

International Occultation Timing Association



Occultations

Chasing Shadows



Tom Heisey
Solar System Ambassador
April 15, 2021

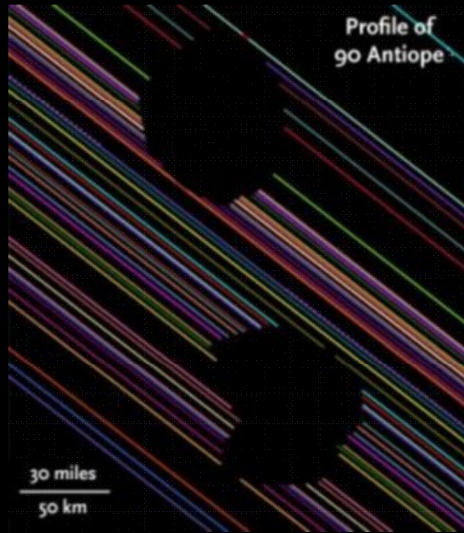
Images from IOTA web sites and materials unless otherwise noted

International Occultation Timing Association (IOTA)

- www.occultations.org
- Scientists from John's Hopkins do the calculations and data consolidation
- Amateur astronomers from around the world collect the data.
- It's a chance to do real citizen science.

Occultation? What's That?

- Mini-eclipses
- A body passing in front of a star
 - Asteroids (primary)
 - Earth's moon
 - Moons/planets
 - Kyper Belt objects
- Moon/planet passing in front of Moon/Planet



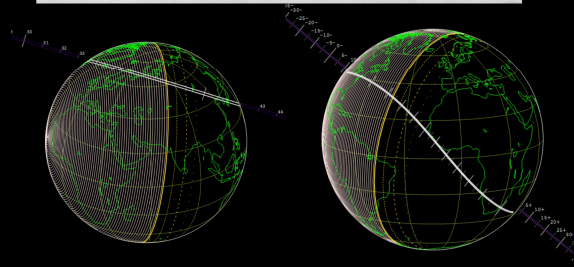
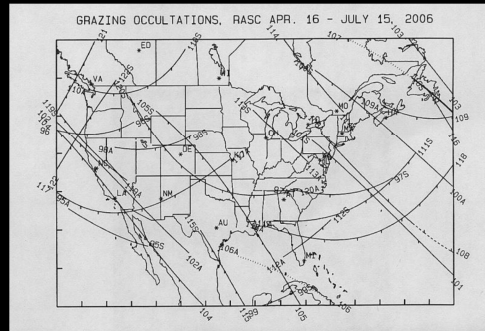
Occultation is just a fancy name for an eclipse of a distant star. The usual eclipsing body is an asteroid, but the Earth's moon, one of the Sun's other planets or their moons, or even a Kyper Belt object are predicted. We also observe eclipsing moons around other planets and shadow transits. I'll mainly talk about asteroid occultations, but the basic physics and procedures apply to the others, with some minor changes.

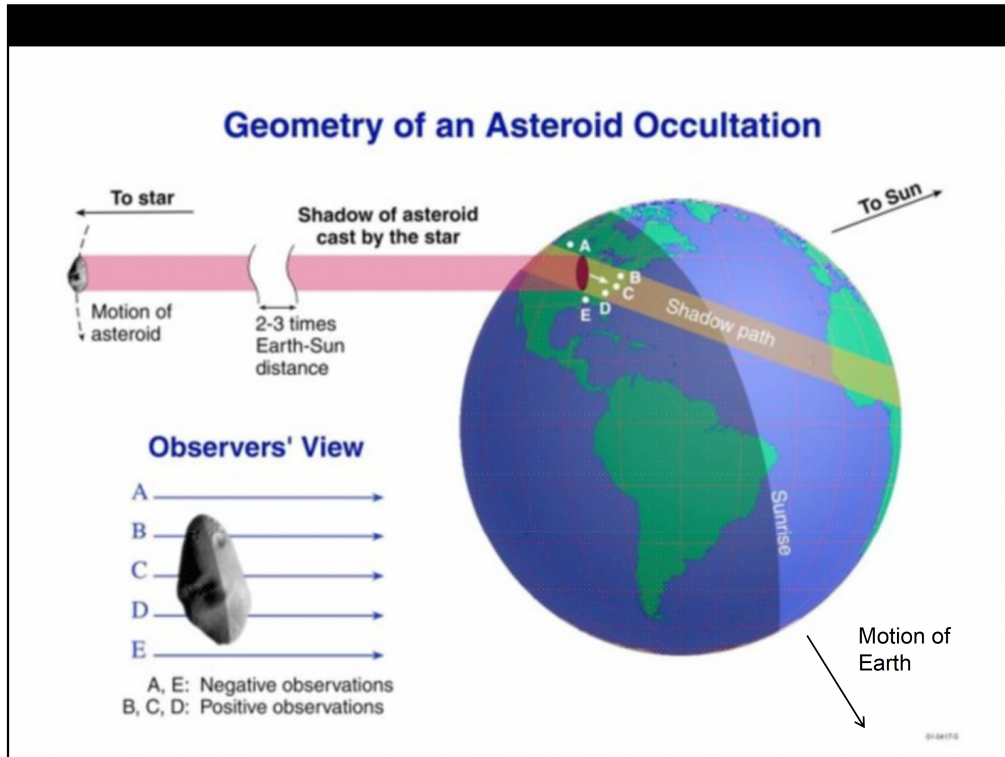


Occultation by asteroid 334 Chicago Dec 24, 2002

Why Do We Need Amateurs?

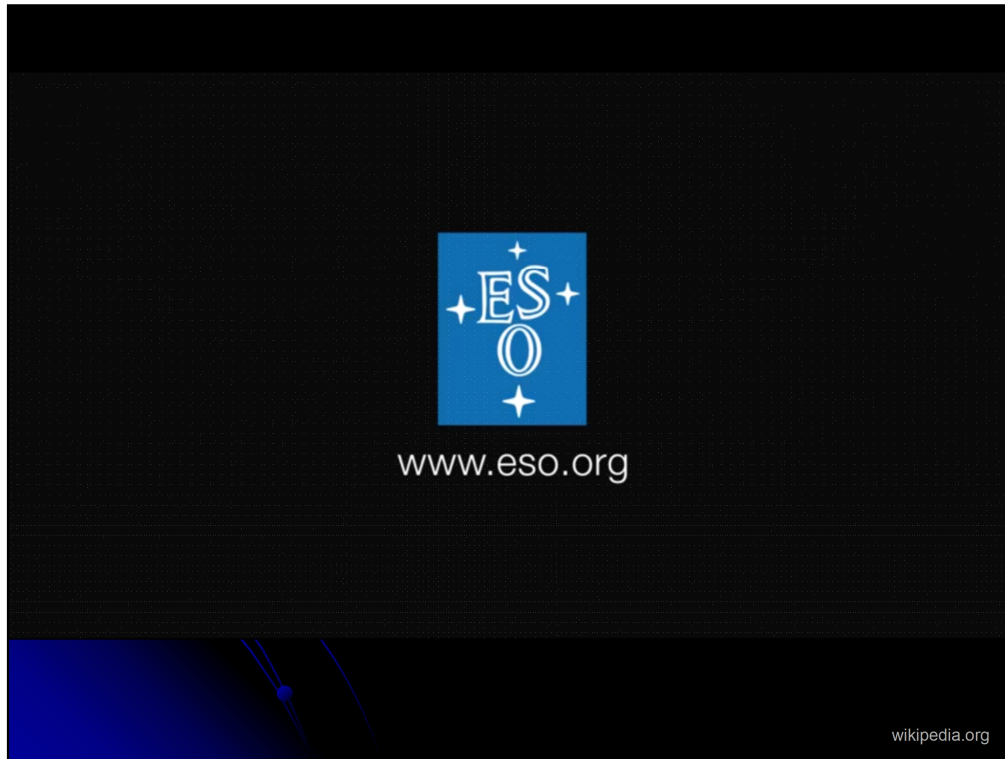
- Random paths
- Scientists lack equipment
- Professional observatories do other work





An occultation only occurs when an asteroid that's barely visible as a disk passes in front of a star that is a point light source. Given the number of stars visible to a 10" or larger scopes, this occurs several times a night somewhere on the Earth. Smaller scopes see fewer occultations.

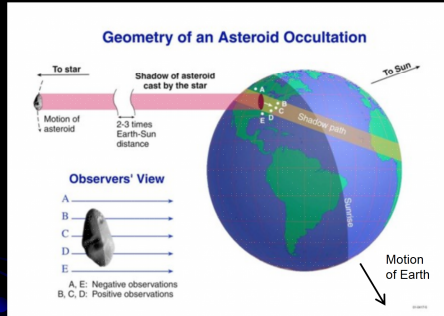
Stunning fact - The light rays from the star are essentially parallel, so the shadow is the size of the asteroid disk.



ESO campaign across South America in 2011 for the dwarf planet Makemake. Observers were at the highlighted locations.

<https://en.wikipedia.org/wiki/Occultation>

Insane Math of Prediction



- Location/Size/Motion:
 - Stars are often well known
 - Asteroids vary wildly
- Earth rotation & asteroid motion cause the shadow path

- Star - point light source
 - 10s or 100s of light years
 - Effectively motionless
- Asteroid - dot/disk
 - light min or hours away
 - Slow motion & rotation
- Earth
 - med. motion and rotation
 - Shadow = asteroid size

Predicting that shadow path involves accounting for the motion of the star (very slow), asteroid (slow), and Earth (medium), plus the spin of the Earth, motion of the solar system, and even the small motion of the galaxy rotation. The precision required is astounding, since misplacing the star or asteroid by even a small fraction of a degree will mean the shadow misses the Earth or is off in time.

Predictions & Campaigns

- IOTA web site
 - www.occultations.org (major campaigns)
 - www.asteroidoccultation.com (general)
- Occult Watcher software
 - (personalized, coordinates 1 event)
- IOTA Mailing List (campaign coordination)

IOTA General Predictions

- World Wide
- Requires manual searching for nearby occultations
- Lots of data available
- Excellent finder charts

Asteroid Occultation Updates
[HELP/FAQ](#)
[Observations/Reservations](#)
[All Events](#)
 Updated: 2021 Apr 09, 03:43 UT

Upcoming Events:

April 2021

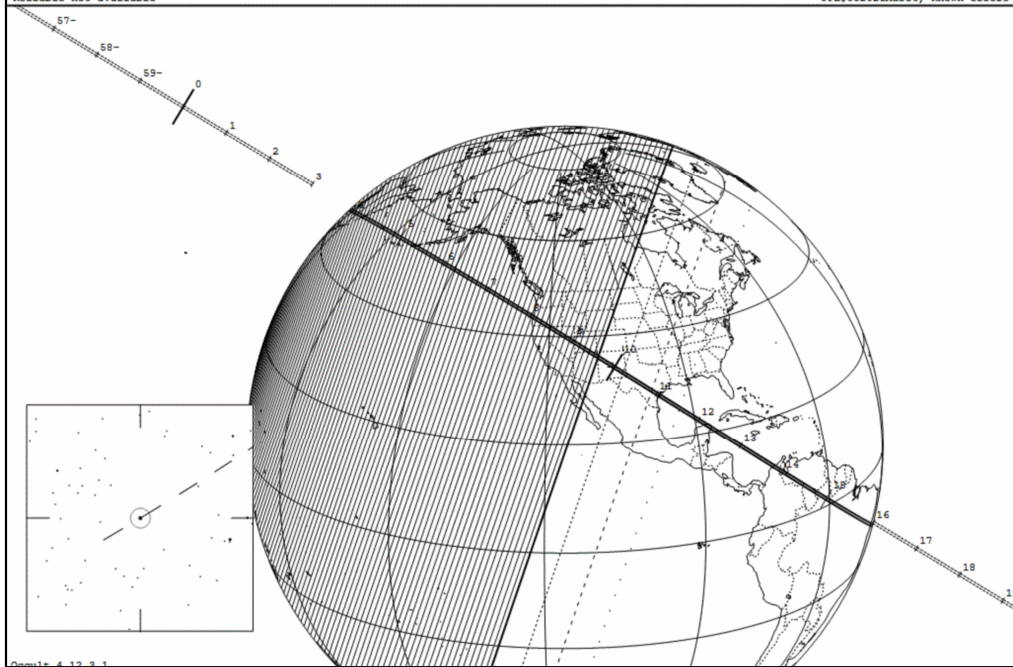
Event Date/Time	Mag	Asteroid	Star	Visibility	Mag. B.A.	Details
09 Apr 23:37:17	10.0	134666 Andra mag 13.9	ICAC 4 94-01123 mag 12.4	Japan, China	3.8m 7.65 51°	March 17, 20:30
09 Apr 14:07:07	09.9	134666 Andra mag 14.5	ICAC 4 94-03646 mag 12.4	Japan, China	4.3m 2.86 62°	March 17, 20:30
09 Apr 18:05:07	10.0	134666 Andra mag 13.4	ICAC 4 90-11479 mag 12.1	Japan	3.6m 11.88 36°	March 17, 20:30
09 Apr 18:10:17	09.9	134666 Andra mag 13.7	ICAC 4 94-22607 mag 11.6	Taiwan, China	6.1m 7.38 56°	March 17, 20:30
09 Apr 21:02:07	10.0	134666 Andra mag 14.3	ICAC 4 112-02255 mag 11.6	Europe	2.4m 5.38 52°	March 17, 20:30
10 Apr 00:44:07	10.0	134666 Andra mag 13.7	ICAC 4 47-07948 mag 12.4	EU, USA	0.5m 8.14 83°	March 17, 20:30
10 Apr 02:18:07	10.0	134666 Andra mag 13.1	ICAC 4 43-10380 mag 11.6	Russia, Europe	0.3m 10.14 27°	March 17, 20:30
10 Apr 04:32:07	10.0	134666 Andra mag 13.1	ICAC 4 139-11392 mag 11.6	Africa, South America	0.7m 11.24 89°	March 17, 20:30
10 Apr 08:14:07	08.8	134666 Andra mag 13.2	PR 4479 mag 11.5	USA, W. Canada	11.7m 1.06 52°	March 17, 20:30
10 Apr 13:20:07	10.0	134666 Andra mag 14.3	PR 46031881 mag 11.1	New Zealand, Australia	4.2m 4.38 52°	March 17, 20:30
10 Apr 16:30:07	10.0	134666 Andra mag 13.5	PR 4604 mag 9.9	Taiwan, China, India, Africa	3.8m 16.66 84°	March 17, 20:30
10 Apr 17:02:07	10.0	134666 Andra mag 11.0	ICAC 4 94-11384 mag 11.6	Japan	0.5m 18.36 62°	March 17, 20:30
10 Apr 21:09:07	10.0	134666 Andra mag 14.2	ICAC 4 11-00391 mag 11.1	Russia	2.1m 12.26 32°	March 17, 20:30
10 Apr 22:36:07	09.1	134666 Andra mag 13.4	PR 4272-00793 mag 7.7	SE Asia	7.9m 17.66 75°	March 17, 20:30
11 Apr 01:00:07	10.0	134666 Andra mag 14.6	ICAC 4 173-02580 mag 12.1	SE USA	2.6m 1.96 82°	April 02, 04:48
11 Apr 05:00:07	10.0	134666 Andra mag 13.5	ICAC 4 11-03889 mag 14.2	SW USA	3.6m 0.96 63°	April 02, 04:48
11 Apr 20:30:07	10.0	134666 Andra mag 13.5	ICAC 4 99-21816 mag 10.8	China, E Russia	4.8m 5.88 56°	March 17, 20:30
11 Apr 20:50:07	07.1	134666 Andra mag 11.5	PR 4606-00361 mag 11.0	Russia, Europe, Africa	5.5m 6.88 57°	March 17, 20:30
11 Apr 23:07:07	07.6	134666 Andra mag 11.7	ICAC 4 113-07646 mag 11.1	Russia, SW Asia, Africa	3.6m 14.06 58°	March 17, 20:30
12 Apr 07:10:07	09.2	134666 Andra mag 11.8	PR 4604-00061 mag 11.1	USA, Mexico	5.7m 1.74 49°	March 17, 20:30
12 Apr 07:35:07	09.9	134666 Andra mag 11.8	ICAC 4 99-14423 mag 11.4	Central America	4.4m 10.38 39°	March 17, 20:30
12 Apr 10:09:07	10.0	134666 Andra mag 14.1	ICAC 4 43-02304 mag 11.6	USA	2.5m 14.46 25°	March 17, 20:30

1961 Dufour occults HIP 47104 on 2021 May 10 from 2h 4m to 2h 16m UT

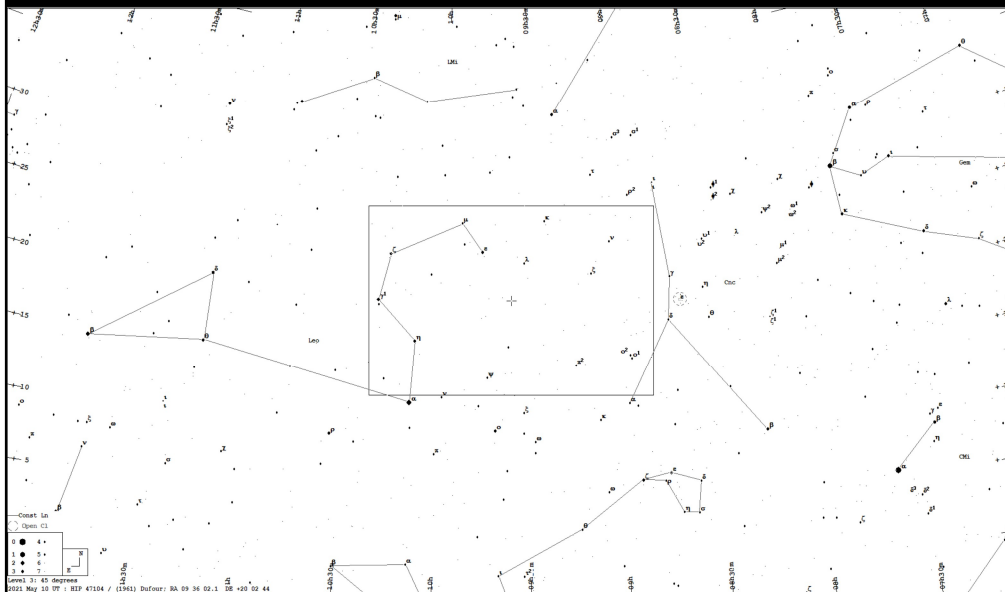
Star: Dia < 0.1 mas
 Mr 6.7
 RA = 9 36 2.1412 (astrometric)
 Dec = 20 2 44.243
 [of Date: 9 37 13, 19 57 6]
 Prediction of 2021 Mar 17.0
 Reliable not available

Max Duration = 3.0 secs
 Mag Drop = 3.8 (0.0r)
 Sun : Dist = 90°
 Moon: Dist = 109°
 Illum = 3 %
 E 0.009"x 0.001" in PA 110

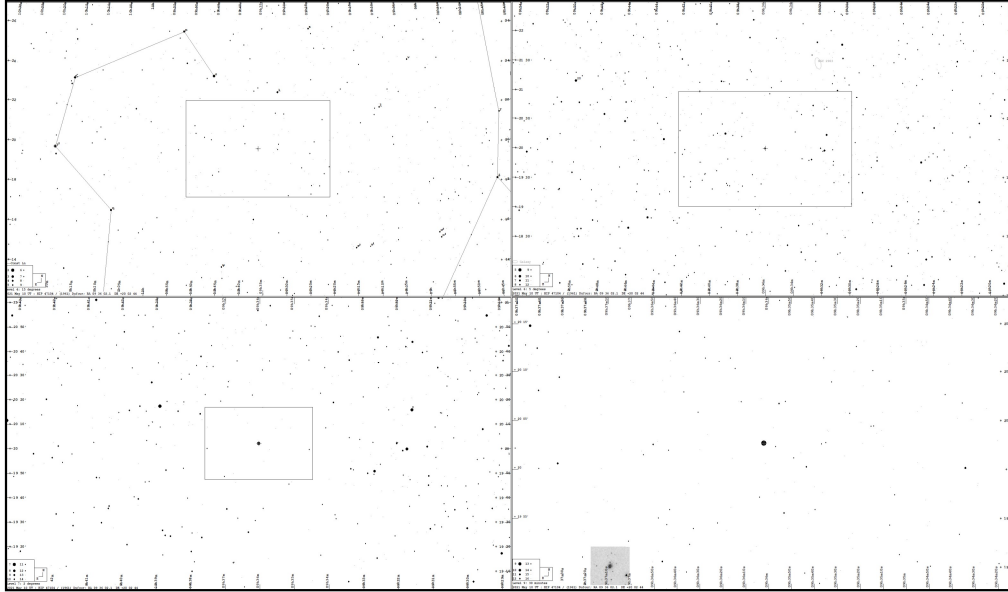
Asteroid: (in DAMIT)
 Mag = 16.5
 Dia = 50 ±3km, 0.02"
 Parallax = 3.083"
 Hourly dRA = 1.779s
 dDec = -15.11"
 JPL4532021Mar16, Known errors



Wide Angle Finder



Finder Charts (IOTA site)



Occult Watcher Software

Occult Watcher, ver. 4.7.0.1 - Horizon West (UTC -05:00 DST)

Synchronise now Configuration Add-ins Help

Event	Date, loc.time	Asteroid Name	Rank	Prob...	Travel Dist.	Star Mag...	Magn Dro...	Star Altitude	Star	Max Duration	Sun ...	Moo...
My Events	Sun 09 May, 21:10	(1961) Dufour	100	0.0%	105 mi @210°	6.7	9.8	72° 8226°	HIP 47104	3.0	-7°...	-25°
All Events	Tue 27 Apr, 08:44	A/2019 O2	0	0.0%	6787 mi (fp)	12.1	12.6	63° 8357°	TYC 4201-01486-1	0.4	-17°...	21°
	Mon 19 Apr, 04:20	A/2019 T1	0	0.0%	3960 mi (fp)	12.1	10.3	65° 864°	UCAC4 681-060421	0.3	-33°...	-17°
	Sat 24 Apr, 23:22	A/2019 U6	0	0.0%	71 mi @313°	12.5	10.0	16° 844°	UCAC4 687-062593	0.3	-32°...	56°
	Fri 14 May, 22:04	(677) Aalste	100	0.0%	42 mi @157°	11.7	3.5	44° 8248°	UCAC4 498-063759	1.5	-16°...	17°
	Wed 19 May, 04:30	(2697) Albina	100	96.5%	12 mi @175°	13.9	2.4	26° 8203°	UCAC4 329-086150	4.1	-24°...	-19°
	Tue 13 Apr, 00:50	(1647) Aliokovki	98	0.0%	148 mi @210°	13.8	1.4	65° 8278°	UCAC4 610-046811	7.9	-45°...	-35°
	Sun 23 May, 03:10	(5070) Arai	100	0.3%	51 mi @354°	13.4	3.1	24° 8176°	UCAC4 291-134616	2.8	-32°...	21°
	Wed 05 May, 02:43	(734) Benda	94	0.0%	143 mi @185°	13.3	2.2	26° 8250°	UCAC4 449-062102	14.5	-30°...	-17°
	Tue 20 Apr, 03:42	(776) Berbericia	100	23.6%	72 mi @4°	13.5	0.4	46° 8170°	UCAC4 403-064955	14.7	-37°...	-4°
	Sat 17 Apr, 00:00	(4837) Bickerton	83	0.0%	61 mi @113°	13.2	4.7	49° 8247°	UCAC4 509-048436	4.6	-35°...	5°
	Fri 14 May, 00:41	(606) Brangane	100	0.0%	75 mi @50°	12.0	3.5	35° 8217°	TYC 5532-00585-1	4.8	-36°...	-15°
	Tue 25 May, 05:08	(253) Brasilia	100	0.0%	134 mi @303°	11.9	3.0	22° 8156°	UCAC4 208-186166	5.2	-17°...	11°
	Mon 26 Apr, 22:11	C/2020 N1 (...)	0	0.1%	2101 mi (fp)	10.6	4.6	27° 8255°	UCAC4 469-020102	0.3	-20°...	21°
	Sat 24 Apr, 04:31	C/2020 O2 (...)	0	0.0%	3972 mi (fp)	12.3	5.8	26° 8169°	UCAC4 301-135891	0.6	-30°...	17°
	Sat 17 Apr, 03:54	C/2020 R4 (...)	1	0.4%	64 mi @14°	12.1	1.4	57° 8110°	TYC 1857-00276-1	0.2	-37°...	-26°
	Tue 13 Apr, 21:37	C/2020 T4 (...)	0	0.0%	4054 mi (fp)	12.6	6.6	12° 8320°	UCAC4 691-011194	0.3	-16°...	4°
	Mon 19 Apr, 06:21	(671) Carnegie	100	0.0%	158 mi @265°	12.5	3.5	23° 8183°	UCAC4 286-155987	13.3	-11°...	-25°
	Tue 04 May, 05:57	(2363) Cebriones	76	0.4%	134 mi @86°	12.2	4.3	67° 8171°	UCAC4 505-103208	5.4	-12°...	24°
	Fri 30 Apr, 01:18	(365) Corduba	100	94.6%	34 mi @226°	11.9	2.8	10° 8105°	UCAC4 414-099455	13.7	-41°...	13°
	Sat 22 May, 22:04	(403) Cyane	100	0.0%	133 mi @156°	13.8	1.0	27° 8269°	UCAC4 517-044650	1.4	-15°...	53°
	Fri 04 Jun, 02:37	(7816) Dolon	96	0.0%	144 mi @183°	12.5	5.2	55° 8216°	UCAC4 469-053904	2.6	-33°...	-12°
	Mon 03 May, 03:05	(1254) Eriofidia	100	0.0%	129 mi @203°	14.4	1.2	20° 8183°	UCAC4 312-075049	4.1	-37°...	2°
	Sat 22 May, 03:27	(1430) Eschscholtz	92	11.6%	67 mi @102°	12.9	9.0	31° 8193°	UCAC4 316-092021	1.9	-31°...	11°

(OTA Updates)

you center shadow 1-sigma 2 & 3-sigma limits

(1961) Dufour occults HIP 47104 Event time: 21:10:17 Combined magnitude: 6.7 m Constellation: Leo

Position: 85 mi outside the 1-sigma zone Error in time: 1 sec Star magnitude: 6.7 m Star altitude: 72° 8226° Moon: (below horizon)

Max duration: 3.0 sec Magnitude drop: 9.8 m Sun altitude: -7° 8296°

There are currently 2 announced stations for this event. 1 of them is yours.

Show online map with stations View details on the web Save Google Earth kmz file View station sorts

Last updated on 2021-04-14 20:50:28 There is a new version of OccultWatcher available!

- 1 General info lines
- 2 Details for selected event:
 - 3 Zone map
 - 4 Links to additional info

The screenshot shows a data table with columns: Date, Loc, Time, Accession Name, Band, Biom., Events, Start, Year Rep., Mass Det., Near, Distance, and Size. A row for '2016 May 18 12:00' is highlighted in red. Annotations are as follows:

- 1**: Points to the 'Accession Name' column.
- 2**: Points to the 'Events' column.
- 3**: Points to the 'Near' column.
- 4**: Points to the 'Distance' column.

General Info Lines

- **Event**
 - Date/Time
 - **Rank**
 - **Probability**
 - **Magnitude Drop**
 - Travel distance*
 - **Duration**
 - Shadow Width
 - Update
 - Data Source
 - Sun/Moon altitude
- **Star**
 - Name
 - **Magnitude**
 - Altitude during event
- **Asteroid**
 - Name
 - Magnitude

Dark Blue highlights are the most important factors on filter events:

- * Rank - likelihood of success (
- * Magnitude drop - A video system will capture a change of 0.1 Magnitude, but greater drops are much easier to record
- * Duration - short duration events are easy to miss, very long duration events are boring
- * Star Magnitude - Stars closer to the limit of your system are harder to record.

Light blue highlights are secondary factors

- * Travel distance - personal choice, but I don't chase distant, low rank events
This can be deceiving depending on the shadow width, so an event with a large object that lists a long distance could be recorded from your back yard.
- * Shadow Width - size of asteroid. Narrow paths with low probability mean a likely miss, but that is data, too.
- * Sun/Moon altitude - If the Sun or Moon is lighting the sky, then the event will be difficult

**RANK: Rank equals the probability of at least one successful observation by a team of two observers where the two observers are positioned 3/4 path width apart symmetrically about the center of the path. This probability is a function of the size of the asteroid in the sky (in arc seconds), the uncertainty in the position of the asteroid, and the uncertainty in the position of the star. Note that due to rounding the event rank can be 100% but in reality there is

Details Pane

(1961) Dufour occults HIP 47104

Event time: 21:10:17 Constellation: Leo

Position: 85 mi outside the 1-sigma zone Error in time: 1 sec

5 There are currently 2 announced stations for this event. Max duration: 3.0 sec 4 Star altitude: 72° 8226°
1 of them is yours. Magnitude drop: 9.8 m Sun altitude: -7° 8296°

Combined magnitude: 6.7 m Moon: (below horizon)

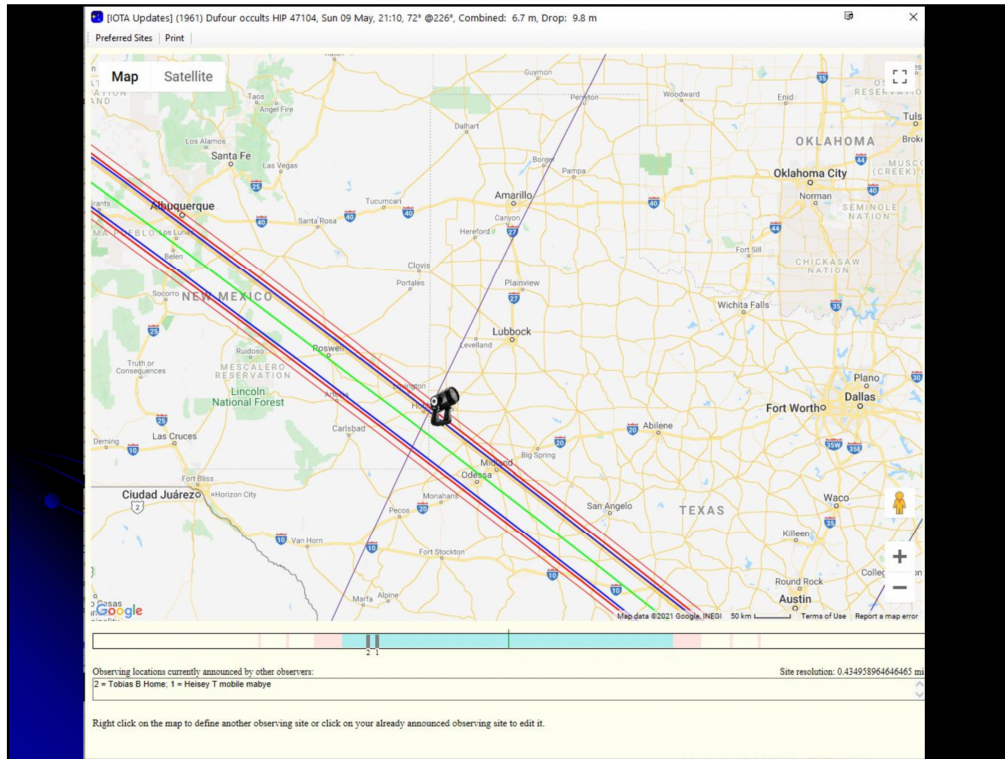
Star magnitude: 6.7 m

6 [Show online map with stations](#) [View details on the web](#) [Save 'Google Earth' kml file](#) [View station sorts](#)

- Zone map showing:
 - Center & sigma lines
 - Shadow width
 - 1 Other observer chords
 - 2 My location & 3 station
- 4 General info repeated
- 5 Notes on stations
- 6 Links to details pages

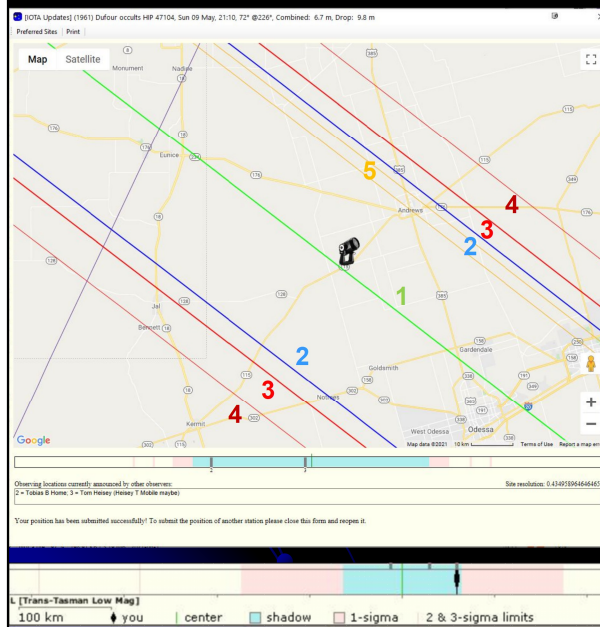
The details page helps me decide if I'm interested in the event. The Zone Map is especially helpful as it gives a good look at the distances and participation in the event. The info is compact enough that you can see at a glance if it's one you'd like shoot.

Note that Right and Left can be confusing because it's based on the shadow movement. In this case, I'm planning to set up just north of the centerline, which is Left in this case. Next event could have left in any direction.



If you double-click the line or the link at bottom, you get the map page. Now you can get down to planning the capture. Here is the first wide view centered on Lubbock. This shows my planned station at the base of the telescope. If I haven't marked a location, then it would just show the path lines.

Path Boundaries



- 1) Path Center
- 2) Shadow Edge
- 3) 1 Sigma
- 4) 2 & 3 Sigma
- 5) Observer

The center line and shadow edges are marked, but may not be accurate if the star or asteroid positions, motions, and sizes are not well known. The thing to remember is that a miss is data, since that's where the asteroid cannot be, so it helps define orbital and size limits.

The sigma lines are an indication of uncertainty. This event is well defined, so the 1 sigma line is close to the edge. New asteroids that have not been well-measured could have huge 1 Sigma zones. See the bottom zone map.

Data Collection

- Video & GPS
 - 50-500mm Telescope
 - Video Overlay w/GPS
 - A-D Video converter
 - Laptop or camcorder
- Manual
 - Telescope
 - Shortwave radio
 - Voice recorder



Scotty's mighty Mini

Today, most recording is done with an 8-12" telescope and a laptop. Some of us still have working digital tape camcorders that include an analog input to do the conversion. This makes for less equipment and easier setup in the field. A new revolution using Scotty's Mighty Mini, which is a modified 50mm binocular objective, allows some members to post up to 6 observations at once, 1-2 KM apart. With the wide view and a star chart with time hashes, you pre-point the scope at the location the event will occur, then move on to the next station. Scotty and others contact land owners to arrange secure locations, though they sometimes just leave a sign on it saying it's doing data collection and asking folks to not mess with it. No thefts so far.

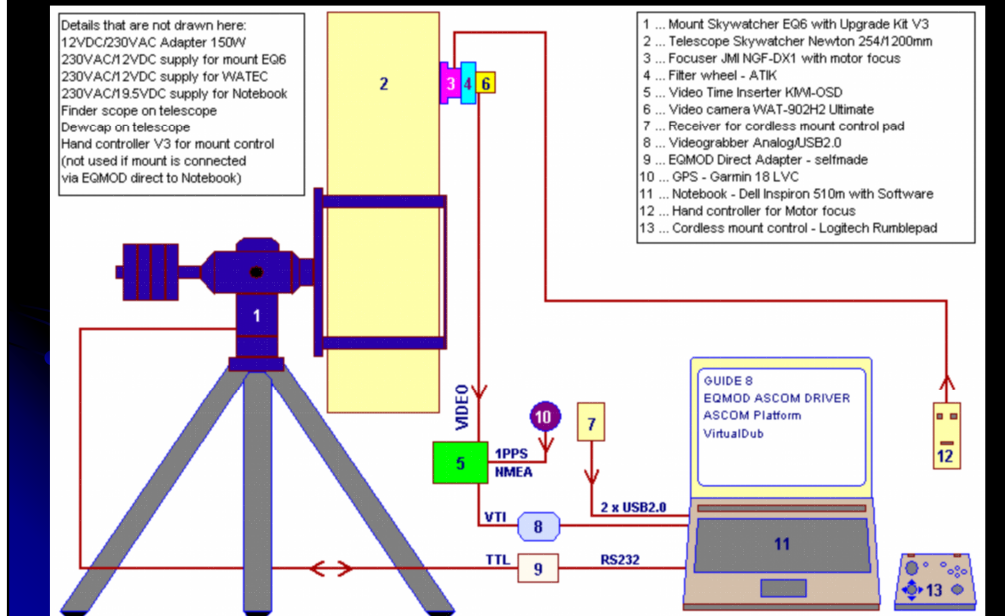
A Common Setup

- Scotty's old system
- 6" telescope tracking
- portable cases
- refreshments
- Chair



Here's Scotty's other system, closer to what I've used. Lots of equipment and time to set up.

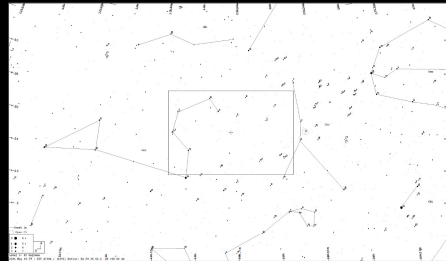
Block Diagram



From http://www.dangl.at/2008/occult_m/gr081021/gr081021e.htm

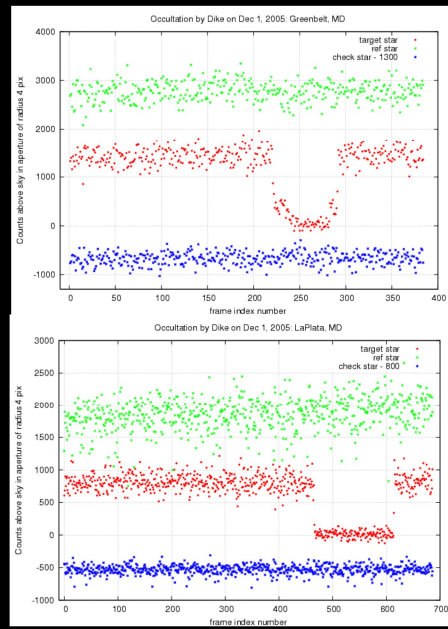
Limiting Magnitude

- We use highly sensitive cameras to increase capture
- Rough Limiting Mag:
 - 50mm - Mag 9 event
 - ST80 - Mag 10.5
 - 8" - Mag 12-13



Data Reduction

- Digital video sampled with software
- Brightness of target star on each frame converted to numeric values (CSV)
- Excel converts to a graph



Once the event is recorded digitally, we use software to give light values for the star. During the event, the star will usually dim unless the asteroid is bright. The software can detect faint changes, allowing us to do star-asteroid combinations that are nearly equal.

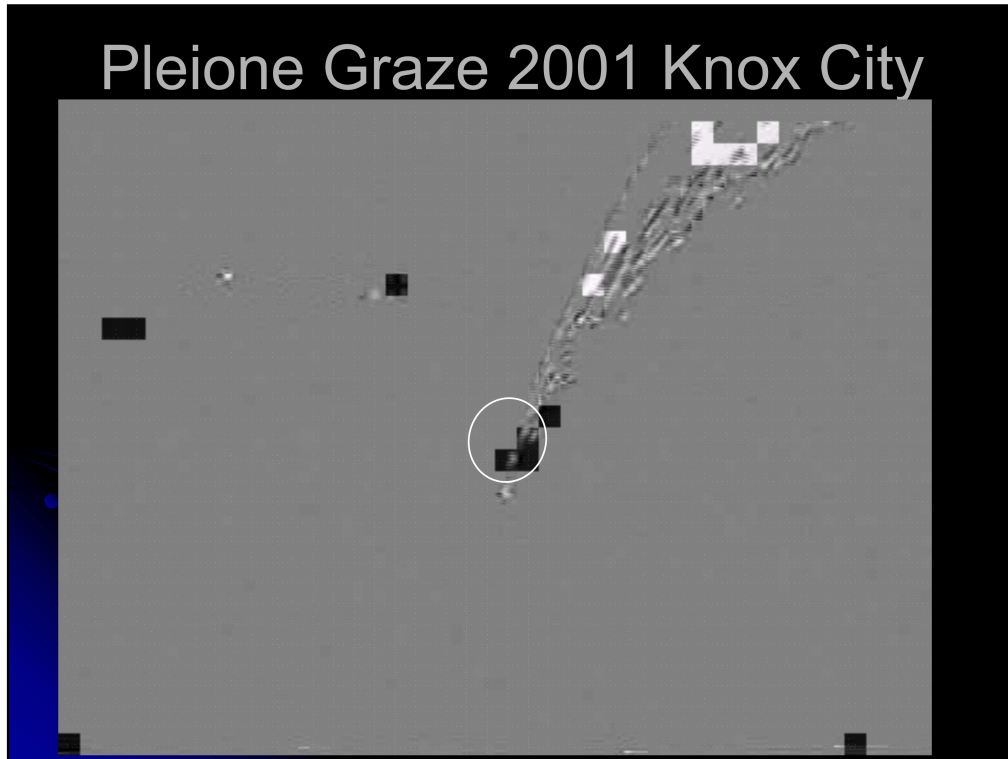
- * A companion star will show two steps down and up as the pair of stars is split.
- * A split companion moon will show a second, smaller dip.
- * An atmosphere will show a gradual dimming similar to the top graph.
- * You monitor the brightness of nearby stars to ensure atmospherics don't affect the measurement.
- * Measurement for each dot is at 1/30th a second

Data Isn't Always Pretty



<http://www.dangl.at/eurast.htm>

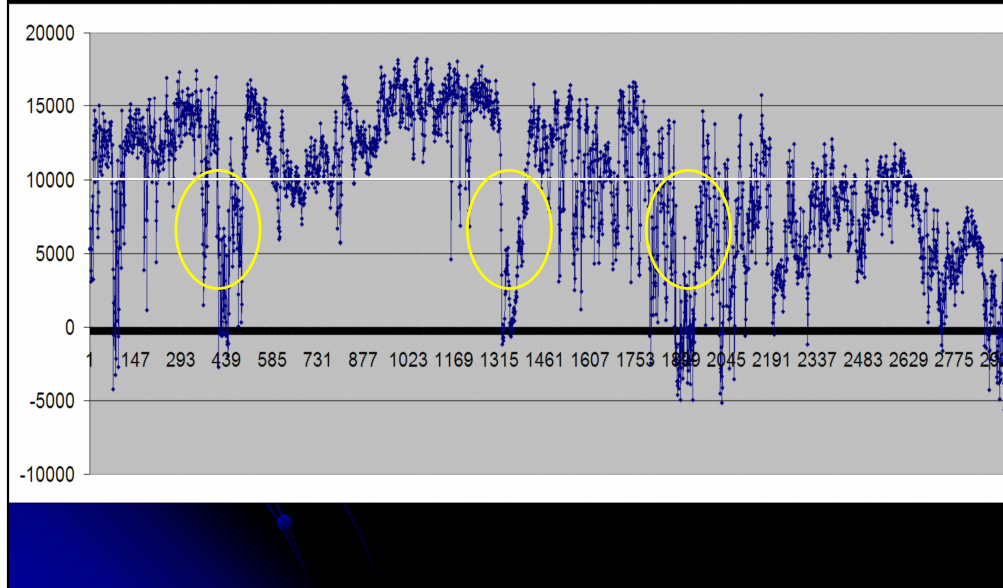
Low magnitude drop combined with atmospheric make for a “dirty” graph.



My capture of Pleione Graze 06/04/2001 just before a thunderstorm hit. (The telescope is shaking from the wind.) Most of my moon grazes were visual with audio recordings and this was my only “good” graze video.

The shadow path is only as tall as the mountains and valleys, usually less than 2km wide and 5-20km long. Grazes can only occur at the lunar poles, as the Moon slides by in front of the star.

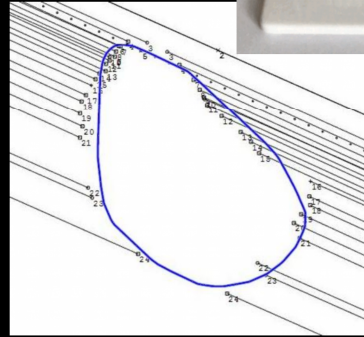
Ugly But Usable Data



Even with all the shaking, the software was able to generate usable data. My path came about the area of the white line. The yellow circles are the 3 definite valleys I spotted. On the right, the star went below the horizon and my camera started picking up the shadowed limb of the moon.

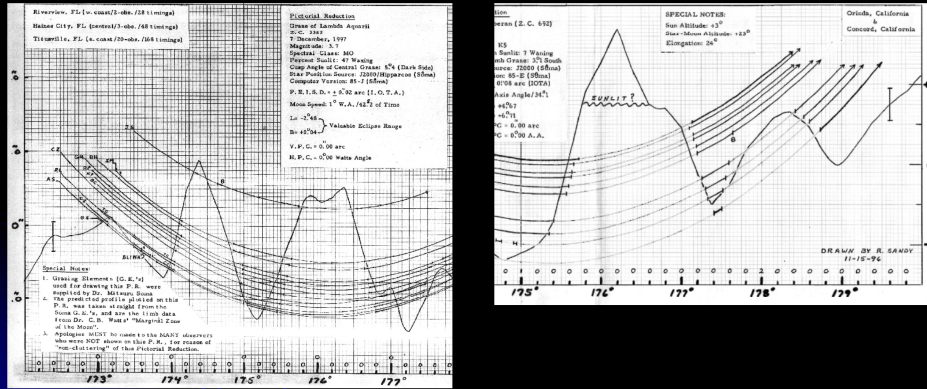
Slicing The Egg

- JHUAPL Scientists normalize data
- Correct timing to a central time
- Each observation is set on the chord
- Stack the egg!



Scientists combined and normalized the observations so that it appears they were all in a line. Each slice is then layered along the proper “Chord” and stacked with the others. Think of restacking a sliced egg. It reveals the shape, and so much more.

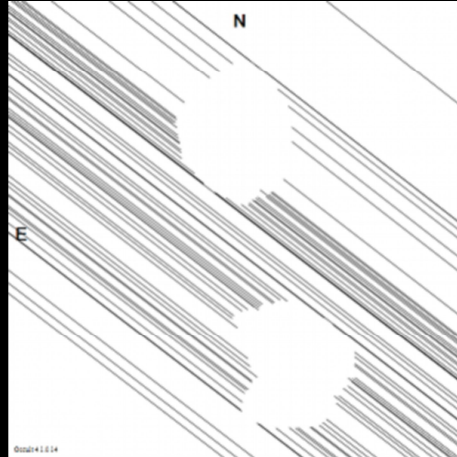
Lunar Occultations (Polar)



Now that we have probes doing RADAR and photographic measurements of the Moon's terrain, we don't do lunar occultations other than as exercises. However, there is nothing like watching a star wink on and off as the Moon glides by. It's really something to watch!

What Can The Data Tell Us?

- Size, shape, & rotation of asteroid
- Refine size, location, brightness of companion star
- Ephemeris data for star/asteroid

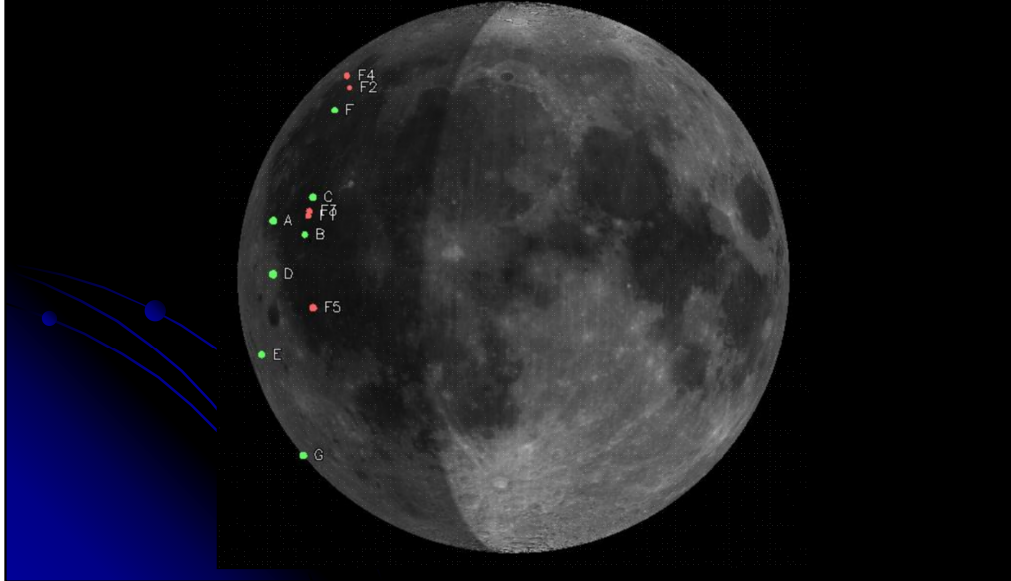


Once the data from several sites is consolidated, you know quite a bit about both objects. Precision comes from using GPS timing down to a video frame 1/30th of a second combined with the point light source of the star. Some of the data:

- * Asteroid precise size, shape, time, orbit, and even rotation (multiple observations)
- * Split a double star that can't be split by optical telescopes, giving information on distance and angle
- * Nearby large stars can show size and atmosphere
- * Atmosphere of Moons and KBOs

1999 Leonids Lunar Impacts

recorded Nov. 18 with 5" telescope at Mt. Airy, MD



Another data some IOTA members collect is meteoric impacts with the Moon. Our cameras are sensitive enough to pick up the flash of impact, though it takes quite a while to sort through the long movies frame by frame.

Leonid Lunar Impact

Recorded 2001 Nov. 18, 23:19:15 UT, Laurel, MD
confirmed by Tony Cook at Arlington, VA
and Roger Venable, Augusta, GA



Sample meteor impacting the Moon. Of course, we can only capture impacts on the shadowed portion of the Moon. The bright area in the corner is still well away from the terminator, thanks to the light gathering capability of the camera.

Links

- IOTA: www.occultations.org
- Predictions: www.asteroidoccultation.com
- John Hopkins Applied Physics Lab:
iota.jhuapl.edu
- Mighty Mini how to: scottysmightymini.com
- North America Asteroidal Occultation Program:
www.asteroidoccultation.com/observations/NA/

Dufour Event Links 5/9/21

- Main page, with links to the others:
www.asteroidoccultation.com/2021_05/0510_1961_69794.htm
- Path/Timing Summary:
www.asteroidoccultation.com/2021_05/0510_1961_69794_Summary.txt
- Overview Map:
www.asteroidoccultation.com/2021_05/0510_1961_69794_Map.gif

