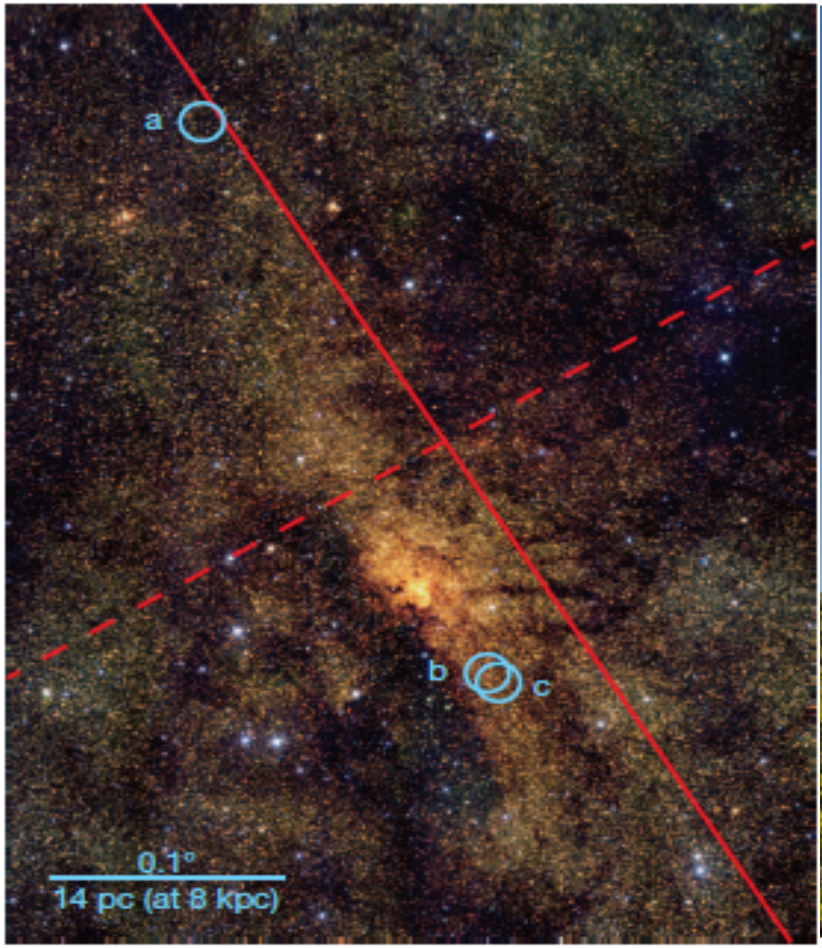
Near infrared high resolution spectroscopy of variable stars

G. Bono, Univ. Of Rome ToV + D. Magurno, M. Urbaneja + many others



Near infrared high resolution spectroscopy of variable stars

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OUTLINE OF THE LECTURES

ONE

- → Why variable stars?
- → Distance indicators
- → Stellar tracers
- → Physics laboratories

TWO

- → Validating the machinery
- → Pulsation cycle
- → Telluric subtraction
- → Metallicity gradients

THREE

- → WINERED + others
- → NIR diagnostics
- → Near Future: ELT

Near infrared high resolution spectroscopy of variable stars

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OUTLINE OF THE LECTURE

TWO

→ Validating the machinery [optical]

→ Pulsation cycle [variations]

→ Telluric subtraction

→ Metallicity gradients

Cepheids, Mira & RR Lyrae

We are dealing with strange bugs:

Variations in Teff, log g, Vtur

→ Validation of the approach

Cepheids: effective temperature estimates

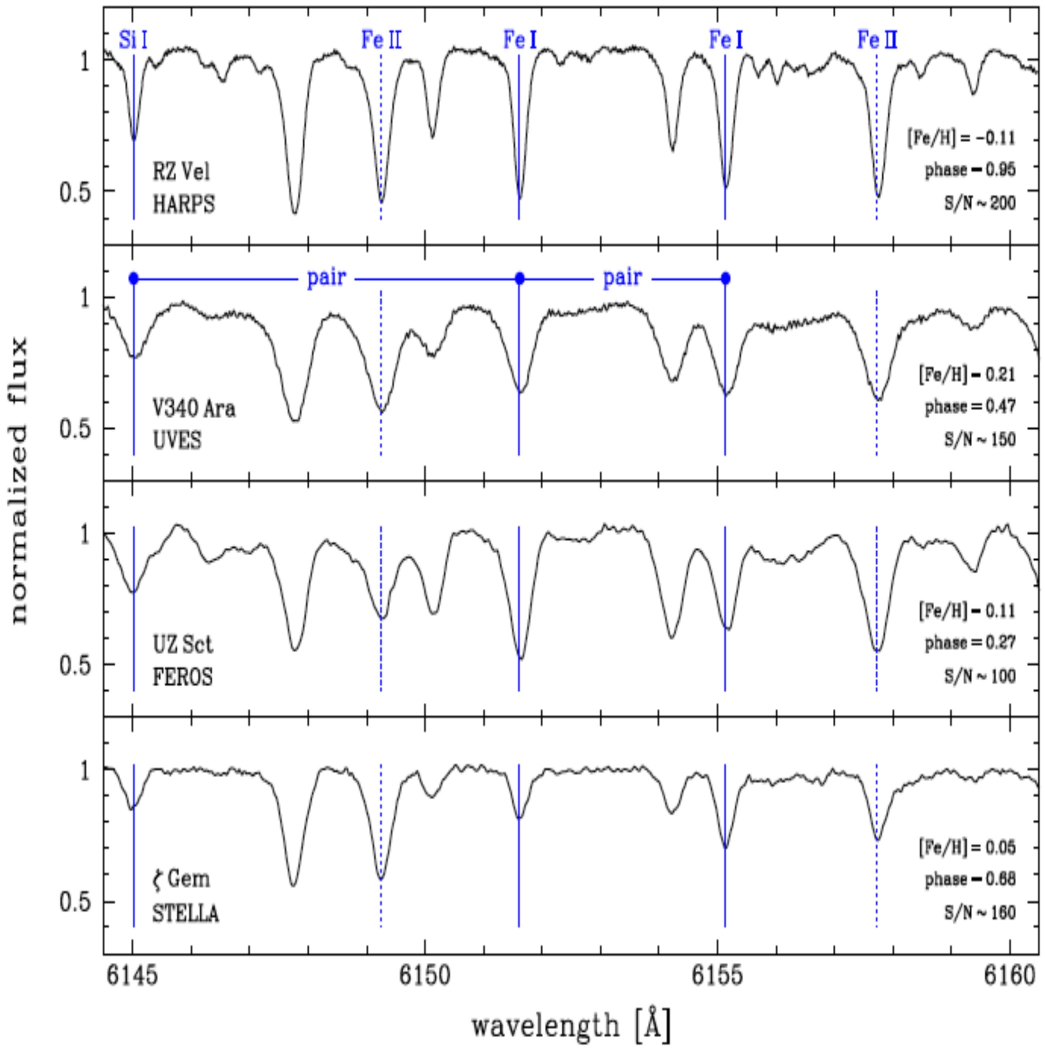
Temperature diagnostics: Line Depth Ratios

The depth ratio of several pairs of absorption lines are correlated with the effective temperature.

To minimize the dependence of the abundance, log g & continuum location, the pairs should come from the same (or a similar) element, similar wavelengths & possibly neutral species (Gray 2005).

The application to variable stars was pioneered by Sasselov & Lester in the 90s

Cepheids: LDRs in action



Luck & Andrievsky 2004
a few Cepheids with multiple spectra

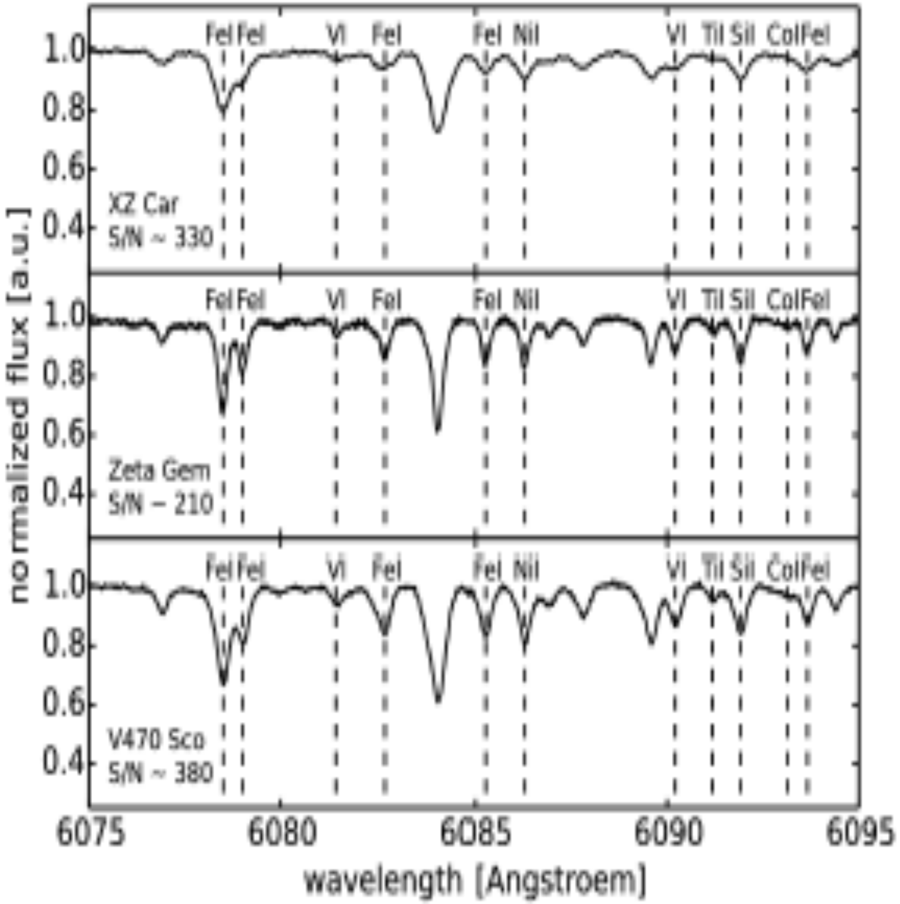
Proxauf et al. (2017)

Calibrating Cepheids

Name	$R_G \pm \sigma$ [pc]	α_{ICRS}	δ_{ICRS}	Period [days]	$[Fe/H]_{lit}$	N_F	N_H	N_U	N_S	N_{tot}
V340 Ara	4657 ± 427[1]	16:45:19.112	−51:20:33.393	20.809	0.33[1]	28	...	6	...	34
S Cru	7593 ± 451[1]	12:54:21.998	−58:25:50.214	4.689596	0.08[1]	1	12	...	...	13
β Dor	7936 ± 451[1]	05:33:37.517	−62:29:23.369	9.842425	−0.06[1]	1	46	...	...	47
ζ Gem	8273 ± 452[1]	07:04:06.531	+20:34:13.074	10.15073	−0.11[1]	...	47	...	81	128
Y Oph	7141 ± 452[1]	17:52:38.702	−06:08:36.870	17.126908	0.12[1]	...	8	...	...	8
RS Pup	8585 ± 444[1]	08:13:04.216	−34:34:42.696	41.3876	0.21[1]	...	15	...	...	15
EV Sct	6135 ± 449[1]	18:36:39.602	−08:11:05.360	3.09099	0.10[1]	25	...	1	...	26
UZ Sct	5309 ± 448[1]	18:31:22.368	−12:55:43.350	14.7442	0.33[1]	28	...	6	...	34
AV Sgr	5980 ± 454[1]	18:04:48.780	−22:43:56.600	15.415	0.35[1]	28	...	5	...	33
VY Sgr	5862 ± 453[1]	18:12:04.568	−20:42:14.580	13.5572	0.33[1]	30	...	4	...	34
X Sgr	7980 ± 500[2]	17:47:33.624	−27:49:50.833	7.012877	−0.36[2]	2	26	...	24	52
XX Sgr	6706 ± 453[1]	18:24:44.501	−16:47:49.816	6.42414	−0.01[1]	4	...	5	...	9
Y Sgr	7483 ± 452[1]	18:21:22.986	−18:51:36.002	5.77338	0.11[1]	...	20	...	3	23
R TrA	7519 ± 451[1]	15:19:45.713	−66:29:45.742	3.389287	0.16[1]	1	14	...	...	15
RZ Vel	8249 ± 445[1]	08:37:01.303	−44:06:52.848	20.39824	0.19[1]	1	11	...	...	12

Covering the entire pulsation cycle

Range in periods (mass, effective temperature)
chemical compositions



A new spin

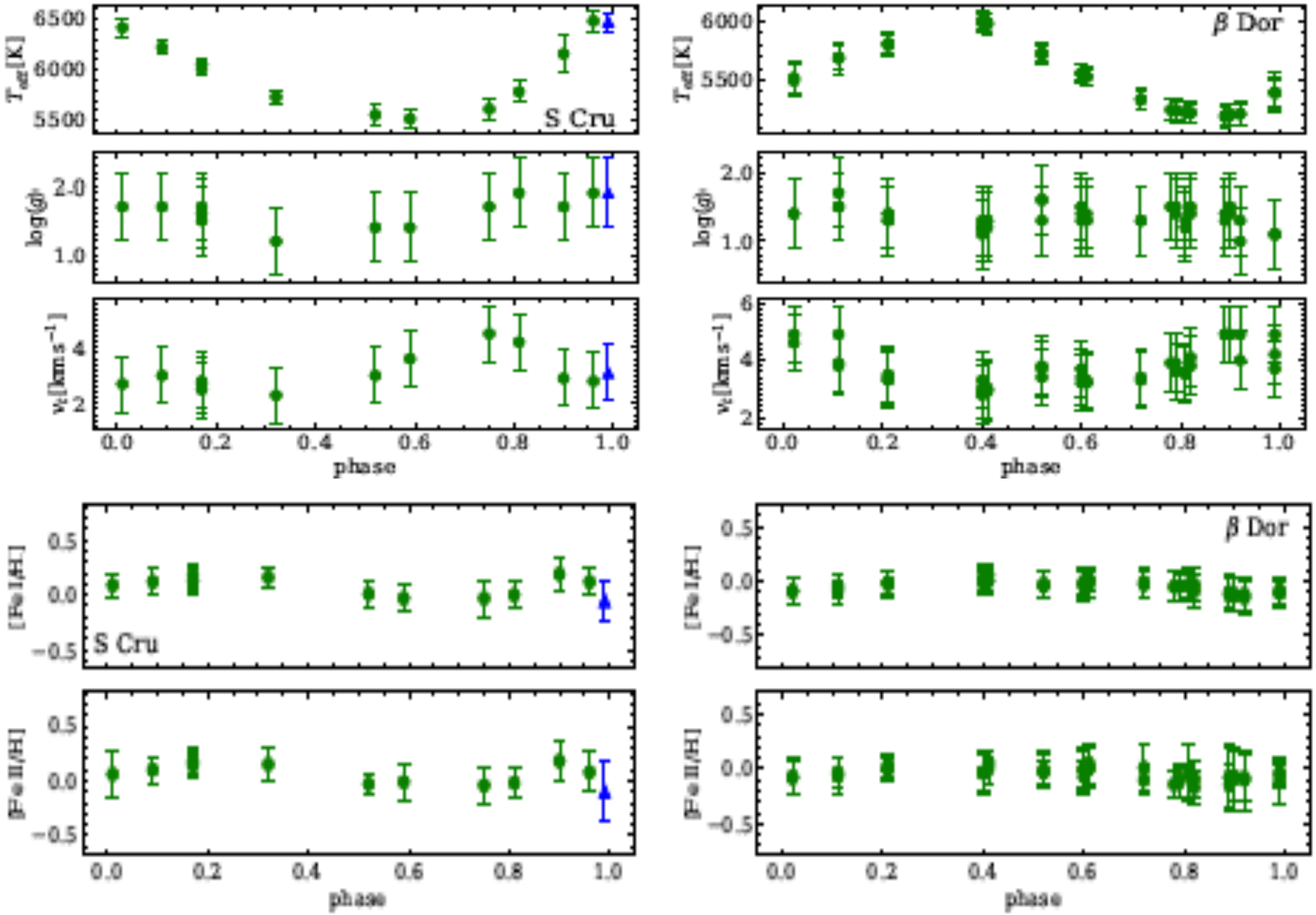
Line depth ratios for 260 pairs
by Kovtyukh & Gorlova old + new

Extended spectral coverage
from ~4000 to 8000 AA

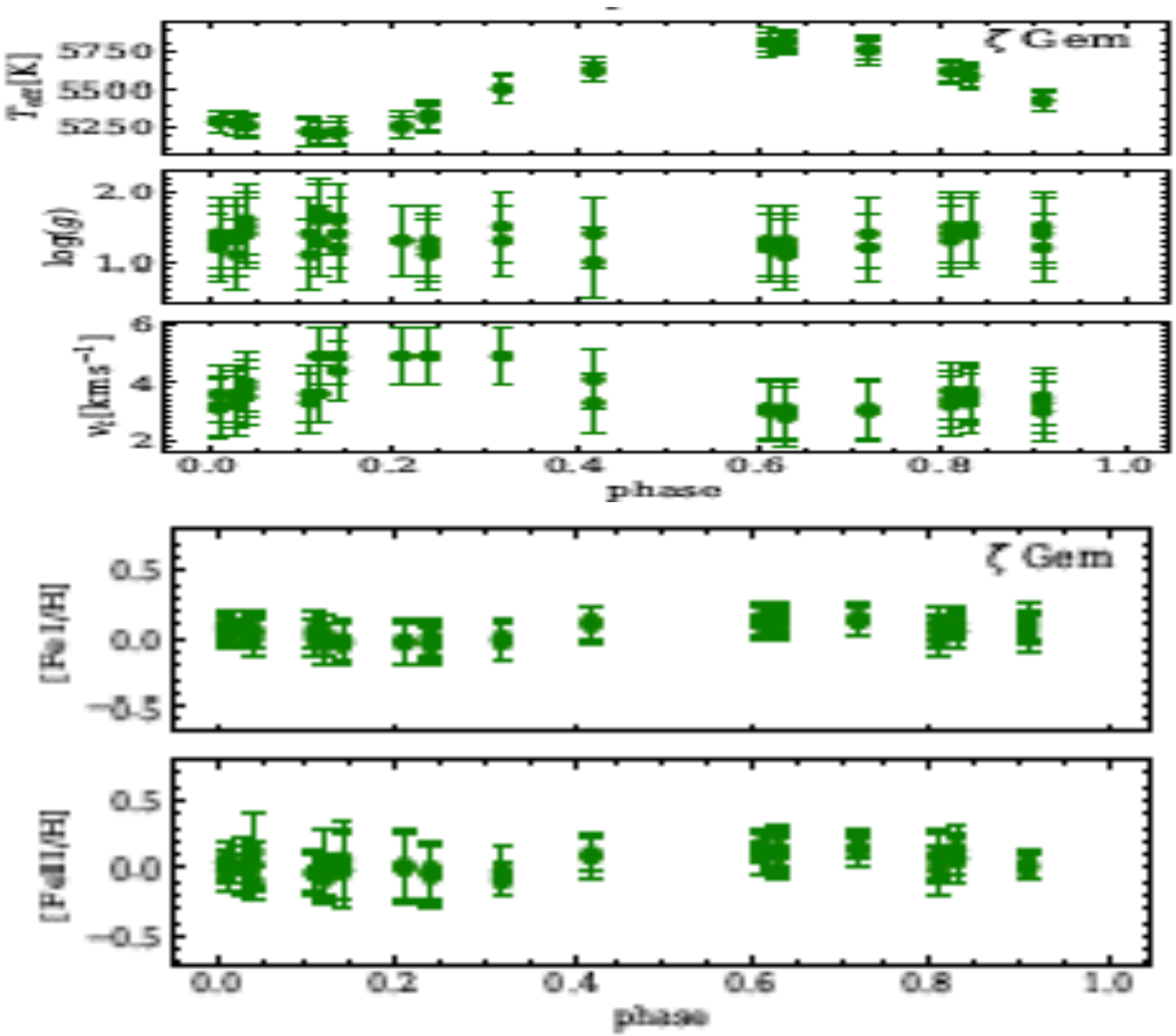
Extended temperature coverage
from ~3500 to 7500 K

Smooth temperature estimates
along the rising branch

Cepheids: intrinsic parameters & abundances



Cepheids: intrinsic parameters & abundances



Cepheids: intrinsic parameters & abundances

New validations to constrain the zero-point using

Baade Wesselink (IRSB)

NIR VLTI measurements of the very same Cepheids

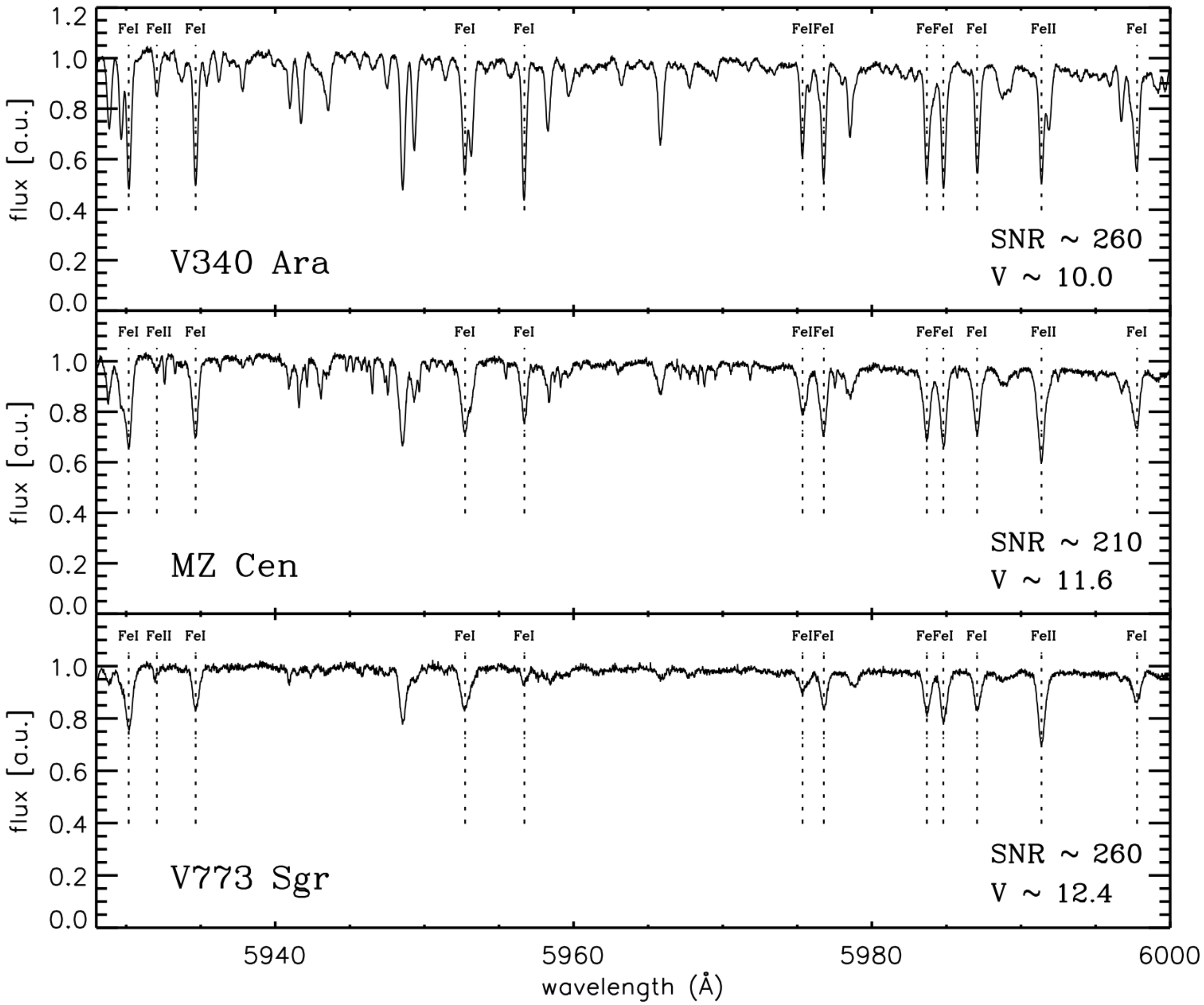
UVES@VLT spectra for ~115 Cepheids

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)

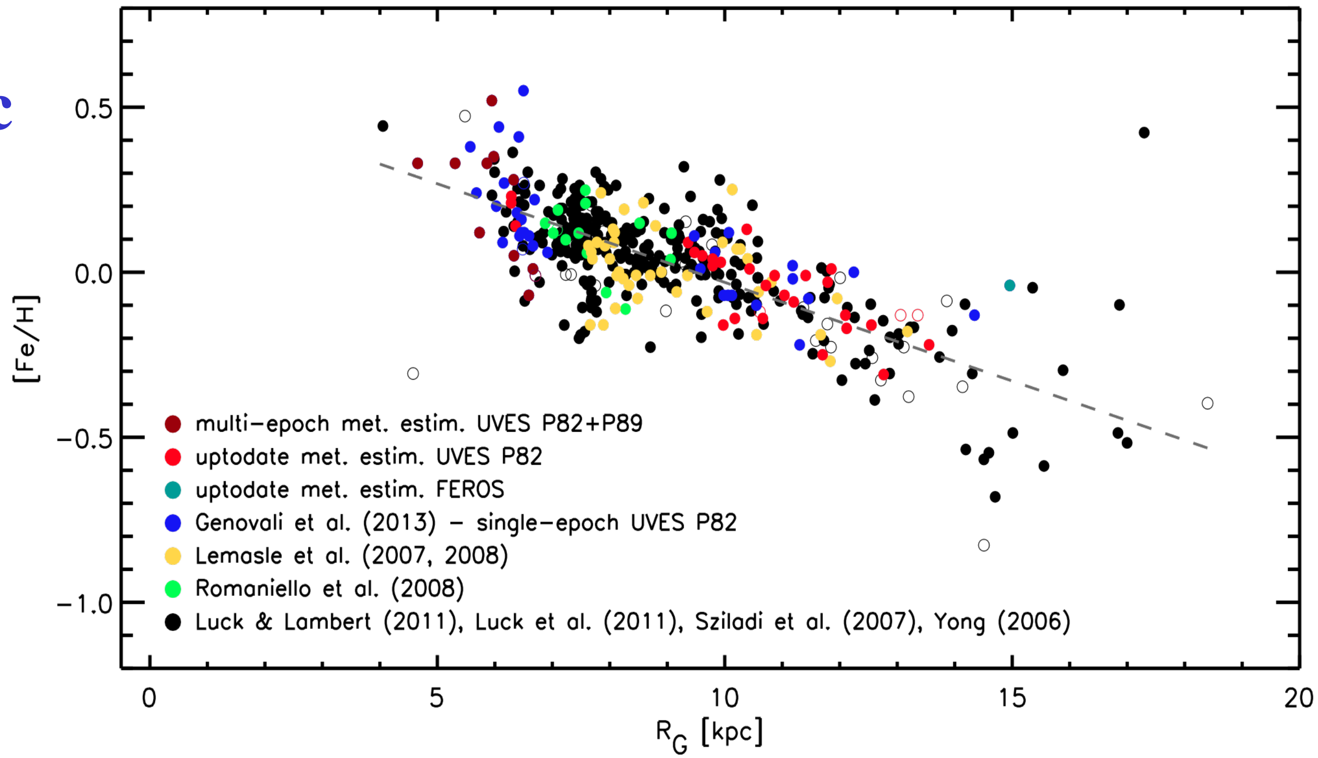
From several to tens of FeII lines

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

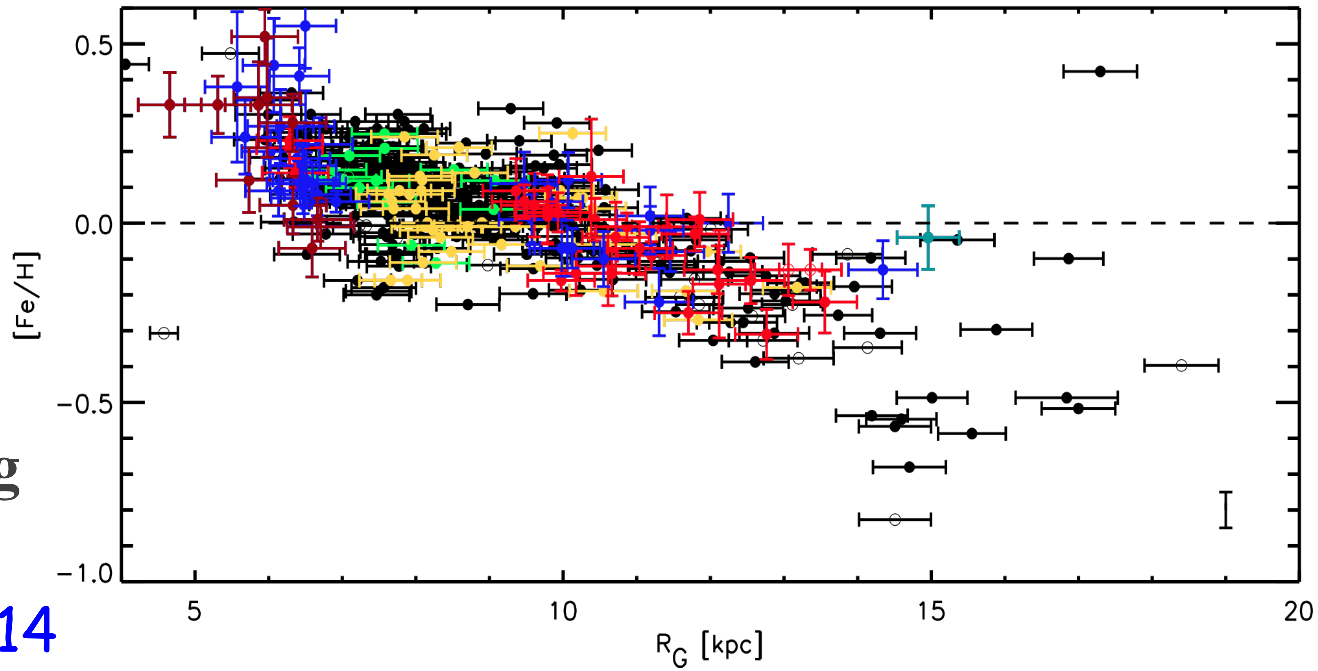
~2/3 Luck + Andriewski +

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



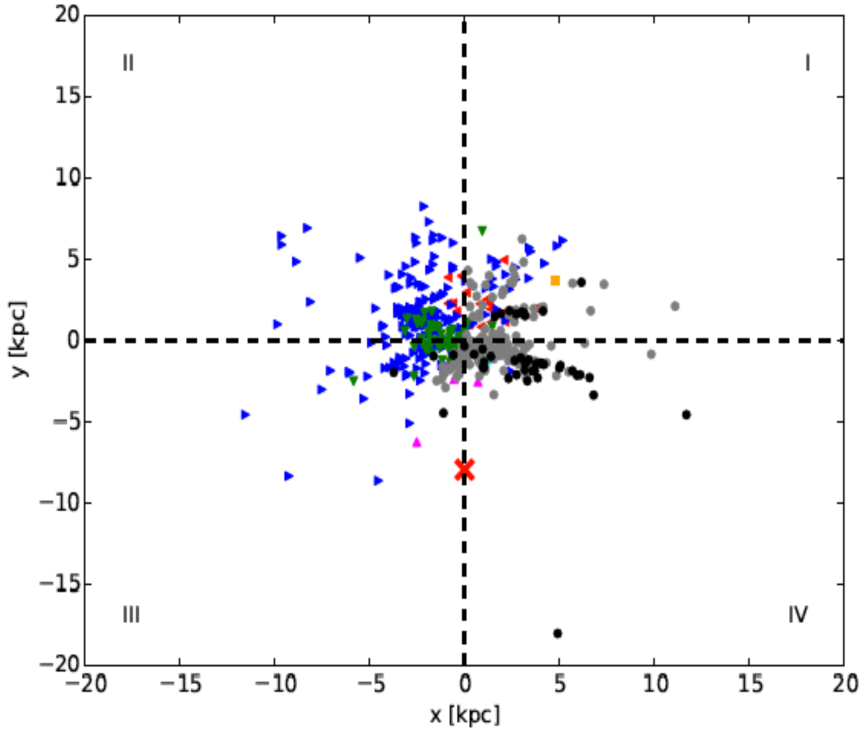
Genovali et al. 2013,2014

Spectrograph	FEROS	HARPS	UVES	All	
No. of objects	169	9	76	205	~250
Nometal cepheids	8	1	0	8	
Cluster cepheids	11	10	8	14	
Calibrators (>2 spectra)	77	9	17	108	
No. of spectra	486	199	152	837	~1000

A new spin

50% of known Cepheids

10% new



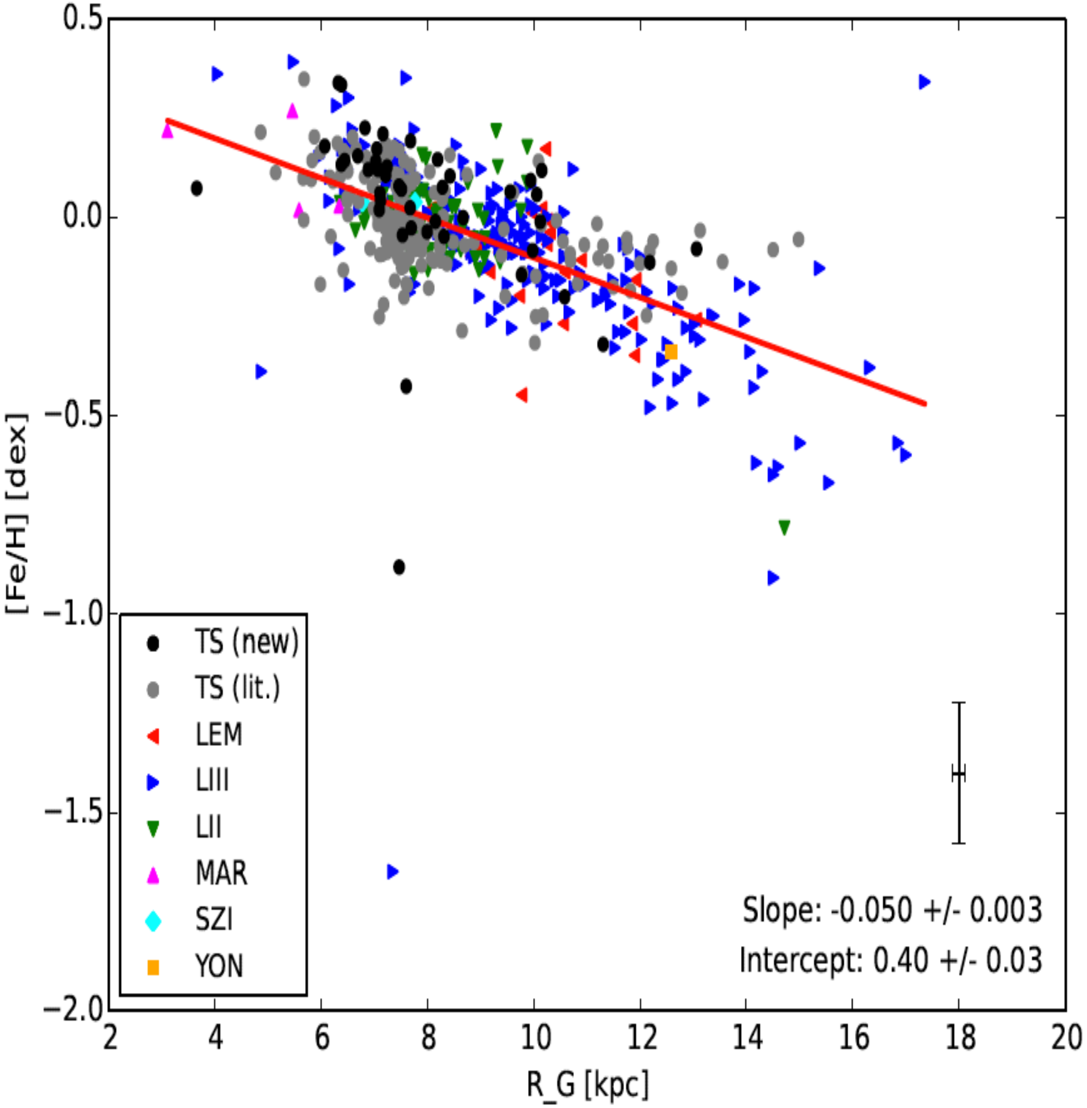
Homogenous temperature & metallicity scale based on EWs → LTE

R≥35,000 – SNR ≥ 100

Approaching a complete census of known Cepheids

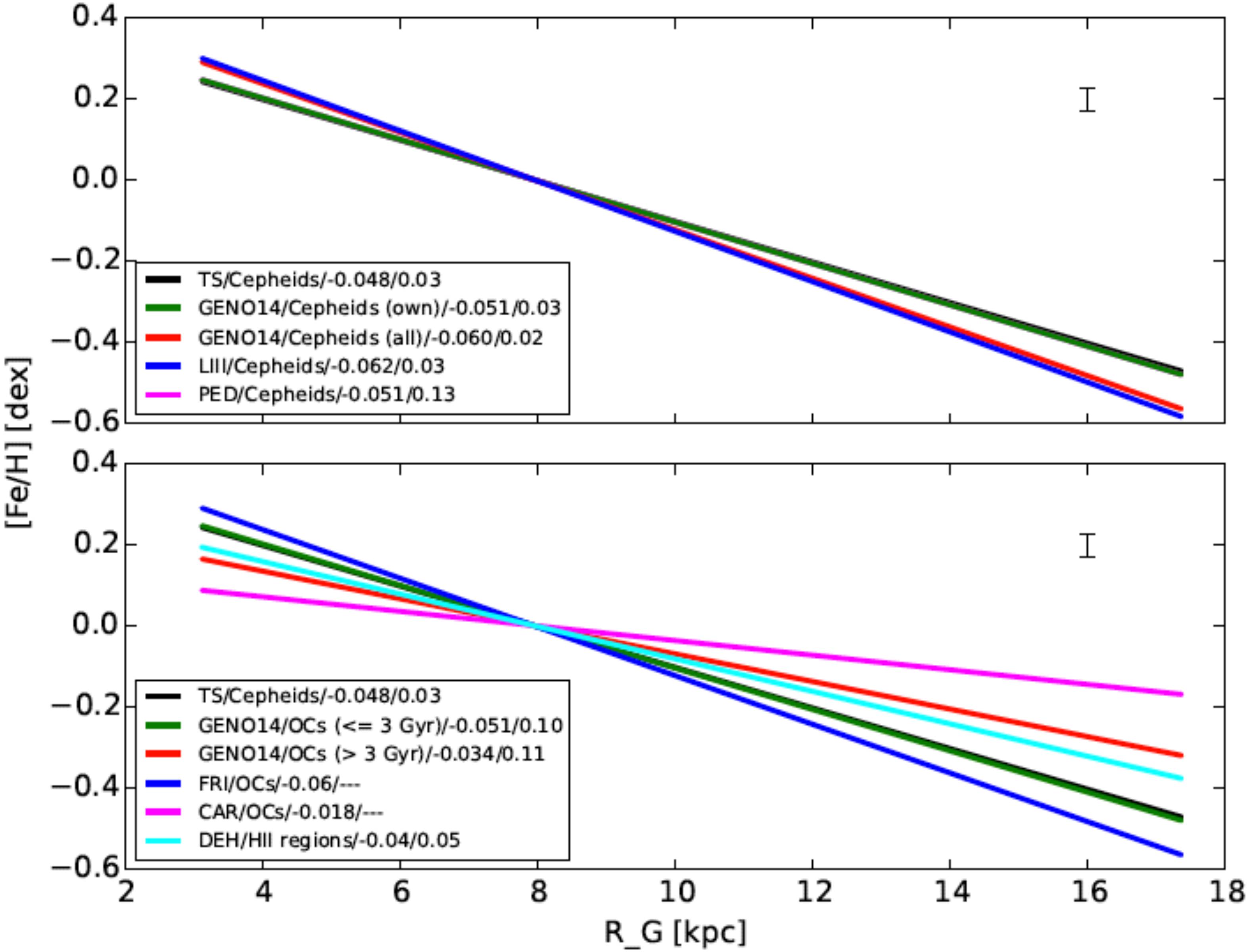
Master Thesis by B. Proxauf

Almost the entire sample (~500) of known Cepheids …. (before Gaia & OGLE IV & VVVX)



The spread at fixed Rg is intrinsic

Metallicity gradients: different tracers



WHY?

Four good reasons!

→Age dependence

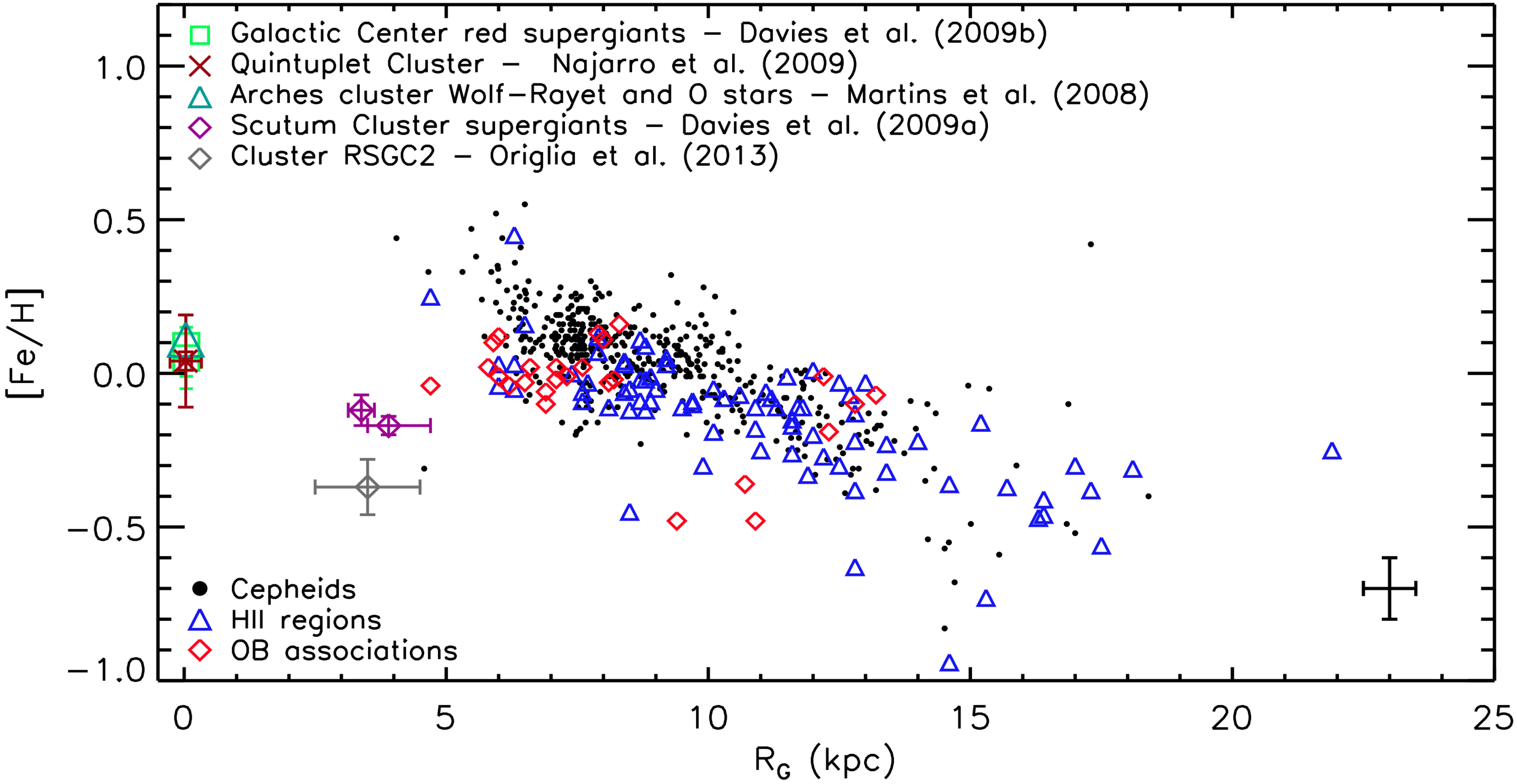
→Disk fine structure

→Inner disk & transition with NB+Bar

→ Chemical enrichment history → Theory

Cepheids and age effects

HII regions & OB associations



Inversion in the chemical gradient in the innermost regions
No relevant change for young tracers

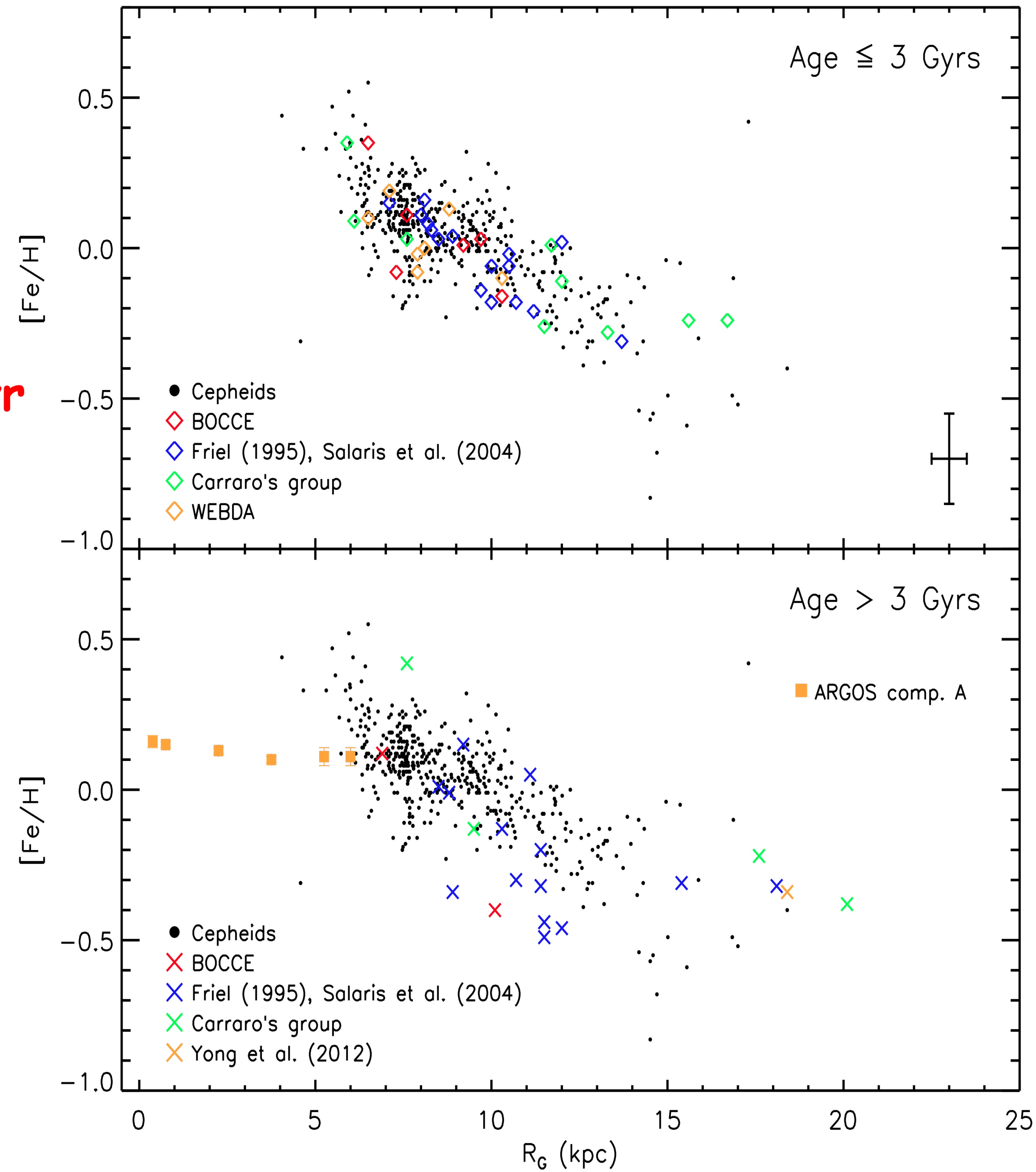
Cepheids & age effects Open Clusters

No changes for t<3 Gyr

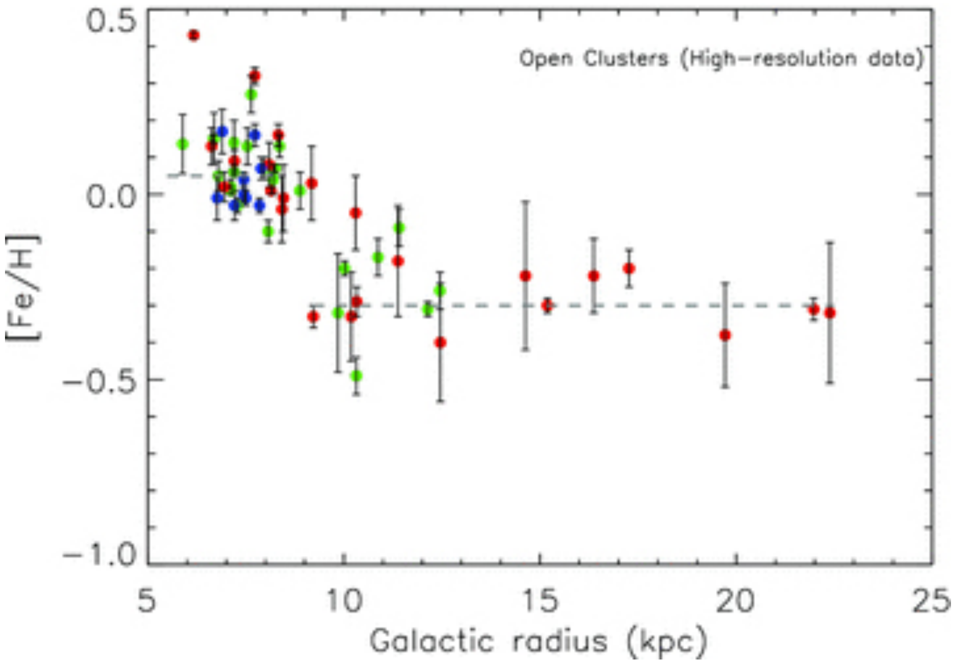
For older ages the distribution becomes more complex (ARGOS Results!)

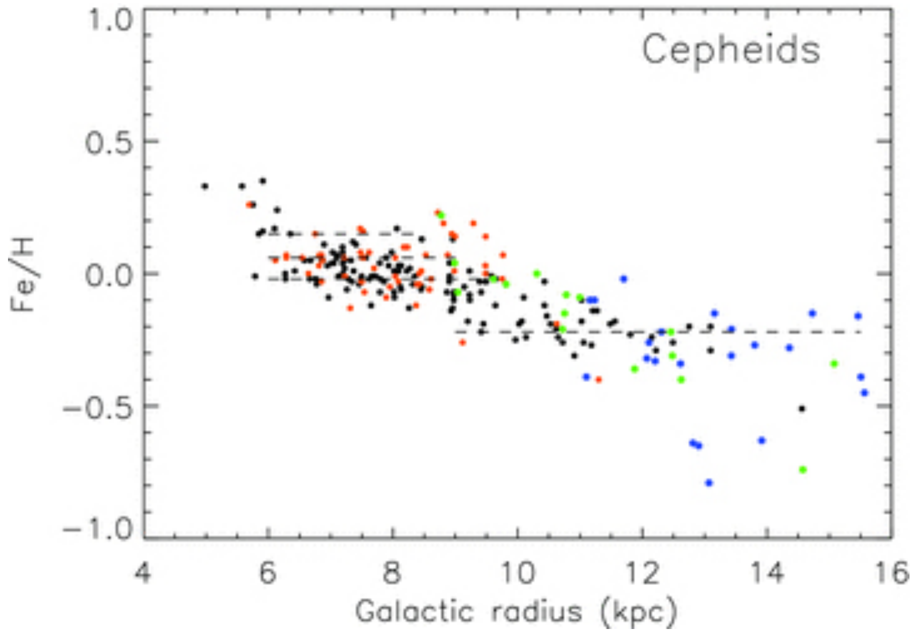
… but data are homogeneous neither in age nor in iron nor in distances!!!

GAIA-ESO Survey!!



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

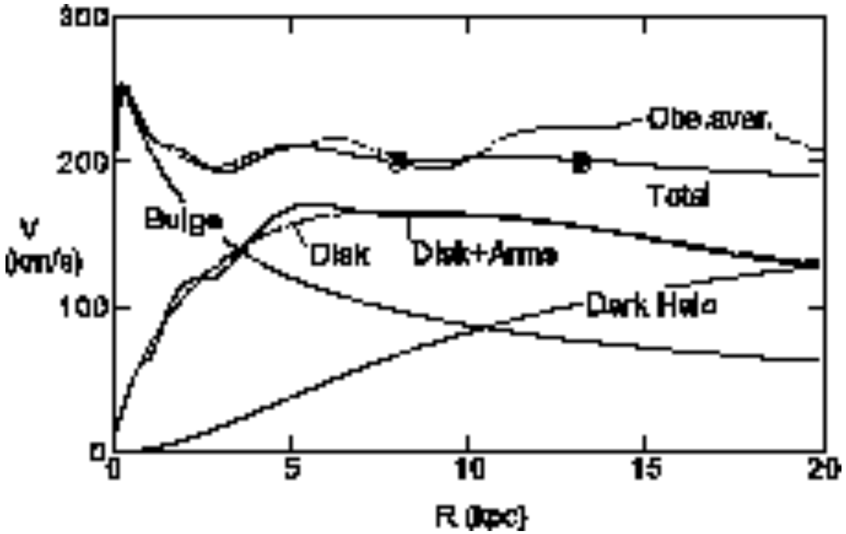




The jump in the metallicity gradient associated with the corotation resonance of the spiral pattern (Rg~9.5 kpc)

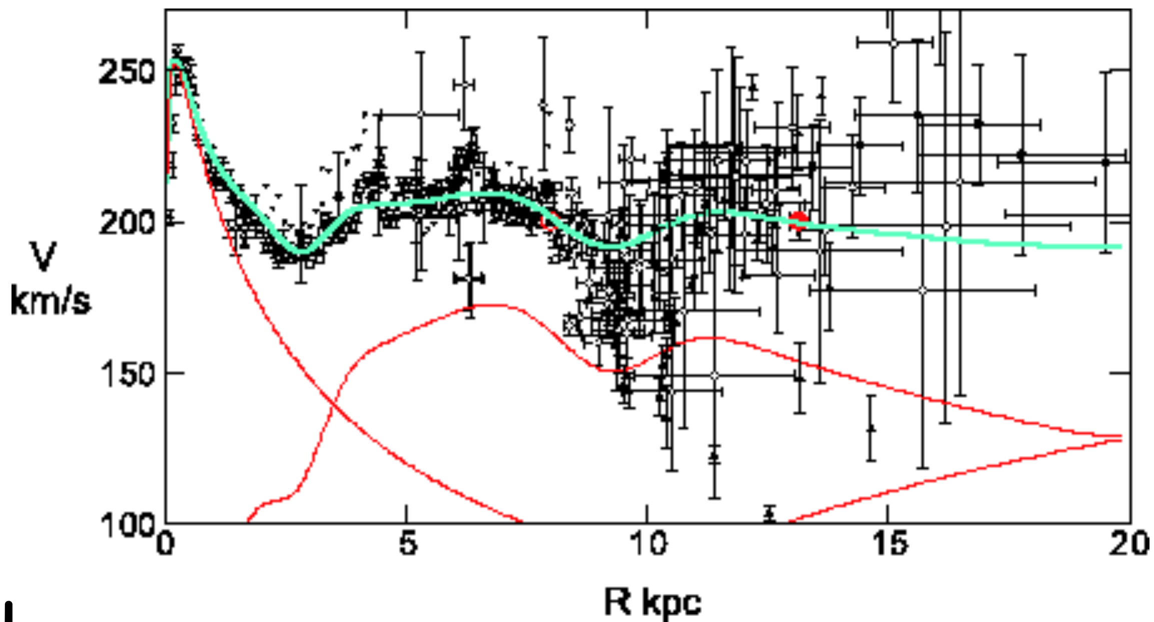
See also Scarano+ (2013) for extragalactic evidence

The fine structure of the rotation curve



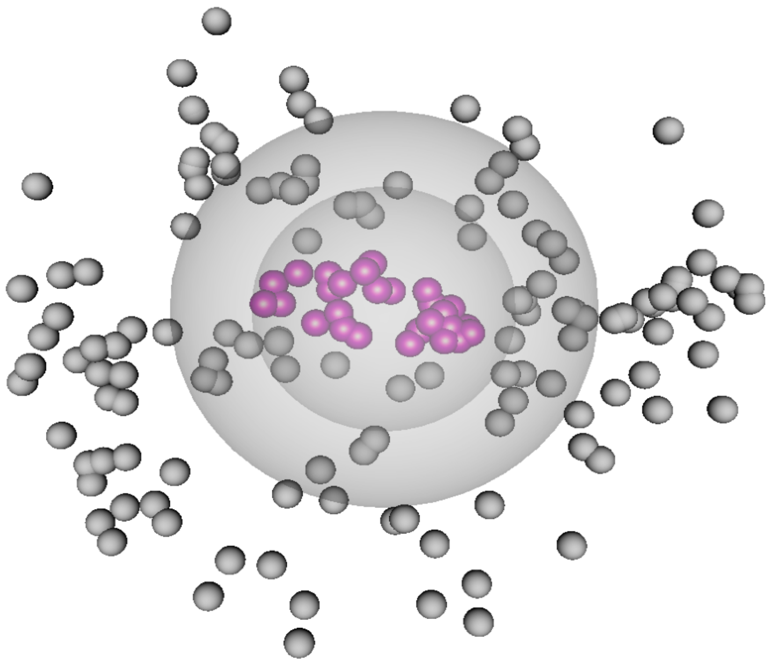
Evidence for a secondary dip located at Rg~9.5 kpc associated to the Perseus arm

Sofue et al. (2009,2013)



A new and independent approach to open the path!

Dispersion at fixed Galactocentric distance

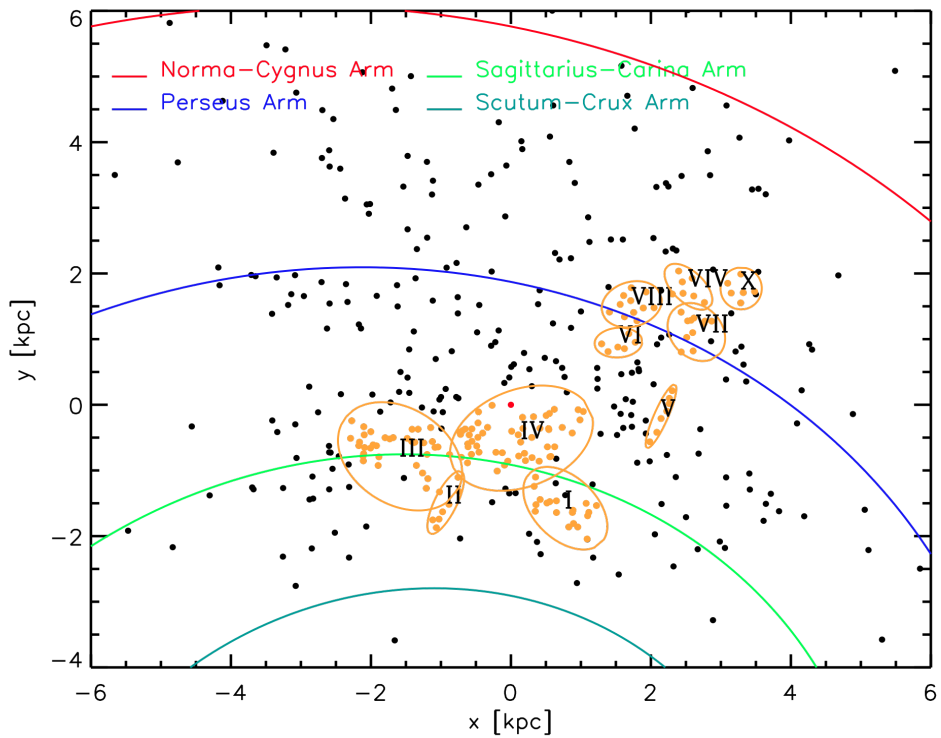


Ten candidate Cepheid Groups correlate with spiral arms: **Perseus** & **Carina-Sagittarius**

sizes from GMCs to super-associations (Baade 1963)

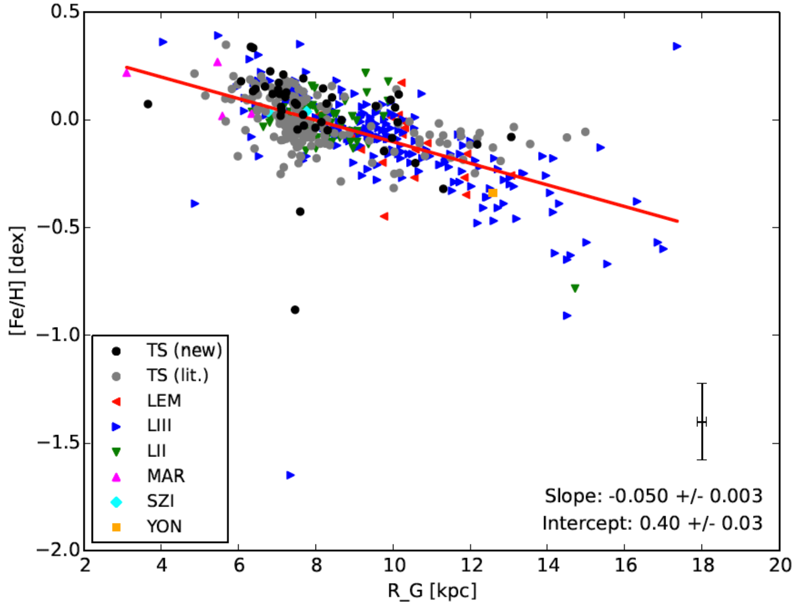
Vallee et al. (2002, 2003)
Xu (2013)

Genovali + (2014)



Clustering Paola's talk

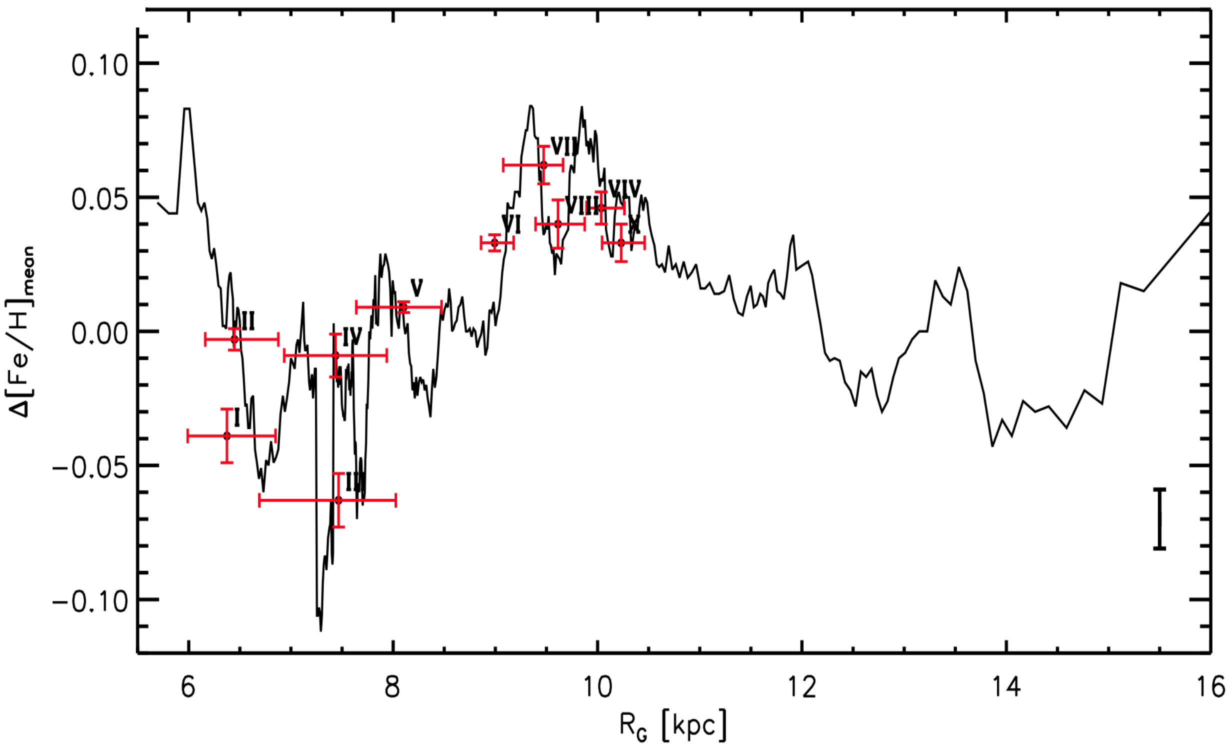
Dispersion at fixed Galactocentric distance



Residuals correlated with candidate Cepheid Groups

This takes account for the large intrinsic spread of the Fe gradient

Current findings support SOFUE + (2009)



Chemical evolution models

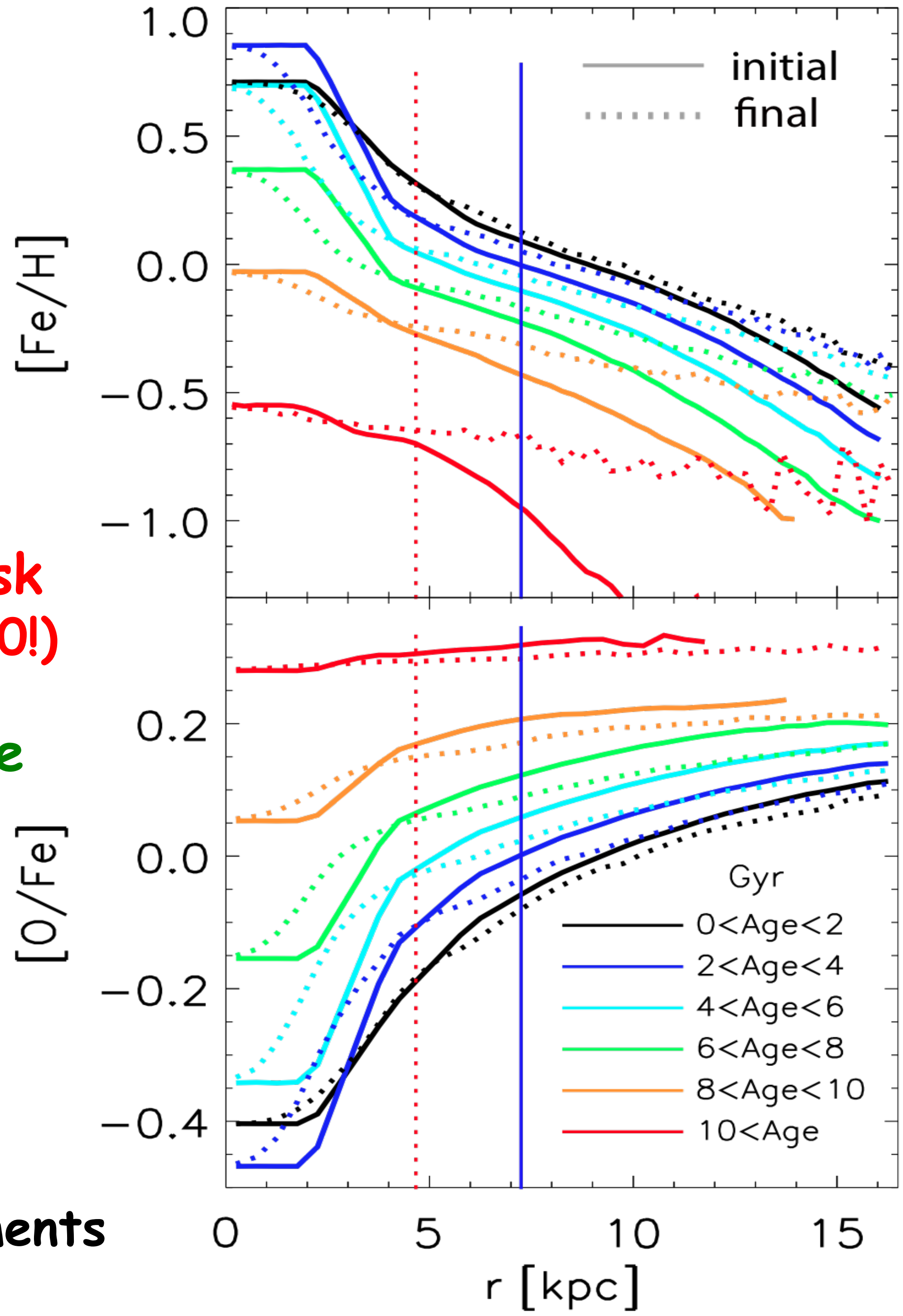
Minchev et al. (2013)
Chemo-dynamical models)

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

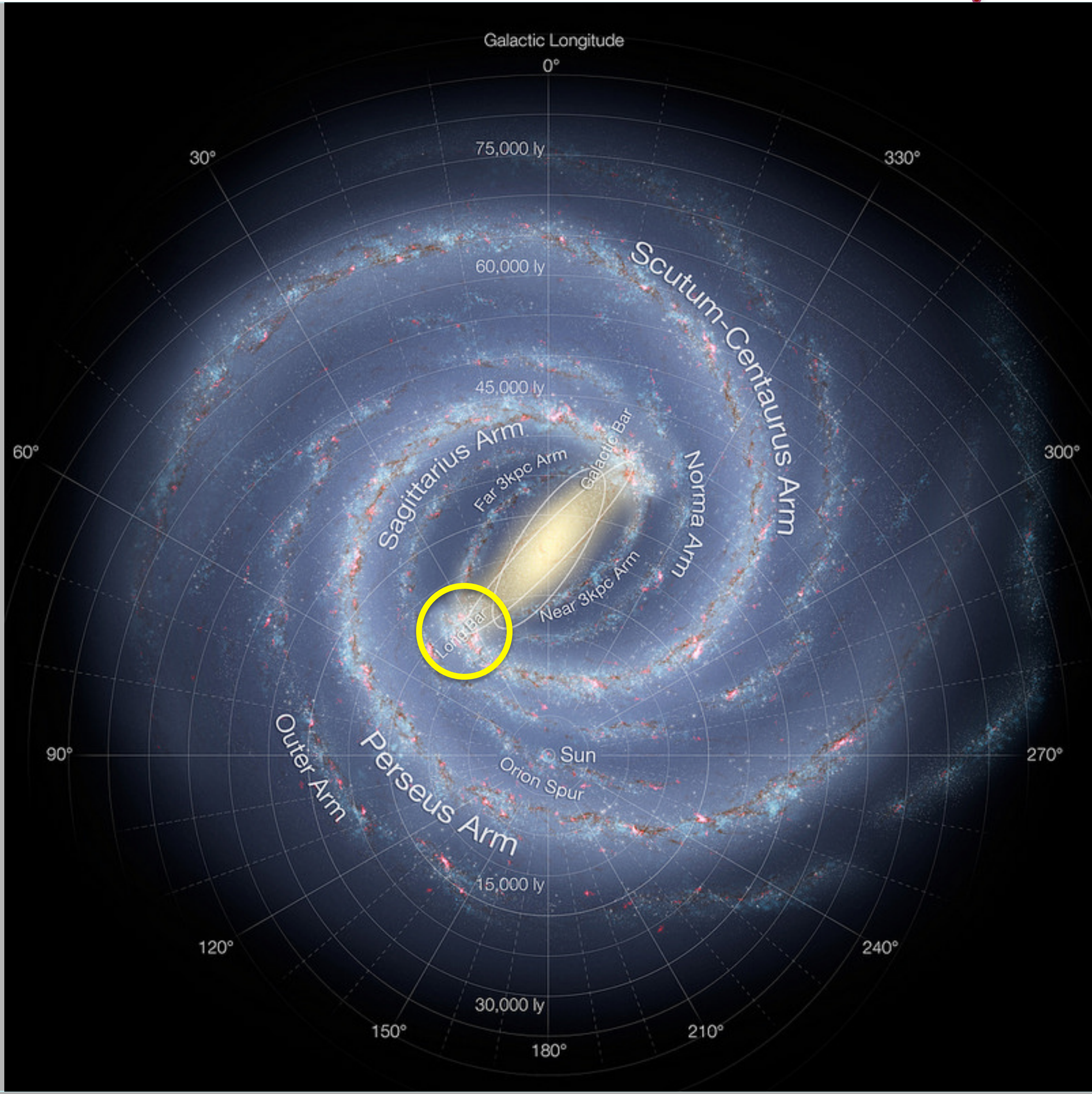
Beyond the corotation resonance of the bar and the OLR

Shallower gradients for ages Older than 4 Gyrs

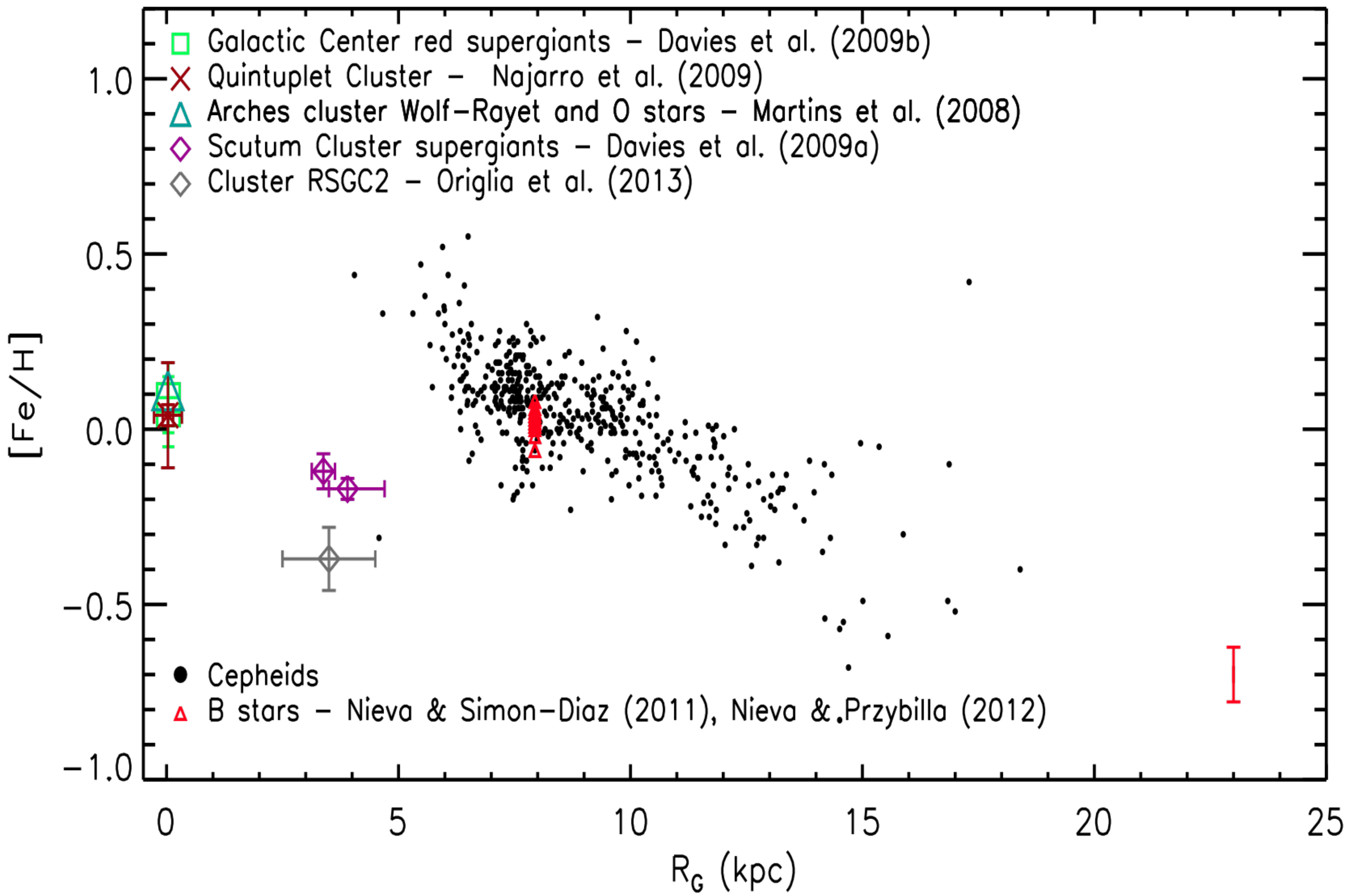
Cescutti et al. (2006,2007)
Predicted gradients for heavy elements



the inner disk chemistry



Evidence of difference in SF regions



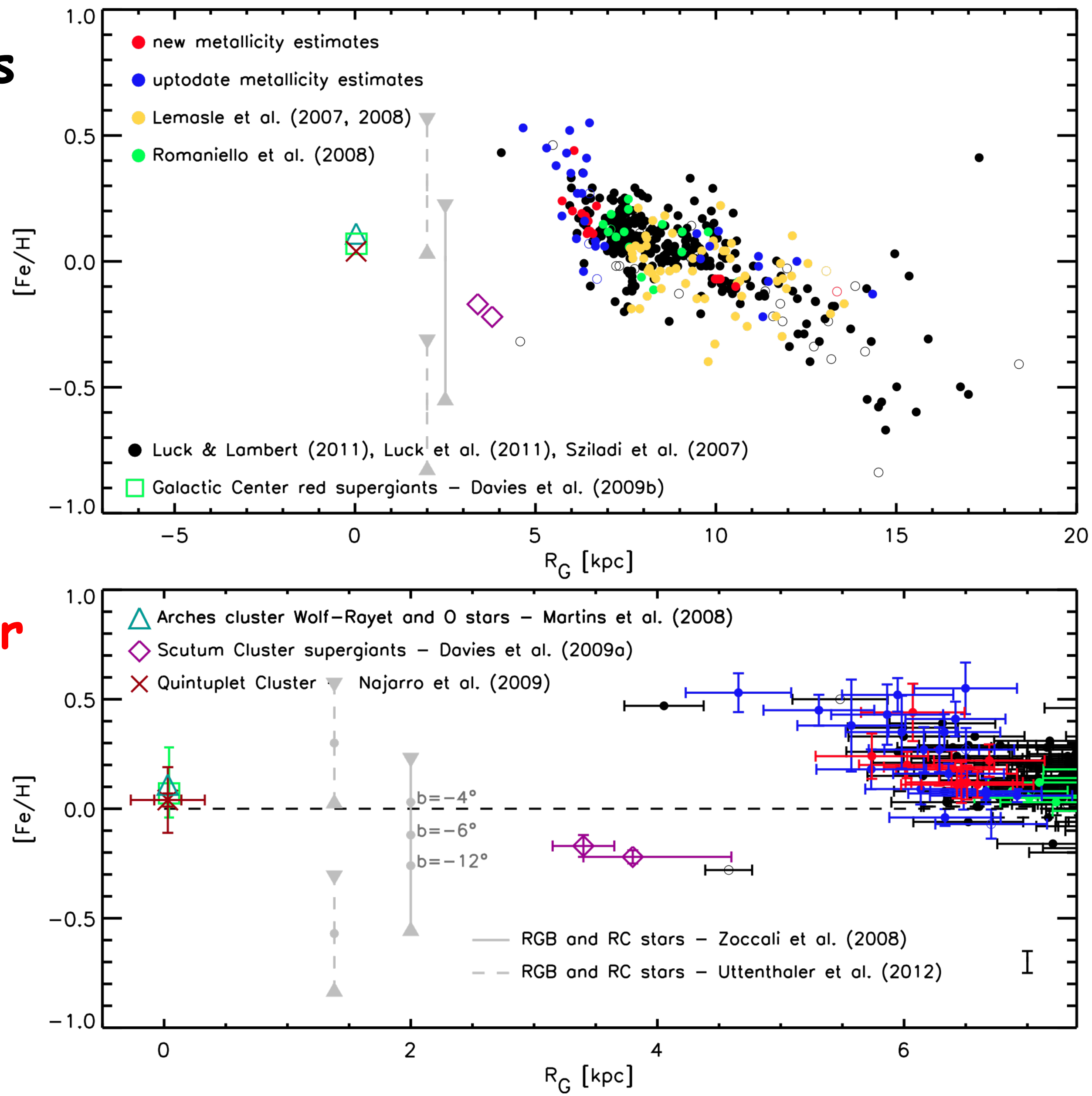
Difference between inner disk & NB+Bar

Young stellar objects in NB+Bar are solar!

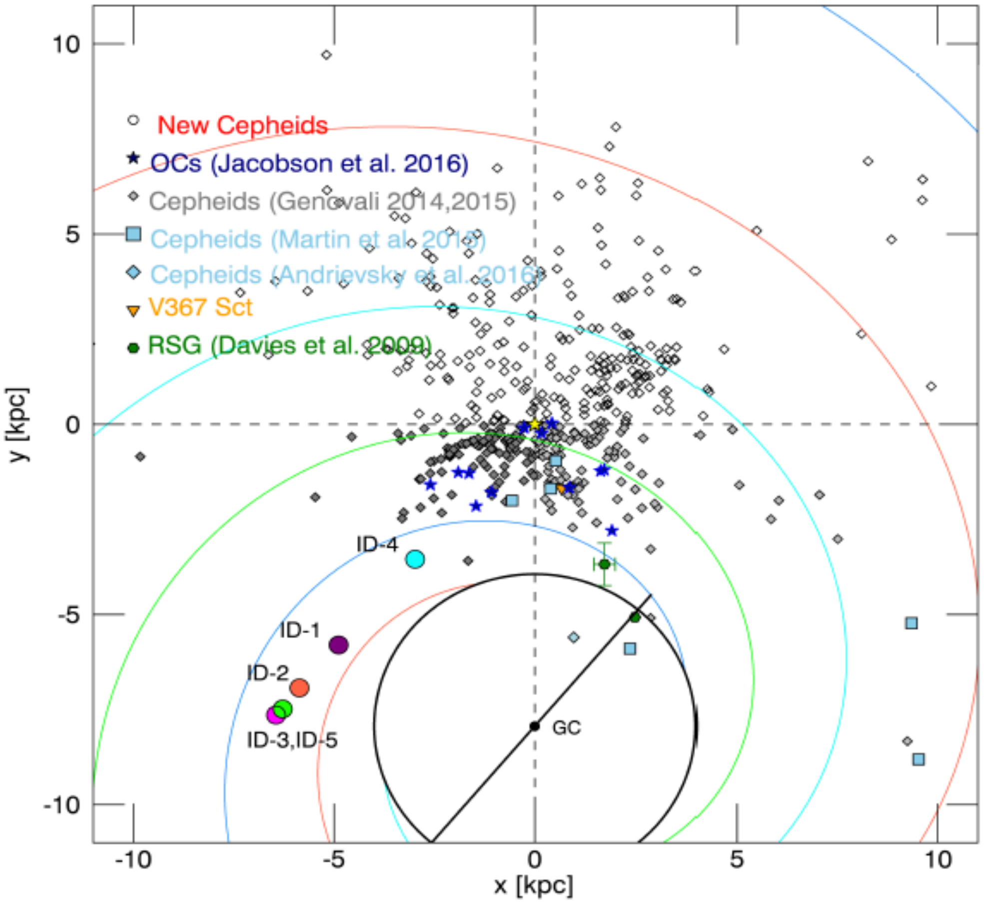
They are more metal-poor than inner disk Cepheids

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

Genovali et al. (2013a)



…. more on the inner disk



Five new Cepheids in the inner disk (IV quadrant)

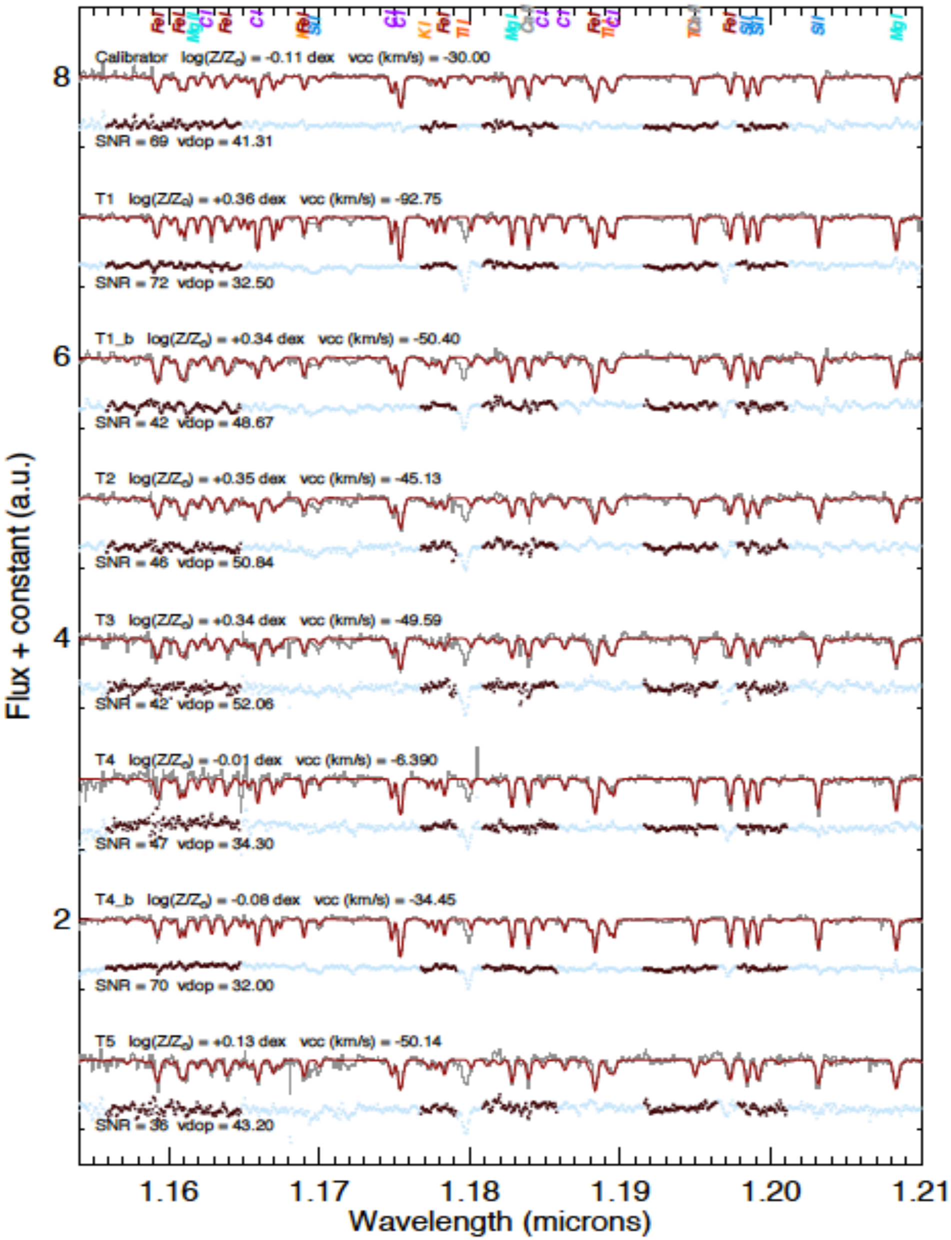
NIR Photometry IRSF at SAAO

MIR Photometry SPITZER + WISE (time series)

Reddening laws by
Cardelli + 1989
Nyshiama + 2006

Inno + (2017, tbs)

…. more on the inner disk



Low-resolution NIR (J,H,K) spectra ISAAC@VLT

SNR=40-80

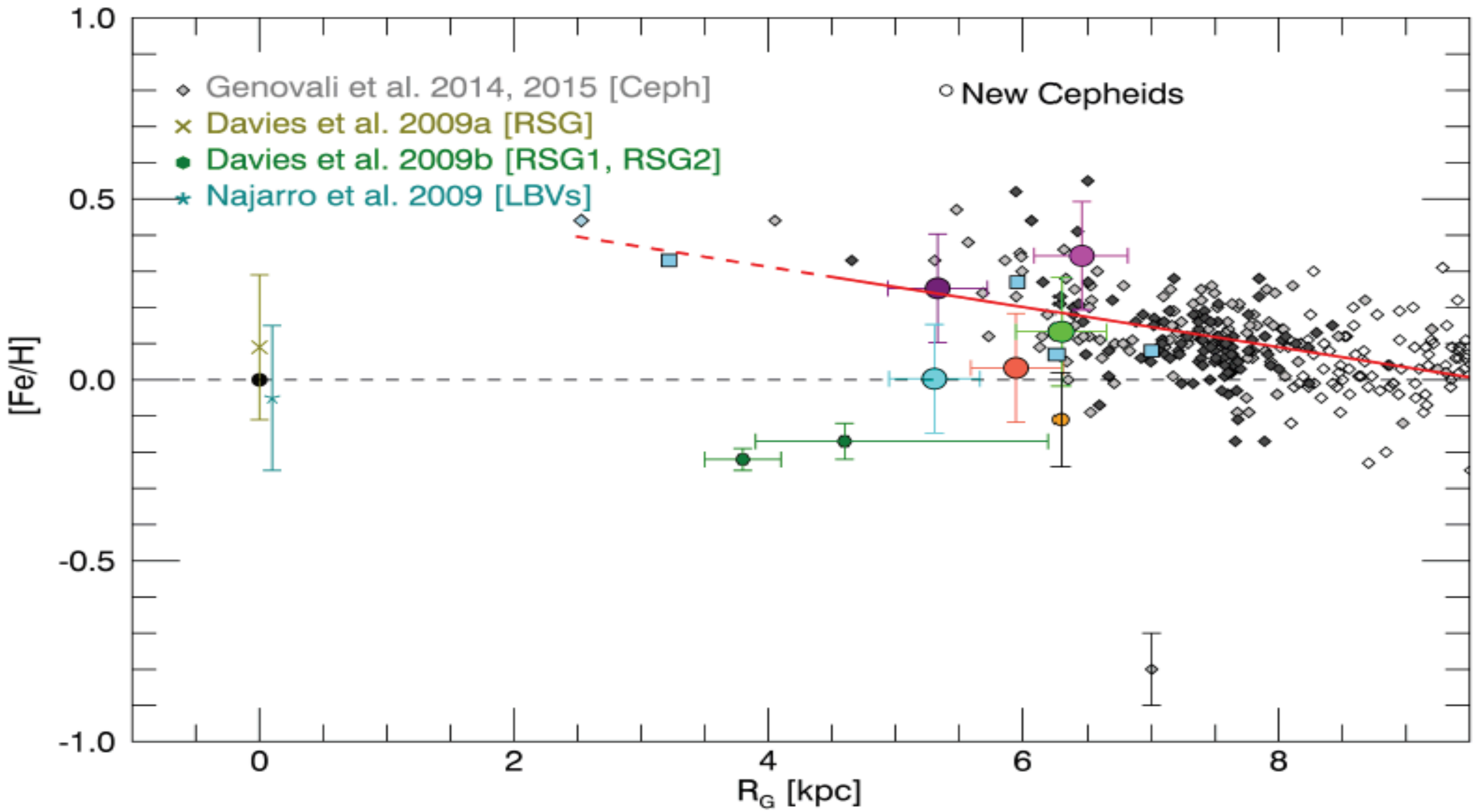
Calibrating Cepheid V367 Sct
7 UVES spectra + ISAAC

Optical & NIR abundances on the same metallicity scale

Inno + (2017, tbs)

…. more on the inner disk

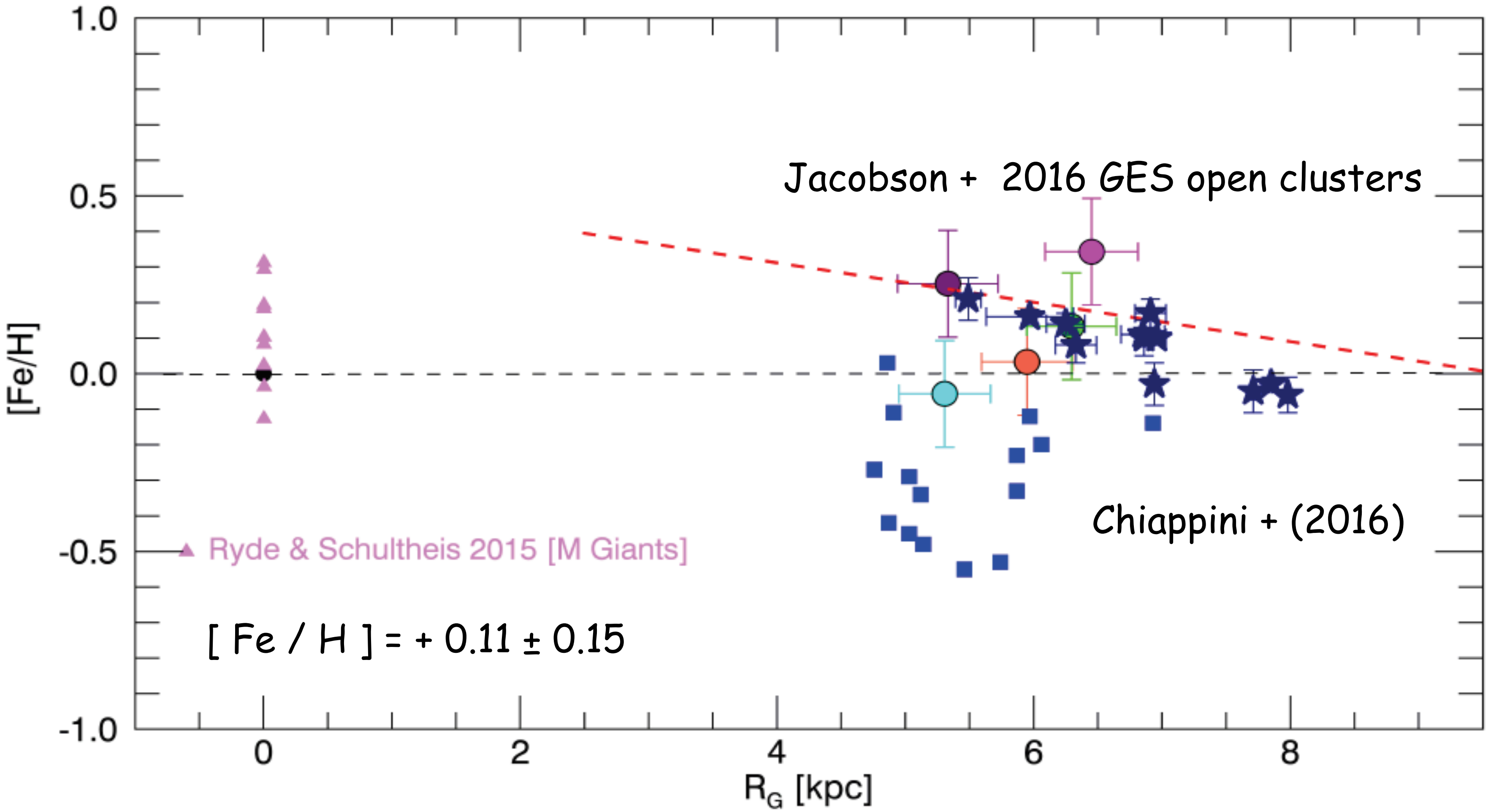
Martin + 2015 – Andrievsky + 2016 → distances based on optical photometry



Flattening vs Slope [?]

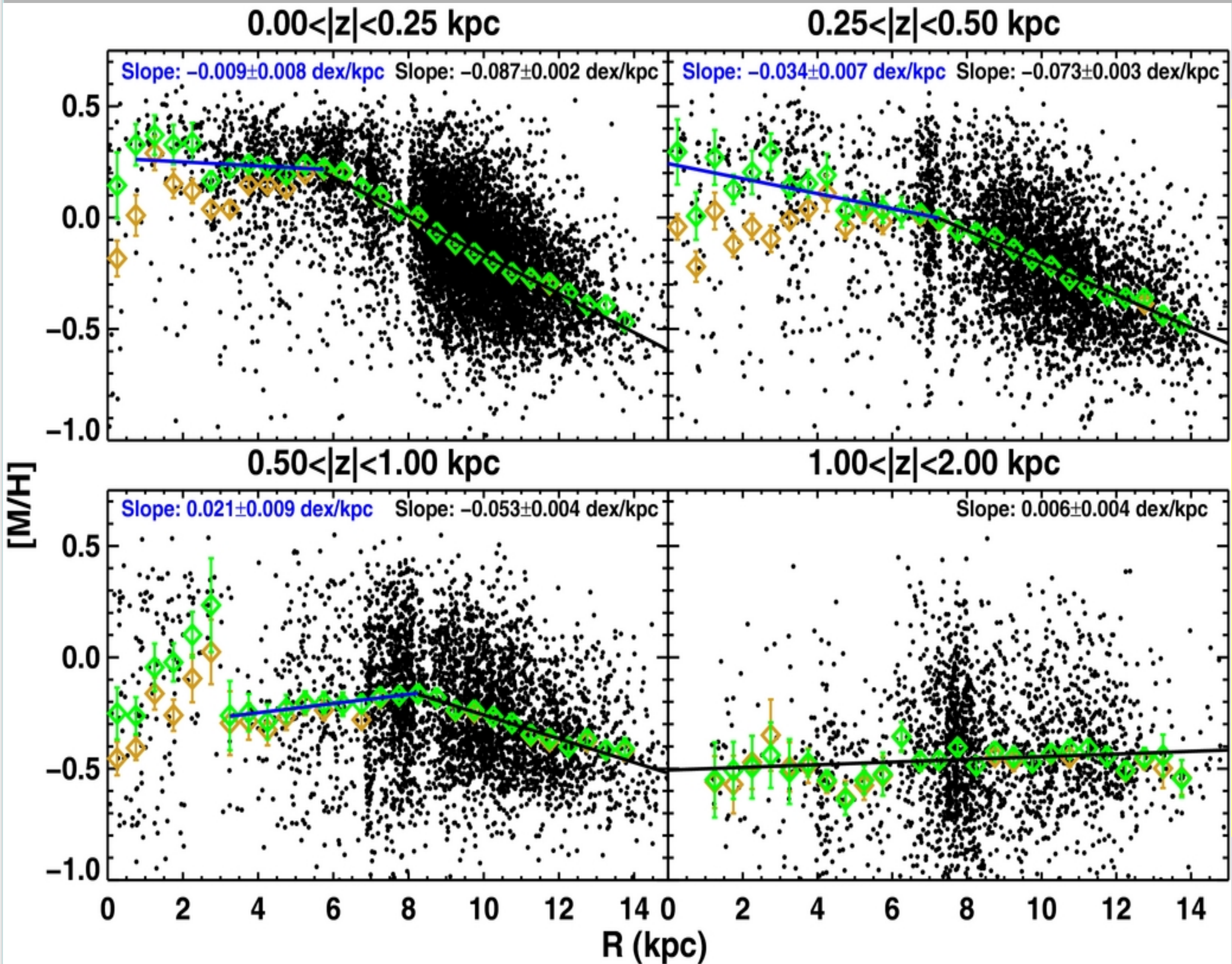
Laura Fecit

…. more on the inner disk



Open Clusters in the inner disk are telling Us the same story ….
Marginal evidence of a large spread

the inner disk chemistry



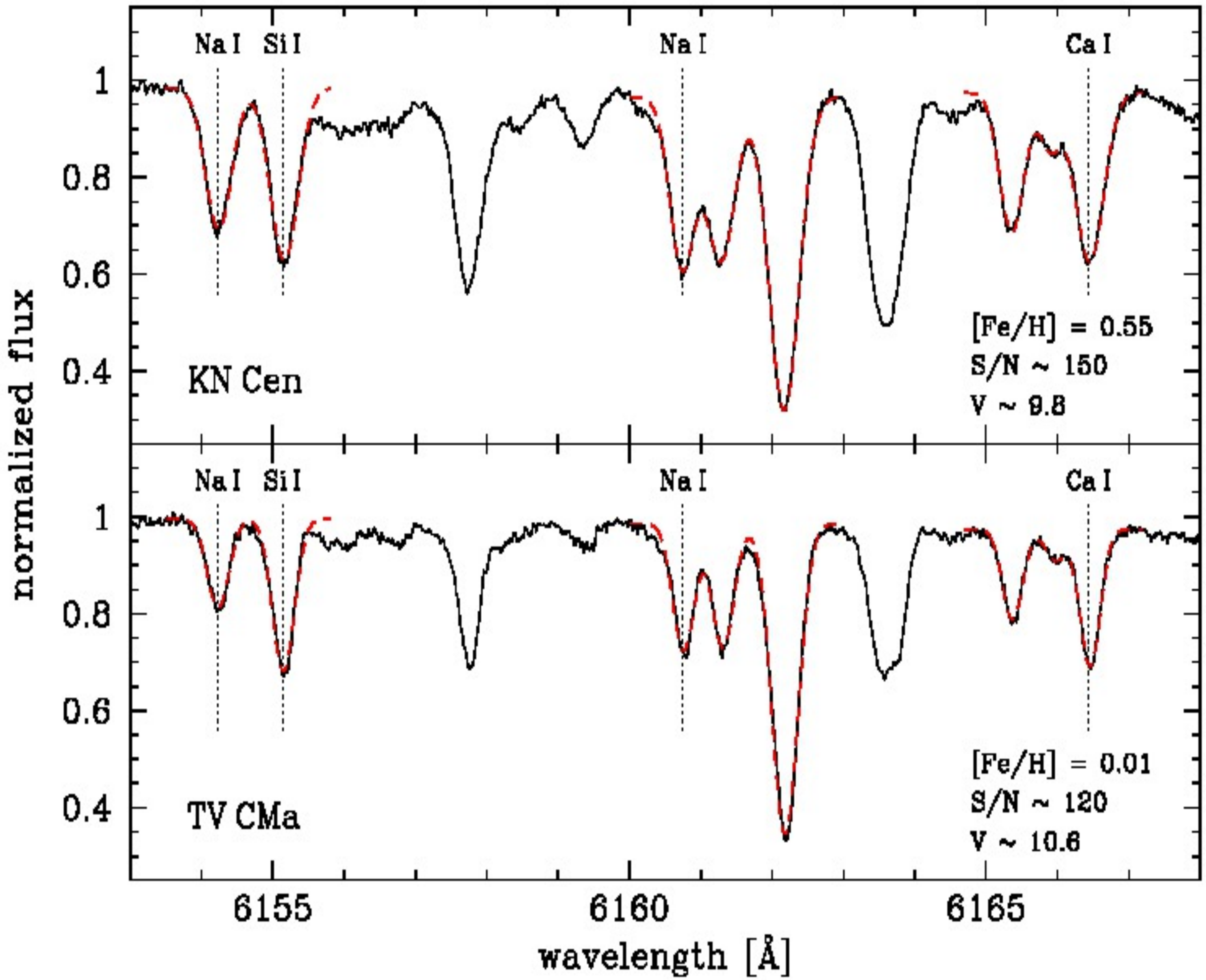
APOGEE
e.g. Hayden+ 2014
flattening in the inner 5 kpc

warmer giants → 2x solar met

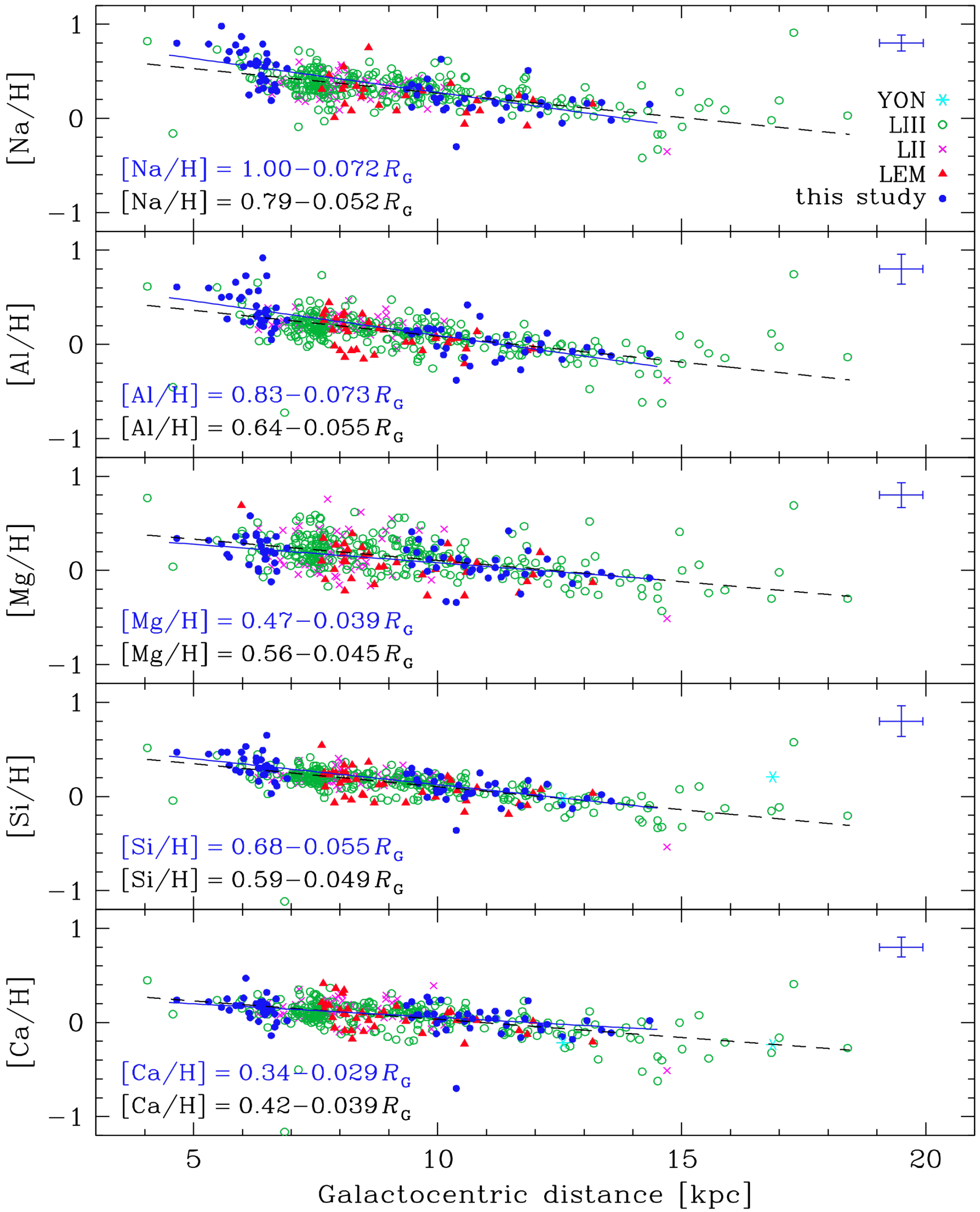
cooler giants → about solar met

Green → log g > 0.9
Yellow → log g < 0.9

Light & α-elements



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



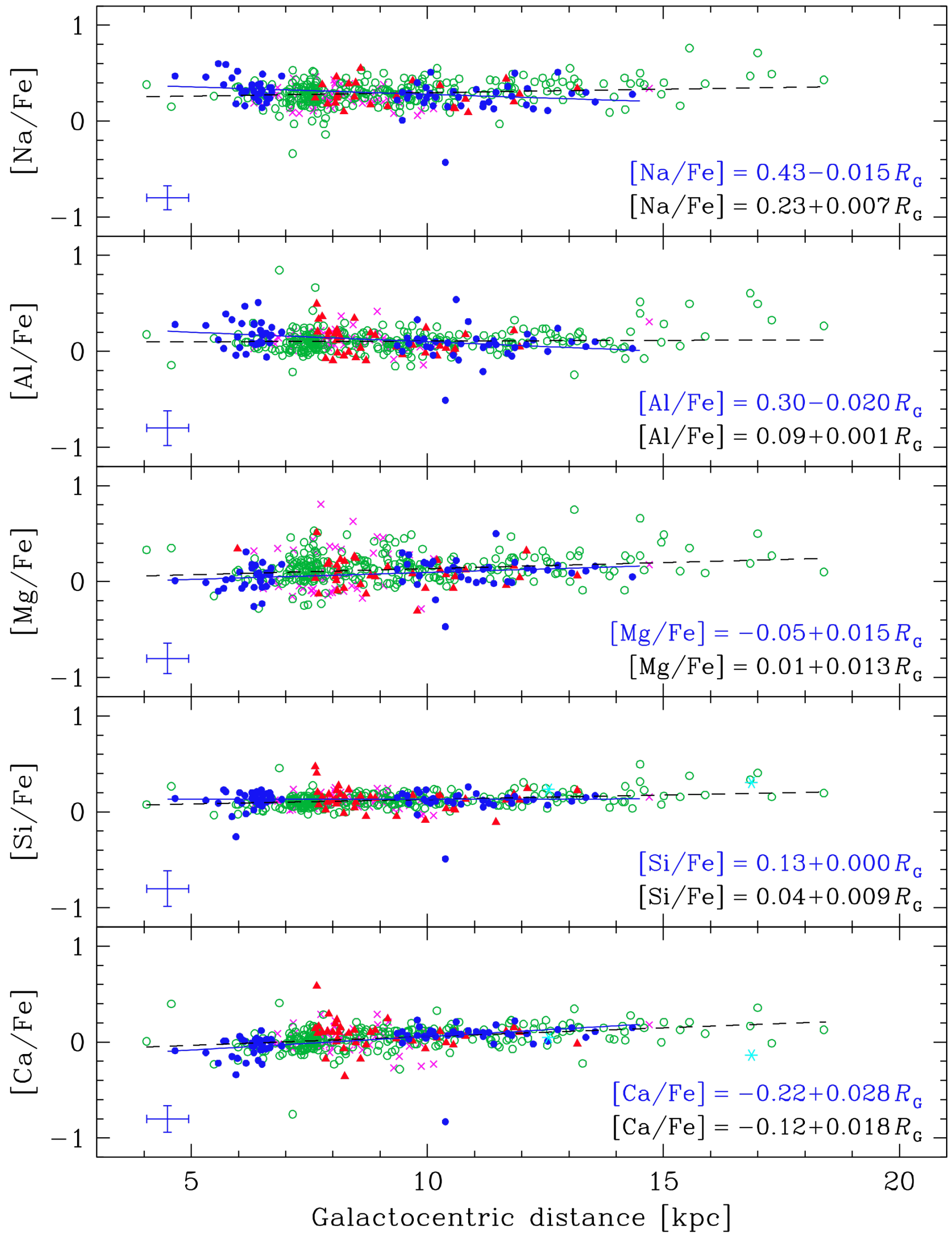
Almost the entire sample of Cepheids (~440) for which we have iron abundances

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

Si & Ca explosive
Mg hydrostatic
McWilliam+ (2013)

Mg+Ca → Dolomiti!!!

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



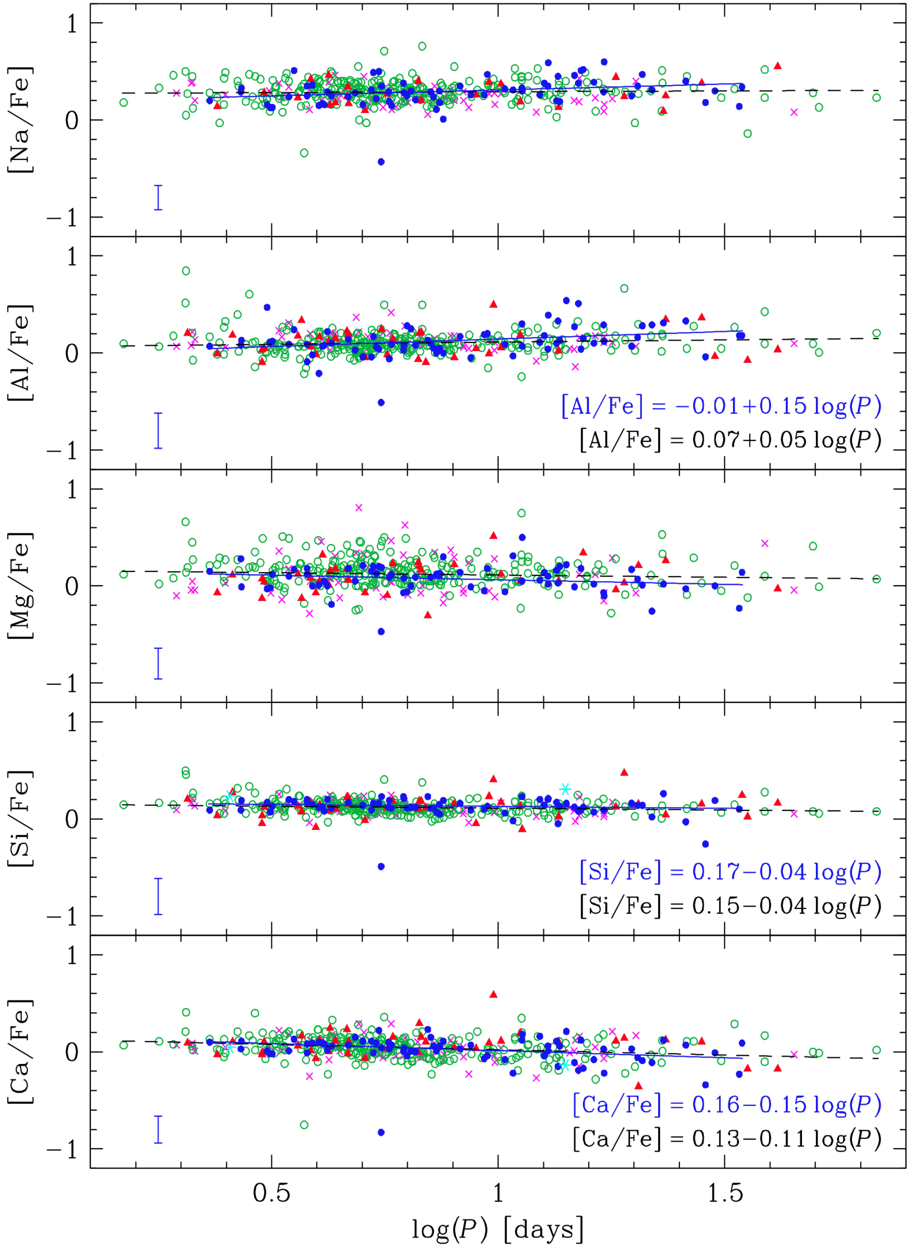
very very flat distribution over the entire Galactocentric

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!!

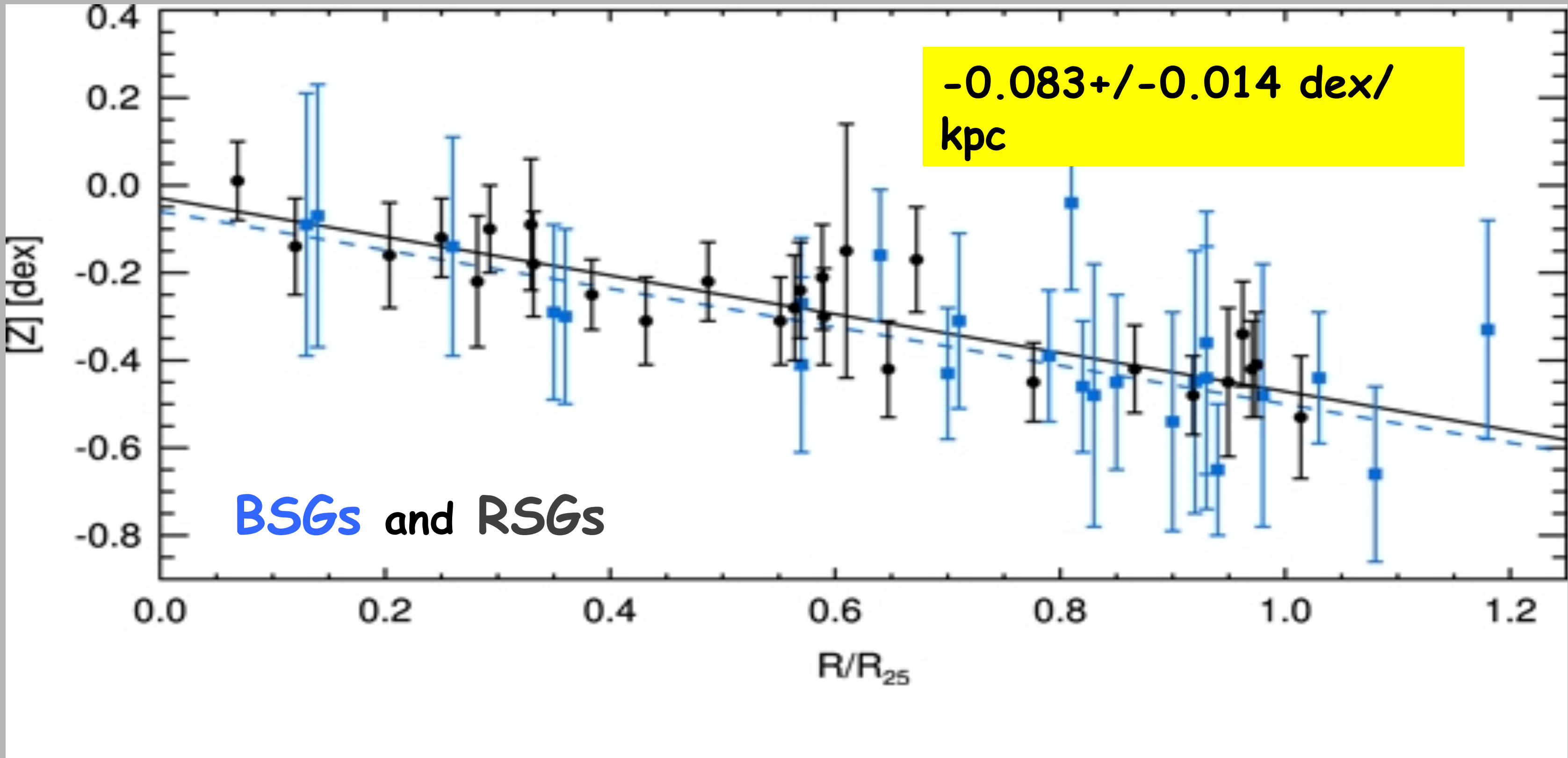
The slopes are minimal (Na, Al, Si, Mg) but Ca

Ca appears real ….

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

RSGs as cosmic abundance probes

low resolution J-band spectroscopy of individual metal-rich RSGs



Gazak+ 2015: RSGs in Sculptor galaxy NGC300 (1.9 Mpc) KMOS@VLT

Evidence of an inversion in the metallicity gradient
CALIFA (Sanchez-Menguiano + 2016)

Conclusions II: (preliminary)

LDR + classical approach are providing a complete census of Galactic Cepheids

The inner disk and the outer disk (possible contamination of type II Cepheids) appear as hot regions for which we really need new Cepheids and more data.

We urgently need a homogeneous metallicity scale among classical Cepheids, B-type, RSGs & Open clusters

Continue …. Stay with us the best has to come!!!