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Speckle observations of double and multiple stars at Pic du Midi: measurements during 1995 and 1997*

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Abstract. We present speckle observations of 48 double and multiple stars observed at the 2-meter “Télescope Bernard Lyot” (TBL) in December 1995, January 1997 and June 1997. Angular separations, absolute position angles and relative photometry result from these observations.

Key words: Methods: data analysis – Techniques: image processing – Techniques: interferometric – binaries: close

1. Introduction

This paper presents the results of double and multiple star speckle observations performed at the 2 m Télescope Bernard Lyot of Pic du Midi observatory (France). Instrumentation and data analysis techniques were partly described in a previous paper (Aristidi *et al.*, 1997b). For the run of June 1997, we tested a real time system described in section 2. Because of bad weather, only five stars could also be observed using the PAPA photon-counting detector (Papaliolios *et al.*, 1982, 1985). It should be emphasized that we accumulated bad luck and got particularly bad weather conditions during all this runs with very short coherence times of a few milliseconds only and a FWHM seeing often larger than 2 arcsec. The output should be appreciated accordingly.

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* Based on observations made at 2 m Télescope Bernard Lyot, Pic du Midi, France.

Double stars measured here are either long-period binaries for which the last observation is old, or stars observed by us previously and found far from the expected position (Aristidi *et al.*, 1997b). Some stars were also selected because the orbits are very uncertain. Two of these stars were recently discovered as double: MOAI 1 (SAO 12917) observed in December 1995 (Carbillet *et al.*, 1996, 1998b), and ν Cyg discovered as double by Hipparcos (The Hipparcos Catalogue, 1997).

Multiple stars were selected from the Multiple Star Catalogue (Tokovinin, 1997). All of them present a lack of measurement: unknown orbits, unknown spectral classes of the components, evidence for a companion detected by spectroscopy, and should be resolved in speckle with a 2 m telescope. These stars were selected together with A.A. Tokovinin.

2. Observations

Data were recorded during three observing runs in December 1995, January 1997 and June 1997 at the TBL. A total of 33 double stars and 15 multiple stars were observed; details are given in Table 1.

The instrumentation is the speckle camera of the Aperture Synthesis group of Observatoire Midi-Pyrénées (OMP) and an ICCD detector. It is described in Aristidi *et al.* (1997b) and Prieur *et al.* (1998). During the runs in January 1995 and January 1997, images were only recorded on video tape for further processing. In June they were also sent to a PC hosting a Matrox Genesis digitizer board equipped with a digital signal processor (C80) which enables near real-time processing. As an example the power spectrum for a 128×128 image size is

computed at a rate of about 20 frames per second. The use of a reference star was sometimes avoided by computing the cross correlation between time-separated images and subtracting it to the autocorrelation (Worden *et al.*, 1977). Though at a lower speed (9 frames/sec) the system is also programmed to compute the cross correlation between the images and their square in order to find the absolute position angles of binaries (Aristidi *et al.*, 1997a). This system does not include yet the classification of images according to the seeing that is used in the data processing as described in (Aristidi *et al.*, 1997b). Real time relative photometry is also not implemented yet. Bright stars ($m_V \lesssim 6$) were re-processed from the video tape for magnitude difference determination by probability imaging (Carbillet *et al.*, 1998a). This provides also the absolute position angle (PA) and has been useful to check the PA computed by the cross-correlation technique (Aristidi *et al.*, 1997a).

The PAPA camera was used during part of these observations but because of technical testing and bad weather conditions it could only lead to measurements on the night of 23/06/97. It is actually a new version of the original camera described in (Papaliolios *et al.*, 1982, 1985). Modifications have been jointly implemented by P. Nisenson, D. Ghezari (Harvard Smithsonian Center for Astrophysics) and L. Koechlin (OMP) in the last five years. The current version has a new binary mask setup and a refurbished image intensifier. A problem (later identified as coming from the power supply of the amplification tube) caused a strong geometric distortion and a variation of the overall scale which imposed quasi permanent scale calibrations during the night. A small “hole” at the center of the autocorrelation function was also noticed, due to a lack of detectivity of the electronics after each photo-event detection. A whole reduction procedure had to be set up in order to correct for these defects:

- Each star image was corrected with the distortion and scaling coefficients interpolated from the two images of the calibrating grid which were taken immediately before and after the star observation.
- To remove the hole at the center of the autocorrelation, each photo-event was correlated with the photo-events of a “gliding” time window located at about 1 msec from the arrival time of the photo-event. The very poor atmospheric conditions did not allow us to use a time window larger than 2 msec (as the typical coherence time was less than 3 msec!).

3. Results and discussion

Measurements are presented in Table 1. For multiple stars, the name of each measured couple is given. Ephemeris are computed for double and/or multiple stars with known orbits. Fig. 1 displays the residuals in ρ and θ as a cloud of points with error bars in the $(\Delta\rho/\rho, \Delta\theta)$ plane. This

cloud of points is centered on (0,0); this validates data reduction and calibration procedure.

The following comments can be made for some individual stars.

- **Moai 1** was discovered as double in December 1995 (Carbillet *et al.*, 1996). An error occurred in that paper with the values of the position angle, actual values being : date=1995.947, $\rho = 0''.110 \pm 0''.003$, $\theta = 167 \pm 1^\circ$ (Carbillet *et al.*, 1998b).
- **ADS 2200**: Observed near periastron, close to the limiting resolution of the telescope ($0''.081$ mas at $\lambda = 644$ nm).
- **ADS 8347**: Quintuple star. AB, AC and AD are expected to be resolved by a 2 m telescope. The couple AC did not fit in our field of view (separation of AC $\simeq 60''$), and we did not measure it. We searched for companions around star D but nothing was detected (separation $\leq 0''.05$ or magnitude difference > 5).
- **ADS 8094**: Double star with very uncertain orbit (Hopmann, 1970) period $P = 4050$ yr, rejected from the WDS orbit database (Worley & Douglass, 1996).
- **ADS 8035**: We observed previously this star in 1995.951 (Aristidi *et al.*, 1997b) and found, as for the present paper, large residuals with the Heintz orbit of 1956. Clearly a new orbit should be calculated.
- ν **Cyg** was initially observed as a reference star and seen double. The first observation (1997.648) being very poor, it has been reobserved in 1997.471 for confirmation and in 1997.561 for three color relative photometry. Its duplicity was discovered by Hipparcos (The Hipparcos Catalogue, 1997).
- **ADS 5925AB**: very uncertain orbit. Possible confusion between stars A and B (small magnitude difference) causing an uncertainty of 180° .
- **WDS09562+1754 (XY Leo)**: Quadruple star. AB is a W-UMa contact binary. The expected separation deduced from spectrophotometric measurements is $\simeq 0''.15$ (Barden, 1987). To our knowledge, it has never been resolved by visible speckle interferometry. We also did not detect this companion.

We also notice a few cases of abnormally large differences between our measurements and the expected values from the previously determined orbits. This is the case of ADS 9392, Cou 1145, ADS 11998, Cou 321 ADS 8347AB, ADS 2200. When comparing with published observations, we see that for xxxx , xxxx (Eric peux-tu voir cela sur le web?). *There is clearly a problem and they should be re-observed for confirmation, or the orbits are not correct and should be re-calculated*

4. Conclusion

Because of the quasi-permanent bad weather conditions that we have experimented at Pic du Midi during all the observing runs from the first light of the speckle camera

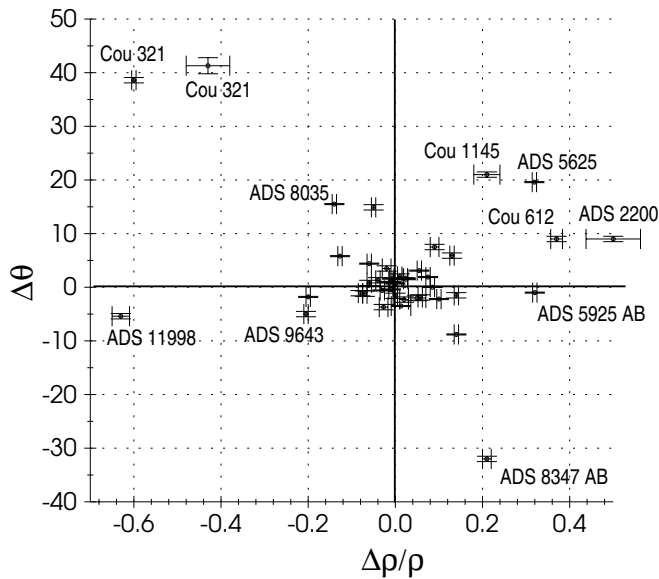


Fig. 1. Two dimensionnal plot of the residuals in position angle ($\Delta\theta$) and relative residuals in separation ($\Delta\rho/\rho$). For couples with known orbit, each measurement corresponds to a point in the graph. Error bars in ρ and θ have been drawn to scale.

in 1993, we revised our primary goal of imaging complex objects at high resolution to binary observations.

These observations have shown that the association of the speckle camera of Observatoire Midi-Pyrénées, the ICCD detector of Université de Nice, and the reduction procedure we have been developping in the last few years is well adapted to this subject. Despite of poor atmospheric conditions, we have obtained a rather long list of measurements and started to reach a productive stage in the field of binary stars.

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Star ID	Star name	Mult.	Reference star	Epoch	$\lambda/\Delta\lambda$ (nm)	Expos. (ms)	Obj.	Latest orbit	ρ (")	ρ_{cal} (")	$\Delta\rho$ (")	θ (°)	θ_{cal} (°)	$\Delta\theta$ (°)	Δm
SAO 12917	MOAI 1	2	SAO 12929	1997.071	530/57	8		—	0.08 ± 0.01	—	—	209 ± 1	—	—	
ADS 2200	20 Per	3	none	1995.931	644/70	16	AB	Heintz, 1980	0.08 ± 0.01	0.04	0.04	194 ± 1	185	9	
ADS 2959		2	HD 25022	1997.070	530/57	10		Couteau, 1990	1.20 ± 0.01	1.112	0.09	64.6 ± 0.2	62.7	1.9	
ADS 4950	4 Lyn	3	SAO 25731	1997.074	530/57	10	AB	—	0.750 ± 0.008	—	—	139.5 ± 0.2	—	—	1.4 ± 0.1
ADS 5400	12 Lyn	3	SAO 13973	1995.930	644/70	16	AB	Popovic, 1995b	1.79 ± 0.02	1.69	0.1	75.3 ± 0.2	72.2	3.1	
ADS 5447		2	SAO 95996	1997.071 1997.071 1997.071	447/47 530/57 644/70	16 15 15		Baize, 1992	0.318 ± 0.003	0.383	-0.065	217.6 ± 0.2	219.4	-1.8	1.09 ± 0.15 0.9 ± 0.2 0.8 ± 0.3
ADS 5625		2	SAO 114523	1997.074	530/57	8		Heintz, 1974*	0.363 ± 0.004	0.247	0.116	139.4 ± 0.2	115.3	19.6	
ADS 5925		3	SAO 152663	1997.071	530/57	8	AB	Mourao, 1962*	0.551 ± 0.005	0.727	-0.176	102.3 ± 0.2	283.3	-181	
ADS 6089	63 Gem	4	64 Gem	1997.074	530/57	8		—	0.078 ± 0.002	—	—	361 ± 1	—	—	1.0 ± 0.2
ADS 6175	α Gem	6	β Gem	1997.074	530/57	1	AB AB	Docobo, 1985 Heintz, 1988	3.58 ± 0.04	—	-0.03 -0.04	69.3 ± 0.2	—	1.6 1	1.3 ± 0.1
ADS 6993	ϵ Hya	5	HR 3418	1997.071 1997.071	530/57 530/57	5 5	AB AC AB×C	Hartkopf 1989 Heintz, 1996	0.264 ± 0.003 2.79 ± 0.03 2.84 ± 0.03	0.273 — 2.87	-0.009 — -0.03	173.9 ± 0.2 294.0 ± 0.2 295.3 ± 0.2	174.5 — 295.7	-0.6 — -0.4	0.9 ± 0.2 1.9 ± 0.2
HD 76943	10 Uma	2	none	1995.930	644/70	16		Hartkopf, 1989	0.373 ± 0.003	0.377	0.004	129 ± 1	131.0	2	
ADS 7341		2	SAO 98554	1997.074	530/57	7		Zulevic, 1967*	0.407 ± 0.004	0.350	0.057	348.1 ± 0.2	356.9	-8.8	
ADS 7480	\circ Leo	3	SAO 98955	1997.071	530/57	5	Ac	—	0.59 ± 0.01	—	—	267.9 ± 0.2	—	—	1.6 ± 0.2
WDS 09562+1754	XY Leo	4	SAO 98976	1997.074	530/57	16		—	-not detected-	—	—	—	—	—	
ADS 7685		2	SAO 81273	1997.074	530/57	16		Heintz, 1962*	1.03 ± 0.01	0.971	0.059	125.9 ± 0.2	121.5	4.4	
ADS 7871		2	SAO 118431	1997.071	530/57	16		Heintz, 1984	0.530 ± 0.005	0.581	-0.051	158.3 ± 0.2	—	-2.2	
ADS 8035	α UMa	4	β UMa	1997.074	530/57	1	AB	Heintz, 1956*	0.470 ± 0.005	—	0.066	226.2 ± 0.2	—	15.5	1.5 ± 0.2
ADS 8094		2	SAO 81770	1997.074	530/57	5		—	0.533 ± 0.005	—	—	321.4 ± 0.2	—	—	
ADS 8311		2	SAO 99973	1997.074	530/57	15		Heintz, 1963*	1.01 ± 0.01	1.129	-0.128	343.1 ± 0.2	337.3	5.8	1.8 ± 0.1
ADS 8347	65 Uma	5	SAO 43839	1997.074 1997.074 1997.074	530/57 530/57 530/57	7 16 7	AB C D	Baize, 1991 — —	0.14 ± 0.002 3.79 ± 0.03 -not detected-	0.109 — —	0.03 — —	276 ± 1 222.3 ± 0.2 —	308 — —	-32 — —	
ADS 8539		2	SAO 82456	1997.074	530/57	8		Aller, 1951*	1.68 ± 0.01	1.641	0.04	325.6 ± 0.2	323.9	1.7	
HD 114519	RS CVn	3	SAO 63388	1997.074	644/70	16		—	-not detected-	—	—	—	—	—	
ADS 8811		4	Weis 22389	1997.071	644/70	16		—	0.257 ± 0.003	—	—	145 ± 1	—	—	
ADS 9301		2	HD 130870	1997.468	644/70	10		Van den Bos, 1949*	0.222 ± 0.01	0.219	0.003	161.2 ± 1	164.7	-3.5	

Table 1. Table of measurements. λ denotes the wavelength and $\Delta\lambda$ the bandwidth. The column labelled Mult. gives the number of stars in the system (multiplicity). The column labelled Obj. give the name of the measured components of the multiple star. Predicted values of ρ and θ are computed from the latest available orbits. For orbits prior to 1982 (followed by a \star), orbital elements were found in the catalogue of Worley & Douglass, 1996. For ϵ Hya the angular separation AB×C was computed from AB, AC and Δm_{AB} as the distance between C and the photocenter of AB. The columns labelled $\Delta\rho$ and $\Delta\theta$ give the residuals in ρ and θ .

Star ID	Star name	Mult.	Reference star	Epoch	$\lambda/\Delta\lambda$ (nm)	Expos. (ms)	Obj.	Latest orbit	ρ (")	ρ_{cal} (")	$\Delta\rho$ (")	θ (°)	θ_{cal} (°)	$\Delta\theta$ (°)	Δm
ADS 9392		2	HD 134169	1997.468	644/70	16		Starikova, 1982	0.773 ± 0.002	0.839	-0.066	283.2 ± 0.2	283.2	0.0	
ADS 9425		2	none	1997.481	530/57	16		Zulevic, 1990	1.23 ± 0.01	1.23	0.000	167 ± 0.2	166.3	0.7	0.84 ± 0.06
ADS 9505		2	HD 137510	1997.468	644/70	12		Eggen, 1946*	-not detected-	0.101	—	—	215.2	—	
ADS 9643		2	none	1997.481	530/57	16		Muller, 1955*	0.180 ± 0.002	0.217	-0.037	318 ± 1	323	-5	
Cou 612		2	HD 137510	1997.468	644/70	16		Baize, 1993	0.256 ± 0.007	0.161	0.095	208.3 ± 0.8	199.3	9.0	
ADS 10235		3	HD 152896	1997.468	644/70	5	AB	Scardia, 1984	1.425 ± 0.01	1.344	0.081	95.3 ± 0.6	97.2	-1.9	
ADS 10531		2	HD 156632	1997.468	644/70	16		Baize, 1988	0.213 ± 0.004	0.183	0.030	275.4 ± 0.2	276.9	-1.5	
Cou 1145		2	HD 156632	1997.468	644/70	16		Baize, 1990	0.124 ± 0.008	0.098	0.026	89 ± 1	68	21	
Fin 381		2	HD 164615	1997.468	644/70	10		Baize, 1990	-not detected-	0.066	—	—	184.6	—	
ADS 11111	73 Oph	2	HD 166073	1997.468	644/70	12		Heintz, 1984	0.490 ± 0.005	0.510	-0.020	300.5	299.2	1.3	
ADS 11530		2	HD 172151	1997.468	644/70	16		Baize, 1987	0.338 ± 0.007	0.306	0.032	67 ± 1	59.5	7.5	
ADS 11842		2	HD 174966	1997.468	644/70	16		Docobo, 1988	0.226 ± 0.002	0.226	0.000	62.8 ± 1	64.2	-1.4	
ADS 11842		2	HD 174966	1997.471	644/70	2 [†]		Docobo, 1988	0.238 ± 0.01	0.226	0.012	62.2 ± 1	64.2	-2.0	
ADS 11998		2	HD 176871	1997.471	644/70	—		Popovic, 1995a	0.231 ± 0.01	0.377	-0.146	253.5	258.9	-5.4	
Cou 321		2	HD 181751	1997.468	644/70	16		Baize, 1991b	0.093 ± 0.001	0.149	-0.056	135.8 ± 1	97.3	38.5	
		2	none	1997.471	644/70	2 [†]		Baize, 1991b	0.104 ± 0.01	0.149	-0.045	138.6 ± 3	97.3	41.3	
ADS 12752		2	HD 181751	1997.468	644/70	16		Baize, 1972*	0.362 ± 0.003	0.381	-0.019	10.6 ± 0.2	14.9	-4.3	
ADS 12972		2	HD 187795	1997.468	644/70	16		Baize, 1961*	0.635 ± 0.006	0.553	0.082	144.5 ± 0.4	138.6	5.9	
ADS 14073	β Del	2	none	1997.561	447/47	2		Hartkopf, 1989	0.373 ± 0.004	0.364	0.009	327.4 ± 0.2	325.9	1.5	0.8 ± 0.2
			1997.561	530/57	2		1.0 ± 0.2								
			1997.561	644/70	1.4		1.0 ± 0.1								
			1997.561	743/69	1		1.0 ± 0.1								
			1997.561	855/74	4		1.1 ± 0.1								
ADS 14296	λ Cyg	3	ν Cyg ν Cyg	1997.468 1997.468	644/70 644/70	16 16	AB Aa	Baize, 1983 Baize, 1991c Balega, 1988	0.873 ± 0.003 -not detected-	0.925 0.055 0.050	-0.052 — —	9.9 ± 0.3 — —	9.1 78.9 92.87	0.8 — —	
ADS 14424		2	none	1997.471	644/70	2 [†]		Heintz, 1962*	0.452 ± 0.01	0.442	0.010	131.6 ± 1	133.9	-2.3	
HD 199629	ν Cyg	2	none HD 200030 α Cyg α Cyg α Cyg	1997.468 1997.471 1997.561 1997.561 1997.561	644/70 644/70 447/47 530/57 644/70	16 2 [†] 3 3 3		— -not detected- —	0.108 ± 0.01 — 0.115 ± 0.008	— — —	— — —	247 ± 3 — 235.8 ± 0.5	— — —	— — —	0.8 ± 0.1 1.0 ± 0.2 1.00 ± 0.07
ADS 14666		2	none	1997.468	644/70	10		Popovic, 1995a	0.288 ± 0.007	0.294	-0.006	123.1 ± 0.5	119.6	3.5	
ADS 15115		2	none	1997.468	644/70	10		Baize, 1961*	0.296 ± 0.006	0.304	-0.008	306.7 ± 0.3	310.4	-3.7	
ADS 15251		2	none none	1997.468 1997.468	644/70 644/70	16 16		Baize, 1981 Starikova, 1984	0.397 ± 0.004	0.426 0.428	-0.029 -0.031	201.8 ± 0.5	203.0 202.9	-1.2 -1.1	
ADS 16214	HR 8652	3	HD 214946 HD 214946	1997.471 1997.471	644/70 644/70	2 [†] 2 [†]	AB BC	— —	0.509 ± 0.01 0.056 ± 0.006	— —	— —	122.8 ± 2 44.0 ± 4	— —	— —	

Table 1. Table of measurements (continued). For observations made with the PAPA detector, a † has been added in superscript to the exposure time (usually 2 ms).

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