Eclipsing Binary V2154 Cyg: Observations versus Models

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ABSTRACT : V2154 Cyg is one of the nearest eclipsing binary systems located at 88 pc and discovered by the HIPPARCOS mission. Based on photometric and spectroscopic observations carried out respectively at the Nevada Observatory, Spain (uvby photometry) and by CORAVEL-ELODIE , at the Haute-Provence Observatory, we determine the masses and radius for both components of the eclipsing binary system. On the other hand we analyze the HR Diagram position of V2154 Cyg 1 and 2 by means of the theoretical models. This system is very interesting thanks to the fact that, being composed by coeval stars, the masses of the binary components (1.267$M_\odot$ + 0.756$M_\odot$) allow the comparison between two stars with clear different internal structures and evolutionary regimes, mainly on convection processes. We present preliminary results on the determination of the age and the helium of the system.

I. Spectroscopic and photometric observations of V2154 Cyg, eclipsing binary in a multiple system.

For the V2154 Cyg triple system, we have, on one hand, the uvby photometric data from Rodriguez et al. (2001) and, on the other hand, the ELODIE spectroscopic observations realized at the Haute-Provence observatory (see in this session the poster : eclipsing binaries in multiple systems : E. Oblak et al). This two sets of observations allows to resolve in totality the system to obtain the masses and the radii of the components of the eclipsing binary, at the one percent level.

Rodriguez et al (2001) carried out also uvby photometry of this system.

The Table 1 shows the physical characteristics of the V2154 Cyg system and the Table 2 the orbital spectroscopic solutions using the SBOP programme (see also the Figure 1).

With an inclination of the orbit of 88.5^o, we found for the masses and radii, respectively, the primary and the secondary: M1 = 1.267 $M_\odot$, M2 = 0.756 $M_\odot$, R1 = 1.53 $R_\odot$ and R2 = 0.76 $R_\odot$, assuming $R_\odot$ = 695990 kms.

Table 1 : Physical characteristics of the V2154 Cyg system

Name	HIP	V	B-V	SpT	Var	P	Rem	N_{RV} C E	Comp 1 2 3	Phot
V2154 Cyg	105584	7.78	0.441	F0	EA	2.630641(6)	A	8 13	1 1 1	C,T(o)

Table 2 : Orbital elements of V2154 Cyg system.

Name	Comp	P	T_0(JD)	e	ω	V_0	K	q/f(m)	asini	$M\sin^3 i$	σ
V2154 Cyg	1	2.630641 ±.000006	1929.227 ±.001	0.0	-	19.98 ±.08	72.78 ±.12	0.597 ±.001	2.633 ±.004	1.258 ±.003	0.36
	2						121.86 ±.17		4.408 ±.006	0.752 ±.002	0.55

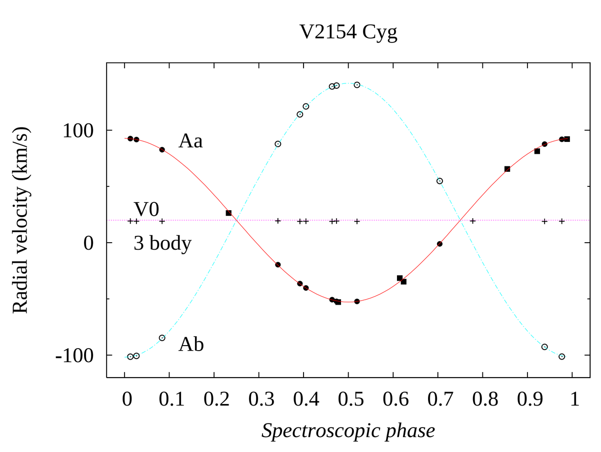

Figure 1. Radial velocity curves for V2154 Cyg triple star in the rest coordinate system.

II. Modeling binary stars: the context

The knowledge of the HRD position of a star is dependent on many different parameters. To first order, it is fixed by the stellar mass (M), the initial individual abundances of helium (Y) and metals (Z) and the age ($t_\star$). The resolution of the stellar internal structure equations using the above parameters will give the values, in particularly, for the surface temperature and luminosity. However, the physical inputs chosen to describe the stellar interior also constrain the evolution of the star in the HRD. In particular, some mechanisms insufficiently known, such as the convection, are dependent on free parameters. For instance, in the framework of the Mixing Length Theory currently used to model stellar convection, two more (unknowns) variables has to be considered: the mixing-length parameter (α) and the overshooting (ov). So, to model a star correctly, we must determine the six parameters against current (only) two observations: luminosity L and the effective temperature T_{eff} (or radius R).

This is an indeterminate problem and it can be solved for the Sun, for which the mass, metallicity and age are observationally known (Christensen-Dalsgaard 1982) and for some binary systems where individual masses are available (eg Noels et al. 1991; Fernandes et al. 1998). In the later situation, its current to consider both binary components as coeval stars. So a initial problem of 12 unknowns ($M, Y, Z, t_\star, \alpha, ov$ for each star) is reduced to a problem of 7 parameters ($Y, Z, t_\star$ for both stars and α, ov for each star).

The eclipsing binaries are particularly interesting for these kinds of studies thanks to the very good accuracy on mass and radius (eg Andersen 1998). In the next section we discuss how the available observations for V2154 Cyg 1 and 2 can be used to model this binary.

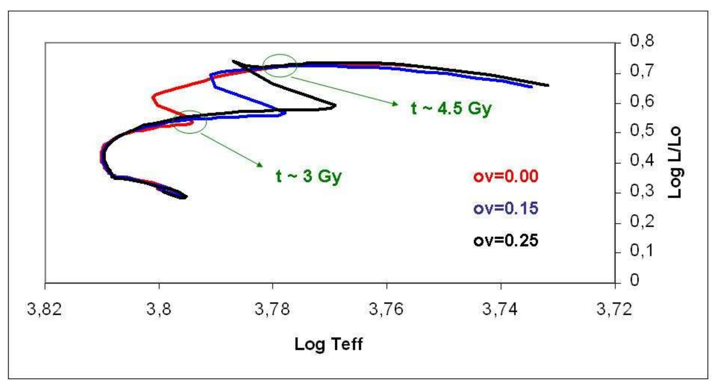

Figure 2. Evolutionary tracks for V2154 1 using different values of overshooting:ov=0.00 - red line; ov=0.15 - blue line; ov=0.25 - black line.

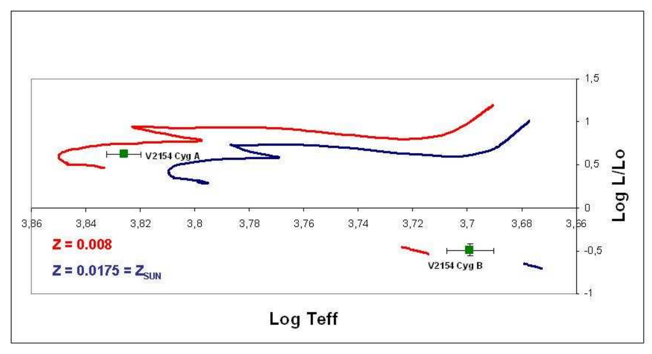

Figure 3. Modelling V2154 1+2: the effect of metal abundance: Z=0.008 - red line, Z=0.0175=Z_{SUN} - black line.

III. Overshooting, solar models and metallicity

In this section we compare the observations of V2154 1 and 2 with theoretical stellar models on the Hertzsprung Russel Diagram. For this analysis, the stellar evolutionary calculations were done with the CESAM code (Morel 1997). Details on the physics of these models can be found in Lebreton et al. (1999). With that input physics the solar model fits the observed luminosity and radius with α=1.63, helium abundance Y=0.268 and Z=0.0175 for the solar age and for the ratio of the solar mixture from Grevesse and Noels (1993). In order to compare models with observations we take the effective temperature for V2154 Cyg 1 and 2 from Rodriguez et al. (2001), respectively 6700 K and 5000 K, assuming an error of 100 K for both cases. The correspondent luminosity is computed using the radius derived above (section I).

The overshooting has a main effect on the structure and evolution of stars with mass higher than the Sun (eg Ribas et al. 2000). In the Figure 2 we present three evolutionary tracks for V2154 1, from the ZAMS to the sub-giant phase, considering different values of overshooting. The presented differences in the tracks are classical for these kinds of stars and its well known and it has been extensively studied (eg Chiosi 1999). We just point out that the different tracks are superposed for ages below 3 Gy and higher than 4.5 Gy.

In Figure 3, we show the blue evolutionary tracks computed for both components with the solar values for Y, Z, α and $ov = 0.25$ (for the main component). It seems clear that the models, assuming the solar values, do not fit the observations. One of the fundamental reasons for that is the, probably, non-solar metallicity for these stars. Unfortunately we could not find, in literature, a detailed spectroscopic analysis on the metallicity for this binary. Some preliminary determinations, using the photometry of both components, indicate that the binary is moderately poor in metals (see also Nordstrom et al. 2004). In Figure 3 the red lines corresponds to the evolutionary tracks similar to the previous blue lines but using Z=0.008, instead the solar value. This result seems to support the sub-solar metallicity for the binary.

Finally, in order to obtain a complete modeling for the system we must estimate the 6 unknown parameters ($Y, Z, t_\star$ for both stars, α for each star and ov for the main component) that predict the L and T_{eff} for both stars (inside the error bars). As we said this is a non-single solution problem thanks to the large number of unknowns compared to the four available observations, L and T_{eff} for each star. In order to obtain a preliminary determination we fix $ov = 0.25$ and $Z = 0.01$ reducing, than, the amount of unknowns to an equal number of observations. The results are: $Y = 0.25, t_\star = 2.2\,Gyr, \alpha_A = 1.3, \alpha_B = 1.6$. We calculate another solution changing the metallicity to Z=0.012 and we obtain: $Y = 0.275, t_\star = 2.5\,Gyr, \alpha_A = 1.6, \alpha_B = 1.8$.

IV. Conclusions

The preliminary conclusions of this work are:

- Using photometric and spectroscopic observations we derive the mass and radius for V2154 Cyg 1 and 2, within accuracy better than 1%;
- Theoretical stellar evolutionary models assuming the solar chemical composition (helium and metals) are not appropriated to reproduce the observations of both components;
- The system seems to be younger than 3 Gy, if a subsolar metallicity is assumed. Thanks to that, the effect of the overshooting on the models of V2154 1 is minimized;
- Models for both stars shows different values of the mixing length parameter;
- The derived helium value is strongly dependent on the metals abundance choice.

Further research is needed in order to obtain a realistic determination for metallicity and to perform a detailed modeling of this binary. In particularly, we expect to improve the analysis on the possible dependence of the mixing length parameter with the stellar mass (eg Lastennet et al. 2003).

References

Andersen, J. 1998, in IAU Symp. 189, Fundamental Stellar Properties: the Interaction between Observation and Theory, ed. T.R. Bedding, p. 99

Chiosi, C. 1999, in ASP Conf. Ser. 173, Theory and Tests of Convection in Stellar Structure, ed. A. Gimenez, E. P. Guinan, & B. Montesinos (San Francisco: ASP), 9 Christensen-Dalsgaard, J., 1982, MNRAS 199, 735

Fernandes, J., Lebreton, Y., Baglin, A., & Morel, P., 1998, A&A 338, 455 Grevesse, N. & Noels, A., 1993, In: Prantzos N., Vangioni-Flam E., Cassé M. (eds.) Origin and Evolution of the Elements. Cambridge University Press

Lastennet, E., Fernandes, J., Valls-Gabaud, D., Oblak, E., 2003, A&A 409, 611

Lebreton, Y., Perrin, M.-N., Cayrel, R., Baglin, A., Fernandes, J., 1999, A&A 350, 587

Morel, P., 1997, A&A Suppl. Ser. 124, 597

Noels, A., Grevesse, N., Magain, P., Neuforge, C., Lebreton, Y., Baglin, A., 1991, A&A 247, 91

Nordstrom, B., Mayor, M., Andersen, J., Holmberg, J., Pont, F., Jorgensen, B. R., Olsen, E. H., Udry, S., Mowlavi, N., 2004, A&A 418, 989

Ribas, I., Jordi, C., Gimenéz, A., 2000, MNRAS 318, 55

Rodriguez, E., Garcia, J.M., Martin, S., Claret, A., 2001, A&A 372, 588