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NEO ORBITS AND SIZES FROM IOTA OCCULTATION OBSERVATIONS

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Abstract: Precise orbit determination is very important for planetary defense against Potentially Hazardous Asteroids (PHAs), to determine their probability of impact at close approaches to Earth as far as possible into the future. Orbits of NEOs, and especially of Near-Earth Asteroids (NEAs) are generally best improved by radar observations, but these are only possible when the NEA is relatively close to the Earth. Well-observed occultations can also give information about the size, shape, and multiplicity of the object. The First occultations by (3200) Phaethon and (99942) Apophis were detailed at PDC2021 in [1]. Since then, more occultations by these NEA's have been observed. New well-observed occultations by Phaethon made in Japan have been used to improve the object's shape model and rotational state. There was an unexpected shift in the path of Phaethon at its most recent occultation, possibly due to a discrete event at its previous perihelion passage. In 2022, the first occultations by Didymos were recorded, but only after the DART impact with Dimorphos. The occultations refined the post-impact orbit of the NEA, and the few detections of Dimorphos confirmed the relative post-impact orbit determined from other observations. Didymos is receding from the Earth and observable occultations by it are now rare. (98943) 2001 CC21 is another NEA of interest as it's a flyby target of Hayabusa2's extended mission. A first occultation of it was recorded in Japan on March 5th, but the star had a high "RUWE" that makes its Gaia data poor for orbit determination. Consequently, efforts to record a 2nd occultation are underway.

1. Introduction:

Two years ago, we gave a paper [1] at PDC2021 about the first results from occultations of stars by Near-Earth Asteroids (NEAs). That showed the great improvement in the accuracy of the orbits that could be achieved with NEA occultations, which complement radar observations to comparable precision in the sky-plane. Details were given about the refinement of the orbits of (3200) Phaethon and (99942 Apophis), which in combination with the radar observations, retired the risk of Apophis collision for at least a century. This paper will describe continued successes with occultations by Phaethon observed in Japan, and attempts to observe occultations by Apophis. We will show that Apophis is probably now too far away from Earth to produce observable occultations due to Fresnel diffraction "smearing". The main recent efforts have been for occultations by (65803) Didymos, primarily organized by the Asteroid Collaborative Research via Occultation Systematic Survey (ACROSS) [2]. The first success wasn't until 2022 October 15, after the DART-Dimorphos impact and after radar observations were obtained at the same time, but there have been several well-observed occultations since then [3]. Several attempts have been made to observe occultations by Dimorphos, but the small object has been elusive; nevertheless, some occultations by it have been recorded, which can help accurately measure the relative orbit. It's unfortunate that none of the pre-impact occultations by either Didymos or Dimorphos were observed, due to unfavorable weather and other factors. Following the early 2023 successes with Didymos events, efforts have concentrated on (98943) 2001 CC21 during its current close ap-proach; the object is a 2026 flyby target of Haya-busa2's extended mission. By the time of the PDC conference, the Didymos occultations will be too short to observe with IOTA's commonly used video systems, and like Apophis, Fresnel diffraction smearing will add to future difficulties. We will report a success with another NEA, (1866) Sisyphus, in November 2022. Results of all asteroidal occultation observations, including by NEOs, reported to the International Occultation Timing Association (IOTA) [4] are archived with the Small Bodies Node of NASA's Planetary Data System [5,6] but are more readily accessed with IOTA's free comprehensive occultation prediction and analysis software, Occult4 [7]. The most important NEA occultations visible from North America are published annually [8] with more details and updated information on a corres-ponding Web site [9] where datasets can be downloaded for use with Occult4 to generate local predictions for anywhere in the world.

Our 2021 paper described and tabulated the first successful observations of occultations by (3200) Phaethon in 2019 and 2020, and the first successful ones by (99942) Apophis in early 2021. This paper discusses further observations of occultations by Phaethon in

2021 and 2022, further efforts to record occultations by Apophis, IOTA's and Japan's successful efforts for occultations by Didymos/Dimorphos in late 2022, and the substantial efforts this year to record occultations by (98943) 2001 CC21, target of Hayabusa2's extended mission, so far with only one success.

In response to interest shown by a question asked after our presentation, a sub-section has been added to the Didymos section to better explain IOTA's remote station deployments.

2. (3200) Phaethon:

Phaethon, the source of the strong annual Geminids meteor shower, is also a flyby target of JAXA's DESTINY+ mission. It is an active asteroid, as shown from spacecraft observations of its dust tail. It suffers strong thermal stress during its close (0.14 A.U.) perihelion passages every 523.6 days; that is likely the source of Phaethon's dust tail and the Geminids.

2.1 2021 October 3 Occultation

On 2021 October 3 (UTC), Phaethon occulted 12.0-mag UCAC4 646−021974 in a path crossing from western Japan to southern Korea. For this stellar occultation, a large observing campaign was called for at the request of the DESTINY+ mission (planning a flyby of Phaethon in 2028) science team, and 72 observers attended. Observations were made at 36 different sites from western Japan to the Korean peninsula, and stellar occultations by the asteroid Phaethon were detected at 18 of these sites. While seven sites got negative detections. This is the first time that this many multiple chord observations have been made for such a small asteroid (5–6 km in diameter). Observational reductions show that the apparent cross-section of Phaethon at the time of the occultation could be approximated using an ellipse with a major diameter of 6.12 ± 0.07 km and a minor diameter of 4.14 ± 0.07 km, and a position angle of $117.^{\circ}4 \pm 1.^{\circ}5$. Most of the sites used a CMOS camera and GPS module, so the observations were made with high time resolution and high precision timing. The measurement error is about 80-140m at most sites. More details are given elsewhere [10]. The observation sites were in four areas, shown in Fig. 1 and Fig. 2 shows the observations projected on the sky plane at Phaethon.

2.2 2022 October 21 Occultation

On 2022 October 21 (UTC), Phaethon occulted 10.8-mag TYC 2844-0735-1 in a path crossing Hokkaido, Japan. The DESTINY+ mission science team conducted again an observation campaign to obtain another cross-sectional profile of Phaethon, different from last year's observation. Thirty-nine people observed the occultation event at 19 separate sites in Hokkaido. 9 sites had positive detection, while five were negative. This observation was also made using a combination of a CMOS camera and a GPS module. The measurement error of each observation point is 45-700m.

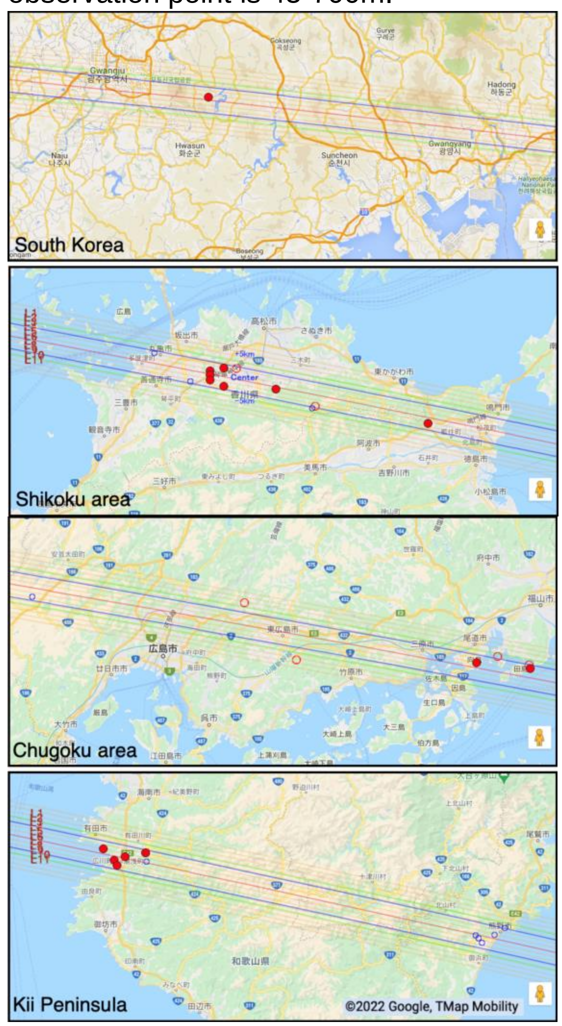

Fig. 1. Observation sites for the 2021 October 3 occultation by Phaethon.

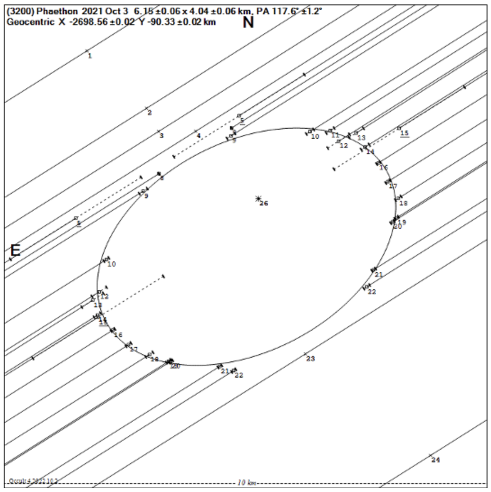

Fig. 2. Sky plane plot for the 2021 October 3 occultation by Phaethon. The point #26 above and a little to the right of the center of the fitted ellipse is for the predicted center of Phaethon.

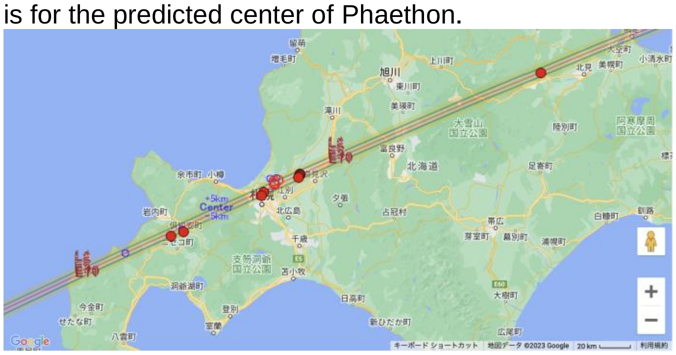
Fig. 3. Observation sites for the 2022 October 21 occultation by Phaethon.

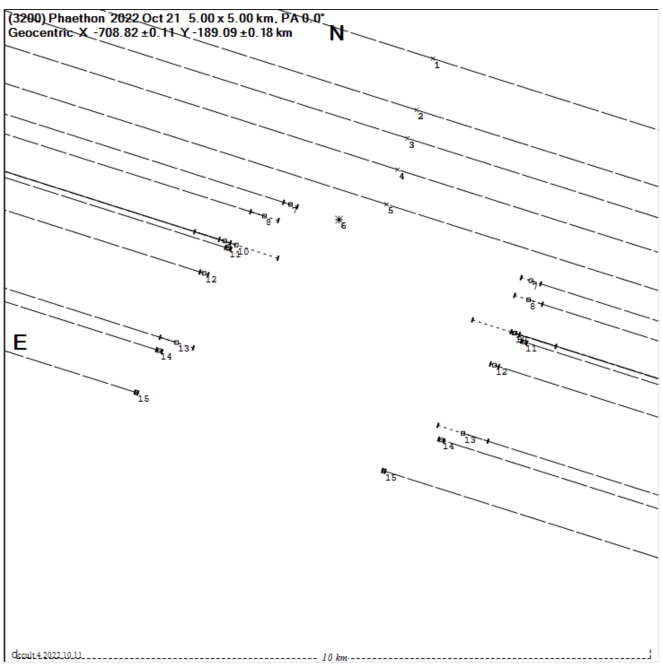

Fig. 4. Sky plane plot for the 2022 October 21 occultation by Phaethon. The point #6 is for the predicted center of Phaethon, near the very northernmost end of the actual shadow.

2.3 Unexpected change in Phaethon's orbit from 2021 to 2022

Starting observations in July 2019 and continuing through October 2021, stellar occultations by Phaethon were occurring almost exactly as predicted in the expected occultation zone, with residuals of only a few tenths of a kilometer. This suggests that Phaethon's orbit was extremely well determined. However, the October 2022 observa-tions showed that the predicted occultation zone was shifted to the south by the radius of Phaethon (by about 2km). Therefore, we were unable to measure the entire cross-sectional shape of Phaethon because we did not deploy observers far enough south, not expecting any occultation to occur in those areas.

The shift of the occultation zone this large must be caused by a significant change in Phaethon's orbit. It may be related to Phaethon's passage through perihelion in 2022 May, between the observation on 2021 October 3 and 2022 October 21. This is because Phaethon shows activity at the time of the perihelion pass. However, we cannot yet say whether the small amount of activity at the time of Phaethon's perihelion passage is sufficient to produce the 2 km shift.

2.4 Other occultations by Phaethon

The Occult4 [7] database shows two other obser-vations of occultations after 2020, on 2021 Decem-ber 17 of a 9.2-magnitude star recorded from two stations in Taiwan, and the other on 2022 October 22 (night after the very successful campaign in Hokkaido) of a 12th-magnitude star recorded from one location near Hiroshima. Five Phaethon occultations of stars brighter than 12th magnitude occurred in North America during 2022, published in the *RASC Observer's Handbook for 2022* and on IOTA's NEA occultations page, but none were observed, partly due to bad weather but mainly because observers concentrated instead on other important occultations, especially the ones by the Didymos system. But now that we know about the shift observed in October last year, there should be more interest in occultations of 12th-mag. stars by Phaethon that will occur in the USA on Aug. 7, Aug. 17, and Sep. 1 this year [8].

3. (99942) Apophis

Only a few Apophis occultations were attepted after PDC2021; the ones observed from 2021 March 7 to April 11 are covered in our PDC2021 paper [1]. We will present results of one rather well-observed Apophis event, and unsuccessful attempts to record two others below. Effects of Fresnel diffraction on the light curves are discussed, including a calculation of the distances from which Apophis, and other small asteroids, become too great for observing occultations.

3.1 2021 May 6 Occultation

After 2021 April 11 described before [1], only one other occultation by Apophis was observed that year, involving an 11.6-mag. star observed in moderately strong twilight from sites in Arizona and one in Mexico. Fig. 5 shows the observations projected on the sky plane at Apophis.

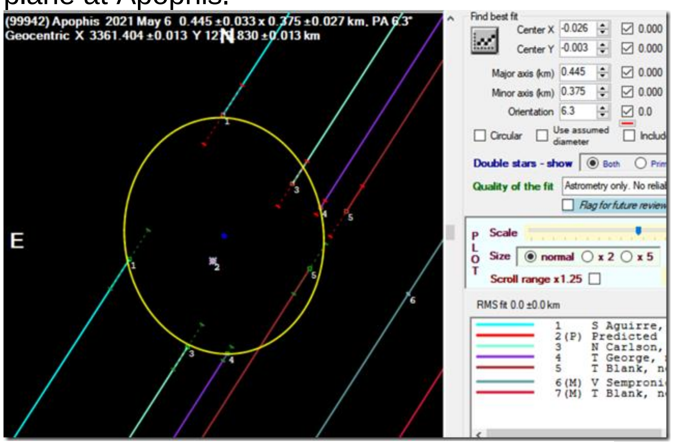

Fig. 5. Sky plane plot for the 2021 May 6 occultation by Apophis. The point #2 is for the predicted center of Apophis, below and a little to the left of the center of the fitted ellipse.

3.2 Later Occultation Attempts

Roger Venable attempted two occultations by Apophis of 8th-mag. stars, but both were too difficult due to very low altitude above the horizon and the observations failed to detect an occultation. They occurred on 2021 Sept. 27 and 2022 April 9; he discussed them in a presentation at the 2022 IOTA meeting [11].

3.3 Fresnel Diffraction for Small NEA's

How can we determine when diffraction effectively precludes the ability to detect an occultation in the light curve? Now that we are putting some focus on these small object occultations, we need a plan for filtering search results to know when an event is infeasible due to diffraction alone (separate from the size of the star). At last year's IOTA meeting, Roger Venable discussed some concerns with diffraction for small objects in one of his presentations [11]. Venable included some plots from a 1987 paper using the Fresnel length, FL = sqrt(lambda x distance/2), all expressed in meters and a term rho = asteroid radius/FL [12]. The plots in Fig. 6 show simulated light curves, for spherical asteroids, where rho is 0.88, 2.9, and 5.9.

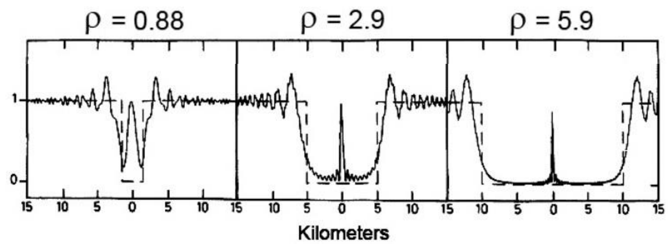

Fig. 6. Occultation light curves for a spherical as-teroid for three different values of rho, adopted from [12].

For lambda, the wavelength of light, we used 600 nanometers, typical for the red-sensitive video cameras used by many IOTA observers. The Poisson spot at the center looks like a central flash, but it is caused by Fresnel diffraction rather than from the refraction focusing observed during occultations by the atmospheres of spherical planets; the central spot all but disappears for rectangular and irregular shapes, and is diminished for ellipsoidal objects, so it is rarely seen in occultations by small asteroids. Then it is clear that for values of rho greater than about 1.0, the light curve is basically U-shaped, approaching the square bottoms seen during most occultations by main-belt asteroids where rho has large values. We just use rho=0.88 as our minimum; for smaller values, the occultation becomes difficult to find, especially in the case of the strong scintillation noise that is typical for occultations of fainter stars, and/or for very small asteroids where the occultation duration is brief. With this assumption, we ask, what is the distance in AU when rho = 0.88 for different asteroids? At larger distances, rho decreases and "diffraction smearing" causes the occultation light curve to be lost in the scintillation noise that plagues all but the brightest stars occulted by NEA's. A more extensive study of Fresnel diffraction effects for NEA occultations was published in 2013 [13], but it was only theoretical since at that time, there were no NEA occultation observations where Fresnel effects were important.

Table 1 gives the distance where diffraction smearing becomes significant, which we consider to be when rho = 0.88; FL is given for that distance. By inverting the equation for Fresnel length, we find this occurs when the distance in AU = 2 x $[Rast/rholim]^2$ x AUinMeters, where Rast is the radius of the asteroid, rholim is the limiting value we set for rho (0.88) and AUinMeters is 149597870000.

Table 1. Distance for four NEA's beyond which diffraction smearing becomes significant (rho = 0.88); see text for explanation.

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

Since Didymos and 2001 CC21 have aphelia less than the distances for them in Table 1 and their inclination to the ecliptic is low, diffraction smearing is not an issue for them, but it is for the smaller NEAs.

4. (65803) Didymos

Helped by extensive astrometric observations organized and analyzed by the ACROSS and DART teams [3,14], IOTA observers in the USA, Europe, and Australia, as well as Japanese observers, tried to record occultations by Didymos before the DART impact on 2022 September 26, but none of these efforts succeeded due to bad weather or not being able to deploy enough stations to cover the rather wide uncertainty zone. There was one especially large effort in Portugal in 2022 August organized by ACROSS and the Southwest Research Institute, but clouds prevented any observation. Around the time of the DART impact, Didymos was finally close enough for a radar detection, which de-creased the error of Didymos' orbit that resulted in better occultation path predictions. Some of the best observations of Didymos and Dimorphos occultations were made in Europe this year are described elsewhere [3,15]. We will cover the more important observations made in the USA and Japan below.

4.1 IOTA Multiple-station Deployments

Before describing the best IOTA Didymos obser-vations, we first discuss this key technique first used by IOTA for asteroidal occultations in 2001 [16,17,18]. It takes advantage of the fact that the Earth's rotation is more accurate than any human-manufactured telescopic tracking system, allowing the setting up, by one or two observers, of several simple stationary (non-tracking) telescopes at dif-ferent sites across a predicted occultation path, all pointed using stars to the altitude and azimuth at which the occultation will occur. Most of these are small telescopes on low alt-az mounts with low profiles that can easily be hidden behind bushes near roads. We call the locus on the sky that is traced by the altitude and azimuth as a function of time, the pre-point line of declination; the star char-ting software Guide 9 [19] and C2A can plot this line, and Occult4 [7] can generate a list of the pre-point times for stars that are close enough to the pre-point line.

For the first observed occultation by Apophis, D. and J. Dunham used 80mm "midi" refractor systems on "paver mounts" designed by J. Broughton to obtain two of the three positive chords [1]; in some places, these are incorrectly labelled as 120mm scopes. R. Venable has had the most success for recording NEA occultations since he mainly uses large Schmidt-Cassegrain telescopes (SCTs), with apertures of 36cm (3), 28cm (1), and 20cm (1), all with the Fastar modification that converts them into f/2.1 systems, giving large FOV's to allow longer drift-through times, as well as other advantages. Rather than use the bulky tripods that come with these scopes, Venable has built special smaller ones that carry their weight, but make it possible to set up more quickly with less effort since the scope OTA's don't have to be lifted onto the usual high tripods. One of his 36cm telescopes is shown in Fig. 7.

Fig. 7. Roger Venable with one of his 36cm SCTs with Fastar modification and a large dew shield. The large battery is used to power his recording and timing equipment, not the telescope, which is manually pointed to the altitude and azimuth of the occultation using stars.

4.2 2022 October 15 Occultation

Venable deployed his 5 SCT'a telescopes like this to record the occultation of a 10.4-mag. star near Cherokee, Oklahoma. His smallest scope, with 20cm aperture, recorded the occultation, while his other scopes had no occultation. His suspected occultation light curve is shown in Fig. 8; it was confirmed by R. Dunford and R. Trank who recorded the event near Forreston, Illinois. The observations are shown in the sky plane in Fig. 9. This allowed an accurate orbit update and much better predicted paths, resulting in several more Didymos occultations to be recorded in the USA, Japan, and Europe.

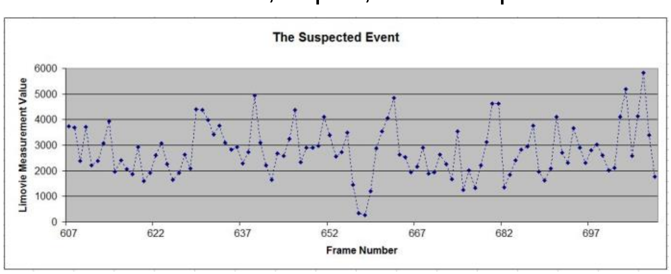

Fig. 8. Recording of the occultation from R. Venable's station 5 near Cherokee, Oklahoma using a 20cm SCT, the first Didymos occultation ever recorded.

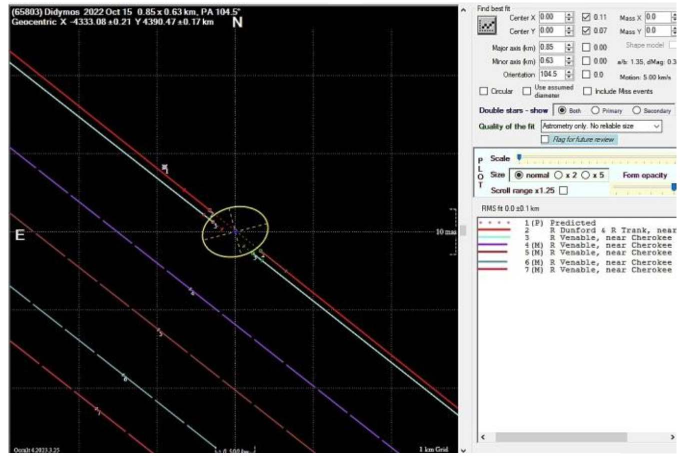

Fig. 9. Sky plane plot for the 2022 Oct. 15th occultation by Didymos. The event was positive for Venable #5 and Dunford/Trank, and negative for Venable stations 1-4.

4.3 All Didymos Occultations in the U.S.A.

The Didymos occultations observed in the USA are listed in Table 2. All of the events occurred during 2022 except the last one in January 2023.

Table 2. Didymos Occultations Observed in the USA in 2022 and 2023. On October 19, R. Venable recorded the first occultation by Dimorphos, as well as his second by Didymos. Collaborating with the DART team via S. Chesley at the Jet Propulsion Laboratory, accurate predictions of Dimorphos relative to Didymos were provided for each event. In some cases, an occultation by the the small moon could not be observed because it was either blended with Didymos, or in transit in front of it, or occulted by it. R. Jones recorded the second occultation by Dimorphos on November 12. R. Venable was able to deploy all 5 of his large SCT's for some of the events; D. and J. Dunham recorded the November 14^{th} occultation from two stations.

UT Date, 2022/23	Star mag.	# Sta.	Pos. chords	Locations	Observers
Oct 15	10.4	6	1	Oklahoma, Illinois	R. Venable B. Dunford
Oct 19	12.2	1	2	Florida	R. Venable
Oct 21	11.9	2	1	Nevada, California	D. & J. Dunham, R. Jones
Oct 26	10.6	3	3	Alabama	R. Venable
Oct 26	11.8	4	3	Oklahoma, Texas	B. Whitehurst, J. Moore, K. Cobble, N. Carlson
Nov 12	10.8	4	4	Southeast California	N. Carlson, P. Maley, R. Jones, R. Nolthenius
Nov. 14	10.0	2	2	N. Carolina	D&J Dunham
Nov. 15	11.2	3	3	California, Washington	G. Lyzenga, R. Jones, S. Preston
Dec. 19	11.1	6	6	S. Carolina	K. Getrost, R. Venable
Dec. 23	11.5	1	1	Georgia	R. Venable
Jan. 18	12.6	6	4	Florida, Arizona	R. Venable, N. Carlson

Fig. 10 shows the sky plane for the first Dimorphos detection by R. Venable on Oct. 19.

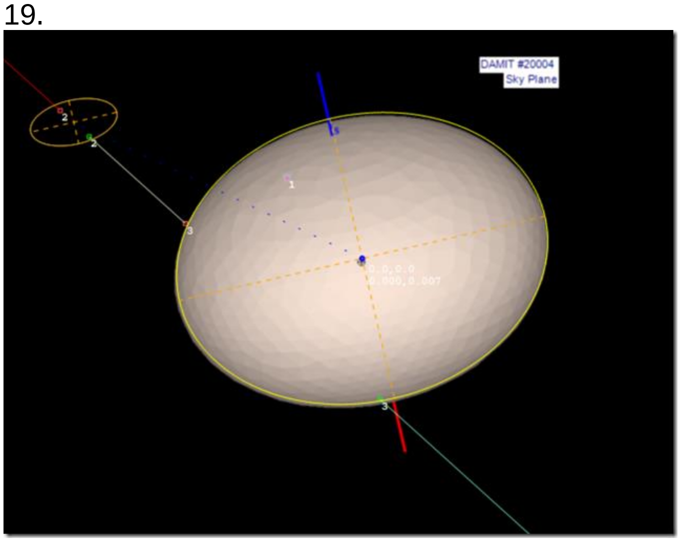

Fig. 10. Sky plane plot for the 2022 Oct. 19 occultation by Didymos in Florida recorded by R. Venable. The probable occultation by Dimorphos is in the upper left.

Fig. 11 shows the sky plane for the better second Dimorphos detection by R. Jones on Nov. 12, with 3 others who recorded the occultation by Didymos.

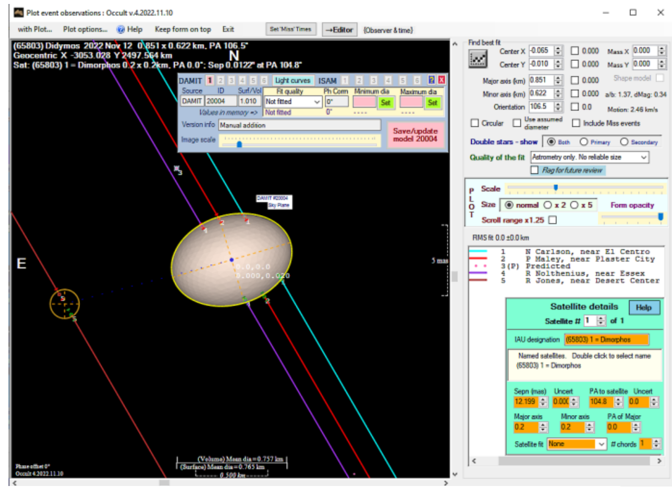

Fig. 11. Sky plane plot for the 2022 Nov. 12 occultation by Didymos and Dimorphos in southern California recorded by three observers. The occultation by Dimorphos, on the left, was recorded by R. Jones.

4.4 2022 October Occultations in Japan

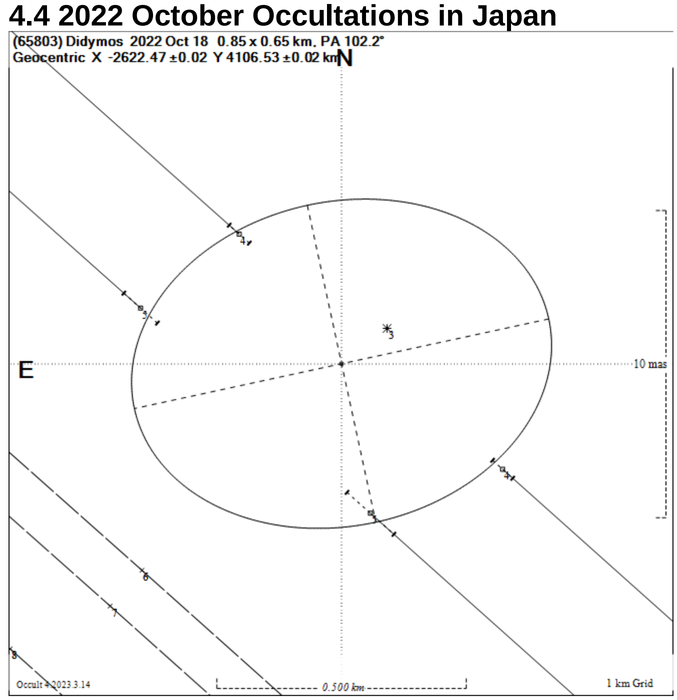

Fig. 12. Sky plane plot for the 2022 Oct. 18th occultation by Didymos, the first observed from Japan.

This was the first of a series of observations made by the Japanese Didymos team led by Hayato Watanabe and Hiroyuki Watanabe. Both Wata-nabes were awarded the 22nd the ASJ Award for the Outstanding Achievement by Amateurs by the Astronomical Society of Japan for their achieve-ments. This occultation was of an 11.2-mag. star. and the sky plane plot is shown in Fig. 12.

For the October 19th occultation of a 12.5-mag. star in Japan, the light curve by Yamamura is shown in Fig. 13.

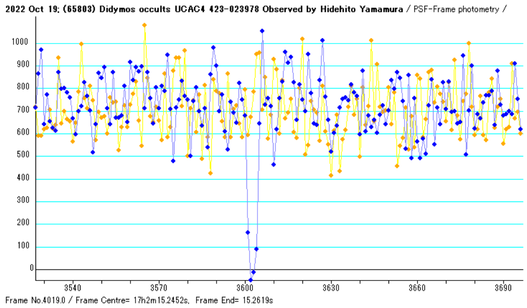

Fig. 13. Recording of the Oct. 19th occultation recorded by Yamamura.

As the Didymos team got positive detections at two locations on the 18th, members could spread out in a tighter formation on the 19th. Eight team members observed the occultation at seven locations in Mie: six were positive and one was negative. The sky plane plot is shown in Fig. 14; it was the best-observed Didymos event in Japan.

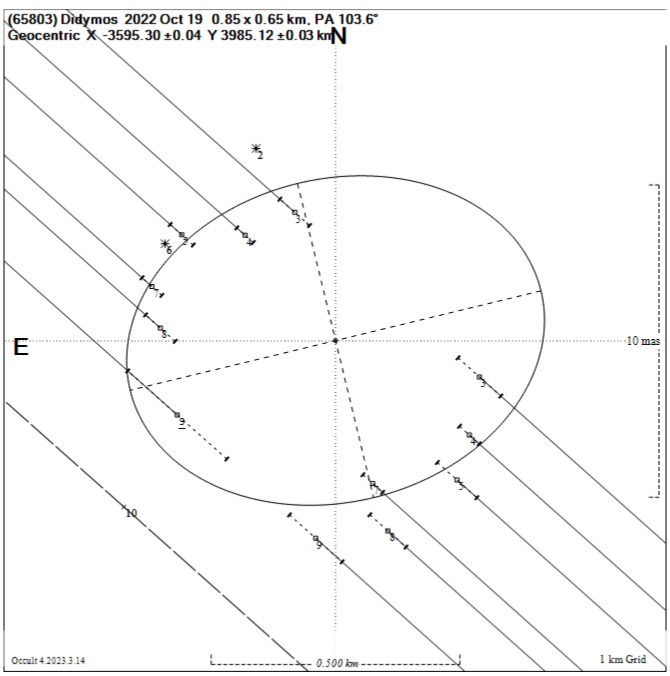

Fig. 14. Sky plane plot for the 2022 Oct. 19th occultation by Didymos, the best observed from Japan.

On October 27th, an occultation of a 10.8-mag. star was observed from Japan; the sky plane plot is shown in Fig. 15.

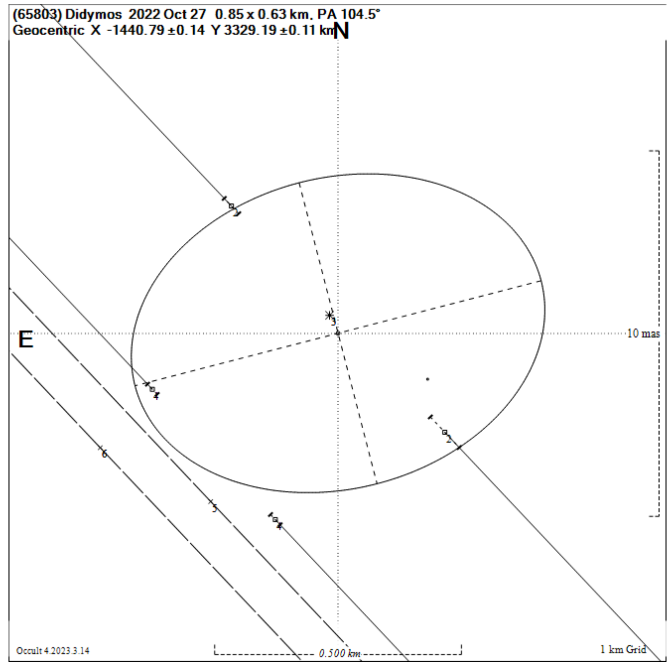

Fig. 15. Sky plane plot for the 2022 Oct. 27th occultation by Didymos observed from Japan.

4.5 Other Didymos Occultations in Japan

Other Didymos occultations were observed in Japan on Nov. 4 (star mag. 13.0) and Dec. 17 (star mag. 13.6), with their sky plane plots in Fig. 16 and 17, respectively.

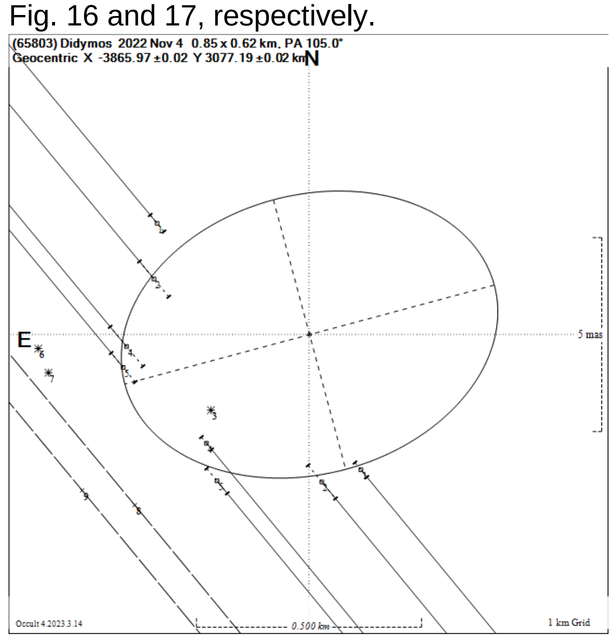

Fig. 16. Sky plane plot for the 2022 Nov. 4th occultation by Didymos observed from Japan.

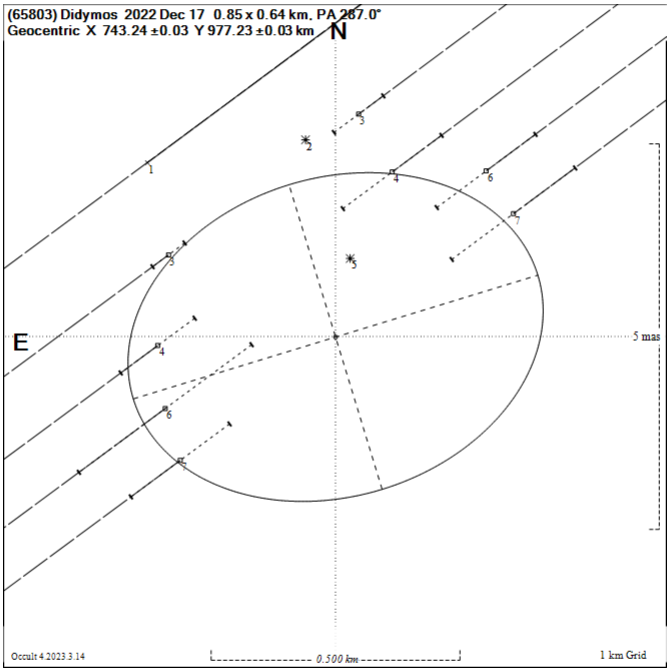

Fig. 17.. Sky plane plot for the 2022 Dec. 17th occul-tation by Didymos observed from Japan.

5. The Hunt for (98943) 2001 CC21

JAXA's planetary exploration mission Hayabusa2 has entered the extended mission phase (https://www.hayabusa2.jaxa.jp/en/topics/20220629_logo_e/) after a successful sample return from the asteroid Ryugu. The extended mission will include a flyby of asteroid 2001CC21 and a rendezvous with 1998 KY26. The flyby of asteroid 2001 CC21 is scheduled for 2026.

The Hayabusa2 Extended Mission Team reques-ted the Japanese Occultation Observation Team to observe stellar occultations by 2001CC21 in order to improve the orbital accuracy and estimate the shape of 2001CC21. In response to this request, they conducted an observing campaign for 2001 CC21. The following are the successful events covered by the observing campaign.

5.1 Large 2023 Efforts to Find 2001 CC21

Fig. 18 plots all of the observations, all made from Japan from January through March 5th, in the sky plane centered on the JPL 209 orbit. The obser-vations made on Jan. 10 and Feb. 8 were all neg-ative, as was all but one of the observations on March 5. The red circle shows the location of 2001 CC21 according to Miyoshi Ida's positive obser-vation of the occultation of a 10.1-mag. star on March 5, in a gap of the coverage by the earlier observations.

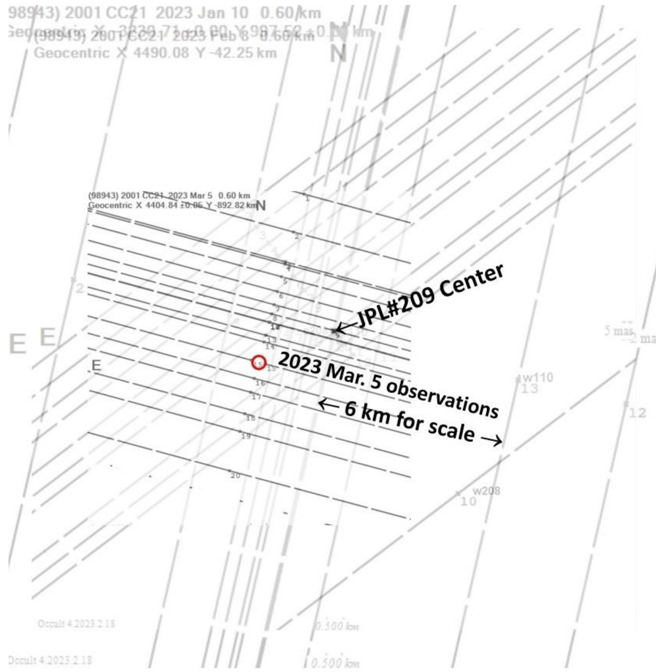

Fig. 18. Sky Plane Plot for 2023 Mar 05 occultation observations in Japan with past observations (Jan. 10 and Feb. 8) also shown.

Fig. 19 shows Ida's light curve fitted to a theoretical light curve that includes the effects of Fresnel diffraction for a spherical object, generated by R. Anderson using IOTA's asteroidal occultation light-curve fitting program PyOTE [20].

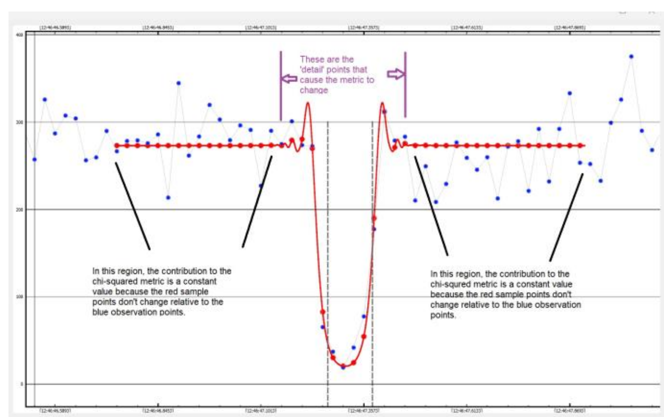

Fig. 19.Ida's observation of the 2023 March 5th occultation fitted with a spherical model Fresnel diffraction pattern..

We thought we had the orbit nailed with this observation, and the JPL Horizons team quickly used it with high weight to update the orbit to #210. But then we realized that the star for the March 5th occultation had a high

(2.1) Gaia Renor-malized Unit Weight Error (RUWE), meaning that the Gaia DR3 astrometric solution for the star's positional information could have actual errors uch larger than the formal errors. Analysis of some well-observed asteroidal occultations of stars with high RUWE showed that the actual errors in these cases could be of the order of 40 mas [21], more than 6 times the angular size of the 600m asteroid at the time, and the fraction is growing as 2001 CC21 recedes from Earth. As a consequence, the JPL210 orbit probably has larger errors than we expected, and none of several attempts after March 5th were successful in detecting an occultation by 2001 CC21, including by a rather large expedition to southern Japan for an occultation on March 26 of the 5.1-mag. star 6 Persei; that very bright star also has a high RUWE (1.9), possibly due to the star being a single-line spectroscopic binary. A revised version of Fig. 16 was generated centered on the JPL210 prediction, but using only previous observations of occultations of stars with good Gaia data, with RUWE <1.4, shown in Fig. 20. We will be able to resume the search for 2001 CC21 in the last 3 months of 2023, when the asteroid will again have elongations far enough from the Sun to observe, but it will be farther from Earth and the occultations will be a little shorter than the occultations early in the year, of the order of 0.10s,

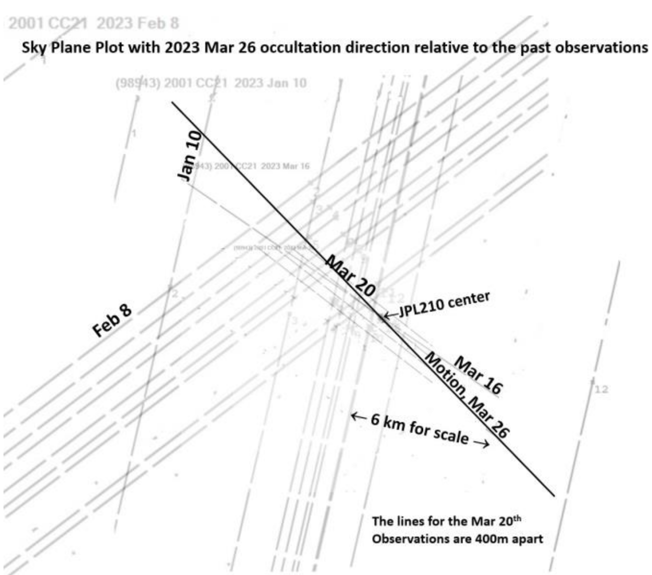

Fig. 20. Sky Plane Plot with the 2023 Mar 26 6 Persei occultation direction shown relative to the JPL 210 orbit for 2001 CC21. The observations were all made in Japan except for the 4 March 20th chords, observed in the U.S.A.

6. Occultations by Other NEAs

6.1 2022 Nov. 26 Occultation by (1866) Sisyphus

The occultation by this relatively large high-inclination NEA was recorded by Steve Messner near his home in southeastern Minnesota.

6.2 2023 May 7 Occultation by (2102) Tantalus

This is an occultation of a bright (mag. 8.2) star by this very high-inclination PHA; we will be able to use small pre-pointed telescopes like we used for the similarly-bright first occultation by Apophis in 2021 March. A map of the path is in the RASC Observer's Handbook [22].

6.3 Occultations by 2005 UD

This is probably a piece of Phaethon, in a similar orbit, that can be reached by DESTINY+ after its flyby of Phaethon, so campaigns will be conducted soon for it.

7. Conclusions

Continued results from the Phaethon and Apophis occultation campaigns, and new ones from campaigns for Didymos/Dimorphos and 2001 CC21, have demonstrated the power of occultation observations for refining NEO orbits, allowing this to be accomplished when the NEO is out of radar range. The implications for planetary defense are clear, allowing accurate propagation of the NEO trajectory far into the future. For the first occultation by a given NEO, a large campaign is needed, to cast a large-enough net to reliably record the occultation, preferably from 2 or more stations. Once a first success is achieved, it is important to observe a second occultation relatively soon, before the orbital geometry changes too much. A sizeable effort should be made for the 2nd event, in case of a star position problem for the first event, like we had for Apophis on March 7th. Roger Venable, with his ability to set up and pre-point 5 large telescopes on March 22nd, saved the day for Apophis, with his single chord at his easternmost station; without that, the accurate orbit of Apophis might have been lost. The efforts vindicated the ability of some IOTA observers to set up and run multiple pre-pointed telescopes, extending that ability, developed for occultations by main-belt asteroids, now to NEAs. We hope that these successes will spark interest in occultations in a new generation of professional and amateur astronomers, so that they learn our techniques, and improve upon them with new technology. Observing NEA occultations is a new activity requiring mobile efforts and careful planning. Maybe someday, you, or one of your students, will secure the orbit of a threatening asteroid and save the planet (or part of it).

Details of the observations presented in this paper are available at the Small Bodies Node of NASA's Planetary Data System [5] but more quickly with the historical asteroidal occultation observations database used by Occult4 [] updated approximately monthly [7].

8. Acknowledgements

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