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RS CHA, A SPECTROSCOPIC BINARY SYSTEM AS A TEST OF STELLAR PHYSICS MODELING DURING THE PRE-MAIN SEQUENCE PHASE

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Abstract. New spectra of the PMS eclipsing binary RS Cha obtained with the GIRAFFE spectrograph at the SAAO, allowed us to measure the metallicity and new masses of both components of RS Cha. The system is therefore observationally well constrained, and modelling both stars (both with masses around 1.8 Msol) at the same (young) age is a severe challenge for stellar evolutionary codes. We find no evidence that our models are deficient. However 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.

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) (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

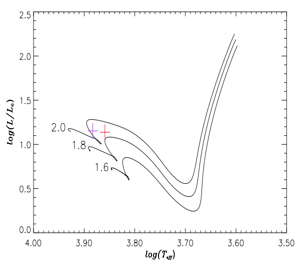

Fig. 1. Evolutionary tracks calculated with CESAM plotted in a HR diagram. Masses are displayed in solar unit (see text).

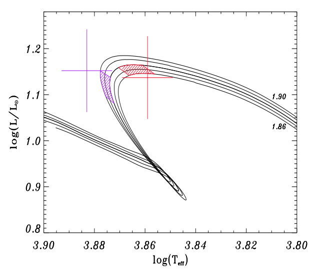

Fig. 2. Evolutionary tracks calculated with CESAM restricted to the RS Cha area of the HR diagram (see text).

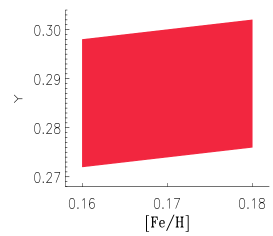

Fig. 3. Set of solutions ([Fe/H],Y) for which stellar models are compatible with observations

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. 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).

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).

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).

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, which is the end of the PMS evolution, the star is totally radiative. So the mixing length parameter α and overshooting have no effect on the evolutionary tracks.

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 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

Many authors discussed the possibility of the presence of oscillations in one of the components of RS Cha (Andersen 1975, Palla & Stahler 2001) but no direct observations of these oscillations were reported.

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 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.

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 of RS Cha stars. The dashed bars represent the stable modes and the solid bars the unstable modes. We computed accurately the rotational splitting of each mode using the well determination of rotational period of both stars (paperI).

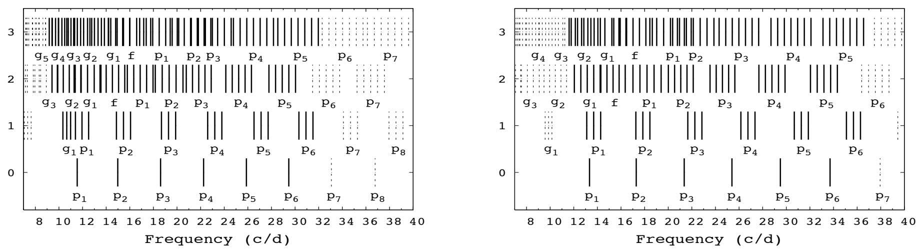

Fig. 4. Theoretical frequencies of pulsation modes obtained with non-adiabatic calculations, for the primary (up) and the secondary (down) stars. Each bar represents one mode located as a function of its frequency (in cycle per day) and its degree l (vertical direction).

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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