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Fluorine in R Coronae Borealis and Extreme Helium Stars

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Abstract. Neutral fluorine (F I) lines are identified in the optical spectra of several R Coronae Borealis stars (RCBs) at maximum light. These lines provide the first measurement of the fluorine abundance in these stars. Fluorine is enriched in some RCBs by factors of 800 to 8000 relative to its likely initial abundance. The overabundances of fluorine are evidence for the synthesis of fluorine. These results are discussed in the light of the scenario that RCBs are formed by accretion of an He white dwarf by a C-O white dwarf. Sakurai's object (V4334 Sgr), a final He-shell flash product, shows no detectable F I lines.

1. Introduction

R Coronae Borealis (RCB) stars comprise a sequence of hydrogen-deficient supergiants with effective temperatures from about $T_{\rm eff} = 3500$ K, as represented by Z UMi and DY Per, to about 19,500 K, as represented by DY Cen. The characteristic of H-deficiency is shared by the H-deficient cool carbon (HdC) stars at low temperatures and by the extreme helium (EHe) stars at high temperatures. A common assumption is that the sequence HdC - RCB - EHe in the ($T_{\rm eff}$, $\log g$) plane reflects a close evolutionary connection. In this sequence, the RCBs are distinguished from HdC and EHe stars by their second principal defining characteristic: their propensity to fade, in visual light, unpredictably as a cloud of carbon dust obscures the star. This propensity is not universally shared: XX Cam has yet to be observed below maximum light. In addition, DY Cen might be considered as an EHe star known to experience RCB-like fadings.

If HdC, RCB, and EHe stars share a common heritage, the expectation is that their atmospheric compositions should show some common features (Pandey et al. 2004; Rao 2005). It is through the compositions that one hopes to test theoretical ideas about the origins of these extremely rare stars; just five HdC, about 40 RCB (Zaniewski et al. 2005), and 21 EHe stars are known in the Galaxy. Currently, two scenarios remain in contention to account for these H-poor high luminosity stars. In the first, a final He-shell flash in a post-AGB star on the white dwarf cooling track creates a H-poor luminous star. This is dubbed the 'final flash' (FF) scenario. In the second, the H-poor star is formed from a merger of a He white dwarf with a C-O white dwarf. In a close binary system, accretion of the He white dwarf by the C-O white dwarf may lead to a H-poor supergiant

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with the C-O white dwarf as its core. This is called the 'double degenerate' (DD) scenario.

Products of both the FF and DD scenarios may be presumed to exist. A determination of which scenario provided which star rests in large part on the observed chemical composition of a star's atmosphere and theoretical predictions about the FF and DD products. Evidence from elemental abundances, especially the H, C, N, and O abundances, suggests that the RCB and EHe stars evolved via the DD rather than the FF route (Asplund et al. 2000; Pandey et al. 2001; Saio & Jeffery 2002; Pandey et al. 2006). Convincing, essentially incontrovertible, evidence that the DD scenario led to the HdCs and some cool RCBs was presented by Clayton et al. (2007) with their discovery that the ^{18}O was very abundant in their atmospheres. This usually rare isotope of oxygen was attributed to nucleosynthesis occurring during and following accretion of the He-rich material onto the C-O white dwarf.

Determination of the oxygen isotopic ratios demands a cool star with the CO vibration-rotation bands in its spectrum. The majority of RCBs and all of the EHes are too hot for CO to contribute to their spectra (Tenenbaum et al. 2005). An alternative tracer of nucleosynthesis during a merger may be provided by the fluorine abundance. Considerable enrichment of EHe stars with F was discovered by Pandey (2006) from detection and analysis of about a dozen F I lines in optical spectra of cool EHe stars. Clayton et al.'s (2007) calculations suggest that F synthesis is possible in the DD scenario. Here, we report on a search for F I lines in spectra of RCBs and discuss the F abundances in light of the results for EHes and the expectations for the DD and FF scenarios.

2. Observations

High-resolution optical spectra of RCBs at maximum light obtained at the W.J. McDonald Observatory and the Vainu Bappu Observatory were examined for the presence of F I lines.

Suitable McDonald spectra of 13 RCBs were available for analysis. In several cases, spectra of the same star from different epochs were available. The stars are listed in Table 1. At VBO, spectra were obtained of UW Cen, a star inaccessible from the McDonald Observatory, and also of XX Cam, R CrB, RY Sgr, and VZ Sgr. The UW Cen spectrum was complemented by a CTIO spectrum from 1992 (see Asplund et al. 2000).

3. F I Lines

In the atmosphere of a RCB star, fluorine is present as neutral atoms. The leading lines of F I in optical spectra come from excited levels with lower excitation potentials of 12.7 eV or higher. The adopted gf-values come from Musielok et al. (1999). The following F I lines were identified as the principal or leading contributor to a stellar line: 7398.68, 7754.69, 6902.47, 7425.65, and 6834.26Å. The measured mean fluorine abundances (Table 1) are given as log ϵ(F), normalized such that log $\Sigma\mu_i\epsilon(i) = 12.15$ where μ_i is the atomic weight of element i. The errors of the derived F abundances given in Table 1 are the line-to-line scatter.

Table 1. The analyzed RCBs, their stellar parameters, and fluorine abundances from individual F I lines. The Sakurai's object, a final He-shell flash product, is also listed.

Star	($T_{\rm eff}$, $\log g$, ξ)	$\log \epsilon$(F)					
		7398.68Å	7754.69Å	6902.47Å	7425.64Å	6834.26Å	Mean
V3795 Sgr	(8000, 1.0, 10.0)	...	6.60	6.65	6.70	6.70	6.66±0.05(4)
UW Cen	(7500, 1.0, 12.0)	7.20	...	7.00	7.10	7.20	7.1±0.1(4)
RY Sgr	(7250, 0.75, 6.0)	...	...	6.80	...	7.10	6.95±0.2(2)
XX Cam	(7250, 0.75, 9.0)	...	...	<5.6	...	<5.6	<5.6
UV Cas	(7250, 0.5, 7.0)	...	...	6.20	...	...	6.2(1)
UX Ant	(7000, 0.5, 5.0)	...	...	<6.2	...	<6.2	<6.2
VZ Sgr	(7000, 0.5, 8.0)	...	...	6.30	...	6.50	6.4±0.1(2)
R CrB	(6750, 0.5, 7.0)	...	...	6.85	...	7.00	6.9±0.1(2)
V2552 Oph	(6750, 0.5, 7.0)	...	...	6.60	...	...	6.6(1)
V854 Cen	(6750, 0.0, 6.0)	...	...	...	...	<5.7	<5.7
SU Tau	(6500, 0.5, 7.0)	...	...	6.90	...	7.00	6.95±0.1(2)
V CrA	(6500, 0.5, 7.0)	...	...	6.5:	...	...	6.5:(1)
V482 Cyg	(6500, 0.5, 4.0)	...	...	...	...	6.6:	6.6:(1)
GU Sgr	(6250, 0.5, 7.0)	...	...	...	...	7.2:	7.2:(1)
FH Sct	(6250, 0.25, 6.0)	...	...	...	...	7.2:	7.2:(1)
Sakurai's object	(7500, 0.0, 8.0)	...	...	...	...	<5.4	<5.4

4. Discussion

The analyzed RCBs (excluding stars with upper limits to the F abundances and, uncertain F abundances) have a mean F abundance of 6.7 which is the same for the analyzed EHes (Pandey 2006). Thus, the F abundances are similar across an effective temperature range from about 6500 K to 14000 K, an indication that non-LTE effects are possibly small. The F abundances of the analyzed RCB and EHe stars show no obvious trend with their abundances of other elements. More interestingly, the F overabundances are extremely large: enhancements of about 800, 2500, and 8000 at $\log\epsilon(\mathrm{Fe})=7.5$, 6.5, and 5.5, respectively.

4.1. The DD Scenario and Fluorine

In the 'cold' (i.e., no nucleosynthesis during the merger) version of the DD scenario, the He white dwarf is stripped and accreted by the C-O white dwarf. In the 'hot' DD scenario, nucleosynthesis occurs during and following accretion. Fluorine in PG1159 stars shows a range of abundances (Werner, Rauch & Kruk 2005; Werner & Herwig 2006) from solar to 250 times solar. As Werner & Herwig discuss, this range is not out of line with theoretical predictions for the He-intershell. But in the cold DD scenario, the He-intershell material is diluted, according to the canonical recipe, by a factor of about ten and, then, overabundances of up to 25 times solar for the RCBs and EHes are predicted. The observed overabundances of F range upward of 1000 times. ^{19}F synthesis is demonstrated by Clayton et al. (2007) which was briefly about 100 times above its solar abundance. Challenge is to show that the 'hot' DD scenario includes the possibility of robustly increasing the F abundances to the observed levels of 1000 times over solar.

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References

Asplund, M., Gustafsson, B., Lambert, D. L., & Rao, N. K. 2000, A&A, 353, 287
Clayton, G. C., Geballe, T. R., Herwig, F., Fryer, C., & Asplund, M. 2007, ApJ, 662, 1220
Musielok, J., Pawelec, E., Griesmann, U., & Wiese, W. L. 1999, Phys.Rev.A, 60, 947
Pandey, G., Rao, N. K., Lambert, D. L., Jeffery, C. S., & Asplund, M. 2001, MNRAS, 324, 937
Pandey, G., Lambert, D. L., Rao, N. K., & Jeffery, C. S. 2004, ApJ, 602, L113
Pandey, G., Lambert, D. L., Jeffery, C. S., & Rao, N. K. 2006, ApJ, 638, 454
Pandey, G. 2006, ApJ, 648, L143
Rao, N. K. 2005, ASP Conf. Ser. 336, 185
Saio, H., & Jeffery, C. S. 2002, MNRAS, 333, 121
Tenenbaum, E. D., Clayton, G. C., Asplund, M., Engelbracht, C. W., Gordon, K. D., Hanson, M. M., Rudy, R. J., Lynch, D. K., Mazuk, S., Venturini, C. C., & Puetter, R. C. 2005, AJ, 130, 256
Werner, K., Rauch, T., & Kruk, J. W. 2005, A&A, 433, 641
Werner, K., & Herwig, F. 2006, PASP, 118, 183
Zaniewski, A., Clayton, G. C., Welch, D. L., Gordon, K. D., Minniti, D., & Cook, K. H. 2005, AJ, 130, 2293