1. Observations

Recent observations of sodium in stars with metallicities up to $[Fe/H] = -0.6$ (with $Z = 1.2 \times 10^{-10}$) from Anders & Grevesse (1993) suggest a secondary component (proportional to the metallicity) in the sodium abundance at high $Z$. (See above figure.)

- Is it a chemical evolution effect?
- If so, what is the source of the sodium?
- How can we make interstellar gas with $[Fe/H] = -0.6$?
- There is considerable scatter, up to half a dex, much larger than the errors in the [Na/Fe] measurements ($\pm 0.1 - 0.2$).

2. Stellar Models

2.1 Synthetic AGB

Our models include 1st, 2nd and 3rd dredge-up, hot-bottom burning (HBB) and mass loss. $[M_3] = 0.5, 0.75, 1.0$.

AGB stars with $[Fe/H] < 0$ make sodium by HBB via the $^{14}N(\alpha,p)^{17}O$ reaction. The rate is uncertain so we vary it within experimental limits (up to $\times 3$).

The figure on the right shows surface abundance during the TPAGB phase in a $[Fe/H] = -0.4$ model, with a varying $^{14}N(\alpha,p)^{17}O$ rate. The surface abundance is uncertain by up to a factor of 40.

2.2 Supernovae

$^{56}Ni$ is made during carbon burning in massive stars and is ejected in the 26 Ni explosion at the end of the star’s life. We use the $^{56}Ni$ yields of Chieffi and Limongi (2004), which, as the figure to the right shows, are a strong function of mass and metallicity.

With a one-zone model we cannot reproduce the scatter seen even at high- $Z = -0.4$.

3. Intermediate vs High Mass

Previous studies used winds from massive stars and core-collapse supernovae models. E.g., Timmes 1995. We include yields of massive stars, from winds and explosions (GN39/95). Low/intermediate and AGB stars and type II supernovae.

The figure below shows the time- and mass-integrated yields from our stellar populations as a function of metallicity $Z$.

1. In the first 1 Gyr since the birth of the Milky Way, halo stars formed with $[Fe/H] < -4$, and the sodium abundance was dominated by yields from short-lived WRs.
2. Later, when $[Fe/H] = -2$, intermediate mass AGB stars make sodium by HBB. Overall these contribute more than supernovae, but on a longer timescale (hundreds of Gyr).
3. At high metallicity supernovae again dominate due to secondary production of sodium.

4. Galactic Chemical Evolution Models

Models:

We have implemented our stellar models into the Chiappini 1997 dual-infall one-zone Milky Way model with various assumptions.

1. Our standard models

2. SN yields of sodium $\times 2$

3. As 2 with $^{56}Ni(\alpha,\gamma)^{60}Fe$ rate $\times 10$

4. As 2 with $^{56}Ni(\alpha,\gamma)^{60}Fe$ rate $\times 2000$

5. As 2 with initial from a polluted instead of primordial IGM

Results:

1. Reducing the SN yield is necessary at solar metallicity, but is not good for $[Fe/H] = -4$.

2. A $\times 10$ increase in the $^{56}Ni(\alpha,\gamma)^{60}Fe$ rate gives too much $^{60}Fe$, but $\times 10$ is compatible with the observations.

3. It is hard to make gas with $[Fe/H] = -4$ unless we include IGM feedback or some thaumaturgy.

4. With one-zone model we cannot reproduce the scatter seen even at high-$[Fe/H]$. Is it real?

5. As 2 with infall from a polluted instead of primordial IGM

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Introduction

Galactic chemical evolution models which include sodium from type II supernovae alone underestimate the abundance of sodium in the interstellar medium. Recent stellar observations of stars with $[Fe/H]$ up to about 0.4 suggest that $[Na/Fe]$ increases at high metallicity. We have combined stellar evolution models of AGB stars, WR stars and the latest supernova yields in an attempt to resolve these problems and have created models many more.

Conclusions

- Galactic chemical evolution models of sodium should include the contribution from AGB stars undergoing hot-bottom burning.
- Our twin-infall GCE models fail to reproduce both the scatter in $[Na/Fe]$ and the high-$[Fe/H]$ stars.
- The hint of an increase in $[Na/Fe]$ at high $[Fe/H]$ may be due to secondary Na from type II supernovae, not AGB stars.

Galactic Sodium from AGB Stars

4.4 As 2 with $^{56}Ni(\alpha,\gamma)^{60}Fe$ rate $\times 2000$

5. As 2 with initial from a polluted instead of primordial IGM

Results:

1. Reducing the SN yield is necessary at solar metallicity, but is not good for $[Fe/H] = -4$.

2. A $\times 10$ increase in the $^{56}Ni(\alpha,\gamma)^{60}Fe$ rate gives too much $^{60}Fe$, but $\times 10$ is compatible with the observations.

3. It is hard to make gas with $[Fe/H] = -4$ unless we include IGM feedback or some thaumaturgy.

4. With one-zone model we cannot reproduce the scatter seen even at high-$[Fe/H]$. Is it real?