Age-Abundance Trends in the Solar Neighborhood

Diane Feuillet
MPIA

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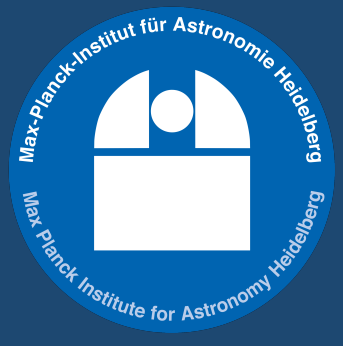
IAUS 330 Nice, France



Galactic Chemical Evolution

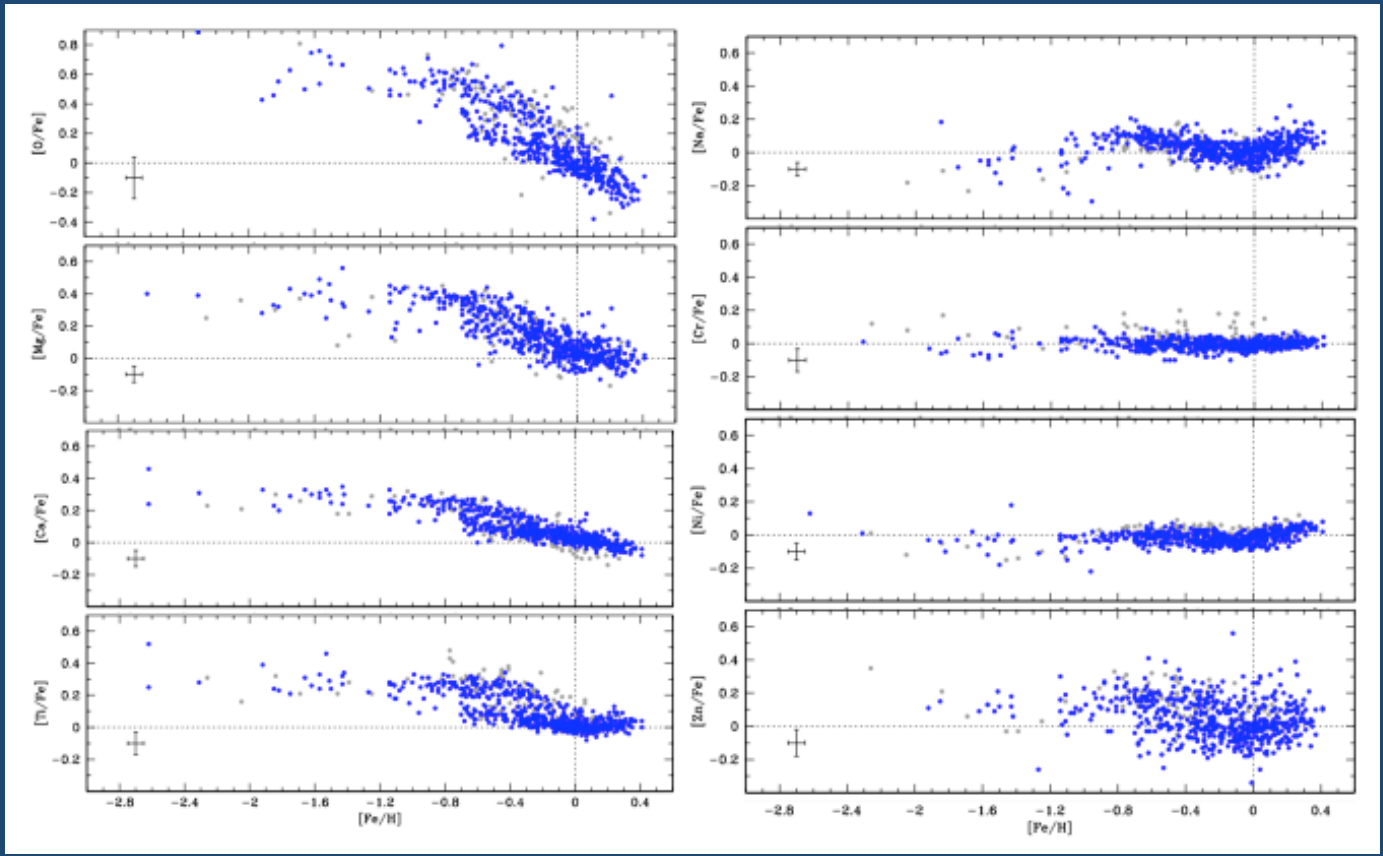
Alpha elements Fe type elements

[O/Fe]

[Mg/Fe]

[Ca/Fe]

[Ti/Fe]



[Na/Fe]

[Cr/Fe]

[Ni/Fe]

[Zn/Fe]

[Fe/H] [Fe/H]

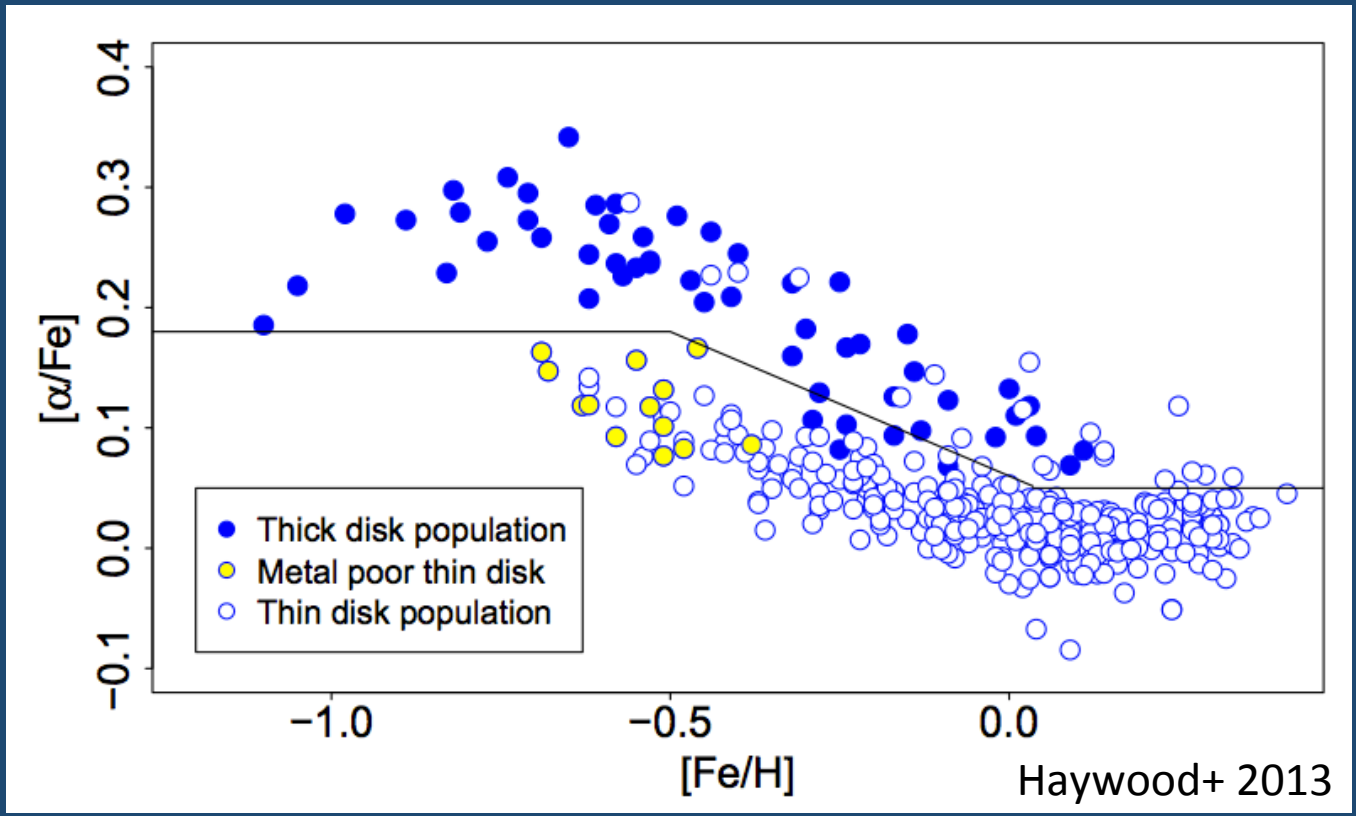
Bensby+ 2014

How do we interpret chemical abundances?

Observed chemical abundance

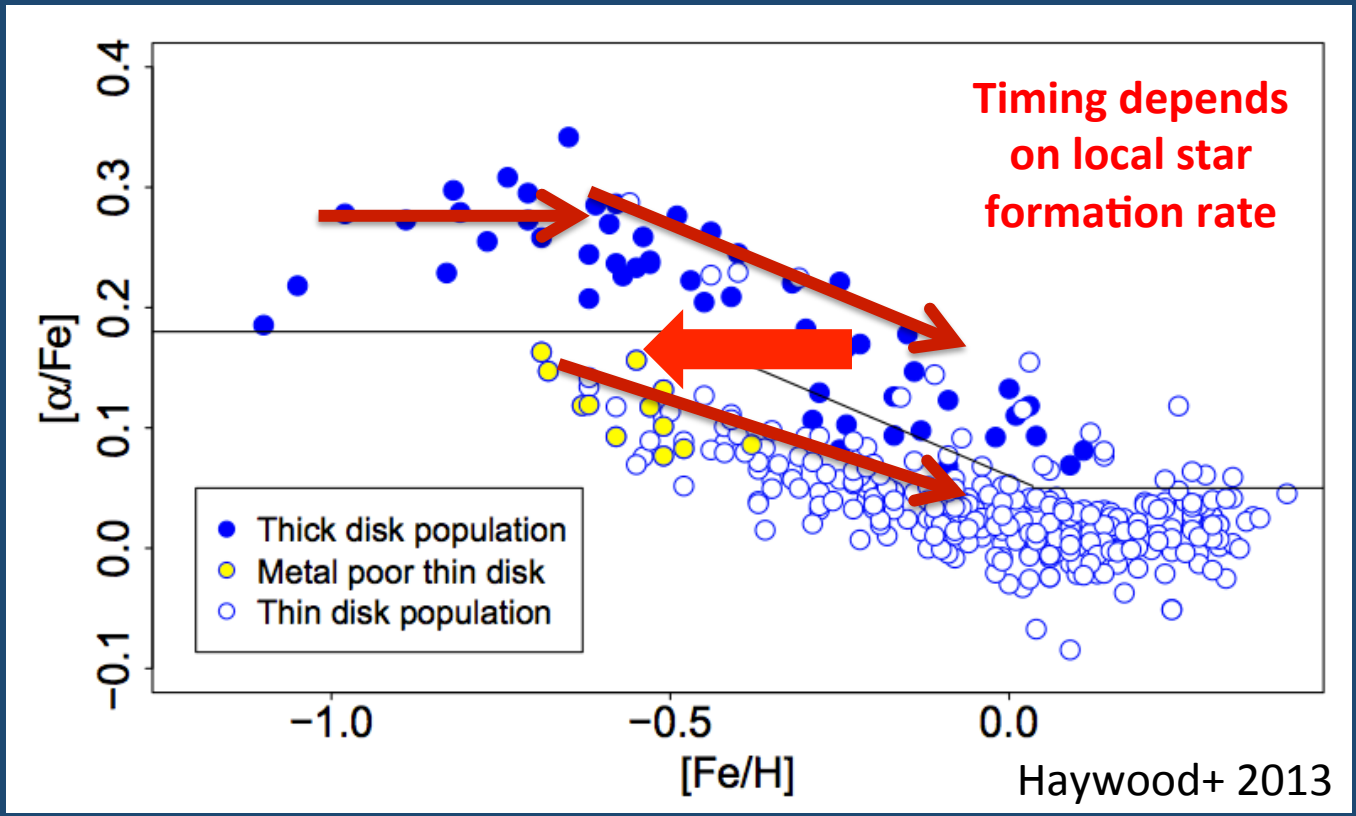
? ? ?

History of the Milky Way



How do we interpret chemical abundances?

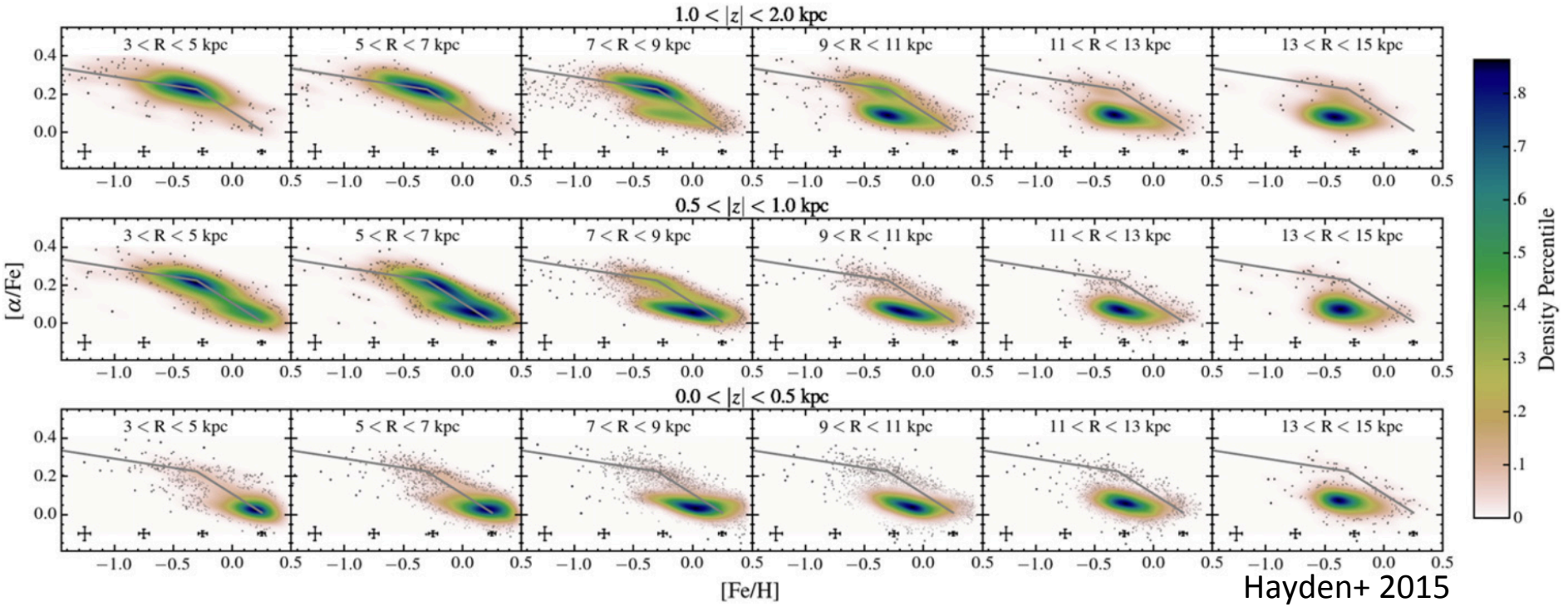
Observed chemical abundance → ? ? ? → History of the Milky Way



Need to describe the full disk

Uniform star formation rate??

APOGEE

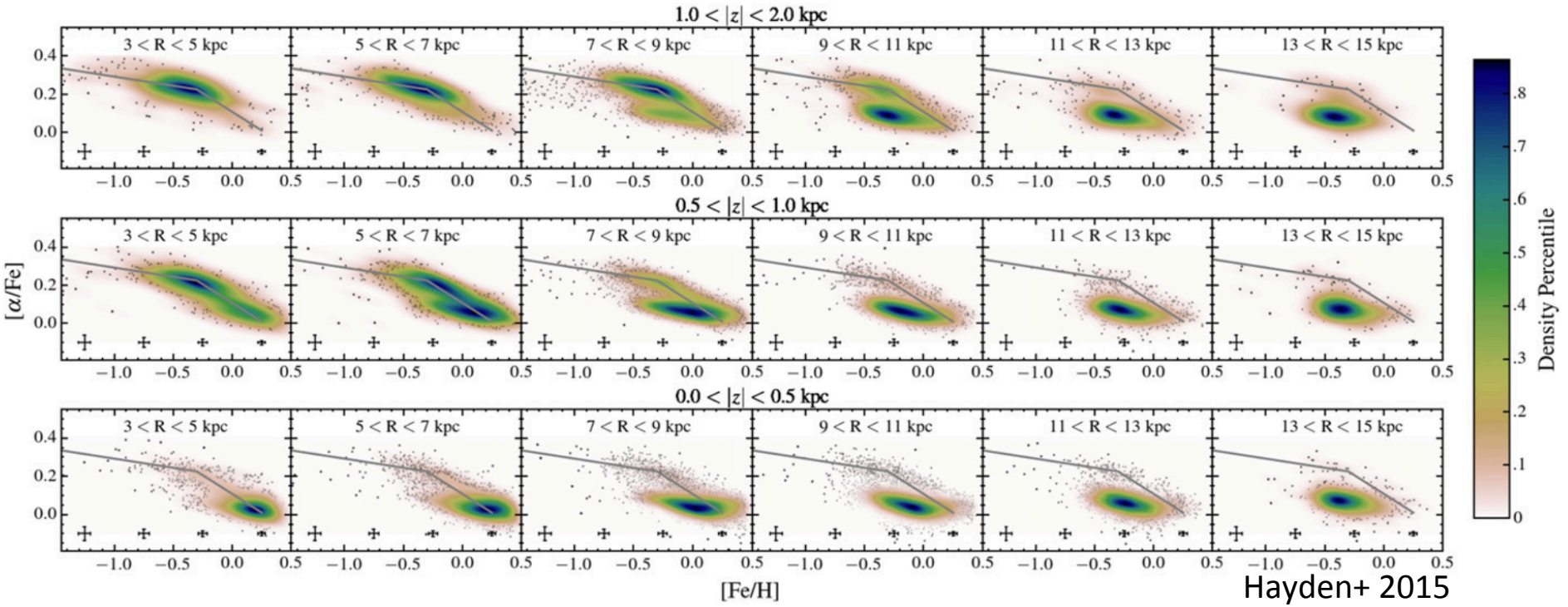


Hayden+ 2015

Need to describe the full disk

Uniform star formation rate??

APOGEE



Hayden+ 2015

Stellar Ages

Stellar Ages

Ages cannot be directly measured

Empirical

- Gyrochronology
- Chromospheric activity
- CN abundances

Model-dependent

- Isochrone model matching
- Asteroseismic mass
- Mass-age relation

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

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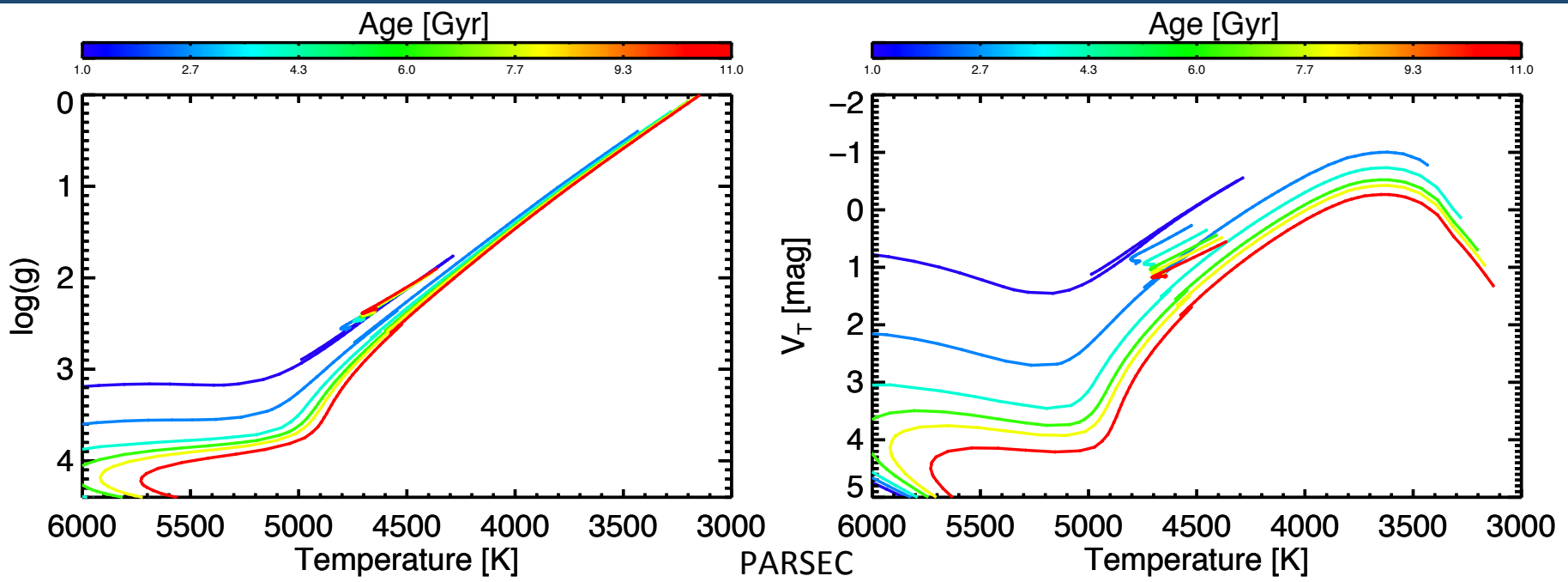


Feuillet+ 2016

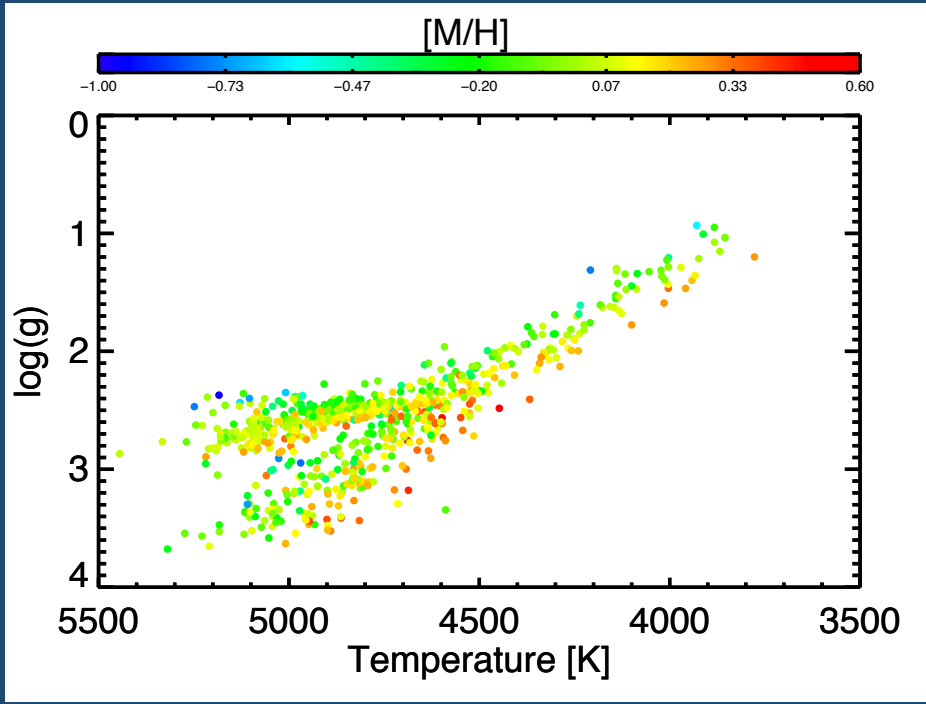
Local Sample

Parallax measurements

- 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



Feuillet+ 2016

Bayesian Likelihood

$$f(\tau,\zeta) \propto \psi(\tau)\phi(\zeta) \int L(\tau,\zeta,m) S(\tau,\zeta,m) \xi(m)\, \mathrm{d}m.$$

Selection function

$\psi(\tau)$ Assume flat SFH in age

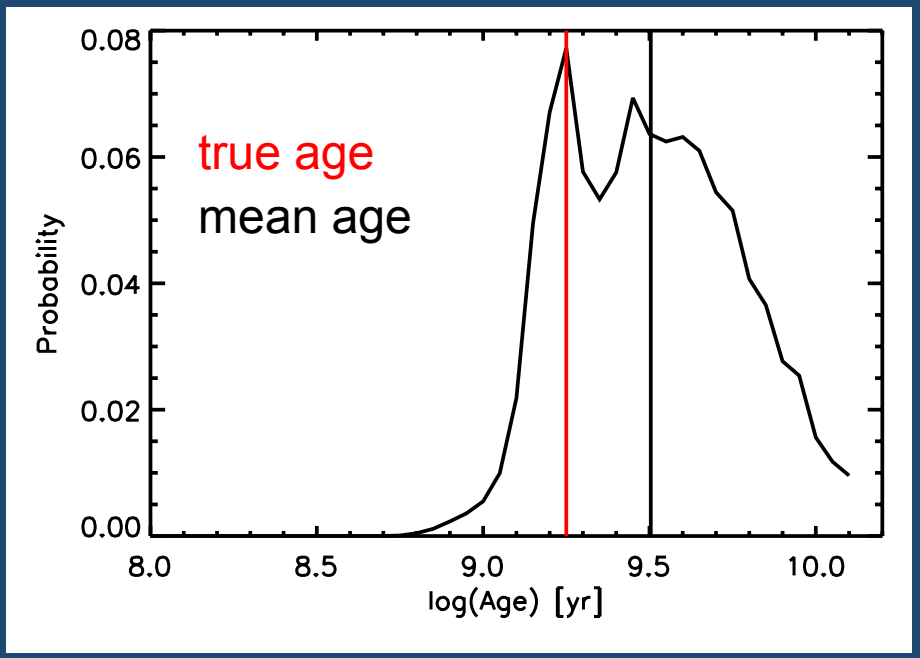
$\xi(m)$ Chabrier IMF

$\phi(\zeta)$ MDF flat within σ

Input parameters:

[Fe/H], T_{eff}, M_V, log *g*

Take mean of age PDF



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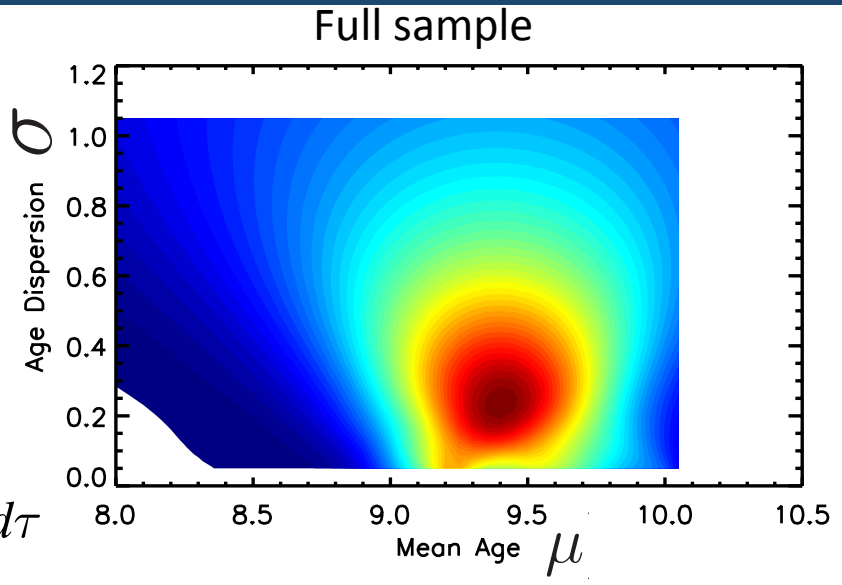
Hierarchical Modeling of SFH

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)



$$p(a|\mathrm{data}) \propto p(a) \prod_i \int L_i(\tau)\, N(a)\, \psi(\tau|a)\, d\tau$$

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
μ – mean age
σ – age dispersion
τ – age

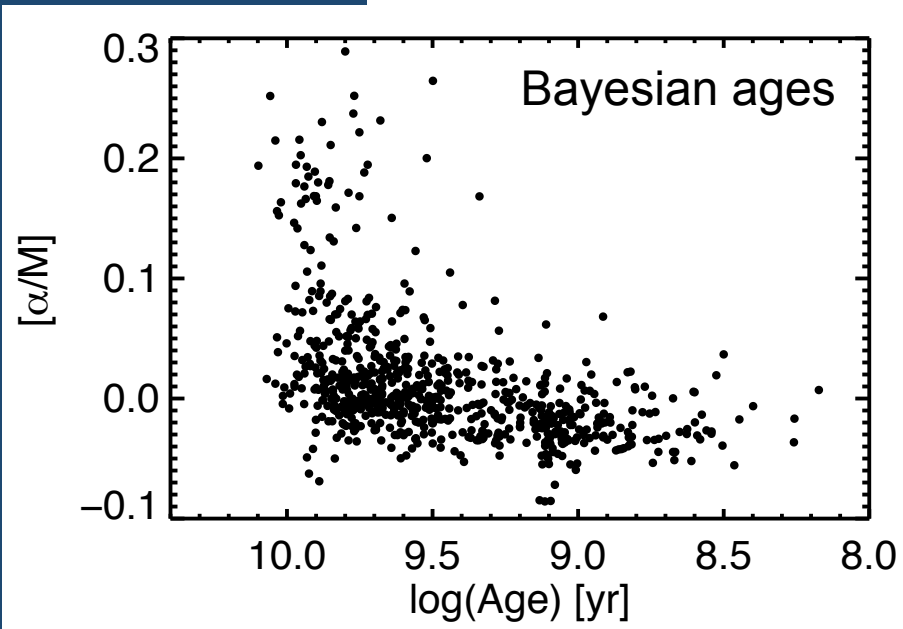
Feuillet+ 2016

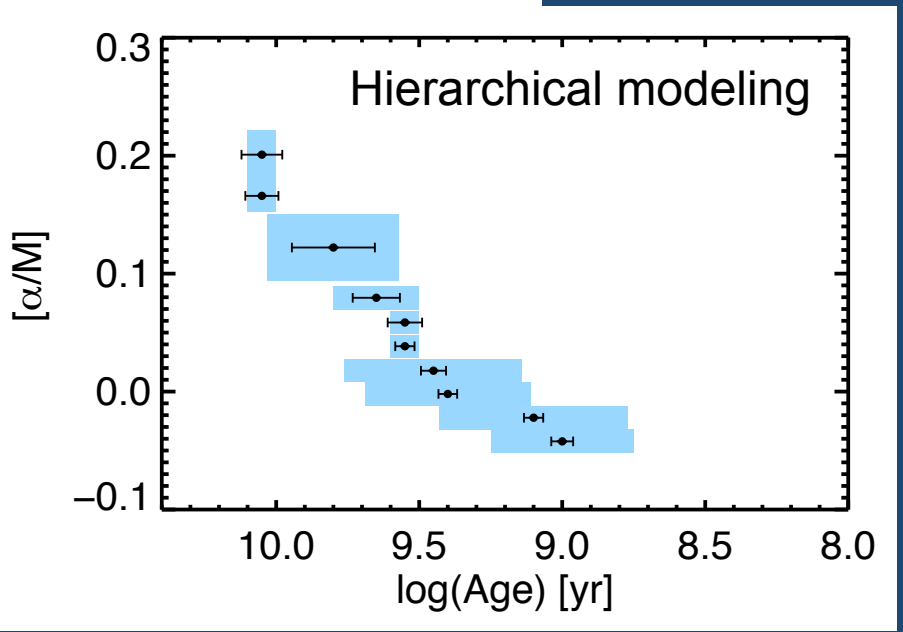
Hierarchical Modeling of Local Sample

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

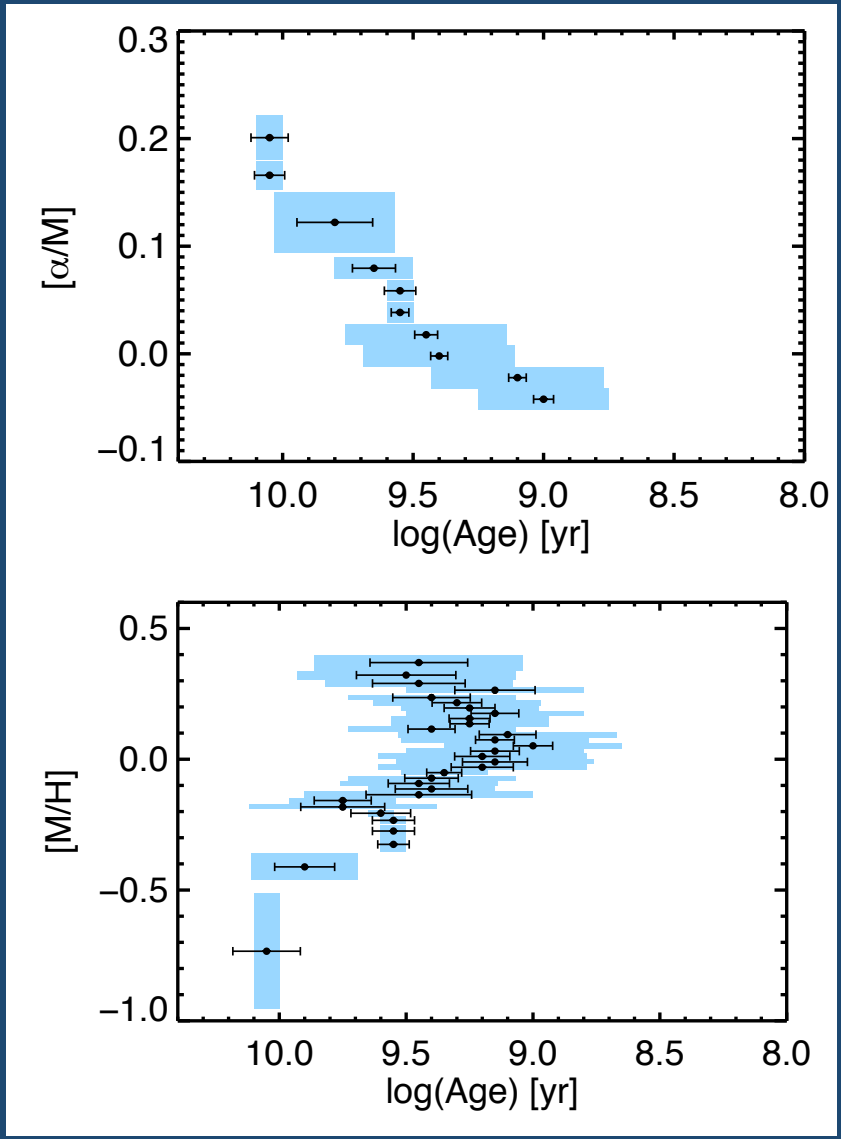
$$\psi(\tau|\mu,\sigma) = \frac{(1-A)}{\sigma\sqrt{2\pi}} \exp\left(\frac{(\tau-\mu)^2}{2\sigma^2}\right) + A \times C$$

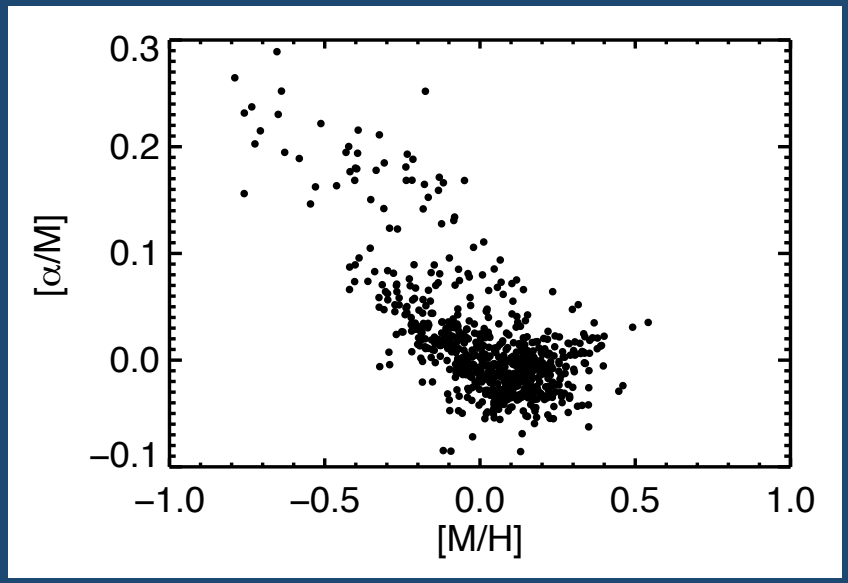




Feuillet+ in prep

Hierarchical Modeling of Local Sample





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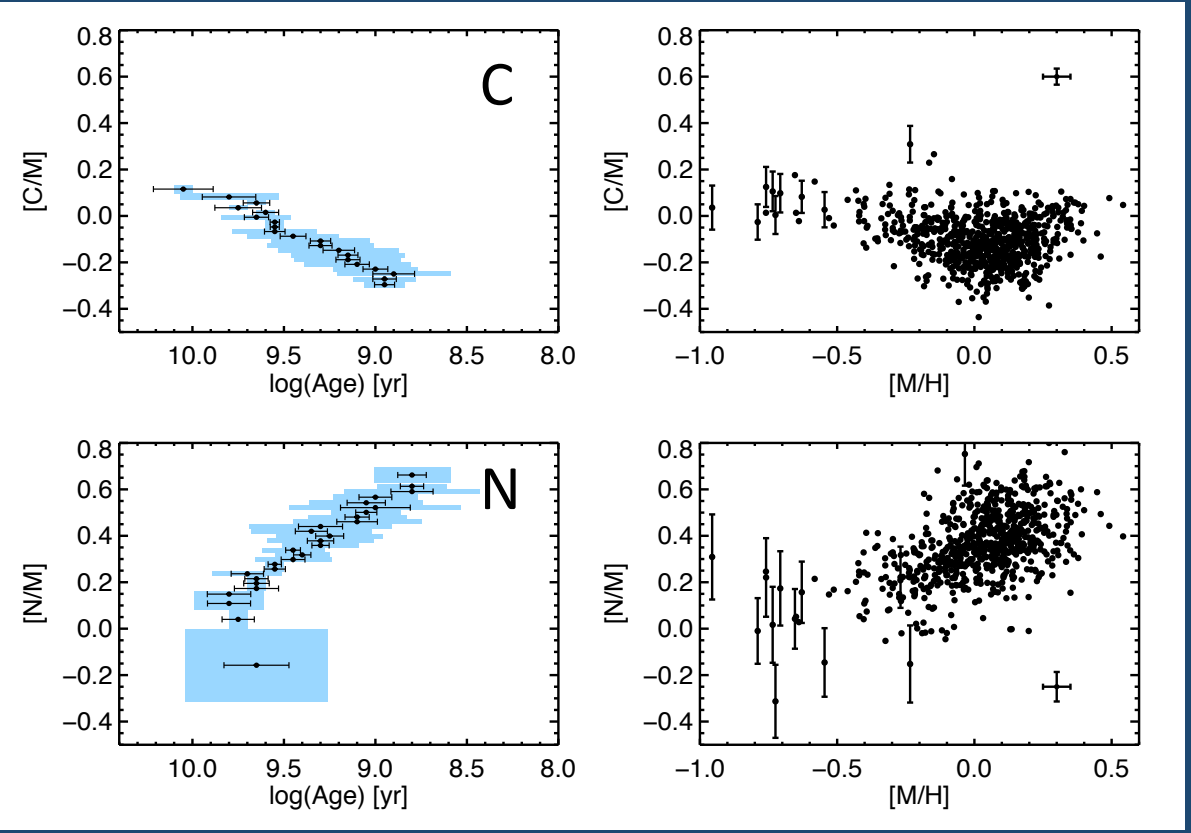
C and N mass dependence

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



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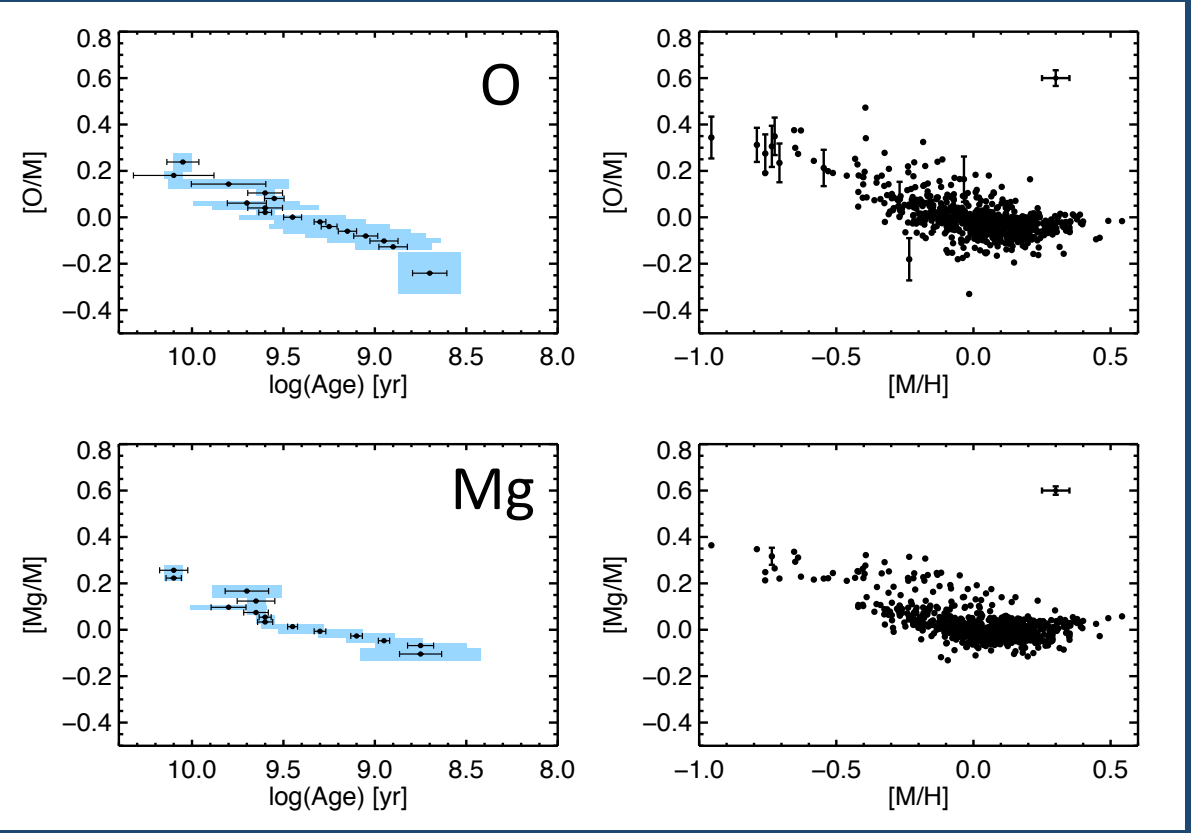
Alpha elements

Individual alpha elements agree with average alpha

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

Difference in light and heavy alphas



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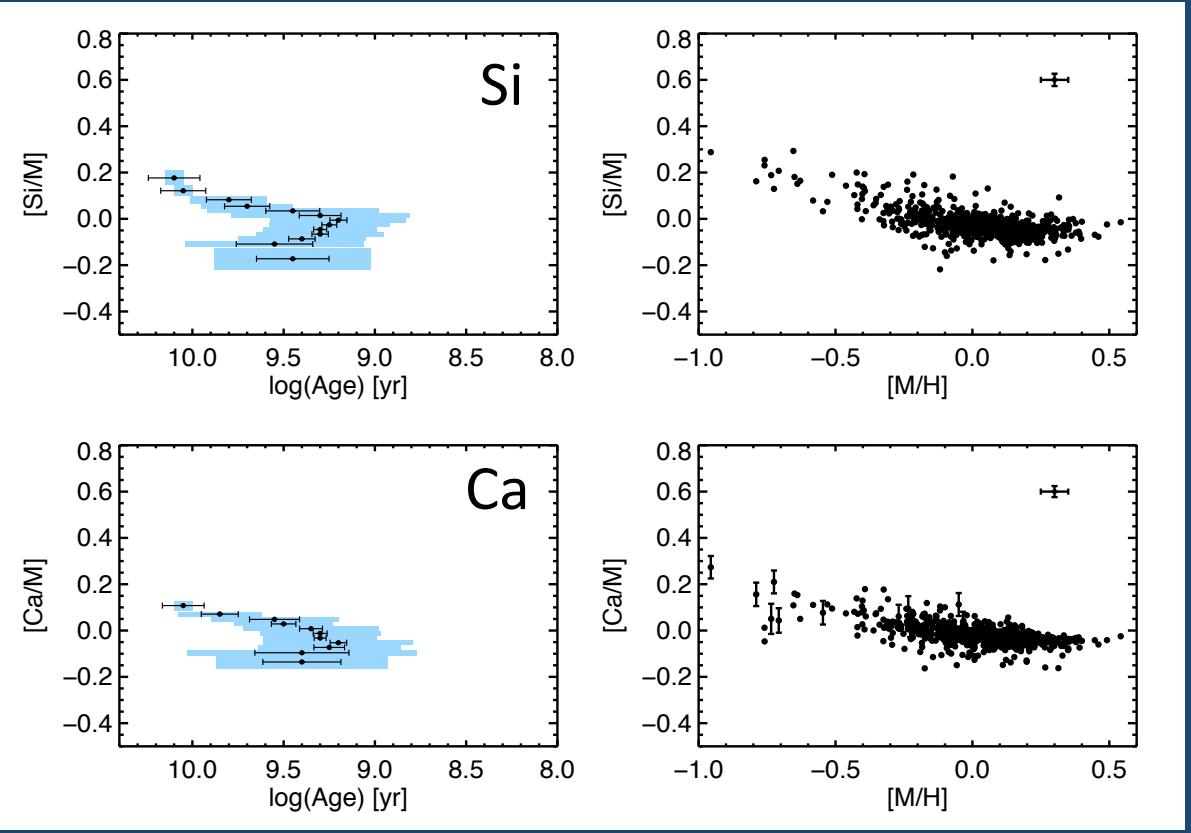

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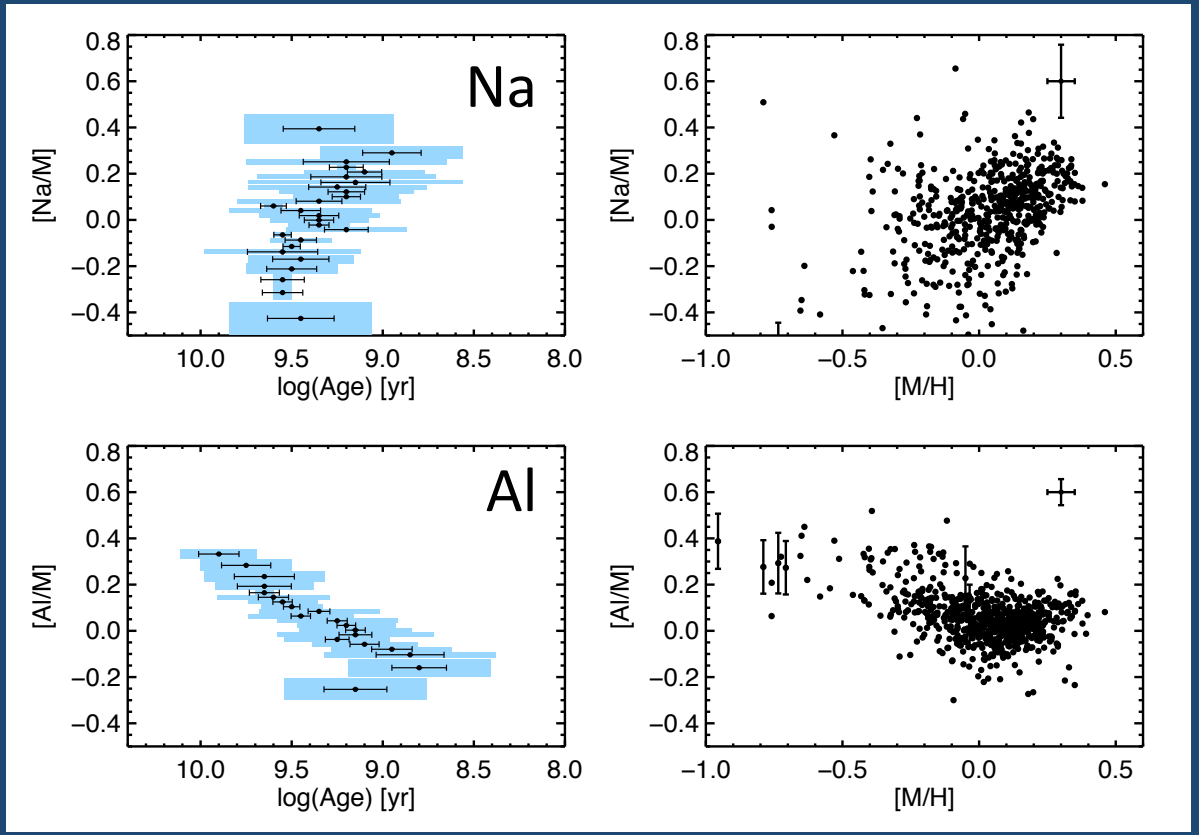
Na and Al

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



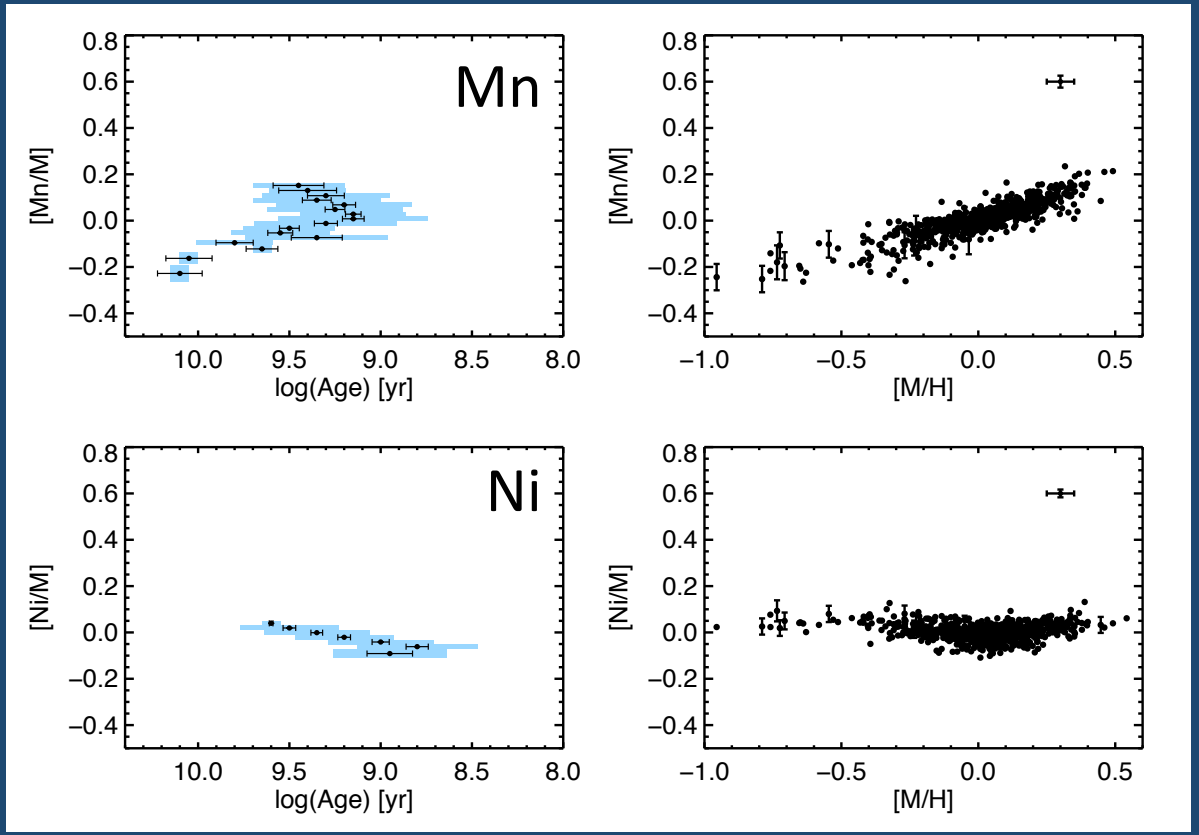
Feuillet+ in prep

Mn and Ni

Most theoretical yields predict similar behavior for Mn and Ni

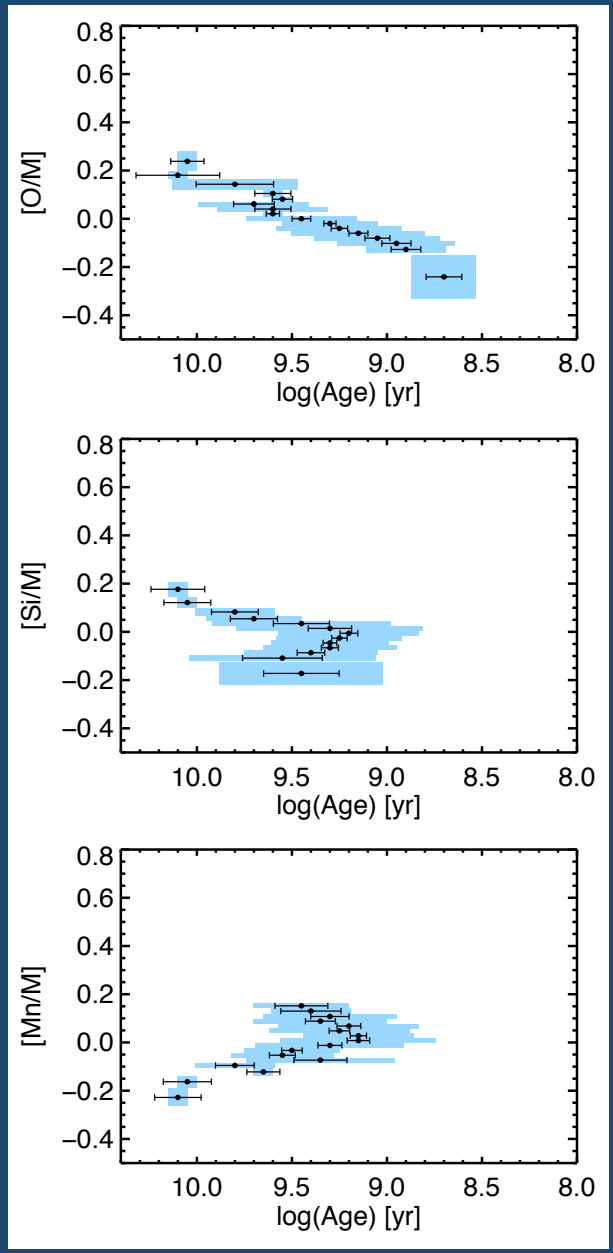
Could be some NLTE effects (see Battistini & Bensby 2015)

Kobayashi+ 2006 solves Mn vs Ni difference with winds

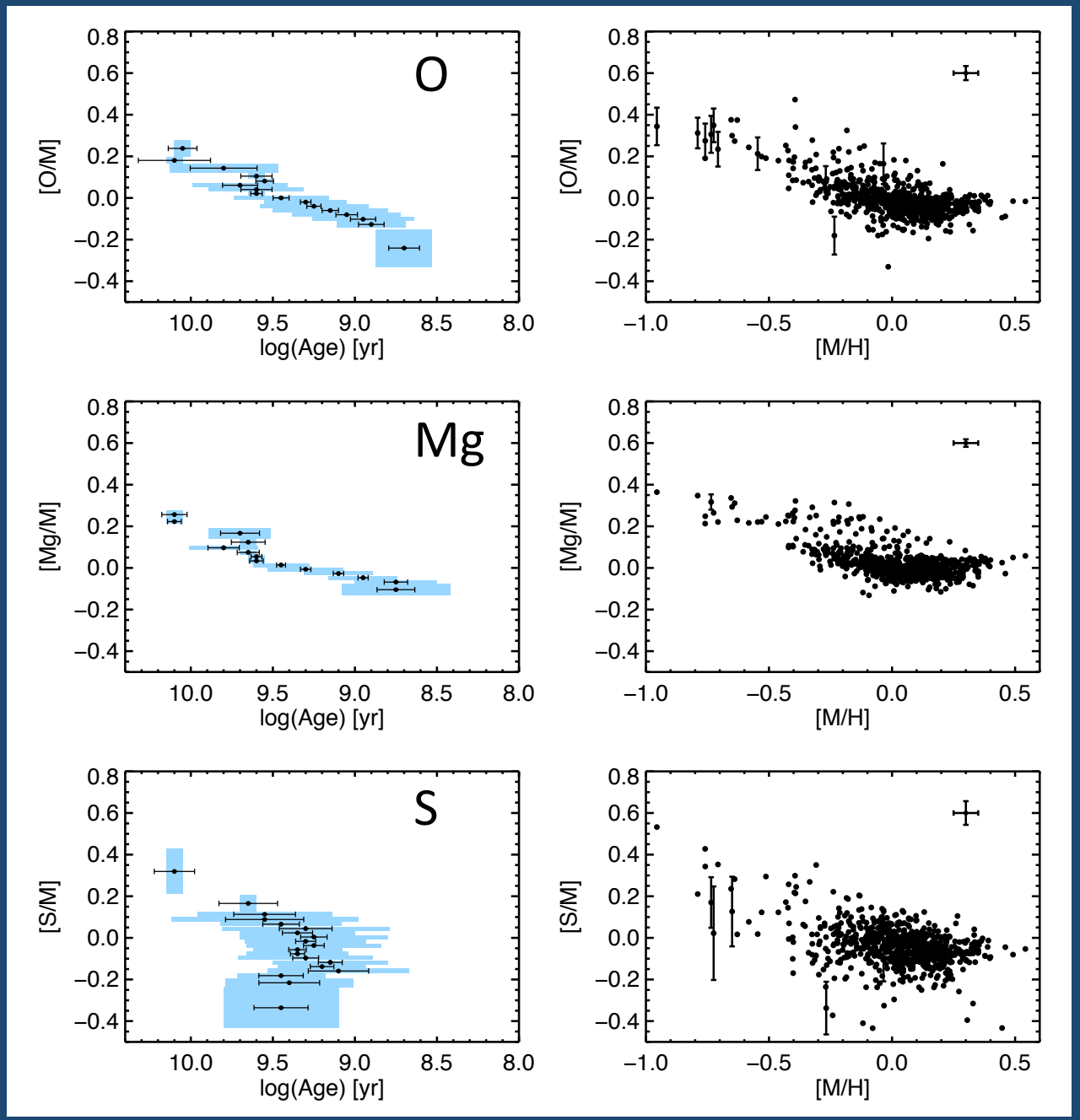


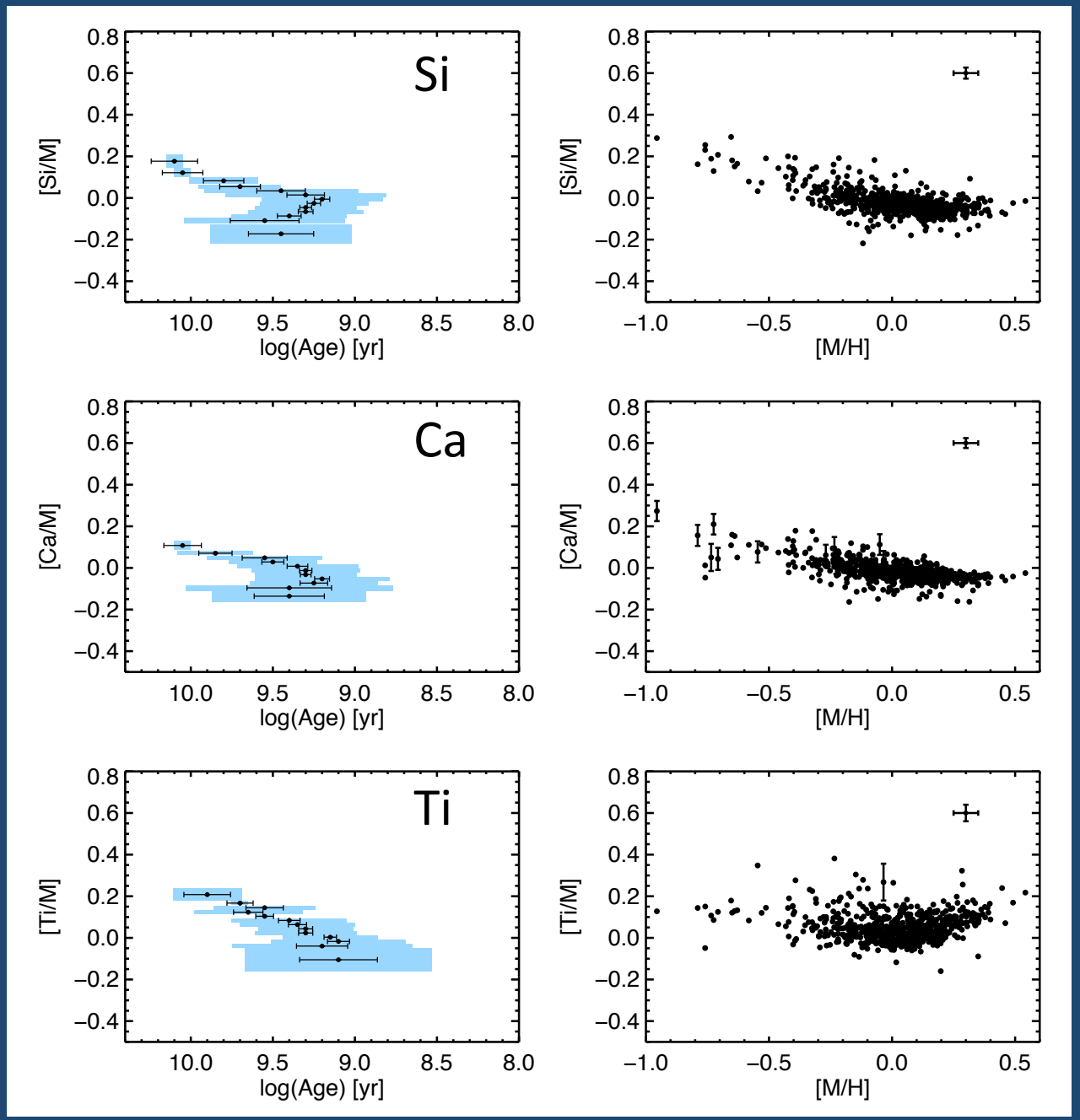
Conclusions

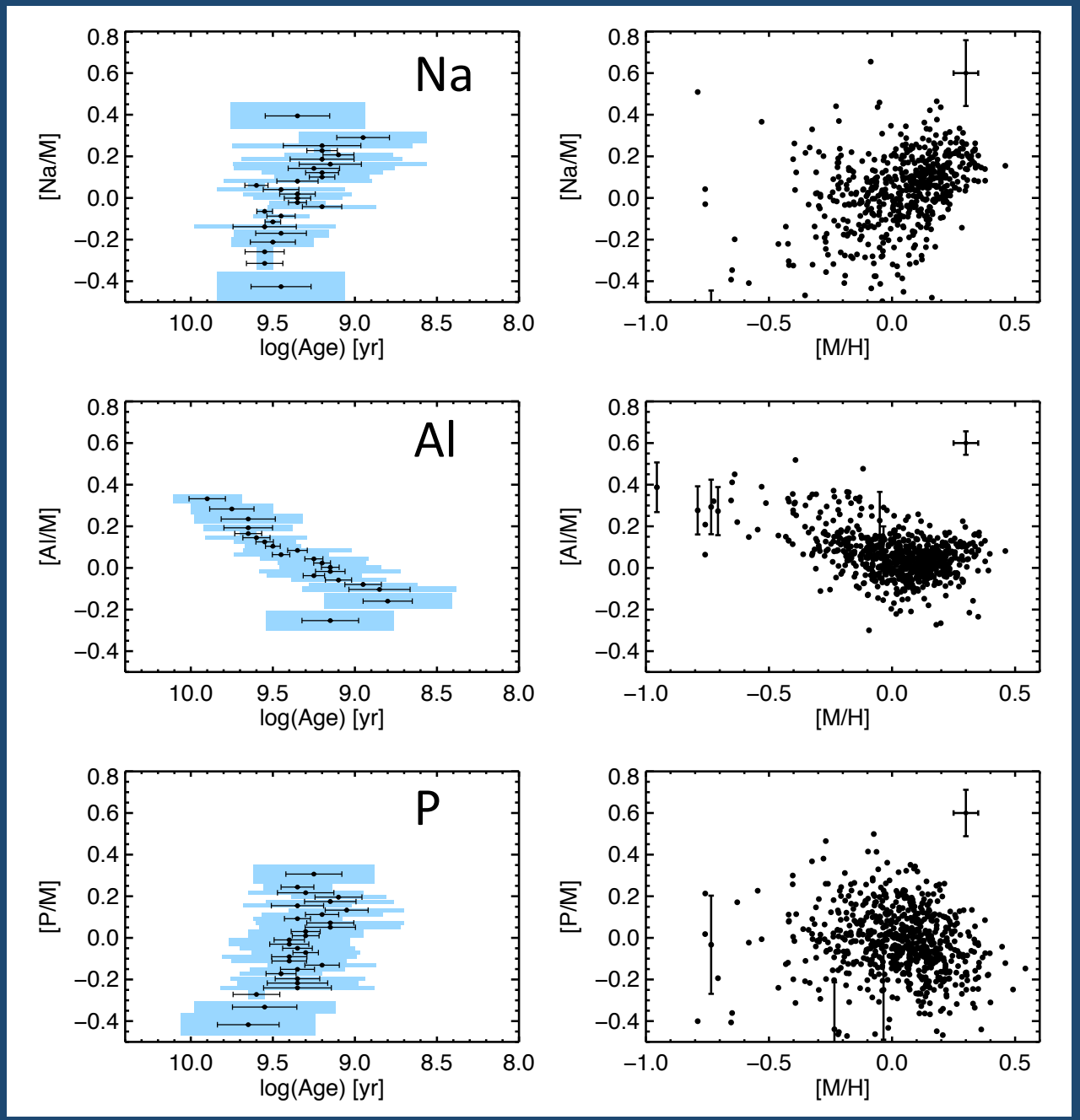
- Hierarchical modeling is a powerful tool for examining age trends for large samples of stars
- Clear relation between C & N and age in the solar neighborhood
- Different behavior of light and heavy alphas
- Gaia will allow for individual age-abundance trends as a function of position through the disk



Questions?


O
Mg
S
[O/M]
[Mg/M]
[S/M]
log(Age) [yr]
[M/H]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
10.0
9.5
9.0
8.5
8.0
−1.0
−0.5
0.0
0.5


Si
Ca
Ti
[Si/M]
[Ca/M]
[Ti/M]
log(Age) [yr]
[M/H]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
10.0
9.5
9.0
8.5
8.0
−1.0
−0.5
0.0
0.5


Na
Al
P
[Na/M]
[Al/M]
[P/M]
[M/H]
log(Age) [yr]
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0.6
0.4
0.2
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−0.2
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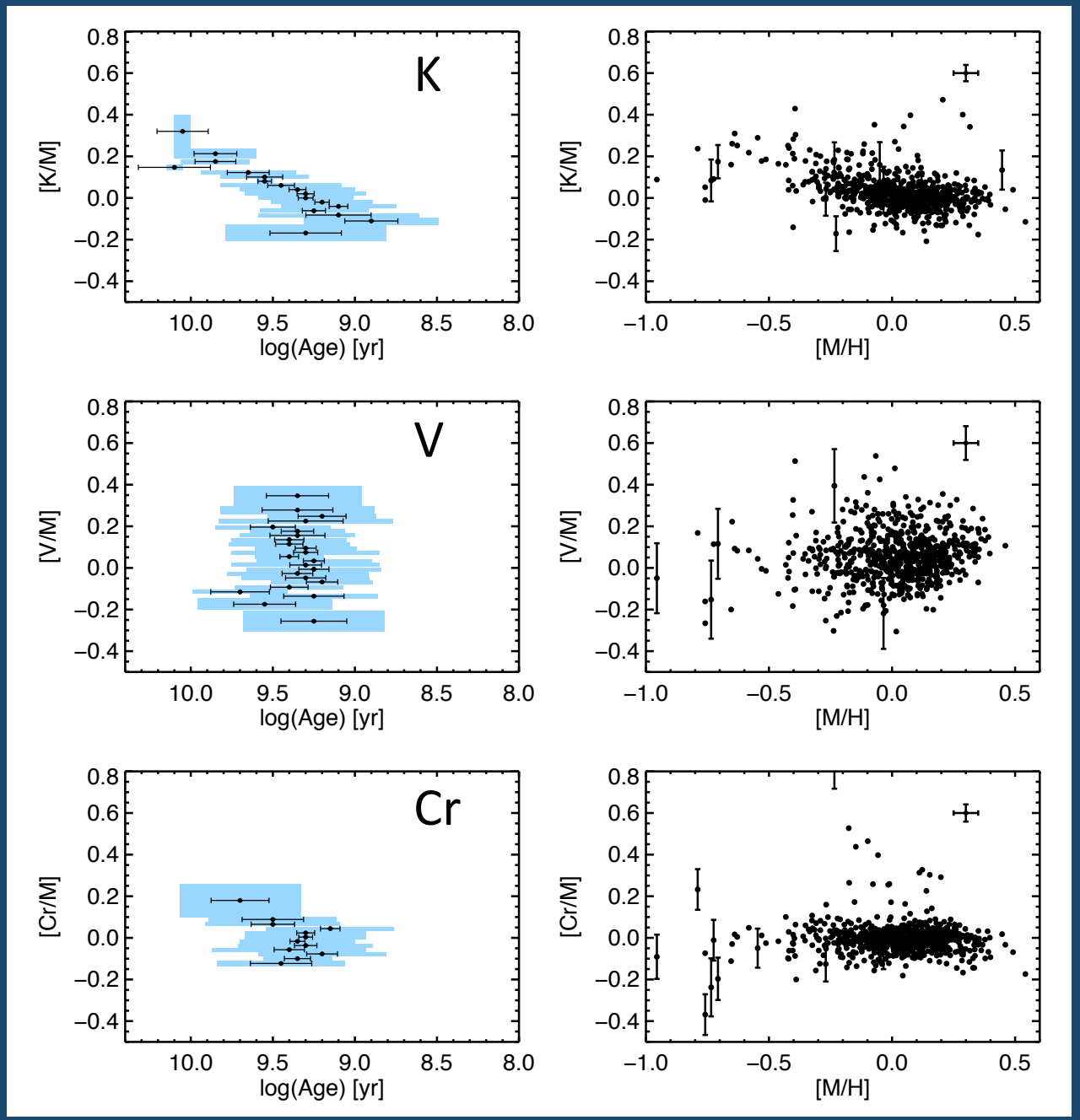
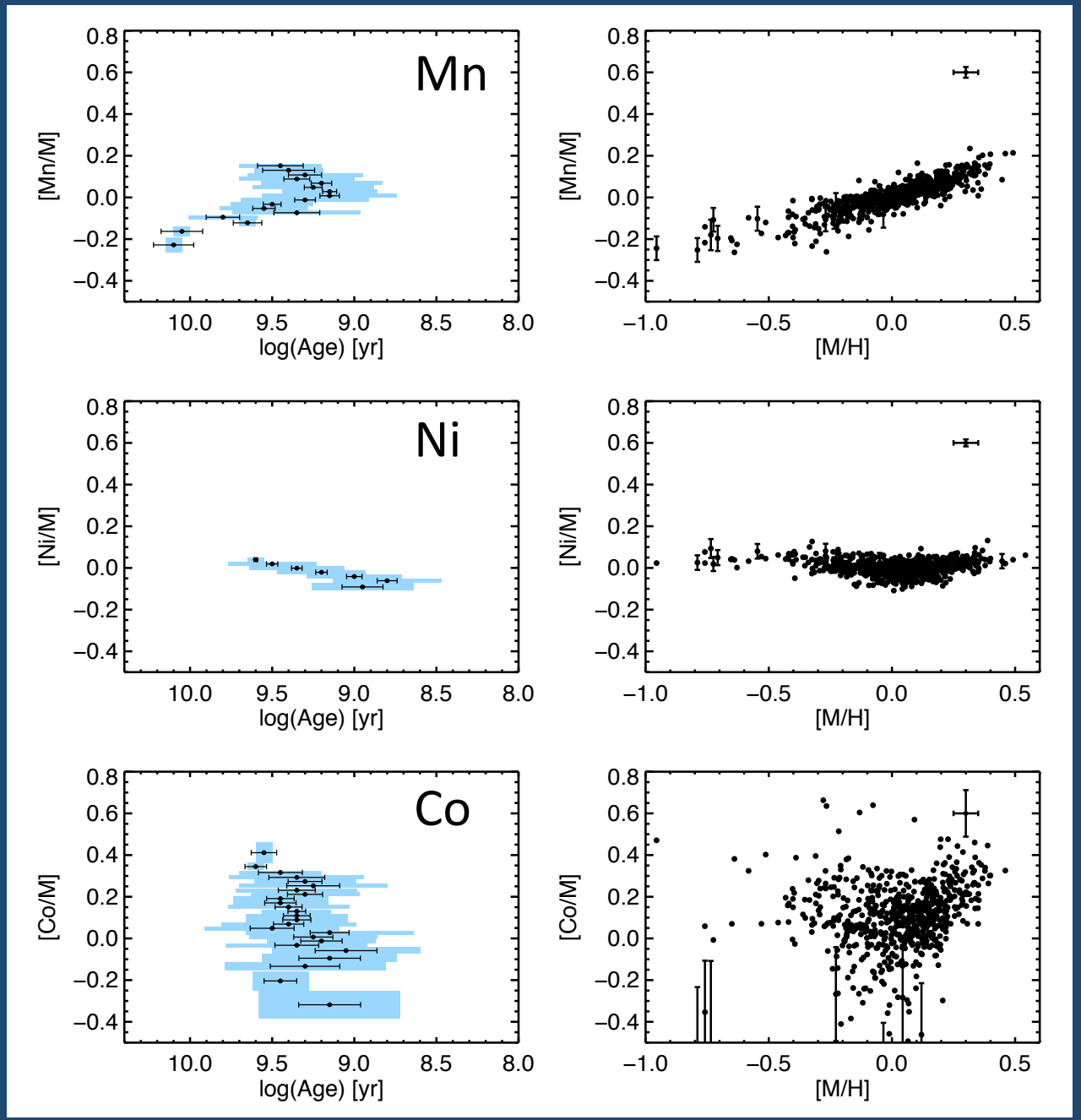
9.0
8.5
8.0
−1.0
−0.5
0.0
0.5


K
V
Cr
[K/M]
[V/M]
[Cr/M]
log(Age) [yr]
[M/H]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
10.0
9.5
9.0
8.5
8.0
−1.0
−0.5
0.0
0.5


Mn
Ni
Co
[Mn/M]
[Ni/M]
[Co/M]
log(Age) [yr]
[M/H]
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0.0
0.5

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