Simultaneous age-metallicity estimates of the Hyades open cluster from three binary systems

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**Abstract.** Three binary systems in the Hyades open cluster (51 Tau, V818 Tau, and θ² Tau), with known metallicity and good Johnson photometric data are used to test the validity of three independent sets of stellar evolutionary tracks. A statistical method is described and applied to the colour-magnitude diagram of the six selected components, giving rise to χ²-contours in the age-metallicity plane. The effects of the Hipparcos parallaxes on these confidence regions are studied in detail for these binaries through a comparison with very accurate but older orbital parallaxes. Independent simultaneous age-metallicity estimates are given and compared with observational constraints.

1. Introduction

Since the members of an open cluster are assumed to be of same age and chemical composition, these stars are currently used to test the validity of stellar evolution theories, mainly because main sequence stars define a tight sequence in a colour-magnitude diagram (CMD). Unfortunately, this tightness is sometimes misleading because of the contamination by field stars, the presence of unresolved binaries and also the influence of stellar rotation on the location of massive stars in CMDs. Alternatively, well-detached binaries are powerful tests when fundamental parameters are accurately known (see the comprehensive review by Andersen 1991 on double-lined eclipsing binaries). Unfortunately, the determination of their chemical composition often remains a difficult and unresolved issue. It appears therefore that a better test could be performed
by combining both advantages, that is, testing the tracks with well-detached
double-lined binaries which are members of open clusters. We have applied this
idea to three well-detached binaries members of the Hyades: 51 Tau, V818 Tau,
and $\theta^2$ Tau.

Observational data : Torres et al., 1997 ([TSL97a], [TSL97b] and [TSL97c])
obtained the first complete visual-spectroscopic solutions for the 3 above-mention-
ned systems, from which they carefully derived very accurate parallaxes and
individual masses. They also gathered some individual photometric data in the
Johnson system. Furthermore, we found useful trigonometric parallaxes informa-
tion in the Hipparcos catalogue (ESA, 1997). By combining the two sources
of data, we investigate the influence of the Hipparcos parallaxes on our method
which was developed to test stellar evolutionary models in HR diagrams.

Theoretical tracks : Among the most widely used stellar theoretical tracks
in the literature are those computed by the Geneva group (see Charbonnel et
al. 1993 and references therein) and the Padova group (see Fagotto et al. 1994
and references therein). We also used the stellar tracks from Claret & Giménez
(1992) (CG92 thereafter). The tests are done with these 3 series of stellar tracks.

Tests in the CMD : The tests we want to perform are the following :

1. to check whether the two components of the systems are on the same
isochrone, i.e. on a line defined by the same age and the same chemical
composition for the two single stars.

2. since all the selected stars are members of the Hyades whose metallicity
has been well measured (according to the review of Perryman et al. (1998):
[Fe/H] = \pm 0.05, i.e: Z =0.024^{+0.005}_{-0.003}), we can also check that the
predicted metallicities from theoretical models are correct.

3. for 51 Tau and $\theta^2$ Tau, the individual stellar masses are known with an
accuracy of about 10%, and for V818 Tau, masses and radii are known
with an accuracy close to 1-2%, allowing further tests with the theoretical
models.

Therefore, if one of these criteria is not clearly fullfilled by a given set of
tracks, then these models have obvious problems since they do not account for
several observational constraints (namely the metallicity, mass, radius, and/or
the photometric data).

Photometric calibrations : We do not claim that the 6 selected Hyades stars
allow us to test without ambiguity any set of theoretical stellar tracks. Since the
data are presented in CMD, we are in fact testing not only the validity of the
tracks but also of the photometric calibrations, and disentangling the relative
influence of both is a tricky task. We use the Basel Stellar Library (BaSeL)
photometric calibrations, extensively tested and regularly updated for a larger
set of parameters (see Lejeune et al. 1997, 1998 and Lastennet et al. 1999a). For
reasons developed in Lastennet et al. (1999b), we assume that the calibrations
from the BaSeL models are reliable enough for this work (for more details and
Figure 1. 51 Tau system: influence of the Hipparcos parallax on the contour levels derived from the Geneva tracks. The location of each star in the CMD is from Torres et al. [TSL97a] (in the bottom panel, $M_V$ is derived from the Hipparcos parallax). In isocontours plots, the best fits ($\chi^2_{\text{min}}$) are marked by open circles. The result of Perryman et al. (log $t = 8.80$, $Z = 0.024$) is shown for comparison (star). The 1, 2, and 3$\sigma$ contour levels (respectively solid, dashed and dot-dashed lines) are not significantly modified. Vertical lines in contour diagrams show the observational limits for the metallicity of the Hyades.

Brief description of the statistical method: In order to derive simultaneously the metallicity ($Z$) and the age ($t$) of the system, and to produce confidence level contours (see Figure 1), we minimize the $\chi^2$-functional defined as:

$$\chi^2(t, Z) = \sum_{i=A}^{B} \left[ \left( \frac{M_V(i)_{\text{mod}} - M_V(i)}{\sigma(M_V(i))} \right)^2 + \left( \frac{(B-V)(i)_{\text{mod}} - (B-V)(i)}{\sigma((B-V)(i))} \right)^2 \right]$$  \hspace{1cm} (1)

where $A$ is the primary and $B$ the secondary component. $M_V$ and $(B-V)$ are the observed values, and $M_V_{\text{mod}}$ and $(B-V)_{\text{mod}}$ are obtained from the synthetic computations of the BaSeL models using a given set of stellar tracks.
2. Results

Table below briefly summarizes the results (see Lastennet et al. 1999b for further details) of the theoretical simultaneous age–metallicity estimates obtained from isochrone age fitting (1σ level) taking into account the Hipparcos parallax.

| System       | Geneva    |       | Padova    |       | CG92     |       |
|--------------|-----------|-------|-----------|-------|----------|-------|
|              | Z log t   |       | Z log t   |       | Z log t  |       |
| 51 Tau       | $0.026^{+0.010}_{-0.008}$ | $8.88^{+0.22}_{-0.23}$ | $0.017^{+0.021}_{-0.005}$ | $8.90^{+0.15}_{-0.05}$ | $0.018^{+0.012}_{-0.006}$ | $8.92^{+0.23}_{-0.17}$ |
| V818 Tau     | $0.033^{+0.017}_{-0.015}$ | $7.30^{+2.50}_{-0.30}$ |
| $\theta^2$ Tau | $0.027^{+0.013}_{-0.010}$ | $8.80^{+0.05}_{-0.09}$ | $0.027^{+0.023}_{-0.011}$ | $8.80^{+0.03}_{-0.11}$ | $0.027^{+0.003}_{-0.005}$ | $8.88^{+0.02}_{-0.02}$ |

- For 51 Tau and $\theta^2$ Tau, the 3 sets of isochrones give good fits in the CMD, in agreement with previous estimates (Perryman et al.) of age (log t = $8.80^{+0.02}_{-0.04}$, from isochrone fitting technique with the CESAM stellar evolutionary code (Morel 1997)) and metallicity ([Fe/H] = 0.14 ± 0.05).

- The Geneva and CG92 models can not be tested with the less massive component of V818 Tau. The Padova tracks provide contours in agreement with the Hyades metallicity only when taking into account the Hipparcos parallax. Otherwise, solutions are too old and metal rich.

- Masses predicted by the 3 sets of tracks are in good agreement with the measured individual masses of each system.

- Padova isochrones can not fit the system V818 Tau in a mass-radius diagram.

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