CCD PHOTOMETRY OF ASTEROIDS AT THE SKALNATÉ PLESO OBSERVATORY AND SHAPES MODELLING METHODS

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Abstract. Some partial results on new observational program at the Skalnaté Pleso Observatory – CCD photometry of asteroids are presented in the paper. Using CCD SBIG-ST8 camera at a Newton focus of 0.61-m f/4.1 reflector we have obtained few photometric observations of chosen asteroids, namely (787) Moskva, (1095) Tulipa, and (1257) Mora. Rotational periods (synodic and sidereal), pole orientations and sense of rotations can be determined by means of long-time observations with basic reduction and image processing. With sufficient covered lightcurves we can construct approximate irregular shapes of minor planets, not only triaxial shapes.

Introduction

Was there a primordial (prograde?) sense of rotation for the asteroids? Do family members have preferred pole orientations that retain a memory of the spin of a parent body? Are there unusual shapes produced by collisional disruption? Are the larger asteroids weak *rubble piles* held together by self-gravity? (Drummond et al. 1998). Physical properties of asteroids such as their shapes, spin periods, and spin axes, can help to improve our knowledge of their evolution as very important part of the evolution of the Solar System. Despite its importance for a complete picture of the evolution of the Solar System, knowledge of asteroid shapes is very poor compared with the number of observed asteroids. Detailed information is known only for a few asteroids explored by spacecrafts, and some shape models are available from radar observations. Photometric lightcurves are and will remain a major source of information about minor planets.

Asteroid selection

Ephemerides of Minor Planets for 2003 (Batrakov 2003) were used as a main source of physical properties of the minor planets - 1600 asteroids approximately with more or less known photometric parameters. The most essential data was rotational period for selection that should not exceed 6 hours due to full lightcurves coverage during short summer nights. Next important parameter was amplitude of brightness variations more than 0.2^m at least. Several candidates were found, but majority of them failed to satisfy claim on long-time observability, suitable brightness in each opposition, and height above horizon. Finally, three asteroids were selected, namely (787) Moskva, (1257) Mora, and (1095) Tulipa. Their rotational periods, amplitudes, and scheduled time of observability are listed in Table 1.

Asteroid	Period (hours)	Amplitude (mag)	Scheduled time of observability
787 Moskva	5.381	0.55	to 20.7.2003
	5.371		1.7.2004 – 31.12.2004
	6.055		1.10.2005 – 28.2.2006
	> 9.6		
1257 Mora	5.28	0.43	15.8.2003 – 15.1.2004
			15.10.2004 – 31.3.2005
1095 Tulipa	2.77	0.21	15.10.2003 – 15.4.2004
			15.2.2005 – 30.6.2005
			15.6.2006 – 30.9.2006

Table 1: Selected asteroids and their rotational periods and amplitudes

Some partial results

A Fourier analysis method was used to derive the composite lightcurve. The method yields a value for the rotational period, mean absolute magnitudes on each night of observation, and Fourier coefficients defining the shape of the composite lightcurve, to any degree specified. A major advantage of the method is that it yields formal error estimates for all the quantities computed. The Fourier coefficients derived can be used for studies of the shapes and pole orientation of asteroids an to define *rotational phase* in a more formal way, for connecting observations from one apparition to another. Also this method is an effective procedure how to determine the quantities from partial lightcurves when the full coverage (two maxima and two minima) is not possible in each night due to unfourable atmospheric conditions (Harris et al., 1989)

$$H(\varphi,t) = \overline{H}(\varphi) + \sum_{l=1}^{m} \left[A_l \sin \frac{2\pi l}{P}(t - T_0) + B_l \cos \frac{2\pi l}{P}(t - T_0) \right], \qquad (1)$$

where $H(\varphi,t)$ is computed reduced magnitude in solar phase angle φ in time t, $\overline{H}(\varphi)$ is mean absolute magnitude in φ, A_l and B_l are Fourier coefficients, P is rotational period, and T_0 is epoch (zero-point time).

Date (UT)	*r* (AU)	Δ (AU)	Phase angle (°)	$\lambda_{2000.0}$ (°)	$\beta_{2000.0}$ (°)	Obs.
			(787) Moskva			
2003 04 25.8	2.530	1.539	4.98	210.98	11.90	Husárik
2003 05 01.8	2.522	1.540	6.66	209.48	12.39	Husárik
2003 05 04.8	2.518	1.545	7.72	208.77	12.60	Bernasconi
2003 05 05.9	2.516	1.547	8.09	208.53	12.67	Bernasconi
2003 05 06.9	2.515	1.549	8.47	208.30	12.73	Bernasconi
			(1257) Mora			
2003 09 25.9	2.646	1.686	7.85	23.32	1.96	Husárik
2003 10 18.8	2.658	1.667	2.69	18.92	1.46	Husárik
2003 10 28.8	2.663	1.705	7.08	15.67	1.20	Husárik
			(1095) Tulipa			
2003 12 19.9	2.977	2.275	14.97	138.16	-10.94	Husárik
2004 03 14.8	2.962	2.223	14.90	125.04	-08.44	Husárik
2004 03 15.8	2.961	2.233	15.13	125.00	-08.37	Husárik

Table 2: Aspect data for 3 selected asteroids, which include the date of observation in UT, heliocentric *r* and geocentric Δ distances (in AU), solar phase angle, ecliptic longitude and latitude in J2000.0 reference frame, and observer's name

(787) Moskva

Asteroid (787) Moskva is classified as a S-type with a diameter of about 27 km. Previous data for this minor planet are given in Greve (1997) and Warner (1999). Greve's rotational period has been estimated more than 9.6 hours. Warner has presented new value about 5.381 hours with amplitude 0.55^m. Other sources (Batrakov 2003, R. Behrend and L. Bernasconi 2003) present different values, 5.371 hours and 6.055 hours respectively. Our data have been obtained during its 2003 apparition (see Table 2). The resulting rotational period from five nights is 6.0553 ± 0.0012 hours with amplitude 0.54^m. CCD images have been reduced by R. Behrend, and period have been calculated by M. Husárik. The composite lightcurve is fitted with Fourier function of order 15 (Fig. 1).

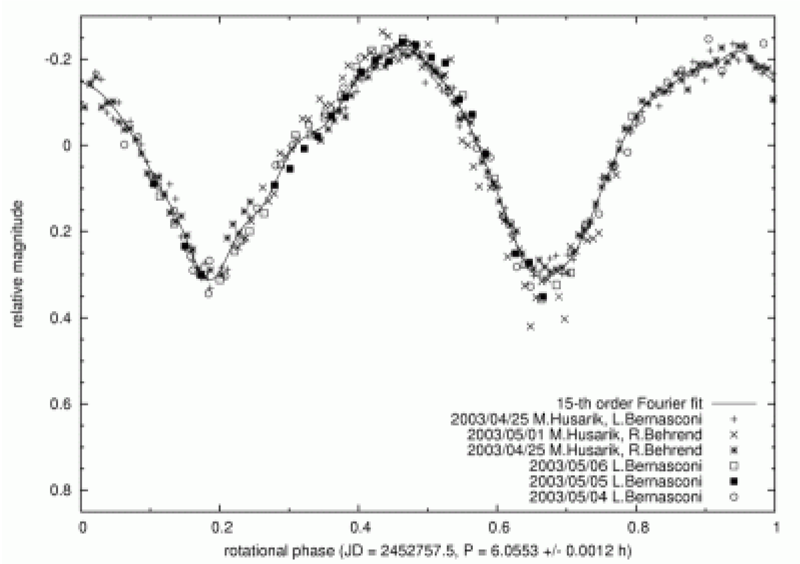

Figure 1: Composite lightcurve of (787) Moskva

(1257) Mora

This minor planet is classified as a C-type with unknown diameter. Photometric data of (1257) Mora have been reported in Binzel (1987). His value of the rotational period is 5.28 hours with amplitude 0.43^m. New data have been performed with our 0.61-m CCD telescope at the Skalnaté Pleso Observatory on three nights (see Table 2). Our solution of rotational period is fitted by the 5-th order Fourier fit and calculated at 5.2969 ± 0.0038 hours with amplitude 0.43^m.

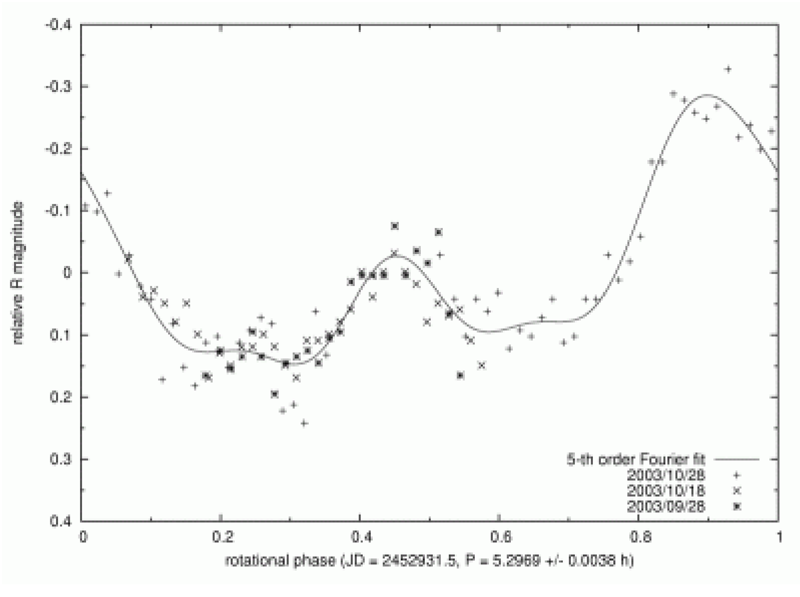

Figure 2: Composite lightcurve of (1257) Mora

(1095) Tulipa

This minor planet is not classified, but its diameter is about 31 km. Earlier photometry of (1095) Tulipa is given in Binzel (1987) and Batrakov (2003). They reported the value of rotational period 2.77 hours and amplitude 0.21^m. New data were carried with 0.61-m CCD telescope at the Skalnaté Pleso Observatory on three nights (see Table 2). The estimated rotational period is 2.765 ± 0.005 hours using the 6-th order

Fourier fit. The big scatter is caused by bad photometric conditions during the nights, but amplitude is more than 0.2^{m} also.

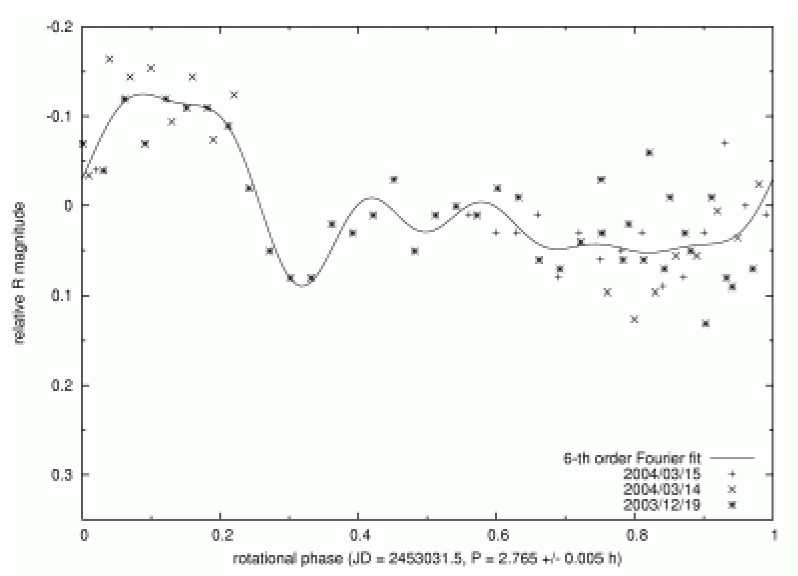

Figure 3: Composite lightcurve of (1095) Tulipa

Methods

Asteroids have been studied by a wide variety of observational techniques - polarimetry, radiometry, radar observations, speckle interferometry, occultations and photometry.
In increasing order of difficulty the purpose of lightcurve inversion is to derive information:

1. an asteroid's spin axis, sense of rotation and sidereal period;
2. its shape;
3. its light-scattering properties.

Epoch Method (Photometric Astrometry)

The use of photometric astrometry allows one to determine the pole orientation, sense of rotation and sidereal period of an asteroid from the observed epochs of the asteroid lightcurve features, usually the extrema, as well as the changing geometry of the Sun-Earth-asteroid system. The basic formula of the photometric asterometry is

$$P_{sid} = \frac{\Delta T_c}{\Delta N \pm \left(\frac{\Delta L}{360} + \frac{\Delta \delta}{360} + \Delta n \right)}, \tag{2}$$

where P_{sid} is sidereal period, ΔT_c a time interval between two light-time-corrected epochs, ΔN is an integer number of sidereal rotation cycles, the sign $\pm$ means that the + is used for direct and - for retrograde spin. More details are in Taylor (1979) or Michałowski (1988)

A-M Method

Other sources of our knowledge of the pole position and shapes of asteroids are amplitudes and magnitudes of their lightcurves. The standard assumption is that the shape of an asteroid is a triaxial *convex* ellipsoid with the principal semiaxex $a \geq b \geq c$. The *c*-axis is assumed to be the axis of rotation. This restrictive hypothesis limits the application of the method only to asteroids showing rather regular lightcurves, with well-defined maxima and minima. More details in Michałowski (1993).

Convex-Profile Inversion

Ostro and Connelly (1984) showed that any lightcurve can be inverted to yield a convex profile, and that, under certain ideal conditions the profile represents a two-dimensional average of the three-dimensional shape. That average is called the mean cross section and is defined as the convex set equal to the average of the convex envelopes on all surface contours parallel to the asteroid's equatorial plane. A convex profile can be represented by a radius-of-curvature function or by the function's Fourier series. The ideal conditions must be:

1. The scattering is uniform and geometric;
2. The viewing-illumination geometry is equatorial (the Sun and the Earth are in the asteroid's equatorial plane);
3. All of the asteroid's surface contours parallel to the equatorial plane are convex;
4. The solar phase angle $\varphi = 0$.

Gauss-Spheres Modelling

Although the triaxial *convex* model can provide a basic representation of the shape, it cannot sufficiently explain all the features present in the lightcurves. The shapes of asteroids and cometary nuclei that are being affected by numerous physical processes – such as collisions, disruptions, aggregations, and evaporations – appear quite irregular and globally *concave* (*non-convex*). The aim is to determine a shape that would give the best possible fit between observed lightcurves and synthetic lightcurves generated by the model. Irregular *non-convex* shapes can be modeled by using lognormal statistics (Gaussian random sphere). The Gaussian sphere is fully described by the mean and covariance function of the radius. Then synthetic lightcurves are computed for rotating Gaussian spheres (Muinonen 1998). Similar approach prefer Kaasalainen and Torppa (2001). The surface is given as a polyhedron with triangles as facets. Each facet is built by three surface points, and each surface point is represented by radius vector in spherical coordinates. Photometric behavior of the surface is described by some of those scattering laws – Lommel-Seeliger law, Lambert's law, Hapke's law and the Lumme-Bowell law.

Conclusion

Our aim is to obtain extensive observational material for the selected asteroids, and then to construct their shapes. In case of (1257) Mora and (1095) Tulipa we can say that their rotational periods are very similar to published periods. It is also important to note that our, Behrend and Bernasconi's observations have shown the definite period for (787) Moskva. We want to make use of Kaasalainen's shape modelling processes and to amplify the information about physical properties of the minor planets.

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