The Rise of AGB Stars in the Galactic Halo

Mg isotopic abundances in metal-poor dwarfs

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CAPES

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SAMPA
Stellar Atmospheres Planets and Abundances

Introduction

- The study of the chemical composition of stars is crucial to understanding the formation history of our Galaxy.
- The formation timescale of the Galactic halo is still in debate → chemical evolution models find values that vary from 0.2 to 2 Gyr (Micali et al. 2013; Chiappini et al. 1997).

Introduction

Magnesium isotopic abundances are a useful tool to shed some light on the timescale formation of the Galactic halo problem:

$\Rightarrow$ The different Mg isotopes, $^{24,25,26}\mathrm{Mg}$, are produced in different sites (different stars) $\rightarrow$ they trace stellar (and Galactic) evolution over short and long timescales!

Introduction

The main sites of production of the Mg isotopes:

- ^{24}Mg is produced during core carbon and neon burning before the supernova explosion:
    - $^{12}\mathrm{C}(^{12}\mathrm{C},\mathrm{p})^{23}\mathrm{Na} \rightarrow {}^{23}\mathrm{Na}(\mathrm{p},\gamma)^{24}\mathrm{Mg} \Rightarrow$ core carbon burning.
    - $^{20}\mathrm{Ne}(\alpha,\gamma)^{24}\mathrm{Mg}$ ($\alpha-$particles generated by $\rightarrow {}^{20}\mathrm{Ne}(\gamma,\alpha)^{16}\mathrm{O}$) $\Rightarrow$ core neon burning (Arnett & Thielemann 1985; Thielemann & Arnett 1985).

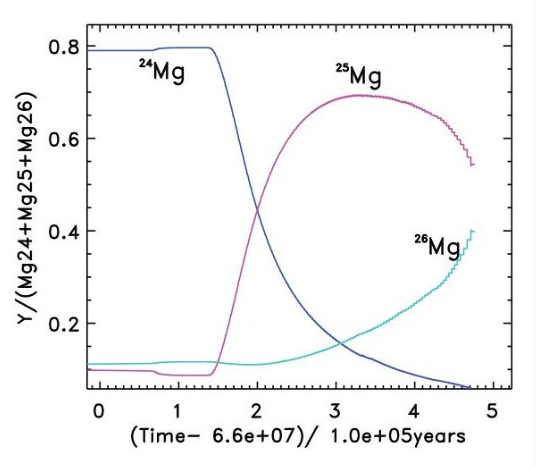
Introduction

- ^{25,26}Mg are produced in smaller amounts in massive stars:
  - $^{22}\mathrm{Na}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$, $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ and $^{25}\mathrm{Mg}(\mathrm{n},\gamma)^{26}\mathrm{Mg}$ ⇒ outer carbon layer during helium burning (Woosley & Weaver, 1995).

- But they are produced mainly in AGB stars:
  - $^{22}\mathrm{Na}(\alpha,\mathrm{n})^{25}\mathrm{Mg}$, $^{22}\mathrm{Ne}(\alpha,\gamma)^{26}\mathrm{Mg}$ and $^{25}\mathrm{Mg}(\mathrm{n},\gamma)^{26}\mathrm{Mg}$ ⇒ in the helium burning shell.
  - Mg - Al chain ⇒ in the hydrogen burning shell and also at the base of the convective envelope at Hot Bottom Burning for most massive stars (Karakas & Lattanzio, 2003).

Introduction

→ The evolution of the Mg isotopes at the surface of a 6M⊙ , Z = 0.004 ([Fe/H] ≈ −0.7) AGB model from Karakas & Lattanzio (2014).

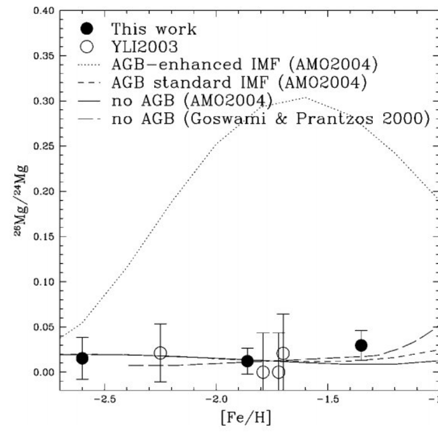


Introduction

- The study of Mg abundances in Galactic halo main sequence stars (do not have their chemical composition affected by stellar evolution yet) can determine the onset of the AGB star in the Galactic halo, adding more insight to the galactic chemical evolution process!

Introduction

- Some chemical evolution models include the chemical abundances of Mg and its stable isotopes (Fenner et al. 2003; Kobayashi et al. 2011)
- Only 7 single metal-poor stars from the Galactic halo have Mg isotopic measurements in the literature (Melendez & Cohen 2007; Yong et al. 2003).



Sample

- We observed 8 K halo dwarfs with HIRES spectrograph at Keck observatory ($\mathrm{R} \sim 10^5$ and $200 \leq \mathrm{S/N} \leq 300$)
- $4000 < \mathrm{T(K)} < 5000$ and $-2.0 < [\mathrm{Fe/H}] < -0.8$
  - → 2 double-lined stars ✗
  - → 1 with peculiar abundances → analyzed separately ✗
  - → thus, 5 stars studied in the current work! ✓

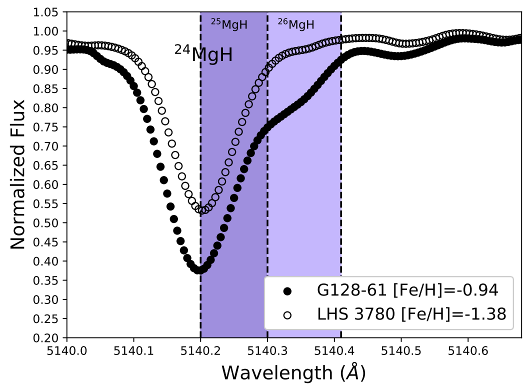
Analysis

Stellar parameters:

- $T_{\mathrm{eff.}}$ was determined using photometric calibration with B, V, J, H and Ks magnitudes.
- $[\mathrm{Fe/H}]$ and microturbulence were determined spectroscopically using Fe lines.
- values from literature for the surface gravity (log g) (Ramirez & Melendez 2005; Yong & Lambert 2003).

Analysis

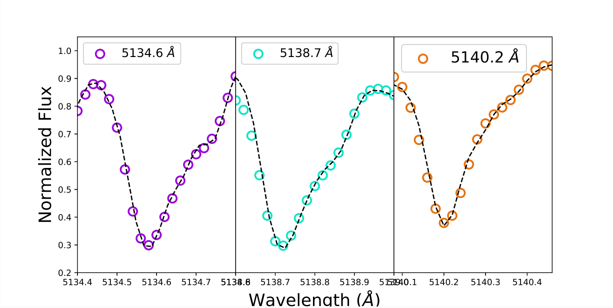
- The weak contribution of $^{25,26}\mathrm{Mg}$ in the wing of the stronger $^{24}\mathrm{MgH}$ line cause a red asymmetry in the MgH feature → spectral synthesis.



Carlos et al., submitted.

Analysis

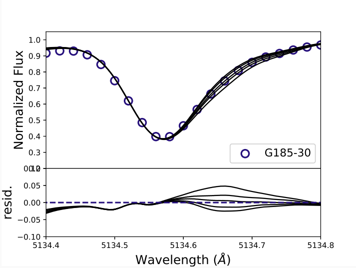
- Spectral Synthesis:
    - We use the 1D LTE code MOOG.
    - Macroturbulence velocity analyzing the line profiles Fe I 6056.0 Å, 6078.5 Å, 6096.7 Å and 6151.6 Å with $vsini = 0$ km s^{-1}
    - Selected spectra regions:
        - → 5134.6 Å
        - → 5138.7 Å
        - → 5140.2 Å
    - The errors are the standard deviation between the isotopic ratios of the three regions adopted.

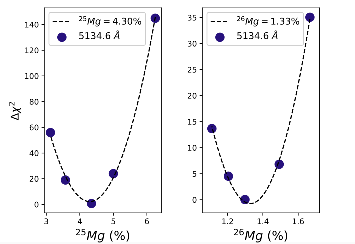


Analysis

- Several spectral synthesis for the same region with different values of $^{25,26}\mathrm{Mg}$. ⇒
- The best isotopic abundance value for each feature was given by:

$$\chi^2 = \frac{\sum(O_i - S_i)}{\sigma^2} \Rightarrow$$





Carlos et al., submitted.

Analysis

- ^{25}Mg/Mg *vs.* ^{26}Mg/Mg:
  - → According to Thygesen et al. 2017, ^{25}Mg is underestimated by up to 5% (depending on star metallicity and temperature) when using 1D models atmospheres against 3D models.
  - → However the measurement of ^{26}Mg with 1D models is more robust!

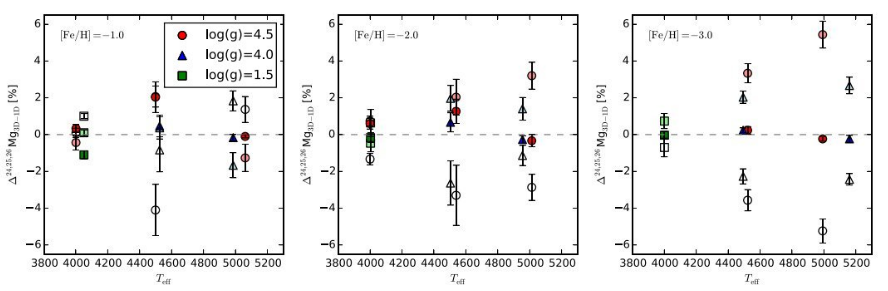


Figure 11. $\Delta^{24,25,26}$Mg$_{3D-1D}$ fractions for all models, against $T_{\rm eff}$. Symbol shapes have the same meaning as in Figure 10, but here are color coded according to the specific isotope (^{24}Mg, open symbols; ^{25}Mg, light shaded symbols; ^{26}Mg, dark shaded symbols). The error bars give the standard deviation of the mean.

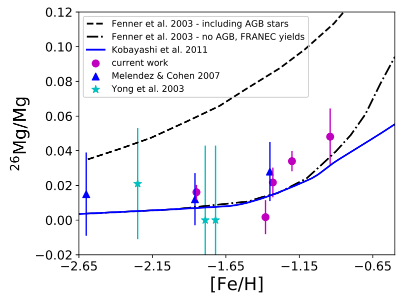
Thygesen et al. 2017

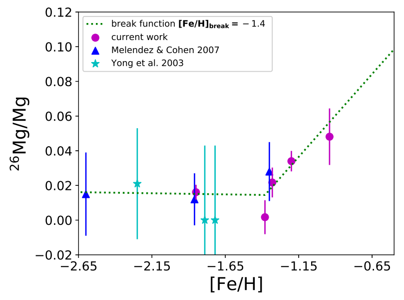
Results

→ The low metallicity AGB stars begin to contribute to galactic chemical enrichment at [Fe/H] $= -1.4$.

→ For [Fe/H] > -1.4 the data differ somewhat from either of the models:

- ∗ higher yields from the neutron rich isotopes?
- ∗ or a different value of the timescale formation of the Galactic halo?

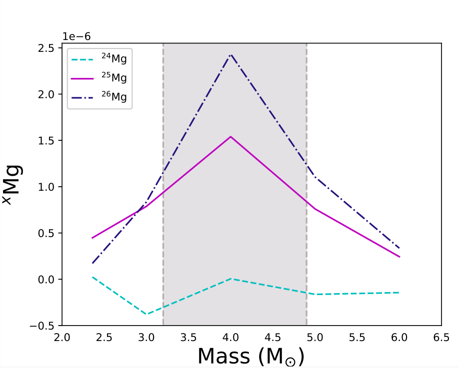




Carlos et al., submitted.

Results

→ The study of Shingles et al. (2015) suggest that for [Fe/H] $= -1.4$ the majority of the contribution of Mg isotopes come from AGB stars with $\gtrsim 4 \pm 1$ M$\odot$, which the lifetime is between $\lesssim 150 - 300$ Myr (indicating an upper limit for the formation of the Galactic halo).

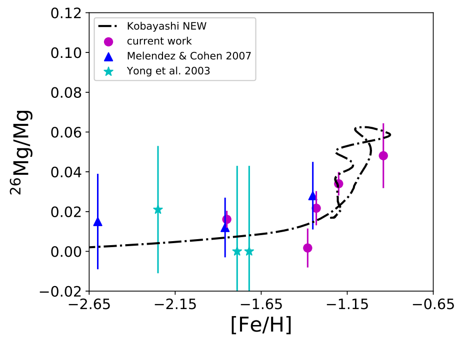


Data from Shingles et al., 2015.

Results

- ○ But we cannot reproduce our data just setting a short timescale for formation of the halo:

→ We have to consider the contribution of core-collapse supernovae for $^{24}\mathrm{Mg}$ at the same time that AGB stars produce $^{26}\mathrm{Mg}$ $\Rightarrow$ If we suppress the contribution from core-collapse supernovae and make the AGB contribution dominant (introducing a strong outflow) we can reproduce our data with a timescale for formation of the Galactic halo of $\tau_{\mathrm{H}} = 1.5$ Gyr.



Carlos et al., submitted.

Summary

- The study of the chemical composition of stars is crucial to understanding the formation history of our Galaxy.
- Magnesium isotopic abundances are a useful tool to determine the onset of effects of AGB evolution in the Galactic halo since different Mg isotopes are produced in different stars.
- The contribution of AGB stars begin at $[\mathrm{Fe/H}] = -1.4$.
- We can reproduce our data with a new model including strong outflow with $\tau_{\mathrm{H}} = 1.5$ Gyr.

Thank you!

References i

- Arnett, W. D., & Thielemann, F.-K. 1985, ApJ, 295, 589
- Chiappini, C., Matteucci, F., & Gratton, R. 1997, ApJ, 477, 765
- Fenner, Y., Gibson, B. K., Lee, H.-c., et al. 2003, PASA, 20, 340
- Karakas, A. I., & Lattanzio, J. C. 2003, PASA, 20, 279
- —. 2014, PASA, 31, e030
- Kobayashi, C., Karakas, A. I., & Umeda, H. 2011, MNRAS, 414, 3231
- Meléndez, J., & Cohen, J. G. 2007, ApJl, 659, L25
- Micali, A., Matteucci, F., & Romano, D. 2013, MNRAS, 436, 1648
- Ramírez, I., & Meléndez, J. 2005, ApJ, 626, 446

References ii

- Shingles, L. J., Doherty, C. L., Karakas, A. I., et al. 2015, MNRAS, 452, 2804
- Thielemann, F. K., & Arnett, W. D. 1985, ApJ, 295, 604
- Thygesen, A. O., Kirby, E. N., Gallagher, A. J., et al. 2017, ApJ, 843, 144
- Woosley, S. E., & Weaver, T. A. 1995, ApJS, 101, 181
- Yong, D., & Lambert, D. L. 2003, PASP, 115, 22
- Yong, D., Lambert, D. L., & Ivans, I. I. 2003, ApJ, 599, 1357