CCD Measurements of Visual Double Stars at NAO Rozhen from 2021 to 2024

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Abstract. In this paper, we present the results of CCD observations of double and multiple stars conducted during the period 2021–2024. These observations were carried out using the 2-m telescope at the Bulgarian National Astronomical Observatory at Rozhen (NAOR), equipped with an Andor iKon-L CCD camera. A total of 302 relative position measurements was obtained for 228 double and multiple star systems, with some systems observed over multiple epochs. Among these, 34 pairs have calculated orbital elements, and 3 pairs have linear solutions. For all these systems, the observed minus calculated (O–C) residuals are provided. The smallest measured separation was $1\overset{''}{.}44$, observed in the pair WDS 14376+2809 = COU 405, while the largest separation was $9\overset{''}{.}90$, recorded for the pair WDS 21596+2453 = POU 5602.
Key words: visual double stars, CCD measurements

Introduction

Between 2021 and 2024, we continued our ongoing series of CCD observations of double and multiple stars at the Bulgarian National Astronomical Observatory Rozhen (NAOR). To date, we have published twelve papers reporting observational results obtained up to the end of 2020 (see the most recent: Cvetković et al. 2021). Until 2020, observations were conducted at two sites: the Serbian Astronomical Station on Mount Vidojevica (ASV) and NAOR, as part of a collaborative program between Serbian and Bulgarian astronomers.

Since 2021, a fast CCD camera (Andor iXon 897 Ultra) has been installed on the 1.4-m telescope at ASV, enabling observations using the Lucky Imaging technique, which significantly improves angular resolution (for more details, see Pavlović et al. 2021). However, the results presented in this paper are based solely on observations carried out at NAOR, using the 2-m telescope and the Andor iKon-L CCD camera, within the framework of continued Serbian-Bulgarian cooperation.

As in previous observing campaigns (Cvetković et al. 2018; 2021), we used classical CCD imaging, which is seeing-limited. Consequently, we focused on observing wider pairs, i.e., systems with angular separations typically greater than $2''$. The targets were selected from WDS[3] catalog based on limited prior data. We selected targets for which the previously available measurements are either fewer than 15 or only cover a short arc of the expected orbital path. Also, the magnitude difference between the components of each pairs is less than 3 mag.

The number of observed double or multiple stars during each observing period was as follows:

[3] https://www.astro.gsu.edu/wds/Webtextfiles/`wdsweb_summ2.txt`

- 74 stars in October 2021
- 63 in March 2022
- 45 in November 2022
- 31 in November 2023
- 60 in June/July 2024
- 53 in October 2024

Some systems were observed on multiple occasions. In 14 cases, measurements could not be performed because the components were unresolved. The main limiting factors included: close proximity of components, camera resolution, exposure time, seeing conditions, and occasionally unfavorable weather.

1. Observing program

Here we present 302 relative coordinates, separations and position angles, for 228 double and multiple stars. Some stars have been observed several times, i.e. they have different observational epochs. Among the 228 pairs, 34 have calculated orbital elements, 3 have determined linear solutions, and for the remaining 191 pairs neither orbital nor linear motion has been determined. The orbital elements are contained in the Sixth Catalog of Orbits of Visual Binary Stars, ORB6[4]. The linear elements are contained in the Catalog of Rectilinear Elements, LIN2[5].

The Gaia Data Release 3 (Gaia DR3)[6] provides more precise parallax measurements than those available in both the Hipparcos and Gaia DR2 catalogs. We cross-identified stars from our observation list with entries in Gaia DR3, selecting only double star for which parallaxes were available for both components, primary and secondary. Our objective was to select physically bound systems, whose components lie at the same distance (and are likely to have Keplerian motion), and optical pairs, whose components are at different distances and therefore not gravitationally bound. In the paper Cvetković et al. (2021) we provided the same analysis for the pairs from the ORB6, and the Catalog of Rectilinear Elements (LIN1), as well as for the pairs from our observing list. We used the Gaia data release 2 (Gaia DR2)[7] that was available at the time.

A total of 191 such pairs, none with previously determined orbital or linear solutions, were analyzed. Among them, 173 pairs showed nearly equal parallaxes for both components (Fig.1), strongly suggesting that they are physically bound and follow Keplerian orbits. For 18 pairs the parallaxes of components are sufficiently different (Fig.2), indicating with high confidence that they are optical pairs, chance alignments of stars at different distances. The proper motions of the components of these 18 pairs also differ.

All observations were conducted using Johnson B and V filters, with 10 frames taken per system, 5 in the V filter and 5 in the B filter. To calibrate

[4] https://www.astro.gsu.edu/wds/orb6/orb6frame.html
[5] https://www.astro.gsu.edu/wds/lin2/lelements.html
[6] https://cdsarc.cds.unistra.fr/viz-bin/cat/I/355
[7] http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=I/345/gaia2

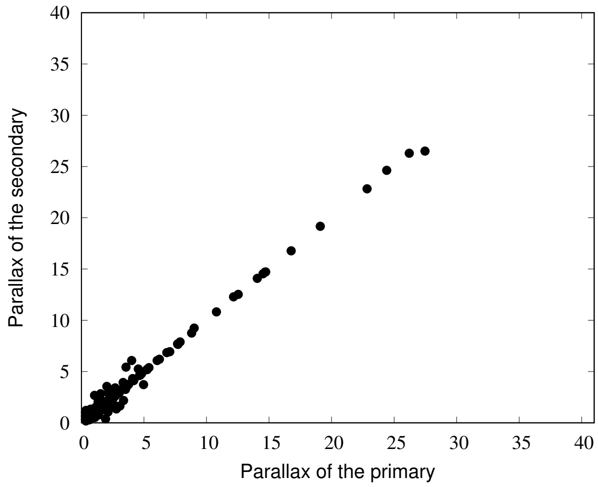

Fig. 1. Parallax of primary vs. parallax of secondary for the 173 pairs. The unit is mas.

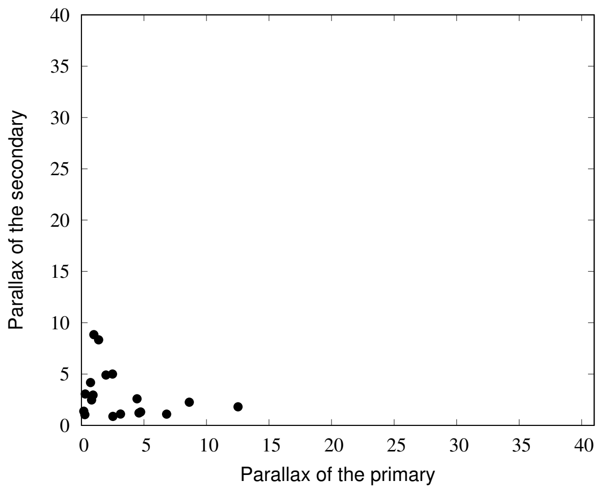

Fig. 2. Parallax of primary vs. parallax of secondary for the 18 pairs. The unit is mas.

position angles and determine the celestial north direction, we used the Astrometry.net software[8] and the PinPoint Astrometric Engine[9]. The orientation for each night was derived from the average solution of all frames. Additionally, nightly tracking data was used to confirm the orientation. The average error in orientation was $0\overset{\circ}{.}14$.

[8] http://www.astrometry.net
[9] http://pinpoint.dc3.com

3. Results of CCD Measurements of Double Stars

The determination of the relative coordinates on CCD frames was done using the AIP4WIN software (Berry & Burnell, 2002) and the IRAF[10] package. More details are given in our paper Cvetković et al. 2016.

The CCD measurements (position angle and angular separation for the epoch of the measurements) of the visual double and multiple stars are given in Table 1 and Table 2. They list 302 measurements for 228 pairs. The smallest measured separation is $1''.44$ for the pair WDS 14376+2809 = COU 405. The largest measured separation is $9''.90$ for the pair WDS 21596+2453 = POU5602. Their median value is $3''.15$. Out of the 302 separations, 285 (94%) are less than $5''$. The distribution of the angular separations measured in this paper is presented in Fig.3.

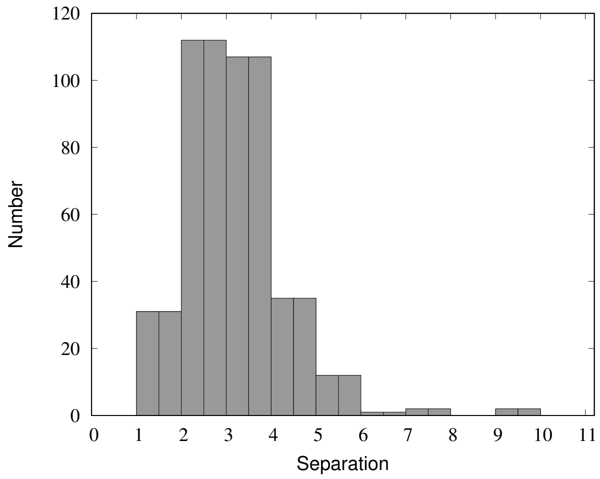

Fig. 3. Distribution of the angular separations of the measurements. The unit for separation is arcsecond.

Table 1 gives the mean relative positions for the 191 pairs for which neither orbital nor linear motion have been determined. The columns are: 1 – WDS designation; 2 – discovery designation on whose basis it is possible to identify each pair; 3 – the epoch of observation (expressed as a fractional Besselian year); 4 – the angular separation ρ; 5 – standard deviation σ_ρ (in arcseconds); 6 – the position angle θ; and 7 – standard deviation σ_θ (in degrees). The separation and position angle are the average of data taken both in the B and V filters. Note that the position angle has not been corrected for precession and it is thus based on the equinox for the epoch of observation. For 18 pairs, which are most likely not gravitationally bound, an asterisk mark is inserted next to the WDS designation in Table 1.

[10] http://iraf.noirlab.edu/

Table 2 presents the mean relative position for 37 pairs with known orbits or linear elements. The first 7 columns are identical to columns 1–7 of Table 1. Columns 8 and 9 give residuals, $(O-C)_\rho$ and $(O-C)_\theta$, to the determination referenced in column 10. Column 10 gives the reference for pairs that have an orbital solution, and the letter L for pairs that have linear elements. We corrected the position angles given in column 6 of this table for precession, i.e. reduced them to the equinox for epoch J 2000.0 and calculated the residuals given in column 9 of Table 2.

Two pairs, WDS 03162+5810 = MLB 115AB and WDS 18443+3940 = STF2382AB, have two orbital solutions each that are given in ORB6. Zirm (2008) and Izmailov (2019) calculated the orbits for the pair MLB 115AB, and Mason et al. (2004) and Docobo & Campo (2020) calculated the orbits for the pair STF2382AB. We calculated the residuals for both solutions (see Table 2).

The errors of separations and position angles are given in Table 1 and Table 2 and they are illustrated in the histograms in Fig.4 and Fig.5. The position angles are corrected for $0\overset{\circ}{.}14$, i.e. for the error in orientation. The mean error in separation is $0\overset{''}{.}04$, whereas in position angle the corresponding value is $0\overset{\circ}{.}44$. Out of the 302 measured relative positions, only 2 separations (less than 1% of the total) have uncertainties slightly exceeding $0\overset{''}{.}20$, specifically $0\overset{''}{.}21$ and $0\overset{''}{.}22$. Additionally, 1 position angle (also less than 1%) has an error slightly greater than $1\overset{\circ}{.}0$, namely $1\overset{\circ}{.}05$. These three errors, (two in separation and one in position angle) are excluded from the histograms presented in the analysis. These larger uncertainties occurred in observations of pairs with a high magnitude difference between the components (greater than 2 mag) and were obtained under worse weather conditions.

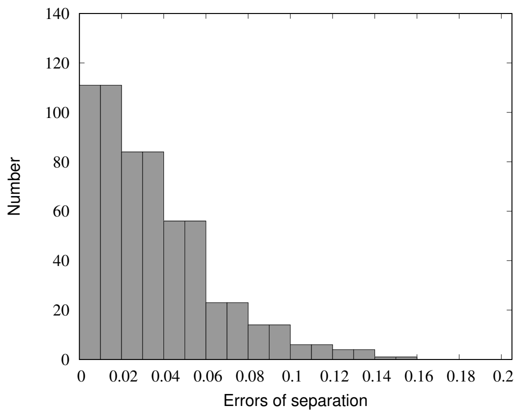

Fig. 4. Distribution of the errors in angular separations. The unit for error angular separation is arcsecond.

Table 1. CCD measurements of double stars

WDS design. α, δ (2000)	Discoverer designation	Epoch 2000.+	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)
00189+1946	J 218	21.7554	4.33	0.04	3.18	0.33
00189+1946	J 218	24.7690	4.36	0.04	3.13	0.34
00200+2443	POU 19	24.7690	2.10	0.06	346.28	0.54
00220+2445	POU 22	21.7555	3.44	0.02	224.62	0.18
00220+2445	POU 22	24.7609	3.31	0.04	223.31	0.27
00323+6543	KPP4420	21.7581	2.27	0.03	0.67	0.47
00521+2520	TDS1644	21.7568	2.17	0.04	0.84	0.50
00530+6358	STI 135	21.7581	4.16	0.03	162.16	0.24
00538+4731*	ES 1297	24.7664	4.18	0.05	209.56	0.27
01054+3204*	SEI 12AB	22.8729	3.77	0.03	125.11	0.37
01054+3204*	SEI 12AB	24.7665	3.53	0.07	125.65	0.46
01076+2354	POU 102AB	21.7555	4.26	0.03	111.69	0.27
01098+3704	J 515	21.7582	3.12	0.01	6.70	0.32
01098+3704	J 515	22.8729	3.12	0.02	6.59	0.33
01168+2643	BRT3257	21.7556	3.68	0.03	223.03	0.24
01168+2643	BRT3257	22.8729	3.72	0.01	223.09	0.24
01241+4522	HJ 2041	22.8729	4.94	0.01	336.40	0.12
01261+2953*	MLB1033BC	22.8730	3.30	0.05	252.69	0.22
01359+5444	STI1635	22.8730	4.35	0.01	115.12	0.20
01359+5444	STI1635	24.7665	4.16	0.12	114.44	0.49
01528+4016	MLB 999	22.8730	4.43	0.04	1.22	0.50
02085+2227	BRT2307	21.7582	2.99	0.02	247.53	0.68
02085+2227	BRT2307	24.7720	3.02	0.01	248.53	0.20
02101+5540	STI1793	21.7556	3.04	0.06	37.83	0.20
02101+5540	STI1793	22.8730	3.15	0.02	37.61	0.28
02101+5540	STI1793	24.7693	2.89	0.14	37.37	0.55
02133+5551	MLB 155	22.8730	4.04	0.03	353.80	0.26
02133+5551	MLB 155	24.7694	4.02	0.04	353.48	0.31
02190+2309	BRT2308	22.8730	3.93	0.05	126.21	0.27
02209+2353	POU 176	22.8731	3.82	0.02	218.96	0.56
02214+4459	BRT 328	21.7582	2.86	0.01	250.31	0.19
02214+4459	BRT 328	22.8731	2.79	0.05	249.27	0.58
02214+4459	BRT 328	24.7694	2.71	0.11	250.14	0.44
02332+3917	MLB 917	22.8731	4.79	0.01	255.70	0.16
02464+4020	COU1374	24.7721	1.48	0.07	130.21	0.74
02490+5908	STI1941	21.7556	3.46	0.01	357.61	0.16
02490+5908	STI1941	22.8731	3.41	0.04	358.11	0.43
02490+5908	STI1941	24.7694	3.23	0.10	357.87	0.59
02491+5910	STI1942	21.7556	4.97	0.02	182.77	0.12
03012+4049	BRT 337	22.8731	4.67	0.01	0.04	0.10
03086+6028*	STI 428	21.7583	2.29	0.02	67.41	0.33
03086+6028*	STI 428	24.7720	2.33	0.02	64.31	0.47
03125+2430	POU 251	22.8731	3.48	0.01	195.26	0.29
03125+2430	POU 251	24.7665	3.12	0.04	194.39	0.57
03242+2347	WOR 4AB	21.7583	2.58	0.03	338.58	0.55
03242+2347	WOR 4AB	24.7721	2.50	0.08	336.90	0.67
03267+4110	J 889	21.7570	2.27	0.02	63.08	0.36
03267+4110	J 889	24.7720	2.37	0.02	61.84	0.31
03341+7438	LDS1573	22.8732	2.88	0.02	201.09	0.38
03401+6310	ES 1881	21.7570	2.86	0.01	158.69	0.17
03401+6310	ES 1881	24.7694	2.52	0.08	159.90	0.76
03435+2935	A 989AB	24.7721	3.20	0.01	355.66	0.22
03466+0403	BAL2116	21.7584	2.69	0.05	289.18	0.48
03466+0403	BAL2116	24.7720	2.67	0.05	289.07	0.34
03480+4233	FOX 57	21.7557	3.37	0.02	140.70	0.10
03480+4233	FOX 57	24.7694	3.32	0.03	140.72	0.25
03492+3651	J 2721	21.7571	2.87	0.02	354.50	0.25
03492+3651	J 2721	24.7721	2.86	0.02	354.49	0.28

Table 1. (continued)

WDS design. α, δ (2000)	Discoverer designation	Epoch 2000.+	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)
04010+3415*	ES 237	24.7721	3.60	0.07	325.82	0.77
04092+4010	STF3114AB	21.7558	3.04	0.08	157.25	0.78
04092+4010	STF3114AB	22.8732	3.18	0.08	157.36	0.92
04092+4010	STF3114AB	23.8865	3.11	0.06	156.86	0.65
04092+4010	STF3114AB	24.7721	3.13	0.06	157.38	0.82
04233+4451	BRT 83	21.7558	2.59	0.05	110.82	0.41
04233+4451	BRT 83	22.8732	2.61	0.02	110.93	0.43
04233+4451	BRT 83	23.8866	2.59	0.03	110.51	0.22
04233+4451	BRT 83	24.7721	2.56	0.07	110.77	0.41
04239+6140	ES 1960	21.7571	2.12	0.04	143.92	0.44
04239+6140	ES 1960	22.8732	2.25	0.07	145.26	0.62
04239+6140	ES 1960	24.7722	2.11	0.05	145.89	0.66
04241+2411*	POU 446	22.8732	2.88	0.03	110.09	0.26
04241+2411*	POU 446	23.8866	2.85	0.03	110.10	0.40
04241+2411*	POU 446	24.7722	2.91	0.01	109.88	0.23
04320+1822	CHN 4AB	21.7559	3.22	0.01	358.17	0.22
04320+1822	CHN 4AB	22.8733	3.31	0.03	359.38	0.79
04320+1822	CHN 4AB	24.7723	3.24	0.05	358.19	0.45
04345+5542	STI2056	21.7558	3.42	0.01	185.25	0.15
04345+5542	STI2056	22.8733	3.48	0.03	184.63	0.46
04345+5542	STI2056	24.7722	3.46	0.02	185.42	0.22
04365+2501	POU 464	21.7558	3.85	0.02	359.53	0.17
04382+5952	STI 528	22.8733	3.99	0.04	73.34	0.43
04384+1900	BRT2317	21.7559	3.90	0.07	185.23	0.54
04384+1900	BRT2317	22.8733	3.91	0.03	185.72	0.73
04395+2316	POU 471	21.7559	3.01	0.04	224.55	0.61
04395+2316	POU 471	23.8866	2.93	0.06	225.52	0.95
04476+3947	ES 2088	21.7560	2.01	0.05	217.98	0.55
04476+3947	ES 2088	23.8866	1.75	0.04	214.71	0.78
04476+3947	ES 2088	24.7724	2.02	0.03	215.84	0.52
05175+2436	POU 636	23.8868	2.46	0.06	182.26	0.61
05180+2437	POU 647	23.8868	3.39	0.01	355.05	0.18
05228+3325	BU 887FU	23.8868	2.94	0.03	187.95	0.30
05280+4110	ES 1724	23.8868	2.69	0.05	44.96	0.72
05284+3544	TDS3208	23.8868	3.71	0.04	103.17	0.54
05284+3544	TDS3208	24.7724	3.70	0.06	103.00	0.58
05314+4152	ES 1625	24.7724	3.63	0.04	80.92	0.56
05317+3225*	J 899	24.7724	2.22	0.03	337.16	0.38
05371+4150	STF 736AB	24.7724	2.52	0.06	359.99	0.83
05526+1402	J 948	24.7724	2.90	0.08	165.55	0.62
06124+2359	J 1102	21.7561	2.81	0.02	347.60	0.17
06124+2359	J 1102	23.8869	2.79	0.02	347.70	0.31
06124+2359	J 1102	24.7724	2.81	0.02	347.69	0.20
06127+2351	J1052	21.7561	2.30	0.02	204.00	0.68
06293+1951	BRT2352	23.8871	3.82	0.03	5.94	0.12
06319+2343	POU1406	23.8872	3.66	0.01	74.56	0.06
06322+0833	GCB 69	23.8872	3.80	0.01	269.95	0.14
06398+2317	POU1793	23.8872	3.41	0.02	183.09	0.10
06406+7828	WFC 40	23.8872	3.10	0.03	295.50	0.46
07533+1733	J 1100	22.2321	5.44	0.01	277.30	0.14
08087+2401	POU2938	22.2321	2.93	0.04	209.92	0.30
08236+1803	BRT2383	22.2321	2.62	0.03	199.61	0.43
08269+3219	SEI 497	22.2321	3.41	0.01	209.20	0.17
08328+1825	BRT2389	22.2321	2.39	0.05	293.44	0.33
08343+2324	POU2992	22.2321	3.66	0.04	109.06	0.27
08437+1109	BRT1255	22.2321	3.95	0.02	359.45	0.13
08540+2339	POU3018	22.2322	5.30	0.00	0.47	0.07
08565+7058	HZG 7	22.2322	4.42	0.04	3.09	0.33

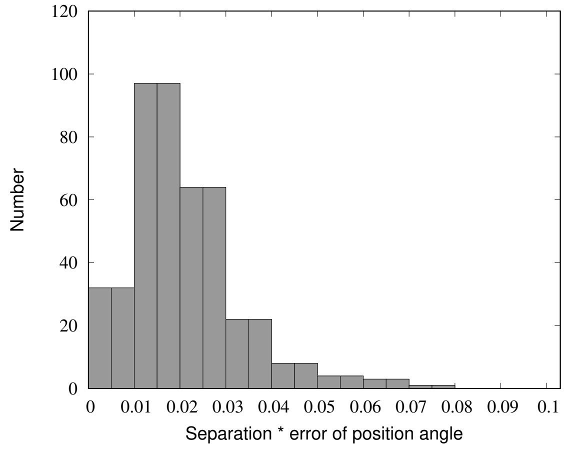

Fig. 5. Distribution of the product angular separation ∗ error of position angle. The unit of the x-axis is arcsecond.

Conclusion

In this paper, we present 302 measurements of relative positions for 228 double and multiple star systems, obtained between 2021 and 2024 through classical CCD observations at the Bulgarian National Astronomical Observatory Rozhen. The full set of measurements is provided in Table 1 and Table 2. All observations were conducted using the 2-m telescope at NAOR, equipped with an Andor iKon-L CCD camera.

Among the 191 pairs from our observation list that do not have a determined orbital or linear solution, 151 pairs were not observed during the last 9 years. Additionally, 135 pairs have less than 10 measurements until now, and 173 pairs have measurements covering an orbital arc of less than 50 degrees. The relative position errors are consistent with previously obtained values in our earlier papers. The values of the residuals in the angular separation are less than $0\overset{''}{.}30$, and in the position angle they are less than $3\overset{\circ}{.}7$. Both deviations ($0\overset{''}{.}30$ and $3\overset{\circ}{.}7$) are for the pair J 420, i.e. from the Olević (2002) orbit. The residual values for two pairs, WDS 03162+5810 = MLB 115AB and WDS 18443+3940 = STF2382AB, which have two orbital solutions each, are almost equal. Both pairs are long-period ones and it is still not possible to say which of the two orbits is better. The residuals of the three linear solutions are small, which confirms the nature of their movement.

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Table 1. (continued)

WDS design. α, δ (2000)	Discoverer designation	Epoch 2000.+	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)
09252+3254	POP 58	22.2352	3.15	0.01	107.70	0.37
10183+3129	LDS1236	22.2353	2.30	0.02	253.68	0.67
10191+3620	ES 2566	22.2353	4.15	0.01	219.44	0.16
10216+4609	STF1425	22.2296	4.72	0.03	357.81	0.27
10420+3005	TDS7425	22.2353	1.87	0.03	177.27	0.84
11051+1026	LDS4055AC	22.2354	2.59	0.02	338.34	0.33
11065+1416	HU 885AB	22.2354	2.16	0.04	252.37	0.57
11245+2037	STF1537	22.2354	2.18	0.04	357.21	0.63
11303+4115	ES 1399	22.2354	3.13	0.01	122.23	0.36
11314+2241	TDS7906	22.2354	1.98	0.07	241.12	0.74
12113+2238	BRT2414	22.2326	3.60	0.09	23.89	0.32
12277+1213	TDS 663BC	22.2354	3.46	0.05	281.22	0.60
12353+3634	ES 2166	22.2326	4.72	0.02	357.47	0.10
13184+3909	LDS4342	22.2327	1.88	0.05	132.72	0.92
13208+3748	UC 2520AB	22.2299	3.99	0.11	224.06	0.77
13208+3748*	PAL 4AC	22.2299	5.56	0.03	25.40	0.67
14007+2404	BRT3304	22.2299	3.35	0.08	356.35	0.25
14098+0822	A 1098	22.2299	3.49	0.10	284.11	0.43
14319+4342	KPP3282	22.2327	1.61	0.04	5.43	0.80
14345+1913	ITF 139AB	24.5006	5.98	0.01	276.67	0.18
14345+1913	ITF 139AC	24.5006	2.31	0.04	200.39	0.84
14363+1924	STF3087AB	24.5006	2.28	0.03	221.92	0.38
14376+2809	COU 405	24.5006	1.44	0.04	104.33	0.88
14546+2252	COU 408AB	22.2355	1.89	0.04	175.07	0.58
15158+1858	KPP3949	24.5007	1.92	0.04	181.24	0.71
15158+4153	POP 118	24.5006	2.78	0.01	343.35	0.17
15429+2624	BRT 167	22.2300	2.80	0.08	235.24	0.40
15436+0209	BAL1907	22.2300	2.01	0.12	346.95	0.80
16139+6420	MLR 138	24.4951	2.45	0.04	317.39	0.23
16159+2340	POU3219	24.4952	3.63	0.07	330.96	0.28
16271+1031	BRT3221	24.4978	4.27	0.01	212.19	0.23
16272+3419	POP 1AB	24.4978	2.45	0.02	178.64	0.16
16289+0425	HEI 892	24.5007	2.12	0.04	348.14	0.33
16332+3535	POP 89	24.4979	3.33	0.02	170.45	0.17
16382+2244	POU3235	22.2303	5.44	0.01	230.12	0.12
16461+5012	ES 969	22.2330	2.69	0.07	237.05	0.28
16469+2701	A 227	22.2300	1.64	0.07	235.97	0.83
17048+0142	BAL1484	22.2300	5.74	0.02	138.36	0.13
17097+4039*	POP 166AB	24.4979	6.31	0.04	280.64	0.71
17113+6930	STF2151	24.5008	2.45	0.02	347.42	0.31
17123+4315	BRT 342	24.5008	2.63	0.01	3.73	0.31
17147+3448	POP 76	24.4979	2.18	0.02	108.67	0.43
17153+4439	POP 131AB	24.4980	3.80	0.01	136.86	0.08
17165+3448	POP 77AB	24.4980	5.49	0.03	321.20	0.72
17202+3438	POP 203	24.4980	3.88	0.03	209.87	0.43
17204+0337	J 3296	24.4980	3.69	0.01	257.03	0.24
17209+2310	POU3285	24.4981	4.41	0.01	161.04	0.14
17272+2250	TDT 363	24.4981	1.58	0.03	189.30	0.96
17284-0201	RST4571	24.4981	1.88	0.02	105.29	0.65
17297+1815	BRT2433	22.2330	4.56	0.01	307.72	0.13
17301+5743	ES 1742	22.2358	1.79	0.05	27.49	0.70
17307+6231	ES 1832	22.2358	3.68	0.03	156.20	0.60
17313+2447	POU3296	22.2358	3.16	0.02	349.21	0.20
17365+4142	ES 636	24.5009	1.98	0.03	128.35	0.62
17370+2150	BRT2435	24.5009	2.84	0.01	299.35	0.24
17372+0649	HEI 862	24.5009	2.79	0.01	66.63	0.24
17377+7102	HEI 863AB	24.4952	4.21	0.02	8.79	0.19
17377+7102	HEI 863AC	24.4952	4.86	0.01	82.96	0.14

Table 1. (continued)

WDS design. α, δ (2000)	Discoverer designation	Epoch 2000.+	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)
17378+2257	AG 210AB	24.4952	4.21	0.01	190.10	0.08
17402+5411	ES 638	22.2330	2.71	0.02	193.49	0.61
17495+3436	AG 214	22.2330	4.67	0.03	204.07	0.13
18077+7858	SKF1082	24.5009	1.90	0.03	279.21	0.60
18248+0714	STT 347	24.4954	3.03	0.02	343.05	0.52
18251+2654	AG 361	24.4954	3.70	0.02	13.16	0.19
18251+0258*	BAL1965	24.4954	5.13	0.02	72.39	0.65
18253+0222	BAL1966	24.4954	3.89	0.02	246.29	0.44
18258+1952	BRT2446AB	24.4954	3.32	0.05	321.51	0.40
18265+0741	A 580	24.4954	4.38	0.07	322.46	0.45
18272+1703*	BKO 729	24.4954	7.32	0.04	313.74	0.14
18475+3647	ES 2022	21.7576	4.52	0.02	125.92	0.15
18504+0900	BRT2610	21.7577	3.92	0.02	352.70	0.24
19137+3454	ES 2238	24.5011	2.00	0.04	218.69	0.63
19141+0820	HEI 809	24.5011	1.96	0.04	88.43	0.92
19170+4225	TDT1347	24.5011	2.97	0.05	168.77	0.56
19184+6159	MLR 139	24.5011	2.89	0.02	10.05	0.36
19222+2502	POU3783	24.4955	5.66	0.05	300.62	0.27
19280+2444	POU3843	24.4983	3.42	0.01	325.17	0.13
19282+3747*	KOI 379AB	24.4983	1.84	0.03	85.63	0.87
19282+2942	AG 380	24.4984	2.57	0.05	226.65	0.95
19283+4811	COU2629	24.4984	3.06	0.02	270.61	0.42
19284+1544	TDT1481	24.4984	3.05	0.03	90.69	0.82
19348+2750	COU1032	24.4984	1.88	0.03	265.27	0.74
20170+4017	CNT 5	24.4955	5.76	0.03	330.59	0.26
20173+2604	BRT3357	24.4956	3.68	0.10	273.31	0.66
20176+6005	STI 960	24.4956	3.82	0.06	83.30	0.35
20178+1350	BRT1340	24.4956	3.58	0.10	315.11	0.39
20196+1925*	BRT2525	21.7577	1.73	0.06	63.28	0.82
20240+2505	J 557AB	21.7577	2.88	0.02	240.00	0.29
20247+0302	J 1342	21.7577	2.42	0.03	359.38	0.43
20271+0948*	J 559	21.7577	2.15	0.02	299.06	0.49
20334+4752	J 4	21.7578	2.55	0.01	0.30	0.18
20396+5450	ES 993	21.7578	2.03	0.02	194.34	0.24
20434+2536	HO 138CD	21.7562	3.50	0.01	6.94	0.18
20445+2123	BRT2483	21.7562	3.47	0.01	304.95	0.14
21066+2356	POU5163	23.8836	3.98	0.22	33.21	0.29
21111+4530	BRT1146AB	21.7550	2.61	0.03	344.04	0.41
21166+4357	BRT1147	21.7550	2.59	0.03	359.92	0.27
21207+3226	POP201	21.7551	7.12	0.05	202.57	0.42
21330+2043	STF2804AB	21.7551	3.37	0.02	359.07	0.29
21330+2043	STF2804AB	23.8753	3.00	0.21	359.53	0.67
21330+2043	STF2804AB	24.7606	3.21	0.08	359.48	0.56
21376+3712	ES 2065	24.7606	3.97	0.05	180.07	0.31
21432+2312	J 3144AB	21.7551	3.43	0.01	346.98	0.24
21432+2312	J 3144AB	22.8726	3.43	0.01	346.83	0.08
21432+2312	J3144AC	21.7551	9.72	0.02	129.54	0.12
21455+2156	AG 276	21.7551	1.80	0.05	2.24	0.64
21455+2156	AG 276	22.8726	1.83	0.05	2.64	0.92
21500+2157	TDT3184	21.7551	2.42	0.09	170.28	0.44
21596+2453	POU5602	21.7551	9.90	0.08	112.38	0.34
21598+2451	POU5603	21.7551	3.51	0.02	359.48	0.18
21598+2451	POU5603	22.8726	3.52	0.01	359.52	0.19
22061+2034*	BRT2840	23.8753	3.38	0.14	343.73	0.43
22164+5454	STI2675	24.7607	3.90	0.09	339.03	0.40
22274+1258	J 855	23.8754	3.58	0.13	76.92	0.27
22274+1258	J 855	24.7689	3.91	0.03	77.52	0.11

Table 1. (continued)

WDS design. α, δ (2000)	Discoverer designation	Epoch 2000.+	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)
22385+1806	BRT2507	21.7553	2.70	0.04	239.78	0.28
22385+1806	BRT2507	22.8726	2.75	0.02	240.14	0.28
22385+1806	BRT2507	23.8754	2.27	0.12	238.83	0.56
22385+1806	BRT2507	24.7689	2.53	0.10	239.31	0.24
22393+4000	MLB 906AB	22.8726	2.64	0.04	150.60	0.79
22393+4000	MLB 906AB	24.7607	2.43	0.06	146.56	0.68
22421+3259	J 2377	22.8727	4.20	0.02	178.27	0.23
22421+3259	J 2377	23.8754	3.94	0.09	178.09	0.64
22449+5035*	ES 848	22.8727	2.45	0.03	45.72	0.52
22513+2914	DOO 91BC	21.7553	4.06	0.01	344.21	0.12
22513+2914	DOO 91BC	22.8727	4.05	0.02	344.58	0.33
22542+7620	STF2963	21.7580	1.81	0.03	3.35	0.44
22547+1812	J 621AB	22.8727	2.92	0.02	153.09	0.26
22566+3037*	ES 395	22.8727	3.00	0.06	0.35	0.73
22576+2820	MLB 726	21.7568	3.40	0.02	14.11	0.25
22576+2820	MLB 726	22.8727	3.39	0.02	14.35	0.48
22576+2820	MLB 726	24.7607	3.40	0.03	14.91	0.28
22597+2553	MLB 727	21.7581	3.63	0.01	356.32	0.19
22597+2553	MLB 727	24.7690	3.48	0.05	356.19	0.22
23479+1703	STF3041BC	21.7554	3.41	0.06	356.18	0.25
23479+1703	STF3041BC	23.8755	3.15	0.15	356.22	0.80
23479+1703	STF3041BC	24.7636	3.34	0.06	356.11	0.37
23573+2333*	POU5879	24.7690	2.82	0.08	23.97	0.59

Table 2. CCD measurements of system with orbits or rectilinear solutions

References: 1 - Izmailov (2019); 2 - Rica Romero (2008); 3 - Zirm (2008); 4 - Kiyaeva & Izmailov (2018); 5 - Heintz (1986); 6 - Kiselev et al. (2009); 7 - Olević (2002); 8 - Olević & Jovanović (2001); 9 - Olević & Popović (2000); 10 - Olević & Cvetković (2003); 11 - Heintz (1990); 12 - Scardia et al. (2013); 13 - Mason et al. (2004); 14 - Docobo & Campo (2020).

WDS design. α, δ (2000)	Discoverer designation	Epoch 2000.+	ρ ($''$)	σ_ρ ($''$)	θ ($^\circ$)	σ_θ ($^\circ$)	$(O-C)_\rho$ ($''$)	$(O-C)_\theta$ ($^\circ$)	Ref.
$01017+4635$	A 927	21.7568	2.20	0.06	11.80	0.76	-0.11	0.6	1
$01032+2006$	LDS 873	21.7582	2.26	0.04	59.01	0.54	-0.13	-1.1	2
$01467+3310$	STF 158AB	21.7569	2.17	0.05	271.32	0.76	0.07	-0.8	1
$01467+3310$	STF 158AB	22.8730	2.26	0.02	270.21	0.62	0.16	-2.0	1
$01467+3310$	STF 158AB	24.7720	2.22	0.03	271.86	0.54	0.13	-0.6	1
$02188+5714$	BKO 168AC	22.8730	3.73	0.01	230.94	0.35	0.03	-1.6	L
$03162+5810$	MLB 115AB	22.8732	5.06	0.01	359.86	0.09	0.07	0.3	3
		22.8732	5.06	0.01	359.86	0.09	-0.01	0.2	1
$03401+3407$	STF 425AB	21.7570	1.80	0.03	56.48	0.82	0.08	-2.6	4
$03401+3407$	STF 425AB	24.7720	1.80	0.05	56.60	0.69	0.09	-1.3	4
$04076+3804$	STT 531AB	22.8732	2.82	0.05	351.44	0.98	0.17	2.3	5
$04367+1930$	STF 567	21.7559	1.91	0.06	345.40	0.62	-0.12	0.4	1
$04367+1930$	STF 567	22.8733	1.81	0.09	346.19	0.76	-0.22	0.9	1
$04367+1930$	STF 567	24.7722	1.89	0.05	345.96	0.66	-0.14	0.3	1
$05013+5015$	STF 619	21.7560	4.24	0.01	161.76	0.35	0.14	-0.1	6
$05013+5015$	STF 619	24.7723	4.24	0.01	162.51	0.08	0.13	-0.4	6
$08062+0201$	J 420	22.2352	2.50	0.05	196.24	0.78	0.30	3.7	7
$08095+3213$	STF1187AB	22.2321	3.03	0.06	20.36	0.79	0.14	-2.6	8
$08547+1637$	AG 338AB	22.2322	2.02	0.05	164.51	1.05	-0.09	-1.0	1
$08554+7048$	STF1280AB	22.2322	3.76	0.01	359.19	0.21	-0.04	0.2	1
$09155+2755$	STF1327AB	22.2352	5.02	0.07	26.40	0.33	-0.11	0.0	L
$09414+3857$	STF1374AB	22.2352	2.74	0.06	309.06	0.83	-0.05	-2.9	1
$11390+4109$	STT 237AB	22.2354	2.12	0.03	241.85	0.71	0.02	-1.0	1
$12160+0538$	STF1621	22.2326	1.67	0.05	49.07	0.95	-0.15	-1.0	1
$12244+2535$	STF1639AB	22.2354	1.84	0.03	321.84	0.63	-0.03	-0.6	9
$12272+2701$	STF1643AB	22.2326	2.72	0.02	2.83	0.38	-0.02	0.6	10
$13120+3205$	STT 261	22.2354	2.66	0.02	338.40	0.18	0.02	0.2	1
$13328+1649$	VYS 6	22.2327	2.38	0.06	56.64	0.62	-0.24	-0.3	11
$14131+5520$	STF1820	22.2299	2.64	0.11	124.86	0.52	-0.20	0.5	1
$15245+3723$	STF1938Ba,Bb	22.2355	2.17	0.05	1.59	0.72	-0.02	0.4	12
$15348+1032$	STF1954AB	22.2303	3.99	0.04	171.91	0.96	-0.04	0.7	1
$16133+1332$	STF2021AB	22.2300	3.95	0.05	358.69	0.17	-0.09	0.1	1
$16160+0721$	STF2026AB	22.2300	3.40	0.08	15.54	0.28	-0.23	-0.1	1
$16160+0721$	STF2026AB	24.4952	3.56	0.06	14.86	0.53	-0.10	-0.5	1
$17053+5428$	STF2130AB	22.2300	2.41	0.13	355.91	0.52	-0.18	0.0	1
$17248+3044$	BU 1250	22.2329	1.90	0.10	121.02	0.75	-0.06	-0.9	1
$17248+3044$	BU 1250	24.4995	2.07	0.03	123.32	0.90	0.09	0.5	1
$17386+5546$	STF2199	22.2330	1.91	0.05	52.52	0.81	-0.14	-0.5	1
$18443+3940$	STF2382AB	21.7576	2.08	0.06	340.43	0.38	-0.21	-3.3	13
		21.7576	2.08	0.06	340.43	0.38	-0.06	-3.0	14
$21208+3227$	STT 437AB	21.7551	2.43	0.03	18.16	0.45	-0.02	-0.4	1
$21506+2216$	HO 467AB	22.8726	2.99	0.05	222.67	0.64	0.15	-1.7	1
$21559+3141$	ES 2360	22.8726	4.23	0.01	223.51	0.09	0.04	-0.2	1
$21559+3141$	ES 2360	24.7689	4.20	0.04	222.49	0.32	0.00	-0.5	1
$22166+5831$	HJ 1748	23.8753	4.75	0.16	314.98	0.27	-0.27	-0.5	L
$22455+1112$	BU 711AB	21.7553	2.55	0.04	347.03	0.74	-0.02	-1.2	1
$22455+1112$	BU 711AB	22.8727	2.51	0.10	345.48	0.88	-0.06	-2.5	1
$23356+2816$	BRT 230AB	21.7568	3.17	0.02	5.98	0.12	-0.06	0.3	1
$23356+2816$	BRT 230AB	24.7609	2.94	0.09	6.08	0.65	-0.29	0.5	1
$23595+3343$	STF3050AB	24.7690	2.49	0.10	345.01	0.61	-0.07	0.4	1