THE ASTROPHYSICAL JOURNAL, 230:497–501, 1979 June 1

SPECKLE INTERFEROMETRIC MEASUREMENTS OF BINARY STARS. IV.

HAROLD A. MCALISTER*
Department of Physics, Georgia State University
Received 1978 November 7; Accepted 1978 December 5

ABSTRACT

Seventy-three measurements of 61 binary stars by means of speckle interferometry with the Mayall 4 m telescope are presented. The measured separations range from 0″.031 to 1″.368. Observations are presented for the three previously unresolved spectroscopic binaries: HR 5472, HR 6237, and HR 8264 and for 18 additional interferometric binaries.

Subject headings: interferometry — stars: binaries — stars: visual multiples

I. INTRODUCTION

This paper is the fourth in a series presenting the results of a program of binary star speckle interferometry begun at Kitt Peak National Observatory in 1975 (McAlister 1977, 1978*c*; McAlister and DeGioia 1979; hereafter Papers I, II, and III, respectively). In addition to those referenced in preceding papers in this series, speckle measurements of two binary stars have been presented by Weigelt (1979*a*), who used the technique of speckle holography to reconstruct diffraction-limited images. This technique is here limited to triple systems in which one component can be used to determine the instantaneous point-spread function and thus the image of the remaining two components as long as all components are within the isoplanatic patch. Weigelt (1979*b*) has measured 12 additional binary stars by the normal technique of speckle interferometry.

Speckle observers have to the present date resolved a total of 39 bright binary stars which were not previously directly resolved. More than half of these are known spectroscopic binaries, and many, if not most, of the remaining newly resolved systems are potential spectroscopic binaries. Thus speckle interferometry is succeeding in bridging the gap between visual and spectroscopic binaries and promises to make a significant contribution to the fundamental mass-luminosity relation.

II. OBSERVATIONS

The observations presented here were obtained during the two nights 1977 June 25 and 27 UT at the Ritchey-Cretien focus of the 4 m Mayall telescope using the KPNO photographic speckle camera described by Breckinridge, McAlister, and Robinson (1979). A total of 163 series of speckle photographs, corresponding to 8750 individual 35 mm frames, were taken during the 13.2 hours of usable observing time. The speckle photographs were optically transformed with the KPNO coherent image processor on loan to Georgia State University, and were measured in Tucson with the KPNO two-coordinate Grant machine. The data analysis technique continues to be as described in Paper I.

Table 1 contains 73 observations of 61 binary stars. Measured separations range from 0″.031 to 1″.368 with 27 observations of separation less than 0″.12. Further observations are given for 18 interferometric binaries, several of which have now been confirmed by visual observers, and first observations are given for the newly resolved spectroscopic binaries HR 5472, HR 6237, and HR 8264 = ξ Aqr. The seven columns in Table 1 contain the following information: (1) the ADS or HR number, (2) discoverer designation or star name, (3) 1900 coordinates, (4) epoch of observation as fraction of Besselian year to be added to 1977.0, (5) observed position angle and its standard error with an asterisk denoting 180° quadrant ambiguity, (6) observed angular separation and its standard error, and (7) reference to the notes accompanying Table 1.

The orbit residuals determined from available orbits are given in Table 2 where the six column headings are generally self-explanatory. The last column gives the computer of the orbit in terms of a literature reference. Orbits found in the *Third Catalogue of Orbits of Visual Binary Stars* (Finsen and Worley 1970) are indicated by parentheses enclosing the letters FW and a number denoting the quality of the orbit as judged by Finsen and Worley (1970). Orbits found in the IAU Commission 26 Circulaire d'Information, edited by P. Muller, are indicated by parentheses enclosing the letters IAU and the particular number of the Circulaire in which the orbit is given. Other orbits are referenced in the usual manner.

III. DISCUSSION

Table 2 contains 19 observations of systems which qualify for at least the "reliable" rating as given by Finsen and Worley (1970). These observations have mean residuals of $\langle \Delta\theta \rangle = +0''.007 \pm 0''.016$ and $\langle \Delta\rho \rangle = -0''.009 \pm 0''.035$. Omission of seven of these observations on the grounds of small observed

* Visiting Astronomer, Kitt Peak National Observatory. KPNO is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

Binary Star Measures

ADS or HR	NAME	POS.(1900)	EPOCH 1977.0+	P.A.	SEP.	NOTE
HR 788	12 Per	02359 +3946	0.4874	136°6±0°4*	0".056±0".003	(1)
HR 4689	η Vir	12148 -0007	0.4865	186.7±0.4	0.124±0.001	(2)
HR 4963	θ Vir	13048 -0500	0.4865	144.4±0.2*	0.498±0.003	(3)
8804	Stf 1728 AB	13051 +1803	0.4865	192.5±0.3	0.293±0.002	
HR 5472	HD 129132	14358 +2224	0.4866	89.4±0.8*	0.057±0.006	(4)
9378	Stt 285	14417 +4248	0.4866	9.9±0.6	0.204±0.001	
9532	B 2351 Ap	15066 -1925	0.4865	67.0±0.5	0.131±0.001	
9578	Stf 1932	15140 +2712	0.4812	248.9±0.2	1.368±0.008	
HR 5747	β CrB	15237 +2927	0.4812	136.2±0.3*	0.241±0.001	(5)
HR 5778	Cou 610	15289 +3142	0.4812	203.1±0.3	0.658±0.004	
9716	Stt 298 AB	15325 +4008	0.4812	27.5±0.3	0.828±0.005	
9744	Hu 580 AB	15371 +2000	0.4812	60.6±0.3	0.130±0.001	(6)
9757	Stf 1967	15386 +2637	0.4812	129.1±0.3	0.282±0.002	
9758	Bu 619	15385 +1359	0.4812	2.2±0.3	0.672±0.004	
HR 5953	δ Sco	15544 -2220	0.4813	189.2±0.4*	0.134±0.001	(7)
			0.4866	188.8±0.2*	0.128±0.001	
9913	Bu 947 AB	15596 -1932	0.4813	126.6±0.7	0.442±0.003	(8)
HR 6032	Fin 354	16067 +0958	0.4813	83.3± 0.3*	0.095±0.005	
HR 6084	σ Sco	16151 -2521	0.4868	105.4±0.6*	0.353±0.002	(9)
HR 6168	σ Her	16309 +4239	0.4813	22.5±0.5*	0.096±0.005	(10)
			0.4867	21.8±0.6*	0.094±0.008	
10157	Stf 2084	16375 +3147	0.4867	160.3±0.2	1.138±0.007	
HR 6237	HD 151613	16434 +5658	0.4813	51.8±3.0*	0.041±0.004	(11)
10360	Hu 1176 AB	17045 +3604	0.4868	119.8±0.4	0.131±0.001	
10531	Hu 1179	17207 +3840	0.4868	103.7±0.5	0.064±0.004	(12)
10598	Stf 2173	17252 -0059	0.4815	16.3±0.3	0.247±0.001	
			0.4868	16.5±0.2	0.251±0.002	
10696	Bu 631	17348 -0035	0.4868	84.7±0.7	0.045±0.005	
11149	B 2545 AB	18081 +3325	0.4815	35.0±0.8	0.079±0.005	(13)
			0.4869	35.4±0.6	0.080±0.006	
-	17 Sgr	18107 -2034	0.4816	134.1±0.3*	0.268±0.002	(14)
HR 6927	χ Dra	18229 +7241	0.4818	14.7±3.0*	0.053±0.005	(15)
			0.4872	10.3±3.0*	0.057±0.006	
11524	Hu 198	18336 +0845	0.4815	140.0±0.4	0.440±0.002	(16)
			0.4870	139.9±0.7	0.434±0.002	
11579	Stf 2367 AB	18374 +3012	0.4869	45°6±0°4	0".110±0".001	
11593	B 2546 Ap	18385 +3439	0.4869	107.4±0.2	0.155±0.001	
11640	Fin 332 AB	18406 +0524	0.4815	136.4±0.5	0.162±0.001	
			0.4870	136.2±0.2	0.164±0.001	
	Fin 332 CD		0.4815	154.6±0.3	0.095±0.004	
			0.4870	154.6±0.3	0.104±0.005	
HR 7166	Kui 89	18538 -1259	0.4816	241.1±0.3	0.231±0.001	
12214	B 430	19094 -2526	0.4817	85.8±3.0	0.043±0.004	
12540	Stf 43	19267 +2745	0.4816	186.1±0.3	0.435±0.002	
12552	A 712	19282 +5626	0.4872	105.7±0.6	0.062±0.003	
HR 7441	Wrh	19309 +2915	0.4816	17.7±3.0*	0.031±0.003	(17)
12741	See 389	19338 -2339	0.4817	326.9±0.5	0.191±0.001	
HR 7486	Kui 93	19365 +1335	0.4817	307.3±0.3	0.149±0.001	
12808	Stt 380 AB	19379 +1135	0.4817	76.3±0.3	0.461±0.002	
HR 7536	δ Sge	19429 +1817	0.4818	40.0±3.0*	0.045±0.004	(18)
			0.4872	44.2±2.5*	0.046±0.005	
12973	Agc 11 AB	19445 +1853	0.4817	133.3±0.3	0.108±0.001	
13449	Stf 2652	20074 +6147	0.4872	223.9±0.5	0.307±0.002	
HR 7906	α Del Aa	20350 +1534	0.4818	8.8±0.3	0.213±0.001	(19)
14412	A 751	20513 +5856	0.4872	203.7±4.0	0.056±0.006	
14585	Bu 1138 AB	20593 +4527	0.4873	175.9±0.3	0.134±0.001	
14893	A 617	21165 +0955	0.4873	86.2±0.4	0.166±0.001	(20)
HR 8238	Cep	21274 +7007	0.4818	48.8±0.2*	0.217±0.001	
			0.4874	48.7±0.4*	0.218±0.001	
15115	Hu 371	21309 +2400	0.4874	292.0±0.3	0.278±0.002	

TABLE 1—*Continued*

ADS or HR	NAME	POS.(1900)	EPOCH 1977.0+	P.A.	SEP.	NOTE
HR 8264	ξ Aqr	21324 -0818	0.4819	122.9±5.0*	0.033±0.004	(21)
HR 8300	Kui 108	21384 +4037	0.4874	130.3±0.5	0.104±0.005	
15281	Bu 989 AB	21401 +2511	0.4874	96.2±0.2	0.176±0.001	
HR 8344	Cou 14	21454 +1649	0.4819	286.1±0.3	0.179±0.001	
HR 8417	ξ Cep Aa	22009 +6408	0.4818	266.9±0.5*	0.054±0.005	(22)
			0.4873	267.0±0.6*	0.058±0.004	
15902	Bu 172 AB	22189 -0521	0.4819	284.6±0.4	0.261±0.002	
HR 8629	Kui 114	22356 -0404	0.4819	313.6±0.3	0.139±0.001	
HR 8704	74 Aqr	22482 -1209	0.4874	92.8±0.3*	0.083±0.006	(23)
HR 8762	o And	22573 +4147	0.4819	2.6±0.3*	0.340±0.002	(24)
			0.4874	2.7±0.2*	0.339±0.002	
HR 8866	94 Aqr	23138 -1400	0.4819	182.5±0.4*	0.207±0.002	(25)
HR 9003	ψ And	23411 +4552	0.4819	107.1±0.5*	0.274±0.002	(26)

NOTES TO TABLE 1

1) The observation of 12 Per reported here was not used in the visual orbit determination (McAlister 1978*b*), but with residuals of −4°.2 and +0″.004 it fits the orbit reasonably well.

2) The pair has moved through 35° in the 1.5 years since its first resolution reported in Paper I. Heintz (1977) has visually confirmed the quadrant.

3) The close companion comprising ADS 8801 Aa was first reported in Paper I and continues to show no significant orbital motion.

4) HR 5472 is a spectroscopic triple system with periods of 9 years and 100 days (Harper and Blanchet 1949). It is probably the long-period system which is resolved here for the first time. Batten (1967) gives this orbit a "poor" rating, and it is thus important that modern spectroscopic observations be obtained. The system was observed to be unresolved on four other occasions and as late as 1977.088. The value of $\Delta m \sim 1.0$ estimated here implies that the pair was actually closer than the 4 m diffraction limit at the previous epochs and was thus opening up in early 1977. Spectroscopic observations in the red might succeed in detecting one or both of the companions.

5) HR 5747 has moved through 20° in the 4.3 years since its first resolution by Labeyrie *et al.* (1974), and it is becoming increasingly unlikely that this is the 10.5 year spectroscopic component of Neubauer (1944).

6) This close pair has opened up again and is now resolvable by visual observers. The ambiguity in the two orbits by van den Bos apparently cannot yet be resolved.

7) HR 7536 continues to close in from its first observed separation of 0″.181 on 1973.22 by Labeyrie *et al.* (1974).

8) The closer components β Sco CE were inadvertently not observed, and only the less interesting wider pair comprising ADS 9913 AB was photographed.

9) HR 6084 was first directly resolved by Morgan *et al.* (1978), who found $\theta = 111°.8$, $\rho = 0''.326$ on 1976.471.

10) HR 6168 is showing very rapid motion, and the need for complementary spectroscopic observations cannot be overstressed.

11) HR 6237 is resolved for the first time. The components reported here probably correspond to the 3.8 year spectroscopic system determined by Abt and Levy (1974). The fringe contrast indicates a Δm exceeding 1.0 mag.

12) ADS 10531 was noted as "too close" on 1965.560 by Worley (1972) and as "round" on 1973.46 by Heintz (1975).

13) The observations reported here and in Paper II are consistent with the speckle observation of Blazit *et al.* (1977), who found $\theta = 18° \pm 4°$, $\rho = 0''.070 \pm 0''.007$ on 1975.627.

14) 17 Sgr has shown only a marginally significant increase in its separation in the year since its first resolution (Paper II).

15) Speckle interferometry is beginning to provide good orbit coverage of the spectroscopic/astrometric binary χ Dra.

16) There is no evidence for the close companion in X Oph tentatively reported in Paper II.

17) This system was unresolved on 1976.45 and is apparently opening up again (McAlister 1978*a*). HR 7441 has a composite spectrum of types F0 + A0 (Hynek 1938).

18) This rapidly moving spectroscopic system has moved through more than 90° of retrograde motion since its first resolution by Blazit *et al.* on 1975.6.

19) HR 7906 has moved through more than 25° of retrograde motion since its first resolution by Wickes (1975) on 1974.65.

20) West (1976) has shown from radial velocity measurements of the A component of ADS 14893 that the period is actually about 6 years, or about half that of the visual orbit of Baize, and that the orbit has the high eccentricity of $e \approx 0.9$. West points out that the next periastron passage will occur during the second half of 1979; thus spectroscopic and speckle observations during that time are very important. Fekel (1978) reports that all three components have been observed spectroscopically in the red, and it thus seems likely that a complete mass-luminosity analysis of the system will be possible in the near future.

21) HR 8264 is a 22 year spectroscopic binary as reported by Abt (1965). The observation reported here is very tentative and should be treated with caution at the present time. The system was definitely unresolved on two previous occasions (McAlister 1978*a*).

22) Sufficient speckle observations of ξ Cep Aa should soon be available for a mass-luminosity analysis in combination with the spectroscopic orbit of Vickers and Scarfe (1976).

23) HR 8704 has moved through nearly 20° of retrograde motion in the 7 months between this and the first direct observation reported in Paper II.

24) HR 8762 has shown no significant orbital motion between 1976.86 and 1977.49. This pair is probably not the close companion observed by Blazit *et al.* (1977) unless the orbit is highly eccentric. The IDS contains one interferometer observation of a close companion by R. H. Wilson, Jr. with the comment "distance less than 0″.1. Uncertain."

25) HR 8866 has shown significant motion since its first observation reported in Paper II, and the companion measured is very likely the 6.4 year spectroscopic companion.

26) HR 9003 has shown some increase in separation since its first observation (Paper II), but is essentially unchanged in position angle.

TABLE 2

RESIDUALS TO MEASURES

ADS or HR	NAME	EPOCH 1977.0+	P.A. RES.	SEP. RES.	ORBIT COMPUTER
HR 788	12 Per	0.4874	$-4.^{\circ}2$	$+0.''004$	McAlister (1978b)
8804	Stf 1728 AB	0.4865	+2.0	+0.035	Haffner (FW 1)
9378	Stt 285	0.4866	+2.9	-0.001	Couteau (FW 2)
9532	B 2351	0.4865	+19.9	+0.016	Heintz (FW 3)
9578	Stf 1932	0.4812	+0.0	+0.016	Heintz (FW 2)
			-10.1	+0.100	Muller (FW 3)
9716	Stt 298 AB	0.4812	+0.4	-0.031	Couteau (FW 1)
9744	Hu 580 AB	0.4812	-0.4	-0.016	van den Bos I (FW A1)
			-1.7	+0.003	van den Bos II (FW A1)
9757	Stf 1967	0.4812	-0.4	-0.040	Baize (FW 2)
10157	Stf 2084	0.4867	+0.7	-0.051	Baize (FW 1)
			-1.6	-0.064	Baize (IAU #67)
			+1.4	-0.047	Silbernagel (1928)
10360	Hu 1176 AB	0.4868	+14.3	-0.030	Wilson (FW A2)
			+9.9	-0.008	Eggen (FW A2)
			-3.5	-0.005	Cester (FW A2)
10598	Stf 2173	0.4815	+8.6	-0.059	Duncombe and Ashbrook (FW 1)
		0.4868	+8.9	-0.055	
11524	Hu 198	0.4815	+8.4	+0.168	Hopman (FW 4)
		0.4870	+8.3	+0.162	
11579	Stf 2367 AB	0.4869	+3.1	+0.031	Baize (FW 2)
12214	B 430	0.4817	-15.1	-0.083	van den Bos (FW 2)
			-17.8	-0.075	Finsen (IAU #69)
12552	A 712	0.4872	-88.7	+0.013	Heintz (FW 4)
12973	Agc 11 AB	0.4817	+4.2	+0.018	Finsen (FW 1)
14412	A 751	0.4872	+7.9	-0.016	Eggen (FW 2)
14893	A 617	0.4873	-2.7	+0.002	Baize (FW A?3)
15115	Hu 371	0.4874	-0.5	-0.016	Baize (FW 5)
HR 8300	Kui 108	0.4874	-16.2	-0.001	Morel (FW 2)
15281	Bu 989 AB	0.4874	+7.8	+0.051	Luyten (FW 1)
			+1.5	+0.010	Morel (IAU #53)
			+2.3	+0.007	Couteau and Morel (1972)
HR 8344	Cou 14	0.4819	+7.3	-0.050	Heintz (1973)
			+11.4	-0.086	Costa-Morales (IAU #78)
15902	Bu 172 AB	0.4819	-1.7	-0.038	Heintz (1975)
HR 8629	Kui 114	0.4819	+1.2	-0.053	Baize (IAU #68)

separations or consistently large residuals leaves $\langle\Delta\theta\rangle = -0.''002 \pm 0.''023$ and $\langle\Delta\rho\rangle = 0.''004 \pm 0.''016$ for 12 observations. Previous external errors as determined from orbit residuals have been discussed in detail (McAlister 1979) and mean residuals have been determined for 117 observations of systems with orbits of at least the "reliable" rating. Inclusion of the above 19 applicable observations gives overall mean residuals of $\langle\Delta\theta\rangle = +0.''0020 \pm 0.''0178$ and $\langle\Delta\rho\rangle = -0.''0057 \pm 0.''0231$ for 136 observations. If the 12 observations referred to unambiguously good orbits are incorporated in the results for the 101 similarly established observations by McAlister (1979), then one obtains qualified mean orbit residuals of $\langle\Delta\theta\rangle = +0.''0003 \pm 0.''0067$ and $\langle\Delta\rho\rangle = -0.''0054 \pm 0.''0145$ for 113 observations. The overall mean residuals continue to demonstrate the clear absence of systematic effects above the level detectable by comparison to visual orbits. On the other hand, as the number of observations of individual systems increases, many orbits of "definitive" rating are revealing considerable and consistent deviations from the observed positions.

The author is grateful to the staff of Kitt Peak National Observatory for their generous continuing support of binary star speckle interferometry. The support of the National Science Foundation through NSF Grant AST 78-01743 is gratefully acknowledged. Partial travel support has been kindly given by the Southern Regional Education Board.

REFERENCES

Abt, H. A. 1965, *Ap. J. Suppl.*, **11**, 429.
Abt, H. A., and Levy, S. G. 1974, *Ap. J.*, **188**, 291.
Batten, A. H. 1967, *Pub. Dom. Ap. Obs. Victoria*, Vol. **13**, No. 8.
Blazit, A., Bonneau, D., Koechlin, L., and Labeyrie, A. 1977, *Ap. J. (Letters)*, **214**, L79.
Breckinridge, J. B., McAlister, H. A., and Robinson, W. G. 1979, *Appl. Optics*, in press.
Fekel, F. C. 1978, private communication.
Finsen, W. S., and Worley, C. E. 1970, *Republic Obs. Johannesburg Circ.*, No. 7.
Harper, W. E., and Blanchet, G. H. 1949, *Pub. Dom. Ap. Obs. Victoria*, Vol. **7**, No. 2.
Heintz, W. D. 1973, *A.J.*, **78**, 307.
———. 1975, *Ap. J. Suppl.*, **29**, 331.
———. 1977, private communication.

Hynek, J. A. 1938, *Contr. Perkins Obs.*, No. 10.
Labeyrie, A., Bonneau, D., Stachnik, R. V., and Gezari, D. Y. 1974, *Ap. J.* (*Letters*), **194**, L147.
McAlister, H. A. 1977, *Ap. J.*, **215**, 159 (Paper I).
———. 1978*a*, *Pub. A.S.P.*, **90**, 288.
———. 1978*b*, *Ap. J.*, **223**, 526.
———. 1978*c*, *Ap. J.*, **225**, 932 (Paper II).
———. 1979, in *Proc. IAU Colloquium 48, Modern Astrometry*, in press.
McAlister, H. A., and DeGioia, K. A. 1979, *Ap. J.*, **230**, 493 (Paper III).
Morgan, B. L., Beddoes, D. R., Dainty, J. C., and Scaddan, R. J. 1978, *M.N.R.A.S.*, **183**, 701.
Neubauer, F. J. 1944, *Ap. J.*, **99**, 134.
Silbernagel, E. 1928, *Astr. Nach.*, **233**, 145.
Vickers, C. R., and Scarfe, C. D. 1976, *Pub. A.S.P.*, **88**, 944.
Weigelt, G. P. 1979*a*, *Appl. Optics*, in press.
———. 1979*b*, *Astr. Ap.*, in press.
West, F. R. 1976, *Ap. J.*, **205**, 194.
Wickes, W. C. 1975, *Ap. J.*, **80**, 1059.
Worley, C. E. 1972, *Pub. U.S. Naval Obs.*, Vol. **22**, Pt. 4.

HAROLD A. MCALISTER: Department of Physics, Georgia State University, Atlanta, GA 30303