On the abundance of Lithium in T Corona Borealis

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ABSTRACT

We have obtained high resolution echelle spectroscopy of the recurrent nova T CrB. We find that the surface lithium abundance in T CrB is significantly enhanced compared to field M giants, where it is not detectable. We offer possible explanations for this in terms of either a delay in the onset of convection in the giant star, enhanced coronal activity due to star-spots or the enhancement of Li resulting from the nova explosion(s).

Key words: stars: – novae, cataclysmic variables – white dwarfs, stars: individual: T CrB

1 INTRODUCTION

T Coronae Borealis (= T CrB) is a recurrent nova which underwent major eruptions in 1866 and 1946. Its quiescent optical spectrum shows M-type absorption features with Balmer and He emission lines, and the Balmer jump (Kenyon 1986, and references therein). An optical spectrum of such a type qualified T CrB to be classed as a symbiotic system.

The optical and infrared light curve show a double humped modulation which is due to the observer seeing differing aspects of the tidally locked, gravitationally distorted M-giant companion star. Shahbaz et al (1997) have modelled these light variations and have concluded that the binary system must contain an accreting white dwarf very close to the Chandrasekhar limiting white dwarf mass of $1.4M_\odot$; this is in agreement with the high mass required to explain the outbursts in the recurrent nova in terms of a thermonuclear runaway process (Webbink 1976; Livio & Truran 1992).

Models of the nova explosion predict that the thermonuclear runaway can produce large amounts of lithium (see Starrfield et al. 1978). In this letter we present high resolution echelle spectroscopy of T CrB. We determine the surface abundance of Li and give possible explanations to its abundance.

2 OBSERVATIONS AND DATA REDUCTION

We obtained high resolution echelle spectra of T CrB on the nights of the 15th and 16th June 1995 using MUSICOS (\textsc{MUlti-Site COntinuous Spectroscopy}; Baudrand \& Bohm 1992) mounted on the 2-m Bernard Lyot telescope at the Pic du Midi Observatory, France. We also observed several template M\textsc{iii} stars (see Table 1 for a log of the observations). Finally, Th-Ar lamps and dome-flats were observed to wavelength calibrate and flat-field the data respectively.

The spectra were extracted, wavelength and flux calibrated using the procedures described by Baudrand \& Bohm (1992). The accuracy of the wavelength calibration was 0.024Å. Our observations which cover the spectral range 5400–8800 Å are composed of 43 orders, each covering about 100 Å with a velocity dispersion of 4 km s$^{-1}$/pixel. The velocity resolution of the spectra was 10 km s$^{-1}$ (FWHM at H$\alpha$). In this paper we only use the order covering the spectral range 6680–6780 Å. We cross correlated all the T CrB spectra in order to determine the velocity shift relative to a standard star. The spectra were then Doppler shifted and summed (see Figure 1).

3 MODELS AND ABUNDANCE ANALYSIS

For this analysis we use model atmospheres with a setup similar to the “NextGen” model grid of Hauschildt et al (1998).
Our models are spherically symmetric LTE models calculated with the general stellar atmosphere code PHOENIX. We use a direct opacity sampling method to include line blanketing of both atoms and molecules. The equation of state includes more than 500 species (atoms, ions and molecules). For the relatively high effective temperatures considered here, the effects of dust condensation and opacities are negligible. The radiative transfer equation is solved using an operator splitting method. Details of the calculational methods are given in the above reference.

We used solar abundance models in the effective temperature range \(3000 \leq T_{\text{eff}} \leq 3600\) with \(2.5 \leq \log(g) \leq 3.5\) as starting point. For the best fitting model, \(\log(g) = 2.5\) and \(T_{\text{eff}} = 3200\) K, we calculated a set of synthetic spectra with lithium abundances \(0.0 \leq \log_{10} \epsilon(\text{Li}) \leq 3.31\). Here, \(\epsilon(\text{Li})\) is the number of lithium nuclei for each \(10^{12}\) hydrogen nuclei. \(\log_{10} \epsilon(\text{Li}) = 1.16\) is the abundance of lithium in the solar atmosphere and \(\log_{10} \epsilon(\text{Li}) = 3.31\) is the meteoritic lithium abundance. The spectra were calculated with the same code and general setup (including spherical symmetry) that was used to calculate the models in the model atmosphere, however, the spectral resolution was set to about 130,000. The sets of synthetic spectra were then compared to the observations to find the model with the best fitting lithium line to estimate the abundance of lithium. For the comparison, the synthetic spectra were convolved with a rotational profile of 15 km/s to account for the rotational broadening of the star (Kenyon & Garcia 1986) and the observed spectrum was converted to vacuum wavelengths. In addition, a global blue-shift of 31 km/s was applied to the synthetic spectra to match observed and computed features. We have also calculated the spectra for effective temperature and gravities close to the best fitting model to establish the error in the estimated lithium abundance. For the purpose of the analysis presented here, we used a fixed micro-turbulent velocity \(\xi = 2\) km/s. In all cases, the quality of the fits was established manually by inspection of the plots comparing the synthetic spectra to the data.

The Li 6708 Å resonance line is well known to be very sensitive to \(T_{\text{eff}}\). Thus we tried different temperatures between \(3000\) K, and \(3600\) K in our abundance analysis. We also tried three different values for the gravity: \(\log g = 2.5\), \(\log g = 3.0\) and \(\log g = 3.5\). The best fitting model for T CrB \([T_{\text{eff}} = 3200\) K, \(\log(g) = 2.5]\) showed the Li abundance to be between 0.5 and 0.7. We estimate uncertainties of \(\sim 200\) K and \(\sim 0.5\) in \(T_{\text{eff}}\) and \(\log(g)\) respectively. As shown in Figure 1 we obtained a good representation of the spectrum without changing the abundances of the other elements (Al, Ca, Fe, Si) present in the synthesised spectral region. Note that the FeI 6707.4 Å line is included in the synthetic spectrum.

A similar analysis for the standard star HD 151203 shows that its Li abundance is at least 0.4 dex below that of T CrB. As one can see from Figure 1 the Li line is not well matched, suggesting that there may be a line missing from the synthetic spectrum, accounting for the missing absorption. However, this could well be that the CN line data, which is included in the model, not being very accurate.

4 DISCUSSION

Normal stars reach sufficiently high temperatures to destroy lithium in their interiors. As a result, if there is significant convection of material to the surface from regions hot enough to destroy lithium, its abundance will decline with age. This effect is seen for cool stars, whilst the surfaces of hotter stars, within which convection does not occur, retain what is thought to be their initial lithium abundance. Although F-stars break this monotonic relationship, it is possible to say that main-sequence stars of \(> 1.5M_\odot\) do not show significant depletion (Balachandran 1988). Once the stars leave the main sequence, the surface abundance of the hotter stars depends crucially on the onset of convection. This yields a possible explanation of the lithium we have detected. The secondary star in T CrB was probably initially greater than \(1.5M_\odot\), and although the star has become a giant, convection or dredge-up may not yet have begun. Just such an explanation is used for the few normal giants which have almost solar abundance lithium, although most giants are, as one would expect, lithium poor (Brown et al 1989).

Another explanation of the lithium abundance may be provided by comparison with other late-type giants. Pallavicini, Randich and Giampapa (1992) show that coronally active K-giants have relatively strong lithium lines. Although sunspots also show strong lithium, starspots alone cannot be the cause of the enhanced lithium line (Pallavicini et al 1993), and it is thought to reflect a true abundance anomaly. The reason for this is unclear, but ideas related to a lack of differential rotation as a function of radius, would fit in with the observation that tidal locking can also inhibit lithium depletion. However, it should be noted that there is observational evidence for this is very limited. Both mechanisms should be present in T CrB, helping to explain the high lithium abundance, although it should be noted that the latest spectral type studied by Pallavicini et al (1992) was K, not M.

A final mechanism which may enhance the surface abundance is material placed there by the nova explosion. Unfortunately the production of lithium in novae is controversial, with estimates for the abundance in the ejecta varying from solar (Boffin et al 1993) to several hundred times solar (Starrfield et al 1978). The observations may be of some help here, since the old nova GK Per shows no lithium enhancement (Martin et al 1995). This would argue that novae do not significantly affect the lithium abundance of their secondary stars, although one should be cautious of extrapolating from one peculiar cataclysmic variable (GK Per), to another (T CrB).

To summarise the above three paragraphs, there are three possible mechanisms for the lithium we observe. It may be that the giant has not yet become convective, it may be related to tidal locking and stellar activity, or it may be due to the nova explosion. Note that we cannot rule out any of these ideas.

5 CONCLUSION

We have obtained high-resolution echelle spectra of T CrB in the Li 6708 Å spectral region. Spectral synthesis fits gives the Li abundance to be \(\log N(\text{Li}) \sim 0.6\), a factor of 4 below
Figure 1. NLTE synthesis fit to the Li 6708 Å region. The upper panel shows a fit to the T CrB (summed) spectrum using $T_{\text{eff}}=3200$ K, $\log g=2.5$. Models for $\log N(\text{Li})=0.4$, 0.6 and 0.8 are shown. The lower panel shows a fit to HD 151203 (M3III) using $T_{\text{eff}}=3600$ K, $\log g=2.5$. Models for $\log N(\text{Li})=0.0$ and 0.2 are shown.

solar. The Li abundance in field stars of the same spectral type as the secondary star in T CrB is not detectable. We offer three possible explanations for the enhancement of Li in T CrB. It is either due to the a delay in the onset of convection in the M-giant, stellar activity on the surface of the companion star or it may be due to the nova explosion.

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