Hidden gems:
~ Chemo(dynamic) characteristics of obscure low-mass globular clusters ~

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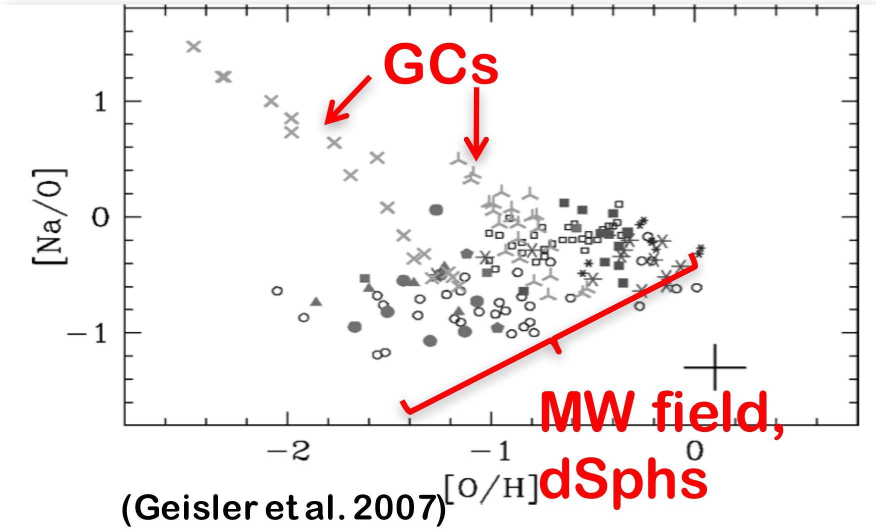
Your average Globular Cluster

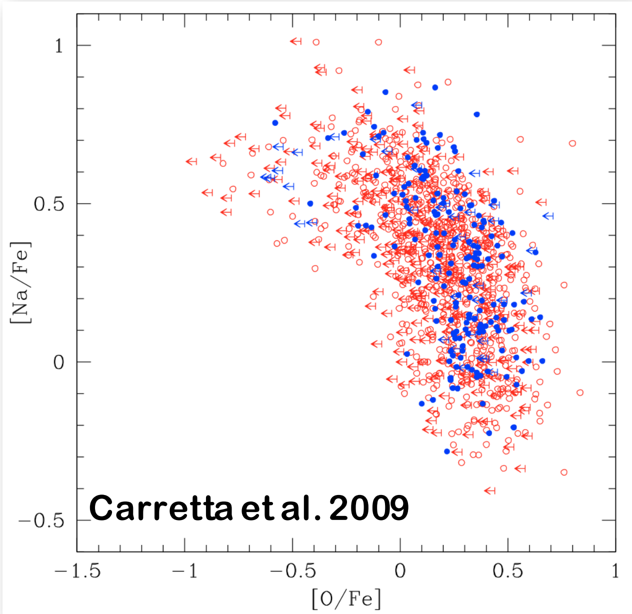
- Historically, GCs were considered "mono-metallic": [X/H] ~ const. within each system.

- Now: GCs host multiple pop's; phot. evidence and light-element (CH/CN; Na-O) variations. (Osborne 1971; Cohen 197N; Gratton et al. 2012)

- *Define* "...GCs as the stellar aggregates showing the Na-O anticorrelation." (Carretta et al. 2010)



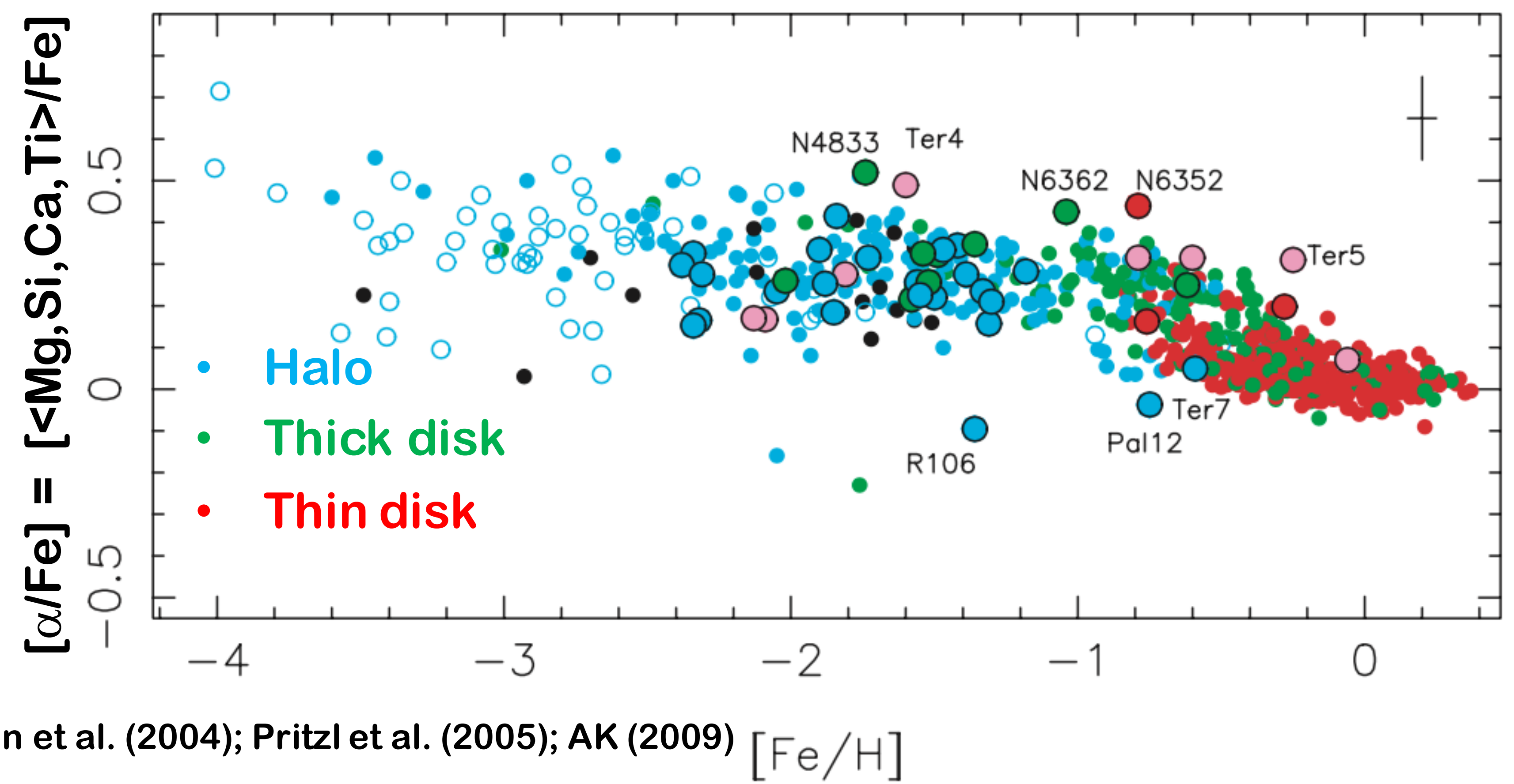
(Geisler et al. 2007)



Not found in field stars, open clusters, or dwarf galaxies.

GC–field connection

Generally, GCs follow the abundance trends of the surrounding field → they are excellent tracers of the Galactic components. Outliers are potentially accreted.



Venn et al. (2004); Pritzl et al. (2005); AK (2009)

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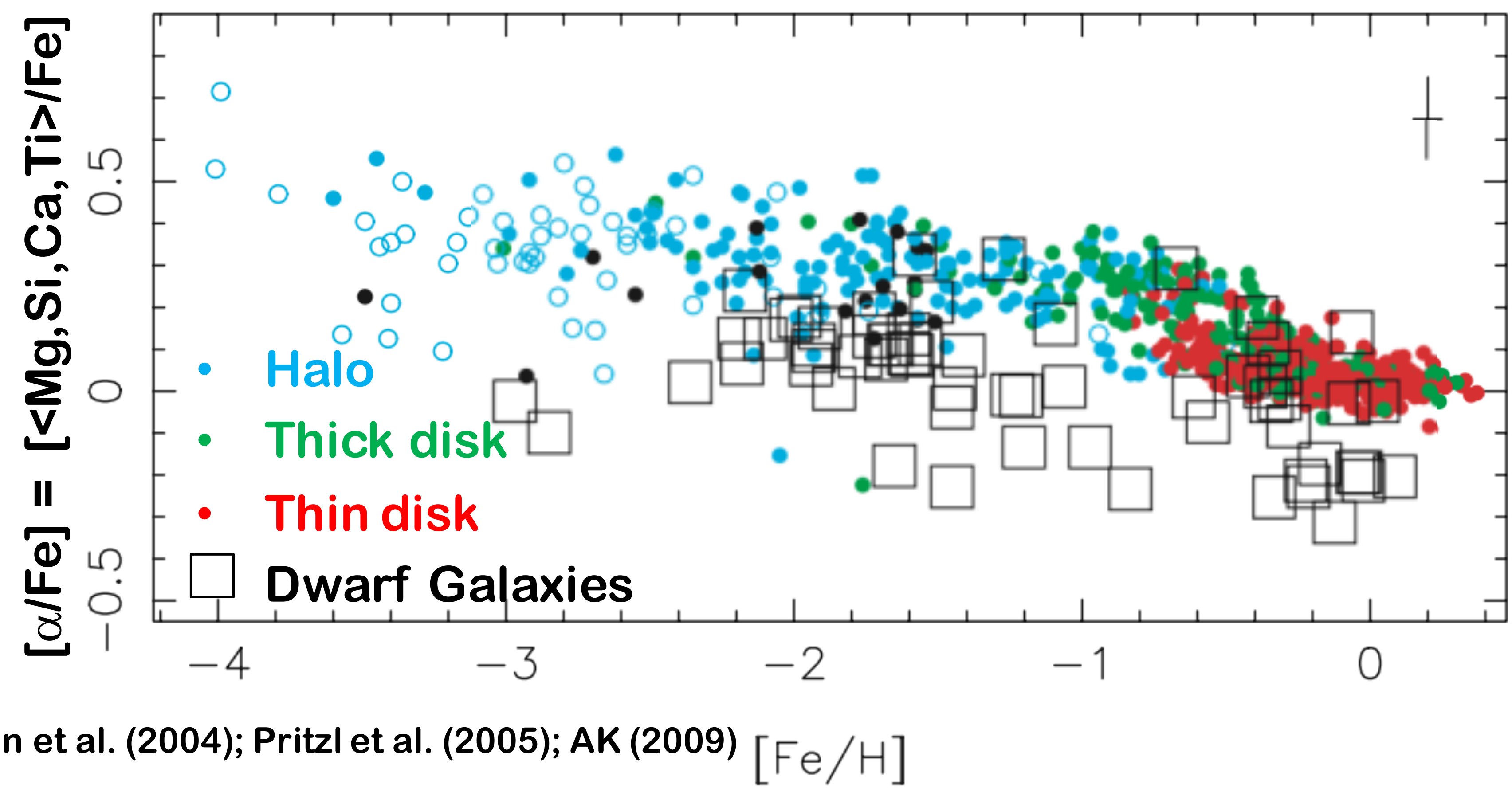
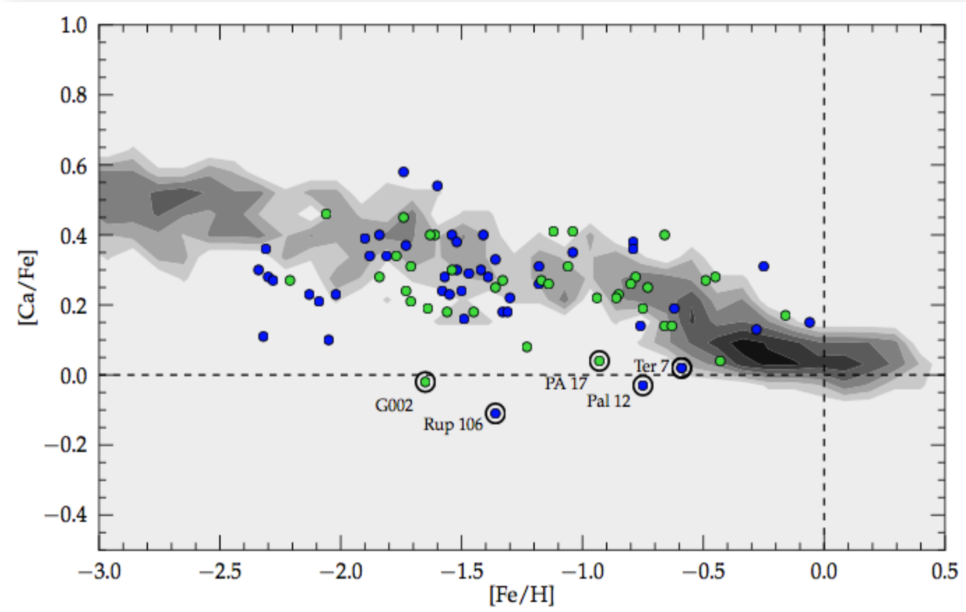
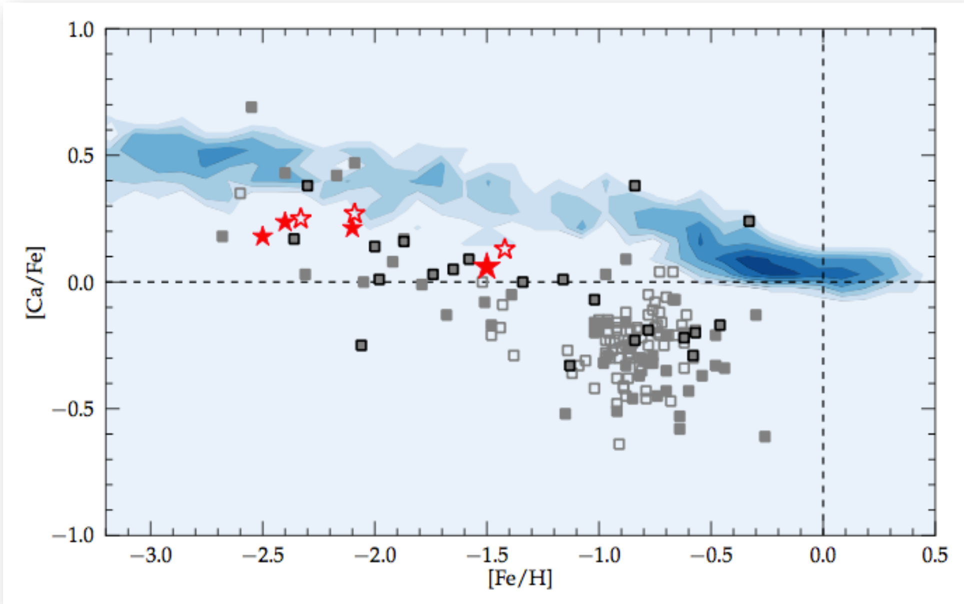


Venn et al. (2004); Pritzl et al. (2005); AK (2009)

GC–dSph–field connection

Also *within* dwarf spheroidals, their globular clusters are coupled to the surrounding field population. Hendricks et al. (2016)

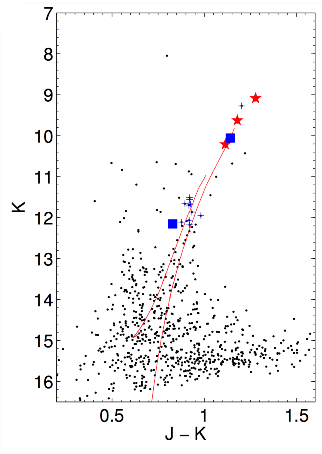




- **MW GCs**
- **M31 GCs** (Colucci et al. 2014; Sakari et al. 2015)

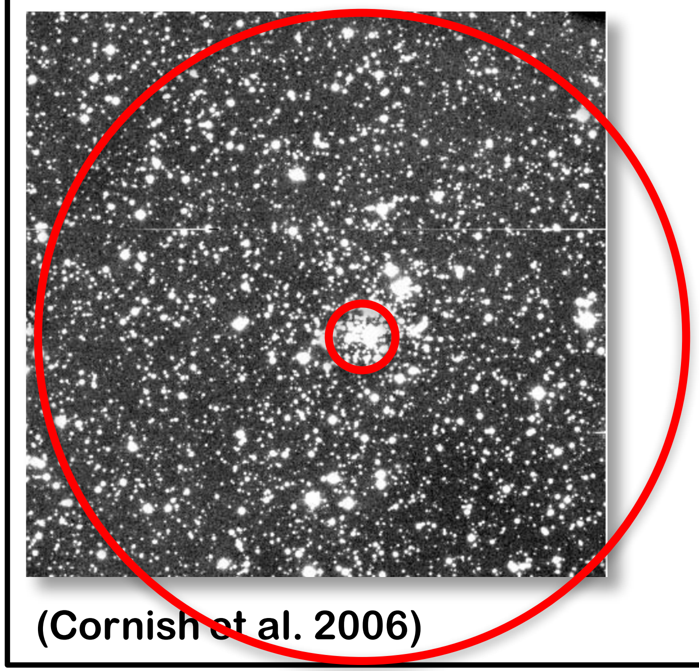
- **Fornax field stars**
  (Letarte et al. 2010; Lemasle et al. 2014; Hendricks, AK, et al. 2014)
- **Fornax GC stars**
  (Letarte et al. 2006; Larsen et al. 2012; Hendricks, AK, et al. 2016)

Tricky ones



Many clusters are tedious to characterize:

- sparsely populated
  → are they luminous OCs or low-mass GCs?
- low latitudes → disentangle from Galactic foreground (using, e.g., kinematics, proper motions); high extinction
- Small (projected) radii and/or high central density
  → challenging for wide-field, multiplex spectrographs



(Cornish et al. 2006)

ESO452-SC11: r_h = 0.5', r_t = 5.0'

cf. FLAMES' field of view = 25'

AAOmega 2dF: 2°

pro : also sample foregound
→ chemical tagging possible

con : small yield in members

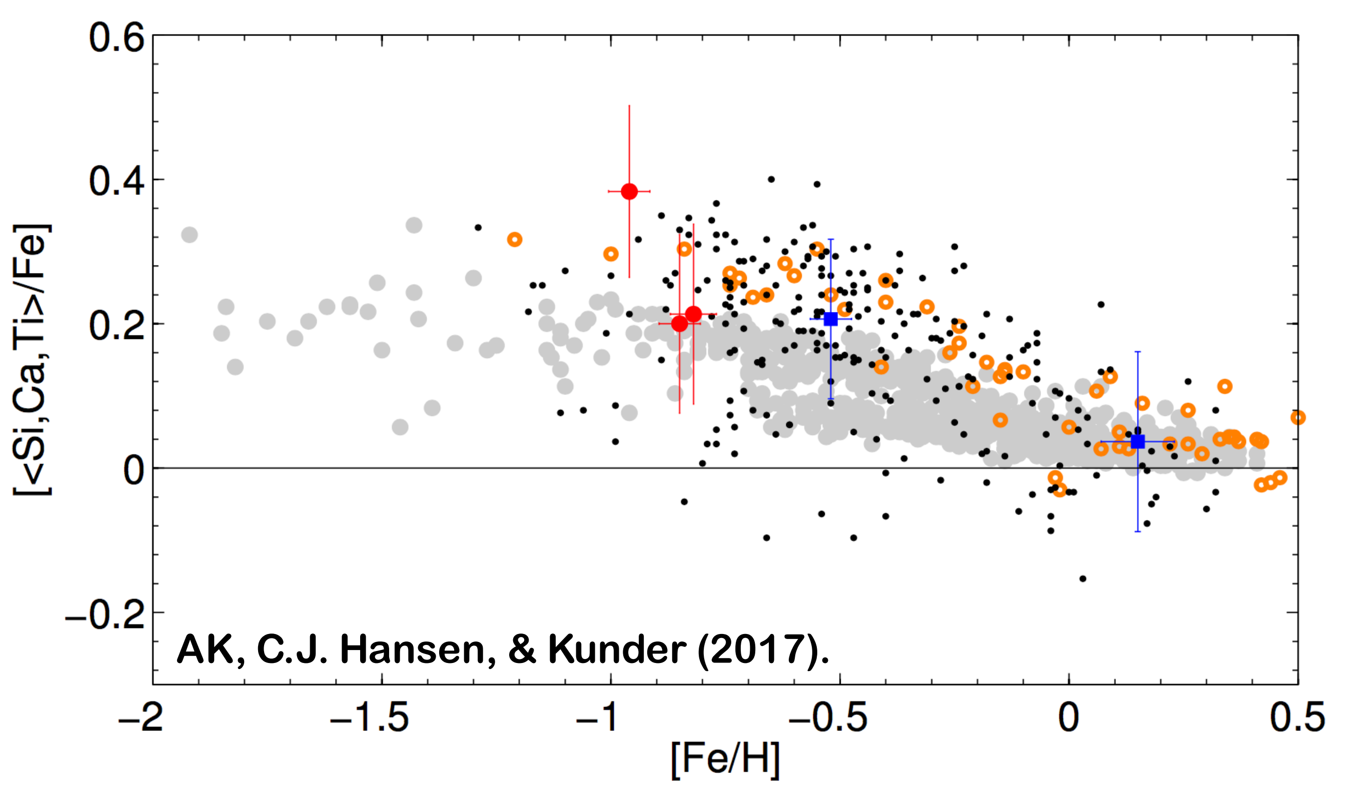
ESO452-SC11

- **Low-mass (~7x10^3 $M_\odot$) object** (Simpson et al. 2017)
- **(l, b) = (352°, 12°); E(B–V) = 0.5 mag**
- **Low velocity dispersion of ~2.8 km/s** (AK et al. 2017);
- **Poorly constrained parameters** (Cornish et al. 2006): **age = 9–16 Gyr; [Fe/H] = -1.4 to -0.4 dex; R_{GC} = 6.6–7.5 kpc**
- **Bulge / inner halo; lower end of bulge MDF, similar to *"somewhat younger halo clusters".* Placed in the bulge by interaction with a satellite** (Cornish et al. 2006)**?**
- **New AAOmega spectra around CaT (R=11000) and 4100 Å (R=9000). 360 stars** (AK, C.J. Hansen, & Kunder 2017).
- **-0.88 ± 0.03 dex (CaT)**

Tagging ESO452-SC11

- Using chemical tagging & kinematics, we could associate ESO452-SC11 with the *bulge* rather than (thick) *disk* or (inner) halo, as had been previously suggested.
- Orbits: within 3 kpc, firmly around the bulge!
- Majority of foreground stars are typical bulge-like.

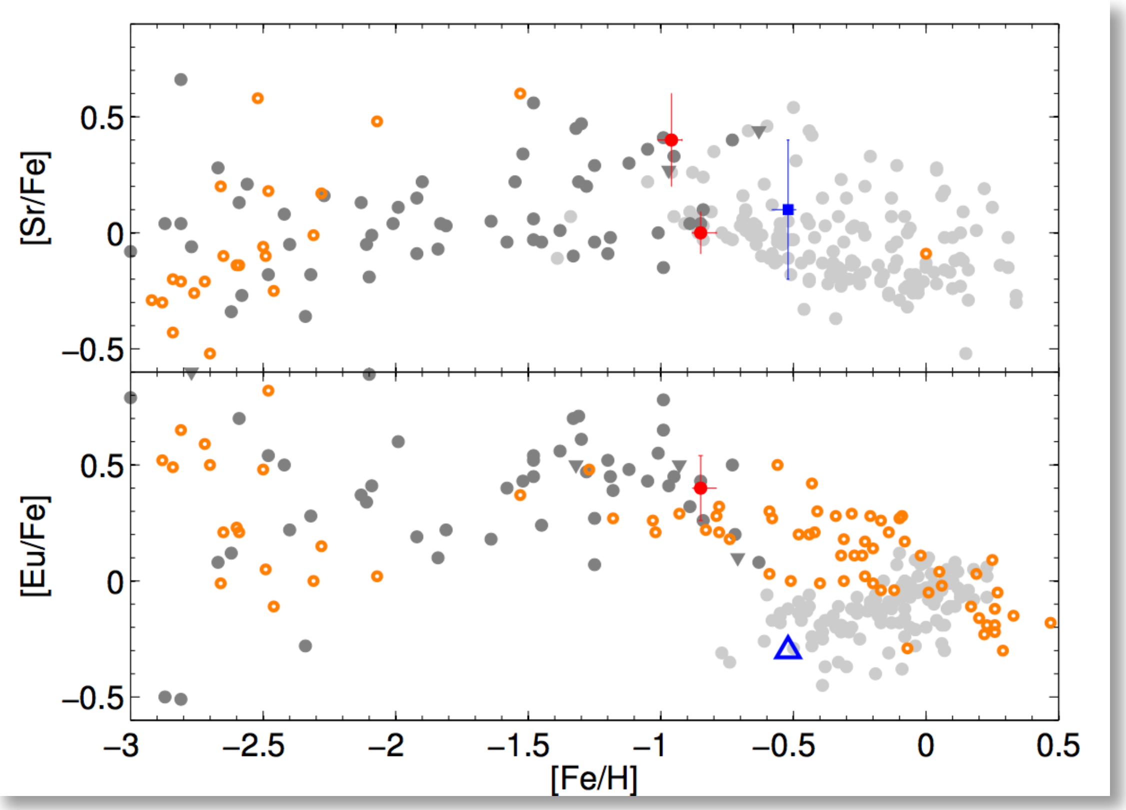
- Bulge
- Disks
- Foreground
- ESO452



ESO452-SC11

The same applies to heavy elements (*s*-, *r*-process)
→ Power of even low-resolution.

Lowest-mass GC with evidence of *light*-element (Na, CN/CH) variations (Simpson et al. 2017)



AK, C.J. Hansen, & Kunder (2017).

FSR 1716: Open of Globular?!

Very low latitude object: (l,b) = (330°, -1.6°).

Prediction: at least 10±3 more clusters like this are lurking undiscovered in the disk (Ivanov et al. 2005).

Ambiguous classification:

- **> 2 Gyr, metal-poor ([Fe/H] = -1.6)** (2MASS /NTT CMD: Froebrich et al. 2007)
- **7 – 12 Gyr, within Solar circle, 200 $M_{\odot}$ old open cluster. This implies that it is a lucky survivor.** (CMD "fit": Bonatto & Bica 2008)
- **Old (> 10 Gyr), metal-poor (-1.5) GC with RR Lyrae, $d_{\odot}$ = 7.5 kpc.** (VVV photometry: Minniti et al. 2017)

AAOmega spectra of 1048 stars toward FSR 1716.

FSR 1716: A pain in the plane

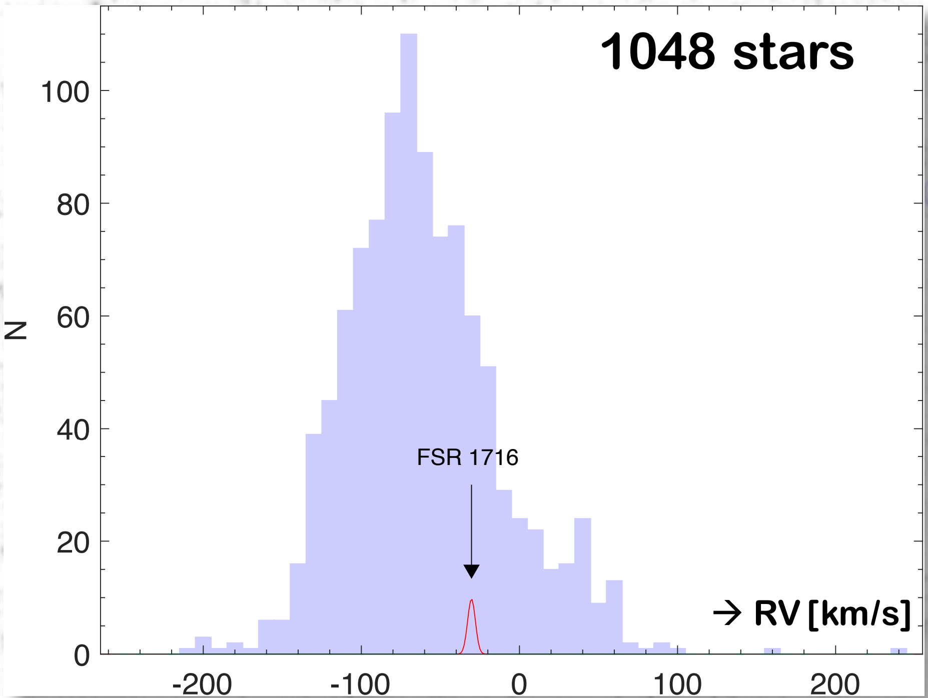
Full extent ~3', r_h ~ 27".

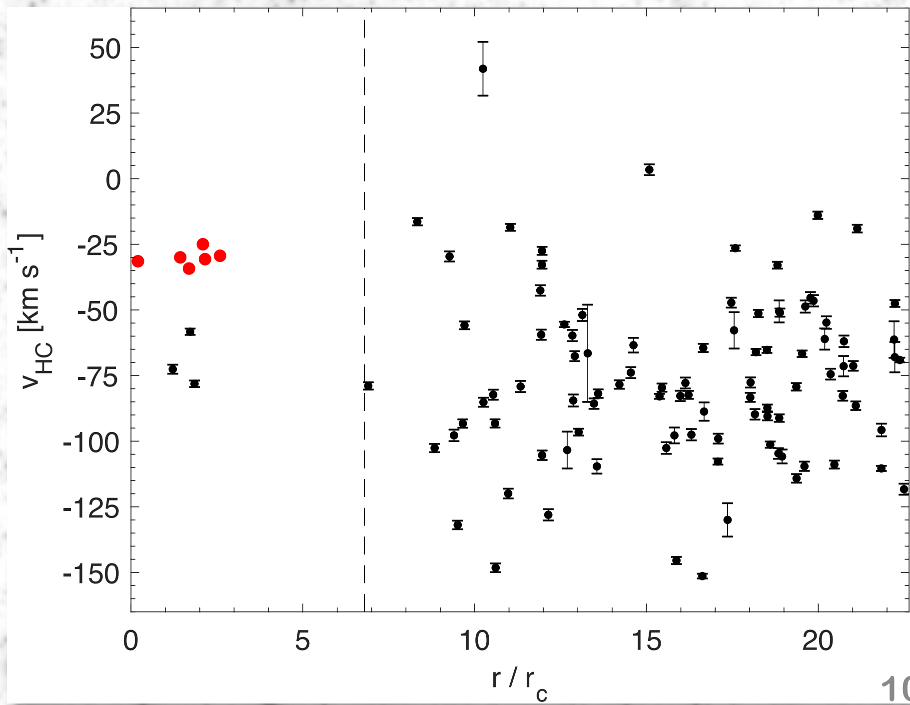
6 member candidates (AK, Kunder, & Wojno 2017)

Kinematic mass & low metallicity:

$1.3 \times 10^4\ M_{\odot}$; $[Fe/H]_{CaT} = -1.38$) confirmed by Apogee (Minniti et al. in prep)

→ old GC rather than low-mass OC

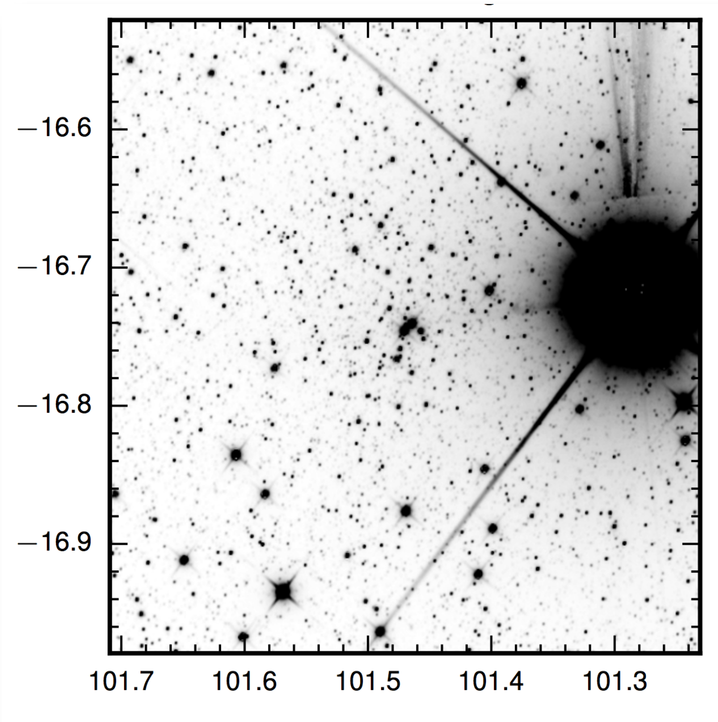




Gaia 1

- **Discovered in Gaia (dooh…), but difficult characterization** (Koposov et al. 2017).
- **Intermediate-age (3 – 6.3 Gyr) Cluster, "most likely globular".**
- **Metal rich (0 to -0.7 dex, spec. vs. phot.).**
- **Previous chemical analysis did not solve discrepancies.** (Simpson et al. 2017; Mucciarelli et al. 2017).

"Siriusly" ?! →
(Koposov+2017; Simpson+2017)

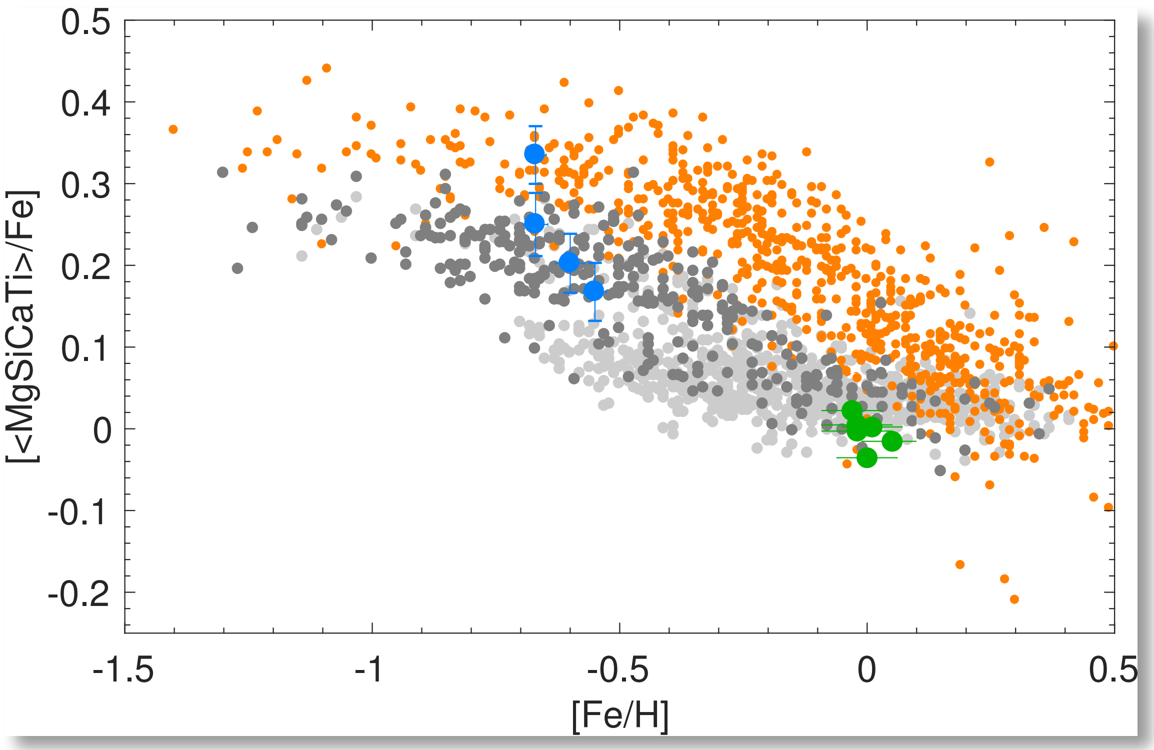


(WISE image)

Tagging Gaia 1

Chemical tagging (R=30,000 at LCO/2.5-m Swope):

- **Clearly a moderately metal-rich GC with thick-disk like abundances (α, Fe-peak, *n*-captures).**
- **Previous studies: more metal-rich, Solar abundance ratios, thin disk object**
  (Simpson et al. 2017;
  Mucciarelli et al. 2017)

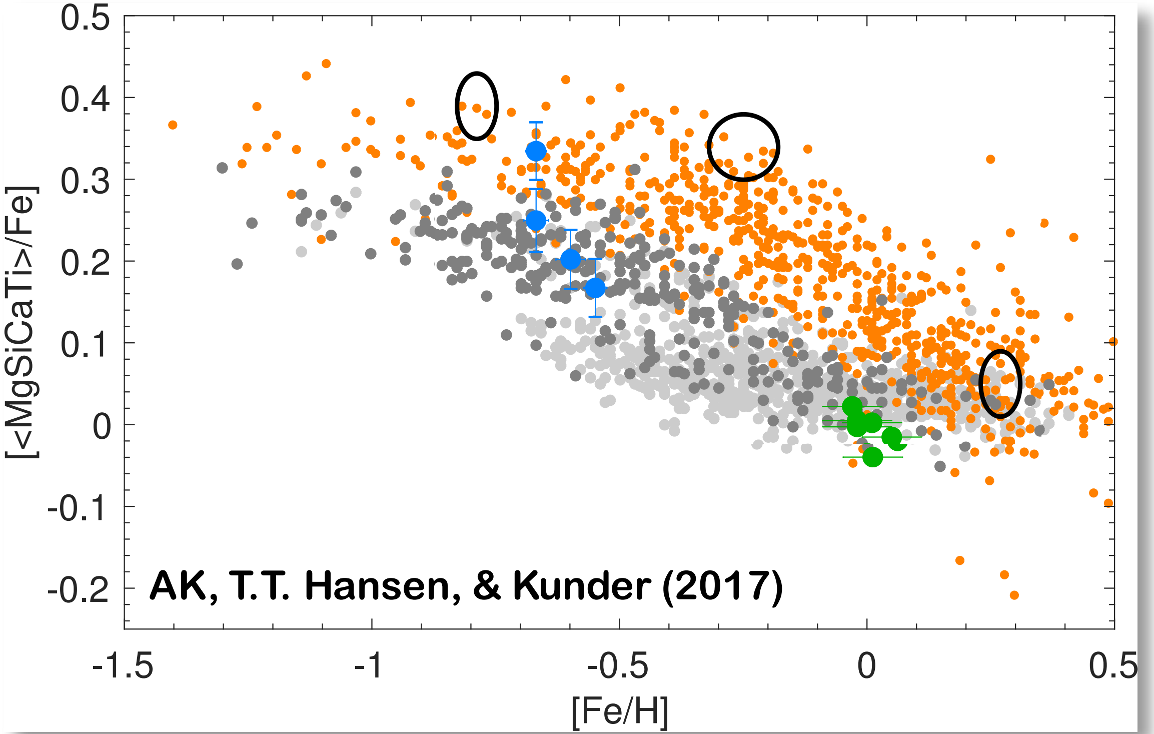


- Bulge
- Thick disk
- Thin Disk
- Gaia 1

AK, T.T. Hansen, & Kunder (2017)

Multiple populations in Gaia 1 ?

Other object with multiple components, also in bulge:
Terzan 5 (Origlia et al. 2011, 2013)**!**
→ Multiple star formation events → more massive past
→ Merger of (sub-solar) subfragments during disk formation, later capturing of (solar) disk material

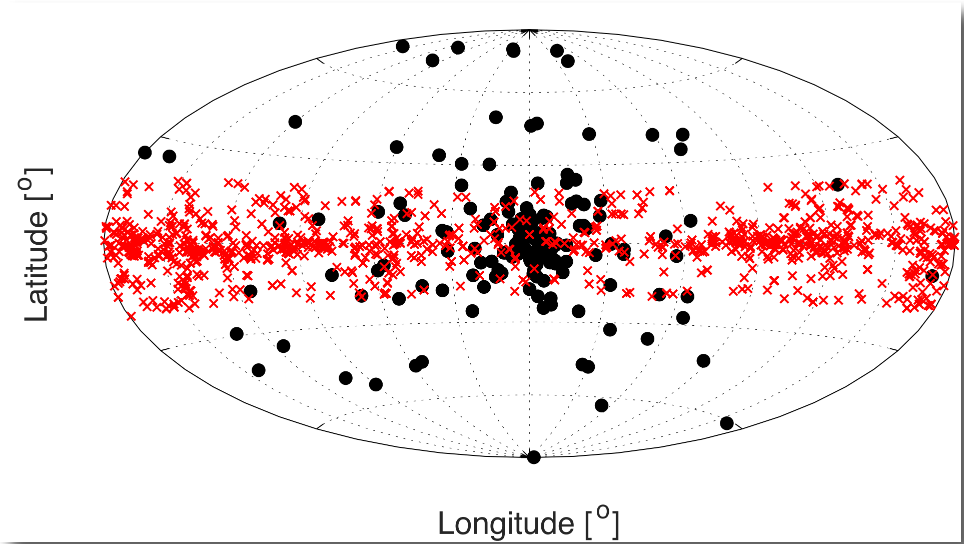


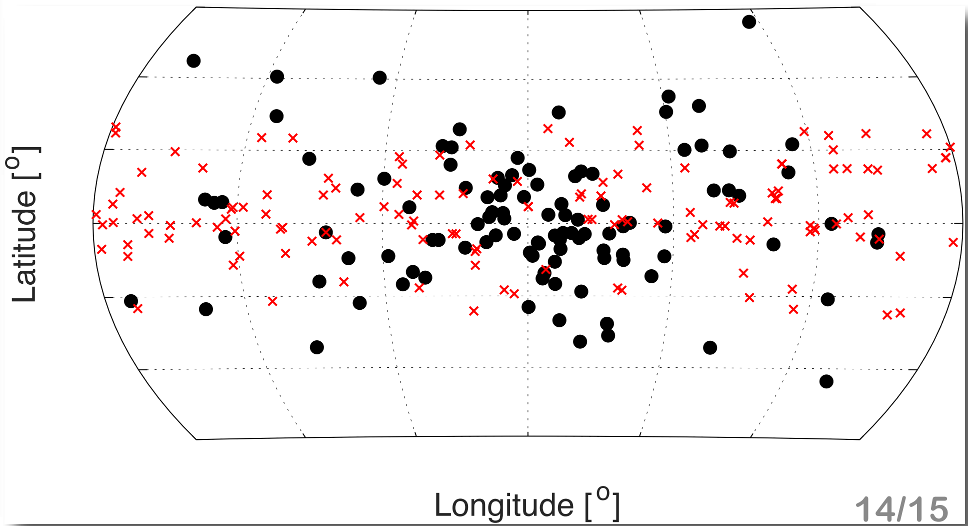
Summary

- Even if GC abundances are utterly like the surrounding field, this tells us about their formation history.

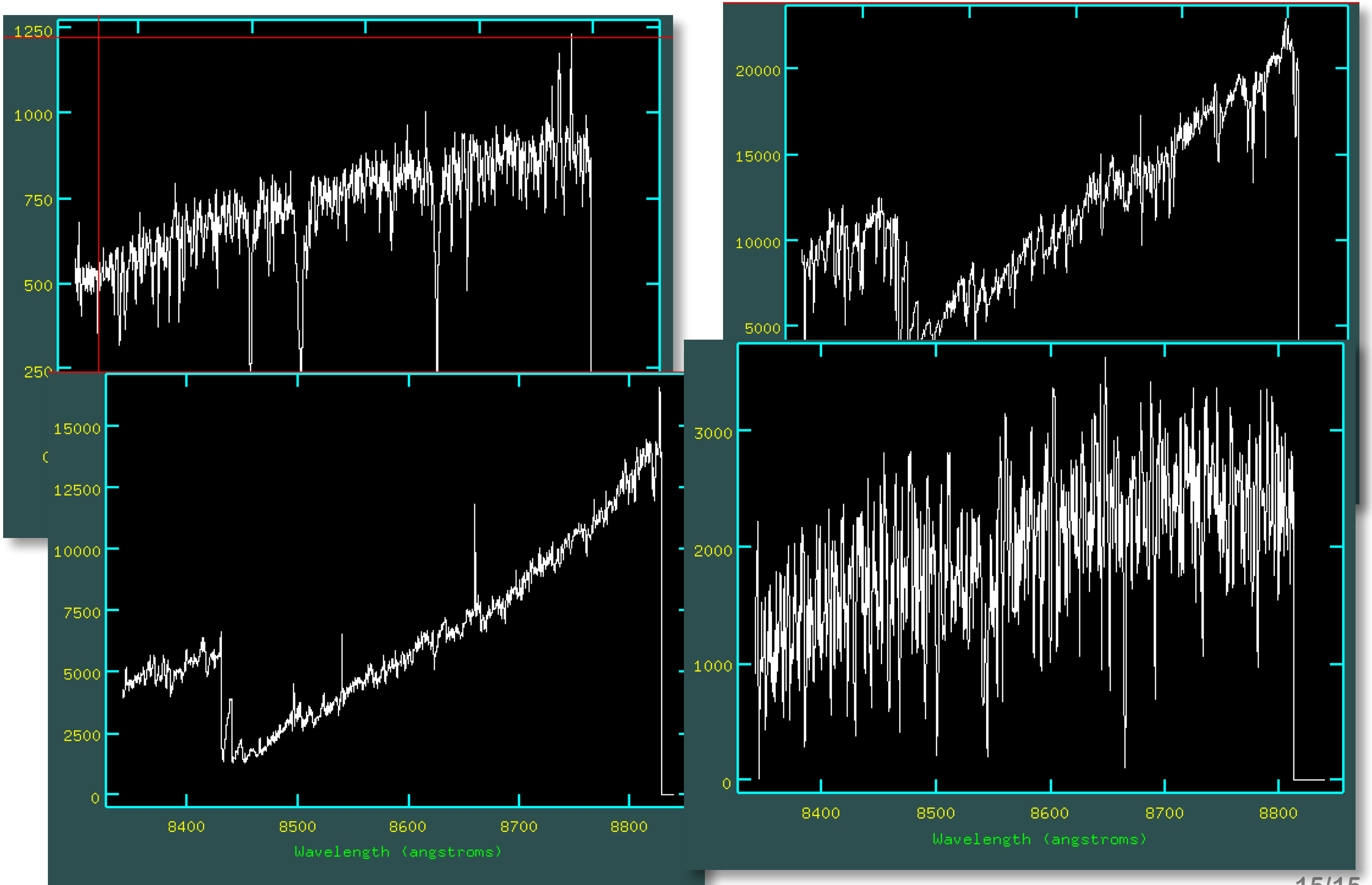
- AAOmega program → chemical tagging of unknown objects can uniquely associate them with Galactic components AND resolve previous (phot.) discrepancies.

- This needs to be systematically explored. FSR (Froebrich et al. 2007) contains 1788 clusters incl. 681 known open, and 86 GCs.





Summary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Wavelength (angstroms)
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2000
1000
0
8400
8500
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8700
8800
Wavelength (angstroms)

Gaia 1: kinematics

- **PMs from UCAC5: Orbits are fully compatible with disk membership.**