NEA AND OTHER OCCULTATION RESULTS FROM RECORDINGS BY IOTA OBSERVERS

For the ChesMont Astronomical Society by zoom, July 9, 2023 updated July 10; adopted from presentations given at the

14th Asteroids Comets Meteors Conference – ACM 2023

2023 June 23, Flagstaff, Arizona and

online at the 2021 and 2023 Planetary Defense Conferences

David W. Dunham[1], **Fumi Yoshida[2,4]**, T. Hayamizu[3], T. Arai[4], Hiroyki Watanabe[5], Hayato Watanabe[5], J. Dunham[1], R. Venable[6], S. Chesley[7], J. Irwin[8], D. Herald[9], R. Nolthenius[10], N. Carlson[11], K. Getrost[12], S. Messner[13], R. Jones[14], R. Anderson[15], T. Blank[16], P. Maley[17], and S. Preston[18]

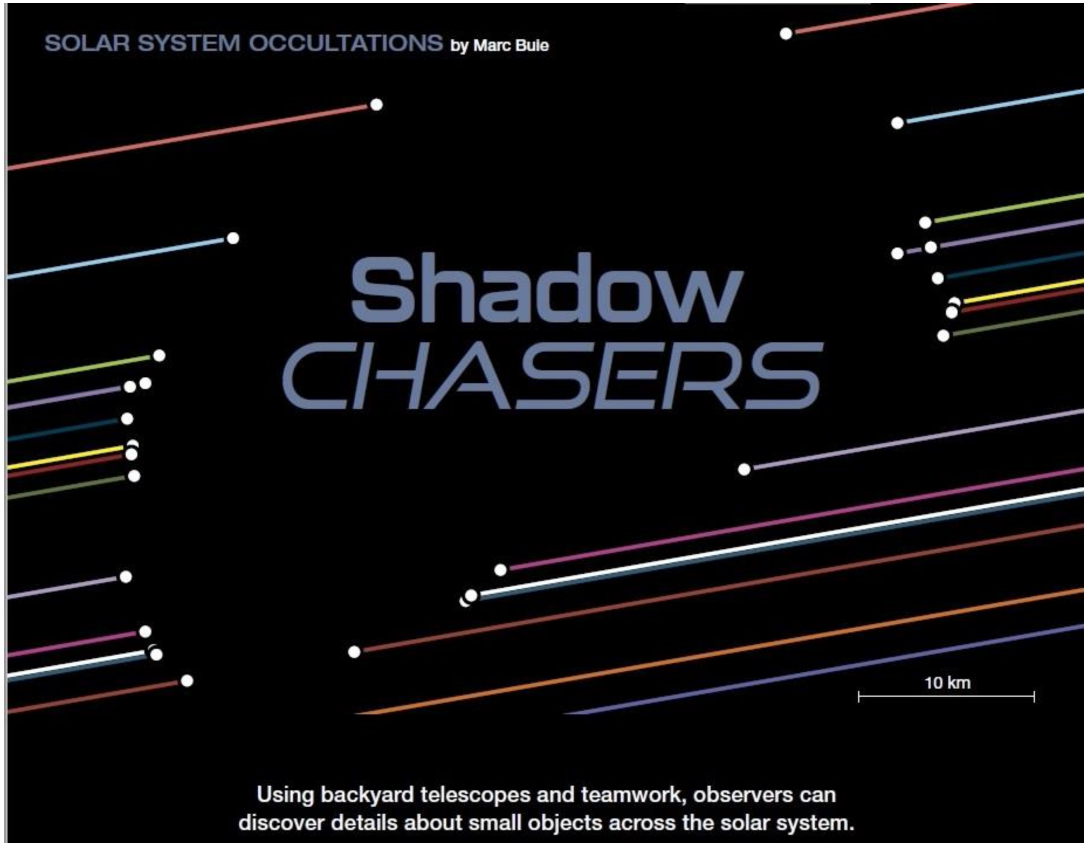
[1]International Occultation Timing Assoc. (IOTA), 16348 E Glenbrook Blvd, Fountain Hills, AZ 85268, USA, **dunham@starpower.net**, [2]S School of Medicine, Univ. of Occupational and Environmental Health, Yahata, Kitakyusyu, Japan, [3]Saga Hoshizora Astronomy Center, Nishiyoka, Saga, Japan, [4]Planetary Exploration Research Center (PERC), Chiba Inst. of Tech., Japan, [5]Japan Occultation Information Network (JOIN), [6]IOTA, Chester, GA, USA, [7]Jet Propulsion Lab., Pasadena, CA, USA, [8]IOTA, Bramley, Guilford, UK, [9]Trans Tasman Occultation Alliance, Murrumbateman, NSW, Australia, [10]Cabrillo College & IOTA, Aptos, CA, USA, [11]IOTA, Tucson, AZ, USA, [12]IOTA, Cleveland, OH, USA, [13]IOTA, Northfield, MN, USA, [14]IOTA, Running Springs, CA, USA, [15]IOTA, Lake Oswego, OR, USA, [16]IOTA, Fountain Hills, AZ, USA, [17]IOTA, Carefree, AZ, USA, and [18]IOTA, Medina, WA, USA

INTERNATIONAL OCCULTATION TIMING ASSOCIATION

PERC
PLANETARY EXPLORATION
RESEARCH CENTER

(Japan)

Good Occultation Article in the September issue of Sky and Telescope

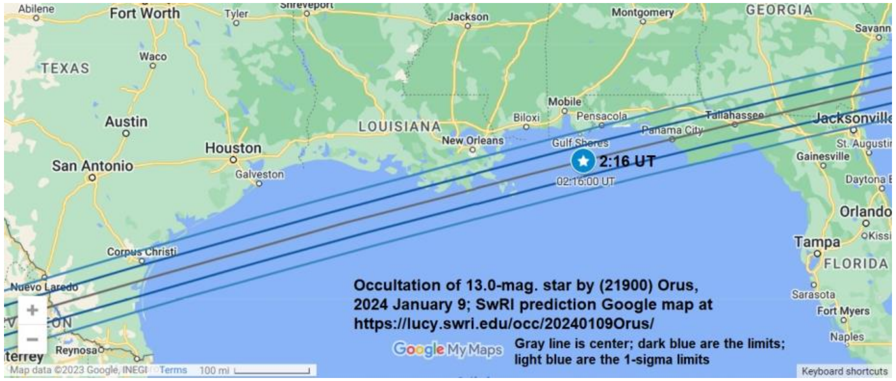


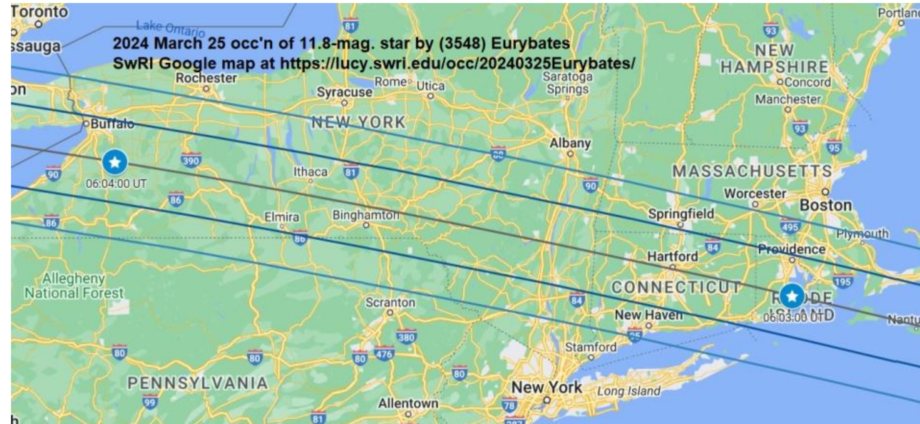
Be sure to read this good article, on pages 34-40; in it, Marc Buie describes the motivation for, and execution of, large occultation campaigns for exploring objects throughout the solar system, especially for the Trojan asteroids that are targets of NASA's Lucy mission.

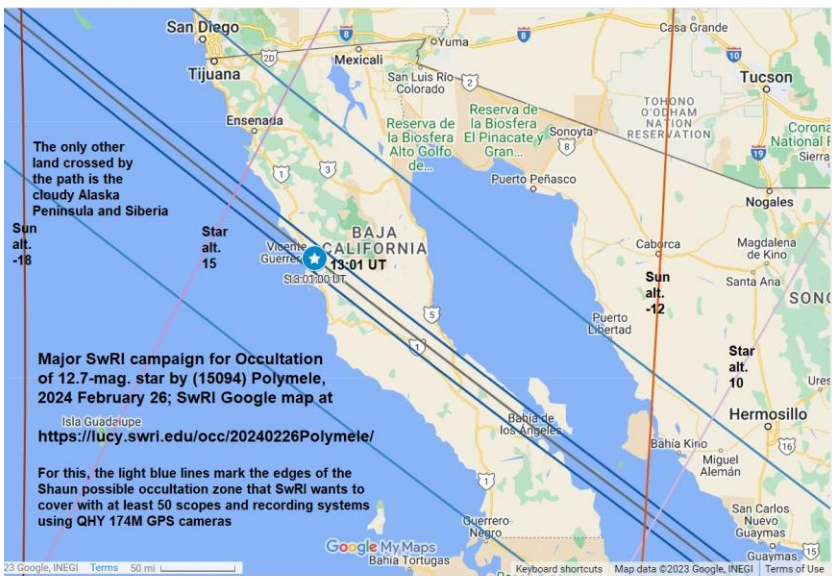
I will talk mostly about occultations by Near-Earth Asteroids (NEAs) but will also show other results, and how IOTA observers make the observations.

Lucy Target Occultations, Early 2024

from https://lucy.swri.edu/occ/predictions.html







The Southwest Research Institute (SwRI) is also interested in occultations by other Jupiter Trojan asteroids, to extend the science that will be obtained by NASA's Lucy mission.

The Chicxulub Impact

10km NEA (or 6km comet) hit shore of Yucatan 65 million years ago.
Over 70% of plant and animal species perished from the blast, worldwide wide fires (from impact debris re-entering the atmosphere), and the collapse of photosynthesis in the cold dark years that followed. **The dinosaurs died, and now humans rule, because dinosaurs didn’t have a space program and didn’t know about planetary defense.**

Outline

- IOTA & Asteroidal Occultations Introduction & History
- The 1975 Jan. 24 Occ'n of κ Gem by Eros
- The 2019 July Occ'n by Phaethon, 1st small NEO occ'n
- The 2019 Sept. 29th Phaethon Occultation in California
- Phaethon occultations in 2019 Oct. and 2020 Oct.
- Improvement of Phaethon's orbit – A2 acceleration
- More Opportunities in 2023
- First Observed Occultation by Apophis, 2021 Mar. 7
- Almost lost it – 2nd Positive Occ'n, 2021 Mar. 22
- 2021 April Occultations – Apophis Orbit Nailed
- Predictions of upcoming occultations
- How to observe/time/record occultations
- Conclusions
- Additional Resources

IOTA and Asteroidal Occultations Introduction

- The observer network that became IOTA formed in 1960’s
- to visually observe lunar grazing occultations with mobile efforts
- 1975 January 24 occultation of κ Gem by (433) Eros, a first event
- The mobile techniques to observe lunar grazes, were used effectively to observe asteroidal occultations in the late 1970’s
- Starting in the 1980’s, IOTA began recording occultations with video equipment, improving the observations
- Using stars and the Earth’s rotation to pre-point stationary telescopes at multiple unattended locations with timed recording became possible
- Working with the NASA PDS Small Bodies Node and the Minor Planet Center, IOTA archives all asteroidal occultation observations
- ESA’s Hipparcos and Gaia missions have greatly improved prediction accuracy, resulting in a large increase in observed occultations
- The sizes, shapes, and accurate positions of several hundred asteroids have been determined
- Dozens of close double stars have been discovered, the diameters of several stars have been measured, and some asteroidal satellites have been discovered, and several characterized.

Lunar Occultation Geometry

IOTA started in the early 1960's by observing lunar occultations, especially grazing ones

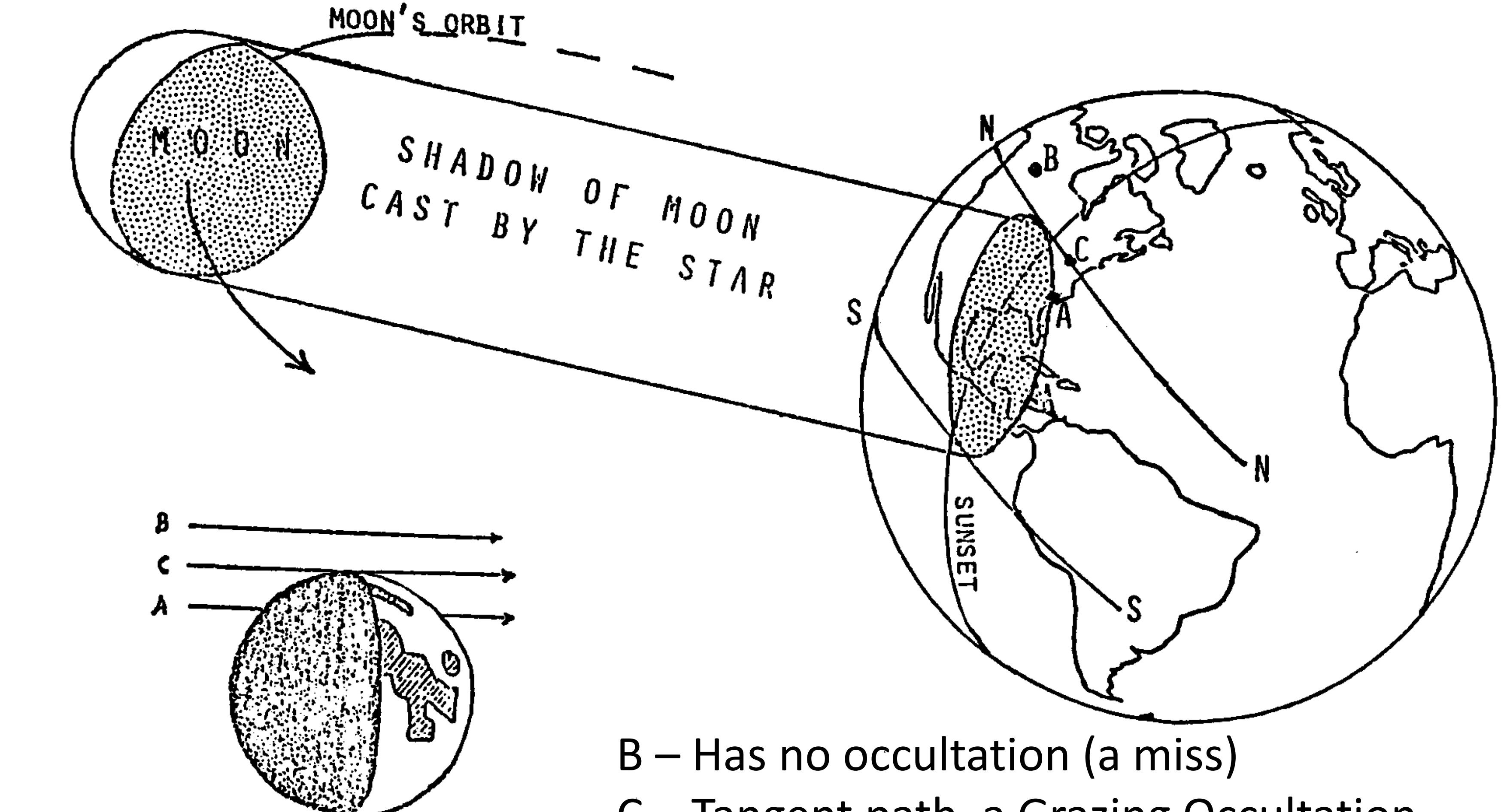


Figure 2-1b

B – Has no occultation (a miss)

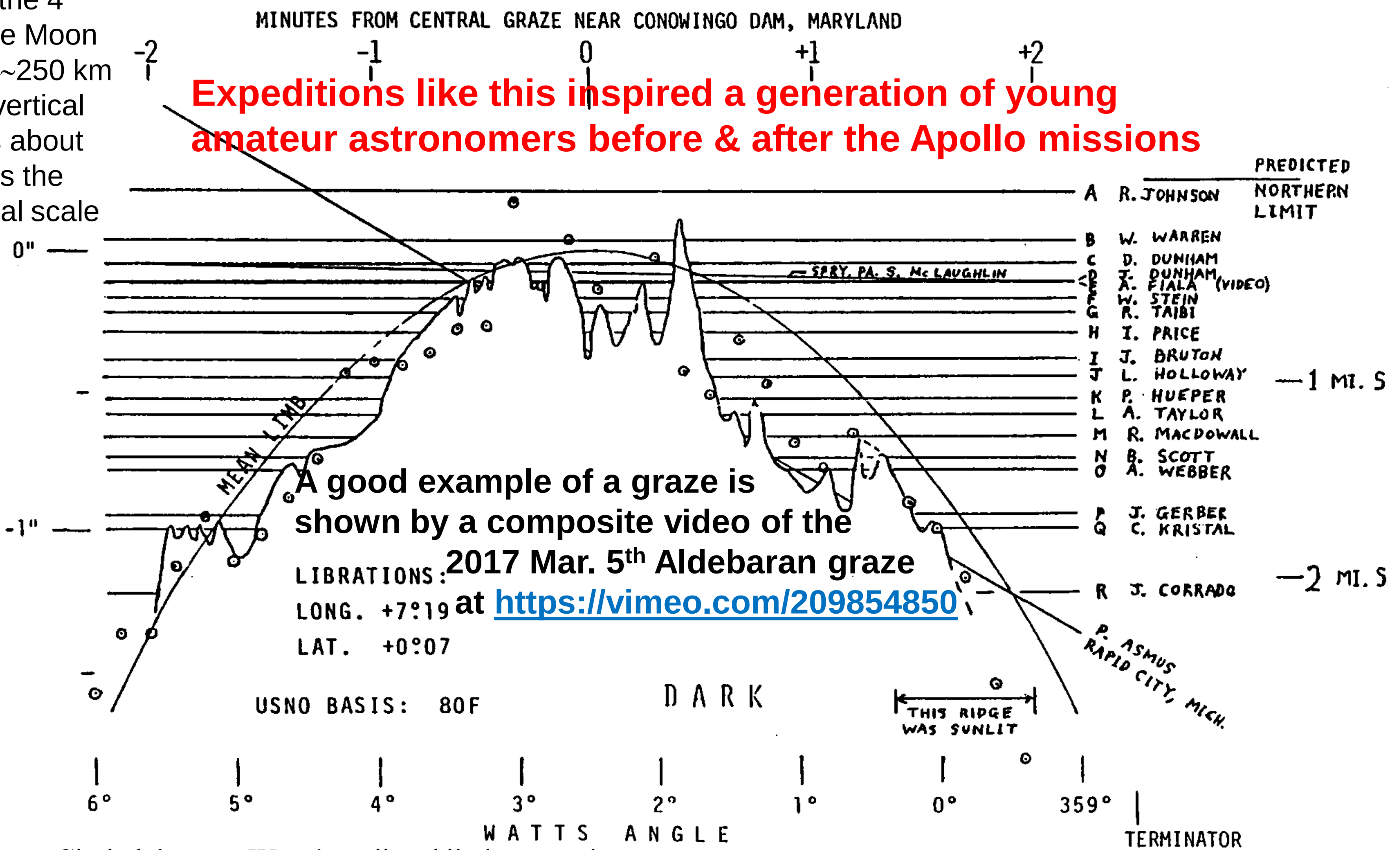
C – Tangent path, a Grazing Occultation

A – Total Occultation

Lunar Profile from Graze of delta Cancri – 1981 May 9-10 Alan Fiala, USNO, obtained the first video recording of multiple events during this graze, with 7 D's and 7 R's

During the 4 min., the Moon moved ~250 km so the vertical scale is about 40 times the horizonal scale

Expeditions like this inspired a generation of young amateur astronomers before & after the Apollo missions



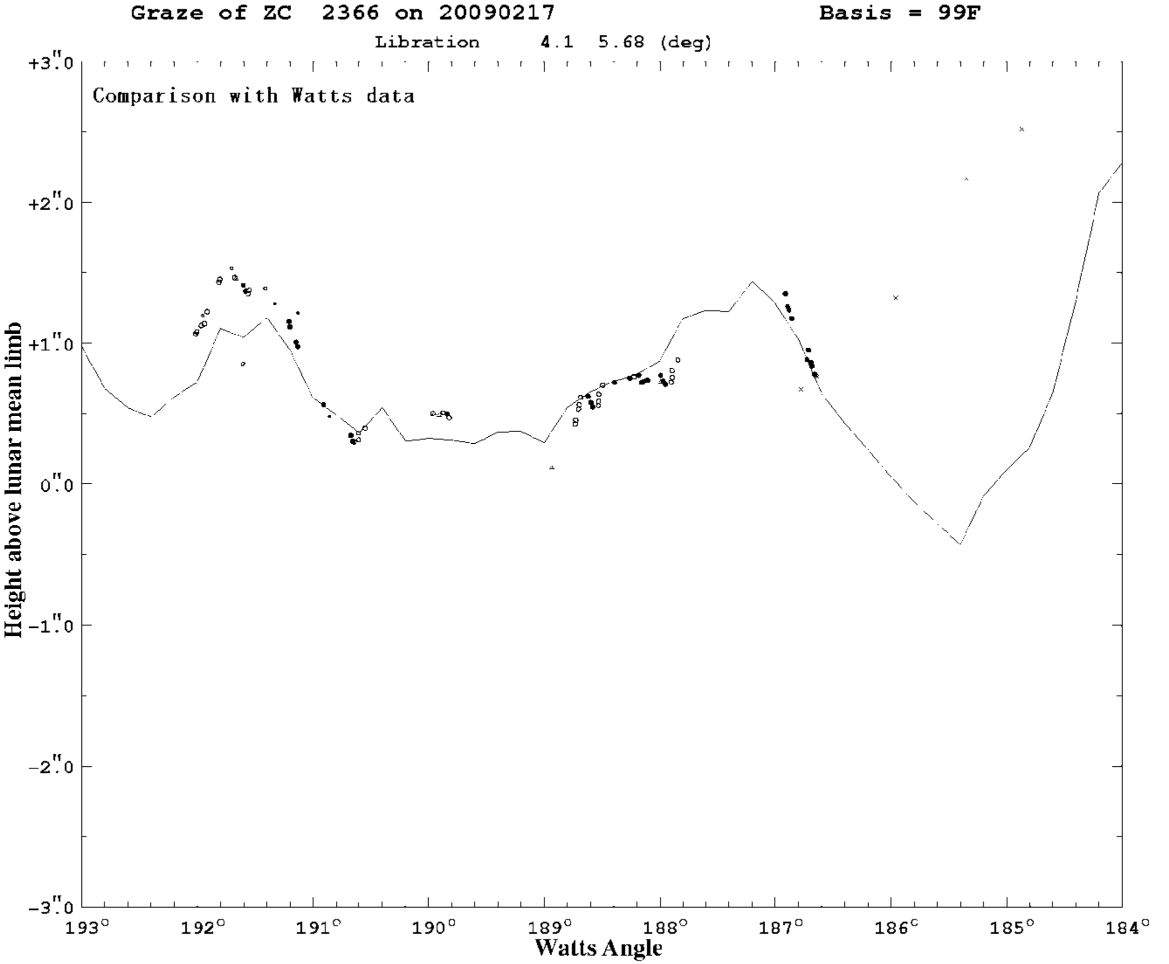
A good example of a graze is shown by a composite video of the 2017 Mar. 5th Aldebaran graze at https://vimeo.com/209854850

Circled dots are Watts' predicted limb corrections

Starting in 1965, cable systems were developed for observing grazing occultations, first at USNO, then by 3 clubs in California (Riverside, Santa Barbara, and Mount Diablo Astronomical Society), and Milwaukee, Wisconsin

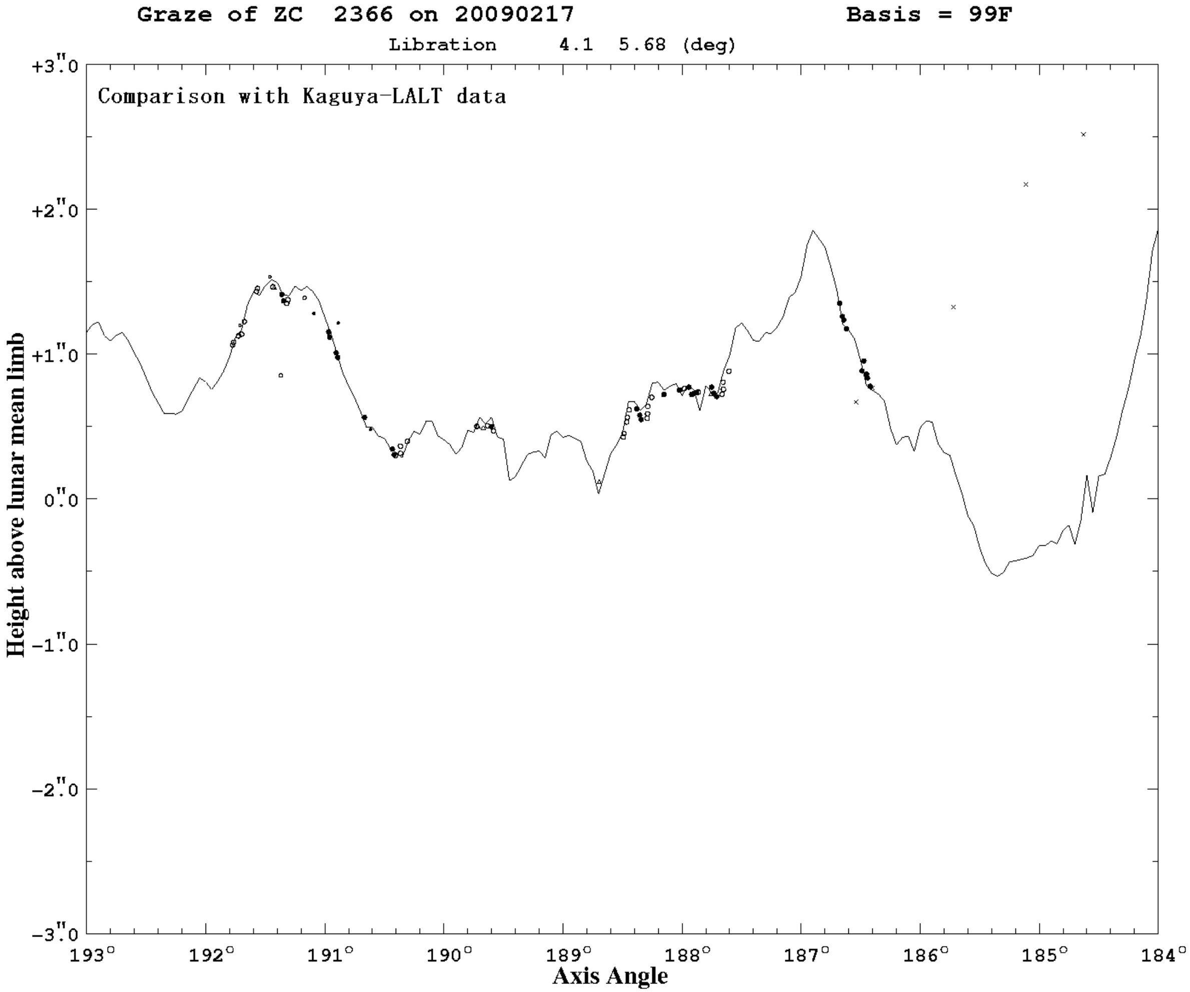
This is a Riverside A.S. expedition near Adelanto in 1966. Mobile observation was needed since graze paths were narrow. The observations were visual, with audio tones recorded at the central station for this cable system.

Grazing occultation analyzed with Watts profile data

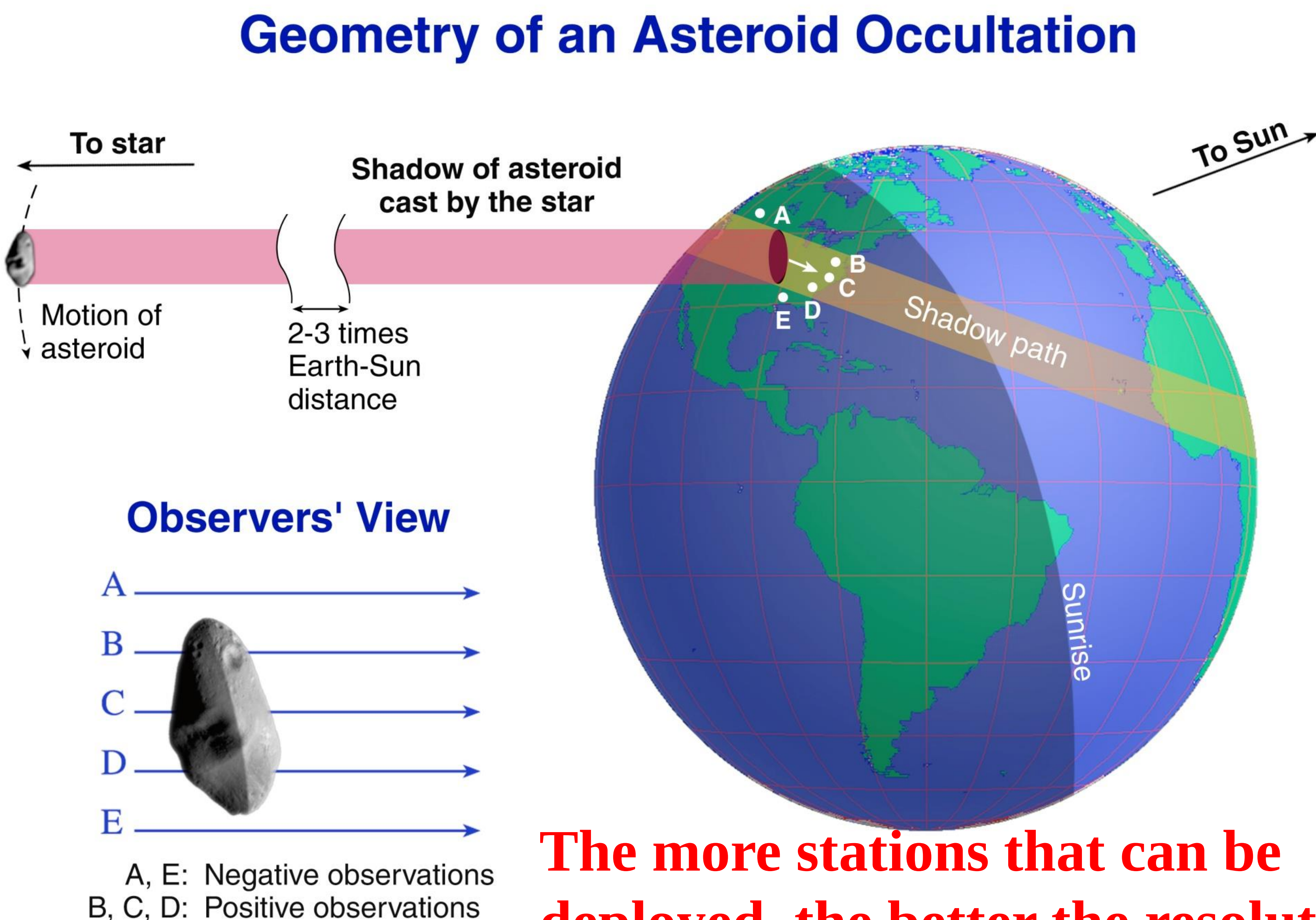


From a grazing occultation of Antares observed from Bardoc, Western Australia, on 2009 February 17

Grazing occultation analyzed with Kaguya profile data



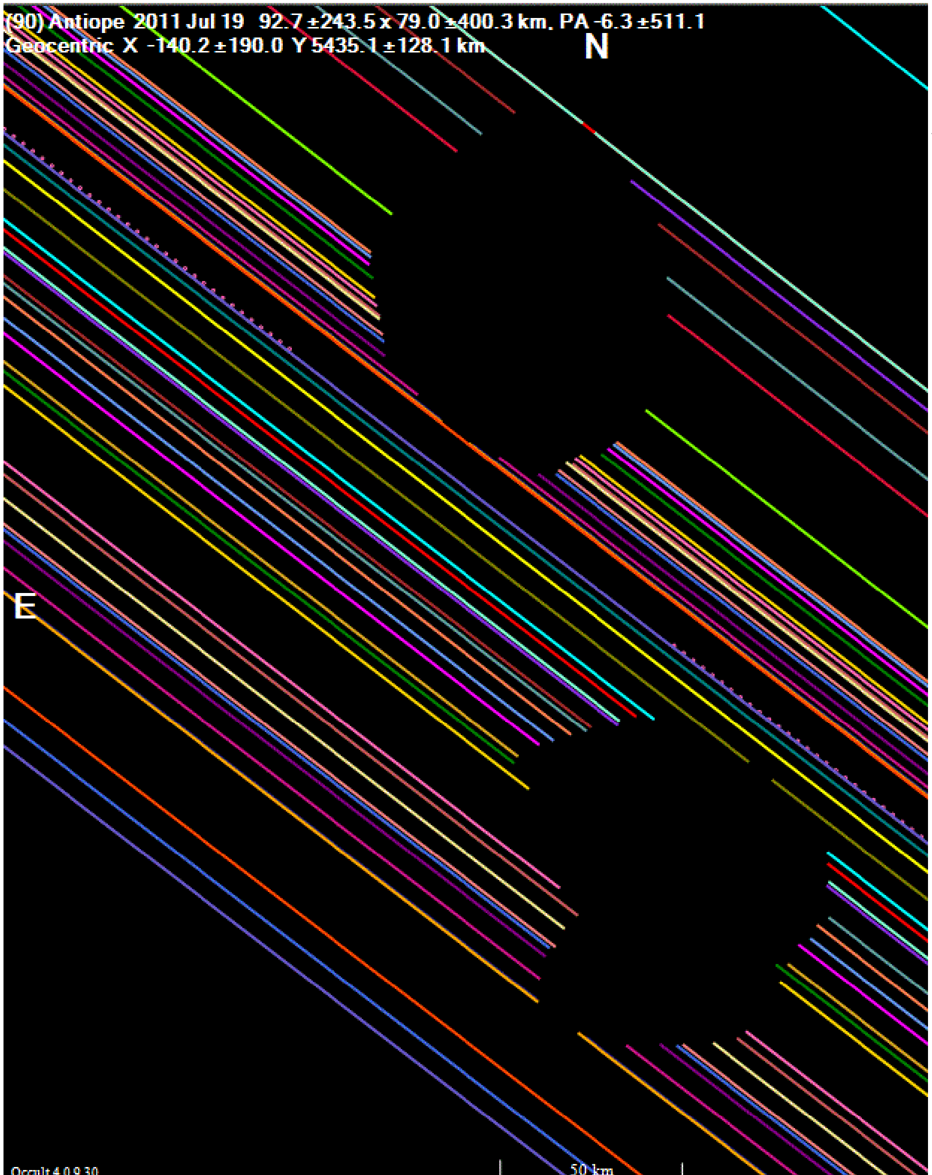
Same Antares graze as shown in the previous slide. Currently available LRO data are even better. Since grazes can now be predicted so well, there is little new we can learn from them, so few try them now. But they are interesting to watch and close double stars can be discovered.



The more stations that can be deployed, the better the resolution of the asteroid’s shape

Many Occultations of Interesting Main Belt Objects

2011 July 19 occ'n of LQ Aquarii by the Binary Asteroid (90) Antiope



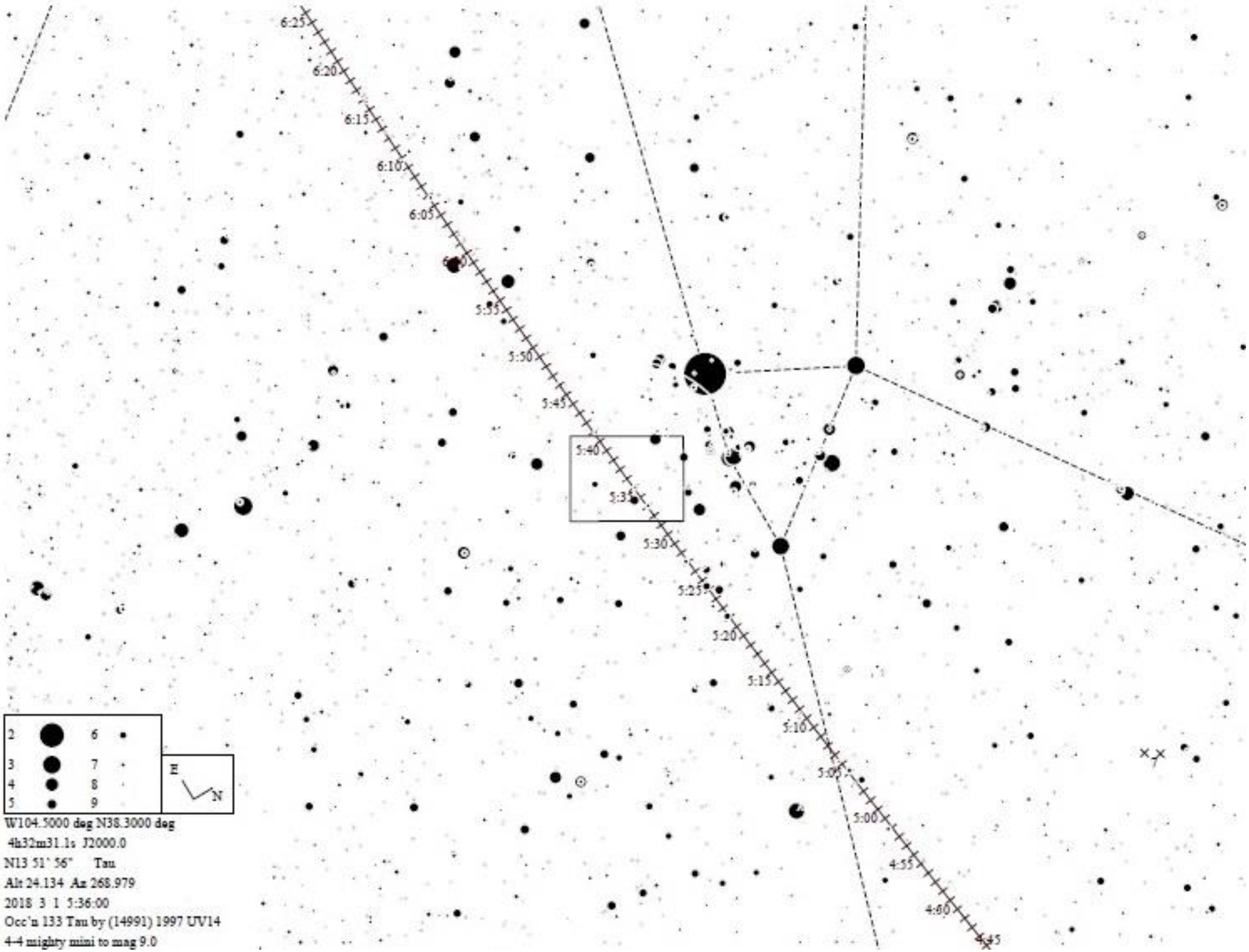
Technology now allows observers to record transient astronomical phenomena more precisely and to fainter magnitudes than ever before. A small, inexpensive, yet very sensitive camera (RunCam Night Eagle Astro) will allow you to participate in IOTA's programs to accurately record occultations and eclipses, to measure the sizes and shapes of hundreds of asteroids, discover duplicity of both close double stars and asteroids with satellites, and measure the angular diameters of many stars. Occultations provide excuses for travel, or you can just observe them from home, to further astronomical knowledge. Some use specially-made easily-transported telescopes; there is room for innovative design & construction of equipment & software to record asteroidal occultations.

Near left: 10-in suitcase tele-scope deployed for an asteroidal occultation in the Australian Outback.

Remote Stations for Asteroidal Occultations

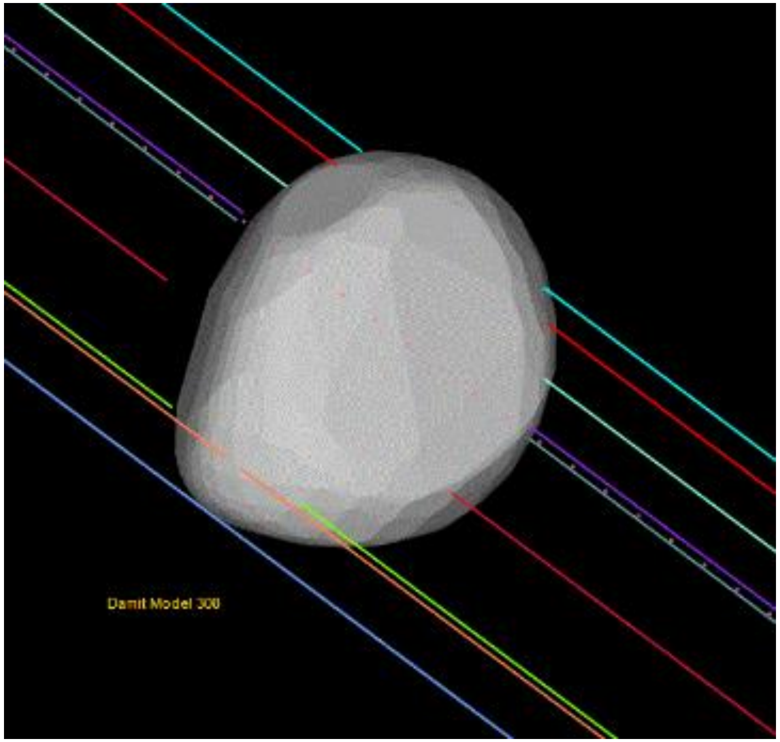
- Separation should be many km, much larger than for grazes, so tracking times & errors are too large
- **Unguided is possible since the prediction times are accurate enough, to less that 1 min. drift-through time = ¼° (FOV)**
- **Point telescope beforehand to same altitude and azimuth that the target star will have at event time and keep it fixed in that direction**
- Plot line of target star's declination on a detailed star atlas; Guide 8 or 9, or C2A can be used to produce the charts
- From the RA difference and event time for the area of observation, calculate times along the declination line
- Adjust the above for sidereal rate that is faster than solar rate, add 10 seconds for each hour before the event**; done automatically by Guide & C2A**
- Can usually find "guide stars" that are easier to find than the target
- Find a safe but accessible place for both the attended & remote scopes
- Separation distance limited by travel, set-up, & pre-pointing time, but we have had success with software to control small Win10 computer recordings; then the main limit is battery life, which can be several hours
- Sometimes it is better to have remote sites attended for starting equipment later (allows larger separations) and security, if enough people can help

Example of Guide8 Pre-Point Chart

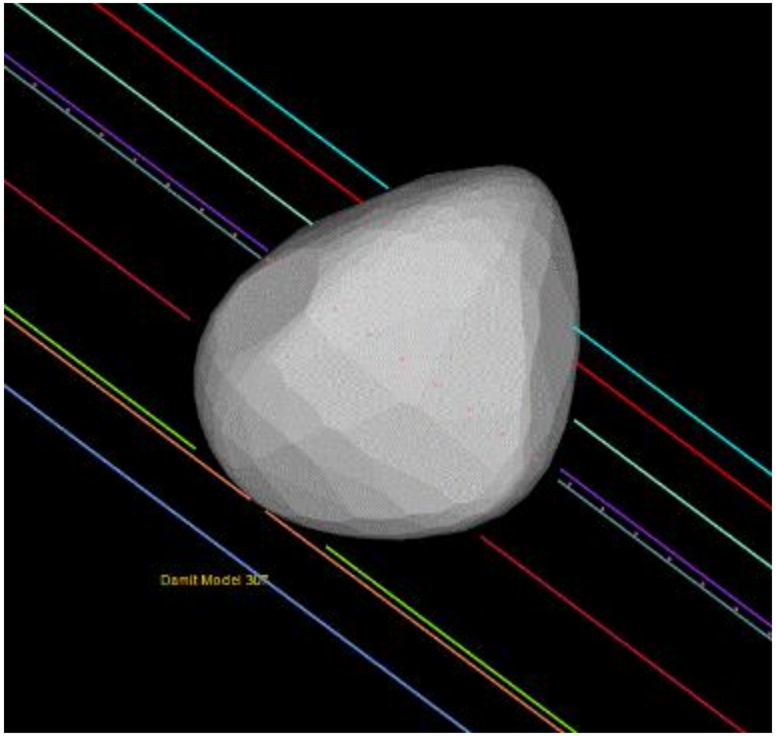


January, 2008 Occultation of (13) Egeria
When Multiple Lightcurve Models Exist, Occultation Data Can Help Distinguish Which Is The Better Fit

Model 1



Model 2



HIP 46249 Duplicity Discovery from Asteroidal Occultation by (160) Una

Tony George, Umatilla, OR, USA (triastro@oregontrail.net)
Brad Timerson, IOTA North American Coordinator
International Occultation Timing Association (IOTA)
Tom Beard, Reno, NV
Ted Blank, Hampton, NH
Ron Dantowitz, Boston, MA
Jack Davis, Dayton, NV
Dennis di Cicco, Sudbury, MA
David W. Dunham, Greenbelt, MD
Mike Hill, Marlboro, MA
Aaron Sliski, Boston, MA
Red Sumner, Dayton, NV

Abstract: An occultation of HIP 46249 by the asteroid (160) Una on 2011 January 24 showed this star to be a double star. Both components of the double star were occulted as recorded by three observers. The separation of the two components is 0.0065 ± 0.0011 arcseconds at a position angle of 50.2 ± 12.2 degrees. The magnitude of the primary component is estimated to be 9.2 ± 0.1 V. The magnitude of the secondary component is estimated to be 10.6 ± 0.1 V.

HIP 46249 Duplicity Discovery from Asteroidal Occultation by (160) Una

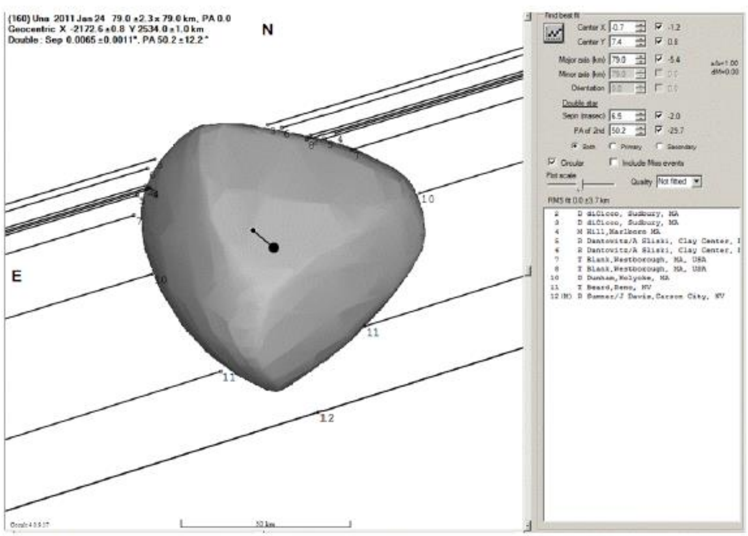


Figure 7: Occultation (160) Una occultation of HIP 46249 and DAMIT inversion model plot. Note that Chord 1 (a miss) was left off the plot to avoid conflict with other plot text. The direction of travel of the asteroid in the diagram is from upper right to lower left.

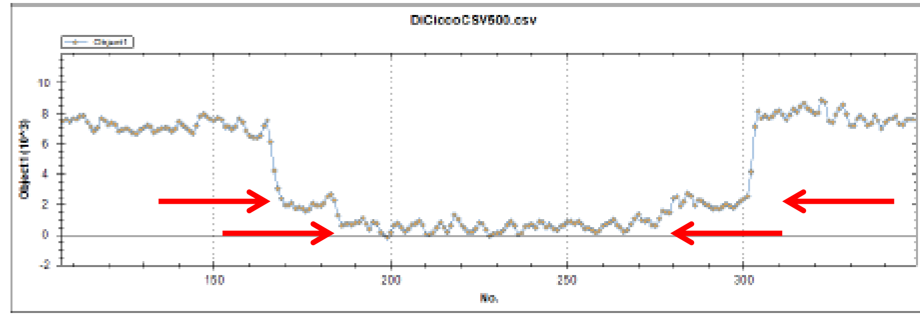
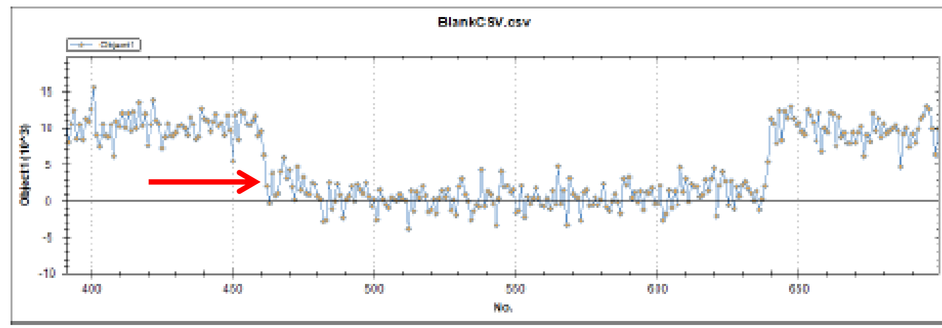
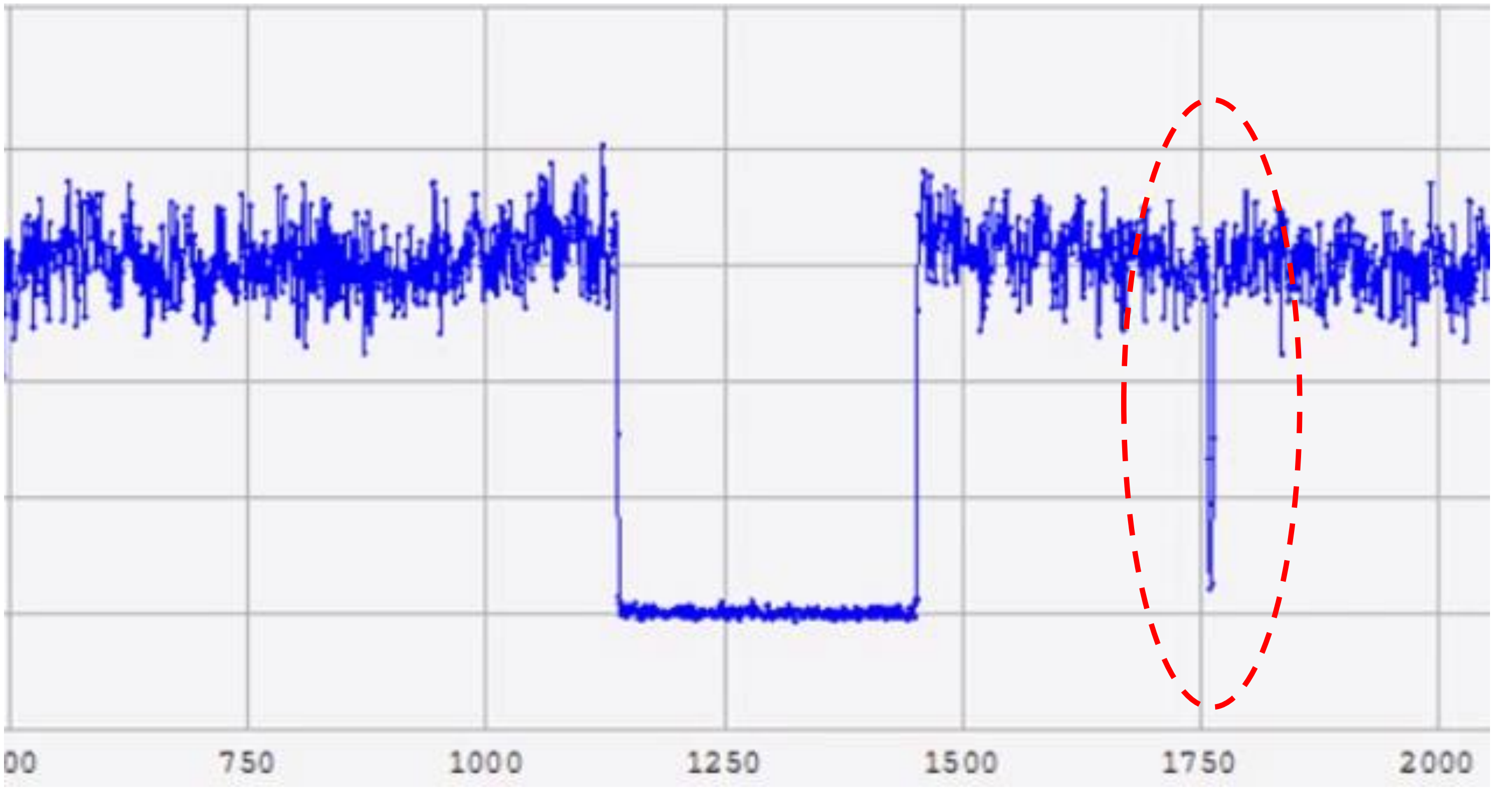


Figure 2: Di Cicco light curve showing distinct two-step event on D and R

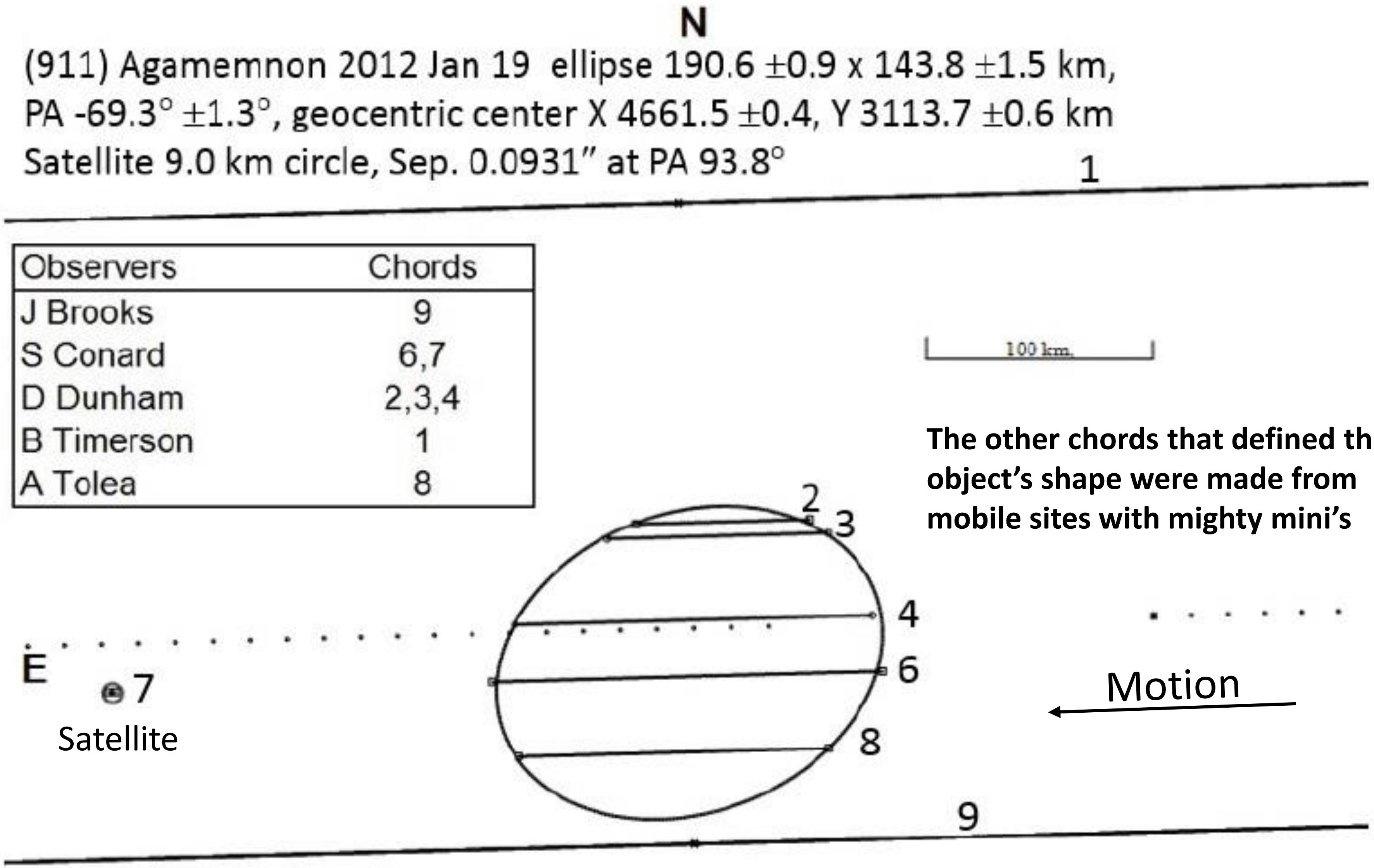


Discovery of Satellites of Asteroids

Trojan Asteroid (911) Agamemnon, observed by Steve Conard, Gamber, MD

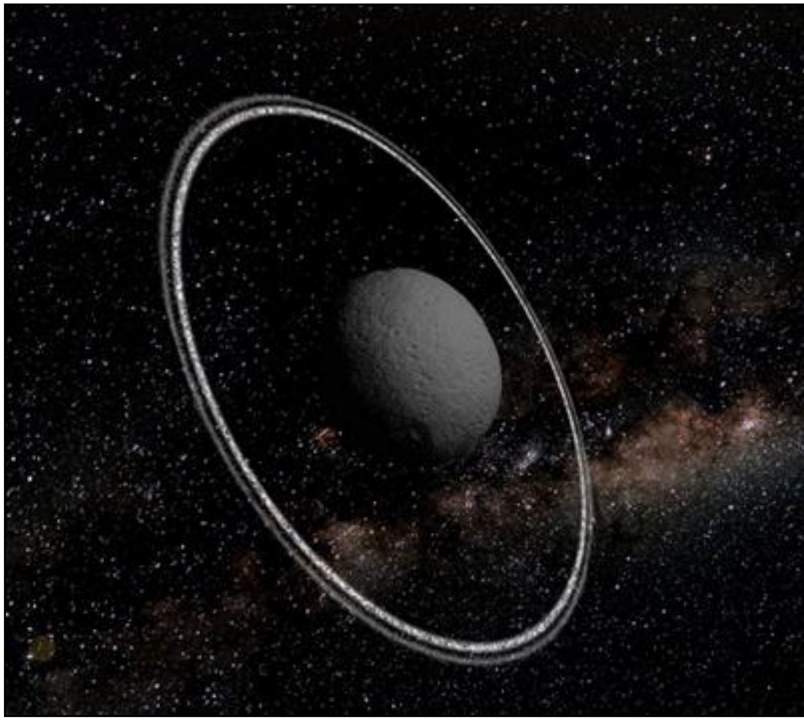


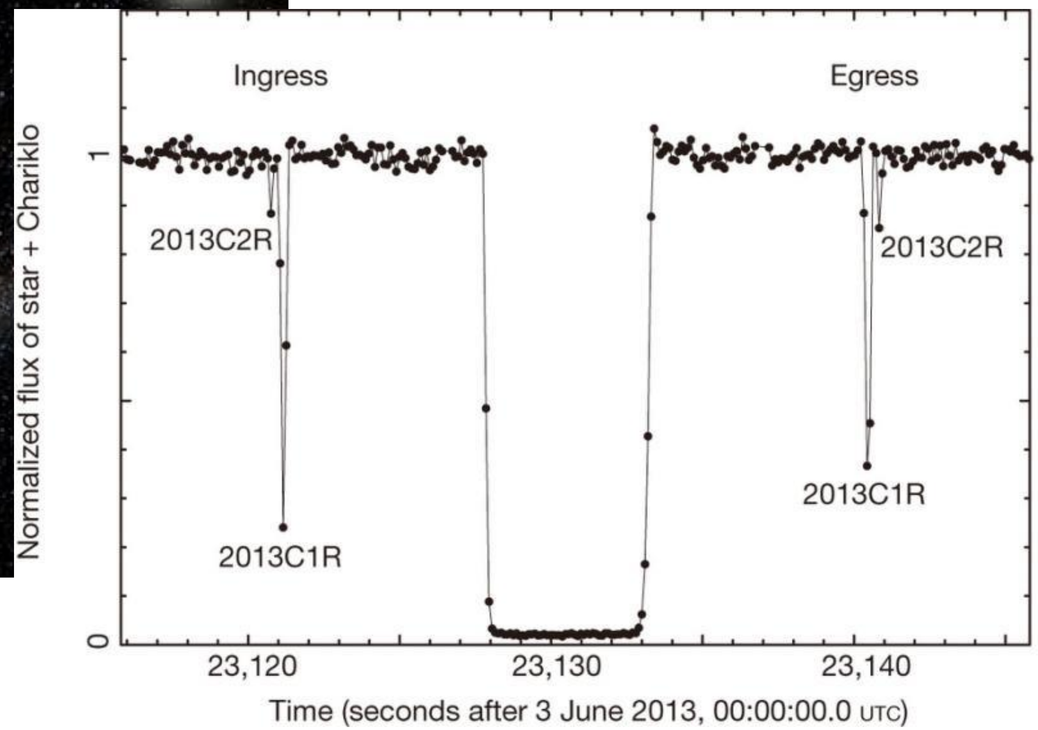
Sky Plane Plot for the Occultation of SAO 60804 by the Trojan asteroid (911) Agamemnon on 2012 Jan. 19



The other chords that defined the object's shape were made from mobile sites with mighty mini's

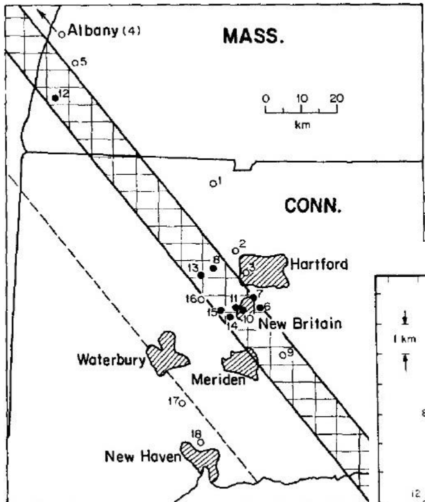
Identification of Asteroid Rings!
(10199) Chariklo [and recently, (50000) Quaoar



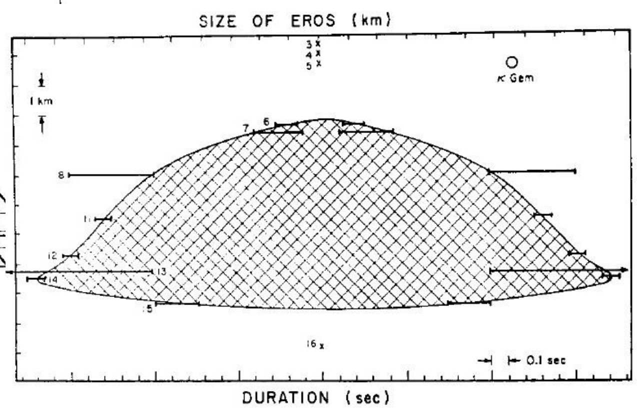


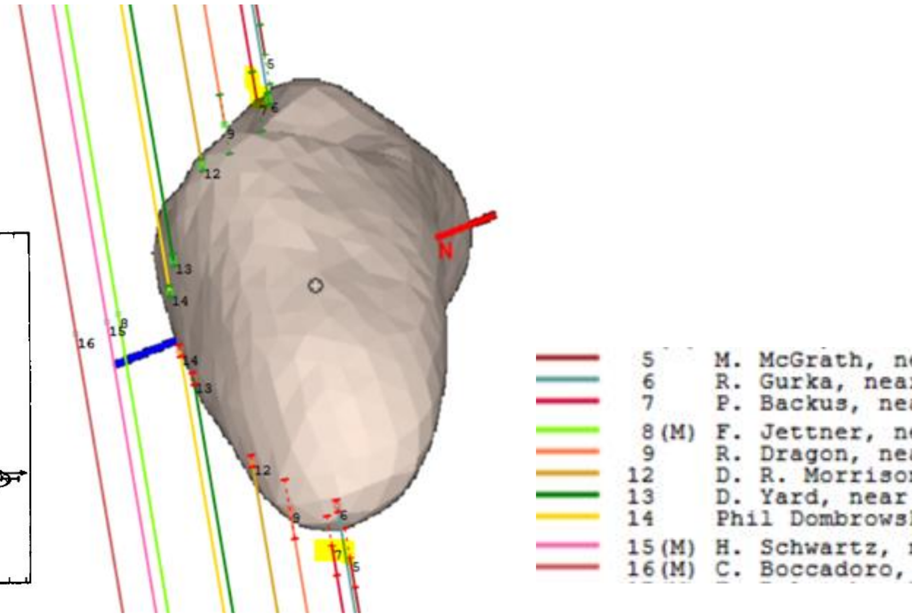
Observation of occultations by Trojans, Centaurs & KBO’s are now some of the most valuable events; these are sought especially by the Paris Obs. Lucky Star Program and SwRI’s RECON network.

First observed occultation by a NEA, 1975 Jan. 24, κ Gem occulted by Eros



from O'Leary et al., **Icarus**, Vol. 28, pp. 133-146 (1976)





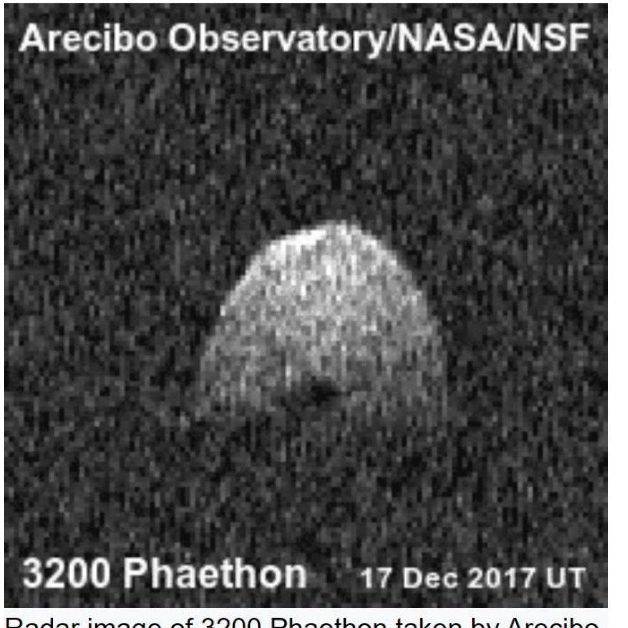
Left, map of observers & sky plane plot from the 1976 Icarus paper. Right, modern sky plane plot of the chords fitted to Eros' shape model derived from NEAR-Shoemaker data. This was the first occultation by ANY asteroid that was observed from multiple stations. Especially, the stations deployed by the Pioneer Valley Colleges led by Brian O'Leary was the first successful coordinated effort to observe such an event by mobile observers. A crucial observation, now known to be a false negative, resulted in the wrong squashed shape shown by O'Leary et al. It would be 44 years before an occultation by another NEO would be observed.

(3200) Phaethon

- (3200) Phaethon was the first asteroid to be discovered by a spacecraft (IRAS).
- Phaethon is the parent body of the Geminids meteor stream that puts on one of the largest annual meteor displays
- This mysterious object may be a (nearly) dead comet nucleus, or a very active asteroid, throwing off boulders like has been observed on Bennu by OSIRIS-REx
- Phaethon is an Apollo asteroid with a perihelion of only 0.14 AU, <half Mercury’s, with aphelion 2.4 AU in the Main Belt. The extreme thermal changes near perihelion likely drive its shedding of pebbles and dust, creating the trail imaged by the Parker Solar Probe. Small non-gravitational forces on its orbit have been detected.

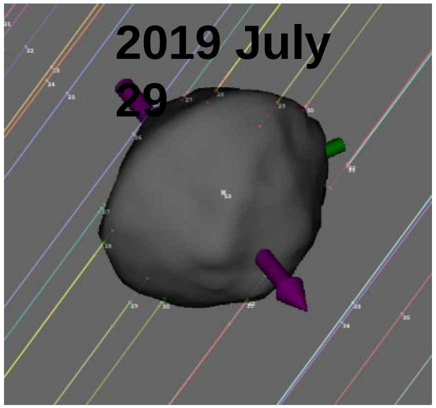
- JAXA’s DESTINY+ spacecraft plans to launch in 2024 and fly by Phaethon in 2025 -see https://en.wikipedia.org/wiki/DESTINY+

- Radar observations show Phaethon to be nearly spherical with a diameter of nearly 6 km
- Thermal IR data give a diameter of ~4.5km



Radar image of 3200 Phaethon taken by Arecibo, December 17, 2017

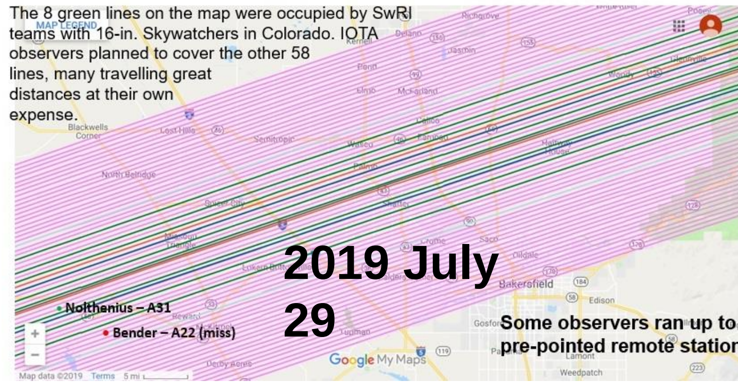
First Occultations by (3200) Phaethon described at PDC 2021



Left: Sky-Plane plot of central timings fitted to Sean Marshall's Phaethon shape model.

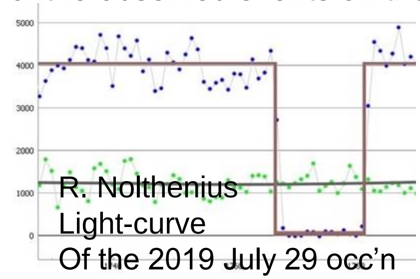
Right: Map showing planned observer lines, central California.

Most stations were n. of Las Vegas; others were n. of Ridgecrest and near Pueblo, Colo.

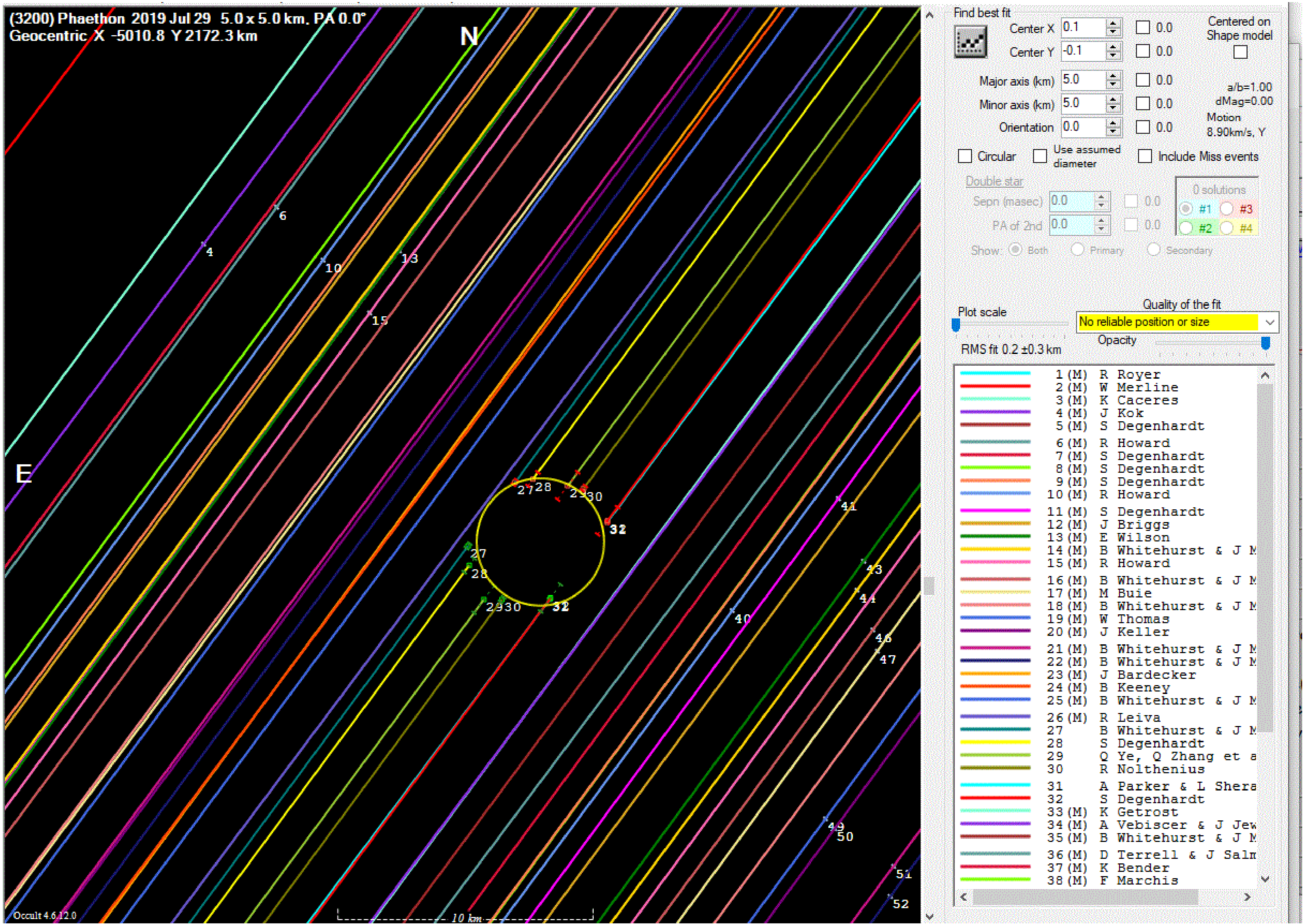


The 1st occultation, of 7.3-mag. SAO 40261 whose path crossed the southwestern USA on 2019 July 29, was found by Isao Sato in Japan. The orbit was refined by the planetary ephemeris team at JPL that provided a prediction that was much more accurate than expected. Almost 70 telescopes were set up, 8 by SwRI and the rest by IOTA, to record the event from a span of 45 km, with the 6 central stations recording the event. The scopes at ~20 unattended stations were pre-pointed to the alt/az of the occultation using Guide star charts with the "pre-point line of declination" plotted. We hope that new plate-solving techniques will enable more to make these multi-station deployments; we seek help in finding solutions that work with simple video systems in the field. Five more Phaethon occultations were observed in late 2019 and one in 2020 that resulted in a 3-times reduction of the error of the determination of the A2 non-gravitational parameter of Phaethon's orbit, with a table of the observed events on the lower left.

Date	Star mag.	# stations positive/all	Locations(s)	Remarks
2019 July 29	7.3	6/52	s.w. USA	8 SwRI 16in., 44 IOTA stations
2019 Sept. 29	12.0	3/4	s. California	2 pre-pointed 10in. scopes, 2 8in. SCTs
2019 Oct. 12	11.3	2/2	Virginia	UVA expedition with 14in. SCTs
2019 Oct. 15, 17h	11.5	2/2	Japan	Clouds at more stations that tried
2019 Oct. 15, 19h	11.1	3/3	DE, FR, Algeria	In FR, a 1m portable scope was used
2019 Oct. 25	11.3	3/3	Italy, Algeria	2nd Phaethon occ'n for D. Baba Aissa
2020 Oct. 5	11.2	1/4	s. Mississippi	R. Venable, pre-pointed 11 & 14in SCTs



2019 July 29 Phaethon occ'n, all successful chords

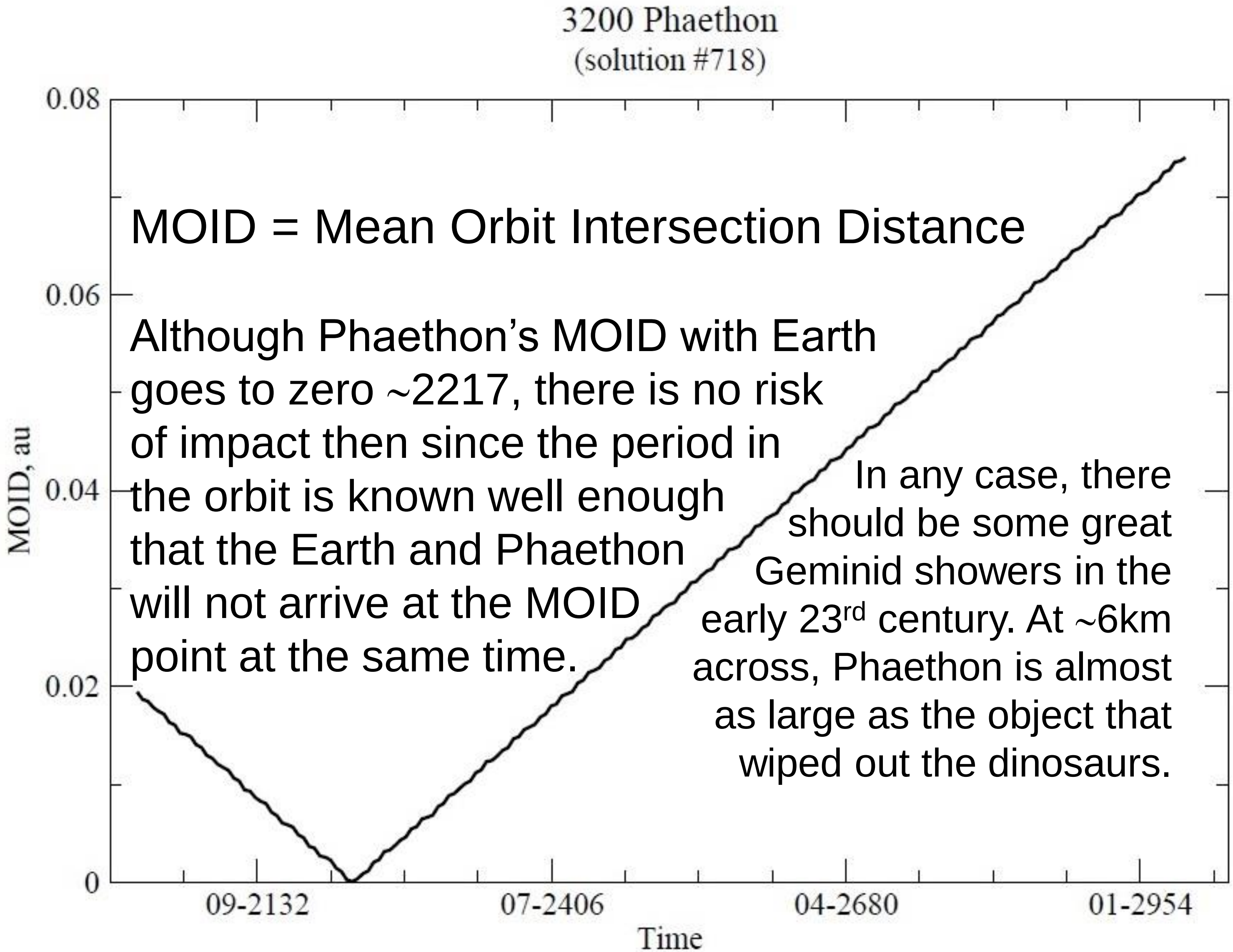


Phaethon Orbit A2 Determinations

(units au/d^2 x10^{-15})

JPL sol. #	Value	Sigma	Value in sigma's	Basis
684	-4.84	±1.39	3.48	MPC obs. & 2017 radar
685	-3.76	±1.74	2.16	Adds Gaia obs.
707	-5.60	±0.67	8.41	Adds 2019 7/29 occ'n point
712	-5.44	±0.59	9.22	Adds 2019 7/29 & 9/29 occ'ns
718	-6.27	±0.61	10.28	Adds the 4 2019 Oct. occ'ns
742	-5.71	±0.87	6.56	Adds more Gaia obs. and 2020 Oct. 5 occ'n point

The A2 term for most NEO's is caused by the Yarkovsky effect, but for Phaethon, mass loss due to strong thermal heating near perihelion is likely the main driver, as evidenced by the Geminids & the Phaethon dust trail imaged by the Parker Solar Probe.



MOID = Mean Orbit Intersection Distance

Although Phaethon's MOID with Earth goes to zero ~2217, there is no risk of impact then since the period in the orbit is known well enough that the Earth and Phaethon will not arrive at the MOID point at the same time.

In any case, there should be some great Geminid showers in the early 23rd century. At ~6km across, Phaethon is almost as large as the object that wiped out the dinosaurs.

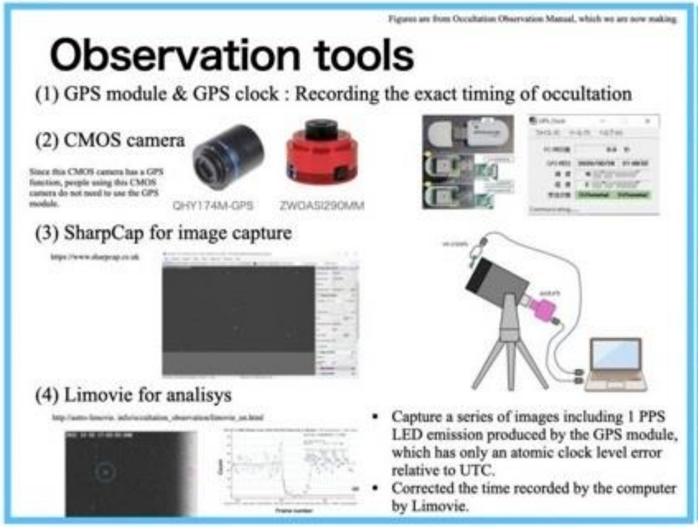
We should keep close tabs on Phaethon since its A2 term could change; its rubble pile structure could change with the severe thermal shocks it suffers, so such a change might alter the orbit period enough to be a concern in 200 years.

Occultation observation in Japan → East Asia

The Japanese Occultation Information Network (JOIN) seeks outreach to neighboring countries

IOTA/EA International Occultation Timing Association/East Asia **Founding**

Equip and develop observation and analysis tools



Workshop on Occultation Observations

Pre-observation meeting, observation study session, and celebration at ZOOM

Writing of observation manuals

An English version of the manual will be available soon.

- After many occultation observations of Phaethon, a mixed pro-am team of occultation observers was formed in Japan. Japanese amateur observers have long experience in occultation observation. They have developed their own observation aids (GPS receiver, time imposer) and analysis software. Such tools are now shared among the team.
- We have also begun holding occultation observation workshops to educate newcomers to the field. The number of occultation observers gradually increased.
- We held zoom meetings before and after observation campaigns to discuss observations, provide guidance and unify observation methods, and hold victory parties after observations.
- We have also prepared an observation manual and are working on an English version so that people overseas can read it as well.

This major movement was triggered by Phaethon's occultation observations for the DESTINY+ mission. Now we are moving toward the establishment of the IOTA/EA involving not only Japan but also neighboring countries.
We will continue observations of stellar occultation by Phaethon until the flyby with the IOTA/EA team.

DESTINY+ provides some support via the Planetary Exploration Research Center (PERC)

2021 October 3 (UT)

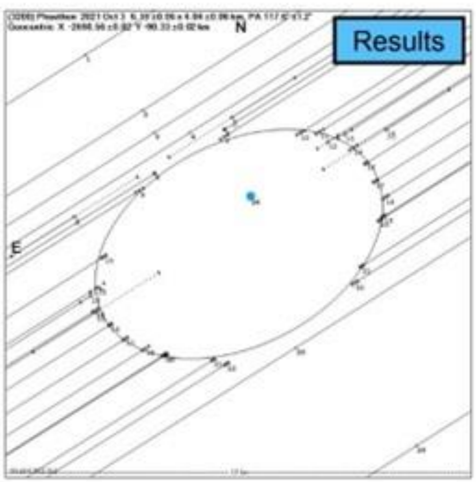
Best-observed Phaethon occultation

UCAC4 646-021974 (12.0 mag)

Yoshida et al. PASJ, 2022, psac096,
https://doi.org/10.1093/pasj/psac096

Phaethon occults a 12.0 mag star along a path across Japan, Korea and China at 16:58 UT on 3 October 2021. When the occultation occurs, the star is dimmed 6.5 mag. **The maximum duration time is 0.68 seconds.**

Seventy-two people observed the occultation event at 36 separate sites from Japan to Korea. 18 sites had positive detection, while seven were negative.

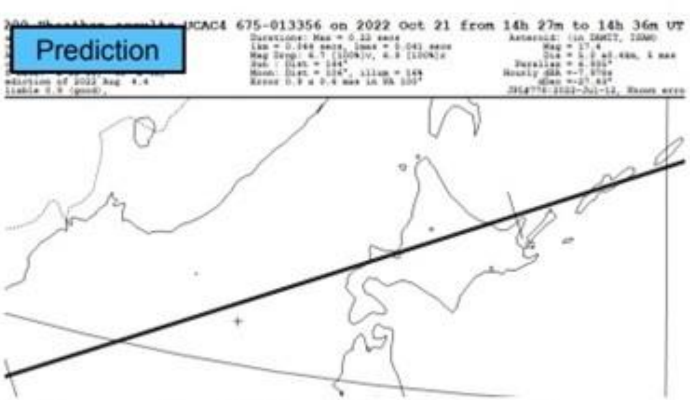


- The Phaethon's cross section at the time of the stellar occultation on October 3 (UT) would be fitted approximately by an ellipse with a **major diameter of** 6.12 ± 0.07 **km** and a **minor diameter of** 4.14 ± 0.07 **km**.
- This is the first successful ultra-precise measurement of stellar occultation by an asteroid 5-6 km in diameter using a CMOS camera and a GPS module. The large number of observation points and the high-precision time keeping method enabled us to obtain a high-resolution outline of Phaethon. The measurement error of each observation point is about 80-140m.

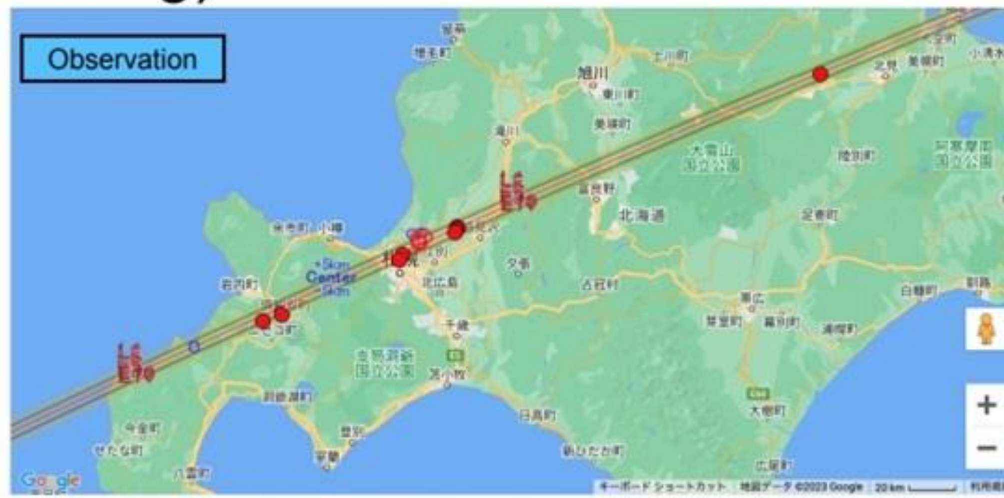
2022 October 21 (UT)

<u>This well-observed occultation had an unexpected large path shift</u>

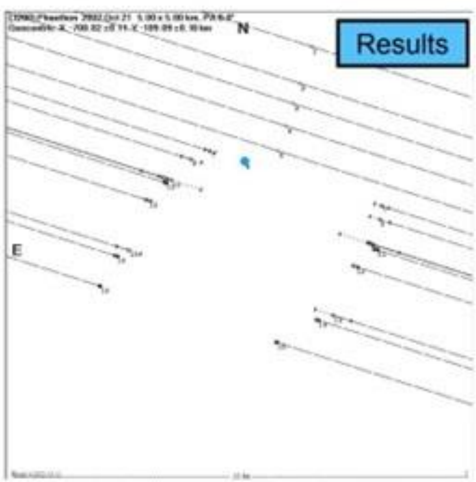
TYC 2844-0735-1 (10.8 mag)



Phaethon occults a 10.8 mag star along a path across Hokkaido Japan, at 14:32 UT on 21 October 2022. When the occultation occurs, the star is dimmed 6.7 mag. **The maximum duration time is 0.22 seconds.**



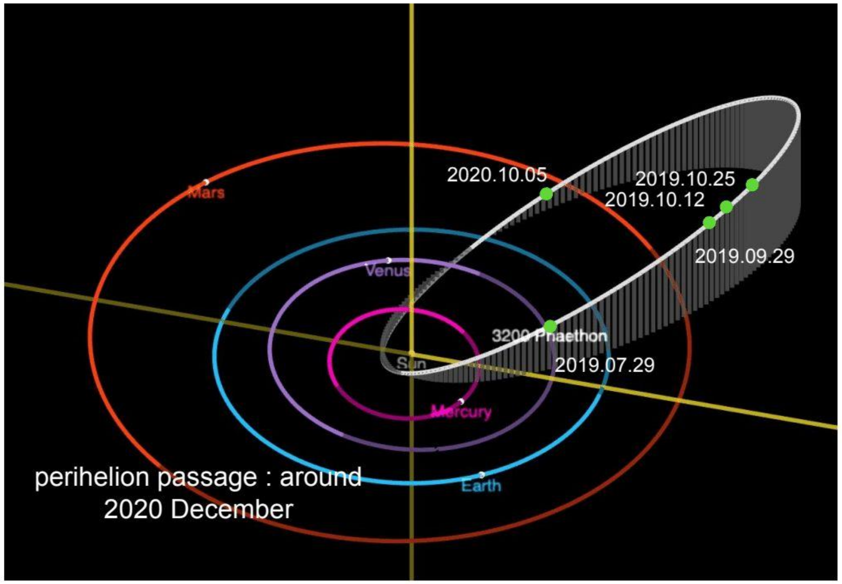
Thirty-nine people observed the occultation event at 19 separate sites in Hokkaido. 9 sites had positive detection, while five were negative.

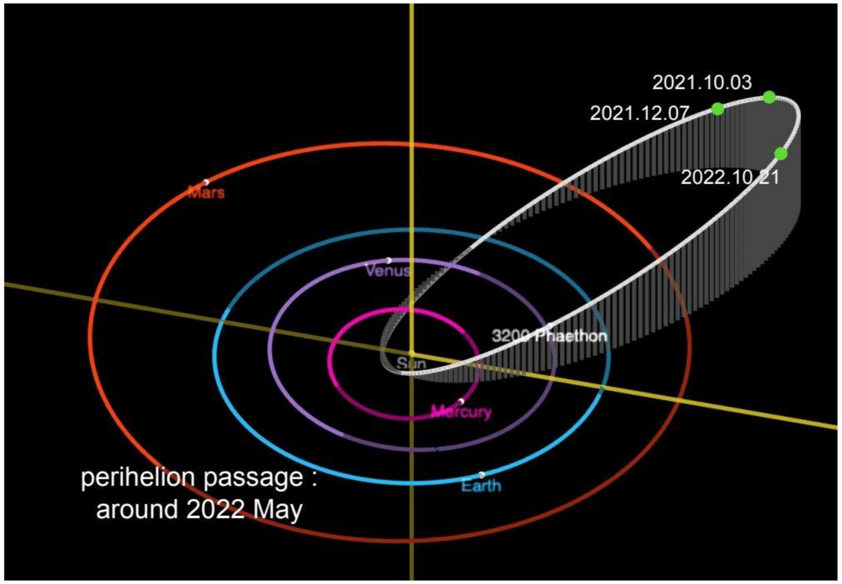


- Starting observations in July 2019 and continuing through October 2021, stellar occultations by Phaethon were occurring almost exactly as predicted in the predicted occultation zone. This suggests that Phaethon's orbit was extremely well determined.
- However, the October 2022 observations showed that the predicted occultation zone was shifted to the south by the radius of Phaethon (about 2km or so). Therefore, we were unable to measure the entire cross-sectional shape of Phaethon.
- The measurement error of each observation point is about 45-700m.

Why did the occultation zone shift?

One possibility is that there may have been some change in Phaethon's orbit at the time of the perihelion passage?

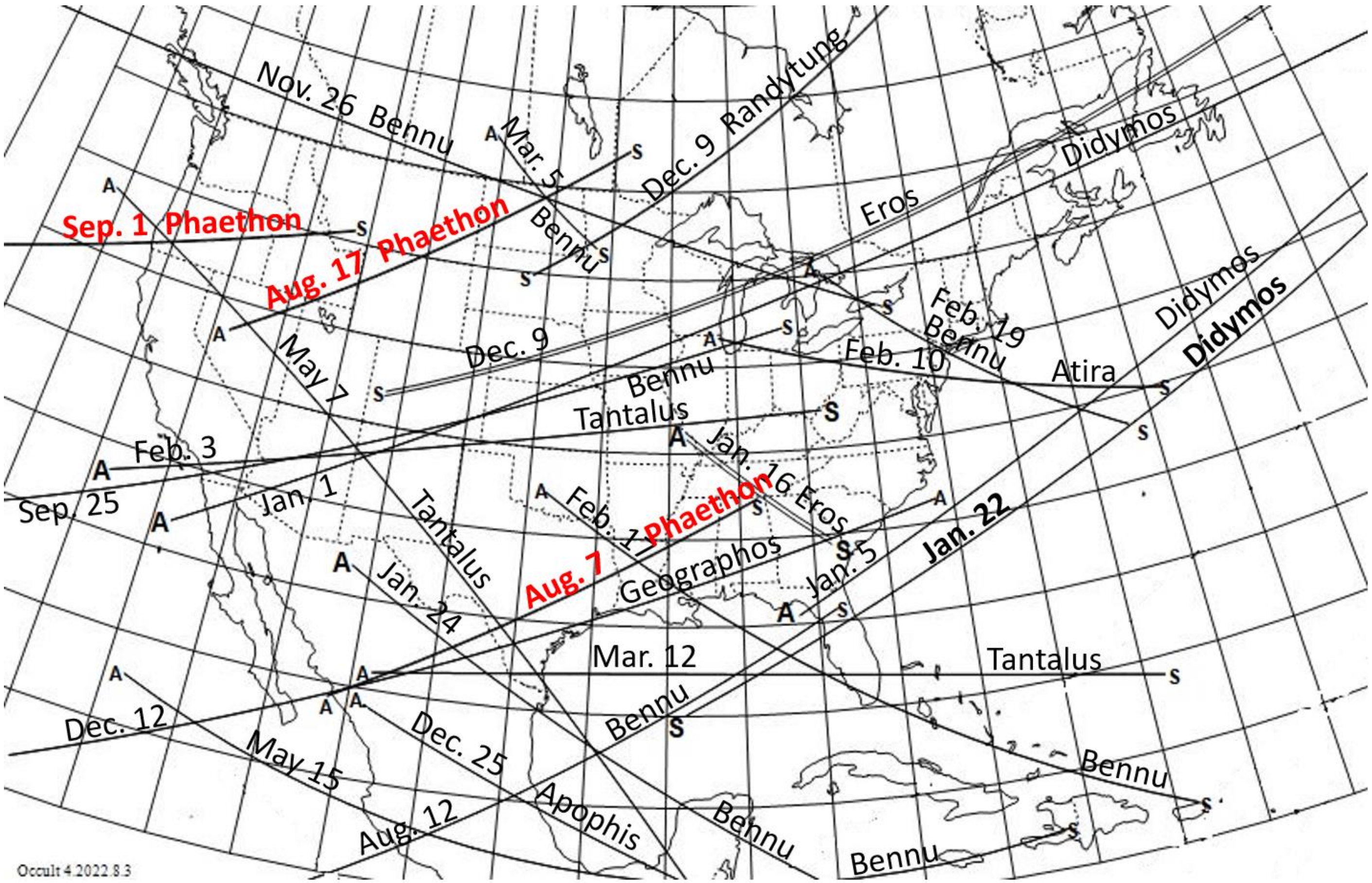




- Before the observation in October 2021, we asked the international occultation community to improve Phaethon's orbit and update the prediction. By the time of the October 2022 observation, I thought that Phaethon's orbit has been well determined, so we just used the usual software to make the prediction. That may be why we did not notice that Phaethon's occultation zone had shifted.
- As I recall, Phaethon's orbit was first improved and the prediction was carefully checked at the time of the 2019 observation. The position of the occultation zone did not shift much until the 2020 observation. Phaethon did not pass the perihelion during this period.
- Phaethon passed the perihelion between the 2021 and 2022 observations, which may have caused a slight orbit change, since Phaethon has been observed to be active near perihelion in the past.

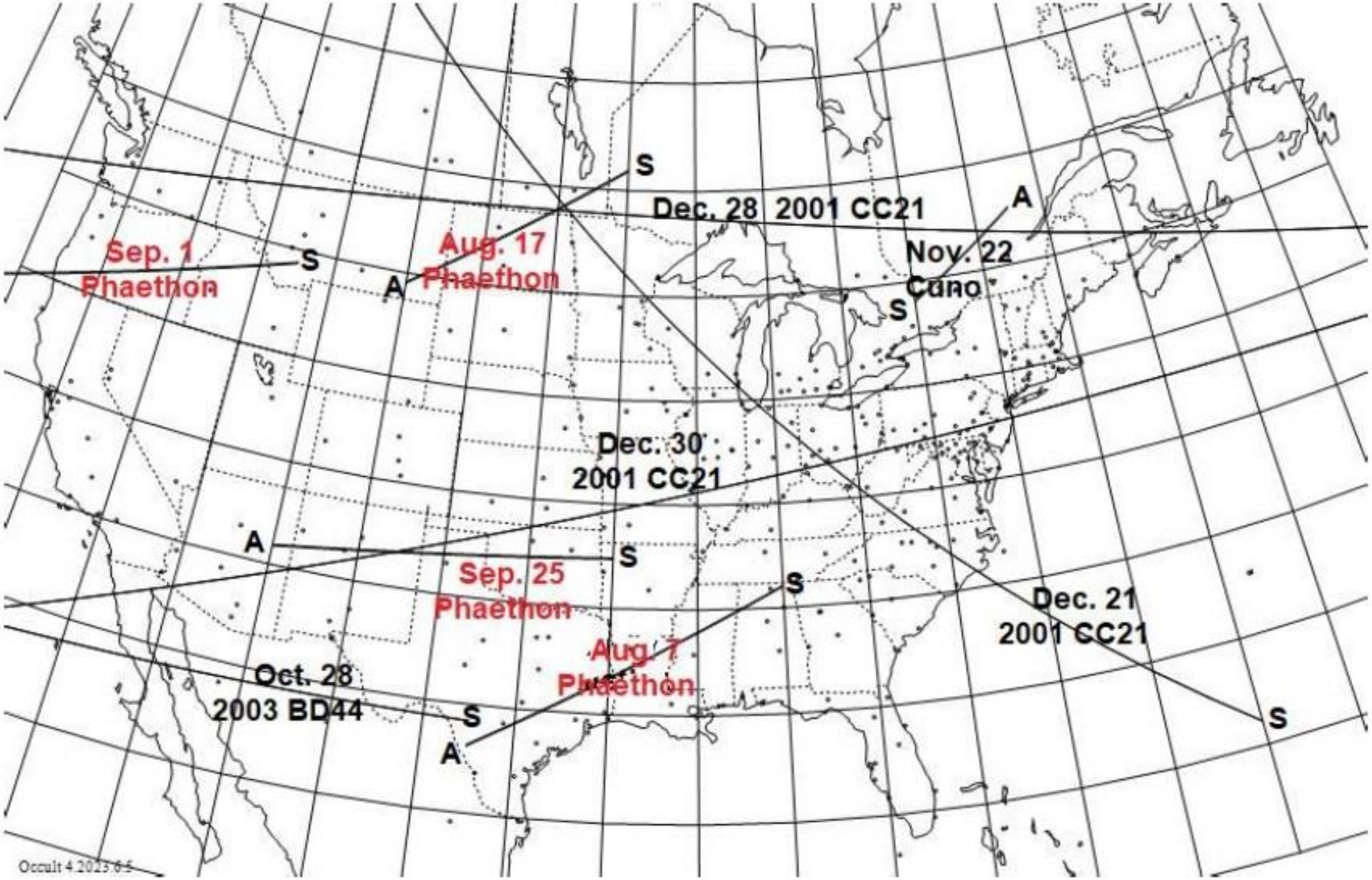
A lesson for the future is that astrometry for orbit improvement is essential before occultation observations.

Occultations by NEAs in North America during 2023
to mag. 12.0 (to mag. 13.0 for Phaethon; 3 chances for it highlighted)



This map is adopted from one that we published in the Royal Astronomical Society of Canada's Observer's Handbook for 2023. It is also available on IOTA's NEA occultations page at https://occultations.org/publications/rasc/2023/nam23NEAoccs.htm along with much more about NEA events worldwide. For more predictions, see https://occultations.org/publications/rasc/2023/ACM2023.htm . IOTA will prioritize the NEAs with uncertain futures given in ACM2023 #2312 presented on Monday in the NEO I session, & mission targets

The more important NEA events in North America during the 2nd half of 2023



2023

Date m	d	U.T. h	m	Diam km	Dur sec	Star mag.	Mag drop	Elon o	Star No.	d	RUWE <1.4	Asteroid No	Name	Moon Dist	ill	R.A. (J2000) h	m	s	Dec. o	'	"	Path
Aug	7	9	53	5.0	0.13	12.9	5.2	39	UCAC4 587-029902		0.95	3200	Phaethon	64	61	6	27	1.234	27	17	37.77	TX-AL
Aug	17	9	36	5.0	0.12	12.6	5.2	41	UCAC4 582-034437		1.15	3200	Phaethon	52	1	6	55	59.803	26	13	24.10	MT-ON
Sep	1	11	40	5.0	0.11	12.6	4.7	44	UCAC4 567-040387		1.00	3200	Phaethon	116	97	7	47	39.991	23	19	16.02	OR-MT
Sep	25	11	9	5.0	0.08	12.8	3.5	37	UCAC4 512-048208		1.25	3200	Phaethon	162	79	9	44	52.207	12	13	45.31	AZ-AR
Oct	28	12	2	1.4	0.15	10.2	11.5	129	UCAC4 551-016864	s	1.20	143404	2003 BD44	55	100	5	38	18.361	20	0	57.98	TX-Mex
Nov	22	22	43	3.4	0.09	10.9	8.1	46	UCAC4 343-184000	s	0.95	4183	Cuno	78	77	19	7	14.750	-21	32	38.70	ON-QC
Dec	21	10	27	0.6	0.09	8.4	8.4	174	TYC 1889-00569-1	s	0.95	98943	2001 CC21	71	68	6	8	23.762	28	58	36.15	NC-SK
Dec	28	4	1	0.6	0.09	10.1	6.9	168	UCAC4 604-023464		1.05	98943	2001 CC21	23	98	5	42	21.443	30	36	57.80	NS-WA
Dec	30	1	57	0.6	0.09	9.5	7.6	165	UCAC4 605-022488	d	badPM	98943	2001 CC21	48	91	5	34	53.984	30	59	41.00	NJ-Baja

Apophis will pass near the geosat ring on 2029 April 13

It will be about 3rd mag. as seen from Europe and Africa

The approach will be about 0.1 lunar distance,

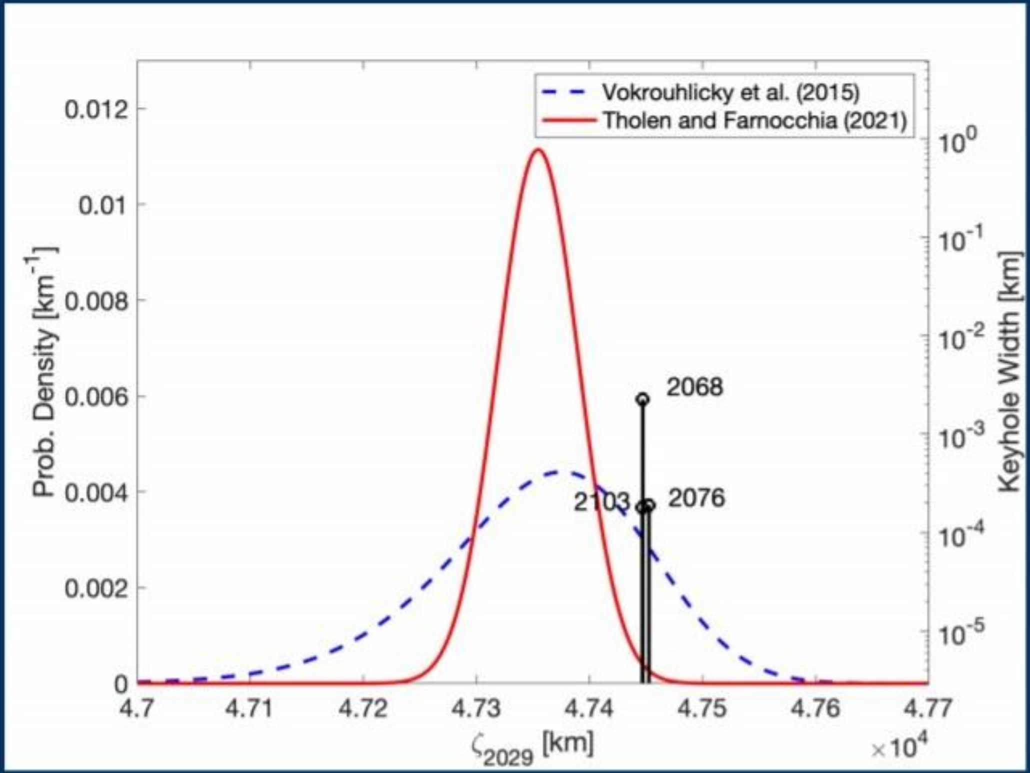
It's the closest approach by an asteroid this large in 1000 years

2013 radar observations showed Apophis to be ~340m across

An impact would destroy everything within 25 km, and produce severe damage out to 300 km from the impact point

Nasa said the Apophis asteroid no longer poses a threat to Earth within the next century

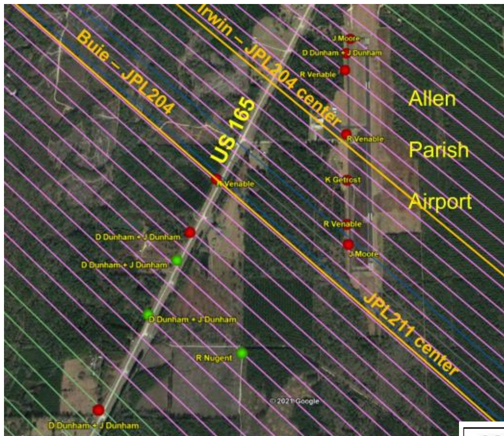
Keyhole Map for 2029 Close Approach



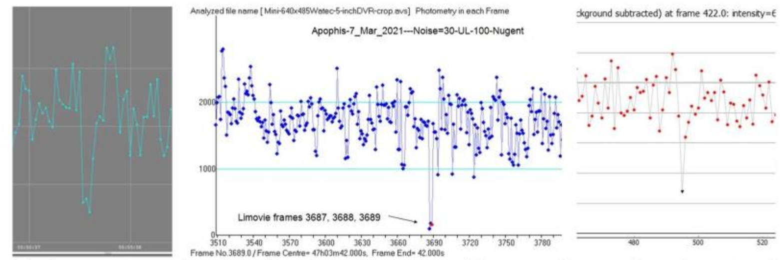
Tholen & Farnocchia, Planetary Defense Conference, 2021

2021 Occultations by (99942) Apophis from PDC 2021-1

The 1st observed event on March 7th benefitted from a JPL prediction based on radar data from Mar. 4-6; the star was 8.4-mag. NY Hydrae, an eclipsing binary with high Gaia RUWE.



Above, the 2 pre-pointed 8cm Dunham unattended systems that recorded positives; 3 others they deployed had misses.



Above, the 3 positive light curves for the March 7th . occultation.

Left: Stations near Oakdale, Louisiana with the planned lines; Green dots mark positive sites, red dots mark sites that had no occultation (negatives).

Right: Residuals from the first 5 Apophis occultations from the JPL 214a orbit that gave 0 weight to Mar. 7 since the star's Gaia RUWE was high. The high-precision orbit, with radar & occultations, retired the risk of impact with Earth for at least a century.

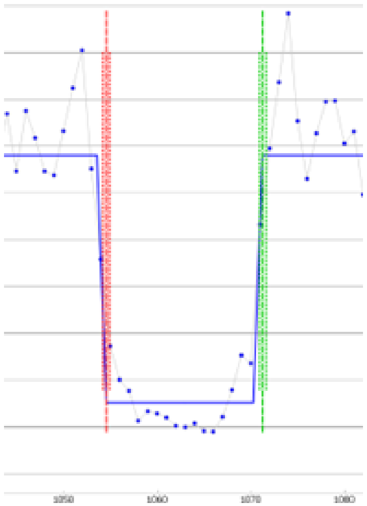
2021 Date	mag. [1]	Loc. [2]	Total #	# pos.	Δα [3]	Δδ [3]	Δt [3]	RUWE [4]
March 7	8.4	LA,OK,CO,BC	29	3	-11.0	+1.2	+0.17	1.45 [5]
March 22	10.0	FL,AL,IL	9	1	+0.4	-0.5	-0.02	1.15
April 4	11.0	NM	8	3	+0.3	-0.1	-0.01	0.90
April 10	12.6	Japan	2	1?	marginal detection, not used			
April 11	10.1	NM	3	3	+0.5	-0.5	-0.03	0.85

[1] This is the Gaia g magnitude of the occulted star.
[2] For location, the country is given, or 2-letter US State/Canadian Province codes.
[3] The O-C residuals are relative to JPL orbit 214a, in mas, but in seconds for Δt.
[4] The RUWE is for the Gaia 3rd Early Data Release (EDR3); values >1.40 indicate stars that are likely to have positional errors larger than the formal errors from the Gaia astrometric solution.
[5] The star is NY Hydrae, an eclipsing variable with a 4.8-day period.

Much information about past observed Apophis occultations ia at **http://iota.jhuapl.edu/Apophis2021.htm.**

2021 Occultations by (99942) Apophis from PDC 2021-2

The 1st observed event on March 7th benefitted from a JPL prediction based on radar data from Mar. 4-6; the star was NY Hydrae, Hydrae, an eclipsing binary with high Gaia RUWE. On 2021 Mar. 22, R. Venable recorded the occultation of a 10.0-mag. star from 5 locations with large pre-pointed telescopes in Florida (**below**); he covered the east side of the predicted (JPL207) path while others covered the west side. To the **right** is Venable with one of his 14-in. Fastar (f/2.1) SCT's with specially-built low mount that adds stability and facilitates quick set-up. His fence of telescopes extended just far enough east to catch the critical occultation observation (green dot, positive) while the others were negative (red dots). With this effort, Venable saved Apophis' accurate orbit that helped retire its risk of impact; the subsequent events listed on the previous slide secured the orbit. Venable's subsequent deployments of his systems have led to other NEA occultation successes, especially for Didymos and Dimorphos, see later Slides.

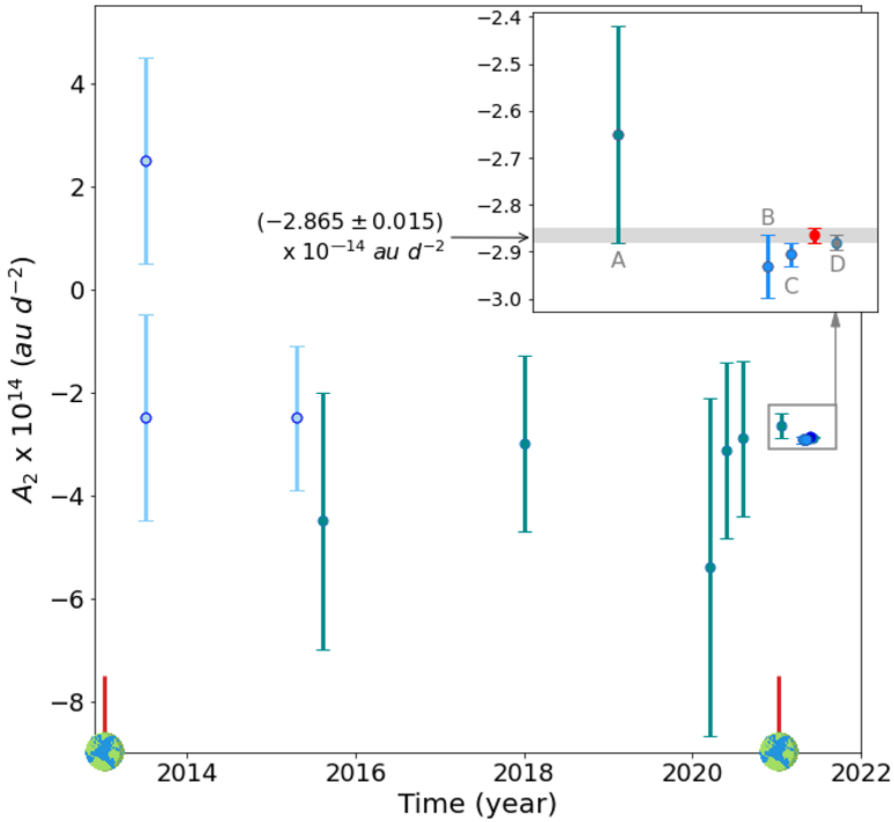


Venable's 2021 Mar. 22 stations, Yeehaw Jct., Florida

Above right, April 11 near Farmington, NM, light curve of the the occultation of a 10.1-mag. star by Apophis, by Kai Getrost, recorded with 100 frames per second with a QHY 174M GPS camera attached to a 20-inch Dobsonian telescope. Effects of Fresnel diffraction are evident.

See the next talk by Damya Souami for the remarkable Reduction of Apophis' orbital errors from the addition of IOTA's asteroidal occultation observations.

Occultations helped retire the risk of Apophis



Gaia Image of the week, 2021 Mar. 29. “Apophis’ Yarkovsky acceleration improved through stellar occultation” – D is the solution that adds the occultation results.

Evolution in time of our knowledge of the average Yarkovsky acceleration for 99942 Apophis. The light blue data represent the early theoretical estimates from approximate models of the physical properties of Apophis1. The other data are measurements enabled by the collection of more optical and radar astrometry. On the horizontal axis, close encounters with the Earth (enabling collection of accurate astrometry) are marked. The inset shows the last estimates compared to our value, in red, obtained from all the observations available on March 15, including the occultation observed on March 7, 2021. For more, see https://www.cosmos.esa.int/web/gaia/iow_20210329.

Improvement of Apophis Ephemeris from Occultations

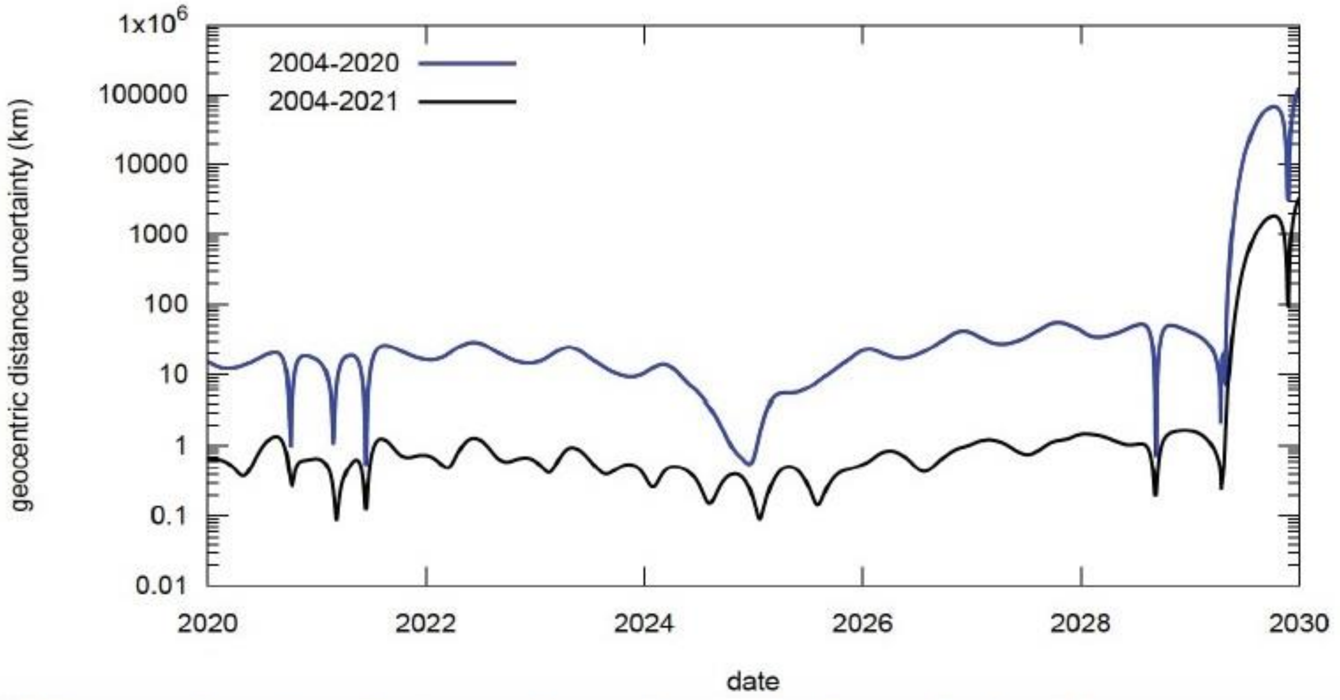
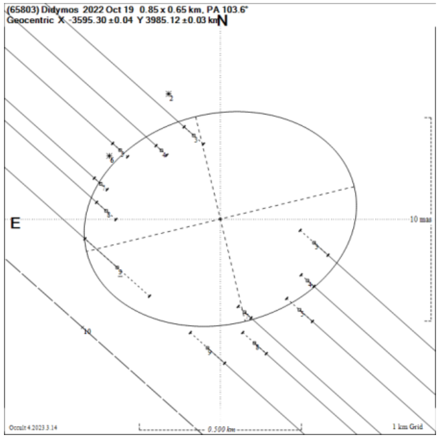
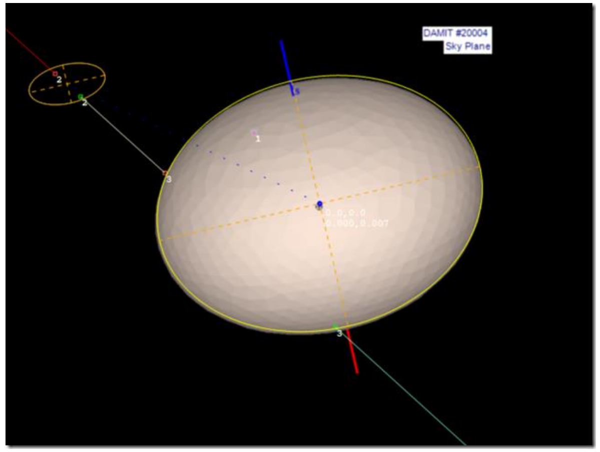


Figure 1 - Evolution of our knowledge of the 1σ uncertainty on Apophis' geocentric distance: using the (2004 - 2020) data and including the modelling of the Yarkovsky acceleration. Blue (upper curve, only optical astrometry and radar).. In black (lower plot): all data is used including the occultation derived astrometry. (D. Souami, ACM2023)

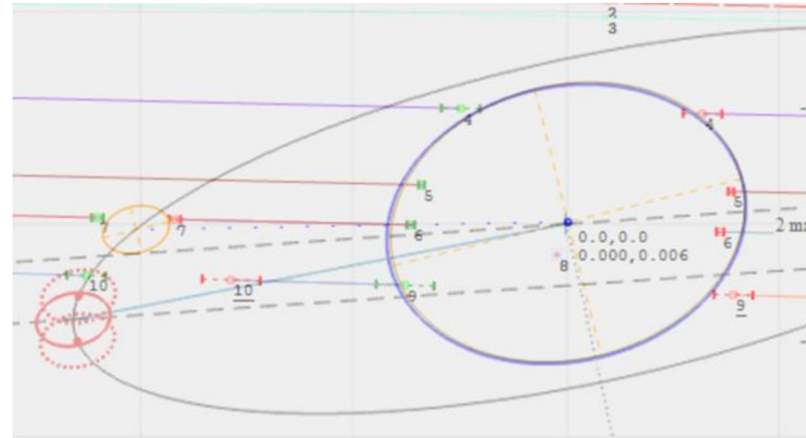
Occultations by the Didymos/Dimorphos System, 2022-2023



Sky plane plot of the Didymos occultation of an 11.2-mag. star in Japan, 2022 Oct. 18, one of the better-observed Didymos occultations.

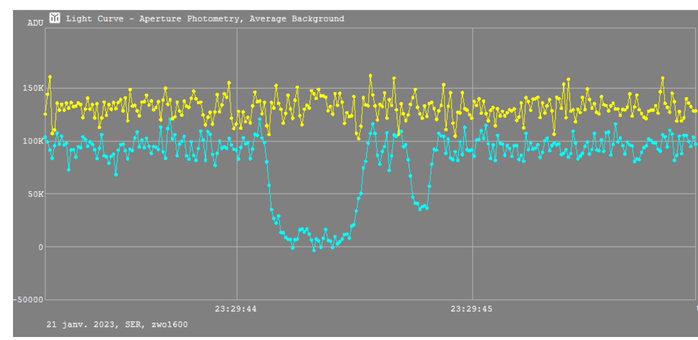


Sky-plane plot of the first observed occultation by Dimorphos, upper left, shortly before the occultation by Didymos, R. Venable, Crawford, FL, 2022 Oct. 19.



Sky plane plot of the occultation of a 9th-mag. star by Dimorphos and Didymos, observations organized by ACROSS in France by P. Tanga et al., 2023 Jan. 21.

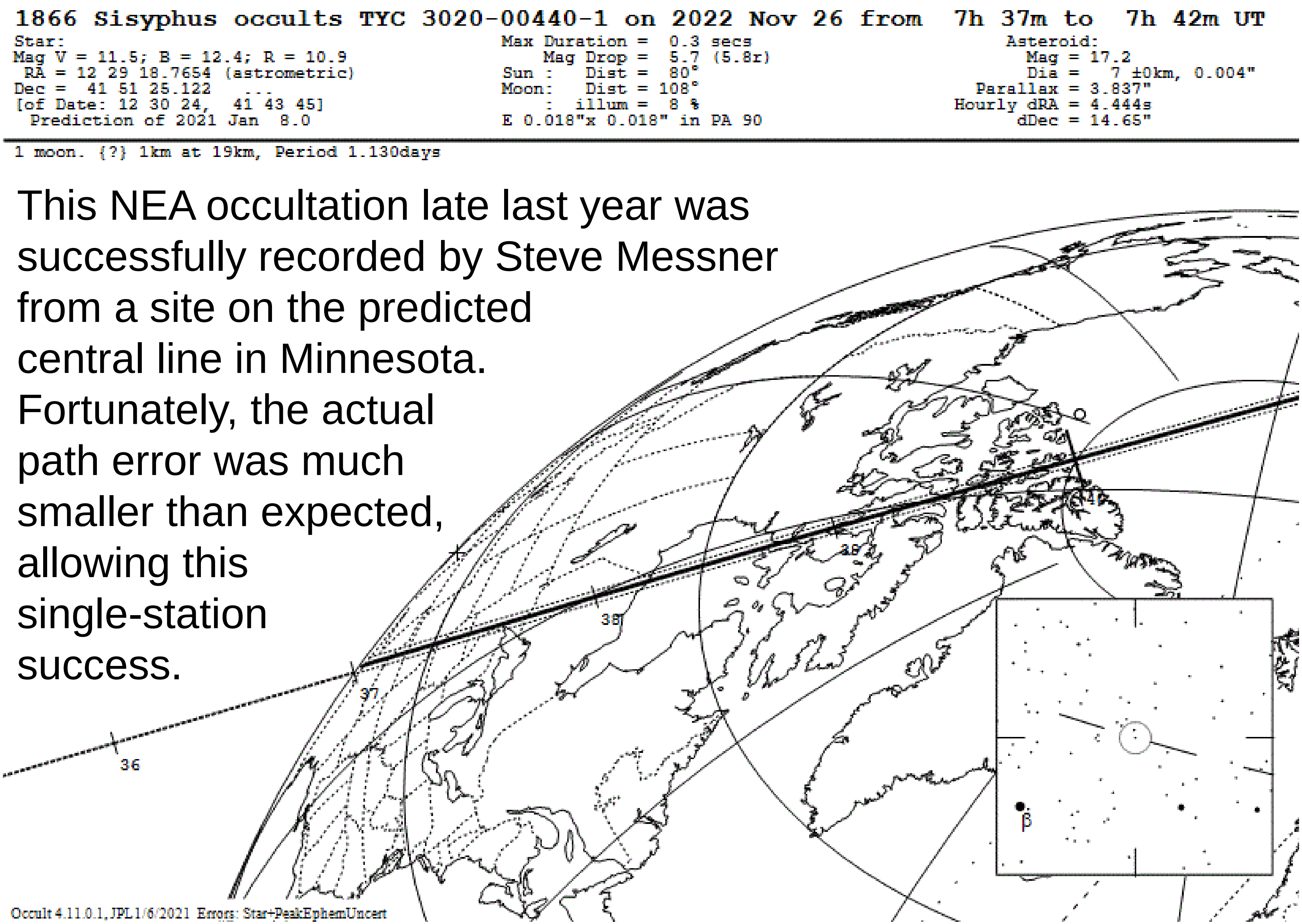
Far right: Lionel Rousselot's light curve of the 2023 Jan 21 Occ'n by Didymos and Dimor-phos near Perigueux, France



Several other Didymos occ'ns have been observed around the world; for more about results from them, especially on the orbits, see papers by Chesley (PDC 2023; ACM 2023); and about ACROSS by Souami et al. (ACM 2023).

More Didymos/Dimorphos occultations can be observed in 2024.

This NEA occultation late last year was successfully recorded by Steve Messner from a site on the predicted central line in Minnesota. Fortunately, the actual path error was much smaller than expected, allowing this single-station success.

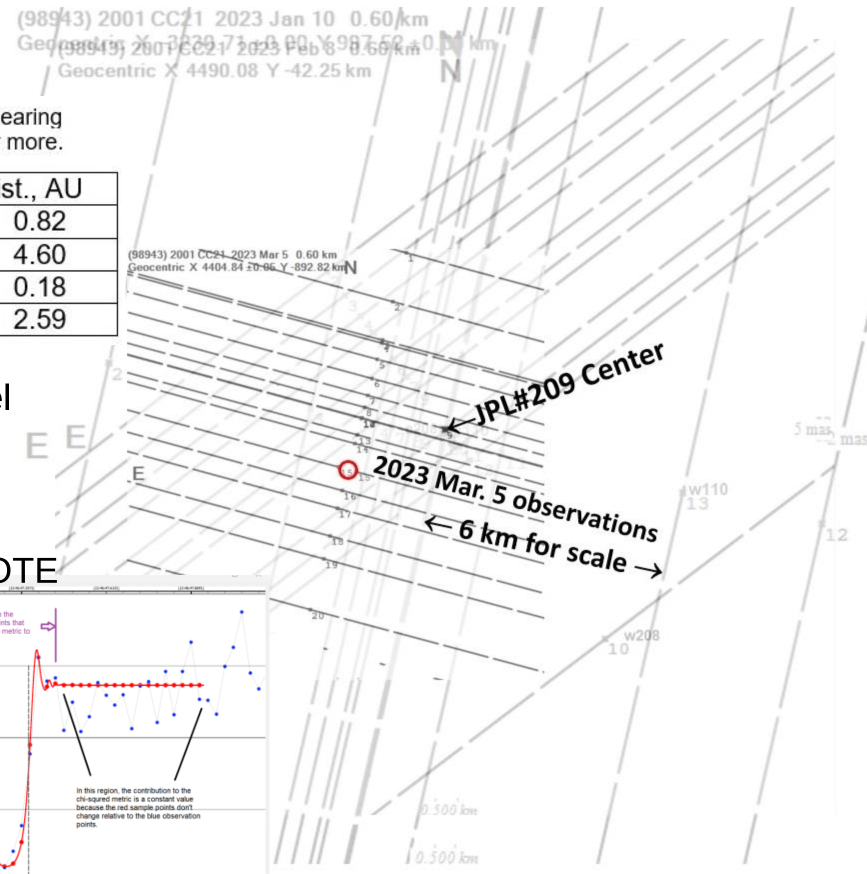


1st Observed Occultation by 2001 CC21, NEA flyby target of Hayabusa2

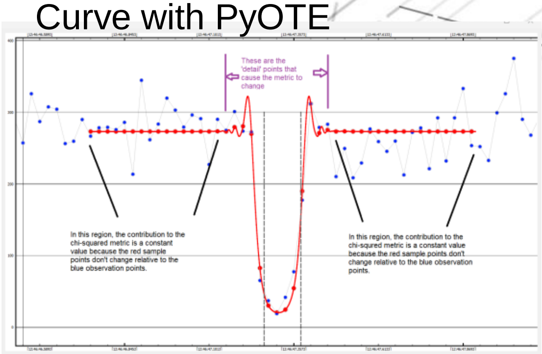
Sky Plane Plot for 2023 Mar 05 occultation observations in Japan with past observations

Distance for 4 NEA's beyond which diffraction smearing becomes significant; see our PDC 2023 paper for more.

NEA	Rast, m	FL, m	Dist., AU
Apophis	169	192	0.82
Didymos	400	455	4.60
Dimorphos	80	91	0.18
2001 CC21	300	341	2.59



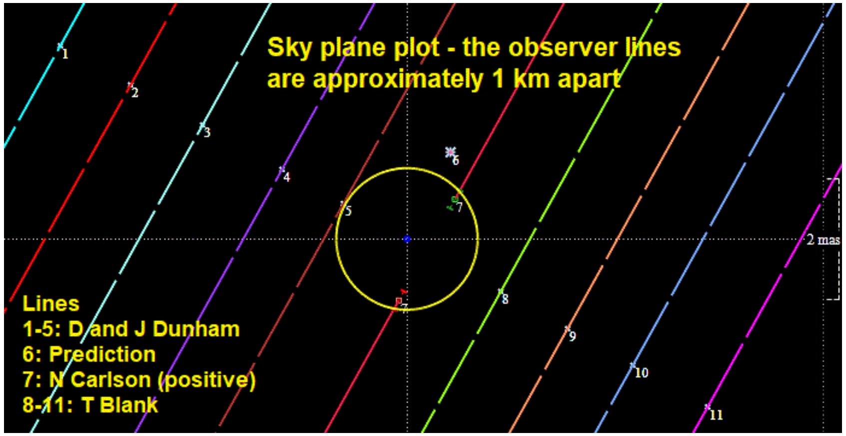
Below: Fresnel Diffraction Model fitted To Ida's Light Curve with PyOTE

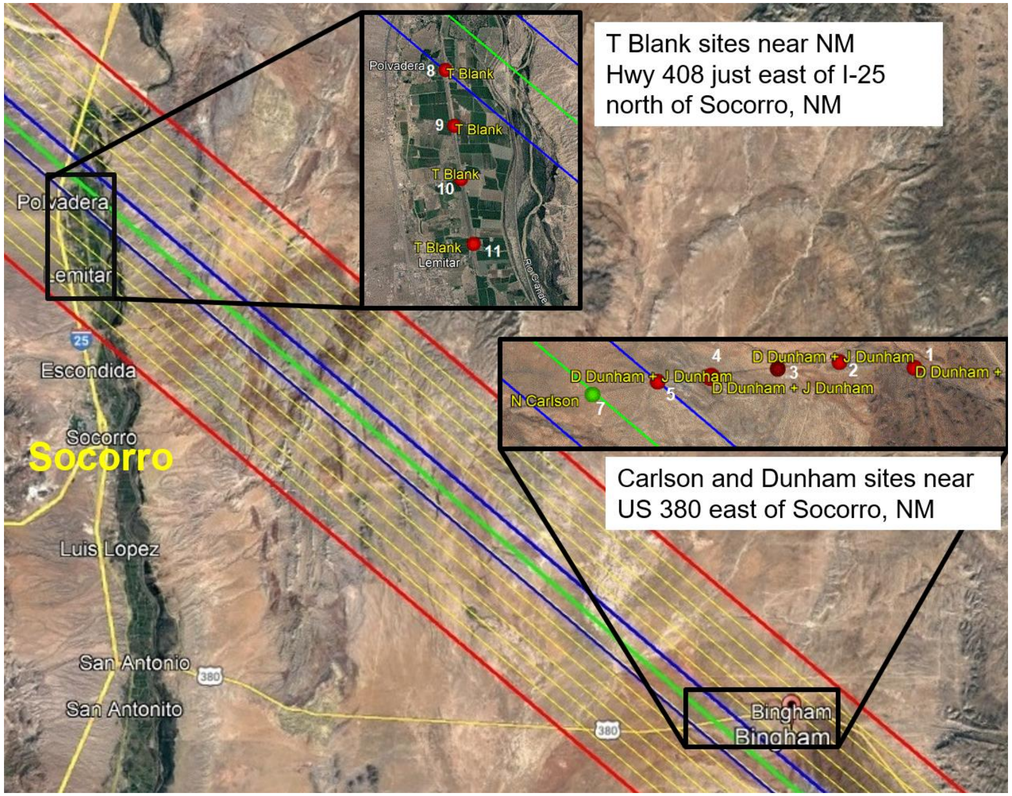


The previous observations, also in Japan, were all misses (negative), made on 2023 Jan. 10 and Feb. 8.

The red circle shows the location of 2001 CC21 according to Miyoshi Ida's observation on 2023 March 5, in a gap of the coverage by the earlier observa-tions.

Occultation of 8.4-mag. SAO 164452 (= HIP 106281) by (2102) Tantalus, 2023 May 7





(2102) Tantalus is a 1.4-km PHA in a highly inclined (64° to the ecliptic) orbit that won't be in radar range again until 2038. This bright event provided a chance to record an occultation with easily-transported 8cm systems, like those we used for Apophis in 2021 March. IOTA members Ted Blank, and David and Joan Dunham, deployed and pre-pointed 10 of these systems near Socorro, N. Mex., to cover most of the 1-σ path error zone while Norm Carlson set up his larger (20cm) scope on the predicted center. We used a predicted 2-km diameter for our planning but later we found a better recently-published radar diameter of 1.4 km; also, the real error was much less than 1-σ. Next time, we'll have more concentration near the center.
On 2022 Nov. 26, IOTA member Steve Messner recorded the 1st occultation by 7-km NEA (1866) Sisyphus in Minn.

Discovery and confirmation of the satellite of (4337) Arecibo, 2021

Discovery by Peter Nosworthy & Dave Gault, May 19, west of Sydney, NSW, Australia
Confirmation by Richard Nolthenius and Kirk Bender, June 9, central California, USA

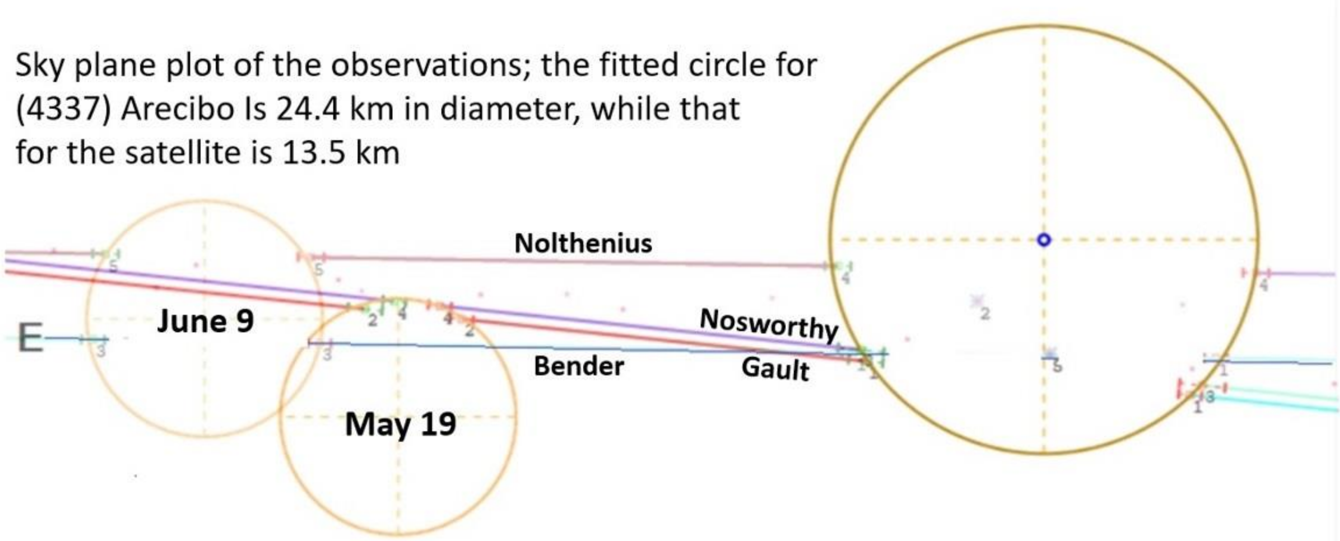
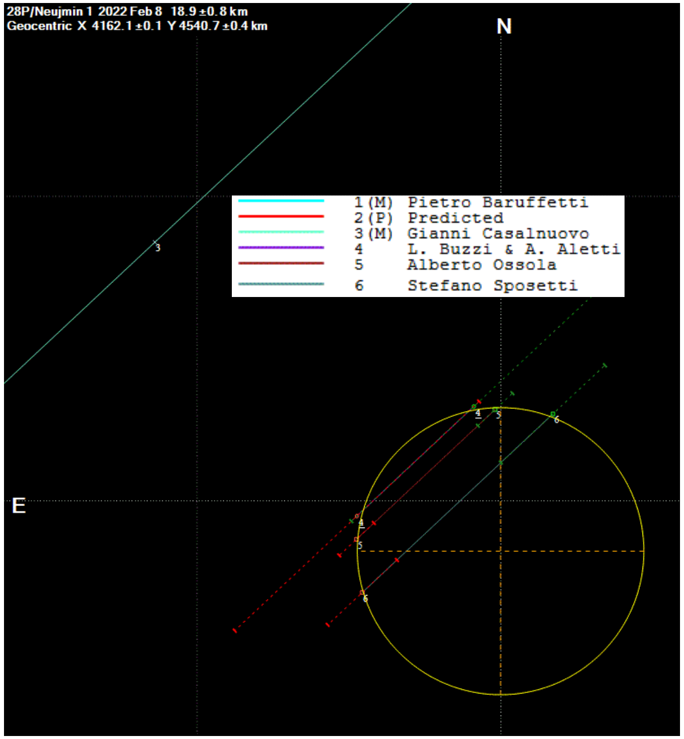
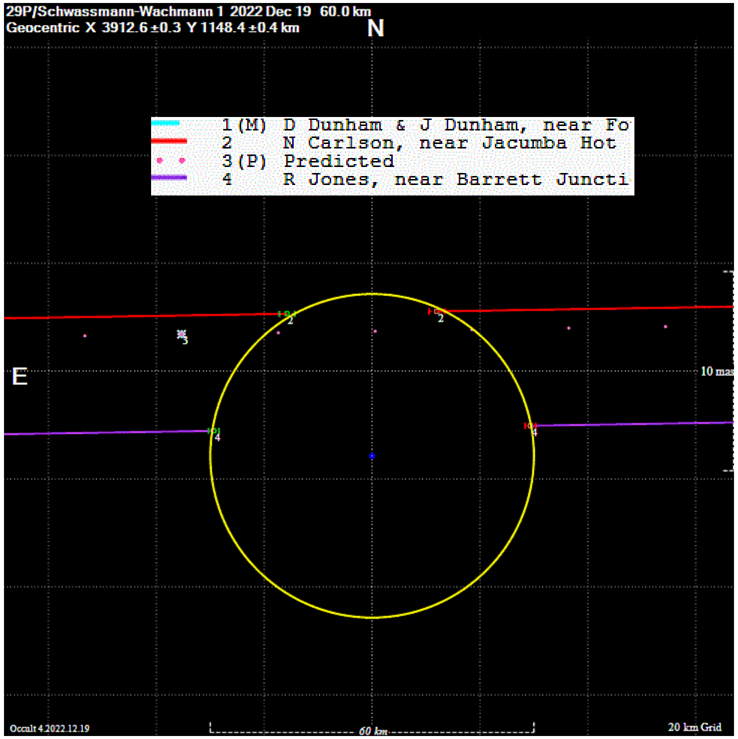


Diagram by Dave Herald using the Occult4 program. For more, including the videos, please visit **https://www.youtube.com/watch?v=w_Cc5Or1FFw** . Gaia confirmed the duplicity from the small wobble of the center of figure, finding a period of 1.3 days. On 2022 May 16, Nosworthy and Gault found from another occultation that (172376) 2002 YE25 is likely a binary with ~3-km objects about 15 km apart; see

http://hazelbrookobservatory.com/ye25/#:~:text=Introduction,is%20probably%20two%20smaller%20objects.

IOTA Observations of Occultations by Comets

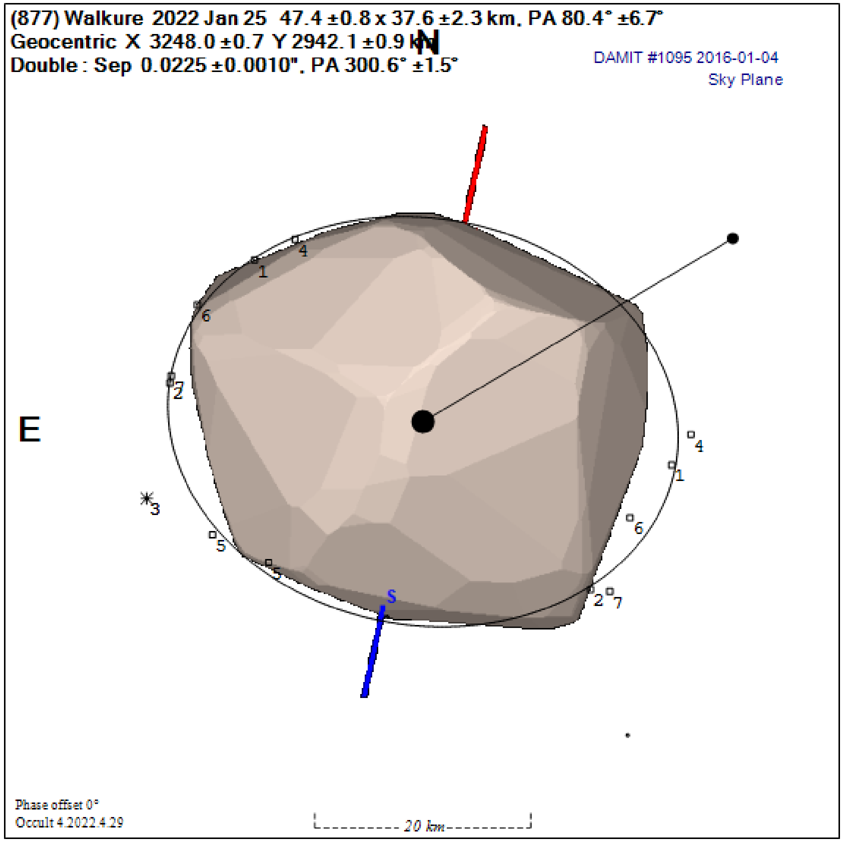


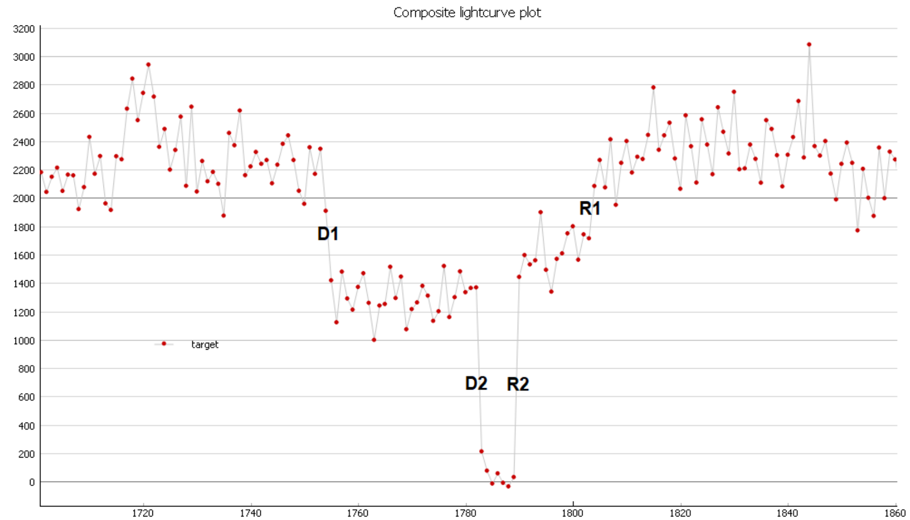


On 2022 February 8, 3 amateur observers in Europe working with IOTA obtained what we believe to be the first unambiguous observations of an occultation by the nucleus of a comet, 28P/Neujmin 1.

On 2022 Dec. 19, IOTA observers worked with Lucky Star & others to record the 1st multi-chord occultation by 29P/Schwassman-Wachmann 1 (SW1). IOTA observed at least 2 more SW1 events, on 2022 Dec 29 in NM and 2023 May 7 in the UK. But for the best info. about SW1 occultations, see Buie et al.'s ACM 2023 E-Poster #2445.

2022 Jan. 25 Occultation of SAO 110026 by (877) Walkure, Close Double Star Resolved and Accurately Measured





In 1984, D. Evans recorded a **lunar occultation** of SAO 110026 (= UCAC4 480-002385) photoelectrically at McDonald Obs., showing the star to likely be double with a sep. of 0.05″. For the 2022 event by Walkure, **Paul Maley** video recorded occultations of **both** components, shown in his light curve above. Also observing near Tucson was Norm Carlson, while D. and J. Dunham deployed 3 pre-pointed 8cm systems. On the left is the sky plane Plot of the timings, with station numbers: 1, Dunham1, Picacho Peak; 2, Carlson; 3, the predicted center; 4, Maley star 1; 5, Maley star 2; 6, Dunham2, Rillito; and 7, Dunham3, Cortaro. The Walkure shape model used for the fit is DAMIT #1096. IOTA has discovered many doubles during asteroidal occultations, see MNRAS **https://arxiv.org/abs/2010.06086.**

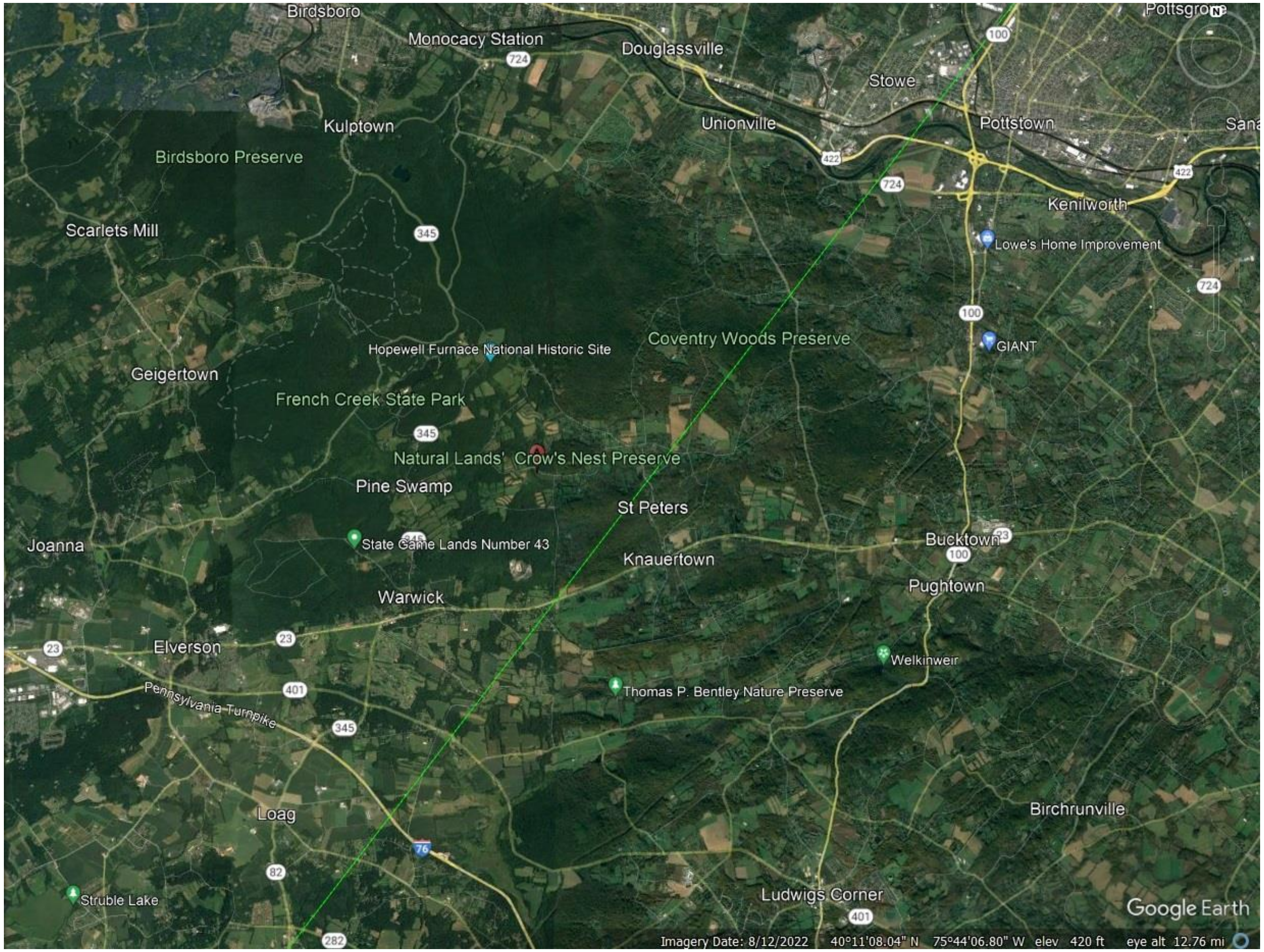
Total lunar occultations for ChesMont AS, Elverson, PA

```
Occultation prediction for Elverson PA ChesMont AS
E. Longitude - 75 45 23.0,  Latitude  40 11 18.0,  Alt.  145m;  Telescope dia 20cm;  dMag 0.0

       day  Time      P   Star  Sp  Mag  Mag    % Elon Sun  Moon   CA   PA  VA  AA
 y  m  d  h  m   s         No  D    v    r V  ill      Alt Alt Az   o    o   o   o
23 Jul 12  7 24 33.8 R   93209 K0  7.0  6.4   27-  62     19  82  49N 295 348 310
23 Jul 12  7 46 31.5 r   93213cA0  8.6  8.5   26-  62     23  86  78S 243 296 257
     93213 is double: AB 8.8 12.3 0.27"  43.8, dT = +0.49sec
     93213 is a close double. Observations are highly desired
23 Jul 12  8 51 48.0 R     442SA0  6.7        26-  61  -9 36  96  89N 256 309 270
   R442 = 50 Arietis
       442 is triple: AB 6.80 9.92 2.40"  48.6, dT = +5sec : AC 6.8 12.9 147" 208.1, dT = -218sec
       442 is a close double. Observations are highly desired
23 Jul 12 16  1 20   M     465 K2  4.4  3.8s  24-  59  67 45 257   6N 340 287 354
   R465 = Botein = delta Arietis
       465 = NSV 1066, 4.33 to 4.37, V
23 Jul 12 16  1 28   Gr    465 K2  4.4  3.8s  24-  59  67 45 ** GRAZE: CA  5.8N; Dist. 48km in az. :
23 Jul 13  6 56 39.5 r   76221kF0  8.4  8.2   18-  50      8  68  54N 296 345 306
23 Jul 13  8 19 18.7 R     573pK0  6.7  6.1S  18-  50     23  80  80S 249 304 260
       573 is double: ** 7.6 7.6 0.10"  90.0, dT = +0.18sec
       573 has been reported as non-instantaneous (OCc1222). Observations are highly desired
       573 = NSV 15816, 6.67, , Type VAR:
23 Jul 15  7 47 43.2 R     849cG9  6.5  5.9    5-  27      2  57  44S 229 274 230
       849 is double: ** 7.3 7.3 0.10"  90.0, dT = +0.15sec
       849 has been reported as non-instantaneous (OCc 210). Observations are highly desired
23 Jul 15  8 16 13.4 r   77367 A5  9.7  9.5    5-  27      7  61  61S 246 295 247
23 Jul 15  8 19 28.6 r X 76471     10.2 10.0   5-  27      8  61  83N 283 331 284
23 Jul 15  8 34 47.2 R   77384cG0  9.2         5-  27 -12 10  63  67N 298 348 299
     77384 is double: AB 9.88 9.94 0.45"  48.3, dT = +0.37sec
     77384 is a close double. Observations are highly desired
23 Jul 15  8 41 11.2 d X  7382 F8  9.3  9.1    5-  27 -11 11  64   4N   1  52   2
23 Jul 15  8 41 47.9 R   77389 A0  8.1  8.1    5-  27 -11 11  64  58N 307 358 308
23 Jul 15 14  7  9.0 d     890cA0  4.6  4.6s   5-  25  47 70 122 -42N  50  98  50
   R890 = 136 Tauri
       890 is double: ** 4.8 6.3 0.050" 270.0, dT = -0.13sec
       890 has been reported as non-instantaneous (OCc 206). Observations are highly desired
       890 = NSV 2696, 4.50 to 4.61, V
23 Jul 15 15 23 27.5 R     890cA0  4.6  4.6s   4-  24  61 78 178  74N 295 296 294
   R890 = 136 Tauri
       890 is double: ** 4.8 6.3 0.050" 270.0, dT = -0.16sec
       890 has been reported as non-instantaneous (OCc 206). Observations are highly desired
       890 = NSV 2696, 4.50 to 4.61, V
23 Jul 21  1 31  3.3 d   99115 G5  8.5  8.0    9+  36 -11  9 279  21S 175 125 155
23 Jul 21  1 36 49   M   99123 K0  7.3  6.5    9+  36 -12  9 280  12N  29 338   8
```

See IOTA's Mid-Atlantic Occultations page:
http://iota.jhuapl.edu/exped.htm (includes some lunar grazes).
Compute your own predictions using IOTA's free Occult program, see
http://www.lunar-occultations.com/iota/2023iotapredictions.pdf .

Lunar Grazing Occ'n in Elverson, PA area



The graze, of 7.7-mag. SAO 109599, will occur Aug. 6 at 2:08 am EDT 15° from the north cusp of the 73% sunlit waning Moon, at alt. 37° in the southeast (az. 119°). No occultation will occur at the green northern limit line shown since the lunar profile is low, see http://iota.jhuapl.edu/20230806SAO109599.jpg observing stations need to be 2.0 to 3.0 km southeast of the line to see it.

Lunar Grazing Occ'n Aug. 6, wider area view

A file that can be used with Google Earth (GE) to plot the northern limit line is at http://iota.jhuapl.edu/20230806SAO109599.kmz . Use GE's measuring tool (click on the ruler symbol at the top of the GE display) to find locations 2.0 to 3.0 km southeast of the line. High magnification (large f-ratios), clean optics, and good transparency are needed to observe stars like this in the glare of a gibbous Moon. The star may be a close double.

Asteroidal occultations over/near Elverson, PA - OW

Occult Watcher, ver. 5.2.0.0 - Home (UTC -04:00 DST)

Synchronise now | Configuration | Add-ins | Help

Asteroid Name	Event Date, UT	Rank	Travel Dist.	Feed	Star Mag...	Max Dur...	Magn Drop...	Probability
All Events								
(364) Isara	Fri 14 Jul, 04:39 UT	99	43 km ...	NALowMag	14.2	2.3	0.3	12.5%
(268) Adorea	Sun 16 Jul, 01:55 UT	100	251 km ...	OwPersonal	13.7	21.7	0.7	0.0%
(1154) Astronomia	Mon 17 Jul, 04:18 UT	100	25 km ...	AZevents	11.2	4.9	3.8	92.3%
Europa (II)	Wed 19 Jul, 06:46 UT	100	66 km ...	WWPlanetsM...	15.7	103.3	0.0	100.0%
(533) Sara	Thu 20 Jul, 04:11 UT	97	48 km ...	NALowMag	12.0	3.6	2.3	7.8%
(2466) Golson	Thu 27 Jul, 07:13 UT	100	198 km ...	NALowMag	13.0	3.0	2.3	0.0%
(459) Signe	Fri 28 Jul, 08:51 UT	100	155 km ...	NALowMag	12.9	2.0	1.9	0.0%
(20) Massalia	Sun 30 Jul, 02:10 UT	100	217 km ...	IOTA	12.2	46.2	0.3	2.6%
(820) Adriana	Mon 31 Jul, 07:22 UT	99	79 km ...	IOTA	10.1	8.6	5.1	4.4%
(491) Carina	Thu 03 Aug, 09:38 UT	100	258 km ...	NALowMag	12.9	2.4	2.3	0.0%
(2365) Interkosmos	Fri 04 Aug, 00:54 UT	100	97 km ...	CentralEurope	10.2	1.3	5.4	0.0%
(1166) Sakuntala	Sun 06 Aug, 03:15 UT	97	153 km ...	NALowMag	12.7	2.3	1.5	0.0%
(8726) Masamotonasu	Mon 07 Aug, 03:31 UT	86	200 km ...	AZevents	12.8	1.2	4.8	0.0%
(899) Jokaste	Thu 17 Aug, 07:01 UT	98	51 km ...	NALowMag	11.0	1.1	4.2	0.6%
(1144) Oda	Fri 18 Aug, 09:20 UT	100	132 km ...	NALowMag	12.8	1.5	3.9	0.0%
(1191) Alfaterna	Mon 21 Aug, 09:31 UT	100	31 km @0°	NALowMag	13.0	1.4	3.7	40.1%
(195) Eurykleia	Wed 23 Aug, 06:40 UT	100	40 km ...	NALowMag	13.2	6.3	1.7	87.7%

L [Community Tags] R

you | center | shadow | 1-sigma | 2 & 3-sigma limits | Horizons (JPL#59)

(1154) Astronomia occults TYC 6864-00325-1

Position: In the shadow, 25 km from the central line

There are currently 4 announced stations for this event.
None of them are yours.

Event time: 04:18:15 UT
Error in time: 3 sec
Max duration: 4.9 sec

Combined magnitude: 11.2 m
Star magnitude: 11.2 m
Magnitude drop: 3.8 m

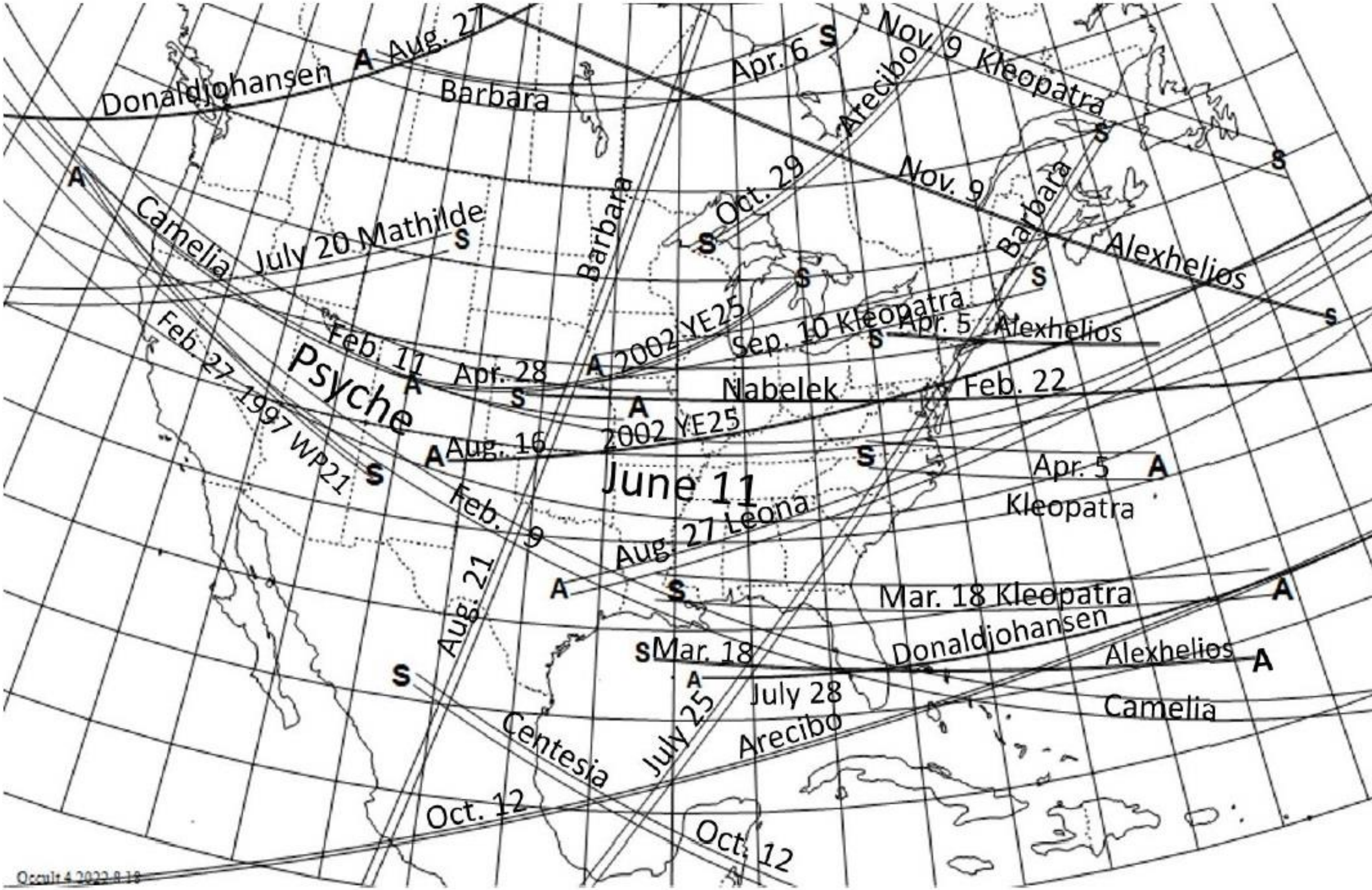
Constellation: Sagittarius
Star altitude: 24° @179°
Sun altitude: -28°

Moon: (below horizon)

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

Computed with Occult Watcher, a free download from http://www.occultwatcher.net/ - you can set magnitude and distance limits to filter out events you are less likely to try.

The best occultations of stars by Special Main-Belt Asteroids in North America during 2023



From the RASC Observer's Handbook and https://occultations.org/publications/rasc/2023/nam23MBspecialoccs.pdf.

Table of information for events on the map on the previous slide.

2023 OCCULTATIONS BY SPECIAL MAIN-BELT ASTEROIDS

Date	UT	Occulting Body	Star	Mag.	RA (2000) h m s	Dec ° ′ ″	ΔMag.	Dur. s	Path
Feb. 9	06:08	957 Camelia	UCAC4 425-048350	13.3	08 39 41.6	–05 05 33	1.2	6.5	BS-CA
Feb. 11	10:40	957 Camelia	UCAC4 426-047968	13.7	08 37 57.0	–04 56 29	0.9	6.6	IL-OR
Feb. 22	01:30	4552 Nabelek	TYC 1247-00212-1	12.8	03 36 01.0	+21 44 22	5.8	0.3	KS-DE
Feb. 27	12:44	33074 1997 WP21	UCAC4 340-175407	12.6	18 55 07.6	–22 08 29	6.4	0.6	CA-NM
Mar. 18	01:00	Alexhelios	TYC 0634-00190-1	10.7	02 19 49.1	+10 35 22	1.5	0.20	FL-BS
Mar. 18	01:00	216 Kleopatra	TYC 0634-00190-1	10.7	02 19 49.1	+10 35 22	1.5	2.9	LA-FL
Apr. 5	00:48	216 Kleopatra	UCAC4 514-004708	12.4	02 57 59.8	+12 41 49	0.5	2.7	VA-NC
Apr. 5	00:48	Alexhelios	UCAC4 514-004708	12.4	02 57 59.8	+12 41 49	0.5	0.19	NY-LI
Apr. 6	09:11	234 Barbara	UCAC4 415-122294	13.9	19 19 54.0	–07 00 60	0.6	2.0	AB-ON
Apr. 28	09:17	172376 2002 YE25	UCAC4 432-115773	12.1	22 14 10.4	–03 41 46	8.8	0.12	CO-MI
Jun. 11	05:53	16 Psyche	UCAC4 391-062150	13.6	14 50 37.7	–11 56 48	0.1	28.3	NC-OR
Jul. 20	10:04	253 Mathilde	UCAC4 531-006629	13.1	03 35 31.9	+16 08 10	2.1	1.8	CA-MT
Jul. 25	07:00	234 Barbara	UCAC4 416-141013	11.9	20 14 26.2	–06 57 13	0.3	5.6	NB-Mex
Jul. 28	02:52	52246 Donaldjohanson	TYC 5234-00643-1	11.5	22 48 20.6	–01 08 58	8.3	0.6	DZ-FL
Aug. 16	02:49	172376 2002 YE25	UCAC4 488-143179	13.0	22 39 09.8	+07 32 19	6.5	0.3	NJ-NM
Aug. 21	05:16	234 Barbara	TYC 5750-00865-1	10.7	19 58 20.0	–14 41 46	0.9	5.9	ON-Mex
Aug. 27	06:23	52246 Donaldjohanson	UCAC4 438-122513	12.3	22 25 23.5	–02 35 50	6.7	0.3	SK-BC
Aug. 27	07:01	319 Leona	UCAC4 525-012493	13.8	05 21 37.5	+14 51 37	2.0	2.2	TX-NC
Sep. 10	08:59	216 Kleopatra	UCAC4 497-050188	13.1	08 21 04.9	+09 15 05	0.4	3.2	IA-ME
Oct. 12	01:09	513 Centesima	TYC 5749-00630-1	8.2	20 21 10.9	–11 45 55	6.6	4.8	Mex
Oct. 12	07:20	4337 Arecibo	UCAC4 537-005401	12.6	03 05 18.8	+17 22 48	5.3	1.7	BS-Mex
Oct. 29	23:51	4337 Arecibo	UCAC4 534-004986	11.7	02 53 22.8	+16 40 34	5.8	1.3	QC-MI
Nov. 9	08:59	Alexhelios	UCAC4 451-048971	12.7	09 38 44.5	+00 07 14	0.6	0.4	SK-NS
Nov. 9	08:59	216 Kleopatra	UCAC4 451-048971	12.7	09 38 44.5	+00 07 14	0.6	5.9	QC-NL

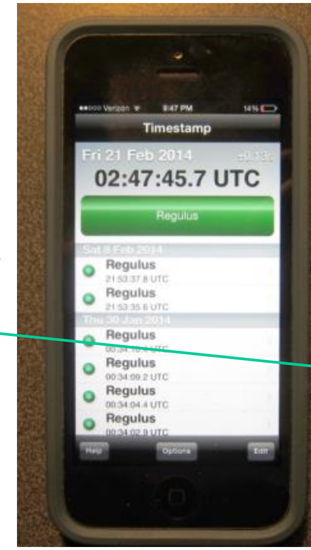
Extra cost for equipment for observing occultations

- If you have a telescope and cell phone, - **$0** – for visual observing. It's best to use 2 cell phones, one to record and one to generate audible time ticks, like those from the "Time The Sat" app. Time to about 0.1s is available with other free apps, like "GPS Test" -Androids and "GPS Diagnostic" –iPhones (they also give geographical coordinates), & web sites like www.time.gov, but they don't have audible signals.
- If you have an astronomical CCD and computer to record images with it, - **$0** – using the drift scan method. Use Dimension 4 or similar to synch your computer clock to accurate UT time 2 to 3 minutes before you start your exposure for the occultation. http://www.asteroidoccultation.com/observations/DriftScan/Index.htm
- If you have a computer but not a CCD, for video, - **$20** – for a device to mount one of the cell phones to the eyepiece of the telescope and the other phone for time, like the first option; see https://www.youtube.com/watch?v=1Df34Hwsm4M .
- Better than a cell phone (gain 3+ magnitudes), -**$224** – for a sensitive camera (IOTA Runcam), Startech frame grabber, Supercircuits PA6 microphone, TAB adapter, & 9V battery to record cell phone (or WWV, if you have a shortwave radio) time ticks.
- For video time insertion (more convenient for analysis), the best option is the IOTA-VTI for **$279**. The British GPSBOXSPRITE3 video time inserter costs £120 but doesn't have the IOTA-VTI's error checking.
- **Use whatever you have – ANY observation is much better than none!**

Visual Timing with Shortwave Radio (for WWV) and cassette audio tape recorder (now can use cell phone video, for the audio recording, & "Time the Sat" app for audible time signals)

Visual timing

- Best: Smartphone timing app which syncs to UTC via NNTP



"Timestamp" by Emerald-Sequoia for iPhone

"Time The Sat" satflare.com for Android

- Stopwatch

- Cellphone stopwatch app (elapsed time only)
- Video or CCD is preferred, but any timing is better than no timing!

More information on using the "Time the Sat" app is on the next page, including how to obtain the most accuracy (smallest time error), and generate audible time ticks. I assume that "Timestamp" has the same capabilities, but I don't have an iPhone so I can't say.

Using “Time The Sat”

“Time The Sat”
satflare.com
for Android

I assume that “Timestamp” by Emerald-Sequoia has capabilities similar to those that I describe below for “Time the Sat”, but I don’t have an iPhone so I can’t test it.

With “Time the Sat”, go to the 3 dots in the upper right; pressing it gives some important options described below:

<u>ReSynch (NTP)</u> resynchronizes; you want to do that less than a minute before you start to observe.

<u>Select NTP Server:</u> The different servers have different accuracies, depending on your location. Try them out, to see which one gives the smallest “TAcc” (time accuracy) and keep it selected (the “>” on the left shows the selected one). A TAcc of 50 ms or less is preferred. In the USA, time.nist.gov often gives the smallest TAcc.

<u>Audio Time:</u> – selecting it causes audible clicks each second, with the # of seconds of the minute announced each 10 seconds, and the minutes of the hour are given at the start of each minute.

<u>Exit:</u> Very important, as this is the only way to exit the app, as far as I can tell. Using the usual “back” button of the cell phone just adds another time and doesn’t actually go back to exit.

“Time the Sat” also gives **<u>coordinates</u>**, longitude, latitude, and altitude above sea level, that you also need for reporting your occultation observation.

Drift Scan Timing with an Astronomical CCD Camera

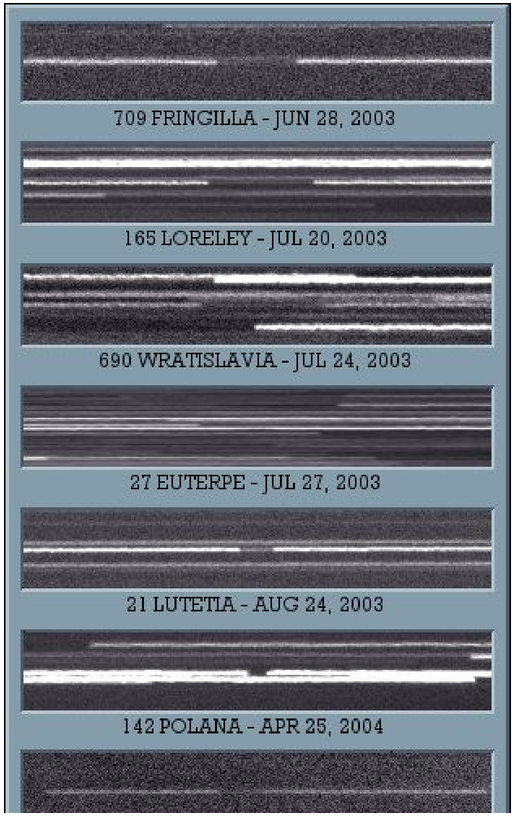
http://www.asteroidoccultation.com/observations/DriftScan/Index.htm

If you have an astronomical CCD camera, you can time occultations!

DRIFT-SCAN TIMING OF ASTEROID OCCULTATIONS

John Broughton (Updated 2014-11-13)

Occultations present the opportunity to remotely investigate shape and dimensions of planetary objects with orders of magnitude gain in resolution over direct imaging. I have in the past observed visually a spectacular Jupiter occultation of 2.6-magnitude Beta SCO and measured brief disappearances of a fifth magnitude star by ringlets of Saturn but until 2003 I had never observed the more common variety of occultation by an asteroid. Following on from the development of Dave Herald's Occult software, the turning point came with the advent of Steve Preston's updated predictions, the accuracy of which made viable a CCD imaging and timing technique I had under consideration many years earlier. The original inspiration was a trailed photograph of a Metis occultation taken by Paul Maley in 1979.



CCD

Due to their slow image transfer rate, most astronomical CCD cameras cannot record short-term variability on consecutive frames without missing out on most of the action; hence an occultation is best recorded on a single frame. One technique that has been particularly useful in recording rapid changes during lunar occultations is called TDI (time delay integration) where the CCD array is read out line by line to produce a trailed image. Not many cameras including my own have operating software supporting this electronic option but any integrating camera attached to a stationary telescope can take trailed images as a consequence of Earth's extremely regular rotation, which just happens to provide a rate of motion well suited to recording asteroid occultations.

With the advantage of noise reduction, a cooled CCD camera provides a substantial magnitude gain over non-integrating video cameras. From a moderately light-polluted location under otherwise favourable circumstances, sidereal-rate star trails as faint as magnitude 14 can be acquired with a telescope of 25cm aperture. A single image provides a convenient record for analysis, producing in most cases an unambiguously positive or negative result. Although cloud induced disappearances can mar an observation, they equally affect all nearby trails, making them easy to differentiate from the real thing.

Rigorous timing methods were devised and first employed for the Lutetia occultation of August 24, 2003. An accuracy of around .05 second can be expected for well-recorded events, leading to kilometre resolution in chord length and potentially an extremely precise celestial position for the asteroid. Lutetia incidentally has since been announced by ESA as the major asteroid flyby target of its currently enroute Rosetta comet rendezvous mission. Events previously considered unobservable may be within reach of observation; at right are the first 11 positive occultations recorded from my Reedy Creek, Gold Coast observatory in eastern Australia. The Euterpe event had a 0.3-magnitude drop, Echo occulted a star of magnitude 11.9 only 15 degrees from a full moon

If you have a DSLR camera, you can also use it to time occultations; see http://occultations.org/observing/educational-materials/equipment/dslr/

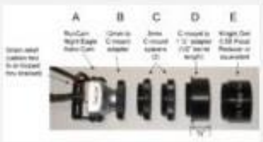
Unistellar eVscope
Easy to use, but beware

This small easily-transported scope will find the target star for you, but its cost is high relative to other systems, and it relies on cell-phone time, which we've found can be in error by 0.5s. A GPS flasher can be added to give more accurate time, but it complicates the system and analysis. The 0.1s minimum exposure time rules out its use for most NEA occultations. We are investigating plate-solve techniques to help any telescope to get on target, but a practical solution for video systems has been elusive.

Occultation Observing Equipment - Video

occultations.org/test-night-eagle-ordering-page/

IOTA is offering several kits based on the RunCam Night Eagle 2 Astro edition video camera and and the adapters needed to use it with a telescope, to meet your various astronomy needs.



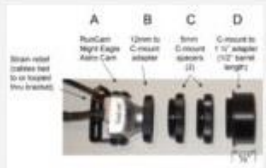
KIT 1 - RUNCAM NIGHT EAGLE ASTRO 2 WITH LENS, ALL ADAPTERS AND A 0.5X FOCAL REDUCER

This kit includes the camera with Astro firmware, W/A lens (not used with telescope), all power, video and OSD controller cables, all necessary adapters for telescopic use, and a 1 1/4 in. 0.5X focal reducer.

Domestic US shipping and handling will be added in shopping cart. For Canada, Mexico or Overseas shipping please add one of the extra shipping items at right.

$179.00

Add to Cart (appears below)



KIT 2 - RUNCAM NIGHT EAGLE ASTRO 2 WITH LENS AND ALL ADAPTERS (NO FOCAL REDUCER)

This kit is recommended only if you already have a 1.25 inch 0.5X focal reducer, as the focal reducer is highly recommended for all occultation observations.

Kit includes the camera with Astro firmware, W/A lens (not used with telescope), power, video and OSD controller cables and all necessary adapters to use it in a telescope, but no focal reducer.

Domestic US shipping and handling will be added in shopping cart. For Canada, Mexico or Overseas shipping please add one of the extra

$149.00

KIT 3 - RUNCAM NIGHT EAGLE ASTRO 2 WITH WIDE ANGLE LENS (CAMERA, LENS AND CABLES ONLY)

This kit is recommended only if you intend to use the camera for something like all-sky or meteor recording.

Kit includes just the camera (with Astro firmware), power, video and OSD controller cables, and wide angle lens. If you wish to use it in a telescope, order Kit 1, or Kit 2 if you already have the focal reducer.

Domestic US shipping and handling will be added in shopping cart. For Canada, Mexico or Overseas shipping please add one of the extra shipping items at right.

$79.00

Additional shipping - Canada and Mexico (Express)

ADDITIONAL SHIPPING - CANADA AND MEXICO (EXPRESS)

For addresses in Canada or Mexico only, please add just this item to your cart to cover additional shipping costs.

$25.00

Add to Cart (appears below)

Additional shipping - Overseas (Express)

ADDITIONAL SHIPPING - OVERSEAS (EXPRESS)

For International orders other than in Canada or Mexico, please add just this item to your cart to cover additional shipping costs.

$40.00

Add to Cart (appears below)

Kits without the IOTA-VTI

Current IOTA kits with VTIs, https://occultations.org/observing/recommended-equipment/iota-vti/

KIT 1 - IOTA VTI V3 WITHOUT EXTERNAL GPS ANTENNA

This kit includes IOTA VTI V3 only. No external GPS antenna included. The VTI will be set to NTSC video unless the purchaser requests PAL in the PayPal comment section.

Domestic US shipping and handling will be added in shopping cart. For Canada, Mexico or Overseas shipping please add one of the extra shipping items at right.

$249.00

KIT 2 - IOTA VTI V3 WITH EXTERNAL GPS ANTENNA

This kit includes the IOTA VTI V3 plus the external GPS antenna. The unit will be set to NTSC video unless the purchaser requests PAL in the PayPal comment section.

Domestic US shipping and handling will be added in shopping cart. For Canada, Mexico or Overseas shipping please add one of the extra shipping items at right.

$274.00

COMPLETE OCCULTATION KIT WITH CAMERA, VTI AND ALL ACCESSORIES

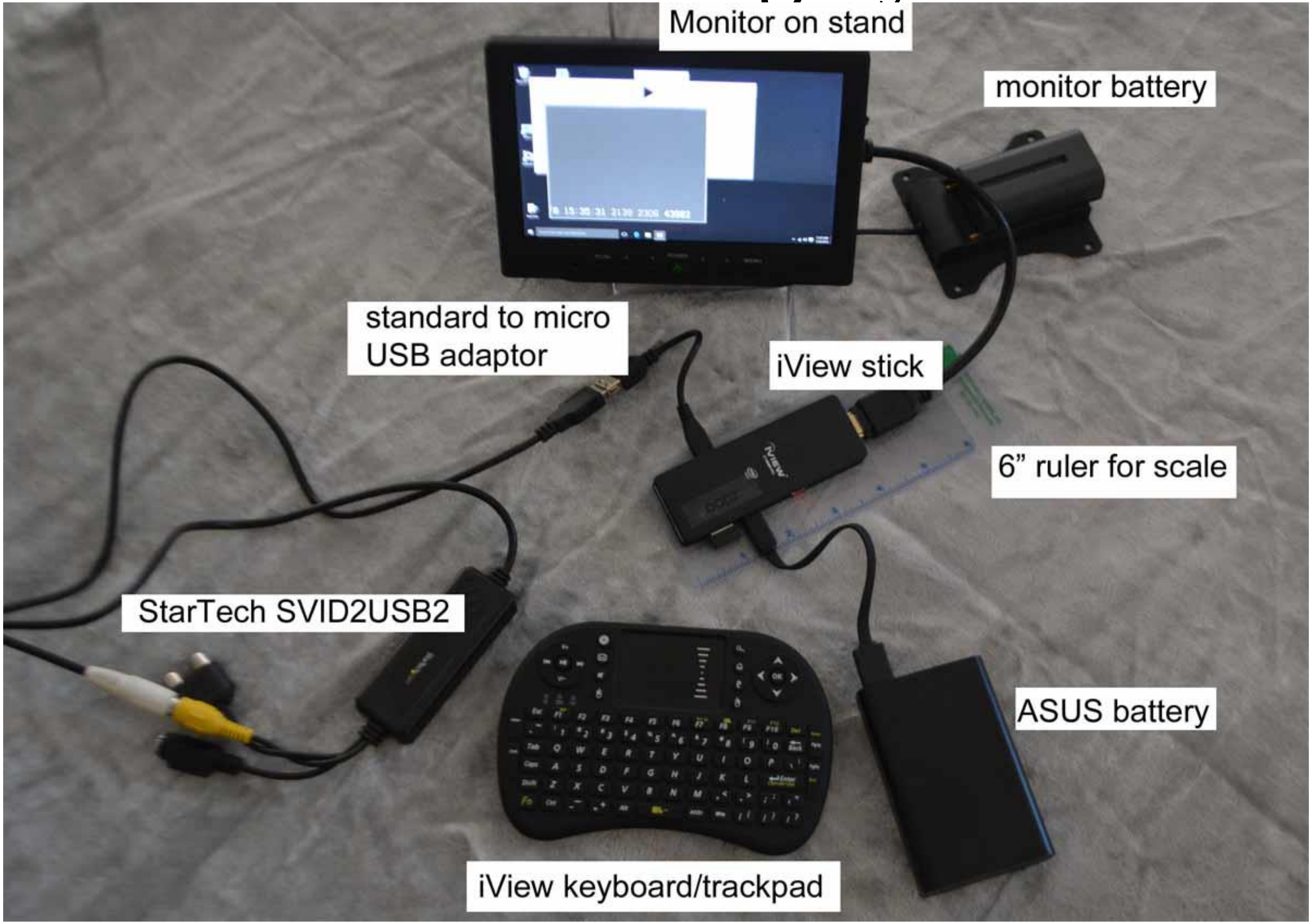
Complete Occultation Recording Kit - see above for details. Just install the free IOTA Video Capture software on your laptop. The VTI will be set to NTSC video unless the purchaser requests PAL in the PayPal comment section.

Domestic US shipping and handling will be added in shopping cart. For Canada, Mexico or Overseas shipping please add one of the extra shipping items at right.

$550.00

The other Items listed on the page can be purchased separately; Ted Blank tedblank@gmail.com runs the IOTA store.

Occ2 Recording System

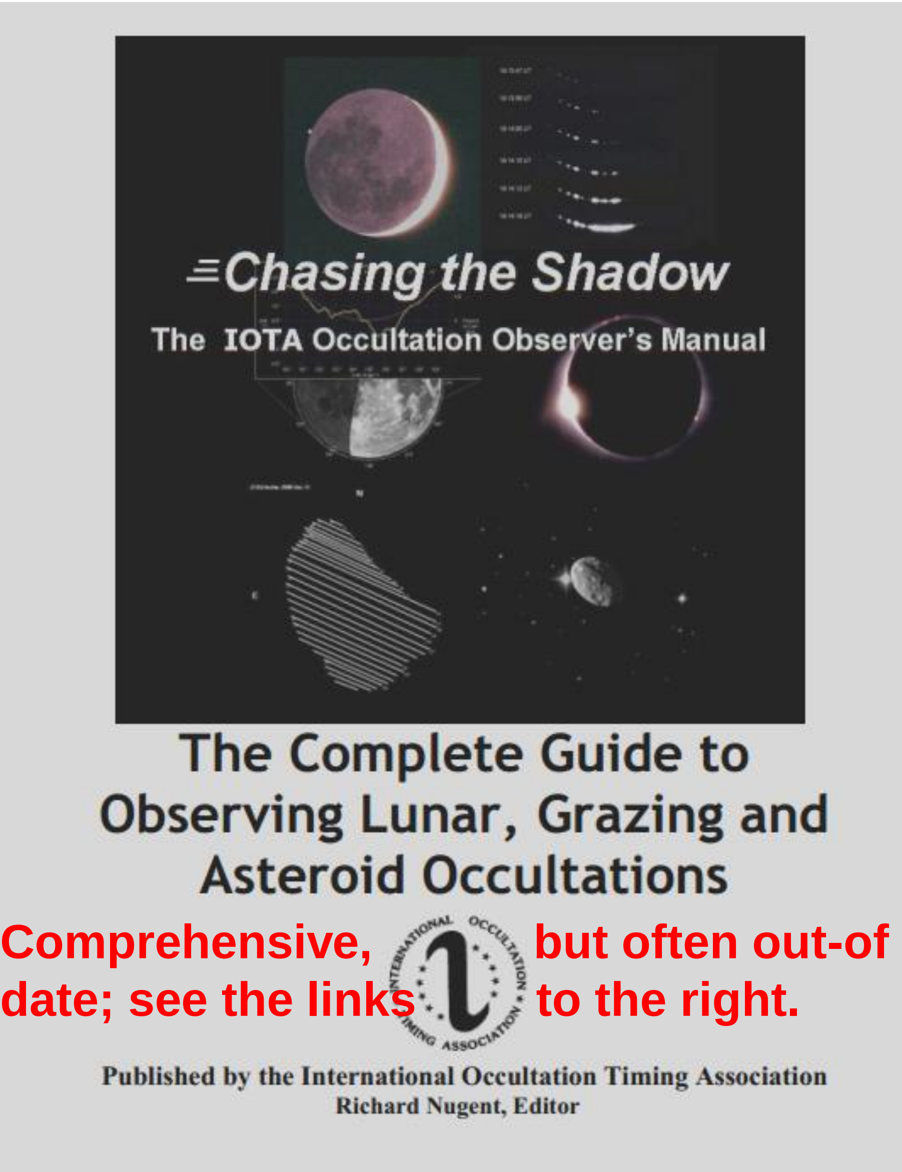


Better, see http://www.occultationpages.com/events/Runcam_Mini.html

GPS Video – IOTA VTI
Provides accurate (msec) timestamps on every video frame

A cheaper alternative, using a raspberry-pi board, is under development, and those with electronic skills can now build a precise timing flasher unit described by Aart Olsen at the online 2022 IOTA meeting.

IOTA Observing Manual



Comprehensive, but often out-of date; see the links to the right.

Available at IOTA's main Web site, http://occultations.org

The observing tab there, directly http://occultations.org/observing/ has the latest information about recommended software and equipment.
Other tabs are for joining IOTA, for our free publications, and meetings ("community")

A good primer, especially for video occultation observing, is at http://occultations.org/documents/OccultationObservingPrimer.pdf

Conclusions

- The rare bright 2019 July 29th occultation was the first successful campaign for a small NEO; until Apophis in 2021, it was the smallest asteroid with multiple timed chords during an occultation. A large collaboration of amateur and professional astronomers enabled that success.
- The radar size and shape were verified, and the improved orbit allowed a good prediction for the next occultation, then subsequent events, and an improvement of Phaethon's A2 non-gravitational parameter by a factor of 3.
- But recent observations show that sudden changes might occur to Phaethon's orbit near perihelion, so more observations by this enigmatic object are needed.
- The occultation technique was successfully applied to Apophis, which is more than 10 times smaller than Phaethon, and also Didymos, further demonstrating the astrometric power of observations of NEO occultations for planetary defense;
- Information about the sizes, shapes, rings, satellites, and even atmospheres of Kuiper Belt objects, Centaurs, Trojans, and other asteroids is proportional to the number of stations that can be deployed for occultations by them
- We encourage as many others as possible to time occultations by NEA's, TNO's and by other asteroids (and sometimes comets) from their observatories
- We want others to learn to make the necessary mobile observations, including the multi-station techniques pioneered by IOTA, to observe NEA and other occultations, to support planetary defense and asteroid science.

Please visit https://occultations.org/publications/rasc/2023/ACM2023.htm to get this presentation, and for links to IOTA's, and other's, Web sites that have predictions and much other information that will allow you, and others at your institution, to take part in this exciting field of astronomy.

Contact: dunham@starpower.net; cell +1-301-526-5590 and
local IOTA member Bruce Hohenstein, BHolenstein@gravic.com .