Precise Astrometry from Occultations of Stars by Didymos and Dimorphos

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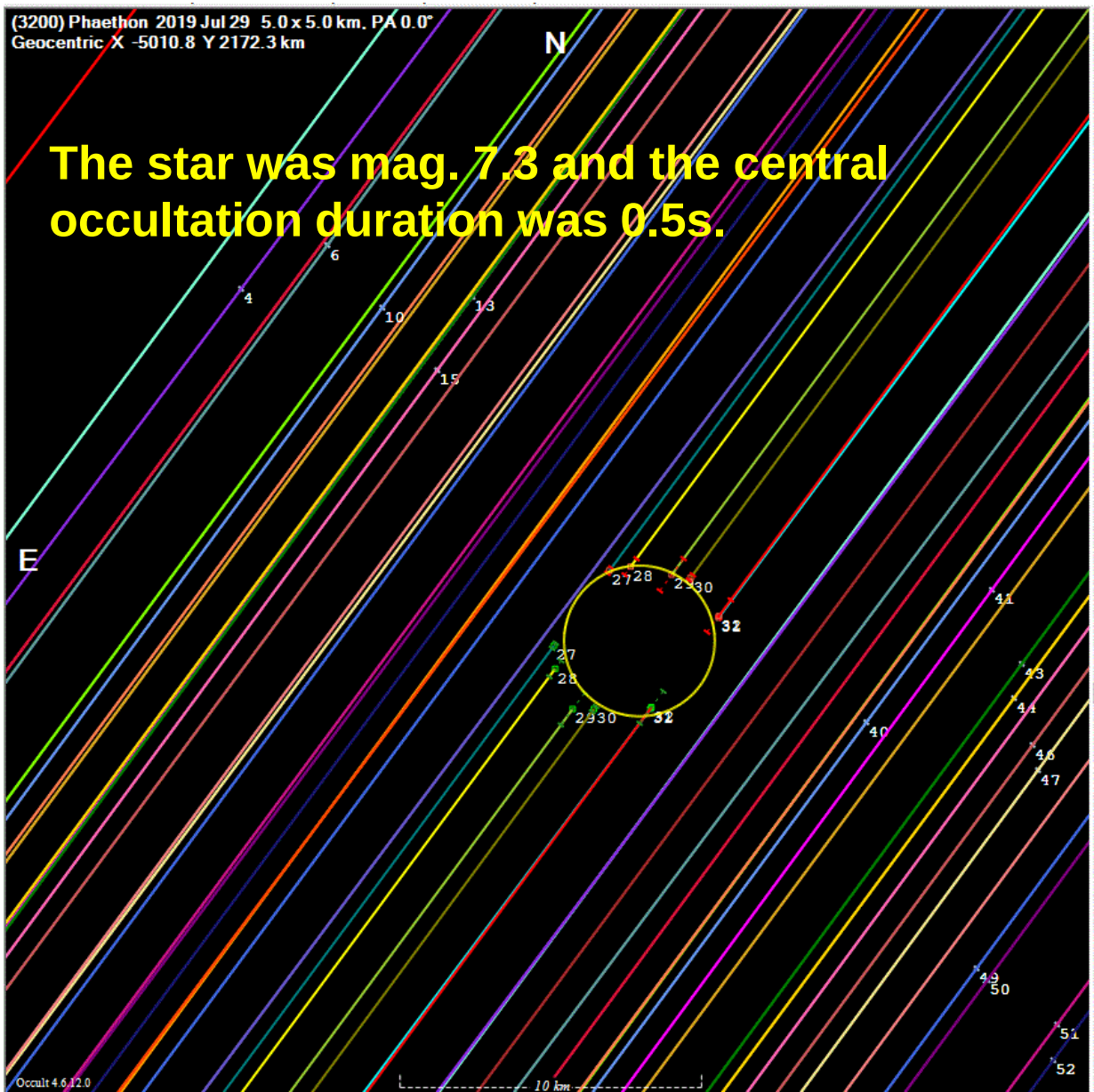
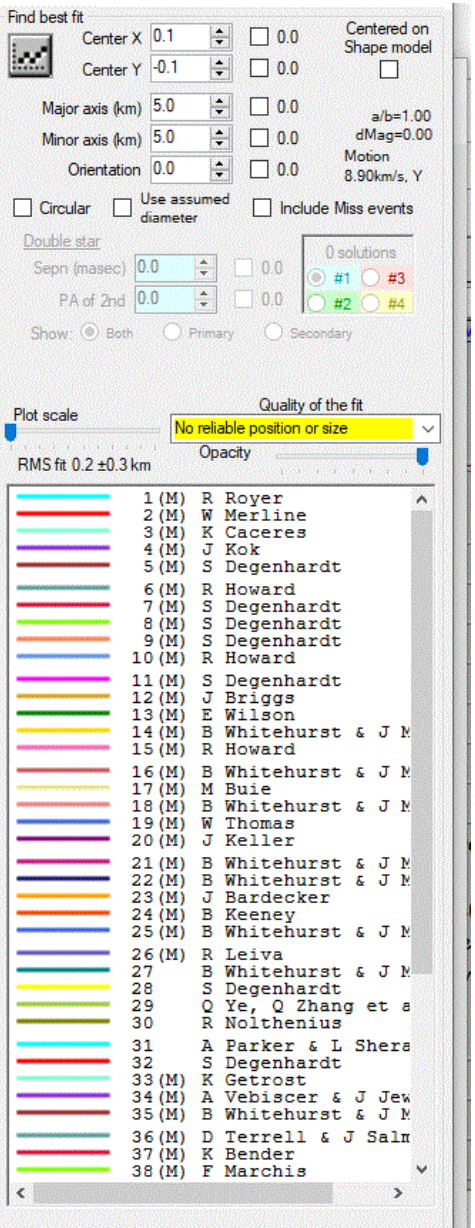
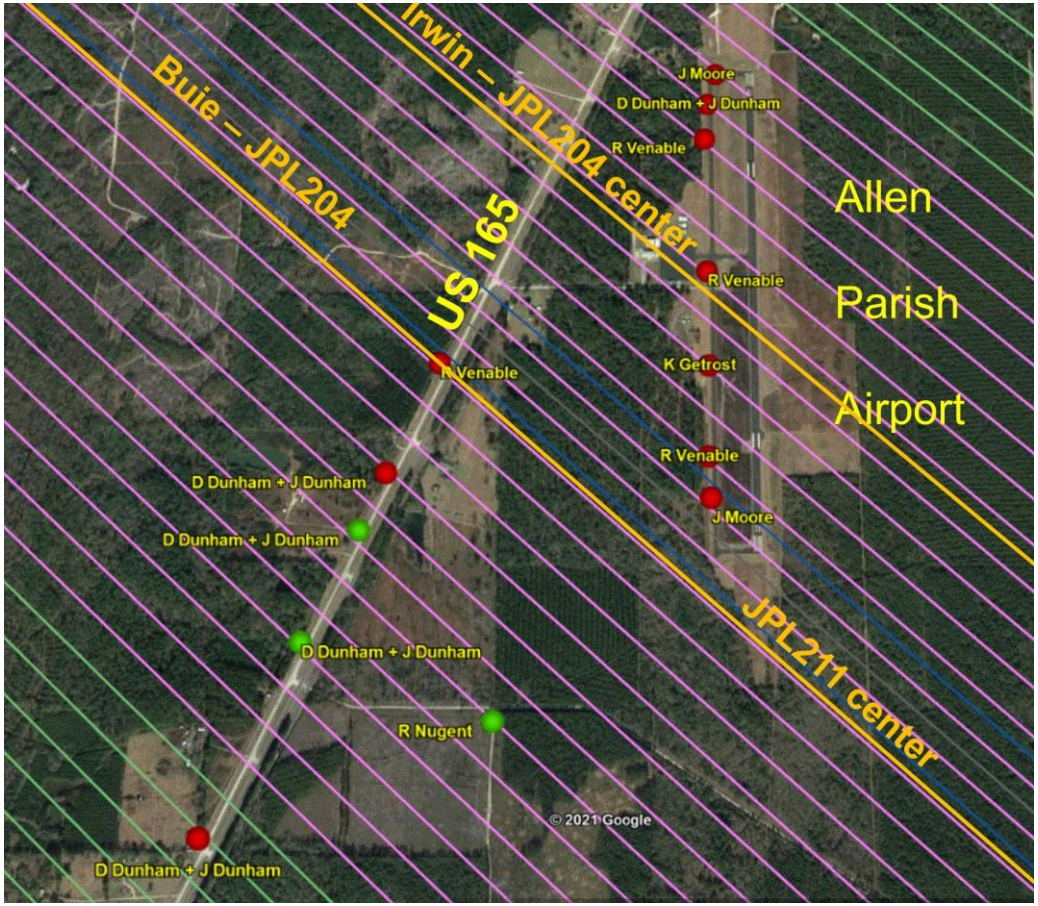
2019 July 29 Phaethon occ'n, 6 positives from 54 stations deployed by IOTA and the Southwest Res. Institute (SwRI)





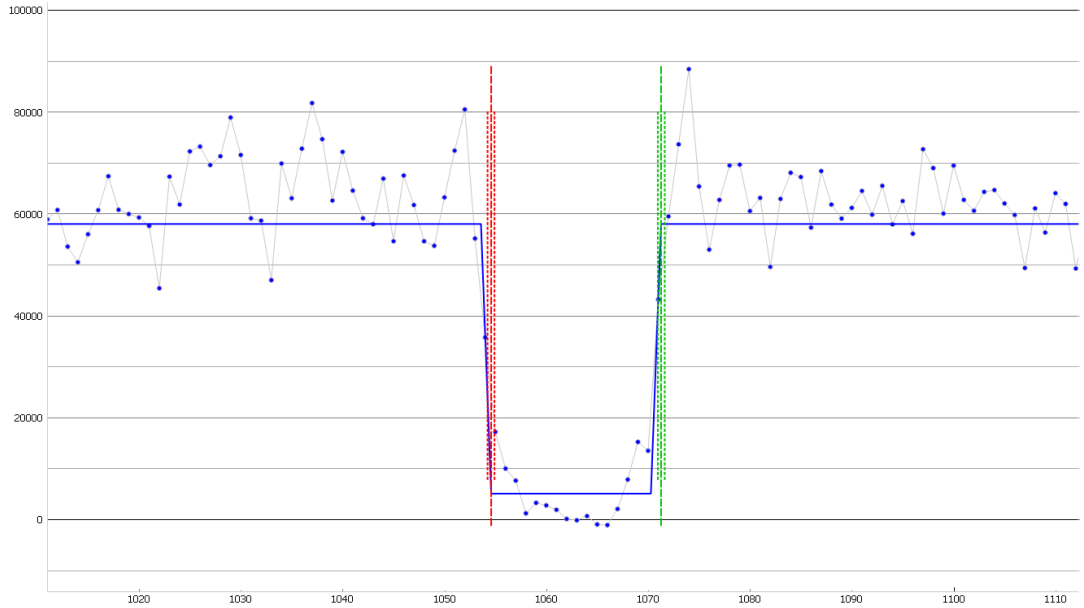
Occultation of 8.4-mag. NY Hydrae by Apophis 2021 March 7, stations near Oakdale, Louisiana



6 IOTA observers set up 13 telescopes, 11 of which recorded the star near Oakdale, Louisiana. Red dots mark stations that had a miss, while 3 green dots mark 3 that recorded the occultation. The station locations were selected to be close to the diagonal tracks shown on the map, 107 meters apart as projected on the ground. They were 80 meters apart on the plane of the sky. J. Moore pre-pointed 2 systems that recorded the star, R. Venable 4, and D & J Dunham, 5, 2 of which (green dots) recorded the occultation, as did R. Nugent between them. K. Getrost recorded a miss.

Some of the lines were covered by observers in Oklahoma, Colorado, and British Columbia; their observations were all negative. The predicted central duration was only 0.09s (3 NTSC video frames).

2021 April 11 Apophis occultation in New Mexico



With Apophis' orbit nailed by the April 4th observations, we were able to accurately locate the three observers, each with one telescope, for the April 11th occultation of a 10.1-mag. star, so that each had occultations. Above is Kai Getrost's light curve of the occultation that was recorded with 100 frames per second from Farmington, New Mexico with a QHY 174M GPS camera attached to a 20-inch Dobsonian telescope. Effects of Fresnel diffraction are evident. A fuller account of all of the observations is in our PDC 2021 paper on NEO occultations available at **http://iota.jhuapl.edu/NEOoccultationsDunham.pdf .**

Summary of all observed positive Apophis occultations with O-C's (in mas) from JPL Orbit 214a

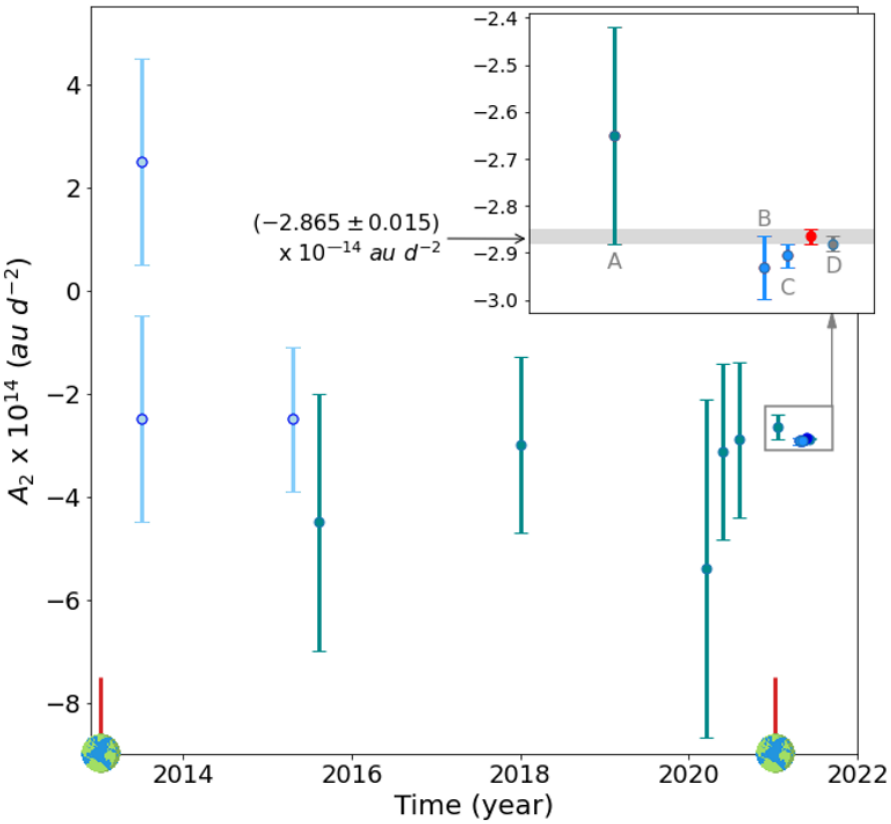
2021 Date	mag. [1]	Loc. [2]	Total #	# pos.	Δα [3]	Δδ [3]	Δt [3]	RUWE [4]
March 7	8.4	LA,OK,CO,BC	29	3	-11.0	+1.2	+0.17	1.45 [5]
March 22	10.0	FL,AL,IL	9	1	+0.4	-0.5	-0.02	1.15
April 4	11.0	NM	8	3	+0.3	-0.1	-0.01	0.90
April 10	12.6	Japan	2	1?				
April 11	10.1	NM	3	3	+0.5	-0.5	-0.03	0.85

[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.

We believe NY Hydrae's duplicity, more than the RUWE value, is the main explanation of the large residuals on Mar. 7.

The table shows that the residuals for March 7th stick out like a sore thumb, demonstrating the astrometric power of observations of occultations by small NEOs.

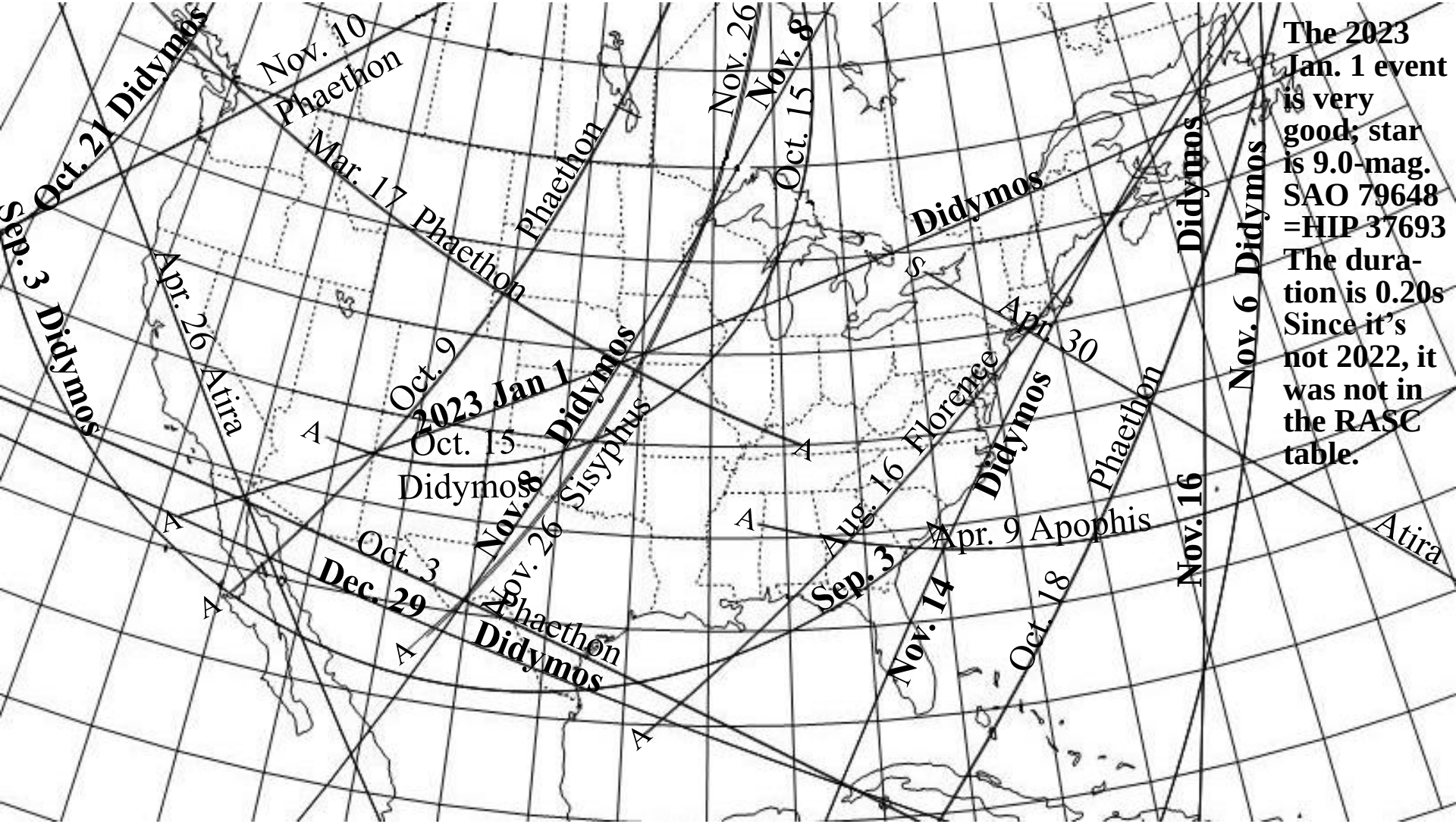
Occultations helped retire the risk of Apophis



Gaia Image of the week, 2021 Mar. 29. “Apophis’ Yarkovsky acceleration improved through stellar occultation”

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.

Occultations by NEAs during 2022 (several by Didymos)



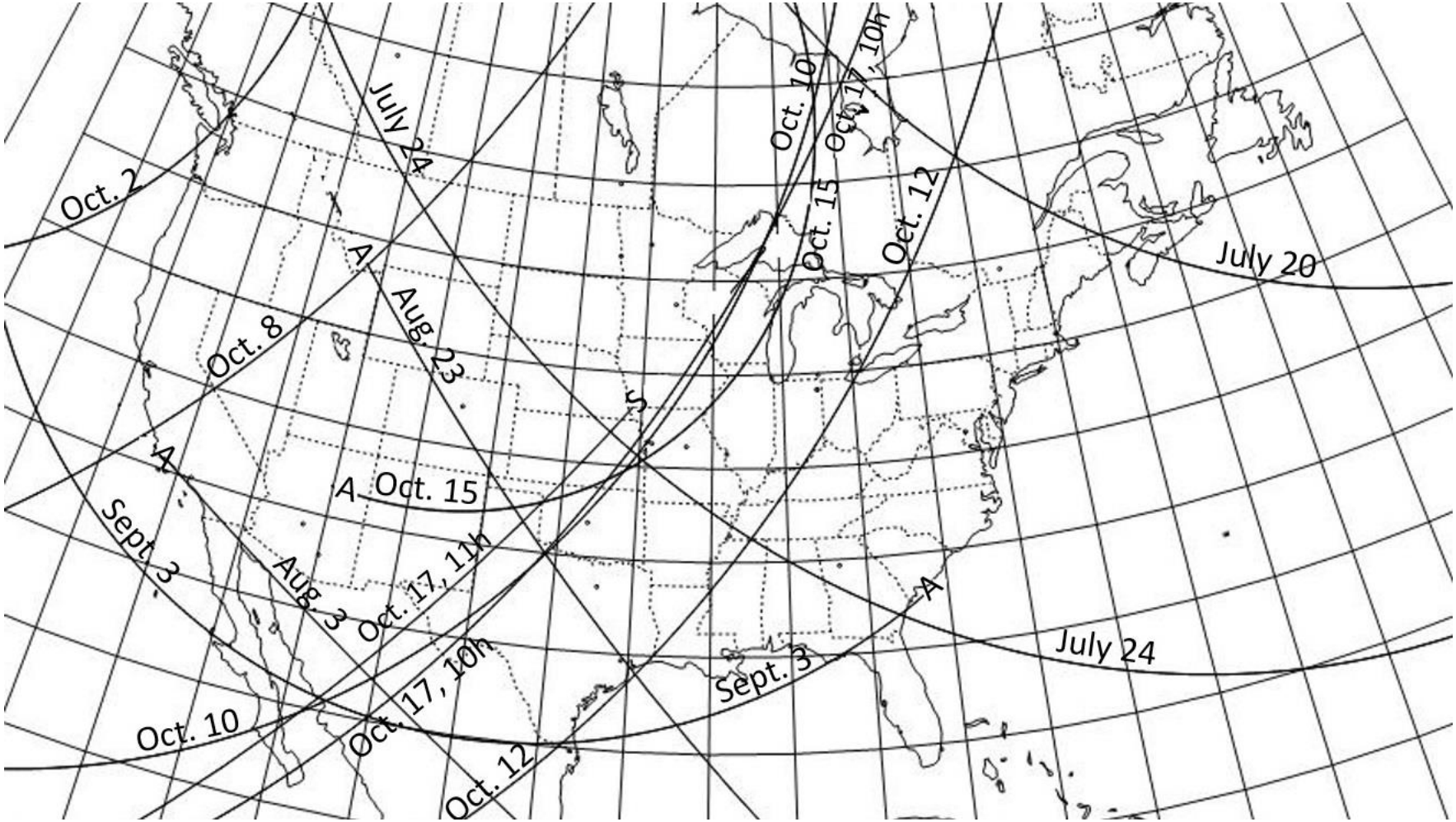
Didymos Occultations are labelled in bold type

Occultations by NEAs during 2022 (key and remarks)

Date	UT	Occulting Body	Star	Mag.	RA (2000) h m s	Dec ° ′ ″	ΔMag.	Dur. s	Path
Mar.17	03:31	3200 Phaethon	TYC 1219-01612-1	10.1	02 32 41.3	+18 16 41	7.4	0.27	BC-KY
Apr. 9	08:43	99942 Apophis	TYC 5782-01139-1	8.5	21 02 38.3	–14 07 51	11.8	0.02	MS-SC
Apr. 26	04:57	163693 Atira	TYC 3769-00890-1	10.8	06 37 06.1	+54 57 57	7.3	0.11	CA-Baja
Apr. 30	00:24	163693 Atira	TYC 3771-01267-1	10.3	06 56 27.8	+54 55 53	7.9	0.11	ON-NY
Aug.16	08:36	3122 Florence	TYC 2463-00303-1	9.9	07 12 22.4	+37 22 46	7.4	0.11	FL-NL
Sep. 3	10:44	65803 Didymos	TYC 6989-00024-1	10.4	00 11 53.9	–30 58 01	4.8	0.19	Baja-GA
Oct. 3	10:49	3200 Phaethon	TYC 3312-02354-1	11.4	03 26 00.4	+46 18 30	6.3	0.29	Cuba-Baja
Oct. 9	01:58	3200 Phaethon	TYC 3310-01992-1	10.7	03 10 44.9	+46 16 50	6.8	0.26	MB-Baja
Oct. 15	07:05	65803 Didymos	UCAC4 395-013761	10.4	06 28 25.0	–11 02 05	4.9	0.16	AZ-ON
Oct. 18	00:30	3200 Phaethon	UCAC4 678-015381	10.8	02 43 32.7	+45 31 21	6.6	0.23	NL-Cuba
Oct. 21	10:13	65803 Didymos	TYC 4818-00021-1	9.3	07 04 46.4	–03 41 43	6.3	0.18	BC
Nov. 6	07:14	65803 Didymos	TYC 0780-01085-1	10.4	07 59 40.9	+09 07 48	5.7	0.27	DR-NL
Nov. 8	10:44	65803 Didymos	TYC 0785-01766-1	10.5	08 04 12.1	+10 23 02	5.6	0.28	Mex-ON
Nov.10	05:34	3200 Phaethon	UCAC4 647-005831	11.8	01 35 45.5	+39 21 32	5.6	0.22	AB-WA
Nov.14	10:32	65803 Didymos	TYC 0806-00754-1	10.2	08 14 07.4	+13 30 54	6.0	0.33	FL-NL
Nov.16	07:59	65803 Didymos	HIP 40525	9.3	08 16 30.0	+14 24 43	6.9	0.34	DR-NL
Nov.26	07:39	1866 Sisyphus	TYC 3020-00440-1	11.5	12 29 18.8	+41 51 25	5.8	0.29	Mex-ON
Dec.29	06:46	65803 Didymos	UCAC4 595-042049	10.6	07 48 47.5	+28 55 57	5.8	0.25	Cuba-Baja

From *RASC Observer's Handbook 2022*, p. 247-8. This includes only Didymos events with mag. <11.0; the 1st is on Sep. 3. But there are many more observable events in the US to mag. 12.0 starting July 24. The events can be observed routinely by IOTA with small groups, but **only after a first event is recorded with a large effort to pin down the orbit** (current 1σ error ~ 12 path-widths) that would need some support like the SwRI efforts for Lucy occultations. Then, even Dimorphos events could be observed to provide accurate astrometric data for that DART target.

Occultations by Didymos to 2022 Oct. 17, <12.0 mag.



This augments the previous two slides, to show only occultations by (65803) Didymos events with mag. <12.0, to show more of the observable Didymos occultations. The map was too cluttered to show all of these Didymos events to the end of the year; another map will be prepared later, to show the 24 such occultations that will occur from 2022 Oct. 18 to 2023 Jan. 1. Paths only in the ocean in the s.e. part were removed.

Occultations by Didymos to 2022 Oct. 17, <12.0 mag., Table

Occultations by (65803) Didymos (diam. 0.8 km) in 2022 to Oct. 17 and to mag. 12.0

Date	U.T.	Diam.	Durn	Star	dMag	Elon	Star	d	RUWE	Moon		Star R.A. (J2000)			Dec.		
m d	h m	"	sec	mag		o	No.		<1.4	Dist	ill	h	m	s	o	'	"	Path
Jul 20	7 19	0.003	0.18s	11.2	6.8	144	UCAC4 354-192857	W	1.10	52	53	22	31	50.718	-19	19	14.00	ON-NS
Jul 24	8 48	0.003	0.19s	11.7	6.0	146	TYC 6389-01164-1		1.25	100	16	22	37	58.052	-19	47	29.20	AB-GA
Aug 3	5 42	0.004	0.21s	11.5	5.6	151	UCAC4 344-200889		1.15	142	27	22	53	26.421	-21	22	31.71	CA-Mex
Aug 23	6 9	0.006	0.21s	11.9	4.0	155	TYC 6983-01234-1		1.05	121	15	23	34	0.807	-26	45	57.35	MT-TX
Sep 3	10 49	0.008	0.19s	10.4	4.8	150	TYC 6989-00024-1		1.20	100	47	0	11	53.866	-30	58	1.44	Baja-GA
Oct 2	10 56	0.015	0.13s	11.3	3.3	115	TYC 6470-00344-1	D	0.85	119	44	4	28	37.288	-28	32	9.25	WA-BC
Oct 8	12 23	0.015	0.14s	11.3	3.6	107	TYC 5924-00164-1	V	4.90	83	98	5	32	52.757	-20	31	3.36	CA-MB
Oct 10	9 31	0.015	0.14s	11.4	3.6	105	TYC 5922-00731-1		2.00	69	100	5	50	6.221	-17	49	23.11	Baja-ON
Oct 12	9 51	0.015	0.15s	11.9	3.3	103	UCAC4 376-011231		1.05	55	93	6	6	55.894	-14	57	49.89	Mex-QC
Oct 15	7 3	0.014	0.16s	10.4	4.9	101	UCAC4 395-013761		1.20	40	72	6	28	24.994	-11	2	4.64	AZ-ON
Oct 17	10 26	0.013	0.16s	11.7	3.7	100	TYC 5378-02094-1		0.85	37	53	6	42	22.253	- 8	18	7.19	Baja-ON
Oct 17	11 46	0.013	0.16s	11.8	3.6	100	UCAC4 409-017214	s	0.95	37	52	6	42	40.991	- 8	14	2.37	Baja-ON

Times are for a point near the center of the path; they will be a few minutes earlier or later for other locations along the path. Listed diam. is in arc seconds.
RUWE is a measure of the astrometric reliability of the Gaia astrometric data for the star. Values >1.4 means that the astrometric data probably have large errors so the event is unsuitable for mobile efforts.
An entry under "d" indicates probable duplicity or variability of the star. "ill" is the percent of the Moon that is sunlit.

Resources

- A paper about the Phaethon and Apophis NEA occultation successes was given at the 2021 Planetary Defense Conference; it is available at **http://iota.jhuapl.edu/NEOoccultationsDunham.pdf**
- MNRAS paper about IOTA's/NASA's asteroidal occultation archive and results: **https://arxiv.org/abs/2010.06086**
- IOTA main Web site, especially the observing pages: **http://occultations.org/**
- IOTA predictions for 2022 NEA occultations: **occultations.org/publications/rasc/2022/nam22NEAoccs.htm**
- Occult Watcher for finding asteroidal occultations for your observatory and area, and for coordinating observations: **http://www.occultwatcher.net/**
- Link to George Viscome's occultation observing primer: **http://occultations.org/documents/OccultationObservingPrimer.pdf**
- SwRI Lucy Mission Trojan occultations Web site (SwRI expeditions planned for many of them): **http://lucy.swri.edu/occultations.html**
- RECON TNO/Centaur occultations Web site (Mainly, w. USA events): **https://www.boulder.swri.edu/~buie/recon/reconlist.html**
- Lucky Star TNO/Centaur/Trojan occultations Web site: **https://lesia.obspm.fr/lucky-star/predictions.php**

Updated 2022 Jan. 23