

OBSERVATIONS OF MUTUAL EVENTS BETWEEN 617 PATROCLUS AND MENOETIUS ON SEPTEMBER 25, OCTOBER 6, AND OCTOBER 23, 2024

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On September 25, October 6, and October 23, 2024 UT, three photometric observational runs of the Trojan asteroid binary system 617 Patroclus-Menoetius were conducted as part of a coordinated effort to support NASA's Lucy mission, which is set to encounter this pair in March 2033. During these runs, lightcurve measurements were obtained to capture the ingress, egress and mid-eclipse timings of the predicted mutual events between the asteroid Patroclus and its satellite, Menoetius.

This paper presents three photometric observational runs of the Patroclus-Menoetius binary system, conducted from Flarestar Observatory in Malta on September 25, October 6, and October 23, 2024 UT, in support of NASA's Lucy mission. Data from the mutual transits and occultations of this Trojan asteroid were gathered to refine the orbital parameters and physical characteristics of the binary system. These observations were made following a call for contributions by Prof. Richard P. Binzel in the *Minor Planet Bulletin* (Binzel, 2024). The results aim to provide a clearer picture that may assist in mission planning and ensure precise targeting during Lucy's flyby in 2033, ultimately enhancing the scientific return and offering new insights into binary Trojan asteroids; a primary goal for the NASA Lucy mission.

Photometric observations were gathered through a 0.25-m Schmidt-Cassegrain telescope equipped with Moravian CCD using a 1603ME CCD sensor. All images were taken through a clear filter (unfiltered) with Sloan r' zero point and calibrated through dark and flat-field subtraction. Each image covered a field of view of 25.4 arcmin $\times$ 17.0 arcmin, with a pixel scale of 0.99 arcsec. The Comparison Star Selector (CSS) feature developed by *MPO Canopus* software (Warner, 2017), was employed to choose near-solar color comparison stars. All brightness measurements were based on the Asteroid Terrestrial-impact Last Alert System (ATLAS) catalogue (Tonry et al., 2018). All data were obtained from Flarestar Observatory in Malta (MPC code:171).

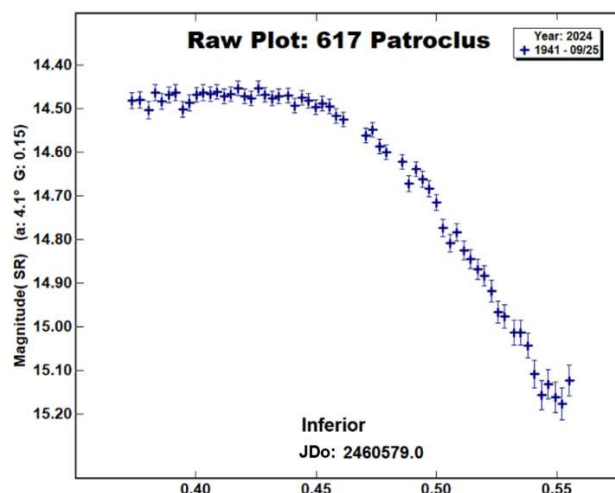
The mutual event data of 2024 September 25-26 of the 617 Patroclus binary system were collected from 21:27 to 01:48 UT, amounting to an observation run of 4 hours and 21 minutes. Observations were taken under good weather conditions. The last quarter moon did not affect the observations, with Patroclus positioned at a moon elongation of 104 degrees. The mutual event

was recorded through 60 frames, each with exposure time of 240 s. The same exposure length also applies to all subsequent runs (October 06 and 23). The observatory PC time has been synchronized through *Dimension 4* software (Thinking Man Software, 2024). *All timings refer to JD time or UT times at Earth, where light-time corrections have not been included in any of the presented figures or discussion of event timings.*

The inferior geometry event observed on 25-26 September was scheduled according to the predictions by Brozovic et al. (2024) where the mutual event was predicted to start at 23 h 02 m and end at 04 h 26 m UT with the mid-timing of the 'eclipse' set to occur at 01h 41m UT. (We note that all timing predictions by Brozovic et al. are for an Earth observer.).

From Flarestar Observatory's location at Long. 14.470 East and Lat. 35.905 N (altitude of 110 m), the target at the start of the run (at 21 h 27 m UT) had an airmass of 1.87, culminating at the meridian at airmass of 1.55 at 23 h 32 m UT and ending the run at 01 h 48 m UT at airmass of 1.98.

Provisional results from this run indicate that the predictions set by Brozovic et al. (2024) are in line with the observations obtained; as the last image at average maximum light was recorded at 23h 00m 19s UT (mid-exposure time) coinciding with the start of the eclipse (ingress) at 23h 02m UT. The least brightest data point obtained was also consistent with the predictions made as the faintest data point on the lightcurve was obtained through the image timed at 01h 44m 29s UT. This coincided just after the predicted timing of mid-eclipse set at 01:41 UT. For this run, due to the absence of post mid-eclipse data, the timing results remain uncertain, as the data available is limited and incomplete. The amplitude recorded is of 0.70 ± 0.02 mag.

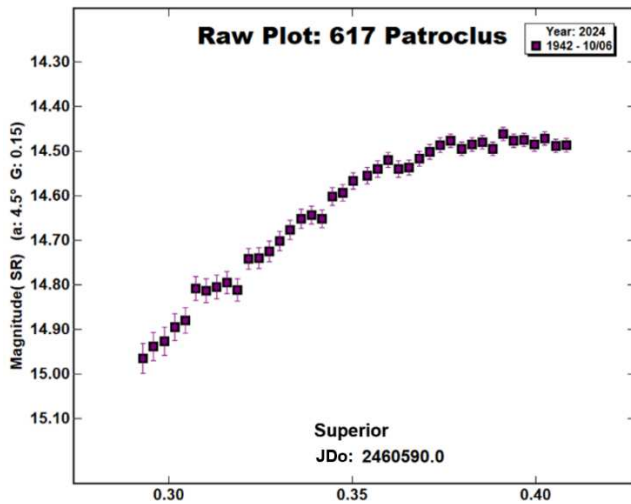


The superior conjunction mutual event predicted on 2024, October 06 provided another opportunity, this time to record the egress of this mutual event. Brozovic et al. (2024) predicted the event to commence at 16 h 12 m UT and end at 21 h 20 m UT with mid-eclipse occurring at 18h 48 m UT.

Number	Name	Family	H	D _{km}	a (au)	e	i (deg)	P(yrs.)	Discovered by	yyyy/mm
617	Patroclus	9202*	8.3	140.81	5.21	0.140	22.06	11.08	A. Kopff	1906/10

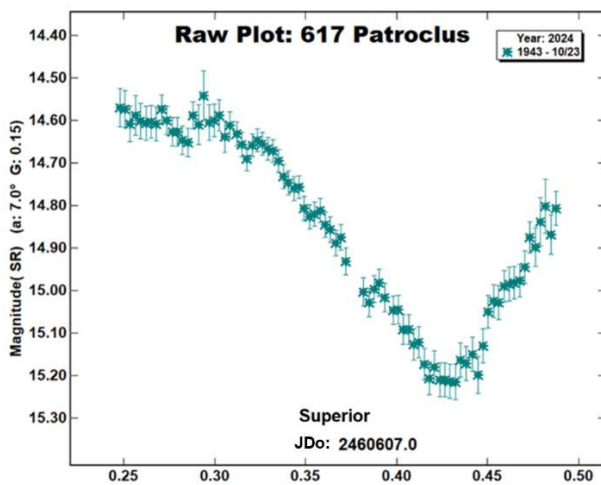
Table I. Orbital and discovery information. Family is the group or family using the LCDB values. An asterisk indicates a generic group, otherwise, the numbers are from Nesvorny et al. (2015).
Web Sources: JPL: https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/. MPInfo: <https://minorplanet.info/php/oneasteroidinfo.php>.

The lightcurve obtained from Flarestar Observatory shows a post mid-eclipse phase with the first observation obtained on 19h 31m 18s UT (mid-exposure time) at airmass of 2.56 and ending at 22h 17m 25s UT at airmass of 1.56. The amplitude recorded is that of 0.49 ± 0.02 mag.

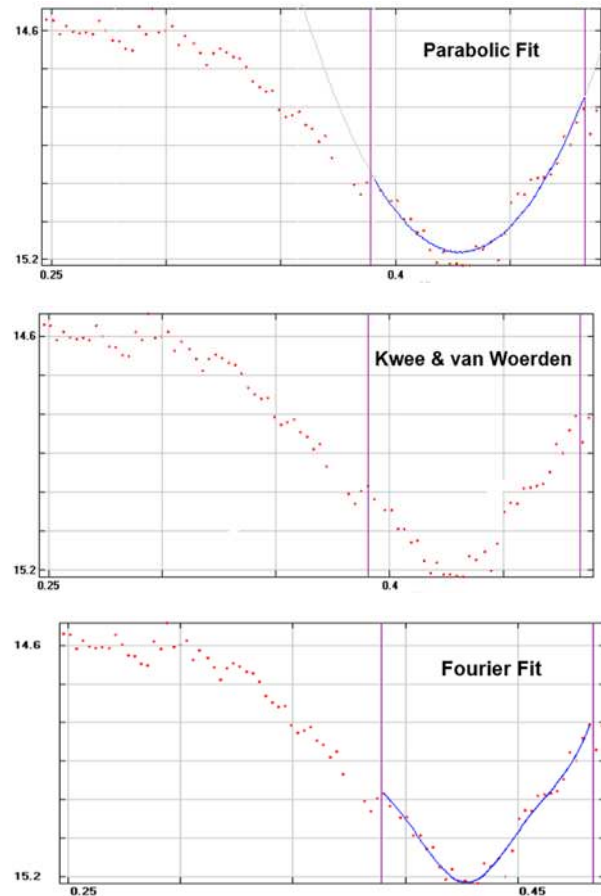


In this instance, mid-eclipse was not recorded as the observation run commenced well after the predicted time of mid-eclipse. Consequently, obtaining a precise minimum time was not possible.

The superior conjunction mutual event on October 23, 2024, was well-documented from Flarestar Observatory, with good coverage of the maximum eclipse phase. For this event, Brozovic et al. (2024) predicted the ingress to start at 19h 22m UT, with the mid-eclipse predicted to occur at 23h 37m UT, and egress at 01h 11m UT.



In order to define the time of mid-eclipse with some accuracy, an exercise was carried out where 3 methodologies were adopted to the lightcurve that comprised, a Parabolic fit, a Kwee & van Woerden fit, and a Fourier fit. Results of the derived time of minimum are shown in Table II as derived through the software *Minima* (Version 2.7) by Nelson (2019).



	Time of Minimum (JD)	Error
Parabolic Fit	2460607.42802	0.00125
Kwee & van Woerden	2460607.42713	0.0012
Fourier Fit	2460607.42719	0.00029

Table II.

The simple mean of the Times of Minimum shown in Table II is of JD 2460607.42745 that translates to 2024 October 23 at 22h 15m 31s (UT). The Weighted Mean derived is JD 2460607.42723 with standard error of 0.00027 d. The derived Weighted Mean translates to 2024 October 23 at 22h 15m 12s. The standard deviation of means is of 0.0005 d. Hence the difference of these means is of 0.32m or 19s. The derived time (weighted mean) of maximum eclipse differs by 21m 48s from that predicted time by Brozovic et al. (2024). As noted above, no light-time corrections were applied and hence all timings shown here are terrestrial time in UT.

The predictions by Brozovic and coauthors are quite impressive in consideration of the limitations faced in orbital modeling and component size estimations taken to derive the predictions. Unfavorable weather conditions prevented the observation of additional events that were expected to be visible from Malta.

Acknowledgements

Thanks is directed to Prof Richard Binzel who brought to the attention of these mutual events through his notification at Binzel (2024).

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PHOTOMETRIC DETECTION OF THE 2024 OCTOBER 23-24 MUTUAL EVENT OF THE PATROCLUS-MENOETIUS BINARY JUPITER TROJAN AT SOPOT ASTRONOMICAL OBSERVATORY

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A single lightcurve partially covering the 2024 October 23-24 superior mutual event was obtained for the binary Jupiter Trojan asteroid system 617 Patroclus - Menoetius from Sopot Astronomical Observatory (K90) in Serbia.

During its 11.89-year long heliocentric orbital period, the orbital plane of the binary Jupiter Trojan asteroid system 617 Patroclus - Menoetius (PMS) twice reaches a favorable position in relation to the Earth, allowing observations of mutual eclipses and occultations (mutual events) of the system components. Such a favorable observational geometry of PMS mutual events occurs in the time span 2024 February - 2025 January.

Following the call for observations of PMS mutual events by Binzel (2024) during 2024 September - October, CCD photometric observations of the superior (Patroclus closer to the Sun than Menoetius) mutual event predicted for 2024 October 23-24 (19:22 - 01:11 UT) by Brozovic et al. (2024) were carried out at Sopot Astronomical Observatory (K90) in Serbia. For this purpose, a 0.35-meter (f/6.3) Meade LX200GPS Schmidt-Cassegrain telescope, equipped with a SBIG ST-10 XME CCD camera operating in 2×2 binning mode, was employed. No photometric filters were used. The integration time for individual CCD frames was 180 seconds to achieve satisfactory level of signal-to-noise ratio enabling the required photometric precision of 0.01 mag. or better for individual data points (Binzel, 2024). Aperture photometric reduction with multiple comparison stars of near solar color ($0.5 \leq B-V \leq 0.9$) was conducted using *MaxIm DL 6* software by Diffraction Limited. Internal calibration of comparison stars was done using the Carlsberg Meridian Catalog 15 (VizieR, 2024) Sloan r' magnitudes and converted to Cousins R-band magnitudes according to the transformation formula: $R = r' - 0.22$. Prior to photometric reductions, all the images were corrected using master dark and master flat field calibration frames. Time synchronization on the data collection computer was performed using Windows Network Time Protocol (NTP) server (time.windows.com).

A total of 95 photometrically usable image frames were acquired in the time interval between ~ 18:42 and ~ 23:50 UT on 2024 October 23. The photometric session termination was determined by the obstruction of the target by local objects on the descending horizon. The weather conditions during the observation time interval are characterized by mostly clear skies with only the occasional appearance of transient thin cirrus clouds. All the frames that were judged to be even slightly affected by weather conditions were removed from the data set.

The obtained data have been uploaded to the Asteroid Lightcurve Data Exchange Format (ALCDEF) database (<https://alcdef.org/>).