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ORBITS OF VISUAL BINARIES WDS 13320+3109, 14310−0548, 14492+1013, AND 16384+3514

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ABSTRACT

Revised orbits and dynamical data of visual binaries WDS 13320+3109, 14310−0548, 14492+1013, and 16384+3514 are presented. For all systems but WDS 16384+3514, the total mass is derived. Some astrophysical properties of the stars are discussed as well.

Key words: binaries: visual — stars: fundamental parameters

1. INTRODUCTION

Speckle measurements of double stars obtained with the 6 m telescope of the Russian Special Astrophysical Observatory (Balega et al. 1999) as part of a program of collaboration with the Observatorio Astronómico Ramón María Aller (Santiago de Compostela, Spain) have shown the need to revise several orbits. Here we present revised orbits for WDS 13320+3109, 14310−0548, 14492+1013, and 16384+3514. Orbits were calculated by Docobo's (1985) analytical method, and dynamical parallaxes by the Baize-Romani algorithm (Heintz 1978). The dynamical parallaxes are compared with the trigonometric parallaxes published in the Hipparcos and Tycho Catalogues (ESA 1997), which were used to calculate both masses and absolute magnitudes, apparent magnitudes being taken from the Washington Double Star Catalog, 1996.0 (Worley & Douglass 1997, hereafter WDS). The physical properties of these binaries are also discussed. All four new orbits have previously been announced by IAU Commission 26 (1998, Inf. Circ. 135), but the orbital elements of WDS 13320+3109, 14310−0548, and 16384+3514 in the present article are slightly improved relative to those announced in the circular.

2. METHOD

One of the chief advantages of Docobo's (1985) analytical method is that it does not require knowledge of the areal constant. The method is based on a mapping from the interval $(0, 2\pi)$ into the family of Keplerian orbits whose apparent orbits pass through three base points (θ_i, ρ_i, t_i); $i = 1, 2, 3$, or, namely, normal places. These base points are taken either coinciding with the most reliable (of high weight) measurements or points belonging to the areas with a maximum of observational evidence in their favor, but do not necessarily coincide with actual observations. If three base points do not belong to the same revolution, then interval $(0, 2\pi)$ must be replaced by $(0, 2\pi n)$, being $n - 1$ the number of full revolutions from the epoch t_1 to t_3. The orbit that fits better to all the known measurements is chosen from all generated possible ones. In this sense, it is important to take into account the data weights. Our criterion is similar, in a certain manner, to that used by Mason, Douglass, & Hartkopf (1999): weight 20 corresponds to the speckle measurements on 4–6 m–class telescopes, 10 corresponds to similar data obtained on 2 m–class telescopes, and 5 corresponds to the poor quality speckle and other interferometric measurements. Regarding the visual observations, their weights are established by means of a formula where the observer, the telescope, and the number of nights appear; a maximum value 2.5 can be reached.

3. RESULTS AND DISCUSSION

Table 1 lists the base points used for the orbits reported in this paper (the position angle of some points has had an extra 360° added in, so as to maintain an increasing or a decreasing sequence). Table 2 lists the calculated orbital elements and their estimated formal errors. Each star is identified by its WDS number, its name, and its Aitken Double Star catalog number (Aitken 1932), if any. The last row of Table 2 shows the correction for precession used to refer position angles to the equinox 2000.0. Table 3 shows WDS magnitudes (cols. [2] and [3]) and spectral types (col. [4]) together with the dynamical parallaxes calculated, using these data, from the orbital periods and semimajor axes obtained in this work (col. [5]); *Hipparcos* (ESA 1997) apparent magnitudes (cols. [6] and [7]) and trigonometric parallaxes (with standard errors; col. [8]) are also given. Table 4 presents ephemerides for each binary for the period 1999–2008. Table 5 lists all known observations of these stars along with the observers (listed by their WDS discoverer codes) and the discrepancies between the observed position angles and angular separations and those given by the new orbits (values in parentheses in the residuals columns are the calculated position angles and angular separations corresponding to observations for which these data were not reported). Asterisks in Table 5 mark observations that were subjected to a change of quadrant for calculation of the orbit.

The improvement of the previous orbits for these pairs in the present article is demonstrated in Table 6 where root mean square (rms) and mean absolute (MA) of residual values for each pair are derived. Only the orbit of the system Wor 24 (Heintz 1998), calculated almost simultaneously with ours, does improve our position angles, but not the separations. Obviously, when deriving the values in Table 6, the criterion mentioned above and corresponding weights have been taken into account.

WDS 13320+3109, Wor 24 (Docobo & Balega 1998). This pair of red dwarfs was discovered by Worley (1961) in 1960.32 with the 36 inch (0.91 m) refractor of the Lick Observatory, and Worley has since described almost two complete revolutions. Prior to our calculations, four orbits had been published: three by Baize (1976, 1981, 1991), whose orbital periods are 36.0, 20.0, and 21.3 yr, respec-

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TABLE 1

BASE POINTS

WDS	t	θ (deg)	ρ (arcsec)
13320+3109......	1984.380	303.8	0.180
	1988.260	92.4	0.220
	1991.330	58.8	0.341
14310−0548......	1976.220	268.0	0.195
	1989.310	371.0	0.255
	1992.460	427.8	0.104
14492+1013......	1985.503	153.7	0.151
	1989.255	393.2	0.075
	1993.197	487.0	0.182
16384+3514......	1973.430	46.0	0.200
	1981.380	79.0	0.210
	1995.440	370.0	0.116

tively, and one by Starikova (1985), with the period 20.346 yr. In addition, almost simultaneously with the announcement of our orbit by IAU Commission 26 (1998), an orbit with a very similar period, 21.07 yr, was published by Heintz (1998). The parallax value 0″.034 obtained photometrically by Weis (1993) agrees well both with the *Hipparcos* value 0″.032 and our calculated dynamical parallax 0″.0332 but differs from 0″.0428 given in the Yale General Catalogue of Trigonometric Stellar Parallaxes (van Altena, Lee, & Hoffleit 1995) for this star.

Several photometric color index values have been reported: $U-B=1.22$ (Weis 1993), $V-R=0.94$, and $R-I=0.70$ (Booth, Caruso, & Weis 1988; Weis 1993). The spectral type M0 V is given in WDS (on the basis of prism spectra), and K7 V is given in the recent spectral survey of Reid, Hawley, & Gizis (1995). The calculated absolute mag-

TABLE 2

ORBITAL ELEMENTS

Element	WDS 13320+3109[a]	WDS 14310−0548[b]	WDS 14492+1013[c]	WDS 16384+3514[d]
P (yr)..................	21.18 ± 0.30	22.98 ± 0.30	9.98 ± 0.04	27.17 ± 0.20
t	1986.02 ± 0.01	1993.62 ± 0.02	1988.059 ± 0.03	1993.65 ± 0.40
e	0.634 ± 0.003	0.499 ± 0.010	0.491 ± 0.001	0.772 ± 0.070
a (arcsec)	0.271 ± 0.002	0.243 ± 0.002	0.127 ± 0.001	0.181 ± 0.050
i (deg)	153.4 ± 4.0	49.1 ± 2.0	45.8 ± 2.0	50.1 ± 8.0
Ω (deg)................	103.9 ± 3.0	13.8 ± 2.0	142.3 ± 2.0	175.7 ± 4.0
ω (deg)................	257.5 ± 2.5	121.0 ± 2.5	156.8 ± 3.0	82.2 ± 4.0
Precession (deg)......	−0.0009	−0.0034	−0.0038	−0.0064

[a] Wor 24.
[b] RST 4529.
[c] A 2983; ADS 9397.
[d] Cou 985.

TABLE 3

STELLAR DATA

WDS (1)	WDS m_A (2)	WDS m_B (3)	WDS Spectral Type (4)	PRESENT WORK π(dyn) (arcsec) (5)	HIPPARCOS m_A (6)	HIPPARCOS m_B (7)	HIPPARCOS π(trig) (arcsec) (8)
13320+3109......	10.44	10.66	M0 V	0.0332	11.141	11.367	0.03205 ± 0.00296
14310−0548......	7.68	8.09	G5	0.0232	8.813	8.390	0.02604 ± 0.00104
14492+1013......	8.42	8.51	K2 V	0.0211	9.362	9.272	0.02421 ± 0.00129
16384+3514......	9.4	9.7	K2	0.0160	...	...	0.01149 ± 0.00117

TABLE 4

EPHEMERIDES

t	WDS 13320+3109 θ (deg)	WDS 13320+3109 ρ (arcsec)	WDS 14310−0548 θ (deg)	WDS 14310−0548 ρ (arcsec)	WDS 14492+1013 θ (deg)	WDS 14492+1013 ρ (arcsec)	WDS 16384+3514 θ (deg)	WDS 16384+3514 ρ (arcsec)
1999.0......	14.4	0.38	265.3	0.19	18.1	0.07	38.1	0.18
2000.0......	8.2	0.37	278.7	0.20	71.2	0.10	43.2	0.19
2001.0......	1.5	0.35	290.6	0.22	97.9	0.14	47.9	0.20
2002.0......	353.8	0.32	301.1	0.23	113.7	0.17	52.3	0.20
2003.0......	344.7	0.29	310.2	0.25	125.4	0.18	56.5	0.21
2004.0......	333.2	0.26	318.3	0.26	135.8	0.18	60.6	0.21
2005.0......	317.2	0.21	325.6	0.28	147.2	0.17	64.6	0.21
2006.0......	290.7	0.15	332.2	0.29	163.1	0.13	68.7	0.21
2007.0......	228.7	0.09	338.3	0.30	199.5	0.07	72.7	0.21
2008.0......	138.0	0.12	344.2	0.30	303.9	0.06	76.8	0.21

TABLE 5

OBSERVATIONS AND RESIDUALS

t[a]	θ (deg)	ρ (arcsec)	n	Observer(s)[b]	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)
WDS 13320+3108:						
1960.32..........	352.8	0.36	4	WOR	5.0	0.06
1961.39..........	355.9	0.26	4	WOR	−0.4	−0.01
1964.204	263.8	0.14	3	WOR	0.2	0.02
1964.362	...	...	1	COU	(252.7)	(0.11)
1965.176	...	0.12	1	WOR	(172.7)	0.03
1966.335*	286.7	0.16	3	WOR	−3.2	−0.01
1967.27*	269.5	0.24	3	COU	−0.3	0.01
1968.30*	252.9	0.19	3	COU	−3.1	−0.09
1970.421*	240.0	0.38	3	WOR	2.6	0.03
1971.32*	240.6	0.27	3	COU	9.2	−0.10
1973.758	41.0	0.36	3	WOR	4.1	−0.04
1975.29*	209.0	0.25	3	COU	0.4	−0.15
1979.363	7.9	0.30	4	HEI 3, WOR 1	3.3	−0.06
1980.30..........	356.4	0.23	3	HEI	−1.5	−0.11
1982.372	336.4	0.24	6	WOR 3, HEI 3	−2.3	−0.03
1984.3794	303.3	0.181	...	MCA	−1.1	0.001
1987.2832*......	291.3:	0.187:	...	CHR	−6.0	0.030
1987.3775*......	292.3	0.148	...	BAG	−1.8	−0.015
1988.2606*......	272.6	0.224	...	CHR	0.5	0.005
1989.2382*......	260.8	0.263	...	CHR	2.0	−0.006
1989.30*	264.1	0.19	2	HEI	6.0	−0.08
1990.2082*......	250.3	0.304	...	BAG	1.6	−0.002
1990.2704*......	255.1:	0.277:	...	CHR	7.0	−0.031
1991.25..........	61	0.33	...	HIP	1.0	−0.008
1991.3270*......	239.3:	0.337:	...	CHR	−0.1	−0.003
1996.40..........	25.3	0.32	2	HEI	−3.7	−0.08
1997.44..........	24.2	0.32	2	HEI	0.9	−0.08
1997.3911	23.5	0.403	...	BAG	−0.1	0.007
WDS 14310−0548:						
1938.51..........	338.5	0.39	2	RST	−2.7	0.09
1943.61..........	12.8	0.37	2	RST	−0.8	0.12
1950.52*	52.7	0.25	3	RST	6.4	0.08
1951.61*	64.7	0.25	1	RST	0.6	0.07
1958.43*	140.9	0.26	9	COU 3, B 6	−0.5	−0.01
1959.35*	150.7	0.28	3	COU	2.9	0.00
1960.46*	160.2	0.29	9	COU 3, BAZ 5, B 1	5.3	0.00
1961.43*	169.6	0.30	2	COU	8.9	0.00
1962.45*	169.3	0.30	16	B 4, COU 3, VBS 1, KNP 2, BAZ 6	2.7	0.00
1963.37*	175.6	0.29	3	COU	3.7	−0.01
1964.47*	167.5	0.34	4	COU 3, HLN 1	−11.0	0.05
1965.57*	179.9	0.28	13	VBS 4, B 4, HLN 3, KNP 2	−5.7	0.01
1966.40*	186.5	0.23	7	WOR 2, BAZ 5	−5.4	−0.02
1968.32*	200.4	0.24	1	COU	−13.8	0.07
1969.447*	195.9	0.28	1	BAZ	−50.8	0.18
1976.22*	262.7	0.19	3	HLN	−5.4	−0.01
1977.415	278.8	0.19	1	WAK	−4.9	−0.02
1978.35..........	305.2	0.19	3	HEI	10.9	−0.03
1980.33..........	320.1	0.22	3	HEI	7.1	−0.03
1983.176*	151.5	0.27	3	WOR	−1.8	−0.02
1989.3090	10.9	0.255	...	CHR	−0.3	0.000
1990.3437	19.6	0.219	...	CHR	−1.2	0.000
1991.25*	209	0.187	...	HIP	−4.2	0.012
1992.4572	68.3	0.102	...	CHR	0.3	−0.002
1995.46*	47.3	0.22	2	HEI	20.0	0.06
1997.3939	241.2	0.177	...	BAG	0.0	−0.004
WDS 14492+1013:						
1916.40*	7.4	0.19	3	A	18.9	0.07
1920.47..........	79.6	0.16	2	A	−2.1	0.05
1923.45..........	128.3	0.16	3	A	−0.4	−0.02
1924.54..........	143.4	0.20	2	A	3.2	0.02
1926.36..........	167.8	0.16	2	A	−0.2	0.04
1927.46..........	Too close		2	A	(224.4)	(0.06)

TABLE 5—*Continued*

t^a	θ (deg)	ρ (arcsec)	n	Observer(s)[b]	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)
1932.54..........	114.8	0.0.22	2	FIN	−4.1	0.05
1933.52*	313.8	0.17	4	VBS 2, A 2	4.1	−0.01
1934.55*	319.2	0.20	2	A	−1.4	0.02
1935.43*	333.3	0.16	3	A	2.0	0.00
1936.16*	332.2	0.15	4	VOU	−11.6	0.02
1936.98..........	166	0.17	4	B	−24.4	0.09
1938.20..........	Too close		1	VOU	(309.4)	(0.06)
1943.94..........	135.3	0.17	3	VBS	1.1	−0.01
1945.38..........	151.1	0.18	3	VBS 2, B 1	0.2	0.02
1949.47..........	Too close		1	B	(41.5)	(0.08)
1950.33*	247.6	0.13	2	VBS	−11.6	0.02
1951.57..........	98.2	0.17	2	WRH	−8.1	0.02
1952.92*	304.4	0.14	2	VBS	0.8	−0.04
1954.14*	317.4	0.16	2	VBS	0.9	−0.02
1955.32..........	185.1	0.10	1	VBS	34.8	−0.06
1957.28..........	205.8	0.09	1	VBS	−7.5	0.03
1958.52*	155.8	0.10	1	B	−2.5	0.03
1958.58*	209.3	0.10	1	B	46.5	0.03
1960.579*	245.3	0.13	5	VBS	−21.6	0.01
1961.43..........	106.1	0.16	4	WOR	1.8	0.01
1962.23..........	113.3	0.18	6	B	−2.4	0.01
1963.364	135.0	0.17	10	WOR 4, B 6	6.5	−0.01
1966.334	174.2	0.10	2	WOR	5.1	−0.02
1972.42..........	119.9	0.16	2	COU	1.6	−0.01
1974.353	146.0	0.13	3	HLN	6.9	−0.05
1975.44..........	144.6	0.20	4	HEI	−7.9	0.05
1981.39..........	Round		2	HEI	(104.2)	(0.15)
1984.1920	146.8	0.167	...	BNU	9.2	−0.015
1984.44..........	158.2	0.13	2	HEI	17.9	−0.05
1985.1862	150.2	0.157	...	BAG	1.0	−0.006
1985.45..........	156.9	0.13	2	HEI	4.0	−0.02
1985.5033	153.2	0.151	...	CHR	−0.5	−0.001
1986.4076	174.5	0.117	...	BAG	2.3	0.006
1987.3801	220.2	0.065	...	BAG	−8.4	0.008
1989.2546*......	212.5	0.077	...	CHR	−0.9	0.002
1989.48..........	75.5	0.14	5	LBU	28.9	0.06
1990.2746*......	259.3	0.112	...	CHR	−0.5	0.005
1991.25..........	108	0.155	...	HIP	5.8	0.007
1991.3244*......	285.1	0.145	...	CHR	1.7	0.000
1992.3074*......	296.2	0.173	...	CHR	−1.1	0.002
1993.1974*......	307.1	0.182	...	CHR	−0.1	0.000
1995.4365*......	332.1	0.151	...	CHR	−0.8	−0.003
1997.394	234.0	0.059	...	BAG	1.7	0.002
WDS 16384+3514:						
1973.43..........	47.9	0.17	3	COU	1.6	−0.03
1974.40..........	50.1	0.18	2	COU	−0.6	−0.02
1976.33..........	57.5	0.19	3	COU	−1.3	−0.02
1978.40..........	68	0.23	3	COU	1.0	0.02
1980.47..........	73.8	0.21	2	COU	−1.6	0.00
1981.38..........	76.9	0.21	3	COU	−2.3	0.01
1983.477	91.7	0.18	3	COU	3.4	−0.02
1984.48..........	104.7	0.15	3	COU	11.7	−0.04
1985.41..........	97.6	0.14	1	COU	−0.1	−0.05
1985.738	138.8	0.104	...	TOK	39.4	−0.079
1989.8150	124.6	0.138	...	BAG	−1.6	−0.005
1990.4429	133.4	0.130	...	ISM	1.3	−0.003
1990.514	128.2	0.137	3	COU	−4.6	0.005
1992.547	140.8	0.118	2	COU	−22.7	0.035
1995.4421*......	189.9	0.116	...	CHR	−0.2	0.003
1996.415	13.7	0.17	2	COU	−7.0	0.03
1997.3915	27.9	0.156	...	BAG	−0.5	−0.004

[a] Asterisks mark observations that were subjected to a change of quadrant for calculation of the orbit.
[b] WDS discoverer codes.

TABLE 6

STATISTICAL RESULTS

		rms(RESIDUALS)		MA(RESIDUALS)	
STAR	AUTHOR(S)	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)
Wor 24	Docobo & Balega; this paper	6.360	0.047	1.680	0.088
	Heintz 1998	4.821	0.100	1.422	0.127
	Baize 1991	14.212	0.162	2.762	0.201
	Starikova 1985	54.213	0.207	9.253	0.260
	Baize 1981	109.874	0.250	17.020	0.286
	Baize 1976	284.435	1.304	63.862	1.625
RST 4529......	Docobo & Tamazian; this paper	6.362	0.031	2.301	0.043
	Söderhjelm 1999	82.643	0.077	10.752	0.082
	Heintz 1981a I	77.055	0.383	10.849	0.246
	Heintz 1981a II	108.623	0.457	16.153	0.313
	Docobo 1977 I	66.083	0.442	10.148	0.295
	Docobo 1977 II	95.514	0.414	15.587	0.275
	Morel 1970	87.341	0.267	15.337	0.174
	Couteau 1960	85.223	0.448	17.617	0.306
A 2983	Balega & Vasyuk; this paper	14.876	0.823	3.628	0.344
	Söderhjelm 1999	23.659	0.825	4.895	0.344
	Eggen 1967 I	54.728	0.773	10.222	0.414
	Eggen 1967 II	129.156	0.770	18.614	0.417
	van den Bos 1964	130.631	0.738	20.762	0.370
	van den Bos 1954	100.187	0.789	17.472	0.450
	Ekenberg 1945	154.125	0.765	31.175	0.482
	van den Bos 1945	247.857	0.737	54.081	0.461
COU 985......	Docobo & Ling; this paper	23.187	0.048	4.795	0.061
	Baize 1993	67.271	0.078	14.104	0.096

nitudes of the components, +7.97 and +8.19, agree better with the latter type and with the value of 0.2 given by Reid et al. (1995) for Δm, the difference in magnitude between the components. The calculated total mass is 1.35 $M_{\odot}$.

WDS 14310−0548, RST 4529 (Docobo & Tamazian 1998). This binary was discovered by Rossiter (1938.51) with the 27 inch (0.69 m) telescope at the Lamont-Hussey Observatory. Prior to our calculations, orbits had been published by Couteau (1960), Morel (1970), Docobo (1977; two orbits, I and II), and Heintz (1981a; two orbits, I and II). An orbit recently published by Söderhjelm (1999) exhibits significant deviation of the position angle from both Rossiter's measurements and the recent measurements of Balega et al. (1999; in the latter case by $\Delta\theta = -46^{\circ}.2$).

The components brightness similarity leads to the change of the quadrant in many observations. However, the possibility of a long period and low-eccentricity solution, as was calculated previously by other authors, is discarded because of an approximately 180° advance in θ from 1992.4572 to 1997.3939.

The Yale catalog (van Altena et al. 1995) lists an absolute trigonometric parallax of +0.″0108. *UBV* photometry has been performed by Knipe (1966) and Alexander (1970). The calculated absolute magnitudes +4.76 and +5.17 and total mass 1.54 $M_{\odot}$ indicate spectral type G5 V.

WDS 14492+1013, A 2983 (Balega & Vasyuk 1998). This binary was discovered by Aitken in 1916.40 at the Lick Observatory. Prior to our work, orbits had been calculated by van den Bos (1945, 1954, 1964), Ekenberg (1945), and Eggen (1967; two orbits, I and II). The solution recently published by Söderhjelm (1999) exhibits excessive deviation of the position angle with respect to Balega et al. (1999)'s 1997.394 speckle measurement ($\Delta\theta = +15^{\circ}.7$). Radial velocity measurements have been published by Heintz (1981b) and in the Wilson-Evans-Batten catalog (WEB; Duflot, Figon, & Meyssonnier 1995). We did not consider the possibility of calculating another orbit of approximately 20 yr period and low eccentricity as was done by Eggen (1967) and Ekenberg (1945) since this provides worse residuals compared with those corresponding to the short-period orbit derived in the present paper.

The Yale catalog (van Altena et al. 1995) lists an absolute trigonometric parallax of −0.″0050. *BVR* photometric data have been reported by Olsen (1993), Eggen (1955, 1965, 1971), and Wallerstain & Westfall (1960).

The absolute magnitudes calculated from the *Hipparcos* photometric system, +6.28 and +6.19, agree better with the WDS spectral type, K2 V, than do those calculated from WDS apparent magnitudes, +5.34 and +5.43. The calculated total mass is 1.45 $M_{\odot}$.

WDS 16384+3514, Cou 985 (Docobo & Ling 1998). Since its discovery by Couteau in 1973.43 with the 50 cm refractor at the Nice Observatory, this star has described almost one complete revolution. The only previous orbit (Baize 1993) deviates by about +9° from the position angles obtained by the Center for High Angular Resolution Astronomy (1995.4421) and Balega et al. (1999; 1997.3915) speckle measurements. It is noteworthy that the measurements performed by Tokovinin in 1985.738 and Couteau in 1992.547 disagree with all others listed in Table 5.

Hipparcos failed to provide separate data for the components of this binary. Moreover, in view of the WDS spectral type (K2), the absolute magnitudes and total mass calculated from the WDS apparent magnitudes and the *Hipparcos* trigonometric parallax, +4.7 and +5.0 and 5.30 $M_{\odot}$, respectively, imply that either the *Hipparcos* parallax is in error or at least one of the components lies off the main sequence.

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