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ASTROMETRY OF NASA LUCY MISSION TARGETS (617) PATROCLUS, (3548) EURYBATES, AND (21900) ORUS AT OPPOSITION 2021

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ABSTRACT. In this paper we present the result of the combined use of the OMT-800, AZT-3, KIT telescopes, and the Lemur software of the CoLiTec project. The paper considers in detail several of the astrometric observations of Jupiter Trojan asteroids: (617) Patroclus, (3548) Eurybates, and (21900) Orus from a long list of small bodies of the Solar System.

Keywords: minor planets, asteroids, observations.

АНОТАЦІЯ. Місія Lucy складається з п'яти прольотів повз троянські астероїди Юпітера, з метою дослідження відмінностей у поверхневих та внутрішніх властивостях цієї популяції. Під час п'яти прольотів ми зможемо спостерігати вісім троянських астероїдів.

У статті детально розглянуто астрометричні спостереження троянських астероїдів Юпітера: (617) Patroclus, (3548) Eurybates і (21900) Orus з метою підтвердження положення (орбіти) астероїдів.

Астрометричні спостереження проводилися протягом 11 ночей на двох обсерваторіях: обсерваторії Одеса–Маяки та Київській кометній станції. У роботі представлено результати спільного використання телескопів OMT-800, AZT-3, KIT та сучасного програмного забезпечення Lemur проекту Collection Light Technology (CoLiTec). Стандартні астрономічні спостереження та обробку зображень виконано за допомогою CoLiTec.

Астероїд (617) Patroclus спостерігався в ніч з 16 на 17 квітня 2021 року в обсерваторії Одеса-Маяки. В результаті спостережень отримано 15 позицій астероїда. Астероїд (3548) Eurybates спостерігався сім ночей (312 позицій) у 2021 році телескопами OMT-800 та AZT-3. Додаткові спостереження цього астероїда проводилися в ніч з 26 на 27 грудня 2021 року на Київській кометній станції. Зібрані дані дають нам можливість визначити 58 положень астероїда за цю ніч. Астероїд (21900) Orus спостерігався в ніч з 17 на 18 жовтня 2021 року телескопом AZT-3 (24 позиції) та в ніч з 27 на 28 жовтня 2021 року телескопом OMT-800 (4 позиції).

У статті представлено астрономічні зображення астероїдів (617) Patroclus, (3548) Eurybates і (21900) Orus у програмі перегляду зображень LookSky програмного

комплексу Lemur. В результаті до бази даних MPC додано усі астрометричні спостереження даних астероїдів.

Ключові слова: малі планети, астероїди, спостереження.

1. Introduction

The Lucy mission (Levison & Lucy Science Team, 2016) consists of five flybys of Trojan asteroids to investigate the differences in surface and internal properties across the population of Trojan asteroids. From these five encounters we will be able to observe eight Trojan asteroids: (3548) Eurybates and its small satellite Queta, (15094) Polymele and its satellite Shaun, (11351) Leucus, (21900) Orus, (617) Patroclus, and Meneotius.

We make astrometric observations of selected targets ((617) Patroclus, (3548) Eurybates, (21900) Orus) to confirm the position (orbit) of asteroids.

2. Observations

Astrometric observations were carried out for 11 nights at the two observatories, namely the Odesa–Mayaky Observatory [code: 583], and the Kyiv Comet Station [code: 585].

2.1. Odesa–Mayaky Observatory

Observations were also made on the OMT-800 and AZT-3 telescopes (Astronomical Observatory of Odesa I. I. Mechnikov National University), which is installed at the Mayaky observation station:

- The OMT-800 telescope (Andrievsky et al., 2013; Troianskyi et al., 2014) has 0.8-m main hyperbolic mirror and effective focus ratio f = 1/2.7. As an imaging detector, the FLI ML09000 camera together with a four-lens field corrector, is installed at the primary focus providing a field of view of 58.6'×58.6' and has an image scale of 1.15 arcsec/pixel. All series of images were obtained in the sensitivity band of the sensor without the use of photometric filters;
- Reflector AZT-3 (Udovichenko, 2012) is a serial telescope of the Leningrad Optical Mechanical Association. A UAI CCD detector is installed on the telescope, which was created by the engineers of the Odesa Observatory. As a result, a field of view of 11.4'×8.58' and an image scale of 0.864 arcsec/pixel. All series of images were obtained with the use of *R* filter.

2.2. Kyiv Comet Station

Observations in Kyiv were made with the KIT telescope of the Main Astronomical Observatory of NASU, which is installed at the Kyiv comet station. The KIT (0.356-m, *f*/11; Romanyuk et al., 2012; Romanyuk & Vidmachenko, 2015), a serial telescope with Celestron 14-inch optical tube installed with the White Swan-240 mount made in Ukraine by Sergii Verbytskyi. As an imaging detector the SBIG ST-8XME camera provides a field of view of 12.3'×8.2' and an image scale of 1.44 arcsec/pixel. All series of images were obtained with the use of *BVRI* filters.

3. Results

We did the standard astronomical observations and image processing using the modern Lemur software of the Collection Light Technology (CoLiTec) project (https://colitec.space) (Khlamov et al., 2024).

The Lemur software (Khlamov et al., 2023) is designed to perform a sequence of the following main steps: preprocessing (astronomical information collection -> worst data rejection -> useful data extraction -> data mining (Khlamov et al., 2022) -> classification -> background alignment -> brightness equalization), image processing (segmentation -> typical form analysis -> recognition patterns applying -> detection of the object's image -> astrometry -> photometry -> objects identification -> tracks detection) (Savanevych et al., 2023), knowledge discovery (Solar System objects or artificial satellites to be discovered, tracks parameters for the investigation, light curves of the variable stars, scientific reports in the international formats) (Khlamov & Savanevych, 2020).

For the astronomical reduction of the raw data, we used bias subtracting, dark subtracting and flat-fielding. For details see Oszkiewicz et al. (2019; 2020; 2021; 2023), Savanevych et al. (2022), and Troianskyi et al. (2023a,b).

In Table 1 presents the accuracy of our observations. Where: Signal-to-Noise Ratio (SNR) - the most important quantity for astronomical observations, the ratio of the signal from an astronomical source to the noise, represented in ADU (Analogue-to-Digital Unit); Full Width at Half Maximum (FWHM in units of pixel) - is a measure of the width of an intensity distribution at the point where the intensity is at its highest; Astrometric observation residuals (normalized value of the root mean squared absolute error; RMS) are the difference between an observed and a calculated position (this is known as an O–C residual).

Table 1: Observation accuracy

Asteroid	**SNR [ADU]**	**FWHM [pix]**	**RMS Residuals by RA [arcsec]**	**RMS Residuals by DE [arcsec]**
(617) Patroclus	350.2	5.20	0.500	0.404
(3548) Eurybates	101.2	2.60	0.565	0.211
(21900) Orus	274.8	3.35	0.489	0.156

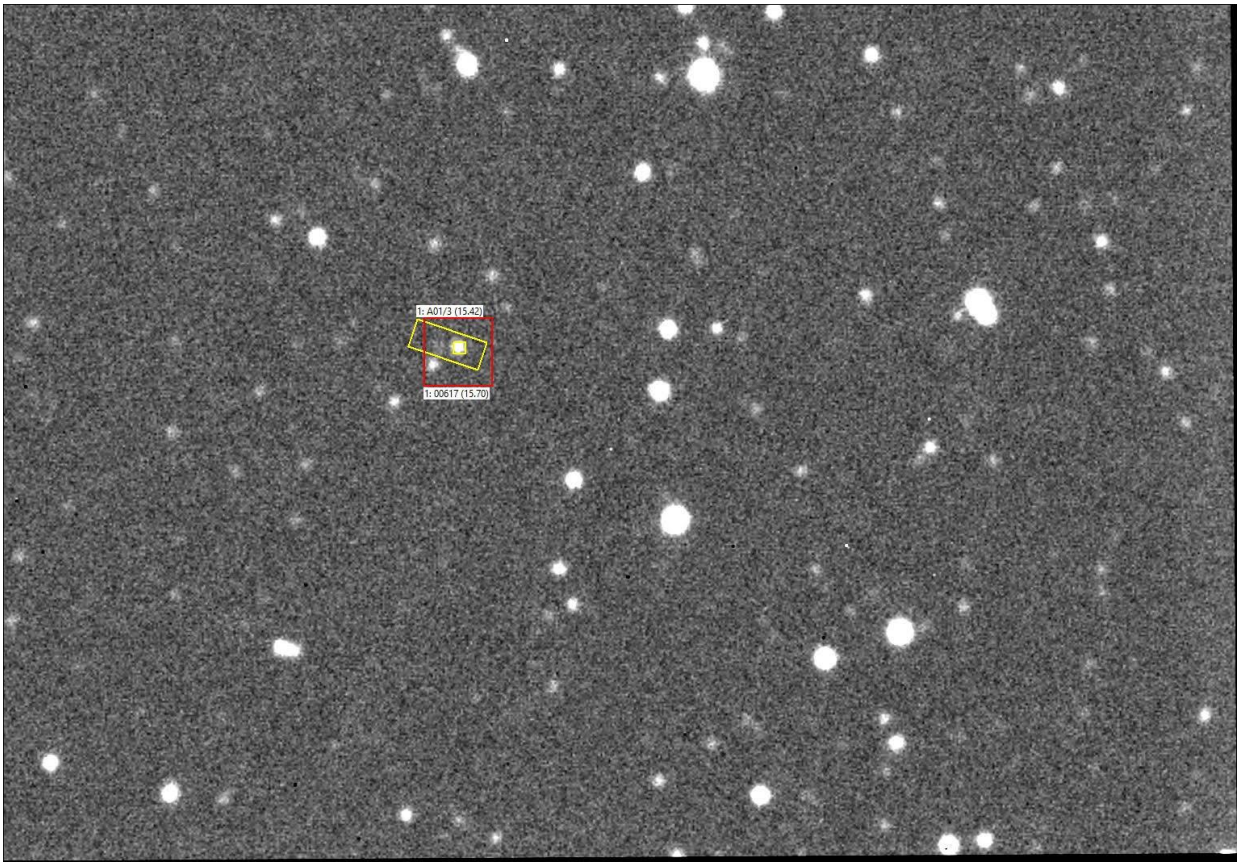

Figure 1: The observed asteroid (617) Patroclus by the AZT-3 telescope

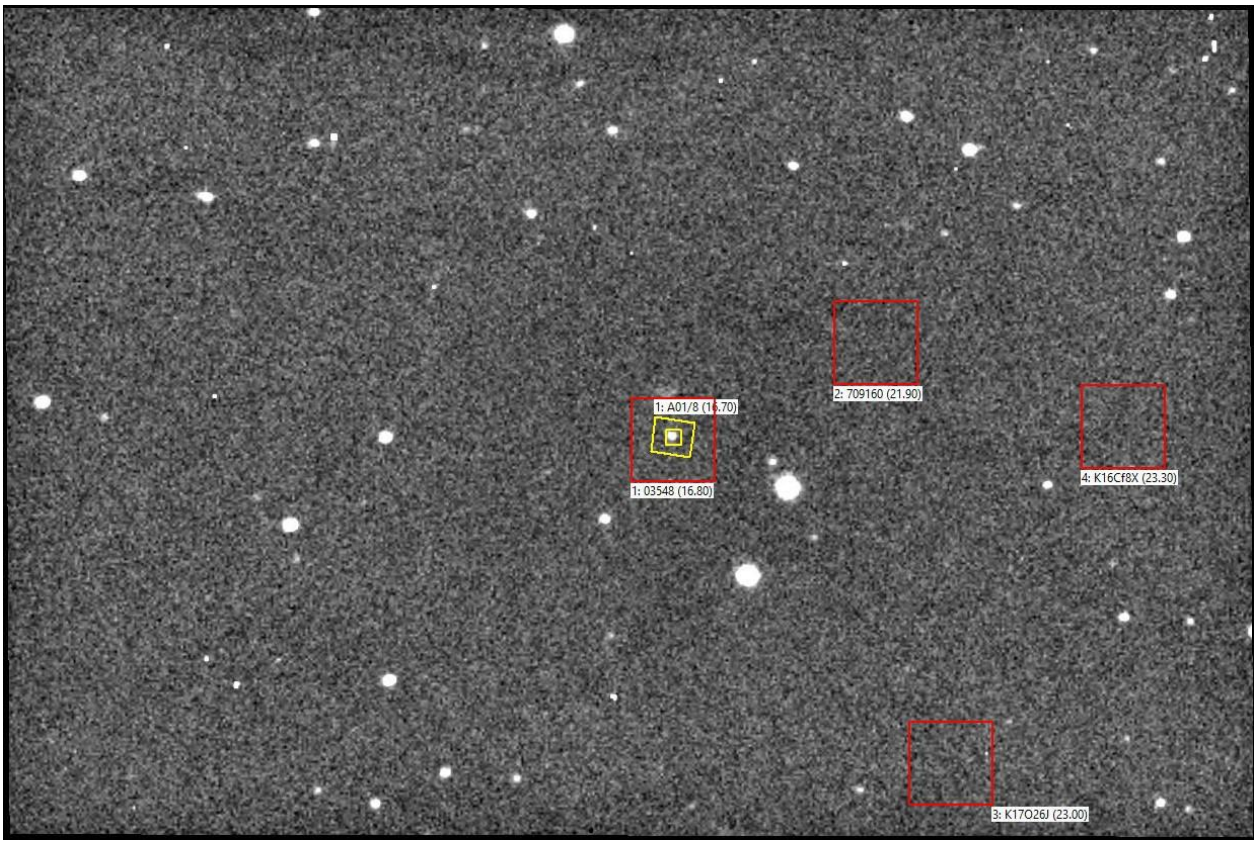

Figure 2: The observed asteroid (3548) Eurybates by the KIT telescope

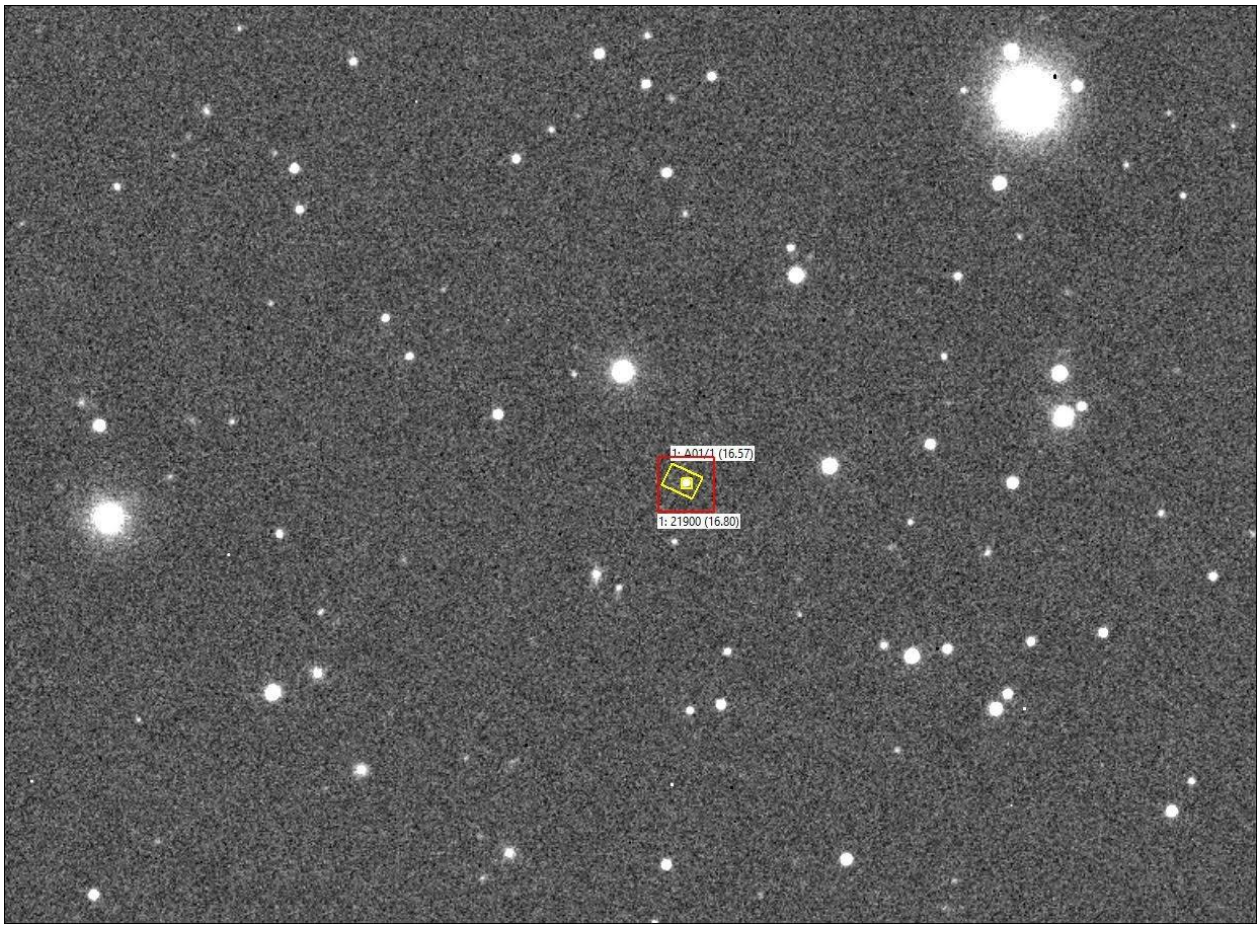

Figure 3: The observed asteroid (21900) Orus by the OMT-800 telescope

3.1. Asteroid (617) Patroclus

Jupiter Trojan asteroid (617) Patroclus was observed during 16th/17th of April 2021 night on Odesa–Mayaky Observatory. As a result, observations of 15 positions, which were obtained on the AZT-3 telescope, were added to the MPC database (https://www.minorplanetcenter.net; MPS 2117685).

An astronomical image of the detected asteroid (617) Patroclus in the LookSky image viewer tool of the Lemur software package is presented in Fig. 1.

3.2. Asteroid (3548) Eurybates

Jupiter Trojan asteroid (3548) Eurybates was observed seven nights (312 positions) in 2021 by the OMT-800 and AZT-3 telescopes at Odesa-Mayaky Observatory. All points added to the MPC database.

Additional observations of this asteroid were done during 26th/27th of December 2021 night on Kyiv comet station. Collected data give us a possibility to determine 58 positions of the asteroid for this night.

An astronomical image of the detected asteroid (3548) Eurybates in the LookSky image viewer tool of the Lemur software package is presented in Fig. 2. All these observations were published in Minor Planet Supplement (see details in MPS 1497901, MPS 1497902, MPS 1518978, MPS 2118348, MPS 2118349, MPS 2118350).

3.3. Asteroid (21900) Orus

Jupiter Trojan asteroid (21900) Orus was observed during 17th / 18th of October 2021 night by the AZT-3 telescope (24 positions) and during 27th/28th of October 2021 night by the OMT-800 telescope (4 positions).

An astronomical image of the detected asteroid (21900) Orus in the LookSky image viewer tool of the Lemur software package is presented in Fig. 3. All points added to the MPC database (MPS 1499517, MPS 2132569).

4. Conclusion

The combined use of the OMT-800, AZT-3, KIT telescopes, and the CoLiTec/Lemur software showed good results for the astrometry of the small bodies in the Solar System.

Astrometric observations are very important for accurate calculations of ephemeris of studied objects and for further research (numerical integration of orbits) of small bodies of the Solar System (Troianskyi & Bazyey, 2018; Troianskyi et al., 2022; Troianskyi et al., 2023a).

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