Seven SB2 masses using Hipparcos intermediate astrometric data

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Abstract

The spectroscopic orbital elements of seven double-lined spectroscopic binaries have been combined to the Hipparcos astrometric data. Dynamical masses and magnitude differences are determined with a precision of about 15% on the average, and the astrometric parameters are improved.

1. Introduction

Although Hipparcos confirmed or discovered the duplicity of about 24 000 stars, there are at least three different categories of binary stars not recognized as such by Hipparcos or which received an inappropriate solution. When the orbital period is much larger than the Hipparcos mission duration, this motion may be absorbed in the Hipparcos 'instantaneous' proper motion measurement. For shorter periods, the components of nearly equal masses/luminosities may not have been detected either, when the photocentre did not show a significant motion. Finally, in the case of an orbital period around one year, the parallactic measurement may have been biased.

This means e.g. that kinematical studies should take into account an extra-dispersion due to undetected binaries of this kind. In the case of relatively long period binaries, a comparison of Hipparcos proper motion with long-term ground-based proper motion may help to detect the duplicity (Wielen et al. 1999). Concerning shorter periods, when spectroscopic orbits are available, the combination of spectroscopic and astrometric data offers the opportunity to correct the astrometric parameters.

However, the primary interest of combining spectroscopic binaries (SBs) parameters with astrometric data is to obtain individual masses without the ambiguity of the inclination of the orbit. In the case of SB1s, the mass of the primary has to be assumed, generally from spectral type. In the case of SB2s, since the mass-ratio is known, the individual masses may be recovered. Moreover, since Hipparcos recorded the path of the photocentre, the magnitude difference between components in the Hipparcos band may also be obtained.

In the course of a Coravel survey of late-type main sequence stars, new spectroscopic binaries have been discovered, and older orbits have been improved. The Hipparcos astrometry has been used to study the distribution of the mass ratios of the SB1s (Halbwachs et al. 2000). As for the SB2s, we selected six of them for which masses are determined with a precision often better than about 15%. The spectroscopic orbits which are used have been derived from Coravel data, with the exception of HIP 35191 from Delfosse et al. (1999). This star has been added to our sample since it provides masses at the end of the main sequence.

Most of the star in our sample have not been published in Martin & Mignard (1998a,b) or Söderhjelm (1999) or a better estimation has been obtained thanks to the spectroscopic data. Our approach differs from theirs in that spectroscopic data is used in place of speckle data and the magnitude difference is estimated from the photocentre path, thus providing a useful cross-check.

2. The combined solution

The semi-major axis of the photocentre may be written as $a_0 = a_1[1-(1+q^{-1})(1+10^{0.4\Delta H_p})^{-1}]$, where a_1 is the semi-major axis of the primary in mas and q is the mass ratio. With the help of $a_1 \sin i$ and q from spectroscopic data, it is possible to obtain the magnitude difference ΔH_p. However, as shown by Martin et al. (1997), Hipparcos did not record exactly the photocentre motion, but what they call the 'hippacentre', which depends on the separation and magnitude difference between components and on the orientation of the satellite scan. We implemented the Martin et al. (1997) method, although the difference between photocentre and hippacentre has only a minor influence on our SB2s with a small separation.

Hipparcos astrometric data are one-dimensional abscissae extracted from the Intermediate Astrometric Data (ESA 1997, CD-ROM 5). To these abscissae and the corresponding formal errors and correlations, we added as supplementary observations the spectroscopic parameters, namely $P, T, e, \omega_1, a_1 \sin i, q$ and associated errors. When a visual orbit was also available, the relative semi-major axis was included if needed. Conceptually, it would be preferable to include individual radial velocity or speckle measurements, using a program such as ORBIT (Forveille et al. 1999, Tokovinin 1992) but this has not been implemented yet.

For a complete solution, 15 parameters have to be determined: the 5 astrometric parameters of the centre of mass, the 7 orbital elements, the masses of the

Table 1: Orbital parameters, astrometric parameters, masses and Hipparcos magnitude difference estimates

HIP	P	T	a_1	e	ω_1	i	Ω	π	$\mu_{\alpha*}$	μ_δ	M_1	M_2	ΔH_p
	d	-2440000	mas		deg	deg	deg	mas	mas/yr	mas/yr	$M_{\rm sun}$	$M_{\rm sun}$	mag
12390	968.28	5441.48	42.8	0.181	250.2	28.6	82.0	40.06	147.28	-235.80	1.55	1.05	1.06
	±5.13	±24.89	±1.6	±0.029	±10.4	±2.3	±14.7	±1.10	±1.39	±1.21	±0.14	±0.10	±0.09
35191	304.35	8826.04	27.3	0.399	273.8	94.2	328.6	85.06	-44.02	-189.46	0.44	0.29	1.91
	±0.25	±1.50	±0.8	±0.008	±0.9	±12.0	±8.2	±2.76	±2.51	±1.94	±0.02	±0.01	±0.41
38018	553.52	6657.52	21.0	0.419	224.1	50.4	88.3	32.64	-89.55	-150.17	0.92	0.66	3.01
	±0.31	±2.85	±1.4	±0.020	±2.7	±4.4	±3.6	±0.80	±0.48	±0.62	±0.20	±0.14	±0.67
61100	1284.37	7512.91	46.9	0.507	248.8	60.1	357.2	40.64	107.08	0.38	0.67	0.58	1.85
	±2.25	±6.50	±2.2	±0.015	±2.5	±3.5	±2.9	±0.93	±1.20	±1.22	±0.17	±0.10	±0.21
78843	105.94	7888.28	12.4	0.151	85.7	83.2	215.2	54.24	299.57	-357.23	0.74	0.65	1.37
	±0.02	±0.73	±0.4	±0.005	±1.9	±10.3	±12.1	±1.17	±1.19	±0.85	±0.06	±0.05	±0.23
95995	494.75	8641.21	40.6	0.340	177.8	144.6	74.6	57.99	-510.14	-397.91	0.83	0.79	0.34
	±0.48	±3.10	±1.5	±0.013	±2.1	±1.7	±6.8	±0.57	±0.57	±0.57	±0.09	±0.09	±0.04
104858	2081.47	6856.10	109.2	0.447	186.3	97.0	243.7	53.55	26.28	-311.43	1.18	1.11	0.45
	±5.73	±5.31	±3.1	±0.009	±0.2	±5.3	±9.1	±0.94	±7.40	±3.74	±0.14	±0.09	±0.19

two components and the magnitude difference. Actually, the six parameters from the spectroscopic data are precise enough, so that no real improvement is obtained for them through the combined analysis. The magnitude difference could have been constrained, in the case of Hipparcos component solution, using the published ΔH_p, but they were judged not accurate enough.

The partial derivatives of all these observations with respect to the 15 parameters were formally computed using the Thiele-Innes elements, and a good starting point of the parameters was needed, since the equations are non-linear. As an initial guess, the orbital parameters were obtained from the photocentric orbit, the mass of the primary component was taken from the spectral type, using the relation of Schmidt-Kaler (1982), the mass of the secondary was deduced from the SB2 mass-ratio and the magnitude difference between components was initially computed from an approximate relation $\Delta H_p \approx -14 \log q$.

In all other aspects, the least-square program is basically the same as the one which has been used for the derivation of the 235 combined FAST+NDAC orbital solutions in the Hipparcos Catalogue. This means that the same criteria for the possible rejections of outliers have been used, providing results homogeneous in a statistical sense with the rest of the Hipparcos Catalogue.

The results of the analysis are given in Table 1, where the index 1 refers to the primary, in particular the longitude of the periastron, following the spectroscopic convention.

3. Notes on individual systems

HIP 12390 (ϵ Cet): This visual binary has a component solution in Hipparcos. There is a discrepancy between the astrometric (0.85 ± 0.08) from Söderhjelm (1999) and the spectroscopic (0.68 ± 0.04) mass ratio, but however also between the Söderhjelm (1999) and Martin et al. (1998) visual+ Hipparcos masses, and our solution lies in-between. The speckle semi-major axis of the relative orbit ($a = 105.5\pm1.2$ mas) from Hartkopf et al. (1989) observations was used to constrain this solution. Compared to the published Hipparcos solution, the proper motion in right ascension has changed by about 25 mas/y.

HIP 35191: A SB2 from the recent Delfosse et al. (1999) M-dwarfs volume-limited survey. The bad goodness-of-fit in the Hipparcos astrometric solution suggested an inadequate solution, although not significantly enough to lead to a stochastic solution. The change in parallax (4 mas) may be due to the ≈ 1 year period.

HIP 38018: A stochastic solution in the Hipparcos Catalogue, with a so-called cosmic error $\epsilon = 7.2$ mas. There is a rough proportionality between the semi-major axis and the cosmic error $a_0 \simeq 2.4\epsilon$, provided that the star is indeed an astrometric binary (Arenou 1997). As for this star, this relation gives exactly the actual photocentre semi-major axis (18 mas). Although fortuitous to some extent, this shows that stochastic solutions may provide in some cases a starting point for the a_0 determination of astrometric binaries.

HIP 61100: A new SB2 from Coravel and also a stochastic solution in the Hipparcos Catalogue, with a cosmic error 9.8 mas suggesting a photocentre semi-major axis of about 24 mas, of the same order as the actual $a_0 = 31$ mas. Hipparcos sampled a major part of the orbit, with a large (60 mas) decrease in declination; the total proper motion differences between the new solution and the old one $\Delta\mu = 15$ mas compares well to what one could predict for the photocentre motion ($|B - \beta| 2\pi a/P$=16 mas) in the simple case of a null eccentricity.

HIP 78843: Also a new SB2 from Coravel, it has not been detected as binary by Hipparcos, although with a large percentage of abscissae rejection. Even if the motion of the photocentre is small, the solution yields good mass estimates.

HIP 95995: A component solution in the Hipparcos Catalogue, with recent Coravel spectroscopic elements. Due to the small size (5 mas) of the photocentre orbit, the visual semi-major axis $a = 84\pm3$

mas from Baize (1989) has been constrained in the solution. Our masses differ from the Martin et al. (1998) ones, but are very close to the Söderhjelm (1999) values.

HIP 104858 (δ Equ): This star was resolved in two components by Hipparcos, and the published proper motion absorbed $\approx$ 15 mas/y due to the orbital motion of this 'long' period binary. Using recent spectroscopic elements, the solution is in very good agreement with Söderhjelm (1999), although (as for HIP 12390) our magnitude difference is larger by 0.3 mag.

4. Discussion and conclusion

The obtained results may be checked using the mass-luminosity relation from F5 to M2.5 dwarf stars. One may note again these results were obtained in a purely dynamical way since even the magnitude differences have been obtained through the astrometric + spectroscopic data adjustment.

The mass-luminosity diagram is presented Fig 1, together with the astrometric solutions from Söderhjelm (1999) concerning dwarfs pairs with a similar or better mass precision. This may be compared to the Henry & McCArthy (1993) relation, after transformation from V to H_p, and no obvious outlier appears. The sample is too small to see a regime variation around 0.5 solar mass, and a line $H_p^{\rm abs} = -13.5(\pm.6)\log M + 5.07(\pm.11)$ fits the data equally well for an illustrative purpose.

Comparing now with the theoretical isochrones of Bertelli et al. (1994) also shows a satisfactory fit and gives confidence in the present mass/luminosity determination, since our SB2s selection has been based solely on the formal errors of the obtained parameters.

Generally the SB2s are not a favorable case for Hipparcos, due to the small motion of the photocentre. Given the current precision of radial velocity surveys, future masses improvement will come from adaptative optics, the Hipparcos intermediate data allowing to better constrain the solution.

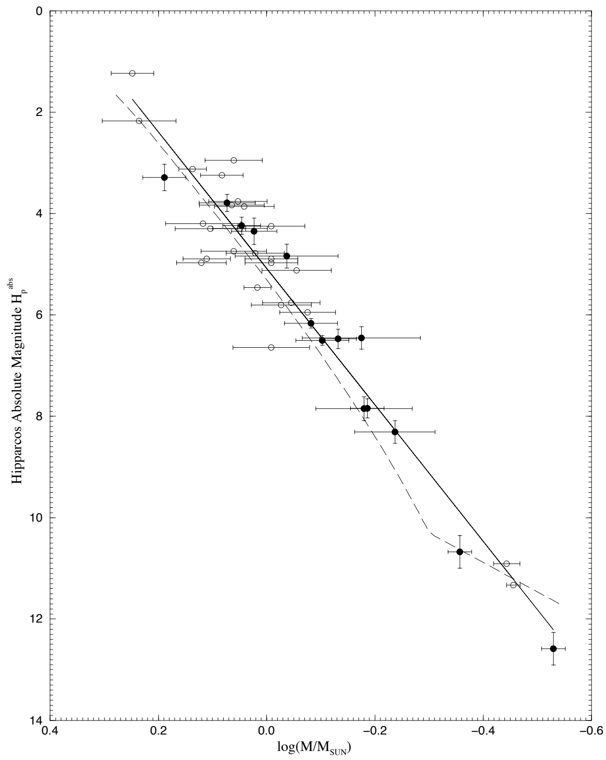

Fig. 1.— Mass Luminosity diagram. Filled circles: our data; open circles: Söderhjelm (1999). Solid line: linear fit; dashed line: Henry & McCarthy relation

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