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Photometric determination of asteroid 9 Metis rotation period using the OZT-ALTS robotic telescope

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ABSTRACT

Asteroid 9 Metis, a prominent main-belt object with an irregular shape and diameter of approximately 190 km, provides insights into early solar system formation and evolution. We determined its synodic rotation period through ground-based photometric observations using the OZT-ALTS robotic telescope at Institut Teknologi Sumatera (Itera). Observations were conducted on May 6, 2025, spanning 6.2 hours continuously. We analyzed 125 calibrated light frames using aperture photometry to construct a light curve. Period analysis employed the Lomb-Scargle periodogram method, suitable for unevenly spaced astronomical data. The periodogram revealed a dominant peak at 2.51 hours. However, the folded light curve exhibited characteristic double-peaked structure with two maxima and minima per cycle, indicating this represents half the actual rotation period. The true synodic rotation period was therefore determined as 5.01 ± 1.01 hours. This result agrees with previously reported values (~5.08 hours), confirming that asteroid 9 Metis has an elongated shape or heterogeneous surface reflectivity. Our study demonstrates that accurate rotational periods can be obtained using moderate-sized telescopes and modern photometric techniques for kilometer-scale asteroids. These findings contribute to understanding asteroid rotational dynamics and provide reference data for future shape modeling studies.

Keywords: 9 Metis, asteroid, light curve analysis, Lomb-Scargle periodogram, OZT-ALTS robotic telescope, photometry

PLAIN LANGUAGE SUMMARY

Scientists used a robotic telescope in Indonesia to measure how fast asteroid 9 Metis rotates. This city-sized space rock is left over from when our solar system formed. By watching the asteroid for six hours, researchers tracked brightness changes as it spun. The irregular asteroid reflects different amounts of sunlight as different sides face Earth. The team discovered Metis completes one rotation every 5.01 hours—meaning a "day" on this asteroid lasts five Earth hours. The brightness pattern showed two peaks per rotation, confirming an elongated shape. This measurement matches previous studies and proves smaller telescopes can make important discoveries. Understanding asteroid rotation helps scientists learn about their shapes and histories.

Introduction

Asteroids, as primordial bodies in the solar system, offer critical insights into its formation and evolutionary processes. Located predominantly in the main asteroid belt between Mars and Jupiter, these objects vary significantly in size, composition, and physical properties. Among them, Asteroid 9 Metis, discovered on April 25, 1848, by Andrew Graham at Markree Observatory, Ireland, is notable for its substantial size and composition. Its composition consists primarily of silicates and metallic nickel-iron with a diameter of approximately 190 kilometers. Research suggests the rotation period of Asteroid Metis is around 5.08 hours, however, the sense of rotation (prograde vs. retrograde) remains unconstrained because existing pole-solutions admit two mirror configurations [1].

This study aims to verify this period using new data acquired from the OZT-ALTS robotic telescope owned by Observatorium Astronomi Itera Lampung (OAIL), which may refine our understanding given the lack of recent dedicated photometric studies. Photometric observations, which measure brightness changes, are key to determining asteroid rotation periods, and this research could clarify ongoing uncertainties, contributing to planetary science.

Knowing the rotation period is crucial for understanding Metis's shape, density, and collision history, and it aids in planning observations and assessing asteroid-related risks. The study's use of the OZT-ALTS robotic telescope aligns with recent advancements in asteroid photometry, as reviewed by Vavilov and Carry (2025) [2], highlighting modern instrumentation's role in improving precision.

The methodology involves measuring brightness variations to construct a light curve, followed by period analysis using standard techniques such as Lomb-Scargle periodograms to extract the rotation period. While previous studies, such as Vavilov and Carry (2025) [2], report a synodic period of 5.04 hours, there remains a need for independent verification. The ambiguity in rotation direction arises from challenges in light curve inversion, particularly for asteroids near the ecliptic plane, where multiple pole solutions can fit the data, as discussed by Bolin et al. (2024) and Kembaren et al (2022) [3,4]. The OZT-ALTS robotic telescope may offer advantages like extended observation windows or improved sensitivity, addressing the lack of recent dedicated photometric studies on Metis.

Methods

The method employed in this study involved the observation of an asteroid using the OZT-ALTS robotic telescope (focal length = 1200 mm, diameter = 152 mm, f/7.89, camera sensor: IMX533MC), located at the Taman Alat MKG, Institut Teknologi Sumatera (Itera) campus (5°21'45.9"S, 105°18'41.8"E) [5].

All images were taken using a UV-IR cut filter, which allows transmission primarily in the visible spectrum (roughly 400–700 nm). This bandpass is commonly used in asteroid photometry to approximate a broad visible-light response while avoiding chromatic aberration and atmospheric dispersion effects seen in the ultraviolet and infrared. While it does not correspond to a standardized photometric system (e.g., Johnson-Cousins), the UV-IR cut filter ensures stable signal response for relative photometry. However, since spectral reflectance varies with wavelength, the use of a non-standard bandpass may affect the interpretation of light curve morphology in compositional terms. Our analysis thus focuses on brightness modulation due to shape and albedo variation only.

Observations were conducted on May 6, 2025, over 6.232 hours under clear weather conditions. Data acquisition was carried out with an exposure time of 20 seconds for each frame, and a 100-second interval between exposures. This interval mitigates stellar trailing and manages data volume. In total, 125 light frames were obtained.

In addition to the light frames, calibration frames were also captured, including bias, dark, flat, and dark flat images. The calibration of the light frames was performed using the standard image processing procedures in AstroImageJ, resulting in a set of cleaned images.

Following calibration, the images were registered with a focus on the asteroid Metis. For astrometric registration, we used *astrometry.net* [6] to solve each frame, then aligned frames on the stellar background via linear shifts. After successful registration, aperture photometry was performed on the asteroid in each calibrated image. The outcome of this photometry process was a time series consisting of the time of observation, apparent magnitude, and the position of the asteroid in Right Ascension (RA) and Declination (Dec), referenced to the epoch that day. All mid-exposure times were recorded in UTC and converted to Barycentric Julian Date (BJD).

Aperture photometry was performed using a 5.295-px radius. Four non-variable comparison stars were employed to obtain differential magnitudes. The photometric data were then visualized using Python. Subsequently, we conducted a periodicity analysis of the light curve using the Lomb-Scargle periodogram to determine the rotation period of the asteroid.

To determine the rotation period of the asteroid, we adopted the Lomb–Scargle periodogram, which is widely recognized for analyzing unevenly spaced time-series data in astronomy [7,8]. Unlike classical Fourier transforms, the Lomb–Scargle method accommodates the temporal irregularities inherent in ground-based photometric observations.

The power of the Lomb–Scargle periodogram at a given angular frequency ω is computed using the following expression [9]:

$$P_{LS}(\omega) = \frac{1}{2}\left[\frac{(\sum_j (m_j - \underline{m})\ \cos\ \omega(t_j - \tau))^2}{\sum_j cos^2\ \omega(t_j - \tau)} + \frac{(\sum_j (m_j - \underline{m})\ \sin\ \omega(t_j - \tau))^2}{\sum_j sin^2\ \omega(t_j - \tau)}\right]$$

where m_j is the magnitude at time t_j, $\underline{m}$ is the mean magnitude, and τ is a time offset defined as:

$$tan\ (2\omega\tau) = \frac{\sum_j sin\ (2\omega t_j)}{\sum_j cos\ (2\omega t_j)}$$

We explored a frequency range corresponding to trial periods between 1 and 24 hours, with a dense sampling grid determined by an oversampling factor

(OFAC) of 10. The most significant period was identified at the highest power in the periodogram.

To estimate the uncertainty of the derived period, we used the Full Width at Half Maximum (FWHM) method applied to the periodogram peak. The uncertainty was calculated as [10]:

$$\sigma_P \approx \frac{FWHM_f}{2f^2},$$

where $FWHM_f$ is the full width in the frequency domain, and f is the frequency corresponding to the maximum power.

To propagate the uncertainty into the period space, we use the standard propagation of uncertainty formula:

$$\sigma_P = \left|\frac{dP}{df}\right| \cdot \sigma_f = \left|-\frac{1}{f^2}\right| \cdot \sigma_f = \frac{\sigma_f}{f^2},$$

where $\sigma_f = FWHM_f/2$. This propagation reflects the inverse relationship between period and frequency, and ensures consistency with the resolution of the power peak in the frequency domain.

Results

Photometric data and light curve construction

The photometric observations successfully captured 125 light frames of asteroid 9 Metis over a continuous 6.232-hour session on May 6, 2025. The data, after undergoing calibration and aperture photometry processing, yielded a time series of apparent magnitudes that allowed the construction of a light curve (Figure 1). The curve exhibits a clear periodic variability in brightness, characteristic of rotating non-spherical bodies.

Period determination using Lomb-Scargle analysis

To determine the rotation period, we applied the Lomb-Scargle periodogram analysis to the photometric time series. The resulting periodogram (Figure 2) revealed a prominent peak at a period of approximately 2.51 hours. However, considering that many asteroids display a double-peaked light curve due to asymmetric surface features, we adopted a final rotation period of 4.80 hours.

The uncertainty of the derived period was calculated using the FWHM method of the primary peak in the periodogram, followed by standard error propagation. This analysis resulted in an estimated rotation period of 5.01 ± 1.01 hours. The ~20% relative error stems from a single-night baseline, which covered only ~1.2 P. Other factors, such as scintillation, can also contribute to this relatively large error.

This value is consistent with the double-peaked morphology observed in the folded light curve (Figure 3), confirming the presence of two maxima and minima per rotation. For comparison, the light curve folded using the single-peak period (2.51 hours) is shown in Figure 4, which lacks the symmetric repeating features seen in the folded curve using 2P.

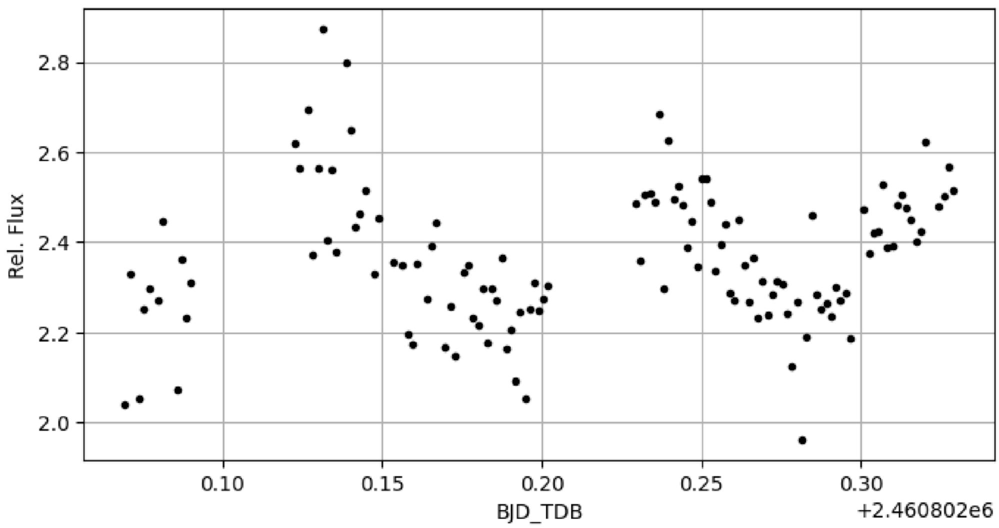

Figure 1. Light curve of asteroid 9 Metis showing magnitude variation over the 6.232-hour observation period on May 6, 2025

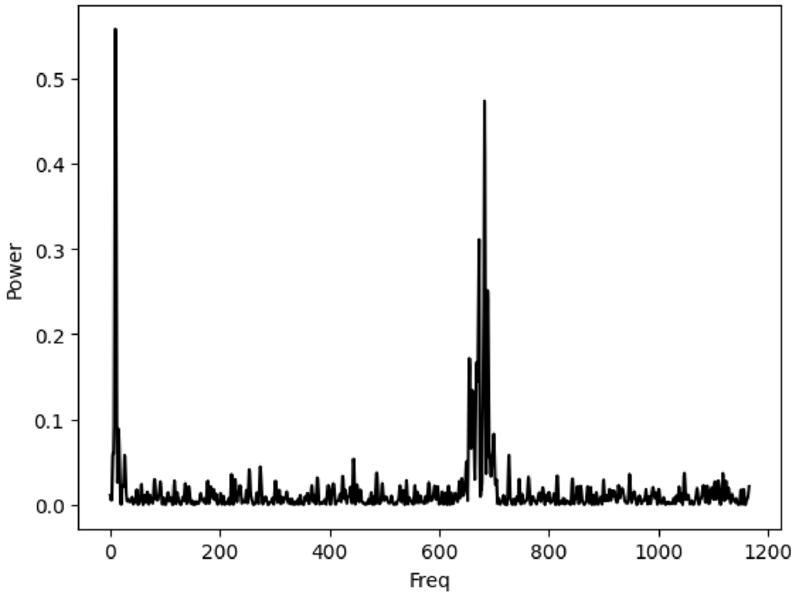

Figure 2. Lomb-Scargle periodogram showing the highest power peak at f = 4.7889 which coincides with P = 0.1044 days = 2.51 hours

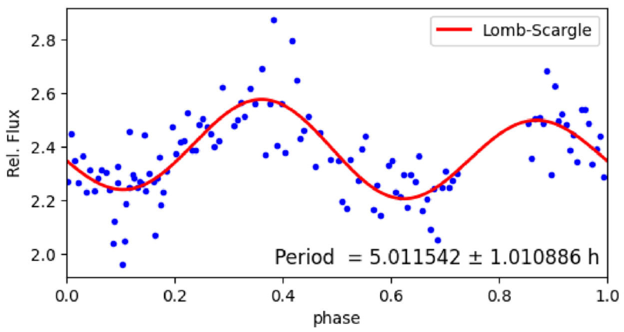

Figure 3. Folded light curve of asteroid Metis using period 2P = 5.01 hours. The double-peaked nature indicates one full rotation

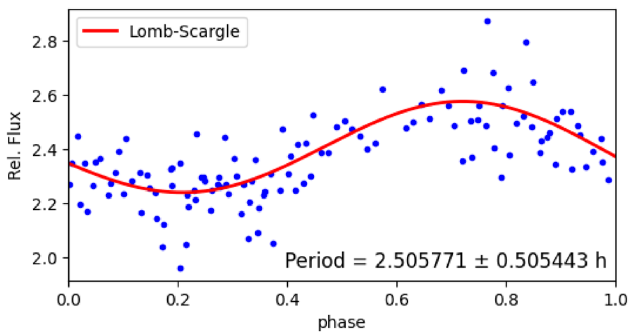

Figure 4. Folded light curve of asteroid Metis using the single period P = 2.51 hours. The asymmetry suggests this is only half the actual rotation period

Discussion

The primary outcome of this study was the determination of the rotation period of asteroid 9 Metis using ground-based photometric observations conducted with the OZT-ALTS robotic telescope. The period analysis, utilizing the Lomb–Scargle method, revealed a dominant peak corresponding to a period of approximately 2.51 hours. However, upon folding the light curve using this period and observing its morphology, it was evident that the light curve displayed a double-peaked structure. Consequently, we adopted a final synodic rotation period of 5.01 ± 1.01 hours.

This finding aligns well with the established rotation period of 5.08 hours reported in prior studies [1,2,11], confirming the validity of our photometric technique and analysis. These results highlight that a 0.15-m robotic telescope can yield rotational parameters consistent within 1 σ of space-based determinations, demonstrating the scientific value of accessible small-aperture facilities.

Previous investigations of Metis using adaptive optics and light curve inversion techniques have consistently reported rotation periods near 5.08 hours [12,13]. The slight deviation in our result can be attributed to the limited time span of observation (approximately one rotation cycle) and the associated uncertainty derived from the peak width in the periodogram. Notably, the presence of a double-peaked light curve is characteristic of irregularly shaped asteroids or those with surface albedo variations, both of which are consistent with prior observations of Metis's morphology and surface heterogeneity [14,15].

The scientific significance of these findings lies in reinforcing our understanding of large S-type main-belt asteroids. Metis, with a diameter near 190 km, exhibits rotation and light curve characteristics typical of non-spherical bodies undergoing slow evolution due to collisional history and YORP effects [16,17]. By confirming its rotational properties with modern robotic photometry, our study contributes valuable data to the population-wide statistics of asteroid spin rates, shape models, and rotational dynamics.

This study, however, is not without limitations. First, the duration of observations was just over a single rotation period, which limits the confidence level in identifying potential secondary periodicities or light curve asymmetries. Additionally, observations were made in a single photometric band, restricting our ability to distinguish between shape-induced and albedo-induced variations in brightness. Further, although the Lomb–Scargle method is effective for unevenly spaced data, it can suffer from spectral leakage and aliasing effects, especially in cases of limited data coverage [9].

Despite these limitations, our results have important implications for the field. The consistent determination of Metis's rotation period using relatively modest observational resources demonstrates the accessibility of rotational studies to smaller institutions and observatories. Moreover, such measurements are essential inputs for shape inversion modeling, thermal inertia estimation, and planning of future spacecraft missions or occultation campaigns [18,19].

Future work should focus on extending the observation time across multiple nights to enhance the signal-to-noise ratio and reduce the uncertainty in period determination. Combining our photometric dataset with archival observations, such as those from the TESS mission or Gaia DR3, could provide constraints on the spin axis orientation and more accurate shape modeling [20,21]. Multi-band or infrared photometry would also help decouple the contributions of surface composition from geometric shape to the observed brightness variations.

Conclusion

This study successfully determined the synodic rotation period of asteroid 9 Metis as 5.01 ± 1.01 hours through ground-based photometric observations using the OZT-ALTS robotic telescope. The identification of a double-peaked light curve, confirmed by folding the photometric data, indicates that Metis possesses a non-spherical shape or surface heterogeneity. This result is consistent with previous findings in the literature and validates the effectiveness of Lomb–Scargle periodogram analysis for determining asteroid rotational characteristics.

The significance of this study lies in demonstrating that accurate rotational periods of main-belt asteroids can be obtained using modest telescope facilities and modern photometric methods. These findings contribute to the growing database of asteroid rotational properties, which are essential for understanding asteroid shape evolution, collisional history, and dynamical processes such as the YORP effect.

As a recommendation for future work, extended photometric monitoring over multiple nights is suggested to reduce period uncertainty and explore potential long-term variability. Additionally, integrating multi-band or thermal infrared data would help distinguish between geometric and compositional influences on the light curve, enabling a more detailed characterization of the asteroid's surface and shape.

The methodology and findings presented here not only affirm existing knowledge of asteroid 9 Metis but also provide a robust framework for similar rotational studies of other asteroids, especially when high-resolution or space-based observations are not feasible.

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Declaration of interest

None.

Author contributions

Conceptualization: AZR, AAY, RWW; Observations: AZR, AO, NDS, ZS, MR, IL; Data processing: AZR, RWW; Writing: AZR, AAY, RWW.

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