Doctoral School of Physics - Eötvös Loránd University (ELTE)

2nd semester report

Nóra Takács
(nora.takacs.97@gmail.com)

PhD Program: **ELTE Astronomy and Space Physics doctoral program**

Supervisors: **Csaba Kiss**[1,2,3], **András Pál**[1,2]

[1] Konkoly Thege Miklós Astronomical Institute, HUN-REN Research Centre for Astronomy and Earth Sciences

[2]CSFK, MTA Centre of Excellence, Budapest, Konkoly Thege 15-17, H-1121, Hungary

[3]ELTE Eötvös Loránd University, Institute of Physics and Astronomy, Budapest, Hungary

Ph.D. Thesis title: **Exploring the physical properties of asteroids with the TESS space telescope**

Introduction

My research focuses on the study of minor planets within the Solar System, aiming to gain deeper insights into their physical characteristics and properties. These celestial bodies hold valuable clues about the formation and evolution of the Solar System, particularly through detailed analysis of their light curves.

A key component of my work involves utilizing data from the Transiting Exoplanet Survey Satellite (TESS), which provides continuous, high-precision photometric time series. Unlike ground-based observations, TESS data offer a more consistent and uninterrupted view of minor planets, significantly enhancing our understanding of these objects. The first data release (DR1) from TESS, covering its initial year of operation, has already yielded high-quality light curves for approximately 10,000 asteroids (Pál et al., 2020).

By applying light curve inversion techniques, my goal is to determine the shapes, rotational characteristics, and surface scattering properties of a large sample of main-belt asteroids, Hildas, and Jupiter Trojans (Muinonen et al., 2020). This in-depth analysis not only provides insights into their physical attributes but also helps reconstruct their collisional history and long-term dynamical evolution.

Description of research work carried out in current semester

Until the end of my 3rd semester of PhD, I focused on refining and automating a Python-based analysis tool that I developed for processing TESS light curves of 44 main-belt asteroids. These asteroids were selected based on three criteria: they must be observed in at least three TESS sectors, have a brightness of at least 18th magnitude, and possess an existing shape model in the `DAMIT` database (Database of Asteroid Models from Inversion Techniques).

The analysis pipeline determines the rotation periods and employs chi-square minimization to estimate the rotational axes and shapes of these selected asteroids. To improve accuracy, we incorporated the Lommel-Seeliger scattering model, which allows for a more realistic representation of surface scattering properties (Muinonen & Lumme, 2015; Muinonen et al., 2015).

I conducted a thorough validation of our results by cross-referencing them with data from the DAMIT database. While DAMIT light curves are derived from ground-based observations and thus tend to have shorter durations and less extensive coverage than TESS data, they offer a greater number of viewing geometries and employ more complex shape modeling techniques (Durech et al., 2010).

For four asteroids in our sample, a direct comparison was possible. However, for the remaining objects, there were insufficient observations meeting the required criteria. Figures 1 and 2 illustrate our results for (22) Kalliope and (1572) Posnania, two of the analyzed asteroids.

For these two objects, we used data from three TESS sectors, while for DAMIT, we relied on light curves from which we could extract meaningful amplitudes. In the case of (22) Kalliope, we obtained four such measurements, whereas for (1572) Posnania, we tested whether including all 16 available DAMIT measurements would yield a more accurate match to the DAMIT-derived rotational parameters. Given that ground-based data tend to be shorter and less continuous than TESS observations, and that the two datasets sample different parts of the asteroid's orbit, some discrepancies emerged. Nevertheless, the TESS-based solutions closely align with those derived from DAMIT.

Moving forward, I plan to expand this analysis to the entire TESS minor planet database. This approach will extend beyond requiring shape models in DAMIT and will include a much larger sample, potentially covering hundreds of thousands of minor planets.

Beyond my work on main-belt asteroids, I have also analyzed the rotational properties of Hilda and Jupiter Trojan asteroids using TESS data. Ground-based observations of these populations often suffer from biases, particularly an under-representation of slow rotators, which can skew estimates of period and amplitude distributions. Space-based surveys like TESS soften these observational limitations. For example, K2 mission data have revealed an excess of long rotation periods (Szabó et al., 2020), which has also been observed in other solar system asteroid populations from the main belt (Pál et al., 2020).

Using TESS, I have obtained several week-long, uninterrupted light curves for a substantial number of Hildas and Jupiter Trojans. Many of these asteroids were observed across multiple sectors, providing significantly more detailed time coverage than what was previously available through ground-based campaigns or even K2.

For this analysis, I utilized a Python code developed by Attila Bódi, which identifies periodicities in photometric data while filtering noise using the LOWESS Smoother algorithm. Initially, I analyzed Hildas up to 19th magnitude, but I have since extended the analysis to fainter objects. Notably, I identified useful light curves for asteroids as faint as 23.88 magnitude, such as (2011_WA52), in one of its observed TESS sectors. Looking ahead, I intend to investigate rotational variations between the 'red' and 'less red' spectral groups within the Hilda and Jupiter Trojan populations, as well as the rotational characteristics of distinct collisional families.

We identified three Trojan and three Hilda asteroids with unusually fast rotation periods compared to others within their respective populations. Their spin rates exceed the expected rotational limit imposed by the spin barrier, which defines the threshold beyond which a loosely bound body would break apart due to fast rotation. This raises intriguing questions about their physical properties and origins. For further investigation, we aim to observe these objects, potentially using the Subaru Telescope. These observations will help us determine whether these asteroids exhibit characteristics similar to typical Main Belt asteroids, assessing the possibility that they were originally ejected from the Main Belt.

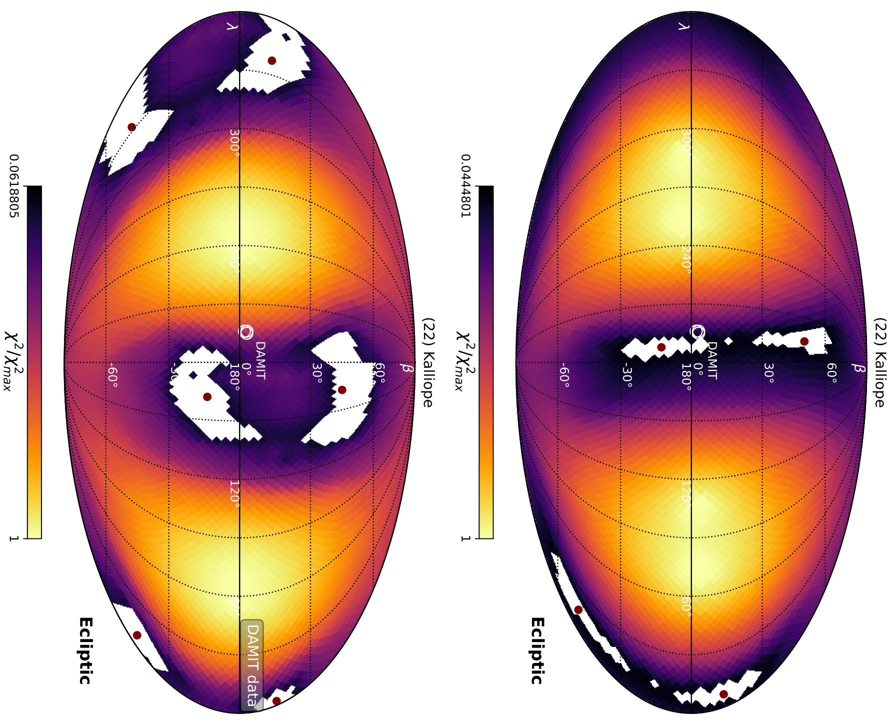

Figure 1: Possible axis of rotation solutions for asteroid (22) Kalliope. The top panel shows the results obtained using TESS data, while the panel on the bottom uses the same procedure but for DAMIT data. The dark areas indicate the possible directions of the axis of rotation. The white dots show the smallest 100 chi^2 values. The three contour levels show the 1, 2 and 3% of the maximum value. The red dots in the middle of the minimum areas show the median of those. The white circles represent the DAMIT coordinates for the axis of rotation.

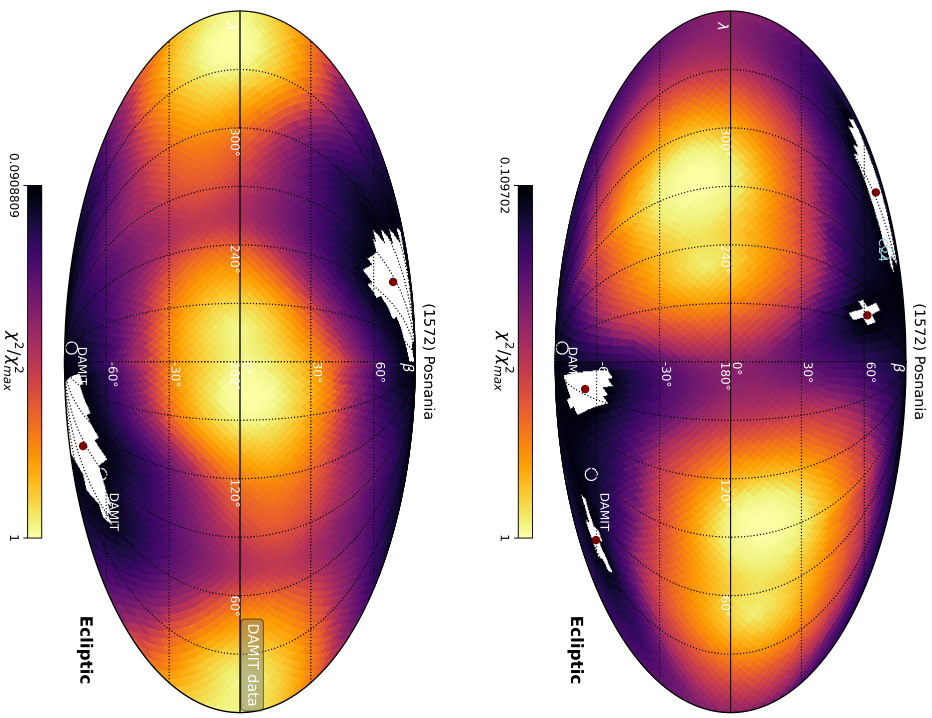

Figure 2: Same as before, but for the asteroid (1572) Posnania.

Publications

- I have submitted a first-authored paper to the journal PASP on the topic of shape modelling of main belt asteroids. Currently, a revised version of the article after the first review has been sent back.

- An article on the topic of three fast-rotating Trojan asteroids has been submitted to Astronomy and Astrophysics (A&A), in which I am a co-author. Currently, a revised version of the article after the first review has been sent back.

Studies in current semester

During my third semester, I completed the following subject, with an excellent grade,

- Chapters from modern celestial mechanics (FIZ/5/053)

Further studies

- From 16 to 20 September 2024, I participated in the EXOHOST summer school "Planet formation and populations" programme, where I had the opportunity to attend a diverse array of presentations on exoplanet formation and observation.

Conferences in current semester

- I have applied for and was accepted to the Europlanet Science Congress 2024, held in Berlin from 8 to 13 September 2024, by contributing a 15-minute presentation and a poster on the abovementioned topics.

Teaching activity in current semester

- This semester I entirely lectured the first-semester MSc course 'Astronomical information technology' (cscsillinfg17gm).

Professional activities

- I participated in the Solar System Workshop held from December 9 to 11, which focused on Trojan asteroids, including the three fast-rotating ones.
- I've been going to the Pészkéstető Observatory for almost 2 years now to do photometric observations of asteroids, on average for 1 week per month.

References

Durech, J., Sidorin, V., & Kaasalainen, M. 2010, A&A, 513, A46
Muinonen, K. & Lumme, K. 2015, A&A, 584, A23
Muinonen, K., Torppa, J., Wang, X. B., Cellino, A., & Penttilä, A. 2020, A&A, 642, A138
Muinonen, K., Wilkman, O., Cellino, A., Wang, X., & Wang, Y. 2015, Planet. Space Sci., 118, 227
Pál, A., Szakáts, R., Kiss, C., et al. 2020, ApJS, 247, 26
Szabó, G. M., Kiss, C., Szakáts, R., et al. 2020, ApJS, 247, 34