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ORBITS OF SIX BINARY STARS

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RESUMEN

Se presentan los elementos orbitales de sistemas binarios WDS 03494–1956 = RST 2324, WDS 03513+2621 = A 1830, WDS 04093–2025 = RST 2333, WDS 06485–1226 = A 2935, WDS 07013–0906 = A 671 y WDS 18323–1439 = CHR 73. Se derivan las masas individuales y las paralajes dinámicas para todos los sistemas con excepción de WDS 18323–1439.

ABSTRACT

Preliminary orbital elements of binary systems WDS 03494–1956 = RST 2324, WDS 03513+2621 = A 1830, WDS 04093–2025 = RST 2333, WDS 06485–1226 = A 2935, WDS 07013–0906 = A 671, and WDS 18323–1439 = CHR 73 are presented. For all systems but WDS 18323–1439 the individual masses and dynamical parallaxes are derived.

Key Words: **BINARIES: VISUAL — STARS: DISTANCES — STARS: FUNDAMENTAL PARAMETERS — STARS: MASSES**

1. INTRODUCTION

The study of multiple stars, especially the orbit calculation, is a very important task in astronomy. The research of orbital motions for binaries is still the only way to determine masses reliably. An important result is also the dynamical parallaxes obtained on this occasion. Therefore, every new orbit is a contribution in the study of binaries.

By analyzing the observational data for binaries: WDS 03494–1956 = RST 2324, WDS 03513+2621 = A 1830, WDS 04093–2025 = RST 2333, WDS 06485–1226 = A 2935, WDS 07013–0906 = A 671, and WDS 18323–1439 = CHR 73 the Keplerian motion is established. By inspecting the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf & Mason 2003) it is established that these stars have no calculated orbits. Among all pairs mentioned above only WDS 18323–1439 = CHR 73 was listed in the Hipparcos Programme as HIP 90884 (ESA 1997). The preliminary orbital elements calculated from observations which were at our disposal in 2002 have been published in the IAUDS Information Circular No. 148 (Olević 2002).

Thanks to the courtesy of Dr. Hartkopf the observation list is completed, so we repeat here the calculation for orbital-element determination. Due to this we can calculate the individual masses of the components and the dynamical mass for five binaries. By using the trigonometric parallax from the Hipparcos Catalogue the total mass is calculated for WDS 18323–1439 = CHR 73. For this pair only the integrated apparent magnitude is known and hence the individual masses cannot be determined even though, according to the existing data (integrated magnitude and spectrum), it belongs to the Main Sequence.

2. METHOD

In the calculations of the orbital elements we use the KOVOLE Method developed by the first author (Olević & Cvetković 2004). This method is based on Kovalski's method and yields satisfactory results from interferometric measurements even when only a short orbital arc is covered by the observations. The original method has failed in this situation. A correct estimation of the observational weights is also of special importance. For this purpose we use a criterion analogous to that applied by Mason, Douglas, & Hartkopf (1999). Individual masses and dynamical parallaxes are calculated by using Angelov's (1993) relation.

3. RESULTS AND COMMENTS

3.1. *Results*

The orbital elements (equinox J2000) and the corresponding errors are listed in Table 1. m_{A} and

TABLE 1

ORBITAL ELEMENTS

Name	RST 2324	A 1830	RST 2333	A 2935	A 671	CHR 73
WDS	03494–1956	03513+2621	04093–2025	06485–1226	07013–0906	18323–1439
ADS	...	2811	...	5477	5703	...
HIP	...	...	...	...	...	90884
$m_A - m_B$	10.0–10.0	9.4–9.4	9.7–9.7	9.6–9.6	9.8–9.9	$v = 6.37$
Sp	G5	F8	G2/3V	G6V	F5	A4V
$P(yr)$	105.42	291.60	154.44	86.45	352.94	5.925
	±2.04	±27.19	±8.75	±0.32	±3.56	±0.147
T	1995.39	1976.77	1996.04	1996.24	2207.99	1989.97
	±1.87	±27.90	±8.29	±0.20	±1.17	±0.14
$a('')$	0.200	0.284	0.337	0.248	0.536	0.0564
	±0.012	±0.062	±0.021	±0.041	±0.077	±0.0085
e	0.349	0.450	0.138	0.579	0.270	0.194
	±0.042	±0.223	±0.031	±0.083	±0.092	±0.103
$i(^o)$	144.3	103.6	74.3	140.3	107.2	136.1
	±5.1	±6.0	±1.8	±4.5	±4.3	±9.8
$\Omega(^o)$	155.8	15.3	17.2	20.2	163.5	65.1
	±10.3	±4.8	±1.8	±7.5	±2.3	±17.4
$\omega(^o)$	131.0	143.1	113.8	23.5	306.8	280.4
	±12.7	±14.2	±24.5	±7.7	±21.3	±43.7

m_B are the apparent magnitudes of the components taken from the WDS Catalog (Mason, Wycoff, & Hartkopf 2003). For binary CHR 73, the value $v = 6.37$ concerns the total magnitude. The spectral type is also from WDS.

Table 2 contains the observational data used and their residuals ($\Delta\theta^\circ$ and $\Delta\rho''$). Asterisks (*) mark observations subjected to a change of quadrant. Double asterisks (**) indicate the measurements not used in the orbit calculation. The sign + refers to a measurement where the position angle θ was replaced by $360^\circ - \theta$ in the calculation. The sign ($\diamond$) indicates the interferometric measurements. The ephemerides values are given within parentheses.

The ephemerides for 2005–2009 are given in Table 3.

Figures 1 to 6 provide the fitted orbit and the line of nodes. The visual observations are given as filled circles and those observed interferometrically as filled squares. The empty circles and empty squares are their corresponding epehemeris positions. The dotted line indicates the rejected observations.

The arrow indicates the sense of the orbital motion.

3.2. *Comments*

WDS 03494–1956 = RST 2324: The arc of the orbit traced since the time of its discovery (R. A. Rossiter in 1935) is 211 degrees. The period published in Information Circular No. 148 is half as long as the one given here. The present elements are calculated with the completed observations. The orbital elements calculated from the published observations yielded significant residuals in the position angle in the case of two interferometric measures: $\Delta\theta = 17.4$ degrees—Hartkopf's observation for epoch 1993.0977 and $\Delta\theta = 29.2$ degrees—

TABLE 2

OBSERVATIONS AND RESIDUALS

WDS 03494–1956 = RST 2324						
t	θ°	ρ''	n	Obs.	$\Delta\theta^\circ$	$\Delta\rho''$
1935.0	208.1	0.20	1	RST	−4.8	−0.027
1936.08	205.0	0.22	4	RST	−5.8	0.010
1936.74	203.8	0.26	4	Vou	−5.7	0.029
1943.12	199.2	0.26	2	RST	1.5	0.017
1951.06	189.2	0.22	3	RST	4.9	−0.030
1952.01	187.6	0.20	1	RST	4.9	−0.051
1960.51	174.0	0.32	2	Knp	5.5	0.075
1965.98	158.	0.20	1	Knp	−0.6	−0.033
1975.725	144.1	0.20	3	Wor	7.8	0.009
1977.73	136.6	0.20	3	Hei	6.3	0.020
1989.9413$^\diamond$	65.8	0.125	1	Hrt	2.0	0.012
1990.9160$^\diamond$	57.0	0.117	1	Hrt	1.3	0.006
1990.9242$^\diamond$	57.7	0.120	1	Hrt	2.1	0.009
1993.0977$^\diamond$	27.8	0.106	1	Hrt	−9.4	−0.006
2001.5704$^{\diamond+}$	26.1	0.144	1	Msn	−0.6	0.004

WDS 03513+2621 = A 1830						
t	θ°	ρ''	n	Obs.	$\Delta\theta^\circ$	$\Delta\rho''$
1908.72	8.4	0.27	3	A	−4.4	−0.049
1918.22	6.7	0.25	2	A	−3.9	−0.035
1931.82	3.1	0.20	4	A	−3.1	−0.020
1932.04	14.5	0.30	1	Fur	8.4	0.081
1944.76	4.5	0.17	4	Vou	7.1	0.031
1953.01	*round*	< 0.1	1	VBS	(341.8)	(0.080)
1954.12**	29. :	0.18 :	1	VBS	(337.7)	(0.072)
1954.80	*round*	< 0.1	1	VBS	(334.9)	(0.068)
1961.75	···	< 0.1	1	Cou	(274.0)	(0.042)
1976.02	66.5	0.14	2	Hei	−9.8	0.017
1982.052	···	···	1	Cou	(199.6)	(0.152)
1986.8862$^\diamond$	194.1	0.118	1	McA	−1.5	−0.048
1987.098*	12.3	0.12	1	Cou	−3.2	−0.046
1987.7654$^\diamond$	194.9	0.145	1	McA	−0.1	−0.022
1988.6636$^\diamond$	195.2	0.162	1	McA	0.9	−0.007
1988.827*	12.5	0.174	1	Cou	−1.7	0.005
1989.054*	13.1	0.14	3	Cou	−0.9	−0.029
1989.103*	17.8	0.18	2	Gii	3.8	0.011
1989.89	205.2	0.14	2	Hei	11.8	−0.030
1991.9045$^\diamond$	192.6	0.216	1	Hrt	0.6	0.044
1994.97	186.4	0.19	2	Hei	−3.4	0.019
1995.9320$^\diamond$	194.2	0.267	1	Hrt	5.1	0.096

TABLE 2 (CONTINUED)

WDS 04093–2025 = RST 2333						
t	θ°	ρ''	n	Obs.	$\Delta\theta^\circ$	$\Delta\rho''$
1935.69	11.2	0.32	3	RST	5.3	0.010
1936.72	9.5	0.32	4	Vou	2.9	0.004
1941.49	11.1	0.34	2	RST	1.3	0.003
1946.08	8.8	0.34	1	RST	−3.8	−0.010
1951.12	6.8	0.32	2	RST	−8.7	−0.033
1960.52	24.0	0.34	2	Knp	2.8	0.014
1978.56	37.0	0.20	3	Hei	−6.3	0.037
1989.9413$^\diamond$	123.4	0.078	1	Hrt	−1.5	−0.004
1990.9160$^\diamond$	137.7	0.086	1	Hrt	3.2	−0.002
1990.9242$^\diamond$	135.0	0.084	1	Hrt	0.4	−0.004
1993.0977$^\diamond$	151.4	0.115	1	Hrt	0.1	0.009

WDS 06485–1226 = A 2935						
t	θ°	ρ''	n	Obs.	$\Delta\theta^\circ$	$\Delta\rho''$
1915.14**	304.6	0.27	2	A	31.0	0.154
1921.82	230.2	0.21	2	A	0.2	−0.003
1922.92	226.4	0.23	2	A	0.1	0.003
1932.84**	183.7	0.19	5	Vou	−21.9	−0.136
1937.15	...	...	1	B	(199.9)	(0.352)
1937.84**	158.4	0.23	4	Vou	−40.4	−0.126
1939.87**	151.0	0.22	4	Smw	−45.3	−0.144
1960.18**	158.5	0.15	1	B	−14.6	−0.209
1972.101	160.5	0.18	3	Wor	5.4	−0.109
1979.20	137.8	0.23	3	Hei	0.0	0.004
1983.176	119.5	0.18	3	Wor	−3.3	−0.008
1990.9246$^\diamond$	73.1	0.126	1	Hrt	4.9	0.000
1993.0898$^\diamond$	45.9	0.126	1	Hrt	1.5	0.010

WDS 07013–0906 = A 671						
t	θ°	ρ''	n	Obs.	$\Delta\theta^\circ$	$\Delta\rho''$
1904.06	155.6	0.41	3	A	0.7	−0.020
1916.50	148.8	0.38	2	A	−0.1	−0.017
1932.57	138.4	0.42	2	A	−0.5	0.091
1934.91	138.6	0.32	3	Vou	1.6	0.002
1939.93	131.2	0.28	2	Smw	−1.4	−0.013
1944.853	124.0	0.29	4	Vou	−3.4	0.020
1954.61	113.3	0.17	3	VBS	−0.7	−0.056
1976.114	63.1	0.17	1	Wor	−5.0	−0.019
1979.20	63.9	0.22	3	Hei	2.9	0.026
1980.256	60.4	0.20	2	Wor	1.7	0.004
1983.180	53.2	0.16	2	Wor	0.6	−0.043
1989.9335$^\diamond$	40.4	0.239	1	Hrt	0.0	0.012
1993.0898$^\diamond$	35.8	0.252	1	Hrt	0.3	0.012

TABLE 2 (CONTINUED)

WDS 18323–1439 = CHR 73						
t	$\theta°$	ρ''	n	Obs.	$\Delta\theta°$	$\Delta\rho''$
1985.5149$^\diamond$	41.1	.043	1	McA	−0.3	−0.011
1988.1630$^\diamond$	269.0	.060	1	McA	2.5	0.002
1989.3041$^\diamond$	209.4	.044	1	McA	−2.4	0.000
1991.3901$^\diamond$	34.0	.066	1	McA	−9.7	0.012
1991.7261$^\diamond$	37.0	.049	1	McA	9.1	−0.004
1992.4550$^\diamond$	349.0	.049	1	McA	0.3	0.001

TABLE 3

EPHEMERIDES

WDS	03494–1956		03513+2621		04093–2025		06485–1226		07013–0906		18323–1439	
t	$\theta°$	ρ''	$\theta°$	ρ''	$\theta°$	ρ''	$\theta°$	ρ''	$\theta°$	ρ''	$\theta°$	ρ''
2005.0	322.9	.151	182.0	.155	185.0	.235	245.2	.166	21.9	.299	308.2	.051
2006.0	318.4	.154	181.1	.152	186.3	.244	239.8	.180	20.9	.305	263.3	.058
2007.0	314.1	.156	180.2	.149	187.4	.253	235.2	.195	20.1	.310	216.1	.045
2008.0	309.8	.158	179.3	.146	188.5	.261	231.3	.209	19.2	.315	111.0	.038
2009.0	305.7	.160	178.3	.144	189.5	.269	227.8	.223	18.4	.321	51.2	.054

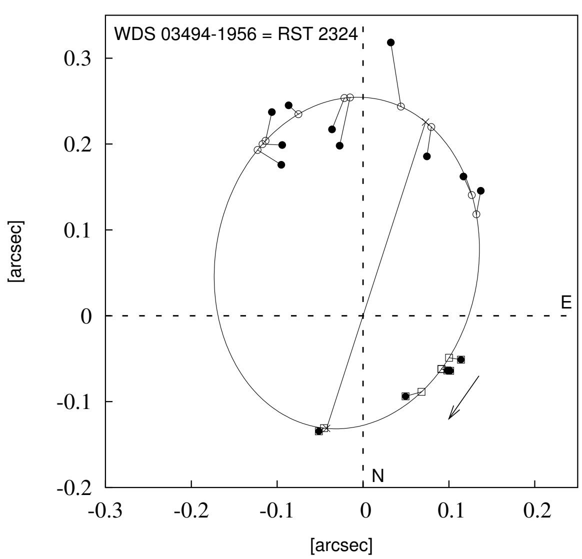

Fig. 1. WDS 03494–1956 = RST 2324.

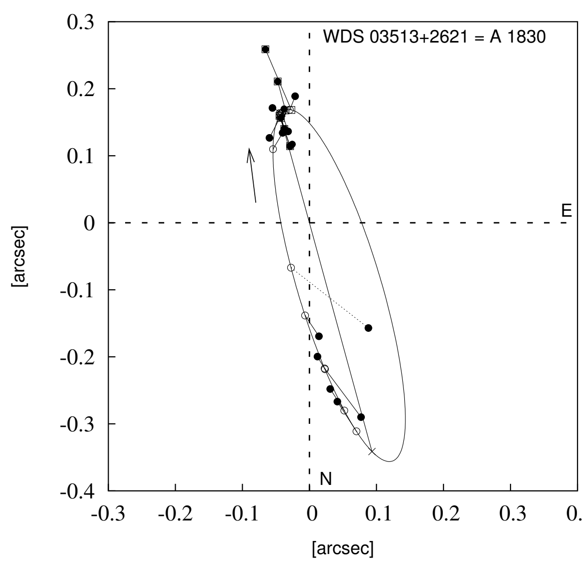

Fig. 2. WDS 035513+2621 = A 1830.

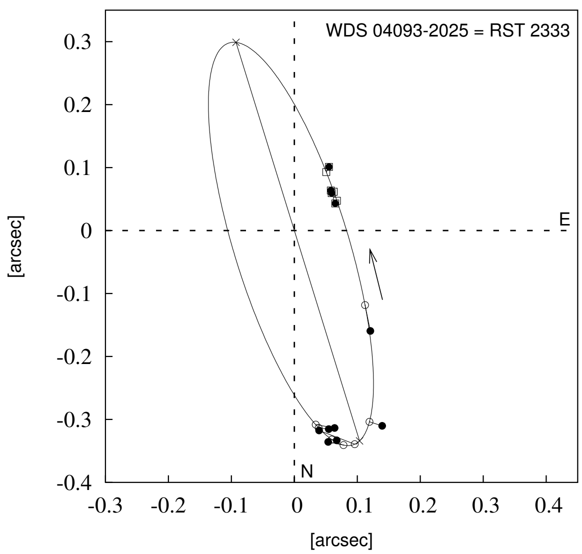

Fig. 3. WDS 04093–2025 = RST 2333.

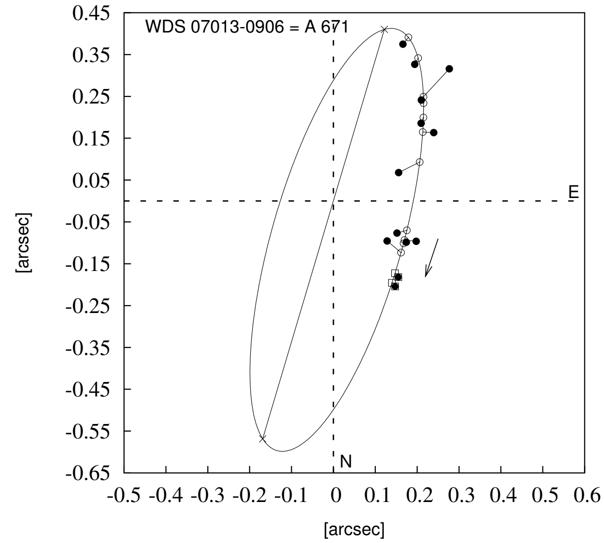

Fig. 5. WDS 07013–0906 = A 671.

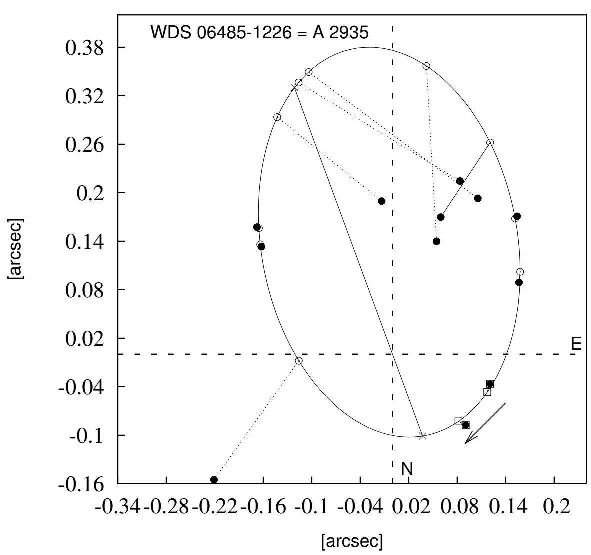

Fig. 4. WDS 06485–1226 = A 2935.

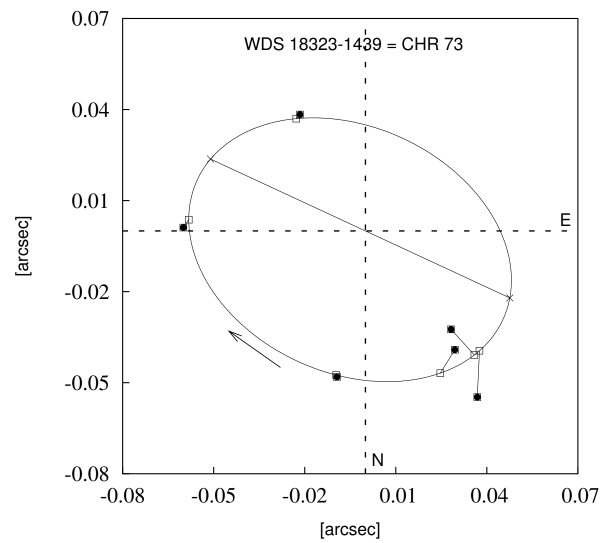

Fig. 6. WDS 18323–1439 = CHR 73.

Mason's observation for epoch 2001.5704. Analyzing the changes of the position angle we correct θ for the epoch of 2001.5704 to be $(360° - \theta)$. The orbital elements calculated after taking into account this correction yield a residual of $\Delta\theta = -0.6$ degrees for epoch 2001.5704, whereas the residual for the observation from 1993.0977 is reduced to $\Delta\theta = -9.4$ degrees. The dynamical masses of the components are 1.21 $M_\odot$ and 1.21 $M_\odot$, respectively (the integrated spectrum is G5). The dynamical parallax is 0.″0067.

WDS 03513+2621 = A 1830: The orbit of this system has a high inclination, namely 103 degrees. Van Biesbroeck and Couteau observed it unsuccessfully between 1953 and 1961. According to our ephemerides ρ is between 0.″08 and 0.″04 so that the estimates of these observers are correct. Heintz's measure from 1976 in our opinion has a *lapsus-calami* error in the position angle. If instead of the published value of 66.°5 one assumes 196.°5, the measurement has a small residual from the calculated orbit. This pair, with an integrated spectrum of F8, has component masses of 1.58 $M_\odot$ and 1.58 $M_\odot$, and its dynamical parallax is 0.″0044.

WDS 04093–2025 = RST 2333: The arc traced from Rossiter's discovery in 1935 until 1993 (last observation at our disposal) is 140 degrees. On the basis of the completed observational data for the period mentioned above one finds observational elements significantly different from those published in Information Circular No. 148. The obtained dynamical masses of the components are 1.16 $M_\odot$ and 1.16 $M_\odot$. In view of the integrated spectral type of G2/3V one concludes that the present orbital elements are more reliable than the previous ones. The obtained dynamical parallax is 0.″00884.

WDS 06485–1226 = A 2935: Out of 12 measurements for this pair five are not included in the calculation because of gross errors. One of them is an observation from the epoch of discovery. The other four rejected measurements were performed between 1932 and 1960 with micrometers on refractors of 24 and 26 inches. In the calculation one takes into account the measurements with 36-inch refractors and reflectors between 36 and 60 inches. Two speckle-interferometric measurements have been done with a 158-inch reflector. From the calculated elements one finds the dynamical masses of the components to be 1.15 $M_\odot$ and 1.15 $M_\odot$ as expected for an integrated spectrum of G6V. The dynamical parallax is 0.″0096.

WDS 07013–0906 = A 671: The arc delineated from the time of its discovery in 1904 until the last measurement in 1993 is 120 degrees. For the individual masses one finds 1.18 $M_\odot$ and 1.16 $M_\odot$, an acceptable value in view of the spectral type (F5) and its Main-Sequence positioning. The dynamical parallax calculated here is 0.″0081.

WDS 18323–1439 = CHR 73: According to our observations (P = 5.925 years, a=0.″056) this interferometric short-period pair has performed more than one revolution from the time of discovery in 1985.5 until the last observation in 1992.455. Within this time interval the pair was observed only six times. According to our ephemerides a large part of the orbit was not observable even with large telescopes. The pair was included in the Hipparcos Program and its trigonometrical parallax was obtained as 0.″01351±0.″00083, yielding for the total mass a value of 2.09±0.51 $M_\odot$. The spectral type is A4V.

4. CONCLUSION

The inclusion of additional observations somewhat changed the orbital elements contained in Information Circular No. 148. For pair WDS 03494-1956 = RST 2324 a twice as long period P was obtained; for pairs WDS 03513+2621 = A 1830, WDS 06485–1226 = A 2935, and WDS 07013–0906 = A 671 the obtained elements P and a suffer insignificant changes. The highest element difference appears for pair WDS 04093–2025 = RST 2333. The reason is that in the previous calculation the five observations from 1936–1978 were not at our disposal.

In the case of WDS 18323–1439 = CHR 73, though there are no additional observations, the recalculation is nevertheless done. Some orbital elements have suffered changes, but the new residuals are significantly smaller.

The masses obtained for the first five binaries are as expected for their spectral types (Lang 1991; Söderhjelm 1999). The mass of WDS 18323–1439 = CHR 73 is according to Lang somewhat less than that expected for the spectral type A4 V, but it is within the error limits for the period P, semimajor axis a and trigonometric parallax according to the analysis in Söderhjelm 1999. Due to the short period definitive elements could be obtained in a short time.

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