ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

Astron. Astrophys. Suppl. Ser. **130**, 299–304 (1998)

CCD astrometry and UBV photometry of visual binaries

II. Visual double stars with mainly G - type primaries and relatively small angular separation*

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Received October 16; accepted December 8, 1997

Abstract. Differences ΔV of magnitude and $\Delta(B-V)$ and $\Delta(U-B)$ colours, as well as separations and position angles of 42 relatively close double stars are presented. The selection criteria of our sample are: the relatively small separation (between 2.5 and 5 arcseconds), magnitude difference under 1.25 mag, and mainly G-type primaries. The CCD observations, performed at the 90 cm Dutch telescope at ESO, were made using the Bessel U, B and V filters; the astrometry was done in the V filter only.

From the analysis of the photometric data we conclude that 16 binaries in our sample have components with practically the same $T_{\rm eff}$, since they have almost the same colours; one binary has components with identical characteristics. We also note the good internal accuracy of the astrometric CCD measurements.

Key words: stars: binaries: visual — astrometry

1. Introduction

The interest in visual binary systems has been boosted with the advent of the Hipparcos mission. They form of course an important element in our knowledge of the constitution of the Universe and our understanding of the evolutionary behaviour of stars near and away from the Main Sequence. Nevertheless, data on visual double stars are still largely incomplete and wanting; especially astrophysical information is fragmentary and often surprisingly poor in quality and quantity.

In the frame of an attempt to close this lack of observations, Nakos et al. (1997) (Paper I) have recently presented V magnitudes, $(B-V)$ and $(U-B)$ colours of close visual double star components, and their differences as well as separations and position angles of 42 such visual double stars.

The sample of paper I and the present paper was selected for angular separations from 2.5″ to about 5″, and magnitude difference under 1.25. The magnitudes of the components given in the WDS (Worley & Douglas 1984) are between 8 and 10 and the spectral type of the primaries as G.

We present now UBV magnitude and colour differences of additional 42 such visual double stars.

2. Observations and data reduction

Our observations were carried out using the 90 cm Dutch telescope and its CCD camera at ESO La Silla, Chile, between the 28$^{\rm th}$ of November and 3$^{\rm rd}$ of December, 1991. The CCD chip installed in the camera had a very low quantum efficiency in U, which caused minutes long exposures in this filter. Its dimensions are 420×580 pixels. Its linearity went up to 12000 ADUs remaining always better than 1%. These factors made it an acceptable tool for observing our relatively bright targets in the U filter as well.

We have selected a fixed window of 180×180 pixels on the CCD chip for all nights and we centered all double stars observed and the photometric standard stars in this window before starting the exposures. On the other hand, we used the whole surface of the CCD chip for the exposures aimed at its astrometric calibration (stellar traces).

All objects were observed in all three filters during each night. It may be remarked that observing such targets in different filters in the same night with CCDs was (and remains) a time consuming method, as the focal length of the telescope depends on the filter properties so that the instrument must be refocused whenever a different filter is used.

Two to four exposures per double star were taken in V. The duration of each exposure was as long as possible, at least two seconds and typically five to ten seconds. The same number of exposures per double star was taken in B. Their duration was at least ten seconds and typically

* Based on observations made at ESO La Silla, Chile.

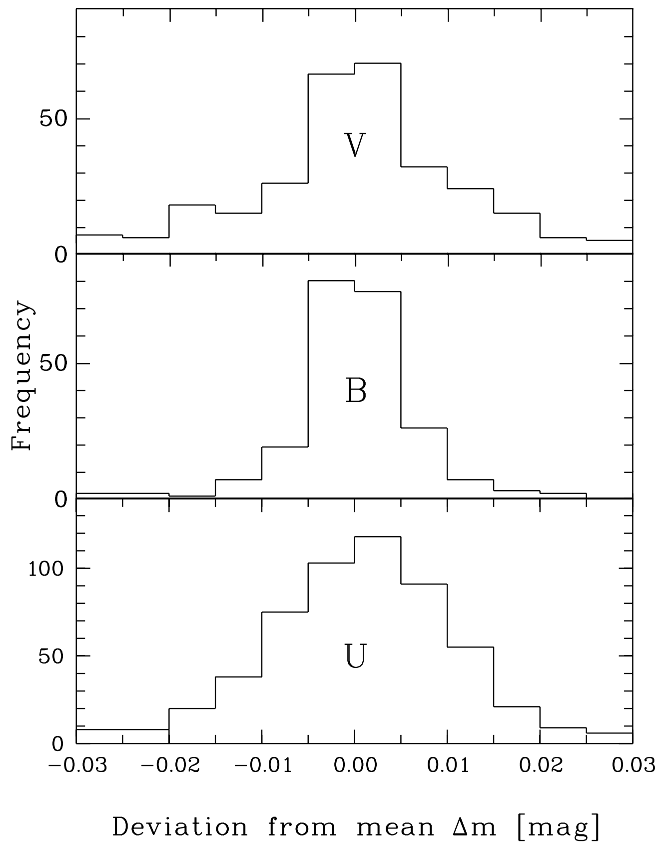

Fig. 1. Accuracy of components magnitude difference determination

around thirty seconds. Finally, six to ten exposures per double star were taken in U. The duration of each exposure was not longer than thirty seconds in order to avoid bad quality images due to telescope guiding errors.

The astrometry was performed in the V filter only. We chose to use some of the stars from the catalogues of Brosche & Sinachopoulos (1988, 1989) for the estimation of the scale of the CCD. For the calculation of the instrumental position angle of the CCD camera we used traces of equatorial bright stars. During the first night (November 28 to 29) photometric standard stars from the E regions (Graham 1982) were observed, in all filters, for the calculation of the transformation coefficients into the UBV system. Five exposures per filter were taken.

The atmospheric conditions under which the observations were carried out were very good. During all nights seeing at the 90 cm Dutch telescope was varying from 1.3 to 1.6 arcseconds, while the temperature was fluctuating from 10.2 °C−16.3 °C.

The data reduction was performed by using the ESO-MIDAS image processing software. Bias offset subtraction and a flat-field correction were included.

Two two-dimensional Moffat profiles were fitted simultaneously to the double star components on each CCD frame according to the classical least square technique, with our FORTRAN program.

The distribution of the accuracy of the components' magnitude difference that resulted from the photometry with this chip can be found in Fig. 1 for the three filters used. We obtain a standard deviation of $\sigma_{\Delta V} = 0.026$ mags, $\sigma_{\Delta B} = 0.009$ mags, and $\sigma_{\Delta U} = 0.014$ mags. Accuracies on all filters are higher than 0.025 mags when the angular separation between the binary components is larger than 8 pixels (3 arcseconds), dropping often down to 0.07 mags for smaller ones.
On the other hand accuracy decreases significantly for component magnitude differences higher than two. Not surprisingly a combination of components' small angular separation plus high magnitude difference results in a low accuracy measurement.

3. The UBV photometry

Nine photometric standard stars from the E1, E2, and E3 regions (Graham 1982) have been used for the determination of the transformation coefficients into the standard photometric system. UBV values from Grenon (1991) have been used in order to obtain a higher accuracy.

In addition, the A3 IV/V star HD 25653 from the E2 region has been used for measuring the first order exctinction in each photometric night.

In this night the mean (O−C) of the magnitudes of the exctinction stars in V was 0.004 mag, in B 0.006 mag, and in U 0.009 mag. The first order extinction coefficients that we obtained are the following:

$$k'_v = 0.22 \pm 0.01 \quad (1)$$

$$k'_b = 0.30 \pm 0.01 \quad (2)$$

$$k'_u = 0.56 \pm 0.02. \quad (3)$$

With the standard stars used, the transformation to the standard UBV system is given by

$$V = v + (0.102 \pm 0.006) \cdot (b - v) - (0.018 \pm 0.012) \quad (4)$$

$$(B{-}V) = (0.972 \pm 0.010) \cdot (b - v) + (0.012 \pm 0.015) \quad (5)$$

$$(U{-}B) = (1.066 \pm 0.017) \cdot (u - b) + (0.005 \pm 0.032). \quad (6)$$

The mean (O−C) value for V is 0.011 mag, for $(B{-}V)$ 0.015 mag, and for $(U{-}B)$ 0.030 mag. We present our photometric measurements in Table 1.
The first two columns of this table contain equatorial coordinates (J2000) of the primaries. Column three their HD number, if available. Column four the primary's spectral type. Column five the components magnitude difference ΔV, column six $\Delta(B{-}V)$ and column seven $\Delta(U{-}B)$.

Table 1. Photometric results

α_{2000}			δ_{2000}			HD		Sp. Class.	ΔV	$\sigma_{\Delta V}$	$\Delta(B{-}V)$		$\Delta(U{-}B)$	
00	14	48.9	−37	36	30			G2	1.143	.013	.024	.016	.045	.030
00	16	03.9	−74	00	38	HD	1220	F5:IV/V+.	.708	.013	.041	.016	−.031	.030
00	21	04.9	−00	15	05	HD	1678	G5	1.143	.012	−.093	.016	−.116	.031
00	22	00.0	−28	22	45			G5	1.106	.012	.318	.016	.694	.034
00	26	11.4	−58	31	28			G0	.436	.012	−.017	.015	.026	.030
00	31	10.0	−64	17	36	HD	2849	F8IV/V	.480	.012	−.088	.015	−.135	.030
00	32	18.0	−30	48	19	HD	2917	G0V	.595	.014	.037	.021	.083	.035
00	44	42	−21	36					.908	.015	−.024	.019	−.009	.031
01	35	29.1	−65	21	58	HD	9971	F2/F3V	.454	.012	.031	.018	−.042	.033
01	41	18.9	−12	08	35	HD	6429	F6V	.672	.012	−.016	.016	−.036	.030
01	41	18.9	−12	08	35			G1V	.310	.012	−.006	.015	−.019	.030
01	41	30.7	−17	58	35	HD	10445	G1V	1.072	.012	.136	.015	.125	.030
01	56	38.8	−42	22	22				.578	.013	.010	.019	.148	.033
02	09	41.9	−51	58	07	HD	13425	G0	.391	.012	.015	.015	.003	.030
02	36	44.7	−25	41	49	HD	16359	K0/1+F/G	.020	.012	−.003	.015	.009	.030
02	37	10.2	−40	36	14			G0	.356	.012	−.028	.015	−.014	.030
02	39	36.5	−39	58	07				.660	.012	.049	.016	.039	.030
03	08	14.3	−49	59	57				.291	.012	.038	.015	.020	.030
03	20	02.8	−45	14	20	HD	20861	G6III/IV	.463	.013	−.371	.016	−.659	.032
03	26	35.9	−01	06	14			G0	.189	.013	.025	.016	.094	.032
03	35	06	−67	50					.346	.012	.088	.016	.011	.030
03	38	06	−50	57					.241	.012	.027	.015	.042	.030
03	43	23.9	−26	35	54	HD	23330	F7/F8V	.532	.012	−.059	.015	−.074	.030
03	45	17.8	−44	22	56	HD	23696	F8	.358	.012	−.143	.015	−.097	.030
03	52	00	−42	19					1.222	.013	.021	.016	.126	.031
04	02	22.5	−07	00	24	HD	25458	G0	.065	.012	.135	.015	.032	.030
04	29	27.7	+00	24	50			G5	.936	.014	−.077	.020		
04	39	51.7	−19	53	08	HD	29702	G2/G3V	.305	.012	.051	.016	.072	.030
05	02	48.2	−55	47	43	HD	32847	F5IV	.133	.013	.006	.017	−.067	.031
05	26	55.1	+00	38	36	HD	35749	G0	.267	.012	−.039	.015	−.011	.030
05	30	45.4	−12	51	21			G0	.232	.016	.031	.018	.072	.031
06	14	30.9	−53	04	48	HD	43677	F8/G0V	1.180	.012	.005	.015	.048	.030
06	26	51.5	−06	45	25	HD	45400	G0	.251	.013	.027	.016	.017	.030
06	34	13.9	−52	19	03			G	.262	.012	.022	.015	.048	.030
06	40	09.5	−49	28	33	HD	48306	G0	.267	.013	.048	.016	.069	.030
06	51	23.1	−27	54	36	HD	50290	B9.5V	.516	.012	−.031	.015	−.011	.030
07	29	34.6	−68	09	17	HD	60483	G5III	.537	.013	−.393	.016	−.698	.033
07	45	14.3	−09	00	15	HD	62770	G0	.464	.013	.024	.016	.052	.031
08	05	03.0	−41	23	17	HD	67193	F5V	.701	.013	.163	.016	.206	.031
08	10	49.6	−41	51	52			G0	.519	.013	−.051	.016		
08	14	18.1	−43	41	43	HD	69238	F7/F8V	.946	.013	.412	.017	.766	.033
08	14	39.9	−66	16	13	HD	69864	G0V	.425	.012	.002	.015		

4. The astrometric results

Figure 2 shows the distribution of the deviation from the mean value of the angular separation ρ for each double star exposure. The standard deviation of this distribution is $\sigma_\rho = 0.046$ pixels, equivalent to $\sigma_\rho = 0.017$ arcseconds

Figure 3 shows the distribution of the deviation from the mean value of the instrumental position angle θ for each double star exposure. The standard deviation of this distribution is $\sigma_\theta = 0.2$ degrees. As expected, with decreasing angular separation, the accuracy of the position angle determination diminishes as well.

We used the four IDS double stars with INDEX codes 01109S5610, 05495N0701, 06386S2221, 23579N0743 in order to determine the CCD scale. Their relative positions are very accurate and listed in Brosche & Sinachopoulos (1988, 1989). We found the scale to be:

$$\begin{aligned} 01109S5610: &\quad .37695 \pm .00085 \\ 05495N0701: &\quad .37676 \pm .00073 \\ 06386S2221: &\quad .37902 \pm .00093 \\ 23579N0743: &\quad .37668 \pm .00090 \end{aligned}$$

arcseconds per pixel.

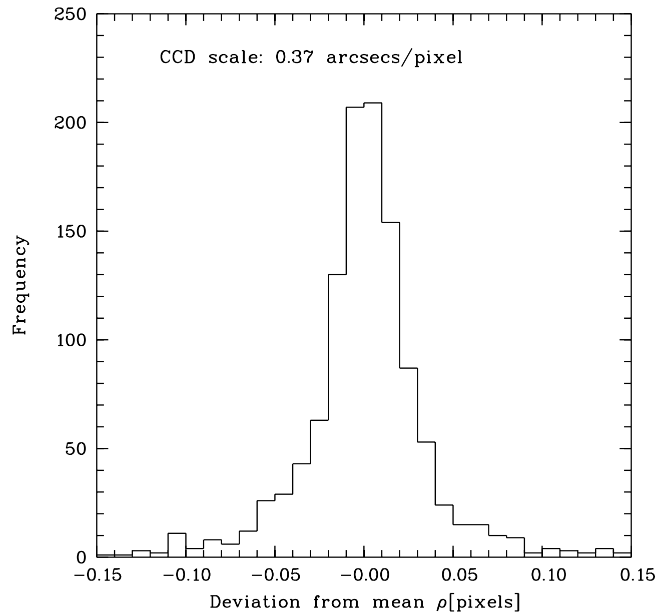

Fig. 2. Accuracy of angular separation determination

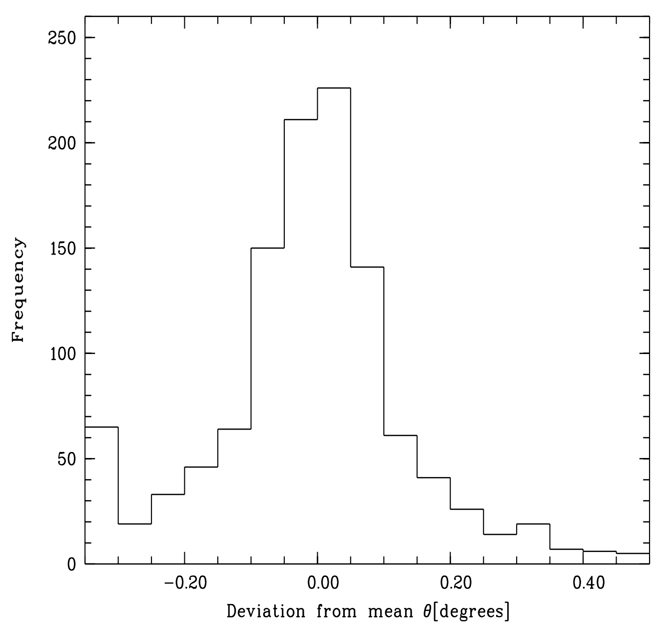

Fig. 3. Accuracy of position angle determination

These values, that are statistically the same at the 95% level of significance, result to the unweighted mean value of the CCD scale of 0.37735 ± 0.00056 arcseconds/pixel.

The output catalogue of the HIPPARCOS satellite (ESA, 1997) has one entry for every component of the double stars IDS23579N0743 (HIC 247, 248) and IDS06386S2221 (HIC 32144, 32145) from the above list. We tried to use the HIPPARCOS results of these two pairs in order to to determine the CCD scale more accurately. We first confirmed that both pairs are common proper motion ones and we remarked that their components have the same parallax on a very high statistical level of significance. So, they seem to have components of common origin. As concerns the scale, we obtain 0.37701 ± 0.00003 arcseconds/pixel for IDS23579N0743 and 0.38855 $\pm$ 0.00053 arcseconds/pixel for IDS06386S2221 . This last value is unexpectedly high. It might be caused by an overestimation of the accuracy of the HIPPARCOS results for this particular pair of stars (HIC 32144, 32145). This seems to be true for the secondary (HIC 32145) at least, because its entry in the Hipparcos catalogue gives an accuracy that is one order of magnitude lower than expected from the Hipparcos mission. We decided to use the scale calculated from the Brosche and Sinachopoulos catalogues.

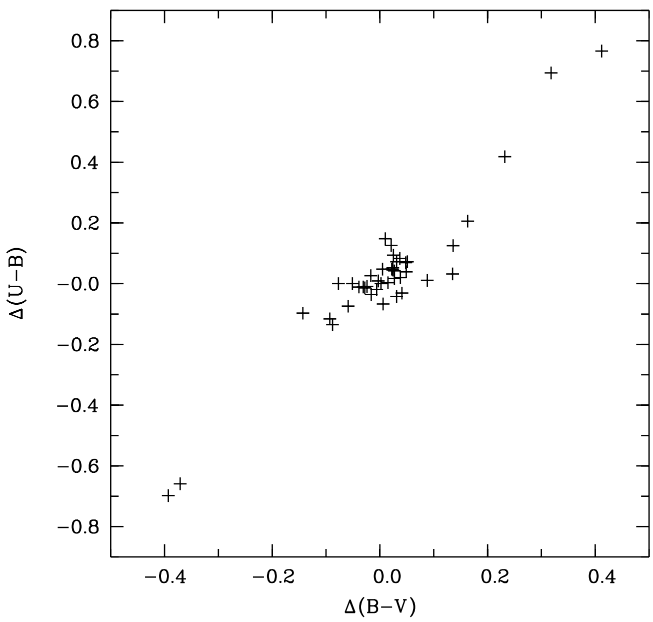

Fig. 4. Two colour diagram

Finally, from several traces of equatorial stars in two different nights we found that the instrumental position angle calculated on the chip was 1.3 ± 0.1 degrees smaller than the correct one.

We present our astrometric measurements in Table 2. Average epoch of the observations is 1991.91. The first two columns of this table contain again equatorial coordinates (J2000) of the primaries. Column three the primary's Durchmusterung code. Column four the angular separation and its accuracy, column five the position angle and its accuracy. Column six contains the number of exposures made in *V* filter.

5. Discussion

What was mentioned in the introduction and in previous papers, namely that photometric data are severely lacking for visual binaries, was confirmed when we consulted the SIMBAD data base of the CDS (Strasbourg, France):

Table 2. Astrometric results (epoch: 1991.91)

α_{2000}			δ_{2000}			DM		ρ	σ_ρ	θ	σ_θ	N.
00	14	48.9	−37	36	30	−38	49	4.357	.008	21.80	.11	2
00	16	03.9	−74	00	38	−74	18	5.198	.009	189.73	.10	4
00	21	04.9	−00	15	05	−01	32	3.870	.011	164.62	.10	2
00	22	00.0	−28	22	45	−29	92	3.534	.006	256.15	.13	4
00	26	11.4	−58	31	28	−59	36	4.200	.007	177.42	.11	4
00	31	10.0	−64	17	36	−64	39	3.580	.005	275.43	.10	2
00	32	18.0	−30	48	19	−31	201	2.814	.016	0.38	.28	2
00	44	42	−21	36		−22	126	3.363	.007	196.06	.10	2
01	35	29.1	−65	21	58	−66	104	2.681	.009	183.66	.11	4
01	41	18.9	−12	08	35	−36	401	4.057	.007	320.63	.11	4
01	41	18.9	−12	08	35	−12	313	4.560	.007	291.89	.11	2
01	41	30.7	−17	58	35	−18	284	3.271	.005	288.45	.10	3
01	56	38.8	−42	22	22	−42	671	3.160	.005	93.89	.11	2
02	09	41.9	−51	58	07	−52	272	3.268	.006	187.43	.11	3
02	36	44.7	−25	41	49	−26	943	4.034	.007	51.21	.10	3
02	37	10.2	−40	36	14	−41	739	3.072	.005	251.62	.10	3
02	39	36.5	−39	58	07	−40	686	3.654	.006	329.80	.10	2
03	08	14.3	−49	59	57	−50	929	2.995	.006	52.80	.10	2
03	20	02.8	−45	14	20	−45	1106	3.743	.006	287.24	.11	2
03	26	35.9	−01	06	14	−01	498	2.666	.005	124.11	.11	2
03	35	06	−67	50		−68	221	4.874	.009	61.61	.10	2
03	38	06	−50	57		−51	856	4.877	.007	77.40	.10	4
03	43	23.9	−26	35	54	−27	1360	3.677	.006	86.57	.13	3
03	45	17.8	−44	22	56	−44	1263	4.269	.008	220.95	.12	4
03	52	00	−42	19		−42	1275	4.597	.010	204.76	.10	3
04	02	22.5	−07	00	24	−07	724	3.115	.005	17.52	.10	2
04	29	27.7	+00	24	50	+00	768	2.715	.007	233.28	.10	3
04	39	51.7	−19	53	08	−20	903	3.534	.006	99.79	.11	4
05	02	48.2	−55	47	43	−55	731	2.812	.008	102.89	.11	4
05	26	55.1	+00	38	36	+00	1068	3.159	.005	86.84	.14	2
05	30	45.4	−12	51	21	−12	1190	2.486	.010	61.92	.14	4
06	14	30.9	−53	04	48	−53	1045	4.616	.008	52.78	.10	4
06	26	51.5	−06	45	25	−06	1551	4.461	.010	219.55	.10	2
06	34	13.9	−52	19	03	−52	951	3.105	.005	270.15	.11	5
06	40	09.5	−49	28	33	−49	2369	3.571	.006	190.15	.10	3
06	51	23.1	−27	54	36	−27	3329	4.323	.007	261.65	.12	4
07	29	34.6	−68	09	17	−67	763	3.075	.005	88.44	.13	2
07	45	14.3	−09	00	15	−08	2052	3.155	.006	124.99	.11	2
08	05	03.0	−41	23	17	−41	3722	5.193	.008	180.20	.10	4
08	10	49.6	−41	51	52	−41	3843	2.892	.006	138.14	.14	4
08	14	18.1	−43	41	43	−43	4070	7.106	.011	212.08	.11	3
08	14	39.9	−66	16	13	−65	897	4.072	.006	262.13	.11	3

hardly any UBV photometry was found for our sample. In addition, there was not any kind of information for five of our targets; these objects are identified by the truncated 2000 coordinates given in the WDS. Notice also that 18 of our targets have no HD identifier.

We could not find any correlation between the measured ΔV and $\Delta(B-V)$, nor between ΔV and $\Delta(U-B)$; the two colour diagram of Fig. 4, however, shows a strong linear correlation between $\Delta(B-V)$ and $\Delta(U-B)$. Components of sixteen binaries have practically the same $(B-V)$ and $(U-B)$ colours, which means the same $T_{\rm eff}$ as well. In particular the binary with primary DM -26° 943 has components that may be considered to be identical stars at identical distances.

The astrometric results show again a very satisfactory internal accuracy, confirming the power of the present CCD observational techniques for the collection of these data.

Table 3 shows that the angular separations presented here are identical with the ones of HIPPARCOS for the common targets.

Table 3. Comparison between HIPPARCOS and our angular separations (in arcseconds)

DM		HIC	$\rho - \rho_{\rm HIP}$	σ_ρ	$\sigma_{\rho_{\rm HIP}}$
−01	498	16045	0.014	0.005	0.014
−12	313	7877	0.000	0.007	0.006
−36	401	5050	0.010	0.007	0.006
−64	39	2449	−0.005	0.005	0.006
−38	49	1186	0.004	0.008	0.008
−07	724	18840	0.027	0.005	0.004
−53	1045	29622	−0.001	0.008	0.006
−43	4070	40350	0.007	0.011	0.008

For these targets, HIPPARCOS gives position angle results rounded to one degree. Our position angles are obviously not rounded and thus expected to be one order of magnitude more accurate. In any case, the position angles of both sources are identical at the statistical level of the HIPPARCOS results (one degree).

Unfortunately, HIPPARCOS gives the magnitude difference between components in the ΔHp system of the satellite. These magnitude differences are not comparable with our ΔV values. They usually differ a few hundreds of magnitudes, but differences up to a few tenths of magnitudes can occur.

Acknowledgements. This research was mainly carried out under contracts with SSTC/DWTC (Services du Premier Ministre Belge - Affaires Scientifiques, Techniques et Culturelles: "Service Centres and Research Networks" SC/005 and "Pôles d' Attraction Interuniversitaires" P4/05). This research has made use of the Simbad database, operated at CDS, Strasbourg, France. We thank Dr. E. Oblak for his useful remarks.

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