Astronomical and Astrophysical Transactions (*AApTr*), 2024, Vol. 34, Issue 4, pp. 363–370,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Light curve analysis of main belt asteroids with Earth MOID less than 1

I. Eglitis[1,*], K. Nagainis[1], V. Eglite[1], G. Campbell[2]

[1] *Institute of Astronomy, University of Latvia, Raina blvd 19, Riga, Latvia*
[2] *Physics and Astronomy Department, Brigham Young University, USA*

Received 18 February, 2024; accepted 12 March, 2024

Seven main belt asteroids Ebella (1205), 2001 EJ18 (26677), 2000 AM127 (27290), 1999 CM6 (40256), 2002 RC100 (84169), 2000 XS14 (98692) and 2000 HB84 (222240) with Earth MOID less than 1AU were studied at the Baldone Astrophysical Observatory of the Institute of Astronomy of the University of Latvia. From Baldone Observatory observations and published MPCs brightness data in a span range of 1999–2023 light curves are constructed and analysed with Fourier series, Lomb–Scargle periodogram, and phase dispersion minimization methods. The computed results from different observatories data are compared and mean-weighted periods are obtained.

Keywords: Asteroids, photometry, rotation periods

1 Introduction

Earth MOID asteroids are main belt asteroids with significantly less eccentricity and therefore from time to time approach the Earth closer than the average Earth–Sun distance and more significantly approach Jupiter. Approaching Jupiter can change the orbit of the asteroid, possibly up to the typical parameters of NEOs ($q < 1.3$ AU). NEO and NEA can collide with the Earth and have significantly changed the biosphere, not only in the past, but now, every five years Chelyabinsk-like amount events occur as seen from the observed bolides radar compilation (NASA 2013). The impact of asteroids can trigger the creation of life, especially with the delivery of heavy elements to the Earth's surface which is a crucial moment for the birth and evolution of complex life (Castillo & Vance 2008; Houtkooper 2011). Asteroid studies will allow us to answer the ambiguous question about the origins of life on Earth. On the other hand, the next step in the human exploration of space will be highly dependent on extracting materials (primarily water and minerals) from the asteroids. The successful expansion into space will probably depend on the ability to exploit space resources. Therefore, a detailed physical and compositional assessment of the

*Email: ilgmars.eglitis@lu.lv

population will be required during the next decade before human missions are sent to these objects. The photometric study of light curves can obtain additional information about size, rotation period, the structure of objects, and the existence of craters and ice fields on the surface, which is very important data for space missions. Asteroids shine due to the Sun's light reflecting on their surface and depend on surface albedo (from surface characteristics: chemical composition; regoliths which cover the object). Most asteroids are not spherical, and their brightness might vary due to the following factors: the distance to the observer, to the Sun and the asteroid's phase. All of the above plus the shape of the asteroid and its periodic rotation, as well as the precession of the axis of rotation, determines its brightness. All previous aspects show the importance and complexity of light curve studies.

2 Data for analysis

At the Baldone Astrophysical Observatory (IAU Code 069) astronomers operate with a Schmidt-type 1.2-meter telescope installed with two 1.6 Mb STX-16803 CCDs. The brightness limit in the visual range of the telescope without a filter is 22 G(RP) magnitude at night with good transparency and calm images. CCD parameters have quantum effectivity of about 80%, the size of one pixel is 9×9 microns, and linear size 4096×4096 pixels, which corresponds to 53×53 arcmin of the field of view. In the past four years, the observation has been devoted to studying the dynamics of main belt asteroids in the G(RP) passband, especially those of which the Earth MOID is less than 1 AU. The list of observable asteroids was compiled using the Minor Planet Center NEO checker (MPC 2023) and the MPC light curve database (ALCDEF, 2023). A sample of studied main belt asteroids with Earth MOID less than 1 AU, with a brightness greater than 18 magnitudes and without period data are given in Table 1.

Table 1 List of studied asteroids.

Asteroid	Design	Earth MOID	P(Sun), y	Absol. magn.
1205	Ebella	0.84761	4.04	13.57
26677	2001 EJ18	0.50025	1.91	16.85
27290	2000 AM127	0.99360	3.75	13.93
40256	1999 CM6	0.78976	2.64	15.36
84169	2002 RC100	0.76457	2.70	16.18
98692	2000 XS14	0.82702	3.40	15.29
222240	2000 HB84	0.93723	5.51	14.20

3 Data processing

The G(RP) magnitudes for reference stars were taken from the GAIA DR2 release (Brown et al. 2018) for processing Baldone Schmidt observation data. To process one series of observations, 20–30 reference stars with colors close to the Sun were considered, some brighter and some dimmer than moving objects. The images were analyzed

by calibration and measured using Lemur software (Savanevych 2022). Measurement of magnitudes of objects was made after the application of standard procedures of master flat and master dark images. For further processing, only those series were selected where the reference star's brightness errors are on average smaller than 0.05 magnitudes. It helps to discard observations with poor sky instant transparency. Each measurement of an asteroid consists of a time and apparent magnitude couple. Both values must be corrected for each measurement series because the distance of an asteroid relative to Earth and to the Sun changes. Time changes by reducing to the first moment of observations were made by the equation:

$$\Delta t_i = t_0 + \frac{D_i - D_0}{c} \tag{1}$$

where D is the asteroid's distance from the observer at i observation and the first observation in the series, respectively. The magnitudes of all series are corrected depending on the distance from the observer and from the Sun (Zeigler & Hanshaw 2016):

$$\Delta m_i = -5 \log \left(\frac{R_i D_i}{R_0 D_0} \right) \tag{2}$$

where D is the asteroids distance from the observer, R is the distance to the Sun, and R_0, D_0 are the same for the first observation in the first series. The last is magnitude correction by the phase effect:

$$\Delta m_j = (Ph_j - Ph_0)k \tag{3}$$

where k is the slope coefficient of the phase diagram for phases in intervals 10 to 30 degrees; Ph_j and Ph_0 are the jth and the first phase in the series, respectively. We thus use linear regression to fit the light curve amplitude-corrected data. After time and brightness corrections, deriving asteroid periods from their light curves is made by the Fourier series analysis method (Pravec & Harris 2000). A detailed description of the algorithm is given by Kwiatkowski et al. (2009). The Fourier method is very sensitive to gaps in observations, especially when summarizing data from a small series of observations, as well as data from different oppositions, that have large shifts in the brightness range. In this situation, the Lomb–Scargle (L–S) periodogram (VanderPlas 2018) and Phase Dispersion Minimization (PDM) (Stellingwerf 1978) methods were used. All asteroid brightness data obtained at the observatories and passbands listed in Table 2 were analyzed in the range of 0.1 to 100 hours.

According to the obtained power diagrams, peaks with a probability greater than 20% were selected (see example in Fig. 1) for further analysis.

The surroundings of these separated periods were studied in more detail within a range of plus or minus 2 hours, to clarify the possible rotation period. Data from all observatories were similarly analyzed. Possible periods must satisfy two criteria. A) The light curve should show two maxima and two minimum troughs during one cycle (an example is presented in Fig. 2). B) The shape of the peak in the power spectrum must be similar somewhat resembling a Gaussian distribution (an example is presented in Fig. 3).

All thus allocated periods were cross-correlated. Matching periods from all observatories with a 3% tolerance were extracted as true rotation period sets. Small

Table 2 Observatories from which data are analyzed.

Observatory (IAU Code)/Space mission	Observation period	Passband
Baldone (069)	2022.03–2023.03	G(RP)
Mauna Loa (T08)	2019.01–2022.08	o, c
Haleakala (T05)	2018.05–2022.08	o, c, w
Catalina Sky Survey (703)	2005.12–2023.05	V, G
Zwicky Transient Facility (I41)	2014.02–2022.08	r, g
Lincoln Laboratory ETS (704)	1999.04–2010.09	c
Catalina Sky Survey (G96)	2019.01–2022.06	G
Ponte Uso (G45)	2014.03–2017.03	r
Transiting Exoplanet Survey Satellite (C57)	2018.08–2022.03	G
El Sauce Observatory, Rio Hurtado (W68)	2022.06–2023.07	o
Pan-STARRS 1, Haleakala (F51)	2014.02–2021.01	w
Purple Mountain Observatory, XuYi Station (D29)	2013.10–2023.05	R

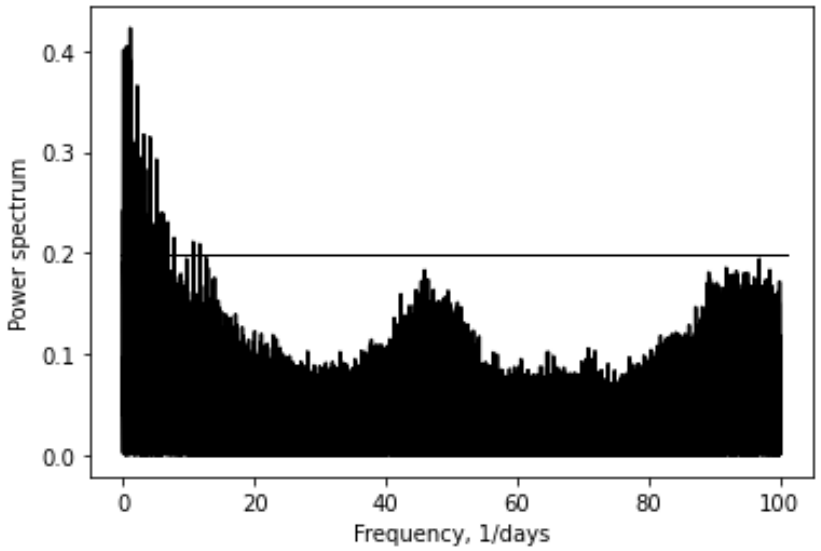


Figure 1 Convincing phase function obtained for asteroid 84169.

discrepancies in values are removed by weighted mean methods. Period values are weighted by the number of observations and by the value of peak probabilities in the power spectrum. The average value is accepted as the true rotation period of the studied asteroids and displaced in Table 3 together with error, the amplitude of variation in G(RP) passband, average slope of phase curve and their classes from ALCDF (2023).

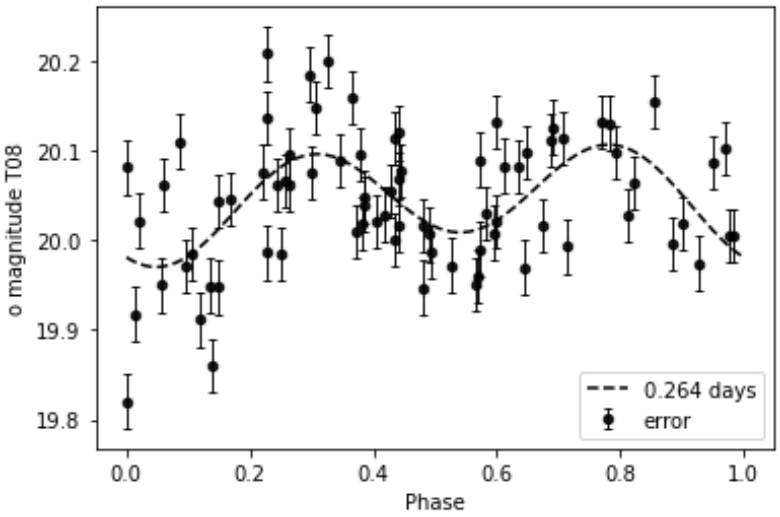


Figure 2 Lomb–Scargle periodogram for 84169.

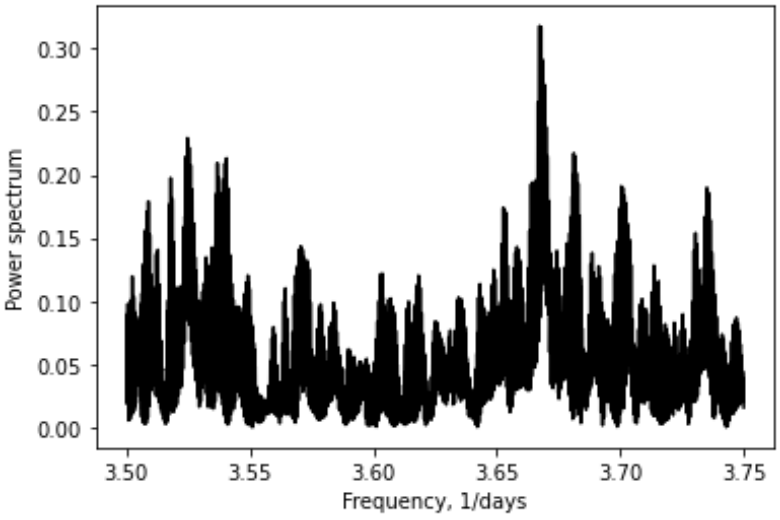


Figure 3 Lomb–Scargle power spectra for 84169 obtained with a step of 5 minutes.

Table 3 Results of analysis.

Asteroid	Period, h	Error, h	Ampl. G(PR)	Slope, deg	Class
1205	2.939	0.026	0.4	0.0324	S*
26677	2.894	0.030	0.7	0.0272	S*
27290	3.592	0.037	0.5	0.0332	S*
40256	4.720	0.018	1.0	0.0293	E
84169	6.242	0.038	0.7	0.0220	SE*
98692	10.512	0.048	0.4	0.0340	S
222240	2.585	0.025	0.3	0.0393	C*

4 Conclusion

Asteroids 98692, 84169 have a greater rotation periods: of 10.512 h and 6.242 h respectively. Other obtained periods are shorter and range between 2.5 and 4.8 h which are typical ranges for rapidly rotating asteroids. From the amplitude of variations in brightness, the asteroids 1295, 98692 and 222240 have a shape close to the ellipses with small differences of minor and major axes, while asteroids 26677, 40256 and 84169 have more elongated shapes. The rotation period of 3.592 h obtained for asteroid 27290 confirms the value of the rotation period (3.5719 h) obtained by Benišek (2023) from observations at the Sopot Astronomical Observatory at the time of writing this paper. In cases of a small series of observations scattered over a large period, with differences in brightness in different oppositions, the L-S and PDM methods work more reliably. The PDM method is sensitive to a small number of observations. If the number of observations is less than a hundred, the PDM method mostly does not work. The shown methodology allows analyzing data whose brightness accuracy is one decimal only when the common number or observations exceeds 400.

ACKNOWLEDGEMENTS

This work was presented at the "Baltic Applied Astroinformatics and Space Data Processing" BAASP conference on September 21, 2023. Work has made use of data from the European Space Agency (ESA) mission Gaia (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC, https://www.cosmos.esa.int/web/gaia/dpac/consortium). Funding for the DPAC was provided by national institutions, in particular, the institutions participating in the Gaia Multilateral Agreement. This research is supported by project 2291 by a MikroTik donation administered by the University of Latvia Foundation.

References

ALCDEF (2023) Asteroid Lightcurve Photometry Database Exchange Format, https://alcdef. org/php/alcdef-GenerateALCDEFPage.php
Benishek, V. (2023) Minor Planet Bull., 50, 278
Brown, A.G.A. et al. (2018), arXiv1804.09365
Castillo, J. and Vance, S. (2008) Astrobiology, 8, 344
Houtkooper, J.M. (2011) Planet Space Sci., 59, 1107.
Kwiatkowski, T. et al. (2009) AAph 495, 967
MPC (2023) Minor Planet Center, https://cgi.minorplanetcenter.net/cgi-bin/checkneo.cgi
NASA (2013) https://www.esa.int/ESA-Multimedia/Images/2016/06/Bolide-air-bursts-1994-2013
Pravec, P. and Harris, A. W. (2000) Icarus, 148, 12
Savanevych, V. E. et al. (2022) Astronomy and Computing, 40, id. 100605
Stellingwerf, R.F. (1978) AJ, 224, 953.

VanderPlas, J. T. (2018) AApS, 236, id.16, 28.
Zeigler, K. and Hanshaw, B. (2016) Minor Planet Bull., 43, 199