Most amateur astronomers look forward to observing eclipses – a nice lunar eclipse, and the all-too-rare solar variety. Some travel for hundreds of miles to “catch the shadow”. ...But did you know there are potential eclipses to observe nearly every clear night? There are ---- Asteroid Occultations.

What's an asteroid occultation?

Assuming you know what an asteroid is.... There are now just over 1 MILLION asteroids that have published orbits. Over 500,000 of them have orbits that are established well enough that they have been “numbered” (in general, the lower the number, the more refined the orbit). There are also billions of stars visible through a telescope in the night sky. It's only inevitable that at times the alignment will be just right for these chunks of rock in space to pass in front of the absolute pinpoint light from stars. If you are in just the right place on Earth, the asteroid will “eclipse” the star, blocking out its light for anywhere from a fraction of a second, to up to 10's of seconds. As the star is essentially infinitely far away – as compared to the distance to the asteroid – the “shadow” the asteroid casts on Earth is basically the size of the asteroid. This shadow moves across the surface of the Earth in a narrow band (the width of which is the diameter of the asteroid), often crossing thousands of miles of the Earth's surface. If you are located somewhere in this narrow band, and it's clear out, you can see the star “blink out”, and then back - an asteroid occultation. As an example, the image to the right shows the shadow path of the asteroid (389) Industria crossing the northern United States.

Of course in order to predict the shadow path, it is also important to know the positions of the stars in the sky to a very high precision. In 2013, the European Space Agency launched a satellite named Gaia. Its mission is to very precisely measure the positions of a couple billion stars in the sky – to an angular accuracy of the diameter of a quarter on the Moon as seen from the Earth. It can measure stars to about magnitude 20 - FAR dimmer than what can be seen with the eye, or even with a moderately size telescope. As Gaia continues to remeasure the same stars over many years, it builds a catalog of the actual individual motions of these stars (in 3D!) - allowing astronomers to know precisely where a star is now, and for many years to come.

By using computer programs (some of which are free, and available to run on home computers) the positions of hundreds of thousands of asteroids can be calculated and compared with the precise star positions measured by Gaia. In this way, the paths of thousands of yearly asteroid occultations can be predicted. On average there's usually a nice “event” potentially visible at least once or twice a week from any place on Earth (and usually lesser ones every clear night).

An interesting aspect of occultations is that your observing location on Earth is unique. As mentioned above, the shadow an asteroid casts across the Earth runs in a very narrow band – often only several to a couple hundred miles wide, but thousands of miles long. As such, YOU have about as much opportunity to view (and possibly record and measure) an occultation as any professional astronomer at a major observatory. As such, observing occultations is one of the few activities in astronomy where amateurs can contribute valuable scientific data which can be on par with that of the professionals.

More info on occultations can be found at: [http://occultations.org/occultations/what-is-an-occultation/](http://occultations.org/occultations/what-is-an-occultation/)
How do you observe an asteroid occultation?

In the simplest way, it can just be observed visually and you can enjoy watching a star blink “off”, then “back on” again. A rather small telescope is sometimes all that is needed – for the brighter events. Predictions are readily available on the Internet or you can generate them with your own computer (more on that below). You should have a program to generate star charts to locate the “Target Star”, and have intermediate computer, telescope and astronomy skills.

This writing is geared more toward observers who might like to do a little more.... record the occultation, measure it, and submit the observation – thus increasing our knowledge of asteroids. The organization that collects this data is the International Occultation Timing Association – IOTA. More info can be found at: http://occultations.org/observing/observing-basics/

How is an asteroid occultation recorded?

In short, you obtain a prediction, locate yourself in or near the predicted shadow path, attach a very sensitive video camera to your telescope, and record the starfield surrounding, and including, your “Target Star” around the time of the predicted “event”. In most cases, the asteroid will be fainter than your Target Star, and you need to VERY accurately record the time the Target Star might disappear (or fade) and reappear – to an accuracy of at least a tenth of a second (and preferably much better). You also need to very accurately know the latitude, longitude and elevation of your observing site.

For various reasons, predictions have uncertainty factors, and you may not witness an event. Usually this is due to the uncertainty of the asteroid's orbit – and to a lesser extent, the uncertainty in the star's position. The predicted shadow paths almost always show this uncertainty. If you are certain that the Target Star was NOT “occulted”, you would report this as a “Miss” (or “Negative”) to IOTA. Reporting a Miss is almost as valuable as observing a “Positive” event – as it says where the asteroid's shadow WASN'T. This can sometimes be a crucial bit of information, as in chord “6” in the image below. That miss helped constrain the bottom edge of the asteroid. If you do witness an event, you measure the times of disappearance and reappearance, and submit your observation to IOTA using a standard report form.

Teamwork can play a very important part in occultation observing. Consider a 20 mile wide asteroid passing in front of a star. It will essentially cast a 20 mile wide “shadow” across the surface of the Earth. Let's say that 20 mile wide shadow runs from Los Angeles to Portland, Maine. Anyone along that narrow, but very long path has the opportunity to witness the event. Asteroid shapes vary, but in general, most are some sort of an ellipse. As a result, an observer near the center of the actual shadow path may witness the star “blink out” for a longer period of time than someone near the edge of the shadow path – as the observer near the “centerline” will see the star pass behind a wider “chord” of the asteroid's shape.

If enough observers are scattered along the WIDTH of the path (irregardless of where they are ALONG the path), each observer will witness the star “disappear” for a different length of time. When the disappearance “chord lengths” are combined (after correction for geographic location), an actual shape (and thus size) for the asteroid can be determined. With between 5 and 10 observations, details in the shape of the asteroid can be determined – FAR exceeding the resolution that can be obtained from any ground based telescope, and even the Hubble. Not bad considering all you may need is a small, perhaps 3 to 6-inch telescope!
Once you are versed in using your equipment, occultation observing (from home) may not take a lot of time. Perhaps 45 minutes to setup the equipment and locate the Target Star, then do the observation, and then 20 minutes to tear down. From experience tho.... ALWAYS allow (considerably?) more time than you think you may need for setting up, and locating the Target Star! This can't be understated.

Sadly, for about half of the “positive” observations (an actual observed disappearance and reappearance) that are reported to IOTA, there is only ONE observation per event. Though that one observation is useful (it does confirm the prediction was reasonably accurate), having just 1 chord doesn't do much to define a size or shape. Thus the need for as many observers as possible. This is the primary reason for why this article was written – more observers are needed!

An important word on ACCURACY...... For those reporting observations, remember the adage, “bad data can be worse than no data at all.” So for persons wanting to measure and report their observations, they need to be willing to work to a rather high degree of precision. This especially pertains to reporting the times of disappearance and reappearance to an accuracy of a tenth of a second – and preferably much better. You will need to obtain these times using a very accurate timing reference. The best time reference is currently time signals obtained from GPS satellites. Submitted observations do get reviewed, and the persons who do this volunteer their time. So it should be noted, if you aren't willing to put care into your efforts, then occultation timing may not be for you.

A description of a “useful” occultation setup:

- **Telescope** – Many brighter events have been nicely captured by telescopes with an aperture of between 2 to 4 inches, however, if possible, a telescope with an aperture of at least 4 to 6 inches is recommended. Unlike in astrophotography, a clock drive helps, but is often NOT necessary when using a smaller telescope. This is because most occultations state a predicted time which is often accurate to +/- 15 seconds, and the cameras used in occultation work usually have a wide enough field of view (FOV) that you can let the star “drift” across the camera frame during the predicted time. To find your camera's FOV, point your telescope to the celestial equator – 0 degrees Dec. Time how long in seconds it takes for a star to drift across the camera frame. Multiply this by 15.04 and divide by 60 to get your FOV in arc minutes. Now, for future Target Stars, you can apply the formula: FOV / (15.04xCos(Dec)) --- and arrive at how many minutes it will take for the Target Star to drift across the camera field. Typically this could be 2 minutes. Thus, for a 2 minute drift time, if you have your Target Star on the east edge of the camera's FOV, 1 minute before the event, the Target Star should be near the center of the frame AT the predicted time of the event. The initial analysis program, PyMovie, has the capability to automatically track (while measuring the brightness of) the recorded Target Star as it drifts across the camera frame. Obviously, if you don't have a clock drive, a shorter focal length instrument (wider FOV) is much preferred. This is also why the recommended “starter” camera (Night Eagle 2 Astro Pro) is supplied with a focal reducer – as it also helps to widen the FOV. There is a trade off though.... more aperture allows fainter stars to be seen (and thus more potential occultations), but usually results in a longer focal length, and a narrower field of view. Thus, a large telescope should ideally have a clock drive. To a point, the longer you can record on the “Target Star”, the better (you could even capture an unknown asteroid satellite!). When possible, your recording should capture the Target Star for at least 1 to 2 minutes before the predicted time, and continue to record the Target Star for 1 to 2 minutes afterward.

- **Camera** – In order to obtain proper timings, video recording the occultation is mandatory, in which case you will need a camera that is very light sensitive, ideally recording at the standard video rate of 29.97 frames per second. The RunCam Night Eagle 2 Astro edition is a low cost starter camera which has been found to work very well (it's obtainable through IOTA – Note.... This camera is no longer being manufactured, though IOTA may still have some left for sale).
• **Timing Device** – You need to use a very accurate time reference, preferably recording it directly onto your video. There are a few ways of doing this. BY FAR the best way is to purchase a “VTI” (video time inserter) device which inserts a running clock readout directly into your video. The two VTI's listed below do that to an accuracy of thousandths of a second. A “temporary” method makes use of the smartphones many people already have. Free apps (“Occult Flash Tag” or "Astro Flash Tag") are available which use the phone's camera flash to put “markers” on the video (before and after the event). The app will record the times of the flashes to an accuracy of a few thousandths of a second, and you can use these flashes in your video to interpolate accurate disappearance and reappearance times. Consider this only as a way to get started – as it does have its quirks. Using a VTI is considered to be the BEST way to time occultations reliably and accurately. Be advised that recording audio time signals (say from a radio station like WWV) on the audio channel of a video recording can have the problem of the audio and video NOT recording in proper time sync. I once tried this and found almost a 0.2 second discrepancy – too inaccurate for proper reporting to IOTA.

• **Computer** – You will need a computer to capture the output of the video camera to a video file – ideally in .AVI or .FITS format. For .AVI you must use the Lagarith codec which saves your video in a lossless, uncompressed format. Laptops are needed if you wish to travel and “go mobile”. Avoid running any non-essential programs during your recording. Running other programs while you are recording your video increases the chance of “dropped frames”.

• **Video Capture Device** (If needed) – Essentially an interface between the camera and VTI, and your computer. Often quite small and inexpensive, they are used to convert the analog output of some cameras (with RCA jacks) to digital form, which is then input into the computer via a USB jack. A commonly used one is the StarTech SVID2USB232, which costs $40.

**Obtaining Asteroid Occultation Predictions:**

There are two very good sources for obtaining predictions specifically for your geographic location. Both are free computer programs you can load onto your home computer. They are “OccultWatcher” and “Occult”. Both are **EXCELLENT**, and highly recommended. Downloads for both programs can be found at: [http://occultations.org/observing/software/](http://occultations.org/observing/software/)

• **OccultWatcher** - (“OW”) is quite an amazing program which serves to both provide local predictions and also to coordinate observers together (worldwide!) to observe the events – kind of an “Occultation Astronomy Club”. In short, it allows observers to “sign-up” for an occultation, and provides precise information for your location. It then displays where each observer falls in relation to the shadow path. Its capabilities are vast – too encompassing to describe here. In general, it displays the “better” occultation possibilities. Above is a screenshot from OW showing observers “signed-up” to try for the occultation of a large Trans-Neptunian Object. (The TNO's estimated diameter encompasses the blue lines, with the center of the predicted shadow being the green line).
- **Occult** - (not to be confused with OccultWatcher) is also quite an amazing program which, among many other things, also provides local predictions, but has the capability to provide MANY more (usually "lesser") events than "OW". It doesn't serve to coordinate observers, but is the actual prediction generating program for many of the events listed in OW. Once set up properly (there are MANY options), this is the program that can generate a “decent” event to try for on almost any clear night. In general, it’s the more “advanced” and “deeper” program. Occult can also predict lunar occultations (and lunar grazes) of stars. (Sample screenshot below).

A general listing of the best worldwide occultation events can also be found via the Internet at: [http://asteroidoccultation.com/](http://asteroidoccultation.com/)

**Regarding Star Chart and Asteroid Plotting Programs:**

Just a quick mention of the open-source freeware program Carte du Ciel (French translation - “Sky Charts”) – which can generate very useful, highly configurable star charts. It can download the asteroid database (MPCOrb) from the Minor Planet Center and very accurately plot asteroid tracks – making great finder charts. Though I like this program, it can at times be a bit finicky when handling the full MPCOrb database of over 1 million asteroids, and updating can sometimes be a tad slow. Still, it’s a very useful program. Note that to ideally use it for occultation work, you must have the program install the optional UCAC4 star catalog. Carte du Ciel can be downloadable from: [https://www.ap-i.net/skychart/en/download](https://www.ap-i.net/skychart/en/download)

Note that some observers recommended the use of the program “Guide9”, tho I have had no experience with it to date. Another program often used is the freeware program “C2A”. Research these programs on the Internet, and you can choose for yourself. As of this writing, the author’s program of choice is Carte du Ciel.
First, visit this site and see what IOTA recommends and read their comments: http://occultations.org/observing/educational-materials/equipment/analog-video-recording-in-windows/

After considerable trial and error, what's listed below is what I've found that works - for me. **MANY other configurations are possible**, and new equipment is coming out all the time. Below is what I've found to work well – as of this writing – February 2022. What's listed below is what might be considered a good “starter” setup. The specific links to equipment below may or may not be valid at the time you read this. (I'll try to keep links updated in subsequent versions of this document).

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* **Camera** - RunCam Night Eagle 2 Astro Edition ($189 with adapters and a focal reducer). This camera gives an analog output (via an RCA video jack) at the standard video rate of 29.97 frames per second. This camera is SMALL and LIGHT! It fits in a standard 1.25" focuser. Originally designed for flying amateur drones at night(!), it has been modified for doing astronomy. How faint can it record?... Roughly speaking, this camera can capture all the stars you can see visually through a telescope, and perhaps go a tad fainter. There are 3 ordering options. It is best to get the kit supplied with the two spacers and a focal reducer. Here's a link for ordering: http://occultations.org/night-eagle-2-pro-astro-edition-ordering-page/

Note that there are other cameras that are also used, but the Night Eagle 2 is perhaps the best, and least expensive “starter” camera. The output of this camera can be captured and digitized into a USB-2 or USB-3 connection. There's even a camera with a built-in GPS unit which internally inserts precise GPS derived time into the video – the QHY 174M-GPS (priced about $1,240, and ideally needs USB-3). New “live video” cameras are starting to become common – though nearly all are MUCH more expensive than the Night Eagle 2. As mentioned before though, **manufacture of this camera has ended**. IOTA is now looking into a replacement camera – the Night Eagle 3 (unavailable as of this writing).

[Note: Though a commonly used camera in the US, it appears that few Night Eagle cameras are used outside of North America. As such, the author can not recommend purchase of this camera outside North America at this time].

* **VTI (Video Time Inserter)** – This unit obtains ultra-precise time (in Universal Time - UT), latitude, longitude, and elevation from GPS satellites, and can insert that information into the video. IOTA sells their own VTI (cost $249 or $274 depending on options). It has the advantage of a fast start-up, and the analysis program – PyMovie - can read its timing stamps automatically. Here's a link to the VTI sold by IOTA: http://occultations.org/observing/recommended-equipment/iota-vti/.

At the time I put my system together, the IOTA VTI was unavailable so I purchased the Sprite3-U VTI from The BlackBoxCamera Company in England (price depends on the current exchange rate but is about $220) http://www.blackboxcamera.com/pic-osd/sprite.htm. (Given the choice between the two VTI's, the IOTA VTI is **much** preferred, as its time stamps are read much more easily by PyMovie).

To the left is a sample of what information the Sprite3-U VTI can insert into video from the Night Eagle Astro 2 camera (the IOTA VTI is similar but usually just lists date & time).

The top line is the latitude and longitude (in this case I grayed-out the exact figures). 2nd line states it is locked to
11 GPS satellites (a min of 4 are required) and the altitude is 525.0 meters. 3rd line lists YY/MM/DD format (2019 Sept 19th) and the time – which in this case is 4:23:09.4XXX UT. (For the Sprite VTI, as a system check, the first digit in fractional seconds should always be a 0. The last 3 digits are blurred as a result of viewing this display in frame mode rather than field mode, but all 4 digits of fractional seconds will be read by PyMovie).

Please note that in using any VTI, after powering it up, you **MUST** give the unit time to receive the latest “almanac” from the GPS satellites, and correctly update its time. Otherwise the displayed time might be wrong by one or more seconds! Read your VTI's manual. Often this time is 15 to 20 minutes. So start your VTI early! It is highly recommended that you then check the displayed VTI time against radio station WWV or smartphone apps that obtain precise time via Network Time Protocol (NTP) servers. **Do NOT assume that just as soon as a time is displayed that it is correct!**

**Computer** – What to buy is up to you. A specific recommendation can’t be given. Note that most of the software used in occultation work tends to be Windows-based. I'm using an old Windows XP laptop that was given to me and it works excellently. Most modern computers should work fine. A laptop is a must if you want to "go mobile". You must reduce to a minimum the number of other programs running when recording occultations. Your recording must not “drop” any video frames. Some modern, large-chip cameras may require that the computer have a USB-3 connection.

**Video Capture Software** (FREE):
This will depend on the computer you have, and simply what works. I use the program VirtualDub and love it, but supposedly it only ideally works with Windows XP. If you have an old computer and you need VirtualDub, do a search for it on the Internet.
For Win10 computers IOTA recommends that you try IOTA VideoCapture, available here:

**PVC Camera Extender Tube:**
(Included in the IOTA “Full-Kit”. Otherwise it's easy and inexpensive to make).
This is very handy as it will allow the RunCam Night Eagle 2 Astro camera to reach focus in nearly any telescope - provided that scope has a 2-inch focuser. NOTE: Most cameras require an "in" focus a bit further in than is required by most all eyepieces - and the stronger the focal reducer, the more "in" focus is required. This can present a problem, especially for reflectors.
When using the Night Eagle 2 Astro camera, this extender tube is also useful in very cold temps as the end extending out of the telescope can be "plugged" lightly with a cloth, and the heat generated by the camera will keep the camera from getting "too cold" - when used in temperatures below, perhaps 10 or 20 degrees. DO NOT plug the end in temps above freezing as the camera DOES generate a notable amount of heat, and in warm temps, that heat MUST be dissipated. Plans (in .pdf format) to build one, which include step-by-step photos, can be found here: [http://occultations.org/observing/recommended-equipment/optics-accessories/](http://occultations.org/observing/recommended-equipment/optics-accessories/)
Once you have recorded an occultation to a video file on your computer, you need to analyze it. Until recently, the “old standard” program that was used was LiMovie (which is still useful), but recently the program - PyMovie - has been developed, and is much preferred.

**PyMovie** - [Initial] Video Analysis Software (Free):
This is an excellent initial video analysis program, which reads an AVI video file, or a series of FITS images (and a few other formats). When used in “Drift” mode it can lock onto the star(s) it is measuring. This is very handy if you recorded video with a telescope that doesn’t have a drive system. PyMovie will clearly allow you to see if you recorded even a low mag dip or very brief occultation. Using Optical Character Recognition (OCR), PyMovie can read the time (timestamps) written into your video from several popular VTIs. It then creates an Excel spreadsheet of your recording that IOTA requires. This program is available as a free download from: [http://occultations.org/observing/software/](http://occultations.org/observing/software/)

Above is a screenshot from an analysis of a positive event detected using PyMovie. Three “apertures” for measurement are shown in the starfield video. The red box encloses the Target Star (shown magnified in the view below). The yellow box is a star that was used for tracking, and the green box was used to sample the background level. In the composite lightcurve, the measurements are shown as the blue, green, and red plots respectively. PyMovie can track on a Target Star as it drifts across the field of view, and can take into account any field rotation when using a stationary alt-az mounting.

Bob Anderson, the author of PyMovie, has several good tutorial videos on YouTube describing the operation of the program (do a YouTube search using the keywords “PyMovie Anderson”). Note that these videos show earlier versions of the software, but for the most part, they still serve the purpose.
To the right, in green, is a plot of what the earlier-mentioned (389) Industria occultation looked like when run through PyMovie (12.4 mag asteroid passing in front of a 12.4 mag star - light drop of 0.7 magnitude). In visually watching the recording, the occultation didn't clearly show. Looking at the graph produced by PyMovie clearly shows the event (the upper plot in red is a comparison star).

If it appears you observed a "Miss" (no occultation), then the next step is to fill out IOTA's standard Occultation Report Form with details of your observation. You may also be required to submit the resulting .CSV file created from PyMovie. IOTA's standard Asteroid Report Form can be found here: [http://www.asteroidoccultation.com/observations/Forms/AsteroidReportForms.html](http://www.asteroidoccultation.com/observations/Forms/AsteroidReportForms.html)

**PyOTE - [Final] Video Analysis Software (Free):**
If you DID observe an occultation, you need to do further analysis to obtain EXACT disappearance (D), and reappearance (R) times. It's suggested you download the free analysis program - PyOTE - from [http://occultations.org/observing/software/ote/](http://occultations.org/observing/software/ote/). Follow the download and operational instructions. Again, submit results via the IOTA Asteroid Report Form. There are several other analysis programs, but PyOTE is perhaps the "easiest", and a good one to start with.

The example above shows the first PyMovie event, which was then analyzed in PyOTE to extract the exact disappearance (D), reappearance (R), as well as the signal to noise ratio and confidence intervals (all values IOTA likes reported). PyOTE reads the Excel-style .CSV file created by PyMovie.

Despite the apparent complexities, after getting used to them, doing an analysis with PyMovie and PyOTE is actually fairly quick and easy, and yields accurate results.

Curious about past occultations that others have observed? Here's a link to IOTA's Reviewed Results for North America page (many years of results are listed): [http://www.asteroidoccultation.com/observations/Results/Reviewed/index.html](http://www.asteroidoccultation.com/observations/Results/Reviewed/index.html)
~ THE USEFULNESS OF OCCULTATION OBSERVING ~

At a very basic level, an observation of an occultation can serve to demonstrate that the universe isn't "static", but is always changing. If the event is relatively bright, and the magnitude drop is large, witnessing an occultation can be rather dramatic. The better, more certain events can be good subjects for showing at star parties (today's video cameras can allow many to view the event at once).

Looking at things from a more "productive" standpoint, a properly observed and timed occultation event can yield valuable scientific data. Here's a few examples:

**Astrometry:**

Astrometry is the branch of astronomy concerned with measuring positions (usually extremely precise positions) of objects in the sky. As mentioned earlier, essentially every star in the sky, visible with the naked eye or through a telescope, has had its position measured to amazing accuracy. Most of these positions have been obtained by specialized satellites dedicated to obtaining this astrometry from space (astrometry by ground-based telescopes is limited by the distorting effect of the Earth's atmosphere). Telescopes on Earth dedicated to astrometry often report an accuracy of 0.1 arc seconds or so for asteroid positions. In comparison, the astrometric satellite Gaia routinely achieves positions for stars well over 100 times better. For the great majority of asteroids (especially the higher-numbered ones), their orbits (and thus their position at a given time) still have varying degrees of uncertainty. In general, the position for an asteroid (at a certain moment in time), is MUCH less certain than the position of a star. Still, we now know many orbits well enough that we can make reasonably reliable occultation predictions (and indicate estimated path uncertainties). As a result, a single occultation observation can 'link' an asteroid's position to the very precise position that has been obtained for the star it "occults". This can greatly aid in refining the orbit of the asteroid. As compared to asteroid astrometry done by dedicated Earth-based telescopes operated by professional astronomers, asteroid astrometry obtained from an occultation is often 20 to 50 times better.

**Discerning Asteroid Sizes and Shapes:**

In general, the more observers there are for a single asteroid occultation, the more useful the observation can become. As mentioned earlier, if a number of observers (perhaps 3 or more) can be spread across the WIDTH of the shadow path, they can all witness the star pass behind different cross-sections ("chords") of the asteroid. As a result, when the different observer's occultations are analyzed, in many cases a size and possibly a shape can be determined.

For some asteroids, a "shape model" (or models) is already available. Most shape models are the result of observers measuring an asteroid's brightness variations (as it rotates) over long periods of time. The resulting "light curves" can be fed into a computer, and the computer may be able to come up with a "shape" (and rotation rate) the asteroid must have in order to display the observed light variations. At times a couple different shape models may satisfy the observed light curves. Observing an asteroid occultation can then help discern which shape model may be correct. (Taking this further, if a size and shape can be determined for an asteroid, studies can be made to ascertain rough densities, and other physical properties for these bodies of our solar system).

**Discoveries.....**

There have been cases where observers have seen a star 'disappear' not once, but TWICE during an occultation. In some cases this has lead to the discovery that the asteroid is not composed of one body, but rather two that are orbiting each other (a "binary" asteroid). In other cases occultations have proven that the occulted star is not a single star, but rather a very close "double star".

**Near-Earth Objects:**

In early 2021 IOTA launched a campaign to observe occultations by the Near Earth Asteroid, (99942) Apophis. At the time there existed a slim chance that this asteroid could pose an impact danger to the Earth in near-future fly-bys. Expeditions to observe occultations of stars by Apophis were organized, and several occultations were observed. These observations combined with other precise positions of the asteroid obtained through radar observations (and conventional astrometry) succeeded in removing any risk of an impact in the next 100 years. Apophis will next pass by the Earth in April 2029 at 1/10th the Earth-Moon distance – so close that it will be visible to the naked eye as a point of light, slowly moving across the sky. The 2021 observations ruled-out any chance for an impact during this close approach.
IOTA sells a “Complete Occultation Kit” - which includes the RunCam Night Eagle 2 Astro camera, IOTA’s own VTI, the StarTech SVID2USB232 A-to-D converter, cables, and battery holders. Install some free video capture software on your computer, add some batteries, and you will be set to record occultations with your telescope. Cost: $530 plus shipping. Here’s a link to the page: http://occultations.org/observing/recommended-equipment/iota-vti/

In the above image, the RunCam Night Eagle 2 camera is at top left with it's 0.5X focal reducer lens (supplied with a yellow plastic cap). The camera is powered by a 2-sided battery holder (holds 8 AA batteries). The camera’s ‘dongle’ is used to control exposure settings, gain, etc. The analog output of the camera runs to the VTI through the yellow RCA plugs. The IOTA VTI is the box at the bottom right. The VTI is also powered by a second 2-sided battery holder (holds 8 AA batteries). From the VTI, the video (still analog at this point), again runs through the yellow RCA plugs into the StarTech SVID2USB232 frame grabber where it is converted into a digital signal. The other end of the frame grabber has a USB connector and plugs into your computer. The computer then records the video (using the supplied IOTA Video Capture software).

The blue 2-inch diameter tube in the image is the PVC holder which allows the camera to be used in a 2-inch focuser. The camera gets inserted into the PVC holder which has set-screws to hold it in place.

A note regarding the StarTech SVID2USB232 frame grabber..... Be sure to ALWAYS load the most up to date video driver for this device (from the StarTech web site)!
Some other example 'Occultation Rig' Images:

The Author's Basic "Mobile Battery Powered Laptop Setup"

A - Video capture device - StarTech SVID2USB23 (now superseded by the SVID2USB232)
B - VTI Unit – Sprite3-U (the IOTA-VTI also works here too)
C - VTI's GPS antenna
D - 12VDC 6000mAh rechargeable Battery Power supply
E - Night Eagle 2 Astro Camera in PVC housing
F - Homemade 12VDC "Y" power splitter (3 male ends – powers VTI & camera)
G - 16-foot cable to camera (video & power)

The laptop is an old Windows XP(!) machine that was simply given to me – but it works great! Nothing against new ones, but older computers, especially if you can obtain them for next to nothing, are worth a try. Once you get them working well, try to avoid any updates or connection to the Internet, and use them ONLY for occultation work.
An "Observatory / AC Power Rig"

(Note: I made the white painted box to house the laptop, power supplies, AtoD converter, and VTI so I could use this setup in quite cold winter temperatures):

A - Laptop (closed and sitting on the box edge)
B - VTI Unit – Sprite3-U (the IOTA-VTI also works here too)
C - Video capture device - StarTech SVID2USB23 (now superseded by the SVID2USB232)
D - Laptop’s AC power supply adapter
E - AC to 12VDC power supply (required for VTI & camera)
F - 16-foot cable to camera (video & power)
G - Night Eagle 2 Astro Camera in PVC housing
H - VTI’s GPS antenna
I - (optional) External Mouse
J - (optional) External Keyboard

When in use (image at right), the laptop is on top of the VTI and power supplies, and just the screen shows (the laptop is held in place by a small black Velcro strip near the VTI). Often the external USB mouse and USB keyboard are used (especially in cold weather). For remote work (no AC power), the 12 Volt Battery Power Supply (from the above mobile rig) replaces the AC power supplies (D & E). (In quite cold temperatures, a rag can be wrapped around the base of the laptop screen and the heat from the laptop and power supplies will keep the laptop, VTI, and electronics warm and dry inside the box). A side benefit of having several components in the box is that it minimizes the flexing (and breakage) of some rather fragile wires.
Some of the components used in the author's rig(s).........

* **12VDC from AC Power Supply** ($15.95):
Powers both camera and VTI. You can use this if you have available AC power.
www.amazon.com/gp/product/B00K919SHG/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1

* **12VDC "Y" Splitter cable** - 1 female end, 2 males ($6.59):
For use with the above AC power supply

* **12VDC Battery Power Supply** ($34.19):
Powers both camera and VTI. Use this if you are "going mobile" or you want pure 12VDC power.
www.amazon.com/gp/product/B00MF70BPU/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1

* **12VDC "Y" Splitter cable** - all (3) male ends
This is required as the above battery power supply needs to power both the camera, and VTI, and all 3 have female jacks. I could not find a splitter with 3 male ends – so I had to custom make one.
Purchase individual male leads (parts $9.49) and solder together an "all male Y".
www.amazon.com/gp/product/B072BXB2Y8/ref=oh_aui_detailpage_o00_s00?ie=UTF8&psc=1

* **Camera video & power cable** ($8.99):
Video from, and power to the camera - all in one cable.
www.amazon.com/gp/product/B019TUJ0MK/ref=oh_aui_detailpage_o06_s00?ie=UTF8&psc=1

* **Camera Analog to Digital USB converter** – StarTech SVID2USB232 ($37.99):
Digitizes the camera signal and inputs that into the computer via USB.
www.amazon.com/StarTech-com-Video-Capture-Adapter-Cable/dp/B089KQJV6S/ref=sr_1_1?keywords=SVID2USB232&qid=1620094175&s=electronics&sr=1-1
IMPORTANT! - Be sure to ALWAYS load the most up to date video driver for this device (from the StarTech web site)!

* **Keyboard** (optional for use with laptop):
Any decent keyboard should work. Be sure you get the correct plug to connect to your laptop. Typical cost about $12.

* **Mouse** (optional for use with laptop):
Any optical mouse. Be sure you get the correct plug to connect to your laptop. Typical cost under $10.

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In short, if using the RunCam Night Eagle 2 Astro camera, all hardware for properly recording occultations should currently run about $500 to $550. (Not including the computer).

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The Basic idea behind Recording an occultation using the method of “Pre-pointing”

Pre-pointing is a method sometimes used to locate your Target Star – especially when the telescope you're using does not have a drive for tracking the stars. In short, if a fairly bright star exists somewhat nearby, and directly west of your Target Star (i.e., at very close to the same Declination), you can center your undriven scope on this brighter star, and wait the “time difference” in Right Ascension between the brighter star and your Target Star. The Earth's rotation will then bring your Target Star to the center of you camera's field of view right at the time of the predicted occultation.

As an example of Pre-pointing, consider the above image generated with Carte du Ciel. The arrow points to the position of a 13.5 mag star (not shown) which was predicted to be occulted by the 12.2 mag asteroid (20) Massalia on September 25th, 2019 at 23:35:44 UT (+/-2 seconds). The field of view of the telescope's camera is shown as the rectangular box around Massalia (the small circle is 1 degree across). Massalia's changing eastward position is marked every 2 hours, with the right-most tick mark being 0 hr UT on the 26th. Looking directly to the west (right) of Massalia, we find that 4th mag Omicron 2 Scorpi is at nearly the same Declination. Using the Measurement tool in Carte du Ciel, we draw a line from Massalia's position at 0 hr UT to Omicron 2 Scorpi, and the measurement lists a R.A. difference of 11 minutes and 59 seconds (call it an even 12 minutes). (In lieu of a measuring tool you just calculate the difference in R.A. between Massalia and Omicron 2 Scorpi). With the occultation predicted for 23:35:44 UT, subtracting 12:00 from this gives us 23:23:44 UT. So if we have our undriven telescope centered on Omicron 2 Scorpi at 23:23:44 UT, we can simply wait 12:00 and the Earth's rotation will put our Target Star very close to dead center in our telescope's camera field of view AT the predicted time of the occultation. Beforehand we had determined that for our telescope it takes about 2 1/2 minutes for a star to drift fully across our camera's FOV. So we can plan to start our video recording at about 23:34:14 UT - 1:30 before the predicted occultation time of 23:35:44, and we should capture the Target Star drifting completely across the frame of our stationary camera – and possibly capture an occultation as it crosses near the center of the frame.

Some issues with Pre-pointing are; 1) You will need to be at your observing site, and have all equipment set-up that much sooner. 2) You may have to settle for some “less than bright” Pre-point stars – sometimes even your most promising ones may be rather dim. 3) Your skies should be completely clear. If it's partly cloudy, there's the chance your Pre-point star might be behind a cloud at the time you should be centered on it! (Even if it is clear, it would be wise to select a couple other Pre-point stars east of your planned one in the case that you don't get on your primary Pre-point star in time). 4) With a stationary telescope the length of time you can record your Target Star is limited.

The above is a basic example of how Pre-pointing can be done. Although I have never used them, it has been mentioned to me that there are plug-ins for OccultWatcher which can call up the star charting programs C2A or Guide9 and automatically generate a Pre-point line for any OW event listing. Both programs can also generate Pre-point lines as “stand alone” programs – without referencing OW. A nice feature of C2A is a real-time moving “bulls-eye” on the Pre-point line which moves in time with the computer's internal clock. In it's upcoming release (after v4.2) Carte du Ciel will also be able to generate a Pre-point line and will have a “moving” Pre-point field of view feature.

As it can be tricky adding and subtracting time, here's a site on the Internet that can help make your time calculations easy:  
https://www.calculator.net/time-calculator.html
Some Thoughts and Considerations:

= If possible, consider having a computer that is dedicated to nothing but recording occultations. Once you set up a system that is reliable, think twice about applying "updates". Do them only when absolutely necessary. (Win 10 updates have been notorious for wreaking havoc with video drivers).

= In setting up a system, don't dismiss the possibility of first trying an older computer. Even an older "given-away" laptop with an earlier operating system may work just fine. If given an older, unwanted laptop, always ask for the original operating system "reinstall disk". Sometimes a slow, older computer can become quite fast if the drive is wiped clean and the operating system is reinstalled. (The laptop I use with my RunCam runs Windows XP, and the laptop I use for my QHY174M-GPS runs Windows Vista - and both work very well). You also won't feel so much pain if the "free" computer dies in the harsh outdoor conditions we sometimes subject them to. Then again, new computers are fine too!!

= When you first start out (and even for the experienced), it's handy to have a checklist of needed items, especially if you plan to do mobile observing. Avoid the headache of doing a long drive, only to realize you forgot a cable or power supply!

= While watching the computer screen during the actual recording of a possible occultation, it can be nice to have an audio time reference playing in the background. It's difficult to watch both the Target Star and the time display from a VTI simultaneously! Don't use the audio time signal as your actual timing reference (that's what the VTI is for), but just use the audio as a background reference so you can visually monitor the Target Star around the time of the predicted event to see if indeed you may have captured an occultation. If the audio time is from a reliable source, it can also help verify that the time on your VTI is correct. Good audio time reference sources are radio station WWV or a phone call to the US Naval Observatory's Master Clock at 202-762-1401 (their alternate number is 202-762-1069). Note that the USNO may only allow a connection for a minute or so.

= If you DO observe a positive event, it is a good practice to verify that the time displayed by your VTI is accurate while your video recording is still in progress. Simply compare your VTI's time display to a known reliable source – like the US Naval Observatory's Master Clock, mentioned above. [Note that in comparing times, your camera should be operating at a fairly high frame rate – 1/8th sec or faster].

= Always try to use the shortest integration (exposure) time possible which can still record your Target Star well. The goal is to adequately record the Target Star, but still use a short integration time which will yield a higher time resolution. As a guide, you should be able to see your Target Star in EVERY frame of video, prior to the event. If not, consider increasing your exposure time.

= Be careful not to saturate the pixels of your camera by a bright Target Star. This is especially important if the anticipated magnitude drop is small. If you are using IOTA Video Capture as your capture software, it can be set to alert you to saturated pixels. To reduce the chance for saturation, always shorten your integration time first. If your camera has a Gain setting, you can then try to reduce that. Next you can try to de-focus the telescope somewhat (PyMovie will still be able to measure it). If that isn't enough, stop down the telescope's aperture until the target is no longer saturated. Always try to avoid saturated pixels on your Target Star.

= If you are using a camera that can display its menu in your video (like the Night Eagle 2 Astro can), then it can be a good practice to call-up the menu on the video display just prior to starting your recording. This can be handy as you can then log details about your integration setting, gain, possibly the latitude and longitude of your site, among other info. Record this info for a few seconds at the start of your video, then turn off the menu and continue recording your event. Having this info right in your video can come in handy. Recording the latitude and longitude can be handy if you are doing mobile observing. When you do an analysis, you can simply start your analysis after the menu information is gone.
For each observation, you should make a note of your sky conditions, the start and end time of your recorded observation (a VTI may log this), the camera integration setting (other camera settings are helpful to record too – such as gain), the latitude and longitude of your site, the telescope used including any focal reducer, and any other pertinent info.

Be conscious of centering up a field of view that includes not only your Target Star, but a few “Comparison Stars” that are preferably a bit brighter or fainter than your Target Star. They should be somewhat near your Target Star. This is especially important if you have intermittent thin cloud conditions. A thin cloud passing through the FOV can mimic the fade of an occultation. If your Comparison Star exhibits a similar “fade” at nearly the same time as your Target Star, then you might question the validity of an event. Comparison Stars may also allow you to “correct” for thin clouds passing by – by a process called Normalization.

For Northern Hemisphere observers, in the summer (and late spring, early fall), you will need an observing site that has a reasonably clear southern (and to some extent SE and SW) horizon. Many occultations occur in the rich starfields around Sagittarius, and the ecliptic runs low there. So in the summer, the less obstructions around your southern horizon, the better.

Consider giving yourself the ability to “go mobile” - that is, to have a transportable occultation rig. You can greatly increase your chances to catch positive events, and you can avoid the frustration of having that “top rated event of the year” fall right BEHIND that lone tall pine as seen from the permanent pier in your yard. Some observers travel hundreds of miles (or more!) to place themselves nicely in the predicted path, greatly increasing the chance of recording a positive event.

Some observers recommend that when possible, it's good to avoid using any power supply that converts 120VAC to 12VDC as it may impart noise in the video and lower the signal to noise ratio. They recommend using pure DC power from batteries.

Be careful of repeated flexing of wires – especially in very cold conditions. If you can, strain-relief cables as best you can. This especially applies to wires coming off cameras (and power supplies).

A note to die-hard, deep-sky astro-imagers... Occultation observing can be a productive project for nights rather unsuitable for taking top notch images, such as during a bright Moon, during rather poor seeing, or under rather hazy, or somewhat light polluted skies. Why not do BOTH?

When possible, a lot more can be accomplished if you consider making teamwork a part of your observing plan. Join in when you see others signed up for an event on OccultWatcher. Ideally if you can find others in your area, you can all observe the same event, and if it's clear for you, it may be clear for all – so it's possible that multiple chords can be obtained.

Hope this helps. Clear Skies and Happy Shadows,

George Viscome / Lake Placid, NY, USA / georvisc@yahoo.com

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