INAF - Osservatorio Astrofisico di Arcetri

The evolution of the Galactic disk with open clusters: the promise of the Gaia-ESO Survey

Laura Magrini
INAF-Osservatorio di Arcetri

"The Milky Way Unraveled by Gaia", GREAT meeting, 1-5 December 2014

Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

- **The thin disk is the Galactic component where most star formation occurs and occurred in the past.**
- **It is rich with astrophysical fossils and is relatively easy to observe (compared to the stellar halo or bulge/bar).**
- **The study of stellar population in the Galactic thin disk allow to resolve spatially (and temporally) its metal distributions**

Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

<u>Open questions in galaxy formation and evolution:</u>

- How did disk(s) galaxies form?
- What is the shape of the radial gradient and how does it evolve with time?
- How do mergers/gas inflow influence the galaxy evolution?

Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

A new era for models of galaxy formation and evolution, including:

- Cosmological context
- Detailed nucleo-synthesis
- Dynamics and Radial migration

Observational constraints are needed:

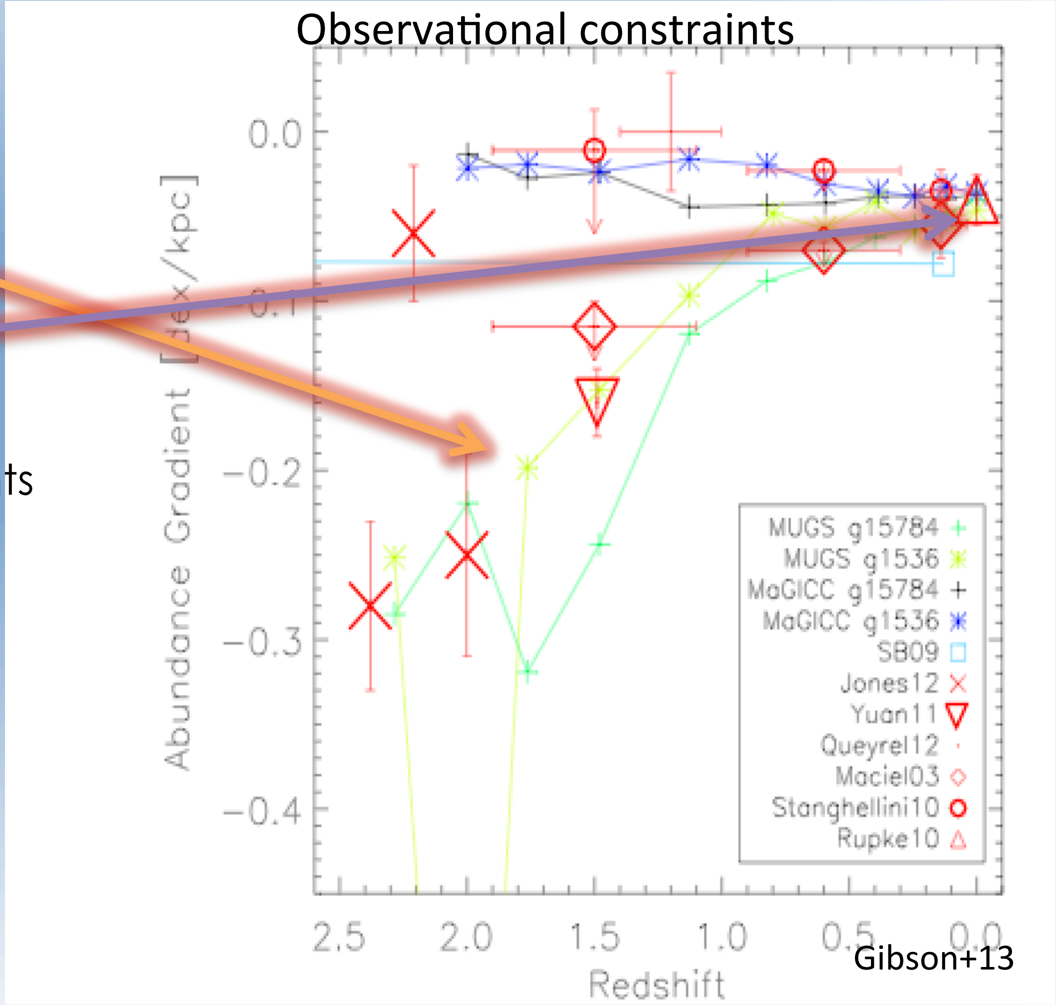
- the shape and the evolution of the radial metallicity gradients

Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

Strong necessity of observational constraints:

- High z-galaxies
- Galactic Archeology
- Can we add more constraints from Galactic Archeology?

Yes, studying populations with known and different ages → Open clusters and PNe



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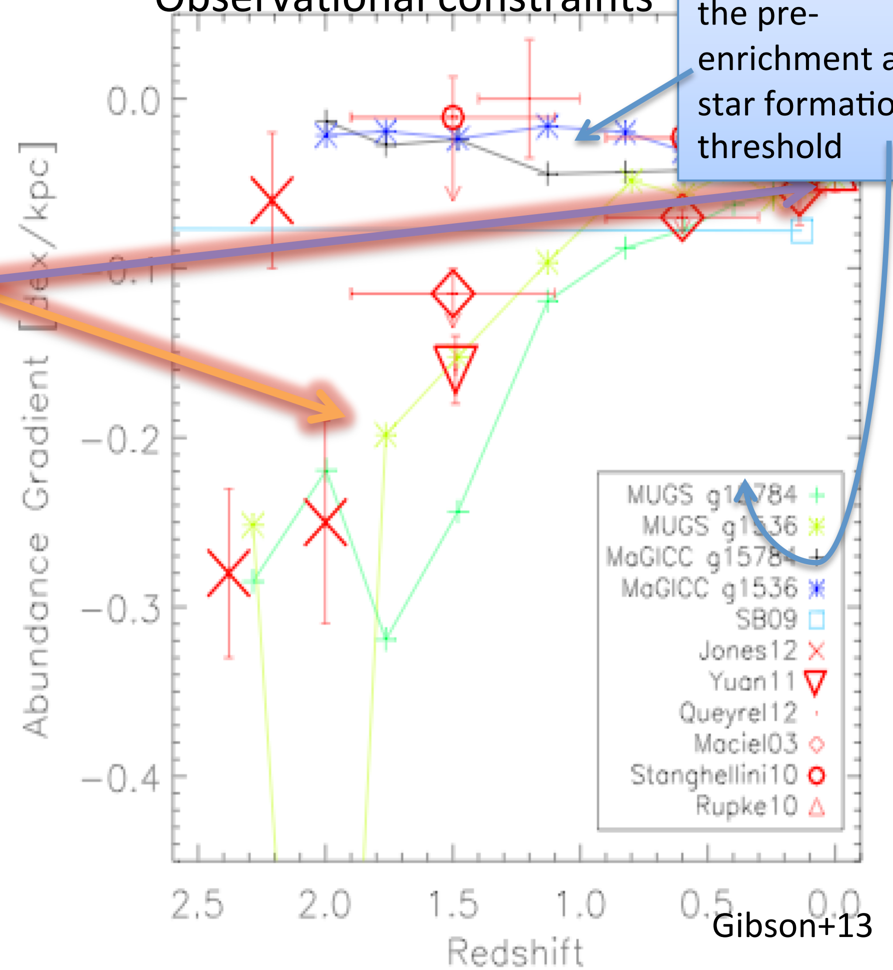

Gibson+13

Classical chemical evolution models: Dependence on the pre-enrichment and star formation threshold

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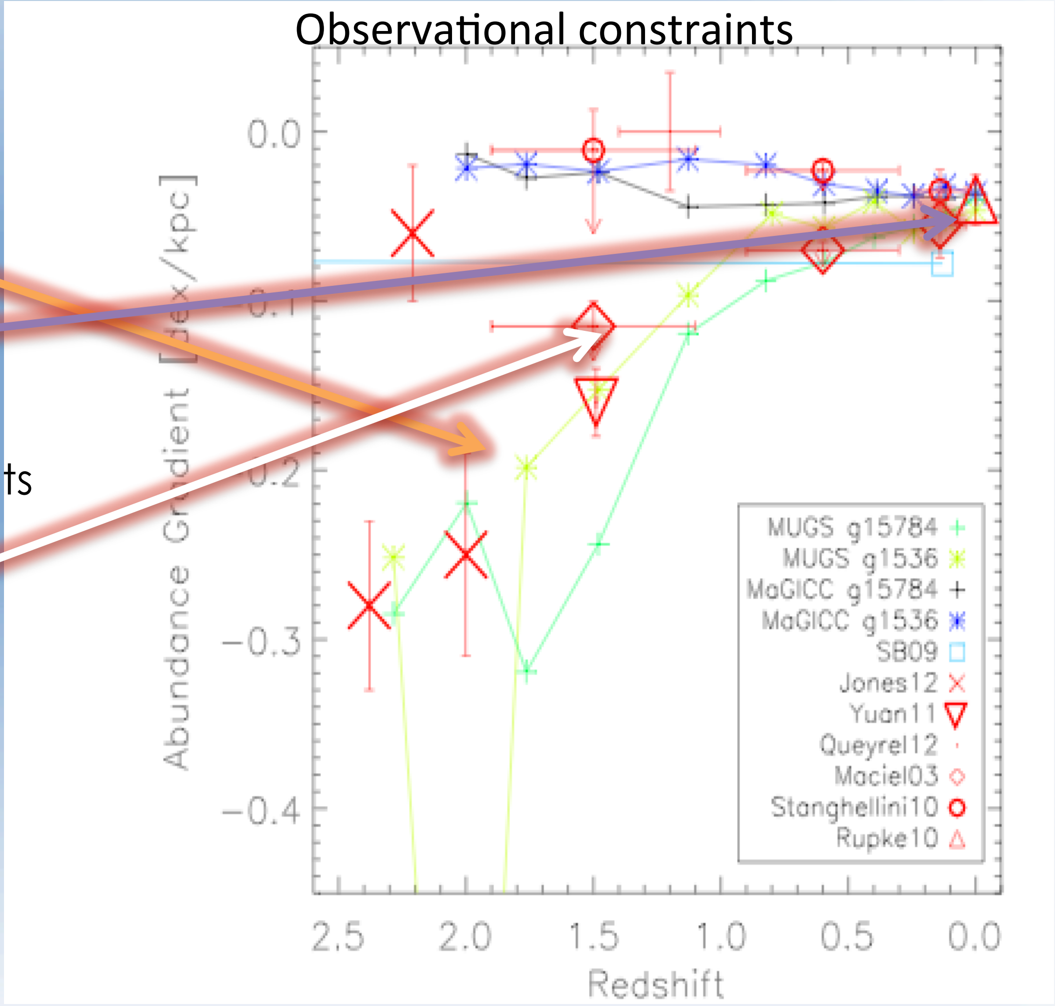
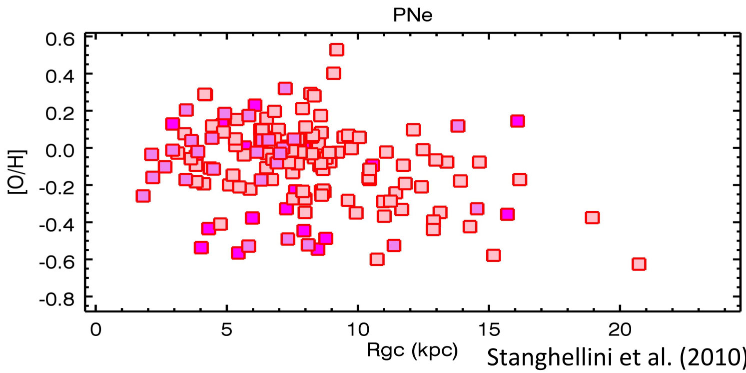
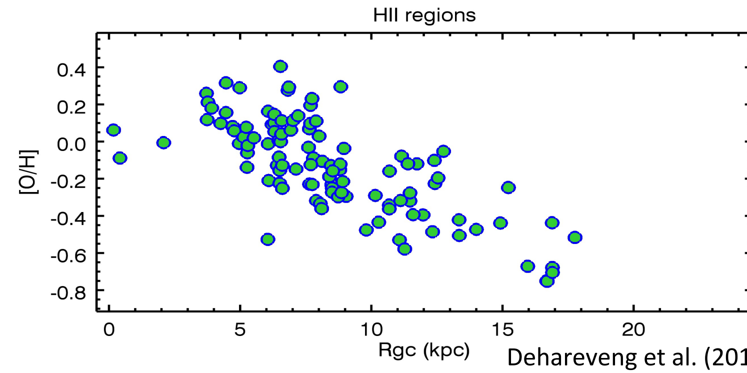


The Galactic gradient: recent literature results from many populations



Stanghellini et al. (2010)



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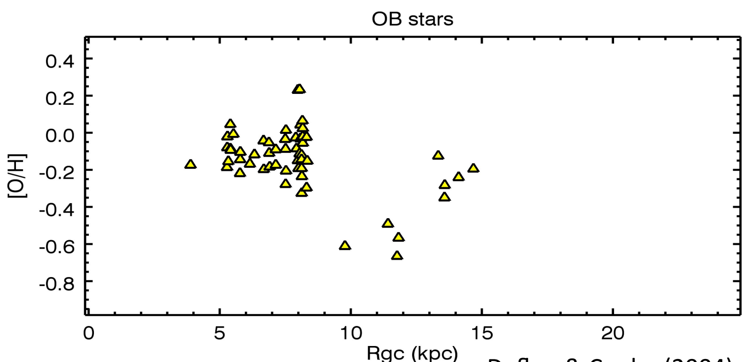

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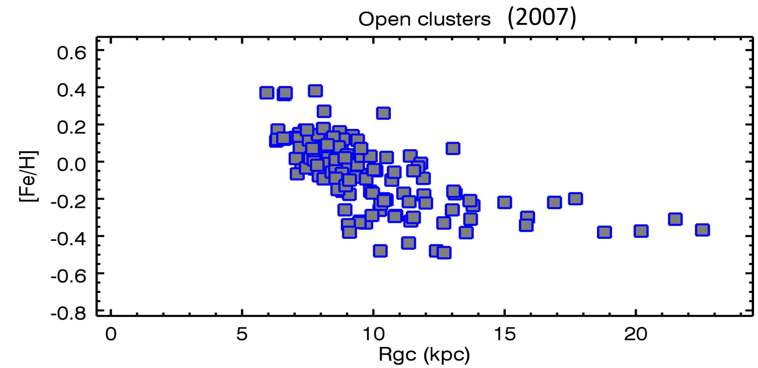

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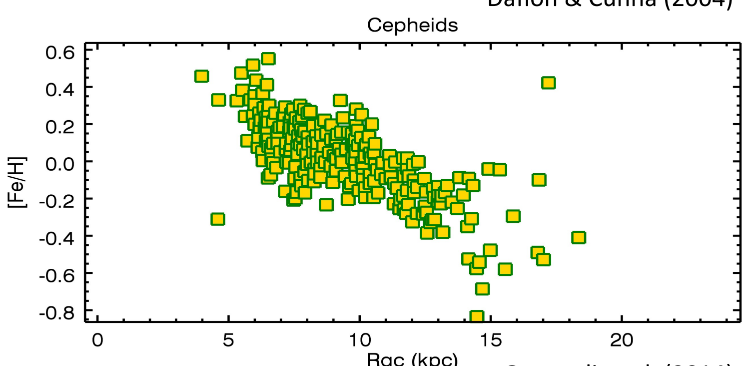

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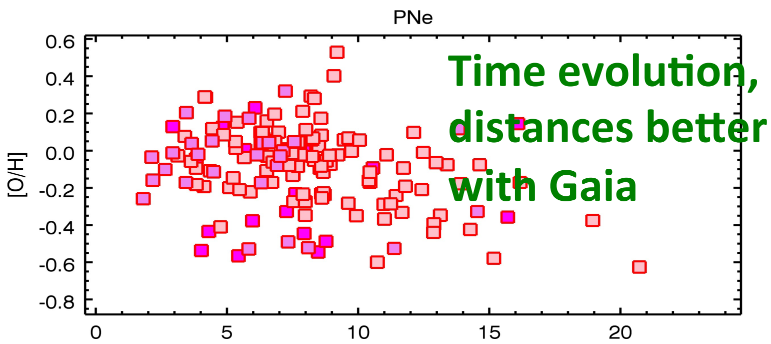

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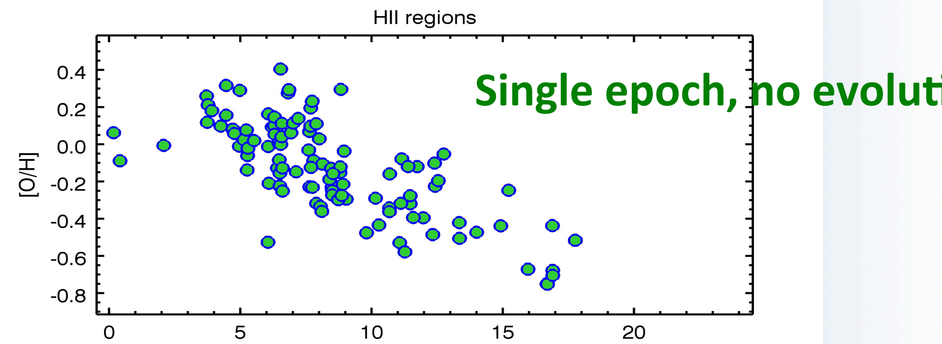

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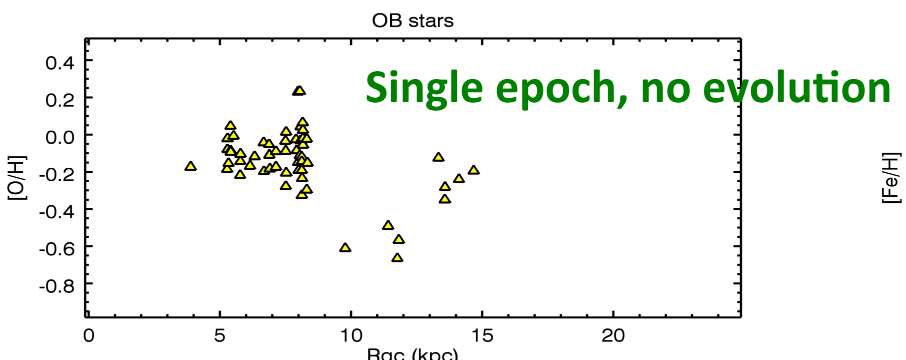

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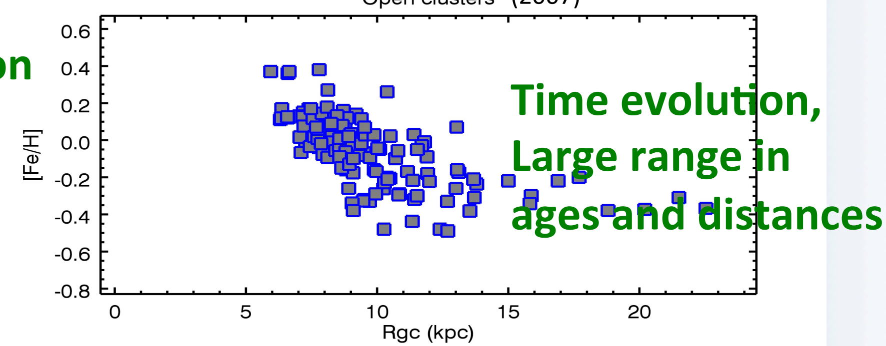

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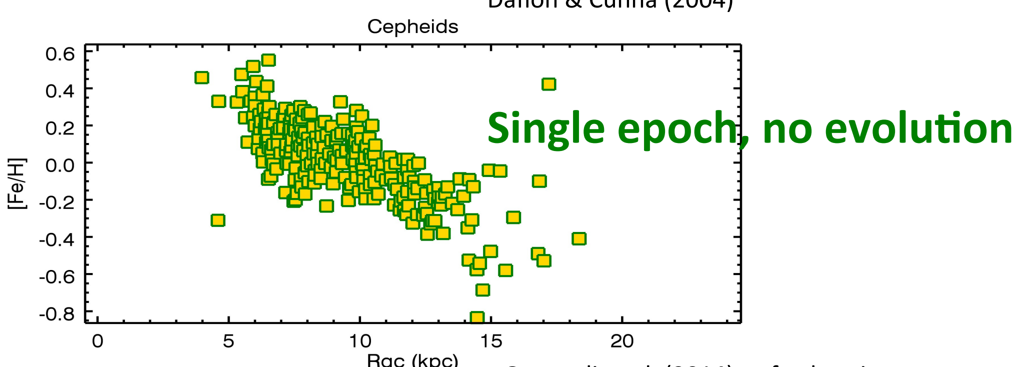

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Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions

They allow to derive the structure, kinematics and chemistry of the disk, and, thanks to the large range of ages, also their time variation.

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1995

THE OLD OPEN CLUSTERS OF THE MILKY WAY

E. D. Friel

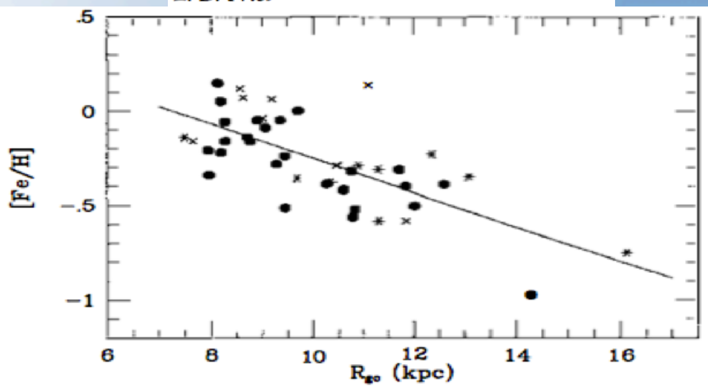

Figure 7 Radial abundance gradient for the old open clusters, with metallicities from Table 1. Filled circles are points from Friel & Janes (1993) or Thogersen et al (1994). Starred symbols are preliminary metallicities from Friel et al (1995). Crosses are data taken from Lynga (1987). The solid line is a least-squares fit to the data that yields an abundance gradient of $\Delta[Fe/H]/R_{gc} = -0.091 \pm 0.014$.

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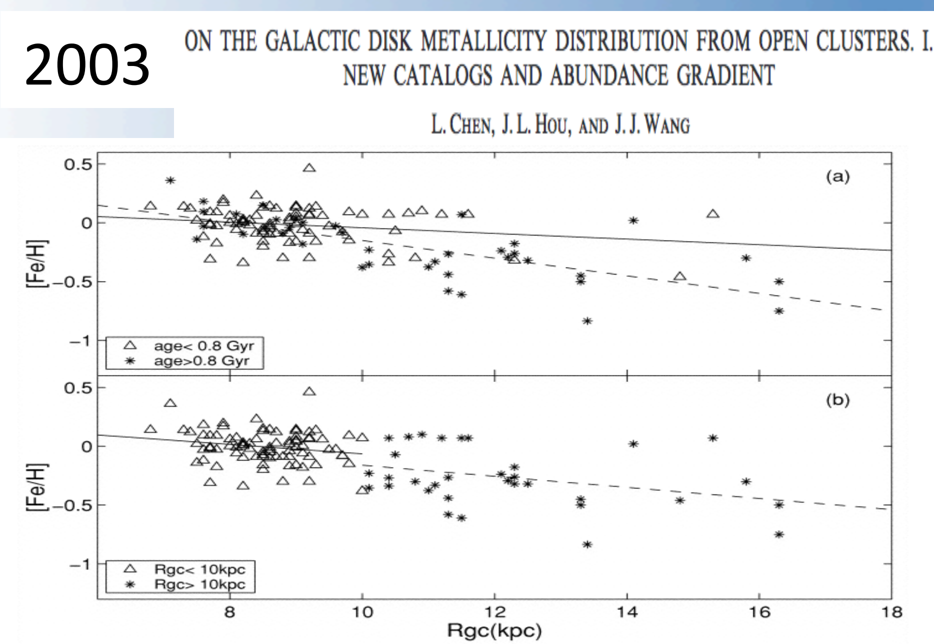

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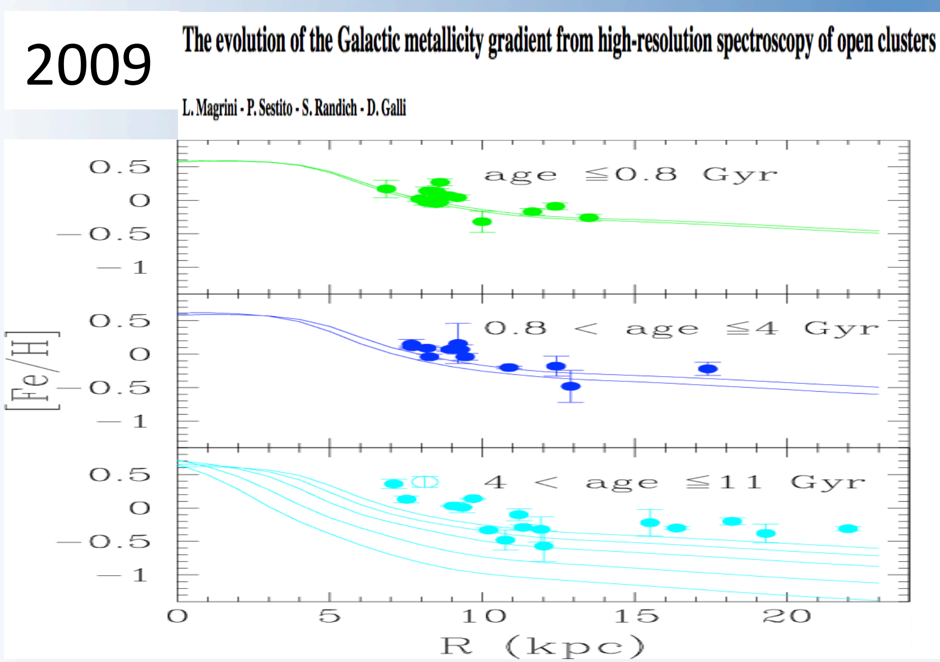

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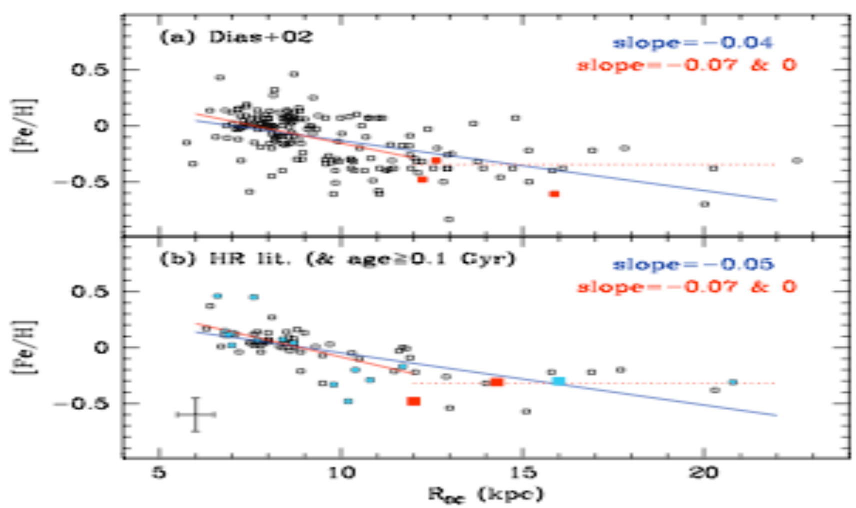
2011

Old open clusters and the Galactic metallicity gradient: Berkeley 20, Berkeley 66 and Tombaugh 2★

Gloria Andreuzzi,[1,2]† Angela Bragaglia,[3]† Monica Tosi[3]† and Gianni Marconi[4]†



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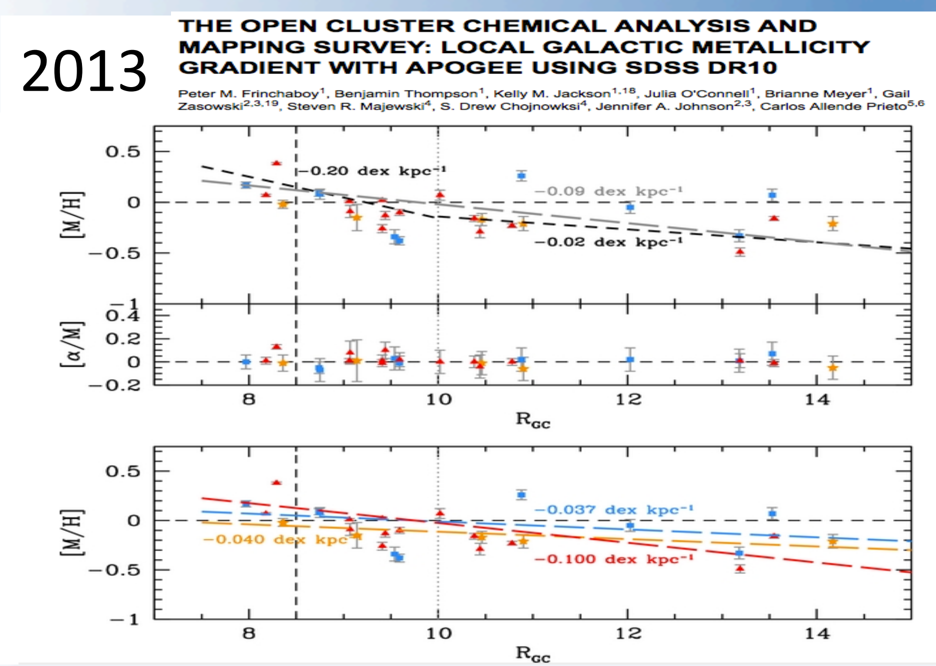

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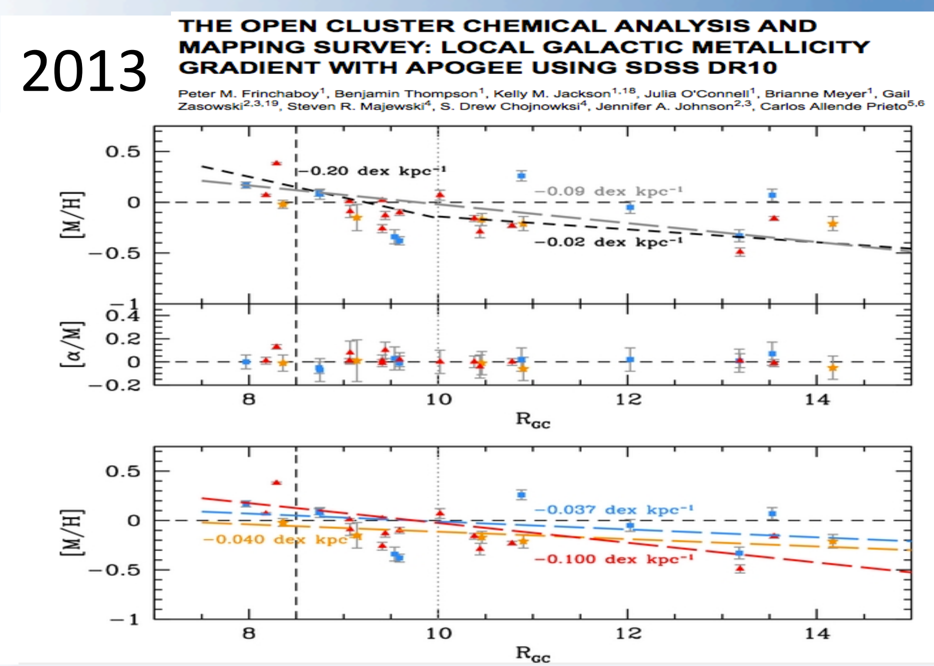

Main results

- **Negative gradient**: inside-out formation of the disk
- **Bi-modal gradient**: different infall-SFR rate balance in the outer and inner Galaxy

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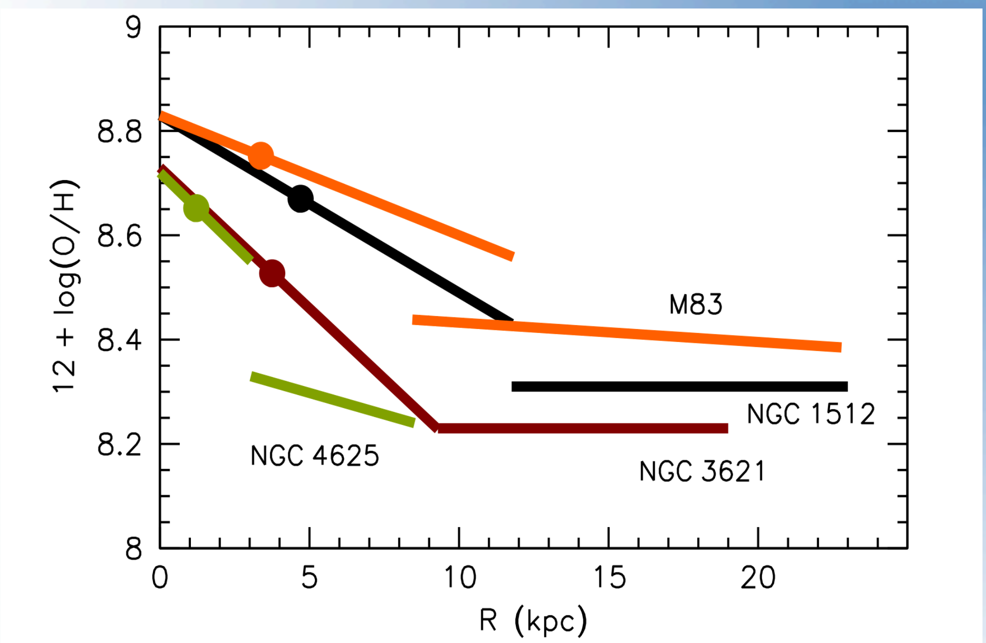


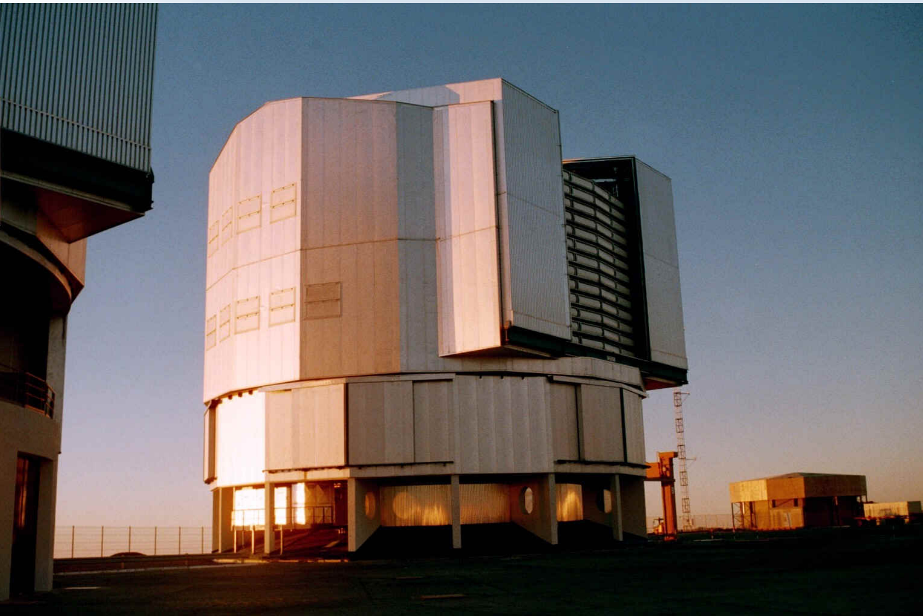
Main results

- **Negative gradient**: inside-out formation of the disk
- **Bi-modal gradient**: different infall-SFR rate balance in the outer and inner Galaxy
- → Now found also in outer galaxies (see e. g. Bresolin et al. 2012)

The contribution of Gaia-ESO survey:

The clusters' side of GES

The Gaia-ESO Survey: overview



Aim: provide complementary data to Gaia (RV, *vsin i, Teff, log(g), chemical abundances*) by high resolution spectroscopy

Science goals:

- Galaxy chemo-dynamics
- Cluster formation and evolution
- Stellar evolution

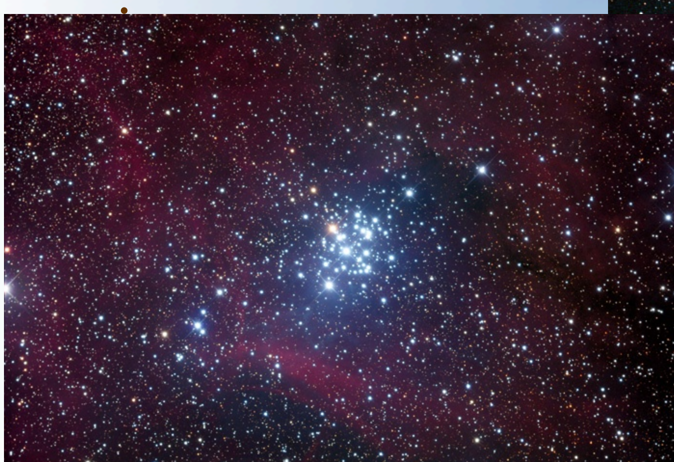
(Gilmore et al. 2012, Randich & Gilmore 2013)

Time & people	Sample	Instrument
PIs: G. Gilmore & S. Randich Co-Is: +400 Start: 31/12/2011 End: 31/12/2016 (4+1 years) Nights: 240+60	10^5 stars at R=20,000 (V < 19 mag) 5000 at R=47,000 (V < 17 mag) Milky Way components Old clusters (age > 100 Myr) Young clusters (age 1-100 Myr)	FLAMES@VLT •GIRAFFE (10^5 stars) (132 fibres at R=20,000) •UVES (10^4 stars) (8 fibres at R=47,000)

Braking by population –Open Clusters

PMS clusters
(10-100 Myr)

Very young
clusters,
star forming



Intermediate-age
and old clusters
(100 Myr – 8 Gyr)

Nearby (< 1.5 kpc) and distant

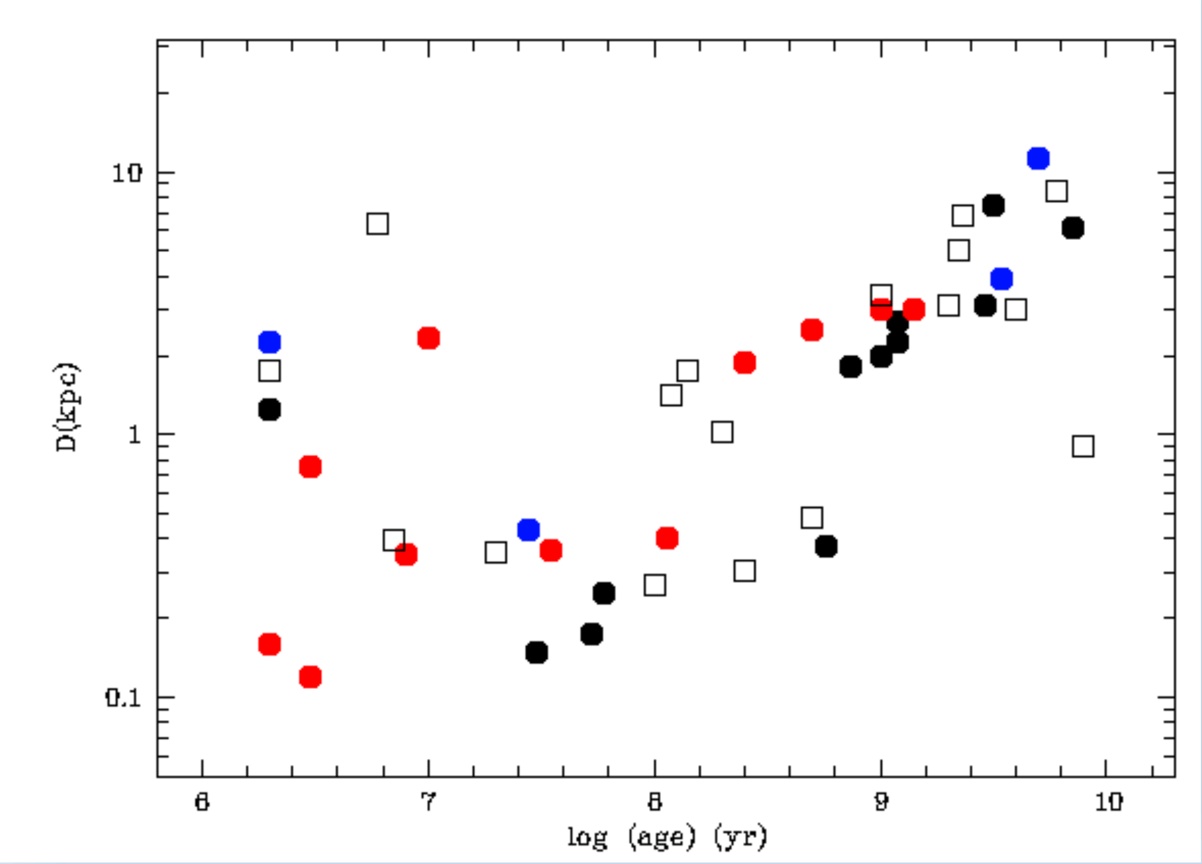
Relevant populations covered

Braking by population – Open Clusters

~ 70-80 OCs in all phases of evolution (~1 Myr → several Gyr), sampling the age-distance-R_{GC}-density-mass-metallicity parameter space

OB type stars → M dwarfs
plus evolved stars (mostly clump giants)
use of literature and VPHAS+ photometry to select target stars within clusters

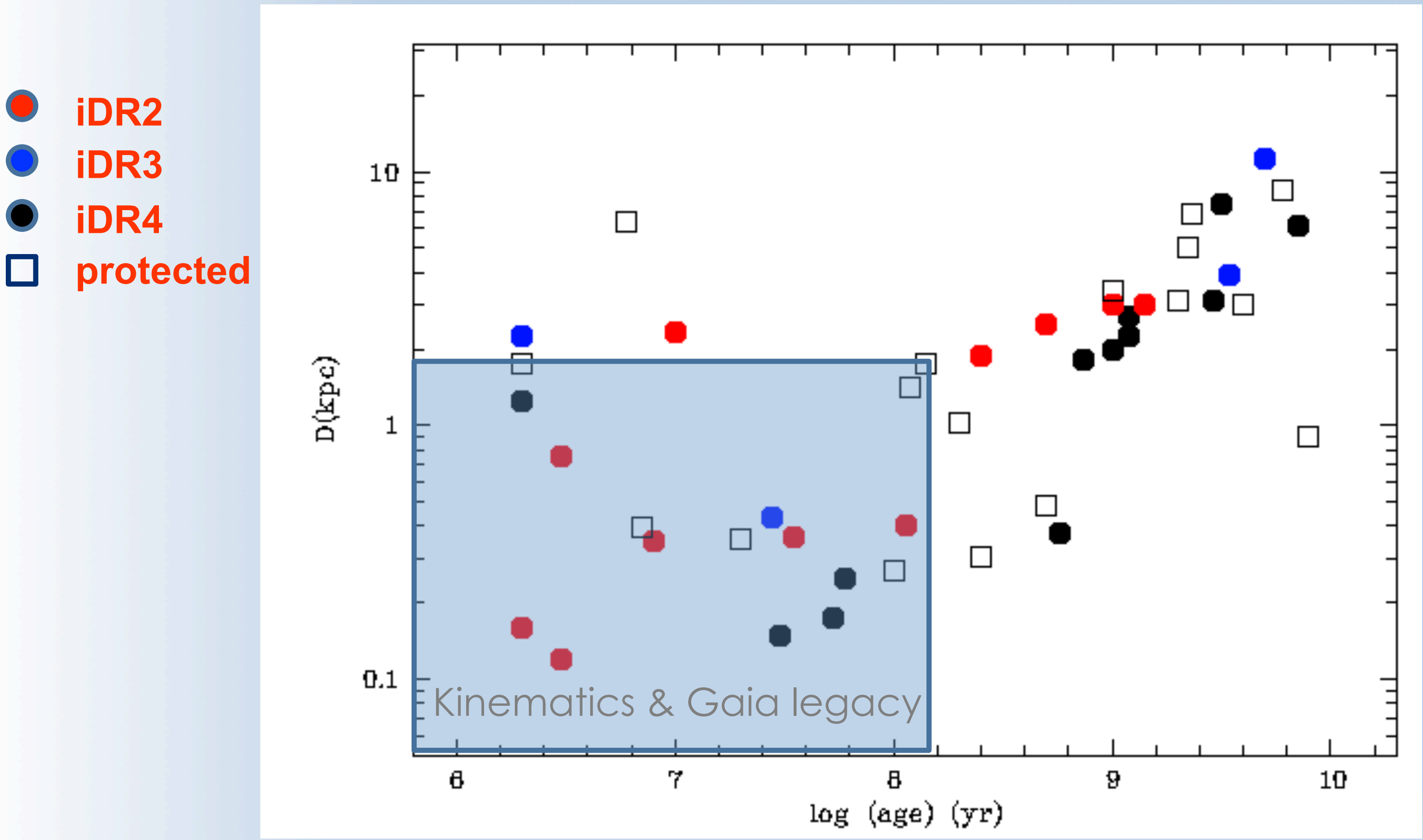
Observed cluster sample



- iDR2
- iDR3
- iDR4
- protected

Courtesy of S. Randich

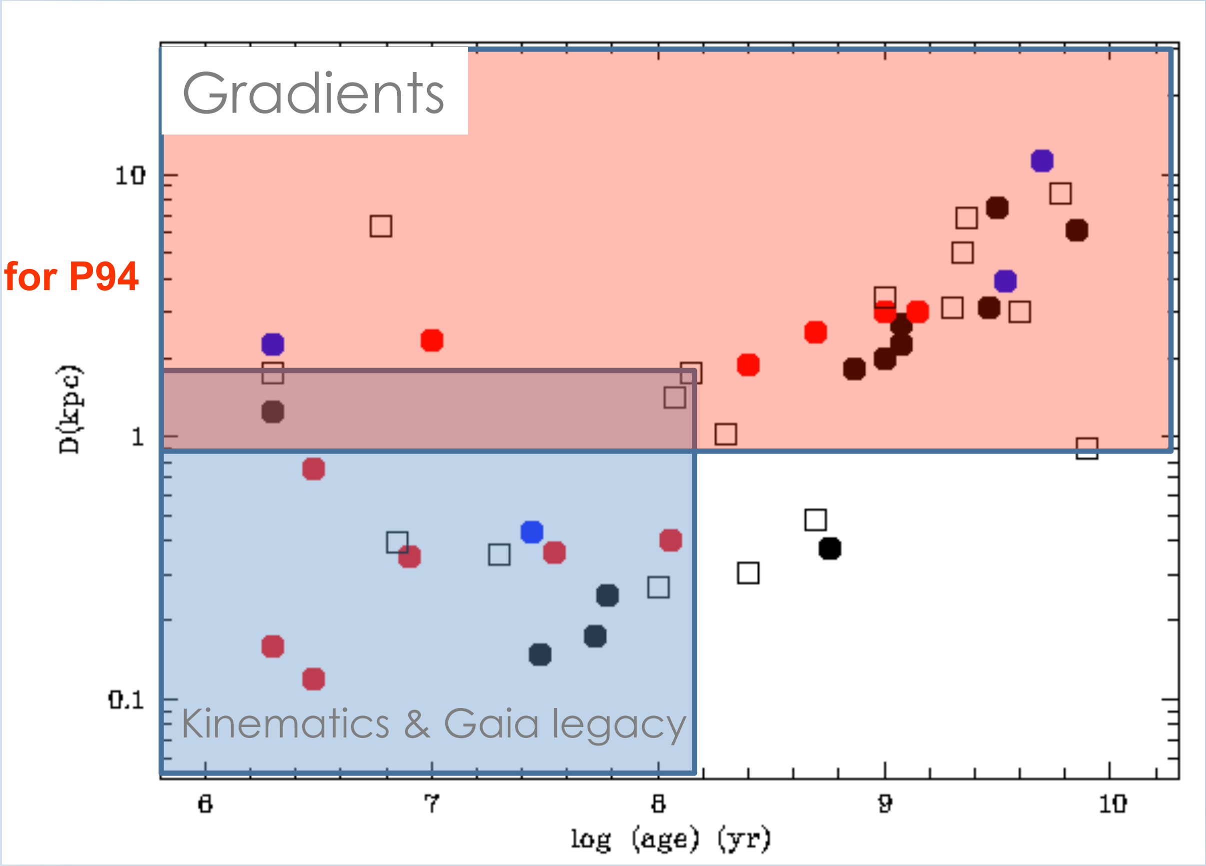
Observed cluster sample



Courtesy of S. Randich

Observations – cluster sample

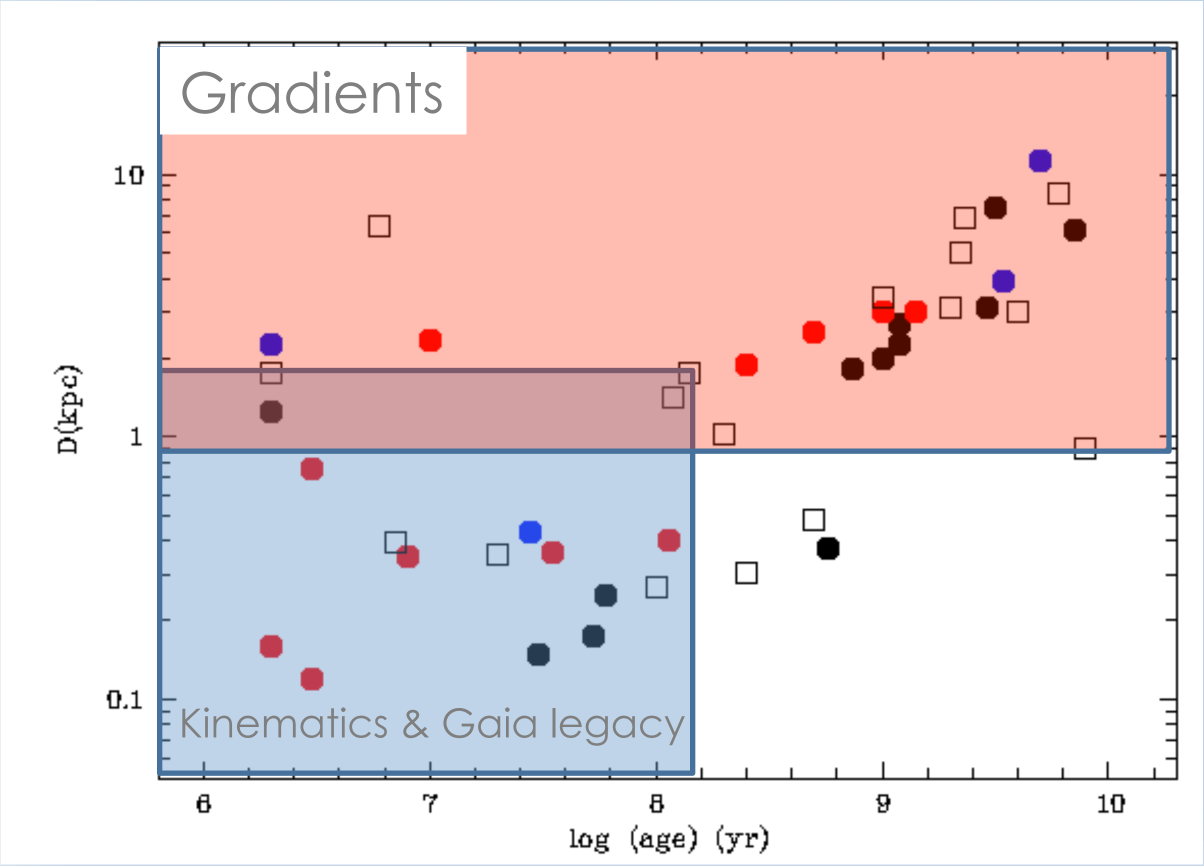
- iDR2
- iDR3
- iDR4
- protected for P94 and P95



Courtesy of S. Randich

Observed cluster sample

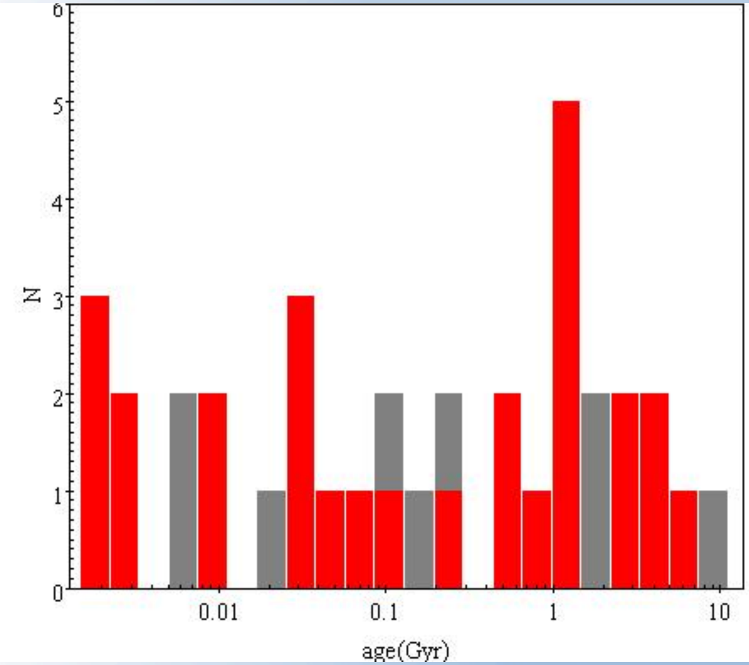
iDR2
iDR3
iDR4
protected

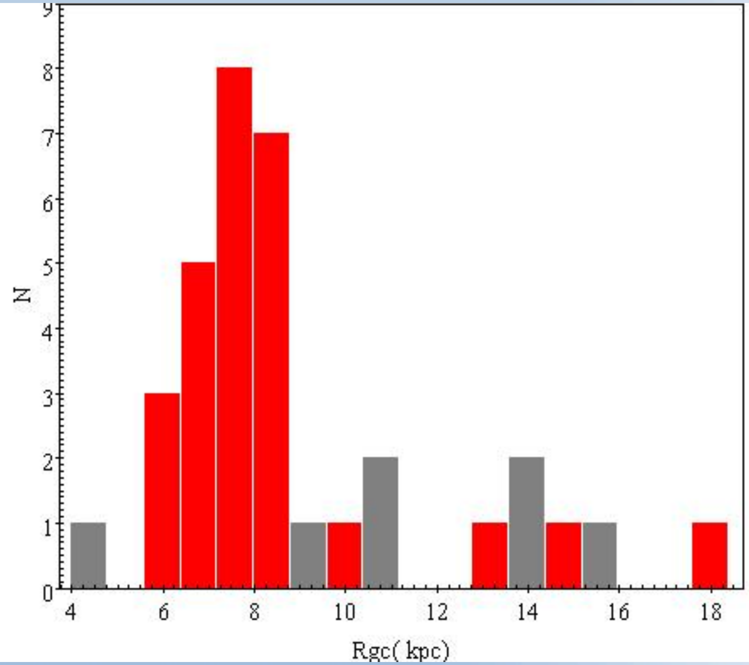


All: stellar evolution

Courtesy of S. Randich

Observed cluster sample





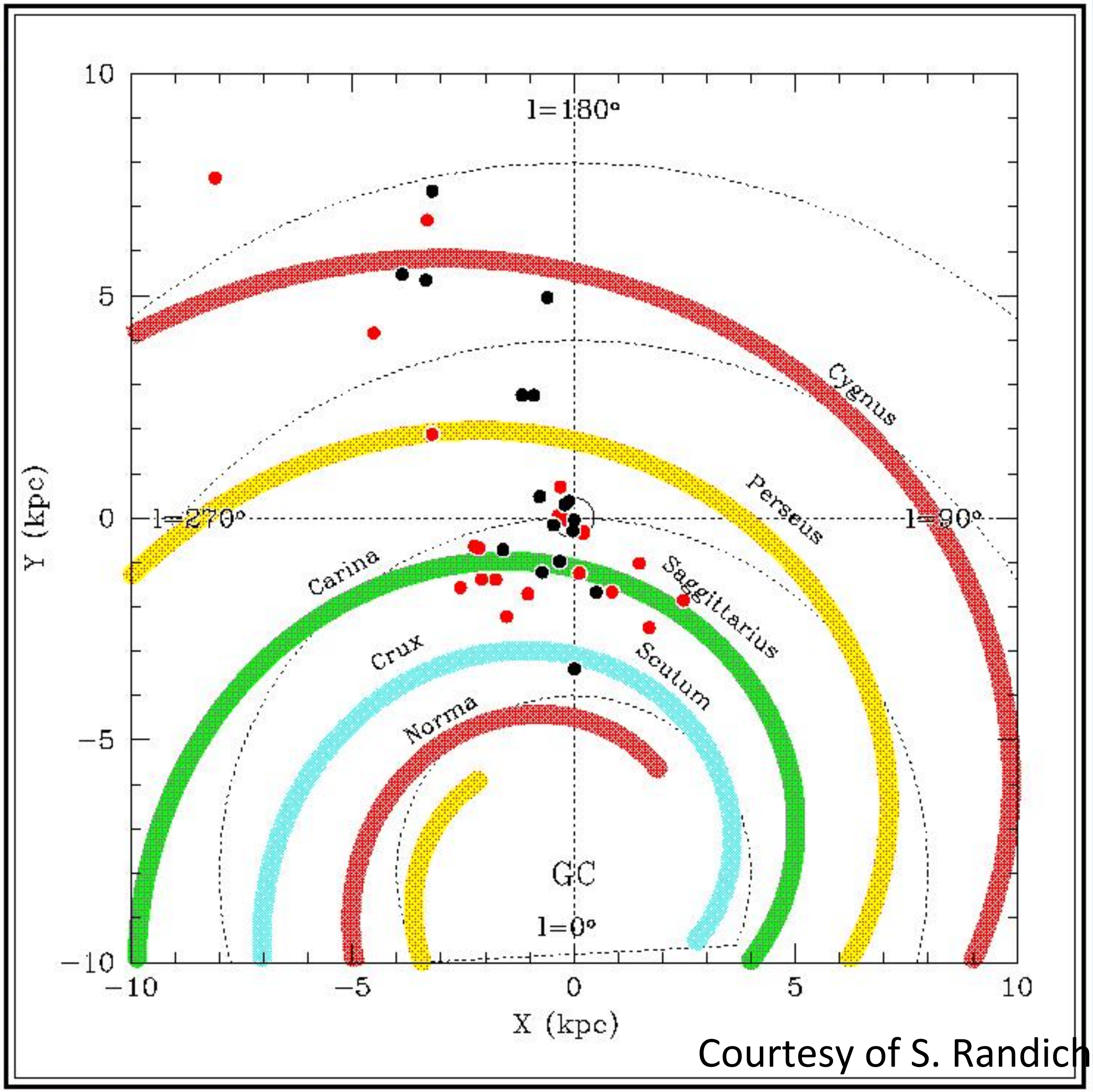
Observed
Protected

Courtesy of S. Randich

Observed cluster sample

Observed
Protected

z sampling to be improved

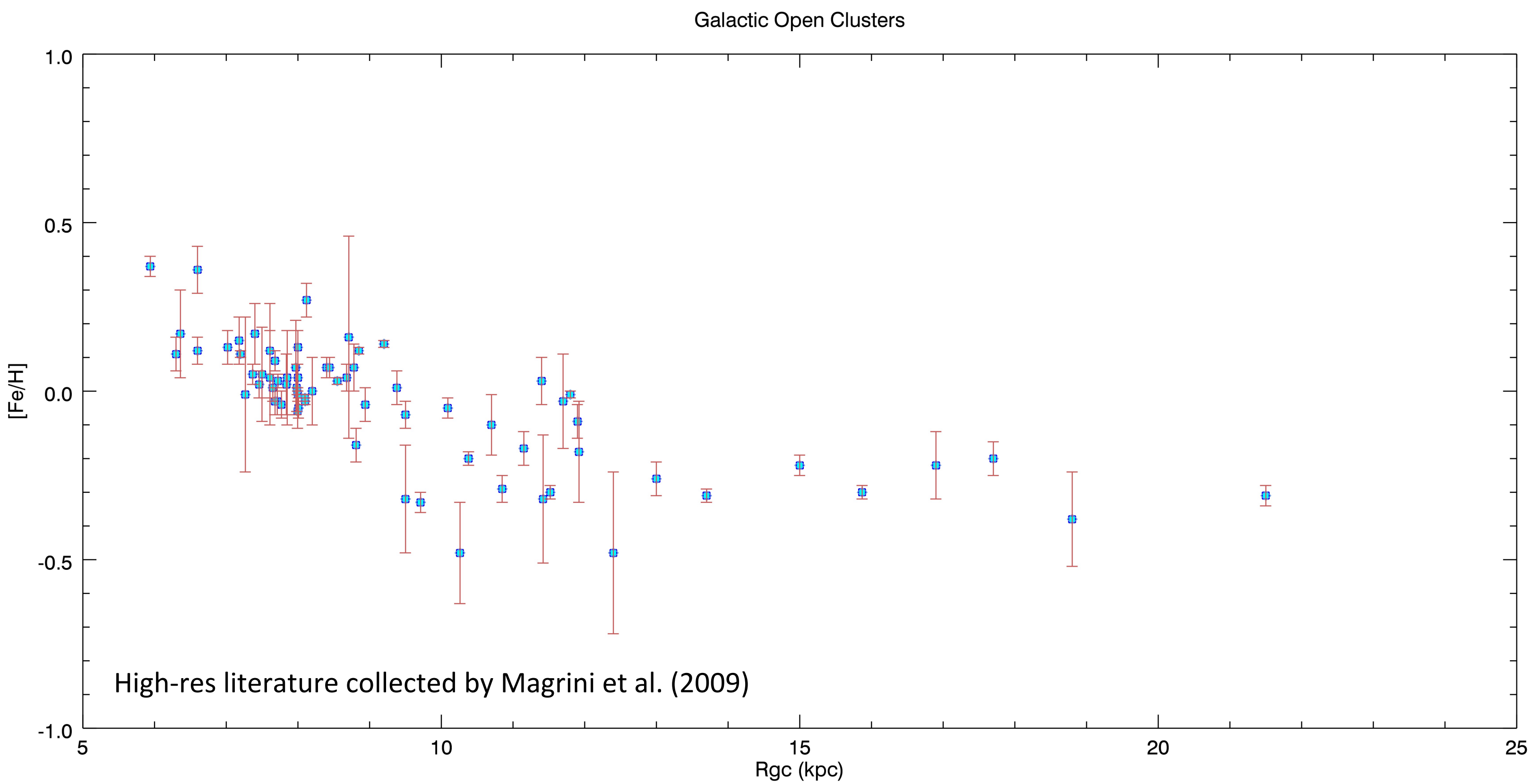


Courtesy of S. Randich

The UVES observations:

the contribution of the Gaia-ESO survey to our understanding of the radial metallicity gradient

The radial gradient: Literature vs. GES



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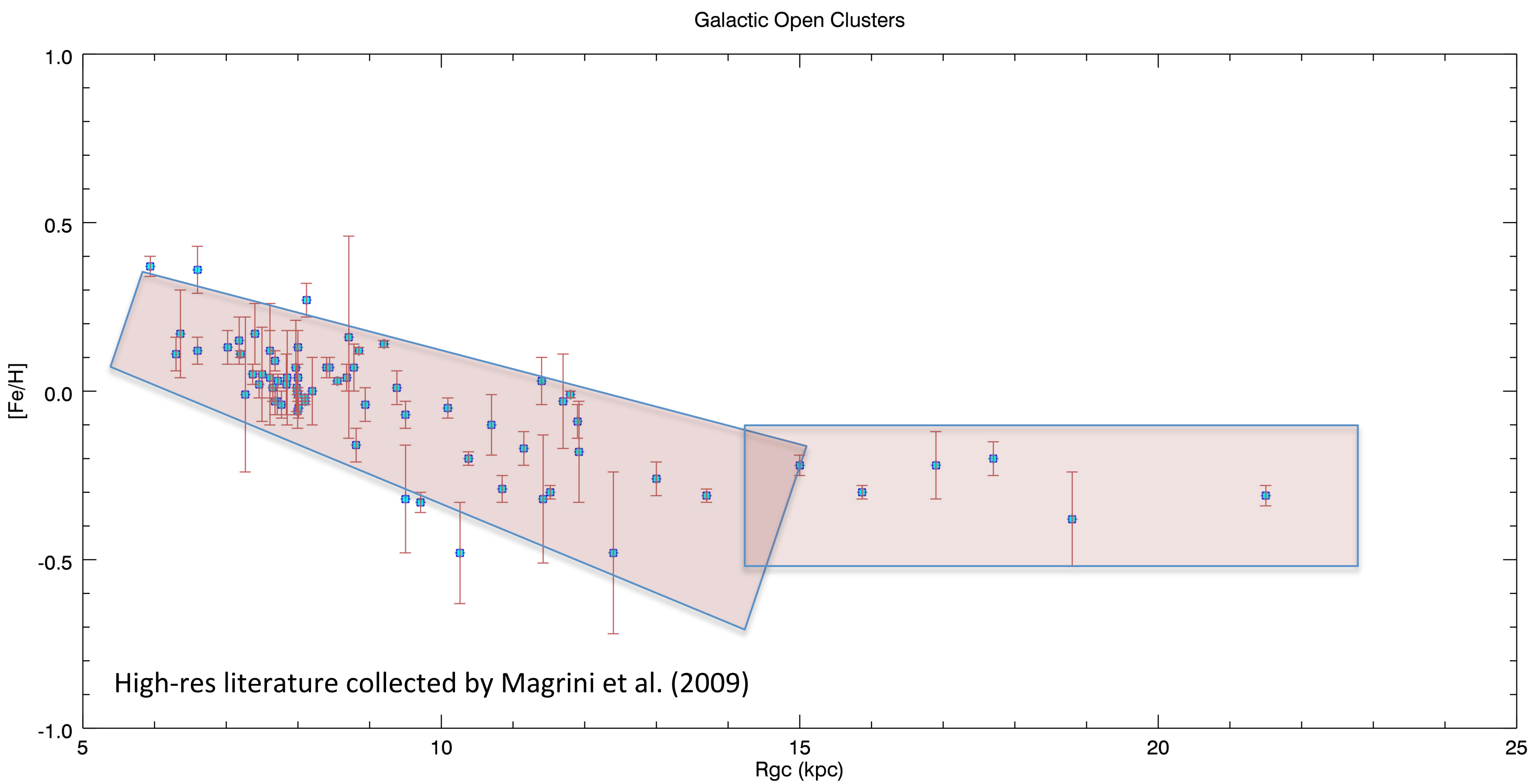

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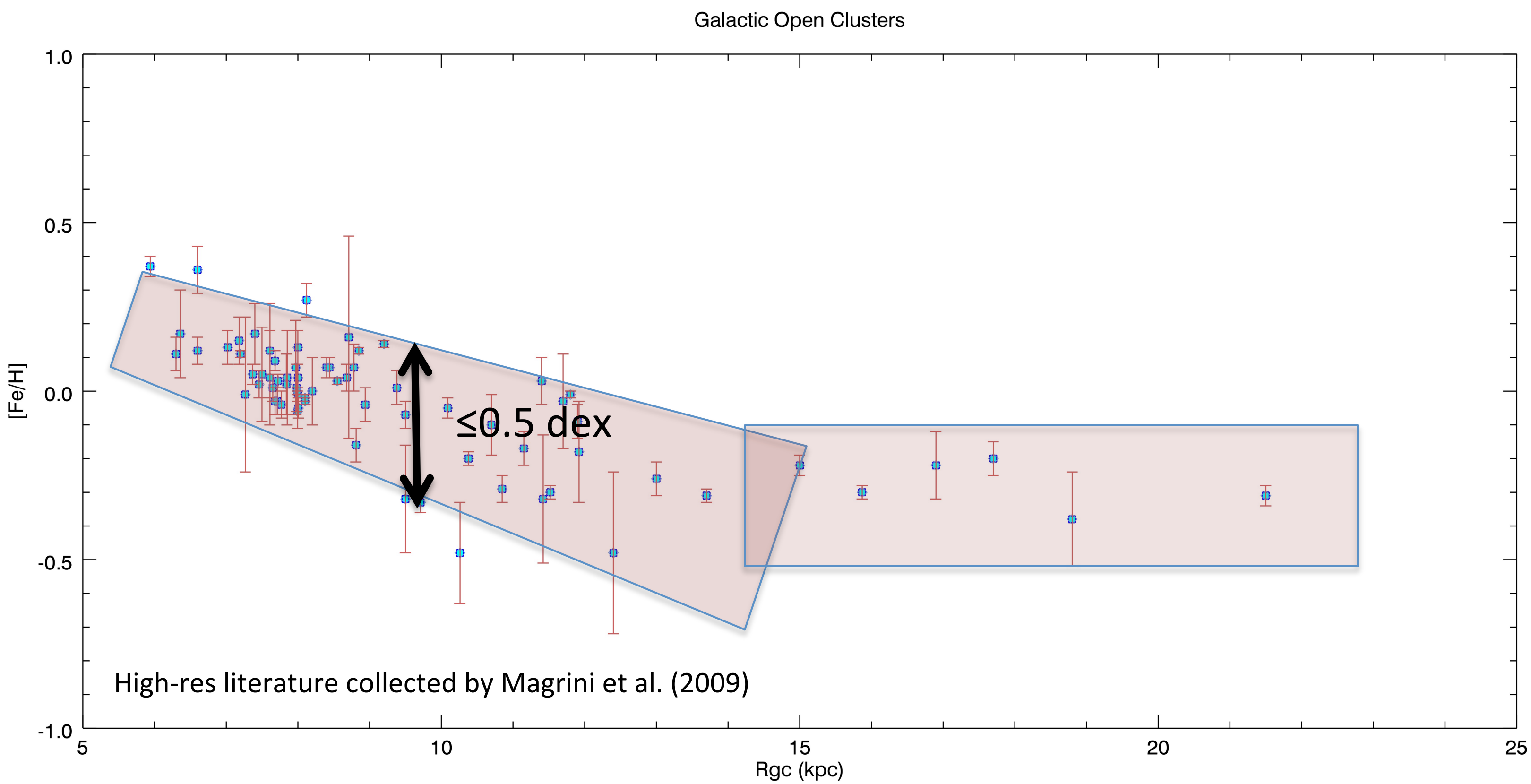

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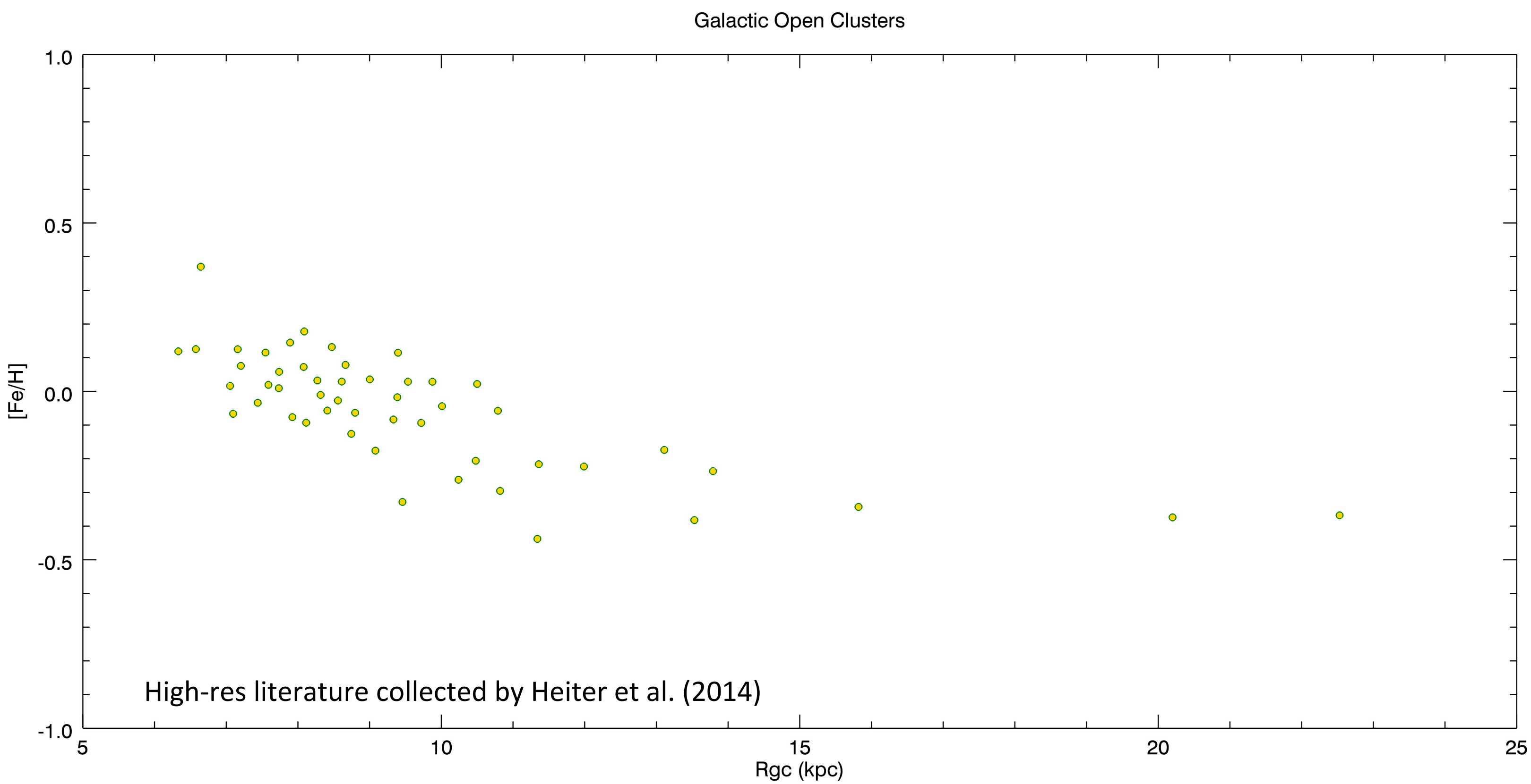

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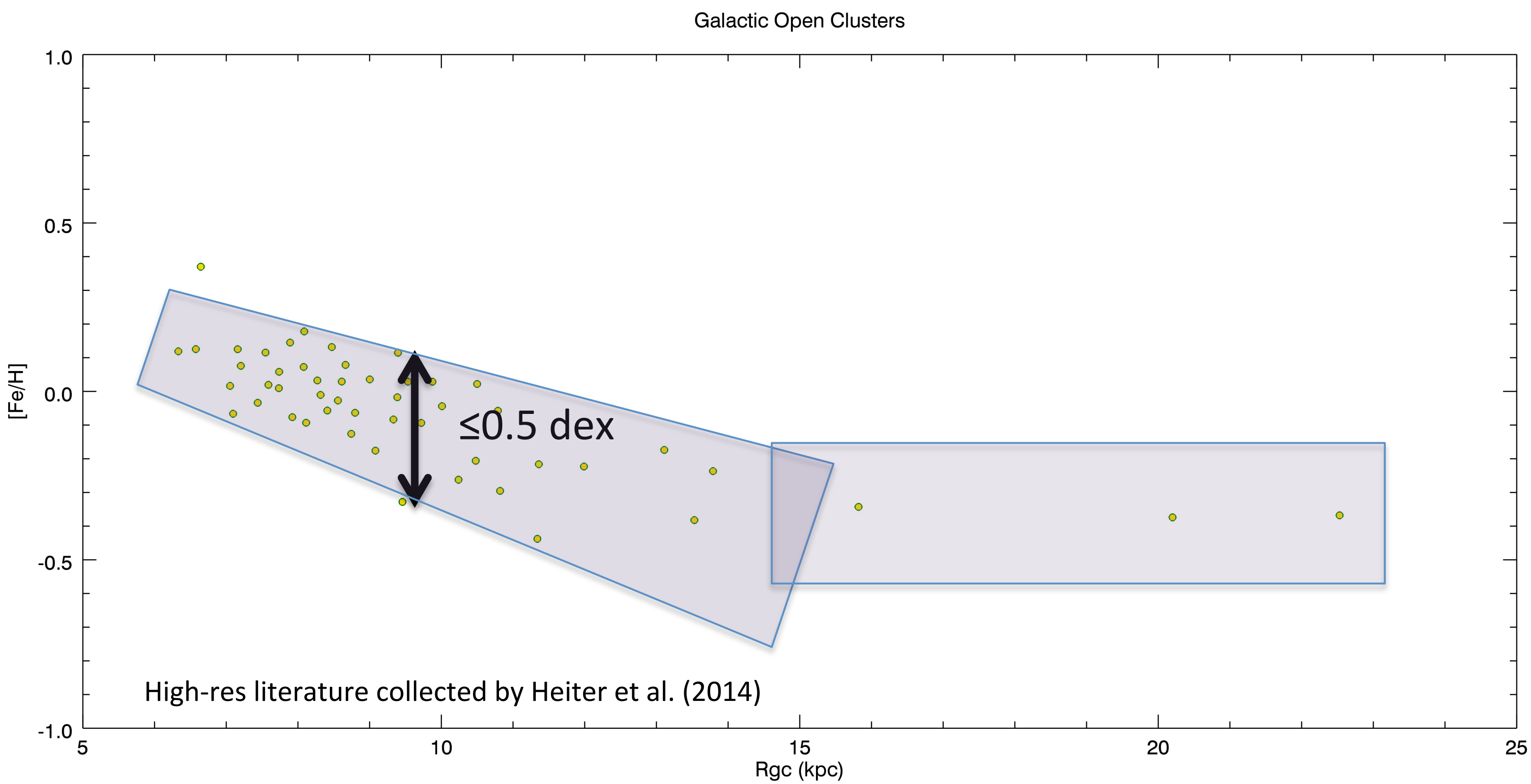
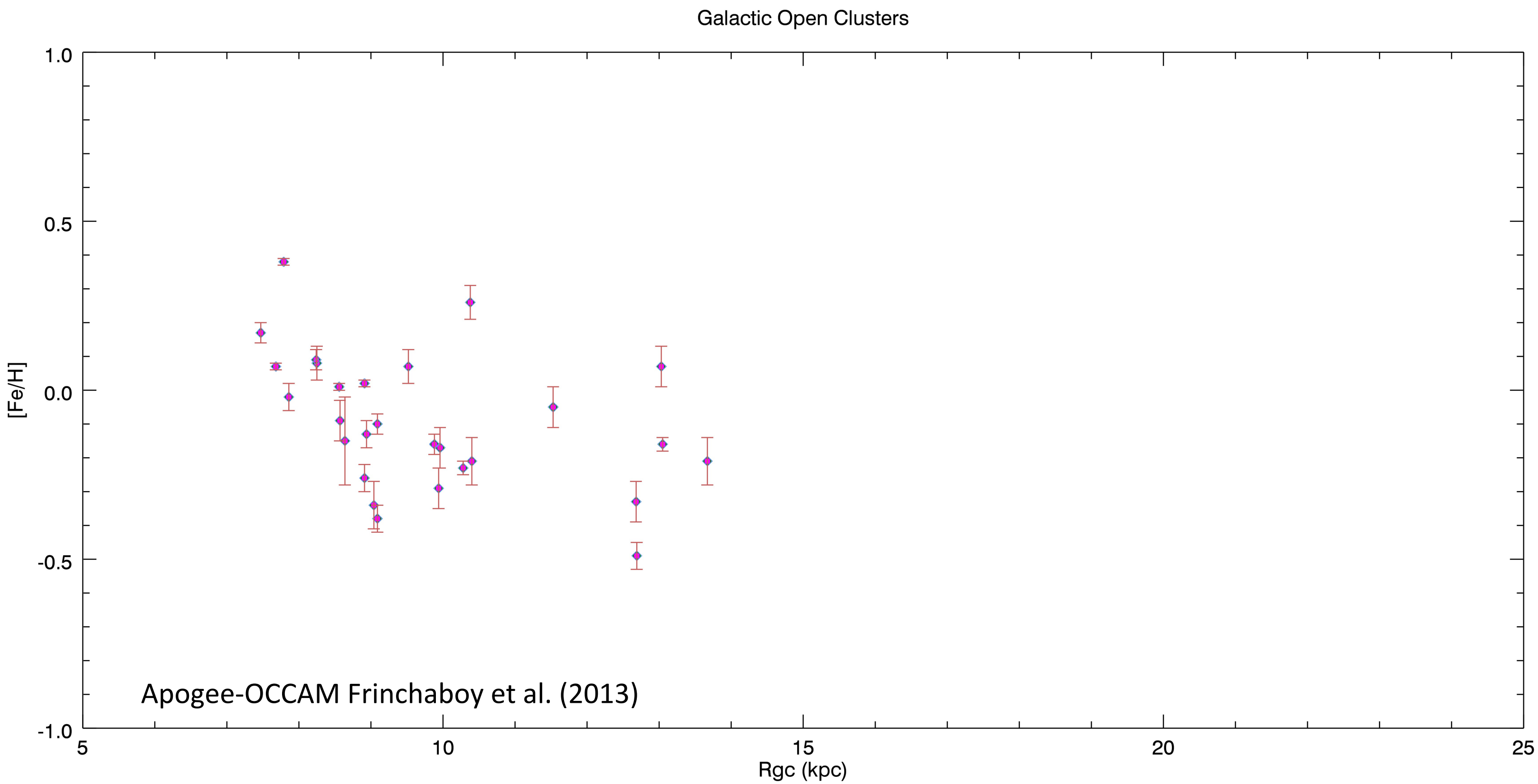


The gradient is well defined → high dispersion at each radii

→ Not homogeneous analysis, observations, etc.

The radial gradient: Literature vs. GES



High dispersion at each radii→ due to outlier clusters
Homogeneous analysis but not sure membership? Occam Apogee clusters have a median of only one member star with reliable [M/H] and [α/M].

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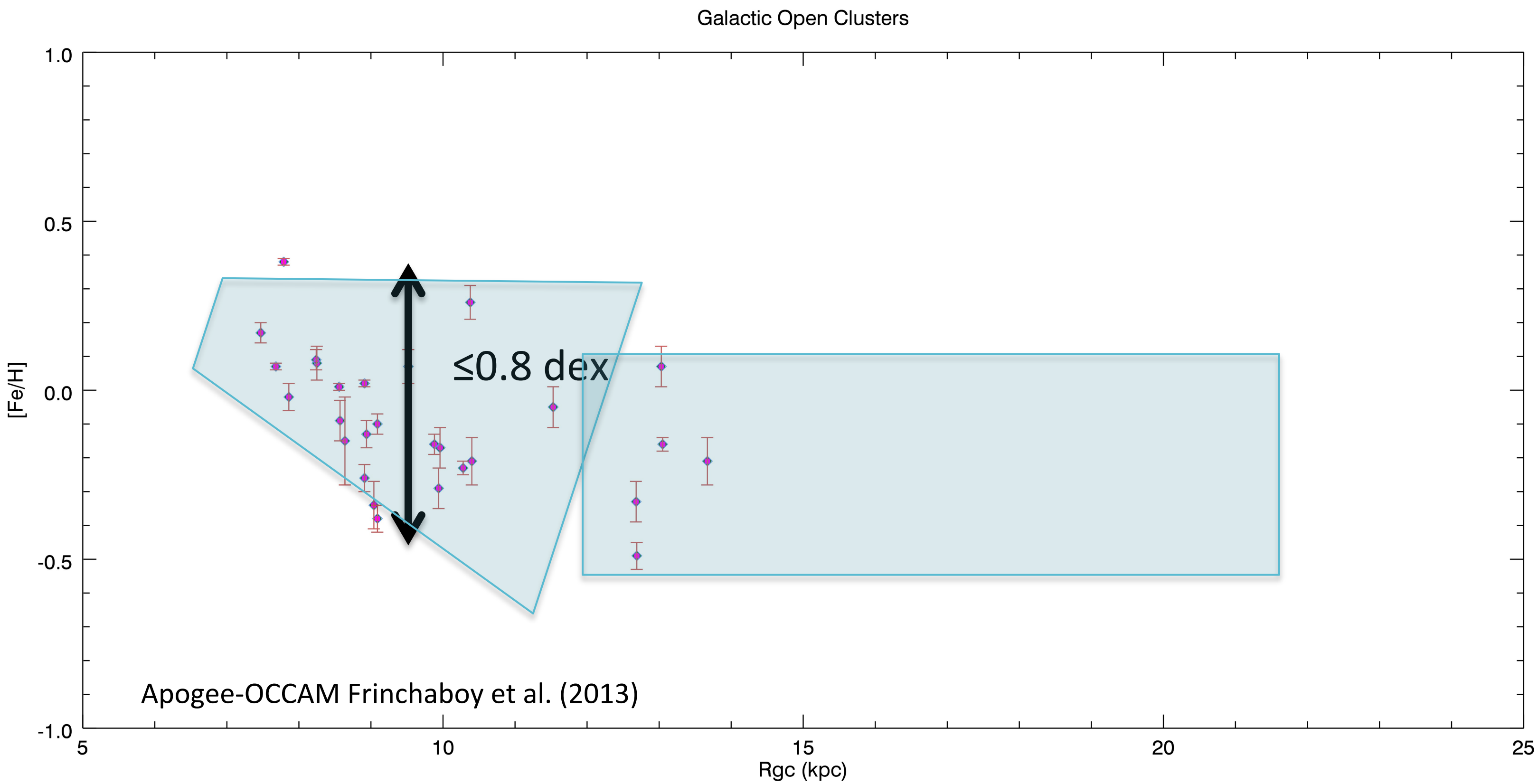

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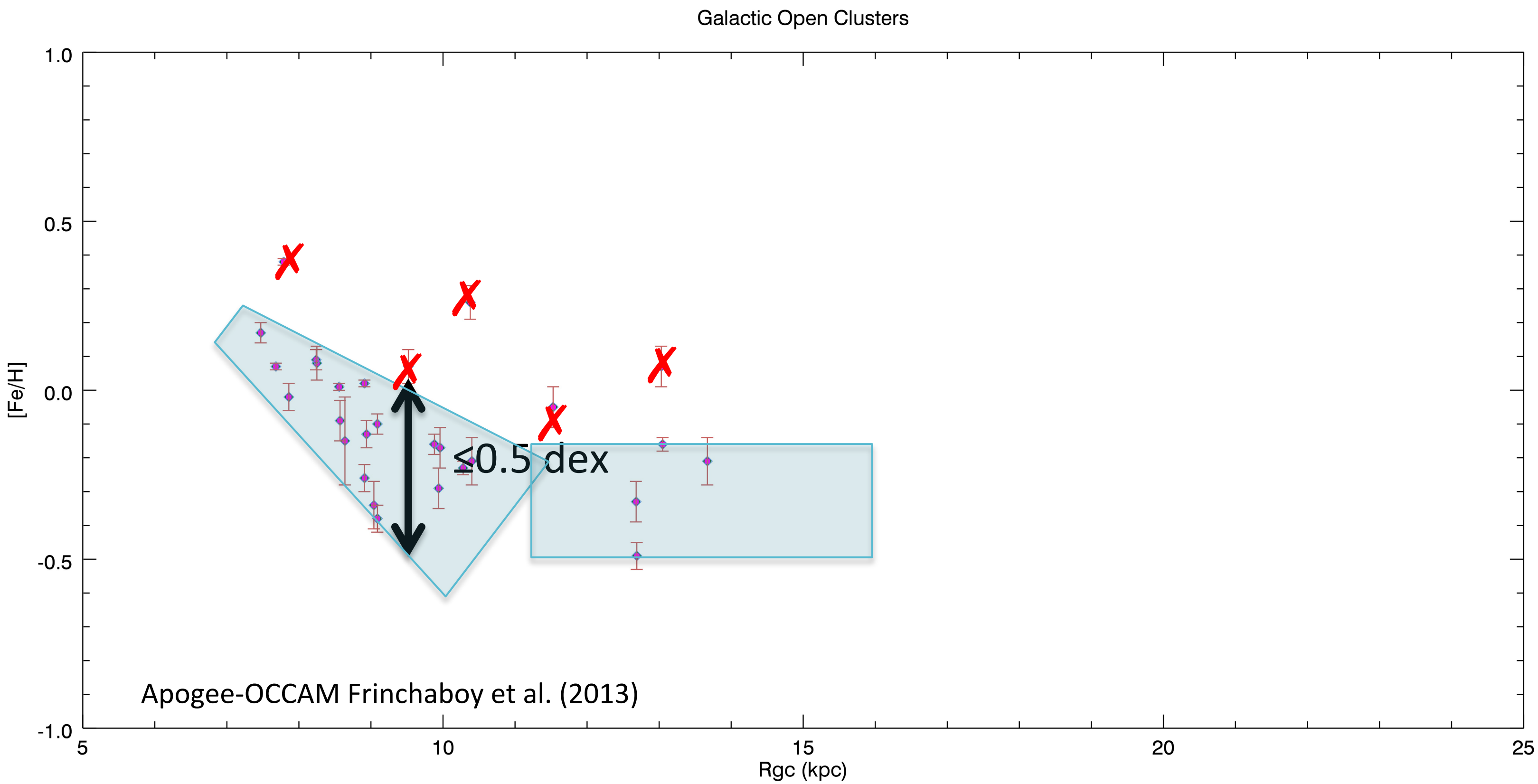

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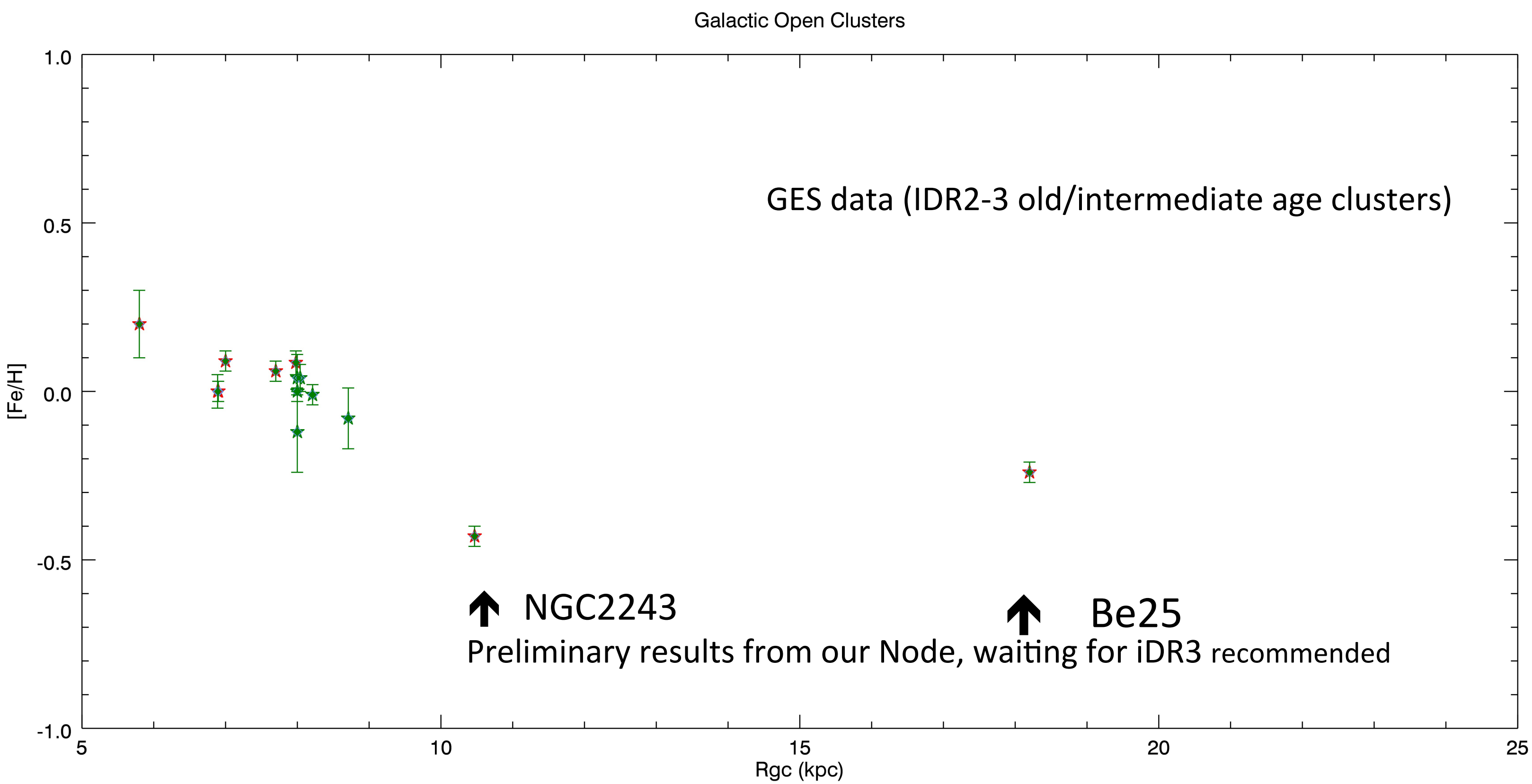

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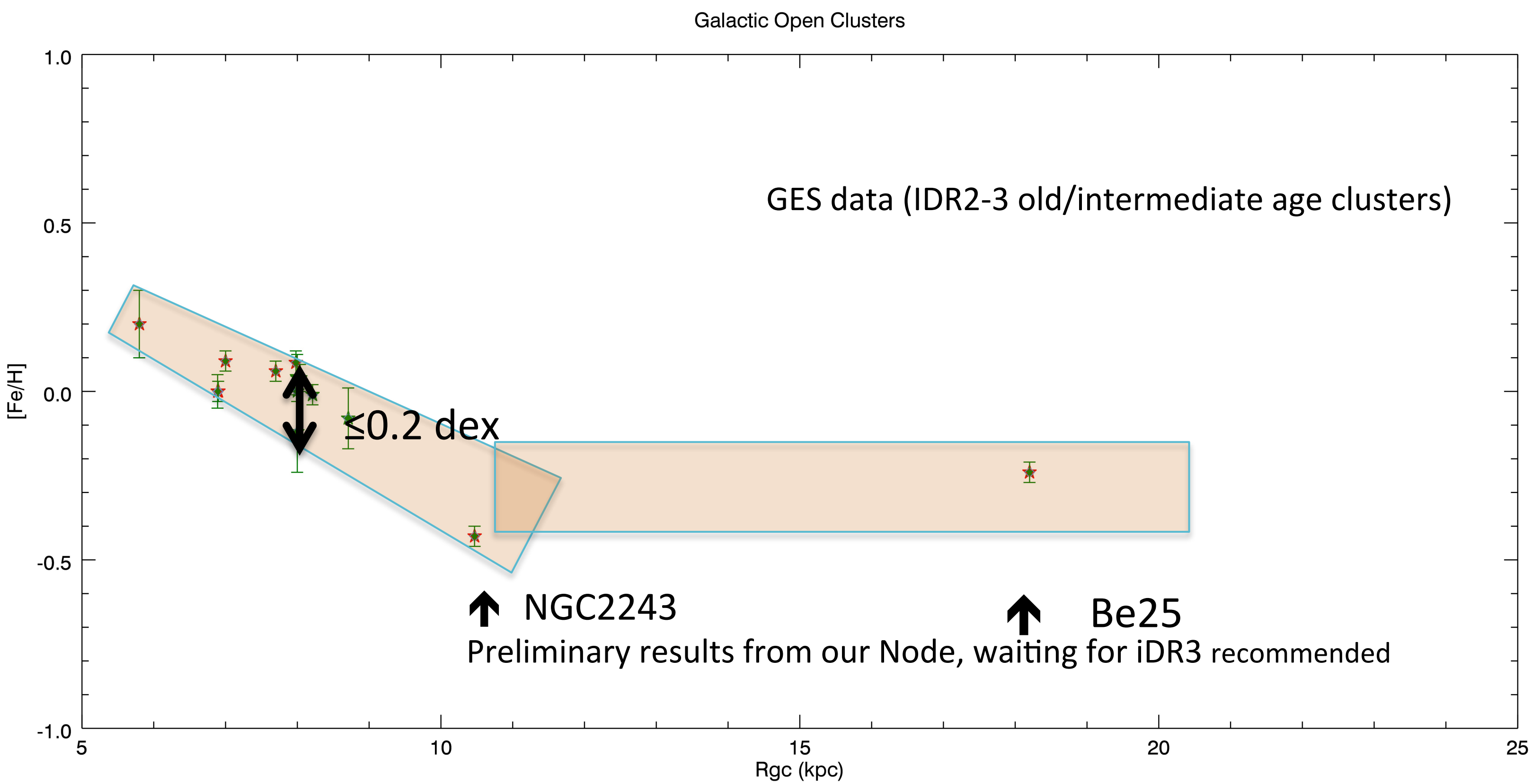

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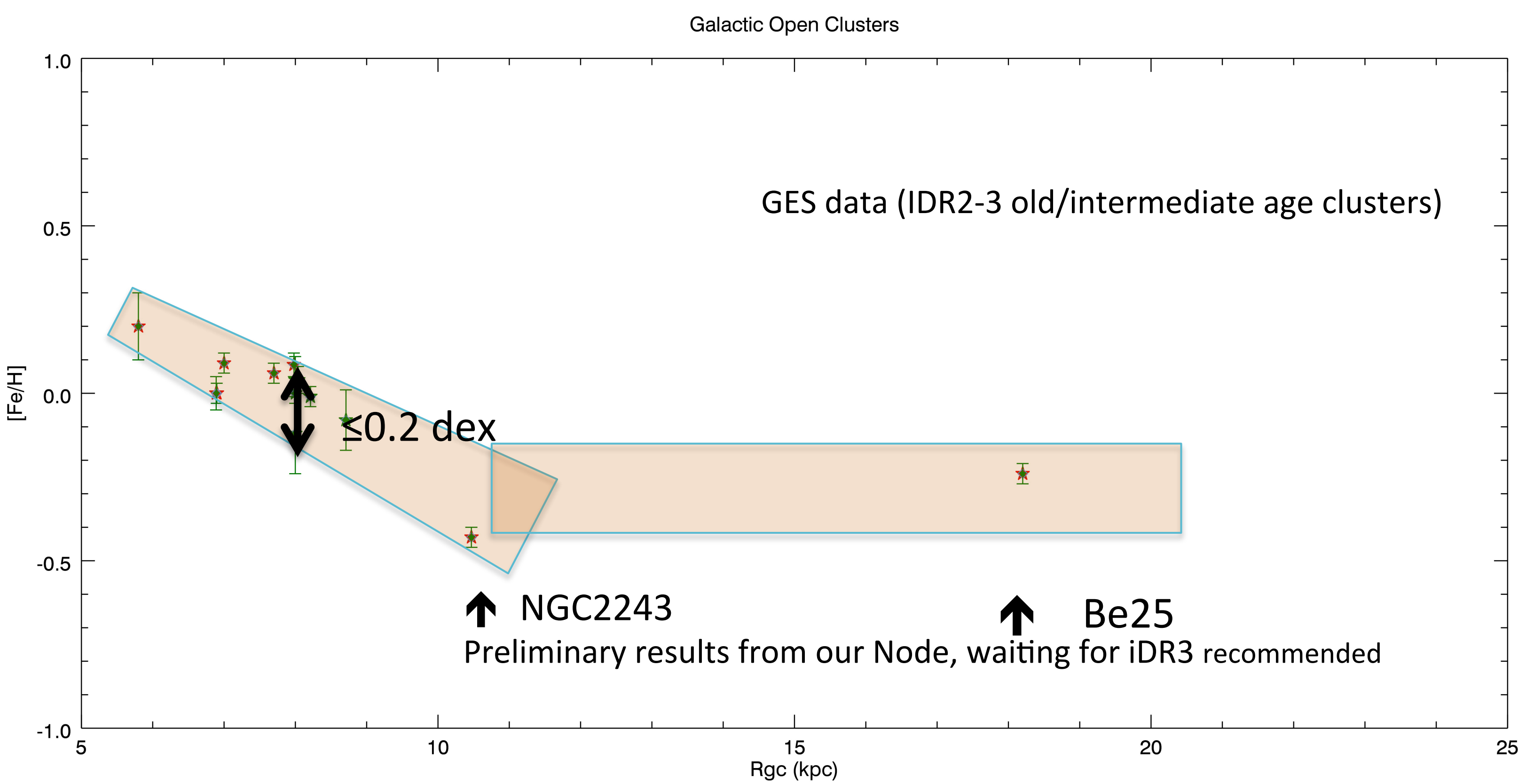
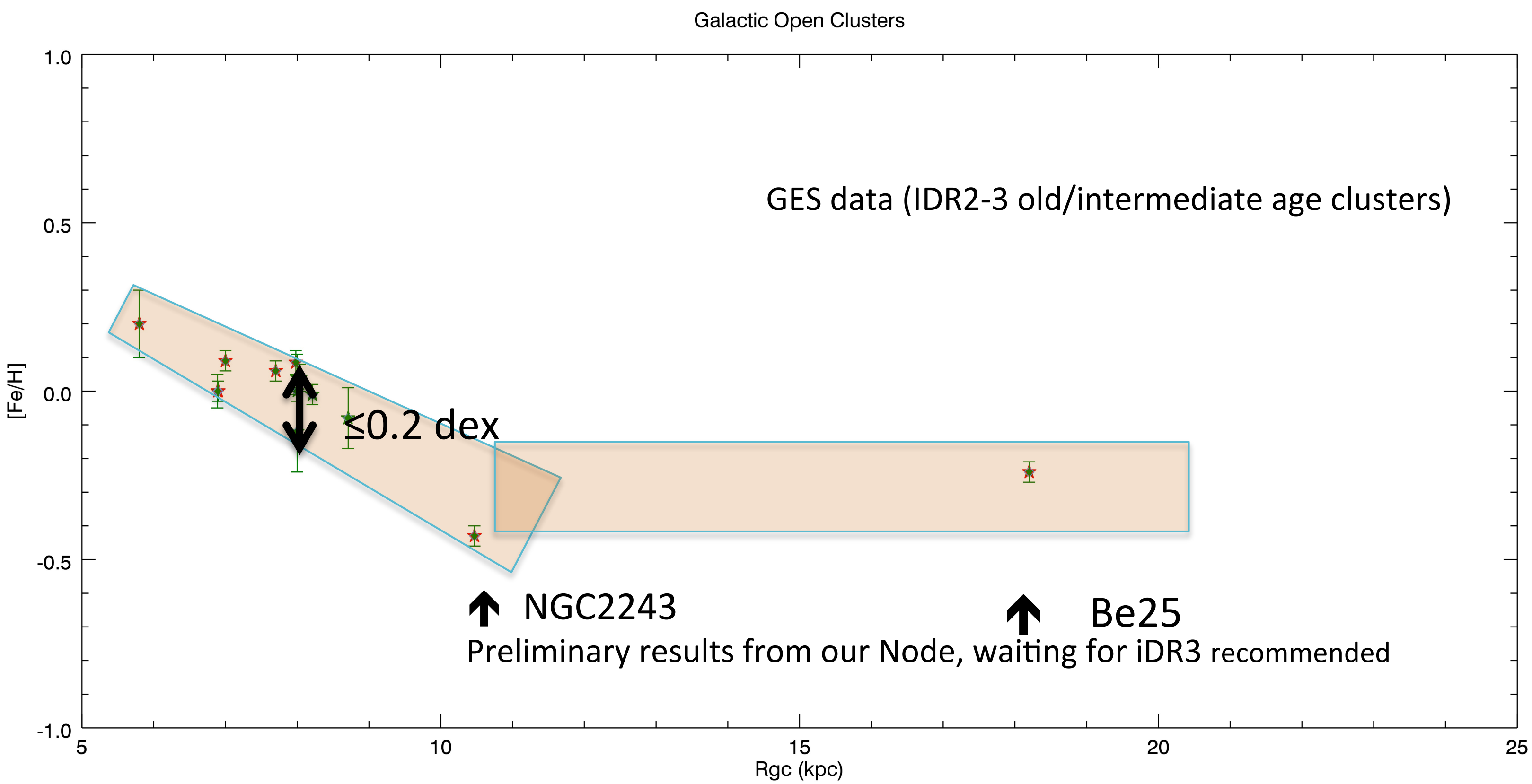


GES open clusters observed in the first 18 months:

- **Low dispersion at each Rgc**
- **Bi-modal shape confirmed**

Still low statistics but we are at the beginning…..and the **results are very promising**!

The radial gradient: Literature vs. GES



Too early for time-evolution studies…..but the GES sample is designed to be able to investigate it!

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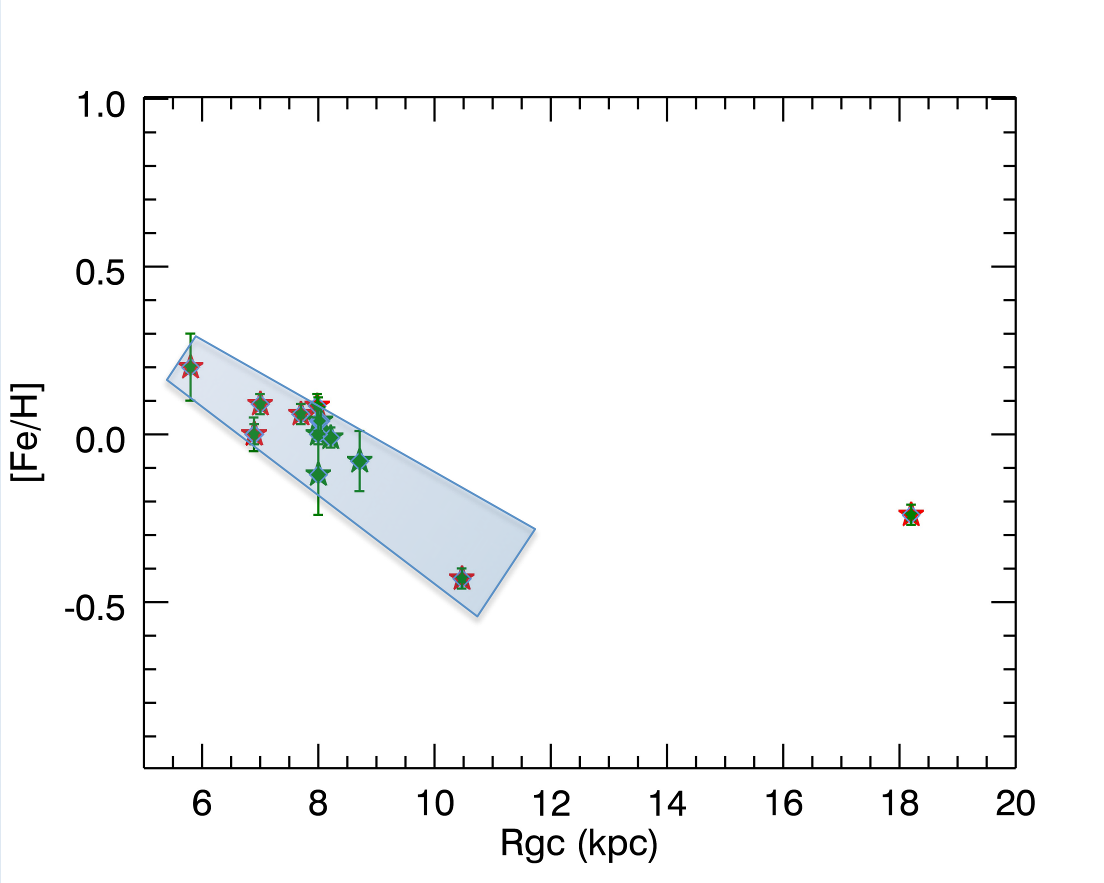

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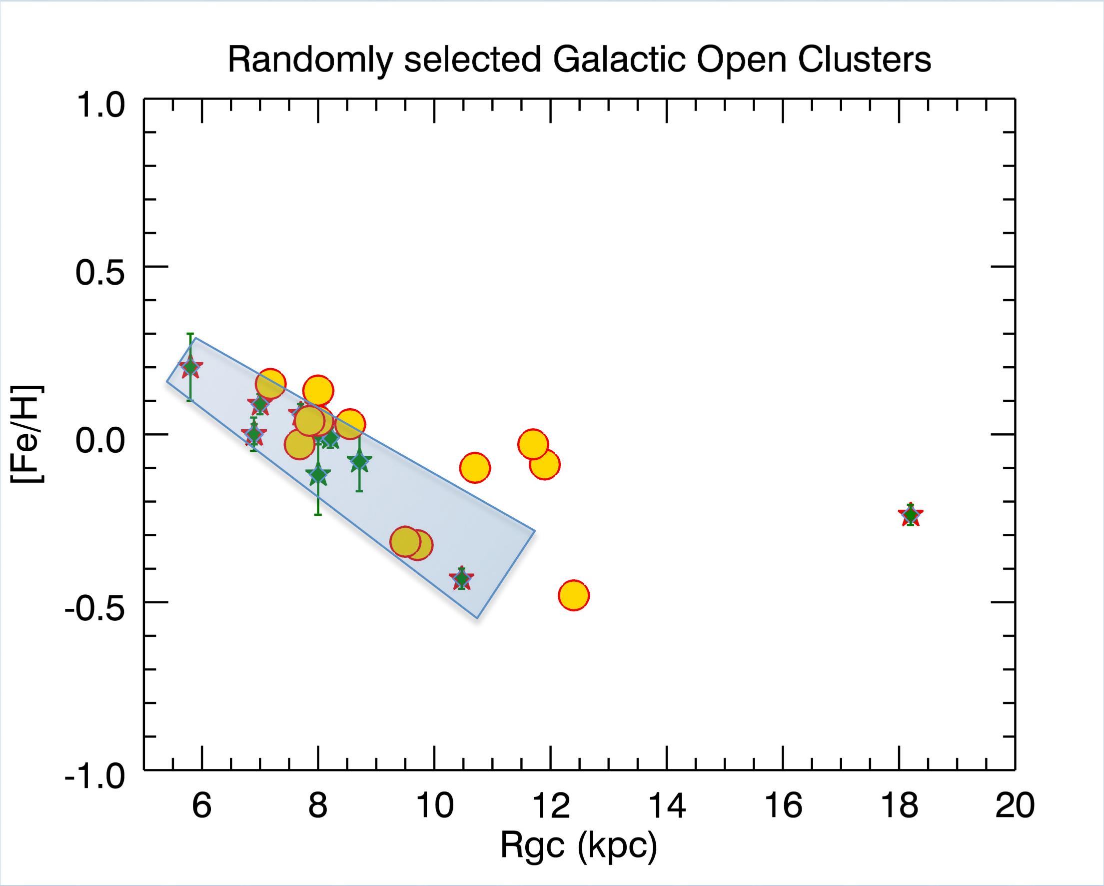

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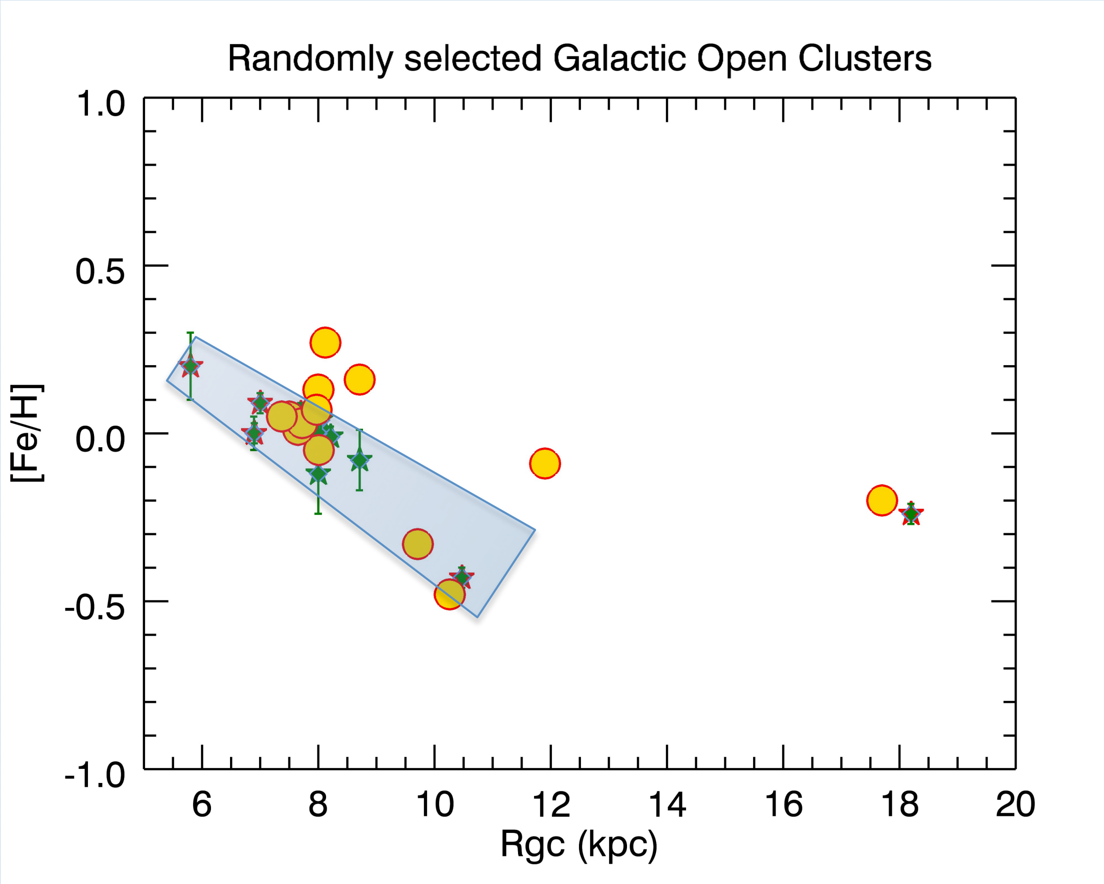

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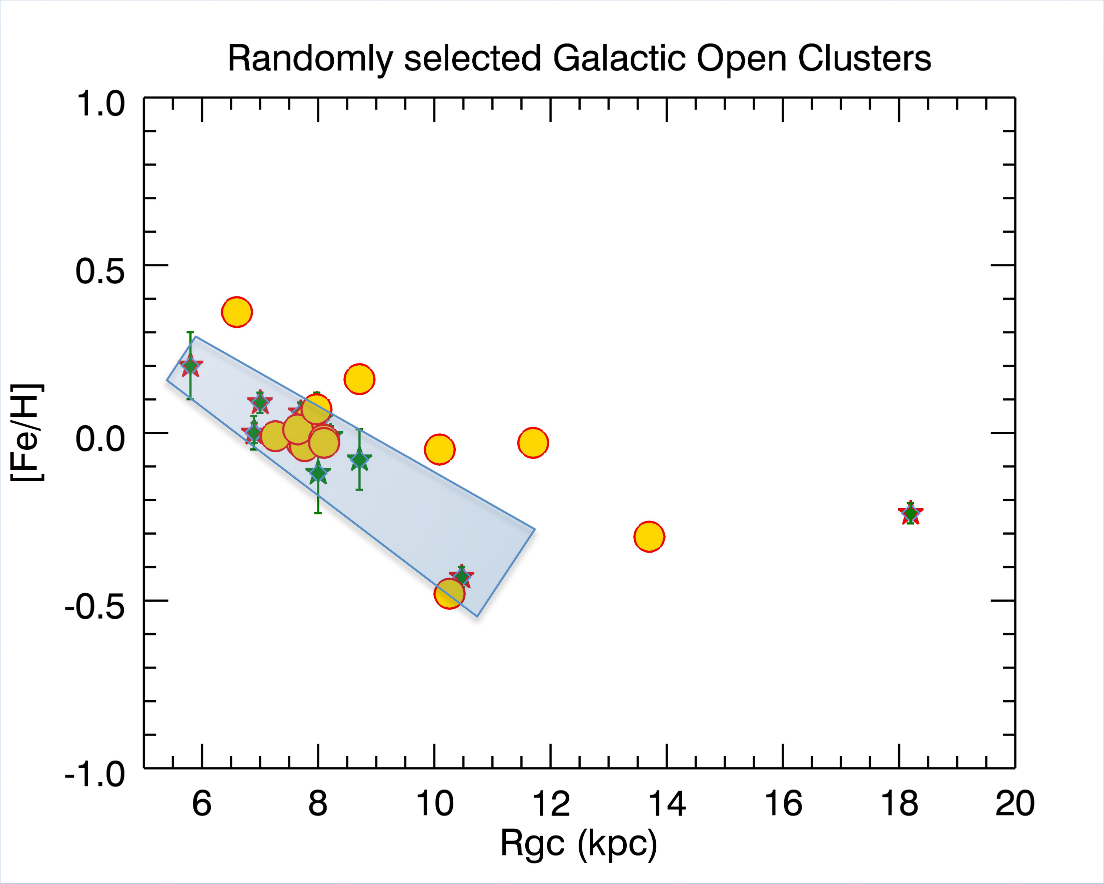

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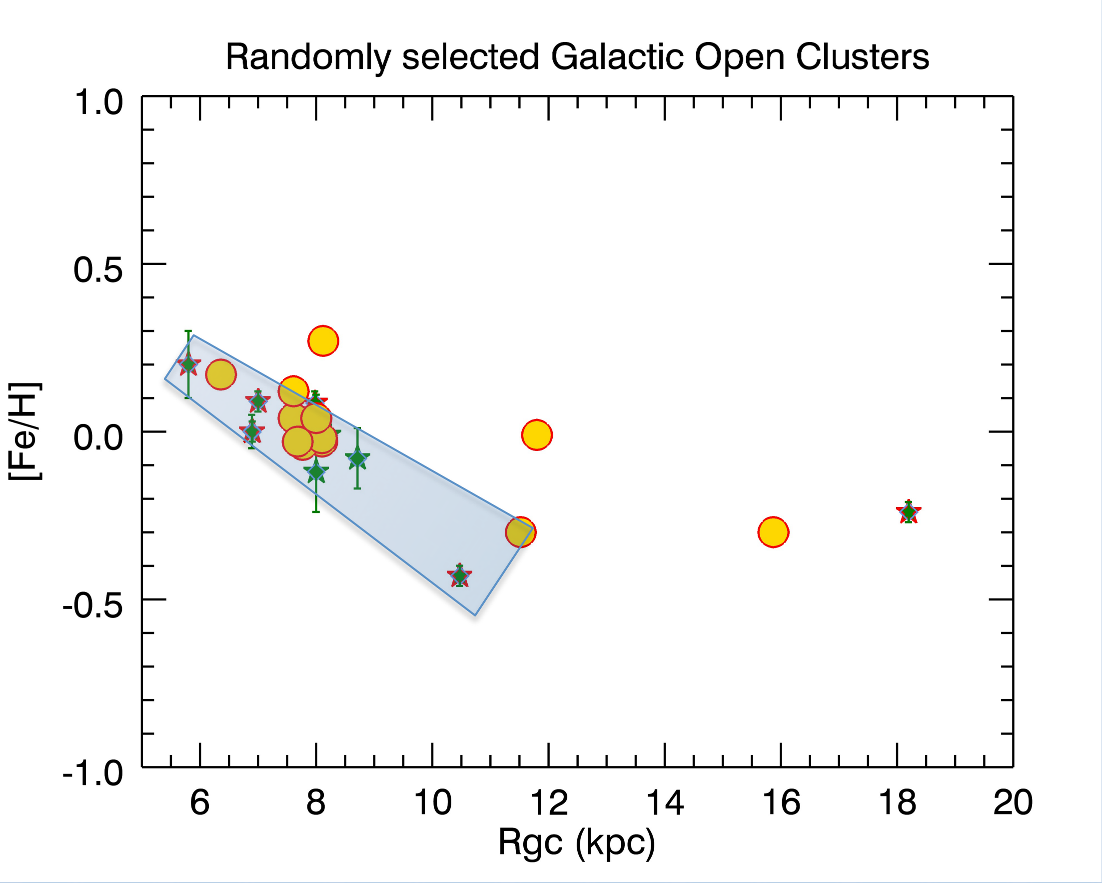

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Open clusters: not only iron!

Elemental abundances in open clusters:

- To study the temporal and spatial variation in the disk of elemental abundances belonging to different nucleo-synthesis channels, as for example [α/Fe] and neutron capture elements

- To investigate to stellar evolution process that affects the surface abundances, as mixing, as a function of cluster parameters (age, metallicity]

- To test the recovering of dispersed clusters via chemical tagging

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Sample of elements in GES iDR2

Element	Main Production Site	mechanism	yield(SNIa/SNII)
^{16}O	Massive Stars	Helium burning	8%
^{23}Na	Massive Stars	C, Ne, H burnings	1%
^{24}Mg	Massive Stars	C, Ne burnings	10%
^{27}Al	Massive Stars	C, Ne burnings	7%
^{28}Si	Massive Stars	explosive and non-explosive O burning	60%
^{40}Ca	Massive Stars	explosive and non-explosive O burning	67%
^{45}Sc	Massive Stars	C, Ne burnings, α and ν-wind (neutrino-powered wind)	49%
^{48}Ti	Massive Stars and SNIa	explosive Si burning and SNIa with He detonation	63%
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^{63}Cu	Massive Stars	He-burning s-process, C and Ne burning	73%
^{64}Zn	Massive Stars	He-burning s-process, α and ν-wind	51%
^{50}Y	Massive Stars	He-burning s-process, and ν-wind	–
^{90}Zr	Massive Stars	He-burning s-process	–
^{138}Ba	Low mass	s-process	–
^{153}Eu	Massive Stars	ν-wind	–

Open clusters: not only iron!

Sample of elements in GES iDR2

ELEMENT	MAIN PRODUCTION SITE	MECHANISM	YIELD(SNIA/SNII)
^{16}O	Massive Stars	Helium burning	8%
^{23}Na	Massive Stars	C, Ne, H burnings	1%
^{24}Mg	Massive Stars	C, Ne burnings	10%
^{27}Al	Massive Stars	C, Ne burnings	7%
^{28}Si	Massive Stars	explosive and non-explosive O burning	60%
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Chemical tagging:

how unique is the chemical pattern of each cluster?

The aims **of chemical tagging:**
understand the patters of open clusters to find dispersed clusters

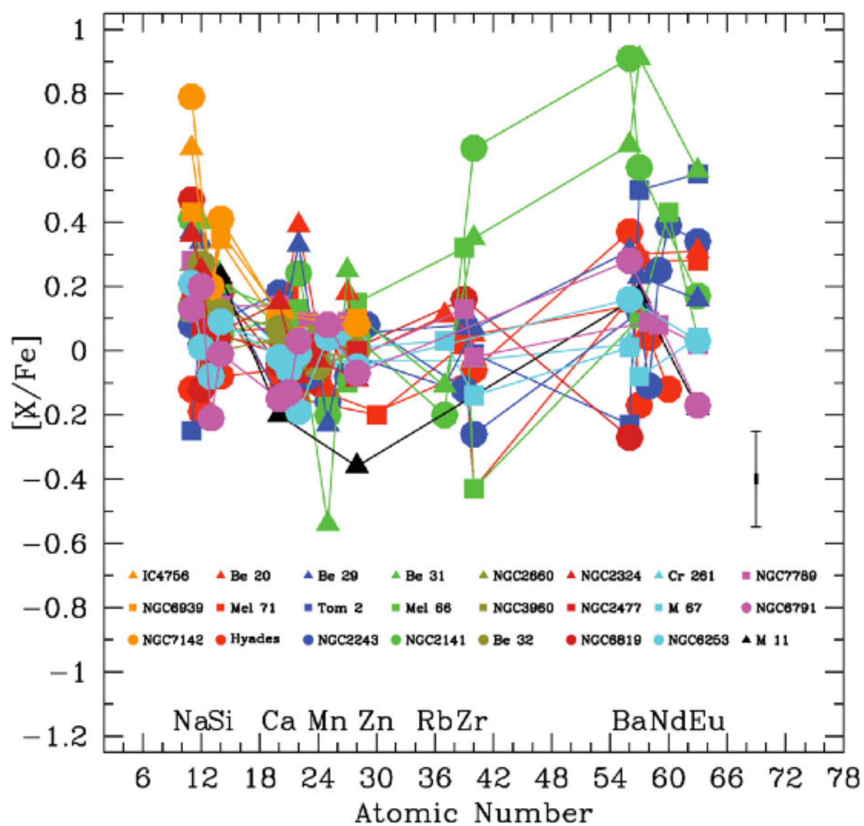


Figure 1. Elemental abundances of old open clusters. Each symbol represents the mean abundance value for individual clusters. The error bars show the typical measurement error. Original references of the cluster data are given in Table 1.

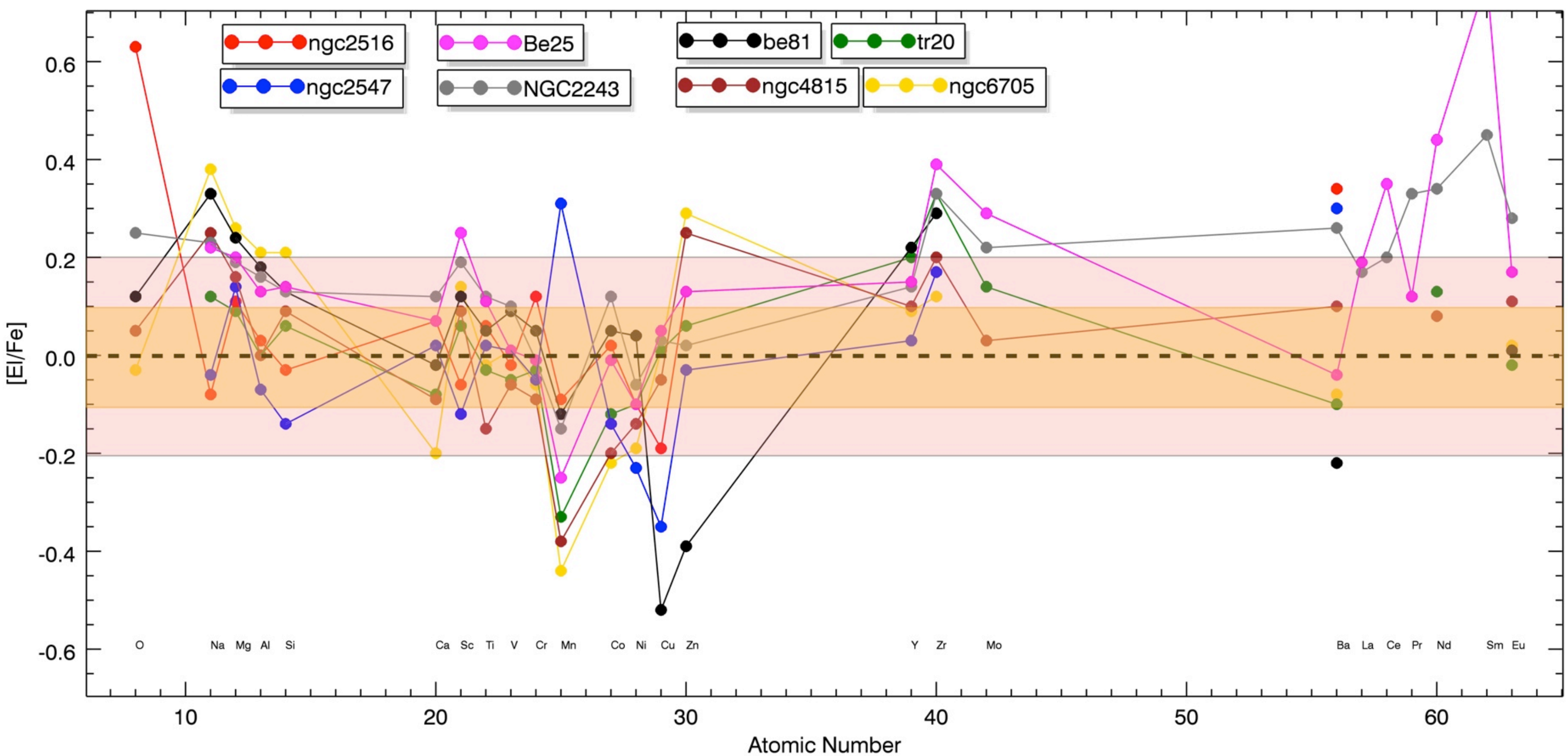
Da Silva+09, Blanco-Cuaresma +14:

- Use open clusters to check our ability to re-construct ancient star-forming aggregates of the Galactic disk, assuming such systems existed from an hierarchical aggregation formation scenario

Chemical tagging:

how unique is the chemical pattern of each cluster?

The aim here: understand common trend in clusters having similar properties (age, distance, [Fe/H]) to understand the Galactic chemical evolution



Different clusters have different elemental abundance patterns.
There is also significant scatter for many of the elements:

- systematic uncertainties in elements with few lines
- intrinsic variations, especially in elements showing excessive scatter

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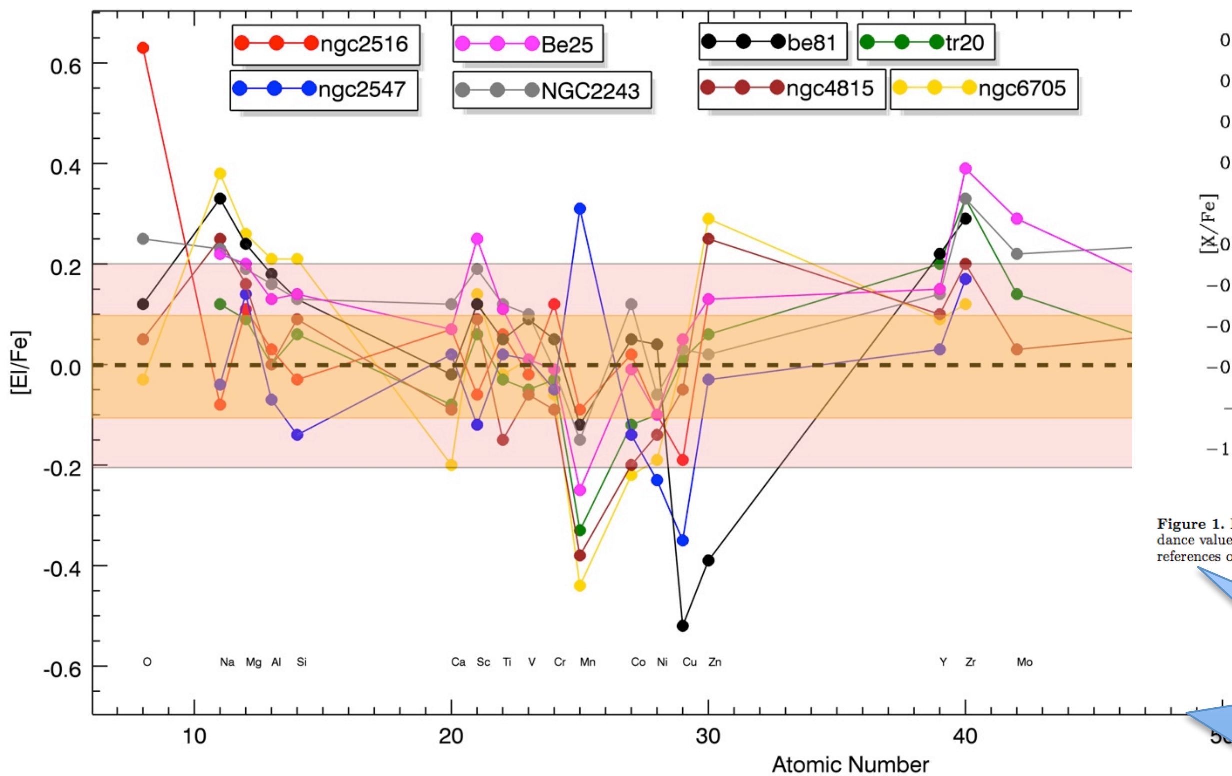

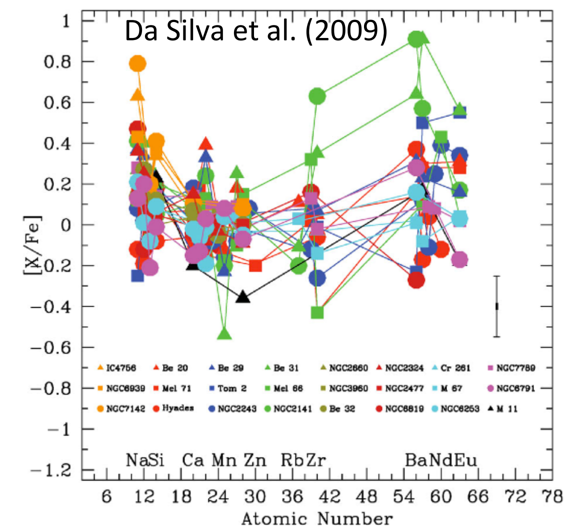

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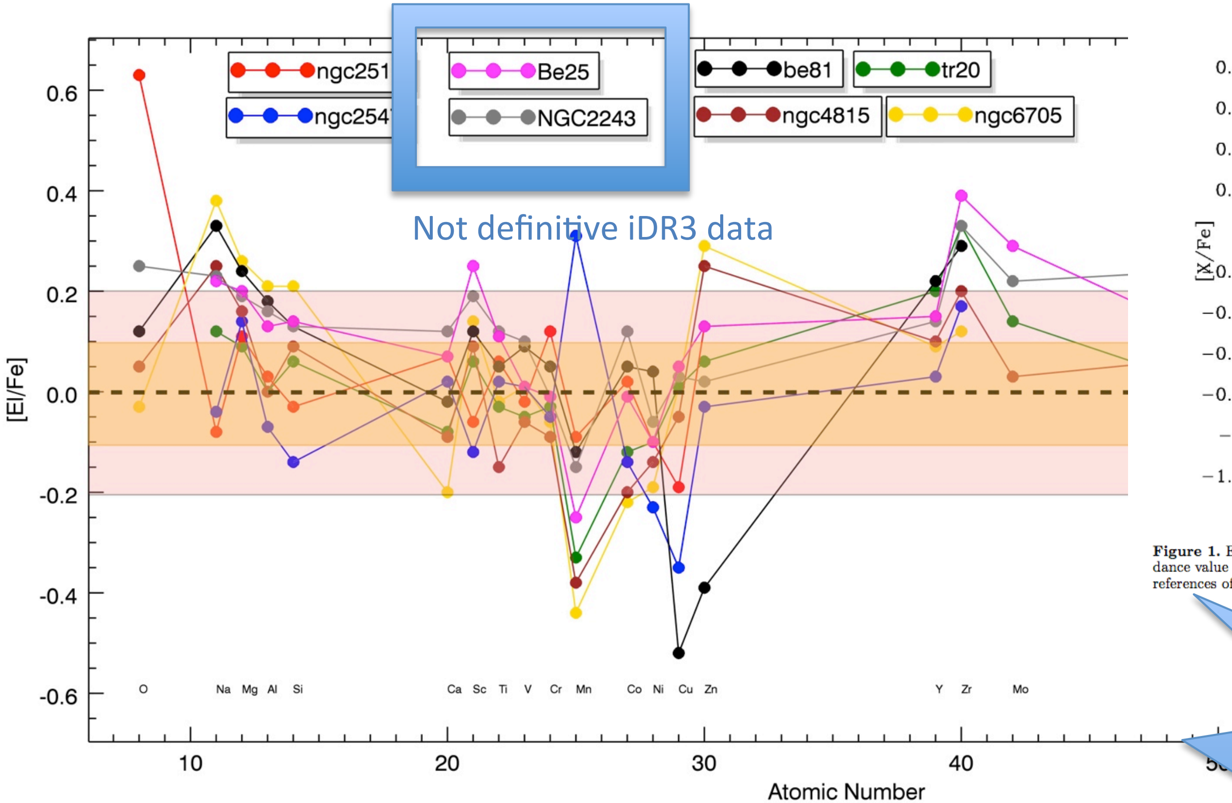

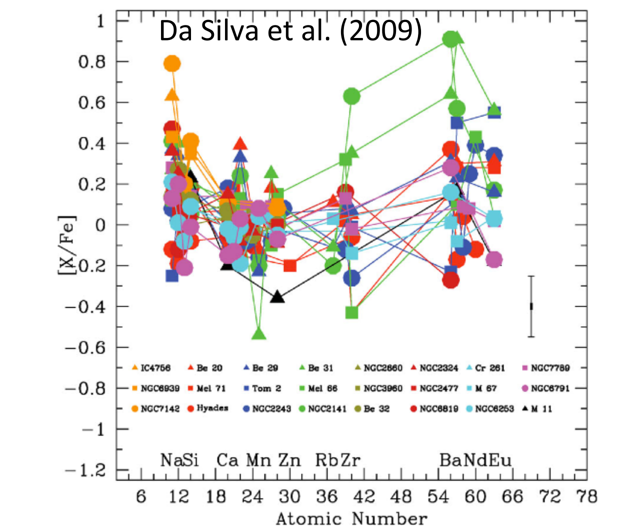

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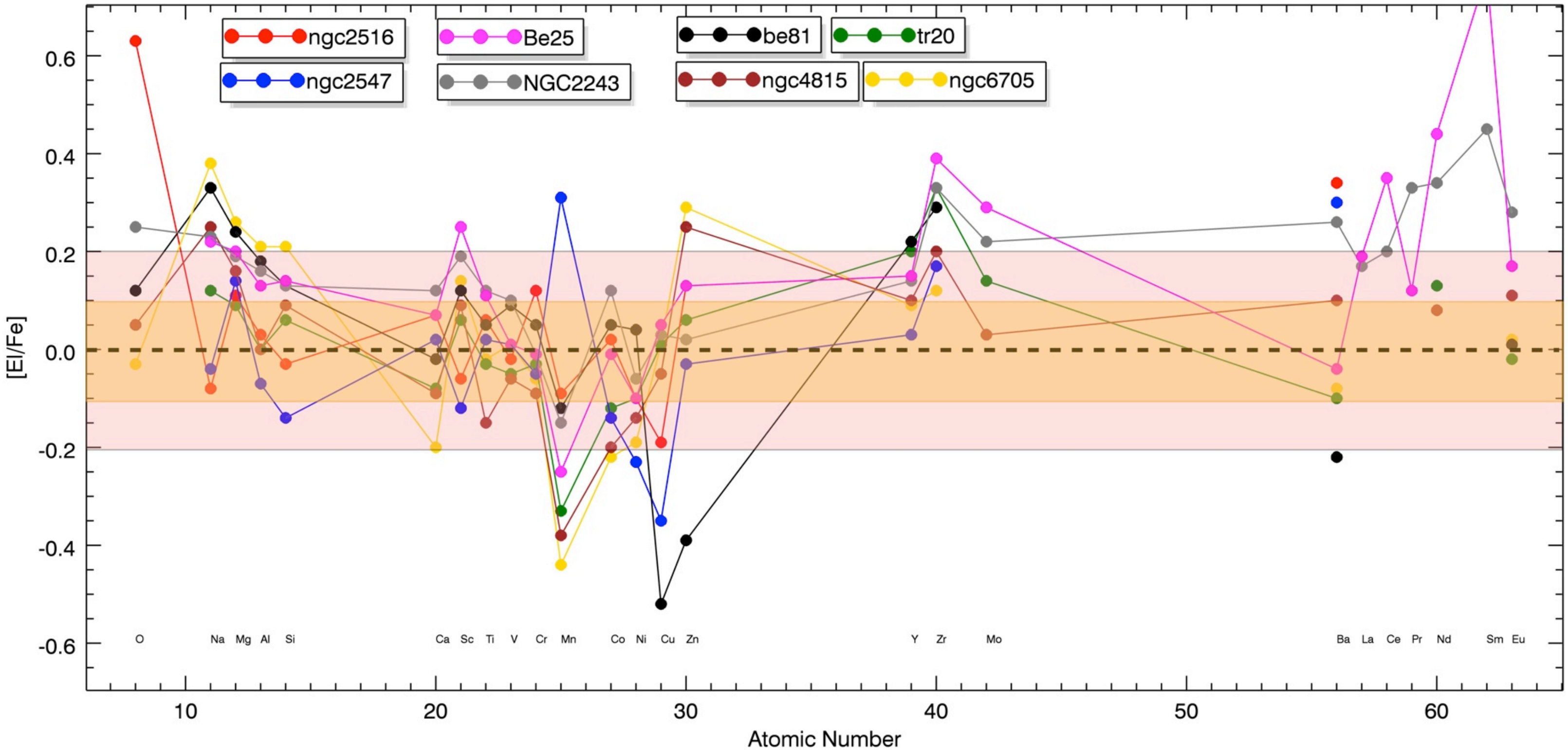
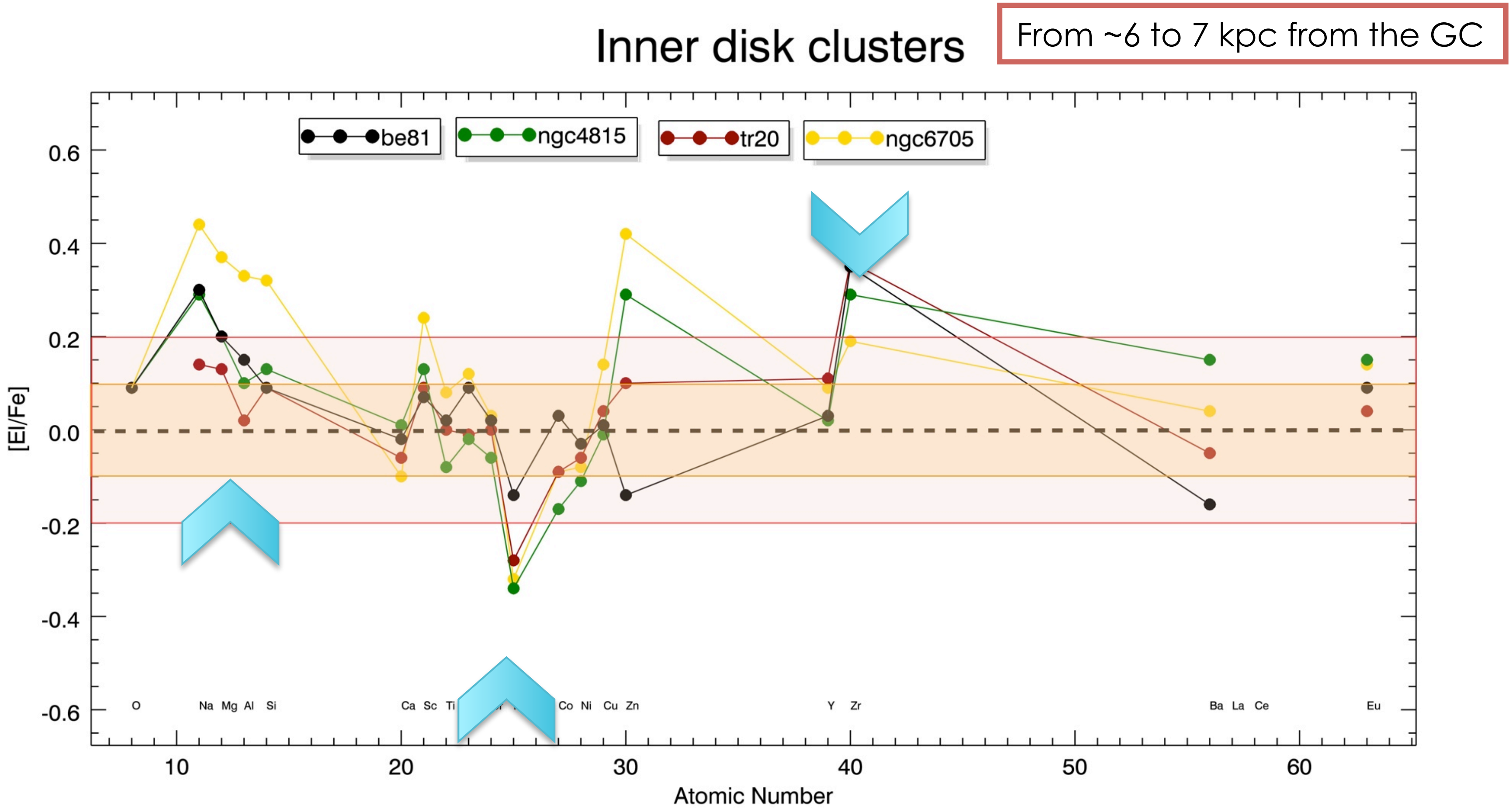
Chemical tagging:

a simple exercise with GES data



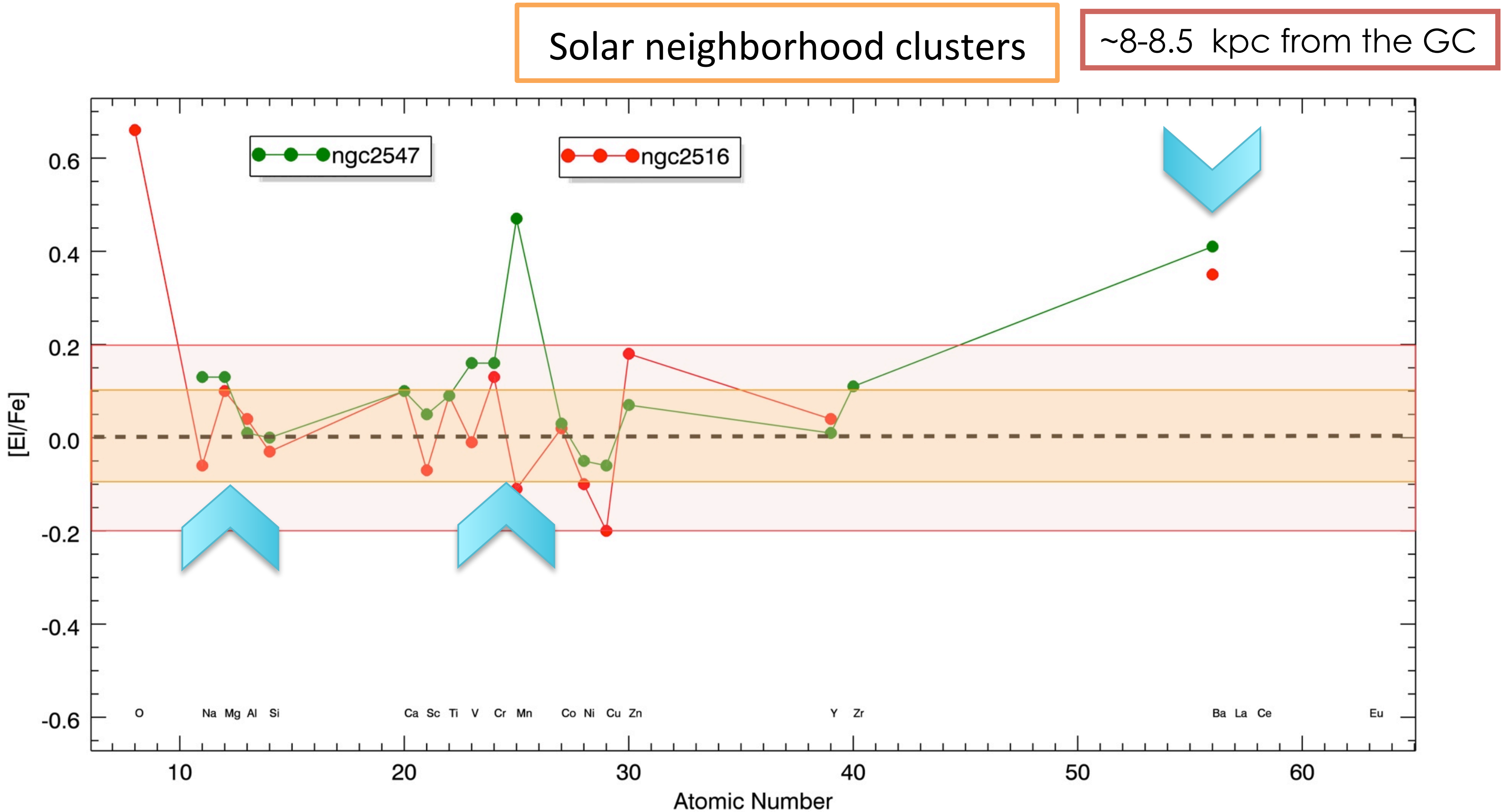
- Try to divide the cluster in bins of Galactocentric distances

Chemical tagging



- Inner disk clusters: common trends in some abundance ratios
- Enhanced Mg and Si, depleted Mn, enhanced 1-peak neutron capture elements

Chemical tagging

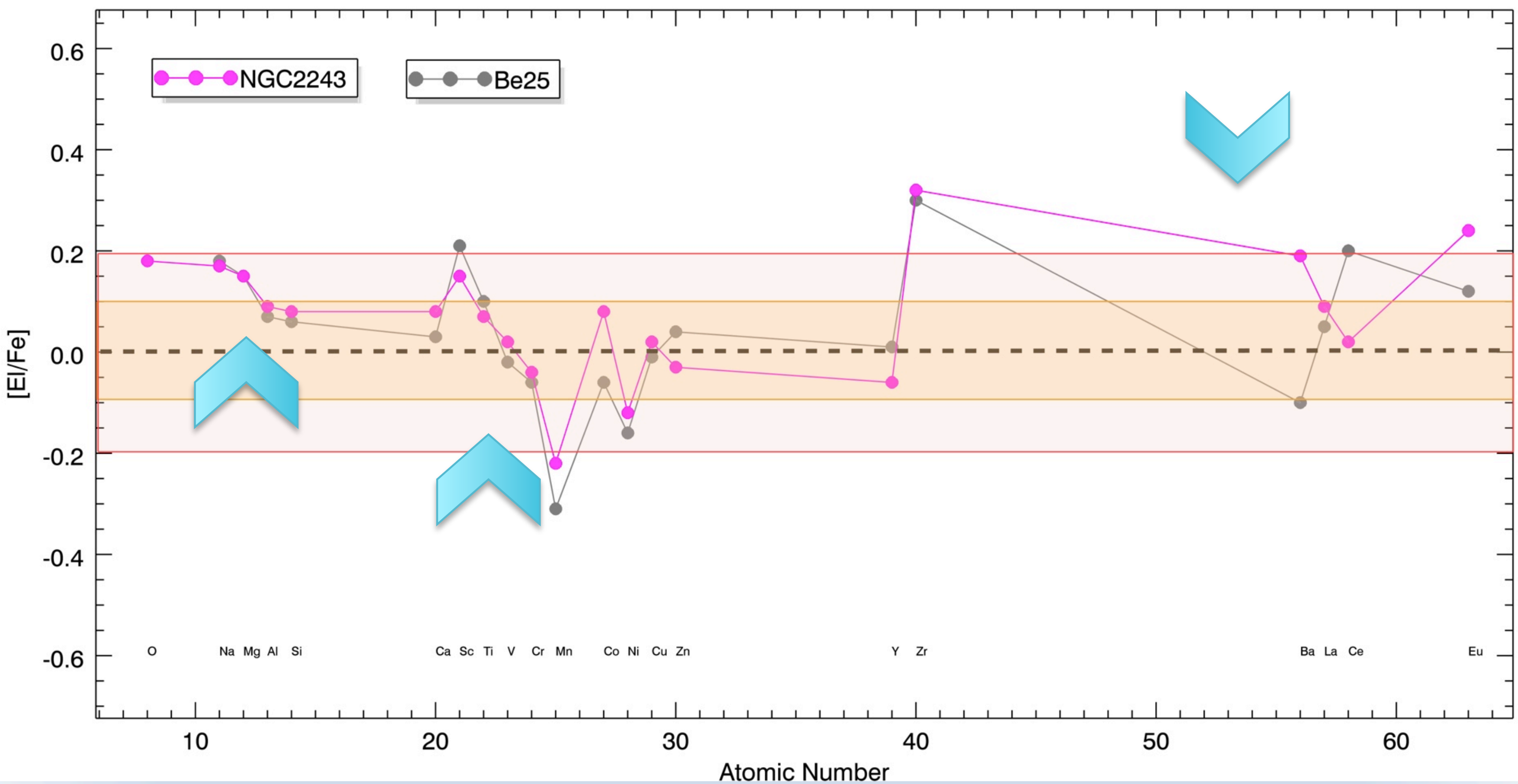


- Solar neighborhood clusters: almost solar in all elements
- Enhanced Ba: Age effect (see D'Orazi et al. (2009), Maiorca et al. 2012)

Chemical tagging

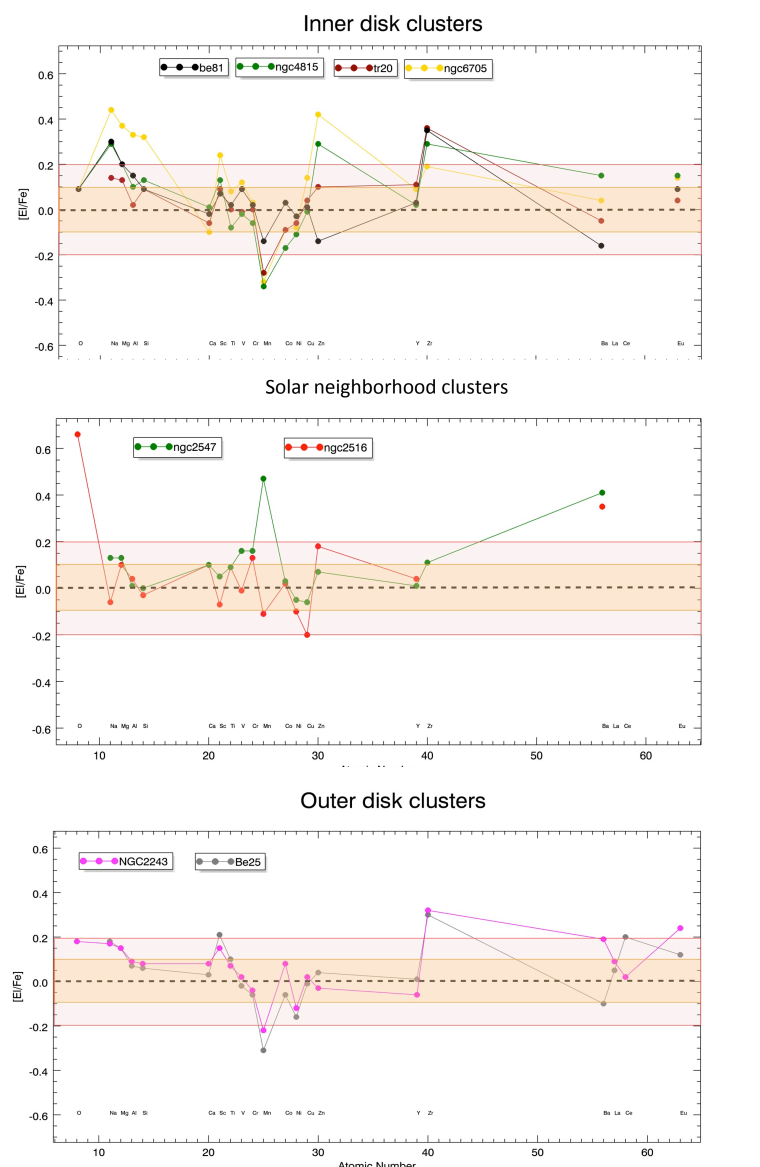
Outer disk clusters

From ~12 to 17 kpc from the GC



- Outer disk clusters: common trends in **many** abundance ratios
- More dispersion in heavy elements (2-peak s-elements, and r-elements)

Chemical tagging: with iDR2/3

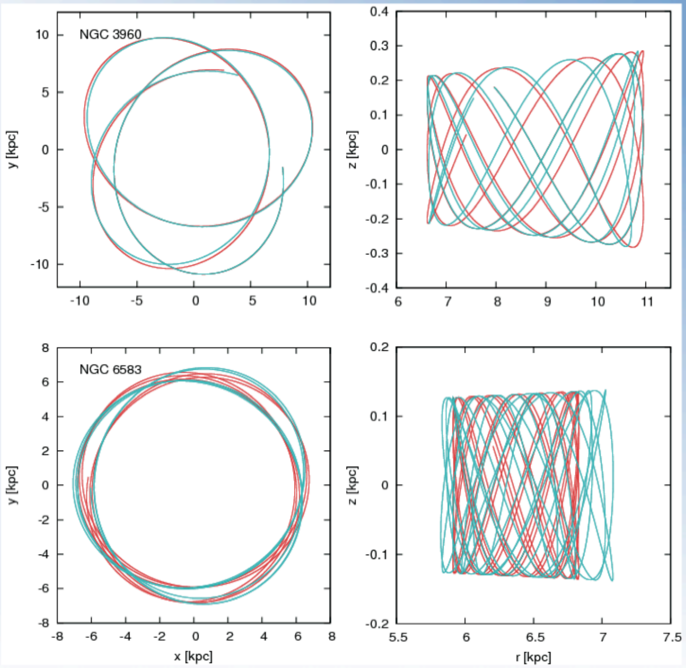


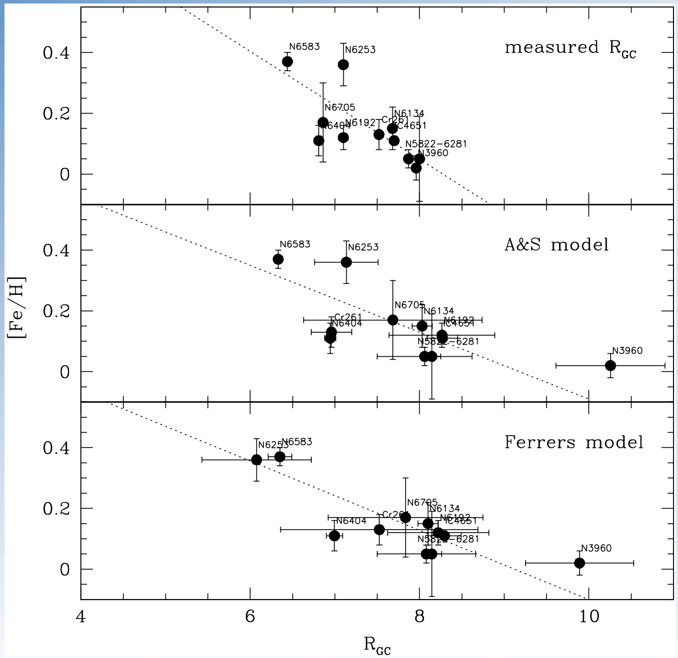
With the larger sample of iDR2/3 we are in the position:

- To compare clusters belonging to different part of the disk
- To search for common behaviors/patterns that might be indicative and tracers of the disk evolution at different radii (as the two outer clusters, extremely similar in almost all elements)

What more with GAIA?

- More accurate distances to be compared with the isochrones fitting
- ..and orbits (proper motion + radial velocities)!





Conclusions:

Open clusters are valuable tools to understand the evolution of the Galactic disk:

- Drawing the shape of the gradient and its temporal evolution
- Preparing for future chemical tagging missions of the disk
- Allowing to disentangle the evolution of different parts of the disk with their complex chemical patters
- And with Gaia:
  - More accurate distances
  - Associating clusters to their birthplace with accurate orbits and ages