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Ten CORAVEL spectroscopic binary orbits of evolved stars*

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Abstract. On the basis of CORAVEL observations, we present orbital parameters for 10 spectroscopic-binary systems including an evolved star, namely HD 13530, HD 28591, HD 47415, HD 78414, HD 123999, HD 153751, HD 174881, HD 179094, HD 212280 and HD 217188. The most significant result is related to HD 13530, for which we have found an orbital period of 1575.48±1.63 days and an eccentricity of 0.8815. Such an eccentricity value is the largest one known up to date for a single-lined spectroscopic binary with a giant component.

The other spectroscopic orbits described in this paper principally confirm with independent data previously obtained orbital solutions except HD 179094 for which the double-lined status was still unknown.

Key words: stars: supergiants stars: binaries: spectroscopic – stars: late-type

1. Introduction

Since March 1986, a systematic survey of about 2000 stars with luminosity classes IV, II and Ib has been carried out at the Geneva Observatory to study the rotational behaviour of evolved stars of low and intermediate masses. The catalogue is about to appear (De Medeiros & Mayor 1999). Although the major aim of such a survey is to obtain rotational velocities, the observational procedure has also produced about 4000 radial-velocity measurements. Consequently, this has revealed a number of new spectroscopic-binary stars, and additionally has confirmed the binary status for a large fraction of stars previously suspected to be radial-velocity variable. For some stars, the radial-velocity variations were followed with a suitable cadence to derive their orbital elements.

In the present work, we report the spectroscopic observations of ten stars for which it was possible to derive an orbital solution and then to obtain orbital parameters. This small sample is described in Table 1 which provides useful stellar parameters as spectral type, color index and rotational velocity. The spectral type, magnitude V and color index (B-V) for HD 212280 and HD 217188 were taken from Strassmeier et al. (1993), whereas for the other stars, they were taken from Hoffleit & Jaschek (1982).

Table 1. Stellar parameters for our sample of evolved spectroscopic binaries. In case of double-lined spectroscopic binaries, the rotational velocity is given for both components

HD	Sp	V	B-V	$v \sin i$ [$\mathrm{km\,s^{-1}}$] comp A	comp B
13530	G8 III	5.31	0.93	1.0	–
28591	K1 III	6.72	0.90	27.2	–
47415	F8 IV[1]	6.38	0.53	6.3	4.5
78418	G5 IV-V	5.98	0.66	1.6	2.3
123999	F8 IV	4.83	0.54	12.5	9.5
153751	G5 III	4.23	0.89	23.0	–
174881	K1 II-III	6.18	1.18	1.0	1.0
179094	K1 IV	5.81	1.09	14.9	1.8
212280	F8/G8 IV	7.51	0.70	9.0	21.7
217188	K0 III	7.30	1.10	3.0	–

[1] For HD 47415 a spectral type F5V seems more appropriate, see discussion below

The paper is organized as follows: Sect. 2 describes briefly the observations whereas Sect. 3 provides the orbital elements and the radial-velocity curves. The stars are commented individually as well.

2. The observations

All the observations reported here were obtained with the two CORAVEL spectrometers (Baranne et al. 1979) mounted on the 1-m Swiss telescope at the Haute-Provence Observatory, Saint Michel (France), and on the 1.54-m Danish telescope at ESO, La Silla (Chile). The radial velocities are obtained by cross-correlations of the stellar spectra with a physical binary (0,1) template, built from the spectrum of a K2 III star (Arcturus) and incorporated in the spectrometers.

The radial-velocity system is the one defined by Mayor & Maurice (1985), which corresponds to the faint IAU standard system. The typical integration time was 5 minutes for the single-lined spectroscopic binaries and 15 minutes for the blended double-lined spectroscopic binaries. The data reduction was made by using standard procedures. For the single-

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* Based on observations collected at the Haute-Provence Observatory, Saint-Michel, France and at ESO, La Silla, Chile.

Table 2. Orbital elements and error estimates. Additional lines are used for the second component of double-lined spectroscopic binaries. N is the number of measurements used to derive the orbital solution and $O-C$ the residue around this solution. ΔT is the span of the observations

Id HD		P [days]	T [HJD -2400000]	e	γ [$\mathrm{km\,s^{-1}}$]	ω_1 [deg]	$K_{1,2}$ [$\mathrm{km\,s^{-1}}$]	$M_{1,2}\sin^3 i$ $f(m)$	$a_{1,2}\sin i$ [Gm]	N	$O-C$ [$\mathrm{km\,s^{-1}}$]	ΔT [days]
13530		1575.48	48731.24	0.8815	25.78	266.76	20.37	1.456e-01	208.382	51	0.360	4881
		1.63	0.13	0.0010	0.10	0.44	0.09	2.510e-03	1.214			
28591[a]		21.2886	48948.54	0.010	5.83	124.03	29.60	5.730e-02	8.663	29	0.550	1475
		0.0017	1.66	0.005	0.10	28.56	0.15	8.502e-04	0.043			
47415[a]	A	5.6991	49003.17	0.009	31.28	41.23	44.01	0.2672	3.449	22	0.722	122
		0.0005	0.56	0.004	0.11	18.58	0.19	0.0029	0.015			
	B						50.53	0.2328	3.960	23		122
							0.26	0.0024	0.020			
78418	A	19.4120	48984.32	0.192	9.65	278.90	26.82	0.1974	7.027	15	0.461	2224
		0.0006	0.08	0.005	0.09	1.37	0.13	0.0025	0.034			
	B						30.99	0.1708	8.119	15		2224
							0.18	0.0021	0.048			
123999	A	9.6046	48990.79	0.193	9.29	286.19	67.11	1.2407	8.697	12	0.896	1818
		0.0001	0.03	0.004	0.19	1.31	0.41	0.0184	0.053			
	B						70.02	1.1892	9.074	11		1818
							0.48	0.0173	0.063			
153751[a]		39.4816	48968.22	0.007	-10.96	86.07	31.82	1.321e-01	17.277	33	0.446	1994
		0.0022	3.14	0.004	0.08	28.73	0.11	1.379e-03	0.060			
174881	A	215.3021	49048.78	0.124	-19.80	105.57	21.69	0.7985	63.725	21	0.546	2703
		0.0665	0.24	0.049	0.09	14.53	0.16	0.0142	0.481			
	B						20.52	0.8442	60.276	21		2703
							0.17	0.0148	0.499			
179094[a]	A	28.5903	48976.38	0.010	4.11	0.00	40.74	0.9843	16.016	28	0.673	5124
		0.0004	0.05	0.004	0.14	31.27	0.16	0.0247	0.064			
	B						45.05	0.8901	17.710	8		4820
							0.69	0.0186	0.271			
212280	A	45.2816	48955.70	0.502	3.71	240.76	44.32	1.7526	23.860	94	0.783	4147
		0.0005	0.03	0.002	0.07	0.28	0.12	0.0182	0.070			
	B						56.61	1.3721	30.475	67		4034
							0.29	0.0129	0.162			
217188		47.1162	48952.73	0.463	-21.03	358.81	10.37	3.803e-03	5.957	31	0.325	843
		0.0075	0.20	0.006	0.06	1.26	0.08	9.845e-05	0.051			

[a] data compatible with a circular orbit according to the Lucy-Sweeney test at a 5% confidence level

lined binaries the radial velocities are mostly derived from a one-gaussian fit to the correlation (cc) dip, whereas for the double-lined spectroscopic binaries the radial velocities are derived from a 2-gaussian fit following the procedure described in Duquennoy (1987) or in Duquennoy et al. (1991).

In all cases, the radial-velocity uncertainty is derived from an instrumental error quadratically added to the photon noise and to the scintillation noise, which are estimated from the parameters of the observations (Baranne et al. 1979). Different studies in large data samples (e.g. Duquennoy et al. 1991, Udry et al. 1997) show that the typical uncertainty for the CORAVEL radial velocities is about 0.3 $\mathrm{km\,s^{-1}}$ for low and moderate rotator stars, typically stars with $v\sin i < 10\,\mathrm{km\,s^{-1}}$. For stars with higher rotation rates, the uncertainty is somewhat larger.

In addition to radial velocities, the cross-correlation technique provides the rotational velocities of the measured stars, through an appropriate calibration of the widths of the cc-dips (De Medeiros & Mayor 1999). For our small sample, these rotational velocities are given in Table 1.

3. Radial-velocity curves and orbital parameters

We report in this section the orbital solutions obtained for ten binary systems including an evolved component. Among them, 4 systems are single-lined spectroscopic binaries whereas the remaining ones present double-lined features. The main results are summarized in Table 2 and Fig. 1 which provide the orbital parameters and the phase-folded radial-velocity curves for our ten star sample. The parameter T given in Table 2 is the epoch of periastron passage for orbits with non-zero eccentricities, and is the instant of maximum radial velocity, or nodal passage, for circular orbits. In the table, additional lines are used for the second components of double-lined spectroscopic binaries. Stars are briefly discussed individually in the following subsections.

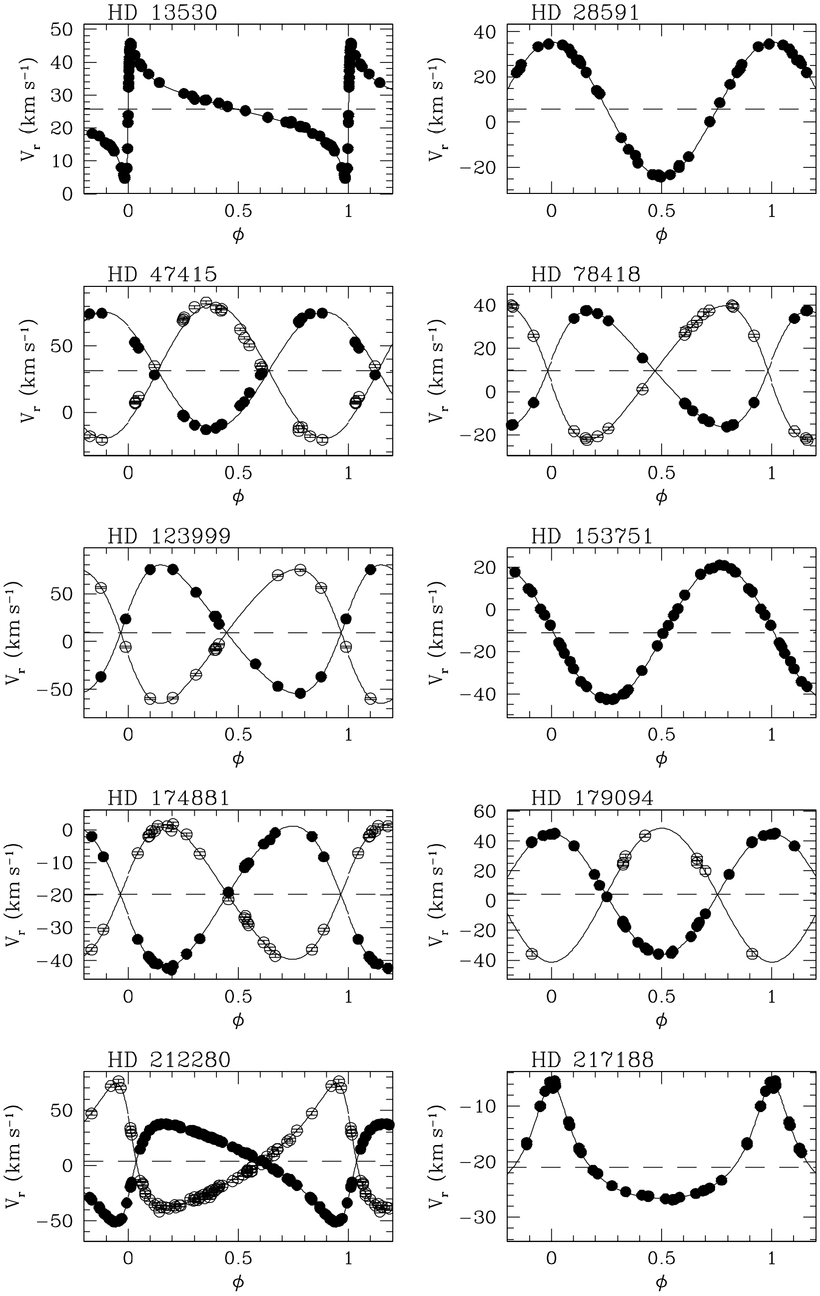

Fig. 1. Phase-folded radial-velocity curves of our evolved binary sample. The velocities of the second components of double-lined systems are indicated by open circles.

The individual radial-velocity measurements and the epoch of observations are available at the CDS “Centre de Données Stellaires” of Strasbourg Observatory.

For 4 of these systems the derived eccentricity is very small and the orbital solution appears to be compatible with a circular orbit according to the Lucy-Sweeney test at the 5% confidence level (Lucy & Sweeney 1971). However, although these systems are found to probably rotate in synchronization with the orbital motion (see below), we chose here to give the e-free solution for the orbits, the circularization time being larger than the synchronization time. These stars are indicated by a superscript a in the first column of Table 2.

a. HD 13530

This star is a fifth-magnitude G8 III giant (Bright Star Catalogue) listed by Batten et al. (1989) as having an orbital period of 1650 days and an eccentricity of 0.75, with a quality of the orbit classified as ‘e’ (poor). Clearly, these data are substantially different from the more reliable ones we present in Table 2. We find an orbital period of 1575.48±1.63 days and an eccentricity of 0.8815±0.0010. This high eccentricity value is the largest one known up to date for a single-lined spectroscopic-binary system including a giant star component. Among visual binary sub-giants, there is one star with an eccentricity value as high as e = 0.911, namely HD 172865, a G5 IV double-lined spectroscopic binary with an orbital period of about 91.8 years (Batten et al. 1989). However, those parameters are based on spectroscopic observations covering only about the eighteen months around the nodal passage.

The system HD 13530 was additionally resolved by Balega et al. (1984) in speckle interferometry and a separation of 0.040$''$ is given by McAlister & Hartkopf (1988).

b. HD 28591

This is a chromospherically active K1 III star quoted in the CABS catalogue (Strassmeier et al. 1993). During the preparation of the present paper, we learned of an independent determination of the orbital parameters for HD 28591 by F. Fekel. The obtained parameters are listed by Strassmeier et al. (1993), they present an excellent agreement with the orbital parameters we report in Table 2.

Letting the eccentricity be free, we find an orbital solution with e=0.010±0.005, which appears to be not significantly different from a circular orbit according to the Lucy-Sweeney test at the 5% confidence level. Boyd et al. (1984) give for HD 28591 a photometric period of 21.3 days. By comparing the orbital and photometric periods, in addition to the almost zero eccentricity, one sees clearly that HD 28591 appears to be in synchronization. This aspect explains the high rotational velocity we measured for this star, namely $v\sin i$ =27 $\mathrm{km\,s^{-1}}$ (From the photometric period and assuming $R_\star$=17R$_\odot$ for a K1 III, we derive $V_{rot} = 40.4$ $\mathrm{km\,s^{-1}}$, $i \simeq 42°$).

c. HD 47415

The determination of the orbital parameters for this double-lined spectroscopic binary, based on classical spectrographic plates, was first made by Nadal et al. (1983). The orbit is classified ‘c’ by Batten et al. (1989). Our measurements, based only on photoelectric radial velocities, confirm the given values with minor differences for the systemic velocity and for the $\mathrm{M}_{1,2}\sin^3 i$ parameters.

The short orbital period of 5.6991 days and the almost zero eccentricity seem to indicate that the system is very probably rotating in synchronization with the orbital motion. Following Nadal et al. (1983), we can estimate the inclination angle. We find $i \sim 33$ °. Hence, the true rotational velocities should be 11.6 $\mathrm{km\,s^{-1}}$ and 8.3 $\mathrm{km\,s^{-1}}$ for the primary and the secondary components, respectively. However, these rotation values are not compatible with the F8IV spectral type given in the literature (Hoffleit & Jaschek 1982). In fact, by considering a typical radius for F8IV, namely $3.5\,R_\odot$, one finds a V_{rot} of about 31 $\mathrm{km\,s^{-1}}$, based on synchonization consideration, which is in discrepancy with the measured values for $v\sin i$ and i. On the other hand, by considering a stellar radius of $1.3\,R_\odot$, typical for a F5V star, one finds a V_{rot} of about 11.5 $\mathrm{km\,s^{-1}}$ in agreement with the measured $v\sin i$ and i. In this context, we think that a F5V spectral type is the most appropriate for this star. Moreover, from the SB2 orbit we derive in this case a mass $M_2 \simeq 1.2\,\mathrm{M}_\odot$ for the secondary component, which is in agreement with the observed depth ratio of the CORAVEL correlation dips.

d. HD 78418

Beavers & Salzer (1982) have found an orbital period of 19.412 days, an eccentricity e = 0.20, $\delta m \simeq 0.9$ and $i \simeq 36°$ for this double-lined system with a G5 IV-V subgiant component. From 15 CORAVEL radial-velocity measurements, we confirm the values for these parameters. We have also determined the rotational velocity for both components (Table 1). The low $v\sin i$ values, 1.6 $\mathrm{km\,s^{-1}}$ and 2.3 $\mathrm{km\,s^{-1}}$, related to the orbital-parameter values (especially e) indicate that this system is very probably not rotating in synchronization with the orbital motion. By considering a typical radius of about $5\,R_\odot$ for this spectral type one finds a $V_{rot} = 13\,\mathrm{km\,s^{-1}}$, in agreement with the non synchronization hypothesis.

e. HD 123999

This is a double-lined system with a fifth-magnitude F8 IV subgiant component. Abt & Levy (1976) have determined an orbital period of 9.60 days and an eccentricity e = 0.19. From 12 CORAVEL radial-velocity measurements, we confirm these orbital parameters. We have also determined the rotational velocity for both components (Table 1). The obtained $v\sin i$ values of 12.5 $\mathrm{km\,s^{-1}}$ and 9.5 $\mathrm{km\,s^{-1}}$ are compatible with the proposed spectral type (De Medeiros et al. 1996).

f. HD 153751

This is a G5 III single-lined binary star for which we confirm all the orbital parameters given by Climenhaga et al. (1951). The eccentricity value when free is e = 0.007±0.0004 which appears to be not significant according to the Lucy-Sweeney test. The orbital period of 39.4816 days and the almost zero eccentricity indicate that the system is rotating in synchronization with the orbital motion, which explains its high rotational velocity of $v\sin i$ =23.0±1.0 $\mathrm{km\,s^{-1}}$. However, by using typical stellar radius for a G5III giant we find a rotation rate of about 12.8 $\mathrm{km\,s^{-1}}$, clearly in discrepancy with the observed $v\sin i$. In addition, by applying the condition for equal periods of rotational and orbital motion for an eclipsing binary system, $v\sin i$ =$(R/a)K$, where R is the stellar radius, a is the semi-major axis of the orbit and K is the semiamplitude of the radial velocity, we find a synchronous rotational velocity of about 15.3 $\mathrm{km\,s^{-1}}$, with (R/a)=0.48 (Hinderer 1958) and K=31.82 from the present work. Hinderer (1958), from photoelectric observations, derived an orbital inclination angle of 85.4°, a visual magnitude difference of 3.44, and masses of 2.8 $\mathrm{M}_\odot$ and 1.3 $\mathrm{M}_\odot$ for the primary and secondary stars, respectively. Shallow eclipses were first observed by Gurthnick (1947).

g. HD 174881

This is a sixth-magnitude giant with a spectral type K1 II-III. CORAVEL observations clearly show that this star is in fact a double-lined spectroscopic binary. From 21 radial-velocity measurements, well defined for both components, we found an orbital period of 215.302 days and an eccentricity $e = 0.12$. During the preparation of this paper we learned of the independent determination of orbital parameters for this binary system by Appleton et al. (1995). These authors have found an orbital period of 215.6 days and an eccentricity e = 0.142, showing in addition the double-lined behavior for the system.

The low rotational velocity $v \sin i \simeq 1.0 \,\mathrm{km\,s^{-1}}$ for both components, and the large orbital period indicate that the system is probably not rotating in synchronization with the orbital motion.

h. HD 179094

Orbital parameters for this K1 IV subgiant were first determined by Young (1944). Nevertheless, this author was unable to detect the double-lined feature of the system. The new orbital parameters presented in Table 2 confirm the period and the eccentricity reported by Young. The CORAVEL rotational velocity for the primary star is about 14.9 km s^{-1}, a very high rotation for a spectral type K1 IV. Such a high rotation associated with a circular orbit and a low orbital period indicates that this system is rotating in synchronization with the orbital motion. In fact, Fried et al. (1982) found a photometric period of 27.8 days which shows no significant difference with the orbital period.

i. HD 212280

This is another chromospherically active subgiant star quoted in the CABS catalogue (Strassmeier et al. 1993). The double-lined behaviour for this star was first noticed by Heard (1956) and was confirmed by Fekel et al. (1986). During the preparation of this paper we learned of the independent determination of the orbital parameters for this double-lined system by Fekel et al. (1993). Their parameters are in excellent agreement with the values quoted in Table 2. In addition, these authors have presented a mean photometric period of 29.46 days.

The behaviour of the orbital period in comparison with the photometric period and the high eccentricity value of 0.5 indicate that the system is not rotating in synchronization with the orbital motion.

For the primary star the rotational velocity amounts to about 21 km s^{-1}. Concerning the luminosity class, Heard (1956) gives a G0 IV composite classification, whereas Strassmeier et al. (1993) list a F5- 8/G8 IV spectral type. By considering that the system is not rotating in synchronization, the high rotational velocity of 21 km s^{-1} indicates that the proposed F5-8/G8 IV spectral type is more appropriate. In fact, as shown by De Medeiros et al. (1996), subgiant stars later than F8IV with rotational velocity larger than 5.0 km s^{-1} are unusual. Only rotating synchronized systems with components presenting spectral type later than F8IV show large rotation rates.

j. HD 217188

This K0 III giant is also quoted in the CABS catalogue (Strassmeier et al. 1993) as a chromospherically active star. Despite the short orbital period given in Table 2, the high eccentricity of 0.46 indicates that the system is not rotating in synchronization, explaining the low CORAVEL rotational velocity of 3.0 km s^{-1} obtained for this star. Furthermore, the photometric period of 84.35 days found by Boyd et al. (1985) confirms the non-synchronization. A determination of the orbital parameters was made independently by F. Fekel (Strassmeier et al. 1993). There is a good agreement between the orbital period and the systemic velocity obtained in the present work and the values quoted by Strassmeier et al. (1993). However, there is a minor difference between the eccentricity values. We have found an eccentricity of 0.4626, whereas Strassmeier et al. quote a value of 0.50.

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References

Abt H.A., Levy S.C., 1976, ApJS 30, 273

Appleton P.N., Eitter J.J., Uecker C., 1995, JA&A 16, 37

Balega Y., Bonneau D., Foy R., 1984, A&AS 57, 31

Baranne A., Mayor M., Poncet J.L., 1979, Vistas in Astron. 23, 279

Batten A.H., Fletcher J.M., MacCarthy D.G., 1989, Pub. Dom. Astrophys. Obs. 17, 1

Beavers W.I., Salzer J.J., 1982, PASP 94, 356

Boyd L.J., Genet R.M., Hall D.S., 1984, IBVS 2546

Boyd L. J., Genet R.M., Hall D.S., Henry G.W., 1985, IBVS 2727

Climenhaga J.L., McKellar A., Petrie R.M., 1951, Pub. Dom. Astrophys. Obs. 17, 1

De Medeiros J.R., Mayor M., 1999, A&AS accepted for publication

De Medeiros J.R., Da Rocha C., Mayor M., 1996, A&A 314, 499

Duquennoy A., 1987, A&A 178, 114

Duquennoy A., Mayor M., Halbwachs J.-L., 1991, A&AS 88, 28

Fekel F.C., Moffet T.J., Henry G.W., 1986, ApJS 60, 551

Fekel F.C., Browning J.C., Henry G.W., Morton M.D., Hall D.S., 1993, AJ 105, 2265

Fried R.E., Eaton J.A., Hall D.S., et al., 1982, Ap&SS 83, 181

Gurthnick P., 1947, Abh. Deutschen Ak. Wiss., Mat Naturwiss. K1, 70

Heard J.F., 1956, Pub. David Dunlop Obs. 2, 107

Hinderer F., 1958, Astron. Nachr. 284, 1

Hoffleit D., Jaschek C., 1982, The Bright Star Catalogue. 4th ed., Yale University Observatory, New Haven

Lucy L.B., Sweeney M.A., 1971, AJ 76, 544

Mayor M., Maurice E., 1985, In: Philip A.G.D., Latham D.W. (eds.) IAU Coll. 188, L. Davis Press, Schenectady, N. Y., p. 35

McAlister H.A., Hartkopf W.I., 1988, CHARA Contribution 2

Nadal R., Carquillat J.M., Pedoussaut A., Ginestet N., 1983, A&AS 52, 293

Strassmeier K.G., Hall D.S., Fekel F.C., Scheek M., 1993, A&AS 100, 173

Udry S., Mayor M., Andersen J., et al., 1997, In: Battrick B. (ed.) Hipparcos Venice 97, ESA SP-402, ESA Publication Division, Noordwijk, The Netherlands

Young R.K., 1944, J. R. Astron. Soc. Can. 38, 366