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NEW LINEAR SOLUTIONS FOR 13 DOUBLE STARS

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Abstract. We present 13 linear solutions of double stars that have been calculated for the first time from 2015 to 2017. For the purpose of calculating the linear solutions, we also use our measurements of the position angle and angular separation obtained from CCD frames performed at NAOR and ASV. Two linear elements, V_x and V_y , are used to calculate the velocity V of relative motion of the secondary with respect to the primary. Also, we can calculate the relative proper motion μ_{rel} for these 13 double stars by using the components of the proper motion, $\mu_\alpha\cos\delta$ and μ_δ, for primary A and secondary B. The components of the proper motion are taken from two sources, WDS catalog and Gaia DR2. Then, we can compare the proper motion μ_{rel} with the values of the relative velocity V for all 13 components in linear solutions. Excellent agreement between them was found when we used the proper motions from the Gaia DR2 catalog to calculate μ_{rel}.

1. INTRODUCTION

Visual double stars have been studied at the Astronomical Observatory in Belgrade (AOB) for almost 70 years, i.e. from late 1950. These objects had been observed till the end of the XX century with the Zeiss refractor (65/1055 cm). The micrometric measuring technique had been used and in this way from AOB more than 260 new pairs had been discovered. After this, for several years the observations were performed with CCD camera ST6 attached to this telescope. In the beginning of this century observations of double stars from AOB ceased, to be continued from Bulgaria with the 2 m telescope of the National Astronomical Observatory at Rozhen (NAOR). CCD observations with VersArray 1300B camera were performed. From 2004 to 2007 the cooperation between Serbian and Bulgarian astronomers in the field of visual double star observations occurred within the framework of a regional project sponsored by UNESCO-ROSTE. The results have been published in (Pavlović et al. 2005, Cvetković et al. 2006, 2007).

From the Serbian side the participants were: Georgije Popović, Dragomir Olević, Rade Pavlović and Zorica Cvetković, from the Bulgarian one Anton Strigachev.

From 2007 till nowadays the observations of visual double stars have been continued with the 2 m telescope of NAOR, first thanks to the understanding of the Bulgarian colleagues (2009–2011), and then in the framework of joint triennial projects between the Serbian Academy of Sciences and Arts and Bulgarian Academy of Sciences for the periods 2012–2014, 2014–2016 and 2017–2019. The results have been published in (Cvetković et al. 2010, 2011, 2012). The participants from the Serbian side have been: Zorica Cvetković, Rade Pavlović and Goran Damljanović all the time, then Slobodan Ninković (2012–2016), Milan Stojanović (2012–2014) and Miljana Jovanović (from 2017). The Bulgarian participants have been: Svetlana Boeva all the time, Alexander Antov, Renada Konstantinova-Antova, Rumen Bogdanovski and Borislav Spassov (2012–2014), Georgi Latev and Maya Belcheva (from 2014) and Yanko Nikolov (from 2017).

Immediately after finishing the building of the new Astronomical Station on the mountain of Vidojevica (ASV) in southern Serbia, in the middle of 2011 CCD observations of visual double stars with a 0.6 m telescope were initiated. The results have been published in (Pavlović et al. 2013; Cvetković et al. 2015, 2016, 2017). When a larger telescope named "Milankovic" with the diameter of the primary mirror equal to 1.4 m was procured in 2016, CCD observations of these objects have been also performed by using it. More details about ASV and its telescopes can be found on the websites http://vidojevica.aob.rs/ and http://belissima.aob.rs/. Two CCD cameras have been utilized at ASV, Apogee Alta U42 and SBIG ST-10ME.

The CCD frames were measured using AIP4WIN software (Berry and Burnell, 2002) and the IRAF[1] package. The observables are two relative coordinates, angular separation between components A (primary) and B (secondary), or separation only, ρ and position angle θ, for the moment of observation t. The task is to establish which double stars are gravitationally bound, or orbital pairs, unlike those not gravitationally bound, i.e. are optical pairs, with close projections onto the tangential plane. Further the orbital or linear elements should be calculated, in order to determine stellar masses, dynamical parallaxes and other parameters.

The linear elements are: X_0 and Y_0 – coordinates of the closest approach of the secondary star relative to the primary; V_X and V_Y – components of the velocity of relative motion of the secondary relative to the primary; T_0 – epoch of the closest approach; ρ_0 – the closest relative separation and θ_0 – position angle of the closest approach. A more detailed explanation concerning the linear elements, figures and the formulae for their obtaining is given in another paper (Pavlović et al. 2018).

[1] http://iraf.noao.edu

2. LINEAR SOLUTIONS

From 2012 we have calculated for the first time the linear elements for a total of 27 double stars. Out of them linear solutions for 13 double stars were obtained between 2015-2017, which are presented here. Their identifications in the Washington Double Stars Catalog (WDS) and discoverer designation are: WDS 01057+3304=MLB 444, WDS 02516+4803=HJ 2160AB, WDS 03342+4837=BU 787AB, WDS 04312+5858=STI 2051AB, WDS 04556+1653=HJ 3263, WDS 05492+2941=BRT 2521, WDS 06092+6424=MLB 259, WDS 07106+1543=J 703, WDS 08503+0125=J 74, WDS 09388+0242=J 78, WDS 17046+3900=HJ 2804AB, WDS 18269+2950=HJ 1325 and WDS 19500+0637=J 1336AB. For the purpose of calculating the linear solutions, in addition to the measurements taken from the database, we also use our measurements of the position angle and angular separation from CCD frames obtained at NAOR and ASV. The linear elements are given in Table 1. They have been already announced so that they are available in the Catalog of Rectilinear Elements (http://www.astro.gsu.edu/wds/lin1.html).

Table 1: Linear elements for 13 double stars.

WDS Designation	Discoverer Designation	X_0 (″)	X_A (″/year)	Y_0 (″)	Y_A (″/year)	T_0 (year)	ρ_0 (″)	θ_0 (°)
01057+3304	MLB 444	7.184849	−0.029876	−2.073079	−0.103544	1948.782	7.478	73.91
02516+4803	HJ 2160AB	−5.833506	−0.013444	3.726437	−0.021046	1743.980	6.922	237.43
03342+4837	BU 787AB	−1.744095	−0.020860	1.467897	−0.024785	1878.073	2.258	229.91
04312+5858	STI2051AB	5.579910	0.042772	2.330326	−0.102417	1939.958	6.047	112.67
04556+1653	HJ 3263	−3.459261	0.039617	−2.136124	−0.064157	1834.786	4.066	301.70
05492+2941	BRT2521	−1.248724	−0.076498	2.026629	−0.047135	1940.824	2.380	211.64
06092+6424	MLB 259	−3.980805	0.013260	1.576882	0.033474	1910.178	4.282	248.39
07106+1543	J 703	0.415380	−0.082381	−1.745080	−0.019609	1892.897	1.794	3.39
08503+0125	J 74	2.191639	0.034511	−1.685230	0.044882	1857.508	2.765	52.44
09388+0242	J 78	0.562050	0.067989	3.036883	−0.012583	1948.224	3.088	169.51
17046+3900	HJ 2804AB	−2.604337	0.083382	4.882575	0.044476	2049.773	5.534	208.08
18269+2950	HJ 1325	−5.030179	0.009846	−4.126053	−0.012003	2001.494	6.506	309.36
19500+0637	J 1336AB	−0.370453	0.047707	−2.036395	−0.008679	1904.829	2.070	349.69

Two linear elements, V_x and V_y , are used to calculate the velocity V of relative motion of the secondary with respect to the primary. Also, we can calculate the relative proper motion μ_{rel} for these 13 double stars by using the components of the proper motion, $\mu_\alpha \cos\delta$ and μ_δ, for primary A and secondary B. The components of the proper motion are taken from two sources, the WDS catalogue (http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds) and Gaia DR2 (http://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=I/345/gaia2). They are given in Table 2. The Gaia DR2 catalogue is available from April 2018. It contains high accuracy data and there one can find parallaxes for both components of all the 13 pairs from our sample. The Gaia DR2 parallaxes are also given in Table 2.

Table 2: The components of the proper motion, $\mu_\alpha \cos\delta$ and μ_δ, for primary A and secondary B taken from WDS and Gaia DR2 and parallaxes π_A and π_B from Gaia DR2.

			WDS catalogue				Gaia DR2 catalogue			
Pair	π_A (mas)	π_B (mas)	$\mu_{\alpha A} \cos\delta$ (mas/yr)	$\mu_{\delta A}$ (mas/yr)	$\mu_{\alpha B} \cos\delta$ (mas/yr)	$\mu_{\delta B}$ (mas/yr)	$\mu_{\alpha A} \cos\delta$ (mas/yr)	$\mu_{\delta A}$ (mas/yr)	$\mu_{\alpha B} \cos\delta$ (mas/yr)	$\mu_{\delta B}$ (mas/yr)
MLB 444	3.5453	3.4627	−18.8	−102.8	87.7	23.7	11.900	−88.981	−14.926	9.472
HJ 2160AB	1.0469	2.3594	8.8	−7.3	−8.0	13.9	9.259	−7.452	−1.936	14.074
BU 787AB	5.8057	1.6200	21.4	−26.5	22.1	17.8	22.419	−26.732	−4.788	1.288
STI2051AB	180.4215	181.2815	1300.2	−2049.0	1335.6	−1962.6	1303.270	−2043.847	1335.042	−1947.632
HJ 3263	2.7324	0.8136	−44.3	−56.5	5.7	5.9	−48.778	−61.537	2.802	−2.488
BRT2521	7.6388	0.9987	92.0	−55.8	−14.9	−41.9	67.125	−56.269	−7.493	−5.842
MLB 259	2.9454	1.3870	4.6	17.8	−15.0	−33.2	−4.564	13.385	11.251	−21.119
J 703	2.7841	12.1025	8.9	−16.9	−23.0	15.8	−12.119	−5.208	−93.538	14.491
J 74	4.4225	1.6365	−61.7	55.8	40.1	−15.5	−40.064	38.112	−7.610	−5.594
J 78	7.9151	5.5372	−76.0	0.0	−30.9	−58.1	−94.165	−30.793	−22.601	−17.829
HJ 2804AB	5.5242	3.4322	−51.7	2.0	25.3	−44.2	−53.121	1.738	30.945	−43.992
HJ 1325	0.3623	0.4096	−1.3	−11.6	−21.0	12.1	−3.200	−11.248	5.956	0.604
J 1336AB	1.0174	4.5890	−11.4	−18.0	28.8	8.7	0.246	−6.148	44.409	−6.481

The relative proper motion is designated as $\mu_{rel}(W)$ when we used the proper motions from the WDS catalogue, and as $\mu_{rel}(G)$ when we used the proper motions from Gaia DR2 catalogue. The relative proper motions $\mu_{rel}(W)$ and $\mu_{rel}(G)$ and the velocity V of relative motion of the secondary with respect to the primary are given in Table 3.

Then, we compared μ_{rel} with V for all 13 components in the linear solutions. As can be seen from Table 3, the values of V are in excellent agreement with $\mu_{rel}(G)$ for all 13 pairs and with $\mu_{rel}(W)$ the agreement is good for eight pairs, HJ 2160, BU 787, STI 2051, HJ 3263, BRT 2521, J 78, HJ 2804 and J 1336. There is a disagreement in V and $\mu_{rel}(W)$ for five pairs: MLB 444, MLB 259, J 703, J 74 and HJ 1325. The reason of disagreement is unreliable proper motion components for the primary and/or secondary in WDS. In the case of these five pairs, as can be seen from Table 2, $\mu_\alpha \cos\delta$ and μ_δ from WDS and Gaia DR2 are significantly different. An agreement between μ_{rel} and V is an argument in favor that the pairs are not gravitationally bound, but instead mutually very distant in space so that only their projections are close in the field of view. Now, the Gaia DR2 catalog is available. In it one can find the parallaxes for both components for all 13 pairs. As can be seen (Table 3), the parallaxes of primary π_A and secondary π_B are different for 11 pairs, i.e. the components are at substantially different heliocentric distances. This is strongly in favor that they are not very long-period physical pairs, but just optical pairs. In the case of two pairs, MLB 444 and STI 2051, the parallaxes of primary π_A and secondary π_B are almost equal to each other, i.e. the components are at the same heliocentric distance. Most likely these two pairs are not bound, but their components have common proper motion. The linear fits for these 13 double stars are presented in Figures 1-3.

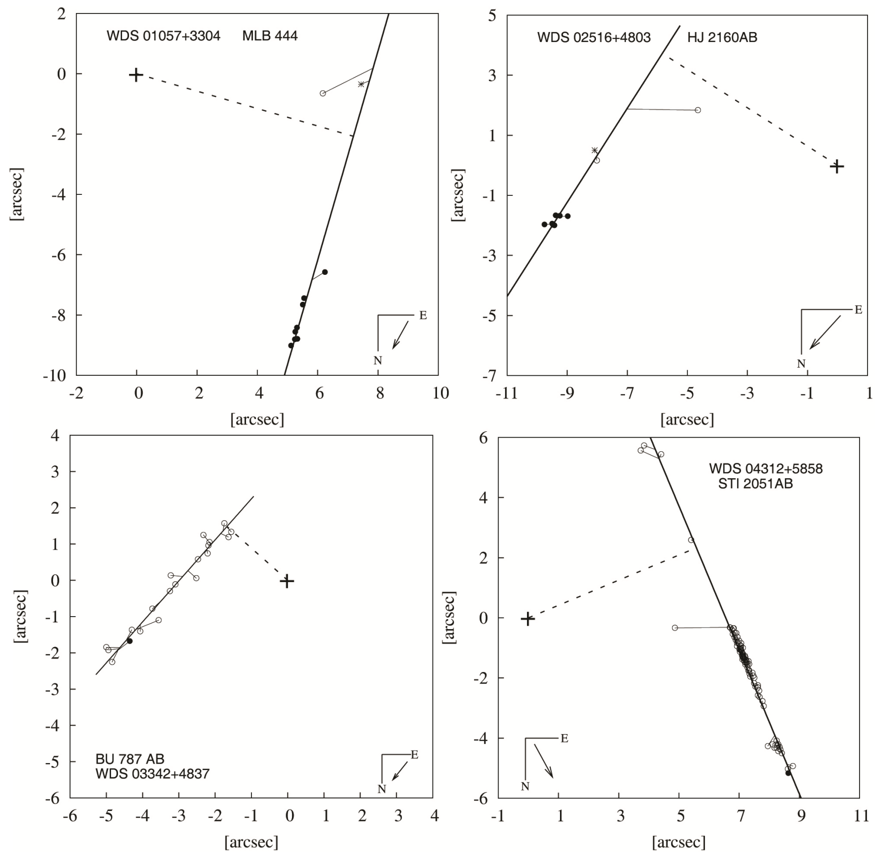

Figure 1: Linear fits for pairs MLB 444, HJ 2160AB, BU 787, STI 2051, HJ 3263 and BRT 2521. The arrow in the lower right corner indicates the direction of the relative motion of the secondary; the dashed perpendicular line from the linear fit to the origin indicates the closest relative separation. The micrometric and photographic observations are represented by open circles and asterisks, respectively. CCD or other two-dimensional electronic imaging observations are denoted by filled circles.

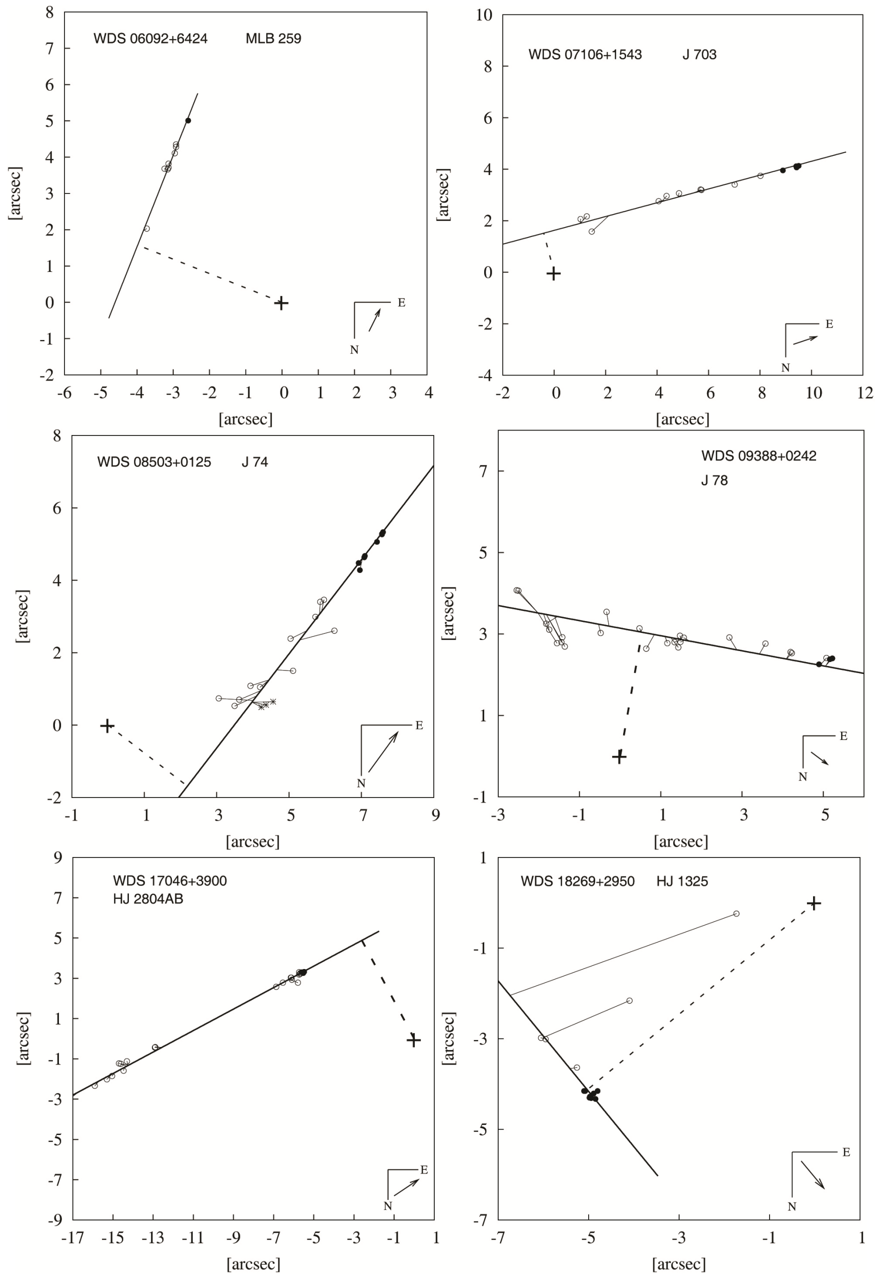

Figure 2: Linear fits for pairs MLB 259, J 703, J 74, J 78, HJ 2804 and HJ 1325. All designations on the plots are the same as in Figure 1.

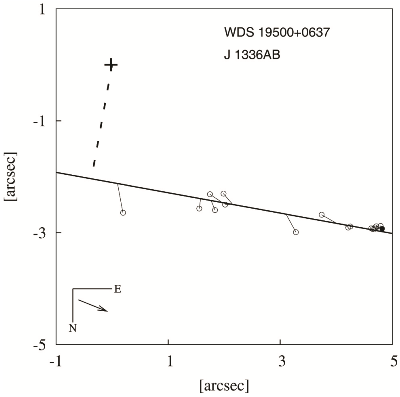

Figure 3: Linear fit for pair J 1336. All designations are the same as in Figure 1.

Table 3: The relative proper motions $\mu_{rel}(W)$ and $\mu_{rel}(G)$ and the velocity V of relative motion of the secondary with respect to the primary.

Pair	$\mu_{rel}(W)$ [″/yr]	$\mu_{rel}(G)$ [″/yr]	V [″/yr]
MLB 444	0.165	0.102	0.108
HJ 2160AB	0.027	0.024	0.025
BU 787AB	0.032	0.039	0.032
STI2051AB	0.093	0.101	0.111
HJ 3263	0.080	0.078	0.075
BRT2521	0.108	0.090	0.090
MLB 259	0.055	0.038	0.036
J 703	0.046	0.084	0.085
J 74	0.124	0.054	0.057
J 78	0.074	0.073	0.069
HJ 2804AB	0.090	0.096	0.094
HJ 1325	0.031	0.015	0.016
J 1336AB	0.048	0.044	0.048

5. CONCLUSIONS

From the comparison of the proper motion μ_{rel} with the values of the velocity V in the linear solutions for 13 pairs we found excellent agreement between them when the proper motions from Gaia DR2 for calculation of $\mu_{rel}(G)$ were used.

The WDS catalog now contains information about the measurements for 142645 double stars, where only for 2775 of them orbits have been calculated, whereas for 1574 double stars there exist linear elements. In the case of the remaining very numerous visual double stars the nature of their motion is to be determined only, to which the Gaia catalog, available from recent times, will contribute significantly. In addition to precise positions, Gaia DR2 provides parallaxes and proper motions for both components for most double stars. Thanks to these parallaxes, in the near future, it will be possible to segregate in WDS gravitationally unbound pairs (components at different distances) from those with Keplerian motion.

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References

Berry, R., Burnell, J.: 2002, *The Handbook of Astronomical Image Processing*, Includes AIP4WIN Software (Richmond, VA: Willmann-Bell).

Cvetković, Z., Novaković, B., Strigachev, A., Popović, G. M.: 2006, “CCD measurements of double and multiple stars at NAO Rozhen. II”, *Serb. Astron. J.*, **172**, 53-58.

Cvetković, Z., Pavlović, R., Strigachev, A., Novaković, B., Popović, G. M.: 2007, “CCD measurements of double and multiple stars at NAO Rozhen. III”, *Serb. Astron. J.*, **174**, 83-88.

Cvetković, Z., Pavlović, R., Boeva, S.: 2010, “CCD measurements of double and multiple stars at NAO Rozhen. IV”, *Serb. Astron. J.*, **180**, 103-107.

Cvetković, Z., Pavlović, R., Damljanović, G., Boeva, S.: 2011, “CCD measurements of double and multiple stars at NAO Rozhen. Orbits and linear fits of five pairs”, *Astronomical Journal*, **142**, 73.

Cvetković, Z., Pavlović, R., Boeva, S., Damljanović, G.: 2012, “CCD measurements of double and multiple stars at NAO Rozhen”, *Bulgarian Astronomical Journal*, **18(1)**, 56-61.

Cvetković, Z., Pavlović, R., Boeva, S.: 2015, “CCD measurements of double and multiple stars at NAO Rozhen and ASV in 2012. Four linear solutions”, *Astronomical Journal*, **149**, 150.

Cvetković, Z., Pavlović, R., Boeva, S.: 2016, “CCD measurements of double and multiple stars at NAO Rozhen and ASV in 2013 and 2014. Eight linear solutions”, *Astronomical Journal*, **151**, 58.

Cvetković, Z., Pavlović, R., Boeva, S.: 2017, “CCD measurements of double and multiple stars at NAO Rozhen and ASV in 2015”, *Astronomical Journal*, **153**, 195.

Pavlović, R., Cvetković, Z., Olević, D., Strigachev, A., Popović, G. M., Novaković, B.: 2005, “CCD measurements of double and multiple stars at NAO Rozhen”, *Serb. Astron. J.*, **171**, 49-53.

Pavlović, R., Cvetković, Z., Boeva, S., Vince, O., Stojanović, M.: 2013, “CCD measurements of double and multiple stars at NAO Rozhen and ASV in 2011. Five linear solutions”, *Astronomical Journal*, **146**, 52.

Pavlović, R., Cvetković, Z., Boeva, S., Damljanović, G.: 2018, “Determination of orbits of visual binary and linear elements of double stars”, *Astronomical and Astrophysical Transactions*, vol. **30**, 3-4 (in press).