A Comprehensive Study of Open Cluster Chemical Homogeneity using APOGEE and Milky Way Mapper Abundances

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Background

- Understanding where and how stars produce and disperse heavy elements is essential to understanding the enrichment of the universe.
- Unanswered questions regarding the chemical enrichment of the universe : how well-mixed giant molecular clouds are or how heavy elements get from their production sites into stars.
- Surface abundances of stars are fossil records of the gas composition from the molecular cloud in which they formed.
- Present-day chemistry of stars can be used to learn the chemistry of the Milky Way in the past.
- Large astronomical surveys are allowing to probe the chemistry of stars in the Milky Way on the scale of ~ 0.1 dex or smaller in multiple elements across different nucleosynthetic families, allowing to trace different chemical enrichment pathways.

Background

- Using the chemistry of OC stars, one can infer the chemistry of the gas available at that point in the Milky Way's history.
- It has been suggested that using assumptions of chemical homogeneity from simple stellar populations like open clusters, it would be possible to reconstruct a dissolved cluster purely by its members' chemistry.
- Many studies support this assumption of OC chemical homogeneity but few studies show that at least some clusters are chemically inhomogeneous.

Background

- ❖ OCs could be heterogeneous in specific elements:
  - Evolution :Slow neutron capture element (Sr, Ba, and Zr), can change over a star's lifetime as it enters the AGB phase.
  - Dredge-up, which occurs in stars on the giant branch, causes the star's convective envelope to expand, and it eventually gets deep enough to pull CNO-cycled elements to the surface.
  - Other: Mg can be affected by effects like mass transfer and atomic diffusion, Mass transfer and pollution events such as planetary engulfment.

- ❖ If an open cluster was measured to have nonzero chemical scatter after accounting for these factors, that could point to interesting and understudied physics that may have occurred during the formation of the OC.
- ❖ Simulations: turbulent mixing during cloud assembly naturally produces a stellar abundance scatter that is ~ 5 times smaller than that in the natal gas suggest that this mixing could explain the observed chemical homogeneity of stars forming from the same molecular cloud.
- ❖ Chemical inhomogeneity in real clouds could be due to effects not fully captured by simulations, related to internal turbulence and gas mixing within the progenitor molecular cloud, pollution events such as core collapse supernovae (CCSNe) that occurred earlier in the cluster's lifetime.

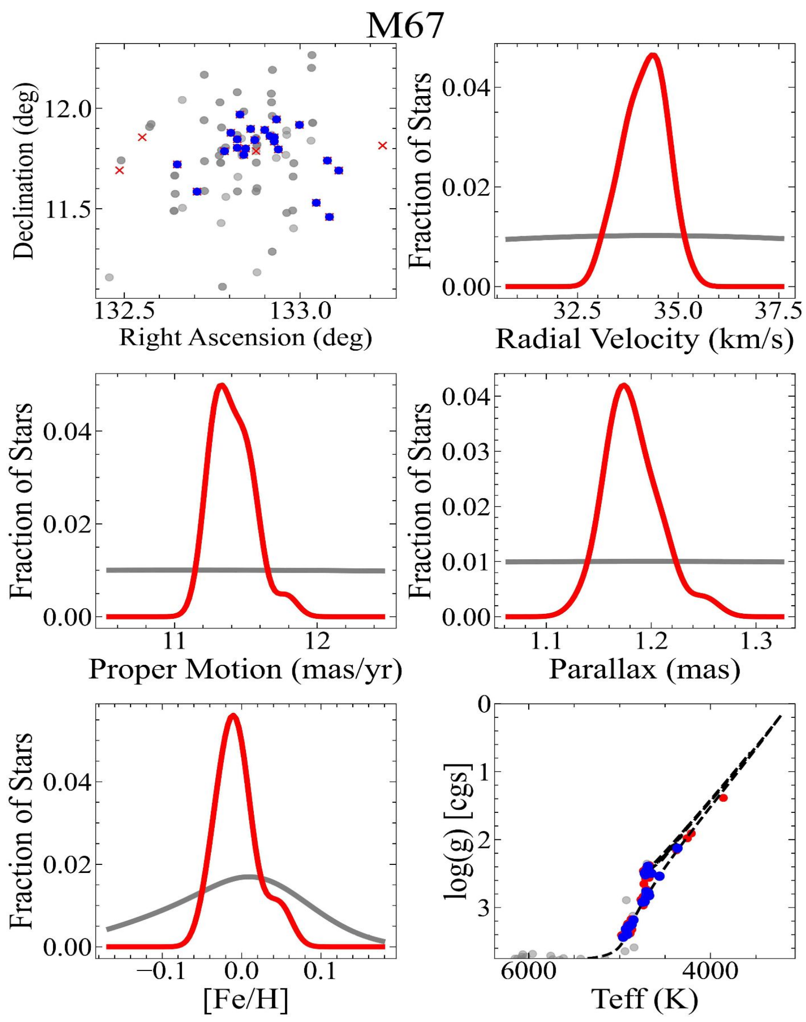
Aim

- Quantifying the level of chemical homogeneity in open clusters across a broad set of elements from various nucleosynthetic families would provide the basis for understanding the physics of early OC formation.

- This work aims to constrain the chemical homogeneity in a large set of abundances and clusters to disentangle the causes of those chemical variances.

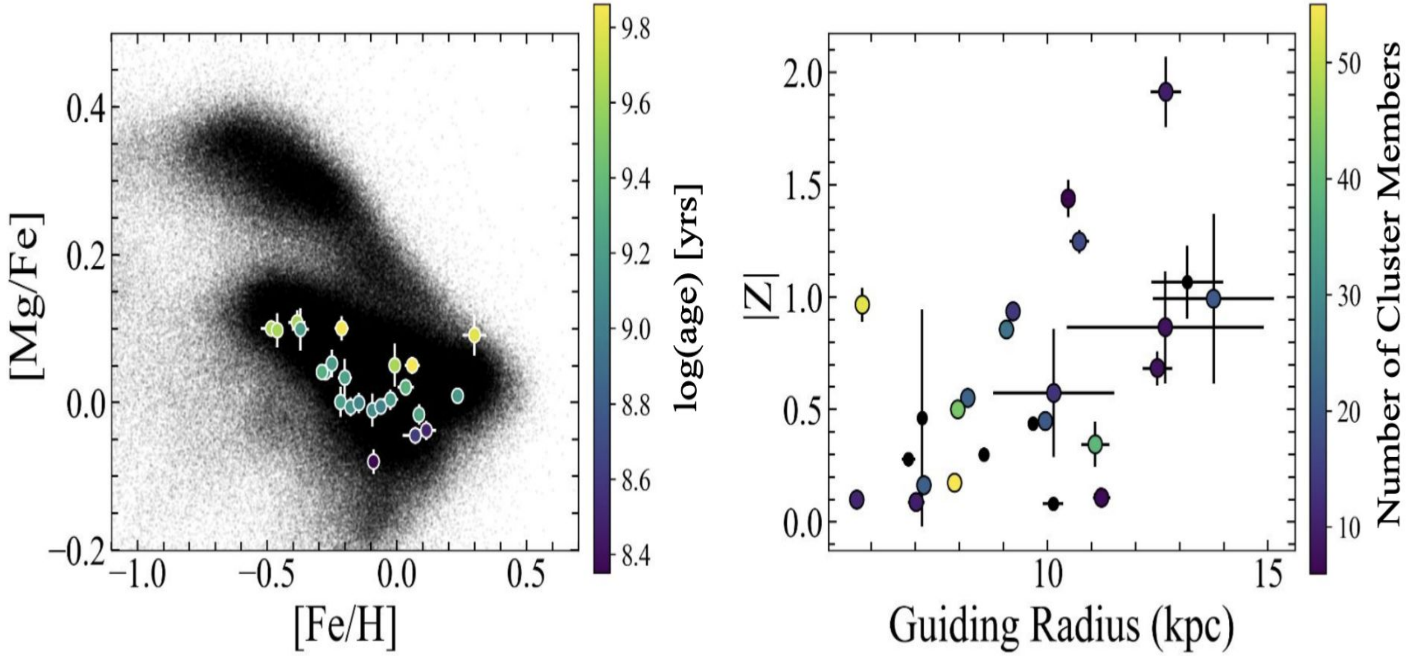
Data

- Abundances and radial velocity: SDSS-V (Milky Way Mapper, IPL-3, DR17, DR18, DR19).
- Position, Proper motion and parallax: Gaia DR3.
- Age, Membership: Cantat-Gaudin et al. (2018).



Final sample

26 clusters after applying several quality cuts in the SDSS data.



MEASURING CHEMICAL SCATTER

Paired Stars Method: Difference in abundances between stars close to one another on the HR diagram.

ΔTeff < 100 K and Δlog g < 0.1 dex.

$$\sigma = \sqrt{\frac{\frac{\pi}{2}|\Delta[X/Fe]|^2 - (e_1^2 + e_2^2))}{2}}$$

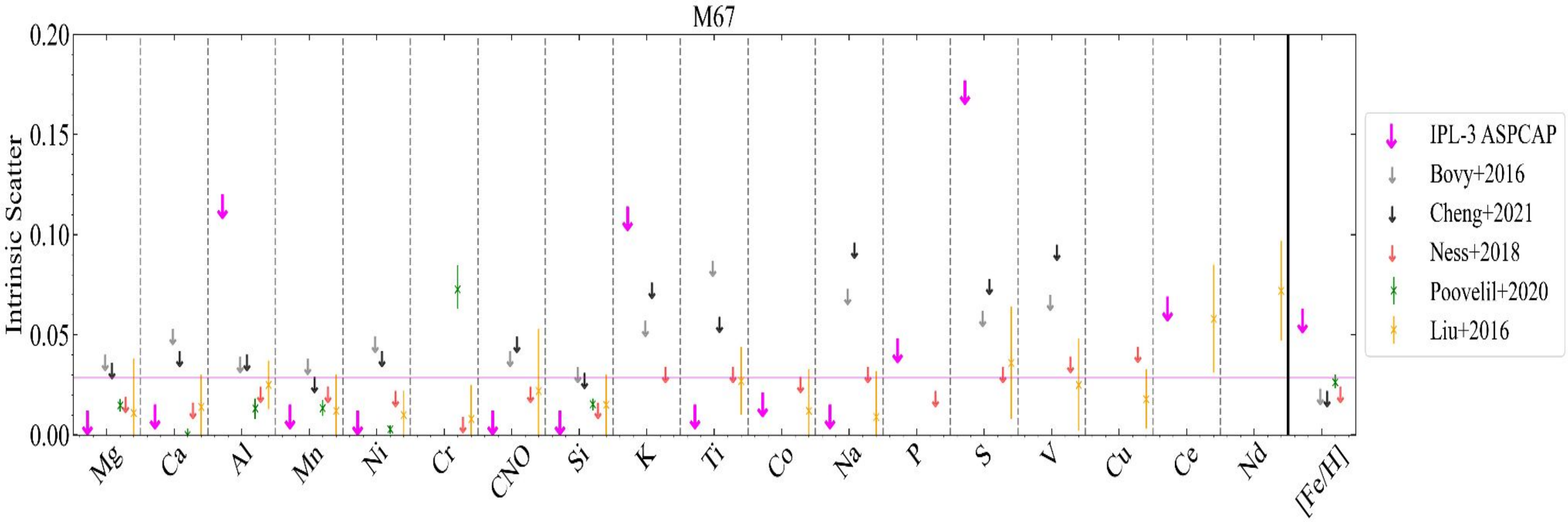
Total : 15 clusters

Maximum Likelihood Estimator: Total: 26 clusters (high errors)

$$\mathrm{lnL} = \prod_{\mathrm{i=1}}^{\infty} \frac{1}{\sqrt{2\pi}(\sigma^2_{\mathrm{[X/Fe]}} + \mathrm{e_i^2})^{1/2}} \exp\left(\frac{-(\mathrm{x_i} - \mu_{\mathrm{[X/Fe]}})^2}{2(\sigma^2_{\mathrm{[X/Fe]}} + \mathrm{e_i^2})}\right)$$

Results

- Within one standard deviation, the only [M/H] showed evidence of inhomogeneity, or consistent nonzero intrinsic scatter, across multiple clusters.
- Within 3 standard deviation no signature of inhomogeneity observed.



Results: comparison with nearby field stars

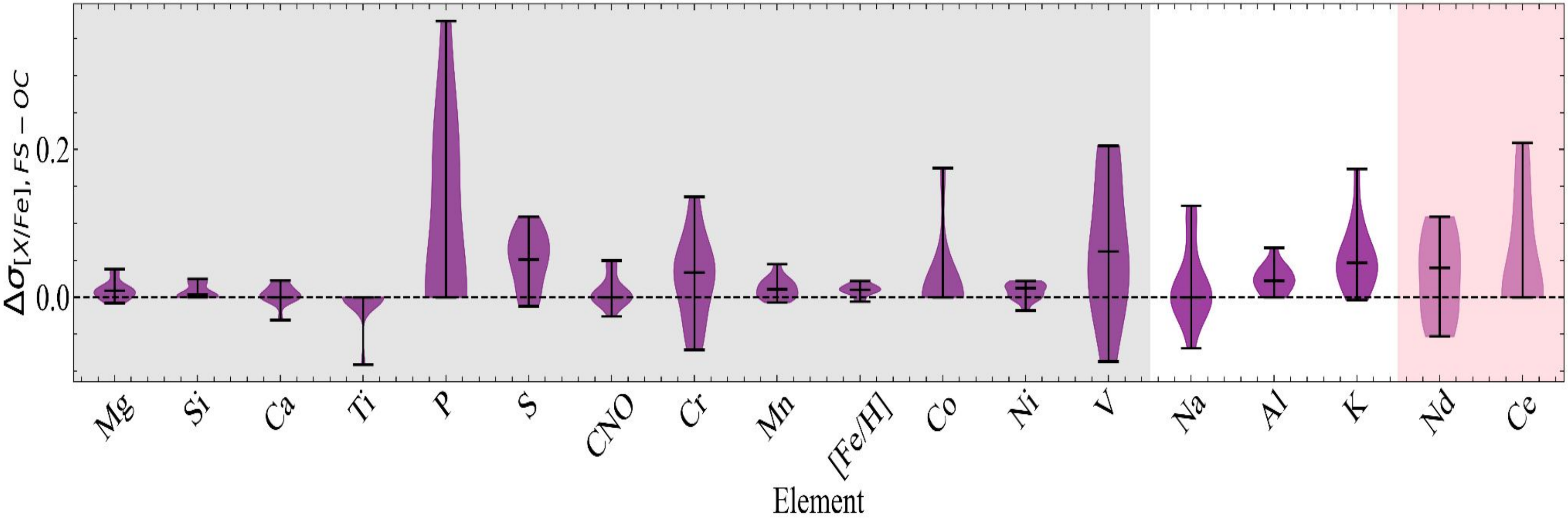
- To quantify the difference in chemical homogeneity between OCs and the Milky Way field they created a matched field star sample (MFS) similar to the existing cluster sample.
- They match each star within the cluster to a field star within two sigma in Galactocentric radius, [M/H], [α/M], Teff , and log g.
- Then they measured the intrinsic scatter in each of the MFS samples,
- Finally, they compared the difference in intrinsic scatter between MFS sample and the OC sample.

Results: comparison with nearby field stars

- On average, across all abundances, the matched field star samples have +0.012 dex more intrinsic scatter than the open clusters.
- This agrees with Ness et al. (2022), which states that stars in the Milky Way are chemically similar (within ~0.01–0.02 dex) when given a fixed Galactocentric radius, [M/H], and [α/Fe].
- The median difference between OC intrinsic scatter and field star intrinsic scatter ($\Delta\sigma$[X/Fe]):

❖ α-elements (Mg, Si, Ca, Ti, P, S): 0.002 dex
❖ Iron-peak elements (Cr, Mn, Fe, Co, Ni, V): 0.012 dex
❖ Odd-Z (Na, Al, K): 0.023 dex
❖ Neutron-capture (Nd, Ce): 0.02 dex

Results



$\Delta\sigma_{[X/Fe],\,FS-OC}$
0.2
0.0
Mg
Si
Ca
Ti
P
S
CNO
Cr
Mn
[Fe/H]
Co
Ni
V
Na
Al
K
Nd
Ce
Element

Conclusion

- These findings have implications for attempts to implement chemical tagging, specifically showing that within the light elements alone it is not possible to confidently separate field stars and co-natal stars given similar stellar parameters and Galactic radii.
- The tightest abundance variation constraints in OCs may also help set limits on the rate of binary interactions and planetary engulfment in different environments.