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RS Cha, a binary system suitable for testing stellar physics modeling during the pre-main sequence phase.

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Abstract. We use accurate spectroscopic data of the pre-main sequence eclipsing binary system RS Cha to redetermine masses and radii of both components and to measure the metallicity of the system. Knowing all fundamental parameters of both stars we are able to test stellar physics modeling during the PMS phase. We find no evidence that our models are deficient. Accurate detection of modes and measurements of periods of the recently discovered pulsations in both components are required to constrain more severely the physical description of PMS stellar models..

Key words. Stars: binary – Stars : pre-main sequence – Stars: pulsations – Stars: evolution – Stars : delta-scuti

1. Introduction

Great efforts have been performed to model the interior and the evolution of the stars. A wealth of tests of standard physics exists for main-sequence (MS) stars. This is not the case for pre-main sequence (PMS) stars. The difficulty is to know accurately all fundamental parameters of a star : its mass, radius, luminosity, effective temperature and metallicity ([Fe/H]). All these quantities are precisely measured for both stars of an eclipsing double lined spectroscopic binary system as RS Cha. Moreover, both components of this system are PMS stars. This then makes RS Cha a particularly interesting object to be used to test stellar physics modeling during the PMS phase. Up to recently all parameters of RS Cha were known except the metallicity. However we found that the knowledge of the metallicity is crucial to test stellar evolution models for RS Cha system (see Seq.2). We therefore used spectroscopic data to measure [Fe/H] of the system and to redetermine masses and radii of both stars (Alecian et al. 2005, hereafter paperI) . We took the orbital inclination measured by Clausen & Nordstrom (1980) and the photometric determination of the effective temperatures and luminosities of Ribas et al. (2000) (see Table 1).

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Table 1. Fundamental parameters of RS Cha. R00 : Ribas et al. (2000), CN80 : Clausen & Nordstroṁ (1980)

	Primary	Secondary	Ref.
$M/M_\odot$	1.89 ± 0.01	1.87 ± 0.01	paperI
$R/R_\odot$	2.15 ± 0.06	2.36 ± 0.06	paperI
$T_{\rm eff}$(K)	7638 ± 76	7228 ± 72	R00
$\log(L/L_\odot)$	1.15 ± 0.09	1.13 ± 0.09	paperI
[Fe/H]	0.17 ± 0.01		paperI
P (day)	1.67		paperI
i (°)	83.4 ± 0.3		CN80

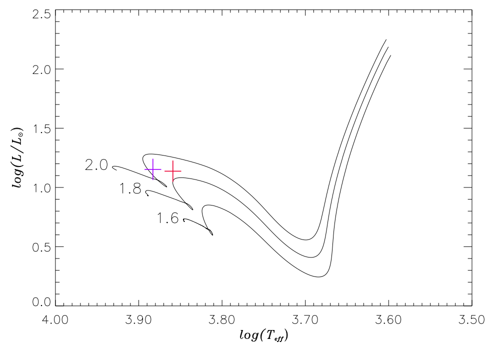

Fig. 1. Evolutionary tracks calculated with CESAM plotted in a HR diagram. Masses are displayed in solar unit (see text).

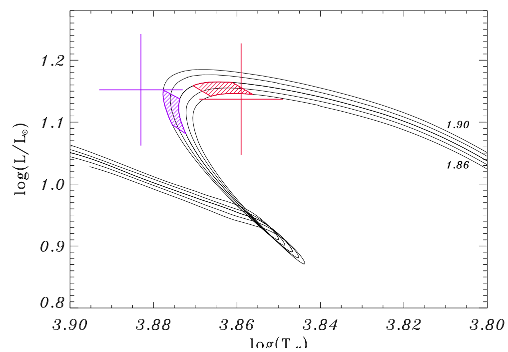

Fig. 2. Evolutionary tracks calculated with CESAM restricted to the RS Cha area of the HR diagram (see text).

2. Stellar models for RS Cha

Models were computed using CESAM stellar evolution code (Morel 1997). The physics implemented in CESAM do not include rotation and magnetic field. We used OPAL equation of state (Rogers et al. 1996) and the opacities of Iglesias & Rogers (1996). The temperature gradient in convection zones is computed using the standard mixing-length theory. The mixing length is defined as $l = \alpha H_{\rm P}$, α being the mixing length parameter and $H_{\rm P}$ the local pressure scale height. The species contained in the nuclear network are : ^{1}H, ^{3}He, ^{4}He, ^{12}C, ^{13}C, ^{14}N, ^{15}N, ^{16}O and ^{17}O. As a first step we considered ^{2}H, ^{7}Li and ^{7}Be in equilibrium and the most important reactions of PP+CNO cycles are solely taken into account. The nuclear reaction rates are taken from the NACRE compilation (Angulo et al. 1999).

Fig. 1 shows evolutionary tracks of PMS phase, plotted in a HR diagram, for different values of masses. Each evolution is initialised with a homogeneous, fully convective model in quasi-static contraction. We stopped the evolution when the star reached the zero-age main-sequence (ZAMS), defined as the first model where nuclear reactions produce more than 99% of the total energy generated by the star.

The crosses represent observational error bars in temperature and luminosity of the primary star (on the left) and of the secondary star (on the right). Both stars are very similar and therefore they cover a small part of the PMS phase which is near the MS (see Seq.2.2).

2.1. Comparison with observations

We compare our models with observations by plotting error boxes determined as follows: for a given ($M_{\rm obs}$,$R_{\rm obs}$) taking into account their uncertainties we derive a (L,$T_{\rm eff}$) from our models. Fig. 2 depicts these boxes. Crosses refer to the observations. We can see that crosses can coincide with boxes but only marginally (see Fig.2 the hatched areas).

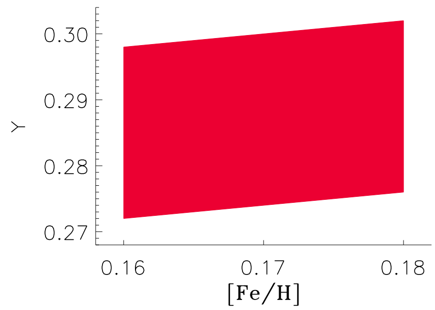

Fig. 3. Set of solutions ([Fe/H],Y) for which stellar models are compatible with observations

2.2. Sensitivity to input physics

We have studied the effect of varying parameters entering the physical description of our stellar models. The purpose is to obtain a better agreement between boxes and crosses in a HR diagram (Fig.2).This would point out an improvement in our modelling of this system. At this stage of the PMS, where are located the components of RS Cha, the star is totally radiative, so the mixing length parameter α and overshooting have no effect on the evolutionary tracks. COmbustion of deuterium and lithium occurs at the very beginning of the PMS phase and is found not to affect the evolutionary tracks in the interested area.

The main phenomenon which takes place at this end phase is the beginning of the CNO cycle with the carbon and nitrogen burning. So the only parameter which affects the tracks is the initial chemical composition of the star.We have then varied the helium mass fraction Y and the metallicity [Fe/H], in order to match better the models to observations.

We have fixed the value of [Fe/H] to the observed maximum (see Tab.1) and we have varied the Y value until one of the crosses does no longer match the associated box. We restarted fixing [Fe/H] to the observed minimum and we find that the stellar models reproduce observations for a set of values ([Fe/H],Y) plotted in Fig.3.

The range of acceptable for Y values is found reasonable. Hence we have no indication of defaults in the stellar physics in this phase. However it would be interesting to constrain more severely our stellar models using the oscillations of both components.

3. Delta Scuti type pulsations in RS Cha

3.1. Observations

Many authors discussed the possibility of the presence of oscillations in one of the components of RS Cha but no direct observations of these oscillations were reported. Andersen (1975) mentionned hints of variability in the residuals from the primary radial velocity curve of the observations, but more accurate data were required to assure that the primary component of RS Cha pulsates. Marconi & Palla (1998) calculated the theoretical location of the instability strip of PMS stars in the HR diagram for radial modes. Palla & Stahler (2001) located RS Cha in the HR diagram and showed that the secondary component is inside the instability strip and should be a PMS δ Scuti star.

Finally, using our data, we have recently shown, that **both** components of RS Cha are pulsating (paperI). We have pointed out temporal variations in the residuals from radial velocity curves of both stars. These variations appear periodic with a period around one hour. We therefore ascribed them to δ Scuti type oscillations.

Unfortunately our data are not accurate enough and do not cover sufficient time to determine precisely the modes and the periods. However we can wonder whether the period around one hour found with our data belongs to the period range of the excited modes that can be expected theoretically.

3.2. Theoretical modes

Theoretical periods of pulsation modes of both components of RS Cha were calculated using Dupret's code MAD. These frequencies were obtained using non-adiabatic calculations in order to distinguish stable from unstable modes. Fig. 4 details these modes for models

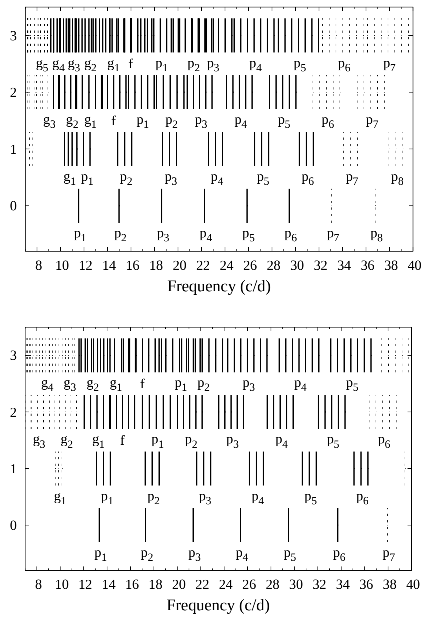

Fig. 4. Theoretical frequencies of pulsation modes obtained with non-adiabatic calculations, for the primary (up) and the secondary (down) stars. Each bar represents one mode located as a function of its frequency (in cycle per day) and its degree l (vertical direction).

of RS Cha stars. The dashed bars display the stable modes and the solid bars the unstable modes.

We have shown that the system is synchronized and the orbital period of the system has been determined accurately (paperI), we therefore know the rotational period of both stars. This enables us to compute accurately the rotational splitting of each mode.

We find theoretically the periods of excited modes around one hour for both stars (those of the secondary are a little larger than in the primary). On one hand this supports that the observed period corresponds to a low order pressure mode of delta-Scuti type and on the other hand this shows our models are not too far from reality.

4. Conclusion

The system RS Cha is now very well known observationally. Thanks to the large quantity of spectra obtained at the SAAO, masses and radii of the stars were redetermined very accurately, and in the same time the metallicity was measured. We were also able to give rise to PMS δ Scuti type pulsations in both components of RS Cha.

The study of this object, theoretically, did not indicate any default in the standard physics modelling of the PMS stars near the MS. However it should be possible to constrain more this physics using pulsations. Indeed, calculations of theoretical modes showed a very simple frequency spectrum for l=0 and l=1 modes (see Fig. 4). To proceed further, the next step is to obtain observations of the modes and frequencies of both stars, separately.

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