CARBON-RICH RR LYRAE TYPE STARS

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ABSTRACT

We have derived CNO abundances in 12 RR Lyrae stars. Four stars show \([\text{C}/\text{Fe}]\) near 0.0 and two stars show \([\text{C}/\text{Fe}]\) = 0.52 and 0.65. Red giant branch stars, which are known to be the predecessors of RR Lyr stars, generally show a deficiency of carbon due to proton captures during their evolution from the main sequence up the giant branch. We suggest that the enhancement of carbon is due to production during the helium flash combined with mixing to the surface by vigorous convection induced by the flash itself.

Key words: stars: abundances – stars: evolution – stars: horizontal-branch – stars: Population II

1. INTRODUCTION

It is generally agreed that the RR Lyrae stars have evolved from the red giant branch (RGB) to their present position on the horizontal branch (HB) of globular clusters when the helium flash initiates the triple-alpha reaction in the degenerate core. Because of the degeneracy, combined with the great temperature dependence of the triple-alpha reaction, the core of the red giant heats extremely rapidly leading to very vigorous convection that must be treated by hydrodynamic methods rather than the conventional theory of steady convection. Recent calculations have been described by Dearborn et al. (2006) as well as by Mocak et al. (2008). There remain many uncertainties in the calculations but it is generally agreed that the star is not disrupted. This is demonstrated by the very existence of HB stars. At the same time the degree of mixing remains uncertain with the distinct possibility that freshly minted \(^{12}\)C may reach the surface. In addition, the \(^{12}\)C must pass through a region rich in hydrogen so it may be reprocessed to \(^{13}\)C and \(^{14}\)N.

As part of a small survey of the chemical composition of specially selected RR Lyr stars and comparison stars of known metallicity, we have found at least two carbon-rich objects.

2. OBSERVATIONS

The spectra of our program stars were obtained with the echelle spectrograph of the Apache Point Observatory (APO). By using a prism as cross-disperser the APO echelle covers all wavelengths from 3500 Å to 10400 Å. However the red-sensitive 2048 \(\times\) 2048 chip has decreasing sensitivity below 4000 Å and beyond 9000 Å. The resolving power is about 35,000. Exposure times were usually about 20–30 minutes. We estimated the S/N ratio at the continuum level depending upon the wavelength interval to be about 70–150 pixel\(^{-1}\) after combining multiple exposures that had been taken sequentially. Table 1 contains the dates, JD, phases, and derived values of \(T_{\text{eff}}\) and \(\log g\) for each phase.

3. DATA REDUCTION AND ANALYSIS

3.1. Data Reduction

The program spectra were extracted from the raw frames using standard IRAF procedures. The continuum level placement, wavelength calibration, and equivalent width measurements were performed with DECH20 code (Galazutdinov 1992).

3.2. Atmospheric Parameters and Abundance Analysis

The elemental abundances were derived using the Kurucz’s WIDTH9 code with atmosphere models interpolated from the ATLAS9 model grid. We used log \(g_f\) values derived from an inverted solar analysis (Kovtyukh & Andrievsky 1999).

Atmospheric parameters \((T_{\text{eff}}, \log g, V_t)\) were derived by enforcing traditional spectroscopic criteria. Lines of Fe\(\text{i}\) were forced to yield zero slope in the relations between total iron abundance and excitation potential. The total abundances of iron as predicted from Fe\(\text{i}\) and Fe\(\text{ii}\) lines were equalized by adjusting the model gravity (i.e., to yield a “spectroscopic gravity”).

4. CNO ABUNDANCES

To derive the carbon abundance the following set of lines was used: 6001.12 Å, 6010.68 Å, 6014.83 Å, 6587.61 Å, 6655.51 Å, 7085.47 Å, 7087.83 Å, 7111.48 Å, 7113.18 Å, 7115.19 Å, 7116.99 Å, and 8335.15 Å. The nitrogen abundance was found from the lines 7442.29 Å, 7468.30 Å, 8216.34 Å, 8242.39 Å, 8629.16 Å, 8683.39 Å, 8703.25 Å, 8711.67 Å and 8718.76 Å. These lines are seen only in the stars with a quite high metallicity. For the metal-poor stars only some of the lines were present. The abundance of oxygen in the program stars was derived from the following lines: 6156.77 Å, 6158.18 Å, and 6300.30 Å. Equivalent widths will be presented in a full paper on abundances of all available elements in the stars in Table 1.

As an example, in Figure 1 we show spectra in the region of the C\(\text{i}\) lines near 7110 Å. Note that all stars showing these lines were observed near the same phase, 0.5, and hence have very nearly the same temperatures.

The results for the CNO abundances in our program stars are given in Table 2 (we have shown the derived abundances on the usual scale letting log \(N(\text{H}) = 12.0\)).

Only a few comparisons may be made with other analyses of RR Lyr star abundances. For SW And, Clementini et al. (1995) found \([\text{C}/\text{Fe}] = -0.10\) while we found +0.09. The difference is almost entirely due to their solar abundance of C of 8.56 (Anders & Grevesse 1990) and our more recent value of 8.39 (Asplund et al. 2005a). For \([\text{O}/\text{Fe}]\) they found -0.03 and we found +0.23.
which corresponds closely to the revision of the solar oxygen abundance from 8.93 to 8.66.

It is also worth noting the carbon and $s$-process enhancements found by Preston et al. (2006) in TY Gru, due probably to mass...
transfer from a companion. We have analyzed the heavy-element content of the two C-rich stars KP Cyg and UY CrB (to be reported on later) and found no significant enhancements.

5. DISCUSSION

It is well known that in evolving metal-poor stars the first dredge-up depletes C in the stellar atmosphere, and that the additional mixing that occurs at the red giant clump further depletes it. Normal or excess carbon indicates that additional carbon has been injected into the atmosphere from deeper layers, presumably from the helium flash without being reprocessed to C. Additional mixing that occurs at the red giant clump further depletes C in the stellar atmosphere, and that the evolutionary stage after the red giant phase is caused by the deep convective mixing. Calculations by Fujimoto et al. (2000) and by Schlattl et al. (2002) for the He flash in extremely metal-poor stars show that thermally driven convection in the core can reach the H-burning shell. When H mixes with the freshly synthesized carbon, rapid proton capture can release further energy to drive the convection to the outer layers of the star.

We are currently expanding our high-resolution survey of RR Lyrae stars to establish any correlation of carbon excesses with period, metallicity, or other parameters.

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Table 3

| Cluster Type of Star | [Fe/H] | log(N(C)/H) | log(N(N)/H) | log(N(O)/H) | ¹²C/¹³C | References |
|---------------------|--------|-------------|-------------|-------------|---------|------------|
| M4                  | 0.79   | 7.07        | 7.07        | 8.24        | 8.3     | a          |
| M7                  | 0.78   | 7.11        | 7.07        | 8.08        | 6.0     | a          |
| M7                  | 0.89   | 6.76        | 8.04        | 8.14        | 5       | a          |
| 47 Tuc              | 0.77   | 7.48        | 8.29        | 8.35        | 4–12    | b, d       |
| M4                  | 1.34   | 6.97        | 7.83        | 8.78        | 4–8     | b          |
| M4                  | 1.18   | 6.64        | 7.35        | 7.73        | 4.5     | c          |

References. a Briley et al. (1997); b Brown & Wallerstein (1990); c Ivans et al. (1999); d Alves-Brito et al. (2005).