Open clusters: tracers of the Galactic disk history

Laura Magrini
INAF-Osservatorio di Arcetri

GES 2014
Gaia-ESO Survey Second Science Meeting

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

Why the disk:

- 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 resolved 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

Open questions in galaxy formation and evolution:

- 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

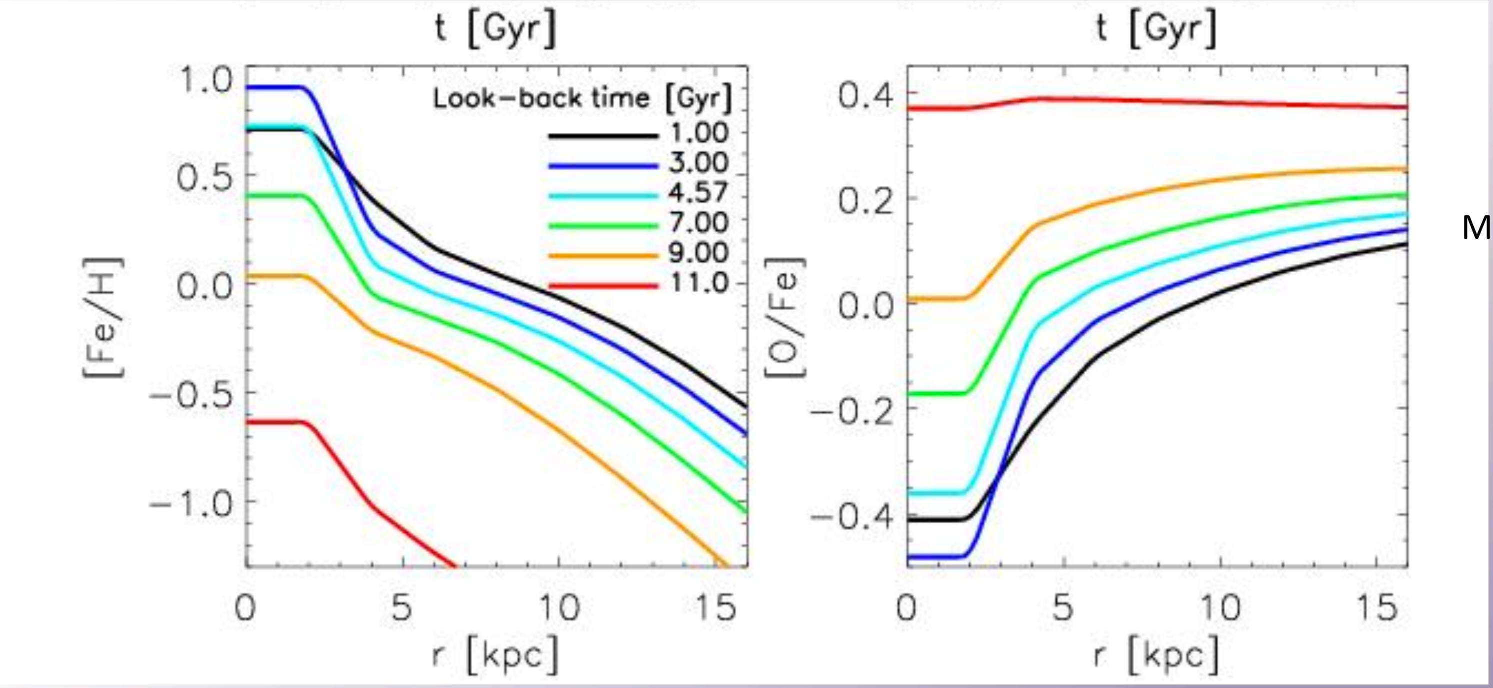
A new era for models of galaxy formation and evolution, including:

- 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

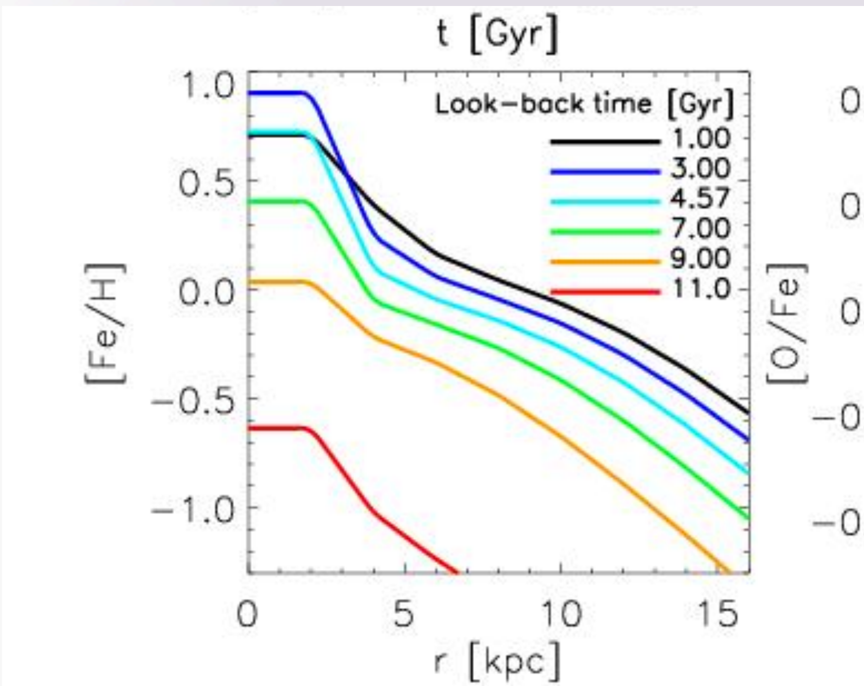


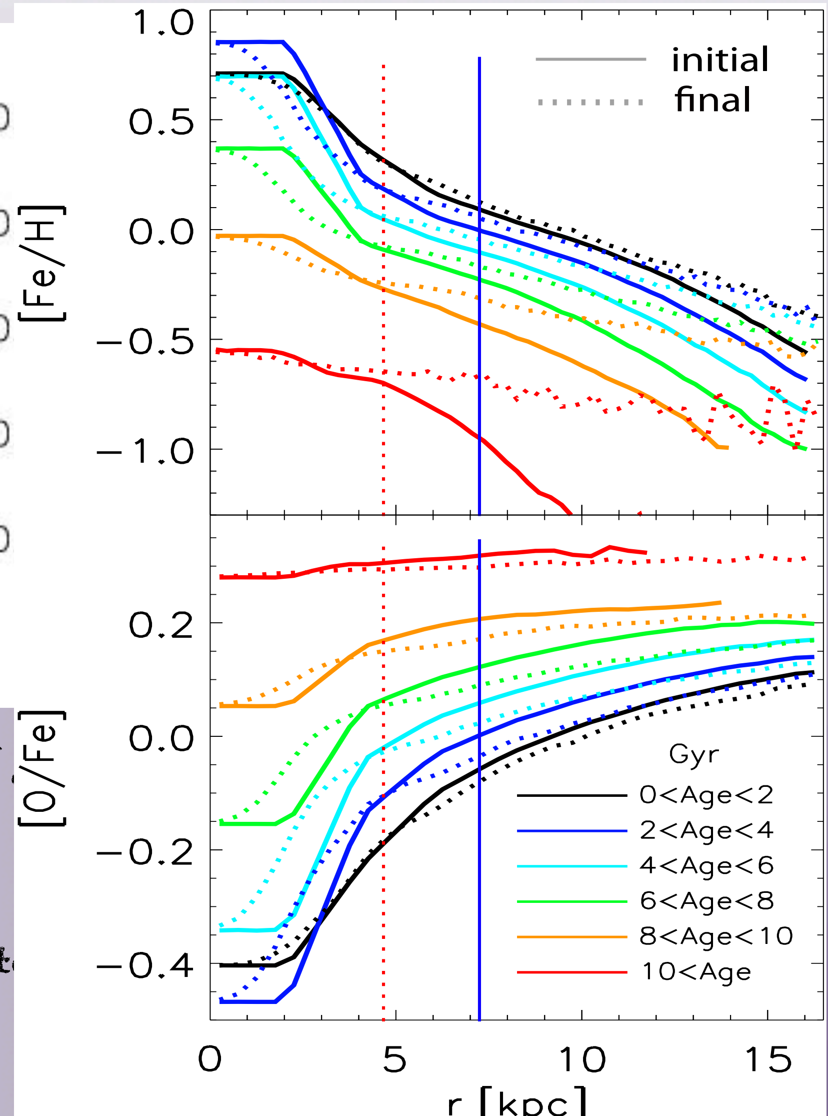
Minchev et al. (2013)

New chemo-dynamical model built as a fusion between a pure chemical evolution model and a high-resolution simulation in the cosmological context

- Including also radial migration
- No sfr threshold, no pre-enrichment
- Predict the time evolution of the radial metallicity gradient
- And of the [O/Fe] gradient

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



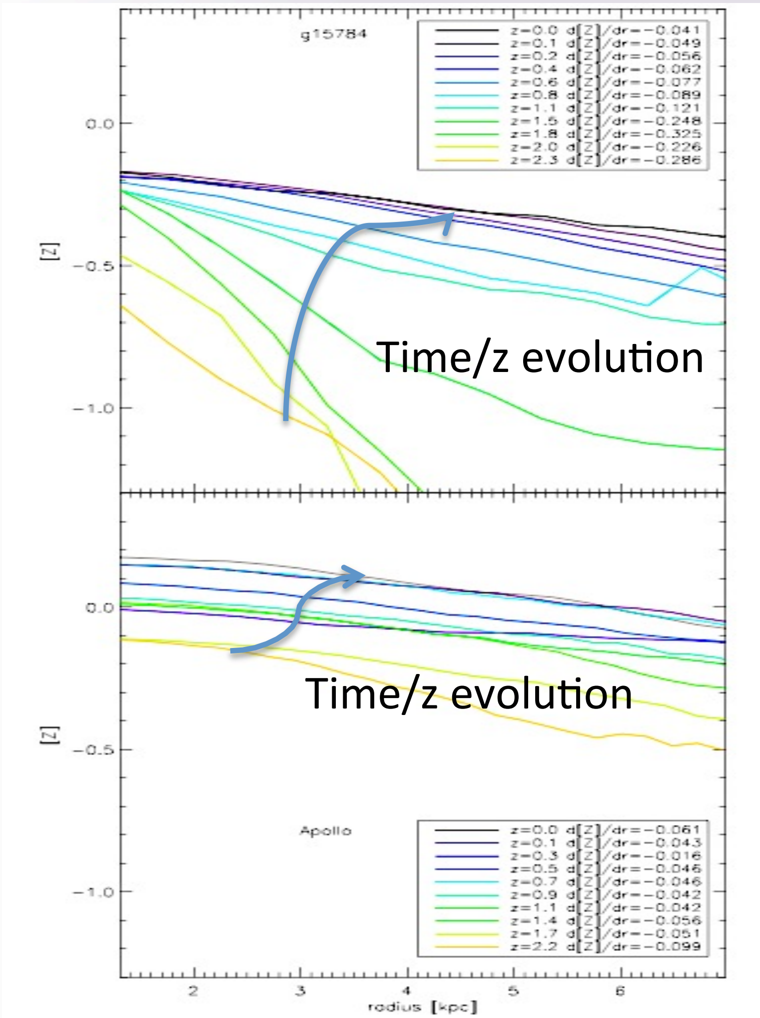


(2013)

New chemo-dynamical model built as a fusion
model and a high-resolution simulation in the

- Including also radial migration
- No sfr threshold, no pre-enrichment
- Predict the time evolution of the radial met
- And of the [O/Fe] gradient

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



Cosmological simulations:

Pilkington et al. (2012):
suite of disk galaxy hydro-dynamical simulations

- the majority of the models predict present gradients → consistent with late-type disks
- Different evolution, despite each adhering to classical 'inside-out' growth.
- <u>The radial dependence of the temporal star-formation efficiency drives the differences seen in the gradients</u>

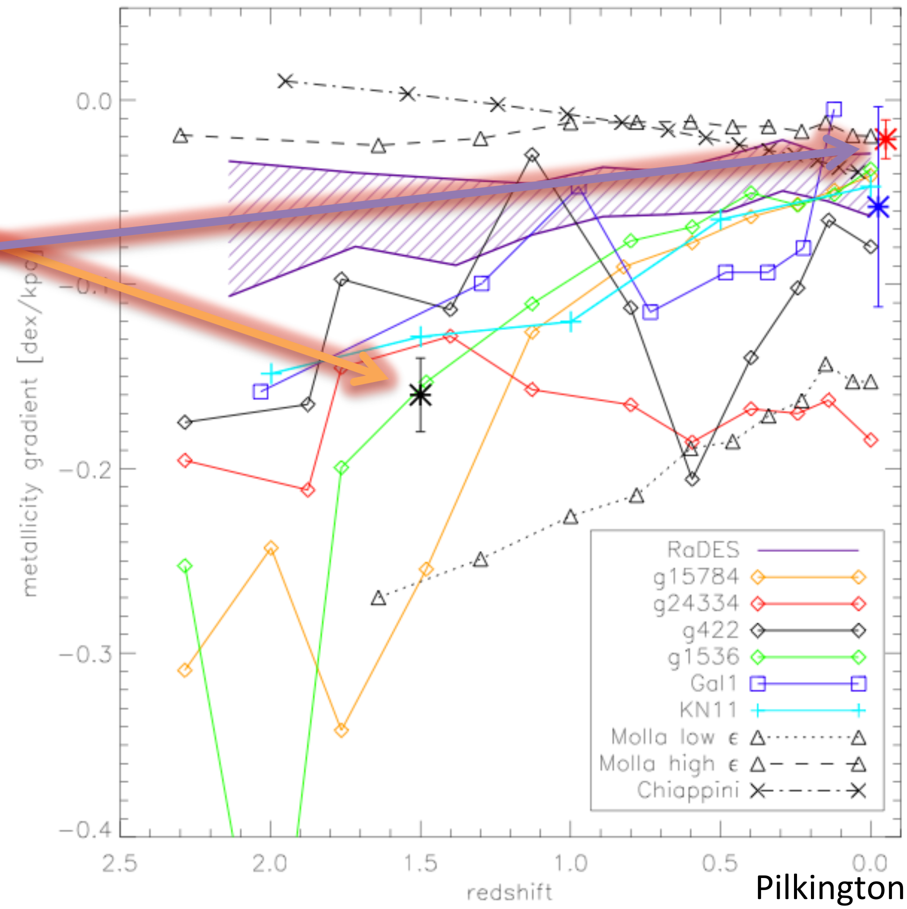
Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

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

Observational constraints



Pilkington+12

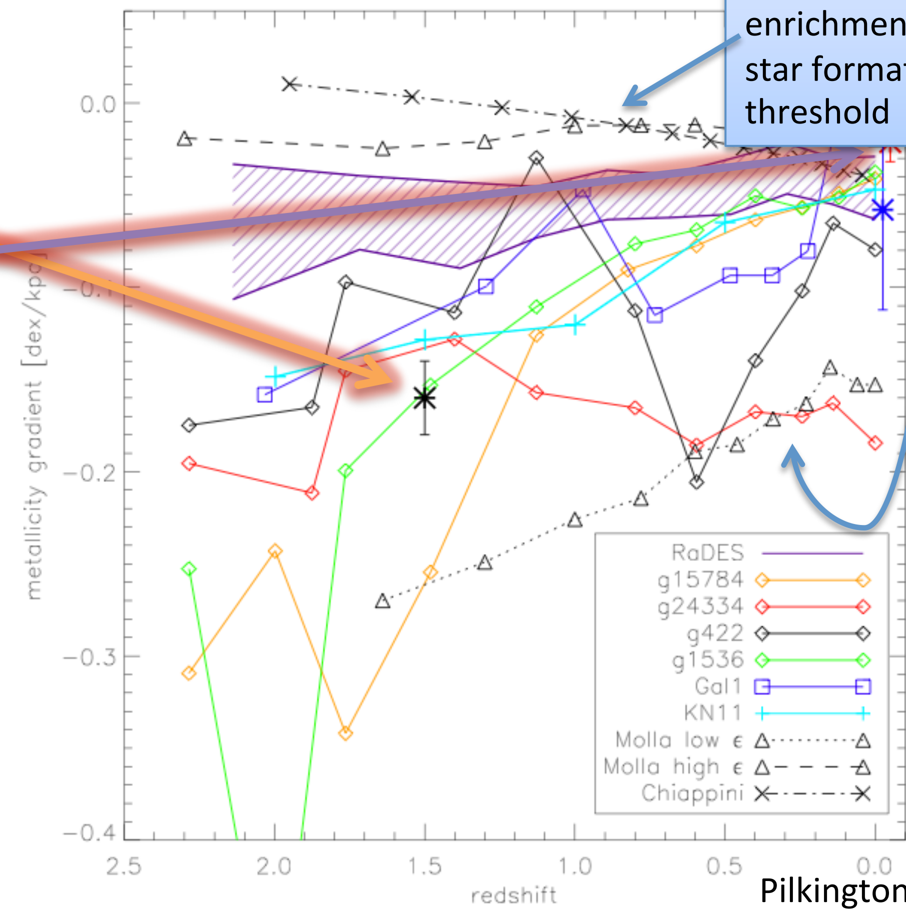
Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

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

Observational constraints



Pilkington+12

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

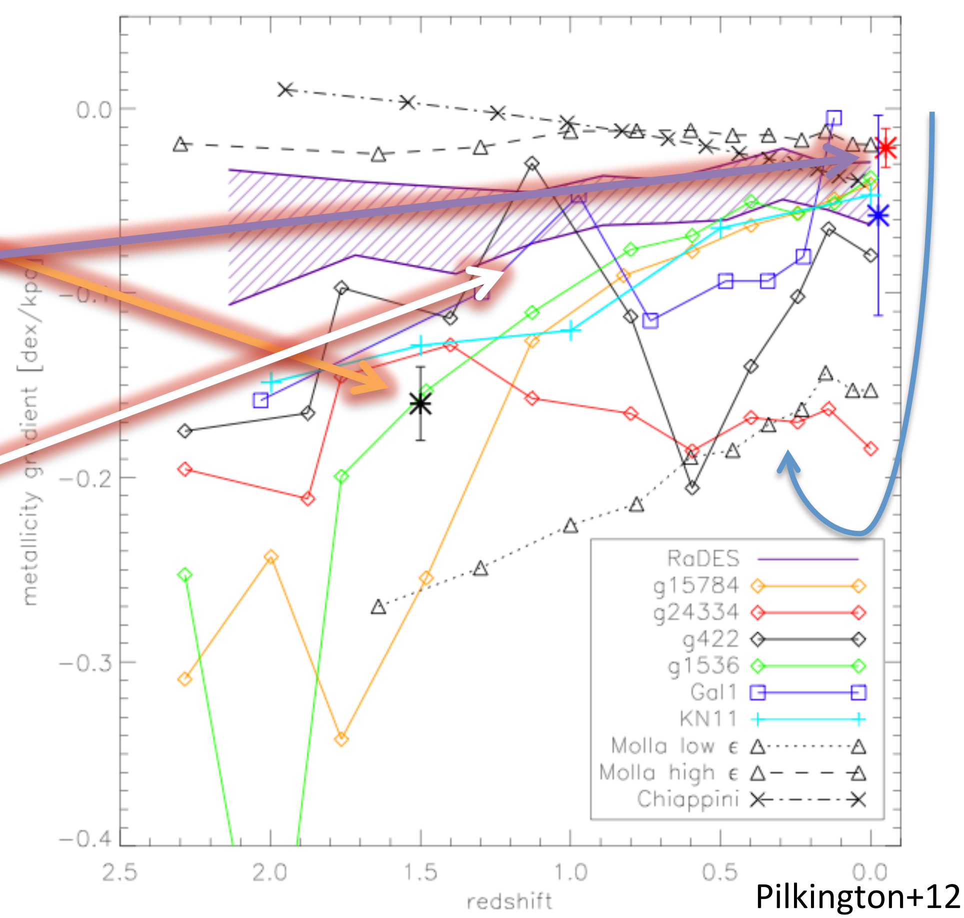
Understanding the Galactic disk to unveil the formation and evolution of the Galaxy and of galaxies

Strong necessity of observational constraints:

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

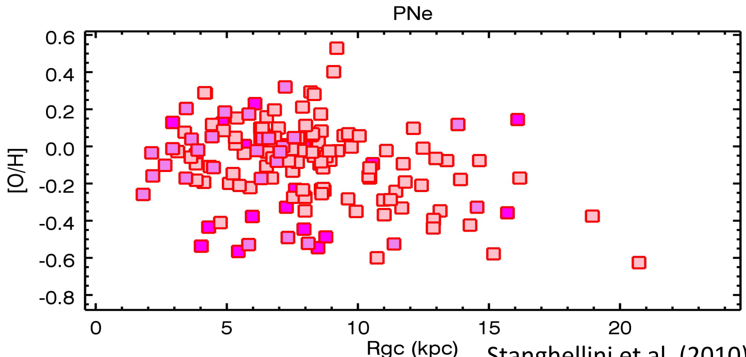
Yes, studying populations with known and different ages → Open clusters

Observational constraints

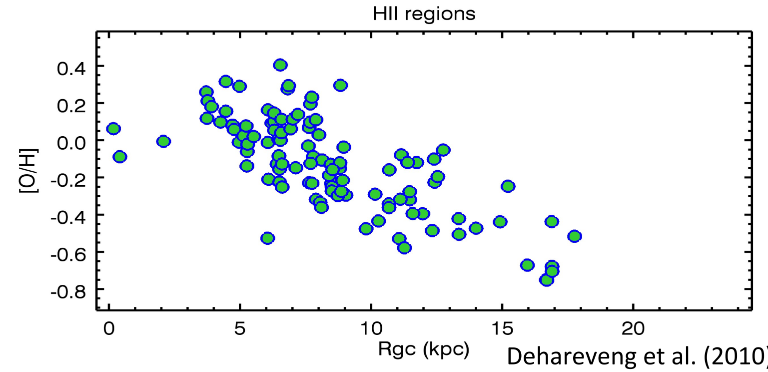


Pilkington+12

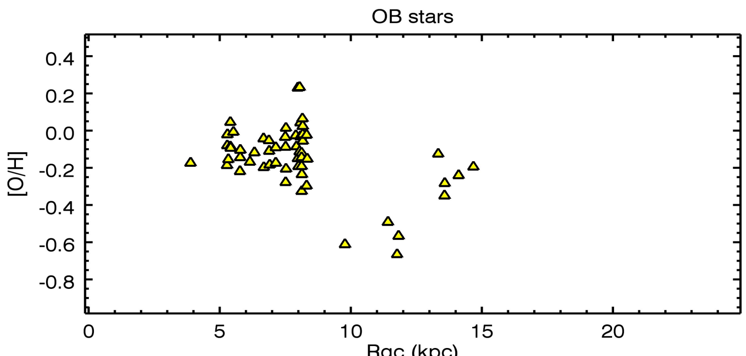
The Galactic gradient: recent literature results from many populations



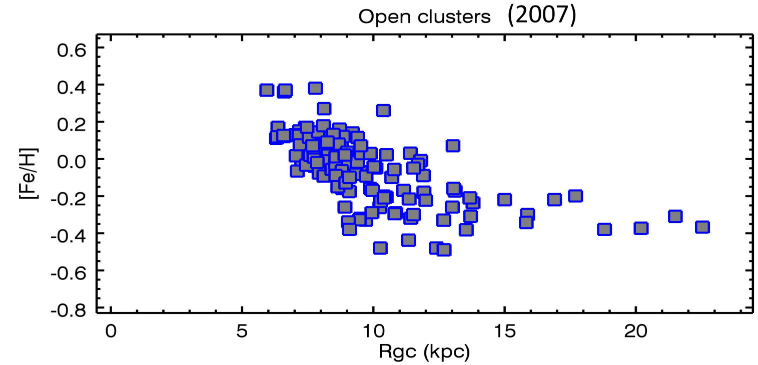
Stanghellini et al. (2010)



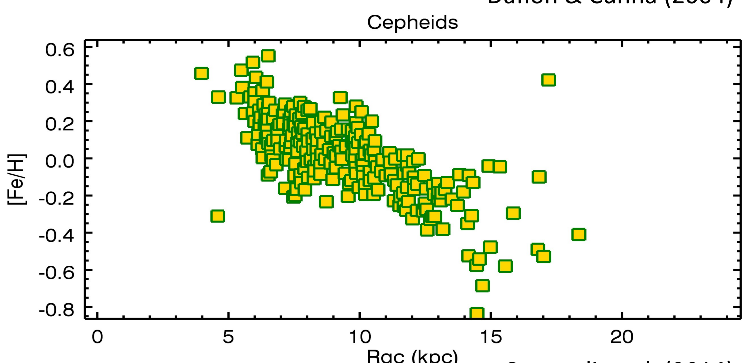
Deharevengetal. (2010), Rood et al. (2007)



Daflon & Cunha (2004)

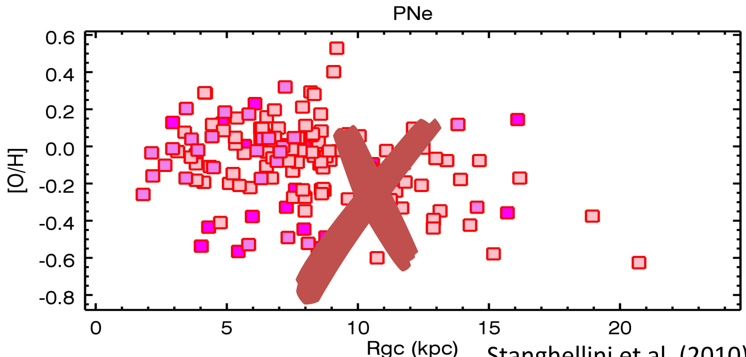


Magrini et al. (2009), Heiter et al. (2014), OCCAM Apogee (2013)

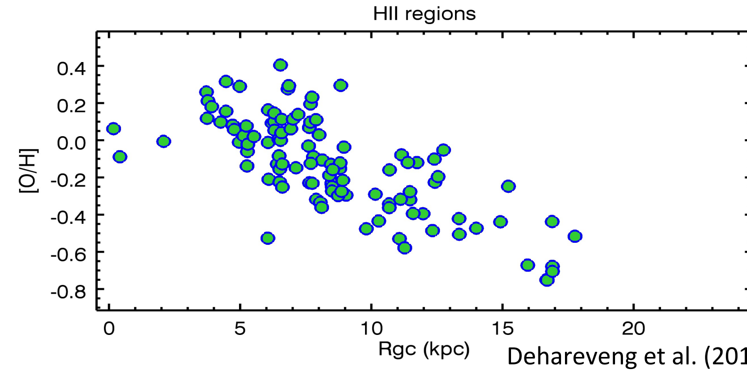


Genovali et al. (2014)+refs. therein

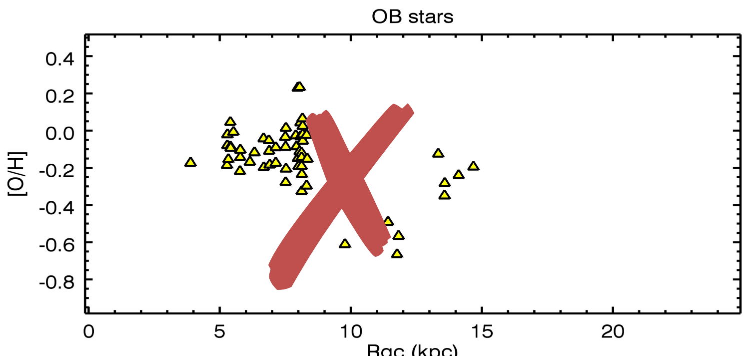
The Galactic gradient: recent literature results from many populations



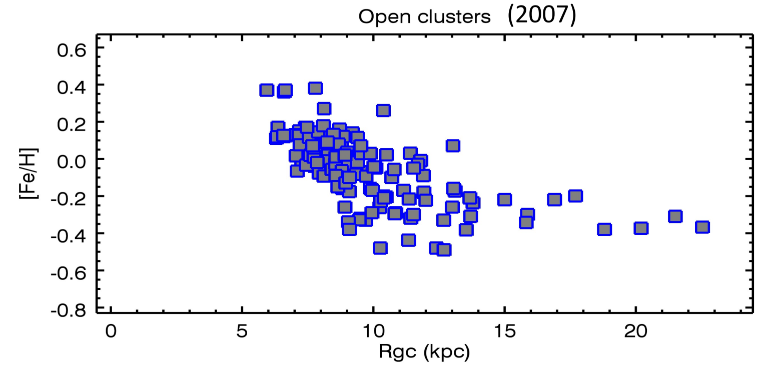
Stanghellini et al. (2010)



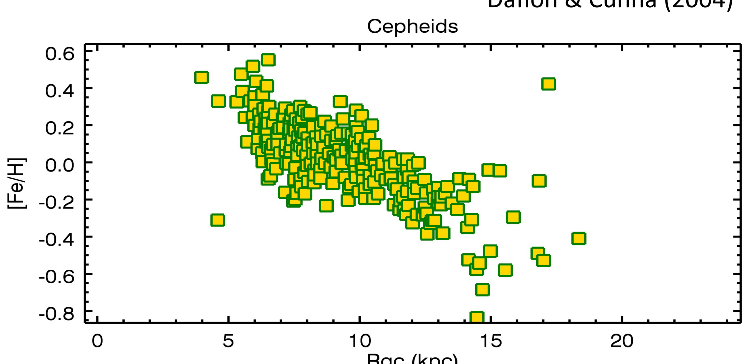
Dehareveng et al. (2010), Rood et al. (2007)



Daflon & Cunha (2004)

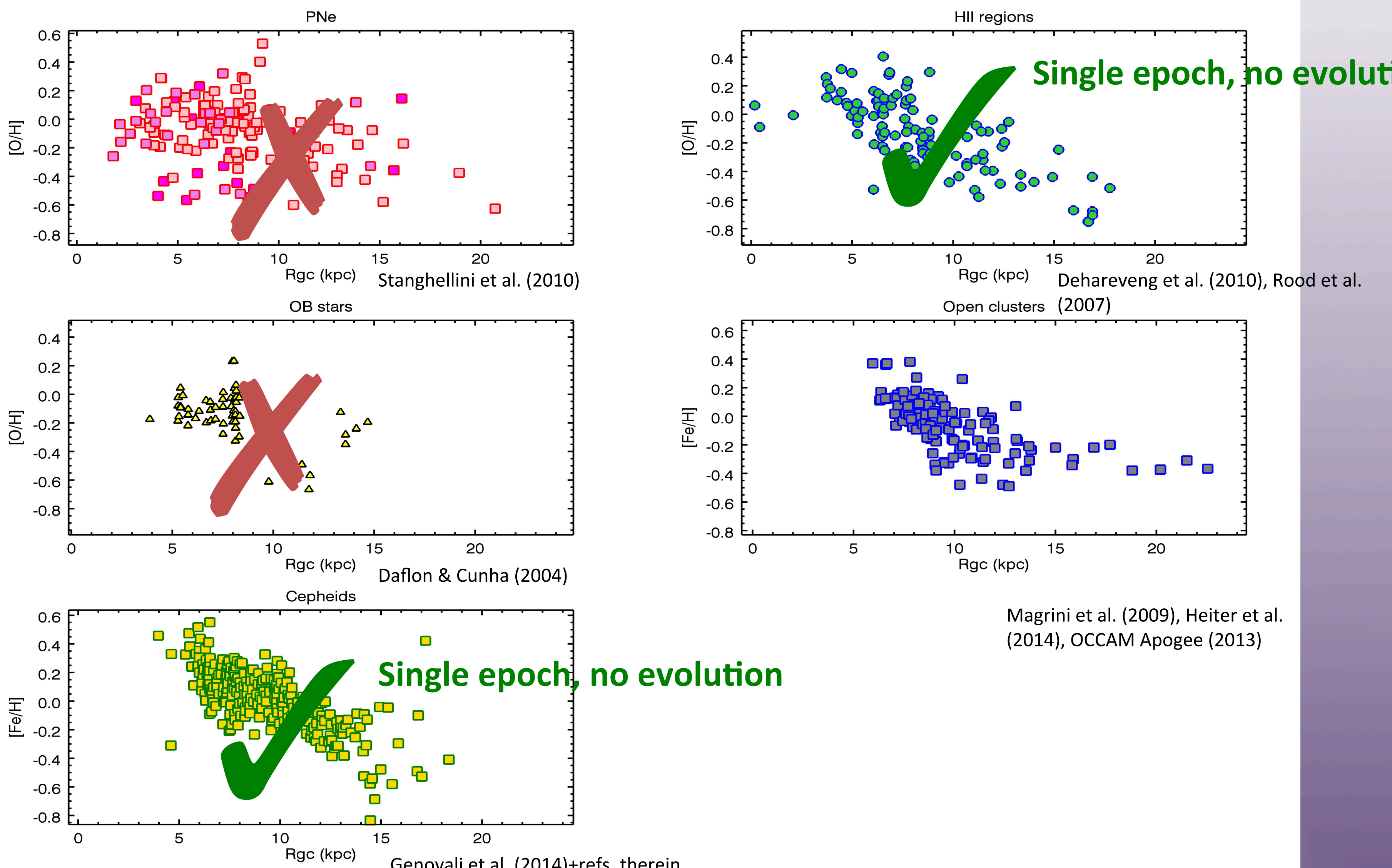


Magrini et al. (2009), Heiter et al. (2014), OCCAM Apogee (2013)

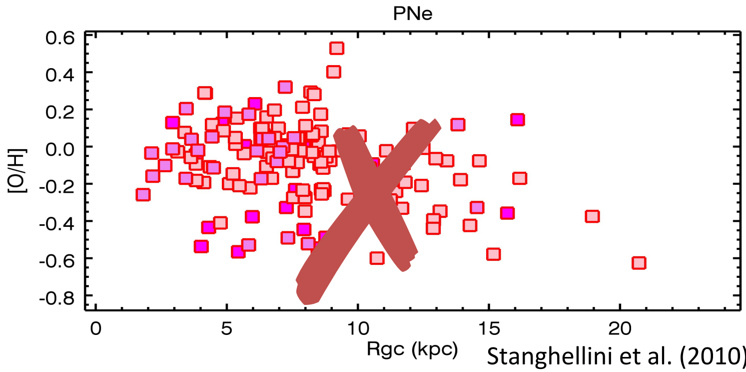


Genovali et al. (2014)+refs. therein

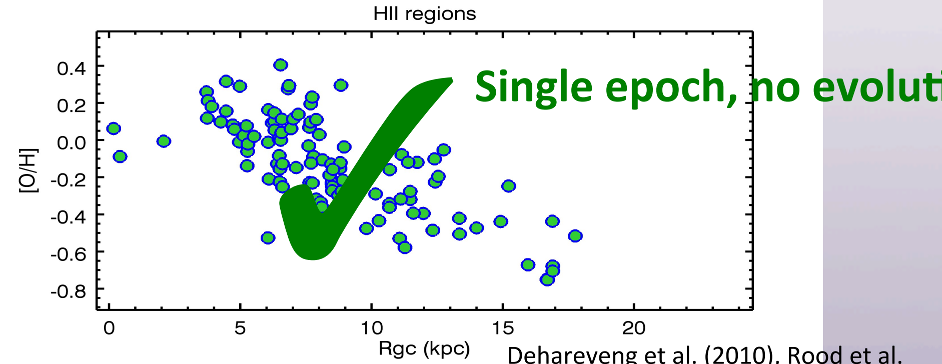
The Galactic gradient: recent literature results from many populations



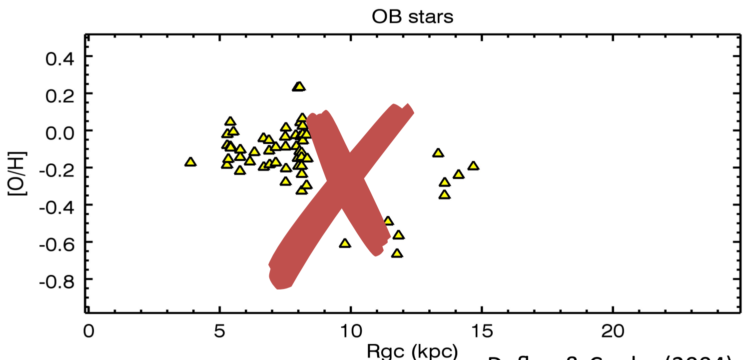
The Galactic gradient: recent literature results from many populations



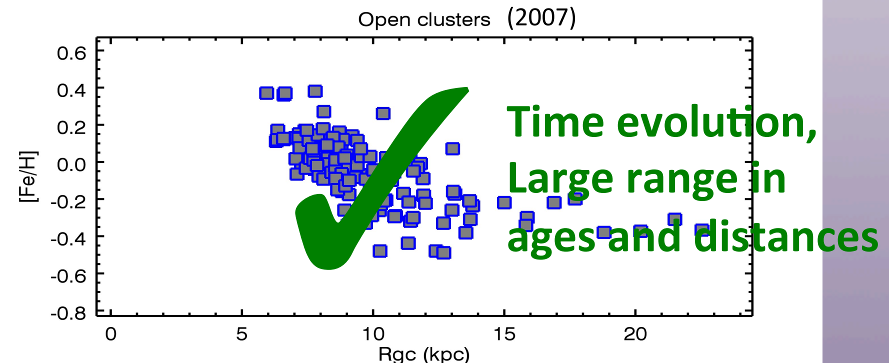
Stanghellini et al. (2010)



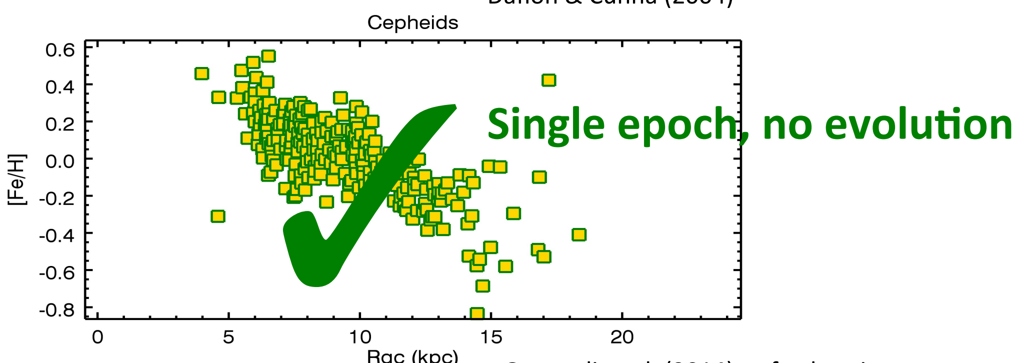
Deharenveng et al. (2010), Rood et al. (2007)



Daflon & Cunha (2004)

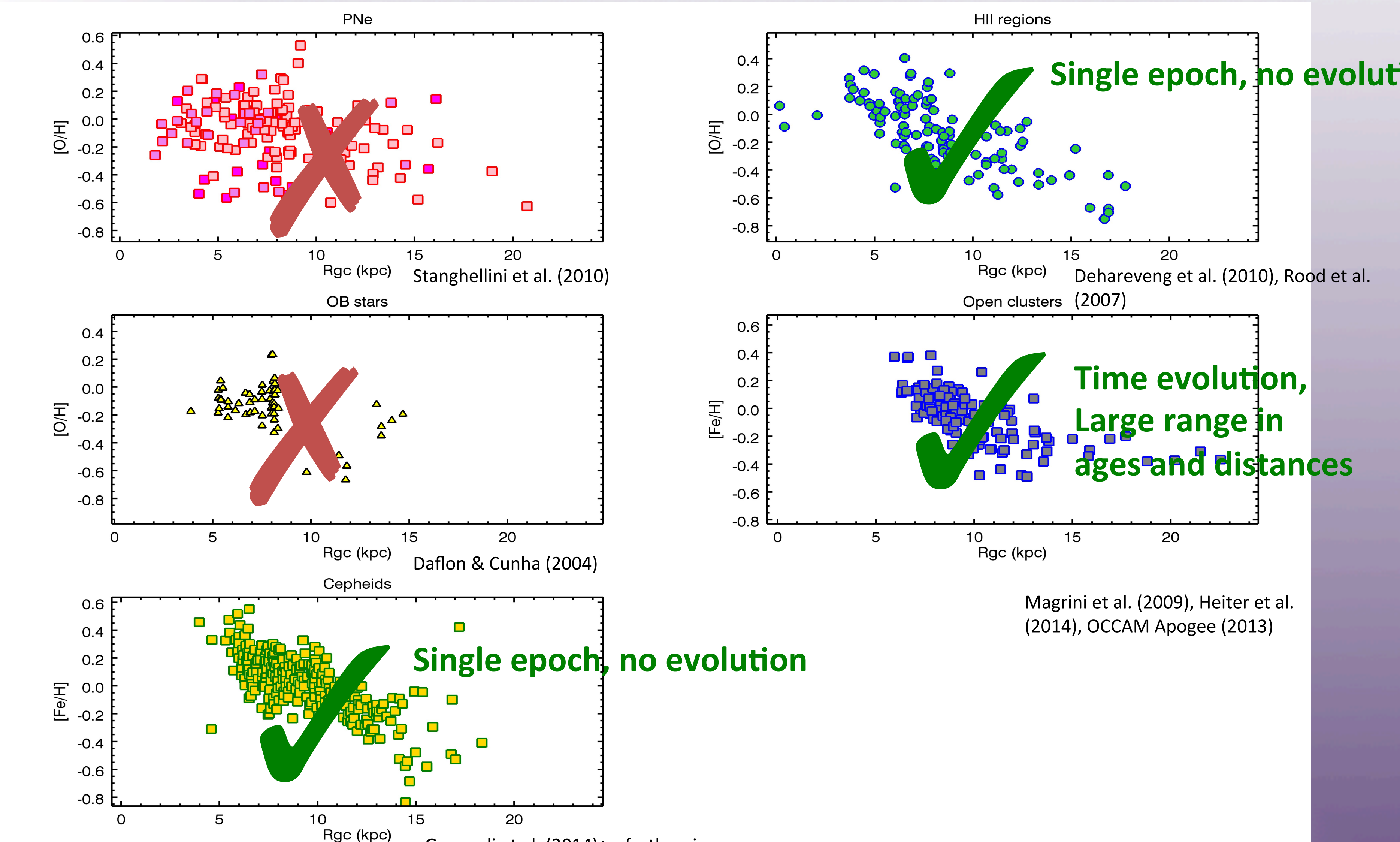


Magrini et al. (2009), Heiter et al. (2014), OCCAM Apogee (2013)



Genovali et al. (2014)+refs. therein

The Galactic gradient: recent literature results from many populations



Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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

Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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

1995

THE OLD OPEN CLUSTERS OF THE MILKY WAY

E. D. Friel

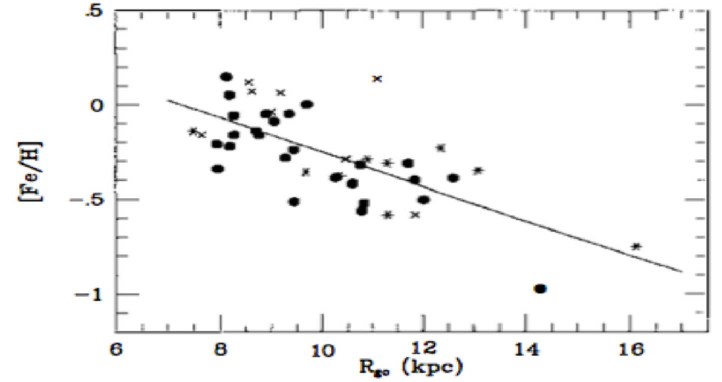


Figure 7 Radial abundance gradient for the old open clusters, with metallicities from Table 1. Filled circles are points from Friel & Janes (1993) or Thogersen et al (1994). Starred symbols are preliminary metallicities from Friel et al (1995). Crosses are data taken from Lynga (1987). The solid line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

Why open clusters:

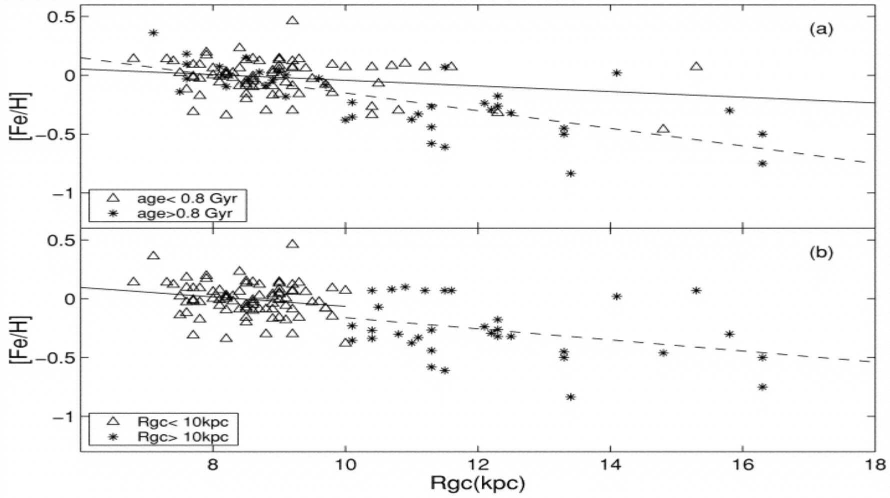
- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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

2003

ON THE GALACTIC DISK METALLICITY DISTRIBUTION FROM OPEN CLUSTERS. I. NEW CATALOGS AND ABUNDANCE GRADIENT

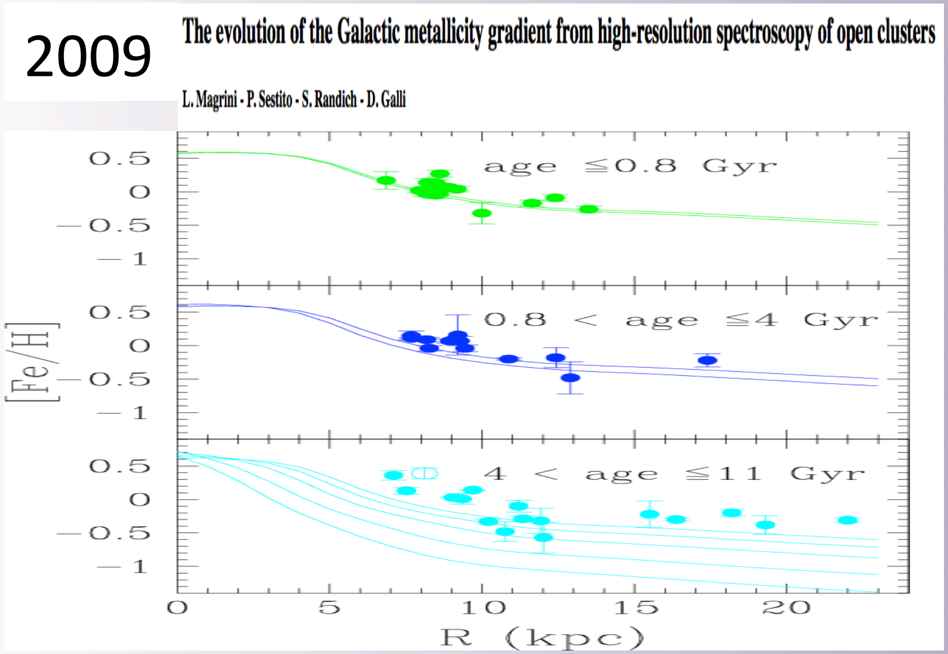
L. Chen, J. L. Hou, and J. J. Wang



Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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



Why open clusters:

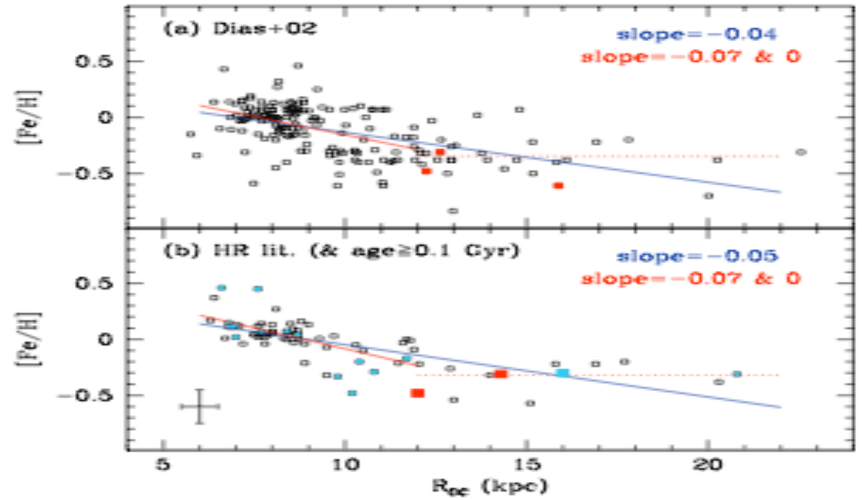
- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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

2011

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

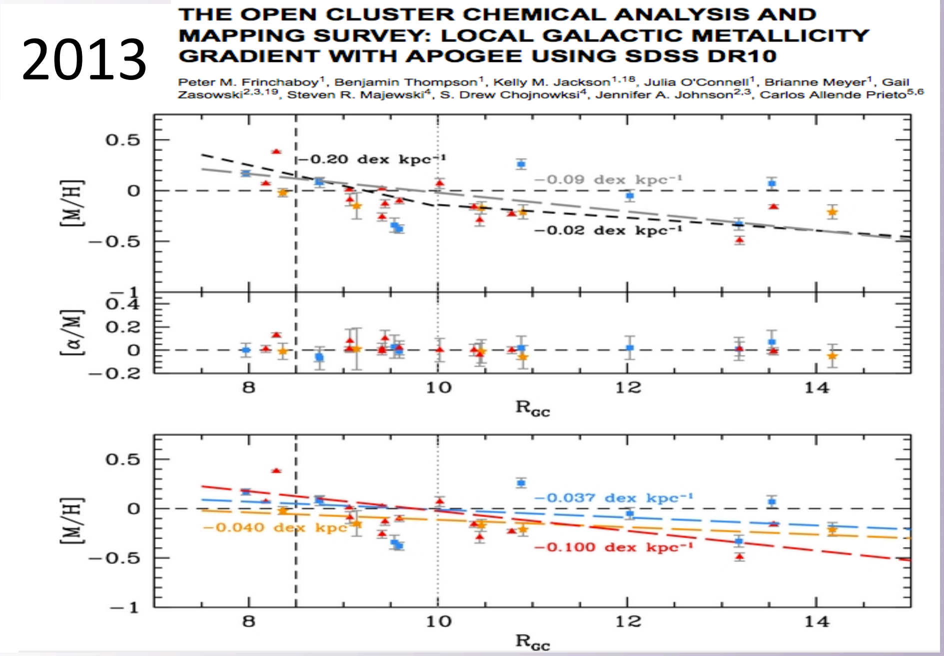
Gloria Andreuzzi,[1,2]† Angela Bragaglia,[3]† Monica Tosi[3]† and Gianni Marconi[4]†



Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

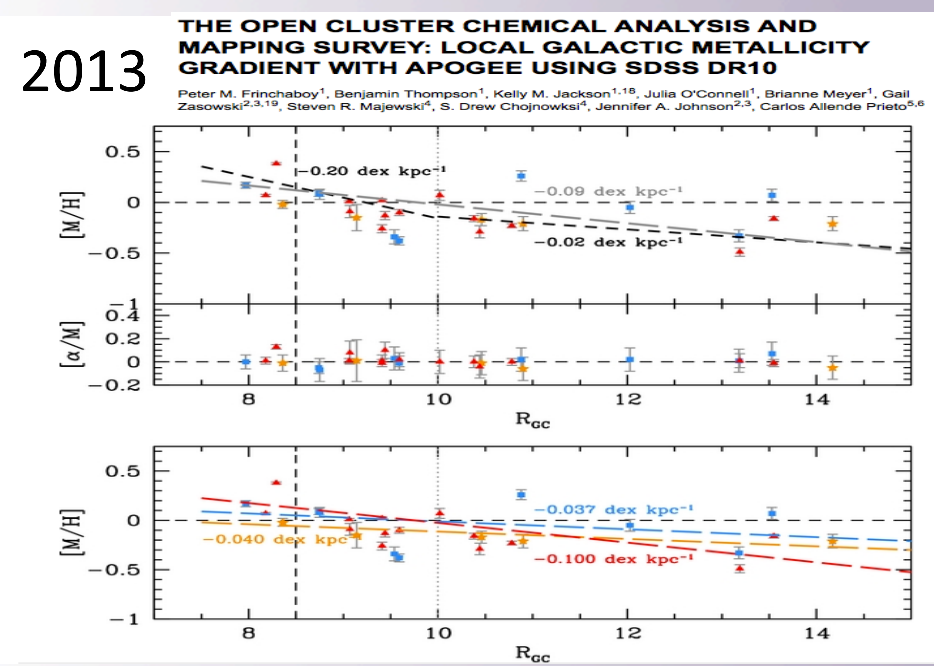
They allow to derive the structure, kinematics and chemistry of the disk, and, thanks to the large range of ages, also their time variation.



Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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



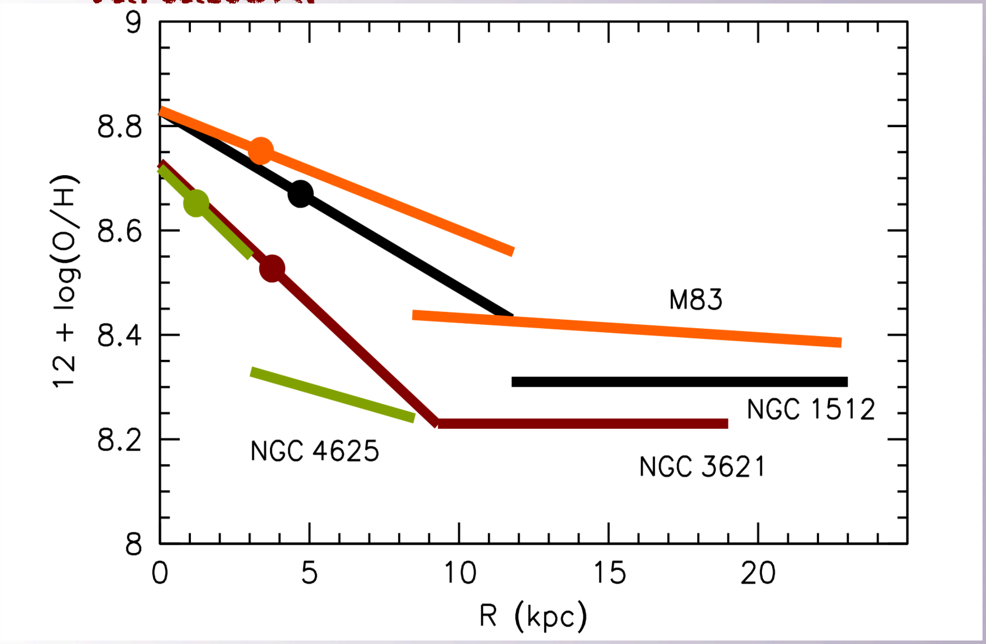
Main results

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

Why open clusters:

- Numerous population
- Ages and distances accurately determined, and spanning large ranges
- Membership and accurate chemical compositions
- In principle, less affected by migration than single stars

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

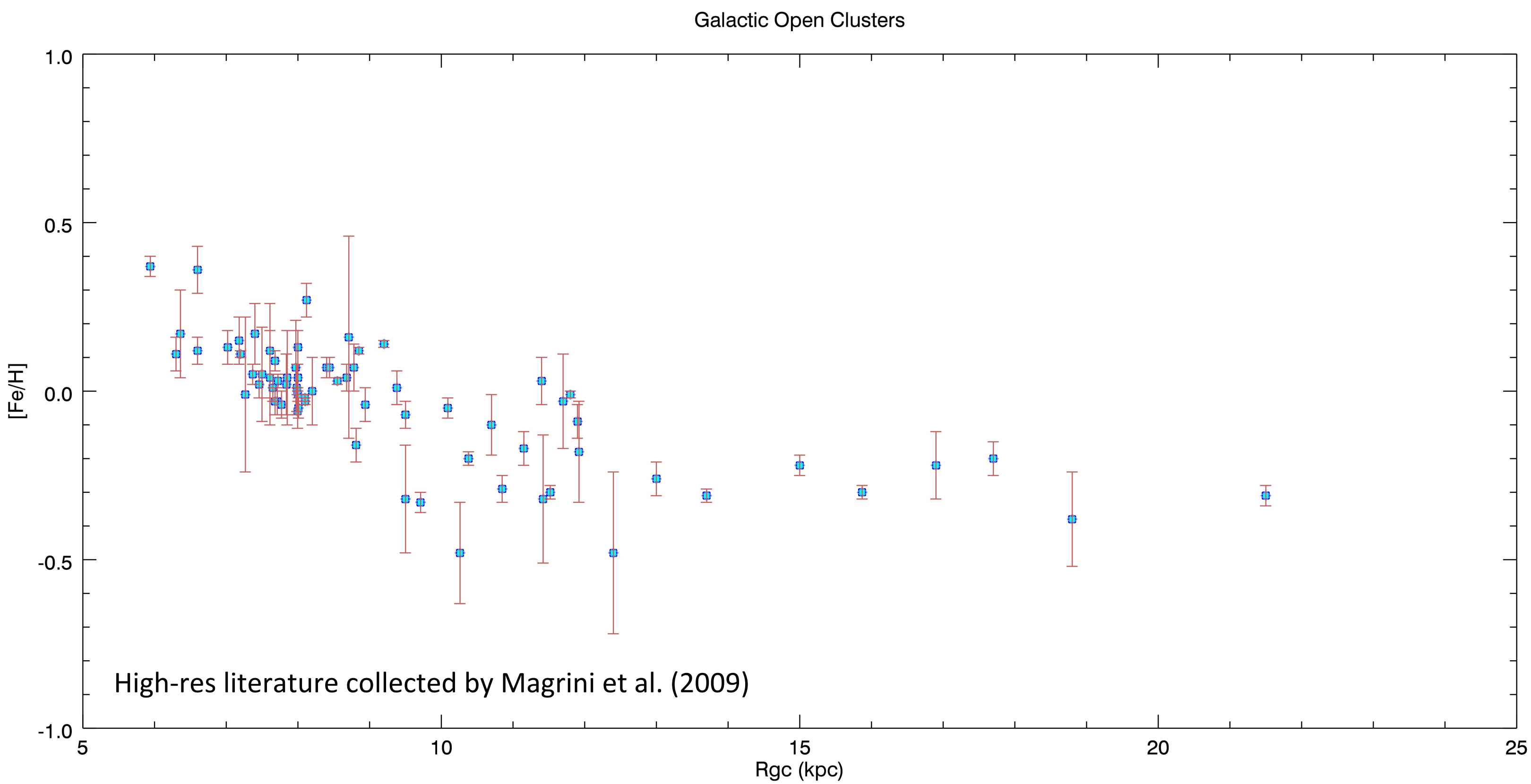


Porto- GES meeting 2014

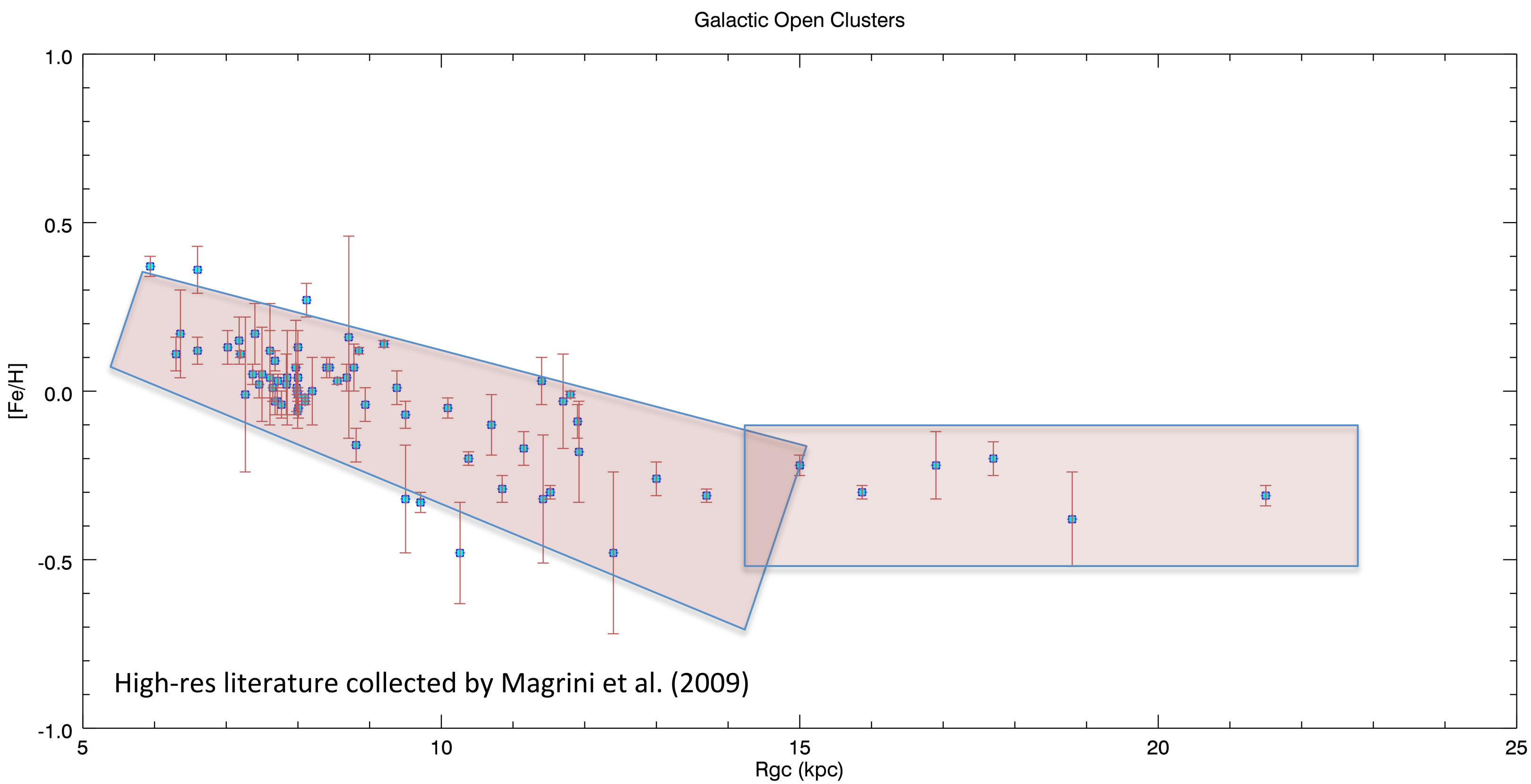
Main results

- 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)

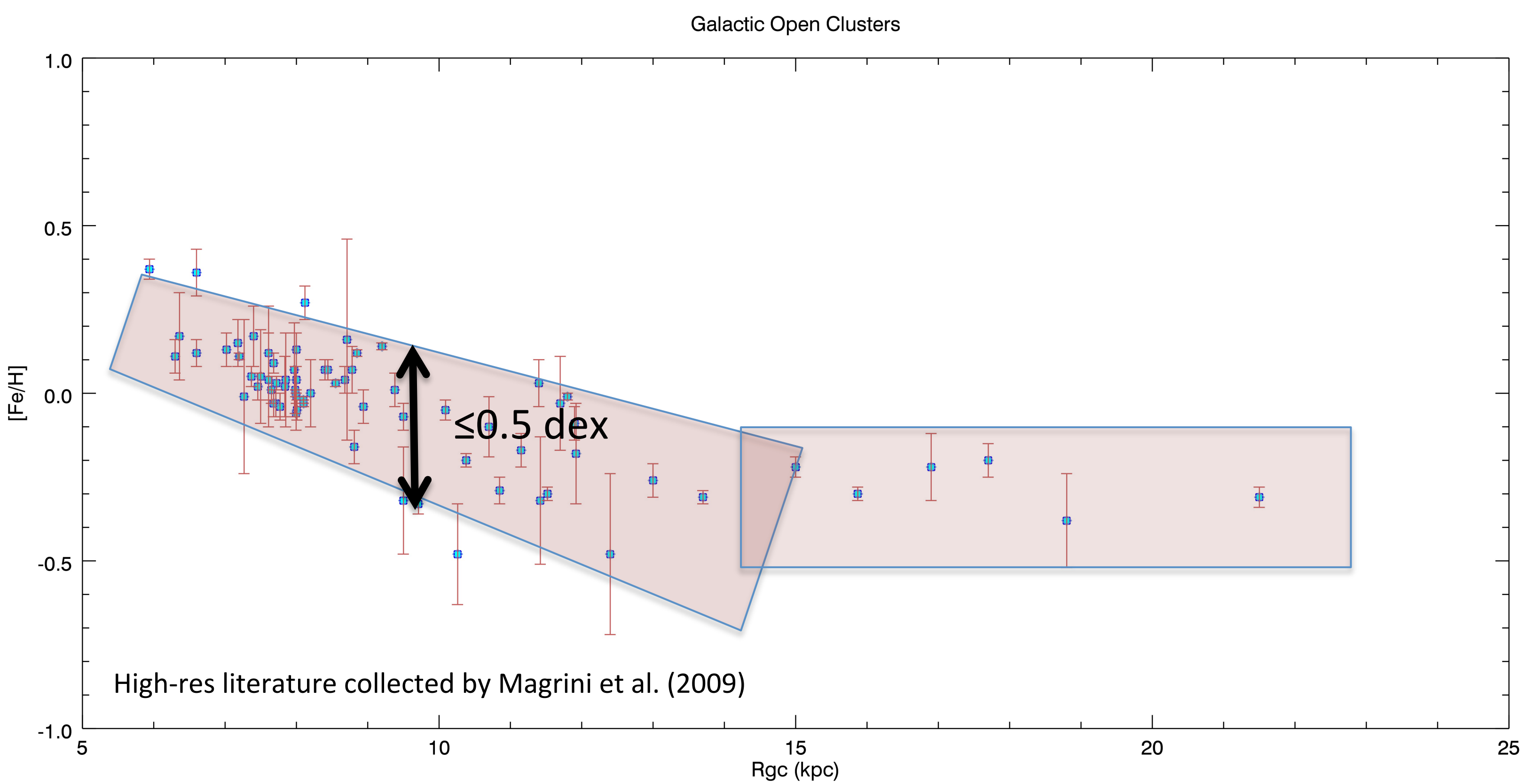
The radial gradient: Literature vs. GES



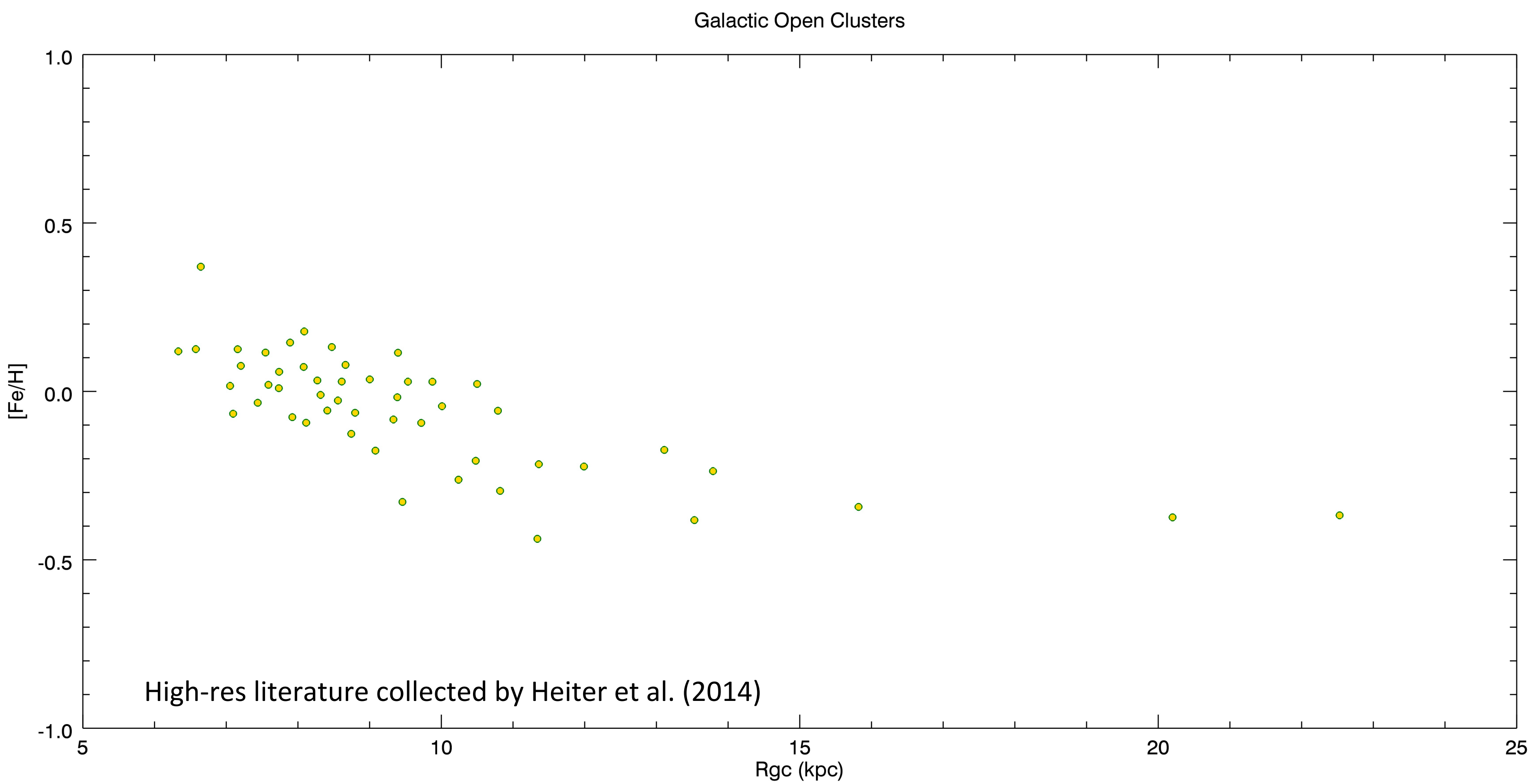
The radial gradient: Literature vs. GES



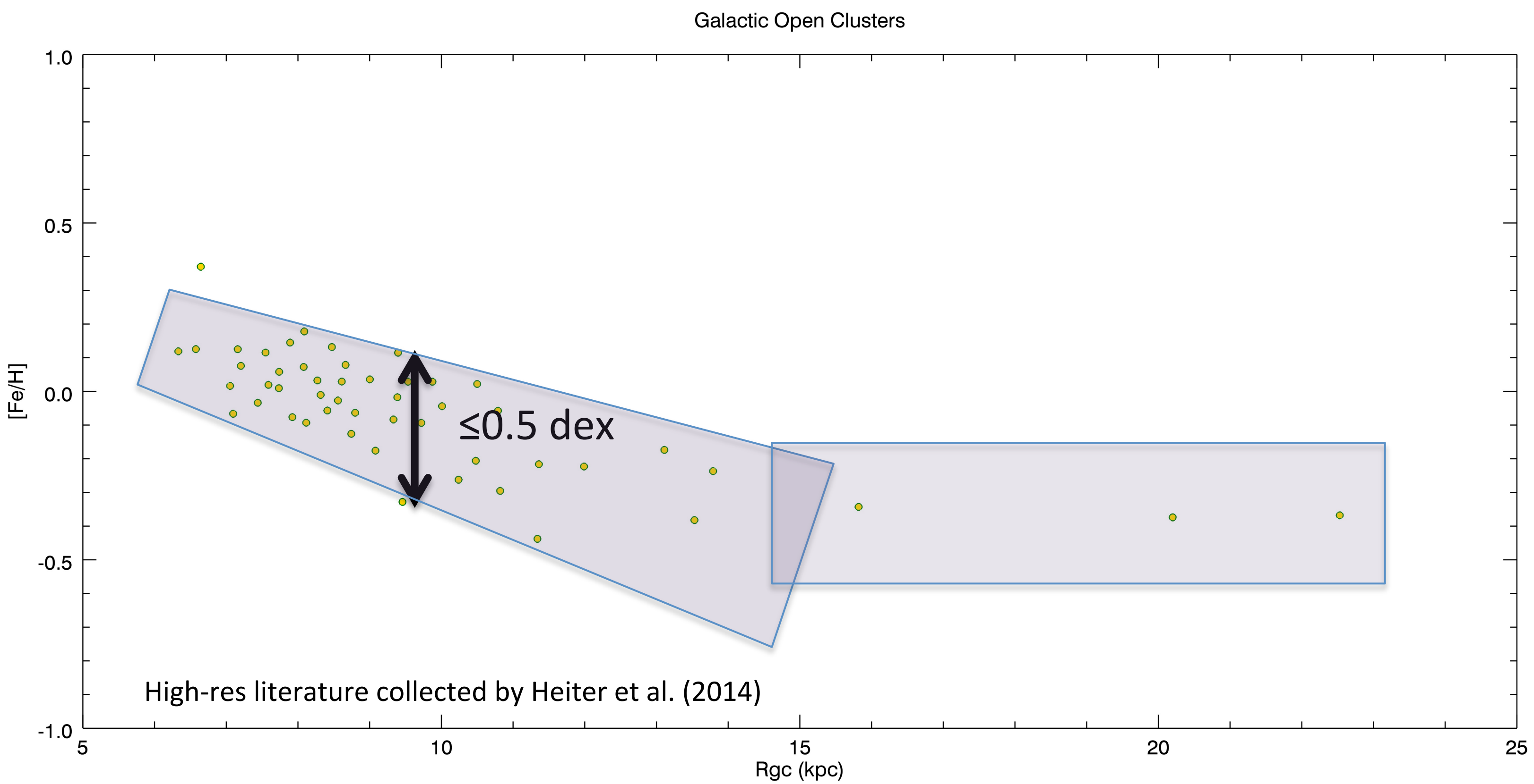
The radial gradient: Literature vs. GES



The radial gradient: Literature vs. GES



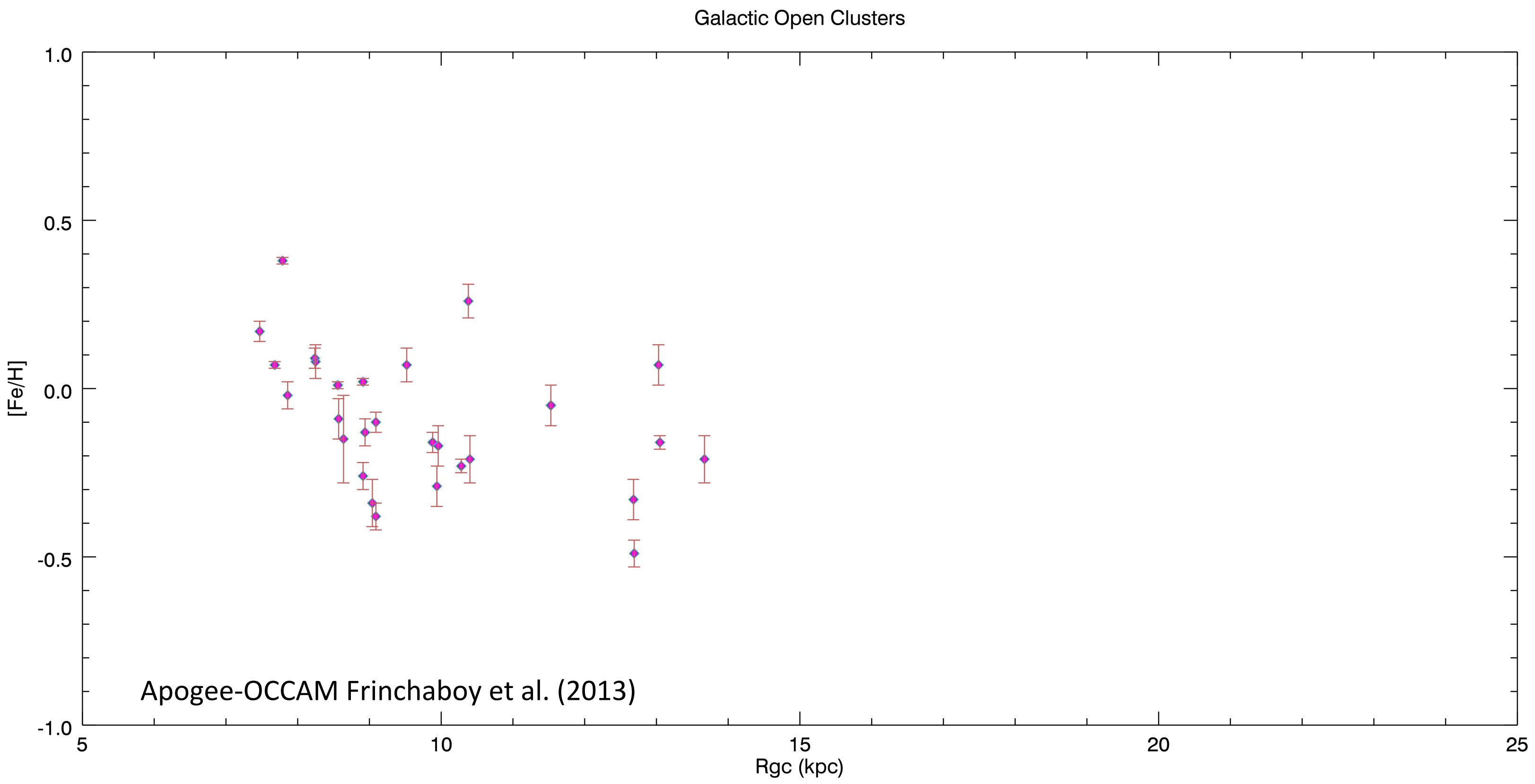
The radial gradient: Literature vs. GES



The gradient is well defined → high dispersion at each radii

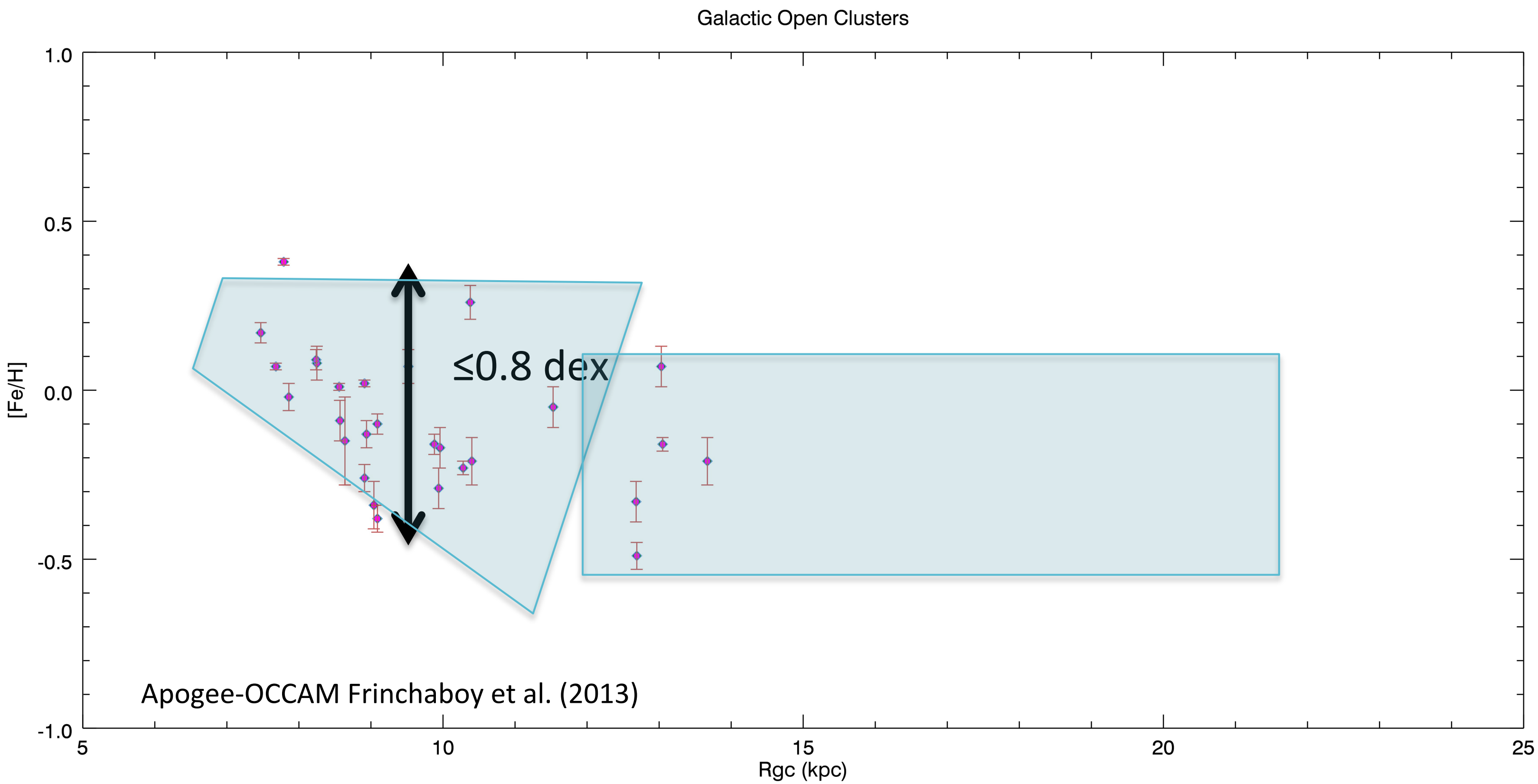
→ Not homogeneous analysis, observations, etc.

The radial gradient: Literature vs. GES



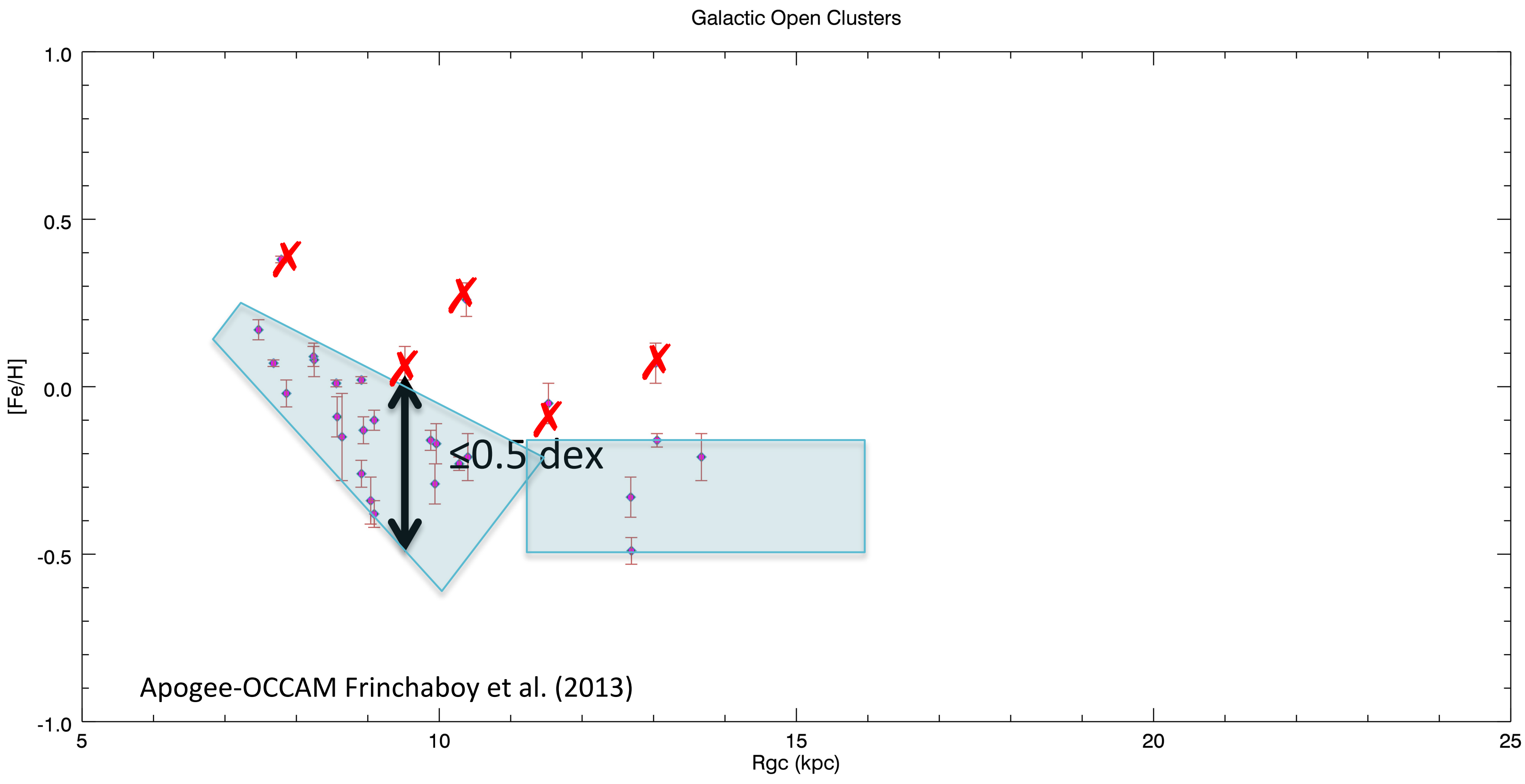
High dispersion at each radii→ due to outlier clusters
Homogeneous analysis but not sure membership? Occam Apogee clusters have a median of only one member star with reliable [M/H] and [α/M].

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].

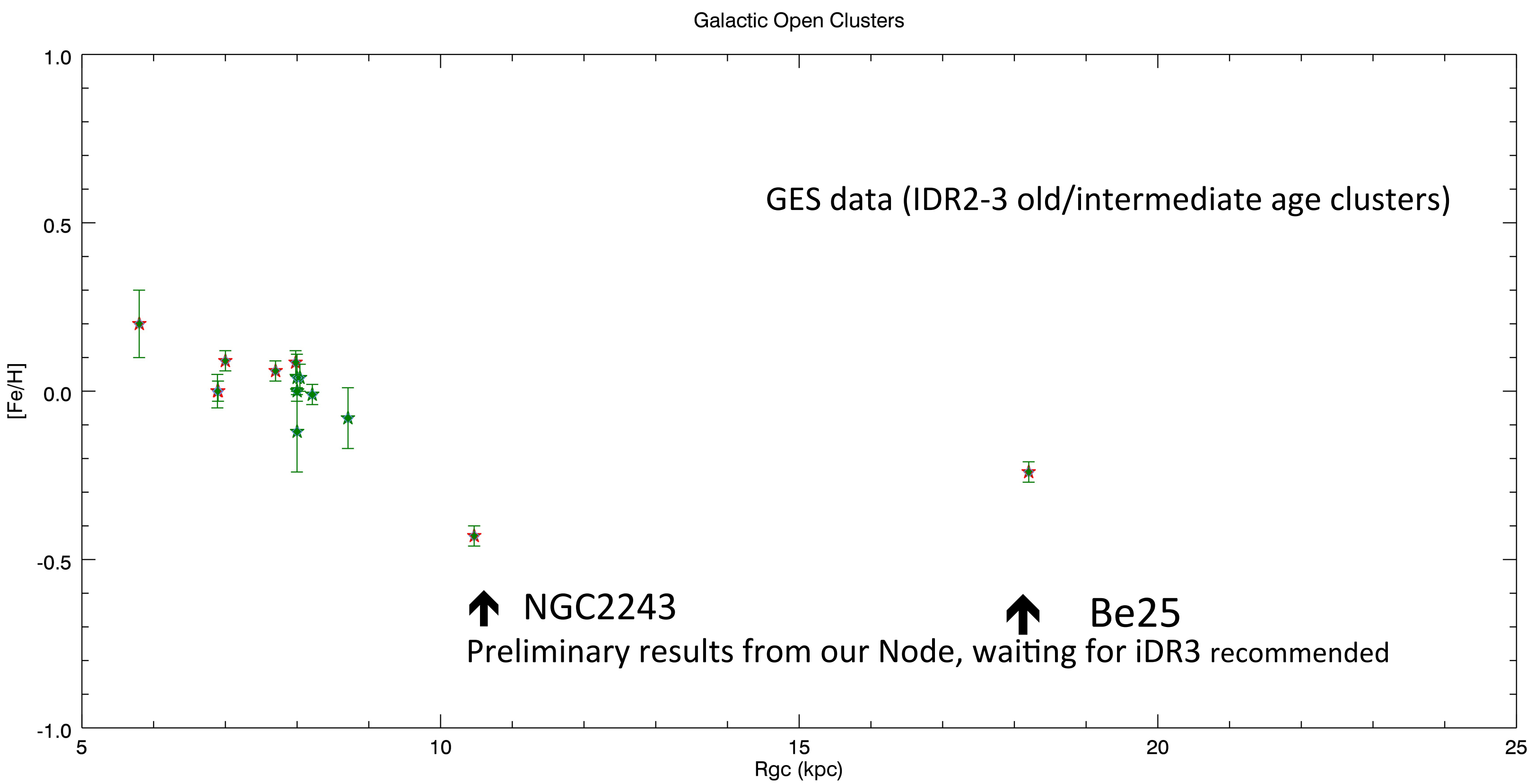
The radial gradient: Literature vs. GES



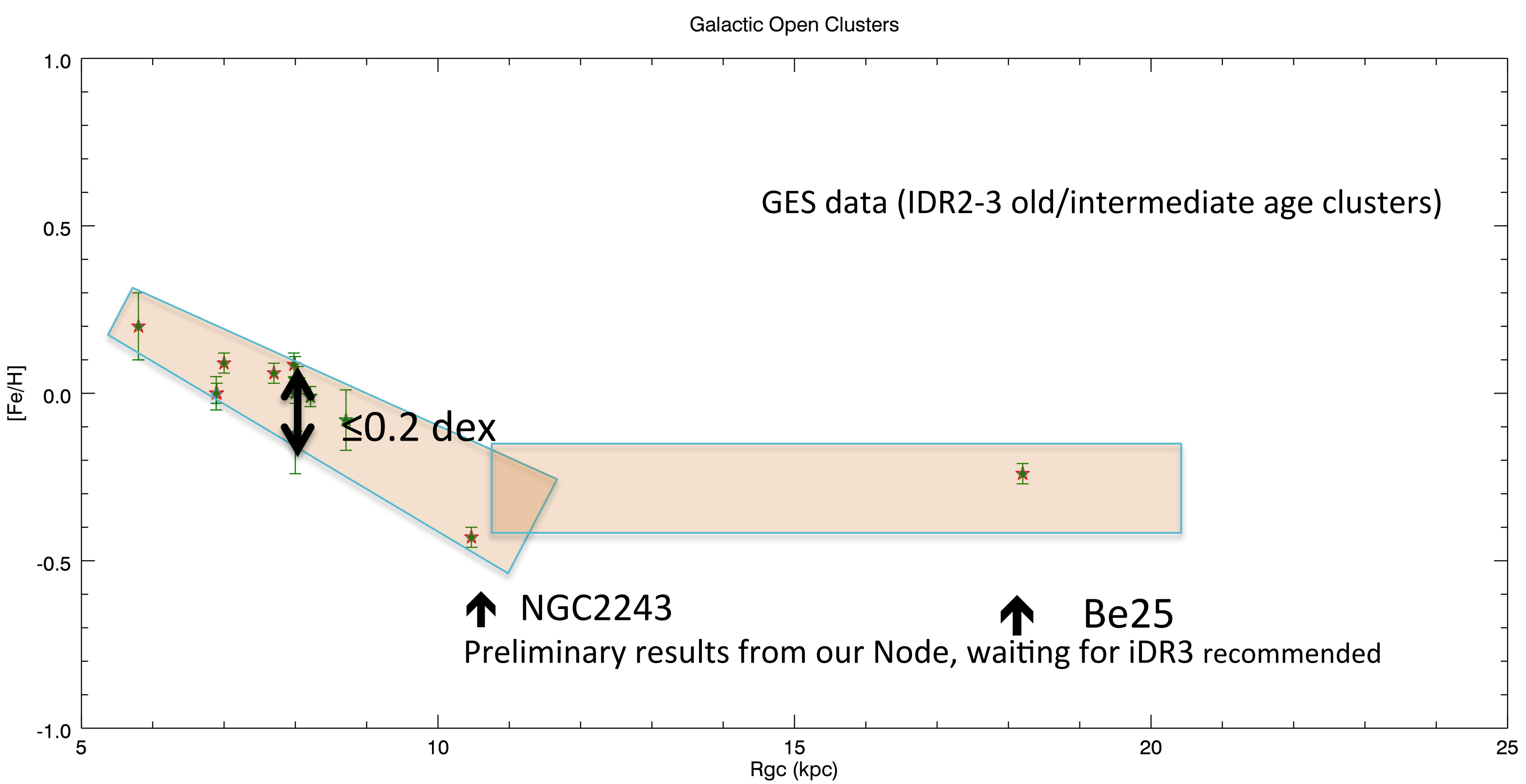
High dispersion at each radii→ due to outlier clusters

Homogeneous analysis but not sure membership? Occam Apogee clusters have a median of only one member star with reliable [M/H] and [α/M].

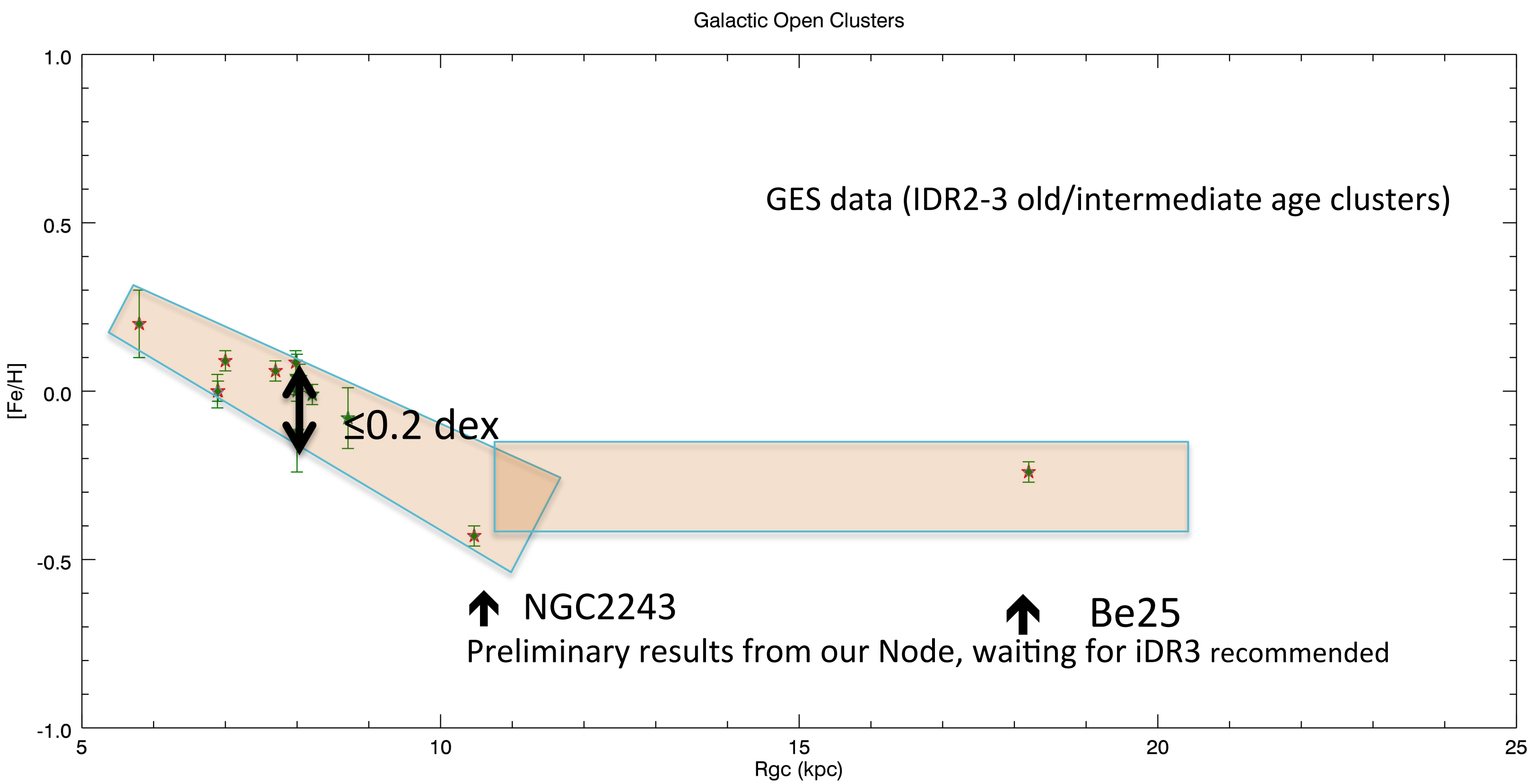
The radial gradient: Literature vs. GES



The radial gradient: Literature vs. GES



The radial gradient: Literature vs. GES

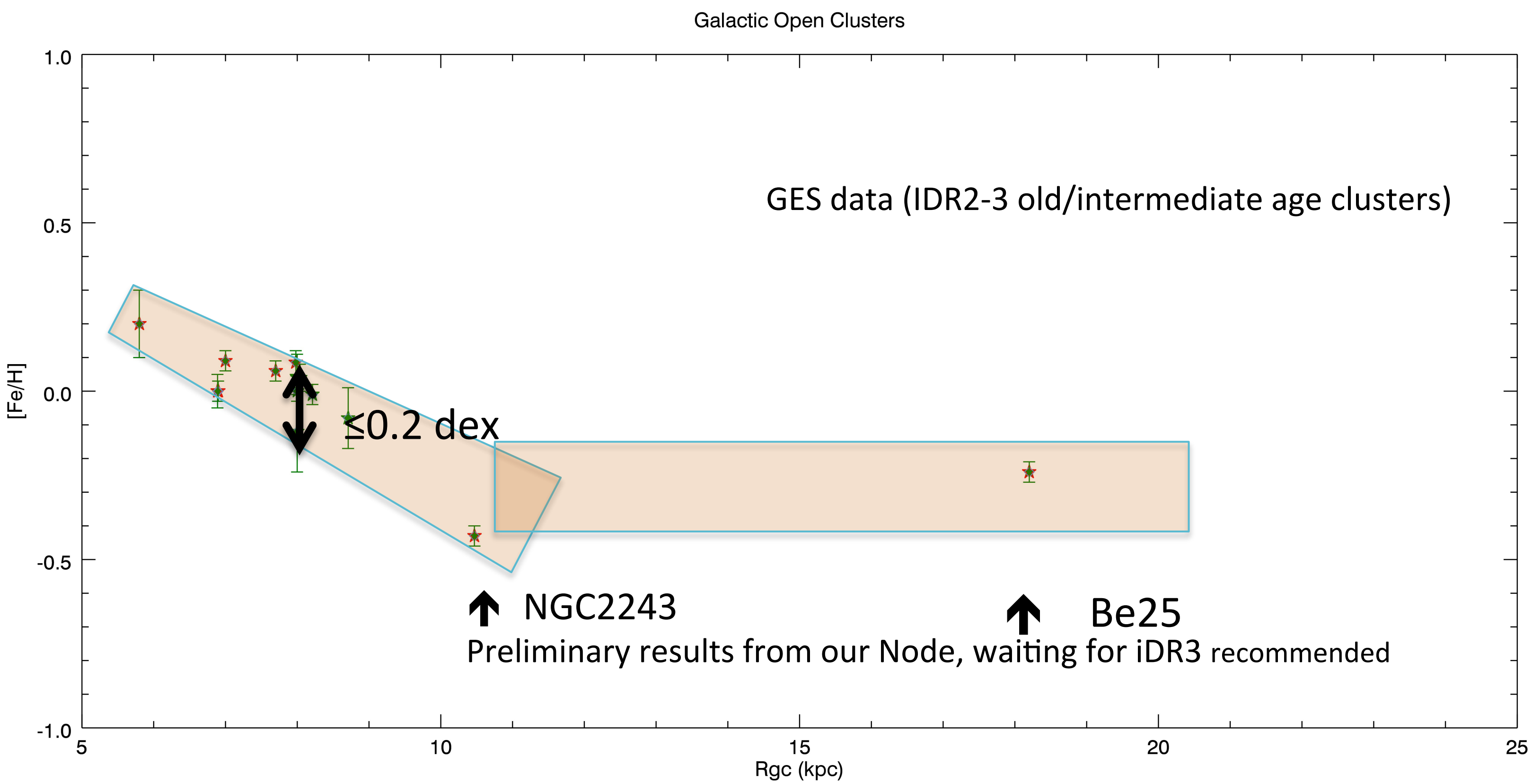


GES open clusters observed in the first 18 months:

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

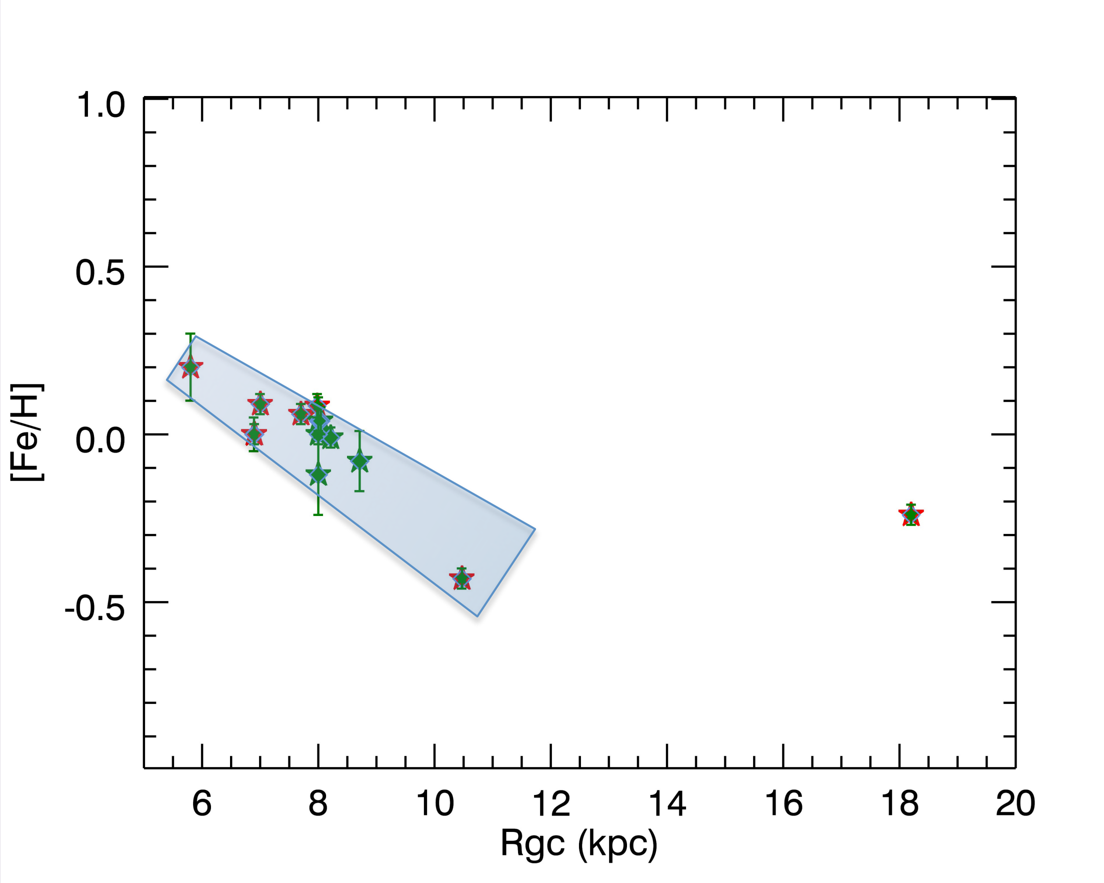
Still low statistics but we are at the beginning.....and the results are very promising!

The radial gradient: Literature vs. GES



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

The radial gradient: Literature vs. GES

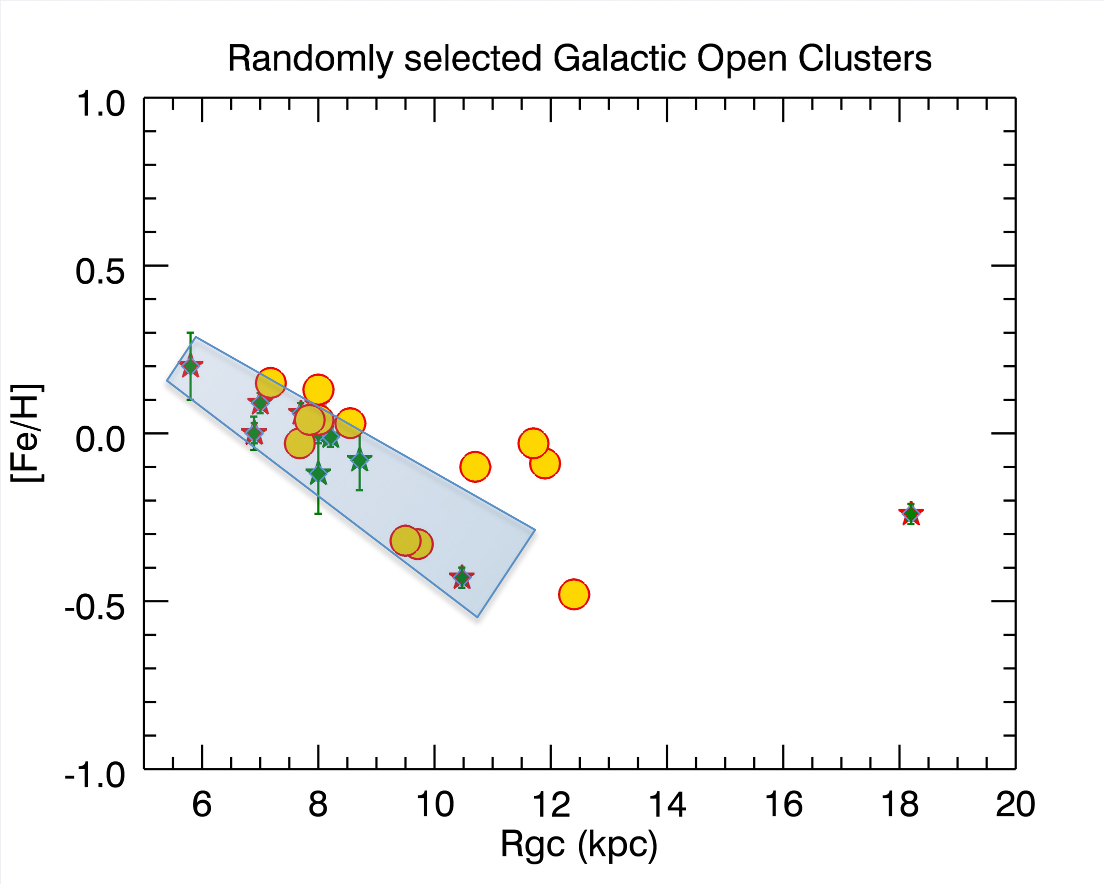


GES open clusters observed in the first 18 months:

- 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

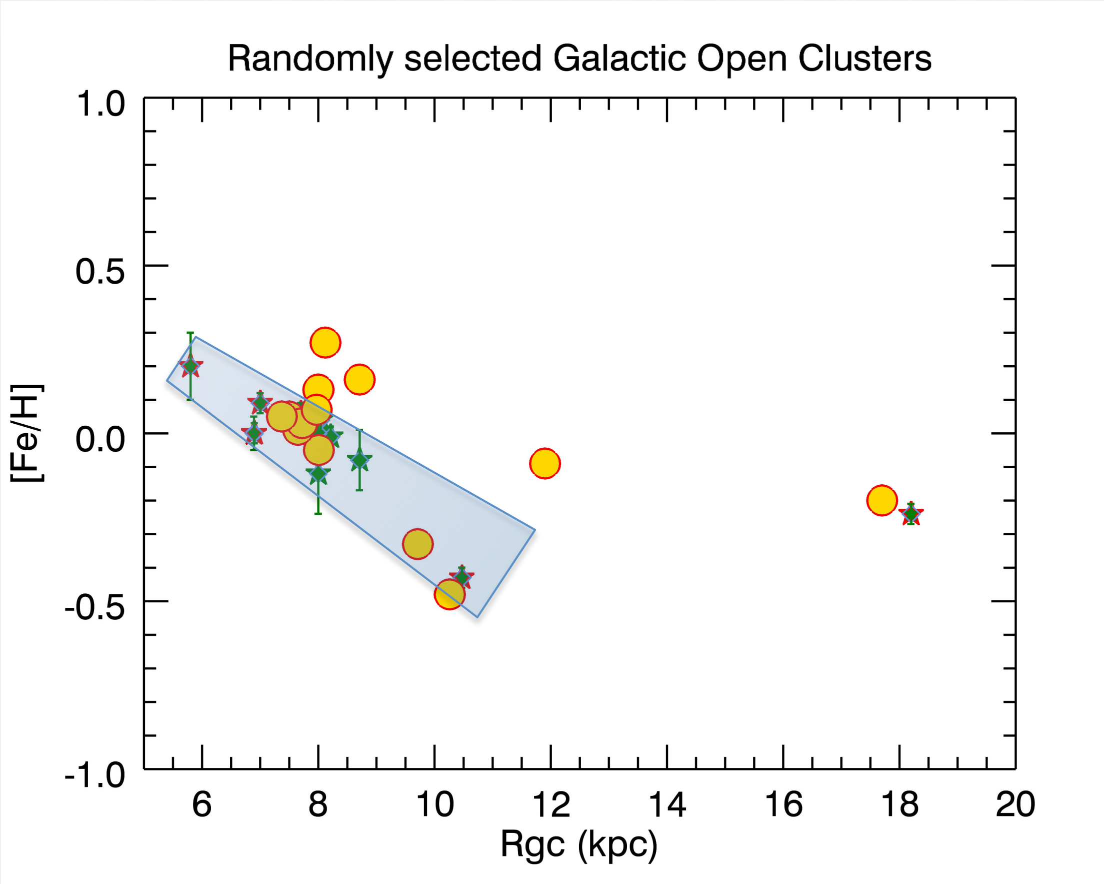


GES open clusters observed in the first 18 months:

- 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

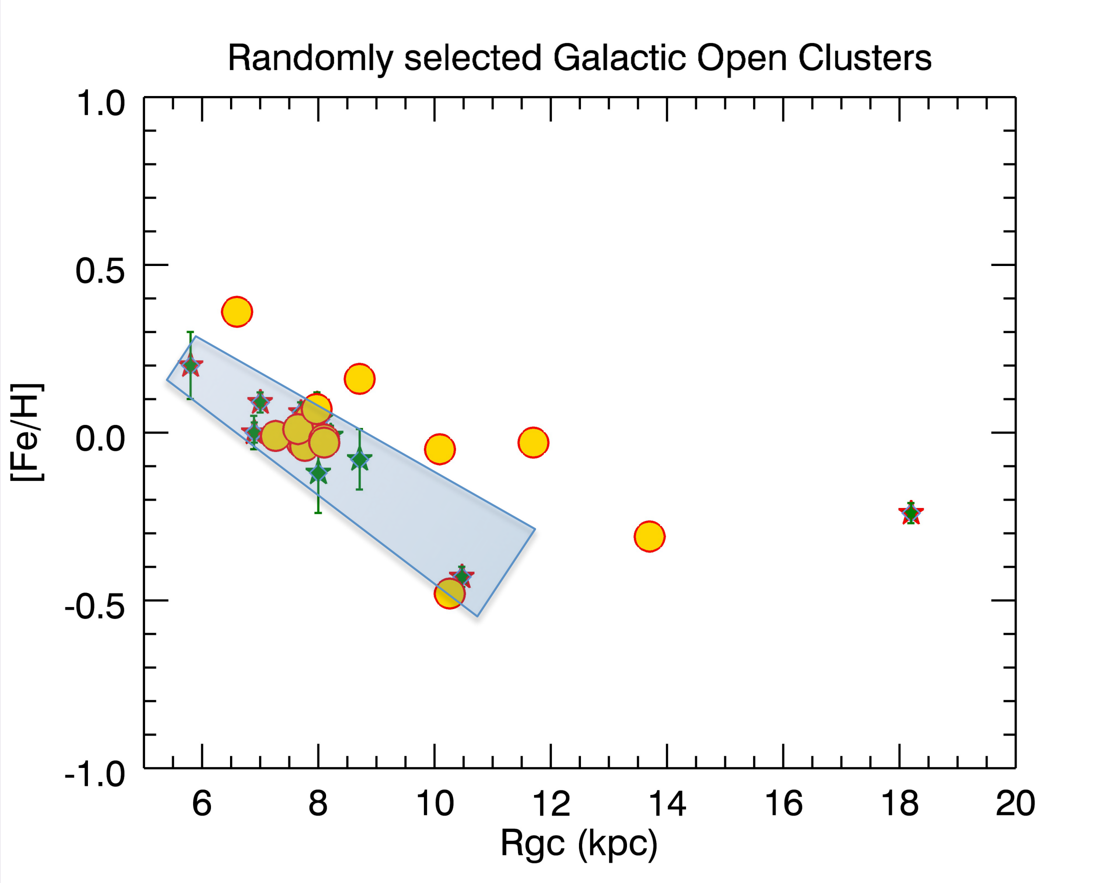


GES open clusters observed in the first 18 months:

- 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

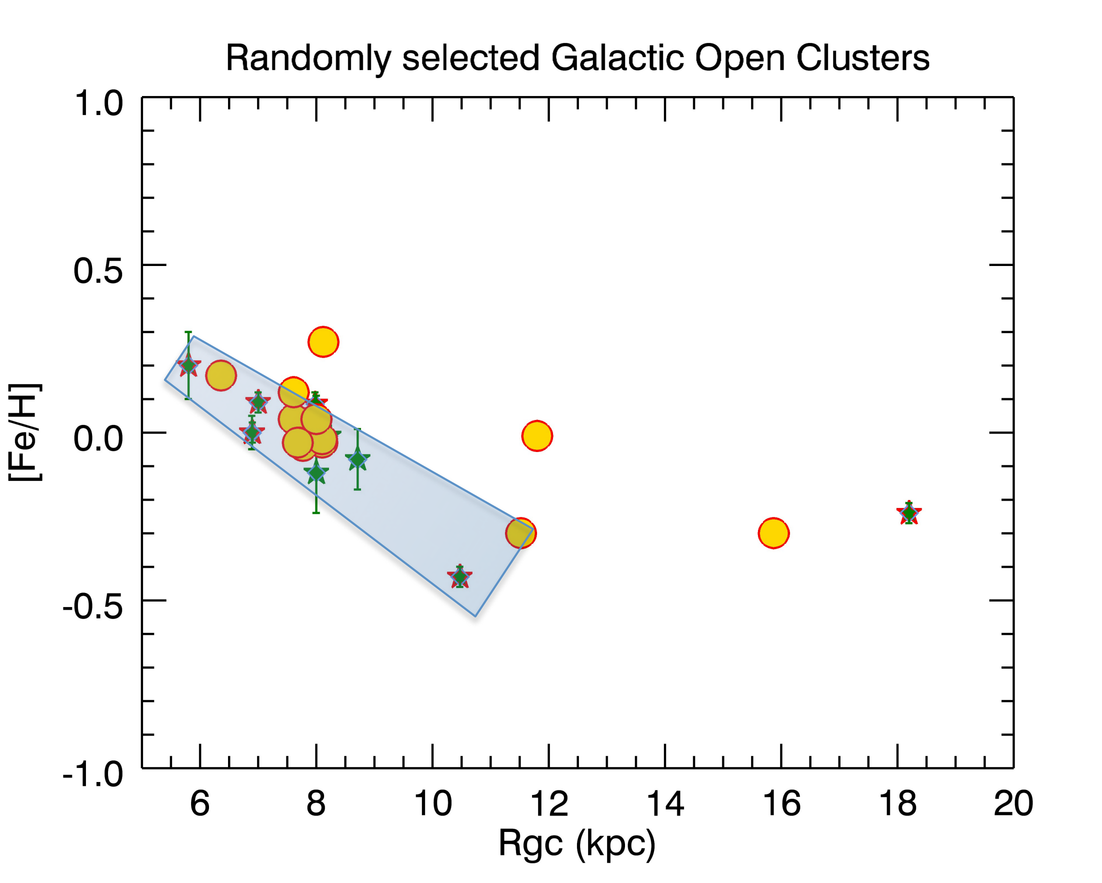


GES open clusters observed in the first 18 months:

- 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



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!

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) [see Grazina's and Rodolfo's talks]
- To test the recovering of dispersed clusters via chemical tagging [see Sergi's work and Daniel Zucker's talk]

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) [see Grazina's and Rodolfo's talks]
- To test the recovering of dispersed clusters via chemical tagging [see Sergi's work and Daniel Zucker's talk]

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%
^{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%
^{51}V	Massive Stars and SNIa	explosive Si and O burnings, SNIa with He detonation, and α and ν	88%
^{52}Cr	Massive Stars and SNIa	explosive Si burning, SNIa with He detonation, and α	84%
^{55}Mn	Massive Stars and SNIa	explosive Si burning, SNIa, and ν-wind	96%
^{56}Fe	Massive Stars and SNIa	explosive Si burning and SNIa	88%
^{58}Ni	Massive Stars (and SNIa)	α (α-rich freeze-out from nuclear statistical equilibrium) and SNIa	75%
^{59}Co	Massive Stars and SNIa	He-burning s-process, α, SNIa, and ν	99%
^{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%
^{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%
^{51}V	Massive Stars and SNIa	explosive Si and O burnings, SNIa with He detonation, and α and ν	88%
^{52}Cr	Massive Stars and SNIa	explosive Si burning, SNIa with He detonation, and α	84%
^{55}Mn	Massive Stars and SNIa	explosive Si burning, SNIa, and ν-wind	96%
^{56}Fe	Massive Stars and SNIa	explosive Si burning and SNIa	88%
^{58}Ni	Massive Stars (and SNIa)	α (α-rich freeze-out from nuclear statistical equilibrium) and SNIa	75%
^{59}Co	Massive Stars and SNIa	He-burning s-process, α, SNIa, and ν	99%
^{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%
^{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%
^{51}V	Massive Stars and SNIa	explosive Si and O burnings, SNIa with He detonation, and α and ν	88%
^{52}Cr	Massive Stars and SNIa	explosive Si burning, SNIa with He detonation, and α	84%
^{55}Mn	Massive Stars and SNIa	explosive Si burning, SNIa, and ν-wind	96%
^{56}Fe	Massive Stars and SNIa	explosive Si burning and SNIa	88%
^{58}Ni	Massive Stars (and SNIa)	α (α-rich freeze-out from nuclear statistical equilibrium) and SNIa	75%
^{59}Co	Massive Stars and SNIa	He-burning s-process, α, SNIa, and ν	99%
^{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%
^{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%
^{51}V	Massive Stars and SNIa	explosive Si and O burnings, SNIa with He detonation, and α and ν	88%
^{52}Cr	Massive Stars and SNIa	explosive Si burning, SNIa with He detonation, and α	84%
^{55}Mn	Massive Stars and SNIa	explosive Si burning, SNIa, and ν-wind	96%
^{56}Fe	Massive Stars and SNIa	explosive Si burning and SNIa	88%
^{58}Ni	Massive Stars (and SNIa)	α (α-rich freeze-out from nuclear statistical equilibrium) and SNIa	75%
^{59}Co	Massive Stars and SNIa	He-burning s-process, α, SNIa, and ν	99%
^{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	–

Chemical tagging:

how unique is the chemical pattern of each cluster?

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

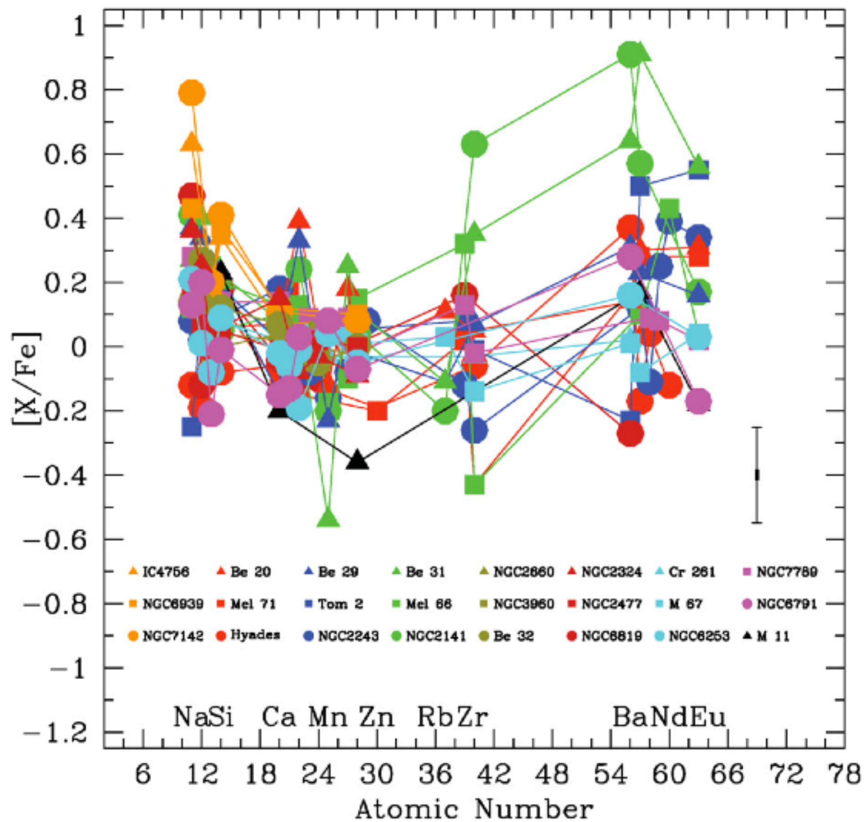


Figure 1. Elemental abundances of old open clusters. Each symbol represents the mean abundance value for individual clusters. The error bars show the typical measurement error. Original references of the cluster data are given in Table 1.

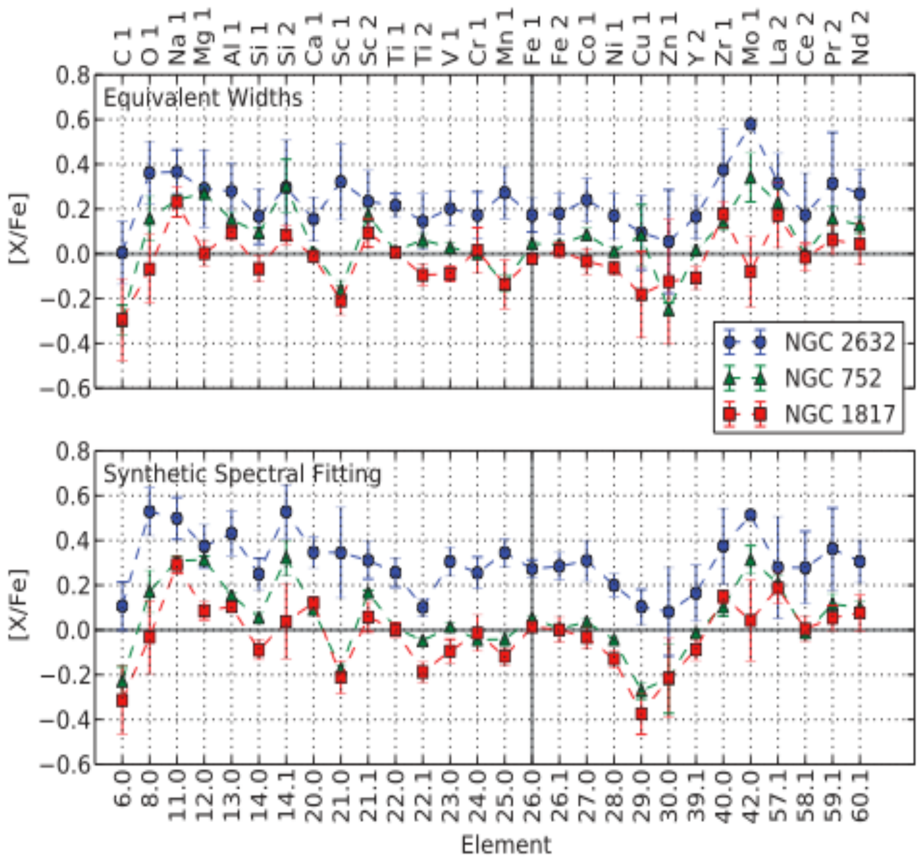
Da Silva+09:

- 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 aims of chemical tagging:
understand open clusters to find dispersed clusters



Blanco-Cuaresma+14:

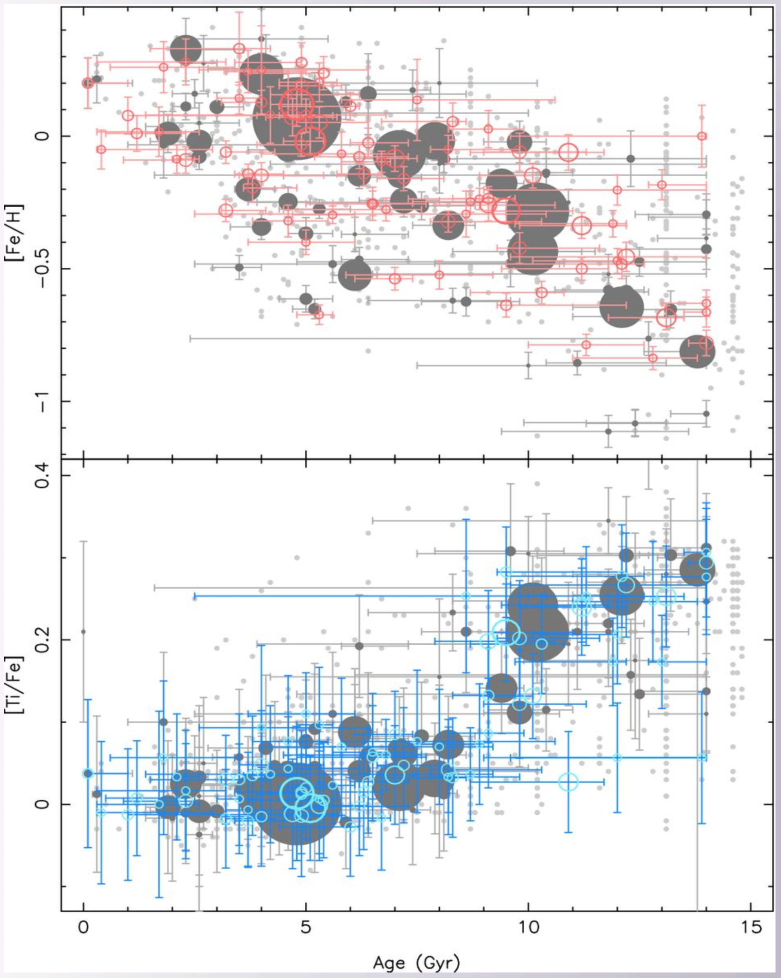
- using the technique of chemical tagging to identify common formation sites in the disk as proposed by Freeman & Bland-Hawthorn (2002)

Chemical tagging:

how unique is the chemical pattern of each cluster?

The aims of chemical tagging:

understand open clusters to find dispersed clusters



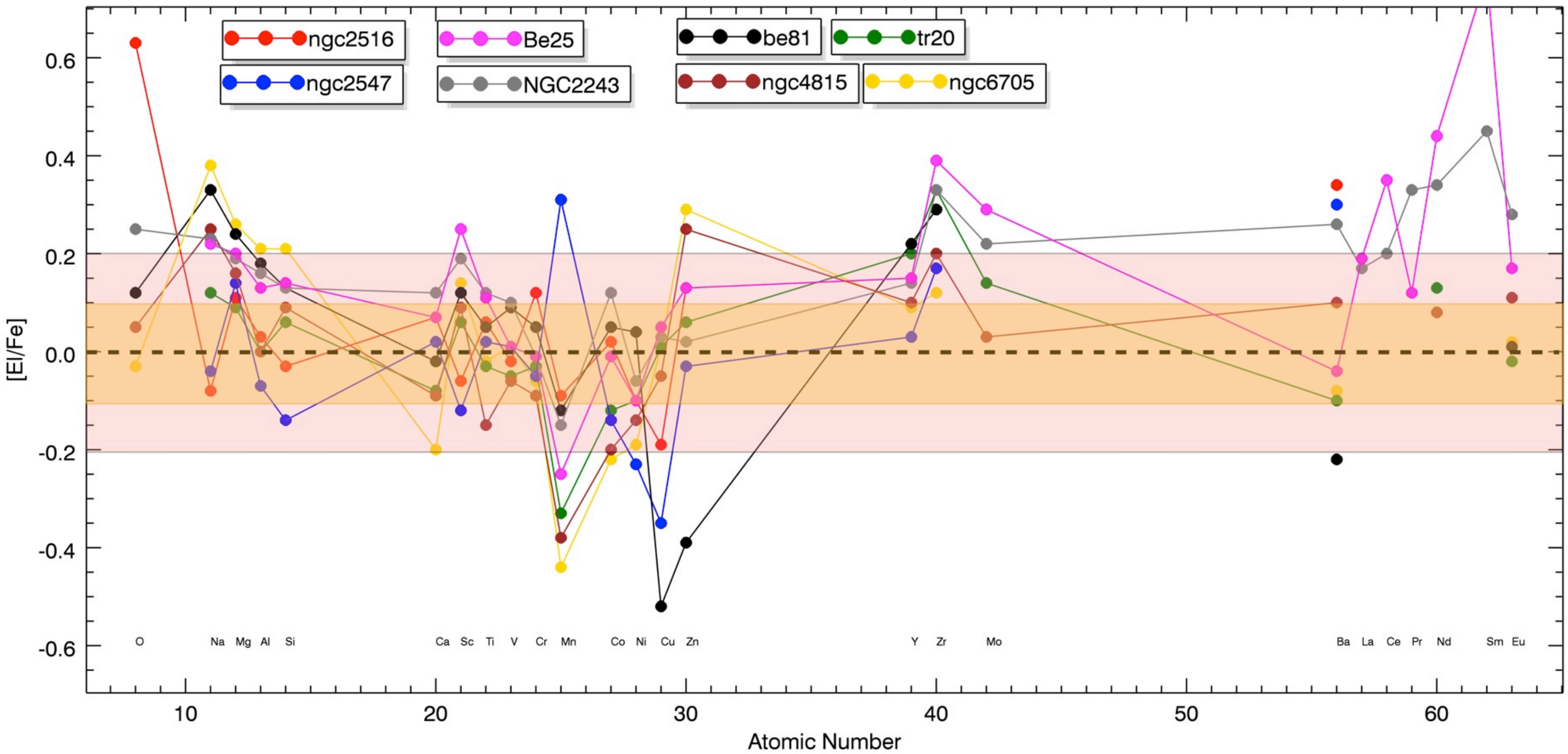
Mitschang+14:

- First blind chemical tagging experiments, after calibrating the method with Open clusters
- 714 field stars to find their possible parent cluster
- identify coeval groups of stars, yet these groups may not represent distinct formation sites, e.g. as in dissolved open clusters, as previously thought.

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)



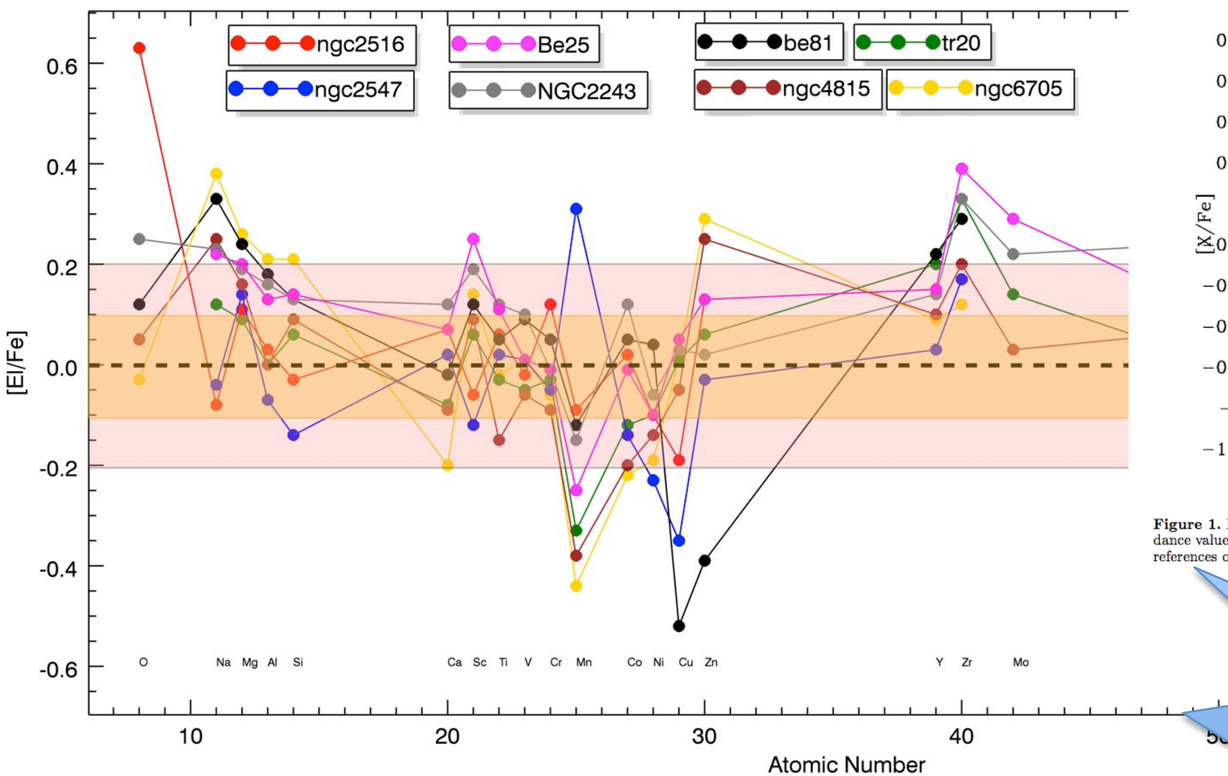
Different clusters have different elemental abundance patterns.
There is also significant scatter for many of the elements:

- systematic uncertainties in elements with few lines
- <u>intrinsic variations</u>, especially in elements showing excessive scatter

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)



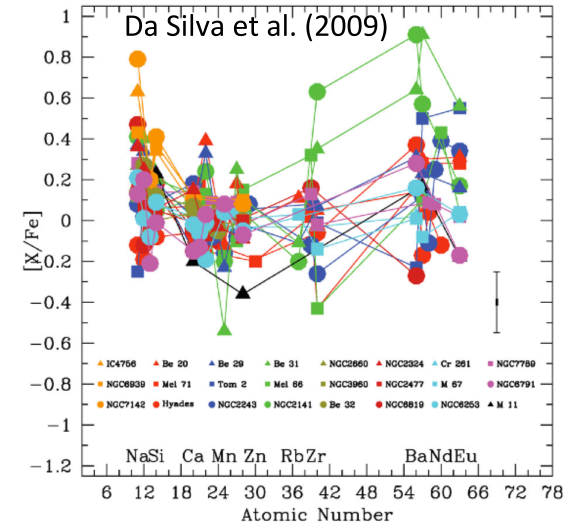


Figure 1. Elemental abundances of old open clusters. Each symbol represents the mean abundance value for individual clusters. The error bars show the typical measurement error. Original references of the cluster data are given in Table 1.

Most of the dispersion is due to different Galactocentric distances

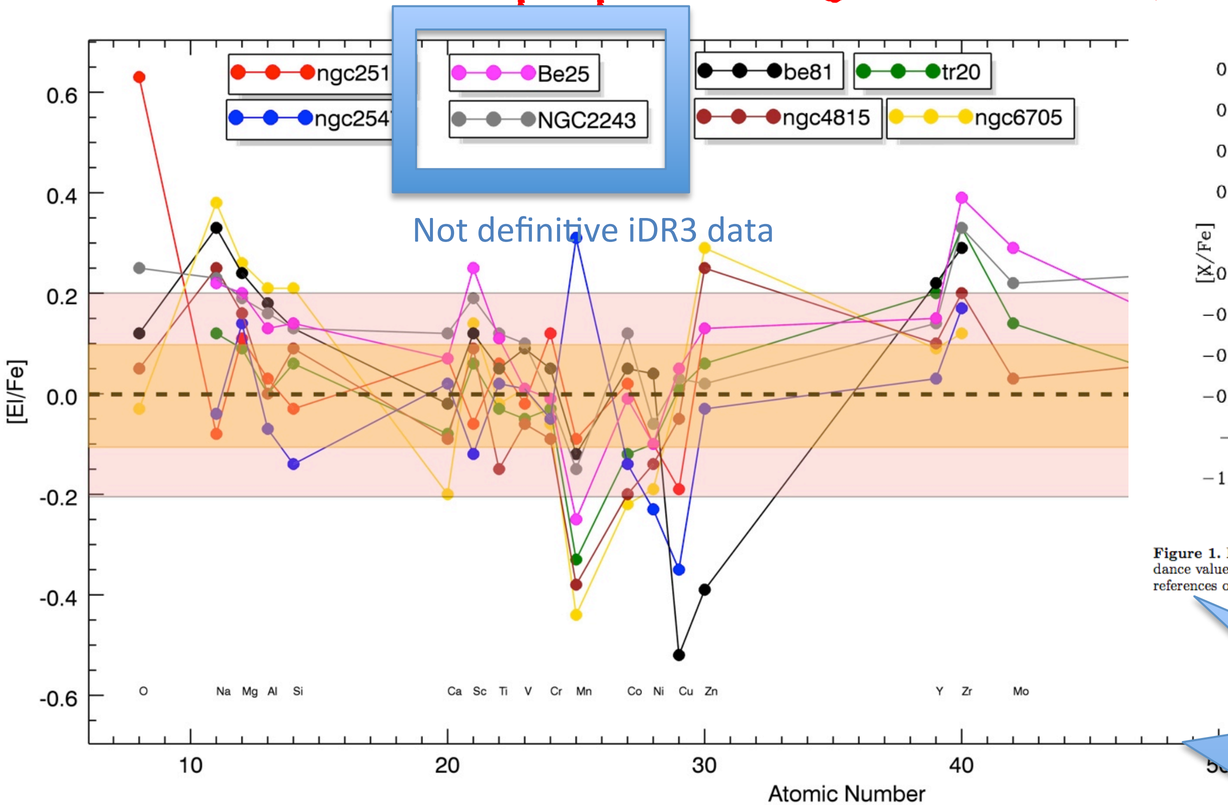
Different clusters have different elemental abundance patterns.
There is also significant scatter for many of the elements:

- systematic uncertainties in elements with few lines
- <u>intrinsic variations</u>, especially in elements showing excessive scatter

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)



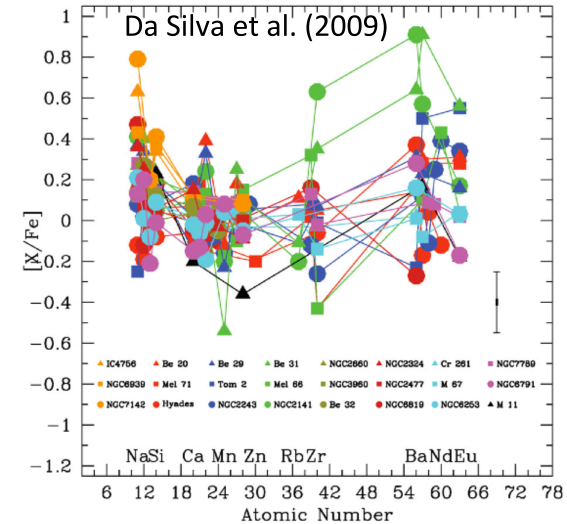


Figure 1. Elemental abundances of old open clusters. Each symbol repr sents the mean abundance value for individual clusters. The error bars show the typical me rement error. Original references of the cluster data are given in Table 1.

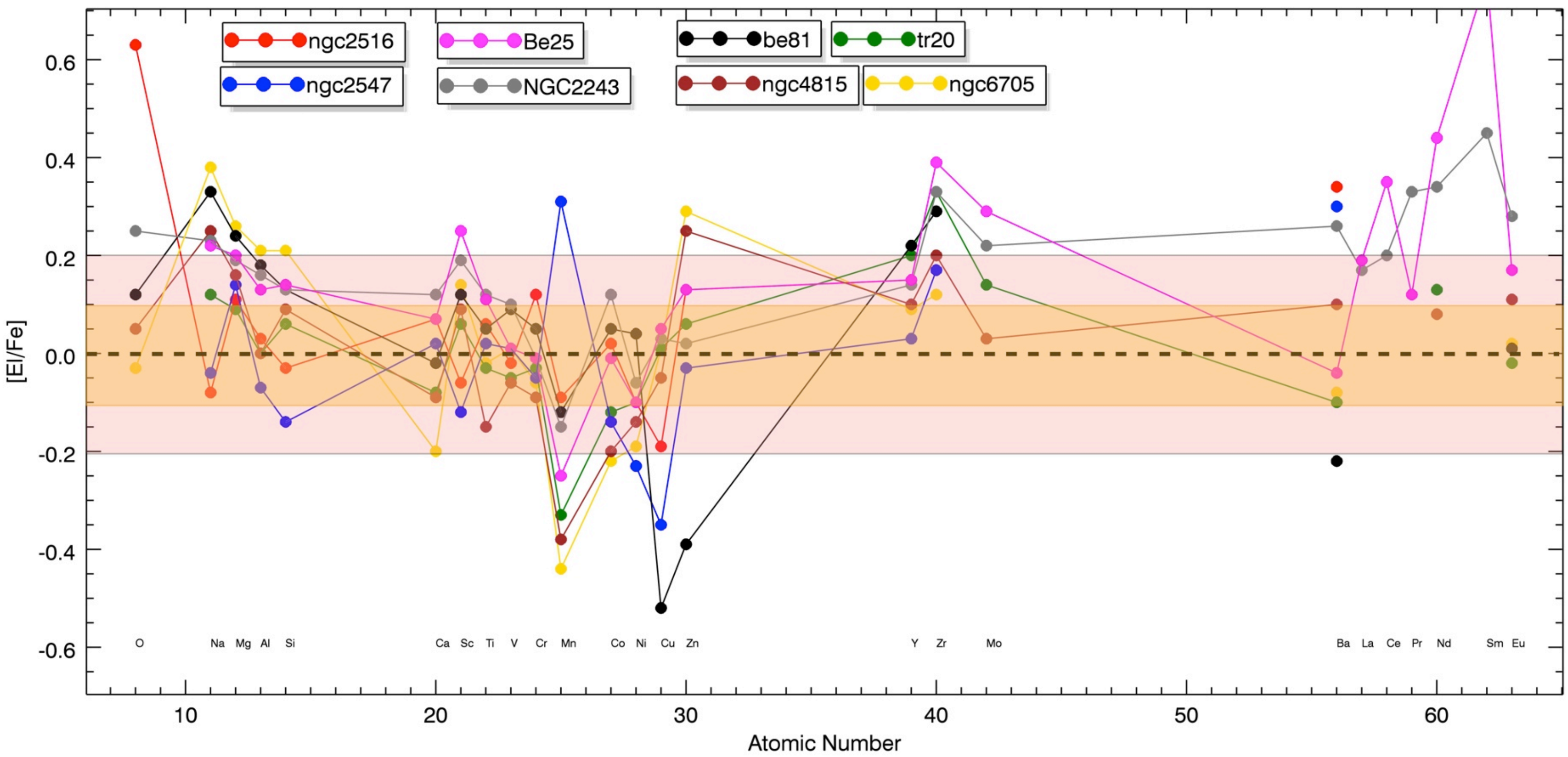
Most of the dispersion is due to different Galactocentric distances

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

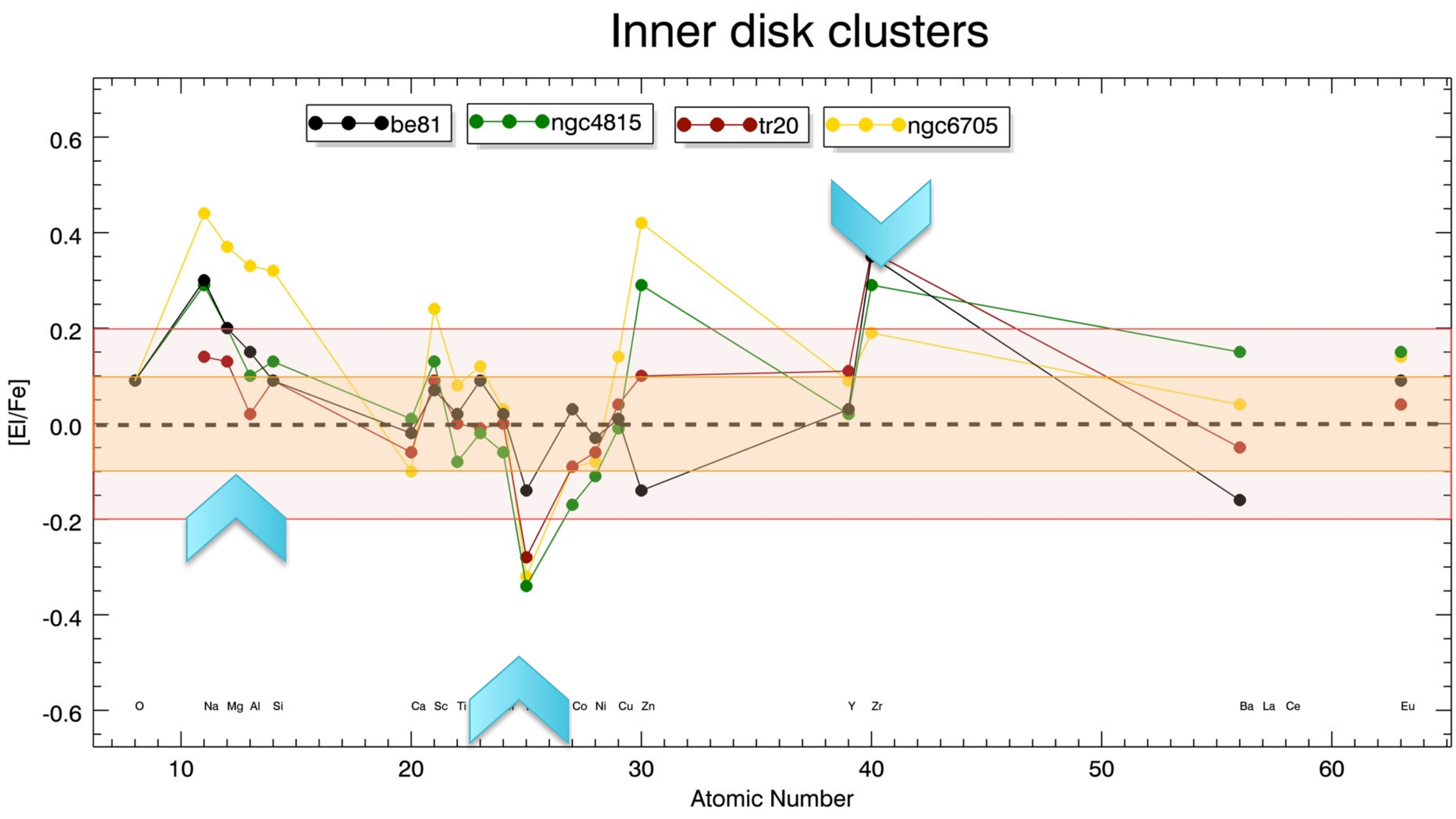
Chemical tagging:

a simple exercise with GES data



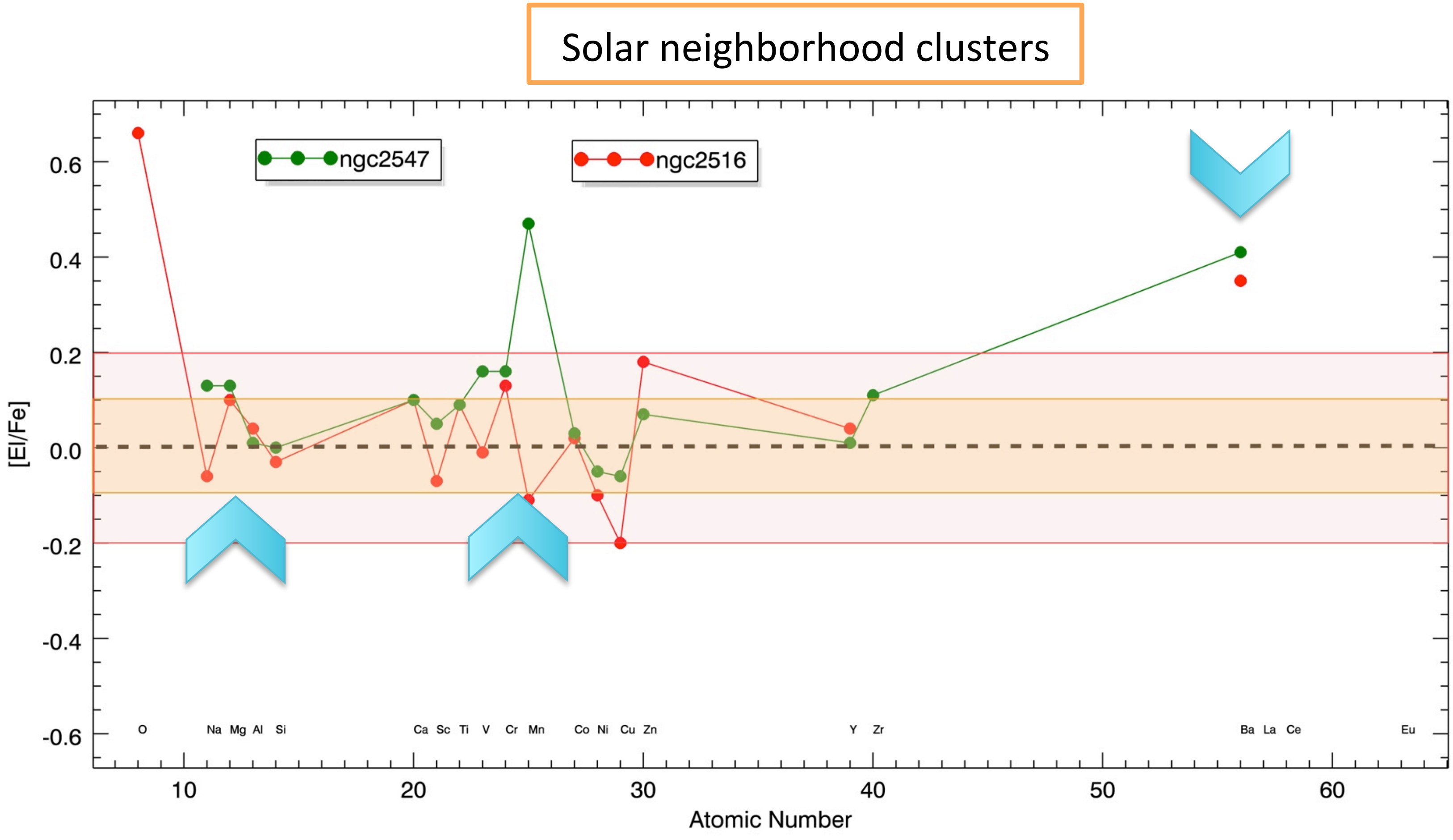
- All abundances are normalized to the Solar abundances as recommended by WG11.
- Enhancement respect to Solar: difference > +1-sigma
- Depletion respect to Solar: difference < -1-sigma

Chemical tagging



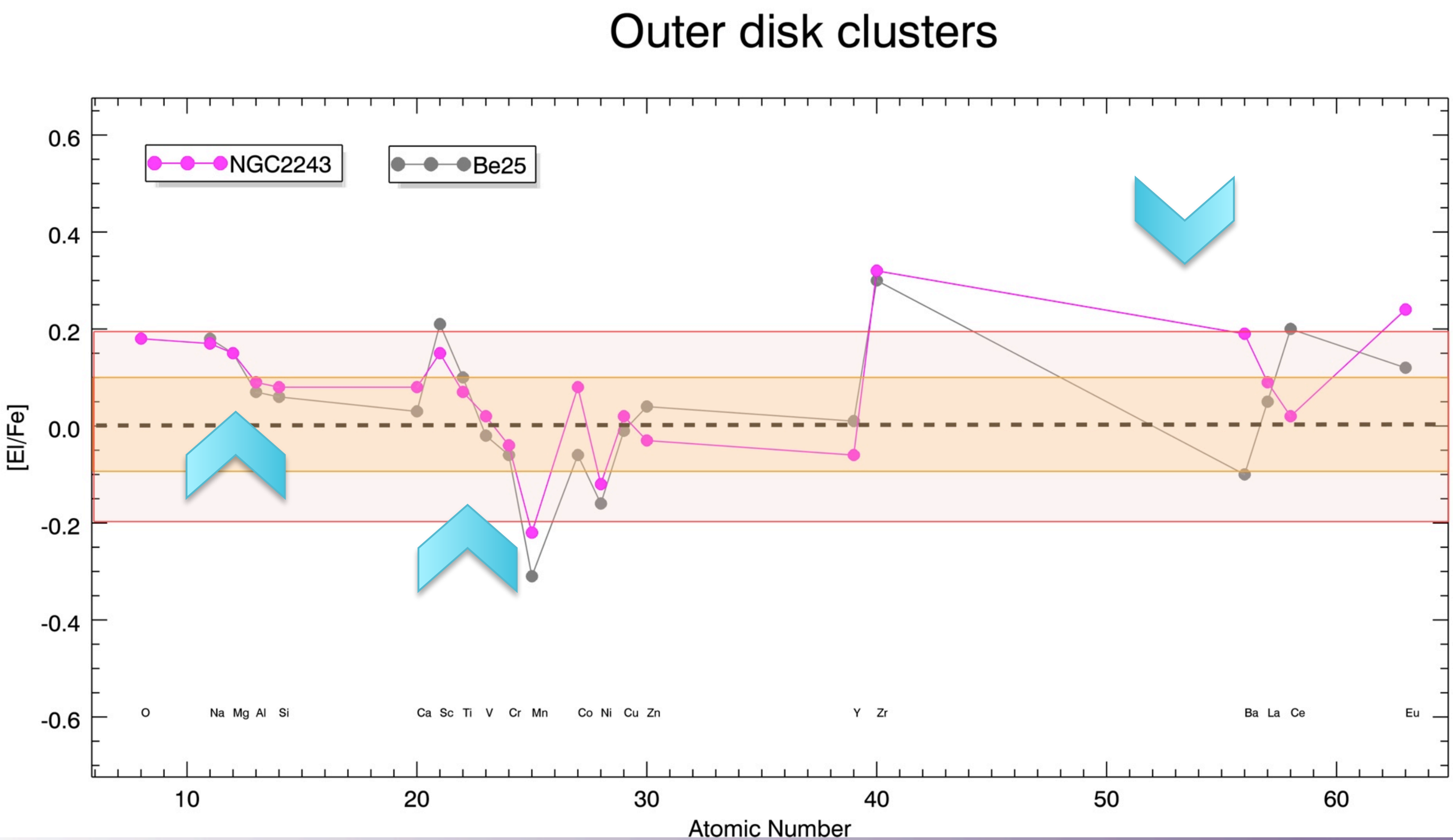
- Inner disk clusters: common trends in some abundance ratios
- Enhanced Mg and Si, depleted Mn, enhanced 1-peak elements

Chemical tagging



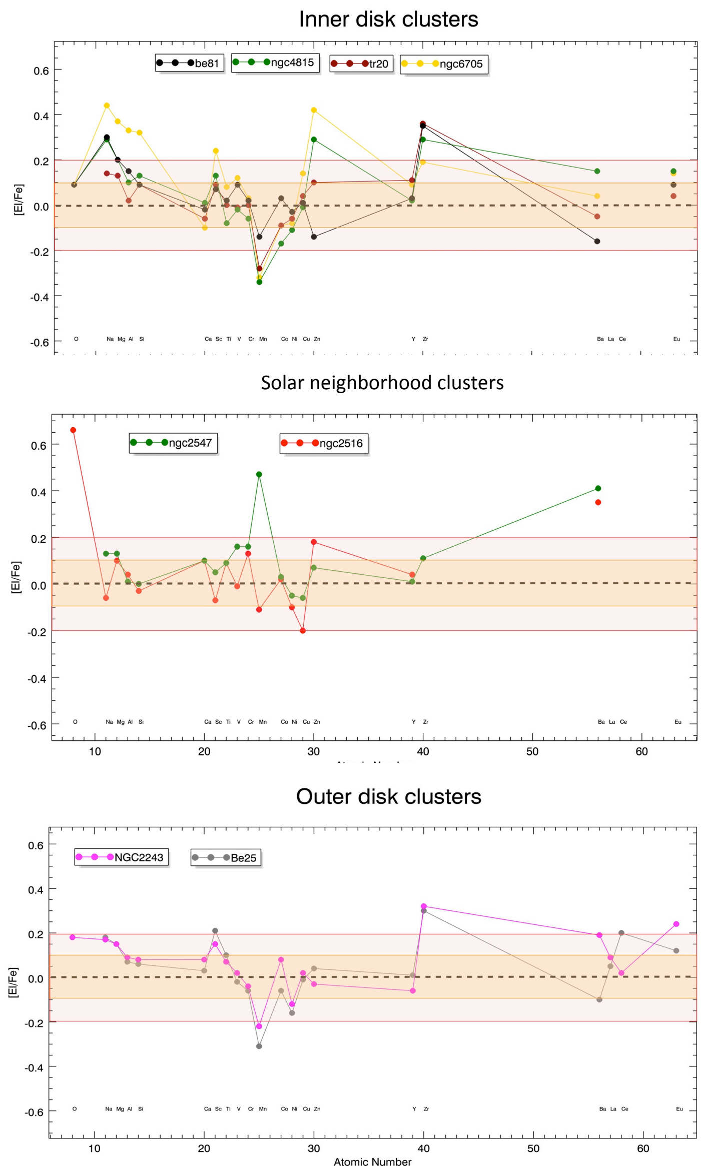
- Solar neighborhood clusters: almost solar in all elements
- Enhanced Ba: Age effect (see D'Orazi et al. (2009), Maiorca et al. 2012)

Chemical tagging



- Outer disk clusters: 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:

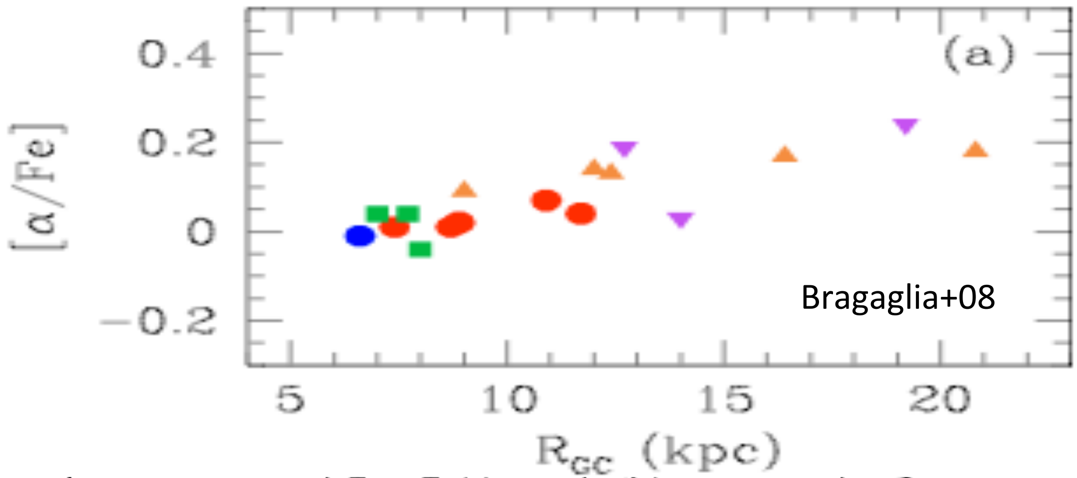
- To compare clusters belonging to different part of the disk
- To search for common behaviors/patterns that might be indicative and tracers of the disk evolution at different radii (as the two outer clusters, extremely similar in almost all elements)

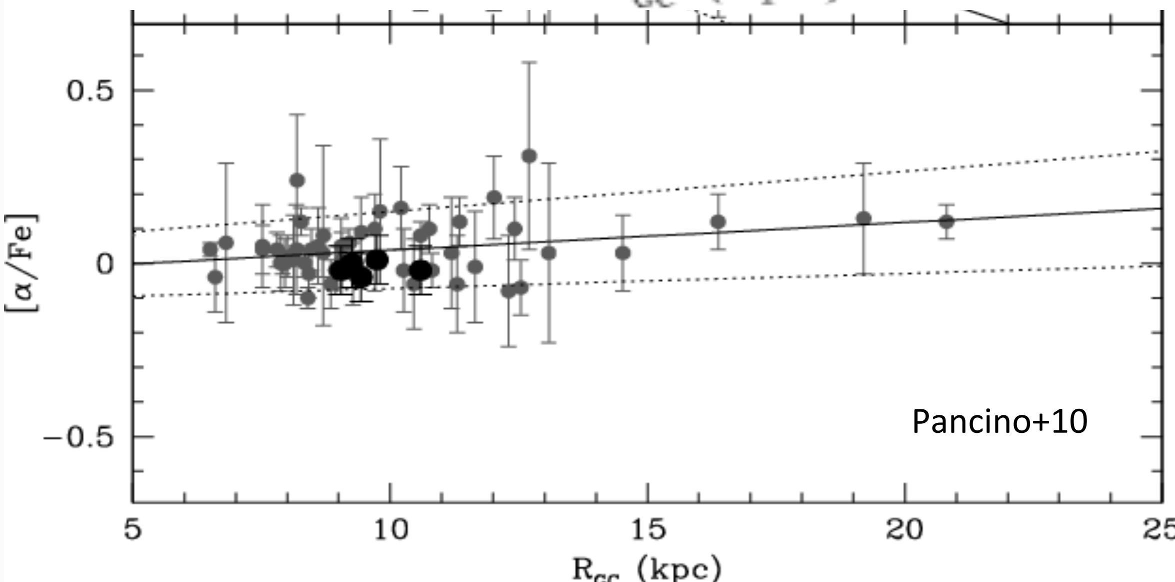
Conclusions:

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

Open clusters: not only iron!

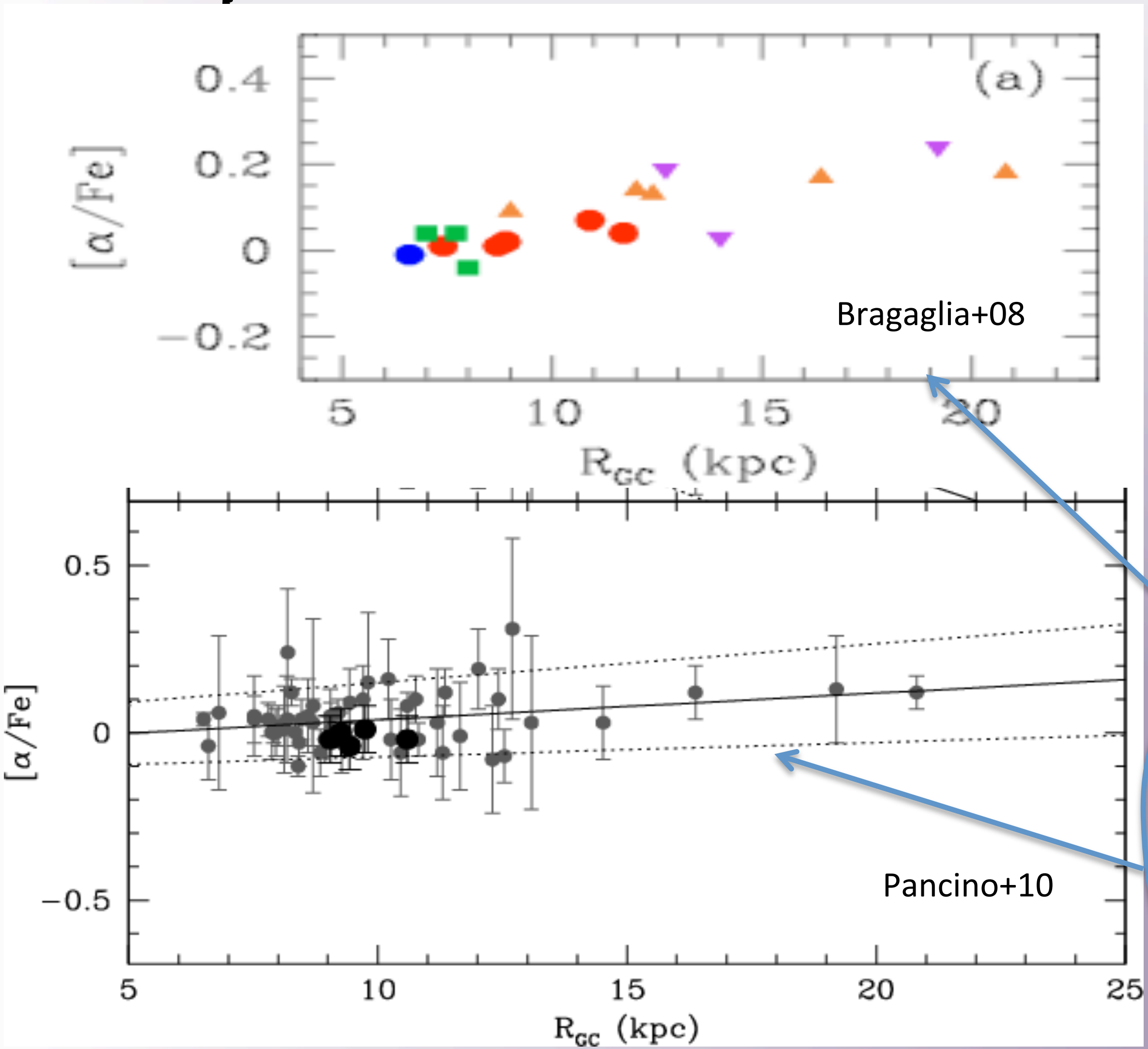




- The presence of a [Fe/H] gradient indicate a radial dependence of SFR/infall balance (the Galaxy forms more stars in its inner parts→ produces more metals)
- [α/Fe] is used to trace the star-formation timescale → it is sensitive to the ratio of SNII/SNIa
- An [α/Fe] enhancement in the outer part of the disk indicate different timescales for its constitution at different radii: merger process/infall/different SFR?????

Figure from Pancino et al. (2010). [α/Fe] enhanced in the outer disk found also by Carraro et al.2004, Yong et al. 2005, Bragaglia et al. (2008) and in field stars (Carney et al. 2005, Bensby et al.2011), and Cepheids (Yong et al.2006).

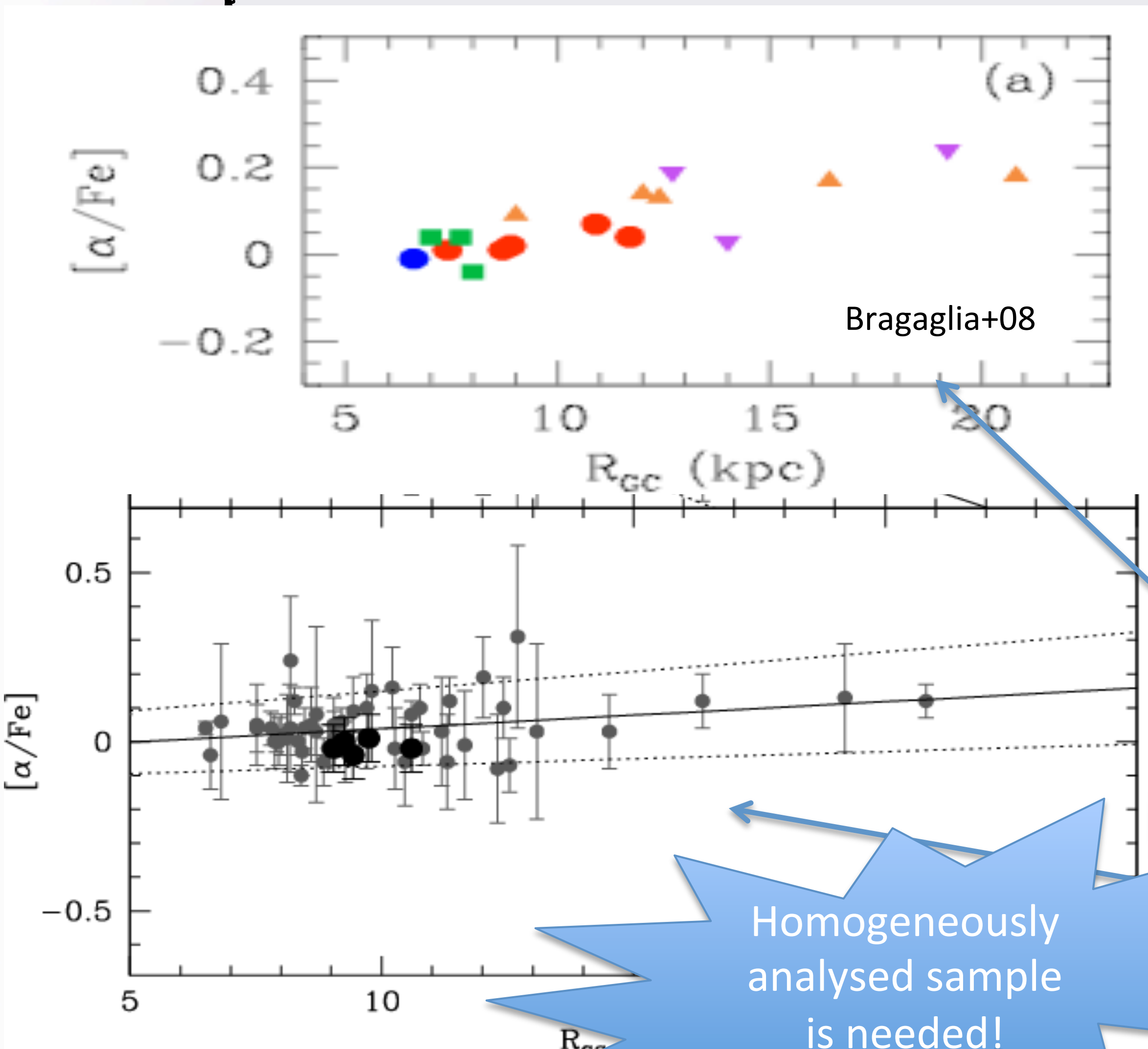
Open clusters: not only iron!



- The presence of a [Fe/H] gradient indicate a radial dependence of SFR fate/infall balance (the Galaxy forms more stars in its inner parts→ produces more metals)
- [α/Fe] is used to trace the star-formation timescale → it is sensitive to the ratio of SNII/SNIa
- An [α/Fe] enhancement in the outer part of the disk indicate different timescales for its constitution at different radii: merger process/infall/different SFR?????

Figure from Pancino et al. (2010). [α/Fe] enhanced in the outer disk found also by Carraro et al.2004, Yong et al. 2005, Bragaglia et al. (2008) and in field stars (Carney et al. 2005, Bensby et al.2011), and Cepheids (Yong et al.2006).

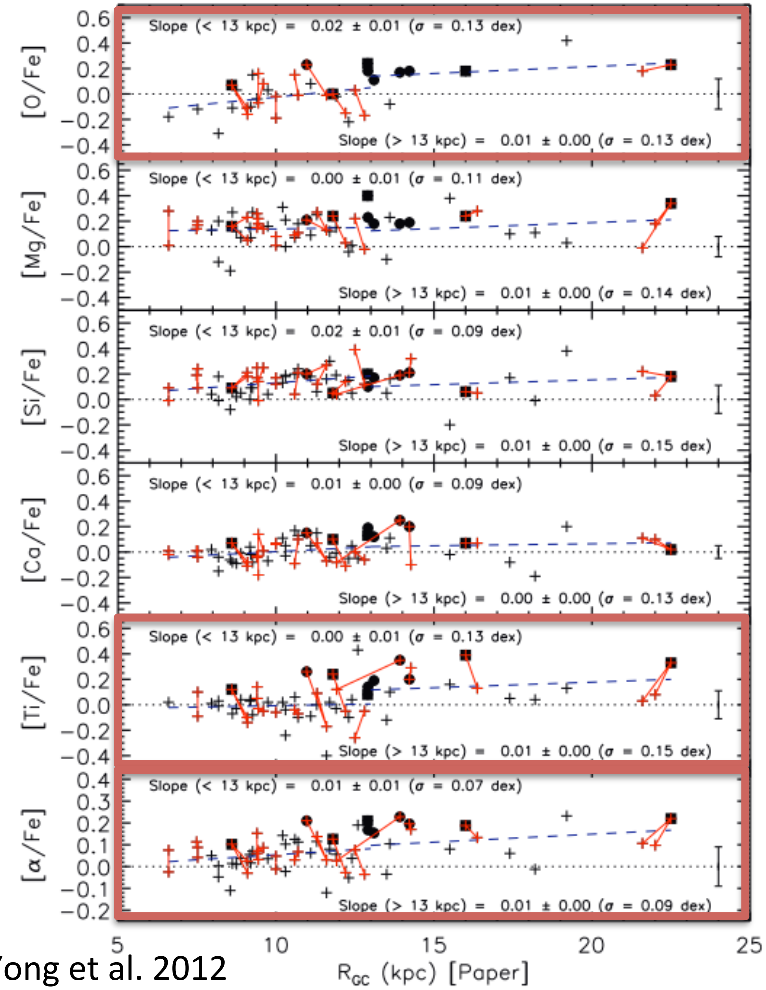
Open clusters: not only iron!



Homogeneously analysed sample is needed!

- The presence of a [Fe/H] gradient indicate a radial dependence of SFR fate/infall balance (the Galaxy forms more stars in its inner parts → produces more metals)
- [α/Fe] is used to trace the star-formation timescale → it is sensitive to the ratio of SNII/SNIa
- An [α/Fe] enhancement in the outer part of the disk indicate different timescales for its constitution at different radii: merger process/infall/different SFR?????

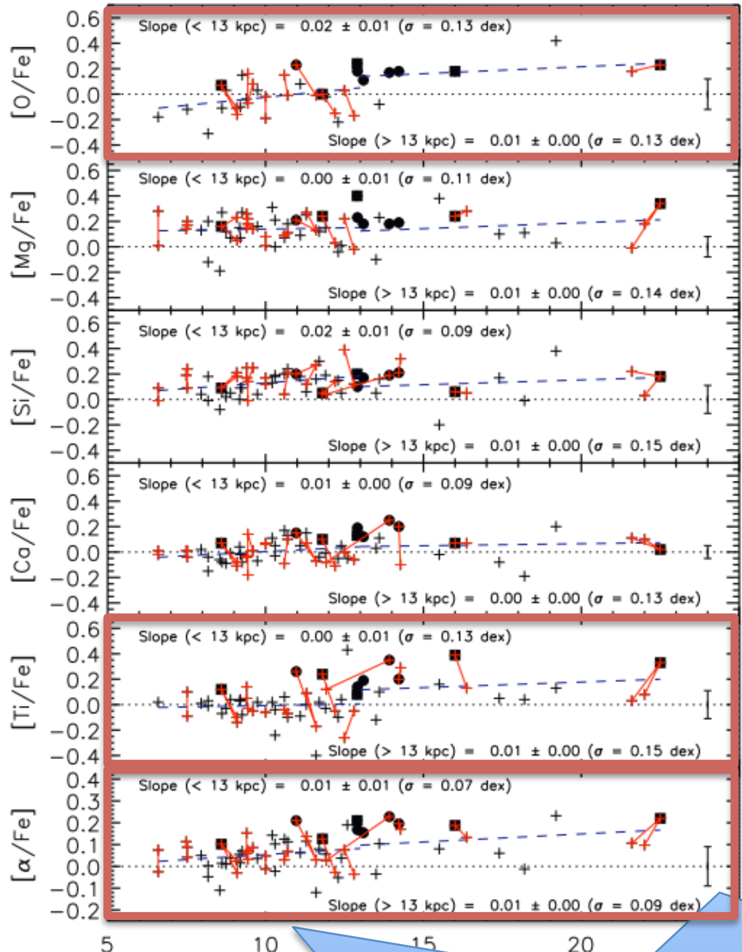
Figure from Pancino et al. (2010). [α/Fe] enhanced in the outer disk found also by Carraro et al.2004, Yong et al. 2005, Bragaglia et al. (2008) and in field stars (Carney et al. 2005, Bensby et al.2011), and Cepheids (Yong et al.2006).



Yong et al. 2012

From the literature (Yong et al. 2012):

- Almost all outer disk open clusters have super-solar [α/Fe] and [Eu/Fe] ratios. Such abundance ratios are different from the values found in the more metal-rich open clusters in the solar neighborhood
- **[O/Fe], [Ti/Fe], and [α/Fe] ratios differ between the inner and outer disks at the 3σ level or higher** (assuming a boundary of 13 kpc). Mg, Si, and Ca do not show significant differences for [X/Fe] between the two regions.



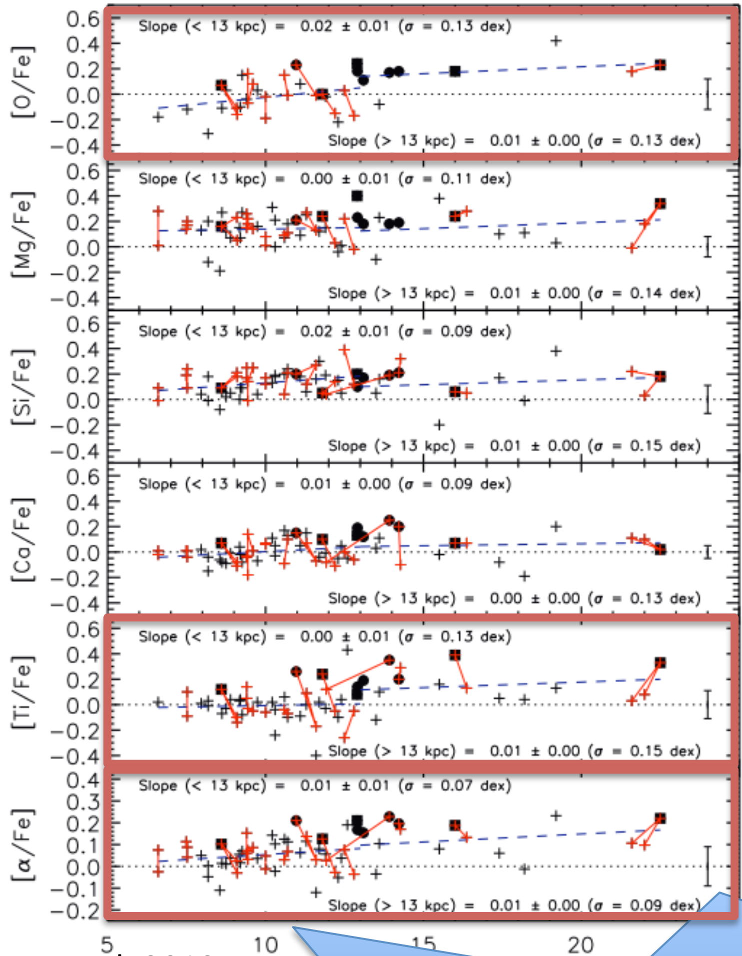
Yong et al. 2012

From the literature (Yong et al. 2012):

- Almost all outer disk open clusters have super-solar [α/Fe] and [Eu/Fe] ratios. Such abundance ratios are different from the values found in the more metal-rich open clusters in the solar neighborhood

- **[O/Fe], [Ti/Fe], and [α/Fe] ratios differ between the inner and outer disks at the 3σ level or higher** (assuming a boundary of 13 kpc). Mg, Si, and Ca do not show significant differences for [X/Fe] between the two regions.

Final remark from Yong+12:
any interpretation of the abundance ratios needs to acknowledge that the open clusters were studied by various authors who adopted different analysis techniques



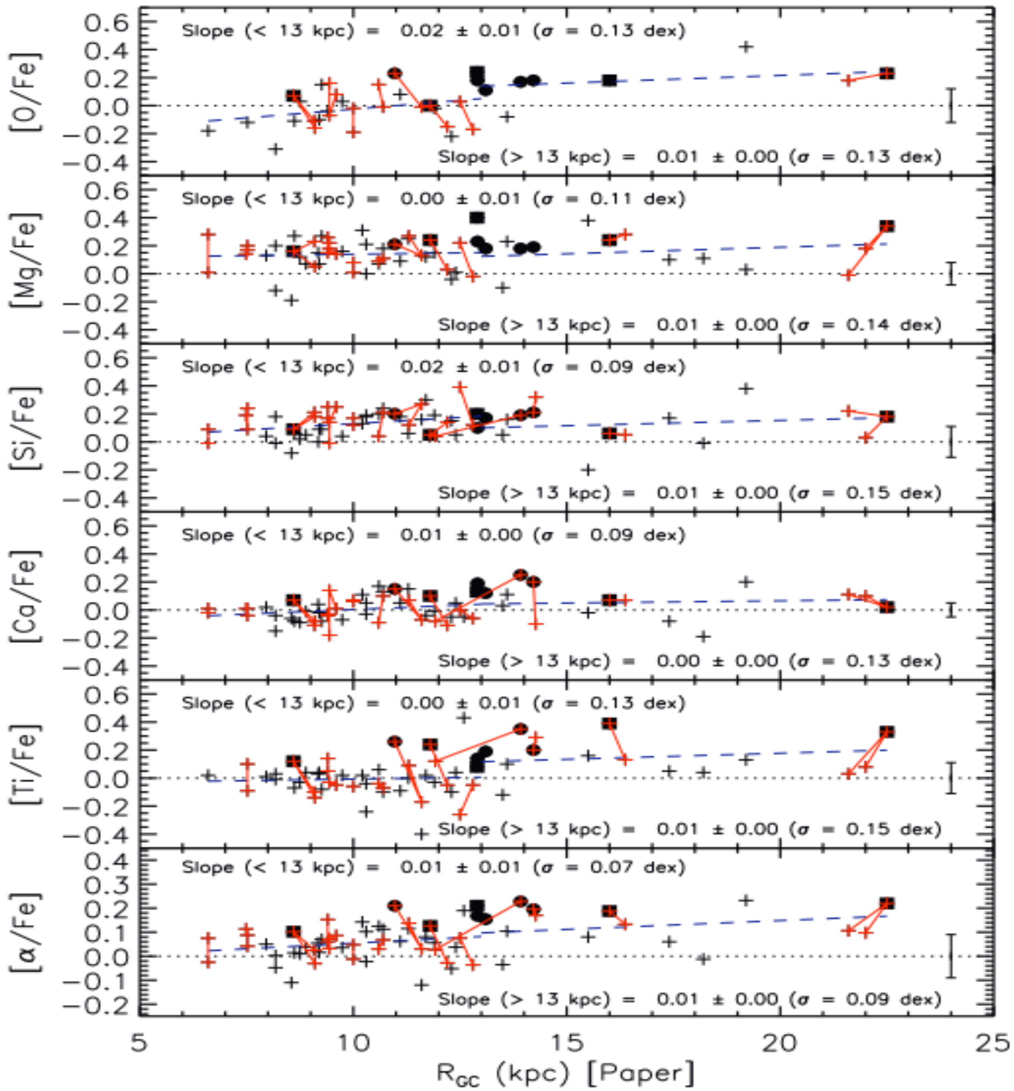
Yong et al. 2012

From the literature (Yong et al. 2012):

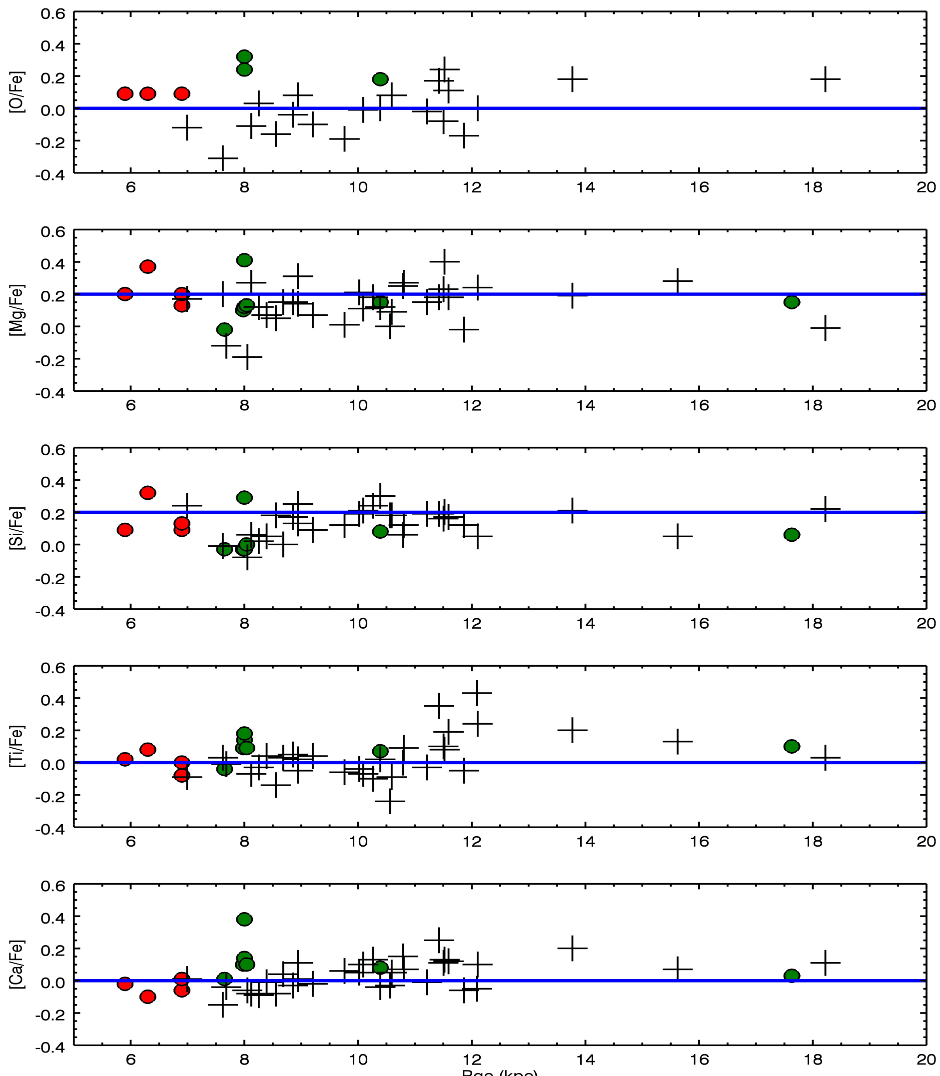
- Almost all outer disk open clusters have super-solar [α/Fe] and [Eu/Fe] ratios. Such abundance ratios are different from the values found in the more metal-rich open clusters in the solar neighborhood

- **[O/Fe], [Ti/Fe], and [α/Fe] ratios differ between the inner and outer disks at the 3σ level or higher** (assuming a boundary of 13 kpc). Mg, Si, and Ca do not show significant differences for [X/Fe] between the two regions.

Final remark from Yong+12:
any interpretation of the abundance ratios needs to acknowledge that the open clusters were studied by various authors who adopted different analysis techniques

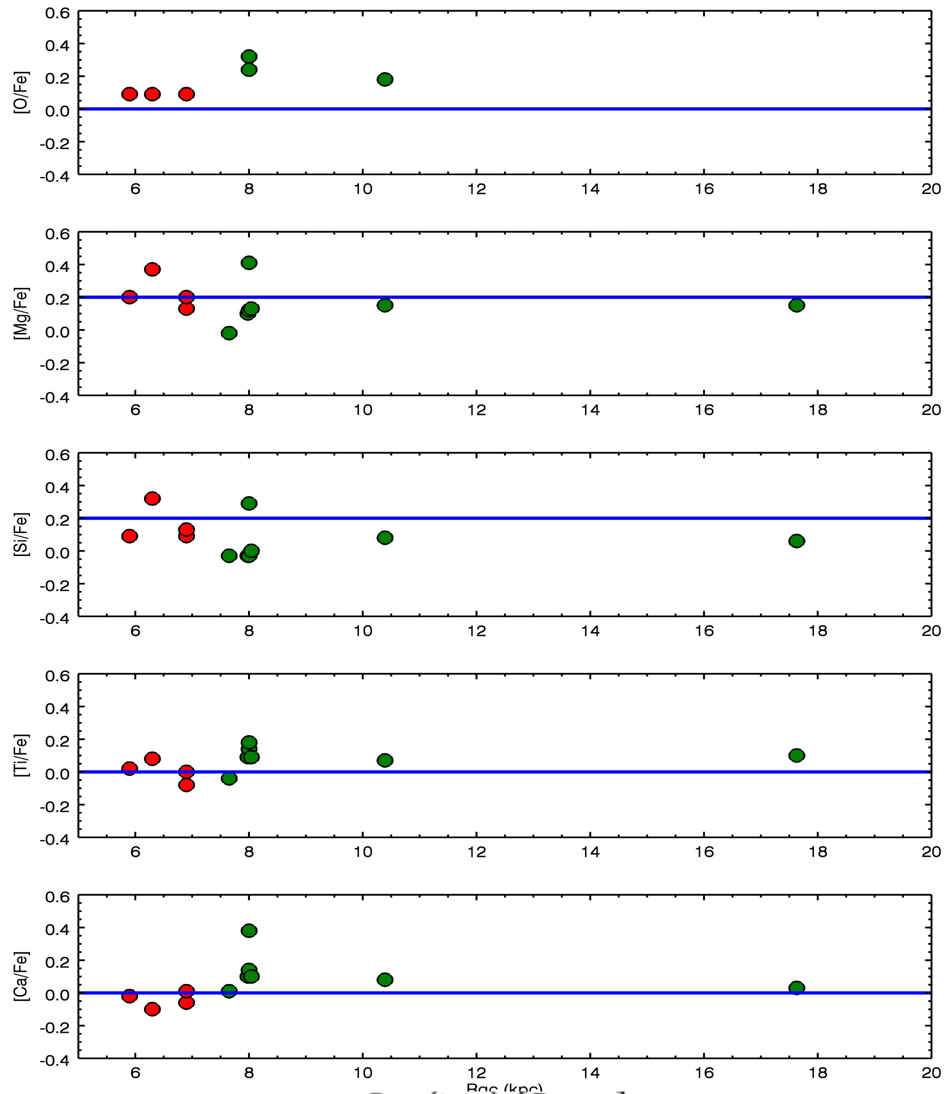


Slope (< 13 kpc) = 0.02 ± 0.01 (σ = 0.13 dex)
Slope (> 13 kpc) = 0.01 ± 0.00 (σ = 0.13 dex)
[O/Fe]
Slope (< 13 kpc) = 0.00 ± 0.01 (σ = 0.11 dex)
Slope (> 13 kpc) = 0.01 ± 0.00 (σ = 0.14 dex)
[Mg/Fe]
Slope (< 13 kpc) = 0.02 ± 0.01 (σ = 0.09 dex)
Slope (> 13 kpc) = 0.01 ± 0.00 (σ = 0.15 dex)
[Si/Fe]
Slope (< 13 kpc) = 0.01 ± 0.00 (σ = 0.09 dex)
Slope (> 13 kpc) = 0.00 ± 0.00 (σ = 0.13 dex)
[Ca/Fe]
Slope (< 13 kpc) = 0.00 ± 0.01 (σ = 0.13 dex)
Slope (> 13 kpc) = 0.01 ± 0.00 (σ = 0.15 dex)
[Ti/Fe]
Slope (< 13 kpc) = 0.01 ± 0.01 (σ = 0.07 dex)
Slope (> 13 kpc) = 0.01 ± 0.00 (σ = 0.09 dex)
[α/Fe]
R_GC (kpc) [Paper]



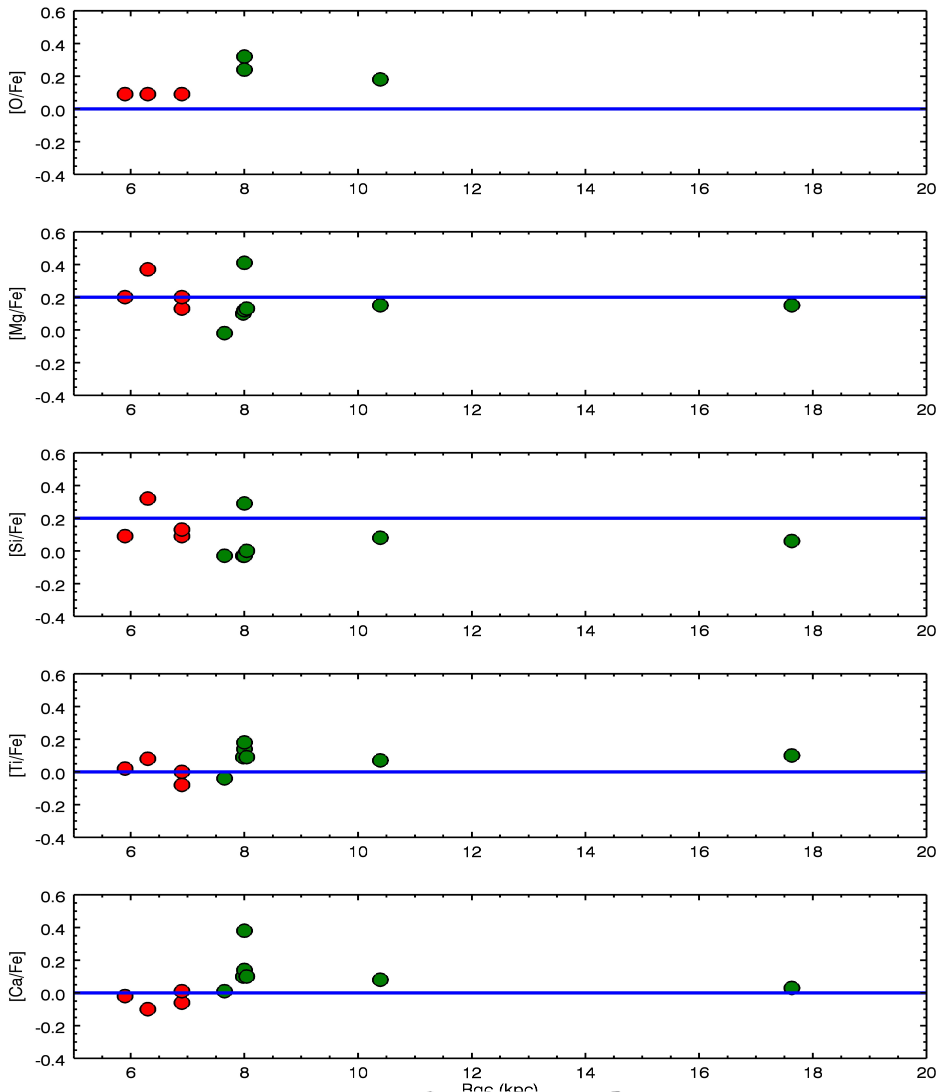
GES open clusters observed in the first 18 months:

- No clear [α/Fe]
- Inner disk cluster more enhanced than the literature sample



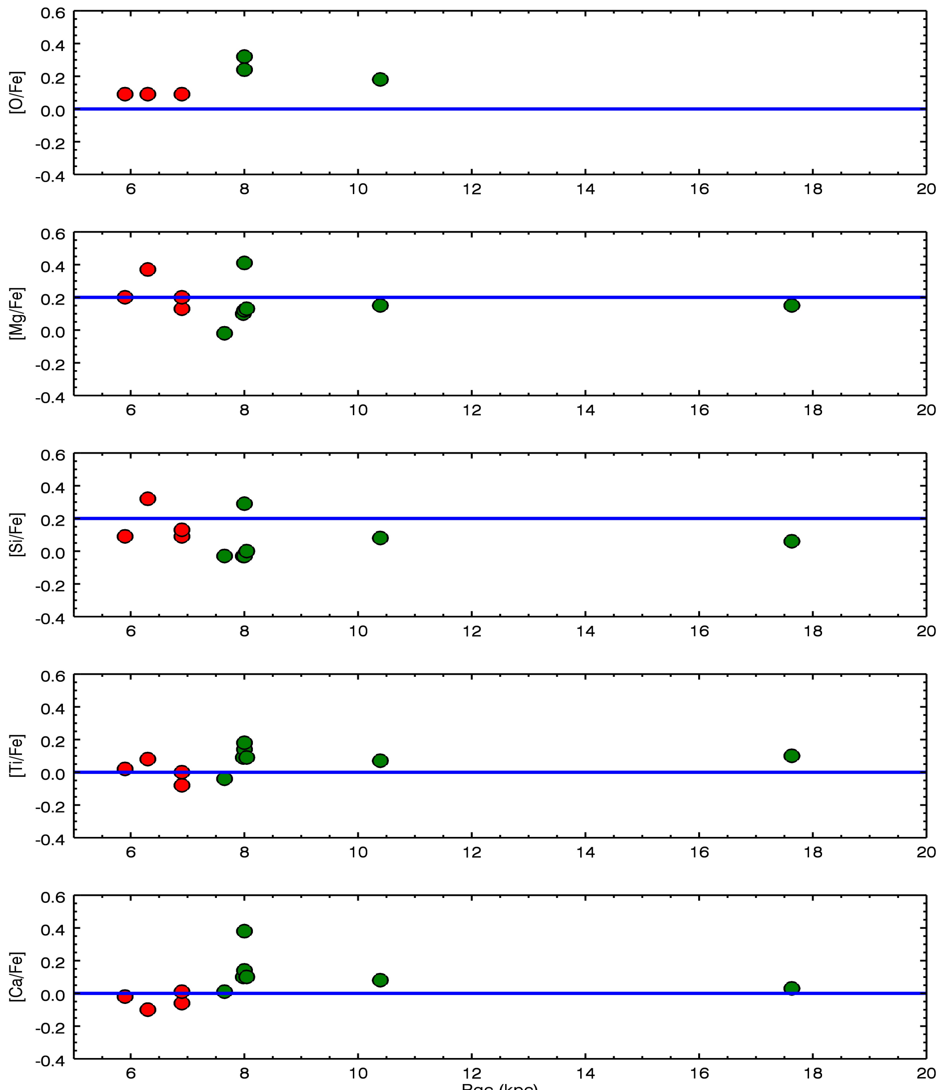
GES open clusters observed in the first 18 months:

- No clear [α/Fe]
- Inner disk cluster more enhanced than the literature sample



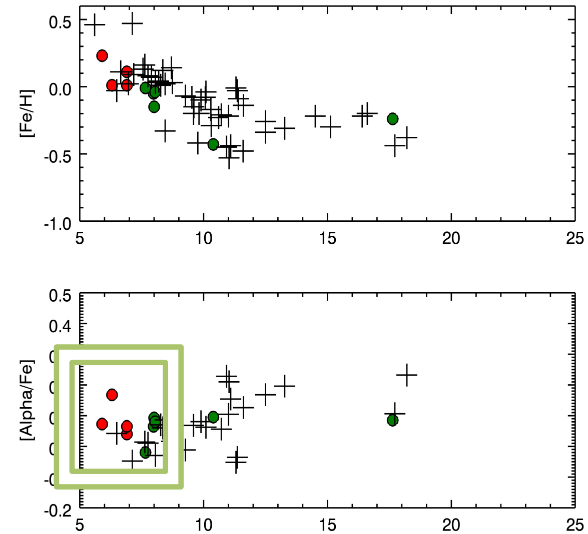
GES open clusters observed in the first 18 months:

- No clear [α/Fe]
- Inner disk cluster more enhanced than the literature sample



GES open clusters observed in the first 18 months:

- No clear [α/Fe]
- Inner disk cluster more enhanced than the literature sample



- The single element enhancement is not appreciable with present GES data, and barely visible with Yong+12 data.
- [α/Fe] shows a more evident trend with Yong+12, low statistics of GES is consistent with a flat trend.
- **α-enhancement in the outer disk Is fundamental to understand the mechanisms of its formations**: has it been growing steadily, perhaps by episodic accretion events involving metal-poor stars and gas? Or it was formed by stars migrated from the co-rotation radius (see Lepine+10)? .