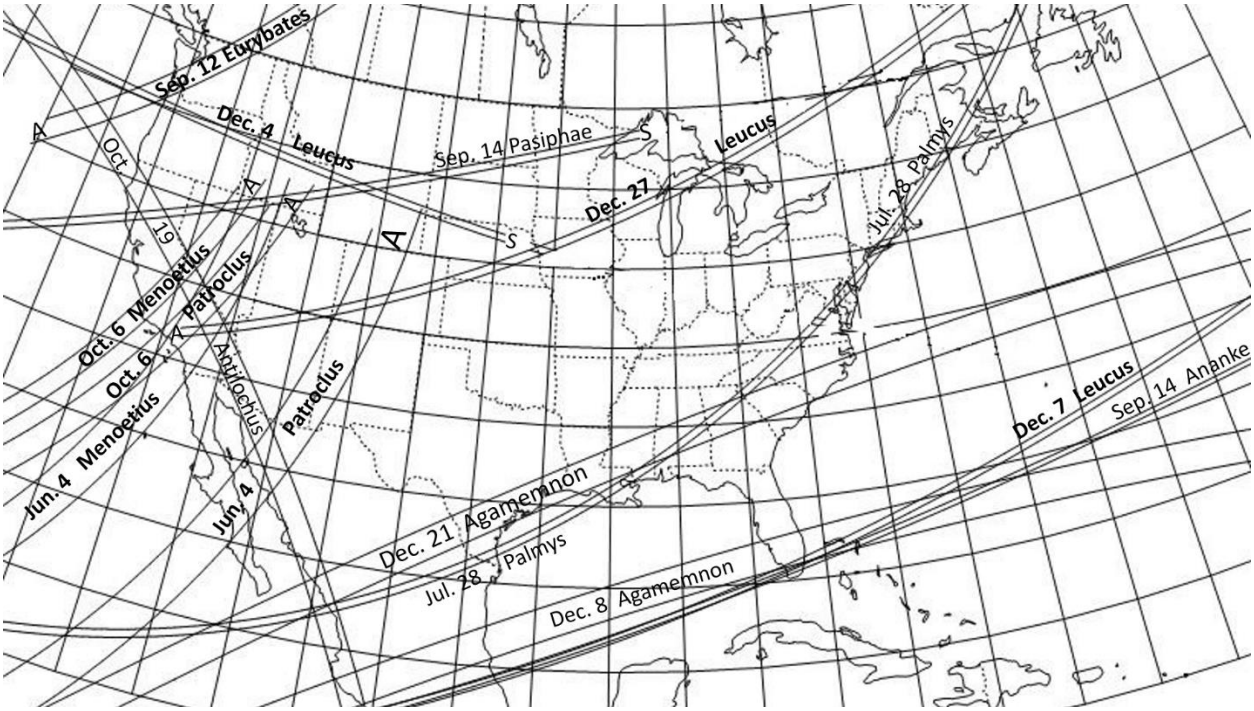
2022 Occultations by Trojan Asteroids

The Trojan asteroids formed, or were captured into, stable orbits about Jupiter's L4 and L5 triangular libration points. It is estimated that there are about a million of them larger than 1 km, about the same number as main-belt asteroids. But because they are about twice as far from the Earth, we know less about the Trojans than the main-belt objects. To learn more about the Trojans, NASA is sending its Lucy spacecraft to fly by five of them, from 2027 to 2033, to study them in detail. Two of them have known moons. Observations of occultations of stars by these asteroids will help determine their sizes, shapes, and precise orbits of the objects, information that will be valuable to the Lucy project for planning the spacecraft observations. For this reason, the Southwest Research Institute (SwRI) in Boulder, Colorado, is organizing campaigns to observe many of these occultations, and others are invited to make their own observations, to help these efforts. The Lucy mission is described in a good article, "Rock On", about it and other NASA missions to asteroids on pages 12-19 of the February 2022 issue of *Sky and Telescope*. On p. 17 is a box called "Get Involved", where SwRI asks interested amateurs to contact them, to possibly join their campaigns to observe occultations by the Lucy asteroids, and gives an example of one by (11351) Leucus that occurred in Arizona in late December, 2019; Joan and I successfully ran 4 stations for that event, obtaining the southernmost positive chord and one other, as well as the constraining miss line on the south side. A more recent success (Eurybates, 2021 Oct. 20) is described in an article at **https://occultations.org/publications/rasc/2022/Eurybates.pdf** that was published in the February 2022 issue of *Stardust*, publication of the National Capital Astronomers.

The best occultations of stars by Trojan Asteroids in North America during 2022



Date	UT	Occulting Body	Star	Mag.	RA (2000) h m s	Dec ° ′ ″	ΔMag.	Dur. s	Path
Jun. 4	**09:27**	**Menoetius**	**TYC 7927-01558-1**	**9.8**	**18 40 22.5**	**–43 52 22**	**5.4**	**8.6**	**ID-CA**
Jun. 4	**09:27**	**617 Patroclus**	**TYC 7927-01558-1**	**9.8**	**18 40 22.5**	**–43 52 22**	**5.4**	**8.6**	**ID-CA**
Jul. 28	04:24	58931 Palmys	UCAC4 354-171572	12.5	19 14 13.5	–19 12 24	5.9	1.9	NL-Mex.
Sep.12	**08:21**	**3548 Eurybates**	**UCAC4 593-034505**	**11.7**	**06 40 09.9**	**+28 26 55**	**5.7**	**2.9**	**OR-SK**
Sep. 14	09:28	Ananke	TYC 0002-99865-1	11.9	00 16 45.7	+00 58 28	6.8	1.6	FL-Mex.
Sep. 14	11:10	Pasiphae	TYC 4664-00887-1	12.0	00 16 15.8	–00 10 10	4.8	3.1	MN-CA
Oct. 6	**02:12**	**617 Patroclus**	**UCAC4 238-151066**	**12.7**	**18 10 36.3**	**–42 30 12**	**3.2**	**6.7**	**CA-ID**
Oct. 6	**02:12**	**Menoetius**	**UCAC4 238-151066**	**12.7**	**18 10 36.3**	**–42 30 12**	**3.2**	**6.7**	**Baja-WY**
Oct. 19	09:19	1583 Antilochus	UCAC4 451-019854	12.8	06 35 39.2	+00 00 37	3.4	7.0	CA-Mex.
Dec. 4	**12:57**	**11351 Leucus**	**UCAC4 539-029629**	**13.6**	**06 36 16.2**	**+17 43 01**	**4.4**	**2.5**	**NE-OR**
Dec. 8	05:09	911 Agamemnon	TYC 3352-01794-1	11.0	04 57 05.5	+49 23 42	3.9	9.6	FL-Mex.
Dec.21	04:44	911 Agamemnon	UCAC4 695-031299	12.5	04 46 47.3	+48 57 21	2.6	9.7	NC-Mex.
Dec.27	**01:07**	**11351 Leucus**	**UCAC4 537-026171**	**13.2**	**06 24 01.9**	**+17 18 08**	**4.4**	**2.1**	**NL-CA**

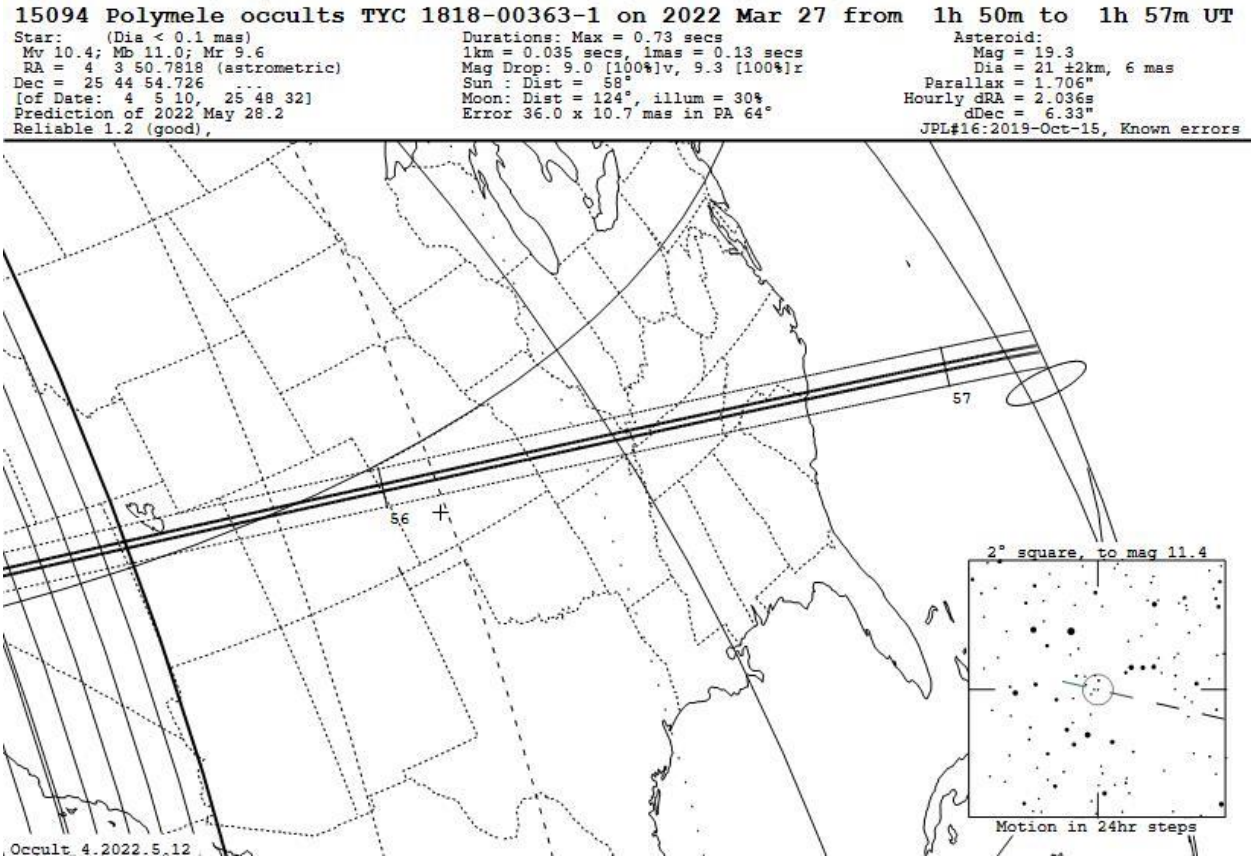
On the bottom of the previous page is a **corrected version** of the map of 2022 Trojan asteroidal occultations that's in the Handbook, and the corresponding table of information about each of the plotted occultations. One event on the map was left out of the table; the table entries for it are **Dec. 7, 04:37, 11351 Leucus, UCAC4 539-029291, 12.2, 06 34 59.2, +17 39 33, 5.7, 2.4, and Mex.-FL**. Unfortunately, the map on p. 248 of the printed Handbook has some errors, in the labeling of the four Patroclus and Menoetius paths, that were found only after the Handbook was printed. The orbital elements are all from the NASA JPL Horizons Web site at **https://ssd.jpl.nasa.gov/horizons.cgi** and the stellar data are from the Early third release (EDR3) of the European Space Agency's Gaia mission, as implemented with UCAC4, Tycho, and Hipparcos catalog identifiers with IOTA's free *Occult* software.

The paths for the June 4th Patroclus and Menoetius occultations on the map above are not accurate; the actual paths are likely to be almost two path-widths farther east, according to predictions by the Southwest Research Institute (SwRI) for their occultation campaigns for NASA's Lucy mission; see **http://lucy.swri.edu/occultations.html** for SwRI's interactive Google maps. Maps and more about the Lucy mission occultations is below.

The European Lucky Star project is also interested in several other large Trojan objects, and is also encouraging observations of occultations by them. On the map above, the dates and asteroid name of the Lucy target occultations are given in bold type, to distinguish them and emphasize their importance. Similarly, the lines for these events in the table are also in bold type.

The successive columns in the table list: (1) the date and central time of the event; (2) the name of the occulting body; (3) the catalogue and number of the occulted star; (4) the star's apparent visual magnitude; (5) the star's right ascension and (6) declination; (7) the expected magnitude change from the combined brightness; (8) the predicted maximum duration of the occultation in seconds; and, (9) the path location specified by the lands crossed by the eastern and western ends of the path shown on the map. The two-letter abbreviations for the US States and Canadian Provinces are given, with the order indicating the direction of motion of the shadow. "Baja" is Baja California, either Norte or Sur, while "Mex" denotes the rest of Mexico. Note that the times are for the geocentric time of closest approach; for any specific location in North America, the event time can be several minutes earlier or later.

There's one good Lucy-target occultation that our searches for the Handbook missed since the orbit was updated after the searches we conducted in August 2021. It is an occultation of a 10.4-mag. star by (15094) Polymele that occurred on March 27 at 1:56 UT (evening of the 26th local time) in a path extending from Colorado to the Carolinas shown on the Occult-produced map below.



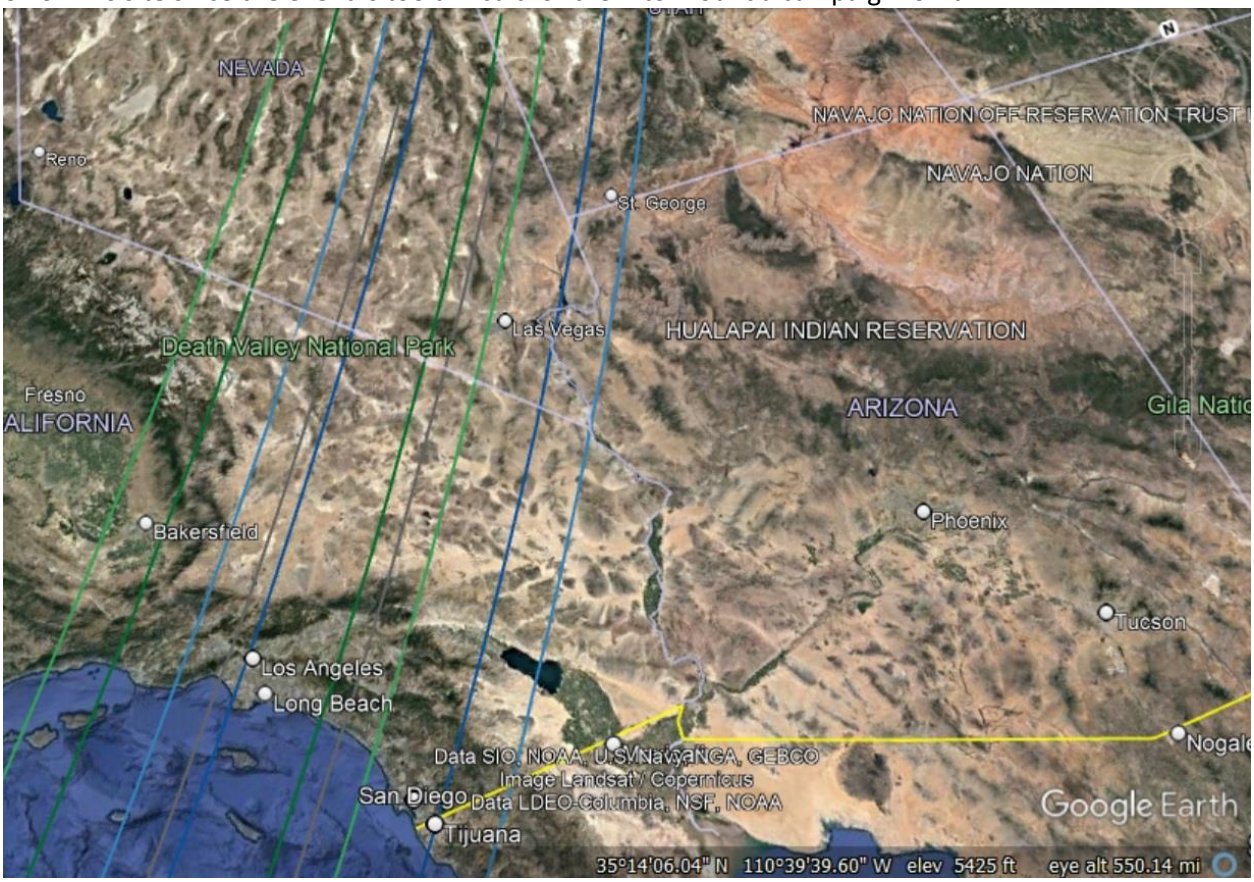
The observation area was decided only a few days beforehand when weather forecasts stabilized. SwRI's Google Map for the path is at **http://lucy.swri.edu/occ/20220327Polymele.html** - it has smaller error bars, less than a path-width, due to an orbit update from three observations of an occultation of a 15th-mag. star in Spain on 2021 Oct. 1. The large SwRI/Lucky Star/IOTA-ES effort to observe that event are described in an article on pages 1-9 of issue 2022-1 of the Journal for Occultation Astronomy (JOA) available at no cost from **https://iota-es.de/joafree.html** . A satellite of Polymele was found from the observations of the 2022 Mar. 27 occultation, as described in a presentation, "Discovering a Moon of Polymele", by Tony George, given at the 2022 IOTA meeting in August, see **https://occultations.org/community/meetingsconferences/na/2022-iota-annual-meeting/** . The better SwRI paths for the Polymele occultations in 2022 are almost 2 path-widths north of the ones shown here based on the JPL Horizons orbit #16. The Patroclus and Menoetius paths computed by SwRI are also different from those that we've generated from the Horizons orbital elements, as noted below for events with that pair on June 4th and Oct. 6. Our predictions using the JPL orbits for the other Lucy targets (those other than Polymele, Patroclus, and Menoetius) seem to be in good agreement.

Special interactive Google maps and other details for the SwRI campaign events is at **http://lucy.swri.edu/occultations.html** especially for the 5 Patroclus and Menoetius occultations in the USA and Australia during June and July**.** Similar information is given for the other occultations at the Lucky Star prediction Web site at **https://lesia.obspm.fr/lucky-star/predictions.php .** It's worth checking these

Web sites a week or two before an occultation that you might observe, since both SwRI and Lucky Star update their predictions with the help of earlier occultation observations which can shift the paths substantially from what we show on our maps.

Some information about some of the occulting NEAs portrayed above is given below:
(617) Patroclus: Patroclus is about 113 km across, but its large (104 km) moon Menoetius is almost as large, so this is a binary pair with a separation of about 680 km in a nearly circular orbit, which is known well enough that we can predict separate paths for the two objects.

We first describe the imminent Oct. 6th occultation by Patroclus and Menoetius that will occur over southern California. Brian Keeney at SwRI provided a Google Earth .kml that you can get at the IOTA 2022 Trojan occultations page at **https://occultations.org/publications/rasc/2022/nam22Trojanoccs.htm** . We have used it to generate the static map of the paths over southern California below; the event is not on SwRI's site since the event is too difficult for them to mount a campaign for it.



The blue lines are for Patroclus and the green ones for Menoetius. The darker lines are the northwestern and southeastern limits of the occultation while the lighter lines are the approximate 3-sigma limits; gray lines mark the central lines for both events. Much of Los Angeles and the San Gabriel mountains will have occultations by both objects, occurring within +/-40 seconds of 2:14:57 UT (7:14:57 pm PDT of Oct. 5). The occultation by each component will last about 5s for a central event. At Griffith Observatory in L.A., the star altitude will be 12° and the Sun alt. will be -10°, so locating the target star in the evening twilight before the occultation will be a challenge. The central time, and the star and Sun altitudes, for many other locations can be found in a list at http://www.poyntsource.com/New/Google/20221006_78660_Sites.txt
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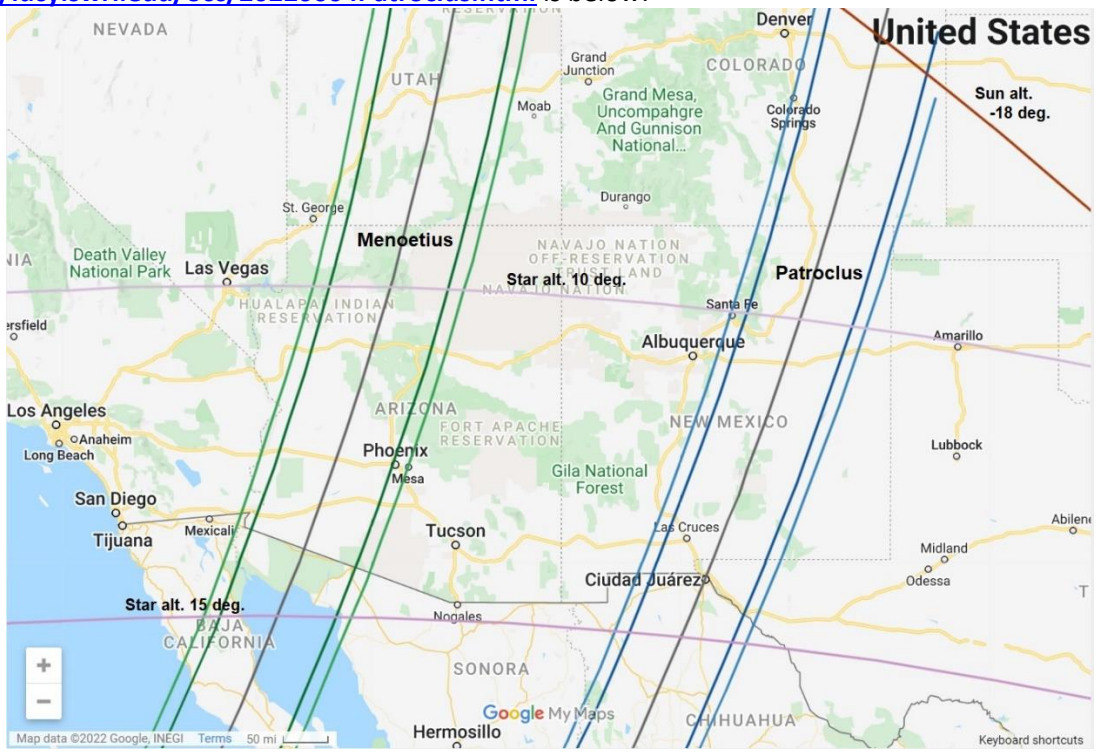
A static map for the June 4th occultations from the SwRI Google map at **http://lucy.swri.edu/occ/20220604Patroclus.html** is below:



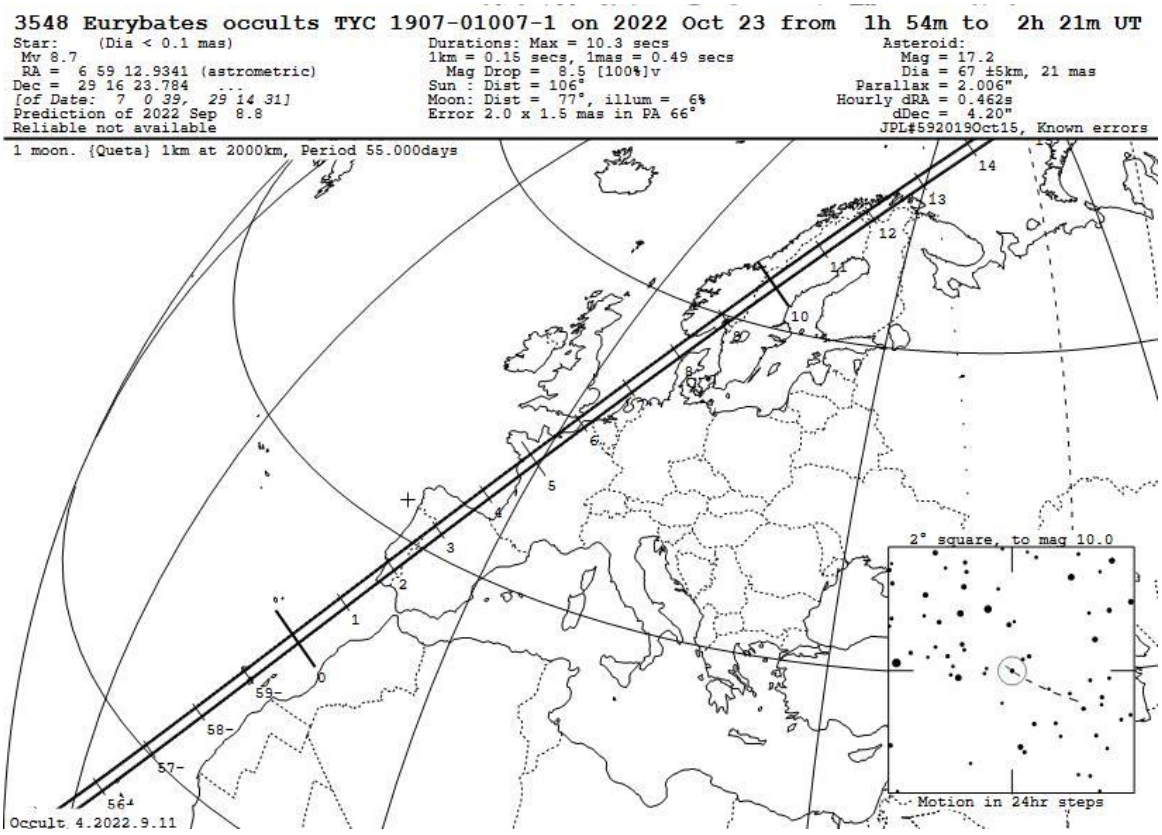
On the map, the gray lines are the central lines, the green lines on the left are the 3-sigma limits for Menoetius, the blended green/gray lines are its predicted path limits, the blue lines on the right are the 3-sigma limits for Patroclus, and the blended blue/gray lines are its predicted path limits. David Dunham, dunham@starpower.net, is coordinated observational coverage for this occultation with the help of parallel line Google Earth files provided by Vadim Nikitin. The observations were used to improve the predictions for the large mobile efforts set up in Australia for 4 occultations by these objects that occurred later in June, and in July. For the June 4th event, SwRI gave a G* mag. of the star as 8.4, but it is 9.8 according to IOTA's Gaia EDR3-based data, and the AAVSO APASS V mag. is 10.0, in agreement with IOTA's data. The altitude was low in the south for all US observers, so selecting sites with a clear view was a challenge. Norm Carlson travelled to NM where he recorded the only positive chord for Patroclus; 7 positives were recorded from stations in Arizona, with Ted Blank and the Dunhams each recording from 3 stations, in each case 2 positive and 1 negative. The actual paths for both objects were about half a path-width east of the SwRI-predicted paths.

(911) Agamemnon: This is not a Lucy target, but it is the second or third largest Trojan asteroid. A 2012 occultation showed a size of about 160 km, but more well-observed events are sought to better determine its size and shape. The 2012 event also revealed a satellite, ~10 km across with a separation of 278 km.

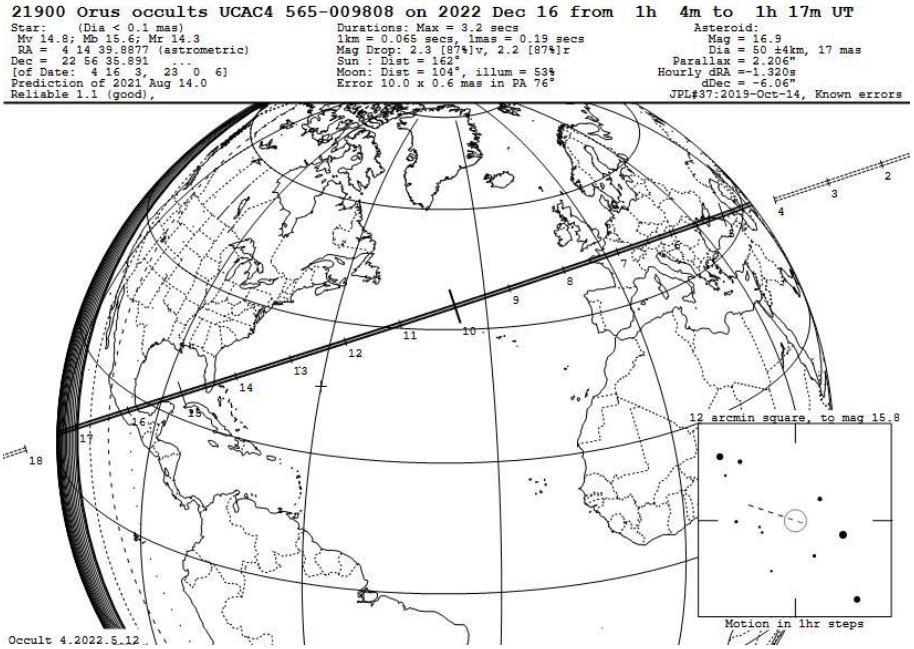
(3548) Eurybates: It has a small moon, Queta, only about a km across, discovered by Hubble Space Telescope images taken in 2018. Queta orbits about 2310 km from Eurybates in a nearly circular orbit. Eurybates is also the main object of one of the few Trojan asteroid families, with 218 known members of carbonaceous and/or primitive composition.

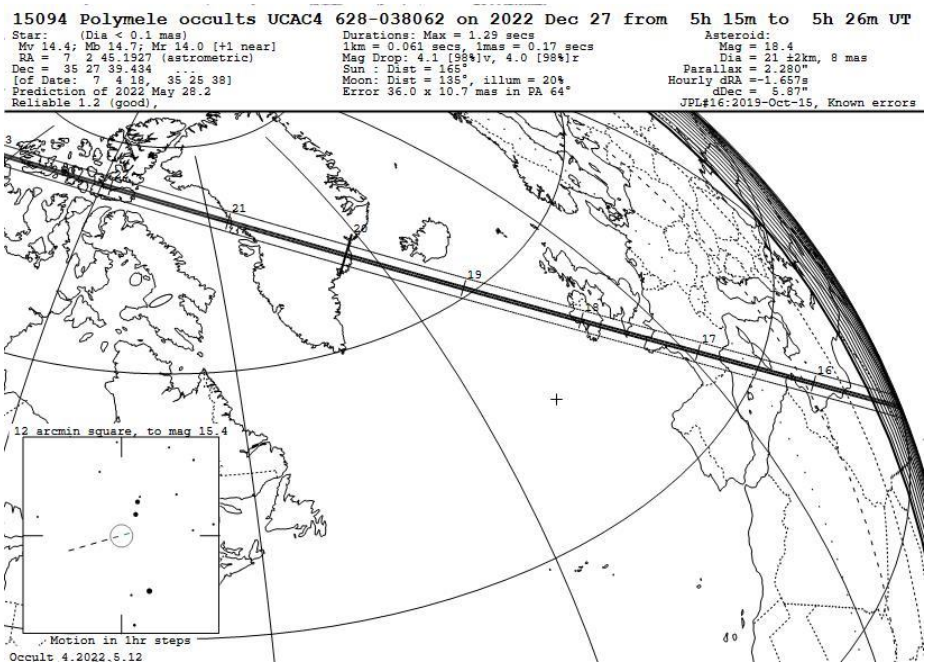
Ananke and **Pasiphae** are not Trojan asteroids, but are small irregular moons of Jupiter, XII and VIII, respectively. Since they are also at Jupiter's distance, they are included in this section. As part of the Lucky Star Project, astronomers in Brazil are especially interested in these intriguing objects. Their occultation paths are very uncertain, but they may be improved before the events.

Occult maps, from which local UT and circumstances can be estimated, are given below for the occultations by Lucy target Trojan asteroids that will occur later this year, and for which SwRI plans campaigns in the USA or Europe, except for those by Patroclus and Menoetius.



You can get an updated Occult input .xml file for this bright event from IOTA's 2022 Trojans events page at **https://occultations.org/publications/rasc/2022/nam22Trojanoccs.htm** . SwRI gives the star's mag. as 6.9, but Gaia EDR3 has 8.7, exactly the same as the AAVSO APASS V magnitude.





The maps were produced with IOTA's free *Occult* software; see **http://www.lunar-occultations.com/iota/occult4.htm** . You can download and use this software and use it to compute your own local lists and information about these and many other occultations. The information for doing this is at **http://www.lunar-occultations.com/iota/2022iotapredictions.pdf** . This describes a prediction input file for planetary and asteroidal files called **All2002.xml**. You can use that file to generate local predictions, but you can replace it with the other files listed below to generate predictions for more occultations, mainly of fainter stars than shown on the maps, or for other parts of the world:

2022NA-TrojansFinal.xml – This is the input for the 14 Trojan occultations for North America shown on the main (top) map above, including the two events by Jovian irregular moons on Sept. 14.

2022WorldLucyAll.xml – This is the input for the 1731 occultations by the Lucy Trojans (6 objects, counting Menoetius separately) worldwide to mag. 16, but the Polymele events are wrong since the searches, conducted in August 2021, were done before the latest orbit update, and the March 27th event in the central and eastern USA described above, is not included.

2022WorldPolymele.xml – This is the input for the 175 occultations by (15094) Polymele worldwide to mag. 16, using the JPL #16 orbit, which is close to, but not as accurate as the SwRI orbit, as noted above.

2022WorldOtherTrojans.xml – This is the worldwide input for 470 other (non-Lucy) Trojan occultations to mag. 14. These are a selected subset of the non-Lucy Trojans covered by the Lucky Star Project; better paths may be available for them at **https://lesia.obspm.fr/lucky-star/predictions.php .**

For worldwide occultations by major and all types of minor planets (mainly main-belt) worldwide for the whole year, fairly comprehensive only to about mag. 12.5, use the **All2002.xml** file noted above, but even more occultations can be found with Occult Watcher, IOTA's free Windows software for finding and coordinating observations of asteroidal occultations, available free at **http://www.occultwatcher.net/** .

David and Joan Dunham, **dunham@starpower.net**, cell 301-526-5590, 2022 Feb. 4; updated May 29 and September 13.