The chemical compositions of solar twins in the open cluster M67

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2016. 09. 19

Why open clusters are important?

- Open clusters

--- basic galactic building blocks

--- form together

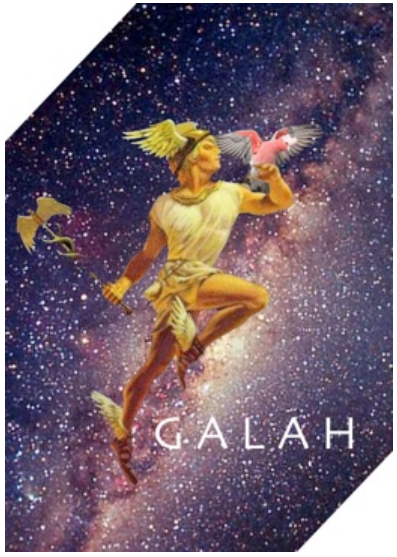
--- no abundance spreads are expected

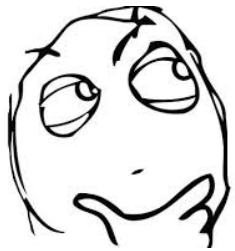
(e.g., Feng & Krumholz, 2014, Nature)

Is it true?

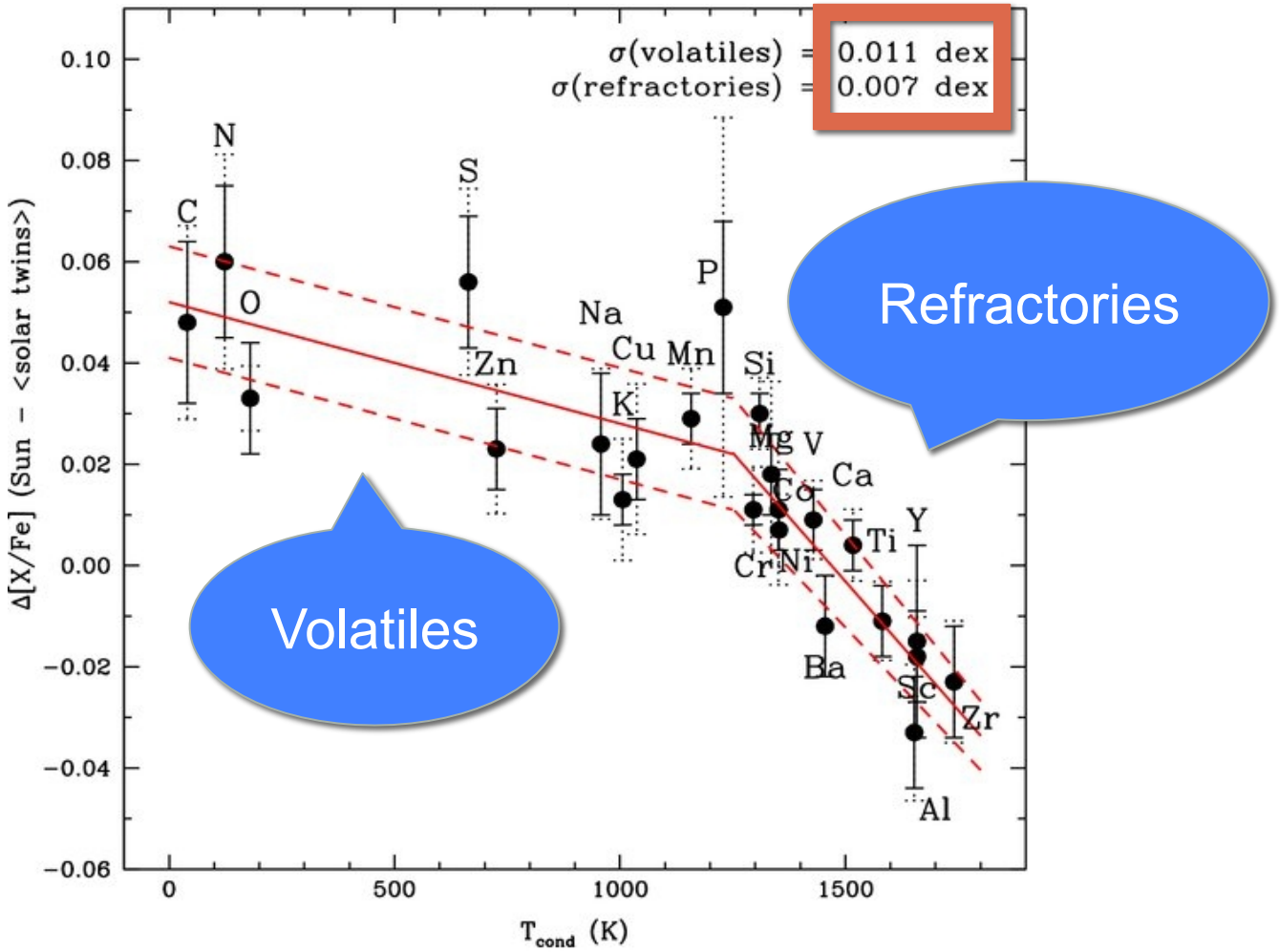
- Basis of chemical tagging

- Clues for Galactic archeology



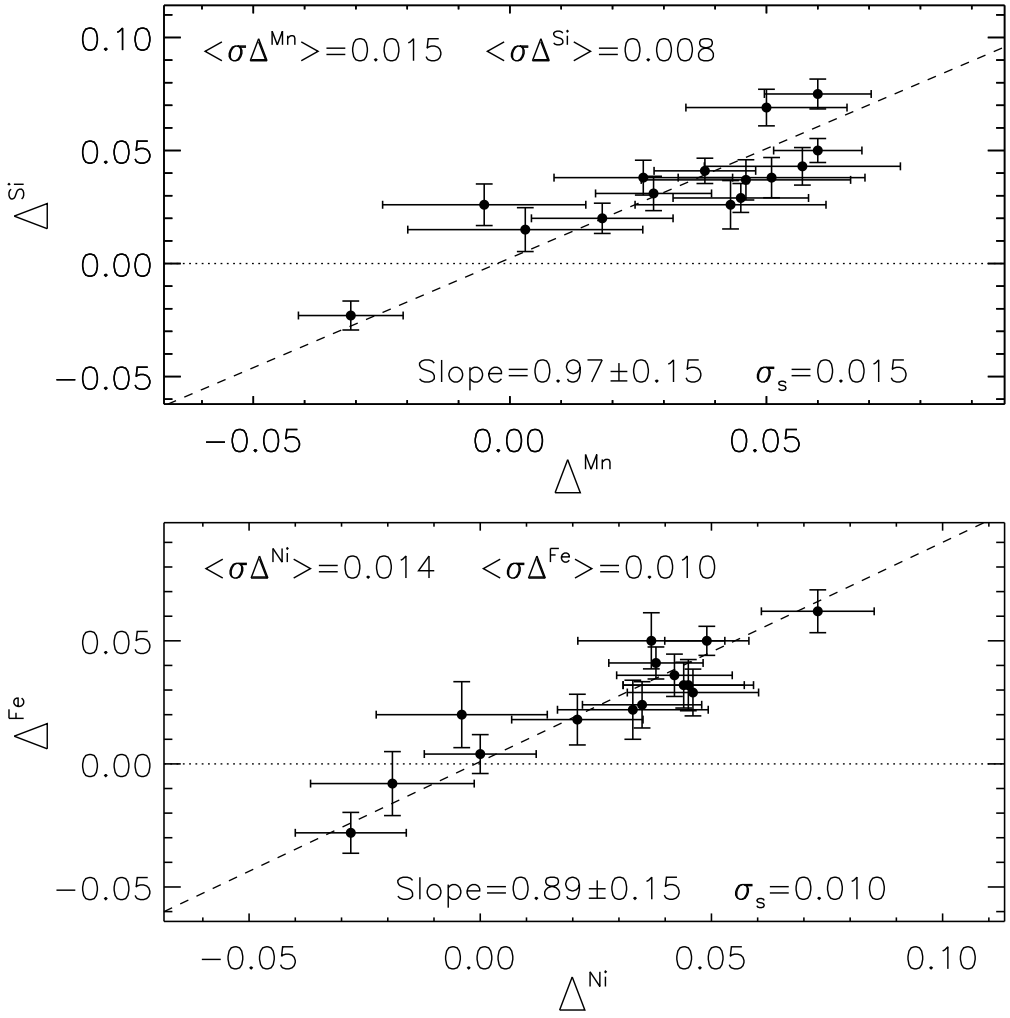


High-precision differential abundance analysis



Melendez et al. 2009

Hyades is chemically inhomogeneous?!



Liu et al. 2016, MNRAS, 457, 3934

Why open cluster M67?

V ~ 14 mag
Age ~ 3.5 – 4.8 Gyr
(Yadav et al. 2008)

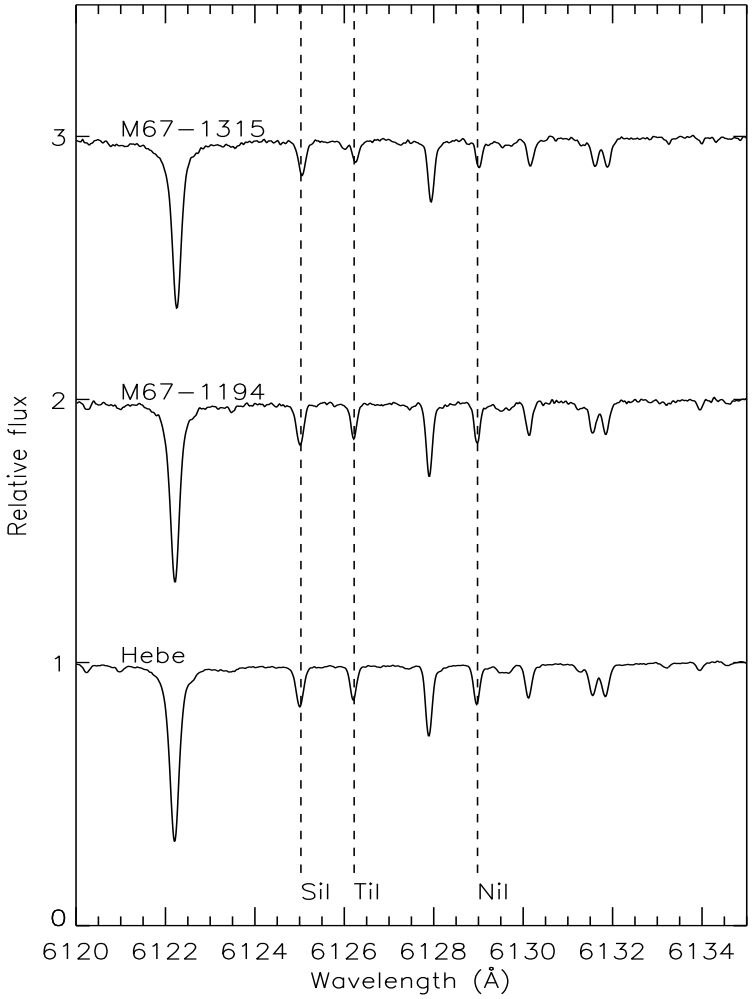
Solar metallicity (-0.04 - +0.03)
(Yong et al. 2005; Randich et al. 2006)

Was the Sun born from M67?

- The chemical composition of one solar twin 1194 is more solar-like (Önehag et al. 2011, 2014)
- The Sun was likely formed in a similar environment?
- Chemical signatures of planet formation?
  1194 hosts a hot Jupiter (0.34 M_{Jup})

Observations

- Keck/HIRES
- R = 50,000, S/N ~ 270
- Wavelength coverage
  (4200 – 8500 Å)
- 1194 and 1315, identified
  by Pasquini et al. 2008
  (7 hrs exp for each star!)



Methodology

Selection of extremely clean spectral lines

↓

Measurements of equivalent width (IRAF)

↓

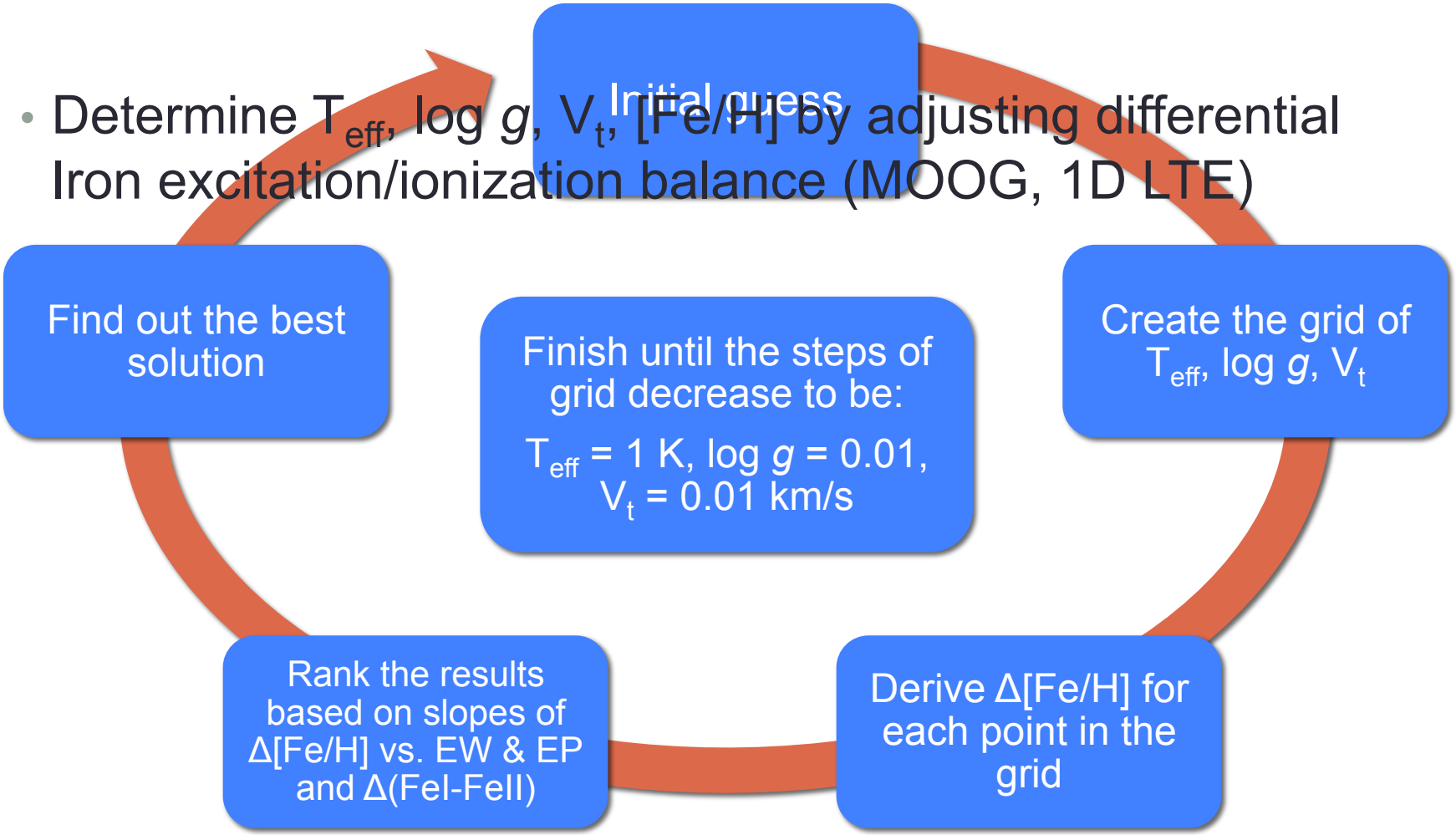
Derivation of stellar atmospheric parameters

↓

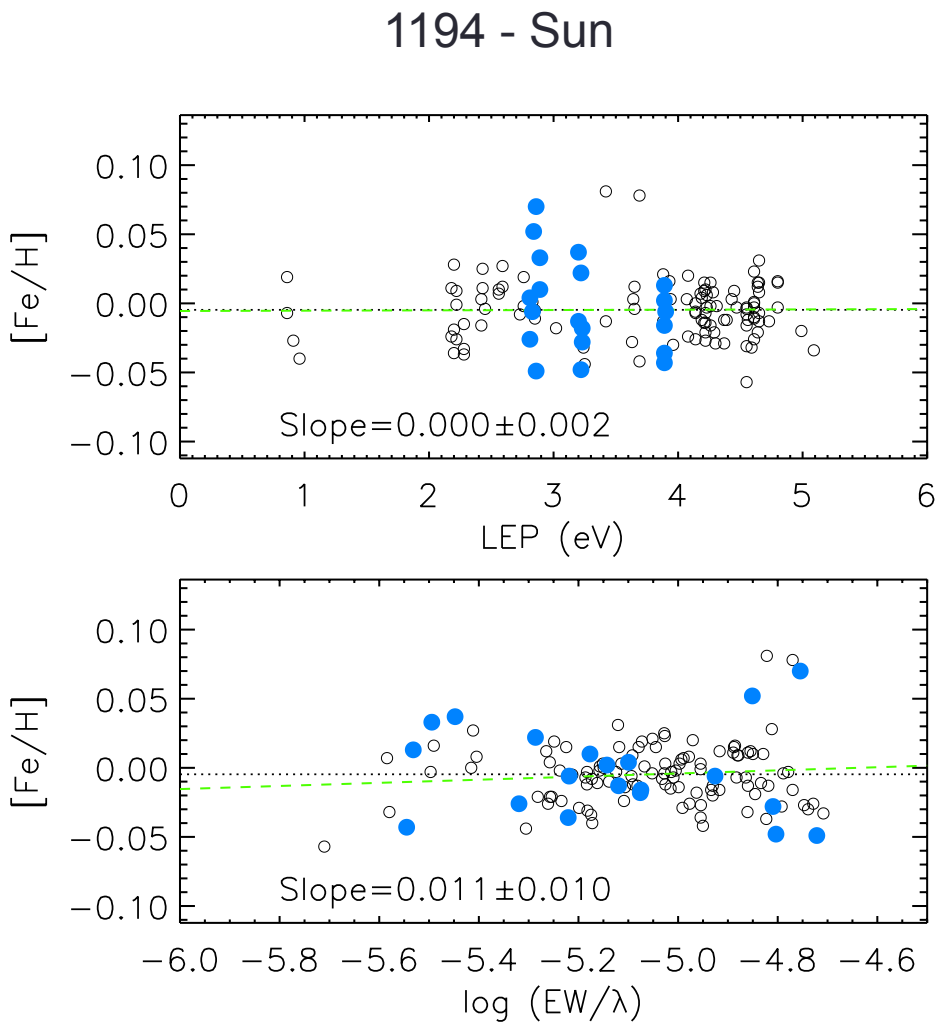
Strictly line-by-line differential abundance analysis

Automatic pipeline

- Determine T_{eff}, log *g*, V_t, [Fe/H] by adjusting differential Iron excitation/ionization balance (MOOG, 1D LTE)



Example of balancing plot



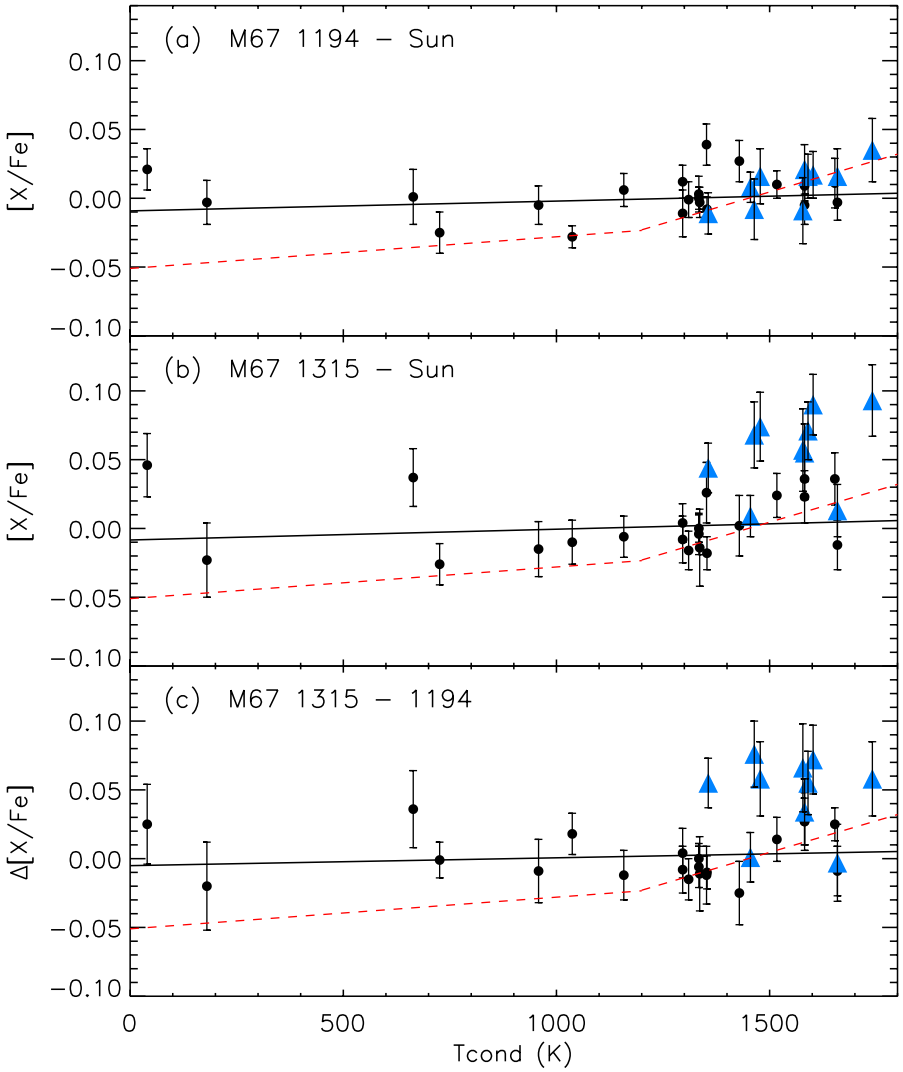
Stellar atmospheric parameters

	T_{eff} (K)	log *g* [cgs]	[Fe/H]
Hebe (Sun)	5777	4.44	0.0
M67 1194	5786 ± 13	4.46 ± 0.02	**-0.005** ± 0.010
M67 1315	5933 ± 23	4.46 ± 0.05	**-0.061** ± 0.014

- 1315 is warmer than 1194 by ~ 150 K
- 1315 is more metal-poor than 1194 by ~ 0.05 dex

Detailed chemical patterns of both stars?

Chemical abundances of 1194 and 1315

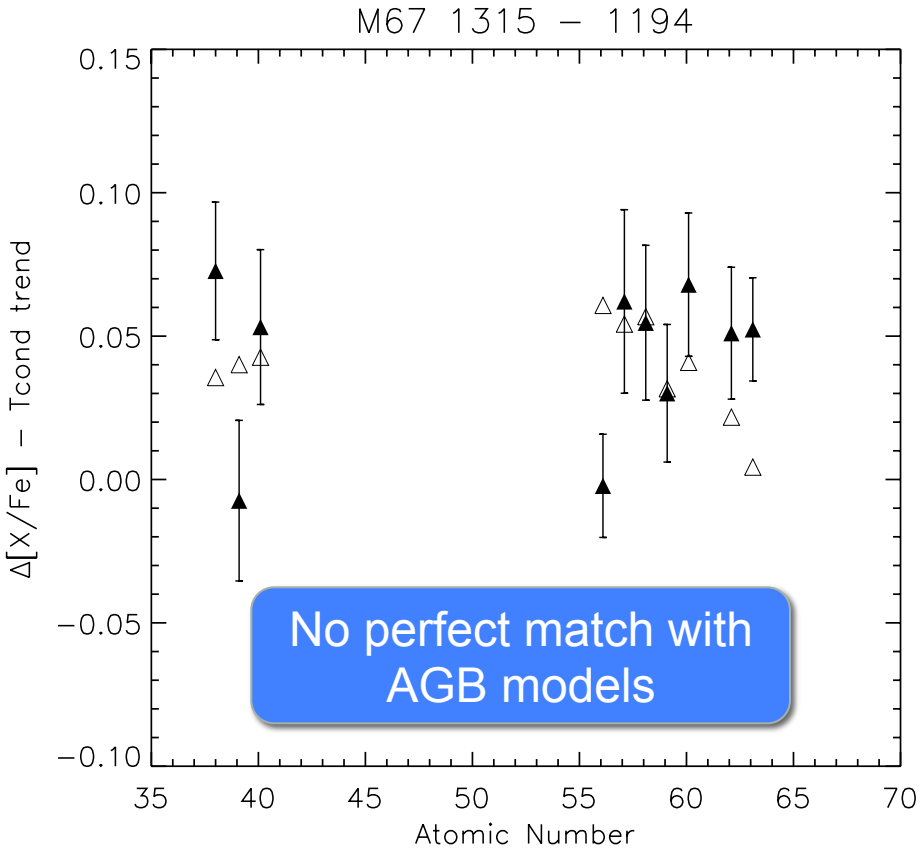


1194 is identical to the Sun

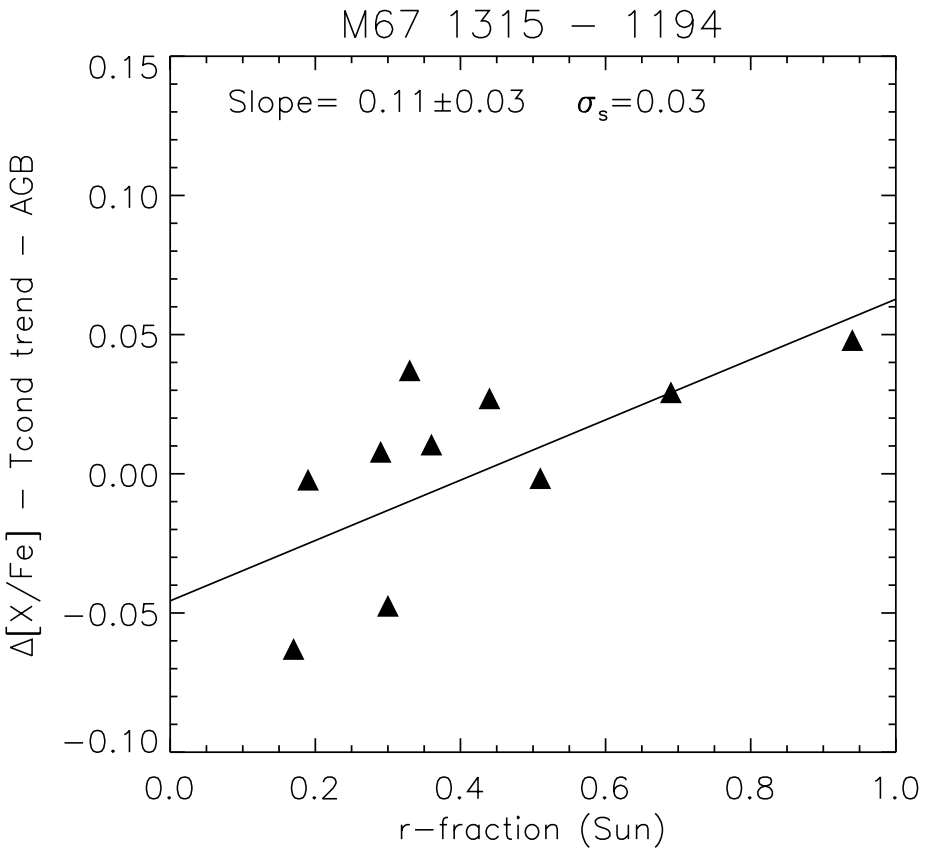
1315 is similar to the Sun and 1194 for Z <= 30

1315 is enriched in neutro-capture elements ([X/Fe]) by ~ 0.05 dex

Enrichment of neutron-capture elements in 1315



No perfect match with AGB models



Enrichment: partly due to AGB companion contributions?

Enrichment of residual material: r-process production, due to neutron star mergers?

Summary

- High-precision differential abundance analysis of two solar twins in M67 (1194 and 1315)

--- 1194 is identical to the Sun

--- 1315 is more metal-poor than 1194 by ~ 0.05 dex

--- 1315 is enriched in neutron-capture elements ([X/Fe])

except for Y and Ba

- Our results provide new constraints and a challenge to the current view of chemical tagging and Galactic archeology

Liu et al. 2016, arXiv:1608.03788

Future work

- More M67 solar twins
- Chemical inhomogeneity in other OCs

  Ruprecht 147 (VLT), Coma Berenices & Praesepe (HET)
- Cluster-to-cluster variations