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Multicolour CCD measurements of nearby visual double stars. II*

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Abstract. We present accurate CCD astrometric and photometric data for 31 nearby visual double stars in the standard filters *BVRI*. The observations were collected with a 1.3-m telescope in 2001–2002**. The results consist of relative astrometric positions (epoch, angular separation and position angle) and differential *BVRI* photometry of the components. Mean errors are: 0.01″ for the separation; 0.06° for the position angle; and $0\overset{m}{.}015$ for the photometric data. Comparing the relative positions at different epochs, we evaluate the physical association of the systems. We additionally derive fractional masses and true separations for the most probable binary systems and, whenever orbits are available, also total and component masses.

Key words. stars: binaries: visual – techniques: photometric – stars: fundamental parameters

1. Introduction

This is the second paper devoted to CCD observations of nearby visual double stars performed at the Skinakas Observatory (Crete). In Paper I (Lampens & Strigachev 2001), we set the context of this research: our goal is to determine with a good accuracy the true separations, relative motions, masses (total and individual), luminosity ratios and temperature differences of the visual binaries in the immediate Solar neighbourhood. The determination of the distribution functions of these properties is known to provide observational constraints to the various scenarios of binary star formation and offers a direct calibration tool for basic stellar properties. We therefore need to accurately measure and monitor the (changing) astrometric parameters providing the fundamental data on the binaries as well as the individual properties of each component such as the magnitude and the colour indices. Accurate magnitude and colour differences of double stars allow the characterization of the evolutionary stage of the components as they allow one to derive basic properties of the system in the form of the luminosity and mass ratios and the temperature difference. It therefore remains surprising that colour differences, – if they exist at all – are seldom accurate, even for the nearest and brightest systems. Of course, the Hipparcos Catalogue provides a precise differential magnitude, ΔHp, for many visual binaries for the first time (ESA 1997). And while the recent Tycho Double Star Catalogue (Fabricius et al. 2002) allows one to derive the differences ΔB_T and ΔV_T (only if $\rho > 0.5''$ and $\Delta m < 3$ mag), its accuracy is much lower and the information is not always complete. Note also that, from a comparison with ground-based CCD measurements, the Tycho-1 mag measurements of the components of double stars with separations up to 34″ (i.e. the width of the star mapper slits) were found to be contaminated by the companions (Halbwachs et al. 1997). For the construction of the Tycho-2 Catalogue, reprocessing with a dedicated tool for double star analysis was applied to visual double stars with separations between 0.8 and 2.5″ only, whereas the components of the wider systems were still treated as independent entries (Fabricius et al. 2002).

In this work we present high-accuracy relative astrometry and *BVRI* differential photometric data for several tens of visual double stars from a programme that is based on the improved census of the Solar neighbourhood from the Hipparcos mission, which led to a significant change of the stellar content in the Solar vicinity (Jahreiss & Wielen 1998). The majority of our programme stars belongs to the intersection of the Catalogue of Nearby Stars (GJ, Gliese & Jahreiss 1991)

* Table 2 is only available in the electronic form at http:www.edpsciences.org. Tables 4 and 5 are only available in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/cgi-bin/qcat?J/A+A/422/1023

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and the Hipparcos Catalogue (ESA 1997) and have parallaxes larger than 0.04″. They have been furthermore chosen among the systems with "intermediate" angular separation (between 1 and 15″) for which CCD observations can provide both accurate and complementary data on each of the components. Their absolute parallax measurements are very accurate. In a few cases however, we made use of the ground-based determined absolute parallaxes from The General Catalogue of Trigonometric Stellar Parallaxes (Van Altena et al. 1995) as they appear to be of higher accuracy than the Hipparcos ones.

The paper is organized as follows: firstly, we present the observations, the reduction method and the astrometric calibrations in Sect. 2. Next we show the resulting astrometric and photometric data (Sect. 3), followed by a discussion of the errors. In Sect. 4 we derive, wherever possible, true separations and masses for the probable physical binaries. Finally, conclusions are presented (Sect. 5).

2. Observations and reductions

2.1. Instrumentation and limitations

The observations were performed at the Skinakas Observatory of the Institute of Astronomy, University of Crete, Greece using the 1.3-m telescope equipped with a CCD camera. The telescope is an f/7.7 Modified Ritchey-Chrétien. The CCD is a Photometrics 1024 × 1024 SITe SI003B chip of grade 1 with a pixel size of 24 μm corresponding to a scale of 0.5″ on the sky. The usable field of view is 8.5′ × 8.5′.

The frames were taken from May to June 2001 and during August 2002 through standard Johnson B, V and Cousins R, I filters (Papadakis et al. 2003). Only visual double stars not brighter than mag 6 and with expected angular separations larger than or equal to about 1″ were observed. These programme stars are listed in Table 1. Their angular separations range from 1 to 22″ while the differential V magnitudes are smaller than $4\overset{m}{.}0$.

During the observations the exposure times were adjusted in order to get the highest possible counts for the primary (brighter) component without overexposing; they were usually a few seconds long. A set of three biases was taken regularly during each night, i.e. every few hours. Flat-fields were obtained during evening and/or morning twilights: a set of 5 to 6 flats per filter was taken every night. The open cluster NGC 6611 (=M 16) was chosen as the astrometric standard field. The seeing during these observations was $1.6 \pm 0.2''$. The logbook of the observations is shown in Table 2.

2.2. The reduction method

All the primary reduction steps were performed using ESO-MIDAS standard routines. The frames were processed for bias and flat-field corrections. They include: subtraction of the residual bias pattern using a median master zero exposure frame, flat-fielding using a median master flat-field frame, and median cosmic ray cleaning.

Next we computed the angular separations (in pixels), the position angles and the magnitude differences in the various filters for the components of the double stars. For this we used a two-dimensional Moffat-Lorentz profile (Moffat 1982) fitting method. This dedicated tool was developed by Cuypers (1997) within the ESO-MIDAS environment and was also used in Paper I.

2.3. Astrometric calibration

To convert the angular positions to absolute units we applied the astrometric corrections as computed from stars observed in the field of NGC 6611. We used the following nine stars with the numbering 166, 197, 205, 223, 235, 246, 254, 280, 314, with the identification numbers and the coordinates following Hillenbrand et al. (1993). We measured their positions on the frames with standard ESO-MIDAS routines. A multi-linear regression fit was applied between the (x, y) positions and the catalogued (α, δ) values to determine the scale and the orientation of the CCD chip, the latter being measured from the direction North towards East. The finally adopted values are presented in Cols. 3 and 5 of Table 3. In Col. 7 we list the Hipparcos numbers of the stars whose astrometric data were corrected with the corresponding values.

The thus computed scale is extremely close to the specifications of the telescope (Sect. 2.1) and to the value derived in Paper I (within the errors).

3. Presentation and discussion of the results

3.1. Astrometric and photometric results

The results consist of relative astrometric positions and differential photometry of the components.

The astrometric data are listed in Table 4. The first column gives the Hipparcos identification number, followed by the epoch (Bessel year), the angular separation (ρ) and the position angle (θ) measured from North to East, with the respective standard errors σ_ρ and σ_θ. The values of ρ and θ are the means of several frames measured in the different filters. The number of frames per filter typically equals 3 (cf. Table 2). The next columns show the comparison of the relative positions with the Hipparcos Catalogue data (at epoch 1991.25) in the sense ours minus Hipparcos. In the last column we mention if the system has a known orbit or shows a linear relative motion (in the case of an optical pair). Other remarks concern the quality of the Hipparcos double-star solution.

In Table 5 the following photometric data are listed: the V magnitude difference (ΔV) and the colour differences (($\Delta B - \Delta V$), ($\Delta V - \Delta R$) and ($\Delta V - \Delta I$)), together with their respective standard errors. We consider that these values reflect the colour differences between the components (e.g. $\Delta(B - V)$) very well.

Specific comments are needed for the following systems:

HIP 2552: the colour differences were computed between the B and the Aa components (Henry & McCarthy 1993).

HIP 17749/50: the colour differences were computed between the A and the BC components.

HIP 54952: component B is too far (at 54.5″) and does not influence our measurements.

Table 1. General information on the observed stars.

HIP Nr	Cmp[1]	GJ[2] Nr	CCDM[3]	Extra Ident.	m_V (mag)	Sp	ρ (Hp) (″)	θ (Hp) (°)	π (mas)	$\sigma(\pi)$ (mas)
473	AB	4	00057+4548	BD +45 4408	9.01	K7	6.041	178.3	85.10	2.74
2552	Aa-B	22	00325+6714	BD +66 34	10.29	M2	4.147	163.4	97.[4]	2.[4]
3937	AB	3060	00506+2449	LDS 3203	11.69	M3.5	2.080	316.	83.20	9.08
10531/29	AB	90	02157+6740	HD 13579	7.18	K2V	18.580	337.3	55.1[5]	1.2[5]
13642	AB	9105	02556+2652	HD 18143	7.58	G5	5.538	220.3	43.71	1.26
15844	AB	140	03241+2347	WOR 4	10.38	M1	2.247	347.1	50.54	4.66
17666	AB	1064	03470+4126	HD 23439	8.18	K1V	7.307	54.2	40.83	2.24
17749/50	A-BC	153	03480+6841	HD 23189	9.07	K0	17.11	14.	57.53	2.68
18512	AB	157	03575 – 0110	HD 24916	8.00	K4V	11.078	17.3	63.41	2.00
21088	AB	169.1	04312+5858	STI 2051	10.82	M4	8.350	69.4	180.6[6]	0.8[6]
54952	AC	420	11153+7328	HD 97584	7.63	K5	6.619	321.0	68.13	1.18
56 809	AB	9370	11387+4506	HD 101177	6.44	G0V	9.224	249.5	42.94	0.95
63253	AB	490	12577+3514	BD +36 2322	10.50	M0.5	15.990	225.8	55.27[7]	3.15
65011/12	BC	507	13192+3507	BD +35 2436	9.52	M0.5	17.650	129.2	75.96	3.31
65343	AB	509	13235+2914	HD 116495	8.90	K5	1.313	77.8	53.97	2.13
66077	AB	516	13327+1649	VYS 6	11.38	M2.5	–	–	61.5[6]	5.7[6]
66492	AB	520	13379+4808	BD +48 2138	9.76	M0	2.166	311.9	45.66	2.72
67422	AB	528	13491+2659	HD 120476	7.04	K2	3.456	166.5	73.25[7]	1.33
79492	AB	615.1	16134+1331	HD 145958	6.68	G8V	4.139	352.2	41.05	1.58
83020	AB	649.1	16578+4722	HD 153557	7.83	K3V	4.915	61.0	55.71	1.21
83988/96	AB	659	17102+5430	HD 155674	8.80	K0	22.189	133.6	47.14	1.88
86282	AB	9596	17378+2257	BD +23 3151	9.89	K5	4.265	185.5	42.0[6]	2.8[6]
87768	AB	698	17557+1830	BD +18 3497	9.23	K5	18.788	46.7	43.40	2.21
91768/72	AB	725	18428+5937	HD 173739	8.91	M3V	13.34	170.4	280.28	2.57
94336	AB	9648	19121+4951	HD 179958	6.57	G4V	7.648	207.8	40.16	0.83
97241	AB	4122	19458+3223	CRI 24	10.86	M1	12.765	338.9	87.57	4.80
97292	AB	767	19464+3201	HD 331161	10.28	M1	4.866	133.7	73.8[6]	1.9[6]
106694	AB	834	21366+3927	VYS 10	10.20	M0	1.783	283.6	46.80	3.37
110526	AB	856	22235+3228	WOR 11	11.40	M3	1.772	199.0	62.18	10.01
110640	AB	857.1	22248+2233	BD +21 4747	8.82	M0	1.613	228.	46.74	1.66
110893	AB	860	22281+5741	HD 239960	9.59	M3	3.400	128.3	249.52	3.03

[1] Component identification.
[2] Gliese & Jahreiss (1991).
[3] Dommanget & Nys (2002).
[4] Revised Hipparcos parallax (Söderhjelm 1999).
[5] The alternative Hipparcos parallax solution is adopted.
[6] Van Altena et al. (1995).
[7] The ground-based and Hipparcos parallaxes are slightly discrepant (2 σ-level).

Table 2. Log of observations (only available online at EDP Sciences).

HIP 65011/12: the colour differences were computed between the C and the B components (ESA 1997). Note that Balega et al. (1999) resolved the latter into a close double (BAG 11 Aa) and that these components are called B and A in the Washington Double Star Catalog (Mason et al. 2001).

3.2. Errors of the astrometry

The error in relative position (cf. Table 4) includes the contributions of the standard error on the mean value and the error of the astrometric calibration following the law of propagation of errors and supposing all the measurements to be independent. The astrometric measurements have typical errors of 0.01–0.04 pixels (5–20 mas), depending on the angular separation and on the magnitude difference between the components (Lampens et al. 2001). Surprisingly, the largest differences are mostly found for the widest angular separations (i.e. ≥15″). This can be explained by the fact that the Hipparcos measurement is not always reliable in this range of separation (ESA 1997, Vol. 1, p. 80). The average accuracy of the

Table 3. Astrometric calibration.

Astrometric standard field	Date	Scale (″/px)	σ(Scale) (″/px)	Orientation (°)	σ(Orientation) (°)	Corrected stars HIP Nr
NGC 6611	17 May 2001	0.499	0.001	0.35	0.01	79492, 83020, 83988/96, 86282, 87768, 91768/72, 94336, 97241, 97292, 106694, 110893
NGC 6611	5 June 2001	0.499	0.001	0.21	0.01	54952, 56809, 63253, 65011/12, 65343, 66492, 67422
NGC 6611	22 August 2002	0.498	0.001	0.39	0.01	473, 2552, 3937, 10531/29, 13642, 15844, 17666, 17749/50, 18512, 21088, 66077, 110526, 110640

Table 4. Astrometric results and comparison of the relative positions with the Hipparcos data (only available online at the CDS).

Table 5. Differential photometry (only available online at the CDS).

stellar coordinates used for the astrometric calibration is 0.3″ according to Hillenbrand et al. (1993). The standard errors of the multi-linear regression are extremely small (of the order of 0.00001) and are thus insignificant. The values of the scale and the orientation in Table 3 are the means of 3 different observational runs. Their rms errors are a factor of 10 smaller than the standard errors on the means of the measurements themselves. Because the astrometric calibration obtained with NGC 6611 is of very high quality, the errors in relative position are mainly a reflection of the internal consistency between the various filters used.

3.3. Errors of the photometry

The internal errors in magnitude difference ΔV in Table 5 are the standard errors of the mean value. The errors on the colours were computed taking into account the contribution of both filters.

In Fig. 1 we plotted the internal error of the magnitude difference ΔV as a function of angular separation for two classes of ΔV for illustration: one can see that errors ≥20 mmag are linked to either a larger ΔV value and/or a smaller angular separation. The mean photometric error is 15 mmag for all observed separations and ΔV values; it is however below 10 mmag in the more favourable cases.

External photometric errors can be estimated by observing the same (non-variable) targets with the same instrument during different campaigns. The stars HIP 2552, 86282, 97292 and 110893 were already observed by us before (cf. Paper I). In three cases (HIP 2552, 86282 and 110893) we were able to compare with the previous measurements (there are not enough measurements of HIP 97292). This result is shown in Table 6. The difference δ is in the sense these data minus those of Paper I. The contribution of various possible error sources was considered. The mean of the differences in differential magnitude and colours weighted with respect to their errors as listed in Table 6 is 0.005 ± 0.001 mag. This is a test

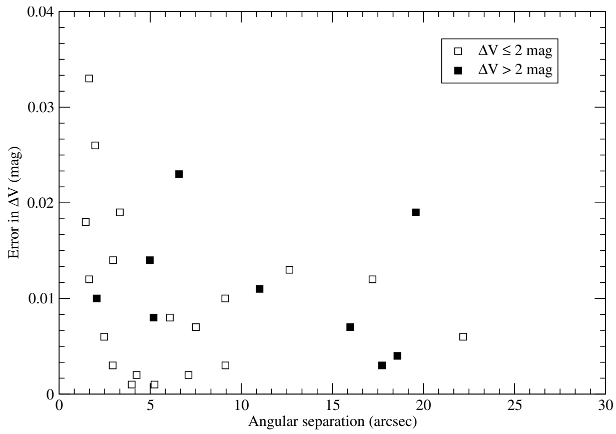

Fig. 1. Photometry error vs. angular separation (in arcsec).

for the quoted internal errors and also shows that there are no significant magnitude changes for these stars over the two years interval (Note, however, that HIP 2552 A = V547 Cas and HIP 110893 B = DO Cep are known flare stars).

4. Determination of total and component masses and of true separations

From the colour differences presented in Table 5 and the joint *UBV* photometry of the systems available in the General Catalogue of Photometric Data (mean values for $(B-V)_{\rm AB}$ or for the measured component colours $(B-V)_{\rm A}(B-V)_{\rm B}$ from Mermilliod et al. 1997), applying Eq. (3) of Mermilliod et al. (1992), we derived the individual colours of the components. We then made use of the bolometric corrections listed as a function of $(B-V)$ for main-sequence stars in Table 3 by Flower (1996). We computed the fractional mass, $\beta = M_{\rm B}/M_{\rm A+B}$, of the probable physical binaries of the sample via the relation:

$$\beta = 1/\left(1 + 10^{\Delta M_{\rm Bol}/(2.5\,{\rm K})}\right),$$

and the mass-luminosity relation with slope $K = 3.82 \pm 0.07$ (Lampens et al. 1998). For binaries on the lower part of the main sequence ($0.18\ M_{\odot} < M_{\rm A+B} < 0.5\ M_{\odot}$ as in the case of HIP 110893), we used the slope of 1.59 as derived by Henry & McCarthy (1993).

The global and component colours, the differences in bolometric correction, $\Delta M_{\rm Bol}$, as well as the resulting fractional

Table 6. Differences of differential magnitude and colours over two years (1999–2001).

HIP	$\delta\Delta V$	$\sigma(\delta\Delta V)$	$\delta(\Delta B-\Delta V)$	$\sigma(\delta(\Delta B-\Delta V))$	$\delta(\Delta V-\Delta R)$	$\sigma(\delta(\Delta V-\Delta R))$	$\delta(\Delta V-\Delta I)$	$\sigma(\delta(\Delta V-\Delta I))$
2552	0.011	0.006	0.010	0.013	0.000	0.008	0.037	0.008
86282	–0.004	0.002	–0.011	0.004	–0.042	0.026	–0.024	0.004
110893	0.011	0.015	–	–	0.001	0.032	0.055	0.046

masses are presented in Table 7. For HIP 2552 and HIP 86282 we compared these values with those of Paper I: the differences are smaller than 0.004. The distance between the primaries and their components (true separation in astronomical units) is also mentioned in Table 7. The quoted error includes the contribution of the standard error of both the angular separation and the parallax (mostly Hipparcos).

The published orbital elements (Hartkopf et al. 2001) are listed in Table 8. In Table 9 we give the sum and the component masses for systems with both known orbits and fractional masses. The majority of these orbits has a quality grade which is bad (grade 4 or 5) except for HIP 67422 and HIP 110893 (grade 2). In the latter cases the residuals are of order 50–70 mas. The relative positions of HIP 473, HIP 18512, HIP 65343, HIP 91768 and, to some extent, also HIP 110893 show large offsets with respect to their published orbits. The listed period, P, and semi-major axis, a, have been used to compute the sum of the masses of the components (except for HIP 13642, which in our case seems to show a relative linear motion, see Table 4). The relative error on the sum of the masses, $E_{\mathcal{M}_{\mathcal{A}+\mathcal{B}}}$, as derived from Kepler's third law,

$$E_{\mathcal{M}_{\mathcal{A}+\mathcal{B}}} = \pm\sqrt{E^2_{a^3/P^2} + 9E^2_{\pi}},$$

– where π is the parallax – depends on the relative error E_π (times a factor 3) and on the relative error E_{a^3/P^2}. The contribution of the relative error of the ratio (a^3/P^2) is usually small compared to the one of the parallax but should not be neglected in the case of a nearby system. One can deduce from the formula above that, in order to reach a relative accuracy of 10% on the mass sum, the relative error of a^3/P^2 should not exceed 1% if E_π equals 3.3% (the latter being valid only for systems within 17 pc, i.e. having a parallax >0.060″, given the standard Hipparcos parallax accuracy of 2 mas. This situation illustrates the typical case for the orbital pairs listed in Table 9. HIP 65343, HIP 66492 and HIP 79492 have slightly larger errors of respectively 4%, 6% and 3.9%). Considering that the majority of the orbits are of grade 4 ("preliminary") or 5 ("indeterminate") a relative error E_{a^3/P^2} of at least 10% must be adopted based on a statistical comparison between orbit grades (assigned by Worley & Heintz 1983) and the relative error E_{a^3/P^2} (called "quality index" by Ruymaekers 1999). The comparison indeed showed that only 25% of the orbits rated grade 4 and none of the orbits rated grade 5 corresponded to $E_{a^3/P^2} < 10\%$ (Table 3.5 in Ruymaekers 1999). When no errors on the orbital elements are published, we adopted a minimal error of 15% (orbits with grade 4 and 5) and of 10% (two orbits with grade 2) for E_{a^3/P^2}. Thus the error $\sigma(\mathcal{M}_{\mathcal{A}+\mathcal{B}})$ is generally a lower limit. Else, we mention the relative sum mass errors following the error propagation law as was previously done (e.g. HIP 110893). Except for two cases (HIP 67422 and HIP 110893), the relative sum mass error will therefore never be smaller than 15%.

5. Conclusions

In this paper we presented high-accuracy astrometric and photometric results of multicolour CCD observations for 31 visual double stars in the Solar neighbourhood. As already mentioned in Paper I, the 1.3-m telescope at the Skinakas Observatory equipped with a professional CCD camera allows one to obtain high-quality data on "intermediate" visual double stars, with an angular separation >1.4″. The mean internal errors are 0.01 ± 0.001″ in angular separation, 0.06 ± 0.005° in position angle and $0^{\mathrm{m}}.015$ ± 0.001 in differential photometry. A comparison with some previous measurements shows that the quoted errors are consistent.

From a comparison of the new relative positions with the Hipparcos ones (with a minimum epoch difference of over 10 years) we can classify the 31 visual double stars as follows: 3 are optical pairs (HIP 3937, HIP 10531/29 – with ambiguous Hipparcos solution – and HIP 97292); 12 have known orbits (Table 8); HIP 13642 has a parabolic orbit (Hopmann 1967) but the data also fit a relative linear motion; 3 have a stable configuration (HIP 63253, HIP 83020 and HIP 86282); 3 have ambiguous Hipparcos solutions (HIP 21088, HIP 87768 and HIP 97241). The remaining 10 show a relative motion.

Comparing with the corresponding ephemeris positions, we conclude that the relative positions of HIP 473, HIP 18512, HIP 65343, HIP 91768 and, to some extent, also HIP 110893 show large offsets with respect to their latest published orbits. These binaries still need to be monitored in the future to improve the accuracy of the orbital parameters, and in particular of the ratio (a^3/P^2) to have more reliable mass determinations for these nearby systems.

We computed the differences ΔB, ΔV, ΔR and ΔI between the components, allowing us to derive at least one colour difference for all these double stars except for one case (HIP 79492). We stress the fact that in 12 of these 31 cases, no ΔB_T values exist in the Tycho Double Star Catalogue (Fabricius et al. 2002). Based on the newly derived component colours, we computed the differences in bolometric magnitude and determined the true separations and the fractional masses whenever joint photometric data were also found in the literature for 10 of the 12 orbital pairs and for 8 visual double stars showing evidence of relative motion as well as for one yet unclassified case (HIP 87768, a wide pair discovered during the Hipparcos

Table 7. Component colours, ΔM_{Bol}, fractional masses and estimated true separations.

HIP	$(B-V)_{AB}$	$(B-V)_A$	$(B-V)_B$	ΔBC	ΔM_{Bol}	β	Sep(AU)	σ(Sep)
473	1.443	1.445	1.440	0.011	0.085	0.495	71	2
2552	1.597	1.586	1.654	–0.456	1.352	0.419	41	1
15844	1.500	1.489	1.537	–0.146	1.162	0.430	49	5
17666	0.799	0.762	0.868	–0.088	0.514	0.469	174	10
17749/50	–	1.335[1]	1.538[1]	–0.463	1.020	0.439	299	14
18512	1.127	1.116	1.439	–0.488	2.984	0.327	174	6
54952	1.034	1.024	1.517	–0.792	3.197	0.316	97	2
56809	–	0.566[1]	0.937[1]	–0.277	1.469	0.412	212	5
65011/12	1.49	1.483	1.574	–0.307	2.345	0.362	233	10
66077	1.538	1.533	1.546	–0.046	0.392	0.476	48	4
66492	1.392	1.416	1.324	0.163	1.355	0.419	43	3
67422	1.112	1.023	1.246	–0.268	0.072	0.496	45	1
79492	0.762	–	–	–	–	–	101	4
87768	1.18	1.159	1.438	–0.435	2.136	0.374	428	22
91768/72	1.557	1.535	1.603	–0.297	0.493	0.470	45	1
94336	0.67	0.645[1]	–	–	–	–	187	4
110526	1.560	1.556	1.564	–0.032	–0.009	0.500	26	4
110640	1.19	1.170	1.366	–0.280	2.002	0.382	44	2
HIP	$(R-I)_{AB}$	$(R-I)_A$	$(R-I)_B$	ΔBC	ΔM_{Bol}	β	Sep(AU)	σ(Sep)
65343	0.61	0.553	0.685	–0.15[2,3]	0.24	0.486	27	1
106694	0.76	0.664	1.142	–0.96[2,3]	1.00	0.440	33	2
110893	1.55	1.465	1.840	–0.63[2]	1.08	0.349	12	1

[1] Observed mean values from Mermilliod et al. (1997).
[2] Derived from Lang (1992).
[3] Using the statistical relations from Caldwell & Cousins (1993).

Table 8. Parameters and residuals (of the relative positions) with respect to known orbits.

HIP Nr	P (yr)	a (″)	i (°)	Ω (°)	T	e	ω (°)	$\Delta\rho$ (″)	$\Delta\theta$ (°)	ΔPos (″)	(Orbit grade)
473	509.65	6.21	54.9	13.5	2115.8	0.22	267.2	0.011	–0.820	0.088	Kiyaeva et al. (2001) (gr 4)
2552	320.0	4.09	53.0	164.0	1782.	0.0	125.0	–0.036	–0.100	0.037	Paper I (gr 5)
18512	3200.0	11.1	180.0	27.6	1900.	0.0	0.0	–0.096	–0.930	0.203	Dommanget (1978) (gr 5)
56809	2050.	10.33	125.86	271.24	2500.	0.05	129.58	0.053	–0.150	0.058	Hale (1994) (gr 5)
65343	229.0	2.14	78.4	118.7	1883.6	0.835	105.2	0.136	–0.400	0.136	Ambruster (1978) (gr 4)
66077	430.	3.17	59.4	33.3	1973.5	0.0	0.0	–0.023	–0.380	0.030	Heintz (1990) (gr 5)
66492	330.	2.13	36.3	157.4	2047.	0.611	280.7	0.025	0.470	0.030	Seymour et al. (2002) (gr 5)
67422	155.75	2.433	47.4	155.4	1916.75	0.446	200.0	0.034	–0.680	0.052	Heintz (1988) (gr 2)
79492	1354.	5.090	58.7	148.5	1754.	0.39	111.4	0.039	–0.440	0.050	Hopmann (1964) (gr 4)
91768	408.	13.88	66.0	136.9	1775.	0.53	234.6	0.161	–0.790	0.236	Heintz (1987) (gr 4)
94336	3100.	12.75	119.06	255.22	2520.	0.50	186.09	0.017	–0.880	0.067	Hale (1994) (gr 5)
110893	44.78	2.381	165.8	170.	1925.66	0.415	227.6	0.045	–1.220	0.077	Paper I (gr 2)

mission but with a very poor solution), i.e. for those systems of the sample showing evidence of a relative (orbital) motion.

Finally, we also derived the sum and the component masses for 10 of the 12 visual binaries whose orbital parameters are known and published. Among these, 2 are fully consistent with a previous determination while 8 are new.

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Table 9. Sum and component mass determinations.

HIP Nr	M_{A+B} ($M_\odot$)	$\sigma(M_{A+B})$ ($M_\odot$)	M_A ($M_\odot$)	M_B ($M_\odot$)
473	1.50	0.27	0.76	0.74
2552	0.69	–[1]	0.40[1]	0.29[1]
18512	0.52	0.09	0.35	0.17
56809	3.31	0.54	1.95	1.36
65343	1.19	0.23	0.61	0.58
66077	0.74	0.32	0.39	0.35
66492	0.93	0.22	0.54	0.39
67422	1.51	0.17	0.76	0.75
79492	1.04	0.20	–	–
91768/72	0.73	0.11	0.39	0.34
94336	3.33	0.54	–	–
110893	0.43	0.02[1]	0.28[1]	0.15[1]

(1) cf. Paper I.

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References

Ambruster, C. 1978, PASP, 90, 219

Balega, I. I., Balega, Y. Y., Maksimov, A. F., et al. 1999, A&AS, 140, 287

Caldwell, J. A. R., & Cousins, A. W. J. 1993, in Proc. of a Conference held to honour A.W.J. Cousins in his 90th year, held Cape Town, South Africa, ed. D. Kilkenny, E. Lastovica, & J. W. Menzies, SAAO, 247

Cuypers, J. 1997, In Proc. of the International Workshop: Visual Double Stars: Formation, Dynamics and Evolutionary Tracks, Santiago de Compostela, ed. J. A. Docobo, A. Elipe, & H. McAlister, ASSL, 223, 35

Dommanget, J. 1978, Bull. R. Astron. Obs. Belgium, 9, 47

Dommanget, J., & Nys, O. 2002, The Catalogue of the Components of Double and Multiple Stars (CCDM), Observations et Travaux, 54, 5 (`http:/www.vizier./u-strasbg.fr/viz-bin/ftp-index?I/274`)

ESA 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200

Fabricius, C., Høg, E., Makarov, V. V., et al. 2002, A&A, 384, 180

Flower, P. J. 1996, ApJ, 469, 355

Gliese, W., & Jahreiss, H. 1991, CD-ROM, Preliminary Version of the Third Catalogue of Nearby Stars, Vol. 1, No. 1 (NSSDC/ADC)

Halbwachs, J.-L., Piquard, S., Virelizier, P., et al. 1997, in HIPPARCOS '97. Presentation of the Hipparcos and Tycho catalogues and first astrophysical results of the Hipparcos space astrometry mission, Venice, Italy, ed. B. Battrick, M. A. C. Perryman, & P. L. Bernacca; ESA SP-402, 263

Hale, A. 1994, AJ, 107, 306

Hartkopf, W. I., Mason, B. D., & Worley, C. E. 2001, The Sixth Catalog of Orbits of Visual Binary Stars (`http://www.ad.usno.navy.mil/wds/orb6/orb6.html`)

Heintz, W. D. 1987, PASP, 99, 1084

Heintz, W. D. 1988, A&AS, 72, 543

Heintz, W. D. 1990, ApJ, 99, 420

Henry, T. J., & McCarthy, D. W. 1993, AJ, 106, 773

Hillenbrand, L. A., Massey, P., Strom, S. E., et al. 1993, AJ, 106, 1906

Hopmann, J. 1964, Ann. Sternw. Wien, 26, #1

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

Jahreiss, H., & Wielen, R. 1998, In HIPPARCOS '97. Presentation of the Hipparcos and Tycho catalogues and first astrophysical results of the Hipparcos space astrometry mission, Venice, Italy, ed. B. Battrick, M. A. C. Perryman, & P. L. Bernacca; ESA SP-402, 675

Kiyaeva, O. V., Kiselev, A. A., Polyakov, E. V., et al. 2001, SvAL, 27, 391

Lampens, P., & Strigachev, A. 2001, A&A, 368, 572 (Paper I)

Lampens, P., Kovalevsky, J., Froeschlé, M., et al. 1998, Joint Discussion 14 of the XXIIIrd General Assembly of the IAU: First results of Hipparcos and Tycho, Kyoto, 1997, Highlights of Astronomy, 11, ed. J. Andersen, 568

Lampens, P., Oblak, E., Duval, D., et al. 2001, A&A, 374, 132L

Lang, K. R. 1992, Astrophysical Data, Part I, 138

Mason, B. D., Wycoff, G. L., Hartkopf, W. I., et al. 2001, AJ, 122, 3466 (`http:// www.ad.usno.navy.mil/wds/wds.html`)

Mason, B. D., Hartkopf, W. I., Wycoff, G. L., et al. 2004, AJ, 127, 539

Mermilliod, J.-C., Rosvick, J. M., Duquennoy, A., et al. 1992, A&A, 265, 513

Mermilliod, J.-C., Mermilliod, M., & Hauck, B. 1997, A&AS, 124, 349 (GCPD) (`http://obswww. unige.ch/gcpd/gcpd.html`)

Moffat, A. F. J. 1982, A&A, 3, 455

Papadakis, I., Boumis, P., Samaritakis, V., et al. 2003, A&A, 397, 565

Ruymaekers, G. 1999, Ph.D. Thesis KULeuven, Leuven (unpublished)

Seymour, D. M., Mason, B. D., Hartkopf, W. I., et al. 2002, AJ, 123, 1023

Söderhjelm, S. 1999, A&A, 341, 121

Van Altena, W. F., Lee, J. T., & Hoffleit, E. D. 1995, The General Catalogue of Trigonometric Stellar Parallaxes, Fourth Edition, Yale University Observatory

Worley, C. E., & Heintz, W. D. 1983, Publ. of the US Naval Observatory, 2nd ser., (Washington), 24, 7

Online Material

Table 2. Log of observations.

Object	RA J2000.00	Dec J2000.00	Date	Filter	Number of frames	Exposures (s)
HIP 473	00 05 41	+45 48 44	22 August 2002	$B/V/R/I$	3/3/3/3	40/6/1/1
HIP 2552	00 32 29	+67 14 08	22 August 2002	$B/V/R/I$	3/3/3/3	120/40/6/2
HIP 3937	00 50 33	+24 49 00	22 August 2002	$B/V/R/I$	3/3/3/3	600/120/20/6
HIP 10531/29	02 15 43	+67 40 20	22 August 2002	$B/V/R/I$	3/3/3/3	6/2/1/1
HIP 13642	02 55 39	+26 52 24	22 August 2002	$B/V/R/I$	3/3/3/3	6/2/1/1
HIP 15844	03 24 06	+23 47 06	22 August 2002	$B/V/R/I$	3/3/3/3	120/40/10/3
HIP 17666	03 47 02	+41 25 38	22 August 2002	$B/V/R/I$	3/3/3/3	6/2/1/1
HIP 17749/50	03 48 01	+68 40 22	22 August 2002	$B/V/R/I$	3/3/3/3	60/6/2/1
HIP 18512	03 57 29	− 01 09 34	22 August 2002	$B/V/R/I$	3/3/3/3	30/5/1/1
HIP 21088	04 31 12	+58 58 38	22 August 2002	$B/V/R/I$	3/3/3/3	120/40/10/2
HIP 54952	11 15 12	+73 28 31	5 June 2001	$B/V/R/I$	2/2/3/3	5/2/1/1
HIP 56809	11 38 45	+45 06 30	5 June 2001	$B/V/R$	3/3/3	1/1/1
HIP 63253	12 57 40	+35 13 30	5 June 2001	$B/V/R/I$	3/3/3/4	120/30/10/6
HIP 65011/12	13 19 34	+35 06 37	5 June 2001	$B/V/R/I$	3/3/3/3	60/10/5/2
HIP 65343	13 23 33	+29 14 15	5 June 2001	$V/R/I$	3/3/3	9/3/1
HIP 66077	13 32 45	+16 48 39	22 August 2002	$B/V/R/I$	3/3/3/3	180/60/20/5
HIP 66492	13 37 51	+48 08 17	5 June 2001	$B/V/R/I$	3/3/3/3	60/10/6/3
HIP 67422	13 49 04	+26 58 48	5 June 2001	$B/V/R/I$	3/3/3/3	6/3/1/1
HIP 79492	16 13 18	+13 31 37	17 May 2001	B/R	3/4	5/1
HIP 83020	16 57 53	+47 22 00	18 May 2001	$V/R/I$	3/2/3	3/1/1
HIP 83988/96	17 10 11	+54 29 40	18 May 2001	$B/V/R/I$	3/3/3/3	10/5/3/2
HIP 86282	17 37 49	+22 57 20	18 May 2001	$B/V/R/I$	3/3/3/3	10/5/3/2
HIP 87768	17 55 45	+18 30 01	17 May 2001	$B/V/R/I$	3/3/3/3	9/3/2/1
HIP 91768/72	18 42 47	+59 37 49	17 May 2001	$B/V/R/I$	3/3/3/3	9/2/1/1
HIP 94336	19 12 05	+49 51 21	18 May 2001	V/I	2/3	1/1
HIP 97241	19 45 50	+32 23 14	19 May 2001	$B/V/R/I$	3/2/2/3	20/10/10/10
HIP 97292	19 46 24	+32 01 01	18 May 2001	R/I	3/3	5/3
HIP 106694	21 36 39	+39 27 21	18 May 2001	R/I	3/3	5/3
HIP 110526	22 23 29	+32 27 34	22 August 2002	$B/V/R/I$	3/3/3/3	120/40/6/2
HIP 110640	22 24 46	+22 33 04	22 August 2002	$B/V/R/I$	3/3/3/3	20/5/1/1
HIP 110893	22 27 59	+57 41 45	19 May 2001	$V/R/I$	3/2/2	20/6/3
NGC 6611	18 18 54	− 13 45 32	17 May 2001	V	2	2/3
NGC 6611	18 18 54	− 13 45 32	5 June 2001	V	3	1/2/3
NGC 6611	18 18 54	− 13 45 32	22 August 2002	V	3	9/9/9