What extent are visual double stars really binaries to?

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Abstract. On the basis of CCD frames, collected from 2013 till now and obtained with the telescopes of ASV and NAOR, of visual double stars for which there exist orbital or linear elements, we have identified both components in the Gaia DR2 Catalogue. Since that catalogue contains precisely determined parallaxes for both components, we have compared them in order to establish exactly how close to each other they really are in space. Thus, the question of which double stars are really binaries, i.e. gravitationally bound pairs, can be answered more reliably.
Key words: double stars

Introduction

From the double stars observed at National Astronomical Observatory Rozhen (NAOR) and Astronomical Station Vidojevica (ASV) within 2013 – 2019 we have extracted 179 pairs for which there exist both calculated orbital elements given in the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf et al. 2001) or linear elements given in the Catalog of Rectilinear Elements (Hartkopf et al. 2011) and Gaia DR2 (Gaia Collaboration et al. 2016, 2018) parallaxes for both components. Our CCD frames have served to identify pair components in the Gaia DR2 Catalogue.

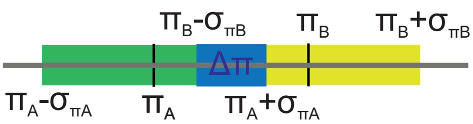

Fig. 1. The overlapping interval $\Delta\pi$ of parallaxes of double star system. The quantities denoted as A concern the primary, those denoted as B concern the secondary component of a binary.

We compare the component parallaxes (π_A, π_B) including the parallax errors (σ_{π_A}, σ_{π_B}) and calculate the overlapping interval (Fig. 1) according to the following equation

$$\Delta\pi = \min\left(\pi_A + \sigma_{\pi_A}, \pi_B + \sigma_{\pi_B}\right) - \max\left(\pi_A - \sigma_{\pi_A}, \pi_B - \sigma_{\pi_B}\right). \qquad (1)$$

In the case of parallax overlapping, i.e. $\Delta\pi > 0$, the components may be regarded as sufficiently close to each other so that probably they form a binary. However, in the case of no overlapping, i.e. $\Delta\pi < 0$, the components are mutually distant so that such a pair is most likely optical, i.e. there is no physical binary. This criterion is not sufficient to establish the nature of a double star. Additional criteria, based on analysis of positions, velocities and masses of the components, would have to be used, but such data are available only for a small number of stellar pairs.

1 Short statistics of overlapping parallaxes

In our observational material we have segregated 179 stellar pairs for which the parallaxes are given in the Gaia DR2 Catalogue. For 64 of them there are orbital elements available, whereas for 118 ones there are linear elements available. In the case of three pairs there are both orbital and linear elements available.

From the 64 pairs with calculated orbital elements, for 36 (56.25 %) parallax overlapping ($\Delta\pi > 0$) has been found, whereas in the case of 28 (43.75 %) the parallaxes do not overlap ($\Delta\pi < 0$). These 64 pairs are presented in Table 1. WDS designation and discovery designation on whose basis it is possible to identify each pair are given in Columns 1 and 2. Column 3 contains the orbit grade. For the three pairs which also have a linear solution to orbits, grade designation (L) is added. Columns 4–7 contain the parallaxes of the primary (π_A), the secondary (π_B) and their errors (σ_{π_A}, σ_{π_B}). In the last column the overlapping value ($\Delta\pi$), is given which is obtained following relation (1).

As can be seen from Table 1, for most of the orbits the grade is 4 or 5. According to the Worley-Heintz criterion (as quoted from the Fourth Catalog) grade 4 is "preliminary = individual elements entitled to little weight, and may be subject to substantial revisions". Grade 5 is "indeterminate = the elements may not even be approximately correct. The observed arc is usually too short, with little curvature, and frequently there are large residuals associated with the computations". In Table 1 there are three binaries where the grade of orbital elements is 2, "good = most of a revolution, well observed, with sufficient curvature to give considerable confidence in the derived elements. No major changes in the elements likely". In other words, we are sure that in the case of a pair with grade 2 the components are gravitationally bound. A simple calculation shows that if we used the 3σ rule, the parallaxes would overlap.

A similar conclusion is also valid for the only one binary from Table 1 where the grade is 3, meaning "reliable = at least half of the orbit defined, but the lesser coverage (in number or distribution) or data consistency leaves the possibility of larger errors than in Grade 2".

From the 118 pairs with linear elements, for 112 (94.92 %) there is no parallax overlapping, as could be expected in the case of linear pairs, whereas for six 6 (5.08 %) the parallaxes overlap. These pairs are given in Table 2. In order to examine the overlapping of parallaxes (distances), once more, we have also used the catalogue by Bailer-Jones et al. (2018) - "Distances to 1.33 billion stars in Gaia DR2". The columns in the upper part of Table 2 are the same as in Table 1, only that of orbits grade is omitted, whereas in the lower part of Table 2 the minimum r_{lo} and maximum r_{hi} distances of the components

Table 1. Double stars which have calculated orbital elements.

WDS designation	Discover designation	Orbit Grade	π_A (mas)	$\sigma\pi_A$ (mas)	π_B (mas)	$\sigma\pi_B$ (mas)	$\Delta\pi$ (mas)
00057 + 4549	STT 547AB	4	86.8735	0.0484	86.9402	0.0588	0.0405
00152 + 2722	J 868	5,L	1.8935	0.0527	3.5488	0.0441	−1.5585
00321 + 6715	VYS 2AB	5	101.4335	0.4733	100.4054	0.0701	−0.4847
00521 + 1036	STF 67	4	8.9917	0.0549	8.9372	0.3136	0.1098
01032 + 2006	LDS 873	5	62.6270	0.0425	62.1000	0.2033	−0.2812
01467 + 3310	STF 158AB	5	9.6544	0.0469	9.5512	0.1216	0.0653
02291 + 6724	STF 262AB	5	21.9604	0.3332	21.7036	0.1392	0.2156
03122 + 3713	STF 360	4,L	24.4423	0.6554	20.5747	0.0873	−3.1249
03162 + 5810	MLB 115AB	5	73.7645	0.0442	73.7407	0.0417	0.0621
03368 + 0035	STF 422	5	33.7528	0.0866	33.7882	0.0703	0.1215
04076 + 3804	STT 531AB	5	47.2101	0.0527	47.1305	0.2613	0.1054
04367 + 1930	STF 567	4	15.0064	0.0503	14.8835	0.0419	−0.0307
05013 + 5015	STF 619	5	4.3061	0.0372	4.5958	0.0375	−0.2150
05364 + 2200	STF 742	5	12.4603	0.1007	13.1274	0.0495	−0.5169
05535 + 3720	BU 1053	5	15.0035	0.0523	15.0920	0.0612	0.0250
07106 + 1543	J 703	5,L	2.7841	0.0389	12.1025	0.0391	−9.2404
08095 + 3213	STF1187AB	5	11.3335	0.7306	13.9676	0.0548	−1.8487
08122 + 1739	STF1196AB,C	4	41.2987	0.1710	42.1256	0.4798	−0.1761
09013 + 1516	STF1300AB	4	54.1310	0.0416	54.2762	0.0528	−0.0508
09144 + 5241	STF1321AB	4	157.8796	0.0366	157.8851	0.0414	0.0725
09273 + 0614	STF1355	4	18.7804	0.0900	18.5979	0.0918	−0.0007
09414 + 3857	STF1374AB	4	19.2207	0.0528	18.5919	0.2024	−0.3736
09524 + 2659	STF1389	4	18.8816	0.0577	18.8412	0.0592	0.0765
10110 + 7508	KUI 47	5	47.4964	0.0432	47.4612	0.0420	0.0500
10227 + 1521	STT 216	3	34.4535	0.0409	34.1930	0.0684	−0.1512
10596 + 2527	AG 342	5	46.9068	0.0457	46.9147	0.0513	0.0891
11080 + 5249	STF1510	5	17.5162	0.0370	17.4440	0.0337	−0.0015
11387 + 4507	STF1561AB	5	42.7909	0.0397	43.6091	0.1011	−0.6774
11390 + 4109	STT 237AB	4	12.4809	0.0760	12.0542	0.0751	−0.2756
12244 + 2535	STF1639AB	4	11.6398	0.0508	11.6948	0.0572	0.0530
12272 + 2701	STF1643AB	4	36.4871	0.0683	36.4672	0.0601	0.1085
13120 + 3205	STT 261	4	13.6916	0.0417	13.7597	0.0414	0.0150
13284 + 1543	STT 266	4	16.7111	0.0626	16.8001	0.0714	0.0450
13328 + 1649	VYS 6	5	60.3012	0.1130	60.3748	0.0826	0.1220
13491 + 2659	STF1785	2	73.9239	0.0653	74.2043	0.0456	−0.1695
13550 − 0804	STF1788AB	5	28.9580	0.0440	28.9488	0.0527	0.0875
14024 + 4620	SWI 1	5	89.3872	0.0661	89.3822	0.0557	0.1114
14131 + 5520	STF1820	4	26.1404	0.1500	26.0256	0.0350	0.0700
14165 + 2007	STF1825	5	30.0609	0.0394	30.1035	0.0545	0.0513
14336 + 3535	STF1858AB	5	25.3724	0.0359	25.3706	0.0371	0.0712
14410 + 5757	STF1872AB	5	17.8573	0.0318	17.8652	0.0384	0.0623
14514 + 1906	STF1888AB	2	148.5195	0.2436	148.2131	0.0464	−0.0164
15245 + 3723	STF1938Ba,Bb	2	27.1525	0.0250	27.2324	0.0276	−0.0273
15348 + 1032	STF1954AB	4	15.5728	0.6571	18.7090	0.2536	−2.2255
15559 − 0210	STF1985	5	26.0630	0.0508	26.1413	0.0610	0.0335
16133 + 1332	STF2021AB	4	41.1510	0.0413	41.2592	0.0352	−0.0317
16147 + 3352	STF2032AB	4	44.1346	0.0644	44.1475	0.0237	0.0474
16160 + 0721	STF2026AB	3	37.1441	0.0551	37.0752	0.0452	0.0314
17053 + 5428	STF2130AB	4	36.7992	0.0974	36.8008	0.0604	0.1208
17248 + 3044	BU 1250	5	2.3733	0.0354	2.2556	0.0439	−0.0384
17386 + 5546	STF2199	5	8.4420	0.0324	8.7367	0.4002	0.0648
18428 + 5938	STF2398AB	4	283.9489	0.0624	283.8624	0.1065	0.0824
18443 + 3940	STF2382AB	4	17.9665	0.2274	20.4080	0.0507	−2.1634
18443 + 3940	STF2383CD	4	20.0603	0.1196	20.1945	0.1275	0.1129
19266 + 2719	STF2525AB	4	16.3459	0.0392	16.2984	0.0448	0.0365
19316 + 1747	STF2536	5	19.1210	0.0572	19.1344	0.0752	0.1144
19458 + 2710	KUI 95AB	5	94.0139	0.0804	93.9479	0.0756	0.0900
20210 + 1028	J 838	5	0.9171	0.0327	2.0803	0.0327	−1.0978
20462 + 1554	STF2725AB	4	25.3160	0.2413	26.6012	0.0370	−1.0069
21208 + 3227	STT 437AB	4	14.0435	0.0297	14.0463	0.0335	0.0594
21289 + 1105	STF2799AB	4	10.2442	0.0502	10.2079	0.0494	0.0633
21370 + 8255	STF2837	5	21.3366	0.3034	16.5980	0.6373	−3.7979
22455 + 1112	BU 711AB	5	23.0586	0.0404	23.0108	0.0409	0.0335
23317 + 1956	WIR 1AB	5	159.7098	0.0827	160.0598	0.1079	−0.1594

(expressed in parsec instead of the component parallaxes) are given. In the last column the overlapping distances (Δr) are given.

From Table 2 (lower part) it is seen that when the distance increases, the overlap interval also increases. This can result in a wrong inference that the stars are gravitationally bound, though this is not the case. WDS14098+0822 = A 1098 can be considered to be an example of the most distant double

Table 2. Double stars which have calculated linear elements, but the parallaxes are congruent.

WDS designation	Discover designation	π_A (mas)	σ_{π_A} (mas)	π_B (mas)	σ_{π_B} (mas)	$\Delta\pi$ (mas)
03401 + 3407	STF 425AB	21.8411	0.0658	21.7646	0.0582	0.0475
12025 + 2145	HO 535	11.5165	0.3809	11.4831	0.0980	0.1960
12151 − 0715	STF1619AB	29.3041	0.0729	29.3916	0.0749	0.0603
14098 + 0822	A 1098	1.2232	0.0453	1.2483	0.0442	0.0644
21330 + 2043	STF2804AB	16.7406	0.0479	16.7396	0.0517	0.0958
22326 + 0725	STF2915AB	4.6630	0.0672	4.6300	0.1079	0.1344
WDS designation	Discover designation	$r_{lo}(A)$ (pc)	$r_{hi}(A)$ (pc)	$r_{lo}(B)$ (pc)	$r_{hi}(B)$ (pc)	Δr (pc)
03401 + 3407	STF 425AB	45.5871	45.8643	45.7625	46.0094	0.1017
12025 + 2145	HO 535	83.9828	89.7738	86.1371	87.6280	1.4908
12151 − 0715	STF1619AB	34.0063	34.1770	33.9031	34.0776	0.0712
14098 + 0822	A 1098	771.2660	829.6147	757.1539	811.9205	40.6545
21330 + 2043	STF2804AB	59.4613	59.8049	59.4517	59.8221	0.3435
22326 + 0725	STF2915AB	210.1633	216.3198	209.9164	219.9566	6.1564

star (in our sample). Its primary is at a distance of (800.44 ± 29.17) pc, the secondary at (784.53 ± 27.38) pc. When we compare the distance between the components with the distance determination errors, we find that the components are 15.9 pc apart, whereas the errors are almost twice as large. A similar situation appears for the other pairs from Table 2. However, in order to make a sufficiently reliable judgement whether these pairs are gravitationally bound or not, it would be necessary, as mentioned earlier, in addition to the parallaxes to include relative positions, velocities and masses of the components, but these data are yet mostly unknown.

2 Conclusion

For more than 60 % of the pairs from our sample which have calculated orbits, the applied criterion showed that the components are really close in space. This can serve as a indicator that the components are gravitationally bound, i.e. they form a binary system.

On the other hand, this criterion in a much higher percentage (more than 94 %) indicates that the pairs with linear elements are not gravitationally bound, i.e. that they do not form a binary system.

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