Spectroscopic Constraints on the Helium Abundance in Globular Cluster Stars

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Abstract.

The globular cluster ω Centauri has a rich population of UV-bright stars, most of which were discovered on a 1620 Å image of the cluster obtained in 1990 with the Ultraviolet Imaging Telescope (UIT). We have obtained ground-based and IUE low-dispersion spectroscopy of seven UV-bright stars in ω Cen, in order to study the variation of photospheric helium abundances across the UV-bright region of the HR diagram. All seven stars are radial velocity members of the cluster and show helium lines in their spectra. The three least luminous target stars have $T_{\text{eff}} \sim 20,000$ K and show photospheric helium depletions characteristic of stars on the hot horizontal branch. The fourth target star (UIT-644) also has $T_{\text{eff}} \sim 20,000$ K but with a large overabundance of helium and nitrogen, perhaps indicating a prior ejection of its hydrogen-rich envelope. The remaining three target stars have sdO spectra with strong Balmer and He II lines, but none from He I. These three stars have an approximately solar helium abundance and are promising spectroscopic probes of the cluster helium abundance.

1. Introduction

The helium abundance, $Y$, in globular cluster stars is of interest in cosmology for two reasons. First, the helium abundance in these old low-metallicity stars can provide a useful upper limit to the primordial abundance, and second, the
isochrone ages of the globular clusters depend upon the assumed helium content (Shi 1995). Most globular cluster stars are too cool to show helium in their spectra, and the hot horizontal branch (HB) stars often show greatly depleted helium abundances due to gravitational settling of helium in their high gravity atmospheres (e.g. Heber et al. 1986). Thus, the determination of the helium content in globular clusters has usually relied on indirect methods, such as number counts of stars in different evolutionary phases (the “R method”, Caputo et al. 1987) or the width of the horizontal branch (Dorman et al. 1989).

The color-magnitude diagrams of globular clusters often show one or two UV-bright stars, which are at least a magnitude more luminous than the zero-age horizontal branch (ZAHB). The most luminous UV-bright stars are thought to be post-asymptotic giant branch (AGB) stars evolving at constant luminosity across the HR diagram toward their final white dwarf stage, while the less luminous UV-bright stars are probably directly evolved from the hot horizontal branch. The UV-bright stars are promising spectroscopic probes of the cluster helium abundance for three reasons. First, because they are lower gravity than stars near the ZAHB, they are less likely to have suffered gravitational settling of photospheric helium. Second, unlike the long-lived (∼10⁸ years) HB stars, the rapid evolutionary time scale (∼10⁶ years) of post-AGB stars may be insufficient to allow stratification of photospheric helium to occur, even if a relevant physical process (e.g. diffusion, radiative levitation) is operating. Finally, the UV-bright stars are easier spectroscopic targets than the hot HB stars in any particular cluster, simply due to their higher luminosity. Note that a small enhancement of the surface helium abundance in UV-bright stars over the main-sequence value (∆Y ∼ 0.02) is expected due to the first dredge-up on the red giant branch (Sweigart et al. 1989). From high-resolution optical spectra, Conlon et al. (1994) find an approximately solar helium abundance (Y = 0.28) in the UV-bright star Barnard 29 in M13 (but also see Adelman et al. 1994).

The globular cluster ω Centauri has an especially rich population of UV-bright stars due to the extreme luminosity of the cluster, and the presence of a populous hot HB. A 1620 Å image of the cluster obtained with the Ultraviolet Imaging Telescope (UIT) in 1990 revealed more than two dozen hot stars at least one magnitude brighter than the ZAHB (Whitney et al. 1994). In February 1995, we obtained low-dispersion (3.1 Å) CTIO 4m spectra of seven of the brightest stars in the Whitney et al. catalog. All seven stars are radial velocity members of the cluster and show helium lines in their spectra. We have also obtained IUE low-dispersion spectra for 6 of the 7 target stars. The optical spectra are analyzed with NLTE hydrogen-helium model atmospheres to estimate the effective temperatures, gravities, and helium abundances.

2. Results

Table 1 summarizes the results of our observations. The first column gives the star ID number from Whitney et al., the second column gives an alternate name from Dickens (1988) if available, and the third column gives the 1620 Å UIT magnitude, m162, as tabulated in Whitney et al. (1994). (Note that UIT-644 and UIT-1275 are two UV-bright stars in the core of ω Cen, labeled as UIT-1 and UIT-2, respectively, by Landsman et al. 1992.) The next three columns give the
approximate temperatures, gravities, and helium abundances as derived from a preliminary model atmosphere analysis. The final column gives the bolometric luminosity, which is derived from $T_{\text{eff}}$ and m162 using the distance (5100 pc) and reddening ($E(B-V) = 0.15$) of $\omega$ Cen.

Table 1. UV-Bright Stars in $\omega$ Cen observed at CTIO

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>m162</th>
<th>$T_{\text{eff}}$ (K)</th>
<th>log $g$</th>
<th>Y</th>
<th>log $L/L_{\odot}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>697</td>
<td>Dk 3089</td>
<td>12.98</td>
<td>20,000</td>
<td>4.0</td>
<td>0.065</td>
<td>2.07</td>
</tr>
<tr>
<td>829</td>
<td>UIT-829</td>
<td>13.52</td>
<td>20,000</td>
<td>4.0</td>
<td>0.065</td>
<td>1.98</td>
</tr>
<tr>
<td>1275</td>
<td>UIT-1275</td>
<td>12.09</td>
<td>22,500</td>
<td>4.0</td>
<td>0.13</td>
<td>2.46</td>
</tr>
<tr>
<td>644</td>
<td>UIT-644</td>
<td>10.46</td>
<td>20,000</td>
<td>3.5</td>
<td>0.68</td>
<td>2.86</td>
</tr>
<tr>
<td>197</td>
<td>ROA 5342</td>
<td>12.01</td>
<td>60,000</td>
<td>4.5</td>
<td>0.26 - 0.43</td>
<td>3.1</td>
</tr>
<tr>
<td>330</td>
<td>Dk 3873</td>
<td>12.63</td>
<td>70,000</td>
<td>5.0</td>
<td>0.26 - 0.43</td>
<td>2.8</td>
</tr>
<tr>
<td>151</td>
<td>UIT-151</td>
<td>12.63</td>
<td>70,000</td>
<td>5.0</td>
<td>0.26 - 0.43</td>
<td>2.8</td>
</tr>
</tbody>
</table>

The seven target stars can be discussed in the following three groups.

1. The three stars (UIT-1275, Dk-3089, and UIT-829) with the lowest luminosity also have the lowest helium abundance. These stars have B-type spectra with Balmer lines and He I lines, but none from He II. Evolutionary tracks suggest that these stars are evolved directly off of the ZAHB, and are similar to the low-gravity field HB stars discussed by Saffer et al. (1995). As these stars evolve off of the ZAHB toward lower gravity, they apparently retain some depletion of photospheric helium.

2. UIT-644 also has a B-type spectrum but with much stronger helium lines and with strong nitrogen lines. The luminosity of UIT-644 is sufficiently high that it probably is on a post-AGB track (c.f. Landsman et al. 1992). UIT-644 may have ejected its hydrogen rich envelope, revealing processed material with a high helium and nitrogen abundance.

3. ROA 5342, UIT-151, and Dk 3873 have sdO type spectra with strong Balmer and He II lines, but none from He I. The absence of He I indicates that $T_{\text{eff}} > 60,000$ K, making these the hottest stars ever found in a globular cluster. However, there is a fairly large ($\pm 10,000$ K) uncertainty in the $T_{\text{eff}}$ determination, because no metal lines are detected in the optical spectra (nor are any expected at our S/N and resolution), and because the slope of the UV continuum is not a useful indicator of $T_{\text{eff}}$ at these high temperatures. The helium abundance is approximately solar, so that these stars might be useful probes of the cluster helium abundance. More precise determinations of the helium abundance will be possible once $T_{\text{eff}}$ is better determined, for example, by modeling the ionization balance of metals in moderate resolution UV spectra. Note that these sdO stars in $\omega$ Cen differ from the hot sdO stars in the field, which are generally helium-rich (e.g. Drilling & Beers 1995)
3. Discussion

There are two important requirements to be met before spectroscopic measurements of hot stars will be useful for constraining the cluster helium abundance. The first is to demonstrate that the photospheric helium abundance in any particular star has not been modified by gravitational settling or other surface effects. In particular, it would be gratifying to find agreement in derived Y values from UV-bright stars with different atmospheric parameters. The results here suggest that the best spectroscopic probes are high-luminosity (log L/L⊙ > 2.5) UV-bright stars on post-AGB tracks.

The second requirement is that the photospheric helium abundance measurements have sufficient precision to critically test the existing indirect helium abundance determinations. For the sdO stars in ω Cen, the accuracy of the helium abundance determinations are currently limited both by the S/N of the optical spectra, and by the lack of moderate resolution UV spectra to better constrain the effective temperatures. FOS spectra of UIT-151 are currently scheduled for early 1996, and should considerably improve the helium abundance measurement presented here.

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References

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