Chemical Abundances of RR Lyrae Type C Star AS162158

JOSE GOVEA¹, THOMAS GOMEZ¹, GEORGE W. PRESTON², CHRISTOPHER SNEDEN¹

Abstract

We report the first extensive model atmosphere and detailed chemical abundance study of eight RR Lyrae variable stars of c subclass throughout their pulsation cycles. Atmospheric parameters effective temperature, surface gravity, microturbulent velocity, and metallicity have been derived. Spectra for this abundance analysis have been obtained with the echelle spectrograph of 100-inch du Pont telescope at Las Campanas Observatory. We have found metallicities and element abundance ratios to be constant within observational uncertainties at all phases of all stars. Moreover, the $\alpha$-element and Fe-group abundance ratios with respect to iron are consistent with other horizontal-branch members (RRab, blue and red non-variables). The [Fe/H] values of these eight RRc stars have been used to anchor the metallicity scale of a much larger sample of RRc stars obtained with low S/N “snapshot” spectra.

1. Introduction

The H-R Diagram horizontal branch is populated with low-metallicity stars that are doing quiescent core helium fusion. The instability strip portion of the horizontal branch contains RR Lyrae stars, which are radially pulsating giant A-F stars. RRc stars occupy the hotter portion of the instability strip while RRab occupy the cooler end. Generally, RRc stars have effective temperatures in the range 7000K-7500K while RRab stars are cooler, with $T_{\text{eff}}$ ranges from 6000K-7000K.

RR Lyrae stars have been used as standard candles to measure galactic distances through photometry and low-resolution spectroscopy because of their uniform brightness. They are also potentially excellent tracers of chemical properties of old stellar

¹ Department of Astronomy and McDonald Observatory, The University of Texas, Austin, TX 78712; jgovea@utexas.edu, gomez@astro.as.utexas.edu, chris@verdi.as.utexas.edu
² The Observatories of the Carnegie Institution of Washington, Pasadena, CA 91101; iii@ociw.edu
populations. But high-resolution spectroscopic analyses of RR Lyr are not plentiful because their short pulsation periods (∼0.1−1.0 days) and large radial-velocity (RV) amplitudes impose limits on exposure times, and consequent signal-to-noise (S/N) ratios in their spectra. The RRc variables have been neglected in these high-resolution studies; there are fewer RRc’s than RRab’s and most are somewhat faint for high-resolution spectroscopy in the past.

Seven of our stars exhibit the so-called Blazhko effect, a slow modulation of their basic pulsational periods; Blazhko periods of these stars are less than 12 days. This period is small enough to produce detectable rotational broadening (V\text{sin}i > 15 km s\(^{-1}\)) of their spectral lines via \(PV = 2\pi R\), in which \(P\), \(V\), and \(R\) are the rotation period, axial rotational velocity, and radius of the star. In this paper we focus on one of our program stars, AS162158, showing the spectroscopic changes that occur throughout its pulsation cycle. Further details regarding the whole set of the program stars are given in Govea et al. (2013).

2. Model Atmosphere and Abundance Determinations

What is of concern here are the line spectrum cyclic changes that AS162158 undergoes throughout its pulsational cycle. We imposed a 20-minute integration limit on the spectroscopic observations that, once normalized, yielded low S/N values (<50). In order to prepare the spectra for equivalent width (EW) measurements and subsequent chemical composition analysis, we combined the spectra in narrow phase intervals to increase mean S/N ratios. We created narrow phase intervals that were grouped into phase bins no larger than ∆\(\phi\) ≃ 0.05 to minimize contamination (e.g., spectral line velocity smearing) due to the rapid atmospheric changes. Once the spectra were normalized we applied a Gaussian line profile fitting to measure equivalent widths.

We acquired model atmosphere parameters \(T_{\text{eff}}\), \(\log g\), \(v_t\), [Fe/H]\(^3\) and relative abundance ratios [X/Fe] for our program stars at each of their co-added phases. Phase elemental abundances were acquired using the latest version of local thermodynamic equilibrium spectral line synthesis code MOOG (Sneden 1973)\(^4\). Model atmospheres were interpolated from the ATLAS grid (Kurucz 1992)\(^5\) which were calculated assuming α-element enhancements and opacity distribution functions (Castelli & Kurucz 2003). Trial Kurucz model atmospheres and EW line lists were input parameters for MOOG, whose output was individual line abundances from iterative force-fitting of predicted EWs to the measured values. We adjusted input model parameters in a similar fashion as For et al. (2011a). To summarize, \(T_{\text{eff}}\) was adjusted until there was no significant trend between abundances and excitation energies of the Fe I lines. Values for \(\log g\) needed to agree with observational errors of the derived abundances from Fe I and Fe II

\(^3\) We adopt the standard spectroscopic notation (Heller, Wallerstein, & Greenstein 1959) that for elements A and B, \([A/B] = \log_{10}(N_A/N_B)_\star - \log_{10}(N_A/N_B)_{\odot}\).

\(^4\) Available at http://www.as.utexas.edu/~chris/moog.html

\(^5\) Available at http://kurucz.harvard.edu/grids.html
lines. Fe I and Fe II lines conceded $v_t$ values when there was a lack of abundance trend. Finally, [M/H] metallicity parameter was obtained by derived Fe abundances. 

Table 1 shows the variation of atmospheric models derived for AS162158 along with [Fe/H] metallicities. We find that atmospheric parameters change in expected ways. That is, the hottest temperatures and highest gravities occur near phase $\phi \sim 0.5$, at which time the photometric brightness of an RRL is at minimum and derived radial velocity is at maximum. However, in spite of the 400K $T_{\text{eff}}$ variation and 0.4 dex log $g$ variation there is only a small variation in derived [Fe/H], especially as indicated by the Fe II lines.

In Figure 1 we show the variations on the relative $[X/Fe]$ abundance ratios for six lighter elements in AS162158. The dotted line in each panel represents the average abundance of the element throughout the pulsation cycle. Inspection of this figure suggests that derived abundance ratios for these elements (a) are essentially independent of pulsational phase, and (b) are consistent with those of other members of the metal-poor horizontal branch (RHB, RRab, and BHB stars). In particular, all of the $\alpha$ and $\alpha$-like elements (Mg, Si, Ca and Ti) are enhanced, $[X/Fe] \simeq +0.3$ to $+0.5$, just as they are in other metal-poor stars. This result holds generally for all of the RRc stars in the Govea et al. (2013) sample.
Figure 1.— Relative abundance ratios for lighter elements as functions of phase for AS162158. Dotted line represents the average chemical abundance.
3. Conclusions

We have calculated model atmospheric parameters, metallicity, and abundance ratios for eight field RRc variable stars. In this paper we narrowed in on AS162158. Further details concerning the rest of the program stars are given in Govea et al. (2013). Each star in our survey has been explored at nearly all pulsational phases by taking short exposure times and co-adding spectra. Deriving $T_{\text{eff}}$, $\log g$, $v_t$, and $[\text{Fe/H}]$ for AS162158 based on spectroscopic constraints, we find that (a) the mean $T_{\text{eff}}$ for AS162158 is approximately 7200K, the mean apparent gravity is about $\log g = 2.2$, while the obtained metallicity value is $[\text{Fe/H}]=-2.00$. Additionally, as detailed in the full paper, the mean microturbulent velocities are $v_t \simeq 2.2 \text{ km/sec}$. These velocities are much lower than those derived by For et al. (2011b) for the cooler RRab stars, and are consistent with the overall smaller photometric and spectroscopic parameter variations of the RRc stars than their RRab counterparts. We also find that the $\alpha$-element (Mg, Si, Ca, Ti) abundances on average are overabundant ($[X/Fe] \simeq +0.3$ to 0.4) and the Fe-group (Sc, Cr, Ni) have solar abundance ratios ($[X/Fe] \simeq 0$) just as they are in other halo population samples. Further implications of our study are detailed in Govea et al. (2013), including the use our program stars’s $[\text{Fe/H}]$ values to calibrate the metallicity estimates of a large-sample RRc snapshot spectroscopic survey of Kollmeier et al. (2012).

4. Acknowledgements

Our investigations of RR Lyrae stars have been supported by NSF grants AST-0908978 and AST-1211585 and by the Baker Centennial Research Endowment to the Astronomy Department of the University of Texas.

References

Castelli, F., & Kurucz, R. L. 2003, in Modelling of Stellar Atmospheres, IAU Symp. 210, ed. N. Piskunov, W. W. Weiss, & D. F. Gray, Ast. Soc. Pacific, 20
For, B.-Q., Preston, G. W., & Sneden, C. 2011a, ApJS, 194, 38
For, B.-Q., Sneden, C., & Preston, G. W. 2011b, ApJS, 197, 29
Govea, J., Gomez, T., Preston, G. W., and Sneden, C. 2013, AJ, submitted
Helfer, H. L., Wallerstein, G., & Greenstein, J. L. 1959, ApJ, 129, 700
Kollmeier, J., et al. 2013, ApJ, submitted
Kurucz, R. L. 1992, in The Stellar Populations of Galaxies, IAU Symp. 149, ed. B. Barbuy & A. Renzini, Dordrecht: Reidel, 225.
Sneden, C. 1973, ApJ, 184, 839