Orbit Determination of Close Binary Systems

F. M. Rica
Editor of News Section, El Observador de Estrellas Dobles (OED) Magazine, Spain
frica0@gmail.com

H. Zirm
Markt Schwaben, Germany
binary71@gmx.de

Abstract: Several years ago we published in IAU circulars the orbital parameters for 6 close binary stars (A 957, HEI 35, A 2833, STF1554, BU 606, I 952). These were the first orbits ever published for those close binaries. The Docobo's method of orbital calculation was used to determine the orbital solutions and it was then improved by using a least square process. A weighting scheme was followed for all astrometric measures (individually for theta and rho). All these orbital solutions are still the most recent published orbits for these binaries.

In this article we publish for the first time, the astrophysical study, the orbit plots and all the astrometric measures with their residuals and ephemerides for these objects.

1. Introduction

In the circular number 174 (June 2011) of IAU G1 Commission, we published the orbital solutions for six close visual binary stars. These orbits were the first calculated for these objects (the literature search produced no evidence of previously computed orbits). These orbital solutions are still the most recent published.

That circular only published the orbital parameters. The orbital plots, the ephemerids for the next few years, the tables with measures, the astrophysical data, etc. are published in this article for the first time. The calculated periods range from 29 to 708 years. The measurements were mostly obtained from the Washington Double Star Catalogue by request from Brian Mason & colleagues.

All the orbits are calculated with the algorithm described in Docobo (1985). The three base points have been chosen carefully from the observational data that seemed most reliable with respect to instrumentation, data density, or critical arc coverage. We also tried to cover as much of the observed arc as possible. Often, we use a parabolic or cubic fit to $\theta(t)$ and $\rho(t)$ to obtain the base points. This may let the area around a single observation represent a base point without additional observational coverage.

Finally, we applied least squares refinement to the preliminary elements by using the formula for differential corrections in polar coordinates (Heintz 1967). The uncertainties of the elements were obtained by the covariance matrix of the normal equations and the sum of the residuals in position angle and separation.

The weights for speckle measures follow the scheme described by Mason (1999). For initial weightings on visual measurements, we choose the algorithm described by Docobo & Ling (2003). The proposal by Heintz (1967, 1978) to reduce the weights for the distances from visual measurements by a factor of 1:4 to 1:5 was used in most cases. Position angles are corrected for precession, Equinox 2000.

The organization of this paper is as follows. In Section 2, we present the general methods for our astrophysical procedures and the data table and figures are published. In Section 3, we include general information for each of the binaries studied.

2. General Information

2.1. Astrophysical procedure

To obtain astrophysical data (spectral type, masses, etc.) of the individual component of close binaries, we used a tool designed by one of us (called Binary_Deblending_Tool) that deblends the combined observed multi-band photometry (Hipparcos, Tycho-2, 2MASS, etc.) into two separate entries corresponding to both stellar components. To create the input table for this tool, we used the CMD 2.7 isochronal to the related photo-metric bands and colors with astrophysical properties. The tool searches in this table for two entries that matches with observational data (multiband photometry, Dmag, reddening and parallax) and selects those which give minimum χ^2.

GAIA-DR2 does not list useful data for these bright and close binary stars.

The reddening in the line of sight was estimated using the maps of Schlegel, Finkbeiner, and Davis (1998) and the more recent of Schlafly and Finkbeiner (2011). The resulting values were scaled to the initial distance using the formula published by Anthony-Twarog, and Twarog (1994).

2.2 Table data and Figures

First, general information about the systems is discussed, followed by important identifications and the calculated orbital elements in Table 3. A comparison of the recalculated Hipparcos parallaxes (van Leeuwen 2007) with the dynamical parallaxes, the resulting masses, absolute magnitudes, and determined spectral types for the individual components can be found in Table 4. The calculation of the dynamical parallaxes and masses follows the Baize-Romani algorithm described by Heintz in 1978. The calculated ephemerids for 2020, 2021, 2022, 2023 and 2024 are available at Table 5. At the appendix we list the astrometric measurements compared with calculated residuals. Finally we show the orbital plots. Tables 6-11 lists the observations for each binary star. The columns are from left to right: the date of the observations, the position angle and angular separation, the number of nights observed, the WDS reference of the publication, the aperture of the telescope (in meters), WDS codes. All these columns are taken directly from WDS. And finally, we list the O-C for θ and ρ. The plots in Figures 1 - 6 came from USNO catalog Sixth Catalog of Orbits of Visual Binary Stars

3. Description of the Close Binary Stars

WDS 02048+6030 = A 957 = ADS 1632

Mag. 8.52 and 10.48. Spectral type F8V.
First measurement: 1905.82
Last measurement: 2011.8569
Used observations: 21

The components are cataloged as HD 12529 and were first resolved by R. G. Aitken in 1905. Since then it has shown relatively consistent visual measurements showing a clear curved arc of about 100 degrees. But the typical scatter in visual measures in regard to the average distance of 0.5 arc seconds makes the calculation of an orbit very difficult. However, our derived orbit is marked as preliminary solution. After the publication of our orbit, two new astrometric points were included in WDS catalog. The residuals for these recent observations suggest that the orbit is opening and that the orbital period is greater than the calculated value (220 years).

This is a system rich in metals (Nordstrom et al. 2004; Casagrande et al. 2011) with an age of 3-4 Gyr and located at 97 pc. The literature shows combined spectral types that ranges from F8V to G2V. Our astrophysical study concludes that this stellar system is composed of F5V and G8V (masses of 1.3 and 0.9 $M_\odot$) stars. The astrophysical parameters were corrected by a reddening of E(B-V) ≈ 0.05. Table 1 lists observed photometric data and compares them with the synthetic photometry determined by using our excel tool Binary_Deblending_Tool. Table 2 lists the individual astrophysical properties for both stellar components deter-

(Continued on page 33)

	Observed Photometry	Source	Syntetic Photometry	Difference
U	...	...	...	
B	8.83 ± 0.01	Hipparcos	8.78	0.05
V	8.22 ± 0.01	Hipparcos	8.21	0.01
I	7.54 ± 0.01	Hipparcos	7.57	-0.03
J	7.12 ± 0.02	2MASS	7.15	-0.03
H	6.84 ± 0.02	2MASS	6.94	-0.10
K	6.80 ± 0.02	2MASS	6.87	-0.06
B-V	0.61 ± 0.02	Hipparcos	0.57	0.04
V-I	0.68 ± 0.02	Hipparcos	0.64	0.04
V-K	1.42 ± 0.02		1.35	0.07
J-H	0.28 ± 0.03		0.21	0.07
H-K	0.04 ± 0.02		0.07	-0.03
J-K	0.28 ± 0.03		0.21	0.07

Table 1. Comparison of observed and synthetic data for A 957

	Comp. A	Bomp. B
V	8.30	10.20
(B-V)o	0.48	0.70
Mv	3.40	5.30
Mass [$M_\odot$]	1.37	1.08
Teff [°K]	6488	5793
log g	0.6	0.8
SpT	F5V	G8V
Distance [pc]	97	
Age [Gyr]	1.4	

Table 2. Astrophysical Data for the Binary A 957

Orbit Determination of Close Binary Systems

WDS	HD	ADS	P^{yr}	T	e	a″	i°	ω°	$\Omega°_{2000}$
D.D.	HIP	other	±	±	±	±	±	±	±
02048+6030	12529	1632	219.97	1870.07	0.462	0.471	125.3	250.1	107.7
A 957	9704		-	-	-	-	-	-	-
04102+1722	285465	-	28.91	2000.53	0.832	0.282	115.7	35.9	165.9
HEI 35	19472		± 1.50	± 0.01	± 0.007	± 0.008	± 0.7	± 1.5	± 0.9
06549+1158	50722	5571	209.09	1987.13	0.927	0.429	43.1	240.7	107.2
A 2833	33240		± 35.98	± 0.19	± 0.010	± 0.040	± 4.6	± 8.3	± 8.9
11361+1251	100797	8230	478.88	1962.44	0.902	0.868	74.8	308.6	84.6
STF1554	56589		± 72.49	± 0.47	± 0.011	± 0.066	± 0.8	± 1.9	± 0.9
12260-1457	108215	8547	707.61	2009.44	0.383	1.441	96.9	123.6	100.1
BU 606	60665		± 36.19	± 6.63	± 0.052	± 0.188	± 3.9	± 4.5	± 6.3
14531-4638	131078	-	99.13	1981.39	0.659	0.521	156.1	268.1	27.1
I 952	72821		± 0.82	± 0.37	± 0.015	± 0.014	± 4.5	± 7.3	± 7.8

Table 3. Identification and orbital elements

WDS / D.D.	V_A / V_B	Sp.	B-V	π^{mas}_{trig} [1]	$\Sigma M/M^{sol}$	π^{mas}_{dyn}	$M/M_{sol\ A}$ / $M/M_{sol\ B}$	$M_{vis\ A}$ / $M_{vis\ B}$
02048+6030	8.5	F5V+G8V	0.61	10.28 ±1.19	2.0	9.8	1.4	3.5
A 957	10.5						0.9	5.4
04102+1722	9.5	K2V+K6V	1.07	26.98	1.37	28.1	0.72	6.7
HEI 35	10.9			±2.27	±0.37		0.50	8.2
06549+1158	8.3	F2IV+F2IV-V	0.39	7.68	4.0	8.6	1.6	3.0
A 2833	8.8			±1.24	±2.6		1.3	3.9
11361+1251	9.4	G0V+G0/1V	0.58	10.25	2.7	11.1	1.1	4.7
STF1554	9.5			±1.16	±1.3		1.0	4.9
12260-1457	7.4	F4V+G5V	0.51	14.07	2.1	13.3	1.6	3.1
BU 606	9.4			±0.69	±0.9		1.0	5.0
14531-4638	8.5	G5V+K1V	0.70	20.96	1.6	20.6	1.0	5.1
I 952	10.1			±1.06	±0.3		0.7	6.7

Table 4. Astrophysical Data

Remarks: The individual visual magnitudes for each component are calculated from combined visual magnitudes adopted from Hipparcos catalogue and the visual magnitude difference adopted from WDS catalogue. Note 1 is the parallax adopted from Van Leeuwen 2007. Note 2 marks the estimation as main sequence stars.

WDS	2020		2021		2022		2023		2024	
	ϑ_{2000} (°)	ρ (")	ϑ_{2000} (°)	ρ (")	ϑ_{2000} (°)	ρ (")	ϑ_{2000} (°)	ρ (")	ϑ_{2000} (°)	ρ (")
02048+6030	2.1	0.368	0.8	0.368	359.4	0.367	358.0	0.367	356.6	0.367
04102+1722	321.1	0.357	319.1	0.332	316.7	0.303	313.8	0.271	310.1	0.235
06549+1158	142.8	0.481	143.1	0.487	143.5	0.494	143.8	0.500	144.2	0.507
11361+1251	220.2	0.338	220.8	0.344	221.3	0.351	221.8	0.357	222.3	0.363
12260-1457	286.6	0.655	286.3	0.668	286.1	0.681	285.8	0.695	285.6	0.708
14531-4638	311.3	0.766	310.2	0.771	309.0	0.774	307.9	0.778	306.8	0.781

Table 5. Ephemerides

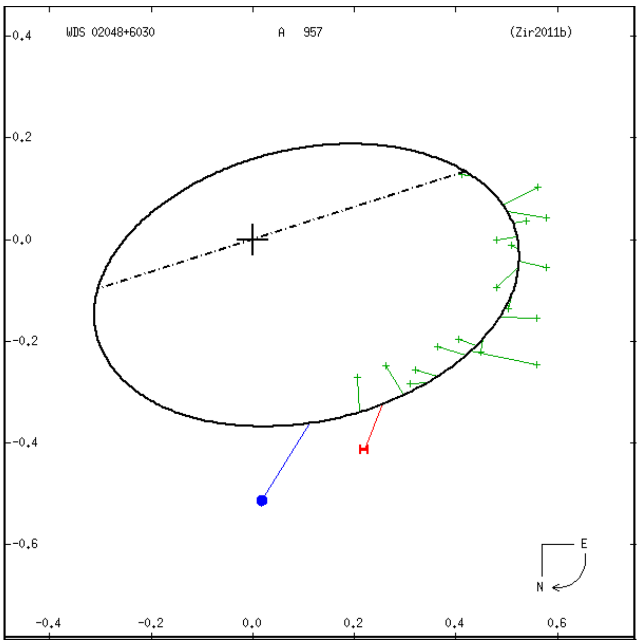

Figure 1. WDS 02048+6030

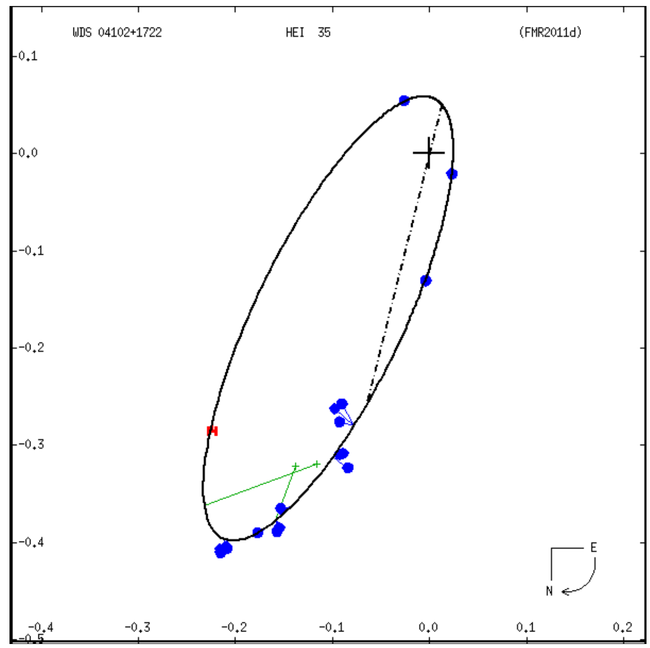

Figure 2. WDS 04102+1722

mined by us using the Excel tool.

The dynamic parallax and dynamic masses are in good agreement with the Hipparcos trigonometric parallax and the expected masses.

The 2012 measure was performed by Francisco Rica using the 1.5-m Carlos Sánchez Telescope and the Fastcam lucky Imaging Camera. It is published here for the first time. For more detail about the instrument used, see Rica et al. (2012).

WDS 04102+1722 = HEI 35

Mag. 9.46 and 10.93; spectral type K5
First measurement: 1979.00
Last measurement: 2016.1338
Used observations: 22

This is a faint system (HD 285465) with high proper motion located in the Hyades open cluster. It was discovered in 1979 by W. D. Heintz and is composed of two stars with a visual brightness difference of 1.5 magnitudes and a medium-K spectrum. It has been measured in 22 occasions, many of them by Elliot Horch. The astrometric measures used for the orbital calculation (up to 2008.69) cover more than one revolution. The work of Y. Y. Balega since 1999 shows a rapid movement nearing a periastron phase. Observations by E. Horch up to now consistently show increasing distances from similar positions nearly 30 years old, observed by Heintz. Since our publication of the orbit in 2011, several astrometric points were published showing small residuals with respect our orbit.

Literature lists combined spectral types of K3 (Bidelman 1985) and K4V (Pickles & Depagne 2010) which is in agreement with our combined spectral type. Our astrophysical study concludes that this stellar system is composed of K2V and K6V stars. The astrophysical parameters were corrected by a reddening of E(B-V) ≈ 0.05. The dynamic parallax and dynamic mass are in good agreement with the Hipparcos trigonometric parallax and the expected masses.

WDS 06549+1158 = A 2833 = ADS 5571

Mag. 8.3 and 9.2; spectral types F5
First measurement: 1914.51
Last measurement: 2008.111
Used observations: 18

This binary system (HD 50722) was discovered by Aitken in 1914, and up to the present day 18 observations have been made. One measurement, obtained by Argue in 1987 via CCD technique, was not used for the calculation. This measurement is listed in the WDS catalog with the comment "... Identification error, position error, or misprint in publication, NOT corrected..." and the calculated theoretical position at this epoch seems to confirm the fact that cannot be the same component. Several tests with different basis points (using Docobo orbital method) showed that the Hipparcos measurement must be assigned a significantly reduced weight (compared to the last speckle measurement).

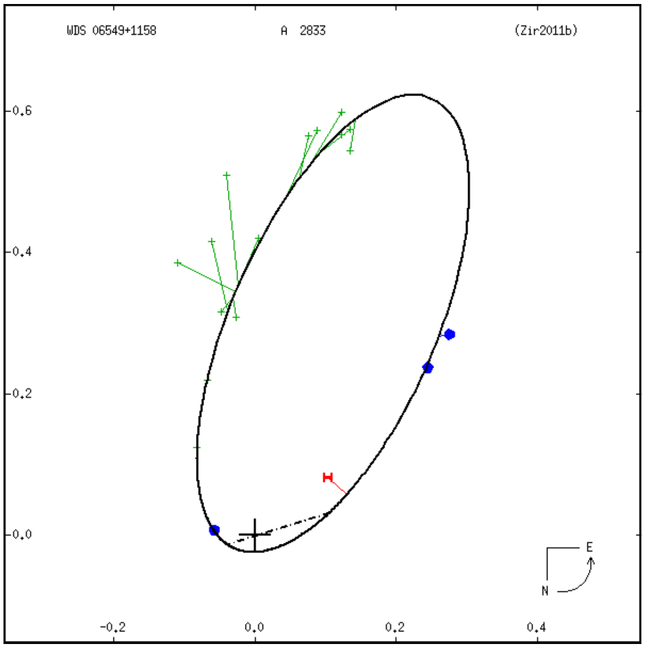

Figure 3. WDS 06549+1158

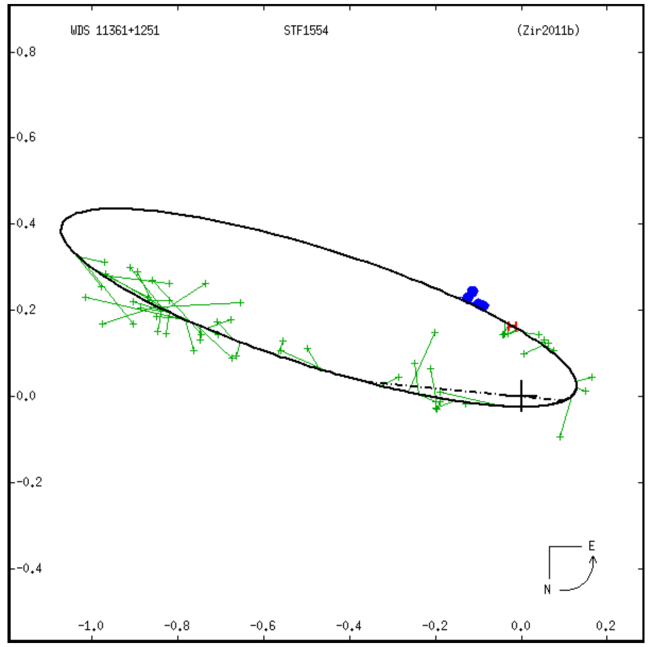

Figure 4. WDS 11361:1251

This binary is listed in the literature as a F5 (ppN catalog) and as a F5IV star by Pickles, Depagne (2010). Fehrenbach, Burnage & Figuiere (1992) catalogued it as a low metallicity star, [Fe/H] = -0.29, with an age of 2.3 Gyr. In this work, we determined the absolute magnitudes from apparent individual components (8.28 and 8.75) and Hipparcos trigonometric parallax. The differential magnitude of Hipparcos has a very significant error and so we don't use its individual photometry. Instead, we use the Hipparcos combined V magnitude and the mean differential magnitude from the WDS historical data. Using evolutionary isochrones for the metallicity listed in the literature and different ages, we determine a stellar age of about 2.2 Gyr (in excellent agreement with the literature) and spectral types of F2IV and F2IV-V. The astrophysical parameters were corrected by a reddening of E(B-V) ≈ 0.02.

Our calculations produced a very eccentric orbit (e = 0.93). The dynamic parallax and dynamic mass are in moderate agreement with the Hipparcos trigonometric parallax and the expected masses.

WDS 11361+1251 = STF1554 = ADS 8230:

Mag. 9.4 and 9.6; spectral types G5
First measurement: 1829.29
Last measurement: 2010.3510
Used observations: 57

This pair (HD 100797) was discovered by Struve in 1829. Nearly 120 years later, there are 57 astrometric measures of its long period orbit. The period is about 480 years and the periastron passage of this eccentric orbit occurred in 1962.

This object has been very poorly studied and no radial velocity and spectral types (except those of Cannon & Pickering 1918) were obtained. Hipparcos determined a distance of 98 pc (GAIA-DR2 does not list this star). Astronomical literature shows combined spectral types of G5 (Cannon & Pickering 1918) and a photometrically determined spectral type of F8V (Pickles & Depagne 2010), in excellent agreement with our results using BVIJHK combined photometry. Therefore, the G5 spectral type listed in Hipparcos catalog must be in error.

Our astrophysical study concludes that this stellar system is composed of G0V and G0/1V stars. The CMD 2.7 isochrone gives two stars with an age of about 3 Gyr. The astrophysical parameters were corrected by a reddening of E(B-V) ≈ 0.01. The dynamic parallax and dynamic mass are in good agreement with the Hipparcos trigonometric parallax and the expected masses.

WDS 12260-1457 = BU 606 = ADS 8547:

Mag. 7.4 and 9.4. Spectral type F6V
First measurement: 1878.3
Last measurement: 2016.3699
Used observations: 24

Orbit Determination of Close Binary Systems

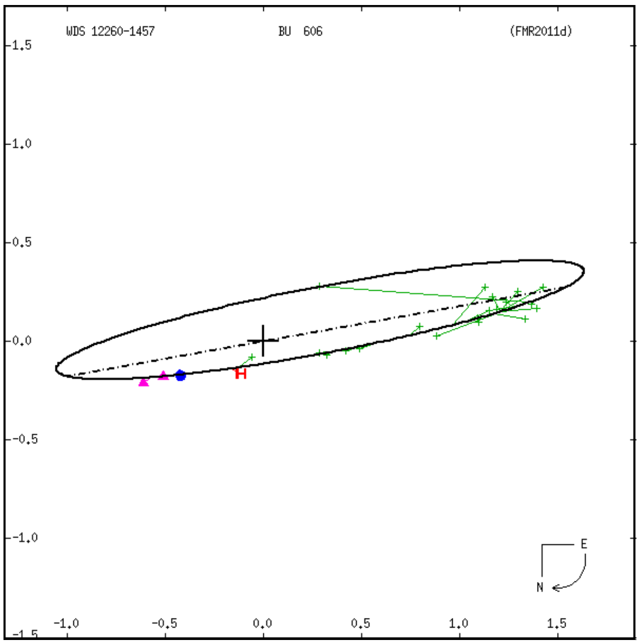

Figure 5. WDS 12260-1457

The components of this binary star (HD 108215) were first resolved by Burnham in 1878. Currently it has 24 measures which are all micrometric except that of Hipparcos satellite. In 138 years, the measures have covered a large, nearly rectilinear arc of about 167 degrees. The older visual measures have significant residuals.

This pair is composed of stars with V magnitudes of 7.32 and 9.26 (Hipparcos magnitudes converted to V band). The Tycho-2 catalog lists a proper motion of -118.3 ± 1.6 mas yr^{-1} in RA and -25.1 ± 1.5 mas yr^{-1} in DEC. The re-reduced (Leeuwen 2007) Hipparcos trigonometric parallax corresponds to a distance of pc. For this distance we calculated a reddening of E(B-V) = 0.02 which was used for our study.

In astronomical literature, BU 606 has been classified as a F6V (Houk & Smith-Moore 1988) or F7V (Abt 1981) star. From combined and differential photometry, we estimated individual spectral types F4V and G5V. Absolute magnitudes +3.1 and +5.1 were calculated using Hipparcos data, which matches the spectral types estimated.

The large linear motion invites the investigation of the nature of the pair of stars. The observed velocity was calculated using the historical measures, with non-zero weights, which covers a time baseline of nearly 128 years (using astrometric data up to 2006). Our result was an apparent motion of -15.42 ± 0.40 mas yr^{-1} in E-W direction and +3.17 ± 0.16 mas yr^{-1} in N-S direction. So, the secondary is moving to the WNW 15.74 ± 0.43 mas yr^{-1} and at the distance of 71.1 pc corresponds to a projected and relative velocity of 5.30 ± 0.15 km s^{-1}. A Monte Carlo simulation shows that the projected observed velocity was less than the escape velocity in 100% of the simulations. We conclude that BU 606 stellar components are gravitationally bound.

Holmberg, Nordström & Andersen (2009) calculated a galactocentric velocity of (U, V, W) = (-33, -20, -16) km s-1 and an age of about 2.6 Gyr. According to this kinematic, this system is a member of the young galactic disk. The calculated fG = 0.18 (Grenon parameter), corresponding to young-middle age thin disk stars of 3-4 Gyr old. This binary is an X-ray emitter whose luminosity in this band suggests that has an age of about 0.1-0.6 Gyr while the projected rotation velocity of 13.5 km/s calculated by Glebocki & Gnacinski (2005) and 15.0 km/s calculated by Nordström (2004) also suggest an age between those of Pleiades and Hyades open clusters. This age is in contradiction with the kinematical age. One possible explanation is that one of the stars is an unresolved and very close binary with synchronized orbital periods.

The derived orbit is very inclined and passed periastron in 2009. The orbital solution presented here is very preliminary. The dynamic parallax and total stellar masses are consistent with Hipparcos trigonometric parallax and with the stellar masses obtained using their spectral types.

A total mass of 2.2 ± 0.4 $M_\odot$ was obtained using our orbital parameters and the Hipparcos trigonometric parallax. This value is in good agreement with that calculated using Baize-Romaní method (1.56 + 0.98 = 2.54 $M_\odot$) and with that calculated from spectral types (2.27 $M_\odot$).

WDS 14531-4638 = I 952:

Mag. 8.5 and 10.1. Spectral type G5V.
First measurement: 1910.6
Last measurement 2013.1276
Used observations: 14

The components of this system were first resolved by Innes in 1910. The last three measures (since 1996) were taken (by Mason and Tokovinin) using speckle technique. The observations span about 103 years, similar to the orbital period, and therefore they cover a complete revolution. The dynamic parallax and total stellar masses are consistent with Hipparcos trigonometric parallax and with the stellar masses obtained using their spectral types. From combined photometric and spec-

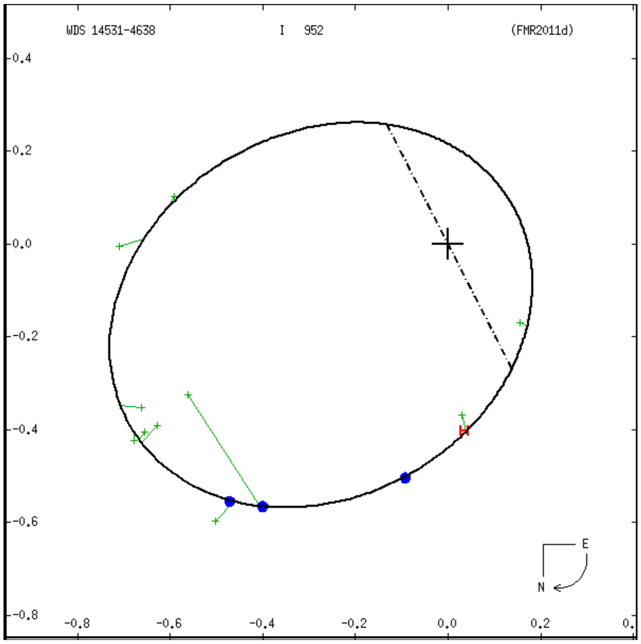

Figure 6. WDS 14531-4638

troscopic data in addition of the differential V magnitude, the individual spectral types of G5V and K1V were determined.

Acknowledgements

This research has made use of the Washington Double Star Catalogue maintained at the U.S. Naval Observatory, the NASA Astrophysics Data System Bibliographic Services and the SIMBAD database (operated at CDS, Strasbourg, France). The authors thank Frank Smith for their respective reviews of this work.

References

Abt, H. A. 1981, *ApJS*, **45**, 437.

Anthony-Twarog B. J., Twarog B. A. 1994, *AJ*, **107**, 1577.

Bidelman, W. P., 1985, *ApJS*, **59**, 197.

Cannon A.J., Pickering E.C. <Harv. Ann. 91-100 (1918-1924)>

Casagrande L. et al., 2011, *A&A*, **530**, 138.

Docobo, J.A., 1985, *CeMec*, **36**, 143.

Docobo, J. A.; Ling, J. F., 2003, *A&A*, **409**, 989.

Fehrenbach, Ch.; Burnage, R.; Figuiere, J., 1992, *A&AS*, **95**, 541.

Glebocki R., Gnacinski P., 2005, *csss*, **13**, 571.

Heintz, W. D., 1978, *Double Stars* (revised edition), Dordrecht, D. Reidel Publishing Co. (*Geophysics and Astrophysics Monographs. Volume 15*), (1978GAM....15.....H).

Heintz, W.D, 1967, *ActaAstr.*, **17**, 311.

Houk N., Smith-Moore M., 1988, Ann Arbor, Dept. of Astronomy, Univ. of Michigan.

Mason, B. D., Douglass, G.G., Hartkopf, W. I., 1999, *AJ*, **117**, 1023.

Nordstrom B. et al., 2004, *A&A*, **418**, 989.

Pickles A., Depagne E., 2010, *PASP*, **122**, 1437.

Rica, F. M., Barrena, R., Vázquez. G., Henríquez, J. A., Hernández, F. et al. 2012, *MNRAS*, **419**, 197R.

Schlafly & Finkbeiner, 2011, *ApJ*, **737**, 103.

Schlegel D.J., Finkbeiner D.P., & Davis M., 1998, *ApJ*, **500**, 525.

van Leeuwen, F., 2007, *Hipparcos, the New Reduction of the Raw Data*, Springer, New York (data obtained from Simbad data base: I/311)

Appendix 1. Observational Data and Residuals

The values in parentheses are the calculated theoretical positions for a given epoch.

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1905.8200	107.2	0.43	3	A__1906a	0.9	Ma		1.8	-0.02
1915.6400	100.4	0.57	1	A__1929a	0.9	Ma		3.0	0.07
1917.8200	94.2	0.58	2	A__1929a	0.9	Ma		-1.6	0.08
1921.6300	93.9	0.54	2	A__1929a	0.9	Ma		0.9	0.03
1925.8200	89.8	0.48	1	A__1929a	0.9	Ma		-0.3	-0.04
1929.7900	88.8	0.51	2	A__1933d	0.9	Ma		1.3	-0.01
1933.7700	84.6	0.58	2	Kui1961b	0.3	Ma		-0.2	0.05
1935.2600	78.9	0.49	2	VBs1954	1.0	Ma		-4.9	-0.04
1943.7900	74.9	0.52	1	VBs1954	2.1	Mb		-3.2	0.00
1952.4000	74.6	0.58	2	Mrz1956	0.7	Ma		2.5	0.07
1960.0200	63.8	0.50	1	Cou1962a	0.4	Ma		-2.7	0.01
1962.7500	64.1	0.45	4	B__1963b	0.9	Ma		-0.3	-0.04
1965.1500	66.2	0.61	2	Baz1967	0.4	Ma		3.7	0.13
1966.7120	60.0	0.42	4	Wor1971	0.7	Ma		-1.3	-0.06
1975.8800	51.4	0.41	3	Hei1978b	0.6	Ma		-2.1	-0.04
1978.8900	47.7	0.42	3	Hei1980a	0.6	Ma		-3.0	-0.02
1985.7400	46.6	0.36	2	Hei1987a	0.6	Ma		2.6	-0.07
1991.2500	28.0	0.468	1	HIP1997a	0.3	Ht		-10.2	0.056
1997.0400	37.2	0.34	2	Hei1998	0.6	Ma		5.5	-0.06
2008.764	**2.0**	**0.514**	**1**	**Gii2012**	**0.7**	**S**		**-15.2**	**0.136**
2011.8569	**39.4**	**0.3**	**1**	**Gur2018**	**2.1**	**S**		**26.2**	**-0.074**
2012.7263	**356.5**	**0.447**	**1**	**Fmr9999**	**1.5**	**Cl**		**15.5**	**0.074**

Table 6. Measurements of WDS 02048+6030

Orbit Determination of Close Binary Systems

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1979.00	336.7	0.35	3	Hei1980a	0.6	Ma		-0.4	-0.06
1986.99	340.0	0.34	3	Hei1987a	0.6	Ma		12.7	-0.09
1991.25	322.0	0.363	1	HIP1997a	0.3	Hh		1.2	0.010
1999.8185	205.6	0.060	1	Bag2004	6.0	S		0.1	0.001
2000.8760	47.6	0.031	1	Bag2006b	6.0	S		0.1	0.000
2001.7585	358.4	0.131	1	Bag2006b	6.0	S	q	0.7	-0.001
2004.1126	340.7	0.273	1	Hor2008	3.5	S		-3.7	-0.018
2004.1126	341.4	0.291	1	Hor2008	3.5	S		-3.0	0.000
2004.1126	339.6	0.280	1	Hor2008	3.5	S		-4.8	-0.011
2004.8241	343.4	0.323	1	Bag2007b	6.0	S		0.8	0.001
2004.9726	345.4	0.334	1	Hor2008	3.5	S		3.1	0.006
2004.9726	343.9	0.321	1	Hor2008	3.5	S		1.6	-0.007
2007.0041	337.2	0.396	1	Hor2010	3.5	S		-1.4	0.006
2007.8178	338.0	0.419	1	Hor2010	3.5	S		0.6	0.011
2007.8204	338.1	0.415	1	Hor2010	3.5	S		0.7	0.007
2008.6900	335.6	0.428	1	Hor2009	3.5	S		-0.6	0.005
2011.6906	**332.1**	**0.4607**	**1**	**Hor2017**	**3.5**	**S**		**0.0**	**0.012**
2011.6906	**332.3**	**0.4636**	**1**	**Hor2017**	**3.5**	**S**		**0.2**	**0.015**
2011.8543	**333.1**	**0.46**	**1**	**Gur2018**	**2.1**	**S**		**0.9**	**0.011**
2012.0949	**332.6**	**0.4557**	**1**	**Hor2017**	**3.5**	**S**		**0.7**	**0.007**
2012.0949	**332.8**	**0.4565**	**1**	**Hor2017**	**3.5**	**S**		**0.9**	**0.008**
2016.1338	**327.3**	**0.4529**	**2**	**Tok2018c**	**4.1**	**St**		**0.3**	**0.026**

Table 7. Measurements of WDS 04102+1722

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1914.51	166.0	0.56	2	A__1914c	0.9	Ma		0.0	-0.05
1921.89	167.8	0.58	2	A__1932a	0.9	Ma		0.0	0.00
1929.20	166.8	0.59	1	Fur1932	0.7	Ma		-3.0	0.04
1933.22	168.4	0.61	2	Fur1932	0.7	Ma		-2.7	0.08
1938.21	172.4	0.57	3	Baz1942b	0.3	Ma		-0.3	0.06
1942.88	171.2	0.58	3	Vou1955	0.4	Ma		-3.2	0.10
1961.15	184.5	0.51	3	Cou1962a	0.4	Ma		1.0	0.15
1961.85	179.4	0.42	2	Cou1962b	0.9	Mb		-4.6	0.07
1962.25	195.9	0.40	4	Hei1963b	0.3	Ma		11.6	0.05
1963.017	188.5	0.32	4	Wor1967b	0.7	Ma		3.6	-0.02
1963.10	184.9	0.31	4	B__1963b	0.9	Ma		-0.1	-0.03
1965.25	188.3	0.42	4	Hei1967b	0.3	Ma		1.6	0.10
1973.12	197.0	0.23	3	Hei1975a	0.6	Ma		1.5	-0.01
1978.12	213.6	0.15	3	Hei1980a	0.6	Ma		8.2	-0.03
1985.8408	262.6	0.058	1	McA1987b	4.0	Sc	P	-0.4	0.000
1987.03	100.0	0.74	1	Aru1992	1.0	C	T	(327.1)	(0.03)
1991.2500	128.0	0.132	1	HIP1997a	1.4	Hh		13.9	-0.010
2004.2034	134.1	0.341	2	Hrt2008	1.5	Su		-0.7	-0.002
2008.111	**135.9**	**0.396**	**1**	**Gii2012**	**0.7**	**S**		**-1.3**	**0.012**

Table 8. Measurements of WDS 06549+1158

Orbit Determination of Close Binary Systems

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1829.29	255.4	1.01	3	StF1837	0.3	Ma		3.8	-0.10
1844.30	252.2	1.02	1	Mad1845	0.3	Ma	Q	-0.2	-0.06
1848.35	259.5	0.92	1	Mad1856	0.3	Ma	Q	6.9	-0.15
1856.28	255.2	0.90	1	Se_1860b	0.3	Ma	Q	2.1	-0.15
1866.30	252.2	0.86	3	D__1884	0.2	Ma		-1.5	-0.16
1892.81	254.8	0.85	4	Sp_1909	0.5	Ma		-0.7	-0.05
1896.50	252.0	0.94	4	A__1914d	0.3	Ma		-3.8	0.06
1898.32	260.2	0.99	2	Glp1899	0.2	Ma	Q	4.2	0.12
1899.28	251.5	0.69	1	Bry1899	0.7	Ma		-4.6	-0.18
1899.29	258.6	0.72	1	L__1899	0.7	Ma		2.5	-0.15
1900.33	259.9	0.86	2	Bow1900	0.7	Ma		3.7	0.00
1901.32	250.4	0.78	1	Bry1901	0.7	Ma		-5.9	-0.08
1901.38	251.9	0.96	1	L__1901	0.7	Ma		-4.4	0.10
1903.28	260.0	0.84	1	L__1903	0.7	Ma		3.6	0.00
1903.29	257.0	0.91	3	Bow1903a	0.7	Ma		0.6	0.07
1904.34	256.3	0.93	1	Bow1904a	0.7	Ma		-0.2	0.09
1906.28	253.6	1.01	1	Frm1907	0.2	Ma		-3.1	0.19
1908.32	257.7	0.87	3	Bow1908	0.7	Ma		0.8	0.06
1909.35	257.2	1.04	1	Bow1909	0.7	Ma	Q	0.2	0.24
1909.35	262.0	0.77	1	L__1909	0.7	Ma	Q	5.0	-0.03
1911.12	252.6	0.90	3	Doo1915b	0.5	Ma	Q	-4.6	0.11
1911.57	259.1	0.76	3	Wz_1923	0.5	Ma		1.9	-0.03
1912.25	262.4	0.68	3	Bow1921	0.7	Ma	Q	5.1	-0.10
1914.30	260.1	0.76	2	Rab1923	0.2	Ma		2.6	-0.01
1916.34	255.2	0.70	2	J__1918	0.7	Ma		-2.6	-0.05
1924.19	256.2	0.73	4	B__1925a	0.3	Ma		-2.5	0.05
1925.71	261.9	0.67	3	Fat1928	0.3	Ma		2.9	0.00
1934.37	256.9	0.57	4	Baz1936b	0.3	Ma		-3.5	0.00
1941.97	257.4	0.51	5	Rab1953	0.3	Ma		-4.8	0.04
1943.13	259.3	0.57	3	Vou1955	0.4	Ma		-3.2	0.11
1950.58	261.3	0.29	4	Baz1952b	0.4	Ma	XQ	-4.4	-0.04
1953.39	233.6	0.25	4	Baz1954a	0.4	Ma	Q	(267.8)	(0.26)
1954.24	273.6	0.20	2	Cou1955c	0.4	Ma	X	5.0	-0.04
1954.40	253.1	0.26	1	Mlr1955c	0.5	Mc	Q	-15.7	0.02
1955.83	253.1	0.22	2	Baz1957b	0.4	Ma		-17.6	0.02
1956.18	273.9	0.19	3	Mlr1956a	0.6	Mc		2.6	0.00
1956.27	278.8	0.20	1	Cou1958a	0.4	Ma		7.3	0.01
1957.31	278.0	0.20	1	Cou1958a	0.4	Ma		4.2	0.04
1958.05	277.2	0.13	2	VBs1960	2.1	Mb		1.1	0.00
1960.25	267.0	0.19	1	Cou1962a	0.4	Ma		(297.1)	(0.05)
1960.25			1	Cou1962a	0.4	Ma	S	(297.1)	(0.05)
1960.32		0.25	3	Hei1961	0.3	Ma	S	(298.9)	(0.05)
1961.27			1	Cou1962a	0.4	Ma	X	(0.5)	(0.02)
1962.23			1	B__1963b	0.9	Ma	F	(61.4)	(0.05)
1965.140	43.3	0.13	1	VBs1975	2.1	Mb	Q	(89.7)	(0.12)
1967.32	94.4	0.15	2	Cou1968b	0.5	Ma	Q	-4.1	0.02
1969.231	104.8	0.17	1	Wak1972	1.5	Mb	Q	-0.8	0.04
1971.24		0.16	1	Mlr1976	0.8	Mc	U	(113.0)	(0.13)

Table 9. Measurements of WDS 11361+1251 . Continues on the next page.

Orbit Determination of Close Binary Systems

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1976.38		0.18	3	Mlr1978b	0.5	Ma	D	(133.2)	(0.13)
1981.65	158.2	0.14	3	Mrl1983	0.7	Ma		3.6	0.01
1982.30	177.0	0.10	2	Hei1983a	0.6	Ma	U	19.8	-0.03
1984.24	152.8	0.14	3	Cou1985a	0.7	Ma		-11.6	0.01
1986.24	144.6	0.13	1	Cou1987b	0.7	Ma		(171.3)	(0.14)
1988.32	163.9	0.15	1	LBu1989	0.5	Ma		-13.8	0.00
1989.36	196.8	0.15	5	LBu1990	0.5	Ma		16.1	0.00
1990.320	191.9	0.15	1	LBu1991	0.5	Ma		8.7	-0.01
1991.2500	187.0	0.163	1	HIP1997a	1.4	Ma		1.4	0.001
1993.21	195.8	0.15	1	LBu1994	0.5	Ma		5.7	-0.02
1994.40	194.8	0.15	1	LBu1996	0.5	Ma		2.2	-0.03
2004.2068	202.8	0.228	1	Hrt2008	1.5	S		-4.7	-0.010
2008.251	**204.9**	**0.269**	**1**	**Gii2012**	**0.7**	**S**		**-6.9**	**0.007**
2008.281	**204.8**	**0.237**	**1**	**Gii2012**	**0.7**	**S**		**-7.0**	**0.026**
2010.3525	**208.7**	**0.26**	**1**	**Orl2015**	**2.1**	**S**		**-4.9**	**-0.016**

Table 9 (conclusion). Measurements of WDS 11361+1251

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1878.30	97.9	1.38	2	Bu_1879	0.5	Ma		-0.8	-0.02
1882.41	134.5	0.40	2	Sp_1888	0.2	Ma	U	(98.3)	(1.36)
1890.70	97.8	1.20	4	Sp_1909	0.5	Ma		-0.1	-0.10
1891.26	99.1	1.25	3	Bu_1894	0.9	Ma		1.3	-0.04
1898.917	96.8	1.40	3	Doo1901	0.5	Ma		-0.4	0.18
1899.431	101.0	1.19	1	Brs1900b	0.7	Ma		3.8	-0.02
1899.431	100.9	1.45	1	See1900e	0.7	Ma		3.7	0.24
1899.432	101.0	1.32	1	Brs1911	0.7	Ma		3.8	0.11
1900.324	92.0	0.88	2	See1911	0.7	Ma		-5.1	-0.33
1902.423	94.9	1.34	3	Doo1905	0.5	Ma		-2.0	0.16
1909.32	95.2	1.10	1	Ol_1909	0.7	Ma		-1.1	-0.01
1915.648	97.7	1.16	5	Fox1925	0.5	Ma		2.0	0.12
1917.20	96.2	1.10	3	Ol_1920c	0.7	Ma		0.7	0.08
1921.82	103.6	1.16	2	Gcb1934	0.4	Ma		8.7	0.20
1938.10	95.4	0.80	3	Fin1951a	0.7	Ma		3.1	0.06
1949.45	85.6	0.49	4	B__1950c	0.7	Ma		-3.5	-0.08
1952.83	83.5	0.42	4	B__1953a	0.7	Ma		-4.2	-0.10
1955.50			5	Hei1956a	0.2	Ma		(86.4)	(0.47)
1959.17	78.2	0.29	2	B__1959d	0.7	Ma		-6.0	-0.12
1962.30	78.3	0.33	4	B__1962d	0.9	Ma		-3.4	-0.03
1989.39	325.0	0.10	2	Hei1990b	1.0	Mb	Q	8.3	-0.08
1991.25	326.0	0.199	1	HIP1997a	1.4	Ht		15.1	-0.011
2006.1997	292.1	0.456	2	Msn2009	4.0	S		0.0	0.007
2014.244	**289.3**	**0.54**	**1**	**Ant2015**	**0.5**	**Cl**		**0.9**	**-0.033**
2016.3699	**289.3**	**0.646**	**5**	**Hsw2017d**	**0.3**	**Cv**		**1.6**	**0.042**

Table 10. Measurements of WDS 06549+1158

Orbit Determination of Close Binary Systems

Date	ϑ (°)	ρ (")	N	Ref.	Ap	Tec	Cod	O-C ϑ (°)	O-C ρ (")
1910.60	300.0	0.65	2	I__9999	9	A		-24.7	-0.05
1913.53	319.8	0.78	2	I__1914	9	A		-0.9	0.06
1928.52	301.9	0.74	2	B__1928d	26	A		-1.2	-0.05
1928.95	301.7	0.77	3	Rst1955	27	A		-0.9	-0.02
1930.33	301.9	0.80	4	Vou1932	24	A		0.8	0.01
1934.55	298.1	0.75	4	B__1937b	26	A		1.6	-0.04
1956.41	270.4	0.71	3	B__1957b	26	A		1.2	0.05
1960.50	260.2	0.60	3	B__1961a	26	A		-2.0	-0.01
1985.36	42.5	0.23	2	Hei1987a	36	B	Q	-1.7	-0.02
1991.18	4.6	0.37	2	Hei1992a	40	B	Q	-0.8	-0.04
1991.25	5.0	0.404	1	HIP1997a	54	T		-0.1	-0.003
1996.1815	349.6	0.512	1	Msn1998b	158	S	Q	0.4	0.001
2009.2602	324.7	0.692	1	Tok2009	160	S	Q	-0.1	0.001
2013.1276	**319.6**	**0.7284**	**2**	**Tok2014a**	**4.1**	**St**		**-0.1**	**0.004**

Table 11. Measurements of WDS 14531-4638