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BINARY STAR SPECKLE INTERFEROMETRY: MEASUREMENTS AND ORBITS

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ABSTRACT

Results of our second observational run of binary star interferometric measurements with an ICCD speckle camera attached to the 1.52 m telescope of the Observatorio Astronómico Nacional at Calar Alto (Almería, Spain) in 2000 June–July are presented. The measured angular separations range from 0".096 to 6".558. With the use of the new speckle data, the orbits of the visual binaries WDS 14369+4813 and WDS 21597+4908 are improved.

Key words: binaries: visual — stars: individual (HD 128718, HD 209103) — techniques: interferometric

1. INTRODUCTION

In the years 1998–1999, a speckle interferometer with a photon-counting intensified CCD detector was developed at the Ramón María Aller Observatory of the University of Santiago de Compostela (OARMA), in cooperation with the Special Astrophysical Observatory of the Russian Academy of Sciences. This instrument, attached to the 1.52 m telescope of the Observatorio Astronómico Nacional (OAN) at Calar Alto, was first used for speckle observations of binary stars in 1999 September. The results were reported in Docobo et al. (2001), where a detailed description of the camera and data reduction procedure was given.[6]

Within the framework of the double and multiple star astrometry and astrophysical research program currently being performed at OARMA, the OAN Time Allocation Committee for the 1.52 m telescope allocated 13 nights from 2000 June 27 to July 9 for speckle interferometry of binary stars. We present in this paper the results of our second observational run.

2. OBSERVATIONS AND DATA REDUCTION

During the second run, the detector configuration and reduction procedure remained practically the same as in the first. The main module of the camera contains a pair of interchangeable microscope objectives with magnifications of 8× and 20×, which are necessary to sample the size of individual speckles to a detector pixel of size 13.4 μm. The detector system consists of a CCD camera with 1280 (horizontal) × 1024 (vertical) pixels of size 6.7 × 6.7 μm, optically coupled to a three-stage image intensifier.

For faster readout, we sample speckle images to 512 × 512 pixels, while the dynamic range of the system is limited by the 12 bit digitization. Single photoelectron events are recorded by the system with a signal-to-noise ratio of about 30. As usual, each star observation implies obtaining between 1000 and 3000 short-exposure frames, which are then downloaded on Exabyte tapes.

An astrometric calibration was made by fitting measurements of a set of 10 wide binaries with very long periods, well-known orbital parameters, or both to their calculated positions (see Table 1).

Figure 1 shows the scale and detector orientation angle used to convert separation and position angle to the final values, given in Table 2 along with their estimated uncertainties. Apart from this, the detector orientation angle was additionally checked using star trails in right ascension with 8× magnification. The resulting error in orientation was less than 0°.3.

The procedure used to obtain the position angle and separation is based on analysis of the mean autocorrelation function and consists of three steps. First, for each speckle frame we make a flat-field photometric correction and geometric correction for field distortions caused by the image intensifier. Then we compute the mean power spectrum of an object following the standard Labeyrie (1970) procedure. The average power spectrum is corrected for the photon noise bias. Finally, we compute 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.

We have measured the position angle using the autocorrelation function, the symmetry of which leaves a 180° ambiguity. Unfortunately, most techniques developed to remove it are not efficient in all cases. For this reason, and taking into account the nature of the observed binaries, we have obtained reliable results by always selecting the position angle value to be compatible with previous data (Mason, Wycoff, & Hartkopf 2003; Docobo et al. 2003; Hartkopf & Mason 2003).[7]

All in all, 130 measurements of 101 stars were obtained under good seeing conditions, between 0".8 and 2".0. They are presented in Table 3, where the first three columns list coordinates from the Washington Double Star Catalog (Mason et al. 2003), discoverer designation, and number from the

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[6] See http://www.usc.es/astro.

[7] See http://ad.usno.navy.mil/wds/wds.html and http://ad.usno.navy.mil/wds/orb6.html.

TABLE 1
CALIBRATION STARS

WDS	P (yr)	Weight
13396+1045	22.46	1
14463+0939	253.5	1
15160−0454	148.00	2
15232+3017	41.585	5
15427+2618	92.94	3
19159+2727	Fixed	3
19490+1909	23.364	2
20035+3601	Fixed	1
21021+5640	Fixed	4
22136+5234	Fixed	1

ADS catalog (Aitken & Doolittle 1932), respectively. The fourth column gives the epoch of observation as a fractional Besselian year. The observations were usually performed using a 520/24 nm filter, but a few were made with a 660/40 nm red filter, as indicated in the fifth column. The last two columns contain the measured position angle ρ (in degrees) and separation θ (in arcseconds). The position angles in Table 3 have not been corrected for precession.

The position angle and separation values obtained from 13 frames taken under worse conditions, when bad seeing (more than 3″.0) coincided with relatively large magnitude differences between components (on the order of 2 mag or

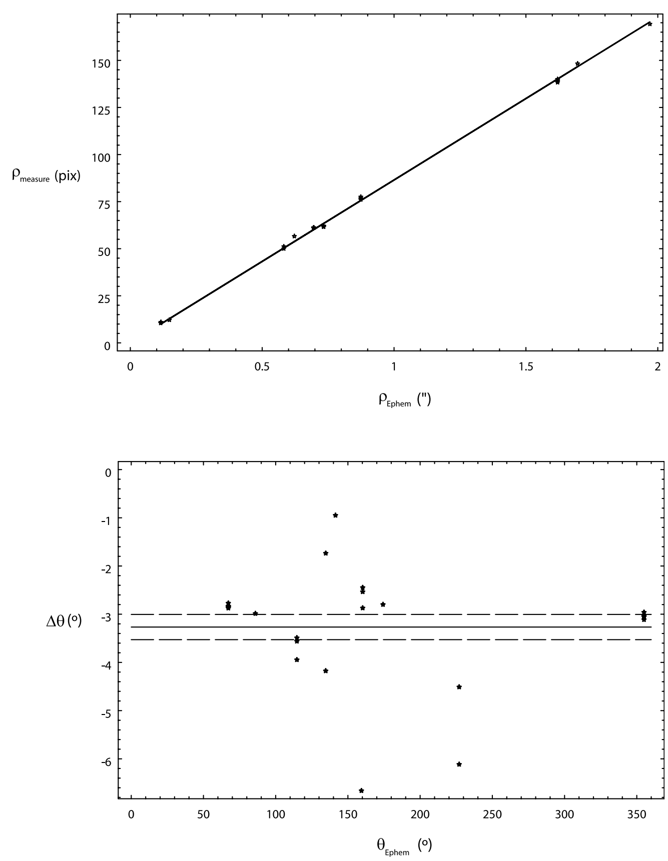

FIG. 1.—Scale calibration and detector orientation angle

TABLE 2
PIXEL SCALE AND POSITION ANGLE OFFSET VALUES

Parameter	Value
Position angle (deg)	−3.27 ± 0.26
Pixel scale (mas pixel^{-1})	11.47 ± 0.07

more), are marked with a colon in the last two columns. We estimate measurement errors on the order of 15 mas in ρ and 1° in θ. Indeed, such estimates confirm that calibration uncertainties play a minor role.

3. NEW ORBITS

Two of the newly obtained measurements confirm a systematic departure of observational residuals (registered on the basis of previous speckle data) from orbits of the visual binaries WDS 14369+4813 and WDS 21597+4908. After being revised and corrected, both orbits were announced in the IAU Commission 26 Information Circular (Andrade 2003; Docobo & Andrade 2003). Their orbital parameters are given in Table 4.

The orbits were calculated using the analytical method of Docobo (1985), taking into account both micrometric and speckle observations. They are shown in Figure 2. The orbital elements are given in Table 4, where we list the star identification, author(s) of the orbit, new orbital elements with corresponding standard errors, and total system mass obtained on the basis of a, P, and *Hipparcos* parallax values (ESA 1997). In conclusion, brief comments on these orbits are given.

WDS 14369+4813 (A 347; HD 128718): Currently, an orbit from Baize (1987) with a period of 151 yr is included in the catalogs of Hartkopf & Mason (2003) and Docobo et al. (2003), and the position angle residuals are negative with respect to observations performed over the last 20 years. This negative trend is corrected in our orbit. The obtained dynamical parallax, 9.92 mas, is concordant with that from *Hipparcos* (9.31 ± 1.74 mas). Figure 3 shows the image power spectrum of this star.

WDS 21597+4908 (Hu 774; HD 209103): Although this binary has already completed one revolution, there is a deficit of observational data at periastron passage that prevents even the orbit presented here from being definitive. The positive trend of the residuals in θ and the negative trend in ρ with respect to Heintz's (1979) orbit have been corrected, and a clearly improved orbit is obtained. It is worth noting the good adjustment of the orbit to the speckle measurements, especially in separation value. Similarly to WDS 14369+4813, the dynamical parallax (4.12 mas) is well concordant with the *Hipparcos* value (3.95 ± 0.67 mas).

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TABLE 3

Speckle Measurements on the 1.52 m Telescope

WDS	Name	ADS	Epoch (2000.0+)	Filter (nm)	θ (deg)	ρ (arcsec)
13237−0043	A 2489	8884	0.4966	520	191.2	0.827
13396+1045	BU 612 AB	8987	0.4966	520	162.8	0.141
			0.5075	520	162.6	0.140
13461+0507	STF 1781	9019	0.4884	520	179.3	0.759
14020+5713	A 1097 AB	9089	0.4938	520	244.2	0.434
14037+0829	BU 1270	9094	0.4911	520	297.1:	0.235:
			0.5130	520	299.5:	0.232:
14135+1234	BU 224	9165	0.4966	520	108.9	0.435
14160−0704	HU 138	9186	0.4967	520	19.5:	0.549:
14179+6914	A 1102	9220	0.4938	520	88.5	0.410
14203+4830	STF 1834	9229	0.4993	520	102.6	1.506
14369+4813	A 347	9324	0.4886	520	253.0	0.557
14411+1344	STF 1865 AB	9343	0.5184	520	300.0	0.751
14455+4223	STT 285 AB	9378	0.4886	520	105.1	0.454
14463+0939	STF 1879 AB	9380	0.5213	520	85.5	1.700
14514+1906	STF 1888 AB	9413	0.5184	520	318.0	6.558
14534+1542	STT 288	9425	0.5213	520	165.5	1.185
15160−0454	STF 3091 AB	9557	0.4939	520	228.2	0.574
			0.5158	520	229.9	0.587
15183+2650	STF 1932 Aa-B	9578	0.4994	520	259.5	1.561
			0.5185	520	259.5	1.558
15232+3017	STF 1937 AB	9617	0.4912	520	66.6	0.703
			0.4994	520	66.6	0.702
			0.5020	520	66.7	0.702
15245+3723	CHR 181 Aa	9626	0.5212	520	283.1	0.118
15329+3122	COU 610	...	0.5021	520	199.4	0.787
			0.5104	520	199.2	0.788
15360+3948	STT 298 AB	9716	0.4885	520	156.9	0.513
			0.5213	520	157.2	0.513
15390+2545	COU 612	...	0.4967	520	200.3	0.249
15416+1940	HU 580 AB	9744	0.4967	520	244.8	0.166
			0.5022	520	247.4	0.166
			0.5185	520	246.2	0.166
15427+2618	STF 1967	9757	0.4912	520	115.2	0.715
			0.4939	520	114.8	0.708
			0.5186	520	114.8	0.707
16044−1122......	STF 1998 AB	9909	0.4968	520	308.4	0.367
16080+4523	BU 355 AB	9935	0.4940	520	280.5	0.206
16115+1507	A 1799	9952	0.4940	520	119.7	0.739
16137+4638	A 1642	9975	0.4941	520	184.5	0.656
16147+3352	STF 2032 AB	9979	0.5214	520	236.0	6.846
16289+1825	STF 2052 AB	10075	0.5213	520	124.2	1.966
16301+3353	HU 1173	10085	0.4968	520	57.2	0.236
16422+4112	STF 2091	10169	0.4913	520	322.7	0.488
16439+4329	D 15	10188	0.4940	520	104.4	0.533
			0.4995	660	104.4	0.537
16438+5133	HU 664	10189	0.4913	520	302.9	0.488
16511+0924	STF 2106	10229	0.4913	520	175.0	0.685
			0.4994	520	175.1	0.687
16514+0113	STT 315	10230	0.5214	520	319.6	0.523
16595+0942	BU 1298 AB	10295	0.4914	520	126.4	0.427
17082−0105	A 1145	10355	0.4915	520	353.8	0.591
17146+1423	STF 2140 Aa-B	10418	0.5188	520	282.8	4.768
17221+2310	COU 415	...	0.4941	520	291.3:	0.229:
			0.4996	520	291.3	0.230
17366+0723	A 1156	10659	0.4942	520	350.0:	0.197:
17412+4139	STF 2203	10722	0.4887	520	295.9	0.734
17418+2130	COU 114	...	0.4887	520	44.7	0.210
17436+2237	HU 1285	10743	0.4996	520	216.9	0.549
17506+0714	STT 337	10828	0.4888	520	171.4	0.482
17520+1520	STT 338 AB	10850	0.4888	520	347.5	0.826
18253+4846	HU 66 AB	11344	0.4968	520	238.0	0.237
	STT 351 AC	11344	0.4968	520	22.3	0.717
	HU 66 BC	11344	0.4970	520	30.3	0.932
18339+5221	A 1377 AB	11468	0.4970	520	114.5	0.249
18384−0312	A 88 AB	11520	0.4915	520	305.3	0.118

TABLE 3—*Continued*

WDS	Name	ADS	Epoch (2000.0+)	Filter (nm)	θ (deg)	ρ (arcsec)
18386+1632	O 87 AB	11530	0.4997	520	72.9	0.335
18413+3018	STF 2367 AB	11579	0.5217	520	78.6	0.328
18443+3940	STF 2383 Cc-D	11635	0.5190	520	80.6	2.388
18466+3821	HU 1191	11680	0.4970	520	358.3	0.207
18570+3254	BU 648 AB	11871	0.4997	520	311.2	0.649
			0.5081	520	311.1	0.650
			0.5134	520	311.8	0.660
18594−1250	KUI 89	. . .	0.4915	520	89.8	0.152
19055+3352	HU 940	12033	0.5189	520	197.4	0.538
19110−0726......	A 95	12126	0.5217	520	48.3	0.266
19121+0237	BU 1204 AB	12147	0.4944	520	184.8	0.219
19159+2727	STT 371 AB	12239	0.4889	660	159.4	0.873
			0.4890	660	159.3	0.890
			0.4943	520	159.7	0.881
19419+2723	STT 382	12798	0.4944	520	324.7	0.303
19449+1047	AGC 10 AB	12864	0.4945	520	139.5:	0.238:
	STF 2570 AB-C	12864	0.4945	520	276.9	4.183
19487+1504	A 1658	12961	0.5163	520	145.0	0.197
19490+1909	AGC 11 AB	12973	0.4891	520	133.0	0.127
			0.4918	520	135.4	0.121
19575+1408	A 1662	13161	0.4972	520	196.5:	0.330:
19598−0957	HO 276	. . .	0.4917	520	125.1:	0.229:
20035+3601	STF 2624 Aa-B	13312	0.4973	520	173.7	1.942
20102+4357	STT 400	13461	0.4999	520	343.6	0.504
20180+3311	BAR 11 AB	13660	0.4918	520	196.0	0.366
20200+3616	BU 431	13719	0.4995	520	29.0	0.512
20203+3924	A 1427 AB	13728	0.5218	520	120.9:	0.307:
20210+4437	A 725	13744	0.5191	520	10.4	0.518
20290+0710	A 610	13894	0.4973	520	55.1	0.387
			0.5191	520	54.8	0.399
20303+1054	BU 63 AB	13920	0.5000	520	349.7	0.907
			0.5002	520	349.8	0.911
20308+6107	HU 761	13966	0.4946	520	130.5	0.498
20375+1436	BU 151 AB	14073	0.4918	520	343.4	0.518
			0.5054	520	343.3	0.520
			0.5219	520	343.3	0.524
20537+5918	A 751	14412	0.4946	520	87.9	0.150
21001+0731	KUI 102	. . .	0.5027	520	7.6	0.314
21021+5640	STF 2751	14575	0.4946	520	354.7	1.598
			0.4947	520	354.6	1.606
			0.5219	520	354.6	1.595
21133+4655	A 884	14766	0.4946	520	120.3	0.424
21152+5531	A 1692	14798	0.4946	520	161.5:	0.296:
21214+1020	A 617	14893	0.5054	520	93.4:	0.166:
21281+4110	COU 2231	. . .	0.5192	520	33.1:	0.208:
21423+0555	HU 280	15236	0.5000	520	343.7	0.184
21424+4105	KUI 108	. . .	0.4973	520	204.2	0.096
21441+2845	STF 2822 AB	15270	0.5164	520	307.7	1.844
21501+1717	COU 14	. . .	0.5027	520	249.3:	0.329:
21545+4403	A 620	15435	0.4947	520	281.9	0.327
21557+0715	STT 452	15452	0.5001	520	178.0	0.761
21597+4907	HU 774	15530	0.5001	520	350.4	0.173
22100+2308	COU 136	. . .	0.5028	520	30.6	0.489
22136+5234	BU 991	15756	0.4947	520	138.5	0.657
			0.5000	520	139.0	0.650
22241−0450	BU 172 AB	15902	0.5165	520	62.7	0.287
22288−0001	STF 2909	15971	0.5165	520	186.6	1.889
22300+0426	STF 2912	15988	0.5002	520	117.2	0.359
22388+4419	HO 295	16138	0.4971	520	150.1:	0.225:
			0.5056	520	151.3:	0.225:
22592+1144	STT 483	16428	0.5002	520	337.2	0.486
23078+6338	HU 994	16530	0.5193	520	314.5	0.212
23186+6807	STF 3001 AB	16666	0.5111	520	219.6	3.247
			0.5139	520	219.7	3.245

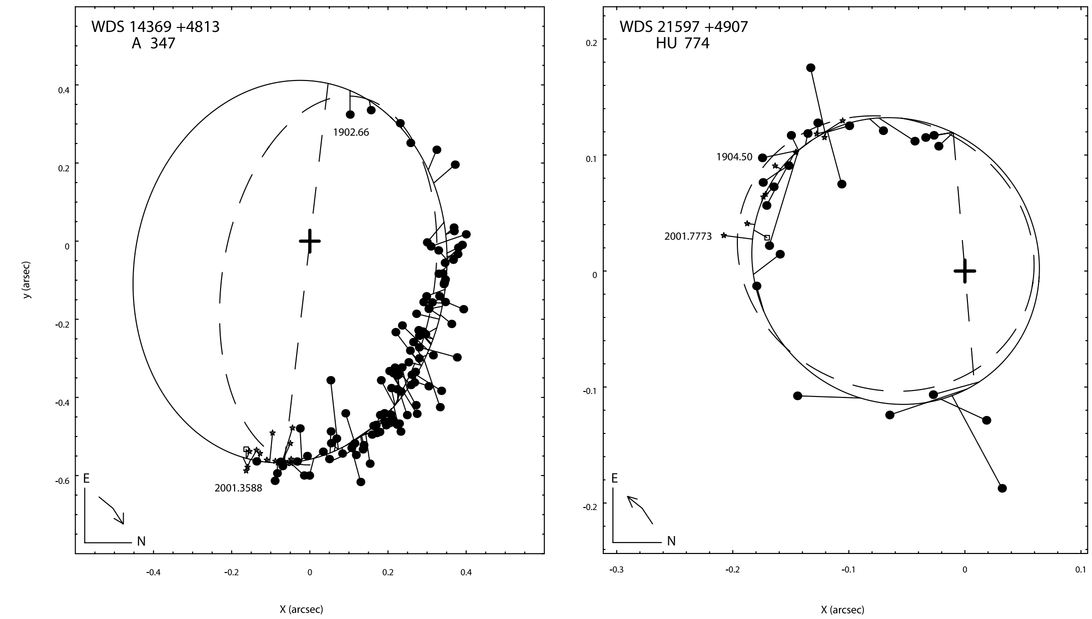

FIG. 2.—New visual apparent orbits for A 347 and Hu 774. Each measurement is connected to its predicted position by an $O-C$ line. The straight dashed line is the line of nodes. Older orbits are overplotted as dashed ellipses. Circles are visual (micrometer) data, five-pointed stars are interferometric data, and squares are data obtained in the present run.

TABLE 4

ORBITAL ELEMENTS FOR A 347 AND HU 774

Element	A 347 (Docobo-Andrade)	Hu 774 (Andrade)
P (yr)........................	212.35 ± 15	83.34 ± 3
T..............................	1910.90 ± 5	1960.27 ± 1
e..............................	0.197 ± 0.01	0.484 ± 0.03
a (arcsec).................	0.494 ± 0.01	0.141 ± 0.05
i (deg)......................	145.1 ± 3	28.5 ± 5
Ω (deg)....................	83.4 ± 3	94.8 ± 3
ω (deg)....................	31.2 ± 15	258.5 ± 5
$\sum$ masses ($M_\odot$)......	3.3 ± 1.2	6.5 ± 2.1

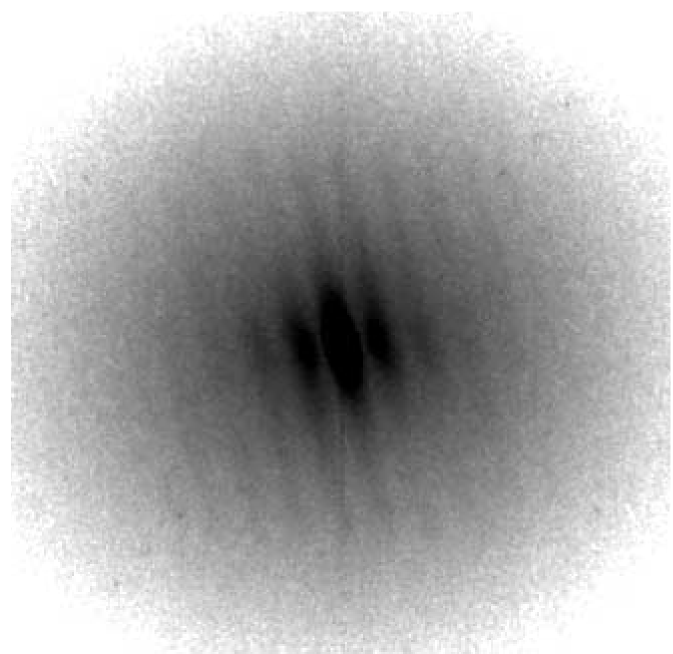

FIG. 3.—Image power spectrum of the binary A 347

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