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Relative astrometry and near-infrared differential photometry of nearby southern orbital binaries with adaptive optics*

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We present relative astrometry and differential photometry measurements for a sample of nearby southern orbital binaries making use of the technique of Adaptive Optics. The observations were made in December 2000, with the ADONIS camera mounted at the 3.6m ESO telescope from La Silla Observatory, equipped with the broad-band near-infrared filters (*J*-, *H*-, *K*-passbands). Our sample contains stars which do not fit very well the empirical mean mass-luminosity relation (according to our previous study), but for which accurate parallaxes (determined by the Hipparcos satellite) and high-quality orbits were available thanks to many previous efforts. We derived accurate positions and *J*, *H*, *K* magnitudes of the individual components of those binaries. The individual stellar components have near-infrared colour indices well grouped in those plots and are comparable to standard single stars.

The data reduction procedure used for deriving those results is described in detail. It is based on a least-squares fit of Moffat-Lorentz profiles in direct imaging for well-resolved systems and on Fourier analysis for very close pairs.

1 Introduction

Binaries with significant orbital motions deserve to be observed and studied because they are essential in deriving stellar masses in a fundamental and direct way. New stellar mass determinations are still much needed to enable detailed comparisons with models of stellar structure and evolution. The required accuracy for this purpose is of the order of 1–2% at least on the individual stellar mass (Andersen, 1991). This requirement is much more difficult to meet for the visual binaries (VB's) which are on the lower part of the Main Sequence than for the eclipsing binaries (EB's) due to the much longer orbital periods and the need for high-angular resolution to resolve the closest pairs. This is why the empirical Mass-Luminosity Relation (noted hereafter as MLR) remains poorly determined for masses *M* less than 1 $M_{\odot}$ (Henry & McCarthy 1993; Henry et al., 1999; Delfosse et al., 2000 – for $M \leq 0.6 M_{\odot}$; Henry 2004 – from end to end with a special emphasis for $M \leq 0.2 M_{\odot}$). However, the class of visual binaries (including the “speckle” or interferometric binaries) is important for various reasons:

- visual binaries have non-interacting components in general. They thus represent better the evolutionary scenario of single stars;

- they carry a lot of angular momentum and therefore represent a different fraction of the binary population than eclipsing binaries whose masses can be very accurately determined;
- they are the only objects which allow calibration of the MLR in the mass range from 0.2 to 1.0 $M_{\odot}$;
- the distributions of their dynamical characteristics (orbital elements such as the period P_{orb} , the true semi major axis *A* and eccentricity *e*) are directly connected to the mechanisms of their formation (Halbwachs et al., 2005; Patience et al., 1998).

Often, the limiting factor in the precise determination of the stellar mass is the poor knowledge of the distance of the system. Thanks to the astrometric satellite mission Hipparcos (ESA, 1997), many of the parallax uncertainties have been reduced by a factor of 2 to 5. However, this improvement is generally not sufficient: after the Hipparcos mission, the principal error contribution on the mass determination of binary systems still comes from the error on the parallax. Indeed, according to Kepler's laws, the relative error on the total mass *M* of the two components is given by $\varepsilon_M = \sqrt{\varepsilon_{a^3/P^2}^2 + 9 \varepsilon_{\pi}^2}$, where *a* is the semi-major axis in AU, *P* the period in yr, *M* the sum of the masses in $M_{\odot}$, and π the parallax in arcseconds, and where ε designates a relative rms error (see for example, Lampens et al., 1997).

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In an early review on the determination of stellar masses, Popper (1980) listed only 8 *VB*'s with a relative error on the sum of masses less than 3%. Twenty years later, thanks to the improvement of the parallax determination obtained by Hipparcos, Ruymaekers (1999) listed 30 *VB*'s with a relative error on the ratio $a^3/P^2 < 3\%$, while Söderhjelm (1999) reported only 10 *VB*'s with a relative error on the sum of masses smaller than 5% (cf. his tables 1 & 2). This illustrates the difficulty for improving our knowledge on stellar masses in specific mass intervals (Xia et al. 2008 - for masses from $0.07 M_\odot$ to $0.2 M_\odot$).

But for a fully consistent picture of the system, the total mass determination is insufficient. Fractional masses as well as absolute luminosities are needed too. The relative error ε_M of the component absolute luminosity M again depends (largely) on the parallax accuracy ε_π , but also on the error of the component magnitude ε_m according to $\varepsilon_M = \sqrt{[(5. \log_{10} e) \varepsilon_\pi]^2 + \varepsilon_m^2}$ (where e is the base of the Napierian logarithm).

Accurate component magnitudes and colours are thus further needed to derive reliable physical properties of the components. The Hipparcos Catalogue provided for the first time a precise differential magnitude, ΔH_p for many visual binaries of sub-arcsecond separation (ESA, 1997; Martin & Mignard, 1998), and the complementary Tycho Double Star Catalogue (Fabricius et al., 2002) also gave ΔB_T and ΔV_T for systems with $\rho > 0''.5$ and $\Delta m < 3$. Unfortunately, many nearby visual binaries were too close to be fully resolved by Hipparcos/Tycho and still lack precise component colours. Existing spectral classifications generally refer to the system as a whole: when component spectral types are reported, these usually rely on a visual estimation of the magnitude difference, with a typical error of the order of ± 0.2 mag (Christy & Walker, 1969; Edwards, 1976). Therefore, the situation is such that the (rare) precise stellar masses of visual binary systems are generally attributed to components with unknown or uncertain colours.

This point is well-illustrated in the study by Delfosse et al. (2000) on M-dwarf binaries with masses accurate to within 10%. Their table 2 in which they collected basic information for 18 pairs, i.e. 3 EBs and 15 VBs, is lacking accurate magnitude differences in several cases: the flux ratios in the near-IR bands were not determined for 7 systems (3 EBs + 4 VBs), while 6 systems had spectroscopically derived magnitude differences, inferred from the relative line depths of double-lined spectra (1 EBs + 5 VBs), and 6 had large errors (0.1 mag or larger) on the visual magnitude difference Δm_V (2 EBs + 4 VBs).

The aim of the present study is to determine differential near-infrared magnitudes and colours for a sample of nearby close visual binaries from a single observation with the technique of adaptive optics (AO).

This technique offers high-angular resolution and allows to derive reliable differential photometry between the components (ten Brummelaar et al. 1996; Roberts & ten Brummelaar 1998; Roberts et al. 2005). In addition, it provides relative astrometric data useful for the computation of improved orbits.

2 Description of the sample

The following criteria were used for selecting the target binaries:

- nearby visual binaries (i.e., located within a distance ≤ 67 pc) for which the combination of accurate Hipparcos parallaxes (for which the relative error is well below 5%) with high-quality orbits allows to derive component masses with an accuracy, ε_M better than 10-15%. This latter information is based on the catalogue of orbital parameters with realistic errors computed by means of the Bootstrap technique (Ruymaekers, 1999);
- with predicted angular separations between $0''.1$ and $1''$ at epoch 2001.0 and with declination less than $+10^\circ$;
- having orbital periods from 2 to 700 yr and total masses from 0.4 to $8 M_\odot$;
- which do not fit well the mean empirical MLR derived from the new Hipparcos parallaxes (Lampens et al., 1997)

To this list we also added some 18 binaries from table 1 of Söderhjelm (1999), with orbital periods less than 29 yr and with new astrometric mass ratios but which were not always consistent with the previous determination (Martin & Mignard, 1998).

This selection led to a list of some 50 bright, close southern visual binaries. The sub-sample of the objects from this list that we could observe is presented in Table 1 and described in the next section.

3 Observations

The observations were performed with the ESO 3.6-m telescope of La Silla, during two nights (13-14 and 14-15 December 2000). The telescope was equipped with ADONIS ('ADaptive Optics Near Infrared System') and the Sharp II+ infrared camera.

We employed a lens scale of $\sim 0''.050/\text{pixel}$ (see Sect. 4) and the ESO broad-band filters J ($\lambda_c=1.253 \mu\text{m}$, $\Delta\lambda=0.296 \mu\text{m}$), H ($\lambda_c=1.643 \mu\text{m}$, $\Delta\lambda=0.353 \mu\text{m}$) and K ($\lambda_c=2.177 \mu\text{m}$, $\Delta\lambda=0.378 \mu\text{m}$). Exposure times ranged from 40 ms (shutter mode) to 500 ms (normal mode). We used the standard configuration with chopping mode between star and sky in order to optimize the number of exposures per star. In this way, for each filter, the observational data consisted of four sets of 20 exposures each: 2×20 exposures with the target

Table 1 Basic information for the sample of observed systems

HIP	CCDM (α, δ) ₂₀₀₀	H _p (mag)	SpT	π_{HIP} (mas)	P _{orb} (year)	Discovery Designation	Notes
730	00090–5400	6.462	G4IV..	7.00	221.	HDO 181	GJ 9
2237	00284–2020	6.558	G3V	31.01	5.7/11.3	B 1909	ambig. solution (ESA 1997)
2762	00352–0336	5.321	F6V	47.51	6.9	HO 212	GI 23, ADS 490
2941	00373–2446	5.713	K1V+...	64.38	25.1	BU 395	GI 25; SB-VB
5165	01061–4643	3.465	G8III	16.46	168.	SLR 1	DMSA/X
5842	01157–6852CD	4.964	K2V	48.94	85.2	I 27	GI 55.1; MLR outlier
7254	01334–4354	7.975	K0/K1V	28.23		HDS 205	
7372	01350–2954	7.253	K3V	42.29	4.6	DAW 31	GI 60; triple
7580	01376–0924	6.355	F7V	26.15	29.	KUI 7	DMSA/G; SB-VB
15382	03184–2231	5.024	K0III	12.79	112.4	SEE 23	
19719	04136+0743	5.374	F3V...	27.04	7.2	A 1938	
20087	04184+2135Aa,Ab	5.713	F0V	18.25	11.3	MCA 14Aa,Ab	51 Tau, SB
21280	04340+1510*	8.637	G5	24.02	13.	CHR 17	multiple?
22550	04512+1104	6.866	F6V	20.15	16.6	BU 883	ADS 3475, MLR outlier
22573	04515–3454	5.863	A2/3V	11.39	37.3	FIN 320	
22607	04518+1339	6.365	F5	23.91	95.1	BU 552	ADS 3483, SB, MLR outlier
25037	05217+1240	8.032	A3	7.39		STT 105	ADS 3936
25119	05226+0236	7.903	K3V	50.24	88.1	A 2641	ADS 3959
27421	05484+2052	6.020	B9V	5.48		STT 118	ADS 4392
27901	05542–2909	6.430	F3V	17.84		FIN 382	
29234	06098–2246	5.808	F5V	18.48	18.3	RST 3442	MLR outlier
30920	06294–0249	10.984	M4.5Ve	242.89	16.5	B 2601	Flare star, DMSA/G, GI 234
30953	06298–5014	5.308	F2V	19.33	98.8	R 65	MLR outlier
33451	06573–3530	6.333	F5V	23.15	16.8	I 65	GI 255
36238	07277+2127	5.337	F5IV-V...	29.38	2.0	MCA 30Aa,Ab	63 Gem, ADS 6089, MLR outlier
40167	08123+1738	4.781	G0V	39.11	59.6	STF 1196	ADS 6650, SB
41261	08251–4910	7.801	K0	30.14	25.6	RST 321	MLR outlier
42075	08345–3236	6.550	G5V	15.93	17.3	FIN 335	giant?
45170	09123+1459Aa,Ab	6.626	G9V	48.83	2.7	FIN 347	81 Cnc, SB-VB
46404	09278–0604	5.504	G2V	32.01	33.8	B 2530	SB, giant?
46454	09285+0903	5.532	F9V	29.05	117.0	STF 1356	ω Leo, SB, giant?
47479	09407–5759	5.367	A3IV	14.85	10.6	B 780	GJ 9305; multiple?
53840	11009–4030	6.886	F7V	15.11	4.5	FIN 365	
114375	23099–2227	4.835	G2IV+A2	6.26		RST 3320	
114576	23126+0241	7.839	G5	15.21	29.2	A 2298	ADS 16591, SB-VB
115126	23191–1328Aa,Ab	5.245	G6/G8IV	48.22	6.3	MCA 74Aa,Ab	94 Aqr, ADS 16672, DMSA/X, GI 894.2, multiple?

* This flag in col. 2 indicates a WDS identifier (as no CCDM identifier was found)

binary on quadrant 1, and 2×20 exposures with the target on quadrant 3. The sky level was estimated on the quadrants 2 and 4, opposite to the quadrants used for the target. In nearly half of the cases, a single reference star was observed immediately after the binary to calibrate its point-spread-function (PSF).

Some 36 close visual binaries, most of them belonging to the all-sky sample described in Sect. 2, were observed during the allocated nights. They are listed in Table 1 with basic information including various identifiers (Cols. 1, 2, and 6), Hipparcos magnitude

H_p (Col. 3), spectral type (Col. 4), Hipparcos parallax (Col. 5), orbital period (Col. 6), (in years) and additional notes in Col. 8 (e.g. SB-VB: spectroscopic-visual binary). Unless specified in Col. 2, they all refer to AB couples. Among those, 11 targets were taken from table 1 from Söderhjelm (1999) and 9 are outliers from the empirical MLR with $\varepsilon_M < 15\%$. We also added a few targets needed for the astrometric calibration.

Because some of our main targets were not accessible during these nights, we completed the observations by inserting additional problematic targets

though they had $\varepsilon_M > 15\%$. For example, we included HIP 7254 which is a new Hipparcos discovery and HIP 2237 for which “two orbital solutions fit the available data equally well: in the case of the high-eccentricity, half-period solution a too high mass-sum is derived” (Söderhjelm, 1999). Unluckily, the latter remained unresolved.

On average the seeing was about $1\text{--}2''$, but the atmospheric conditions were more stable during the first night. This explains why ADONIS performed better and faster, resulting into a higher detection rate on the first night than on the second night. We were able to resolve 17 objects of the 20 binary systems observed on Dec. 13th 2000 whereas only 11 objects of the 17 observed on Dec. 14th 2000 (see Tables 2 and 3 in Sect. 5).

4 Data reduction

The reduction steps were performed in the following order:

- 1 - Preprocessing: bad pixel correction (darks), sky-subtraction, flat-field division (using sky flats taken at twilight) were done using the excellent ESO Eclipse software package (Devillard, 1997).
- 2 - a) When the components were clearly resolved, we used a profile-fitting algorithm on each single frame. It is based on the fitting of two-dimensional Moffat-Lorentz profiles (see Fig. 1 and Sect. 4.1).
b) When the binaries were not well-resolved, we performed a Fourier analysis of the power spectrum of the AO images. We calibrated the transfer function of the imaging system with observations of (unresolved) PSF reference stars located within $\sim 5^\circ$ from the binary targets. The ratio of the corresponding power spectra exhibited fringes when two stars were detected (e.g. Fig. 2). The determination of the position angle (θ_0) and period (d_0) of those fringes then led to the astrometric parameters of the binary: $\rho = n/d_0$ (with $n \times n$ the size of the images), and $\theta = \theta_0 + \pi/2$. In this case, the position angle θ was determined with a 180° ambiguity, which could sometimes be solved by direct inspection of the AO images.
- 3 - We used the astrometric calibration from Berthier et al. (2002) based on observations of the Trapezium cluster in the nights preceding and following our observations (since too few of our calibration double stars fitted the available field). We thus adopted the scale of $0''.0496/\text{pixel}$ and the orientation of $269^\circ.609$ and $179^\circ.619$ for the X and Y axes, respectively (In Figs. 1 and 2, North is to the bottom, East to the left).

4.1 Fitting procedure of Moffat profiles to long exposures

Experience has shown that the point spread function of long exposure images is generally well represented by the semi-empirical Moffat-Lorentz profile (Moffat, 1982):

$$I_1(x, y) = \frac{h_1}{(1 + b r_1^2)^q}$$

where (x, y) are the Cartesian coordinates of the image, q is a real value, generally in the range $[1, 2]$ (it is a Lorentz profile when $q = 2$), and r_1 is the distance of the current point (x, y) to the centre of the profile (x_1, y_1) . The parameter b is used to take into account the profile width. It is related to s , the full width at half maximum of the profile (FWHM or “seeing”) with:

$$s = \frac{2\sqrt{2^{1/q} - 1}}{b}$$

This profile was originally proposed by Moffat to model stellar profiles of photographic plates, to take into account the diffusion of light inside photographic emulsions. It was then widely used for many other applications and appeared to be well suited to images obtained with electronic detectors. In particular, we used this model for extracting the relative positions and differential magnitudes of CCD images of binary stars when profiles of the components overlap (Oblak et al., 1997, Lampens & Strigachev, 2001, Lampens et al., 2001, Strigachev & Lampens, 2004, and Lampens et al., 2007).

To obtain the differential photometry and relative astrometry measurements presented in Table 2, we have fitted the following brightness function corresponding to the sum of two Moffat two-dimensional profiles, to the ADONIS images:

$$I(x, y) = \sum_{m=1}^2 I_m(x, y) + n(x, y)$$

with

$$I_m(x, y) = \frac{h_m}{[1 + (b r_m)^2]^q}$$

where $m = 1, 2$ are the indices of the two stellar components. For each profile, h_m is the central intensity and r_m is the distance of the current point to the centre (x_m, y_m) of the profile. The function $n(x, y)$ is a two dimensional polynomial that is used to model the sky background. For our application, a first order polynomial was sufficient:

$$n(x, y) = n_0 + n_1 x + n_2 y + n_3 xy$$

For the images where the profile isophotes of many frames were not circular, we took their ellipticity into account by changing the expression of r_m :

$$r_m = \sqrt{(x - x_m)^2 + e(x - x_m)(y - y_m) + (1 + k)(y - y_m)^2}$$

where e and k are two additional parameters.

The problem to be solved consists therefore in minimizing a function $f(\mathbf{p})$ where the vector $\mathbf{p}$ belongs to $\mathbb{R}^{14}$. The corresponding 14 coordinates are (x_m, y_m, h_m) (for $m = 1, 2$), $b, q, k, e, n_0, n_1, n_2$ and n_3 :

$$f(\mathbf{p}) = \sum_{(x,y) \in \mathcal{A}} [z(x,y) - I_{\mathbf{p}}(x,y)]^2$$

In this expression, $z(x,y)$ is the value of the brightness function as measured on the detector and $\mathcal{A}$ is the image domain within which the minimisation is performed.

This method was first implemented by one of us (JC) as a procedure in the ESO/MIDAS software, using a Newton-Raphson minimisation algorithm (J. Cuypers, 1997). For this application, we also developed a new stand-alone program `fit_moffat.cpp`, with the bound constrained LBFGS minimisation algorithm (Byrd et al, 1995). Both programs require the knowledge of the gradient vector g of $f(\mathbf{p})$, whose components g_i are given by:

$$g_i = \sum_{(x,y) \in \mathcal{A}} -2 [z(x,y) - I_{\mathbf{p}}(x,y)] \frac{\partial I_{\mathbf{p}}(x,y)}{\partial p_i}$$

In appendix, we provide the expression of the gradient $\frac{\partial I_{\mathbf{p}}(x,y)}{\partial p_i}$ that may be useful for the readers who want to create their own fitting program.

5 Main results

The relative astrometric and differential near-infrared photometric measurements obtained with the method of Moffat profile fitting for 32 components of 29 binary and multiple systems are listed in Table 2. For each couple we indicate its HIP number in Col. 1, and the component names in Col. 2, the Besselian epoch of observation in Col. 3 (in Besselian years, after subtraction from 2000), the number N of quadrants used for the astrometric measurements in Col. 4, the average relative astrometric measurements ρ_{all} (Col. 5), θ_{all} (Col. 7), and their corresponding errors $\sigma_{\rho_{all}}$ (Col. 6) and $\sigma_{\theta_{all}}$ (Col. 8). The subscript ‘all’ is added to indicate that the current measurement corresponds to the average of all the measurements obtained with the three filters J , H , and K . In the next columns we report the differential photometric measurements Δm_J , Δm_H , and Δm_K with their corresponding errors $\sigma_{\Delta m_J}$, $\sigma_{\Delta m_H}$, and $\sigma_{\Delta m_K}$, and the numbers of quadrants used for those photometric measurements: N_J , N_H , and N_K , respectively.

Table 3 lists the values we obtained using the method of Fourier analysis, i.e., for 8 resolved components of 6 multiple systems. For each system we indicate its HIP number in Col. 1, the component names

in Col. 2, the fractional Besselian epoch of observation and the relative astrometric measurements ρ , θ and their corresponding errors σ_ρ , σ_θ for each filter J , H , and K . The subscript ‘all’ indicates that the current measurement corresponds to the average of the measurements in the different filters.

5.1 Analysis of astrometric data

The distribution of the angular separations ρ_{all} reported in Tables 2 and 3 is plotted in Fig. 3. The average rms errors for $(\rho_{all}, \theta_{all})$ are $(0''.008, 0''.8)$ and $(0''.010, 2''.3)$ for Moffat profile fitting and Fourier analysis, respectively. In the case of Fourier analysis, the larger error on θ_{all} is due to the difficulty of determining the direction of the fringes accurately (see Sect. 4).

We detected a new candidate binary star among our (supposed single) reference stars, HIP 19233, which was resolved in all the direct images obtained with the JH and K filters (see Table 2). This object (also known as HR 9233) is also the high proper-motion nearby star LTT 1877 (parallax 42.3 mas). This new pair has a magnitude difference close to 3 mag (in JH and K), which may explain why it was not previously resolved. Further observations are needed to confirm its nature.

The technique of Fourier analysis (see Sect. 4) allowed the measurement of angular separations close to the diffraction limit of the 3.6 m telescope (which is $0''.069$ in J , i.e., λ/D). In particular, this analysis revealed the presence of possible components Ab, Ac and Ad around HIP 20087Aa that could not be measured with the Moffat profile fitting procedure. Components Ac and Ad would be newly-discovered components, located very close to the primary star, nearly at the theoretical diffraction limit (see Fig 2). Further confirmation is needed, especially for the Ad component which was only detected with the J filter. The latter could be an artifact caused by a bad estimation of the PSF (let us recall that the PSF could only be calibrated by observations of single stars before or after the observation of our targets, see Sect. 4). The existence of the Ac component is more secure since it was detected at the same location, both in H and K .

Table 4 illustrates the comparison of our relative positions with the positions computed at the given Besselian epoch (B 2000.95) for those systems which have a published orbit. For each measurement taken from Tables 2 and 3, we report the HIP number in Col. 1, the component names in Col. 2, the astrometric measurements ρ_{all} , θ_{all} in Cols. 4 and 6, with their corresponding errors $\sigma_{\rho_{all}}$, $\sigma_{\theta_{all}}$ in Cols. 5 and 7, and the numbers of quadrants used for those measurements in Col. 3. We write the HD number in *italic* in Col. 1 when the measurement was taken from Table 3, else it was taken from Table 2. In Cols. 8 and 9, we report the computed positions ρ_c , θ_c at the epoch of observation, from the orbit whose bibliographic reference is indicated in

Fig. 1 Example of a Moffat-Lorentz profile fitted to the profile of the ADONIS image of calibration star HR 8658 obtained in K : raw image (a), residual image (b) and comparison of the corresponding profiles (c), with the raw image profile (solid line) and the Moffat-Lorentz profile (dashed line).

Fig. 2 Processing example of the image of HIP 20087 in H . The AO correction leads to integrated frames (left panel) which only show a single bright patch. When dividing the corresponding power spectrum with that of a calibration star, we obtain a “restored” power spectrum (right panel) which exhibits two systems of fringes betraying the presence of two companions ‘Ab’ and ‘Ac’ around the primary star (named ‘Aa’). The inner disk that clearly appears in this power spectrum is bounded by the circle corresponding to the maximum resolution that can be reached with the 3.6-m telescope in H . The structure of the noise which is present outside of this disk also perturbs the “useful” signal inside of this disk.

Fig. 3 Distribution of the angular separations reported in Tables 2 and 3

Col. 14. The corresponding residuals for ρ , θ are given in Col. 10 and 11, respectively. The position difference in Cartesian coordinates ΔPos is indicated in arcseconds in Col. 12, and the percentual ratio $\Delta\text{Pos}/\rho_{\text{all}}$ is displayed in Col. 13. Most of the orbits used here were taken from the “Sixth Catalog of Orbits of Visual Binary Stars” (Hartkopf et al, 2012b), but we also added some orbits computed by Ruymaekers (1999) and a few more found from in the recent literature.

The residuals in the form $\rho \cdot \Delta\theta_{O-C}$ versus $\Delta\rho_{O-C}/\rho$ are plotted in Fig. 4. The largest residuals are noticeable for HIP 7372 AC and HIP 46404, indicating that their orbits are only preliminary. When using the criterion $\Delta\text{Pos}/\rho_{\text{all}} > 13\%$ (see Col. 13 of Table 4, two more objects appear with large residuals: HIP 20087 and HIP 27901, indicating that a revision of the orbit will also be needed in the future. In all other cases, the residuals are smaller than 13%, which is an indication that our measurements agree rather well with the adopted ephemeris.

Table 2 Relative astrometry and differential photometry obtained with Moffat profile fitting.

HIP	Cp	Epoch (2000.)	N	ρ_{all} ($''$)	$\sigma_{\rho_{all}}$ ($''$)	θ_{all} ($^\circ$)	$\sigma_{\theta_{all}}$ ($^\circ$)	N_J	Δm_J (mag)	$\sigma_{\Delta m_J}$ (mag)	N_H	Δm_H (mag)	$\sigma_{\Delta m_H}$ (mag)	N_K	Δm_K (mag)	$\sigma_{\Delta m_K}$ (mag)
730	AB	.953	11	0.281	0.022	59.6	5.0	4	2.39	0.03	4	2.75	0.10	3	2.92	0.11
2941	AB	.956	12	0.554	0.003	292.5	0.4	4	0.26	0.02	4	0.24	0.02	4	0.25	0.04
5165	AB	.956	4	0.241	0.002	238.3	0.6	–	–	–	–	–	–	4	0.32	0.04
5842	CD	.956	4	0.947	0.011	275.8	0.2	–	–	–	–	–	–	4	0.29	0.02
7254	AB	.953	12	0.157	0.003	182.8	1.3	4	1.07	0.15	4	0.56	0.10	4	0.52	0.08
7372	AB	.953	11	0.111	0.005	276.9	3.0	4	0.24	0.13	3	0.47	0.23	4	0.28	0.15
7372	AC	.953	12	1.794	0.004	333.5	0.2	4	2.87	0.04	4	2.72	0.14	4	2.46	0.02
7580	AB	.953	12	0.263	0.006	147.4	0.5	4	0.99	0.03	4	0.91	0.07	4	0.85	0.05
15382	AB	.956	11	0.366	0.044	273.6	4.8	3	2.10	0.24	4	2.11	0.11	4	2.45	0.31
19233 ⁽¹⁾	AB	.953	12	0.415	0.016	294.3	1.1	4	2.86	0.12	4	2.85	0.07	4	2.83	0.08
21280	AB	.956	12	0.170	0.003	232.4	2.1	4	1.15	0.15	4	0.68	0.02	4	0.66	0.06
22550	AB	.953	12	0.210	0.003	274.1	0.5	4	0.08	0.02	4	0.10	0.02	4	0.13	0.02
22573	AB	.953	12	0.206	0.005	31.6	0.3	4	0.40	0.02	4	0.29	0.03	4	0.29	0.04
22607	AB	.953	12	0.527	0.005	228.8	0.2	4	1.25	0.02	4	1.12	0.02	4	1.11	0.02
25037	AB	.956	8	0.177	0.006	301.7	1.3	–	–	–	4	0.67	0.09	4	0.67	0.05
25119	AB	.953	12	1.225	0.002	171.4	0.2	4	1.52	0.02	4	1.12	0.03	4	1.07	0.02
27901	AB	.953	8	0.177	0.004	176.2	0.8	–	–	–	4	1.10	0.17	4	1.06	0.04
29234	AB	.953	12	0.178	0.003	294.1	0.7	4	–0.03	0.04	4	0.09	0.08	4	0.12	0.04
30920	AB	.956	5	0.562	0.007	339.1	0.8	5	1.63	0.04	–	–	–	–	–	–
30953	AB	.956	12	0.732	0.001	265.8	0.2	4	0.05	0.02	4	0.07	0.02	4	0.05	0.02
33451	AB	.953	12	0.265	0.013	185.2	0.6	4	0.29	0.03	4	0.24	0.04	4	0.28	0.03
40167	AB	.956	1	0.859	–	78.2	–	–	–	–	–	–	–	1	0.18	–
40167	A,Ca	.956	1	6.220	–	73.2	–	–	–	–	–	–	–	1	0.56	–
40167	A,Cb	.956	1	6.546	–	72.9	–	–	–	–	–	–	–	1	1.61	–
41261	AB	.953	12	0.199	0.003	355.4	0.4	4	0.34	0.06	4	0.30	0.02	4	0.30	0.02
42075	AB	.953	12	0.190	0.007	96.4	1.5	4	0.99	0.16	4	0.98	0.07	4	0.97	0.12
45170	Aa,Ab	.953	12	0.117	0.007	296.1	3.5	4	0.26	0.28	4	0.09	0.10	4	0.03	0.03
46404	AB	.956	12	0.372	0.026	153.4	0.9	4	1.30	0.04	4	1.62	0.03	4	1.71	0.12
46454	AB	.956	12	0.591	0.004	86.3	0.3	4	0.64	0.02	4	0.76	0.03	4	0.84	0.02
47479	AB	.953	12	0.161	0.004	71.2	0.8	4	0.10	0.03	4	0.13	0.02	4	0.13	0.02
53840	AB	.953	12	0.165	0.002	285.4	0.6	4	0.18	0.04	4	0.25	0.04	4	0.30	0.02
114576	AB	.953	12	0.243	0.007	113.3	0.9	4	0.23	0.02	4	0.25	0.03	4	0.18	0.01

⁽¹⁾ new candidate binary star.

In Table 5, we report some measurements of our selected targets made by other observers. For each target, we indicate the concerned pair in Col. 2, and display our measurements ρ_{all} , θ_{all} in Cols. 3 and 4, the measurements ρ_d , θ_d from other sources in Cols. 5 and 6, and the corresponding position differences in Cols. 7, 8, 9 in polar ($\rho_{all} - \rho_d$, $\theta_{all} - \theta_d$) and Cartesian coordinates (ΔPos), with the epoch of observation of those measurements in Col. 7 and their bibliographic reference in Col. 8. The mention “WDS” is used when the data come from the Washington Double Star Catalog (Mason et al., 2012). Note that this comparison is meaningful only when the epoch of the other measurements is close to 2000.95, the epoch of our observations, or when the couples have a very long orbital period.

There is a fair agreement, with $\Delta\text{Pos} < 0.1''$ in general. The largest discrepancy concerns HIP 27901

(FIN 382). This is also the object having the second largest $O - C$ residual reported in Table 4. Our new measurement of HIP 27901 appears to be inconsistent both with orbits of Cvetkovic (2008) and Hartkopf et al. (2012a). We still think that our measurements are valid and discard an identification error, because they are in close agreement with those made by Hipparcos for the epoch 1991.25 (see Table 5). The situation is not at all clear, the more that some older measurements too were discarded by Cvetkovic (2008) in his orbit computation because they were found to be incompatible with the proposed 32-yr period (e.g. the measurement from 1979). Clearly more observations are needed for this system.

The case of HIP 25037 (STT 105) is also particularly interesting since the companion had not been measured for nearly thirty years and high-angular res-

Table 3 Relative astrometry obtained by Fourier analysis. In col. 6, the asterisk indicates a possible 180°-ambiguity on θ .

HIP	Cp	Epoch (2000.)	ρ_{all} ($''$)	$\sigma_{\rho_{all}}$ ($''$)	θ_{all} ($^{\circ}$)	$\sigma_{\theta_{all}}$ ($^{\circ}$)	ρ_J ($''$)	σ_{ρ_J} ($''$)	θ_J ($^{\circ}$)	σ_{θ_J} ($^{\circ}$)	ρ_H ($''$)	σ_{ρ_H} ($''$)	θ_H ($^{\circ}$)	σ_{θ_H} ($^{\circ}$)	ρ_K ($''$)	σ_{ρ_K} ($''$)	θ_K ($^{\circ}$)	σ_{θ_K} ($^{\circ}$)
2237	AB	.953	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
2762	AB	.956	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
7254	AB	.953	0.150	0.002	182	4	0.151	0.004	178	6	0.149	0.002	184	2	0.150	0.002	185	1
7372	AB	.953	0.110	0.002	280*	1	0.111	0.002	279*	1	0.109	0.003	280*	1	0.111	0.003	280*	1
15382	AB	.956	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
19719	AB	.956	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
20087	Aa,Ab	.953	0.128	0.009	175	3	unres.	—	—	—	0.134	0.003	175	3	0.122	0.005	175	3
20087	Aa,Ac	.953	0.245	0.035	132*	2	unres.	—	—	—	0.22	0.02	130*	2	0.27	0.03	133*	3
20087	Aa,Ad?	.953	0.259	0.006	270	3	0.259	0.006	270	3	unres.	—	—	—	unres.	—	—	—
21280	AB	.956	0.169	0.010	230	2	0.172	0.006	230	2	0.176	0.008	230	5	0.158	0.005	229	4
25037	AB	.956	0.168	0.002	298	2	unres.	—	—	—	0.167	0.008	295	3	0.169	0.006	301	2
27421	AB	.953	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
36238	Aa,Ab	.956	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
114375	AB	.956	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—	unres.	—	—	—
114576	AB	.953	0.244	0.008	113	1	0.253	0.002	114.2	1	0.241	0.001	113.5	1	0.237	0.002	112.2	1
115126	AB	.956									unres.	—	—	—

Fig. 4 Illustration of the (O–C) residuals from Table 4: $\rho\Delta\theta_{(O-C)}$ versus $\Delta\rho_{(O-C)}/\rho$. The units used here are arcseconds for ρ and $\Delta\rho_{O-C}$, and radians for $\Delta\theta_{O-C}$.

olution data obtained from speckle or AO measurements were deemed necessary. Our measurement is the first direct observation made since 1971 and perfectly matches the model of a linear motion of component A. This target is thus likely to be a (close) optical pair with an apparent closest approach during the interval 1980–1990 (see Fig. 5 where we plotted the apparent

Fig. 5 HIP 25037 (STT 105): relative motion of component B versus component A in the period 1980–1990. In fact A has a proper motion in the direction of 169°, whereas B seems still relative to the celestial sphere. North is to the bottom and East to the right.

motion of B relative to A). This (recti)linear motion is also compatible with the proper motion of component A measured by Hipparcos ($\mu_{\alpha}(\ast) = 5.67$ mas/yr; $\mu_{\delta} = -29.35$ mas/yr (ESA, 1997), indicating a proper motion in the direction of 169°. It seems that the B star has no significant proper motion and was still relative to the celestial sphere in the period 1980–1990.

Table 4 Comparison between observations and predicted relative positions.

HIP ^a	Cp	N	ρ_{all} ($''$)	σ_ρ ($''$)	θ_{all} ($^\circ$)	σ_θ ($^\circ$)	ρ_c ($''$)	θ_c ($^\circ$)	$\Delta\rho_{(O-C)}$ ($''$)	$\Delta\theta_{(O-C)}$ ($^\circ$)	ΔPos ($''$)	$\Delta Pos / \rho$ (%)	Orbit reference
730	AB	11	0.281	0.022	59.6	5.0	0.292	57.1	-0.011	2.5	0.016	5.9	Argyle et al. (2002)
2941	AB	12	0.554	0.003	292.5	0.4	0.558	293.2	-0.004	-0.7	0.008	1.4	Hartkopf et al. (2010)
5165	AB	4	0.241	0.002	238.3	0.6	0.253	238.8	-0.012	-0.5	0.012	5.1	Alzner et al. (2009)
5842	CD	4	0.947	0.011	275.8	0.2	0.961	275.3	-0.014	0.5	0.016	1.7	Ruymaekers (1999)
7372	AB	11	0.111	0.005	276.9	3.0	0.120	281.4 ^Q	-0.009	-4.5	0.013	11.3	Mason et al. (1999)
7372	AB	11	0.110	0.001	279.7 ^Q	1.	0.120	281.4 ^Q	-0.010	-1.7	0.011	9.6	Mason et al. (1999)
7372	AC	12	1.794	0.004	333.5	0.2	1.606	328.9	0.188	4.6	0.233	13.2	Ruymaekers (1999)
7580	AB	12	0.263	0.006	147.4	0.5	0.256	146.6	0.007	0.8	0.008	3.0	Pourbaix (2000)
15382	AB	11	0.366	0.044	273.6	4.8	0.325	270.6 ^Q	0.041	3.0	0.045	12.4	Seymour et al. (2002)
20087	Aa,Ab	8	0.128	0.009	175.0	3.0	0.112	170.1 ^Q	0.016	4.9	0.019	15.1	Pourbaix (2000)
21280	AB	12	0.170	0.003	232.4	2.1	0.163	232.4	0.007	0.0	0.007	4.1	Cvetkovic & Ninkovic (2008)
21280	AB	12	0.169	0.010	230.0	2.	0.163	232.4	0.006	-2.4	0.009	5.5	Cvetkovic & Ninkovic (2008)
22550	AB	12	0.210	0.003	274.1	0.5	0.209	273.5	-0.001	0.6	0.002	1.2	Söderhjelm (1999)
22573	AB	12	0.206	0.005	31.6	0.3	0.207	35.4	-0.001	-3.8	0.014	6.7	Docobo & Andrade (2012)
22607	AB	12	0.527	0.005	228.8	0.2	0.546	228.6	-0.019	0.2	0.019	3.6	Söderhjelm (1999)
25119	AB	12	1.225	0.002	171.4	0.1	1.209	169.6	0.016	1.8	0.042	3.4	Söderhjelm (1999)
27901	AB	8	0.177	0.004	176.2	0.8	0.254	179.1 ^Q	-0.077	-2.9	0.078	43.8	Cvetkovic (2008)
"	"	"	"	"	"	"	0.249	212.4 ^Q	-0.072	-36.0	0.132	74.8	Hartkopf et al. (2012a)
29234	AB	12	0.178	0.003	294.1	0.7	0.174	296.3	0.004	-2.2	0.008	4.5	Hartkopf et al. (1996)
30920	AB	5	0.562	0.007	339.1	0.8	0.559	337.4	0.003	1.7	0.017	3.0	Ségransan et al. (2000)
30953	AB	12	0.732	0.001	265.8	0.1	0.738	266.4	-0.006	-0.6	0.010	1.3	Hartkopf et al. (2010)
33451	AB	12	0.265	0.013	185.2	0.6	0.256	187.2	0.009	-2.0	0.013	4.9	Docobo et al. (2009)
40167	AB	1	0.859	-	78.2	-	0.861	78.4	-0.002	-0.2	0.004	0.4	Ruymaekers (1999)
"	"	"	"	"	"	"	0.854	78.9	0.005	-0.7	0.012	1.4	Mason et al. (2006)
41261	AB	12	0.199	0.003	355.4	0.4	0.197	353.0	0.002	2.4	0.009	4.3	Hartkopf et al. (2012a)
42075	AB	12	0.190	0.007	96.4	1.5	0.174	97.9	0.016	-1.5	0.017	8.8	Docobo & Andrade (2012)
45170	Aa,Ab	12	0.117	0.007	296.1	3.5	0.117	294.8 ^Q	0.000	1.3	0.003	2.3	Mason et al. (1996)
"	"	"	"	"	"	"	0.108	289.2 ^Q	0.009	6.9	0.017	14.3	Ruymaekers (1999)
46404	AB	12	0.372	0.026	153.4	0.9	0.295	156.0	0.077	-2.6	0.079	21.2	Söderhjelm (1999)
46454	AB	12	0.591	0.004	86.3	0.3	0.592	86.7	-0.001	-0.4	0.004	0.7	Muterspaugh et al. (2010)
47479	AB	12	0.161	0.004	71.2	0.8	0.157	70.8	0.004	0.4	0.004	2.6	Söderhjelm (1999)
114576	AB	12	0.243	0.007	113.3	0.9	0.240	114.3	0.004	-1.0	0.005	2.1	Pourbaix (2000)
114576	AB	12	0.244	0.008	113.0	1.	0.240	114.3	0.004	-1.3	0.007	2.8	Pourbaix (2000)

^a: The HIP identifier is in italic font when the corresponding measurement was derived by Fourier analysis.

^Q: This symbol is used when a quadrant correction of 180° has been applied.

5.2 Analysis of photometric measurements

Another important piece of information derived from Moffat profile fitting is the differential photometry between the two stellar components. The values we obtained are reported in Table 2, in Cols. 10, 13 and 16, for the filters *J*, *H* and *K*, respectively, with the corresponding errors in Cols. 11, 14 and 17. As shown in Figs. 6 and 7, we were able to measure large differences of magnitudes, up to 3 mag. The average rms photometric errors for $\sigma_{\Delta m_J}$, $\sigma_{\Delta m_H}$, and $\sigma_{\Delta m_K}$ are 0.06, 0.06 and 0.07 mag, respectively.

We next made use of archived information from the 2MASS Catalogue (a survey operated by IPAC Infrared Science Archive (IRSA), Caltech/JPL) to extract to-

tal magnitudes in the near-infrared passbands for the observed systems. We also searched through the bibliographic data base of SIMBAD (CDS, Strasbourg). Table 6 lists the total magnitudes in the *J*-, *H*- and *K*-bands with their respective errors collected in this way. The 2MASS JHK photometric system is very close to the ADONIS ESO JHK filter system we used (see Bouchet, 1991, and Bessel, 2005).

In combination with the measured differential magnitudes (see Table 2), we then derived the component magnitudes from the above-mentioned data for 27 binary and multiple systems. This enabled us to also derive the component colours for most of these systems. These results are reported in Table 7 and plotted in Fig. 8. In this figure, we also plotted the average val-

Table 5 Comparison between some of our measurements (ρ_{all}, θ_{all}) made in 2000.95 and other published data (ρ_d, θ_d).

HIP ^a	Cp	ρ_{all} ($''$)	θ_{all} ($^\circ$)	ρ_d ($''$)	θ_d ($^\circ$)	$\rho_{all} - \rho_d$ ($''$)	$\theta_{all} - \theta_d$ ($^\circ$)	ΔPos ($''$)	Epoch	Reference
7254	AB	0.157	182.8	0.1	185.	0.057	-2.2	0.057	1991.25	ESA, 1997
<i>7254</i>	AB	0.150	182.0	0.1	185.	0.050	-3.0	0.050	1991.25	ESA, 1997
27901	AB	0.177	176.2	0.165	179.	0.012	-2.8	0.015	1991.25	ESA, 1997
"	"	"	"	0.1	142.	0.077	34.2	0.110	1993.10	Hartkopf et al., 2000
40167	AC	6.22	73.2	6.17	73.5	0.050	-0.3	0.062	2001.24	Mason et al., 2002
40167	Ca,Cb	0.327	67.7	0.317	84.5	0.010	-16.8	0.096	2000.14	Hutchings et al., 2000
"	"	"	"	0.338	62.1	-0.011	5.6	0.034	2001.27	Balega et al., 2006
53840	AB	0.165	285.4	0.1	304. ^Q	0.065	18.7	0.077	1994.31	Hartkopf et al., 1996b

^a: For a given identifier in italic font, the measurement was derived by Fourier analysis.

^Q: This symbol is used when a quadrant correction of 180° has been applied.

Table 6 Infrared (system) photometry from 2MASS survey and other bibliographic sources

HIP	J_{tot} (mag)	H_{tot} (mag)	K_{tot} (mag)	Comments
730	-	4.590 ± 0.075	4.408 ± 0.029	2MASS
2941	4.08	3.78	3.73	HD 3443, Alonso et al. (1994)
5165	1.831 ± 0.020	1.390 ± 0.020	1.286 ± 0.020	Bouchet et al. (1991)
5842	5.588 ± 0.019	5.066 ± 0.021	4.980 ± 0.013	NLTT 4206, 2MASS
7254	6.388 ± 0.017	5.992 ± 0.027	5.894 ± 0.005	NLTT 5201, 2MASS
7372	5.340 ± 0.015	4.973 ± 0.075	4.690 ± 0.011	GJ 60 ABC, 2MASS
7580	5.211 ± 0.011	5.024 ± 0.025	4.893 ± 0.011	NLTT 5442, 2MASS
15382	3.405 ± 0.284	2.844 ± 0.254	2.741 ± 0.270	2MASS
19233	5.220 ± 0.010	4.905 ± 0.007	4.824 ± 0.008	Bouchet et al. (1991)
21280	6.989 ± 0.019	6.576 ± 0.019	6.465 ± 0.019	2MASS, vA 727 Carney (1982)
22550	5.710 ± 0.025	5.523 ± 0.033	5.436 ± 0.007	2MASS
22573	5.604 ± 0.015	5.553 ± 0.037	5.520 ± 0.015	2MASS
22607	5.235 ± 0.023	5.030 ± 0.011	4.941 ± 0.003	2MASS
25037	7.318 ± 0.011	7.235 ± 0.019	7.172 ± 0.015	2MASS
25119	5.940 ± 0.011	5.456 ± 0.033	5.302 ± 0.015	2MASS
27901	5.606 ± 0.017	5.439 ± 0.023	5.381 ± 0.011	2MASS
29234	4.974 ± 0.272	4.653 ± 0.236	4.586 ± 0.007	2MASS
30920	6.376 ± 0.015	5.754 ± 0.031	5.486 ± 0.005	V577 Mon, 2MASS
30953	4.774 ± 0.234	4.477 ± 0.240	4.334 ± 0.016	2MASS
33451	5.379 ± 0.013	5.171 ± 0.019	5.090 ± 0.015	2MASS
41261	6.262 ± 0.015	5.902 ± 0.023	5.790 ± 0.017	2MASS
42075	5.328 ± 0.262	4.748 ± 0.268	4.460 ± 0.019	2MASS
45170	5.121 ± 0.013	4.773 ± 0.033	4.664 ± 0.009	LHS 2114, 2MASS
46404	4.125 ± 0.007	3.815 ± 0.007	3.760 ± 0.014	HD 81809, Alonso et al. (1994)
46454	4.656 ± 0.236	4.262 ± 0.214	3.946 ± 0.033	2MASS
47479	5.369 ± 0.312	5.055 ± 0.338	4.798 ± 0.013	GJ 9305, 2MASS
53840	5.764 ± 0.007	5.471 ± 0.021	5.396 ± 0.013	NLTT 26003, 2MASS
114576	6.546 ± 0.013	6.308 ± 0.015	6.184 ± 0.009	2MASS

Fig. 6 Distributions of the magnitude differences between the two components Δm_J (blue solid line), Δm_H (green dotted line) and Δm_K (red dashed line), reported in Table 2.

ues obtained on sample of about 200 standard stars by other observers at ESO (Bouchet et al. (1991). Those standard stars were apparently single stars. Some of the spectral types are indicated close to the corresponding data points.

The individual stellar components have near-infrared colour indices rather well grouped along the line formed by the ESO standard stars. The dispersion is rather small. The only possible outlier is the B component of HIP 15382 AB (whose primary is indicated to be a K0-III star), which has an $H - K$ index slightly smaller from the other stars of our sample. However our sample is very small which makes any conclusion on this object too premature.

6 Conclusion

We obtained relative astrometric and differential photometric data for a sample of nearby southern orbital binaries for which high-quality Hipparcos parallaxes and supposed well-known orbits were already available, but for which accurate component magnitudes and/or colour indices were lacking. This lack of information may explain why some of these binaries did not fit well the empirical mean mass-luminosity relation first derived with the new Hipparcos parallaxes (Lampens et al. 1997). For about 30 binary systems of the sample, we additionally derived the component magnitudes and colour indices by combining existing total J -, H -, and K - magnitudes with our measurements of differential colours in the near-infrared J -, H -, K -passbands. Among these 30 observed systems,

Fig. 7 Magnitude difference between the two components plotted versus their angular separation. Those parameters were obtained by fitting Moffat profiles to the AO images (see Table 2).

Fig. 8 Near-infrared colour indices of the individual stellar components derived from Table 7. Used symbols are blue open circles for the primary components and blue open squares for the secondary components. Standard stars (from Bouchet et al., 1991) are plotted as black filled squares for main sequence stars and red filled circles for giant stars.

Table 7 Derived infrared component magnitudes and colours.

HIP	Cp	N _{tot}	J ₁ (mag)	J ₂ (mag)	H ₁ (mag)	H ₂ (mag)	K ₁ (mag)	K ₂ (mag)	(J–H) ₁ (mag)	(J–K) ₁ (mag)	(H–K) ₁ (mag)	(J–H) ₂ (mag)	(J–K) ₂ (mag)	(H–K) ₂ (mag)
730	AB	11	-	-	4.67	7.42	4.48	7.40	-	-	0.19	-	-	0.02
2941	AB	12	4.71	4.97	4.42	4.66	4.36	4.62	0.29	0.35	0.06	0.31	0.35	0.04
7254	AB	12	6.73	7.80	6.50	7.06	6.42	6.94	0.23	0.31	0.08	0.74	0.86	0.13
7372	AB	11	5.98	6.22	5.52	5.98	5.31	5.60	0.46	0.67	0.21	0.24	0.63	0.40
7372	AC	12	5.98	8.85	5.52	8.24	5.31	7.77	0.46	0.67	0.21	0.61	1.08	0.47
7580	AB	12	5.58	6.56	5.41	6.33	5.30	6.15	0.17	0.28	0.11	0.24	0.41	0.18
15382	AB	11	3.55	5.65	2.99	5.10	2.85	5.30	0.56	0.70	0.14	0.55	0.35	-0.20
19233	AB	12	5.30	8.16	4.98	7.83	4.90	7.73	0.31	0.40	0.08	0.33	0.42	0.10
21280	AB	12	7.31	8.46	7.04	7.72	6.94	7.59	0.27	0.37	0.10	0.74	0.87	0.12
22550	AB	12	6.42	6.50	6.23	6.33	6.13	6.25	0.20	0.30	0.10	0.18	0.25	0.07
22573	AB	12	6.18	6.57	6.17	6.46	6.14	6.43	0.01	0.04	0.03	0.11	0.15	0.03
22607	AB	12	5.53	6.78	5.36	6.48	5.27	6.39	0.17	0.26	0.09	0.30	0.40	0.09
25037	AB	8	-	-	7.70	8.37	7.64	8.31	-	-	0.06	-	-	0.06
25119	AB	12	6.18	7.70	5.79	6.91	5.65	6.72	0.39	0.53	0.14	0.79	0.98	0.19
27901	AB	8	-	-	5.78	6.88	5.73	6.78	-	-	0.05	-	-	0.09
29234	AB	12	5.74	5.71	5.36	5.45	5.28	5.40	0.38	0.46	0.08	0.26	0.31	0.05
30920	AB	5	6.60	8.22	-	-	-	-	-	-	-	-	-	-
30953	AB	12	5.50	5.55	5.20	5.25	5.06	5.11	0.30	0.44	0.14	0.30	0.44	0.14
33451	AB	12	6.00	6.28	5.81	6.05	5.71	5.99	0.19	0.29	0.10	0.24	0.30	0.06
41261	AB	12	6.86	7.20	6.51	6.82	6.40	6.70	0.35	0.46	0.11	0.38	0.49	0.11
42075	AB	12	5.70	6.68	5.12	6.10	4.83	5.80	0.58	0.86	0.29	0.59	0.88	0.30
45170	Aa	12	5.75	6.01	5.48	5.57	5.40	5.43	0.27	0.35	0.08	0.44	0.58	0.14
46404	AB	12	4.41	5.71	4.04	5.65	3.97	5.67	0.38	0.45	0.07	0.06	0.04	-0.02
46454	AB	12	5.13	5.78	4.70	5.46	4.36	5.20	0.44	0.78	0.34	0.32	0.58	0.26
47479	AB	12	6.07	6.17	5.75	5.87	5.49	5.62	0.33	0.58	0.26	0.30	0.56	0.25
53840	AB	12	6.43	6.61	6.11	6.36	6.01	6.31	0.33	0.42	0.10	0.25	0.30	0.05
114576	AB	12	7.19	7.42	6.94	7.19	6.85	7.03	0.24	0.34	0.10	0.23	0.39	0.16

seven targets pertain to the list of systems used by Xia & Fu (2010), though sometimes without information on the secondary component. We thus provide original data for the secondary (in casu tertiary) components of HIP 2941, HIP 7372, HIP 20087 and HIP 40167.

Our study took advantage of Adaptive Optics observations on a large telescope, that allowed us to derive relative astrometric and differential photometric measurements of the individual components of close binaries. We explained in detail the data reduction procedure that we used, in particular the Moffat profile fitting and the Fourier analysis. The Moffat profile method was very efficient in deriving accurate position and differential magnitude measurements. Fourier analysis was a useful complement for very close binaries, but a major problem was the difficulty to estimate accurately the PSF, since this PSF could not be calibrated simultaneously with the observations of the targets.

Based on a study of the astrometric $O - C$ residuals, we concluded that the orbits of HIP 7372 AC and HIP 46404 as well as those of HIP 21280 and HIP 41261

will need revision in the near future. The measurement we obtained for HIP 27901 is incompatible with the recently proposed orbit(s) and some previous measurements. However, it fits well the Hipparcos data. We suggest that this system needs more follow-up data before any reliable conclusion on its orbit can be drawn. For HIP 25037 AB, we showed that component A follows a rectilinear path on the sky which is also compatible with its proper motion. The system is an optical visual double star.

Fourier analysis furthermore revealed the presence of possibly two new components around HIP 20087, both of which are very close to the diffraction limit of the telescope. We also found another possible new binary star, HIP 19233, with a large magnitude difference. Those two possible serendipitous discoveries need confirming observations.

The newly presented photometric measurements show that most of the stellar components have near-infrared colour indices comparable to those of normal (apparently single) standard stars.

7 Appendix: computation of the gradient of the Moffat profile

In this appendix, we derive the gradient of our model (see Eq. 4.1 presented in Sect. 4):

$$I(x, y) = \sum_{m=1,2} I_m(x, y) + n_0 + n_1 x + n_2 y + n_3 xy$$

with

$$I_m(x, y) = \frac{h_m}{[1 + (b r_m)^2]^q}$$

The results are reported in Table 8.

The function $I_m(x, y)$ can be also written as:

$$I_m(x, y) = h_m \exp(-q \log A_m) \quad \text{with} \quad A_m = 1 + (b r_m)^2$$

It comes:

$$\frac{\partial I_m(x, y)}{\partial h_m} = \exp(-q \log A_m) = \frac{I_m(x, y)}{h_m}$$

and:

$$\frac{\partial I_m(x, y)}{\partial q} = -(\log A_m) I_m(x, y)$$

Since $\partial A_m(x, y)/\partial b = 2 r_m^2 b$, it comes:

$$\frac{\partial I_m(x, y)}{\partial b} = -q I_m(x, y) \frac{1}{A_m} (2 r_m^2 b)$$

This can also be written as:

$$\frac{\partial I_m(x, y)}{\partial b} = -B_m r_m \quad \text{with:} \quad B_m = \frac{2 I_m(x, y) q r_m b}{A_m}$$

Let us now consider the parameters e and k that are used in the expression of r_m . Since $\partial A_m(x, y)/\partial r_m = 2 r_m b^2$, we deduce:

$$\frac{\partial I_m(x, y)}{\partial e} = -\frac{q I_m(x, y) (2 r_m b^2)}{A_m} \frac{\partial r_m}{\partial e} = -B_m b \frac{\partial r_m}{\partial e} \quad (1)$$

and also:

$$\frac{\partial I_m(x, y)}{\partial k} = -B_m b \frac{\partial r_m}{\partial k} \quad (2)$$

Let us recall the expression (4.1) of Sect. 4:

$$r_m^2 = (x - x_m)^2 + e (x - x_m)(y - y_m) + (1 + k) (y - y_m)^2 \quad (3)$$

Let us differentiate with respect to e and k :

$$2 r_m \partial r_m = (x - x_m)(y - y_m) \partial e + (y - y_m)^2 \partial k$$

It comes:

$$\frac{\partial r_m}{\partial e} = \frac{(x - x_m)(y - y_m)}{2 r_m}$$

and

$$\frac{\partial r_m}{\partial k} = \frac{(y - y_m)^2}{2 r_m}$$

When substituting in (1) and (2), we obtain:

$$\frac{\partial I_m(x, y)}{\partial e} = -\frac{B_m b}{2 r_m} (x - x_m)(y - y_m)$$

and

$$\frac{\partial I_m(x, y)}{\partial k} = -\frac{B_m b}{2 r_m} (y - y_m)^2$$

Let us now consider the last parameters, which are x_m and y_m . The partial derivative of $I_m(x, y)$ relative to those variables are equal to:

$$\frac{\partial I_m(x, y)}{\partial x_m} = -B_m b \frac{\partial r_m}{\partial x_m} \quad (4)$$

and

$$\frac{\partial I_m(x, y)}{\partial y_m} = -B_m b \frac{\partial r_m}{\partial y_m} \quad (5)$$

To obtain the expression of the partial derivatives of r_m relative to x_m and y_m , let us develop the expression (3):

$$\begin{aligned} r_m^2 &= [x^2 + e x y + (1 + k) y_m^2] - x_m(2 x + e y) \\ &\quad + x_m^2 + e x_m y_m - y_m[x e + 2 y (1 + k)] \\ &\quad + y_m^2 (1 + k) \end{aligned} \quad (6)$$

Let us differentiate (6) with respect to x_m :

$$2 r_m \partial r_m = -(2 x + e y) \partial x_m + 2 x_m \partial x_m + e y_m \partial x_m$$

It comes:

$$\frac{\partial r_m}{\partial x_m} = \frac{-2 x - e y + 2 x_m + e y_m}{2 r_m}$$

After substitution in (5), we finally obtain:

$$\frac{\partial I_m(x, y)}{\partial x_m} = -\frac{B_m b}{2 r_m} (-2 x - e y + 2 x_m + e y_m)$$

Similarly, when differentiating the expression (6) with respect to y_m , we obtain:

$$\begin{aligned} 2 r_m \partial r_m &= -[e x + 2 y (1 + k)] \partial y_m \\ &\quad + 2 y_m (1 + k) \partial y_m + e x_m \partial y_m \end{aligned}$$

Hence:

$$\frac{\partial r_m}{\partial y_m} = \frac{-e x - 2 y (1 + k) + 2 y_m (1 + k) + e x_m}{2 r_m}$$

Let us substitute in (5):

$$\frac{\partial I_m(x, y)}{\partial y_m} = -\frac{B_m b}{2 r_m} [-e x - 2 y (1 + k) + 2 y_m (1 + k) + e x_m]$$

All the gradient components computed in this appendix are reported in Table 8.

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Table 8 Expression of the components of the gradient of $I_m(x, y)$, as a function of the parameters $A_m = 1 + (br_m)^2$ and $B_m = 2 I_m(x, y) q r_m b / A_m$. The symbol $\log$ designates the Napierian logarithm.

$\frac{\partial I(x, y)}{\partial n_0} = 1$
$\frac{\partial I(x, y)}{\partial n_1} = x$
$\frac{\partial I(x, y)}{\partial n_2} = y$
$\frac{\partial I(x, y)}{\partial n_3} = xy$
$\frac{\partial I_m(x, y)}{\partial h_m} = \frac{I_m(x, y)}{h_m}$
$\frac{\partial I_m(x, y)}{\partial b} = -B_m r_m$
$\frac{\partial I_m(x, y)}{\partial q} = -(\log A_m) I_m(x, y)$
$\frac{\partial I_m(x, y)}{\partial e} = -\frac{B_m b}{2 r_m} (x - x_m)(y - y_m)$
$\frac{\partial I_m(x, y)}{\partial k} = -\frac{B_m b}{2 r_m} (y - y_m)^2$
$\frac{\partial I_m(x, y)}{\partial x_m} = -\frac{B_m b}{2 r_m} (-2x - ey + 2x_m + ey_m)$
$\frac{\partial I_m(x, y)}{\partial y_m} = -\frac{B_m b}{2 r_m} [-ex - 2y(1+k) + 2y_m(1+k) + ex_m]$

References

- Alves, D.R., 2000, ApJ 539, 732
- Alonso, A., Arribas, S., Martínez-Roger, C., 1994, A&A Suppl. 107, 365
- Andersen, J., 1991, A&A Rev. 3, 91
- Argyle, R.W., Alzner, A., Horch, E.P., 2002, A&A 384, 171
- Alzner, A., Argyle, R.W., Anton, R., 2009, Commission 26 Circular No 169
- Balega, I.I., Balega, Yu. Yu., Maksimov, A.F., Malogolovets, E.V., Pluzhnik, E.A., Shkhagosheva, Z., 2006, Bull. Spec. Astrophys. Obs. 59, 20
- Berthier, J., et al. 2002, <http://www.bdl.fr/priam/adonis>
- Bessel, M.S., 2005, ARAA, 43, 293
- Bouchet, P., Manfroid, J., Schmider, F.X., 1991, A&AS 91, 409
- Byrd, R.H., Lu, P., Nocedal, J., Zhu, C., 1995, SIAM Journal on Scientific Computing, 16, 5, 1190
- Carney, B.W., 1982, AJ 87, 1527
- Christy, J.W., Walker, R.L., 1969, PASP 81, 643
- Cuyppers, J., 1997, ASSL 223, eds. J.A. Docobo et al., 35
- Cvetkovic, Z., 2008, AJ, 136, 1746
- Cvetkovic, Z., Ninkovic, S., 2008, New Astronomy 13, 587
- Delfosse, X., Forveille, T., Ségransan, D., Beuzit, J.-L., Udry, S. et al., 2000, A&A 364, 217
- Devillard, N., 1997, The ESO Messenger, 87, 19
- Docobo, J.A., Ling, J.F., 2009, AJ 138, 1159
- Docobo, J.A., Andrade, M., 2010, IAU Comm. 26, Inf. Circ 177
- Dommanget, J. & Nijs, O., 2002 Observations et Travaux 54, 5 (CCDM)
- Edwards, T.W., 1976, AJ 81, 245
- ESA, 1997, “The Hipparchos and Tycho Catalogues”, ESA-SP 1200
- Fabricius, C., Høg, E., Makarov, V.V., Mason, B.D., Wycoff, G.L., Urban, S.E., 2002, A&A 384, 180
- Halbwachs, J. L., Mayor, M., Udry, S., 2005, A&A 431, 1129
- Hartkopf, W.I., Mason, B.D., McAlister, H.A., 1996a, AJ 111, 370
- Hartkopf, W.I., et al., 1996b, AJ 111, 936
- Hartkopf, W.I., et al., 2000, AJ, 119, 308
- Hartkopf, W.I., Mason, B.D., 2010, IAU Comm. 26 Inf. Circ. 170
- Hartkopf, W.I., et al., 2012a, AJ, 143, 42
- Hartkopf, W.I., Mason, B.D., Worley, C.E., 2012b, “Sixth Catalog of Orbits of Visual Binary Stars”, <http://ad.usno.navy.mil/wds/orb6.html>
- Henry, T.J., McCarthy, D.W. Jr., 1993, AJ, 106, 773
- Henry, T.J., Franz, O.G., Wasserman, L.H., Benedict, G.F., Shelus, P.J., Ianna, P.A., Kirkpatrick, J.D., McCarthy, D.W., 1999, ApJ, 512, 864
- Henry, T.J., 2004, in: Hilditch, R.W., Hensberge, H., Pavlovski, K. (eds.) ‘The Mass-Luminosity Relation from End to End’, ASP Conf. Ser., vol. 318, p. 159
- Hutchings, J. B., Griffin, R. F., Ménard, F., 2000, PASP, 112, 833
- Imanishi, M., Alonso-Herrero, A., 2004, ApJ 614, 122
- Kimeswenger, S., Lederle, C., Richichi, A., Percheron, I., Paresce, F., Armsdorfer, B., Bacher, A., et al., 2004, A&A 413, 1037
- Patience, J., Ghez, A., M., Reid, I., N., Weinberger, A., J., Matthews, K., 1998, AJ 115, 1972
- Lampens, P., Kovalevsky, J., Froeschlé, M., Ruymaekers, G., 1997, in Proc. JD 14, IAU GA XXIII, Kyoto, 1997
- Lampens, P., Strigachev, A., 2001, A&A 368, 572
- Lampens, P., Oblak, E., Duval, D., Chareton, M., 2001, A&A 374, 132
- Lampens, P., Strigachev, A., Duval, D., 2007, A&A 464, 641
- Martin, C., Mignard, F., 1998, A&A 330, 585
- Mason, B.D., et al., 1996, AJ, 112, 276
- Mason, B.D., Douglas, G.G., Hartkopf, W.I., 1999, AJ 117, 1023
- Mason, B.D., et al., 2002, AJ, 124, 2254
- Mason, B.D., Hartkopf, W.I., Wycoff, G.L., Rafferty, T.J., 2006, AJ 131, 2687
- Mason, B.D., Wycoff, G.L., Hartkopf, W.I., 2012, “The Washington Double Star Catalogue” <http://ad.usno.navy.mil/wds/wds.html>
- Moffat, A.F.J., 1982, A&A, 3, 455
- Muterspaugh et al., 2010, AJ, 140, 1623
- Oblak, E., Cuyppers, J., Lampens, P., Seggewiss, W., Chareton, M., Duval, D., 1997, Proc of the ESA symposium “Hipparcos-Venice 97”, ESA SP-402, 445.
- Persson, S.E., Aaronson, M.A., Frogel, J.A., 1977, AJ 82, 729
- Popper, D.M., 1980, ARAA 18, 115
- Pourbaix, D., 2000, A&A Suppl. 145, 215
- Roberts, L.C., ten Brummelaar, T.A., 1998, “Poster Proceedings on Fundamental Stellar Properties”, IAU 189, 72.

- Ruymaekers, G., 1999, unpublished Ph. D. Thesis, Catholic Univ. of Leuven
- Söderhjelm, S., 1999, A&A 341, 121
- Seymour, D.M., Mason, B.D., Hartkopf, W.I., Wycoff, G.L., 2002, AJ 123, 1023
- Ségransan, D., Delfosse, X., Forveille, T., Beuzit, J.-L., Udry, S., Perrier, C., Mayor, M., 2000, A&A 364, 665
- Strigachev, A., Lampens, P., 2004, A&A 422, 1023
- ten Brummelaar, T.A., Mason, B.D., Bagnuolo, W.G., Hartkopf, W.I., McAlister, H.A., Turner, N.H., 1996, AJ 112, 1180
- Xia, F., Ren, S., Fu, Y., 2008, Ap&SS 314, 51
- Xia, F., Fu, Y., 2010, Chin. A&A 34, 277