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The rise of AGB stars on the Galactic halo

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Abstract. We determine isotopic magnesium abundances of metal poor dwarf stars to shed light on the onset of AGB stars in the galactic halo and constrain its formation timescale. We obtain magnesium isotopic abundances by spectral synthesis on three MgH features for six halo K dwarfs observed with the HIRES spectrograph at the Keck Observatory (R $\approx 10^5$ and $200 \leq S/N \leq 300$). We compare our results with galactic chemical evolution models. With the current sample we almost double the data from the literature, which allowed us to determine the metallicity when the ^{25,26}Mg abundances start to became important over ^{24}Mg abundances, [Fe/H] ~ -1.4.

Key words. Galaxy: halo stars – magnesium isotopes – AGB stars

1. Introduction

The study of the chemical composition of stars is crucial to understanding the formation history of our Galaxy. Elemental abundances in disk and halo stars in our galaxy provide information about the formation and evolution of those objects. In particular, main sequence stars (that is, stars not affected by stellar evolution) provide the chemical composition at the time and place that the stars were formed. Thus, studying dwarf stars of different populations, metallicities and ages, can provide clues about the different components of our galaxy and also how it was formed and how it evolved.

There are several models in the literature that predict the chemical evolution of the Galaxy (e. g. Timmes et al. 1995; Chiappini et al. 1997; Goswami & Prantzos 2000). Chemical evolution models include many uncertain inputs including the star formation rate, the initial mass function and stellar yields. The most powerful way to test the validity of these assumptions is to use observational data of stars. Therefore, the observation of the chemical composition of stars of different populations of the Milky Way is extremely important since they provide observational links to models of formation and evolution of the Galaxy.

In particular, the models of Fenner et al. (2003), Kobayashi et al. (2011) and others include the chemical abundances of magnesium and its stable isotopes: ^{24}Mg, ^{25}Mg and ^{26}Mg.

The isotope ^{24}Mg is produced inside massive stars before the supernova explosion (Woosley & Weaver, 1995), while the isotopes ^{25}Mg and ^{26}Mg are also produced in massive stars and in intermediate mass stars through the reactions $^{22}Ne(\alpha,n)^{25}Mg$ and $^{25}Mg(n,\gamma)^{26}Mg$ (Karakas & Lattanzio, 2003).

As the different magnesium isotopes are formed in different types of stars, understanding how this element is produced is crucial to understanding how the chemical evolution of the galaxy works.

Despite the fact that there are several works in the literature about magnesium isotopes (e.g. Barbuy 1985, Barbuy 1987, Gay &

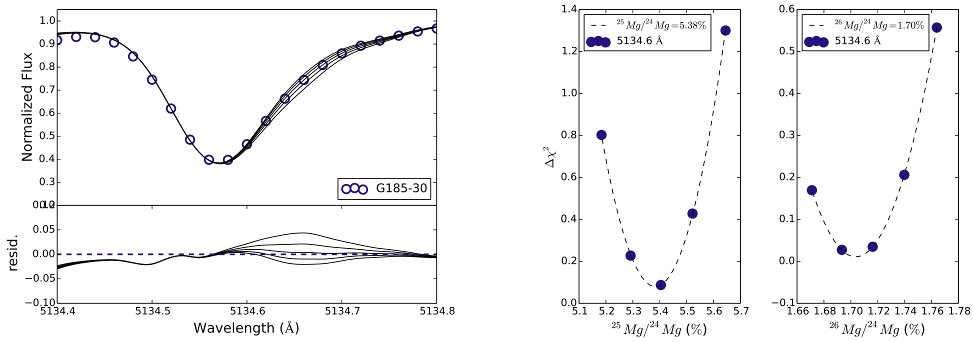

Fig. 1. The left panel shows the MgH 5134.6 Å region with the observed spectrum (blue open circles) and the respective spectral synthesis for five different values represented by black solid lines. The right panel shows the χ^2 analysis with the best value of ^{25}Mg and ^{26}Mg. Both panels are for the star G 185-30. Figure from Carlos et al. 2017 (submitted).

Lambert 2000, Yong et al. 2003a, Yong et al. 2003b, Meléndez & Cohen 2007, Meléndez & Cohen 2009), we have limited data for halo dwarfs. In this work we expand the limited data set with a new sample, trying to evaluate when the ^{25,26}Mg abundances start to became important over ^{24}Mg abundances and, therefore, the onset of AGB stars on the Galactic halo.

2. Observations

In the present work we analyze five K dwarf stars from the galactic halo.

These stars were observed with the HIRES spectrograph (Vogt et al., 1994) at the Keck Observatory ($R \approx 10^5$ and $200 \leq \mathrm{S/N} \leq 300$). The spectral orders were extracted with MAKEE[1]. For other calibrations such as Doppler correction, combining spectra and continuum normalization we used IRAF[2].

The stellar temperatures were inferred adopting the photometric calibration from Casagrande et al. (2010). The [Fe/H] and microturbulence values were determined by measuring FeI and FeII lines with the aid of IRAF and the July 2014 version of the 1D LTE code MOOG (Sneden, 1973), using the line list of Chen & Zhao (2006). Surface gravity values are adopted from the literature (Ramírez & Meléndez 2005 and Yong & Lambert 2003). The stellar parameters are shown in Table 1.

3. Analysis and discussion

To derive the Mg isotopic abundances we have to employ spectral synthesis of MgH features.

The magnesium isotopic abundances were measured with the aid of the code MOOG and by performing a χ^2 fit, where $\chi^2 = \Sigma(O_i - S_i)/\sigma^2$, with O_i and S_i being the observed and synthetic spectrum and $\sigma = (S/N)^{-1}$.

A comparison of spectral synthesis and observed spectra is shown in the left panel of Fig. 1. The right panel of the Fig. 1 displays the variations of the χ^2 fits.

The isotopic values are presented in Table 1. The ^{25,26}Mg errors are the standard deviation between the isotopic ratios of the three regions adopted in this work. The scatter in the isotopic percentages is only about 1%, showing the high precision achieved.

The results including our analysis plus data from the literature are shown in Fig. 2. There is a fine agreement between the stars from our sample with those from the literature and the models of Fenner et al. (2003) (which do not include AGB stars) and Kobayashi et al.

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[1] MAKEE was developed by T. A. Barlow specifically for reduction of Keck HIRES data. It is freely available at `http://www.astro.caltech.edu/~tb/makee/`.

[2] `http://iraf.noao.edu/`.

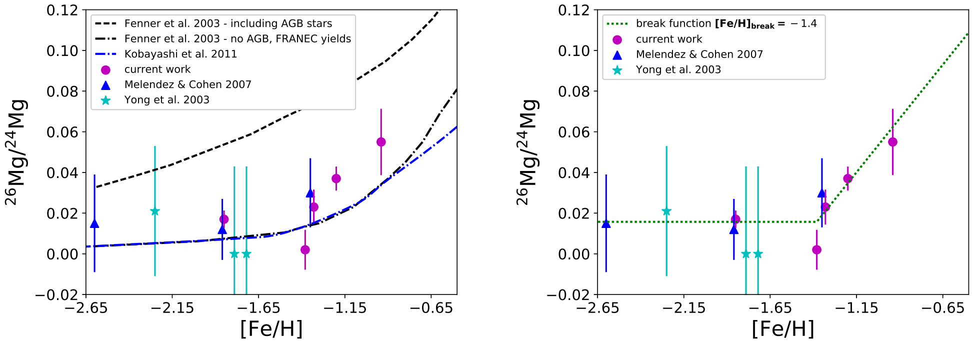

Fig. 2. In both panels purple circles represent our data , blue triangles show the data from Meléndez & Cohen (2007) and the cyan stars are from Yong et al. (2003b). In the left panel the black solid line shows a model from Fenner et al. (2003) with no AGB contribution, the black dashed line shows a model from the same work with AGB contribution and the model from Kobayashi et al. (2011) is represented by the blue dash-doted line. The green dotted line in the right panel shows the break function for all the observed data. Figure from Carlos et al. 2017 (submitted).

Table 1. Stellar parameters and Magnesium isotopic ratios (Carlos et al. 2017, submitted).

Object	$T_{eff.}$ (K)	[Fe/H]	log g (dex)	$v_{mic.}$ (km.s^{-1})	^{25}Mg (%)	^{26}Mg (%)
G 185-30	4524	-1.85±0.01	4.5^{a}	0.00	4.0±0.3	1.6±0.4
G 128-61	4664	-0.94±0.02	5.0^{b}	0.00	8.0±1.0	4.8±1.6
G 78-26	4288	-1.20±0.02	4.7^{b}	0.24	5.3±0.2	3.4±0.6
G 189-45	4937	-1.33±0.01	4.3^{b}	0.00	4.6±1.1	2.2±0.9
LHS 3780	4880	-1.38±0.01	4.5^{b}	0.00	4.5±0.1	0.0±1.0
Sun	5777	0.00	4.44	1.00	10.00^{c}	11.01^{c}

Notes. $^{(a)}$Ramírez & Meléndez (2005). $^{(b)}$Yong & Lambert (2003). $^{(c)}$Asplund et al. (2009). $^{(*)}$Magnesium isotopic ratios are given with respect to ^{24}Mg + ^{25}Mg + ^{26}Mg.

(2011) (which includes AGB stars) for stars with [Fe/H] < −1.4. However, the model of Fenner et al. (2003) considering the AGB contribution does not match with any results.

For stars with [Fe/H] > −1.4, the data differ considerably from the models. The data suggest higher yields of the neutron rich isotopes, in contrast to current yield predictions.

We can see in Fig. 3 the ^{25,26}Mg contribution to the interstellar medium from AGB stars with different masses and [Fe/H] = −1.4.

From Fig. 3 it is possible to note that the largest contribution comes from stars between $\sim 3-4$ M$_{\odot}$, as showed in Shingles et al. (2015). In this mass interval the estimated lifetime is between ~ 150 and ~ 300 million years. Thus, our preliminary results suggest this upper limit for the formation timescale of the Galactic halo, in agreement with another approach by Brusadin et al. (2013).

4. Conclusions

We conclude that ^{25,26}Mg abundances start to became important over ^{24}Mg abundances for stars with [Fe/H] > −1.4.

For this metallicity the largest contribution to the heaviest Mg isotopes come from AGB stars with mass about 3 to 4 M$_{\odot}$, which have a lifetime between about 150 and 300 million of

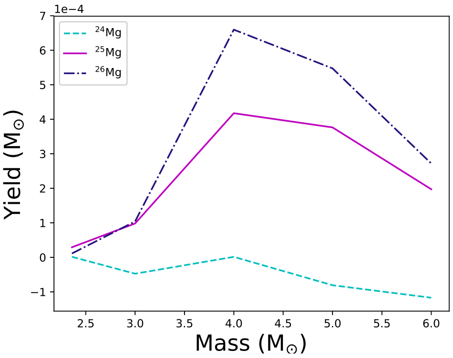

Fig. 3. Data from Shingles et al. (2015) showing the yields for stars with [Fe/H] > −1.4 and masses from 2.4 $M_\odot$ to 6 $M_\odot$.

years, which is therefore an upper limit for the timescale formation of the Galactic halo.

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