Astron. Astrophys. 341, 121–140 (1999)

ASTRONOMY
AND
ASTROPHYSICS

Visual binary orbits and masses post Hipparcos*

Staffan Söderhjelm

Lund Observatory, Box 43, SE-22100 Lund, Sweden (e-mail: staffan@astro.lu.se)

Received 23 June 1998 / Accepted 24 September 1998

Abstract. The parallaxes from Hipparcos are an important ingredient to derive more accurate masses for known orbital binaries, but in order to exploit the parallaxes fully, the orbital elements have to be known to similar precision. The present work gives improved orbital elements for some 205 systems by combining the Hipparcos astrometry with existing ground-based observations. The new solutions avoid the linearity constraints and omissions in the Hipparcos Catalog by using the intermediate Transit Data which can be combined with ground-based observations in arbitarily complex orbital models. The new orbital elements and parallaxes give new mass-sum values together with realistic total error-estimates. To get individual masses at least for main-sequence systems, the mass-ratios have been generally estimated from theoretical isochrones and observed magnitude-differences. For some 25 short-period systems, however, true astrometric mass-ratios have been determined through the observed orbital curvature in the 3-year Hipparcos observation interval. The final result is an observed 'mass-luminosity relation' which falls close to theoretical expectation, but with 'outliers' due to undetected multiplicity or to composition- and age-effects in the nonuniform near-star sample.

Key words: stars: fundamental parameters – stars: binaries: visual – stars: binaries: general – astrometry – catalogs

1. Introduction

The Hipparcos Catalogue (ESA, 1997, hereafter abbreviated HIP) was published in June 1997, and an obvious use of the Hipparcos parallaxes is for improved mass-determinations for visual binaries with known orbits. Because of Kepler's third law $[m_1+m_2=(\frac{a}{\pi})^3/P^2]$, the relative mass-error is very sensitive to both the parallax-error *and* to the errors in the orbital elements a and P. Interesting mass-sums can only be obtained when these are all small, and a bit unexpectedly, the orbit uncertainties turn out to be often the limiting factor. For many 'known' orbits, the relative positions of the components as observed by Hipparcos fall many standard deviations from the calculated ones, and new orbit-determinations were found necessary in order to diminish these discrepancies and give more reliable mass-estimates. Although one may agree with some of the concerns expressed by Dommanget(1995), it seems clear that any reliable orbit *has* to fit the 'modern' speckle interferometry plus Hipparcos observations, with the 'old' visual observations serving as a (surely very important) handle on the long-period behaviour of the system. Instead of simply combining the Hipparcos parallaxes with the old orbits, the present paper has turned into a large-scale orbit determination effort. The key idea is to combine ground-based data with partly reduced Hipparcos data to give a 'best' interpretation of each individual system. This explicit use of ground-based data, plus a more dedicated individual effort than was possible in the routine Hipparcos reductions, makes it possible also to derive 'resolved' observations of a number of binaries that have only single-star or photocentre orbit solutions in HIP. A major key to the success of this approach is the availability of speckle-interferometry observations, and the WWW-version of the 3:rd CHARA Catalogue (Hartkopf et al., 1997a, hereafter CH3), has been an invaluable tool throughout this investigation. Similarly, most of the old visual observations are individually available in the unique Washington database (cf. Worley & Douglass, 1997, 'WDS'). Many systems are listed in the 4:th catalogue of orbits of visual binary stars by (Worley & Heintz, 1983, 'WH4'), and many subsystems in the 8:th catalogue of orbits of spectroscopic binaries (Batten et al., 1989, 'B8').

In order to have reasonably small final mass-errors, the original plan was to use only systems having a relative parallax-error below 5%, a period shorter than 250 years, and a calculated separation between the components above 0.10 arcsec during some part of the Hipparcos mission. These limits were later relaxed in order to include e.g. well-observed speckle-binaries, Hyades systems or interesting multiple systems. The final list of 200+ systems is therefore somewhat arbitrary, but a large majority of the objects of primary interest for mass-determination should be included. New 'obvious' candidate systems have been found regularly in the 20+ months spent on this study, however, and there are certainly remaining omissions. From the orbits and parallaxes, only the sum of the masses can be obtained, and mass-ratios had to be estimated from the magnitude-difference

---

[*] Based in part on observations collected with the ESA Hipparcos astrometry satellite. Tables 1, 3, 4 and 6 are also 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/Abstract.html

between the components. In some favourable cases, the observable curvature of the motion during the 3-year observation interval of Hipparcos has given also some purely astrometric mass-ratios.

The present investigation was started in the autumn of 1996 with pre-publication Hipparcos data available within the reduction consortia. It was soon apparent, however, that the 'few weeks'-project of adding Hipparcos parallaxes to 'known' orbits would in reality be a long-term one of visual binary orbit determinations. Preliminary results have been presented by Söderhjelm et al. (1997) and Söderhjelm & Lindegren (1997), but the present paper is the first reasonably complete version. The work has proved unexpectedly difficult and time-consuming, due mostly to many 'problem'-systems, but also to the many additions of new systems and to duplicate work reflecting an evolving methodology. The present summary of these various results may still contain a few non-optimal solutions, but hopefully the list of new orbital elements ('osculating' at the Hipparcos epoch 1991.25) may serve as a useful compilation for some years to come.

2. Principles for the orbit-determinations

Because the Hipparcos observations were basically 1-dimensional, some geometrical modelling was needed even to derive the standard astrometric parameters given in the published catalogue. For binaries, the linear model used gave in principle a single HIP position and proper motion (at epoch 1991.25) for each component. In practice, to add to the determinacy of the solutions, most of the HIP binaries were forced to have the same proper motion for each component, making for model mismatch for all orbital systems. For periods shorter than some 25 years, orbital curvature makes even the full linear model erroneous, but fortunately, the intermediate 'Hipparcos Transit Data' enable a post-reduction fit to more complex models.

In the reductions of the Hipparcos data, we tried unsuccessfully to go beyond the linear model for the resolved binaries. There is simply so much variation in the orbital arcs described (and the sampling by Hipparcos) during the 3-year observation interval, that any 'general' scheme (free from a priori inputs) will too often fail. The parametrization of the motion needs to be tailored to the individual orbits, and the solutions are then no longer 'free'. In principle thus, the present paper makes improved Hipparcos reductions (for a small subset of stars) by combining the Transit Data with the available ground-based data, at the cost of no longer clearly separating their respective contributions.

2.1. Hipparcos transit data

The Transit Data are described in Volume 1, Sect. 2.9 of HIP, and in more detail in a forthcoming A&A paper by Quist & Lindegren. They can be thought of as 'rectified Fourier coefficients' $b_1 - b_5$ describing the light variation at the main detector as an object transited the modulating grid at some 100 different epochs during the 1990–93 Hipparcos lifetime. For a point source, five coefficients are redundant, and they can be replaced by an intensity and a phase. For a double star, each scan was made in a new direction with a new 'effective' separation between the components, and the b_i-values contain now also information about this varying separation and about the intensities of both components. The key point to note is that the phase of the light-modulation is fixed in the ICRS reference system (to within any multiple of the 1.2 arcsec grid-period), and with a suitable model, we obtain new 'absolute' astrometric data. The b_i-values are also photometrically calibrated, giving directly standard Hp-magnitudes for the component stars. (On the negative side, it can be noted that the Transit Data derive solely from the NDAC reduction consortium, and that they may therfore show subtle biases not discovered by direct comparisons with FAST data. Also, Transit Data are available only for about a third of the Hipparcos objects, but hopefully for most of the non-single ones).

2.2. The solution model

The observational input to the new solutions consists of two different types of data. First, there are the $b_1 - b_5$ Transit Data, together with full information about the scanning geometry, at each of some 100 epochs (1990–1993). This gives absolute position information for each component, and also determines e.g. the system parallax. Secondly, there are standard relative double-star observations. Speckle-interferometry separations and position angles were taken when available from CH3, and ideally, for short-period binaries, no more may be required. Usually, however, one has to go back and use also visual double-star observations. In some cases, these data were taken directly from the literature, but mostly the unique WDS observation database was used. (In the early stages of the work, published orbital elements were sometimes used to create 'fake visual observations', but with the convenient email-provision of WDS-data by Dr Douglass, most of these solutions have been rerun with the full set of visual observations).

The basic model to be fitted is an undisturbed orbital binary, and the positions of each of the two components is specified by the mass-ratio (q), the seven orbital elements $(P, T, a, e, i, \omega, \Omega)$ plus the five astrometric parameters $(\alpha, \delta, \mu_\alpha, \mu_\delta, \pi)$ for the center of mass. With two added Hipparcos magnitudes (Hp_i), this gives normally 15 parameters to solve for. In several cases (see below), more complex models were needed, and the flexible GaussFit environment (Jefferys et al. 1988) proved very useful. After the model and input data have been specified, this runs 'automatically' an iterated least squares solution with the fitted parameters and their errors as output.

2.3. Weighting principles

Although the Hipparcos Fourier amplitudes come with well-determined observational errors, there is a complex problem with correlations between data with similar scanning directions. Because nearly the same set of stars was used for the attitude determination when the scanning-directions are equal, there are similar systematic errors, and one can not assume independent b_i-sets. To correct approximately for this effect, one may solve an extra set of normal equations (derived from the scanning history of the object), giving an 'extra' set of covariances to add to the absolute astrometric data. There are additional problems for the brightest stars, where the Transit Data mean errors are known to be severely underestimated, as well as for variables, but in most cases, rescalings gave in the end unit weight variances around unity.

From some detailed comparisons reported in HIP, it is found that the systematic differences between the speckle and Hipparcos relative positions are less than some 0.003-0.004 arcsec (3-4 mas), and each of these sources can presumably be trusted at that level of accuracy. The speckle data were usually assumed to have mean errors about 5 mas in both coordinates, but with provision for modification. (An extra problem with speckle-interferometry is of course also the frequent 180-degree ambiguities in the position angles, but usually, the correct quadrant could be iteratively inferred).

It is a well-known fact that visual observations are plagued by observer- and instrument-dependent systematic errors. A 'correct' weighting is almost impossible to achieve, as can be clearly seen when 'visual' orbits are compared with ones derived from more accurate and unbiased speckle-observations (cf. e.g. Hartkopf et al. 1989, 1996). In the present study, the simple assumption is that visual position angles are reasonably unbiased, while the separations are given much lower weight. A visual 'observation' is usually a normal point from a number N of nights and/or observers, and in order to lessen the influence of systematic errors, the weights were usually proportional to $\ln N$. They were adjusted to give in the end slightly less unit-weight-variance for the position angles (and much less for the separations) than for the speckle and Hipparcos data.

2.4. Solution details

Schematically, the parameters can be collected in an orbit vector $\mathbf{p_o}$, an astrometric parameter vector $\mathbf{p_a}$, plus a 'physics' vector $\mathbf{p_p} = (Hp_1, Hp_2, q)$. From the actual values of these parameters, the relative positions and the expected Fourier-amplitudes can be calculated, and GaussFit makes an iterative adjustment minimizing the squared deviations of $\rho - \rho_{\rm calc}(t, \mathbf{p_o})$ and $\theta - \theta_{\rm calc}(t, \mathbf{p_o})$ for the relative positions, and $b_i - (b_i)_{\rm calc}(t, \mathbf{p_o}, \mathbf{p_a}, \mathbf{p_p})$ for the Hipparcos Transit File data, each divided with the appropriate mean errors. Analytical partial derivatives are computed at each iteration, making the process quite slow. A Levenberg-Marquardt scheme is used, but usually several tens of iterations are needed for convergence. One or more of the parameters can be fixed at prescribed values, as was sometimes necessary in order to have any solution at all. The whole processing is surprisingly sensitive and needs a lot of interactive fine-tuning. Subtle element-correlations and/or poor input-data caused some systems simply to 'refuse' to converge despite days and dozens of tries, while superficially similar ones got a solution in minutes.

For the problem-cases, a 'pre-processing' element-finding program was constructed with the *AMOEBA* minimization routine described by Press et al. (1986). With only the relative positions as input, a useable set of start elements could often be obtained when GaussFit otherwise failed to converge. A separate problem is to have good enough 'absolute' starting positions for the components, especially for multiple systems. As shown by Quist et al. (1997), the Transit Data may be used in an 'interferometric mode' to give actual images of any troublesome system. In this way, a system like HIP 28442 (where the HIP astrometry is grossly in error) could be correctly interpreted.

A major advantage of using GaussFit is the ease with which more complicated models may be implemented. When any one of the components shows light-variability, an arroximate solution could still be obtained using the b_1-data as a 'photometer' (giving an instantaneous intensity for the variable component at each transit by assuming a constant value for the other). It was also not difficult to take into account third and fourth visual components that were sometimes included in the Hipparcos observations as described by Söderhjelm & Lindegren(1997). In the present work, even solutions with two superposed Keplerian orbits were run successfully for a few systems (e.g. ξ UMa and ζ Cnc), but in each case real three-body perturbations are probably significant. The easy implementation has a cost in slow execution times and complicated administration, but for the still rather few and very 'individualistic' objects treated, a more streamlined operation with dedicated programming would probably have been an even less efficient alternative.

3. Solution results

In Tables 1–4 are given orbital elements, masses and other relevant data for the new solutions. In HIP, the main identifier for doubles and multiples is the positional CCDM-number (Dommanget & Nys, 1994), mostly identical to the WDS identifier. Both are constructed in principle from J2000 hexagesimal positions [hhmm.m(+/-)ddmm], but due to bad positions and/or different inclusions of wide companions, the last figures sometimes differ. For reasons of space, and because the present work relies heavily on Hipparcos data, the shorter HIP identifiers are used in Tables 1–5. Table 6 (in the Appendix) gives some cross-identifications, including the discoverer and/or a Bayer/Flamsteed designation.

Because the mass-sums depend directly on a^3/P^2, a (relative) mean error for this quantity had to be estimated. This was calculated from the mean errors on the (angular) a and P, and it is listed as $\epsilon(\rm o)$ in the tables. In order to allow for remaining systematic errors, the formal σ:s on a and P were increased whenever the solution depended strongly on visual observations. Normally, the increase was by a factor of 2, but for systems like 70 Oph and ξ Boo, with very many visual observations and no correcting speckle-data, the formal mean errors were increased up to five times. For the 'parallax' contribution $\epsilon(\rm p)$, the formal $\sigma(\pi)$ was deemed realistic (see below), and the total mass-sum error estimate is simply $\epsilon = [\epsilon({\rm o})^2 + \epsilon({\rm p})^2]^{1/2}$.

Table 1. Astrometrically determined mass-ratios together with improved orbital elements and parallaxes (mean errors in parentheses). The Hp_1 and Δm columns give the primary magnitude and the magnitude difference as derived in the present solutions. The N-column has an m for a previously known or suspected spectroscopic subsystem, an n for a note in Table 6, and a g for a giant spectrum. The calculated mass-sums ($M_\odot$) are in the ΣM column, with estimated mean errors ϵ (%), parallax and orbit contributions in parentheses.

HIP	Hp_1	Δm	q	π(present)	π(HIP)	ϵ	(p	o)	ΣM	N	P	T	a	e	i	ω	Ω
2237	7.27	.08	1.02(.10)	33.43(1.02)	31.01(0.87)	9	(9	1)	2.61	n	5.65	1994.1	0.146	.66	64	134	134
	7.27	.07	1.01(.08)	33.41(0.99)		11	(9	6)	1.96		11.33	1993.	0.211	.06	72	45	119
2762	5.61	1.27	.67(.06)	47.73(1.21)	47.51(1.15)	13	(8	10)	2.48	m	6.890	1994.05	0.23	.76	47	283	149
7372	7.94	.18	2.30(.32)	46.42(1.10)	42.29(1.47)	10	(7	7)	2.45	m	4.561	1991.86	0.172	.33	22	307	158
7580	6.71	1.03	.93(.08)	25.73(0.93)	26.15(0.81)	12	(11	4)	2.18	n	29.	1989.8	0.312	.78	96	250	160
12390	5.36	.76	.85(.08)	40.59(1.31)	36.99(1.76)	10	(10	3)	2.60	n	2.654	1991.12	0.107	.23	24	46	86
19719	5.76	.91	.95(.12)	27.41(0.93)	27.04(0.90)	10	(10	2)	2.25	n	7.20	1990.68	0.134	.33	65	305	144
20087	5.87	2.03	.76(.10)	18.23(0.86)	18.25(0.82)	14	(14	2)	3.03	n	11.320	1989.2	0.133	.17	125	344	352
22550	7.50	.24	1.15(.17)	20.21(1.08)	20.15(1.14)	16	(16	0)	3.04	n	16.28	1988.39	0.188	.46	17	257	147
33451	6.89	.42	.84(.11)	24.41(0.65)	23.15(0.56)	12	(8	9)	2.14	n	16.8	1992.3	0.21	.41	29	240	126
36238	5.51	1.87	.45(.04)	27.90(0.97)	29.38(1.39)	15	(10	10)	7.30	m?	2.038	1990.40	0.087	.48	97	51	172
38052	7.72	.38	.76(.13)	25.42(0.91)	26.60(0.83)	11	(11	4)	2.03	n	18.7	1990.72	0.227	.48	122	108	71
44248	4.18	2.34	.76(.04)	61.50(1.01)	60.86(1.30)	5	(5	1)	2.42	n	21.80	1993.8	0.644	.15	131	33	204
45170	7.28	.19	.94(.18)	49.66(1.09)	48.83(0.92)	7	(7	3)	1.74	n	2.705	1993.51	0.116	.43	124	170	317
47479	5.95	.37	1.29(.24)	15.23(0.60)	14.85(0.69)	23	(12	19)	4.88	m?	10.6	1995.1	0.13	.32	129	20	91
60129	4.03	2.18	.54(.05)	13.78(1.06)	13.06(0.84)	23	(23	2)	5.44	m	13.1	1990.2	0.135	.08	50	4	173
75695	3.89	2.01	.68(.03)	29.31(0.82)	28.60(0.69)	9	(8	1)	2.98	n	10.551	1990.98	0.203	.55	111	357	327
82817	9.71	.11	1.60(.15)	155.63(1.81)	174.23(3.90)	8	(3	7)	1.07	m?	1.717	1991.60	0.23	.06	161	104	147
84140	9.93	.42	.97(.03)	156.66(1.37)	158.17(3.26)	4	(3	3)	.71	n	12.96	1991.04	0.77	.75	146	97	158
87655	6.45	1.80	.41(.04)	14.13(0.89)	14.72(0.81)	22	(19	10)	3.04	m	8.9	1989.2	0.088	.32	157	233	169
87895	6.57	2.34	.77(.12)	35.20(0.87)	35.02(0.65)	13	(7	11)	2.25		2.41	1991.94	0.083	.40	68	317	177
89937	3.78	2.40	.72(.02)	124.37(0.52)	124.11(0.48)	3	(1	3)	1.70	n	0.768	1990.97	0.124	.45	75	297	230
98416	6.23	1.50	.84(.08)	40.86(1.29)	40.75(1.35)	11	(9	6)	2.06	n	9.7	1989.	0.236	.02	54	326	111
104858	5.31	.08	.94(.03)	54.32(0.90)	54.11(0.85)	5	(5	2)	2.35	n	5.713	1992.85	0.231	.44	99	3	203
107354	4.97	.04	1.76(.11)	27.24(0.74)	28.34(0.88)	8	(8	2)	4.90	m	11.59	1990.81	0.237	.31	108	305	290
107522	9.56	.13	1.61(.30)	53.38(1.63)	52.56(1.88)	9	(9	1)	1.47	m?	6.21	1988.9	0.205	.59	129	347	103
	9.56	.13	1.88(.34)	53.30(1.41)		9	(8	4)	1.45		12.46	1986.0	0.324	.00	113	0	109
108431	5.00	.51	.79(.10)	18.67(0.84)	17.65(0.78)	60	(13	58)	4.50	g?	6.11	1996.3	0.10	.86	32	100	178
	4.94	.68	.70(.09)	18.92(0.84)		20	(13	15)	4.36		12.2	1990.	0.16	.06	71	258	94
115126	5.41	3.27	.55(.11)	40.28(1.51)	48.22(5.25)	13	(11	7)	2.60	m?	6.30	1993.5	0.189	.18	45	42	157

Mainly for lack of space, the individual orbital elements are given without mean errors and not in all cases to full accuracy. For a and P, however, the number of decimals given reflects the mean errors, which can be also roughly recovered from $\epsilon(\mathrm{o}) \approx 3\frac{\sigma(\mathrm{a})}{\mathrm{a}} + 2\frac{\sigma(\mathrm{P})}{\mathrm{P}}$. The primary Hipparcos magnitude and the (always positive) Δm-value from the new solution is listed, and an ω-value about 180° different from previous results reflects this new choice of primary component. With many different inputs (choice of start elements, fixed parameters, weights), several different solutions were sometimes obtained for one system. The choice of a resonable 'compromise', with suiably increased mean errors, was of course rather subjective, but all really troublesome cases are indicated in the notes in Table 6.

Because of the 'survey'-purpose of the present paper, no attempt was made to record the full details about every solution. More interesting particulars can be found in Sect. 5 and in Table 6, but references to earlier work are very incomplete.(For much of the older work, one may consult the references in WH4). Ideally, all elements should be compared with earlier orbit determinations, but to recover the most recent ones was deemed too laborious. For well-observed systems, the improvement may be slight, but for many others, the new elements are certainly as good as any available. See also the comparisons in Sect. 4.2.

3.1. Systems with astrometrically determined mass-ratios

For the systems with orbital period below 25 years, a solution for the mass-ratio was always attempted. In many cases, this was too unstable to converge, or the mean error on q was very large. For the 27 systems in Tables 1–2, an 'interesting' q was obtained, defined ad hoc as one giving less than 5% error in the fractional mass $\mu \equiv q/(1+q)$.

In Table 1 are given relevant data from from the new solutions, together with the parallaxes as published in HIP. These are the systems where the largest parallax-discrepancies are expected, but in most cases, the HIP value is still useable. A blatant exception is HIP 82817, where the short period together with an appreciable size orbit has led to a grossly erroneous HIP

Table 2. Individual masses determined only from astrometric information. The V-I column gives the mean colour given in HIP, and the last two columns give the absolute magnitudes of the components. (The values in brackets are known or suspected to refer to a giant or a binary subsystem).

HIP	V-I	M_1	M_2	$Hp_1(a)$	$Hp_2(a)$
2237	.62	1.29(.13)	1.32(.14)	4.89	4.97
		.98(.11)	.98(.11)	4.89	4.97
2762	.64	[1.49(.20)]	.99(.14)	4.00	5.27
7372	.95	.74(.10)	[1.70(.18)]	6.28	6.46
7580	.60	1.13(.14)	1.05(.13)	3.76	4.78
12390	.53	1.41(.15)	1.19(.13)	3.40	4.16
19719	.42	1.15(.14)	1.10(.14)	2.95	3.86
20087	.34	1.72(.27)	1.31(.21)	2.17	4.20
22550	.59	1.41(.25)	[1.63(.28)]	4.03	4.27
33451	.53	1.16(.16)	.98(.14)	3.83	4.25
36238	.51	[5.04(.75)]	[2.26(.36)]	2.74	4.61
38052	.66	1.15(.16)	.88(.13)	4.74	5.12
44248	.53	1.37(.08)	1.04(.06)	3.12	5.46
45170	.78	.90(.11)	.84(.10)	5.76	5.95
47479	.21	2.13(.53)	[2.75(.66)]	1.87	2.24
60129	.03	[3.52(.83)]	1.92(.46)	-.27	1.91
75695	.37	1.77(.16)	1.21(.11)	1.23	3.24
82817	2.46	.41(.04)	[.66(.06)]	10.67	10.77
84140	1.98	.36(.02)	.35(.01)	10.91	11.33
87655	.55	[2.16(.47)]	.89(.20)	2.20	4.00
87895	.68	1.27(.19)	.98(.16)	4.30	6.64
89937	.62	.98(.03)	.71(.02)	4.25	6.65
98416	.67	1.12(.13)	.94(.12)	4.29	5.80
104858	.57	1.21(.07)	1.13(.06)	3.98	4.06
107354	.48	1.78(.16)	[3.13(.27)]	2.15	2.19
107522	1.58	.56(.08)	[.91(.11)]	8.19	8.32
		.50(.07)	[.95(.10)]	8.19	8.31
108431	.35	[2.52(1.51)]	1.98(1.19)	1.36	1.87
		[2.56(.53)]	1.80(.38)	1.33	2.00
115126	.82	[1.68(.25)]	.92(.17)	3.43	6.70

parallax. (The present value agrees with previous ground-based results and also with the rediscussion of Hipparcos data by Martin & Mignard, 1998). The shortest periods (that could a priori be expected to give the best q-values) have generally also small a-values, sometimes with only a photocentre orbit given in the DMSA/O Annex of HIP. Generally, a good speckle-coverage is needed to define a (resolved) semi-major axis, with the Hipparcos data then providing a q-value via an (increasingly more uncertain) magnitude-difference and the (well-defined) photocentre orbit. This follows directly from the fundamental relation

$$\alpha/a = q/(1+q) - 10^{-0.4\Delta m}/(1+10^{-0.4\Delta m}) \qquad (1)$$

for the size of the photocentre orbit as a function of the fractional mass and the fractional luminosity. The individual masses in Table 2 are based completely on astrometric information, but usually, their mean errors are too large for more stringent astrophysical tests.

It is interesting to note that some of the systems in Table 1 have q-values significantly above unity, that is, the fainter secondary star is actually the more massive one. The normal explanation is of course that the system is triple, with the secondary really a (closer) binary. In other cases, a 'too low' q-value signals the presence of a third component in orbit with the primary. Of the 27 systems listed in Table 1, 5 are known and 5 suspected multiples, a clear indication that 'simple' duplicity can not uncritically be assumed for typical visual binaries.

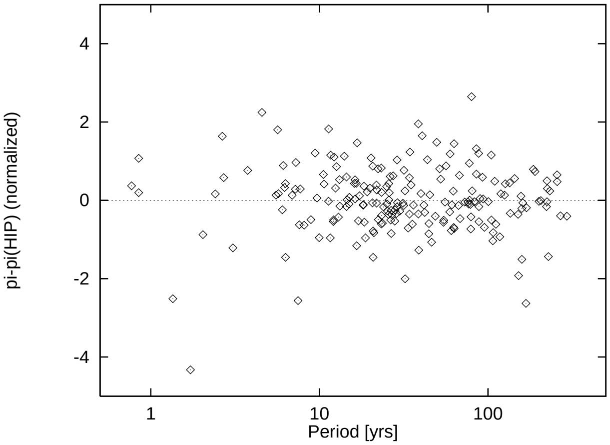

Fig. 1. The normalized parallax-differences between the present solutions and HIP, as a function of the orbital period of the systems.

3.2. Mass-sums without astrometric q-values

For some of the short-period systems and most of the longer-period ones, one may derive a reasonable solution only by assuming a fixed value for the mass-ratio. For systems with large enough angular separation, any value will do, and usually $q = 1$ was assumed. The solution magnitude-difference was later used to derive another q, but this changes only the position and proper motion of the center-of-mass, which are not used in the present context. There were some extra problems for systems with very small angular separations, where (as explained above) the Hipparcos observations mostly sample the position and motion of the photocentre. In order to satisfy Eq. (1), the standard unit mass-ratio gives a biased Δm, which could not later be used to derive a mass-ratio. For some such systems, an iterated sequence of solutions were made, forcing the $q/\Delta m$-values to consistency. (Most of these systems had rather poor solutions anyway, and the impact on the final results are negligible).

As for the parallaxes, both the values derived in the present runs and the ones published in HIP are given in Tables 3 and 4. The estimated mean errors are remarkably similar (although derived in very different ways), and it is not obvious which parallax value should be used for the mass-determinations. When the differences are plotted versus e.g. the orbital periods (cf. Fig. 1) or the semi-major axes, there are no systematic trends, and a somewhat ad hoc combination of parallax values has been used. When the mean errors differ by less than 50%, the straight mean was taken, otherwise a standard weighting inversely to the variances. Only when the new parallax was more than 3σ from the HIP-value was it deemed superior, and the HIP-value was

Table 3. The most accurate mass-sums and orbital elements for the systems without astrometric mass-ratio. The Hp and Δm columns give the primary magnitude and the magnitude difference from the present solutions, while the colour V-I is taken from HIP. The absolute magnitude of the primary (Hp_a) and the mass-sum(ΣM, $M_\odot$) are normally calculated from a mean π (see text). The column ϵ gives the estimated mass-sum error (%), with the parallax and orbit contributions in parentheses. The q-column gives a photometric mass-ratio, and in the N-column is given an m for a spectroscopic subsystem, a g for a non-MS component, and an n for any other note in Table 6.

HIP	Hp	Δm	$V-I$	π(present)	π(HIP)	Hp_a	ϵ	(p	o)	ΣM	q	N	P	T	a	e	i	ω	Ω
171	5.93	3.12	.82	82.5(0.8)	80.6(3.0)	5.5	6	(4	5)	1.49	.64	n	26.28	1989.4	0.83	.38	49	96	290
518	6.49	.94	.74	47.8(0.9)	49.3(1.1)	4.9	9	(6	7)	2.31	.85		106.7	1943.1	1.44	.45	45	277	221
2941	6.32	.32	.78	65.0(1.0)	64.4(1.4)	5.4	6	(6	2)	1.76	.95		25.04	1999.2	0.669	.21	78	143	111
5842	7.90	.55	1.02	49.4(0.9)	47.4(1.3)	6.3	10	(7	7)	1.78	.93		85.2	1919.	1.14	.04	35	141	142
9480	4.69	2.14	.20	27.2(0.7)	27.9(0.6)	1.9	8	(7	4)	3.12	.67		60.5	1965.	0.62	.36	17	24	44
11452	9.45	.16	1.66	59.7(1.2)	60.2(1.8)	8.3	7	(7	3)	1.41	.98		25.3	1987.7	0.58	.22	74	223	109
40167	5.72	.35	.60	41.1(0.9)	39.1(1.4)	3.7	9	(9	1)	2.80	.95	n	59.56	1989.19	0.862	.32	167	187	13
42430	5.44	1.46	.73	50.8(0.9)	50.2(1.0)	4.0	9	(6	7)	2.32	.86		127.	1986.	1.69	.32	83	124	211
45617	8.09	.01	.90	56.5(1.0)	57.1(1.1)	6.9	6	(6	3)	1.48	1.00		34.17	1981.0	0.68	.32	76	311	24
46651	3.97	1.21	.43	54.6(0.9)	53.9(0.7)	2.6	9	(4	8)	2.70	.81		34.2	1970.0	0.80	.44	57	48	287
54061	2.02	2.98	1.03	25.6(0.7)	26.4(0.5)	-.9	8	(7	4)	5.94		g?	44.5	1958.0	0.59	.39	180	222	0
55203	4.39	.52	.68	119.7(0.8)	–	4.8	2	(2	1)	2.62		m	59.95	1995.04	2.53	.41	121	126	100
56290	5.80	1.56	.59	36.3(0.7)	36.3(0.7)	3.6	6	(6	2)	1.95	.79		72.7	1981.8	0.790	.40	46	132	80
61941	3.55	.05	.43	84.2(0.9)	84.5(1.2)	3.2	5	(4	4)	2.90	.99		168.9	1836.4	3.68	.89	148	257	37
63503	5.07	3.21	.45	39.6(0.8)	40.1(0.6)	3.1	9	(5	8)	2.86	.59		105.	1920.	1.26	.38	47	295	269
64241	5.17	.02	.53	55.9(1.4)	69.8(28:)	3.9	8	(8	1)	2.54	1.00	n	26.5	1989.24	0.678	.53	90	99	12
65026	8.89	1.08	1.89	95.4(1.6)	96.4(2.0)	8.8	7	(6	4)	1.65	(0.70)	m?	48.7	1968.9	1.51	.22	94	74	90
67422	7.69	.44	1.16	73.4(1.1)	73.3(1.3)	7.0	5	(5	1)	1.50	.95		157.	1916.7	2.44	.45	47	199	155
71683/1	0.24	1.25	.69	747.1(1.2)	742.1(1.4)	4.6	1	(0	1)	2.05	.83	n	79.85	1955.61	17.6	.52	79	232	204
72659	4.80	2.27	.82	147.1(0.8)	149.3(0.8)	5.7	2	(2	1)	1.61	.72		151.6	1909.3	4.94	.51	139	203	347
73695	5.31	.78	.71	78.4(0.6)	78.4(1.0)	4.8	6	(3	6)	2.70		m	206.	2013.	3.8	.55	84	45	57
75312	5.73	.29	.65	53.5(0.9)	53.7(1.2)	4.4	6	(6	2)	2.41	.96		41.61	1975.5	0.863	.28	58	219	23
75411	4.96	.37	.35	27.7(0.7)	27.0(0.7)	2.1	9	(7	6)	3.70	.94	n	3.75	1991.39	0.102	.28	131	51	134
75415	7.13	.60	.64	27.5(0.7)	26.8(0.9)	4.3	9	(9	3)	2.42	.92		257.	1864.2	1.47	.58	134	336	174
76382	7.59	.19	.95	45.8(0.7)	45.9(0.8)	5.9	5	(5	2)	1.68	.98		55.6	1993.99	0.794	.59	63	23	0
80725	7.79	.18	.94	52.1(0.9)	51.2(1.5)	6.4	9	(6	7)	1.56	.98		224.	1921.1	2.21	.75	108	130	94
81693	3.02	2.66	.70	93.7(0.6)	92.6(0.6)	2.9	4	(2	3)	2.45		g?	34.45	1967.7	1.33	.46	131	111	50
84709	6.37	1.00	1.21	138.2(0.7)	143.5(17:)	7.1	3	(2	2)	1.27	.88	n	42.15	1975.9	1.81	.58	128	247	313
85667	6.16	.07	.74	59.0(0.8)	60.8(1.4)	5.0	5	(5	2)	2.03	.99		46.3	1962.4	0.97	.17	99	326	151
86036	5.40	3.36	.67	71.0(0.5)	71.0(0.6)	4.7	7	(2	7)	1.72	.60		76.1	1947.	1.53	.18	104	307	151
88601	4.33	1.85	.96	195.7(0.9)	196.6(1.4)	5.8	2	(2	1)	1.61	.84		88.34	1984.32	4.56	.50	120	13	301
93017	5.42	2.61	.66	66.7(0.6)	66.8(0.5)	4.5	5	(3	5)	1.78	.67		61.0	1971.8	1.25	.25	114	279	48
93506	3.27	.20	.06	35.3(0.9)	36.6(1.4)	1.0	9	(8	2)	5.63	.96		21.02	1984.7	0.483	.22	111	181	253
95995	7.37	.31	.90	57.6(0.6)	59.8(0.6)	6.2	6	(3	5)	1.64	.96	n	1.351	1990.66	0.083	.38	142	355	66
97222	8.47	.16	1.04	49.5(0.8)	49.1(1.4)	6.9	8	(6	6)	1.37	.98		232.	1945.3	2.07	.77	156	128	91
101769	4.11	.90	.50	32.5(0.7)	33.5(0.9)	1.7	8	(7	3)	3.34		g?	26.66	1989.5	0.440	.36	61	349	177
104887	3.89	2.90	.46	49.1(0.6)	47.8(0.6)	2.3	4	(4	2)	2.71	.62		49.6	1989.0	0.91	.24	133	118	159
107788	5.74	1.17	.46	29.6(0.8)	29.9(0.8)	3.1	9	(8	4)	2.67	.80	n	26.6	1989.8	0.368	.24	70	248	231
110893	9.78	1.62	2.63	247.5(1.5)	249.5(3.0)	11.8	2	(2	1)	.47	.59		44.64	1970.3	2.42	.41	172	209	152
111974	6.28	.81	.83	29.5(0.8)	30.5(1.0)	3.7	9	(9	1)	2.01		g?	20.83	1983.56	0.287	.74	141	24	253
113445	7.07	.58	.70	32.6(0.9)	32.3(0.9)	4.6	10	(8	5)	1.93	.92	n	26.0	1978.1	0.35	.50	89	262	166

then neglected. In principle, one may object to giving equal weight to the HIP parallaxes (generally a combination of two independent values derived by the reduction consortia NDAC and FAST) and the present 'NDAC-biased' (through the use of NDAC-derived Transit Data) values. In practice, however, some tests using the spread around a mean mass-luminosity relation did find marginally smaller deviations using the combined parallaxes as compared with either alone. Unfortunately, there are too few systems with enough parallax difference (in a mass-range with small enough evolutionary effects) to quantify these findings, but any final mass-bias should be indiscernible at the present level of accuracy.

Most of the systems in Tables 3 and 4 are on the main sequence, and it is quite feasible to use the luminosity-ratios (magnitude-differences) as a clue to the mass-ratios. The main problem here is the lack of individual colours (generally unobservable at sub-arcsecond separation) for the components. What is available is a combined colour $(V-I)_c$, the absolute

Table 4. Parallaxes, mass-sums (ΣM, solar units) and orbital elements for systems where an astrometric mass-ratio can not be derived and where the total ϵ is estimated to be above 10%. Otherwise as Table 3.

HIP	Hp_1	Δm	$V-I$	π(present)	π(HIP)	Hp_a	ϵ	(p	o)	ΣM	q	N	P	T	a	e	i	ω	Ω
1242	11.47	3:	3.01	186.7(3.3)	191.9(17:)	12.8	70	(6	69)	.28		n	4.8	1991.0	0.35:	.08	133	45	96
1674	8.62	.37	.84	31.4(1.0)	31.5(1.5)	6.1	49	(11	47)	1.19	.95	n	161.	1941.	1.0	.89	88	202	87
2552	10.57	3.25	2.06	97.0(2.0)	98.7(3.4)	10.5	23	(7	21)	.41	(.34)	n	15.4	1989.	0.45	.00	27	0	24
5300	5.54	1.35	.19	16.3(0.9)	16.5(0.6)	1.6	26	(14	22)	4.22	.78		29.	1979.	0.25	.46	66	329	143
6486	7.11	.21	.53	17.2(0.8)	17.3(0.7)	3.3	23	(13	18)	2.24	.96	n	222.	1984.8	0.83	.93	99	130	137
6564	6.55	.46	.47	22.9(1.0)	22.3(1.0)	3.3	13	(13	3)	2.62	.91	n	16.110	1988.84	0.199	.93	117	348	29
7918	5.09	> 6	.67	78.9(0.9)	79.1(0.8)	4.6	17	(3	17)	1.06	.29	n	19.5	1997.1	0.58	.43	105	22	33
10403	6.61	.65	.49	24.8(0.8)	24.1(1.0)	3.5	11	(11	2)	2.39	.89		144.	1898.	0.896	.27	63	319	99
10535	6.41	.08	.59	20.0(0.9)	20.8(0.9)	3.0	14	(13	4)	2.70	1.00	n	23.7	1986.22	0.234	.68	104	84	236
10542	8.52	.75	1.11	45.6(1.2)	45.0(1.7)	6.8	48	(10	47)	1.59	.91	n	225.	1803.	2.0	.14	41	19	170
11569	4.68	4.03	.17	23.6(0.8)	23.0(0.8)	1.5	30	(10	28)	10.21		m?	52.	1980.	0.7	.30	106	156	175
12717	6.93	.37	.65	17.9(0.5)	18.4(0.6)	3.2	39	(9	38)	3.14	.99	n	36.	1999.	0.29	.85	94	15	36
14879	4.05	3.04	.63	70.4(0.9)	70.9(0.7)	3.3	32	(3	31)	2.47	.63	n	269.	1947.	4.0	.73	81	43	117
14913	6.55	.71	.51	23.0(0.7)	22.8(0.8)	3.4	18	(10	15)	2.88	.87	n	45.2	1977.5	0.41	.90	165	118	110
15799	7.07	4.14	.88	57.8(0.7)	58.5(1.0)	5.9	57	(4	57)	2.25	.71	n	111.	1982.	1.8	.20	32	348	49
16602	7.12	.24	.60	14.7(1.0)	13.9(0.9)	2.9	22	(19	11)	2.82	1.00	n	14.	1990.14	0.120	.35	45	235	236
16628	6.69	.95	.55	23.8(0.8)	23.5(0.8)	3.6	21	(10	18)	2.45	.85		19.2	1997.	0.23	.36	87	8	141
17954	5.73	.80	.26	17.2(0.9)	17.0(0.8)	1.9	22	(15	16)	3.87	.86		62.	2000.	0.42	.62	84	353	25
19758	7.18	1.28	.64	22.2(0.6)	22.3(0.6)	3.9	58	(9	57)	4.46	.83	n	18.2	1987.1	0.25	.79	57	252	84
	7.18	1.29		22.2(0.6)		3.9	12	(8	9)	1.74	.82		36.1	1975.9	0.29	.00	58	180	132
20215	7.27	1.31	.61	23.3(1.2)	23.3(1.1)	4.1	15	(15	5)	2.01	.82	n	89.7	1987.	0.59	.60	53	134	62
20347	6.80	.25	.43	18.8(1.1)	18.4(1.2)	3.1	22	(18	13)	2.83	.95	n	80.	1924.	0.49	.61	36	106	359
20661	7.23	.15	.58	22.1(1.1)	21.5(1.0)	3.9	18	(14	11)	2.84	.97	n	6.28	1988.70	0.105	.73	122	271	215
20686	8.06	.85	.74	24.1(1.1)	23.1(1.2)	4.9	16	(15	5)	1.77	.86	n	27.4	1996.	0.259	.04	97	235	23
20885	4.06	3.04	1.02	21.3(1.0)	20.7(0.9)	.7	14	(13	4)	4.29		g	16.26	1998.5	0.219	.57	92	250	355
20916	7.15	.70	.59	24.5(1.6)	20.6(1.7)	3.9	24	(23	8)	3.09	.90	n	40.7	1960.	0.39	.33	92	311	78
21280	8.93	1.29	.86	26.0(1.5)	24.0(1.7)	5.9	29	(19	22)	4.94		m?	13.	1989.9	0.23	.66	70	88	80
21281	3.61	.94	-.08	18.2(0.6)	18.6(0.5)	-.1	35	(8	34)	6.03	.78		12.1	1986.	0.18	.80	31	193	140
21594	4.11	2.76	1.09	30.9(0.9)	29.8(0.6)	1.5	16	(8	14)	2.49		g	77.	1975.	0.75	.55	67	24	171
21698	9.38	.97	.95	22.7(1.0)	22.3(1.1)	6.1	25	(14	21)	1.96	.88		32.	1999.	0.29	.11	77	308	80
22505	8.24	.95	.79	20.0(1.0)	23.6(1.0)	4.7	21	(15	15)	1.97	.90	n	7.5	1994.3	0.096	.00	71	0	132
22607	6.52	2.00	.58	22.9(1.0)	23.9(1.0)	3.4	14	(13	5)	3.11		m	95.2	1982.0	0.71	.59	48	310	143
23166	6.00	1.52	.52	22.6(0.9)	23.2(0.8)	2.8	16	(11	11)	2.33	.78		55.	1979.	0.44	.88	118	0	141
23395	7.06	1.97	.58	25.1(1.0)	25.3(1.8)	4.1	19	(14	14)	1.85	.73	n	25.1	1975.	0.26	.29	19	190	15
23452	8.53	2.14	1.81	119.9(1.7)	117.4(1.8)	8.9	99	(4	99)	1.84	.58	n	44.	1996.	1.8	.89	76	94	63
25119	7.98	2.79	.96	50.3(1.4)	50.2(1.5)	6.5	27	(9	25)	1.24	.68		93.	1950.	1.1	.13	114	153	164
26926	6.56	.60	.52	21.3(0.9)	19.9(0.8)	3.1	35	(13	32)	2.43	.90		20.3	1999.	0.21	.40	72	273	95
28442	9.07	.96	1.23	55.4(1.8)	66.8(24:)	7.8	29	(10	27)	.93	.88	n	68.	1998.	0.9	.45	103	279	125
28614	4.34	1.93	.19	20.8(0.9)	21.5(0.8)	1.0	14	(13	7)	6.18		m	18.5	1985.1	0.27	.75	96	217	25
28734	4.88	.45	.88	21.4(1.2)	21.6(1.1)	1.5	17	(16	4)	5.16		m	13.2	1995.4	0.208	.34	62	190	178
29234	6.55	.02	.52	18.3(0.8)	18.5(0.7)	2.9	13	(12	3)	4.30		m?	18.2	1997.8	0.207	.33	46	299	265
30920	11.00	2.68	3.04	244.4(2.4)	242.9(2.6)	12.9	23	(3	23)	.31	(.42)	n	16.5	1983.5	1.1	.38	54	229	30
30953	9.17	.05	.43	19.3(0.6)	19.3(0.7)	5.6	23	(10	21)	1.86	.99	n	101.	1905.	0.51	.23	33	17	112
31509	6.76	1.27	.56	25.7(0.7)	24.8(0.6)	3.8	23	(7	22)	2.03	.82		28.9	1993.1	0.30	.47	100	286	156
33142	11.21	1.44	2.45	97.4(2.0)	94.0(2.2)	11.1	68	(7	68)	.46	.65	n	12.	1996.	0.4	.30	109	73	101
33449	4.89	.91	.85	20.0(0.8)	19.1(0.8)	1.3	50	(12	48)	3.65		g	190.	1993.	1.0	.66	79	100	42
34860	7.28	.08	.57	23.0(0.9)	22.7(2.0)	4.1	26	(13	23)	2.93	.99		119.	1920.7	0.8	.93	141	244	19
38382	5.68	.88	.67	61.1(0.9)	60.0(1.0)	4.6	11	(5	10)	1.82	.87	n	23.3	1985.8	0.60	.75	80	72	102
38474	6.21	1.04	.48	24.3(1.0)	24.5(1.0)	3.1	14	(12	6)	2.42	.82	n	32.	1989.3	0.33	.66	77	122	185
40239	9.95	.58	1.72	53.0(2.2)	46.2(4.1)	8.6	15	(12	9)	1.14	.90	n	62.9	1998.7	0.87	.68	51	167	142
41261	8.28	.64	.82	30.6(0.8)	30.1(0.8)	5.7	24	(8	23)	1.27	.90		25.8	1975.2	0.29	.25	36	231	130
41426	6.97	.89	.49	18.5(0.6)	18.5(0.5)	3.3	18	(9	15)	2.92	.85		14.6	1997.	0.16	.32	62	177	103
41820	7.62	1.62	.78	34.7(1.0)	34.8(1.4)	5.3	25	(10	23)	1.72	.78		31.3	1984.	0.41	.71	120	243	143
42075	7.12	.38	.86	16.0(0.7)	15.9(0.7)	3.1	44	(13	42)	1.80		g?	17.3	1996.	0.13	.59	19	230	79
42455	6.52	1.22	.49	24.7(0.7)	24.9(0.6)	3.5	34	(7	33)	1.78	.82		67.	1992.	0.50	.80	105	355	58

Table 4. (continued)

HIP	Hp_1	Δm	$V-I$	π(present)	π(HIP)	Hp_a	ϵ	(p	o)	ΣM	q	N	P	T	a	e	i	ω	Ω
43109	3.96	.84	.78	24.3(1.0)	24.1(1.3)	.9	15	(14	4)	5.28		g	15.07	1991.26	0.257	.65	50	265	108
43671	5.73	1.05	.31	13.2(0.6)	12.5(0.5)	1.3	24	(13	20)	6.09	1.50	m	7.25	1993.4	0.09	.28	15	220	0
45571	6.06	.39	.48	28.8(0.5)	29.8(0.6)	3.4	25	(6	24)	3.49	.93	n	3.07	1992.8	0.09	.50	141	102	125
46404	5.74	1.51	.73	29.1(1.1)	32.0(1.0)	3.2	12	(10	6)	2.54		g?	32.	1975.1	0.422	.31	85	150	151
46454	6.01	.65	.67	27.5(1.1)	29.1(1.3)	3.3	13	(13	3)	1.92		g?	117.6	1959.4	0.84	.56	64	302	326
46706	10.73	.19	2.39	96.9(3.4)	95.0(4.3)	10.6	21	(12	17)	.85	.94		18.4	1983.9	0.63	.29	143	285	48
51233	4.64	1.32	.89	21.9(0.8)	22.3(0.9)	1.4	71	(12	70)	2.63		g	39.	1998.	0.3	.69	79	24	42
51885	6.73	1.10	.55	22.4(1.0)	22.7(1.1)	3.5	20	(14	14)	2.25	.83		159.	1949.	0.87	.75	128	40	147
51986	4.14	1.62	.35	36.6(0.8)	37.7(0.5)	2.0	23	(5	23)	2.76		m	16.6	1986.5	0.3	.73	131	295	41
53423	6.07	3.05	.49	23.5(0.9)	22.9(1.1)	2.9	48	(13	46)	1.96	.61	n	134.	1919.	0.8	.67	121	143	42
54155	10.99	.00	.81	40.9(1.1)	40.6(1.4)	9.0	21	(9	19)	1.20	1.00	n	23.3	1995.	0.35	.08	65	105	70
54204	5.73	.06	.43	22.3(0.7)	23.0(0.7)	2.5	14	(10	10)	4.00	.99		7.6	1991.1	0.139	.35	92	166	45
55266	5.40	.33	.11	18.4(0.9)	17.8(0.8)	1.7	15	(13	7)	5.21		m	5.09	1992.6	0.093	.12	57	68	121
55425	4.08	1.49	-.16	9.1(0.6)	10.2(0.5)	-1.0	27	(18	21)	9.25	.54	n	39.	1973.	0.23	.84	38	202	113
55642	4.11	2.75	.47	42.6(1.3)	41.3(1.2)	2.2	10	(9	6)	2.73	.63		186.	1948.8	1.91	.53	128	325	235
57994	7.24	1.05	.65	17.4(0.6)	17.5(0.7)	3.5	14	(11	9)	2.27	.84		76.7	1987.3	0.41	.50	39	247	22
58799	7.13	.54	.57	22.1(0.9)	21.4(1.0)	3.8	15	(13	7)	2.37	.91		110.	1913.	0.66	.57	159	123	49
59780	10.17	1.11	1.63	47.0(2.1)	49.6(3.1)	8.6	33	(16	29)	1.04	.80		63.	1984.	0.8	.21	54	239	109
59816	10.11	.48	1.35	30.3(2.2)	38.7(3.7)	7.5	23	(22	7)	1.25	.94	n	1100.	1973.67	3.5	.89	26	275	2
60994	6.54	3.04	.68	39.6(0.9)	40.0(1.0)	4.5	15	(7	13)	1.75	.63		151.	1944.	1.4	.71	24	75	94
61932	2.84	.10	-.01	25.0(0.7)	25.0(1.0)	-.2	11	(10	5)	5.82	.99		83.	1931.2	0.86	.79	114	186	2
66438	6.30	.40	.57	28.7(0.8)	28.2(1.2)	3.6	25	(10	23)	3.09	.93		35.0	1967.5	0.45	.78	117	94	71
66458	5.02	2.03	.31	15.4(0.9)	17.0(0.7)	1.1	21	(14	15)	4.84		g	228.	1864.	1.02	.80	147	159	87
66640	6.35	.12	.41	18.0(0.9)	18.7(0.9)	2.7	15	(15	2)	2.51	.98		22.3	1997.1	0.198	.55	44	355	37
70327	7.43	.66	.07	15.4(0.9)	15.2(0.9)	3.4	20	(18	8)	2.45	.88	n	40.0	1998.	0.24	.25	42	141	46
70973	8.43	.32	.82	25.9(1.1)	26.0(1.0)	5.5	18	(12	13)	1.61	.95	n	20.6	1994.2	0.23	.54	52	163	177
71914	9.78	.23	1.48	47.1(1.8)	44.5(2.6)	8.1	15	(14	3)	1.03	.97		51.7	1982.	0.64	.09	120	204	178
72217	7.30	.00	.61	23.7(0.9)	23.6(1.1)	4.2	13	(13	4)	2.82	1.00		25.8	1993.	0.292	.03	58	67	137
72479	9.30	.02	.91	22.4(1.4)	24.2(1.3)	6.1	20	(17	10)	1.44	1.00	n	9.97	1988.2	0.122	.51	40	338	143
73182	8.38	1.77	2.22	169.7(1.0)	133.6(34:)	9.5	13	(2	13)	.83	.71	n	.847	1991.45	0.14	.76	109	308	14
74893	7.42	.05	.64	26.1(0.9)	26.1(1.3)	4.5	13	(12	3)	2.53	.99		200.	1941.4	1.22	.65	58	52	62
76466	9.49	.23	.83	18.6(0.8)	18.8(0.9)	5.8	22	(14	17)	1.34	.96		88.	1985.	0.41	.63	121	232	130
76852	5.21	.14	.07	17.3(0.8)	17.0(0.8)	1.4	14	(14	3)	3.79	.97	n	21.9	1984.8	0.209	.07	83	72	70
76952	4.05	1.56	.04	23.1(0.7)	22.5(0.7)	.8	13	(9	10)	4.23	.70	n	92.7	1931.	0.75	.51	94	103	111
78662	5.36	.26	.30	22.8(0.9)	23.3(1.0)	2.2	15	(12	9)	3.87	.95	n	26.9	1991.0	0.32	.52	159	33	114
78727	5.05	.02	.53	37.0(1.2)	–	2.9	10	(10	1)	2.75	1.00	n	45.68	1997.0	0.663	.75	33	343	206
83838	6.15	.18	.35	18.0(0.7)	18.6(0.6)	2.5	14	(11	8)	3.32	.97	n	8.11	1991.70	0.110	.55	120	55	130
84012	2.97	.50	.06	40.3(0.9)	38.8(0.9)	1.0	69	(7	68)	4.81	.90	n	88.0	1936.8	1.3	.94	95	275	39
84123	12.13	.02	2.60	87.4(5.2)	92.6(5.1)	11.9	22	(17	13)	.57	.99	n	34.	1989.	0.78	.19	14	284	98
84425	6.30	1.57	.64	31.9(0.8)	32.6(1.7)	3.8	16	(10	13)	1.24		n	23.3	1986.5	0.28	.50	123	349	4
84949	6.22	.78	.73	15.7(0.6)	15.5(1.2)	2.2	15	(14	6)	4.20		m	5.525	1991.94	0.079	.69	55	47	318
85141	8.44	.65	.69	15.4(1.1)	15.5(1.2)	4.4	24	(22	9)	3.77		m?	15.0	1990.6	0.146	.57	22	1	82
85582	9.66	.40	1.24	41.1(2.3)	42.4(3.8)	7.7	21	(19	7)	1.08	.95		59.	1972.	0.65	.19	81	64	66
85846	8.70	.29	.65	16.2(0.7)	16.8(0.7)	4.8	20	(13	15)	1.71	.96		23.3	1992.	0.16	.26	70	205	157
86221	9.80	.61	1.26	31.6(1.8)	32.1(2.3)	7.3	20	(19	6)	1.30	.93	n	24.0	1985.3	0.29	.21	165	190	140
87204	8.01	.05	.59	17.5(0.7)	18.8(0.6)	4.3	12	(11	6)	2.22	.99	n	20.8	1988.77	0.179	.62	110	81	135
88404	5.32	.67	.45	19.9(1.2)	19.2(1.0)	1.8	40	(16	37)	5.28		g?	257.	1829.	1.4	.77	52	42	60
88637	7.64	.79	.72	27.1(1.2)	26.5(1.4)	4.8	15	(14	2)	2.19		m	19.94	1998.3	0.256	.96	77	359	271
88745	5.19	3.71	.60	64.6(0.7)	63.9(0.6)	4.2	19	(3	19)	1.25	.58		56.4	1998.	1.0	.75	34	301	216
88932	9.57	.32	1.04	31.9(1.3)	29.6(1.4)	7.0	44	(13	42)	1.50	.96	n	9.4	1988.	0.16	.52	55	60	69
88964	6.07	1.33	.42	19.0(0.8)	19.6(1.2)	2.5	19	(16	11)	2.70	.79		294.	1912.8	1.19	.61	103	307	71
91394	7.14	.48	.64	19.3(1.2)	20.0(0.9)	3.6	17	(16	4)	2.85	.93	n	12.13	1995.0	0.147	.25	124	258	173
91395	8.29	.69	.70	18.8(0.6)	19.1(0.6)	4.7	26	(10	24)	2.19	.90	n	135.	1868.	0.65	.60	88	353	129
92122	8.67	.72	.87	26.8(0.8)	27.0(0.9)	5.8	26	(10	24)	2.69	.90		14.5	1995.7	0.22	.56	131	285	75
93574	6.56	.40	.57	18.8(0.7)	17.7(0.8)	2.9	17	(12	12)	3.23	.99		14.1	1990.1	0.16	.34	152	227	135
94252	8.98	.38	.80	19.4(1.0)	20.5(1.3)	5.5	18	(17	6)	2.28	.94	n	63.0	1957.	0.42	.46	110	190	93

Table 4. (continued)

HIP	Hp_1	Δm	$V-I$	π(present)	π(HIP)	Hp_a	ϵ	(p	o)	ΣM	q	N	P	T	a	e	i	ω	Ω
94739	10.16	.07	1.89	64.3(1.9)	63.4(2.2)	9.2	31	(9	30)	1.18	.99	n	7.70	1995.3	0.26	.32	117	69	20
96907	6.49	1.66	.20	11.9(0.6)	12.0(0.6)	1.9	33	(15	30)	3.66	.73	n	79.	1981.	0.34	.38	106	12	338
97237	12.88	.67	2.93	88.8(7.1)	–	12.6	33	(24	23)	.61	.78	n	228:	1961.	2.8:	.50	78	179	67
98001	8.01	.75	.83	21.9(0.6)	22.3(0.8)	4.7	12	(10	7)	2.73		m	25.7	1988.2	0.27	.50	34	236	43
99376	8.05	.54	.73	20.2(0.7)	19.5(0.8)	4.5	13	(11	7)	1.71	.93		85.3	1970.1	0.46	.48	115	339	142
101750	7.70	2.72	.87	37.0(0.6)	36.2(1.0)	5.5	61	(5	60)	1.92		m	32.	1998.	0.5	.58	27	226	202
101955	8.23	1.45	1.44	59.8(2.1)	53.8(2.2)	7.0	16	(11	11)	2.26		m	39.	1967.	0.85	.10	85	143	128
101958	3.86	2.55	-.01	13.0(0.8)	13.6(0.7)	-.5	18	(17	6)	5.81	.60	n	17.0	1983.8	0.158	.47	160	99	129
102782	10.07	.20	1.14	23.1(2.3)	29.2(3.3)	7.2	39	(32	22)	1.53	.98	n	159.	1958.	0.88	.26	123	296	31
103655	10.34	2.06	2.22	66.0(1.8)	66.2(2.5)	9.4	24	(10	22)	1.38		m	29.	1979.	0.70	.55	54	207	67
104019	5.02	2.30	.18	20.2(1.1)	20.6(1.5)	1.6	26	(19	18)	2.87	.65		28.	1974.5	0.27	.39	160	39	150
104788	7.15	.24	.69	23.6(0.5)	24.2(0.5)	4.0	34	(6	33)	2.58	.98		79.	1921.	0.6	.82	82	37	62
105200	7.39	1.48	.67	19.1(1.0)	19.8(1.2)	3.8	18	(17	7)	3.07		m	79.	1987.0	0.52	.87	99	169	253
105431	7.39	.43	.61	21.2(0.9)	21.5(0.8)	4.0	15	(12	9)	2.56		m	6.03	1991.90	0.097	.86	135	23	288
106811	9.97	3.63	1.52	78.2(2.1)	76.1(2.5)	9.4	40	(9	39)	1.57		n	68.	1945.	1.5	.22	153	184	64
111062	5.82	1.55	.40	19.1(0.9)	18.9(1.2)	2.2	20	(16	12)	3.46	.76		125.	1911.	0.72	.50	89	214	116
111314	6.68	.36	.39	13.1(0.7)	13.1(0.6)	2.3	21	(14	16)	3.66	.94	n	224.	1973.	0.74	.30	79	185	262
111528	8.78	.70	.68	14.7(0.8)	13.8(0.8)	4.5	24	(17	17)	2.00	.90		22.3	1985.3	0.14	.37	60	145	111
111805	7.49	.46	.65	26.0(0.8)	26.3(0.8)	4.6	11	(9	6)	2.15		m	29.9	1979.8	0.33	.32	88	82	154
111965	6.77	1.03	.63	29.1(1.0)	29.9(1.1)	4.1	19	(10	16)	.61		n	28.	1982.7	0.23	.74	85	206	128
	6.77	1.03		29.1(0.9)		4.1	11	(10	6)	.77			54.	1994.9	0.383	.00	87	0	130
112915	8.59	.85	1.01	39.8(1.0)	41.2(1.4)	6.6	31	(9	30)	1.86	.90	n	107.	1932.	1.1	.84	104	68	20
113048	6.04	1.78	.30	20.6(1.0)	19.2(0.7)	2.5	14	(12	7)	2.62		m	105.	1940.	0.60	.59	38	13	26
113996	6.12	.30	.36	17.2(1.0)	17.3(1.0)	2.3	18	(17	3)	3.41	.95	n	21.84	1983.04	0.203	.39	47	82	204
114222	4.66	2.32	.84	12.3(0.7)	14.8(0.6)	.1	20	(17	10)	9.95		m	168.	1934.	0.81	.61	30	98	81
116436	6.97	1.84	.63	26.0(1.0)	26.0(1.1)	4.0	23	(12	19)	2.08	.75		78.	1968.	0.60	.49	51	108	69
116849	7.81	.04	.55	15.4(0.9)	14.4(0.8)	3.7	18	(17	5)	2.28	.99	n	20.7	1989.3	0.148	.29	50	112	105
117570	8.38	.27	.80	23.4(1.6)	24.5(2.4)	5.3	26	(23	12)	3.01	.97	n	120.	1978.	0.83	.28	152	210	51

magnitudes, plus some clues from the spectra. Using theoretical stellar evolution results, one may try to put each system on an isochrone and then fit a mass-ratio from the luminosity-ratio.

A useful set of isochrones for standard (Z=0.02) stellar models is given by Bertelli et al. (1994). They give the data in e.g. $M_V/(V-I)$, which can easily be transformed (using the calibration relations given in HIP, Vol. 1, Sect. 1.3) to the observed $Hp(abs)/(V-I)$ coordinates. For the low-mass extension below 0.6$M_\odot$, we used the models by vandenBerg et al. (1983), with a more ad hoc transformation to $Hp/(V-I)$. With an empirical fit to the overlapping 0.6-0.75 $M_\odot$ region, this gave at least an illustrative mass-luminosity relation, showing the downturn for absolute magnitudes fainter than 10-11.

For each binary, a first estimate has the primary colour close to $(V-I)_c$. The absolute magnitude is known, and a search finds an isochrone passing close to the primary. The known Δm along this isochrone gives the secondary colour, and thus a more accurate correction from mean to primary $V-I$. The loop is repeated to convergence, and the primary and secondary masses along the isochrone give the mass-ratio. Of course this simple scheme only works for true main-sequence pairs. Stars definitely above the main sequence were excluded (as probably giants), while those below were deemed more likely to have poor colours than to be true subdwarfs. They were therefore simply shifted in colour back to the ZAMS, and the masses evaluated along a young isochrone.

To verify the (programming) correctness of the above procedure, it was compared with an alternative method developed for a statistical study of Hipparcos double star mass-ratios (Söderhjelm, 1997). This is based on putting each star 'in the middle' (vertically) of the main sequence, and it uses another set of isochrones by Schaller et al. (1992). The q-values produced by each method agree closely (no bias and an rms-deviation below 0.02), and thus the present 'photometric' q-values are little dependent on the detailed isochrones used. Any systematic errors in the Δm-values will give a bias, however, and it is again interesting to compare the present values with the HIP ones. For the sample of systems with HIP data, there is very good agreement when the separation is above 0.2 arcsec, but at smaller separations, the present Δm:s get systematically smaller (-0.08 mag at 0.16 arcsec, -0.25 mag at 0.12 arcsec). Because the present solutions give Δm:s for many systems that are unresolved in HIP, the present values were used for the ones with HIP data too. The possible bias is in the sense that the Δm:s may be too small, that is, the q-values too large at the smallest angular separations, but because of the steep slope of all $q(\Delta m)$ relations, the total effect is small.

The orbital elements, parallaxes and mass-sums are listed in Tables 3 or 4 according to the estimated total mass-uncertainty.

For the 41 ‘best’ systems in Table 3, ϵ is thought to be below 10%, while it is larger for the 137 others in Table 4.

Table 5. HIP entries with much improved solutions. The Ax column lists the DMSA Annex where the object is found, with an (S) for a ‘Suspected non-single’ flag in the Main Catalogue. The ρ, and $\dot{\theta}$ columns give the calculated separation (arcsec) and angular motion (deg/yr). The ‘absolute’ position differences (present-HIP, mas) at epoch 1991.25 for the component given in column ‘cp’ (with the relevant components indicated for a multiple photocentre) is given in column Δp, and the corresponding proper motion difference (mas/yr) is in $\Delta\mu$, in both cases with the HIP mean errors in parentheses.

HIP	Ax	ρ	$\dot{\theta}$	cp	$\Delta p(\sigma)$	$\Delta\mu(\sigma)$
171	X	.55	19	pr	11(3)	11(3)
1242	X	.24	-107	–	16(16)	80(22)
7580	G	.17	-3	pc	1(1)	5(1)
11569	C	.20	-22	(Aa)	2(1)	3(1)
15799	X	1.42	4	pr	0(1)	1(1)
28442	X	.68	-2	C	1379(44)	603(50)
30920	G	1.22	9	pr	38(3)	9(4)
33142	(S)	.16	-54	pc	1(2)	3(3)
33449	(S)	.09	33	pc	0(1)	1(1)
36238	C	.10	-15	pr	9(2)	26(2)
43109	C	.06	230	(AB)	9(1)	67(2)
45170	(S)	.06	-222	pc	1(1)	5(1)
45617	(S)	.19	30	pc	0(1)	1(1)
55203	(S)	.99	-19	–	–	–
60129	G	.11	26	pc	1(1)	3(1)
64241	X	.45	0	pc	20(30)	19(30)
70327	C	.20	10	(BC)	14(10)	11(1)
73182	C	.18	-58	(Bb)	75(74)	41(53)
78727	(S)	.63	5	–	–	–
82817	C	.22	-208	pr	46(12)	256(5)
84123	(S)	.63	15	pc	88(23)	74(27)
84140	C	.23	-178	pr	108(8)	266(9)
84709	X	2.13	-3	pr	61(18)	24(19)
88932	C	.19	13	pr	109(21)	20(2)
96907	(S)	.10	-13	pc	2(1)	0(1)
97237	(S)	.81	29	–	–	–
102782/4	C	11.93	-1	C	7477:	155:
106811	C	1.58	-4	pr	24(17)	1(3)
115126	X	.15	62	pc	13(6)	5(8)

4. Comparisons with earlier data

4.1. Major improvements relative to the published HIP

The present detailed investigations give for each listed binary a set of orbital elements that can be used to calculate the relative position between the components to good precision at least for the Hipparcos interval 1990-1993. The solutions give also ‘absolute’ position information, that is, one may calculate the position and proper motion for each component in the ICRS system. For the shorter-period resolved pairs, these data are generally superior to the single 1991.25 point (often not even including linear relative motion) given in HIP. Still, in most cases, the differences are small, and the HIP data give good system proper motions and parallaxes. Similarly, for the ‘single’ HIP entries that are now resolved (using speckle-interferometry information), the newly derived separations are generally below 0.10 arcsec, and the HIP photocentre astrometric parameters are fully useable.

Table 5 shows a list of systems where the mean separation during 1990-1993 was above 0.10 arcsec, but where the pair is listed in HIP as unresolved. Often, the photocentre parameters are given in the DMSA /G or /O Annexes, meaning that the object is at least known to be non-single. Otherwise, a triple system may be given in HIP as a double, with a closer pair neglected. In most such cases, the new photocentre astrometric parameters correspond well to the published data. In the table are also given a few systems with resolved but poor HIP solutions (deviating at the 5 σ-level by 100 mas in position or 25 mas/year in proper motion). A number of solutions (HIP 72479, 85846, 87204, 94739 and 116849) initially flagged as deviant were found to be simply reversed by about 180°, reflecting a different choice of primary component for systems with small Δm.

There are a few more serious discrepancies. For HIP 28442, the poor (‘X’) HIP parameters are far from all components in the C+AB triple. Even with reversed components, the solution for HIP 82817 (noted in Sect. 3.1 above) is very poor. A similar case is HIP 84140, mostly because of its rapid motion near periastron. Finally, the faint optical companion (HIP 102784) to the HIP 102782 pair is grossly misplaced (7 arcsec!) in HIP, but with mean errors signalling an almost useless solution.

For the extremely wide α Cen system (HIP 71683/71681), there is a difficult problem with one star falling in the wing of the sensitivity-profile when the other is observed. It is also problematically bright, and the orbital motion is definitely non-linear. The present solution (including the parallax) for this unique binary should be more reliable than the preliminary one given in HIP, and further improvement will need a big effort.

4.2. Comparisons with earlier mass-determinations

Orbits and masses have usually been derived previously for most of the systems in this study, but no attempt has been made to make any general comparison between old and new data. There are a few papers of extra interest however that warrants a closer look.

One is the study by Martin & Mignard (1997, 1998) using Hipparcos astrometric binaries. Their methods differ completely from the present study, but there are almost 30 systems in common, and it is clearly interesting to compare some results. With a few exceptions (see below), the mass-sums and their mean errors are reasonably similar. A naive mean and standard deviation of the mass-sum ratios (present/MM) gives 0.98(0.15), and similarly for the ratio of mass-sum mean errors 1.30(0.85). The slight bias towards larger MM masses is reflected in the normalized mass-sum difference -0.18(0.92). (In the comparisons, the high-mass system HIP 43671 has been excluded, given 12.4(2.0) $M_\odot$ by MM versus 6.1(1.5) in the present paper). For a few more systems, however, the mass-ratios given by MM are notably different from the present ones.

For HIP 171, MM finds the secondary more massive than the primary ($q = 1.12$), while for HIP 94739 the primary is found conspicuously massive ($q = 0.61$). In both cases, the values derived from the photometry ($q = 0.64$ and $q = 0.99$ respectively) seem more unproblematic. In three other cases, MM give q-values that differ significantly from the directly determined astrometric ones in Table 1. For HIP 12390 MM finds 0.52 instead of 0.85(0.08), for HIP 19719 1.50 instead of 0.95(0.12) and for HIP 108431 1.29 instead of 0.79(0.10). The source of these discrepancies needs some further investigation.

Important results for the low-mass main-sequence are given in the paper by Henry & McCarthy (1993), and again many of their systems are included also in the present paper. In many cases, the present orbits are improvements, and the mean errors on the masses are consequently diminished. For at least three systems, the masses differ so much as to warrant a note. For HIP 46706 (GJ 352) HM uses the orbit and parallax from Heintz(1979). In the present work the semi-major axis is increased and the parallax decreased so as to increase the masses by more than a factor of two. For HIP 84140 (GJ 661), the semi-major axis is increased and the parallax marginally decreased w.r.t. the study by Heintz & Borgman (1984), making for a 36% mass-increase at a 5 σ level. For HIP 85582 (GJ 677) finally, it is mainly a parallax decrease but also a size-increase over the orbit by Lippincott (1982) that again increases the masses by a factor of two. All three systems are conspicuous outliers in Fig. 2 in HM, and the increased masses makes the fit to a mean mass-luminosity relation much better. The same poor data are used also in the more recent paper by Malkov et al. (1997), and there is certainly scope for improvement (cf. Sect. 6 below).

A more problematic low-mass system is HIP 1242 (=GJ 1005). Adding the astrometric orbit by Ianna et al.(1988) plus a few resolved observations by Heintz (1990a) to the Hipparcos data produced a preliminary solution that was thought to have at least a reliable parallax (instead of the unuseable 'X' solution in HIP). As quoted by Chance & Hershey (1998), however, Taff and Hershey have found from HST observations an appreciably ($> 5\sigma$) smaller value, and some further investigation is necessary.

5. Interesting systems for further study

5.1. Known orbits

One very interesting system is the hierarchical quadruple HIP 7372, consisting of an (AB) 4.6-year K-dwarf pair in a 115-year orbit with a fainter M-dwarf companion (C). The B-component was discovered by Hipparcos (cf. Vol 11 in HIP) to be a 0.48 d eclipsing binary, named BB Scl. The Hipparcos observations are mostly sensitive to the AB orbit, but C has to be included in a realistic model. The combined light from all three stars shows 0.20 mag eclipses, and a complex triple plus eclipse model was tried. The eclipsing period and phases are well determined, and a rough 'triangular' light-curve model was adopted. As it turned out, there is a strong correlation between the AB mass-ratio and the 'real' eclipse-depth, and in the end the most stable solution was obtained with the eclipse-observations excluded. The derived mass-ratio m_B/m_A (cf. Table 1) is still a bit large, but with one or two nights of spectroscopy and photometry, the masses and sizes for BB Scl could be obtained with high precision. The system has 0.48 day period and equal minima, the inclination should be around 84°, and one may thus estimate the large velocity-amplitudes $K_1 \approx K_2 \approx 165$ km/s. The crude Hipparcos light-curve gives relative radii around 0.27(0.03). This corresponds to about 0.8 $R_\odot$, in good agreement with the 0.8 $M_\odot$ masses.

Another interesting K-dwarf system is HIP 65026, where the solution gives an accurate and definitely too high mass-sum, corroborated by a low mass-ratio (Heintz, 1969b). The primary component is thus very likely a closer double, and it may be significant that CH3 lists a single (unconfirmed) speckle observation of a third component. The fit to the Hipparcos observations is a bit poor, and there are hints that it can be improved by an (as yet very indeterminate) triple-star solution. Even such a 'resolved' orbit has most likely a period below 2-3 years, however, and spectroscopic observations seems the most fruitful way to confirm it (or the otherwise shorter-period spectroscopic orbit).

For four other systems, there is clear evidence from both the mass-sum *and* the astrometric mass-ratio that one of the components is in fact a closer binary. For HIP 47479, HIP 82817 and HIP 107522 (the last two again K-dwarfs), the secondaries should be double, while in HIP 115126 the primary is suspected. The third components are unlikely to be seen by speckle (small separation, high Δm), but spectroscopy should reveal the orbits. There are a number of other systems where the mass-sums seem abnormally large, e.g. HIP 11569, HIP 21280, HIP 29234 and HIP 85141, and again spectroscopic investigations may be worthwile. The triple system HIP 36238 has a mass-sum that is large enough to harbour a 4:th component.

For HIP 111965 and HIP 84425, the mass-sums are abnormally low, and improved speckle-coverage of the orbits is greatly needed. HIP 7918 has an unobservably faint secondary, and the orbit-size and mass-ratio hinges on a few IR speckle observations (Henry et al. 1992). The derived primary mass is a bit low, and a few more IR observations are clearly needed. The visual speckle observation by Hartkopf et al (1997b) is most likely spurious.

A system with potential for good low-mass data is HIP 2552 (GJ 22), where the infrared speckle resolution of the astrometric Aa pair by McCarthy et al. (1990) defines the scale of the orbit. Using the original photocentre obervations (as re-created from the orbit+residuals listed by Hershey 1973), a circular orbit is all that can be reliably fitted, probably with a lower inclination than given by Hershey. As noted by McCarthy et al., the scaling of the semi-major axis is very dependent on the assumed orbit, and a few more IR speckle observations will strengthen the mass-determination appreciably. Still, the 13.8 mag secondary (close to the predicted Δm) is clearly detectable in the Hipparcos data, and the combined solution gives an improved period and a very reasonable mass-sum.

For HIP 55203 (ξ UMa), analytical 3-body modelling has been frequently tried, but if it is in reality quadruple as assumed by Mason et al. (1995), realistic models can probably only be made by numerical integration. Some other interesting triples are HIP 43671, HIP 65026(if a 'speckle' third component can be confirmed), HIP 60129, HIP 98001, HIP 101955 and HIP 111805. For these systems, the 'apse-node' timescale (cf. Söderhjelm 1982) P_2^2/P_1 is below some 2000 years, meaning that orbit precession might be observable. Unfortunately, however, none of the close orbits are eclipsing, and the inclination-changes are consequently hard to detect. The most interesting eclipsing triple should be HIP 84949, but with an apse-node time-scale around 5000 years, any light-curve changes are probably undetectable.

5.2. New systems

Among the doubles discovered by Hipparcos, the known parallaxes makes it easy to single out the relatively few ones with small linear separation which may show rapid orbital motion. Among 3000 new doubles, the projected linear separation is below 10 a.u. for only 75 systems, and with a further restricion to $\Delta m < 3$ and primary magnitude brighter than V=8, we are down to 30 cases. All of these are high-priority objects for speckle-interferometry observation, but at least 10-20 years are needed before many of them could have high-quality orbits.

The published HIP solutions for these close pairs are generally compromise 'Constant' ones (identical p.m. for the two components), although a linear relative motion would have been a better choice. For HIP 7254, the system (on the list of 30) with smallest linear separation (3.7 a.u.), an unpublished NDAC solution gave a 24 deg/yr relative motion at 0.09 arcsec separation, and this southern (01334-4354) K-dwarf pair should give a good speckle-spectroscopic orbit. HIP 105382 is the brightest star ($Hp = 4.8$) on the list, and one of its components is a low-amplitude (ecl?) variable. Again there are indications of a 10 deg/yr relative motion, and the magnitude-difference is probably smaller than the published 2.5. HIP 68380 was unresolved by McAlister et al. (1993), and the Hipparcos 0.08 arcsec result should be checked by further observations. The only clear case of detected motion is HIP 17891(=MOAI 1). The HIP result is $\mathrm{PA} = 81^\circ + 18^\circ(t - 1991.25)$, and it was observed in 1995.95 at 167° by Carbillet et al.(1996).

The somewhat disappointing results of the last paragraph can be understood in the light of the final 'merging' of double star data from the two reduction consortia NDAC and FAST. New doubles with rapid motion were hard to treat for each consortium, and with conspicuously different reduction methods, the number of 'consensus' cases was especially low for this category. Thus, as shown above, there are few (linearly) close systems with an explicit solution given in HIP, and the interesting systems have to be sought in the 'suspected non-single' category, where most 'one-consortium' solutions ended up. There are about 400 'S'-systems with a parallax above 20 mas, and still about 60 with $\pi > 50$ mas. Most of these are probably single, but especially among the ones with both an 'X' and and 'S'-flag, one may find some definitely worth observing.

In fact, many low-mass systems in the present selection were found by looking at the old NDAC-solutions for large-parallax 'S'-systems, and several more can probably be obtained by a greater effort. One should be aware that so far the Hipparcos data (solutions and/or suspected non-singles) have *not* been compared in detail against e.g. the WDS. Such an undertaking is hard to automate (because it generally needs more data than is available in the on-line 'summary' WDS) and thus time consuming, but it would presumably identify several more orbital systems worth re-reducing.

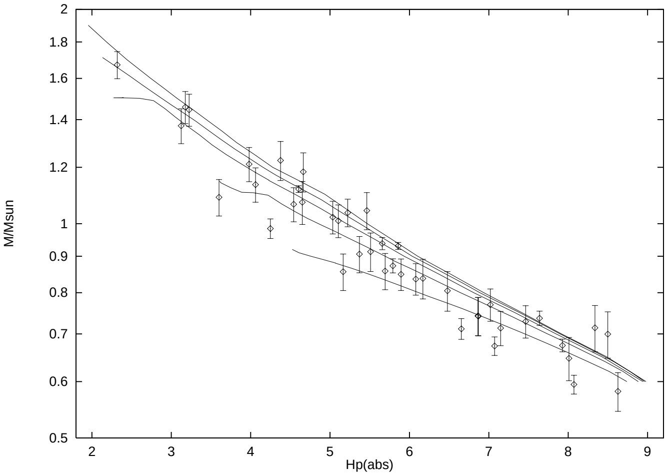

Fig. 2. The 'mass-luminosity' plot for 42 individual main-sequence stars with a mass-uncertainty below 7.5 per cent. Known or suspected multiples or non-MS systems excluded. The theoretical isochrones are for lg age=9.0,9.4,9.8 and 10.2.

6. The mass-luminosity diagram

As described in Sect. 3, a number of individual mass-values (with uncertainties normally dominated by the ϵ of the mass-sum) were obtained for a sample of assumed main-sequence stars. We also know accurately the distances to the stars, and a plot of the masses versus the absolute Hp magnitudes gives in principle a 'mass-luminosity diagram'. In Fig. 2, all accepted main-sequence masses in the range $0.5-2M_\odot$ with an estimated error below 7.5% are plotted together with Bertelli isochrones for lg age = 9.0-10.2. In Figs. 3 and 4, the full plots for ϵ <15% and ϵ <30% are shown, including the interesting but more sparsely covered low-mass region. The theoretical low-mass ZAMS is here the one given by Malkov et al. (1997), slightly tranformed from V to Hp magnitudes using the calibration tables in HIP together with the observed Hp(V-I) main sequence. By design, only the 'reasonable' systems are plotted (excepting those with an *m* or a *g* in Tables 1, 3 or 4), and no conspicuous outliers are expected to remain. Even so, the fit is very satisfactory, giving confidence both in the stellar models and in the present mass-determinations. In fact, the dispersion in Fig. 4 is rather lower than 30%, showing that the 'safety-increase' of the visual orbit-errors described in Sect. 3 was often too large.

The removed systems are shown separately in Fig. 5. The known or suspected multiples lie generally above the theoret-

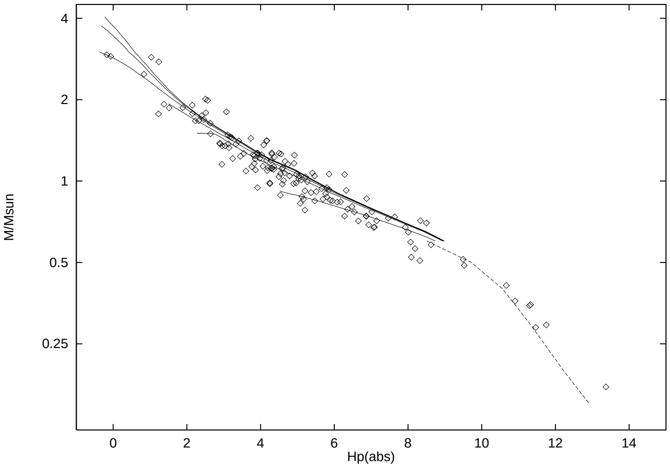

Fig. 3. The 'mass-luminosity' plot for 146 individual main-sequence stars with a mass-uncertainty below 15 per cent. Known or suspected multiples or non-MS systems excluded. The theoretical isochrones are for lg age=7.5,8.0,8.5,9.0,9.4 and 10.2.

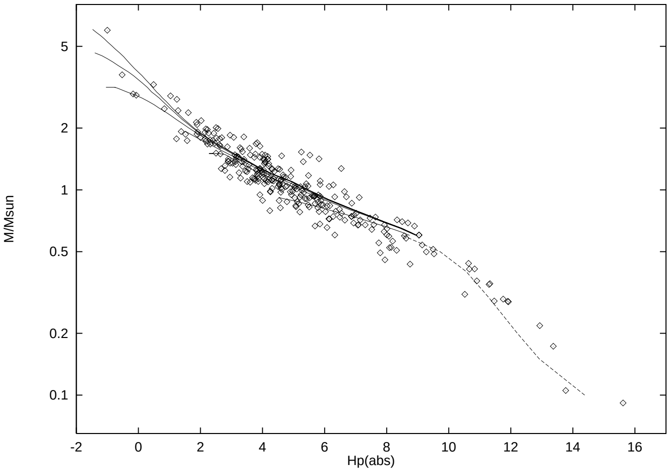

Fig. 4. The 'mass-luminosity' plot for 276 individual main-sequence stars with a mass-uncertainty below 30 per cent. Known or suspected multiples or non-MS systems excluded. Theoretical isochrones as in Fig. 3.

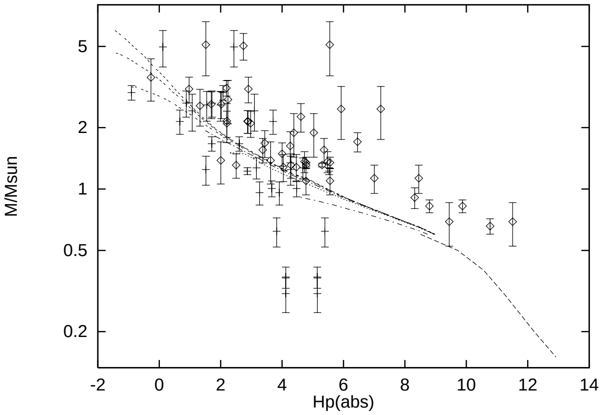

Fig. 5. The 'removed' stars with an uncertainty in the mass-sum below 30 per cent. Theoretical isochrones as in Figs. 3 and 4.

ical isochrones, while the 'giant systems' do not deviate very much from the main-sequence isochrones. The few conspicuous 'low-mass' systems are a priori more problematic, but the most conspicuous ones (HIP 84425 and HIP 111965) are probably due to poor orbits. One or two may also be low-metal subdwarfs, expected from theory to lie clearly below the standard relation, but no detailed fits for specific objects have been attempted.

It is apparent from the theoretical isochrones that there is no *single* 'mass-luminosity relation' valid for all ages and metallicities. To some useful approximation, one could however well make an empirical 'mean' relation from the data in Fig. 3. The low-mass part is the most interesting (cf. Malkov et al., 1997), but it suffers from a lack of systems observable by Hipparcos (or observed only with large mean errors at magnitude 11-14). More systems are needed to confirm the seeming slight disagreement with the theoretical ZAMS, but even the present data may be improved by more dedicated orbit determinations. Typically, an optimal combination of old (photographic) astrometry with IR speckle and Hipparcos observations is needed to pin down the lowest masses like Ross 614 (HIP 30920), Hei 299 (HIP 1242) and MCy 1 (HIP 2552).

Obviously also, many of the 'best' systems in Fig. 2 should be studied in more detail, with attempts e.g. at metallicity determination using photometric or spectral observations. For some systems, spectroscopic mass-ratios may be determined at favourable orbital phases, and spectroscopic sub-systems may be confirmed or ruled out. The final mean errors in the masses may be larger than the few percent allowed by Andersen (1991), but the present wide systems are definitely non-interacting and should be rigorously comparable to single stars. The eclipsing systems giving the highest precision masses are normally tidally interacting, and could in principle show peculiarities that make them less suitable for comparisons with single-star stellar models.

7. Conclusions

A main conclusion from the present work is the value of combining earlier observations with those by Hipparcos. For long-period pairs, the 1991.25 explicit position in HIP may be used, but for periods below some 30 years, there is more to be gained by fitting the intermediate Transit Data to an orbital model along the lines presented in the present paper. Such studies can be made by any future researcher, as the Transit Data File is available on the published HIP CD-ROM:s. Its detailed interpretation should be clear from the description in Sect. 2.9 of Vol 1 of HIP and from an A&A paper in preparation by Quist & Lindegren.

The constraint on both datasets (Hipparcos and ground-based) to fit a common model clears up a number of inadvertencies, and the derived orbits should be mostly quite realistic. For the shortest-period systems, one should go on and incorporate the radial velocities in the same model, to even greater advantage. As can be seen e.g. in Fekel (1992), there are sometimes spectroscopic periods and eccentricities available of much higher precision than those derived here. Instead of 'fixing' a parameter from the observations that best determine it, the goal should be to make full combined solutions using (visual and speckle) relative positions, radial velocities plus Hipparcos (Transit) data. But as has already been very apparent, all such 'star-by-star' work is quite laborious and time-consuming, and the addition of another source of data or an extension to the 1000+ known orbital pairs is quite impractical. Future rediscussions should mainly be limited to astrophysically interesting systems, especially the complex ones where the Hipparcos data may aid in their interpretation.

As for the derived masses, astrophysically interesting values (with relative errors below some 5 per cent) can be obtained only for a select few well-observed visual binaries. Except for an accurate (Hipparcos) parallax, one needs a relative orbit defined accurately by unbiased (preferably speckle interferometric) observations, and only about a dozen systems of this sort have been found in the present study. With 7.5 per cent accuracy, we get the ~ 20 systems in Fig. 1, but allowing 15 per cent (the original parallax error limit) increases the sample quite markedly. To increase it further, one needs better ground-based observations (especially for southern hemisphere systems), and 10 more years of speckle-work will make an appreciable difference. (Many of the '30%'-systems in Fig. 4 need only a few confirming speckle-points in order that the visual orbits can be trusted to their internal accuaracy). At any time, when enough relative positions are available, they can be combined with Hipparcos Transit File data along the present lines to yield new 'parallax+orbit'-solutions. In other cases, especially at faint magnitudes, the Hipparcos parallaxes may be the limiting factor. For many interesting low-mass systems, there is a continuing need for modern ground-based parallax determinations. On a longer time-scale, one may envision a 'GAIA'-type space-mission (cf. Lindegren & Perryman 1997) to supply one or two orders of magnitude more accurate parallaxes, making the orbit-determination still more the priority.

Turning back to the diagrams in Figs. 2–4, the tentative conclusion is that the observed masses seem to be in good agreement with the stellar evolution models. One can not expect a very narrow 'mass-luminosity relation' because of age and abundance-differences in the random near-star sample. In principle, the seven or eight main-sequence Hyades binaries included in the present study should fall on a single mass-luminosity isochrone, but their mass-uncertainties are so far too large to allow any interesting tests. (The dominating error-source is in the parallaxes, however, and a full cluster-model utilizing also the proper motions could give a large enough improvement for the parallaxes to be very worthwile in this respect, cf. Dravins et al. 1997 and a forthcoming A&A article by Lindegren, Dravins and Madsen.)

Finally, as seen in the tables and notes above, the number of hierarchical triples or quadruples with a spectroscopic or speckle subsystem in one of the visual components may be higher than generally realized. An important task is the continued compilation of catalogues collecting all the different kinds of data for multiple systems (which may contain both 'visual', 'astrometric' and 'spectroscopic' components), as sucessfully started by Tokovinin (1997). From this and similar catalogs, one may try to develop more realistic multiple-star statistics, but the observational selection effects makes it still very difficult. A complementary approach will be to study the rather subtle observational consequences of different assumed multiplicity-distributions in uniform surveys like Hipparcos.

Acknowledgements. The important starting impetus to use GaussFit for the present analyses was provided by Dr Lennart Lindegren, who also supplied many basic routines for handling the Hipparcos data. The prompt and efficient handling by Dr Geoff Douglass (following the sad death of Dr Charles Worley) of my requests for more than 30000 individual observations from the WDS database is gratefully acknowledged. I thank also the referee Dr William Hartkopf for his careful reading of the manuscript and some valuable comments. This work is supported by the Swedish National Space Board and the Swedish Natural Science Research Council.

Appendix

Table 6. Cross-identifications and notes for the systems mentioned in this paper. The Tab column points at the result-table where this object can be found. In the notes, the shorthand references H1(=Hartkopf et al., 1989), H2=(Hartkopf et al., 1996), CH3(=Hartkopf et al., 1997a), WH4(=Worley and Heintz, 1983) and B8(=Batten et al., 1989) are used.

Const	HIP	CCDM	ADS	Disc.	Tab	Note
85 Peg	171	00021+2706	17175	Bu 733	3	Poor HIP sol
	518	00063+5826	61	StF 3062	3	
	1242	(00155-1608)		Hei 299	4	Too poor astrometric orbit (Ianna et al. 1988) and too few resolved observations (cf. Heintz 1990a) to give definite orbit. Present solution at least preferable to ‘X’ HIP-sol.
	1674	00210+6740	283	h 1018	4	Uncertain ‘visual’ edge-on orbit.
	2237	00284−2020		B 1909	1	High-eccentricity, half-period solution fits equally well but gives too high mass-sum (with no third component allowed by q).
	2552	00325+6714		MCy1 Aa		Aa-B triple sol (double (Aa)-B in HIP). Orbit mostly dependent on Hershey(1973) pc observations, more IR speckle needed.
13 Cet	2762	00352−0336	490	Ho 212	1	Visual primary is 2.1 d SB 1 (#27 in B8). Speckle orbit in H1.
	2941	00373−2446	520	Bu 395	3	
υ Phe	5300	01078−4149		Rst 3352	4	
	5842	01157−6852		I 27 CD	3	
	6486	01233+5808	1105	StF 115	4	$\rho < 0.07$ arcsec during Hipparcos obs(!)$\Rightarrow$ assumed Δm(=0.2) necessary for solution. Speckle orbit in H1.
	6564	01243−0655	1123	Bu 1163	4	Speckle orbit in H2
	7372	01350−2954		Daw 31 AB	1	AB-C triple+var sol (AB in HIP). B is 0.47 d ecl bin (BB Scl).
	7580	01376−0924		Kui 7	1	Speckle orbit in H2
	7918	01418+4237		MCy2	4	Improved pc ($\Delta m > 6$) orbit combining pg(Lippincott et al. 1983) and Hipparcos obs. Scaling by the speckle IR (Henry et al. 1992) gives orbit size and mass-ratio.
48 Cas	9480	02020+7054	1598	Bu 513	3	
	10403	02140+4729	1709	StF 228	4	
ϵ Cet	12390	02396−1152		Fin 312	1	Speckle orbit in H1.
21 Ari	10535	02157+2503		Cou 79	4	Speckle orbit in H2.
	10542	02158−1814		Hst 1	4	Orbit poorly covered, period rather indeterminate.
	11452	02278+0426	1865	A 2329	3	
ι Cas	11569	02292+6725	1860	CHARA 6 Aa	4	Aa-B-C quadruple solution (AB in HIP). High mass-sum, strangely well-behaved speckle obs at $\Delta m = 4$??
	12717	02434−6643		Fin 333	4	More speckle obs needed to define orbit.
α For	14879	03121−2859	2402	h 3555	4	Another century needed for apastron coverage.
	14913	03124−4425		Jc 8 AB	4	AB-C triple solution
	15799	03236-4005		I 468	4	Possible orbit from two widely spaced vis obs + Hipparcos data.
	16602	(03337+5752)		CHARA 117	4	Cf orbit in McAlister et al. (1992).
	16628	03339−3105		B 52	4	
	17954	03503+2535	2799	Stt 65	4	
46 Tau	19719	04136+0743	3064	A 1938	1	Speckle orbit in H2.
	19758	04142−4608		Rst 2338	4	Half-period solution equally good, but gives large mass-sum. More speckle-obs needed (the only existing one erroneous?).
51 Tau	20087	04184+2135		McA 14	1	Hyad(vB 24), cf. Torres et al. (1997a).
55 Tau	20215	04199+1631	3135	Stt 79	4	Hyad(vB 29).
	20347	04215−2544	3159	Bu 744	4	The 4 d SB 1 (WH4) probably spurious.
70 Tau	20661	04256+1557		Fin 342	4	Hyad(vB 57), assumed period from Torres et al(1997b).
	20686	04259+1852	3210	Bu 1185	4	Hyad(vB 58).
θ^1 Tau	20885	04286+1554		McA 15	4	Hyad(vB 71), G7III spectrum, assumed period and mass-ratio from Torres et al. (1997c).
	20916	04290+1610	3248	Hu 1080	4	Hyad(VB 75).
	21280	04340+1510		CHARA 17	4	Hyad(vB 96). High mass-sum, illustrative solution only, speckle/spectroscopic orbit needed, cf. Griffin et al. (1988).
α Dor	21281	04340−5503		B 2092	4	
53 Eri	21594	04382−1418		Kui 18	4	K1III spectrum, speckle orbit in H2.
	21698	04395−4507		I 1489	4	

Table 6. (continued)

Const	HIP	CCDM	ADS	Disc	Tab	Note
	22505	04506+1505		CHARA 20	4	Hyad(vB 120). Preliminary circular orbit, speckle/spectroscopic orbit needed, cf. Griffin et al.(1988).
	22550	04512+1104	3475	Bu 883	1	Hyad(vB 122). Mass-sum calls for sp subsystem, but RV-ampl $<$ 1 km/s according to Griffin et al.(1988).
	22607	04518+1339	3483	Bu 552	4	Hyad(vB 124), primary is 143 d sp bin (Griffin et al. 1985).
	23166	04590−1622	3588	Bu 314	4	
	23395	05017+2640	3608	A 1844	4	Visual separations systematically too small.
	23452	05025−2115		Don 91	4	Good period, indeterminate a/e/i, more obs needed!
104 Tau	23835	05075+1839	3701	A 3010	–	Visual and speckle observations at 0.1 arcsec separation ruled out as spurious by constant RV (Duquennoy and Mayor 1991).
	25119	05226+0236	3959	A 2641	4	
	26926	05429−0648	4299	A 494	4	
	28442	06003−3103		Hu 1399 AB	4	AB-C triple solution (HIP data unuseable!). Speckle obs needed to strengthen orbit.
μ Ori	28614	06024+0939	4617	A 2715	4	Pr 4.4 SB 1, sec 4.8 d SB 2 (Fekel 1980), reasonable mass-sum.
1 Gem	28734	06041+2316		Kui 23	4	Pr 9.6 d SB1 (#377 in B8), sec K1III (Strassmeier and Fekel 1990), mass-sum close to expected.
	29234	06098−2246		Rst 3442	4	High mass-sum, speckle orbit in H2.
	30920	06294−0249		Ross 614	4	Good resolved solution with the aid of scattered visual+(IR)speckle observations. Mass-ratio calculated from pc orbit size(Probst 1977).
	30953	06298−5014		R 65 AB	–	Difficult a/e/i-correlation, more obs needed.
	30953	06298−5014		HdO 195 CD	4	AB-CD quadruple solution.
	31509	06359−3605		Fin 19	4	
	33142	06541+6052		Hei 334	4	Fixed e, i, ω, Ω from Heintz(1990b). Needs combined astrometric/visual/Hipparcos solution.
	33449	06573+5825	5586	Stt 159	4	G5III-IV spectrum. Period poorly determined from old vis obs.
	33451	06573−3530		I 65	1	A few more speckle-obs will strengthen orbit considerably.
	34860	07128+2713	5871	StF 1037	4	
	35296	07175−4659		I 7	–	The 94-yr orbit by Heintz(1995) plus the HIP parallax gives impossibly small mass-sum. Probably both a and P are much larger (no orbit for another century), but motion should be followed.
	36238	07277+2127		McA 30	1	Good fit to speckle/Hip, but implausibly large masses even for a multiple system. Speckle/spectr sol pending(CH3). HIP sol spurious.
	38052	07480+6018	6354	Hu 1247	1	Speckle orbit in H2.
9 Pup	38382	07518−1354	6420	Bu 101	4	Speckle orbit in H1.
	38474	07528−0526		Fin 325	4	Speckle orbit in H2.
ζ Cnc	40167	08123+1738	6650	StF 1196 AB	3	2-orbit AB-Cc quadruple sol (AB-C in HIP).
	40239	08131−1355	6664	Hu 115	4	Present π-value adopted instead of poor HIP-value.
	41261	08251−4910		Rst 321	4	
	41426	08270−5242		B 1606	4	
	41820	08316+3458	6851	Hu 716	4	
	42075	08345−3236		Fin 335	4	Giant primary according to isochrone fit.
	42430	08391−2240	6914	Bu 208	3	
	42455	08394−3636		I 314	4	
	42748	08427+0933		St 8		Period around 100 y, rapid motion at present, more obs needed.
ϵ Hya	43109	08468+0625	6993	Sp 1 AB	4	AB-C triple sol ((AB)-C in HIP). G0III-IV spectr, speckle orb in H2
	43671	08538−4731		Fin 316	4	Low incl fixed at 15°, ($\Omega = 0$). High mass-sum and q=1.5(0.3). corroborates secondary 9.1 d SB2 (WH4).
10 UMa	44248	09007+4147		Kui 37	1	Speckle orbit in H2.
81 Cnc	45170	09123+1459		Fin 347	1	Reversed Δm and slightly larger parallax/smaller masses than in the speckle-spectroscopic study by Mason et al.(1996).
	45571	09173−6841		Fin 363	4	Speckle observations needed to refine relative orbit.
	45617	09179+2834	7284	StF 3121	3	
	46404	09278−0604		B 2530	4	Giant primary according to isochrone fit.
ω Leo	46454	09285+0903	7390	StF 1356	4	Giant primary according to isochrone fit.
ψ Vel	46651	09307−4028			3	
	46706	09313−1329		Kui 41	4	

Table 6. (continued)

Const	HIP	CCDM	ADS	Disc	Tab	Note
	47479	09407−5759		B 780	1	Speckle observations needed to confirm orbit. Sp subsystem in sec?
	49868	10110+7508		Kui 47	–	Poorly determined (long) period, only periastron-part covered.
β LMi	51233	10279+3642	7780	Hu 879	4	G8III-IV spectrum.
	51885	10361−2641	7846	Bu 411	4	
p Vel	51986	10373−4814		See 119	4	Visual primary is 10 d SB2 (#623 in B8).
55 Leo	53423	10557+0044	7982	Bu 1076	4	F2III classification probably erroneous.
	53840	11009−4030		Fin 365	–	Probably 4-5 year period, more speckle observations needed.
α UMa	54061	11037+6145	8035	Bu 1077	3	Low incl. fixed at 180 deg, observations lacking near periastron. Giant primary according to isochrone fit.
	54155	11047−0413	8048	A 676 BC	4	A-BC triple solution.
χ Hya	54204	11053−2718		Fin 47	4	
ξ UMa	55203	11182+3132	8119	StF 1523 AB	3	Preliminary Keplerian Aa-B 2-orbit model gives good solution (failure in HIP). Many-body perturbations observable but not yet studied. Cf. Aa-Bb analysis in Mason et al.(1995).
55 UMa	55266	(11191+3811)		CHARA 133	4	Primary is 2.6 d SB1 (#669 in B8). Mass-sum in fair agreement with Liu et al.(1997)
π Cen	55425	11210−5429		I 879	4	A few more speckle obs needed to constrain the eccentricity.
ι Leo	55642	11239+1032	8148	StF 1536	4	
	56290	11323+6105	8197	Stt 235	3	
	57994	11537+7345	8337	Bu 794	4	
89 Cen	58799	12036−3901		See 143	4	
	59780	12155−3106		Rst 1658	4	
	59816	12160+0538	8486	StF 1621	4	Indeterminate (long) period, useable a^3/P^2. Poor HIP parallax
η Vir	60129	12199−0040		McA 37	1	Observed parallax corroborates closely the orbital value given by Hartkopf et al(1992). Primary is 72 d SB2 (#718 in B8).
	60994	12301−1324	8573	Bu 28	4	
γ Cen	61932	12415−4858		h 4539	4	
γ Vir	61941	12417−0127	8630	StF 1670	3	
78 UMa	63503	13007+5622	8739	Bu 1082	3	
α Com	64241	13100+1732	8804	StF 1728	3	Components reversed rel std sol:s, e.g. in H1. Poor HIP sol.
	65026	13198+4747	8862	Hu 644	3	Marginal hints that the the unconfirmed speckle 3:rd comp (CH3) could be real. Mass-sum and mass-ratio (Heintz, 1969b) clearly requires the primary to be a closer binary.
	65343	13235+2914	8887	Ho 260	–	Undetermined (long) period in nearby K-dwarf pair.
	66438	13372−6142		I 365	4	
25 CVn	66458	13375+3617	8974	StF 1768	4	A7III spectrum.
	66640	13395+1045	8987	Bu 612	4	
	67422	13491+2659	9031	StF 1785	3	
	70327	14234+0827	9247	Bu 1111 BC	4	A-BC triple solution (double A-(BC) in HIP).
	70973	14310−0548		Rst 4529	4	Double-period, circular orbit ruled out by speckle obs.
α Cen	71683	14396−6050			3	Difficult for Hipparcos with secondary (=HIP 71681) at edge of the sensitivity profile. Present parallax preferable to HIP value. Mass-ratio from Kamper and Wesselink(1978).
	71914	14426+1930		Hu 575	4	
17 Lib	72217	14462−2110		Fin 309	4	
	72479	14492+1013	9397	A 2983	4	Double-period solution ruled out by speckle observations.
ξ Boo	72659	14513+1906	9413	StF 1888	3	
	73182	14574-2124	9446	GJ 570 Bb	4	Hipparcos triple solution together with A(=HIP73184). P, T, e, ω and q fixed from Duquennoy and Mayor(1988), cf orbit in Mariotti et al. (1990). Poor HIP-sol.
44 Boo	73695	15038+4739	9494	StF 1909	3	Secondary is 0.27 d W UMa ecl. bin.
	74537	15138-0121	9544	A 691		Unresolved by speckle(?), no easy vis+Hipparcos sol.
	74893	15183+2650	9578	StF 1932	4	
η CrB	75312	15233+3018	9617	StF 1937	3	
μ Boo	75411	15245+3722		CHARA 181 Aa	3	More speckle-obs needed to confirm preliminary orbit
μ Boo	75415	15245+3722	9626	StF 1938 BC	3	
	75529	15258+8430		Mlr 347	–	More observations needed to define ($\sim$20-year) orbit.

Table 6. (continued)

Const	HIP	CCDM	ADS	Disc	Tab	Note
β CrB	75695	15278+2906			1	The speckle-observations and derived masses leave no room for a conjectured third component, cf. Kamper et al. (1990).
	76382	15360+3949	9716	Stt 298	3	
	76466	15370+6426	9730	Hu 1168	4	
ι Ser	76852	15416+1940	9744	Hu 580	4	Half-period orbit ruled out by speckle-obs.
γ CrB	76952	15427+2618	9757	StF 1967	4	Speckle orbit in H1.
ι Nor	78662	16035−5747		See 258 AB	4	AB-C triple solution (AB in HIP).
ξ Sco	78727	16044−1123	9909	StF 1998 AB	4	AB-C triple solution. (Failed HIP sol because of bad pointing with C-comp at IFOV edge).
	80199	16224−3220		Jsp 691	–	Poorly determined period, needs many decades yet.
	80460	16254+3724		CHARA 55	–	Strong a/e-correlation, more speckle-obs needed.
	80725	16289+1825	10075	StF 2052	3	
ζ Her	81693	16413+3136	10157	StF 2084	3	No evidence in the speckle or Hipparcos data for the large-ampl third-body orbit given by Baize(1976). Giant primary according to isochrone fit.
	82817	16555−0820		Kui 75	1	Flare M-dwarf (V1054 Oph). Mass-ratio and mass-sum requires secondary to be a closer sp bin. Unuseable HIP solution.
c Her	83838	17080+3556	10360	Hu 1176	4	Speckle orbit in H1.
η Oph	84012	17104−1544	10374	Bu 1118	4	Difficult a/e correlation, needs 20 more years of speckle obs.
	84123	17119−0151		LPM 629	4	Poor HIP sol.
	84140	17121+4540		Kui 79	1	Poor HIP-solution, speckle orbit in H2.
	84425	17156−3836		Fin 355	4	(New) orbit based on few observations, mass-sum too small.
	84709	17190−3459		MlbO 4	3	Good double-sol instead of unuseable HIP-data.
	84949	(17217+3958)		McA 47	4	Period fixed from sp. orbit. Visual secondary is 2.2 d ecl bin (V 819 Her). Mass-sum in agreement with Scarfe et al. (1994)
	85141	17240−0921		Rst 3972	4	High mass-sum, sp duplicity? Speckle orbit in H2.
	85582	17293+2924	10585	A 351	4	
	85667	17304−0104	10598	StF 2173	3	
	85846	17326+3445	10624	Hu 1181	4	
26 Dra	86036	17351+6152	10660	Bu 962	3	
	86221	17372+2754		Kui 83 AB	4	AB-C triple solution.
	87204	17490+3704		Cou 1145	4	Speckle orbit in H2.
	87655	17542+1108		Fin 381	1	Pr is 0.80 d W UMa ecl. bin (V 2388 Oph). Speckle orbit in H2.
	87895	(17572+2400)		McA 50	1	
τ Oph	88404	18031−0811	11005	StF 2262	4	Primary giant according to isochrone fit.
70 Oph	88601	18055+0230	11046	StF 2272	3	
	88637	18058+2127	11060	Stt 341 AB	4	Triple sol with C (HIP 88639). Pr is 0.88 d ecl. bin (V 772 Her).
99 Her	88745	18071+3034	11077	AC 15	4	
	88932	18092−2211		Rst 3157	4	Poor fit for visual observations, speckle needed. Poor HIP sol.
73 Oph	88964	18096+0359	11111	StF 2281	4	
ϕ Dra	89908	18208+7120	11311	Stt 353	–	Almost rectilinear relative motion, long period!
χ Dra	89937	18211+7245			1	P,e fixed from spectroscopy (Tomkin et al., 1987).
	91394	18384−0312	11520	A 88	4	Speckle orbit in H1.
	91395	18384+6707	11568	StF 2384	4	Unobserved periastron can be covered by speckle in near future.
	92122	18466+3821	11680	Hu 1191	4	
	93017	18570+3254	11871	Bu 648	3	
ζ Sgr	93506	19026−2953	11950	HdO 150	3	
	93574	19035−6845		Fin 357	4	
	94056	19089+3404		Cou 1462	–	More observations needed to define orbit.
	94252	19111+3847	12145	Se 2 BC	4	A-BC triple solution.
	94739	19167−4553		Rst 4036	4	Strange (but useable) reference point for the Transit Data due to reversed signs for proper motions in the Hipparcos Input Catalog.
	95995	19311+5835		McA 56	3	Spurious HIP-sol for fast-moving 1.35 y pair. SB2-sol in B8(# 1162), speckle-spectroscopic orbit worthwile.
	96907	19420+4015		Kui 94	4	Apastron poorly covered. Speckle orbit in H2.
	97222	19456+3336	12889	StF 2576	3	

Table 6. (continued)

Const	HIP	CCDM	ADS	Disc	Tab	Note
	97237	19458+2707		Kui 95	4	Indeterminate (long) period but useable a^3/P^2. Missing in HIP. because of poor Input Catalogue position.
	98001	19550+4152	13125	Ho 581	4	One component is 155 d SB1 (#1187 in B8).
	98416	19598−0957		Ho 276	1	Orbit in H2.
	99376	20102+4357	13461	Stt 400	4	
	101227	20311+3333		Cou 1962	–	More speckle obs needed to cover the orbit.
	101750	20374+7536		Hei 7	4	Visual primary is 0.28 d W UMa ecl. bin (VW Cep).
β Del	101769	20375+1436	14073	Bu 151	3	Primary giant according to isochrone fit, speckle orbit in H1.
	101955	20396+0458		Kui 99	4	Visual primary is 920 d SB2 (#1253 in B8).
α Del	101958	20396+1555	14121	Wck Aa	4	Speckle orbit in H1.
	102782	20494+1124	14333	J 194 AB	4	Triple solution together with C(102784), which is clearly optical with a faulty HIP position.
	103655	21001+4004		Kui 103	4	Visual primary is 3.3 d SB2 (#1280 in B8).
	104019	21044−1951		Fin 328	4	
	104788	21137+6424	14783	H 48	4	
δ Equ	104858	21145+1001	14773	Stt 535	1	Speckle orbit in H2.
τ Cyg	104887	21148+3803	14787	AGC 13	3	
	105200	21186+1134	14839	Bu 163	4	Pr is 4.0 d SB2. Mass-sum in good agreement with the complete speckle-spectroscopic analysis (Fekel et al 1997).
	105431	21214+1020	14893	A 617	4	One component is 2.2 d SB1 (#1297 in B8).
	106255	(21313-0947)		Bla 9		1.9 y (circular) astrometric orbit by McNamara et al. (1987) combined with one speckle obs (Blazit et al. 1987) gives too high mass-sum for this M-dwarf binary. More (IR) speckle needed.
	106811	21380+2743		CC 1299	4	Marginal detection of 14:th mag secondary, but mass-sum too large and more GB obs needed to define orbit. (HIP sol is slit-error).
κ Peg	107354	21446+2539	15281	Bu 989	1	Visual secondary is 6.0 d SB1 (#1329 in B8). Speckle orbit in H1.
	107522	21466−5742		Fin 283	1	Double-period orbit almost as good fit, but in both cases probable secondary sub-system. Speckle and spectroscopic obs needed.
13 Peg	107788	21501+1717		Cou 14	3	Giant (F2 III-IV) class. probably wrong. Speckle orbit in H1.
δ Ind	108431	21579−5500		Fin 307	1	Illustrative solutions with useable astrometric mass-ratios. Short-P solution marginally better, but indeterminate with strong element-correlations. Probably giant primary, more speckle-data needed.
33 Peg	110548	22236+2051	15896	StF 2900	–	Long period (almost linear motion in definitely physical system).
	110893	22281+5741	15972	Kr 60	3	
37 Peg	111062	22300+0426	15988	StF 2912	4	
	111293	22327+5347		Kui 112	–	Wrong object observed by Hipparcos.
	111314	22330+6954	16057	StF 2924	4	Giant (A9 III) classification probably wrong.
	111528	22357+5312	16098	A 1470	4	
	111805	22388+4419	16138	Ho 295	4	Visual sec. is 552 d SB2 (Duquennoy, 1987). Speckle orbit in H2.
	111965	22408−0333		Kui 114	4	Long-period (circular) orbit prefered, but strangely low mass-sum, probably still underestimated a.
	111974	22409+1433	16173	Ho 296	3	Primary giant according to isochrone fit. Speckle orbit in H1.
	112915	22520+5743	16326	A 632	4	Giant (K5III) classification probably wrong.
	113048	22537+4445	16345	Bu 382	4	Visual primary is 24 d SB1 (#1406 in B8).
	113445	22586+0921	16417	Stt 536	3	Edge-on system, most speckle-obs ‘wrong’ quadrant.
83 Aqr	113996	23052−0743	16497	A 417	4	Speckle orbit in H2.
π Cep	114222	23078+7523	16538	Stt 489	4	Visual primary (G2 III) is 557 d SB1 (#1425 in B8).
94 Aqr	115126	23191−1328	16672	McA 74 Aa	1	Triple solution with B (HIP 115125) instead of poor HIP-sol. Pr overmassive, probably sp. bin., cf. McAlister and Hartkopf(1982).
	116436	23357−2729	16850	See 492	4	
	116849	23411+4613		Mlr 4	4	Speckle orbit in H2.
	117570	23506−5142		Slr 14	4	High but rather imprecise mass-sum.

References

Andersen J., 1991, A&AR 3, 91

Baize P., 1976, A&AS 26, 177

Batten A.H., Fletcher J.M., McCarthy D.G., 1989, Publ. DAO 17, 1

Bertelli G., Bressan A., Chiosi C., Fagotto P., Nasi E., 1994, A&AS 106, 275

Blazit A., Bonneau D., Foy R., 1987, A&AS 71, 57

Carbillet M., Lopez B., Aristidi E., et al., 1996, A&A 314, 112 (erratum A&A 329, 1172, 1998)

Chance D.R., Hershey J.L., 1998, PASP 110, 425

Dommanget J., 1995, A&A 301, 919

Dommanget J., Nys O., 1994, Comm. Obs. R. Belg., Ser A, No 115

Dravins D., Lindegren L., Madsen S., Holmberg J., Proc. Hipparcos Venice '97, ESA-SP402, p. 733

Duquennoy A., 1987, A&A 178, 114

Duquennoy A., Mayor M., 1988, A&A 200, 135

Duquennoy A., Mayor M., 1991, A&A 248, 485

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

Fekel F.C., 1980, PASP 92, 785

Fekel F.C., 1992, In: McAlister H.A., Hartkopf W.I. (eds.) IAU Coll. 135, p. 89

Fekel F.C., Scarfe C.D., Barlow D.J., et al., 1997, AJ 113, 1095

Griffin R.F., Gunn J.E., Zimmerman B.A., Griffin R.E.M., 1985, AJ 90, 609

Griffin R.F., Gunn J.E., Zimmerman B.A., Griffin R.E.M., 1988, AJ 96, 172

Hartkopf W.I., McAlister H.A., Franz O.G., 1989, AJ 98, 1014

Hartkopf W.I., McAlister H.A., Yang X., Fekel F.C., 1992, AJ 103, 1976

Hartkopf W.I., Mason B.D., McAlister H.A., 1996, AJ 111, 370

Hartkopf W.I., McAlister H.A., Mason B.D., 1997a, CHARA Contr. No. 4, (on-line electronic version)

Hartkopf W.I., McAlister H.A., Mason B.D., et al., 1997b, AJ 114, 1639

Heintz W.D., 1969b, AJ 74, 768

Heintz W.D., 1979, AJ 84, 1223

Heintz W.D., 1990a, Observatory 110, 131

Heintz W.D., 1990b, A&AS 82, 65

Heintz W.D., 1995, ApJS 99, 693

Heintz W.D., Borgman E.R., 1984, AJ 89, 1068

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

Henry T.J., McCarthy D.W. Jr., Freeman J., Christou J.C., 1992, AJ 103, 1369

Hershey J.L., 1973, AJ 78, 935

Ianna P.A., Rohde J.R., McCarthy D.W. Jr., 1988, AJ 95, 1226

Jefferys W.H., Fitzpatrick M.J., McArthur B.E., McCartney J.E., 1988, GaussFit user's manual. University of Texas, Austin

Kamper K.W., Wesselink A.J., 1978, AJ 83, 1653

Kamper K.W., McAlister H.A., Hartkopf W.I., 1990, AJ 100, 239

Lindegren L., Perryman M.A.C., 1997, Proc. Hipparcos Venice '97, ESA SP-402, p. 799

Lippincott S.L., 1982, AJ 87, 1237

Lippincott S.L., Braun D., McCarthy D.W., 1983, PASP 95, 271

Liu N., Gies D.R., Xiong Y., et al., 1997, ApJ 485, 350

Malkov O.Yu, Piskunov A.E., Shpil'kina D.A., 1997, A&A 320, 79

Mariotti J.-M., Perrier C., Duquennoy A., Duhoux P., 1990, A&A 230, 77

Martin C., Mignard F., 1997, Proc. Hipparcos Venice '97, ESA SP-402, p. 417

Martin C., Mignard F., 1998, A&A 330,585

Mason B.D., McAlister H., Hartkopf W.I., 1995, AJ 109, 332

Mason B.D., McAlister H., Hartkopf W.I., 1996, AJ 112, 276

McAlister H.A., Hartkopf W.I., 1982, PASP 94, 832

McAlister H.A., Hartkopf W.I., Mason B.D., 1992, AJ 104, 1961

McAlister H.A., Mason B.D., Hartkopf W.I., Roberts L.C. Jr., Shara M.M., 1993, AJ 112, 1169

McCarthy D.W. Jr., Henry T.J., McLeod B., Christou J.C., 1990, AJ 101, 214

McNamara B.R., Ianna P.A., Fredrick L.W., 1987, AJ 93, 1245

Press W.H., Flannery B.P., Teukolsky S.A., Vetterling W.T., 1986, Numerical Recipes. Cambridge Univ. Press

Probst R.G., 1977, AJ 82, 656

Quist C.F., Lindegren L., Söderhjelm S., 1997, Proc. Hipparcos Venice '97, ESA SP-402, p. 257

Scarfe C.D., Barlow D.J., Fekel F.C., et al., 1994, AJ 107, 1529

Schaller G., Schaerer D., Meynet G., Maeder A., 1992, A&A 258, 157

Strassmeier K.G., Fekel F.C., 1990, A&A 230, 389

Söderhjelm S., 1982, A&A 107, 54

Söderhjelm S., 1997, In: Docobo J.A., Elipe A., McAlister H. (eds.) Visual double stars: Formation, dynamics and evolutionary tracks. Kluwer, p. 497

Söderhjelm S., Lindegren L., 1997, Proc. Hipparcos Venice '97, ESA SP-402, p. 425

Söderhjelm S., Lindegren L., Perryman M.A.C., 1997, Proc. Hipparcos Venice '97, ESA SP-402, p. 251

Tokovinin A.A., 1997, A&AS 124, 75

Tomkin J., McAlister H.A., Hartkopf W.I., Fekel F.C., 1987, AJ 93, 1236

Torres G., Stefanik R.P., Latham D.W., 1997a, ApJ 474, 256

Torres G., Stefanik R.P., Latham D.W., 1997b, ApJ 479, 268

Torres G., Stefanik R.P., Latham D.W., 1997c, ApJ 485, 167

VandenBerg D.A., Hartwick F.D.A., Dawson P., Alexander D.R., 1983, ApJ 266, 747

Worley C.E., Douglass G.E., 1997, In: Docobo J.A., Elipe A., McAlister H. (eds.) Visual double stars: Formation, dynamics and evolutionary tracks. Kluwer Academic Publishers, p. 485

Worley C.E., Heintz W.D., 1983, Publ. USNO Vol 24, No 7