Age-Abundance Trends in the Solar Neighborhood

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Galactic Chemical Evolution

Alpha elements

Fe type elements

[O/Fe]

[Mg/Fe]

[Ca/Fe]

[Ti/Fe]

[Fe/H]

[Na/Fe]

[Cr/Fe]

[Ni/Fe]

[Zn/Fe]

[Fe/H]

Bensby+ 2014
How do we interpret chemical abundances?

Observed chemical abundance $\rightarrow$ History of the Milky Way

Haywood+ 2013

[Graph showing scatter plot with different populations labeled: Thick disk population, Metal poor thin disk, Thin disk population]
How do we interpret chemical abundances?

Observed chemical abundance \rightarrow History of the Milky Way

Timing depends on local star formation rate

Haywood+ 2013
Need to describe the full disk

Uniform star formation rate??

APOGEE

Hayden+ 2015
Need to describe the full disk

Uniform star formation rate??

APOGEE

Stellar Ages

Hayden+ 2015
Stellar Ages

Ages cannot be directly measured

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Requirements for APOGEE stars

– Works for giant stars
– Applicable to a large sample (> 100,000)
– Preserves ability to examine detailed chemical abundance patterns with time
– Small uncertainties
Stellar Ages

Ages cannot be directly measured

**Empirical**
- Gyrochronology
- Chromospheric activity
- CN abundances

**Model-dependent**
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**Stellar Ages**

Ages cannot be directly measured

**Empirical**
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- Chromospheric activity
- CN abundances

**Model-dependent**
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**PARSEC**
Local Sample

1m+APOGEE
700 stars within 400 pc of the sun
Hipparcos parallax uncertainty < 10%
(J-K) > 0.5, $M_H > 2$
[Fe/H], Teff, log(g), $M_V$
Test sample for Gaia+APOGEE
Bayesian Likelihood

\[ f(\tau, \zeta) \propto \psi(\tau) \phi(\zeta) \int L(\tau, \zeta, m) S(\tau, \zeta, m) \xi(m) \, dm. \]

- \( \psi(\tau) \): Assume flat SFH in age
- \( \phi(\zeta) \): MDF flat within \( \sigma \)
- \( \xi(m) \): Chabrier IMF

Input parameters:

\([\text{Fe/H}], T_{\text{eff}}, M_V, \log g\]

Take mean of age PDF

The diagram shows a probability distribution of age, with the true age and mean age indicated. The selection function is also marked.
Hierarchical Modeling of SFH

Find a more informed prior for the SFH of a sample of stars

-- propose a model

Use the full age PDFs to constrain the model parameter(s)

\[
p(a|\text{data}) \propto p(a) \prod_i \int L_i(\tau) N(a) \psi(\tau|a) \, d\tau
\]

Gaussian + uniform SFH

\[
\psi(\tau|\mu, \sigma) = \frac{(1 - A)}{\sigma \sqrt{2\pi}} \exp \left( \frac{(\tau - \mu)^2}{2\sigma^2} \right) + A \times C
\]

A – outlier fraction
C – normalized constant
\(\mu\) – mean age
\(\sigma\) – age dispersion
\(\tau\) – age
Hierarchical Modeling of Local Sample

Model the SFH for stars with similar abundance

Results in the mean age of giants currently in the solar neighborhood with the same alpha abundance

$$\psi(\tau|\mu, \sigma) = \frac{(1 - A)}{\sigma\sqrt{2\pi}} \exp\left(\frac{(\tau - \mu)^2}{2\sigma^2}\right) + A \times C$$
Hierarchical Modeling of Local Sample

Feuillet+ in prep
C and N mass dependence

Driven by mass(temperature)-dependence of CNO cycle and internal mixing from first dredge-up

Supports methods of Martig+ 2016
Must be tested outside solar neighborhood
Alpha elements

Individual alpha elements agree with average alpha
Consistent with previous work on solar-like stars and local dwarfs
Difference in light and heavy alphas
Individual alpha elements agree with average alpha

Consistent with previous work on solar-like stars and local dwarfs

Difference in light and heavy alphas
Smiljanic+ 2016 suggest internal mixing in red giant stars enhances Na in massive stars.

Al is consistent with results from solar-like stars.

Na is not, perhaps there is some effect of mixing.
Most theoretical yields predict similar behavior for Mn and Ni

Could be some NLTE effects (see Battistini & Bensby 2015)

Kobayashi+ 2006 solves Mn vs Ni difference with winds
Conclusions

• Hierarchical modeling is a powerful tool for examining age trends for large samples of stars
• Clear relation between C & N and age in the solar neighborhood
• Different behavior of light and heavy alphas
• Gaia will allow for individual age-abundance trends as a function of position through the disk
Questions?
Galactic Archaeology

- Stars are good tracers of Galactic evolution
- Elemental abundances in stellar atmospheres reflect the composition of the ISM
- The composition of the ISM changes with time
- IN GENERAL... the ISM is enriched with time → [Fe/H] increases
- Different elements are enriched differently