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# HIPPARCOS

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## Abstract

The HIPPARCOS mission will permit a decisive step forward in the comparison between observed and predicted global properties of stars, in producing distances and apparent magitudes with accuracies more than one order of magnitude higher than before. Nearby stars of intermediate and low mass will allow for statistical tests on the validity of the equation of state, like for instance the steepness of the main sequence.

La mission HIPPARCOS va permettre un pas en avant fondamental dans les tests des propriéés thermodynamiques des étoiles de masse intermédiaire en fournissant des distances et des magnitudes apparentes beaucoup plus précises que celles obtenues au sol.

## 24.1 Introduction.

Tests of the physical description of stellar interiors rely on a theory vs observation comparison. The stellar evolution theory predicts the variation with time of the state of the interior of a star and, also, of its fundamental, observable parameters, i.e. luminosity, surface temperature, for a given mass. The HIPPARCOS (High Precision PARallax COllecting Satellite) mission will permit a decisive step forward in this confrontation by producing distances and apparent magnitudes with accuracies more than one order of magnitude higher than before (Baglin, 1988).

For a description of the mission see for instance Perryman et al., 1992, and the 'Hipparcos Input Catalogue' (Turon et al., 1992).

## 24.2 Distances measurements.

HIPPARCOS measures parallaxes i.e. distances, and proper motions. Aproximately 120 000 stars brighter than $mv \approx 12.5$ are observed; the survey is complete up to the apparent magnitude 7.5.

The accuracy is 2 milliarcseconds or better, i.e. 10 to 50 times better than from the ground.

This high accuracy is reached by accumulation of individual measurements, i.e. it increases with the duration of the mission. After slightly more than 3 years of observations, the nominal accuracy is obtained despite the poor quality of the orbit, far from the expected one (Perryman, 1993). The results obtained from only one year of data is given in Figure 1.

## 24.3 Apparent H magnitudes.

Hipparcos has proven to be an excellent photometric instrument, working in only one large H band. It will provide H apparent magnitudes with an accuracy of few milli-magnitudes. In addition, $B_T$ and $U_T$ Tycho magnitudes will be obtained for star brighter than about 11.

## 24.4 Luminosities.

Accurate distances provide accurate luminosities for the closest objects, if an apparent magnitude is known also accurately, and if the so-called 'bolometric correction' is also well known.

$$L == l_H \, d^2 \, BC \qquad (1)$$

$L$ total flux radiated in one second; $l_H$ flux received on earth in the $H$ band in one second; $d$ distance, expressed in 10 parsecs; $BC$ bolometric correction associated to the H magnitude, which corrects the energy radiated in the electromagnetic spectrum outside the H band.

At 5 parsecs the relative precision on the distance is 1 %; it generates an uncertainty of 2% on luminosities, i.e. 10 to 50 times better than presently.

The progress of spectrophotometry and of the modelisation of stellar atmosphere have also reduced drastically the uncertainties on the effective temperature and on the bolometric correction.

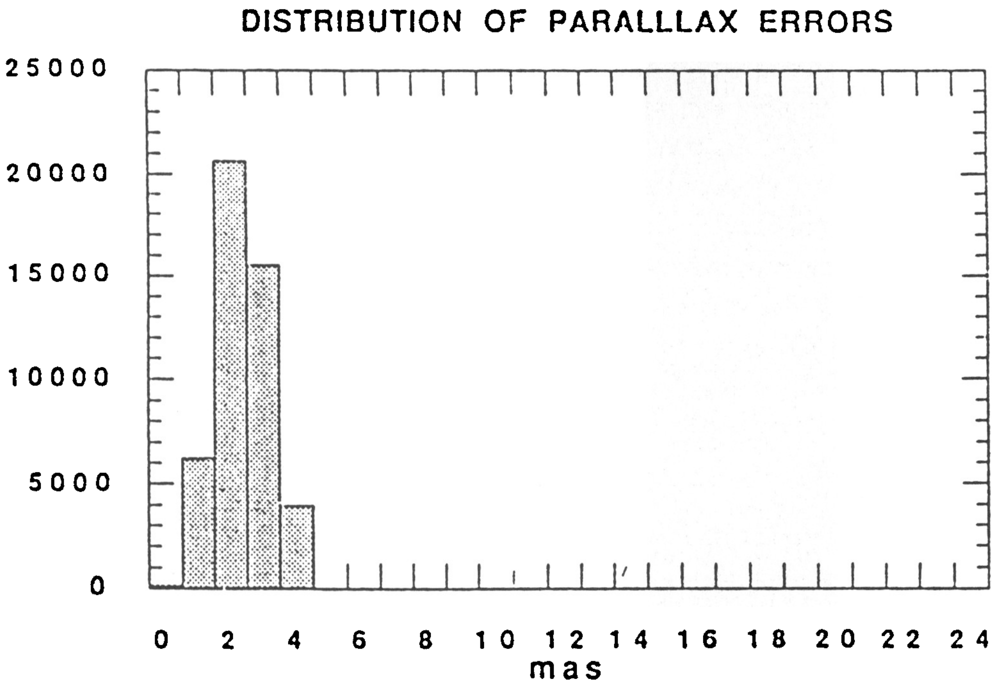

Fig. 24.1 The accuracy of the parallax measurements after only one year of observations (2000 stars observed more than 5 times) is already of the order of 2 milliarcseconds.

## 24.5 Low mass-stars.

One of the most fundamental reasons to study low-mass stars ($M \leq 1.0 M_{\odot}$), is that they form, by number and mass the largest class in the Galaxy. More than 80 % of stars closest than 10 pc belong to this domain (Figure 2).

In Figure 3 we present the internal structure of 0.6 and $0.8 M_{\odot}$ stars compared to the Sun.

In the domain of temperature and density covered by their interior, the plasma is far from ideal gas. The main contribution comes from the coulombien interaction. In this domain, it is described accurately by Debye-Hückel formalism (Cox & Giulli, 1968).

The gas pressure $P_g$ is express in terms of the pressure $P_p$ of the ideal gas (Guenther et al., 1992), $P_p$, ideal gas law by,

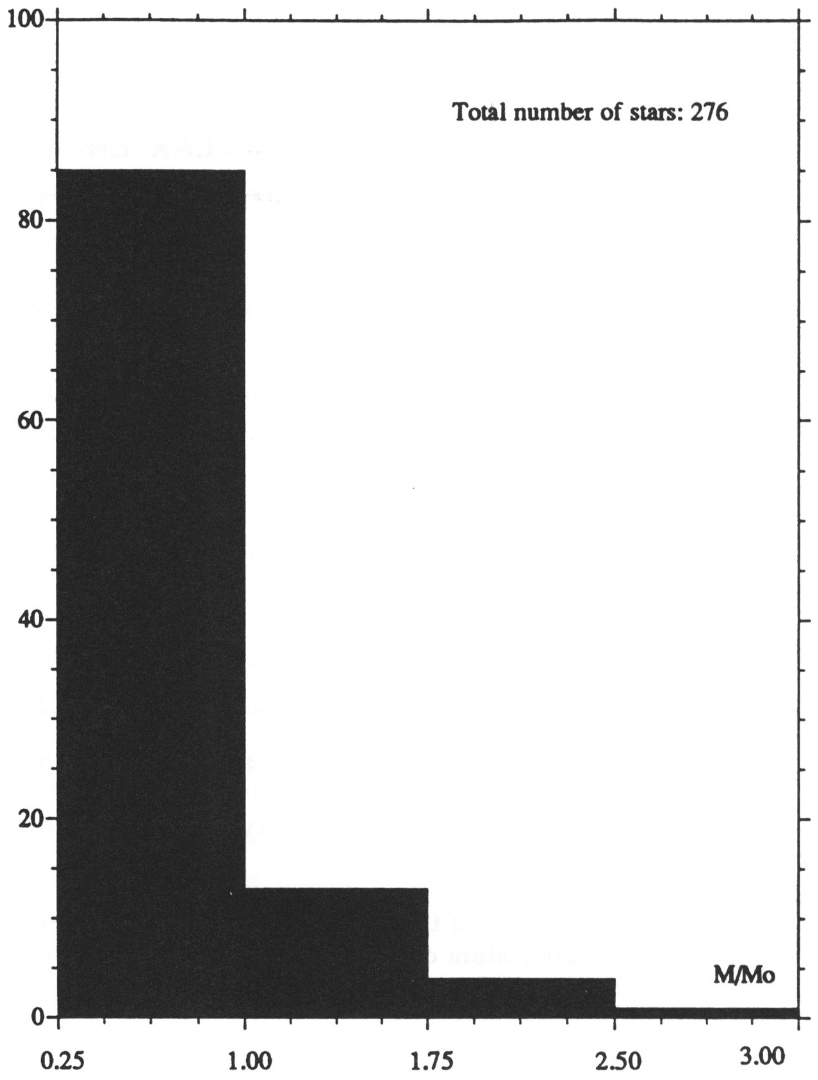

**Fig. 24.2** Histogram for stars closest than 10 pc (Gliese et al., 1991), with mass between 0.25 and 3.00$M_{\odot}$.

$$P_g = P_p\left[1 - 0.044\frac{\rho^{1/2}(3+X)^{3/2}}{T_6^{3/2}(5X+3)}\right] \quad (2)$$

where $\rho$ is density, X is the mass abundance of hydrogen and $T_6$ the temperature in $10^6$ K.

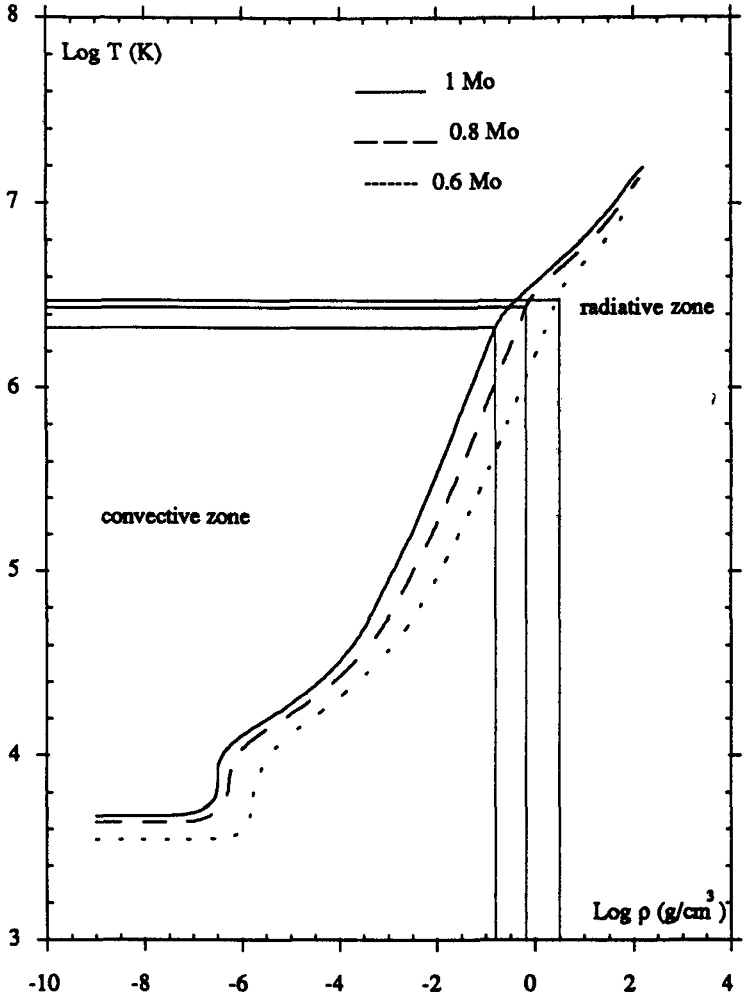

Fig. 24.3 Internal structure of 0.6, 0.8 and $1.0 M_{\odot}$ main sequence stars in $\log \rho / \log$ T plane. Full lines represents the limit of convective and radiative zones, for each model.

Figure 4, gives the ratio between $P_g$ and $P_p$ as function of temperature, for two models of 1.0 and $0.6 M_{\odot}$. It shows that the importance of corrective term (here after DHc) decreases with increasing mass.

A quantitative estimate of the influence of the DHc term on the global structure is given by comparing stellar main sequence models of 1.0 and $0.6 M_{\odot}$ computed using two different equations of state: EFF formalism (Eggleton et al., 1972) and CEFF (Christensen-Dalsgaard, 1991), which is

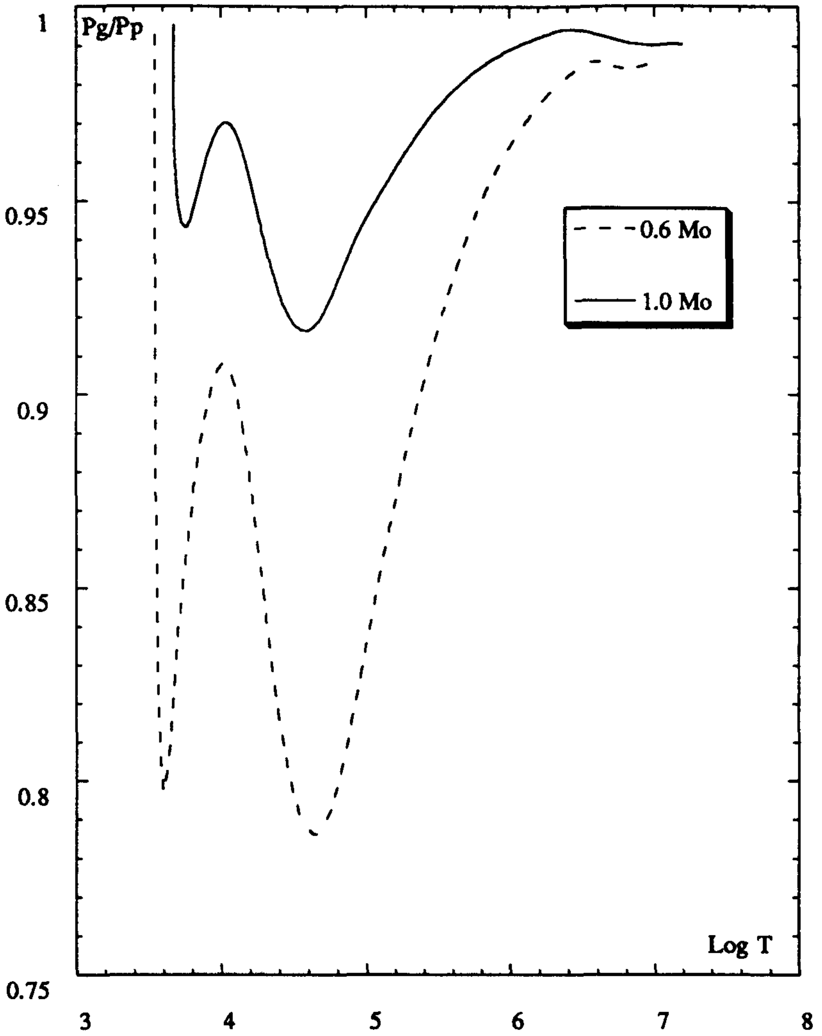

Fig. 24.4 Ratio between gas pressure corrected by DHc, according (2), $P_g$, and gas ideal pressure, $P_p$, as function of Log T. DHc becames very important in convective region for low-mass stars.

the EFF equation where the Coulomb effects have been included according to the Debye-Hückel theory (see also Lebreton et al., 1992).

On Figure 5, these results are compared to the observations of 10 close low-mass stars in the HR diagram. Vertical bars represent the errors on luminosity presently and using Hipparcos results. A mean error bar in effective temperature is also presented.

Here we have assumed that convective transport is represented correctly by the mixing length theory, using a constant value for the mixing length

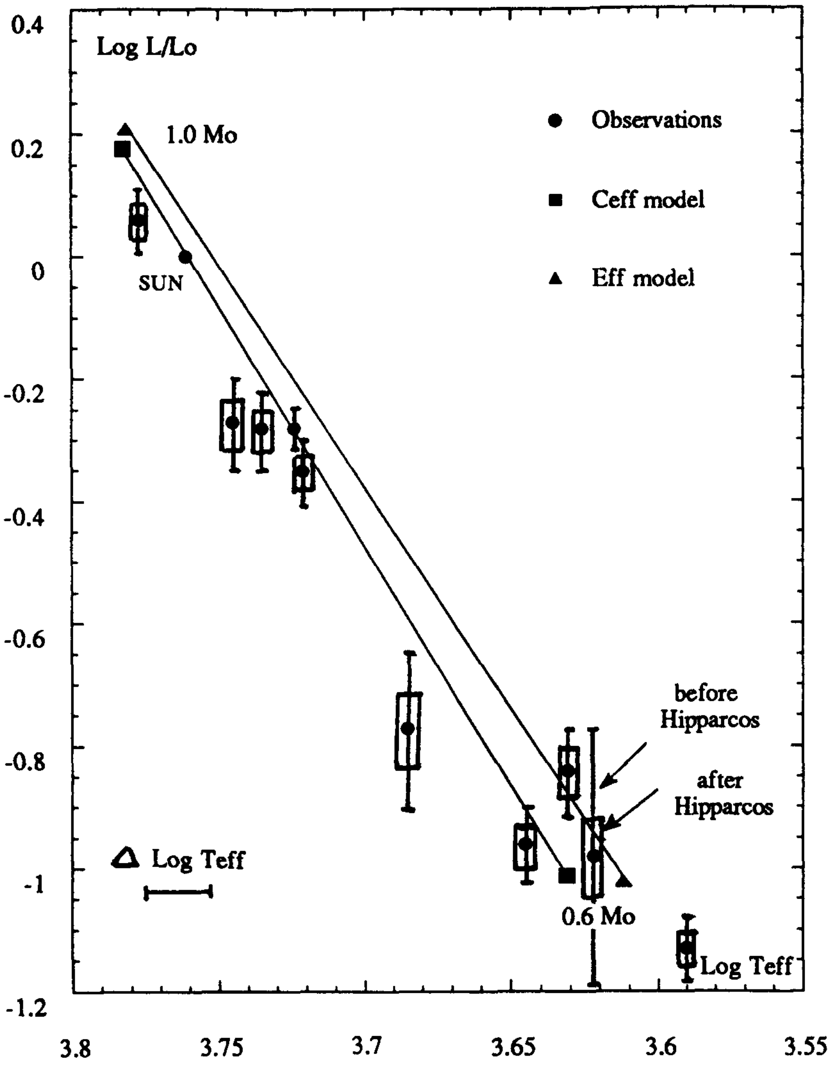

Fig. 24.5 HR diagram of 10 low-mass stars closer than 10 parsecs, for which HIPPARCOS will improve luminosities determinations. Vertical error bars correspond to the present accuracy and the accuracy after reduction of the HIPPARCOS data on luminosity. Horisontal bar represents a mean error in effective temperature for these stars.

parameter, $\alpha$, the solar one. This hypothesis is confirmed by recent results on calibration of the $\alpha$ Centauri binary system (Fernandes et al., 1993).

## 24.6 Conclusion.

This example ilustrates the power of low mass stars to test the equation of state.

Figure 5 shows already a better agreement of CEFF formalism.

The reduction of the error bars on luminosity, as expected from Hipparcos will allow to test precisely more refined treatement of the thermodynamics.

As nearby cool stars are numerous, the steepness of the main sequence will be very accuratly determined.

A further improvement on luminosity measurements is foreseen as a new generation of astrometric missions, designed to increase the accuracy up to 1 micro mas (100 times better than HIPPARCOS) and is already under study.

**Acknowlegements**

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## References

Baglin A.: 1988, in: Scientific Aspects of Input Catalogue Preparation II. Eds. J. Torra, C. Turon

Christensen-Dalsgaard J.: 1991, Challengs to Theories of Structure of Moderate-Mass Stars, Springer Verlag. Eds. D.O. Gough, J. Toomre

Cox J.P., Giulli T.: 1968, 'Principles of stellar structure, volume I'. Eds. Gordon and Breach

Eggleton P.P, Faulkner J., Flannery B.P.: 1993, A&A, **23**, 325

Fernandes J., Neuforge C., work in progress

Gliese W., Jahreiss H.: 1991, 'Catalogue of nearby stars, 3rd edition', Astron. Rechen-Institut, Heidelberg.

Guenther D.B., Demarque P., Kim Y.C., & Pinsonneault M.H.: 1992, ApJ, **387**, 372

Lebreton Y., Däppen W.: 1988, Symp. Seismology of Sun and Sun-like Stars, ESA SP-286

Perryman M.A.C. et al.: 1992, A&A, **258**, 1

Perryman M.A.C.: 1993, 27th Symposium, ESTEC, 10-14 May 1993

Turon C. et al: 1992, 'Hipparcos Input Catalogue', ESA SP 1136