HIPPARCOS OBSERVATIONS OF PRE-MAIN-SEQUENCE STARS

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ABSTRACT

We present first results of Hipparcos observations of nearby low-mass pre-main-sequence (PMS) stars (T Tauri and Herbig Ae/Be stars). The data obtained by Hipparcos allow us to derive weighted mean parallaxes for three major nearby star-forming regions (SFRs), Lupus, Chamaeleon I, and Taurus-Auriga.

Furthermore, results on the isolated objects AB Dor and TW Hya are presented. Finally, we discuss the evolutionary status of Herbig Ae/Be (HAEBE) stars on the basis of Hipparcos results.

Key words: Stars: formation; Stars: late-type; Stars: pre-main-sequence.

1. INTRODUCTION

The evolutionary status of pre-main-sequence (PMS) stars can be determined by placing them in the HR diagram. This allows to estimate the stellar masses and ages by comparison with theoretical evolutionary tracks. Thus, the stellar populations of star-forming regions (SFRs) can be studied, and different SFRs can be compared.

Another important scientific goal is the determination of the 'birthline' (Stahler 1988, Palla & Stahler 1993), which is the location in the HR diagram at which PMS stars first appear as visible objects. Theoretically, this depends on the initial mass accretion rate. There are indications that the birthline of the Lupus SFR is anomalously low as compared with Taurus-Auriga and Chamaeleon (Hughes et al. 1994).

Observations of the Hipparcos satellite for the first time allow to determine trigonometric parallaxes towards nearby SFRs, as well as yielding parallaxes for some isolated objects and a number of Herbig Ae/Be (HAEBE) stars. Thus, previous estimates of luminosities, and therefore locations in the HR diagram, can be tested and refined. Here we present first results. A more complete account of this work will be given elsewhere (Wichmann et al., 1997, submitted to MNRAS).

2. NEARBY STAR-FORMING REGIONS

2.1. Taurus-Auriga

For Taurus-Auriga, Elias (1978) concluded that the most likely value of the distance is about 140 ± 20 pc.

In this SFR, five T Tauri stars and one HAEBE star (AB Aur) have been observed by Hipparcos. For the binary system RW Aur only a 'stochastic' solution (in the sense of the Hipparcos Catalogue's internal astrometric quality classification) was found. We consider its parallax as dubious and do not use it further.

For the remaining five stars, we obtain a weighted mean parallax of $\langle \pi \rangle = 7.06 \pm 0.71$ mas, or 7.14 ± 0.70 mas if RW Aur is included (1 mas = 1 milliarcsec = 10^{-3} arcsec). Thus our estimate for the distance is 142 ± 14 pc, in perfect agreement with previous estimates.

2.2. Chamaeleon I

Distance estimates for the Cha I SFR mainly rely on the two stars HD 97300 and HD 97048. A critical discussion of distance estimates can be found in a recent review by Schwartz (1991), who concluded that the distance is most likely about $140 - 150$ pc.

Four T Tauri stars and one HAEBE star (HD 97048) in Cha I were observed by Hipparcos. Again, we exclude one star (Sz 19) from the analysis because only a 'stochastic' solution was achieved.

The weighted mean parallax of the remaining four stars is $\langle \pi \rangle = 6.25 \pm 0.68$ mas (6.16 ± 0.67 mas if Sz 19 is included), equivalent to a distance of 160 ± 17 pc, in good agreement with the conclusions of Schwartz (1991). On the other hand, it does not support the large distance of 220 pc derived by Thé et al. (1986), which is based on a multi-parameter model of HD 97300 including a seemingly implausible hot (2740 K) dust shell close (0.1 AU) to the star.

2.3. Lupus

The most recent determination of the distance towards the Lupus SFR is from Hughes et al. (1993), who proposed a distance of 140 ± 20 pc, based on spectroscopic parallaxes of foreground stars.

Five PMS stars in Lupus (including the HAEBE star HR5999) were observed by Hipparcos. For these stars, we determined a weighted mean parallax of $\langle\pi\rangle = 5.26 \pm 0.75$ mas, corresponding to a distance of 190 ± 27 pc.

Murphy et al. (1986) have pointed out that the Lupus SFR is seen projected onto a gap between two subgroups of the Scorpius-Centaurus OB association. The Hipparcos parallax indicates that the Lupus SFR is actually connected with Sco-Cen (distance 170 pc, according to Gutiérrez-Moreno & Moreno 1968), rather than being located in the foreground.

Hughes et al. (1994) concluded that the Lupus SFR is older than Taurus-Auriga and Cha I, with the age distribution of its PMS stars peaking at $\sim 3\times10^6$ yrs (assuming a distance of 140 pc), compared to $\sim 3\times10^5$ yrs for Taurus-Auriga and Cha I. Scaling their luminosities to a distance of 190 pc, we find an average reduction of the age by a factor of about 2.3. Thus, although the difference to Taurus-Auriga and Cha I is reduced, it is still significant.

The larger Hipparcos distance also moves the Lupus birthline up by about 0.25 mag. However, a distance of 300 pc for the Lupus SFR would be required in order to match its birthline to that of the Taurus-Auriga and Cha I SFRs. Probably the birthline is low because there are no newly born stars to define it. This tentative explanation is in agreement with the observed lack of deeply embedded near-IR objects in the Lupus SFR.

3. ISOLATED STARS

Within the Hipparcos program, a small number of apparently isolated stars have been observed that were suspected to be of PMS nature. Rather accurate parallaxes were measured for AB Dor and TW Hya ($\pi = 66.92 \pm 0.54$ mas and $\pi = 17.72 \pm 2.21$ mas, respectively), while the observations of FK Ser and CoD-27° 11363 are inconclusive due to the large errors ($\pi = 9.42 \pm 6.17$ mas and $\pi = 3.23 \pm 5.65$ mas, respectively).

AB Dor is a well-studied star, whose spectral type has been estimated as K0V (Ruciński 1985), while the age has been estimated as $10^6 - 3\times10^7$ yrs (Vilhu et al. 1987).

The Hipparcos parallax is $\pi = 66.92 \pm 0.54$ mas, corresponding to 14.9 ± 0.1 pc. Converting the Tycho photometry to Johnson V, and assuming negligible foreground extinction, we obtain an absolute magnitude of $M_V = 6.07 \pm 0.02$, in perfect agreement with the standard value for a K1 ZAMS star.

TW Hya is a K7Ve (Li) star that was classified by Ruciński & Krautter (1983) as classical T Tauri star (on the basis of strong Hα emission as well as on the presence of ultraviolet and infrared excess), although it is located far from any dark cloud.

For this star, Hipparcos has measured a parallax of $\pi = 17.72 \pm 2.21$ mas (56.4 ± 7.0 pc). Again, using Tycho photometry and assuming $A_V = 0$, we derive an absolute magnitude of $M_V = 7.32 \pm 0.27$ (i.e. 0.8 mag above the main sequence), which should be regarded as a lower limit only. Using the evolutionary tracks from D'Antona & Mazzitelli (1994), we estimate the age of the star to about 1.5×10^7 yrs, and the mass to about $0.8 M_\odot$. It is noted that the location in the HR diagram and the age estimate given here are somewhat in disagreement with the classical T Tauri nature of the star.

Ruciński & Krautter (1983) speculated that TW Hya might have escaped from a cloud about 13^o distant, at $l = 279^\circ$, $b = +10^\circ$. According to Hipparcos observations, it has a large proper motion: $\mu_\alpha \cos\delta = -66.9$ mas/yr, $\mu_\delta = -12.4$ mas/yr. However, almost all of this is due to solar apex motion. The reflex proper motion of TW Hya is, using the standard solar apex, $\mu_\alpha \cos\delta = -67.3$ mas/yr, $\mu_\delta = -18.5$ mas/yr. Thus the transverse motion after correction is only $\mu_\alpha \cos\delta = +0.4$ mas/yr, $\mu_\delta = +6.1$ mas/yr, corresponding to only 1.6 km s^{-1} transverse velocity at 56 pc. The solar-motion-corrected radial velocity is only -3.5 km s^{-1} (± 3 km s^{-1}), so that the galactic space motion is only of the order of 4 km s^{-1}. This small motion makes it clear that TW Hya cannot have escaped from any known dark cloud within the last few million years. Even in 15 million years it would have travelled only 60 pc relative to the galactic standard of rest. Thus, both the Hipparcos parallax and the Hipparcos proper motion deepen the mystery about the nature and location of this star.

4. HERBIG Ae/Be STARS

Most of the HAEBE observed by Hipparcos are located in distant SFRs, and thus individual parallaxes are of low precision usually. We have therefore calculated the weighted mean offset to the ZAMS, ΔM_v, defined as:

$$\Delta M_V = \langle M_V - M_{V,ZAMS} \rangle \qquad (1)$$

for these stars, in order to evaluate their evolutionary status and to check the calculations for the birthline (Palla & Stahler 1993).

Following Feast & Catchpole (1997), we calculate the mean of the function DX, which we define as:

$$DX \equiv 10^{0.2\Delta M_v} = 0.01\pi 10^{0.2(V - A_V - M_{V,ZAMS})} \qquad (2)$$

weighted by the inverse square of the errors of DX for the individual stars. In the above formula, V is in the Johnson system, π is in milliarcsec, and $M_{V,ZAMS}$ denotes the absolute V magnitude of a ZAMS star of the same spectral type. We average DX rather than ΔM_v, because contrary to ΔM_v, the function DX has a useful (compact and symmetric, in this case even gaussian) error distribution.

We use the Tycho photometry to calculate V_J for the stars of our sample, while values for the extinction A_V were compiled from the literature (Lopez et al. 1992, Hillenbrand et al. 1992, Finkenzeller & Mundt 1984, Racine 1968, Strom et al. 1972). In case of binaries, we use ΔM_H as measured by Hipparcos to correct for the contribution of the secondary to V_J. Stars with 'stochastic' solutions were not used.

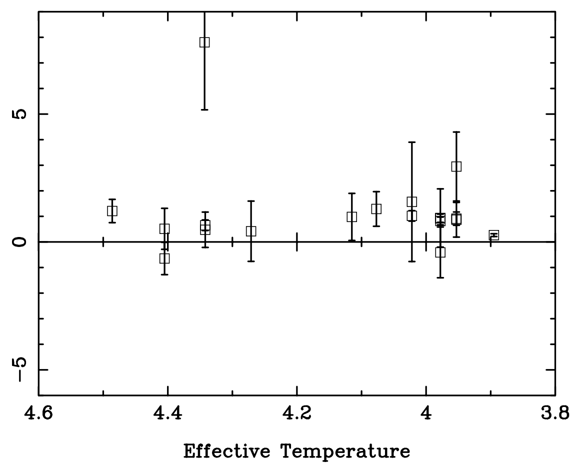

Figure 1. DX versus effective temperature for Herbig Ae/Be stars.

In the error budget for individual stars, besides the errors in the photometry and the parallaxes, we assume squared errors of $\sigma^2 = 0.015$ mag^2 for $M_{V,ZAMS}$ and $\sigma^2 = 0.05$ mag^2 for A_V. Then, for DX, we obtain the following values: $\langle DX \rangle = 0.46 \pm 0.04$ (all, i.e 19 stars), $\langle DX \rangle = 0.82 \pm 0.13$ (Herbig Be stars (11) only), and $\langle DX \rangle = 0.43 \pm 0.06$ (Herbig Ae stars (8) only). Figure 1 shows the individual values of DX plotted versus effective temperature. The respective values of χ^2/f (where f is the degree of freedom, i.e. the number of stars minus 1), are 2.9 (all stars), 4.6 (Herbig Ae stars) and 1.3 (Herbig Be stars). The high values, especially for the samples of all HAEBE and Herbig Ae stars, indicate the presence of some additional spread in the data not accounted for in our error budget. This clearly is the intrinsic spread of ΔM_V due to the different evolutionary stages of the individual stars.

We therefore chose to multiply the errors for ΔM_V, as calculated from the formal errors of DX, by a factor of $\sqrt{\chi^2/f}$, in order to take into account this additional spread. We obtain the following values: $\Delta M_v = -1.7 \pm 0.3$ (all), $\Delta M_v = -0.4 \pm 0.3$ (Herbig Be stars only), and $\Delta M_v = -1.8 \pm 0.6$ (Herbig Ae stars only).

Thus, on average the stars of our sample are in fact located above the ZAMS in the HR diagram, in the region expected for PMS stars. Moreover, the B-type stars are closer to the ZAMS than A-type stars. This fact, and the observed size of the offset, are in good agreement with the calculated birthline from Palla & Stahler (1993). For B-type stars the birthline is expected to be located nearer to the ZAMS than for A-type stars, because the PMS evolutionary timescale decreases with increasing mass. Thus B-type stars will be already very near the ZAMS when the circumstellar material disperses and the star becomes visible.

5. CONCLUSIONS

Within the errors, Hipparcos observations have confirmed the distances of three nearby SFRs as previously determined with the aid of spectroscopic parallaxes. This result not only is important with respect to the study of these particular SFRs, but also supports previous distance determinations of more distant SFRs like Orion or the Gum Nebula, as their distances are based on similar methods.

AB Dor is confirmed as ZAMS star, and TW Hya as isolated PMS star. Moreover, apparently TW Hya has not been ejected recently from a nearby cloud, but seems to be practically stationary in the galactic reference frame.

Finally, it could be shown that on average HAEBE stars are located above the ZAMS, and are seen nearer to the ZAMS at earlier spectral types, in agreement with theoretical calculations (Palla & Stahler 1993).

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