Orbital Elements for BU 741 AB, STF 333 AB, BU 920 and R 207

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Abstract: New orbital parameters and dynamical masses for WDS 02572-2458 (BU 741 AB), WDS 02592+2120 (STF 333 AB), WDS 12158-2321 (BU 920) and WDS 12463-6806 (R 207) were determined due to large residuals. The Thiele-van den Bos method was used to obtain initial orbits for all the binaries (except for STF 333 AB where the Docobo method was used). The initial orbital solutions were improved using the differential correction method of Heintz. The physical relation of wide components was studied using BVIJHK photometry, historical astrometry and kinematical data. A search for new unreported companions around the binaries was performed as well.

Introduction

As a result of part of the work on visual double stars carried our by the Double Star Section of Liga Iberoamericana de Astronomía (LIADA), I present orbital parameters and other data (residuals, ephemerides, masses, parallaxes, apparent orbits, etc.) for four visual binary systems: WDS 02572-2458 (BU 741 AB), WDS 02592+2120 (STF 333 AB), WDS 12158-2321 (BU 920) and WDS 12463-6806 (R 207).

For all binaries, except STF 333 AB, initial orbits were calculated using the method of Thiele-van den Bos which were improved using the differential correction method of Heintz (1978a). For STF 333 AB, the analytical method of Docobo (1985) was used.

Dynamical parallaxes were calculated using the Baize-Romaní algorithm (1946).

The physical relation for wide components was studied using BVIJHK photometry, historical astrometry and kinematical data. The nature for these wide components was determined by the use of several criteria.

Astrophysical properties for binaries were determined and discussed. All the orbits presented here have previously been announced in the Information Circular of IAU Commission 26 (hereafter IAUDS).

Method of Orbital Calculation

Before using any analytical method, θ was corrected for precession and proper motion. Theta and ρ were plotted against time which allows the detection of measures with important errors and quadrant problems. The measures with very large errors are assigned zero weight.

Preliminary orbits were determined by the method of Thiele van den Bos. Three base points and a crude value of areal constant *c* are needed. I obtained a set of Keplerian orbits changing the initial value of the areal constant over a range of ±50 percent of the initial value of *c*. The apparent orbits for the set of orbits pass through the three given points. Only periodic orbits are taken into account. The step size and the search range for *c* are customizable.

The orbit with minimum RMS residuals is retained. In the next iteration the search range and the step size are reduced and the areal constant is centered in the *c* value for the orbit retained. The process is repeated until the result for two iterations doesn't show a significant difference. Two or three iterations are sufficient for most of the binaries.

The orbital elements of STF 333 were calculated using Docobo's analytical method (Docobo 1985). It is briefly summarized in Docobo *et al.* (2000) and Tamazian *et al.* (2002). This method is applicable even when only a relatively short and linear arc of the orbit has been measured. The advantage of this method, over other formal solutions, is that it does not require knowledge of the areal constant. A family of Keplerian orbits is generated whose apparent orbits pass through three base points. Simultaneously, O-C (observed minus calculated) residuals in both ρ and θ are determined for these orbits.

The next step is to select the orbit with smallest weighted rms values for ρ and θ. Usually, the orbit with the smallest rms values in θ is not exactly the same as the orbit with the smallest rms values in ρ. In this case, I selected the orbit with minimum residuals calculated by the followed formula:

$$\chi^2 = \sum_{i=1}^{n} w_{\theta i}(\rho_i \, \Delta\theta_i)^2 + \sum_{i=1}^{n} w_{\rho i}\Delta\rho_i^2 \qquad (1)$$

where $w_{\theta\, i}$ and $w_{\rho\, i}$ are the weights for the i^{th} θ and ρ measure. $\Delta\theta$ (expressed in radians) and $\Delta\rho$ are the O-C residuals for θ and ρ.

If the set of Keplerian orbits shows a flat gradient for RMS, then some orbits are rejected by the comparison of the dynamic mass with those determined using spectral types.

The three base points have to be chosen carefully where the observational data seems most reliable with respect to instrumentation, data density, or critical arc coverage. I also tried to cover as much of the observed arc as possible. This may let the area around a single observation represent a base point without additional observational coverage.

Initial orbits were improved using the Heintz differential correction method (1978a).

The initial weights were assigned using a data weighting scheme based on Hartkopf *et al.* (1989), Mason *et al.* (1999a), Seymour *et al.* (2002), and Docobo & Ling (2003). The initial θ weights were 5 times larger than ρ weights.

After several iterations in the differential correction process the measures with residuals larger than 3σ were assigned zero weight. Later the non-zero weight measures were reassigned following the work of Irwin *et al.* (1996).

Results

Table 1 lists, for each binary, the date of its discovery, the final orbital elements, the root mean squared (RMS) residuals and mean absolute residuals (MA) residuals. These are in both cases weighted averages calculated using the data-weighting scheme described in earlier.

The a^3/P^2 values are also listed. Errors for the elements were calculated from the covariance matrix and the residuals to all observations.

Table 2 presents ephemerides for the period 2012-2021. Table 3 lists the stellar data for the system studied. The WDS magnitudes in columns (3) and (4) and WDS spectral types in column (5); in column (6), the dynamical parallaxes calculated therefrom using the orbital periods and semimajor axes obtained in this work; in columns (7) and (8) the apparent magnitudes published in the Hipparcos and Tycho catalogs (ESA 1997) and in column (9) the corresponding trigonometric parallaxes (with their standard errors) from the re-reduced Hipparcos parallax (Leeuwen 2007); in column (10) the total mass of the binary (± estimated standard error), as calculated from the Hipparcos parallax.

Figures 1-4 show the new apparent orbits drawn together with the observational data; the x and y scales are in arcseconds. The solid curve represents the newly determined orbit, while the dashed curve represents the previous orbit. The line passing through the origin indicates the line of nodes. Speckle measures are shown as filled squares, visual interferometric observations are showed as open circles, visual measures as plus signs, and measures from the ESA Hipparcos instrument are indicated as a red empty square. The rejected observations are shown as red points. All measures are connected to their predicted positions on the new orbit by O - C lines.

Notes for Same Systems

In the next section, photometric, astrometric, spectroscopy and kinematical data are analyzed. Spectral types and luminosity classes, masses and dynamical parallaxes are obtained. The dynamical parallax was calculated using the Baize-Romani method (Baize & Romaní 1946).

A kinematical study was performed to determine the stellar age. From galactocentric velocity (U, V, W), I use the Eggen (1969a, 1969b) and Chiba & Beers (2000) diagrams the kinematic age parameter of

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Table 1: Orbital parameters, parallaxes, and residuals.

Name WDS ADS HIP	BU 741 AB 02572-2458 2242 18455	STF 333 AB 02592+2120 2257 13914	R 207 12463-6806 62322	BU 920 12158-2321 8481 59801
Disc. date	1879.70	1827.16	1880.34	1879.57
P [years]	149.89±4.48	1215.913±1.540	194.276±2.65	873.041±25.251
T [years]	1870.68±4.22	704.111±1.778	1857.504±3.79	1764.260±6.576
e	0.602±0.016	0.317±0.006	0.598±0.057	0.166±0.026
a ["]	1.425±0.077	2.174±0.035	0.969±0.068	2.012±0.137
i [º]	83.0±0.2	84.2±0.8	37.1±6.5	63.5±3.9
ω [º]	260.8±1.6	162.1±1.0	209.0±4.1	28.0±3.6
Ω [º]	163.5±0.5	25.6±0.7	349.4±4.2	142.2±3.7
Residuals:				
RMS(θ)[º]	1.06	0.99	1.62	2.19
RMS(ρ)["]	0.021	0.042	0.13	0.058
MA(θ)[º]	0.64	0.63	1.14	1.46
MA(ρ)["]	0.009	0.021	0.077	0.034
a^3/P^2 [$arcsec^3*yr^{-2}$]	$9.03813*10^{-5}$	$3.196790*10^{-6}$	$2.48776*10^{-5}$	$5.311127*10^{-6}$

Table 2: Ephemerides

	02572-2458		02592+2120		12463-6806		12158-2321	
Epoch	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)
2012	343.6	0.818	209.5	1.358	54.9	0.934	306.5	1.872
2013	344.4	0.767	209.6	1.353	56.2	0.918	306.7	1.879
2014	345.3	0.709	209.7	1.347	57.5	0.903	306.9	1.886
2015	346.3	0.642	209.7	1.342	58.9	0.887	307.1	1.894
2016	347.6	0.565	209.8	1.336	60.4	0.870	307.3	1.901
2017	349.4	0.478	209.9	1.331	61.9	0.854	307.5	1.908
2018	352.0	0.382	209.9	1.331	63.4	0.838	307.7	1.915
2019	356.4	0.278	209.9	1.331	65.0	0.821	307.9	1.922
2020	6.4	0.171	209.9	1.331	66.7	0.805	308.1	1.929
2021	43.8	0.080	209.9	1.331	68.5	0.788	308.3	1.936

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Table 3: Stellar data

STAR		WDS			PRESENT WORK	Hipparcos			
WDS (1)	HIP (2)	m_A (3)	m_B (4)	Spectral Type (5)	π (Dynamical) (mas) (6)	HpA (7)	HpB (8)	π (Trigonometric) (mas) (9)	Σ ($M_\odot$) (10)
02572-2458	18455	8.06	8.20	K1/2V	45.0	8.19	8.26	44.51 ± 2.09	1.5 ± 0.3
02592+2120	13914	5.17	5.57	A2Vs A2Vs	…	5.24	5.59	9.81 ± 0.79	7.4 ± 1.8
12463-6806	62322	3.52	3.98	B2.5V	11.3	3.51	4.01	10.48 ± 0.65	20.9 ± 5.9
12158-2321	59801	6.86	8.22	F7V	15.6	6.91	8.29	14.37 ± 0.71	3.60 ± 0.93

Grenon (1987), fG. Bartkevicius & Gudas (2002) determined the relation between fG and the age. Statistically, the stars with fG < 0.20 belong to the young-middle age group (with an age less than 3 - 4 Gyr) of the thin disk population. The stars with 0.20 < fG < 0.35 belong to the old (with age of 3 - 10 Gyrs) thin disk population. The stars with 0.35 < fG < 0.70 belong to the thick disk population (age greater than 10 Gyrs) and the stars with fG > 0.70 belong to the halo population.

In order to check the membership of the binaries to young kinematic groups, I consulted Table 1 published in Montes *et al*. (2001) and Soderblom & Mayor (1993).

WDS 02572-2458 = BU 741 AB

Since the first measure in 1879 (Burnham 1887) this binary has had 69 measures which cover an arc of about 184 deg. The orbital elements have previously been announced in the Information IAUDS No. 172 (Rica 2010).

BU 741 AB (HD18455 = HIP13772) is composed by stars of 8.06 and 8.20 magnitudes (ESA 1997) in Hipparcos system and the previous orbit was calculated by Scardia (2002).

Tycho-2 catalog lists a proper motion of +31.5 ± 2.6 mas/yr in RA and –35.1 ± 2.4 mas/yr in dec. The reduced Hipparcos trigonometric parallax is 44.51 ± 2.09 mas which corresponds to a distance of 25 +/-

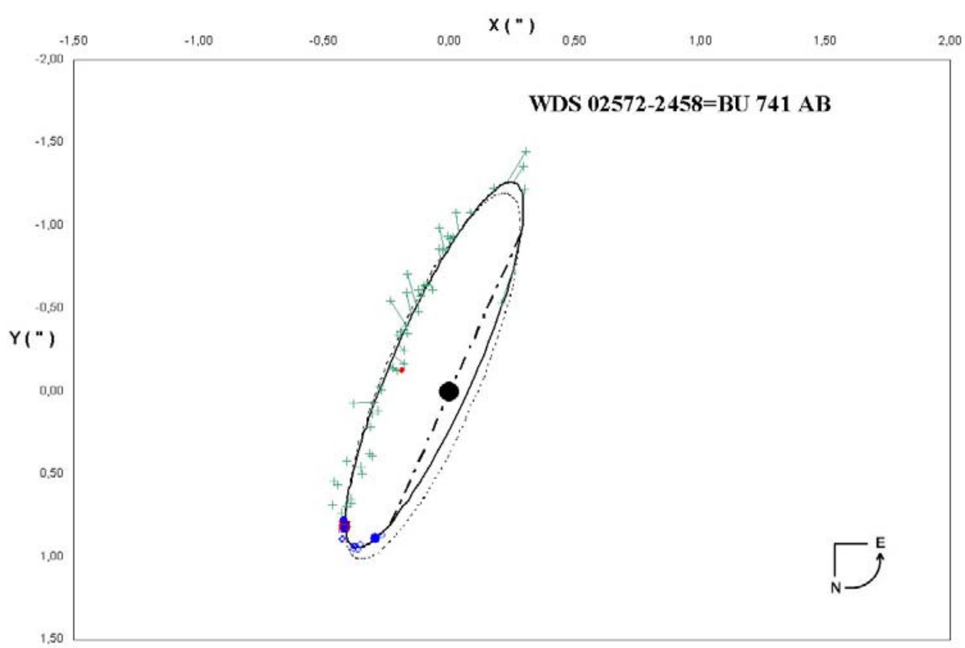

Figure 1: Apparent orbit for BU 741.

1.1/1.0 pc.

Masses were calculated taking into account the standard deviation for Hipparcos trigonometric parallax, P and a. A total dynamic mass of 1.46 ± 0.33 M⊙ was obtained. From spectral types, stellar masses of 0.73 and 0.73 M⊙ were calculated using Allen's tables (1973) and so the sum of the masses is in excellent agreement with that calculated using orbital parameters. The dynamic parallax is 45.0 mas in good agree with Hipparcos data.

In the astronomical literature BU 741 AB has been classified as a K1/2V star (Houk 1988) while Gray (2006) classified it as a K2V star. From differential magnitude and combined spectral type, I determined individual spectral type of about K2V and K2V (tables from Cowley *et al.* (1969), Christy & Walker (1969) and Edwards (1976) were used). From V apparent magnitudes and Hipparcos parallax the absolute magnitudes are +6.30 and +6.44 which corresponds to a spectral type of K1/2V and K2V.

Favata, Micela & Sciortino (1997) measured a metallicity [Fe/H] = -0.47 ± 0.05 for GJ 120.1A (matching with BU 741 AB). While Taylor (2005) measured a metallicity of -0.216 ± 0.087, Gray (2006) gave a value of -0.15 ± 0.06 and Holmberg, Nordstrom & Andersen (2009), -0.10.

Bobylev, Goncharov, & Bajkova (2006) measured a radial velocity for AB of +50.4 ± 0.2 Km s^{-1} while Gontcharov (2006) measured a radial velocity of +50.7 ± 0.3 km s^{-1} . In 2012 the calculated relative radial velocity will be of -9.1 km s^{-1} when the secondary is at 0.815 arcsec of angular distance. Perhaps this would be a good time for this system to be observed spectroscopically.

Age and Stellar Population.

Bobylev, Goncharov, & Bajkova calculated a galactocentric velocity of (U,V,W) = (-18.5, -18.8, -43.3) km/s. According to this kinematic data this system is a member of the young galactic disk in agree with the study of Bartkevicius & Gudas (2002). A fG = 0.29 was obtained in this work corresponding to old age thin disk stars of 3-10 Gyr old.

The *ROSAT All-Sky Survey Faint Source Catalog* (Voges *et. al.* 2000) lists the X-ray source 1RXS J025714.6-245828 located at 20 arcsec from AB and about 19 arcsec from component C. The positional error for this source is of 20 arcsec and the count rate is of 0.0291 ± 0.0125 cts/s with a HR1 = -1.00 ± 0.68. The optical source that emits in X-ray is unknown.

How can I identify the possible X-ray optical counterpart? Agüeros et al. (2009) calculated that most of the optical counterpart is at less than twice the ROSAT positional error. So I search for an optical source in a radius of 40 arcsec from the X-ray source. There are no galaxies near the X-ray source so only two candidates were found: BU 741 AB and S 423 C. Both candidates have a log fx/fv that match with K dwarf stars.

Using ROSAT data and the Hipparcos parallax I calculated a log Lx = 29.7 +/- 0.5/2.1 ergs/s for the AB pair. If I consider that A and B stars contribute equally to the X-ray emission then the Lx for each component would be of about 29.4. This very high level of X-ray emission is a strong indicator of stellar youth and it is a level typical for very young stars. Using he graphics cited in Catalán *et al.* (2008) and Daminani *et al.* (1995), the age for AB could be of about 200 Myr but the large errors in the count rate and in HR1 gave high limits of about 6 Gyr.

WDS 02592+2120 = STF 333 AB

This stellar system is located behind the dark cloud MBM12 (Abt & Morrell (1995)). Since Struve (1837) discovered it in 1827, STF 333 AB (= ADS 2257 AB = HD 18520/HD18519 = ε Ari = 48 Ari) has had 439 measures which cover about 19 degrees in a large nearly rectilinear arc. In the x(t) and y(t) plots can be observed a slightly curve cloud of points, clear evidence that STF 333 AB is a binary star.

The first speckle measure was performed in 1978 (McAlister & Fekel 1980). Since then, 45 speckle measures have been made. This binary is wide enough for amateurs to measure. For example Comellas (2003) measured it in 1973 and 1980, Le Beau (1987) in 1985, Kaznika (1994) in 1991, Tofol Tobal (2003) between 1984 and 1990, Benavides Palencia (2003) in 2002; Alzner (1998, 2003, 2005) between 1997 and 2004, Roberto Caloi (2008) in 2007, James Daley (2003) in 2001.

This orbit has previously been announced in the Information IAUDS No. 169 (Rica 2009).

STF 333 AB has stars of 5.17 and 5.57 magnitudes (ESA 1997) with combined spectral type of A2Vs. Tycho-2 catalog (Hog et al. 2000) determined a proper motion of –9.4 mas yr^{-1} in AR and –5.0 mas yr^{-1} in DEC. The Hipparcos trigonometric parallax of 9.81 ± 0.79 mas (Leeuwen 2007) corresponds to a distance of 101.9 +/- 8.9/7.6

Masses were calculated taking into account the standard deviation for Hipparcos trigonometric parallax and the errors of P and a. A total mass of 7.35 ± 1.81 M⊙ was obtained.

Gray & Garrison (1987) obtained a spectral type

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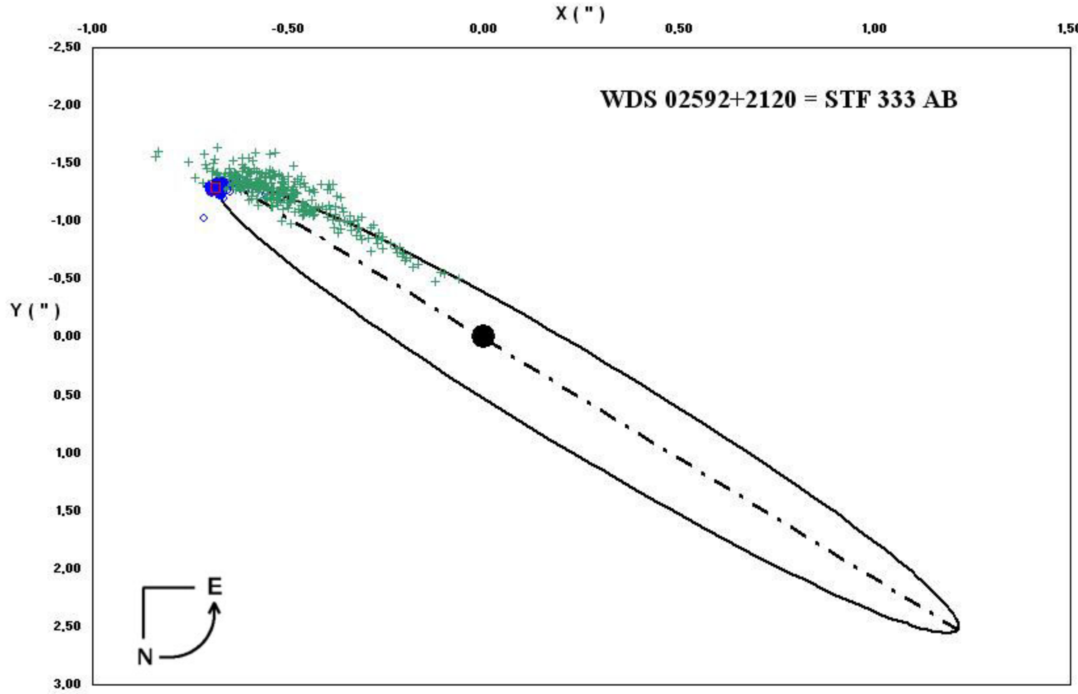

Figure 2: Apparent orbit for STF 333 AB.

of A2IV for primary and secondary, while Abt & Morrell (1995) obtained A2IV and A3IV. Others references classify the components as dwarf stars. From apparent magnitudes and Hipparcos parallaxes, the absolute magnitudes for the components were determined to be +0.13 ± 0.18 and +0.53 ± 0.18. It is a suspected variable star cataloged as NSV 1001.

The result of differential photometry from the Hipparcos satellite is +0.40. The mean result using the historical values from the WDS catalog was +0.38 ± 0.55.

Using theoretical isochrones, I calculated a stellar mass of 2.4 for an A2 subgiant, therefore, the sum of the masses is 4.8 M☉.

Age and Stellar Population

In this work, theoretical isochrones were used to determine that both stars seems to be subgiant stars with an age of about 550 - 650 Myr. King *et al*. (2003) obtained a galactic heliocentric velocity of (U, V, W) = (+9.9,+4.1,-1.0) km/s and considered that both component could be members of the Ursa Major moving group based in photometric data. The age for the Ursa Major moving group calculated by King et al. (2003) was 500 ± 100 Myr in excellent agreement with the age calculated in this work. According to Eggen's diagrams, STF 333 AB is a member of the young Galactic disk.

Coster (2009) published other orbital parameters with a very shorter orbital period (313 years). The ephemerids for both orbits are very similar and new measures in the followed years could not determine which orbit was correct.

WDS 12463-6806 = R 207

Since Russell (1871) discovered it in 1871, R 207 (= β Muscae = HD 110879 = HIP 62322) has had 78 measures which cover about 2/3 of the period. Only three speckle measures were made (Hartkopf *et al*. 1993; Davis & North 2001; Horch *et. al*. 2006). The last two measures were performed by the German amateur Rainer Anton (2006, 2008) in 2002.686 and 2007.373 using telescopes of 0.20 and 0.28 meters by CCD lucky imaging technique.

The official orbit was calculated by Mourao (1964) and it is an orbit of grade 5. Since the previous orbit, 20 measures have been made covering about 28 degrees.

R 207 is composed of stars of 3.54 and 3.99 magnitudes (Hog *et al.* 2000) with combined spectral type of B2V (Houk & Cowley 1975; Kennedy 1983; Burnashev 1985; Buscombe & Foster 1995).

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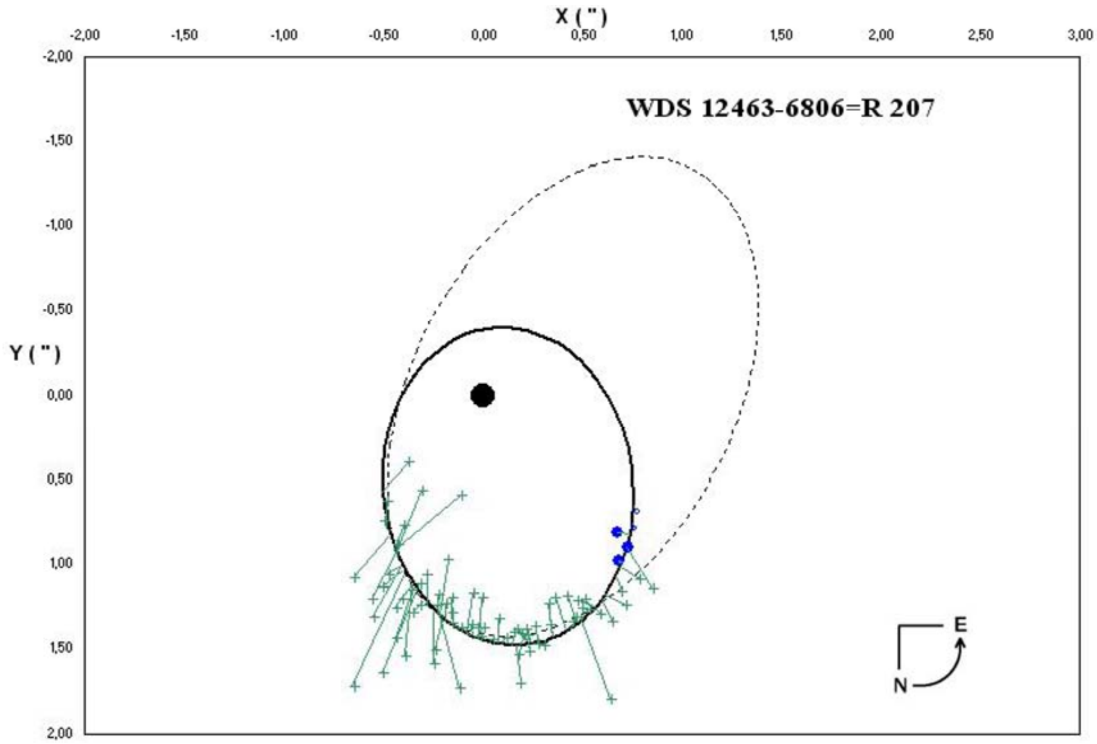

Figure 3: Apparent orbit for R 207.

Corbally (1984) obtained the followed photometric data: V = 3.58, B-V = -0.20, U-B = -0.77, and Mv = -2.50 for the primary. For the secondary V = 4.10, B-V = -0.18, U-B = -0.69, and Mv = -2.00. Tycho-2 catalog listed photometric data which transformed to standard system are: V = 3.54 ± 0.01, B-V = -0.16 ± 0.01 for the primary and V = 3.99 ± 0.01, B-V = -0.15 ± 0.01 for the secondary.

Corbally also estimated spectral types B2V and B2.5V for the components and a reddening E(B-V) of 0.04. Sartori, Lepine & Dias (2003) estimated a color V-I = -0.19 and Av = 0.05 and a bolometric correction of -2.05.

Hipparcos catalog (ESA 1997) determined a proper motion of –40.40 mas yr^{-1} in AR and –10.32 mas yr^{-1} in DEC and a trigonometric parallax of 10.48 ± 0.65 mas which corresponds to a distance of 95 +/- 6.3/-5.6.

Stellar masses were calculated taking into account the standard deviation for Hipparcos trigonometric parallax. A total mass of 20.9 ± 5.9 $M_\odot$ was obtained.

From Tycho-2 apparent magnitudes and Hipparcos parallaxes the absolute magnitudes were calculated for the components (-1.48 ± 0.13 and -1.03 ± 0.13).

From spectral types obtained by Corbally (1984), stellar masses of 11.6 and 10.4 $M_\odot$ were calculated using Allen's tables (1973). The sum of the masses is 22.0 $M_\odot$ and the dynamic parallax is 11.3 mas in agreement with what I expected.

Age and Stellar Population

Sartori, Lepine & Dias (2003) obtained a galactic heliocentric velocity with respect to the LSR of (U, V, W) = (+16.9, -39.4, -1.6) km s^{-1} and a radial velocity of +42.0 km/s.

According to this kinematic data, R 207 is a member of the old Galactic disk. A value of 0.22 for fG was obtained in this work corresponding to old age thin disk stars. This is not in agreement with the age inferred by their spectral types. I estimate the most probable age using the stellar models by Girardi et al. (2002; using the web interface PARAM 1.1, Da Silva *et al.* 2006). It yields stellar ages of about 100 Myrs (assuming solar metallicity). I know no reason for this different conclusion using kinematic data but is obviously more logical think that two dwarfs of B spectral type are very young objects.

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WDS 12158-2321 = BU 920

The first measure was performed in 1879 (Burnham 1883) In this work, a combined spectral type of F5V (using BVIJHK photometry) was obtained. From apparent magnitudes and Hipparcos parallax the absolute magnitude for the components are +2.65 ± 0.11 and +4.01 ± 0.11. This binary has had 62 measures which cover an arc of 70 degrees. BU 920 is composed of stars of 6.86 and 8.22 magnitudes (ESA 1997). Tycho-2 catalog lists a proper motion of -8.7 ± 3.4 mas yr^{-1} in RA and -38.5 ± 3.3 mas yr^{-1} in DEC and a trigonometric parallax of 14.37 ± 0.71 mas which corresponds to a distance of 69.6 +/- +3.6/-3.3 pc.

In the astronomical literature BU 920 has been classified as an F3V star (Malaroda 1975), F5/6V (Houk & Smith-Moore 1988), F7V

The astronomical literature gives values for the radial velocity ranging from +18.1 ± 4.0 km/s (Gontcharov 2006) to +22.1 ± 1.5 km/s (Beavers & Eitter 1986).

If both stars are dwarfs, the individual spectral types determined in this work would be F3V and G1V. Using an evolutionary isochronal, the primary could be an evolved star of spectral type F3IV/V. The sum of the masses could be 3.6 M⊙ (2.3 solar masses for the primary). A total mass of 3.60 ± 0.93 M⊙ was obtained using the orbit of this work and the errors in trigonometric parallax, *P* and *a*.

No common proper motion companion was found.

Age and Stellar Population.

Holmberg, Nordström & Andersen (2009) calculated a galactocentric velocity of (U, V, W) = (+8, -21, +1) km s^{-1}, a metallicity [Fe/H] = +0.01 and an age of 1.8 +/- 0.2/0.1 Gyr. Philip & Egret (1980) calculated [Fe/H] = +0.16. According to the diagram of Chiba & Beers (2000) this system is a member of the thin galactic disk. A fG = 0.11 was obtained in this work corresponding to young-middle age thin disk stars of 3-4 Gyr old.

Study of Wide Companions

The astronomical literature was consulted in order to obtain photometric, astrometric and kinematic data. VizieR, Simbad (Wenger et al. 2003) and the "services abstract" tools were used from the website of Centre De Données Astronomiques de Strasbourg. Photometry in B, V and I bands came from Hipparcos (ESA 1997) and Tycho-2 catalogs (Høg et al. 2000). Infrared J, H and K photometry came from Two Micron All Sky Catalogue (Cutri et al. 2000), hereafter 2MASS. Proper motion came from Tycho-2 catalog.

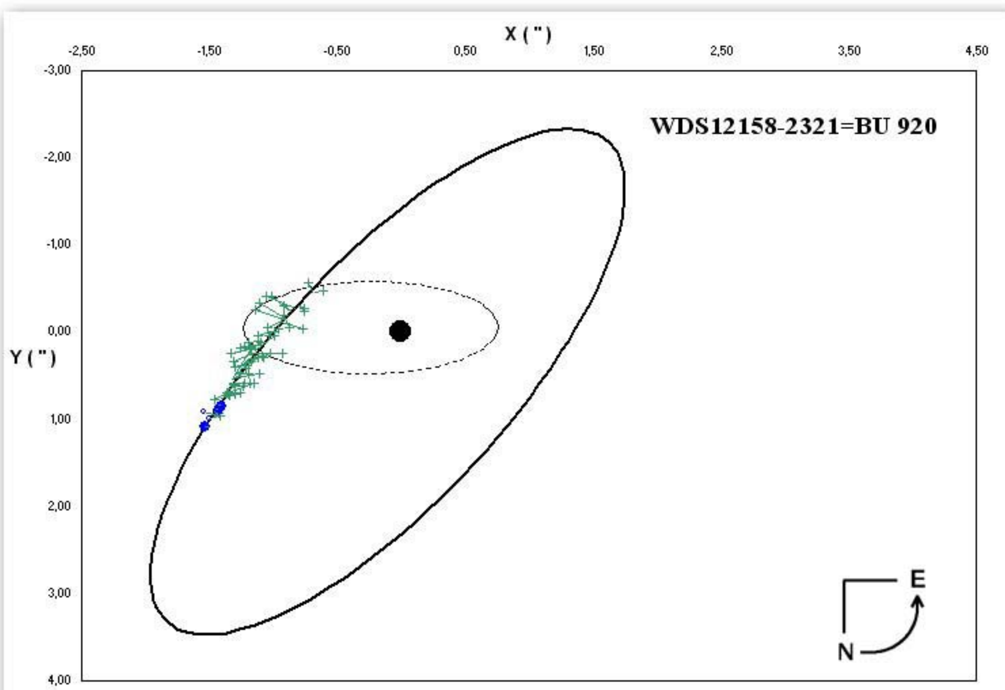

Figure 4: Apparent orbit of BU 920

This catalog was chosen because the Hipparcos proper motions could be affected by Keplerian motion due to its smaller time baseline. Historical astrometric data were supplied kindly by Mason. Spectral types and other astrophysical data were taken from other sources.

The details about the process to estimate spectral types and luminosity classes for the members, the calculus of interstellar reddening, determination of the nature for the stellar systems, the expected semi-major axis and the orbital period were explained in detail in an earlier paper (Rica 2008).

5.2 STF 333 C.

The component C of STF 333 is a star of 12.7 magnitudes (from WDS) at about 145.0 arcsec to the primary component. It was measured for the first time in 1912 by Burnham (1918) when the angular separation was 145.4 arcsec. But later, an earlier measure on 1896 was added from the WFC (Urban *et al.* 1998). Since then, it has been measured only 4 times, the last in 1998 from 2MASS catalog.

Using these four measures I calculated that the relative motion of C with respect to A was: $\Delta x = -4.6 \pm 1.3$ mas/yr and $\Delta y = +3.5 \pm 2.9$ mas/yr. The time baseline of the 4 measures used was nearly 102 years. The proper motion of C was calculated using the proper motion of A and the relative motion of C: $\mu(\alpha) = -14.0 \pm 1.8$ mas/yr and $\mu(\delta) = +1.5 \pm 4.1$ mas/yr. The UCAC-2 catalog lists a proper motion of $\mu(\alpha) = -14.0 \pm 1.9$ mas/yr and $\mu(\delta) = 0.0 \pm 1.9$ mas/yr in good agreement with our result.

Using the magnitude r from CMC14 and JHK from 2MASS, I determined the V magnitude for C using the relation of John Greaves (private communication; see Rica 2011). The result was V = 12.51 ± 0.06. In order to obtain another independent result for V magnitude, I obtained calibrated photometric data from GSC 1.2 catalog, using Tycho-2 stars for the region of the sky where the component C is located. A magnitude V = 12.48 ± 0.40 was calculated.

No spectral type information was found in the literature. Using V magnitude, JHK photometric data from 2MASS, and proper motion, a spectral type of K0V was determined. But this stellar system is behind the dark nebula MBM12 and could be very reddened. A value of E(B-V) = +0.32 was calculated. This suggests that the C component is an F8V star at a distance of about 322 pc.

In order to determine the nature of the wide C component, several tests were used: Dommanget test (1955, 1956), van de Kamp test (1961), Sinachopoulos & Mouzourakis test (1992). Consult Benavides et al. (2010) for detailed information about these criteria. The component C is not bound gravitationally to the A component.

5.3. S 423 AB-C.

The C component (HD 18445 = HIP 13769) of the WDS 02572-2458 stellar system is a star of magnitude 7.84 (ESA 1997) at about 29 arcsecs to BU 741 AB. It was measured for the first time in 1824 by South (1826) when the angular separation was of 27.75 arcsecs from the AB close pair. Since then, it has been measured 32 times, the last in 2008 by Anton (2010) when the angular separation was of 28.93 arcsecs.

According to the data from the Hipparcos satellite, the trigonometric parallax is 38.35 ± 1.24 (distance of 26.1 +/- 0.9/-0.8 pc with magnitudes and colors V = +7.83; B-V = +0.960 ± 0.006 and V-I = +0.95 ± 0.01.

Beuzit *et al.* (2004) discovered in 2000 that C is a binary star (the binary star was called BEU 4 Ca, Cb). At that moment, Cb component was at 0.083 arcsecs to Ca in direction 170.1 deg. Beuzit *et al.* observed a difference of 0.02 magnitudes in K band and Tokovinin, Mason, & Hartkopf (2010) determined a difference of 0.4 magnitudes in R band. Since its discovery, BEU 4 Ca, Cb has been measures three times.

I calculated the relative motion of C with respect to AB: $\Delta x = -16.8 \pm 0.6$ mas/yr and $\Delta y = +3.1 \pm 0.6$ mas/yr. The time baseline of the 32 measures used was nearly 184 years. The proper motion of C is listed in Tycho-2 catalog: $\mu(\alpha) = +15.0 \pm 1.2$ mas/yr and $\mu(\delta) = -32.6 \pm 1.3$ mas/yr in good agreement with our results.

In the literature, the C component is listed as a K2V star (Houk (1988) and Montes *et al.* (2001)) and as a K3V star of [Fe/H] = -0.09 ± 0.06 (Gray *et al.* 2006). In this work, I used the BVI photometry from Hipparcos and JHK photometry from 2MASS to obtain a K3V spectral type.

In order to determine the nature of the wide C component, I estimate that AB and C are at the same distance at a 2σ level (Hipparcos lists a trigonometric parallax of 44.51 ± 2.09 for AB and 38.35 ± 1.24 for C (Leuwann 2007)). The proper motions for AB and C are mathematically incompatible, but taking into account that they are nearby stars, the relative motion could be caused by the orbital motion. The radial velocity for the components is an excellent test. In the literature the radial velocity for C ranges from +49.5 ± 0.2 km/s (Kharchenko *et al.* 2007) to +51.6 km/s

(Valenti & Fischer 2005). Other values: +49.6 ± 0.5 km/s (Montes *et al.* 2001); +49.877 ± 0.222 km/s (Nidever *et al.* 2002); +49.7 ± 0.2 km/s (Gontcharov 2006). For AB pair, the radial velocity in the literature range from +50.4 to +50.7 km/s and so AB and C has nearly the same radial velocity within error margins.

I have used several tests (those of Dommanget (1955, 1956), Peter van de Kamp (1961) and Sinachopoulos & Mouzourakis (1992)) that are based on astromechanics. They are detailed in Benavides *et al.* (2010). The Dommanget test determined that C would be bound to AB if the stellar system is nearer than 26.9 pc. Since the mean distance for AB and C is 24.03 pc then, C could be bound to AB. The criterion of van de Kamp shows that the true critical value for a parabolic orbit is 236.9 $AU^3\ yr^{-2}$ while the observed projected critical value is of 118.2 $AU^3\ yr^{-2}$, smaller than the true value, so it is possible that C is bound to AB. The tangential velocity corresponding to the observed relative proper motion for C with respect to AB is 2.0 ± 0.1 km/s. Using the criterion of Sinachopoulos & Mouzou, a maximum orbital velocity (circular and face-on orbit assumed) of 2.1 km/s was calculated so C could be bound to AB. In summary, the three tests agree in the physical relationship of C with AB.

Using the expression obtained by Fischer & Marcy (1992) the expected semimajor axis is of 865 UA (about 35.6 arcseconds) and the orbital period of ~13,660 yrs (using the Kepler's Third Law and assuming circular and face-on orbit). The arc covered by this component is only of 5.38 deg. If I consider this angular motion as the mean motion then, a complete orbit will be covered in about ~12,300 yrs.

Burningham *et al.* (2009) used the method of Torres (1999) to obtain a relationship between ρ and $\boldsymbol{a}$. They assumed random viewing angles (i.e. random inclinations) and an uniform eccentricity distribution between 0 < e < 1 to derive a relationship of

then, the expected semimajor axis is

$$E(a) = \rho * 1.10^{+0.91}_{-0.36} \qquad (2)$$

And the orbital period is

$$E(a) = 31.8^{+26.3}_{-10.4}\ arc\sec \equiv 772^{+639}_{-253}\ AU$$

$$P \cong 12{,}400^{+18{,}277}_{-5{,}558}\ years$$

Search for New Bound Companions

I search for unreported bound companions using SIMBAD and VizieR tools to find common proper motion pairs, consulting astrometric catalogs and photographics plates. If the target is a near one then I search for companions by plotting the neighbor stars in a color-magnitude diagram where apparent 2MASS J-K and K data are plotted. A dwarf sequence to the distance of the target is also plotted. Dwarf companion candidates must be located on or near this dwarf sequence. Subdwarf or white dwarf companions will be not detected unless I use reduced proper motion diagrams. Giant companions will be bright enough to be detected and they will be located well above the dwarf sequence.

The expression of Abt (1988) which relates stellar masses of the primary with the maximum projected separation (in A.U.) was used to define the sky region to search. I selected our companion candidates consulting 2MASS where only stars located within the search region and with a S/N > 10 were selected.

Conclusions

The increase of residuals for the last orbital solutions for WDS 02572-2458 (BU 741 AB), WDS 02592+2120 (STF 333 AB), WDS 12158-2321 (BU 920) and WDS 12463-6806 (R 207) indicated that a new revision was needed. The Thiele-Innes-van den Boss method and Docobo analytical method were used to determine new orbital elements.

The orbit for STF333 is preliminary and very different from the orbit calculated by Coster (2009). In the next 10 years the difference in the ephemeris for rho is 0.03 - 0.04" so we should be able to determine in the next years which orbit is the nearest to the correct one. In this work theoretical isochrones confirm the subgiant nature for both members with an age of about 550-650 Myr, matching the age for its membership in the Ursa Major moving group.

The new orbit of R 207 has a smaller period and semimajor axis than the previous orbit. In this work I estimate an age of about 100 Myrs.

BU 920 shows clear and large residuals in the last years. The motion is large and rectilinear and the new orbit was very different from the previous orbit. Using evolutionary isochronal, I determined that the primary could be a slightly evolved star.

The separation for BU 741 AB has started to close

Orbital Elements for BU 741 AB, STF 333 AB, BU 920 and R 207

in the last years, increasing the residuals. The new orbit makes slight corrections to the previous orbit. In 2012 the calculated relative radial velocity will be -9.1 km/s, when the secondary is at 0.815 arcsec of angular distance. This would be a good time for the system to be observed spectroscopically.

STF 333 AB has a wide optical component of 12.7 magnitude and K0V spectral type. BU 741 AB has a bright physical companion (listed as S 423 C) of 7.84 magnitude at a separation of 29". The semimajor axis is about 772 AU and the orbital period is about 12,400 years.

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