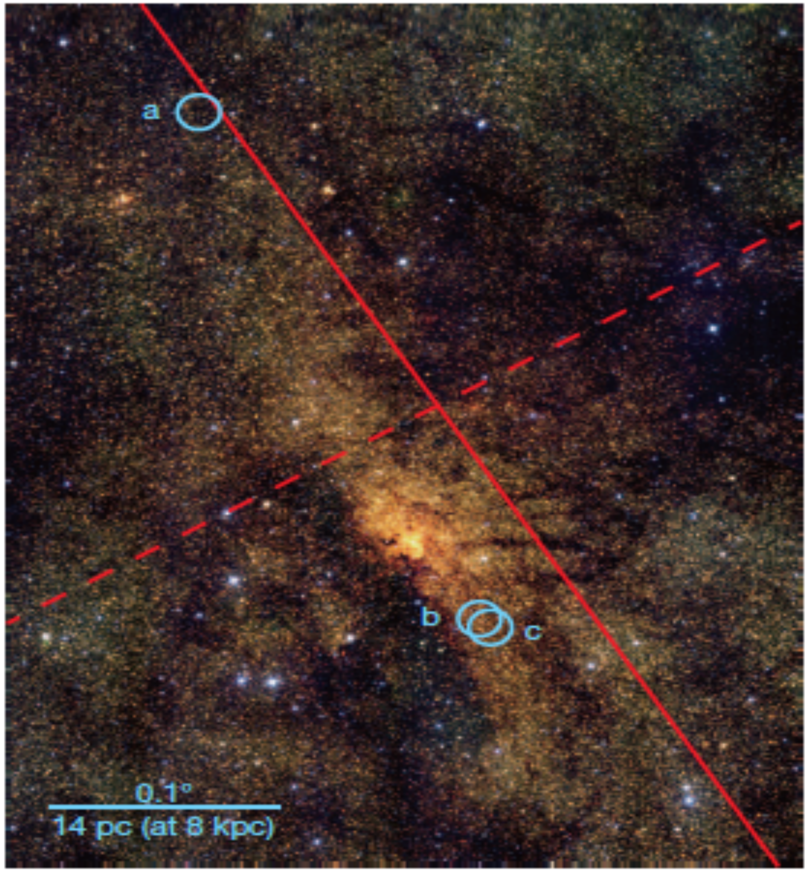
On the metallicity distribution across the Galactic thin disk using Cepheids

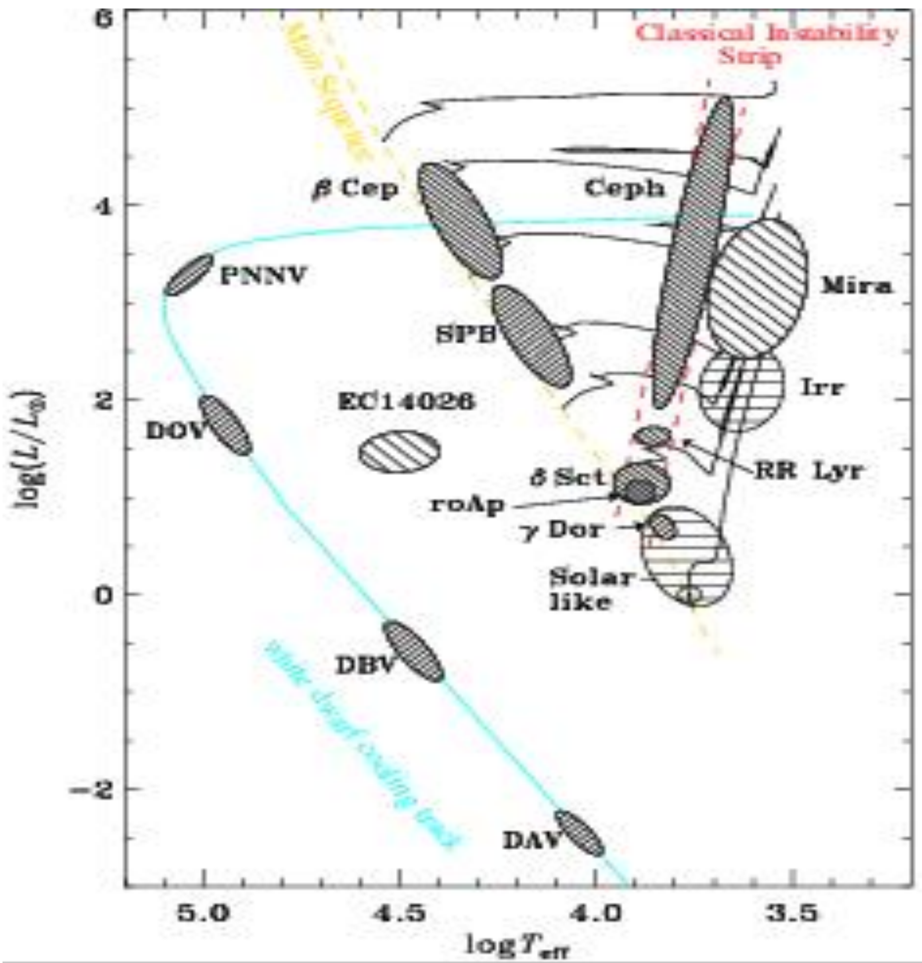
G. Bono, (Univ. of Rome TOV), R. Oliveira da Silva + **DIONYSOS**

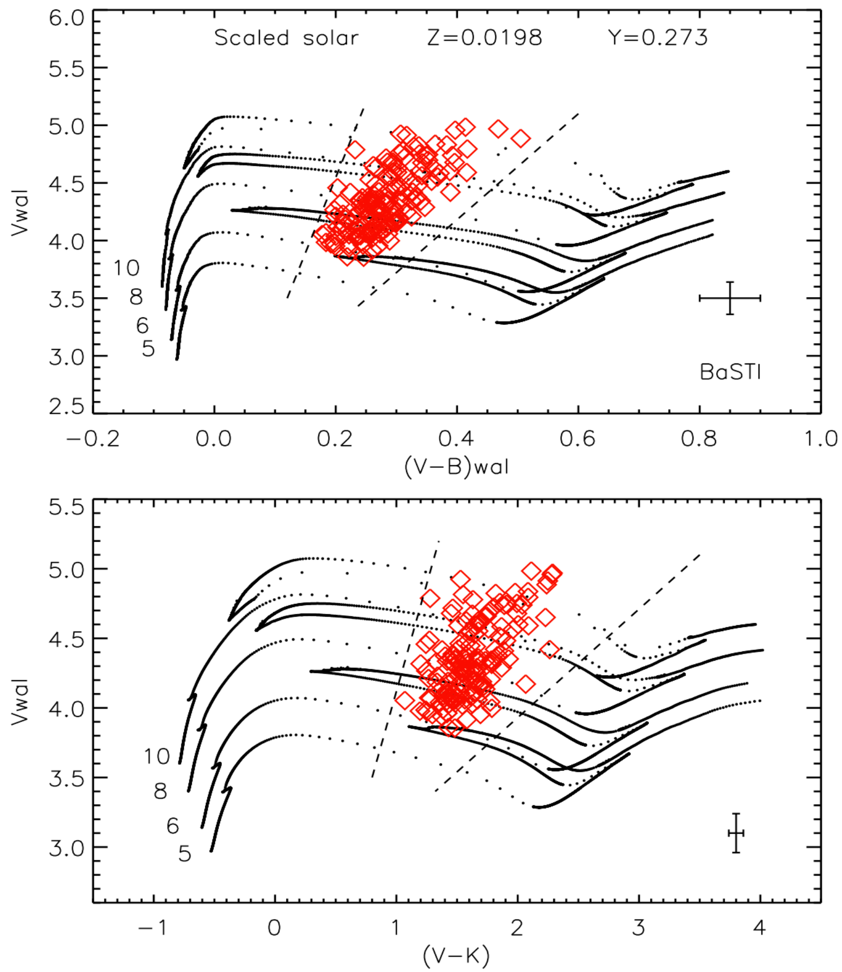


OUTLINE OF THE TALK

- → Setting the scene
- → Metallicity gradients
- → Age dependence
- → [La/Eu] &[hs/ls] element ratios
- →Future developments
- →Conclusions

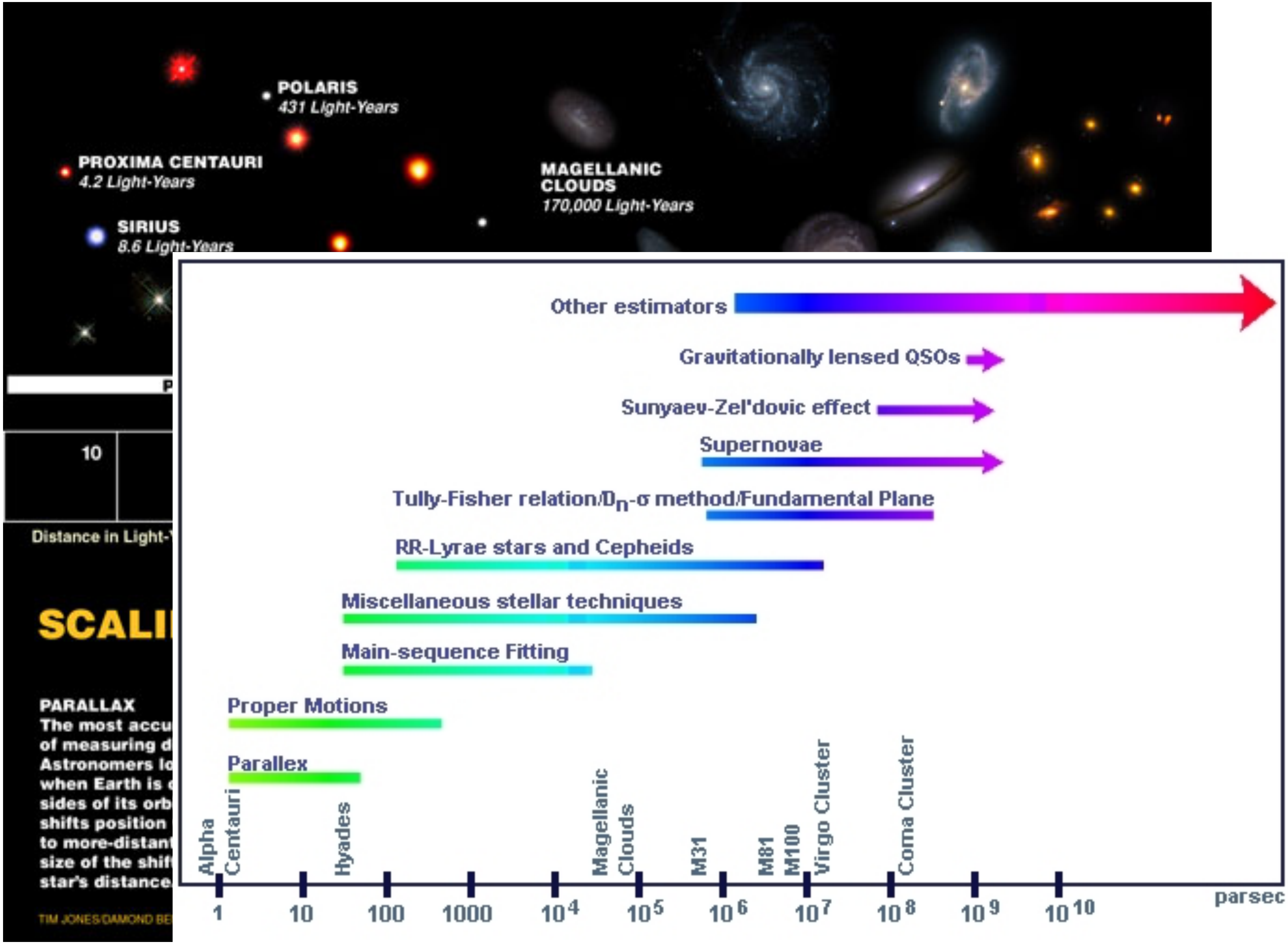
Cepheid Pulsation & Evolutionary Properties





Cepheid Instability Strip

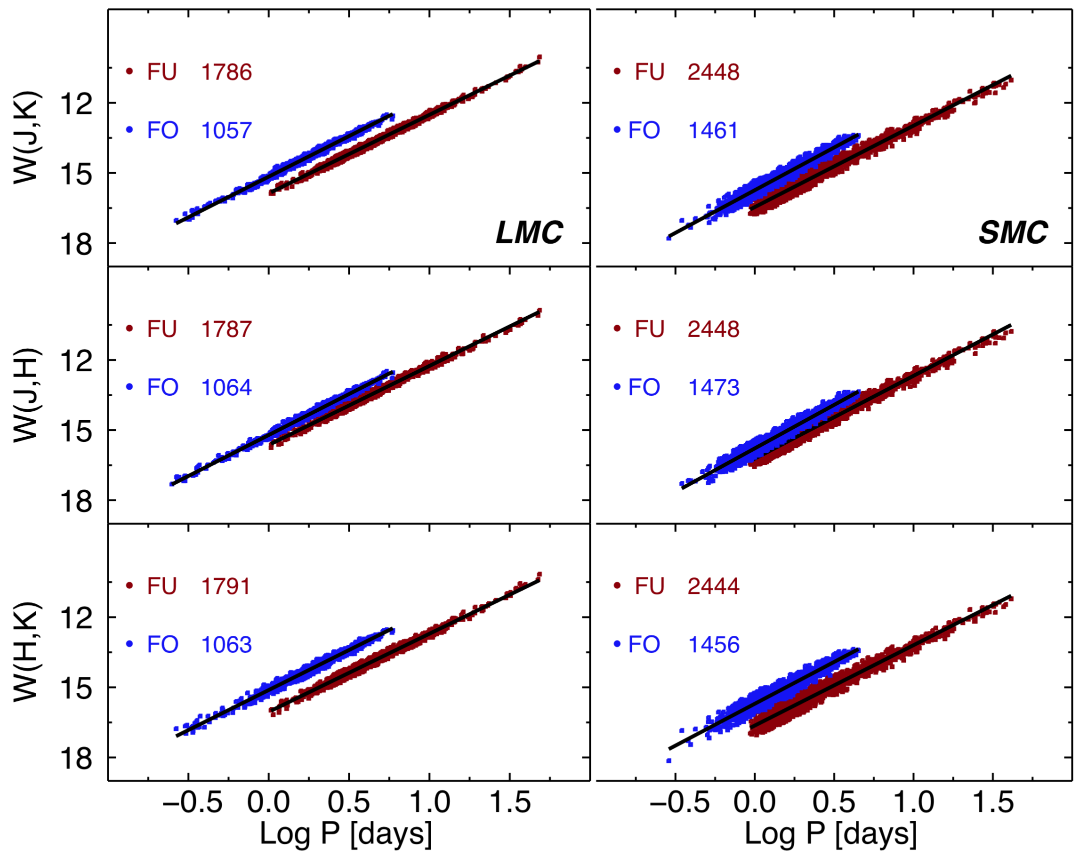
Intermediate-mass stars central He-burning phase


POLARIS
431 Light-Years
PROXIMA CENTAURI
4.2 Light-Years
SIRIUS
8.6 Light-Years
MAGELLANIC CLOUDS
170,000 Light-Years
10
PARALLAX
Other estimators
Gravitationally lensed QSOs
Sunyaev-Zel'dovic effect
Supernovae
Tully-Fisher relation/D_n-σ method/Fundamental Plane
RR-Lyrae stars and Cepheids
Miscellaneous stellar techniques
Main-sequence Fitting
Proper Motions
Parallex
Alpha Centauri
Hyades
Magellanic Clouds
M31
M81
M100
Virgo Cluster
Coma Cluster
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
10^9
10^{10}
parsec

The largest NIR data set ever collected for MC Cepheids

Inno et al. (2013, NIR light curve template by Soszynski et al. 2005 + single epoch measurements - IRSF survey Matsunaga, Kato et al. 2007)

Absolute calibration Based on HST Galactic Cepheids (9, Benedict + + new ones Riess et al.)



WHY CEPHEIDS as stellar tracers?

PROS

1) They are bright & can be easily recognized
2) Robust primary distance indicators (individual)
3) Robust stellar tracers of young SPs
4) Overcome reddening uncertainties (PW relations)
5) We know the physics of their engines

CONS

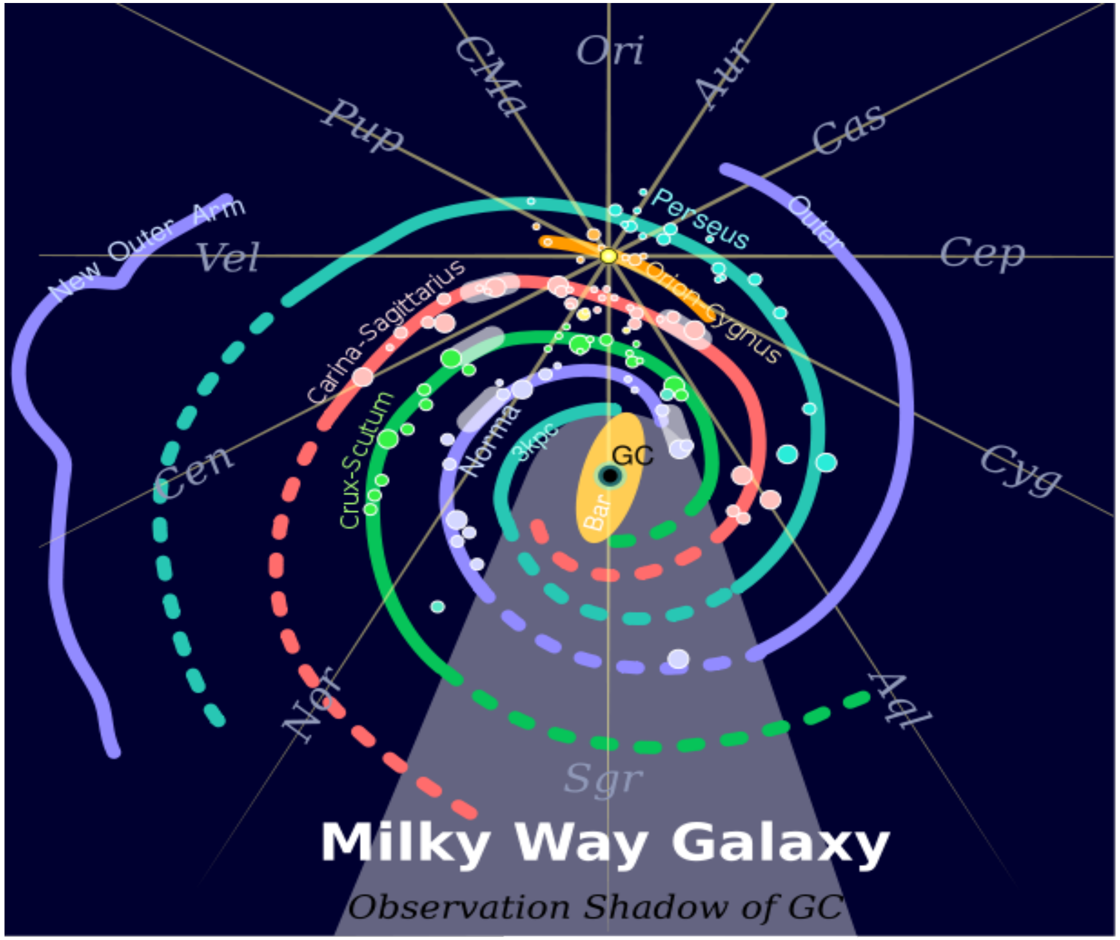
1) Identification → time series data
2) Multiband observations
3) Pulsation amplitude decreases from optical to NIR
4) Limited range in age 10-300 Myr

DIONYSOS

DIsk Optical Near-infrared Young Stellar Objects Spectroscopy

Mosaic House of the faun (Pompei)

Homogenous individual iron & α-element & n-capture abundances + NIR distances



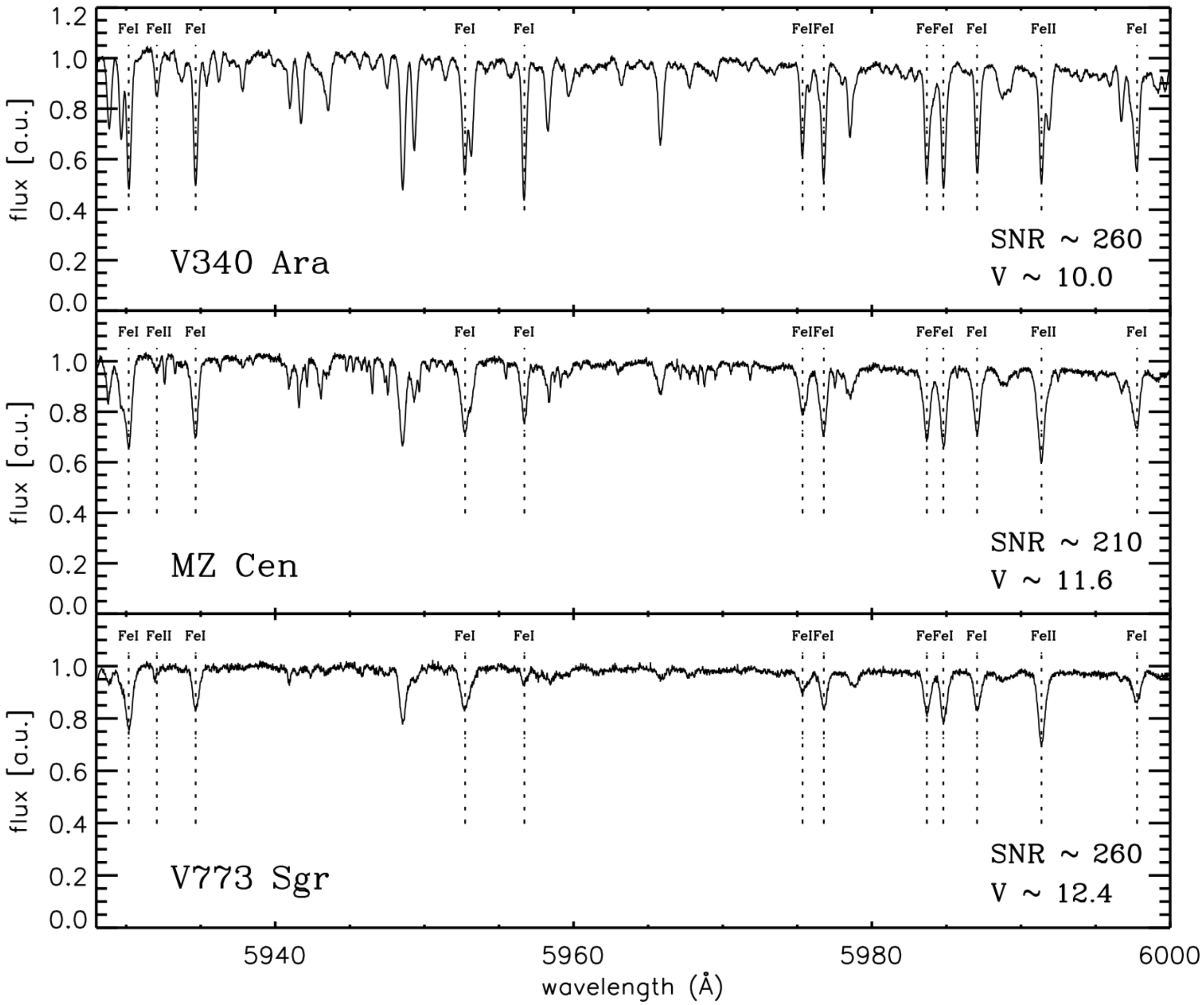
UVES@VLT spectra for ~115 Cepheids

R~38,000
Red & blue arm
Δλ=3750—9500A
t~80—2000 s
S/N > 100-200

From several tens to hundreds of weak FeI lines (EW<120mA)

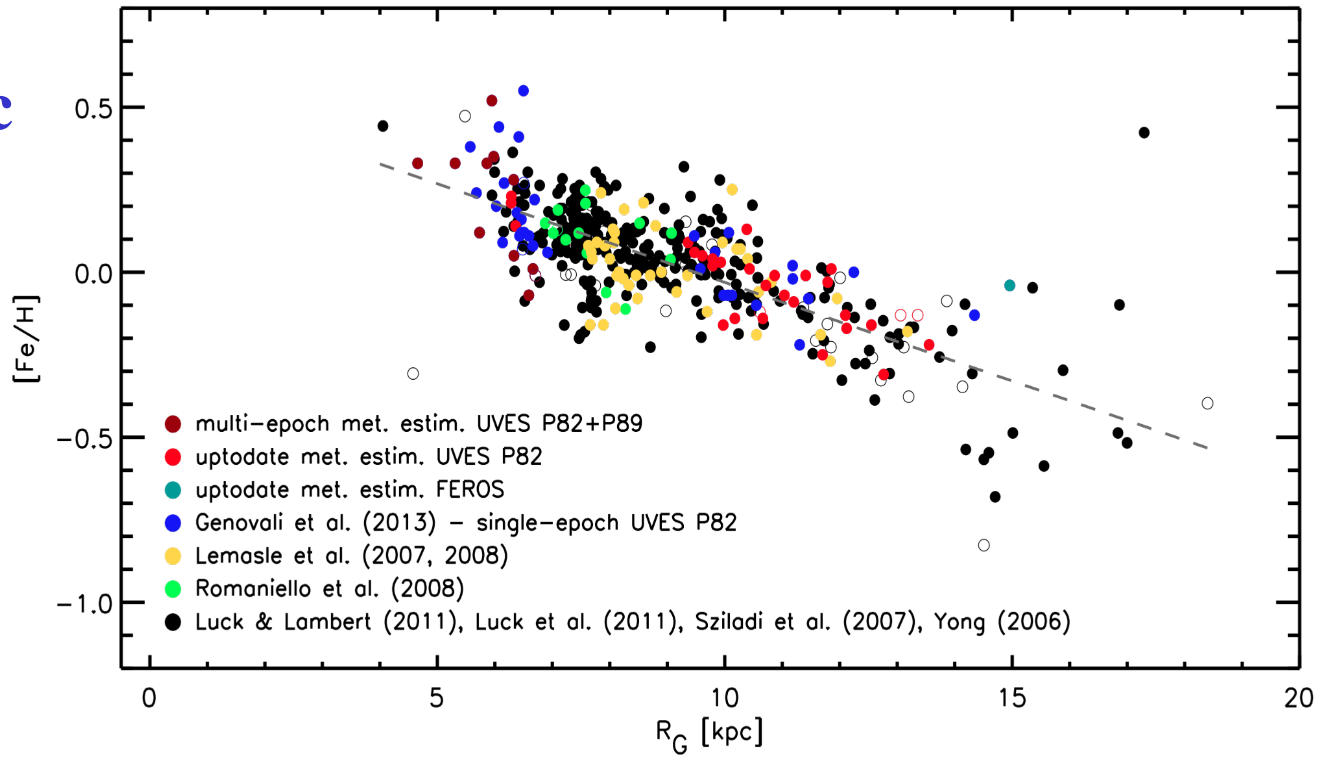
From several to tens of FeII lines

Multiple spectra for Calibrating Cepheids (~12)



Genovali et al. (2013;2014)

Homogeneous iron scale for 440 Galactic Cepheids



High spectral-resolution, a few tens of Cepheids in common.

~1/3 proprietary

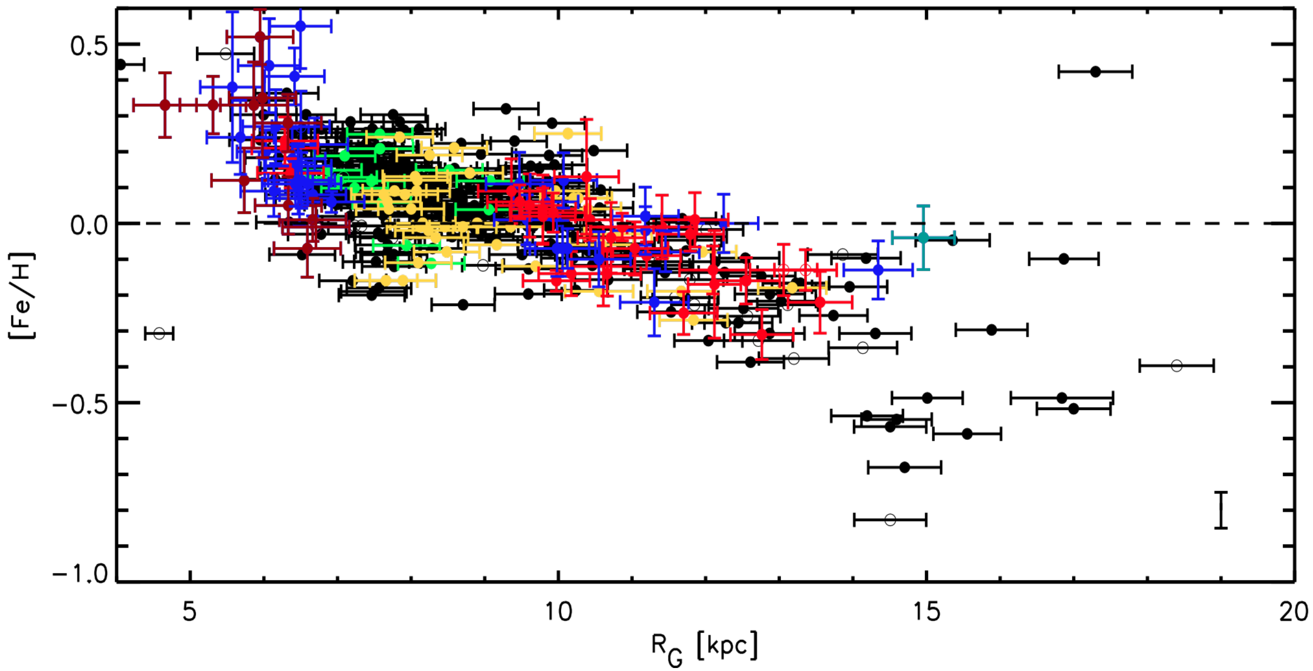
~2/3 Luck + Andriewski +

Linear trend -0.060±0.002 dex/kpc

Steepening in the inner disk (Rg ≤ 6/7 kpc)

Increase in spread in the outer disk (Rg> 13 kpc)

Large spread at fixed Rg



Genovali et al. 2013a,b

WHY?

Four good reasons!

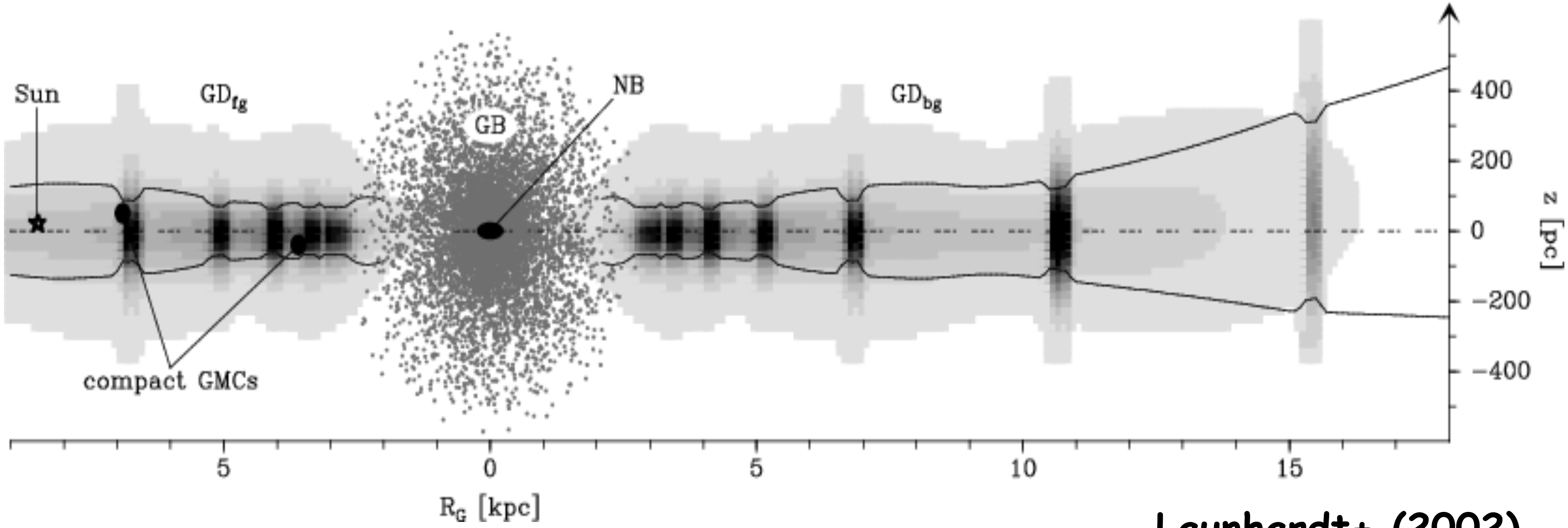
1) Inner disk & transition with NB+Bar

2) Age dependence

3) Disk fine structure

4) Chemical enrichment history → Theory

[1] The inner disk



Launhardt+ (2002)

Nuclear Bulge—Galactic Bulge—Inner disk Reid+ (2009)

The presence of a bar-like structure is crucial to explain the high SFR of the NB (Yusef+ 2009; Davies+ 2009, Matsunaga+ 2011)

It is the bar-like structure to drag the gas & the molecular clouds from the inner disk into the Nuclear Bulge (Athanassoula+ 1992; Kim+ 2011, Freeman+ 2012; Ness+2013a,b)

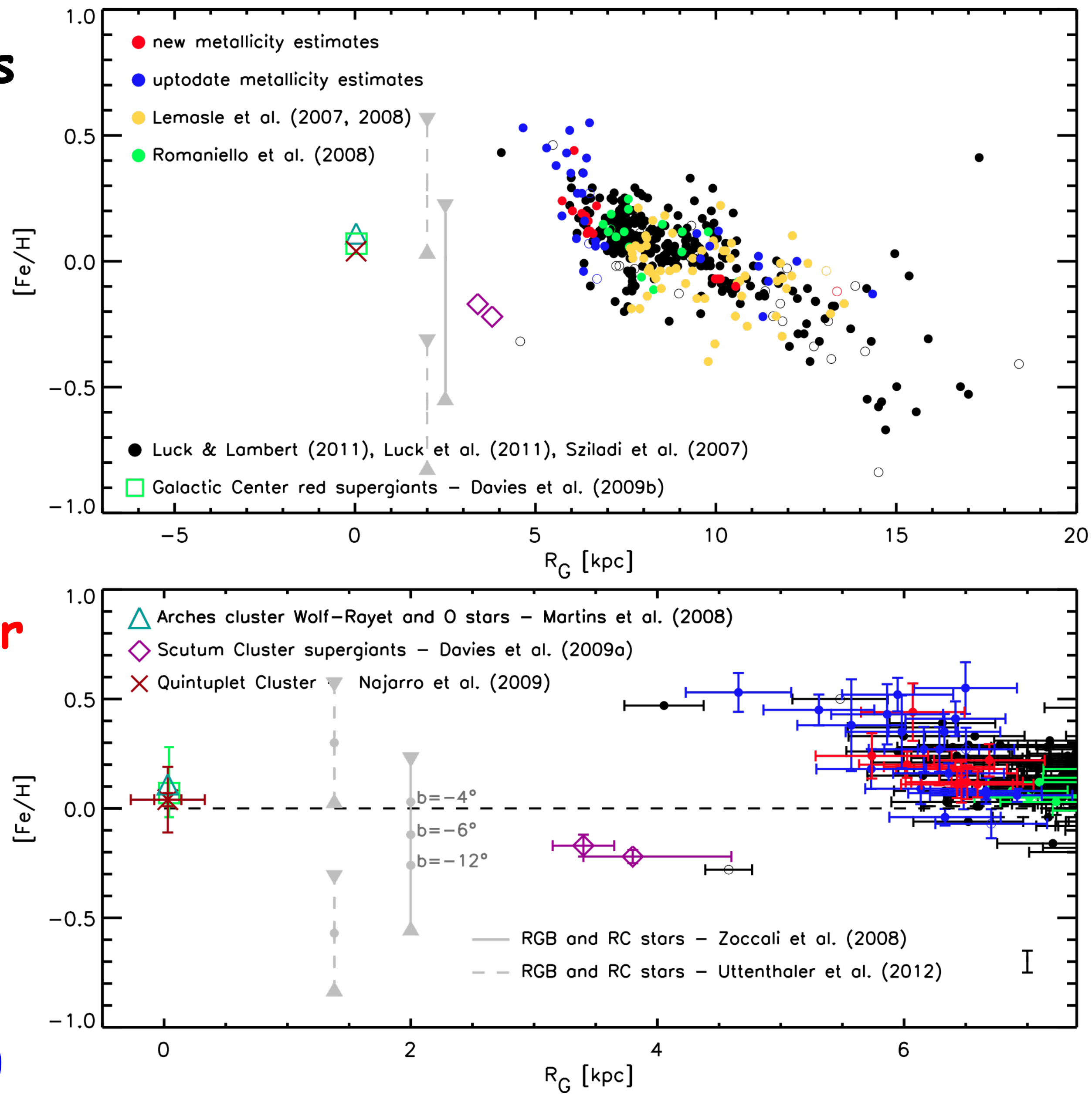
Difference between inner disk & NB+Bar

Young stellar objects in NB+Bar are solar!

They are more metal-poor than inner disk Cepheids

Their metallicity distribution is narrower than in Galactic Bulge (Johnson et al. 2011)

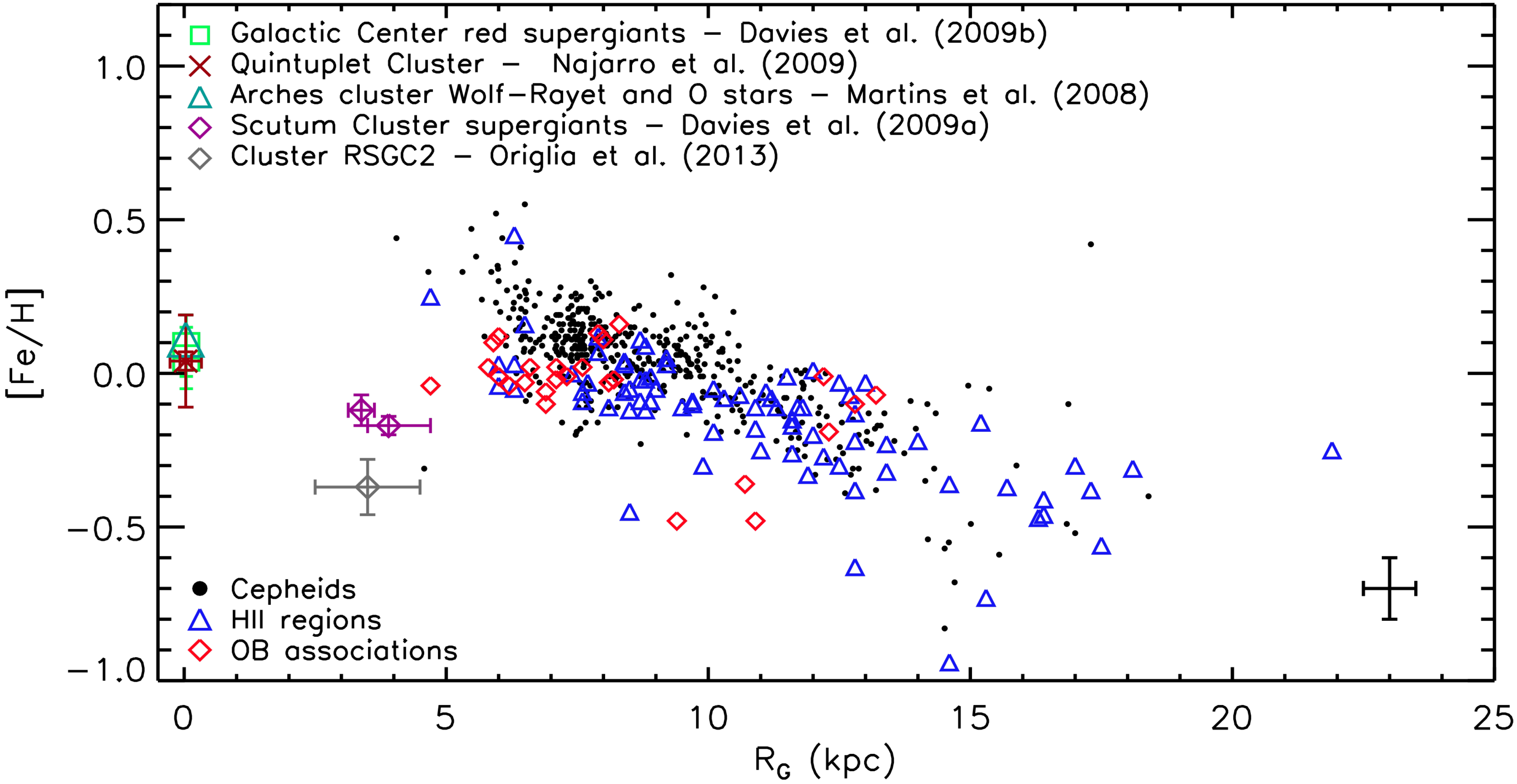
young α-rich RGs Chiappini +(2015)



Genovali et al. (2013a)

[2] Cepheids and age effects

HII regions & OB associations



Inversion in the chemical gradient in the innermost regions

No relevant change for young tracers

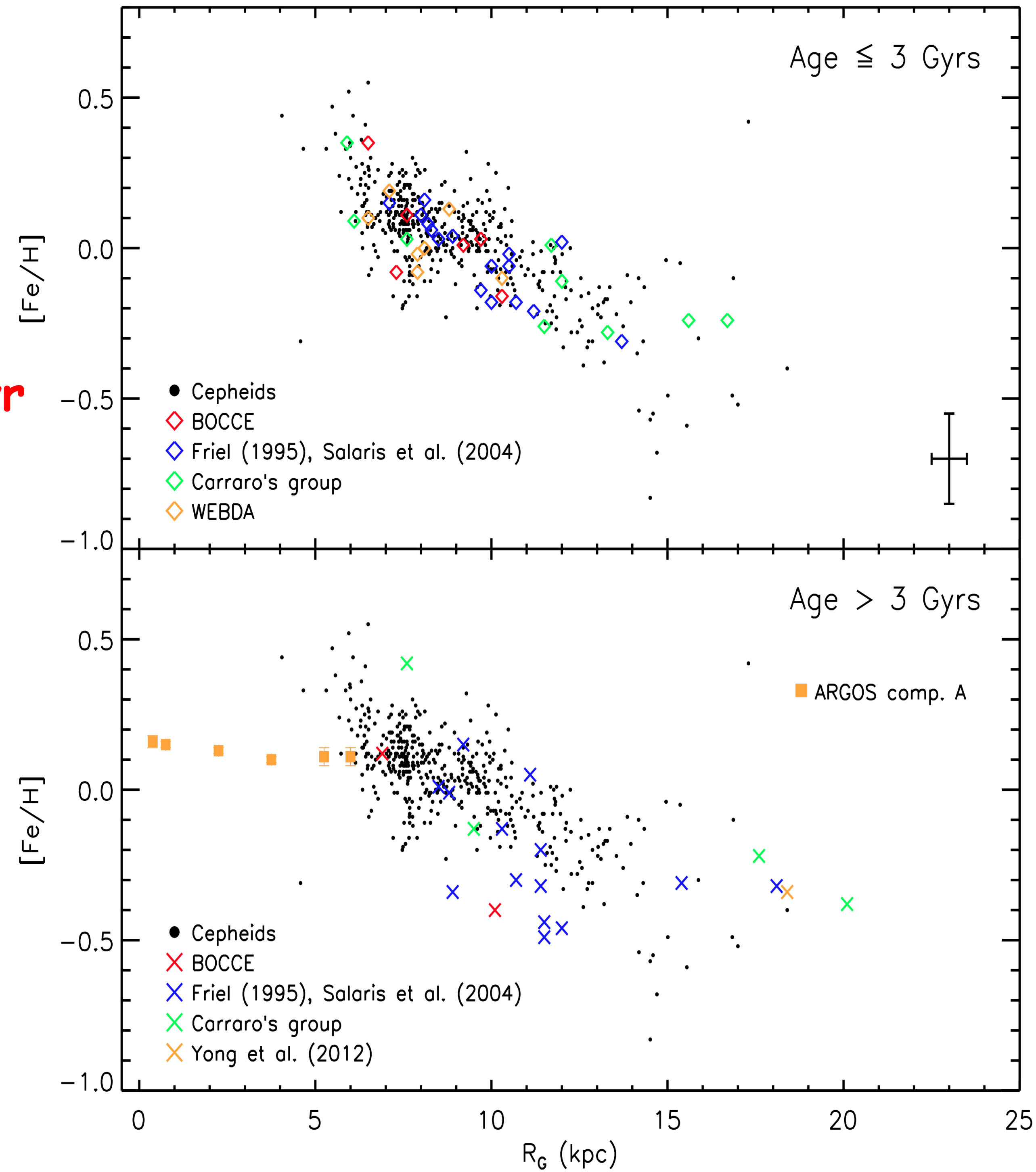
Cepheids & age effects Open Clusters

No changes for t<3 Gyr

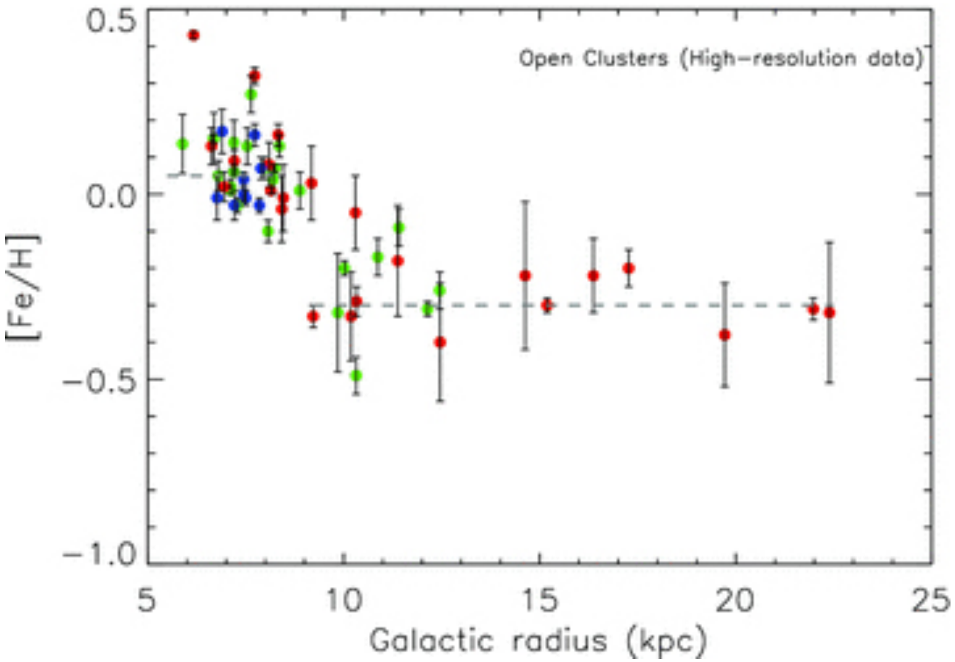
For older ages the distribution becomes more complex (ARGOS Results!)

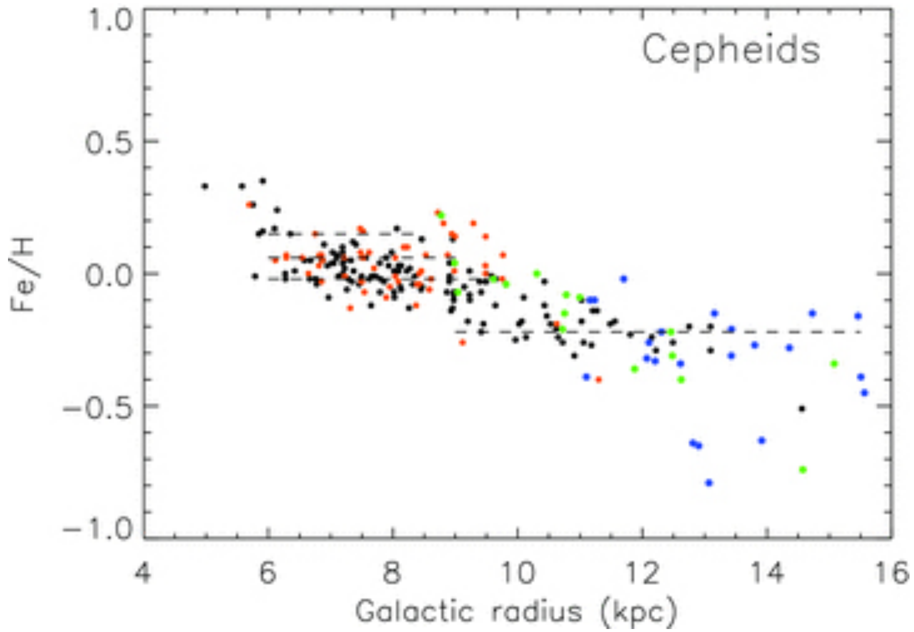
... but data are homogeneous neither in age nor in iron nor in distances!!!

But GAIA-ESO Survey!!



[3] Evidence for a bi-modal chemical evolution model (Lepine+ 2011,2013)

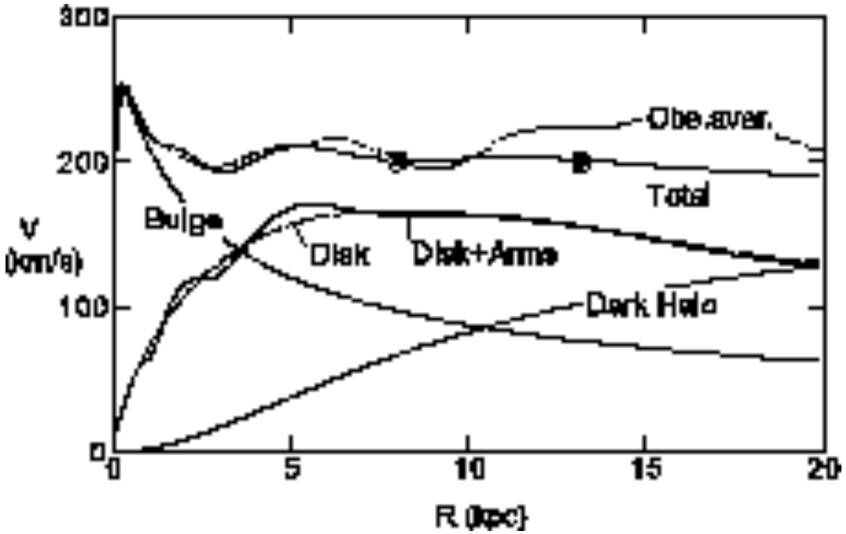




The jump in the metallicity gradient associated with the corotation resonance of the spiral pattern (Rg~9.5 kpc)

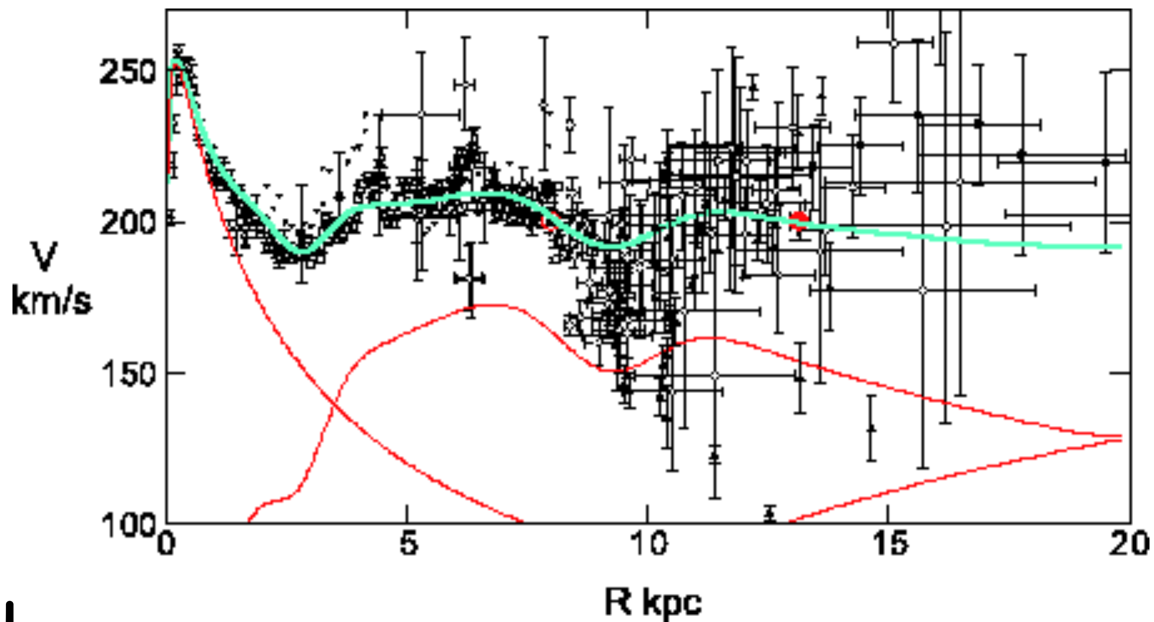
See also Scarano+ (2013) for extragalactic evidence

The fine structure of the rotation curve



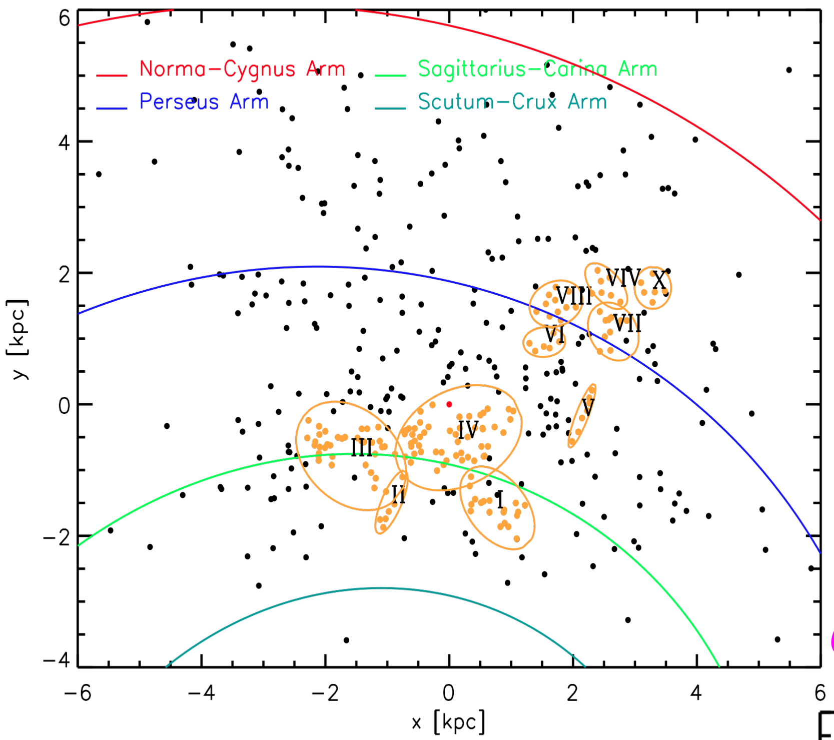
Evidence for a secondary dip located at Rg~9.5 kpc associated to the Perseus arm

Sofue et al. (2009,2013)



A new and independent approach to open the path!

The fine structure of the metallicity gradient

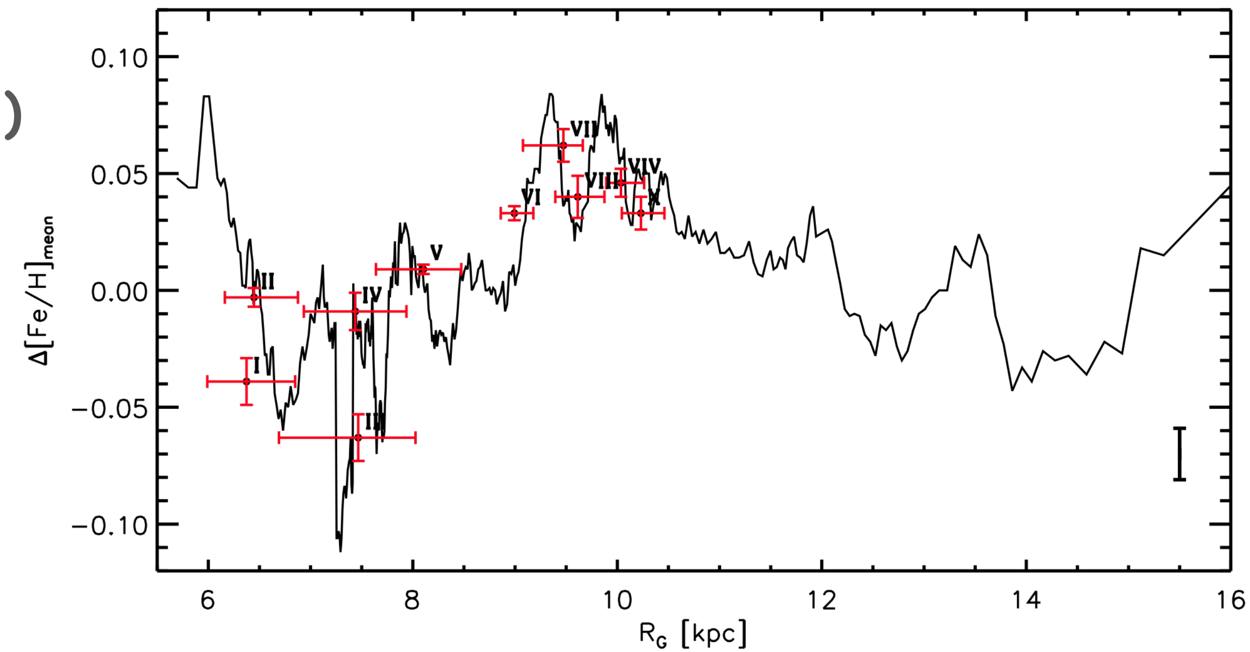


Ten candidate Cepheid Groups correlate with spiral arms: Perseus & Carina-Sagittarius

sizes from GMCs to super-associations (Baade 1963)

Current findings support Sofue+ (2009)

Vallee et al. (2002, 2003)
Xu (2013)



Residuals correlated with candidate Cepheid Groups

This accounts for the large intrinsic spread of the iron gradient

[4] Chemical evolution models

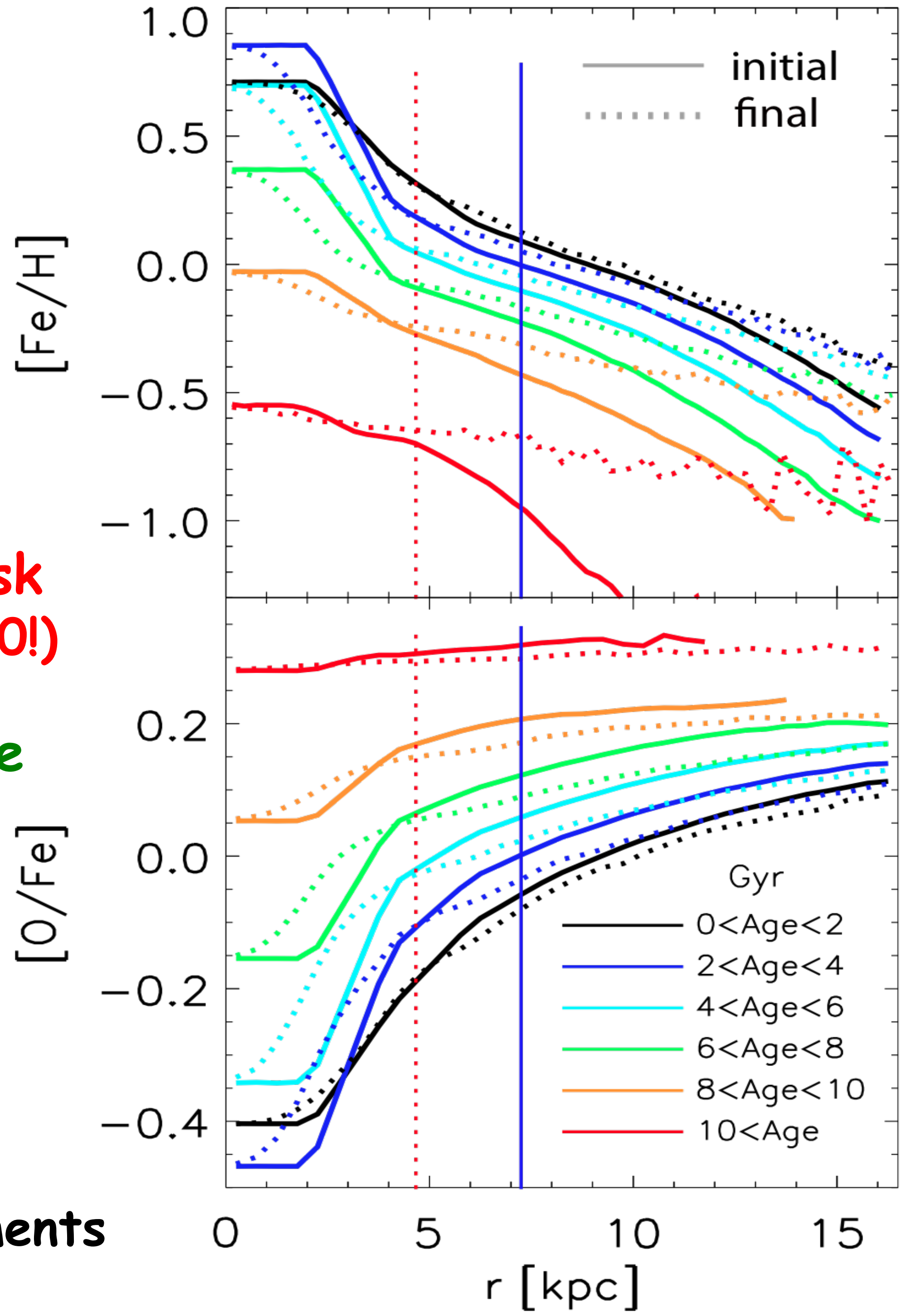
Minchev et al. (2013)
Chemo-dynamical models)

Steady increase in the inner disk
& in the NB+Bar ([Fe/H]~0.8-1.0!)

Beyond the corotation resonance
of the bar and the OLR

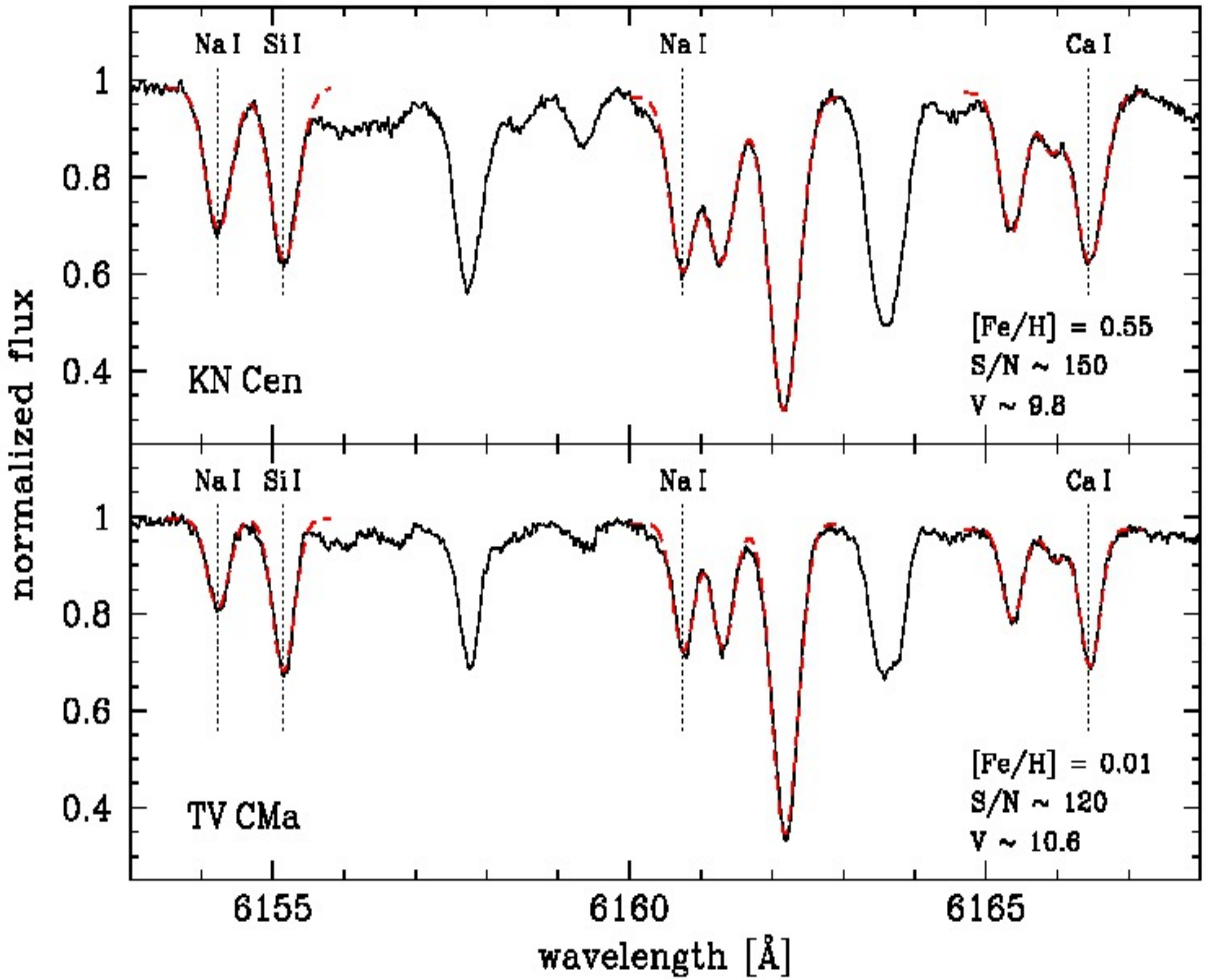
Shallower gradients for ages
Older than 4 Gyrs

Cescutti et al. (2006,2007)
Predicted gradients for heavy elements

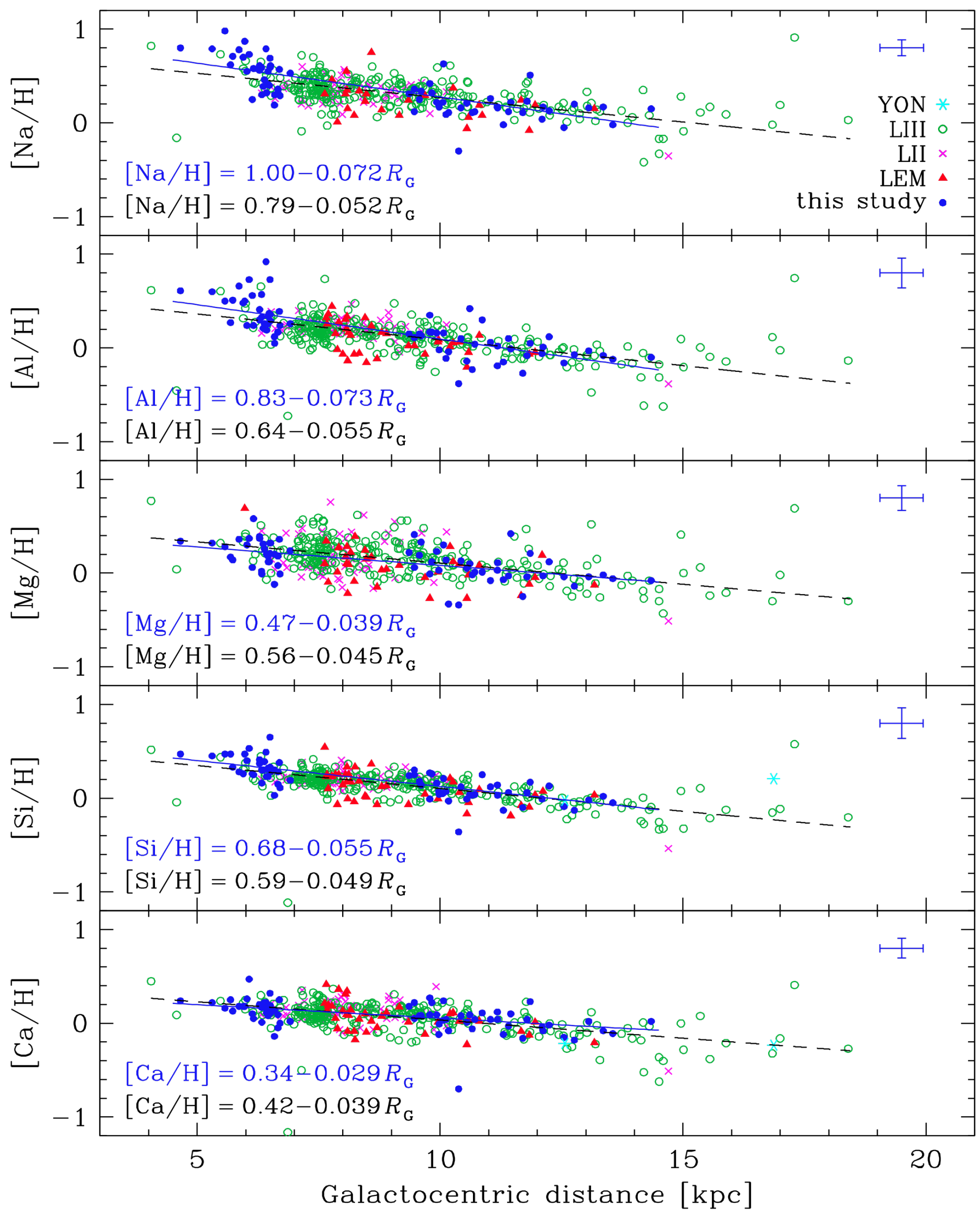


α-element abundance gradients

Light & α-elements



α-element gradients: a new spin (Genovali + 2015)

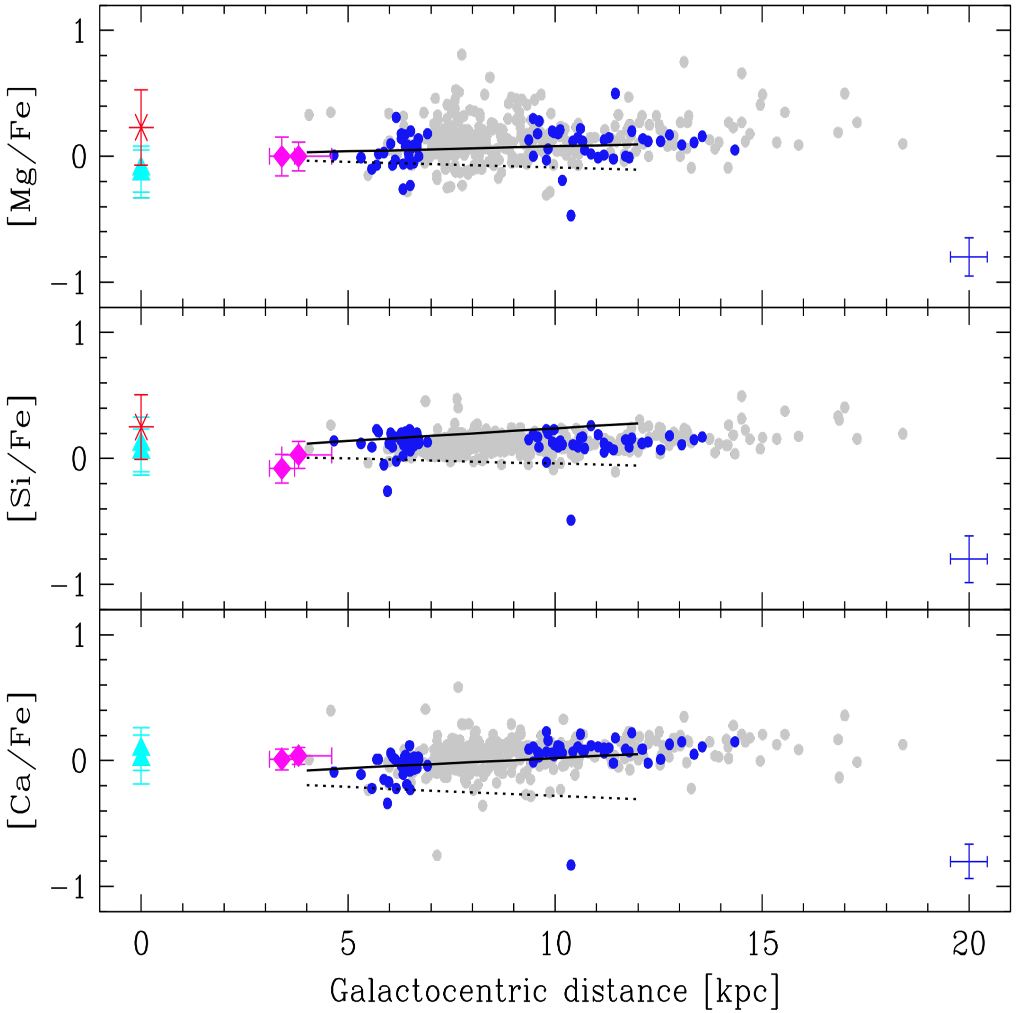


Almost the entire sample of Cepheids (~440) for which we have iron abundances

α-elements (Mg, Si,Ca) + Na,Al show abundance gradients similar to Fe

Si & Ca explosive
Mg hydrostatic
McWilliam+ (2013)

[α/Fe]: comparison with the literature



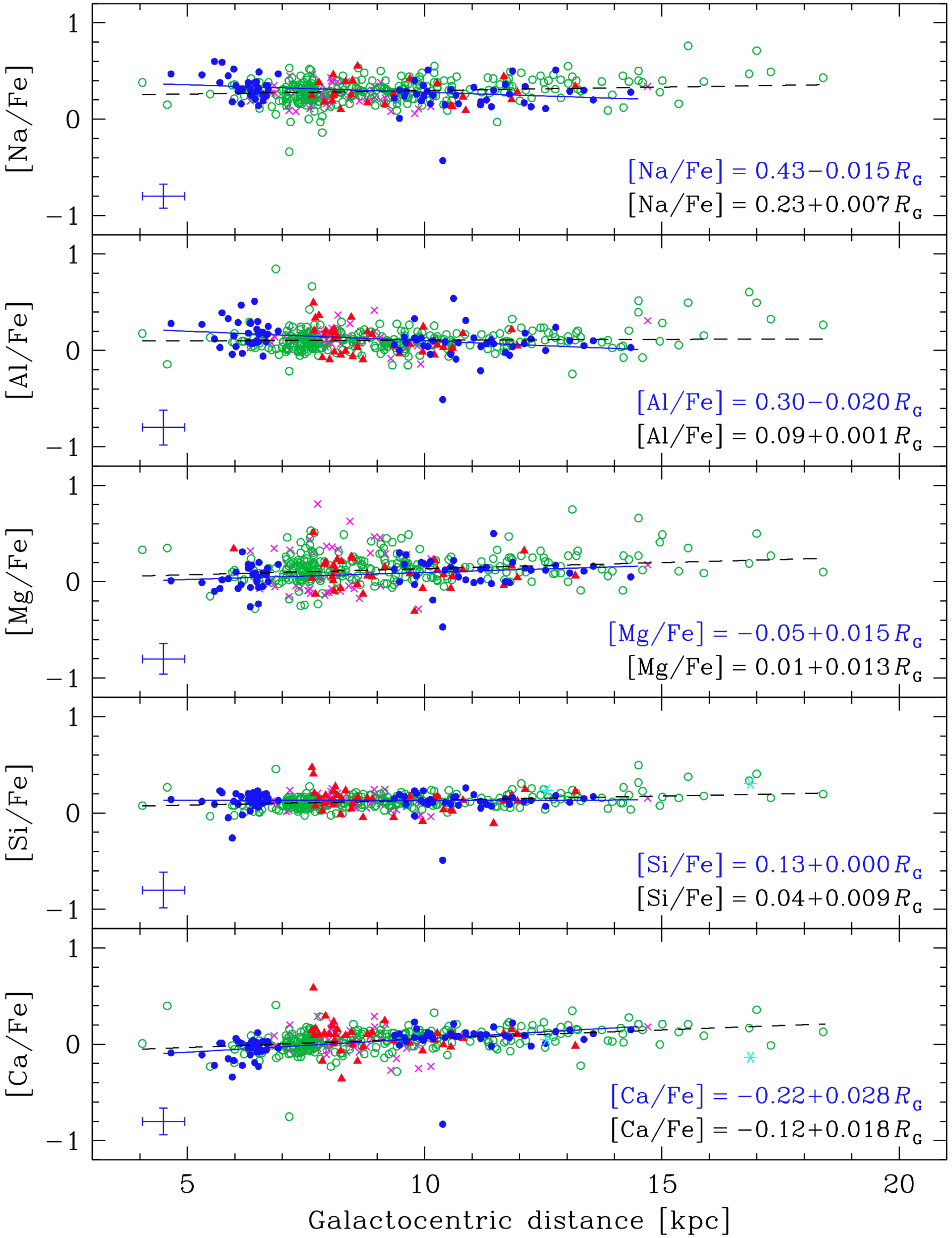
Najarro + 2009 → LBVs

Davies + 2009a,b → RSGs

Mikolaitis + 2014 Gaia/ESO
good agreement with this disk
but Si

Solar ratios across the entire disk + the Bar + the Centre!!

α-element gradients: a new spin (Genovali + 2015)



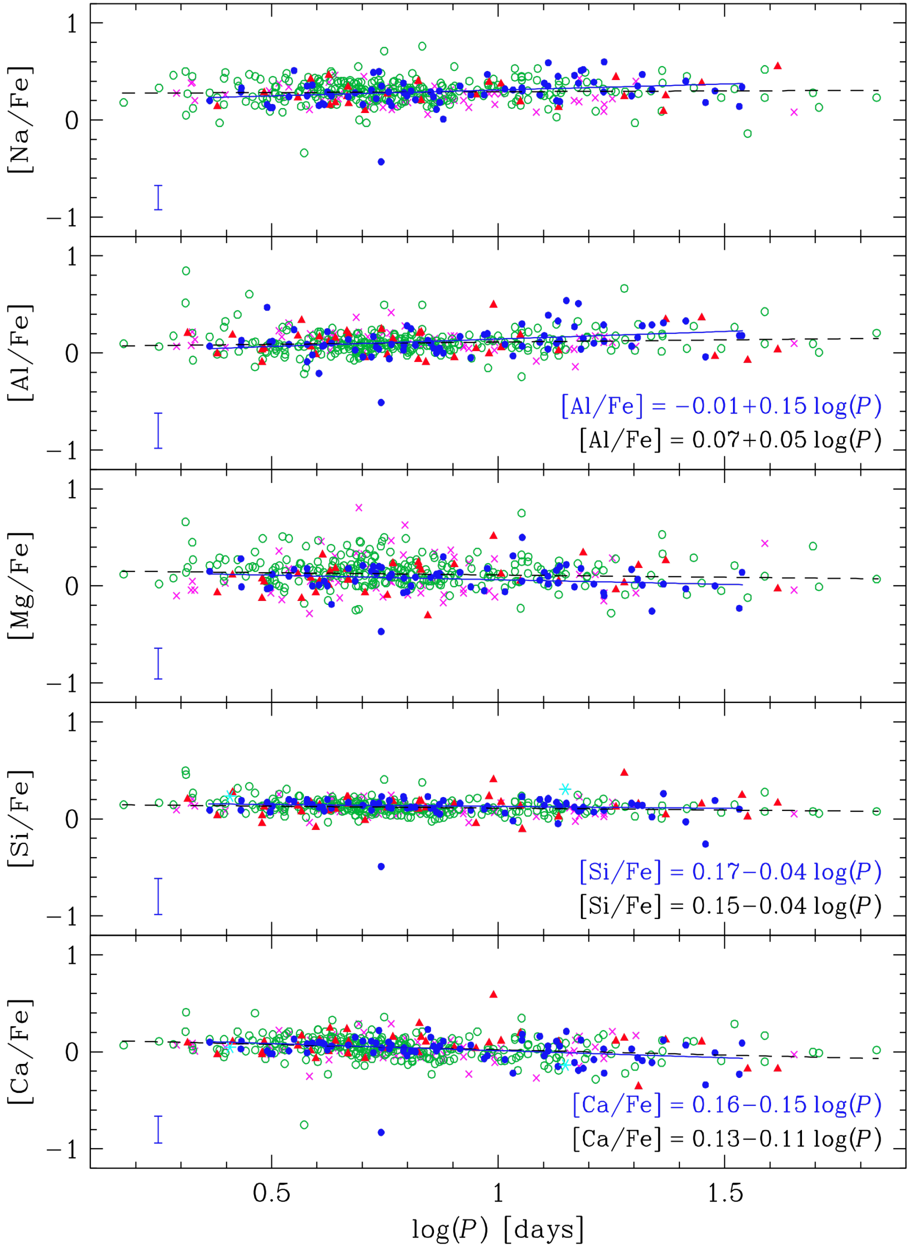
very very flat distribution over the entire Galactocentric

The slopes are minimal (Na, Al, Si) but Mg & Ca

Mg probably dominated by intrinsic scatter

Ca appears real ….
But what about the age dependence!!

[element/Fe]: age dependence (Genovali + 2015)



very very flat distribution over the entire Period/Age range!!

The slopes are minimal (Na, Al, Si, Mg) but Ca

Ca appears real ….

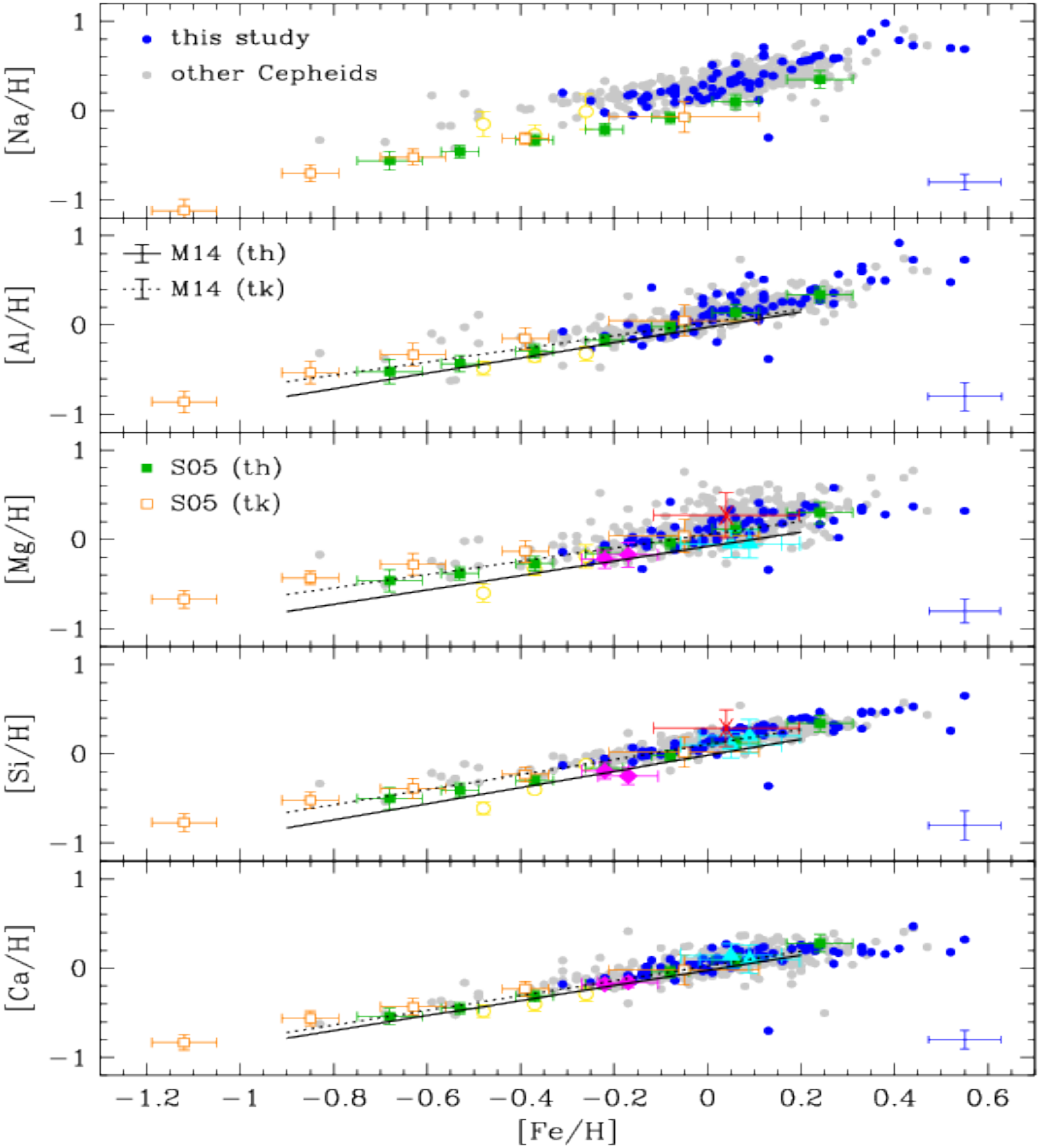
Note that Cepheids in the outer disk have periods ranging from 2 to 20 days!

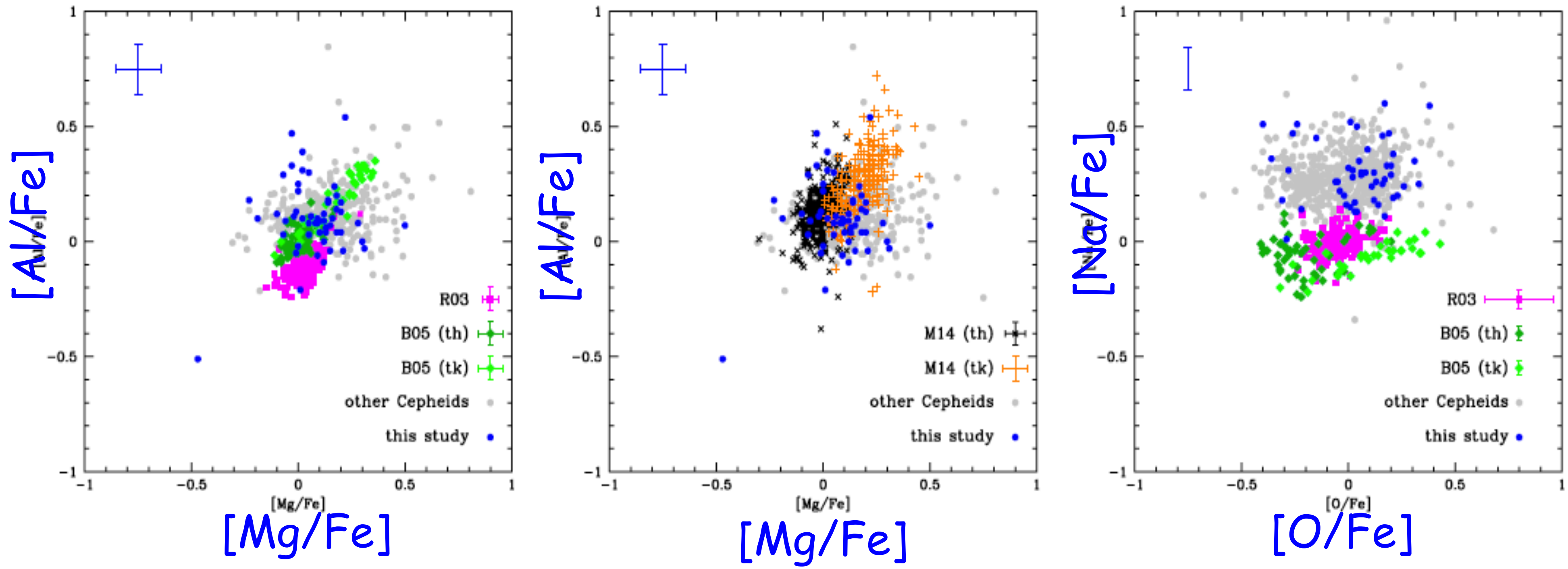
Comparison with the literature

Soubiran & Girad (2005)
743 thin & thick disk dwarves

Mikolaitis + (2014)
Gaia-ESO

Good agreement but Na due to evolutionary & NLTE effects

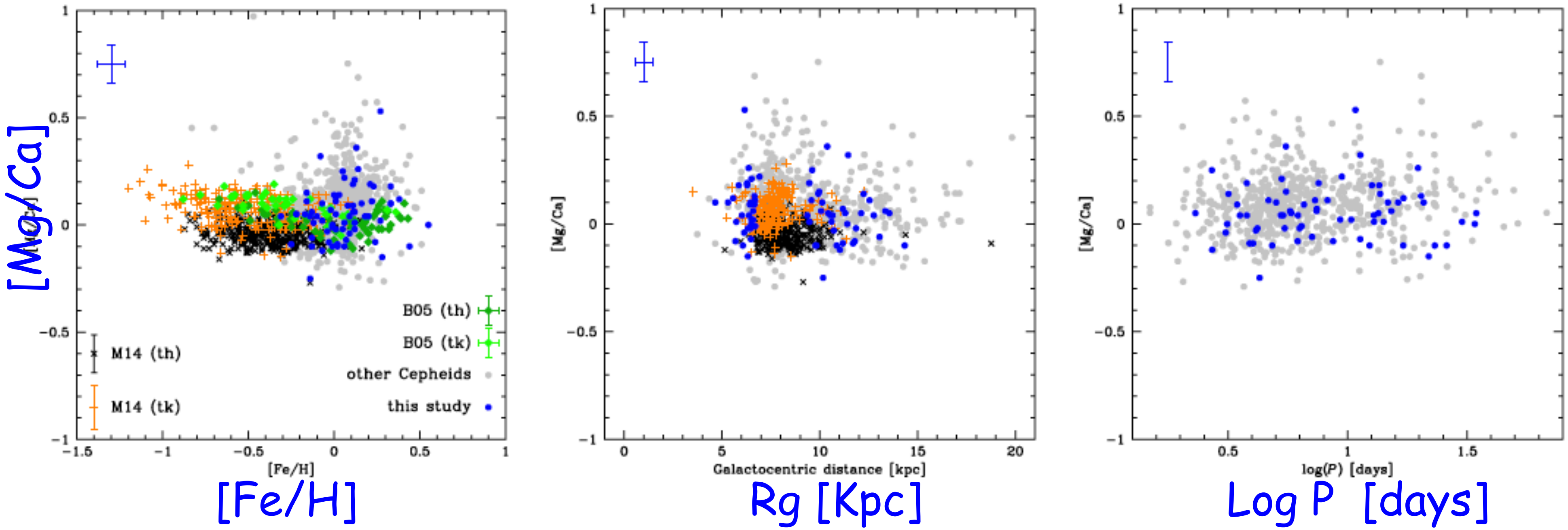




Field stars display well defined correlation between Mg & Al

The offset in Na—O is due to NLTE effects in Na
giants vs dwarves [O corrected]

Carretta + McWilliam + (Sagittarius)



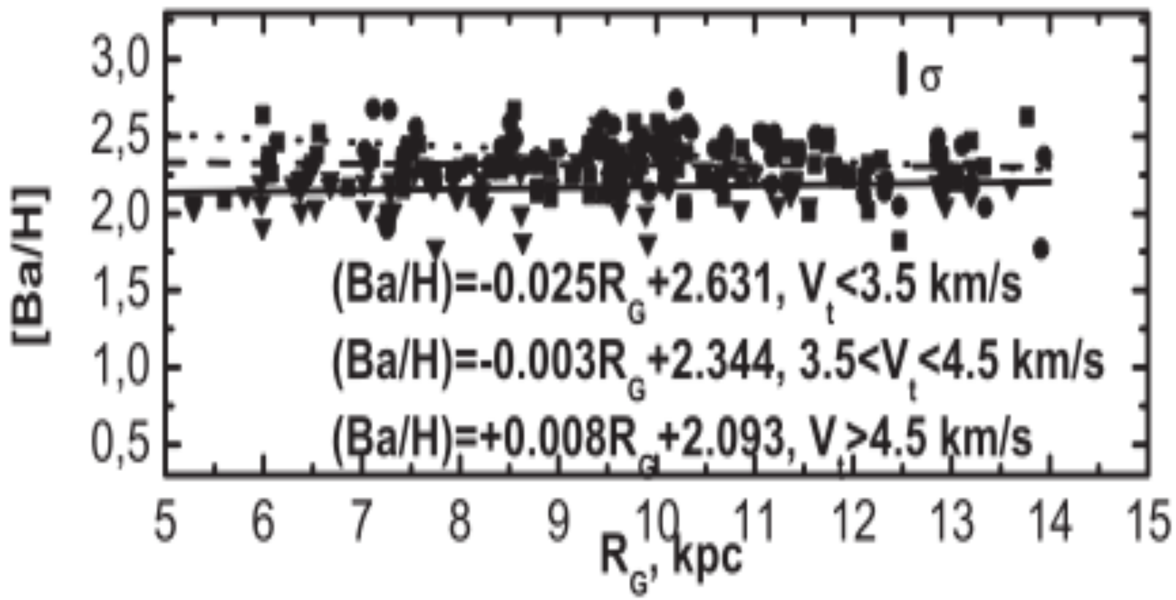
[Mg/Ca] abundance ratio of hydrostatic & explosive elements

+ field dwarves by Bensy + (2005) and Mikolaitis + (2015)

Flat distribution in the metal-poor regime increase for supersolar Iron abundances

n-capture element gradients

Ba → no evidence of gradient



Andriewski + (2014)

NLTE analysis of Ba abundances for a sub-sample of 210 Galactic Cepheids with Galactocentric distances from 5 to 18 kpc found a vanishing gradient d[Ba/H]/dR ≈ -0.01 dex kpc^{-1} ~thre times smaller than other n-capture elements

Ba is mainly produced in low-mass AGB stars [1.5Mo 10X > 3Mo]

→**Only those elements that are produced by more massive AGB stars and/or SNe should show a negative gradient.**

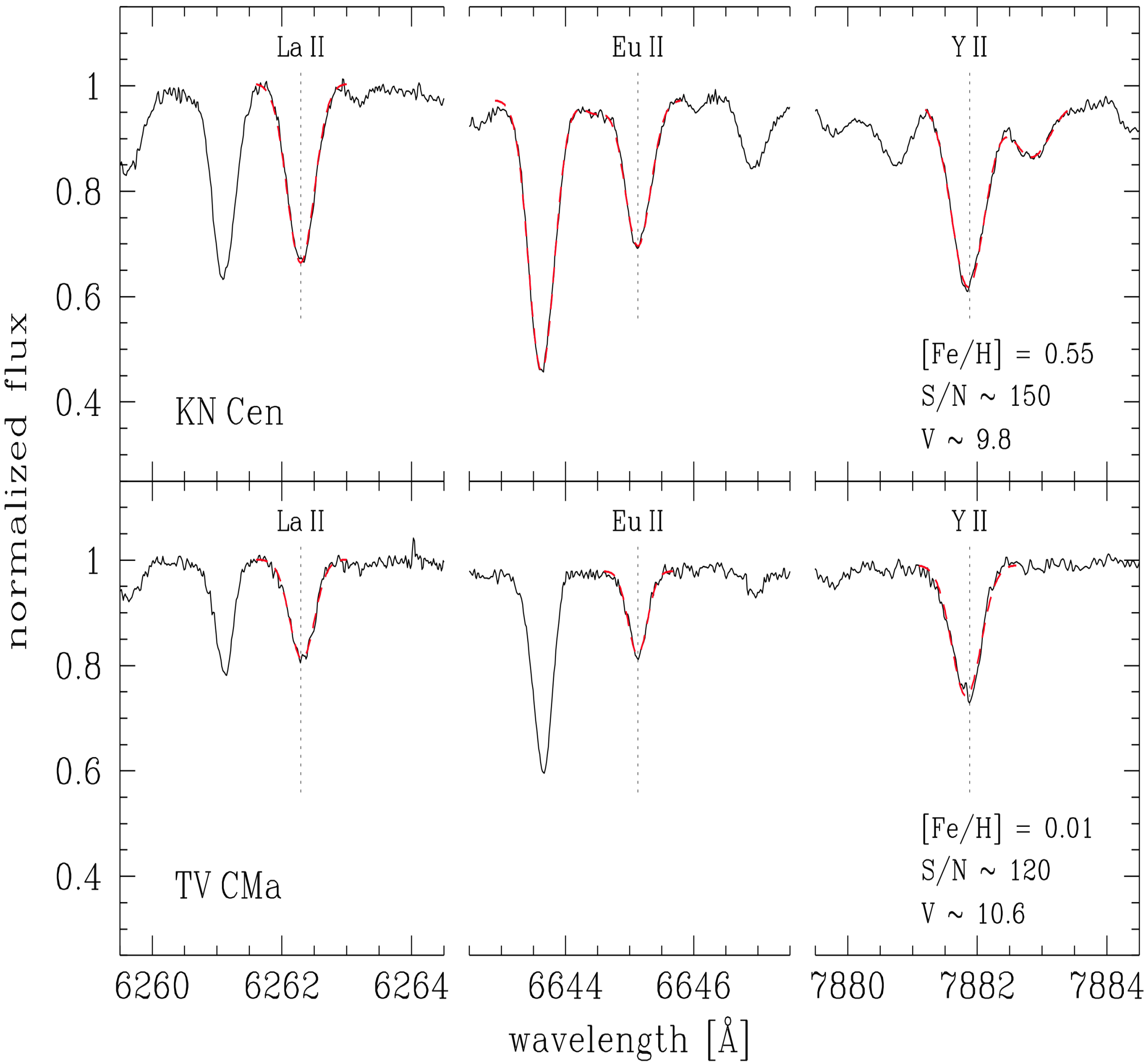
n-capture elements

s:
Weak: Y
Main: Ba, La, Ce, Nd

r: Eu (A=63)

light-s:
Sr, Y, Zr
38≤A≤40

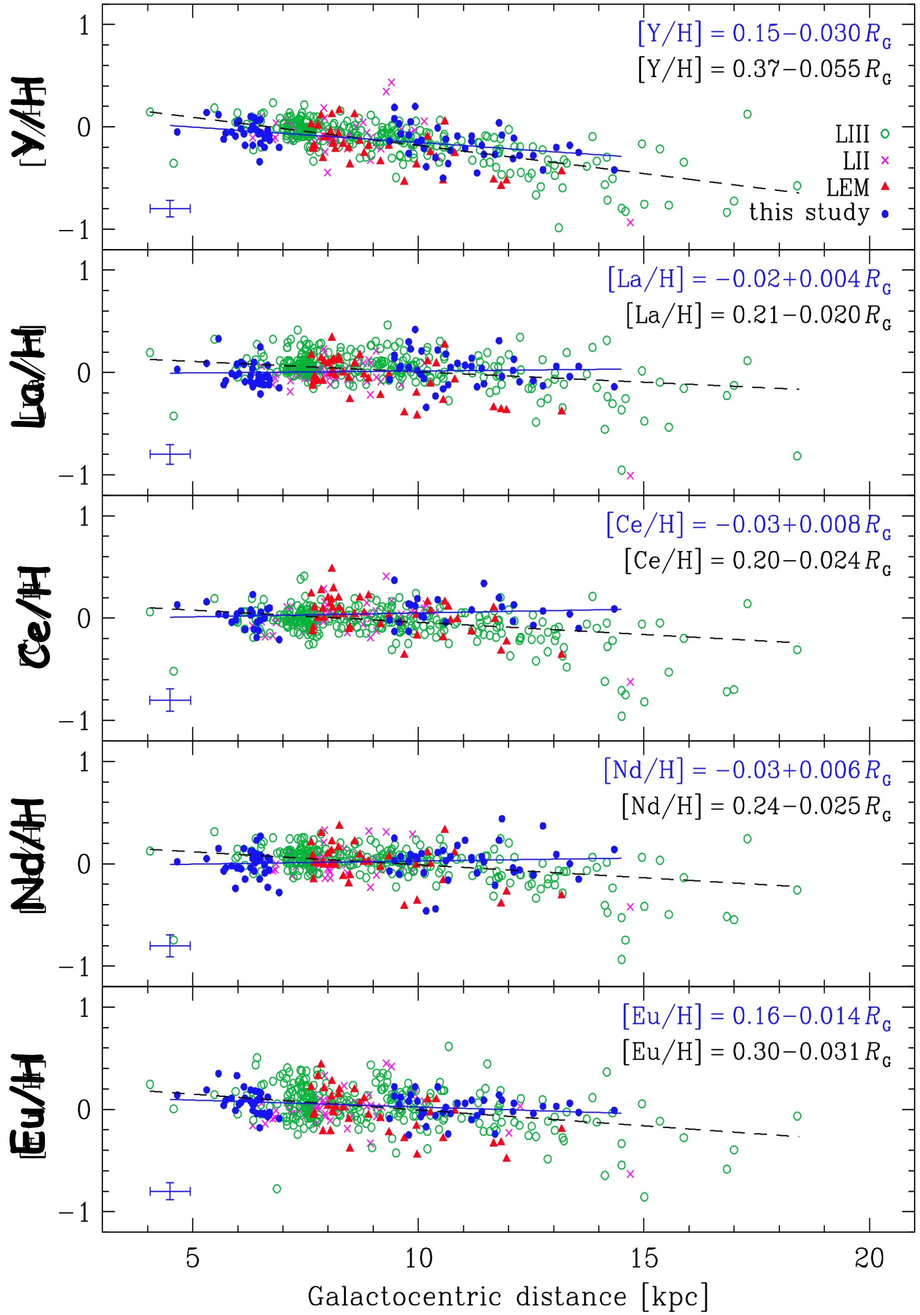
Heavy-s:
Ba, La, Ce, Nd, Sm
56 ≤A≤ 62



n-capture elements

Slopes shallower than Fe & α-elements ….
But Yittrium

No Clear difference Between s- & r elements

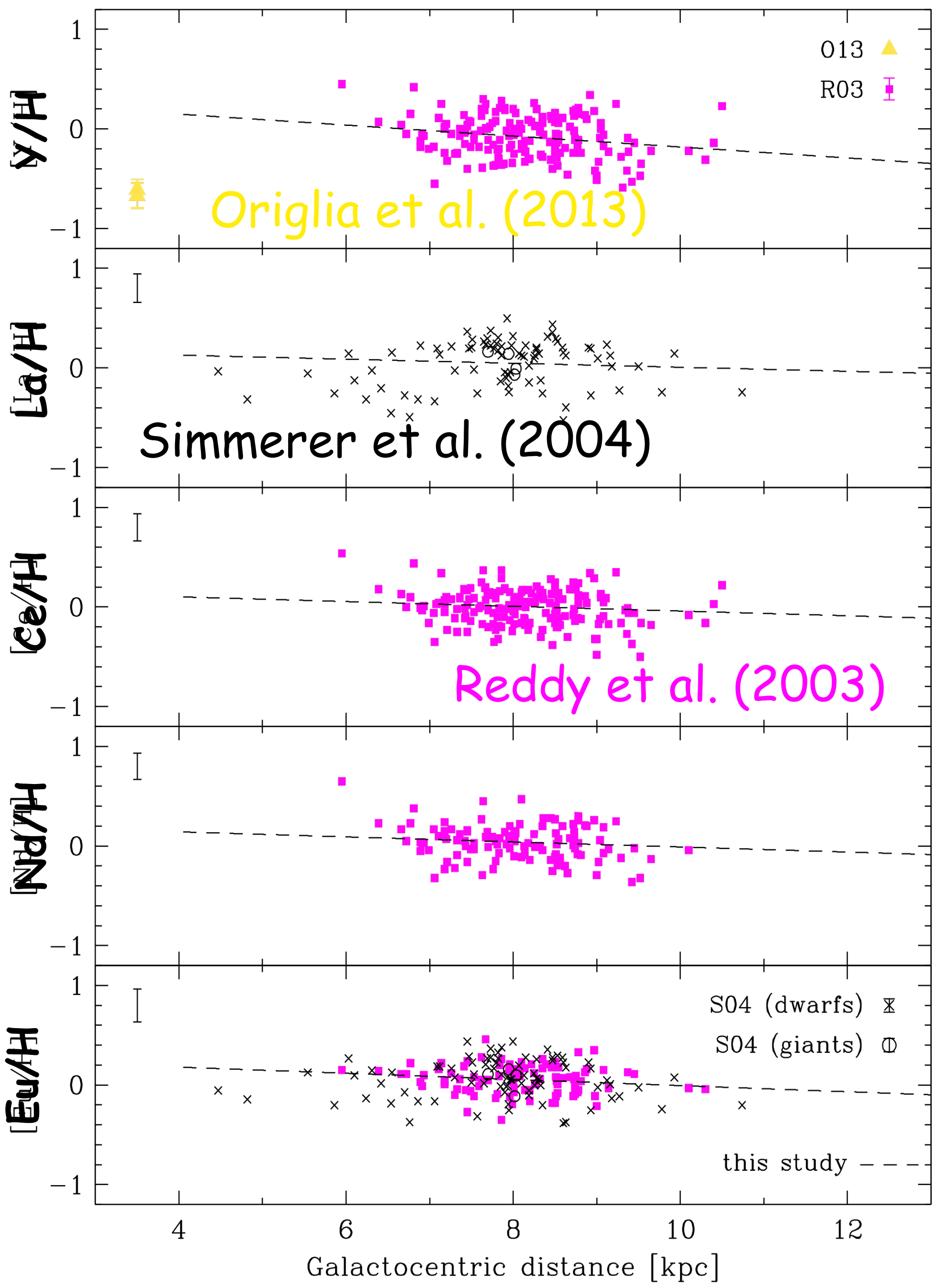


n-capture elements comparison with the literature

Good agreement with field dwarves & giants in the thick & thin disk …..

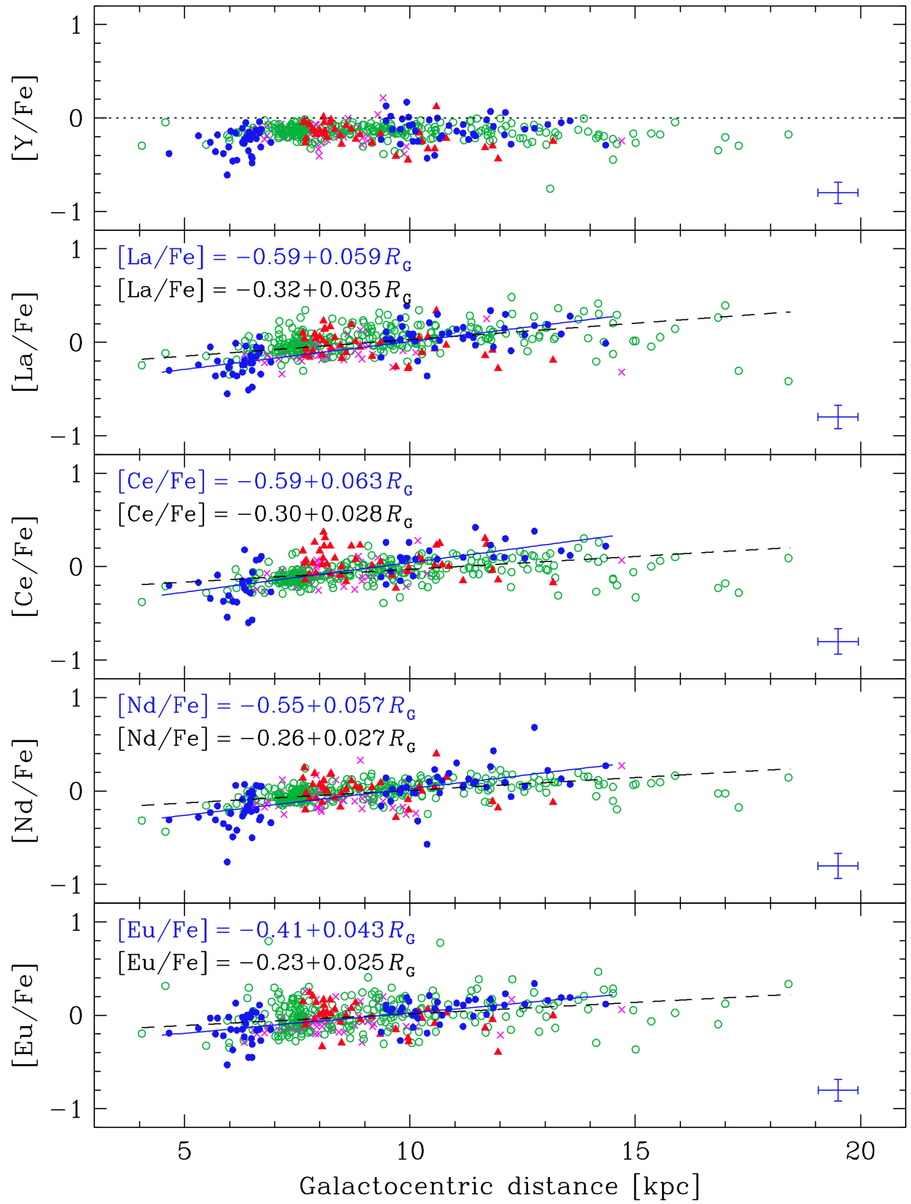
But the Galactic center

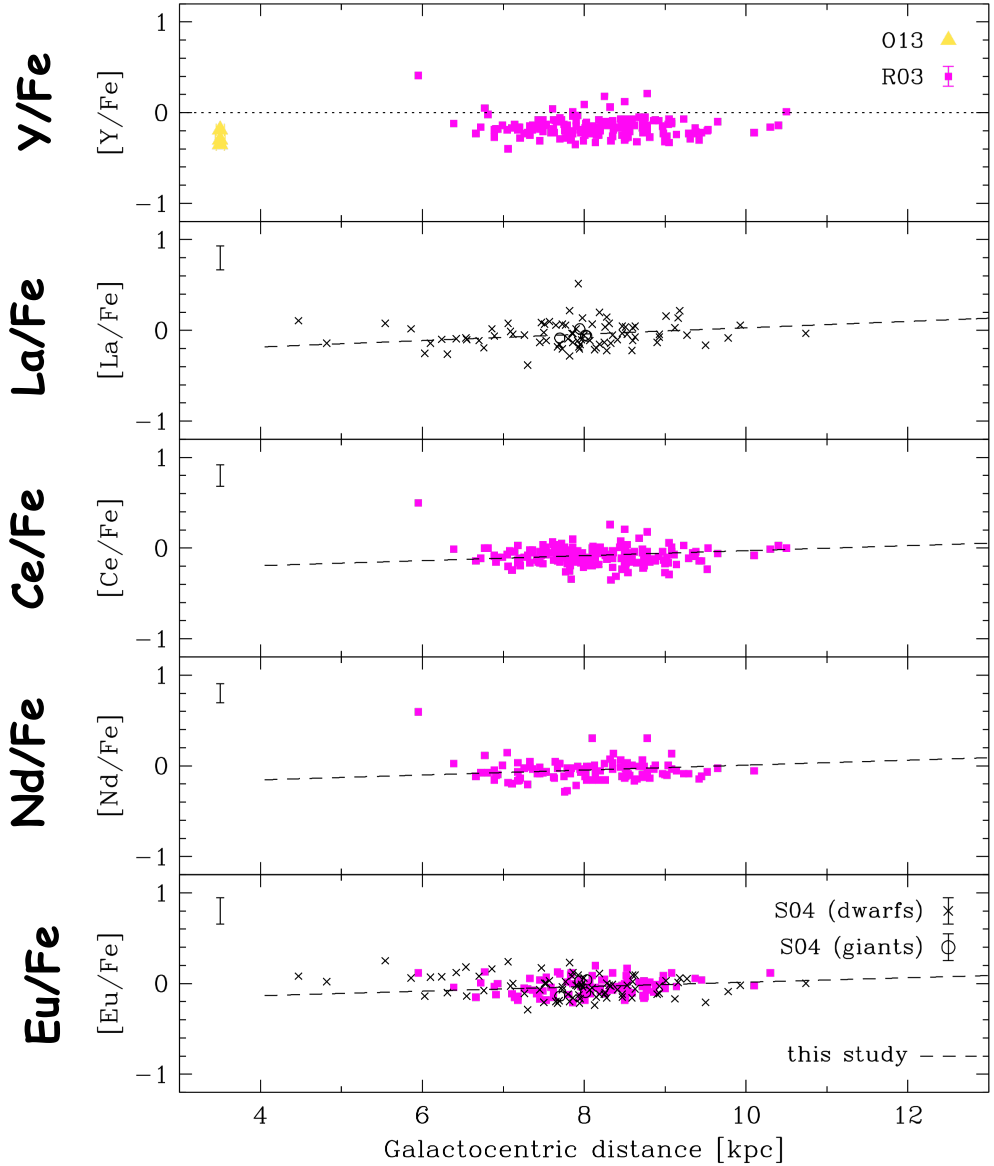
No evidence for an age effect



n-capture element/Fe ratios

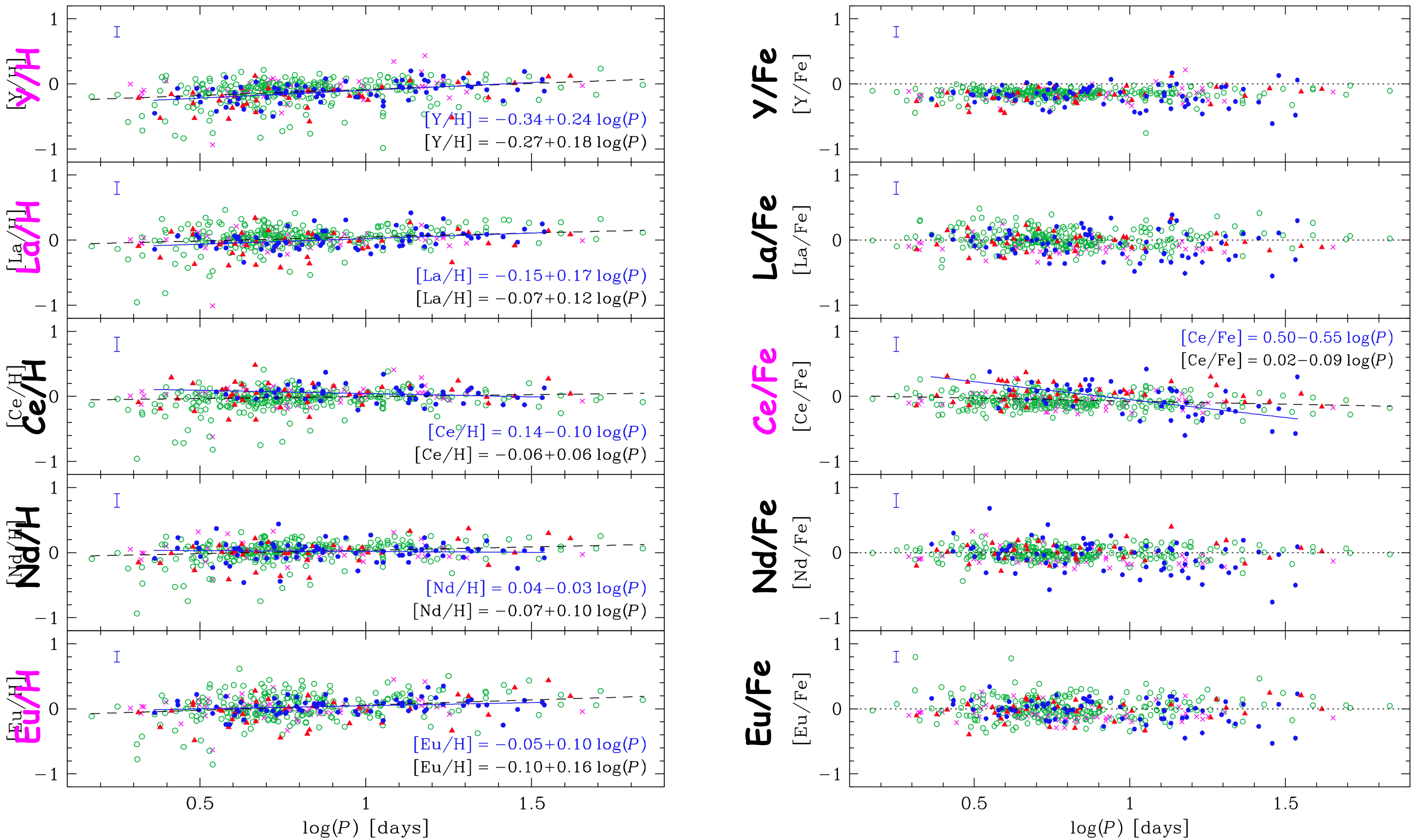
Negative slopes mainly caused by [Fe/H] gradient → Y flat



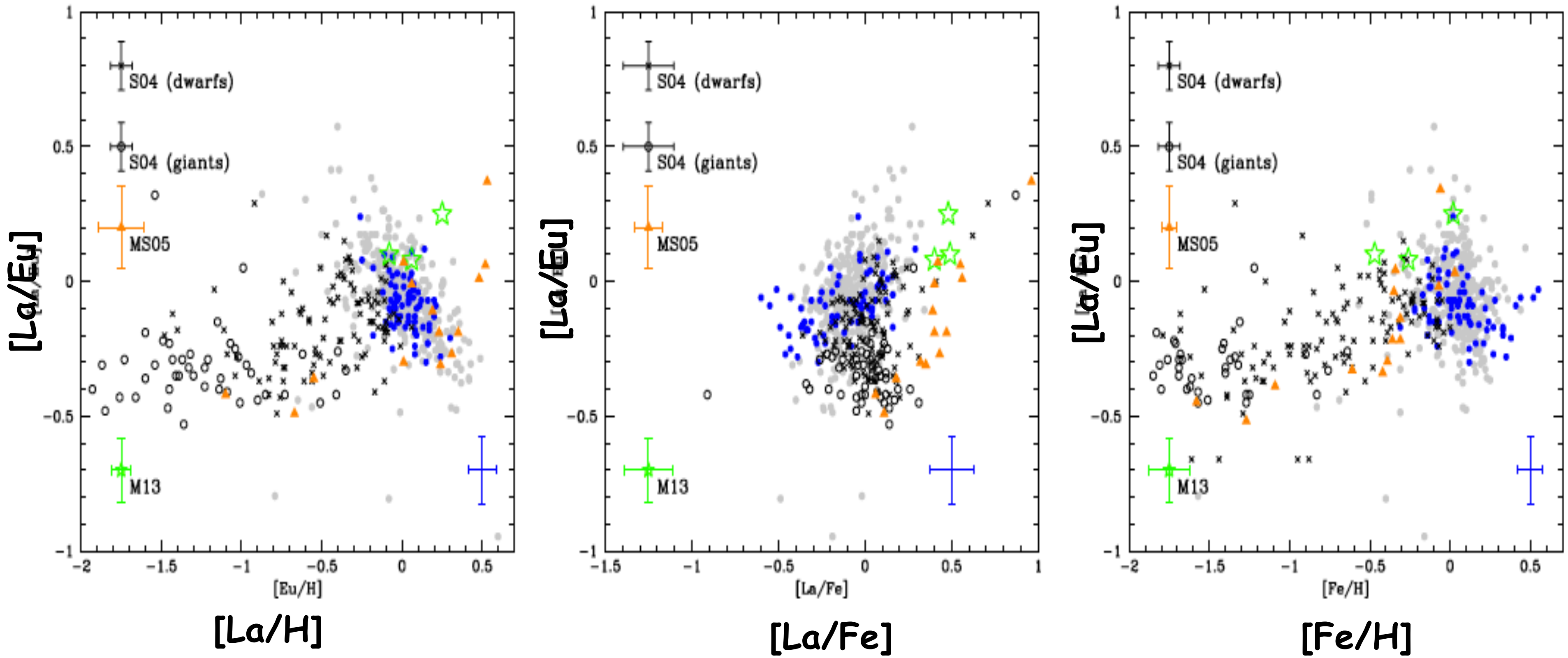


n-capture elements: age dependence

Positive slopes with age … younger Cepheids more polluted by AGB



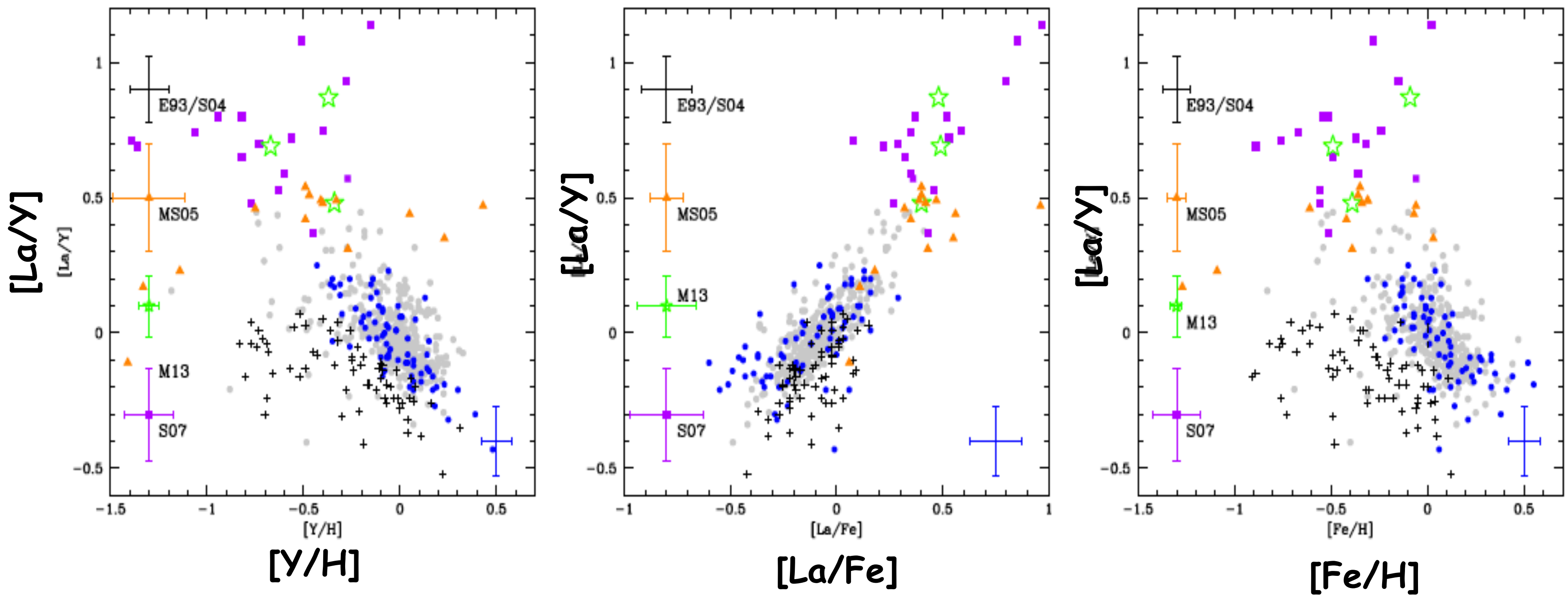
[s/r] [La/Eu] adundance ratio



Thin disk Galactic dwarves & giants by Simmerer + (2004)

+ Sagittarius dSph RGs collected by McWilliam + (2013)

[hs/ls] [La/Y] adundance ratio



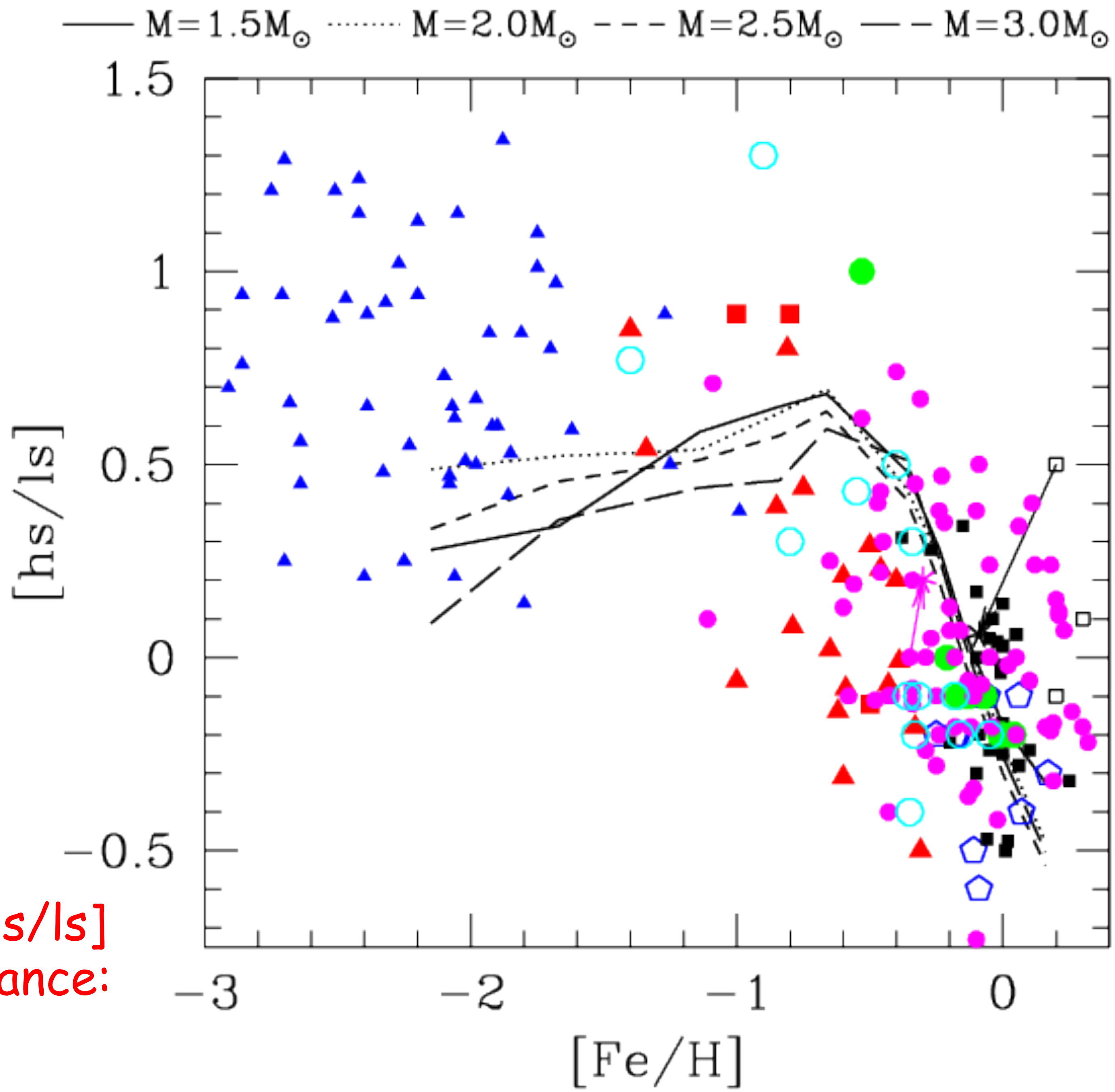
M-P AGB stars favor production of hs elements such as La
M-R AGB stars favor production of ls elements such as Y

current data display a well defined anticorrelation with Fe
more complex La enrichment in Sagittarius

Comparison between theory & observations by Cristallo + (2011)

O-rich
C-rich
Ba-rich
CH-stars

Field stars



Large spread in [hs/ls] at fixed Fe abundance:

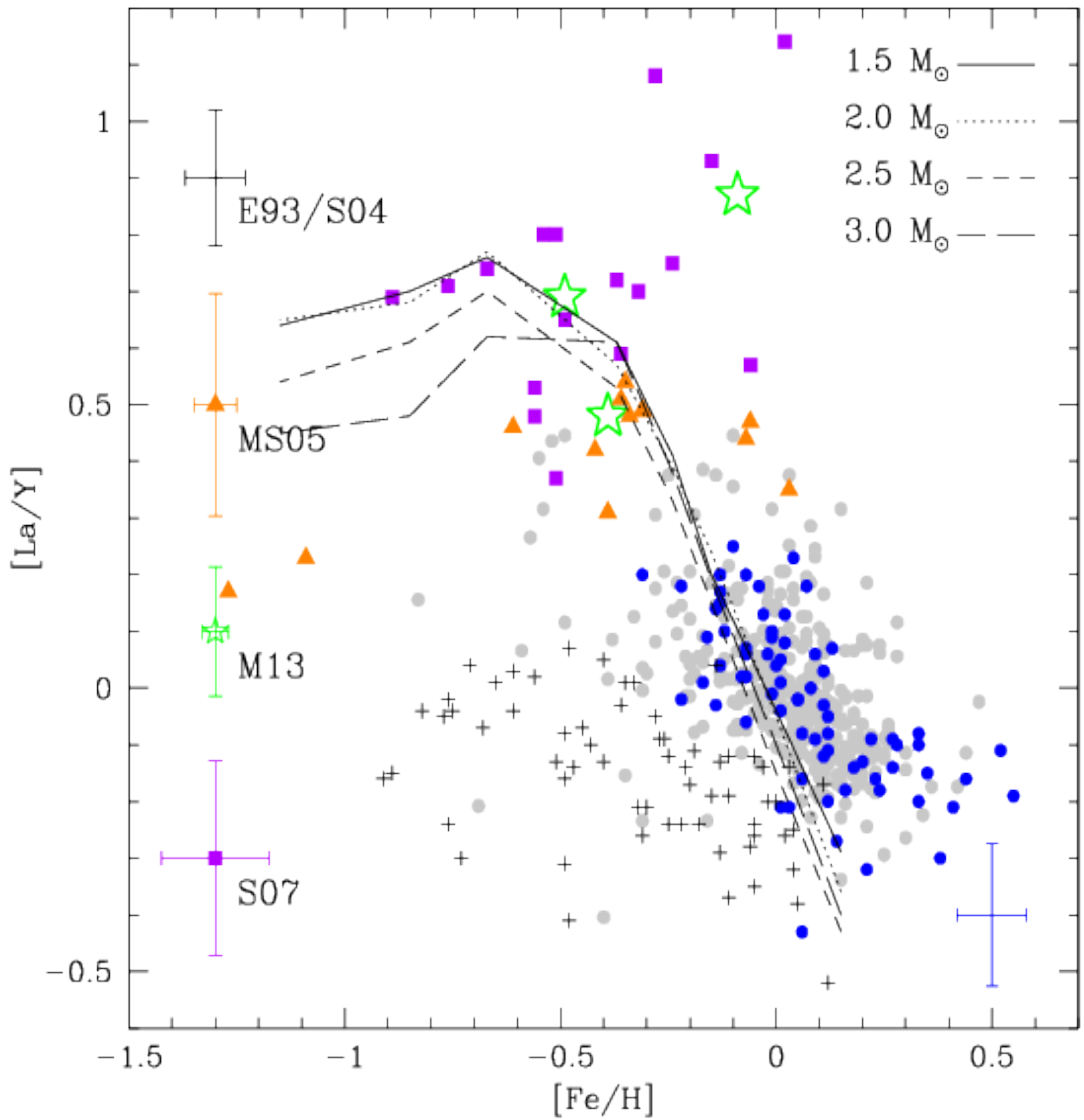
empirical errors
+ neutrons, poisons, seeds

A very good agreement between the current data & simple yields from AGB

NO SHIFT!!!!

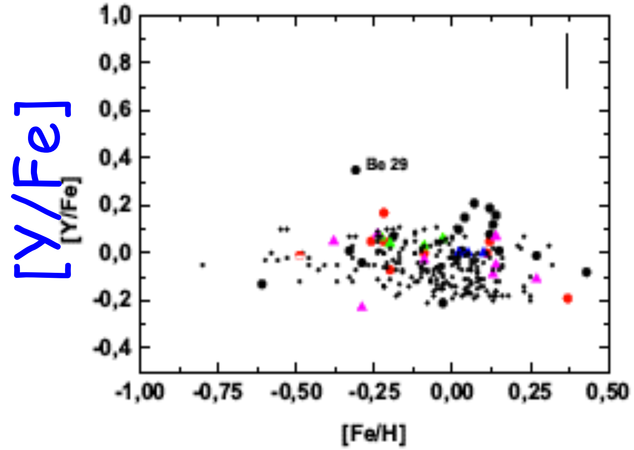
More detailed chemical evolution models are required

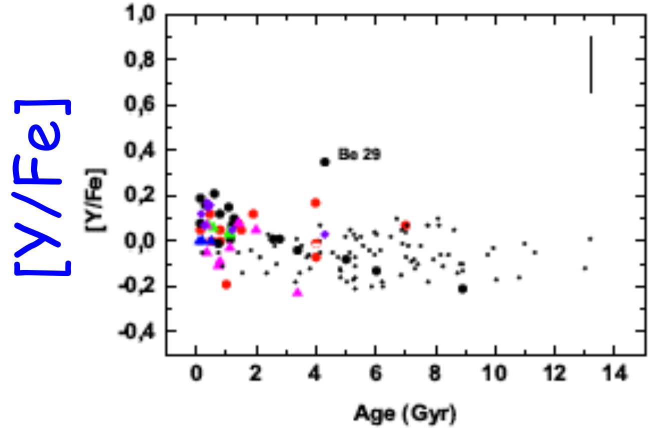
Very promising to constrain chemical enrichment in nearby dwarf gal.



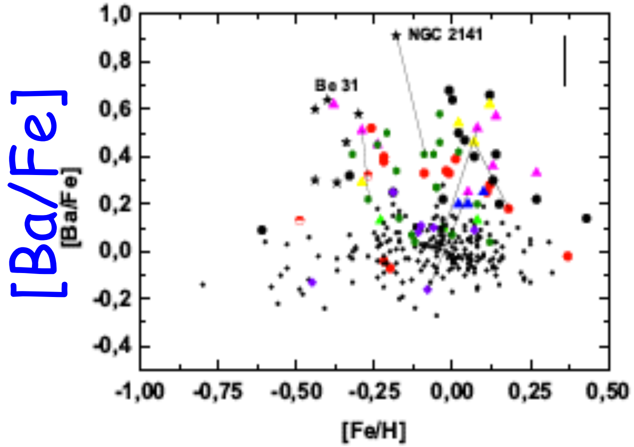
Mishenina + (2015)

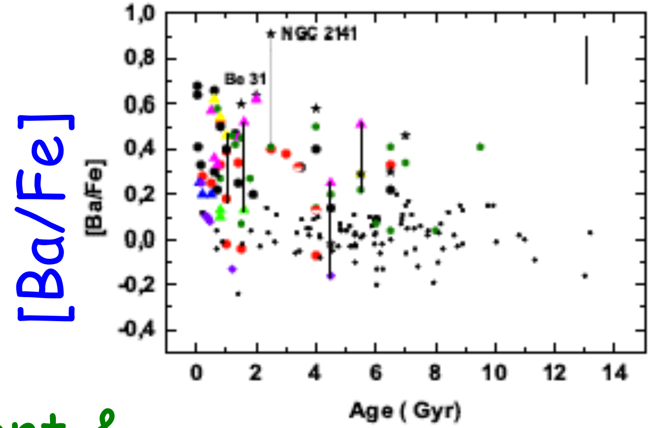
27 RGs in 5 OCs
with UVES@VLT
+ literature values



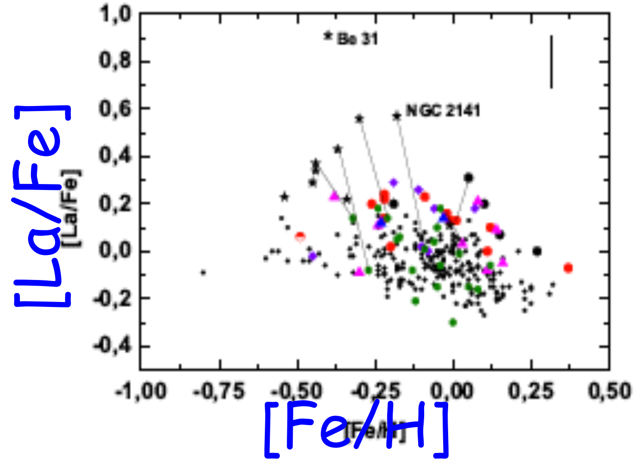


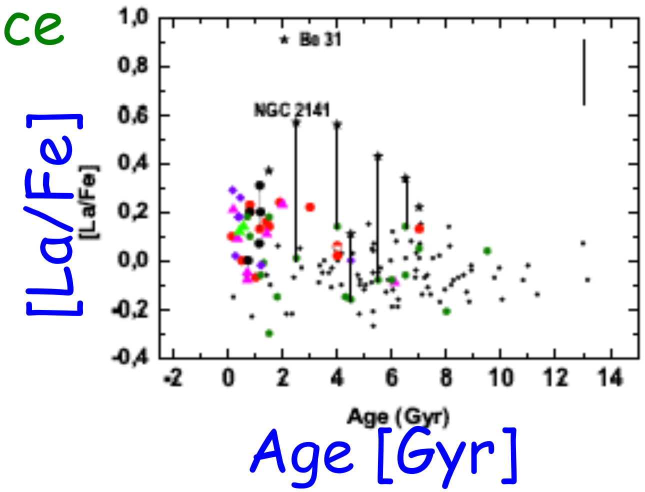
Ba overabundance
in OCs + increased
spread for t ≤ 4 Gyr



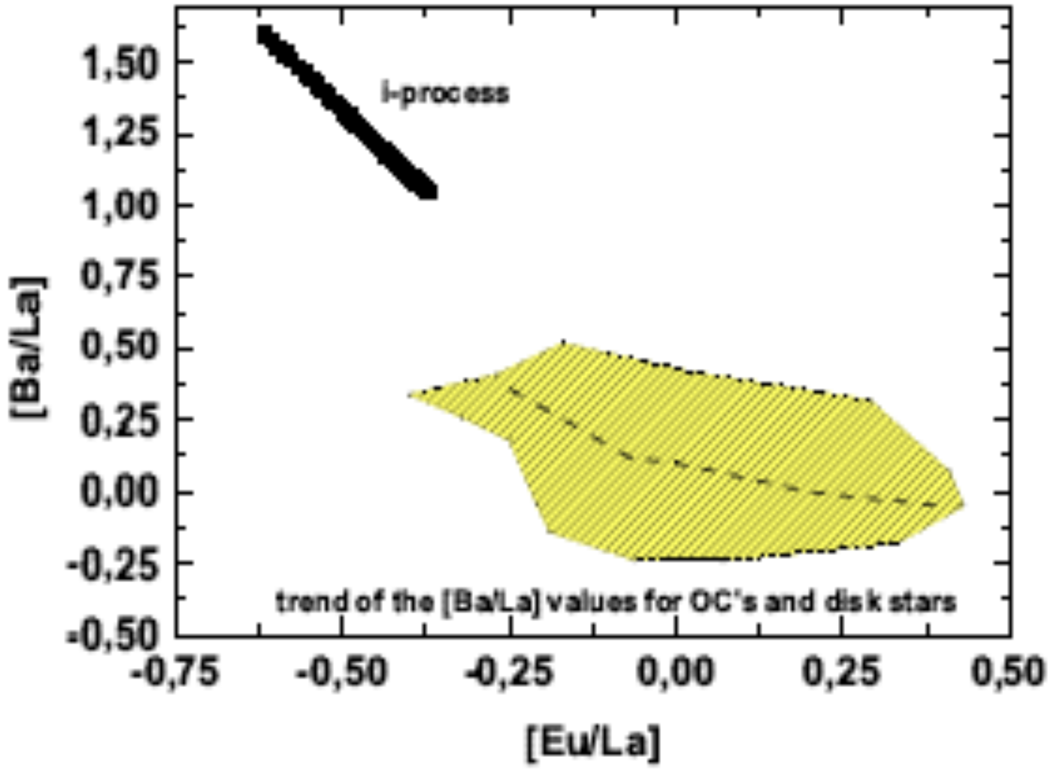


La milder enhancement &
similar age dependence





Mishenina + (2015)



Ba enrichment when compared with other n-capture elements in OCs cannot be explained as a s-/r-process element.

It can explained assuming an additional contribution from intermediate-neutron capture process.

CONCLUSIONS

→ Cepheids are solid young stellar tracers

→n-capture elements provide a new spin to constrain the recent chemical enrichment of the Galactic thin disk strong link with AGB

→There is evidence of a similarity between hs & ls in the MW disk & in Sagittarius dSph

→Very good agreement between predicted (AGB yields) & observed [hs/ls] abundance ratios

Future developments

→ Galaxy:

Outer disk - KISOGP survery

Inner disk + NB → IRFS survey

Open Clusters!!!

→ Magellanic Clouds: field & cluster Cepheids

→ Transition from HR optical to HR NIR spectra

GIANO, WINERED, CRIRES

→ Kinematics & chemo-dynamical models

First Generation E-ELT Instruments

First Light

E-ELT -- CAM (MICADO): R. Davies

E-ELT -- IFS (HARMONI): N. Thatte

E-ELT – MIR: L, M, N: B. Brandl

MAORY (AO module) E. Diolaiti

4) E-ELT – HIRES (Optical – NIR)

5) E-ELT – MOS: Fibers + IFUs (optical, NIR)

6) E-ELT – Not defined yet

GLOBAL GROWTH

Evolutionary, Pulsation, Atmosphere models → 1D vs 3D

Opacity, EOS, line identifications, molecules (NIR)

Multiband Asymmetric PSF

Integral field spectroscopy

Credits

To young, differently young & senior colleagues with whom I have the pleasure to share this wonderful adventure

M. Fabrizio[ASDC], L. Inno[ESO], B. Lemasle[heid], R. Oliveira da Silva(asdc), K. Fukue (Tokyo)

THANKS!