Speckle observations with PISCO in Merate - III. Astrometric measurements of visual binaries in 2005 and scale calibration with a grating mask

M. Scardia, J.-L. Prieur, L. Pansecchi, R. W. Argyle, S. Basso, M. Sala, M. Ghigo, L. Koechlin, E. Aristidi

Mon. Not. R. Astron. Soc. **000**, 000–000 (0000) Printed 12th October, 2006 (MN LaTeX style file v2.2)

Speckle observations with PISCO in Merate. III. Astrometric measurements of visual binaries in 2005 and scale calibration with a grating mask.

M. Scardia,[1] J.-L. Prieur,[2] L. Pansecchi,[1] R.W. Argyle,[3]
S. Basso,[1] M. Sala,[1] M. Ghigo,[1] L. Koechlin[2] and E. Aristidi[4].

[1] *I.N.A.F. – Osservatorio Astronomico di Brera, Via E. Bianchi 46, 23807 Merate, Italy*

[2] *UMR 5572 d'Astrophysique, Observatoire Midi-Pyrénées – Université Paul Sabatier – CNRS,*

14 Avenue Edouard Belin, 31400 Toulouse, France

[3] *Institute of Astronomy, Madingley Road, Cambridge, CB3 0HA, U.K.*

[4] *UMR 6525 d'Astrophysique, Université de Nice Sophia - Antipolis – CNRS, Parc Valrose, 06108 Nice Cedex 2, France*

Received 12th October, 2006; accepted

ABSTRACT

We present relative astrometric measurements of visual binaries made during the first semester of 2005, with the speckle camera PISCO at the 102 cm Zeiss telescope of Brera Astronomical Observatory, in Merate. We performed 214 new observations of 192 objects, with angular separations in the range $0''.2$ — $4''.3$, and with an average accuracy of $0''.01$. Most of the position angles could be determined without the usual 180 degree ambiguity, and their mean error is $0^\circ.5$. Our sample contains orbital couples as well as binaries whose motion is still uncertain. The purpose of this long term program is to improve the accuracy of the orbits and constrain the masses of the components.

For the first time with PISCO, the astrometric calibration was made with a grating mask mounted at the entrance of the telescope. The advantage of this procedure is to provide a reliable and fully independent scale determination. We have found two possible new triple systems: ADS 7871 and KUI 15. We propose a preliminary orbit for ADS 4208.

Key words: Stars: binaries: close – binaries: visual — astrometry — techniques: interferometric

1 INTRODUCTION

This paper is the third of a series (Scardia et al. 2005a, 2005b, herein: Papers I and II), whose purpose is to contribute to the determination of binary orbits, using speckle observations made in Merate (Italy) with the Pupil Interferometry Speckle camera and COronagraph (PISCO) on the 102 cm Zeiss telescope of *I.N.A.F. – Osservatorio Astronomico di Brera* (OAB, Brera Astronomical Observatory). More information about the context and the purpose of this program can be found in Paper I. The present paper concerns the results of the observations performed during the first semester of 2005.

In Sect. 2, we describe our sample, the instrumental setup and the reduction procedure. We then present in Sect. 3 the new calibration procedure that we used for this work. The astrometric measurements derived from our observations are presented and discussed in Sect. 4. Finally, in Sect. 5 we provide the first orbital parameters of ADS 4208, partly derived from those observations, and give some estimates of the component masses.

2 OBSERVATIONS AND DATA REDUCTION

As stated in Paper I, the purpose of our long term program is to observe all the visual binaries accessible with PISCO on the Zeiss telescope in Merate, for which new measurements are needed to improve their orbits. This program already started in the years 1990's when PISCO was used with the 2-meter telescope of Pic du Midi observatory, but since the installation of PISCO in Merate in November 2003, the reduction of the telescope size by a factor of two has induced some changes on the possible targets. The sample studied in Merate consists of visual binaries with the following characteristics:

- declination north of -5 degrees,
- brighter than 9.5 magnitude in V,
- a magnitude difference less than 4,
- an angular separation smaller than $4''.3$.

The observations presented here were carried out with the PISCO speckle camera developed at Observatoire Midi-Pyrénées with the ICCD detector (CCD intensified with a micro-channel plate) belonging to Nice University. Details about the telescope and the instrumentation can be found in Paper I and in Prieur et al. (1998).

For each observation, a series of about 10 000 short exposure frames were digitized and processed in real-time with a PC, to compute the mean auto-correlation (with Worden (1977)'s method, which subtracts most part of the continuum), the mean power spectrum and the integration of the individual frames. Those frames were also recorded on a SVHS video tape for archiving and further processing.

As the auto-correlation function is symmetric relative to the origin, it does not contain information about the location of the faintest companion. This is why speckle position angle measurements of binaries have a well-known 180-degree ambiguity. This ambiguity can be solved by using the mean triple-correlation function of the elementary frames (Weigelt, 1977). Let $f^{(3)}(\vec{x}_1, \vec{x}_2)$ be the triple correlation of the detected irradiance function $f(\vec{x})$ on the detector (where $\vec{x}$ is the two-dimensional vector measuring the position of the pixels on the CCD detector), defined as:

$$f^{(3)}(\vec{x}_1, \vec{x}_2) = \int f(\vec{x})\, f(\vec{x} + \vec{x}_1)\, f(\vec{x} + \vec{x}_2)\, d\vec{x} \qquad (1)$$

Aristidi et al. (1997) have shown that the restricted triple correlation function to $\vec{x}_1 = 0$, i.e. $f^{(3)}(\vec{0}, \vec{x}_2)$, contains information about the actual position of the faintest companion, which solves the 180-degree ambiguity. We used this method to determine the "quadrant" in which the companion lay and computed those triple-correlation files for each observation. To optimize the utilization of the observation time, the computation of those files was done *a posteriori* on the recorded SVHS tapes, since their calculation would have lengthened by about 30% the processing time during the observations and reduced the effective observation time by the same proportion.

The positions of the secondary peaks on the mean auto-correlations were then carefully measured with an interactive program that fitted and subtracted the residual background. For each file, we performed a series of at least 8 measurements, that we obtained by varying the parameters used to compute the background and the methods used to determine the center. The final measurement corresponds to the mean of this series and the standard deviation provides an estimate of the internal error. The total error can then be estimated by adding quadratically this value to the corresponding calibration error. An evaluation of the reliability of this procedure will be described in Sect. 4.1.

3 ASTROMETRIC CALIBRATION

3.1 Scale calibration

Two eyepieces, of focal lengths 10 and 20 mm, can be used to control the last magnification stage of PISCO. In this section we describe the new procedure that we followed to calibrate the resulting scales on the detector.

In 2005 we designed and built a calibrating grating mask to allow an independent scale determination (Fig. 1a). Placed at the entrance of the telescope, this mask generates a diffraction fringe pattern (see Fig. 1b) whose period is λ/a (in radians), where λ is the wavelength of the incoming light (or the "effective wavelength" when using non-monochromatic light) and a is the grating step (i.e. the distance between two successive slits). The knowledge of this period allows to calibrate the magnification of the whole optical system (telescope+instrument+detector). The grating was designed to provide a periodic pattern with a period close to $1''$ in V, which was suitable for fields of view obtained with both the 10 and 20 mm eyepieces. Nevertheless, as the seeing is generally worse than $1''$, the elementary images do not permit direct measurement of the secondary peaks of this diffraction pattern. The same speckle techniques we use for binary star measurements had also to be used for the calibration procedure. In Fig. 1c, we show the mean auto-correlation function of elementary frames obtained with the R filter and the 20 mm eyepiece, when pointing the telescope to Deneb on November 20th 2005.

For the scale calibration, we used the four filters whose characteristics are given in Table 1. For each filter, the central wavelength λ_c corresponding to the barycenter of the transmission curve is indicated in Col. 3, the width at half maximum Δ_λ in Col. 4, and the relative transmission T in Col. 5. The transmission curves were measured with a spectrophotometer in the laboratory. To compute the "effective wavelength" $\lambda_c^{\rm eff}$ to be used for the calibration, we multiplied each transmission curve with both the ICCD sensitivity-response and the energy spectral distribution of the astronomical target used for the calibration (i.e. Deneb). The corresponding characteristics of the combination (filter+ICCD+Deneb) are indicated in Table 1 for each filter with the central wavelength $\lambda_c^{\rm eff}$ in Col. 6, and the width at half maximum in Col. 7.

The mean value of the grating step was also accurately measured and we found: $a_1 = 87.99 \pm 0.01$ mm at a temperature of $T_1 = 20°$C. This value was corrected for thermal effects since the observations were performed at $T_2 = 6°$C. Since the relative expansion coefficient

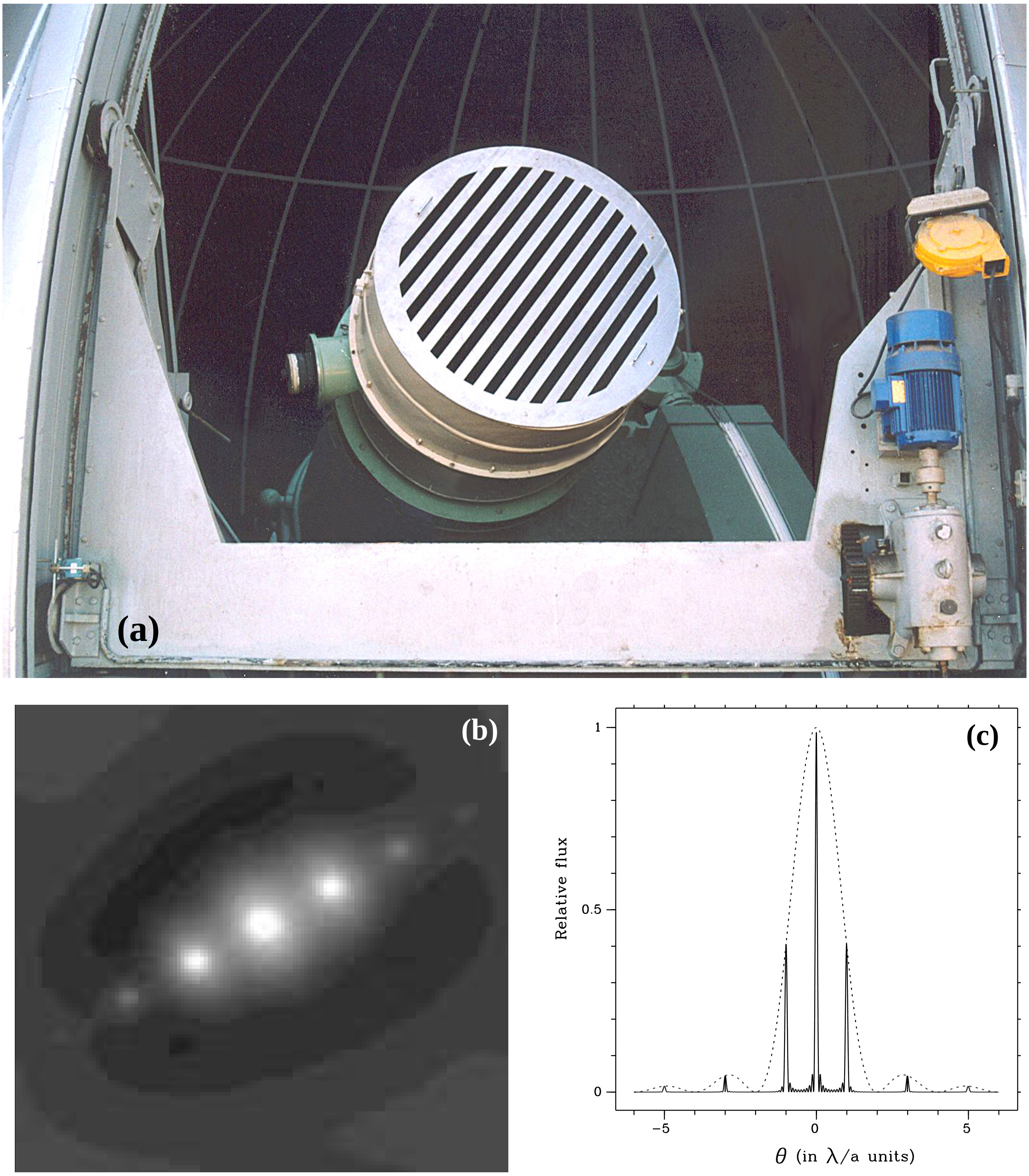

Figure 1. Calibration grating mask on the Zeiss telescope in Merate (a). Corresponding mean auto-correlation of the elementary frames obtained with Deneb in November 2005 (b), and theoretical auto-correlation response of the grating mask (c), in solid line.

of the duraluminium alloy 2017A constituting this mask is $\chi = 2.2 \times 10^{-5} (^{\circ}\mathrm{C})^{-1}$, the value of the grating step to be used for the observations is $a_2 = a_1 \; [1 - \chi(T_1 - T_2)] = 87.964$ mm.

By measuring the mean separation of the auto-correlation peaks, we obtained the scale values displayed in Fig 2, each data point corresponding to a different filter. The weighted mean scale values derived from all those measurements are $0.0320 \pm 0.0001''$/pixel and

Table 1. Characteristics of the filters used for the scale calibration (Cols 1 to 5) and effective values when taking into account the ICCD sensitivity and the spectral energy distribution of Deneb (Cols 6 and 7).

Name	identification	λ_c (nm)	Δ_λ (nm)	T (%)	$\lambda_c^{\rm eff}$ (nm)	$\Delta_\lambda^{\rm eff}$ (nm)
B	ORIEL/57541	447	47	74	452	44
OIII	ORIEL/54341	501	11	63	501	11
V	ORIEL/57581	530	57	67	530	56
R	ORIEL/57621	644	70	61	641	70

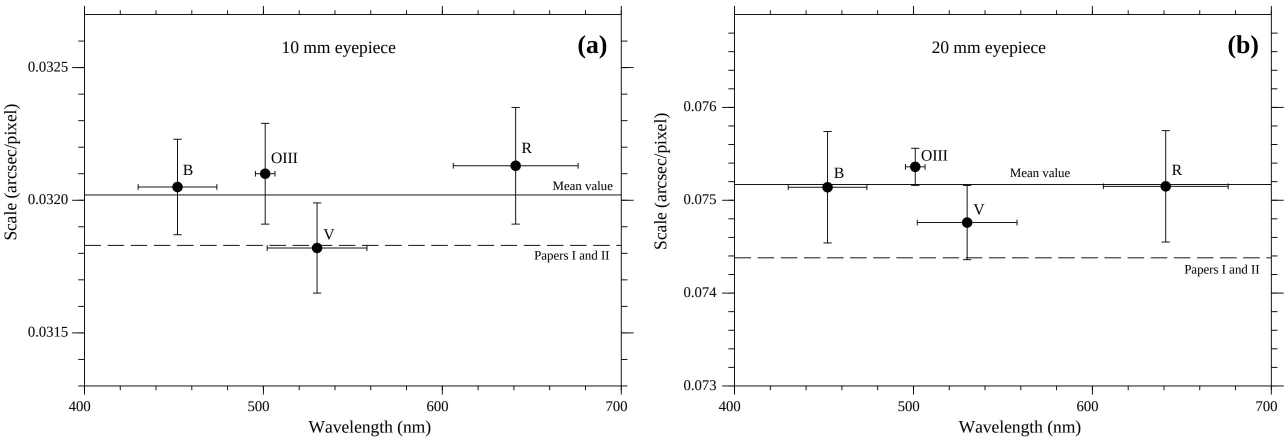

Figure 2. Scale values obtained with the filters of Table 1 for two magnifications available with PISCO (eyepieces of 10 mm and 20 mm). The corresponding weighted means are plotted as solid lines and the values used for Papers I and II are indicated with dashed lines.

$0.0752 \pm 0.0002''$/pixel, for the 10 and 20 mm eyepieces, respectively. They are displayed as solid horizontal lines in Fig. 2.

We have shown in Paper I that the focal length of the Zeiss Cassegrain telescope could be considered as constant throughout the year. Indeed, the variations of the focal length caused by the temperature changes between summer and winter periods were found negligible (i.e., smaller than 0.02%). As PISCO has not been dismounted since its first installation in 2003, the scale values determined in November 2005 can be considered as valid for the observations of the first semester of 2005 and for those published in Papers I and II. In those papers, we used the scale values of $0.0318 \pm 0.0001''$/pixel and $0.0744 \pm 0.0002''$/pixel for the 10 and 20 mm eyepieces, respectively, that we obtained by fitting our measurements with published ephemerides. Those values are displayed as dotted lines in Fig. 2. It appears that there is a good agreement, with a relative error of 0.6% and 1.1% for the 10 and 20 mm eyepieces, respectively, which is comparable to the smallest estimated errors of our measurements. This shows *a posteriori* the validity of the method we had used.

3.2 Orientation calibration

We calibrated the orientation of the ICCD detector mounted on PISCO using the daily rotation of the Earth. Taking advantage of nights with good seeing, we stopped the RA motors and let the target star drift from East to West, while recording long exposures with the lowest magnification (50 mm eyepiece, with a field of view of 180″ on a great circle). In February and August 2006, we obtained a series of 46 images with stars at various declinations from 0° to 44° and various hour angles (from 0 to 2 hours). Using a specially designed program to fit a straight line to the star tracks on the ICCD images, we obtained an accurate value for θ_0, the origin of θ, the position angle in the celestial reference frame (North corresponding to $\theta = 0°$, and East to $\theta = 90°$):

$$\theta = \theta_{\rm detector} + \theta_0 \quad \text{with} \quad \theta_0 = 89°.8 \pm 0°.1 \tag{2}$$

No special trend of θ_0 was noticed with the position of the telescope. The Zeiss telescope equatorial mount seems rigid enough and well aligned to the North pole, at least to the accuracy given above and in the range of positions that we use for most of our observations (close to the meridian and with declinations above $-5°$).

For Papers I and II, we used a calibration based on published ephemerides that led to $\theta_0 = 90°.0 \pm 0°.1$. Hence, according to our new calibration, all the θ measurements published in those two papers should be corrected by a translation of $-0°.2$. This is smaller than the value of the smallest errors ($\sigma_\theta = 0°.3$) given for those measurements. Similarly, we have seen that the ρ values published in those papers and obtained with the 10 and 20 mm eyepieces should be multiplied by 1.006 and 1.011 respectively.

4 ASTROMETRIC MEASUREMENTS

The astrometric measurements are displayed in Table 2. The designation of the binary is given in the first 3 columns: the WDS name (Washington Double Star Catalogue, Mason et al. 2006) in Col. 1, the official double star designation in Col. 2 (sequence is discoverer-number), and the ADS number in Col. 3 (Aitken, 1932). For each observing sequence, we give the epoch of observation (Col. 4) in Besselian years, the filter (Col. 5) (whose characteristics are listed in Table 1), the focal length of the eyepiece used for magnifying the image (Col. 6), the angular separation ρ (Col. 7) and its error (Col. 8) in arcseconds, and the position angle θ (Col. 9) and its error (Col. 10) in degrees.

ADS 8820 was observed without any filter because it was too faint. This is shown with a dash in the filter column (Col. 5). The corresponding central wavelength is about 650 nm, close to that of the R filter.

The errors were estimated by adding quadratically the calibration errors to the standard deviations of series of measurements obtained with the same data sets (see Sect. 2). The smallest (one-sigma) errors for the angular separation (Col. 8) were estimated at $0''.003$ for close pairs (i.e., $\rho < 1''$) which corresponds to 0.1 pixel in the elementary frames and at 0.05% of ρ for wide pairs (i.e., $\rho > 1''$), on the basis of the uncertainties coming from the determination of the centers of the auto-correlation peaks and those affecting the scale calibration. Similarly, the minimum (one-sigma) errors for the position angle (Col. 10) were estimated at $0^\circ.3$. The average values of the errors displayed in this table are $0''.011 \pm 0''.006$ and $0^\circ.5 \pm 0^\circ.3$ for ρ and θ, respectively. The validity of our error determination will be discussed in Sect. 4.1.

The position angles presented in Col. 9 follow the standard convention with the North corresponding to $\theta = 0^\circ$ and the East to $\theta = 90^\circ$. Those angles were measured on the auto-correlation functions, which leads to an ambiguity of 180°. When the triple correlation files allowed us to determine in which quadrant the companion lay (see Sect. 2 and 4.2), an asterisk was added in Col. 9, which indicates that our determination is absolute. Otherwise, we used the quadrant value of the "Fourth Catalogue of Interferometric Measurements of Binary Stars" (Hartkopf et al. 2006, hereafter IC4). There is only one exception for the new component of STT 224 (see Sect 4.5), for which the quadrant could not be determined by any of those means.

In Col. 11, a flag is set to one for all the systems for which an orbit is known. The residuals derived from the corresponding ephemerides will be discussed in Sect. 4.3.

In the notes column, "NF" means that no fringes were visible in the power spectrum and no companion could be detected on the auto-correlation. We also give some information about the secondary peaks in the auto-correlation (e.g., "Faint", "Elongated", "Diffuse", ...).

4.1 Evaluation of the error determination

We have been using the reduction method described in Sect. 2 for more than ten years, at Pic du Midi Observatory during the period 1993–1998 and then in Merate. We have found its error determination reliable, for example with observations of the same object with different

Table 2. Measurements (beginning)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ (arcsec)	σ_ρ (arcsec)	θ (deg.)	σ_θ (deg.)	Orb.	Notes
00029+4715	A 800	10	2005.029	R	20	1.623	0.008	292.8*	0.3	0	
00134+2659	STT 2 AB	161	2005.032	R	10	0.400	0.003	164.8*	0.6	1	
00174+0853	STF 22 AB-C	238	2005.029	R	20	4.013	0.020	234.5*	0.3	0	
00209+1059	BU 1093	287	2005.029	R	20	0.761	0.011	115.1*	0.9	0	
00210+6740	HJ 1018	283	2005.029	R	20	1.692	0.016	86.9*	0.4	1	
00214+6700	STT 6 AB	293	2005.029	R	20	0.648	0.009	153.8*	0.8	1	
00310+3406	STF 33	421	2005.029	R	20	2.805	0.014	212.6	0.3	0	
00318+5431	STT 12	434	2005.034	R	10	0.324	0.003	200.8	0.4	1	
00352-0336	HO 212 AB	490	2005.032	R	10	0.281	0.004	268.8*	0.3	1	Diffuse
00366+5609	A 914	504	2005.034	R	20	0.484	0.010	25.2*	0.7	0	
00373+5801	BU 1097	515	2005.034	R	10	0.506	0.004	72.8	0.3	0	
00504+5038	BU 232 AB	684	2005.034	R	20	0.895	0.013	248.4*	0.7	1	
01006+4719	MAD 1	829	2005.029	R	20	0.795	0.014	2.7*	1.0	0	
01089+4512	AC 13 AB	936	2005.034	R	20	0.615	0.013	263.7	0.4	0	
01106+5101	BU 235Aa	963	2005.032	R	20	0.873	0.011	134.5*	0.7	1	
01127+6501	STF 96	983	2005.032	R	20	0.919	0.012	286.3	0.7	0	
01356+7227	A 816	1226	2005.032	R	20	0.867	0.008	127.6*	0.4	0	
01360+0739	STF 138 AB	1254	2005.103	R	20	1.727	0.010	57.8*	0.3	0	
01443+5732	BU 870AB	1359	2005.032	R	10	0.644	0.003	339.9*	0.4	1	
01501+2217	STF 174	1457	2005.103	R	20	2.877	0.014	164.2*	0.3	0	Elongated
01520+1049	STF 178	1487	2005.103	R	20	3.051	0.015	204.1	0.3	0	
01532+3719	STF 179	1500	2005.111	R	20	3.489	0.017	160.3*	0.3	0	
01564+6116	STF 182 AB	1531	2005.111	R	20	3.562	0.022	123.7	0.3	0	
02020+0246	STF 202 AB	1615	2005.029	R	20	1.839	0.014	269.8*	0.3	1	
02020+7054	BU 513 AB	1598	2005.032	R	10	0.751	0.004	278.4*	0.3	1	
02022+7530	STF 185 AB	1588	2005.111	R	20	1.092	0.008	9.9*	0.8	0	
02124+3018	STF 227	1697	2005.103	R	20	3.958	0.020	68.9*	0.3	0	
02231+7021	MLR 377	–	2005.111	R	20	0.656	0.009	142.0	0.7	1	
02294+5532	STF 268	1878	2005.111	R	20	2.819	0.020	130.2*	0.3	0	
02331+5828	STF 272	1933	2005.111	R	20	1.938	0.011	36.7*	0.4	0	
02388+3325	STF 285	2004	2005.108	R	20	1.709	0.009	163.1*	0.5	0	
02411+1848	STF 291 AB	2042	2005.108	R	20	3.394	0.017	117.0*	0.3	0	
02446+2928	STF 300	2091	2005.108	R	20	3.146	0.016	314.1*	0.3	0	
02471+3533	BU 9 AB	2117	2005.108	R	20	1.048	0.011	207.1*	0.8	0	
02475+1922	STF 305 AB	2122	2005.133	R	20	3.635	0.018	307.4*	0.3	1	
02493+1728	STF 311 AB	2151	2005.133	R	20	3.279	0.016	118.1*	0.3	0	
02527+0628	STF 323	2193	2005.136	R	20	2.760	0.015	277.6*	0.3	0	
02529+5300	STF 314 AB-C	2185	2005.111	R	20	1.559	0.022	313.1*	0.5	0	
02537+3820	BU 524 AB	2200	2005.103	R	10	0.215	0.010	337.6*	1.3	1	Elongated with a halo
02592+2120	STF 333 AB	2257	2005.103	R	20	1.426	0.010	209.2*	0.3	0	
02594+0639	STF 334	2261	2005.136	R	20	1.138	0.017	308.4*	0.8	0	
03054+2515	STF 346 AB	2336	2005.103	R	10	0.381	0.004	252.2	0.3	1	
03122+3713	STF 360	2390	2005.111	R	20	2.805	0.014	125.3*	0.3	1	
03127+7133	STT 50 AB	2377	2005.032	R	20	1.041	0.009	153.2	0.4	1	
03171+4029	STF 369	2443	2005.133	R	20	3.624	0.018	29.4*	0.3	0	
03177+3838	STT 53	2446	2005.108	R	20	0.716	0.008	244.4*	0.3	1	
03212+2109	COU 259	–	2005.136	R	20	0.876	0.014	219.7*	0.9	0	
03293+4503	STF 391	2559	2005.111	R	20	3.921	0.020	95.2*	0.3	0	Perturbed spectrum
03344+2428	STF 412 AB	2616	2005.029	R	10	0.711	0.004	355.4	0.3	1	
”	”	”	2005.103	R	10	0.713	0.004	355.4	0.3	1	
”	”	”	2005.108	R	10	0.713	0.004	355.4	0.3	1	
03356+3141	BU 533	2628	2005.103	R	20	1.072	0.008	221.5*	0.3	0	
03401+3407	STF 425	2668	2005.133	R	20	1.988	0.011	63.4*	0.3	0	
03443+3217	BU 535	2726	2005.136	R	20	1.055	0.011	23.7*	1.1	0	
03520+0632	KUI 15 Aa?	–	2005.136	R	10	0.195	0.013	129.8*	1.0	0	New system
03520+0632	KUI 15	–	2005.136	R	10	0.765	0.007	207.1*	0.4	0	
04064+4325	A 1710	2980	2005.133	R	20	0.622	0.008	135.5*	0.7	1	
04077+1510	STF 495	2999	2005.169	R	20	3.688	0.018	222.4*	0.3	0	
04139+0916	BU 547 AB	3072	2005.136	R	20	1.266	0.024	341.5*	0.5	0	

Table 2. Measurements (cont.)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ (arcsec)	σ_ρ (arcsec)	θ (deg.)	σ_θ (deg.)	Orb.	Notes
04159+3142	STT 77 AB	3082	2005.133	R	20	0.589	0.008	288.8	0.7	1	
04227+1503	STT 82 AB	3169	2005.035	R	20	1.284	0.008	338.6*	0.3	1	
04233+1123	STF 535	3174	2005.035	R	20	1.142	0.008	276.9*	0.3	1	
04239+0928	HU 304	3182	2005.103	R	10	0.232	0.008	12.6	0.9	1	
04255+1756	KUI 17 AB	3206	2005.169	R	20	1.757	0.010	340.9*	0.6	0	
04301+1538	STF 554	3264	2005.035	R	20	1.594	0.011	17.7*	0.3	1	
04335+1801	STF 559	3297	2005.169	R	20	3.065	0.015	276.4*	0.3	0	
04422+3731	STF 577	3390	2005.169	R	20	0.770	0.011	350.8	0.9	1	
05055+1948	STT 95	3672	2005.169	R	20	0.923	0.011	298.2*	0.3	1	
05079+0830	STT 98	3711	2005.103	R	20	0.808	0.014	308.8*	0.6	1	
05103+3718	STF 644 AB	3734	2005.169	R	20	1.635	0.008	221.4*	0.3	0	
05135+0158	STT 517 AB	3799	2005.108	R	20	0.658	0.010	58.7*	0.7	1	
05172+3320	STF 666	3853	2005.169	R	20	3.090	0.015	74.2	0.3	0	
05247+6323	STF 677	3956	2005.108	R	20	1.041	0.011	125.2*	0.3	1	
05308+0557	STF 728	4115	2005.108	R	20	1.204	0.008	45.4*	0.3	1	
05364+2200	STF 742	4200	2005.215	R	20	4.035	0.022	272.9*	0.3	1	
05371+2655	STF 749 AB	4208	2005.215	R	20	1.144	0.008	141.6*	0.6	1	
05373+6642	MLR 314	–	2005.109	R	10	0.220	0.015	247.1	1.4	1	Very diffuse
05386+3030	BU 1240 AB	4229	2005.103	R	10	0.213	0.003	334.7*	0.9	1	
05399+3757	STT 112	4243	2005.218	R	20	0.882	0.008	48.1	0.7	0	
05407-0157	STF 774 Aa-B	4263	2005.215	R	20	2.394	0.012	165.8*	0.5	1	
05413+1632	BU 1007	4265	2005.133	R	10	0.249	0.003	245.7*	0.4	1	Very diffuse
05417-0254	BU 1052	4279	2005.218	R	20	0.588	0.008	188.5*	0.6	1	
05474+2939	BU 560	4371	2005.218	R	20	1.643	0.012	126.2*	0.3	0	
06024+0939	A 2715 AB	4617	2005.133	V	10	0.179	0.022	26.4*	2.6	1	Very diffuse
06041+2316	KUI 23 AB	–	2005.103	V	10	0.187	0.015	214.3*	0.5	1	Diffuse
06085+1358	STF 848 AB	4728	2005.218	R	20	2.558	0.013	109.9*	0.3	0	
06145+1754	KUI 24	–	2005.218	R	10	0.388	0.003	141.6*	1.1	0	
06149+2230	BU 1008	4841	2005.111	R	20	1.703	0.012	257.2*	0.3	1	
06228+1734	STF 899	4991	2005.218	R	20	2.196	0.014	18.2*	0.4	0	
06344+1445	STF 932	5197	2005.215	R	20	1.681	0.008	307.4*	0.5	1	
06396+2816	STT 152	5289	2005.259	R	20	0.862	0.019	35.0*	0.6	0	
06404+4058	STF 945	5296	2005.259	R	10	0.466	0.003	327.5*	0.4	0	Haloes around peaks
06462+5927	STF 948 AB	5400	2005.111	R	20	1.869	0.010	70.7*	0.3	1	
06474+1812	STT 156	5447	2005.136	R	10	0.262	0.003	195.0	0.4	1	
06531+5927	STF 963 AB	5514	2005.259	V	10	0.225	0.006	325.0*	1.2	1	
”	”	”	2005.259	R	10	0.232	0.008	324.8*	2.0	1	
06573+5825	STT 159 AB	5586	2005.136	R	10	0.581	0.003	227.1*	0.3	1	
07057+5245	STF1009 AB	5746	2005.215	R	20	4.243	0.021	148.2*	0.3	0	
07128+2713	STF1037 AB	5871	2005.136	R	20	1.070	0.011	310.6*	0.5	1	
07351+3058	STT 175 AB	6185	2005.136	V	10	–	–	–	–	1	NF
08507+1800	A 2473	7039	2005.259	R	10	0.259	0.004	75.0	0.4	1	
08531+5457	A 1584	7054	2005.256	R	20	0.621	0.015	78.5*	0.8	1	
09104+6708	STF1306AB	7203	2005.256	R	20	4.049	0.020	351.3*	0.3	1	
09179+2834	STF3121AB	7284	2005.256	R	20	0.774	0.009	205.1*	0.4	1	
09245+0621	STF1348AB	7352	2005.319	R	20	1.973	0.010	314.7*	0.3	0	
09245+1808	A 2477	7341	2005.333	R	10	0.426	0.006	355.8*	1.0	1	Elongated and faint
09249+5134	STT 200	7348	2005.330	R	20	1.273	0.008	334.3*	0.5	0	
09327+0152	FIN 349	–	2005.333	R	10	–	–	–	–	0	Elongated central peak
09414+3857	STF1374AB	7477	2005.330	R	20	2.845	0.014	307.6*	0.3	0	
09498+2111	KUI 44	–	2005.259	R	10	–	–	–	–	1	NF
10250+2437	STF1429	7758	2005.259	R	20	0.740	0.010	163.1	0.4	1	
10269+1713	STT 217	7775	2005.319	R	20	0.735	0.010	147.8*	0.7	1	
10397+0851	STT 224	7871	2005.327	R	20	0.505	0.011	147.1	1.0	1	
10397+0851	STT 224 AC?	7871	2005.327	R	20	2.091	0.014	36.6	0.3	0	New system
10406+4209	STF1460	7878	2005.330	R	20	3.722	0.019	161.9	0.3	0	
10426+0335	A 2768	7896	2005.327	R	20	0.565	0.020	255.6	1.0	1	Diffuse
10480+4107	STT 229	7929	2005.319	R	20	0.710	0.008	265.3	0.4	1	
11000-0328	STF1500	8007	2005.327	R	20	1.406	0.028	300.2	0.4	0	

Table 2. Measurements (cont.)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ (arcsec)	σ_ρ (arcsec)	θ (deg.)	σ_θ (deg.)	Orb.	Notes
11037+6145	BU 1077AB	8035	2005.259	V	10	0.388	0.005	72.0*	0.5	1	
”	”	”	2005.382	V	10	0.389	0.006	70.4*	0.7	1	
”	”	”	2005.385	V	10	0.388	0.004	70.6*	0.7	1	
11050+3825	HO 378AB	8047	2005.330	R	20	1.061	0.015	236.4	0.5	0	
11137+2008	STF1517	8094	2005.319	R	20	0.609	0.008	139.0*	0.8	1	
11154+2734	STF1521	8105	2005.319	R	20	3.686	0.022	97.1*	0.3	0	
11347+1648	STF1552AB	8220	2005.259	R	20	3.483	0.017	207.7*	0.3	0	
11363+2747	STF1555AB	8231	2005.357	R	20	0.719	0.008	147.7*	0.6	1	
11388+6421	STF1559	8249	2005.330	R	20	1.953	0.010	322.8*	0.5	0	
11447-0431	RST4484	–	2005.396	R	20	0.776	0.011	62.8*	0.3	0	
11486+1417	BU 603	8311	2005.327	R	20	1.011	0.008	337.7*	0.3	1	
11537+7345	BU 794 AB	8337	2005.380	R	10	0.473	0.003	43.1*	0.5	1	
11551+4629	STF1579 AB-C	8347	2005.333	R	20	3.889	0.019	41.4*	0.3	0	
11563+3527	STT 241	8355	2005.319	R	20	1.788	0.009	143.3*	0.3	0	
12035-0227	STF1593 AB	8403	2005.396	R	20	1.276	0.008	13.9	0.6	0	
12108+3953	STF1606	8446	2005.328	R	10	0.390	0.010	166.1	0.8	1	
12417-0127	STF1670AB	8630	2005.259	V	10	0.392	0.003	161.9	0.3	1	
”	”	”	2005.319	V	10	0.386	0.003	157.6*	0.5	1	
”	”	”	2005.328	V	10	0.380	0.003	157.4*	0.6	1	
”	”	”	2005.330	V	10	0.380	0.003	157.1*	0.5	1	
”	”	”	2005.333	R	10	0.378	0.003	157.0*	0.3	1	
”	”	”	2005.382	V	10	0.373	0.006	151.7*	1.6	1	Elongated
”	”	”	2005.385	V	10	0.382	0.003	152.7*	0.6	1	
”	”	”	2005.396	R	10	0.383	0.003	151.6*	0.3	1	
”	”	”	2005.398	R	10	0.382	0.003	151.4*	0.3	1	
”	”	”	2005.404	R	10	0.386	0.003	151.2	0.3	1	
”	”	”	2005.409	R	10	0.377	0.003	150.5*	0.3	1	
”	”	”	2005.440	R	10	0.378	0.003	147.4	0.7	1	
”	”	”	2005.442	R	10	0.383	0.003	148.1*	0.6	1	
”	”	”	2005.464	R	10	0.377	0.005	146.5*	0.4	1	
”	”	”	2005.470	R	10	0.372	0.003	146.2*	0.4	1	
”	”	”	2005.478	R	10	0.375	0.003	145.2*	0.5	1	
”	”	”	2005.486	R	10	0.371	0.003	144.7*	0.4	1	
12438+0733	STF1674	8646	2005.398	R	20	2.333	0.012	174.1	0.6	0	
12493+2733	CHR 179 Aa	–	2005.385	R	10	–	–	–	–	0	NF
12563+5406	STF1695AB	8710	2005.333	R	20	3.780	0.019	280.3*	0.3	0	
12564-0057	STT 256	8708	2005.319	R	20	1.064	0.008	98.5*	0.3	0	
12572+0818	FIN 380	–	2005.404	R	10	0.243	0.003	161.4	1.3	0	
12574+3022	STF1696	8716	2005.396	R	20	3.614	0.018	203.7	0.4	0	
13006-0322	AGC 5AB	8732	2005.409	R	20	0.701	0.020	180.1*	0.5	0	Very diffuse
13007+5622	BU 1082	8739	2005.330	R	20	1.231	0.013	89.8*	0.3	1	
13064+2109	CHR 150Aa	–	2005.409	R	10	–	–	–	–	0	NF
13064+2109	COU 11Aa-B	–	2005.385	R	20	1.674	0.013	315.8*	0.3	0	
13084+1529	STF1722	8796	2005.399	R	20	2.688	0.013	336.1*	0.4	0	
13101+3830	BU 608 BC	8805	2005.410	R	20	1.270	0.008	269.3*	0.3	0	
13128+4030	A 1606	8820	2005.396	–	20	1.300	0.014	196.9*	0.6	0	
13189+0030	A 2585AB	8855	2005.442	R	20	0.841	0.008	218.9	1.1	0	
13243+0124	STF1742	8890	2005.382	R	20	0.982	0.008	357.4	1.1	0	
13258+4430	A 1609AB	8901	2005.385	R	20	0.498	0.008	24.3	1.4	1	
13324+3649	STF1755	8934	2005.382	R	20	4.217	0.021	130.3*	0.3	0	
13329+3454	STT 269 AB	8939	2005.382	R	10	0.263	0.008	218.8	0.3	1	
13329+4908	STF1758	8940	2005.385	R	20	3.417	0.017	292.1*	0.3	0	
13340+0847	A 1792	8946	2005.410	R	20	0.674	0.013	308.7	0.5	0	
13368+0650	A 1611	8968	2005.399	R	20	0.852	0.015	121.4	0.8	0	Faint
13431+0332	STF1777	9000	2005.382	R	20	2.808	0.014	227.3*	0.3	0	
13571+3426	BU 937	9067	2005.399	R	20	1.011	0.008	132.3	0.3	0	
13577+5200	A 1614	9071	2005.385	R	20	1.373	0.017	123.7*	1.0	1	
14135+1234	BU 224	9165	2005.399	R	20	0.515	0.011	105.4	1.4	1	
14138+1200	STT 279	9168	2005.399	R	20	2.219	0.020	254.8*	0.3	0	

Table 2. Measurements (end)

WDS	Name	ADS	Epoch	Fil.	Eyep. (mm)	ρ (arcsec)	σ_ρ (arcsec)	θ (deg.)	σ_θ (deg.)	Orb.	Notes
14139+2906	STF1816	9174	2005.385	R	20	0.520	0.019	92.1*	1.0	0	
14220+5107	A 148	9238	2005.404	R	20	0.578	0.014	8.5	0.8	0	
14336+3535	STF1858AB	9312	2005.404	R	20	3.054	0.015	37.9*	0.3	0	
14339+5514	STF1860	9315	2005.404	R	20	1.052	0.009	110.5*	0.3	0	
14375+0217	CHR 42Aa	9323	2005.410	R	20	–	–	–	–	1	Ring around cent. peak
14455+4223	STT 285AB	9378	2005.404	R	10	0.473	0.003	96.2	0.5	1	
14471+0058	STF1881	9383	2005.442	R	20	3.438	0.017	0.3*	0.3	0	
14497+0759	A 1110 AB	9400	2005.404	R	20	0.673	0.011	243.9*	0.3	0	
14506-0001	STF1885	9407	2005.404	R	20	4.045	0.029	145.2*	0.3	0	
14568+7050	STF1905	9460	2005.470	R	20	2.853	0.014	340.9*	0.3	0	
14584+4403	STF1896AB	9461	2005.470	R	20	4.115	0.021	276.6*	0.3	0	
15018-0008	BU 348AB	9480	2005.464	R	10	0.489	0.003	107.9*	0.3	0	
15038+4739	STF1909	9494	2005.442	R	20	1.946	0.013	56.8*	0.3	1	
15056+1138	STF1907	9498	2005.464	R	20	0.910	0.008	351.1	0.3	0	
15075+0914	STF1910	9507	2005.442	R	20	4.018	0.020	211.0*	0.3	0	
15087-0059	STF3090AB	9514	2005.486	R	20	0.688	0.016	285.8	0.8	0	
15116+1007	A 1116	9530	2005.464	R	20	0.805	0.008	50.2*	0.4	0	
15121+1859	COU 189	–	2005.464	R	10	0.477	0.007	141.5*	0.3	0	
15160-0454	STF3091AB	9557	2005.478	R	20	0.565	0.008	49.0*	0.7	1	
15183+2650	STF1932Aa-B	9578	2005.442	R	20	1.618	0.012	261.6	0.3	1	
15210+0043	BU 32	9596	2005.464	R	20	3.329	0.017	21.8	0.3	0	
15210+2104	HU 146	9600	2005.470	R	20	0.673	0.013	121.2	1.0	0	Faint
15232+3017	STF1937AB	9617	2005.443	R	10	0.504	0.003	113.2*	0.3	1	
15245+3723	STF1938BC	9626	2005.385	R	20	2.265	0.011	7.1*	0.3	1	
15246+5413	HU 149	9628	2005.478	R	20	0.649	0.010	90.4*	0.4	0	
15261+1810	STF1940	9634	2005.478	R	20	0.456	0.008	328.8	0.8	0	
15264+4400	STT 296AB	9639	2005.486	R	20	2.102	0.011	275.8*	0.3	0	
15277+0606	STF1944	9647	2005.486	R	20	0.701	0.008	298.9	0.4	0	
15278+2906	JEF 1	–	2005.486	R	10	0.239	0.003	154.3*	0.8	1	
15300+2530	STF1950	9675	2005.486	R	20	3.291	0.017	90.9*	0.3	0	
15329+3122	COU 610	–	2005.465	R	10	0.809	0.004	199.3*	0.3	0	
15348+1032	STF1954AB	9701	2005.465	R	20	3.982	0.020	173.3*	0.3	1	
15360+3948	STT 298AB	9716	2005.464	R	20	0.879	0.008	172.2*	0.3	1	
15405+1840	A 2076	9742	2005.465	R	20	0.716	0.008	184.2	0.5	0	
23587-0333	BU 730	17137	2005.034	R	20	–	–	–	–	1	NF
23595+3343	STF 3050 AB	17149	2005.029	R	20	2.136	0.011	332.3*	0.3	1	
”	”	”	2005.034	R	20	2.123	0.011	332.4*	0.5	1	

filters during a short time interval. The validity of this estimation can also be tested with multiple observations in different conditions of binary systems with very long orbital periods over a longer time interval. In this section we present such an analysis with the observations of ADS 2616, 12880 and 17149 made in Merate in 2004–2005.

These three systems are well suited for such a study since they have a rather well determined orbit with a long period and far from periastron passage. We have checked that the relative motion of the two components was negligible during four series of observations and their characteristics are presented in Table 3. We give the name of the object in Line 1, the origin of the data in Line 2, the mean epoch of observation in Line 3 and the time interval Δt in Line 4, when the observations were done (in Besselian years). The latest

Table 3. Error determination on some series of observations

(1)	Target	ADS 2616	ADS 2616	ADS 12880	ADS 17149
(2)	Reference	Paper I	Papers II & III	Paper II	Papers II & III
(3)	Mean epoch	2004.08	2005.08	2004.71	2005.97
(4)	Δt (yr)	0.09	0.06	0.29	0.15
(5)	Period (yr)	522	522	780	320
(6)	n	6	4	5	5
(7)	Filters	R, V	R	R	R
(8)	Eyepiece	10 mm	10 mm	20 mm	20 mm
(9)	$< \theta >$ (deg)	355.67	355.35	221.58	332.22
(10)	$\sigma_{<\theta>}$ (deg)	0.23	0.10	0.38	0.13
(11)	$< \sigma_\theta >$ (deg)	0.48	0.30	0.36	0.34
(12)	$< \rho >$ (arcsec)	0.711	0.712	2.645	2.135
(13)	$\sigma_{<\rho>}$ (arcsec)	0.005	0.002	0.009	0.011
(14)	$< \sigma_\rho >$ (arcsec)	0.005	0.004	0.013	0.012

orbits of ADS 2616, 12880 and 17149 are those from Scardia et al. (2002), Scardia (1983) and Starikova (1977), respectively, whose periods are quoted in Line 5. For each series, the number n of observations is given in Line 6, the filter(s) in Line 7 and the eyepiece focal length in Line 8.

The means $< \theta >$ and $< \rho >$ computed for each series of measurements are given in Lines 9 and 12, with their standard deviations $\sigma_{<\theta>}$ and $\sigma_{<\rho>}$ in Lines 10 and 13. Those values should be compared with the average values given in Lines 11 and 14 of the errors σ_θ and σ_ρ that have been computed by our reduction procedure and published in Papers I and II or quoted in Table 2. One can see that our reduction procedure gives realistic (and generally pessimistic) error estimates and that the errors of our measurements are small. Indeed, despite its large separation, ADS 12880 is not a binary particularly easy to observe because of the large magnitude difference between the two components: $\Delta m_V = 3.7$ mag. Hence the small errors that we find for the series of observations of this difficult object are a good diagnostic about the whole chain of observation and data reduction procedure that we use.

Note that this procedure allows us to estimate the errors within a series of measurements but cannot be used to diagnose the existence of systematic errors that could affect all those values by the same offset. The value of this offset can be estimated with the analysis of the large sample of $O - C$ (Observed minus Computed) residuals. With a list of about one hundred objects, we have found a very small value for this offset ($< \Delta\rho_{O-C} >= 0''.00 \pm 0''.04$, and $< \Delta\theta_{O-C} >= 0^\circ.1 \pm 1^\circ.4$, see Sect. 4.3), much smaller than the errors than we have found in Table 3, which gives some evidence that significant systematic errors are not present.

4.2 Quadrant determination

As mentioned in Sect. 2, we have used the restricted triple-correlation technique of Aristidi et al. (1997) to solve the 180° ambiguity in the θ measurements made from the auto-correlation files and determine the quadrant in which the companion lay. For each observation, we examined the location on the triple-correlation file of the faintest secondary spot, which corresponded to that of the companion. When the signal-to-noise ratio was good enough, we were able to determine the location of this spot and thus solve the 180° ambiguity. This occurred in 152 out of 214 observations, i.e. 71% of the total (marked with an asterisk in Col 9 of Table 2). We then checked whether those "absolute" θ values were consistent with the ones tabulated in IC4. We found a good agreement for all objects, except for the following 11 cases, where a difference of about 180° was observed for θ: ADS 1226, 2628, 2980, 3799, 4208, 5514, 8094, 8820, 9460, 9557 and 9628.

ADS 1226 – There was an inversion of magnitudes in the IC4 Catalogue, the primary appearing fainter than the secondary. We have mentioned this anomaly to Dr. Brian Mason who agreed to correct it (private communication). Hence in the new version of this catalogue, the discrepancy with our measurement has disappeared. The last measurement with θ = 311°.0 (for the year 2003) is now reported as θ = 131°.0 which is in agreement with our value for 2005.032, θ = 127°.4.

ADS 2628 – Same case as above. Here, the previously reported measurement of θ = 42°.0 (for the year 1998) in IC4 has become θ = 222°.0, in agreement with our value for 2005.103 (i.e. θ = 221°.3).

ADS 5514 – In the IC4 catalogue, there is a discrepancy only with the last reported value, θ = 138°.0, that came from our Paper I. The other previous values of IC4 and the ephemerides derived from the last orbit (Docobo & Costa, 1984) are in agreement with our quadrant determination. In fact the quadrant could not be determined in 2004, as indicated in the notes of table 2 of Paper I, and the position angle of ADS 5514 reported in this paper has a 180-degree ambiguity. We have asked Dr Mason to correct our measurement of 2004.211 to θ = 318°.0 in the IC4 catalogue.

ADS 4208 – Our observation was obtained with the R filter, whereas most of the previous measurements reported in IC4 were made in V. The integrated spectral class of the system is B9 IV-V and the difference of magnitude is only 0.01 in V ($m_{V,A} = 6.54$ and $m_{V,B} = 6.55$).

There is probably an inversion of brightness between the components in V and R, which would account for a different quadrant determination in those two spectral bands.

ADS 2980, 3799, 8094, 8820, 9460, 9557 and 9628 – We have not found here a justification for the 180-degree discrepancy with the last reported values. It should be noted that in some cases, part of the published data are in agreement with our quadrant value, even sometimes over a long period of time.

4.3 Comparison with published ephemerides

Table 4 contains the $(O-C)$ residuals of the 102 measurements for the systems with a known orbit. The orbital elements used for computing the ephemerides were retrieved from the "Sixth Catalogue of Orbits of Visual Binary Stars" (Hartkopf & Mason, 2006, hereafter OC6) and the bibliographic references of Col. 2 can also be found in this catalogue. For ADS 684, the residuals were computed with our new orbit (Scardia et al. 2006a). For ADS 4208 we used our new orbit described in Sect. 5. For ADS 8630, we also used a new orbit that we computed with the measurements of Table 2 and some others that we obtained in 2006 (Scardia et al. 2006b). The residuals relative to the separation ρ and position angle θ are given in Cols. 5 and 6, respectively. In the cases when the companion was not detected (see Sect. 4.4), we displayed instead in brackets the ephemerides for ρ and θ in Cols. 5 and 6, respectively. The values in Col. 4 are the relevant observed separations, extracted from Col. 7 of Table 2. They are repeated here for the convenience of the reader, to be able to identify the cases when ρ is small.

As shown in Fig. 3, the residuals are well centered around the origin, with a rather large scatter that can be explained by the (old) age of many orbits. The average values computed with the 101 residuals of Table 4 (after rejecting 5 outliers) are $< \Delta\rho_{O-C} >= 0''.00 \pm 0''.04$ and $< \Delta\theta_{O-C} >= 0^\circ.1 \pm 1^\circ.4$. The mean relative ρ residual is $< \Delta\rho_{O-C}/\rho >= 0.01 \pm 0.05$. The very small values obtained for those offsets provide another validation of our calibration with the grating mask and the star trails (see Sect. 3), which appears in good agreement with the measurements made by the other observers.

Let us examine now the cases of the binaries with the largest residuals, that are located outside of the circle plotted in Fig. 3 whose radius corresponds to $\Delta\rho_{O-C}/\rho = 15\%$ and $\Delta\theta_{O-C} = 4^\circ$, i.e. about 3 times the standard deviations obtained with the residuals of

Table 4. Residuals with published orbits (begin)

ADS/Name	Orbit	Epoch	$\rho(O)$ (arcsec)	$\Delta\rho(O-C)$ (arcsec)	$\Delta\theta(O-C)$ (deg)
161	Scardia (2000)	2005.032	0.400	−0.02	−1.2
”	Olevic (2001)	”	”	+0.04	+4.4
283	Soderhjelm (1999)	2005.029	1.692	−0.06	−0.7
293	Olevic (2001)	2005.029	0.648	+0.04	+0.2
434	Ling (2005)	2005.034	0.324	+0.04	−0.4
490	Mason (2005)	2005.032	0.281	−0.01	+0.2
684	Scardia et al (2006a)	2005.034	0.895	+0.05	−1.6
963	Seymour (2002)	2005.032	0.873	−0.04	+1.3
1359	Popovic (1995)	2005.032	0.644	+0.08	+5.4
1615	Scardia (1983)	2005.029	1.839	+0.05	+1.7
1598	Mason (1999)	2005.032	0.751	−0.02	−0.8
MLR 377	Pavlovic (2005)	2005.111	0.656	+0.09	−3.8
2122	Rabe (1961)	2005.133	3.635	−0.07	+0.7
2200	Docobo (2001)	2005.103	0.215	+0.01	+0.6
2336	Heintz (1981)	2005.103	0.381	−0.04	−3.1
2390	Mason (2004)	2005.111	2.805	+0.02	−1.0
2377	Scardia (2001)	2005.032	1.041	+0.07	+0.1
2446	Alzner (1998)	2005.108	0.716	+0.03	−1.5
2616	Scardia (2002)	2005.029	0.711	+0.00	+0.3
”	”	2005.103	0.713	+0.00	+0.4
”	”	2005.108	0.713	+0.00	+0.4
2980	Heintz (1982)	2005.133	0.622	+0.01	+0.6
3082	Starikova (1985)	2005.133	0.589	−0.00	−1.3
3169	Mason (2004)	2005.035	1.284	+0.01	−1.9
3174	Hartkopf (2000)	2005.035	1.142	+0.04	+1.0
3182	Hartkopf (2000)	2005.103	0.232	+0.00	+1.0
3264	Baize (1980)	2005.035	1.594	−0.09	+1.3
3390	Mason (2004)	2005.169	0.770	+0.05	+2.6
3672	Jasinta (1996)	2005.169	0.923	−0.03	−0.4
3711	Baize (1969)	2005.103	0.808	−0.04	−1.3
3799	Mason (1999)	2005.108	0.658	+0.03	−1.4
3956	Heintz (1996)	2005.108	1.041	−0.10	−1.7
4115	Seymour (1999)	2005.108	1.204	−0.02	+0.0
4200	Hopmann (1973)	2005.215	4.035	−0.08	−1.4
4208	This paper	2005.215	1.144	−0.01	−0.6
MLR 314	Mante (2001)	2005.109	0.220	+0.06	−3.1
4229	Romero (2006)	2005.103	0.213	+0.01	−0.6
4263	Hopmann (1967)	2005.215	2.394	+0.15	+1.1
4265	Docobo (1999)	2005.133	0.249	−0.02	+1.0
4279	Baize (1991)	2005.218	0.588	−0.04	−1.1
4617	Fekel (2002)	2005.133	0.179	+0.01	−1.1
KUI 23 AB	Heintz (1986)	2005.103	0.187	+0.03	−2.6
4841	Baize (1980)	2005.111	1.703	+0.11	+2.4
5197	Hopmann (1960)	2005.215	1.681	+0.02	+3.7
5400	Popovic (1996)	2005.111	1.869	+0.18	+3.0
5447	Scardia (2005)	2005.136	0.262	−0.00	+1.9
5514	Docobo (1984)	2005.259	0.225	+0.02	+0.1
”	”	2005.259	0.232	+0.03	−0.1
5586	Alzner (2000)	2005.136	0.581	−0.00	−0.1
5871	Soderhjelm (1999)	2005.136	1.070	−0.02	−1.0
6185	Hartkopf (1989)	2005.136	–	(0.07)	(132.1)
7039	Hartkopf (2000)	2005.259	0.259	+0.01	−1.0
7054	Heintz (1991)	2005.256	0.621	+0.01	−2.1
7203	Scardia (1985)	2005.256	4.049	+0.06	−0.3
7284	Soderhjelm (1999)	2005.256	0.774	−0.01	+2.1
7341	Mason (1998)	2005.333	0.426	−0.03	+1.7
KUI 44	Docobo (2005)	2005.259	–	(0.04)	(251.4)
7758	Zulevic (1981)	2005.259	0.740	+0.04	−0.3
7775	Heintz (1975)	2005.319	0.735	+0.03	+0.3
7871	Heintz (1984)	2005.327	0.505	−0.07	−5.4
7896	Hartkopf (1989)	2005.327	0.565	+0.03	−1.2
7929	Alzner (1998)	2005.319	0.710	+0.03	+0.1

Table 4. Residuals with published orbits (end)

ADS/Name	Orbit	Epoch	$\rho(O)$ (arcsec)	$\Delta\rho(O-C)$ (arcsec)	$\Delta\theta(O-C)$ (deg)
8035	Scardia (2005)	2005.259	0.388	−0.02	−2.1
"	"	2005.382	0.389	−0.03	−1.8
"	"	2005.385	0.388	−0.03	−1.6
8094	Hopmann (1970)	2005.319	0.609	+0.38	+7.6
8231	Docobo (2004)	2005.357	0.719	+0.03	−0.8
8311	Heintz (1991)	2005.327	1.011	−0.16	−0.6
8337	Söderhjelm (1999)	2005.380	0.473	+0.01	+1.9
8446	Mason (1999)	2005.328	0.390	−0.02	+2.6
8630	Scardia et al (2006b)	2005.259	0.392	−0.00	+0.1
"	"	2005.319	0.386	0.00	+0.3
"	"	2005.328	0.380	−0.00	+0.8
"	"	2005.330	0.380	−0.00	+0.6
"	"	2005.333	0.378	−0.01	+0.8
"	"	2005.382	0.373	−0.01	−0.7
"	"	2005.385	0.382	+0.00	+0.6
"	"	2005.396	0.383	+0.01	+0.4
"	"	2005.398	0.382	+0.01	+0.3
"	"	2005.404	0.386	+0.01	+0.6
"	"	2005.409	0.377	+0.00	+0.3
"	"	2005.440	0.378	+0.00	−0.3
"	"	2005.442	0.383	+0.01	+0.6
"	"	2005.464	0.377	+0.01	+0.8
"	"	2005.470	0.372	0.00	+1.0
"	"	2005.478	0.375	+0.00	+0.8
"	"	2005.486	0.371	+0.00	+0.8
8739	Scardia (2005)	2005.330	1.231	−0.10	+0.7
8901	Heintz (1991)	2005.385	0.498	+0.02	+2.8
8939	Heintz (1997)	2005.382	0.263	−0.02	−1.0
9071	Heintz (2001)	2005.385	1.373	−0.05	−0.8
9165	Ling (1985)	2005.399	0.515	−0.01	−0.3
9323	Hartkopf (2000)	2005.410	–	(0.22)	(341.0)
9378	Couteau (1973)	2005.404	0.473	−0.00	−0.2
9494	Söderhjelm (1999)	2005.442	1.946	+0.00	+0.3
9557	Mason (1999)	2005.478	0.565	−0.02	+2.5
9578	Heintz (1965)	2005.442	1.618	−0.00	−0.1
9617	Mason (1999)	2005.443	0.504	+0.01	−4.2
9626	Söderhjelm (1999)	2005.385	2.265	+0.01	+0.3
JEF1	Tokovinin (1984)	2005.486	0.239	−0.07	+3.3
9701	Mason (2004)	2005.465	3.982	−0.01	+0.1
9716	Söderhjelm (1999)	2005.464	0.879	−0.01	+0.9
17137	Seymour (2002)	2005.034	–	(0.91)	(319.0)
17149	Starikova (1977)	2005.029	2.136	+0.09	+0.3
"	"	2005.034	2.123	+0.07	+0.5

Table 4. This concerns the following list: ADS 161, 1359, 2336, 5400, 7871, 8094, 8311, 9617, JEF 1, KUI 23 AB, MLR 314 and MLR 377.

ADS 161 – The most recent and short period orbit proposed by Olevic in 2001 leads to larger residuals than the orbit with a longer period, that we published in 2000.

ADS 1359 – The preliminary orbit of Popovic & Pavlovic (1995) was based on a small arc of orbit ($\approx 70°$), with the last observation made in 1987. It does not account for the most recent observations, the motion of the companion being slightly slower than expected.

ADS 2336 – the orbit of Heintz (1981) is rather old but the residuals are still reasonable. The revision of the orbit requires more data to bring a significant improvement on the

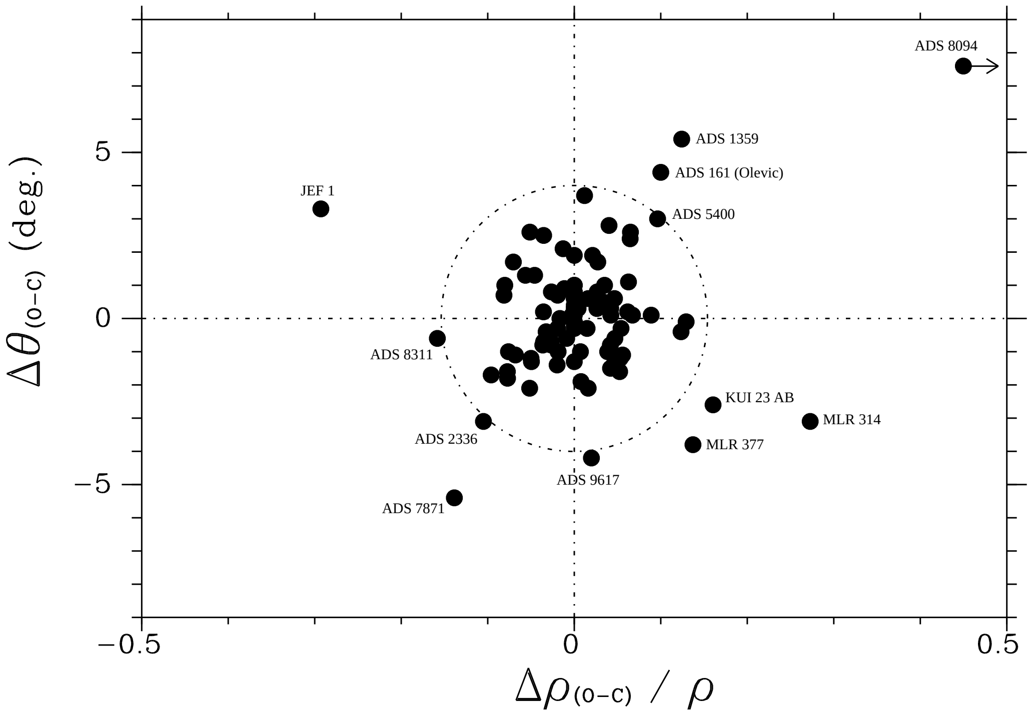

Figure 3. Residuals from published orbits. The dashed circle has a radius of about 3 times the residual sigma. For ADS 8094, the large residual $\Delta\rho_{O-C}/\rho = 0.60$ leads to a point out of the frame.

ephemerides since the observations close to periastron in 1938, when the angular separation was smaller than $0''.1$, are lacking.

ADS 5400 – Popovic & Pavlovic (1996)'s preliminary orbit, with the last observation made in 1990, begins to show a discrepancy with the most recent measurements of angular separation. Since its discovery, the observations now cover an arc of orbit of about 80° with a small curvature and a large scatter. It is wiser to wait for more observations before computing a new orbit.

ADS 7871 – The preliminary orbit of Heintz (1984) is becoming outdated. The scattered measurements obtained in the 19th century cover about 3/4 of the orbit. The companion is about to reach apastron, but the residuals are still acceptable. It is better to wait until the companion has passed apastron before computing a new orbit.

ADS 8094 – the latest orbit from Hopmann (1970) is clearly to be rejected, and the companion trajectory seems to be a straight line. This object must be an optical pair.

ADS 8311 – This binary is difficult to observe because the two components have a large magnitude difference ($\Delta m_V \approx 2.7$ in IC4). Consequently, the measurements have a large scatter and the preliminary orbit of Heintz (1991), with only two measurements before periastron, is rather uncertain. In this case also, more observations are required before computing a more significant orbit. The few measures obtained with the speckle technique result in a slightly different orbit with a smaller major axis. This "observation effect" is probably caused by the large Δm_V. In this case, the companion appears superimposed on the steep profile produced by the brightest star, and the visual observers often overestimate the angular separation, as already noted by Scardia (1990): *"as far as the separation is concerned, one sometimes gets the impression that the speckle measurements are systematically shorter than the visual ones, which on the whole, nevertheless, appear to have a higher dispersion."* In the presence of a faint companion, the speckle techniques are more robust since they allow a better subtraction of the bright background of the main component.

ADS 9617 – The recent short period orbit computed by Mason (1999) seems reliable since it is based on many observations of both visual and speckle origin. The companion should reach the periastron in 2016. The present part of the orbit was only observed visually in the past, which may be the origin of the current discrepancy. More observations in the next few years are needed to check whether this tendency is confirmed.

JEF 1 – The short period orbit of Tokovinin (1984), with $P = 10.3$ yr, was nearly entirely based on speckle observations. The companion is currently close to apastron. Given its small angular separation ($\rho = 0''.24$) the residuals that we obtain for this object ($-0''.07$, $+3^\circ.3$) are still acceptable.

KUI 23 AB – Heintz (1986)'s orbit was computed from nearly entirely speckle observations and is still good when we take into account its small angular separation ($\rho = 0''.19$). Note that some other observers have obtained measurements with large separations, comparable to ours. More observations are needed to confirm this tendency but unfortunately the angular separation is expected to be smaller than $0''.1$ after 2007, which puts this object beyond the range of PISCO in Merate.

MLR 314 – Mante (2001)'s orbit was computed with old observations, with the most recent made in 1993. The part of the orbit that is now being explored by the companion lacks observations and it is likely that the orbit will have to be revised when enough data is available.

MLR 377 – The very recent orbit of Pavlovic and Todorovic (2005) relies on a very small arc of orbit (only 20° !), which makes it very uncertain.

Among this list, we have not found any object where revision of the orbit was yet justified. The number of observations made since the last orbit computation is still insufficient to enable the determination of a significantly different and more meaningful new orbit.

Table 5. Last known measurements of our unresolved objects.

Name	Epoch	ρ (arcsec)	θ (deg.)
FIN 349	2004	0.1	101
KUI 44	1997	0.1	195
CHR 179 Aa	2004	0.3	13
CHR 150Aa	1990	0.2	279
ADS 6185	2002	0.1	148
ADS 9323	1997	0.1	138
ADS 17137	1997	0.9	311

4.4 Unresolved objects

In Table 2, there are 7 unresolved objects: FIN 349, KUI 44, CHR 179Aa, CHR 150Aa, ADS 6185, 9323 and 17137. Among this list four objects have a known orbit: KUI 44, ADS 6185, 9323 and 17137, with ephemerides for ρ equal to $0''.04$, $0''.07$, $0''.22$ and $0''.91$ respectively (see Table 4). The last measurements of those systems are given in Table 5. Since the diffraction limit of the Zeiss telescope in R is $\lambda/D \approx 0''.13$, the absence of resolution of binaries for which $\rho \lesssim 0''.2$ is not unreasonable. For ADS 17137, the difficulty comes from the large brightness difference between the two components, with $\Delta m_V \approx 4$.

For the remaining object, CHR 179 Aa, the absence of detection may come from the low luminosity of the companion. In IC4, there is only an indication of $m_V = 5.8$ for the whole system. To be able to resolve $0''.3$, we have used the large magnification (10 mm eyepiece) which corresponds to a limiting magnitude of $m_V \approx 7$–8. Hence if $\Delta m_V \gtrsim 1.2$, the companion of CHR 179 Aa is difficult to detect with our instrumentation.

Note finally that the central peak of the auto-correlation of FIN 349 is elongated, which may indicate that this binary is marginally resolved.

4.5 Detection of new components

We have found two objects, ADS 7871 and KUI 15, for which the power spectra and the auto-correlations suggest the presence of a third component with separations of $2''.1$ and $0''.2$ respectively (see Table 2). To our knowledge those objects are not known as triple in the literature.

We also noticed a perturbed system of fringes in the center of the power spectrum of ADS 2559 in February 2005, which was also seen in other observations in January 2006. Unfortunately this was only seen in the "direct" files, i.e. the files obtained by real-time processing. When re-processing the recorded images on SVHS video tapes, those perturbations

Table 6. New orbital elements of ADS 4208

Name	Ω (2000)	ω (deg.)	i (deg.)	e	T (yr)	P (yr)	n (deg./yr)	a (arcsec)	A (arcsec)	B (arcsec)	F (arcsec)	G (arcsec)
ADS 4208	164.0	70.9	153.3	0.411	1756.846	986.6	0.36489	1.015	−0.08308	0.91521	1.00375	0.02085

Table 7. New ephemeris of ADS 4208.

Epoch	ρ (arcsec)	θ (deg.)
2006.0	1.155	322.0
2007.0	1.157	321.8
2008.0	1.159	321.6
2009.0	1.160	321.3
2010.0	1.162	321.1
2011.0	1.164	320.9
2012.0	1.165	320.7
2013.0	1.167	320.4
2014.0	1.168	320.2
2015.0	1.170	320.0

were strongly attenuated and nearly invisible. We restored images from those tapes with bispectral methods (Prieur et al. 1991) and obtained images with a resolution around $0''.2$, but we did not see anything around the circular dots of the two stars.

5 NEW ORBIT OF STF 749 – ADS 4208

In this section we present a first orbit for ADS 4208. We did not revise any published orbit since the analysis presented in Sect. 4.3 for the objects with large residuals has shown that the number of new observations was still unsufficient to justify the revision of their orbits.

Orbit computation requires a long-term observational effort that needs to be shared among the whole community of double-star astronomers. Using our measurement with PISCO and all the available observations, from the data base maintained by the United States Naval Observatory, we have been able to compute a first orbit for WDS 05371+2655 – STF 749 – ADS 4208. The companion has moved along an arc of about 70° (see Fig. 4), which is still small but is sufficient to calculate a preliminary orbit.

Using the analytical method of Kowalsky (1873), we obtained the preliminary elements presented in Table 6 and the ephemerides of Table 7. The observations are numerous but the separation measurements made in the early 1900's have a large scatter.

In Table 6, Ω is the position angle of the ascending node, measured in the plane of the

Table 8. ADS 4208: residuals with new orbit (for measurements made after 1985).

Epoch	ρ (arcsec)	θ (deg.)	$\Delta\rho_{O-C}$ (arcsec)	$\Delta\theta_{O-C}$ (deg.)	n	Observer
1985.835	1.119	326.3	0.00	−0.4	1	MCA
1986.892	1.122	325.6	0.00	−0.9	1	MCA
1989.970	1.22	325.7	0.09	−0.0	1	ZUL
1991.158	1.12	324.8	−0.01	−0.6	1	WSI
1991.161	1.12	326.2	−0.01	0.8	1	WSI
1991.25	1.130	325.2	0.00	−0.2	1	HIP
1991.36	1.140	325.3	0.01	−0.1	1	TYC
1991.905	1.137	325.3	0.01	0.0	1	HRT
1992.089	1.11	326.2	−0.02	1.0	1	WSI
1992.111	1.12	325.1	−0.01	−0.1	1	WSI
1992.166	1.13	325.3	−0.00	0.1	1	WSI
1993.053	1.15	324.4	0.02	−0.6	1	WSI
1993.20	1.17	324.8	0.04	−0.2	4	ARY
1994.100	0.93	323.3	−0.20	−1.5	1	ALZ
1995.07	1.00	323.7	−0.14	−0.8	2	ALZ
1995.770	1.11	324.5	−0.03	0.1	1	WSI
1996.174	1.16	324.7	0.02	0.4	1	WSI
1997.126	1.135	324.2	−0.01	0.1	1	HRT
1999.108	1.11	323.8	−0.03	0.2	1	WSI
2002.174	1.11	322.7	−0.04	−0.2	1	WSI
2005.215	1.144	321.6	−0.01	−0.6	1	SCA

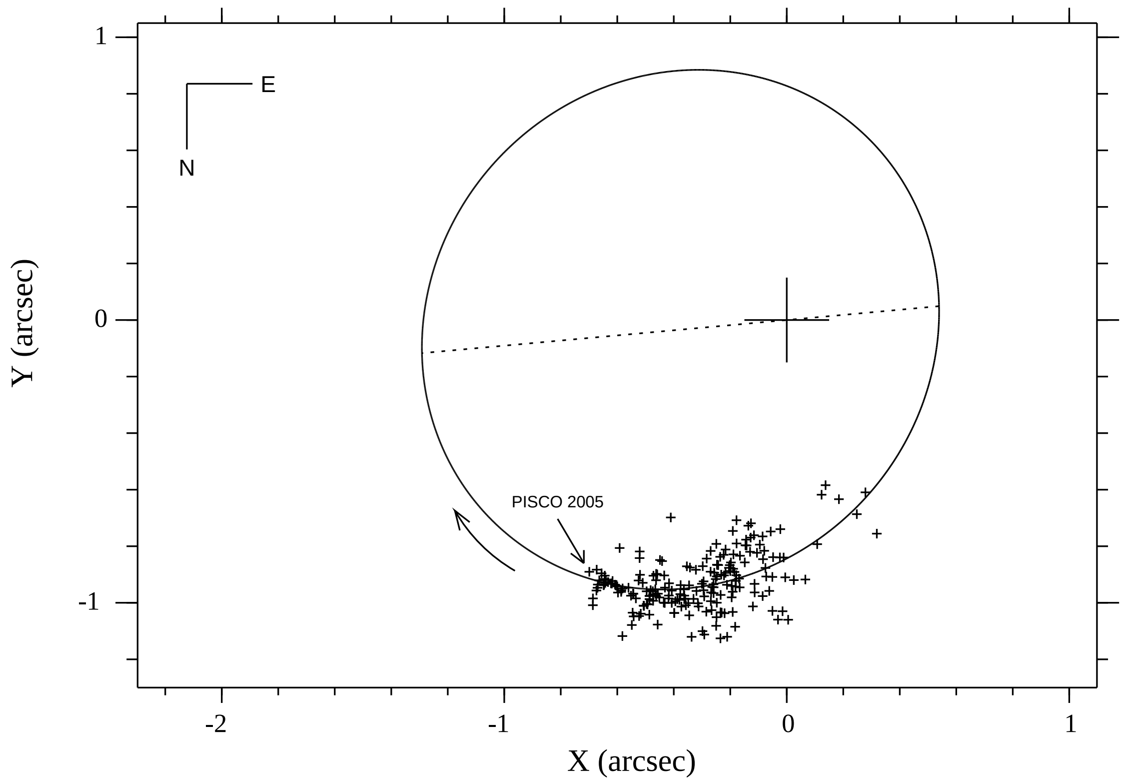

Figure 4. New orbit of ADS 4208.

sky from north through east and ω is the longitude of the periastron in the plane of the true orbit, measured from the ascending node to the periastron, in the direction of motion of the companion. i is the inclination of the orbit relative to the plane of the sky, e the eccentricity, T the epoch of periastron passage, P the period, n the mean angular motion, and a is the semi-major axis. The four parameters A, B, F, and G are the Thiele-Innes constants (useful for an easier computation of the ephemerides).

The ephemerides are presented in Table 7, with the date in Besselian years in Col. 1, the angular separation ρ in Col. 2 and the position angle θ in Col. 3.

Table 8 of the new $(O-C)$ residuals is restricted for reasons of space to the observations made since 1985. For each observation, the date in Besselian years is given in Col. 1, the observed separation and position angle (reduced to 2000) in Cols. 2 and 3, the corresponding residuals in ρ and θ in Cols. 4 and 5, the number of nights used for obtaining this measurement in Col. 6 and the name of the observer in Col. 7, as given in OC6, where the full bibliographic references can be found.

The apparent orbit that we obtained is shown in Fig. 4 as a solid line and the observational data used for the calculation of the orbital elements are plotted as small crosses. Our measurement is indicated with the label "PISCO 2005". The big cross indicates the location of the primary component. The straight dashed line going through this point is the line of apsides. The rotation of the companion is indicated with an arrow in the lower left part of the orbit. The orientation of the orbit conforms with the convention adopted by the observers of visual binary stars.

The parallax as measured by Hipparcos is $0''.0068 \pm 0''.0019$. This leads to a semi-major axis of 149 AU and a sum of masses of 3.4 $M_{\odot}$, which is compatible with the spectral type of the system: B9 IV-V.

6 CONCLUSION

In the first semester of 2005, we performed 214 observations of 192 objects with PISCO in Merate. When adding those made in 2004, the sum reaches 555 observations, which is already larger than the number of double star observations (≈ 400) made with PISCO on the 2-meter Bernard Lyot telescope of Pic du Midi during the period 1993–1998. The new exploitation of PISCO in Merate has thus already provided a significant contribution to the measurements of close visual binary stars.

For the first time, we have calibrated our measurements with a grating mask placed at the entrance of the telescope. The advantage of this procedure is to provide a reliable and fully independent scale determination. Its principle only relies on the optical diffraction theory. The scale values we derived are in good agreement with those obtained with the calibration used for Papers I and II that was based on published ephemerides. To correct the measurements published those two papers, one should remove $-0^{\circ}.2$ to the position angles θ, and multiply the ρ values obtained with the 10 and 20 mm eyepieces by 1.006 and 1.011 respectively.

We have found two candidates as new triple systems: ADS 7871 and KUI 15. We invite other observers to perform independent observations to confirm our findings.

Acknowledgments: We are grateful to Paolo Conconi (G.O.Le.M.) for his help in designing the calibration grating mask. We thank the anonymous referee of Paper I for suggesting that we build such a device and Chris Haniff, the referee of this paper, for his useful comments for improving the accuracy of our calibration.

The authors wish to thank the United States Naval Observatory, Washington DC, for kindly sending on request some lists of measurements of visual binaries.

This work has made use of the "Fourth Catalogue of Interferometric Measurements of Binary Stars" (http://ad.usno.navy.mil/wds/int4.html), the "Sixth Catalogue of Orbits of Visual Binary Stars" (http://ad.usno.navy.mil/wds/orb6.html), and the Washington Double Star Catalogue maintained at the U.S. Naval Observatory (http://ad.usno.navy.mil/wds/wds.html).

For bibliographic references, we used the SIMBAD data base, operated by the "Centre de Données Astronomiques de Strasbourg" (France).

REFERENCES

Aitken R.G., 1932, "New General Catalogue of Double Stars", Carnegie Institute, Washington

Aristidi E., Carbillet M., Lyon J.-F., Aime C., 1997, A&AS, 125, 139

Baize P., 1980, A&AS, 39, 83

Docobo J. A., & Costa, J. M.,, 1984, IAU Commission 26 Circulars, No. 93

Hartkopf W.I., & Mason B.D., 2006, "Sixth Catalogue of Orbits of Visual Binary Stars" http://ad.usno.navy.mil/wds/orb6.html

Hartkopf W.I., Mason B.D., Wycoff G.L., McAlister H.A., 2006, "Fourth Catalogue of Interferometric Measurements of Binary Stars" http://ad.usno.navy.mil/wds/int4.html

Heintz W.D., 1984, A&AS, 56, 5

Heintz W.D., 1991, A&AS, 90, 311

Heintz W.D., 1996, AJ, 111, 412

Hopmann J., 1967, Mitt. Sternw. Wien, 13, 49

Hopmann. J., 1970, Astron. Mitt. Wien, 5, 224

Kowalsky M., 1873, Procès-verbaux de l'Université Imperiale de Kasan

Mason B.D., Wycoff G.L., Hartkopf W.I., 2006, "Washington Double Star Catalogue" http://ad.usno.navy.mil/wds/wds.html

Popovic G.M., Pavlovic R., 1995, Bull. Obs. Astron. Belgrade 151, 45

Popovic G.M., Pavlovic R., 1996, Bull. Obs. Astron. Belgrade 153, 57

Prieur J.-L., Lannes A., Cullum M., 1991, Proc. of the ESO conference on *High Resolution Imaging by interferometry II*, (Ed. J.M. Beckers and F. Merckle) Garching (14–18 October 1991), 353

Prieur J.-L, Koechlin L., André C., Gallou G., Lucuix C., 1998, Experimental Astronomy, vol 8, Issue 4, 297

Prieur J.-L., Oblak E., Lampens P., Aristidi E., Kurpinska-Winiarska M., Koechlin L., Ruymaekers G., 2001, A&A, 367, 865

Scardia M., 1983, IAU Commission 26 Circulars, No 89

Scardia M., 1990, "The ESO Messenger", 61, 36

Scardia M., Prieur J.-L., Koechlin L., Aristidi E., 2002, IAU Commission 26 Circulars, No 146

Scardia M., Prieur J.-L., Sala M., Ghigo M., Koechlin L., Aristidi E., Mazzoleni F., 2005a, MNRAS, 357, 1255 (Paper I)

Scardia M., Prieur J.-L., Pansecchi L., Argyle R.W., Sala M., Ghigo M., Koechlin L., Aristidi E., 2005b, MNRAS, 367, 1170 (Paper II)

Scardia M., Prieur J.-L., Pansecchi L., Argyle R., Basso S., 2006a, IAU Commission 26 Circulars, No 158

Scardia M., Argyle R.W., Prieur J.-L., Pansecchi L., Basso S., Law N.M., Mackay C.D., 2006b, Astron. Nachr., submitted

Starikova G.A., 1977, Soobchen. Gos. Astr. Inst. Sternberg 199, 12

Weigelt G., 1977, Opt. Comm., 21, 55

Worden S.P., Murray K.S., Schmidt G.D., Angel J.R.P., 1977, Icarus 32, 450