Observations of NEO and Main Belt asteroids in 2018-2021 using the Baldone Schmidt telescope

I. Eglitis*[1], A. Bule†[1], A. Sokolova‡[1] and K. Nagainis§[1]

[1]Institute of Astronomy, University of Latvia, , Raina blvd 19, Riga, LV-1586

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Abstract

During 2018-2021 in the Baldone observatory, 49 new asteroids were discovered and more than 6000 astrometric positions for 1122 asteroids were published in MPC circulars. In this period in 221 observation nights were obtained 5544 CCD images, which covered 648 square degrees of sky. Of them, about 1000 CCD images were devoted to studying the dynamics of NEO-type and Main belt asteroids. For asteroids, rotation periods and amplitude of brightness variation in the G(RP) passband were obtained. Photometric data reductions for the CCD images were done using the MaxIM DL program. The G(RP) photometric magnitudes for reference stars were taken from the Gaia DR2 release. Through 15 minutes and 5 minutes steps using second-order Fourier analysis were determined the best size of periods for eleven NEO and main belt asteroids.

Our main goals are contributing to checking our methodology obtaining the rotation periods by analyzing photometric broadband measurements.

*e-mail: ilgmars.eglitis@lu.lv

†e-mail: anna.bule@lu.lv

‡e-mail: adela94@inbox.lv

§e-mail: nagainiskristers@gmail.com

Key words: asteroids, photometry, rotation periods.

1 Introduction

At Baldone observatory astronomers operate with Schmidt-type 1.2 meter telescope installed with the four-degree objective prism and two square degrees STX-16803 CCD. The studies of space in observatories connect with the possibilities of the Baldone Schmidt telescope. The brightness limit of the telescope in G(RP) passband is 22 magnitude. CCD parameters are: 4096*4096 pixels, size of one pixel is 9 * 9 micron which corresponds to 53*53 arcmin of the field of view. Monitoring of asteroids in the Baldone observatory took place from 2008 mainly without a filter. During thirteen years period, 139 new asteroids are developed, 49 of them were discovered in the last four years. During 2018-2021 more than 6000 astrometric positions for 1122 asteroids were published in MPC circulars. In this period in 221 observation nights were obtained 5544 CCD images, which covered 648 square degrees of sky.

2 Observations

Part of more clearly nights devoted to the studying of dynamics of NEO-type asteroids. Observations also managed to use nights with a small phase of the Moon. The list of observable asteroids was compiled using the links of the Small Planet Center NEO checker *MPC, 2020a* (`https://cgi.minorplanetcenter.net/cgi-bin/checkneo.cgi`)and MPC light curve database *MPC, 2020b* (`https://alcdef.org/php/alcdef_GenerateALCDEFPage.php`. The list included those NEO asteroids with a brightness greater than 18 mag without period data.

Four to eight series of observations were made for each asteroid. On average, it makes about a hundred observations for each object. Observations were made in the period 2020-2021 mainly with exposures of 180 or 240 sec, to achieve a signal to noise ratio greater than 20 in G(RP) passband.

3 Data processing

The coordinates of NEO asteroids were obtained from the online Minor Planet Comet Ephemeris Service (MPES). Observations were made with SBIG camera STX-16803 CCD installed in the main focus of Baldone Schmidt 1.2 m telescope. The exposures were from180 till 240 sec so that the S / N is in the range of 20-50.

Each measurement of an asteroid consists of time and apparent magnitude. Measurements are usually made on multiple days. Apparent magnitude can differ for each measurement day for several reasons - changing distance of an asteroid relative to Earth, astro-climate and atmosphere thickness dependency on asteroid location. All images were dark and flat-field corrected and then measured using MaxIM DL program with a differential photometry technique. Night-to-night zero point calibration was accomplished by selecting up to five reference stars with near solar colors. The G(RP) magnitudes for reference stars were taken from the GAIA DR2 release(Gaia Collaboration 2018). For further processing was selected only that series where reference stars brightness errors at an average are smaller than 0.03 mag. It helps to discard observations with poor sky transparency.

As time is in Julian Days (JD) and the interval between measurements can be days, weeks, or even months, time needs to be converted for each measurement set by subtracting all JD with the first measurement JD_0. We must also take into account that light travels longer for more distance, so:

$$t = (JD - JD_0) - \frac{R}{c} \tag{1}$$

where R is the distance to observer, c is light speed and JD_0 is the Julian day of moment of the first measurement. But as there are different times for measurements, they need to be in phase. For that we will use:

$$\Theta = \frac{t}{P} - int\frac{t}{P} \tag{2}$$

where P is period. This allows the data to be in the range from 0 to 1.

The magnitudes of all series are corrected depending on the distance from the observer and from the Sun (Zeigler, 2016):

$$\Delta m = -2.5 log \frac{\frac{R_i^2}{R_0^2}}{\frac{D_i^2}{D_0^2}} \tag{3}$$

where R_i is a distance to the observer and D_i is a distance of asteroid to the Sun in the next series, and R_0 , D_0 is the same in the first series. Further magnitude must be corrected depending on the phase. All subsequent series magnitude measurements are reduced to the magnitudes of the first series of observations:

$$\Delta m = (Ph_i - Ph_0)p \tag{4}$$

where Ph_i and Ph_0 is a phases of i and the first series (taken for each observation series from Minor Planet & Comet Ephemeris Service data) and p is the slope coefficient of the phase functions obtained from observations of brightness which ussually varies from 0.034 for D class asteroids till 0.063 for M and S classes asteroids in according to Shevchenko et al. (2019). C-type phase curve is the most suitable model among the one-parameter models, therefore in situations when phase function from observations is obtained with a large error p=0.047 is accepted for magnitude correction (see Fig. 1.).

In Fourier analysis, the greater problem is that we do not know the period to do this. It needs to be guessed at this moment, but if it is guessed wrong, data will not be in phase.

The goal is to iterate through an interval of periods and keep only those graphs that seem to be in phase. To calculate rotation period of an asteroid from a light curve, the second-order Fourier series is used (Pravec & Harris, 2000):

$$V_r = A_0 + \sum_{i=1}^{n} B_n \sin((2\pi i \Theta)/P) + \sum_{i=1}^{n} C_n \cos((2\pi i \Theta)/P) \tag{5}$$

where V_r is the apparent magnitude or relative magnitude, A_0, B_n, C_n are Fourier constants, P is the period and t is time in Julian days. To approximate the light curve correctly, a good initial guess is needed and for that several steps need to be made.

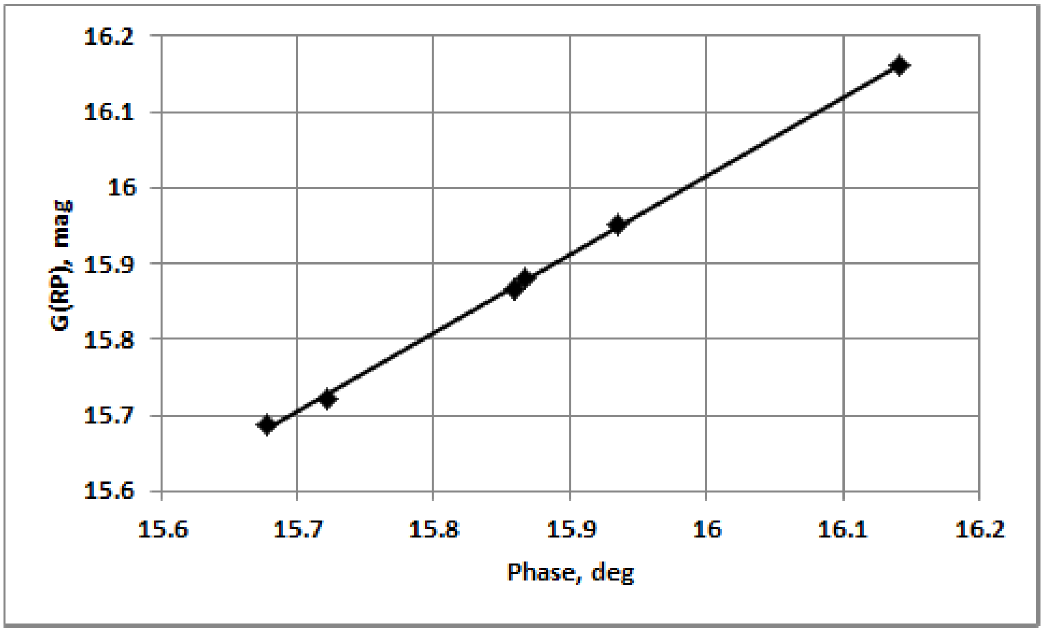

Figure 1: Convincing phase function obtained for asteroid 1999 JM81.

At the first iteration Fourier analyses with 15 min steps in time range 0 - 80 hours is done. Obtained relation between approximated periods and r^2 are shown in Fig. 2.

From this graph, it can be seen which periods are approximated the most and which have the best r^2. Firstly, periods that have big gaps between points are discarded. All periods that have $\Theta_{i+1} - \Theta_i > \alpha(N)1/N$, where N is a number of points, but $\alpha(N)$ is a coefficient that can be chosen according to the user, but in this paper, we chose $\alpha(N)1/N = 0.2$. This requirement follows the Gaussian process. But there still might be some artifacts, which have high accuracy approximations but do not produce a valid rotation period. For that reason, the following is done: only periods with r^2 higher than 0.4 are taken into consideration. From these points, from the histogram, we pick periods around maximums and calculate the average period. If there are multiple maximums, then the average period is calculated separately for all of them. After that with the obtained periods the second, more thorough, iteration can be done. An interval of 0.1 days around the averaged period is taken for Fourier analyses. The step in the second iteration is 5 min. With this, the same process can be done as previously (result see in Fig. 3.), only

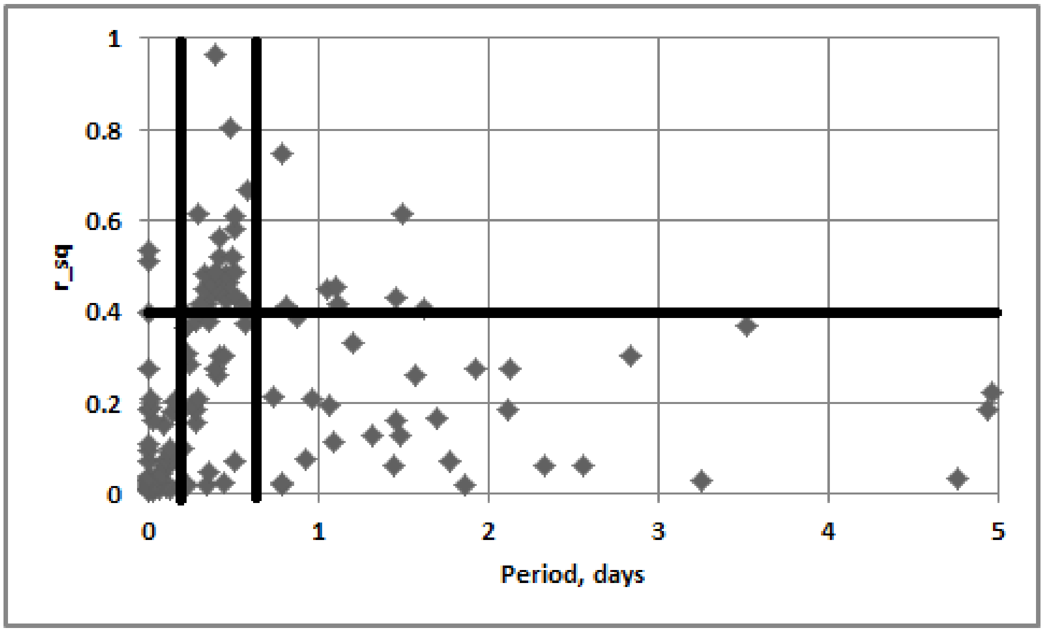

Figure 2: Fourier periodogram for 1999 JM81 obtained with a step 15 minutes.

now, the best fit is taken as the asteroid rotation period, and the program gives out 3 best-fit graphs. If the computational artifact is still with the highest r^2 value, then it can be seen manually (samples are shown in Figures from 4 till 15). If there were multiple averaged periods after the first iteration then the results with the best r^2 are taken as the correct ones.

Program is created in Python script.

4 Results

4.1 1642=Hill=1951 RU

The Main belt asteroid was discovered at Heidelberg observatory by K. Reinmuth in April 1951. Period P=6.056h of this C class asteroid obtained by Behrend on measurement in August 2006 (taken from MPC Light Curve Database) and period P=6.043h obtained by Durech et al (2020) from ATLAS photometry. Our observations were made in three nights on February 17 - 19 2021 after 44.opposition at phases $21.1^o - 20.9^0$ respectively. The

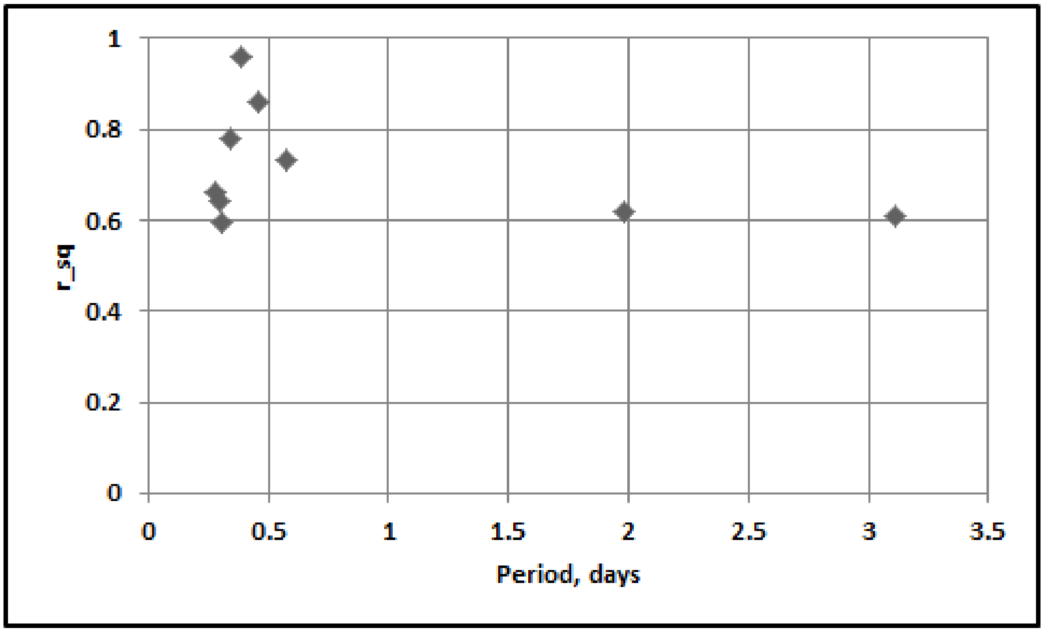

Figure 3: Fourier periodogram for 1999 JM81 obtained with a step 5 minutes.

best fit period was P=6.125±0.019h from 77 measurements. The normalized sum of the square of differences (r) from the model which approximate data is 0.82. Amplitude in G(RP) system is 0.43 mag.

4.2 2583=Fatyanov=1975 XA3

The Main belt asteroid was discovered at Heidelberg observatory by K. Reinmuth in September 1951. A search of the asteroid MPC Light Curve Database (MPC LCD) revealed no known period for this asteroid. During the months 2020 January through March, we gathered CCD data obtained with Baldone Schmidt telescope. Observations were made at phase range $12^0 - 25^0$. Fourier analyze gave period P=0.2559d=6.142h±0.022h from 155 measurements. The normalized sum of square of differences (r) from the model which approximate data is very low 0.336. It is possible that the asteroid has a satellite. Amplitude in G(RP) system is 0.25 mag.

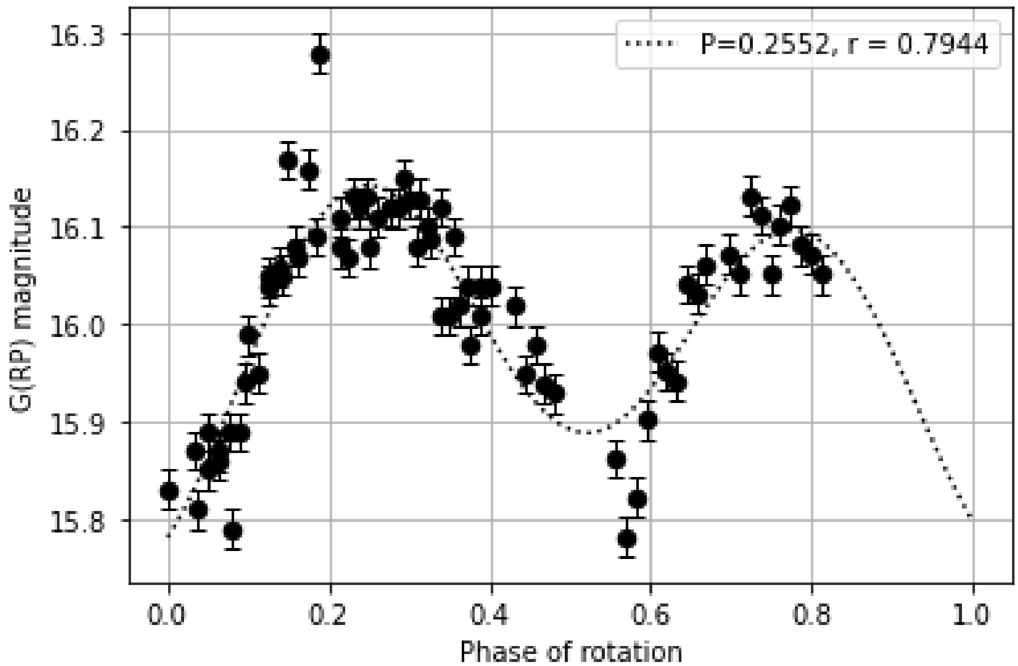

Figure 4: Light curve for asteroid Hill.

4.3 2890=Vilyujsk=1978 SY7

The Main belt asteroid was discovered at the Crimea observatory by Zhuravleva on September 1978. Period P=3.4610h of this S class asteroid obtained by Benishek (2020) on measurement in January 2020 at Sopot Astronomical Observatory. Some smaller period P=3.45h obtained by Ruthroff (2013) and Koff (2003). An even shorter period P=3.42h has been shown by the Waller in his publication (Waller 2013). Our observations were made on March 19 2020 at phase 29^0. The best fit period was P=1.505h$\pm$0.019h from 48 measurements. The normalized sum of the square of differences (r) from the model which approximate data is 0.622. Amplitude in G(RP) system is 0.25 mag.

4.4 5425=Vojtech=1984 SA1

The Main belt asteroid was discovered at Klet observatory by Mrkos in September 1984. Period P=2.64759h of this V class asteroid obtained by

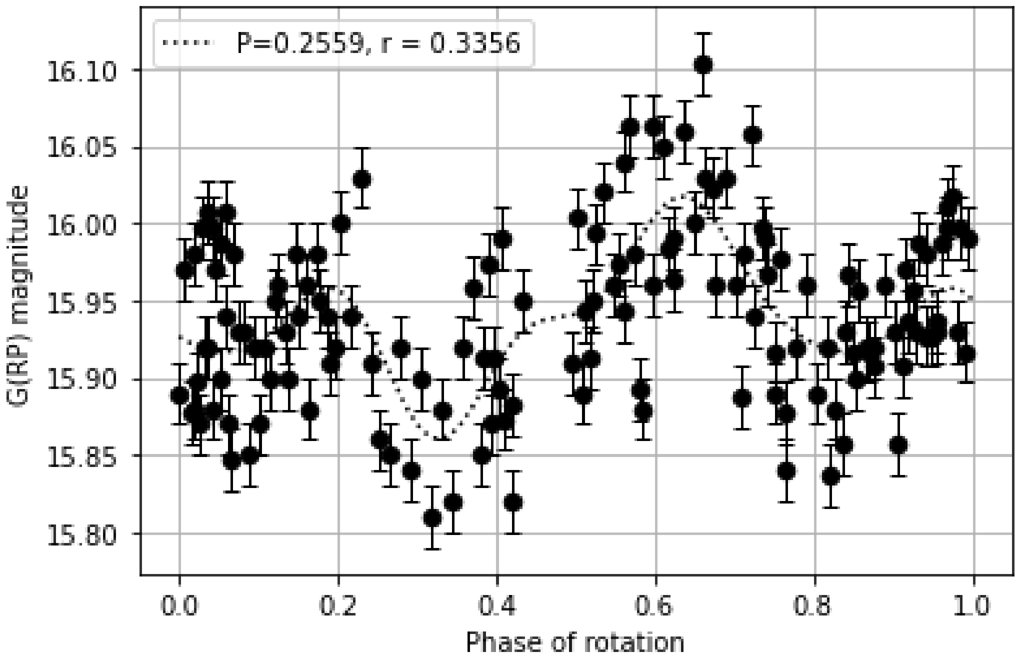

Figure 5: Light curve for asteroid Fatyanov.

Stephens & Warner (2015) on measurement in October and November 2011 at Center for Solar System. This research confirms the previous obtained period 2.648h by Vander Haagen (2012). The CCD observations of Vojtech took place at Baldone in March 2020 at phase 25^0. Fourier analysis of a very short series of 42 observations gave a period P=2.635±0.022h. The normalized sum of the square of differences (r) from the model which approximate data is 0.751. Amplitude in G(RP) system is 0.48 mag.

4.5 9450=Akikoizumo=1998 BT1

The NEO-type asteroid was discovered at Oizumi private Observatory by Kobayashi in January 1998. The period P=9.012h for this S class asteroid is obtained by Waszczak et al. (2015) on measurements from TESS program.

The large field of view of Baldone Schmidt when observing the asteroid Fatyanov on January 2, 2020, also covered the position of the Akikoizumo asteroid. The 91 observations gave rotation period P=9.245h±0.012h. The probability of period reliability is very high. It shows the very higher normal-

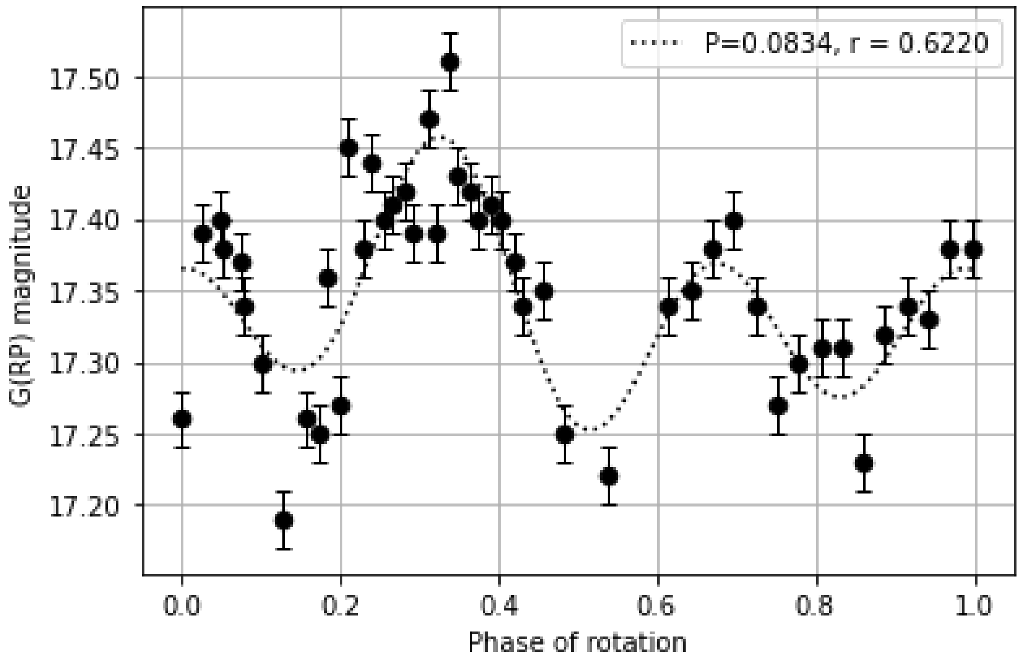

Figure 6: Light curve for asteroid Vilyujsk.

ized sum of the square of differences r=0.975. Amplitude in G(RP) system is 0.72 mag.

4.6 24298=1999 XC221

The NEO-type asteroid was discovered during the realization project LINEAR at Lincoln Laboratory's Experimental Test Site in December 1999. A search of the asteroid MPC LCD revealed no known period for this asteroid. During the months 2020 October through December, we gathered CCD measurements obtained with Baldone Schmidt telescope. Observations were made at phase range $8^0 - 23^0$. Fourier analysis gave the period P=11.940h±0.032h from 119 measurements. The normalized sum of the square of differences (r) from the model which approximate data is 0.468. Amplitude in G(RP) system is 0.64 mag.

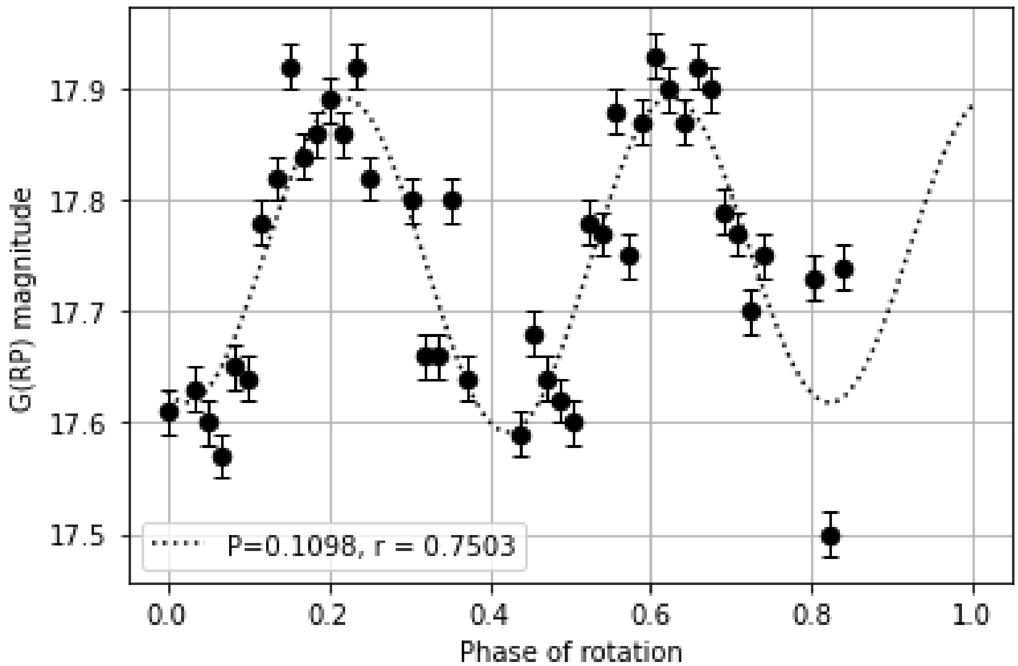

Figure 7: Light curve for asteroid Vojtech.

4.7 19562=1999 JM81

The NEO-type asteroid was discovered during the realization project LINEAR at Lincoln Laboratory's Experimental Test Site in May 1999. A search of the asteroid MPC LCD revealed period P=33.53h for this asteroid which was obtained by Ferrero (2021) from 2020 summer observation at Bigmuskie Observatory. Really, the article of Ferrero shows that it is a mistake. The value of the period is mixed up with another asteroid period published in this research, too. A real obtained period is P=9.024h. During the months 2020 October through December, we gathered CCD measurements obtained with Baldone Schmidt telescope. Observations were made at phase range $9^0 - 11^0$. Fourier analysis gave the longer period P=9.343h±0.011h from 208 measurements. The normalized sum of the square of differences (r) from the model which approximate data is high 0.961. Amplitude in G(RP) system is 0.94 mag.

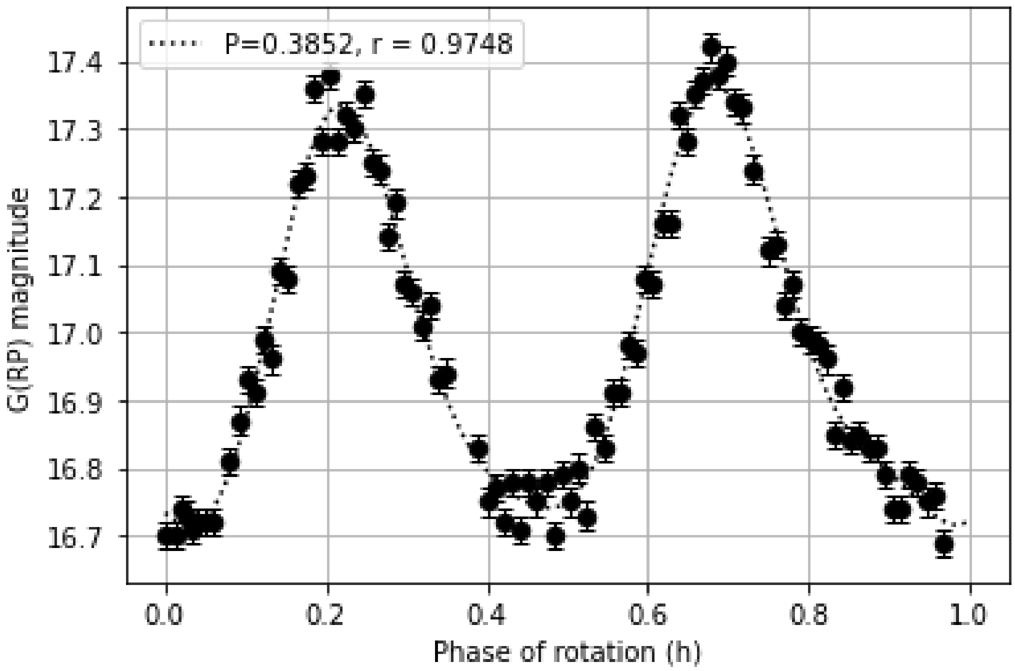

Figure 8: Light curve for asteroid Akikoizumo.

4.8 12349=1993 GO

The Main belt asteroid was discovered at Dynic Astronomical Observatory by A. Sugie in April 1993. Period P=18.2068h obtained by Durech et al. (2020) from ATLAS photometry. Our observations were made in four nights during March - April 2021 near 23 opposition at phases $10^0 - 16^0$, respectively. The best fit period was P=15.710±0.019h from 82 measurements. The normalized sum of the square of differences (r) from the model which approximate data is 0.86. Amplitude in G(RP) system is greater than 0.9 mag.

4.9 11508=Stolte=1990 TF13

The Main belt asteroid was discovered at Tautenburg observatory by Shmadel and Borngen in October 1990. A search of the asteroid MPC LCD revealed period P=3.064h for this asteroid which was obtained by Waszczak et al. (2015) from Palomar Transient Factory (PTF) survey. In 2020 Pal

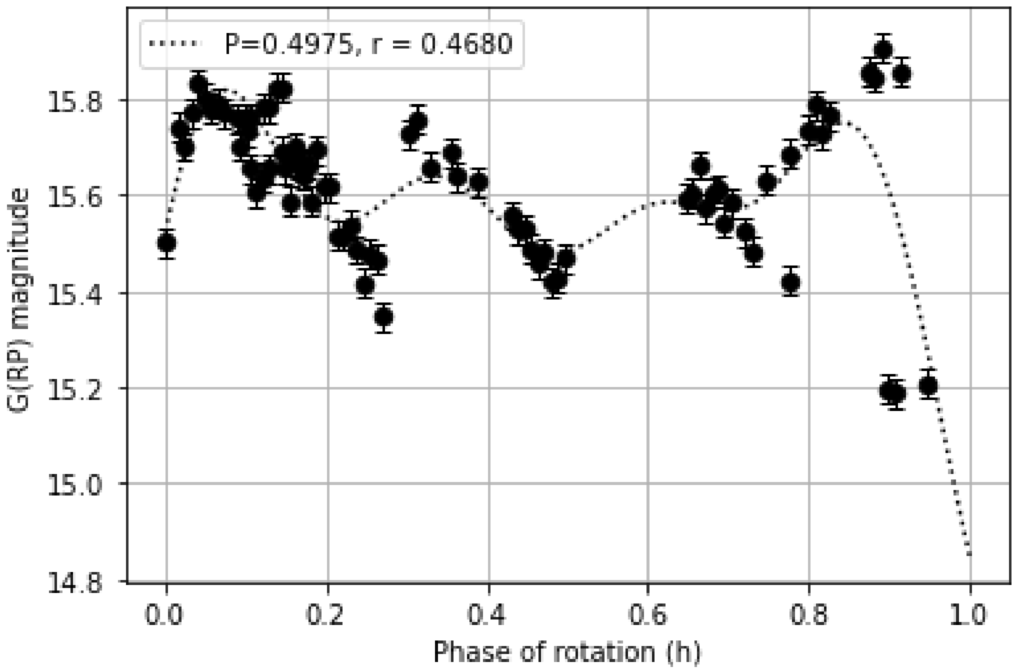

Figure 9: Light curve for asteroid 1999 XC221.

et al. (2020) specified the rotation period P=3.0643h from TESS data measurements.

During the months 2020 March through April, we gathered CCD measurements obtained with Baldone Schmidt telescope.. Observations were made at phase range $16^0 - 23^0$. Fourier second-order analysis gave period P=3.057h±0.015h from 135 measurements. The normalized sum of the square of differences (r) from the model which approximate data is high 0.847. Amplitude in G(RP) system is 0.59.

4.10 558307=2015 AS45

The NEA-type asteroid was discovered during the realization project LINEAR at Lincoln Laboratory's Experimental Test Site in December 1999. A search of the asteroid MPC LCD revealed that asteroid is less studied and have a great rotaton period (Warner & Stephens,2021).

During the months 2021 March through May, we gathered CCD data

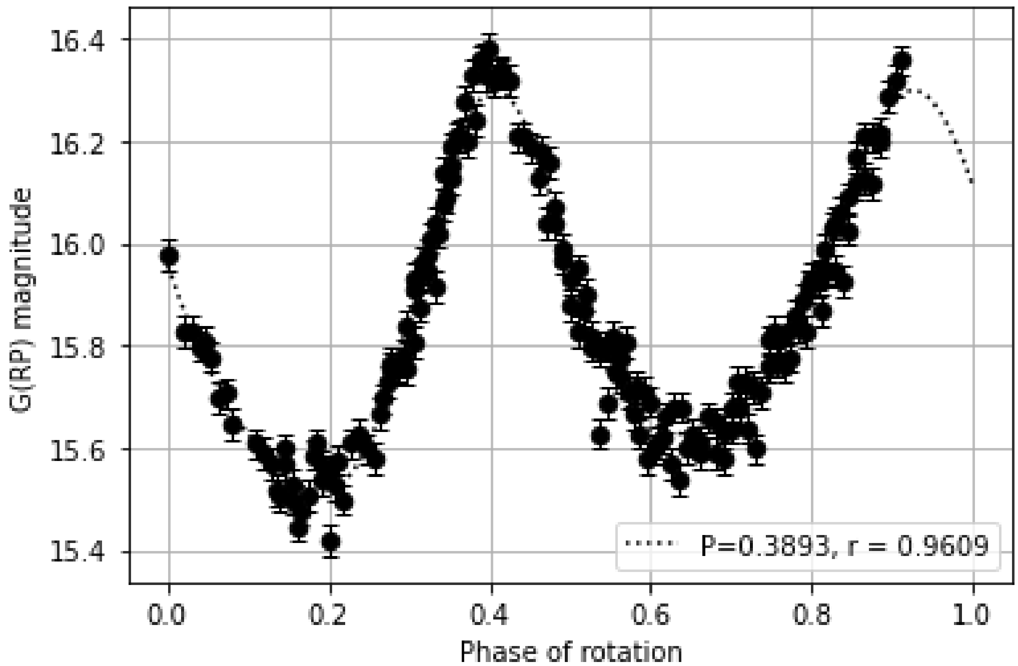

Figure 10: Light curve for asteroid 1999 JM81.

obtained with Baldone Schmidt telescope. Observations were made near the fourth opposition. Fourier analysis of 65 measurements gave more than twice longer period than obtained by Warner, respectively P=105.7h±0.3h. The normalized sum of the square of differences (r) from the model which approximate data is high 0.80. Amplitude in G(RP) system is 0.32 mag.

4.11 8081=Leopardi=1998 DD

The NEO-type asteroid was discovered during NASA Near-Earth Object Observations program Pan-STARRS 1 with 1.8 meters telescope displaced near the summit of Haleakala on the Island of Maui in January 2015. A search of the asteroid MPC LCD revealed no known period for this asteroid.

During the months 2020 April through May, we gathered CCD measurements obtained with Baldone Schmidt telescope. Observations were made at phase range $18.6^0 - 23.8^0$. Fourier analysis gave the two possibilities: rotation period P=2.561h±0.032h or nearly twice longer 4.913h±0.032h from

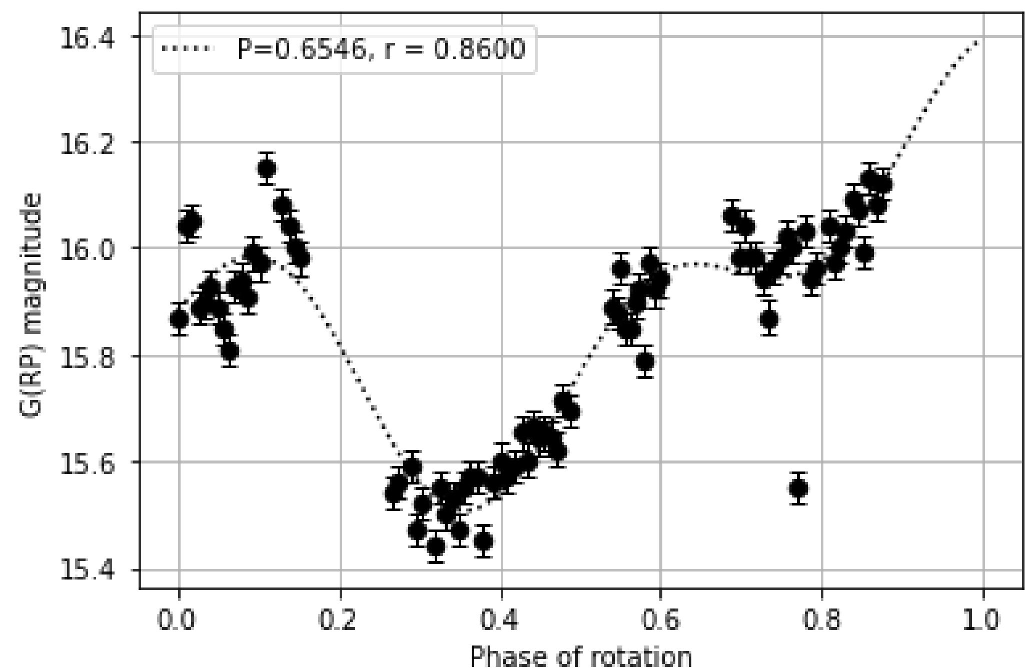

Figure 11: Light curve for asteroid 1993 GO.

74 measurements. The normalized sum of the square of differences (r) from the model which approximate data is 0.453, indicate the need for additional monitoring. Amplitude in G(RP) system is 0.31 mag.

5 Conclusion

NEA and NEO asteroid monitoring has in some cases made it possible to observe the main belt asteroids due to the large field of view of the Baldone Schmidt telescope. Many of the main belt asteroids have periods and it reveals possibilities to check the reality of our methodology. Basically, the obtained results are in agreement with the data of other authors, as can be seen by comparing the values of the rotation periods of the specific asteroids and as shown in Fig. 16. There is a strong difference between the asteroid Vilyujsk, for which the period obtained almost twice less than that acquired Benishek (2020). The correlation of phase brightness for Vilyujsk has a very complex form, which indicates an insufficient coverage of observations

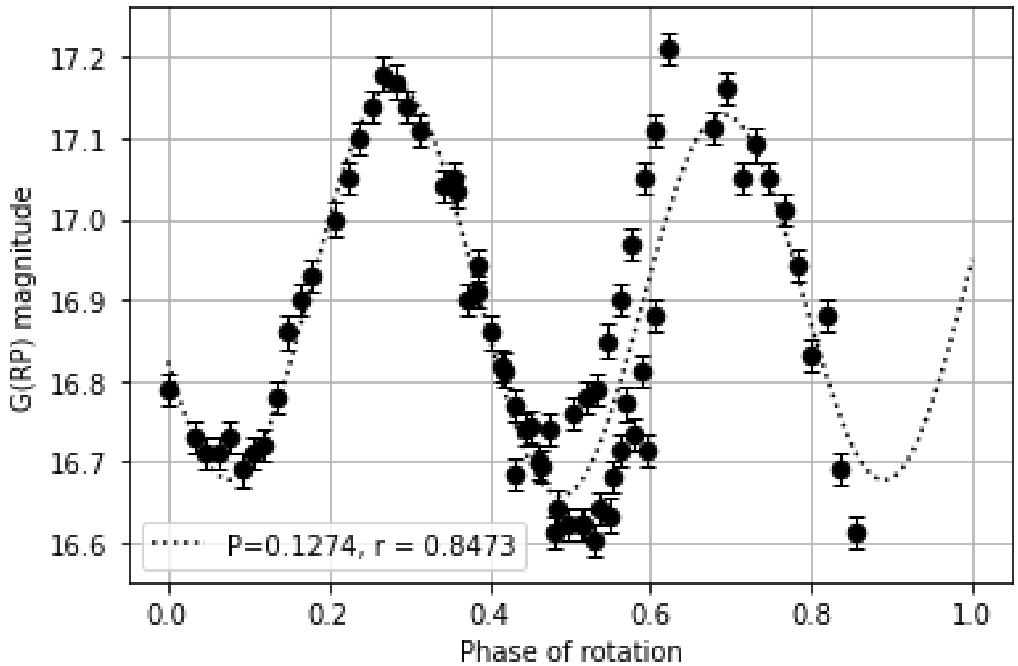

Figure 12: Light curve for asteroid Stolte.

throughout the rotation period, as a result of which the Fourier analysis leads to a shorter period. The second asteroid for which a significant period difference is obtained is the 1999 GO, for which the period we obtained is smaller than that found Durech et al (2020). In this case, it is more difficult to understand the reason for the differences in results.

The conclusions of the study are as follows: The proposed methodology works satisfactorily. It is necessary to continue testing the methodology on the basis of a larger data array. Observations in as long a series as possible are required to obtain a sufficiently accurate rotation period. The number of long observation series must be greater than four. The analysis gives better results when observations are used under stable weather conditions.

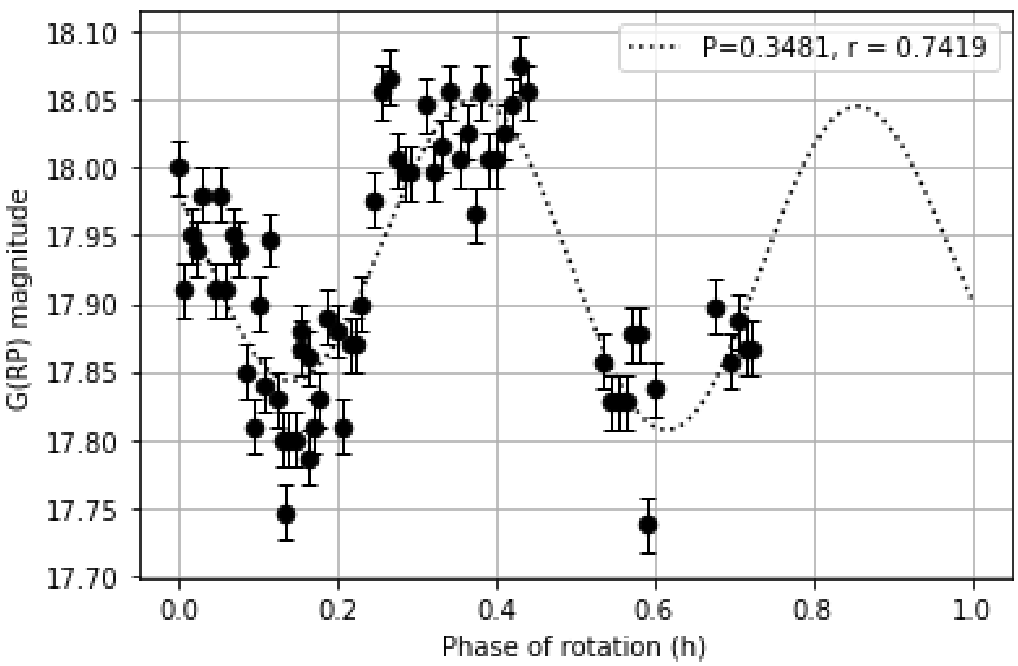

Figure 13: Light curve for asteroid 2015 AS45.

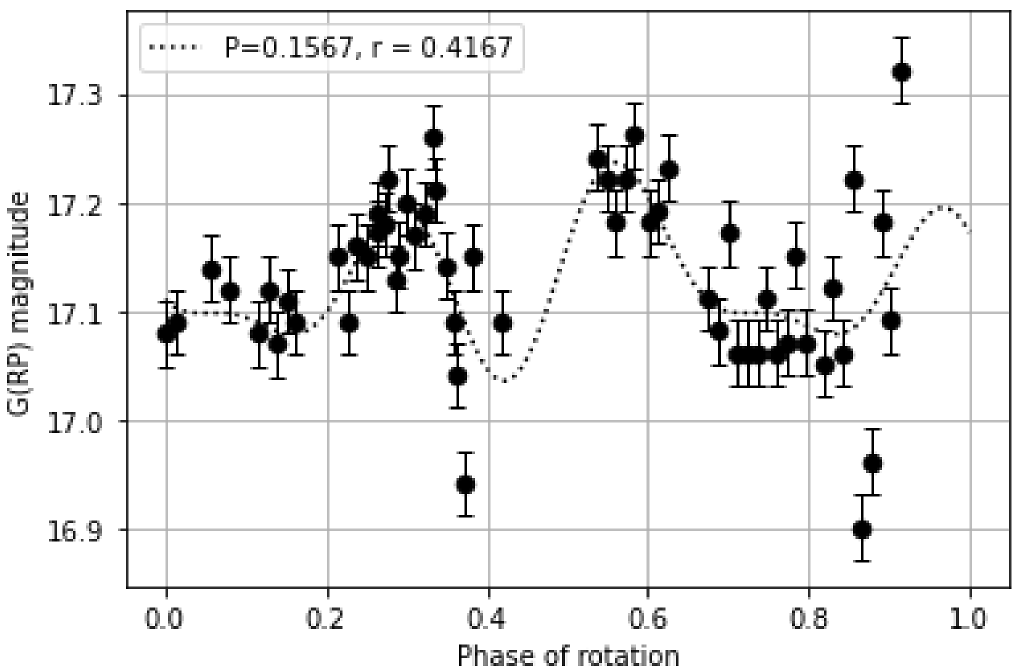

Figure 14: Light curve for asteroid Leopardi P=2.561h.

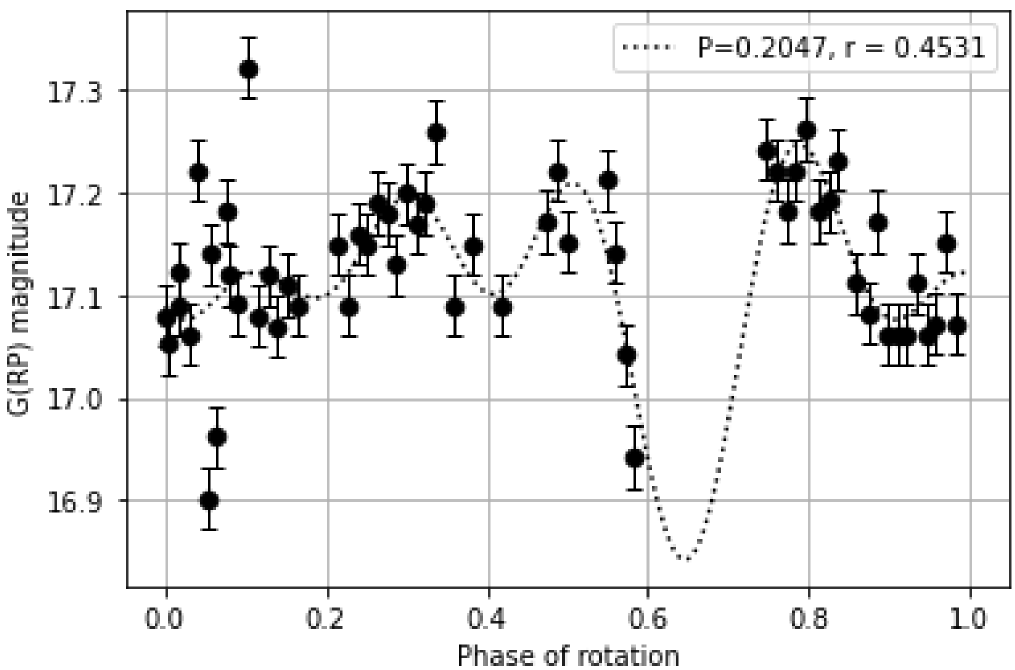

Figure 15: Light curve for asteroid Leopardi P=4.913h.

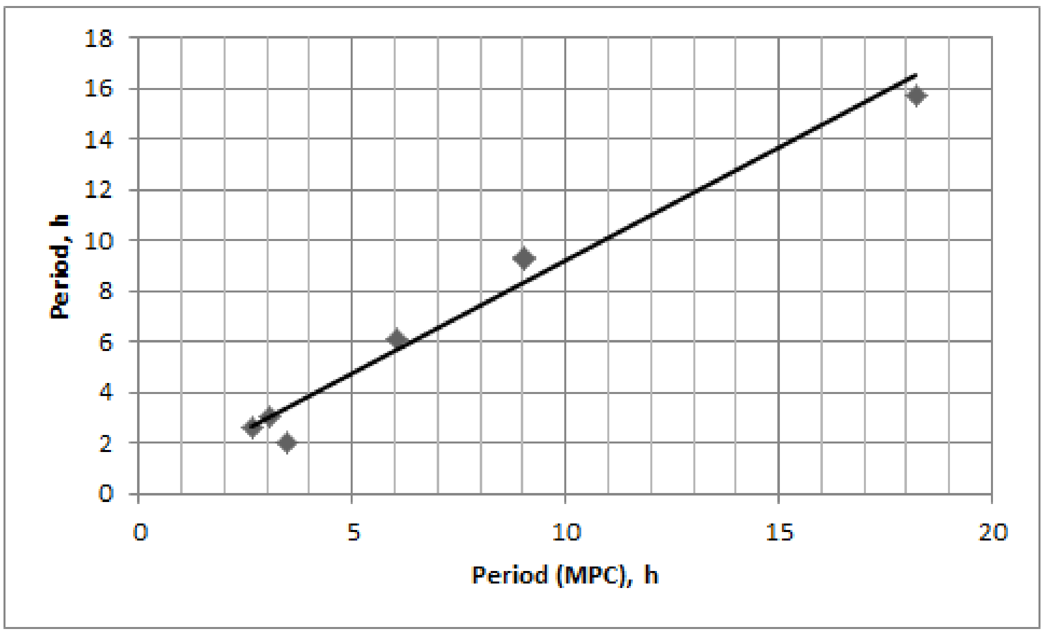

Figure 16: Correlation between MPC periods and obtained in this paper.

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References

Benishek, V. (2020) Minor Planet Bull., 47, 231

Gaia Collaboration, A. G. A. Brown, A. Vallenari, et al. (2018) arXiv1804.09365

Durech, J. et al., (2020) A&A, 643, A59

Ferrero, I. (2021) Minor Planet Bull., 48, 7

Koff, R. A. (2003) Minor Planet Bull., 30, 38

Pal, A. et al., (2020) ApJS, 247, A26

Pravec, P. and Harris, A. W. (2000) Icarus, 148, 12

Ruthroff, J. C. (2013) Minor Planet Bull. 40, 90

Shevchenko, V. G. et al., (2019) A&A, 626, A87

Stephens, R.D. and Warner, B. D. (2015) Central Bureau Electronic Telegrams, 4200, 1

Vander Haagen, G. A. (2012) Minor Planet Bull., 39, 48

Waller, E. B.(2013) Minor Planet Bull., 40, 109

Warner, B. D. and Stephens, R. D. (2021) Minor Planet Bull., 48, 294

Waszczak, A. et al., (2015) AJ, 150, 75

Zeigler K. and Hanshaw, B. (2016) Minor Planet Bull., 43, 199