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Mass determination of astrometric binaries with Hipparcos

III. New results for 28 systems

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Abstract. This paper is the third of a series devoted to the determination of stellar masses from Hipparcos data. This is a continuation of Martin et al. (1997), who introduced the theory and assessed the performance of the method from simulated data, and of a second paper with the first results for 46 systems, (Martin & Mignard 1998). The orbit file maintained by the CHARA group and new publications of orbital elements made the processing of 70 additional candidate systems possible, including 28 of the 145 systems already tested in the previous work. Significant results were obtained on 22 systems, with relative accuracy better than 25% for the masses of 17 binaries. New estimates are also given for 6 systems previously investigated, thanks to reliable values of the magnitude difference from the Hipparcos catalogue (ESA 1997). New orbital elements are proposed for HIP 12623 (12 Persei) from speckle/spectroscopic measurements. Results are discussed for each system, alongside the mass-luminosity relation based on Hipparcos magnitudes and distances.

Key words: stars: fundamental parameters — binaries: visual — astrometry

1. Introduction

The possibilities to derive stellar masses by a direct method (non model dependent) are not very numerous, and in nearly all cases involve the gravitational attractions in a system formed by two or more stars, (a notable exception to this rule is the binary pulsar PSR $1913+16$, where the individual masses are determined unambiguously from the relativistic periastron shift and the gravitational redshift of the pulsar signal). When the components are close enough to exhibit a fast relative motion and if the two stars are of comparable brightness, spectroscopic measurements may yield the radial velocity of each component with respect to the centre of mass, and thus the mass ratio of the components. The difficulty in this case is to obtain the total mass from Kepler's third law, since only a function of the semi-major axis and inclination of the relative orbit can be reached by this method. Moreover, the number of objects (double-lined spectroscopic binaries) is not very large. The alternative method, using photographic plates, rests upon the astrometric analysis of the motion of the components (when the separation is larger than $1\farcs5$) or of the photocentre, with respect to nearby stars. When the scale of the relative orbit is known, the previous analysis yields the proper motion, parallax and mass ratio of the system. Whatever the method, its combination with other techniques like speckle interferometry (orbital elements) or visual CCD observations (magnitude difference) is often needed to make the full analysis and derive the individual masses.

The method used in this study has been extensively described in the first paper of the present series (Martin et al. 1997), and is nothing else than a modern version of the astrometric method, with the reservation that in some cases the Hipparcos signal is tied to a point which is not the photocentre (we called it "Hippacentre"). Unlike the situation prevailing with standard astrometric binaries, this fortunate circumstance allows the direct determination of the mass fraction (the independent knowledge of the magnitude difference Δm is no longer needed).

This third paper is a continuation of the work presented in Martin & Mignard (1998). This has been possible essentially through the access to new or previously overlooked orbital data. One of our purposes is to present all the available results, and not only the best ones (it could have been limited to the 10 best results, in good agreement with ground-based determinations), since the anomalous results may question the validity of the orbital elements, or simply reveal the true limitation of the

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Hipparcos sampling. As for Algol in the previous paper, an emphasis is made on a specific system, namely 12 Persei, which has been simultaneously studied by McAlister and his colleagues from a set of ground-based data (this paper, Sect. 5.2). A mass-luminosity relation is also derived from the set of reliable results, including those presented in the previous paper.

For the sake of clarity and conciseness, we will refer in the following to the first two papers of this series as "Paper I" (Martin et al. 1997) and "Paper II" (Martin & Mignard 1998).

2. Selection of new candidates and other targets

2.1. Origin

The main result of Paper I was a set of criteria to be met by a binary system, so that one can expect to determine the mass of its components from the Hipparcos astrometric measurements. These criteria are still applicable in the present study (an orbital period $P \leq 30$ years and the semi-major axis $a'' >$ a few tenths of arcsecond), even if the application to real data has shown that our expectations for pairs with periods larger than 20 years were slightly too optimistic. Two different sources, again largely redundant, were used to select the new candidate systems:

1. The most recent version of the catalog of orbits of visual binary stars compiled by Worley in mid 1997 (not yet published), containing 1403 orbits for 1038 systems.
2. The compilation file of orbits of Scardia (June 1997), also unpublished, containing 1744 orbits for 709 systems.

After elimination of all the objects already studied in our previous paper, and elimination of the systems presenting one or more additional disturbing companions, we are left with 37 systems matching the above criteria in the first source and 5 additional systems in the second one. These 42 new candidates are listed in Table 1.

In addition, we have checked the orbital elements of the 145 systems already processed in Paper II, allowing us in some cases to estimate new masses based on revised orbits, or even get masses for systems where the previous treatment failed.

These 28 systems are listed in Table 2, followed by six systems whose masses were successfully computed in Paper II. For these six binaries flagged "C" in the Hipparcos Catalog (component solution), the current processing is based on the Hipparcos magnitude differences, when they are of comparable or better quality than the ground-based Δm that we used before (but the orbital elements remain unchanged). Eventually, the application of our selection rules yields a total of 99 orbits for 76 systems $(42 + 34)$.

Table 1. HIP numbers of the 42 new preselected systems

1242	11542	28691	45383	68682	86722	105200
2548	11548	30883	47250	71729	95995	106255
3951	12153	31737	48029	80677	96302	107288
5064	12640	34025	55016	81126	97365	113031
5317	19009	36238	60129	83895	101227	116164
8903	20087	38474	63510	84949	102589	117761

Table 2. HIP numbers of the 34 reprocessed systems. For the last six systems, masses were already derived in the previous paper

7918	12623	22196	45571	82817	94144	107788
10535	20661	29746	51147	85141	98001	111528
11452	20686	33451	71094	85846	103655	113445
12421	21281	39261	76852	87895	104858	114576
2237	2762	44248	84140	93574	107354	

2.2. Elimination of objects

The same rules as in Paper II apply here; no significant results can be obtained for multiple systems if a third (or more) bright components is within 25″ of the pair under consideration. This restriction is directly linked to the Hipparcos observing field. In some cases, when the magnitude of the parasitic source was close to or beyond the sensibility threshold, a solution could however be derived. Among the new candidates, 5 such systems were removed in the present study (18 in Paper II).

2.3. Description of the systems

The description of the sample shown in Fig. 1 aims to distinguish between two categories of systems:

1. the so called "Type I" stars for which the mass fraction $B = M_2/(M_1 + M_2)$ can be derived solely from the Hipparcos data (pairs with semi-major axis typically larger than $0\farcs3$),
2. the "Type II" stars, with a possible determination of the scale factor between the relative and photocentric orbits, namely the difference $\beta - B$ between the intensity and mass fractions.

Although there are five likely candidates of the first kind in this study (exception made of the last 6 systems in Table 2), HIP 7918 was the only object for which a separate computation of the mass fraction was possible. This is primarily due to the limitations caused by the large period characterizing this type of object.

More interesting are the systems with periods smaller than 10 years, making 40% of the stars selected so far.

Table 3. The 13 "new" astrometric binaries whose processing yields satisfactory results. The columns give the Hipparcos, ADS and HD identifiers when available, the usual name, the seven orbital elements and their reference

HIP	ADS	HD	Name[1]	$a('')$	P(yr)	e	i	Ω	ω	T	ref.[2]
8903	–	11636	β Ari	0.036	0.29	0.903	44.70	79.10	209.10	1980.098	Pan90
12153	–	16234	McA 7, 31 Ari	0.119	1.92	0.884	101.00	171.30	256.90	1986.830	Mas97a
20087	–	27176	McA 14, 51 Tau	0.129	11.38	0.171	125.90	170.00	160.90	1977.830	Bal89
55016	–	97907	McA 35, 73 Leo	0.046	8.11	0.415	49.10	283.30	156.50	1974.015	Mas97b
60129	–	107259	McA 37, 15 Vir	0.136	13.12	0.079	51.10	173.00	1.40	1963.800	Har92
68682	–	122742	–	0.330	9.90	0.547	93.50	252.30	189.00	1951.960	Kam87[3]
71729	–	129132	McA 40	0.073	9.26	0.040	106.40	78.00	241.90	1984.852	Bai89
81126	–	149630	σ Her	0.074	7.48	0.533	108.70	13.20	175.70	1982.560	Bal89
83895	–	155763	ζ Dra	0.067	6.09	0.000	0.00	0.00	0.00	1980.760	Zul92
84949	–	157482	McA 47	0.075	5.53	0.672	56.20	323.70	40.60	1986.364	Sca94
86722	–	161198	G 170-61	0.174	7.00	0.936	42.80	309.20	129.60	1994.189	Duq96
95995	–	184467	McA 56	0.084	1.35	0.370	148.10	63.70	0.00	1989.328	Bai89
96302	–	184759	9 Cyg	0.030	4.56	0.820	114.60	29.30	45.50	1985.560	Bai89

[1] When available, the more common name of the star, or the discoverer designation.
[2] The three first characters of the author's name followed by the two last digits of the publication's year.
[3] Ground-based measurements yield the size of the photocentric orbit (0.″108). The value 0.″33, which refers to the relative orbit, is just an assumption (see Kamper 1987).

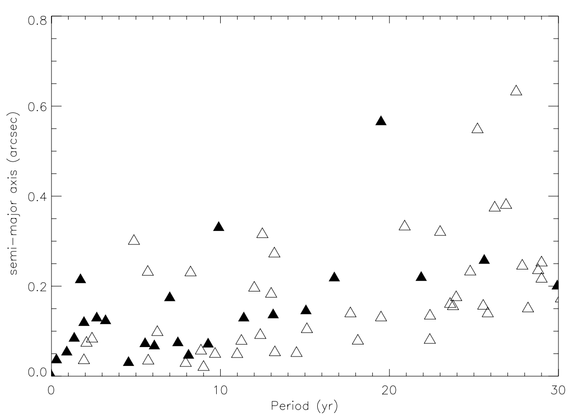

Fig. 1. Distribution of the 70 candidate systems (42 new systems + 34 reprocessed, minus the last 6 systems of Table 2) in period–semi-major axis space. The filled symbols correspond to the stars whose processing has been successful. Only one orbit per system was considered

Two thirds of the accepted results fall in this group (see Table 6). There are two good reasons accounting for this fact: first, the odds that the orbital motion shows up in the Hipparcos data are more favorable for short periods, and secondly most of these systems have quasi-definitive orbits, allowing a good matching between the set of observations and the model.

3. Main features of the processing

The practical implementation of the processing is described in Paper I, Sect. 4.2 and will not be repeated here. The important points are simply summarized below.

The general astrometric processing of the observations carried out by Hipparcos produced for each of the 118 300 program stars, the five astrometric parameters representing the position, the parallax and the proper motion. When the program star was single, the previous quantities were associated with the centre of light of the star, that is to say its astrometric direction. In the case of a double star with or without detectable orbital motion, each one–dimensional observation along the scan direction was linked to a point specific to the Hipparcos detection system which was closely related to the photocentre of the pair, but not always identical. The term *Hippacentre* was coined to convey this idea. For very close pairs, the Hippacentre and the photocentre could not be distinguished by Hipparcos.

For orbital astrometric binaries, the absolute motion of the photocentre F referred to the barycentre G, is related to the relative orbit ρ by,

$$\mathbf{GF} = (\beta - B)\ \rho \qquad (1)$$

where $\beta = \frac{I_2}{I_1+I_2}$ and $B = \frac{M_2}{M_1+M_2}$ are the relative intensity and mass of the secondary component. A more general expression is given in Paper I.

The processing consists of extending the standard Hipparcos astrometric treatment by adding to the usual five astrometric unknowns (l, b, π, μ_l and μ_b) related to

Table 4. The 9 astrometric binaries unpublished in the previous paper or reprocessed with different orbital elements, followed by 6 revised systems whose masses have already been presented in the previous work

HIP	ADS	HD	Name[1]	$a('')$	P(yr)	e	i	Ω	ω	T	ref.[2]
7918	–	10307	Gl 67	0.565	19.500	0.420	104.00	32.60	100.00	1977.600	Lip83
12623	–	16739	12 Per	0.053	0.906	0.656	126.75	230.62	89.54	1995.148	this paper
33451	–	51825	I 65	0.218	16.740	0.430	35.00	128.50	241.60	1958.850	Fin63
45571	–	80671	128 Car	0.123	3.200	0.510	123.60	156.10	294.20	1961.730	Fin64
71094	9301	127726	A 570	0.200	29.930	0.160	158.00	23.30	57.00	1983.850	Hei91
76852	9744	140159	21 Ser	0.219	21.880	0.053	83.90	70.10	74.50	1984.880	Hei94
82817	–	152751	Kui 75	0.214	1.717	0.049	165.70	144.50	101.00	1983.002	Hei84a
85141	–	157498	Rst 3972	0.145	15.060	0.575	20.00	43.00	46.00	1975.700	Hei97
98001	13125	188753	Ho 581	0.257	25.610	0.470	31.00	61.00	217.00	1988.060	Hei90
2237	–	2475	B 1909	0.214	11.25	0.000	69.80	119.00	0.00	1940.880	Van56
2762	490	3196	13 Cet	0.240	6.89	0.767	49.00	149.20	283.50	1973.389	Har89
44248	–	76943	10 Uma	0.647	21.77	0.151	131.26	204.39	32.52	1993.725	Har96
84140	–	155876	Kui 79	0.762	12.95	0.743	149.14	160.00	99.00	1991.032	Har96
93574	–	175986	Fin 357	0.155	14.38	0.390	161.00	171.90	270.00	1976.550	Hei84b
107354	15281	206901	κ Peg	0.236	11.60	0.313	108.04	288.85	304.17	1979.207	Har89

[1] When available, the more common name of the star, or the discoverer designation.
[2] The three first characters of the author's name followed by the two last digits of the publication's year.

Table 5. Spectral types and Johnson-Morgan's colour indices of the components of 13 binaries. The last column indicates the type of transformation* to be made in order to get the Cousin's $(V-I)$ index (see Sect. 5.2 and Fig. 4 in Paper II)

HIP	ST_1	ST_2	$(V-I)_1$	$(V-I)_2$	Conv.
7918	G1.5 V	M4 V	0.85	3.19	A B
8903	A5 V	G0 V	0.22	0.81	A A
12153	F7 V	F8 V	0.72	0.76	A A
12623	F9 V	F9 V	0.79	0.79	A A
20087	A8 V	G0 V	0.31	0.81	A A
33451	F8 IV-V	F8 IV-V	0.80	0.80	A A
55016	K3 III	F1 V	1.61	0.51	A A
76852	B9 V	A1 V	−0.06	0.05	A A
82817	M4.5 V	M4.5 V	3.33	3.33	B B
84949	G5 IV	F2 V	1.03	0.55	A A
85141	G0 III	G0 III	1.09	1.09	A A
86722	K0 V	M3 V	1.06	2.94	B B
96302	A0 V	F8 III	0.00	1.04	A A

* Not all the listed systems need this transformation; it depends on the origin of Δm (see Tables 7–8).

the centre of mass, the two unknowns β and B or simply the combination $\beta - B$ for the closest pairs. The full process goes by successive iterations, starting with reference values β_r and B_r of the intensity and mass fractions, until a satisfactory convergence is reached. When several orbits were competing, each of them was tested individually. In each case the reversed orbit was also systematically checked (exchange of the components on the celestial sphere), allowing us to detect an eventual 180 degrees error in the ascending node's position Ω or in the argument of periastron ω.

In addition to the position and proper motion, the output includes the parallaxes, which can be slightly different from the Hipparcos published values, because our model accounts for the photocentric displacement. In general the effect is very small and within the error bar. The results of this processing are presented in Table 6.

4. Results

The raw results of the processing are presented for 22 systems in Table 6, in the same layout as in Paper II. Five values of $\beta - B$ have a formal error less than 0.01, 3 are in the range $0.01 - 0.02$ while the remaining 14 have errors larger than 0.02, a maximum being reached for HIP 55016 (0.084) and HIP 81126 (0.087).

For 16 systems, estimates of Δm (and thus of β) are taken from ground–based sources while the Hipparcos data (ESA 1997) were used for the other systems. The transformation into the Hipparcos photometric system was done for the 10 systems with available spectral types for each component (see Table 5). The procedure is described in Paper II, Sect. 5.2. The details of the mass computation will be found in Paper II.

Table 6. Astrometric binaries processing: raw results for 22 systems. See the orbit's reference in Tables 3−4

HIP	Name	orient.	N_i	N_p	$\beta - B$	σ	B	σ	$(\beta - B)_\mathrm{r}$	σ	B_r	σ
7918	Gl 67	−	2	7	−0.145	0.049	0.147	0.050	−0.230	0.014	0.231	0.014
8903	β Ari	+	3	6	−0.332	0.047	−	−	−0.309	0.017	0.363	0.013
12153	McA 7	+	2	6	−0.008	0.014	−	−	−0.041	−	0.495	−
12623	12 Per	+	2	6	−0.121	0.027	−	−	−0.047	0.037	0.478	0.014
20087	McA 14	+	3	6	−0.222	0.058	−	−	−	−	−	−
33451	I 65	+	3	6	−0.031	0.018	−	−	−	−	−	−
45571	128 Car	+	3	6	0.000	0.009	−	−	−	−	−	−
55016	McA 35	+	1	6	−0.400	0.084	−	−	−0.400	−	0.465	−
60129	McA 37	−	6	6	0.223	0.055	−	−	0.051	0.102	0.273	0.022
68682	−	−	3	6	−0.312	0.007	−	−	−0.301	−	0.320	−
71094	A 570	+	3	6	0.013	0.008	−	−	−0.047	0.036	0.440	0.030
71729	McA 40	+	3	6	−0.109	0.065	−	−	0.029	−	0.358	−
76852	21 Ser	+	11	6	−0.028	0.033	−	−	−	−	−	−
81126	σ Her	−	4	6	−0.144	0.087	−	−	−	−	−	−
82817	Kui 75	+	4	6	−0.149	0.005	−	−	−0.019	0.097	0.500	0.084
83895	ζ Dra	−	3	6	−0.103	0.023	−	−	−	−	−	−
84949	McA 47	+	3	6	−0.208	0.012	−	−	−	−	0.587	0.015
85141	Rst 3972	+	3	6	−0.040	0.042	−	−	−	−	−	−
86722	G 170-61	+	10	6	−0.238	0.032	−	−	−0.267	−	0.291	−
95995	McA 56	+	3	6	−0.055	0.009	−	−	−	−	−	−
96302	9 Cyg	+	2	6	0.034	0.043	−	−	−	−	−	−
98001	Ho 581	+	6	6	−0.113	0.047	−	−	−0.310	0.030	0.656	0.020

orient.: The orientation is that of the published orbit (+) or has been reversed after examination of the residuals (−).
N_i, N_p: Number of iterations and number of unknowns in the model.
$\beta - B$, B: the two "physical" solutions of the reduction followed by the corresponding standard errors.
$(\beta - B)_\mathrm{r}$, B_r: reference values used to start the algorithm (see Table 9).

5. Comments on individual systems

5.1. General cases

• **HIP 7918 (Gl 67)**: A close astrometric binary comprised of a solar-type star and a cool low-mass companion 1000 times fainter. In this sample of 70 candidates, this is the only system with a direct determination of the fractional mass (a consequence of its large separation, see Paper I). The companion was resolved for the first time by Henry et al. (1992), using infrared speckle imaging techniques. With the same orbital elements, Kepler's third law and the Hipparcos parallax yield a total mass about 30% smaller than Henry's value. The most surprising discrepancy lies with the fractional mass B of the companion, significantly smaller in this study. The combination of both effects yields a secondary's mass about half the value derived by Henry, although affected by a large relative error. Our result may be not very reliable, as suggested by the large correlations found between the unknowns.

• **HIP 8903 (β Ari)**: Famous double-lined spectroscopic binary with an unusually large orbital eccentricity. The new Hipparcos parallax value, slightly larger than the one determined by Pan et al. (1990), leads to smaller individual masses, but still consistent with Pan's estimates of 2.34 ± 0.10 and 1.34 ± 0.07 $M_\odot$.

• **HIP 12153 (31 Ari)**: This object was first detected as double by lunar occultation (Africano et al. 1978), then studied with speckle interferometry and spectroscopy. A preliminary orbit has been computed very recently from speckle data (Mason 1997a), in good agreement with the Hipparcos observations. It provides an accurate estimate of $\beta - B$. The true value of the parallax remains puzzling however. Balega's dynamical value of 21 mas (Balega & Balega 1988) is not consistent with Hipparcos (28.15 mas), still too small to yield realistic masses for this system (see the position of HIP 12153 in the mass-luminosity diagram, Fig. 2). If the latter value is confirmed, a revision of both the orbital period and the size of the relative orbit will be needed. The value of Δm taken here is the average of two estimates (Africano et al. 1978), one in the red (0.3), the other in the blue (0.1).

• **HIP 20087 (51 Tau)**: Single-lined spectroscopic binary, whose probable large magnitude difference is not yet accurately known. Considering the dynamical parallax, Baize (1989) suggested a total mass of 3.4 $M_\odot$ and accounted for the large mass of the secondary (about 1.6 $M_\odot$) by assuming that the star is an evolved subgiant. The new

Table 7. Masses of 22 systems. See comments at the end of the table

HIP	Corr.[(1)]	π mas	σ_π mas	$\Delta\pi^{(2)}$ mas	$\sigma_{\Delta\pi}$ mas	$\Delta m^{(3)}$	$\sigma^{(4)}$	M $M_\odot$	σ $M_\odot$	M_1 $M_\odot$	σ $M_\odot$	M_2 $M_\odot$	σ $M_\odot$	$N^{(5)}$
7918	yes	79.86	0.91	0.77	1.23	7.451	0.50	0.931	0.178	0.795	0.159	0.136	0.053	3
8903	yes	54.55	0.99	−0.19	1.24	3.180	0.22	3.348	0.201	2.067	0.203	1.281	0.178	2
12153	yes	28.15	1.09	−0.25	1.39	0.205	0.10	20.408	3.509	11.001	1.969	9.407	1.707	3
12623	yes	41.94	1.56	1.42	2.00	0.300	0.15	2.514	0.289	1.125	0.169	1.389	0.193	3
20087	yes	18.29	0.97	0.04	1.27	2.066	0.40	2.709	0.437	1.756	0.343	0.953	0.247	3
33451	–	23.44	0.62	0.29	0.84	0.410	0.25	2.871	0.228	1.614	0.211	1.256	0.195	1
45571	no	29.17	0.57	−0.66	0.83	0.000	0.15	7.322	0.429	3.661	0.338	3.661	0.338	1
55016	yes	6.72	0.94	−0.10	1.24	2.830	0.40	4.938	2.102	2.624	1.197	2.315	1.075	3
60129	no	12.98	0.90	−0.08	1.23	0.800	0.50	6.682	2.250	6.009	2.164	0.673	0.800	3
68682	no	60.50	0.97	0.26	1.24	4.300	0.50	1.657	0.080	1.109	0.057	0.548	0.033	2
71094	–	14.30	1.02	0.27	1.37	0.470	0.09	3.054	0.654	1.892	0.410	1.162	0.257	1
71729	no	8.81	0.75	−0.66	1.03	1.000	0.20	6.633	1.694	3.344	1.000	3.289	0.988	1
76852	–	17.66	0.93	0.69	1.21	0.153	0.06	3.984	0.629	1.999	0.346	1.984	0.344	1
81126	no	11.69	0.70	0.90	0.93	1.600	0.30	4.534	0.842	3.036	0.714	1.498	0.519	3
82817	–	155.42	1.85	−18.81	4.32	0.080	0.21	0.885	0.032	0.327	0.045	0.558	0.047	1
83895	no	9.46	0.56	−0.14	0.73	1.040	0.20	9.585	1.702	5.940	1.134	3.645	0.770	1
84949	yes	15.41	0.63	−0.12	1.32	0.055	0.20	3.774	0.469	1.150	0.229	2.624	0.372	3
85141	yes	15.60	1.30	0.09	1.75	0.200	0.20	3.541	0.885	1.791	0.499	1.749	0.489	1
86722	yes	43.80	1.29	1.35	1.62	3.958	0.50	1.279	0.217	0.942	0.166	0.337	0.072	3
95995	–	58.01	0.69	−1.83	0.94	1.390	0.63	1.673	0.060	1.217	0.172	0.456	0.167	1
96302	yes	6.41	0.72	0.35	0.92	0.645	0.20	4.930	1.661	3.344	1.165	1.586	0.612	1
98001	–	22.06	0.78	−0.25	1.10	0.690	0.11	2.411	0.256	1.304	0.187	1.107	0.172	1

[1] Correction: "yes" indicates that the Δm estimate has been brought into the Hipparcos photometric system, via the spectral types of the components (see Sect. 5.2). "no" means that this conversion could not be done due to the lack of individual spectral types, and "–" means that Δm is taken from the Hipparcos catalogue and thus does not need any conversion.
[2] Difference between the parallax derived from this processing and the Hipparcos catalogue's value (ESA 1997), followed by its standard deviation. Most of the differences are not significant, except for HIP 82817 = Kui75, where the catalogue's value is probably wrong.
[3] It is the Hipparcos estimate if "–" stands in the second column, a ground-based one otherwise.
[4] When unknown, σ is taken equal to 0.15.
[5] Number of available terms for the computation of the standard deviation of the total mass M. $N = 3$ if σ_a, σ_π and σ_P are known. $N = 2$ if σ_P is unknown. $N = 1$ if both σ_a and σ_P are ignored. In the latter case, $\sigma(M)$ is underestimated.

Table 8. Masses for 6 systems already studied in the previous paper, reprocessed with the Hipparcos magnitude difference estimate. See comments at the end of the previous table

HIP	Corr.[(1)]	π mas	σ_π mas	$\Delta\pi^{(2)}$ mas	$\sigma_{\Delta\pi}$ mas	$\Delta m^{(3)}$	$\sigma^{(4)}$	M $M_\odot$	σ $M_\odot$	M_1 $M_\odot$	σ $M_\odot$	M_2 $M_\odot$	σ $M_\odot$	$N^{(5)}$
2237	–	30.24	0.98	−0.77	1.31	0.17	0.12	2.800	0.272	1.563	0.177	1.238	0.151	1
2762	–	46.74	0.97	−0.77	1.50	1.29	0.07	2.852	0.425	1.712	0.296	1.140	0.226	3
44248	–	61.61	1.13	0.75	1.72	2.30	0.04	2.445	0.135	1.525	0.104	0.920	0.080	3
84140	–	152.20	1.82	−5.97	3.73	0.23	0.17	0.748	0.027	0.379	0.035	0.369	0.035	3
93574	–	17.20	0.61	−0.45	0.99	0.38	0.21	3.539	0.377	1.892	0.265	1.647	0.246	1
107354	–	28.63	0.92	0.29	1.27	0.10	0.11	4.163	0.411	1.561	0.197	2.602	0.284	3

parallax and mass fraction estimates confirm the mass of the primary (about 1.8 $M_\odot$) but yield a companion's mass more typical of a main sequence dwarf with a G0 spectral type (≈ 1 $M_\odot$).

• **HIP 33451 (I 65)**: Visual/speckle binary mostly observed by visual techniques during the last century. The orbit is flagged "definitive" in the catalog of Worley & Heintz (1983). Unfortunately we did not find any information concerning the masses of the components. Our masses and absolute magnitudes agree nicely with the empirical mass-luminosity relation.

• **HIP 45571 (128 Car)**: First detected as double in 1960, this system is in fact triple, the C component with a magnitude 12.2 lies at 18″ from the close AB binary. At this distance from the central pair, the attenuation effect caused by the Hipparcos dissector tube makes the C component nearly invisible, and thus too faint to disturb the signal of AB. The magnitude difference derived from Hipparcos is very poor (1.37 ± 0.87) and we have used the value given by Worley. This pair is one of the 6 stars of this sample with a standard deviation of $\beta - B$ smaller than 0.01. The two masses are found nearly equal which suggests either a pair of two G7 giant stars, or a pair of A0 dwarfs. This is not compatible with the absolute magnitudes, however (see the mass luminosity relation, Fig. 2). The orbital elements are indeed still preliminary and need to be confirmed.

• **HIP 55016 (73 Leo)**: Speckle and spectroscopic binary, the very first star to have a photoelectric velocity published (see Griffin 1990). As it is mentioned by Mason (1997b), the exact determination of spectral types and Δm are now no clearer than they were in 1990, so the mass fraction proposed in this paper is not very reliable (we have taken $\Delta m \approx 2.9$, which is probably too large). Unfortunately the high relative error of the parallax does not improve the situation and yields an inaccurate total mass. This system will probably remain problematic for another few years, since a recent attempt to study it with adaptive optics has failed.

• **HIP 60129 (McA 37)**: η Virginis is a triple system formed by a close spectroscopic pair (undetectable by Hipparcos) and a more distant speckle companion. Again, the large relative errors of the parallax and semi-major axis prevent a good determination of the total mass. The even worst quality of the individual masses is caused by the uncertain value of Δm, as derived by speckle interferometry (Hartkopf et al. 1992). The masses and the mass ratio listed as references in Table 9 are based on arbitrary assumptions and must be considered with caution. Due to its long orbital period, η Vir clearly deserves further investigations, both with adaptive optics (Δm) and speckle (orbital elements).

• **HIP 68682 (HR 5273)**: Astrometric-spectroscopic binary, recently studied by Kamper (1987). This is one of the 3 best results of the present research (mass uncertainties at about 5%), but some restrictions must be mentioned. The secondary component is actually unseen and the Δm proposed by Kamper and used in this study is uncertain. This is not a serious problem however, since the value of the fractional intensity β is anyway close to zero and the calculation of the fractional mass B is not very sensitive to a possible error of Δm. More important is the consequence of the semi-major axis of the relative orbit, estimated at about $0\farcs33$ by Kamper, a value based on uncertain assumptions (see the two last paragraphs of the previously mentioned paper). The adoption of a different value would of course change the estimate of B and of the total mass M. Taking $a = 0\farcs33$ yields a mass ratio perfectly consistent with Kamper's value, but our mass estimates are slightly larger, a consequence of the Hipparcos parallax. The periastron argument ω should be rotated by 180 degrees.

• **HIP 71094 (A 570)**: Variable speckle binary, one of the best results regarding $\beta - B$ despite the long period. The fairly small parallax is consistent with the dynamical estimate of 15 ± 5 mas (Heintz 1991). The lack of individual spectral types for this system makes the validation of the masses difficult. The location of the two components in the mass-luminosity diagram is reasonable.

• **HIP 71729 (McA 40)**: Single-lined spectroscopic and speckle triple system formed by a very short-period ($\approx$100 days) pair and a more distant speckle companion. The closest companion was unresolved by Hipparcos and the primary is in fact composite. The new parallax yields a total mass about 30% larger than the previous estimate by Barlow & Scarfe (1991). The mass ratio also differs, so that the total mass of the primary component (Aa+Ab) is conserved, while the secondary mass appears to be much larger, with fairly large underestimated relative errors. We are not very confident in these new results. The magnitude difference and the spectral types also need more checks.

• **HIP 76852 (21 Ser)**: Astrometric/speckle binary. No mass estimates have been found in the literature, but the spectral types B9V and A1V are not compatible with the masses derived here (they suggest masses close to 3 $M_\odot$ instead of 2 $M_\odot$). The new parallax compares quite well with previous estimates and is probably not suspect. Thus, either the orbital elements (there is still a doubt regarding the period) or the spectral types may be wrong. A couple of A4V stars would fit better.

• **HIP 81126 (σ Her)**: Speckle binary star containing an object suspected to be a β Pictoris-like star, due to its large colour excess in the infrared. The mass excess mentioned by Baize (1989), based on a dynamical parallax close to 10 mas (Balega & Balega 1988) is not confirmed here, due to the new parallax estimate. The value of Δm is still not very clear, since Balega proposed 1.6 ± 0.3 instead of 3.5, as previously assumed.

• **HIP 82817 (Kui 75)**: Famous UV emitting flare star and visual/speckle binary. This is the only system in the present sample for which the new parallax produced by the specific processing for short-period binaries is significantly different (about 12% smaller) from the catalogue's value (ESA 1997). This new estimate (155.42 ± 1.85 mas) agrees well with the most recent ground-based trigonometric determination: 152 ± 4 (Jenkins 1963) and is much more accurate than the Hipparcos value. The latter determination was in fact quite uncertain because no orbital model was used in the data reduction, and there is little doubt that the new value is closer to reality. This situation is very akin to that of Algol.

• **HIP 83895 (ζ Dra)**: The most recent paper concerning this object (Olević et al. 1997) supports a significant change in the orbital elements previously computed by Zulević (1992). The new elements are still considered as preliminary, however, and indeed do not improve the results already obtained with the former orbit. Unfortunately, masses and parallax of the pair were not calculated because of the lack of magnitudes and spectra, as mentioned by Olević (1997). It is thus difficult to assess the quality of the present results, based on Zulević's orbit (1992) and differential photometry (1993). The total mass derived here ($\approx 10\ M_\odot$) suggests a pair of giants.

• **HIP 84949 (McA 47, HR 6469)**: Speckle/spectroscopic triple system consisting of a close eclipsing pair containing a F2V star, orbitting a more distant G5IV variable component. This very interesting system was the subject of three papers published at the same time (Wasson et al.; Van Hamme et al.; Scarfe et al. 1994) in the same journal. We have used the more recent orbital elements proposed by Scarfe et al. (1994) together with $\Delta m = 0$ as suggested by Baize (1991), although this must be used with care because of the photometric peculiarities of the system. The evolved G5 star is referred to as the primary and has a period of variability of about 83 days in V, while the secondary is taken as the brighter star of the close eclipsing pair, whose period is 2.23 days (Van Hamme 1994). The duplicity of the second component could not be seen by Hipparcos, and the double variability phenomenon (eclipse + spotted variable) entails reasonably small change of the magnitude (< 0.09 mag), so the set of Hipparcos observations may be considered as photometrically homogeneous, at least for the purpose of this study. We obtain a mass of 1.15 $M_\odot$ for the evolved primary and a total mass of 2.63 $M_\odot$ for the eclipsing pair, with formal errors of 20% and 14% respectively. While the mass of the secondary is perfectly consistent with Scarfe's determination, it is not true for the primary ($1.86 \pm 0.09\ M_\odot$). This can be traced to small discrepancies in the estimates of the parallax and the fractional mass. Combining Scarfe's fractional mass $B = 0.587$ with our $\beta - B$ yields an estimate of β and thus of the approximative magnitude difference between the evolved primary and the close eclipsing pair, $\Delta m \approx 0.54$ (in the Hipparcos band), half a magnitude larger than Baize's. This assumption leads to individual masses of $1.56 \pm 0.31\ M_\odot$ and $2.21 \pm 0.31\ M_\odot$. The composite secondary has been excluded from the mass-luminosity diagram (Sect. 6.2) and thus does not contribute to the fit.

• **HIP 85141 (Rst 3972)**: Visual/speckle binary formed by two G0 giant stars. For many years the orbital period was assumed to be close to 30 years, until Hartkopf et al. (1996) set forth a half-period alternative, which fits better the recent measurements. We used these orbital elements in Paper II to derive masses of 1.51 $M_\odot$ and 2.94 $M_\odot$ with formal errors at the level of 30%. These elements are now superseded by the new orbit computed by Heintz (1997), in better agreement with the whole set of obervations. We find this time two identical masses of about 1.8 $M_\odot$, with errors at the same level. Values of $\beta - B$ and Δm agree well with the fact that both components have indentical spectral types, but the total mass is slightly too small for two G0III stars. If we consider the smallest possible parallax allowed by the error bar (≈ 14.3 mas), we find a total mass of 4.6 $M_\odot$, closer to the expected value.

• **HIP 86722 (Gl 692.1)**: Single-lined spectroscopic and speckle binary, recently studied by Duquennoy using the CORAVEL and RVM radial-velocity spectrometers and near IR speckle data (Duquennoy et al. 1996). All the values derived here (masses and absolute magnitudes) agree perfectly with Duquennoy's assumptions, except for the mass of the primary component, which we found to be 20% larger. These new results are the most accurate to date and must replace any previous determination.

• **HIP 95995 (McA 56)**: This K star of the solar neighbourhood is a speckle-spectroscopic binary containing a low mass companion, mainly noticed for its high proper motion. Very precise total mass and $\beta - B$ have been determined in this study, but the quality of Δm is still too poor and causes the estimates of the individual masses to be rather uncertain. Better differential photometry is needed.

• **HIP 96302 (9 Cyg)**: Single-lined spectroscopic binary presenting one of the smallest separations of this set. As with all the most distant stars, the masses are not very reliable. The Δm estimate of Baize (1989) does not agree with the value (which we have adopted) found in the Worley catalogue. Moreover, the period is not accurately known.

• **HIP 98001 (Ho 581)**: Visual binary star containing a spectroscopic system (the A component is associated with a low mass spectroscopic companion, see Griffin 1997). The parallax and total mass derived here are

Table 9. Reference values of component's masses and physical ratios

HIP	M_1 $M_\odot$	σ $M_\odot$	M_2 $M_\odot$	σ $M_\odot$	B	σ	ref.[1]	β	σ	ref.[1]
7918	0.93	0.23	0.28	0.07	0.231	0.014	Hen93	0.001	<0.001	Hen93
8903	2.34	0.10	1.34	0.07	0.363	0.013	Pan90	0.054	0.010	Pan90
12153	1.20?	–	1.20?	–	0.500	–	Afr78	0.454	0.023	Afr78
12623	1.28	0.05	1.17	0.05	0.478	0.014	This paper	0.431	0.034	Col35
20087	1.80	–	1.60	–	0.470	–	Bai89	0.137	0.043	Bai89
33451	–	–	–	–	–	–	–	0.407	0.055	ESA97
45571	–	–	–	–	–	–	–	0.500	0.034	Wor96
55016	2.07?	–	1.80?	–	0.465	–	Mas97b	0.065	0.022	Mas97b
60129	4.29	0.40	1.61	0.10	0.273	0.022	Har92	0.324	0.100	Har92
68682	0.85	–	0.40	–	0.320	–	Kam87	0.019	0.008	Kam87
71094	–	–	–	–	0.440	0.030	Hei91	0.393	0.020	ESA97
71729	3.26	–	1.82	–	–	–	Bar91	0.387	0.045	Bar91
76852	–	–	–	–	–	–	–	0.470	0.014	ESA97
81126	–	–	–	–	–	–	–	0.186	0.042	Bal88
82817	0.42	0.10	0.42	0.10	0.500	0.084	Mal93	0.481	0.048	ESA97
83895	–	–	–	–	–	–	–	0.277	0.037	Zul93
84949	1.86	0.09	2.64	0.10	0.587	0.015	Sca94	0.500	0.046	Bai91
85141	–	–	–	–	–	–	–	0.454	0.046	Hei97
86722	0.78	–	0.32	–	0.291	–	Duq96	0.024	0.011	Duq96
94144	–	–	–	–	–	–	–	0.452	0.023	Bai50
95995	–	–	–	–	–	–	–	0.217	0.098	ESA97
96302	–	–	–	–	–	–	–	0.387	0.044	Wor96
98001	–	–	–	–	0.656	0.020	Hei90	0.346	0.023	ESA97

[1] The three first characters of the author's name followed by the two last digits of the publication's year.

compatible with the determination of Heintz (1990), but the very large mass fraction ($B = 0.656$) is not confirmed here. We find a $B = 0.459 \pm 0.052$, yielding a primary component slightly more massive than the secondary. The positions of both stars in the empirical mass-luminosity diagram look satisfactory.

5.2. A special attention for 12 Per (HIP 12623)

The system was identified by McAlister (1976) as a likely candidate for resolution by speckle interferometry, and, indeed, the two components had been resolved by C.R. Lynds in an unpublished, exploratory speckle program at the Kitt Peak 4-meter telescope in 1973. Routine speckle measurements of the system were begun in 1975, and McAlister (1976) published an orbital solution based upon five speckle measurements and the spectroscopic elements of Colacevich (1941). Some 40 speckle measures are now available for analysis. We have calculated new orbital elements for this system, presented in Table 11. They do not differ strongly from the previous estimations, see for example McAlister (1978) although the formal errors are significantly reduced. The Δm estimate of 0.30 is originally from Colacevich (1935), and no better value has been proposed since then. A confirmation would be especially helpful for a mass determination free of bias. We have studied this system in two different ways:

1. The specific processing from Hipparcos data and a ground-based orbit (like all the other stars of this paper),
2. A combination of available spectroscopic and speckle interferometric data for a three-dimensional orbit solution.

Because of the quantity and quality of available data, the second method yields better results. The available radial velocity data span 97 orbital revolutions of 12 Persei while the speckle measurements cover 25 orbits. The relevant data for 12 Persei have been analyzed thanks to the reduction softwares routinely used for CHARA binary star orbit studies, namely a least-squares "grid search" algorithm for the speckle observations and a program developed by Tokovinin for combining radial velocities and speckle astrometry.

In a first step, the orbital elements for 12 Per given in Table 11 were determined from the entire dataset composed of speckle measurements from the CHARA Catalogue of Speckle Interferometric Measurements of Binary Stars (maintained by W.I. Hartkopf and available on-line) and of the radial velocities of Colacevich (1935,

Table 10. Comparison of parameters for 12 Persei

origin	π(mas)	$M(M_\odot)$	$M_1(M_\odot)$	$M_2(M_\odot)$
Ground-based	42.6	2.446	1.276	1.170
	1.0	0.067	0.046	0.049
Hipparcos	41.9	2.51	1.13	1.39
	1.6	0.29	0.17	0.19

Table 11. New speckle orbital elements of 12 Per

$a('')$	P(d)	e	i	Ω	ω	T
0.0534	330.957	0.656	126.75	230.62	89.54	1995.1475
.0005	.013	.005	.62	.82	.41	.0023

1941) and Duquennoy & Mayor (1991). The orbital period from this solution was then fixed and the remaining orbital elements were determined by combining the speckle data with the Duquennoy and Mayor spectroscopic data, leaving out the old measurements of Colacevich. Independent orbits from these two datasets show excellent agreement between common elements.

The combination of the two data types also permits the determination of an orbital parallax of 42.6 ± 1.0 mas which is in excellent agreement with the Hipparcos parallax of 41.9 ± 1.6 mas corrected for the orbital motion of the binary.

While we adopt the masses derived from the combined speckle/spectroscopic analysis, we note that masses can also be derived by applying the Hipparcos parallax to the ground-based orbit, i.e. option number 1 above. Table 10 shows the different values obtained by each method.

The discrepancy observed for the individual masses probably arises from the fact that the value of Δm used to retrieve the fractional mass B in the first method is uncertain. Assuming the values $B = 0.478$ (ground-based) and $\beta - B = -0.121$ (Hipparcos) are correct, we find $\Delta m = 0.64 \pm 0.10$, which is not unrealistic. With the Hipparcos parallax, this would produce the following masses: $M_1 = 1.31 \pm 0.16$ and $M_2 = 1.20 \pm 0.13$. An accurate determination of Δm would result in truly definitive masses for this system, and we note that ground-based, long-baseline optical interferometers offer this potential.

5.3. The 6 revised systems

The results presented in Table 8 for 6 revised systems of Paper II are simply an update of the individual masses and their errors, coming from a more reliable Δm estimate. Thus, the parallaxes and total masses are unchanged. The modifications are briefly discussed below.

• **HIP 2237 (B 1909)**: The slight increase of Δm makes the mass of the secondary closer to the primary's one.

• **HIP 2762 (Kui 7)**: Δm is unchanged but known with a better precision, resulting in more accurate estimates of the masses.

• **HIP 44248 (10 Uma)**: Δm is 10% larger and 4 times more accurate. The mass difference between the components is then slightly larger.

• **HIP 84140 (Kui 79)**: A Δm about 2 times smaller reduces the mass difference in a significant way. The almost identical small masses obtained are therefore more acceptable for this pair of quasi-similar red dwarfs.

• **HIP 93574 (Fin 357)**: The magnitude difference is significantly larger than the previous estimate, and allows the primary component to recover his logical status of more massive star of the pair. Its mass is actually 14% larger than the secondary's mass (instead of 22% smaller before).

• **HIP 107354 (κ Peg)**: The components are this time found to be almost of equal brightness, a fact which increases the mass difference, already fairly large, between the two stars. The respective status of both components is thus not clear, and we should probably exchange them in order to have the primary more massive than the secondary. The spectral types are still needed to check the solution.

6. The mass luminosity relation

6.1. Computation

The masses and parallaxes derived from the previous study and the Hipparcos magnitudes have been used to determine the relation between the mass and the luminosity of the stars in this sample. This aims firstly to detect anomalous results from the residuals of the fit and secondly to compare this fit to other investigations of the mass–luminosity relation for the early type stars. The absolute magnitudes have been computed by using our parallax solution listed in Tables 7−8. The individual magnitudes of the components came either directly from the Hipparcos results (when Δm's computation was possible), or from the combination of a ground-based Δm with the Hipparcos composite magnitude H_p. In any case the relation is,

$$H^{\mathrm{abs}}_{1,2} = H_{1,2} + 5\log\pi - 10 \qquad (2)$$

where H^{abs}_1 and H^{abs}_2 are respectively the Hipparcos absolute magnitudes of the primary and secondary components, π is the Hipparcos parallax in mas, and H_1, H_2 are the apparent magnitudes, derived by,

$$H_1 = H_\mathrm{p} + 2.5\log(1 + 10^{-0.4\Delta m});\ H_2 = H_1 + \Delta m\ . \qquad (3)$$

Table 12. Absolute magnitudes for 52 (17 + 35) systems with relative errors on individual masses less than 25%

HIP	$H_1^{\rm abs}$	σ	$H_2^{\rm abs}$	σ	HIP	$H_1^{\rm abs}$	σ	$H_2^{\rm abs}$	σ	HIP	$H_1^{\rm abs}$	σ	$H_2^{\rm abs}$	σ
7918	4.60	0.03	12.05	0.50	45571	3.57	0.09	3.57	0.09	83895	−1.63	0.14	−0.59	0.19
8903	1.45	0.04	4.63	0.21	68682	5.34	0.04	9.64	0.49	84949	2.35	0.13	2.41	0.14
12153	3.66	0.09	3.86	0.10	71094	2.39	0.16	2.85	0.16	86722	5.88	0.06	9.84	0.49
12623	3.75	0.10	4.05	0.12	76852	1.46	0.12	1.59	0.12	95995	5.83	0.14	7.22	0.50
20087	2.18	0.13	4.24	0.37	81126	−0.24	0.14	1.37	0.28	98001	4.75	0.09	5.44	0.10
33451	3.75	0.12	4.16	0.16	82817	10.68	0.10	10.77	0.11					
171	5.50	0.03	8.71	0.15	43671	1.53	0.14	1.54	0.14	91394	3.77	0.14	3.89	0.14
2237	4.63	0.09	4.80	0.09	44248	3.13	0.04	5.43	0.05	93574	2.75	0.12	3.13	0.15
2762	3.96	0.05	5.25	0.07	45170	5.61	0.08	6.01	0.10	94349	11.14	0.10	13.84	0.17
7580	4.01	0.11	4.42	0.13	54204	2.52	0.11	2.62	0.11	94739	9.18	0.10	9.19	0.10
12390	2.74	0.11	2.80	0.12	75695	1.16	0.07	2.76	0.12	96683	1.20	0.12	1.50	0.14
14328	−1.03	0.14	0.53	0.18	83838	2.48	0.11	2.61	0.12	104858	4.03	0.06	4.04	0.06
14576	−0.13	0.05	2.90	0.15	84140	10.93	0.08	11.16	0.10	105431	4.12	0.12	4.22	0.13
19508	4.22	0.16	4.32	0.16	86032	1.37	0.03	4.87	0.15	107354	2.22	0.09	2.32	0.09
19719	3.14	0.11	3.29	0.11	87204	4.43	0.11	4.44	0.11	108431	1.42	0.14	1.52	0.14
24608	0.35	0.03	0.51	0.04	87655	2.97	0.13	3.17	0.14	112158	−0.79	0.13	−2.91	0.19
31509	3.93	0.08	4.33	0.11	87895	4.26	0.06	7.08	0.28					
38052	4.94	0.10	5.04	0.11	89937	4.29	0.05	6.31	0.34					

The ground-based Δm has been expressed in the Hipparcos photometric system when possible (see Sect. 4). The results are listed in Table 12.

In the following, two sets of data are considered: the first one (Fig. 2) concerns the objects studied in the present paper (excluding the 6 revised stars taken from Paper II), while the second one includes also all the results obtained in our previous work (Figs. 3, 4 and 5). For the first three plots the components with relative error of the mass larger than 25% have been discarded. This limit is reduced to 13% in the case of the last plot, Fig. 5. There are 30 components belonging to 17 systems in the first set and 99 components belonging to 52 systems in the second group, including the non-main sequence objects and the stars lying outside of the main distribution, called "outliers".

The size of each dot in Figs. 2, 3, 4 and 5 is a visual indication of the relative quality of the mass: the bigger dots correspond to the better results ($\sigma_M/M < 10\%$) and so on to the smaller dots by steps of 5%, up to 25%. The error bars in both $\log(M/M_\odot)$ and absolute magnitude are only represented on the last two plots.

6.2. The different fits

We have used a very simple and robust procedure to fit a weighted polynomial model to the data. The obvious outliers have been first excluded from the fit by assigning a null weight to their contribution. Then, two dashed lines parallel to the fitted straight line have been drawn to highlight the main distribution of the scatter, arbitrarily taken at a distance of ± 0.15 in $\log(M/M_\odot)$. Eventually we could identify additional outliers by this way and iterate the procedure. The rejected systems, shown in Fig. 3, have been discussed on a case by case basis in Sect. 5.1.

Table 13. List of the non-main sequence components excluded from the fit in Figs. 4 and 5

HIP	Sp. Type	HIP	Sp. Type
14328 B	G8III	91394 A+B	F9IV
24608 A+B	G1III+G8III	96683 A+B	K0III+K0III
83895 A+B	B6III	107354 A+B	F5IV
84949 A	G5IV	108431 A+B	F0IV
86032 A+B	A5III	112158 A+B	G2II-III+G8II

The fits are based on a cleaned sample obtained after the removal of every non-main sequence object, identified by their assumed spectral class (SIMBAD database, Hipparcos catalogue, literature), an exception being made for the intermediate class IV-V objects. The rejected systems are listed in Table 13. When the composite spectral class of the pair is the only available information, we assume the components belong to the same class, and thus probably reject more stars than needed. The outliers are naturally also removed and we are left with 75 components of 42 systems when $\sigma_M/M < 25\%$ (Fig. 4), or just 32 components of 18 systems if the restriction is pushed to 13% (Fig. 5).

It is well known that a single linear relation cannot fit all mass ranges at a time. The M-L relations for the very high or very low mass stars differ from that concerning the

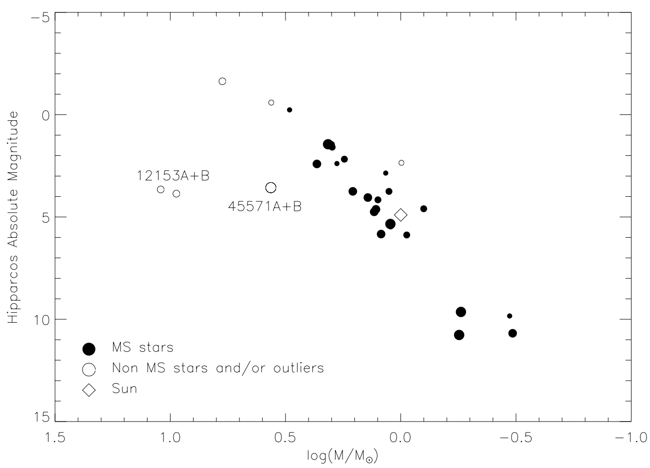

Fig. 2. Mass Luminosity diagram for 30 components belonging to 17 systems studied in this paper, with $\sigma_M/M < 25\%$. The dot's size depends on the quality of the mass (see Sect. 6.1). Open circles stand for the components outside the main sequence and for the outliers, the latter being identified by their Hipparcos ID. The diamond represents the position of the Sun, assuming its absolute mag is 4.9. Note: the parameter in ordinate is not the luminosity but the absolute magnitude in the Hipparcos band; this distinction is significant for the stars outside the range $0.6 - 2.0\ M_\odot$

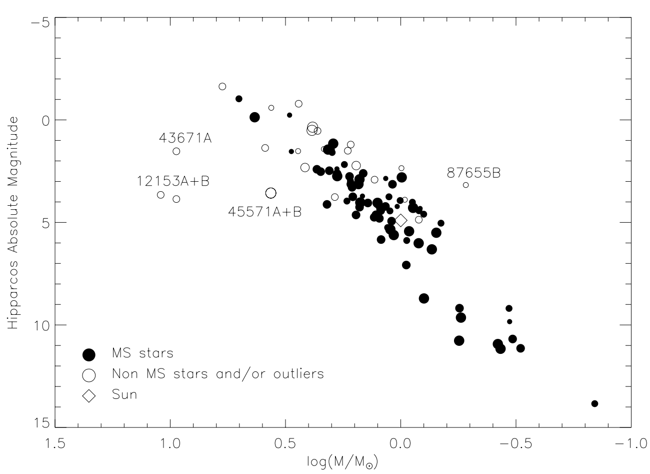

Fig. 3. Same as Fig. 2 for the whole set of binaries: 99 components belonging to 52 systems (compilation of the stars contained in this paper and the previous one)

central part of the diagram (see for example Cester et al. 1983, or Söderhjelm et al. 1997). In the present case, the components with masses larger than 2 $M_\odot$ or smaller than 0.6 $M_\odot$ were not taken into account in the fit of the central part. These limits are materialized on the plots by two vertical dotted lines. An additional restriction was applied to the absolute magnitude, namely $H^{\rm abs} < 8$, in order to rule out any ambiguous object. Due to the very small number of objects in the extreme ranges of the diagram, we did not try to fit a relation in these two areas. Thus, the number of stars used in the fit is respectively 54 and 23 in Figs. 4 and 5.

The linear regression was computed in a very classic way, already used by Cester (1983). Briefly, It consists of fitting the data with two different straight lines by minimizing a χ^2 function estimated in two orthogonal directions, and by taking the line which intercepts the two previous ones and whose slope is the average of the two slopes. In each case the weights of the data points have been set to $1/\sigma_i^2$, σ_i representing the standard deviation of the i $^{\rm th}$ point in $\log(M)$ or in absolute magnitude, depending on the direction considered. The errors of each coefficient of the solution and the correlation coefficient between the two parameters $\log(M/M_\odot)$ and $H^{\rm abs}$ are also determined.

This gives for the first case (Fig. 4),

$$\log(M/M_\odot) \;=\; 0.625 - 0.1292 H^{\rm abs} \qquad (4)$$
$$\pm.011 \quad \pm.0024.$$

For this set of early type main sequence stars, the bolometric correction with respect to the Hipparcos absolute magnitude has been determined by Cayrel (1997) and can be rounded to $BC_{\rm Hp} \approx -0.2$ (or $m_{\rm bol} = Hp - 0.2$), which is accurate enough in the present context. Using $m_{b_\odot} = 4.72$, the above fit can be expressed with the luminosity as,

$$\log(L/L_\odot) \;=\; 0.033 + 3.096 \log(M/M_\odot) \qquad (5)$$
$$\pm.066 \quad \pm.057.$$

In the second case limited to the best solutions (Fig. 5) we get,

$$\log(M/M_\odot) \;=\; 0.537 - 0.1074 H^{\rm abs} \qquad (6)$$
$$\pm.010 \quad \pm.0020$$

or equivalently for the luminosity,

$$\log(L/L_\odot) \;=\; -0.032 + 3.724 \log(M/M_\odot) \qquad (7)$$
$$\pm.079 \quad \pm.070.$$

The correlation coefficient between the "X" and "Y" variables of the diagram equals 0.62 in the first case (Eqs. (4) and (5)) and 0.70 in the second one (Eqs. (6) and (7)). According to the number of data points in each case, these values show that the linear dependance is highly significant (the probability to produce such correlation values by chance if the variables were independant is less than 0.001).

6.3. Discussion

We have processed the same data as above with a similar filtering in mass, including this time the non-main sequence objects. It turns out that their influence to the fit is negligible, since each numerical coefficient of Eqs. (4)–(7) changes only by about 3%. The restriction in mass is on the other hand very important, even for such a sample with a fairly large scatter.

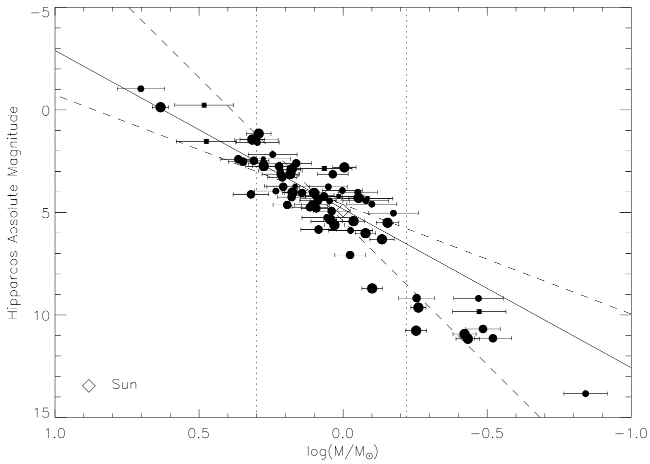

Fig. 4. Mass Luminosity relation fitted over 54 main sequence components with $\sigma_M/M < 25\%$ (75 components visible in total). Non-main sequence stars and outliers have been removed. The dot's size depends on the quality of the mass. The two vertical dotted lines indicate the limits of the mass range considered for the fit, represented by the plain straight line. See details in Sect. 6.2. As bolometric corrections were not computed, the scatter's behaviour in the two extreme mass ranges of the diagram is not physically significant. The Sun is at the centre of the diagram (diamond)

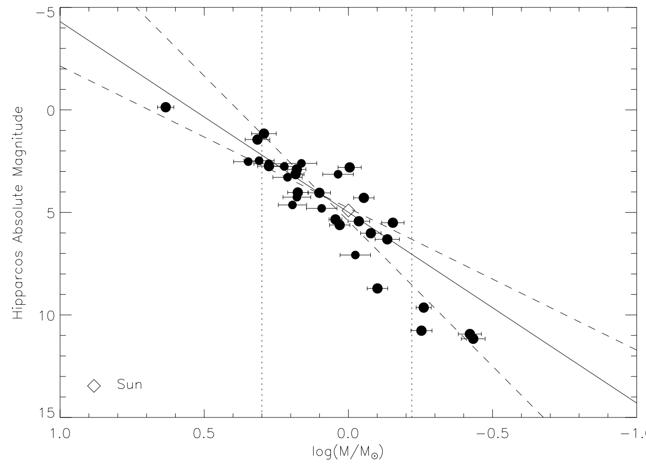

Fig. 5. Same as Fig. 4 (the previous remarks still hold here) with a stronger restriction in mass quality: $\sigma_M/M < 13\%$. Over the 32 visible components, 23 are effectively participating to the fit

The slopes of the mass-luminosity relation are significantly different according to the selection threshold. This may indicate that the formal errors in the linear fit are underestimated. One must notice that the procedure to allow for the absence of an independent and perfectly controlled variable in the model fitting, is rather ad-hoc and lacks statistical rigor. Given the precision of the masses, it is however an acceptable approach. The value $K = 3.7$ found in the second and more reliable solution agrees well with recent determinations on similar material (Lampens et al. 1997). A more refined solution and thoughtful discussion would not only require an improved knowledge of the masses, but that of the spectral type and luminosity class for every component and was beyond the main scope of this paper.

7. Conclusion and further works

This series of papers illustrates meaningfully the scientific interest of combining the high quality astrometry from space with ground based data. On one hand the absolute astrometry from space enables astronomers to track the tiny motion of the photocenter of close binaries with orbital periods less than a couple of decades, while the relative astrometry from the ground carried out over many years is the only efficient source of orbital parameters. The Hipparcos data have been carefully archived and there are still several systems pinpointed by Hipparcos awaiting the availability of a better orbit to be checked in view of determining the masses of their components.

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References

Africano J.L., et al., 1978, AJ 83, 1100
Baize P., 1950, J. Obs. 33, 1
Baize P., 1989, A&AS 81, 415
Baize P., 1991, A&AS 87, 49
Barlow D.J., Scarfe C.D., 1991, AJ 102, 2098
Balega I.I., Balega Y.Y., 1988, Sov. Astron. Lett. 14, 393
Blazit A., 1977, ApJ 214, L79
Cayrel R., et al., 1997, Proceedings of the ESA Symposium "Hipparcos - Venice'97", ESA SP-402, 433
Cester B., Ferluga S., Boehm C., 1983, Astrophys. Space Sci. 96, 125
Colacevich A., 1935, PASP 47, 284
Colacevich A., 1941, Oss. e. Mem. Arcetri 59, 15
Docobo J.A., Costa J.M., 1984, Circ. Inf., No. 92
Duquennoy A., Tokovinin A.A., 1996, A&A 314, 846
Duquennoy A., Mayor M., 1991, A&A 248, 485
ESA, 1997, The Hipparcos and Tycho Catalogues, SP-1200
Finsen W.S., 1963, Republic Obs. Circ. 7, 39
Finsen W.S., 1964, J. Obs. 47, 98
Griffin R.F., 1977, The Obs. 97, 15

Griffin R.F., 1990, The Obs. 110, 177
Hartkopf W.I., et al., 1989, AJ 98, 1014
Hartkopf W.I., et al., 1992, AJ 103, 1976
Hartkopf W.I., et al., 1996, AJ 111, 370
Heintz W.D., 1984a, Circ. Inf., No. 93
Heintz W.D., 1984b, AJ 89, 1063
Heintz W.D., 1990, A&AS 82, 65
Heintz W.D., 1991, A&AS 90, 311
Heintz W.D., 1994, AJ 108, 2388
Heintz W.D., 1997, ApJS 111, 335
Henry T.J., et al., 1992, AJ 103, 1369
Henry T.J., et al., 1993, AJ 106, 773
Jenkins L.F., 1963, General Catalog of Trigonometric Parallaxes
Kamper K.W., 1987, AJ 93, 683
Lampens P., et al., 1997, Proceedings of the ESA Symposium "Hipparcos - Venice'97", ESA SP-402, 421
Lindegren L., et al., 1997, A&A 323, L53-56
Lippincott S.L., et al., 1983, PASP 95, 271
McAlister H.A., 1978, ApJ 223, 526
McAlister H.A., 1976, PASP 88, 317
Martin C., Mignard F., Frœschlé M., 1997, A&AS 122, 571-580
Martin C., Mignard F., 1998, A&A 330, 585
Mason B.D., 1997a, ApJ 114, 808
Mason B.D., McAlister H.A., Hartkopf W.I., 1997b, AJ 114, 1607
Mazeh T., et al., 1992, AJ 401, 265
Mignard F., et al, 1992, A&A 258, 165
Mignard F., et al., 1996, A&A 304, 94
Olević D., Jovanović P., 1997, Bull. Astron. Belgrade 155, 103
Pan X.P., et al., 1990, ApJ 356, 641
Scarfe C.D., et al., 1994, AJ 107, 1529
Söderhjelm, et al., 1997, Proceedings of the ESA Symposium "Hipparcos - Venice'97", ESA SP-402, 251
Tokovinin A.A., 1986, Soviet. Astron. Lett. 12, 480
Van den Bos W.H., 1956, Union Obs. Circ. 6, 279
Van Hamme W.V., et al., 1994, AJ 107, 1521
Voronov. N., 1934, Tashkent Obs. Circ, 27
Wasson R., et al., 1994, AJ 107, 1514
Worley C.E., Heintz W.D., 1983, Fourth Catalog of Orbits of Visual Binary Stars, Publ. U.S. Naval Obs.
Worley C.E., Douglass G.G., 1996, The Washington Visual Double Star Catalog, Publ. U.S. Naval Obs.
Zombeck M.V., 1990, Handbook of Space Astronomy & Astrophysics, Cambridge U.P.
Zulević D.J., 1992, Bull. Astron. Obs. Belgrade 146, 61
Zulević D.J., 1993, Circ. Inf., No. 119