(3200) PHAETHON, FIRST SUCCESSFUL OCCULTATION OBSERVATIONS OF A SMALL NEAR-EARTH OBJECT.

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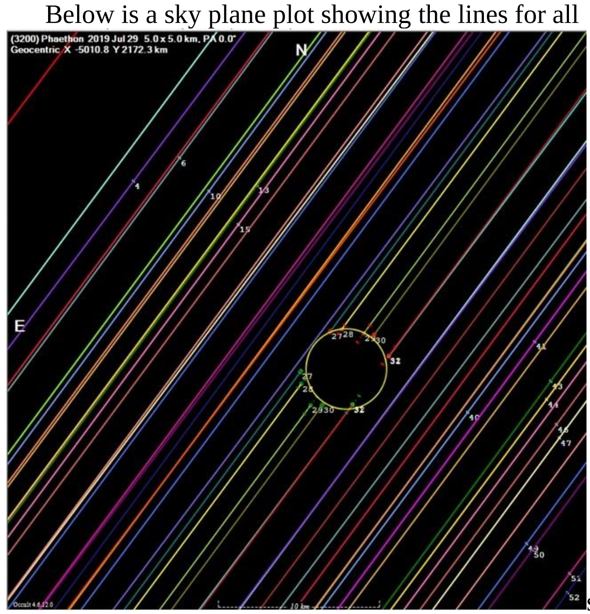
Introduction: For more than 40 years, members of the International Occultation Timing Association (IOTA) have observed occultations of stars by asteroids, the large majority of them being main-belt objects [1]. Of the over 4000 asteroidal occultations observed before 2019, almost all involved asteroids of 30km or more in diameter. As part of IOTA's process of predicting occultations, an occultation of 7.3-mag. SAO 40261 = HIP 24973 in Auriga by (3200) Phaethon with the path crossing the southwestern USA was identified. Phaethon is important as it is the apparent source of the strong Geminid meteor shower. Most meteor streams originate from comets, so the mechanism for Geminids originating from Phaethon is unknown. Observations of the July 29th occultation might give new information, but with a diameter of less than 6 km, the path would be hard to predict; would a large campaign even succeed, or be worth the effort, considering that Phaethon's shape was already determined rather well from radar observations during the close approach in December 2017 [2,3].

Preparation for the July 29th Event: The Japan Aerospace Exploration Agency (JAXA) plans to fly by Phaethon in 2025 with its DESTINY+ mission [4]. Tomoko Arai, Principal Investigator of DESTINY+, asked NASA and IOTA to try to observe the July 29th occultation, mainly to resolve uncertainties in the size of Phaethon, and provide an accurate astrometric fix to improve the orbit. The path of the occultation missed most known observatories and cities with astronomy clubs, so all observations would need to be made with mobile equipment; the bright star allowed very small systems to be used. But the occultation would only last half a second, requiring video and CCD observations to obtain accurate enough timings. We wanted to deploy 50 or more stations in a tight "fence" coordinated across four States to catch the fleeting shadow. This required calculations at the milli-arc-second level, and better than 100m for the path on the ground; meeting these requirements necessitated changes in software and consideration of ever smaller effects. Even the difference in the gravitational deflection of light by the Sun, for Phaethon and the star, became significant.

Deployment for the July 29th Event: The final plan included 71 stations (63 by IOTA and 8 by SwRI), to be set up by 45 observers (29 from IOTA and 16 from SwRI). With this many stations, the agreed-upon spacing was 680m, covering a range of 45 km. That covered the 3-sigma uncertainty zone plus 10 km on each side, since an event like this had never been tried before, Phaethon had been unobserved after its perihelion passage a few months before, and Phaethon's orbit is modeled with a small comet-like non-gravitational term that was uncertain for this unusual object. Most stations were deployed north of Las Vegas, NV, while several were deployed in and southwest of the southern San Joaquin Valley in California, and several more south of Pueblo, Colorado where tests showed that the dawn twilight there would be manageable. A number of IOTA observers deployed unattended remote "pre-pointed" small telescopes with video cameras and timers at several sites [5].

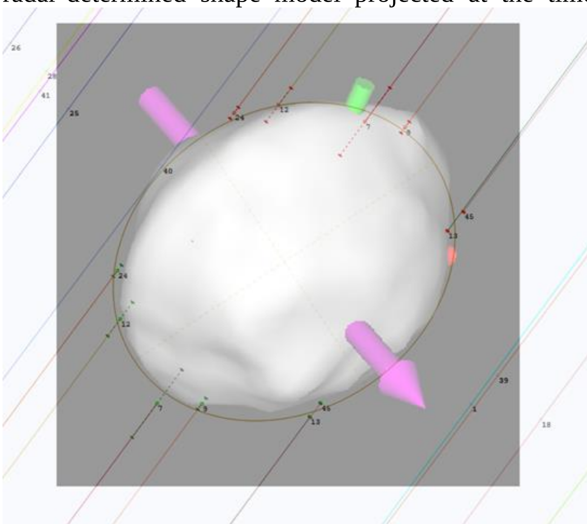
Observations: The target star was recorded at the right time from 52 stations. 10 stations that were deployed failed to record the target star for one reason or another (only one was clouded out). Another 9 stations that were planned, were not set up, due to 100 "new" AA batteries purchased the day before, needed to power the equipment, were all were dead.

Below is a sky plane plot showing the lines for all



s stations except the northernmost one, which was 10 km north of the northern (red) line shown). The six positive chords near the center showed that the JPL Horizons solution 702 for Phaethon turned out to be very accurate, showing only about a 2-km south shift from the prediction, a little less than 1-sigma.

The positive observations are shown in more detail in the sky plane figure below; it includes a fit to the radar-determined shape model projected at the time



and direction of the occultation. The station numbers for this figure are different from those for the first figure on the previous page. The miss line 40 tightly constrains the fit on the north (upper left) side. In spite of our efforts to space stations apart, stations 13 and 45 on this plot were virtually in line, and reveals a small timing error for one of them. The reason that the chords are virtually the same was because the observers did not take height above sea level into account and they were at very different heights; we knew before the event that an increase in height of 1 km resulted in a shift of the path to the north of 0.48 km, but the prediction map used for selecting observing sites didn't take this into account. Nevertheless, the coverage of the asteroid was rather good, and will allow a tighter spacing of stations for future occultations.

Other Occultations: IOTA has a Web site showing predictions for future Phaethon occultations [6]. Fifteen stations were deployed in northern Japan for an occultation of an 11.9-mag. star on August 21, but it was very cloudy at all stations so that no observations were obtained. There are some promising events between the abstract deadline and the conference, so we may be able to report more observations at the conference.

Acknowledgments: We thank the many IOTA observers who participated in this event, travelling long distances (3 travelled by air, and others drove their vehicles as much as 4200 miles round-trip) at their own expense, with the full knowledge that most would have no occultation, guaranteeing the success of the overall effort.

References: [1] Dunham D. W. et al. (2016), in *Asteroids: New Observations, New Models – Proc. of the 318th Symposium of the IAU*, 177. [2] Agle D. C. et al. (2017) https://www.jpl.nasa.gov/news/news.php?feature=7030 . [3] Durech, J. (2019) DAMIT asteroid shape model at https://astro.troja.mff.cuni.cz/projects/asteroids3D/web.php?page=db_search .[4] DESTINY+ https://en.wikipedia.org/wiki/DESTINY%2B . [5] Dunham, D. W. et al. (2019) *Journal for Occultation Astronomy* #1, 3. [6] Dunham, D. (2019) http://iota.jhuapl.edu/2019Phaethon.htm .