The transition between the Galactic inner disk & the bulge

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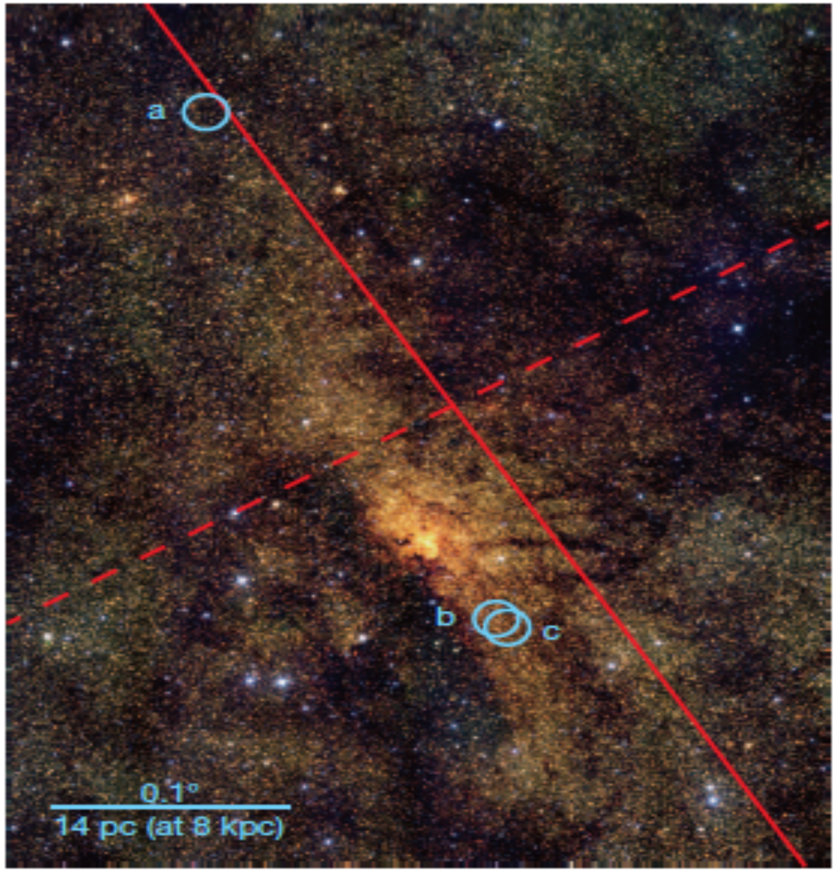


OUTLINE OF THE TALK

→ The disk metallicity gradient
→ Why the inner disk?
→ Why the nuclear bulge?
→ NGC6528 bulge globular
→ Conclusions

GALACTIC DISK METALLICITY GRADIENT

→Disk enrichment history: Fe, CNO & α-elements
Chemical evolution models (Portinari + 2000, Cescutti + 2007)

→Disk formation and evolution
disk kinematics (interaction with Bulge & Bar/Nuclear Bulge)

Different tracers:
PNs, B-type, RGs, Cepheids, Open clusters, HII regions
(Deharveng + 2000, Friel + 2002, Andrievsky + 2003, Luck + 2006, Yong + 2006, Carraro + 2007, Lemasle + 2008)

Gradient from medium Δ[Fe/H]~-0.04—0.06 dex/kpc
to shallow Δ[Fe/H]~-0.02 dex/kpc

for 5 ≤ RG ≤ 17kpc

GALACTIC DISK METALLICITY GRADIENT

→ Open Issues:

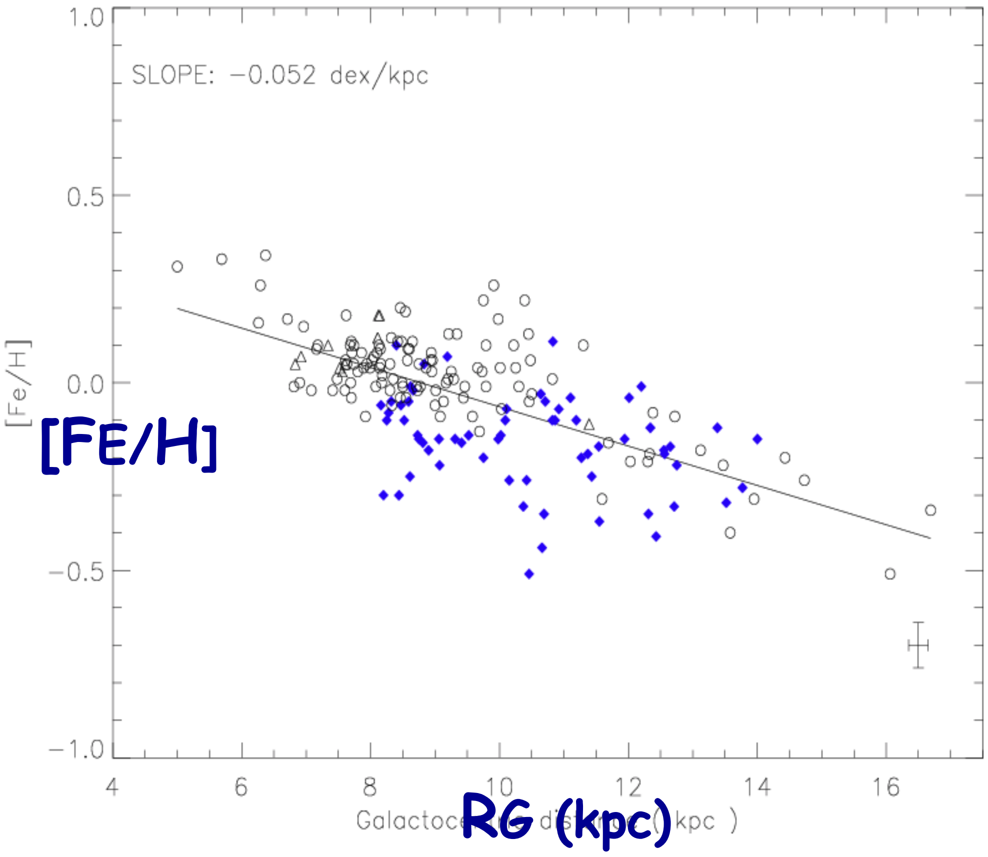
Linear slope: change at solar circle (Twarog + 1997, Caputo + 2001)

Local Inhomogeneities: clumpy distribution (Pedicelli+ 2009)

Azimuthal dependence (Luck + 2011)

Chemical tagging: tracers of different ages & metallicities

CEPHEIDS IN THE GALACTIC DISK



Metallicity gradient across the Galactic disk

Δ[Fe/H]=-0.052±0.003 dex/kpc
for 5 ≤ RG ≤ 17kpc

Homogeneous PLK distances

Lemasle et al. 2007, A&A, 467, 283; **2008**, ***A&A***, 490, 61 [73]
Andrievsky et al. (2002,2003,2004,2005) [115]
Luck & Lambert (2012)

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 intermediate-age SPs
4) Overcome reddening uncertainties (PW relations)
5) We know the physics of their engines

CONS

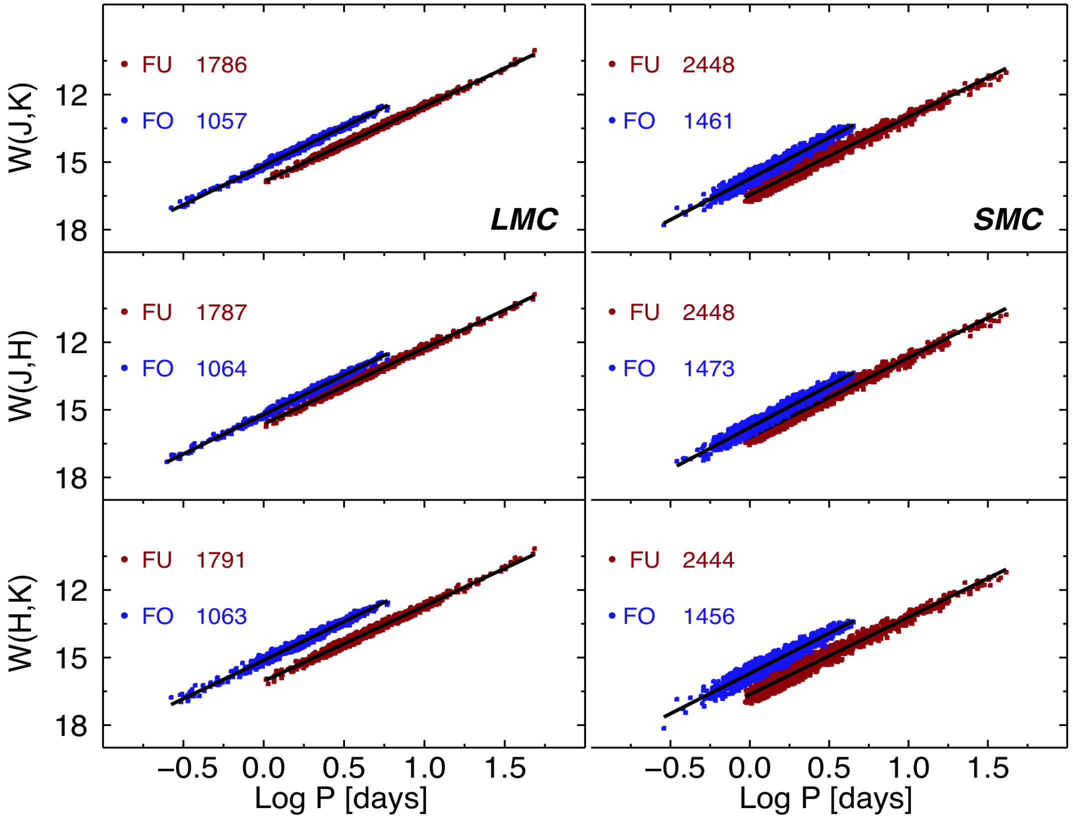
1) Identification → time series data
2) Multiband observations
3) Pulsation amplitude decreases from optical to NIR
4) Limited range in age 10-200 Myr

The largest NIR data set ever collected for MC Cepheids

[Laura & Noriyuki]

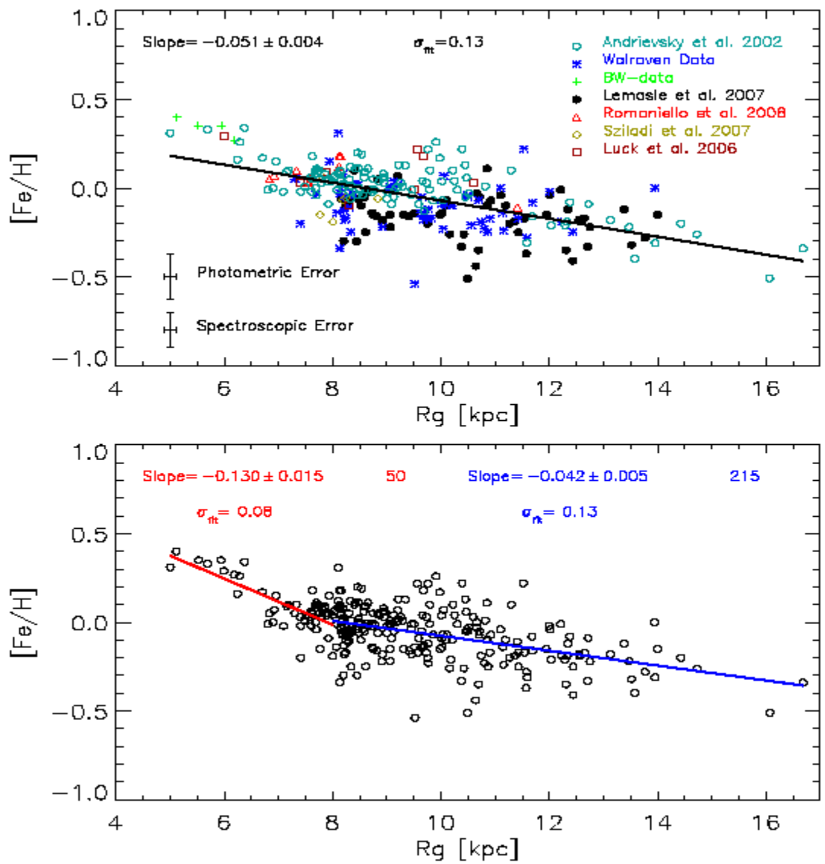
VI & NIR PW relations slopes & ZPs are minimally affected by metallicity

NO MAGIC PROPERTY
Just WIEN & V,I + JHK

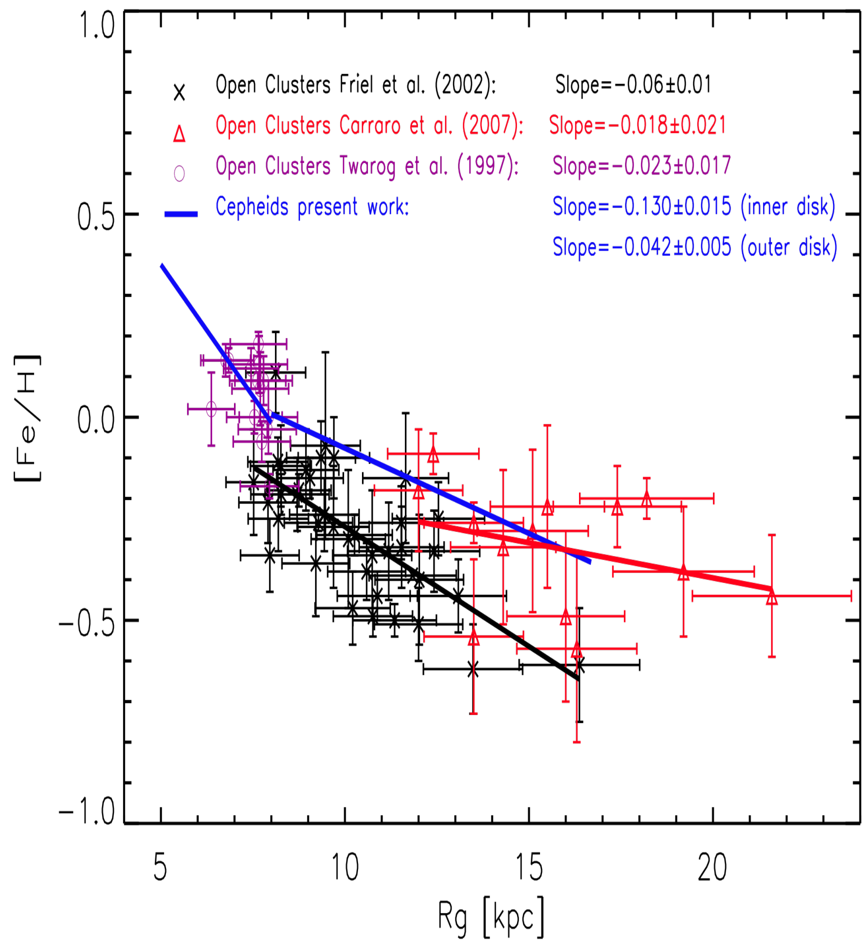


By Inno et al. (2013)

Metallicity Gradients in the Galactic disk

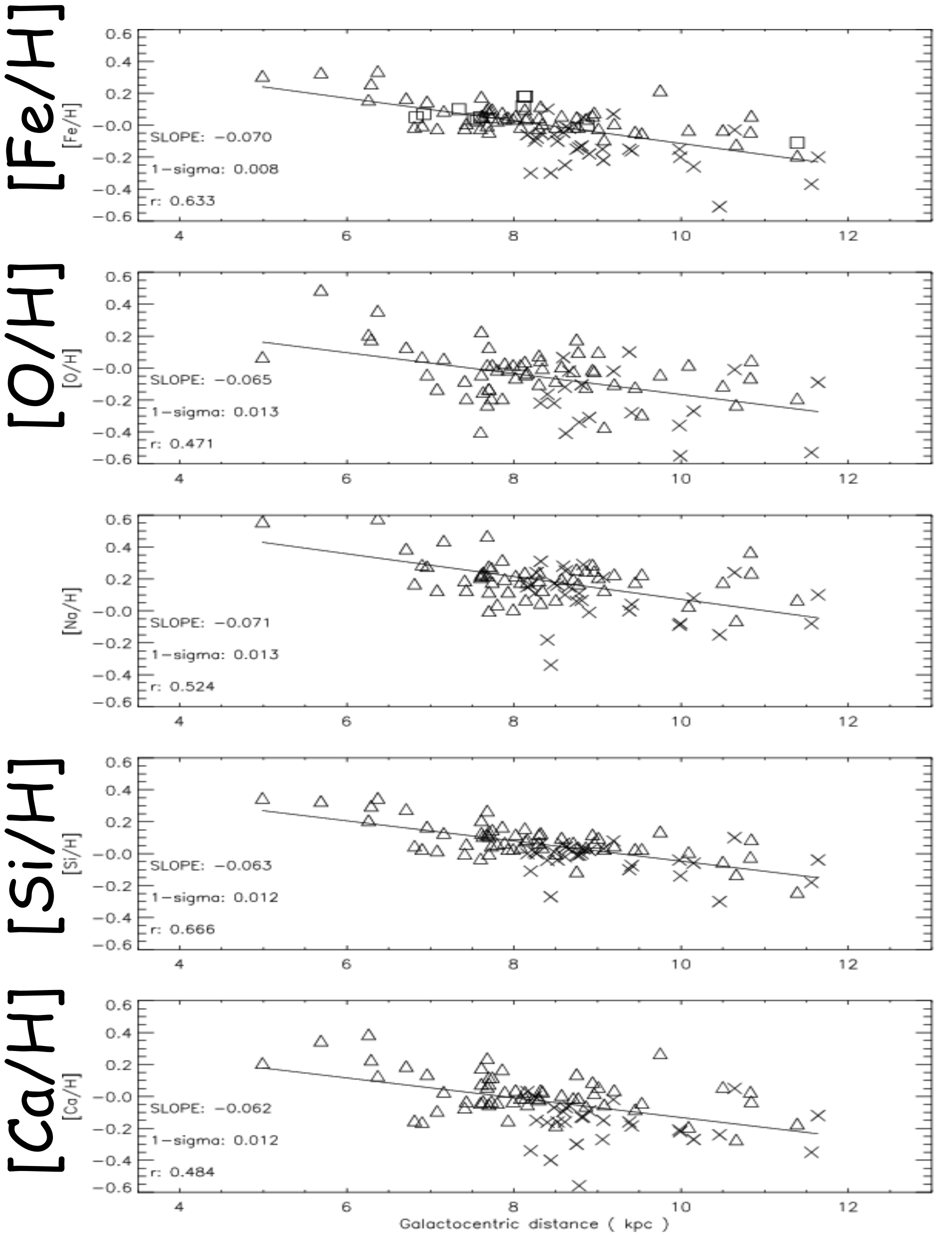


Comparison with Open Clust.
Different radial distribution
Different ages



Linear vs nonlinear
Large dispersion at fixed RG

Alpha-element gradients

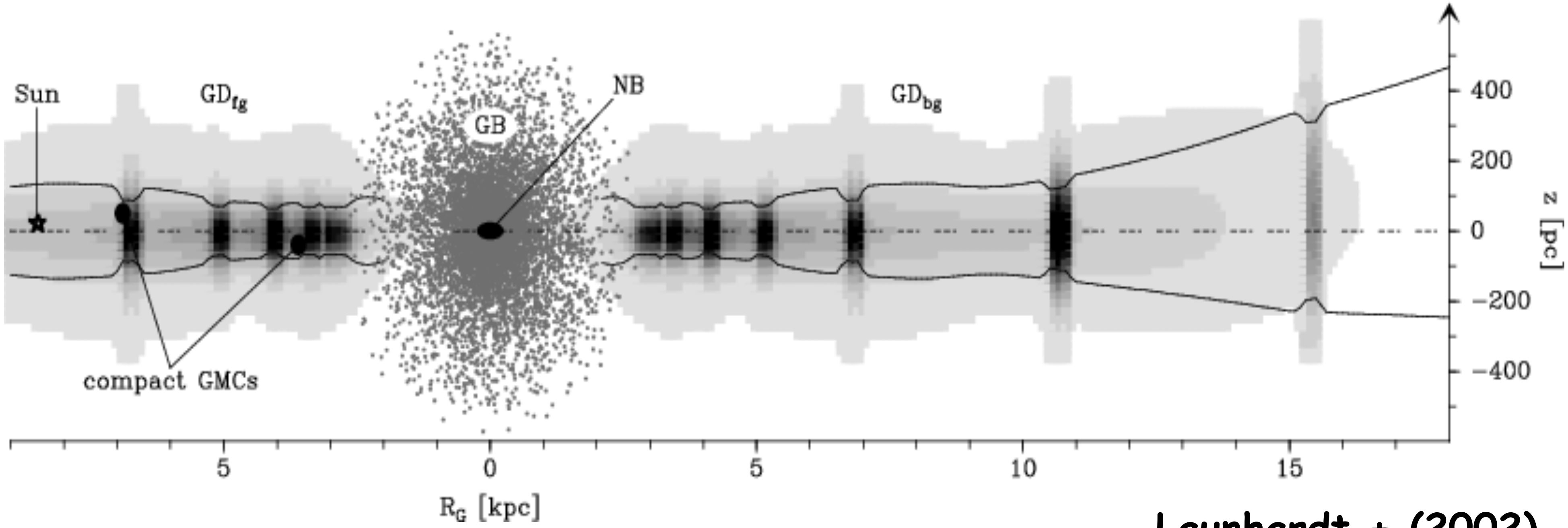


The slopes of iron and robust alpha elements (Si, Ca) are –within the errors- very similar!

Is this empirical evidence suggesting that the recent chemical enrichment is mainly dominated by SNII?

Lemasle et al. (2007)

Why 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)

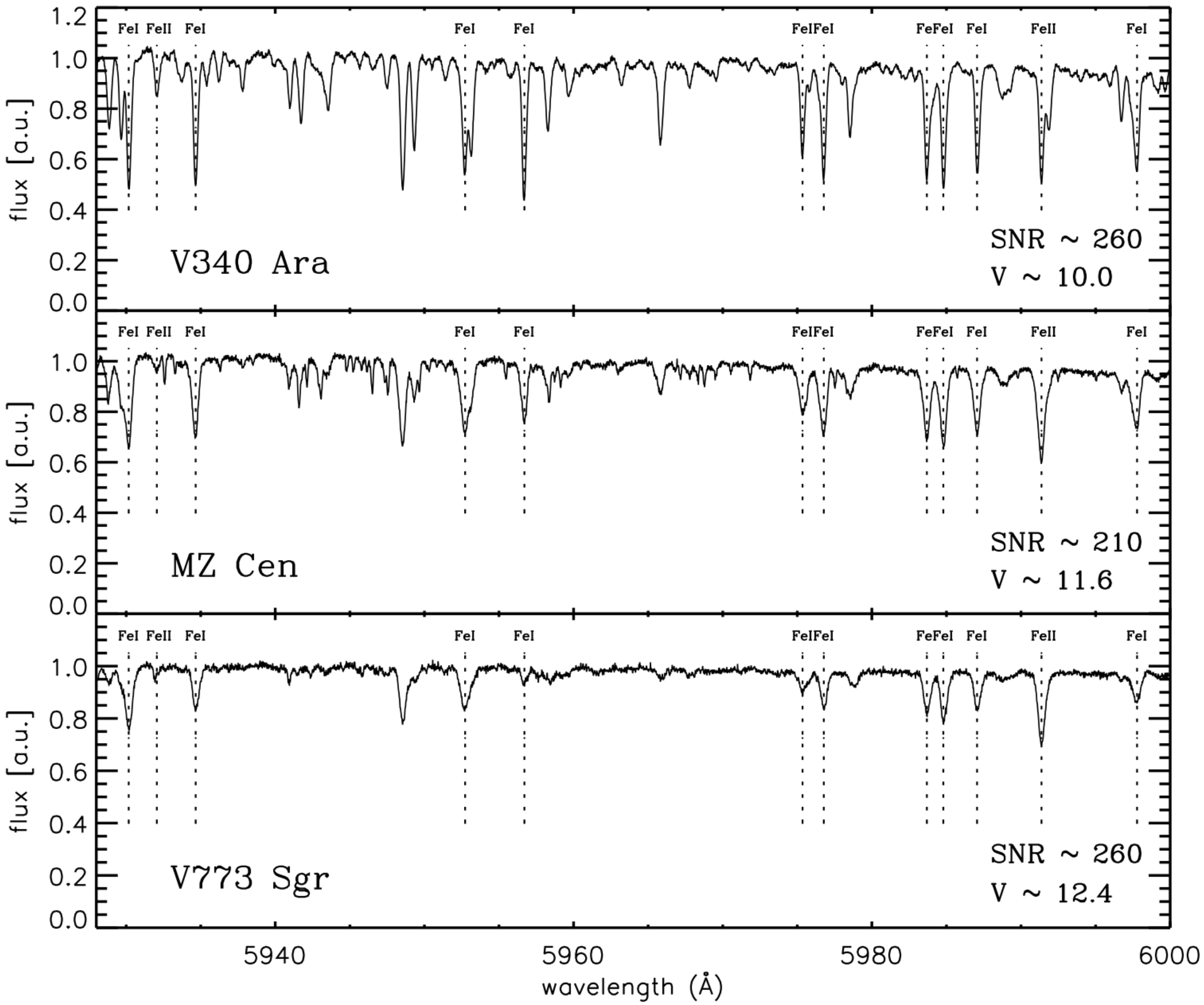
UVES@VLT spectra for 77 Cepheids

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

Inner disk cepheids: 47 out of the 77



Genovali et al. (2013, A&A, accep.)

INNER DISK CEPHEIDS

Proprietary → 120

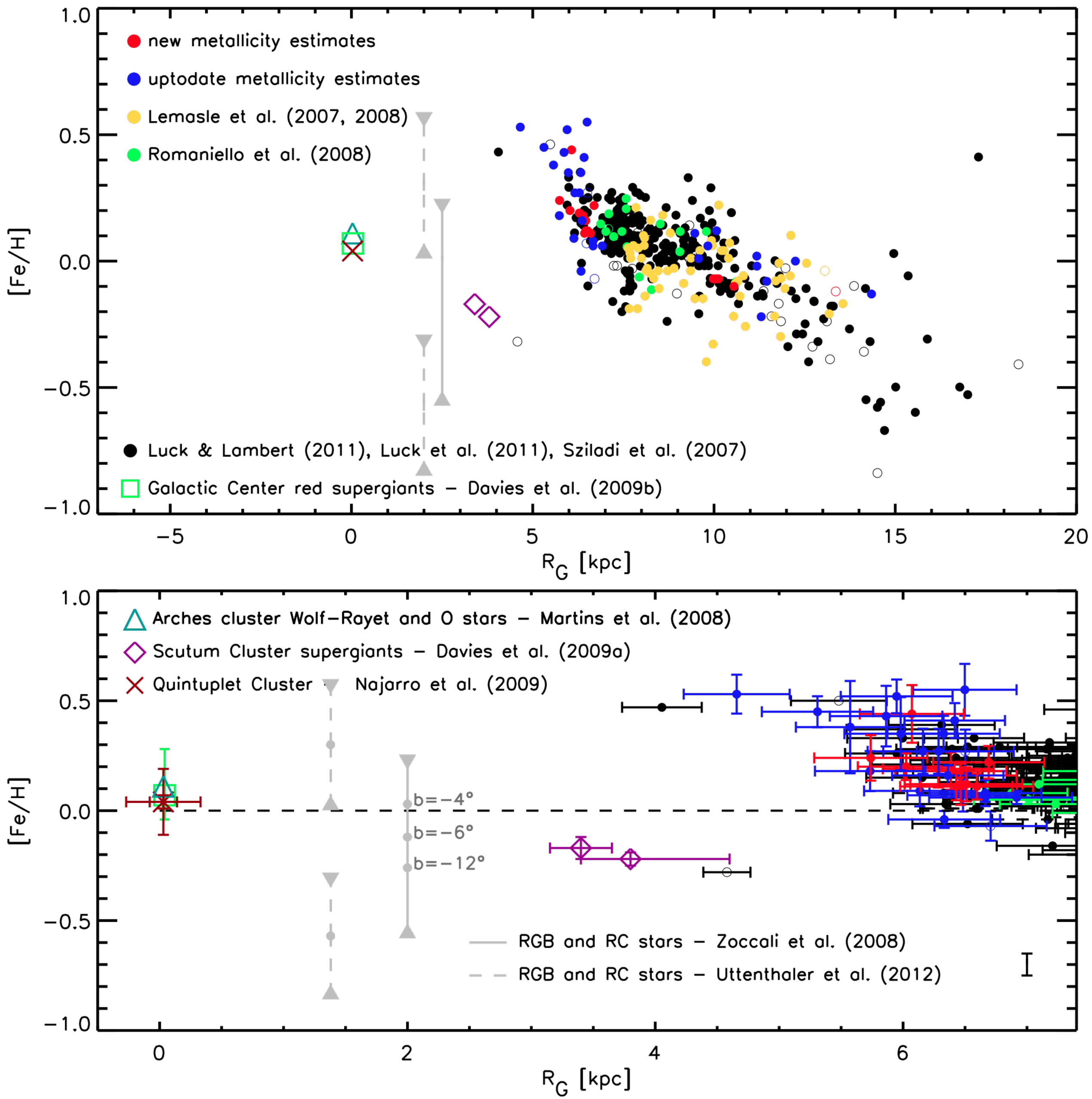
Literature → 300

We ended up with

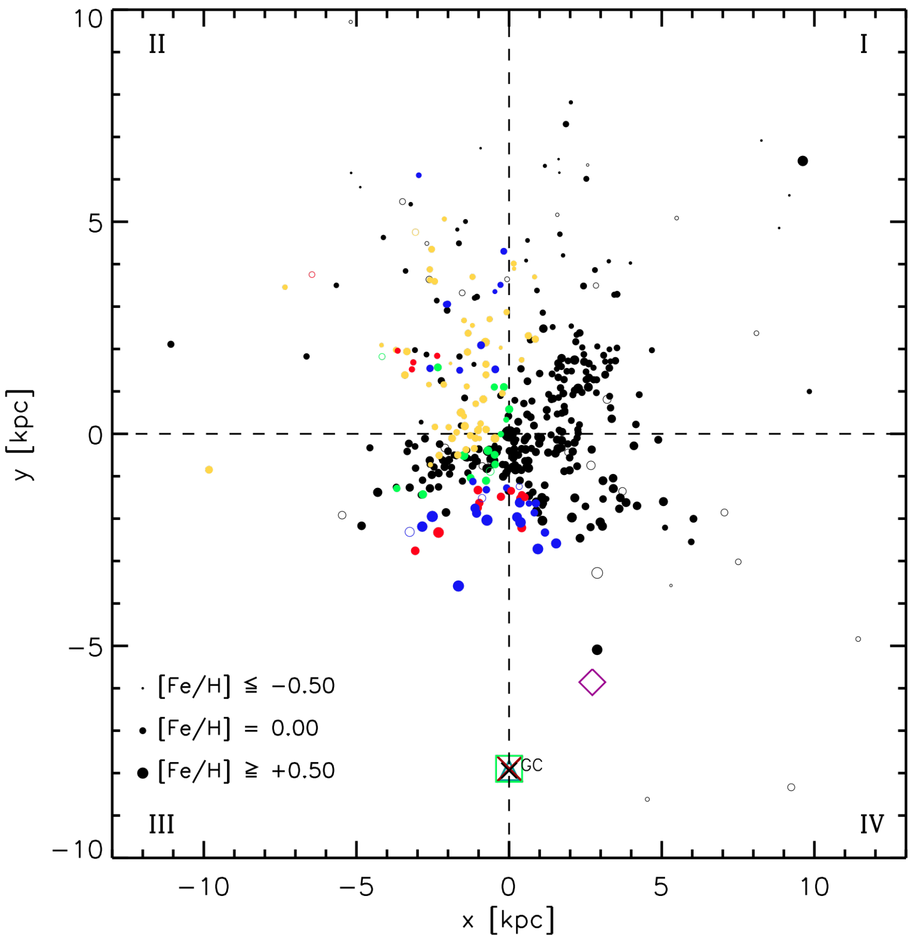
a sample of → 420

i.e. 85% of known

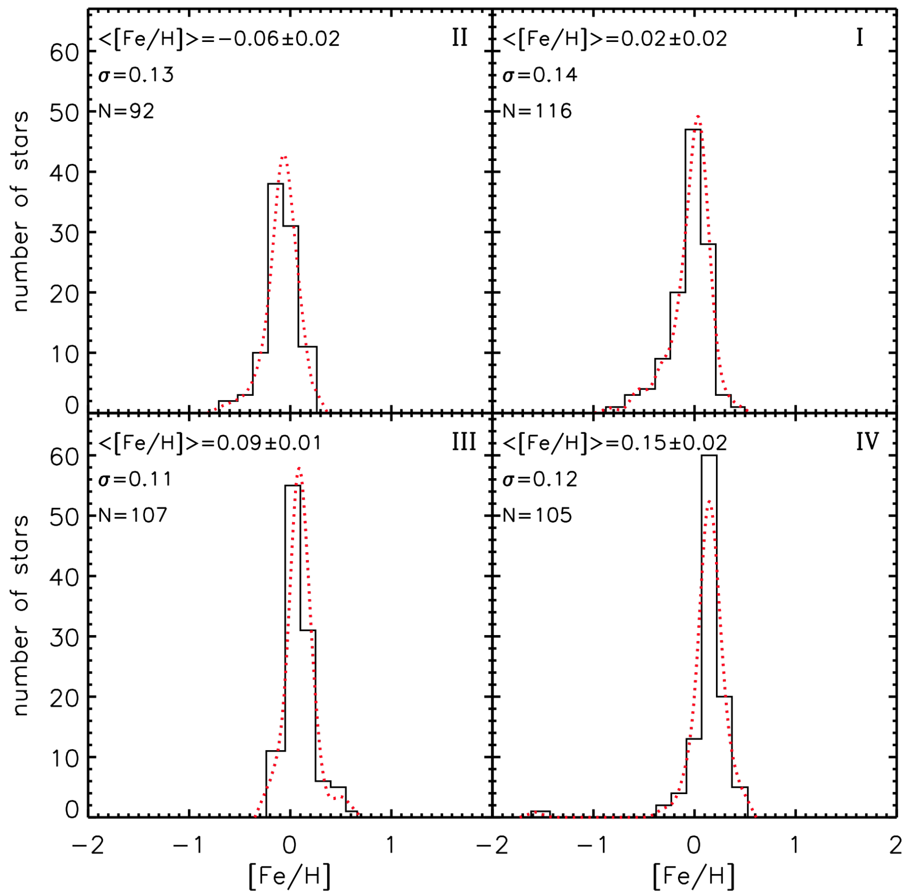
Galactic Cepheids



CEPHEIDS AS STELLAR TRACERS

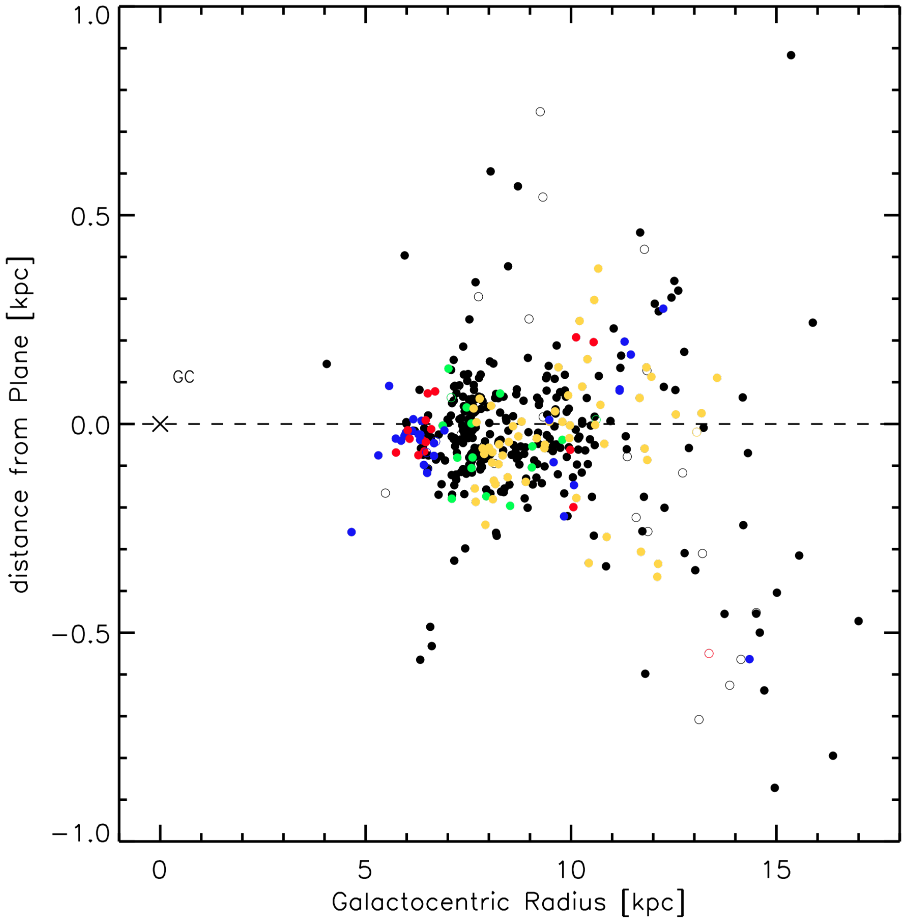


No strong evidence concerning a relevant change in the spread among the 4 quadrants



Genovali + (2013)

CEPHEIDS AS STELLAR TRACERS



Δ Z=-43±13 pc (420 stars)

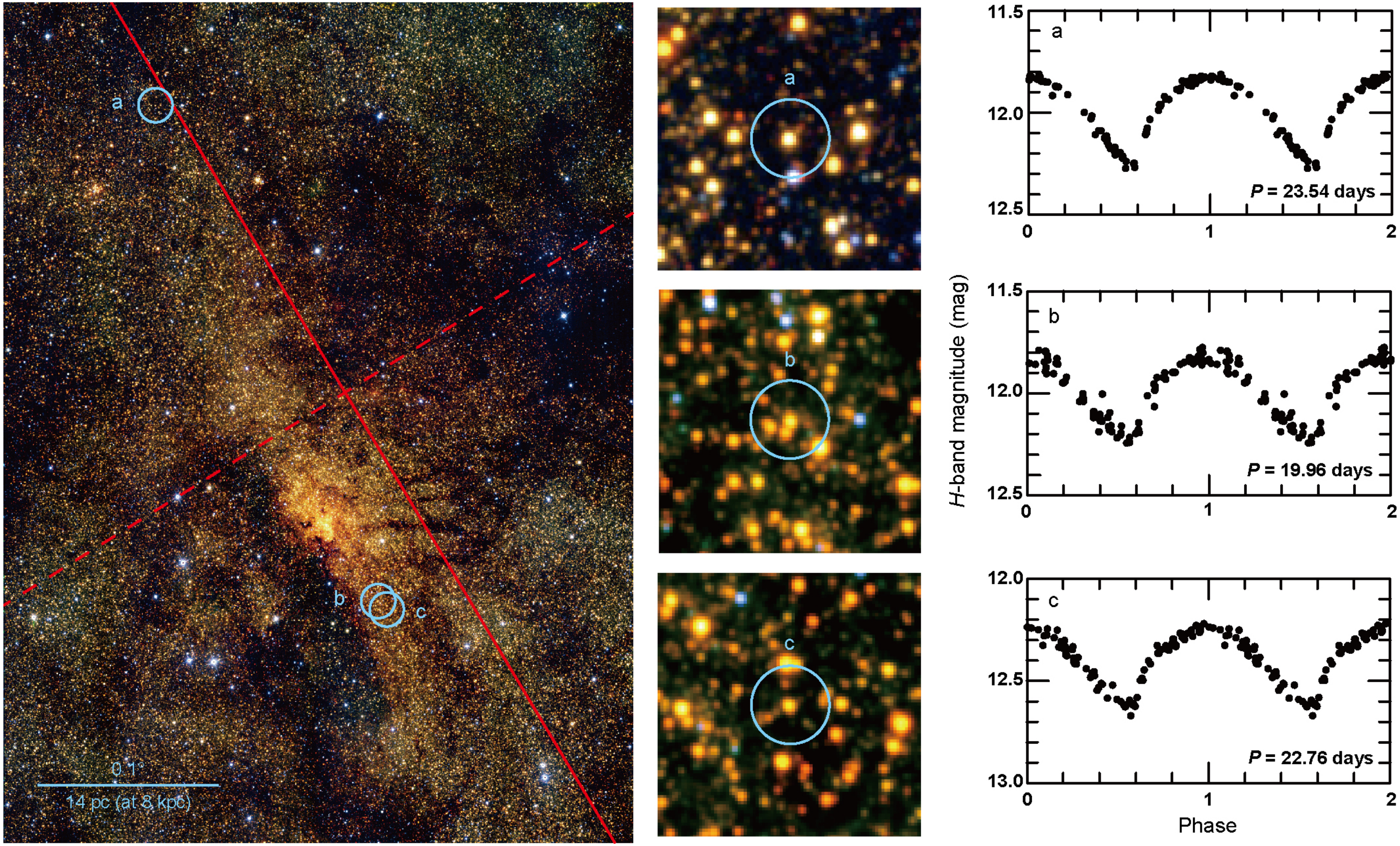
Kraft (1964!!)

No evidence of azimuthal Variations ….

.. but the outer disk affected by observational bias → desert!!

Waiting for GAIA and LSST!

DETECTION OF THREE CEPHEIDS IN THE NUCLEAR BULGE!!!



Matsunaga et al. (2011), nature

Three classical Cepheids in the NB

Periods from ~20 to 23.5 days

True distance modulus = 14.50±0.07 mag (7.9±0.2±0.3 Kpc)
Spitzer single epoch magnitude support this distance

projected distance from the central black hole
Δl = -6.9, -7.8, 33.9 (pc)
Δb = 0.4, 0.7, 6.5 (pc)
located in the thin disk-like structure of the NB

Mean J magnitude ~ 15.5
Mean K magnitude ~10.2
Ak (selective absorption) 2.5-2.7 → Av~25-30 mag!!

The link between the nuclear Bulge and the inner disk

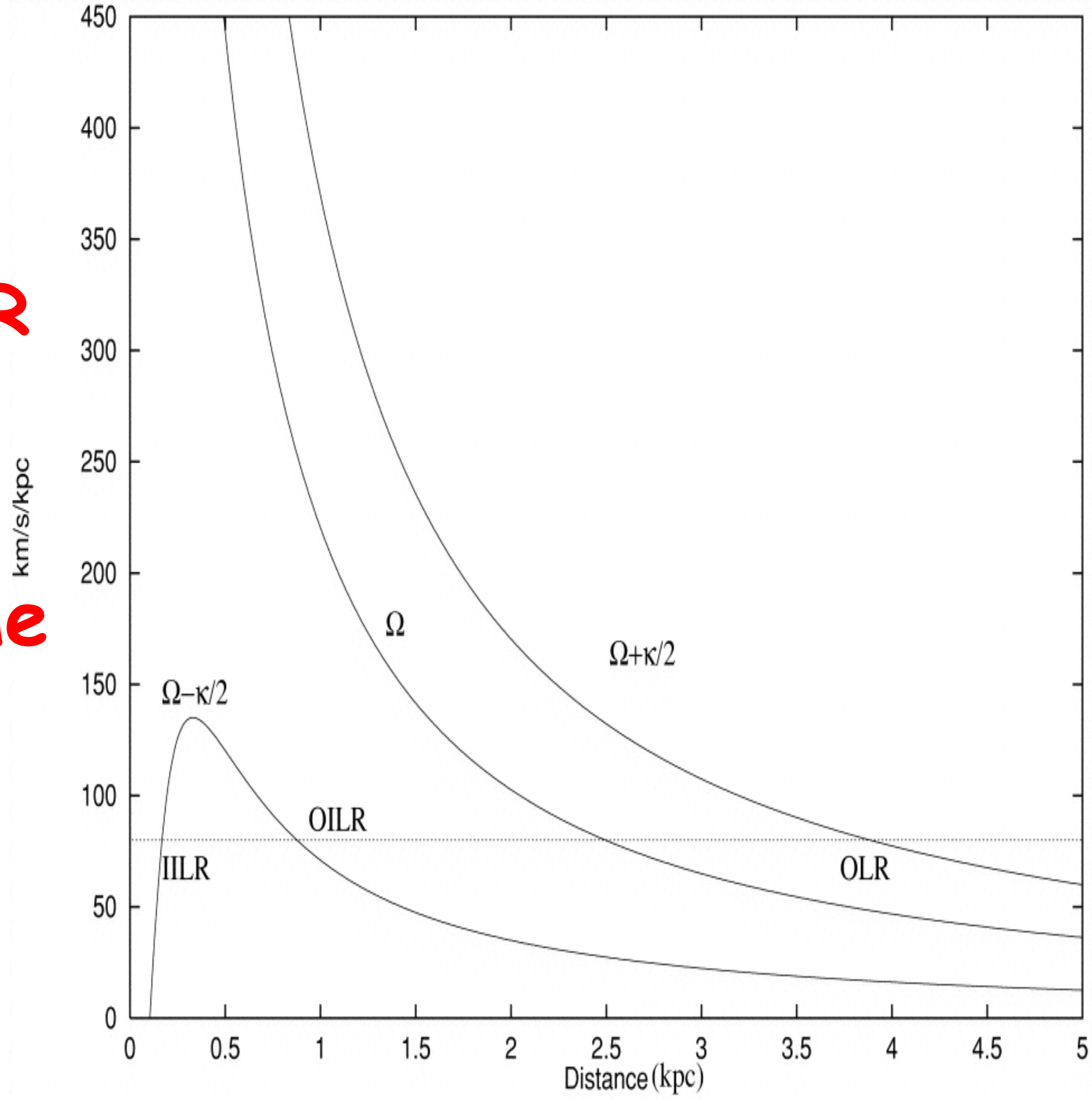
A new spin with CRIRES/ISAAC @VLT

Precise radial velocity & abundance measurements (HR & LR) of ~ a dozen Cepheids in the nuclear Bulge and in the inner disk …

Nuclear Bulge & inner disk CEPHEIDS

Current sample approaches OLR

Where are the Cepheids of the inner (~3Kpc) arm?



Conclusions I

Current empirical evidence are better explained by a high level of "astration" in the Nuclear Bulge than with a Bar instability

Steady increase in metallicity in the inner disk

Recent disk chemical evolution seems to be dominated by SNII

Several open issue concerning transitions!!!

Why the bulge cluster NGC6528?

→NGC6528 & NGC6522 define the center of the Baade window

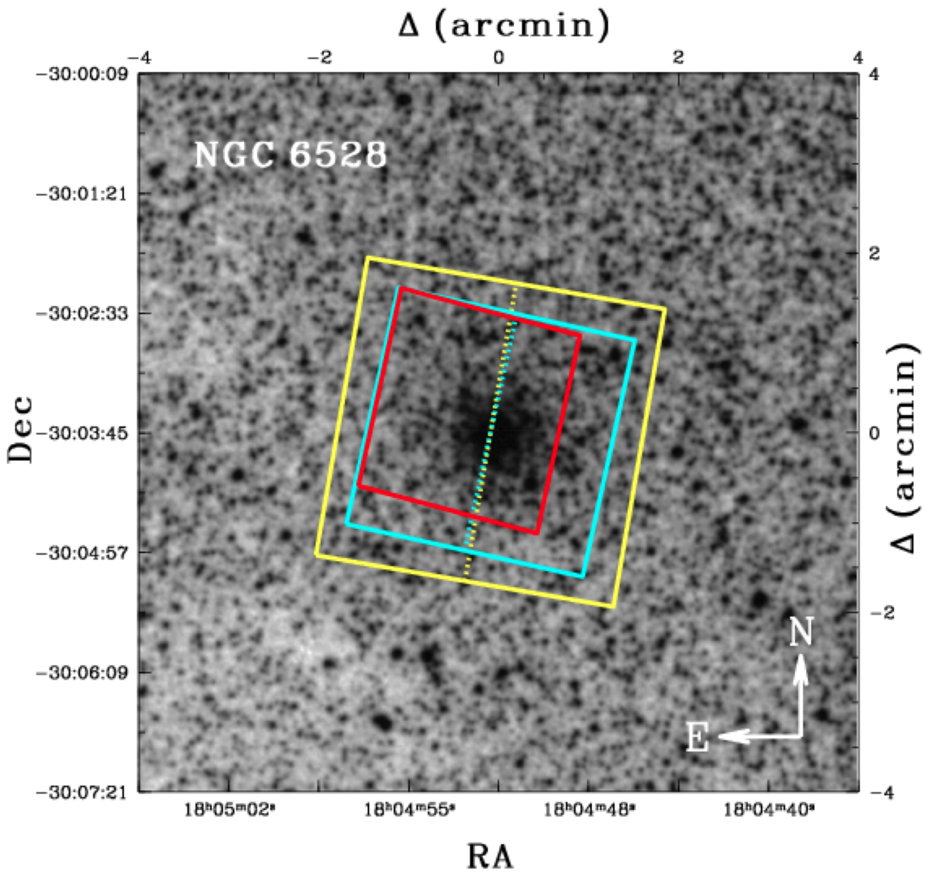
→NGC 6528 is among the happy few GCs more MR than 47 Tuc

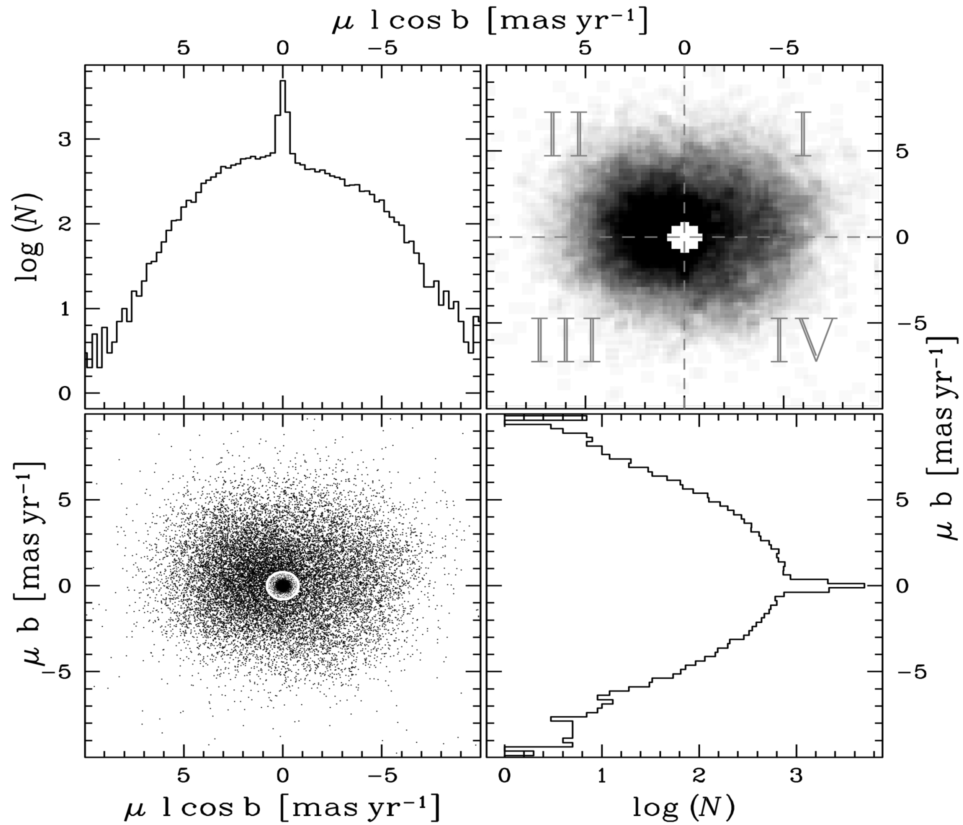
→NGC6528 is a perfect lab for stellar evol. and stellar pop.

→NGC6528 & NGC6553 are considered the template of MR bulge GCs [talks by Maria, Manuela, Doug ….]

A few references:
Ortolani + 1995,2001; Zoccali + 2001, age + composition
Feltzing + 2002, proper motion selection WFPC2 images
Momany + 2003, absolute age
Calamida + 2009, Stroemgren phot. metallicity distribution
Carretta + 2001, Fe & α
Zoccali + 2004, Fe & α
Origlia + 2004, Fe & α

The bulge cluster NGC6528 in the BW





ACS (opt)+WFC3 (NIR) HST archive images → proper motion

Clear separation between cluster and field stars

Lagioia et al. (2013, ApJ, subm)

The bulge cluster NGC6528 in the BW

Corrected for differential reddening

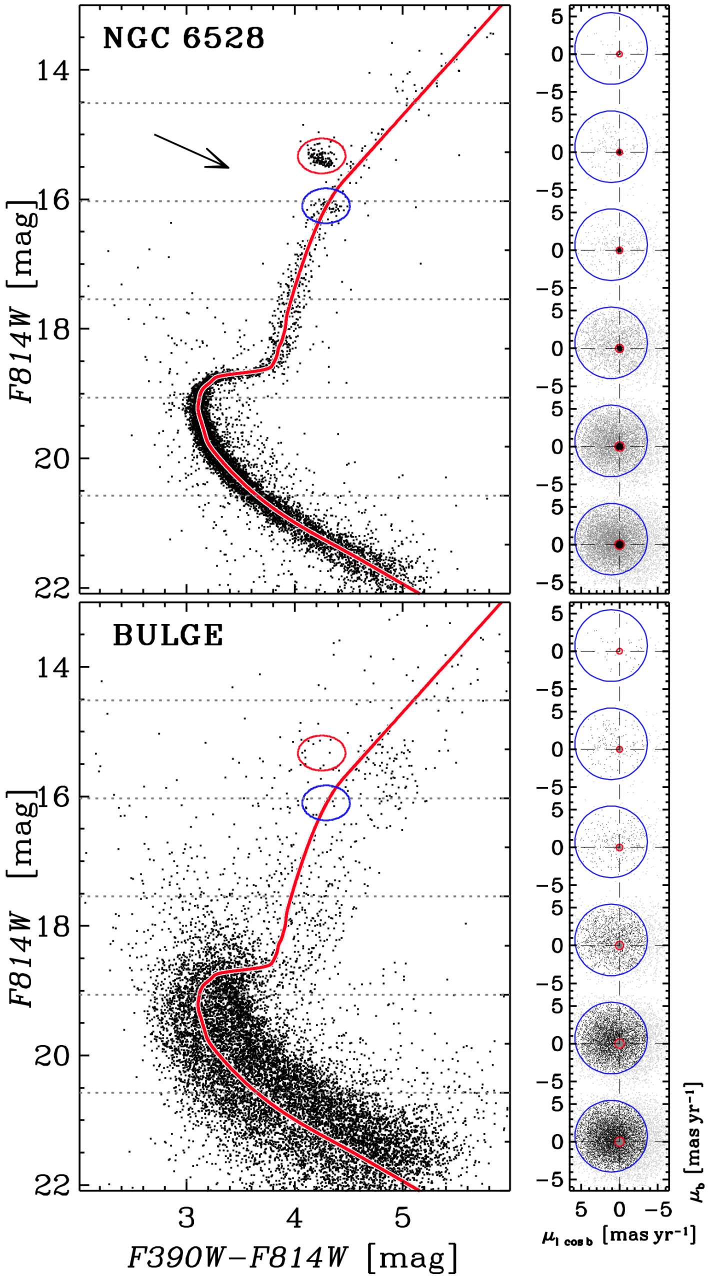
Well defined overdensities:
Red HB + RGB Bump

Well defined MSTO and SGB

The field appears more metal-rich, larger spread in age/metallicity/differential reddening

Limited field disk contamination (blue spure)

Lagioia et al. (2013, ApJ, subm)



Empirical Calibrators

47 Tuc → template MR GC

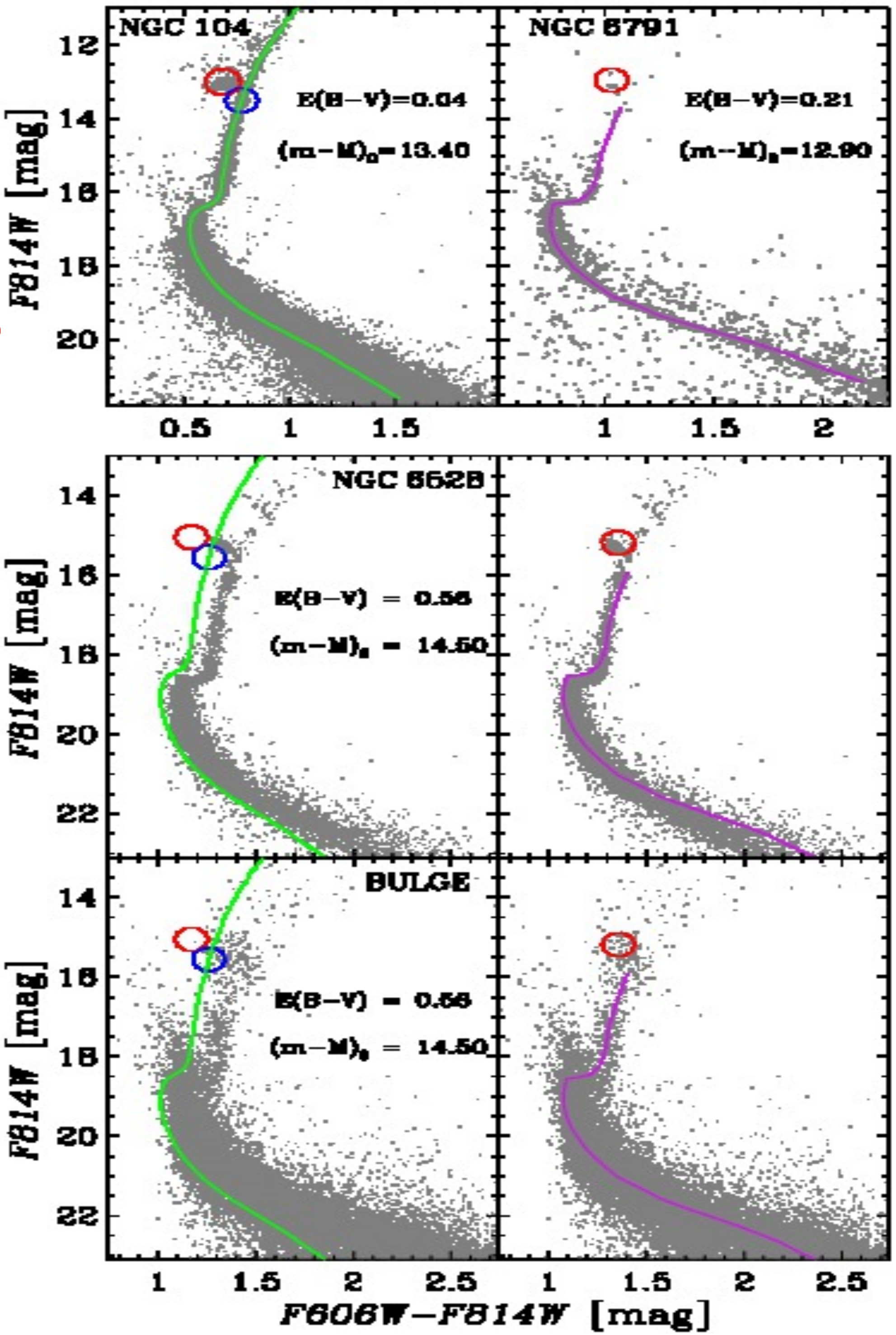
NGC6791 → template old globular

Comparison using the same photometric system

NGC6528 seems coeval & more MR than 47TUC →
Shape of the SGB
Δm between Bump & RHB

NGC6528 seems older & less MR than NGC6528 →
The slope of the ridgeline

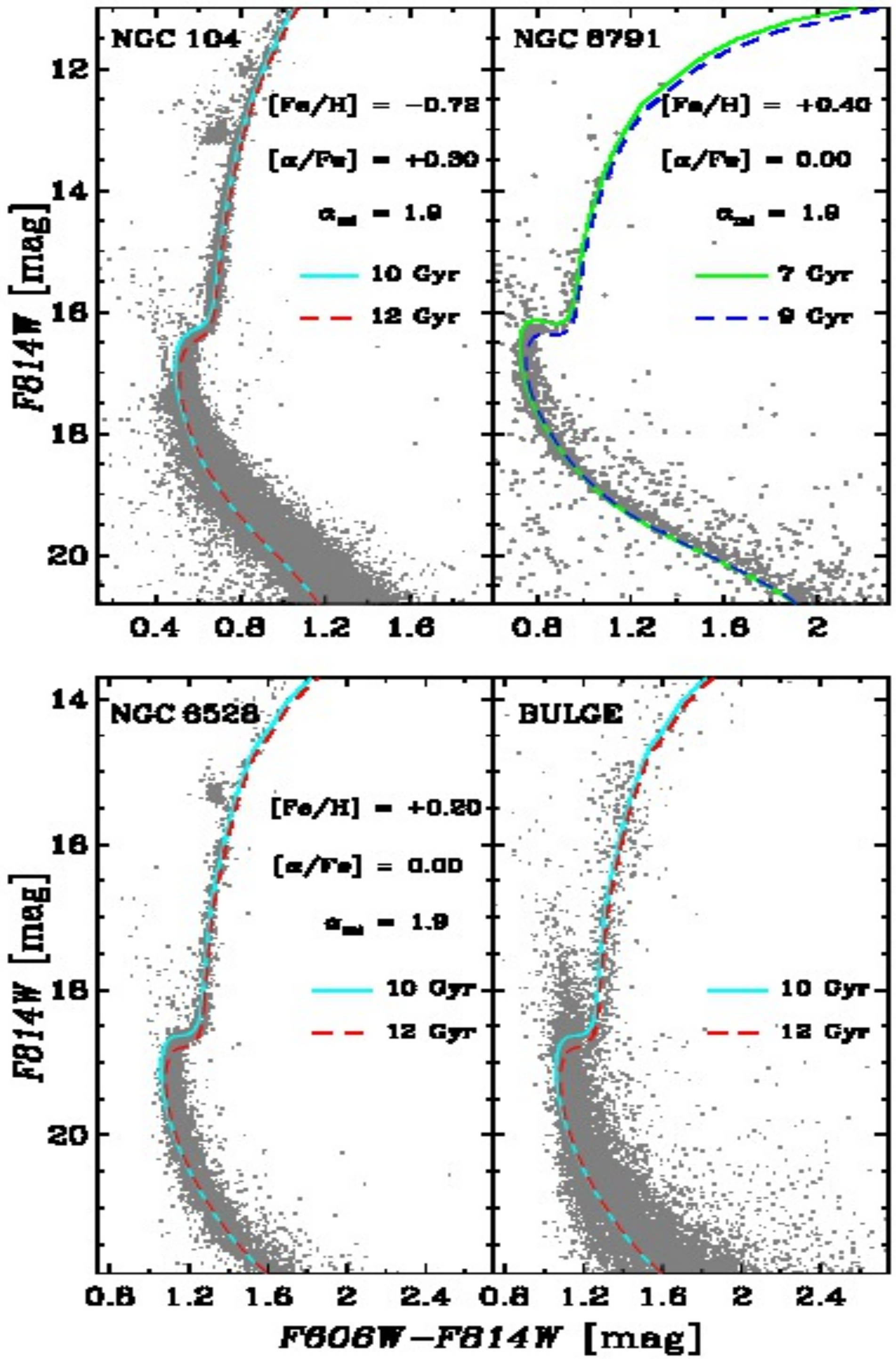
No firm conclusion concerning the field ….



Fitting with cluster isochrones

Isochrones based on both scaled-solar & α-enhanced evol. models (Pisa Library) Pier fecit

NGC6528 seems, within the uncertainties (mainly distance & reddening), old metal-rich hints for super-solar iron abundance



Lagioia et al. (2013, ApJ, subm)

NGC6528 & WFC3

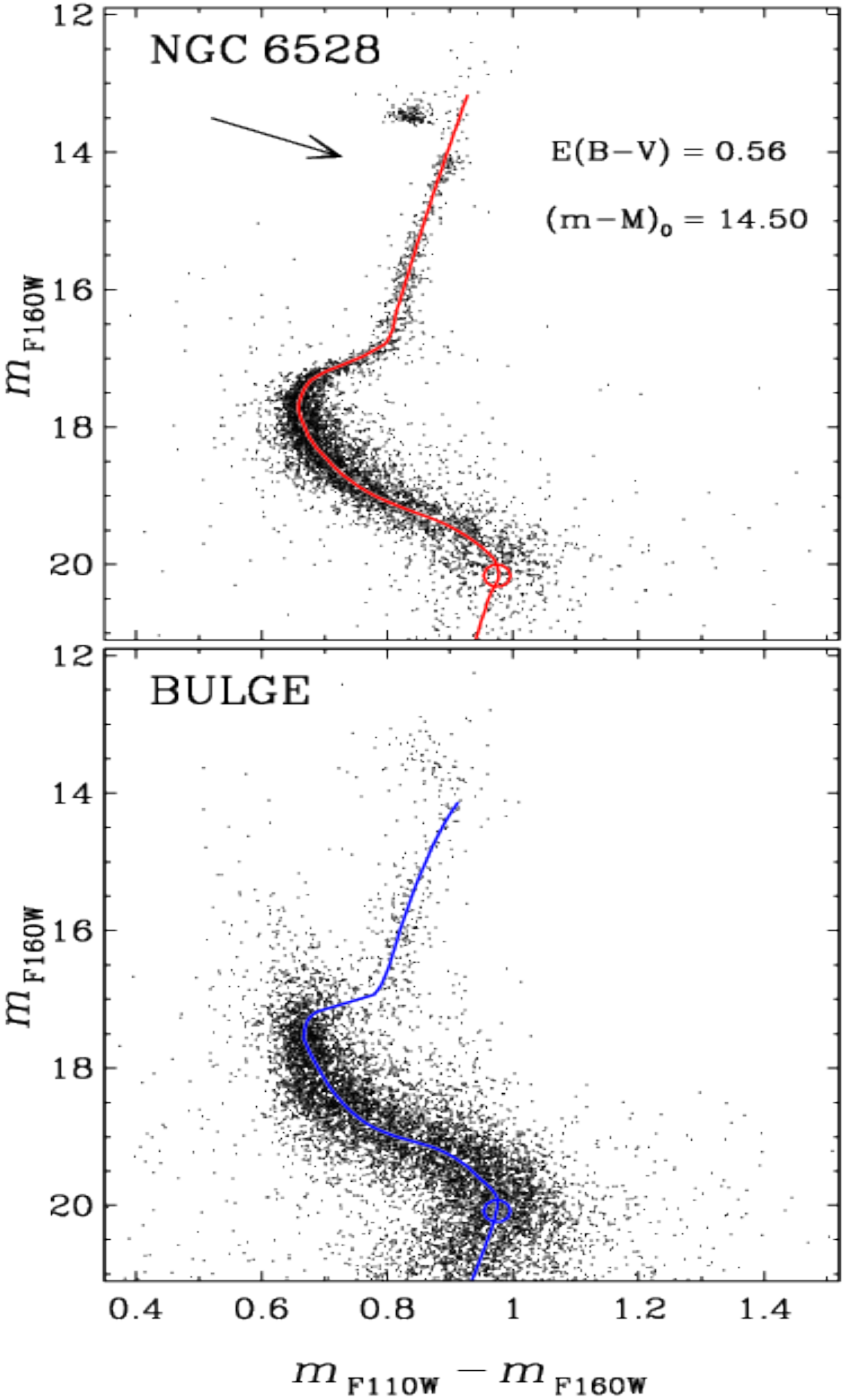
Same selection for proper motion

RGB Bump and RHB are well defined

Bending along the MS due to CIA appears in NIR Bands very robust absolute age indicator

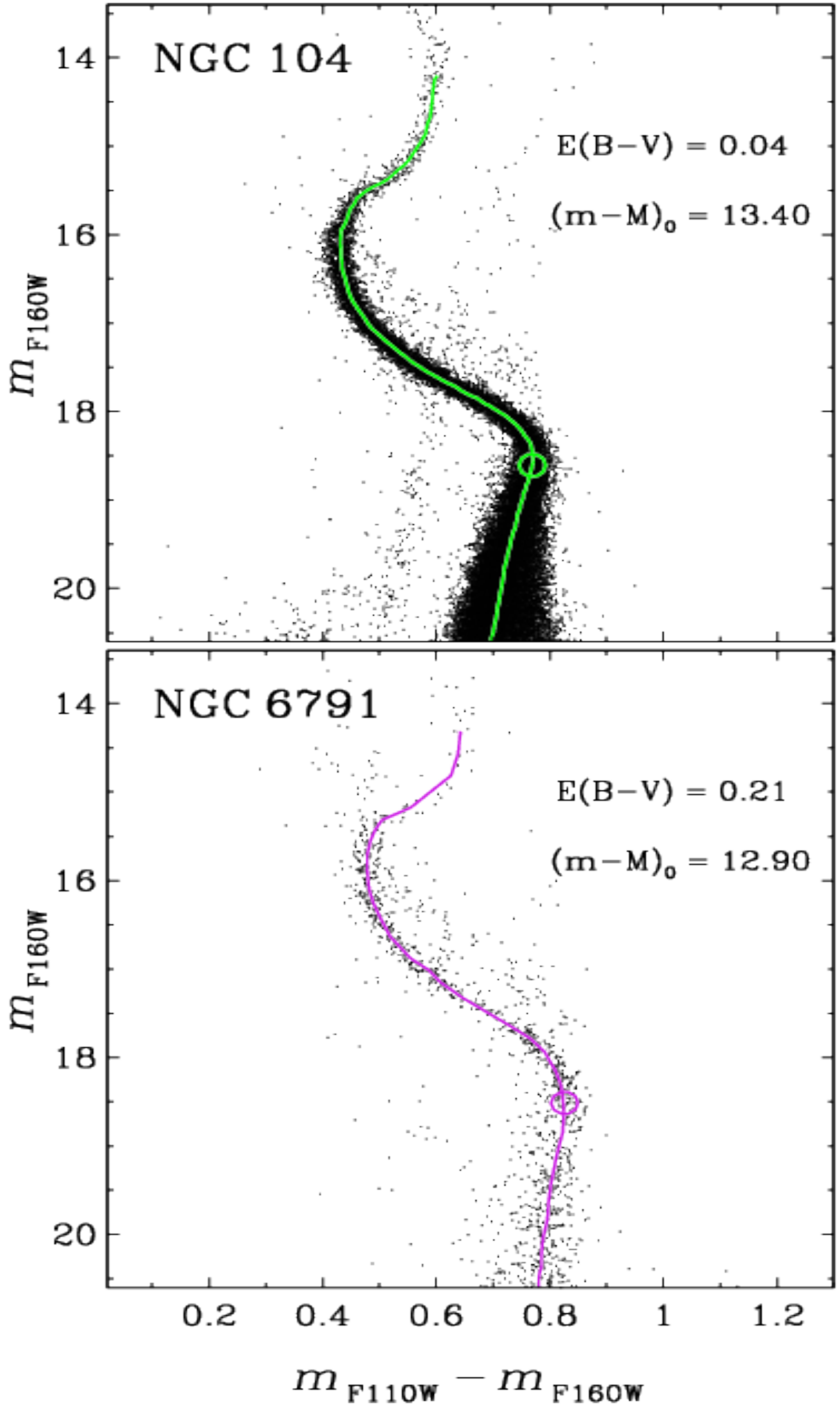
Robust selection for field stars

Lagioia, Milone + to be subm.



Calibrating Clusters
47 Tuc & NGC6791

NIR photometry 2 mag fainter than MS knee .....



Lagioia, Milone + to be subm.

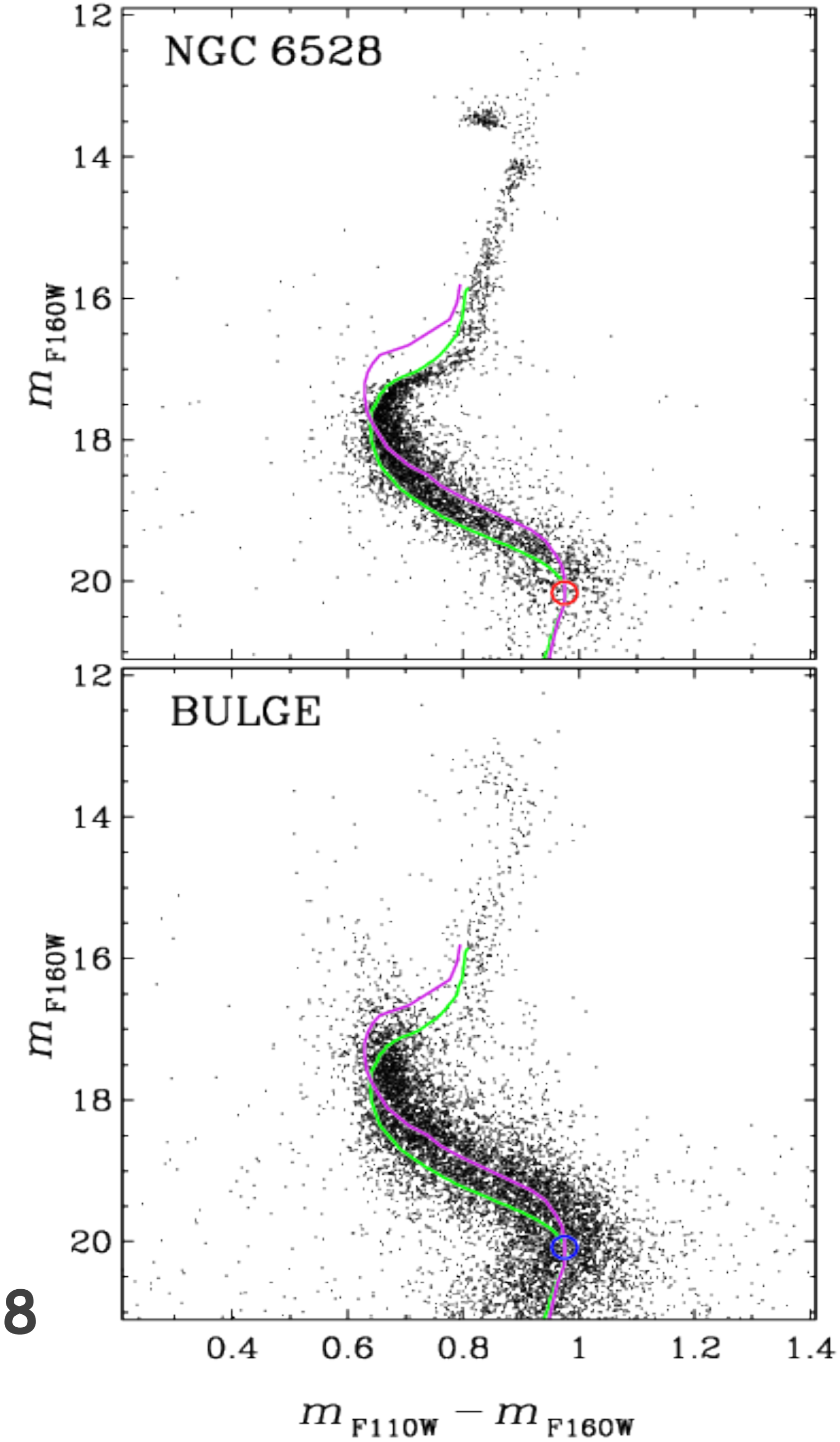
NGC6528 & calibrating clusters

NGC6528 is coeval & more
MR than 47TUC →
Slope of the RGB
Shape of the MS knee

NGC6528 seems older & less
MR than NGC6528 →
The MSTO

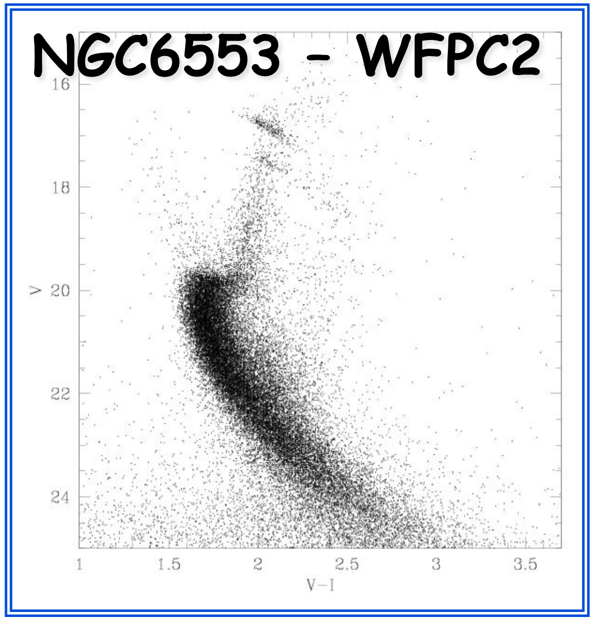
INDEPENDENT OF DISTANCE & REDDENING!!!

The bulge shows a spread in age
BUT BETWEEN NGC6791 & NGC6528
Larger spread in metallicity

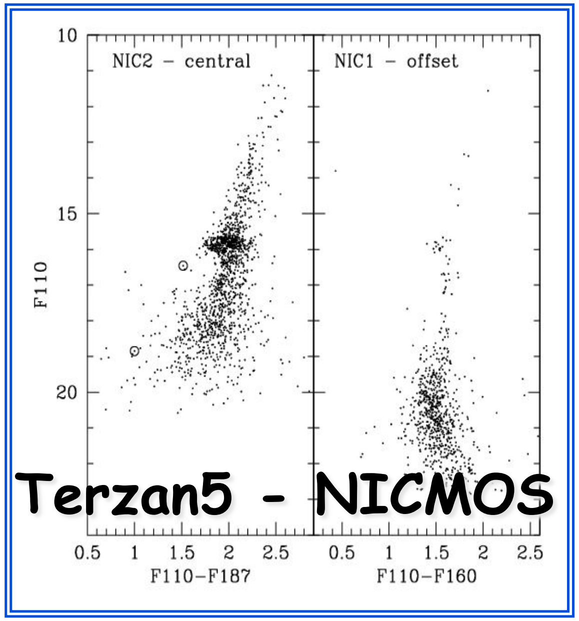


the bulge: age - GCs

47Tuc-like→ old

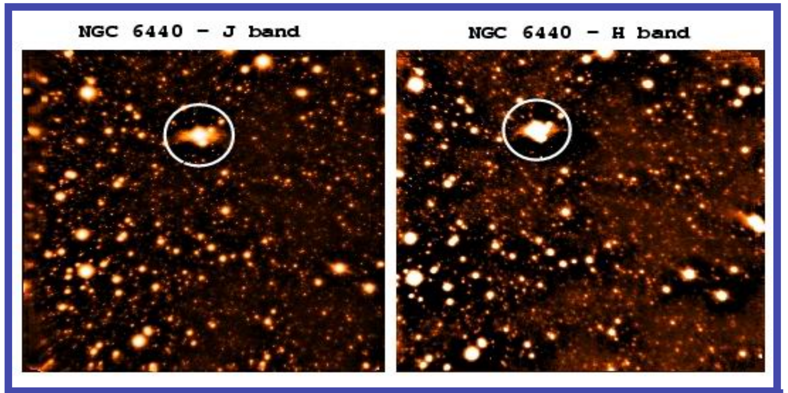


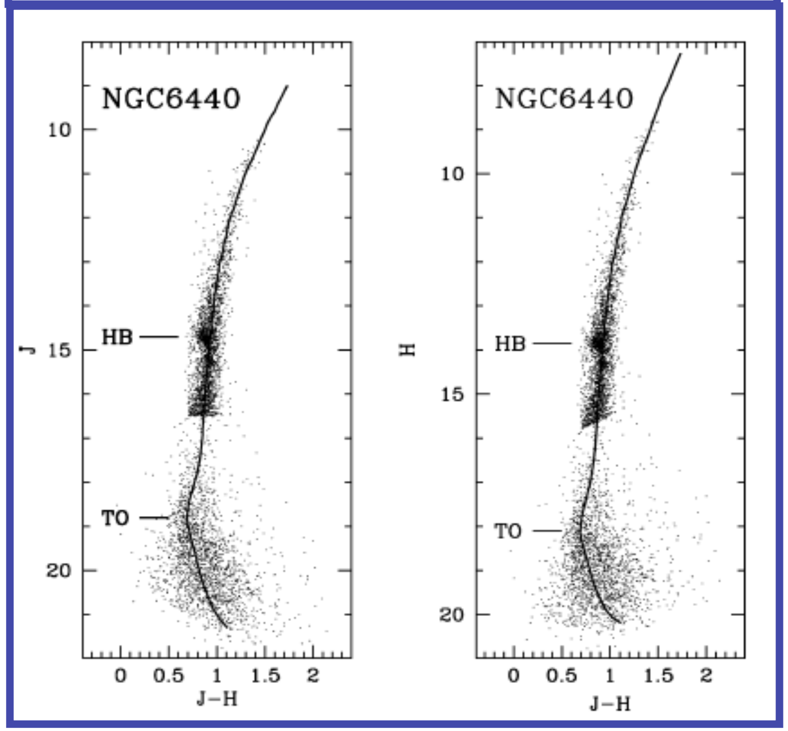
Zoccali etal '01



Cohn etal '02

NGC6440: VLT-NACO





Origlia etal '08

see also
Ortolani etal '95,'01
Heasley '00
Barbuy etal. '09

Courtesy by L. Origlia

NGC6528 intrinsic properties

No solid constraints concerning the α-enhancement from photometry

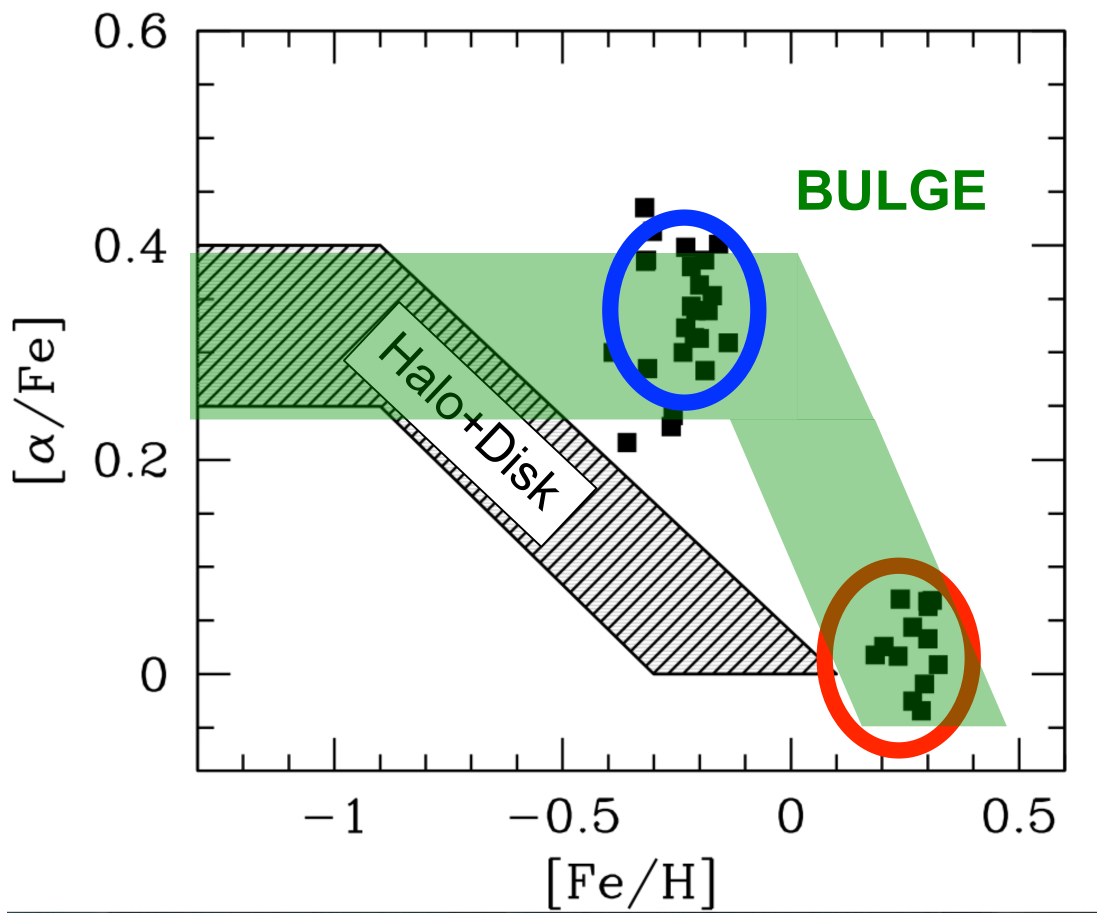
The α-enhancement from spectroscopy

$[\alpha/Fe] \sim +0.1 \pm 0.2$ → Carretta + 2001 (4 RHBs)

$[\alpha/Fe] \sim +0.1 \pm 0.1$ → Zoccali + 2004 (3 RHBs+RGBs)

$[\alpha/Fe] \sim +0.33 \pm 0.01$ → Origlia + 2005 (4 RHBs+RGBs)

Iron and alpha –elements abundance are similar to those measured in the **Bulge**, thus suggesting **quite similar star formation and chemical enrichment processes**



Terzan 5 courtesy by F.R. Ferraro

Conclusions II

Further solid evidence of a fast Bulge chemical enrichment of Bulge field stars & GCs

If supported by independent investigations, this would imply the lack of an age-metallicity relation over the entire metallicity range covered by old halo & bulge stars

Ness & Freeman + → Argos Galactic Bulge Survey

in the NEAR FUTURE (photometry)

The CTIO cluster RR Lyrae survey (PI: A. Kunder)
Multiband optical and NIR (N. Matsunaga) photometry
for cluster RR Lyrae

The Carnegie RR Lyrae Program (PI: W. Freedman)
800 Hours approved with Spitzer, data collected includes
Bulge fields and Bulge clusters

GEMS@GEMINI (PI: A. McConnachie, P.B. Stetson, G. Fiorentino, GB +)
Deep NIR photometry for a number of GGCs including bulge GCs

in the NEAR FUTURE (spectroscopy)

MMFS (opt) at Magellan

4MOST (opt) at VISTA/NTT

K-MOS&MOONS (NIR) at VLT

HARMONI[IFU]@E-ELT!!

CONCLUSIONS III

There is evidence that 1962 was a very good year: CTIO & ESO [happy birthday!!]

Up to now very good complementary facilities → [Carina project!!]

James Bond!!

Good year for Port!!

Credits

To young & senior researchers

with whom I have the pleasure to share this new wonderful adventure

E. Lagioia[OAB], K. Genovali[TOV], L. Inno[ESO], A. Calamida[ESO], B. Lemasle[AMU]

THANKS!