

The Results of Positional Observations of Near Earth Asteroids Using the Combined Observation Method

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Abstract—The high velocity of the apparent motion of near Earth asteroids (NEAs) is the main problem in their observation. This problem is solved at the Research Institute of Nikolaev Astronomical Observatory (RINAO) with a combined observation method using the time delay and integration mode of a CCD array and a camera rotator. A total of 1317 positions of 74 NEAs were obtained at RINAO in 2008–2012. All the observations were made using the combined-observation method. The error in observations made at RINAO is compared with the results that were obtained at other observatories in this work.

Keywords: time delay and integration

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1. INTRODUCTION

According to data of the Near Earth Objects–Dynamic Site (NEODYs) project, 8893 near Earth asteroids (NEAs) were recorded as of May 2012. Using the NEODYs data on NEAs detected in 2010, the distribution of the number of NEAs over the distance to the Earth at the instant of detection was constructed. It turned out that 36% of 870 NEAs that were detected in 2010 were detected at distances of less than 0.05 a.u. (Fig. 1a). The high percentage of the new objects that were detected when approaching the Earth at distances of less than 0.05 a.u. is connected with an increase in the NEA brightness, which makes small objects observable. To calculate NEA orbits and estimate their hazard to the Earth, mass observations of

these objects are required. However, when approaching the Earth, the velocity of the apparent motion of NEAs increases (Fig. 1b), which makes their observations difficult using classical methods.

On the other hand, observations of NEAs at minimal distances from the Earth provide for data with a high spatial resolution, that is, the linear error becomes smaller due a decrease in the distance to an NEA at the same angular observation error.

2. OBSERVATION INSTRUMENTS AND METHODS

During NEA observations by classical methods, the maximum exposure is calculated while accounting

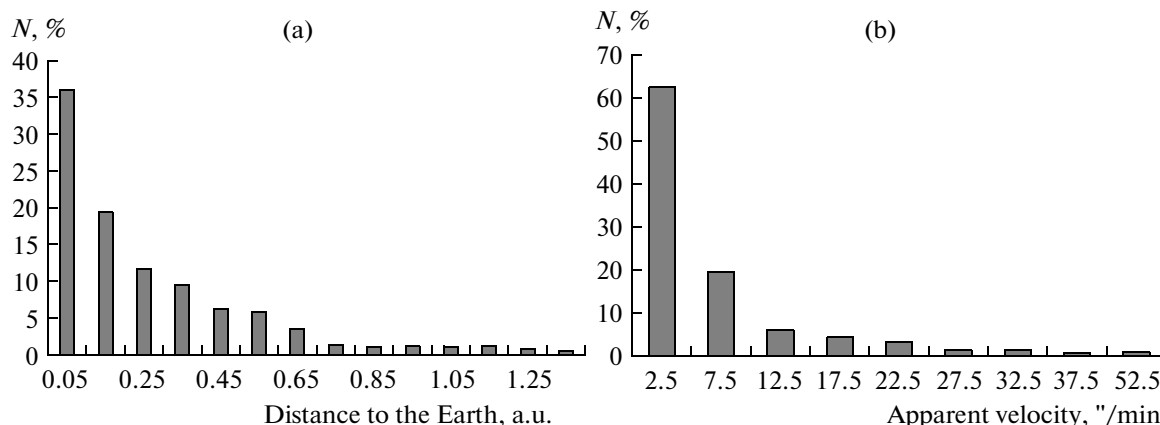


Fig. 1. NEA observation conditions at the instant of detection: (a) distribution of the number of NEAs over the distance to the Earth, (b) the velocity of apparent motion of NEAs as a function of the distance to the Earth.

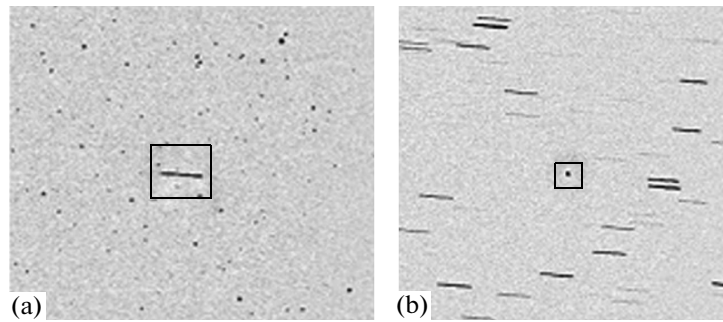


Fig. 2. Image of 2003UV11 NEA during observations (a) with daily tracking in the image accumulation mode of the CCD array and (b) with the immovable telescope in the TDI mode of the CCD array.

for the object's velocity, the linear size of a pixel, and the image scale:

$$t_0 = \frac{Md}{V}, \quad (1)$$

where M is the image scale ("/micron), d is the linear size of a pixel (micron), and V is the velocity ("/min). That is, the smaller the angular size of a pixel and the higher the object velocity, the lower the admissible exposure is, which results in a decrease in the optical resolving power and an increase in the coordinate determination error. To compensate for the NEA velocity, quite complicated and expensive hardware-software complexes of mechanical tracking of NEAs are used in telescopes all over the globe; when using these complexes, the exposure is limited by the length of reference star dashes; specialized software for processing long images are implemented in practice, binning is used during imaging (Badubesku et al., 2011).

High-velocity objects, such as NEAs and potentially hazardous asteroids (PHAs) are studied at RINAO using the combined observation method (COM) (Shulga et al., 2007); within this method, a telescope remains immovable during observations. The method consists in the separation of imaging processes for objects and reference stars. The time delay and integration (TDI) mode of a CCD camera is used within the COM. This mode allows electronic tracking of NEAs with exposures no longer than the time of an image traveling through a CCD array in the focal plane of a telescope. An essential condition for the use of TDI is the arrangement of the columns of a CCD array parallel to the motion direction of an object that is being observed. A specially designed device, viz., a camera rotator, is used for this purpose at RINAO. The camera rotator allows rotation of the CCD camera around the optical axis of the lens; it is equipped with an engine and an absolute angle sensor. To match the object coordinates to the system of reference stars, a modified model of observation reduction (Kozyrev et al., 2010) is used.

Two telescopes are used at RINAO for NEA observations: a rapid automatic complex (RAC) ($D = 300$ mm,

$F = 3000$ mm, field of view is $1.4 \times 1.4^\circ$, the limiting stellar magnitude is 17) and a KT-50 telescope ($D = 500$ mm, $F = 3000$ mm, field of view is $0.7 \times 0.7^\circ$, the limiting stellar magnitude is 18.5) of the MOBITEL mobile complex (Shulga et al., 2011). The telescopes are equipped with Apogee Alta U9000 CCD cameras ($3k \times 3k$, 12μ is the pixel size). Both telescopes are totally automated. The software for controlling the telescopes and automating the observation process was developed at RINAO.

The COM provides for point imaging of both reference stars and NEAs. Figure 2 shows an image that was obtained with the immovable telescope in the TDI mode in comparison with the image obtained in the accumulation mode with daily tracking for 2003UV11 NEA as an example. The observations were carried out on October 29, 2010. The apparent velocity of the NEA at the instant of observation was -134.3 "/min in right ascension and -10.9 "/min in declination. The object brightness was 11.9^m . The observations were carried out with the KT-50 telescope with an exposure of 50 s. As a result, the length of the NEA image track, which was received with the use of daily tracking, was 123.67 " (Fig. 2a); this corresponded to the apparent motion velocity. The TDI mode at the immovable telescope provided point imaging of the NEA (Fig. 2b). The signal-to-noise ratio of the NEA image increased by 9.8 times with the use of the TDI mode as compared to the accumulation mode with daily tracking.

3. ANALYSIS OF THE OBSERVATION RESULTS

Observations of NEAs and PHAs with the use of the combined method were started at RINAO in 2008. A total of 1317 positions of 74 NEAs were obtained in 2008–2012 using the RAC and KT-50 telescope; among them are 19 PHAs and 30 NEAs that were observed in the first opposition. A total of 178 positions of five NEAs with 12.8 – 15.0^m were obtained using the RAC in 2008–2010 with an apparent velocity of $(15$ – $68.3)$ "/min at the instant of observation. The use of the KT-50 telescope allowed a significant increase in the number of NEAs that were observed. A

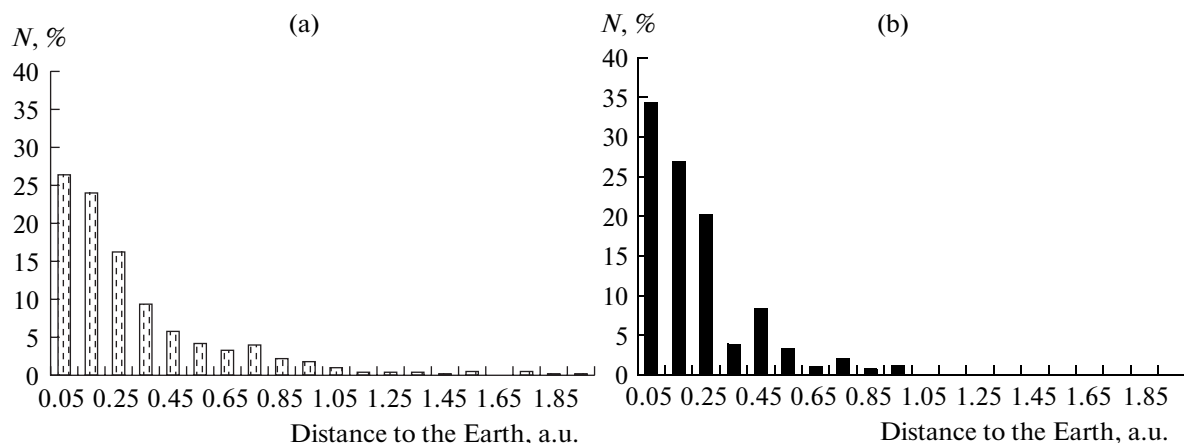


Fig. 3. The number of NEA positions as a function the distance to the Earth at the instant of observation for (a) all observatories all over the globe (in percentage of the total number of observations) and (b) for RINAO (in percentage of the total number of observations at RINAO).

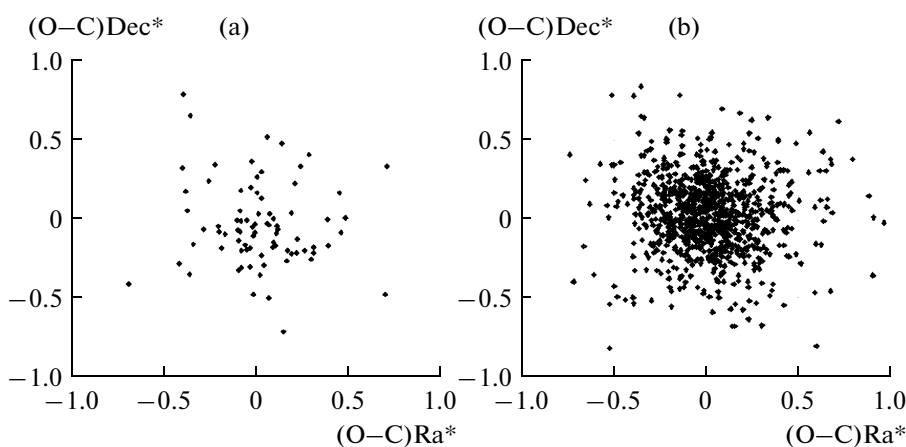


Fig. 4. The discrepancy in the right ascension versus the discrepancy in the declination for NEAs observed at (a) the RAC and (b) the KT-50 telescope.

total of 1139 positions of 70 NEAs with $9.4\text{--}18.5^m$ were obtained with the KT-50 telescope in 2010–2012 with an apparent velocity of $(0.5\text{--}306.2)''/\text{min}$ at the instant of observation. The observations were carried out at distances of $0.005\text{--}1.0$ a.u. from the Earth. The distributions of the number of NEA observations over the distance to the Earth carried out at RINAO and other observatories are compared in Fig. 3. Data for 70 NEAs for 2010–2012 from the NEODyS site were used for the analysis.

As seen from Fig. 3, about 26% of all the NEA observations at observatories all over the globe were obtained in periods when the distance between the Earth and NEAs were less than 0.1 a.u. Observations at such distances equal about 35% at RINAO. All the observation results that were obtained at RINAO were sent to the Minor Planet Center (Shulga et al., 2012). The mean discrepancy values (O-C) according to the NEODyS data and the standard errors (SE) for NEA

observations are given in Table 1 for observations with the RAC; the KT-50 observation data on NEAs in the first opposition for 2012 are given in Table 2. PHAs in the tables are marked by an asterisk. Figure 4 shows the discrepancy (O-C) in right ascension as a function of (O-C) in declination for NEAs observed at (a) the RAC and (b) the KT-50 telescope.

The dependence in Fig. 3 shows that the discrepancies of observations at the telescopes of RINAO are within the $\pm 1''$ limits and are distributed homogeneously relative to zero, which points to the absence of systematic errors in the NEA positioning. In the NEA observations carried out at RINAO, the SE of is equal to:

- $\pm(0.23\text{--}0.43)''$ for $(12.8\text{--}15.9)^m$ for RAC and
- $\pm(0.15\text{--}0.31)''$ for $(13.0\text{--}18.5)^m$ for KT-50.

To compare the observation errors, the discrepancies (O-C) obtained at other observatories (NEODyS data) were used. A total of 20034 positions of 70 NEAs

Table 1. Results of RAC observations of NEAs

No.	Name	Velocity ("'/min)	Stellar magnitude	Distance to the Earth (a.u.)	Number of positions	Average (O-C)		SE	
						$\frac{(O-C)["]}{\alpha}$	$\frac{["']}{\delta}$	α	δ
1	2008TT26	46.1	14.7	0.010	77	0.05	-0.05	0.41	0.42
2	2008SV11*	24.5	12.8	0.045	19	-0.17	0.10	0.26	0.23
3	2005YU55*	64.9	15.3	0.016	37	0.15	-0.12	0.27	0.27
4	2010JO33	68.5	15.9	0.009	29	-0.27	-0.06	0.38	0.29
5	2010GU21*	37.2	14.5	0.021	16	0.30	-0.24	0.43	0.32
Total				178					

Table 2. Results of KT-50 observations of NEAs in the first opposition in 2012

No.	Name	Velocity ("'/min)	Stellar magnitude	Distance to the Earth (a.u.)	Number of positions	Average (O-C)		SE	
						$\frac{(O-C)["]}{\alpha}$	$\frac{["']}{\delta}$	α	δ
1	2012AA11	8.1	16.0	0.08	24	-0.04	0.19	0.18	0.32
2	2012BJ134	7.8	18.0	0.25	6	0.08	0.15	0.19	0.25
3	2012DH4	21	16.9	0.06	6	-0.08	0.1	0.13	0.17
4	2012DO	5.9	16.5	0.11	23	-0.1	-0.04	0.30	0.41
5	2012DX75*	6.7	16.5	0.1	19	0.02	-0.21	0.20	0.29
6	2012EK8	14.1	17.4	0.04	4	-0.15	0.1	0.30	0.20
7	2012EO8	82.8	17.1	0.01	6	0.1	0.03	0.70	0.40
8	2012ES14	7.2	18.2	0.2	15	-0.01	0.2	0.21	0.34
9	2012FQ35	15.5	18.3	0.04	8	0.22	0.17	0.40	0.37
10	2012FY23	10.9	17.1	0.09	35	-0.08	0	0.19	0.25
11	2012GD2	33.1	17.3	0.05	4	-0.01	-0.25	0.26	0.33
12	2012HL	7.2	18.5	0.08	9	0.04	-0.25	0.25	0.41
13	2012HM	46.3	15.7	0.01	19	0.19	-0.1	0.33	0.20
14	2012HP13	174.7	15.8	0.01	20	0.33	0.24	0.37	0.30
15	2012LJ	306.3	18.2	0.005	7	-0.02	0.09	0.23	0.25
Total				205					

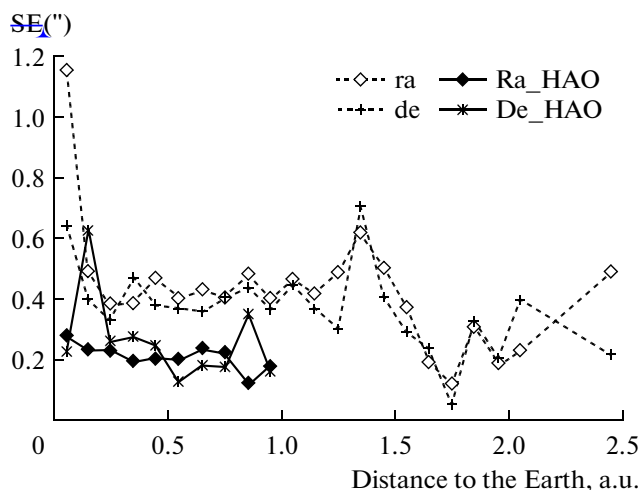


Fig. 5. NEA SE as a function of the distance to the Earth at the instant of observation.

were used for this comparison. The average error was calculated with a step of 0.1 a.u. Figure 5 shows the standard error of NEA positioning as a function of the distance to the Earth according to observation data of RINAO and other observatories; it indicates that the RINAO observation error is lower than the averaged error of other observatories.

4. CONCLUSIONS

The specific circumstances of observations of NEAs, i.e., the high velocity of apparent motion when approaching the Earth, require the use of high-power telescopes or the development of new observation

methods with the use of electronic tracking modes in modern CCD cameras.

The combined observation method has been developed at RINAO, successfully implemented at the telescopes of the observatory, and used for observation of NEAs, including PHAs, during their maximum approach to the Earth. A total of 1317 positions of 74 NEAs with apparent velocities of (0.5–306.3)"/min at the instant of observation were obtained for 2008–2012 using the COM.

The observation discrepancies are within the $\pm 1''$ limits, according to the NEODyS data; this confirms the efficiency and availability of the COM for NEA observation.

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