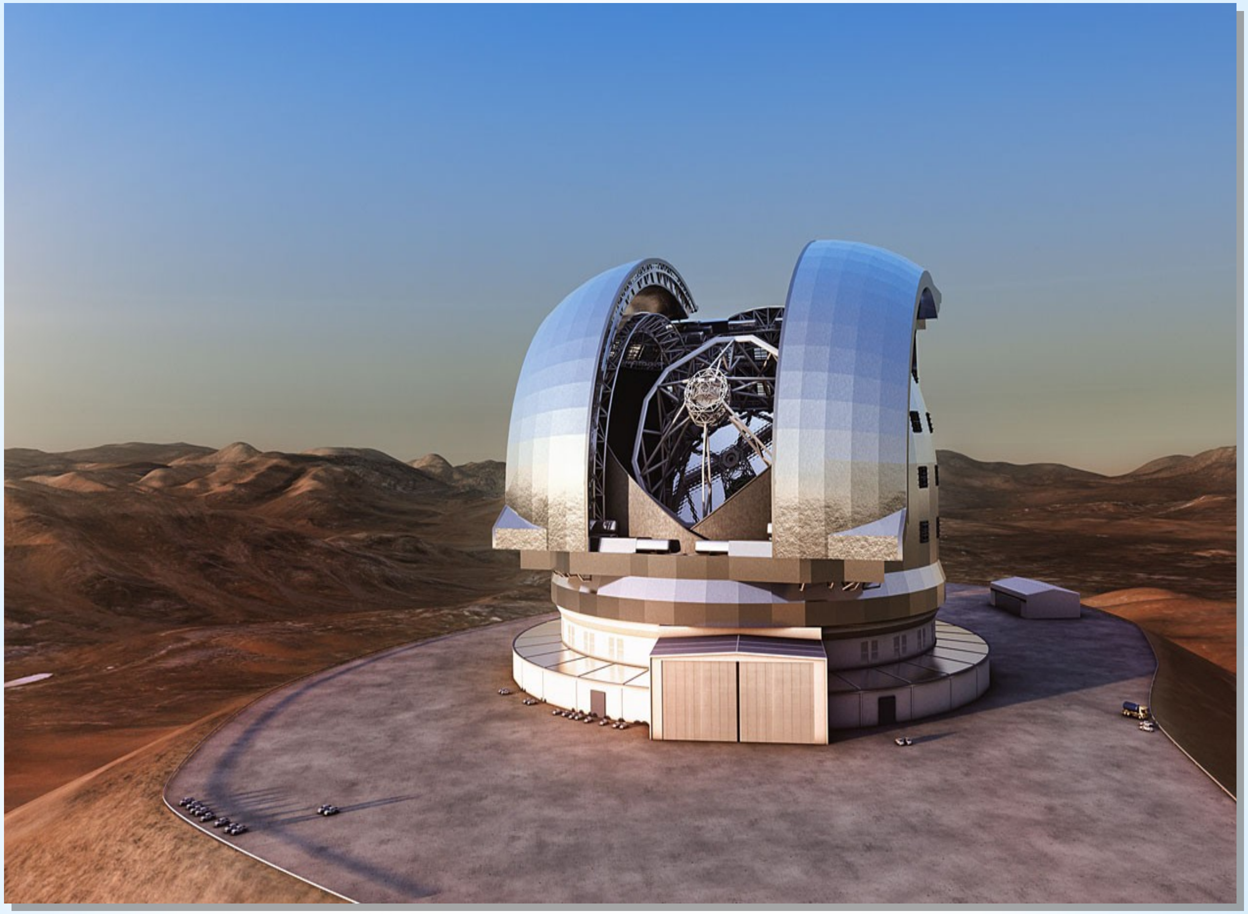
Stellar populations & E-ELT

G.
BONO

UNIVERSITA' DEGLI STUDI DI ROMA
Tor Vergata



PhD School "F. Lucchin", Science & Technology with E-ELT, Erice, 8-20 October 2015

Setting the scene

E-ELT in a nutshell

Paving the road for E-ELT

Galactic Center

Nearby dwarf galaxies

[transition between VLMS & GP]

Future Perspectives

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

4) E-ELT – HIRES (Optical – NIR)

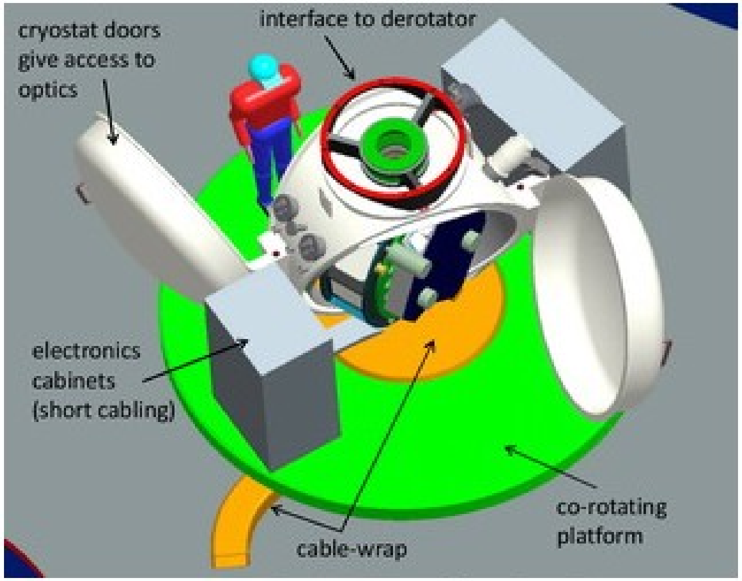
5) E-ELT – MOS: Fibers + IFUs (optical, NIR)

6) E-ELT – Not defined yet

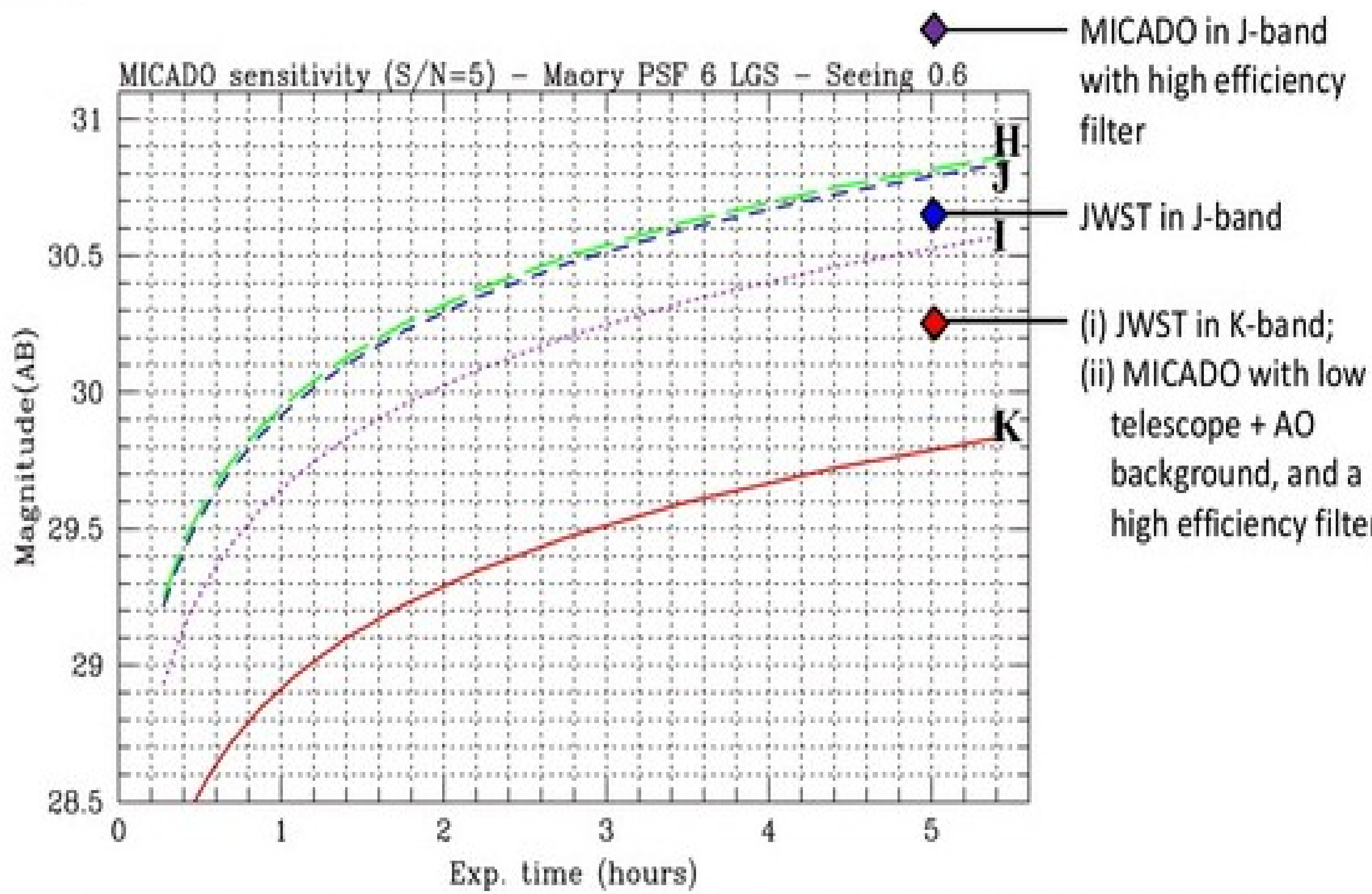
E-ELT CAM: MICADO

Plus SCAO + MCAO (MAORY)

NIR long-slit medium resolution spectrog.



Overview of MICADO



Broadband imaging sensitivity of MICADO as a function of integration time

MICADO@E-ELT vs NIRCAM@JWST

	MICADO@E-ELT	NIRCAM@JWST
FoV	~1' X 1'	2 X (2.16' X 2.16')
Pixel scale	~3 mas + "HR"	~30 mas
K-band	~29.5	~30
J-band	~31	~29.5

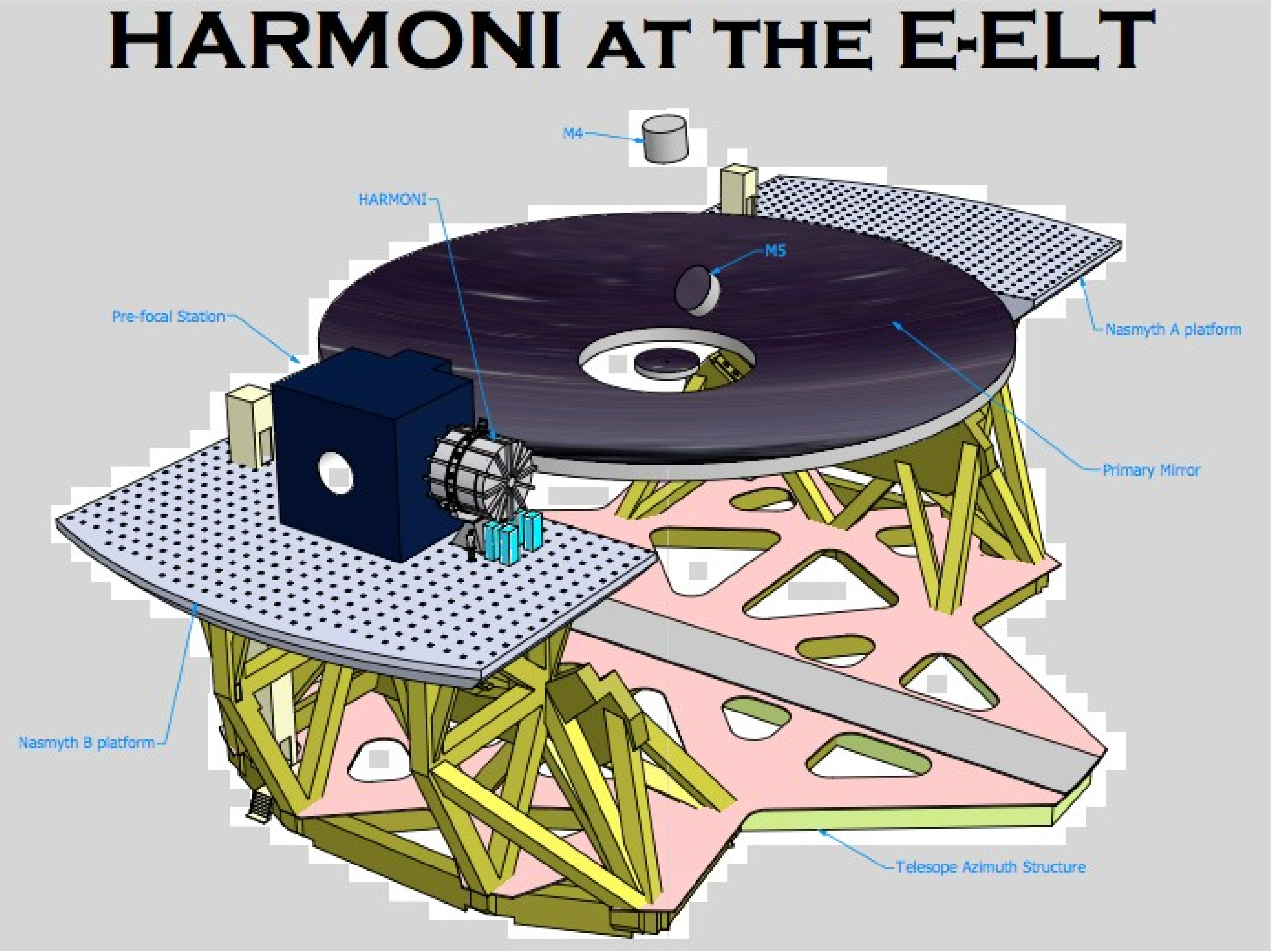
t_exp=5 hrs -- S/N=5 -- MAORY + 6 LGS -- seeing 0.06

high efficiency filters → AB Mag -- HR→ 1.5 mas smaller FoV

F115W & F200W -- t_exp=5 hrs -- S/N~5
Extraction region in a circle of 0.8''"

Synergies among JWST, EUCLID & ERIS@VLT

E-ELT Integral Field Spectrograph: HARMONI



NIRSPEC@JWST

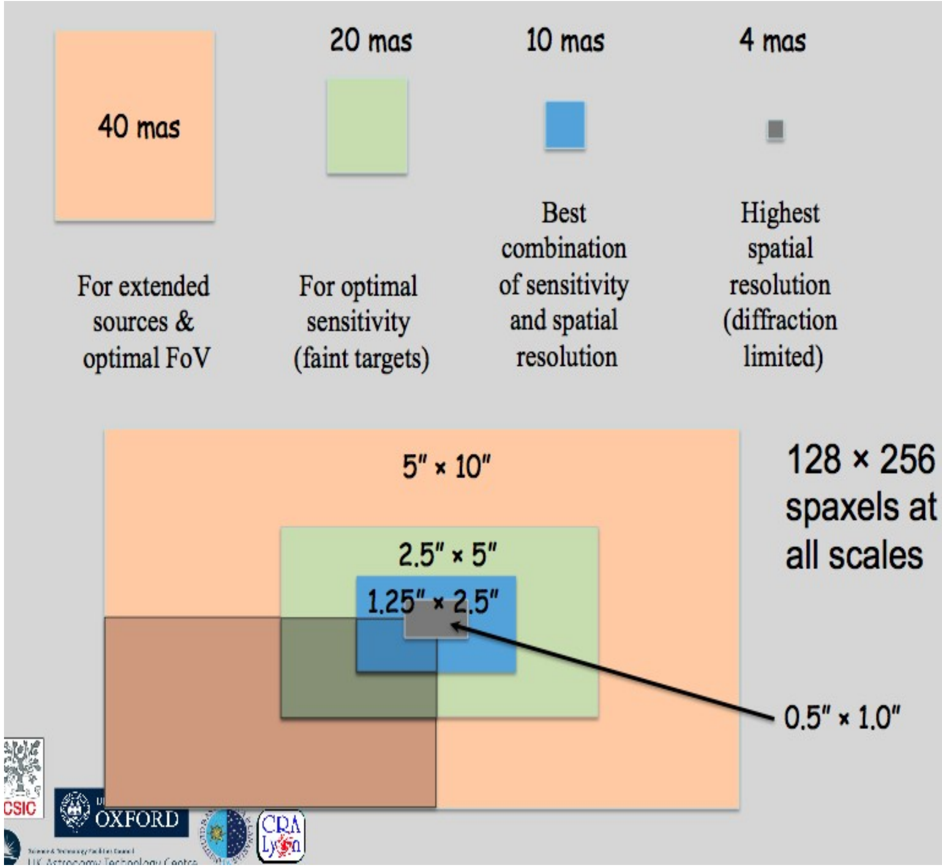
FoV	~3' X 3' for MOS
Slit width	~200 mas
Slits	Micro Shutter Array Fixed slits IFU (3"" X 3")
Spectral Resolution	R~100 → 0.7 -- 5 μm (single prism) R~1000 → 1 -- 5 μm (3 gratings) R~2700 → 1 -- 5 μm (3 gratings)

R=100 → t_exp ~ 10,000 sec point source continuum at 3 μm

S/N=10 is AB~26 mag

Synergies between JWST & ELTs

E-ELT Integral Field Spectrograph: HARMONI



Plus SCAO + MAORY

33,000 spaxels per exposure!

Wavelength Ranges & Resolving Powers

Bands	R
V+R, I+z+J, H+K	~4000
V, R, I+z, J, H, K	~10000
Z, J_high, H_high, K_high	~20000

- ❖ Exploring adding simultaneous V-K coverage at R~500-1000
- ❖ Re-assessing the need for high spectral resolving power at visible wavelengths (< 0.8 micron)

Requirements for IFS@E-ELT in J,H,K-band

FoV	> a few arcsec
High multiplex	> intrinsic
Spatial res.	< 0.004—0.005 arcsec

Abundances (Iron, α-, s-, r-elements)

High-res R~20,000

Limiting mag. K~23 mag

CRIRES (+GIANO) update crucial step,

atmosphere models, line identifications, molecules (NIR regime)

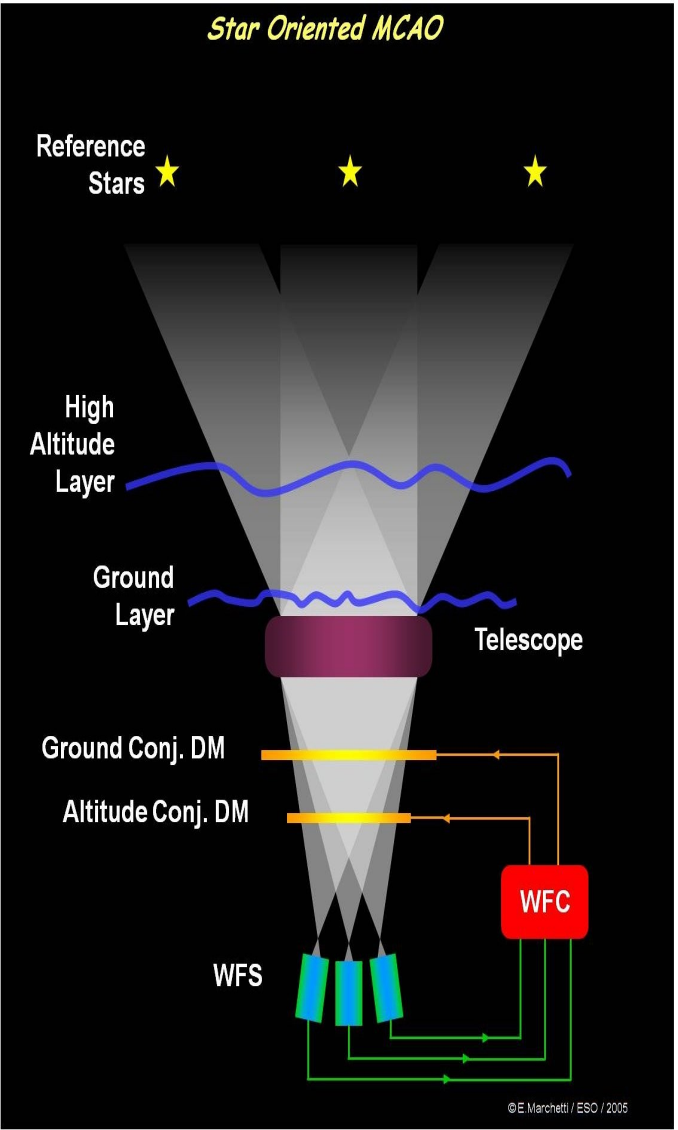
Adaptive Optics

SCAO, MCAO, GMCAO, LTAO

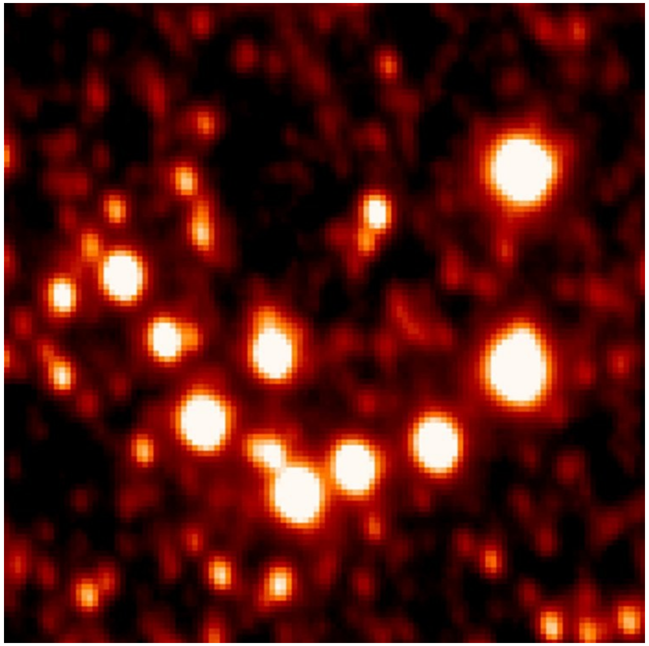
HERE & NOW

.....But life isn't a bed of roses!!

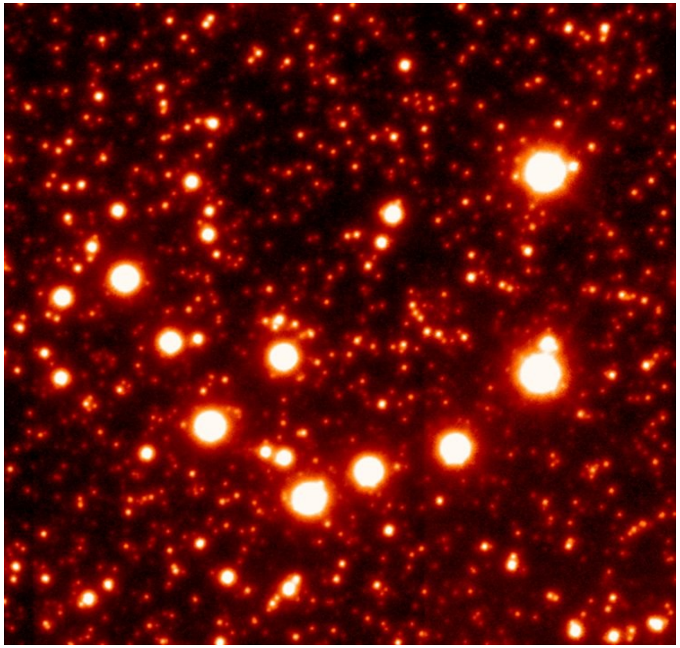
In the beginning was …. MAD@VLT



ISAAC@VLT



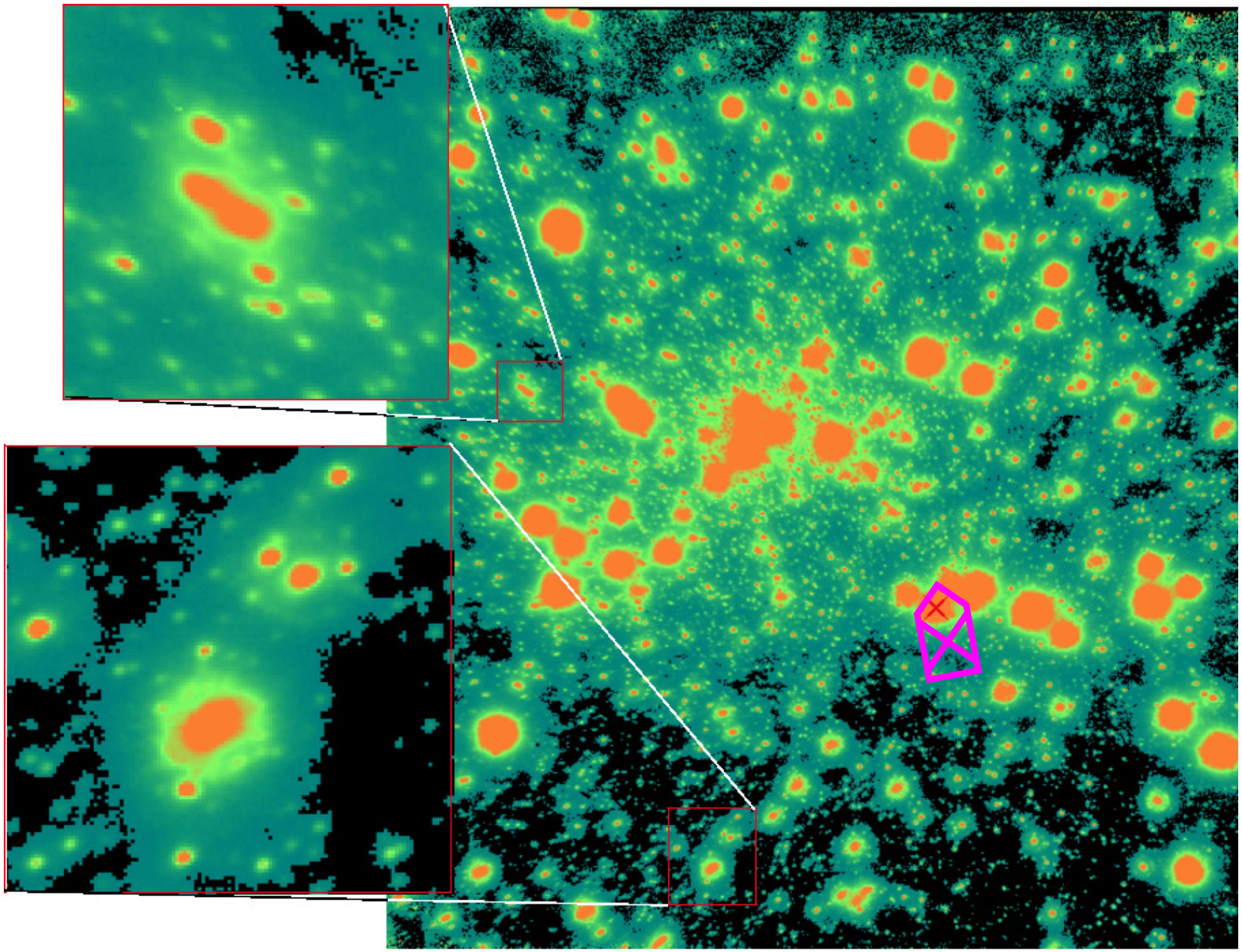
MAD@VLT



ω Centauri the very center crowded field!!
Log ρ = 3.5

Photometric & astrometric precision similar to HST!!! Marchetti et al. (2008) + lecture

Later on was FLAO@LBT



J-band image

Drift of the PSF shape at larger
Distances from the NGS

SCAO

M15 core (pcc)

FWHM of 0.05 (J) &
0.06 (Ks) arcsec.

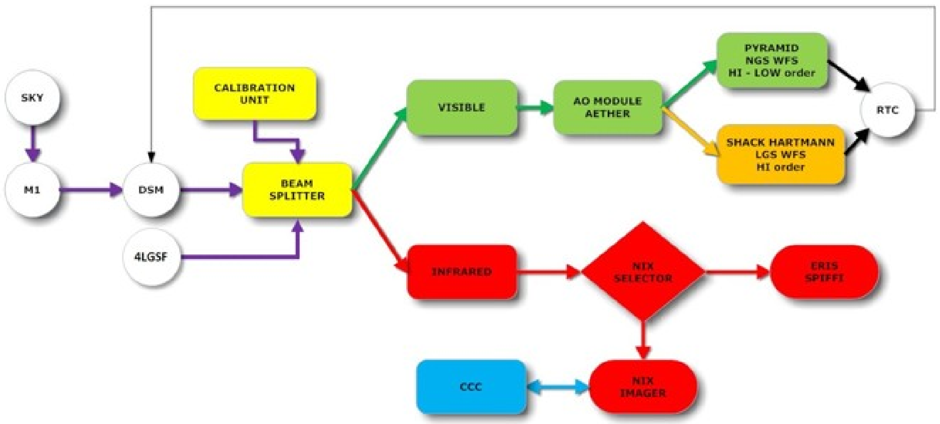
Strehl ratio
13–30% (J), 50–65% (Ks)

Limiting magnitudes:
J~22.5 mag
Ks~23 mag

Esposito + (2010)+lecture

GF's lecture

ERIS@VLT



Enhanced Resolution Imager & Spectrograph

1-5 μm for UT4 + DSM

Imager

FoV 27x27, 54x54 arcsec^2

Pixel scale 0.013, 0.027 mas/pix

Spectral coverage J -- M

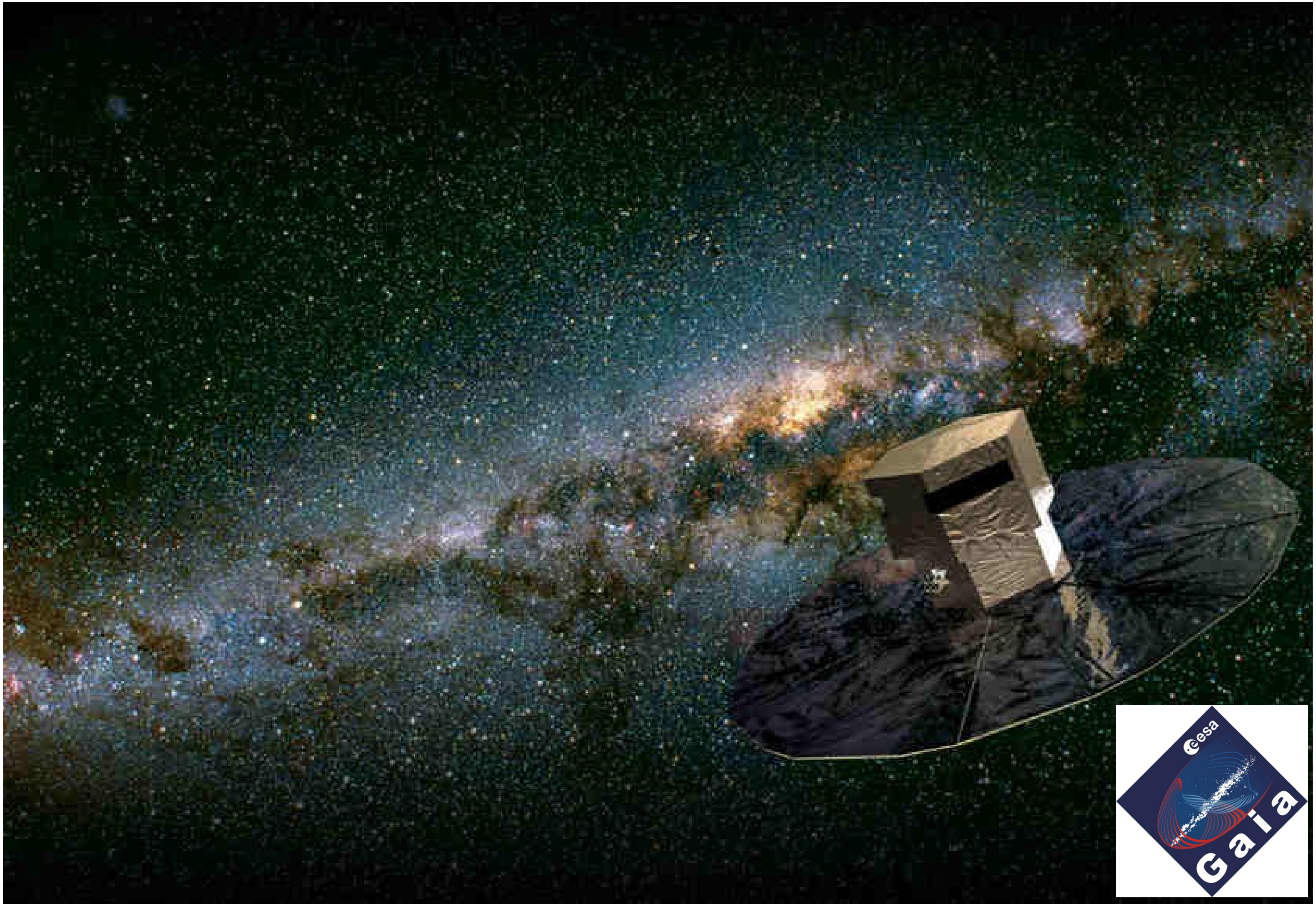
Integral Field Spectrograph

FoV 8x8, 3.2x3.2, 0.8x0.8 arcsec^2

Pixel scale 250—25 mas/spaxel

Spectral coverage JHK → R up to 8000

GAIA
Global Astrometric Interferometer for Astrophysics



COSMIC TIMES

1955

Age of the Universe:
6 Billion Years

Size of the Universe
4 Billion Light Years

"Yardsticks" in Neighbor Galaxy Double Universe's Size

Walter Baade, an astronomer at the California Institute of Technology, says the Universe is twice as large as we thought. He has used the giant 200-inch reflecting at Mount Palomar to measure the scale of the Universe.

The telescope that confirmed the scale of the cosmos: Mount Palomar's 200-inch Hale Telescope was completed in 1949.

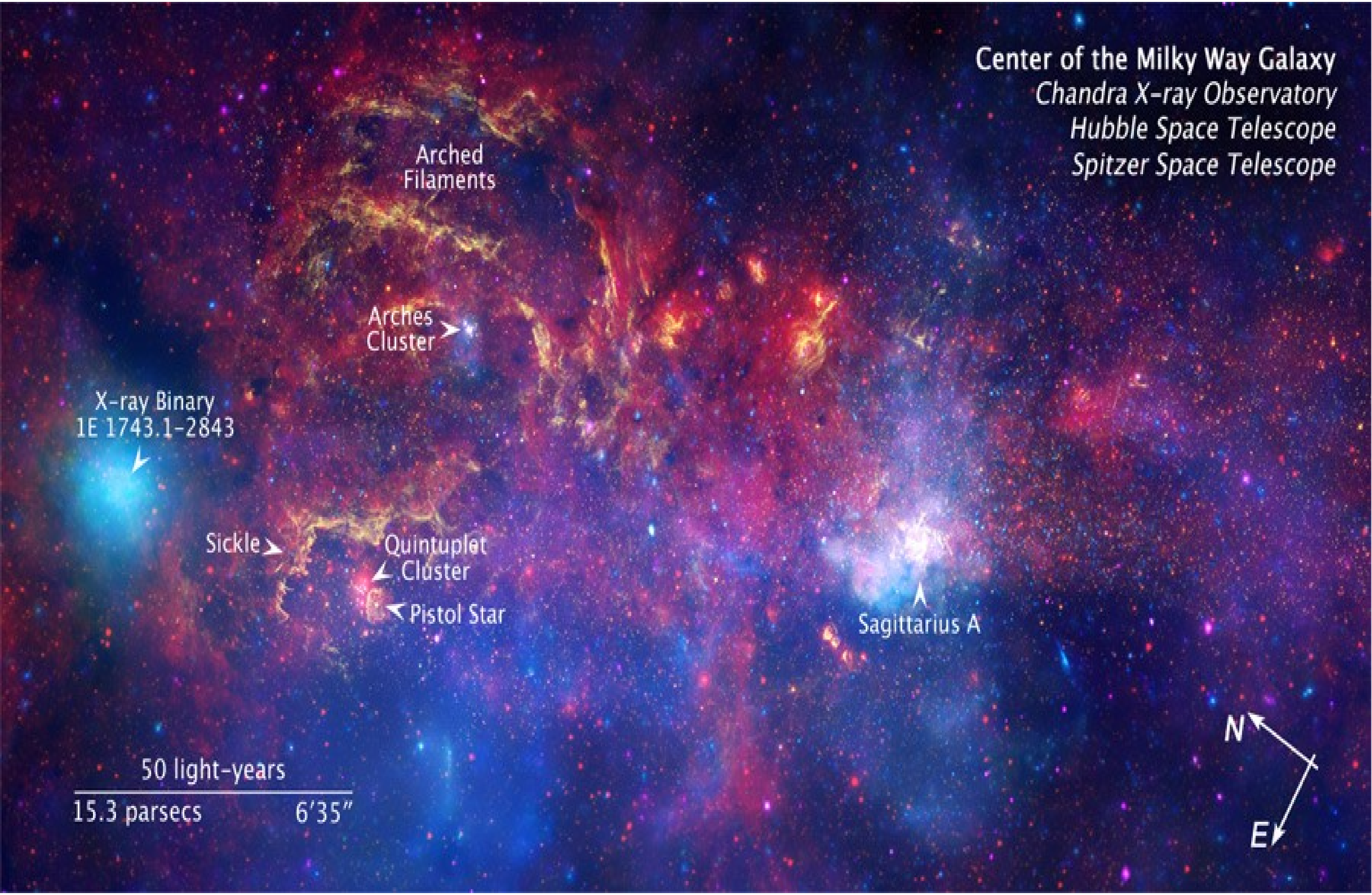
Baade's discovery hasn't come from simply reading mile markers in space. To properly determine the distance to stars and the scale of the Universe, he first had to discover that Nature has created more than one kind of measuring tool ("yardstick"). Until a few years ago, there was just one measuring tool known to astronomers, and it was being used incorrectly. Oddly enough, it took the wartime black-outs in Los Angeles to begin setting things straight. (These blackouts were periods of time at night when people had to turn off all lights or make certain all lights were blocked by heavy curtains to minimize the danger of night-time bombings or spying raids. During

Gaia & MW

Almost a perfect experiment
→Distance scale   primary
→Metallicity scale V~11-13
→Kinematics   V~15-17

However (M-type stars)
→ G-band → optical
→ RVS   → CaT

LIMITED by CROWDING & REDDENING


Center of the Milky Way Galaxy
Chandra X-ray Observatory
Hubble Space Telescope
Spitzer Space Telescope
Arched Filaments
Arches Cluster
X-ray Binary 1E 1743.1-2843
Sickle
Quintuplet Cluster
Pistol Star
Sagittarius A
N
E
50 light-years
15.3 parsecs
6′35″

Ancient views of Creation

Cappella Palatina

Duomo di Monreale

Fiat luminaria in firmamento coeli ….

Galactic center (no lumen!!!)

Crowded stellar field → log ρ >> than in globulars

High reddening → less reddened regions: A_k~3 → A_v~30

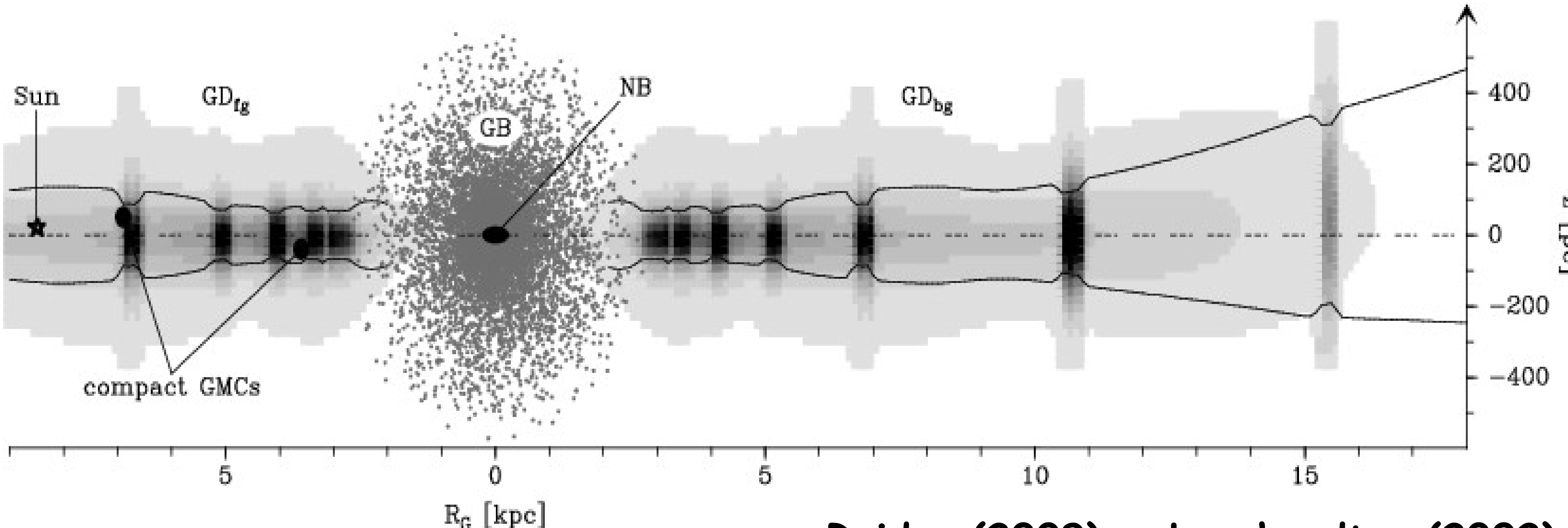
High differential reddening (a few arcsec scale)

Different reddening law

No solid identification of old stellar pop.

Share similar problems with the inner Bulge

Why Nuclear Bulge - Galactic Bar - inner disk?



Reid + (2009) Launhardt + (2002)

Nuclear Bulge—Galactic Bulge—Inner disk

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)

Obvious plausible consequence

The metallicity distribution

in the inner disk
in the Nucear Bulge
& along the Galactic Bar

should be quite similar

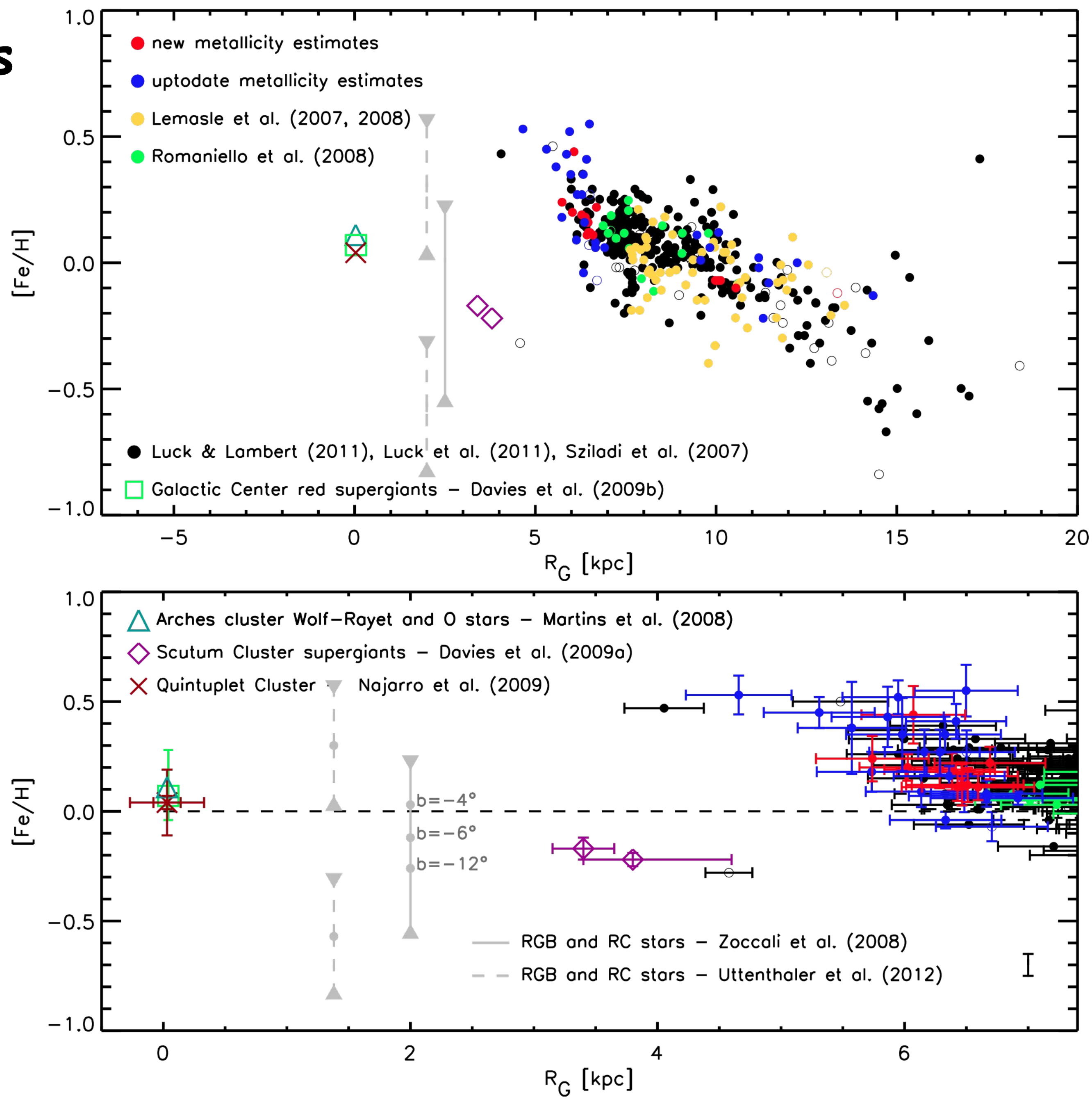
Difference between inner disk & NB+Bar

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 (Zoccali + 2008, Johnson + 2011)

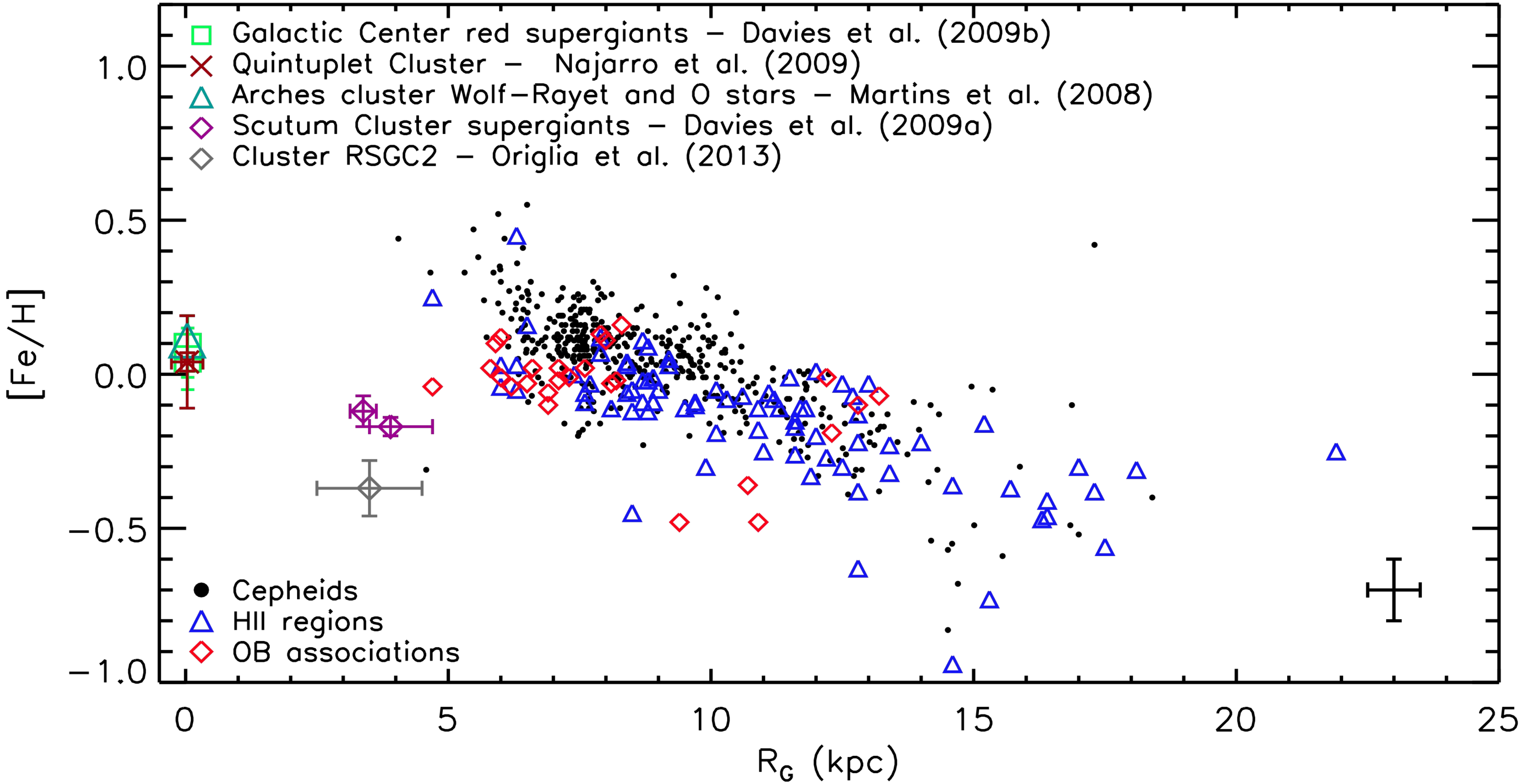
Evidence of a bulge gradient (Ness + 2013 Gonzalez + 2013 Pietrukovic + 2015)



Genovali et al. (2013a)

Cepheids and age effects (1)

HII regions & OB associations



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

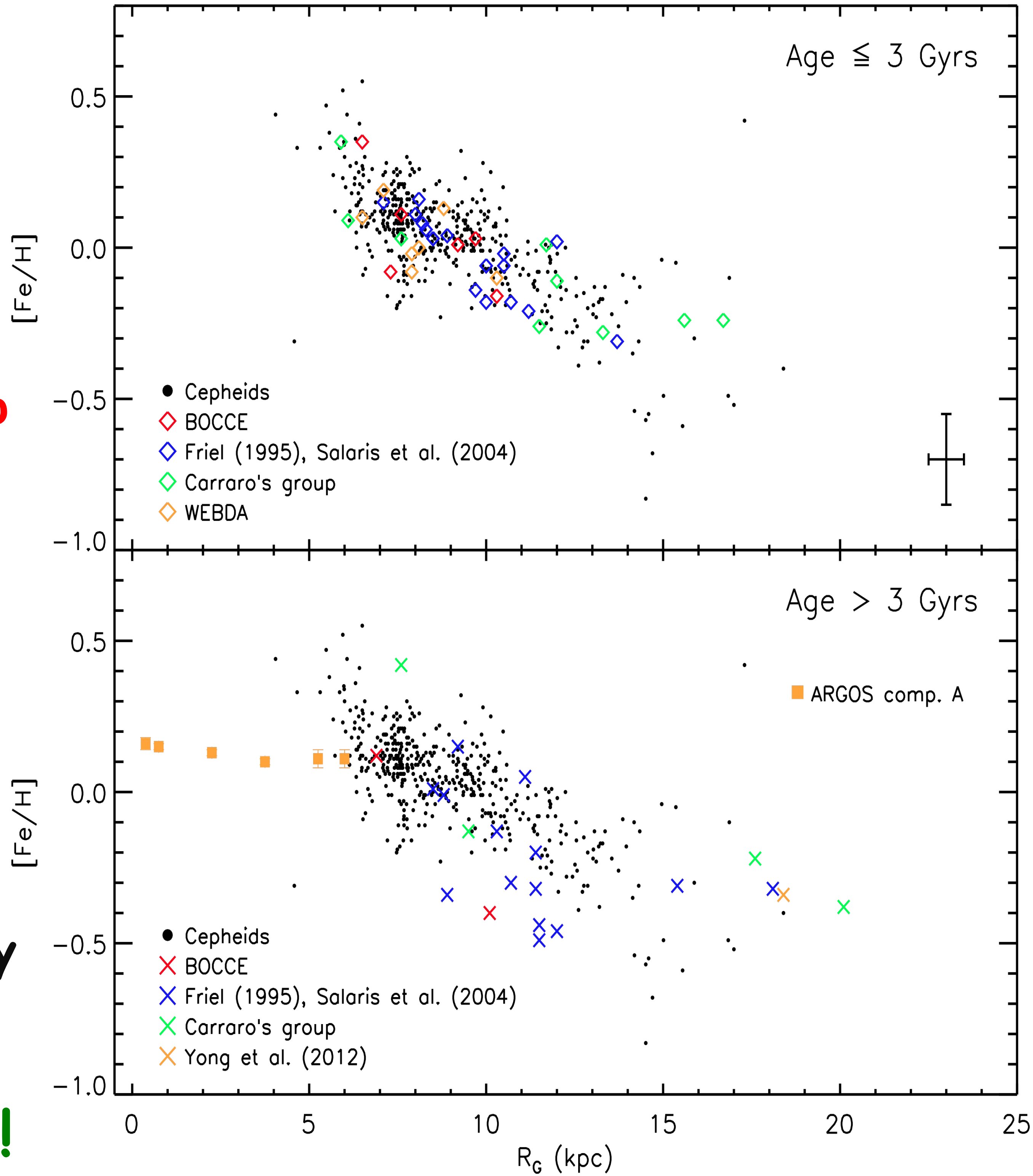
Cepheids & age effects (2)
Open Clusters

No relevant changes up to 3 Gyrs

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

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

Difficult selection!!

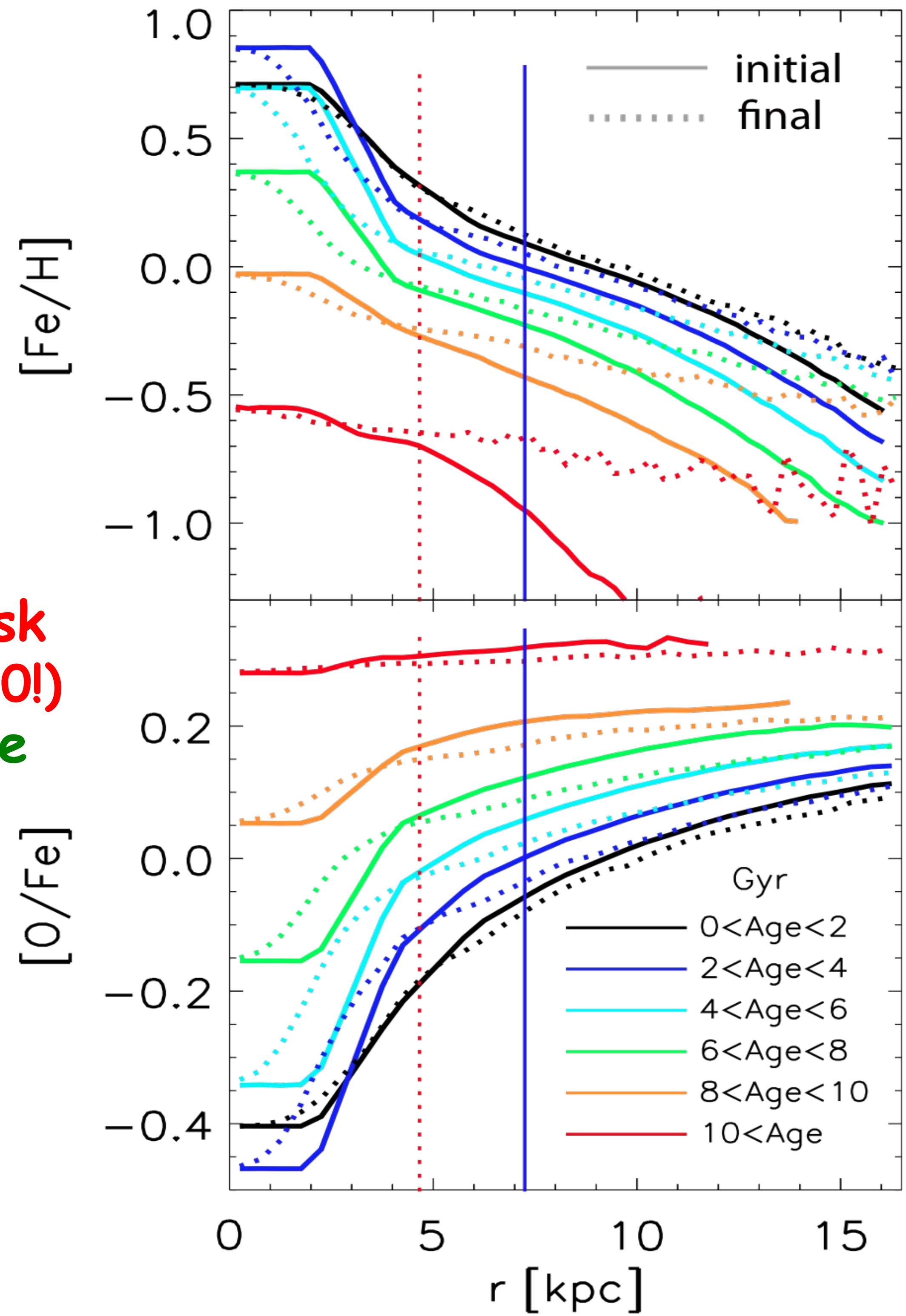


Chemical evolution models

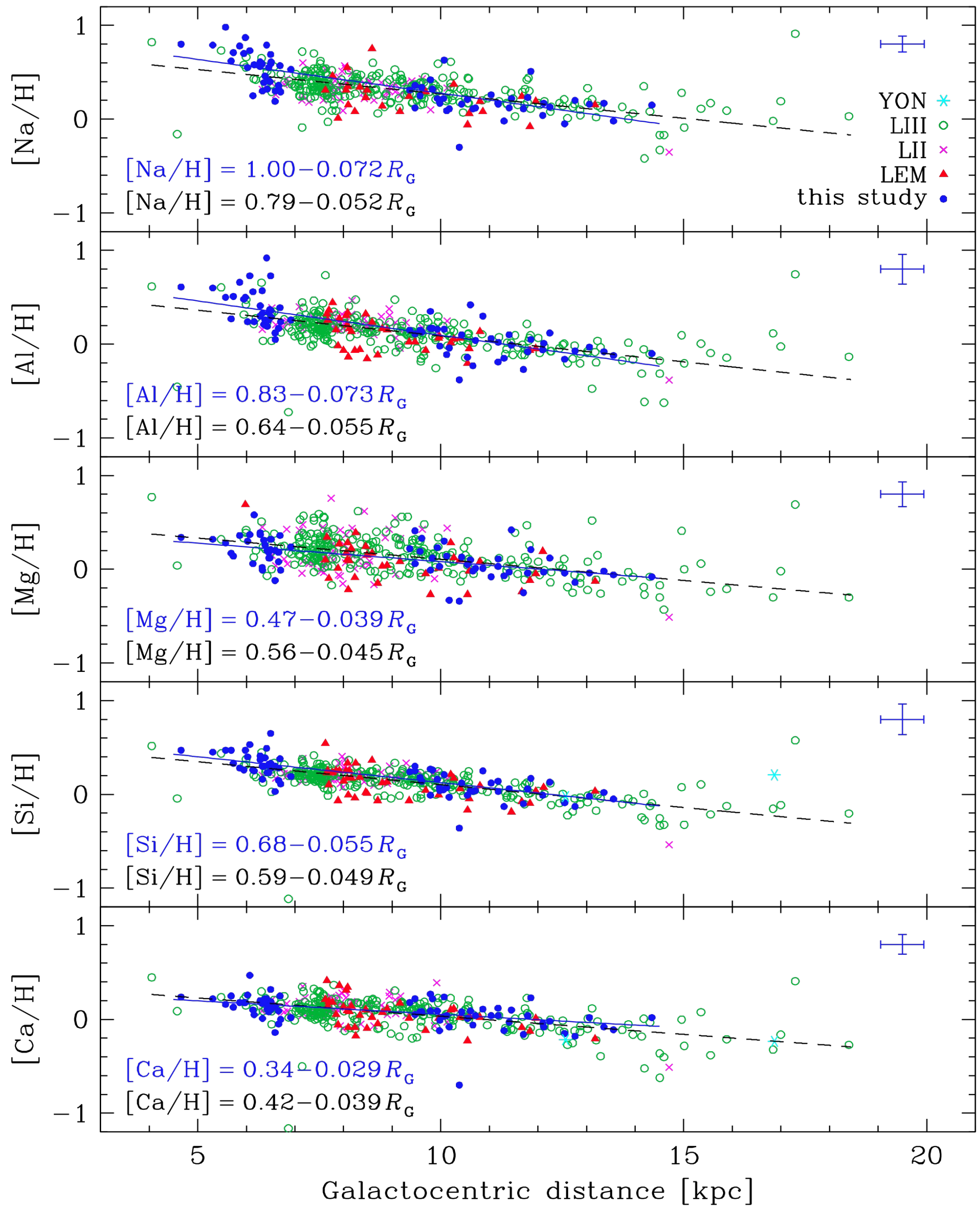
Minchev et al. (2013)
Chemo-dynamical models

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



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

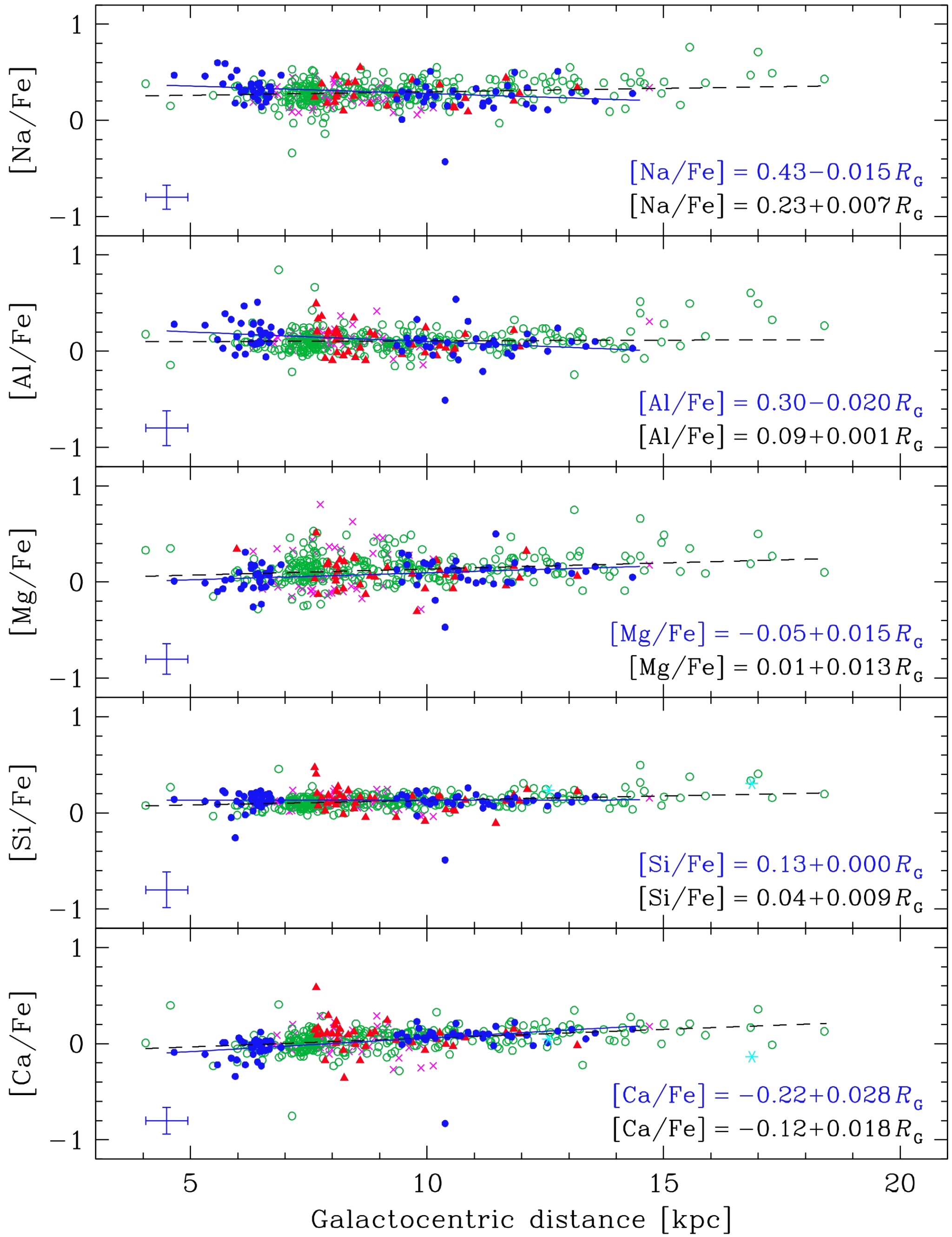


Almost the entire sample of Cepheids (~440) for which we have iron abundances

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

Si & Ca explosive
Mg hydrostatic
McWilliam+ (2013)

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



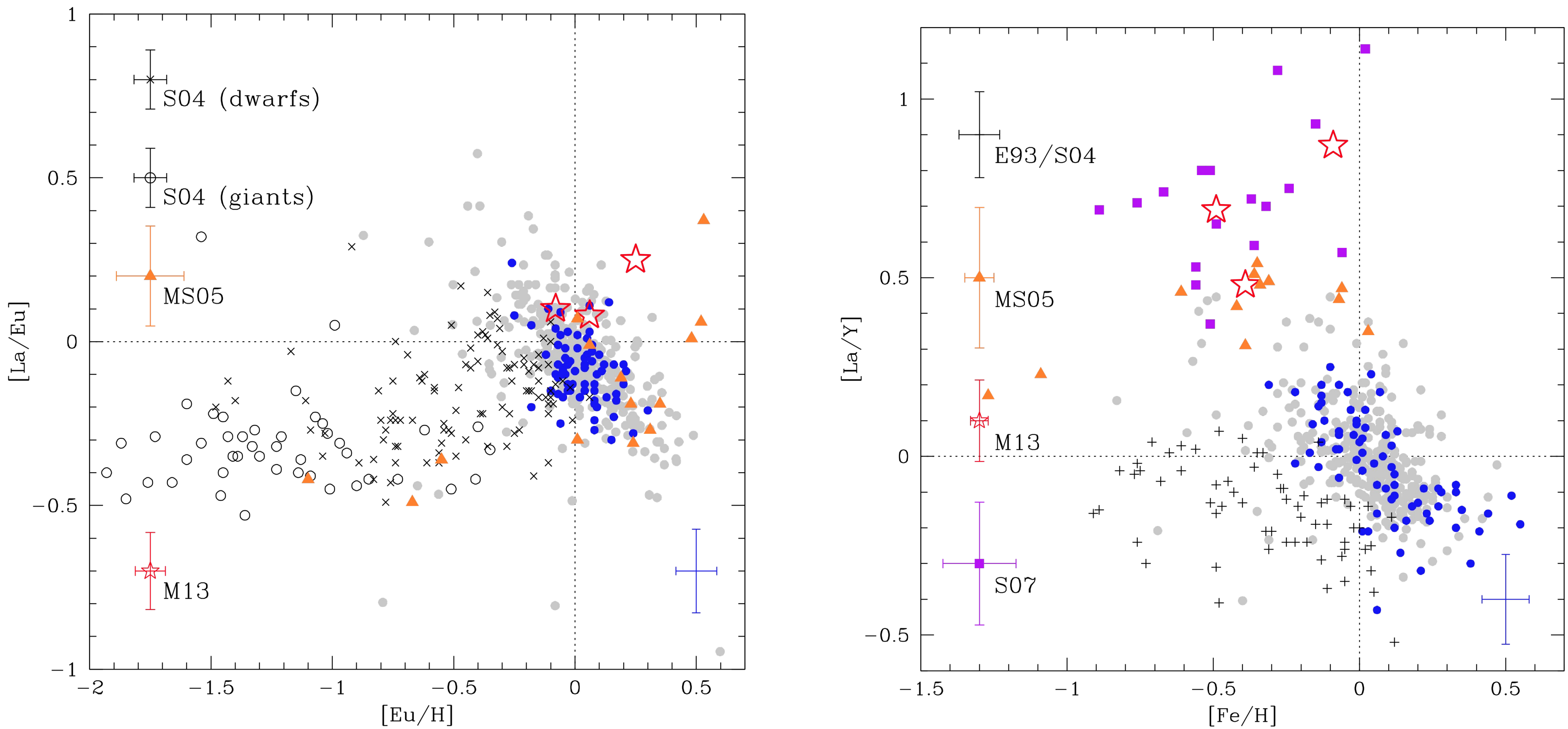
very very flat distribution over the entire range of Galactocentric distances

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!!

Paving the road for E-ELT

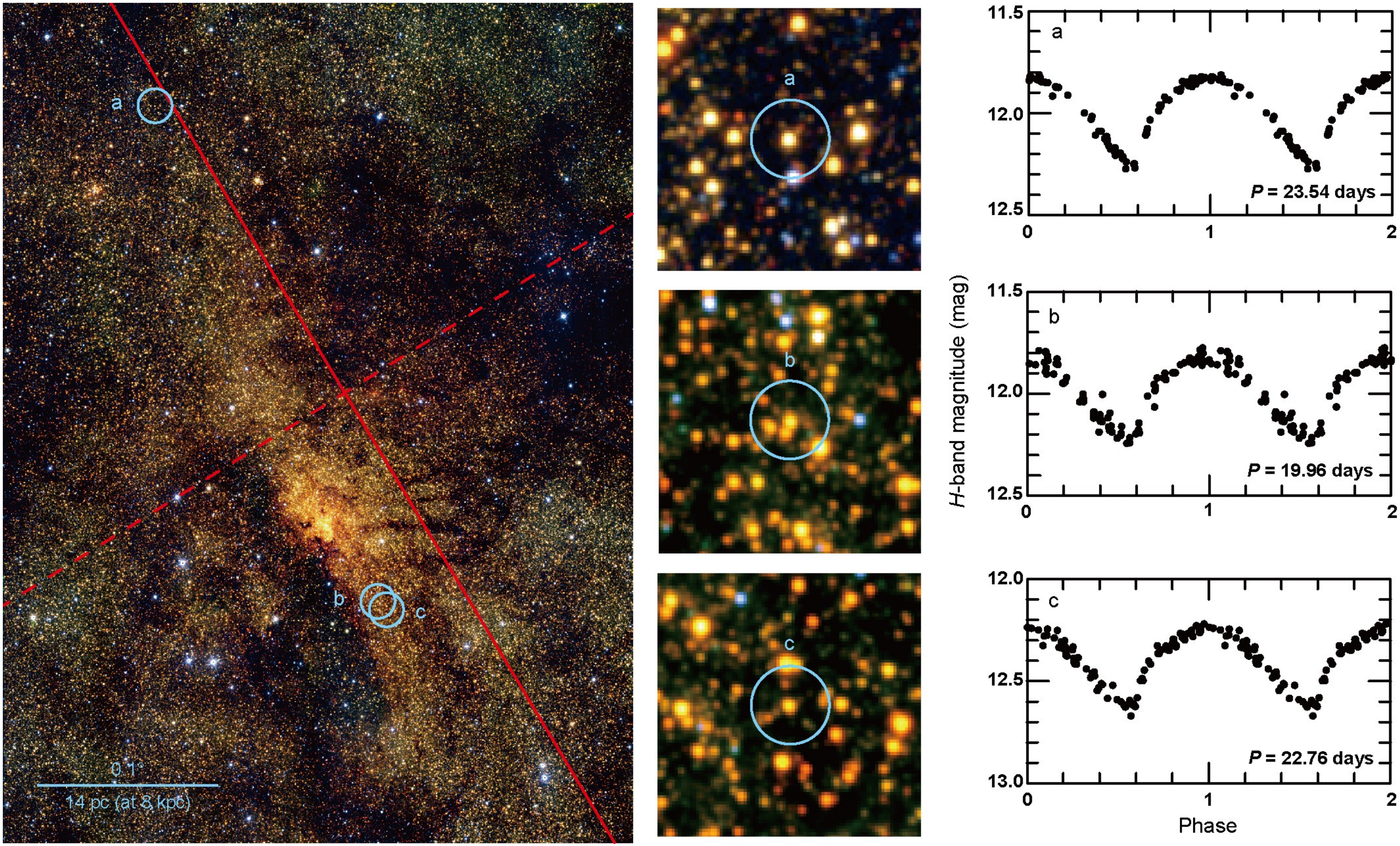


da Silva + (2015)

GOOD NEWS!!!

Er (85% r-) & Eu (95% r-) lines in the Y-band

Star clusters in the Galactic centre

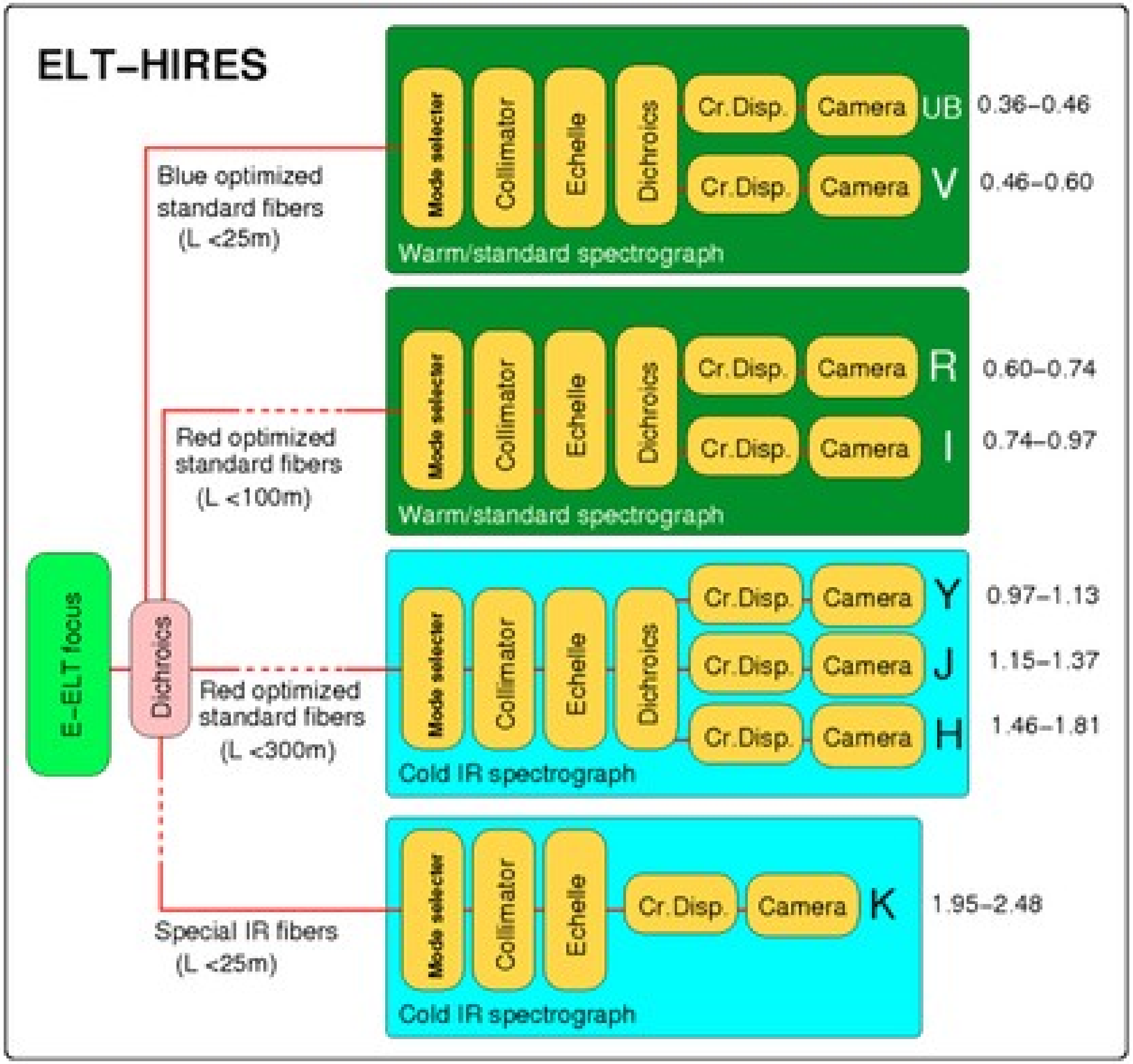


Ak ~ 3
Av ~30!!

Quintuplet, Arches
Nuclear star cluster

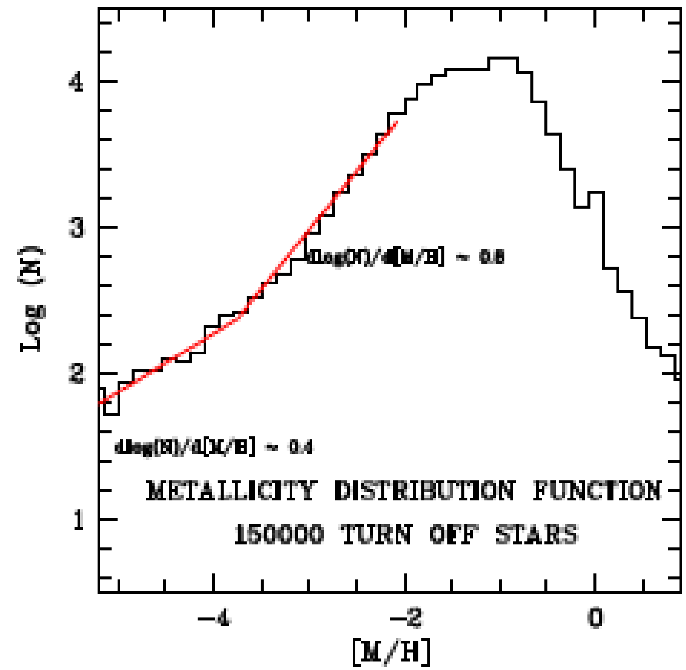
Matsunaga + (2011)

E-ELT: HIRES


ELT–HIRES
E–ELT focus
Dichroics
Blue optimized standard fibers (L <25m)
Red optimized standard fibers (L <100m)
Red optimized standard fibers (L <300m)
Special IR fibers (L <25m)
Mode selecter
Collimator
Echelle
Dichroics
Cr.Disp.
Camera
UB 0.36–0.46
V 0.46–0.60
Warm/standard spectrograph
R 0.60–0.74
I 0.74–0.97
Warm/standard spectrograph
Y 0.97–1.13
J 1.15–1.37
H 1.46–1.81
Cold IR spectrograph
K 1.95–2.48
Cold IR spectrograph

Metal-poor stars

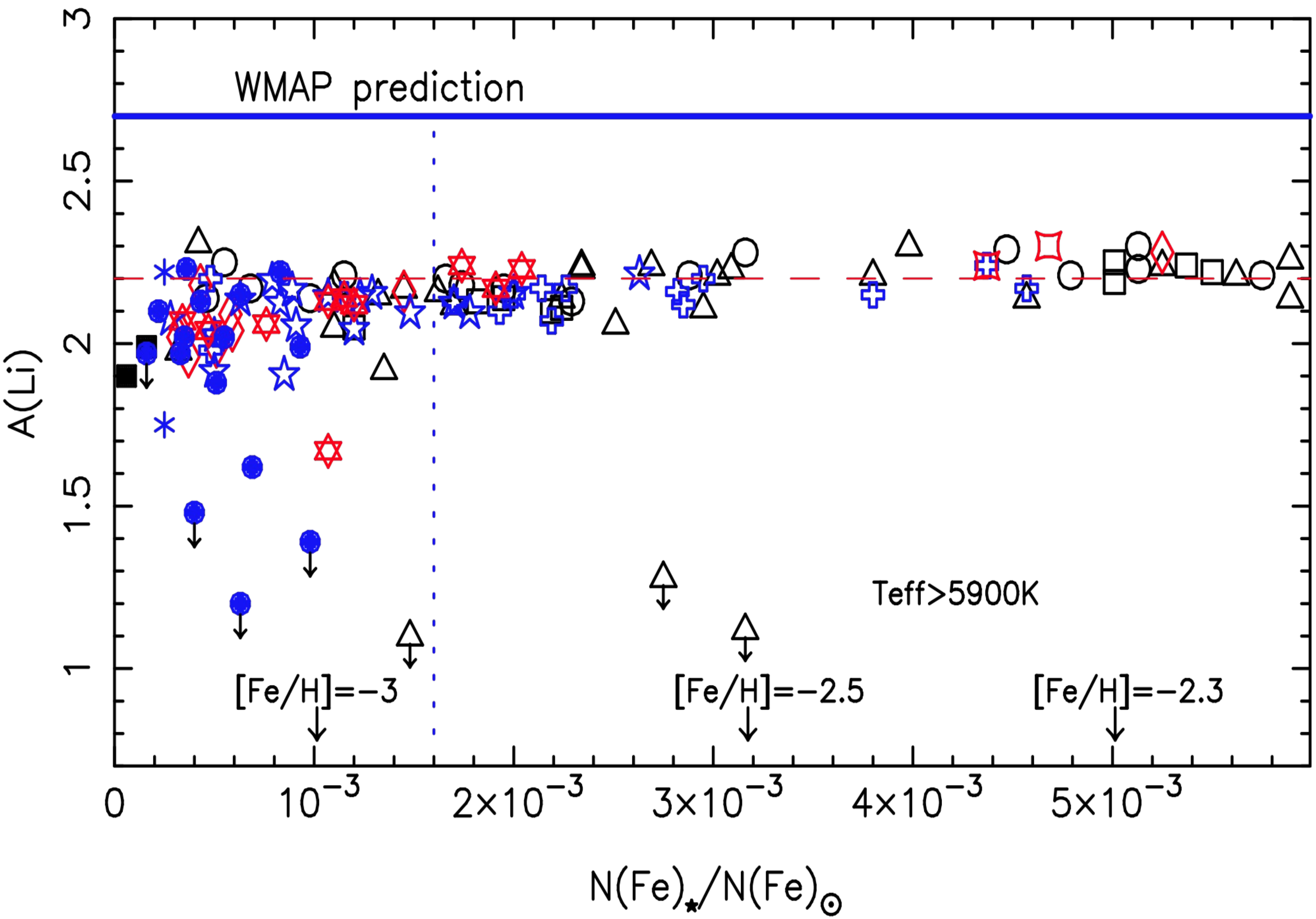
Why metal-poor stars?



- to determine the metal-weak tail of the Halo metallicity distribution function, below [M/H]=−3.5, where the low resolution is not sufficient
- to determine the relative abundance of the elements in the metal-poor stars, signature of the massive first stars
- to determine the trend of the lithium abundance in the matter of the primordial Universe
- to find the most metal-poor stars

Courtesy by E. Caffau, P. Bonifacio

Is the Spite plateau an universal relation?



Extremely MP Halo Stars

Five objects:
[Christlieb+2002; Frebel+2005; Norris+2007; Caffau+2011
Keller+2013 → **skymapper**

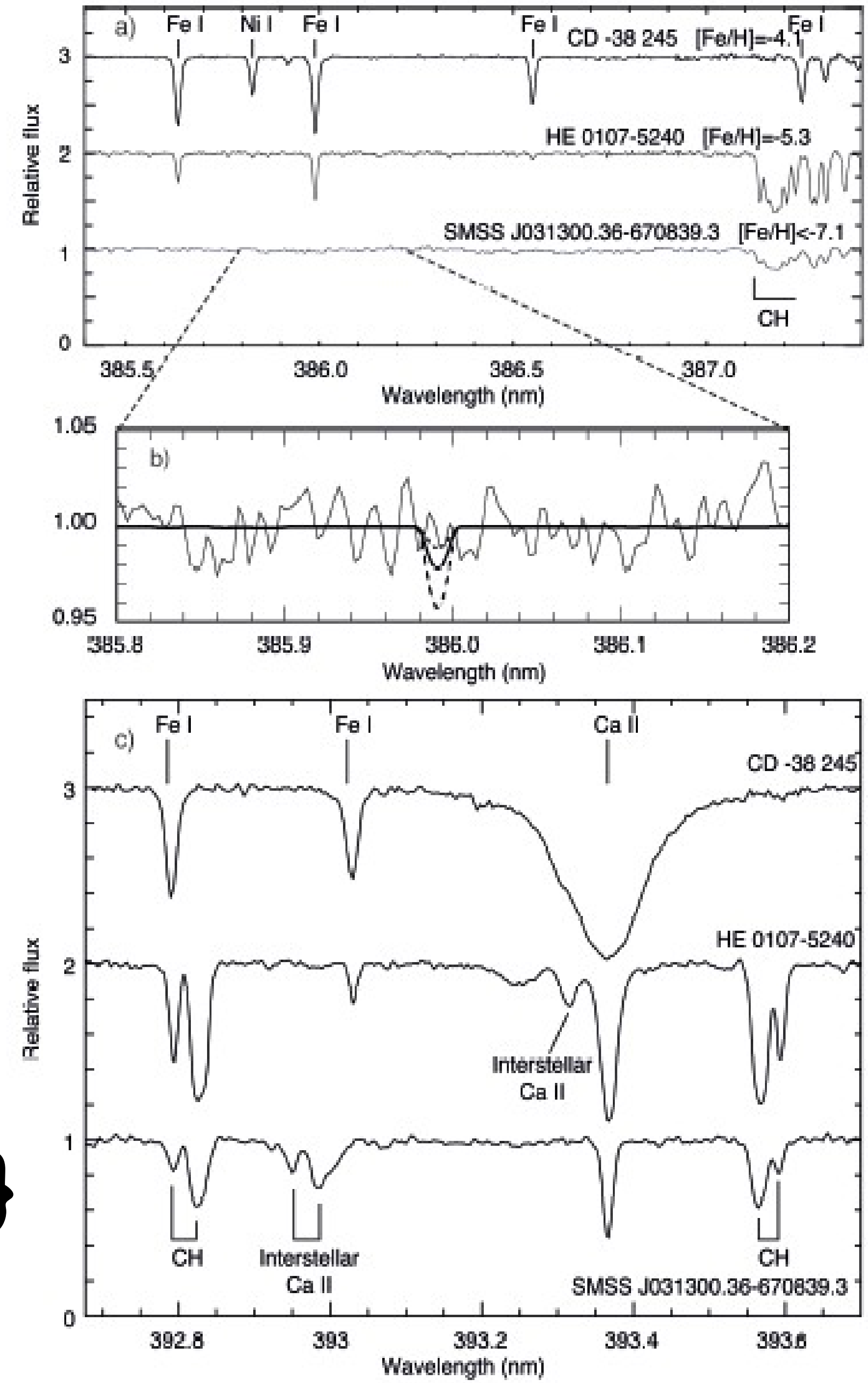
Carbon enhanced
Extremely Iron poor

A few & probably a single low-energy SN

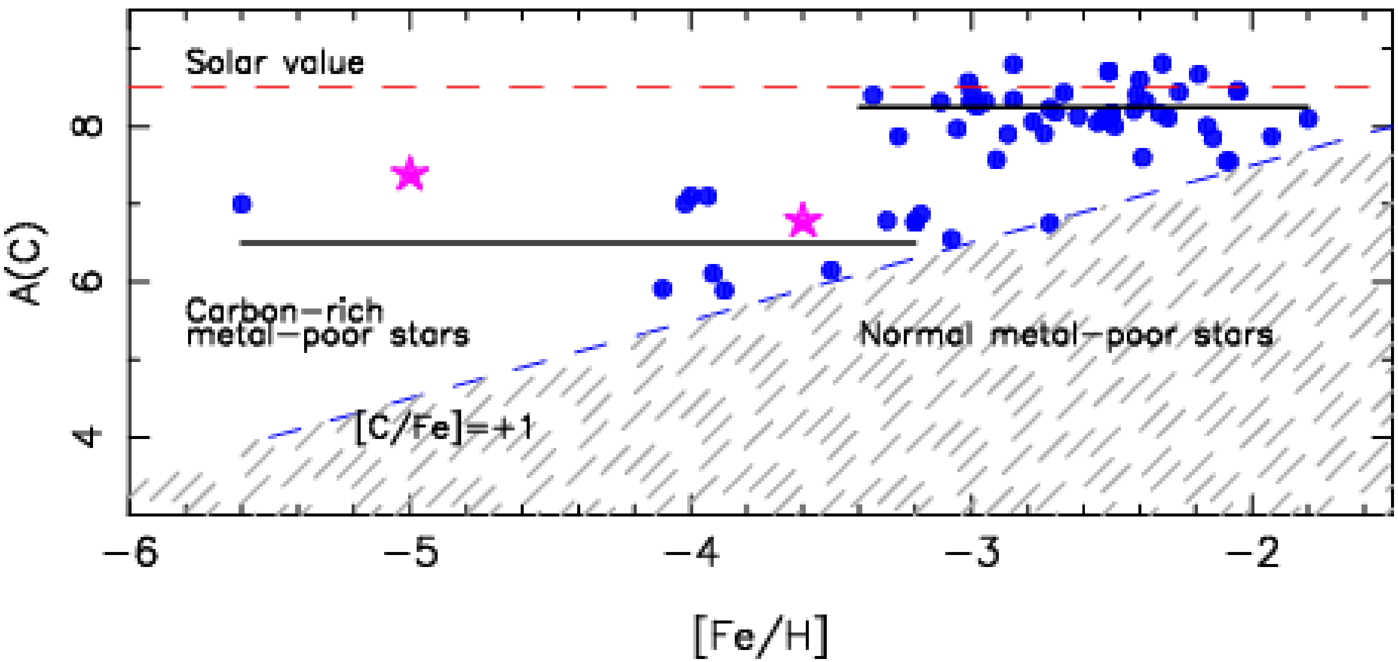
Extremely massive SN (pair-instability) should Rapidly increase Fe content

UPPER LIMIT 10^{-7.1}
3σ c.l.

SMSS J031300.36-670839.3



Carbon-enhanced M.P. stars



Only MSTO & dwarves

blue- dashed line → [C/Fe]=+1

Spite+ (2013)

Caffau+ (2013)
+
X-SHOOTER LP pending!

Identification of a few C enhanced & α-poor

SMSSJ031300.36→ A(C)~9~solar!!

Requirements for MOS@E-ELT in Optical seeing limited

Large FoV	> 7'x7'
High multiplex	> 100-200 fibers
Spatial res.	< 0.3—0.9 arcsec

Identification

(DA vs DO – He and/or C enhanced)

Low-res R~3,000

Limiting mag. V~23 mag

Abundances

High-res R~10,000—20,000

Limiting mag. V~21 mag

S/N~80--100 (30h)

Roadmap: detailed investigation of hot stars with low/medium resolution NIR spectra.

Requirements for MOS@E-ELT in the NIR AO assisted

Large FoV	> 7'x7'
High multiplex	> 20 → IFUs
Spatial res.	< 0.003—0.009 arcsec

Kinematics (+met. Ind.)

Low-res R~3,000—4000

Limiting mag. J,H~23--25 mag

S/N ~10-15 (50h)

Abundances

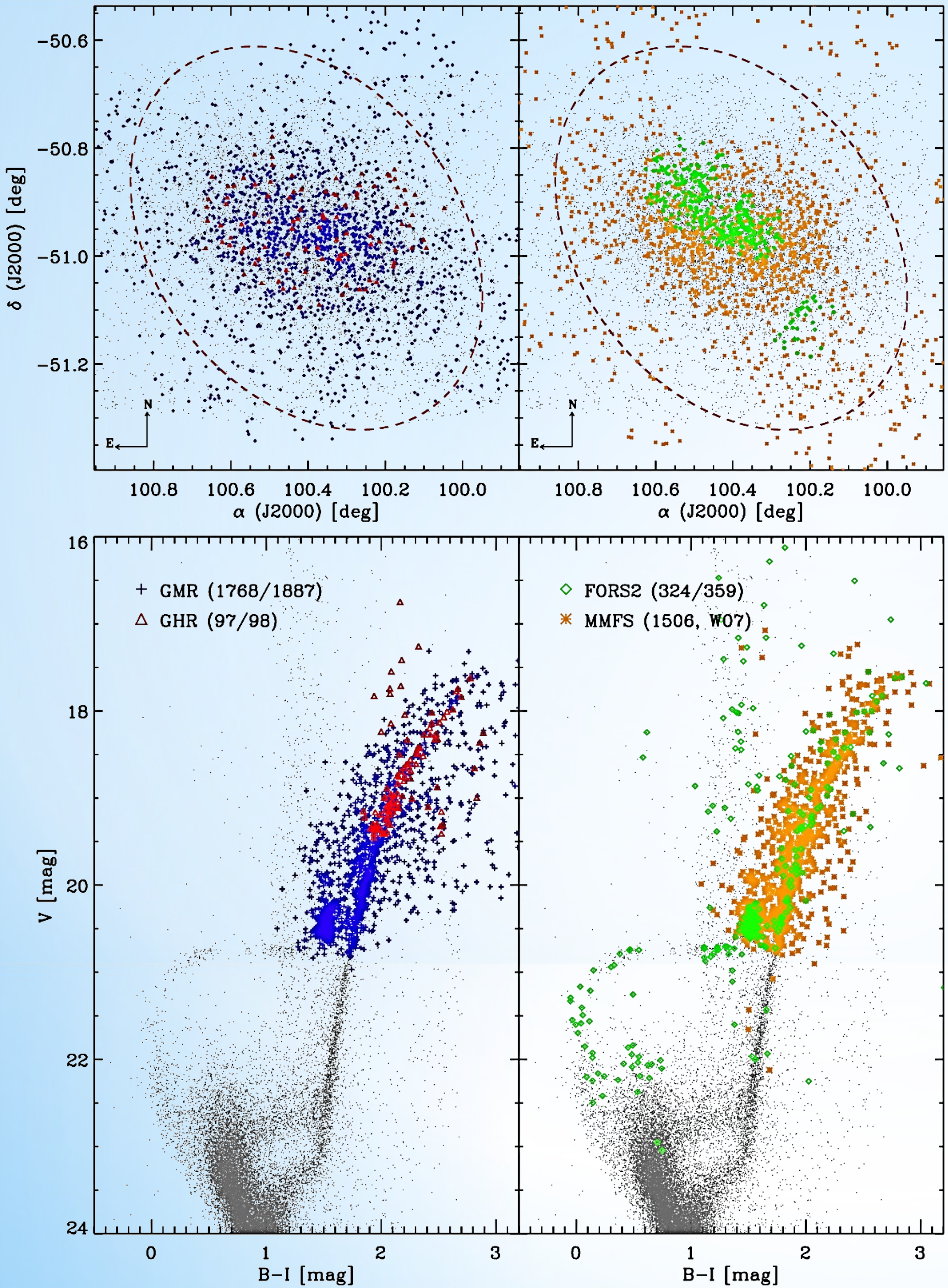
High-res R~10,000—20,000

Limiting mag. J,H~21--23 mag

S/N~60-80 (30h)

Simultaneous medium and high-resolution

INTEGRAL FIELD SPECTROSCOPY – PSF fitting spectra extraction at the confusion limit (Bastian lectures)



We collected more than 1370 RV measurements of Carina peak stars.

The spectroscopic dataset covers the entire body of Carina and beyond the tidal radius (up to ~1 deg)

Lack of a pure OLD tracer

Age-metallicity degeneracy ONLY along bright RGB!!!

Fabrizio et al. 2011

Tolstoy + 2009; Venn + 2012

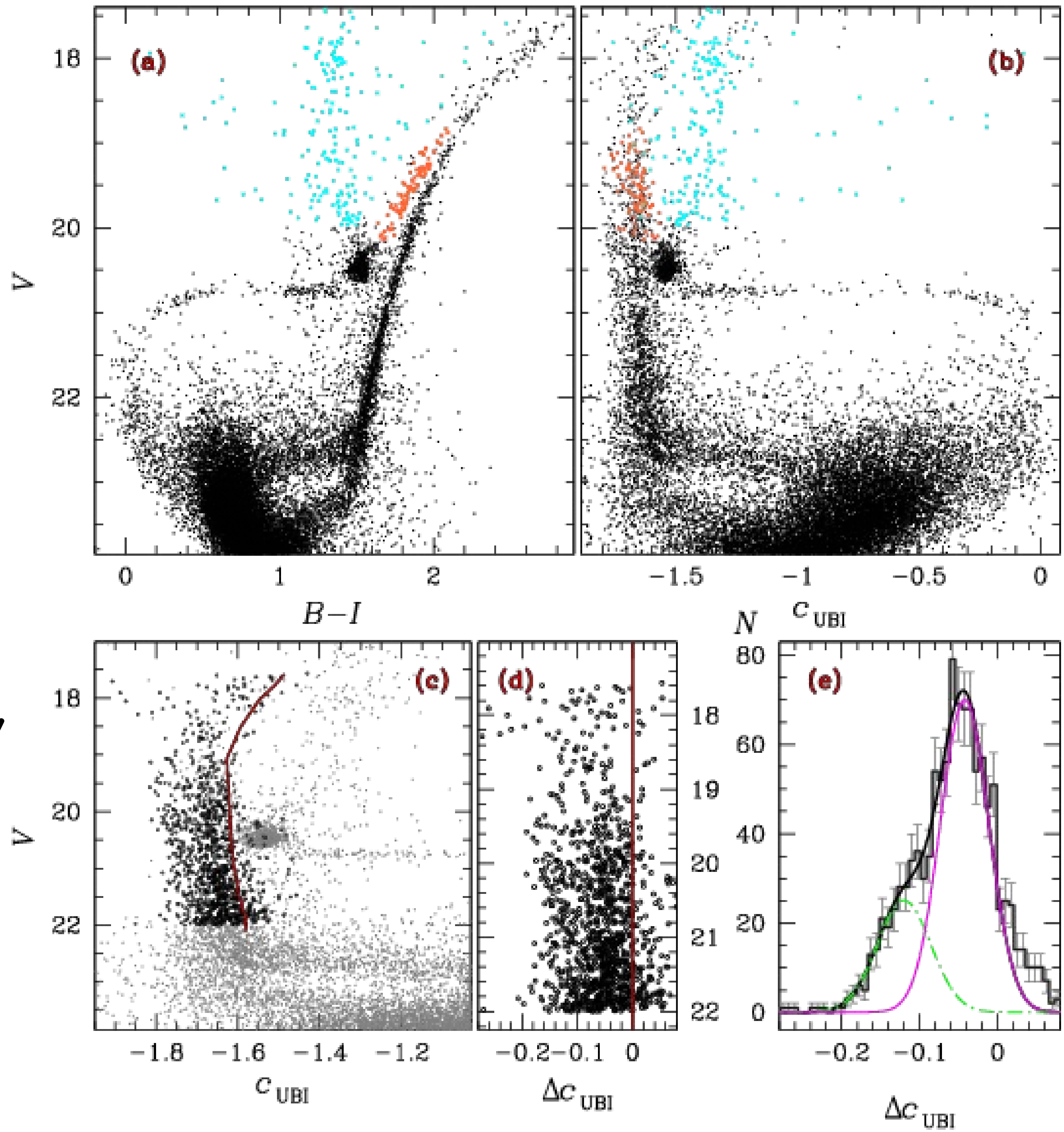
A new spin on dSphs: Carina

C_UBI=(U-B)-(B-I)

A clear separation between old & intermediate-age along the RGB

The age-metallicity Degeneracy fixed!!

Monelli + (2014)

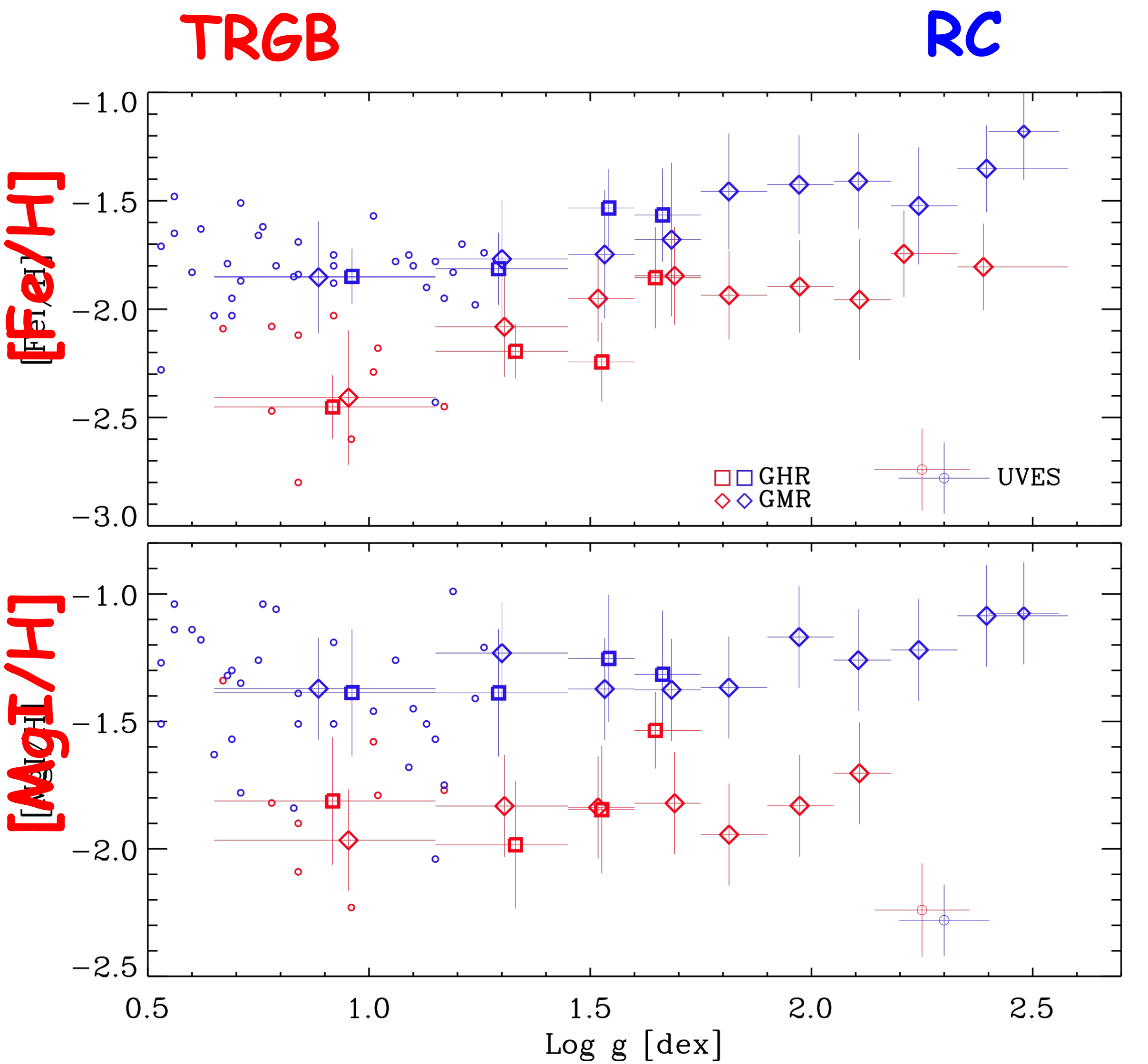


Carina dSph: metallicity distribution
Old & intermadiate-age stars

[Fe/H]
μ(int) =-1.74±0.38±0.20

μ(old)=-2.13±0.06±0.28

They differ 75% c.l.

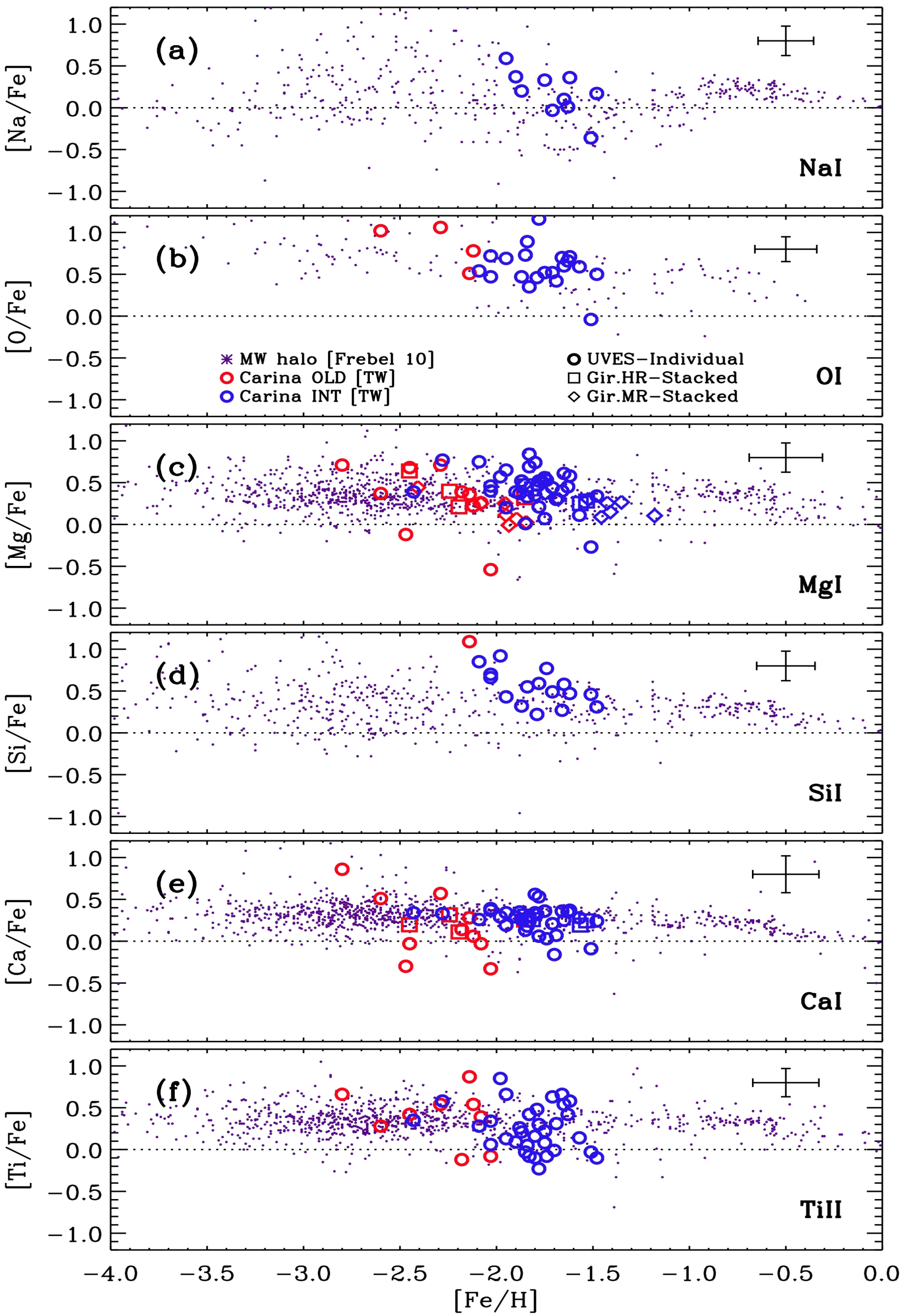


[Mg/H]
μ(int) =-1.37±0.04±0.27

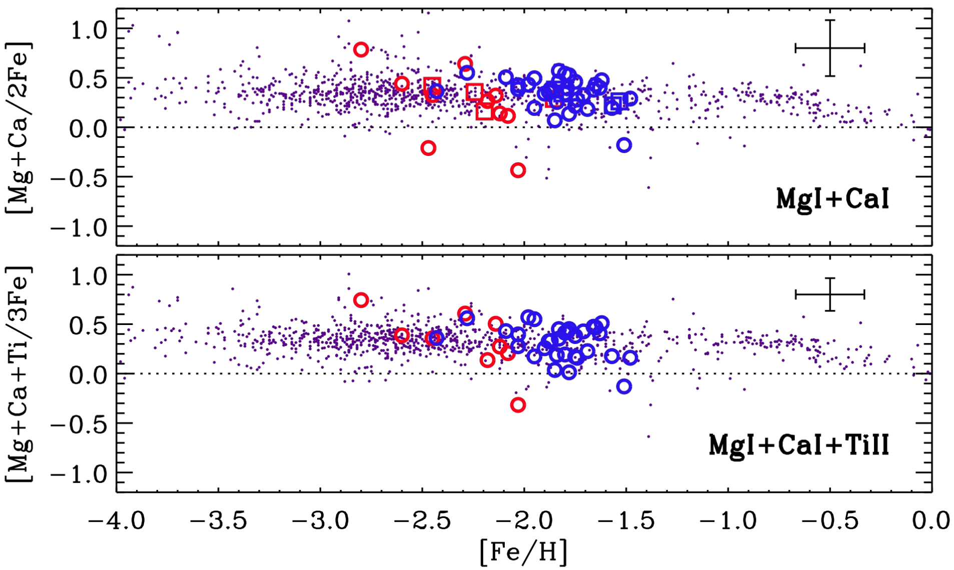
μ(old)=-1.77±0.08±0.36

They differ 83% c.l.

Carina dSph: comparison with MW field stars



Frebel + 2010



No difference, within errors, between Carina and field stars and UFDs

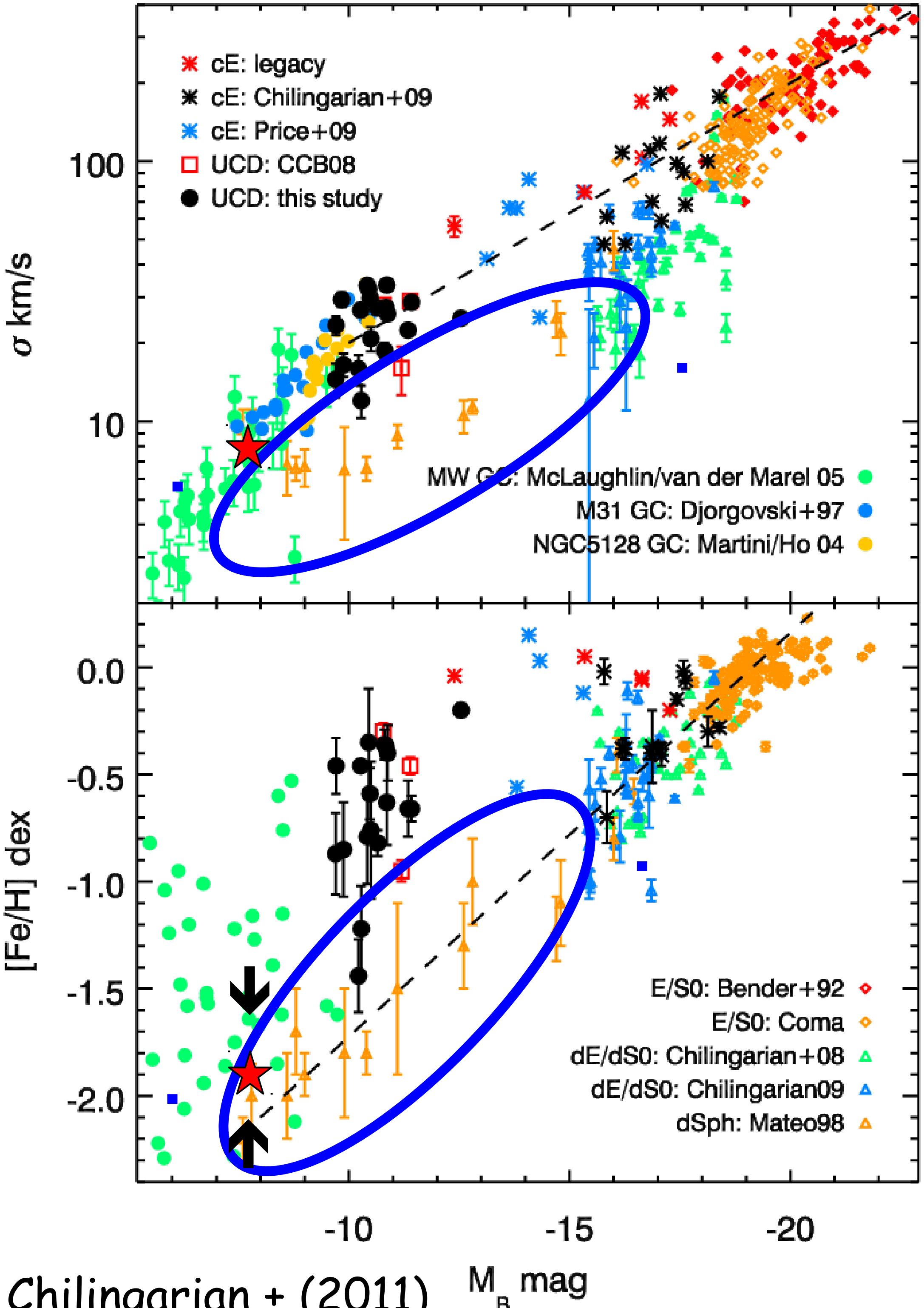
Fabrizio + (2015)

Our possible precursos!!

Science & Technology …

Archimede's Globe

Plato's Accademy, Mosaic T. Siminio's house
I cen. AD by Pompei, Archeol. Museum Naples



Chilingarian + (2011)

Dichotomy in the Faber-Jackson relation
$L \approx \sigma^4$

dSphs follow the metallicity-luminosity relations

Are these relations age invariant?

Age is becoming more popular ...

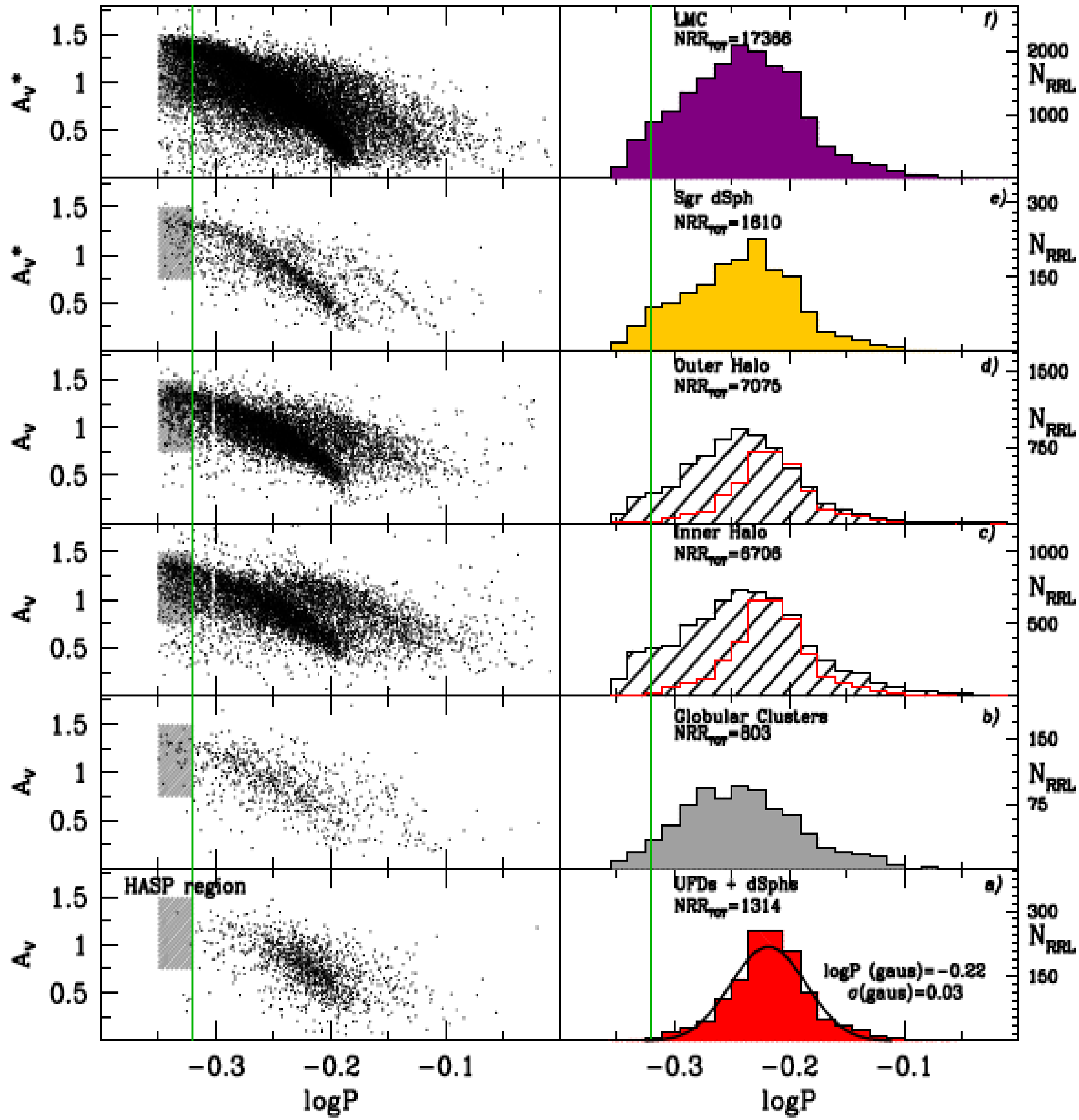
BUT NO RGB!!!! asteroseismology

RR Lyrae as tracers of the Halo

Building blocks:

globulars vs dwarves

accreted vs in situ!



Need for very accurate metallicity Gradients!!!

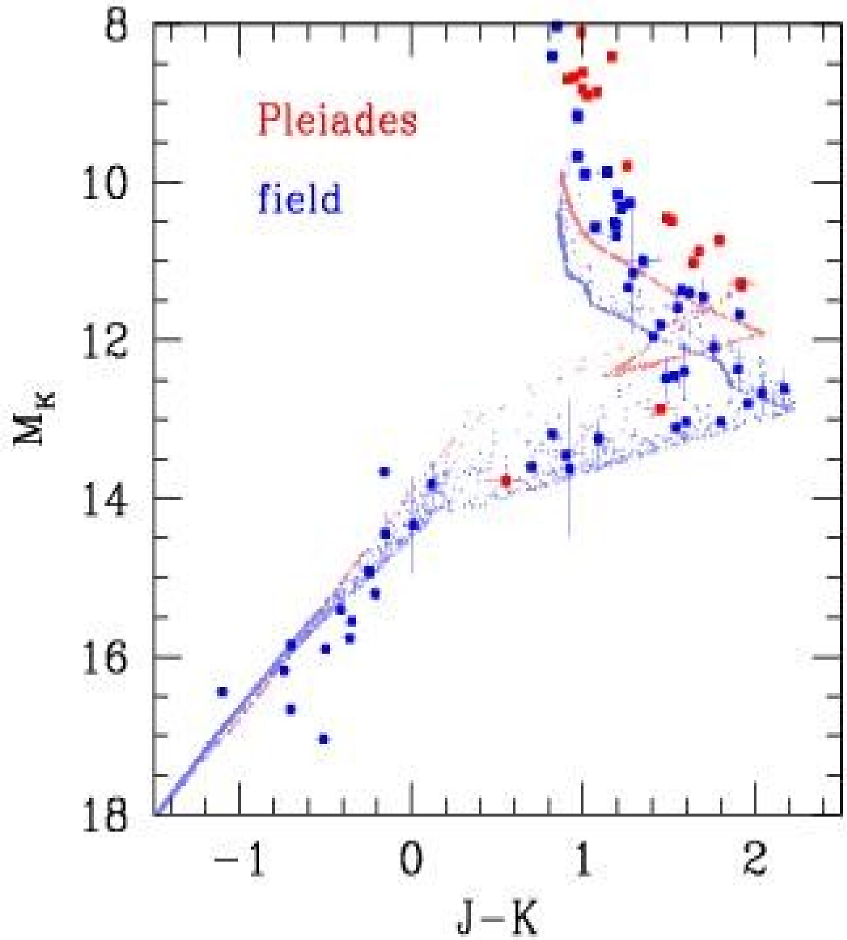
Fiorentino et al. (2014) + Vittorio's talk & Giuliana's lecture

Extrasolar planets

A different path ….

Approaching H-burning limit & beyond Transition between VLMS & BDs

MS-Knee → Mk~5.5



Saumon et al. (2008) +
France's lectures

Transition from late-M to L-type

Diatomic metal species (TiO, VO, FeH) incorporated in grains

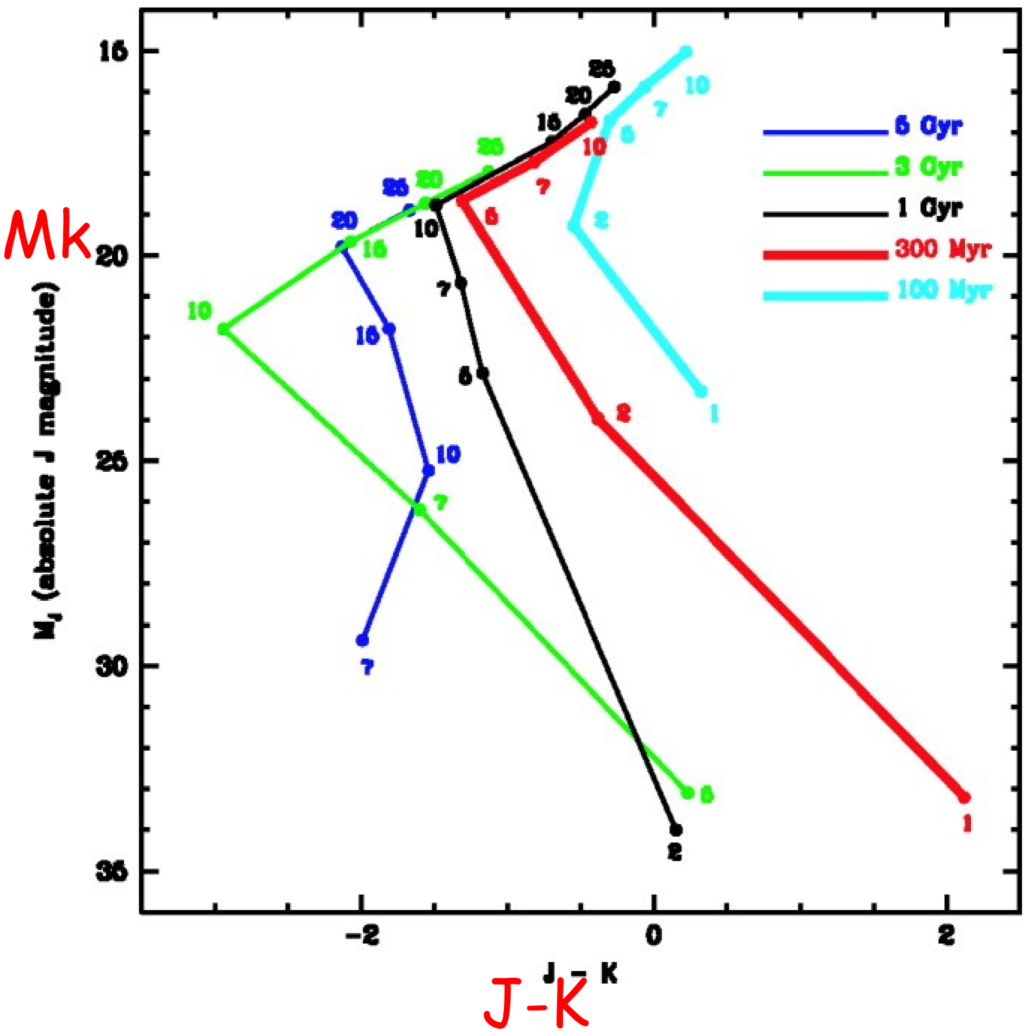
Formation of Fe & Si grains produce optically thick clouds that veil gaseous absorption bands →
L-type Redder NIR colors 1.5k-2.0k K

At lower Teff the clouds start to sink and CH4 supplant CO as the dominat C-bearing molecule →
T-type Bluer NIR colors (Te~1.0k K)

For types later than T5 CIA by H2 enhances bluer NIR colors

Transition between BDs & Free Floating Giant Planets

Late T-type → Mk~16



For Teff ~600K the NH3 join Water and CH4 absorption

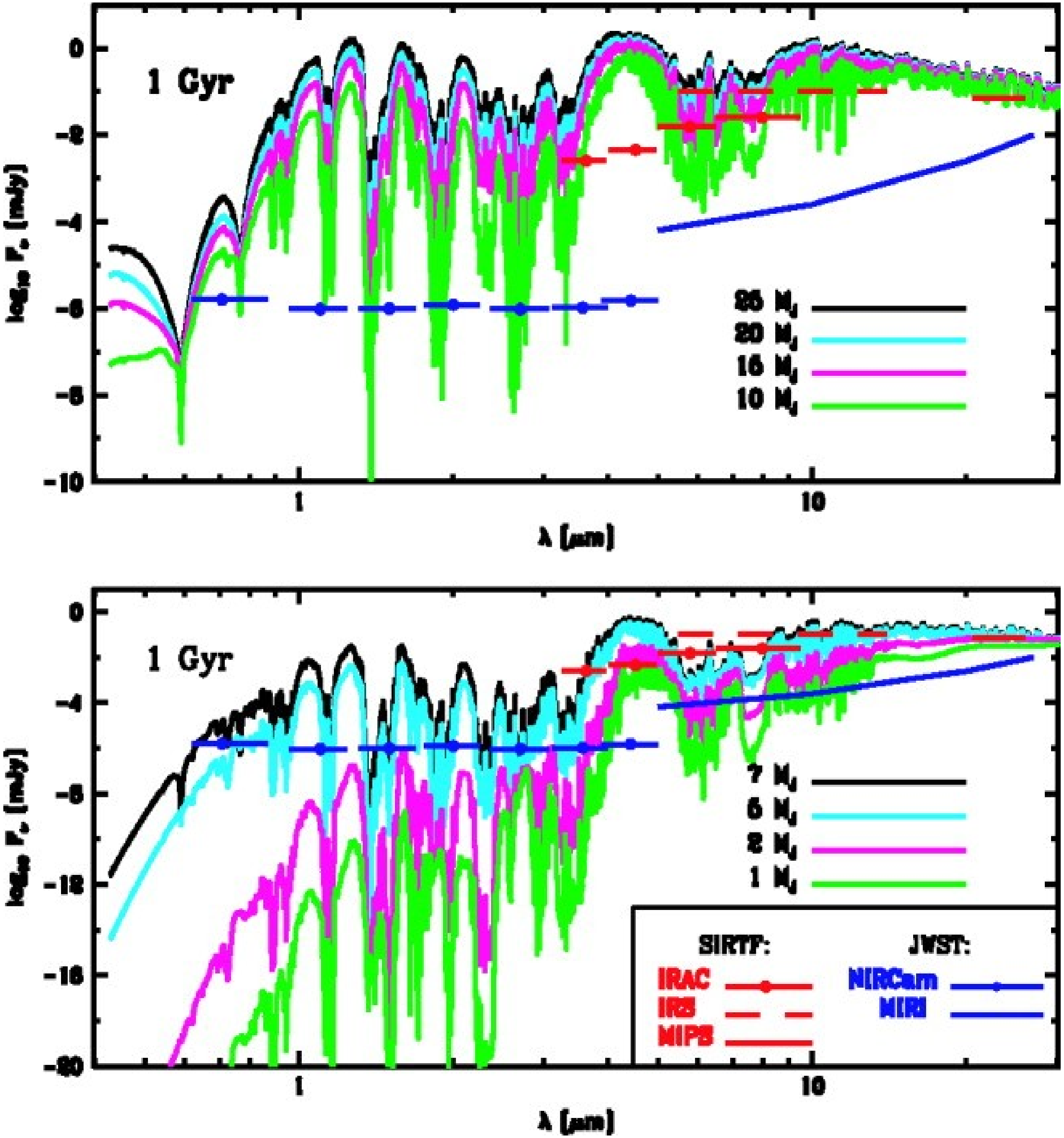
N2 vertical mixing the NIR Flux COLLAPSE →
Y spectral type!!

For ages older than 1 Gyr the Decrease is 10-15 mag!!!

NIRCAM@JWST & E-ELT CAM Will constrain the change in the IMF in the transition
VLMs-BDs-GPs

Burrows et al. (2003)

MICADO + METIS



Spectroscopy in the MIR region

HR spectroscopy in L, M bands

Line list of NH3 and N2 are incomplete in NIR!

Two crucial numbers

21—26 Spectroscopy → HR / MR / LR

RSG,AGB,TRGB, [RC] → Cen A → μ~27.5

RSG,AGB,[TRGB] → Virgo → μ~29.5

29—31 Photometry → NIR [0.9—2.3μm]

TRGB, RC, HB, MSTO → Cen A → μ~27.5

TRGB, RC, HB → Virgo → μ~29.5

Global growth

LETTER

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A higher-than-predicted measurement of iron opacity at solar interior temperatures

J. E. Bailey[1], T. Nagayama[1], G. P. Loisel[1], G. A. Rochau[1], C. Blancard[2], J. Colgan[3], Ph. Cosse[2], G. Faussurier[2], C. J. Fontes[3], F. Gilleron[2], I. Golovkin[4], S. B. Hansen[1], C. A. Iglesias[5], D. P. Kilcrease[3], J. J. MacFarlane[4], R. C. Mancini[6], S. N. Nahar[7], C. Orban[7], J.-C. Pain[2], A. K. Pradhan[7], M. Sherrill[3] & B. G. Wilson[5]

Here we report measurements of iron opacity at electron temperatures of 1.9–2.3 million kelvin and electron densities of (0.7–4.0)10^22 per cubic cm, conditions very similar to those in the solar region at radiation/convection boundary.

The measured opacity is 30–400% higher than predicted.

This represents roughly half the change in the mean opacity needed to resolve the solar discrepancy …..

Cocnclusions I

The 8-10m class telescopes are paving the road for ELTs:

Relevant impact on

seeing limited (GLAO):
optical spectroscopy (HARMONI, HIRES, MOSAIC)

Adaptive optics (SCAO, MCAO, MOAO):
Imaging: MICADO
Spectroscopy: HARMONI, HIRES, MOSAIC, METIS

The transitions to ELTs is not trivial at all ….

A new spin on theoretical modeling: atmospheres (nir lines), envelopes, interiors

Opening new approaches to handle data from IFS & NIR images

Conclusions II

We are facing a substantial change in the approach for doing astrophysics:

User Oriented → Experiment Oriented

I suspect that we are lagging in this paradigm change

Personal approach to learn …

Books & papers

Give a course

Organize a School!!!

Tomorrow the outlook may change and new methods may dwarf Our knowledge and beliefs of today, or convert them into remote history.

We, or our successors, may actually know familiarly the farthest borders of this vast Universe and learn facts about it so astounding that astronomers of today would be nearly unable to comprehend their significance.

E. Hubble 1927

"Le temps vous appartient"