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Rubidium and lead abundances in globular clusters

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Abstract. We present a brief and biased summary of key star-to-star abundance variations recently observed in globular clusters and some possible explanations for these variations. Measurements of the neutron-capture elements rubidium (Rb) and lead (Pb) in the globular clusters M 13 and NGC 6752 are then presented along with preliminary measurements in M 4 and M 5. The abundance ratios [Rb/Zr] and [Pb/Fe] are used to test the globular cluster AGB pollution scenario and to gain insight into AGB nucleosynthesis.

Key words. Stars: abundances – Galaxy: globular clusters – Galaxy: abundances

1. Introduction

For many years globular clusters have been known to exhibit star-to-star abundance variations of the light elements C, N, O, Na, Mg, Al and now F. The familiar anticorrelations between C and N, O and Na, and Mg and Al indicate that the abundance variations are the likely result of hydrogen-burning at high temperatures via the CNO, Ne-Na, and Mg-Al cycles. However, the nucleosynthetic sites and mechanisms responsible for the star-to-star abundance variations remain unknown. (See contributions by D'Antona and Karakas for additional details as well as the recent review by Gratton et al. 2004 and references within.)

An evolutionary component to the abundance variations is demanded by the systematic variation of C (Suntzeff & Smith 1991) and Li (Grundahl et al. 2002) abundances along the RGB. That is, internal mixing and nucleosynthesis within the present cluster members is required to account for some of the observed abundance variations.

A primordial component must also be invoked to explain the O, Na, Mg, and Al variations now observed in main sequence turn-off stars and early subgiants (Gratton et al. 2001). That is, the cluster gas must have been inhomogeneous when the stars formed since the internal temperatures of main sequence stars do not allow the operation of the Ne-Na and Mg-Al cycles. One possibility is that the cluster gas was polluted by intermediate mass AGB stars

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(Cottrell & Da Costa 1981) that have experienced hot bottom burning.

While the AGB pollution scenario is appealing and can qualitatively account for the abundance variations, a quantitative test reveals serious problems (Fenner et al. 2004; Lattanzio et al. 2004). Even the highest mass AGB models do not have envelope compositions that match the most O-poor, Al-rich cluster stars. And even if the highest mass AGB models did have the correct envelope compositions, an extremely unusual IMF may then be required to provide sufficient material to pollute an entire globular cluster. However, theoretical AGB yields are critically dependent on the treatment of convection and the assumed mass-loss rate such that the predictive power of AGB models is limited (see the contribution by Ventura as well as Ventura & D'Antona 2005).

Isotope ratios of Mg offer a powerful insight into the stars responsible for the abundance variations since the individual isotopes are destroyed at different temperatures within RGB and AGB stars. Indeed, the observed variation in isotope ratios (Shetrone 1996; Yong et al. 2003, 2006a) require very high temperatures such as those found in AGB stars of the highest mass at their maximum luminosity (Karakas & Lattanzio 2003).

While measurements also reveal that O-rich, Al-poor cluster giants have elemental abundance ratios identical to field stars at the same metallicity, the Mg isotope ratios in cluster giants far exceed those expected from metal-poor supernovae alone (Timmes et al. 1995). The Mg isotope ratios in O-rich, Al-poor cluster giants also exceed those found found in field stars at the same metallicity. We therefore suggested that two separate generations of AGB stars have affected globular clusters. A prior generation of metal-poor AGB stars can raise the small amounts of ^{25}Mg and ^{26}Mg produced by metal-poor supernovae to match the higher levels observed in the O-rich, Al-poor cluster stars. Varying degrees of pollution from intermediate-mass AGB stars (of the same metallicity as the present cluster members) then produces the star-to-star abundance variations.

2. Heavy element variations?

For elements heavier than Al, there is evidence that some clusters show star-to-star abundance variations. In the metal-poor globular cluster M 15, Ba and Eu have been found to vary (Sneden et al. 1997) but the ratio [Ba/Eu] is constant and matches the scaled solar *r*-process value. So AGB stars have not played a role in the evolution of M 15.

For NGC 6752, we found correlations between Si and Al, Y and Al, Zr and Al, and Ba and Al. Though the correlations were statistically significant, the amplitude of the variation was small, i.e., Si, Y, Zr, and Ba may increase by 0.1 dex as Al increases by 1.3 dex (Yong et al. 2005). The possible Si variation can be understood to result from leakage from the Mg-Al chain into Si via ^{27}Al(p,γ)^{28}Si. The possible variations of Y, Zr, and Ba imply that the stars responsible for the Al variation (and presumably O, Na, and Mg) also produced a small amount of *s*-process elements.

3. Rb and Pb measurements and results

The neutron-capture elements Rb and Pb offer further insight into the stars responsible for the O-Al variations. In particular, these elements provide a powerful test for the AGB pollution scenario.

In metal-poor AGB stars, large overabundances of Pb can be expected if the number of neutrons per seed nuclei exceeds a certain value (Busso et al. 2001). Due to a critical branching point at ^{85}Kr, high mass AGB stars may produce a large amount of Rb relative to Sr, Y, and Zr (Lambert et al. 1995). (See contribution by Pignatari regarding possible complications with the ^{85}Kr branch and the contribution by García who found a star with very high [Rb/Fe] and [Rb/Zr].) Therefore, if high mass metal-poor AGB stars have affected the evolution of globular clusters, we may expect to find high ratios of [Pb/Fe], [Rb/Fe], and [Rb/Zr] along with correlations between Rb and Al as well as Pb and Al.

High resolution, high signal-to-noise ratio spectra were obtained using the Subaru

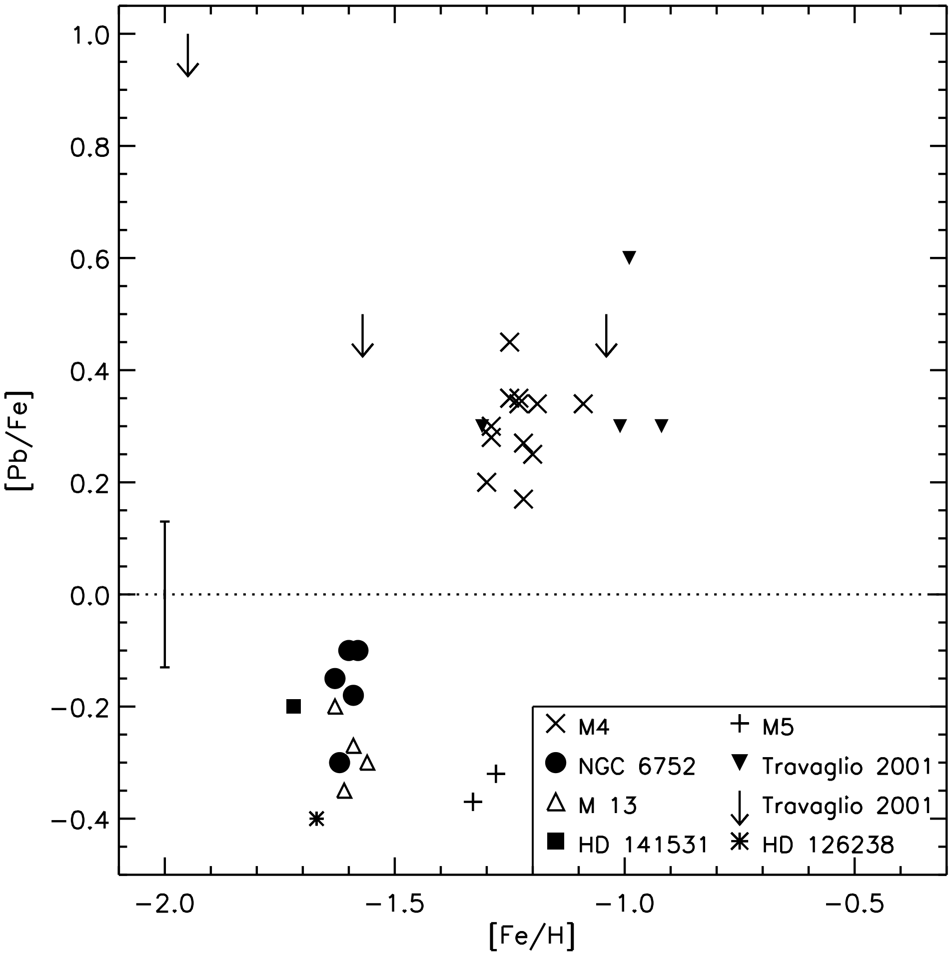

Fig. 1. Lead abundances versus metallicity for globular clusters and comparison field stars. (HD 141531 is a field giant studied by Yong et al. 2006b; HD 128238 is a field giant studied by Sneden et al. 1998; additional field stars were studied by Travaglio et al. 2001.)

Telescope and the Magellan Telescope. Data reduction and determination of the stellar parameters were conducted in the standard manner. Measurements of the Pb abundance were based on the 4058 Å line for which spectrum synthesis was required. The Rb abundance was determined from spectrum synthesis of the 7800 Å line. (See Yong et al. 2006b for further details.)

In Figure 1, the lead abundances [Pb/Fe] are plotted against metallicity [Fe/H]. For M 13 and NGC 6752 (the 2 clusters that exhibit the largest Al variation), we do not find any evidence for variation in the ratio [Pb/Fe] nor do we find a correlation between Pb and Al. While there are very few comparison field stars, we note that the lowest Pb abundances in field stars match the globular clusters.

In Figure 2, the rubidium abundances relative to zirconium [Rb/Zr] are plotted against metallicity [Fe/H]. Again, there is no evidence for variation in the Rb abundance nor is there a correlation between Rb and Al.

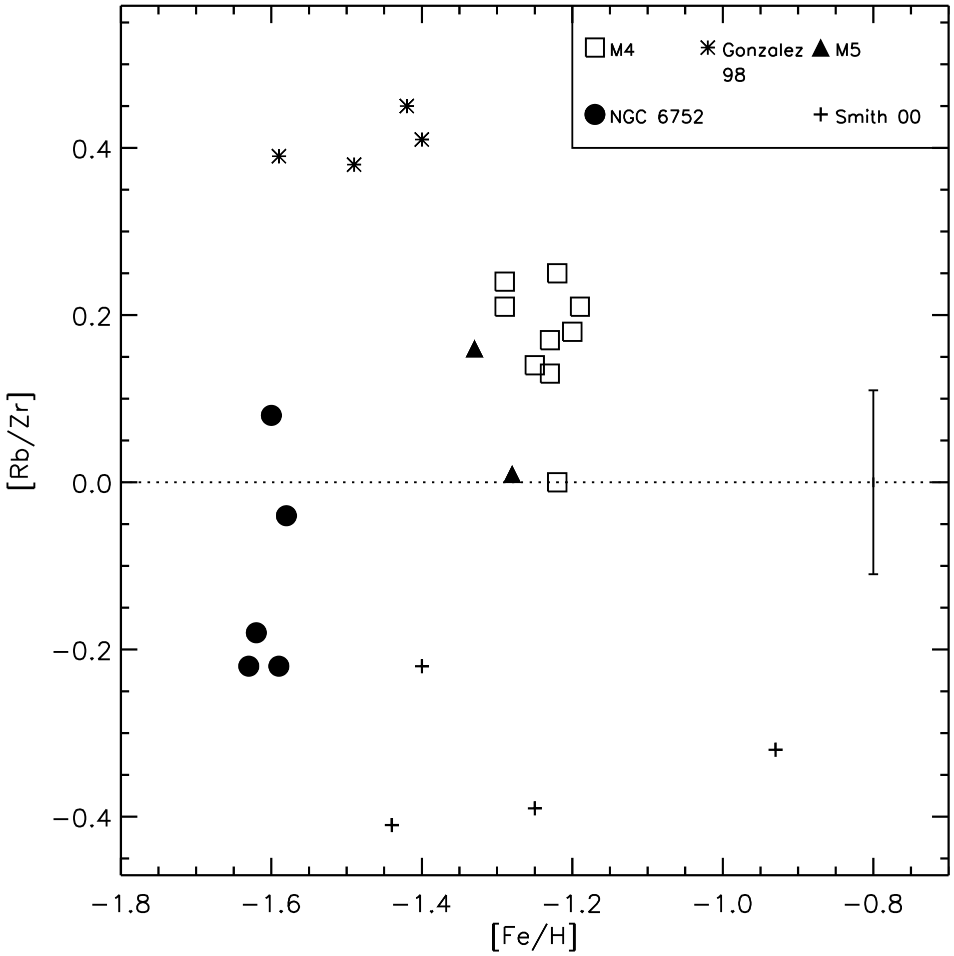

Fig. 2. Rubidium abundances versus metallicity for globular clusters. (Smith et al. 2000 studied ω Cen; Gonzalez & Wallerstein 1998 studied NGC 3201.)

4. Conclusions

For the neutron-capture elements Rb and Pb, we found no star-to-star abundance variation in the globular clusters M 13 and NGC 6752 nor did we find a correlation between Rb and Al or Pb and Al. Therefore, if metal-poor intermediate mass AGB stars are responsible for the globular cluster abundance anomalies, then they do not synthesize Rb or Pb. If such stars do synthesize Rb or Pb, then they are not responsible for the abundance variations. Most likely, metal-poor intermediate mass AGB stars do not synthesize Rb or Pb since such stars have a very small helium-burning shell, very short thermal pulse durations, and possibly a small number of thermal pulses (Lattanzio et al. 2004 and Straniero 2006 priv. comm.). The possibility exists that super-AGB stars may have contributed to the abundance variations (see contributions by Siess, Doherty, and García-Berro).

Preliminary measurements for Rb and Pb in the globular clusters M 4 and M 5 are also made and these new data are included in Figures 1 and 2. These clusters are interesting since they have comparable iron abundances and dispersions for O-Al, but M 4 is globally enhanced in Ba and La as well as Si and Al relative to M 5 (Ivans et al. 1999, 2001). The s-process enhancements in M 4 and ω Cen are likely due to pollution from a large number of AGB stars which may require an unusual IMF. The ratios [Zr/Fe], [Ba/Fe], and [La/Fe] are about 0.3 dex higher in M 4 than in M 5. Comparing Rb and Pb between these 2 clusters offers an insight into AGB nucleosynthesis. While [Rb/Fe] is higher in M 4 than in M 5, the ratio [Rb/Zr] is essentially identical in these 2 clusters. This suggests that similar mass AGB stars (presumably low mass) synthesized the s-process elements in both clusters. The ratio [Pb/Fe] is roughly 0.6 dex higher in M 4 than in M 5. Therefore, the AGB stars that affected the evolution of M 4 overproduced Pb relative to lighter s-process elements. We note that neither cluster shows any evidence for variation in Rb or Pb. More measurements of Rb and Pb in field and cluster stars offer the chance to further refine our knowledge of AGB evolution and nucleosynthesis.

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