The Ages of the α-Rich and α-Poor Populations in the Galactic Halo

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ING Multi-object Spectroscopy in the Next Generation
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Big Question(s)

- What is the assembly history of our Milky Way?
- What is the importance of accretion vs ‘in situ’ formed stars

Toward Answering these Questions:

- Ages: Stellar Ages in the (Halo) Field
- Chemistry: The importance of $[\alpha/Fe]$ 
- Ages/fractions of $\alpha$-rich and $\alpha$-poor populations
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Ages of Stars

Assume Single Stellar Population

Turnoff temperature / Main-sequence turnoff (MSTO) give age of stellar population

Halo population is old

Age-dating single stars is extremely difficult!
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• Ages/fractions of $\alpha$-rich and $\alpha$-poor populations
Chemistry: The Importance of $[\alpha/Fe]$  
α-elements: Mg, Ti, Si, Ca, O, etc dispersed primarily via Type II SNe.

$[\alpha/Fe]$ reveals how fast star formation was and mass of system.
Two Populations in the Inner Halo

Schuster+ 2012
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• Is there an Age difference for the $\alpha$-rich and $\alpha$-poor populations?
Current Methods to Extract [\text{\alpha}/\text{Fe}] in Low-Resolution Spectra

- Employ large sample from MSTO SDSS
- SSPP - Spectral Grid Matching: Lee +, (2011), obtain [\text{\alpha}/\text{Fe}] down to [\text{Fe}/\text{H}] \sim - 1.5 \text{ dex with errors} \sim 0.1 \text{ dex}
- Not in public DR9, DR10-12?
- Spectral Index: Hawkins+2014
[α/Fe] and Low-Resolution Spectra
Our $[\alpha/Fe]$ VS SSPP

Random sampling of 10,000 stars

Offset = 0.00 dex; Dispersion = 0.12 dex

Y. S. Lee/T. Beers, private comm.
SDSS Sample: Main-Sequence Turnoff Stars (MSTO)

- $0.1 < (g-r)_o < 0.48$
- $-0.8 < [\text{Fe/H}] < -2.0$
- $b > 30 \text{ degrees}$
- $\log g > 3.5$
- $\text{SNR} > 40$

Smaller $T_{\text{eff}}$

Larger $T_{\text{eff}}$
[\alpha/\text{Fe}] Distribution

![Graph showing [\alpha/\text{Fe}] distribution with categories poor, mod, and rich.](image)
**Age-Metallicity Relation (AMR)**

Mean age = 10.0 Gyr

- **Normalized Age**
  - α-rich
  - α-poor

- **Age Difference (Gyr)**
  - [Fe/H]

- Mean age = 10.0 Gyr
GCs VS Field AMR

Marin-Franch+2012

(A)

(B)

$[M/H]_{cc}$

$\alpha$-rich

$\alpha$-poor
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• What is the relative fraction of the two populations?
Fraction of α-rich to α-poor for metal-poor stars in Gaia-ESO

Two components in SDSS?
Addressed in Hawkins+2015b, in prep.
Summary

• Developed simple method estimate \([\alpha/Fe]\) from low-res spectra

• The Galactic halo formed/assembled quickly

• At high metallicity \(\alpha\)-rich stars are older than \(\alpha\)-poor stars and become coeval at low metallicity

• \(\alpha\)-poor stars may have formed in chemically slower environments than their \(\alpha\)-rich counterparts (AMR)

• Surveys with higher precision and larger sample sizes (GALAH, 4MOST) needed to fully study the \([\alpha/Fe]\) distribution.
Future Work:

• Improve index to giants, more metal poor and add soft priors on stellar parameters

• Extend the index to [Ba/Fe] or an s-process index to study blue stragglers
Chemistry: The Importance of $[\alpha/\text{Fe}]$

Type II SNe  α-element  Type Ia SNe  Fe-peak/other

From Frebel+2013
Converting the Index to \([\alpha/\text{Fe}]\)

Index = \([\alpha/\text{Fe}] \times 4.32 + 6.28\)

\[
\begin{align*}
\text{Teff} &\quad \text{[Fe/H]} &\quad \log g \\
\end{align*}
\]
Thick Disk Contamination in SDSS G-dwarf Sample

\[ (U^2 + W^2)^{1/2} \text{ (km/s)} \]

\[ V \text{ (km/s)} \]

\[ \sim 45\% \text{ thick disk contamination} \]
[α/Fe] Distribution in SDSS
“Halo” G-dwarfs

1-component model
selected by BIC/AIC
[\alpha/\text{Fe}] Distribution Nissen ++2010

2-component model
selected by BIC/AIC

\begin{center}
\begin{figure}
\centering
\includegraphics[width=\textwidth]{example_graph.png}
\end{figure}
\end{center}
Velocity-Alpha Trends

![Graph showing the relationship between [α/Fe] and V_{tot,LSR} (km/s). The graph includes data from this study and Nissen et al. 2010.]
Effect of Sample Size and Precision

\[ \text{beta} = \text{BIC1d} - \text{BIC2d}; \text{ (negative = Bad)} \]
Our [$\alpha$/Fe] VS SSPP DR7

Random sampling of 10,000 stars
MSTO Detection: Sobel-Edge

\[ \Phi(T_{eff}) = \sum_{i=1}^{N} \frac{1}{\sqrt{2\pi} \sigma_i} \exp \left( \frac{(T_{eff} - T_{eff,i})^2}{2\sigma_i^2} \right) \]

\[ E(T_{eff}) = \Phi(T_{eff} - \Delta T_{eff}) - \Phi(T_{eff} + \Delta T_{eff}) \]
Two Populations in the Inner Halo

Nissen+ 2010
Schuster+ 2012
Effects of Stellar Parameters

Dwarfs (log g > 3.5)
Effects of Continuum Placement

Rogers et al. 2012
Validation: Nissen+ (2010)
47 Stars
Validation: SDSS Targets

74 Stars
Validation: Nissen+ (2010)

mean offset = 0.01 dex, spread = ±0.05 dex
Effects of SNR

![Graph showing the effects of SNR on index. The graph has two sets of data points labeled $[\alpha/\text{Fe}] = 0.0$ and $[\alpha/\text{Fe}] = 0.4$. The x-axis represents SNR, ranging from 20 to 100, and the y-axis represents the index, ranging from 5 to 10. The data points are indicated with blue line segments.](image-url)
Control Band Idea

- Band that has the same or very similar response function to stellar parameters as the $\alpha$-sensitive bands

$log g = 3.6, \ [Fe/H] = -1.5$
Finding Control Bands

- Automated search routine:
  - Searches grid of possible bands from 4000 - 8000 A (widths ranging from 10 - 100 A)
  - Computes an index (defined as $\alpha$-sensitive band over randomly selected control band)
  - Computes index over full range of stellar parameters for $[\alpha/Fe] = 0$ and $[\alpha/Fe] = 0.4$
  - Finds best ‘control’ bands which maximize distance between $[\alpha/Fe] = 0$ and $[\alpha/Fe] = 0.4$ and minimize spread in index at a constant $[\alpha/Fe]$
Finding Control Bands
Index = $\alpha$-sensitive bands/random control band

$\log g = 3.6$, $[\text{Fe/H}] = -1.5$

$\text{Index value}$

$[\text{Fe/H}] = +0.4$
$[\text{Fe/H}] = 0.0$

Due to stellar parameters - minimize this

Due to $[\text{Fe/H}]$ sensitivity - maximize this

$log g = 3.6$, $[\text{Fe/H}] = -1.5$