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What can we learn from binaries in clusters? The example of the Hyades

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Abstract. Observations have provided precise data for stars in the Hyades cluster: mass-luminosity relation, Hertzsprung-Russell diagram, abundances. On the basis of the constraints that these data put on the stellar models inputs, we estimate the cluster helium content to be $Y = 0.255 \pm 0.015$ and obtain an upper limit for its age of $t \sim 650$ Myr. We examine the models input physics and the conversion of the models outputs (luminosity, effective temperature) toward their observational counterparts (colors, magnitudes). We evaluate the age and Y error budgets resulting from the metallicity error bar, the stellar rotation and overshooting. We suggest that the mixing-length parameter could decrease with mass, in the mass range $0.8 - 1.5 M_{\odot}$ and point out that the misfit at very low mass can be due to uncertain colors or model atmospheres.

1. Introduction

Some stellar properties of paramount astrophysical interest, such as the age or the initial helium content of stars, not directly accessible, have to be estimated by comparing observations with stellar models. The number of observational quantities that can be obtained for a given star is generally small while the number of model parameters used to describe the physics of the stellar plasma is large. The stars properties inferred from models are therefore uncertain and depend on many parameters.

The problem becomes simpler when stars belong to groups sharing similar properties, as stars in clusters or members of binary systems: they can be assumed to have similar age and initial chemical composition, and for binary systems, stellar masses can sometimes be measured accurately. In such cases, model calibrations involve a reduced number of parameters.

Here, we examine the case of the Hyades, the nearer open cluster, where many members had their distances measured by Hipparcos and where the masses of stars in five binary systems have been measured. We use these data to draw constraints on the input physics of the stellar models and to infer the age and helium content of the cluster.

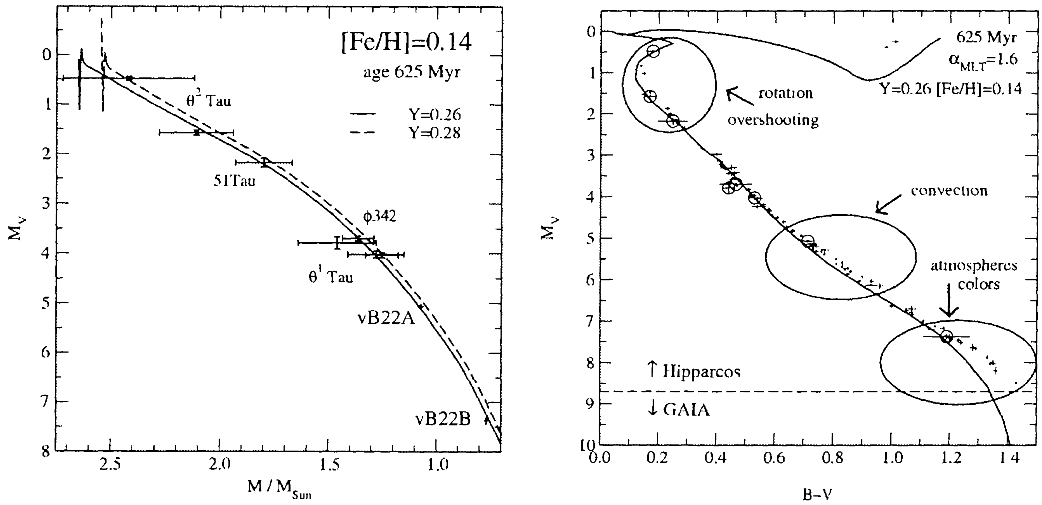

Figure 1. Left: empirical M-L relation and models; right: HR diagram

2. Stellar Models and Related Observational Constraints

After Hipparcos, the parameters of a hundred secure Hyades members are measured accurately : $\frac{\sigma_\pi}{\pi} \simeq 2.5\%$ (π is the parallax), $\sigma_{B,V} < 0.01$ mag leading to $\sigma_{B-V} \simeq 0.01$ mag and $\sigma_{M_V} \simeq 0.05$ mag (Dravins et al. 1997; Perryman et al. 1998; de Bruijne et al. 2000). Spectroscopic and photometric determinations of the metallicity are in remarkable agreement yielding [Fe/H] = 0.14 ± 0.05/0.144 ± 0.013 dex (Cayrel de Strobel et al. 1997, Grenon 2000). Also, precise masses of stars in five binary systems are available (Torres et al. 1997 and references therein). Figure 1 shows the corresponding mass-luminosity (M-L) relation and the HR diagram.

Models are calculated with the CESAM code (see Lebreton et al. 2001). The external boundary conditions are taken from ATLAS9 model atmospheres (Kurucz 1991). Calibration of the solar model radius yields the mixing-length ratio $\alpha_{\mathrm{MLT},\odot}$=1.79 (classical mixing length theory) or $\alpha_{\mathrm{CM},\odot}$=0.98 (convection treatment of Canuto & Mazzitelli, 1992). Models include microscopic diffusion and convective core overshooting ($\mathrm{d_{ov}} = 0.2\mathrm{H_p}$). The conversion of ($M_{\mathrm{bol}}$, T_{eff}) to (M_{V}, $B-V$) is obtained from the BaSeL stellar library (Lejeune et al. 1998).

3. Results from the vB22 System Mass-Luminosity Relation

We calibrated the helium abundance of the models to reproduce the M-L relation defined by the two components of vB22: we found $Y = 0.255 \pm 0.015$. The individual contributions to the Y-error budget ($\Delta Y = 0.015$) are the following: the errors on the mass, on M_{V} and on the bolometric correction each give $\Delta Y = 0.005$, a 0.05 dex error on [Fe/H] translates into $\Delta Y = 0.01$ and the error on the input physics is estimated to give $\Delta Y = 0.002$. Parameters can have a similar signature in the M-L plane, for instance decreasing [Fe/H] by 0.05 dex at given mass is equivalent to increasing Y by 0.01. Let us note that models of vB22 A & B calculated with a solar-scaled helium value $Y = 0.28$ (i.e. Y derived from

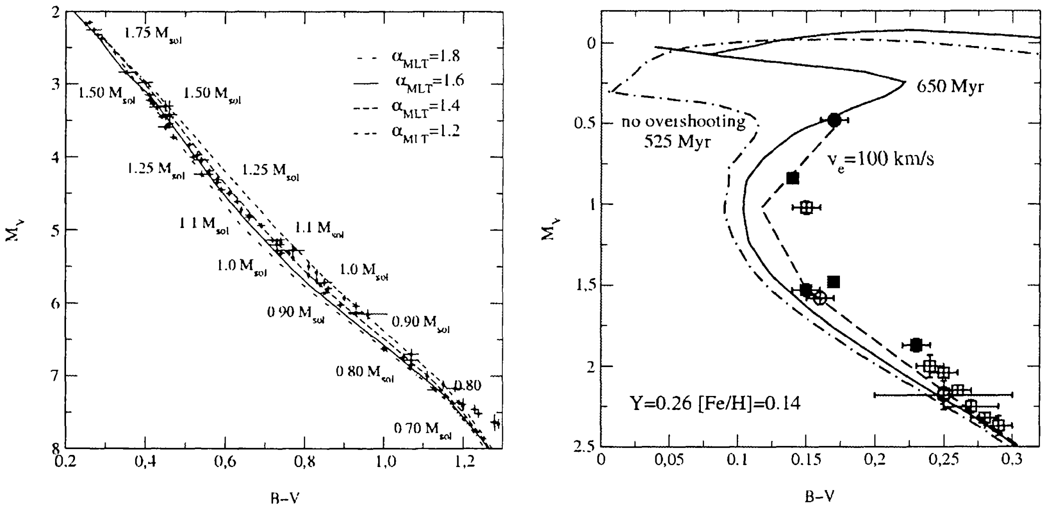

Figure 2. Left: effect of a $\alpha_{\rm MLT}$-change on the MS slope; right: turn-off : overshooting/rotation effects, open squares: stars with $v \sin i > 90$

$(Y - Y_p)/Z = (\Delta Y/\Delta Z)_{\odot} = 1.9$, $Y_p = 0.235$) are overluminous, sitting 3σ above the data. Also, our results give a mixing length higher in vB22 A than in vB22 B.

4. Results from the HR Diagram Analysis

As shown in Figure 1 (right), there is a misfit at high $(B-V)$, i.e. for $(B-V) \gtrsim 1.15$ where the model isochrone is much too blue. The reason for that misfit has not been elucidated yet but it could either result from problems with colors or with the model atmospheres (see P.H. Hauschildt, these proceedings).

The fit is good for $(B-V) \in [0.3, 1.15]$ although for $(B-V) \in [0.7, 0.9]$ some stars sit above the isochrone. In that region, models are sensitive to the convection treatment. As shown in Figure 2 (left), the fit of the observed main sequence (MS) slope in the mass range 0.8-1.5$M_{\odot}$ is better if $\alpha_{\rm MLT}$ values decreasing with mass are adopted. This result does not appear to depend on the convection treatment or on the model external boundary conditions.

The cluster age is derived by the model fit of the turn-off: models including overshooting yield an age of 650 Myr whereas models without overshooting have an age of 525 Myr. As shown in Figure 2 (right), in the turn-off region a few stars are found on the right of the 650 Myr-model isochrone. In the Hyades, the turn-off corresponds to A-stars, in the δ Scuti instability strip, which rotate quite fast (Fig. 2). Rotation affects the photometric data (Pérez-Hernández et al. 1999), it is expected to spread the rotating stars on the red side of the isochrone with no rotation (Fig. 2 shows the position of the isochrone corresponding to stars with equatorial velocities v = 100 km.s^{-1}). This effect can be responsible for an age overestimate of $\sim$50 Myr. Moreover, internal rotation may induce internal mixing. In the HR diagram, the mixing due to rotation and the mixing resulting from convective core overshooting have similar signatures (Goupil et al. 1999). Additional information, has to be obtained by the seismological analysis to discriminate these two mixing mechanisms.

5. Conclusion

We confirm that the degeneracy between the different unkonwn parameters of stellar models can be partially removed by the study of cluster stars, if the masses of several cluster members are accurately known (1%). In particular, we improved the Hyades helium determination and showed that interesting constraints on the convection treatment can be obtained if the MS slope is well-defined. We pointed out that models fail in reproducing the lower part of the MS (red dwarfs) probably due to inappropriate colors or model atmospheres. We discussed the effects of overshooting and rotation on the age of turnoff A-stars.

What is expected for the future? Seismological analysis is the only way to sound stellar interiors and better understand mixing processes: this will be possible for several representative stars with COROT and other missions (Baglin et al. 1998). High resolution spectroscopy (with UVES at VLT-UT2 for instance) will allow to improve the precision on [Fe/H] and give access to other elements. The GAIA mission (http://astro.estec.esa.nl/GAIA) will provide ultra precise parallaxes (a 10% accuracy is expected for 22 10^7 stars) and high quality masses (a 1% accuracy is expected for 17 10^3 binary stars). Ten binary systems are expected to be observed in each nearby open cluster. As a result, $\sim$ 100 open clusters (d<1 kpc) will be brought to the present Hyades accuracy level.

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