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Speckle observations of binary systems measured by Hipparcos*

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Abstract. From speckle observations made with the PISCO speckle camera at the Pic du Midi Observatory, we present high angular resolution astrometric data for 43 binary stars already observed by the Hipparcos satellite. This sample consists of mainly new Hipparcos eclipsing binaries with a visual companion closer than one arcsecond, chosen with the aim to study the dynamical implications of a third component on the observational parameters of the eclipsing system. In addition, we also included a selection of close visual binaries with few speckle data in order to analyse possible systematic departures between the speckle and the non-speckle orbits. The reduction method and the results are presented in detail. For the close visual binaries we confront our observations with the ephemerides based on the best known orbits. For the wide visual binaries the confrontation is made directly with the Hipparcos data. Our observations are consistent both with previous speckle data and with most of the Hipparcos measurements.

Key words. methods: data analysis – techniques: image processing – techniques: interferometric – astrometry – stars: binaries: visual

1. Introduction

This work is part of a larger observational program to study a sample of binary systems from the Hipparcos Catalogue in various aspects: morphology, multiplicity, orbits, fundamental stellar parameters, dynamics and evolution (Ribas et al. 1998; Aristidi et al. 1999; Lastennet et al. 1999; Lampens & Strigachev 2000).

A primary aspect concerns the characterization of the dynamical perturbations due to a third close companion on the orbital parameters of eclipsing binaries. Among the one hundred Hipparcos eclipsing binaries which have a companion closer than one arcsecond (Oblak et al. 2000), we have selected 26 triple systems for interferometric observations of the close companion, 11 being eclipsing binaries newly discovered by Hipparcos. For these new variables, the light curves are acquired at Cracow and Kryonerion (Greece) observatories, while the radial velocity curves are obtained at the Observatoire de Haute-Provence (OHP, France). Some preliminary results are presented in Kurpinska et al. (2000b).

The second aspect concerns the study of a sample of close visual binaries whose orbits are based on a combination of non-speckle and speckle data, in order to analyze possible systematic departures (particularly in angular separation) between these two modes of observation. As the speckle orbits are generally not well defined for these objects, speckle observations are needed to perform this analysis.

The observations presented here were performed with the 2-meter Bernard Lyot telescope (TBL) of the Pic du Midi Observatory making use of the PISCO speckle camera developed by the Observatoire Midi-Pyrénées (Prieur et al. 1994, 1998) which constitutes a powerful tool for investigating the field of close binary stars (Carbillet et al. 1996; Aristidi et al. 1997b, 1999). Under normal or good observing conditions, the angular resolution reached by PISCO at the TBL is of the order of 60 milliarcsec in V, which corresponds to the diffraction limit of the telescope.

In the following we describe the conditions of our observations at Pic du Midi (Sect. 2) and the procedures

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* Based on observations made with the *Télescope Bernard Lyot* at the Pic du Midi Observatory, France and on data obtained by the Hipparcos astrometry satellite. This work has also made use of the Simbad database, operated at CDS, Strasbourg, France.

Table 1. Filters available with PISCO. "W" means "white" when no filter was used, and the limitation of the spectral band was only done by the spectral response of the ICCD camera

Name	Central wavelength (nm)	Bandwith (nm)
B	447	47
OIII	501	11
V	530	57
R	644	70
R'	658	43
RL	743	69
I	855	74
W	650	418

we used to process the data (Sect. 3). Finally we present our results and compare them both with Hipparcos and ground-based measurements (Sect. 4).

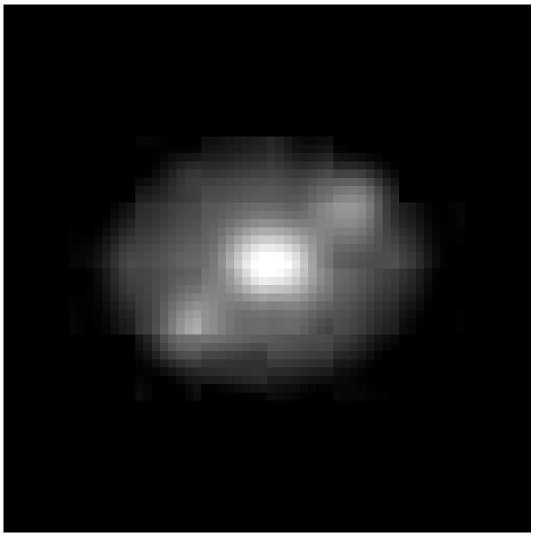

Fig. 1. Auto-correlation function of HIP 25930, after subtracting the mean cross-correlation of elementary frames separated by 100 msec as explained in the text

2. Observations

Observations were carried out on September 8th and 9th, 1998. Additional observations were obtained during some observing runs allocated to other programmes in June 7th and September 1st 1998. We also added a measurement of HIP 107162 made in August 9th 1993 while testing PISCO with the CAR photon-counting detector (Prieur et al. 1998).

The PISCO speckle camera was used in its full pupil imaging mode with its standard filter set (see Table 1). The atmospheric chromatic dispersion was automatically corrected with Risley prisms. The reliability of our correction scheme was confirmed by circular auto-correlation peaks (cf. Sect. 3), except for the observations of HIP 15627 (filter V) and HIP 16042 (filter W) due to a strong wind that caused an elongation of these peaks.

The detector was the intensified CCD detector (Philips IP800T, hereafter called ICCD) of the Université de Nice, which is described in detail by Aristidi et al. (1997b). It generates video output at 50 frames/sec recorded on SVHS video tapes.

During both nights of September 8th and 9th, 1998 the weather conditions were rather bad with strong wind and high humidity. As shown in Table 2, the seeing was poor and the average of the Full Width at Half Maximum (FWHM) was larger than $4''$. The immediate consequence was a scattering of the light over a larger area and a lower apparent luminosity, which required a longer integration time for the elementary frames. As the speed of the wind was high, the coherence time of the atmosphere (i.e. the time when the turbulence of the atmosphere can be considered as "frozen") was very short, sometimes less than a few millisec. Let us recall that when the integration time t of the elementary frames is significantly larger than the coherence time τ_c of the atmosphere (e.g. $t >\sim 5\,\tau_c$), we are no longer in the *speckle regime* but rather in the *long exposure regime*: all the speckle patterns are blurred and the high angular frequencies are lost.

Hence the combination of poor seeing and strong wind may explain the rather low detection rate for the companions: 16 binaries out of the 43 targets could not be resolved.

3. Data reduction

3.1. Processing of the elementary frames

The data recorded on SVHS video tapes during the observations were digitized by a "Full RIO" PCI board made by Ellips (Ellips 2000). It is an 8-bit frame grabber which allows real-time processing at a rate of 50 frames/sec with a format of 288×384 pixels. A programme was developed by one of us (J.-L. Prieur, hereafter JLP) to control the video cassette recorder and automatically process the digitized frames.

The auto-correlation was computed for each elementary frame and averaged over a whole sequence. Likewise a mean cross-correlation between two elementary frames separated by 100 msec (i.e., much larger than the coherence time $\tau_c \sim$ 5–10 msec) was also computed. We then followed the procedure described by Worden et al. (1977) and subtracted the mean auto-correlation from this cross-correlation, which substancially reduces the level of the background and greatly facilitates the detection and localization of the secondary peaks (e.g. Fig. 1). Although this method was originally developed for photon-counting detectors, we have experienced (Aristidi et al. 1999; Scardia et al. 2000) that it is still very efficient for the detection and the measurement of the relative positions of double and multiple stars, and it leads to the same results of more elaborated (and time-consuming) methods such as the algorithms using the bispectrum (see Prieur et al. 1991).

3.2. Astrometric measurements

The centre of the auto-correlation peaks was then determined with a specially-designed programme written by JLP. The first step was to interactively select a disk whose centre had to be determined. The background was then computed by fitting a 3rd order polynomial in a concentric annulus outside of this disk and its interpolation on the disk displayed back on the original image to check if it was correct. This procedure was originally used for removing artefacts in images (derived from "PATCH" of the U.K. STARLINK package) and generates a smooth background with no discontinuity at the boundaries of the disk. The centre was then determined by two methods: either by computing the barycentre or by fitting a two-dimensional Gaussian, which generally gives a similar result, the crucial point being the selection of the appropriate size and location of the disk. To measure the *internal* errors and obtain a more precise value, independent measurements were made on each auto-correlation peak with different values of the diameter of the disk and different parameters for displaying the image (linear and logarithmic intensity transfer table). These internal errors were generally smaller than the calibration errors (cf. Sect. 3).

We checked on a few well separated systems that this method was in good agreement with the profile fitting technique developed in the context of small-field CCD observations of visual double stars (Cuypers 1997), which was unfortunately not applicable to most of the closest systems due to a non uniform background.

3.3. Calibration

The orientation of the frames was calibrated using the tracks of stars obtained by allowing the telescope to move in declination and right ascension. The estimated uncertainty of this calibration is $\pm 0.35°$, which is the main source of error for the position angle θ of our measurements in the case of a good signal-to-noise ratio.

The magnification scale was obtained by measuring a calibrating grid that was placed at the entrance focal plane of the speckle camera. Using the value of 50.4 ± 0.1 m for the focal length of the TBL, we derived the values of 0.0109 ± 0.0001, 0.0258 ± 0.0001 and 0.1654 ± 0.0005 arcsec/pixel for the three available magnifications obtained with the eyepieces of respectively 10 mm, 20 mm and 50 mm focal lengths.

The validity of these calibrations was verified in two ways: (a) internally by observing the same object with different magnifications and (b) externally with the observations of the "astrometric standards" HIP 1447/1446 and 4065. We also intended to observe HIP 109186 but, due to very bad seeing, we could not resolve this pair at that time. These visual double stars were recently observed in the context of a European observational programme of CCD photometry of visual double stars undertaken at ESO (Oblak et al. 1999). They would allow an accurate astrometric calibration of the speckle observations as these data were accurately calibrated using the Hipparcos relative astrometry (Cuypers & Seggewiss 1999). Unfortunately, since only two pairs were measured, no improvement of the calibration parameters could be derived. In Table 3 we list our measurements of HIP 1447/1446 and 4065, compared to the ESO data. One can see that both residuals in angular separation and position angle have opposite signs and therefore do not show any systematic deviation nor allow to reduce the errors of the used calibration. We shall also see that there are no systematic differences between the rest of our measurements and the Hipparcos data (cf. Sect. 4.2).

3.4. Problem of 180°-ambiguity

As the position angle was measured on the auto-correlation function, which is symmetrical (cf. Fig. 1) this determination leaves a 180° ambiguity. To remove this ambiguity, we used the method proposed by Aristidi et al. (1997a) based on the analysis of a zero plane of the triple correlation of elementary frames. Unfortunately, this technique did not produce clear results for many objects, because the acquisition was made at a very low flux, close to the photon-counting mode. This procedure fails when the dynamical range of the elementary frames becomes close to unity. A possible alternative in some cases was a full image restoration with bispectral techniques (Prieur et al. 1991).

4. Results and discussion

The list of observed targets (cf. Sect. 4.1/Table 2) displays mainly three types:

- eclipsing binaries with a close companion, most of which were discovered by Hipparcos and for which the existing information is insufficient;
- visual double stars with an angular separation smaller than 1″ which require new observations to better constrain the speckle orbits;
- "astrometric standards" chosen among visual double stars with an angular separation larger than 1″ and thought to have a stable configuration useful to determine the scale of the instrument.

Two additional objects were selected because they are suspected binaries by Hipparcos: both components of the very wide system CCDM 19282-0932 (HIP 95724/95726) carry a variability flag "D" in the catalogue meaning *variability induced by duplicity*; however we could not resolve these objects.

The following convention was used to assign a type to each programme star:

- (a) an "astrometric standard";
- (b) a close companion was discovered by Hipparcos;
- (e) a known eclipsing binary;
- (h) a new eclipsing binary discovered by Hipparcos;
- (o) binary with a known orbit;

Table 2. Relative astrometric measurements made with PISCO. Description of the columns: (1) Hipparcos number, (2) CCDM number, (3) Other denomination, (4) Focal length of the eyepiece in the magnification wheel of PISCO, (5) Filter, (6) Type of object (see in the text), (7) Epoch as a fraction of Besselian year, (8) Position angle with error, (9) Angular separation with error, (10) Full Width at Half Maximum seeing, (11) Comments on the quality of the data ("n" when there is an additional note). This table is also available in electronic form at the CDS via anonymous ftp to `cdsarc.u-strasbg.fr (130.79.128.5)` or via `http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/367/865`

Identifier			FL	Filter	Type	Epoch	θ	ρ	Seeing	Comments
HIP	CCDM	Other	(mm)				°	″	″	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
981	00121+5337	ADS 148	10	*V*	o	1998.665	295.1 ± 0.5	0.268 ± 0.003	3.0	(Best: FL=10)
"	"	"	20	*V*		1998.665	297.0 ± 0.4	0.277 ± 0.003	3.8	Strong artefacts.
1447	00180+0931		50	*W*	a	1998.687	$210.9 \pm 0.8^*$	11.77 ± 0.06	4.3	(n)
4065	00521+1036	ADS 709	20	*R*	a	1998.687	351.4 ± 0.8	2.248 ± 0.011	>5	
"	"	"	20	*W*		1998.687	351.4 ± 0.4	2.258 ± 0.007	>5	
"	"	"				(1998.687)	(351.4 ± 0.8)	(2.253 ± 0.01)		(Best: mean)
6287	01207+5136	V766 Cas, ADS 1083	20	*W*	h	1998.687	90.3 ± 1.7	0.378 ± 0.004	3.4	
8115	01443+5732	V733 Cas, ADS1359AB	20	*W*	o,h	1998.687	-	-	5.0	
10280	02124+3018	TZ Tri, ADS1697	20	*RL*	u	1998.687	$69.5 \pm 0.1^*$	3.941 ± 0.010	>5	(n)
10952	02211+4246	ADS 1786	20	*W*	o	1998.687	247.8 ± 2.4	0.307 ± 0.009	5.0	
11318	02257+6133	V559 Cas, ADS 1833	20	*W*	o,e	1998.687	63.1 ± 1.0	0.392 ± 0.004	3.7	
12136	02363+4012	V377 And, Baz 2	20	*RL*	h	1998.687	-	-	>5	
14542	03078+6735	RX Cas	20	*W*	b,e	1998.687	-	-	4.7	
15627	03212+2109	τ1 Aur, COU 259	20	*V*	h	1998.688	-	-	5.0	Elongated (wind)
"	"	"	20	*W*		1998.688	225.1 ± 0.6	0.818 ± 0.006	4.1	
16042	03266+2842	UX Ari, CHA 9	20	*R*	u	1998.688	-	-	>5	(n)
"	"	"	20	*W*		1998.688	-	-	3.8	Elongated (wind)
16083	03272+0944	ξ Tau	20	*RL*	b,h	1998.688	340.1 ± 1.6	0.450 ± 0.008	3.9	
"	"	"	"	"	"	"	342.8 ± 0.8	0.463 ± 0.004		Removing XY sym.
"	"	"	"	"	"	(1998.688)	(341.9 ± 1.8)	(0.459 ± 0.009)		(Best: mean)
"	"	"	20	*V*		1998.688	-	-	4.1	
16920	03378+4046	AB Per, COU 1517	20	*W*	e	1998.687	-	-	>5	
19201	04069+3327	AG Per, ADS 2990	20	*W*	e	1998.688	227.3 ± 0.5	0.787 ± 0.005	4.1	
22050	04445+3953	V592 Per, COU 1524	20	*W*	h	1998.688	$207.8 \pm 5.$	0.195 ± 0.010	5.0	Faint;
22272	04477+4014	V593 Per, ADS 3447	20	*W*	h	1998.688	-	-	5.0	
23699	05056+2304	V1154 Tau, Stt 97	10	*W*	u	1998.688	$151.0 \pm 0.5^*$	0.358 ± 0.003	4.7	(Best: FL=10)
"	"	"	20	*W*		1998.688	$149.8 \pm 0.7^*$	0.353 ± 0.004	3.9	
25252	05240+3238	V424 Aur, COU 1090	20	*W*	h	1998.688	229.0 ± 1.2	0.254 ± 0.008	5.0	Faint
25930	05320-0018	δ Ori, ADS 4134	20	OIII	e	1998.688	136.0 ± 0.5	0.305 ± 0.004	4.4	
27309	05471+0018	V1380 Ori	20	*W*	b,e	1998.688	216.9 ± 0.8	0.587 ± 0.014	>5	(n)
29757	06160+2347	PW Gem, COU 578	20	*W*	u	1998.688	-	-	4.7	
54061	11037+6145	ADS 8035	20	*V*	o	1998.430	$207.6 \pm 0.4^*$	0.427 ± 0.004	-	
58112	11551+4629	DN UMa, ADS8347AB	20	*RL*	o,e	1998.430	$286.0 \pm 1.0^*$	0.120 ± 0.005	-	
93867	19070+1104	Y Aql, Heintz 568	20	*V*	e	1998.689	289.3 ± 0.8	0.317 ± 0.007	3.8	(n)
95724	19282-0932	ADS 12472	20	*W*		1998.689	-	-	4.2	A comp.
95726			20	*W*		1998.689	-	-	4.2	B comp.
96840	19411+1349	QS Aql, Kui 93	20	*W*	o,e	1998.689	310.5 ± 0.9	0.201 ± 0.009	3.0	
97091	19439+2708	PS Vul, ADS 12850	20	*R*	e	1998.657	$283.6 \pm 0.5^*$	$0.349 \pm .004$	3.6	
"	"	"	20	*R*		1998.689	-	-	5.0	
"	"	"	20	*W*		1998.689	-	-	3.1	
97849	19532-1436	V505 Sgr, CHA 90	10	*W*	e	1998.689	-	-	3.9	
98234			20	*W*		1998.689	-	-	3.1	
98416	19598-0957		20	*W*	o	1998.690	-	-	3.4	
100982			20	*W*		1998.690	-	-	3.6	
101236	20312+0513	MR Del, ADS 13940	20	*W*	h	1998.690	$71.5 \pm 0.25^*$	1.762 ± 0.006	4.0	
101769	20375+1436	β Del, ADS 14073	20	*V*	o	1998.430	$333.9 \pm 0.2^*$	0.443 ± 0.004	-	
101958	20396+1555	α Del	20	*R*	o	1998.690	-	-	3.3	
103505	20582+3510	CG Cyg, COU 1813	20	*W*	e	1998.690	308.9 ± 0.9	1.169 ± 0.006	4.3	(n)
107162	21424+4105	Kui 108	10	*V*	o	1998.690	255.8 ± 1.8	0.101 ± 0.004	2.2	
"	"	"	10	*V*		1993.602	$335.5 \pm 2.$	0.166 ± 0.01	-	(CAR detector)
108819			20	*R*		1998.690	-	-	4.0	
"			20	*W*		1998.690	-	-	3.5	
109186	22071+0034	ADS 15639	20	*R*	a	1998.689	-	-	>5	
"			20	*W*		1998.689	-	-	>5	

Table 2. continued

Identifier			FL	Filter	Type	Epoch	θ	ρ	Seeing	Comments
HIP	CCDM	Other	(mm)				°	″	″	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
111805	22388+4419	ADS 16138	20	V	o	1998.690	146.7 ± 1.7	0.163 ± 0.009	4.0	
116164	23322+0705	ADS 16819	10	V	o	1998.687	-	-	>5	
"	"	"	20	V		1998.687	329.3 ± 3.0	0.205 ± 0.021	>5	
"	"	"	10	R		1998.690	329.0 ± 0.3	0.201 ± 0.002	3.0	(Best: FL=10)
"	"	"	20	R		1998.690	329.1 ± 1.5	0.204 ± 0.013	3.8	
116167	23322+1458	DI Peg	20	W	b,e	1998.690	-	-	4.1	

Notes to Table 2:
HIP 1447: the (wide) secondary component is HIP 1446.
HIP 10280: the components of this RS CVn type variable were resolved by Near Infrared Long-Baseline Interferometry (Koresko et al. 1998)
HIP 16042: variable of RS CVn type.
HIP 27309: the (wide) primary component is HIP 29746.
HIP 93867: not belonging to the Hipparcos Variability Annex. Noted Elliptical Variable Star in SIMBAD, at the CDS;
HIP 103505: variable of RS CVn type; the Hipparcos light curve possibly indicates an Algol type.

Table 3. Astrometric calibration: comparison with measurements made at ESO with a CCD camera (Epoch 1991.797, Cuypers & Seggewiss 1999)

Identifier	ESO		PISCO		PISCO - ESO			
	ρ ″	θ °	ρ ″	θ °	$\Delta\rho$ ″	$\Delta\theta$ °	Δpos ″	Ratio
HIP 1447	11.811 ±.005	210.36 ±.01	11.770 ±.06	210.9 ±.8	−.041	.54	.118	0.997
HIP 4065	2.250 ±.003	351.78 ±.02	2.253 ±.01	351.4 ±.8	.003	−.38	.015	1.001

– (u) a new unsolved Hipparcos variable: variable star entry in the Hipparcos Variability Annex without a period determination (Part 2).

In our list HIP 6287, 22050, 25252, 93867, 96840, 101236 belong to the OHP programme for the determination of the radial velocity curves in order to fully understand the dynamics of these systems. All of them have been resolved by these observations which will then provide useful data for the orbit determination of the visual companion.

Some objects of the list were not resolved. This may be the consequence of a particularly poor FWHM seeing. Several objects may also present a configuration of close periastron passage: e.g., for HIP 98234, McAlister et al. (1987) gives an angular separation less than 0.038″ which is beyond our detection limit.

Among the four objects of our list discovered to be double by Hipparcos, we confirm the binarity for HIP 16083 and 27309, but we have not been able to do the same for HIP 14542 and 116167.

4.1. Astrometric measurements

The astrometric measurements are presented in Table 2. The position angle θ (relative to the North and increasing to the East) was generally measured on the autocorrelation function which leaves a 180° ambiguity (cf. Sect. 3.4). An asterisk following the value of θ indicates that the absolute angle could be determined by using a complementary processing: Aristidi's triple correlation technique for HIP 1447, 10280, 54061, 58112, 97091 and 101769, and a full image restoration with a bispectrum method for HIP 23699 and 101236.

When this ambiguity could not be solved, we chose the value between 0 and 180°, or, when available, we selected a value compatible with previous data sources (Hartkopf et al. 1998; ESA 1997) for the following stars: HIP 981, 4065, 15627, 16083, 19201, 22050, 25252, 27309, 96840, 103505, 107162, 111805 and 116164.

In the case of HIP 93867, Hartkopf et al. (1998) list position angles between 140° and 121° for the period 1987–1993, whereas Hipparcos and micrometric observations (Heintz 1996b) give respectively $\theta = 305°$ and 305.6°. It seems there is simply a problem of 180° ambiguity with the speckle measurements. To keep quadrant consistency with the visual observations, we chose $\theta = 289.3°$.

When two or more measurements were available, we determined the best value using the following procedure:

- if available, we adopted the value with the magnification scale of 10 mm since the accuracy was larger than with the 20 mm scale and there were less artefacts near the centre;
- else we computed the mean value and the corresponding error by taking the signal-to-noise ratio of the data into account (measurement in brackets).

This value, coded "Best" in Table 2, was used for the comparison with other sources (cf. next sections).

Table 4. Hipparcos data and comparison with our measurements; (1) Hip number; (2) source of the multiplicity data in the Hipparcos Catalogue: I = Input Catalogue, M = known as double although not mentioned as double in the Input Catalogue, H = Hipparcos discovery; (3) solution quality; (4) component identifiers; (5) Hipparcos position angle; (6) Hipparcos angular separation; (7) Hipparcos sigma of separation; (8) difference of magnitude $H_{\rm p}$; (9) total V (Johnson) magnitude; (10) trigonometric parallax; difference (PISCO-Hipparcos) for the position angle (11), the angular separation (12), and distance (13). Bottom part: systems with a known orbit

	HIPPARCOS									PISCO-HIP		
Number	Notes			θ	ρ	σ_ρ	$\Delta H_{\rm p}$	V	π	$\Delta\theta$	$\Delta\rho$	Δpos
HIP	S	Q	Comp.	$^\circ$	$''$	$''$	mag	mag	mas	$^\circ$	$''$	$''$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
1447-1446	I	A	AB	210.54	11.83	-	0.83	9.16	4.17	0.36	–0.06	0.095
4065	I	A	AB	352	2.240	0.003	0.65	8.41	9.61	–0.60*	0.013*	0.027
6287	I	A	AB	90	0.381	0.005	1.89	7.10	1.63	0.31*	–0.003*	0.004
10280	I	A	AB	70	3.920	0.004	1.50	4.94	10.68	–0.50	0.021	0.040
15627	I	A	AB	227	0.809	0.014	2.81	5.27	7.06	–1.90*	0.009*	0.028
16083	H	A	AB	315	0.628	0.017	3.81	3.73	14.68	26.91	–0.169	0.302
19201	I	A	AB	226	0.803	0.008	1.81	6.70	3.89	1.30*	–0.016*	0.024
22050	M	A	AB	194	0.206	0.010	0.85	8.31	5.12	13.85	–0.011	0.050
23699	I	A	AB	152	0.355	0.003	1.48	6.69	4.02	–1.00*	0.003*	0.007
25252	I	A	AB	227	0.230	0.013	0.94	8.34	–0.11	2.01*	0.024*	0.025
25930	I	A	AD	140	0.267	0.003	1.35	2.25	3.56	–4.00	0.038	0.043
27309	H	A	AB	219	0.580	0.012	0.96	9.70	5.70	–2.10*	0.007*	0.023
93867	M	A	AB	305	0.310	0.004	0.95	5.07	6.43	–15.70	0.007	0.086
97091	I	A	AB	283	0.336	0.003	1.20	6.27	0.75	0.60*	0.013*	0.013
101236	I	B	AB	69	1.802	0.012	0.28	8.77	22.53	2.50	–0.040	0.087
103505	M	A	AB	309	1.212	0.038	1.67	9.99	9.25	–0.10*	–0.043*	0.043
981	I	A	AB	278	0.172	0.007	1.21	6.87	9.42	17.1	0.096	0.110
10952	I	A	AS	305	0.196	0.006	0.28	8.79	16.36	57.18	0.111	0.260
11318	I	A	AB	56	0.360	0.003	0.44	7.00	4.43	7.11	0.032	0.057
54061	I	A	AB	270	0.672	0.006	2.92	1.81	26.38	–62.4	–0.245	0.607
96840	I	A	AS	311	0.189	0.002	0.06	5.98	1.98	–0.50	0.012	0.012
101769	I	A	AB	205	0.240	0.006	0.91	3.64	33.49	128.9	0.203	0.622
107162	I	A	AB	355	0.189	0.003	0.39	5.73	8.76	–99.2	–0.088	0.228
111805	I	A	AB	337	0.214	0.003	0.51	6.82	26.33	–169.7	–0.051	0.376
116164	I	A	AB	261	0.157	0.012	0.46	6.60	13.00	68.0	0.044	0.203

4.2. Comparison with Hipparcos measurements: visual binaries without known orbits

In addition to some information retrieved from the Hipparcos Main Catalogue (ESA 1997) we list the differences in θ, ρ and in relative position in the sense (PISCO – HIP) in Table 4. Sometimes, as in the case of the double entry HIP 1447/1446, we refer to the Double and Multiple Star Annex (ESA 1997).

The bottom part of Table 4 contains the systems with a known orbit that will not be considered here, since we shall compare more adequately the Hipparcos measurements with the ephemerides computed for epoch 1991.25 in Sect. 4.3.

To evaluate possible systematic differences, we have selected from the upper part of Table 4 all the objects which did not show any relative motion according to the observational data available in the literature (asterisked in Cols. 11 and 12 in Table 4). The derived mean differences between PISCO and Hipparcos measurements for these systems are $\langle\Delta\theta\rangle = -0.16^\circ$ and $\langle\Delta\rho\rangle = +0.001''$. Note that the typical error values for PISCO measurements of $\sim 0.8^\circ$ in θ and $\sim 0.01''$ in ρ are actually lower limits for the error estimates for $\langle\Delta\theta\rangle$ and $\langle\Delta\rho\rangle$ respectively, if we do not take into consideration Hipparcos errors. As the derived mean differences are much smaller than their estimated errors, one can state that no significant systematic difference is present between these measurements.

With the same selection of the asterisked objects, we obtained an estimate of the standard error: $\sigma_\theta = 0.99^\circ$, and $\sigma_\rho = 0.014''$. Applying a 3-σ level criterion and checking the value of Δpos allowed us to point some objects as possible candidates for orbital motion: HIP 16083, 22050, 93867 and 101236.

HIP 16083 is an interesting case. We resolved it, whereas five unresolved observations are listed in Hartkopf et al. (1998), probably due to a large magnitude difference of the two components: Δm = 3.8 mag.

As mentioned in Mason et al. (1999), the CHARA team found one previous measurement among their archival data of 1983. They suggested that the change in relative position between their and the Hipparcos data might be due to rapid orbital motion. From our measurements we deduce a mean motion of 3.6°/yr (cf. Table 5 and Kurpinska & Oblak 2000a). Assuming a circular motion, the period would then be of order 100–150 yrs.

Table 5. Evidence of rapid motion for HIP 16083

Epoch	θ °	ρ ″	Source	Derived motion
1983.713	297.8	0.689	Mason et al. 1999	
1991.25	315	0.628	Hipparcos	2.3°/yr; −8.09 mas/yr
1998.688	341.9	0.459	PISCO	3.6°/yr; −22.7 mas/yr

HIP 22050, 93867 and 101236 are known to be visual binaries showing small changes in measured positions over the last 20 years, but it is still too early to decide about their orbital motion. Only for one of them, HIP 93867, is there a suggestion of orbital motion from the photometric data which shows drastic changes in the depth of the minima during the last 100 years, as probably due to the effect of a large-scale secular decrease in the inclination of its orbit, caused by a third, close visual component on a non-coplanar orbit. Note that HIP 22050 and 101236 were discovered as eclipsing binaries by Hipparcos.

4.3. Comparison with Hipparcos measurements: visual binaries with a known orbit

Ephemerides for epoch 1991.25 were computed based on the best known orbit, either a speckle orbit (Hartkopf et al. 1989; Hartkopf & McAlister 1996) or else a combined speckle-visual orbit (Ruymaekers & Cuypers 2000, in preparation) for the pairs with a known orbit not discussed previously. We have considered the relative error criterion

$$Q = \frac{\sigma(a^3/P^2)}{(a^3/P^2)} < 0.1$$

(where a is the semi major axis and P the orbital period, and $\sigma(a^3/P^2)$ the rms error on (a^3/P^2)), which is an indication of the quality of the orbital parameters that are important for a useful determination of the sum of the masses (provided an accurate parallax is also available). This criterion is however not applicable for HIP 10952 ($Q = 0.24$) and HIP 54061 for which an orbit was determined based on both ground-based and Hipparcos Transit data (Söderhjelm 1999).

In Table 6 we see that the overall smallest differences in relative position for each system (Col. 9) are of the order of 0.01–0.02″ (which is similar to the standard error in separation from Sect. 4.2) and the corresponding differences in position angle rarely exceed 1°, therefore matching our estimated error in orientation. We can thus state that the agreement between the ephemerides and the Hipparcos measurements is generally good to very good. One exception is HIP 101769 for which the orbit proposed by Hartkopf et al. (1989) leads to a difference of 0.074″ in position on the sky. Let us now look to individual cases in more detail.

For HIP 10952, the orbit derived by Couteau (1991) matches better than more recent orbit determinations, indicating a clear need for more data. For HIP 11318 the correspondence is good for both orbits even though the periods are very different (resp. 830 or 530 yrs). Two cases show large discrepancies: there is no good match for HIP 101769 (best concordance with Ruymaekers 1999) nor for HIP 116164 (best concordance with Cester 1963) – both have periods of about 30 yrs – although the orbits have high-quality (relative error $Q < 8\%$). This supports the conclusion that the Hipparcos relative position at epoch 1991.25 is not useful for orbit determination when the orbital period is of order 30 yrs or less. For the other cases with a longer orbital period such as HIP 981 ($P \sim 67$ yrs), HIP 10952 ($P \sim 300$ yrs), HIP 11318 ($P > 500$ yrs), we do not expect nor find evidence for a systematic effect in the Hipparcos relative position.

Note that for HIP 58112, this comparison was not possible, because the speckle orbits and our observations refer to the close pair (AB), whereas Hipparcos measured the wide pair (AB-C).

4.4. Comparison with ephemerides from known orbits

Our goal was to confront three types of orbits:
- an orbit based on speckle data mainly (e.g. as derived by the CHARA group (Hartkopf et al. 1989; Hartkopf & McAlister 1996), with a quite recent date);
- an orbit based on mostly visual non-speckle data (from the literature, rarely very recent) and;
- a combined orbit taken from a new catalogue of orbits of visual binaries (Ruymaekers 1999). When the solution of the combined orbit was such that the associated relative error Q was larger than 1, no combined orbit was given since such a solution was not retained in the catalogue (for reasons of insufficient quality). This was the case for HIP 54061 and HIP 98416.

Most of the binaries that we have observed have periods smaller than 50 yrs (cf. Table 6). An exception was made for HIP 11318 and 96840 which belong to the programme of eclipsing systems, HIP 10952, a spectroscopic-visual binary for which – partly thanks to the additional data – new masses have been derived lately by Pourbaix (2000), and HIP 54061 and 58112 for which Aristidi et al. (1999) have computed a new orbit. We have re-observed them to check their orbits. The residuals are still quite large for HIP 54061: it is indeed the first time that it is observed at periastron. Speckle observations are presently particularly valuable since they will considerably constrain the orbit.

Table 6. Comparison of Hipparcos measurements (Hip) with ephemerides (C) computed for epoch 1991.25 for the visual binaries with orbits (bottom part of Table 4)

Identifiers		ρ_C	θ_C	ρ_{Hip}	θ_{Hip}	$\Delta\rho_{Hip-C}$	$\Delta\theta_{Hip-C}$	Δpos_{Hip-C}	ρ_{Hip}/ρ_C	Period	Source
HIP	CCDM	$''$	$\circ$	$''$	$\circ$	$''$	$\circ$	$''$		yr	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
981	00121+5337	0.171	276.11	0.172	278.	0.001	1.89	0.006	1.006	66.8	(Hartkopf & McA. 1996)
10952	02211+4246	0.192	311.84	0.196	305.	0.004	–6.82	0.023	1.021	299.	(Ruymaekers 1999)
”	”	0.203	304.68	0.196	305.	–0.007	0.32	0.007	0.966	277.	(Couteau 1991)
”	”	0.192	314.40	0.196	305.	0.004	–9.40	0.032	1.021	300.	(Heintz 1996a)
11318	02257+6133	0.363	58.04	0.360	55.6	–0.003	–2.44	0.016	0.992	530.	(Ruymaekers 1999)
”	”	0.366	54.18	0.360	55.6	–0.006	1.42	0.011	0.984	836.	(Zaera de Toledo 1985)
54061	11037+6145	0.681	271.48	0.672	269.6	–0.009	–1.88	0.024	0.987	44.6	(Aristidi et al. 1999)
”	”	0.675	269.66	0.672	269.6	–0.003	–0.06	0.003	0.997	44.5	(Söderhjelm 1999)
96840	19411+1349	0.190	310.77	0.189	311.	–0.001	0.23	0.001	0.995	68.21	(Docobo & Ling 2000)
101769	20375+1436	0.267	201.57	0.240	205.	–0.027	3.43	0.031	0.899	26.55	(Ruymaekers 1999)
”	”	0.284	191.83	0.240	205.	–0.044	13.17	0.074	0.845	26.60	(Hartkopf et al. 1989)
107162	21424+4105	0.193	354.89	0.189	355.	–0.004	0.04	0.004	0.979	26.54	(Ruymaekers 1999)
”	”	0.194	354.94	0.189	355.	–0.005	0.11	0.005	0.974	26.51	(Hartkopf et al. 1989)
111805	22388+4419	0.216	338.83	0.214	337.	–0.002	–1.83	0.007	0.991	29.74	(Ruymaekers 1999)
”	”	0.214	337.49	0.214	337.	0.000	–0.49	0.002	1.000	29.89	(Hartkopf & McA. 1996)
116164	23322+0705	0.132	251.46	0.157	261.	0.025	9.54	0.035	1.189	30.80	(Ruymaekers 1999)
”	”	0.132	261.48	0.157	261.	0.025	–0.48	0.025	1.189	30.53	(Cester 1963)

The case of HIP 98416 is peculiar. Due to a quadrant ambiguity of the relative positions two orbits can be derived for this binary: an orbit with period 9.8 yrs and small eccentricity or an orbit with half the period and high eccentricity. The first one is proposed by Baize (1990) and also by Hartkopf & McAlister (1996). However, radial velocities confirm the period of ~4.9 yrs (Duquennoy & Mayor 1991; Pourbaix 2000), but with errors still too large to be useful at present. With the available observations, the objective function of the least-square minimization has a lot of local minima that cannot be distinguished. More observations are clearly needed.

In Table 7, we present ephemerides based on the best orbits obtained from ground-based observations for the sample of binaries observed with PISCO for which an orbit was known (i.e. objects with the mention “o” in Table 2). We list the residuals in ρ, θ and in relative position in the sense (observed minus computed values). The last column gives the reference code of the published orbit.

The residuals are of the order of 20 milliarcsec on average. There are no systematic errors as shown in Fig. 2, which illustrates the quality of the calibration. The large scatter in this figure shows the level of inaccuracy that still exists for the orbits under discussion and the need for more speckle observations.

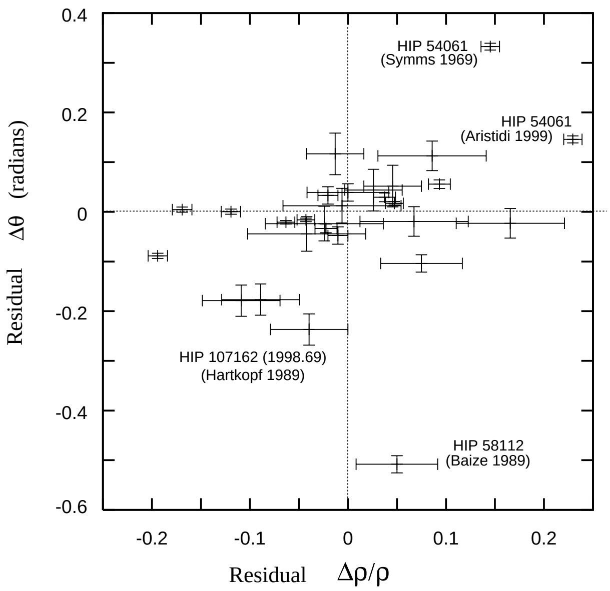

Fig. 2. Residuals of our measurements with orbits ephemerides for the position angle θ and the angular separation ρ (cf. Table 7)

4.5. Relative photometry of HIP 101769

A full set of B, V, R photometric differential magnitudes (cf. Table 8) was obtained for the nearby object HIP 101769 (β Del) using the probability imaging technique described by Carbillet et al. (1998). When computing the average values of the colour differences one finds a small colour trend in the sense that the differences increase towards the redder wavelengths: $\Delta B = 0.72 \pm 0.15$, $\Delta V = 0.83 \pm 0.15$, $\Delta R = 0.87 \pm 0.15$ and $\Delta I = 1.0 \pm 0.1$ mag.

Using the mass-luminosity relations based on the new Hipparcos parallaxes (Lampens et al. 1997; Ruymaekers 1999), these measurements can lead to an estimation of the component masses for this object which is highly desirable since there is no spectroscopic mass ratio available (the system is a single-lined spectroscopic binary).

Table 7. Comparison of PISCO measurements (P) with ephemerides (C) of known orbits

Identifiers HIP (1)	CCDM (2)	Epoch (3)	ρ_C ″ (4)	θ_C ° (5)	$\Delta\rho_{(P-C)}$ ″ (6)	$\Delta\theta_{(P-C)}$ ° (7)	$\Delta pos_{(P-C)}$ ″ (8)	ρ_P/ρ_C (9)	Source (10)
981(v1)	00121+5337	1998.665	0.259	293.45	.010	1.65	.012	1.037	(Ruymaekers 1999)
”	”	”	0.242	291.91	.025	3.19	.029	1.105	(Baize 1983)
”	”	”	0.274	297.02	–.006	–1.92	.011	0.979	(Hartkopf & McA. 1996)
10952	02211+4246	1998.687	0.311	241.11	–.004	6.69	.036	0.988	(Ruymaekers 1999)
”	”	”	0.321	244.83	–.014	2.97	.022	0.956	(Couteau 1991)
”	”	”	0.299	245.29	.008	2.51	.015	1.027	(Heintz 1996a)
11318	02257+6133	1998.687	0.396	65.84	–.004	–2.74	.019	0.991	(Ruymaekers 1999)
”	”	”	0.400	61.21	–.008	1.89	.015	0.980	(Zaera de Toledo 1985)
54061	11037+6145	1998.430	0.365	188.55	.062	19.05	.145	1.171	(Symms 1969)
”	”	”	0.329	199.25	.098	8.35	.112	1.298	(Aristidi et al. 1999)
58112	11551+4629	1998.430	0.111	291.95	.009	–.012	.015	1.077	(Ruymaekers 1999)
”	”	”	0.114	315.12	.006	–29.12	.059	1.050	(Baize 1989)
”	”	”	0.120	283.77	.000	2.23	.005	1.000	(Aristidi et al. 1999)
96840	19411+1349	1998.689	0.194	312.85	.007	–2.35	.011	1.036	(Docobo & Ling 2000)
101769	20375+1436	1998.430	0.471	335.10	–.028	–1.20	.030	0.940	(Ruymaekers 1999)
”	”	”	0.422	332.92	.021	0.98	.022	1.049	(Hartkopf et al. 1989)
”	”	”	0.462	334.83	–.019	–0.93	.020	0.959	(Couteau 1962)
107162	21424+4105	1993.602	0.170	336.86	–.004	–1.36	.006	0.977	(Ruymaekers 1999)
”	”	”	0.167	334.79	–.001	.002	.710	0.994	(Baize 1984)
”	”	”	0.173	338.05	–.007	–2.55	.010	0.960	(Hartkopf et al. 1989)
107162	21424+4105	1998.690	0.112	266.05	–.011	–10.25	.022	0.899	(Ruymaekers 1999)
”	”	”	0.110	265.93	–.009	–10.13	.021	0.918	(Baize 1984)
”	”	”	0.105	269.37	–.004	–13.57	.025	0.961	(Hartkopf et al. 1989)
111805	22388+4419	1998.690	0.152	147.81	.011	–1.11	.011	1.072	(Ruymaekers 1999)
”	”	”	0.137	148.03	.027	–1.33	.027	1.194	(Hartkopf & McA. 1996)
”	”	”	0.149	140.24	.014	6.46	.022	1.093	(Cester 1962)
116164	23322+0705	1998.690	0.225	328.98	–.024	0.02	.024	0.892	(Ruymaekers 1999)
”	”	”	0.240	334.08	–.039	–5.08	.044	0.836	(Cester 1963)
”	”	”	0.235	328.75	–.034	0.25	.034	0.854	(Muller 1955)

The mass ratio can be derived from the difference in bolometric magnitude, $\Delta M_{\rm bol}$ using:

$$q = 10^{-\Delta M_{\rm Bol}/(2.5\,K)},$$

where the coefficient K is the slope of the used mass-luminosity relation. From the photoelectric UBV data of the combined system $V_{\rm AB}$=3.63, $(B-V)_{\rm AB}$=+0.44 (Mermilliod et al. 1996) and our measurements of ΔB and ΔV one can derive the colours of both components: $(B-V)_{\rm A}$=+0.48 and $(B-V)_{\rm B}$=+0.37. The corresponding temperatures and bolometric corrections are $T_{\rm eff,A}$ = 6400 K, $BC_{\rm A} = -0.004$ and $T_{\rm eff,B}$ = 6900 K, $\rm BC_B$ = +0.026 (Flower 1996), which leads to: ΔBC = +0.03. Since $\Delta M_{\rm bol} = \Delta V + \Delta$BC we obtain $\Delta M_{\rm bol} = 0.86 \pm 0.15$. With $K = 3.82 \pm 0.07$ (Lampens et al. 1997) we derive a mass ratio $q = 0.81 \pm 0.03$. Note that this determination of the bolometric magnitude difference is in agreement with the value $\Delta H_{\rm p} = 0.91 \pm 0.05$ (ESA 1997), which is a good estimation for $\Delta M_{\rm Bol}$ due to the broadness of the $H_{\rm p}$ passband since the difference in bolometric correction between the two components is small (they have very similar spectral types of F5III and F5IV). However, we

Table 8. Photometric measurements for HIP 101769 (β Del) with PISCO.

Date	Filter	Δm mag	Error mag	Source
11/09/1994	R'	0.88	0.06	Aristidi et al., 1997b
25/07/1997	B	0.8	0.2	Aristidi et al., 1999
"	V	1.0	0.2	Aristidi et al., 1999
"	R	1.0	0.1	Aristidi et al., 1999
"	RL	1.0	0.1	Aristidi et al., 1999
"	I	1.1	0.1	Aristidi et al., 1999
07/06/1998	B	0.63	0.18	This work
"	V	0.65	0.14	This work
"	R	0.74	0.19	This work

caution these spectral classifications as they are simply based on a global spectral type designation and a not very precise visual estimate of the magnitude difference (Christy & Walker 1969). With this approach, a precision of ~3–5 subclasses on the secondary spectral class is obtained for a magnitude difference smaller than 1.3 mag.

In the Hipparcos photometric system the slope of the mass-luminosity relation is $K = 4.45 \pm 0.08$ (Ruymaekers 1999) and leads to $q = 0.83 \pm 0.01$, which is consistent with the first determination. Adopting the mean value $q = 0.82 \pm 0.02$ and using for the sum of the masses the value of $3.66{\pm}0.31\ \mathcal{M}_{\odot}$ derived by Ruymaekers (1999), we obtain the following estimation for the component masses: $\mathcal{M}_{\rm A} = 2.01 \pm 0.17$ and $\mathcal{M}_{\rm B} = 1.65 \pm 0.17\ \mathcal{M}_{\odot}$.

5. Conclusion

The PISCO speckle camera of the Observatoire Midi-Pyrénées equipped with the ICCD camera from the Université de Nice has proven to be a high angular resolution instrument that allows to efficiently observe close visual binaries. The associated digitizing hardware and specifically designed software have been tested and validated for the first time for this programme and have also shown their reliability. Despite the bad weather, we have been able to resolve 27 objects with components as close as $0.1''$ in less than two nights of observations.

These observations have allowed us to confirm the binarity for two cases previously discovered by Hipparcos: HIP 16083 and HIP 27309. In the case of HIP 16083 we confirm the fast orbital motion of the companion. We have also obtained the relative positions of the companions for 7 Hipparcos eclipsing binaries. Out of the 10 nearby stars closer than 100 pc, we resolved 8 objects and thus obtained useful data for a future accurate mass determination.

With regard to the study of systematic departure effects between the speckle and the non-speckle orbits, no results can be given yet, on the basis of one additional speckle observation. The case of HIP 10952, because it is also a single-lined spectroscopic binary system, is an exception. More speckle data are needed in order to obtain a highly accurate speckle orbit for most of the observed binaries, which in general have orbital periods smaller than 50 yrs.

Besides the astrometric measurements of eclipsing binaries, another contribution of PISCO could be the photometric measurements during eclipses. In the case of objects having light curves with total eclipses, such observations taken at different phases would provide the magnitudes and colour indices of the three components.

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References

Aristidi, E., Carbillet, M., Lyon, J.-F., & Aime, C. 1997a, A&AS, 125, 139
Aristidi, E., Carbillet, M., Prieur, J.-L., et al. 1997b, A&AS, 126, 555
Aristidi, E., Prieur, J.-L., Scardia, M., et al. 1999, A&AS, 134, 545-552
Baize, P. 1983, IAU Circ. (Commission 26), No. 90
Baize, P. 1984, IAU Circ. (Commission 26), No. 94
Baize, P. 1989, IAU Circ. (Commission 26), No. 107
Baize, P. 1990, IAU Circ. (Commission 26), No. 112
Carbillet, M., Lopez, B., Aristidi, E., et al. 1996, A&A, 314, 112
Carbillet, M., Aime, C., Aristidi, E., & Ricort, G. 1998, A&AS, 127, 1
Cester, B. 1962, Mem. Soc. Astron. Ital., 33, 177
Cester, B. 1963, Mem. Soc. Astron. Ital., 34, 1
Christy, J. W., & Walker, R. L. 1969, PASP, 81, 643
Couteau, P. 1962, J. Observateurs, 45, 39
Couteau, P. 1979, A&AS, 314, 112
Couteau, P. 1991, IAU Circ. (Commission 26), No. 113
Cuypers, J. 1997, Proceedings of the International Workshop, Visual Double Stars: Formation, Dymanics and Evolutionary Tracks, Santiago de Compostela, ed. J. A. Docobo, A. Elipe, & H. McAlister, ASSL, 223, 35
Cuypers, J., & Seggewiss, W. 1999, A&AS, 139, 425
Docobo, J. A., & Ling, J. F. 2000, IAU Circ. (Commission 26), No. 140
Duquennoy, A., & Mayor, M. 1991, A&A, 248, 485
Ellips 2000, Rio PCI frame grabber described in `http://www.ellips.nl/rio.html`
ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP–1200
Flower, Ph. 1996, ApJ, 469, 355
Hartkopf, W. I., McAlister, H. A., & Franz, O. G. 1989, AJ, 98, 1014
Hartkopf, W. I., & McAlister, H. A. 1996, AJ, 111, 370
Hartkopf, W. I., McAlister, H. A., & Mason, B. D. 1998, Third Catalogue of Interferometric Measurements of Binary Stars, `http://www.chara.gsu.edu/DoubleStars/Catalogues/Speckle/intro.html`

Heintz, W. D. 1996a, AJ, 111, 412
Heintz, W. D. 1996b, ApJS, 105, 475
Kurpinska-Winiarska, M., & Oblak, E. 2000a, in Birth and Evolution of Binary Stars, Poster Proceedings of IAU Symposium 2000, ed. B. Reipurth, & H. Zinnecker, Potsdam, 141, `http://casa.colorado.edu/reipurth/iau200www/posterbook/index.html`
Kurpinska-Winiarska, M., Oblak, E., Winiarski, M., & Kundera, T. 2000b, IBVS, 4823
Koresko, C. D., van Belle, G. T., Boden, A. F., et al. 1998, ApJ, 509, L45
Lampens, P., Kovalevsky, J., Froeschlé, M., & Ruymaekers, G. 1997, On the mass-luminosity relation, Joint Discussion 14 of the XXIIIrd General Assembly of the IAU, Kyoto, August 1997 (poster)
Lampens, P., & Strigachev, A. 2000, A&A, accepted
Lastennet, E., Valls-Gabaud, D., Lejeune, T., & Oblak., E. 1999, A&A, 349, 485
Mason, B. D., Martin, C., Hartkopf, W. I., et al. 1999, AJ, 117, 1890
McAlister, H. A., Hartkopf, W. I., Hutter, D. J., Shara, M. M., & Frantz, O. G. 1987, AJ, 83, 183
Mermilliod, J. C., Hauck, B., & Mermilliod, M. 1996, The General Catalogue of Photometric Data, [`http://obswww.unige.ch/gcpd/gcpd.html`]
Muller, P. 1955, J. Observateurs, 38, 25
Oblak, E., Lampens, P., Cuypers, J., et al. 1999, A&A, 346, 523
Oblak, E., Kurpinska-Winiarska, M., Kundera, T., & Zola, S. 2000, A&A, submitted
Pourbaix, D. 2000, A&AS, 145, 215
Prieur, J.-L., Lannes, A., & Cullum, M. 1991, Proc. of the ESO conference on High Resolution Imaging by interferometry II, ed. J. M. Beckers, & F. Merckle, Garching (14–18 October 1991), 353
Prieur, J.-L., Festou, M. C, Koechlin, L., & André, C. 1994, Coll. National de Planétologie de l'INSU, Toulouse, 13–16 Juin 1994, p S16
Prieur, J.-L, Koechlin, L., André, C., Gallou, G., & Lucuix, C. 1998, Experimental Astronomy, vol. 8, Issue 4, 297
Ribas, I., Gimenez, A., Torra, J., Jordi, C., & Oblak, E. 1998, A&A, 330, 600
Ruymaekers, G. 1999, Ph.D., Katholieke Universiteit Leuven, Leuven
Scardia, M., Prieur, J.-L., Aristidi, E., & Koechlin, L. 2000, ApJ, Suppl., in press
Söderhjelm, S. 1999, A&A, 341, 121
Symms, L. S. T. 1969, Royal Observatory Bulletin Greenwich, No. 157
Worden, S. P., Murray, K. S., Schmidt, G. D., & Angel, J. R. P. 1977, Icarus, 32, 450
Zaera de Toledo, J. A. 1985, IAU Circ. (Commission 26), No. 96