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New Semi-Automated Photometric Telescope at the Skalnate Pleso Observatory

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Abstract A semi-automated photometric telescope built at the Skalnate Pleso Observatory is described. In December 2000, the 0.3-m f/5 Zeiss astrograph was replaced by a 0.61-m f/4.3 mirror telescope equipped with a CCD camera. The observing programme is created to conform to the photometry of asteroids which are suspected to be of binary nature; photometry of NEAs and MBAs; a long-term photometry for theoretical modelling of the shape of asteroids; and photometry and astrometry of active comets and asteroids. Some results concerning the binary character of the asteroids are described in the paper.

Keywords Telescopes · Observational methods · Asteroids · CCD photometry · Shape modelling

1 The Old System

1.1 The Astrograph

The research of comets and asteroids at the Astronomical Institute of the Slovak Academy of Sciences has been a long tradition. Its beginnings go well back to the 40s and 50s of the last century, when altogether 18 new comets were discovered at both Skalnate Pleso and Lomnicky stit.

The Skalnate Pleso Observatory (MPC Code 056) had used since 1965 a 0.3-m f/5 Zeiss astrograph for photographic astrometry of comets and asteroids (Svoren 2002; Svoren

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2006). The photoelectric photometry of comets at the 0.6-m Zeiss reflector was based on a set of IHW filters—for CN, C_2 and C_3 emission lines and U and B continua. The first results were obtained by Vanysek and Tremko (1958).

1.2 The First CCD Camera

The first step towards improving the instrumental equipment was, in 1999, an installation of a CCD camera SBIG ST-8. Already during the year 2000, one noticed a significant increase of the acquired positions of comets and asteroids. This camera was equipped with a set of filters from the Johnson-Cousins photometrical system.

2 The New System

2.1 A Mirror Telescope

In December 2000, the astrograph was replaced on the same mounting by a 0.61-m f/4.3 mirror telescope equipped with the same CCD camera SBIG ST-8. This telescope was designed and manufactured by the J. Drbohlav and son (Rtyne v Podkrkonosi). The focal length of the system is 2.62 m; the effective light-gathering power amounts to 1:4.4.

2.2 Automatic Positioning and Guiding

The change from photography to CCD, accompanied by a significant reduction of the displayed field, forced us to automatize a search and a guidance system of the telescope. A semi-automated regime for the telescope is connected with the simultaneous motion of the 4-m dome.

It was inevitably to do some basic changes and corrections of the mounting (type Zeiss 6) in the computerization process performed by AstroLab Brno company: (i) serious lightening of the mounting and tube holding modification, (ii) former arrest and fine movement device disassambling, free motion worm steering in declination assembling, (iii) modification of movement device in RA and exchange of the old clock mechanism by a new one and (iv) dome movement mechanization and necessary sensors installation. Movements of telescope are performed by motors equipped by microprocessor-based control units produced by TG-Drives company, Brno. The main processor controls the movement units (RA, DEC and dome), receives commands from PC and returns the status information. Navigation accuracy is about 5 arcminutes. This value does not reflect the considerable mounting and body tube deformation.

The software created by one of the authors (J.A.) in the programming language C++ enables: (i) the original positioning/pointing-out of the telescope to the selected object of observation by giving its coordinates into a control PC, (ii) a fast transition from one object to the other, (iii) fine-tuning of the position of the object with respect to repeated expositions and/or expected proper motion of the object itself, (iv) doing flatfields, (v) coordinated motion of the dome and the telescope and (vi) software blockage of a possible overturn of the telescope to such positions that could cause its serious damage.

A continuous determination of the position was abandoned and replaced by the system of parking of the telescope in one and the same position in horizontal coordinates. After the set up of the system, the computer determines, given the azimuth and constant height above the horizon, the right ascension and declination of the original position. All subsequent positions are inferred in a differential manner; at the end of an observation the telescope is again parked into the starting position. When developing the control software we made use of mathematical methods created by Pribulla (private communication).

2.3 The Second CCD Camera

The new photometric system was completed in 2006 when a new camera SBIG ST-10XME-Class 1 with glass BK7 was built in the Newtonian focus.

Although the telescope is only a medium-sized instrument, excellent observational conditions at the Skalnate Pleso Observatory (1,783 m above sea level) enabled us to measure interplanetary objects up to the 18th magnitude and the limit for stellar objects during moonless nights is far beyond the 20th mag. The camera is equipped with a set of UBVRI filters of the Johnson-Cousins photometric system.

3 Observing Programme

3.1 Methodology of Observations

In order to make use of an observing time as effectively as possible, one of us (M.H.) created for the purposes of observations a web site which is updated on a regular basis as per objects planned for photometry and astrometry in an electronic form, which serves to find out the ephemeris of an astronomical body for the current or arbitrary time and date as inferred from the Minor Planet and Comet Ephemeris Service of the SAO.

The observing programme is created to conform the: (i) photometry of asteroids which are suspected to be of binary nature, (ii) photometry of NEAs and MBAs (Pray et al. 2007; Warner et al. 2006), (iii) a long-term photometry for theoretical modelling of the shape of asteroids and (iv) photometry and astrometry of active comets and asteroids.

3.2 Observation of Asteroids

Just recently, we have finished a long-term photometric research of three selected asteroids (787) Moskva, (1095) Tulipa and (1257) Mora, having in mind to find out some of their physical characteristics.

Our procedure, from photometric observations to the 3D shape models formation, is illustrated by the asteroid (787) Moskva. The first photometric observation of (787) Moskva was published by Greve et al. (1997) with a determination of the rotational period of $\sim$9.6 h with an amplitude of 0.6 mag. Warner (1999) published a value of 5.381 h with the amplitude of 0.55 mag. Two widely differing values are based on various long observational intervals with a varying density of coverage. We observed this asteroid at three intervals from May 2003 to March 2006. Nine high-quality light-curves were obtained, from which the sidereal rotational period of 6.055 795 $\pm$ 0.000 014 h was calculated (Fig. 1).

Hereafter, we determined ecliptical coordinates of the asteroid's spin axis. We obtained two solutions for the positions (122, +27) and (333, +61) deg. The positive second coordinate of both the solutions tells us about a prograde sense of rotation. With respect to the root mean square value between the observed light-curve and the light-curve computed

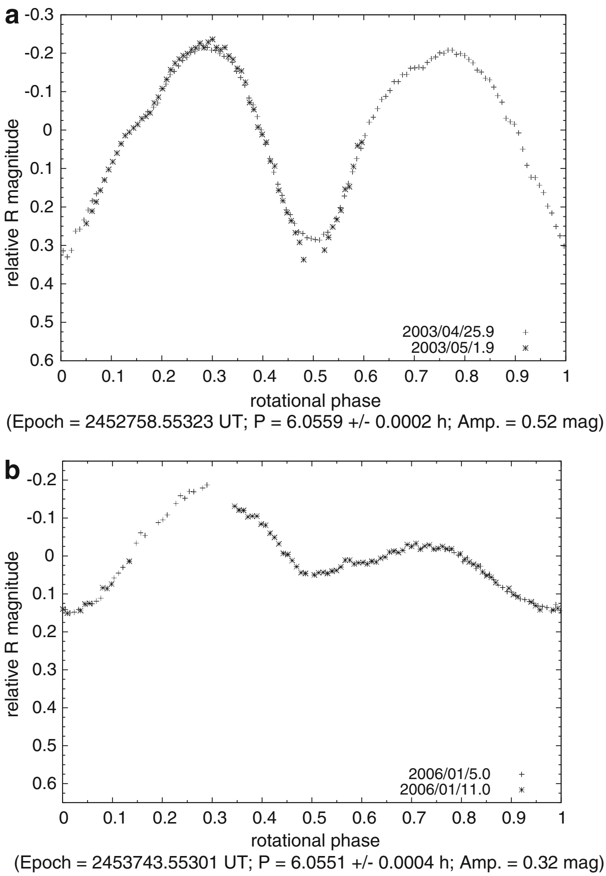

Fig. 1 Composite light-curves of the asteroid (787) Moskva during the oppositions in the years 2003 and 2006. [Description: Epoch—the time of the beginning rotational phase in UT, P—the rotational period and its error in hours, *Amp.*–the amplitude of brightness' changes in the light-curve in magnitudes]

from the synthetic model of a rotating ellipsoid, the value of the second pole is found more probable (0.013 mag vs. 0.010 mag).

We have also constructed its 3D shape models (Husarik 2008) based on the method developed by Kaasalainen and Torppa (2001) and Kaasalainen et al. (2001). We calculated models for both pole solutions; in what follows we shall show as an example the second, more probable solution. For the rotational pole (333, +61) deg, the model is drawn in three projections with the plasticity highlighting sheath covering, as depicted in Fig. 2. The *z* axis corresponds to the *c* axis (momentum of the inertia). Semi-major axes ratios are: $a/b = 1.4$ and $b/c = 1.2$. A shift from the rotational elipsoid to a more realistic model of a convex shape asteroid led to a reduction of the root mean square value between the observed and synthetic light-curves to the value of 0.008 mag.

Since 2004, the Skalnate Pleso Observatory has taken an active part in the photometric research of asynchronous binary asteroids within the international project "Photometric Survey for Asynchronous Binary Asteroids", led by P. Pravec (Astronomical Institute, Ondrejov, Czech Republic). The main objective of this project is to detect such object close to the Earth, in the vicinity of the orbit of the planet Mars and inside the interior main belt of asteroids, and in a controlled manner simulate selection effects and influences in the given sample. More than 20 observatories in the world have joined this campaign.

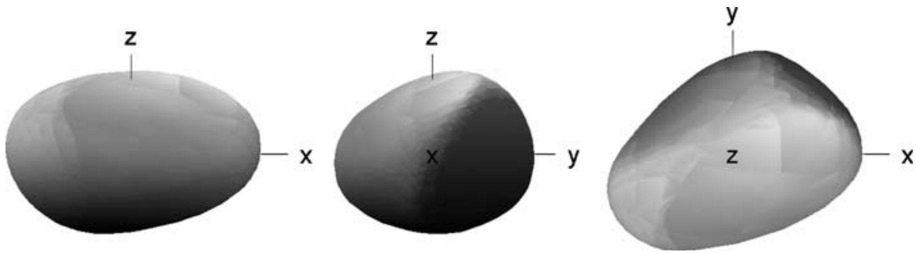

Fig. 2 Shape model of the asteroid (787) Moskva

Observations made at the Skalnate Pleso have already revealed the binary character of three asteroids—(9260) Edwardolson (mutual eclipse/occultation events that are 0.08–0.15 mag deep indicate a secondary-to-primary mean-diameter ratio of 0.27 ± 0.03), (2486) Metsahovi (lightcurve consisting of two linearly additive components with periods 4.4518 and 2.6404 h and amplitudes 0.12 and 0.04 mag, respectively) and (8116) Jeanperrin (mutual eclipse/occultation events indicate a lower limit on the secondary-to-primary mean-diameter ratio of 0.33). We have also contributed to the discoveries of binary nature of 10 more asteroids. Within this campaign we have so far observed another 80 ordinary asteroids where we either determined or helped to determine their rotational periods.

3.3 Future

Alongside the photometry of asteroids, we also intend to use our semi-automatic photometric telescope for observations of comets at large distances from the Sun. Here the detailed photometry could reveal naked cometary nuclei at the stage when they lack comas and exhibit activity other than that based on H_2O ice (Meech and Svoren 2004). We also aim at monitoring of larger objects from the population of Centaurs in the periods of their visibility thanks to their closer distance to the Sun.

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