ON THE MASS-LUMINOSITY RELATION[*]

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ABSTRACT

Hipparcos has provided a lot of new data about double stars including accurate relative positions, magnitudes of the components and parallaxes. Some 170 visual binaries with relatively well known orbits and accurate parallaxes have been selected in order to determine or improve their component masses by making use of these new data. Additional colour information allowed us to obtain the conversion between Hipparcos and bolometric magnitudes. By combining the newly determined parallaxes and differential magnitudes with available ground-based colours and spectral types, we were able to derive component luminosities for our sample of visual binaries. This increase in stellar mass material allows to re-assess the currently adopted mass-luminosity relation (MLR) in the range $0 < M_{\rm bol} < 7$ mag.

Key words: Hipparcos; binaries; mass-luminosity relation.

1. INTRODUCTION

The quality improvement of the Hipparcos parallaxes is extremely valuable for nearby binaries with orbits since these data can lead to more accurate total mass and absolute magnitude determinations, fundamental keys to our astrophysical understanding. The vast and homogeneous acquisition of accurate Hp magnitudes and the differences between components is another aspect of the mission that significantly contributes to a better knowledge of double stars. The impact of these new data on the mass-luminosity relation (MLR) is hereby evaluated.

2. DETERMINATION OF TOTAL MASSES

To determine the total mass of a binary system (in solar units), one needs to know the parallax (π) and two of the orbital elements (the semi-major axis a, and the period P). According to Kepler's third law, the *relative* error E on the total mass, $\mathcal{M}_{\mathcal{AB}}$, is given by:

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

Thus, until very recently, the errors on the total mass were largely dominated by parallax uncertainties.

2.1. Selection on Parallax

Data on 1200 Hipparcos entries of double stars with known orbits were treated. From these, 633 binaries satisfy the constraint $\sigma_\pi/\pi < 10$ per cent, i.e. the binary is situated within 50 pc. However, not all of these were useful: we checked on component consistency (i.e. the Hipparcos component should be the orbiting component) and removed cases with incomplete information (e.g. lacking ΔHp). Our sample then consisted of 503 binaries with 839 orbits (some binaries have several published orbits).

2.2. Selection on Multiplicity and Evolution

We removed some 100 binaries with partial information (Hipparcos single or astrometric pairs), for which the number of detected components related to that entry is one (the cases for which the entry exists in the Double and Multiple Star Annex, Parts O, G, V or X). We next removed multiple systems (the number of detected components related to that entry is three or more) and newly resolved astrometric pairs with orbits unresolved from ground-based observations. Exclusion of the binaries with evolved components has been done on the basis of spectral type and by plotting Hp as a function of the global colour information $(V - I)$ from the Hipparcos Catalogue (ESA 1997). After selection, 385 presumed main-sequence binaries with 500 orbits remained.

2.3. Selection on Orbit Quality

In this investigation we have carefully selected the orbits in two different ways. First, a comparison of the ephemeris (1987-1996) with the Hipparcos relative astrometry (1991.25) was made (Figures 1a–d). Cases where the discrepancy in position is typically ≥ 0.1 arcsec have been rejected (≈ 130, see Figure 1d for an example). Then, we have taken errors on the

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[*] Based on data from the Hipparcos astrometry satellite.

Figure 2. Hipparcos bolometric corrections.

4. DETERMINATION OF COMPONENT BOLOMETRIC MAGNITUDES

Absolute magnitudes for the components were derived by combining Hp, ΔHp and π. Errors on $M_{\mathrm{Hip,A}}, M_{\mathrm{Hip,B}}$ have been determined and can be shown not to exceed 0.2 mag (cf. constraint of Section 2.1). In order to convert these into bolometric magnitudes, bolometric corrections $\mathrm{BC}(Hp)$ with respect to Hp were determined as follows. Making use of the tables provided by Bessell et al. (1997) giving $\mathrm{BC}(V)$ as a function of T_{eff} and the colour $(V-I)$, and transforming V magnitudes into Hp (ESA 1997), a relation $\mathrm{BC}(Hp)$ was obtained as a function of T_{eff}. In Figure 2, this result is compared to the relation proposed by Cayrel et al. (1997). For 55 systems, we found spectral types for both components in the literature. For the 117 remaining systems, a colour or spectral type decomposition was obtained based on the knowledge of the spectral type of the primary and of the global colour $(\mathrm{B}-\mathrm{V})$, following Mermilliod et al. (1992). We then converted the absolute Hipparcos magnitudes to bolometric ones.

5. MASS-LUMINOSITY RELATION

Lutz & Kelker (1973) determined corrections on absolute magnitudes obtained from trigonometric parallaxes for use in luminosity calibrations. Following van Altena et al. (1992), we applied corrections on both luminosities and masses in the case of a uniform stellar distribution ($n=4$). In order to check that assumption, we plan to investigate the distribution of proper motions of the binaries in our sample. Figures 3 and 4 illustrate our results with errors on both axes. A doubly weighted linear regression model (Babu & Feigelson 1996) gave very similar results for the slope of the MLR in both samples: for 55 A- and 50 B-components: $K = 3.58 \pm 0.14$; for 172 primaries only: $K = 3.93 \pm 0.12$; for 344 components: $K = 3.70 \pm 0.06$. Figure 5 shows the distribution of the individual slopes in the $(\log(\mathcal{M}), \mathrm{M}_{\mathrm{bol}})$ plane for each of the 172 binaries.

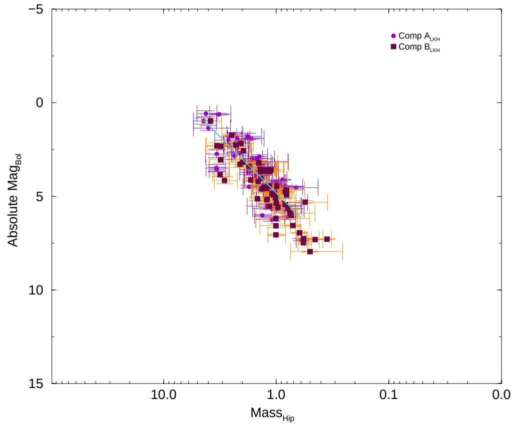

Figure 3. Mass-luminosity diagram for 55 systems.

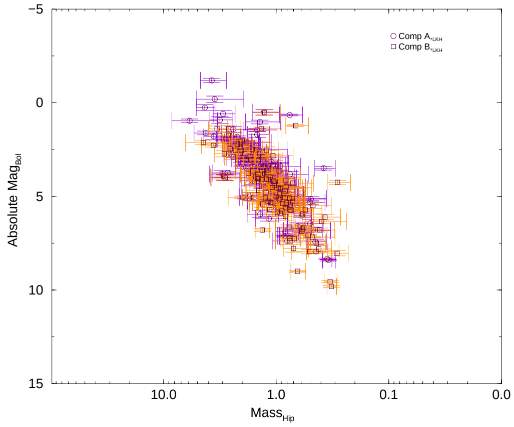

Figure 4. Mass-luminosity diagram for 117 systems.

6. DISCUSSION

The values of the MLR found differ from the initially assumed values given in Section 3. An iteration of the procedure is desirable, but was not made in this first study. However, we may already propose the following conclusions:

(a) the improvement of the data on masses and magnitudes by Hipparcos is illustrated by the large number of binaries used in this analysis. The present data extend from $0 < M_{\rm bol} < +7$ mag only, with a mean slope K=3.9. This corroborates previous determinations for the same luminosity range;

(b) however, the presented diagrams still show a wide dispersion and may indicate that our selection criteria should be kept more stringent. Since the error analysis has been quite substantial, it may also indicate some intrinsic differences. This will be further investigated;

(c) parallax errors are still dominant for most of the known double-lined spectroscopic binaries. Although masses for the components of some eclipsing binaries have been precisely determined (Andersen 1992), inclusion of data on eclipsing binaries based on Hipparcos measurements in order to cover the high-luminosity range has only an indicative value, because the parallaxes determined from the study of eclipsing binaries are much more precise then those of Hipparcos;

(d) the break in the slope of the MLR in the low-luminosity range (near $M_{\rm bol} = +7$) could not be assessed with these data due to a lack of low-mass binaries in our sample.

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Table 1. Comparison of published masses with our computed values.

HIP	Mass_A	Mass_B	σ_{MA}	σ_{MB}	Source	$\mathrm{Mass}_{A,Hp}$	$\mathrm{Mass}_{B,Hp}$	$\sigma_{A,Hp}$	$\sigma_{B,Hp}$
011452	0.47	0.39	0.20	0.20	Belikov (1995)	0.590	0.566	0.065(11)	0.063(11)
012390	1.886	0.99	0.171	0.092	Martin & Mignard (1997)	1.902	1.392	0.346(18)	0.287(21)
026926	0.5	0.5	-	-	Belikov (1995)	1.379	1.156	0.226(16)	0.198(17)
038382	1.05	1.10	0.17	0.18	Belikov (1995)	0.887	0.713	0.095(11)	0.076(11)
038382	0.59	0.73	-	-	Belikov (1995)	”	”	”	”
038382	0.64	0.81	-	-	Belikov (1995)	”	”	”	”
038382	0.99	0.86	0.19	0.17	Belikov (1995)	”	”	”	”
044248	1.13	0.84	0.200	0.150	Eggen (1956)	1.613	0.923	0.113(7)	0.144(7)
044248	1.473	0.972	0.102	0.081	Martin & Mignard (1997)	”	”	”	”
045593	0.33	0.30	0.1	0.1	Belikov (1995)	0.421	0.419	0.261(62)	0.260(62)
075312	1.14	1.02	-	-	Belikov (1995)	1.143	1.065	0.082(7)	0.076(7)
075312	0.95	0.94	0.27	0.26	Belikov (1995)	”	”	”	”
075312	1.10	1.00	0.2	0.2	Belikov (1995)	”	”	”	”
076382	1.1	1.0	0.4	0.4	Belikov (1995)	0.866	0.827	0.050(6)	0.047(6)
082817	0.354	0.511	0.021	0.029	Martin & Mignard (1997)	0.338	0.328	0.044(13)	0.043(13)
084140	0.264	0.26	0.020	0.019	Heintz (1984)	0.348	0.319	0.034(10)	0.032(10)
084140	0.404	0.344	0.02	0.018	Martin & Mignard (1997)	”	”	”	”
087991	0.3	0.6	-	-	Belikov (1995)	0.912	0.766	0.550(60)	0.461(60)
087991	0.3	0.7	-	-	Belikov (1995)	”	”	”	”
101955	0.69	0.65	0.13	0.13	Belikov (1995)	1.321	0.931	0.205(16)	0.145(16)
104858	1.17	1.16	0.025	0.026	Belikov (1995)	1.481	1.368	0.212(14)	0.199(15)
104858	1.67	1.089	0.108	0.083	Martin & Mignard (1997)	”	”	”	”

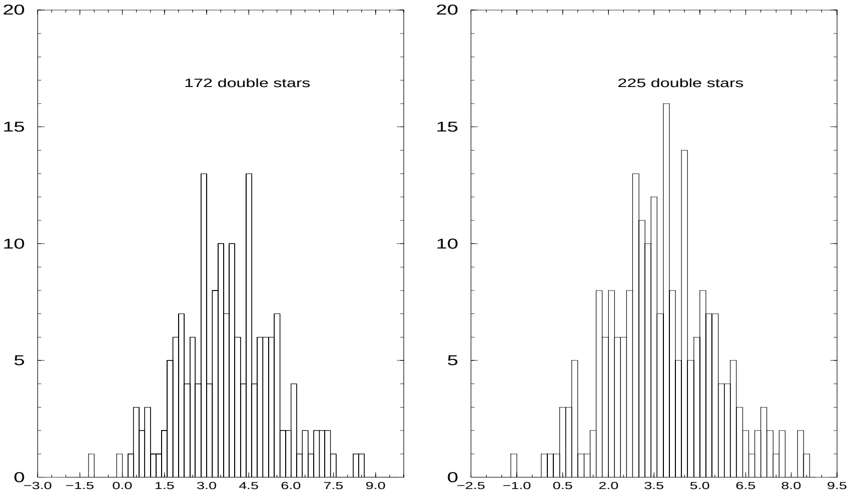

Figure 5. Distributions of the slopes of the line joining the primary and secondary of respectively 172 (left) and 225 (right) systems in the $(\log(\mathcal{M}), M_{\mathrm{bol}})$ *plane.*