Magnesium Isotopes in Halo Stars

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Abstract. We have determined Mg isotope ratios in halo field dwarfs and giants in the globular cluster M71 based on high S/N high spectral resolution (R = 10^5) Keck HIRES spectra. Unlike previous claims of an important contribution from intermediate-mass AGB stars to the Galactic halo, we find that our $^{26}Mg/^{24}Mg$ ratios can be explained by massive stars.

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INTRODUCTION

Magnesium is composed of three stable isotopes ^{24}Mg, ^{25}Mg and ^{26}Mg, which can be formed in massive stars (e.g. Woosley & Weaver 1995). The lightest isotope is formed as a primary isotope from H, while $^{25,26}Mg$ are formed as secondary isotopes. The heaviest Mg isotopes are also produced in intermediate-mass AGB stars (Karakas & Lattanzio 2003), so the isotopic ratios $^{25,26}Mg/^{24}Mg$ increase with the onset of AGB stars. Therefore, Mg isotopic ratios in halo stars could be used to constrain the rise of AGB stars in our Galaxy.

It is important to know when AGB stars begin to enrich the halo in order to disentangle the contribution of elements produced by intermediate-mass stars from those produced by massive stars. For example, the high nitrogen abundances observed in metal-poor stars can be explained by fast-rotating massive stars (e.g. Chiappini et al. 2006) or alternatively by intermediate-mass stars, although the latter option may be unlikely because those stars may not have had time to enrich the halo due to their longer lifetime.

The study of Mg isotope ratios is also important to understand the abundance variations in globular clusters (e.g. Yong, Aoki & Lambert 2006; Prantzos, Charbonnel & Iliadis 2007).

Mg isotopic abundances can be obtained from the analysis of MgH lines in cool stars (e.g. Boesgaard 1968; Tomkin & Lambert 1980; Barbuy 1985, 1987; McWilliam & Lambert 1988; Gay & Lambert 2000; Yong, Lambert & Ivans 2003; Meléndez & Cohen 2007).

In this work, we determine Mg isotopic ratios in cool halo dwarfs and giants in the globular cluster M71 employing high resolution high S/N spectra taken at Keck.

MG ISOTOPES IN HALO DWARFS

Three cool halo dwarfs were observed at Keck I employing the upgraded HIRES (Vogt et al. 1994) which provides now a maximum resolving power of R $\approx 10^5$. For details see Melendez & Cohen (2007).

The isotopic ratios were obtained from three wavelength regions at 5134.6, 5138.7 & 5140.2 Å (e.g. McWilliam & Lambert 1988; Yong et al. 2003). Isotope ratios were obtained by spectral synthesis using a new line list including atomic lines, C_2 & MgH lines (Meléndez & Cohen 2007). Macroturbulence was estimated using the Ni I 5115.4 Å and Ti I 5145.5 Å lines, and other lines around 5585 Å.

Low $^{25,26}Mg/Mg$ ratios were obtained (Meléndez & Cohen 2007), in agreement with bona-fide halo dwarfs from Yong et al. (2003). These low ratios are in good agreement with yields of massive stars (e.g. Goswami & Prantzos 2000; Fenner et al. 2003).

MG ISOTOPES IN M71 GIANTS

Five giants in the globular cluster M71 ([Fe/H] = -0.7, Ramírez et al. 2001) were observed with HIRES at R = 10^5. We present the analysis of three of them and also of M71 A4 obtained with the HDS at Subaru by Yong et al. (2006). The latter reduced spectrum was kindly made available to us by D. Yong & W. Aoki.

In Fig. 1 we compare our M71 1-77 Keck spectrum with the Subaru spectrum of M71 A4 (Yong et al. 2006). As it can be seen, even though the spectra are of two different stars (although of similar stellar parameters), the similarity is very impressive, showing that both data reductions are in excellent agreement.

The atmospheric parameters have been determined as in Cohen et al. (2001). Iron lines were used to estimate
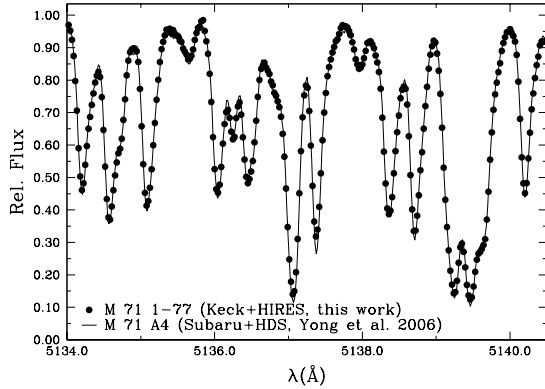
FIGURE 1. Comparison of M71 1-77 observed with Keck+HIRES (circles, this work) and M71 A4 observed with Subaru+HDS (line, Yong et al. 2006). Both stars have similar stellar parameters.
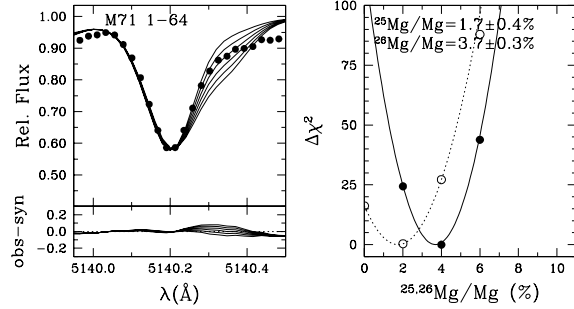

FIGURE 2. Fits for the 5140.2 Å region in the giant M71 1-64. Observed spectra are represented with filled circles, and synthetic spectra with solid lines. The calculations were performed for ^{25,26}Mg/Mg ratios of 0, 2, ... 10 %. The relative variation of the χ^2 fits are shown as a function of the isotopic abundance.

the microturbulence, [Fe/H] and to check the stellar parameters. The iron lines were carefully selected in order to avoid blends by atomic and CN lines. CN blends were visually inspected by comparing a synthetic spectrum computed with laboratory CN lines (e.g. Meléndez & Barbuy 1999; Coelho et al. 2005) with the high resolution visible atlas of the cool giant Arcturus (Hinkle et al. 2000).

Reliable laboratory oscillators strengths are not available for a large fraction of the FeI lines, so the lines with accurate oscillator strengths were used to provide the zero point of astrophysical gf-values. The oscillator strengths for FeII lines are from the laboratory normalization performed by Meléndez et al. (2006).
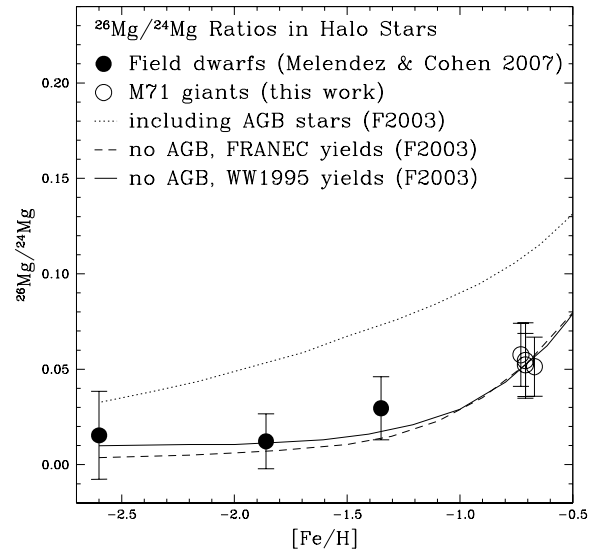
A good determination of the stellar intrinsic broadening is necessary for a reliable determination of Mg isotope ratios. The intrinsic broadening is due to both rotation and macroturbulence (e.g. Hekker & Meléndez 2007), but in old metal-poor stars we expect the intrinsic broadening to be mostly due to macroturbulence. In these cool metal-rich giants the usual diagnostics for macroturbulence (Ni I 5115.4 & Ti I 5145.5 Å) seem blended so other lines were used for the determination of the macroturbulence velocity.

As for the field dwarfs, the isotope ratios in giants were determined from three regions, except that in our cool giants the 5134.6 Å feature seems blended, so instead we use the 5134.3 Å feature. A χ^2 fit for the 5140.2 Å region is shown in Figure 2.

Our Mg isotope ratios are shown in Figure 3, where a comparison with models (Fenner et al. 2003) is also shown. Our data favors massive stars instead of intermediate-mass AGB stars even at the high metallicity of M71 ([Fe/H] = -0.7)

FIGURE 3. ^{26}MgH/^{24}MgH as a function of [Fe/H] in halo dwarfs (filled circles) and M71 giants (open circles). Models including massive stars and intermediate-mass AGB stars (Fenner et al. 2003 [F2003]) are also shown. The no AGB model agrees better with the observed data.

O, NA, MG AND AL IN M71 GIANTS

We have also determined abundances of O, Na, Mg and Al in M71 giants. The abundances were determined by both equivalent widths and spectral synthesis.

Unlike other clusters that show large abundance variations (e.g. Cohen & Meléndez 2005), the four giants in M71 have essentially identical O, Na, Mg and Al abundances. Note that the Mg isotope ratios in these four giants is also constant within the errors (Fig. 3). High reso-

lution observations of a larger number of M71 giants will be important in order to determine how homogeneous this cluster is.

The oxygen abundance of M71 giants seems undepleted, and consistent with the constant [O/Fe] ratio for halo stars found by Meléndez et al. (2006) and Ramírez, Allende Prieto & Lambert (2007), in the broad metallicity range $-3.2 < $ [Fe/H] $ < -0.4$.

CONCLUSIONS

Our ^{26}Mg/ ^{24}Mg ratios in both field dwarfs and M71 giants can be explained by massive stars (e.g. Fenner et al. 2003). Even at the high metallicity of M71 ([Fe/H] = -0.7) there is no need to invoke an important contribution from intermediate-mass AGB stars.

We plan to obtain more high resolution high S/N HIRES spectra of more field halo dwarfs and M71 giants.

ACKNOWLEDGMENTS

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