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DETERMINATION OF NATURE FOR ELEVEN DOUBLE STARS

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Abstract. We determined the linear solutions for eleven double stars by using the relative coordinates among which there are those obtained from our CCD frames, taken at NAO Rozhen and AS Vidojevica. Also, we applied existing criteria for establishing the nature of these double stars. The criteria are mostly based on some fundamental properties, such as the energy-conservation law, Kepler's third law, etc, which should be obeyed by bound pairs. Our analysis shows that all eleven double stars are most likely not gravitationally bound, i.e. they are optical pairs.

1. INTRODUCTION

The study of double stars makes possible more accurate determinations of masses and distances, as well as a better understanding of stellar formation and evolution. Systematic observations of these objects have been carried out for about 200 years. The results of measurements have been collected and the corresponding database is kept by the United States Naval Observatory. The Washington Double Star Catalog (WDS)[1] contains the data for more than 117000 pairs, components of double or multiple stars. Out of this number almost 90% pairs have been observed less than 10 times. Only for a small number of pairs, about 2100, the orbital elements have been calculated, i.e. a Keplerian motion has been confirmed. Their orbital elements can be found in the Sixth Catalog of Orbits of Visual Binary Stars.[2] In the case of more than 1200 pairs there are linear solutions given in the Catalog of Rectilinear Elements.[3] In the case of such pairs there are, in principle, three possibilities: to be gravitationally bound, but with large orbital periods, to be kinematically similar (say, common-proper-motion pairs) and to be mere optical pairs. For the purpose of

[1]http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/WDS
[2]http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/orb6
[3]http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/lin1

establishing which of the three possibilities is the true one observations covering long time intervals or detailed analysis of their data are needed.

From 2004 till now a group of astronomers from the Belgrade Observatory have regularly stayed at the National Astronomical Observatory Rozhen (NAOR) in Bulgaria and taken frames of visual double and multiple stars. Series of observations of these stars at the NAOR have been made with a CCD camera attached to their 2-m telescope. The observations have been performed with the CCD camera VersArray: 1300B. More details can be found at website.[4] The results of observations have been published in Pavlović et al. (2005), Cvetković et al. (2006), Cvetković et al. (2007), Cvetković et al. (2010), Cvetković et al. (2011) and Pavlović et al. (2013).

During the summer of 2011 the first observations of celestial bodies from the new Astronomical Station on the mountain of Vidojevica (ASV) took place. More details can be found at website.[5] Series of observations of double and multiple stars at the ASV have been made with a CCD camera attached to the 60-cm telescope. For these series we used either SBIG ST-10ME or Apogee Alta U42 CCD cameras.

The basic characteristics of all three used cameras are given in Pavlović et al. (2013).

2. RESULTS

We calculated first linear solutions for eleven pairs for which the measurements show a linear trend: WDS 00057+4549 = STT 547 AC, WDS 00057+4549 = STT 547 AD, WDS 00057+4549 = STT 547 AE, WDS 00057+4549 = POP 217 AP, WDS 00121+5337 = CHR 1 AC, WDS 00251+1824 = HJ 621, WDS 03342+4837 = BU 787 AB, WDS 06092+6424 = MLB 259, WDS 07106+1543 = J 703, WDS 19289+3515 = POP 34 AC and WDS 23581+2840 = HJ 995. Except CHR 1 AC, for the calculation of other pairs we used the measuring results from our CCD frames obtained at NAOR and ASV. The linear solutions for pairs STT 547 AC, STT 547 AD, STT 547 AE, POP 217 AP and MLB 259 have been previously published in (Pavlović at al. 2013). The linear solutions for pairs HJ 621, BU 787 AB and HJ 995 have been previously published in (Cvetković at al. 2011). For the other three pairs CHR 1 AC, J 703 and POP 34 AC, the linear solutions are given in this paper for the first time.

In Figure 1 linear fits for eleven pairs are presented. In the lower right (or left) corner the arrow indicates the sense of the motion for the secondaries with respect to the primary (brighter star). The linear solutions for these pairs have been determined from a set of measurements also including our ones from the frames obtained at NAOR and/or ASV. Our measurements are indicated by filled circles in Figure 1.

The linear elements (equinox J2000) are listed in Table 1. The pair designation is given in Column 1, whereas Columns 2-8 show the linear elements: X_0 and Y_0 (coordinates of point with the closest relative separation, in arcseconds), X_A and Y_A (components of velocity of relative motion of the secondary for one year, in arcseconds), T_0 (epoch of the closest passage, in fractional Besselian year), ρ_0 (the closest relative separation, in arcseconds), θ_0 (position angle of the closest passage, in degrees). The velocity V of relative motion of the secondary is given in Column 9. The relative proper motion μ_{rel} is given in the final column.

[4] http://www.nao-rozhen.org/telescopes/fr_en.htm
[5] http://belissima.aob.rs/

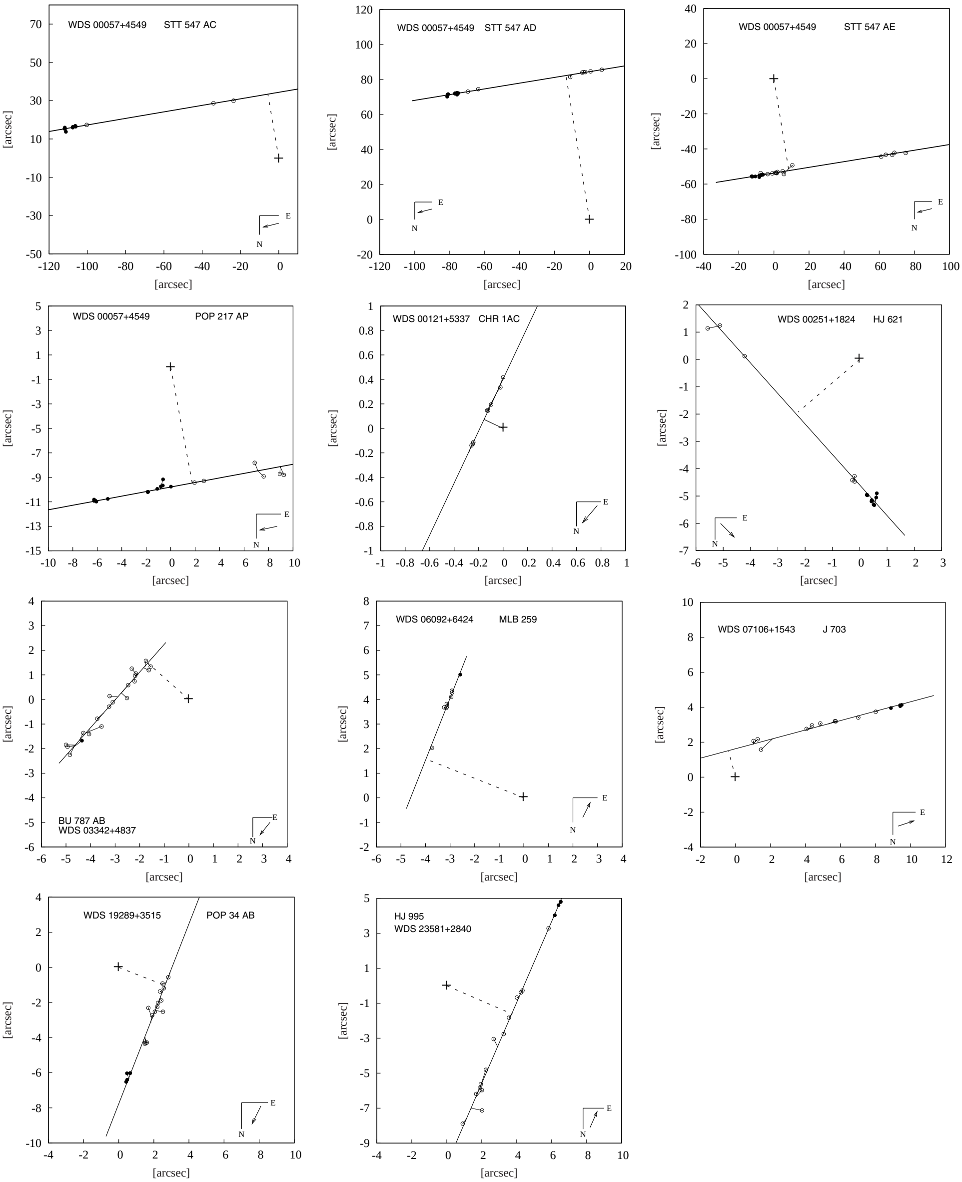

Figure 1: Linear fits for eleven pairs: the arrow at the lower right corner indicates the direction of relative motion of the secondary; the dashed perpendicular line from the linear fit to the origin indicates the closest relative separation. The micrometric observations and photographic measurements are represented by open circles and our CCD measurements are denoted by filled circles.

Our aim is to establish nature of these eleven pairs, i.e. whether they are gravitationally bound or they are mutually very distant in space so that only their projections are close in the field of view.

Table 1: Linear elements, relative velocity and relative proper motion of the eleven double stars.

Pair	X_0 [$''$]	X_A [$''$/yr]	Y_0 [$''$]	Y_A [$''$/yr]	T_0 [yr]	ρ_0 [$''$]	θ_0 [°]	V [$''$/yr]	μ_{rel} [$''$/yr]
STT 547 AC	-5.6938	-0.8863	33.4055	-0.1511	1892.05	33.89	189.7	0.899	0.900
STT 547 AD	-13.4829	-0.8802	82.3063	-0.1442	1934.84	83.40	189.3	0.892	0.897
STT 547 AE	8.4875	-0.8836	-52.3353	-0.1433	1988.03	53.02	9.2	0.895	0.887
POP 217 AP	1.7603	-0.8897	-9.4639	-0.1655	2002.88	9.63	10.5	0.905	0.900
CHR 1 AC	-0.1553	-0.0129	0.0731	-0.0274	1991.93	0.17	244.8	0.030	0.040
HJ 621	-2.2541	0.0475	-1.9247	-0.0556	1954.07	2.96	0.1	0.011	0.011
BU 787 AB	-1.6755	-0.0235	1.4820	-0.0266	1881.37	2.24	228.5	0.035	0.037
MLB 259	-3.9808	0.0133	1.5769	0.0335	1910.18	4.28	248.4	0.036	0.055
J 703	-0.4066	0.0840	1.5165	0.0225	1895.17	1.57	195.0	0.087	0.046
POP 34 AB	2.6319	-0.0557	-1.0271	-0.1428	1974.75	2.82	68.7	0.153	0.154
HJ 995	3.7184	0.0434	-1.6069	0.1004	1948.56	4.05	66.6	0.109	0.037

Table 2: Magnitudes, spectral type, components of proper motion and parallax of the eleven pairs.

Pair	m_A	m_B	Sp	$\mu_{\alpha A}\cos\delta$ [$''$/yr]	$\mu_{\delta A}$ [$''$/yr]	$\mu_{\alpha B}\cos\delta$ [$''$/yr]	$\mu_{\delta B}$ [$''$/yr]	π [mas]
STT 547 AC	8.98	12.79	K6	+0.88748	−0.15202	0.	0.	88.44
STT 547 AD	8.98	12.51	K6	+0.88748	−0.15202	+0.003	+0.000	88.44
STT 547 AE	8.98	11.75	K6	+0.88748	−0.15202	+0.012	−0.008	88.44
POP 217 AP	8.98	13.40	K6	+0.88748	−0.15202	0.	0.	88.44
CHR 1 AC	7.25	.	A7Vn-F2V	+0.03846	−0.01120	0.	0.	8.34
HJ 621	10.2	11.4		0.	0.	−0.011	−0.001	-
BU 787 AB	7.38	11.9	B9.5V	+0.01884	−0.03217	0.	0.	3.83
MLB 259	12.1	13.0		+0.005	+0.018	−0.015	−0.033	-
J 703	10.43	12.4		+0.009	−0.017	−0.023	+0.016	-
POP 34 AB	10.63	13.6		+0.072	−0.137	0.001	0.	-
HJ 995	8.80	11.3	K0	−0.021	−0.030	0.	0.	-

To us of interest are X_A and Y_A - the components of the velocity of the secondary with respect to the primary (Table 1) which are used to calculate the velocities V of relative motion.

The basic parameters for our pairs are listed in Table 2. The pair designation is given in Column 1, the apparent magnitudes of the primary m_A and secondary m_B are given in Columns 2 and 3 and the spectral type Sp is given in Column 4. The proper motion in right ascension $\mu_\alpha \cos\delta$ and the proper motion in declination μ_δ are given in Columns 5 and 6 (for the primary A) and in Columns 7 and 8 (for the secondary B). The parallax π is given in the final column. For six pairs the parallax and components proper motion are given in the Hipparcos catalog. The other five pairs do not have parallax and the components of proper motion are given in the WDS catalog.

We can calculate the relative proper motion μ_{rel} for the pairs following this formula

$$\mu_{rel} = \sqrt{(\mu_{\alpha A}\cos\delta - \mu_{\alpha B}\cos\delta)^2 + (\mu_{\delta A} - \mu_{\delta B})^2}\ . \qquad (1)$$

Than, we can compare the proper motion μ_{rel} with the values of the velocity V for all eleven components in linear solutions. An agreement between them is argument in favor that pairs are not gravitationally bound, but they are mutually very distant in space so that only their projections are close in the field of view. As can be seen in Table 1, the values of V and μ_{rel} are in excellent agreement for eight pairs. In the remaining three pairs there is a disagreement and the reason for that may be unreliably determined components of proper motion for the primary and/or secondary. Also, as can be seen in Table 2, there are no proper motion in right ascension $\mu_\alpha \cos\delta$ and declination μ_δ for all components of the pairs.

3. DETERMINING THE NATURE OF STAR PAIRS

In the consideration of the nature of star pairs we used the minimum separation ρ_0 (Table 1) and the basic parameters given in Table 2.

Four considered pairs, *STT 547 AC, STT 547 AD, STT 547 AE* and *POP 217 AP*, belong to a multiple system registered in ADS - Aitken Double Stars catalogue (Aitken 1932) - as ADS 48. The detailed analysis of the system ADS 48 is given in the paper Cvetković et al. (2012).

CHR 1AC: If for the brighter star one applied the absolute magnitude M_v=2.3 mag, expected on the basis of the spectral type (Gray 2005), the corresponding distance (extinction neglected) would be 98 pc, whereas the given parallax yields 120 pc. From these spectral types the masses are 1.93 and 1.56 solar masses, for the brighter and fainter component, respectively (Gray 2005). Besides, the distance of the brighter component combined with the proper motion yields tangential velocity of almost 23 km s^{-1}, a typical thin-disc star. If the two stars were at 120 pc from the Sun, the minimum separation (0.172 arcseconds) would correspond to 20.64 au. This is a lower limit for the mutual distance only. A semimajor axis of the order of 10^2 au with this total mass would result in a period of a few centuries. Such result is not unexpected for binaries, which means that this pair may be bound. The other well known dynamical criteria (Dommanget 1955a, 1955b; Sinachopoulos and Mouzourakis 1992) lead to a similar conclusion. The reason is the very small minimum separation used in this calculation, but the measurements show a very rapid increase of separation and they fit a straight line very well (Figure 1). Besides, all dynamical criteria apply the same distance for both components, but this can be valid only if they are bound.

HJ 621: Since the parallax is not known for either star, the distance(s) will be estimated from the given data. It is probable that these two stars belong to the thin disc and they are G K dwarfs (main sequence). Let their absolute magnitudes be, say, 5.6 and 6.8. Then the distance would be 83 pc. The proper motion of the brighter star is practically zero, for the fainter one it is small and, with this distance, it would result in a tangential velocity of 4.3 km s^{-1}. This value is rather small, so due to small proper motions these two stars are expected to be significantly farther from the Sun. Nevertheless, it is hard to believe that they are intrinsically very luminous. If they were two A main-sequence stars, the distance to them would be 794 pc, with corresponding masses of 2.34 and 2.04. This distance would agree with their small proper motions (also, note that the parallax is unknown). However, the minimum separation of almost $3''$ at this distance would yield 2353 au. A distance of about 3000 au at the periastron is really too large and even two rather massive stars (supposed total of 4.38 solar masses) could not keep them bound. The probability that this pair is bound seems to be very low. Due to small proper motions the heliocentric distances of these stars may be comparable, but far from to be the same, very likely their mutual distance is of the order of 10^2 pc.

BU 787 AB: From the available data the distance to the brighter star can be calculated, i.e. estimated, in three different ways: from the parallax, by using photometry and by assuming a "reasonable" value for its tangential velocity. The results are: 261 pc, 238 pc (absolute visual magnitude 0.5 mag according to Gray (2005), extinction neglected) and 283 pc (50 km s^{-1}). Thus the distance to this star seems reliable enough. Therefore, it remains to examine if such a distance is acceptable for the fainter star. The fainter star is significantly less bright, by 4.52 mag (Table 2). Thus, at the same distance this must be a G star (G5 - Gray (2005)). The total mass would be: 2.5+1.05=3.55 solar masses. At the given distance (260 pc) the minimum separation results in about 580 au. If these two stars were bound, then their periastron distance would be at least some 700-800 au. Due to this, for an eccentricity of 0.5, one would have a period of about 30 thousand years, a value extremely improbable. In other words, though it is difficult to find strong arguments that the distance found for the brighter star is unacceptable for the fainter one, most likely this pair is not bound and also, the real distance between the stars is rather large.

MLB 259: No parallax value is at our disposal, it is possible to assume a distance value valid for both stars and examine the consequences. Any such value will yield the values for the absolute magnitudes, masses, tangential velocities and finally, via minimum separation, the corresponding distance in projection. This procedure must converge, but if the convergence occurs for a very small distance to the Sun, then such system is likely to be unrealistic. It is difficult to accept a system composed by two substellar objects at, say, 5 pc from the Sun, which both have almost zero heliocentric tangential velocities. These two stars may be bound, but provided that they are at less than 10 pc from the Sun and with tangential velocities almost zero for both. A similar result (13 pc) is obtained by applying Dommanget's criterion. The conclusion is clear, it is highly improbable that this star pair forms a binary. If these stars were really so close to the Sun, at least for one of them there would exist the trigonometric parallax.

J 703: The same procedure is applied as for the preceding pair. The convergence occurs between 10 pc and 20 pc. The application of Dommanget's criterion yields 25 pc as the maximum distance for which they are still bound. For the same reason as in the preceding case this pair is regarded as very improbable to be bound.

POP 34 AB: Since the distance is not available, it can be estimated based on photometry and also tangential velocity of the the brighter star. If the fainter star still belongs to type K (K8), the distance would be 136 pc and tangential velocity of brighter star about 100 km s^{-1}. Perhaps it is closer to the Sun, or it is a thick-disc star. If the former is correct, the fainter component would have to be a low luminosity object, which seems to be against the same distance (Δm about 3 mag). If a distance over 100 pc is realistic for the brighter component, then due to the minimum separation a semimajor axis of the order of 1000 au would be obtained. With assumed masses one would have a period of $\sim 10^4$ years. This pair does not seem to be bound.

HJ 995: If assumed to belong to both main sequence and thin disc, the brighter component would be at a distance of 36.3 pc and tangential velocity of 6.3 km s^{-1}. The same distance applied to the fainter component, if it also is a main-sequence star, according to Gray 2005, yields an absolute magnitude of 8.5 (K8-9); the corresponding total mass would be 0.9+0.5=1.4 solar masses. The projected distance for the minimum separation, which corresponds to the assumed heliocentric distance is 147 au. Here one finds no strong arguments against the same distance for both stars. However, the smallest possible periastron distance exceeds 100 au. Therefore, for a not too high eccentricity (say 0.5) a semimajor axis of a few hundreds au is expected. This, combined with the mass values, yields a period of about 12,500 years. A situation similar to the preceding one, very probably not bound.

4. CONCLUSION

The relative coordinates obtained from our CCD frames for the pairs, except for CHR 1 AC, are used in the calculation of linear fits.

There is a good agreement between the relative velocity V obtained from our linear fits and relative proper motion μ_{rel} for almost all pairs. This fact is in favour that these pairs are optical (not gravitationally bound).

This conclusion is strengthened by applying dynamical criteria based on well-known laws (Kepler's third law, energy conservation, etc.).

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