SPECTROSCOPY OF MAIN-SEQUENCE AND SUBGIANT STARS IN GLOBULAR STAR CLUSTERS

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Since the mid-1970's it has been apparent that giant stars of similar V and B-V within a "normal" globular cluster [i.e., one with a narrow giant branch in its color-magnitude diagram (CMD)] exhibit a perplexing range of strengths for such spectral features as CH, CN and NH. This complex subject has been reviewed by Kraft (1979), McClure (1979) and Freeman and Norris (1981). DDO photometry first revealed star-to-star differences of CN strengths at $M_V>+1$, where observational confusion between asymptotic and first-ascent giant stars is removed (Hesser, Hartwick and McClure 1976, 1977; Hesser 1978). Subsequently, we have sought to place observational constraints on possible mechanisms by studying such questions as: At what M_V's do spectral differences first become observable? Do spectral features other than those from CNO-based molecules vary from star-to-star? Can small temperature or gravity differences produce the observed ranges?

Spectra covering ~3750-4500 Å with 3-4 Å resolution have been taken with the CTIO 4-m telescope, R-C spectrograph and SIT vidicon detector (Atwood et al. 1979). To achieve a perspective on the range of spectral characteristics of very faint (B ~ 18) globular cluster stars, our philosophy has generally been to survey many stars to modest S/N levels, rather than concentrating on achieving high S/N for only a few. Our analysis relies heavily upon comparisons with synthetic spectra computed using model atmospheres (e.g., Gustafsson et al. 1975; Bell and Gustafsson 1978; Gustafsson and Bell 1979). Some of our results follow.

NGC 6752: 26 stars, ranging from the main-sequence to the tip of the giant branch, have been observed in this cluster, for which we estimate [M/H]~-1.5 (Bell, Hesser and Cannon 1984). To our knowledge this is the first time that spectral observations made with the same equipment for globular cluster stars exhibiting such a range of M_V have been compared with model calculations; the overall agreement is very gratifying. We find no evidence for star-to-star abundance differences

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at any M_V of any elements except C and N, but our modest-resolution and modest-S/N data are not particularly suitable for studying the correlation between CN, Ca and Al abundances found by Cottrell and Da Costa (1981) among pairs of bright giants. Varying amounts of carbon depletion are inferred for all giants. Nitrogen enhancements >3 are inferred for the brightest giants. We observe a range of CN strengths among the faintest giants, but the sample is too small to ascertain if the bimodality seen in bright giants by Norris et al. (1981) persists to M_V~+2-3. At $(B-V)_o$~0.45 the main-sequence stars are too warm for CN or CH formation. Our spectra suggest that the observed color width of the CMD at faint levels is due largely, if not entirely, to observational scatter in the photometry, rather than to real temperature variations induced by metal-abundance.

NGC 1851: A dramatic range of CN band strengths has been found among bright giants in this [M/H]~-1.0 cluster (Hesser et al. 1982); and a marked range in CN strength persists to the M_V ~+2 limit of our survey.

NGC 104 (47 Tuc): DDO photometry first indicated the existence of CN strength differences at M_V ~+2 in this metal-rich globular. That finding was extended (with ~16 Å resolution spectra) to the base of the giant branch (Hesser 1978) and then to the turnoff region (Hesser and Bell 1980). New 3-4 Å resolution spectra include 11 dwarfs and show a range of CN strengths among both turnoff and subgiant stars (Bell, Hesser and Cannon 1983). Observational scatter in the CMD (Harris, Hesser and Atwood 1983, 1984), or in our spectra of dwarfs, seems too small to account for the observed range by temperature differences. Thus, we conclude that abundance differences are responsible. To interpret our spectra, we adopted, following Dickens, Bell and Gustafsson (1979), [M/H]~-0.8, a value intermediate between the lower values obtained from high-dispersion spectroscopy (Pilachowski, Sneden and Wallerstein 1983) and the higher-values favored by, e.g., DDO (Hesser, Hartwick and McClure 1977) or IR (Frogel, Cohen and Persson 1983) photometry. From comparison with synthetic spectra we deduce that the observed range of CN strengths could be produced by a star-to-star range of nitrogen abundances of ~5; this range is similar to that required to explain observations of highly evolved stars in the cluster (see, e.g., Dickens, Bell and Gustafsson 1979).

NGC5139 (ω Centauri) and NGC 6656 (M22): Photometric and spectroscopic observations of bright giant and HB stars in ω Cen, the most massive and luminous globular in the Galaxy, have firmly established that [M/H] ranges from -2.0 to ~-0.5, with very few stars having [M/H]>-1.0. Such a metallicity range is often inferred for giants in dwarf spheroidal galaxies. From our initial spectra for 11 stars having $+2<M_V<+3.5$, we found five probable members to have -1.0<[M/H]<-1.5, while a sixth has [M/H]~-0.5, i.e., as high as those deduced for any of the brighter stars in the cluster (Bell et al. 1981). Its nitrogen appears to be enhanced by as much as a factor of 3. Subsequent spectra bring to 40 the number of faint (B~18) subgiants observed in the Cannon and Stewart (1981) CMD. We are working as close

(~0.3 r_t) to the cluster center as crowding will permit, but half of the observed stars appear to be radial-velocity (V_r) non-members! Furthermore, 90% of the stars with B-V>0.8 are V_r non-members. Spectra of V_r members reflect real temperature and abundance differences, with a total range very similar to that observed for more highly evolved stars. The spectral differences, combined with the B-V range of 0.2 for confirmed members, show conclusively that the wide range of colors, etc. observed among giants in ω Cen originates near, if not on, its main sequence. We also suspect that there may be a range of [M/H] among subgiants at a given T_{eff}. Higher S/N spectra are required to substantiate our inference; if correct, it may indicate a range of ages among ω Cen stars. Finally, the suggestion that M22 may share some of the distinguishing anomalies of ω Cen (Hesser, Hartwick and McClure 1977, Hesser and Harris 1979) has been confirmed by Pilachowski et al. (1982) and Norris and Freeman (1983); thus, ω Cen is no longer unique in the Galaxy.

In summary, among the salient findings of our observational program are that: (1) All "normal" globular clusters studied have shown a range of CN, and often CH, strengths for stars within a magnitude or so of the turnoff. (2) Enhancements of nitrogen seem commonplace. (3) Some, and perhaps many, spectral differences among highly evolved stars of similar V, B-V originate on or near the main-sequence. Four possible ways in which a high nitrogen abundance can arise in class IV-V stars are differences in abundance at the time of star formation, mixing of stars during their evolution, accretion of material lost by other cluster stars, and accretion of material lost by a binary companion (Bell et al. 1981). No single explanation seems adequate to explain the observations. More and better data are clearly needed. (4) There is evidence that the behavior of spectral features due to CNO elements differs in Pop. I and II stars (Hesser, Hartwick, and McClure 1976; Kraft et al. 1982; Kraft 1983).

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DISCUSSION

Demarque: You mentioned variations in C abundances from star to star. Are these variations correlated to the observed variations in N abundances?

Hesser: Our observed samples in 47 Tuc and NGC 6752 are small and the S/N modest. Bearing those caveats in mind, it is my impression that in NGC 6752 we see generally weaker G bands in stars with stronger CN bands; for 47 Tuc this does not seem to be the case (see Table 4 of Bell, Hesser and Cannon, 1983).

Wing: Have you tried computing synthetic B-V colors from the Bell-Gustafsson model spectra to see what range in B-V can be produced by the observed range in molecular band strength?

Hesser: The general question of colors of the models is discussed briefly by Bell, Hesser and Cannon (1983). For the 47 Tuc dwarfs the UV CN-bands are enhanced in some stars, but the 4216 Å bands are too weak to affect the (B-V) color at observable levels. For extreme CN stars, such as those observed on the NGC 1851 giant branch (Hesser et al, 1982), color differences would be expected, but Roger Bell would have to answer your question.