Program of astrometric CCD-observations with the Pulkovo Normal astrograph and current results ⋆

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Abstract

An astrometric CCD observations of asteroids and comets have been carried out with the Normal astrograph (D/F=330/3467mm) of the Pulkovo observatory since December 2004. CCD detector S2C-017AP is used (full frame format is 1160 × 1040 with 16 micron square pixel, FOV is 16 × 18 arcmins). The limiting magnitude with 2 mins exposure is 17. Achieved positional accuracy of observations of asteroids is 20 to 80 mas depending on magnitude. Double and probably double asteroids, near Earth asteroids (occultations of stars and close approaches to the Hipparcos and Tycho-2 stars), asteroids at the point of maximum curvature of visible trajectory have been included into observational program. The observations of several asteroids with about 50 years observational history have been continued. The results of observations have been submitted to the MPC and published in the Astrometric databases of the Pulkovo observatory (www.puldb.ru).

Key words:
astrometric CCD observations, reduction technique, double asteroids, orbit improvement
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1. Introduction

The middle focal length telescopes with CCD-detectors are widely used in modern astrometric observations of stars and Solar system bodies. It is one of the powerful technique for obtaining high quality positional data in astronomy. The first results of astrometric CCD observations with the Pulkovo Normal astrograph ($D/F = 330\,mm/3467\,mm$) and the program of current and future observations are described in this paper.

The CCD-detector S2C-017AP (Electron Optronic, Saint-Petersburg, Russia) had been installed on the Pulkovo Normal astrograph by December 2004. The full frame format of the CCD detector is 1160 x 1040 with 16 micron square pixels. The Normal astrograph field of view with the S2C-017AP is 18x16 arcmins.

Synchronization with UTC is realized using minute signals of time service of observatory via LPT PC port converter. The AccuTime driver (V.V. Kouprianov et al., 2002) is providing connection between signals of time and CCD software.

A six-constant linear model was adopted for CCD-frames astrometric reductions. The IZMCCD software was applied (I.S. Izmailov, www.izmccd.puldb.ru). Accuracy estimations of the results were obtained from the (O-C) values convergence. (O-C) were calculated with the EPOS software (L'vov V.N. et. al., 2001).

All results of the positional observations of the minor planets and comets have been submitted to MPC (Khrutskaya E.V et. al., 2005), (Devyatkin A.V., Khrutskaya E.V et. al., 2005) and presented in Astrometric database of the Pulkovo observatory, in the Solar system bodies section (www.puldb.ru) (Khrutskaya E.V et. al., 2005).

2. The first results of the astrometric CCD observations

The comet C/2004 Q2 (Machholz) was an object for the first CCD observations. It was being observed within the period from 31 of December 2004 to 9 of February 2005. 138 separate CCD frames with the C/2004 Q2 were obtained. The comet magnitude was changing within 4.2 to 5.2 and declination was increased from +8 to +70 degrees. The

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Table 1
The mean values of the (O-C) in RA and DEC. The internal and external positional standard errors (S.E.) of one observation. The results have been derived in 2005. Units: mas.

asteroid	Number of observations/nifgts	Mean of $(O-C)_\alpha \cos\delta$	Mean of $(O-C)_\delta$	Internal S.E.	External S.E.	magnitudes
6	46/5	23± 13	-14± 15	40/39	91/102	9.9 to 10.2
29	29/3	-87± 13	-101± 12	53/46	72/62	9.9 to 10.2
45	10/1	79± 10	-258± 17	31/54	-	11.4
65	5/1	58± 13	76± 13	29/30	-	13.1
121	90/6	-132± 5	109± 8	36/37	48/66	13.0 to 13.8
130	41/2	-90± 8	122± 9	36/35	53/59	12.5 to 12.7
129	18/2	263± 15	-157± 15	51/49	92/88	9.9 to 10.1
283	22/3	47± 24	87± 18	113/69	114/84	14.0 to 14.5
564	10/1	-155± 17	-135± 23	53/73	-	14.7
617	42/8	-292± 66	177± 59	111/161	228/202	15.8 to 16.3
762	77/6	-75± 6	-11± 9	47/61	51/75	13.6 to 13.9
816	10/1	-418± 25	45± 22	59/73	-	15.0
1062	11/1	19 ± 44	-55± 29	144/95	-	15.1

UCAC2 and USNO-A2.0 (for $DEC > 50$ degrees) were used as reference catalogues for CCD frames processing. Internal standard error was calculated from the separate series of CCD frames. The values of internal standard error are 100 mas in RA and 175 mas in DEC. The estimation of the external standard error was derived from the results of different nights. The values of external standard errors are 180 mas in RA and 275 mas in DEC.

Further CCD observations and investigation of the CCD detector were made in parallel mode. Estimation and analysis of the instrument possibilities such as limiting magnitude, quality of the images and accuracy of the results are the main goal of the CCD observations in 2005.

Several asteroids from the list of 13 minor planets that have been observed at Pulkovo observatory during last fifty years were included into observational program. In addition, several double and probably double asteroids were observed.

The CCD frames processing was made according to simplified scheme. Flat fielding and possible systematic effect corrections have not been taken into account in that stage. The UCAC2 was applied as a reference catalogue. These observations have shown that the limiting magnitude is 16.5 to 17 for 2 minutes exposure.

A considerable improvement of the accuracy of the CCD astrometric observations in comparison with the photographic observations of the same objects has been achieved. The standard positional errors of one observation obtained from CCD observations are 55/60 mas for RA/DEC. The same errors that have been calculated from the results of photographic observations of the minor planets with the same telescope in 1995-2000 are 175/195 mas (Bronnikova N.M. and Vasil'eva T.A., 2002). The mean external accuracies are 90/95 mas in the case of CCD observations and 310/290 mas for photographic observations. Accuracy estimations of the CCD observations in 2005 and the mean values of the (O-C) are presented in Table 1. The internal standard error (S.E.) characterizes one night convergence of the results and the external error has been derived from convergence of full set of the results.

3. The program of astrometric CCD observations

The achieved accuracy demonstrates that instrument may be used in the field of problems of modern astronomy. The observational program has been expanded in 2006. The astrometric observations of traditional targets were continued and the NEAs, double, probably double asteroids were also added into observational program. In addition, the list of asteroids has been formed in order to find double asteroids astrometric signature in their motions.

3.1. *The double asteroids*

The problem of the double asteroids hunting using the telescopes such as Normal astrograph may be solved by detecting wavy-like motion relative to background stars from long series of high precision astrometric observations. This effect is caused by distinction between motion of the center of mass of the double asteroid system and the photocenter motion. One of possible approach of data analysis is a spectral analysis of the (O-C) series (Kikwaya J.B. et. al., 2003).

The goal of the double asteroids hunting observational program is detecting of perturbations of the motion of target asteroid that may be caused by presence of invisible satellite and estimation of the orbital period in the double asteroid system.

One of the hypotheses about double asteroids population is the idea that relative quantity of double asteroids is depend on the asteroids families. And the asteroids that are

Table 2
The estimations of the linear (D) and angular (Δ_1, Δ_2) distances photocenter - center of mass for selected double asteroids. The values Δ_1 and Δ_2 were calculated for favorable and unfavorable oppositions correspondingly.

asteroid	D, km	Δ_1, mas	Δ_2, mas
2 Pallas	44	53	25
532 Herculina	29	31	17
18 Melpomene	95	164	73
9 Metis	86	107	70
216 Kleopatra	16	20	9
15 Eunomia	22	27	14

the member of the common families with the known double asteroids are included into observational list.

If the distance between the photocenter and center of mass is within 50 to 100 km, the maximum appropriate angular displacement is within 20 to 50 mas at the geocentrical distance of 3 a.u. (within the main belt). Such values of angular displacement correspond to signal-to-noise ratio is near 1 for Normal astrograph positional accuracy.

Near 300 asteroids up to 16 magnitude in opposition with declinations more than -10 degrees over the whole observational period have been chosen for double asteroids hunting.

Different estimations have shown that the values of angular displacement for known double asteroids may up to 100 mas. Such effect may be detected from observations with the Normal astrograph. Several known double asteroids have been added to observational list in order to verify of the validity of methods of double asteroids hunting. The results of calculations of the distance between the photocenter and center of mass for these asteroids are shown in Table 2. These estimations are based on assumptions that the primary to secondary mass ratio is proportional to cube of the appropriate sizes ratio and the brightness ratio is proportional to quadrate of the sizes ratio.

The orbital periods in double asteroids systems are within from several hours to several days. And two or three observations of every asteroid per night are being taken. The results of observations of 28 asteroids which have been obtained during the period from January to May 2006 are seen in Table 3. The mean values of the internal standard errors are 49/48 mas in RA/DEC. The mean external standard errors are 65/60 mas correspondingly. The Fig. 1 demonstrates behaviour of the external standard errors as function of magnitude. A natural increasing of standard errors from 20 to 80 mas with magnitude is seen in Fig. 1.

3.2. *Near Earth asteroids*

The main part of the NEAs observational strategy is observations of the stellar occultations and close approaches of the NEAs to the Hipparcos and Tycho-2 stars. The results of astrometric observations of such events which had been obtained at the Pulkovo observatory has shown that

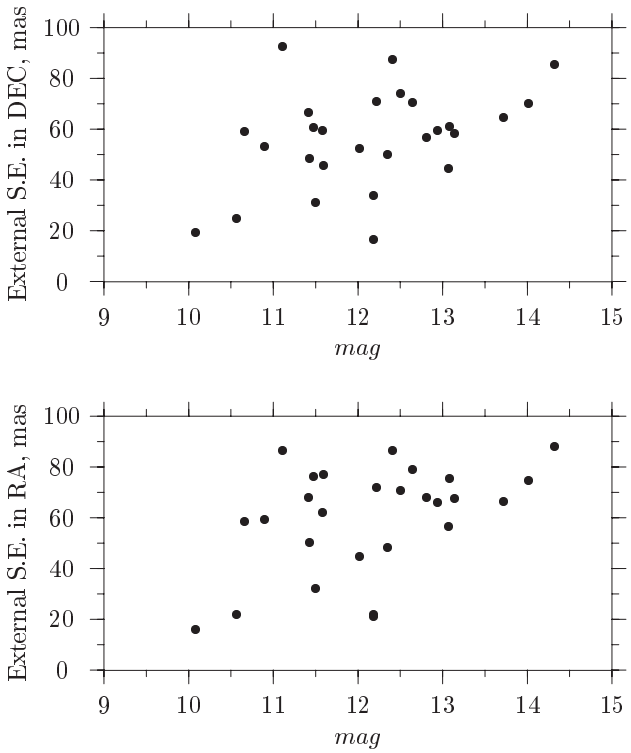

Fig. 1. External standard errors of the asteroids astrometric observations with the Pulkovo Normal Astrograph as a function of the magnitude.

the minimal angular distance between star and asteroid and the moment of maximum approach/occultation may be derived with accuracy at the 10 mas level and 0.1 to 1 seconds of time correspondingly. These are valuable data for improvement of the orbital elements of the NEAs.

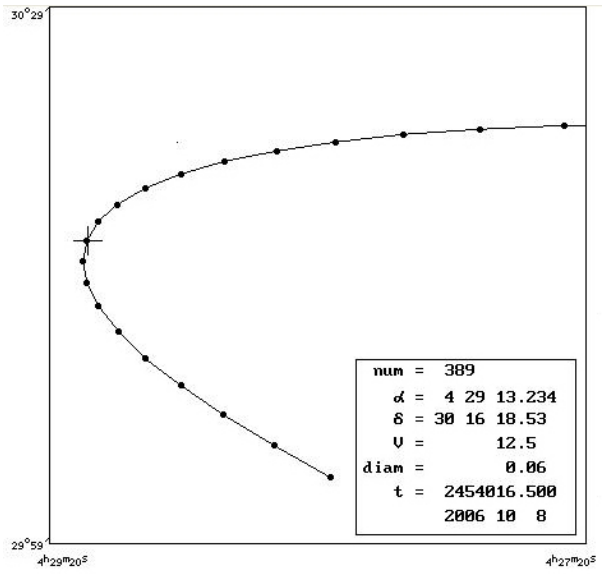

Fig. 2. The motion of the asteroid (389) Industria near the point of maximum curvature of it's visible trajectory.

Table 3
The mean values of the (O-C) in RA and DEC. The internal and external positional standard errors (S.E.) of one observation. The results have been derived in 2006. Units: mas.

asteroid	Number of observations/nifgts	Mean of $(O-C)_\alpha \cos\delta$	Mean of $(O-C)_\delta$	Internal S.E.	External S.E.	magnitudes
9	242/2	-33 ± 4	21 ± 4	46/38	61/61	9.0 to 11.4
712	8/1	114 ± 11	-79 ± 11	32/31	-	11.5 to 12.6
71	133/11	-218± 7	35 ± 6	52/55	71/67	10.5 to 14.6
65	125/11	8 ± 5	67 ± 4	31/29	56/44	11.9 to 14.1
64	143/12	21 ± 5	133 ± 5	54/55	62/59	9.9 to 12.3
60	112/7	162 ± 5	106 ± 5	34/27	50/48	10.2 to 13.5
53	74/7	-52 ± 6	-27 ± 6	38/42	48/50	11.1 to 13.4
52	58/5	-53 ± 11	-18 ± 11	69/69	86/87	12.3 to 12.9
505	77/5	-88 ± 9	-68 ± 7	70/61	75/61	12.5 to 13.6
481	20/1	33 ± 5	126 ± 4	21/16	-	12.2
472	8/1	33 ± 31	-134± 33	86/92	-	14.5
40	145/14	45 ± 6	29 ± 6	45/42	68/66	10.4 to 12.1
38	11/1	-185± 7	-22 ± 10	22/33	-	12.2
354	282/26	173 ± 3	18 ± 3	47/47	58/59	9.5 to 13.3
283	39/3	-4 ± 12	-122± 11	68/72	74/70	13.8 to 14.2
245	8/1	-165± 23	-74 ± 23	66/64	-	13.7
202	58/4	-153± 9	194 ± 10	56/48	70/74	12.0 to 12.6
2	73/5	-14 ± 7	108 ± 6	38/42	59/53	10.7 to 11.3
192	7/1	-6 ± 27	-1 ± 27	71/71	-	12.2
185	128/11	-217± 7	101 ± 6	61/50	78/70	12.9 to 13.5
181	117/10	-80 ± 6	-75 ± 5	46/47	66/59	12.4 to 12.7
173	74/3	39 ± 13	-6 ± 13	42/37	74/45	11.3 to 12.2
16	19/1	-43 ± 4	21 ± 4	16/19	-	10.1
130	206/18	-200± 5	-27 ± 4	54/47	67/58	12.8 to 13.2
121	49/3	-100± 10	-13 ± 8	63/53	67/57	12.9 to 13.8
111	72/4	-274± 5	30 ± 6	38/36	44/52	10.6 to 13.8
11	10/1	-207± 7	-43 ± 8	22/25	-	10.4
1021	9/1	-342± 29	-124± 28	88/85	-	14.4

Table 4
Mean values of the (O-C) in right ascension and declination and internal and external positional standard errors (S.E.) of the one observation of two bright comets. Units: mas.

designation	Number of observations/nifgts	Mean of $(O-C)_\alpha \cos\delta$	Mean of $(O-C)_\delta$	Internal S.E.	External S.E.	magnitudes
C/2006 A1	27/3	343 ± 63	-51 ± 123	258/498	325/637	7.9 to 10.1
73P-B	167/10	-3872 ± 214	-4449 ± 86	586/600	2771/3699	8.8 to 6.8
73P-C	204/13	62 ± 51	-1205 ± 34	115/79	722/483	10.9 to 6.5

3.3. *Astrometric observations of the asteroids at the point of maximum curvature of visible trajectory*

The observations of the asteroids near the points of maximum curvature of their visible motion have been included into new program of investigations. The aim of such observations is determination of curvature of visible trajectory directly from CCD frames. All necessary data (equatorial coordinates at the mean epoch of observations, angular velocity, acceleration and curvature of visible trajectory) may be obtained to determine of the parameters of instantaneous orbit of asteroid from short arc observations by AMP-method (A.A. Kiselev., 1989). The period of observations of asteroids according this strategy is several days.

The improvement of orbital parameters and investigation of the orbital evolution may be possible using such

observational material. The list of events within asteroids magnitudes 11.5 to 16.5 has been prepared for Pulkovo observatory. For example, the motion curve of the event of asteroid (389) Industria is seen in Fig. 2.

4. The results of astrometric observations of the comets in 2006

The astrometric CCD observations of two interesting comets were being done in 2006. The mean values of the (O-C) and positional errors for C/2006 A1 (Pojmanski) and 73P (Schwassmann-Wachmann) (fragments B and C) are seen in Table 4.

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