Occultation Newsletter

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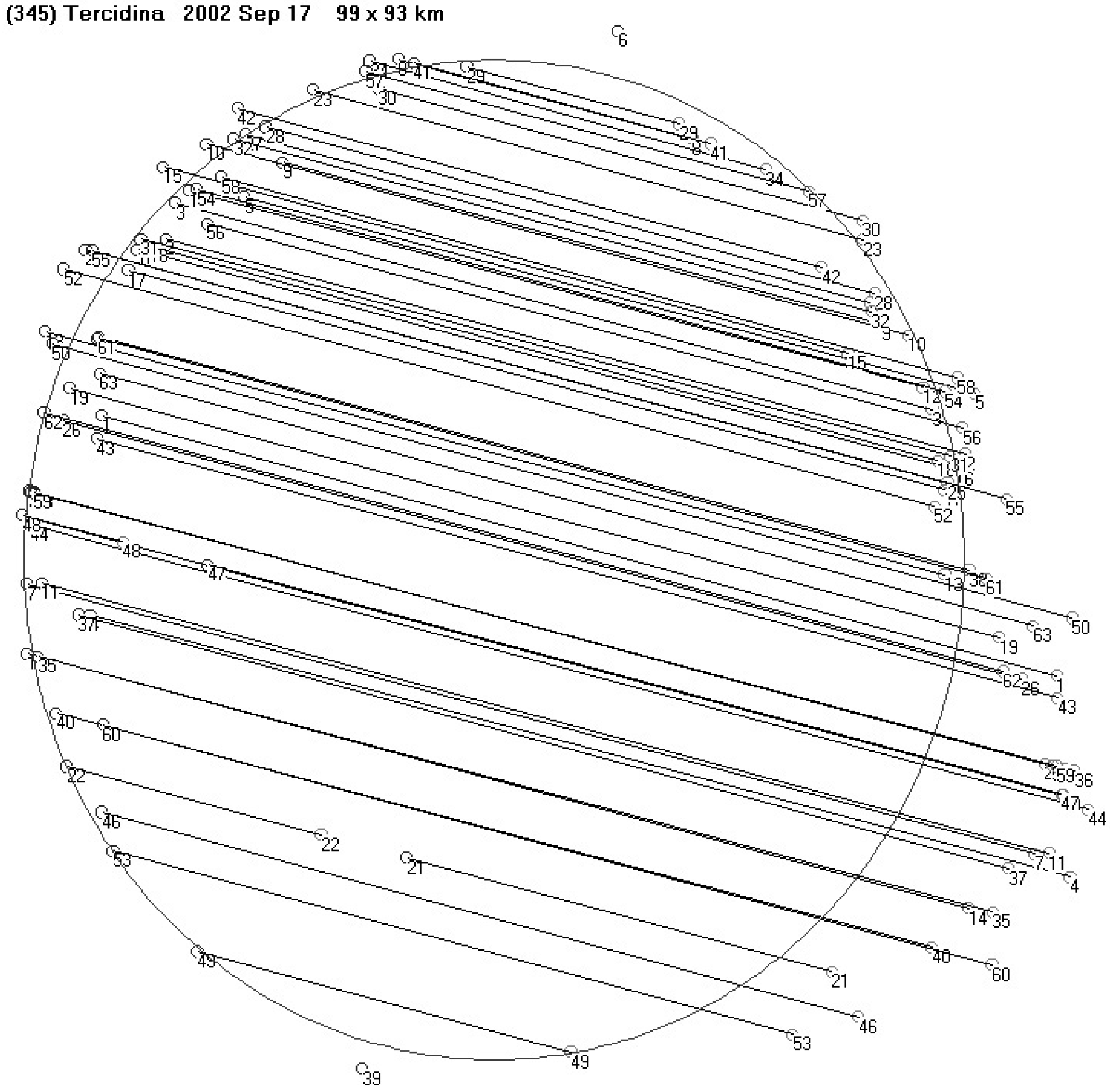

In this Issue

Articles *Page*

(701) Oriola observations (4/21/2002) 4
The Newly Confirmed Binary Star, 43 Tau or Zodiacal Catalog 614 5
Uncertainty Is Not the Same As Standard Error 5
The Spectacular Grazing Occultation of Jupiter On August 18, 1990 7
Occultations and Small Bodies 8

Resources *Page*

What to Send to Whom 3
Membership and Subscription Information 3
IOTA Publications. 3
The Offices and Officers of IOTA 13
IOTA European Section (IOTA/ES) 13
IOTA on the World Wide Web. . . . . Back Cover
IOTA's Telephone Network . . . . Back Cover

ON THE COVER:

A drawing of chords from the data obtained during the Occultation of HIP 19388 by 345 Tercidina.

Image from http://sorry.vse.cz/~ludek/mp/results/
A WWW page maintained by Jan Manek, jan.manek@worldonline.cz

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Memberships include the *Occultation Newsletter* and annual predictions and supplements. Memberships are US$30.00 per year for USA, Canada, and Mexico; and US$35.00 per year for all others. Observers from Europe and the British Isles should join the European Service (IOTA/ES). See the inside back cover for more information.

IOTA Publications

Although the following are included in membership, nonmembers will be charged for:

Local Circumstances for Appulses of Solar System Objects with Stars predictions US$1.00
Graze Limit and Profile predictions US$1.50 per graze.
Papers explaining the use of the above predictions US$2.50
IOTA Observer's Manual US$5.00

Asteroidal Occultation Supplements will be available for US$2.50 from the following regional coordinators:
South America--Orlando A. Naranjo; Universidad de los Andes; Dept. de Fisica; Mérida, Venezuela
Europe--Roland Boninsegna; Rue de Mariembourg, 33; B-6381 DOURBES; Belgium or IOTA/ES (see back cover)
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All other areas-Jan Manek; (see address at left)

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(701) Oriola observations (4/21/2002)

Steve Preston

In retrospect, I must have been due for some good luck. During the four months of December 2001 through March 2002, nineteen events passed within reach of my home. Unfortunately, the Pacific Northwest was completely covered with clouds during those months. The Oriola event was an unexpected bonus after a long bout of cloud-outs: a mag 5.2 star and statistical rank of 62%. This event was not on Goffin's list of events for North America. Jan Manek discovered the Oriola event only a month beforehand and alerted us. The occulted star was known to be a double star but the components were too close for us to generate a reliable estimate of the separation or position angle. Despite all the uncertainty, I couldn't resist trying for an event with such a bright star – particularly when the weather started to look promising.

Prelude to the event

Since the target star was bright enough to record with a PC-23C on my smaller scope (a 76mm refractor), I decided to take a chance and make my first attempt two stations for an event. I already had most of a second setup for recording because I had been accumulating "backup" equipment. I gathered the necessary pieces to complete a second setup and performed some equipment tests prior to the event. The one element I could not locate was a partner to operate the telescope at the second station. Although I had hoped to recruit a friend to mind the second scope, no one was available that night. Had I fully realized the logistic challenges of two stations I might have "wimped out" and just tried for one station.

Finding Locations for the scopes

After reviewing the weather forecast I decided to make the four hour drive to a location in Eastern Washington. My original plan called for locations just South of Toppenish, WA near a location where I had observed in the past. Fortunately, I called ahead first to discuss my options with the local police. The area South of Toppenish is part of the Yakima Indian reservation. After a brief conversation with the Yakima Tribal police it was apparent that I would need to look elsewhere – I didn't have the appropriate "permit" so I would be ticketed if I tried to setup anywhere off the state highway.

So I headed to the area near Prosser, WA. The police in Prosser were much more helpful and suggested that I try a couple of local wineries. The Columbia Crest Winery was located in the Southern part of the path. I gave them a call and they were very helpful. They even offered to have the security guards keep an eye on my scope. My next task was finding a location in the Northern part of the path (nearer to Prosser). I stopped at a small winery outside of Prosser (Chinook Winery) and the owner suggested that I setup my scope behind one of the storage buildings. As an additional plus I was able to use AC power from the storage building. I setup the small scope at the Chinook Winery, drove approximately twenty miles South to the Columbia Crest Winery, setup the big scope (where the security guards could keep an eye on the scope), and returned to the Chinook Winery to wait for dusk.

For both scopes I used my compass to make a guess at the polar alignment. The event was slated for 9:04pm – not long after sunset (7:50pm). I connected everything so that the only remaining task was to point the scope at the star and start the recording on the VCR.

Final Setup for the event

As dusk approached at the Northern location (small scope), I located Venus with the PC-23c attached to the scope. I then used the setting circles and my star charts to star hop to the target star. The sky was still fairly light when I finally located the target star. If the star hadn't been so bright, I would never have found it in time. At about 8:35 I set the VCR to record, hopped in my car, and drove down to the Southern telescope location. I somehow managed to find the star in the Southern telescope with about two minutes to spare. It helped a great deal that the sky had darkened by this time and I had the benefit of recently locating the star in the Northern scope.

I sat back and watched the star disappear in the Southern scope. Given the 60% statistic I was elated that I had caught the event. I quickly packed up the Southern scope and headed back to the Northern scope to review the tape. Upon reviewing the tape at the Northern location I became nervous as the star drifted almost off the frame near the time of the event (my polar alignment wasn't very good). Fortunately, the field of view on the small scope was wide enough and the Northern Scope also caught a positive event.

Next time…

1) The next time I try to setup two stations, I will work harder to find someone else to help. I was very lucky to find the star in time at both scopes.
2) It would have helped to make a try at the star at the same time of night a few days before the event. Of course, spring weather in Seattle doesn't always provide this opportunity.
3) Next time I will try to allow time to use the drift method to improve the polar alignment of the scope that I leave unattended.

Observers for (701) Oriola:

Daniel Durda (one station)
Tony George (one station)
Steve Preston (two stations)
Roger Venable (one station)
Richard Wilds (HART – three sites)

Roger Venable and I were the only two observers reporting observations. Daniel Durda and the HART team were clouded out. Unfortunately, Tony didn't find the correct star in time. He would have been near the center of the path not far from my locations. ●

The Newly Confirmed Binary Star, 43 Tau or Zodiacal Catalog 614

Hal Povenmire

The star, Zodiacal Catalog 614 is a magnitude +5.67, orange star in Taurus. It is also known as SAO 93785, HIP 19388, BD +19 0672, HD 26162 and 43 Tau. It is of spectral class G5 or K2 depending on the source or catalog.

On January 13, 1976, this star was occulted by the Moon as observed from Osage station at Indian Harbour Beach, FL. The observation was made with a 6 inch f/10 Newtonian reflector at 90X. In spite of an 83% sunlit, waxing Moon there was an obvious dimming as the star was occulted. The time of occultation with personal correction applied was 7:36:49.6 U.T.

This observation was reported to David Dunham of the International Occultation Timing Association (IOTA) and to the International Lunar Occultation Center (ILOC) in Tokyo. Later, it was reported to the Center for High Angular Resolution in Astronomy (CHARA) in Atlanta, GA. Apparently, no further reduction work or confirmation was attempted. It was also reported to Drs. B. Mason and W. Hartkopf of the U.S. Naval Observatory.

More than 26 years later, on the morning of August 3, 2002, a spectacular grazing occultation of Z.C. 614 occurred over New Mexico, Oklahoma and Kansas. The Moon was 31% sunlit waning crescent which was high in the eastern sky. The star grazed an astounding 15° on the dark northern limb. This observer attempted an observation from New Mexico but clouds covered most of the path. The skies were clear in western Kansas.

The highly experienced, grazing occultation observer, Robert Sandy of Blue Springs, MO and Franklin Miller of CO videotaped this graze from near Ellis, KS. The telescope used was a clock driven, 8 inch, f/5 Newtonian using a PC 23C CCD (0.04 lux) camera. The excellent videotapes clearly showed 9 spectacular dimming phenomena, partial reappearances and other phenomena consistent with a binary star. Some of these phenomena indicated the dimming was not due to the large angular diameter of the orange giant star.

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Uncertainty Is Not the Same As Standard Error

Roger Venable

We IOTA folks measure the positions of things a lot. We measure our geographical positions on the surface of the earth, we measure the positions of asteroids and the location of the edge of the moon, and indirectly we measure the positions of stars. We often refer to the "uncertainty" of the measurement. For example, the uncertainty of the observer's latitude is requested on the grazing occultation report form (1), and the uncertainty of the position of an asteroid is given on Steve Preston's updated asteroidal occultation predictions (2).

In talking with amateur astronomers, I have found that many of them consider the uncertainty of such measurements to be the sample standard deviation of the set of measurements. This is completely incorrect. Lest that assertion confuse you, I'll illustrate the principle with an imaginary example that I think you all will understand.

Imagine that I have been asked to find the average height of men in Georgia who are between their 40th and 50th birthdays. I set up a group of sampling rules to make my sample as representative as possible of the group I am studying, and decide that I will need about 10,000 measurements taken from among the 159 counties in proportion to the county populations. Then I begin measuring. I notice after only 100 measurements that the mean is not changing much from measurement to measurement -- it's staying at about 70.1 inches. However, the individual measurements continue to fluctuate widely, with a standard deviation of 3.3 inches. After 1000 measurements, these two figures are still about the same. And after I am all done, I discover that my sample has a mean of 70.109 inches and a standard deviation of 3.285 inches. Is the standard deviation the uncertainty in the mean? Of course not! The mean has been determined to a high degree of accuracy. In fact, there is a 95% chance that the true mean for the entire population, not just for my sample, is within 0.064 inches of the sample mean. This is the uncertainty. The standard deviation is about 51 times as large.

When we measure the position of an asteroid, we consider it to have an absolutely correct position that is unknown to us. Because of this characteristic, the standard deviation of our position measurements is called the "standard error". It represents the trustworthiness of a single measurement. It does not represent the uncertainty of the mean position measurement any more than the standard deviation of the height of men represents the error of the mean height. By making a large number of measurements, we can get an accurate asteroidal position measurement despite a large standard error -- just as we can find an accurate mean height of men in spite of a large standard deviation in their heights.

The uncertainty of the mean is called the "confidence interval of the mean." It is related to two parameters: the standard deviation (or standard error) and the sample size. It is not easily computable, so you look it up in a table that you find in a book of statistical tables. The value in the table is the number, for the specified sample size, that you multiply by the standard deviation to obtain the confidence interval of the mean. Typically, the heading of the table will tell you to use N - 1 in the denominator of the sample standard deviation calculation if the sample size is smaller than 200. The following table may be enough to meet the needs of many IOTA members.

N	95%	99%
2	8.985	45.010
3	2.484	5.730
4	1.591	2.921
5	1.242	2.059
6	1.049	1.646
7	0.925	1.401
8	0.836	1.237
9	0.769	1.119
10	0.715	1.028
11	0.672	0.956
12	0.635	0.897
13	0.604	0.847
14	0.577	0.805
15	0.554	0.769
16	0.533	0.737
17	0.514	0.708
18	0.497	0.693
31	0.367	0.494
37	0.333	0.447
64	0.250	0.333
99	0.200	0.264
110	0.189	0.250
200	0.139	0.184
300	0.113	0.149
400	0.098	0.129
500	0.088	0.115
600	0.080	0.105
700	0.074	0.097
800	0.069	0.091
900	0.065	0.086
1000	0.062	0.082

Here is an example of the use of the table. Last week, to measure my position as a mobile observer of an asteroidal occultation, I made a list of 5 GPS readings each separated by five or more minutes from the preceding one. I calculated the mean and standard error of the latitude. Then I looked in the table's first column and found the number 5 -- the number of my measurements -- and next to it in the second column I found the number 1.242, by which I multiplied the standard error to ascertain the range from my computed mean that will contain the true mean 95% of the time. The result is the "95% confidence interval of the mean" of the latitude measurements. This is the measure of uncertainty, and it is what I put on the report form. I always call it "95% confidence interval of the mean" rather than "uncertainty" or "two sigma uncertainty," because the term 'uncertainty' is unclear.

If you stare long and hard at the table, a number of weird things will jump out of it at you. For example, you have to make seven measurements to render the 95% confidence interval smaller than the sample standard deviation, and eleven measureents to do the same for the 99%confidence interval. Eighteen measurements will make the 95% confidence interval of the mean smaller than half the standard deviation, while 31 are required for the 99% one. Sixty four measurements seems to be a magic number. The factors in the table diminish depressingly slowly as the number of measurements increases. If you make only two or three measurements, your confidence intervals will be very high, which means that you won't have much confidence.

There is a secret bonus to all this. Recall that, in the example involving the heights of men, I was able to find the mean height more accurately than my ability to differentiate the markings on my ruler! Similarly, by using averaging techniques you can determine your position more accurately than the resolution of the GPS device you are using. At first, this sounds so counterintuitive that it makes you want to go back to school. I use an inexpensive Garmin 12, which gives my position to the thousandth of an arcminute. I can set the device to "averaging" mode, and it will continually average the position until I reset it. The average obtained this way is read out to a thousandth of an arcminute, never better. Upon obtaining such an average reading, I don't know how accurate it is because I don't know the confidence interval of the mean! So, I don't allow the machine to do my math for me -- I turn off the averaging function. Then, if I write down the readout position every five minutes for 85 minutes, I'll get 18 positions,and the 95% confidence interval of the mean will be half the standard error. Typically, the total range in latitude readings will be 0.004 arcminutes and the standard error about 0.001. If I have the patience to hang around for this many readings, I can get a mean and confidence interval more accurate than any my device can read out to me.

For such calculations to be accurate, the readings should be independent of one another. That is why I wait five minutes between GPS readings. The GPS satellites have to be given time to shuffle their locations, or else the next reading will be related to the last one. The independence of sequential measurements is a special problem for determining the confidence interval in the location of an asteroid. If the same astrometry comparison stars are used from one reading to the next, the readings are not independent of one another. If only a few comparison stars are the same, then the readings are partially independent. It can get pretty complicated. That's fine if you are a really good statistician, like a baseball announcer, but the rest of us leave this matter in the hands of professors.

The Spectacular Grazing Occultation of Jupiter On August 18, 1990

Hal and Katie Povenmire

An occultation occurs when a large object like the Moon covers up a smaller object like a planet or star. A grazing occultation occurs when only the northern or southern edge of the Moon covers a smaller object. Favorable grazing occultations of bright planets are not common events. This following observation is one of the most spectacular ever observed and scientifically recorded.

On early Saturday morning, August 18, 1990, the skies were clear over west Texas. Just east of Crystal City, a group of 13 amateur astronomers were lined up on a north-south county road and had their telescopes pointed towards the dawn sky. Low in the eastern sky was the thin crescent Moon with the bright planet Jupiter and its four Galilean moons just east of it. The earthshine was very bright as the thin cusp of the 5% sunlit waning Moon appeared to move up to Jupiter. The surface brightness of Jupiter was much greater than that of the Moon so the contrast was striking. The profile of the Moon could be seen against Jupiter. The dawn twilight did not detract much from the spectacle.

Spectacular lunar grazing occultations of bright planets are rare events and the partial occultation zone of this event was about 34 miles wide. Jupiter had an angular diameter of 32 arc seconds and the belts were clearly visible but not prominent. Jupiter had a visual magnitude of –1.8.

The line up of Jupiter's moons were nearly parallel with the motion of the Moon so that they began to be occulted. Since the Jovian moons have an angular diameter of approximately 1.0 arc second, they would fade out rather than snapping out as with a stellar occultation. The moons disappeared on the thin sliver of the bright side so the timings of their D's are not extremely accurate.

The first moon to be occulted was Callisto, then Ganymede and Io. Then the bright portion of the Moon moved up to Jupiter and slowly began to cover it. The partial occultation took about 16 minutes and the area of central graze was over the south pole of the Moon. The heights of the lunar mountains were not well known in this area and most of the observers were too far south to see a complete occultation. After Jupiter, the Jovian moon Europa was occulted.

Another small team of experienced occultation observers went about another 40 miles further west to observe this event in a slightly darker sky. They set up just north of the town of El Indio on Rt. 1021. The Mexican-American border is marked by the shallow Rio Grand River and this was 2.8 miles from our southernmost station. This is cattle range and dry, desolate country. The Javalines or large, native wild pigs frequently ran across the road. A western diamond back rattlesnake was seen during the graze layout the night before.

The site selected was on the USGS 7.'5 El Indio, Texas-Coah, Mexico Provisional 1983 topographical map. Farm roads allowed the exact locations to be determined. By chance or luck, the sites selected were slightly further north of the predicted limit and excellent limb data was obtained.

The technical data is as follows:

North Station – Hal Povenmire – 10" F/5.6 Newtonian at 112X, Alt-Azimuth, Long. 100d 19' 52."9 W. and Lat. 28d 33' 08."1 N. Alt. = 710 ft. Duration= 214.0 seconds 6800'N. of Predicted Limit. Seeing was fair and transparency was excellent. WWV reception – excellent.

1. 1st Contact
   11:32:00 ±
2. Callisto R
   11:32:26.0
3. Jupiter 1/3 gone
   11:32:33.0
4. Jupiter ½ gone
   11:34:41.0
5. Ganymede R
   11:35:41.5
6. Second Contact
   11:37:56.0
7. Partition visible
   11:38:27.0
8. Io R
   11:41:01.0
9. Third Contact
   11:41:30.0
10. Jupiter ¼ out
    11:42:25.0
11. Earthshine still barely visible
    11:45:44.0
12. Europa R
    11:47:04.0

South Station – Katie Povenmire – 6" F/6.0 Newtonian at 108X, Alt-Azimuth Long. 100d 19' 22."2 W. Lat. 28d 32: 27."0 N. Alt. = 740 ft. Duration= 193.0 seconds 1360'N of Predicted

Limit. Seeing was fair and transparency was excellent.

1. Callisto D
   11:25:27.0
2. Ganymede D
   11:30:26.5
3. Jupiter First Contact
   11:31:46.5 ±
4. Jupiter ½ Gone
   11:34:06.0
5. Callisto R
   11:36:00 ±
6. Jupiter Second Contact
   11:37:59.0 very slow fade
7. Europa D
   11:40:29.0 ±
8. Ganymede R
   11:40:58.0
9. Jupiter Third Contact
   11:41:12.0
10. Jupiter 1/8 visible
    11:42:20.0
11. Jupiter ¼ visible
    11:44:23.0
12. Jupiter ½ visible
    11:45:52.0
13. Europa R
    11:46:55.0
14. Jupiter Fourth Contact
    11:47:49.0 ±

What was learned from this observation was that an equatorial mounted, driven telescope of larger aperture, using about twice the power, about 250X would have increased accuracy even more. I believe the accuracy of this observation was quite good.

The beauty of this event was one of the most spectacular sights I have ever experienced in 42 years of astronomical observations.

References: (1) Sky and Telescope (1990) A Thin Crescent Moon Covers Jupiter August pp. 177-179. (2) Sky and Telescope (1991) World News Jupiter Occultation April pp. 423-424.

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Occultations and Small Bodies

Terri McManus

An occultation occurs when one body moves in front of another, covering it and blocking its light. When an airplane flies between an earthbound observer and the sun, the plane's shadow passes over the observer. The airplane occulted the sun. If the person were standing 20 feet away, the plane's shadow would miss the person completely and no occultation would be observed. If the observer arrived at the first location one minute later, they would not see the occultation. Occultations are very location and time dependent. The observer must be in the right place at the right time for the occulted body's shadow to pass over them. Occultations of objects in space happen whenever one body moves in front of another and are observed when the resultant shadow passes over an observer. This paper will examine how occultations are used to study the moon, asteroids, Kuiper belt objects (KBOs), and comets.

Lunar Occultations

Predictions

To observe a lunar occultation (the moon moves in front of a star) observers must know where the occulted object's shadow will fall and when this will occur. Predictions of these data sets are available from the International Occultation Timing Association (IOTA) and from many software programs.

Observation Methods

The majority of occultations timed are lunar occultations. For these observations to be scientifically relevant, the observer's latitude and longitude must be known within 50 feet (Dunham 2002). Although location data obtained from topographic maps is acceptable, David Dunham, IOTA's president, prefers GPS data for better accuracy. The actual event must be recorded. The least accurate method is to record an approved time signal and the observer's description of telescopic observations together on an audiotape. Dunham prefers the event to be videotaped through the telescope with the time signal inserted to reduce personal errors. The more preferred method would be with a CCD camera. Photometric data would be the ultimate!

Data Usage

Originally, results from lunar occultations were used to map the topography of the lunar limb and the Cassini Regions at the poles. Clementine and Lunar Prospector mission data added to the wealth of information, however occultation data is still valuable. Lunar occultation data helps refine star positions and is also used to predict eclispses. This was most important before and after the Hipparcos and Tycho epochs of star locations. Lunar occultation data provides double star discoveries. When the moon occults one of the pair, the other member can be visible. This is often seen as a step decrease in the starlight instead of an on-off event.

Asteroidal Occultations

David Herald analyzed the asteroidal occultation data for 1996. Assuming that was an average year for asteroid occultations, Herald predicts there should be about seven asteroid occultations each day. Any particular asteroid statistically should occult 1.8 times each year (Herald, 1997). This is certainly enough to keep dedicated observers busy! David Dunham reports, however, that this was not representative of later years since 1996 was the last year before the more accurate Hipparcos data became available, (see below) (Dunham, personal communication, April 24, 2002).

Predictions

Accurate predictions are imperative for successful asteroidal occultation observations, and until recently, the predictions left much to be desired. In 1998, Dunham and coworkers report that they had created a catalog of 1,200,135 stars from a combination of seven catalogues (Dunham et al., 1998). Dunham and Timerson (2000) state that astrometry based upon the Hipparcos Space Astrometry Mission with help from the US Naval Observatory - Flagstaff and the Table Mountain Observatory gives still more accurate star positions. The Hipparcos data has also been incorporated into the Tycho-2 Catalogue (Dunham 2002). These refinements give more accurate predictions for both the star and asteroid positions and give asteroidal occultation observers more chance for success. Instructions for obtaining these predictions are available from IOTA on their website.

Observation Methods

Positional accuracy is not as important for asteroidal occultations as it is for lunar occultations. Observer's latitude and longitude correct to within 200 feet is acceptable as this is about equal to the error caused by starlight diffracting around the asteroid (Dunham 2002).

The observations must be recorded by one of the methods described in the Lunar Occultations section above. Because asteroidal occultations happen so quickly, Dunham feels video timings are best (Dunham 2002). He maintains that the timing should be accurate to +/- 2% of the predicted central duration. Assuming event duration of ten seconds, the timing accuracy should be +/-0.2 seconds, an accuracy level that is difficult to obtain. If the event duration is even shorter, say five seconds, the timing should be accurate to +/- 0.1 second. When an event is recorded on audiotape for these shorter events, the observer's reaction time becomes a variable in the interpretation of the data. A video record with time insertion removes the personal equation from the data.

Data Usage

The data from asteroid occultations has many uses. Gathering the data fosters collaboration between amateur and professional astronomers. The data is used to delineate the occultation path across the Earth, which can then be extrapolated to help refine the asteroid's orbit. With enough observers, an asteroid's shape and size become apparent.

Asteroid occultations have even predicted asteroid satellites. Asteroid occultations provide excellent opportunities for professional and amateur astronomers to work together. Dunham and coworkers feel that given the number of amateur astronomers across the world and their more portable equipment, someone is usually within travel distance of an asteroid event. The more observers recording an event, the more accurate the results. In that vein, professional astronomers provide the detailed astrometric data for more accurate prediction updates and can make photometric observations of interesting targets (Dunham et al., 2001). The 216 Kleopatra occultation discussed below is a specific example of amateur/professional collaboration.

Astronomers use the most inaccurate data, made with audiotape and time signal, to delineate the edges of the occultation path (Dunham 2002). Even though the audiotaped data may be considered less accurate, many observations of the same event recorded in this way can be put together to form a profile of the asteroid's edges (Dunham 2002). Dunham reports that "more than three or four" separate observations are needed to get a good idea of the outline. Dunham et al. (1997) used an audiotaped occultation observation by the small asteroid 170 Maria based upon Hipparcos predictions to help confirm the accuracy of the Hipparcos-based predictions of asteroid Mathilde's orbit used in programming the NEAR spacecraft. In 1980, nine observers timed an occultation by 216 Kleopatra near the minimum of its light curve. Data reduction revealed an elliptical shaped object. In 1991, Kleopatra occulted again. Nine observers timed this event occurring at near maximum of the light curve. Data reduction revealed an elongated object four times longer than wide. Dunham believes the asteroid's orientation when occulted caused the different profiles. Dunham published these results in the January 1992 issue of Sky and Telescope and later presented the findings at a conference attended by Steven Ostro, a JPL astronomer. Ostro's interest was piqued, and partly as a result, 216 Kleopatra was chosen to be the first main-belt asteroid target of the upgraded Aricebo telescope. (Prior to the Aricebo upgrade in 2000, several main-belt asteroids had been observed, but they were barely detected and little could be interpreted about their sizes and shapes (Dunham, personal communication, April 24, 2002)). The Aricebo radar images were adjusted to fit the occultation data. The discovery of the dog bone shape resulted. (Dunham, 2000). 216 Kleopatra was also imaged by speckle interferometry with the 10 meter Keck 1 telescope by four Lawrence Livermore National Laboratory scientists (More Super-Sharp Images, 2000). (See images at the end of this paper.)

Data from asteroid occultations observed by amateurs led Dunham and Maley to suggest in 1977 that asteroids may have satellites. Images by the Galileo spacecraft of 243 Ida and Dactyl, its satellite, later confirmed this belief. Dunham feels that next to space-based observations, adaptive optics with large telescopes, light curve data, and radar images, occultation data are the best ways to detect satellites of asteroids (Dunham, personal communication, April 24, 2002; Dunham, 1994).

Kuiper Belt Objects (KBOs) Occultations

The Kuiper Belt lies between 30 – 50 AUs from the sun. Hundreds of 50 – 200 km objects have been identified in this region. Roques and Moncuquet (2000) extrapolate this data to say there are potentially 40,000 to 70,000 KBOs in the 50 – 200 km range. They further estimate there may be more than 1011 objects more than one kilometer in size! Occultations present a method for their discovery

Predictions

The lack of predictions is a major drawback to observing KBO occultations, but then, it is difficult to predict something uncertain. David Dunham feels that KBO occultations by amateurs are currently not practical due to lack of reliable predictions. The predictions are not accurate for two reasons. The KBOs' orbits are not adequately defined to predict their paths and the Hipparcos star data is becoming outdated as we move farther from the early 1990s when the data was collected. Unlike asteroid prediction error bars of a few hundred miles, prediction error bars are the size of Earth for KBO occultation paths only 100 – 200 km wide. Dunham feels that as more refined star catalogues are produced, such as UCAC (USNO CCD Astrograph Catalog), the number of predicted events should increase. This is because the massive number of stars included in the catalog gives more opportunities for KBO astrometry and orbital determination. There will be only a small improvement in prediction accuracy however. (Dunham, personal communications, March 6 and April 24, 2002). Richard Wilds, a long-time, experienced occultation observer, has discussed KBO occultations with both Herald and Dunham. Herald has produced predictions for two events using the Occult program that he authored (Wilds, personal communication). KBO predictions are not routinely produced at this time.

Observation Methods

Aside from accurate KBO occultation predictions, the success of the occultation also depends upon the position of the object itself. Brown and Webster (1997) and Roques and Moncuquet (2000) mathematically show that the velocity of KBOs affects both the number of occultations and the duration of the occultation. The number of occultations is proportional to the KBO's velocity and the duration of the occultations is proportional to 1/KBO velocity. The velocity is maximum toward opposition, and is minimum at +/-81 degrees (quadrature) at 40 AU. Because the velocity is slower at quadrature, each occultation event would last longer. However, since the number of occultations is proportional to the velocity, it follows that the slower the velocity, the less occultations. Therefore less occultations would be observed at quadrature.

Assuming predictions are available and accurate, the positional accuracy for reporting KBO observations is less stringent than what is required for asteroidal occultations. Dunham states that since KBOs are so far away, the accuracy required is proportional to the square root of the distance from the object, the diffraction effect (Dunham, personal communication, March 13, 2002).

Audio timings of KBO occultations would not be accurate enough to be useful. Herald predicted star 5492 00455 to be occulted by 10199 Chariklo on October 26, 2001; stellar magnitude = 10.1 with a 7.9 magnitude drop during the occultation. KBO Chariklo's magnitude = 18.0. The event was predicted to last 5.9 seconds (Herald from Wilds, personal communication). Following Dunham's timing accuracy above, the event should be timed to within +/- 0.118 seconds. This event clearly needs a telescope with excellent recording capabilities. Dunham feels a 6-inch telescope with a good CCD camera would suffice for this event, but fainter KBO occultations, 13th magnitude and above, which are more frequent, require larger telescopes. KBO astrometry requires very large telescopes (Dunham, personal communication, April 24, 2002). Ticha et al. (2000) report recording a KBO with a 0.57m reflector and a CCD. Roques and Moncuquet (2000) feel that very high-speed photometers and the largest ground based telescopes are needed. They believe a ten-meter telescope should be able to detect a 40km radius KBO at 40 AU. Roques and Moncuquet show the observability of KBO occultations depends upon the precision of the photometer, the stellar radius, and the diffraction effects. Statistically, the highest precision photometers will observe more KBO occultations and smaller size KBOs. More occultations will be observed when the target star has a small radius. Their calculations are based upon the assumptions that: KBOs are circular objects; there is a constant slope for the size distribution; and that there is a radial KBO distribution to 50Aus.

Instead of focusing on only one star hoping to catch the occultation, another approach for observing KBO occultations is to capture a wide field CCD recording of the sky. Roques and Moncuquet (2000) suggest continuing the recording for as long as possible to get as much data as possible and to have a higher probability of recording an event. Brown and Webster (1997) suggest using two separated telescopes to eliminate false occultations caused by birds, planes, etc.. Data from the two separated telescopes also allows an estimate of the KBO's velocity to be calculated.

A fascinating project incorporating both ideas is taking shape in Taiwan. The Taiwan-America Occultation Survey (TAOS) plans to take a census of KBOs using three 20-inch robotic telescopes located along a seven kilometer east/west line at 3000m elevation in the Yu-Shan National Park in Taiwan. The plan is to take full-sky CCD images continuously each clear night, imaging 3,000 target stars five times each second. TAOS predicts between 10 – 40,000 KBO occultation events from 100 billion measurements will be observed each year

(TAOS website). Unfortunately, TAOS ran into telescope trouble and is reengineering the entire optical assemblies. Currently they have one working telescope but are not collecting data. They expect to be fully operational and to begin data collection in the fall of 2002 (Lehner, personal communication, March 11, 2002).

Brown and Webster (1997) propose searching MACHO data sets (2 X 107 stars monitored) for increases in apparent magnitude caused by KBO occultations. By increase in apparent magnitude, Brown and Webster are referring to an increase in magnitude number, i.e. 21 to 22, meaning the star appears dimmer, not the star actually increasing in brightness (Brown, April 22, 2002).

The French satellite, COROT, launch date 2004, will use high precision photometry and a 25cm telescope to study astroseismology and transits of exoplanets. Roques and Moncuquet (2000) propose using this data to search for KBO occultations. The astroseismology experiment will image a few bright stars at a frequency of 1 Hz. Roques and Moncuquet expect it to record between one and 100 KBO occultations per month of KBOs larger than 200m. The exoplanet study will image thousands of stars at a minimum 30 second integrations. The slow integration time will limit the number of occultations detected to an estimated 0.5 – 50 per month, 1km or larger. They also propose a dedicated KBO one month observing program studying 100 stars possibly detecting 250 KBO occultation events per day.

Data Usage

Regardless of which method is used, occultation data of KBOs will be used to determine the number of objects, their size and spatial distributions, and to get an estimate of their velocity.

Comets

Predictions

Dunham (personal communication, March 6, 2002) reports that since the orbits of comets are not as well defined as main-belt asteroids, predictions for cometary occultations are not very accurate and are not routinely produced at this time.

Observation Methods

None the less, if a cometary occultation were observed, to be scientifically valid, the observer's position should be reported to 200 feet accuracy. This is the same as for asteroids as they are in the same general vicinity (Dunham, personal communication, March 13, 2002).

The most accurate timing method available should be used. Observations of cometary occultations have been recorded with audiotape and a time signal. Sato (1997) reports of an amateur's observation of Comet Hyakutake and SAO 16342 and, from the data, estimates the diameter to be 65 – 100km. (Radar imagery showed the nucleus to be 1 –3km.) Comet Hale-Bopp occulted PPM200723 in October 1996. Although seven stations attempted the event, only three teams recorded events. Two teams used C-14 telescopes with CCD cameras. The other station recorded it with a C-14 and a photometer (Buie website). The astronomers estimate the nucleus to be between 30 – 48km (Fernandez 1999), a bold statement since the observations were made through high cirrus clouds.

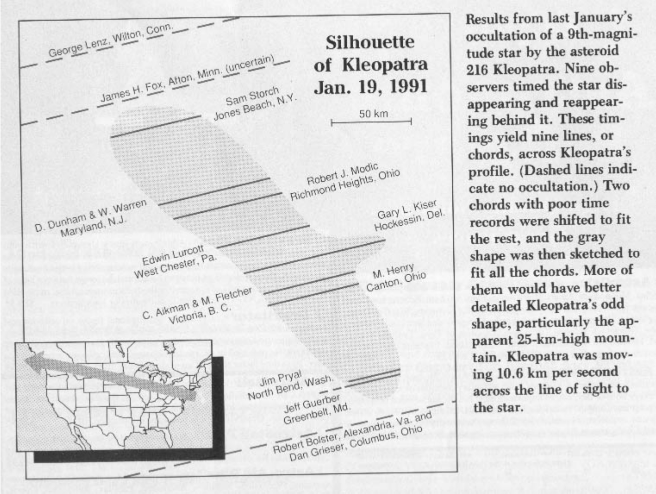
Uses for Data

What little comet occultation data there is has been used to determine the size of the coma and its nucleus.

Conclusions

Lunar occultations are used to: refine the topography of the lunar limb and Cassini Regions, refine star positions, predict eclipses, and discover double stars. For asteroids, Kuiper belt objects, and comets, occultations are used to determine size, shape, numbers, spatial distributions, and velocity. One observation of an object gives an idea of its possible characteristics. Many observations taken together outline the object's size and shape and can give an idea of its velocity. Occultation surveys refine the estimation of the number of objects, their distribution in the sky, and (with two or more simultaneous observations) their velocity. The usefulness of the data depends upon the accuracy of the predictions, the observer's location, the number of observers, and the timing and recording methods used.

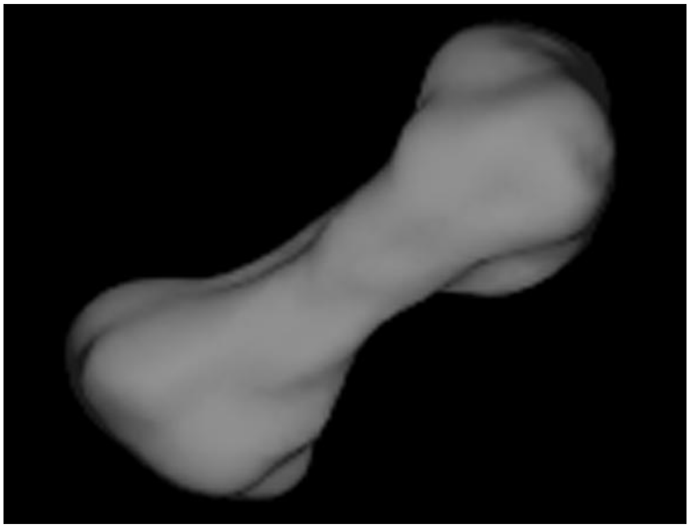
216 Kleopatra Images



Results from last January's occultation of a 9th-magnitude star by the asteroid 216 Kleopatra. Nine observers timed the star disappearing and reappearing behind it. These timings yield nine lines, or chords, across Kleopatra's profile. (Dashed lines indicate no occultation.) Two chords with poor time records were shifted to fit the rest, and the gray shape was then sketched to fit all the chords. More of them would have better detailed Kleopatra's odd shape, particularly the apparent 25-km-high mountain. Kleopatra was moving 10.6 km per second across the line of sight to the star.

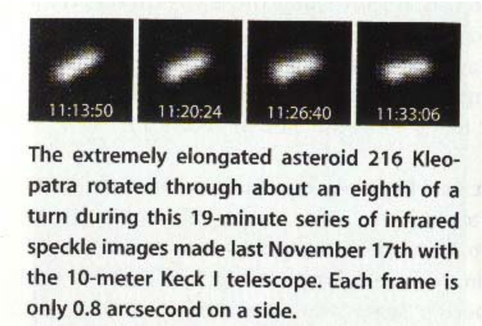
Estimated shape of 216 Kleopatra based upon Jan.19, 1991 Occultation from:

Dunham, David W. (1992). Planetary Occultations of Stars in 1992, Sky & Telescope, 83(1), 72-77.



Radar Image of 216 Kleopatra

Credit: Stephen Ostro et al. (JPL), Arecibo Radio Telescope, NSF, NASA. Image found at: http://antwrp.gsfc.nasa.gov/apod/ap000510.html



The extremely elongated asteroid 216 Kleopatra rotated through about an eighth of a turn during this 19-minute series of infrared speckle images made last November 17th with the 10-meter Keck I telescope. Each frame is only 0.8 arcsecond on a side.

Speckle Interferometry Image of 216 Kleopatra

From: More Super-Sharp Images from Keck, Sky and Telescope, 99(4), 18-19.

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www.astropa.unipa.it/Asteroids2001/Abstracts/Posters/dunham.doc

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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 reports to the members of observations made.

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Observers from Europe and the British Isles should join IOTA/ES, sending a Eurocheck for EURO 20,00 to the account IOTA/ES; Bartoldknaust Strasse 8; D-30459 Hannover, Germany; Postgiro Hannover 555 829-303; bank code number (Bankleitzahl) 250 100 30. 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:

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IOTA on the World Wide Web

(IOTA maintains the following web sites for your information and rapid notification of events.)

IOTA Member Site
http://www.occultations.org

This site contains information about the organization known as IOTA and provides information about joining IOTA and IOTA/ES, topics related to the *Occultation Newsletter*, and information about the membership--including the membership directory.

IOTA Lunar Occultations, Eclipses, and Asteroidal and Planetary Occultations Site
http://www.lunar-occultations.com

This site contains information on lunar occultations, eclipses, and asteroidal and planetary occultations and the latest information on upcoming events. It also includes information explaining what occultations are and how to report them.

IOTA's Telephone Network

The Occultation Information Line at 301-474-4945 is maintained by David and Joan Dunham. Messages may also be left at that number. When updates become available for asteroidal occultations in the central USA, the information can also be obtained from 708-259-2376 (Chicago, IL).