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Relative photometry of numbered asteroids (1314), (2257), (3541), (4080), (4155), (12081) and (15415)

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Abstract. In this paper we present results of CCD photometry at the Skalnaté Pleso Observatory enhanced following a recent collaboration with the Ondřejov Observatory. We derived in September–November 2006 and in March 2007 synodic periods and amplitudes of composite lightcurves of 7 inner main belt asteroids: (1314) Paula, 5.9505 h, 0.82 mag; (2257) Kaarina, 3.04866 h, 0.13 mag; (3541) Graham, 3.529 h, 0.13 mag; (4080) Galinskij, 7.3600 h, 1.01 mag; (4155) Watanabe, 4.4972 h, 0.19 mag; (12081) 1998 FH_{115}, 16.6062, 0.24 mag; and (15415) Rika, 6.3636, 1.05 mag.

Key words: asteroids – photometry

1. Introduction

The Skalnaté Pleso Observatory (MPC code 056, longitude $20^\circ\,14'\,01.75''$ E, latitude $49^\circ\,11'\,21.77''$ N, altitude 1 786 m above sea level) has a new observational programme to do CCD photometry with a 0.61-m, f/4.3 Newtonian reflector and a CCD camera SBIG ST-8XME in its primary focus. The first photometrical results are given in Husárik (2004) where which selected asteroids are under a long-term study of the determination of rotational spins and shape modelling. This paper is a by-product with the Ondřejov Observatory on the Photometric Survey of Asynchronous Binary Asteroids (Pravec *et al.*, 2006, and references therein). Other collaborative observations in the Survey with Ondřejov and other observatories have also been obtained (Pray *et al.*, 2006; Warner *et al.*, 2006).

2. Observations, reduction and analysis

The photometric observations of these 7 inner main belt asteroids were performed using the 0.61-m reflecting telescope of the Skalnaté Pleso Observatory and the CCD SBIG ST-8XME camera located in the primary focus. Lightcurve observations were done in the standard R band on every observing night during September–November 2006 and in March 2007.

All frames from the Skalnaté Pleso Observatory were processed using the software SBIG CCDOPS. Standard calibration with dark and flatfield frames was applied with IRAF tools. Next, we used a differential aperture photometry technique with APHOT32 developed by M. Velen and P. Pravec at the Ondřejov Observatory. Result lightcurves are relative. The lightcurve analysis was performed with the ALC software by P. Kušnirák. The period and amplitude analysis was performed following the procedure described by Harris *et al.* (1989). All data presented in figures in the next section were light–time corrected.

The observational circumstances and aspect data for the asteroids on each observing night are listed in Table 1. The table gives the date of observation given to the nearest tenth of a day to the midtime of the observational interval, the heliocentric and geocentric distances, the solar phase angle, and J2000.0 ecliptic coordinates of the phase angle bisector (PAB, that is the vector connecting the center of the asteroid and the midpoint of the great circle arc between the sub-Earth and sub-solar points; for more information on the PAB, see Magnusson *et al.* (1989)). In addition to the period P here it is shown the reliability code U (Harris, Young 1983) and the maximum synodic-sidereal period difference ΔP (Pravec *et al.*, 2005) throughout the text.

3. Results for individual asteroids

None of these 7 asteroids had a synodic rotation period P published prior to our observations.

3.1. (1314) Paula

Our observations on five nights in September 2006 revealed a synodic rotation period $P = 5.9505 \pm 0.0001$ h (Figure 1) with the maximum synodic-sidereal period difference $\Delta P = 0.0002$ h. The data were fitted with a 6th-order Fourier series. The data were of a good quality with the rms residual of 0.012 mag, and the amplitude of the lightcurve $A = 0.82$ mag. The reliability code is $U = 3$. We estimated the mean absolute R magnitude $H_R = 12.43$ mag assuming the slope parameter $G = 0.15$ from the data obtained by Peter Kušnirák.

3.2. (2257) Kaarina

The observations on five nights from the end of October until the mid of November 2006 provide a unique synodic period $P = 3.04866 \pm 0.00006$ h (Figure 2) with the synodic-sidereal period difference $\Delta P = 0.0001$ h and this solution is valued by the reliability code $U = 3$. Using a 4th-order Fourier fit we estimated the amplitude $A = 0.13$ mag.

Table 1. The aspect data for 7 numbered asteroids observed at the Skalnaté Pleso Observatory; r and Δ are the heliocentric and geocentric distances, respectively, α is the phase angle, and $L_{\rm PAB}$ and $B_{\rm PAB}$ are the ecliptic coordinates of the phase angle bisector.

Date [UT]	r [AU]	Δ [AU]	α [deg]	$L_{\rm PAB}$ [deg]	$B_{\rm PAB}$ [deg]
		(1314) Paula			
2006 09 14.9	2.044	1.049	5.7	347.8	7.7
2006 09 15.9	2.042	1.048	5.9	347.8	7.7
2006 09 16.9	2.041	1.048	6.3	347.9	7.7
2006 09 19.0	2.037	1.049	7.1	348.0	7.7
2006 09 20.9	2.034	1.050	7.9	348.1	7.7
		(2257) Kaarina			
2006 10 27.1	1.989	1.026	9.9	48.6	1.4
2006 10 31.0	1.996	1.021	7.6	48.9	1.2
2006 11 16.9	2.027	1.039	2.2	49.9	0.4
2006 11 16.9	2.028	1.042	2.7	50.0	0.4
2006 11 17.0	2.030	1.045	3.4	50.1	0.3
		(3541) Graham			
2007 03 11.9	2.196	1.211	4.5	176.2	5.6
2007 03 13.0	2.195	1.208	4.1	176.2	1.2
2007 03 13.8	2.194	1.206	3.9	176.3	5.6
2007 03 14.9	2.193	1.203	3.6	176.3	5.6
		(4080) Galinskij			
2006 09 23.1	1.904	1.014	19.3	28.8	2.2
2006 09 28.1	1.915	0.995	16.6	29.5	2.0
2006 09 29.0	1.917	0.992	16.1	29.6	2.0
2006 09 30.0	1.919	0.989	15.6	29.7	2.0
		(4155) Watanabe			
2006 11 23.8	1.918	0.979	12.8	42.7	4.7
2006 11 24.8	1.919	0.985	13.3	42.8	4.7
2006 11 26.9	1.923	0.999	14.4	43.1	4.8
		(12081) 1998 FH_{115}			
2006 09 23.9	1.779	0.843	16.9	21.9	7.9
2006 09 24.9	1.779	0.839	16.4	23.1	7.9
2006 09 31.0	1.779	0.817	13.2	23.4	7.9
2006 10 15.0	1.783	0.795	6.5	25.0	7.7
2006 10 16.9	1.783	0.795	6.1	25.2	7.6
2006 10 17.9	1.784	0.795	5.9	25.3	7.6
		(15415) Rika			
2006 10 10.1	1.719	0.732	7.7	15.4	9.4
2006 10 10.9	1.719	0.733	7.8	15.5	9.5
2006 10 11.9	1.720	0.735	8.0	15.6	9.5

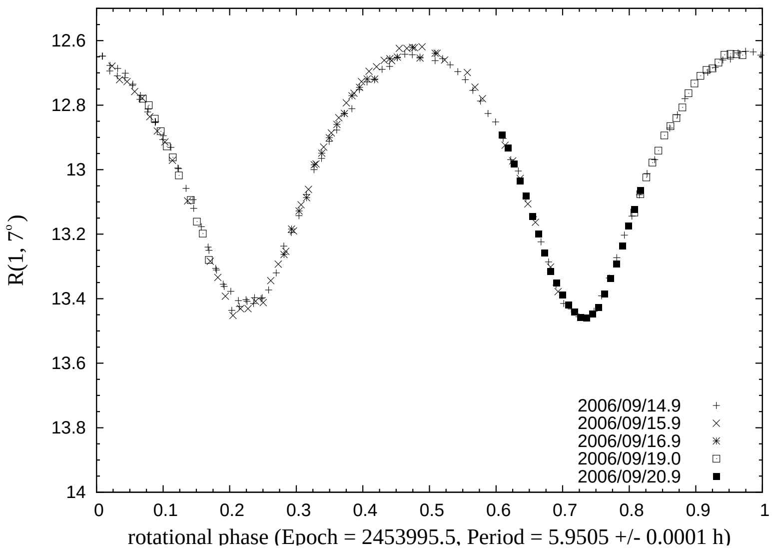

Figure 1. The composite lightcurve of (1314) Paula.

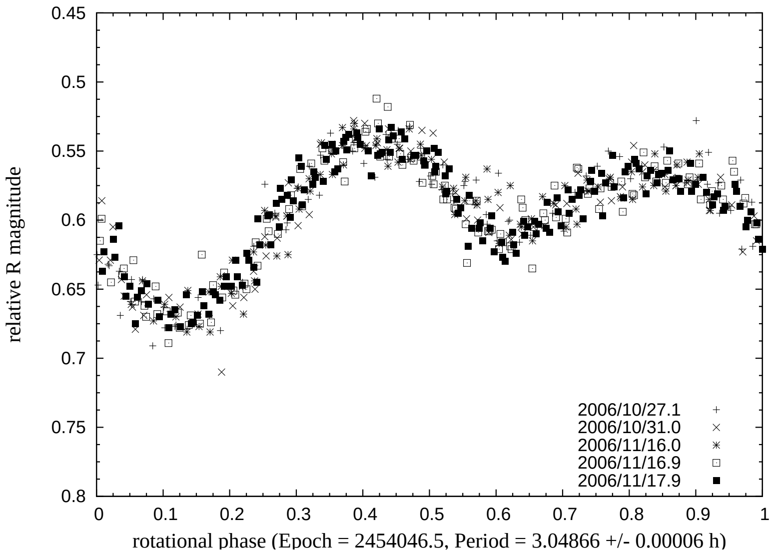

Figure 2. The composite lightcurve of (2257) Kaarina.

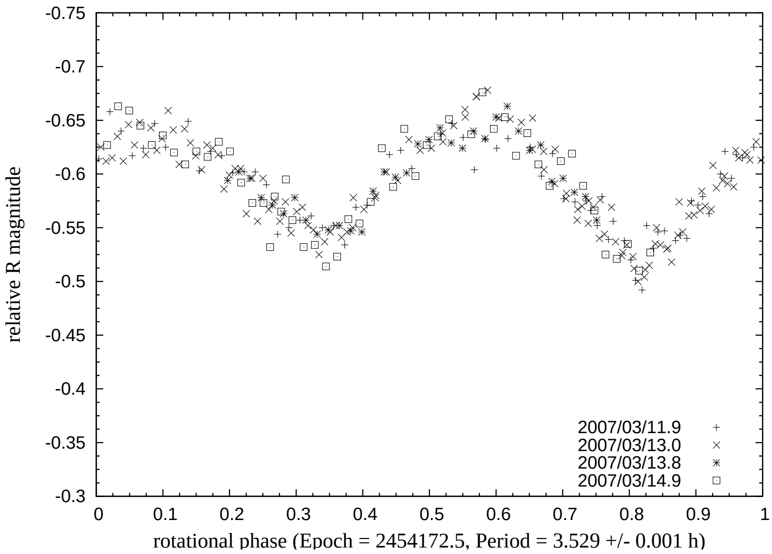

Figure 3. The composite lightcurve of (3541) Graham.

3.3. (3541) Graham

The synodic rotation period $P = 3.529 \pm 0.001$ h (Figure 3) was revealed from our observations on four nights in March 2007. We used a 7th-order Fourier fit with $A = 0.13$ mag. The synodic-sidereal period difference was calculated at $\Delta P = 0.00006$ h. The data were fitted with a 7th-order Fourier series with the amplitude $A = 0.13$ mag. The reliability code is $U = 3$.

3.4. (4080) Galinskij

An apparition in four nights at the end of September 2006 allowed us to reveal a synodic rotation period $P = 7.3600 \pm 0.0003$ h (Figure 4) with the maximum synodic-sidereal period difference $\Delta P = 0.0009$ h. An 11th-order Fourier fit shows a high lightcurve amplitude $A = 1.01$ mag. This solution has a reliability code $U = 3$.

3.5. (4155) Watanabe

Our observations are the first to estimate main photometric parameters. They were carried out on three nights at the end of November 2006 and show a synodic rotation period $P = 4.4972 \pm 0.0006$ h (Figure 5) with the maximum synodic-sidereal period difference $\Delta P = 0.0003$ h. The lightcurve with the amplitude $A = 0.19$ mag is very irregular, obviously due to a more complex asteroid shape.

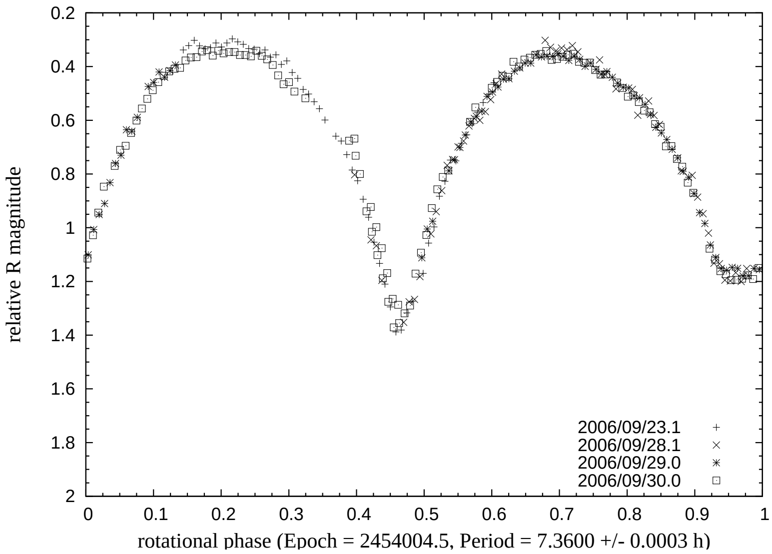

Figure 4. The composite lightcurve of (4080) Galinskij.

An 8th-order Fourier series was the best for fitting. Similar to other asteroids the reliability code was determined to be $U = 3$.

3.6. (12081) 1998 FH$_{115}$

Six nights in September–October 2006 yield up a synodic rotation period $P = 16.6062 \pm 0.0008$ h (Figure 6) and the maximum difference between the synodic and the sidereal period $\Delta P = 0.006$ h. The data were fitted with an 8th-order Fourier series. The data were of a good quality with the rms residual of 0.012 mag and the amplitude of the lightcurve $A = 0.24$ mag. The reliability code is $U = 3$.

3.7. (15415) Rika

Three nights in October 2006 revealed a synodic period $P = 6.3636 \pm\ 0.0008$ h (Figure 7) with the maximum synodic-sidereal period difference $\Delta P = 0.0007$ h. The data were fitted with an 8th-order Fourier series. The data were of a good quality with the rms residual of 0.022 mag and the amplitude of the lightcurve $A = 1.05$ mag. The reliability code is $U = 3$.

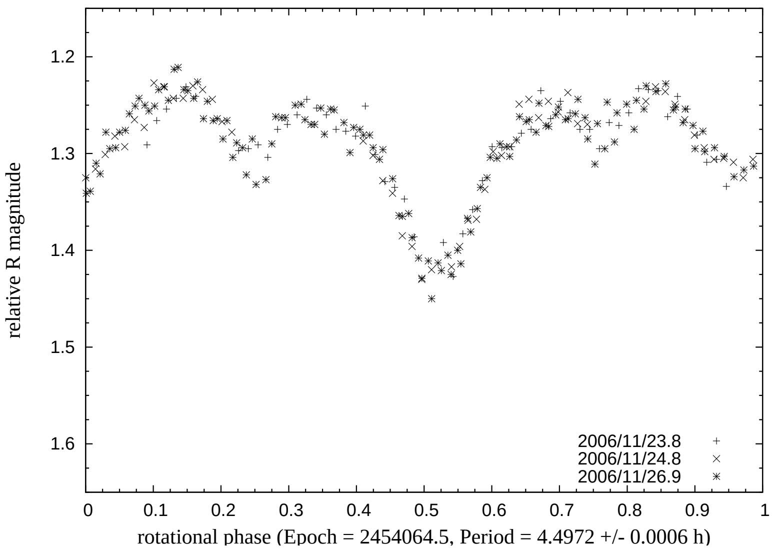

Figure 5. The composite lightcurve of (4155) Watanabe.

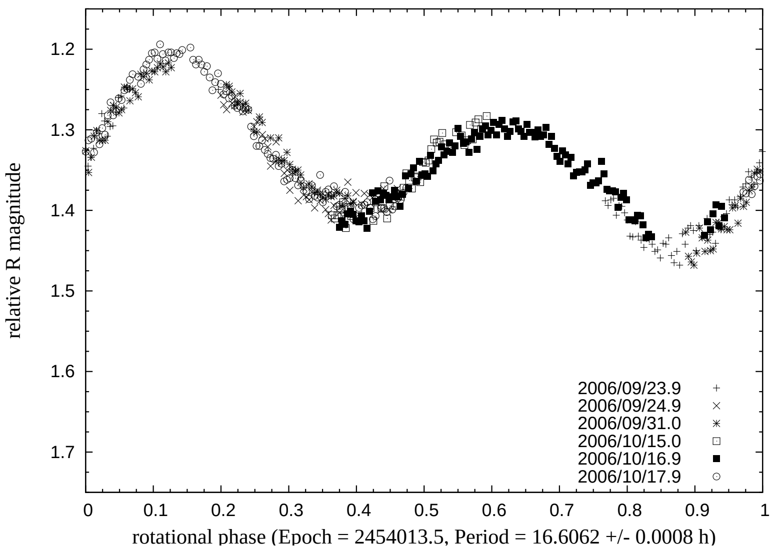

Figure 6. The composite lightcurve of (12081) 1998 FH_{115}.

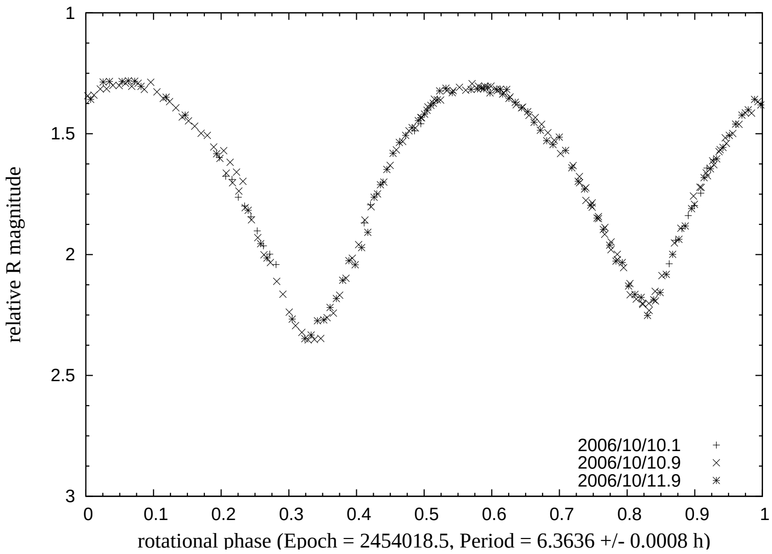

Figure 7. The composite lightcurve of (15415) Rika.

4. Outlook for next observations

In this section we want to review possible observing windows in the next 10 years (2008–2018) for the Skalnaté Pleso Observatory or another northern observatories with a similar equipment due to potential opportunities to determine some physical characteristics: spin axis orientation, sense of rotation and convex shapes. There are four ephemeris parameters needed to be considered (limits displayed in figures are defined for the Skalnaté Pleso Observatory):

1. *Elongation* is required whether an object is in the evening, night or morning sky; the lower limit is 60°.

2. *Declination* tells how high is an object above the horizon and how long it can be observable; the lower limit is $-11°$.

3. *Apparent V magnitude* tells whether an object's brightness is available for our reflector to get good signal-to-noise ratios; $V = 17$ mag was chosen as the maximum magnitude value.

4. *Galactic latitude* is important due to maximum coverage of lightcurves, because the density of background stars on the CCD frames can disrupt intriguing parts of lightcurves; latitude values more/less than ±20° were chosen as optimal for observations.

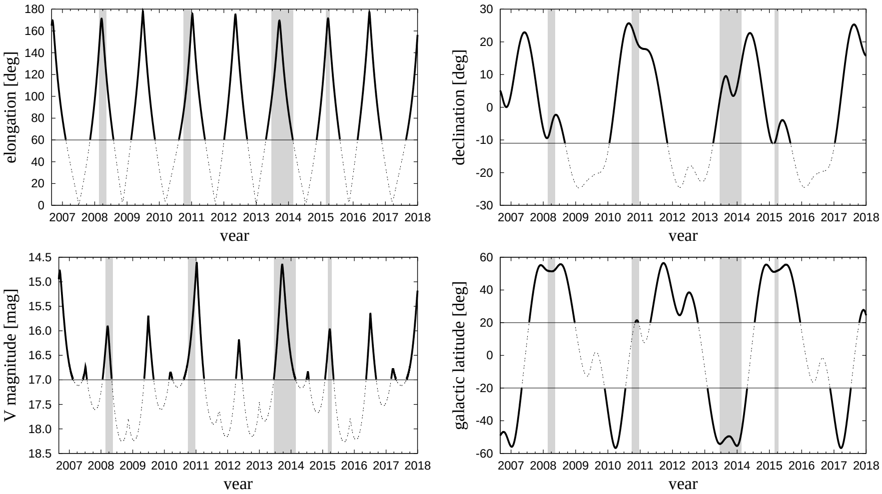

Figure 8. Asteroid (1314) Paula – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017. The highlighted gray stripes belong to the suitable observing windows.

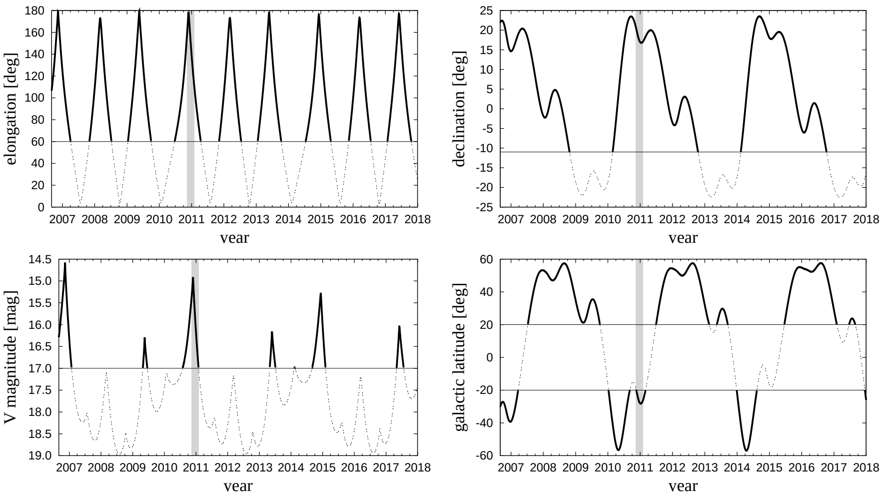

Figure 9. Asteroid (2257) Kaarina – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017. The highlighted gray stripes belong to the suitable observing windows.

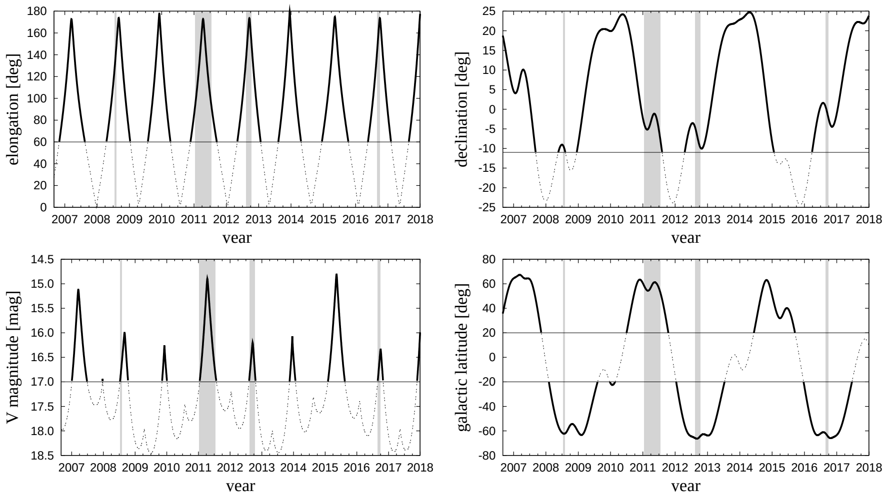

Figure 10. Asteroid (3541) Graham – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017. The highlighted gray stripes belong to the suitable observing windows.

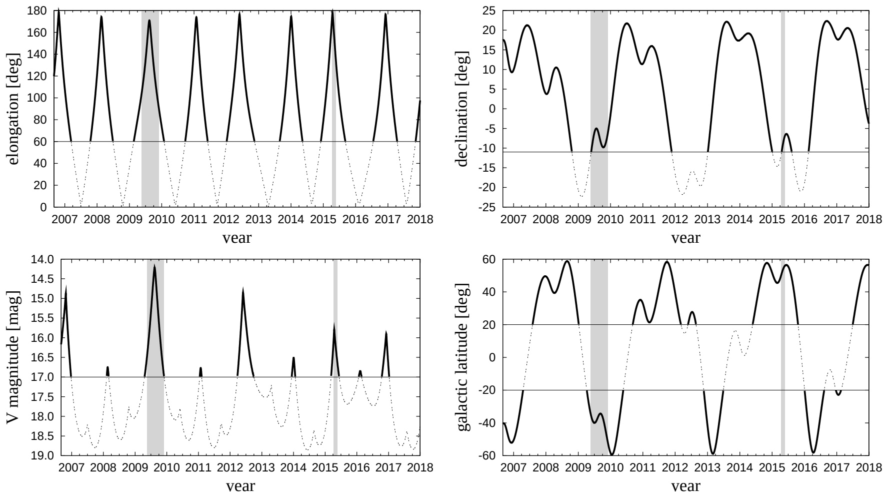

Figure 11. Asteroid (4080) Galinskij – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017. The highlighted gray stripes belong to the suitable observing windows.

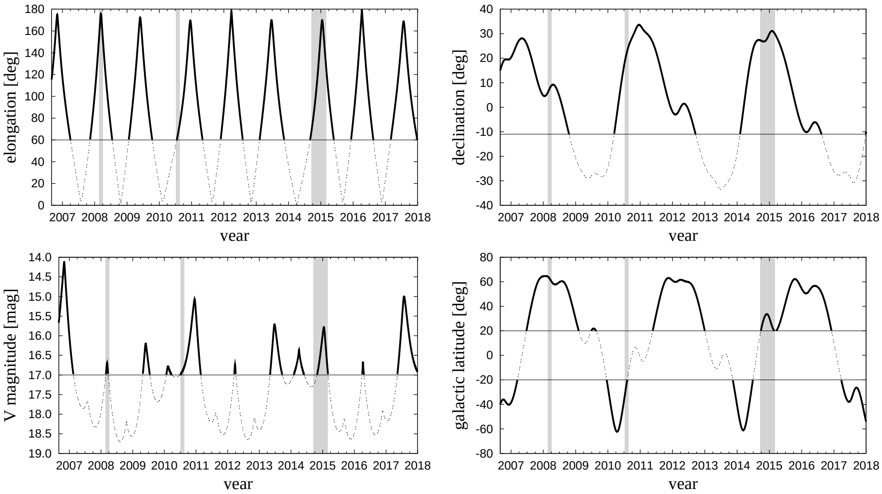

Figure 12. Asteroid (4155) Watanabe – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017. The highlighted gray stripes belong to the suitable observing windows.

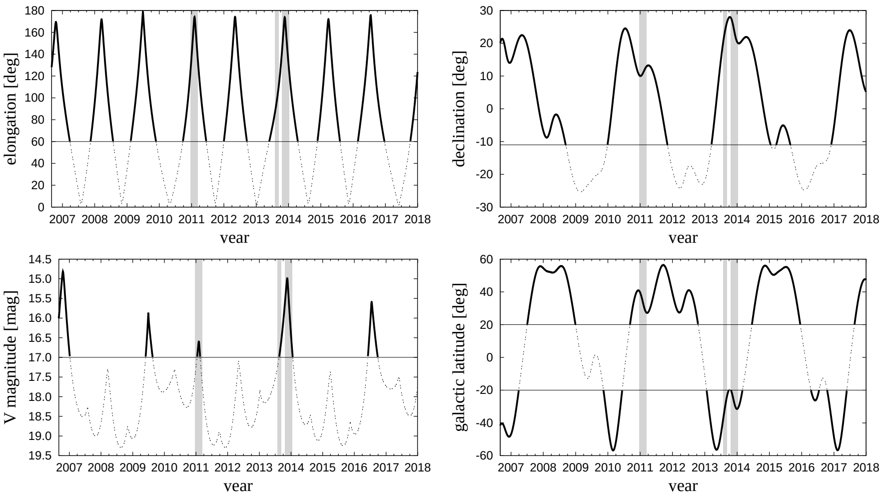

Figure 13. Asteroid (12081) 1998 FH_{115} – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017. The highlighted gray stripes belong to the suitable observing windows.

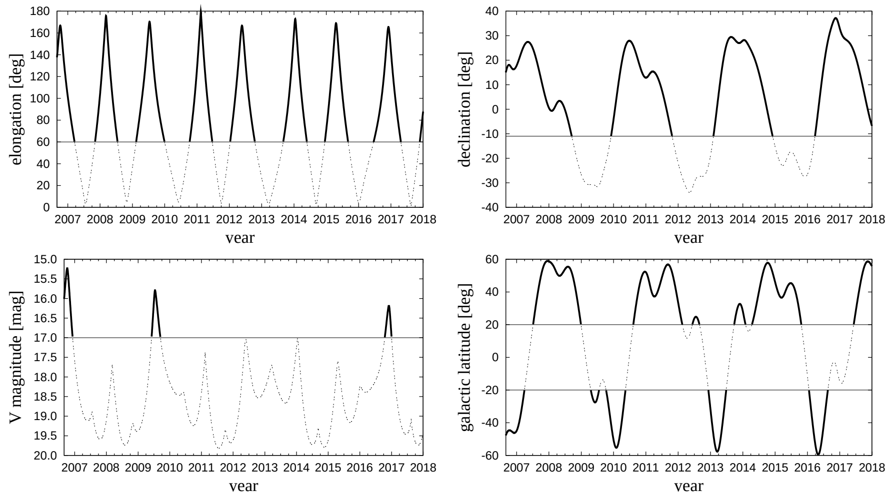

Figure 14. Asteroid (15415) Rika – trends of elongation, declination, apparent V magnitude, and galactic latitude in the time interval from September 2006 until December 2017.

Asteroid (1314) Paula has three observing windows: the spring of 2008, the end of 2010, the second half of 2013 and the beginning of 2014, and a few days in March 2015 (see Figure 8). The third one is the best to cover a wide interval of the phase angles ($5° - 30°$).

Asteroid (2257) Kaarina has one suitable window only. We can use a few weeks from 2010 until February 2011, but galactic latitude $< 30°$ can obstruct to acquire a full lightcurve rotational phase (Figure 9).

Four observing windows can be used for asteroid (3541) Graham: July 2008, January – July 2011, the autumn of 2012, and the autumn of 2016. The best conditions has the second one (Figure 10).

For next observations we can use only two good scheduled observing windows for asteroid (4080) Galinskij: the summer – late autumn of 2009, and the late spring of 2015. In the first one (Figure 11) there is an opportunity to catch new features in lightcurve caused by any shape irregularities and due to phase angles greater than 30°. Visualization of these features can help to construct a more accurate model.

For the asteroid (4155) Watanabe we found three good apparitions: the spring of 2008, the summer of 2010, and the late summer of 2014 – the spring of 2015, where the latter this one is the best (Figure 12).

Asteroid (12081) 1998 FH_{115} has two scheduled observing windows: the beginning of 2011 and the second half of 2013, with a short pause due to a low galactic latitude (Figure 13).

Table 2. The main results of our observations. The table contains: P is the synodic rotational period, ΔP is the maximum synodic-sidereal period difference, A is the amplitude of the lightcurve, U is the reliability code of the period solution, N means the order of the Fourier fit, and rms res. is the residual fit.

P [h]	ΔP [h]	A [mag]	U	N	rms res. [mag]
	(1314) Paula				
5.9505 ± 0.0001	0.0002	0.82	3	6	0.012
	(2257) Kaarina				
3.04866 ± 0.00006	0.0001	0.13	3	4	0.013
	(3541) Graham				
3.529 ± 0.001	0.00006	0.13	3	7	0.015
	(4080) Galinskij				
7.3600 ± 0.0003	0.0009	1.01	3	11	0.026
	(4155) Watanabe				
4.4972 ± 0.0006	0.0003	0.19	3	8	0.013
	(12081) 1998 FH_{115}				
16.6062 ± 0.0008	0.006	0.24	3	8	0.012
	(15415) Rika				
6.3636 ± 0.0008	0.0007	1.05	3	8	0.022

Asteroid (15415) Rika has no observing windows in the 10 years for our conditions (Figure 14).

5. Conclusion

In Table 2 we summarize the derived parameters: the synodic rotational period P, the maximum synodic-sidereal period difference ΔP, the amplitude of the lightcurve A, the reliability code of the period solution U, the fitted Fourier order N, and the rms residual of the fit.

Unique lightcurve data can be a useful starting point for a future determination of other photometric parameters of these asteroids even thought they are only relative. In the future we would like to replace the ST-8XME by a newer CCD camera ST-10XME with higher sensitivity, a larger field of the CCD chip and Johnson–Cousins photometric filters. The Skalnaté Pleso Observatory is ready to produce reliable good-quality and calibrated data which can be used for some physical parameters determination.

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