(3200) PHAETHON, FIRST SUCCESSFUL OBSERVATIONS OF OCCULTATIONS BY A SMALL NEAR-EARTH OBJECT

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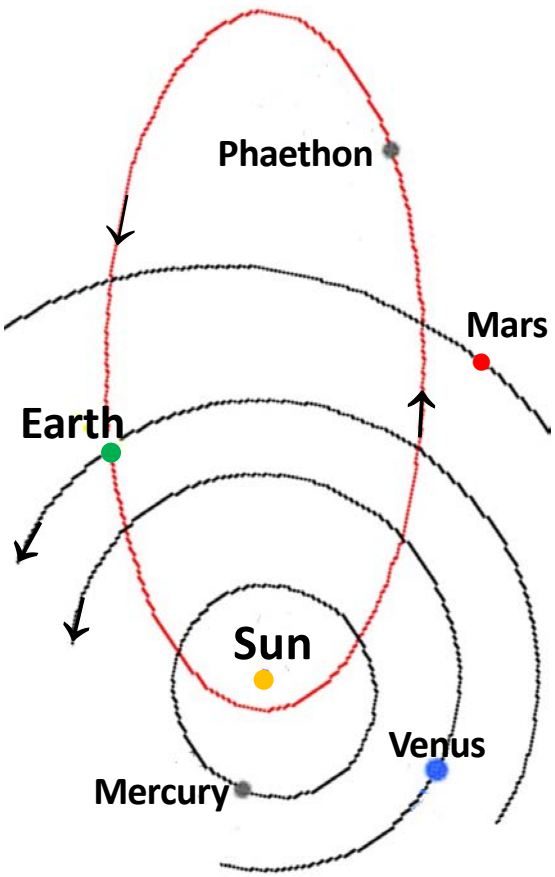
Why (3200) Phaethon?



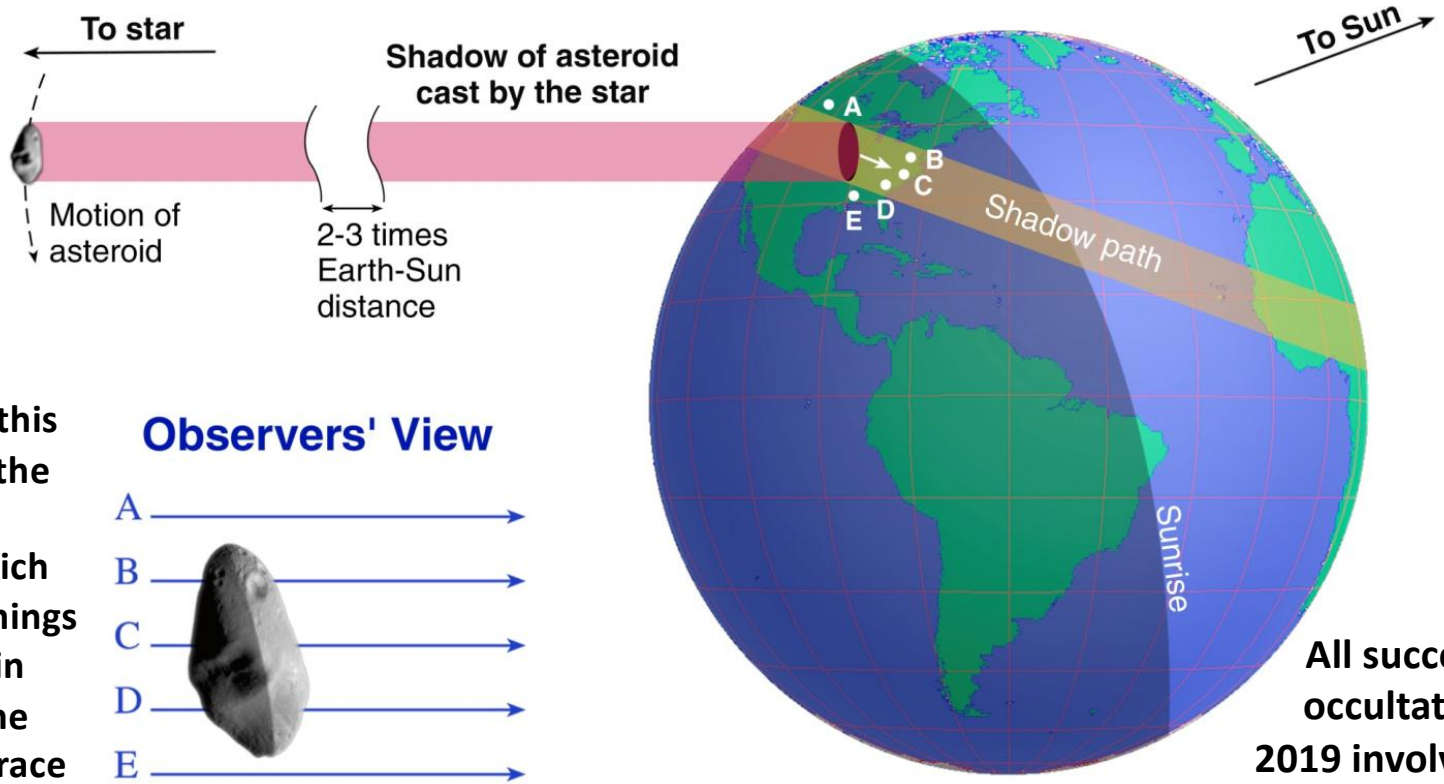
Phaethon's orbit in the inner Solar System

- **Phaethon is the parent body of the Geminids meteor stream that produces one of the strongest meteor showers, in mid December each year; all other meteor streams emanate from comets.**
- **Phaethon has an unusually elongated orbit, so at its closest approach to the Sun (perihelion), the sunlight is 294 times as intense as at the farthest point in its orbit (aphelion). This strong thermal shock causes it to shed of pebbles and dust, creating the Geminids meteoroid trail that was imaged by the Parker Solar Probe in 2019. Phaethon's orbital period is 524 days = 1.43 years (see orbit at left).**
- The Japanese Space Agency's DESTINY+ spacecraft plans to launch in 2024 and fly by Phaethon in 2025 - see https://en.wikipedia.org/wiki/DESTINY+.
- Radar observations (right) show Phaethon to be nearly spherical with a diameter of 4 miles (6 km)
- **Phaethon is a potentially hazardous object that could have global consequences if it hits the Earth in the far future. The closest approach to Earth's orbit is now 1.81 million miles = 7.6 lunar distances. There are no threatening Phaethon close approaches to Earth in the next 1000 years.**

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

Geometry of an Asteroid Occultation

Like a solar eclipse, with the Sun replaced by a distant star and the Moon by an asteroid



Astronomers call this Observers' View, the sky-plane at the asteroid, onto which the observers' timings can be projected in the direction of the occulted star, to trace the silhouette of the occulting object.

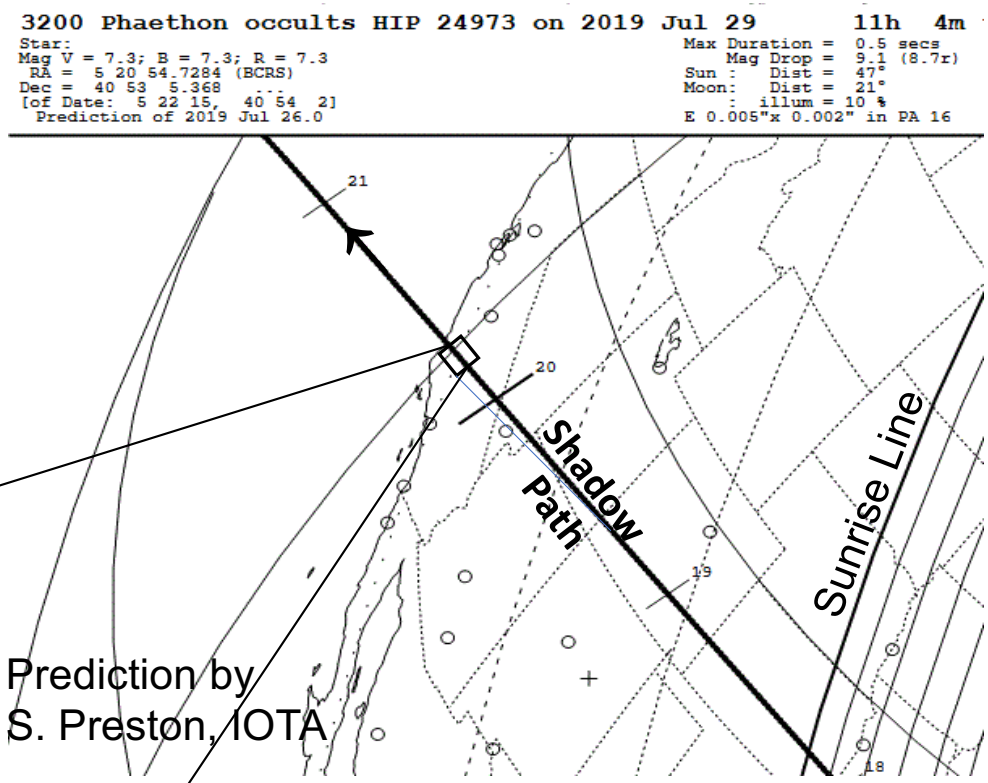
Observers' View

A, E: Negative observations
B, C, D: Positive observations, called "chords"

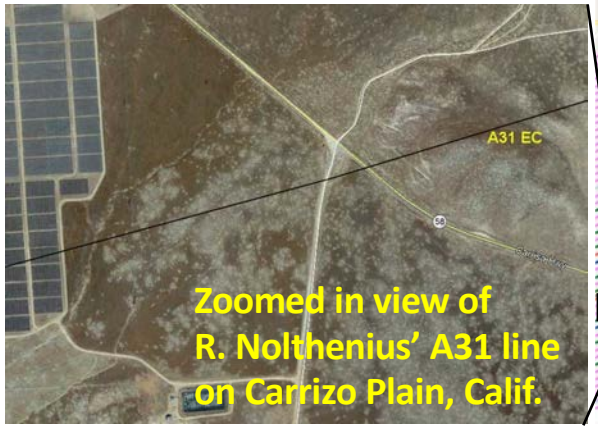
All successfully observed occultations before July 2019 involved objects 20 miles across or larger, and the typical spacing between stations was more than 5 miles.

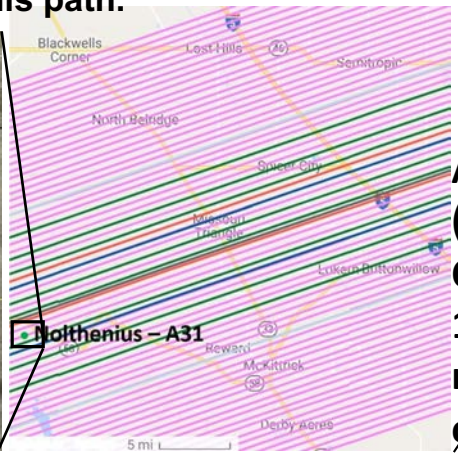
THE 2019 JULY 29 OCCULTATION OF 7.3-MAG. HIP 24973 BY PHAETHON

- This event was first identified by Isao Sato in Japan. In January 2019, he alerted US observers. The path across the USA is shown to the right.
- To obtain more accurate information about Phaethon and its orbit, Tomoko Arai, the DESTINY+ Principal Investigator, requested that NASA & the International Occultation Timing Association (IOTA) try to observe this rare bright occultation by Phaethon
- This was by far the smallest object that IOTA had tried to predict and observe; we needed help.
- Observers and their telescopes were deployed to a net-work (below) of 66 lines, parallel to the central line and spaced only 680m (about the height of the Empire State Building) apart, to define the tightest fence of stations ever set up for an occultation. This was one of the larger professional-amateur collaborations, between SwRI, NASA, JPL, JAXA, and IOTA, to cover the unknown but possibly large uncertainty in this path.



Prediction by
S. Preston, IOTA





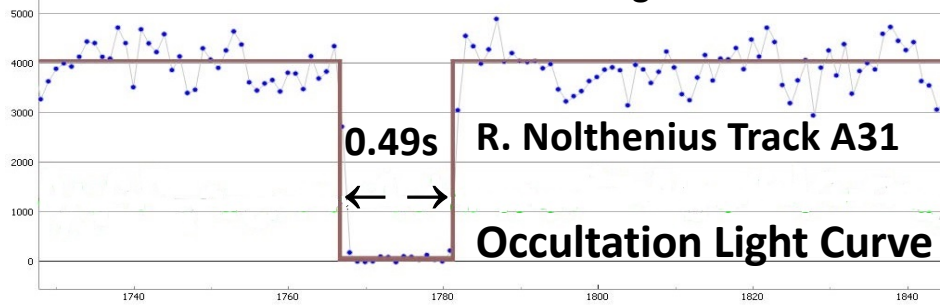
At near left, part of the Google Map showing the 27-mile (44 km) wide network of 66 lines over part of central California. Observers were asked to select a site within 150 ft. of their assigned line. Nolthenius used an entrance road to the Topaz Solar Farm for his site. Some IOTA observers ran up to 8 prepointed automatic stations.

Richard Nolthenius' Video Recording of the July 29th Occultation by Phaethon at Line A31, Carrizo Plain, California

This video is posted at http://iota.jhuapl.edu/20190729Phaethon-RNcompNoSlo.mp4

The video recording is trimmed to the event, and comments made right after it. Equipment used is below.

Phaethon's velocity was 10.8 km/s, so times the 0.49s duration gives 5.3 km or 3.3 miles for the chord length.

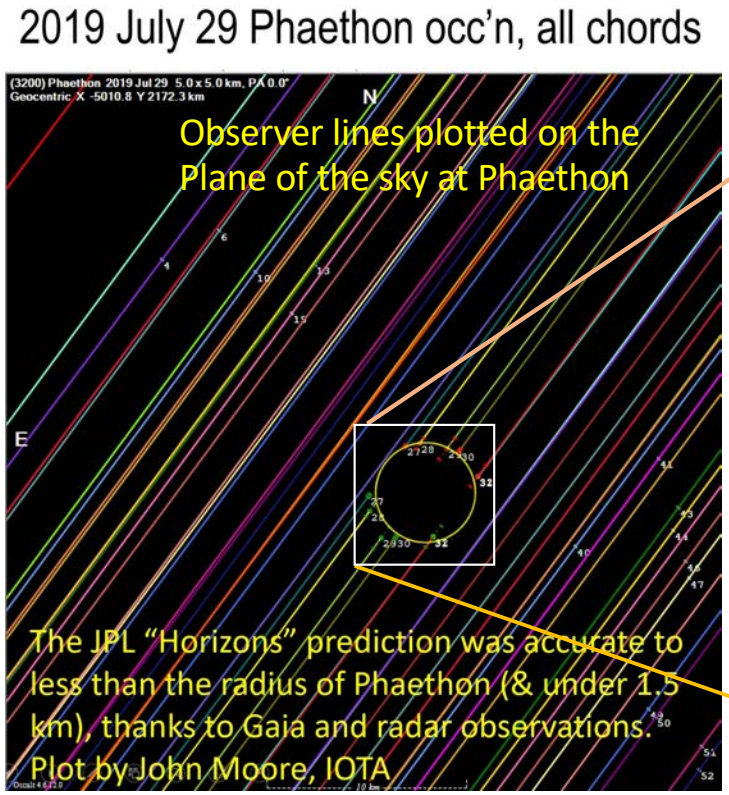


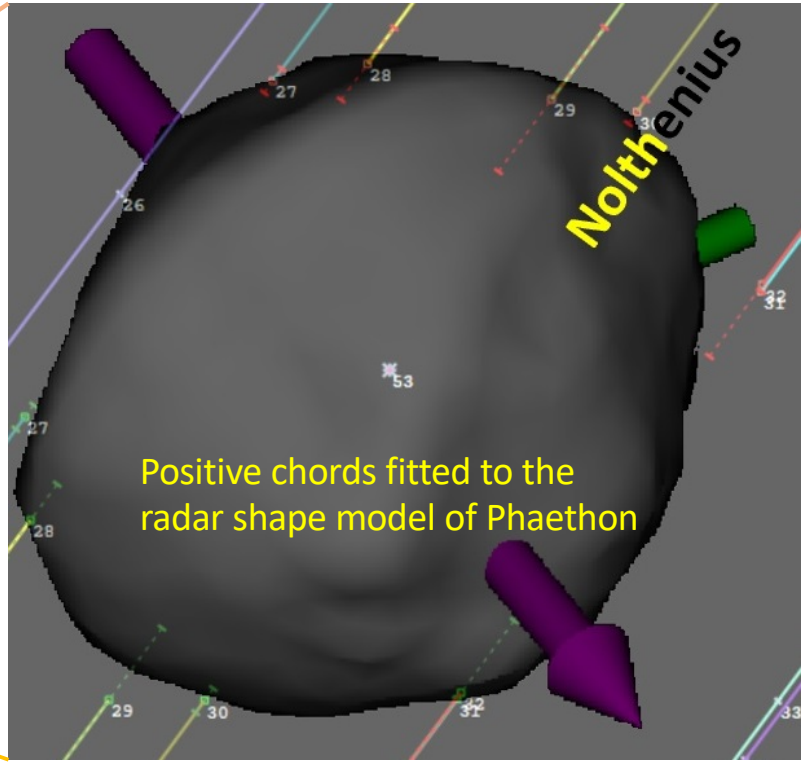
A page about Nolthenius' observation is at https://www.dr-ricknolthenius.com/events/20190729Phaethon/index.html

SKY PLANE PLOTS OF THE OBSERVATIONS OF THE 2019 JULY 29 OCCULTATION

The left panel shows the lines in the sky plane at Phaethon for all 52 stations from which the star was recorded during the expected time. Although observations from 71 lines were planned, several sites were found to be unsuitable when observers arrived there, and equipment failures plagued some of the stations.

Most stations had no occultation; the panel on the right shows in more detail the lines for the six stations that had an occultation. The recordings were all accurately time-stamped with GPS receivers.





All Observed Occultations by (3200) Phaethon

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

To ensure success, the first event needed a deployment across 4 States by scores of professional and amateur observers, forming a network of stations with an unprecedentedly small spacing between them.
After the 2019 July 29th success, it was possible to predict the Sept. 29th event, and then each of the others, with better improvement each time as more observations were added to the orbit solutions.

"Star mag." measures the star's magnitude, with lower numbers for brighter stars, like rankings. The first event was visible with binoculars; all the others needed telescopes.

Positive chords recorded the occultation, while **all** includes negative observations; SCT= Scmidt-Cassegrain Telescope.

More about these observations is in the longer presentation I gave at the 2020 meeting of the International Occultation Timing Association. It is the 4th from the bottom, on the 2020 IOTA presentations page at: http://occultations.org/community/meetingsconferences/na/2020-iota-annual-meeting/presentations-at-the-2020-annual-meeting/ .

Science Results and Promise for the Future

- Phaethon's orbit is pushed slightly as it sheds mass during each solar pass
- This "non-gravitational" force is much smaller than is the case for comets
- Occultations are far more accurate than regular astrometric observations and can then provide strong constraints on an object's trajectory
- The observations of the Phaethon occultations has resulted in a 3-fold improvement of the determination of the small non-gravitational force
- This information helps constrain physical models of Phaethon's mass loss and the resulting Geminids meteoroid stream, allowing long propagations of its trajectory
- **The techniques demonstrated by the Phaethon occultation campaigns can be applied to other NEO's, including potentially hazardous ones, to characterize them and greatly improve their orbits, contributing to an improved assessment of their risk.**
- **The pro-am collaborations of future occultation campaigns can inspire and educate future generations of astronomers, as well as help determine the physical and dynamical properties of small bodies throughout the Solar System**
- **Sky observers everywhere are invited to participate with IOTA and SwRI in this exciting work; the opportunities are frequent and ubiquitous**

Recap of 1st Observations of Occultations by a Small NEO

- (3200) Phaethon is a strange active asteroid, producing the spectacular annual Geminids meteors.
- The 2019 July 29th occultation of a star visible with binoculars in the USA provided a rare opportunity to learn more about Phaethon and its orbit; the Japanese space agency requested observations to aid their DESTINY+ mission.
- In one of the larger pro-am collaborations, 7 SwRI telescopes and 45 from IOTA recorded the star in the tightest ever occultation "fence", 27 miles (44 km) long, netting 6 chords that showed the size and shape of Phaethon.
- The observations, and refinement of the orbit, resulted in the successful observations of 6 more events.
- The occultation data improved knowledge of Phaethon's mass loss 3-fold, enabling more accurate predictions of its future path.
- Occultations can become an important technique in improving our asteroid catalog and help secure the knowledge of future motion of near-Earth objects, some potentially hazardous, for long time intervals.
- The effort demonstrates how exciting occultation campaigns can give interesting new information about small Solar System bodies, even NEO's. Others are encouraged to take up this activity; resources are given in the last slide of a longer presentation at **http://iota.jhuapl.edu/DPS52PhaethonOccultationsDunham.pptx.**

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