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BINARY STAR SPECKLE MEASUREMENTS WITH THE 1.52-M TELESCOPE AT CALAR ALTO

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RESUMEN

En este artículo presentamos medidas interferométricas de estrellas binarias, resultado de las campañas de observación llevadas a cabo en julio de 2001 y febrero de 2004 con nuestra cámara de motas (speckle) acoplada al telescopio de 1.52-m del Observatorio Astronómico Nacional en Calar Alto (Almería, España). Los datos contienen 120 observaciones de 87 sistemas con separaciones angulares desde 0.″102 a 6.″076. Los elementos orbitales de las binarias STT 170 y STF 1670 AB se mejoraron utilizando las observaciones de los sistemas incluidos en este trabajo.

ABSTRACT

We present binary star interferometric measurements carried out on 2001 July and 2004 February with our ICCD speckle camera attached to the 1.52-m telescope of the Observatorio Astronómico Nacional at Calar Alto (Almería, Spain). Data comprise 120 observations of 87 systems with the measured angular separations ranging from 0.″102 to 6.″076. They are used to improve the orbital elements for STT 170 and STF 1670 AB.

Key Words: **BINARIES: VISUAL — STARS: INDIVIDUAL (STT 170, STF 1670 AB) — TECHNIQUES: INTERFEROMETRIC**

1. INTRODUCTION

It is well known that double stars, in particular visual binaries (VB), are the main source of data to calculate accurate stellar masses. Since Labeyrie (1970) proposed the speckle interferometry as a new technique to perform astrometric measurements of VB, this field has undergone a big development. In fact, using this technique both the accuracy and limiting magnitude of the measured objects are broadly increased. In the case of a 1.5-m telescope the Rayleigh resolution limit of 70 mas (0.″07) can be achieved. On the other hand, binary star components as weak as 11 mag can be observed separately.

With the aim to obtain a high quality astrometric measurements, the speckle interferometer with a photon counting intensified CCD detector was developed at the Astronomical Observatory R. M. Aller of the University of Santiago de Compostela in cooperation with the Special Astrophysical Observatory (SAO) of the Russian Academy of Sciences. The camera was already in use for speckle observations of binary stars with the 1.52-m telescope at Calar Alto in 1999 and 2000, and results were reported in Docobo et al. (2001) and Docobo et al. (2004), respectively, along with a detailed description of both the camera and data reduction procedure.

The observations reported in this paper are obtained within the framework of studies on binary and multiple stars traditionally carried out at the Astronomical Observatory Ramón María Aller. They are closely related to research topics developed within the Commission 26 of the International Astronomical Union.

In Section 2, we provide a brief description of our camera. Some comments on the calibration process are made in Section 3, where we also present the results obtained. Then, in Section 4, improved orbits of visual binaries STT 170 and STF 1670 AB using the new measurements are reported. The last section

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presents some brief conclusions drawn on the basis of the obtained results.

2. A BRIEF DESCRIPTION OF THE SPECKLE CAMERA

The main module (see Figure 1) contains a pair of interchangeable microscope objectives with magnifications 8× and 20×, which are used to sample the size of individual speckles (about 4 μm at 500 nm at the f/8 Cassegrain focus of the 1.52-m telescope) to a detector's pixel, with a size of 13.4 μm. The corresponding scale on the detector is 0.″028 or 0.″011 per pixel with total fields of view of 5.6 and 14.3 square arcseconds. We normally use a 20× microscope objective.

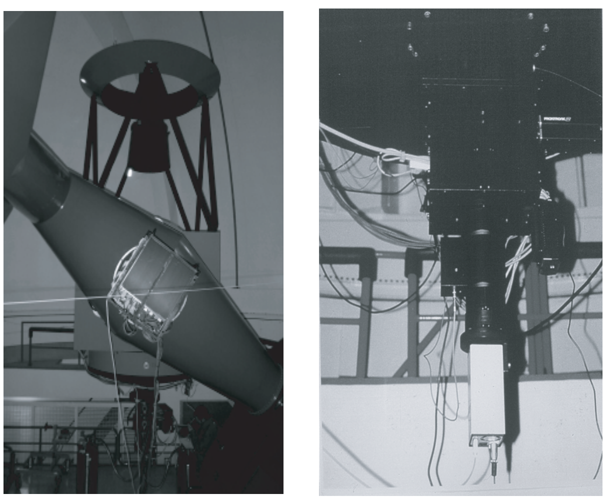

Fig. 1. The 1.52-m telescope and the speckle camera attached to it.

In order to provide an exposure value in the range 5 to 40 ms an Uniblitz remote-controlled electronic shutter placed in front of the microscope objective is synchronized with the CCD detector readout.

Data are routinely obtained through the 520/24-nm filter; however, a filter wheel assembly also includes 600/50-nm and 660/40-nm filters. In addition, a set of four zero mean deviation prisms, mounted on a rotation stage, is used for atmospheric dispersion compensation at different zenith angles (for a 20° radius from the zenith, the clear aperture is selected).

The detector system consists of a PCO Computer Optics (Germany) Sensicam CCD camera with 1280(H)×1024(V) pixels of 6.7×6.7μm, optically coupled by means of a pair of f/1.5 transfer lenses to a 3-stage electrostatically focused image intensifier. The input 24-mm photocathode of the intensifier has an S-25 spectral response with a peak sensitivity of 12% at 510 nm, and about 2% sensitivity is still available at 800 nm. For faster readout we use the sampling of speckle images to 512×512 pixels. The dynamic range of the system is limited by the 12-bit digitisation. Single photoelectron events are recorded by the system with a signal-to-noise ratio of about 30.

TABLE 1

PIXEL SCALE AND POSITION ANGLE OFFSET VALUES

Campaign	$\widehat{\rho}$ (mas pixel^{-1})	$\widehat{\theta}$[°]
2001	11.72 ± 0.09	-1.34 ± 0.33
2004	11.77 ± 0.09	-2.21 ± 0.42

3. OBSERVATIONS AND DATA REDUCTION

Two observational runs were carried out on July 17-27, 2001 and February 3-10, 2004. For each binary, a typical observing procedure involved the accumulation of 1000 to 3000 short exposure images on Exabyte tapes.

An astrometric calibration was made separately for each campaign by fitting measurements of several wide binaries with very long periods, well-known orbital parameters (or a combination of both) to their calculated positions (see Table 1). Figures 2 and 3 show the scale and detector orientation angle used to convert separation and position angle to their final values given in Table 3, along with the estimated uncertainties for the 2001 and 2004 observational runs, respectively.

The difference in the position angle offsets between the two observational runs could be related to calibration methodology. With the aim to obtain a more reliable calibration the authors will consider to determine the scale by means of the focal length of the telescope and the orientation using a slit mask on future runs.

Position angle and separation have been obtained by analyzing the mean autocorrelation function. For each speckle frame, we made a flat-field photometric correction and geometric correction for field distortions caused by the image intensifier. Then we computed the mean power spectrum of an object following the standard Labeyrie (1970) procedure and corrected it for the photon noise bias. Finally, we com-

TABLE 2

2001-2004 SPECKLE MEASUREMENTS ON THE 1.52-M TELESCOPE

WDS	Name	ADS	2000.0+	$\theta(^\circ)$	$\sigma_\theta(^\circ)$	$\rho('')$	$\sigma_\rho('')$	CS
00121+5337	BU 1026Aa-b	148Aa-B	1.5647	298.3	0.5	0.293	0.003	
00546+1911	STT 20AB	746	1.5592	189.7	0.5	0.523	0.005	
01243−0655	BU 1163	1123	1.5619	209.4	0.5	0.286	0.003	c
02020+0246	STF 202AB	1615	4.0966	271.4	0.4	1.837	0.015	c
			4.0995	270.4	0.4	1.837	0.014	c
02140+4729	STF 228	1709	4.0945	285.9	0.5	0.957	0.009	
02537+3820	BU 524AB	2200	4.0939	344.2	0.8	0.207	0.002	
03054+2515	STF 346AB	2336	4.0943	252.4	0.5	0.368	0.003	
03175+6540	STT 52AB	2436	4.0967	60.3	0.5	0.490	0.004	
04136+0743	A 1938	3064	4.0941	347.3		0.120		
04199+1631	STT 79	3135	4.1049	326.4		0.383		
04239+0928	HU 304	3182	4.0942	7.4	0.5	0.220	0.002	
04290+1610	HU 1080	3248	4.1021	84.0		0.270		
04357+1010	CHR 18Aa		4.1049	208.9		0.128		
04400+5328	BU 1295AB	3358	4.0968	153.3	0.6	0.277	0.003	
	STF 566AC	3358	4.0968	184.1	0.4	0.788	0.006	
	STF 566BC	3358	4.0968	198.7	0.7	0.558	0.013	
04433+5931	A 1013	3391	4.0970	283.9	0.6	0.322	0.003	
05079+0830	STT 98	3711	4.1000	310.4	0.4	0.793	0.007	
			4.1050	311.7	0.4	0.810	0.006	
05386+3030	BU 1240AB	4229	4.0970	337.9	0.6	0.204	0.002	
05387−0236	BU 1032AB	4241	4.0970	100.6	0.5	0.250	0.004	
			4.1021	101.5	0.6	0.256	0.003	
			4.1050	100.7	0.4	0.245	0.002	
05413+1632	BU 1007	4265	4.0971	253.0	0.7	0.244	0.003	
05429−0648	A 494 AB	4299	4.0971	102.9	0.9	0.193	0.002	
06041+2316	KUI 23AB		4.1000	200.1	0.8	0.210	0.002	
			4.1022	198.9	0.6	0.207	0.002	
06462+5927	STF 948AB	5400	4.1078	71.5	0.4	1.874	0.015	
06531+5927	STF 963AB	5514	4.1055	317.6	0.7	0.239	0.003	
06573+5825	STT 159AB	5586	4.1079	226.9	0.4	0.565	0.005	
07176+0918	STT 170	5958	4.0996	37.3	0.5	0.295	0.004	c
07518−1354	BU 101	6420	4.1027	60.4	0.6	0.179	0.002	
08122+1739	STF 1196AB	6650	4.1001	62.7	0.4	0.953	0.007	c
			4.1027	62.8	0.4	0.955	0.007	c
			4.1079	62.3	0.4	0.934	0.008	c
			4.1080	62.8	0.4	0.957	0.008	c
08468+0625	SP 1AB	6993	4.1000	266.9		0.204		
	STF 1273AB-C	6993	4.1000	299.2		2.884		
09036+4709	A 1585	7158	4.1027	308.2	1.3	0.167	0.002	
09285+0903	STF 1356	7390	4.1028	93.2	0.4	0.643	0.005	
10279+3642	HU 879	7780	4.0974	218.4	0.5	0.313	0.003	
11182+3132	STF 1523AB	8119	4.0946	250.8	0.4	1.774	0.014	c
12244+2535	STF 1639AB	8539	4.0948	324.7	0.4	1.763	0.014	c
12417−0127	STF 1670AB	8630	4.0921	215.1	0.4	0.654	0.005	
			4.1003	214.9	0.4	0.650	0.005	
13100+1732	STF 1728AB	8804	4.0921	12.2	0.4	0.355	0.003	c
			4.0948	12.0	0.4	0.359	0.003	c
			4.0977	11.8	0.4	0.358	0.003	c
13329+3454	STT 269AB	8939	4.1004	219.1	0.6	0.275	0.005	
13347−1313	BU 923AB	8954	4.0949	61.2	0.5	0.404	0.003	
			4.1004	61.2	0.5	0.404	0.004	
13396+1045	BU 612AB	8987	4.0949	192.9	0.5	0.259	0.003	c
			4.0975	192.5	0.5	0.251	0.002	c
			4.1058	194.2	0.6	0.260	0.002	c
14234+0827	STF 1835AB	9247	4.0979	193.8	0.4	6.076	0.050	
14323+2641	A 570	9301	4.0978	93.2	0.5	0.192	0.002	
14411+1344	STF 1865AB	9343	4.0950	298.1	0.4	0.694	0.005	
			4.1005	298.5	0.4	0.699	0.011	
14455+4223	STT 285AB	9378	4.0976	90.1		0.444		
14489+0557	STF 1883	9392	4.0976	280.8	0.4	0.881	0.007	
			4.1005	281.4	0.4	0.880	0.007	
15038+4739	STF1909	9494	4.0951	56.4	0.4	2.000	0.016	

TABLE 2 (CONTINUED)

WDS	Name	ADS	2000.0+	$\theta(^\circ)$	$\sigma_\theta(^\circ)$	$\rho('')$	$\sigma_\rho('')$	CS
15232+3017	STF 1937AB	9617	4.0951	97.3	0.4	0.542	0.004	c
			4.1058	97.4	0.4	0.544	0.004	c
15360+3948	STT 298AB	9716	1.5455	161.5	0.4	0.613	0.005	c
			4.0977	169.5	0.4	0.802	0.007	c
			4.1006	169.6	0.4	0.811	0.007	c
15416+1940	HU 580AB	9744	1.5483	247.5	2.2	0.204	0.003	
			1.5592	247.6	0.4	0.201	0.002	
			4.0976	254.6	0.5	0.194	0.002	
			4.1006	254.4	0.5	0.173	0.002	
			4.1059	253.6	0.4	0.178	0.002	
16044−1122	STF 1998AB	9909	1.5510	320.6	0.3	0.464	0.004	c
			1.5592	320.1	0.4	0.462	0.004	c
16080+4523	BU 355AB	9935	1.5619	287.3	0.7	0.224	0.005	
16085−1006	BU 949	9932	1.5510	197.2	0.4	0.453	0.004	
16309+0159	STF 2055AB	10087	1.5565	30.7	0.3	1.402	0.011	
16511+0924	STF 2106	10229	1.5592	175.1	0.4	0.679	0.006	
16514+0113	STT 315	10230	1.5483	318.6	0.4	0.546	0.005	
17053+5428	STF 2130AB	10345	1.5565	17.7	0.3	2.260	0.018	
17141+5608	STT 327	10425	1.5619	327.5	0.6	0.446	0.006	
17304−0104	STF 2173	10598	1.5455	125.1	0.4	0.318	0.003	c
17506+0714	STT 337	10828	1.5592	170.9	0.4	0.490	0.006	
18017+4011	STF 2267AB	11001	1.5428	266.8	0.5	0.614	0.007	
18031−0811	STF 2262AB	11005	1.5483	282.9	0.3	1.703	0.013	
18055+0230	STF 2272AB	11046	1.5455	144.5	0.3	4.114	0.034	c
18096+0400	STF 2281AB	11111	1.5483	116.2	0.4	0.543	0.005	
18359+1659	STT 358AB	11483	1.5455	154.4	0.3	1.686	0.013	
18384−0312	A 88AB	11520	1.5592	266.9	0.7	0.102	0.002	c
18558+0327	A 2192	11842	1.5537	51.4	0.6	0.202	0.002	
18570+3254	BU 648 AB	11871	1.5483	301.9	0.3	0.692	0.006	c
			1.5592	302.5	0.4	0.684	0.006	c
19159+2727	STT 371AB	12239	1.5428	159.4	0.4	0.888	0.008	c
			1.5483	159.6	0.3	0.892	0.007	c
			1.5537	159.6	0.3	0.889	0.007	c
19487+3519	STT 387	12972	1.5428	137.9	0.4	0.615	0.005	
20035+3601	STF 2624	13312	1.5483	174.1	0.3	1.951	0.015	c
20375+1436	BU 151AB	14073	1.5537	346.5	0.4	0.566	0.005	
			4.5619	346.8	0.4	0.564	0.005	
20537+5918	A 751	14412	1.5619	89.5	0.5	0.135	0.002	
21021+5640	STF 2751AB	14575	1.5619	354.7	0.3	1.623	0.013	c
21145+1000	STT 535AB	14773	1.5455	23.1	0.7	0.314	0.004	c
21186+1134	BU 163AB	14839	1.5428	260.6	0.4	0.594	0.006	
			1.5565	260.6	0.5	0.565	0.007	
			1.5592	260.5	0.4	0.616	0.006	
21441+2845	STF 2822AB	15270	1.5592	308.0	0.3	1.936	0.016	
22288−0001	STF 2909	15971	1.5565	184.7	0.3	1.911	0.015	
22485+3106	BU 1146	16278	1.5592	265.4	0.7	0.227	0.002	
22514+2623	HO 482AB	16314	1.5428	22.5	0.4	0.458	0.004	
23078+6338	HU 994	16530	1.5592	133.6	1.1	0.205	0.012	
			1.5647	134.0	1.1	0.200	0.012	
23186+6807	STF 3001AB	16666	1.5592	220.3	0.3	3.310	0.026	
			1.5647	222.9	0.4	3.348	0.028	
23322+0705	HU 298	16819	1.5619	358.0	0.5	0.200	0.002	
23340+3120	BU 720	16836	1.5592	95.4	0.3	0.542	0.005	
23393+4543	A 643A, Ba	16904	1.5647	145.7	0.9	0.247	0.003	
23487+6453	STT 507AB	17020	1.5592	314.0	0.4	0.740	0.007	
23498+2741	A 424	17030	1.5428	138.6	0.5	0.149	0.003	
			1.5592	137.3	0.7	0.151	0.002	

puted a set of radial cross sections through the power spectrum up to the diffraction cutoff frequency of the telescope and fit them with a model binary star spectrum to find the distance and position angle.

Due to the use of the autocorrelation function to calculate the position angle, we obtain it with a 180° ambiguity. Although there are several techniques to remove it, they are not efficient in all cases. We have

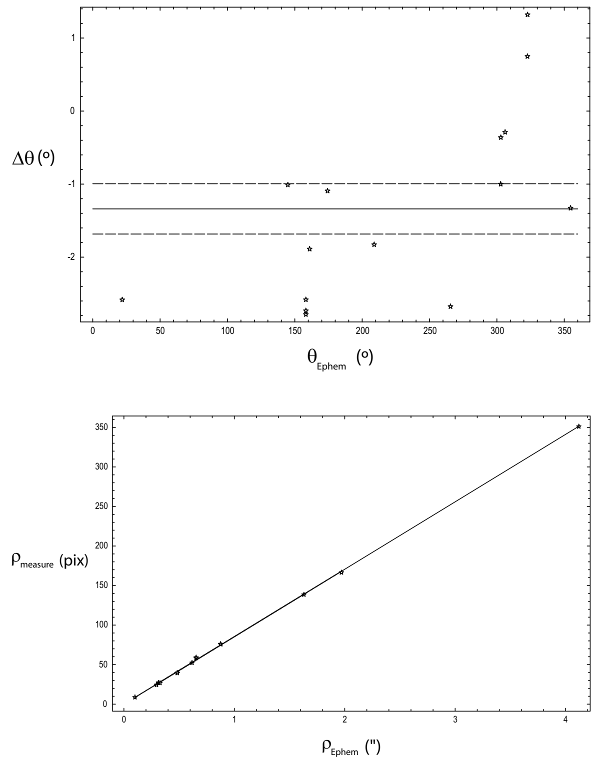

Fig. 2. Detector orientation angle and scale, respectively, for the 2001 observational run.

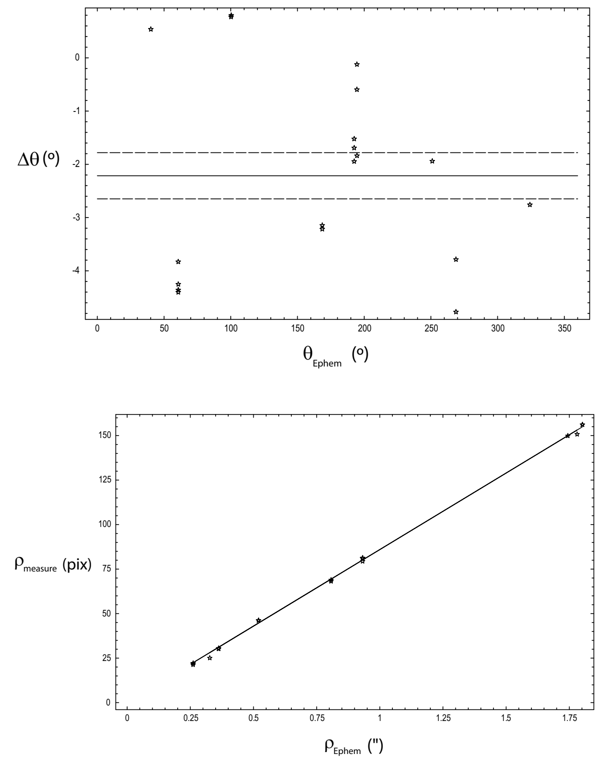

Fig. 3. Detector orientation angle and scale, respectively, for the 2004 observational run.

overcome this trouble by taking into account that new measurements must be compatible with previous data (Mason, Wycoff, & Hartkopf 2003; Docobo et al. 2003; Hartkopf & Mason 2003)

In all, 120 measurements of 87 stars were obtained under good seeing conditions, between 1.″1 and 1.″5. They are presented in Table 3, where the first three columns list the Washington Double Star (WDS) Catalog number (Mason et al. 2003), binary designation and ADS number from the catalog of Aitken & Doolittle (1932), respectively. The fourth column gives the epoch of observation as a fractional Besselian year. The observations were routinely performed using the 520/24 nm filter.

The next four columns contain the measured position angle θ and its error (in degrees) and separation ρ and its error (in arcseconds), respectively. Some uncertain position angle and separation measurements obtained from frames taken under adverse conditions and/or with relatively large magnitude differences between components (on the order of 2 mag or more), are marked with a colon in the last two columns. We can estimate mean errors of 0.″007 in ρ and 0.°5 in θ. In last column the note "c" indicates that this star was used for calibration.

4. NEW ORBITS

Some orbits whose predicted positions do not agree with the measurements have been detected. We have recalculated two of them (STT 170 and STF 1670 AB) by using the analytical method of Docobo (1985). They are shown in Figures 4 and 5. Micrometric measurements are indicated by filled circles, whereas the speckle observations are indicated by stars. The measurements reported in this paper are marked separately. The orbital elements are given in Table 3.

4.1. *STT 170*

The previous orbit of this G0 star was calculated by Heintz (2001), who obtained a period of 355.0 years. In contrast, we have found (Andrade 2006) that the set of measurements is better fitted if we consider a longer period. In this case we obtain a mass of 2.9 $\mathcal{M}_{\odot}$, which agrees with the calibrated masses for two G0IV stars.

The orbital elements of this orbit have been submitted for publication in the IAU Commission 26 Information Circular 160.

TABLE 3

ORBITAL ELEMENTS AND MASSES FOR STT 170 AND STF 1670 AB

Elements	STT 170[1]	STF 1670 AB[2]
P (yr)	429±76	169.10±0.10
T	2006.9±5.0	2005.51±0.01
e	0.479±0.008	0.883±0.002
a ($''$)	1.86±0.25	3.644±0.015
i (°)	104.5±2.0	149.1±0.5
Ω (°)	93.1±0.5	37.1±2.5
ω (°)	88±16	256.7±2.5
$\mathcal{M}_{total}$ ($\mathcal{M}_\odot$)	2.9±1.7	2.80±0.12

[1]Andrade (2006).

[2]Docobo & Tamazian (2006).

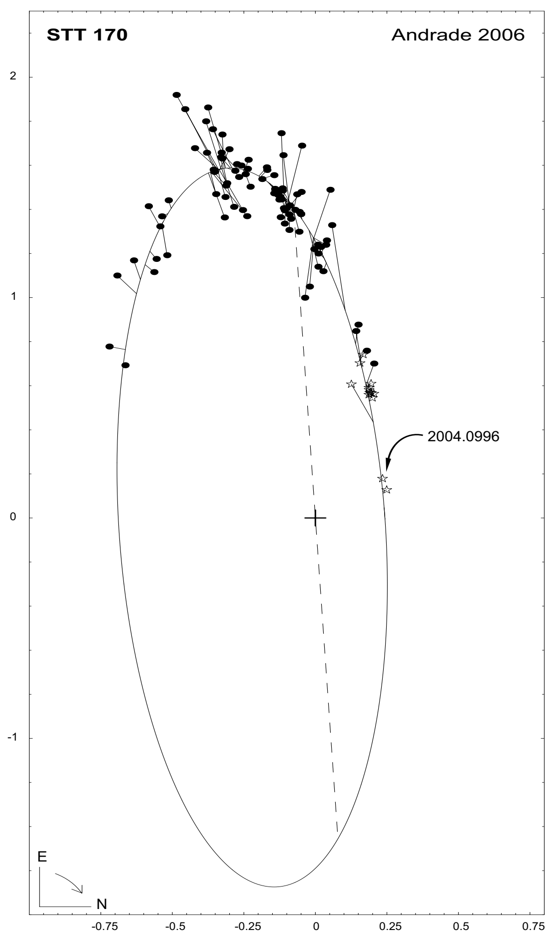

Fig. 4. Apparent orbit of STT 170.

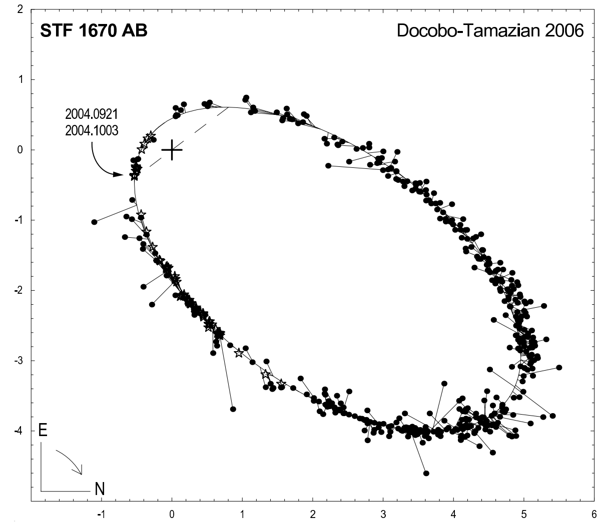

Fig. 5. Apparent orbit of STF 1670 AB.

4.2. *STF 1670 AB*

Numerous orbits were calculated for this bright and wide pair, most recent those of Heintz (1990), Söderhjelm (1999) and Girard et al. (2000). However, the recent periastron passage revealed significant O-C residuals in θ. Further speckle and visual observations in 2005 and 2006 confirmed the same trend. Thus, we consider necessary to revise its orbital elements, especially the dynamical ones.

The obtained solution represents correctly the large number of more than 500 observations that begun in 1718, although there is no significant variation in its total mass with respect to orbits mentioned above. Simultaneously with our result, Scardia et al. (2006) calculated a similar orbit. Both orbits were announced in IAUDS Inf. Circ. 159.

5. CONCLUSIONS

On the basis of four observational runs of speckle interferometric measurements with our speckle camera attached to the 1.52-m telescope of the Observatorio Astronómico Nacional at Calar Alto, we conclude that the telescope+camera configuration has proved to be especially useful for binary star research within the natural limits of resolution and brightness imposed by the telescope.

In any event, an ample program of binary stars research can be carried out with this telescope, complementing results obtained by our team with much larger instruments (Docobo et al. 2006).

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