
Uniquely Large Excesses of ^{18}O in HdC and RCB Stars: Evidence for White Dwarf Mergers

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Summary. We have discovered, mainly using Gemini/GNIRS, that several hydrogen-deficient carbon (HdC) and R Coronae Borealis (RCB) stars, have $^{16}\text{O}/^{18}\text{O}$ ratios close to and sometimes less than unity, a value orders of magnitude smaller than measured in other known stars (the Solar value is 500). This discovery is an important step in determining the evolutionary pathway of HdC and RCB stars in general, for which two models have been proposed: double degenerate (white dwarf (WD) merger), and the final helium-shell flash (FF). The FF model for producing RCB stars has been discredited recently due to a mismatch of abundances and timescales needed to produce the RCB stars. We have explored the idea that HdC and RCB stars originate in the merger of CO- and He-WDs in the light of the new observations. Understanding the RCB and HdC stars is a key test for any theory that aims to explain hydrogen deficiency in post-AGB stars. These new results on the $^{16}\text{O}/^{18}\text{O}$ ratio and our work on the FF star V605 Aql represent an opportunity for a huge breakthrough. Confirmation of the WD merger scenario, which is suggested, by both the models and these observations, will allow the use of RCB and HdC stars as probes for WD merger simulations.

Key words: R Coronae Borealis stars, evolution, abundances

New optical spectra have been obtained with VLT/FORS2 of the final helium shell flash (FF) star, V605 Aql, which peaked in brightness in 1919 (Clayton et al. 2006, 2007). New models suggest that this star is experiencing a very late thermal pulse. The evolution to a cool luminous giant and then back to a compact hot star takes place in only a few years. V605 Aql, the central star of the Planetary Nebula (PN), A58, has evolved from $T(\text{eff}) = 5000$ K in 1921 to 95,000 K today. There are indications that the new FF star, Sakurai's Object (V4334 Sgr), which appeared in 1996, is evolving along a similar path. The abundances of Sakurai's Object today

and V605 Aql 80 years ago mimic the hydrogen deficient RCB stars with 98% He and 1% C, except that they show significant amounts of ^{13}C . The new spectra show that V605 Aql has stellar abundances similar to those seen in Wolf-Rayet [WC] central stars of PNe with 55% He, and 40% C. In the present state of evolution of V605 Aql, we may be seeing the not too distant future of Sakurai's Object. The short timescales of these FF stars with temperatures and abundances appropriate to RCB stars imply that the FF may not be the primary source of these stars.

Because the recent studies above imply that a FF origin for the RCB and HdC stars is unlikely (Clayton et al. 2006, 2007), we have explored the alternative possibility of WD-WD mergers, and in particular the details of the onset of He-burning nucleosynthesis in a He-WD/CO-WD merger. Webbink (1984) proposed that an RCB star evolves from the merger of a He-WD and a CO-WD which has passed through a common envelope phase. He suggested that as the binary begins to coalesce because of the loss of angular momentum by gravitational wave radiation, the (lower mass) He-WD is disrupted. A fraction of the He is accreted onto the CO-WD and starts to burn, while the remainder forms an extended envelope around the CO-WD. This structure, a star with a He-burning shell in the center of a ~ 100 solar radii H-deficient envelope, is believed to be that of an RCB star. Saio & Jeffery (2002) suggested that a WD-WD merger could also account for the elemental abundances seen in RCB stars.

The search for $^{12}\text{C}^{18}\text{O}$ in HdC and RCB stars has resulted in two significant findings: (1) in all HdC stars and most or all RCB stars where oxygen isotopic ratios can be measured, ^{18}O is enhanced relative to ^{16}O by factors of 100–1000 compared to standard Galactic values; and (2) the lowest $^{16}\text{O}/^{18}\text{O}$ ratios are found in the HdC stars. We are investigating evolutionary paths that might consistently produce such high relative ^{18}O abundances and distinguish between these two types of carbon stars. Using the temperatures and densities inferred from our merger model, we constructed a parametric nucleosynthesis model (Clayton et al. 2007). We consider a single zone nucleosynthesis model with a solar initial abundance distribution. The density is assumed to be $2 \times 10^3 \text{ g cm}^{-3}$ and the temperature initially is 5×10^7 K. We follow the nucleosynthesis with a nuclear network code until the H has been burned to a mass fraction of 10^{-4} . Initially the CNO H-burning equilibrium ratios, including the large ^{14}N abundance are established. Then, as the temperature increases, a modest increase in the ^{16}O abundance can be seen (at 220 yr), resulting from the activation of $^{13}\text{C}(\alpha, n)^{16}\text{O}$. Thereafter, ^{16}O remains largely unchanged because the temperature does not become high enough for $^{13}\text{C}(\alpha, \gamma)^{16}\text{O}$. Instead, just after ^{13}C burning, ^{14}N begins undergoing α -capture and produces ^{18}O . This reaction very quickly makes ^{18}O the most abundant of the CNO isotopes, a situation that lasts until ^{18}O begins capturing a particles to produce ^{22}Ne , at which time it is overtaken by ^{12}C whose abundance has been increasing since 230 yr because of the triple- α reaction. Both the observed C/N and N/O ratios are consistent with nucleosynthesis after full completion of H-burning and at the beginning of He-burning. The model N/O ratio is in good agreement at ~ 250 yr whereas the C/N match is delayed. However, both times are consistent with a very high and only slightly decreased He abundance at this early time of He-burning. The most interesting information comes from the $^{16}\text{O}/^{18}\text{O}$ and the $^{12}\text{C}/^{13}\text{C}$ ratios. The enormous production of ^{18}O from ^{14}N leads to a rapid decrease of the $^{16}\text{O}/^{18}\text{O}$ ratio at the onset of He-burning, which passes through the observed value for HD 137613 at around 250 yr. The $^{12}\text{C}/^{13}\text{C}$ ratio increases to the point that it exceeds its observed lower

limit of 500 for RCB stars (Fujita & Tsuji 1977) at a slightly earlier time. In the HdC and RCB stars, the nucleosynthesis seems to have stopped at the point when $^{16}\text{O}/^{18}\text{O}$ is very low and $^{12}\text{C}/^{13}\text{C}$ is very high. Overall, our analysis shows that WD mergers may very well be the progenitors of ^{18}O -rich RCB and HdC stars, and that more detailed simulations and modeling are justified.

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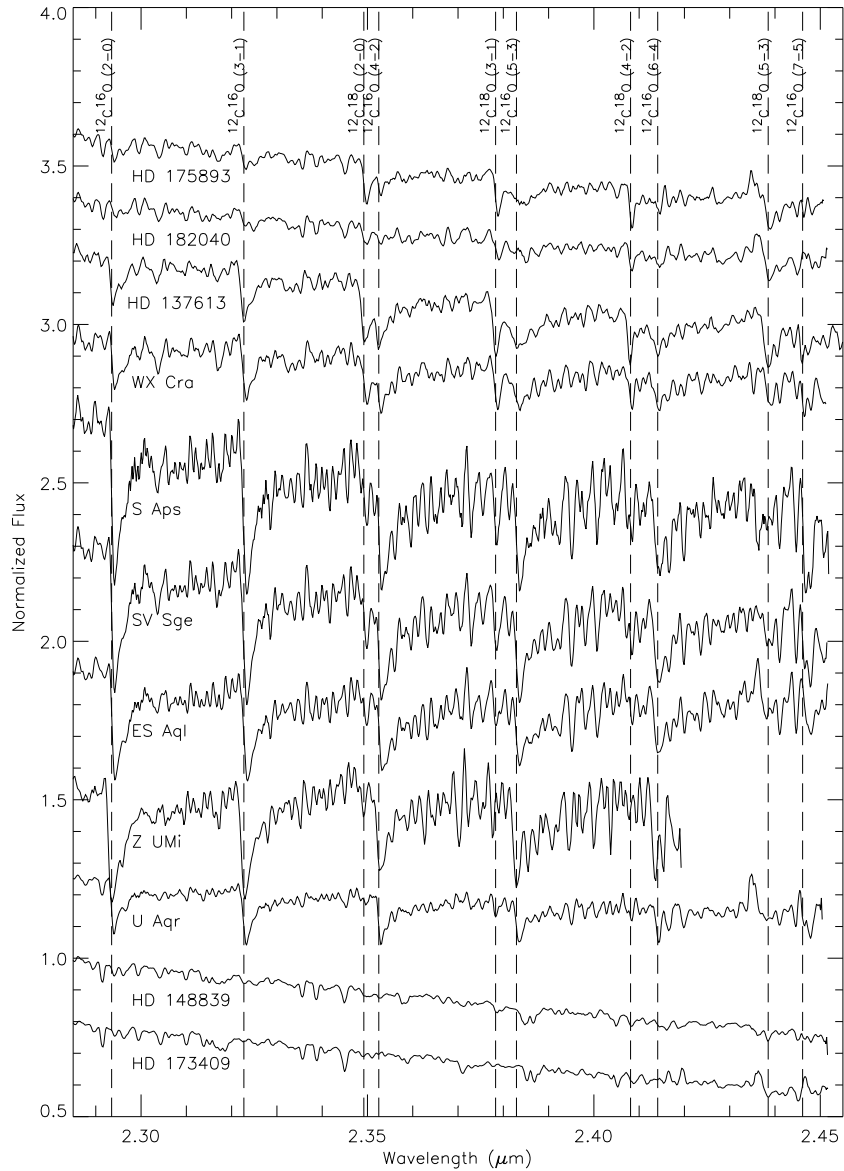


Fig. 1. The 2.28 - 2.45 μm spectra of RCB and HdC stars, with wavelengths of $^{12}\text{C}^{16}\text{O}$ and $^{12}\text{C}^{18}\text{O}$ band heads indicated by vertical lines. The stars are ordered by the strengths of the $^{12}\text{C}^{18}\text{O}$ bands. The first three spectra at the top and the last two at the bottom are of HdC stars. The rest are of RCB stars.