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SPECKLE MEASUREMENTS AND DIFFERENTIAL PHOTOMETRY OF VISUAL BINARIES WITH THE 6 METER TELESCOPE OF THE SPECIAL ASTROPHYSICAL OBSERVATORY

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ABSTRACT

Results of speckle measurements and differential photometry carried out with the 6 m telescope of the Special Astrophysical Observatory (Russia) at the end of 2004 are presented. One new (COU 1569) and four improved orbits (ADS 440AC, ADS 1729, ADS 5726, and COU 1897), as well as their dynamical mass estimates, are reported.

Key words: binaries: visual — stars: fundamental parameters — techniques: photometric

1. INTRODUCTION

This paper is the next in a series dedicated to the speckle measurements of visual binaries carried out in the recent years at the Observatorio Astronómico Ramón María Aller (OARMA) of the University of Santiago de Compostela (Docobo et al. 2001c, 2004). The results of speckle measurements made with the 6 m telescope of the Special Astrophysical Observatory (SAO) (Russia) are reported. The objective of these studies is to obtain orbital parameters and dynamical and individual masses for mostly (but not only) late-type visual binaries.

Yet a close follow-up of some flare- and UV Ceti–type variables is being made, with the aim of revealing the possible duplicity of these stars. Apart from this, in the known binary systems a possible relationship between components' activity and their position on the orbit is studied.

2. SPECKLE OBSERVATIONS

The speckle interferometric observations were performed with the speckle camera and an intensified 1280×1024 pixel CCD coupled with an S25 photocathode. Under good seeing conditions, this system allows us to observe binary components as faint as 15.0 mag in optical wavelengths with a dynamic range of about 5.0 mag. The diffraction-limited resolution is about 22 mas.

The image motion-compensated seeing (FWHM) during the observations was $1''.0$–$1''.5$. The relative position and magnitude difference Δm of each binary was derived from the ensemble averaged power spectrum. A double-slit pupil mask and interferometric binaries with slow orbital motion were used for calibration. More details regarding the observation and reduction procedure can be found in Balega et al. (2002) and remained essentially unchanged.

In total, we have obtained 33 measurements for 32 systems, out of which 9 were unresolved. The observations are listed in Table 1, the columns of which list (1) the Washington Double Star Catalog (WDS) number (Mason et al. 2003), (2) the ADS number (Aitken & Doolittle 1932) or other designation, (3) the observation epoch (in fraction of the Besselian year), (4) the position angle (in degrees) with its corresponding error, (5) the separation (in arcseconds) with its corresponding error, (6) the magnitude difference between components and the corresponding error of photometry, (7, 8) and the central wavelength and bandwidth of the filter used (in nanometers).

3. NEW AND IMPROVED ORBITS AND DYNAMICAL MASSES

The first orbit for COU 1569 and improved orbits for ADS 440AC, ADS 1729, ADS 5726, and COU 1897 are presented. They are calculated using the method of Docobo (1985), the essence of which is briefly summarized in Docobo et al. (2000) and Tamazian et al. (2002). The apparent orbits of these binaries are shown in Figure 1.

Except for ADS 440AC, none of the systems are included in the Multiple Star Catalog (Tokovinin 1997) and/or the Ninth Catalogue of Spectroscopic Binary Orbits (Pourbaix et al. 2004). At the same time, since all components of these binaries are main-sequence stars, a well-known Baize-Romani algorithm (Baize & Romani 1946; Heintz 1978, p. 62) can be applied in order to obtain their dynamical parallaxes.

In Table 1 the measurements previously used by the authors for orbit calculation are marked with an asterisk. These orbits were announced in IAU Commission 26 Information Circulars (ICs) 156, 157, and 158, and some of them have already been published by Tamazian et al. (2005) and Tamazian & Docobo (2006). The new orbit for ADS 440AC was submitted for publication to IC 159. The measurements used to calculate the new orbits reported in this work are marked with two asterisks.

Table 2 gives the residuals of our observations with those orbits that do not need to be recalculated or are still in the process of calculation, and Table 3 contains orbital elements, total masses, and the *Hipparcos* (Perryman et al. 1997) and dynamical parallaxes of the newly calculated binaries.

We report in Table 4 the weighted rms of the observational residuals ($O - C$) for our newly calculated orbits, as well as for previously known orbits taken from the USNO (Hartkopf & Mason 2006) and OARMA (Docobo et al. 2001b) catalogs, using the observation-weighting rules described in Docobo & Ling (2003).

Finally, Table 5 contains the ephemerides for the newly calculated orbits. In the following, comments on individual systems are given.

ADS 440AC (=MCY 1): This system consists of the M-type dwarf components A and C of Gl 22 (ADS 440). It was first resolved in 1989 by near-infrared speckle interferometry with

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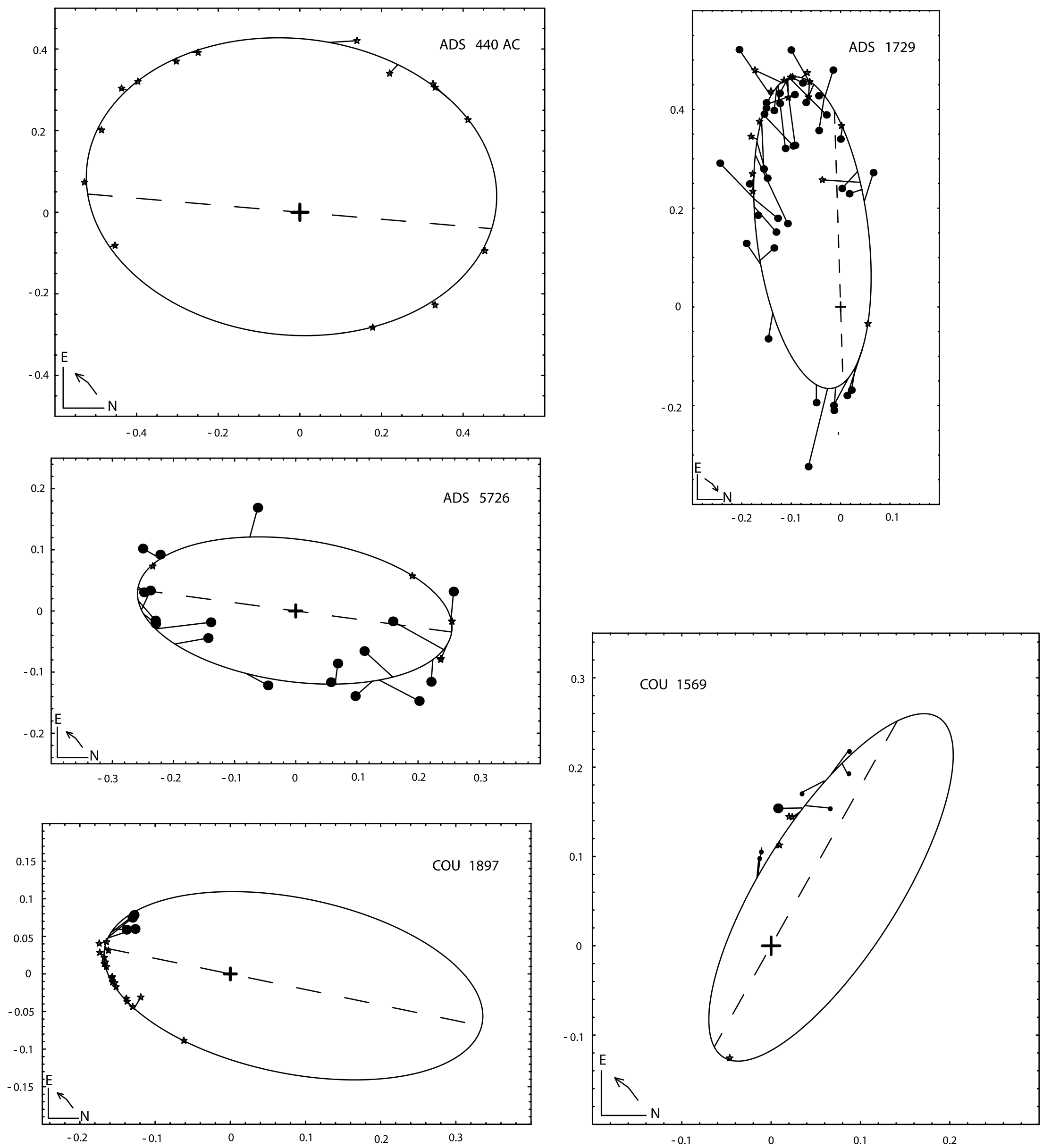

FIG. 1.—Apparent orbits of the newly calculated binaries (the scale on both axes is in arcseconds). Each measurement is connected to its predicted position by an $O-C$ line. The dashed line passing through the primary star represents the line of nodes. The circles and stars represent visual and speckle measurements, respectively, and the arrow shows the direction of the orbital motion.

the 2.3 m telescope of the Steward Observatory located on Kitt Peak (McCarthy et al. 1991).

An astrometric orbit with a period of 15.95 yr was first calculated by Hershey (1973) and then improved by Heintz (1993) on the basis of a larger set of astrometric plates obtained with the Sproul 24 inch (0.6 m) refractor. Using the infrared speckle interferometry data obtained by J. Woitas with the 3.5 m telescope of Calar Alto and covering an orbital arc of more than 300°, Docobo et al. (2002) computed an improved solution with a period of 16.12 yr.

Our latest observation with the 6 m telescope indicates that the period is somewhat lower, and it would be reasonable to recalculate the orbit. We obtain a new 15.64 yr solution (see Table 3), which, however, does not affect the previous value of its total mass, 0.59 $M_{\odot}$ (Woitas et al. 2003).

If a seemingly erroneous one-dimensional measurement of this pair at the epoch 1991.7201 (Woitas et al. 2003) is removed, the rms of residuals in position angle and separation is clearly improved (see Table 4).

ADS 1729 (=A2013): This binary star was discovered in 1909 by Aitken (1909b) with the 36 inch (0.9 m) telescope of the Lick Observatory. Since then, various orbits have been calculated for this star, all with a period close to 35 yr. An exception is the orbit of Costa & Docobo (1983) with a period of 73 yr based on the possibility of rotating some measurements 180°.

Our measurement has been performed exactly at the time of minimal separation, thus allowing us to improve (especially in position angle) the previous orbit of Heintz (1994), whose predicted position was deviating by 17°.5 with regard to the latest speckle datum.

As is seen from Table 3, the *Hipparcos* parallax coincides with the dynamical parallax to within a 1 σ margin. The total mass of the system (1.8 $M_{\odot}$) is close to that expected for a pair of K5 dwarfs.

TABLE 1

Speckle Measurements

WDS[a] (1)	ADS or Other Designation (2)	Epoch 2004.0+ (3)	$\theta \pm \sigma$ (deg) (4)	$\rho \pm \sigma$ (arcsec) (5)	$\Delta m \pm \sigma$ (mag) (6)	Filter (nm) λ_c (7)	$\Delta\lambda$ (8)
00155−1608	HEI 299	0.99015	2.7 ± 1.8	0.218 ± 0.007	1.80 ± 0.30	800	110
00243+5201*	ADS 328	0.99019	87.4 ± 0.4	0.115 ± 0.001	0.83 ± 0.10	545	30
00321+6715**	ADS 440AC	0.99022	28.8 ± 0.5	0.470 ± 0.003	2.40 ± 0.20	800	110
00516+2237*	ADS 701	0.99026	197.3 ± 0.3	0.182 ± 0.001	0.0 ± 0.13	545	30
01450+2703*	COU 750	0.99030	24.8 ± 0.4	0.257 ± 0.002	0.40 ± 0.07	800	110
02159+0638**	ADS 1729	0.99042	148.6 ± 1.1	0.065 ± 0.002	0.17 ± 0.10	800	110
02278+0426	ADS 1865	0.99044	207.5 ± 0.5	0.182 ± 0.002	0.11 ± 0.09	800	110
02288+3215*	WOR 2	0.99033	100.0 ± 0.4	0.399 ± 0.002	0.55 ± 0.10	800	110
02399+0009	ADS 2028	0.99048	270.9 ± 0.5	0.145 ± 0.001	1.20 ± 0.05	545	30
02415+4053	COU 1511	0.99051	64.1 ± 0.5	0.135 ± 0.001	0.75 ± 0.04	545	30
03006+4753*	ADS 2271	0.99053	163.1 ± 0.4	0.243 ± 0.002	1.53 ± 0.03	545	30
03128−0112	ADS 2406	0.99056	Unres.[b]	...	...	545	30
03321+4340	COU 1688	0.99058	Unres.	...	...	545	30
03503+2535*	ADS 2799	0.99060	164.5 ± 0.8	0.050 ± 0.002	0.81 ± 0.05	545	30
04298+1741	COU 567	0.99062	176.0 ± 0.8	0.056 ± 0.002	0.91 ± 0.05	545	30
04364+3413*	ADS 3323	0.99067	77.7 ± 1.2	0.100 ± 0.003	0.33 ± 0.23	545	30
04464+4221*	COU 2031	0.99070	221.1 ± 3.5	0.022 ± 0.003	0.92 ± 0.06	545	30
07036+3941**	ADS 5726	0.99106	162.6 ± 0.4	0.245 ± 0.001	0.24 ± 0.12	800	110
07208−0516	AR Mon	0.99103	Unres.	...	...	800	110
07208−0516	AR Mon	0.99107	Unres.	...	...	545	30
08285−0231*	ADS 6828	0.99109	290.7 ± 1.1	0.025 ± 0.003	0.0[c]	545	30
08427+0935	ST 8AB	0.99111	68.2 ± 0.4	1.236 ± 0.005	3.90 ± 0.50	800	110
08585+3548**	COU 1897	0.99114	55.1 ± 0.8	0.108 ± 0.002	1.70 ± 0.03	545	30
09036+4709	ADS 7158	0.99116	303.8 ± 0.7	0.164 ± 0.002	0.37 ± 0.03	545	30
09476+1126	R Leo	0.99122	Unres.	...	...	545	30
09498+2111*	KUI 44AB	0.99124	254.3 ± 0.6	0.041 ± 0.002	0.70 ± 0.10	545	30
10059+3412**	COU 1569	0.99126	69.8 ± 0.6	0.134 ± 0.002	0.45 ± 0.04	545	30
10140+2227	COU 169	0.99131	343.3 ± 0.3	0.550 ± 0.002	0.00 ± 0.21	800	110
10200+1950	AD Leo	0.99130	Unres.	...	...	800	110
10269+1931	COU 292	0.99134	280.0 ± 0.5	0.081 ± 0.002	0.40 ± 0.02	545	30
11200+6551	SZ Uma	0.99138	334.0 ± 1.4	0.132 ± 0.004	3.70 ± 0.70	800	110
11294+4205	COU 1905	0.99141	Unres.	...	...	800	110
12385+0659	R Vir	0.99144	Unres.	...	...	800	110

[a] Double asterisks (**) denote orbits revised in this work, and single asterisks (*) denote orbits revised in other papers.
[b] Pair unresolved.
[c] Bad power spectrum.

ADS 5726 (=A1959): This is a pair of red dwarfs discovered by Aitken (1909a), the orbit of which has completed various revolutions since its discovery; there are, sensibly, a lower number of observations in comparison with the pair A2013.

The orbit of Seymour & Mason (2000) gives small but systematic residuals since 1991. The rms in position angle, at least, can be improved with a practically circular orbit.

Both *Hipparcos* and dynamical parallaxes coincide to within a 1 σ margin, while the total mass is slightly larger than that expected for a pair of M dwarfs.

COU 1897: Both this and the following binary were discovered by P. Couteau with the 50 cm refractor of the Nice Observatory. Only one provisional orbit with a period of 104 yr has been obtained for this system (Couteau 1999), but our latest

TABLE 2

Observational Residuals with No Recalculated Orbits

WDS	$\Delta\theta$ (deg)	$\Delta\rho$ (arcsec)	Reference
00155−1608	−2.2	+0.008	Hershey & Taff (1998)
02278+0426	0.0	−0.006	Andrade (2001)
02399+0009	+0.7	+0.004	Docobo & Ling (2001a)
02415+4053	−2.5	−0.010	Hartkopf & Mason (2001)
09036+4709	+0.8	+0.002	Barnaby et al. (2000)
09036+4709	+1.1	−0.007	Hartkopf et al. (2000)
10140+2227	−2.4	−0.004	Couteau (1999)
10269+1931	+51.8[a]	+0.011	Couteau (1997)

[a] Orbit under revision (B. Mason 2006, private communication).

TABLE 3
ORBITAL ELEMENTS

Element	ADS 440AC	ADS 1729	ADS 5726	COU 1897	COU 1569
P (yr)	15.64 ± 0.20	34.66 ± 0.15	31.85 ± 0.25	165.0 ± 10	117.0 ± 15
T	2000.76 ± 0.20	2005.69 ± 0.2	1988.36 ± 4.6	1985.8 ± 2	1997.78 ± 0.5
e	0.174 ± 0.003	0.593 ± 0.01	0.008 ± 0.008	0.334 ± 0.02	0.494 ± 0.06
a (arcsec)	0.511 ± 0.005	0.346 ± 0.002	0.259 ± 0.003	0.255 ± 0.009	0.237 ± 0.02
i (deg)	44.6 ± 1.5	112.3 ± 2.0	63.3 ± 2.5	61.1 ± 2	69.3 ± 2
Ω (deg)	175.1 ± 1.0	91.8 ± 2.0	172.3 ± 3.5	168.1 ± 5	60.7 ± 2
ω (deg)	106.8 ± 5.0	137.6 ± 3.0	147.7 ± 35	2.3 ± 15	140.1 ± 3
Hipparcos Parallax					
$\pi_{\rm Hip}$ (mas)	98.74 ± 3.37	26.37 ± 3.69	21.30 ± 2.80	4.11 ± 0.84	5.92 ± 1.13
Total mass ($M_\odot$)	0.57 ± 0.06	1.86 ± 0.78	1.77 ± 0.70	8.77 ± 5.58	4.69 ± 3.17
Dynamical Parallax					
$\pi_{\rm dyn}$ (mas)	89.33 ± 1.5	29.41 ± 0.9	22.13 ± 1.1	4.92 ± 0.5	6.69 ± 0.5
Total mass ($M_\odot$)	0.77 ± 0.05	1.34 ± 0.14	1.58 ± 0.24	5.11 ± 1.76	3.25 ± 1.38

TABLE 4
rms OF $(O - C)$ RESIDUALS

STAR	ORBIT'S SOURCE	rms $(O-C)_\theta$ (deg)	rms $(O-C)_\rho$ (arcsec)
ADS 440AC	This paper[a]	1.3	0.011
	Woitas et al. (2003)[a]	1.6	0.024
ADS 1729	This paper	3.9	0.031
	Heintz (1994)	5.8	0.036
ADS 5726	This paper	3.5	0.020
	Seymour & Mason (2000)	4.1	0.020
COU 1897	This paper	1.9	0.005
	Couteau (1999)	3.4	0.008
COU 1569	This paper	3.2	0.008

[a] Without the 1991.7201 measurement.

TABLE 5
EPHEMERIDES

	ADS 440AC		ADS 1729		ADS 5726		COU 1897		COU 1569	
EPOCH	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)	θ (deg)	ρ (arcsec)
2007.0	71.8	0.424	265.8	0.165	181.7	0.247	247.2	0.107	255.9	0.133
2008.0	95.2	0.429	252.3	0.166	187.7	0.230	252.9	0.107	259.0	0.130
2009.0	116.8	0.459	237.4	0.153	194.8	0.206	258.5	0.109	262.2	0.126
2010.0	135.2	0.498	219.5	0.140	204.0	0.179	263.9	0.111	265.7	0.122
2011.0	151.1	0.529	199.1	0.135	216.6	0.151	269.1	0.113	269.3	0.118
2012.0	165.8	0.536	179.3	0.144	234.4	0.128	274.0	0.117	273.3	0.114
2013.0	181.2	0.505	162.9	0.163	257.9	0.116	278.6	0.121	277.6	0.109
2014.0	200.1	0.436	150.5	0.190	282.6	0.122	282.9	0.125	282.2	0.105
2015.0	228.0	0.347	141.4	0.219	302.6	0.142	286.9	0.130	287.3	0.101
2016.0	270.1	0.302	134.5	0.251	316.9	0.169	290.6	0.136	292.7	0.097

observation reveals that period should be larger. Apart from this, the provisional orbit demonstrates systematic $(O - C)$ residuals with observations since 1991.

Due to a less than 10 mas parallax, its value measured by *Hipparcos* (4.11 ± 0.84 mas) has a large uncertainty, although it coincides well with the obtained dynamical parallax of 4.9 mas. Such a large uncertainty is translated to the total mass of the system. A parallax of 4.8 mas would provide a total mass of 5.5 $M_{\odot}$, expected for a pair of A1 V components.

COU 1569: We present the first orbit for this pair. While the number of observations is still small, three successful speckle measurements at the 1980s epochs 1984.0527 (McAlister et al. 1987), 1984.3832 (Hartkopf et al. 2000), and 1987.2637 (McAlister et al. 1989) demonstrate that the star had at that time just passed the separation minimum. It was not resolved by Couteau at the epoch 1988.306 nor by *Hipparcos* in 1991.25.

Currently, when the covered orbital arc surpasses 180° the components are at the relative maximum in separation. Couteau's 1997.271 (Couteau 1999) measurement is incompatible with our orbital solution.

The dynamical mass of the system suffers strongly from the low relative accuracy of the *Hipparcos* parallax, so the comments regarding COU 1897 are completely valid in this case, too. Adopting a 1.9 $M_{\odot}$ mass for this system of two G5 dwarfs, the corresponding parallax should be close to 8 mas. Further observations of this pair are welcome in order to adjust its preliminary orbit.

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REFERENCES

Aitken, R. G. 1909a, Lick Obs. Bull., 5, 115
———. 1909b, Lick Obs. Bull., 5, 166
Aitken, R. G., & Doolittle, E. 1932, New General Catalogue of Double Stars within 120° of the North Pole (Washington: Carnegie Inst.)
Andrade, M. 2001, IAU Commission 26, Circ. 144
Baize, P., & Romani, L. 1946, Ann. d'Astrophys., 9, 13
Balega, I. I., Balega, Y. Y., Hofmann, K.-H., Maksimov, A. F., Pluzhnik, E. A., Schertl, D., Shkhagosheva, Z. U., & Weigelt, G. 2002, A&A, 385, 87
Barnaby, D., Spillar, E., Christou, J. C., & Drummond, J. D. 2000, AJ, 119, 378
Costa, J., & Docobo, J. A. 1983, IAU Commission 26, Circ. 89
Couteau, P. 1997, IAU Commission 26, Circ. 131
———. 1999, Catalogue de 2700 Etoiles Doubles COU (Nice: Obs. Côte d'Azur)
Docobo, J. A. 1985, Celest. Mech., 36, 143
Docobo, J. A., Balega, Y. Y., Ling, J. F., Tamazian, V. S., & Vasyuk, V. A. 2000, AJ, 119, 2422
Docobo, J. A., & Ling, J. F. 2001a, IAU Commission 26, Circ. 145
———. 2003, A&A, 409, 989
Docobo, J. A., Ling, J. F., Prieto, C., Costa, J. M., Costado, M. T., & Magdalena, P. 2001b, Acta Astron., 51, 353
Docobo, J. A., Tamazian, V. S., Balega, Y. Y., Blanco, J., Maximov, A. F., & Vasyuk, V. A. 2001c, A&A, 366, 868
Docobo, J. A., Tamazian, V. S., Woitas, J., & Leinert, Ch. 2002, IAU Commission 26, Circ. 147
Docobo, J. A., et al. 2004, AJ, 127, 1181
Hartkopf, W. I., & Mason, B. D. 2001, IAU Commission 26, Circ. 145
———. 2006, Sixth Catalog of Orbits of Visual Binary Stars (Washington: USNO), http://ad.usno.navy.mil/wds/orb6.html
Hartkopf, W. I., et al. 2000, AJ, 119, 3084
Heintz, W. D. 1978, Double Stars (Dordrecht: Reidel)
———. 1993, PASP, 105, 44
———. 1994, AJ, 108, 2338
Hershey, J. L. 1973, AJ, 78, 935
Hershey, J. L., & Taff, L. G. 1998, AJ, 116, 1440
Mason, B. D., Wycoff, G. L., & Hartkopf, W. I. 2003, The Washington Double Star Catalog (Washington: USNO) (updated version at http://ad.usno.navy.mil/wds/wds.html)
McAlister, H. A., Hartkopf, W. I., Hutter, D. J., & Franz, O. G. 1987, AJ, 93, 688
McAlister, H. A., Hartkopf, W. I., Sowell, J. R., Dombrowski, E. G., & Franz, O. G. 1989, AJ, 97, 510
McCarthy, D. W., Jr., Henry, T. J., McLeod, B., & Christou, J. C. 1991, AJ, 101, 214
Perryman, M. A. C., et al. 1997, The *Hipparcos* and Tycho Catalogues (ESA SP-1200; Noordwijk: ESA)
Pourbaix, D., et al. 2004, A&A, 424, 727
Seymour, D., & Mason, B. D. 2000, IAU Commission 26, Circ. 140
Tamazian, V. S., & Docobo, J. A. 2006, AJ, 131, 2681
Tamazian, V. S., Docobo, J. A., Melikian, N. D., Balega, Y. Y., & Karapetian, A. A. 2005, AJ, 130, 2847
Tamazian, V. S., Docobo, J. A., White, R., & Woitas, J. 2002, ApJ, 578, 925
Tokovinin, A. A. 1997, A&AS, 124, 75 (updated version at http://www.ctio.noao.edu/~atokovin/stars/index.php)
Woitas, J., Tamazian, V. S., Docobo, J. A., & Leinert, C. 2003, A&A, 406, 293