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A Comparison of Globular Cluster and Halo Field Stars

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Abstract. Abundances of the light elements O, Na, Mg and Al in giants of four globular clusters having [Fe/H](~ -1.6) are compared with halo field giants having [Fe/H] between -1.0 and -2.5. The last-named reflect the abundances expected in Type II supernova ejecta. Abundance anomalies among these elements, reflecting proton-capture synthesis, increase in severity along a "sequence" corrresponding to "halo field", NGC 7006, M3, NGC 6752 and finally M13. The results are discussed in terms of deep mixing vs primordial scenarios.

Key words. Abundances in Globular Cluster stars – halo stars – self–pollution – deep mixing

1. Introduction

It is generally agreed that deep convective mixing of envelope material into a region just above the hydrogen-burning shell of low-mass, low-metallicity giants results in the conversion of ^{12}C into ^{13}C and C into N; halo field and globular cluster giants having [Fe/H] <–1.0 all share in this phenomenon (e.g. Gratton et al. 2000; Smith 2002; Briley, Cohen & Stetson 2003). Less clear, however, is the origin of the anomalous abundances of light elements such as O, Na, Mg and Al which are found among low-metallicity globular cluster giants but not among their halo field giant analogs. Many clusters exhibit a pronounced anticorrelation of O and Na plus an equally pronounced correlation of Al with Na. In M13 the largest O depletions and Na and Al enhancements are found among the most luminous cluster giants (Kraft et al. 1993; Sneden et al. 1997; Cavallo & Nagar 2000), thus suggesting an evolutionary, deep mixing origin for these light metal anomalies. But whatever the mechanism, the surface chemical compositions of most cluster giants reflect the products of multiple proton-capture chains (e.g., Langer, Hoffman & Zaidins 1997; Denissenkov et al. 1998) which involve conversion not only of C to N, but also O to N, Ne to Na and Mg to Al. Recently, however, evidence has surfaced from studies of near main sequence stars in NGC 6752 (Gratton et al. 2001) which shows that these light element anomalies exist ab initio, long before stars ascend the first giant branch, and therefore must be the product of nucleosynthetic events occurring in material destined to be incorporated in the low-mass stars we presently see turning off the main sequence. Moreover, giants of NGC 6752 (Yong et al. 2003) exhibit anomalously high ratios of ^{25}Mg and ^{26}Mg relative to ^{24}Mg, values at odds with the predicted ratios in Type II supernovae ejecta. Similar overabundances had been found earlier in a small sample of giants in M13 (Shetrone 1996). These results strongly suggest that metal-poor globular cluster stars suffer significant "pollution" from material that had been processed by 3 to 6 solar-mass low-metallicity cluster AGB stars (Siess, Livio & Lattanzio 2002; Ventura, D'Antona & Mazzitelli 2002), despite the fact that oxygen often shows depletions of a factor of 10 or more.

Confronted with this contradictory evidence, we eschew extensive discussion of the causes and use the occasion to illustrate the striking differences among halo stellar populations at a common metallicity, in this case [Fe/H] $\sim$ -1.6, the peak of the halo metallicity distribution function. We compare halo field giants with dwarfs, and these with globular clusters M13, NGC 6752, M3, and NGC 7006. The main difference among these clusters is the so-called 2nd parameter, which describes their differing HB morphologies. In order listed, their HB's become redder: M13 and NG 6752 have similarly blue HB's. Although age is widely believed to be the cause of the 2nd parameter, other factors have been invoked including deep mixing (Sweigart 1997) in giants, and differences in the ab initio He abundance (Johnson & Bolte 1998). We consider whether the 2nd parameter problem is related at all to the light-metal abundance anomalies.

Space limitations preclude an extensive discussion of these anomalies, including figures that illustrate the correlations among light elements. We therefore summarize conclusions reached from inspection of the two most interesting relationships: (1) Na vs O and (2) Na vs Mg.

2. The Na vs O Anticorrelation: Deep mixing or primordial effect?

There is no anticorrelation of Na with respect to O among halo low-metallicity ([Fe/H] <– 1.0) field giants. Average values of [O/Fe] and [Na/Fe] are +0.3 and –0.05, respectively.

The four clusters considered here, which have metallicities near –1.6, exhibit a Na/O anticorrelation, which becomes progressively more extreme as we pass from NGC 7006 through M3, NGC 6752 and on to M13, where [O/Fe] approaches –1.0 as [Na/Fe] approaches +0.8 (Sneden et al. 2004).

The anticorrelation no doubt results from proton captures on ^{22}Ne to produce ^{23}Na in a nucleosynthetic site where O is being transformed to N.

In M13, the most O-poor giants are found nearest the red giant tip, suggesting that the Na to O anticorrelation is related to stellar evolution and deep mixing.

Against this interpretation is the finding that M3 and M13 giants exhibit a strong correlation of [Al/Fe] and [Na/Fe] (Shetrone 1996; Cavallo & Nagar 2000). The largest values of [Al/Fe] in M13 exceed those in M3 by a factor of 2. If ^{23}Na and ^{27}Al arise in the same nucleosynthetic site as a result of proton captures on ^{22}Ne and ^{24}Mg, then deep mixing is ruled out, since the H-shell temperature is too low for the effective operation of the reaction ^{24}Mg(p,γ)^{25}Al (Powell et al. 1999).

The HB morphologies of NGC 6752 and M13 are quite similar, yet their Na vs O anticorrelations are distinctly different.

3. [Na/Fe] vs [Mg/Fe] as a Surrogate for the Odd-Even Effect

Halo field giants and subdwarfs having [Fe/H] < –1 lie along the relationship [Na/Fe] = 3.50[Mg/Fe] - 0.9, thus indicating that the relationship is not dependent on stellar evolution.

The [Na/Mg] ratio among halo field stars varies from about –0.9 to 0.0, in agreement with the predictions of explosive and/or hydrostatic carbon burning (Arnett 1971).

Halo field stars on high energy and high (absolute) angular momentum orbits statistically prefer the smallest values of [Na/Fe] and [Mg/Fe], with [Na/Mg] near -0.7. Since the range in Na abundance is about 3 times that of the range in Mg, Na much exceeds Mg as an effective probe of the relationship between abundances and Galactic kinematics (Fulbright 2002).

In three of the clusters considered here, NGC 7006, M3 and NGC 6752, most of the giants lie near the field star Na vs Mg relationship, with [Na/Mg] in the range –0.5 to +0.3. In M3 and NGC 6752, a few giants show evidence of proton capture synthesis of ^{22}Ne into ^{23}Na.

Giants of M13 present a strikingly different picture, many stars, especially ones near the red giant tip, having [Na/Mg] approaching +1.0. There is little doubt that many M13 giants suffer significant proton capture synthesis of ^{22}Ne into ^{23}Na.

Red giant tip stars of M13 (Shetrone 1996) and NGC 6752 (Yong et al. 2003) satisfy the same anticorrelated behavior of (^{25}Mg + ^{26}Mg)/^{24}Mg and [O/Fe], but the relationship is more extreme in M13 than NGC 6752 (Sneden et al. 2004). Enhancement of the rare isotopes of Mg would be expected in the material forming the secular outflow of 3 to 6 solar mass cluster stars. This suggests that the atmospheres of present red giants in M13 and NGC 6752 have been ablated or polluted by such material, and thus that the low oxygen seen in these M13 giants is not a result of deep mixing, but rather of primordial or pollution processes.

It is a curious coincidence that the most polluted red giants of M13 have only just now arrived at the red giant tip, exactly where the effect of deep mixing, if indeed it exists, would be most easily manifest.

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