Astrometric and Photometric Observations of Solar System Bodies with Telescopes of Pulkovo Observatory

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Introduction

The Laboratory of Observational Astrometry of the Central (Pulkovo) Observatory of RAS makes observations of minor bodies of Solar System, such as Near Earth Objects (NEOs), Main belt asteroids, binary and multiple asteroids, comets, natural satellites of Jupiter and Saturn. Also observations of exoplanets, variable stars and search for gamma ray bursts afterglows are made. The observations are carried out with MTM-500M telescope, placed on Mount Astronomical Station of Pulkovo observatory (Northern Caucasus), and ZA-320M mirror astrograph of Pulkovo observatory.

In the Laboratory, investigations are carried on among the following topics: improvement of asteroid and comet orbits; photometry of minor bodies and their physical parameters definition; modeling of binary and multiple asteroids and their lightcurves; astrometry and physical parameters definition of the satellites of Jupiter and Saturn; observations of exoplanet transits.

1. Telescopes

MTM-500M telescope (Maksutov reflector, \(D = 500\) mm, \(F = 4100\) mm) is located in the Mount Astronomical station of Pulkovo Observatory at Northern Caucasus \((\lambda = 42^\circ 40', \varphi = 43^\circ 44', h = 2070\) m). It is equipped with SBIG ST-L 1001E CCD camera (1024×1024 pix., 24×24 µm, pixel size = 1.19 arcsec/pix, \(BVRI\) filters, field of view \(\approx 21' \times 21'\), limiting magnitude \(-21\) m).

ZA-320M telescope (Cassegrain reflector, \(D = 320\) mm, \(F = 3200\) mm) is located in the Pulkovo Observatory at Saint-Petersburg \((\lambda = 30^\circ 19', \varphi = 59^\circ 46', h = 75\) m). It is equipped with FLI IMG 1001E CCD camera (1024×1024 pix., 24×24 µm, pixel size = 1.54 arcsec/pix, \(BVRI\) filters, field of view \(\approx 28' \times 28'\), limiting magnitude \(-18.5\) m).

2. Research of Near Earth Objects and binary and multiple asteroids

2.1 Discovering

With MTM-500M telescope, 4 asteroids (2010 UP67, 2010 XA15, 2010 XL46, 2010 XM46) were discovered, 1 comet (P/2004 F3 = P/2010 V2 = 246P/NEAT, 20.5 \(m\)) and 3 asteroids (2004 TR356, 2008 EG30, 2008 FM60) were rediscovered.

2.2 Research and observations of 2008 TC3 asteroid impacted to the Earth in 7 October 2008

On October 6, 2008, at 6h 39m UTC in the Mount Lemmon Observatory in Arizona, Richard Kowalski discovered a small asteroid approaching Earth. The first calculations of its orbit showed that the asteroid would fall to Earth 19 hours after its discovery, presumably in
northern Sudan (Jenniskens et al., 2009). 26 observatories all over the world made more than 800 observations of the asteroid, which was named 2008 TC3. A one third of them were made with the mirror astrograph ZA-320M at the Pulkovo observatory. Based on the analysis of observations, physical parameters of the asteroid were assessed (Aleshkina et al, 2011). The estimates of the absolute magnitude of the asteroid M = 30.6 ± 0.4 m, its size 4.8 ± 0.8 meters, and weight 131 ± 5 ton were obtained. The frequency analysis of each observational series using three methods has showed that a total period of 48.6 ± 0.6 sec with the amplitude of 0.27 ± 0.08 m presents in all series. The trajectory of the asteroid was simulated (Fig. 1).

Fig. 1 – a) Estimated descent trajectory of the asteroid 2008 TC3 to the Earth. The vertical axis represents the altitude in kilometers. The horizontal axis represents the moments of time in minutes from 2 h UTC of October 7, 2008. The explosion site at the altitude of 37 km and geographic coordinates (latitude and longitude) of the asteroid at the altitudes of 50, 37, and 20 km are indicated. For comparison, the corresponding coordinate values, recorded by meteorological satellites, are given in parentheses. The coordinates of the probable asteroid impact point in the absence of the explosion are also designated; b) Map of the asteroid 2008 TC3 impact area. 1 is the site of the asteroid explosion at the altitude of 37 km according to the meteorological satellite observation, 2 is the location of the asteroid at the altitude of 37 km for the model trajectory, 3 is the location of the asteroid at the altitude of 0 km for the model trajectories assuming that the explosion had not happened. The shaded circle is the impact area of asteroid fragments.

2.3 Research of binary 2006 VV2 asteroid

For this asteroid, the color indices, the absolute magnitude and its possible taxonomy class A were determined on the basis of our observations (Vereshchagina et al, 2009). Based on these results, the density of the system was estimated (2.71 ± 0.04 g/cm³). Using this value, estimates of the components masses were obtained (Table 1). Evaluation of the main component shape of the asteroid was determined, the position of the pole of rotation was defined and the period of axial rotation was specified (Table 2). Figure 1 shows the obtained shape of the main component in three different viewpoints.

Table 1 – Estimates of the components masses of the 2006 VV2 asteroid in assumption that its density is 2.71 ± 0.04 g/cm³ (classes A, Q, V).

<table>
<thead>
<tr>
<th></th>
<th>Mass, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main component</strong></td>
<td>8.275 ×10^{12} ± 0.122 ×10^{12}</td>
</tr>
<tr>
<td><strong>Satellite</strong></td>
<td>1.77 ×10^{11} ± 0.03 ×10^{11}</td>
</tr>
<tr>
<td><strong>System mass</strong></td>
<td>8.45 ×10^{12} ± 0.13 ×10^{12}</td>
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Table 2 – Estimates of the ecliptic coordinates of the pole, the rotation period and the dimensions of the main component of the 2006 VV2 asteroid.

<table>
<thead>
<tr>
<th>$\beta$, °</th>
<th>$\lambda$, °</th>
<th>$P$, h</th>
</tr>
</thead>
<tbody>
<tr>
<td>$37 \pm 2$</td>
<td>$29 \pm 3$</td>
<td>$2.410541 \pm 0.000003$</td>
</tr>
<tr>
<td>Dimensions $a \times b \times c$, km</td>
<td>$0.92 \times 0.89 \times 0.89 \pm 0.05$</td>
<td></td>
</tr>
</tbody>
</table>

Table 3 – Elements of stable orbit of 2006 VV2 asteroid. Also estimates of orbital parameters taken from IAU Circular 8826, 2007 are presented.

<table>
<thead>
<tr>
<th></th>
<th>Semimajor axis $a$, km</th>
<th>Eccentricity, $e$</th>
<th>Inclination, $i$, °</th>
<th>Period $P$, h</th>
</tr>
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<tbody>
<tr>
<td>IAU Circular 8826, 2007</td>
<td>$\geq 1.5$</td>
<td>-</td>
<td>-</td>
<td>$-5$</td>
</tr>
<tr>
<td>Our results</td>
<td>$1.9 \pm 0.2$</td>
<td>$0.10 \pm 0.06$</td>
<td>$0.0 \pm 0.002$</td>
<td>$6.1 \pm 0.2$</td>
</tr>
</tbody>
</table>

The obtained shape and estimates of the masses allow determining the possible stable orbit of its satellite. It is the closest orbit to the data of radar observations (Table 3).

2.4 Research of 2009 WZ104 asteroid

The 2009 WZ104 asteroid was attributed as potentially hazardous near Earth asteroid. The minimal orbit intersection distance is 0.0304 a.e. The observations were made in the framework of NEOs investigation program. The following research-work were made for this asteroid: getting astrometric and photometric (in $BVRI$ bands) series of observations, improving the asteroid orbit on the base of the observational data, determining its taxonomic class and absolute magnitude, investigating the dynamics of its rotation, estimating its physical parameters. The asteroid was attributed to Aten group.

2.5 Research of triple main belt 45 Eugenia asteroid

For this asteroid, shape of its main component has been refined. Direct image of the main component obtained with the Keck II telescope, the previous shape of main component (Marchis et al, 2006) and the new shape obtained in this work are shown in Fig. 3. One can see that the shape obtained in this work is in better agreement with observations than the previous one.
Elements of the asteroid satellites stable orbits were found. For second satellite, the possible range of stable orbits begin since $a_2 = 1.65 \cdot a_1 = 1930 \text{ km}$, where $a_1 = 1170 \text{ km}$. Our model shows that the axis of rotation of the main component is in forced precession associated with the perturbation by the satellites, with an angle of 10 degrees and a period of 66 days. This fact explains the existing uncertainty in the inclination of main component rotation axis to the ecliptic (Marchis et al, 2006).

2.7 Research of binary main belt 762 Pulcova asteroid

For this asteroid, shape of its main component and the pole position of its rotation ($\beta = 71 \pm 3^\circ$, $\lambda = 53 \pm 2^\circ$) were identified using our observations. The resulting shape at three different viewpoints and the comparison of this shape with a direct image of an asteroid obtained with Keck II telescope (Merlin et al, 2000) is shows in Figure 4.

2.6 Research of binary main belt 90 Antiope asteroid

For this asteroid, light variations with a period of 0.54 years and an amplitude up to $2^m$ were discovered. These changes in brightness are due to the changes in phase angle and it deal with the features of the reflective properties of their surfaces (Vereshchagina et al, 2008). It was defined that a model lightcurve obtained using the Lumme-Bowell reflection law with the asymmetry factor $g = -0.8$ gives the best agreement with the observations. Also an estimation of slope-parameter for this asteroid was obtained ($G = 0.046 \pm 0.023$).

3. Mutual phenomena of satellites of Jupiter and Saturn

Since 1995, Pulkovo observatory participates in international campaign of observations of the mutual phenomena of satellites of Jupiter and Saturn. The Laboratory of observational astrometry had got data by the automated telescopes: ZA-320M — during 2002-2003; ZA-320M and MTM-500M — during 2008-2009. All observations were sent to IMCCE for
further analysis. During the campaign PHEMU09 was carried out 25% of all observations made with Russian telescopes.

![Fig. 5 – a) A frame of mutual phenomena with the use “planetary coronograph”; b) Graph of the mutual event Jup 1 Ecl 2.](image)

### 4. Extra-solar planets

Our observations of extrasolar transit planets were started in the mid of 2010 and will be continued. During this time there were made a few observations of transits of extrasolar planets with telescopes MTM-500M and ZA-320M.

![Fig. 6 – Lightcurves of the transiting exoplanets: TrES-3b (2010-07-30) observed with MTM-500M telescope (left) and WASP-12b (2010-10-12) – with ZA-320M telescope (right).](image)

### Conclusions

With the MTM-500M and ZA-320M telescopes its carried out observations of large number of the Minor Solar System bodies and other objects. These telescopes can participate in Gaia-FUN-SSO Network (Gaia follow-up network for the Solar System Objects).

### References


