Spectra disentangling and combined orbital solution for the Hyades binary θ^2 Tau

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Abstract

θ^2 Tau is a detached and "single-lined" binary as well as the most massive spectroscopic binary of the Hyades cluster. Its light curve shows a complex pattern of δ Scuti type pulsations. Because the fainter secondary is hidden in the composite, blended spectrum, the few yet published radial velocities are inaccurate. From recent high-resolution spectroscopic data obtained with the ELODIE spectrograph (OHP, France), we derived accurate radial velocities for both components applying a spectra disentangling algorithm. We combined these measurements with long-baseline optical interferometric data in order to improve the knowledge of the orbital parameters and their derived fundamental properties in a consistent way. Such constraints are also very pertinent to revisit the evolutionary status of both components.

1. Introduction

Binary and multiple stars with detached, well-characterized components are a direct source of fundamental stellar properties and as such very attractive objects to study various phenomena of high astrophysical value including their own formation and evolution.

Our interest in θ^2 Tau comes from the fact that this well-detached and single-lined binary (SB1) consists of two stars which both lie in the lower Cepheid instability strip. Component A is a small-amplitude, multiperiodic δ Scuti pulsating star (B02). The binary furthermore belongs to one of the nearest open clusters at a distance of 45 pc (Hyades). Because of this interesting combination of facts, it is an attractive target for an in-depth study of its component properties: both theories of stellar evolution and of pulsation could be verified and refined. It is furthermore a most suitable astrophysical tool to explore in an empirical way the possible interaction(s) between pulsation, rotation and binarity.

θ^2 Tau (HIP 20894) is a SB1 in an eccentric orbit which was resolved by long-baseline optical interferometry (AM06). The primary component, θ^2 Tau A, is of spectral type A7 III and rotates at a speed of about 70 km/s. The secondary component, θ^2 Tau B, is not easily detectable in the composite spectrum, mainly because of the broader lines and larger v sin i. TSL97 analyzed it as a double-lined spectroscopic binary (SB2) for the first time using a 2D-cross correlation method. These authors obtained more accurate radial velocities of the primary, but without direct detection of the secondary's spectrum. As a member of a well-studied cluster, the metallicity and distance of θ^2 Tau are known within narrow boundaries. Nonetheless, the evolutionary status of the components is still unclear (Lastennet et al. 1999; AM06).

2. The new observational campaign

Though an important set of high-resolution spectra already exists (TSL97), new spectra extending on a larger spectral domain (e.g. including the hydrogen lines) were needed for adequate extraction of the individual component contributions (F06). Therefore, additional high-resolution spectra were acquired with the ELODIE Echelle spectrograph at the 1.93-m telescope of the Observatoire de Haute-Provence (OHP, France) through service mode observations from March 2005 till March 2006 (JD 2453431.2665 – 2453806.3850). These spectra were obtained over the full wavelength range with a typical S/N of 100 and cover an entire orbital cycle.

3. Spectra disentangling

The newly acquired ELODIE spectra (**Sect. 2**) were combined with older observations from the ELODIE data base (JD 2449668.3645 – 2449670.6825) as well as with the spectra obtained by TSL97 at the Oak Ridge Observatory (JD 2447844.6740 – 2450154.5463).

We applied the spectra disentangling technique using the code KOREL developed by Hadrava (1995). This code determines the individual contributions of the components to the composite spectra together with the orbital parameters in a self-consistent way. Although the intermediate step of deriving radial velocities is not required, cross-correlation of the input spectra with the disentangled component spectra provides KOREL relative radial velocities useful in combination with other data. Since the method requires spectral ranges with equal and constant edge values, we selected suitable wavelength domains by compromising between the intrinsic sensitivity to radial velocity variations and the possibility to distinguish the stellar continuum. We then produced for each component of the binary a set of 117 KOREL radial velocities with a homogeneous coverage in amplitude and in orbital phase.

Next, we performed a consistency check on these component radial velocities using a different algorithm to derive the spectroscopic orbital elements (VCURVE based on the method of Lehmann-Filhés (Bertiau et al. 1969)). **Fig. 1** shows the disentangled component spectra with theoretical spectra for two different metallicities superposed in four wavelength regions.

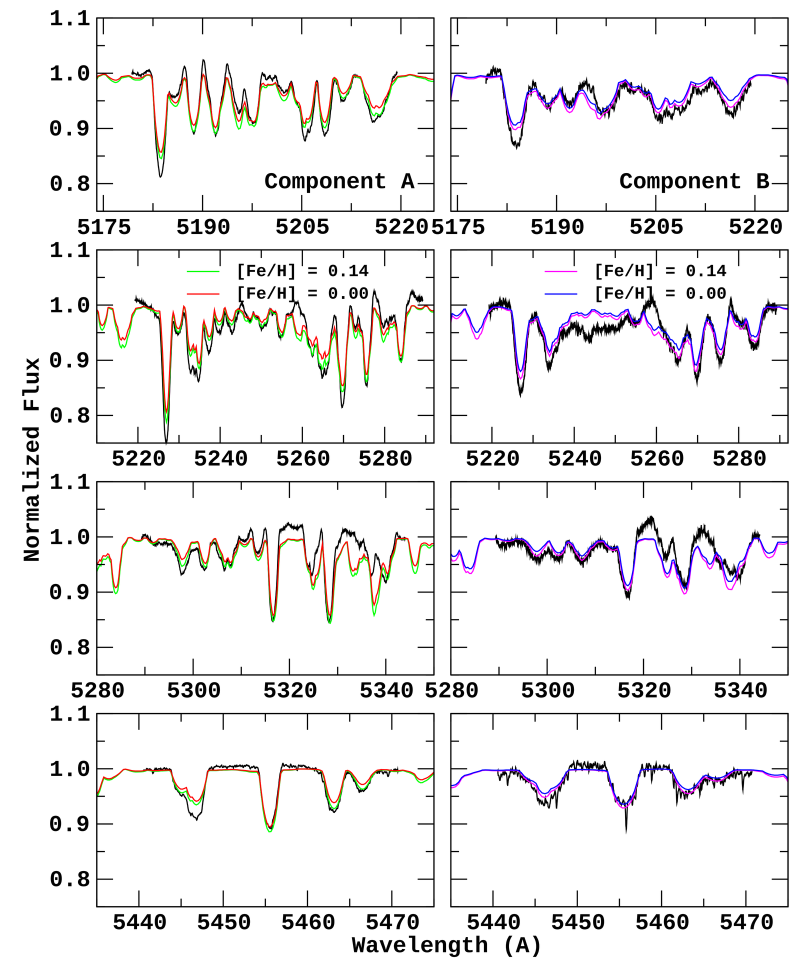

Fig. 1: Individual spectra of θ^2 Tau A and θ^2 Tau B (black) compared to synthetic spectra computed adopting the solar and Hyades metallicity (coloured) (P98; Grenon 2000). T_{eff} values are from AM06 while log g was estimated from interpolation in the evolutionary tracks (log g[θ^2 Tau A] = 3.45 and log g[θ^2 Tau B] = 3.95). Adopted v sin i values are 66 ± 5 km s^{-1}(comp. A) and 103 ± 8 km s^{-1}(comp. B) (F06).

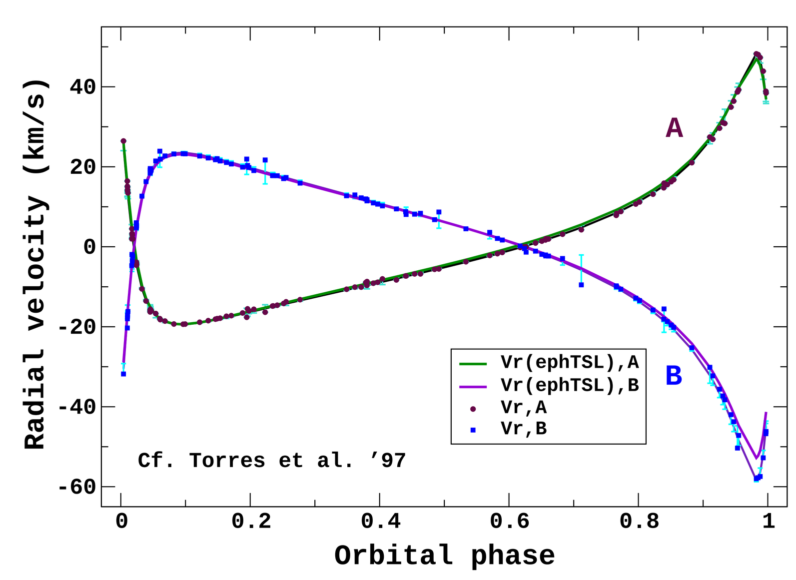

Fig. 2: Component radial velocities derived with KOREL (different symbols for A and B) and combined orbital solutions (this work– black & indigo – TSL97 – green & purple lines).

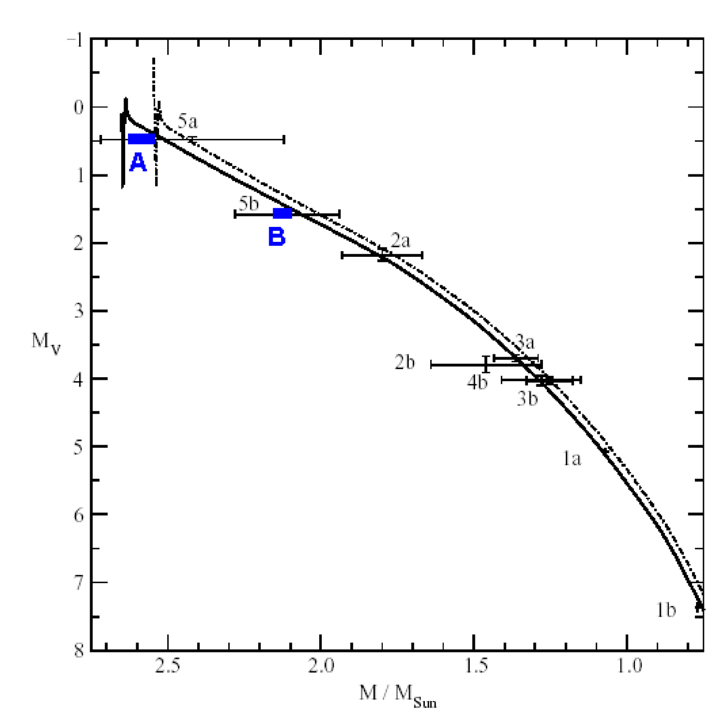

Fig. 3: Hyades M-L relation from L01 (Fig. 4) using the binaries vB22 (1), 51 Tau (2), ϕ342 (3), θ^1 Tau (4) and θ^2 Tau (5). Model isochrones aged 625 Myr – continuous line: three indistinguishable isochrones with ([Fe/H],Y) = (0.09,0.25), (0.14,0.26) and (0.19,0.27) – Dot-dash line: [Fe/H] = 0.14 dex and solar-scaled helium Y = 0.28. The new masses and luminosities for θ^2 Tau A and B with their respective errors are plotted in blue.

4. Combined orbital solution

The powerful combination of astrometry and spectroscopy leads to an independent determination of both distance and component masses. To this aim, we combined the previous data set with 34 best-fit angular separations (ρ) and position angles (θ) as derived from the interferometric measurements (AM06). An astrometric-spectroscopic orbit was computed using the VBSB2 code which performs a global exploration of the parameter space followed by a simultaneous least-squares minimization (Pourbaix 1998).

Table 1: Orbital elements with standard deviations including orbital parallax and dynamical masses.

Orbital element	This work	TSL97 results
P (days)	140.7285 ± 0.0004	140.7282 ± 0.0009
T	1990.7630 ± 0.0002	1993.0752 ± 0.0008
e	0.7353 ± 0.0004	0.727 ± 0.005
a (″)	0.0188 ± 0.0001	0.0186 ± 0.0002
i (°)	47.65 ± 0.12	46.2 ± 1.0
Ω (°)	354.59 ± 0.12	171.2 ± 1.8
ω (°)	234.61 ± 0.12	236.4 ± 1.1
V_0 (km/s)	+0.02* ± 0.04	+39.5 ± 0.2
$\kappa = \frac{M_B}{M_A+M_B}$	0.452 ± 0.002	0.46 ± 0.05
π_{dyn} (mas)	21.20 ± 0.13	21.22 ± 0.76
A (A.U.)	0.8879 ± 0.0005	0.88 ± 0.04
mass A ($M_\odot$)	2.58 ± 0.04	2.4 ± 0.3
mass B ($M_\odot$)	2.13 ± 0.02	2.1 ± 0.2
K1 (km/s)	33.86 ± 0.11	33.18 ± 0.49
K2 (km/s)	40.98 ± 0.21	38 ± 2
System mass ($M_\odot$)	4.71 ± 0.10 (2.1%)	4.54 ± 0.51 (11.2%)
Time span (yr)	16.5	6.3

*: the value reflects our use of KOREL's relative radial velocities.

Tab. 1 lists the resulting orbital elements and standard deviations of the best solution in the sense of minimum least-squares residuals exploring a small period interval around 0.38530 yr (the orbital period derived by TSL97). The associated residuals are small and without systematic deviations. The new orbital solution is graphically illustrated by **Fig. 2**. The combined orbital solution previously derived by TSL97 is plotted for comparison. The most obvious difference is the larger radial velocity amplitude of comp. B.

Using the orbital parallax of **Tab. 1**, we obtained the following component absolute magnitudes: Mv_A = 0.36 ± 0.04 mag and Mv_B = 1.48 ± 0.04 mag, with a better accuracy than before (thanks to the accurate parallax determination). We compare these new masses and luminosities with theoretical isochrones suitable for the Hyades in **Fig. 3** (cf. L01), and find a good match for Y = 0.26 adopting [Fe/H] = +0.14 (P98; Grenon 2000).

5. Conclusion and future work

We applied the spectra disentangling algorithm KOREL to a large series of older and recent high-resolution spectra and extracted the spectral contributions of θ^2 Tau A and B. Using the new radial velocities together with existing interferometric data, we derived the orbital parameters and the component masses with an accuracy better than ever attained before (i.e. within 2%). Our component masses are in good agreement with those of TSL97, but significantly larger than the recently published values (AM06). Using the disentangled component spectra, we will perform a detailed chemical analysis and determine accurate fundamental properties of both stars in order to determine their evolutionary status and whether or not convective overshooting is needed in the models. If more high-resolution spectra can be obtained, we also intend to study the pulsational behaviour of θ^2 Tau A and θ^2 Tau B.

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