Advances in Astronomy and Space Physics, **3**, 113-115 (2013)

# Optical observations of selected asteroids with measurable Yarkovsky effect

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The results of the observations of 10 asteroids for 2009–2012 and their analysis are presented here. The asteroids were selected based on the available list of asteroids with relatively large deviations from the unperturbed semi-major axis of the orbit that can be caused by Yarkovsky effect. The observations were made at RTT-150 (NO TUBITAK, Turkey) and Mobitel (RI NAO, Ukraine). We have calculated the differences between the observed ($O$) and the calculated ($C$) positions, as well as the standard deviations (RMS) of the measurements. For the telescope RTT-150, the RMS is approximately $0.05''$ in both coordinates, and for the telescope Mobitel, the RMS is less than $0.1''$.

**Key words:** astrometry, asteroids, accuracy position

## INTRODUCTION

In recent decades, interest in non-gravitational effects in the motion of the small Solar System bodies, has been increasing. These effects, together with gravitational forces and collisions, significantly affect the dynamic evolution of the orbits of small bodies in the Solar System. The accumulation of a long series of high-precision optical observations of asteroids, and the presence of radar observations, will reveal such small effects.

The Yarkovsky effect is one of the most powerful non-gravitational effects. This effect causes the shift of the semi-major axis $a$ of the orbit of an asteroid, which could cause asteroids to drift from the main belt to near-Earth space [1, 2]. Depending on the direction of rotation of the asteroid, the Yarkovsky effect can either increase or decrease the semi-major axis of the orbit. When rotation is prograde, the jet force from the thermal re-emission of absorbed solar radiation is tangential to the direction of the asteroid revolution, which causes a lengthening of the semi-major axis ($da/dt > 0$). For retrograde rotation of an asteroid, the force direction is opposite to the direction of its velocity revolution, which causes a shortening of the semi-major axis ($da/dt < 0$) [1, 5]. In the papers [6, 7], it is shown that for an accurate calculation of the orbital position, the Yarkovsky effect must be taken into account when constructing motion models of small asteroids, along with the gravitational perturbations of the planets, their moons, large asteroids, and several relativistic effects.

This effect has the most significant affect on the dynamic evolution of irregularly shaped kilometre-sized asteroids. According to [5], an estimated value of the semi-major axis drift for such asteroids caused by the Yarkovsky effect, is $\sim 10^{-3}$ a.u./My. Such asteroids typically have faint magnitude, however modern precision radar and even optical observations, which have accuracy better than $0.1''$, enable the detection of small differences between the actual position of the asteroid and the calculated position, purely from the gravitational model of motion, even at short time intervals (i. e. several decades).

## OBSERVATIONAL PROGRAM AND INSTRUMENTS

The list of 94 asteroids given in [3] was used to create an observation plan. Objects for observation were chosen based on the technical characteristics of the telescope and the presence of a well-documented observational history of objects. Table 1 shows the characteristics of asteroids which are included in the plan of observations (data taken from the `HORIZONS` system[1]).

From the Table 1 we can see that the semi-major axis of an asteroid's orbit is determined with a precision of the order of $10^{-9}$ a.u., which allows us to distinguish drifts $da/dt$ on the order of $10^{-8}$ a.u., caused by the Yarkovsky effect for a ten-year observational period.

The observations of asteroids were carried out at two telescopes: the telescope Mobitel (RI NAO) and the Russian-Turkish telescope RTT-150 (Turkey).

The telescope Mobitel ($D = 0.5$ m, $F = 3.0$ m) is equipped with the CCD camera Alta U9000

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[1] `http://ssd.jpl.nasa.gov/`

(3056×3056, 12×12 mkm$^2$) of Apogee Imaging Systems, which allows us to obtain imaging with a $42' \times 42'$ field of view, with $0.83''$/pix scale. That system enables us to obtain a sufficient number of reference stars for reduction in the UCAC catalogues. The observations were made in $R$ Johnson-Cousins-Bessel band.

The Russian-Turkish telescope RTT-150 (Turkey) ($D = 1.5$ m, $F = 11.6$ m) is equipped with the modern CCD camera Andor DW436 (2048×2048, 13.5×13.5 mkm$^2$), which enables to obtain imaging with a $8' \times 8'$ field of view and scale of $0.24''$/pix. The telescope is equipped with a set of $UBVRI$ standard filters of Johnson-Cousins-Bessel band, which enables to conduct observations in multiple colour bands during one night [4].

## THE OBSERVATIONS AND ANALYSIS OF MEASURING OBSERVATIONS OF ASTEROIDS

The 120 positions for 5 selected asteroids, from the observations of 2011, were measured at the Mobitel telescope. The equatorial coordinates of the asteroids at the epoch of observation were obtained as result of standard astrometric reductions. We have used the UCAC4 as the reference astrometric catalogue for reduction.

We have made the comparison of observed positions ($O$) with the calculated ephemeris ($C$) provided by on-line service HORIZONS of the Jet Propulsion Laboratory, USA[2] and have calculated the residuals ($O - C$) in both coordinates, which are listed in Table 2.

The Table 2 contains the date of observation, the number of frames, magnitude of the object, ($O - C$) differences and their standard errors ($RMS$) in both coordinates. The mean internal accuracy of a single position is $0.07''$ in right ascension and $0.08''$ in declination for objects 9–16.5$^m$. It was calculated using standard deviations ($O - C$) in positions for each series of observations.

Since 2004, regular observations of selected asteroids were carried out with telescope RTT-150 in various international projects. Images of objects listed in [3], were selected from the available array of observations. The observations were reprocessed using the catalogue UCAC4 as reference. Results of the astrometric processing are presented in Table 3. The mean internal accuracy of a single position is approximately $0.056''$ in right ascension and $0.042''$ in declination for objects 14–19$^m$.

## CONCLUSIONS

The use of high-precision CCD techniques has made it possible to obtain accurate positions of small asteroids, the size of which does not exceed several kilometres, even using telescopes with a mirror diameter of less than 1 meter. High positional accuracy of the observational data suggests that these observations, together with other observations from Minor Planet Centre (MPC), can be used to identify and determine the value of the Yarkovsky effect.

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Table 1: Characteristics of selected asteroids.

| Number | diameter, km | a, a.u. | a-sigma, $10^{-9}$ a.u. | e | H (mag) | N | Revolution period, year | Observation interval |
|---|---|---|---|---|---|---|---|---|
| 1036 | 31.6 | 2.66 | 2.49 | 0.54 | 15.9 | 3423 | 4.34 | 1924–2013 |
| 1866 | 8.48 | 1.89 | 1.84 | 0.54 | 16.6 | 2194 | 2.61 | 1955–2013 |
| 1917 | 5.7 | 2.15 | 2.99 | 0.50 | 19.2 | 1082 | 3.15 | 1954–2013 |
| 1943 | 2.3 | 1.43 | 1.12 | 0.26 | 18.2 | 1649 | 1.71 | 1973–2012 |
| 2201 | 1.8 | 2.17 | 3.28 | 0.71 | 21.4 | 573 | 3.2 | 1931–2012 |
| 4179 | 5.4 | 2.53 | 0.15 | 0.63 | 20.3 | 5053 | 4.03 | 1934–2013 |
| 8567 | 3.1 | 2.05 | 10.68 | 0.45 | 19.8 | 2709 | 2.93 | 1955–2013 |

[2] http://ssd.jpl.nasa.gov/?horizons

Table 2: The $(O-C)$ differences and their standard errors for asteroids from observations at the telescope Mobitel.

| Asteroid | Date | N | H, (mag) | $(O-C)$, $''$ RA | Dec | rms, $''$ RA | Dec |
|---|---|---|---|---|---|---|---|
| 1036 | 2011-06-07 | 8 | 11.50 | −0.032 | −0.067 | 0.056 | 0.038 |
| 1036 | 2011-06-08 | 10 | 11.1 | −0.045 | −0.007 | 0.017 | 0.021 |
| 1036 | 2011-09-21 | 14 | 9.1 | −0.043 | 0.13 | 0.036 | 0.02 |
| 1866 | 2011-06-07 | 9 | 14.2 | −0.021 | −0.005 | 0.1 | 0.083 |
| 1917 | 2011-06-06 | 5 | 16.3 | −0.037 | −0.136 | 0.06 | 0.026 |
| 1917 | 2011-06-08 | 10 | 16.7 | −0.074 | 0.018 | 0.101 | 0.177 |
| 1917 | 2011-06-15 | 10 | 16.4 | −0.035 | 0.04 | 0.069 | 0.099 |
| 1917 | 2011-06-16 | 3 | 16.4 | 0.029 | −0.02 | 0.092 | 0.126 |
| 1917 | 2011-07-07 | 12 | 16.1 | −0.088 | −0.026 | 0.068 | 0.053 |
| 1917 | 2011-07-08 | 9 | 16.0 | −0.105 | −0.013 | 0.079 | 0.037 |
| 4179 | 2011-07-26 | 16 | 15.3 | 0.089 | 0.1 | 0.099 | 0.12 |
| 8567 | 2011-11-24 | 14 | 15.7 | −0.251 | 0.144 | 0.068 | 0.174 |
| mean | | | | | | 0.07 | 0.08 |

Table 3: The (O-C) differences and their standard errors for asteroids from observations at the telescope RTT-150.

| Asteroid | Date | N | H, (mag) | (O-C), $''$ RA | Dec | rms, $''$ RA | Dec |
|---|---|---|---|---|---|---|---|
| 1943 | 2009-08-04 | 12 | 16.1 | 0.139 | 0.122 | 0.091 | 0.132 |
| 1943 | 2009-08-05 | 14 | 16.0 | −0.015 | 0 | 0.061 | 0.006 |
| 1943 | 2009-08-06 | 14 | 16.2 | −0.126 | −0.03 | 0.049 | 0.017 |
| 1943 | 2009-08-07 | 12 | 16.1 | 0.017 | −0.102 | 0.093 | 0.015 |
| 1943 | 2009-08-11 | 11 | 16.0 | 0.001 | 0.066 | 0.032 | 0.031 |
| 1943 | 2009-08-13 | 13 | 16.4 | 0.021 | 0.027 | 0.024 | 0.036 |
| 1943 | 2009-08-19 | 12 | 16.0 | 0.036 | −0.024 | 0.016 | 0.015 |
| 2201 | 2009-08-11 | 6 | 18.9 | 0.05 | −0.071 | 0.052 | 0.056 |
| 4179 | 2008-06-27 | 10 | 17.2 | 0.017 | −0.03 | 0.036 | 0.055 |
| 4179 | 2008-06-30 | 7 | 17.2 | −0.081 | −0.042 | 0.078 | 0.073 |
| 4179 | 2008-07-03 | 7 | 17.5 | −0.075 | −0.017 | 0.08 | 0.026 |
| 4179 | 2008-12-02 | 32 | 14.1 | −0.19 | −0.026 | 0.06 | 0.038 |
| mean | | | | | | 0.056 | 0.042 |