CCD Drift Scan Method for Asteroid Occultations

Most astronomy CCD cameras used in the conventional sense will not work for occultation timings because the download time per exposure is too slow, even though they can be set for a very short exposures, the download time is excessively long. For a CCD camera to be equivalent to a video recording it would need to shoot and download frames at the rate of 30 images/second for at least one minute which is the video frame rate on VCR's and camcorders. The CCD system should also be able to determine the exact UT time for each exposure. At the current time no such CCD system exists on the market.

CCD cameras can record an asteroid occultation by using the *CCD drift scan method* which does require sophisticated telescope tracking capabilities. Although this method may limit the number of potential participants, it yields good results if careful effort is placed in the setup.

The method can be visualized from Figure 8.2 below. Notice the gap in the star trail caused by the asteroid occulting the star for 16 seconds. During the 4 minute exposure centered around the occultation the telescope clock drives were turned off allowing the stars to trail.

The minimum equipment needed for this method is:

1. Telescope: The instrument must have the capability of changing the tracking rates in both declination and right ascension, either faster or slower than sidereal rates.

2. CCD camera: The field of view (FOV) should be at least 60 arc minutes. The Earth's rotation causes the sky to drift at 1 degree per 4 minutes across the FOV. A minimum interval for constant recording of an asteroid occultation is 4 minutes, thus the need for a FOV of 1 degree. The user must be able to control the start and total length of integration very accurately so that you know exactly when the shutter opens. In some cases the software controlling a CCD camera may cause a small delay when the shutter is asked to open to when the shutter actually does in fact open. The observer will need to determine if there is a delay and what it is.

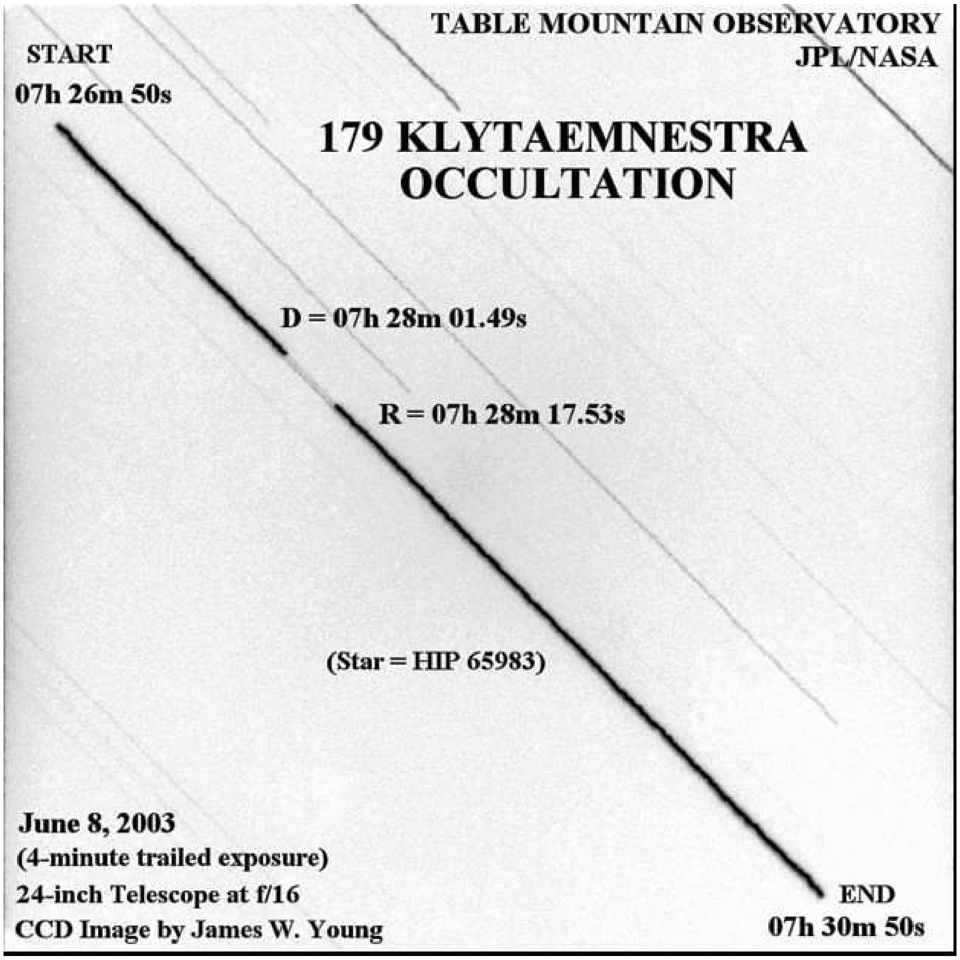


Figure 8.2. CCD drift scan (negative image) of the 179 Klytaemnestra occultation from June 8, 2003. Taken at Table Mountain Observatory, Arizona. See text for method to reduce the timings. Image courtesy James W. Young.

3. A method of displaying CCD image(s) in a large scale format for measuring purposes, such as printing on a sheet of paper or displaying it on our computer with a picture viewer program such as Paint Shop Pro.

Typical CCD images are in FITS format. If the camera can save the raw image file in JPEG format, this allows enlargement of the image for timing reduction. If converting to a printable file format, you will be able to enlarge the image to make the measuring task much easier and certainly more accurate.

John Broughton from Australia has written a freeware program that aids the CCD drift scan user to set up, analyze, and calculate the event times for an occultation. His program, SCANTRACKER is listed in Appendix A under "*Software Downloads*."

8.9.1 Observational Methods for CCD Drift Scan Technique

An accurate prediction of any asteroid occultation event is required. Those predictions must have the path well defined, correct timing of the event and a reasonable suggestion of the length of the occultation. IOTA's main asteroid occultation prediction website, www.asteroidoccultation.com has predictions that meet these requirements. Depending upon the field size of your CCD images, plan your camera exposure centered on the predicted mid-event time. Since most asteroid occultations are less than one minute (usually a matter of seconds), calculate a drift rate that will 'trail' the target star diagonally across the CCD image from one corner to the opposing corner. Since every telescope/CCD camera combination will produce different field sizes, the observer will have to test several drive rate adjustments to find the optimum drift rate for the particular setup. If the CCD image scale has a diagonal measurement of 20 arc minutes, then star images should trail between 16 and 18 arc minutes and no more. This will maximize your star trail for measurement later. It is very important to be sure of star placement at the start of the exposure and the direction of travel. This entire process must be thoroughly tested prior to any actual event. Setting similar tracking in both axes will almost always yield diagonal star trails. If the asteroid occults the star, your star trail will show a noticeable gap and depending upon the asteroid's brightness you may still see a much fainter trail of the asteroid between the actual star's disappearance and reappearance.

8.9.2 Measuring Event Times

Once the trailed star image is obtained in a measurable format, it's a simple matter to measure the length of the occultation event. You will need to know the following to time the occultation event: 1) the exposure's start and end times accurately, and 2) the image scale.

If the star trailed for 4 minutes, then measure from the start of the exposure to the star's disappearance then to the reappearance. Knowing the total time of the exposure and using an accurate scale in millimeters, the results will yield times as accurate as your particular telescope's scale permits. After converting the image to a JPEG format, print the image and make measurements. The four minute exposure is 240 seconds of time. If the star trail is 10 inches long, you have a line that is now 254.0 millimeters long, or 0.945 seconds of time per millimeter.

Next find how many millimeters from the star of the exposure along the trail to the star's disappearance and reappearance. If measuring with a millimeter ruler, estimate to tenths of a millimeter. Multiply the number of millimeters by 0.945. To get the actual times of the stars' disappearance and reappearance add these measurements to the start time of the exposure. If the start time of an exposure is 3h 12m 25.0 sec UT, and your measurements of the distance to the D and R are 112.5 mm and 120.8 mm respectively, then the D would be 108.6 seconds after the start of the exposure (112.5 x 0.965) and the R would be 116.6 seconds (120.8 x 0.965) after the start of the exposure. The actual D would be 3h 12m 25.0sec + 108.6 seconds = 3h 14m 13.6 sec UT. The actual R would be 3h 12m 25.0 sec + 116.6 sec = 3h 14m 21.6 sec UT. With the D and R known, subtract them to get the occultation's duration, i.e., 8.0 seconds. Remember to take into account the seeing characteristics and the fact that the star (especially if it is bright), may bleed a bit along the trail. This means you will have to understand the way your particular CCD chip responds to brightness. If the star is quite bright use a filter to cut it's brightness since you are only looking for the gap to measure.

Smaller telescopes have larger field sizes and the star's occulted gap will be quite small in many cases, especially when such events are very short in duration. Use of a telescope with the longest focal length will decrease the field of view and thus increase the accuracy of the measurements.

In Figure 8.2 of the 179 Klytaemnestra event the brightest star was occulted. The exposure was started at the upper left and the drift rates to the telescope allowed the star to trail across the field to the bottom right. Notice the gap. This is where the asteroid occulted the star.

Example of CCD Drift Scan Method:

In Figure 8.2, the observer would make a printout of the CCD frame on paper (negative image preferred).

a) Measure the distance in millimeters (mm) of the entire length of the trailed star image.

b) In this example, the length of the trailed star is 240 mm. The total length of the exposure was from 7h 26m 50s to 7h 30m 50s, or 4 minutes or 240 seconds. Thus the scale factor is 1 second = 1 mm. So for each mm of distance along the trailed star image on the CCD frame 1 second of time has passed.

c) Next measure the distance along the trailed star from the start of the exposure to the start of the disappearance, D, and to the reappearance of the star R. In our example, the D is 71.5mm and the R is 87.5 mm from the start of the exposure.

d) D calculation: Add 71.5 seconds (recall 1 mm = 1 second) to the start of the exposure,

D = 7h 26m 50s + 71.5 seconds = 7h 28m 1.5s

R calculation: Add 87.5 seconds to the start of the exposure,

R = 7h 26m 50s + 87.5s = 7h 28m 17.5s

e) As a check, additional measurements for D and R can be made from the end of the exposure 7h 30m 50s. These measurements of distance to the D and R would then be subtracted from the ending time of the exposure to arrive at the D and R times. The final D and R times would then be the average of the direct and reverse calculations.

8.10 Video Recording of Occultations

Video equipment has become increasingly sophisticated and more sensitive so that it is now possible to assemble a low cost portable video system capable of observing occultations of stars to 8-9th magnitude with a 4 inch aperture telescope. The sensitivity with the same telescope can reach to fainter magnitudes (to $m_v = 12.0$) with image intensifiers added to the setup. For example, the Supercircuits (See Appendix D, *Equipment Suppliers*) black and white camera the PC-164C introduced in 2002 (retails for about $120) can record stars down to m_v = 8.5 in a 4" Meade 2045D SCT operating at *f* /3.3. Adding a Collins I^3 image intensifier (an expensive device retailing for $2,800) to this camera can yield stars down to $m_v = 12.0$ in a dark sky. This is fainter than can be seen by the human eye in this same telescope !

a b

Figure 8.4. a) Supercircuits PC-164C black and white video camera. The yellow jack is the BNC connector for input into a VCR or camcorder. The black plug is for the 12v power source. b) PC-164C connected to the back of a SCT telescope with a C-mount and T-adapter.

American video equipment designed to be compatible with American TV (National TV Standards Committee, NTSC) records images at 30 frames per second so that timings may be made to an accuracy of 1/30 second. Systems for other television broadcast formats may be at speeds of 25 frames or 50 frames per second. All of them are capable of producing timings of better than 0.04 sec accuracy.

Timings made with video equipment have the advantages that they can be played to audiences that might not otherwise have the experience of observing an occultation. The collecting areas of their CCD chips (although small) permit the use of simple telescope drives and polar axis that do not have to be perfectly aligned to the pole. Video systems offer a more efficient means of recording occultations than other methods described here. To record an occultation with video equipment the observer will need a camera sensitive to low light levels (the aforementioned PC-164C is highly recommended), a TV monitor to watch as the event is recorded, a VCR, camcorder or digital video recorder to record the video, a time signal source and a telescope with a clock drive. VCRs with a frame by frame playback are the best for reducing the occultation timing as opposed to those with only a standard rate forward play. Time information can be obtained by recording WWV simultaneously with the occultation event on the audio or video track.

Some camcorders have an input jack for recording audio (in this case the WWV radio signal) directly onto the video. Plug the cable from the radio's earphone jack directly into the camcorder. This has the advantage that no outside noises (passing cars, animals, observer excitement, etc.) would be on the video except the WWV time signal. Most 8mm camcorders lack an input jack for recording the radio signal directly onto the video tape, however many digital camcorders do have separate audio/video inputs. Without a direct input, use the camcorder's built in microphone to pick up the shortwave time signals. This allows the observer to describe things as they happen in real time such as describing momentary changes in sky conditions, flashes, blinks or step events occurring with the target star, etc. Be wise as not to say too much during the recording as you'll need to hear the WWV time signals clearly. Keep in mind that passing cars and other surrounding noises will also be recorded onto the tape.

IOTA provides a free video time insertion service for your occultation videos. If you are going to use this service, be sure you can hear the top of the minute marker clearly from your video. Too much static or a weak WWV signal inhibits the ability of the video time inserter's micro chip to pick up the mark resulting in no time insertion. See Section 8.12 for more details.

There are some occultation events that cannot be observed with video or photoelectric equipment. Any occultation occurring near or at sunlit features, or when the Moon is highly gibbous, is difficult to video record because of the glare and brightness of the lunar features. On automatic gain control (AGC) video cameras, the AGC will reduce the camera sensitivity due the bright sunlit side of the Moon and the star might be lost. To minimize this effect place the Moon's sunlit feature as far off to the side (or outside) of the field of view as possible. Remember, it is only important to see the star to be able to record a successful occultation observation.

Since both video cameras and photoelectric photometers (usually only used at professional observatories) have smaller fields of view than the human eye, it is more difficult to observe reappearances of stars from behind the Moon with this equipment than visually. However video timings of reappearances are not degraded by the long reaction times common with visual observations of these events.

For further information on using video equipment with small telescopes for a wide variety of astronomical applications, including occultation work, the reader is referred to the main IOTA web page (Appendix A). Appendix G illustrates several variations of setting up a video system for recording occultations.

Figure 8.6. Portable video occultation system. The PC-164C camera and Collins I^3 intensifier are attached to the f3.3 focal reducer on the back of a 4 inch telescope with dew shield. The camcorder receives audio input from the shortwave radio and video input from the PC-164C camera. The AA battery pack (lower right) powers the PC-164C camera. This system can video record stars to m_v = 12.0 in a dark sky and the whole system fits in a medium size backpack or large briefcase fitting in the overhead compartment of airplanes.

GPS video time inserters (VTIs) are available which display the running time to 0.001sec on the video (See Section 8.13). Keep in mind that the video frames advance in intervals of 0.03 second so the displayed time will be in increments of about 0.03 second. Another device called the WWV time inserter, effectively filters out audio noise to produce a crisper shortwave time signal that can be used to trigger the visual time display. The trigger starts a running time clock which overlays 0.01 sec onto the video. This WWV time inserter can be added after the recording is made. If the recording is going to be with a telescope on a fixed mounting, the video equipment need not be portable. If the telescope is portable, most video equipment may be used to observe grazing and asteroid occultations allowing mobility, which is crucial for one to become a successful occultation observer. Owning a camcorder or digital camcorder is highly useful if one is to be a mobile occultation observer. New video equipment and accessories are appearing on the market frequently. IOTA's web page and E-group listserver keeps up with the latest developments.

8.11 Reducing Event Times from Video

Event times may be extracted from a video recording of an occultation with far greater accuracy than a stopwatch time or from any of the above non-video methods. A video can be played back one frame at a time to determine the duration of an event (asteroid occultations) and the exact frame in which the disappearance or reappearance occurs. Many VCRs can advance a video tape one frame at a time. If yours cannot, ask around. VCR prices have dropped tremendously and now usually sell for around $50-$75 at discount stores.

If you do not have your video time inserted, event times accurate to 0.1 – 0.2 second can be achieved by using a technique with the reference circle shown below as Figure 8.7. The reference circle has tick marks spaced from 0 to 9 representing tenths of a second (0.1 sec).

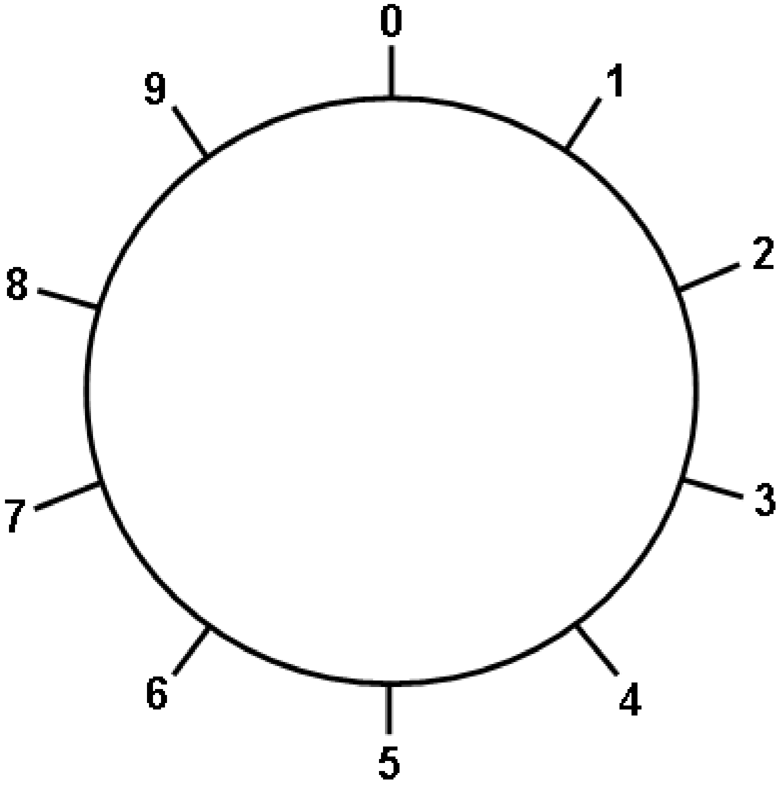


Figure 8.7. Time reduction circle. Tick marks represent tenths of a second. See Figure 8.8 on how to use this method to reduce video tapes.

To use this technique, hold a pen steadily and move it clockwise around the reference circle (see Figure 8.8) and move at a rate of once around per second. Use the WWV second pulses to calibrate your clockwise motion around the circle. The pen should reach the top of the circle (the “0” tick mark) at the moment of each WWV second pulse. At the same time monitor the video as it nears the disappearance event. As you continue to monitor the video, at the moment of disappearance, using your peripheral vision note the position of the pen on the reference circle, 0 – 9. Write this down. Replay the tape 4 or 5 more times and write down each position of the pen at the instant of disappearance. Then average the values (they should be fairly consistent) and you will have an accurate time of the event usually to ±0.1 second.

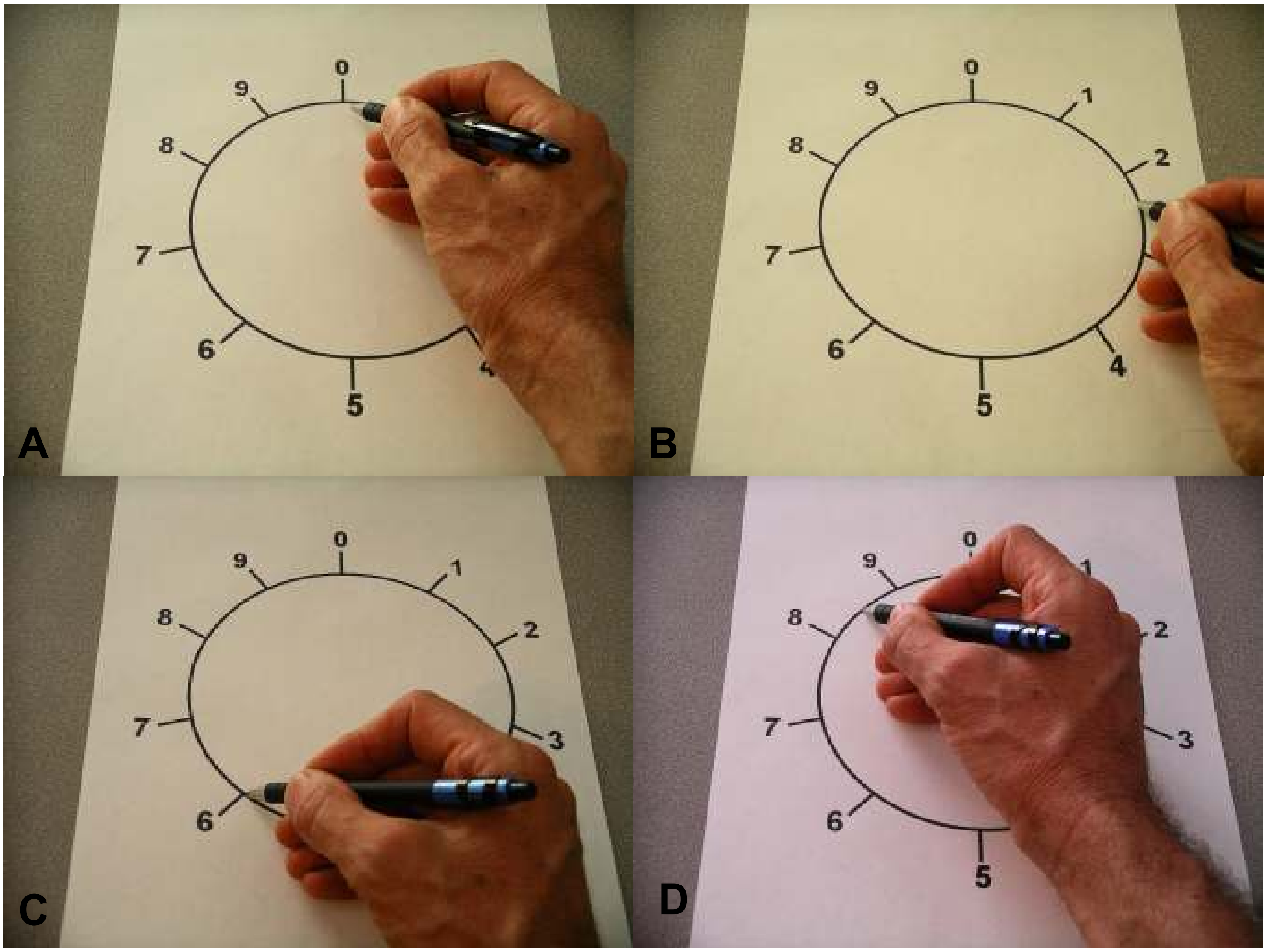


Figure 8.8**.** Using the time reduction circle to reduce video tapes. Move your hand clockwise (A, B, C, D) around the circle once per second in unison with WWV second tones. This allows your eyes to see the video tape and with peripheral vision notice where the pen is pointing at the time of the occultation event to the nearest tenth of a second.

With this accurate determination of the disappearance now count how many frames until reappearance. Divide the total number of frames the star remained occulted by 30 (for NTSC format, divide by 25 for PAL format video) and this gives the duration of the occultation to a precision of 1 frame or ±0.03 second. Thus, without time insertion you can extract a disappearance and reappearance to ±0.1 second.

This method eliminates reaction time from the reduction. This is because you are ‘seeing’ the WWV second tones in real time on the reference circle as you watch the video. This method may also be used for audio recordings and tapes of voice call outs. When you hear the D or R on the tape, note the position of the pen around the timing circle. Then apply your personal equation to this time.

8.12 Video Time Insertion

Video time insertion is the method of adding accurate WWV (UT) time to 0.033 second to a video either during or after the occultation. With time inserted video overlaid onto the video (See also GPS time insertion below 8.13 or Appendix H, IOTA's free time insertion service), as individual frames are advanced, the UT time may be read on each frame advancing at the rate of 0.033 sec per video frame. When the frame is reached where the D occurred simply read off the UT time displayed. This will be accurate to ±0.03 second.

IOTA/USA provides a free service to time insert your occultation videos (NTSC format only). Send your video tape to the address found in Appendix H and when it is returned it will have the UT overlaid onto the video showing hh:mm:ss.tf format. An explanation of the time display format will be enclosed and how to reduce it. The seconds portion ss.tf is converted using t = 1/10 sec and f =1/60 sec, so 34.83sec display = 34 + 8/10 + 3/60 = 34.85 sec. Video time insertion after the occultation is based upon a microchip that listens for the top of the minute WWV marker tone to start a running clock recorded on your video tape. Please note that WWV audio tones must be heard clearly in order for this time insertion process to work.

As you play the tape you'll notice the display time ss.tf changing in agreement with the WWV audio second tones. The ss.tf will be changing at the rate of about 0.033 second per video frame. (See Figure 8.9). A stated above, to extract the occultation event times play the tape back frame by frame and note the time when the star is visible on one frame and disappears on the next frame. If the star was visible on one frame and gone on the next frame the occultation occurred at a time in between the frames. This time will have to be assumed to occur halfway in between frames.

Figure 8.9. Consecutive time inserted video frames from an asteroid occultation. Time on left frame reads 4:18:09.72 = 4:18:09:733 UT (see text for explanation of decimal seconds conversion), the right frame reads 4:18:09.74 = 4:18:09.766 UT. Star has reappeared over this 0.033sec interval. The video images are quite noisy due to the use of an image intensifier. From the asteroid occultation by 129 Antigone on 9 September 2001, video by Richard Nugent and Marilyn Burke.

Some IOTA members have built their own time insertion devices. This is a complicated task and requires a working knowledge of electronics and soldering small parts. Information on how to do this and contact information of where to get parts lists can be found on the IOTA E-groups listserver noted in Appendix K.

8.13 GPS Time Insertion

The GPS constellation of satellites provide position and altitude information to ground based receivers and Universal Time (UT) information. (Section 8.8.5). Several model GPS receiver units generate a one pulse per second (1 pps) signal synched to within one microsecond (0.000001 sec) of the onboard atomic clocks in orbiting GPS satellites. With UT transmitted information and the 1 pps generated by certain GPS units, this has allowed the extraction of UT by these units independent of the WWV signals from short wave radio stations. The UT, date and time information can be added to the image information transmitted by any video camera for a combined video output. The UT and position information is overlaid on the screen of any camcorder or VCR for simultaneous recording during an occultation. See Figure 8.10 below for sample frames.

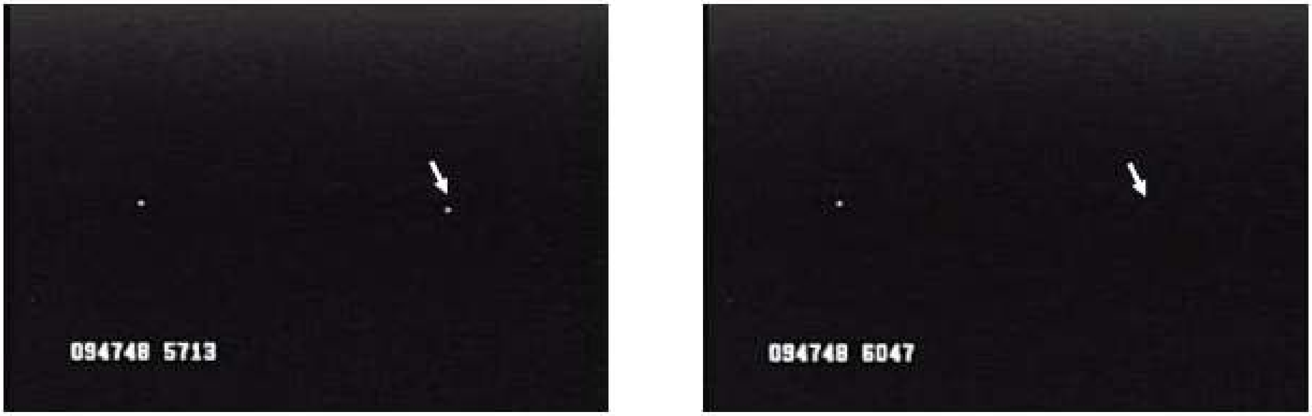


Figure 8.10. Successive GPS time inserted video frame from the occultation by the asteroid 372 Palma on 26 January 2007. Note the disappearance of the target star in the right video frame. The displayed time for the left frame reads 9h 47m 48.5713 sec and for the right frame 9h 47m 48.6047 sec UT (0.033 sec difference). This video was made using a Supercircuits PC-164 camera. The target star is at the right of each frame and a field star is at the left of each video frame. Field size is 15 x 20 arc minutes. From video by Richard Nugent.

The principal of how a GPS video time inserter (VTI) works (refer to Figure 8.11a):

a) The GPS receiver receives constant UT signals (accurate to 0.0001 sec) from the atomic clocks on board the GPS satellites.

b) Each second, the GPS receiver sends a 1 pps signal (synchronized to 0.0001 sec) along with latitude, longitude, altitude, date and other information through a serial port into the VTI unit (See Figure 8.11a)

c) The VTI unit has internal crystal clocks which maintain whole second timing (1,2,3…) and sub-second timing (0.001, 0.002, 0.003…).

d) Sub-second timing: An internal crystal clock in the VTI unit provides 0.0001sec accuracy for display on a video monitor screen. The 1 pps signal from the GPS receiver triggers an interrupt to reset the clock's sub-second timer to zero in the microprocessor at the start of each second. The microprocessor reads the timer and transmits this sub-second time information (accurate to 0.0001 sec).

e) Whole second timing: Whole seconds are increased until the seconds timer reaches 60 seconds (the top of each minute) and reset to back to "1" to restart the next minute.

f) The VTI unit has an on-screen display board which transmits the processed data on UT, date and position information via a video signal for display on a video or TV monitor, and can be recorded by a camcorder or VCR.

Although the VTI unit can transmit incremental Universal Time to 0.0001 sec, most camcorders, VCRs and digital video recorders (DVR) can only record up to 30 frames/sec or in increments of 0.033 seconds per frame. While the VTI unit is transmitting the time at 0.001 sec intervals the camcorder/VCR will only be able to record every 33rd transmitted incremental time. This is illustrated by the following table:

VTI unit time output(sec)	**VCR/Camcorder frame No.**
0.001	
0.002	
0.003	
0.004	
•	
•	
•	
0.030	
0.032	
0.033	1
0.034	
•	
•	
•	
0.065	
0.066	2
0.067	
0.068	
0.069	
•	

•	
•	
0.099	3
0.100	
0.101	
.	
.	
.	
0.995	
0.996	
0.997	
0.998	
0.999	30

--- The VTI sub-second timer is reset to 0.0 while whole seconds continue to increment----

1.000	
1.001	
1.002	
1.003	
1.004	
•	
•	
•	
1.030	
1.032	
1.033	31
1.034	
•	
•	
•	

Table 8.1. How video frames record corresponding incremental time output. As can be seen by the left hand column vs. the right hand column a camcorder/VCR/DVR records every 33rd time increment.

As you analyze the occultation tape frame by frame the displayed time will increment by 0.033 second. The first frame will show a time of 0.000 second, the next frame will display 0.033 second, the next frame will display 0.066 sec, the next frame 0.099 sec, the next frame 0.132 second, etc. When the sub-second timer reaches 0.999 (VCR frame 30) it is reset to 0.000. The microprocessor then adds another whole second and the timer starts all over again, this time to 1.000, 1.001, 1.002, etc.

Most VCR's and digital camcorders have the ability to advance a tape frame by frame allowing the user to read off the displayed Universal Time to an accuracy of 0.03 sec. This is TEN times more accurate than by visual timings plus there is the added benefit that a time inserted tape provides a permanent record of the occultation event. The time inserted tape can be analyzed over and over again for possible secondary occultation events from asteroid moons, close double stars step events and other purposes requiring detailed analysis. Such a video recording usually dazzles and amazes audiences illustrating real time occultation events and their resulting analysis.

GPS time inserters are now becoming widely available for occultation users. Several IOTA members have built their own GPS VTI units and will offer detailed plans to build one, and as mentioned earlier in Section 8.12 this requires a good working knowledge of electronics and soldering small parts. One such unit made and sold ready to use is the McAfee Astrometrics GPS Video Time Inserter Model MAVTI-G18 pictured as Figure 8.11. Another popular unit used by IOTA members is the KIWI-OSD sold by PFD Systems. An advantage of the KIWI-OSD unit is its display of the start and end time of each video frame. Each video frame consists of an odd and even field, thus there are 60 fields per second that the KIWI unit time stamps. Appendix D *Equipment Suppliers* lists several manufacturers of GPS time inserters in the USA, Europe, and Australia. Check their websites for more information and availability.

Figure 8.11. McAfee Astrometrics GPS Video Time Inserter. The toggle switch at left has 3 positions, **RST** (reset), **UT** (Universal Time) and **POS** (position). In the **POS** mode the unit displays latitude, longitude and date information to the output video monitor, camcorder or VCR. In **UT** position, the toggle switch outputs UT to 0.001 sec. The **RST** is a reset function used at the start of a recording session. The **1PPS** LED light blinks once per second when the unit has a fix on the GPS satellites (this could take up to several minutes) letting the user know the unit is working. The **VIDEO OUT IN** are jacks for input of cables to a video camera and output to a camcorder or VCR. The hockey puck looking object in front of the VTI unit is the Garmin model G18LVS GPS receiver that outputs the 1 pps signal to the VTI unit along with UT and position information. It plugs into the back of the unit and has a magnetic base for easy attachment to metal (such as a car roof) up to the length of the cord.

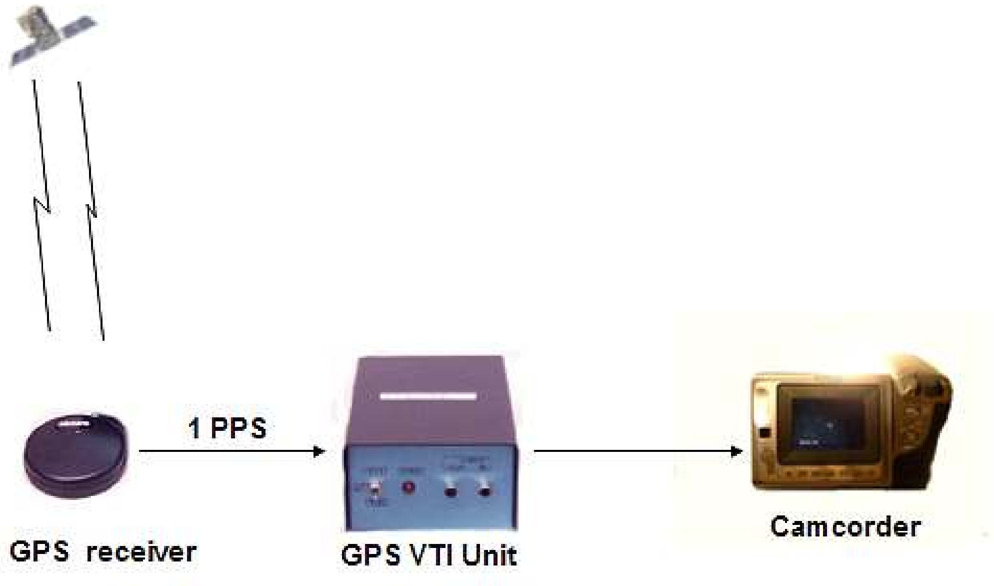


Figure 8.11a. The GPS video time inserter (VTI) processes GPS time signals into sub-second timing accurate to 0.001sec and overlays this directly into the screen of a camcorder or VCR.

For more information of the McAfee GPS Video Time Inserter see Appendix D, *Equipment Suppliers*. Sample video frames from the McAfee unit are shown as Figures 8.10 and 8.12.

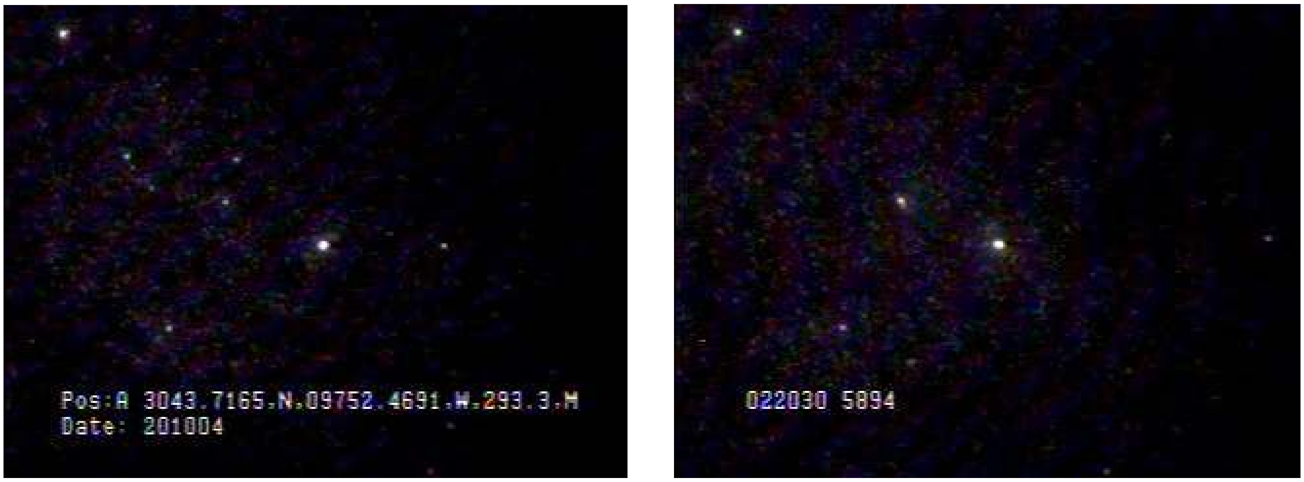


Figure 8.12. Sample GPS time inserted video frames**.** The left frame shows the target star at the center and the position information at the bottom. The position information shows latitude, longitude, altitude and date. The right frame displays the UT. See text for explanation. Video by Richard Nugent.

Note about Figure 8.12: These video frames were taken from a video made with the Collins I^3 image intensifier. There is an unavoidable amount of noise associated with the recordings. In Figure 8.12, the target star is in the center of the frame and a field star is near the upper left hand corner of the frame. Most other white marks are noise associated with the intense amplification of the light entering the intensifier. Despite the noise, the Collins I^3 device is a highly useful tool for the asteroid occultation observer.

In Figure 8.12, the position information format is (left frame) :

Pos: A ddmm.mmmm,L,dddmm.mmmm,L,aaaa.a,M
Date: ddmmyy

In Figure 8.12 left frame, the position, altitude and date information thus reads:

Latitude = 3043.7165,N = 30° 43.7165′ N = 30° 43′ 42.99" North
Longitude = 09752.4691,W = 97° 52.4691′W = 97° 52′ 28.15" West
Altitude = 293.3 meters
Date = 201004 = day/month/year = October 20, 2004

For Figure 8.12, right fame, the display format is:

hhmmss cccc

where:

hh = UT hours
mm = UT minutes
ss = UT seconds
cccc = Counter increment in decimal seconds

For Figure 8.12 right frame, the display reads 022030 5894. This corresponds to 2h 20m 30.5894 sec UT (round to 2h 20m 30.59 sec). For more about GPS time inserters see Appendix D for individual web addresses of units and the IOTA listserver discussion group (Appendix K).

Possible Problems

When using GPS for time insertion onto a video, an experienced user reported that the displayed GPS time differed from UT by as much as 1-2 seconds. This is due to the loss of stored almanac information in the GPS receiver. Included in the almanac information is timing offsets from GPS time to UT. The almanac data can be lost either by not using the GPS unit and letting its internal rechargeable battery drain completely causing the loss of data and/or a low battery without enough power to retain the data.

The almanac data transmitted by the GPS satellites is part of the normal navigation information. A complete almanac download could take up to 10 minutes. If the almanac data is lost in the GPS receiver the switch from GPS time to UT will depend on when the UT offset time is received by the GPS unit. If the reception of the transmitting satellite is interrupted (e.g. as when a satellite travels below the horizon or is blocked by a building) the almanac collection process will start over again.

In rare cases it could take up to 30 minutes to acquire UT offset information by a GPS receiver. So even though the positional information is accurate incorrect timing can be sent through a video time inserter without the observer even knowing it. More likely the GPS receiver will have the updated almanac in just a few seconds to a minute. **The solution:** Use WWV to check the GPS times for accuracy and/or wait sufficient time for the almanac information to be acquired by the GPS receiver.

8.13.1 LiMovie: Photometric Analysis of the Occultation

Occultation videos may be analyzed by a program called LiMovie written by Kazuhisa Miyashita of Japan. LiMovie provides a photometric analysis of videos. LiMovie provides the following from an AVI (audio video interleave) video file:

1) brightness information of a target star (object) compared to the background sky
2) Video playback and reverse playback in increments of one second, ten seconds, normal speed, or frame by frame
3) Tabular brightness data for any interval of frames
4) Three dimensional contour plot of star brightness compared to background with ability to rotate and adjust viewing angle
5) Tabular data can be exported to a Microsoft Excel spreadsheet with one click
6) Excel spreadsheet then provides plots of brightness vs. time for analysis
7) Adjustable measurement region for the target star (or meteor), and background sky

LiMovie is a useful tool for identifying occultations by asteroids especially those with low magnitude drops. Such events can be difficult or even impossible to see visually on a video. With LiMovie's data output and Excel's scatter plot ability even a small 0.10 magnitude drop may be detected.

In Figure 8.13 three successive frames of an asteroid occultation are shown zoomed in on the target star located within the inner circle. This circle represents an adjustable size region to measure the brightness of the star. The other two outer circles surrounding the inner circle measure the brightness of the region and provide the background brightness around the star. LiMovie defines these regions in pixel radius and allows the user to adjust the size of the inner and two outer regions.

Each of the three frames shown has a three dimensional contour plot, video frame no., brightness within the inner circle (the star) and the UT of the frame. Shown in Figure 8.13 is the star and its defining brightness measurement regions (red and blue circles). These same circles are shown as they are used on the contour plots. Notice how the star fades rapidly from frame 497 to 498 and is invisible in frame 499. The contour plots confirm this. The peak in frame 497 shows the star at full brightness (value 2176.9). In the next frame, (498) as the occultation progresses the peak drops to just above the background level with a brightness of 621.4. The next frame (499) shows the peak virtually non existent for the star with a brightness of 333.0, the brightness of the background sky.

In this example the star was occulted in two frames or 0.066 sec. Thus for practical purposes this occultation was instantaneous with no gradual or stepwise events.

Note that the values for brightness are calculated by LiMovie inside the measurement regions (circles) and represent the average numerical value of the pixels in these regions which is the sum total of the numerical values of the pixels divided by the total number of pixels within that region.

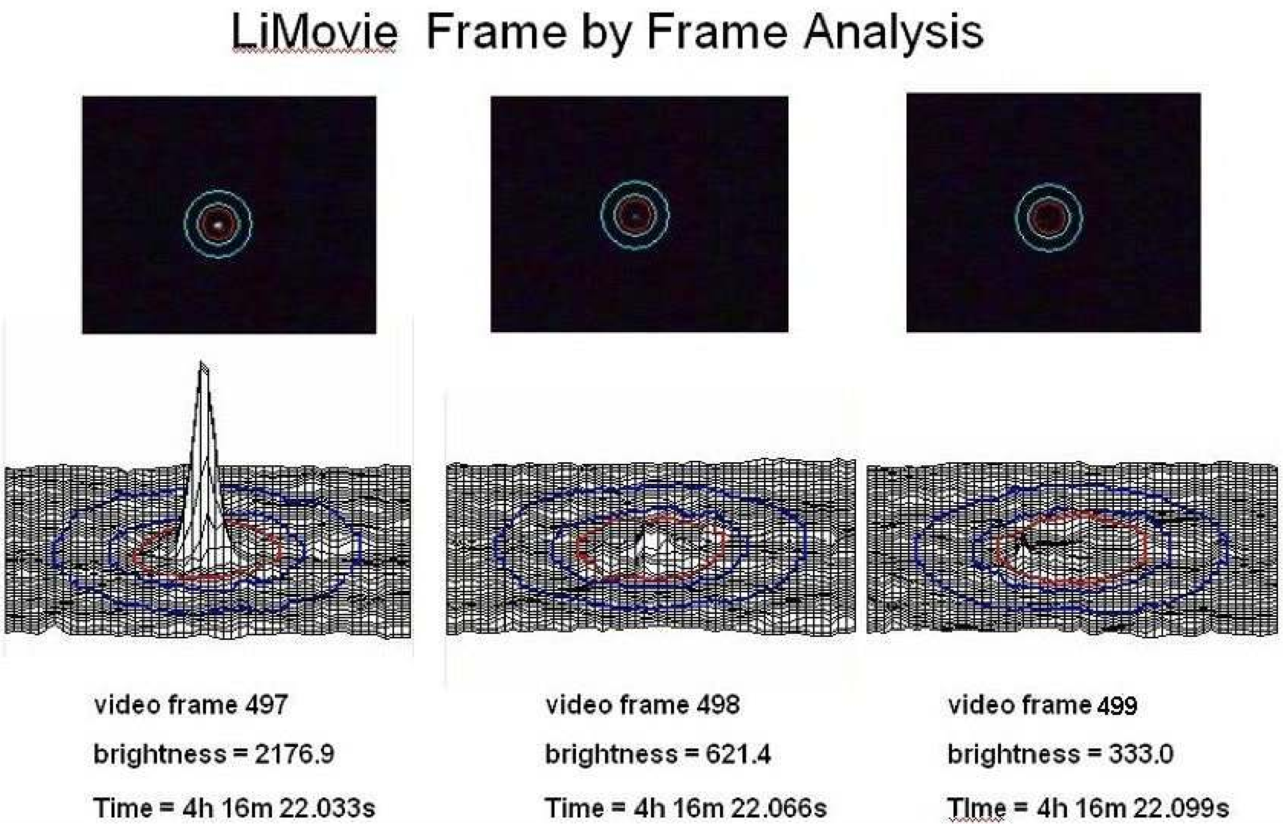


Figure 8.13. LiMovie analysis of three successive video frames**.** See text for explanation.

In Figure 8.13a, LiMovie was used to analyze a spectacular occultation of the $m = +6.6$ star HIP 41975 by the asteroid 372 Palma on January 26, 2007. The AVI format video was loaded into LiMovie resulting in the video frame/brightness plot:

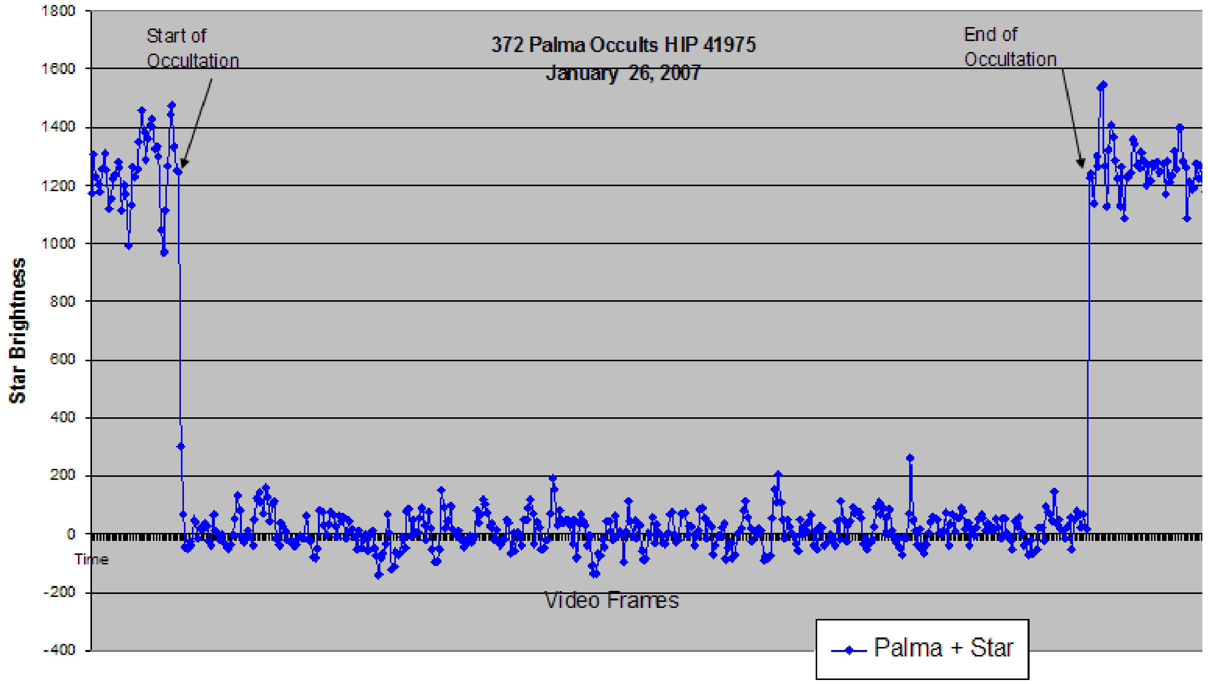


Figure 8.13a. LiMovie Excel plot of the occultation by 372 Palma on a $m = +6.6$ star January 26, 2007. Each blue data point represents the brightness of the asteroid/star combination in a single video frame. Chart shows 17.5 seconds of data or about 530 video frames. Chart from video of the 372 Palma event by Richard Nugent.

Notice the nearly instantaneous D and R for this Palma occultation lasting just one video frame. By counting frames, the duration of the occultation is established. Rechecking the video, the time of R may be alternatively computed from the D time by adding the duration of the occultation by counting LiMovie data points, each of which represents a single video frame.

For Figure 8.14, LiMovie produced the data for this plot of the occultation by 9 Metis on February 13, 2006. The target star was TYC 0862:01003, magnitude 11.8 and Metis was $m = 9.4$ at the time of the event. The magnitude drop is computed by:

$$\Delta m = 2.5 \log (10^{x} + 1) \qquad 6\text{-}1$$

where $x = 0.4(m_2 - m_1)$

m_2 = magnitude of asteroid
m_1 = magnitude of target star being occulted

For this occultation, $\Delta m = 0.11$. Normally this would be an almost impossible magnitude drop to detect visually on a video monitor even after multiple playbacks, but with LiMovie and Excel's trendline option the occultation may be seen in the lower data points by a drop in brightness as indicated in Figure 8.14. The occultation starts near frame 911 and terminates near frame 1331. As a check on the validity of the occultation, an $m = 8.8$ field star (upper data points) showed no drop in brightness before, during, or after the event. If there were some fluctuation in the atmosphere in the field of view of the target star, then all of the stars in the field would likely showed some drop in brightness at the time of the event.

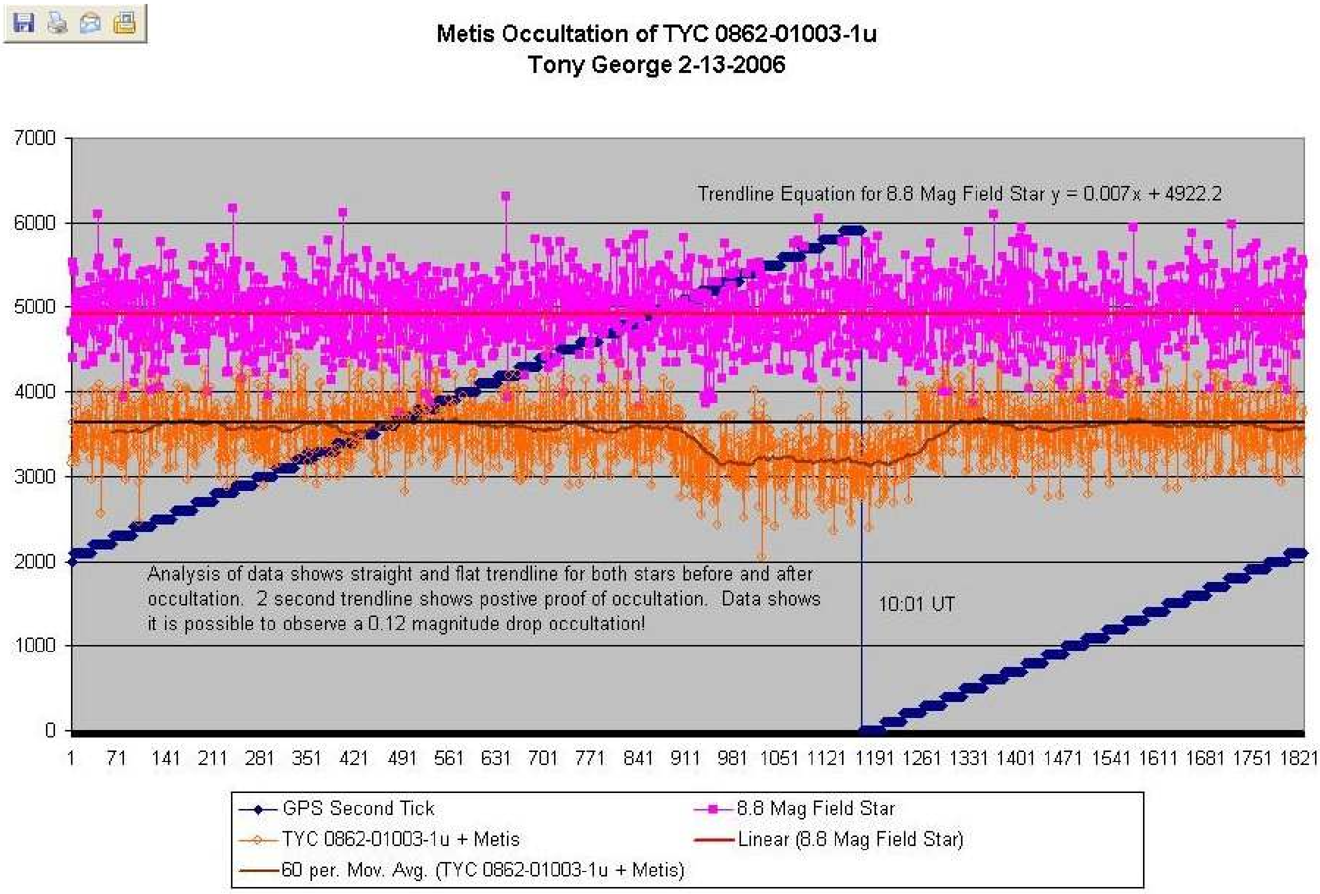


Figure 8.14. Photometric chart of brightness data vs. time for the occultation of the star TYC 862:1003 by asteroid 9 Metis on February 13, 2006. LiMovie data was used in Microsoft's Excel to produce this chart covering 60 seconds of video data. Chart courtesy Tony George.

Further analysis of the occultation by 9 Metis on February 13, 2006 shows that a moving average of the data points produces a sharper view of the event. See Figure 8.14a. In this chart a 10 video frame moving average shows the occultation clearly. In Figure 8.14a the top data line is a reference star, the center data line is the star occulted by 9 Metis, and the lower data line is the background sky. At the time the target star is occulted by the asteroid (frames 1600 – 1900), the reference stars light remains constant. This demonstrates the importance of Limovie in analyzing marginal occultation events which would otherwise be written off as misses.

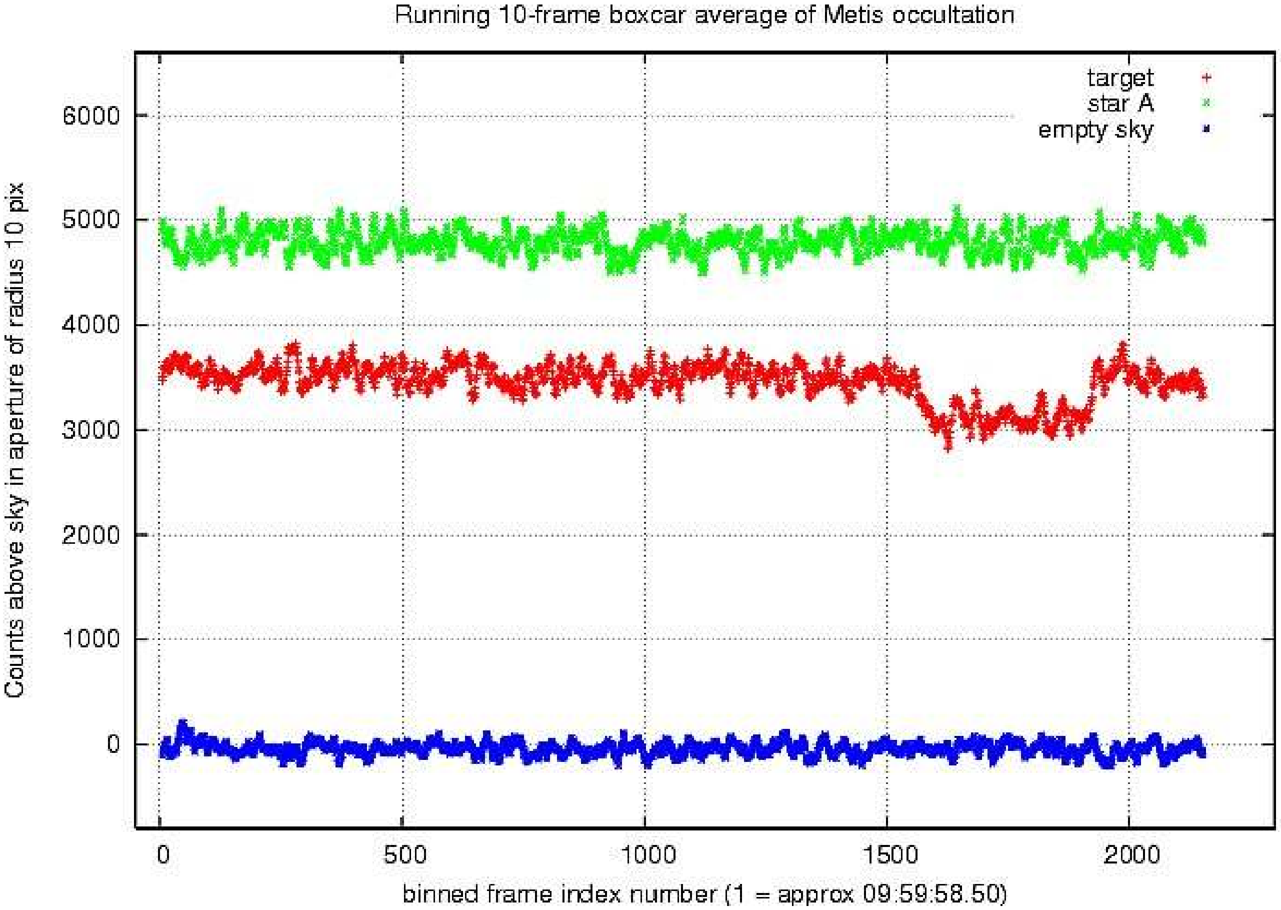


Figure 8.14a. Refined analysis of the data of the February 13, 2006 occultation by 9 Metis. A 10 frame moving average of the raw video data makes a less noisy view of the occultation. The target star is the center data line. The light of the reference star (upper data line) remained fairly constant while the target star's light was dimmed by 9 Metis between frames 1600 and 1900. The bottom data line shows the brightness of the background sky scaled to zero. Chart courtesy Michael Richmond.

LiMovie is a freeware program and download information is given in Appendix K, *Useful Web Addresses*.

8.14 International Time and Time Standards

Many fields of astronomy and astrodynamics require a time scale which is uniform, consistent and easy to acquire and record in an investigation. In the past, as advances in measuring time have been made, variations have been detected in the time scale in use. This leads to newer, precise time scales. The custom has been to avoid discontinuities in time scales by defining each new scale in terms of those in use previously. Modern time scales are defined by international agreement among members of the International Council of Scientific Unions (ICSU) and by other international organizations such as the International Astronomical Union (IAU). A brief overview of the time scales used is astronomy is presented here.

8.15 Time Scale Definitions

The time scales in use are based on the diurnal motion of the Earth (universal time, solar time, civil time), the period of rotation of the Earth as compared with the stars (sidereal time), the orbital motions of the major solar system bodies (ephemeris time, dynamical time) and the oscillation of the cesium atom (atomic time). The following is a short description of each:

Barycentric Dynamical Time (TBD)	Independent variable in equations of motion referred to the solar system barycenter; coordinate time
Terrestrial Dynamical Time (TDT)	Independent variable in equations of motion referred to Earth center; proper time referred to the Earth
Ephemeris Time (ET)	Independent variable in equations of motion; original definition now replaced with one for TDT in most usages
International Atomic Time (TAI)	Time provided by atomic standard; an International System (SI) atomic second is 9,192,631,770 oscillations of the cesium nuclide 133Cs
Universal Time (UT)	Measure of time based on the diurnal (rotational) motion of the Earth
UT0	UT observed from observations of stellar transits
UT1	UT0 corrected for polar motion, used for precise instantaneous orientation of the Earth in inertial space
UT	Coordinated UT, the basis for civil time; seconds of UT is the same as a second of TAI, but UT is kept within 0.9 sec of UT1 With adjustments of 1sec increments
Greenwich Mean Time (GMT)	Now usually means UT, sometimes UT1
Mean Solar Time	Time determined by the motion of the fictitious mean Sun, a way of defining a uniform time based on the Earth's rotation
Sidereal Time (ST)	Time defined by the Earth's rotation relative to a fixed point in space
Local Sidereal Time (LST)	The hour angle of the vernal equinox at the observing location
Greenwich Mean Sidereal Time (GMST)	The right ascension of the mean Sun minus 12 hours plus UT1
Julian Date (JD)	The number of days and fraction of a day since UT noon January 1, 4713 BC

Delta T (ΔT)	The difference between ET and UT; ΔT = ET – UT; (ΔT) a measure of the slowing of the Earth's rotation as compared with a uniform time scale.

8.16 Coordinated Universal Time

For thousands of years, people have measured time based on the position of the Sun. It is noon when the Sun is highest in the sky. Sundials were the main source of time information into the Middle Ages. Then, mechanical clocks began to appear. Cities had town clocks, which would be set by measuring the position of the Sun. Every city was on a slightly different time.

Great Britain became the first country to set a standard time throughout a region when it established the Greenwich Mean Time standard in the 1840s since railways cared most about the inconsistencies of local time.

Since Great Britain was the major world power at the time, it placed the center of the first time zone at England's Royal Greenwich Observatory, which was located on the 0-degree longitude meridian. That line was determined by the Astronomer Royal using a transit telescope. The international date line was set at the 180-degree longitude meridian in the Pacific. As time pieces became more accurate and communication became global, there needed to be a point from which all other world times were based. As a result, when the concept of time zones was introduced, the starting point for calculating the different time zones was the Royal Greenwich Observatory. When it is noon at the observatory, it is five hours behind (under Standard Time) in Washington, D.C.; six hours in Chicago; seven hours in Denver; and eight hours in Los Angeles.

Time zones in the U.S. weren't considered necessary until trains crisscrossed the country in the 1800's. Before that, cities relied on their own local "Sun time." Of course, there were a lot of problems associated with tracking hundreds of local times and publishing timetables. These problems were overcome partially by the establishment of some 100 different, but consistent, railroad time zones.

The United States government fixed the problem by dividing the country into four time zones. Congress made this law in 1918. At noon on November 18, 1883, the master clock at the United States Naval Observatory (USNO) transmitted the time by telegraph lines to major cities, each of which adjusted their clocks to their time zone's correct time. The railroads then began using the standard time zones or their schedules.

The International Meridian Conference met in Washington, D.C. on November 1, 1884, with delegates from 25 countries. It established time zones with a one hour difference between adjacent time zones. The zones referenced mean solar time to the 24 standard meridians, based 15 degrees east and west of Greenwich, the point from which reckoning for each day should begin.

The rotation of the Earth is not uniform and this has been known since the 1800’s. Approximately once a year starting in 1972, a leap second is introduced into UT, the world's atomic time scale for civil time, in order to keep it in phase with the rotation of the Earth. Leap seconds ensure that, on average, the Sun continues to be overhead on the Greenwich meridian at noon to within about 1 sec. When the atomic definition of the International System of Units (SI) second was introduced in 1967, it was effectively made equivalent to an astronomical second based on a mean solar day of 86,400 sec in about 1820. However, over approximately the past 1,000 years, the Earth's rotation has been slowing at an average rate of 1.4 ms per day per century. Now the solar day is now about 2.5 ms longer than it was in 1820. A difference of 2.5 ms per day amounts to about 1 second/year and this is the reason for the more or less regular insertion of leap seconds. Superimposed on this very slowly increasing difference are shorter term variations in the length of the day. Periods between leap seconds are not, therefore, constant and, in fact, over the past thirty years there have been several years in which leap seconds have been omitted.

When did UT start? Several time scales existed until 1972. Each was offset from the others and constructed for special purposes, such as navigation and satellite tracking. The proliferation of time scales posed a problem because Earth's rotation affected UT. It didn't affect atomic time, so UT was developed as a compromise time scale effective January 1, 1972.

The first leap second occurred on June 30, 1972. Since then leap seconds have occurred on average once every 18 months, always on June 30 or December 31. As of 2008 there have been 24 leap seconds in total (the last one was December 31, 2008), all positive, putting UT 33 seconds behind TAI. It seems unlikely that a negative leap second will ever occur, but there is a small chance of one due to the acceleration of the Earth's crust in the 2000’s. This acceleration has already led to the longest ever period without a leap second, from 1999 to 2005.

8.17 Radio Propagation Delay

To obtain accurate occultation timings, propagation delay of the time signal must be taken into account over long distances. To do this, first calculate the great circle distance from the time signal radio station to the observing site in kilometers and divide by 299,792 km/sec. The result is the propagation time delay of the signal in milliseconds.

For example, the great circle distance from WWVH in Hawaii to Sawdust, FL is 7,412 km. The resulting propagation delay is 24.7 ms (0.0247 sec) which is subtracted to the reduced video times. The equation for the great circle distance *D*, in kilometers:

$$D = 111 \cos^{-1} \left[\sin\varphi_1 \sin \varphi_2 + \cos \varphi_1 \cos \varphi_2 \cos \mathrm{abs}(\lambda_1 - \lambda_2) \right] \qquad \text{6-2}$$

where:

$\varphi_1 \lambda_1$, – latitude and longitude of observing station, in degrees,
$\varphi_2 \lambda_2$ – latitude and longitude of radio station, in degrees.

The arc cosine in the formula ($\cos^{-1}$) is the great circle angular distance between the two stations in degrees. It is converted to km by multiplying it by 111. This assumes a spherical Earth but for this calculation the Earth's oblateness is negligible. The geographical coordinates of frequently used time stations are given in the following table.

STATION	**LONGITUDE**	**LATITUDE**
CHU (Canada)	75° 45′ W	+45° 18′ N
DCF77 (Germany)	9° 00' E	+50° 01' N
JJY (Japan)	140° 51' E	+37° 22' N
LOL, Buenos Aires, Argentina	58° 21' W	–34° 37'
MSF, Anthorn, United Kingdom	3° 15' W	+54° 55' N
RWM, Moscow, Russia	38° 18' E	+55° 48' N
WWVH, Kekaha, Hawaii	159° 46' W	+21° 59' N
WWV, Ft. Collins, Colorado	105° 02' W	+40° 41' N
YVTO, Caracas, Venezuela	66° 56' W	+10° 30' N

Table 8.1 Geographical coordinates of time stations. See Appendix J for more information on these stations transmitting format.

8.18 Time Delay of Sound

If your field clock uses an acoustic coupled (microphone) device to trigger from the time signal minute tone then the distance from the time signal speaker to the microphone must be known. Sound travels about 33.5 cm/millisecond.

Radio signal propagation and sound delay corrections are not necessary for visual timings during grazes. The reason is the current errors in Watts lunar limb data are significantly larger than propagation time errors. However for video and photoelectric timings the time signal used and whether or not propagation delay was applied should be reported for possible future use.

8.19 Short Wave Radio Signal Reception Quality

The short wave radio equipment used by most observers to receive time signals is not particularly sophisticated or sensitive and it is not uncommon for observers to report that just before their events they were no longer able to hear the radio signals and obtained no data. There are a few things that can be done to improve the reception and to provide alternate timing methods that can carry the observer through the few critical moments when time signals might be lost.

According to the National Institute of Standards (NIST), WWV signal coverage decreases significantly during the daytime and is maximized at night. This is largely due to the Sun and if effect on the Earth’s upper atmosphere. A WWV coverage map is shown in Figure 8.15.

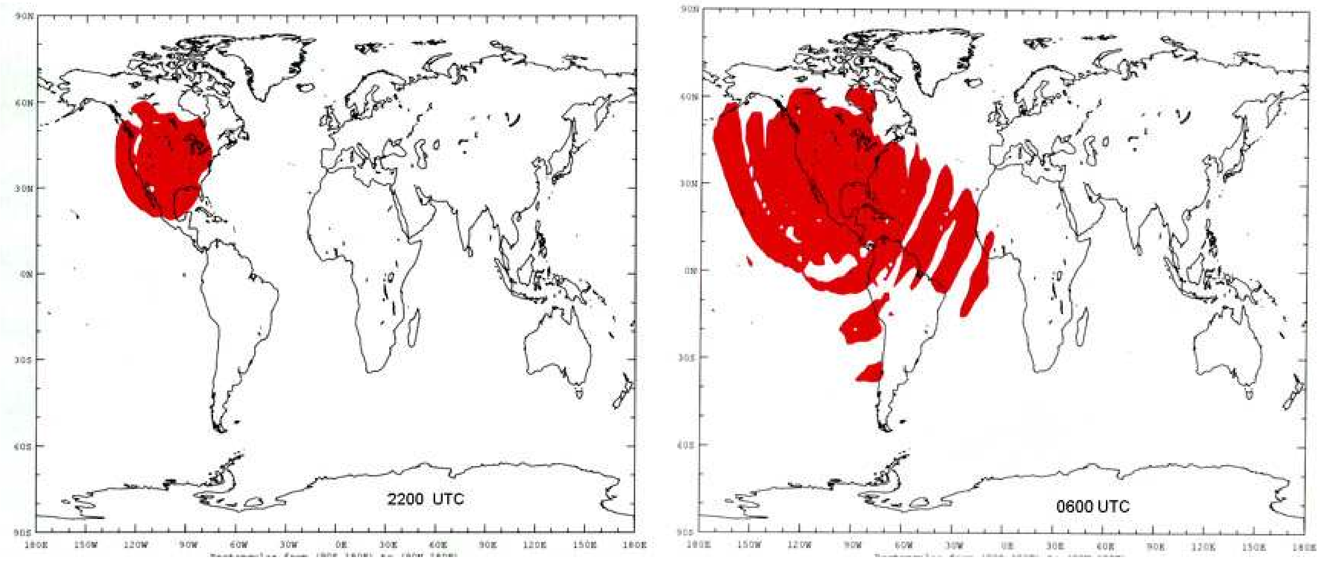


Figure 8.15. WWV coverage. The left map shows signal coverage at 22h UT, when the Sun is above the horizon over much of the United States. With the Sun well below the horizon, the map on the right shows the increased coverage (and hence signal strength) at 6h UT, near local midnight for much of the Unites States. WWV transmitters are located in Ft. Collins, Colorado. Coverage maps from NIST website.

Use fresh batteries for the radio. In very cold weather batteries will lose power as they cool. Keeping them in a pocket or the radio in a warm location until just before observing will help. (Remember to install them just prior to observing.) In humid climates the radio should be kept dry to avoid moisture formation from dew.

Reception can be improved by providing an auxiliary antenna using 20 meters (60 feet) of copper wire and strung above the ground from the radio antenna. Do not run this wire across a road with passing cars! One method to do this is to use a fishing reel to hold the wire. The antenna can then be reeled in following observing and can be stored compactly and conveniently in an observing equipment box.

There are some observing circumstances where reception is going to be more difficult. Signals are often much fainter during the day at which time reception is generally better at the higher transmitting frequencies (15 MHz for WWV). During solar eclipses, the Earth's ionosphere is disturbed and radio reception suffers. Under those circumstances observers must provide for a backup timing standard. This can be a serious problem in a foreign country. This is where GPS time insertion has the advantage.

8.20 Timings Without Shortwave Time Signals

The use of a digital clock or watch with alarm calibrated by recording its alarm with time signals a few hours before and after an event may be used for timings in the field or at home if you don't have a shortwave receiver in the field. But you must have a SW receiver to do the initial calibration. The watch alarm should also be set to sound at the beginning of the recorded observing period. If events were recorded, maintain the tape recorder activated after the event and reset the watch alarm to go off again. The recorder's rate can then be determined by using these two reference marks. At the beginning it is also useful to set the alarm to go off near the middle of the observing period. With three reference marks it is possible to test for any significant variations of the recorder's rate during the observing period.

References for Chapter 8

Dunham, D., Dunham, J., Warren, Jr., W., *IOTA Observer's Manual*, draft version, July 1994.

McAfee,,D., *McAfee Time Inserter*, www.McAfeeAstrometrics.com, 2004.

Miyashita, K., *LiMovie*, http://www005.upp.so-net.ne.jp:80/k_miyash/occ02/limovie_en.html , 2006.

National Institute of Standards and Technology Time & Frequency Division: http://tf.nist.gov. 2007

9 Cold Weather Observing

9.1 Personal Safety

One of the obstacles the occultation observer must deal with is the weather. At mid to high-latitudes, more occultation opportunities present themselves during the winter months simply because of the increased hours of darkness. Therefore the observer must be prepared to endure cold weather for long periods. The single most important issue regarding cold weather is that given the opportunity cold can kill. Mother Nature does not tolerate the unprepared lightly. Shivering is one of the first signs of the onset of hypothermia – depression of the core body temperature. If you begin shivering, abandon the project immediately and seek warmth. Don't kid yourself into thinking, “I only need a few more minutes to get the data”. No data are worth risking your personal safety.

It is extremely important never to work alone outdoors in sub-freezing conditions, especially at night in remote areas. The buddy system is essential for safety, not only so one can get help if another needs it, but also to monitor each other for signs of hypothermia and **frostbite**.

Cold is the enemy and wind and moisture are its agents. The way to defeat them is to dress appropriately. That means dressing for the predicted temperature and taking into account the effects of wind and low personal activity. Consult the accompanying Wind Chill Factor Charts in Table 9.1 to determine the real temperature to which you will be exposed, then dress for 5-10 degrees colder to allow for the sedentary nature of occultation work.

Wind Chill Calculation Chart,
where T air = Air temperature in °C and V_{10} = Observed wind speed at 10m elevation, in km/h.

T air	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45	-50
V_{10}												
5	4	-2	-7	-13	-19	-24	-30	-36	-41	-47	-53	-58
10	3	-3	-9	-15	-21	-27	-33	-39	-45	-51	-57	**-63**
15	2	-4	-11	-17	-23	-29	-35	-41	-48	-54	**-60**	**-66**
20	1	-5	-12	-18	-24	-31	-37	-43	-49	-56	**-62**	**-68**
25	1	-6	-12	-19	-25	-32	-38	-45	-51	-57	**-64**	**-70**
30	0	-7	-13	-20	-26	-33	-39	-46	-52	-59	**-65**	**-72**
35	0	-7	-14	-20	-27	-33	-40	-47	-53	**-60**	**-66**	**-73**
40	-1	-7	-14	-21	-27	-34	-41	-48	-54	**-61**	**-68**	**-74**
45	-1	-8	-15	-21	-28	-35	-42	-48	-55	**-62**	**-69**	**-75**
50	-1	-8	-15	-22	-29	-35	-42	-49	-56	**-63**	**-70**	**-76**
55	-2	-9	-15	-22	-29	-36	-43	-50	-57	**-63**	**-70**	**-77**
60	-2	-9	-16	-23	-30	-37	-43	-50	-57	**-64**	**-71**	**-78**
65	-2	-9	-16	-23	-30	-37	-44	-51	-58	**-65**	**-72**	**-79**
70	-2	-9	-16	-23	-30	-37	-44	-51	-59	**-66**	**-73**	**-80**
75	-3	-10	-17	-24	-31	-38	-45	-52	-59	**-66**	**-73**	**-80**

80	-3	-10	-17	-24	-31	-38	-45	-52	**-60**	**-67**	**-74**	**-81**

Approximate Thresholds:

Risk of frostbite in prolonged exposure: wind chill below	**-25**	
Frostbite possible in 10 minutes at	**-35**	Warm skin, suddenly exposed. Shorter time if skin is cool at the start.
Frostbite possible in less than 2 minutes at	**-60**	Warm skin, suddenly exposed. Shorter time if skin is cool at the start.

Table 9.1 Wind chill chart.

The **wind chill factor** is designed to calculate the actual mitigating effect that wind has on exposed skin at low temperatures. The greater the wind speed the more heat is lost per unit time.

Inactivity must also be considered. When remaining still for long periods of time, such as at the telescope you are generating much less heat than when conducting more active pursuits. The temperature ratings published by clothing suppliers presuppose fairly high activity levels and typically their products are designed for the construction industry or active recreation, such as hiking. Winter boots rated for -40°C will not keep your inactive feet warm for long even at -10°C.

Here is a suggested clothing list suitable for a quiescent observer working at -18°C (0°F) in a 15 km/h (9mph) wind for 2 hours:

1. Polypropylene (preferred) or wool 2-piece long underwear
2. Two (2) pairs of polypropylene ("polypro"), wool or wool-blend socks
3. Wool or synthetic trousers
4. Wool or synthetic shirt
5. Wool sweater, sweatshirt or synthetic "fleece"
6. Bib-type or "Farmer John" snowmobile overalls
7. Hooded winter parka
8. Snowmobile-type boots rated for -60C or colder
9. Light polypro or wool gloves
10. Sheepskin mittens (or similar)
11. Balaclava (preferred) or wool toque

Note the complete absence of cotton in the above list. Moisture is cold's agent and we sweat even at freezing temperatures. Wool, polypropylene, polyester, and even silk will wick moisture away from the skin. When cotton gets wet, it stays wet and keeps the moisture pressed to your skin, causing rapid cooling.

For less extreme conditions, the snowmobile overalls and sheepskin mitts may not be necessary but if you have them take them along. Long underwear is essential even when it is a bit above freezing. In any case, pay special attention to your extremities: hands, feet and especially your head. Fingers, toes and ears feel the cold first, but most of your body heat is lost from the top of your head. A toque or full balaclava is highly recommended along with a hood, either attached to a parka or a sweatshirt (not cotton) worn beneath a heavy jacket or coat.

Here are a few tips to keep the cold at bay. Take along a mat or old carpet remnant and place it under your feet while observing, whether standing or sitting. Wear light gloves inside larger mittens. Slip a mitten off when you need fine finger control to adjust something at the telescope, then put it back on immediately. Choose a coat or jacket with large pockets that you can place your bare hands into when gloves and mittens are not required.

After your equipment is set up, checked and ready, go for a brisk walk to elevate your heart rate and warm your extremities. Do this even if you are perfectly comfortable at the time. Take along a thermos of hot beverage and have a few sips before you begin observing. Decaf coffee, herbal tea, hot chocolate, or soup is recommended.

Avoid caffeine. It’s a diuretic and it adversely affects your resistance to cold. The same applies to alcohol. For this and other obvious reasons, save your hot rum to toast your success (or soothe your sorrow) only when you have returned safely home and not before. If you drive to your observing site, do not wear all your winter clothing in your vehicle. Wear ordinary boots or shoes over one pair of socks and shed the parka and overalls until you arrive on site. Then put on the extra socks, the big boots, overalls and parka before setting up your equipment. This will keep you comfortable en route and more importantly keep you from overheating and sweating. Remember, moisture is cold's agent. Do not allow bare skin to come in contact with any metal object when the temperature is below freezing. If you do so, you will find that you are instantly stuck to the object. Do not try to pull free, or you will leave skin behind. Instead, warm the object in close vicinity to your affected body part until it is released.

When in the field, personal cold weather safety goes beyond your apparel. Especially in a remote or infrequently used area you must give careful thought to your transportation. Before setting out make sure your vehicle is in good working order with properly inflated tires and a full tank of fuel. Keeping a winter safety kit in your vehicle is always a good idea, so check that it is complete and operational. It should include basic tools, jumper cables, a tow rope, a snow shovel, safety flares, a first aid kit, candles, waterproof matches and a traction aid such as a bag of sand or “kitty litter”. Remember to check your spare tire.

The Buddy System applies to vehicles as well as people. Rather than piling a number of observers and their gear into one vehicle, spread them over two or more. If one vehicle gets stuck or breaks down, there is another at hand to help. On site, consider keeping your engine running, especially in extremely cold weather. Check that the tailpipe is not blocked by snow or other obstructions which may cause the passenger area to fill with lethal exhaust gases.

Open a window slightly just in case. You should also keep the running vehicle away from the direction the telescope is pointed so as not to cause air turbulence in the direction of the target star.

For safety, carry a cellular telephone (including a spare fully charged battery) or two-way radio if you expect to be out of cell phone range. Always tell someone at home where you are going, the route you plan to take and when you expect to return. Additional safety considerations can be found in Chapter 6, Section 6.10).

9.2 Equipment in the Cold

In general telescope optics should not be adversely affected by extreme cold once they reach ambient temperature. However, moving parts and electronics are. For moving parts such as focusers, gear trains and axle shafts (both RA and DEC), the major problem is the lubricant supplied by the manufacturers of commercial telescopes and mounts. Only Russian manufacturers such as Intes pay any attention to designing their equipment to operate in the cold.

If you use your telescope at temperatures near or below freezing, it's a good idea to replace the stock lubricant with a grease designed to perform well at sub-freezing temperatures. The lubricant of choice is Dow Corning's *Molykote® 33 Extreme Low Temp. Bearing Grease, Light.* It's a phenyl/methyl silicone grease with a lithium thickener that is rated for use from -73ºC to +208ºC (-100ºF to +400ºF). It is sold in small 180gram tubes, 400gram cartridges and larger pails and drums. For more information, visit:

http://www.dowcorning.com/applications/Product_Finder.

For proper instructions on how to dismantle, clean, re-lubricate and reassemble your mount, focuser, etc., consult your owner's manual, or refer to either the manufacturer's service department or a reputable user's group on the Internet such as the following:

http://groups.yahoo.com/group/telescopes/ (Talking Telescopes) - founded in 1999 by Phil Harrington, an online extension of his book Star Ware.

http://groups.yahoo.com/group/skyquest-telescopes/ - despite its name, covers all Chinese and Taiwanese Dobsonians.

http://groups.yahoo.com/group/sct-user/ - covers all catadioptrics, run by Rod Mollise.

http://www.astronomyboy.com/cg5/index.html A fine site for brand-specific instructions is Jeff DeTray's detailed instructions for dismantling and refurbishing the ubiquitous Chinese CG-5/EQ-4/EQ-5 telescope.

http://www.mapug.com. Lot of Meade-specific information in organized form.

Electronic devices and LCD displays do not operate well in extremely cold conditions. One way to keep them warm is to strap chemical type hand-warmers to them. *Kendrick*-type heaters also work well but are heavy users of DC power. (See 9.3 Batteries) Tuck portable tape recorders or digital voice recorders into an inner pocket out of the cold and clip an external microphone to the outside of your parka where it can pick up your voice and the radio time signal.

Experience has shown that small portable radios, like the *Grundig* YB300PE and other similar units are virtually cold proof if the batteries are fresh. It is best to keep them warm as long as possible before the occultation. A digital tuning radio which allows the press of a memory button to recapture radio station WWV or CHU is recommended in lieu of a manual tuning radio.

Perhaps the most important piece of advice for cold weather observing: Allow Extra Time. Everything takes longer in the cold. There is extra gear to prepare and load. You need time to get into cold weather clothing on site. Equipment set up is slower and requires more rigorous testing. Things will go wrong much more frequently requiring extra time to rectify.

9.3 Batteries

Whenever possible, electrical power should be drawn from an AC source (110v in North America, or 220v elsewhere). However this is rarely possible in remote areas often frequented by occultation observers. Usually 12v DC power is required to drive our telescopes, cameras, radios, tape recorders and TV/VCR combo units. Most of these devices are extremely efficient these days, requiring less than 1 amp to operate. Battery packs supplied by the manufacturer, or an upgrade to a portable Power Tank or Port-a-Wattz unit may be sufficient, especially if kept warm.

One exception is TV/VCR combination units that some observers use to view and record video signals which will accept either 110v AC line current or 12v DC battery power. Although rated at 12v, this is a nominal figure since they actually require more than 13v DC. A more substantial battery is required to keep them operating in cold weather. To drive these and other high draw devices, use a sealed AGM deep-cycle lead-acid battery of at least 35AH (Amp-Hour) rating (20-hour rate).

Examining the terminology:

Deep-Cycle: Lead-acid batteries come in two types: automotive and deep-cycle. Automotive batteries are rated by the number of cold cranking amps (CCA) they produce. Built with many thin lead plates, they can fire an enormous electrical shot down the wires to get your car started on a prairie winter morning. However they do not tolerate cycling (draining and recharging) very well at all. If you leave your headlights on overnight once or twice then your Die-Hard will become a Dead-Hard.

Cycling ability and a steady ample flow of electrons is important so steer clear of any battery that mentions cranking amps. Choose deep-cycle batteries instead which contain thicker lead plates and can tolerate a certain amount of repeated draining of their capacity. These batteries are sometimes called **stationary** because they're meant to be used in fixed locations (not in automobiles) or marine batteries because they are meant to be used to power electric trolling motors that fisherman use to quietly stalk their prey. They are rated in Amp Hours (AH), not CCA's.

Sealed AGM: Choose a battery that is sealed and filled with "absorbed glass mat". Sealed AGM batteries are the safest lead-acid batteries available. All lead-acid and gel-cell batteries produce hydrogen gas, H_2. Capped or refillable batteries vent H_2, which can be very dangerous (See Section 9.4 *Keeping Batteries Warm*). Sealed batteries reabsorb the H_2 keeping it safely inside. In addition, the glass matting prevents liquid sulphuric acid from leaking out when tipped or cracked. Being non-vented and spill proof, sealed AGM batteries are the only lead-acid batteries that may be transported by airlines and many other commercial carriers. (Eclipse chasers take note).

Lead-Acid: Gel-cell and lead-acid batteries are similar in construction and performance characteristics, but gel-cells are less robust than lead acid batteries. In particular, they require gentler recharging rates and therefore take longer to bring back to peak charge. Depending on your time requirements this could be important.

Amp Hours: Batteries are rated in terms of the number of amperes they can produce per unit time. In theory, a 50 AH battery provides 50 amps for one hour, or 25 amps for two hours, or five amps for 10 hours. In reality, however, because no battery has perfect efficiency, that same battery may only yield 20 amps over two hours or 3.5 amp for 10 hours.

20-Hour Rate: A battery rated at 50 AH (20-hour rate) is assured by its manufacturer to yield 2.5 amps for 20 hours, but not necessarily 5 amps for 10 hours. Another battery also rated at 50AH, at the 10-hour rate should produce 5 amps for 10 hours but not necessarily 2.5 amps for 20 hours. Assure that you are using the same hour rate when comparing batteries. The 20-hour rate is the norm and other rates are uncommon.

9.4 Keeping Batteries Warm

Battery performance is temperature-dependant. Lead acid batteries (and their cousins, gel-cells) lose considerable capacity as the temperature drops. Manufacturers normally rate their batteries at 25°C (77°F). But batteries typically lose about 1% of their capacity for every 1°C that the temperature drops. In other words, at +10°C (50°F) the battery will have 85% capacity, at 0°C (32°F) it's down to 75% and at -10°C (+14°F) power is reduced to 65%. And so on.

Always store your batteries in a warm place. (See Section 9.5 *Care and Feeding of Batteries*.) In addition to being better for their health, it is much easier to keep batteries at a warm temperature than it is to bring them from freezing to room temperature when required.

Keep your batteries warm while transporting them to the observing site. If you place them in the heated part of your car, such as on the floor in the backseat, be sure that they are secure and will not move in the event of a mishap. When at your observing station it is a good idea to keep them in the warm vehicle as long as possible.

Neat Trick: Put your battery in a non-metallic picnic cooler and drop in a couple of activated chemical-type hand warmers (available at sporting goods stores and outdoor outfitters) and close the lid. Do this while still in the warmth and comfort of your home and then add a fresh warmer every 2-3 hours until your expedition is complete. Find a cooler that is only slightly larger than the battery to increase the warmer's effectiveness. **Warning: Use only the chemical type of hand warmer, NEVER the fuel burning type! Batteries produce hydrogen gas, which is explosive in the presence of flame.** Although sealed AGM batteries should not emit any H_2, take no chances with fuel burning hand warmers.

9.5 Care and Feeding of Batteries

Do not skimp on your batteries. Choose high quality units that are designed for the specific use to which you will put them. It only takes one battery failure to waste your time, effort and money.

Carefully maintained and properly used, a good quality battery will last for many years. Neglected and abused, its lifetime will be short and costly. Keep your batteries fully charged, but do not over-charge them. The best way to do that is to purchase a desulfater-charger, such as the *Optimate 3 Battery Optimizer* (manufactured by TecMate International, S.A., Belgium) or similar product. This is a device that charges the battery and tests for possible deep discharge or sulphation and engages a high voltage low current mode to remove sulphation from the plates. It charges the battery, then maintains a peak charge. It tests for self-discharge and alerts you if the battery is unable to retain its charge. It is designed to remain connected to your battery and plugged into your household outlet whenever the battery is not being used. Look for them at motorcycle or snowmobile stores.

"Deep-cycle" is a relative term. The shallower the cycling, the longer the battery will last. For instance, battery manufacturer Yuasa Inc. states that for their 12v 38 AH (20-hour rate) battery, one should expect a lifetime of 250 cycles at 100% depth of discharge, (DoD). At 30% DoD, it should last for 1200 cycles. Therefore, to maintain battery life, try to keep your cycles as shallow as possible. Remember that 100% DoD does not mean zero volts. A 12v battery is considered to be completely discharged (flat) at 10.7v. Nor is it "fully charged" at 12v. When properly charged up it should reach ~ 14v.

9.6 Lithium Batteries

Portable electronic equipment used for occultation work such as telescope drives, GoTo telescope mounts, radios, lap-tops, etc. are normally powered by Nickel-Cadmium (NiCad), Nickel-Metal-Hydride (NiMH) or Lithium-Ion (Li-Ion) batteries. Li-Ion has quickly become the emerging standard for portable power in consumer devices. Li-Ion batteries produce the same energy as Nickel Metal Hydride (NiMH) batteries, and twice that of Nickel-Cadmiums (NiCads) but weigh approximately 35% less. Perhaps more importantly they do not suffer from the memory effect from recharging of batteries that are not fully discharged. They are also environmentally friendly since they do not contain toxic materials such as Cadmium or Mercury.

Recharging pattern differs for each technology, so replacing Ni-Cads or NiMHs with Li-Ion batteries is not recommended for portable devices unless the manufacturer has configured them accordingly. Refer to your owner's manual to find out which rechargeable battery types the particular device supports.

It is a good idea to replace AA, C and D battery packs that are commonly supplied with telescope drives. For instance, Celestron specifies the minimum input voltage of 8v for their series of baby NexStars. They supply a clip that takes 8 AA batteries. At 1.5v each, that's 12V maximum at 25°C (77°F). Subtract 20% at 0°C (32°F) and you get 9.6v which at sub-freezing temperatures, that won't last long. And forget about rechargeable AA, C or D batteries. At best, they produce only 1.3v each, so a pack of 8 will give you a maximum of 10.4 volts. At 0°C you're down to ~7.8v, the bare minimum specified.

For telescope drives we suggest a deep-cycle unit of at least 15AH to drive these telescopes in cold conditions which is obtainable with Celestron's own Power Tank or most portable auto battery power boosters. This will give you enough power for both the telescope, video camera and radio (if it's 12v and equipped with an external power jack). Whatever you use keep it warm.

For more information about batteries, visit Dynasty Inc. at
http://www.batteryweb.com/dynasty.cfm

or Yuasa, Inc at http://www.yuasastationary.com. The Dynasty site's FAQ section is a good source of battery information, while Yuasa has good cold-weather data.

References for Chapter 9

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10 Unattended Video Stations

Even though occultation observers correspond with each another and correlate their observing plans, the fact remains that many occultation observations are made by lone observers with a single station rather than by teams with multiple stations.

Acquiring data from a second station doubles the usefulness of some types of observations. These types include the search for asteroidal moons in an asteroidal occultation or appulse, and the refinement of the orbit of an asteroid of which the orbit is known with low precision, by approximately doubling the chance that an occultation will be detected. An observer's contribution is also doubled by his addition of a second chord when measuring the shape of the lunar limb by either grazing or total occultations, and in those few asteroidal occultations that are well observed by a number of stations.

However, the addition of a second station's data may more than double the usefulness of certain types of observations. These are: (1) lunar grazing occultations involving double stars whose duplicity is detectable only by occultations, since data from two stations may enable the complete computation of the position angle of the companion star; and (2) asteroidal occultations in which only one or no other chords are observed, so that the addition of the extra chord greatly enhances the determination of the asteroid's shape.

In general, it is necessary to leave one of the two stations unattended during the occultation. Unattended stations are video stations and the observer must be sure that the sensitivity of the video system is sufficient to record the target star. Information on videocamera sensitivity, with diagrams of focal length reduction equipment, is in Section 10.6 *Videocamera Sensitivity*.

Experienced observers are encouraged to try second, unattended stations for both lunar grazes and asteroidal occultations. In the case of grazes, it will double the work involved in making the observation while for asteroidal events, it will quadruple it. In the case of asteroidal occultations, the addition of a second station will turn a midnight excursion into a major expedition, while the addition of a third station will ensure that the astronomer gets no sleep at all. A good way for an observer to get started with the use of unattended stations is to leave one in his own backyard the next time he travels to a nearby path of an asteroidal occultation. With practice, the observer will soon feel comfortable in setting up such an unattended station at a hidden spot far from his home.

10.1 Planning the Expedition

For a lunar grazing occultation the two stations are likely to be relatively close, perhaps a kilometer apart but perhaps as close as 50 or 100 meters. While awaiting the occultation, an observer can go back and forth between the two stations to tend to details of the pointing of the telescope or the function of the equipment. In contrast, for an asteroidal occultation a separation of 50 kilometers is typical. There is no time to drive back to the unattended station so the telescope and other equipment must work perfectly as originally set up.

10.1.1 Techniques of Pointing the Telescope

There are two ways to make an unattended telescope point at a target star at the moment of an occultation. One way is to set up a motorized telescope and video equipment, find the target star, and allow the telescope's motor drive to follow the star across the sky while the observer runs down the road to the next station. The other way is to find a fixed point in the sky in the exact direction at which the target star will be located at the moment of the occultation, point a telescope at it *undriven*, and leave it there so that the star will drift through the field of view at the time of the event. The former technique will be referred to as the tracking method and the latter as the drift-through method.

10.1.2 The Tracking Method

The tracking method requires that the polar alignment of an equatorial mounting at a remote location be highly accurate. Typically a rapid polar alignment in the field will not suffice to allow a lengthy recording since the star will likely drift out of the field of view. The new alt-azimuth computerized mountings are no more accurate. This problem is multiplied especially with the relatively small fields of view with typical video cameras (15 – 25 arc minutes).

The hallmark of inaccurate polar alignment of an equatorial mounting, whether the polar axis is displaced in altitude, azimuth, or both, is drift in declination (DEC) with little drift in right ascension (RA). If this seems counterintuitive, the reader is encouraged to prove it to himself.

As the drift in DEC (caused by the inaccurate polar alignment) carries the image of the star across the video field of view, the observer can measure the time required for the star to drift across a certain fraction of the field and can then compute how far to displace the telescope in DEC so that the star's image will be in the field of view at the moment of the occultation. For example, on a graze expedition the observer might find that DEC drift carries the star across about a ¼ of the video field of view in four minutes. Therefore, he expects it to drift across half of a field of view in eight minutes. Plan to leave this station about eight minutes before central graze, and adjust the telescope's pointing so that the star is exactly on the edge of the field of view. The observer then leaves the telescope and goes to tend to the other station. The telescope so pointed allows the star to drift halfway across the field so that it is centrally located during the few minutes around central graze.

It is difficult to judge exactly how far to displace the telescope in DEC if the displacement needed is larger than about half of a field of view. For example, in one instance, an observer failed to get data on an asteroidal occultation by making a mistake in the magnitude of this tracking displacement when the needed displacement was two fields of view. To maintain the required displacement as small as half a field of view it is necessary to minimize the time between the final pointing of the telescope and the occultation event. Since this time interval is used for travel between the first and second stations, the tracking technique may not be useful when there is a wide separation between the two stations. This works well for grazing occultations, in which the observer can travel between the two stations in a couple of minutes. However, during an asteroidal occultation when an observer will leave the telescope unattended for one to four hours, the drift-through technique is preferred.

The observer can minimize the time between final pointing of the unattended telescope and the event by using the following sequence of actions:

1. Set up the station that is to be attended during the occultation, start the video equipment, find the target star, and initiate tracking.

2. Travel to the second, unattended station's site, and set up that station completely.

3. Time the DEC drift at the second station and use it to make a final pointing of the telescope as described above.

4. Return to the first station and adjust the pointing of the telescope, and tend to it during the occultation. This sequence eliminates set up of equipment between the times of final pointing of the unattended telescope and the occultation.

When using the tracking technique for grazes, the observer should track the star, not the Moon, because the moon's direction and rate of motion are variable and are not adequately accommodated by the so called lunar rate of tracking which certain commercially available telescopes have.

10.1.3 The Drift-through Method

This method involves a considerable amount of planning. In advance of the event, the observer must select a target area of the sky at which the unattended telescope is to be pointed. This sky target will be at the same DEC as the star that is to be occulted, but offset from the occultation star westward in RA. After pointing the non-driven telescopic video system at this fixed point in the sky, the observer will leave the telescope unattended, travel to the next station, set up the equipment there, and find the star that is to be occulted. The amount of time needed to do this determines the amount of the first station's sky target's offset in RA.

One must allow extra time to accommodate unforeseeable mishaps. The plan for travel and equipment set-up is subject to delays caused by such phenomena as road construction, car problems, getting lost, possible heavy traffic and any damage to equipment requiring improvising a repair. Accordingly, it is wise to select multiple candidate sky targets for the unattended telescope. These sky targets are chosen according to the following reasoning:

Figure 10.1 Remote video station. Equipment consists of a video camera attached to a stationary tripod, a shortwave radio, power source, and a camcorder to record the event. Courtesy David Dunham.

1. Before you leave the unattended station, you will need to point the telescope/video setup at the exact altitude/azimuth in the sky where the occultation star will be at the time of the event.

2. If it’s 2 hours until the occultation after setting up the unattended station, point the system to a target that is 2 hours in RA west of the target star.

3. If it’s 1½ hours until the occultation after setting up the unattended station, you’ll need to point the system to a target that is 1½ hours in RA west of the target star.

As stated above, the goal is to point the unattended system at a target whose RA offset closely matches the amount of time you’ll need to travel to the station you’ll personally be at.

The westernmost sky target is used if no mishaps delay arrival and set up at the unattended site. This will provide enough time to work around any issues that may occur in traveling to the second site or setting up its equipment. Any problem that causes a delay in acquiring the first site’s sky target will require the use one of the later sky targets. The easternmost sky target is for the latest time the observer can leave the first site and still arrive at the second site on time. The observer will not know which of the candidate sky targets is best to use until actually into the process of finding it, and at this time he will know how long it is until the occultation.

In planning the expedition there are two ways to choose a group of candidate sky targets. One way is to find the critical points in the sky for specific times at which the telescope may be pointed at those spots, using the time as the main criterion for selection. For example, if an asteroidal occultation is to occur at 22 seconds after 12:48 AM local time, and the observer expects that he can travel to the second station and set up his equipment there in less than two hours, he may wish to find the point in the sky at which he should point the first telescope at exactly 11:00 PM To accommodate unforeseeable deviations from this expedition plan, one may also select sky targets for exactly 10:30, 10:40, and 10:50 PM. This method has the advantage of using prominent times that are easily planned, but it has the disadvantage that most of the sky targets are video fields of view that contain only faint stars, typically 11th magnitude and fainter. These fields are hard to find by star hopping, and hard to verify even for observers with computerized telescopes. On two occasions, one observer failed to obtain data at a planned, unattended station because of difficulty in finding such faint sky targets.

It is better to select candidate sky targets by the brightness of the stars that they contain. Using a computerized star chart, the observer searches across the desired range of RA for prominent stars that have the same DEC as the occultation star. A number of stars can usually be found that are brighter than the 9th magnitude, and often some as bright as 6th magnitude, simplifying the telescope pointing process.

In choosing candidate sky targets for use in the RA offset pointing, the observer will need star chart software that places an outline of a CCD chip's size on the chart. The software should also have a drawing function so that the observer can add lines and text to the star map. The star chart programs *Guide* and *Megastar*, among others, have these functions. The observer should set the dimensions of the video chip outline so that they match the field of view of the video system of the unattended telescope. The procedure to identify offset sky targets is as follows (Note: here we mean CCD chip = video chip):

1. Zoom in on the star map so that the CCD chip outline is large enough to be traced accurately by using the drawing function (See Figure 10.2).

2. Begin the search at the point in the sky that is at the same DEC as the star that is to be occulted but located *westward* on the sky by a distance in RA that is equal to the minimum travel time that's needed between stations.

3. Examine the sky from that point westward, along the occultation target star's DEC, until coming to a prominent star that is within half a field of view of this DEC. Click on the mouse

so as to center the CCD chip outline on the RA of this prominent star but on the DEC of the occultation star.

4. Trace the outline of the centered CCD chip creating on the star map a rectangular overlay that contains the prominent star and matches the size of the video field of view, and is centered on the DEC of the occultation star.

5. On the night of the occultation, hop to this star, acquire it on the telescopic video screen, and adjust the pointing of the telescope so that the position of the star on the video screen matches the position of the star in the star chart's CCD chip outline.

The time offset between the moment of final pointing of the unattended telescope and the occultation event is similar to, but not precisely the same as, the RA offset between the selected sky target and the occultation star. The observer's wristwatch, the GPS device used and radio time signals all indicate solar time. However, the RA framework of the sky moves by sidereal time, which carries the stars around the earth 366.24 times for every 365.24 revolutions of the sun around the Earth. The difference between the two is 10 seconds per hour, as RA moves faster than the observer's watch. If an observer acquires the sky target at an unattended station three hours before the occultation, and fails to account for the solar-sidereal difference, then the occultation star will cross his video field of view 30 seconds too soon. Since the width of a telescopic video field of view may be only one minute of RA, this mistake can mean the difference between good data and no data. The solar sidereal correction is made by subtracting from the expedition's time offset an adjustment of 10 seconds per hour of RA offset from the occultation star.

To illustrate and clarify this method of planning for the use of the drift-through technique, Table 10.1 is a series of calculations for a set of candidate sky targets. These are the actual candidate sky targets used for a drift-through video observation of the occultation of star TYC 6288-01527-1 by asteroid 1468 Zomba on September 25, 2003. The values are rounded to the nearest second. The calculations are simplified by placing the coordinates of the occultation star and the time of the occultation in the heading of the table, as was done here. For each of the seven candidate sky targets, the left column provides the sky target star's RA. The second column gives the offset in RA between the candidate sky target and the occultation star, found by subtracting the sky target's RA given in the first column from that of the occultation star, given in the heading. The third column gives the solar sidereal correction, amounting to 10 seconds per hour (5 seconds for 30 minutes, etc.) of the RA offset listed in the second column. The fourth column gives the offset in time, derived by subtracting the value in column three from that in column two. The last column gives the time the observer must leave his telescopic video system pointing at this sky target, if this is the one to be used. It is derived by subtracting the time offset given in column four from the time of the event given in the heading.

Occultation star: RA 18h 46m 58s, DEC –20° 27′ 58″, event at 9:35:50 P.M. EDT				
Sky target RA	RA offset	Solar-sidereal	Time offset	Pointing time
18h 00m 00s	00h 46m 58s	8 sec	46m 49s	8:49:01 EDT
17h 51m 56s	00h 55m 02s	9 sec	54m 53s	8:40:56 EDT
17h 48m 52s	00h 58m 06s	10 sec	57m 56s	8:37:54 EDT
17h 21m 51s	01h 25m 07s	14 sec	1h 24m 53s	8:10:57 EDT
17h 11m 22s	01h 35m 36s	16 sec	1h 35m 20s	8:00:30 EDT
17h 04m 45s	01h 42m 13s	17 sec	1h 41m 56s	7:53:54 EDT
16h 53m 25s	01h 53m 33s	19 sec	1h 53m 14s	7:42:36 EDT

Table 10.1. Pointing times for different sky target areas.

Figure 10.2 is a star map created for this occultation using *Guide* software showing only the first three stars of Table 1. It is the close up map that was used in the final phase of star hopping. It was used in conjunction with another close up map showing the other four stars of Table 1, as well as another star map showing a wide view of the sky for use in the first phase of star hopping. Notice the rectangles drawn during the planning for this observation, each delimiting a telescopic video field of view. The three rectangles have exactly the same DEC, centered on the DEC of the occultation star, while the positions that the selected prominent stars have in the fields of view range slightly northward and southward from that DEC. By acquiring one of these stars on video and placing it in the same position in the field of view as in the drawn rectangle, this places the DEC of the occultation star at the center of the field of view. Thus, the star field can be found with a few minutes to spare and tracked until pointing time. At that moment of pointing time, stop tracking. This causes the occultation star to be centered in the video field of view at the moment of occultation.

As an example, in Figure 10.2, consider the center rectangle situated above the EDT (Eastern Daylight Time) of 8:40:56. Point your telescope video system centered on this rectangle. When the EDT reaches 8:40:56, turn your tracking system (motor drives) off. The occultation star should then drift in the field 54m 54s later at the time of occultation, at 9:35:50 EDT.

It is easy to confuse north and south on the video screen because the image may be rotated or reversed. The observer must be certain that the prominent star on the video is displaced from the center of the field of view in the same sky direction in which it is displaced on the star map's rectangle. The easy way to ascertain the sky directions on the telescopic video is to push gently on the telescope and watch the motion of the star. Pushing the skyward end of the telescope northward makes the star drift to the south side of the field.

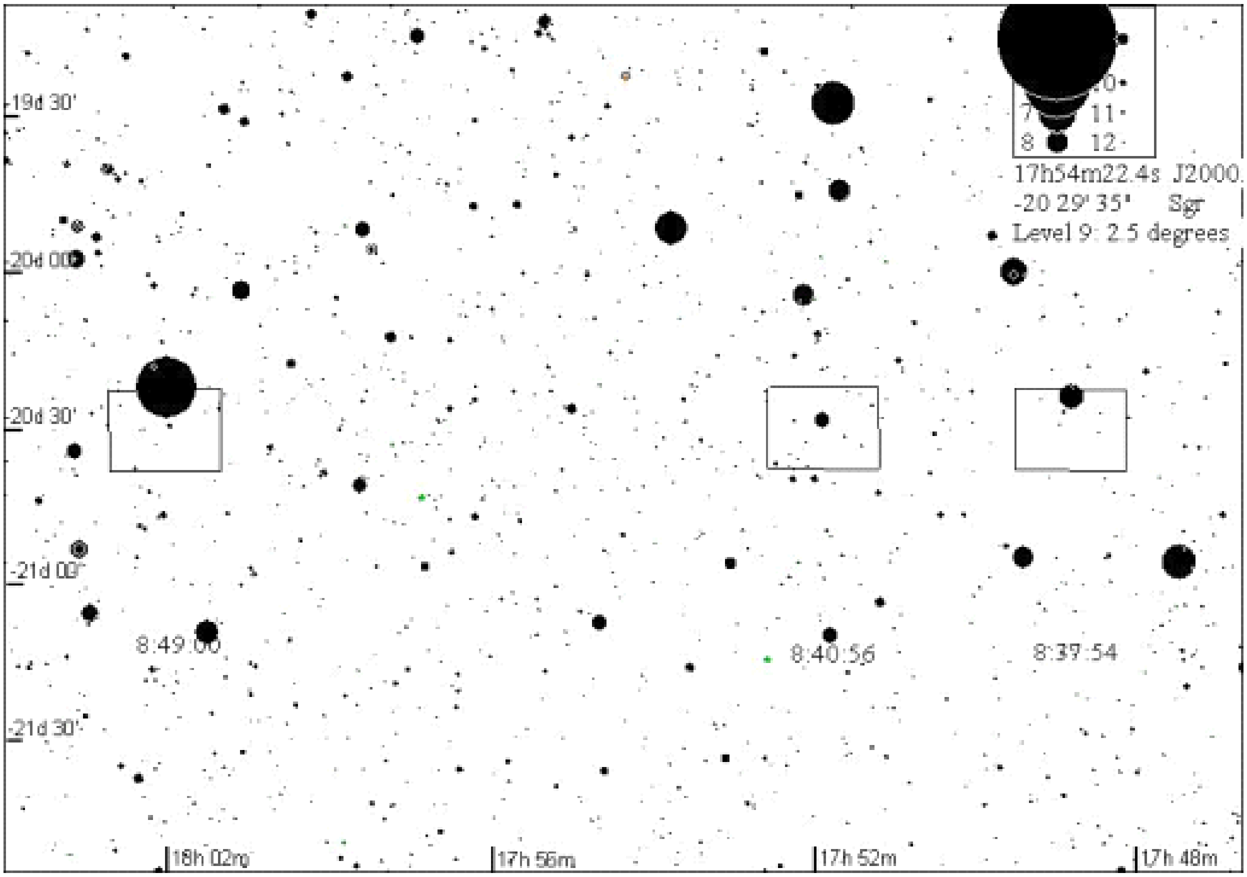

Figure 10.2. Pointing areas for sky target stars. Field of view approximately 2 x 4 degrees.

Figure 10.2 illustrates the advantage of this technique, using prominent stars, over the technique of selecting sky targets using time as the criterion. The latter technique requires the observer to use faint stars such as those between the rectangles drawn in the figure. Imagine star hopping to such a faint area, and then making a video verification of the field of view. Then imagine doing so in bright moonlight while you are in a hurry and bothered by the headlights of passing vehicles.

Incidentally, the leftmost target star of Figure 10.2 is just outside the designated field of view. Choosing such a target is risky because, in making the final adjustment in the pointing of the video telescope, it is hard to judge how far the telescope moves off the target after the target moves out of the field of view. The risk may be justified in this case by the ease in finding this 6th-magnitude star and by its small offset from the field of view.

10.2 Equipment

What equipment an observer selects for an unattended station depends on the interplay of the type of event, camera sensitivity, telescope aperture, video field of view, battery life, observing site, and the abilities of the observer.

10.2.1 Type of event

As discussed earlier, the tracking technique works well for unattended stations for lunar grazing occultations, so that a telescope mounting capable of motor driven tracking, whether it is of equatorial or computerized alt-azimuth type, will be useful for this type of event. The drift-through technique works well for asteroidal occultations, so a less sophisticated mounting can be used at unattended stations for these events.

For lunar grazes of naked eye stars with large cusp angles (i.e., grazes relatively far from the terminator), the drift-through technique works well when used with a videocamera with a telephoto lens. Although some color videocameras may be sufficiently sensitive to record such events, greater sensitivity can be had with a supersensitive black and white security camera used with either a C-mount or CS-mount lens, whichever is required by the camera. These lenses have wider fields of view than telescopes, allowing the capture of the whole graze without adjustment of the pointing of the system. A photographic tripod can be used as the mounting for the telephoto video system.

The use of a computerized GOTO telescope with automated pointing can decrease the time involved with the set up of equipment and the acquisition of a sky target. Such time efficiency is especially important for asteroidal occultations that occur early in the night, in which there is little time to find the sky target after sundown, or for occultation events allowing little time between stations, or for events occurring near the eastern horizon so that there is little time to star hop after the rising of the occultation star. These telescopes are also a big help on partly cloudy nights when star hopping is frustrating. However these GOTO telescopes also have the problem on partly cloudy nights of sometimes not being able to locate the alignment stars for the initial setup.

10.2.2 Camera Sensitivity

Details of camera sensitivity are discussed in Section 10.6 below. For the purpose of the present discussion, it is sufficient to point out that the use of a larger aperture may not enhance the video sensitivity of a telescopic system unless the focal length is quite short.

Cameras with automatically adjustable gain are problematic for grazing occultations because the glare of the sunlit portion of the moon will turn down the gain, causing the star to appear fainter. In order to remedy this, place the sunlit portion of the Moon out of the field of view to maximize the sensitivity of the video chip. Sometimes this is not possible at an unattended station due to the fact that the Moon’s sunlit side could drift into the field of view while the setup is not manned.

10.2.3 Video Field of View

Observers of asteroidal occultations typically use a videocamera with a nominal 1/3-inch video chip that has a true dimension of 4.87-mm in its long axis, mounted at the prime focus of a Schmidt-Cassegrain telescope of 203 mm (Celestron 8, Meade 8) aperture using an *f* /3.3 focal reducer. This equipment will yield a video field of view of 25 minutes of arc in the long dimension of the video chip and allow the observation of a target star for about 100 seconds using the drift-through technique.

Although 100 seconds of observation is sufficient for more than 99% of asteroidal occultations, it is less sufficient in the search for asteroidal moons. It has been calculated that the orbit of an asteroidal moon can be stable if the semimajor axis is less than 100 radii of the asteroid. However, most known asteroidal moons are within 20 radii (10 diameters) of the primary. You will want to look for a moon within 10 diameters of the asteroid both before and after the primary event. Consequently, a duration of twenty times the expected maximum duration of the primary occultation should be sufficient in the search for moons. Since a typical unattended system can observe an asteroid for 100 seconds, only those occultation events with predicted maximum (midline chord) durations of five seconds or less will be efficiently studied for the presence of moons. Of the 336 asteroidal occultation predictions published by IOTA astronomer Steve Preston for the first six months of 2003, 36% have a maximum duration of 5.0 seconds or less. Thus, the drift through technique with typical equipment will be sub-optimally effective in looking for moons 64% of the time. Ninety-five percent of those 336 occultations had a midline chord duration of 30.5 seconds or less. So, to look efficiently for moons in 95% of events, the field of view must be 2.5 degrees so as to allow a transit time of 610 seconds. The focal length will have to be much shorter to allow such a wide field of view. Although this degree of shortening of the focal length is not feasible without hampering sensitivity by reducing aperture, the advantage of a short focal length is evident.

Graze observers using telescopic video with the tracking technique usually do not need to use focal length reducers for unattended stations. In fact, by reducing glare and internal reflections caused by the nearby sunlit portion of the moon, a narrow field of view may render the occultation star more easily visible.

10.2.4 Battery Life

Battery life is more of an issue with unattended stations for asteroidal occultations than it is for grazes because with the former the station must operate for hours. A deep cycle or marine battery can run a small television, VCR, and videocamera for hours, and it is therefore a good choice for the powering of equipment at such a station. The battery should be recharged after each such extended use. Regular automobile batteries, though of a size similar to deep cycle batteries, are not made for this type of service and will be damaged by such deep cycling.

Of all the equipment the observer will need, the television has the largest power requirement. A black and white television requires considerably less power than a color set, and a small television requires less power than a large one. The choice of television with respect to the amount of power drawn is not likely to make a difference in the function of the battery during a single night, but after many nights of powering unattended video stations even a deep cycle battery will wear out. Its life will be longer if the observer uses equipment that draws less power, thus reducing the depth of the cycling of the battery.

Radios and timecubes for receiving a radio time signal can also run for hours if they can be connected to a large battery, but many of these devices have no plug for connection to an external power source. The internal battery may or may not have sufficient storage to power the device for the length of time required by an unattended station for an asteroidal occultation. It is worthwhile to test the life of a radio battery before relying on it at an occultation. The observer can devise a small battery pack to supplement the internal battery's storage if needed. Lithium batteries are now available in the common A, AA, AAA, C and D sizes.

Starting each event with a new radio battery is not nearly as costly as failing to get data due to the death of a battery.

A number of observers have successfully observed asteroidal occultations with very small telescopes and image intensified eyepieces. Video may be connected to these eyepieces afocally with a lens between the eyepiece and the video chip. The Collins Image Intensifier shown in Chapter 6, Figure 6.9 has a replaceable 3.6v lithium battery that can easily last for hours. However some of these eyepieces have an internal battery with a limited life. As with radios, the life of the battery should be tested before relying on it to operate the device for hours at an unattended station. The limited life of these batteries renders the currently available image intensified eyepiece of limited value for unattended stations, unless the observer can rig an external DC power source. For more information see Chapter 9, Section 10.3, *Batteries*.

10.3 Timekeeping

There are two types of timekeeping needed in operating an unattended station. First, as in all occultation work, the event itself must be timed. A radio blaring an audio signal is usually not acceptable because it might attract unwanted attention to the unattended station. The radio time signal is fed directly from the radio into the recording device using a suitable adapter. The ideal method of timing is video time insertion using GPS time, which is discussed in detail in Chapter 8, Sections 12 and 13.

Second, the observer must keep track of time so as to arrive at his destinations on time and point his telescope at the sky target or graze star at precisely the desired time. In Figure 10.2, notice that the observer labeled each candidate sky target on the star map with its critical pointing time from the last column in Table 1, in terms of local time (wristwatch time) for convenience in judging which target to acquire. Although a wristwatch is useful for this, it may not be reliably accurate in signaling the exact second at which the observer should turn off the clock drive so as to allow the sky target to drift out of the field of view. Use either a WWV radio time signal or the GPS time insertion method into the video signal for an accurate indication of the pointing time.

10.3.1 Observing Site

If the unattended station is in a backyard or at an observatory, the observer can use AC power for the television and VCR, and thus does not need to hide the telescope and video equipment. However, some or most of an observer’s unattended stations will be hidden in public places. These will need battery power, inaudible timekeeping, and black or very darkly colored equipment.

When a telescope tripod is left on an unpaved surface there is a possibility that the tripod feet will gradually sink into the ground. Because this will disturb the pointing direction of the telescope, it is unacceptable for any unattended station whether it is using the tracking technique or the drift-through technique. Small boards under the feet are effective as a preventative measure. Don’t leave home without them.

10.3.2 Observer’s Abilities

Observers who always find star hopping to be difficult will find that an equatorial mounting is an aid to star hopping. For an observer with an inflexible spine, a computerized telescope will be a boon. The large mass of a telescope of large aperture may be prohibitive for some observers, and fortunately a Schmidt-Cassegrain telescope of 8-inch aperture, when used with an $f/3.3$ focal reducer and a very sensitive video camera, is adequate for the detection of many occultation stars.

10.3.3 A Note about VCR’s

With an unattended station, the most frequent cause of equipment failure is an error in programming a VCR. These devices are all different. For example, some require that the VCR’s power be turned off in order to make a timed, programmed recording, while others require that both the television and VCR be left on. Some have an internal clock powered by an automatically recharging battery so that the observer does not need to reprogram it for every event, while some do not. Some have a special button that the observer must push to initiate the programmed recording mode, while others do not. In these and other respects, the VCR that the observer uses in the field is likely to be quite different from the one he uses at home and there is a risk that he will forget the differences. The observer must take care to program his VCR properly and practice before hand to learn exactly how the VCR works to avoid problems in the field. It is advisable to write the programming instructions on paper and attach them to the VCR for easy reference.

10.4 Site Selection

A telescope and television in the plain sight of many people is likely to be repositioned, damaged, or stolen. The main concern in site selection is equipment security.

10.4.1 Lunar Grazing Occultations

Since the observer will not be far from the unattended station he may not have to hide it. Along a secluded, rural, dirt road, or on some beaches, stations may be set up within sight of each other, and the observer can feel assured that very few persons will pass by. The observer can move between stations if needed to secure the equipment.

In suburban and urban locales there are more passers by and more light so that the equipment will be hard to hide. If the expedition plan involves moving back and forth between stations, both stations will be left unattended at times, and both will need to be secured. It may be difficult to find good hiding places in a city, and a simple solution is to use unattended stations in secluded areas only.

10.4.2 Asteroidal Occultations

Unless the unattended station for these events is to be in the observer's backyard or observatory, special care will have to be taken to secure the equipment. There are fundamentally two ways to do this: one can solicit permission to use private property, or one can surreptitiously hide it in the dark.

10.4.3 Using Private Property

David Dunham, IOTA's President, has developed this technique. He introduces himself as an astronomer from Maryland or from Johns Hopkins University and he explains that in a few hours there will be an eclipse (not an "occultation") of a star by an asteroid and that this location is a good one from which to observe it. Dunham asks whether he may set up his telescope there. If they agree, he then explains that he plans to leave the equipment unattended part of the time so as to travel to another location to set up another telescope, and that consequently he would like it to be hidden from easy view from the road. He tells them when he will be done and when he plans to leave with the equipment. He sometimes asks for AC power, and brings an extension cord.

He estimates that strangers are cooperative at least 80% of the time. Of those who are not, most are renters who are uncertain whether the property owner would agree, or someone in the house may be ill and want to be undisturbed. In these cases, he has always been able to find a cooperative neighbor.

The prospect of knocking on doors to find an observing site appears daunting to some observers. As with salesmen, the chance of success in such solicitation is dependent on the presentation the observer makes. He should not only be able to offer a concise and interesting explanation of the nature of the event and the observation, but he should be clean and decently dressed and have excellent interpersonal skills. A calling card or business card to identify himself may help. Substantial time in the expedition plan would have to be allotted to this activity.

For evening events, this is Dunham's preferred method of finding a site, since it avoids calls to the police about suspicious activity. For early morning events it is better not to awaken anyone and the hidden approach is better.

10.4.4 Hiding the Telescope and Equipment

Although an observer may approach this topic with trepidation, it is not hard to make a telescope invisible at night. The first principle is to use a black telescope and black instruments or cover them with black shrouds. The television, if left on, or if it turns on during the timed recording, will have to be covered by a couple of layers of dark blanket or a jacket, which may have to be taped in place. Red lights on the telescope or videocamera and other faint glows from equipment should be covered with black tape or a shroud.

Along a straight two lane road at night, a set of black instruments is invisible to passing motorists if it is 30 meters from the road. The station can be left standing in the middle of a field. However, if near an intersection or turn it may catch the headlights of turning vehicles. Brush along the road is particularly good for hiding a station, because it masks the instruments but does not occlude the view of the sky.

Many isolated buildings are unlit at night. A station next to such a place is not only very difficult to discern, but when it is detected it seems to be a nondescript part of the paraphernalia around the building rather than a valuable piece of equipment.

The glare of security lights around buildings, ironically, is a big help to hiding a station. The deep shadows of unlit sides of buildings are impenetrable unless a vehicle's headlights shine directly into them. Very little can be seen in the relative darkness at the edge of a brightly lit parking lot, so that a station at the edge of the lot likely cannot be seen against the unlit background.

Avoid diffuse lighting. Full cut off light fixtures with no glare illuminate an area more effectively and make a telescope stand out. Many urban areas are lit by multiple streetlights and skyglow so that there are no dark shadows.

Using these ideas, the following are particularly useful types of sites and have been in both rural and suburban areas.

1. Churches. Many of them are labeled on USGS topographic maps and road/atlas computer programs, so that the observer can plan on using them. Likely hiding places include shadowed walls in the back or on a side, or the back edge of a parking lot. Churches often have meetings on Wednesdays or Sunday evenings making them unusable for early events on those nights. Large churches may have meetings every evening.

2. Schools. These tend to be brightly lit but the glare may render objects at the edge of the parking lot very hard to discern against the background. There are often gatherings at schools early in the evenings.

3. Small businesses that are closed for the night. Many of these have no lights on some sides of the building. Astronomical equipment looks inconspicuous because it blends in with other equipment located around the site.

4. Abandoned business sites such as old gas stations, motels, miscellaneous old buildings and quarries are usually dark and no one visits them at night.

5. Playgrounds. A tripod looks like just another swing set.

Observers should not leave equipment on property that has a sign forbidding trespassing and they should take care when using a secluded road that it is not the driveway of a home.

10.4.5 Leaving a Note

It is a good idea to leave a note on the equipment, stating very briefly what it is and how to contact the observer. A cellular telephone number may be included, but if the station is hidden the observer is not likely to receive a call. David Dunham has used the following sign:

"Please do not disturb. This is a precisely pointed automatic astronomical station to record the eclipse of the bright star Tau-2 Aquarii by the southern edge of the Moon starting at 7:52 PM. You can see it too, either with binoculars or by zooming in with a camcorder. Questions, call my cell phone, 301-xxx-yyyy. I'm nearby."

10.5 Additional Applications

The utility of the drift-through technique is not limited to unattended stations. Because it uses target stars that are brighter than the occultation star, it makes star hopping easier. An observer should consider using it for an asteroidal occultation any time he anticipates that star-hopping will be difficult. Such difficulty occurs when the occultation star is in the glare of the nearby moon, when it is close to the horizon, when the event occurs in twilight, or when the sky is partly cloudy.

10.6 Videocamera Sensitivity and the Detection of Faint Stars

The sensitivity of a videocamera is limited by two factors. One factor is its quantum efficiency, which is the efficiency with which the detector converts incident photons to stored charge. The other factor is the electronic noise generated by its hardware. Continual advances in electronic technology have improved both of these factors greatly in the last few decades, and further advances may be expected for many years to come. The quantum efficiency of state of the art, black-and-white videocameras is high already, so that much of the sensitivity enhancement of the future will be due to the reduction of electronic noise. As a result of these advances, occultation observers will increase the number of occultation events within the sensitivity range of their instruments by occasionally upgrading their video cameras.

An advertisement for a video camera may mislead a buyer about the usefulness of a camera for occultation work. The sensitivities of video cameras are usually rated in units called lux. One lux is the light created by a point source of one candle illuminating a surface that is everywhere one meter from the source. The rating is supposed to indicate that the camera is capable of imaging a scene with illumination at or above the specified lux. Unfortunately, the methods of rating video cameras are not standardized. Some camera ratings are established using a lens of *f* 1.2, while others use *f* 1.4, *f* 1.8, or *f* 2.0. Furthermore, the means of judging whether a camera successfully images a scene with low illumination is subjective. The once widely used Supercircuits PC-23C camera is rated at 0.04 lux while the Watec 902H camera is rated at 0.0001 lux, so that one might think that the latter can image stars 400 times as faint as the former, a difference of more than six magnitudes. However, the latter camera can image stars only 1.5 magnitudes fainter than the former, which corresponds to a 4-fold increase in sensitivity. Observers can avoid such rating pitfalls by keeping in touch with other occultation observers and sharing their knowledge and experiences in the use of these cameras. Supercircuits also sells an economical very low light black and white camera, the PC-164C, rated at 0.0003 lux. The company also sells a newer more sensitive version, the PC-164EX-2. It is rated at 0.00001 lux comparable to the Watec 902H.

Observers often think of the limiting magnitude of a telescope-camera combination as the faintest star that can be imaged with the system. In the videotaping of occultations, the concept of limiting magnitude is not that simple. The faintest star that can be detected with a telescopic video system will be glimpsed intermittently on the monitor, so that, if it is occulted, its disappearance cannot be accurately timed. Stars approximately 0.5 mag brighter than that faintest star will have a stable appearance on the streaming video, so that their occultation times can be judged to an accuracy of one or two tenths of a second by review of the moving videotape. These stars will not be seen on every video field if the tape is reviewed field by field, and therefore highly accurate timing of their disappearances will not be possible. About a half magnitude brighter still, stars will be evident on every field as the videotape is stepped through, field by field. Occultations of these stars can be timed to an accuracy limited by the field rate of the video camera, which is 50 fields or 25 frames per second (PAL standard) in Europe and 60 fields or 30 frames per second (NTSC standard) in the United States. Thus there are three types of video limiting magnitude: an absolute limiting magnitude, a stable limiting magnitude, and a step-through limiting magnitude.

Accurate timing is of major importance for asteroid occultations, which makes it desirable to use a videocamera-telescope combination of which the step through limiting magnitude is fainter than the occultation star. With most lunar grazing occultations, accuracy better than a tenth of a second is not required and a system is useful so long as the stable limiting magnitude is fainter than the star. Useful occultation work cannot be done with stars that are fainter than the stable limiting magnitude, even though they are intermittently detectable. Solar eclipse observations are unique in that the timing of the disappearances and appearances of Baily's Beads may be dependent on the sensitivity of the camera. More work is needed to confirm this. Until the possibility is confirmed or refuted, it is recommended that an observer use the Supercircuits PC-23C video camera, or one with a similar sensitivity rating for Baily's Bead timings.

Usually, fainter stars can be detected on video when the camera's gain and gamma are adjusted to their highest settings. Such adjustment causes a grainy image, which in some cases is so severe as to mask faint stars, defeating the purpose of the gain. In most video systems, graininess can be reduced and useful sensitivity increased by adjusting the sharpness of the television to the lowest setting, a fact that seems counterintuitive at first. Two other television settings affect the detectability of faint stars: contrast or picture, and brightness. The former should be adjusted to its highest contrast setting, while the latter should be adjusted so that the background sky appears a medium gray on the screen.

A larger telescope may not reveal fainter stars on video. The longer focal length of the larger instrument increases the image scale so that the light of a star is spread over more pixels (See Figure 6.7 Chapter 6), thus two telescopes of different apertures but of the same focal ratio will have the same image brightness. The way to image fainter stars is to use a telescope with a larger aperture with a focal reducer to shorten its focal length, concentrating a star's light on fewer pixels. Common focal reducers for Meade/Celestron Schmidt-Cassegrain telescopes are the *f* 6.3 and *f* 3.3 sold by many astronomy suppliers.

Table 10.2. Sensitivity of Watec 902H with C-11 SCT

Nominal *f* ratio	Measured *f* ratio	Arcsec per pixel	Standard lim mag	Stable lim mag	Freeze-frame lim mag
10	10*	0.54	11.8	11.0	10.7
6.3	6.83	0.79	12.4	11.7	11.5
3.3	3.60	1.50	13.2	12.7	12.1

*This *f* ratio was not measured but was stated by the manufacturer, the other f ratios were measured in comparison to it.

Table 10.2 shows this effect with a video camera on a Schmidt-Cassegrain telescope of 280mm (11 inch) aperture at *f* /10 and with focal reducers yielding *f* /6.83 and *f* /3.60. Ultimately, the increasing sensitivity brought about by decreasing focal length will reach a limit when all the light of a star's seeing disc is concentrated on a single pixel. The seeing disc of a faint star may be as small as an arc second on a night of good seeing, but two arc seconds is typical. A stellar image two arc seconds across will fit on a 7 micrometer pixel when the focal length is about 700 millimeters. A brighter star will have a larger seeing disc.

Table 10.3 shows a comparison of various CCD camera chip distances as compared to corresponding effective focal ratios and limiting magnitudes. Figure 10.3 is a diagram showing the relative focal lengths and positions of placement of the video camera and focal reducers in an *f*/10 telescope.

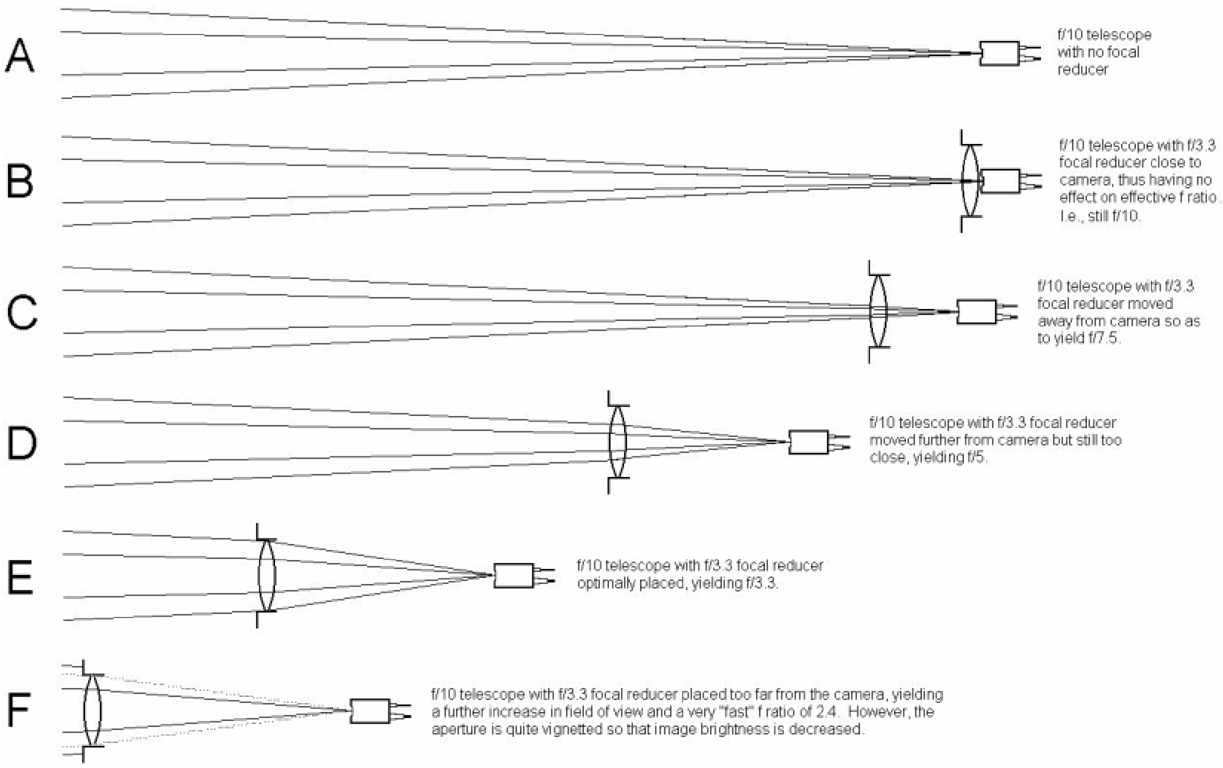

Figure 10.3. Video camera and a *f* /3.3 focal reducer placement in a *f* /10 system.

Table 10.3. Use of Watec 902H with Celestron 5-inch SCT and *f*/3.3 focal reducer

Distance, chip to glass, mm	----	10.5	23.2	35.9	48.6	61.3	74.0
Hor. field of view, arcminutes	18.5	22.4	25.2	29.3	34.3	45.2	59.1
Focal length, effective, mm	1250	1033	918	789	674	512	391
Focal ratio, effective	10	8.26	7.34	6.31	5.39	4.09	3.13
Limiting magnitude, absolute	10.1	10.5	11.3	11.7	11.8	11.3	10.4
Diameter, faintest star, mm	2.5	2.5	2.5	2.0	2.3	2.0	2.3

The leftmost column is data for the f/10 prime focus without a focal reducer. The chip to glass distance is from the CCD chip to the camera-side surface of the focal reducer's lens. The absolute limiting magnitude is about 0.4 and 1.1 magnitudes fainter than the stable limiting magnitude and freeze-frame limiting magnitude, respectively (see Table 10.2).

Since noise is the limiting factor in video camera sensitivity it is worthwhile to minimize the electronic noise produced by the observer's equipment. This can be done by avoiding the use of computers, making sure wire connections are secure and clean, shielding power cords, and separately grounding the power supply and video equipment.

References for Chapter 10

Venable, R., “Some Sensitivity Characteristics of the Watec 902H Videocamera” *Occultation Newsletter*, Volume 10, No. 2, January 2003.

Venable, R., “The 2 Pallas Occultation of June 12, 2006”, *Occultation Newsletter Cover*, Volume 13, No. 1, January 2006.

11 Solar Eclipses and the Solar Diameter

Introduction

As the Sun evolves during its ten billion year lifespan its diameter is expected to change over periods of time. An interesting question is will it change significantly over a lifetime and/or human timescales?

The study of the variability of the Sun's size is of prime importance for the study of long and short term climate on Earth. Geologists have discovered evidence in the 20th century that demonstrate the Earth's climate has changed. They cite as examples of this as the glacier retreats and the accelerating melting of the Greenland ice cap. Knowing how and when the solar radius varies can assist scientists in understanding how ice ages come and go, explain the Little Ice Age that occurred in the 1600's across Europe, why there few if any sunspots visible on the Sun for the period from 1645-1715 and other climate questions. Climatologists' current mathematical models indicate that even a small one or two per cent change in the Sun's total radiation output would have significant effects on the Earth's climate. According to solar researcher J. B. Zirker, if the Sun's energy were to decrease by just four to six percent, the Earth's oceans would freeze solid and the world's continents would be buried with snow and no subsequent brightening of the Sun could revitalize the frozen Earth. This change, he says, would be irreversible since once the Earth was painted white it would reflect nearly all incident sunlight !

Two very important questions arise from this discussion: 1) Has the Sun's luminosity varied even at the 1% level during recent history? 2) If so, can such changes be linked to known climatic changes and linked to the variation in the Sun's diameter ?

One of the research areas conducted by the International Occultation Timing Association is the study of the possible variability of the Sun's diameter and if these changes affect the varying solar luminosity and whether or not this variation would affect the Earth's climate. IOTA's method of studying the Sun's size will be discussed in Section 11.3 below.

11.1 Historical Measurements of the Sun's Radius

Throughout the history of astronomy as far back as the ancient Greek astronomers, numerous investigators have made attempts to measure the Sun's size. A partial list of the historical Solar radius measurements is presented in Table 11.1 below. Table 11.2 lists some long term solar radius studies using different techniques and historical data. Since the Earth's orbit is elliptical with an eccentricity of 0.0167, the Earth-Sun distance varies by some 3% throughout the year causing the Sun to appear to grow and shrink in size. This small change in apparent (not actual) size can be seen in photographs taken of the Sun six months apart in January (perihelion) and July (aphelion) using identical equipment. The *standard solar diameter* is the diameter we are seeking to measure and is the apparent size the Sun would be at a distance of one AU from Earth. Therefore any solar radius measurement needs to be reduced to this one AU standard before any interpretation can be made.

Table 11.1

Author	Date	Method	$R_{\odot}$ (″)*
Aristarchus	230BC	VI	900
Archimedes	212BC	VI	810-990
Ptolemy	150AD	VI	950
Kepler/Tycho	1604	VI	962
Moulton	1660	PP	951.7
Auzout	1666	MI	960.5
Picard	1670	MI	959.9
Richer	1672	DP	957.2
Picard	1674	DP	958.2
La Hire	1683	MI	958.5
La Hire	1684	DP	960.7
La Hire	1701	DP	958.9
Louville	1724	DP	959.4
Bouguer	1753	HE	956.6
Mayer	1759	DP	960.4
Lalande	1760	HE	950.4
Lalande	1764	HE	960.7
Bessel	1824	ME	959.7
Airy	1837	ME	961.3
Goujon	1842	ME	961.3
Smith, M.	1877	ME	960.5
Auwers	1880	HE	959.9
Gething	1895	ME	960.0
Schur	1896	HE	960.4
Ambronn	1897	HE	960.2
Cimino	1907	ME	960.3
Smith, M.	1946	ME	960.4
Wittmann	1974	DP	959.7
Wittmann	1978	PP	960.0
Ribes	1981	ME	960.5
Leister	1984	AS	959.7
Journet	1986	AS	959.3
Laclare	1987	AS	959.7
Noel	1991	AS	961.1
Chollet	1998	CCD	959.64
Sigismondi	2006	EC	959.22

Table 11.1. Columns defined left to right: Investigator, date of measurement(s), method used (see Table 11.2 Notes below for description) and Solar radius in arc-seconds. Data adapted from Toulmonde 1997.

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* Measurements corrected by M. Toulmonde for atmospheric refraction (0.6″), seeing ~1″, personal equation 1″ to 2″, diffraction of the objective 12″ (~1680), 6″(~1750), 2″~(1850), 1.4″ (~1900). Toulmonde estimated the diffraction of the objectives based on the probable quality of the optics.

TABLE 11.2. Long Term Solar Radius Change Studies

Investigator	Dates Studied	Method	Radius or change in $R_\odot$
Eddy	1836-1953	ME	2.25″ shrinkage per century
Shapiro	1737-1973	TM	0.05 ± 0.1″ shrinkage per century
Dunham	1715-1979	EC	-0.34 ± 0.2″
Dunham	1925-1979	EC	-0.49 ± 0.1″
Kubo	1970-1991	EC	959.74-959.88
Noel	1990-1995	AS	961.07-959.98
Wittmann	1990-2000	DT	960.63-960.66
Sofia	1994-1997	SDS	959.50-959.72
Dunham	1991-2002	EC	+0.09″ to -0.21″ with respect to 959.63
Emilio	1996-2000	SOHO	0.0081 ± 0.0009″ per year

Tables 11.1 and 11.2. Historical measurements and studies of the Solar diameter. Although this table is not a comprehensive list of Solar radius studies over the time periods given, it shows the difficulty in reaching a level of consistency in ground based measurements attempting to measure the Sun's radius. Data adapted from Toulmonde 1997

Key to Methods: VI= visual, PP= projected transit time, MI= micrometer, DP= observed transit time, HE= heliometer,
ME= transit time at meridian circle, AS= solar astrolabe, TM= transit of Mercury across Sun,
EC= solar eclipses (see Section 11.3) , DT=Drift time across field of view, SDS=Solar Disk Sextant.
SOHO= Solar and Heliospheric Observatory

The earliest detailed attempts to measure the size of the Sun were made by Tycho in 1591 and Kepler in 1601-2. Prior to Tycho and Kepler, Archimedes (287-212 BC) made a visual measurement of the Sun's radius by comparing a moving disc on a rigid rod. The size of the disc was made to barely cover the Sun. The Sun was observed directly with the naked eye at sunrise and at sunset in order to prevent eye damage. Archimedes' measurements of the Sun's diameter was stated as $R_\odot = 33' - 27'$. Archimedes also quoted a measurement of $R_\odot = 30'$ made by Aristarchus (310 -230 BC), while Ptolemy found the solar diameter to be $R_\odot = 31'\ 20''$ (950″) with no variability worth mentioning throughout the year. Ptolemy found a systematic discrepancy between the direct measurements and the angular dimensions from calculations during lunar eclipses. In fact, he judged the solar diameter equal to the lunar diameter at apogee and calculated the latter from lunar eclipses at apogee.

11.2 Methods Used to Measure the Solar Diameter

Investigators over the last 400 years have used a variety of methods to measure the Sun's radius. Since filters were not widely available to place between the observer and telescope instrument to block out the Sun's extreme brightness, most visual measurements were made either near sunrise and sunset or during the day when clouds and haze filtered the Sun to make visual observations safe. Meridian transit measurements were usually made with the Sun projected onto a surface. From Tables 11.1 and 11.2 above several methods are briefly described below:

MI: Measurements made with a micrometer and a screw that had graduated scales. Just like the modern day micrometer, the observer would measure the width of the Sun by turning a screw and read off the numbers on the scales then convert the results to angular measure.

DP & ME: Transit time and meridian transit measurements involved the timing of the passage of the Sun's disk across a series of cross hairs (series of wires) in the eyepiece. The Sun's radius is calculated by timing the duration of the transit across a cross hair and knowing the Earth's angular rotation rate. This technique required proper filtering of the Sun. The use and choice of a filter introduces an error depending upon which wavelength of the Sun's light is being transmitted.

HE: A heliometer is an obsolete refracting telescope with a split objective lens. The two sections of the objective lens were moved (or a prism was moved at the focal point) until the images of the Sun coincided. The amount the prism (lens) had to be moved gave a measure of the angular size of the Sun's diameter.

AS: The astrolabe was used to measure altitudes of celestial objects. To measure the Sun's diameter, one would measure one side of the disk and then the other as quickly as possible to minimize the effect of the diurnal motion of the Sun across the sky. Measuring the Sun at the meridian minimized altitude errors.

Jack Eddy in 1980 reported from his study of daily meridian transit observations made at the Royal Greenwich Observatory from 1836 – 1953 that the Sun appears to have been decreasing in size by 0.1 % per century (method **ME** in Table 11.2). He reported that the horizontal diameter of the Sun had shrunk by 2.25″ per century while the vertical size had diminished by 0.75″ per century. The horizontal value was chosen as the result since it didn't suffer from the unavoidable atmospheric refraction effects.

In the same year, I. Shapiro challenged Eddy's results from his analysis of 23 transits of the planet Mercury from the years 1736 through 1973. A transit of Mercury across the Sun's disk would give an accurate check on any progressive change in the Sun's diameter (method TM in Table 11.2). Shapiro found a change of only 0.05 ± 0.10″ per century. This result, taking in consideration the errors of the observations, shows the Sun's diameter to be fairly constant.

Modern methods used to measure the change in size of the Sun from Table 11.2 covering only a decade or so give inconsistent results. As can be seen from the numbers in Table 11.2 from the long term solar radius studies, Eddy's 2.25″ per century shrinkage of the Sun is significantly larger than Dunham's 0.34″ shrinkage over a 264 year baseline of solar eclipse observations. The studies by Kubo (who used the flash spectrum during solar eclipses to derive diameters), Noel, Wittman, and Sofia also show inconsistent results in the Solar diameter with nearly a 2″ difference in the measured radius. Emilio's five year study (1996-2000) from the Solar and Heliospheric Observatory (SOHO) satellite reported a small 0.008″ variation in the solar diameter which is likely the most accurate of all observations. SOHO data was obtained with the Michelson Doppler Imager (MDI) on board the satellite. Emilio's study of SOHO data published in the *Astrophysical Journal* in the year 2000, also reported a yearly fluctuation with a secular change of 0.1″ which he reports is due to the changing thermal environment of the SOHO spacecraft. Temperature changes caused small but measurable differences in the telescope's focal length causing the yearly 0.1″ fluctuation.

Nearly all of the pre 1970 observations of the Sun's size were made with ground-based instruments and naturally have suffered due to the effects of the Earth's often turbulent atmosphere. The atmosphere is more active in the daytime due to solar heating than at night, when it cools off and calms down. Measurements have been made by sending instruments on high altitude balloons which have also revealed inconsistent results. Instruments have also been sent up on the Nimbus 6 and 7 weather satellites and aboard the Solar Maximum mission. This satellite data has recorded interesting short term fluctuations in the solar constant but no permanent change large enough to be of any significance. The Solar Disk Sextant (SDS) has been lifted by high altitude balloon several times from 1992 to 1997 and has given accurate values of the Sun's radius consistent with those obtained from eclipses and the SOHO satellite.

Thus far, no dedicated satellite has been launched to measure the Sun's size. The French plan to deploy the PICARD microsatellite in late 2009 with the objective of simultaneous measurement of the absolute and spectral solar irradiance (previously named the solar constant), the diameter and solar shape and the Sun's interior probing by the helioseismology method. This data will allow the study of the variations of these quantities as a function of solar activity. PICARD is named after the French astronomer of the 17th century Jean Picard (1620-1682) who achieved one of the first accurate measurements of the solar diameter.

The primary goal of the PICARD mission is to study the influence of solar activity on the Earth's climate. One instrument, SODISM (Solar Diameter Imager and Surface Mapper) is an imaging telescope that will be accurately pointed and have a CCD measure the solar diameter and shape with an accuracy of 0.004″. SODISM will also acquire helioseismologic observations to probe the solar interior.

Until the launch of PICARD we must rely upon indirect methods from existing satellites and sophisticated ground based methods.

11.3 How IOTA Measures the Sun's Diameter During a Solar Eclipse

In the early 1970's Drs. David and Joan Dunham devised a novel approach to measure the size of the Sun by utilizing solar eclipses. The principal stems from the concept of grazing occultations by the Moon. Since it is possible to determine the height of lunar mountains on the limb to ± 100 feet (the distance between observer's stations on the ground), it is reasonable to use the same principle to measure the north and south limb of the Sun during a solar eclipse.

IOTA's method of determining the Sun's radius is by studying the Baily's Bead phenomena that only occurs during a solar eclipse. Baily's Beads are named in honor of Francis Baily who first described them while observing an annular eclipse in 1836 from Jedburgh, Scotland. Baily's Beads refer to sunlight passing between the lunar mountain peaks at the lunar limb and are seen during total and annular solar eclipses. Figure 11.4 shows why we see Baily's Beads during an eclipse. The jagged edge of the Moon (enlarged 60 times for illustration purposes) breaks up the sunlight into beads. A 31-second time lapse sequence of Baily's Beads from the February 26, 1998 total eclipse in Curacao is shown in Figure 11.1.

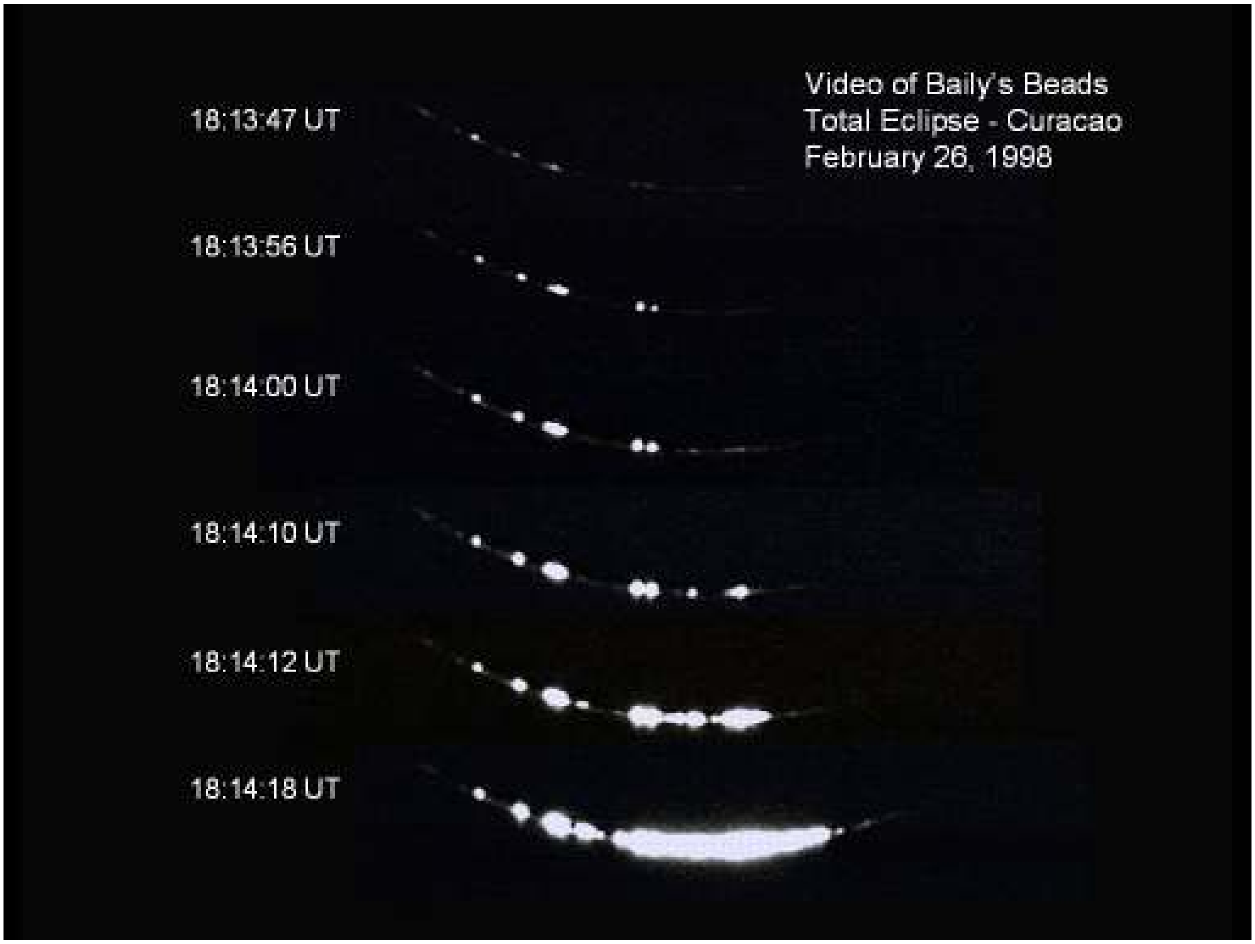

Figure 11.1. Baily's Beads. These are screen captures off a video encompassing a 31 second time interval during the central phase of the total eclipse which occurred in Curacao on February 26, 1998. Video frames by Richard Nugent.

When a total solar eclipse occurs the Moon's shadow defines a cone extending from the Earth's surface to the Sun (See Figure 11.2). This cone is tangent to the Sun. In advance of the eclipse the known quantities are the Moon's distance, the Sun's distance and the size of the Moon with high accuracy. Following the eclipse, the width of the umbra (the vertex of the cone) on the Earth's surface is determined from the eclipse observations. The only remaining unknown is the Sun's diameter. Earth's atmosphere has only a secondary influence on observations as compared to the many ground based methods from Table 11.1. The expected precision of this method exceeds 0.1″ and the results from several eclipses have confirmed this.

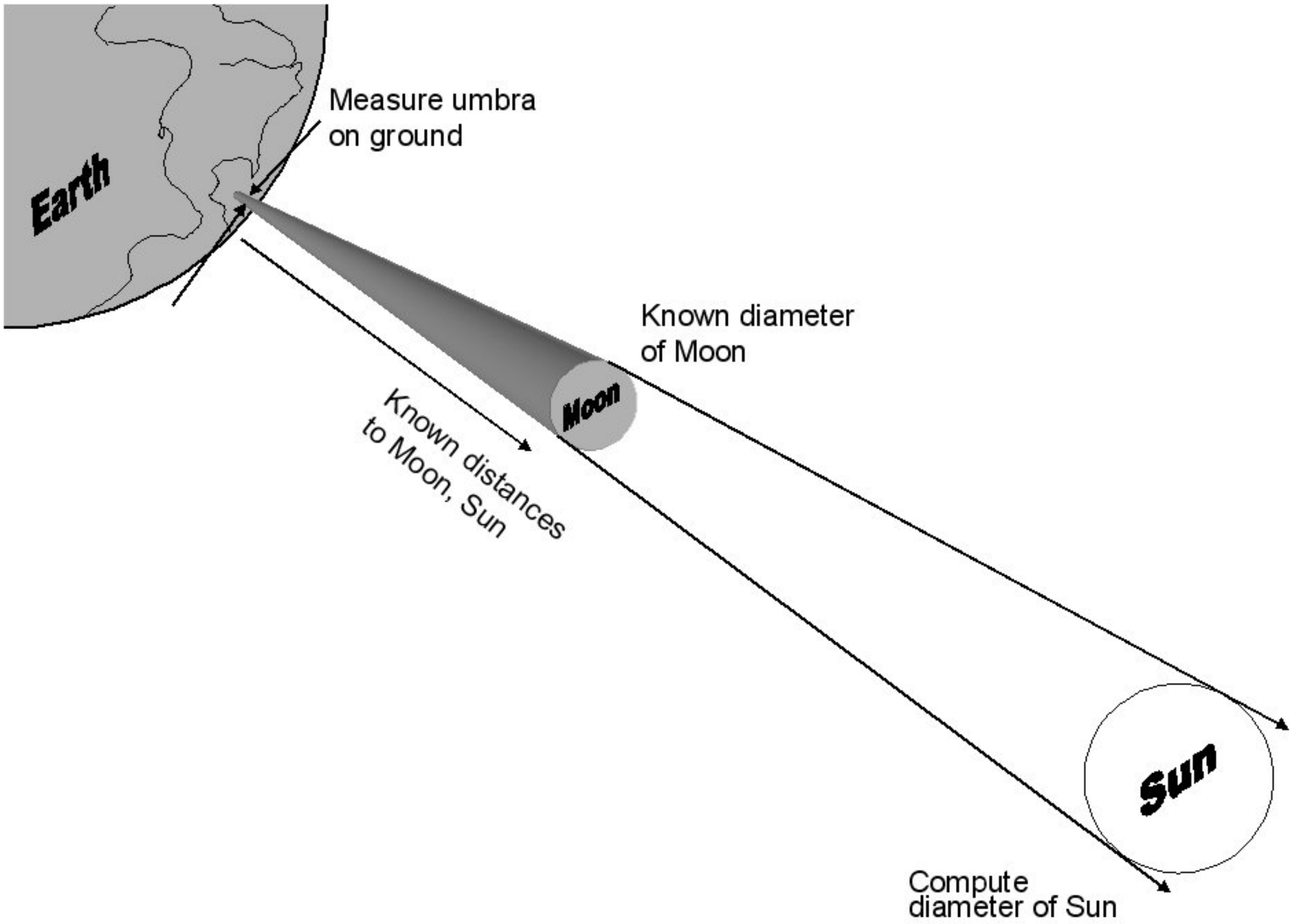

Figure 11.2. Geometry of the solar eclipse method to determine the Sun's radius. During an eclipse all quantities are known in the shadow cone except the Sun's diameter, which is computed following the determination of the umbral shadow limits on the ground.

Dunham's method has observers stationed at the north and south eclipse limits perpendicular to the Moon's motion as demonstrated in Figure 11.3. As the Moon moves across the solar disk the lunar mountains and valleys along the limb will gradually allow beads of sunlight to show through. If an observer sees only Baily's Beads and no totality, would be *slightly outside* the Moon's umbral shadow. An observer that sees totality and some Baily's Beads would be inside the Moon's shadow. From the analysis of the appearance, duration and disappearance of the beads using WWV or GPS Time inserters an accurate point on the ground of the Moon's north and south shadow limits can be derived. A line of observers can establish the geographical location of the edge of the Moon's shadow to within 100 meters. This uncertainty corresponds to an error in the Sun's diameter of 0.05 arc seconds. Early results using this technique showed a precision of better than 0.1 arc second and although this is quite an impressive figure it was not enough to detect any changes in the Solar diameter over short time periods of under 50 years. A comparison of a historical eclipse observed in the year 1715 and timed by Sir Edmund Halley with eclipses through the year 1979 have shown the measured change in the Sun's size to be -0.34 ± 0.2 arc second. Dunham's colleagues Wayne Warren, Jr. Alan Fiala, Paul Maley, Richard Nugent, Hal Povenmire, (United States), David Herald (Australia), Patricia Rosenzweig (Venezuela), Hans Bode (Europe) and other IOTA colleagues have painstakingly traveled to some of the most remote places on Earth to collect data along the eclipse umbral shadow limits.

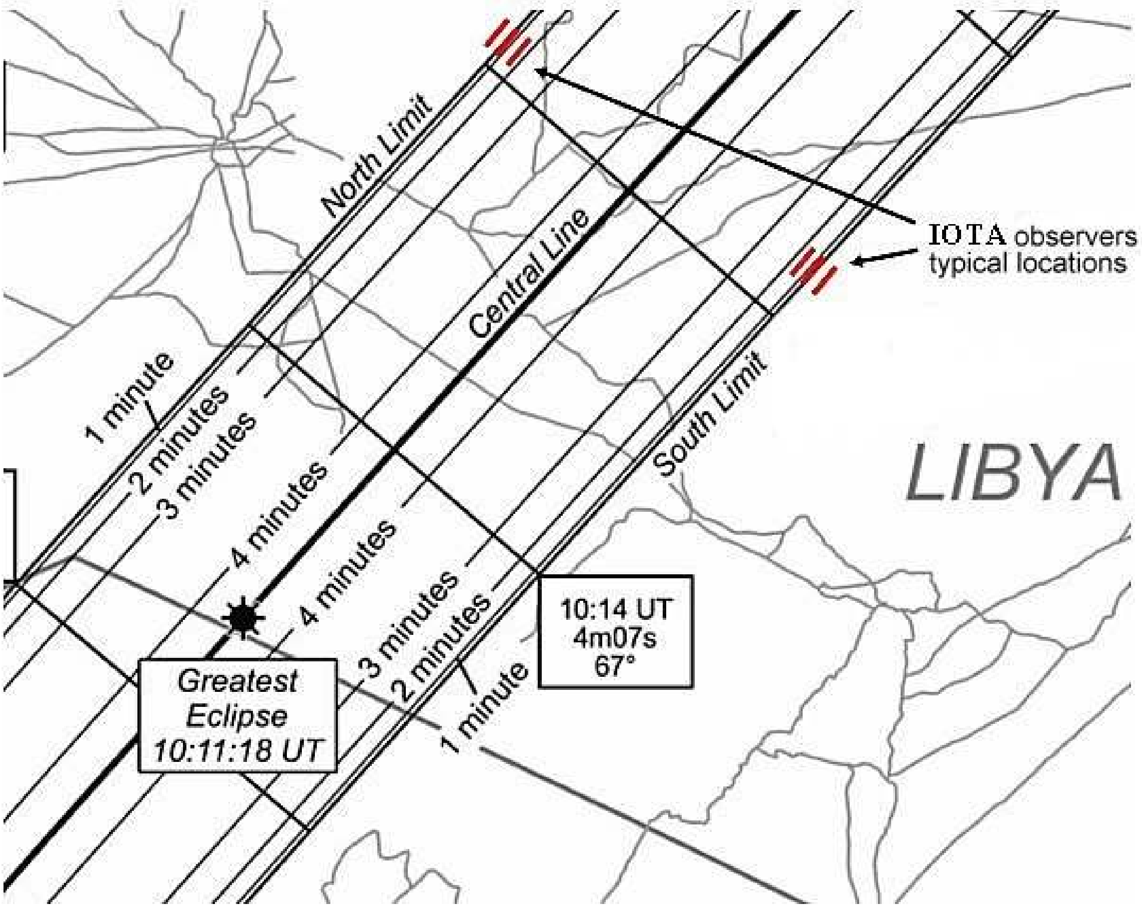

Figure 11.3. IOTA observers shown here by lines are stationed at the eclipse edges at both the northern and southern eclipse limits. The eclipse path shown here is the March 29, 2006 total eclipse across Africa. From this eclipse the Italian astronomer Costantino Sigismondi determined the Solar radius to be 959.22 ±0.04 arcsec. Reprinted from Espenak and Anderson's NASA Eclipse Bulletin 2004-212762, page 58.

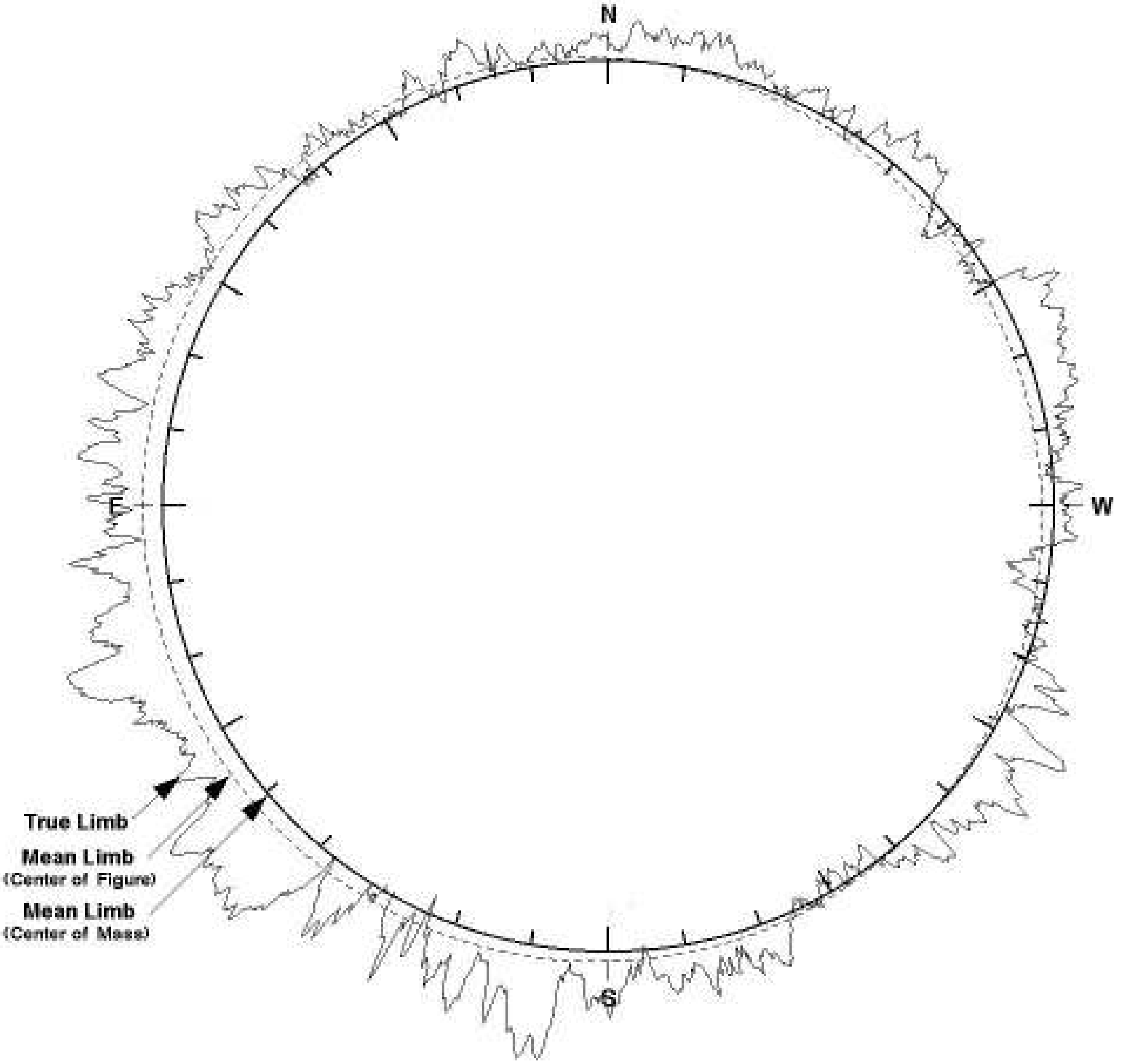

Figure 11.4. Exaggerated profile of the Moon's limb. Dashed line represents the Moon's mean limb. Some of this profile data (within 20 degrees of the North and South poles) has been obtained from grazing occultation observations from 1962-2002. Profile shown is 60x times larger than the actual limb profile in order to illustrate the rugged lunar surface. Diagram adapted from Espenak and Anderson, 2004.

As stated earlier, ground based measurements of the Sun's diameter suffer from atmospheric effects. Observations of total and annular solar eclipses can provide the most accurate ground based determinations of the solar radius since the geometry of the fast moving shadow is set in space. Thus atmospheric seeing has only a small secondary effect on the observations.

11.4 The Total Eclipses of 1715 and 1925

On May 3, 1715 a total eclipse occurred across England. The significance of this eclipse formed the basis of IOTA's long term study to measure solar radius variations. Sir Edmund

Halley had organized observers throughout England; three happened to be near the limits at in Darrington, Kent County, Bocton and Cranbrook, England.

The observer in Darrington was Theophilus Shelton and he reported as totality approached: "*The Sun at 9^h 11^m was reduced to almost a point, which both in Colour and size resembled the planet Mars, but whilst I watched for the total eclipse, that point grew bigger and the darkness diminished*." What Shelton had seen was a Baily's Bead that never quite vanished completely and thus he thought he was just outside the path of totality. Although the interpretation of Shelton's observation was considered ambiguous, Dunham and his colleagues determined that he actually had a short amount of totality and was within 1.3 km of the northern path limit.

Observers at the southern limit stations filed reports with Halley about totality as: "*Duration of totality instant*" (Angley House, Cranbrook), and "*Point like a star that remained visible*", (Bocton). The red color seen showed the photosphere. The interpretation from these observers is that they bracketed the limit and Dunham's analysis at their respective locations showed them to be just outside the path of totality.

The total eclipse of January 24, 1925 was well observed since the path of totality crossed over the heavily populated areas of the northeastern states in the US: New York, Connecticut, Rhode Island, Massachusetts, and New Jersey (Figure 11.5). Yale University astronomer Ernest W. Brown had recruited a large number of observers to acquire positional observations to test his eclipse calculations. Prior to the eclipse he mailed observing questionnaires, published an article describing the many eclipse observing projects he had planned in scientific journals as well as announcing his plans using the daily press. He received large numbers of time and positional observations which he divided into the following classes:

A. Observations of the time of 2nd contact made by trained observers with good positional information for their stations and accurate timing with their equipment.

B. Observations of the duration of totality by trained observers, most withine the eclipse north and south limits.

C. Photographs of the partial phases at recorded times made at Middletown and New Haven, Connecticut.

D. Observations of the duration of totality made by untrained observers near the edge of the shadow limits.

E. Observations stating whether or not the eclipse was total or not at the observer's station.

Figure 11.5. The path of the total eclipse of January 24, 1925 over the northeast US.

One year after the eclipse Brown published a paper in the *Astronomical Journal* reporting his results and analysis. He reported accurate timing made by professional and advanced amateur astronomers of eclipse durations at several sites. Brown also described observations made close to the eclipse limits including those made by 140 employees of the Affiliated Electric Company who were distributed at intervals of 100 yards to the north and south of the predicted edge of the shadow band in New York City. This effort was organized by company officials. This well organized group activity made it possible to calculate the shadow's edge to within 100 yards which corresponded to 0.03″ in the declination of the Moon's edge. Brown suggested after this eclipse that this figure could be off by 0.5″ owing to the inequalities in the Moon's limb.

11.5 The Eclipses of 1976 and 1979

IOTA members in Australia and North America observed the eclipses in 1976 and 1979 near the edges of the paths of totality and recorded careful timings of Baily's Beads as totality approached. See Table 11.3 for corrections made to the Sun's radius along with the results of the 1715 and 1925 eclipses.

Table 11.3. Solar Radius corrections

Eclipse	Radius correction (″)
1715	+0.48 ± 0.2

1925	+0.21 ± 0.08
1976	+0.13 ± 0.05
1979	+0.14 ± 0.06
2002	+0.03 ± 0.08

These figures represent the corrections with respect to the Sun's radius of 959.63″ at a distance of exactly 1 astronomical unit (AU).

From the results in Table 11.3 the Sun has contracted by 0.34 ± 0.2″ since 1715 and +0.01 ± 0.06″ between 1976 and 1979 and by an additional 0.11 ± 0.08″ between 1979 and 2002.

11.6 The Eclipses of 1995, 1998, 1999, and 2002

Dr. Dunham's results from solar eclipses from 1995 (India), 1998 (Curacao), 1999 (Turkey) have yielded solar diameter results logged in Figure 11.6. The data suggests that small but measurable changes in the solar radius may be determined from eclipse observations as compared to the SOHO data. On the theoretical side, there exists a debate among the experts on whether or not a numerical relationship exists between a radius change and a change in the luminosity of the Sun.

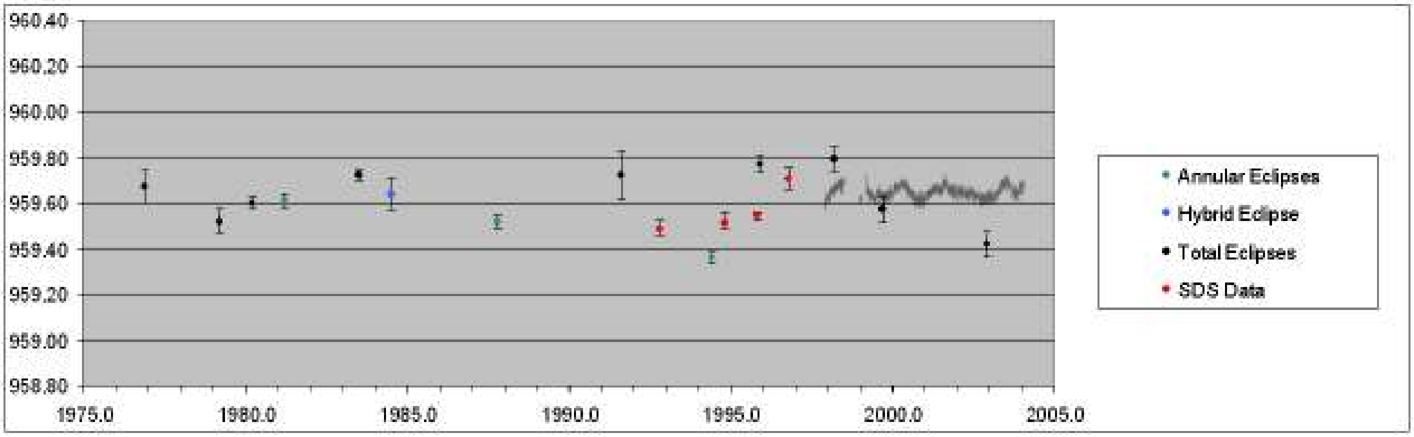

Figure 11.6. Comparison of data from several methods to measure the Sun's radius. The gray wavy line from years 1997-2004 is from the SOHO data. The vertical axis is the solar radius in arc seconds, the horizontal axis is the year the measurements were made. Diagram from Dunham, et.al., 2007.

11.7 Observing Solar Eclipses

For more than an hour before the onset of totality the edge of the Moon gradually covers the solar disk. During this partial phase there is only a gradual, barely noticeable reduction in the general illumination of the landscape. Observations of partial phases have no scientific value from IOTA's standpoint. From three minutes to one minute before totality only a thin crescent shaped sliver of the Sun remains. The landscape appears darker than usual with perhaps a shimmering tawny cast. If atmospheric conditions are right, shadow bands will resemble the ripples of light and darkness seen at the bottom of a pool of water. These bands are an enigmatic atmospheric phenomenon and their cause is not entirely understood. It has been the experience that observers at different locations along the eclipse path see quite different shadow band effects, with some locations reporting almost unobservable bands, while others see them quite distinctly. Some observers attempt to photograph them or measure their spacing plus the speed and direction of their motion.

About one minute before totality the tips of the remaining solar crescent become progressively narrower and tall lunar mountaintops break the tips of remaining sunlight into beads of light that soon disappear. These are the much revered Baily's Beads which form and disappear at an accelerating rate as totality approaches. During the fifteen seconds prior to central eclipse the diminishing solar crescent breaks into many beads of solar pearls as the edge of the Sun's disk shines through the deeper lunar valleys. The western sky darkens as the eclipse shadow envelopes the Earth at a speed in excess of over 2000 miles/hour. The last bead then disappears marking the beginning of totality.

During totality the sky is about as dark as twilight since considerable light is diffused by the atmosphere from areas outside the shadow. Intermingling clouds may block additional light assisting in darkening the sky however it will not be as dark at the edge of the eclipse path as it is at the center. The chromosphere, a reddish or pink layer of the Sun just above its bright disk, remains visible at the northern or southern edge of the lunar disk, depending on which limit the observer is near. The color is due to hot glowing (ionized) hydrogen, the most abundant element in the Sun. Reddish flame-like extensions called prominences may be visible as may the corona, a white structured halo of light extending for a distance of a few lunar diameters away from the solar surface.

As totality progresses the chromosphere travels around the limb of the Moon from the location where second contact took place to where third contact is soon to occur. As the end of totality approaches the chromosphere appears to brighten and the solar limb is observed illuminating the deep lunar valleys. The Baily's Beads phenomena occur again with small beads enlarging and merging to become a crescent. After approximately one minute the last beads merge at the tips of the crescent and the totality phenomena comes to an end.

The Sun's bright disk, called the *photosphere*, has an imperfect edge and it merges into the brighter lower part of the chromosphere. The passage of the Sun behind the Moon is much more abrupt at the center of the path of totality than at the edge. At the edge of the path the Moon’s limb grazes the photosphere taking longer to cover the Sun's limb compared to the center of the eclipse path.

11.8 Eye and Telescope Safety

More nonsense has been published about the dangers of observing the Sun during a total eclipse than just about any other astronomical topic. If there were risk of injury from “sneaking a dangerous peek” with the unaided eye, a lot more of us would be blinded by the glances we take toward the Sun almost every day. The real danger in visual observations of the partial phases of eclipses or of the Sun at any time is the use of equipment that doesn't filter enough of the Sun's radiation. Cheap filters that clip over the eyepiece of a telescope are an especially poor idea as they can crack from the heat of the Sun while in use. This danger of having the Sun's image focused by unfiltered optics can generate considerable heat which can damage the retina. Its best to use a filter that covers the ENTIRE front end of the telescope.

The risk of observing the partial phases of the eclipse can be minimized with a little common sense. Refrain from using unfiltered optics to look at the Sun at any time except during totality. Only use filters that are specifically designed for visual observations of the partial phases of an eclipse. Their design blocks damaging ultraviolet rays from entering the eye. Equipment such as video cameras, photometers and heat sensitive film should be protected with filters if used to record the partial phases and sometimes the Baily's Beads as well. Unprepared and inexperienced eclipse observers have had equipment damaged or special films ruined by insufficient protection during the partial phases.

It is completely safe to look at a totally eclipsed Sun even with a telescope or binoculars. Observers presented with such an opportunity should not miss the spectacular and unforgettable sight of the total eclipse.

11.9 Observing Techniques

The information used in determining the Sun's diameter from eclipse observations is acquired through timings of the second and third contacts, and of specific Baily's Bead events before second contact and after third contact. The Sun's image may be observed directly or by projection methods. The timing information can be obtained from radio time signal broadcasts, portable clocks, GPS time insertion or other precision timing devices. In addition, the observer's location is needed to 0.5" in latitude and longitude, and to 20 meters in height above mean sea level. The site location information is very important as the observations are worthless without it.

11.9.1 Video

Video is the prime method of recording Baily's Beads during Solar eclipses. The constantly changing pattern of beads (Figure 11.1) makes it very difficult to record their times accurately using obsolete methods to the precision that is needed for the reductions. Considering the distances needed to travel to see a total eclipse it is wise to have an up to date video system to record Baily's Beads.

The eclipse is recorded with a video camera mounted at the back of the telescope as in asteroid or grazing occultations using a proper solar filter over the front end of the telescope tube. Timing information is recorded using WWV or one of the various time frequencies available at the particular country where the observer is located. Several world shortwave time frequencies are listed in Appendix J. GPS time insertion is strongly recommended.

Without a proper solar filter, the Sun's projected image onto a piece of paper or cardboard can be videotaped. This method should be considered a last resort if something happens to one's solar filter. The length of time needed to record the Baily's Beads varies for each eclipse, the average being about the same as for a grazing occultation, i.e., approximately five minutes.

11.9.2 Video Field of View

The field of view of the Sun required to record Baily's Beads will vary slightly from eclipse to eclipse. It will also depend if the observation is being made from the northern or southern eclipse limit as the lunar limb profile differs significantly between these limits (See Figure 11.4). A good observing rule is to have your video system cover between 30° – 70° of the Sun's limb as demonstrated from the video frames shown in Figure 11.1. If the field of view of your video system covers more than 90°, the beads will be smaller and more difficult to identify in the reduction of the tape.

Test all video equipment and filters before leaving home. The time to adjust the field of view is at your home with all of your focal reducers, C-mounts and other adapters before you travel to a foreign country where it may be impossible to acquire specialized equipment.

11.10 Site Selection

The most sensitive region for eclipse edge observations extends from 1 km outside the predicted path of totality to 2.5 km inside the path. However some useful observations may be made as far as 8 km inside the predicted path. At distances greater than 6 or 8 km from the edge, the duration of the limb phenomena rapidly decreases so that the advantages of being near the edge of the path start to be lost. The closer the observer is to the actual edge while still being within the path of totality the more accurate will be the solar radius determined from the observational data.

As stated earlier, the observation site must be reported to an accuracy of not more than 1″ in latitude and longitude (preferably 0.5″ or better), and 20 meters in height. Observers without GPS receivers who are unable to provide this information are asked to supply enough data to allow someone to locate their position unambiguously on a map. A diagram and site description is also recommended. The site must be described to an accuracy of 20 ft. with respect to any identifying landmarks such as a building, highway intersection, creek, or other feature that will be shown on a detailed topographic map. Documenting older, substantial buildings are recommended in this case to increase the chances that they will be on the map. Distances of less than about 100 meters can be measured by pacing. A tape measure is recommended for some measurements whereas a car odometer is not accurate enough for specifying locations, but can be used for identifying landmarks only.

Designation of observing locations for eclipses is worked out and site locations are planned prior to travel. Observers are positioned in a manner similar to grazing occultation events and are positioned at a specified distance from the eclipse limit, usually in kilometers. Observers then use a GPS receiver to program waypoints along the eclipse limit and position themselves perpendicular as in a grazing occultation (See Figure 7.4).

Contact Dr. David Dunham or any of IOTA's Officers (Appendix A) if you desire to be part of the Solar Eclipse Team.

11.11 Reporting Observations

Reports of observations should contain:

1. A description of the technique used to obtain the timings including information on the accuracy of the time source.

2. A list of the events to within 0.1 to 0.3 second with an estimate of the accuracy of the times if the observations were done visually.

3. Estimates of reaction times for the events and a statement saying whether or not these were applied to the final reported times.

4. The observing location to 0.5" in latitude and longitude and 20 meters in elevation, or a detailed description of the observing site.

Submit observation reports to Dr. David W. Dunham whose email address can be found in Appendix A. In most instances, observers will submit copies of their video tapes to IOTA for reductions.

11.12 Observing Hints and Suggestions

The following are offered based on eclipse observing experiences:

1. Long before the eclipse practice setting up the equipment and know the work area. If several people are observing together this is the time to be sure each understands their individual job. You might also consider preparing a second tape recorder to play timed prerecorded instructions during the eclipse. This could be useful since the excitement during an eclipse could cause an observer to quickly forget what to do.

2. Do not assign multiple duties to a single piece of equipment. In particular, do not try to record a projection of Baily's Beads and the corona at totality with the same camera. Minimize the necessity to change lenses, film, digital camera memory cards, or focus, during the eclipse. Plan ahead to work as a team to photograph the whole sky at different focal lengths, gather timings of the projected image, and to photograph the eclipse with different types of cameras and film. Get together with other observers before the eclipse and arrange to trade photographs and data. It is too much for a single observer to video Baily's Beads, take telephoto photos of the Sun during totality, monitor the video equipment and adjust the telescope to move around the Sun's limb as the beads swing around.

3. Make arrangements for your observing site before the day of the eclipse. In foreign countries, have a handout translated for local people. A pre-site survey the day before is desirable to ensure that there are no surprises or problems. However observers should be flexible to change locations if doubts exist for the main sites.

4. Protect your equipment from the Sun's heat and be prepared to cover it in the event of rain. The lightweight aluminized mylar sheets sold as Space Blankets are good for both purposes. Plastic trash bags are useful for this purpose also and are easily folded into one’s equipment case.

5. WWV and other shortwave broadcasts seem to fade significantly during the central phase of total eclipses. The onset of an eclipse affects the Earth’s upper atmosphere interfering with WWV signal strength. For this reason, GPS time insertion is strongly encouraged.

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12 Half a Century of Occultations

12.1 Introduction

As remarkable as it may seem, no truly comprehensive history has been written of occultation observations and their role in astronomy, geography, and geodesy from antiquity to the present. Science writer and author Trudy Bell, while attending the University of California at Santa Cruz wrote her senior thesis "One Bright Star Within the Nether Tip': The History of Lunar Occultation Observations," in March 1971. This was an early attempt to explore the basic outlines of the history of lunar occultations, but the thesis hardly would meet historical or journalistic standards today; moreover, it was written before the foundation of IOTA and any systematic observations of asteroidal occultations. This chapter will summarize the early roles of occultation observers in founding this valuable field of astronomy, to which hundreds of dedicated amateur observers now contribute.

12.2 The Beginning of Modern Occultation Observing

One autumn night on October 29, 1957, 15 year old high school sophomore David Dunham was watching an occultation of 6.2 magnitude Beta 2 Capricorni when he saw that the waxing crescent Moon barely missed brighter 3.1 magnitude Beta 1. He was fascinated to see the star appear to skim over the tops of the Moon's brightly lit Leibniz Mountains, and a little frustrated when he realized that if only he were just a few kilometers farther north he could have seen the star flash off and on as it were obscured by those mountains and revealed in the valleys between. Was it possible, he wondered, to *predict* where on the Earth to stand to see a star just grazed by the very northern or southern limb of the Moon? Could someone predict graze paths so one could travel to them?

In the mid 1950s, no one was formally predicting grazes or even seemed aware of their potential scientific value. To be sure, accurate timings of *total* lunar occultations were in high demand by H. M. Nautical Almanac Office at the Royal Greenwich Observatory in England. Total occultations had been proving their scientific value for centuries, especially for problems of both terrestrial and lunar longitude. From the 18th through the early 20th centuries, long before the days of reliable chronometers or radio based global positioning systems, ships' navigators and land surveyors and Antarctic explorers timed total lunar occultations to determine their longitude on trackless ocean, wilderness, or ice floes, a nighttime technique that effectively cross checked the daytime "shooting the Sun" at local noon. Also since the late 18th century, total occultations have been crucial in refining lunar orbital theory, the mathematical formulae that predict where the Moon will be in the sky at any future time, especially its celestial longitude. And in the 1950s, a comparison of total occultations timed over the centuries had revealed the amazing fact that the Moon is gradually spiraling away from the Earth, as the friction of land and sea tides is causing some of the Earth's angular (rotational) momentum to be transferred out to the Moon.

In December 1959, Her Majesty's Nautical Almanac Office (HMNAO) at the Royal Greenwich Observatory in England published a feature article in *Sky and Telescope* appealing for more timings from North American observers. The same issue inaugurated HMNAO's annual eight page Occultation Supplement of predictions for the next year for a dozen standard stations around the United States, with correction factors that allowed a reader to calculate rough times for any other observing location. However, the feature's author noted, "Occultations in which the star appears to graze the Moon's edge are not predicted."

12.3 Chasing the Moon's shadow

After seeing two more near misses in the fall of 1961, one involving the brilliant red giant star Aldebaran, Dunham began searching for a mathematical way of predicting which stars could be seen to be just grazed by the Moon's northern or southern edge. By this time, he was a 19 year-old sophomore astronomy major at the University of California at Berkeley, armed with greater formal mathematical skills than he had had in high school.

One Friday evening in March, 1962, he noted from *Sky and Telescope*'s Occultation Supplement that there was to be another occultation of Aldebaran that very weekend. In fact, it was to be at the extreme southern edge of the Moon, so it *might* just be a graze practically in his own backyard. He sat down with a mechanical desk calculator and tables of logarithms and trigonometric functions, and began working out the formulae to compute the geographical position of the predicted limit—that is, the line that would be traced out on the Earth's surface by the very southernmost point of the cylindrical lunar "shadow" cast by the star, assuming the Moon were perfectly spherical and smooth.

It was a race against the clock. The task, which took 36 straight hours to compute six points on the Earth, turned out to be more demanding and time consuming than he anticipated. Finally, just an hour before the event late at night, he finished: he had calculated that the predicted limit was about 80 km south of Berkeley. As Dunham did not have a car, he convinced an astronomy graduate student to drive him down the eastern edge of the San Francisco Bay.

But time ticked faster than the two were able to push the speed limit. As they sped across the Dumbarton Bridge to get as close to the graze path as they could, Dunham held his head out the car window and noticed with his unaided eye that Aldebaran had already disappeared. On the first land they reached in Palo Alto—the campus of Stanford University—he rapidly set up his 60mm refractor just in time to see Aldebaran reappear on the Moon's bright side, lingering a few tenths of a second like a drop of water emerging from a faucet. Although disappointed at the time that he saw only a short total occultation, Dunham later realized they were close enough to the predicted limit for Aldebaran to reappear at an angle shallow enough for him actually to perceive the angular diameter of the star.

12.4 Pioneering Successes and Chasing Star Shadows

After many years of inventive mathematical calculations and unsuccessful occultation chasing, on September 18, 1962, using David Dunham's predicted geographical positions, Leonard Kalish of the Los Angeles Astronomical Society observed a multiple event graze of 4.3 magnitude 5 Tauri near Castaic Junction, roughly 65 km northwest of L.A. That historic occasion was the first time an observer in the United States had traveled to a predicted limit and successfully observed a graze. This was not the first graze to be predicted and actually observed; that honor probably belongs to Jean Meeus, who predicted a graze for Lambda Geminorum in November, 1959 whose predicted limit would come within a few hundred yards of his house. He observed three disappearances and three reappearances from his observatory in Kessel-lo, Belgium. A once thought graze was observed on the evening of November 25-26, 1960, by Leo Deming and his son from Terre Haute, Indiana ("An Unusual Occultation," *Sky and Telescope*, v. XXI, No. 2, February 1961, p. 98). However this observation was later analyzed by Richard Nugent in 2000 using both occultation software programs *Low* and *Occult* and he concluded that it was a total occultation observation of the double star, ZC 3333.

By now, Dunham realized that grazing lunar occultations could be a powerful technique for determining the Moon's precise latitude complementing the lunar longitude determinations obtainable from total occultations. It is the sheer geometry of grazes that makes their observation extraordinarily precise. Essentially, the star parallel rays from a distant star cast an exact, full sized shadow of the Moon: its jagged edges reproduce a full scale profile of the Moon's mountains, valleys, and plains, distorted only by the curvature of the Earth on which it is projected. As the revolution of the Moon in its orbit causes the shadow to sweep across the Earth from west to east, any observer over whom the shadow passes will observe an occultation. Most will see a total occultation. But at the very northern or southern edge of the shadow's path, a graze can be observed anywhere from within a band several thousand kilometers long and only a few kilometers wide. Depending on the lunar topography, graze observers only 50 or 100 feet north or south of one another on the Earth witness a different pattern of the star's disappearances and reappearances, indicating altitude differences in the lunar terrain literally to an accuracy of 50 feet. That is equivalent to an angular resolution of 0.01 arc seconds, 10 times greater than the angular resolution of the largest astronomical telescope on the Earth limited by atmospheric seeing (turbulence). This is comparable to the resolution attainable with techniques such as adaptive optics and speckle interferometry that compensate for atmospheric seeing.

Gaining confidence in his technique for predicting grazes, Dunham wrote and debugged a FORTRAN program for running calculations on a mainframe computer by February 1963. Computerizing the calculations not only saved enormous raw number computational effort but it also allowed him to generate graze predictions for fainter stars and to begin responding to out of state and out of country requests for predictions. These requests had begun trickling in as word of his work was spreading among amateur astronomers.

To answer frequently asked questions, Dunham composed a two page tip sheet called “Observing Grazing Occultations,” which was mailed to interested observers. Throughout the rest of the 1960s, this paper evolved to updated successors, creating a series that became known as “OGO” followed by a number in Roman numerals for its place in the sequence. Predictions and OGO papers were sent to astronomy clubs around the country as well as to the editors at *Sky and Telescope* and the *Review of Popular Astronomy* (a bimonthly magazine recreated from the older *Monthly Evening Sky Map* that had a loyal following of active observers). OGO-I, for example, was reprinted in the December 1963-January 1964 issue of *RPA* as well as in *The Eyepiece*, the monthly bulletin of the Amateur Astronomers Association of New York City.

12.5 Early Publicity

In October 1963, *Sky and Telescope* published Dunham’s first predictions acknowledging him as the author and point of contact (See Figure 1.3, Chapter 1). They were for a graze of 3rdmagnitude Zeta Tauri on the night of October 7-8; an accompanying map showed that the northern limit swept from roughly Fort Worth, Texas to near Montreal, Quebec. This published appeal inspired teams of observers at two locations in Texas, one in Little Rock, Arkansas, and one each in Dayton and Columbus, Ohio; all sent their results to *Sky and Telescope*, which printed them in December.

From early on in the graze program, the number of observers had been growing rapidly. For this October 8, 1963 graze of ζ Tauri, $m = 3.0$ (just 1 degree from the Crab Nebula) one of the observers for this event was Harold R. “Hal” Povenmire. He observed this graze from Perkins Observatory near Delaware, Ohio. Although he observed a miss, being several hundred yards from the limit, he became very interested in observing grazes and this event started a new chapter in lunar occultation and graze work. To date Povenmire has led over 500 successful grazing occultation expeditions (and many unsuccessful ones), more than any other observer. Over 400 of these expeditions were with the central Florida based Canaveral Area Graze Observers, a group he formed in 1968.

In Dayton, physics teacher David E. Laird began promoting the event to classes at Washington Township High School, inspiring 30 students to show up “with all the telescopes and binoculars they could find.” They separated into eight groups along the predicted graze path, each with a tape recorder and radio tuned to Dayton radio station WONE, which cooperatively broadcast voice time signals every 15 seconds. One observer was rewarded with a spectacular 10 events, five disappearances and five reappearances in less than two minutes. “At four other stations, the star disappeared at least twice, making our program so successful that almost everyone offered to travel a hundred kilometers to see future grazes,” exulted Laird.

By the end of 1963, at least 13 grazing occultation expeditions had been organized and observations made or attempted. Most of them were California based, led by Dunham himself. But several had been organized by local observers out of state including New Mexico, Ohio, Wisconsin, and even in New Zealand. The Wisconsin chapter was the first of many such expeditions led by Ed Halbach of the Milwaukee Astronomical Society (MAS). It was not long before Milwaukee (through the MAS) and Ohio (led by Laird) became important centers for chasing grazes in the Midwest.

Against this background of awakening consciousness occurred the graze expedition of February 18, 1964, in which Dunham led 19 other amateur astronomers near Davis, California. The dozen stations secured 60 accurate timings for the southern limit graze, making it the most successful graze observed up to then, a record it held through 1964.

Sky and Telescope's illustrated report of the Davis expedition, published in the July, 1964 issue, inspired worldwide fascination with chasing grazes, as can be seen by the dramatic growth in the number of expedition leaders receiving predictions and the expeditions they fielded. From then on, Dunham's roster of observers and expedition leaders nearly doubled each year. In 1964, Dunham's two page roster of observers listed 67 individuals and amateur astronomical societies in 26 states and four countries. In 1965, the mimeographed roster had grown to three pages listing 119 individuals and societies in 33 states and five countries. By 1966, the roster had doubled to seven pages, including 25 countries on six continents. By 1968, it was 10 pages long and obsolete the day it was duplicated.

Moreover, while in 1964 observers chased 21 grazes, by 1966 the number had leaped to 52. Even those numbers hide the true magnitude of amateurs' fascination, as a number of favorable grazes (bright star, early evening crescent Moon) had been timed independently by anywhere from two to half a dozen separate expeditions; moreover, some expeditions comprised dozens of observers. By mid 1967, the sheer volume of observations (plus the pressure of graduate studies and work on his dissertation in astronomy at Yale University) forced Dunham to discontinue his practice of compiling an annual annotated list of all the grazes observed the preceding year.

By 1968, Dunham was sending predictions to hundreds of individuals from dozens of countries on six continents, who collectively were chasing more than 100 grazes a year, some grazes attracting up to half a dozen independent expeditions, each comprising dozens of observers. That same year, the Western Amateur Astronomers at its annual regional convention awarded Dunham (by then an astronomy graduate student at Yale University) its prestigious G. Bruce Blair Award, essentially the "Nobel Prize" of amateur astronomy.

Hal Povenmire met Dunham during the graze of Antares on January 25, 1968 from Fairmont West, Virginia. This graze was the first time in which dimming phenomena was observed due to the large angular size of Antares. It was not surprising that dimming events were observed, but no one expected them to last up to ten seconds. This important observation led to the use of occultations to determine stellar diameters of which several hundred have been determined to date.

Six months later on July 29, 1968, a graze of the 7th magnitude star SAO 138613 was observed by a large team near Cincinnati, Ohio. All of the stations had a miss, but this event was not forgotten. Later that year the same star had a southern limit graze over south Florida. Povenmire led a team of observers who drove through the night in rain and observed the graze near dawn under clear skies. Shortly after the star was occulted a faint companion was observed. This was likely the explanation of why the January graze had a miss – the position of the star was poor due to its unknown double nature.

12.6 Of Cables and Radios

Early graze chasers and expedition leaders were more than just pioneers in amateur observations of scientific value to astronomy (even helping to refine the position of the Moon in time for the Apollo Moon landings of 1969-72). They also pioneered technical inventions.

In the early 1960s, the optimal independent or self contained graze observing station (as it was named) had all the minimum equipment necessary for scientifically useful timings and could be deployed anywhere. It consisted of an eyeball and a brain, a telescope, a battery powered capstan driven reel to reel tape recorder, and a battery powered short wave radio receiver tuned to standard U.S. (WWV or WWVH) or Canadian (CHU) time signals. When the star disappeared or reappeared, the solitary observer simply exclaimed D or R, which was recorded on tape along with the time signals. The tape, played back after the graze, revealed the actual times of each event, as well as the observer's comments about any peculiar observations such as whether the star dimmed first before blinking out.

In the never ending search to reduce reaction time and personal error, observers were forever innovating. One frustration, for example, was that voice comments have a fuzzy beginning and that eye-voice reaction time was largely unknown compared with eye-hand reaction time. Several amateurs around the country independently found the Holy Grail in the form of a child's metallic noisemaker cricket or frog, which sounded a sharp click when pressed or released. The best toy noisemakers had a distinctly different pitch when pressed than when released, so that the difference between a click for a disappearance and one for a reappearance was easily heard on tape. But this clever innovation could backfire; when one observer used such a mechanical cricket for a graze crossing a marshy area, the response of *real* frogs and crickets drowned out his timing signals on his tape recorder!

The most revolutionary innovation, however, was the invention of timing cables around 1965, an idea of U.S. Naval Observatory astronomer Thomas C. Van Flandern. Van Flandern thought a cable would offer two major advantages: it would provide a common recording system, and it would space observers at known distance intervals, thus saving the trouble of having to determine geodetic coordinates of each observing station separately. He designed a 4,000 foot long cable that was built at the U.S. Naval Observatory in Washington, D.C. Although the original design called for stations to be 500 feet apart, a workman's error, wrapping cable around a 100 foot length four times instead of five, caused the stations to be placed 400 feet apart instead. Push buttons at the 400 foot intervals along the cable activated tone generators, each with a unique pitch; an observer would press the pushbutton once to signify that the star had disappeared and twice quickly to signify it had reappeared. The signals were recorded on one master tape, along with WWV time signals.

The nine station cable debuted on June 9, 1965 for the graze of 4th magnitude Kappa Virginis near Richmond, Virginia. Observers and members of the Richmond Astronomical Society and the National Capital Astronomers obtained the best observations of a northern limit grazing occultation yet. (Among other things, this pioneering cable-timed graze showed more distinctly than earlier observations that the lunar limb correction data used for the northern region of the Moon was too high by about one km, necessitating a change in the radius and center of the lunar reference sphere used for the lunar limb.) By August, success had inspired the USNO to double the cable's length to 8,000 feet.

Now, in the 1960s, well before the era of cheap microchips, many amateur astronomers loved tinkering with electronics to build equipment they could not afford to buy ready made (a fair number, for example, built their own WWV receivers and stereo systems from Heathkit kits). So news about the USNO. timing cable galvanized Midwestern and California amateurs to scrounge up donations of wire, pushbuttons, and other equipment from local telephone companies and electronics houses to build their own graze-timing cables.

Several had an innovative design twist. In 1966, the Milwaukee Astronomical Society, under the leadership of Ed Halbach, fielded a cable that was fully three km long with stations at intervals of 0.16 km. Instead of recording on tape, however, the observations were displayed on a 20-pen chart recorder—19 for stations and the 20th for WWV time signals. By 1968, the Santa Barbara Star Cluster in Santa Barbara, California had built a 1.5 km long cable with stations 400 feet apart; in theirs, the tone generators were built into telephone headsets so that the whole cable became an open phone line enabling each amateur to communicate to everyone else, making technical checkout and observer sign in very easy. Meanwhile, the Riverside Astronomical Society in southern California, under the leadership of Clifford W. Holmes, built a cable 1.5 km long with 13 stations and the Mount Diablo Astronomical Society in Concord, California, under the leadership of Jack A. Borde had fielded a seven station cable about 1.5 km long.

12.7 Strengths…and Weaknesses

Within a year of the USNO's cable debut, timing cables had clearly demonstrated their power. The expedition leader no longer had to wait for individual observers to analyze tapes and turn in timings at their own leisure, but could drive home from the graze site with all the data in hand. Timing cables also allowed much bigger expeditions by eliminating the need for each observer to provide his or her own timing equipment—very helpful, since in the 1960s it was common for an amateur to own a telescope but not a short wave receiver. Thus anyone who showed up with just a telescope could be positioned at a cable station. By August, 1966, six out of the all time top 10 most successful grazes (as measured by the number of accurately timed events, disappearances and reappearances, not by number of observers) had been timed using cables, a number that further increased to eight out of 10 by 1968.

Timing cables also had disadvantages, which were less well publicized. Since the distance between stations was set by the length of the intervening wire, they allowed only limited flexibility in spacing observers (a potential issue for southern limit grazes where the especially rugged terrain of the Moon's profile called for scattering observers along a line up to 6.5 km long perpendicular to the predicted limit. So there was still great need for supplemental independent stations) usually manned by the most dedicated and experienced graze chasers, who were the ones who typically spent the extra money for WWV receivers. Cables also required more careful logistical planning for an expedition, as rolling out all the cable lengths (whose weight totaled hundreds of pounds), connecting them, and testing the set-up usually took several hours, as did spooling them back up onto a trailer or pickup truck after the graze.

The greatest problem with the earliest cables was their uncertain reliability and when a cable failed, it usually meant *all* the stations on it failed. A graze of a 6.6 magnitude star at Virginia Beach, Virginia on March 29, 1966 offered the first chance for the USNO to test the full 8,000 foot length of its 21 station cable, which was stretched out along the boardwalk. The city even graciously turned out the street lights during the observing period. When the lights were turned back on, over 100 timings had been secured, potentially making it one of the most successfully observed grazes of its time, but the master tape turned out to have so much noise that few of the timings were ever recovered.

Two northern California grazes in October, 1967, to be timed with the Mount Diablo Astronomical Society's cable, further showed how technical difficulties with a newly constructed cable posed cliffhangers. For one graze on the 15th, the cable's designer Jack Borde worked until 2 AM four nights straight to troubleshoot some persistent problems, and on graze day the cable still failed, taking with it all the timings. By the next graze on the 24th, Borde had the problems solved; the cable was laid out and the stations manned. But an hour before graze time, the cable failed yet again; Borde and the expedition leader Povenmire scrambled to double up the observers with extra radios and recorders, thus obtaining data from only five stations instead of more than 10. Thereafter, Povenmire backed up both ends of the cable with independent stations manned by the most dependable observers, while he positioned himself near the middle.

But Povenmire held the faith: "When the cable works—it works like magic! Cables are new-bugs haven't been all worked out.—They will be." And he was right. On October 24, 1970, for a graze of Nu Leonis, an expedition led by Robert Fischer using the Borde cable near Westmoreland, Calif., set a record by capturing 135 accurate timings. Word of this notable event sparked the interest amateur astronomers in getting involved in graze observations. Two months later on December 4, 1970 this record was broken by another expedition led by Povenmire (See Section 12.10 below).

12.8 The Founding of IOTA

Throughout the 1960s, momentum built and grazes were an amateur's dream. They were pioneering, and wholly a new type of observation. They were scientifically valuable, complementing total occultations as a way of measuring the latitude of the Moon and its mountainous terrain with unprecedented accuracy—important for the Apollo Moon landings. They were accessible to the humblest telescopes: indeed, since the Moon's shadow was cast life sized on the Earth, modest 60 mm refractors 0.16 km apart on the Earth could readily distinguish between lunar features less than 150 meters feet apart at the distance of the Moon, giving the observers an effective resolution of 0.01 second of arc—10 times better than that of the largest telescope in the world! Grazes were gorgeous, one of the few kinds of astronomical events where an observer could watch dramatic changes in just a few minutes. And they were social, as getting the best data from a graze required positioning as many observers as possible along a line three to six km long straddling the predicted limit—requiring true expeditions to caravan out into the middle of nowhere in the middle of the night.

By 1974, Dunham's mailing list was so huge that the costs of computing predictions, photocopying instructions, and postage exceeded the budget of either his personal finances or what he felt he could cadge from any institution with which he was affiliated. So after years of resisting a formal structure, he was compelled to start a quarterly *Occultation Newsletter* for an annual subscription fee, which included the cost of local graze predictions. The first editor of *Occultation Newsletter* was Homer F. DaBoll. DaBoll was a major graze observer/leader in the Chicago area and was the person that coined the term "IOTA" as the International Occultation Timing Association. In 1975, Dunham founded the International Occultation Timing Association (IOTA). In 1983, Paul Maley, IOTA's Vice President secured IOTA tax exempt status as a Texas non-profit Corporation. Annual meetings were held in Houston, Texas until 1998 when newly elected Executive Secretary Richard Nugent showed that meetings could be held anywhere. This allowed IOTA's annual meetings to be held at locations in the USA surrounding important and spectacular occultation events.

By then, grazing occultations had become a staple of amateur observing along with total occultations, variable star observing, meteor watching, and comet hunting. Grazes had also been applied to geodesy, that is, precision mapping of the Earth, as well as to refining predictions of the orbital motion of the Moon (although both applications were later superseded by the advent of global positioning system satellites and by laser ranging to reflective lunar targets left by the Apollo astronauts). With unprecedented accuracy still not surpassed today even by the lunar orbiting spacecraft Clementine, grazes also helped refine maps of the polar lunar topography that can be seen in profile against the sky. They also have revealed hundreds of hitherto unknown close double stars, especially for fainter stars (8th and 9th magnitude). Today IOTA's data base includes the results of over 3,100 grazes observed since 1706.

12.9 Pursuing Shadows of Asteroids

Around the time Dunham founded IOTA, he became intrigued by an even more challenging type of occultation: that of a star by a distant asteroid. The idea wasn't new. Back in the 1950s, Gordon Taylor at the Royal Greenwich Observatory had started predicting the occultations of stars by the first four asteroids (1 Ceres, 2 Pallas, 3 Juno, and 4 Vesta) hoping to learn more about their exact sizes and shapes. In 1958 and 1961, observers in Sweden and India had succeeded in watching stars blink out behind 3 Juno and 2 Pallas, respectively.

The same geometry that gives such extraordinary accuracy to grazing lunar occultations of stars gives equivalent accuracy to asteroidal occultations of stars. The parallel rays of light from a distant star again casts a full scale shadow or silhouette of an asteroid on the Earth. The perpendicular cross section of the shadow is the exact size of the asteroid, and thus can be used to measure its size and shape, with any of the asteroid's surface irregularities (craters, mountains, boulders) in profile at that instant revealed in life sized detail. The shadow sweeps across the Earth at about 10 km per second (about 10 times faster than the Moon's); so for an asteroid 50 km in diameter, an observer on the Earth would see a total occultation with about 5 seconds between the star's disappearance and reappearance. The more observers of the occultation, the more accurate is the representation of the asteroid. Ideally, many observers would be stationed not only along the central line of the shadow's path, but also north and south of the path to obtain different chords across the asteroid as well as to account for errors in the predicted path. This is particularly important for determining the shapes of medium sized and smaller asteroids, which are often quite elongated.

Compared to grazing lunar occultations, however, both predicting and observing asteroidal occultations are problematic. First, unlike the Moon, asteroids are tiny. A handful of the largest asteroids are all only 400 to 925 km across and more distant than the planet Mars. Worse, their distance means that a small angular uncertainty in their position in the sky translates into a significant uncertainty in predictions of their orbits, and thus of the paths their star-cast shadows would sweep across the Earth. In addition, the average star in the path of an asteroid is also relatively faint (8th to 11th magnitude). It was not until the mid-1970s that computational methods were refined enough to yield predictions that gave observers a reasonable probability of actually seeing asteroidal occultations semi regularly.

Dunham, however, has always relished a challenge. So when Brian Marsden of the Smithsonian Astrophysical Observatory issued predictions that as seen from New England the asteroid 433 Eros was due to occult the 3.6 magnitude star Kappa Geminorum on January 24, 1975, Dunham tirelessly encouraged IOTA members in the northeast to try to observe it. Although he was unable to try the observation (as a low paid researcher at the University of Texas, he did not have the wherewithal to finance such a long trip) results from the event fired his imagination. This was the first asteroid occultation observed in the United States that had more than one chord and only the third one observed in the US. Six observers made occultation timings. The derived profile of 433 Eros came in at an elongated 14.8 km x 6.9 km. At this time asteroid occultations were in their infancy and not much was known about these elusive solar system objects since even the largest ground based telescopes could only show them as points of light.

A few months before the Eros event an observation was made by Hal Povenmire on October 12, 1974. The asteroid event was that of 129 Antigone occulting an $m = +6.4$ star from south Florida. He planned on observing a graze that night of SAO 118338 from Cooper City, Florida so he set up his equipment early for the asteroid event. At this point in time, predicting asteroid events was truly a wild goose chase since highly accurate star positions and asteroid orbits were not available. Povenmire observed a brief 0.7 second occultation of the star at the predicted time of the event and sent his report to the US Naval Observatory, the Smithsonian Astrophysical Observatory and the Royal Greenwich Observatory in England. At the time Povenmire thought he had observed a graze of Antigone. Gordon Taylor of the Royal Greenwich Observatory, HM Nautical Almanac Office sent Povenmire a letter notifying him of a south shift of Antigone's path. Povenmire's observation was within 0.1 minute (6 seconds) of the predicted time of the event. Later astrometric (positional) updates had shown that the asteroid's shadow passed well south of Povenmire's location through the Central American countries Guatemala and Belize. To this day it is unknown what Povenmire saw. A word of caution should be noted here – asteroid occultation predictions in 1974 were subject to large errors. No other observers saw the Antigone occultation along the primary path (being clouded out) hence there is no way to confirm what Povenmire actually saw.

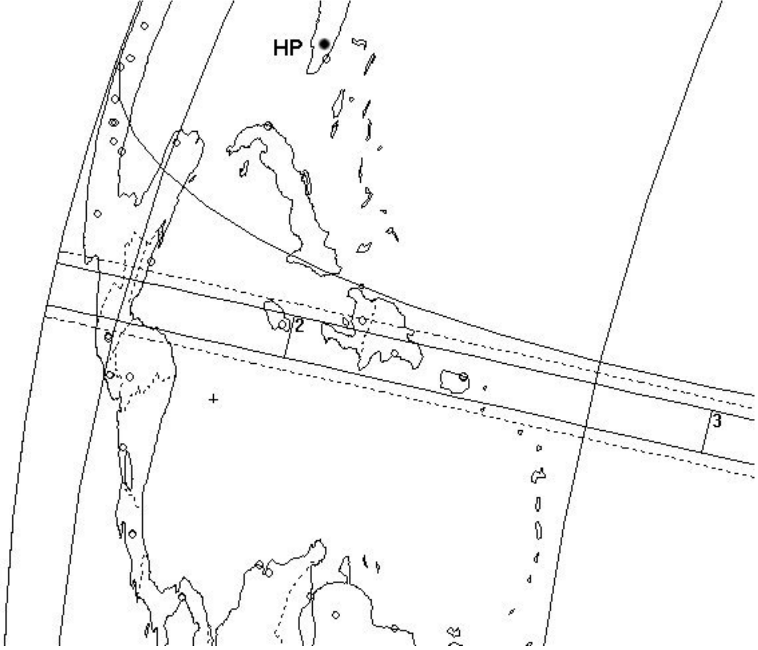

Figure 12.1 Predicted path of 129 Antigone over Central America on October 12, 1974 using *Occult* software. Hal Povenmire was located in south Florida a the point marked "HP", well north of the path when he observed a 0.7 second occultation.

Dunham's chance to observe such an asteroid event came in March 5, 1977, when he and Gordon Taylor predicted that observers in the southern United States could see the 200 km diameter asteroid 6 Hebe occult another 3.6 magnitude star Gamma Ceti. From Mexico through Texas and Florida, Dunham organized observers to time the event. "Right after the event I first heard from Paul Maley," a veteran Texas occultation and eclipse observer watching from Victoria, Texas, who reported seeing a 0.5 second occultation through his 5-inch refractor, Dunham recalled. But when an hour later he heard that three separate observers around Mexico City timed longer occultations, Dunham realized the two sets of observations could not have been the same.

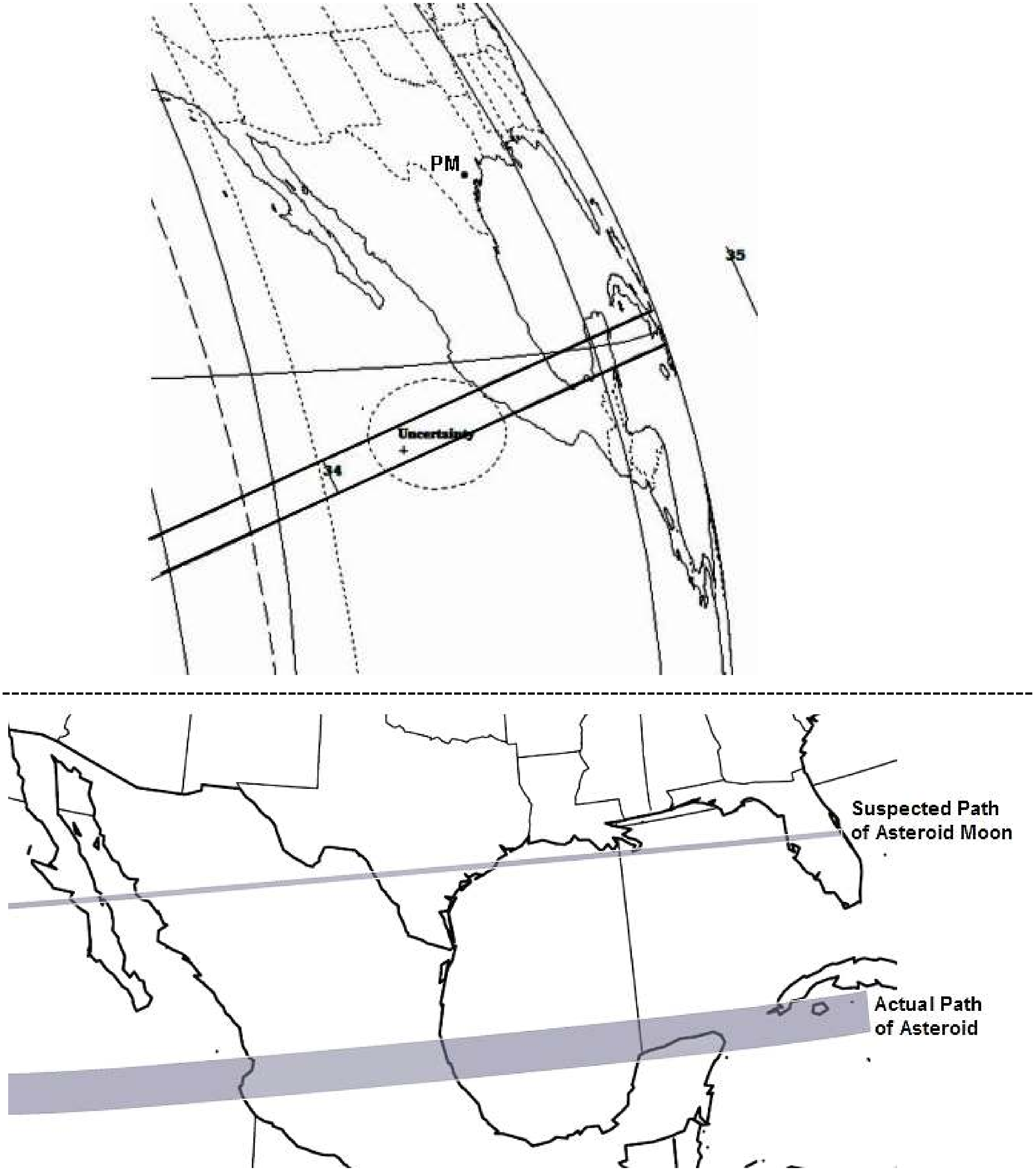

Figure 12.2. Path of 6 Hebe on March 5, 1977. Upper diagram is the prediction from *Occult*. Lower diagram shows the actual path from occultation observations over Central Mexico. Paul Maley (PM in upper diagram) was located in southeast Texas, well north of the path in central Mexico and the Yucatan, when he observed a 0.5 second occultation.

When Maley found out about the Mexico City observations, he suggested to Dunham that his observation could have been due to an asteroidal moon. The time of Maley's observation and its certainty (Maley was a highly experienced occultation observer) make the asteroid moon hypothesis a probable reality.

"Our claim is that we made a discovery of an asteroidal satellite!" Dunham later recollected, "although at the time few would believe us." Following the Antigone and Hebe event, and the possibility of the existence of asteroidal satellites, it was later determined that an asteroidal moon can have a stable orbit at a distance out to 10 times the diameter of the parent asteroid. Only after 1993, when close-up images by the Jupiter bound Galileo spacecraft revealed that the 58 x 23 km asteroid 253 Ida was accompanied by a 1.6 km diameter companion (later named Dactyl) was it acknowledged that some asteroids do have their own moons.

As with Povenmire's observation, Maley's location was well within 10 times the diameter where a stable asteroidal satellite can orbit the parent asteroid. Povenmire and Maley are some of the finest occultation observers in the USA. Maley's observation of an asteroid satellite were considered credible. Since 1978, short secondary occultations have been reported for perhaps 15 or 20 asteroidal occultations, but none has been independently confirmed as an asteroidal satellite. Nevertheless it is known asteroid satellites are out there and this makes the exciting potential for discovery.

Another biggest ever demonstration of the power of asteroidal occultations was the enormous push to observe 2 Pallas—the second largest main belt asteroid—obscure the 4.8 magnitude binary star 1 Vulpeculae on May 29, 1983 across the southern United States. Maley led the effort in Texas and organized the bulk of the observing stations. The organizers made numerous presentations to astronomy clubs and groups in an effort to recruit as many observers as possible. Together Dunham, Maley and Povenmire fielded more than *240 expeditions* at more than 130 locations, totaling more than *400 observers* across Arizona, Texas, Louisiana, Florida, and Baja California, and mainland Mexico with 131 obtaining timings (the southern portion of the path was obscured by clouds and some observers were outside the actual path). The asteroidal occultation revealed that Pallas was somewhat elongated with rough topography, the observations revealing features 10 to 20 kilometers across, about 2 to 4 percent the asteroid's diameter—the most accurate size and shape for 2 Pallas then known.

Since then, Dunham has been predicting and chasing asteroidal occultations all around the country and even around the world, devoting his same tireless skills in talking and writing up this new type of event as he had previously for grazes. For some observers—notably those who preferred not to stir from their large backyard observatories—asteroidal occultations are more appealing than grazes. First, small telescopes still can be used to see fainter stars along with sensitive video cameras to record the events with an accuracy to 0.03 sec. Second, because of the number of asteroids and the width of their paths, an observer at one location has a far greater chance of seeing an asteroidal occultation than a graze—three or four times a year compared with once a decade—so there's less need for travel. Third, although the shadow of an asteroid cast by a star on the Earth is the same diameter as the asteroid in space, uncertainty in the *path* of that shadow (owing to uncertainties in knowledge of asteroidal orbits) could be as wide as the shadow itself ! Thus observers as far as 50 or 100 km north or south of the predicted path have some chance of seeing an occultation—and even if they don't, their observations are useful in defining the northern and southern limits of an asteroid's shadow. Lastly, there is always an outside chance of discovering an asteroidal satellite. Nowadays Paul Maley, Richard Nugent, Tony George and others now use image intensifiers routinely as part of their equipment setup and can video record stars down to *m* = +12.0 with a 4-inch telescope, and *m* = +13.5 in a 10 inch.

Asteroid occultations are significantly more challenging to observe than most grazing or total lunar occultations. Many observers use moderately large telescopes, even ones permanently mounted in observatories, and rely on highly sensitive video cameras rather than on their eyes to record the events. Many asteroids are fainter than 14th magnitude thus there are no regular astrometic observations made to update their orbits. Thus uncertainties still result in the predicted position of an asteroid's shadow on the Earth being shifted north or south by up to the diameter of the asteroid itself. Prior to 1997, asteroid occultation predictions were dependant on positions of the star from ground based star catalogs in addition to the asteroid ephemeris. These ground based star catalogs suffered from positional uncertainties mainly due to the earth's atmospheric seeing. Due to these positional uncertainties and the many observers who had negative observations over the years, for a long time some people referred these events as "David Dunham wild goose chases." This all changed with the release of the European Space Agency's Hipparcos Star Catalog in 1997. The high accurate star position data from the orbiting satellite Hipparcos greatly improved the prediction of the paths. Since 1976, more than 1,000 occultations of stars by asteroids have been observed. Today IOTA records more asteroid occultations than grazes per year, with some observers attempting more than 30-50 asteroid events per year.

As a result, observers scattered along the observing path—even ones who from the predictions alone might not expect to see an occultation—could make useful and even surprising observations.

12.10 Notable Occultation Events

Hal Povenmire's unswerving dedication to chase grazes has resulted in discoveries of new double stars, possible asteroid moons and novae undergoing flares.

On September 3, 1981 Povenmire got an excited phone call from one of his student amateurs from a local astronomy club, Jim Getson. He said a star of 1st magnitude or brighter was about to be occulted by the Moon. Povenmire knew of no such occultation, but quickly set up his equipment and observed a bluish star of magnitude +2.0 near the earthshine of the thin waxing crescent Moon. Glancing over his predictions he saw that there was no bright star scheduled to be occulted. The star had then faded to *m* = +4.0 and disappeared behind the earthshine lit portion of the Moon's east limb. He recorded the time and estimated the cusp angle (angle along the limb from the terminator).

The predictions showed a star of m = 7.1, spectral class F2 at the cusp angle where he observed the occultation at the right time. The star, SAO 158835, had clearly undergone a flare. While the star was still behind the Moon, Povenmire called the US Naval Observatory, David Dunham and the American Association of Variable Star Observers (AAVSO). West coast observers were alerted and reported a star of approximate m = 5.0 near the Moon's bright limb after it reappeared. By the time the news of this event got into the hands of the professional scientific community, the star had returned to its normal magnitude and spectral class.

In 1975 after chasing grazing occultations for 12 years, Povenmire published the first book of its kind, "*The Graze Observer's Handbook*". The 2nd edition was published in 1979 and the 3rd edition in Italian in 1999.

One of the most successful grazing occultation expeditions Povenmire led was that of Iota Capricorni on December 4, 1970 in central Florida. Months of planning and recruiting observers paid off. A record 235 accurate timings were acquired making this the most successful graze observed as of that date. This event held the record for the most timings event until February 10, 1973 when Paul Maley and Hal Povenmire led the highly successful Merope (Pleiades star) graze in both Texas and Florida with over 310 total timings.

Povenmire's interest in astronomy was not limited to grazes. He has done extensive research and field work on tektites and their origin and published two books on the subject. For his extensive contributions to occultation science, on August 4, 2000 Carolyn Shoemaker named asteroid 12753 in honor of Hal Povenmire and his wife Katie for their many contributions to IOTA and their studies in the field of meteors and meteorites. For his contributions to the field of tektites and planetary astronomy, Povenmire had the honor of having a 2nd asteroid named after him, 15146 HalPov in 2003.

Povenmire has published eight books and over 230 articles in the field of occultations, planetary astronomy and meteoritics. Hal Povenmire has truly been a giant in the field of occultations.

As occultation observing continued, and with the influx of new observers with fresh ideas, new techniques and methods became available. Take for example video recording of events. No longer did the observer have to rely upon memory to reduce the data and estimate personal equation. A video tape can be played back repeatedly to determine the start and end time of an event and the duration to 0.03 sec accuracy. In addition to being played back to audiences, video is perhaps the best method to recruit new observers for upcoming major occultation events. Few astronomical events are as spectacular to watch as a video of a star vanishing for several seconds and reappear instantaneously as an asteroid passes in front of it.

Video systems have fallen in price dramatically since the first bulky systems were used in the early 1980's. 21st century technology has made available occultation cameras weighing just a few ounces that quickly attach to any telescope, and cost less than $100.

The first successful video observation of a total occultation by the Moon was made by Susumu Hosoi of Japan who video recorded the occultation of the bright star Aldebaran in 1979.

In June 1980, a TV station cameraman in New Orleans video recorded a graze of the star Regulus with one disappearance and one reappearance. On May 10, 1981, Alan Fiala of the US Naval Observatory video recorded 14 events (7 seven disappearances and 7 seven reappearances) of δ Canceri near Conowingo Dam, Maryland. Fiala had the most timings of anyone in that 20 station expedition.

The first video observation of an asteroid occultation was made on November 22, 1982 by Peter Manly. He taped 93 Minerva occulting the m = 7.8 star SAO 76017. Also using intensified video to record this event was J. Vedere, Pierre Laques and Lecacheaux at Pic Du Midi Observatory, France. Video techniques were further refined in the 1980's when Peter Manly developed a WWV time inserter. This device allowed extraction of the WWV time signals to be overlaid upon a video recording allowing 0.03 sec accuracy to be obtained. Later, in the 1990's the Japanese and Europeans independently developed a GPS time inserter that used times signals from GPS satellites to overlay high precision times onto the video allowing frame by frame playback to achieve the same 0.03 sec accuracy. Many such devices are now made for occultation work by German, Australian and American amateur astronomers. (See Appendix D, *Equipment Suppliers*)

On January 10, 2000, Dr. Alan Stern of the Southwest Research Institute in a NASA F-18 Fighter Jet recorded the occultation of an 8th magnitude star by the asteroid 308 Polyxo while flying over Death Valley, California. Three other ground based observers, Joe Hobart of Flagstaff, AZ, J. Sanford of Springville, CA along with Richard Nugent and Marilyn Burke in Oklahoma also observed the occultation (see Figure 6.16 for Polyxo's profile). The F-18 jet was able to maneuver to the precise position to record the occultation while cruising above the clouds and much of the Earth's obscuring atmosphere. This was the second occultation event from an aircraft. In 1979, Pallas was observed by the KAO. The F-18 onboard GPS navigation system fed data into the imaging system during the occultation to account for the near Mach 1 speed.

Another giant in the field of occultations comes from another major occultation center, the Royal Astronomical Society of Australia. David Herald is the author of the most comprehensive computer software program for lunar, asteroid occultations and solar eclipses, *Occult*, described in detail in Chapter 4, Predictions. The computational methods and graphical charts within *Occult* are the standard for predicting asteroid occultations on IOTA's asteroid prediction webpage. Herald has been involved since the early 1980's in the long term study of possible solar radius variations. In 2004, Herald became IOTA's first recipient of the Homer F. DaBoll award for his lifelong contributions to occultation science.

12.11 Planetary occultations

In March 1977, the distant planet Uranus passed in front of the 9th magnitude star SAO 158687. Although eagerly anticipated by many astronomers, the best results came from a team led by James L. Elliot of Cornell University, who watched the occultation high above the Indian Ocean with the 36inch (91cm) reflecting telescope aboard NASA's former Kuiper Airborne Observatory. They recorded the star instantaneously dimming nine distinct times before it disappeared behind the ball of Uranus, and dimming another nine times at symmetrical distances away from Uranus after it reappeared. From the data, Elliot and others deduced that Uranus is surrounded by a system of nine rings that are both remarkably dense and remarkably narrow (most less than 10 km wide and only the outermost ring being as wide as 100 km). Subsequent occultations of stars by Uranus have revealed that the rings are not circular, but appear to have elliptical bulges.

The fact that the solar system's largest Kuiper Belt Object (KBO) Pluto has an atmosphere was also discovered when Pluto passed in front of a 13th magnitude star in 1985 and confirmed during Pluto's occultation of a 12th magnitude star in 1988. Half a dozen subsequent occultations have revealed that Pluto's atmosphere has several layers, and that its temperature has been rising following the planet's closest approach to the Sun in its highly elliptical orbit.

Temperature changes have also been observed in the atmosphere of Neptune's largest moon Triton during its own occultations of stars. Occultations of stars by comets have also proven useful in learning more about cometary structure, particularly the gases in the coma surrounding the comet's bright nucleus.

Dr. Dunham has given some thought to occultations of stars by outer solar system objects such as smaller KBOs beyond the orbit of Neptune, which may be distant asteroids or the icy nuclei of comets, of which Pluto is one of the larger representatives. As seen from the Earth, KBOs less than 10 km across would be comparable in size to the apparent diameter of many stars and the occultation of a star by a KBO would give rise to fringes due to the interference of light. If recorded using sensitive high speed photometry (instrumentation for measuring changes in a star's brightness on a time scale of about 0.1 second) from several ground based observatories simultaneously, such interference fringes and their timing could reveal information about the size, density, and distance of KBOs. In turn, that information could help determine the mass of KBOs, possibly yielding clues about the formation of the solar system. By the early 21st century, several programs had been proposed to observe occultations by KBOs from robotic ground based observatories and from satellites. Still, for the most part, KBOs would be "out of reach of most amateurs, as they usually involve stars fainter than 14th magnitude," Dunham commented. Also, "They're harder to predict with uncertainties of 5 to 20 pathwidths." But he's hopeful that future astrometry satellites might change all that.

12.12 IOTA Worldwide

The role of occultation observers was not limited to the United States. IOTA's sister organization, IOTA European Section (IOTA-ES) has been heavily involved with occultation work. The Dutch Occultation Association was founded in 1946 as one of the world's first associations to promote observations by amateur astronomers of celestial occultation events. DOA now counts over 65 members, of whom some 20 actively observe occultation phenomena. With its annual production of over 400 timed occultation events, the group is among the most active in the world. DOA, or the Nederlandse Vereniging van Waarnemers van Sterbedekkingen as it is known in the Netherlands, is related to the Dutch Meteorological and Astronomical Society (Nederlandse Vereniging van Weer- en Sterrenkunde). Every year in May or June (depending on holidays in The Netherlands) the DOA has its annual meetings in one of the many public observatories. It has regular meetings with fellow organizations in Belgium and Germany, and is often represented at the European Symposium on Occultation Projects (ESOP). DOA organized ESOP twice in 1993: ESOP XIII in Roden and ESOP XXV (www.esop2006.nl) at the University of Leiden. The DOA is also a member of IOTA-ES.

Some of the major contributors to occultation work from Europe are Eberhard Bredner, Hans Bode, Wolfgang Biesker, Eberhard Riedel (author of *Grazereg* program described in Chapter 5), Eric Limburg (author of Lunar Occultation Workbench software, *Low*), Jan Manek, (asteroid occultation predictions and catalog of all observed events), Edwin Goffin (asteroid occultation predictions worldwide), Henk Bulder (double stars) and many more.

Since the early 1990's Edwin Goffin has been producing the standard asteroid occultation prediction charts, which include global views of the path and detailed star chart in a one page easy to read format (see Figure 6.5). These are available on the Internet for download via a ftp server (ftp://ftp.ster.kuleuven.ac.be/dist/vvs/asteroids/) in the convenient PDF format. Goffin makes the predictions of favorable events and published them in April or May of the preceding year to allow planning for the truly spectacular events which sometimes require international cooperation. Such was the case of the occultation of a bright star by the asteroid 345 Tercidina on September 17, 2002. The occultation was timed by over 70 observing stations located in 5 countries in Europe. This resulted in a very accurate pear shaped profile of Tercidina, See Figure 6.2, Chapter 6.

Eric Limburg is one of the software pioneers of IOTA-ES, writing the program used extensively for predicting total occultations and grazes, the Lunar Occultation Workbench, *Low*, described in Chapter 5. In August 1993, while he attended the European Symposium on Occultation Projects (ESOP) XIII in Roden, the Netherlands, he had become an amateur astronomer again. For a few years he had been working professionally at the European Southern Observatory (ESO) in Chile, and at the National Optical Astronomy Observatories (NOAO) in Tucson, AZ. After having gone into business, and settling in the Netherlands again, his old passion for observing occultation phenomena came back. He attended ESOP to learn what the latest developments in the field of occultations were. He found himself listening to presentations about and demonstrations of the various software programs that were being used to calculate predictions of stellar occultations. The programs presented ran on

PC's, Atari, VAX VMS or Unix computers. In most cases the programmer of the program was its only user. The only occultation program publicly available was called the Evans program. Unfortunately it needed to be treated to an annual floppy feed to update its (Besselean Element) data. Limburg thought this process was rather cumbersome and limiting: a user could only calculate predictions for the coming year and most user interfaces that were shown, were rather rudimentary and not very user friendly. He discovered that there wasn't a single program running under the world's most proliferated operating system, Windows ! He had discovered the proverbial hole in the market and believed that a program could be written to meet the needs of many interested in observing stellar occultations. The program needed to be user friendly to both amateur and professional astronomers. In 1995 he released his first version of a Windows based freeware *Low* program. *Low* 1.0 was developed on a 386 laptop and presented during ESOP XV in Pizen, Czech Republic in 1995. In September 1997 version 2.0 became available and on January 29, 1998 users were able to download the program from the Internet for the first time. An estimated 40,000 downloads have been made from the ftp site since. *Low* was reviewed in Sky and Telescope, and included in the book "Software and Data for Practical Astronomers", the best of the Internet which was edited by Sir Patrick Moore. Based also on suggestions for further improvement from users from all over the world a third version was made. It became available in October 2001.

Low has met Limburg's goals – it was easy to install, appealed to both the novice and experts in the field, took advantage of the fast algorithms for high speed computational accuracy, had color graphics and allowed custom filtering of a whole variety of occultation and observing parameters.

For his contributions to IOTA-ES and the field of occultations, Eric Limburg, creator of *Low* received the Van der Bilt prize in 2004. The Van der Bilt prize is an annual prize awarded by the KNVWS (Koninklijke Nederlandse Vereniging voor Weer en Sterrenkunde) Royal Netherlands Association for Meteorology and Astronomy to an amateur astronomer who is member of the KNWS and whose work has proved to be of great value either for popularization of Astronomy or for scientific use.

Other Dutch Occultation Association members who have received the Van der Bilt prize for Occultation related work are: Arie Mak in 1950 (deceased), Johan C. van der Meulen in 1954 (deceased), Berend J. Vastenholt in 1954 (deceased), Dik Schmidt in 1978 (deceased), Cor Booy in 1981 and Adri Gerritsen in 1994 and Henk Bril in 2005.

The Japanese have also been extensively involved in occultations. The International Lunar Occultation Centre (ILOC) was originally founded in 1923 by the International Astronomical Union (IAU) based in the United States. It was later transferred to the Hydrographic Department of the Maritime Safety Agency of Japan in 1981 which by then had already established itself as a leader in the field of occultation observations. In the early 1990's the ILOC had taken over the task of providing lunar occultation predictions as well as collecting and recording occultation observations from the US Naval Observatory. Due to funding issues, the ILOC ceased operation in March 2009.

Dr. Mitsuru Soma of the National Observatory of Japan has been a leading researcher in the field of occultations. Dr. Soma had analyzed grazing occultations of Aldebaran in 1979-1980 and those of 1997-1998 and determined that the FK5 proper motions of this star are more accurate than those derived from the Hipparcos satellite. This was a surprising result since the Hipparcos satellite was thought to free of many sources of systematic errors from being in orbit above the Earth's turbulent atmosphere. Dr. Soma has analyzed nearly all occultation observations since 1955 to determine the systematic errors in the Hipparcos proper motion system. This crucial work is important for accurate long term occultation predictions and is basic for the establishment of an precise inertial reference frame used in astronomy. Occultations have long been used to analyze corrections to star catalogs and their reference frames. These results have been used to updating the lunar limb profiles which in turn have been used by Dunham in IOTA's long term solar radius studies.

Notable occultation observations from Japan include the first grazing observation on February 2, 1950 by Iwao Kusano, and the possible visual detection of the Uranus ring system from its occultation of an 8th magnitude star in March 1977 by Kazuyuki Yamada. On December 10, 1980 the first asteroid occultation observation by 739 Mandeville over Japan was made by Miyoshi Ida. Two more asteroid events observed over Japan were 106 Dione on January 19, 1983 and 324 Bamberga on December 8, 1987.

On January 13, 1991, an asteroid occultation of the bright star (*m* = 1.9) Alhena (Gamma Geminorium), in Gemini by 381 Myrrha occurred over Japan. It was Japanese occultation expert Isao Sato that organized this event over Japan. This naked eye occultation was visible over a broad track over heavily populated Tokyo 9PM on a Sunday night. In addition a large national campaign was organized in China where the occultation track also crossed which resulted in more than 5000 people watching !

Thirty-two sites including some in Tokyo had occultations and the results were published by Sato and Soma in the Astronomical Journal for April 1993. From this occultation Sato and Soma found the asteroid's size to be 147.2 km x 126.6 km to an accuracy of about 1%. This was the brightest star observed to be occulted until 2005 when Regulus was occulted in Southern Europe. Sato has been a contributor, promoter, predictor, analyzer, and observer of asteroid occultations in Japan since 1978.

Sato has made valuable scientific contributions to occultation science. In 1986 he published a J2000 version of the famous Zodical Catalog (ZC), a standard star catalog of 3539 stars. Many ZC stars are occultation targets by the Moon and asteroids and Sato's precise updates of their positions in the year 2000 reference frame has improved the accuracy of lunar and asteroid occultation predictions of these stars. In March 2003, Dr. Sato organized the Japanese effort to observe the occultation by the asteroid 704 Interamnia. This was an international effort since the occultation path passed over Japan and the Hawaiian Islands. Sato analyzed these observations and he determined the first three dimensional shape of Interamnia.

In 1996 Sato received his Ph.D in astronomy, with the first ever dissertation on asteroid Occultations, entitled "Asteroid Occultation Observations from Japan" from the National Astronomical Observatory in Tokyo. For their many contributions to the field of occultations Mitsuru Soma, Isao Sato and Miyoshi Ida have had asteroids named after them, 2815 Soma, 6338 Isaosato and 6326 Idamiyoshi.

12.13 A Half Century of Grazes and Asteroid Occultations

What have occultations contributed to astronomy between the mid 1950s and today ?

Both total and grazing occultations have helped correct charts of the marginal zone of the Moon, that is, the band of territory encircling the Moon's limb that can, at some times, appear in profiles against the sky. The Moon does not present just one fixed face toward the Earth and so it does not present just one profile silhouetted against the sky. Instead, over the course of its monthly orbit as well as over the 18.6 year long regression of its nodes plus other periodic movements, the Moon—as seen from the Earth—goes through a series of motions called librations, appearing to nod, or wobble, slowly north and south as well as east and west. Over the course of its librations, almost *30 percent* of the Moon's area can be projected in profile against the sky. Although F. Hayn in Germany first attempted to map the marginal zone of the Moon in 1907, the greatest systematic effort was undertaken by Chester B. Watts of the U.S. Naval Observatory. Between 1946 and 1963, Watts took 867 photographs of the sunlit limb of the Moon at all librations, and from them constructed a series 1,800 topographic charts of the marginal zone of the Moon. Watts's publication *The Marginal Zone of the Moon*, published in 1963, remained the most accurate source of altitude measurements about the Moon for more than three decades. The Watts' charts contained several important systematic errors that were first revealed and later quantified and corrected by timings of total and grazing lunar occultations.

Even today, grazes *still* remain the primary source of accurate knowledge of the terrain at the Moon's poles, despite the Clementine mission in 1994. The mission was to assess the surface mineralogy of the Moon and map the Moon's global topography. The spacecraft mapped only narrow meridianal strips of the lunar surface separated by three degrees in selenographic longitude, however, and altimeter data for the polar regions were not obtained; moreover, video timing accuracies of occultations made from the Earth are better than the Clementine laser altimeter errors.

Both total and grazing occultations have also helped refine the accuracy of the celestial positions of stars in the Moon's path. For decades, uncertainties in the positions of fainter stars were so great that sometimes graze observers saw the target star actually missed by the Moon, or to be grazed by different terrain than expected. The role of occultations in correcting star catalogues was not surpassed until the release in 1997 of the first high accuracy star catalogues free of errors due to the refraction and turbulence of the Earth's atmosphere from data collected by the Hipparcos space astrometry satellite (launched in 1989 and terminated in 1993).

Hipparcos catalogue star positions help graze observers further refine determinations of lunar polar topography. Graze expedition leaders can cluster observers on the Earth either where they will see a star disappear and reappear a dozen or more times (such as behind a series of peaks in a lunar mountain range) or where they could determine unknown fine features on a lunar plain. As a result, in attempts to make timings accurate to a few hundredths of a second instead of merely to a tenth, many graze observers no longer rely on their eyes and ears, but commonly aim a sensitive video recorder through a telescope's eyepiece to capture the visible event while recording the time signals on the same tape. Similarly, accurate grazing occultation times with high accuracy are proving useful in detecting and analyzing errors in the Hipparcos proper motion system (measurements Hipparcos made of the motions of stars in the heavens across the line of sight).

Both total and grazing occultations have also revealed the presence of hundreds of hitherto unknown binary (double) stars in the path of the Moon. Many binaries are such close pairs that they cannot be resolved as separate stars either visually photographically, except perhaps with the help of a spectroscope (which might reveal two sets of spectral lines Doppler shifted with respect to one another). During total or grazing occultations, however, many stars have been revealed to be binaries and their separations measured when an observer has recorded a sudden stepwise decrease in the magnitude of the disappearing star, or a stepwise increase in the magnitude of a reappearing star. Although the Hipparcos satellite discovered many double stars, it and other astronomical techniques such as speckle interferometry are of limited usefulness in cases when there is a great magnitude (brightness) difference between close pairs. This problem is reduced during occultations. Occultation observations have no such trouble if the position of the binary in the sky is such that the brighter star is obscured first or revealed last. Thus, even in the early 21st century observers of both total and grazing occultations are still discovering many stars brighter than 8th or 9th magnitude are binary. Moreover, both total and grazing occultations, when measured with photometers (brightness measuring instruments) with fast time resolution at both visible and infrared wavelengths, have directly measured of the diameters of distant stars (especially of red giants) as well as the size of gaseous envelopes surrounding the stars.

Occultations, or more accurately, their contribution to topography of the Moon's limb, may even help indirectly in measuring the diameter of the closest star to the Earth, the Sun, and indirectly its effects on climate. Measuring the Sun's diameter directly is extraordinarily difficult by conventional photographic techniques, due to the turbulence of the Earth's atmosphere both near the ground and in upper layers, which blur the Sun's image even under the best of observing conditions. But knowing the Sun's diameter and how it may (or may not) have varied over time is crucial to several solar theories, with different consequences for understanding the Earth's climate.

In time for the three minute total eclipse of the Sun of March 7, 1970, Dr. Dunham devised a sensitive technique to measure the diameter of the Sun during a total eclipse by observing Baily's Beads (sunlight shining through valleys between lunar mountains seen in profile) near the northern or southern limits of the predicted path of totality. Similar to a lunar grazing occultation, a line of observers perpendicular to the edge of the path of totality can establish the geographical location of the Moon's shadow to within 100 meters, corresponding to an error in the solar diameter of only 0.05 second of arc. Since 1970, IOTA has pushed the edge of totality for 19 eclipses. "You still see totality," Dunham assures, "but you prolong the dramatic spectacle of Baily's Beads and the diamond ring effect, and can watch them migrate around the edge of the Moon's black disk."

The solar eclipse effort to measure the Baily's Beads phenomena over the last three decades has largely been organized and led by IOTA's Vice President Paul Maley. Maley has led 47 solar eclipse expeditions from 1970 through 2017 under the logo RING OF FIRE EXPEDITIONS to some of the most remote corners of the globe. As Vice President of IOTA he has included in a number of these ventures either a primary or secondary team dispatched to gather data needed to aid in the solar radius variation study. Measuring Baily's Beads requires observers to be stationed at the eclipse path edges as opposed to being at the center. The amount of totality is reduced at the path edges but the Baily's Beads effect is prolonged for several minutes. So in effect IOTA observers are watching the Moon graze by the Sun at both north and south path limits simultaneously. Combining the observational data at each eclipse is used to solve for the unknown solar diameter. Comparisons with observations made during historical eclipses as well as with the known topography of the Moon's actual limb as determined from total and grazing lunar occultations may determine any changes in the Sun's diameter over past centuries.

Maley has also led many large grazing occultation and asteroid occultation expeditions in his home state Texas since 1970. And for international expeditions, he's the man to call on to lead the way. He has coordinated with local professional and amateur astronomers in Central America, Papua New Guinea, New Zealand, India, Pakistan, China, Japan, Algeria, Venezuela, Singapore, Macedonia, Iraq, South Africa and elsewhere to engage in cooperative expeditions to promote the techniques used by IOTA. He has trained amateur astronomers to collect Baily's Beads data photographically and with video and established educational web pages on eclipses and occultations. In pursuit of solar eclipses, artificial satellite observations, grazing and asteroid occultations Maley has traveled to over 291 countries. And ever since that observation of the blink of the asteroid 6 Hebe on March 5, 1977 he has also been searching for asteroidal moons. As of December 2007, he has watched over 1,900 asteroid events that come within 2,000 km of his house in an effort to catch another asteroid satellite, but has yet to see another secondary occultation demonstrative of such a possible satellite event. At the end of 2017 he had recorded 218 separate minor planet occultations from 5 continents.

Maley helped create the IOTA Middle East section centered in Iran as well as begun the framework for an asteroid occultation group within India. Further he engaged with the Minor Planet Bulletin to initiate publication of major IOTA-collected event results beginning in 2008 and obtained partial funding for some IOTA members from Southwest Research Institute for a number of asteroid occultation expeditions of joint interest to SWRI and IOTA.

Another application of the solar radius project employed by IOTA astronomers is the attempt to measure the radius of the Moon. During total lunar eclipses (which are rare) there is the chance to observe the same star graze the Moon from both the north and south limit lines simultaneously. This requires observers to be stationed equal to the Moon's diameter apart – 3,476 km. These observations were attempted with lunar eclipse of May 4, 1985 of the 2nd magnitude star Alpha Libra. Maley and Dunham led two groups consisting of eight observers in El Geteina and Hag Abdullah, Sudan and thirty-six observers at five stations watching from the Republic of South Africa. The Sudan expedition marked the first IOTA attempt to make such a complete measurement. A second and more successful one occurred with the November 29, 1993 lunar eclipse. Maley and D. Hube led separate expeditions to Mexico and Canada, respectively which observed the same star graze the Moon from the south and north limits.

12.14 Notable Recognition

The work of IOTA astronomers worldwide, both amateur and professional has not gone unnoticed. In addition to various awards previous mentioned received by individuals in the field of occultation astronomy, one of the highest honors a person can receive is to have an asteroid named after them. A list of named asteroids for persons involved in occultation science is given here:

1722 Goffin	Edwin Goffin, Belgium
2815 Soma	Mitsuru Soma, Japan
2873 Binzel	Rick Binzel, USA
3123 Dunham	David Dunham, IOTA President, USA
3685 Derdenye	Derald and Denise Nye (deceased), USA
3696 Herald	David Herald, Australia
4091 Lowe	Andrew Lowe, Canada
5038 Overbeek	Danie Overbeek, South Africa (deceased)
6010 Lyzenga	Greg Lyzenga, USA
6326 Idamiyoshi	Miyoshi Ida, Japan
6338 IsaoSato	Isao Sato, Japan
12753 Povenmire	Hal and Katie Povenmire, USA
12789 Salvadoraguirre	Salvador Aguirre, Mexico
15146 HalPov	Hal Povenmire, USA
15819 Alisterling	Alister Ling, Canada
17250 GeneLucas	Gene Lucas, USA
47494 Gerhardangl	Gehard Dangl, Austria
85121 Loehde	Franklin C. Loehde, Canada

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APPENDIX A. Occultation Sources and Further Information

International Occultation Timing Association, Inc. (IOTA)

IOTA's Mission

The International Occultation Timing Association, Inc. was established to encourage and facilitate the observation of occultations and eclipses. It provides predictions for grazing occultations of stars by the Moon and predictions for occultations of stars by asteroids and planets, information on observing equipment and techniques, and provides analysis of the observations made.

The Offices and Officers of IOTA

President	David Dunham, dunham@starpower.net
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Executive Secretary	Richard Nugent, RNugent@wt.net
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Vice President for Lunar Occultation Services	Walt Robinson, webmaster@lunar-occultations.com
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IOTA European Section (IOTA/ES)

Observers from Europe and the British Isles should join IOTA/ES, sending a Eurocheck for EURO 25,00 (bank transfer costs included) to the account IOTA/ES; Bartold-Knaust Strasse-8; D-30459 Hannover, Germany; Postgiro Hannover 555 829-303; bank code number (Bankleitzahl) 250 100 30. Sending EURO 20 EU-members must use the IBAN- and BIC-code as additional bank address (IBAN: DE97 2501 0030 0555 8293 03, BIC: PBNKDEFF). German members should give IOTA/ES an "authorization for collection" or "Einzugs-Ermaechtigung" to their bank account. Please contact the Secretary for a blank form. Full membership in IOTA/ES includes one supplement for European observers (total and grazing occultations) and minor planet occultation data, including last minute predictions; when available. The addresses for IOTA/ES are:

Eberhard H. R. Bredner
IOTA/ES Secretary
Ginsterweg 14
D-59229 Ahlen 4 (Dolberg)

Hans-Joachim Bode
IOTA/ES Section President
Bartold-Knaust-Str. 8
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Germany

Phone: 49-511-424696 (in Germany 0-511-424696)

Fax: 49-511-233112 (in Germany 0-511- 233112)

IOTA Worldwide Web Centers:

International Occultation Timing Association (IOTA) main web page:
http://www.lunar-occultations.com/iota/iotandx.htm

IOTA's main web site includes information on how to join IOTA, subscribing to *Occultation Newsletter* published since 1974, accessing back issues, where to send lunar grazing and occultation reports, asteroid occultation reports, observations that that indicate stellar duplicity, and where to send video tapes for processing and WWV time insertion.

IOTA site for new members: http://www.occultations.org/

IOTA, Argentina (Spanish): http://www.ocultacionesliada.8k.com/principal.htm

IOTA Asia/India:
http://meghnad.iucaa.ernet.in/~aaa/occultations/asteroid/a_occult.html

IOTA/European Section: http://www.iota-es.de/

IOTA Northwest USA: http://www.doso-observatory.org/IOTA.htm

Mid-Atlantic USA Occultation Page: http://iota.jhuapl.edu/

Occultation section of the Stefanik Observatory, Prague Czech Republic:
http://sorry.vse.cz/~ludek/zakryty/weleng.phtml

Occultation updates for Belgium, Spain, France Portugal
http://astrosurf.com/apex-occult/

Royal Astronomical Society of New Zealand Occultation Section:
http://occsec.wellington.net.nz

South America Asteroid Occultation Page (Spanish):
http://www.ocultaciones.neositios.com/

Asteroid information

Asteroid Occultation Predictions: http://www.asteroidoccultation.com

European Asteroidal Occultation Network: http://www.astrosurf.com/eaon/

Low Probability Asteroid Events for North America:
http://www.fingerlakessynthetics.com/AstOccult/

Ondrejov Observatory Nearth Earth Object Program:
http://sunkl.asu.cas.cz/~ppravec/neo.htm

Possible Asteroid Moons and binary asteroids :
http://hea.iki.rssi.ru/~denis/doublemp.html

Trans Neptunion Objects (TNO's) List:
http://cfa-www.harvard.edu/iau/lists/TNOs.html

Trans Neptunion Objects (TNO's) Occultation Page:
http://www.nevski.nm.ru/Rus/info/occultinf_tno.html

Maps and GPS Resources:

Delorme Gazetteer atlases. These state maps have scales of 1 mile per inch (Rhode Island) to 6.3 miles per inch (Texas) on 11" x 15.5" pages. http://www.delorme.com

KIWI Precision Time Stamp Utility**:** http://www.pfdsystems.com

Maps On Us page for determining low precision coordinates:
http://www.MapsOnUs.com

McAfee Video Time Inserter: http://McAfeeAstrometrics.com

North American City Coordinates for Major Occultation event Predictions:
http://www.lunar-occultations.com/iota/nadat.htm

Time Resources, New Zealand and Australia
http://tufi.alphalink.com.au/time/time_gps.html

TOPO Maps (for elevation and low precision position determination):
http://www.topozone.com

United States Geological Survey TOPO Map page: http://topomaps.usgs.gov/

Universal Map. Publishes state atlases for Florida, Georgia, Indiana, North and South Carolina, Ohio, and Texas. Map scale is 1 inch = 7.5 miles.
http://www.universalmap.com

IOTA Discussion Groups

IOTA discussion group: http://groups.yahoo.com/group/IOTAoccultations/

KIWI-OSD (On Screen Display) video time inserter (VTI) product discussion group: http://finance.groups.yahoo.com/group/kiwiosd/

Royal Astronomical Society of New Zealand Occultation discussion group: http://tech.groups.yahoo.com/group/RASNZOccultations/join

Video Occultations discussion group: http://tech.groups.yahoo.com/group/VideoOccs/join

Win-Occult and Dos-Occult software discussion group: http://tech.groups.yahoo.com/group/occult-software/join

IOTA Misc.

IOTA Expense report form: http://www.lunar-occultations.com/iota/iotatax.htm

Publications with Occultation Announcements

Occultation Newsletter (*ON*): http://www.occultations.org.

Recent circulars of the IAU: http://cfa-www.harvard.edu/iauc/RecentIAUCs.html

Royal Astronomical Society of Canada (RASC) yearly Observer's Handbook: http://www.rasc.ca

Sky and Telescope Occultation Primer: http://skyandtelescope.com/observing/objects/occultations/article_92_1.asp

Report Forms

Lunar occultations and grazes: http://www.timerson.net/IOTA/

Asteroid occultations: http://www.asteroidoccultation.com/observations/Forms/AsteroidReportForms.html

Solar Eclipse

Fred Espenak's Eclipse page: http://sunearth.gsfc.nasa.gov/eclipse/eclipse.html

Star Catalogs

Hipparcos Space Astrometry Mission and Catalog Search:
http://astro.estec.esa.nl/SA-general/Projects/Hipparcos/hipparcos.html

Hubble Guide Star Catalog 2.2 Data Access:
http://www-gsss.stsci.edu/support/data_access.htm

Tycho-2 and Hipparcos Catalog Retrieval:
http://archive.eso.org/skycat/servers/ASTROM

United States Naval Observatory CCD Astrograph Catalog (UCAC):
http://ad.usno.navy.mil/ucac/

Star Charts on line

Taki's on line mag 8.5 star charts
http://www.asahi-net.or.jp:80/~zs3t-tk/index.htm

Andrew Johnson's Mag-7 Star Atlas Project:
http://www.cloudynights.com/item.php?item_id=1052Software downloads

Software downloads

LiMovie: Program for analyzing videos of occultations.
http://www005.upp.so-net.ne.jp:80/k_miyash/occ02/limovie_en.html

Lunar Occultation Workbench (*Low*) Software download:
http://www.doa-site.nl/

Occult Software download/update page:
http://www.lunar-occultations.com/iota/occult4.htm

OccuLAR: Occultation LiMovie Analysis Routine
http://www.asteroidoccultation.com/observations/NA/

Occult Watcher; lists all asteroid events near your site:
http://www.hristopavlov.net/OccultWatcher/OccultWatcher.html

Scantracker, for using the CCD drift scan technique to time occultations:
http://users.bigpond.com/reedycrk/driftscantiming.htm

WOTAP, determines the time between the German DCF 77 shortwave signals and

when a star disappears in an AVI sequence from a web cam:
http://home.wanadoo.nl:80/adri.gerritsen/wotap.htm

NOTE: Software download pages may change since the date of this publication. If the program cannot be found contact IOTA or someone from the IOTA discussion groups (Appendix A)

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For additional references go to: http://www.poyntsource.com/IOTAmanual/References.htm

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APPENDIX C. Sample Graze Profile

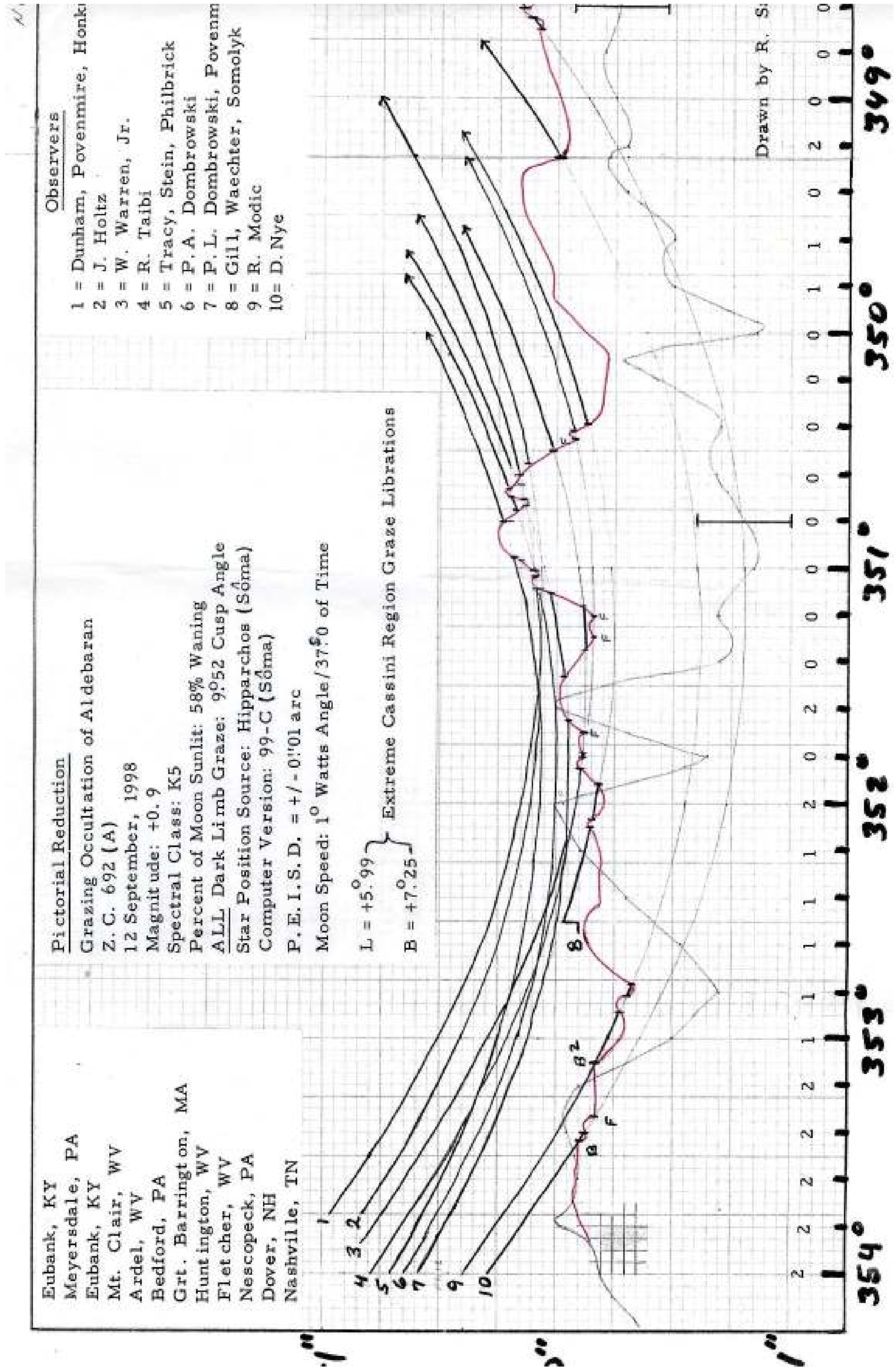


Figure A-1. Limb profile from Aldebaran graze September 12, 1998.

The graze profiles shown are from a spectacular graze of the star Aldebaran on September 12, 1998 south of Nashville, Tennessee made by the attendees of IOTA's 16th annual meeting.

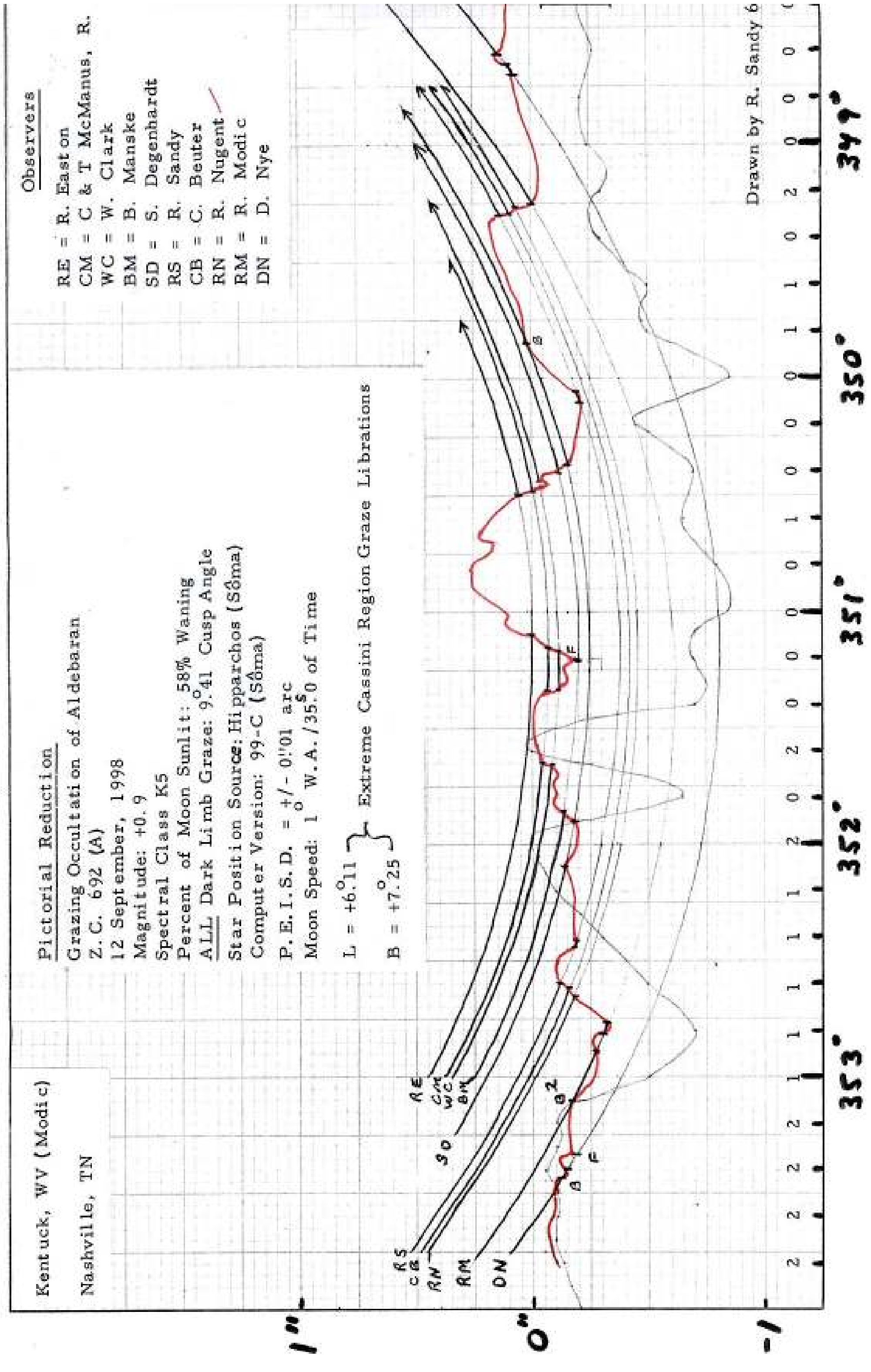


Figure A-2. Limb profile from Aldebaran graze September 12, 1998.

Each graze profile shows the Moon's limb centered at Watts angle of 351°. The solid bold line with data points on it is the limb profile derived from the observations made by the observers in the upper right corner. Each point plotted along this line represents a disappearance or reappearance event. Figure A-1 shows observations made on the upper portion of the lunar limb, while Figure A-2 shows observations made on the lower portion of the limb. Two plots were made to avoid clutter when the profile was made. The lower wavy black line on both plots represents the Watts data, which in this case gave a poor representation of the lunar limb profile compared to the consistent observations made by over 20 observers during this graze.

Although these plots were dawn by hand, the data was added to the lunar limb profile database. Computer drawn profiles are shown as Figures 5.9, 5.14a and 5.14b in Chapter 5.

Profiles drawn by long time occultation observer Bob Sandy of Blue Springs, Missouri.

APPENDIX D. Equipment Suppliers

The equipment and information and web addresses contained herein was compiled from sources deemed to be reliable. Users are advised that Internet information and products/ product information change frequently. The authors, editors and publisher assume no responsibility for errors in web resources and product information.

ADAPTERS

C mount, T-C mount adapters, and others for video cameras. Scopetronix and Adirondak Video
http://www.scopetronix.com
http://www.astrovid.com

FOCAL REDUCERS

Meade f3.3, for video use only. Most Meade telescope retailers carry this focal reducer. Typical street Price $150-$175.
http:///www.Meade.com

Celestron f6.3. Most Celestron telescope retailers carry this focal reducer. Typical street price $130.
http://www.Celestron.com

GPS RECEIVERS

Garmin, http://www.garmin.com

Garmin's eTrex series is useful for occultation observations. The eTrex Venture model (see Figure 7.4) can draw a line on the display screen based upon 2 waypoints showing a path limit to an occultation for easy navigation. This unit also displays the perpendicular distance to the path at your location. This is called the "off course" feature and several GPS units have it.

Magellan: http://www.magellangps.com

The Magellan Meridian series GPS units also have the feature to draw a line between two waypoints and display the perpendicular distance from the user to that line.

GPS receivers can be found at many electronics and sporting goods stores such as Best Buy, Circuit City, Wal-Mart, and many others.

GPS TIME INSERTERS

KIWI OSD Model 2 GPS Time Inserter:

PFD Systems, LLC offers a precision GPS time inserter for use with the Garmin 18 LVC GPS receiver. The time inserter unit and the Garmin GPS receiver can be purchased separately.

Note: As of April 2009, production for the KIWI GPS Time inserter has been discontinued. PFD Systems is planning on replacing the unit with similar design. The company plans to have a replacement unit available by the end of 2009 or early 2010. Check their web page:

PFD Systems, LLC
5900 Rudyard Dr.
Bethesda, MD 20814
pfd@pfdsystems.com
http://www.pfdsystems.com

GPS Time inserter in Europe:

The company Alexander Meier Elektronik in Germany builds a compact GPS time inserter and has the same features as most other units on the market. The manufacturer's website has a 19 page downloadable PDF manual with plenty of photos describing it's use: http://ame-webshop.de/index.php?cPath=3

TIVi Time Inserter for Video:

This unit manufactured in Japan by Tsutomu Hayamizu and is used with the GHS15-clock to produce an overlay of GPS time on video. For more about the units and sample screen shots and ordering information see: http://www2.synapse.ne.jp/haya/ghstivi/ghstivi.html

HORITA

Horita offers time code and video equipment for desk top, rack mount or field use. The current price of their GPS time inserted unit is in the $2,000 price range and far higher than the other units offered by other suppliers listed here.

Post Office Box 3993
Mission Viejo, California 92690
949-489-0240
http://www.horita.com/gpsvideo.htm
horita@horita.com

IMAGE INTENSIFIER

Collins I^3 Piece
Collins Electro Optics
9025 E. Kenyon Ave.
Denver, CO 80237
303-889-5910
http://www.ceoptics.com

Collins Electro Optics has come up with a marvelous easy to use ready to use image intensifier, the I^3 Piece for small telescopes. This product was reviewed in ***Sky and Telescope***, February 1999, page 63. See photos in Figures 6.9 and 8.6. This device may be used as a visual eyepiece adding 2 magnitudes to the visible limit and adding 3-4 magnitudes to a video camera's limit.

RED LED FLASHLIGHTS

Orion Telescopes & Binoculars
89 Hanger Way
Watsonville, CA
1-800-447-1001
http://www.telescope.com

Orion offers a red LED flashlight (Cat #5755) and one with a dual red/white beam (Cat #5756).

SHORTWAVE RADIOS

Grundig digital shortwave radios: http://www.etoncorp.com, 1-800-872-2228 USA
1-800-637-1648 Canada
Grundig manufactures high quality digital shortwave radios. They are sold at many electronics retailers in the USA including Radio Shack. An excellent choice for occultations is the Grundig digital tuning radio model YB300PE, See Figure 3.3 in Chapter 3 and Figure 8.6 in Chapter 8.

Radio Shack: http://www.radioshack.com
Grundig SW digital tuning radios at Radio Shack:
Model # G1000A, Catalog 20-239, retails for around \$50 (digital tuning radio)
Model # S350, Catalog # 12-894, retails for around \$100 (digital tuning radio)

WWV radio controlled alarm clock:
Oregon Scientific sells several WWV driven travel alarm clocks, Models #RM932A, RM323A both for about \$25. The time displayed on this clock is WWV. Many other brands are available.
http://www.atomic-clocks.com
http://www.oregonscientificstore.com

SLOW MOTION CONTOL

Vixen 1¼" low profile fine adjustment control for use with tripod mounted telescopes, spotting scopes and telephoto lenses. Model AM-FA-8798.
http://www.optbinoculars.com/product.aspx?pid=6797

STAR CHARTS

Sky Atlas 2000.0 – from Sky Publishing Corp. This atlas has 26 large fold out charts and retails for about \$50. Used Book suppliers on the Internet usually offer these charts at discount.

Pocket Sky Atlas – New in 2006 from Sky and Telescope Corp. A smaller format spiral bound high quality atlas showing stars to magnitude +7.5 plus 1000's of NGC, Messier and other deep sky objects. Retail price \$20, however used book suppliers on the Internet offer these charts at discount.

Uranometria – also from Sky Publishing Corp.
http://www.SkyandTelescope.com

These atlases are discounted heavily at used book suppliers on the internet.

PLANETARIUM PROGRAMS

These are needed for making detailed finder charts down to at least the magnitude of the target star. Some of the many programs are: *The Sky, MegaStar* and *SkyMap.*

The Sky – http://www.softwarebisque.com
MegaStar – http://www.willbell.com
SkyMap – http://www.skymap.com

USED EQUIPMENT

http://www.Astromart.com – Astromart has links to other telescope and equipment suppliers.
http://www.ebay.com

VOICE RECORDERS

These can be found at most electronics stores such as Circuit City, Best Buy, Office Depot, OfficeMax, Wal-Mart, Fry's, Radio Shack. Brands to look for are Olympus, Sony, Panasonic, Sharp.

Olympus: http://www.OlympusAmerica.com
Panasonic: http://www.Panasonic.com/consumer_electronics
Sharp: http://www.SharpUSA.com
Sony: http://www.Sony.com

VIDEO CAMERAS

Supercircuits
One Supercircuits Plaza
Liberty Hill, TX 78642
1-800-335-9777
http://www.Supercircuits.com

The PC-164CEX-2 is the recommended low light black and white C-mount camera for occultations, with a sensitivity of 0.0001 lux. The PC-180XS, it uses the slightly less sensitive

1/3" CCD chip then the PC-164CEX-2 but is much smaller, allowing the video attachment to the telescope to easily swing through the fork arms of a Schmidt-Cassegrain. The PC-164CEX-2 retails for about $139, the PC-180XS for about $90. The PC180XS is not a C-mount camera, the user will have to attach a C-ring to the camera using glue.

Figure D-1. Use of a C-ring for attachment (glued) to Supercircuits PC 180XS camera.

Watec Cameras
60 Dutch Hill Road
Orangeburg, NY 10962
888-567-4294
http://www.wateccameras.com

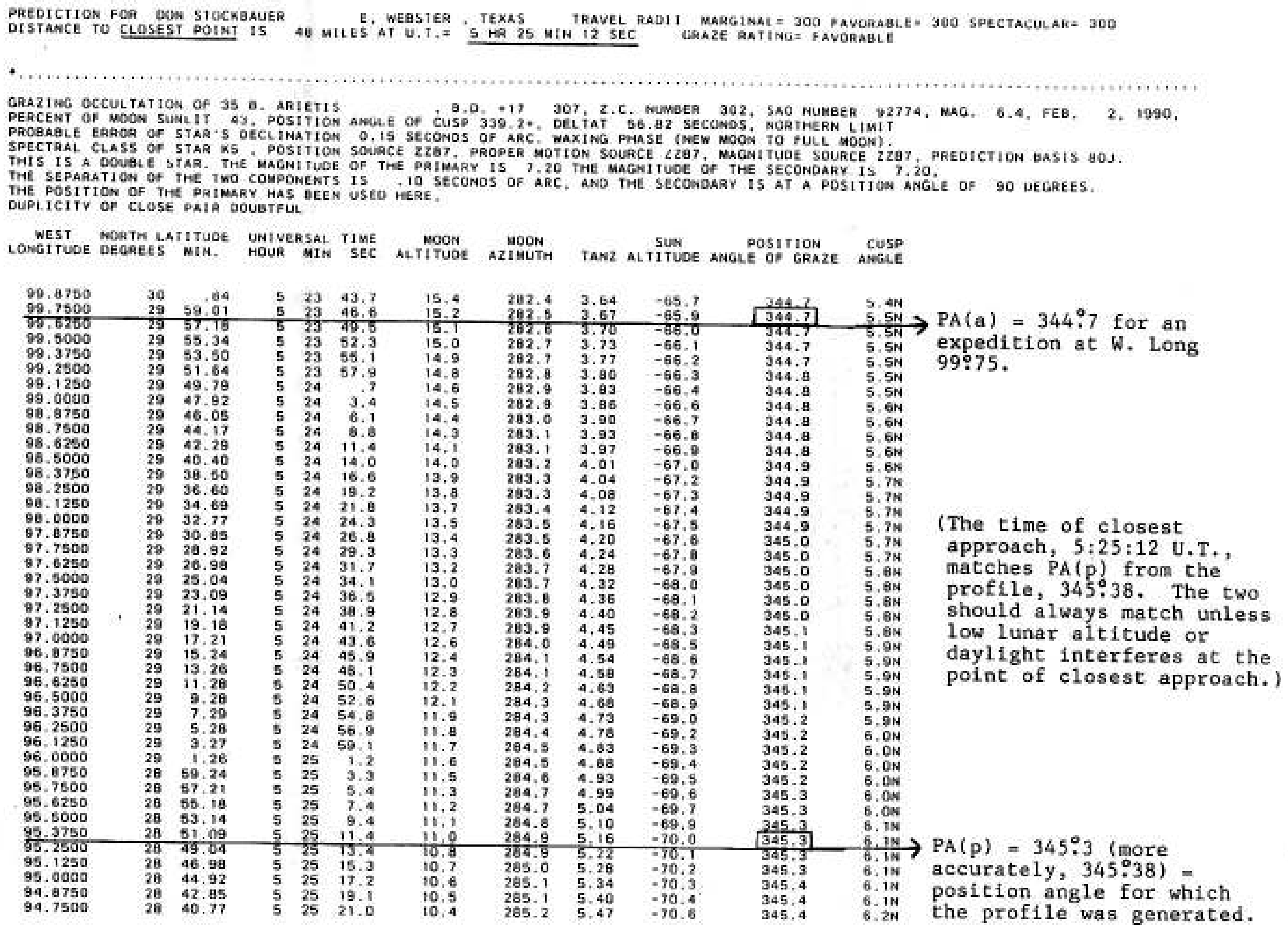
Watec 902H2 Ultimate: Several electronics and security company suppliers carry this camera, which retails for about $325. The Watec 902H2 Ultimate has the same sensitivity as the Supercircuits PC164CEX-2, 0.00015 lux but has a larger 1/2" CCD chip, providing a larger field of view, plus has adjustment controls for shutter speed, manual gain control and Gamma correction.

APPENDIX E. Correction of Profile To Actual Observing Location

The predicted profile of a grazing occultation provided by IOTA Computors is generated for a point in the limit near the closest approach to the coordinates the observer specified when requesting IOTA predictions; this is usually one's home. If no point was specified, then an approximate location would have been established by IOTA based on the mailing address (latitude, longitude, and elevation), along with very small (3-mile) default) ravel radii for marginal, favorable, and spectacular grazes. If the graze was not observable at the point of closest approach due to a low lunar altitude or to strong twilight or daylight there, then the profile will be generated for the first point in the limit at which the graze can actually be observed. A correction will usually be needed if the actual location of the expedition was either up or down track from the point for which the profile was generated. The position angle of graze for the actual location of the expedition, PA(a), is determined from the limit prediction (see Figure E-1). The position angle for which the profile was generated, PA(p), is given in the footer of the profile as "POS ANGLE XXX.XXX PROFILE FOR (your name)" (see Figure E-2). If PA(a) and PA(p) are within approximately 0.2º, the correction is small and may be neglected.

For a difference greater than 0.2º, a new line of central graze and a new sloping predicted limit line should be drawn on the profile for the actual location.(7)It is necessary to use the Watts angle scale to position the newline of central graze, since position angle is not graphed on the profile; the two have the same scale and direction, but are usually shifted with respect to one another. Let WA(p) be the central graze Watts angle for which the profile was plotted (given in the footer data); then the Watts angle of the new line of central graze, WA(a), is given by the equation

$$WA(a) = WA(p) + PA(a) - PA(p)$$



```
PREDICTION FOR  DON STOCKBAUER        E, WEBSTER , TEXAS     TRAVEL RADII  MARGINAL= 300 FAVORABLE= 300 SPECTACULAR= 300
DISTANCE TO CLOSEST POINT IS   48 MILES AT U.T.=  5 HR 25 MIN 12 SEC       GRAZE RATING= FAVORABLE

*..........................................................................................................................

GRAZING OCCULTATION OF 35 B. ARIETIS          , B.D. +17   307, Z.C. NUMBER  302, SAO NUMBER  92774, MAG.  6.4, FEB.   2, 1990,
PERCENT OF MOON SUNLIT  43, POSITION ANGLE OF CUSP 339.2*, DELTAT  56.82 SECONDS, NORTHERN LIMIT
PROBABLE ERROR OF STAR'S DECLINATION  0.15 SECONDS OF ARC. WAXING PHASE (NEW MOON TO FULL MOON).
SPECTRAL CLASS OF STAR K5 , POSITION SOURCE ZZ87, PROPER MOTION SOURCE ZZ87, MAGNITUDE SOURCE ZZ87, PREDICTION BASIS 80J.
THIS IS A DOUBLE STAR. THE MAGNITUDE OF THE PRIMARY IS  7.20 THE MAGNITUDE OF THE SECONDARY IS  7.20,
THE SEPARATION OF THE TWO COMPONENTS IS   .10 SECONDS OF ARC. AND THE SECONDARY IS AT A POSITION ANGLE OF  90 DEGREES.
THE POSITION OF THE PRIMARY HAS BEEN USED HERE.
DUPLICITY OF CLOSE PAIR DOUBTFUL

   WEST    NORTH LATITUDE  UNIVERSAL TIME     MOON      MOON              SUN      POSITION     CUSP
LONGITUDE DEGREES   MIN.   HOUR  MIN  SEC   ALTITUDE  AZIMUTH    TANZ ALTITUDE ANGLE OF GRAZE  ANGLE


  99.8750     30      .84    5  23   43.7     15.4     282.4     3.64   -65.7       344.7       5.4N
  99.7500     29    59.01    5  23   46.6     15.2     282.5     3.67   -65.9       344.7       5.5N
  99.6250     29    57.18    5  23   49.5     15.1     282.6     3.70   -66.0       344.7       5.5N
  99.5000     29    55.34    5  23   52.3     15.0     282.7     3.73   -66.1       344.7       5.5N
  99.3750     29    53.50    5  23   55.1     14.9     282.7     3.77   -66.2       344.7       5.5N
  99.2500     29    51.64    5  23   57.9     14.8     282.8     3.80   -66.3       344.8       5.5N
  99.1250     29    49.79    5  24     .7     14.6     282.9     3.83   -66.4       344.8       5.5N
  99.0000     29    47.92    5  24    3.4     14.5     282.9     3.86   -66.6       344.8       5.6N
  98.8750     29    46.05    5  24    6.1     14.4     283.0     3.90   -66.7       344.8       5.6N
  98.7500     29    44.17    5  24    8.8     14.3     283.1     3.93   -66.8       344.8       5.6N
  98.6250     29    42.28    5  24   11.4     14.1     283.1     3.97   -66.9       344.8       5.6N
  98.5000     29    40.40    5  24   14.0     14.0     283.2     4.01   -67.0       344.9       5.6N
  98.3750     29    38.50    5  24   16.6     13.9     283.3     4.04   -67.2       344.9       5.7N
  98.2500     29    36.60    5  24   19.2     13.8     283.3     4.08   -67.3       344.9       5.7N
  98.1250     29    34.69    5  24   21.8     13.7     283.4     4.12   -67.4       344.9       5.7N
  98.0000     29    32.77    5  24   24.3     13.5     283.5     4.16   -67.5       344.9       5.7N
  97.8750     29    30.85    5  24   26.8     13.4     283.5     4.20   -67.6       345.0       5.7N
  97.7500     29    28.92    5  24   29.3     13.3     283.6     4.24   -67.8       345.0       5.7N
  97.6250     29    26.98    5  24   31.7     13.2     283.7     4.28   -67.9       345.0       5.8N
  97.5000     29    25.04    5  24   34.1     13.0     283.7     4.32   -68.0       345.0       5.8N
  97.3750     29    23.09    5  24   36.5     12.9     283.8     4.36   -68.1       345.0       5.8N
  97.2500     29    21.14    5  24   38.9     12.8     283.9     4.40   -68.2       345.0       5.8N
  97.1250     29    19.18    5  24   41.2     12.7     283.9     4.45   -68.3       345.1       5.8N
  97.0000     29    17.21    5  24   43.6     12.6     284.0     4.49   -68.5       345.1       5.9N
  96.8750     29    15.24    5  24   45.9     12.4     284.1     4.54   -68.6       345.1       5.9N
  96.7500     29    13.26    5  24   48.1     12.3     284.1     4.58   -68.7       345.1       5.9N
  96.6250     29    11.28    5  24   50.4     12.2     284.2     4.63   -68.8       345.1       5.9N
  96.5000     29     9.28    5  24   52.6     12.1     284.3     4.68   -68.9       345.1       5.9N
  96.3750     29     7.29    5  24   54.8     11.9     284.3     4.73   -69.0       345.2       5.9N
  96.2500     29     5.28    5  24   56.9     11.8     284.4     4.78   -69.2       345.2       6.0N
  96.1250     29     3.27    5  24   59.1     11.7     284.5     4.83   -69.3       345.2       6.0N
  96.0000     29     1.26    5  25    1.2     11.6     284.5     4.88   -69.4       345.2       6.0N
  95.8750     28    59.24    5  25    3.3     11.5     284.6     4.93   -69.5       345.2       6.0N
  95.7500     28    57.21    5  25    5.4     11.3     284.7     4.99   -69.6       345.3       6.0N
  95.6250     28    55.18    5  25    7.4     11.2     284.7     5.04   -69.7       345.3       6.0N
  95.5000     28    53.14    5  25    9.4     11.1     284.8     5.10   -69.9       345.3       6.1N
  95.3750     28    51.09    5  25   11.4     11.0     284.9     5.16   -70.0       345.3       6.1N
  95.2500     28    49.04    5  25   13.4     10.8     284.9     5.22   -70.1       345.3       6.1N
  95.1250     28    46.98    5  25   15.3     10.7     285.0     5.28   -70.2       345.3       6.1N
  95.0000     28    44.92    5  25   17.2     10.6     285.1     5.34   -70.3       345.4       6.1N
  94.8750     28    42.85    5  25   19.1     10.5     285.1     5.40   -70.4       345.4       6.1N
  94.7500     28    40.77    5  25   21.0     10.4     285.2     5.47   -70.6       345.4       6.2N
```

PA(a) = 344°.7 for an expedition at W. Long 99°.75.

(The time of closest approach, 5:25:12 U.T., matches PA(p) from the profile, 345°.38. The two should always match unless low lunar altitude or daylight interferes at the point of closest approach.)

PA(p) = 345°.3 (more accurately, 345°.38) = position angle for which the profile was generated.

Figure E-1. Graze limit prediction for a specific site.

If WA(a) does not fall within the range of 0° to 360°, it should be normalized by either adding or subtracting 360. A new line of central graze for the actual location is then drawn vertically at a Watts angle of WA(a). The new limit's intersection point with the new central graze line is at the same distance above the mean limb as the original limit was above the mean limb. Due to the vertical exaggeration (VE) of profile plots, the new predicted limit line will slope with respect to the original profile's limit. Slope is defined as the change in the vertical (y) coordinate divided by the change in the horizontal (x) coordinate.

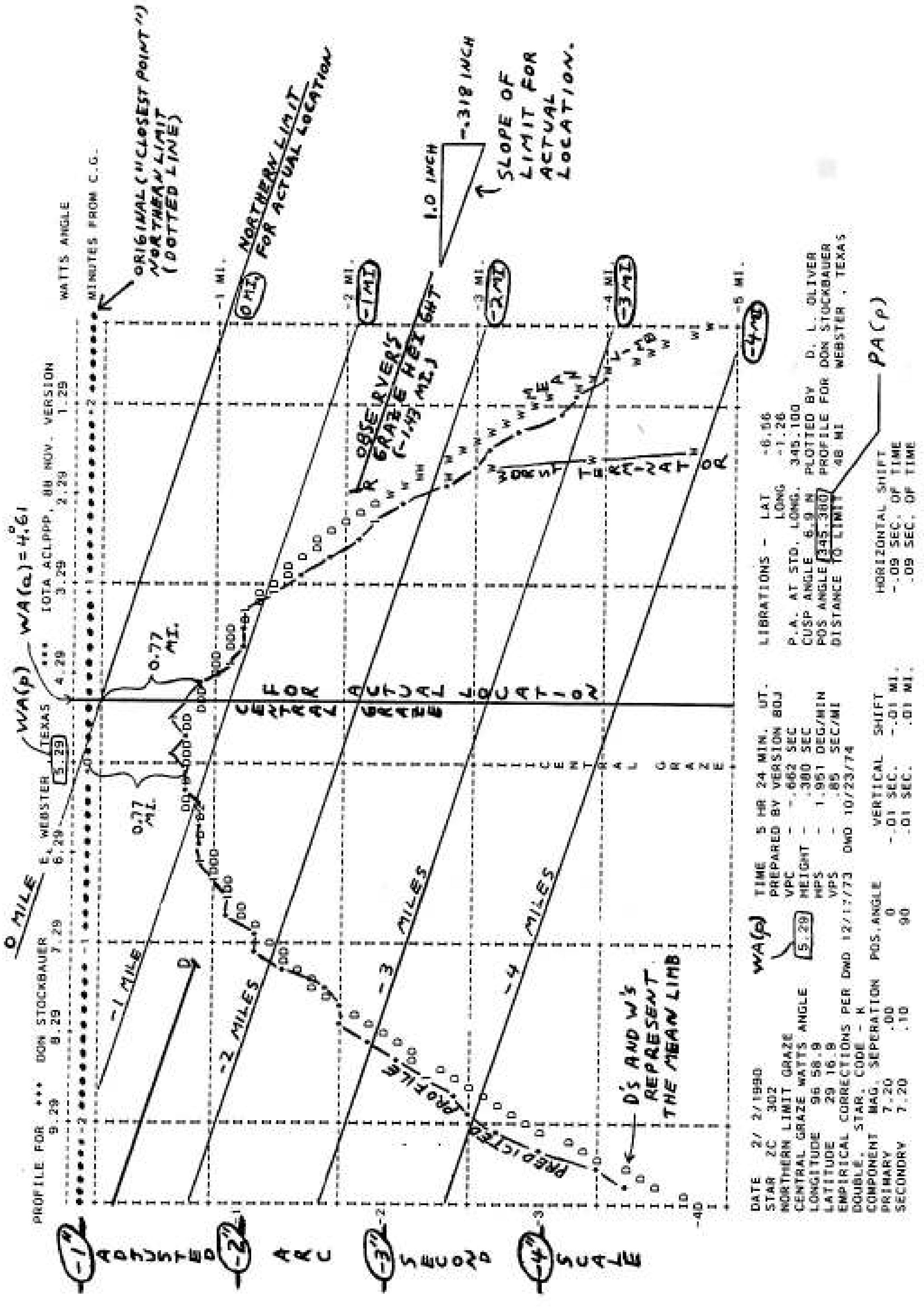


Figure E-2. Profile prediction with correction for observed location.

When using this method to combine the results of two or more expeditions on one profile, the profile of one of the expeditions should be considered the "original" profile (the one calculated for the "point closest to home" in the previous discussion) and the other expedition's profile should be considered the "actual", or "new" location. More than two expeditions may be combined by. having multiple "actual" locations. If the HEIGHT values listed in the footer data of the profiles differ significantly, the difference should be applied when plotting the actual limit's vertical position. (These HEIGHT values represent a set of global empirical vertical corrections applied to the lunar mean limb at the time the profile is generated). The same is true for the HPS; since its value is available for both locations when combining results, any difference between expeditions should also be taken into account when plotting the observations.

A fictitious example using an actual graze prediction follows (no expedition was actually attempted). Figure E-2 is a profile generated for a position angle PA(p) of 345.38° (POS ANGLE 345.380 PROFILE FOR DON STOCKBAUER). If an expedition had actually obtained data at longitude 99.75° West, the actual position angle of graze, PA(a), would be 344.7° (from the limit prediction, Figure E-1). The Watts angle for which the profile was generated, WA(p), is 5.29° ; the Watts angle at which to draw the new line of central graze for the actual location, WA(a), is 5.29° + 344.7° - 345.38° = 4.61°. Since the predicted limit was scaled off the top of the northern boundary of the plot, it is drawn in as a dotted line.

The original limit is 0.77 miles north of the mean limb (represented by the series of D's), so the actual limit must maintain this distance above the mean limb at its new position. The ratio of one mile to one degree of Watts angle is measured as
(1.04/0.74) inch, which equals 1.40. The vertical profile scale,VPS is given as 0.85"/1 mile in the profile's footer data. The vertical exaggeration is

$$VE = \frac{(\ 16.2766 * 1.40\ )}{0.85} = 26.81,$$

and the new limit's slope is:

$$s = \tan(\ 344.7 - 345.38\ ) * 26.81 = -0.318.$$

The new limit for the actual location slopes 0.318 unit down (south) for every unit of distance to the right (toward increasing time). "Graze height" is defined as an observer's perpendicular distance on the ground to the elevation-corrected limit, with north positive by convention (not to be confused with the HEIGHT shown in the profile's footer mentioned earlier). In Figure E-3, the graze height for an observer at point N would be NF; since N is south of the corrected limit, it is a negative quantity. In Figure E-2, parallel lines representing graze heights of 1 to 4 miles are also drawn. These graze heights are offset vertically on the profile from the new sloping limit, not at a right angle to it. The graze height scales along the right-hand border of the plot (in miles or kilometers) and the left-hand border (in seconds of arc) should be relabeled with the new values; the new values are circled in the example.

N = Location of observer
AB = Sea level limit
CD = Elevation corrected limit
Angle VAB = Bearing of limit
HB = Elevation correction's projection onto the horizontal plane
HE = Elevation correction's perpendicular to the sea level limit
R = Point used to determine the time of central graze
NF = Observer's perpendicular distance to the elevation corrected limit (i.e., the graze height)

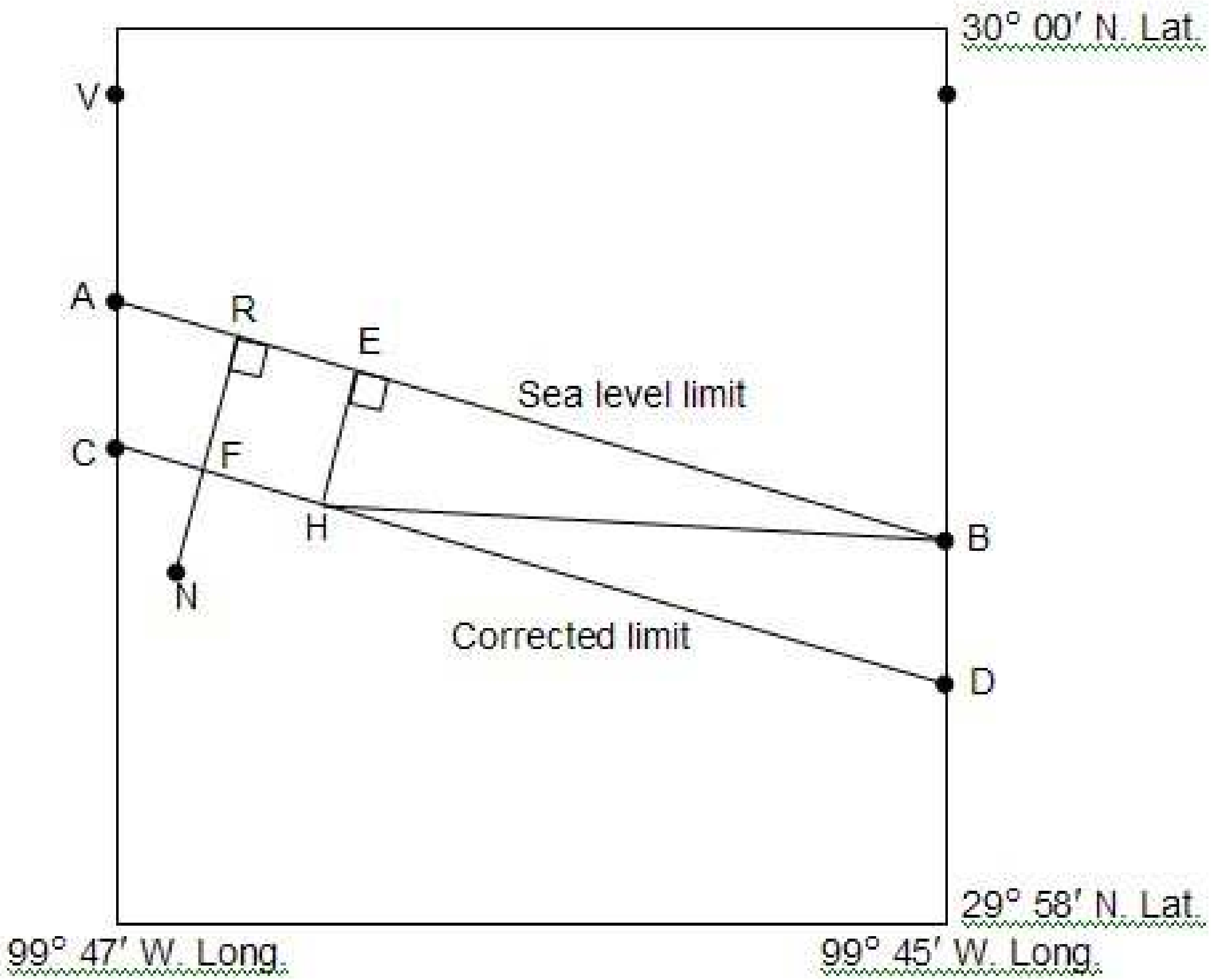


Figure E-3. Corrected limit.

APPENDIX F. Report Forms and How to Report Observations

This Appendix describes the reporting of total, grazing and asteroid occultations:

F1. Total occultations and grazes Excel Report form
F2. Asteroid Occultation form

Report forms for submitting total, grazing and asteroid occultations appear below. Email submission of forms is required as paper submission of observations is no longer accepted.

F.1 TOTAL AND GRAZING OCCULTATIONS - *NEW* EXCEL REPORTING FORM

The method of reporting total lunar and grazing occultations has changed effective September 1, 2008. The International Lunar Occultation Center's (ILOC) no longer collects lunar occultations reports due to funding issues and the ILOC will cease operations effective March 2009. IOTA has agreed to take over this work starting September 1, 2008. A description of the new reporting procedures, the history and details of the entire process can be found on IOTA's main website: http://www.lunar-occultations.com/iota/lunarreport.htm and the European website: http://www.iota-es.de/lunoccult03.html

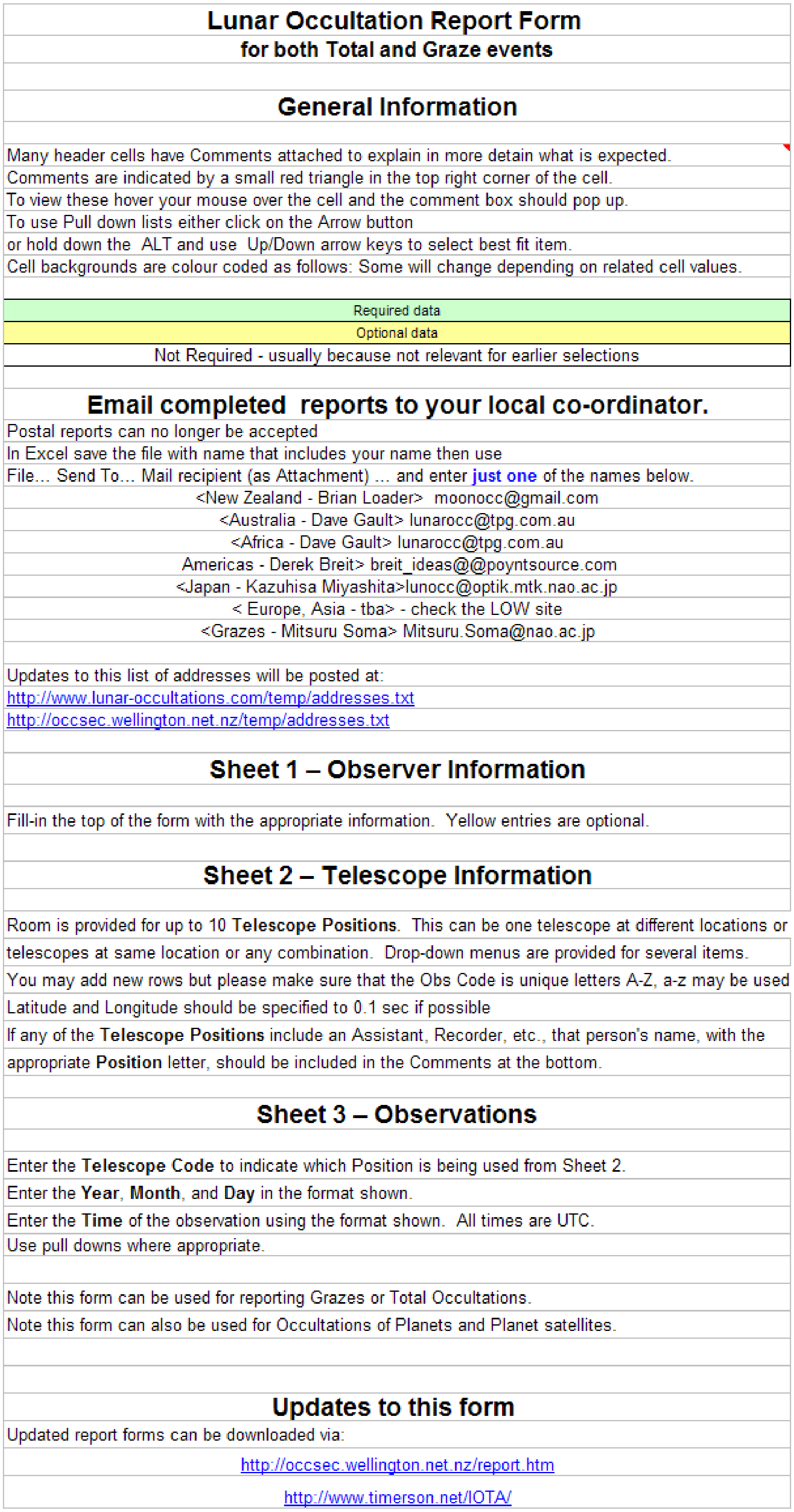
For observers of lunar occultations, both total and grazing, several methods will be available to report observations. Each observer is free to use whatever method they are most familiar with – all will provide the Local Coordinator with the information they need to reduce observations. Once the report is finished, it should be sent to the regional coordinator.

The methods of report your lunar occultation observations are:

1. The Lunar Occultation Observations editor within *OCCULT*. Those familiar with the operation of this editor within *OCCULT* may want to use this method.

2. *LOW*, the Lunar Occultation Workbench, by Eric Limburg. In common use in many parts of the world, Eric Limburg has worked to allow this program to create reports in the new ASCII format. Users familiar with *LOW* should use this program for reporting observations.

3. **A New Excel-based Lunar Occultation Report Form**. This form is based on the widely accepted Asteroid Report Form now used. Worksheets for a) Observer Information, b)Telescope Information, and c) Observations make up the Form. The Form makes extensive use of drop-down lists with common terminology. The form can be downloaded from Brad Timerson's website:
http://www.timerson.net/IOTA/LunarOccultationReportFormV2.0b.xls
The new form is shown below as Figures F.1 – F.4.



Lunar Occultation Report Form

for both Total and Graze events

General Information

Many header cells have Comments attached to explain in more detain what is expected.
Comments are indicated by a small red triangle in the top right corner of the cell.
To view these hover your mouse over the cell and the comment box should pop up.
To use Pull down lists either click on the Arrow button
or hold down the ALT and use Up/Down arrow keys to select best fit item.
Cell backgrounds are colour coded as follows: Some will change depending on related cell values.

Required data
Optional data
Not Required - usually because not relevant for earlier selections

Email completed reports to your local co-ordinator.

Postal reports can no longer be accepted
In Excel save the file with name that includes your name then use
File… Send To… Mail recipient (as Attachment) … and enter **just one** of the names below.

<New Zealand - Brian Loader> moonocc@gmail.com
<Australia - Dave Gault> lunarocc@tpg.com.au
<Africa - Dave Gault> lunarocc@tpg.com.au
Americas - Derek Breit> breit_ideas@@poyntsource.com
<Japan - Kazuhisa Miyashita>lunocc@optik.mtk.nao.ac.jp
< Europe, Asia - tba> - check the LOW site
<Grazes - Mitsuru Soma> Mitsuru.Soma@nao.ac.jp

Updates to this list of addresses will be posted at:
http://www.lunar-occultations.com/temp/addresses.txt
http://occsec.wellington.net.nz/temp/addresses.txt

Sheet 1 – Observer Information

Fill-in the top of the form with the appropriate information. Yellow entries are optional.

Sheet 2 – Telescope Information

Room is provided for up to 10 **Telescope Positions**. This can be one telescope at different locations or telescopes at same location or any combination. Drop-down menus are provided for several items.
You may add new rows but please make sure that the Obs Code is unique letters A-Z, a-z may be used
Latitude and Longitude should be specified to 0.1 sec if possible
If any of the **Telescope Positions** include an Assistant, Recorder, etc., that person's name, with the appropriate **Position** letter, should be included in the Comments at the bottom.

Sheet 3 – Observations

Enter the **Telescope Code** to indicate which Position is being used from Sheet 2.
Enter the **Year**, **Month**, and **Day** in the format shown.
Enter the **Time** of the observation using the format shown. All times are UTC.
Use pull downs where appropriate.

Note this form can be used for reporting Grazes or Total Occultations.
Note this form can also be used for Occultations of Planets and Planet satellites.

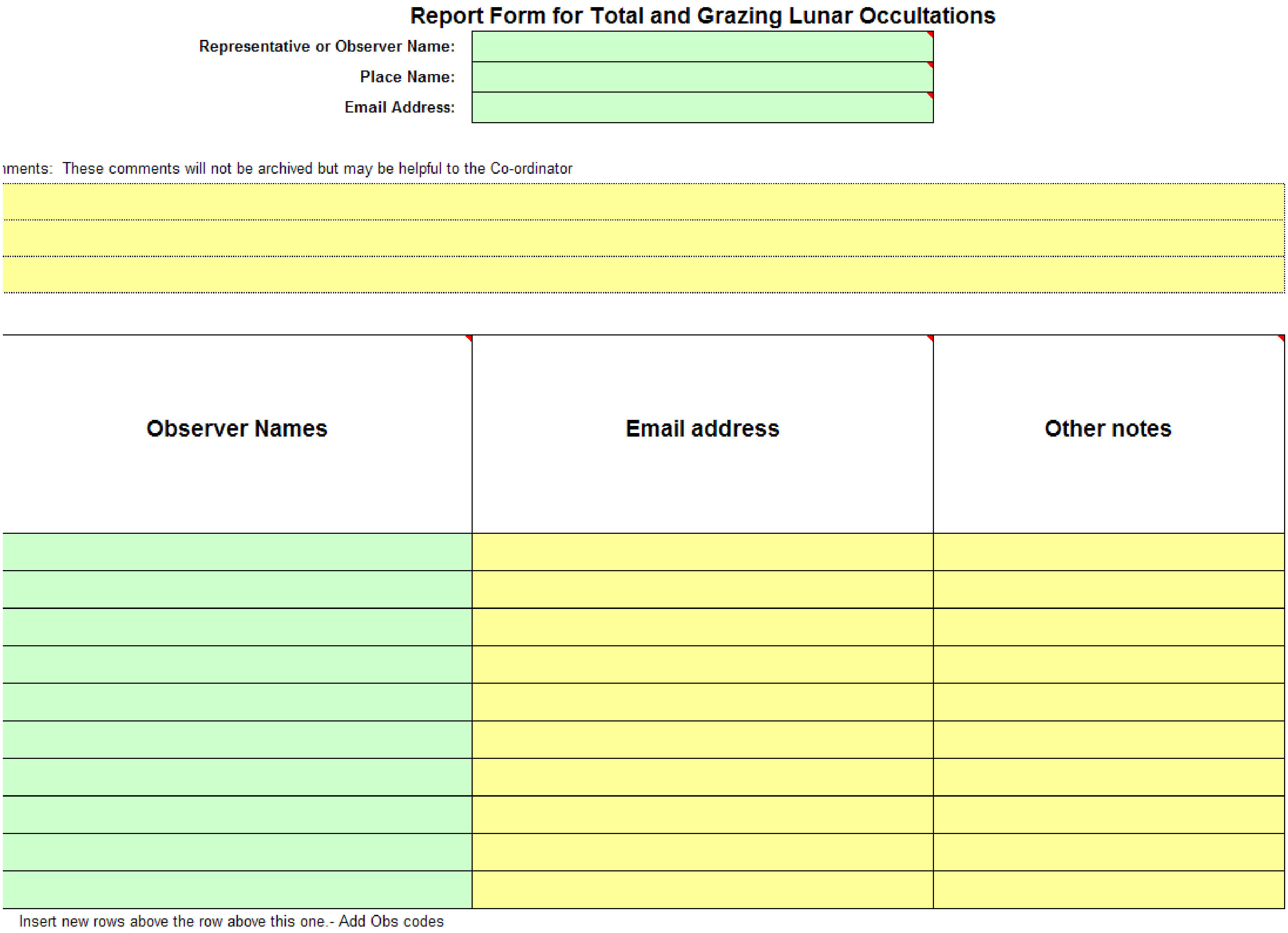
Updates to this form

Updated report forms can be downloaded via:

http://occsec.wellington.net.nz/report.htm

http://www.timerson.net/IOTA/

Figure F.1. Lunar occultation report form – Directions Worksheet.



Report Form for Total and Grazing Lunar Occultations

Representative or Observer Name:

Place Name:

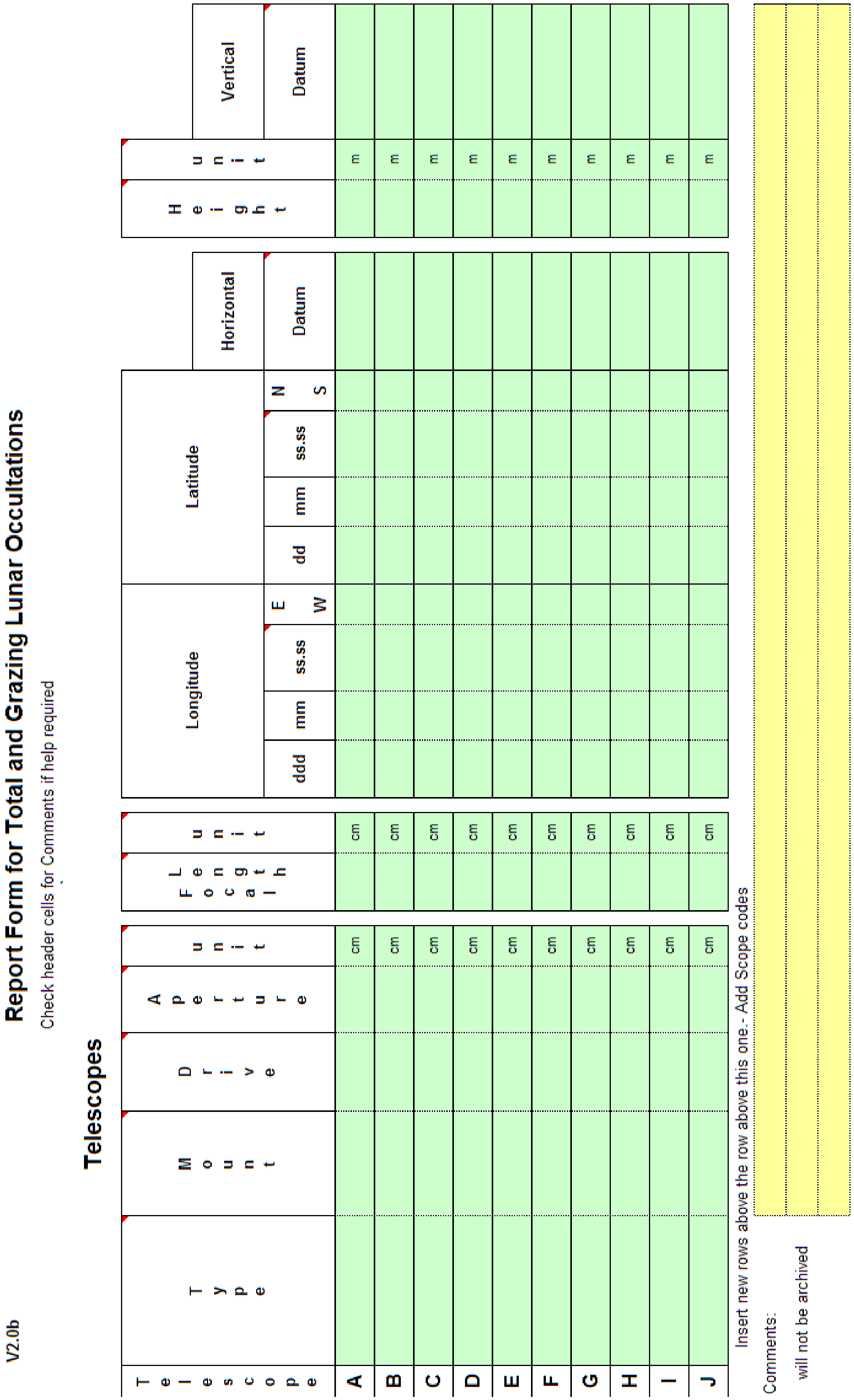
Email Address:

ments: These comments will not be archived but may be helpful to the Co-ordinator

Observer Names	Email address	Other notes

Insert new rows above the row above this one.- Add Obs codes

Figure F.2. Lunar Occultation Report Form - Observer information worksheet



V2.0b

Report Form for Total and Grazing Lunar Occultations

Check header cells for Comments if help required

Telescopes

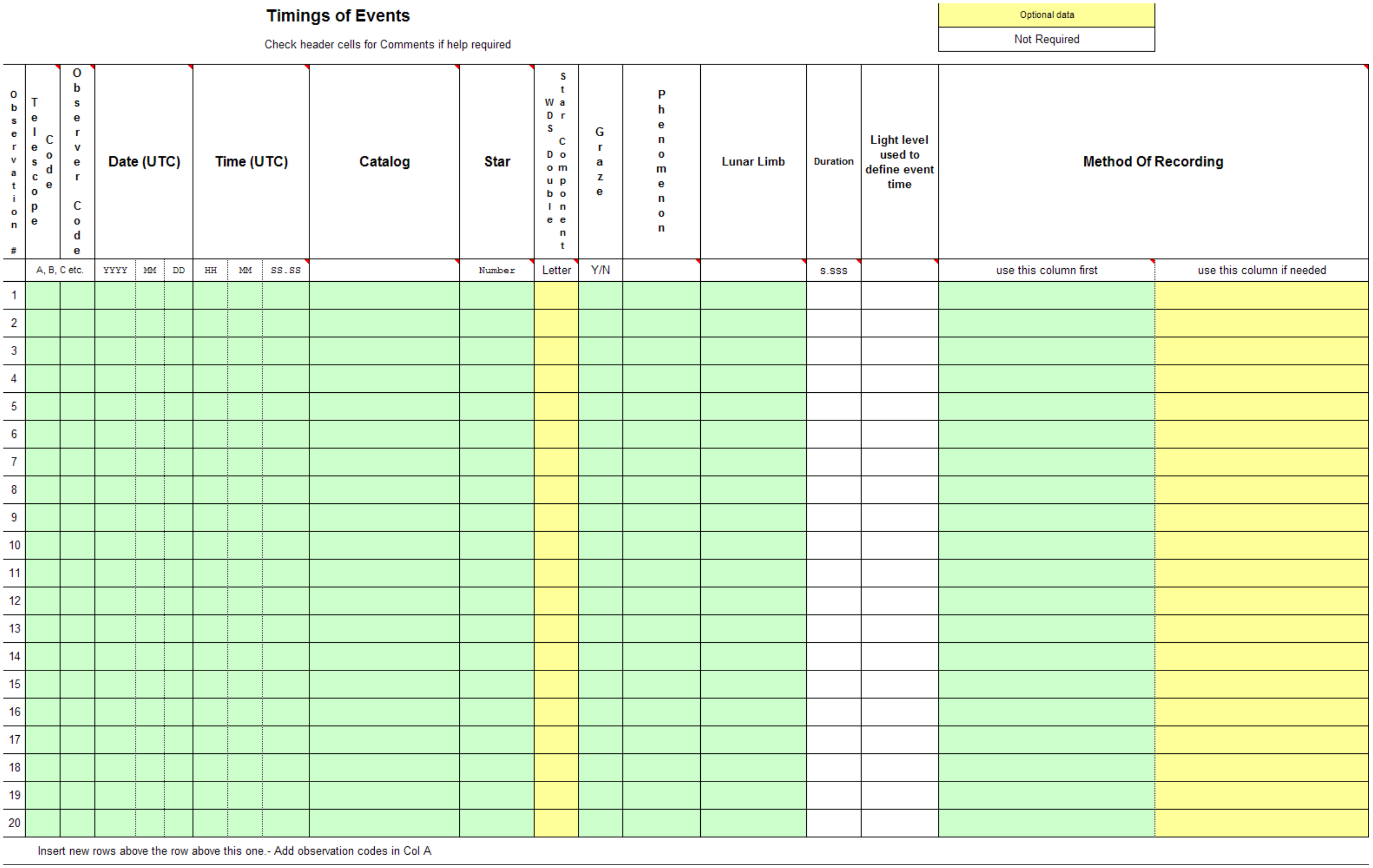
Telescope	Type	Mount	Drive	Aperture	unit	Focal Length	unit	Longitude ddd	mm	ss.ss	E W	Latitude dd	mm	ss.ss	N S	Horizontal Datum	Height	unit	Vertical Datum
A					cm		cm											m	
B					cm		cm											m	
C					cm		cm											m	
D					cm		cm											m	
E					cm		cm											m	
F					cm		cm											m	
G					cm		cm											m	
H					cm		cm											m	
I					cm		cm											m	
J					cm		cm											m	

Insert new rows above the row above this one.- Add Scope codes

Comments:

will not be archived

Figure F.3. Lunar Occultation Report Form – Telescope info worksheet



Timings of Events

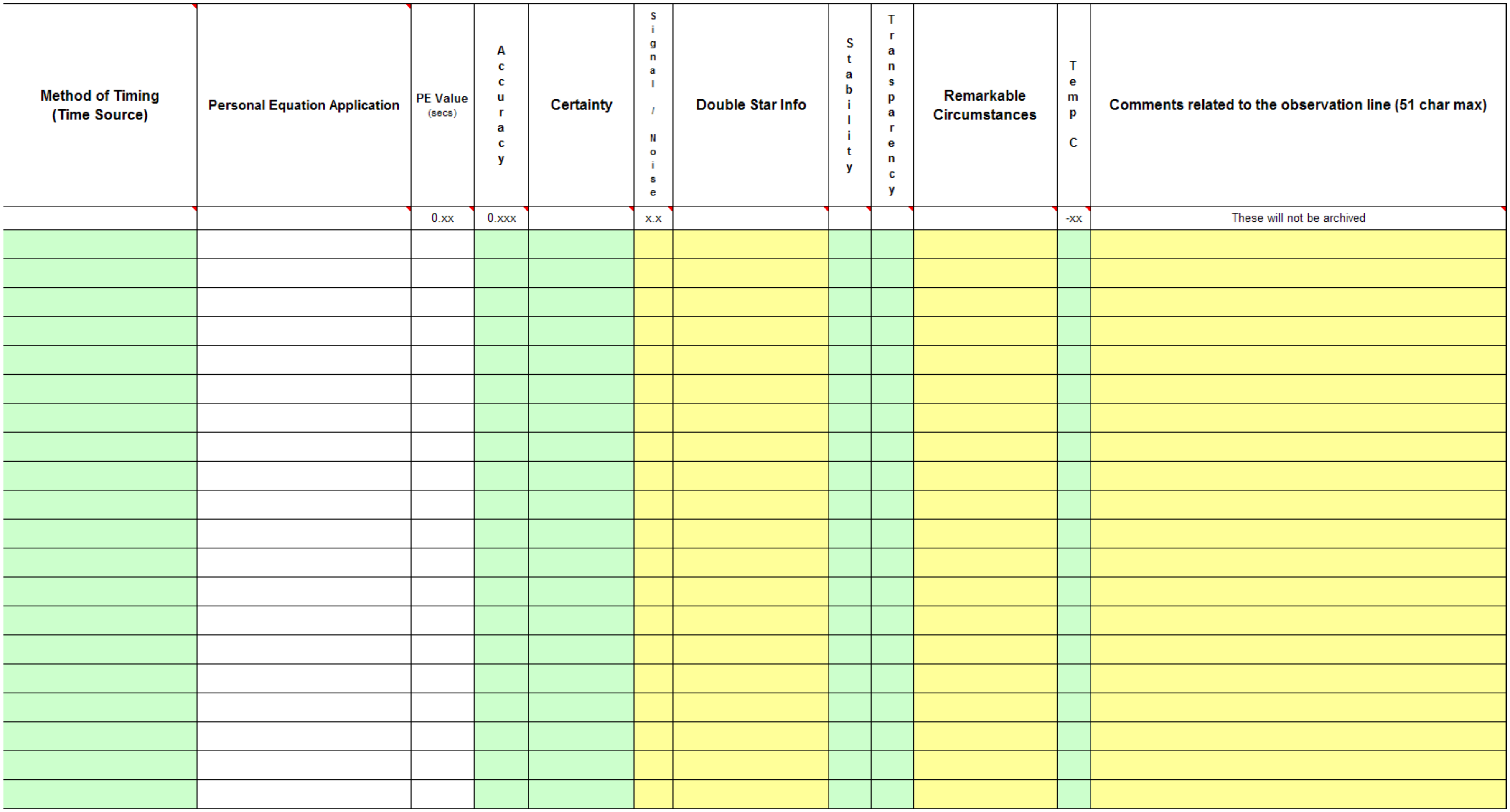
Check header cells for Comments if help required

Optional data
Not Required

Observation #	Telescope Code	Observer Code	Date (UTC)			Time (UTC)			Catalog	Star	WDS Double Star Component	Graze	Phenomenon	Lunar Limb	Duration	Light level used to define event time	Method Of Recording	
	A, B, C etc.		YYYY	MM	DD	HH	MM	SS.SS		Number	Letter	Y/N			s.sss		use this column first	use this column if needed
1																		
2																		
3																		
4																		
5																		
6																		
7																		
8																		
9																		
10																		
11																		
12																		
13																		
14																		
15																		
16																		
17																		
18																		
19																		
20																		

Insert new rows above the row above this one.- Add observation codes in Col A

Figure F.4. Lunar Occultation Report Form – Observations. This part of the worksheet is to wide to fit on the page, the rest of the worksheet showing the “Method of Timing” is shown on the next page.



Method of Timing (Time Source)	Personal Equation Application	PE Value (secs)	Accuracy	Certainty	Signal / Noise	Double Star Info	Stability	Transparency	Remarkable Circumstances	Temp C	Comments related to the observation line (51 char max)
		0.xx	0.xxx		x.x					-xx	These will not be archived

Figure F.4. Lunar Occultation Report Form Observation worksheet continued from previous page.

In the Excel form from Figures F.1 – F.4, the green colored cells are required information. The yellow colored cells are optional information.

Using either the new Excel format form, or the programs OCCULT or *LOW*, observers will report their lunar occultations to a Local Coordinator. The Reports will be in the form of an ASCII file if *OCCULT*, (using the LunarReport feature), or *LOW* is used. If the Excel form is used, the Local Coordinator will receive an Excel .xls file and then use a macro to convert this data into the ASCII format. The Local Coordinator will then use *OCCULT* to reduce the observations and return the results to the observer. Any concerns or errors with the observations will be worked out at this level.

An exception to this is in the reporting of Grazes. In this case, the Graze Coordinator should collect all observations, fill in the report form of choice, and submit the results to Mitsuru Soma directly.

The Local Coordinators will forward this ASCII file to the North American Regional Coordinator. The Regional Coordinator will collate the results, resolve any remaining issues, remove duplicates, and upload the results to a dedicated webpage. The URL's of these Regional Lunar Occultation Results pages have yet to be determined.

The Regional Coordinator will forward all completed archive files to the Global Coordinator for final review, archiving, and reporting to the **Astronomical Data Center**. Local Coordinators have yet to be named (October 2008). All Regions will be seeking volunteers to be Local Coordinators.

SEND YOUR REPORT TO REGIONAL COORDINATORS

Your lunar occultation reports (total occultations and grazes) should be sent to the coordinator below in your area:

Australian Regional Coordinator	Dave Gault	daveg@tpg.com.au
New Zealand Regional Coordinator	Brian Loader	palbrl@clear.net.nz
Africa Coordinator	Dave Gault	lunarocc@tpg.com.au
North/South America Coordinator	Derek Breit	breit_ideas@poyntsource.com
European Coordinator		lunoccult@iota-es.de
Japanese Regional Coordinator	Kazuhisa Miyashita	lunocc@optik.mtk.nao.ac.jp
Grazing Occultation Coordinator	Mitsuru Soma	Mitsuru.Soma@nao.ac.jp
Global Coordinator	Dave Herald	DRHerald@bigpond.net.au

Regional Coordinators in Asia, and South America will be announced when ready.

Observers are encouraged to begin trying out the different reporting techniques immediately so that they can decide which is best for them.

OCCULT download available here:
http://www.lunar-occultations.com/iota/occult4.htm

LOW (Lunar Occultation Workbench) download (88Mb) at:
http://low4.doa-site.nl/index.html

F.2 ASTEROID OCCULTATION REPORT FORMS

Usually, IOTA doesn't need a report if it was cloudy, or if for any other reason you were not able to see or record the target star during the minute or two when the occultation was predicted to occur at your location. If you did observe the star during the predicted time, whether it was occulted (positive) or not (negative), you should send a report to us or to one of the coordinators listed below.

TO WHOM REPORTS SHOULD BE SENT:

There are national and regional coordinators to whom you should report your observations in certain regions - they are:

North America:

Send asteroid occultation reports (positive and negative) using the new Microsoft Excel form (see Figure F.5 below) to: reports@asteroidoccultation.com. Brad Timerson takes in the report forms and forwards them to the three North American regional coordinators for reduction and analysis.

Regional Coordinators:
Western North America: Tony George
Central North America: Richard Nugent
Eastern North America: Brad Timerson

Latin America, for Spanish- or Portuguese-speaking observers:
Report to Claudio Martinez, Occultation Coordinator for LIADA,
e-mail: cmjm91@hotmail.com.

Australia and New Zealand:
Graham Blow, RASNZ Occultation Section coordinator,
Graham.Blow@actrix.gen.nz

and Steve Kerr, Queensland, Australia, srkak@iinet.net.au .

Europe: Jan Manek jan.manek@worldonline.cz and Eric Frappa, EAON & Euraster Web site, frappa@euraster.net.
Most European observations are reported on the Planoccult e-group list moderated by Jan Van Gestel, jan@key.be - send him a message if you want to join. Reports sent to Planoccult will reach Jan Manek, and Eric Frappa and is the preferred way to report observations in Europe.

Japan: Japanese observers are encouraged to join the Japanese Occultation Information Network (JOIN) e-group, which, like Planoccult, reports observational results as well as predictions.

Those analyzing asteroidal occultation observations in Japan include:

Toshio Hirose, NBC00716@nifty.ne.jp
Tsutomu Hayamizu, uchukan@bronze.ocn.ne.jp
Isao Sato, ANA65381@nifty.ne.jp

If you are not from any of the above areas, send a report to:

David Dunham at home, dunham@starpower.net
- sending to this address is not necessary if you send your report to the IOTAoccultations e-group or to Planoccult e-group lists.

Jan Manek, IOTA asteroidal occultation coordinator,

e-mail jan.manek@worldonline.cz
- but you don't need to send to this address if you send your report to Planoccult.

WHAT SHOULD BE SENT:

It is sufficient to just send an e-mail reporting the details of your observation:
The location name,
longitude,
latitude,
height above sea level,
and geodetic datum (or how determined). Datum WGS84 determined by GPS is preferred. An accuracy of at least 0.1 arc minute, but preferably to 2 arc seconds or better, and to 30m or better for elevations is preferred
and your elevations as determined below

If your observation was video:

Provide the disappearance and reappearance times (UT = Coordinated Universal Time, not local time) and their estimated accuracy (or just give to nearest 0.01sec if video). Describe how the times were determined, and what time basis (shortwave radio time signal or GPS 1 PPS signal) was used. For example, for video observations, we want to know whether you had time insertion and single-framed to determine the times "frame analysis", or if you played back your tape a few times to obtain an average result using a stopwatch.

If your observation was visual:

Provide UT to nearest 0.1sec if possible, and estimate the reaction times (= personal equation or pe) to the event, and state whether or not it was applied to the reported times.

The *OCCULT* observations file, which we use to archive all of the observations, also asks for the telescope aperture and type. Also, note any conditions that might adversely affect the observation, such as passing clouds, and if at all uncertain of the observation, estimate the probability of its reality (caused by the asteroid rather than a possible terrestrial cause).

The Euraster Web site also records the start and end of monitoring the star, which in general is good to report.

Rather than just send a free-form e-mail, which is all right, especially for negative observations, it is preferred that you use one of the formal reporting methods:

1. If you have *OCCULT* on your PC, run its asteroidal occultation module, vbAsteroid.exe and select "record and reduce observations" to create an .obs file for the event (by entering the observational data in the boxes provided on the reporting page). If you do this, it will be useful to have the Tycho2 catalog installed; otherwise, you will need to input the coordinates of the stars manually (which you need to do for UCAC2 stars, unless you have the UCAC2 CD's). Send the .obs file that you create as an attached file, or just include it in your message (it's just a text file), especially if you send to IOTAoccultations e-group, which doesn't allow attached files.

2. Visit Jan Manek's reporting Web site at http://mpocc.astro.cz/results/report.html and either complete the form there, or download one of the text files, edit it with a word processor like Notepad or Word, and send it to us by e-mail. Remember that attached files are not allowed on messages sent to the IOTAoccultations e-group.

3. Download the text file report form from David Dunham's Web site at http://iota.jhuapl.edu/report.txt and proceed with the 2nd part of #2 above.

The European asteroid occultation report form is available online here:
http://mpocc.astro.cz/results/iotarep.txt

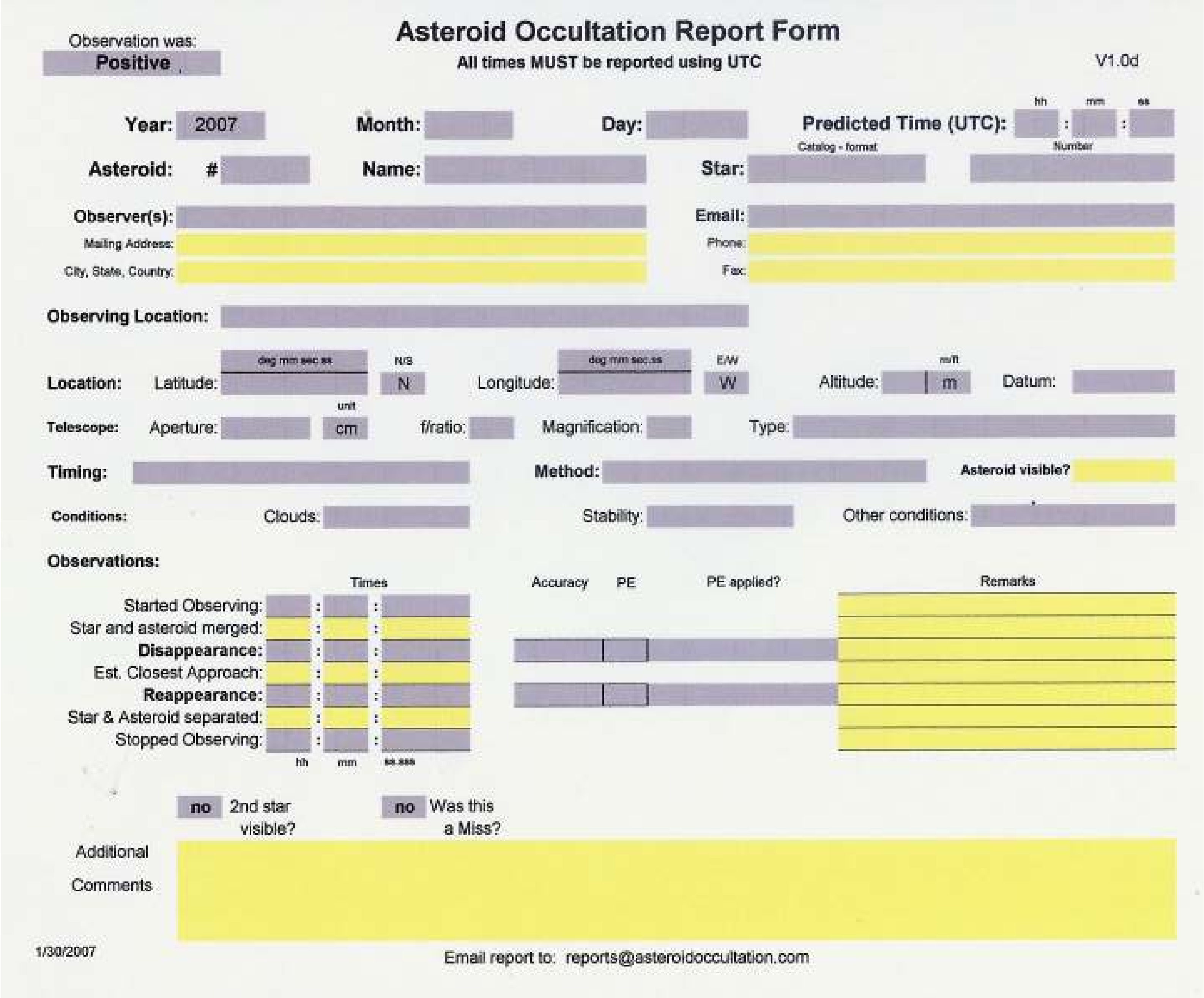
NEW NORTH AMERICAN ASTEROID OCCULTATION REPORT FORM:

http://www.asteroidoccultation.com/observations/Forms/AsteroidReportForms.html

This new form (began late 2006) uses an Excel file with drop down menu's to key in data such as Star Catalog #, type of telescope, ground position, timing method, sky conditions, etc.

The form requests the user to identify his/her observation as positive/negative. Plenty of space is allowed for any remarks that affect the observation, including any trip highlights for mobile observations.

A sample of the form is shown below:



Observation was: **Positive**

Asteroid Occultation Report Form

All times MUST be reported using UTC

V1.0d

Year: 2007 **Month:** **Day:** **Predicted Time (UTC):** hh : mm : ss

Asteroid: # **Name:** **Star:** Catalog - format Number

Observer(s): **Email:**

Mailing Address: Phone:

City, State, Country: Fax:

Observing Location:

Location: Latitude: deg mm sec.ss N/S N Longitude: deg mm sec.ss E/W W Altitude: m/ft m Datum:

Telescope: Aperture: unit cm f/ratio: Magnification: Type:

Timing: **Method:** **Asteroid visible?**

Conditions: Clouds: Stability: Other conditions:

Observations:

	Times hh	mm	ss.sss	Accuracy	PE	PE applied?	Remarks
Started Observing:	:	:					
Star and asteroid merged:	:	:					
Disappearance:	:	:					
Est. Closest Approach:	:	:					
Reappearance:	:	:					
Star & Asteroid separated:	:	:					
Stopped Observing:	:	:					

no 2nd star visible? **no** Was this a Miss?

Additional Comments

1/30/2007

Email report to: reports@asteroidoccultation.com

Figure F-5. North American Asteroid Occultation Report form. When filled out it should be sent to reports@asteroidoccultation.com

APPENDIX G: Equipment Setup Configuration

Basic Video Setup

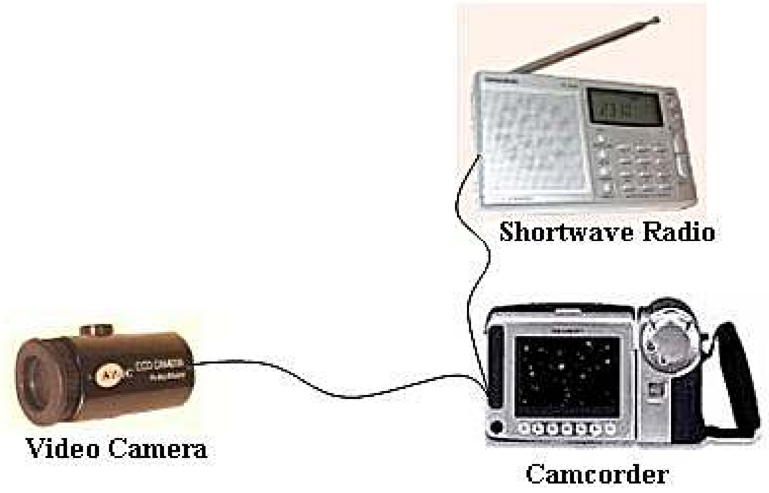


Figure G-1. Basic Video Setup.

In this basic video setup, the video camera’s output goes into the camcorder. The WWV shortwave radio is the primary time source and is also input into the audio track of the camcorder. If the camcorder doesn’t accept audio input, use the built in microphone of the camcorder to record WWV. Choose a camcorder that accepts video and audio inputs.

Video Setup With GPS Time Insertion

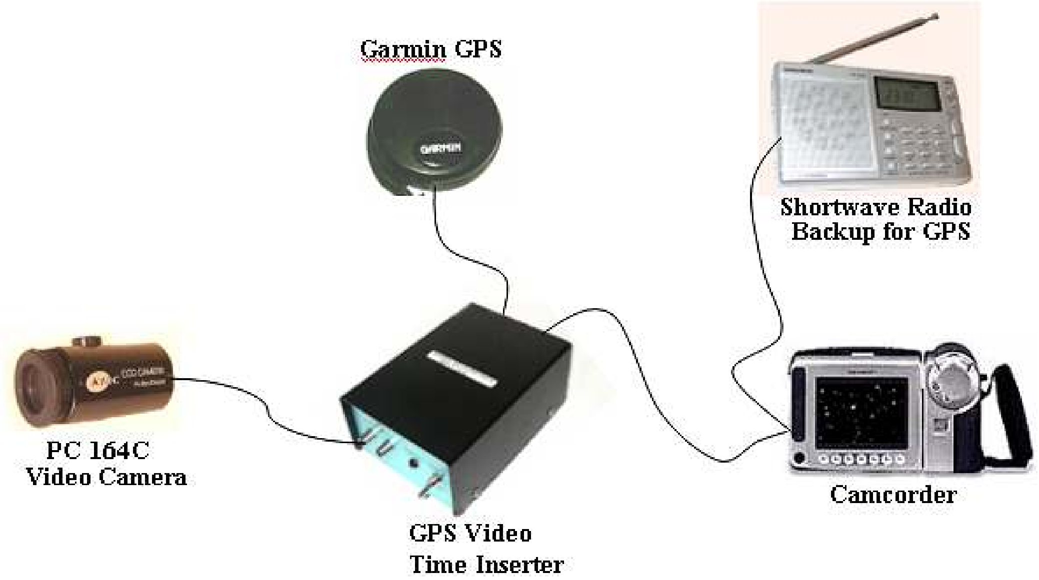


Figure G-2. Video Setup with GPS time insertion.

In this video setup, a GPS time inserter is placed between the video camera and the camcorder. This allows GPS time to be overlaid on the video during the occultation recording.

GPS time insertion is the primary source of timing. WWV is also recorded on to the audio track of the camcorder (audio input jack) strictly as a backup and to complement the GPS time insertion.

The GPS time inserter has the Garmin GPS receiver (model G18LVS) that feeds the GPS time information from the satellites.

Video Setup With GPS Time Insertion And Image Intensifier

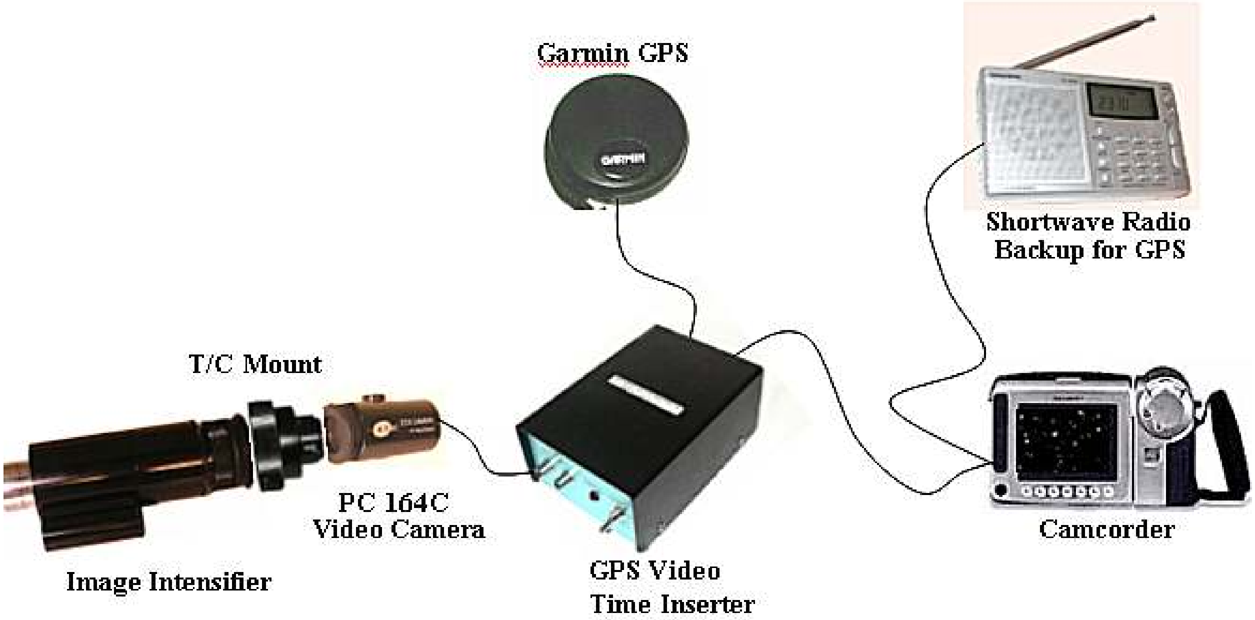


Figure G-3. Video Setup with GPS time insertion and image intensifier.

This is the same setup as in the figure above, except that the video camera is attached to the image intensifier. This intensifier is the Collins I^3 piece, which adds approximately 3-4 magnitudes to the video limit of the system. The Collins image intensifier has a 1¼ inch barrel allowing it to be inserted into standard size eyepiece holders. See Chapter 6, Figure 6.9.

Video Camera Adapted To Telescope With F 3.3 Focal Reducer

Figure G-4. Video camera adapted to telescope with f.3 focal reducer and T-adapter.

This configuration illustrates how to connect your video camera to the telescope using a f3.3 focal reducer. The telescope is a commercially available Schmidt-Cassegrain with 42mm thread size for accessories. The focal reducer screws onto the back of the telescope followed by the T-adapter and the T/C mount. The video camera has a C-mount and threads into the T/C mount. The focal reducer increases the FOV (having the effect of low magnification) and thus allows more starlight to fall on individual pixels on the camera's CCD chip compared to a reduced FOV (high magnification). The effect is to make the star images brighter allowing fainter stars to be seen. See Chapter 6, Figure 6.7.

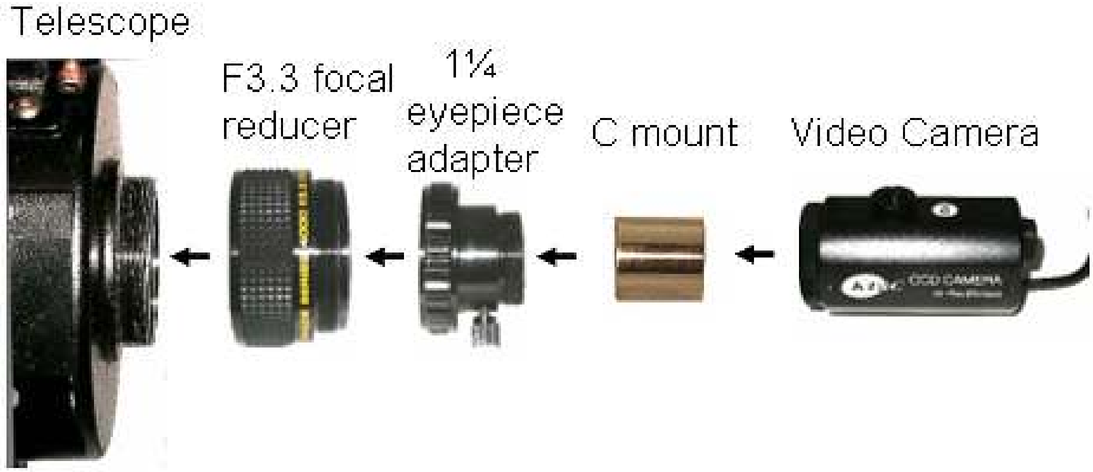


Figure G-5. Video camera attached to telescope with f3.3 focal reducer and C-mount.

In this setup, the T-adapter and T/C mount is replaced by the 1¼ inch eyepiece adapter (also known as a visual back) and short 1 inch cylinder-C mount adapter from Adirondack Video (http://www.astrovid.com).

Video Camera Adapted To Telescope
With F 3.3 Focal Reducer and Image Intensifier

Figure G-6. Video Camera, image intensifier, f3.3 focal reducer attached to telescope.

This is the same setup as in Figure G.5 except that the Collins I^3 Piece Image Intensifier is added to the system. This setup on the Meade 4 inch can reach stars to *m* = 12.0 in a dark sky.

Unattended Video Station Setups

Figure G-7. Unattended video station setup.

In this unattended video station setup, the telescope will be pre-pointed to the area of the sky where the target star will be located at the time of the occultation, thus there will be no tracking. The Supercircuits PC-164C camera is attached with adapters to a spotting scope (a telephoto lens could also be used) and to the camcorder. The shortwave radio's output from its earphone jack is fed directly into the camcorder. For camcorders that cannot input audio directly, the camcorders built in microphone should be used. The spotting scope shown is the Williams Optics Phoenix 80mm mounted on a piggyback 1¼″ fine adjustment unit (slow motion control) made by Vixen (model AM-FA-8798, http://www.opticsplanet.com). Its fine tuning knobs allow for slow motion pointing accurately to the target area. The spotting scope and slow motion control are attached to a sturdy camera tripod.

Pre-pointing the telescope and methods to use unattended video stations are covered in Chapter 10, *Unattended Video Stations*. An additional unattended video station setup is shown in Figure 10.1.

Figure G-8. Video setup on site during an occultation.

This video setup can be used as an attended or unattended video station. It has the motor driven Meade 2045D 4″ SCT ready to record. The Supercircuits PC-164C camera is mounted to a small C-adapter to a visual back to the rear of the tube. The camcorder is to the lower left with the shortwave radio. Near the center of the photo behind the telescope is the rechargeable gel cell power source for the PC-164C. Towels on the ground allow the observer to use the straight through finder scope. The whole system fits in the suitcase (which can be seen on the right side of the picture) for easy portability. Photo by James Thompson. More about this setup can be found at http://iota.jhuapl.edu/mp089824.htm

Additional equipment configurations are shown in Chapter 8, Figures 8.4 and 8.6.

APPENDIX H. Where to Send Observation Reports

Send Lunar and Grazing Occultation reports to your regional coordinator. Use the forms described in Appendix F:

Australian Regional Coordinator	Dave Gault	daveg@tpg.com.au
New Zealand Regional Coordinator	Brian Loader	palbrl@clear.net.nz
Africa Coordinator	Dave Gault	lunarocc@tpg.com.au
North/South American Regional Coordinator	Derek Breit	breit_ideas@poyntsource.com
Japanese Regional Coordinator	Kazuhisa Miyashita	lunocc@optik.mtk.nao.ac.jp
Grazing Occultation Coordinator	Mitsuru Soma	Mitsuru.Soma@nao.ac.jp
Global Coordinator	Dave Herald	DRHerald@bigpond.net.au

Send interesting stories of lunar grazing occultations to:

Richard P. Wilds
2541 SW Beverly Court
Topeka, Kansas 66611-1114 USA
Email: **astromaster@cox.net**

Send North American Asteroid Occultation reports to:

Brad Timerson
Reports@asteroidoccultation.com

Send Europe Asteroid occultation reports to:

Jan Manek
IOTA V.P. for Planetary Occultation Services
Stefanik Observatory
Petrin 205
118 46 Praha 1
Czech Republic
Email: **JManek@mbox.vol.cz or jan.manek@worldonline.cz**
and copy to Eric Frappa, EAON & Euraster Web site, frappa@euraster.net

Send Australia/New Zealand Asteroid occultation reports to:

Graham Blow
P.O. Box 2241
Wellington
New Zealand
Ph/Fax: +64-4-479-2504
Email: **Graham.Blow@actrix.gen.nz**

Send Japan Asteroid occultation reports to:

Isao Sato
Email: **ana65381@nifty.ne.jp**

For North American asteroid occultation events, also send a copy to:
Dr. David Dunham, E-mail: **dunham@starpower.net**
Use report form located at: http://mpocc.astro.cz/results/iotarep.txt also shown in Appendix F.4.

Send observations of occultations that indicate stellar duplicity to:

Henk Bulder
Noorderstraat 10E
NL-9524 PD Buinerveen
The Netherlands
Email: **h.j.jbulder@freeler.nl, hjjbulder@scarlet.nl**

Send Video Tapes of Occultations to be Time Inserted to:

Rick Frankenberger (See Section 8.12)
8702 Timberbriar Drive
San Antonio, Texas 78250
E-mail: **rickf@stic.net**

Videos to be time inserted must have WWV (or other radio station time signal) on the audio track of the tape. Be sure to include the date of the event, star designation or catalog number, asteroid number (if applicable) and your start and stop times in Universal Time. Always ask the Post Office for “media rate” when sending tapes, it is less expensive than 1st class postage.

Send Occultation Newsletter articles and editorial matters (in electronic form) to:

Email: **editor@occultations.org**

Send business related requests including IOTA subscriptions, back issue requests, address changes, email address changes, graze prediction requests, special requests and other IOTA business to:
Email: **business@occultations.org**

Greek Alphabet:

			Astronomical use/ quantity
Alpha	Α	α	right ascension, RA, relativistic bending of light angle
Beta	Β	β	
Gamma	Γ	γ	
Delta	Δ	δ	declination, DEC
Epsilon	Ε	ε	error quantity
Zeta	Ζ	ζ	
Eta	Η	η	standard coordinates, *y*
Theta	Θ	θ	angular measure
Iota	Ι	ι	
Kappa	Κ	κ	
Lambda	Λ	λ	longitude angle; wavelength
Mu	Μ	μ	proper motion (″/yr)
Nu	Ν	ν	
Xi	Ξ	ξ	standard coordinates, *x*
Omicron	Ο	ο	
Pi	Π	π	trigonometric parallax, trig constant 3.141
Rho	Ρ	ρ	density
Sigma	Σ	σ	standard deviation
Tau	Τ	τ	statistical parallax component
Upsilon	Υ	υ	statistical parallax component
Phi	Φ	φ, ϕ	latitude
Chi	Χ	χ	
Psi	Ψ	ψ	
Omega	Ω	ω	Ω - longitude of ascending node, ω - argument of pericenter

APPENDIX I. Glossary

Text in **bold** appears as a definition elsewhere.

Annular eclipse: Eclipse of the Sun where the moon is near apogee in its orbit (near the farthest point) from the Earth causing a small ring (annulus) of light to be visible around the Sun at central eclipse.

Annulus: The ring of light seen circling the Sun at central eclipse time during an annular eclipse.

Appulse: The close alignment of two or more celestial objects during which an occultation does not occur.

Arc-second: Angular unit of measurement that equals 1/3600 of a degree. 60 arc-seconds = 1 arc minute and 60 arc-minutes = 1 degree.

Asteroid (minor planet): Small rocky body with typical sizes ranging from meters to hundreds of kilometers in orbit between Mars and Jupiter, typically 1.7 – 4.0 Astronomical Units from the Sun. Largest asteroids are Ceres, (900 km diameter), Pallas (520 km diameter), and Vesta, (500 km diameter).

Asteroid occultation: Celestial event in which an asteroid, while moving in its orbit around the Sun, passes in front of a star (eclipses the star) as seen from an observer on Earth. The star will dim considerably or vanish from sight for several seconds as the dark asteroid moves in front of it.

Asteroid profile: The two dimensional graphical representation of the line of sight size and shape of an asteroid determined from occultation observations.

Astrometric (Astrometry): Having to do with astrometry, that branch of astronomy dealing with the precise positions of celestial bodies in the sky and the various factors that cause them to change their position with time. Also called positional astronomy.

Astronomical Unit (AU): Sun Earth distance

AVI: Audio Video Interleave, a Microsoft format used for videos.

Balaclava: A hood worn over the entire head with openings for the eyes and (sometimes) the mouth.

Baily's Beads: A string of brilliant points of sunlight seen shining through the lunar mountains/valleys along the moon's limb during a solar eclipse. They were named after the discoverer, Francis Baily, who first described them during the solar eclipse of 1836.

Benchmark: A specific standard landmark with a highly accurate known **geodetic** position.

Binary: term used to describe two objects orbiting a common center of gravity.

Bright limb: edge of the moon that is visible from reflected sunlight. See **Dark Limb**.

Call outs: Your spoken prompts into a digital voice or tape recorder when making occultation observations.

Carrier frequency: The frequency of the unmodulated fundamental output of a radio transmitter.

Cassini region: A Cassini region is a sector of surface of the Moon never illuminated by the Sun.

Cassini third law areas: Area of the moon's poles where it is flatter than other limb areas.

Celestial sphere: An immense imaginary sphere that surrounds the Earth and is the basis for celestial coordinate systems.

Central eclipse: For a total eclipse it is the time when the middle of the total phase occurs; for an annular eclipse, it is the middle of the annular phase.

Clouded out: Term used to described that the clouds at the time of an observation totally covered up the target star or target object.

Computor: IOTA volunteers who prepare detailed occultation predictions for interested observers.

Contours: wavy lines identifying equal elevations on USGS and other topographical maps.

Coordinated Universal Time: Time reference used to establish accurate time signals. The local time at Greenwich, England.

Cross-track: GPS term to denote the perpendicular distance away from a fixed line on Earth. The line is defined by 2 **waypoints**. The line can be the center path of an asteroid occultation, solar eclipse **umbral limit** or center limit**.** Also known as "**Off Course,** "**X-Track**" or "**XTE**" distance on some GPS model units.

Cusp: The boundary between illuminated and dark sides of the moon where the cusp itself is thought of as the bright portion at this boundary.

Dark limb: Edge of the moon that is not sunlit and shines only by earthshine. See **Bright Limb**.

Datum: A reference model of the Earth's shape. Unites States Geological Survey Maps use the North American 1927 datum, GPS receivers generally use the WGS 1984 datum.

Deflection angle: Relativity, the angle by which a photon's path is bent when passing near a massive body.

Delta T: Also known as ΔT. Since 1984, ΔT □is an increment added to Universal Time (UT) to give Terrestrial dynamical time TDT. Delta T is not constant and is increasing in an irregular manner. Between 1970 and 1990 it changed from +40 to +57 seconds. It is predicted to be +67 seconds by 2010. See also ΔT.

Dew: Moisture that forms on telescope optics in humid conditions that fogs the corrector plate/exterior optics of telescopes and finder scopes.

Dew shield: Device used to protect the exterior front end of a telescope from the formation of dew.

Differential corrections: A mathematical method to average large numbers of GPS measurements to derive a single accurate latitude, longitude and elevation. This procedure usually takes 30-60 minutes of data point collection, and the purpose of using this technique is to go around the (*SA*) function, which was the intentional degradation of the GPS signals by the US government. The differential corrections technique is no longer used since the *SA* function was terminated on May 2, 2000.

Diffraction: The apparent bending of light or other electromagnetic radiation at the edges of the aperture (obstacle) with the resulting formation of light and dark bands or rings (diffraction patterns) at the edges of the shadow.

Diffraction effects: The momentary brightness changes of a light source at the beginning and the end of an occultation caused by diffraction.

Disappearance: The complete disappearance of a star as it is eclipsed by the moon or occulted by an asteroid.

Dimming: A non instantaneous drop in the light of a star as it passes behind a lunar peak or asteroid.

Diurnal motion: The apparent daily motion of a celestial body across the celestial sphere from east to west.

DMS: degrees, minutes and seconds of arc.

Doppler shift: The apparent change in the frequency of a signal caused by the relative motion of the transmitter and receiver.

Double Star: A pair of stars that appear close together in the sky. See **Optical double** and **Binary**. **Visual binary** stars. Some double stars are physically connected by their mutual gravitational forces.

Eclipse: Where one body passes in front of another (typically the moon passing in front of the Sun) such that the shadow is cast onto the Earth where observers can view it.

Ecliptic: The plane of the Earth's orbit around the Sun. The Earth-moon center of mass actually defines the ecliptic.

Ecliptic latitude: The latitude angle in the Ecliptic Coordinate System. See "ecliptic." It ranges from −90° to +90°.

Ecliptic longitude: The longitude angle in the Ecliptic Coordinate System. It ranges from 0° to 360°.

Elevation: Height above the Earth's mean sea level. See **datum.**

Elevation correction: A correction applied to the TOPO map in the direction of the moon's azimuth to account for the observer's height above mean sea level.

Elongation: Term used to describe the angular distance of one celestial body from another.

Ephemerides: Tabulated list of positions of the Sun, moon, planets, eclipses and other astronomical events published at regular intervals

Ephemeris Time: Independent variable in the gravitational theories of the solar system, i.e. a measure of time for which a constant rate was defined and was used from 1958-1983.

Event: Refers to the incidence of an event such as solar eclipse, asteroid occultation, disappearance, reappearance, etc.

Extrasolar planet: A planet that orbits any star besides the Sun. Detection of these planets has been recently been discovered using the occultation technique, where the planet moves in front of the star causing the star's brightness to dim during the passage.

First contact: For a solar eclipse, it is the moment when the moon's disc appears to touch the Sun's disc. See also **Second Contact**, **Third Contact** and **Fourth Contact**.

FITS: Flexible image transport system, a format for digital image files that has a header with relevant information on exposure/observer/object details.

FK6: Fundamental Catalogue 6, the 6th in the series of fundamental star catalogues that contains approximately 1600 stars of very high precision. These star positions are used to define as close as possible an inertial coordinate system.

Focal reducer: A lens typically attached on to the back of a telescope that changes the focal ratio in such a way to provide a wider field of view at prime focus.

Fourth contact: For a solar eclipse, it is the moment when the moon's disc finally appears to leave from that of the Sun. See also **First Contact**, **Second Contact,** and **Third Contact.**

FOV: Field of view.

Fresnel diffraction: Diffraction is the apparent bending of light at the edge of obstacles with a resulting formation of dark bands of rings at the edges of the shadow. Fresnel diffraction is a diffraction pattern caused by the finite distances between the source of light and the obstacle.

Frostbite: Damage to the flesh caused by exposure to extreme cold.

Gazeteer: A set of maps used for finding streets, highways and other features, that have accurate locations of geographical coordinates and many County roads.

Geodetic: Having to do with the Earth, the geoid.

Geographic location: the latitude/longitude/elevation position on Earth measured with respect to one of the geodetic datums.

GMT: Greenwich mean time. Now obsolete and replaced by **UTC**.

Goffin charts: Asteroid occultation prediction charts calculated by Edwin Goffin of **IOTA/ES**. They are published on line at a FTP download site for the next year in advance and the current year. The FTP site is listed in Appendix K.

GO TO telescope: a telescope which uses computer control to locate a star or other celestial object by slewing the telescope axes automatically using motors, without the observer having to manually move them.

GPS: Global Positioning System; a cluster of satellites located about 12,000 miles above the Earth providing signals that enable a position to be determined with a receiver to an accuracy of several meters.

GPS receiver: Electronic device capable of receiving signals from the Global Positioning System satellite network. Once signals from 3 or more satellites are received, an accurate location can be determined.

GPS time inserter: Unit that can insert GPS information (latitude, longitude, elevation and precise UT) overlaid on video. The UT displayed time can be accurate to 0.001 sec or better. When playing back a GPS time inserter video, the user can advance one frame at a time and read off the UT to 0.03 second thus providing precise UT of the event.

Grazing eclipse zone: Region that defines either the north or south limit where the Baily's Beads phenomena can be recorded at the north or south limit of a solar eclipse path.

Graze line: The line on the Earth that corresponds to the projected north or south limb of the moon in the direction of the target star.

Graze profile: The graphical representation of the mountains along the limb of the moon. The heights of these mountains are usually compared to the average or mean limb. The deviations from the mean limb can be upward to 3″.

Grazing occultation/graze: An occultation of a star (typically) occurring by the moon in which the target star is momentarily hidden behind mountain peaks along the lunar limb.

Ground position: The geographic position on the Earth's surface measured in latitude, longitude and elevation.

GSC: Hubble Guide Star Catalog that contains over 15 million stars. Produced by scanning the Palomar Observatory's Sky Survey (POSS) glass plates taken in the 1950's – 1960's.

Hipparcos: Name of a European satellite launched in 1989 as a space astrometry mission from the early 1990's in which 118,000 stars had highly accurate position and proper motion measurements, typically to ±0.002″. The stars from this catalog are labeled HIP or Hipparcos Catalog.

Hour circle: The great circle on the celestial sphere that passes through the celestial object and the north and south celestial poles.

Hypothermia: The repression of core body temperature below 37C (98.6F).

IAU: International Astronomical Union, the official worldwide organization of professional astronomers, the IAU meets every 3 years and has 51 commissions on various fields of astronomy.

ILOC: International Lunar Occultation Center, Tokyo, Japan. ILOC was formerly the worldwide data collection center for lunar occultation observations. ILOC ceased operations March 2009.

Image intensifier: An electronic device used to amplify light thus enabling a dramatic increase in detection capability by either the eye or another device such as a video camera attached to a telescope.

Inclinometer: A small device used to measure elevation angle during polar alignment of a telescope mount or of any object with respect to the local horizon. .

Interpolation: A mathematical process to derive an intermediate value of a variable between two known values of the same variable.

Into the moon: Used to describe the position of an observer who places themselves either north or south on the Earth so that they are closer to the center of the projected moon.

Ionosphere: The band of charged particles 50 to 1000 kilometers above the Earth's surface.

Ionospheric refraction: The change in propagation speed of a signal as it passes through the ionosphere.

IOTA: International Occultation Timing Association, which is the organization dedicated to predicting, observing, analyzing and archiving occultation data and phenomena worldwide.

IOTA/ES: International Occultation Timing Association European Section.

J2000: Refers to the standard equinox of the year 2000 of which star positions are referred to.

JPG: Joint Picture Group, a compressed format for images. Also known as JPEG.

Kuiper Belt: Zone of 10,000,000 to 1 billion comets and other small bodies that extend beyond the orbit of Pluto, some 35 - 1000 AU's from the Sun.

Leap second: A whole second that is added to UT when necessary (usually once per year at the end of June or December) to account for the irregularities in the Earth's revolution around the Sun.

Libration: Despite the moon's synchronous rotation, libration of the moon causes it to appear to "tilt" toward or away from Earth. This allows more of the moon's far side to be observed. The maximum libration angles are about 9 degrees and occur over an approximate 30 year period. Thus about 59° of the moon's surface is made visible by libration. Libration occurs in both latitude and longitude. During a lunar month, a libration in latitude produces a 6° tilt toward Earth making the moon's poles more visible.

Limb: The apparent edge of the moon as seen from Earth.

Limb correction: A correction that must be made to the moon's mean limb to account for the irregular surface of the moon. Limb corrections are a function of the librations in longitude and latitude and the position angle from the central meridian.

Limb profile: Refers to the actual outline of the moon's limb as seen from Earth.

Limit line: The projected line from the moon's north or south limb in the direction of the moon's motion on Earth. Also called the graze line.

LiMovie: **LI**ght **M**easurement tool for **O**ccultation observation , using **VI**deo r**E**corder, a computer program written by Kazuhisa Miyashita of Japan. LiMovie takes **AVI** video files and provides tabular data on star brightness for occultation analysis.

Low: Lunar Occultation Workbench, a versatile computer program written by Eric Limburg (IOTA/ES, Dutch Occultation Association) that computes predictions of all aspects of total and grazing occultations.

Lunar: Referring to the moon.

Lunar Eclipse: A partial or complete obscuration of the moon as it drifts into the Earth's shadow cone. Lunar eclipses can only occur at full moon, when the Sun, Earth, and moon are in a straight line. When the moon passes completely into the Earth's umbral shadow, this is called a total lunar eclipse. If only part of the moon enters the umbral shadow, it is called a partial eclipse of the moon. Lunar eclipses occur on average about every 2 years and are visible from ½ of the Earth.

Lux: A unit of illumination. One lux is the amount of light created by a point source of one candle illuminating a surface that is everywhere one meter from the source.

Magnitude drop: In asteroid occultations, the drop in brightness of the combined asteroid/target star image during the duration of the occultation.

Marginal Zone: A series of limb corrections from the Watts Limb profiles.

Mascons: mass concentrations on the moon located just under the circular lunar seas, or maria. The gravitational attraction is somewhat higher in these areas and this peturbs the orbits of lunar satellites.

Maunder minimum: A period of time from 1645-1710 in which there was very little Sunspot activity on the Sun. This time has sometimes been referred to as the "Little Ice Age."

Mhz: Mega Hertz. The scale of shortwave radio frequencies such a those transmitted by WWV, i.e. 2.5, 5, 10, 15 and 20 Mhz.

Minor Planet (asteroid): Small solid body typically meters to kilometers in size orbiting between the orbits of Mars and Jupiter (typically). Many asteroids have orbits beyond Jupiter's orbit. Kuiper Belt objects are usually in orbit well beyond Pluto.

Minor Planet Center (MPC): Cambridge, Massachusetts based center responsible for collecting and updating all data on the solar system objects including orbital parameters, discovery announcements of comets and supernovae, and related astronomical information.

Mobile: Having the ability to travel with occultation and eclipse observation equipment: telescopes, video, shortwave radios, battery power, etc.

MPEG: Motion Picture Experts Group, a widely used digital format for videos.

Multi-channel receiver: A GPS receiver that can simultaneously track more than one satellite.

Negative observation: Term used to describe a situation where an expected event does not occur at all.

NIST: National Institute of Standards and Technology.

North celestial pole: Abbreviated NCP, this is the direction the Earth's axis points northward and is direction of the Earth's rotation axis. It is the point in the Equator System which the declination is +90°. Similarly the South Celestial Pole is in the southern hemisphere, the declination is -90°.

NTSC: National Television System Committee. The NTSC is responsible for setting television and video standards in the United States (in Europe and the rest of the world, the dominant television standards are PAL and SECAM). The NTSC standard for television defines a composite video signal with a refresh rate of 60 half-frames (interlaced) per second. Each frame contains 525 lines and can contain 16 million different colors.

Node: The intersecting point(s) of an orbit with respect to a reference plane, usually the **Ecliptic** or **Equator**.

Nutation: a periodic motion of the Earth's pole superimposed on the precessional circle caused by the combined torques of the Sun and moon upon the Earth. The Earth's celestial pole wanders by an amount of about ±9 arc seconds from the mean pole over a period of 18.6 years.

Obliquity of the ecliptic: The angle subtended from the intersection of the ecliptic and the celestial equator. This angle is equal to the tilt of the Earth's rotational axis, 23° 26′.

Obscuration: The covering of a more distant celestial object by a closer one.

Observer's position: The geographic coordinates of the observer, usually measured in latitude, longitude and elevation. Also referred to the position of the observer relative to the graze line, or the asteroid occultation path limit line.

Occult: A comprehensive software program developed by Australian astronomer David Herald which enables the prediction of lunar, grazing and asteroid occultations, plus solar and lunar eclipses and transits.

Occultation: The complete or partial obscuration (eclipse) of an astronomical object by another of a larger apparent angular diameter momentarily blocking the light of the further object. The occulting body is the closer larger object, usually the moon, asteroid, comet or planet. The object being occulted is usually a star, planet or comet.

Occultation timing: The process of timing an occultation event. This is done by time from any shortwave radio station described in Appendix J that broadcasts minute and second tones, or by using time signals from a GPS satellite.

Occulting bar: any material (usually black paper/plastic) inserted into the focal plane of the eyepiece to block out unwanted light such as the bright portion of the moon.

Occulting body: The object passing in front of the more distant object. When the moon passes in front of a star, the moon is the occulting body.

Off course: **GPS** term to denote the perpendicular distance away from a fixed line on Earth. The line is created by 2 **waypoints**. The line can be the center path of an asteroid occultation, solar eclipse **umbral limit** or center limit**.** Also known a "**X-Track** or "**Cross Track**" distance on some GPS model units.

Oort's constants: The set of constants A and B used in differential galactic rotation formulae to express the motions of stars in our galaxy. Not to be confused with coefficients A and B used for correcting occultation event times from Standard Stations.

Optical double star: A chance alignment of two stars which appear close together in the sky. Optical double stars are not physically connected and do not appear to be members of dynamically linked gravitational systems.

Orbit: The path a celestial body travels around the parent (more massive) body in a gravitational field. Examples: Objects can orbit the Sun, planet or parent asteroid.

Orbital parameters (elements): The set of quantities that define the position and motion of a celestial body in its orbit. These can be established by a minimum of three observations. The size and shape of an orbit are determined by the quantities: a, semi-major axis, e, eccentricity, i, inclination, Ω, longitude of the ascending node, ω, longitude of Perihelion, P, Period, and T, time of perihelion passage.

PAL: **P**hase **A**lternating **L**ine, a video format used in Europe. See **NTSC**.

Partial eclipse: An eclipse of the Sun or moon which is not total.

Penumbra: The portion of a shadow from which only part of the light source is occulted by an opaque body.

Peripheral vision: Vision using only the periphery of the retina.

Personal equation: The unique reaction time for an observer. It is the difference between the time an occultation event was observed and the actual time it occurred.

Polar alignment: The process of pointing a telescope so that its polar axis points to the North or South celestial pole. Such an alignment allows for continuous tracking of celestial objects using a motorized drive.

POSS: Palomar Observatory Sky Survey. A survey of over 2,000 plates (in red and blue light) taken in the 1950's to map the sky as seen from southern California.

Positional astronomy: That branch of astronomy dealing with the precise positions of celestial bodies in the sky and the various factors that cause them to change their position with time. Also called astrometry.

PPM: Position and Proper Motion Catalog. PPM north has 181,731 stars north of declination –2.5 deg. PPM south has 191,179 south of declination –2.5 deg. PPM was published in 1991.

Precession: The motion of the North Pole of the Earth caused by the combined forces of the Sun and moon that makes a 47° circle on the celestial sphere. The complete period of precession takes about 25,800 years and as a result of precession, RA and Dec coordinates need to be constantly updated.

Pre pointing: The method of aligning a telescope-video system in advance for an asteroid occultation.

Probable error: The error in a measurement that is exceeded by a variable with a probability of ½. Denoted by σ.

Profile: A graphical depiction of the lunar topography as predicted or observed; also applies to the two dimensional shape of an asteroid based on a combined group of observations.

Proper motion: The apparent angular motion of a star per year across the celestial sphere. Denoted by the symbol: μ. Measured in arc-seconds/year ("/yr) or milli arc-seconds (mas) per year.

Pseudo-random code: A signal with random noise like properties that has a complicated but repeated pattern of 0's and 1's.

Pseudo range: The range measurement computed in a GPS receiver using a "code phase" measurement to extract the time difference of the transmit and receive times.

Radial velocity: line of sight velocity of celestial object usually measured in km/sec. A positive (+) value indicates object is receding, a negative (–) value indicates object is approaching.

Radian: Angle equal to 57.29577951 degrees. In a circle of 360 degrees, there are 6π radians. π is the constant 3.141.

Rank: Term used as applied to asteroid occultation predictions; it is the probability of at least one successful observation by a team of two observers where the two observers are positioned ¾ path width apart symmetrically about the center of the path.

RASC: Royal Astronomical Society of Canada.

Reaction time: See **Personal Equation.**

Reappearance: The re-emergence (comeback) of a star which had been occulted from behind the moon, asteroid or other celestial body.

Remote video station: A video station setup to record an occultation event without an observer watching over it. The video station consists of a video camera, camcorder or VCR, telescope and/or telephoto lens. The telescope system will either be tracking the object being occulted or pointed at the portion of the sky waiting for the object to move into the field of view of at the time of the occultation event. Remote video stations are not controlled by a remote transmitters, rather they are placed somewhere, turned on and left.

Report form: A form filled out by an observer (and emailed) describing an occultation observation. For an asteroid occultation report form, information requested in the form includes the date, time and geographic coordinates where the occultation was observed, the telescope system used, all occultation times made, weather conditions, plus any other relevant information. A similar form is used for total and grazing occultations, these have a special 76 column email format.

Running time: The displayed time over laid onto a video in at least 0.01 second increments inserted by special video or GPS time inserters.

SAO: Smithsonian Astrophysical Observatory Star Catalog. A compilation catalog of 258, 997 stars and their proper motions plus other positional data published by the Smithsonian Astrophysical Observatory in 1966. This catalog is now out of date but its identifying star numbers are routinely used to avoid mistakes in star identifications.

Saros: The 18.6 year cycle of solar and lunar eclipses. This is where the Sun, moon and the nodes of the orbit return to nearly their origin relative position.

Schmidt-Cassegrain: A popular folded optical telescope system with a corrector plate on the front end.

Scintillation (twinkling): Rapid irregular variations in the brightness of light from celestial sources, usually stars, produced as the light passes through the Earth's constantly moving atmosphere.

SCT: **Schmidt-Cassegrain** telescope.

Sea level limit line: A line projected from the moon's north or south limb that would fall on the Earth at sea level.

Second contact: For a solar eclipse, it is the moment when the total phase of the eclipse begins. See also **First Contact**, **Third Contact,** and **Fouth Contact.**

Secular: Continuing over a long period of time.

Seeing: Astronomical seeing is the measure of the atmospheric steadiness at the time of a telescopic observation. Good and bad seeing vary due to the amount of turbulence in the Earth's atmosphere.

Selective availability: The intentional degradation of GPS signals by the US Government to limit the accuracy of a GPS receiver's computed position. Abbreviated *SA*. *SA* was turned off by Presidential Order on May 2, 2000, however it is possible for military reasons for it to be reinstated for random periods.

Selenographic coordinates: Coordinates on the surface of the moon.

Separation: The angular distance between the two components of a double star or binary star system, its value is expressed in arc-seconds (").

Setting circles: circular scales on telescopes that provide right ascension and declination coordinates for a celestial target.

Shadow (or asteroid's shadow): When an asteroid is located in-line between the Earth and a star, it cuts off the light from the star and thus casts a shadow on the Earth.

Shadow cone: The shadow formed by the moon blocking the Sun's light during a solar eclipse. It is shaped like a cone with the vertex touching the Earth (total eclipse) and vertex just short of the Earth (annular eclipse).

Shadow path (or occultation path or path of an occultation): As an asteroid moves across the sky its shadow passes across the Earth. This path of the asteroid's shadow is the "shadow path" or "occultation path".

Shift: The movement of the path of a predicted occultation determined as a result of observations.

Short wave time signals: Time signals in the form of tones broadcast usually every second in the short wave frequencies ranging from 2.5 Mega Hertz to 20,000 Mega Hertz. A list of radio stations broadcasting these time signals is given in Appendix J.

SOHO: Solar Heliosphereic Observatory satellite launched in 1995 to study the Sun.

Solar eclipse: An eclipse of the Sun in which the moon passes in front of the Sun blocking its light from several minutes to up to one hour. When the moon covers up the entire Sun this is called a total eclipse, when the moon only covers up part of the Sun this is called a partial eclipse. When the moon passes directly in front of the Sun and its apparent diameter is not wide enough to cover the complete Sun, leaving a ring of sunlight visible, this is called an annular eclipse. Total and partial eclipses can occur at the same time. If the observer is right in the moon's shadow he will see a total eclipse, if he is outside the moon's shadow he will see a partial eclipse.

Speckle interferometry: Technique in which the resolution limit of a telescope normally imposed by the atmospheric seeing can be greatly improved by taking multiple short exposures of a star (10 - 20 milliseconds) and combining them into a distortion free image.

Spectacular graze: A grazing occultation in which to expect a stunning view/observation, such as a graze of one of the four 1st magnitude stars, Antares, Aldebaran, Regulus or Spica. Also refers to a graze in which the moon passes through a bright cluster, such as the Pleiades when the moon is at crescent phase.

Spectral Class: The groups into which stars are classified based upon their temperature, spectral absorption lines and color index. For occultation work the spectral class is used to determine the color of the star as it appears in the telescope.

Standard solar diameter: The apparent diameter of the Sun at exactly 1 **AU** distance.

Standard station: One of the 18 cities in North America and Honolulu in which occultations predictions are made yearly and published in the Royal Astronomical Society's Observers Handbook and on IOTA's website.

Star catalog: A collection of data, compiled from observations, of stars down to a specified limiting magnitude, or of stars with certain physical or other characteristics. Data can include position in right ascension and declination, magnitude, proper motion, trigonometric parallax, spectral type, radial velocity, estimated errors in measurements of these quantities, etc.

Star hopping: A manual technique of pointing a telescope by using star charts to find the target star prior to an asteroid occultation. The observer 'hops' from one star or star field to another to eventually pin down the target object being sought.

Stellar companions: A second or third star orbiting the main parent or brighter star. If the companions are too faint to be seen by the naked eye using a telescope, they can be discovered during an occultation as a step event. This happens when the star's brightness dims gradually rather than instantly at the moment of the occultation.

Stellar diameter: The diameter of a star. These can be computed for the larger giant and supergiant stars during an occultation when their brightness increases or decreases gradually over several video frames or by the time interval of the brightness drop on a photometer. Hundreds of stars have had their diameters derived from occultations.

Stellar duplicity: Double star. The appearance of a close double star as a result of an occultation observation.

Step events: An occultation event of a star in which the disappearance or reappearance takes place gradually rather than instantaneously. The brightness of the star will gradually change over several video frames rather than consecutive frames. Visual observers will also notice this gradual brightening/dimming effect.

Stopwatch: A timepiece that can be instantly stopped and started by pushing a button. The time of stopping and starting is displayed on the dial for recording.

Sun: The star at the center of our solar system

TAN Z correction: Used in the formula Tan Z = d/h, where h is the observers elevation above sea level and d is the correction being computed. Z = zenith distance of star to be observed at the time of the graze. Solving for d, d = h Tan Z.

ΔT: also known as Delta T. Since 1984 an increment added to Universal Time (UT) to give Terrestrial Dynamical Time TDT. ΔT is not constant and is increasing in an irregular manner. From 1970 and 1990 it changed from +40 to +57 seconds. It is predicted to be +67 seconds by 2010. See Appendix O for current values.

Target star: the star that will be occulted by an asteroid during an asteroid or planetary occultation. Also the star being occulted by the moon.

Terminator: The line dividing the bright Sunlit portion and dark shadowed portion of the moon.

Terrestrial dynamic time: This is the timescale used for the calculation of orbital motions within the solar system. It is the independent variable in the equation of motion.

Time signal receiver: Electronic device used to display or produce accurate time signals from a recognized source such as radio station WWV in the USA.

Thermal equilibrium: The condition referred to when the air temperature outside the telescope tube is equal to the inside of the telescope tube. If a telescope is not in thermal equilibrium with the outside air, then tube currents will cause the star images to appear to boil, be unsteady and shake making an occultation observation extremely difficult if not impossible. This equilibrium also applies to the telescope optics, especially mirrors. Mirrors will flex if their temperature is going through large changes causing the star images to be deformed.

Third contact: For a solar eclipse, it is the moment when the total phase of the eclipse ends .See also **First Contact**, **Second Contact,** and **Fourth Contact**.

Topographic (TOPO) map: United States Geological Survey (USGS) quadrangle maps. These maps are 7.5' square, which covers an approximate 7.5 miles per side.

Topography: Elevation of features typically at the poles of the moon when applied to occultations.

Toque: A wool or similar cap that covers the head and ears to protect against cold. Sometimes called a stocking cap. Differs from a nautical watch cap in that it covers the ears.

Total solar eclipse: Where the moon completely covers the Sun such that none of the solar disc is visible at central eclipse.

Total occultation: Where the moon completely occults (covers up) a star or other celestial body.

Transit: The passage of an inferior planet (Mercury or Venus) across the Sun's disk. In extrasolar planet research, the extrasolar object will transit across the host star causing a detectable dimming on sensitive photometers.

Trilateration: The technique of using multiple GPS satellites to determine an observer's ground position.

TYC: Tycho Star Catalog.

Tycho-2 catalogue: A star catalog containing accurate positions, proper motions and two color photometry compiled from data from the Hipparcos astrometry mission and numerous ground based star catalogs. This catalog contains the 2.5 million brightest stars in the sky.

UCAC2: A star catalog of over 48 million stars with position, proper motion and photometry. It is the second USNO CCD Astrographic catalog.

Umbra: The central completely dark part of a shadow.

Umbral Distance: Distance of a star from the center of the umbra during a lunar eclipse. Units are expressed as a percentage of the radius of the umbra.

Umbral limit: The edge of the umbra, the dark inner region of a shadow cast during an eclipse.

Uncertainty: An estimate of sigma (square root of the variance) for the confidence interval of the path prediction.

Uncertainty Ellipse: A two dimensional version of the path uncertainty which is usually plotted on the path prediction maps (applies to asteroid occultation predictions).

USNO: United States Naval Observatory, located in Washington, D.C The USNO is responsible for the determination of the positions and motions of stars and solar system objects and the establishment of celestial reference frames. Advanced equipment and methods, such as large scale CCD measuring devices, speckle and radio interferometry, are being used or developed to extend the accuracy and brightness limits of the reference frames.

Update: A revised path prediction which is usually computed near the time of an event such as an asteroid occultation (or solar eclipse, grazing occultation, etc.) An asteroid occultation update is usually more accurate than the initial prediction because it utilizes more recent observations of the asteroid.

UT: Coordinated Universal Time, the time used to define the reference to which occultations are predicted, i.e. the local time at the zero longitude on Earth, Greenwich, England. GMT, or Greenwich Mean Time is no longer used in the terminology.

Visual binary: A multiple star system whose components are sufficiently far apart to resolve visually, either with the naked eye or with a telescope. In most cases the stars are of different magnitudes, the brighter component is called the *primary*, and the other is called the *secondary* or *companion.* Over a period of time (years) observation reveals the changes in the positions of the components in their orbit.

Vernal Equinox: The intersecting point of the celestial equator and ecliptic in which the Sun moves south to north of he equator.

WAAS: Wide Area Augmentation System, a series of ground reference stations that transmit differential correction information allowing GPS receivers to produce high accuracy positions (3 meters nominal). WAAS was developed by the Federal Aviation Administration (FAA).

Waning moon: The phase of the moon from full moon until new moon. Waning moon’s rise in the mornings after local midnight and before Sunrise.

Watts angle: The axis angle around the limb of the moon, measured positive eastward from the moon's North Pole. The Watts angle is offset from axis angle by a constant 0.2", and is given on predicted graze profiles; they are not the same due to a mistake in the reference point made when Watts' limb correction charts were created.

Watts lunar limb/Watts charts: Lunar limb profiles compiled by Chester Watts in the 1940’s and 1950’s.

Waxing moon: The phase of the moon from new moon until full moon. Waxing moon’s occur in the evenings after Sunset and before local midnight.

Waypoint: a latitude and longitude and elevation that defines a position on the Earth’s surface.

WGS: World Geodetic System, one of the many models to define the Earth’s shape.

Wind Chill factor: Adjustment to ambient temperature to account for the effect of wind upon exposed skin.

WWV: Shortwave Radio station broadcasting time signals at frequencies 2.5, 5, 10, 15 and 20 Mhz. Time signals include a short tone each second, and an announcement eight seconds before the top of the next minute. Geomagnetic and GPS satellite status and reports are broadcast from time to time. WWV broadcasts originate from Ft. Collins, Colorado.

XTE: Cross track error, a term used in several GPS receivers to indicate the perpendicular distance the user is from a line defined by two **waypoints**.

X-track: GPS term to denote the perpendicular distance away from a fixed line on Earth. The line is defined by two **waypoints**. The line can be the center path of an asteroid occultation, solar eclipse **umbral limit** or center limit**.** Also known a "**Off Course** or "**Cross Track**" distance on some GPS model units.

XZ catalog: A catalog made from the compilation of several other star catalogs, the Position and Proper Motion (**PPM**), Hipparcos, (**HIP**), and **ACT** covering the ecliptic zone where lunar occultations can occur. The XZ catalog contains 53,933 stars.

ZC catalog: Zodiacal Catalog. A catalog of 3539 stars in the zodiac region originally published by J. Robertson in 1939, it was republished by the Japanese astronomer Isao Sato in 1986 to the J2000 reference frame.

Zodaical region: That band on the celestial sphere extending around 9 degrees of the ecliptic. This is the region of the sky in which originally the Greeks defined the 12 zodiac constellations.

APPENDIX J. Details of Shortwave Time Signals for Occultation Timings

Shortwave radio stations and their transmitting frequencies are given in the table below for easy reference. Detailed information for each radio station follows the table. This list courtesy Klaus Betke, DL4BBL, http://www.longwave.de/TSS.pdf

STATION	**Transmit Frequency**
CHU (Canada)	3330, 7850, 14670 kHz
DCF77 (Germany)	77.5 kHz
JJY (Japan)	40 , 60 kHz
LOL, Buenos Aires, Argentina	5000, 10000, 15000 kHz
MSF, Rugby, United Kingdom	60 kHz
RWM, Moscow, Russia	4996, 9996, 14996 kHz
WWVH, Kekaha, Hawaii	2500, 5000, 10000, 15000, kHz
WWV, Ft. Collins, Colorado	2500, 5000, 10000, 15000, 20000 kHz
YVTO, Caracas, Venezuela	5000 kHz

CHU, Ottawa, Canada

Frequencies:	3330, 7850 (effective January 1, 2009) , 14670 kHz
Call sign:	CHU
Location:	Ottawa, Canada, 45° 18' N, 75° 45' W
Operating hours:	Continuous
Power:	3 kW at 3330 and 14670 kHz, 10 kW at 7335 kHz
Modulation:	AM (USB only), tones and voice

The first minute of each hour commences with a 1 second pulse of a 1000 Hz tone, followed by 9 seconds of silence, and then the normal pattern of 0.3sec pulses of 1000 Hz at one second intervals. The normal pattern for each of the next 59 minutes starts with a 0.5sec 1000 Hz pulse.

The pulse in second 29 is omitted. Following the normal pulse at 30 seconds, for a 9 second period, 1000 Hz pulses of 0.01sec occur, each Followed by the CHU time code. The pulses between 40 and 50 seconds are of normal length.

Identification Signal: Alternating French/English station identification in the last 10 seconds of each minute, followed by UT time announcement, valid for the following minute. During the announcement period, the 1000 Hz second pulses are shortened to “ticks.”

Further information: NRC time services: http://inms-ienm.nrc-cnrc.gc.ca/

DCF77, Mainflingen, Germany

Frequencies: 77.5 kHz
Call sign: DCF77
Location: Mainflingen, near Frankfurt, Germany, 50° 01' N, 9° 00' E
Operating hours: Continuous
Power: 50 kW. Estimated radiated power 30 kW
Modulation: Amplitude keying.

Identification Signal: The call sign is transmitted twice in Morse code in minutes 19, 39 and 59. Also in seconds 20 to 32 in AM, the amplitude is switched between 85% and 100% with a 250 Hz rectangular waveform. The signal may be omitted in the future.

Further information: Physikalisch-Technische Bundesanstalt, http://www.ptb.de

JJY, Japan

Frequencies: 40 kHz and 60 kHz
Call sign: JJY
Location 40 kHz: Ohtakadoyayama, Fukushima prefecture, 200 km N of Tokyo, 37° 22' N, 140° 51' W
Location 60 kHz Haganeyama, Saga prefecture, Kyushi lsl., 37° 22' N, 140° 51' W

Operating hours: Continuous
Power: 50 kW, Radiated power > 10 kW
Modulation: Top of each minute has a 0.2sec tone. Seconds 9, 19, 29, 39, 49 and 59 have 0.2sec tones.

Further information: National Institute of Information and Communications Technology NICT, Their web site has information in Japanese only: http://jjy.nict.go.jp/

LOL, Buenos Aires, Argentina

Frequencies:	5000, 10000, 15000 kHz
Call sign:	LOL
Location:	Buenos Aires, Argentina, 34° 37' S, 58° 21' W
Operating hours:	1100-1200, 1400-1500, 1700-1800, 2000-2100, 2300-2400
Power:	2 kW
Modulation:	AM 440 Hz and 1000 Hz tones and voice
	The beginning of each second is marked with a 5 ms long tick (5 periods of 1000 Hz), except second 59.
Identification Signal	Call sign in morse and announcement. Different minutes after the full hour have different transmission contents. Full details on web site. Further information: Observatorio Naval Buenos Aires. http://www.hidro.gov.ar

MSF, Rugby, United Kingdom

Frequencies:	60 kHz
Call sign:	MSF
Location:	Rugby, England, 52° 22' N, 01° 11' W (until 31 March 2007) Anthorn, England, 54° 55' N, 03° 15' W (starting 1 April 2007)
Operating hours:	Continuous
Power:	15 kW
Further information:	National Physics Laboratory Time and Frequency Service. http://www.npl.co.uk/npl/time

RWM, Moscow, Russia

Frequencies:	4996, 9996, 14996 kHz
Call sign:	RWM
Location:	Moscow, 55° 48' N, 38° 18' E
Operating hours:	Continuous
Power:	5 kW at 4996 and 9996 kHz, 8 kW at 14996 kHz
Modulation:	On-off keying (A1B)
Identification Signal:	Call sign in Morse in minutes 09 and 39.
Further information:	http://longwave.de/TSS.pdf

00m00s – 07m55s, 30m00s – 37m55s Unmodulated carrier

08m00s – 09m00s, 38m00s – 39m00s	No transmission
09m00s – 10m00s, 39m00s – 40m00s	Morse Code
10m00s – 19m55s, 40m00s – 49m55s	1 Hz pulses with UT1-UTC code. Pulse duration 100ms, minute pulse 500 ms
20m00s – 29m55s, 50m00s – 59m55s	10 Hz pulses. Duration 20 ms. Second pulse = 40 ms, minute pulse = 500 ms

WWV, Fort Collins, USA and WWVH, Kekaha, Hawaii

Frequencies: 2500, 5000, 10000, 15000, 20000 kHz
Call sign: WWV and WWVH
Location: Fort Collins, Colorado, 40° 41' N, 105° 02' W
Kekaha, Hawaii, 21° 59' N, 159° 46' W
Operating hours: Continuous
Power: Radiated power: 2.5 kW on 2.5MHz (WWVH: 5 kW), 10 kW on 5/10/15 MHz 2.5 kW on 20 MHz
Modulation: AM. Various tones and voice announcements. Top of each minute 1000 kHz, 800 ms tone. Second pulses 01 – 28, 30 – 59 are 1000 Hz, 5 ms duration. Top of each hour tone: 1500 Hz 800 ms duration.
WWV – male voice announcement seconds 52 – 58
WWVH – female voice announcement seconds 45 - 52

During each hour various voice announcements are made concerning storm information, GPS reports, Geomagnetic alerts, Station ID.

Identification Signal: Announcement in minutes 00 and 30 (WWV), minutes 20 and 59 (WWVH)

Further information: National Institute of Standards and Tecnology, NIST, Time and Frequency Division, http://www.boulder.nist.gov/timefreq/

YVTO, Caracas, Venezuela

Frequencies: 5000 kHz
Call sign: YVTO
Location: Caracas, Venezuela, 10° 30' N, 66° 56' W
Operating hours: Continuous
Power: 1 kW
Modulation: AM, tones and voice

Each second marker starts with a 1000 Hz tone of 100ms duration, except second 30, when the tone is omitted. A 800 Hz tone of

500 ms duration is emitted at the beginning of a minute. Time announcement in Spanish in seconds 52 – 57.

Identification Signal:	Announcement in seconds 41…50: “Observatorio Naval Cagigal – Caracas – Venezuela
Further information:	Observatorio Naval Cagigal. http://www.dhn.mil.ve/

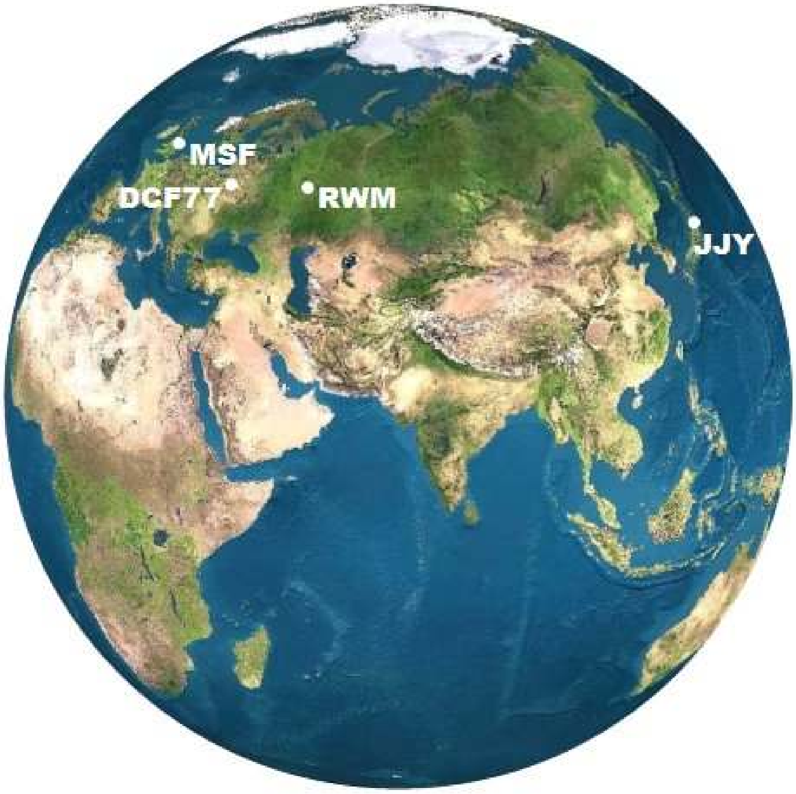


Figure J-1. Locations of major time signal shortwave radio stations.

APPENDIX K. Useful Web Addresses

World Wide Web addresses for IOTA and related web pages are given here. Many of these URL's are linked from the main IOTA web page. Several appear in Appendix A.

ASTEROID PAGES

Asteroid Occultation predictions worldwide: http://www.asteroidoccultation.com/

Asteroid Occultation predictions, Europe, North Africa, Middle East: http://mpocc.astro.cz/

Asteroid Occultation predictions, Japan (English and Japanese):
http://uchukan.sendai-net.jp/asteroid/prepre.html

Asteroid Occultation page, Mexico: http://pw1.netcom.com/~psada/mex_asteroid.htm

Asteroid Occultation predictions, Russia (Russian): http://hea.iki.rssi.ru/~denis/occ2003.html

Asteroid Occultation Results page, North America:
http://www.asteroidoccultation.com/observations/results/

Asteroid occultations: North American Asteroid Occultation Program:
http://www.asteroidoccultation.com/observations/NA/

Asteroid Occultation Simulator program for Windows:
http://www.lunar-occultations.com/iota/aops.htm

Asteroid Occultation Search Page by distance from site: http://occult.tungstentech.com/

Asteroid Occultation website for European Observers: http://www.euraster.net/

Asteroid Path Maps for North America using Google Earth Maps (linked from this page): http://www.poyntsource.com/New/Google.htm

Asteroid Satellite Page (Bob Johnston): http://www.johnstonsarchive.net/astro/asteroidmoons.html

Asteroid Occultation Path Observer Station Update Page for USA (Derek Breit): http://www.poyntsource.com/New/Global.htm

Binary Near Earth Asteroids: http://www.asu.cas.cz/~asteroid/binneas.htm

Catalog of Observed Asteroid Occultation events worldwide: http://sorry.vse.cz/~ludek/mp/world/mpocc1.txt

European Asteroidal Occultation Network, EAON: http://www.astrosurf.com/eaon/

FTP download of asteroid events worldwide (Goffin Charts): ftp://ftp.ster.kuleuven.ac.be/dist/vvs/asteroids/

Ondrejov Observatory Near Earth Object Program: http://sunkl.asu.cas.cz/~ppravec/neo.htm

Possible Asteroid Moons and binary asteroids : http://hea.iki.rssi.ru/~denis/doublemp.html

Trans Neptunion Objects (TNO's) List: http://cfa-www.harvard.edu/iau/lists/TNOs.html

GPS/ MAPS/ TIME

GPS general info: http://www.edu-observatory.org/gps/gps.html

GPS World Magazine: http://www.GPSworld.com

KIWI Precision Time Stamp Utility: http://www.pfdsystems.com

Maps On Us page for determining low precision coordinates: http://www.MapsOnUs.com

National Institute of Standards Time & Frequency Division: http://tf.nist.gov

North American City Coordinates for Major Occultation event Predictions: http://www.lunar-occultations.com/iota/nadat.htm

Time Resources, New Zealand and Australia: http://tufi.alphalink.com.au/time/time_gps.html

TOPO Maps (for elevation determination): http://www.topozone.com

United States Geological Survey TOPO Map page: http://topomaps.usgs.gov/

IAU

International Astronomical Union (IAU): http://www.iau.org/

Recent circulars of the IAU: http://cfa-www.harvard.edu/iauc/RecentIAUCs.html

IOTA

IOTA main web page:
http://www.lunar-occultations.com/iota/iotandx.htm Many occultation links are listed on this page.

IOTA site for new members: http://www.occultations.org/

IOTA/European Section: http://www.iota-es.de/

IOTA/Dutch Occultation Association: http://www.doa-site.nl

IOTA, Argentina (Spanish): http://www.ocultacionesliada.8k.com/principal.htm

IOTA Asia/India: http://meghnad.iucaa.ernet.in/~aaa/occultations/asteroid/a_occult.html

IOTA discussion group: http://groups.yahoo.com/group/IOTAoccultations/

International Lunar Occultation Center, ILOC: http://www1.kaiho.mlit.go.jp/KOHO/iloc/obsrep

IOTA President David Dunham's Occultation Page: http://iota.jhapl.edu/

IOTA Vice-President Paul Maley's Occultation Page: http://www.eclipsetours.com/occultationa

IOTA Executive Secretary Richard Nugent's Asteroid Occultation Page:
http://weblore.com/richard/AsteroidPage.htm

IOTA Expense report form: http://www.lunar-occultations.com/iota/iotatax.htm

IOTA Northwest, occultation reports from the northwest USA
http://www.doso-observatory.org/IOTA.htm

New Lunar Occultation Reporting Excel Form and instructions:
http://www.timerson.net/IOTA

Why Occultation Flyer, http://www.occultations.org/maindownload/WhyFlyer2006.pdf

Why Occultation Flyer, Spanish version:
http://www.occultations.org/maindownload/WhyFlyer_sp.pdf

OCCULTATION SOFTWARE DOWNLOADS

LiMovie: http://www005.upp.so-net.ne.jp/k_miyash/occ02/limovie_en.html

Lunar Occultation Workbench (LOW) Software download: http://www.doa-site.nl/

OccuLAR: Occultation LiMovie Analysis Routine:

http://www.asteroidoccultation.com/observations/NA/

Occult Watcher; lists all asteroid events near your site:
http://www.hristopavlov.net/OccultWatcher/OccultWatcher.html

Occult Software download/update page: http://www.lunar-occultations.com/iota/occult4.htm

Scantracker, for using the CCD drift scan technique to time occultations:
http://www.asteroidoccultation.com/observations/DriftScan.htm

NOTE: Software download pages may change since the date of this publication. If the program cannot be found, use a web search engine such as Google.com or Yahoo.com, type in the name of the program or ask an IOTA member on the IOTA discussion group.

WOTAP, determines the time between the sequential German DCF 77 shortwave signals and when a star disappears in an AVI sequence from a web cam:
http://home.wanadoo.nl/adri.gerritsen/wotap.htm

OCCULTATION SOURCES:

Dutch Occultation Association (Netherlands): http://www.doa-site.nl

Occultation section of the Stefanik Observatory, Prague Czech Republic:
http://sorry.vse.cz/~ludek/zakryty/weleng.phtml

Royal Astronomical Society of New Zealand Occultation Section: http://occsec.wellington.net.nz

Royal Astronomical Society of Canada (RASC): http://www.rasc.ca

Sky and Telescope Occultation Primer:
http://skyandtelescope.com/observing/objects/occultations/article_92_1.asp

South America asteroid occultation page(Spanish): http://www.ciens.ula.ve/~gatula/ocultaciones.html

STAR CATALOGS

Hipparcos Space Astrometry Mission and Catalog Search:
http://astro.estec.esa.nl/SA-general/Projects/Hipparcos/hipparcos.html

Hubble Guide Star Catalog 2.2 Data Access:
http://www-gsss.stsci.edu/support/data_access.htm

Tycho-2 and Hipparcos Catalog Retrieval: http://archive.eso.org/skycat/servers/ASTROM

United States Naval Observatory CCD Astrograph Catalog (UCAC): http://ad.usno.navy.mil/ucac/

MISC.

Dow Corning low temperature bearing grease:
http://www.dowcorning.com/applications/Product_Finder.

APPENDIX L. “Why Observe Asteroid Eclipses” Flyer

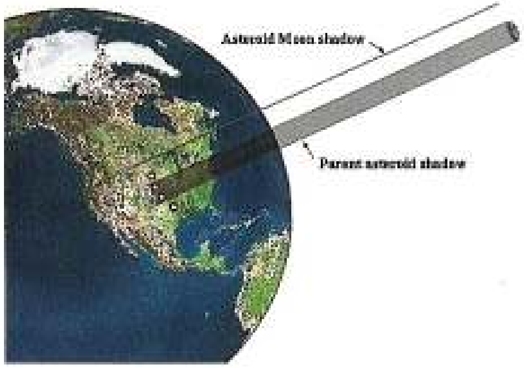
Disperse this tri-fold flyer at astronomy club and astronomy club novice meetings, star parties, astronomy conventions, astronomy day and to any and all other persons anywhere interesting in your involvement with IOTA.

This flyer was created by Derek C Breit of BREIT IDEAS Obs. Please contact him if you would like a copy that you can personalize. There is also available a Spanish version graciously translated by Pedro Sada:

Spanish language version: http://www.occultations.org/maindownload/WhyFlyer_sp.pdf

ASTEROID ECLIPSES

Thousands of small planet-like bodies exist between the orbits of Mars and Jupiter in our solar system called asteroids. They are usually too small to and too far away to be accurately imaged by ground based telescopes. We can study the size and shape of an asteroid by placing an observer with a telescope in the path of this a***steroid eclipse* or *"occultation"***. This is where an asteroid passes between the Earth and a star causing the star to be briefly eclipsed. The shadow of the asteroid is projected onto the Earth and crosses a finite area proportional to the asteroid diameter. If many observers are placed in a perpendicular line across the occultation path, their individual timings of the disappearance and reappearance of the target star will vary depending upon where along the path they are located.



In the diagram, the asteroid passes in front of a star and its moving shadow touches the Earth. As the shadow passes across the Earth, it crosses the 4 observers located at A, B, C, and D. Observers at A and D are outside the path and don't see the asteroid eclipse the star. Meanwhile observers B and C are located within the asteroids shadow path and they do see a brief eclipse (occultation). When many observers line up to observe an asteroid occultation, their timings of the duration of the length of the eclipse can be combined to provide a representation of the size and shape of the asteroid.

The observations, combined with those of others can lead to the following results:

Asteroid Profile of 345 Tercidina

The observation of these types of events also provides a unique opportunity to discover *asteroid moons,* of which only two dozen are known. Asteroid Moons were first realized by IOTA astronomers using the occultation technique in 1977.

More information about IOTA and occultations can be found at:

http://www.lunar-occultations.com/IOTA
http://www.occultations.org
http://IOTA.jhapl.edu
http://weblore.com/richard
http://www.asteroidoccultation.com
http://eclipsetours.com/occultationa

WHY OBSERVE ASTEROID ECLIPSES ?

The International Occultation Timing Association (IOTA) provides predictions, promotes the observation, data reduction and reporting of lunar & asteroid occultations and solar eclipses

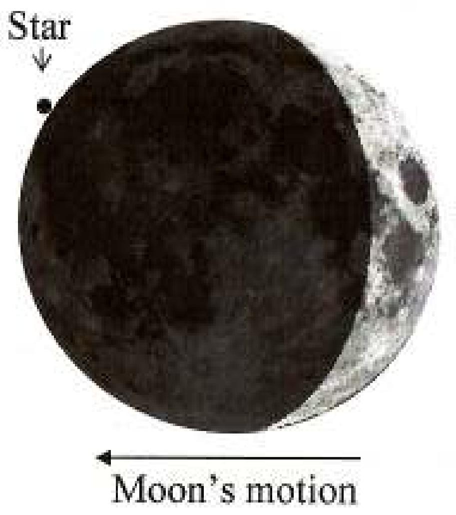
www.occultations.org

http://www.lunar-occultations.com/iota

OCCULTATIONS

An occultation (special type of eclipse) is undoubtedly one of the most amazing sights that the amateur astronomer can ever witness. Occultations are similar to eclipses in that they involve the passage of one celestial body in front of another. This process creates an opportunity to study the nature of one or both objects. And it offers professional and amateur astronomers exciting opportunities for continuing research.

If, as an amateur astronomer or telescope owner, you are thirsting to feel relevant, to do something meaningful, and to see the sights that few have ever witnessed, then occultations are for you. The occultation process offers a means for discovery and research. It is possible for amateur astronomers to discover new companions to stars, help to improve the polar diameters of the Sun and Moon, identify the existence of possible satellites orbiting asteroids, to improve knowledge of heights of lunar mountains peaks and depths of valleys in the polar regions, determine corrections to ephemeris errors and assess star position errors, improve knowledge of the shape, sizes and orbits of asteroids, and more through occultation science. It does not matter where you live in the world. If you have access to a computer and possess a telescope of at least 4-6 inches, know your geodetic position either from GPS or a good topographic map, have a source of receiving shortwave time signals and have a taper recorder, you can make your own observations of these rare and critical events.



ECLIPSES OF STARS BY THE MOON

As the Moon moves in its orbit about the Earth, it covers stars along the way. We can take full advantage of this to record the star's disappearances and reappearances. There are two types of occultations of stars by the Moon: 1) ***total occultations*** where the Moon completely hides the star for many minutes, 2) ***grazing occultations***, where a star undergoes a series of disappearances and reappearances caused by lunar mountains at either the north or south lunar pole. The latter is more interesting and offers the opportunity to: a) determine heights of lunar features and depths of lunar valleys, 2) determine if the star is single or may have a close companion, c) improve information on the orbit of the Moon, d) improve positional information on the star being occulted (eclipsed).

GRAZES OF STARS BY THE MOON

A grazing occultation is visible from a zone about two miles wide, which can be predicted approximately from lunar charts. If several observers with telescopes and timing equipment are positioned at intervals across the zone, they can each time the sequence of disappearances and reappearances as seen from their location. If the positions of the observing sites can be measured, the timings can be reduced afterwards to determine details of the lunar profile, and give a very accurate fix of the position of the Moon relative to the star. Such observations are useful for refining knowledge of the positions and motions of stars, and can be used to improve the parameters such as the tilt of the earth's equator and even study the rotation of the Milky Way galaxy. Knowledge gains of the lunar profile for these observations aids in analysis of total solar eclipse timings, which can be used to study climatically small important changes in the diameter of the Sun over periods of many years. Also the star's disappearances or reappearances may occur in steps, indicating a previously undiscovered close double star that cannot be resolved by direct observations.

The person who gave you this flyer can be reached in the following way:

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APPENDIX M. IOTA Annual Meetings

INVITATION TO ATTEND IOTA ANNUAL MEETINGS

The International Occultation Timing Association has annual meetings at locations in the United States in close proximity to important occultation events. This allows the coordination of IOTA’s most experienced along with new and prospective observers to participate in spectacular grazes and/or notable asteroid occultation expeditions. Details and meeting announcements are posted on IOTA’s main website:

http://occultations.org/community/meetingsconferences/

News of the meetings is usually broadcast on the IOTA listserver and other occultation publications. Annual meeting highlights including photos are located here:

http://www.poyntsource.com/Richard/IOTA_Annual_Meetings.htm

ESOP – European Symposium on Occultation Projects

INTERNATIONAL OCCULTATION TIMING ASSOCIATION
EUROPEAN SECTION

XXVIII ESOP2009
European Symposium on Occultation Projects
NIEPOLOMICE - POLAND

Each year in late summer, IOTA's European Section, IOTA-ES, holds its annual ESOP conference on occultation science, observing techniques and methods involving the Moon, planets, satellites of planets, rings of planets, asteroids, eclipses, etc. Previous meetings have been held in the United Kingdom, Belgium, Germany, The Netherlands, Poland, Spain, Italy, Finland and other European countries. Details of upcoming conferences and announcements are located on the IOTA/ES home page:

http://www.iota-es.de

APPENDIX O. Conversions, Units, Coordinate Systems

Length

Angstrom	Å = 10^{-8} cm = 10^{-10} m
Micron	μ = 10^{-4} cm = 10^{-6} m
Millimeter	mm = 1,000 microns
Centimeter	cm = 0.3937 in
Inch	in = 2.5400 cm
Foot	ft = 30.48 cm = 12 in
Yard	yd = 91.44 cm = 3 ft
Meter	m = 100 cm = 3.2808 ft = 1.0936 yd
Kilometer	km = 10^{5} cm = 0.621371 mile (statute)
Mile (statute)	mi = 1.609344 km = 5,280 ft
Mile (nautical)	mi = 1.8531 km = 6,080 ft
Astronomical Unit (AU)	= 1.4959787061 x 10^{11} m
Light year	ly = 9.460530 x 10^{17} cm
Light time for 1 AU	= 499.004782 s = 0.00577552 days = 8 min 19.004 s
Parsec	pc = 3.085678 x 10^{16} m
Parsec	pc = 3.261633 light year
Parsec	pc = 206,264.8062 AU

General astronomical constants

Velocity of light	c = 299,792,458 m/sec
Solar mass	$M_{\odot}$ = 1.9891 x 10^{33} gm
Solar radius	$R_{\odot}$ = 6.9599 x 10^{10} cm
Solar mean density	$\rho_{\odot}$ = 1.409 g/cm^{3}
Solar absolute luminosity	$L_{\odot}$ = 3.8268 x 10^{33} erg s-1
Solar effective temperature	T_{eff} = 5780 °K
Earth's mass	M_e = 5.9742 x 10^{27} gm
Earth equatorial radius	R_e = 6,378.14 km
Earth polar radius	= 6,356.75 km
Earth mean density	P_e = 5.52 g/cm^{3}
Moon's mass	M_m= 7. 3483 x 10^{25} gm
Solar parallax	= 8.79415"
Geocentric gravitational constant	= 3.986005 x 10^{20} cm^{3}/sec^{2}
Constant of gravitation	G = 6.672 x 10^{-8} cm^{3}/gm/sec^{2}

Time

Day: mean sidereal	= 86,164.0909 sec

Day: mean rotation (star to star) = 86,164.0993 sec
Day: mean solar = 86,400 sec
Month:Draconic (node to node) = 27.212221 d
Month:Tropical (equinox to rquinox) = 27.321582 d
Month:Sidereal = 27.321662 d
Month:Anomalistic:perigee to perigee = 27.554550 d
Month:Synodic: successive new Moons
= 29.530589 d
Tropical year = $3.15569259747 \times 10^7$ sec
Tropical year = 365.24219 days
Julian century = 36525 days
Eclipse year: successive lunar nodes = 346.620075 d
Gregorian year = 365.2425 d
Sidereal year: fixed star to fixed star = 365.256363 d
Anomalistic year: perihelion to perihelion
= 365.259635 d

Values of ΔT

Recent observed values for delta-T (ΔT) are as follows:

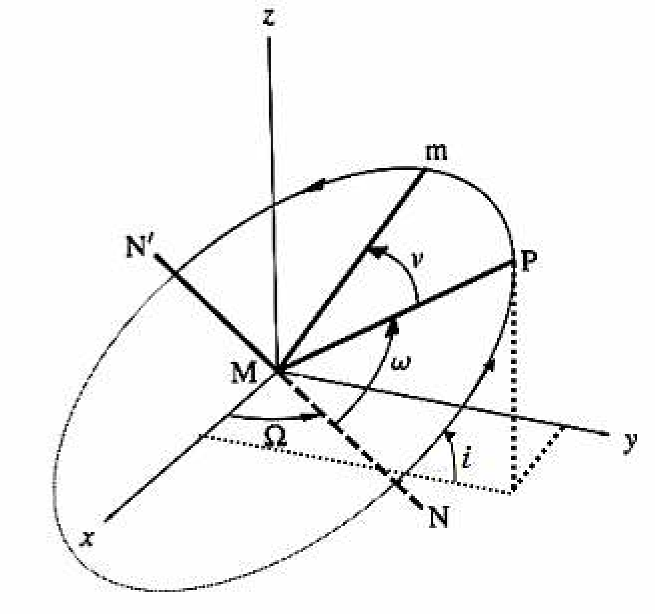
Year	ΔT (sec)
1970.0	40.18
1975.0	45.48
1980.0	50.54
1985.0	54.34
1990.0	56.86
1991.0	57.57
1992.0	58.31
1993.0	59.12
1994.0	59.99
1995.0	60.79
1996.0	61.63
1997.0	62.30
1998.0	62.97
1999.0	63.46
2000.0	63.83
2001.0	64.09
2002.0	64.30
2003.0	64.55
2005.0	64.70
2006.0	64.85
2007.0	65.14
2008.0	65.48

Angular Measure

1 radian rad = 2.0626480625×10^5 arc seconds (″)
1 radian rad = 57.2957795131 degrees
Pi π = 3.1415926536
π radians = 180°
1 deg deg = 0.0174532925 rad
1 deg deg = 3,600"
1 arcmin arcmin = 0.016666667 deg = 60″

1° of latitude = $111.13295 - 0.55982 \cos \varphi + 0.00117 \cos 4\varphi$ km (φ = latitude)
1° of longitude = $111.41288 \cos \varphi - 0.09350 \cos 3\varphi + 0.00012 \cos 5\varphi$ km
1° of latitude at equator = 110.5743 km
1° of longitude at equator ($\varphi = 0°$) = 111.3195 km

The orbit in Space



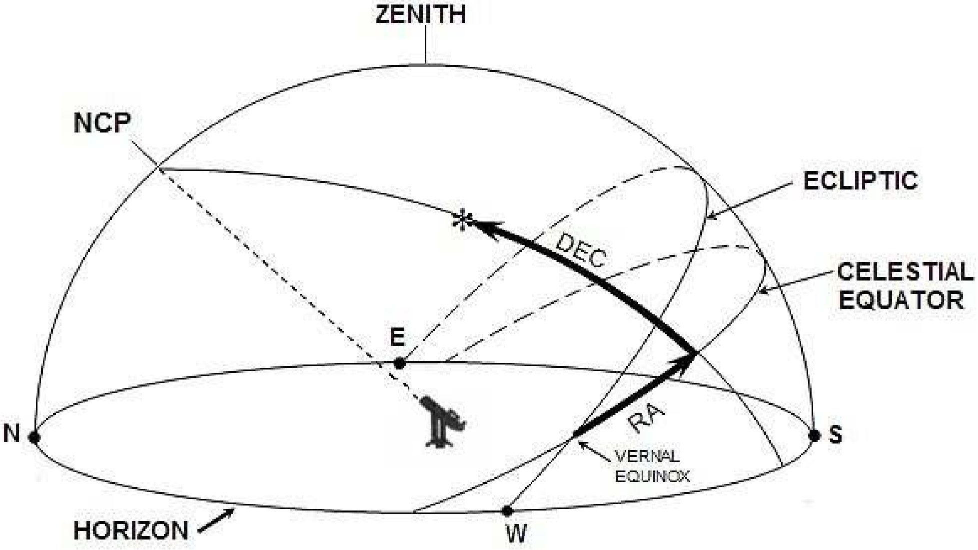
Orbital parameters. The position of a body in an elliptical orbit can be calculated from a set of six orbital elements. They are:

a = semi-major axis of the ellipse, the line MP
e = eccentricity of the ellipse
i = inclination of the orbit with respect to the ecliptic

Ω = longitude of the ascending node
ω = argument of pericenter, angle along the orbit from the ascending node MN to the point of pericenter MP
T = Epoch at which the body is at pericenter
N = true anomaly = $\omega + \nu$

Celestial Coordinates

Equator (Right Ascension) System



N, E, S, W = North, East, South and West points along the local horizon

NCP = North Celestial Pole

Zenith = point on the celestial sphere that lies 90° from all points on the local horizon

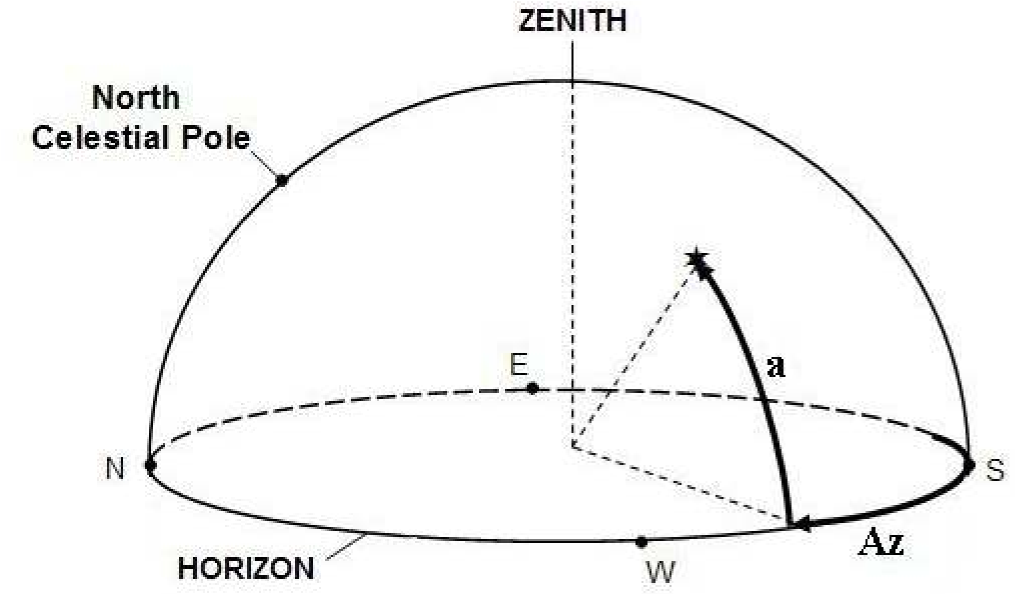
Ecliptic = Apparent path of the Sun along the celestial sphere

Celestial Equator = great circle projected onto the celestial sphere representing the extension of the Earth’s equatorial plane

Vernal equinox = The point where the Sun’s apparent annual motion intersects the celestial equator moving northward along the ecliptic. It represents the zero point of right ascension system.

RA = Right Ascension angle, varies from 0 – 24h, also denoted as α.
DEC = Declination angle, ranges from –90° to +90°, also denoted as δ.

Horizon System



N, E, S, W = North, East, South and West points along the local horizon

Zenith = point on the celestial sphere that lies 90° from all points on the local horizon

Azimuth = angle measured from the North point eastward along the horizon to the intersection of the object's vertical circle. Azimuth ranges from 0° to 360°. Azimuth is also denoted by **A**.

a = Altitude of the object above/below the horizon range –90° to +90°. A negative altitude indicates the object is below the horizon. a = 90° – z, where z = zenith distance.

Coordinate System Mathematical Relationships

$$\sin z \sin A = -\cos\delta \sin h$$
$$\cos z = \sin\delta \sin\varphi + \cos\delta \cos h \cos\varphi$$
$$\sin z \cos h = \sin\delta \cos\varphi - \cos\delta \cos h \sin\varphi$$

$$\cos\delta \sin h = -\sin z \sin A$$
$$\sin\delta = \cos z \sin\varphi + \sin z \cos A \cos\varphi$$
$$\cos\delta \cos h = \cos z \cos\varphi - \sin z \cos A \sin\varphi$$

where:

z = zenith distance

A = Azimuth
φ = observer's latitude
δ = declination
h = hour angle

The hour angle h is derived from   ST = h + RA, where ST = local sidereal time. The sidereal time is defined as the hour angle of the vernal equinox.

Useful Formulas

Distance Modulus: $m - M = 5 \log r - 5$

or:

$$M = m + 5 + 5\log(\pi'')$$

where:

m = apparent magnitude of object
M = absolute magnitude of object (this is the apparent magnitude of the object at the standard distance of 10 parsecs)
r = distance of the object in parsecs
π = trigonometric parallax angle of the object in arc seconds

The solution for r:

$$r = 10^{[(m-M+5)/5]}$$

Magnitude drop between 2 objects, star + asteroid:

$$\Delta m = 2.5 \log(10^{x} + 1)$$

where $x = 0.4(m_2 - m_1)$

m_2 = magnitude of asteroid
m_1 = magnitude of target star being occulted

Stellar distance, $r = 1/\pi$, π = trig parallax arc seconds

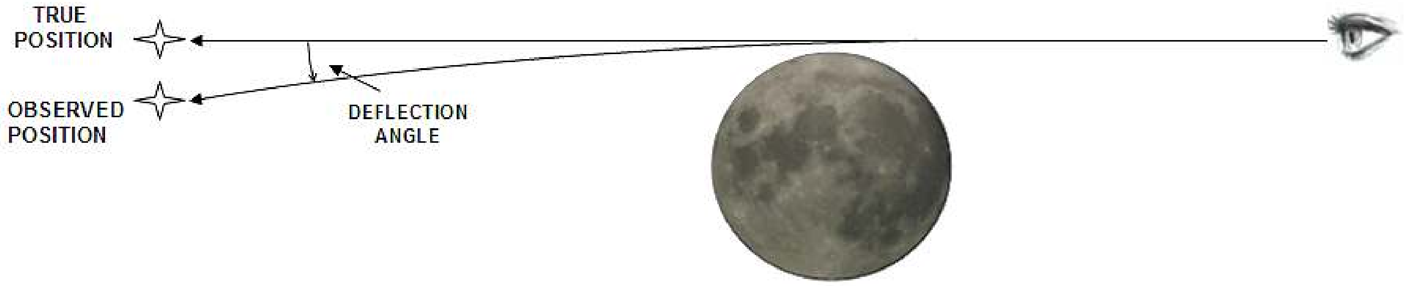
Relationship between distance, diameter and angular size

$$d = \frac{\alpha D}{206{,}265}$$

where: d = diameter of object
α = angular diameter in arc seconds (″)
D = distance of object (same units as d)

Relativistic Bending of Light

Einstein's General Theory of Relativity predicts that light passing near to a massive body will undergo a bending effect, rather than travel in a straight line. This effect is illustrated in the diagram below.



The relativistic equation used to compute the deflection angle α (to first order):

$$\alpha = \frac{4GM}{c^2R}$$

where α = deflection angle in radians (there are 206,265 ″/radian)
G = gravitational constant
M = mass of body light is grazing by
c = velocity of light
R = radius of body

For light grazing by the Sun, relativity predicts a deflection angle of 1.75″ (or 0.875″ at the Sun's limb). This value has been measured and verified. For the Moon, the deflection angle is 0.000013″ at the limb, far too small to measure with current occultation technology and equipment used by amateurs.

APPENDIX P. Tips from the Archives of IOTA Observers

The tips below are just a sample of techniques used by numerous observers to simplify and make the occultation experience easier and more enjoyable. If you can add to the list please pass on your idea to the IOTA discussion group listserver at:

http://groups.yahoo.com/group/IOTAoccultations/

Backup Equipment

If videotaping an event, bring a cassette or digital recorder as a backup. If your video system fails, the voice recorder and WWV can save the day.

Batteries

Always bring extra new batteries with you. Test your batteries the day of the event.

Equipment

Bring a portable folding chair to relax and rest while waiting for the occultation event. Consider using it while making the observation. Personal comfort during the observation increases the chances of obtaining accurate data.

Law Enforcement

Avoid confrontations with law enforcement officials. One approach is to go to a local police station on the day of the event and get a business card from an Officer. This way, if you are confronted, you can show that you attempted to notify the sheriff or police official in advance. Always be polite to Law enforcement.

Miscellaneous

Plan your occultation observing by marking your calendar weeks ahead of time for accessible events so you can plan accordingly. If you will be traveling, take along a portable system (most occultation observers are mobile anyway) and make your observation while traveling. Have some “Why Observe Asteroid Eclipses” flyers (Appendix L) to hand out to onlookers.

Observing Technique

For events that have a low magnitude drop, 0.1 – 0.2, defocus the star image so the video CCD camera pixels are not saturated and the magnitude drop is not lost in the over saturated image.

While waiting for an asteroid occultation turn off your video systems to save battery power. Turn them back on every 5 minutes to check for telescope drift. Make adjustments to the FOV to re-center the target star. Use the same strategy for your shortwave radio. But do not turn off your GPS time inserter – if you wait until 2 or 3 minutes before the event to turn on the GPS time inserter, it may not be enough time to acquire satellites and the GPS time signals.

For asteroid occultations, write down on the world map (from http://www.asteroidoccultation.com) your observation times which should be ± 3 minutes around the predicted time of the event. This minimizes any confusion as you get near to start your observation (visual or video).

Don’t use too much magnification (more than 150x) when observing occultations. Higher powers amplify not only the star but the turbulence in the atmosphere making it difficult to distinguish a real occultation event compared to the shaking turbulent, flickering image of the star. Higher powers with non-motor driven telescopes also make for constant hand adjustments to the telescope.

Setup

Practice setting up your equipment in the dark, so as to identify problems or issues ahead of time rather than the night of the event.

When parking on the side of a road for an occultation, set the telescope facing away from the road to avoid passing car’s headlights interfering.

When setup for an occultation along the side of a road, and a well meaning passer-by stops to question if your OK, hand them the “Why Observe Asteroid Eclipses ?” flyer (Appendix L) or a business card that explains your involvement with IOTA.

When setting up a mobile telescope on the hood of a car, be sure your tires don’t have a slow leak. This could alter the telescope’s alignment and cause you to lose the field of view while waiting for the occultation.

Site Position

Write down your latitude/longitude coordinates and elevation from your GPS receiver on arrival at your observing location. If your GPS fails (loses power, loses data) you may not be able to determine the position.

Star Atlas-Target star

For asteroid occultations print the star field you are using on a transparency (use black stars on a white background). Place the transparency on a white piece of paper. This allows you to flip the transparency in any orientation to match the field of view of your telescope. Sometimes it is difficult to visually re-orient the telescope field of view to match the star chart.

To facilitate locating the target star for an asteroid occultation, draw the 3° x 5° Goffin star chart outline (Figure 6.5, Chapter 6) on your star atlas. This allows quick locating of the target star area.

Draw a rectangle showing the field of view of your video camera system on the 3° x 5° Goffin star chart. This illustrates your video FOV with respect to the target star area.

Use the following procedure to rapidly find the target star for a video observation:

a) Find the target star visually with a low power eyepiece
b) Center the target star in the field of view and start you motor drive
c) Remove your eyepiece and replace with your video system (See Appendix G, *Equipment setup Configuration*
d) Target star should be in or near your video field of view
e) Verify the video field of view matches the star chart

Shortwave Radio

Use a digital tuning shortwave radio for receiving WWV. Program the memory (one-touch) keys to hold WWV's frequencies of 5, 10 and 15 Mhz. If you accidentally lose the station, pressing the simple one-touch keys brings back the station.

Telescope

Use small boards or tripod pads under the telescope legs to keep them from sinking into the ground while waiting for the occultation. Moving a heavy telescope or realigning it to place it back into alignment could be extremely difficult.

Use dew shields even if you are in a dry climate. The shield keeps extraneous light from entering the telescope tube from passing cars, and mishaps when pointing your flashlight. To remove dew, use a clothes dryer flexible duct attached to the hot air vent of a car dashboard. This acts as a "hot air" blower.

Travel

When traveling to another city for an occultation, rather than take a telescope that can't fit on an airplane, coordinate with observers in the destination city. Bring your video/timing equipment which is easily transportable. Astronomy clubs can be found on the Internet.

When traveling by plane, leave a note in your checked bags with a copy of the 'Why Observe Asteroid Eclipses" flyer to explain the reason for the strange looking telescope and/or video equipment. Have your name and cell phone on the note in case airport security officials examining your bags need to contact you. A quick explanation over the phone might save your equipment from being seized and make for the first part of successful occultation – getting the equipment to the site.

When in a humid climate driving to an event drive with the air conditioner off so the telescope optics don't have to go thru the dew formation/fog up stage up upon arrival at the site. In a cold climate consider placing the telescope in the back of your pickup instead the heated interior to eliminate the cool down time for the optics.

Video

Know the field of view of your eyepiece or video system. Draw this outline on a transparency and attach to the star chart/or just draw it on the star chart. With the field of view outlined on the chart it's easier and faster to identify the target star area.

With unattended video stations, leave a note attached to the equipment with your name and cell phone number on it. This could prompt a passer by to call rather than to walk away with the equipment.

Mark your video cables with a pen to indicate VIDEO and AUDIO. The yellow video jack and the white or red audio jack colors are not distinguishable at night with a red flashlight.

Map out a copy of your cable connections and keep a copy in one of your cases. Make sure it's readable in red light.

Know in advance the focus change from visual to video for your system. This will speed up the focus process when setting up your video system and avoid a frustrating time trying to achieve focus. Mark this down on your telescope.

APPENDIX Q. Abbreviations and Acronyms

AAVSO	American Association of Variable Star Observers
AC	alternating current
ACLPPP	Automated Computer Limb Profile Prediction Program
AGM	absorbed glass mat
AH	amp hours
AJ	Astronomical Journal
ALPO	Association of Lunar and Planetary Observers
alt	altitude
AM	after midnight
AOPS	asteroid occultation program simulator
ApJ	Astrophysical Journal
AS	solar astrolabe
AVI	audio video interleave
AZ	azimuth
b	latitude
B	blink
CA	cusp angle
CCA	cold cranking amps
CCD	charged coupled device
CDT	central daylight time
CHU	call letters for Canadian shortwave time signal radio station
CST	Central Standard Time
D	disappearance
DC	direct current
dDEC	hourly change in declination
DEC	declination
dia	diameter
dms	degrees, minutes , seconds
DOA	Dutch Occultation Association
DoD	Department of Defense
DP	observed transit time
dRA	hourly change right ascension
E	East
EDT	Eastern Daylight Time
el	elevation
elon	elongation
ESOP	European Symposium on Occultation Projects
EST	Eastern Standard Time
ET	Ephemeris Time
F	flash
f/10	focal length, focal ratio
FITS	Flexible image transport
FK6	Fundamental Catalogue #6
FOV	field of view
ft	feet
ftp	file transfer protocol
gm	grams
GMST	Greenwich Mean Standard Time
GMT	Greenwich Mean Time
GPS	Global Positioning System
GSC	Guide Star Catalog
H	hour
HE	heliometer
HIP	Hipparcos
HMNAO	Her Majesty's Nautical Almanac Office
hms	hours, minutes, seconds
IAU	International Astronomical Union
ICSU	International Council of Scientific Unions
ILOC	International Lunar Occultation Center
Ilum	illumination
IOTA	International Occultation Timing Association
IOTA	I'm Out of Town A lot
IOTA-ES	International Occultation Timing Association European Section
IRAS	Infrared Astronomy Satellite
J2000	refers to the standard equator of the year 2000.0
JD	Julian date
JPG	Joint Picture Group
JRASC	Journal of the Royal Astronomical Society of Canada
KBO	Kuiper Belt Object
kHz	kilohertz
km	kilometer
l	latitude
lat	latitude

LCD	liquid crystal display
Lib	libration
Li-Ion	Lithium Ion
Long	longitude
Low	Lunar Occultation Workbench
LP	long play
LST	Local Standard Time
lux	unit of illumination
m	magnitude; meter
M	absolute magnitude
Mag	magnitude
mas	milli-arc seconds
MASCON	mass concentrations
MDT	Mountain Daylight Time
ME	transit time at meridian circle
mHz	megahertz
MI	micrometer
mi	miles
MNRAS	Monthly Notices of the Royal Astronomical Society
MPC	Minor Planet Center
MST	Mountain Standard Time
MSL	Mean Seal Level
N	North
NAD27	North American Datum 1927
NASA	National Aeronautics and Space Administration
NCP	north celestial pole
NEAR	Near Earth Asteroid Rendezvous
NGC	New General Catalog
NiCAD	Nickel Cadmium
Nimh	Nickel-Metal-Hydride
NIST	National Institute of Standards and Technology
NTSC	National Television System Committee
O	occultation
Occult	Occult software program
OGO	observing grazing occultations
ON	Occultation Newsletter
OSD	on screen display
PA	position angle
PAL	phase alternation line
PASP	Publications of the Astronomical Society of the Pacific
PDA	personal data assistant
PDT	Pacific Daylight Time
PE	personal equation
Ph mag	photographic magnitude
PM	prior to midnight
POS	position
PP	projected transit time
PPM	Position and Proper Motion Catalog
pps	pulse per second
PRC	pseudo random code
R	Reappearance
RA	Right Ascension
RASC	Royal Astronomical Society of Canada
RPA	Review of Popular Astronomy
Rv	radial velocity
RV (″/sec)	radial rate in milli-arcsec per second
S	South
SA	Selective Availability
SAO	Smithsonian Astrophysical Observatory
SCP	south celestial pole
SCT	Schmidt-Cassegrain Telescope
SDS	Solar Disk Sextant
sec	second
sep	separation
SI	International System
SODISM	Solar Diameter Imager and Surface Mapper
SOHO	Solar and Heliospheric Observatory
SP	standard play
sp	spectral type
ST	sidereal time
SW	shortwave
TAI	International Atomic Time
TAN Z	tangent of the angle z
TBD	Barycentric Dynamical Time
T-C	telescope to camera
TDT	Terrestrial Dynamical Time
TNO	Trans-Neptunian Object
TOPO	topographic
TYC	Tycho
UCAC2	Second U.S. Naval Observatory CCD Astrograph Catalog

UCAC3	Third U.S. Naval Observatory CCD Astrograph Catalog
USGS	United States Geological Survey
USNO	United States Naval Observatory
UT	Universal Time
Vmag	visual magnitude
VA	vertex angle
VCR	video cassette recorder
VI	visual
VTI	video time inserter
WA	Watts angle
WAAS	Wide Area Augmentation System
WGS84	World Geodetic System 1984
WWV	Call letters for Ft. Collins, CO shortwave time signal radio station
WWVH	Call letters for Hawaii shortwave time signal radio station
ZC	Zone Catalog
XTE	Cross track error
X-TRACT	Cross tract
XZ	Star catalog covering the ecliptic zone
z	zenith

Δm	difference in magnitude
ΔT	difference between UT and TDT
%SNL	per cent sunlit
°C	degrees Celsius
°F	degrees Fahrenheit
3D	three dimensional
°	degrees
′	arc minutes
″	arc seconds

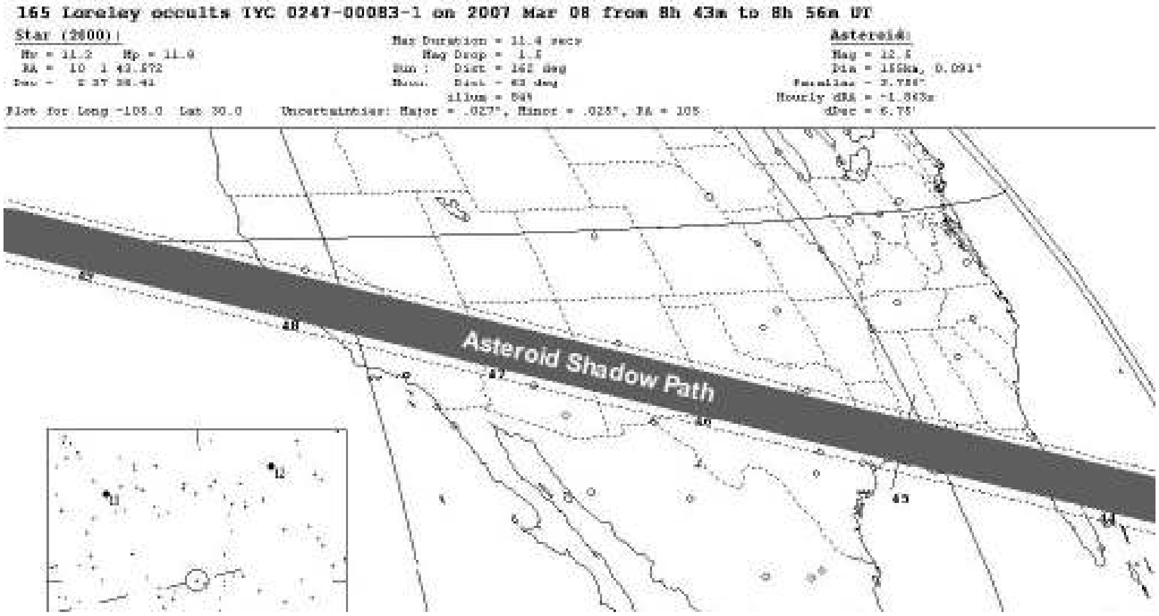
INDEX – draft

WANTED

By the International Occultation Timing Association

☞ OCCULTATION OBSERVERS ☜

And Information Leading to Accurate Timings of Lunar and Asteroid Occultations



The International Occultation Timing Association (IOTA) wants you for the most exciting observations you can make – occultations! Occultations occur when one celestial body passes in front of another momentarily blocking its light. The observation of these events provides important information about the eclipsing body. Never before has there been an opportunity to contribute to the body of scientific knowledge about the lunar limb profile and the size of shape of asteroids and a host of other occultation phenomena. *And all with simple inexpensive equipment!* ***Chasing the Shadow: The IOTA Occultation Observers Manual*** is the only book of its kind that shows observers how to get started in occultations, what equipment to use and how to predict, make, and report valuable occultation observations. IOTA is here to assist you in this exciting field. All astronomers, both amateur and professional, can make occultation observations whether from a fixed site observatory or from a mobile location. This book has all the necessary information one needs to begin a successful occultation program. Whether you are a novice observer, or an advanced observer with a video system, you can assist in the search for asteroidal moons, help discover new double stars and help determine the size of the Sun during solar eclipses. Written by IOTA's most experienced astronomers, this is the only book you'll need for occultation observations of stars by the Moon, by asteroids, and other solar system bodies. It includes an extensive set of Appendices, and 136 figures and diagrams, 378 pages.

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