

Exploring Neutron Capture Elements in Globular Clusters with the GALAH Survey

Madeleine (Madi/Maddie) McKenzie
NASA Hubble Fellow, Carnegie Observatories



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1. Magnesium

^{24}Mg , ^{25}Mg , ^{26}Mg ratios in globular clusters

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2. GALAH

What is GALAH?

The globulars of GALAH

Should you use n-cap. elements in GALAH?

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The globulars of GALAH

Should you use n-cap. elements in GALAH?

3. Lead

Constraining 3rd peak s-process abundances with Pb

AGB stars

Based on Karakas, Lattanzio, & Pols (2002), Karakas & Lattanzio (2014).

Convective envelope

H-burning

Intershell region

He-burning

Core

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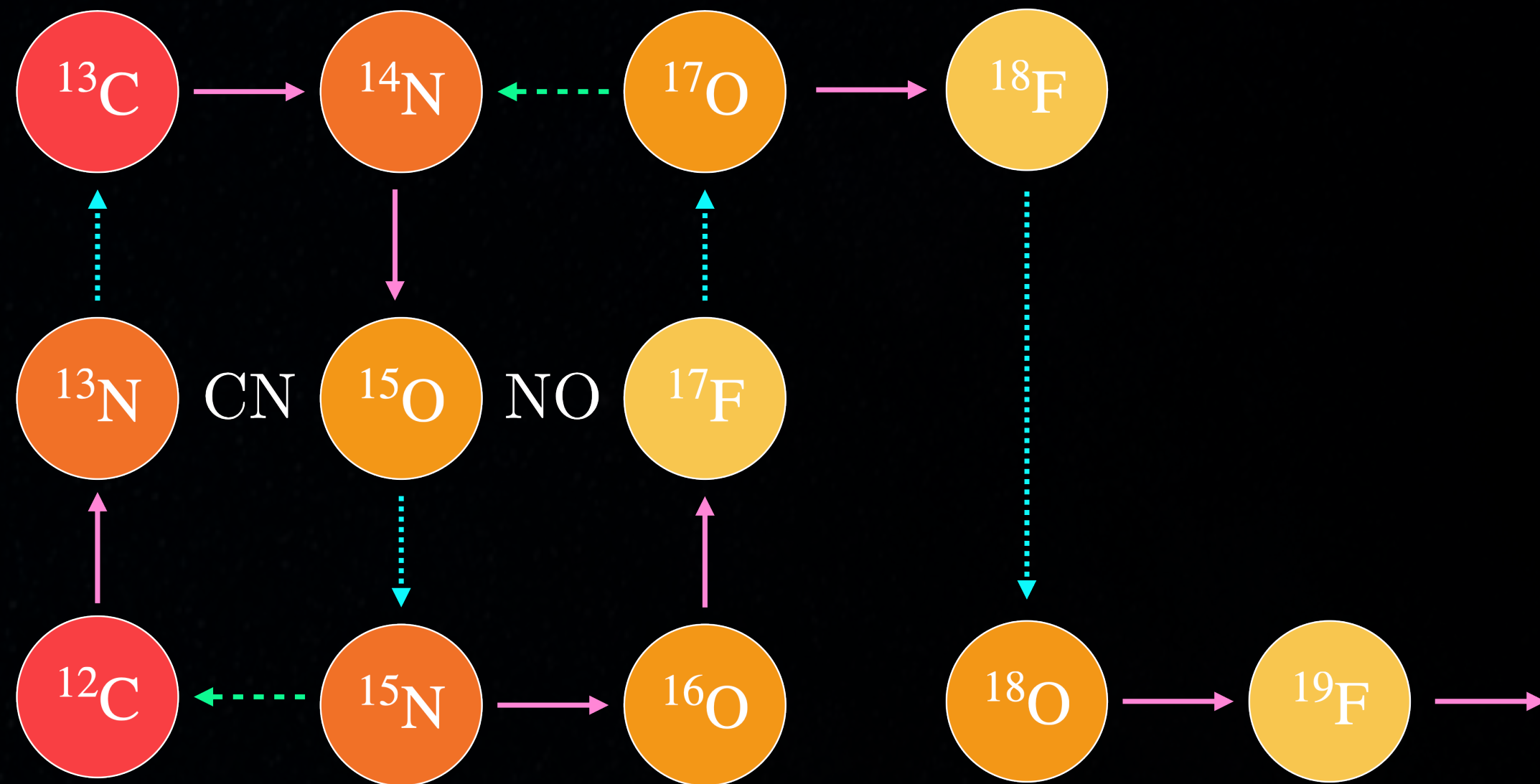
Adapted from Boeltzig et al. 2016

..... $\rightarrow$ $e^+\nu$

— $\rightarrow$ (p, γ)

--- $\rightarrow$ (p, α)

H-burning shell



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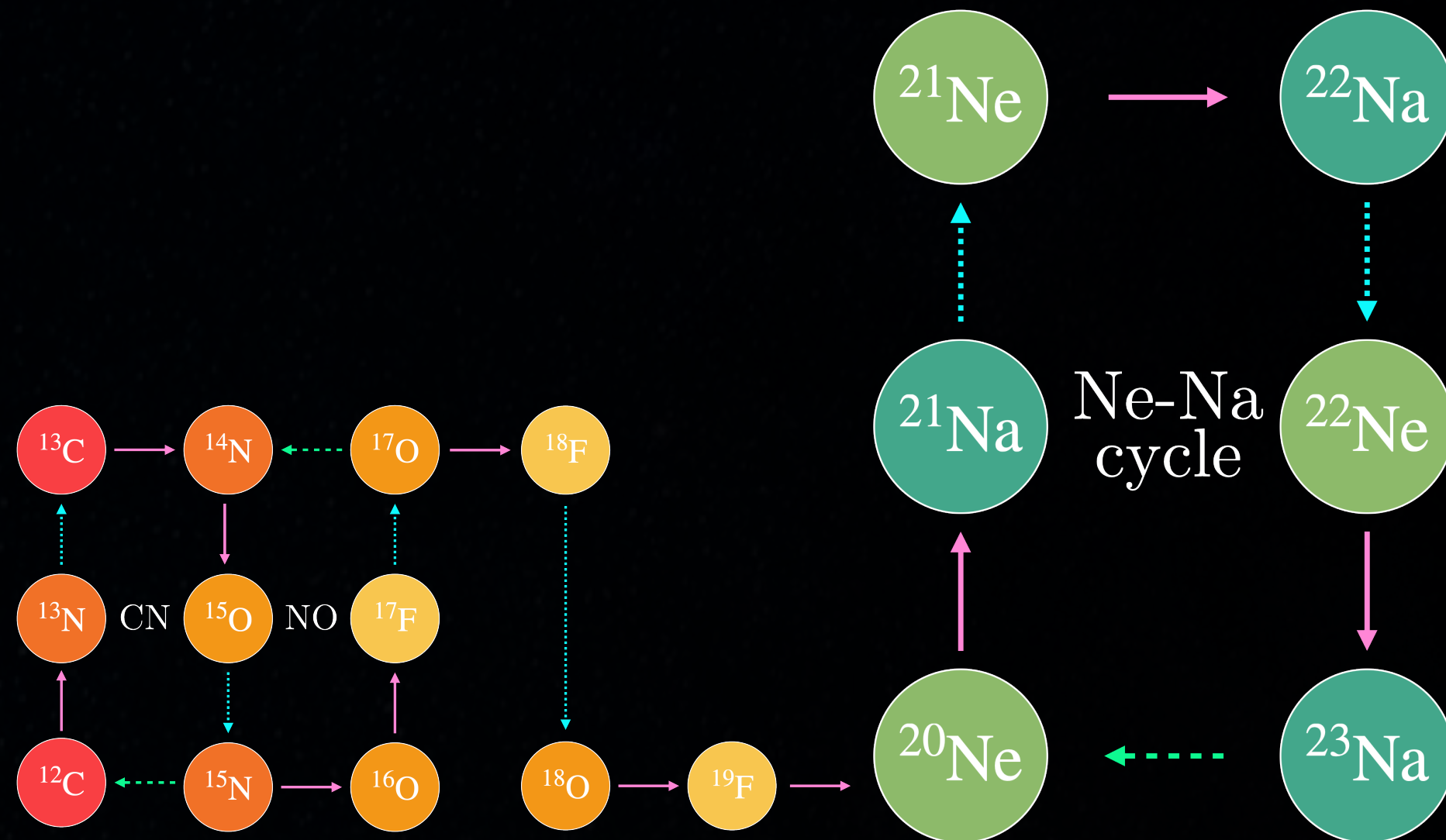
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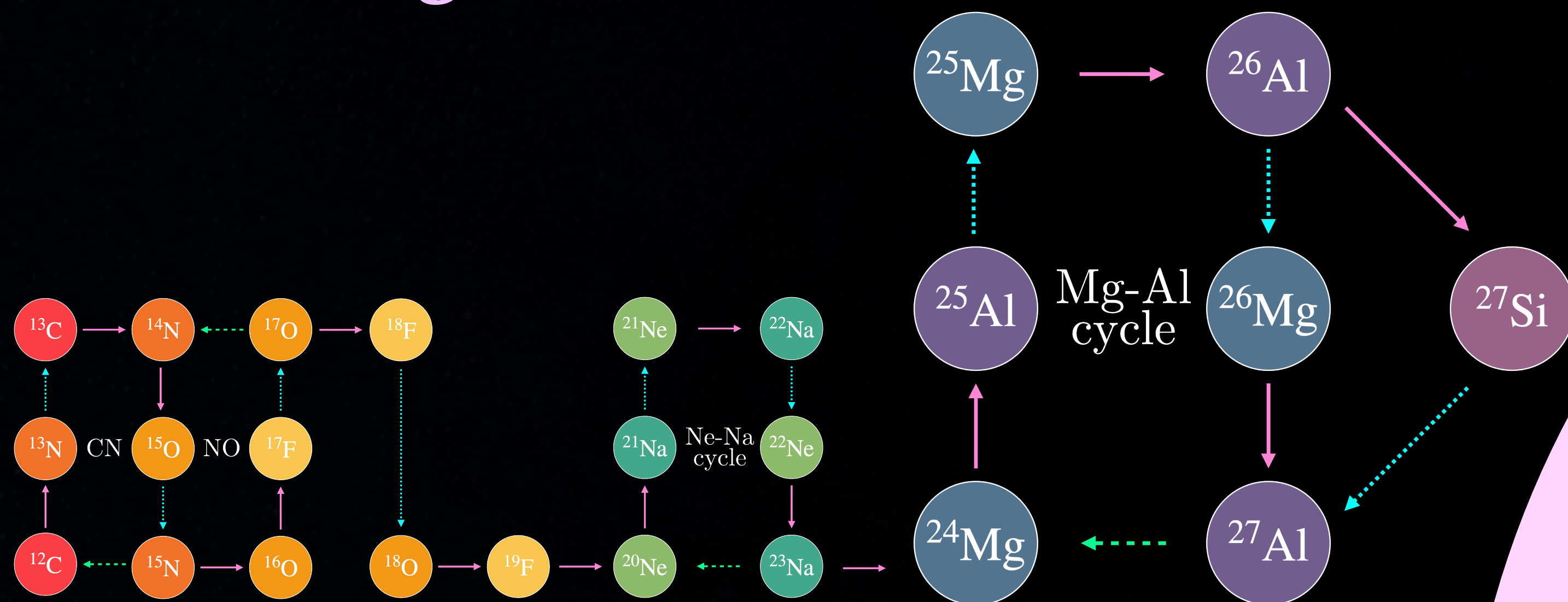
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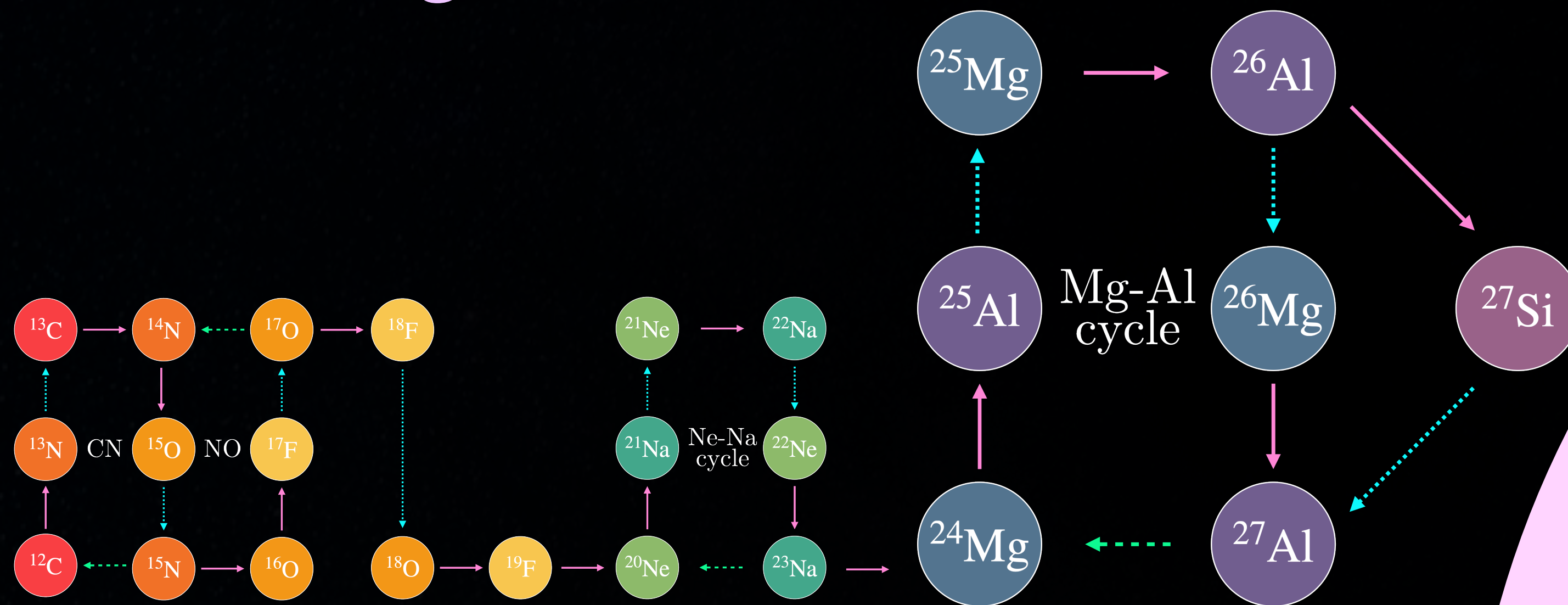
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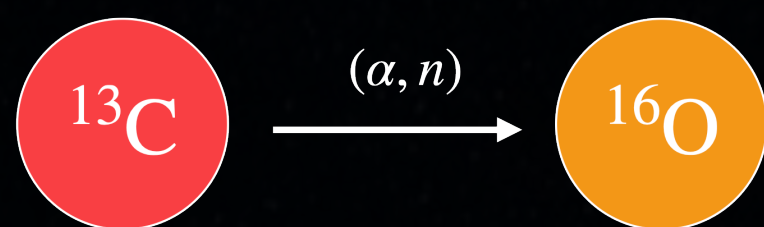
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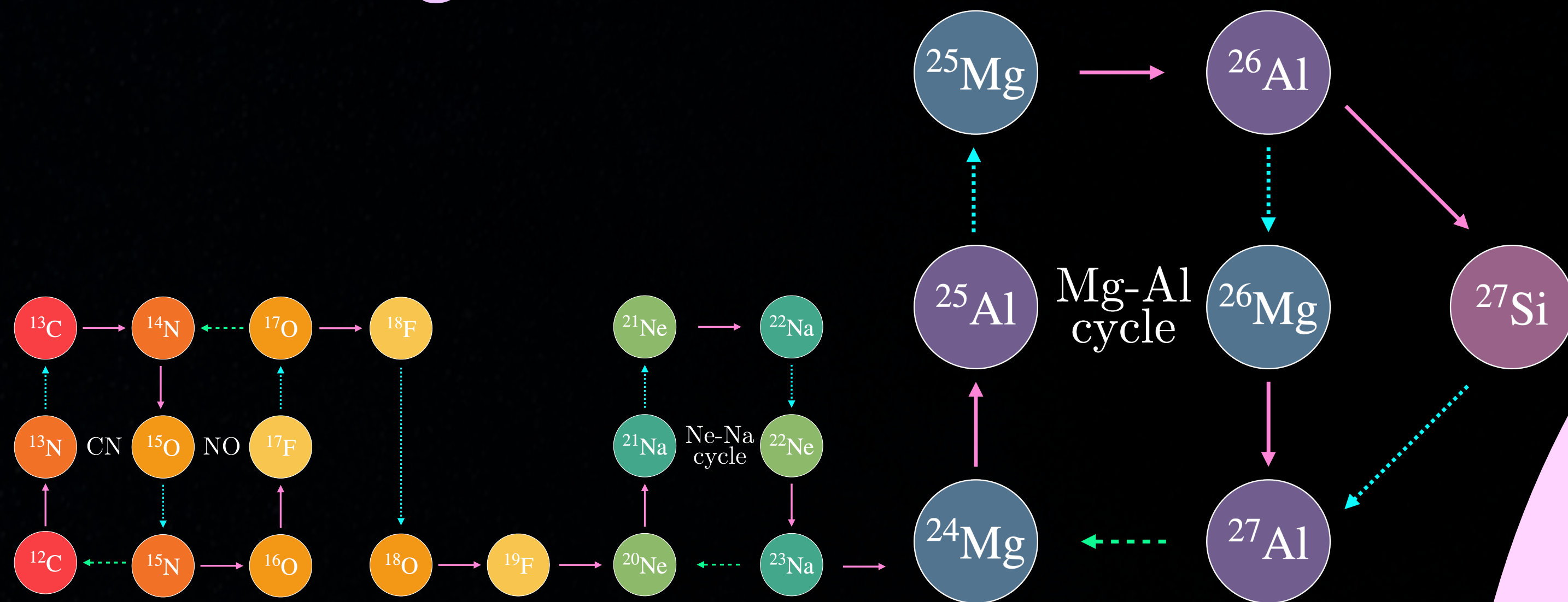
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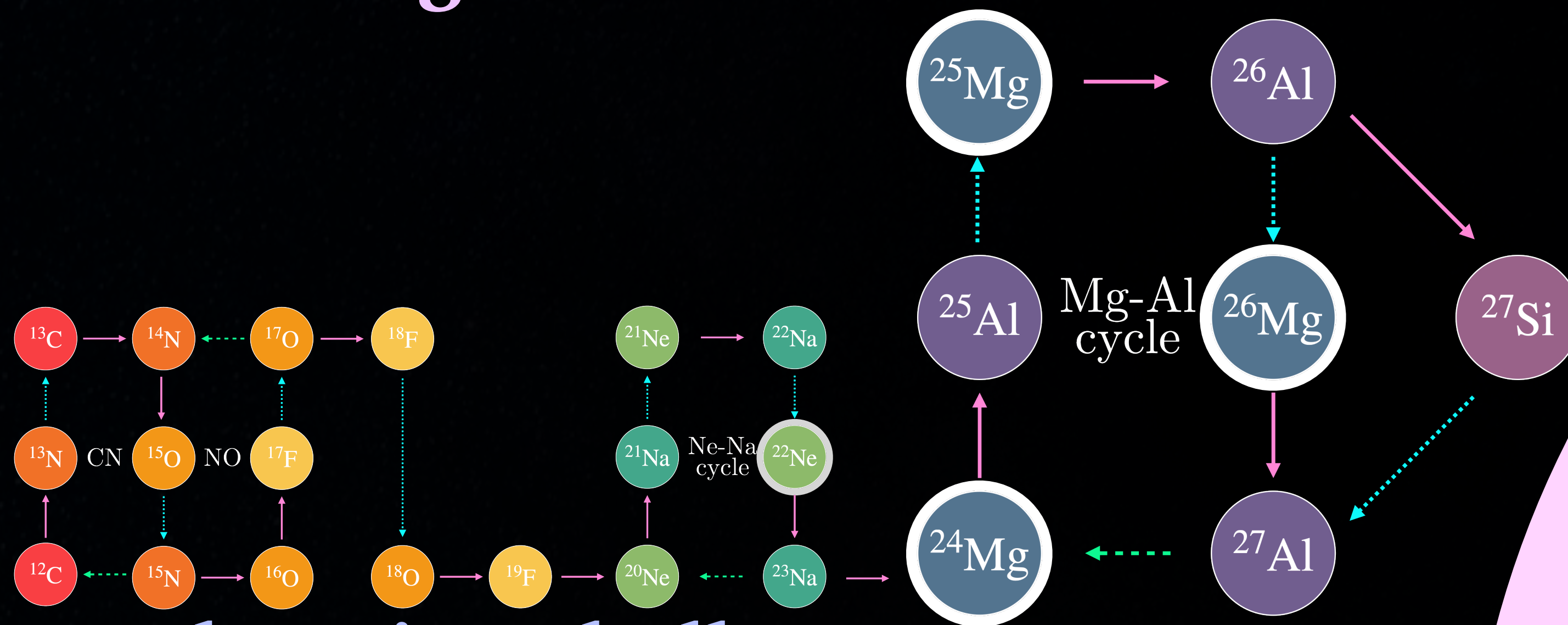
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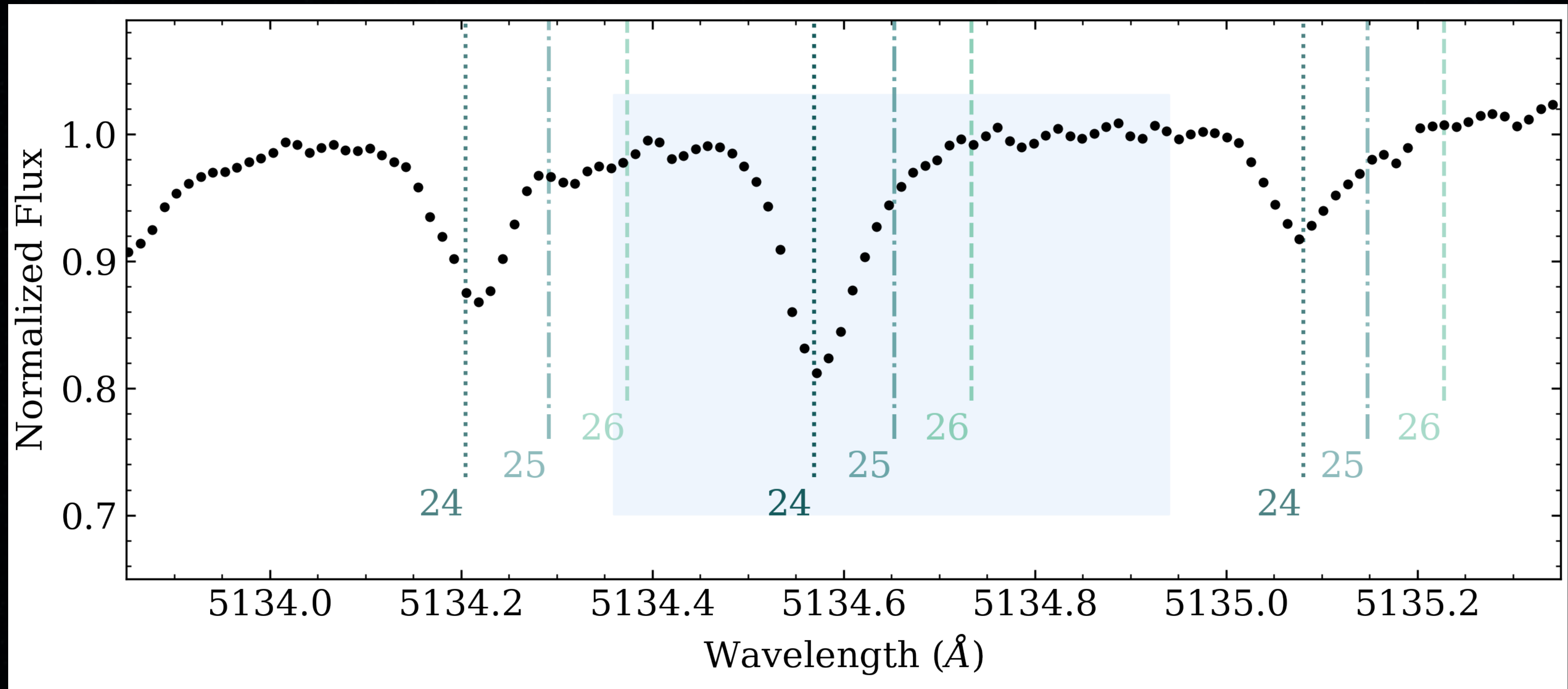
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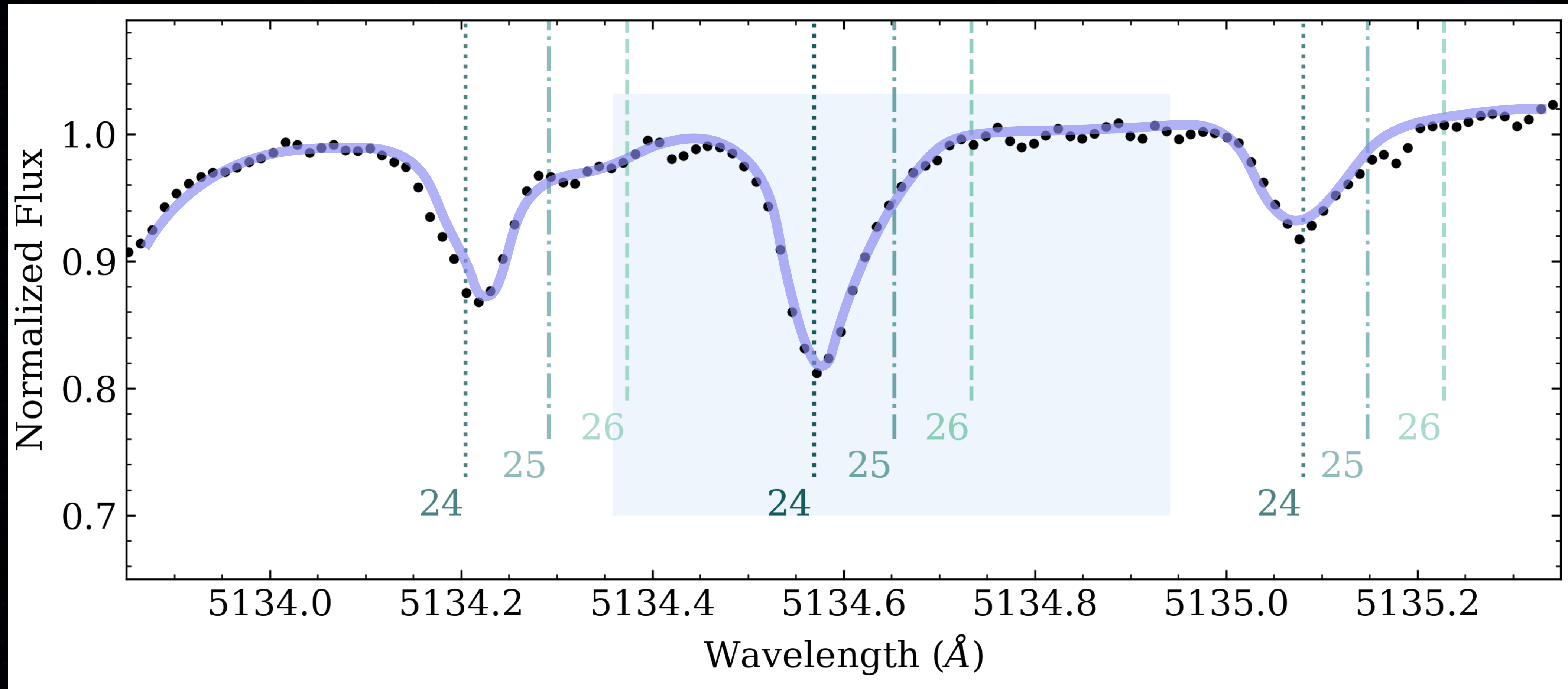
Core

MgH (not Mg)



$$^{24}\text{Mg} : ^{25}\text{Mg} : ^{26}\text{Mg} = 90 : 9 : 1$$

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$$^{24}\text{Mg} : ^{25}\text{Mg} : ^{26}\text{Mg} = 90 : 9 : 1$$

M 22

A Milky Way disc globular cluster
with nuclear star cluster chemistry



Distance from us: 3.2 kpc

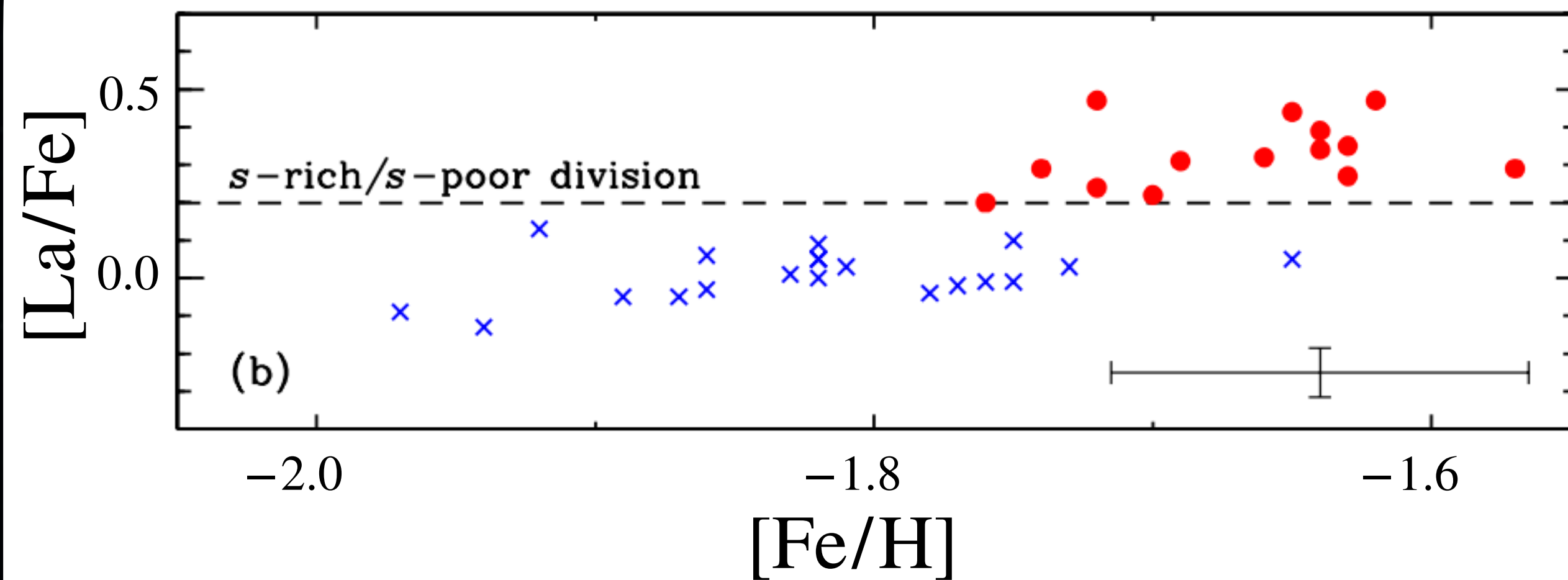
Distance to the galactic centre: 4.9 kpc

[Fe/H] $\sim$ -1.7

Mass: $4.67 \times 10^5 M_{\odot}$

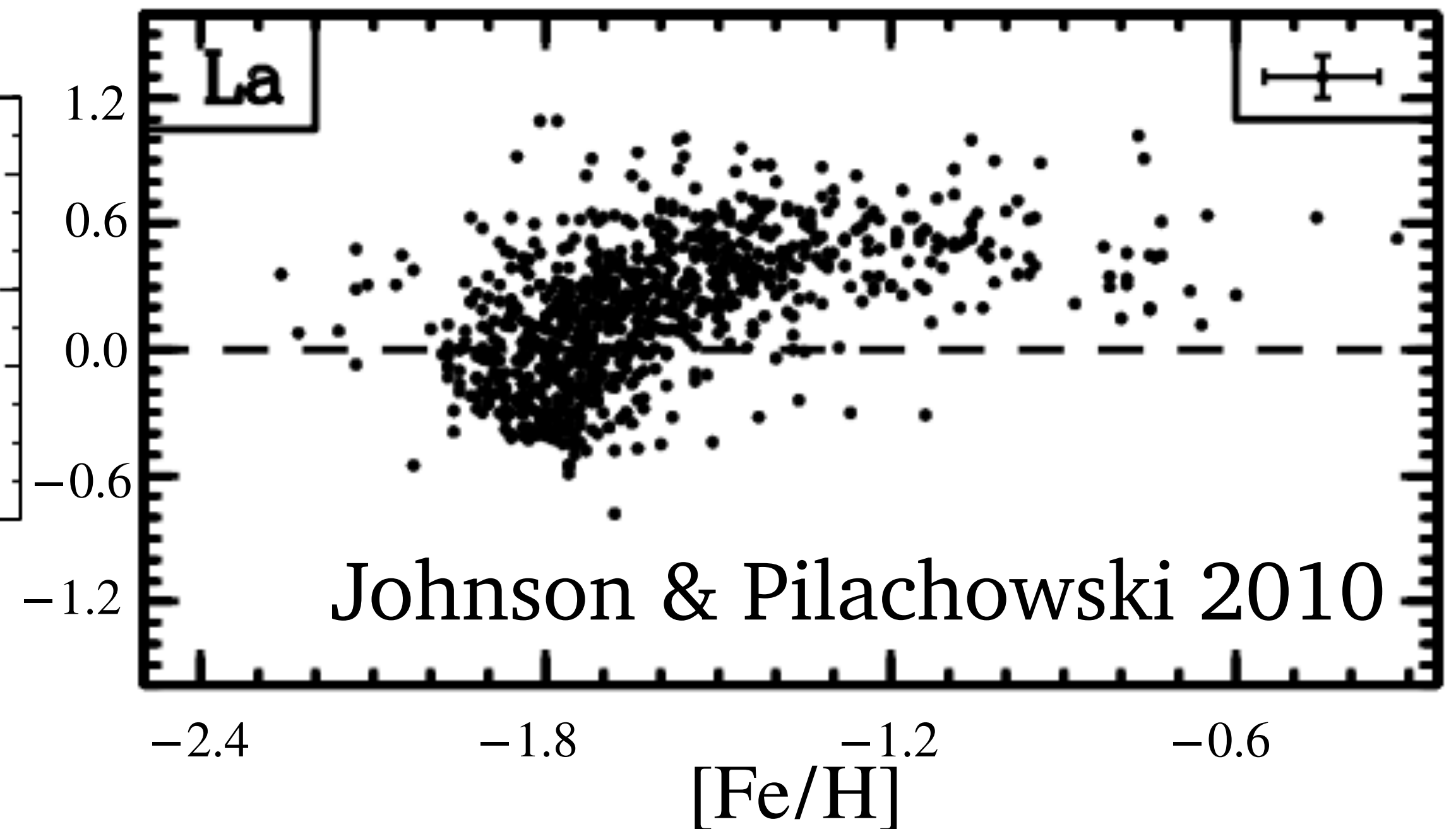
Chemical abundances in M 22 and ω Centauri

M 22



Marino et al. 2011

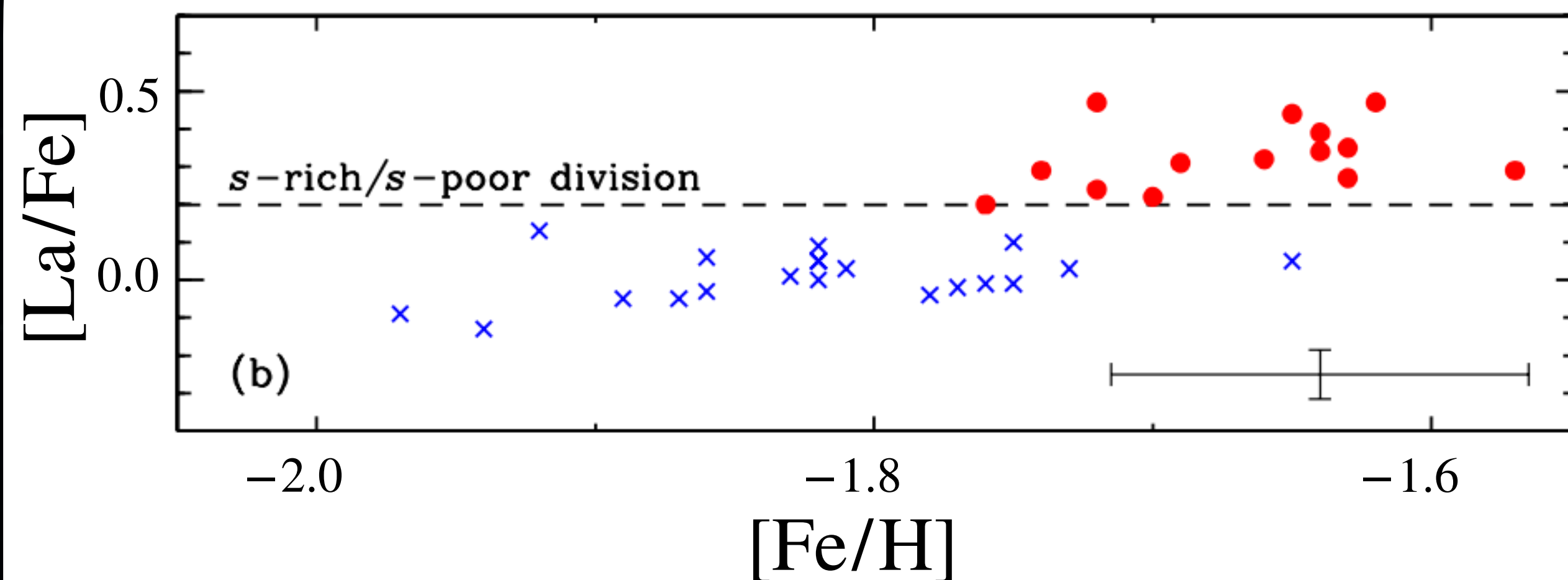
ω Centauri



Johnson & Pilachowski 2010

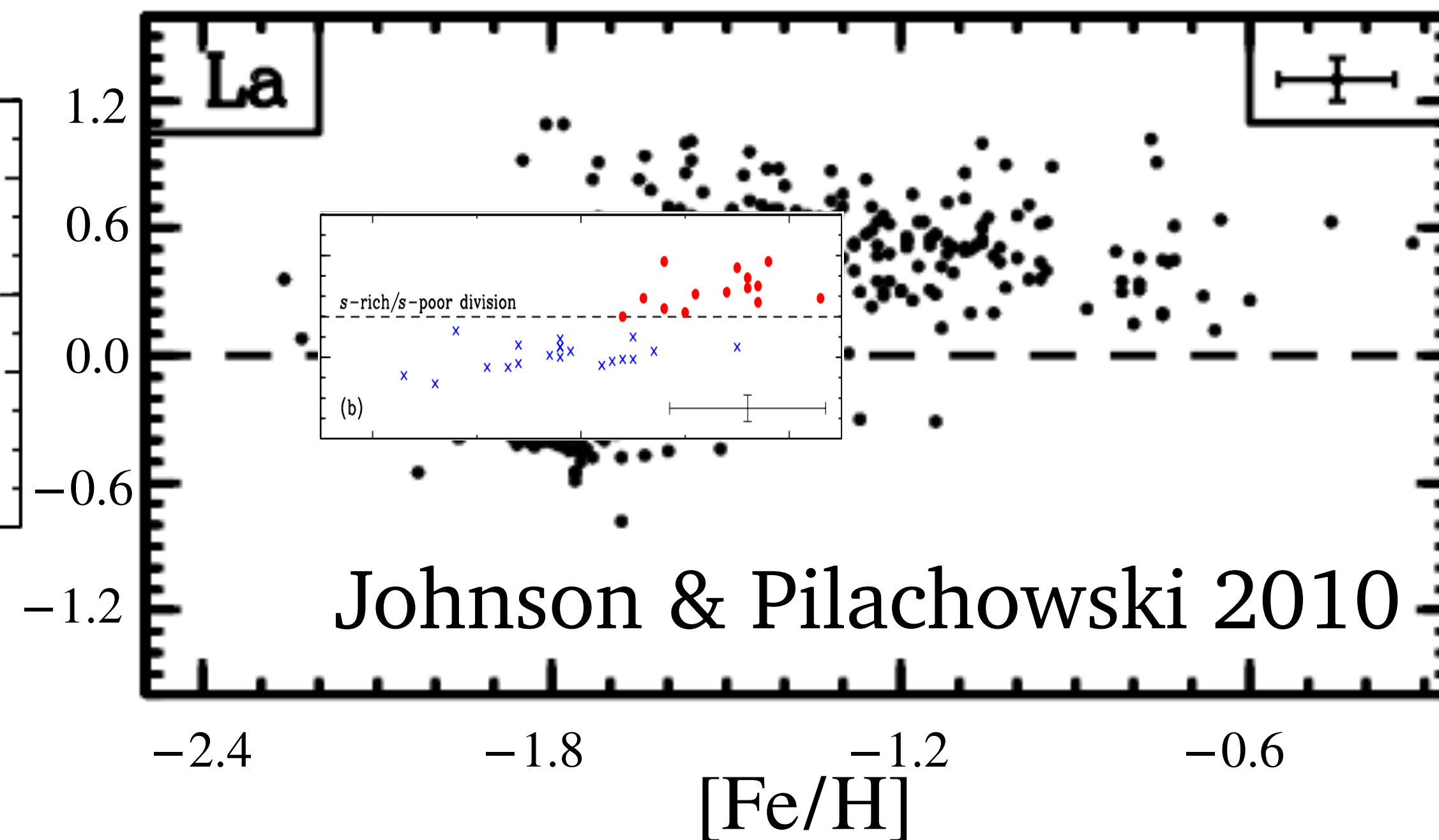
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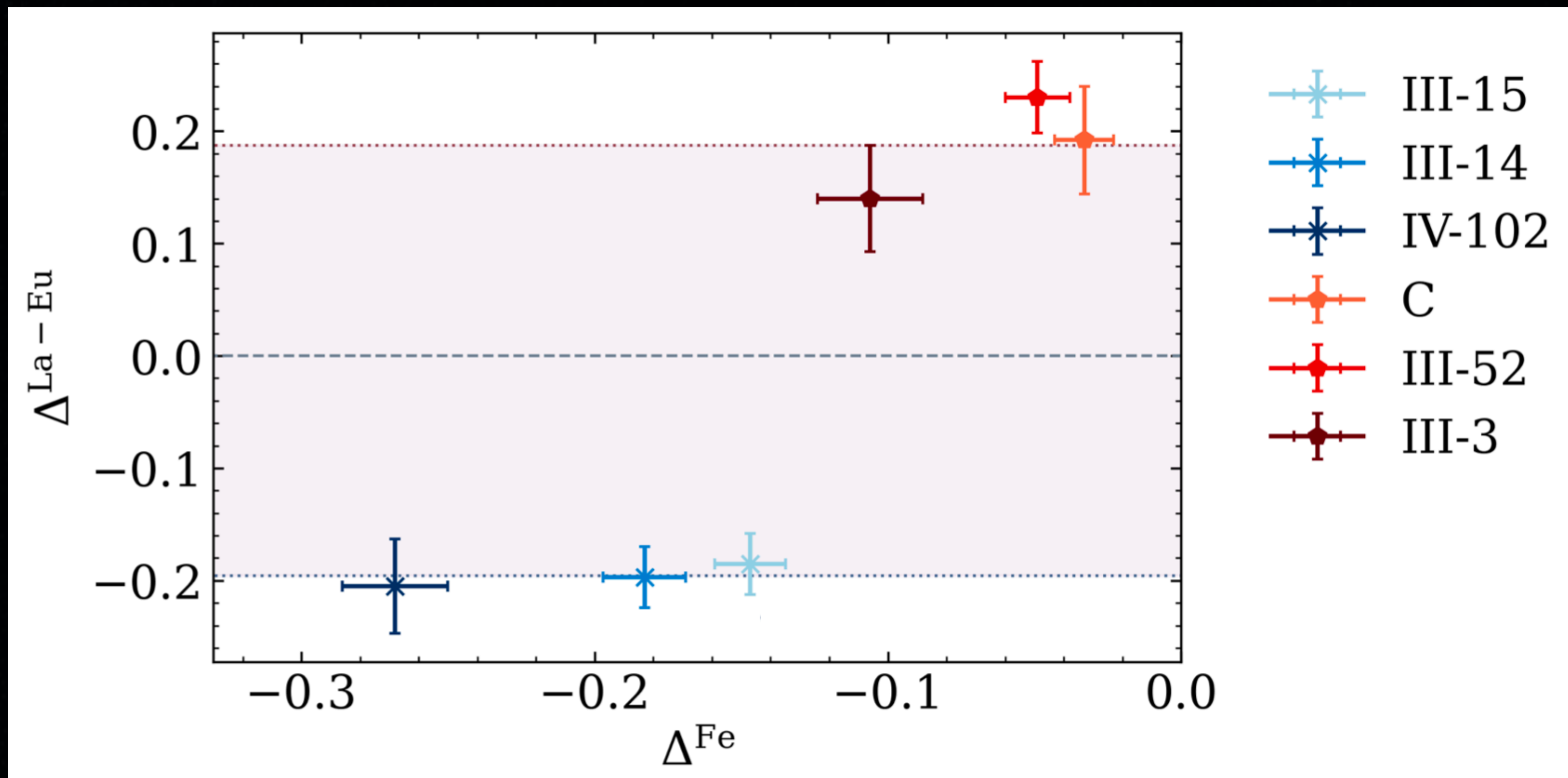
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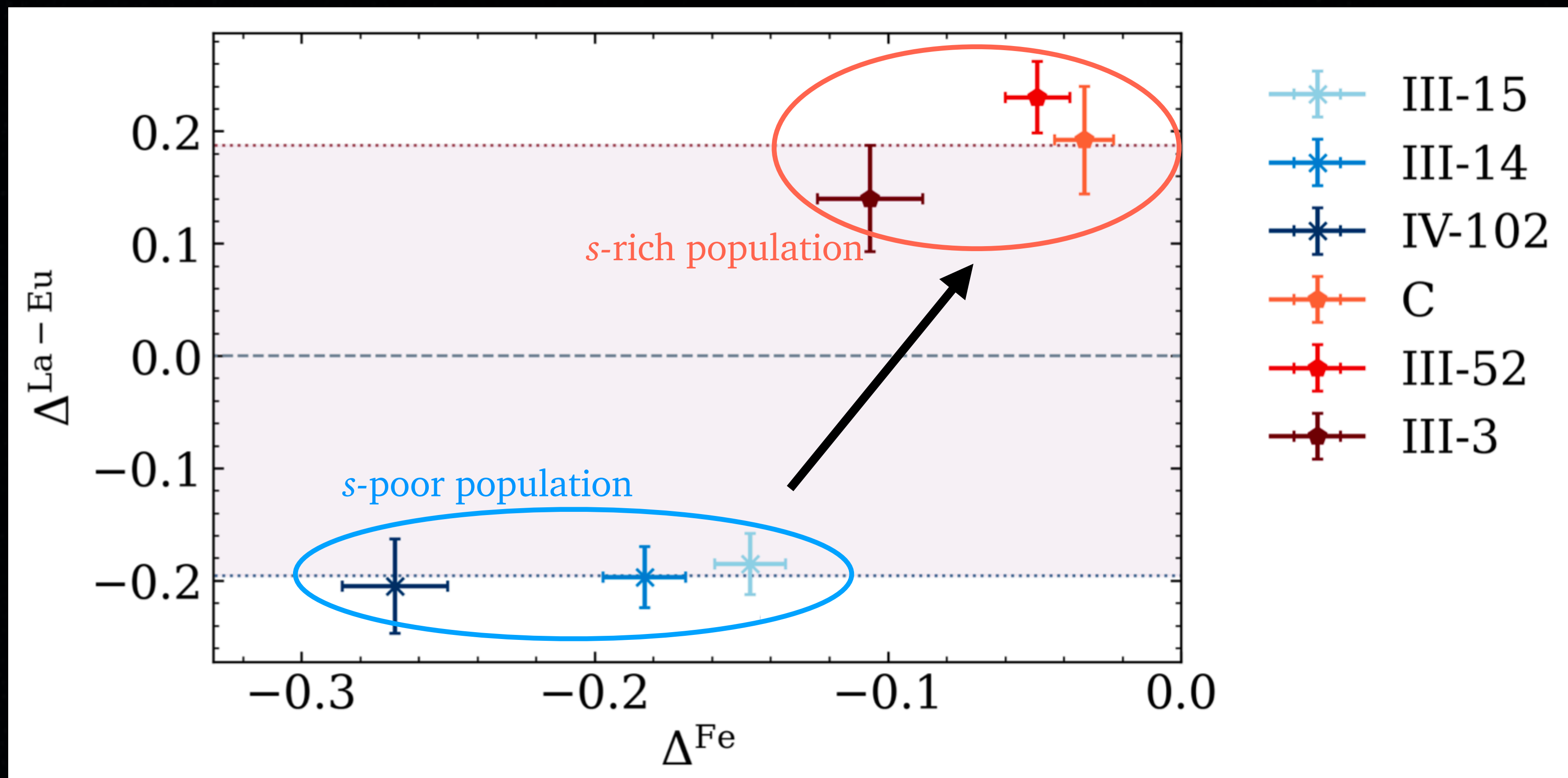
High precision differential abundance analysis of M 22

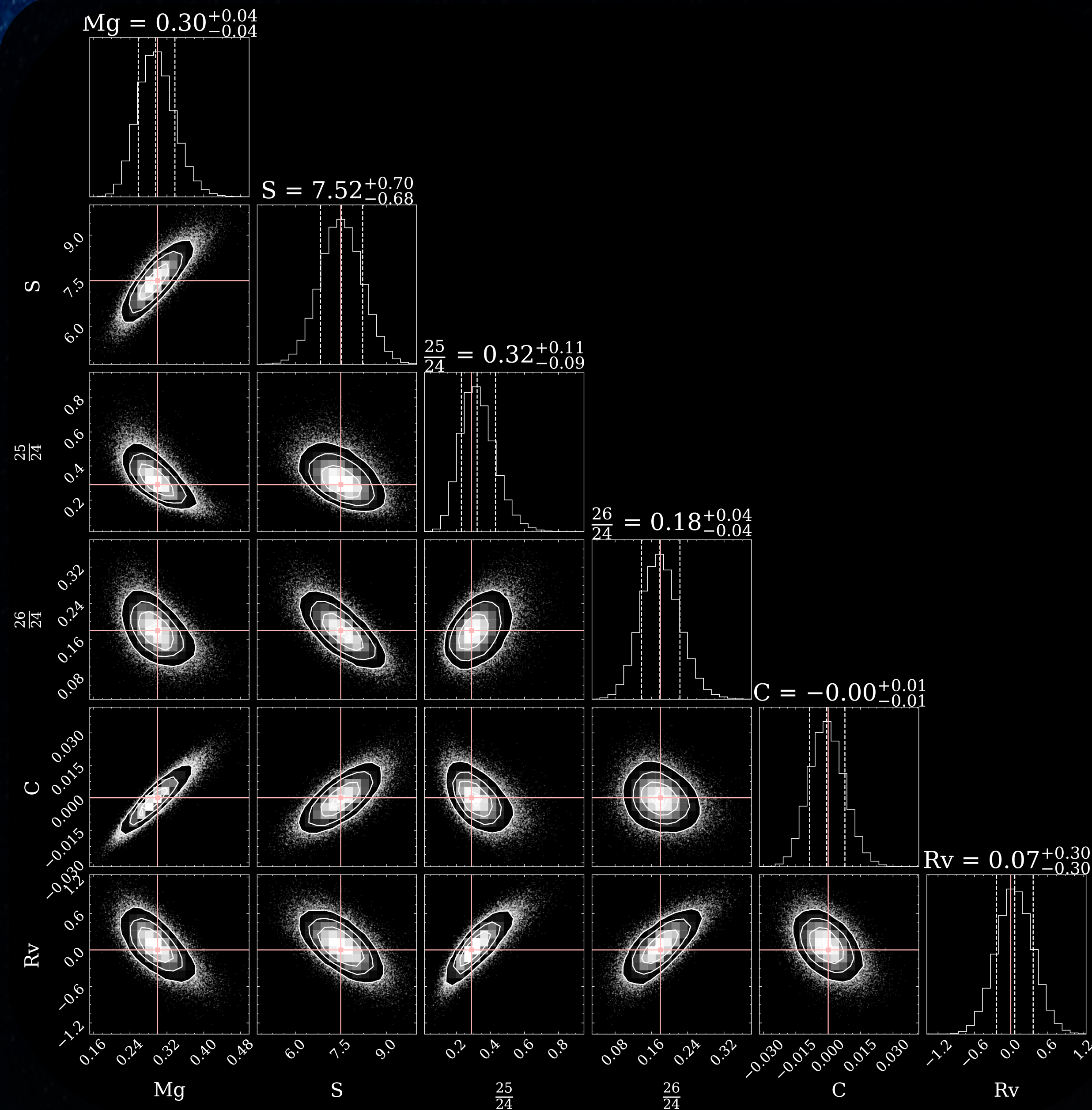
McKenzie et al. 2023



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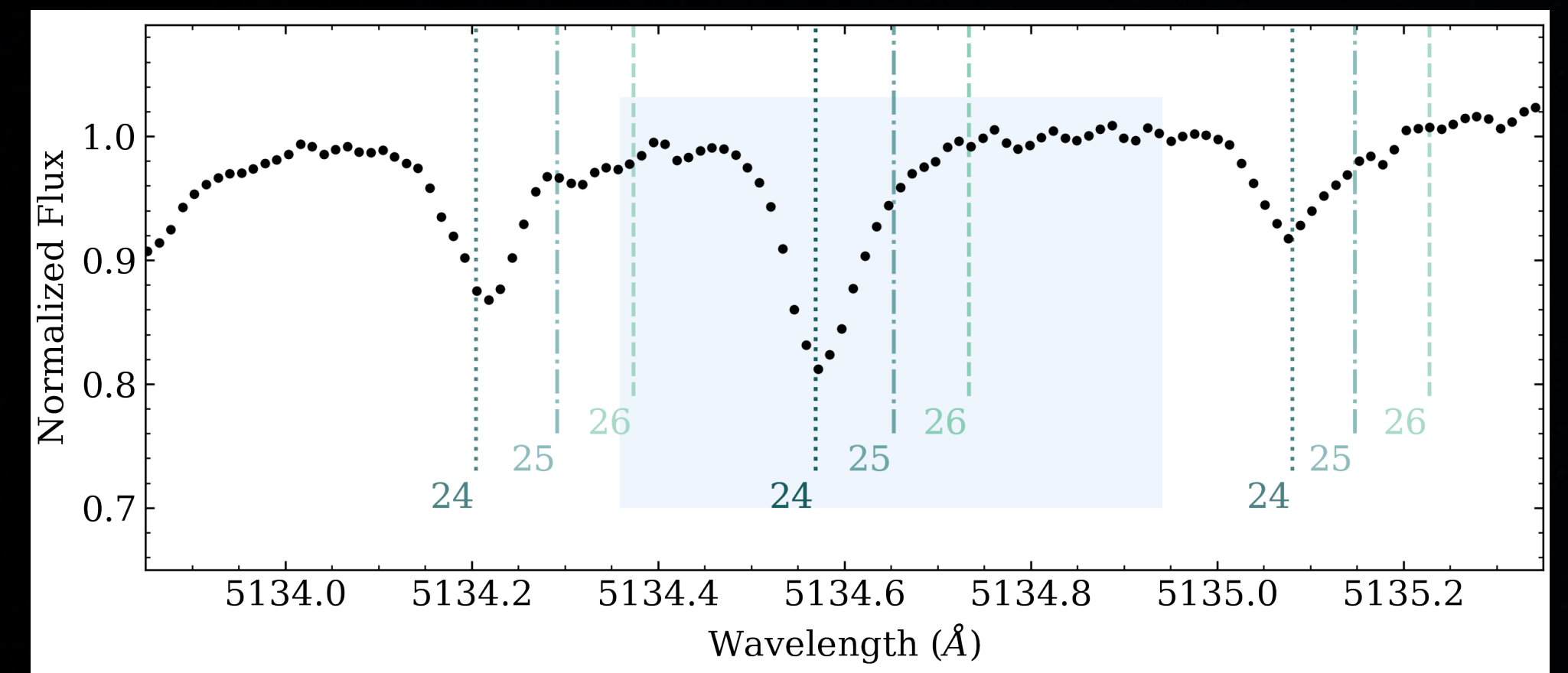




RAtIO

Rapid Automatic Isotope Optimisation

Wrapper for MOOG (Snedden 1977)
 Chains analysed using Chainconsumer (Hinton 2016)



$$\text{Mg} = 0.30^{+0.04}_{-0.04}$$

→ **Total Mg abundance**

RAtIO

Rapid **A**utomatic **I**sotope **O**ptimisation

Wrapper for MOOG (Snedden 1977)

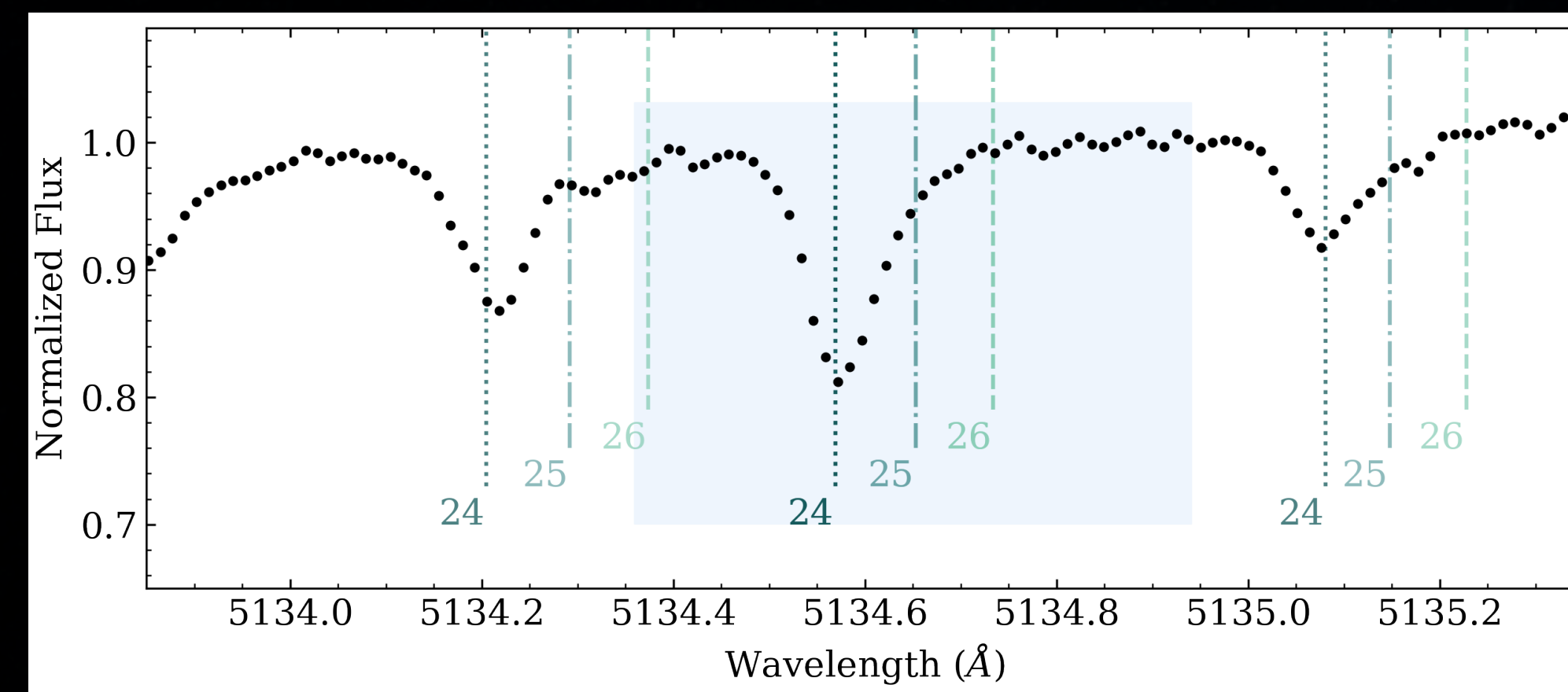
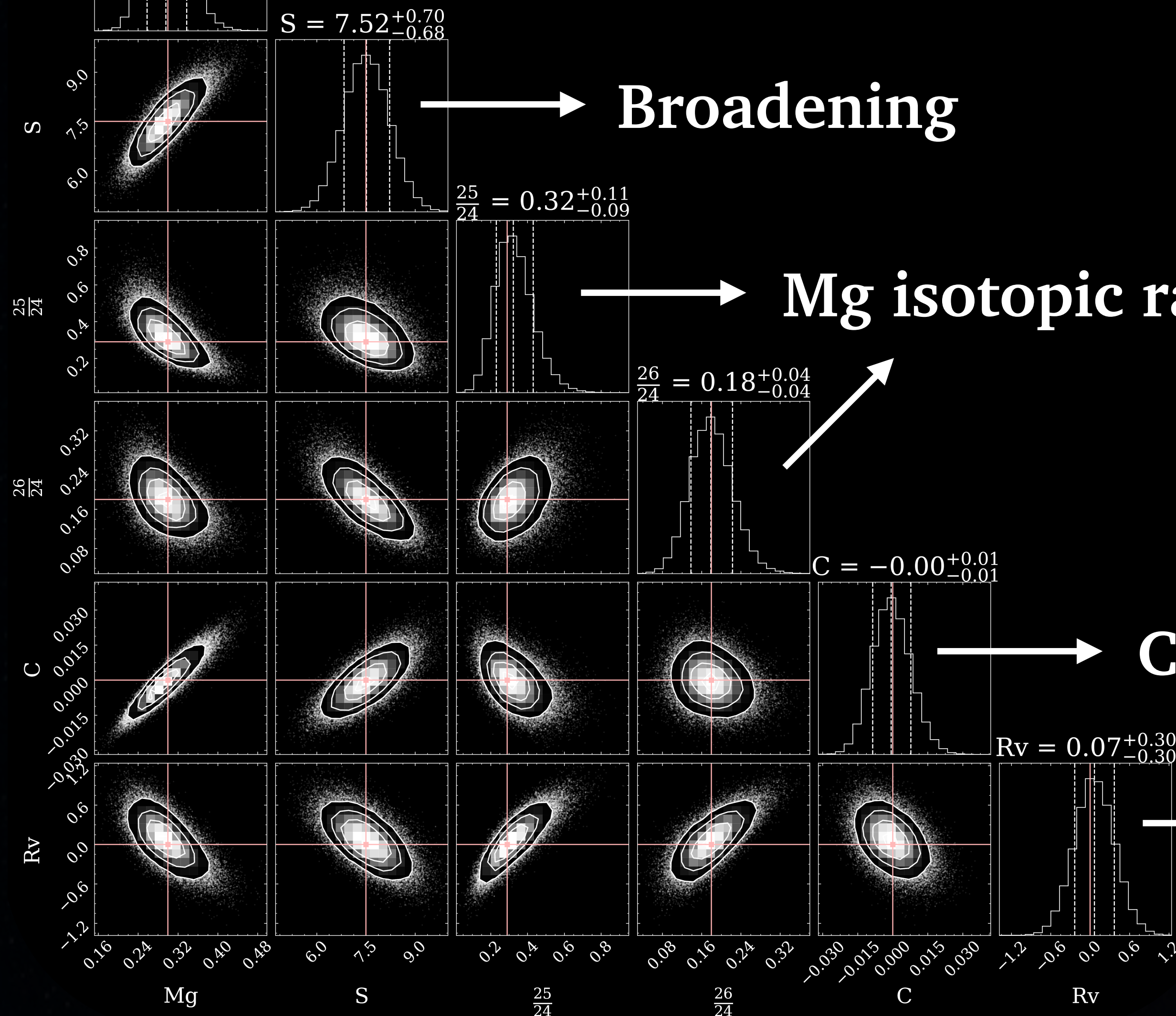
Chains analysed using Chainconsumer (Hinton 2016)

→ **Broadening**

→ **Mg isotopic ratios**

→ **Continuum placement**

→ **Radial velocity correction**



RAtIO

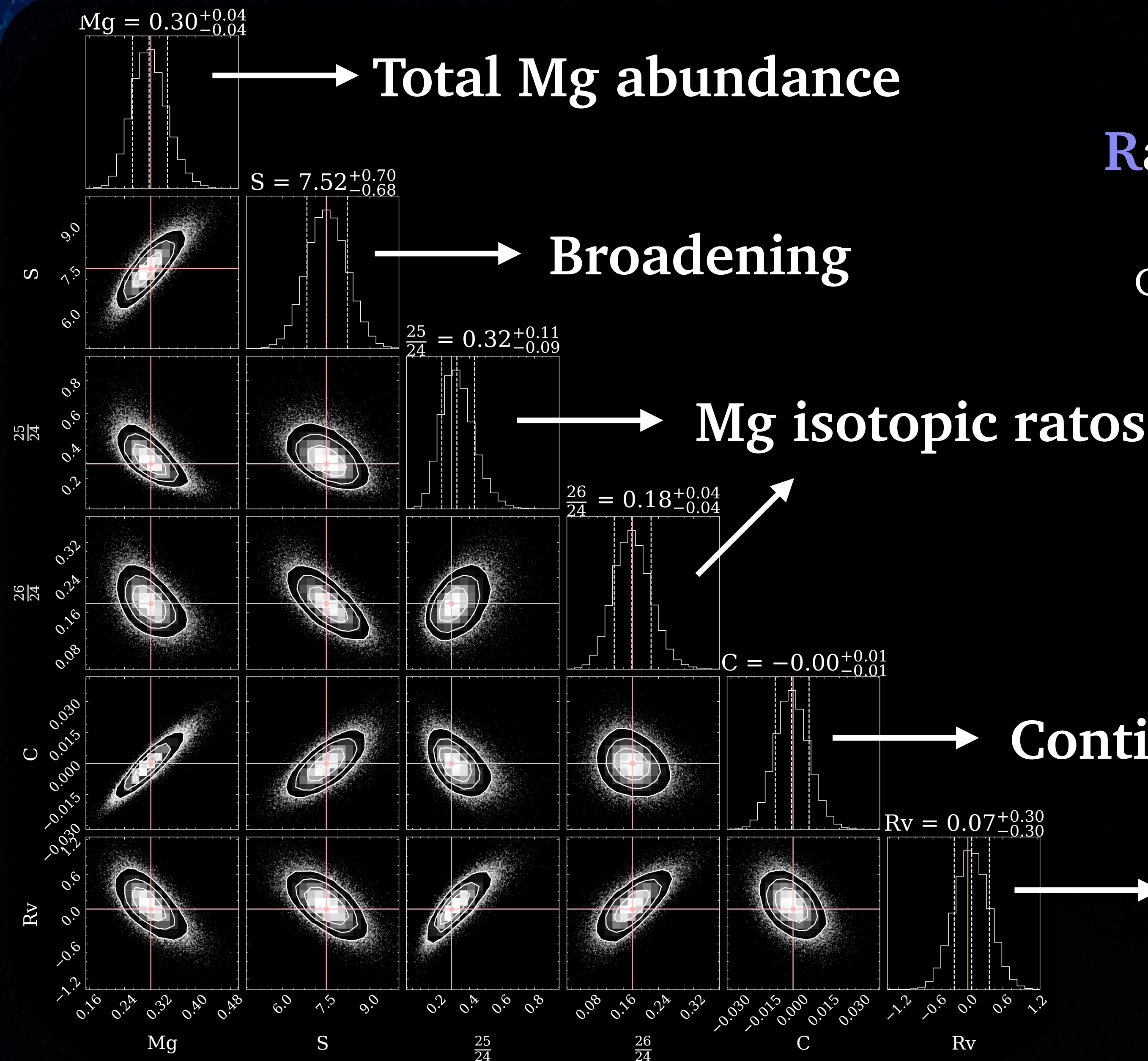
Rapid Automatic Isotope Optimisation

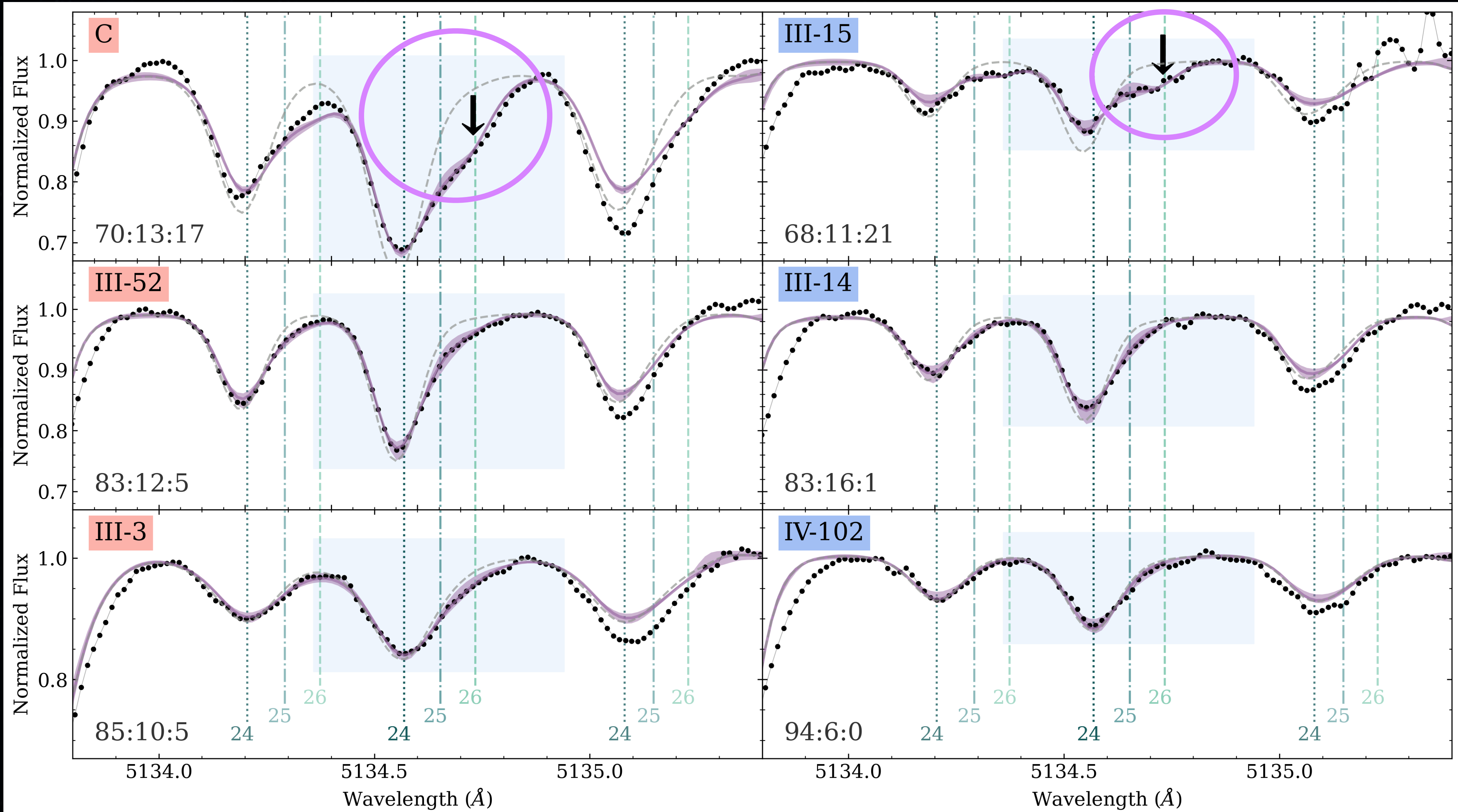
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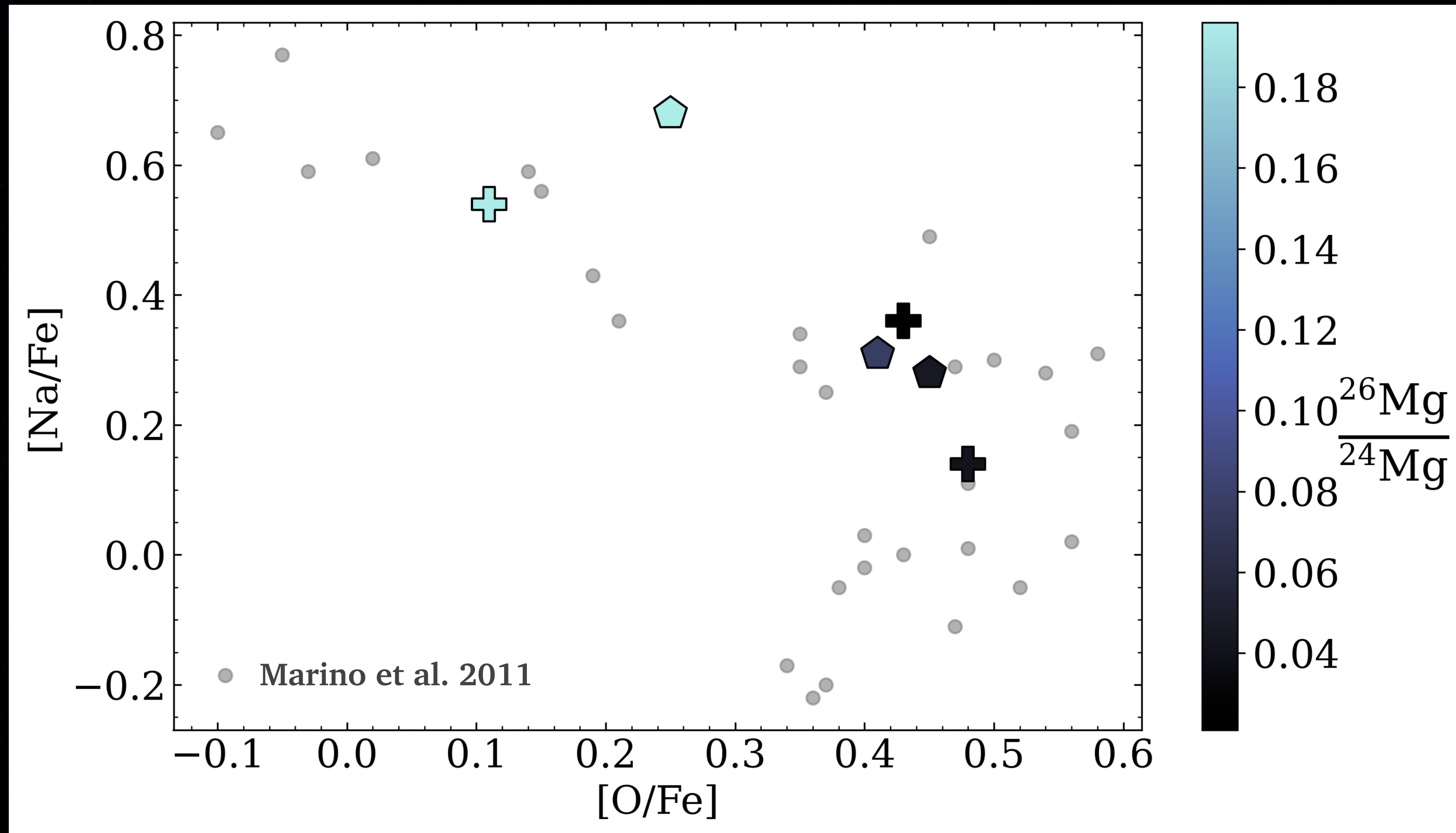
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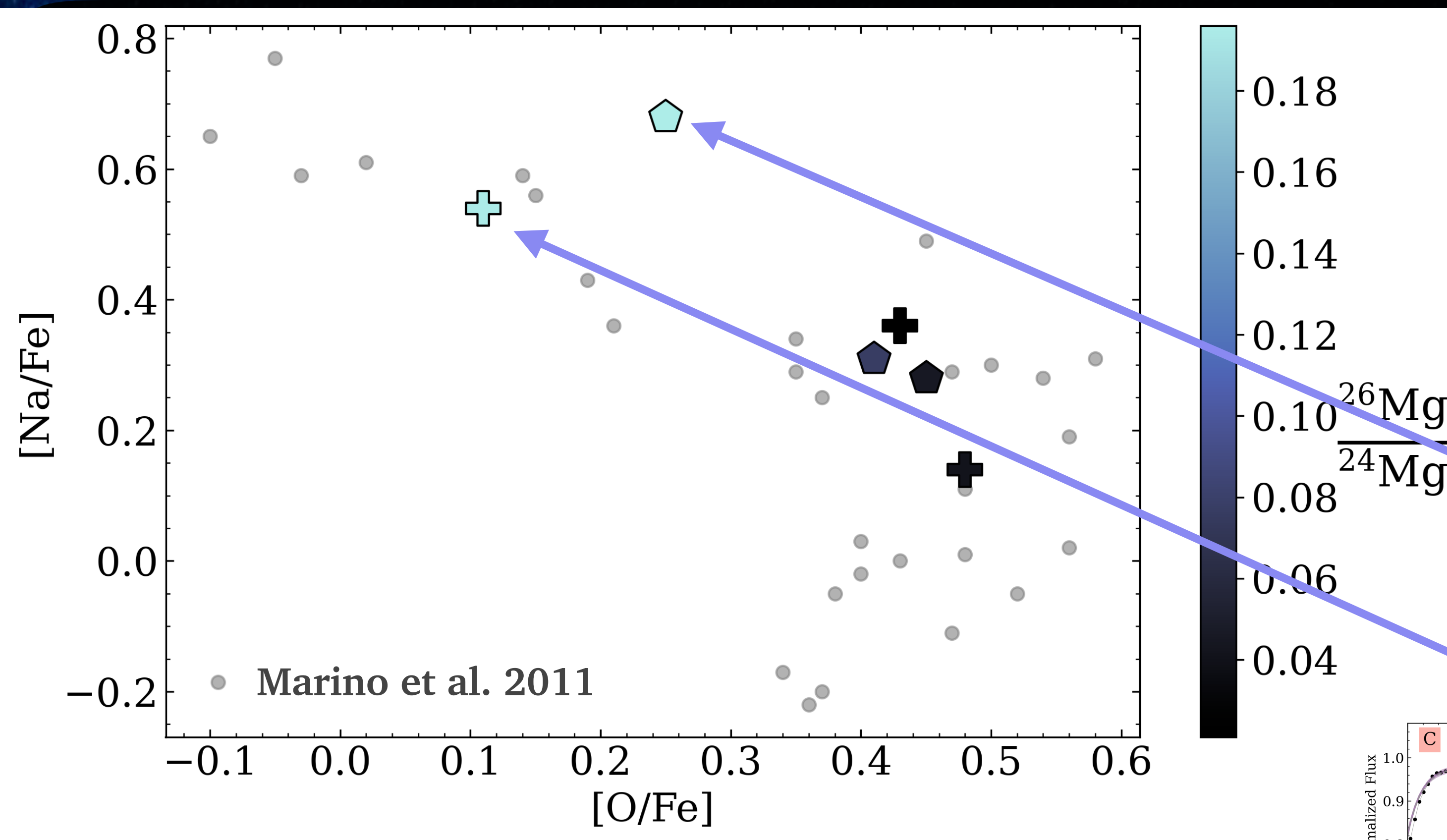


Migrating to KOROS later this year
(Wheeler et al. 2023, 2024)

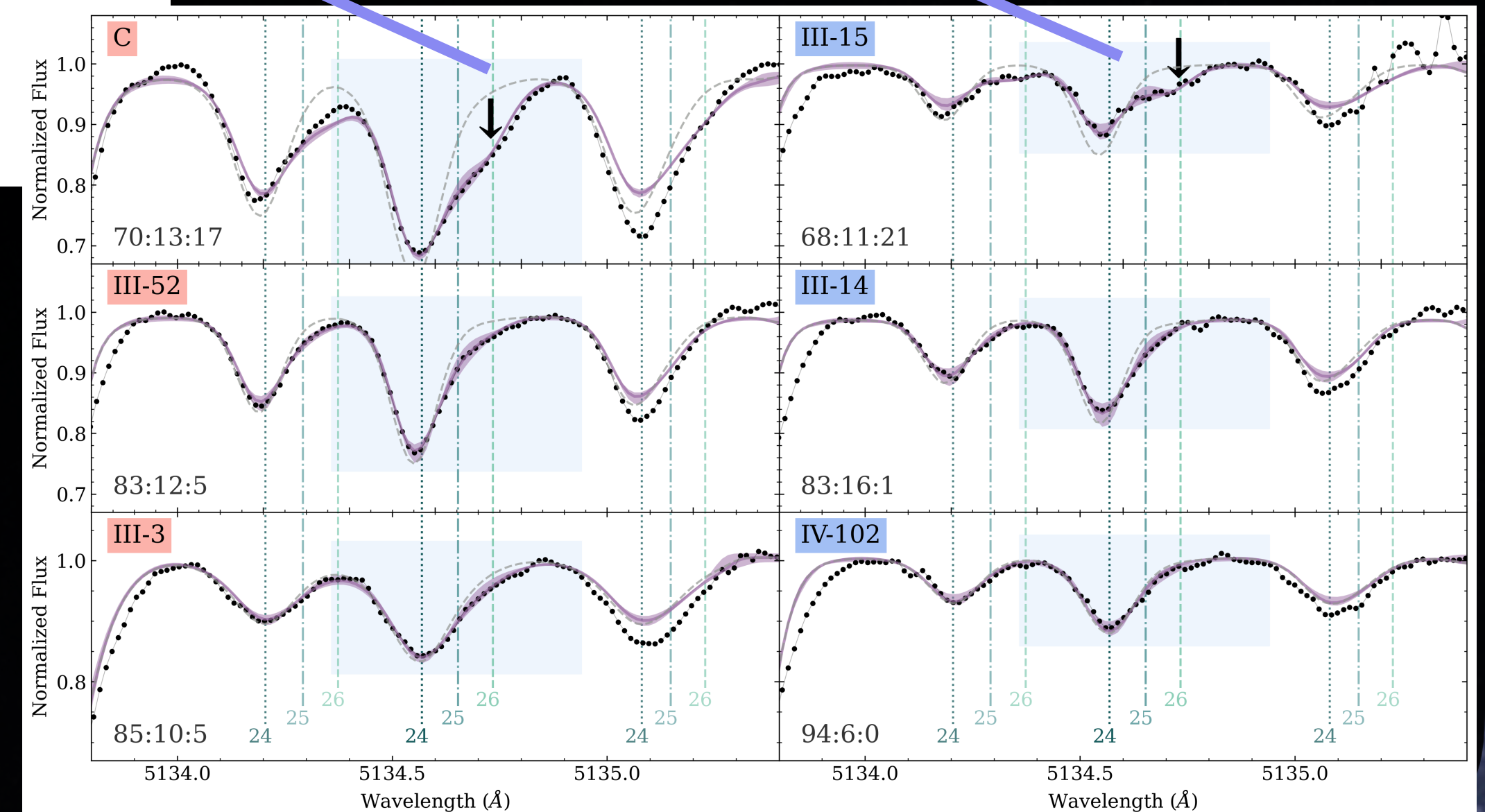


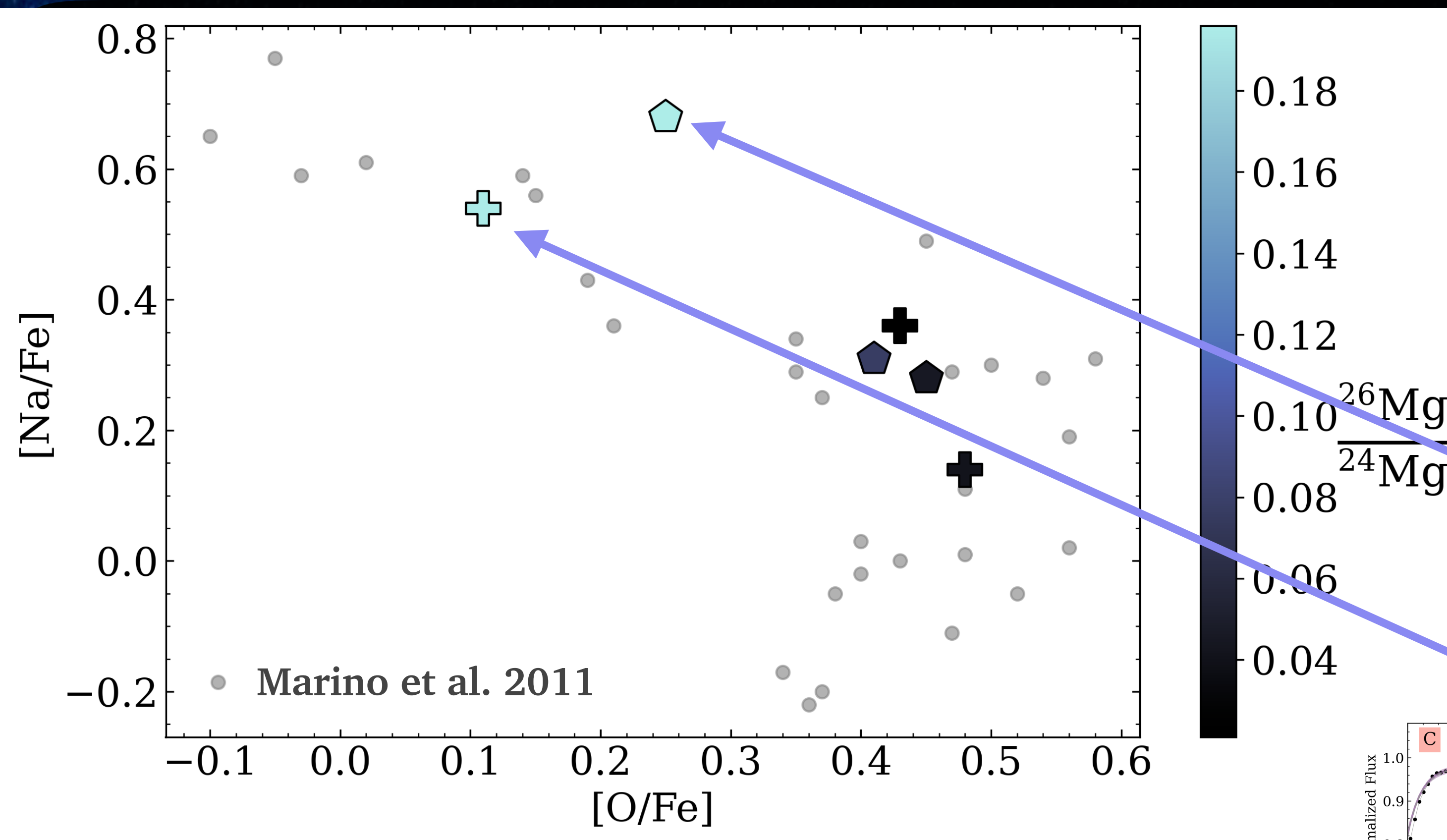






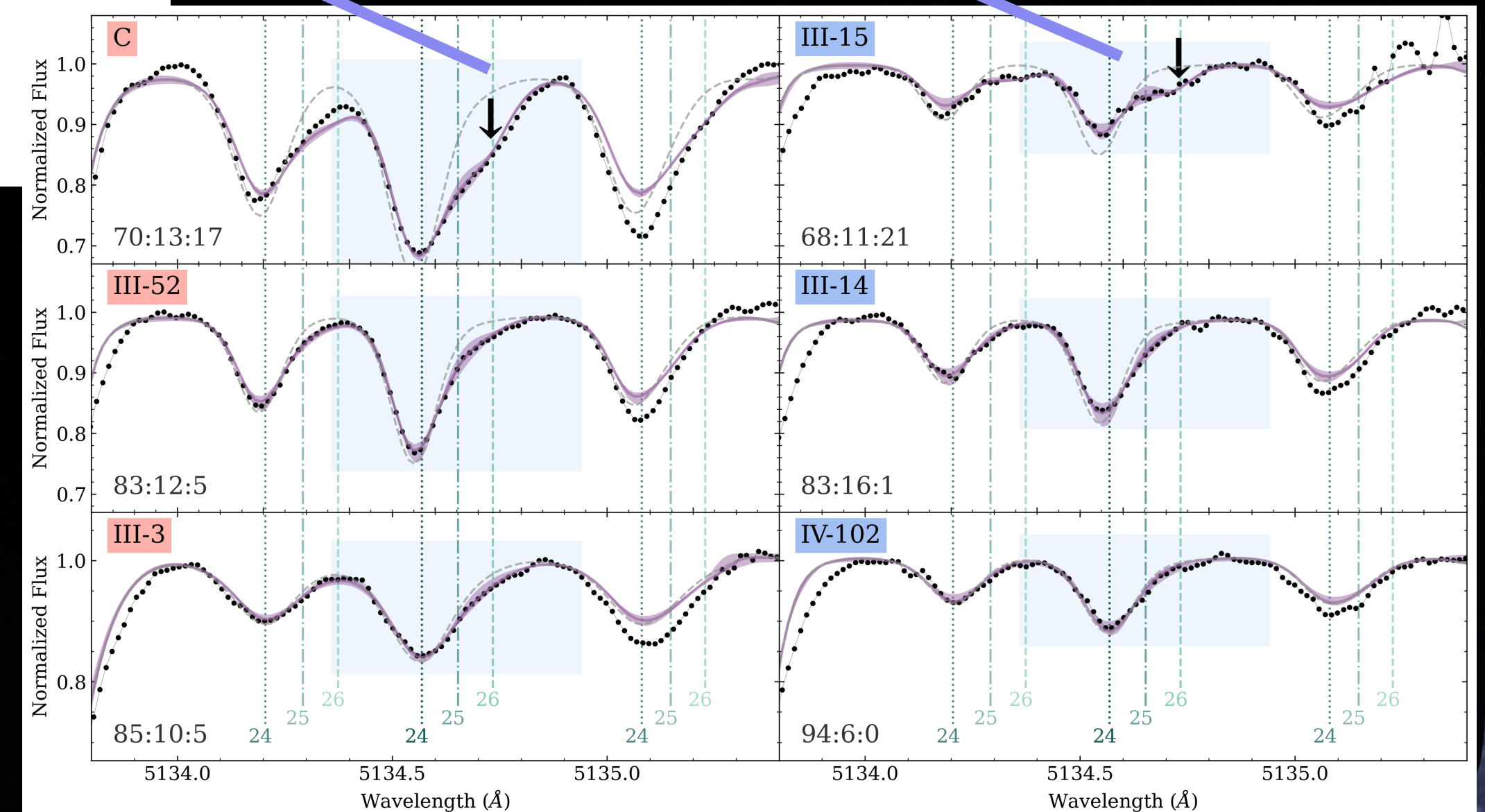
Mg isotope ratios in
M 22 trace light
element, not neutron
capture elements



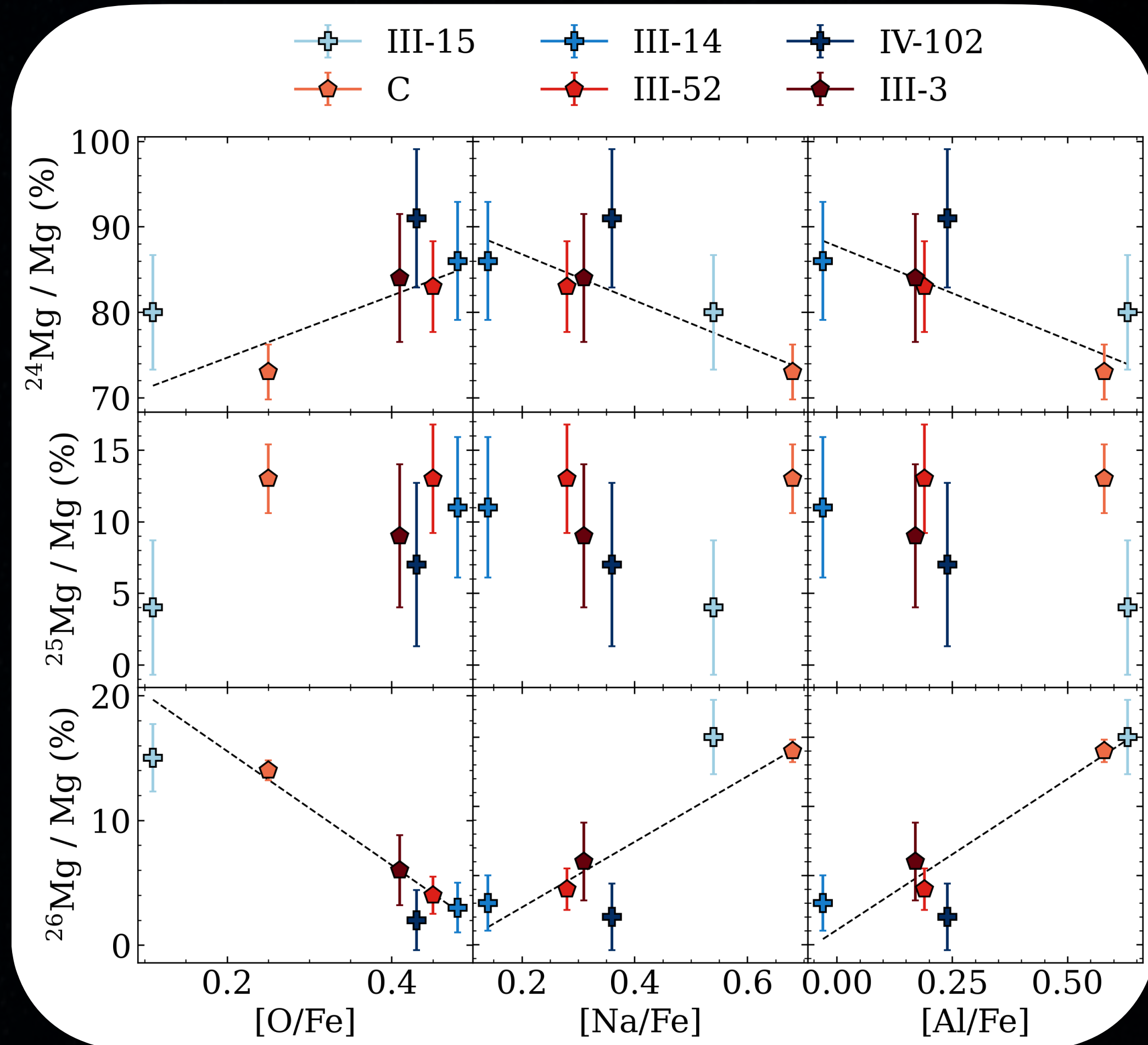


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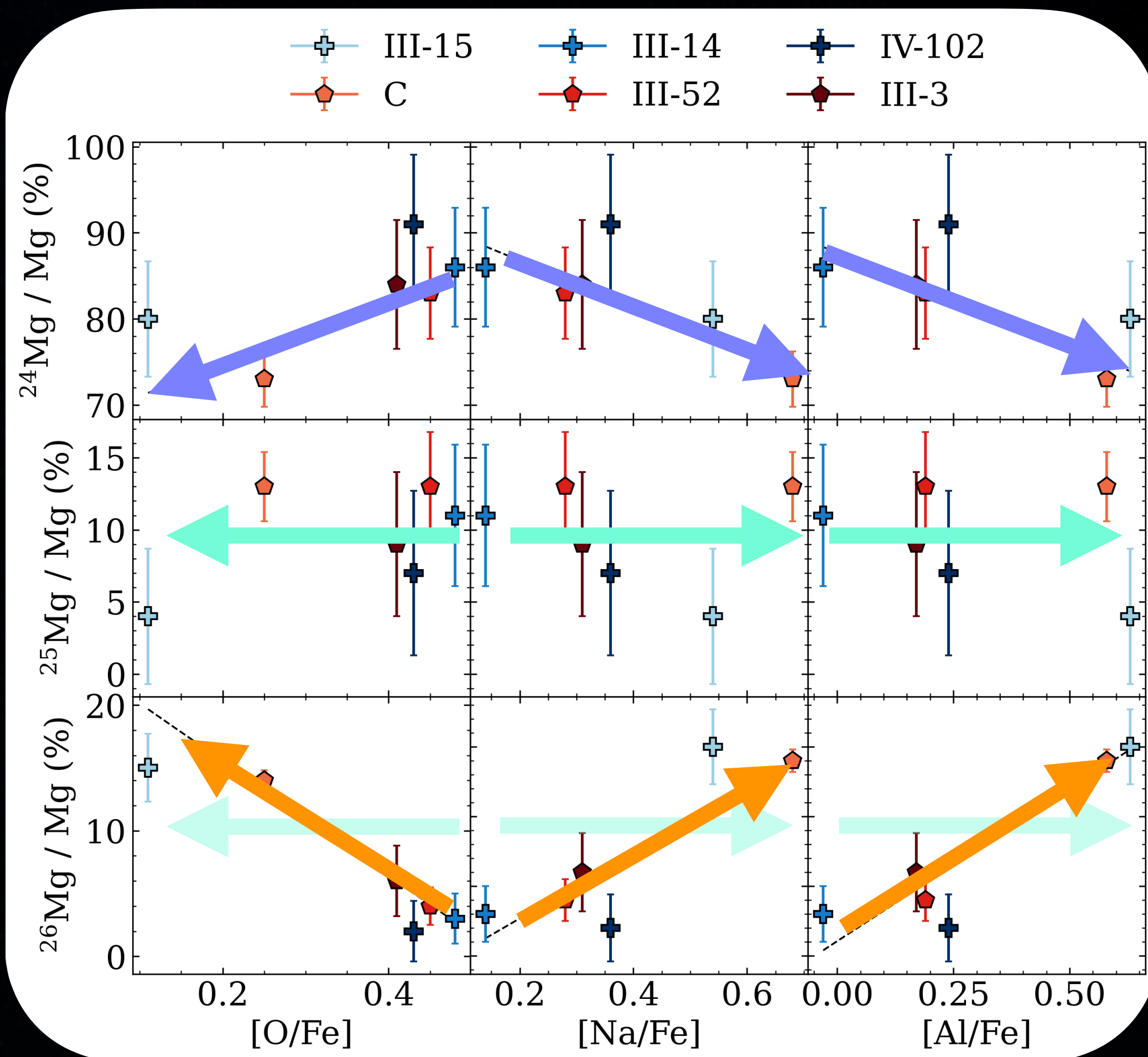
Mg-Al cycle dominating over
 $^{22}\text{Ne}(\alpha, n)^{25}\text{Mg}$ and
 $^{22}\text{Ne}(n, \gamma)^{26}\text{Mg}$?



Mg isotope anti-correlations



Mg isotope anti-correlations

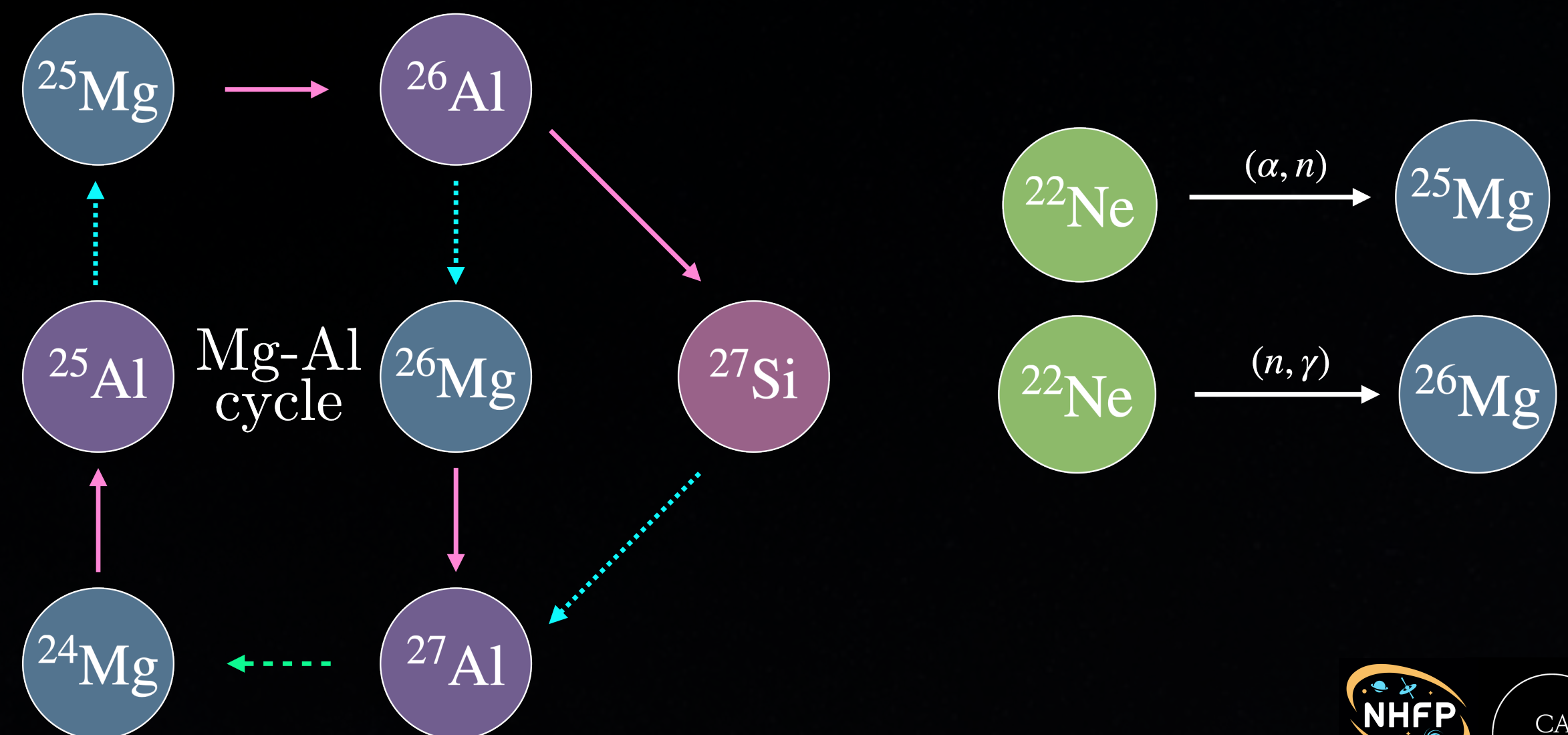


^{24}Mg & ^{26}Mg anti-correlate.
No correlation with ^{25}Mg ?

See also, e.g., Yong et al. 2003, Da Costa et al. 2013, Thygesen et al. 2016

Proton capture

Neutron capture

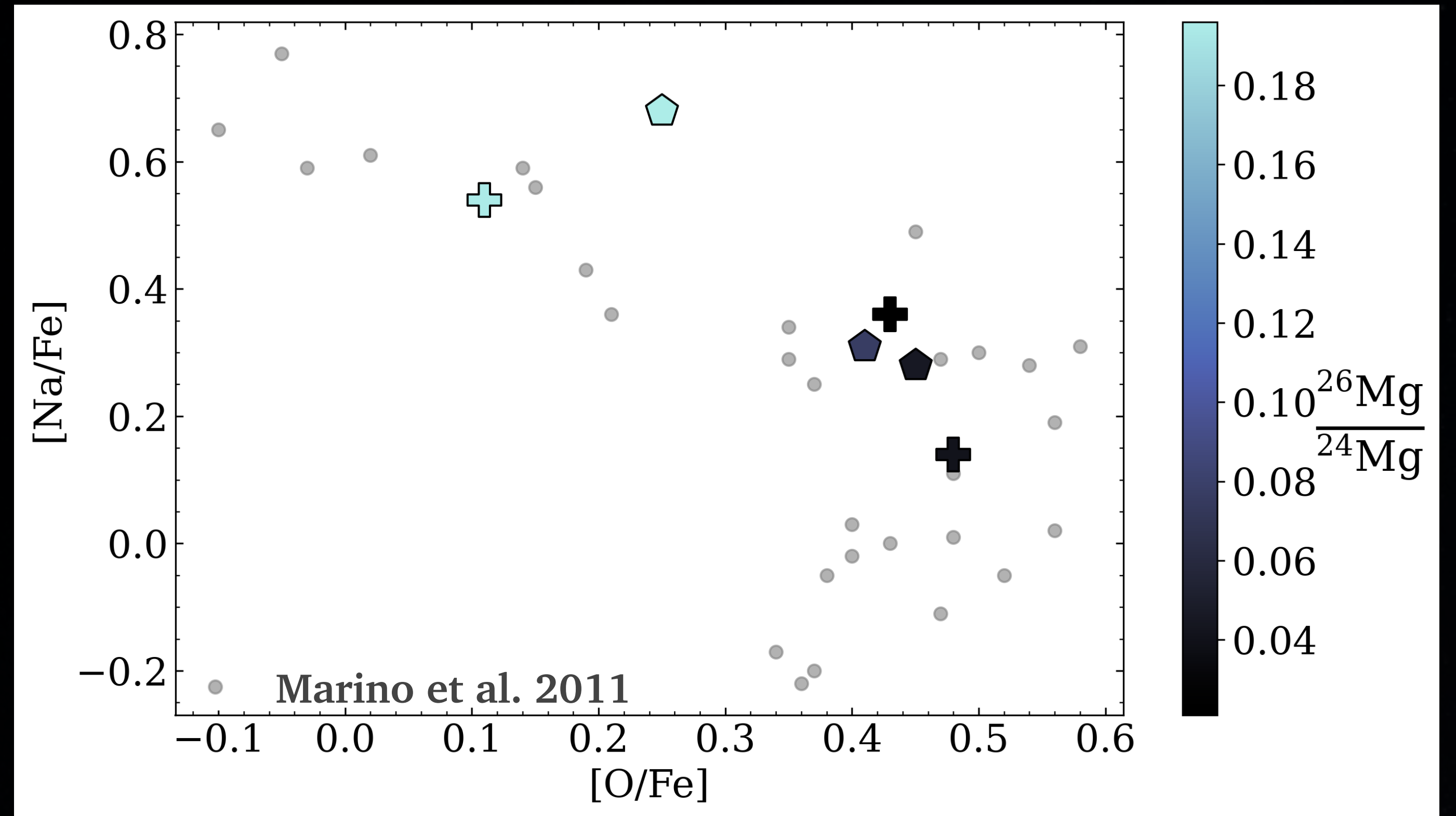


Upcoming work

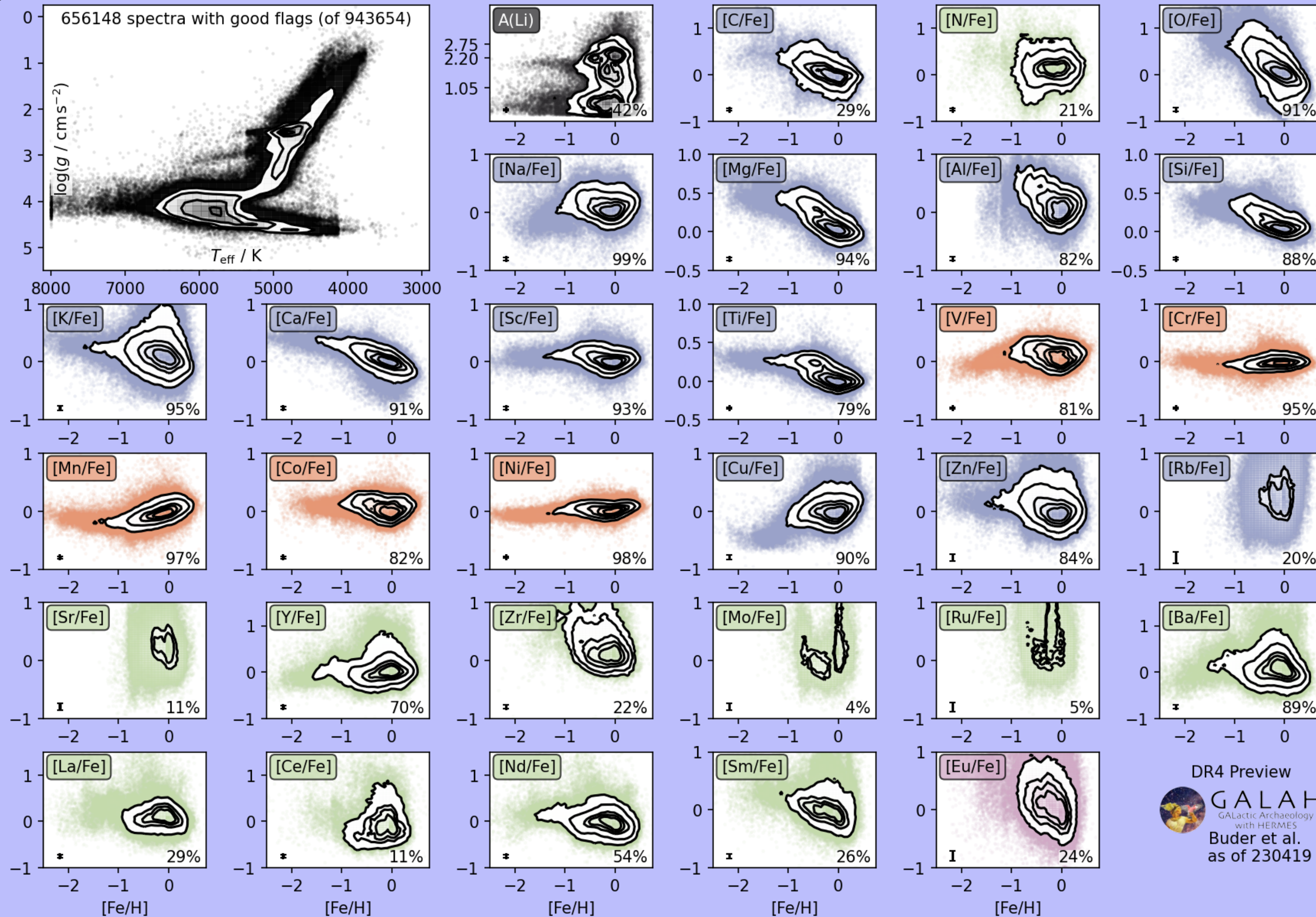
Results from NGC 288 &
NGC 362 (EAS meeting,
23rd June, S13)

ω Centauri UVES/VLT
observations (P114)

M4 using PFS/Magellan

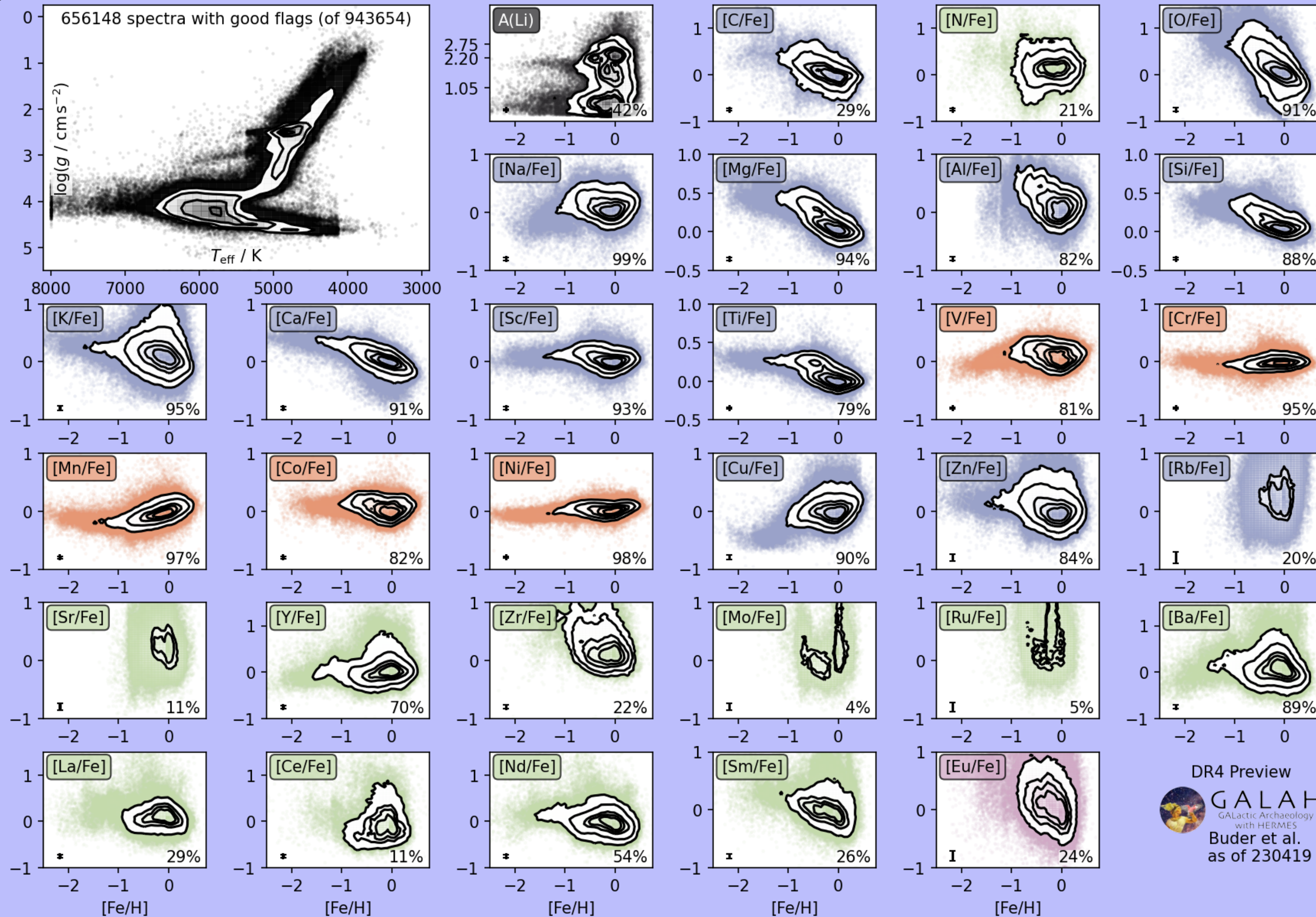


The GALAH survey



See Buder et al. (inc. McKenzie) 2024

The GALAH survey

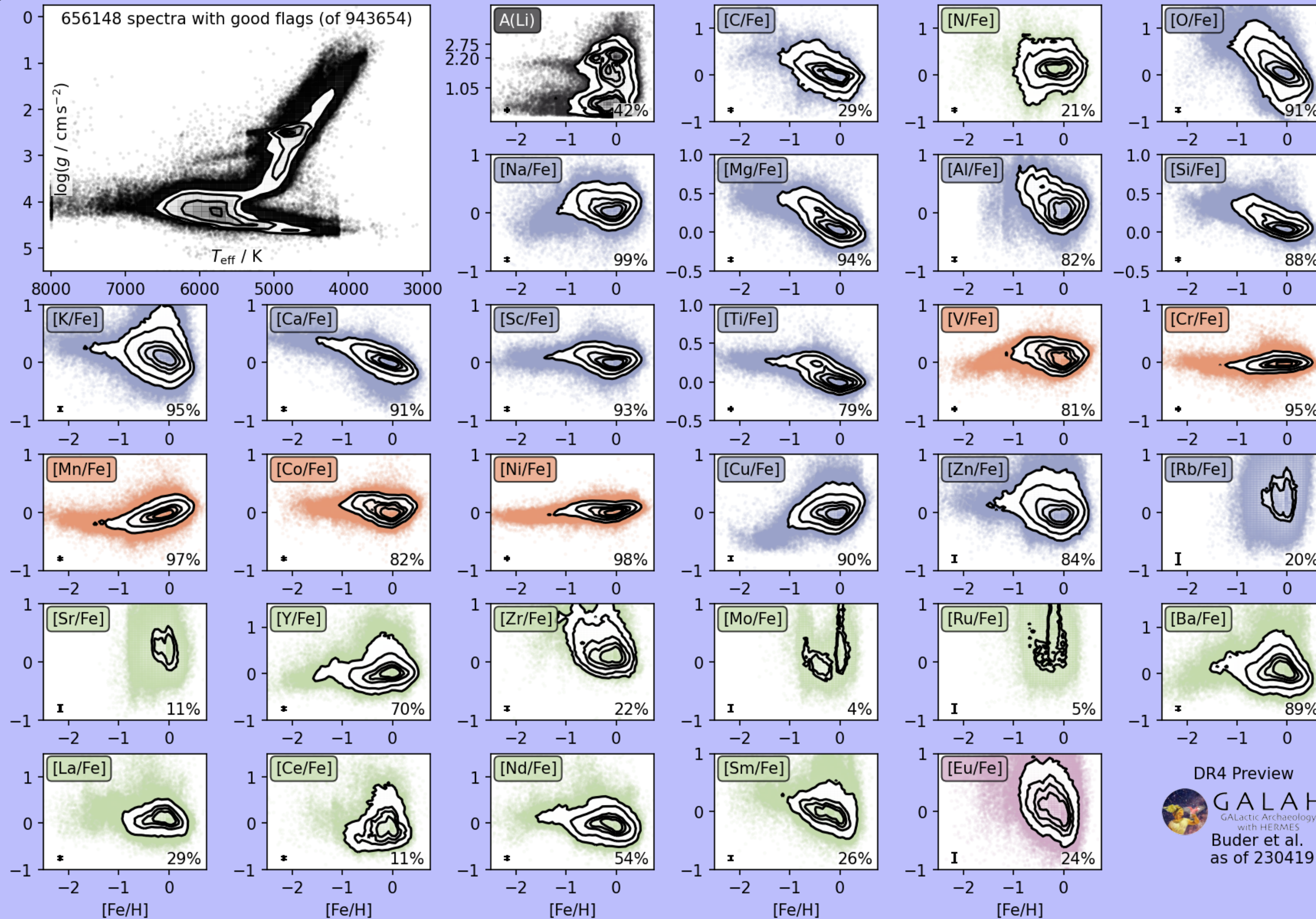


See Buder et al. (inc. McKenzie) 2024

Total number of stars in clusters: 3,674,
mean SNR (red) = 95.

Stars with “good” stellar parameters: 1,757,
mean SNR (red) = 120 (~48%).

The GALAH survey



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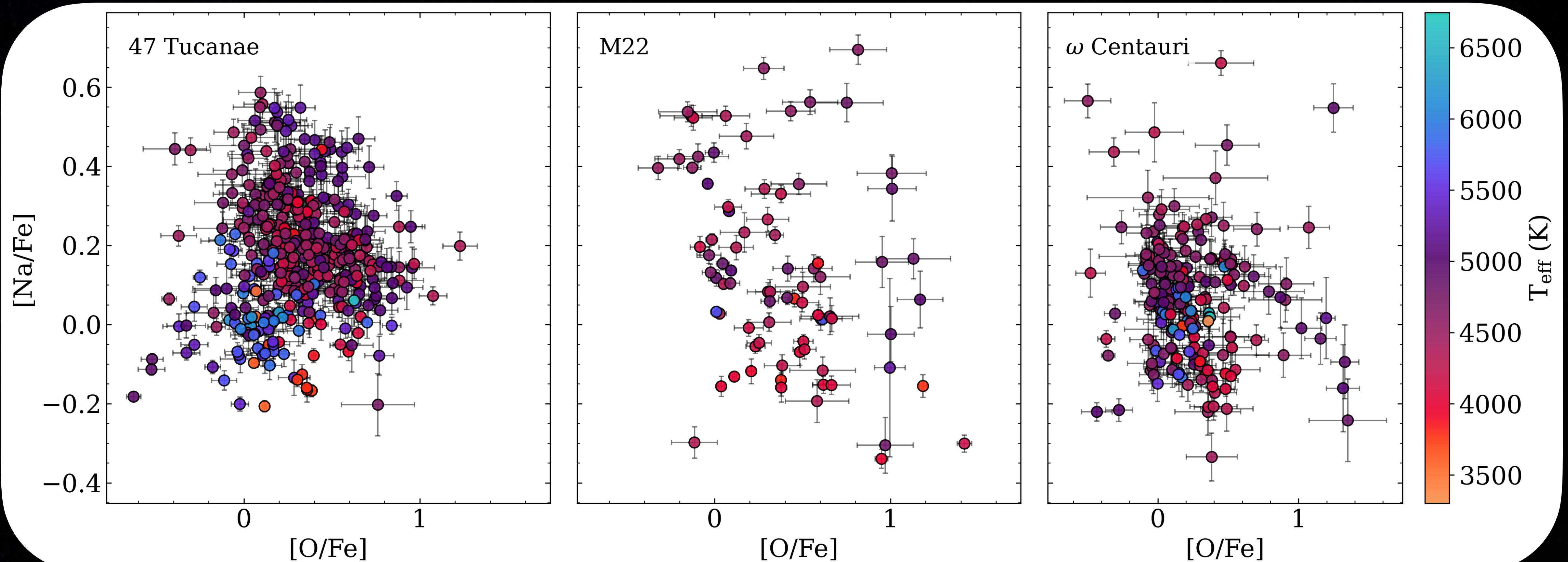
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47 Tuc, no flags = 723
Good flags = 424 (~59%)

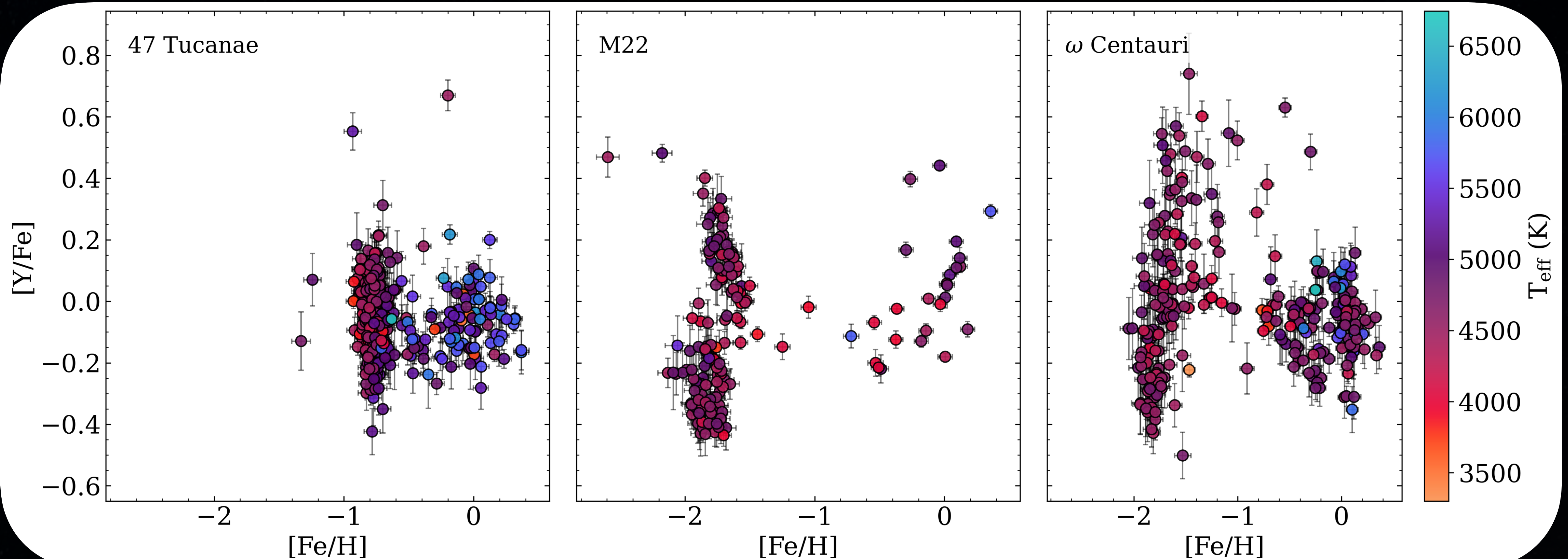
M 22, no flags = 285
Good flags = 190 (~67%)

ω Centauri, no flags = 616
Good flags = 301 (~49%)

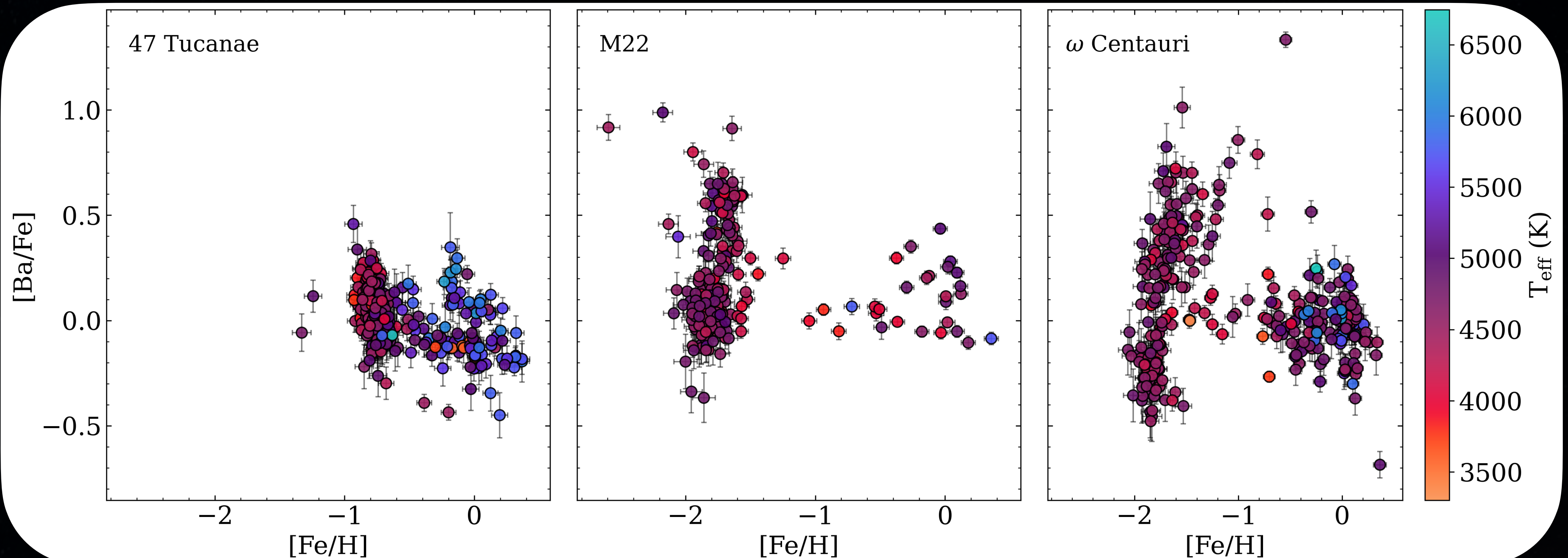
Na-O anti-correlation



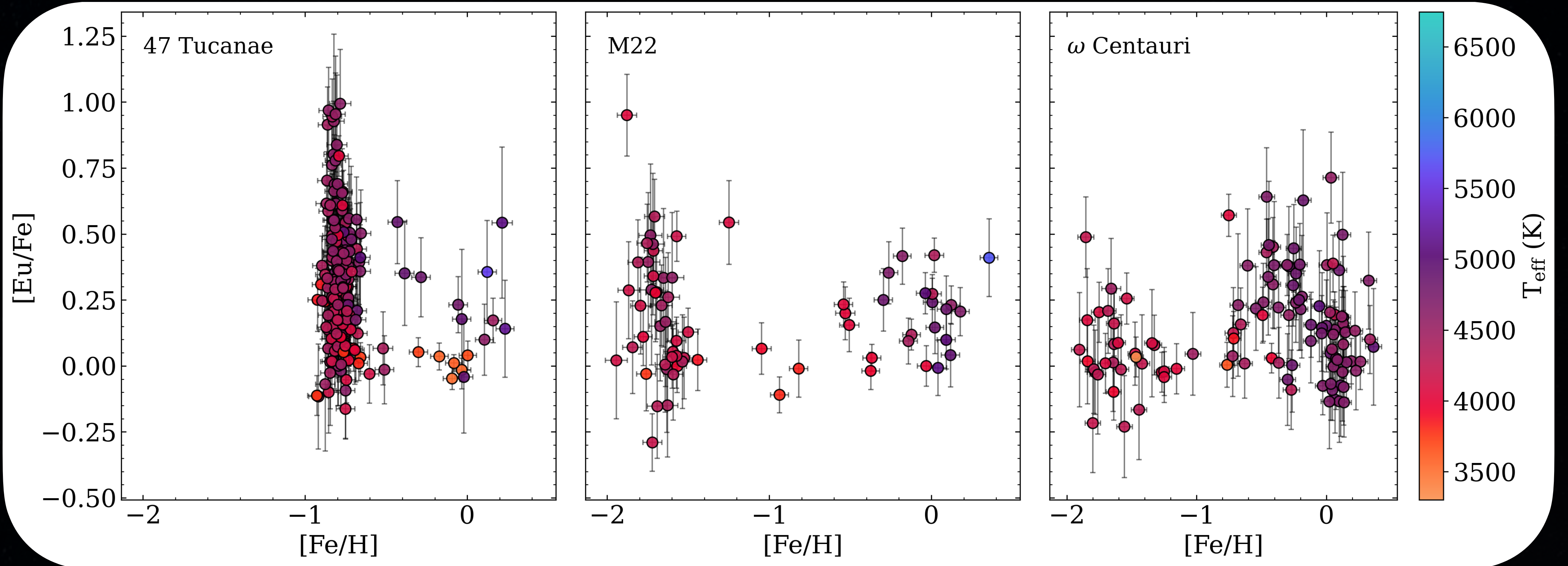
s -process abundance - $[Y/Fe]$



s -process abundance - $[\text{Ba}/\text{Fe}]$



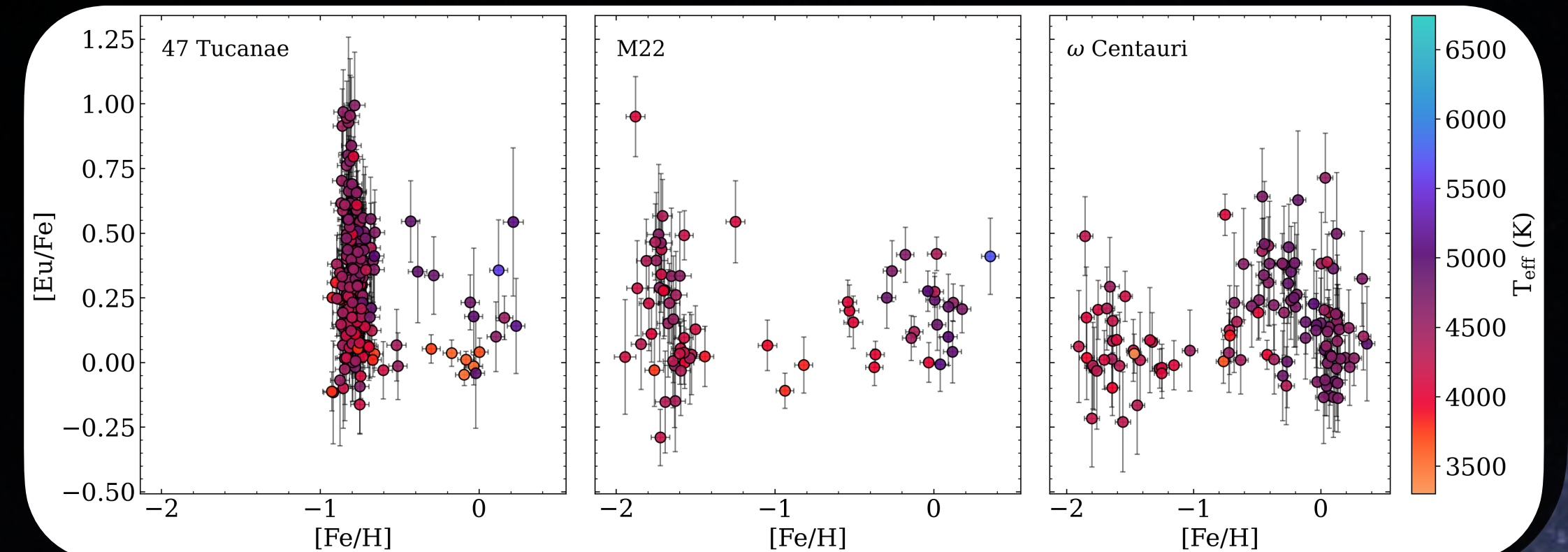
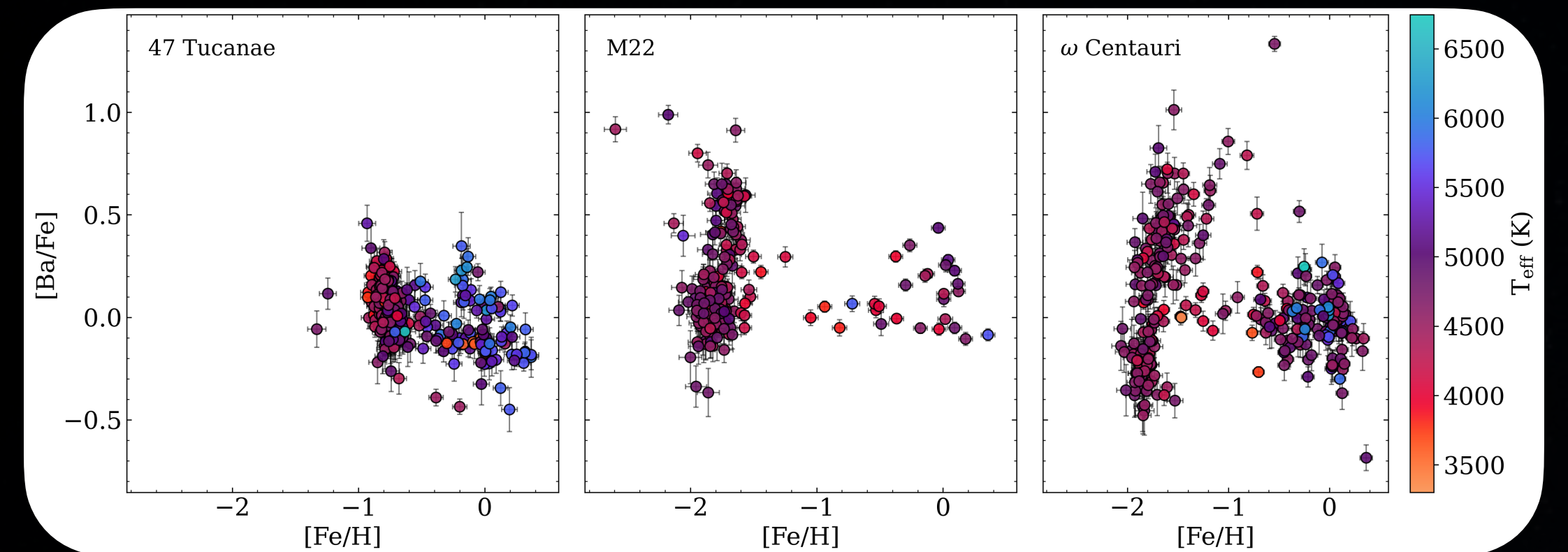
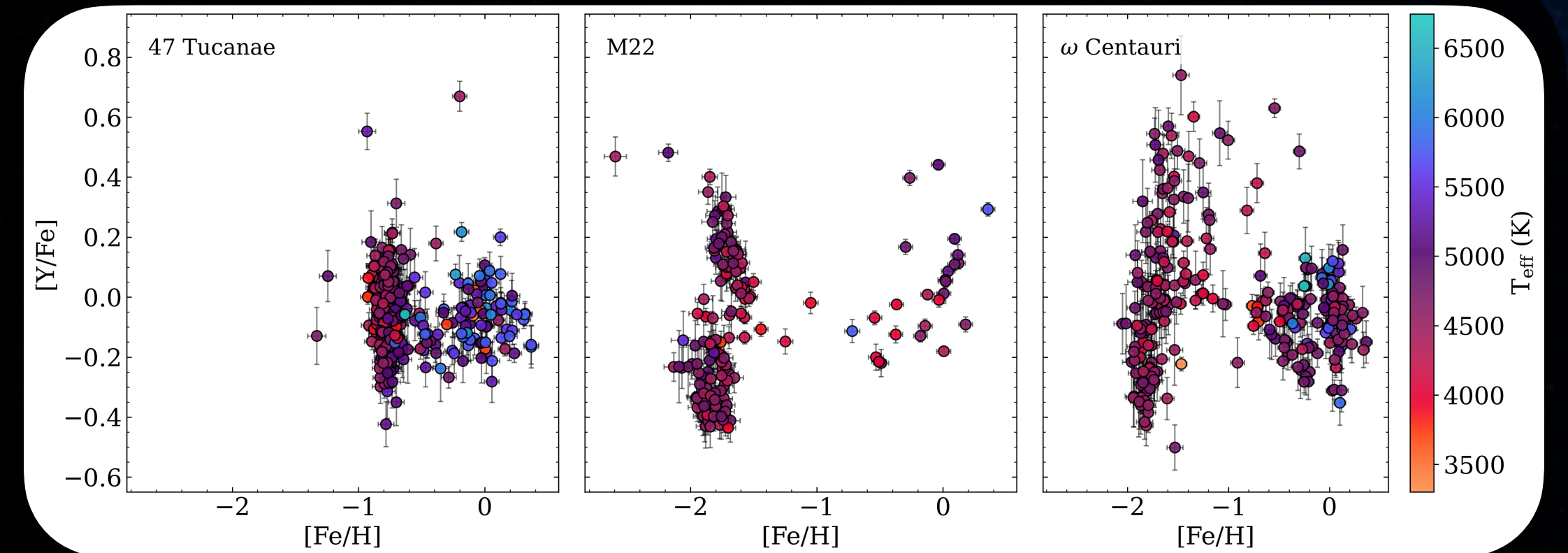
r -process abundances - $[\text{Eu}/\text{Fe}]$



GALAH globular cluster reanalysis

> 3,000 stars @ $R \sim 28,000$

Aim: understand the internal dispersion within each cluster.

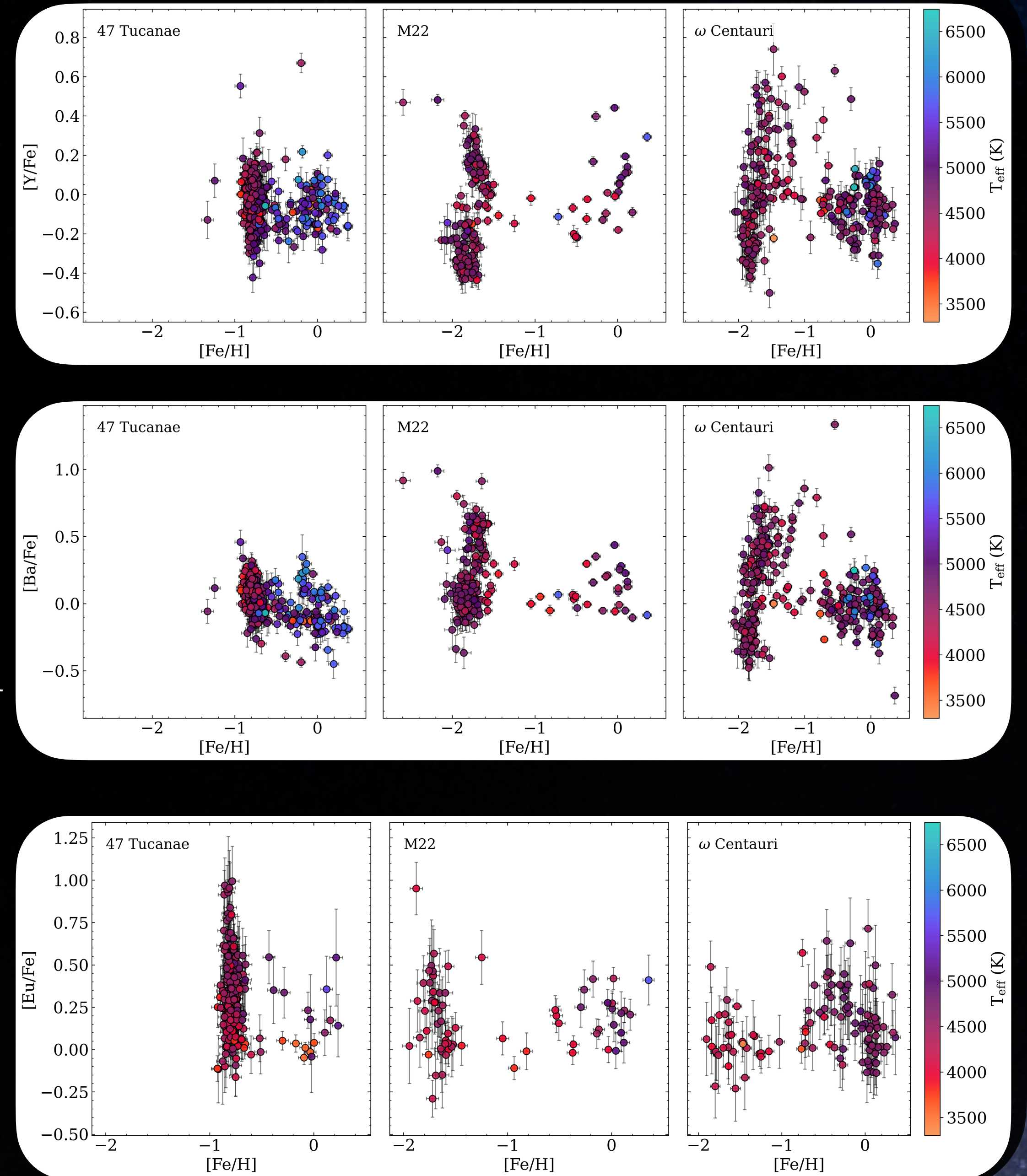


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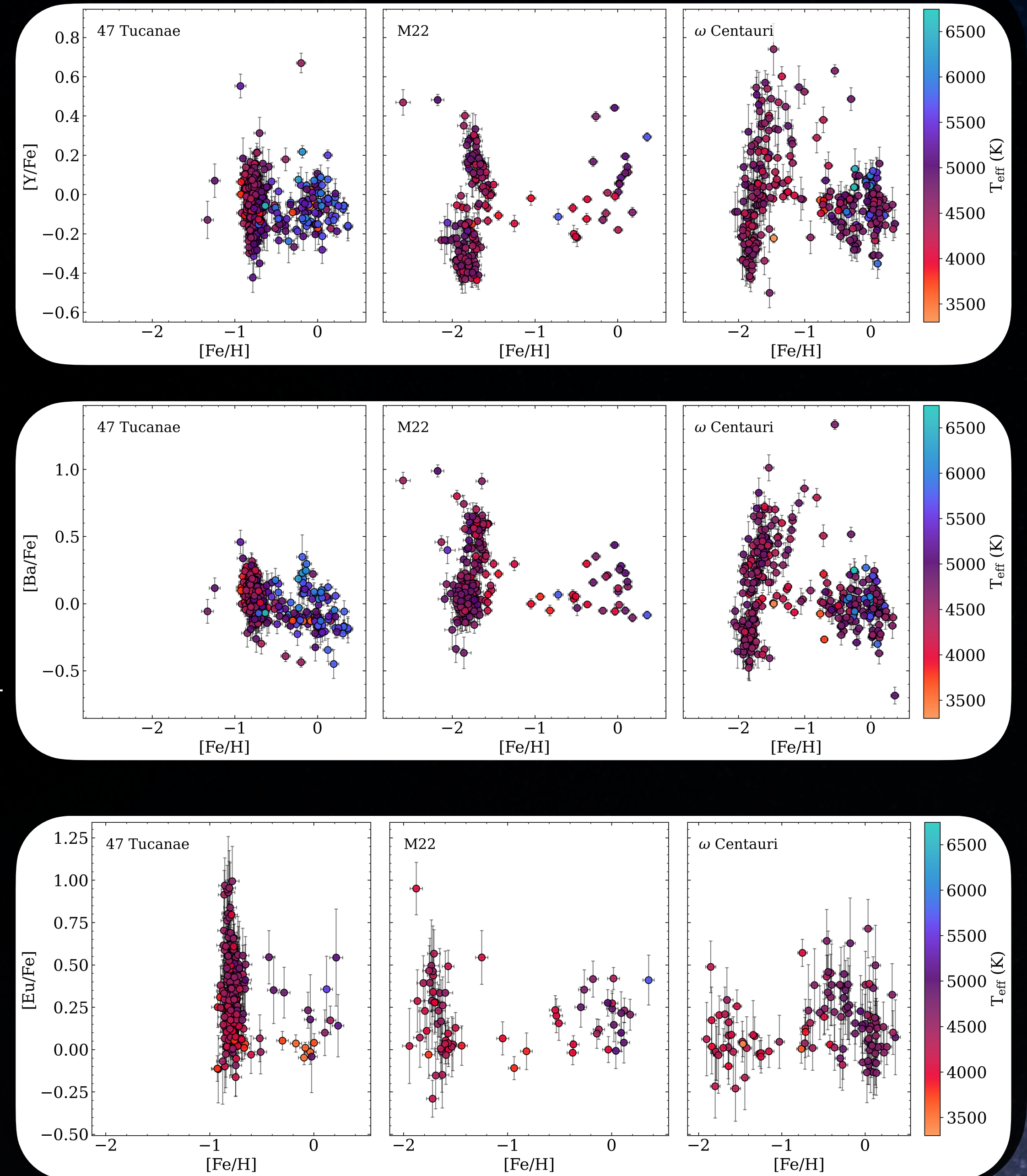
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Outcome: outline a framework for what is a globular cluster - implications of the build up of the Milky Way.

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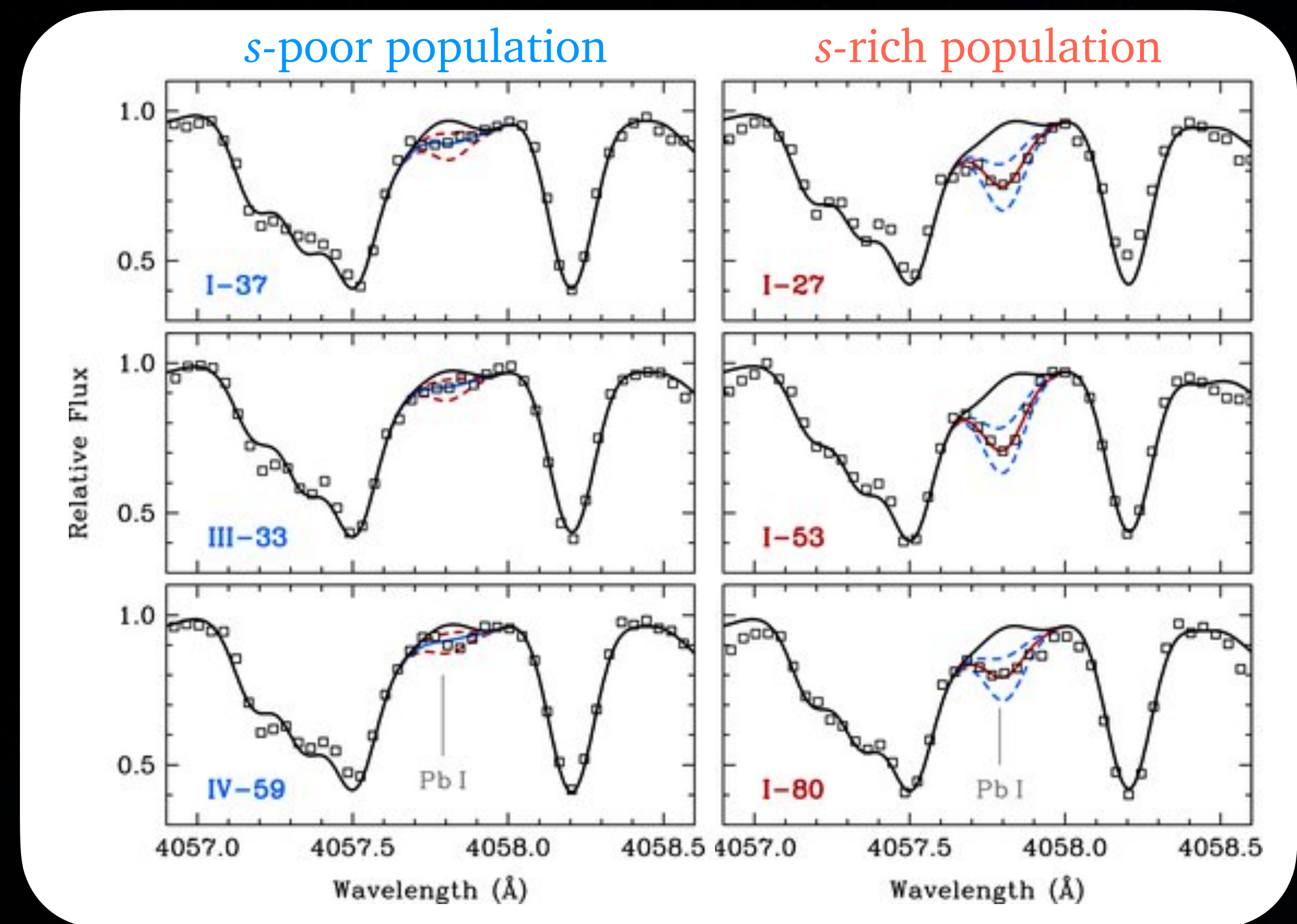


Lead

The 3rd peak of the *s*–process (?)

Proposals for Magellan 2025B and onwards:

- Connections between Pb & Li-richness,
- High precision differential sample with respect to Arcturus,
- What Pb abundances do theorists want?



Roederer et al. 2014
MIKE spectra of M22

Exploring Neutron Capture Elements in Globular Clusters with the GALAH Survey

1. Magnesium

^{24}Mg , ^{25}Mg , ^{26}Mg ratios are measurable in stellar atmospheres. More observations and constraints are coming.

2. GALAH

GALAH clusters require a by hand reanalysis. Exercise caution when using GALAH DR4 abundances.

3. Lead

Future observational campaigns will target Pb, and will compare to 1st and 2nd peak s-process abundances.