The Addictive Properties of Occultations

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Abstract

Observing asteroid occultations is challenging and rewarding—and is addictive! Techniques are evolving rapidly, with almost monthly contributions to the field. While the predictions of occultaitons are frequently accurate to a few seconds and a few tens of miles, there are still many challenges of location, weather, equipment, and data analysis that make every observation effort unique. In this paper, we discuss why occultations are useful to observe and how one finds out when/where occultations will occur. We consider the theory of the observation and the pros and cons of the different methods of observing. We also consider other applications of the observing methods used in occultation work.

1. Introduction

What is an occultation? The basic idea of an occultation is simple: it occurs whenever an observer on the earth is lined up with an asteroid and a star. From the earth, the asteroid is eclipsing the star. From outside the earth, the (very faint) shadow of the asteroid is cast on the earth. Of course, the trick is in calculating when and where this will happen. The earth and asteroid are moving in 3D space, there are uncertainties in the positions of the stars and the asteroid orbits. However, in the past several decades these data are now known well enough so that the calculated uncertainties at the earth are typically tens of miles on the earth and a few seconds of time.

These are amazingly small uncertainties, given that the velocities involved are up to 20km/sec, and the distance is typically a billion miles! But, of course, a 20 mile error on the shadow for a 20 mile asteroid means there are good odds that even if one is in the right place, the observation will be a "miss". So, one immediately thinks of multiple stations across the shadow path.

So, if one is in the right place and right time, the shadow sweeps across at some 15km/sec. What one sees is the asteroid approaching the star, merging with the star, then as the asteroid exactly covers the star, the combined star-asteroid light level drops to that of the asteroid alone. After the shadow has passed over, the intensity returns to the combined level, then the objects appear to separate in the sky.

If one has timed the duration (typically 5-30 sec) accurately (precision 0.01-0.1sec) then knowing the velocity of the shadow, we can calculate the length of the chord along the shadow path. Multiple chords then define the shape and size of the asteroid. Other than using radar or space probe visits, this is the only way to get this information. Note that most asteroid sizes in reference tables are only estimates derived from brightness measurements. And while photocurves of satellites can provide shape information, the occultation data can provide verification of the shape results and absolute scaling for the size. And if there was an asteroid satellite (or an unknown binary star), then you may have measured that, too, by successive steps in the occultation curve.

In practice, most observers send their results via email to a central location that combines the various data on different chords into a "best guess" profile of the asteroid. The result is a graphic such as shown in Fig1.

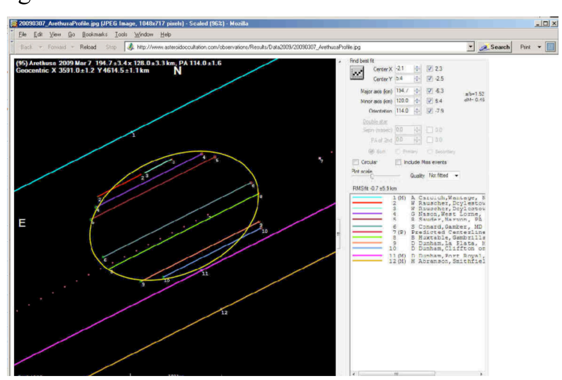


Figure 1 Arethusa Chords

So, the observing problem is to measure the occultation duration, preferably tied to UTC, and also the magnitude of the occultation.

We note that in common with occultation work generally, these measurements can yield almost incredible precision. For example, a shadow traveling at 15km/sec whose passage is timed to +/- 8ms defines the chord length to about 0.1 km (about 100yd). If this were to be done using standard optical imaging, the implied resolution is about 2x10^-3 a-s. Of course, to achieve 100 yard precision on the shape of the asteroid, the observer must know his/her position on earth to an even better accuracy.

Occultation Predictions. But first you have to know when/where an occultation will occur! We have all seen occultation maps in Sky and Telescope--but these are only the major events--meaning, a bright star, a large asteroid, and good observing conditions. Now you know why there are so few on the S&T map--life is not like that! The real science is in observing faint stars, small asteroids, and to doing so in what are often poor conditions (low in the sky, near twilight, in the presence of the moon, etc.)

So how does one find out the ones that a person may have a chance to observe?

Almost everyone has heard of David Dunham. Lately retired from Johns Hopkins Applied Physics Lab, he led the development of observing lunar occultations and grazes, which in turn developed the techniques used for asteroid occultation work. David puts out a newsletter on the East Coast that lists all the "good ones". Other people, including Derek Breit, do it for the West Coast.

But there is a better way to find out what is happening for a particular location. The occultation community is one of the most vital I have ever seen--there are dozens of people who work together, mostly via the Web, to solve these kinds of problems. Several people have developed programs to predict when and with which asteroids and stars the events will occur, and maintain web sites with all the needed data. Others have taken this a step farther, and have developed freeware programs that cull from these lists those that relate to any particular site. The most popular of these is Occult Watcher. Using OW, one can go online (or rather, OccultWatcher does), and get a listing, updated every day, for the next 90 days or so for my particular location.

Fig. 2 shows a screen shot of OW. One can see predicted events for many weeks into the future, along with sufficient information to judge whether you wish to try for a particular event. However, OW does many other things too. For example, OW can register my intent to observe an event, whether at my

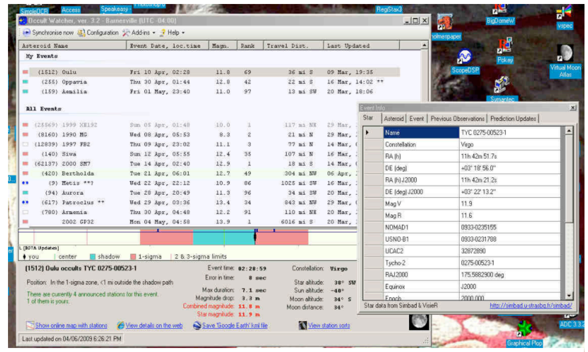


Figure 2 Occult Watcher Window

house, or at mobile locations, and it adds me to a map for that event that all observers can all access, as shown in Fig. 3. It is easy to build a real community of interested observers that adjusts itself to space out the observations across the shadow path.

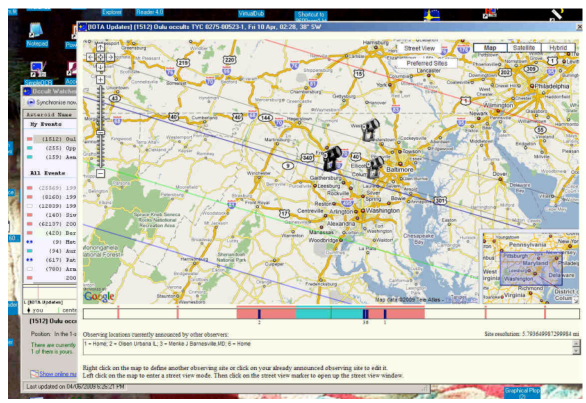


Figure 3 Occult Watcher Map

And of course, OW includes a variety of other screens with more details on the events. And there are numerous other web sites with different data from the predictions--enough to satisfy almost any data junkie. One such is shown in Fig. 4 and Fig. 5.

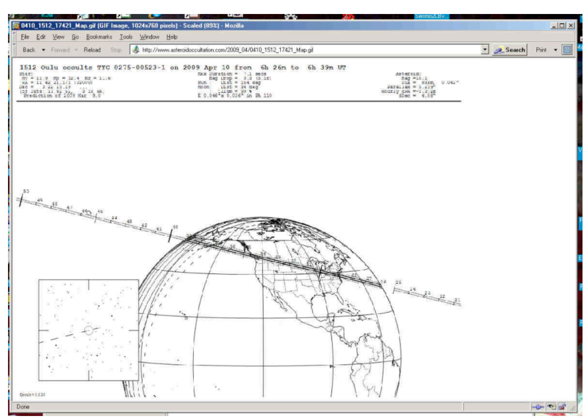


Figure 4 Preston Map

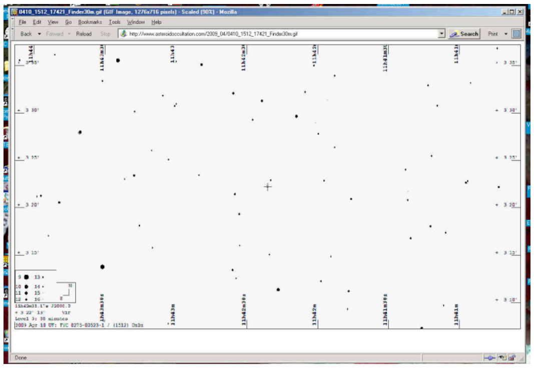


Figure 5 Preston Star Chart

Incidentally, you can see from the screen shots that the predictions go down to about 12-13 mag stars. All of us photometrists know that it is easy to observe such bright stars--right? But few of us try for 10ms time resolution in our photometry! And how do you even find a faint target star when the sun just set 40 minutes ago or there is a full moon only 30deg away? And your GOTO scope is slow getting settled? Or in a mobile setup at 3am in a strange place, you're not even sure when/if you are going to be attacked by some unknown critter of the night? It is a challenge!

2. How the occultation is observed

So, now we know what event we want to observe: how do we actually do it? And just what are the measurements we are trying to make?

There are three general methods of detecting an event: Using a telescope, we can use the eye (i.e., visual), a CCD camera, or a video camera. Each detector type has its own recording mechanism: visual uses a pencil and notebook, video uses a recorder, and a CCD uses a PC.

For occultations, telescopes as small as 2-3 inches are often used, but of course, the fainter events require larger optics. However, the mounting is equally important, but in a different way from what you might expect. You might think a GOTO telescope is the best thing--and many of us do use them. However, for portable, field work, a GOTO telescope is expensive, and slow to set up, so methods have been developed using non-GOTO scopes. But it gets even more interesting, as many people now are using telescopes with no drive at all, i.e., the telescope is on a tripod with a very, very simple mount. So for each detector type (visual, CCD, video) we have three types of telescope (tracking GOTO, tracking non-GOTO, and non-tracking tripod).

So we have a sensor and a telescope on some type of mount, but we also need some method of measuring time duration, and preferably UTC time, and a means of connecting the time measurement to the actual occultation observation. You name it--it's been tried. Stopwatches, beepers, metronomes, WWV, Internet, and GPS have all been tried, and there are still people using each of these successfully. Tiny microphones have even been put on CCD cameras to detect when the shutter actually operates.

However, in the past several years, it is safe to say that GPS timing has taken the lead as the basic time source. We are NOT talking about using the clock display on a GPS receiver--that is frequently off by several seconds. Instead, we use special (cheap) GPS receivers that deliver a pulse at the beginning of every UTC second accurate to about a microsecond. The GPS also provides very accurate location data (especially important for mobile stations). But I emphasize that while GPS time is great, it is NOT the only way to do timing! The remaining issue is then how to connect the time mark to the observation--but how to do that depends on the sensor chosen.

3. Observing Methods

So what are the basic methods of occultation observation, and the major pros and cons of each? The three major methods are visual, CCD, and video observing.

3.1 Visual Observation.

The simplest observing method is to use the human eye. Once the observer finds the star, the major observing challenge is watching for the occultation. However, it is amazingly difficult to pay close attention for more than a minute to a faint star

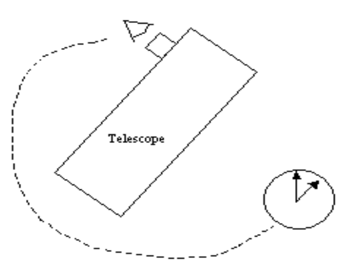


Figure 6 Visual Observer Setup

that is already varying with scintillation. And remember, you don't dare look away to rest your eyes! Using an accurate clock, however, one can limit the time to pay attention. An occultation that is not very strong, egg, <0.5mag for <2 sec is additionally difficult to observe.

However, as with all methods, the other crucial issue is timing the duration of the event and also, preferably the accurate UTC of the event. The personal time equation (i.e., personal response times) in recognizing the dimming and the brightening limits most of us to perhaps 0.3 sec or so precision in the duration measurement. A good event (bright star, deep occultation) combined with an accurate determination of the time equation may allow duration as accurate as 0.1 sec. Obviously, a stopwatch is adequate for measuring duration. However, to obtain the UTC of the event usually requires some form of electronic recording (e.g., WWV and spoken time marks).

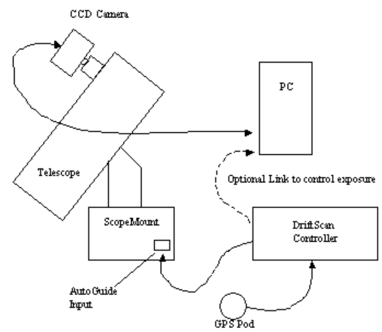
Visual timing is a fine alternative, especially for the "good" events (and it is a method that may salvage an event when more sophisticated methods fail!). However, the difficulty of assessing timing errors, and lack of a non-subjective record, make visual observation a marginal contributor to science (though a lot of fun to try).

3.2 CCD Camera Observation.

But most of us already have a CCD camera (operated by a PC) on a mount, so why won't that work? The short answer is: it can!

Virtually all CCD cameras are limited in their ability to take a rapid series of short exposures, and this is what limits the use of CCD cameras for occultations if one sticks to standard CCD imaging methods. For example, even for subframe exposures, while my ST402 can take an image as short as about 0.1 sec, it can take only about 1 image every second or so as it downloads and prepares for the next image. This introduces an unacceptable error in the occultation timing.

However, one can use a CCD camera in a drift scan mode to spread out the star image during a single exposure. There are various ways to do this, but rather than describe all the ways, as an example let me discuss in detail a method I have been using. Under either manual or computer control, while the telescope is tracking the target, one starts the exposure (say, 50 sec) several seconds before the earliest predicted probable occultation time. The target star image will begin to build. After several seconds, one turns OFF the telescope tracking (e.g., using the mount guide button, either manually or with a custom controller, and the image of the star will start drifting in the westward directions across the Field of View (FOV) at the sidereal rate (times the cosine of the declination of the object). At some time, the occultation occurs and the star dims then



Figurre 7 CCD/Drift Scan Setup

recovers. After the end of the expected occultation time, restart the drive, and then end the exposure. The result is an image with the target (and other) star streaking across the FOV. Knowing the scan drift rate, and the duration the tracking was off, a simple analysis of the image (egg, using the tools in MaximDL to produce a text file of intensity vs. scan distance for use in a spreadsheet) will give the occultation duration, usually to a precision of better than 0.1 sec.

While this sounds simple when you say it fast, performing these steps manually without error is not at all easy when it is 3am in the cold and you haven't done it for several months. And if manually, how do you do the timing accurately (WWV?). One might think of doing a script or other software program within the computer. While this is entirely feasible, if the computer is running Windows, there is no assurance of when any command will actually be executed--Windows actions can easily be off by more than a second, at random, even if the PC clock is right on (which is also difficult to set accurately).

In past years, observers have developed a variety of techniques to obtain accurate timings on drift scans (see discussions on the IOTA sites), requiring both an accurate timing signal, and means of correlating the CCD exposure (or scope drive) to the time. As one variation, I'll describe a simple controller that I use (details are on my web site).

As mentioned above, we do have a system of accurate UTC time available using the global GPS system. While the standard hand-held gps time may be off by more than one second, there exist small and inexpensive gps sensors that provide an electronic UTC time mark good to 1us--much better than we need. With the addition of an inexpensive controller chip, the gps time can be used automatically to control the scope mount as well as the CCD camera exposure to high accuracy, certainly enough to achieve better than 0.1 sec measures of both duration and UTC time.

Fig. 8 shows a DriftScan of an occultation of Davida using a C11 (at f6.3) and an ST7E. This was my first positive. The analysis was done using the tools within MaximDL, and clearly shows the occultation. Using a second scope, I simultaneously used the video method below to measure this same occultation (with identical results).

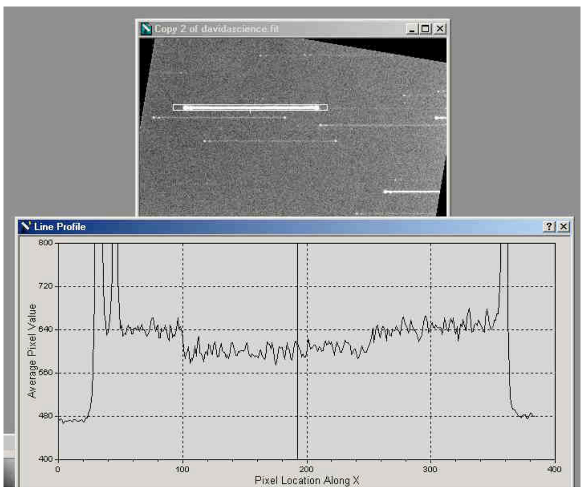


Figure 8 Davida DriftScan Result

So, there are feasible ways to use a CCD camera to do accurate occultation measurements. What are some of the advantages and disadvantages of this method? Advantages include that many of us already have most of the equipment, and many of the skills. The CCD camera is sensitive (and cooled), and has a reasonable field of view. A disadvantage is that if the star field is crowded, a non-target star trail may interfere with the target. Using either manual or automatic control, one may drift to the west, to the south, or both at the same time, which will usually resolve this problem. The long exposure also does increase the background light (and associated noise), and reduces the ability to measure faint stars.

3.3 Video Camera Observation.

The third, and increasingly common method of observing asteroid occultations is to use a video camera on the telescope as the sensor and to record the image to a vcr, camcorder, or DVD recorder. There is a device called a KIWI-OSD (KIWI named after the New Zealander who designed it, and OSD for On Screen Display) that inserts human readable time characters into the video, thus stamping each 1/60 sec. field with its accurate UTC time code. After the recording is done, the observer can view the tape (visual) to detect the occultation; however, normally it is fed into a PC running VirtualDub or a similar program to create a video *.AVI file.

Why not create the video file directly when observing? Usually, one wants to start the video recording many minutes or even as much as two hours before the event. At about 1000MB per minute, the AVI file gets pretty big! Also, a fast PC

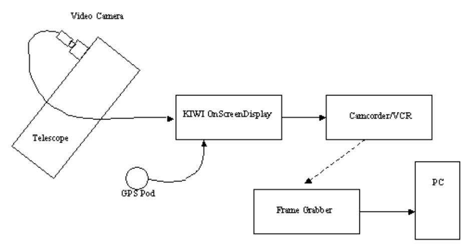


Figure 9 Video/GPS Setup

may not be available for this purpose--fast PCs are expensive, and you don't want dropped frames. Compression schemes may introduce timing or sensitivity issues, so are unwelcome.

Once the AVI file is created (for perhaps the 60 sec surrounding the predicted event), the observer analyzes the file with LiMovie, a piece of freeware that reads the intensity minus background of up to three targets, field by field, and produces a graph or text file (*.CSV) for later analysis by spreadsheet.

Fig. 10 shows a screenshot of the LiMovie

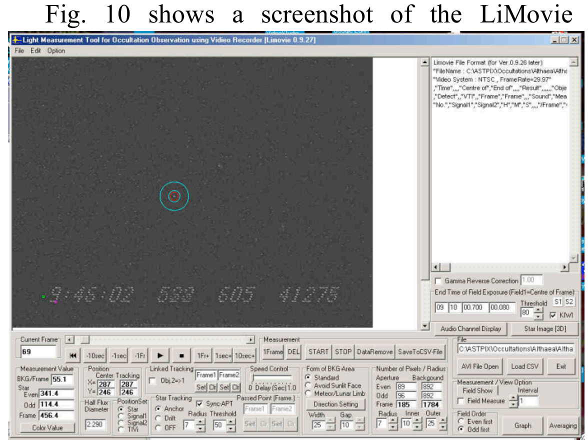


Figure 10 LiMovie Window

control panel, while Fig. 11 shows an LiMovie graph of a typical result (i.e., no occultation in the brighter,

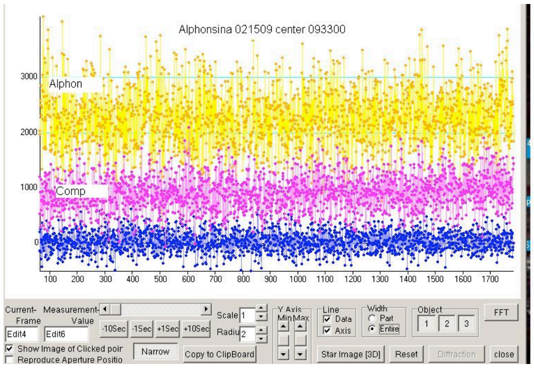


Figure 11 LiMovie (miss)

target star). But you might see something like Fig. 12, which is MY first positive result. There was no

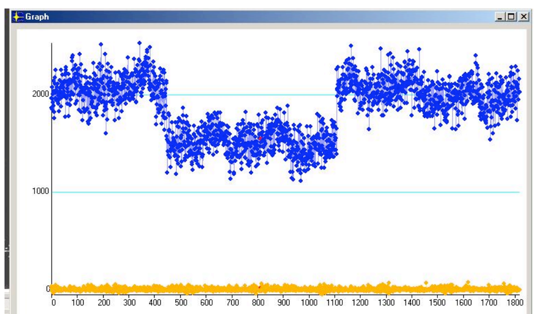


Figure 12 LiMovie Graph (Davida positive)

doubt! This was taken using my 18in f3.5 Newtonian, with a standard video camera recorded into an old (Ebay) Hi8 Sony camcorder. Fig. 13 shows a picture of this setup. Incidentally, a comparison of the drift scan and video results showed agreement on all parameters within statistical errors.

The text file of intensity vs. time for both the

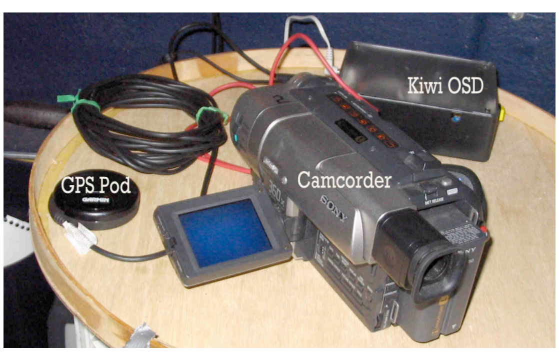


Figure 13 Video Setup

CCD scan or video recording contain scintillation and other brightness (e.g., clouds) variations, as well as the possible occultation signal. For occultations that are shorter and shallower, there is always the statistical question: is the observed dip a real occultation? While detective work on the data will often yield the answer, additional free software (OCCULT) will perform statistical tests to help resolve the question. Fig. 14 shows a DriftScan of Delia, with a suspicious dip at the expected time. Additional analysis by others and myself eventually showed that this was an artifact, and was not real.

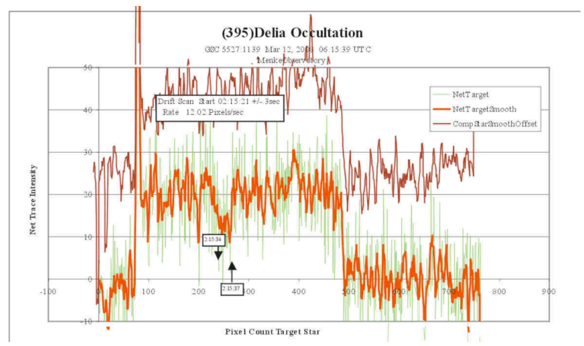


Figure 14 Delia False Positive

The use of highly accurate timing can lead to really interesting results. As we saw in Fig. 1, there were a good number of chords on this 100km asteroid, but some did not align smoothly with others, even though virtually all were using video/Kiwi systems known to be very precise. One observer took the liberty of sketching a possible shape that in fact would satisfy the observations, as shown in Fig. 13. Wouldn't this be interesting to compare to a photocurve-derived shape?

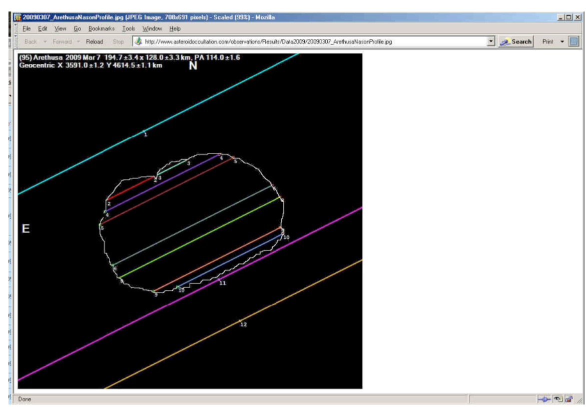


Figure 15 Arethusa Shape Guess

Video details. Let us discuss the video camera in a bit more detail. Although it can be done, aiming a camcorder into the eyepiece is a very clumsy method of doing the observation. Most observers use a small, standalone video camera inserted into the eyepiece holder. These have small (1/3-1/2 in. sensors), no cooling, and automatic brightness control (with dark fields, the camera is usually at full sensitivity). These cameras range in price from $15 to about $150, with the higher cost obtaining a slightly larger sensor of substantially (3 mag) higher sensitivity. There are also more expensive ($300-800) cameras that offer integration (up to 128 fields) and the ability to set the sensitivity. Of course, integration allows fainter stars to be observed but at the price of decreased time resolution.

For those who have never used video, let me describe it very briefly. The video signal out of a video camera is a sequence of fields at 60 per second. A field is a scan of the even lines of the sensor, then the next field is of the odd lines. Two fields make a frame (think, movie film "frame"). KIWI timing pastes the times of start/end of each field onto the electronic data for that field. When you convert the electronic signal to an AVI file, you are building a file at 60 (partial) images per second, with each image containing its own timing information. This is literally a perfect way to combine the observation and the timing data!

I mentioned camcorders. While too bulky to use effectively as the sensor, some camcorders have analog inputs so that the camcorder can serve as a video recorder and monitor for an external video camera. The camcorder can then play back over its own monitor or to an external device. Camcorder batteries will usually operate for many hours, which is also a big benefit.

Video with non-tracking telescope. I have been describing a video observing system that uses a "standard" tracking telescope such as most of us use every clear night. However, out of the ferment of the occultation community has come a truly minimalist idea driven by the very purpose of the measurement. Remember, the purpose is to measure the shape and size of the asteroid. This requires multiple chords of measurements across the asteroid--the more the better. There is a tremendous amount of cooperation in this field, but along a given occultation path, there are usually only a few interested and available observers. Thus, to do a thorough job, one really wants to use multiple mobile stations across the path.

Multiple stations in a small area requires that the stations be inexpensive, simple and quick to install (think 3am along roadsides in the boonies), and yet capable of capturing good data from at least the brighter subset of interesting occultations. Again, many people have contributed to this, but Scotty Degenhardt who follows me this morning, has been a leader both in developing such systems and in learning how to deploy them. He surely holds the record--he has deployed as many as 15 stations in only 3 hours--and virtually all the stations functioned properly!

Fig. 16 from Scotty shows the components of his

Figure 16 Degenhardt MiniStation

setup, which he calls the MightyMini. As he will describe, the apparatus is a short focal length scope (wide field, small star images) feeding a video camera. The video is recorded on a camcorder or DVD recorder. The apparatus is mounted on a simple, but stable tripod--no tracking is provided! In setting up a station in advance of the occultation, the observer prepoints the scope so that the target will be traversing the FOV at the time of the occultation. Thus, at say 45 minutes before the occultation, you point the telescope at a pre-determined, easy to find star, which is where the target will be 45 minutes from now (remember, the earth has very smooth gears!). You start the video recorder, and move on to the next station site 5 miles down the road. Wait till you see the methods Scotty uses to make this work! Fig. 17 shows Scotty with a subset of his equipment.

Figure 17 Degenhardt Five Stations

3.4 Observing Methods Summary.

In summary, we can observe occultations visually, use our CCD cameras, use a video camera, or go with a portable setup. All you need to do is find the star, start recording, then analyze the record the next morning. Actually, that IS the story: one of the advantages of occultation work is that it is (almost) instant gratification--the observer does not have to accumulate data for days or even weeks, analyze the heck out of it, all in the hopes of finding (for example) a unique period solution for an asteroid rotation curve.

4. Additional uses of occultation observing methods

Which brings up several more points. A little calculation shows that once an occultation has been observed and a shape measured, it is very important that within a few weeks at most that a new photocurve be obtained for the asteroid. This may not be easy: the asteroid may be rather far from opposition, and poorly located. However, if the occultation data are to be used in shape modeling, tying the occultation accurately to the phase of the photocurve may be very important. We do not yet have a systematic liaison between the photocurve folks and the occultationists to accomplish this--here is a task for SAS!

Another point is that many of the video and timing skills being developed for occultations fit perfectly into NEO observations. A NEO may be travel at high apparent speeds across the sky, requiring fast exposures (e.g., 16ms) at high rates, with accurate timing, to obtain an accurate orbit. In just the last three months, David Herald of Australia and others have has pioneered this very application of occultation methods and equipment. In fact, David even put a video of an NEO on YouTube where it garnered over 100,000 views in a few days! These techniques are sure to be more widely applied in the next few years.

Finally, the new, convenient ability to combine high image rates (60/sec) with accurate UTC timing may allow other new applications. For example, one can use the same techniques in meteor observation, scintillation measurement, photocurve measurement of high-speed phenomena (occultation diffraction, pulsar periods, etc). In many cases, this opens up the ability accurately to combine data from multiple observing sites. The integration of UTC right into the recorded observation is a fundamental advance only now being exploited.

I would also note that I reported last year at SAS (and my web site describes) a home-built photometer that takes measurements as fast as 1000/sec and produces a simple text file that is time stamped to 1ms using the gps time signal. However, where feasible to use, the video is preferable since it does not require accurate pointing and guiding, and provides at least the potential of comparison stars in the same FOV. Because the measurement aperture can be made quite small thus excluding stray and background light while providing a good measure of it, the S/N with the video camera may be better than with the photometer.

5. Getting Started

This field is new enough so that the web provides most of the information needed with many papers and reports available. The starting point is certainly the IOTA web site, misleadingly named
http://www.lunar-occultations.com/iota/iotandx.htm
even though it is much, much broader than lunar occultations. Another site with many links is
http://www.asteroidoccultation.com/observations/
which includes more non-US links, as well.

Between these two sites, you will find scores of links to introductory and advanced papers on how to do occultation work, the equipment needed, where to find software, etc. If you are interested in this field, you MUST carefully go through the list of links. You will find many links to individuals who specialize in various aspects of occultation work.

Another source of information is the very busy list serve for occultations. This can be found at
www.IOTAoccultations@yahoogroups.com
and is a treasure of activity and interesting information.

Asteroid occultation reports are usually sent to Brad Timerson who runs
http://www.asteroidoccultation.com/observations/Forms/AsteroidReportForms.html
This site also includes links to "results" pages, which tabulate the reduced observations sent to him.

6. Conclusion

Are there frustrations in occultation work? Yes, there are: at 3 AM, everything that can go wrong, does! Each occultation event is a one-time event--it won't repeat itself 4.7 or even 24 hours later as do well behaved asteroid light curves! In my own case, I scheduled occultations for observation approximately 30 times in two years. More than half were wiped out by weather (clouds, rain, snow, fog), half the remainder I or my equipment failed (or both), 3/4 of what is left were misses (the shadow went somewhere else), but I got two positives--but only after some 20 months of trying! And of course, "misses" are not wasted--it is essential that we know the boundary of the shadow.

On the other hand, seeing that unmistakable dip in the brightness is really cool--it is truly addictive. And that first positive could just as easily have occurred the first time out: instant addiction!

Acknowledgement

Any listing of names will inevitably leave out major contributors to this field. However, David Dunham should certainly be singled out as one of the early pioneers in lunar occultation and grazing work, and then helped start the amateur observing of occultations. He continues to support the field and encourage others with a seemingly inexhaustible fund of energy and enthusiasm.