The timescale of SNe Ia in LG Dwarf Galaxies from the α-element knee

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Star formation & chemical evolution of LG dwarfs

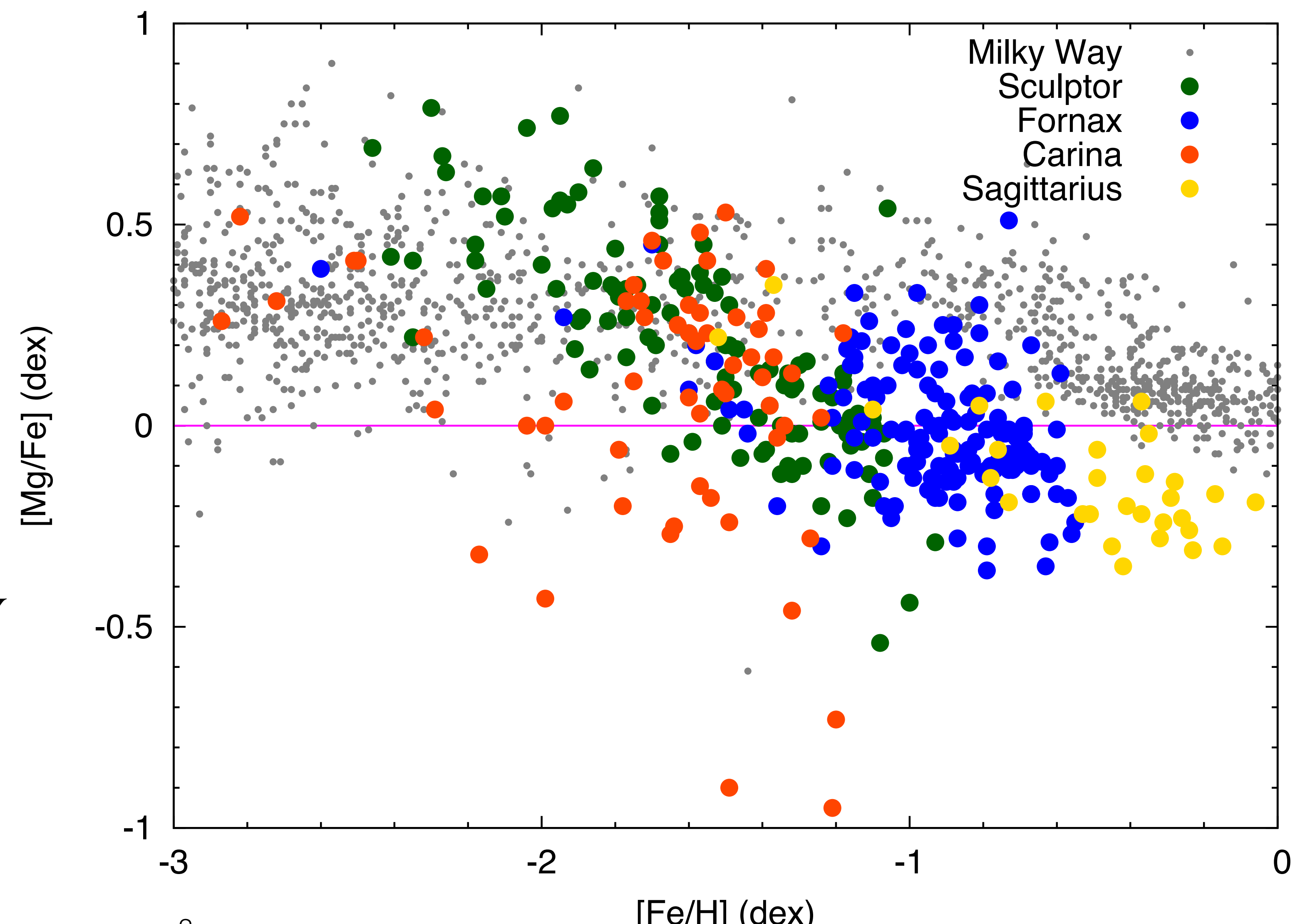
LG dwarfs can be studied in remarkable detail (deep CMDs, kinematics, abundances)

Study evolution history of LG dwarf galaxies as function of age, metallicity, radius...

Stellar population variations
-> radial changes?

Determine accurate SFH
-> including MDF fitting

Evolution of elements directly as a function of age
-> individual age estimates



Local Group sample

Three LG dSph galaxies with very different properties
does galaxy evolution proceed the same in all?

Sculptor:
-> dominated by old (>10 Gyr) stars
-> clear view of ancient processes

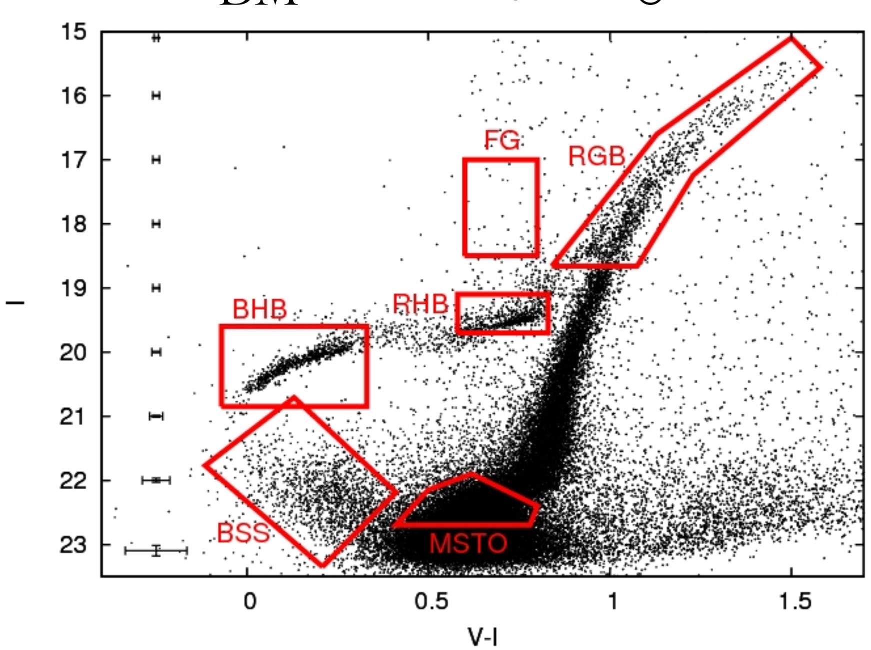
M_V= -11.1
M_{DM}= $1.4 \times 10^7\ M_\odot$

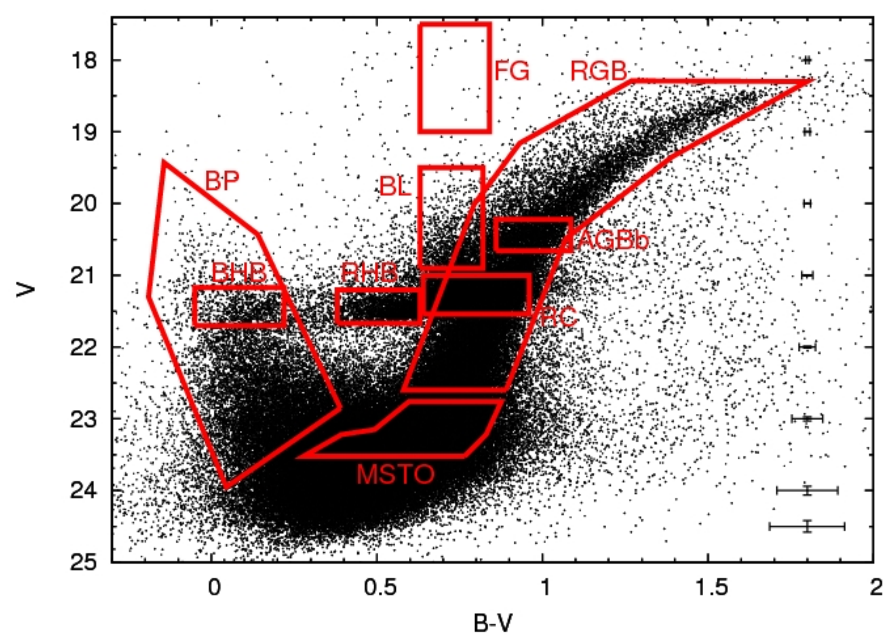
Fornax:
-> strong intermediate age population
-> study stellar evolution over time

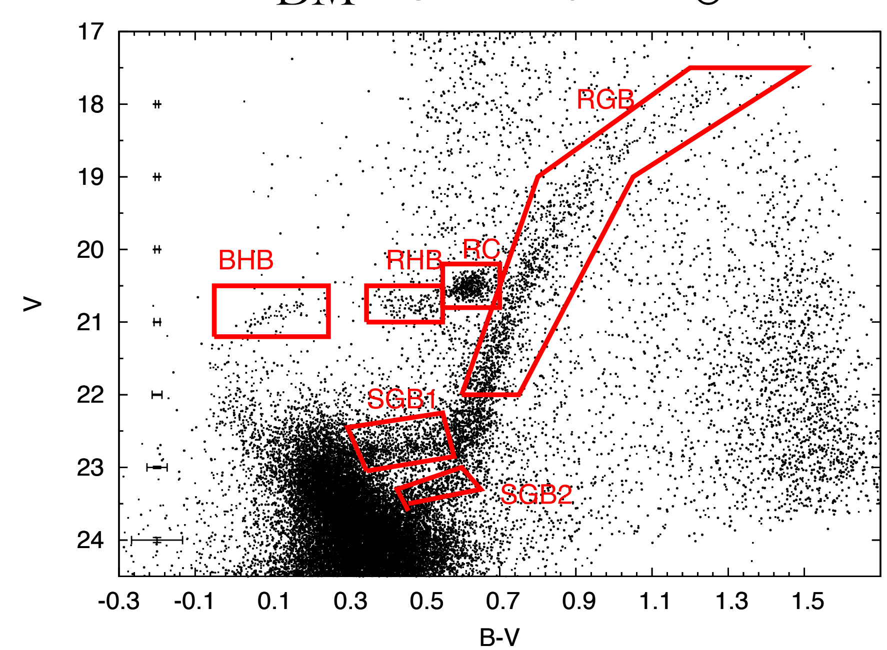
M_V= -13.4
M_{DM}= $5.6 \times 10^7\ M_\odot$

Carina:
-> clearly episodic star formation
-> study effect of episodes on evolution

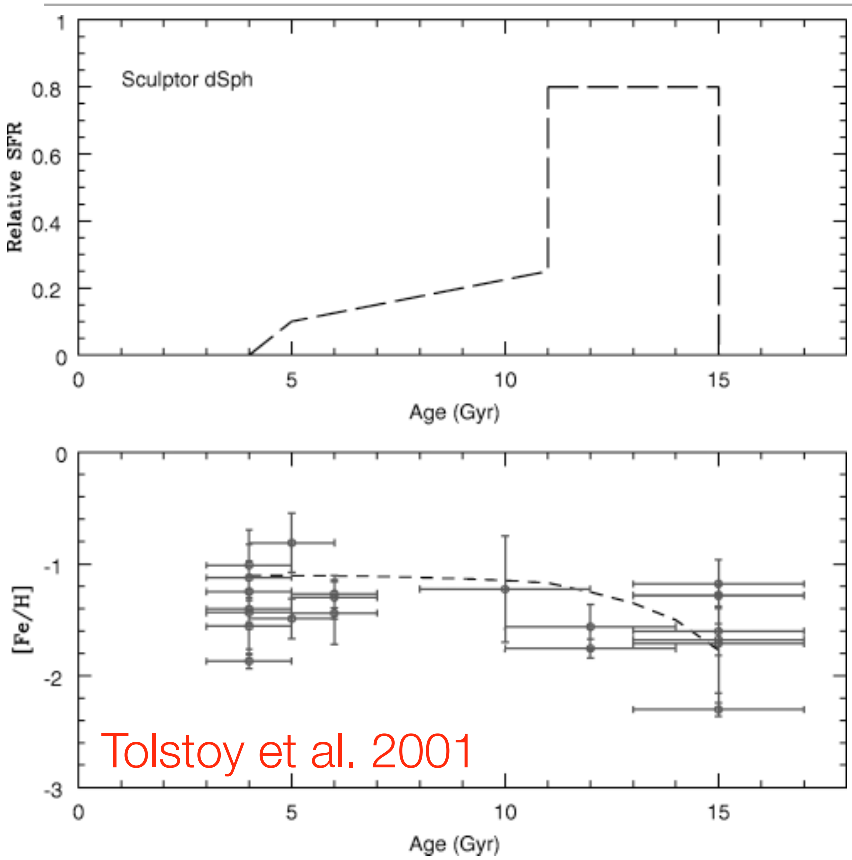
M_V= -9.1
M_{DM}= $3.4 \times 10^6\ M_\odot$





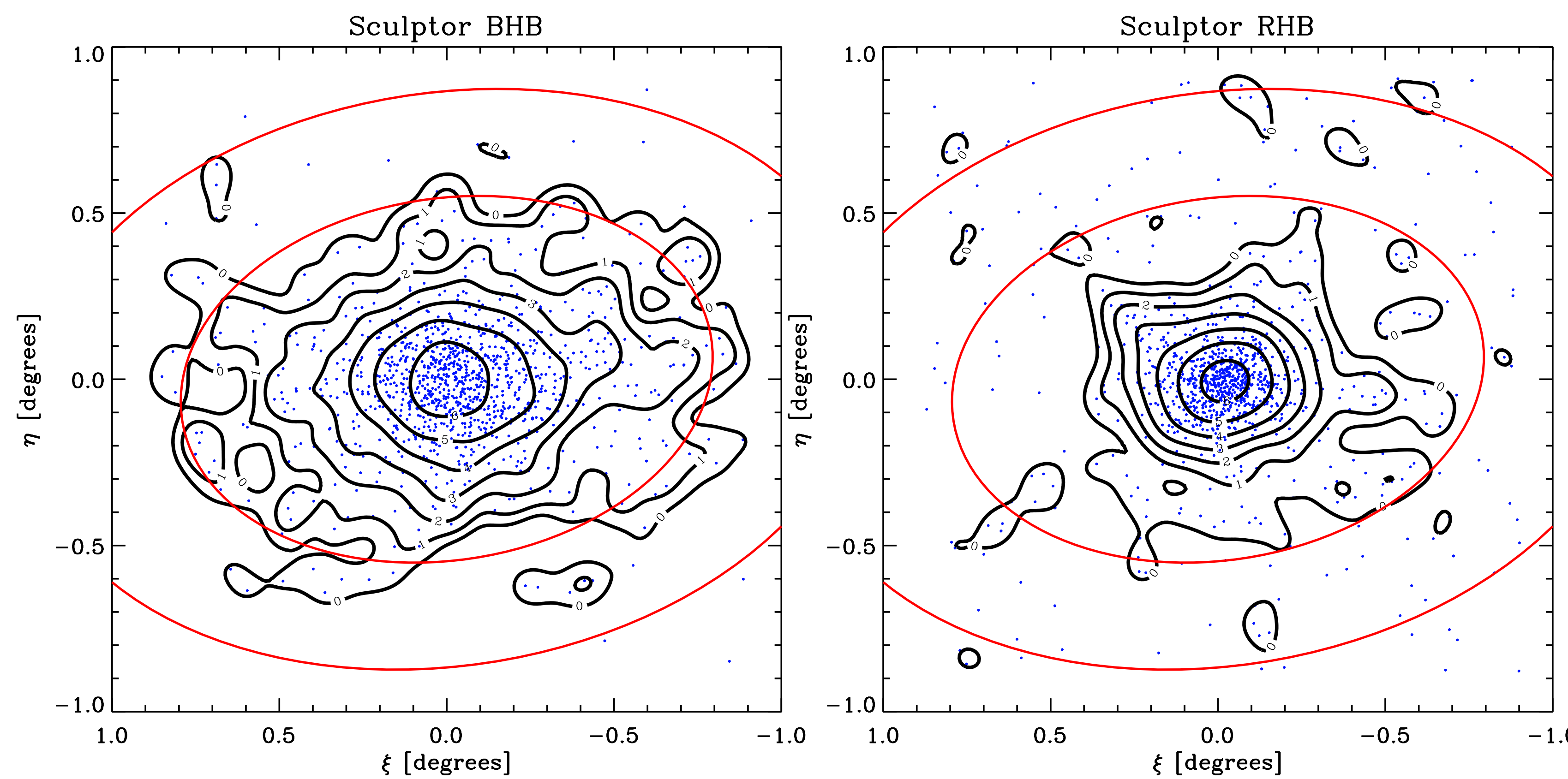


Sculptor: old populations



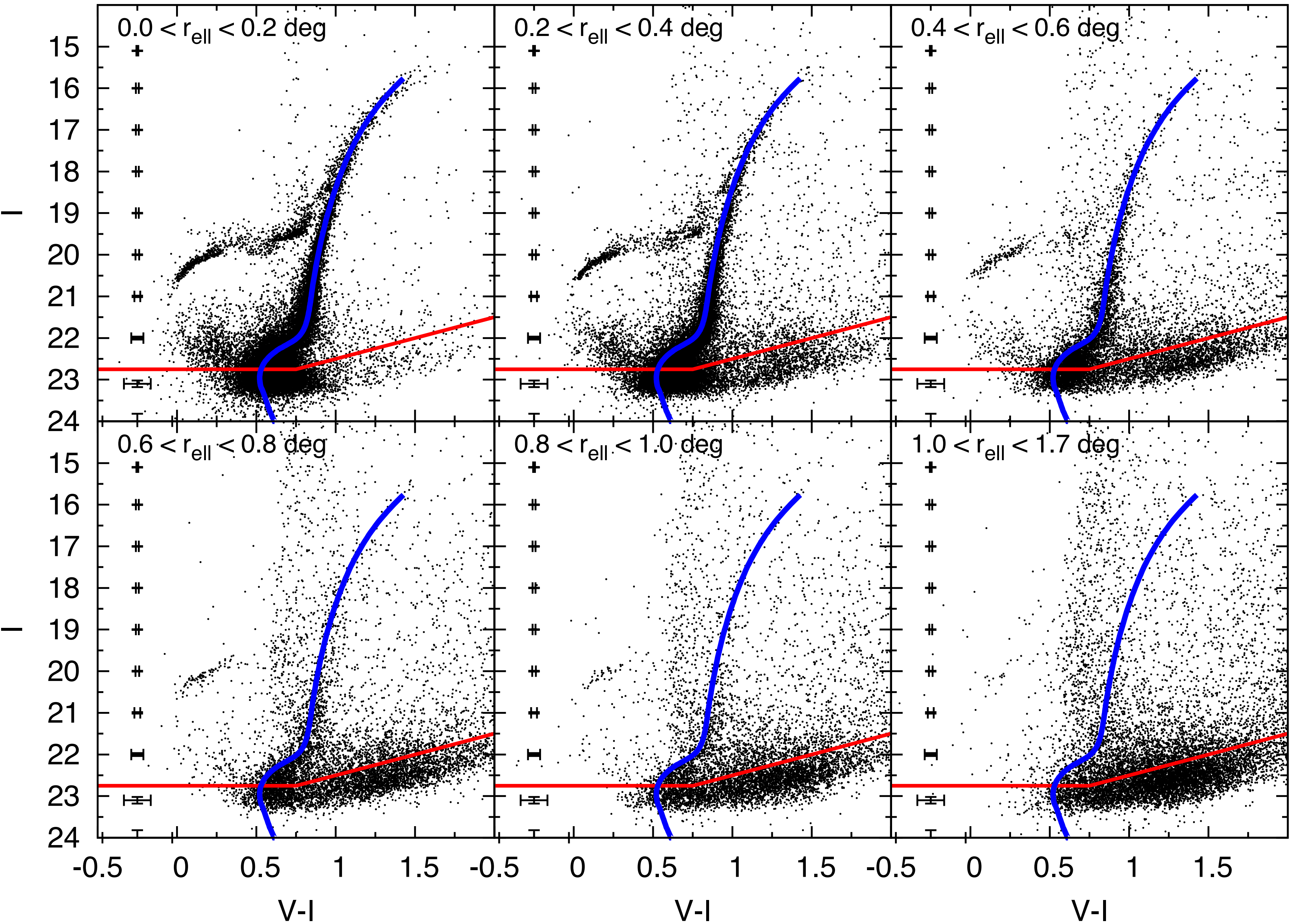
Early deep CMDs: (Hurley-Keller et al. '99)
small Field-of-View, mostly centre only
-> dominated by old stars (>10 Gyr)
-> but extended SFH

Early wide-field CMDs: (Majewski et al. '99, Tolstoy et al. 2004)
shallow CMDs, probing RGB/HB only
-> different radial distributions of RHB/BHB
-> different central concentration of populations



To study full age/metallicity behaviour:
-> need deep photometry covering large area to study spatial distribution of all evolutionary features!

Stellar populations: CMD



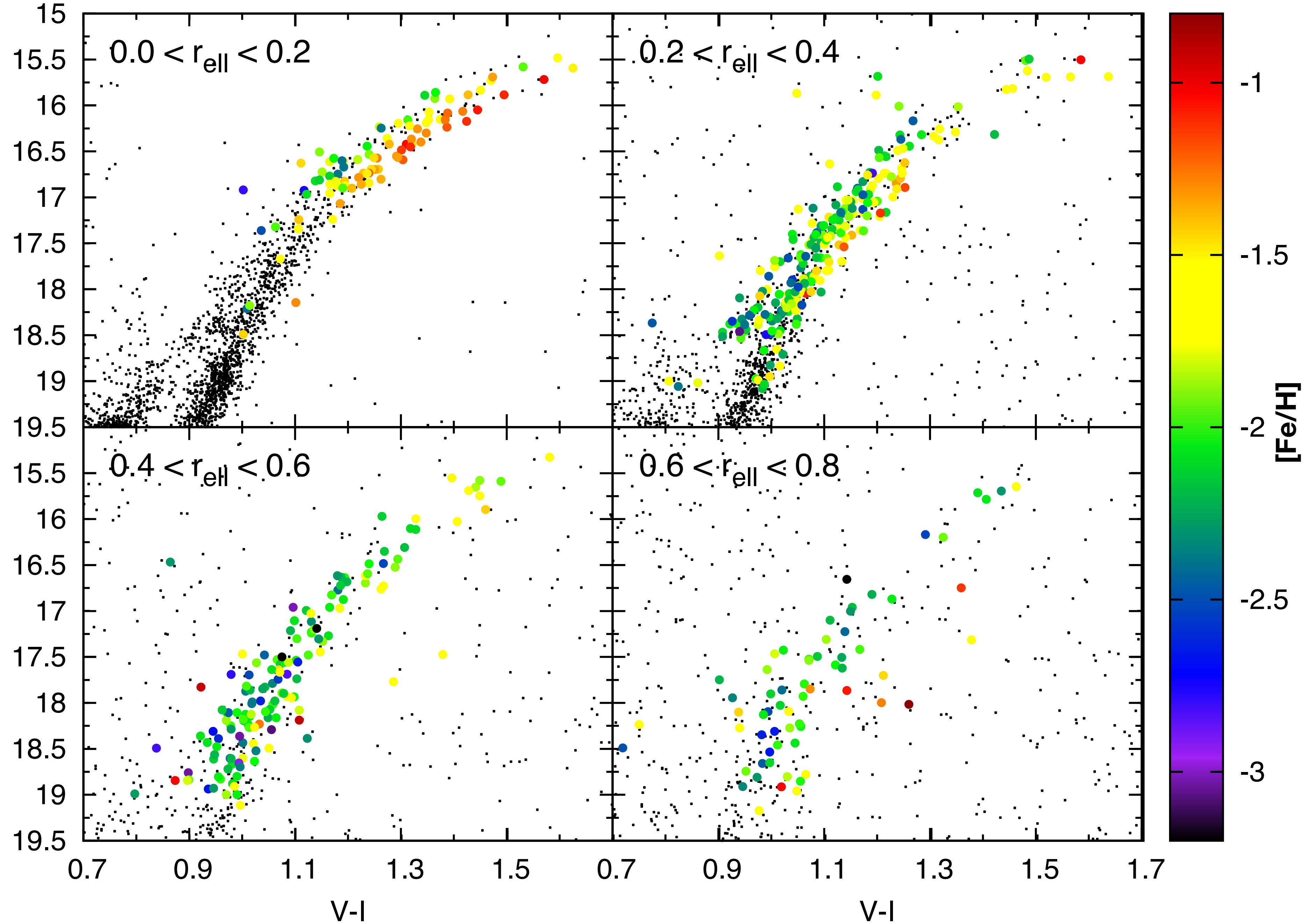
de Boer et al., 2011, A&A, 528, A119

Wide-field imaging on CTIO/MOSAIC
->covering ≈80% of tidal radius down to oldest MSTO

no clear young turn-offs
-> mainly old stars

Shape of CMD changes
-> BHB (metal-poor) at all radii, RHB (metal-rich) in inner part
->changes in RGB and MS width with radius

Stellar populations: spectroscopic [Fe/H]



Spectroscopic [Fe/H] of ~600 stars (Battaglia et al. 2008)

Clear mapping of [Fe/H] across RGB

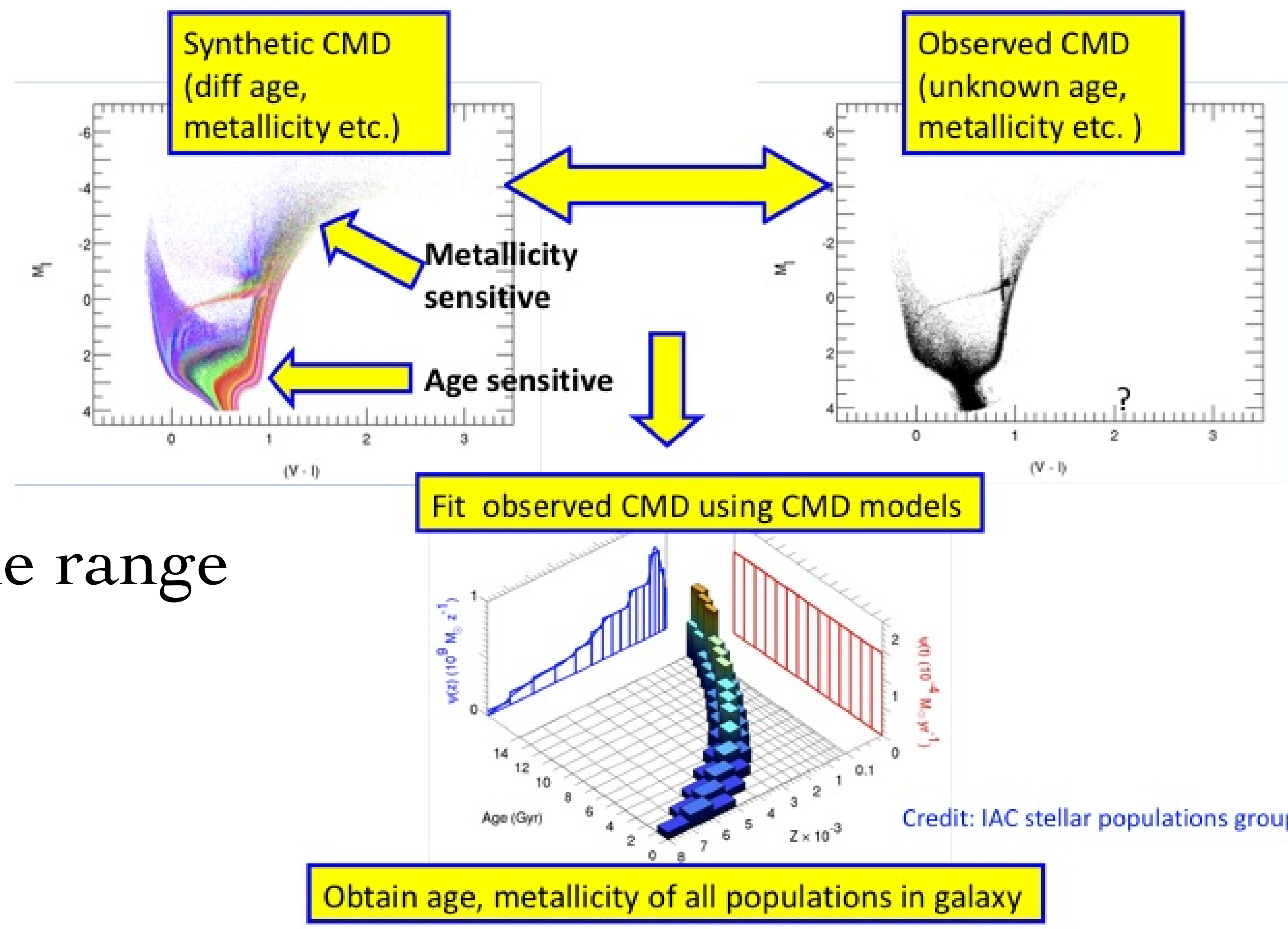
More metal-rich components disappear for larger radii -> radial metallicity gradient

Consistent with changing HB morphology

Combining all pieces: the SFH

Combine photometry and spectroscopy directly to constrain ages

Construct synthetic CMD’s
-> arbitrary age, [Fe/H], [α/Fe]
-> different isochrone sets
-> artificial star tests (millions of stars)



Construct synthetic MDFs
-> extract stars with similar magnitude range
-> bin in [Fe/H]
-> convolve with Gaussian

SFH using MSTO photometry (age sensitive) and RGB MDF (direct metallicity)

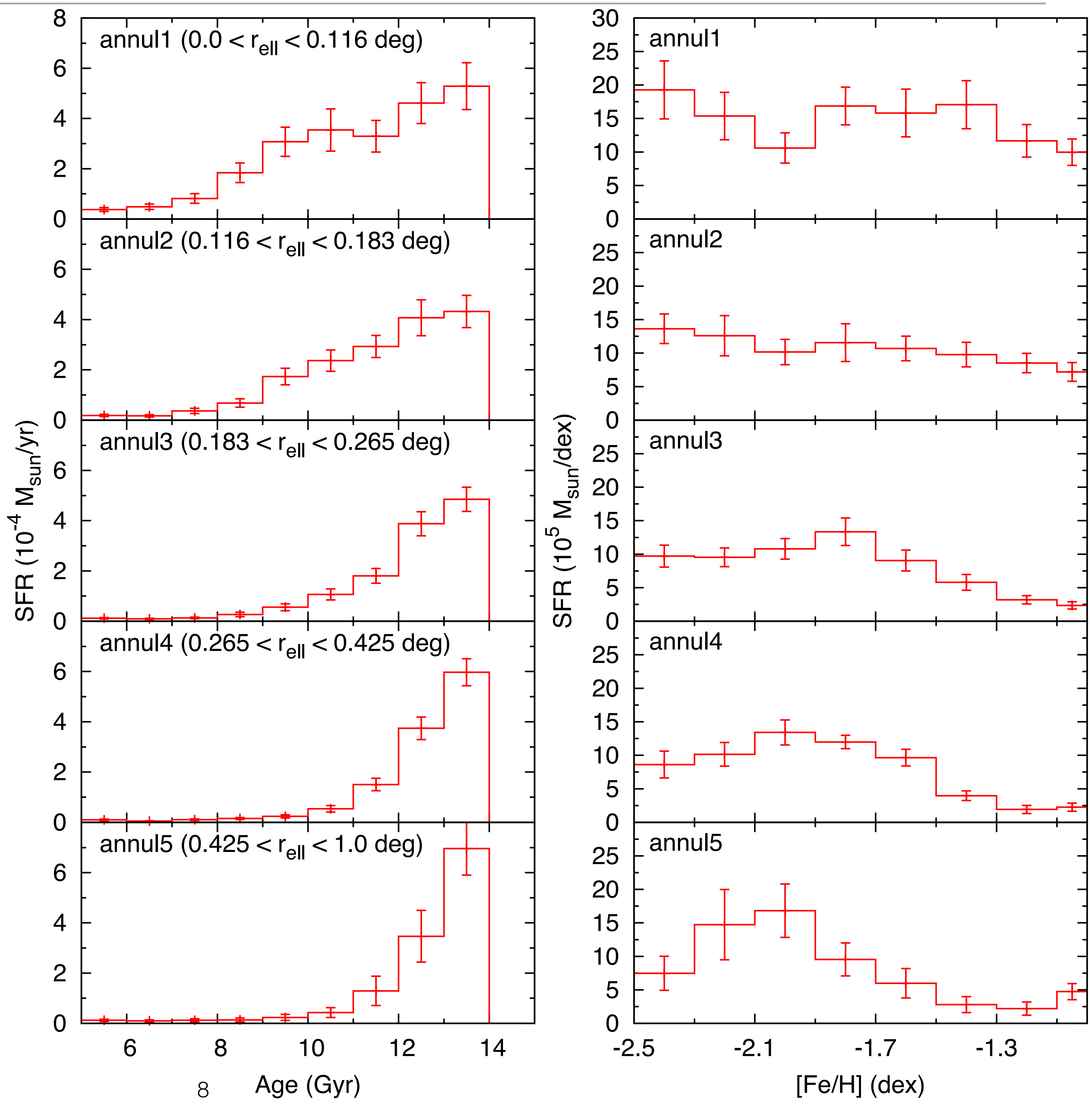
Sculptor SFH and chemical evolution history

SFH and CEH in 5 regions
-> equal number of stars

Radial age gradient as well as metallicity gradient!
-> old population everywhere
-> younger, metal-rich stars more towards centre

Outer region consistent with single, short SF episode

Total stellar mass within R_{tidal}:
$9.30 \times 10^6 M_\odot$



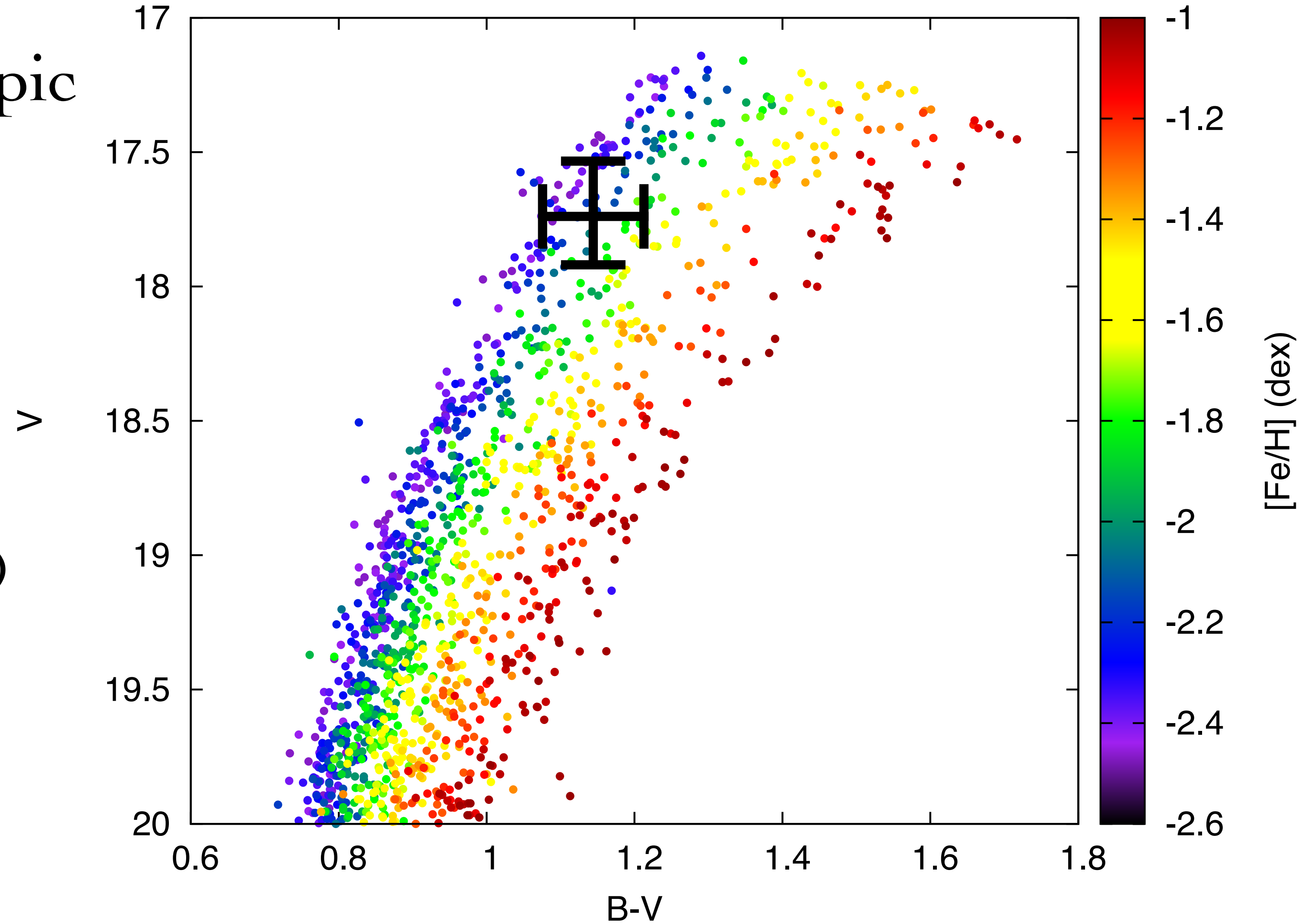
de Boer et al., 2012, A&A, 539, A103

Using the SFH: ages of individual stars

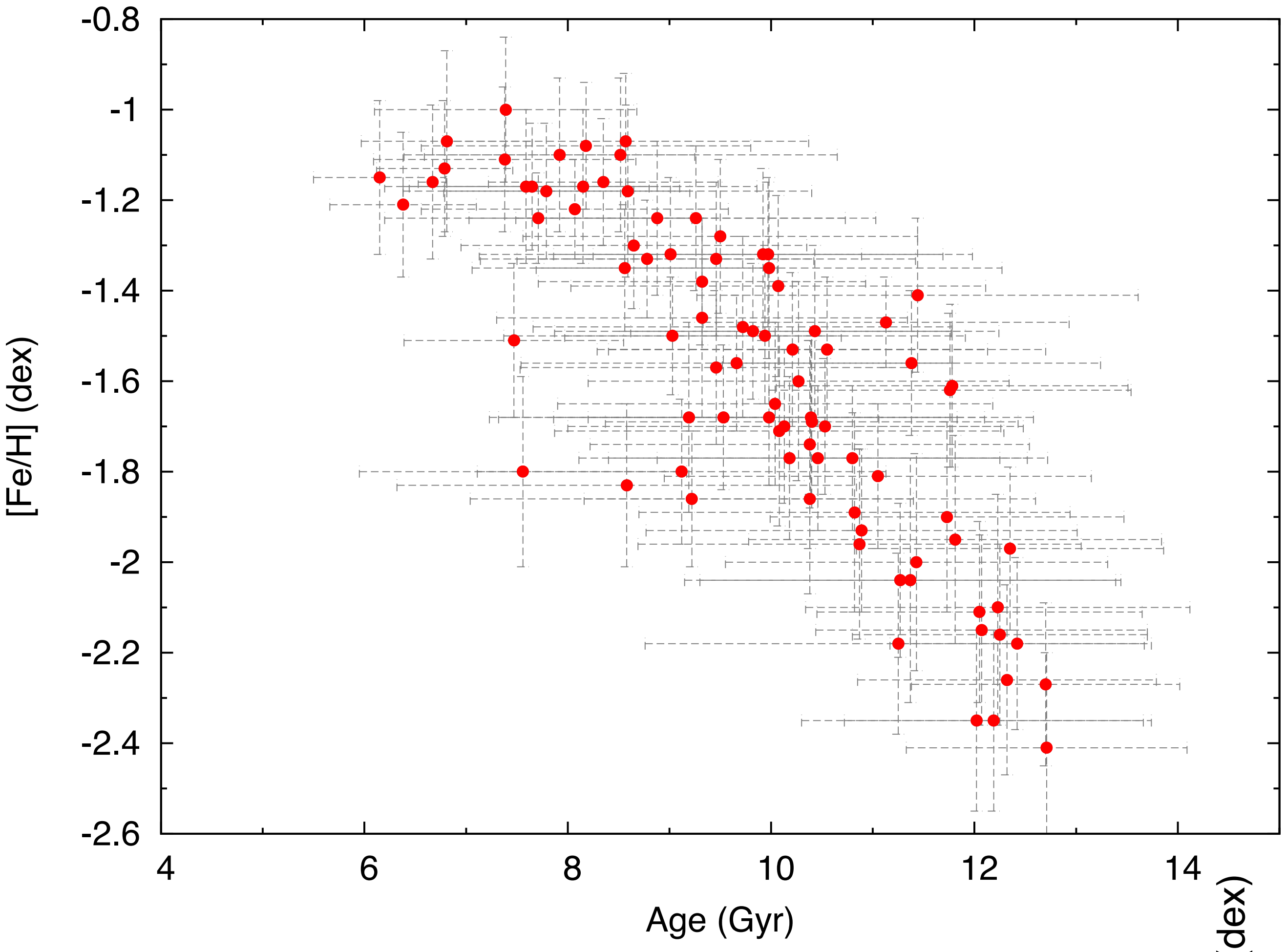
Derive statistical age of spectroscopic stars
->construct synthetic CMD from SFH

->find synthetic stars with same parameters (colour, magnitude, [Fe/H])

->obtain mean age and uncertainty



Sculptor: Chemical evolution timescale

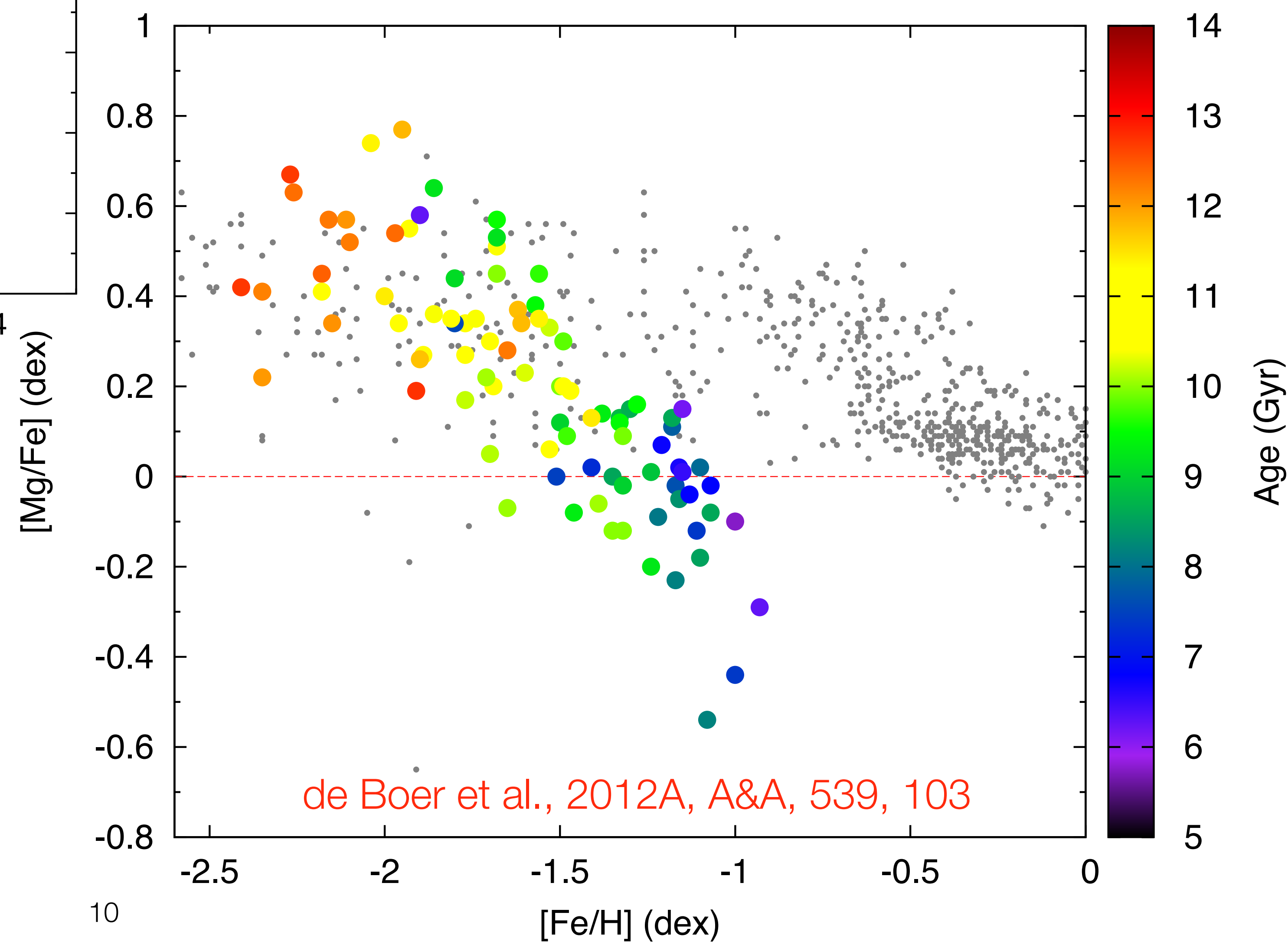


Narrow AMR:
-> slowly built up over several Gyr
-> consistent with simple evolution

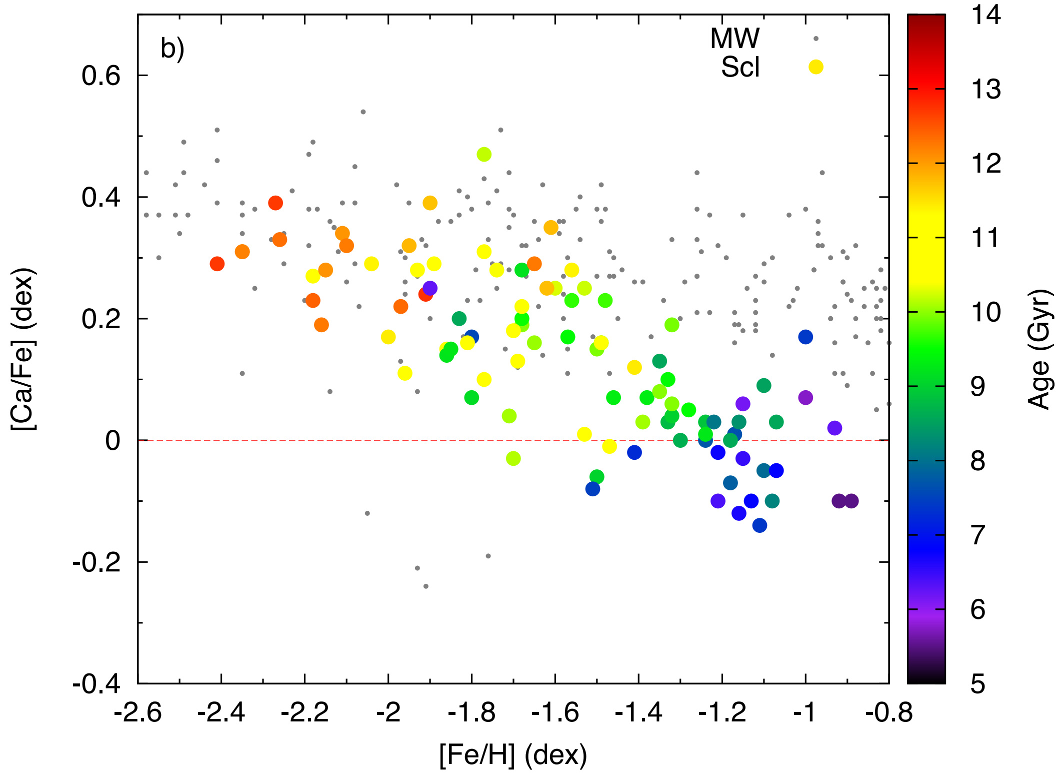
Sculptor is a benchmark for quiescent evolution!

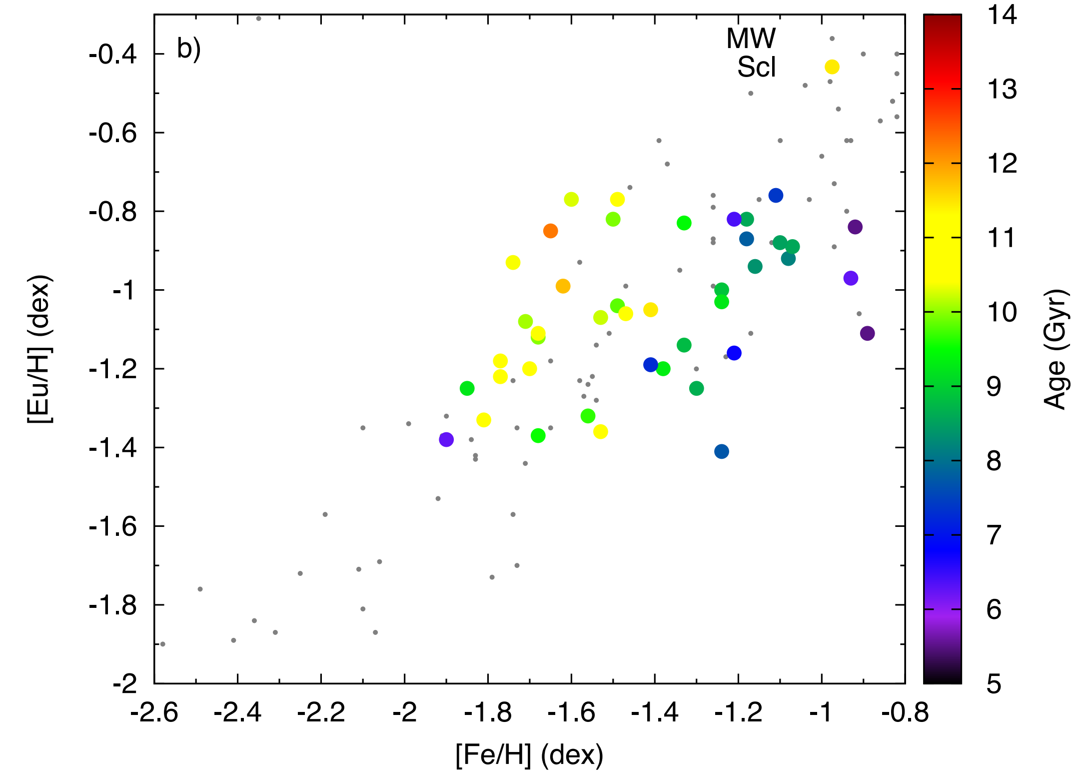
For the first time, put age on [Mg/Fe] abundances directly!

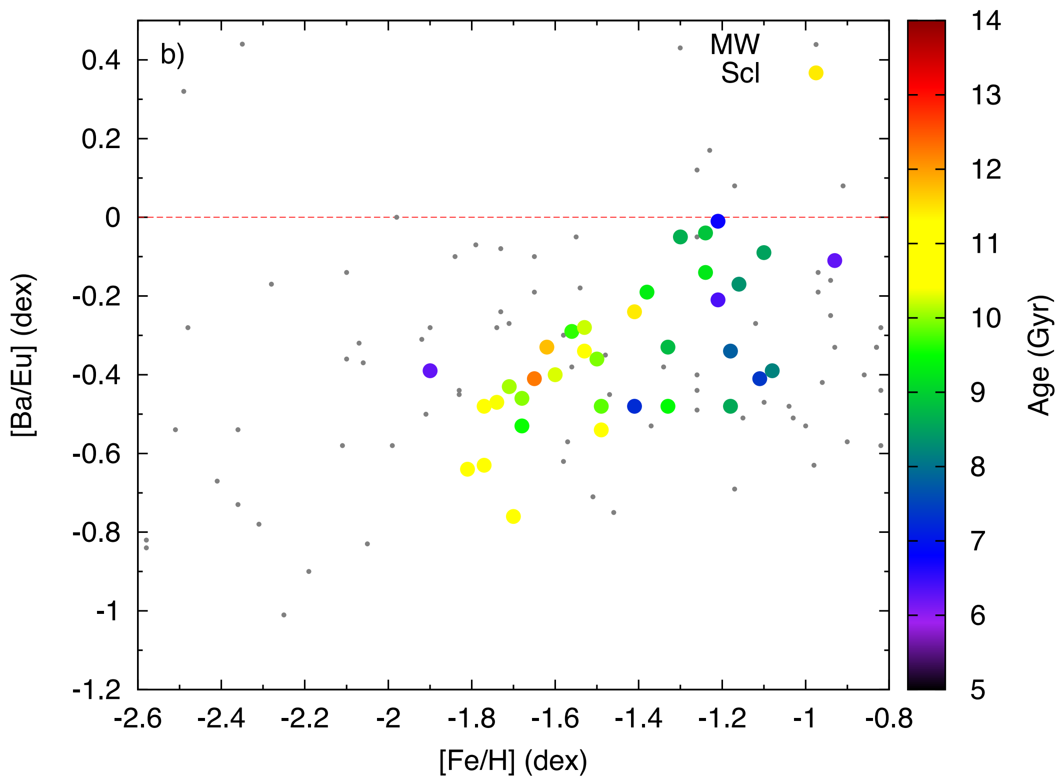
[Mg/Fe] -'knee' at ~10.9±1.0 Gyr
-> probing start of SNe Ia contribution to abundance pattern

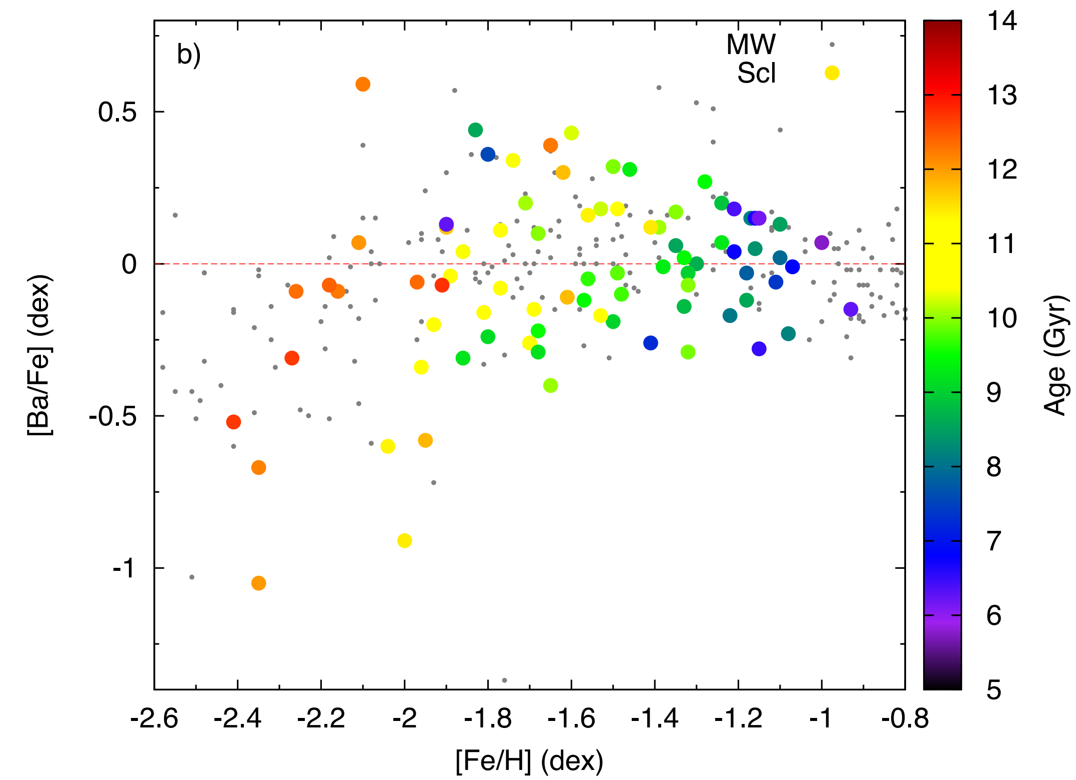


Scl other abundances









Sculptor conclusions

Sculptor displays age gradient as well as [Fe/H] gradient

Dominated by old metal-poor stars, but subsequent generations present, as young as ~7 Gyr

Extended period of star formation (over ~7 Gyr) during which SF continued without discernible disturbance in this galaxy

Detailed abundance evolution shows narrow AMR and clear magnesium “knee” at ~10.9±1.0 Gyr
--> benchmark for quiescent evolution?

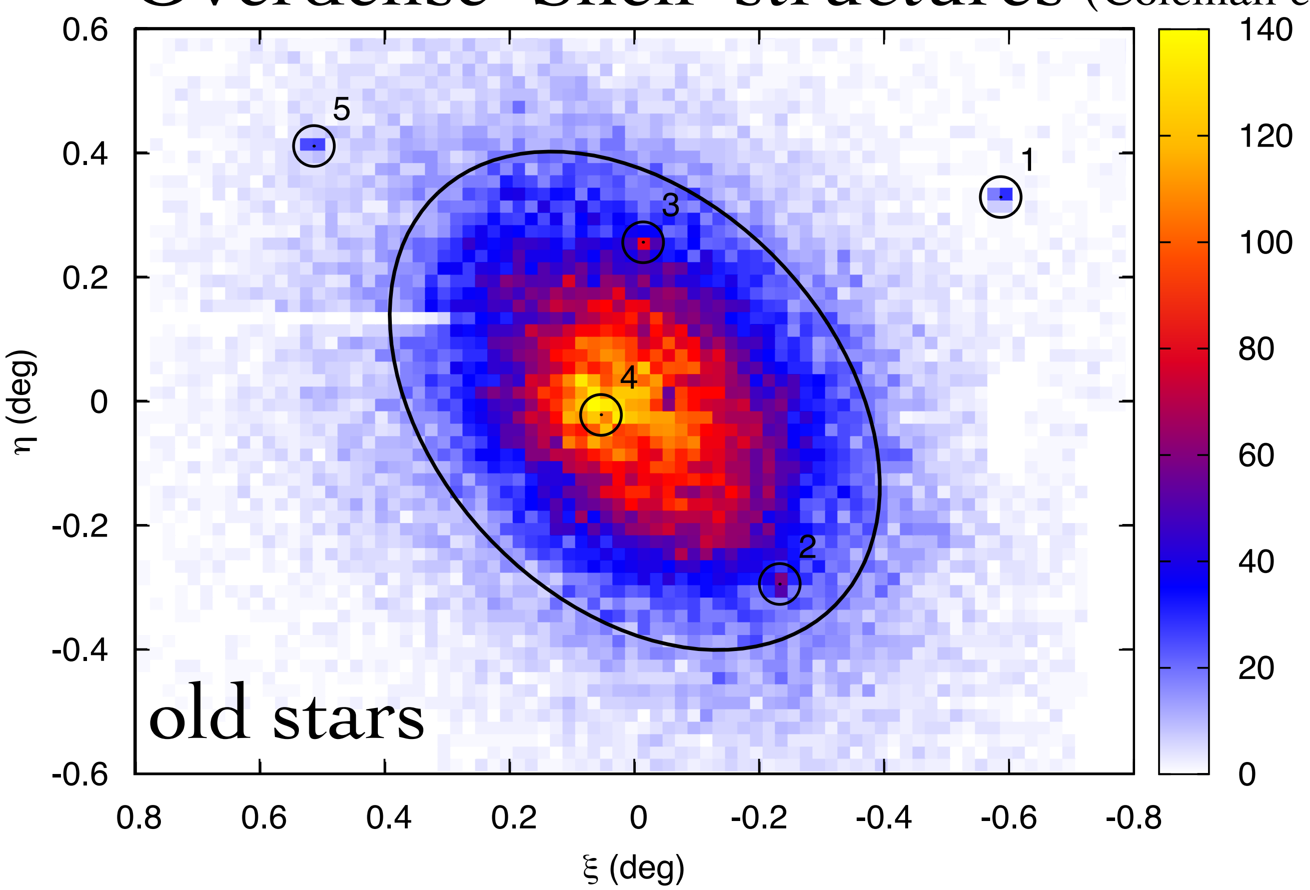
Fornax: complex population mix

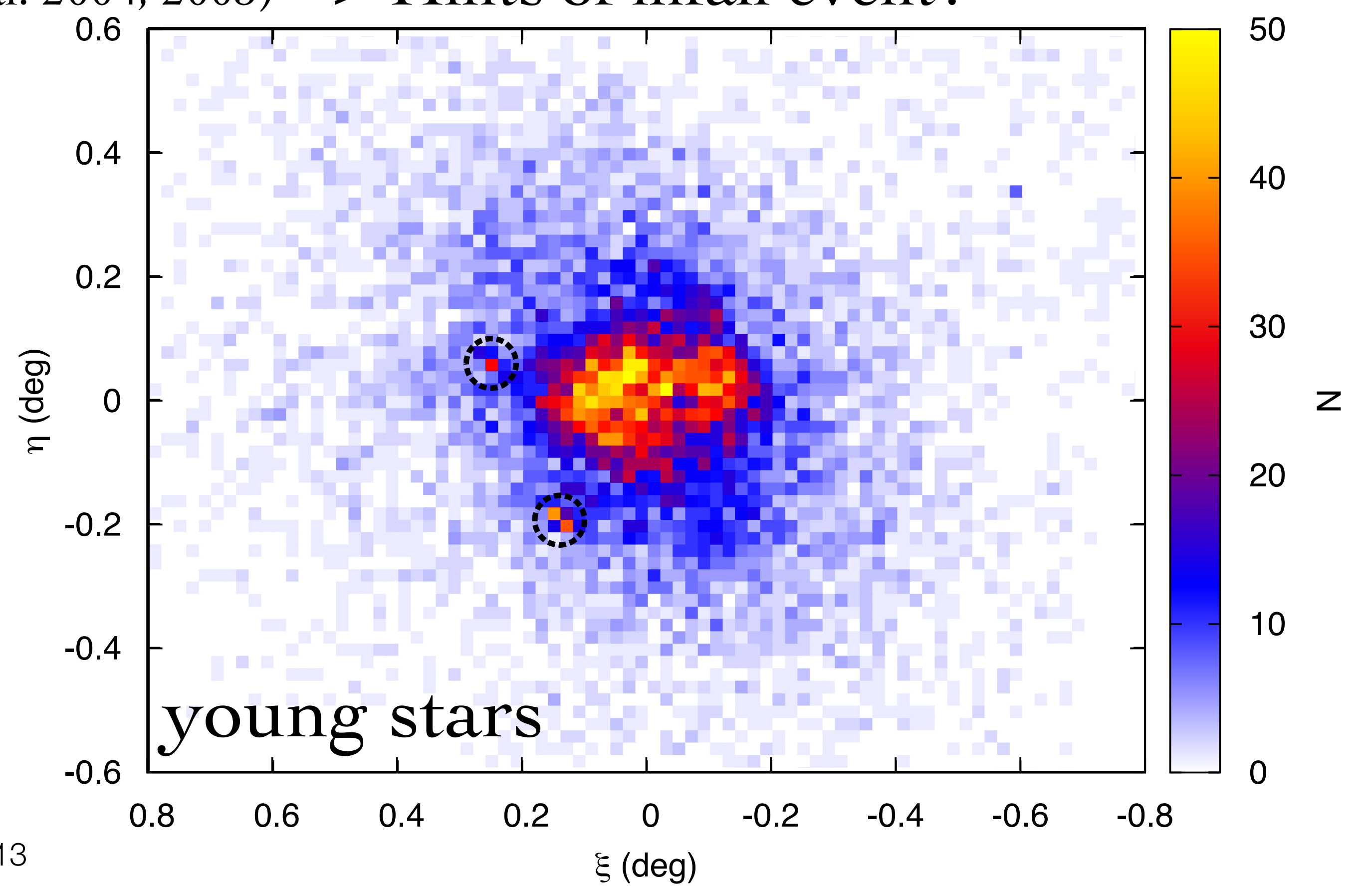
Complex, extended SFH
- ->old populations at all radii from RR Lyrae stars (Bersier et al. 2002)
- ->dominant intermediate age (2-10 Gyr) population (Gallart et al. 2005, Coleman et al. 2008)
- ->young stellar populations (<2 Gyr) in centre (Buonanno et al. 1985, de Boer et al. 2013)

Hosts Globular Cluster system

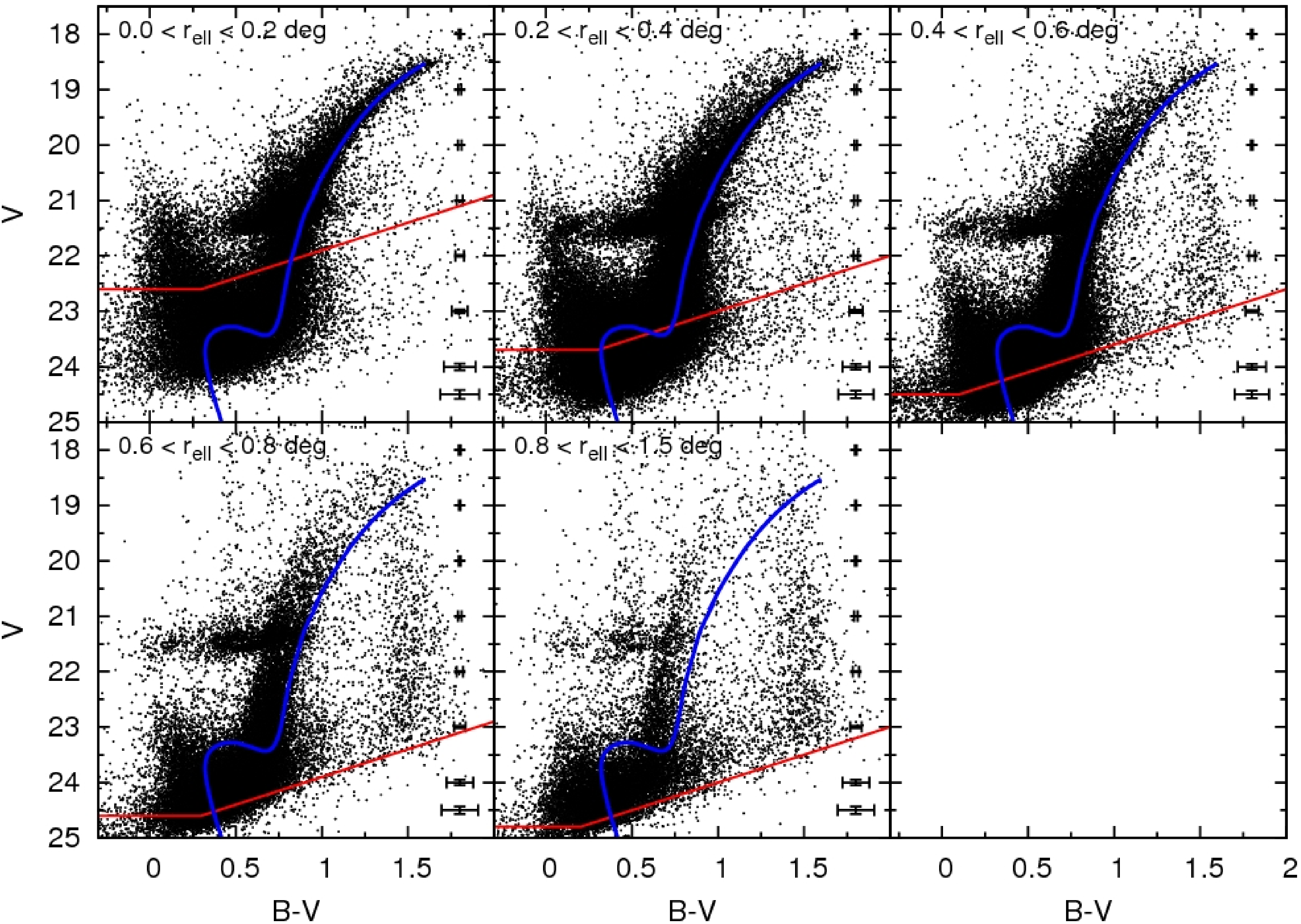
Populations with distinctly different kinematics (Amorisco et al. 2012)

Overdense 'Shell' structures (Coleman et al. 2004, 2005)--> Hints of infall event?





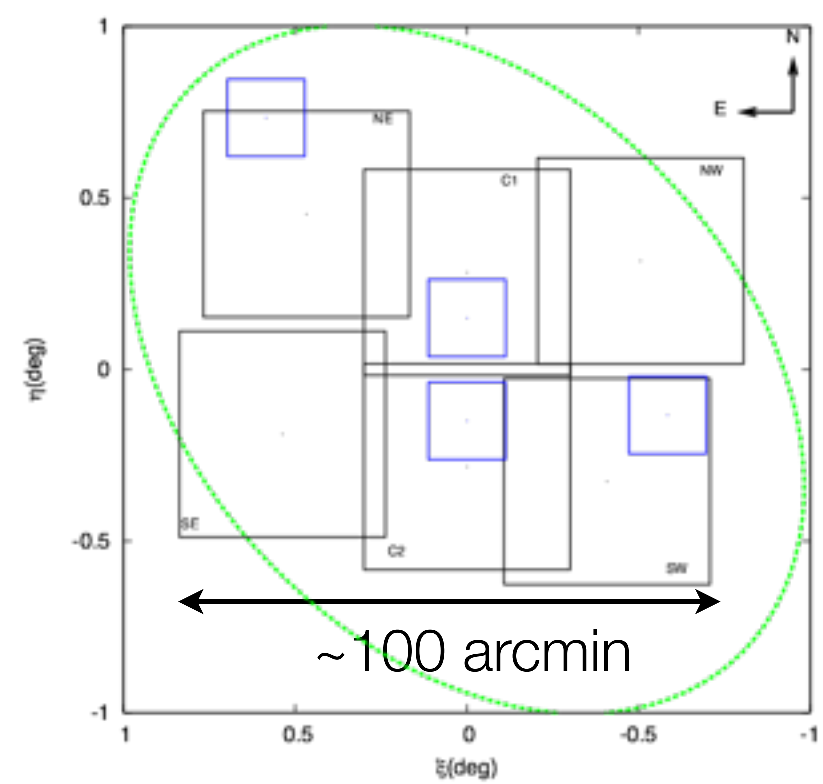
Fornax CMDs



de Boer et al., 2012B, A&A, 544, 73

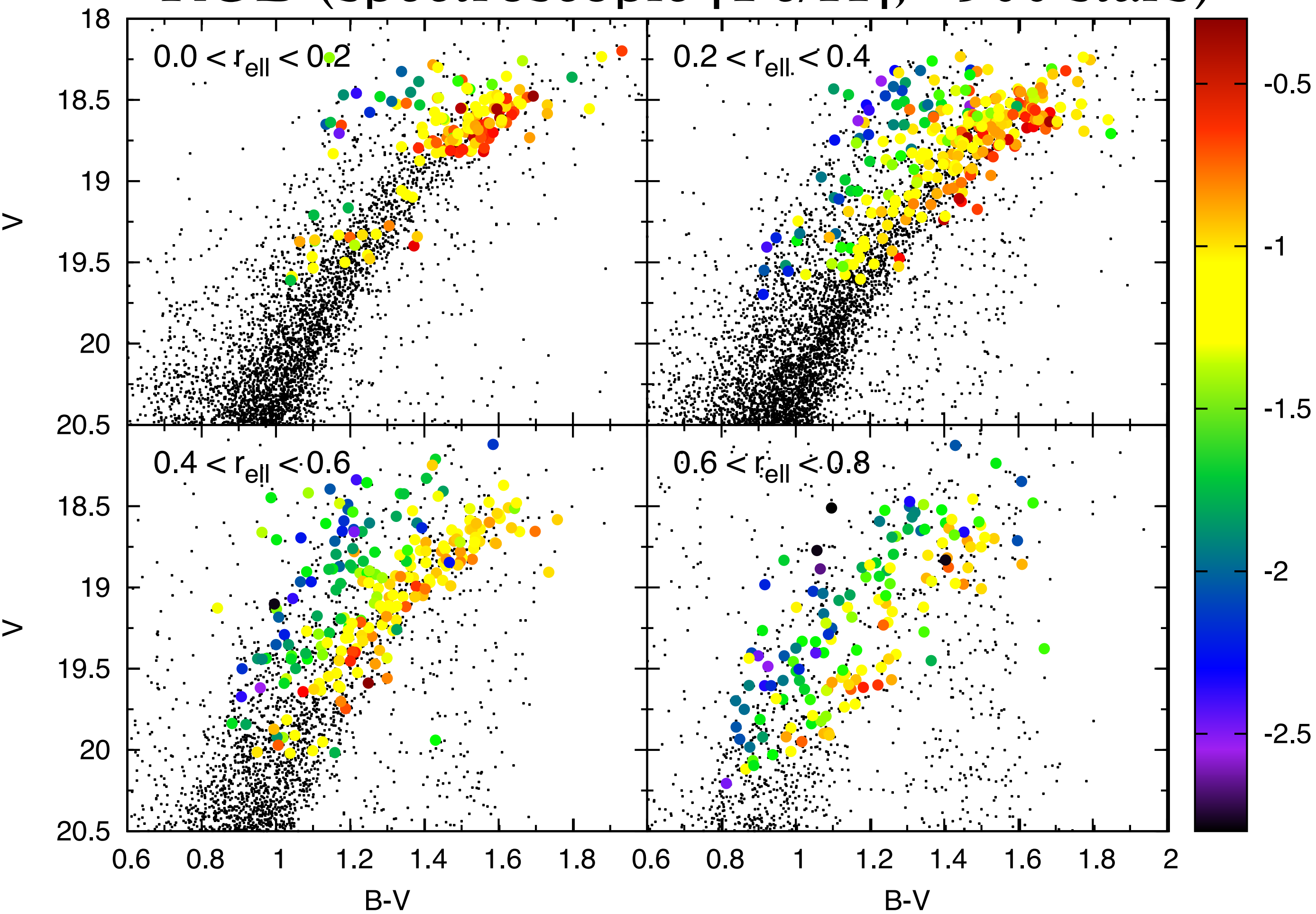
Different populations than Sculptor
-> dominant intermediate age RGB

Clear change with radius:
-> old BHB at all radii
-> young population (<2 Gyr) in inner part

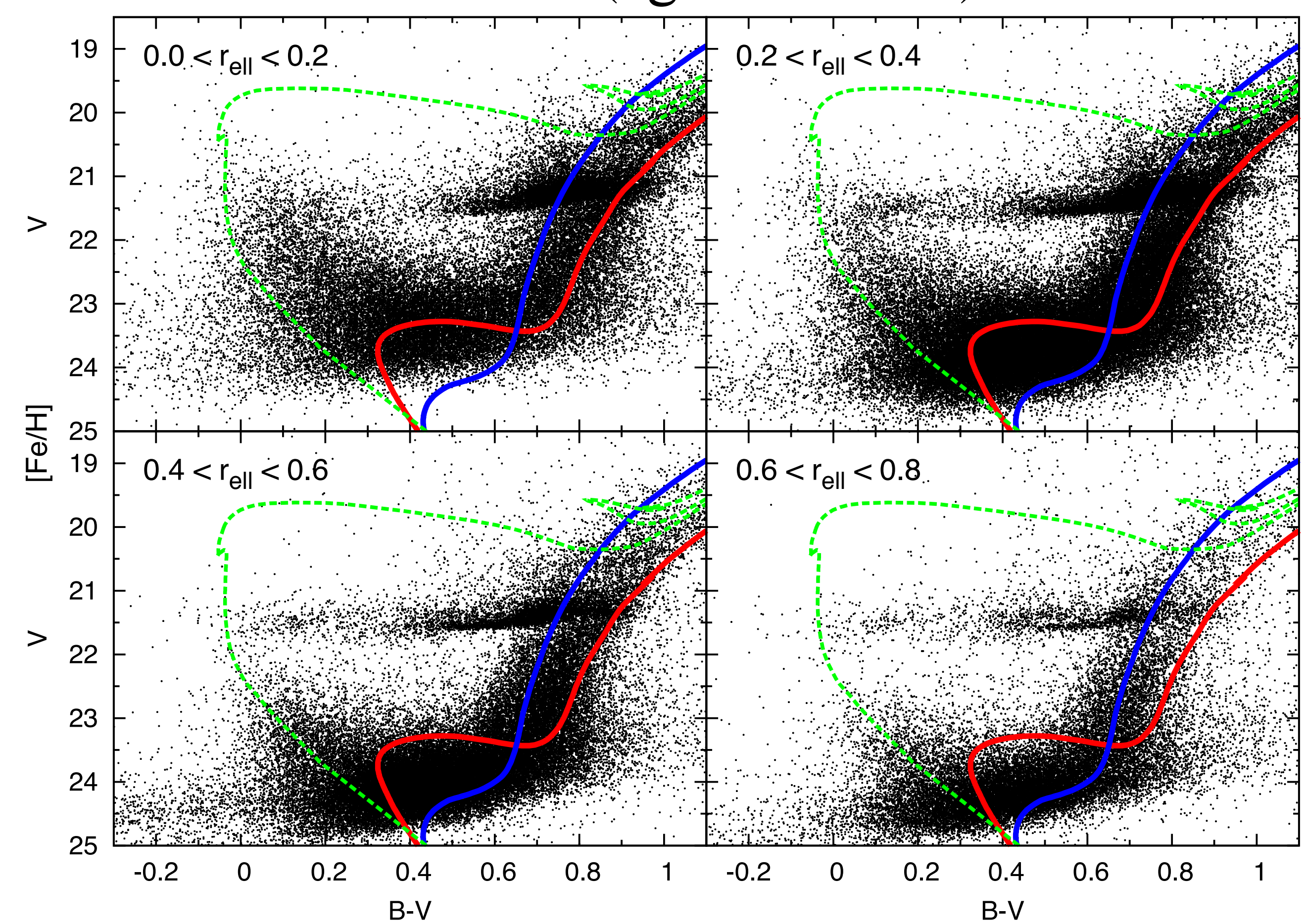


Spatial variations in Fornax

RGB (spectroscopic [Fe/H], ~900 stars)



MSTO (age sensitive)



Radial metallicity gradient on the RGB
-> metal-poor populations at all radii
-> metal-rich populations centrally concentrated

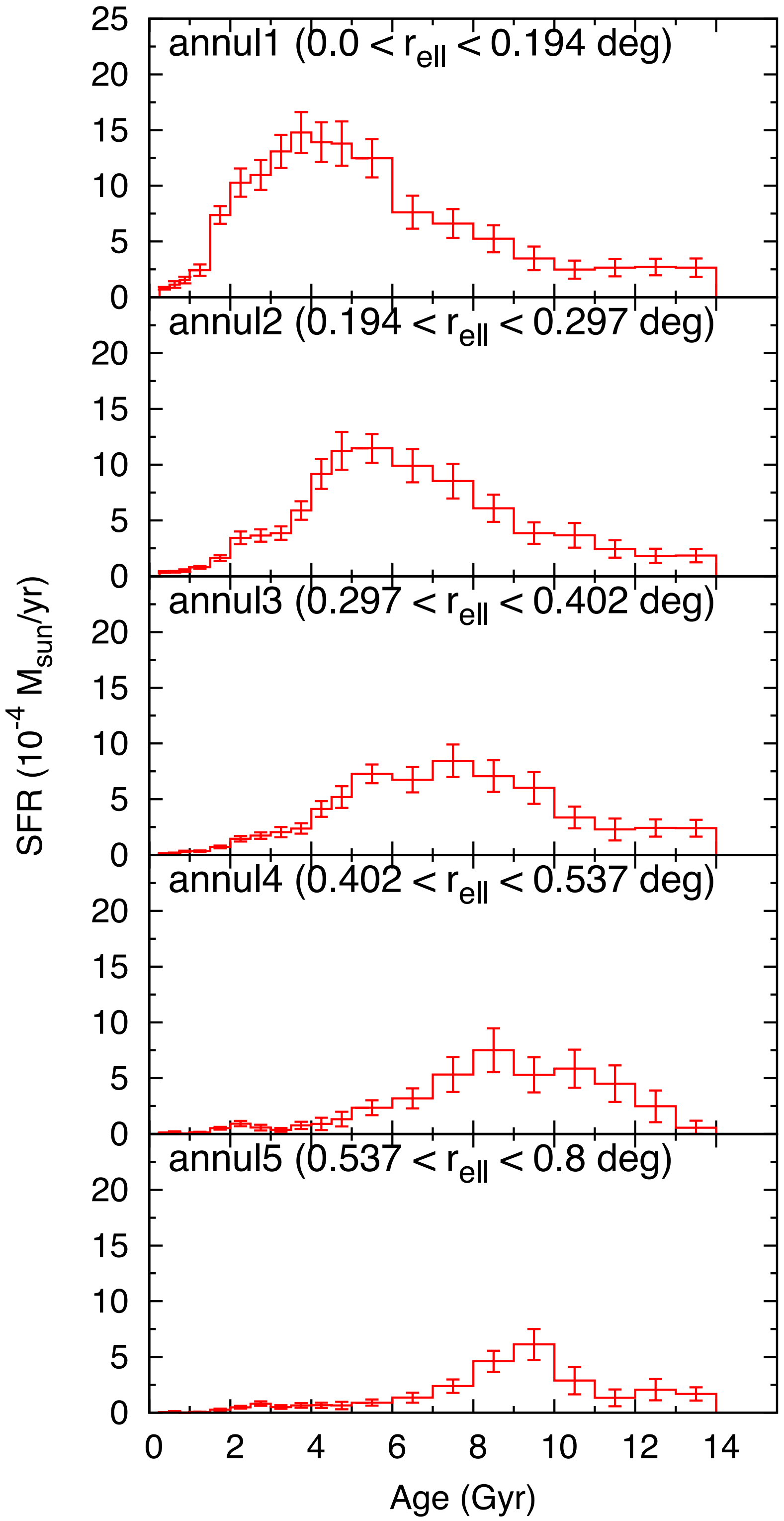
Radial age gradient on MSTO
-> old populations at all radii
-> young populations in centre

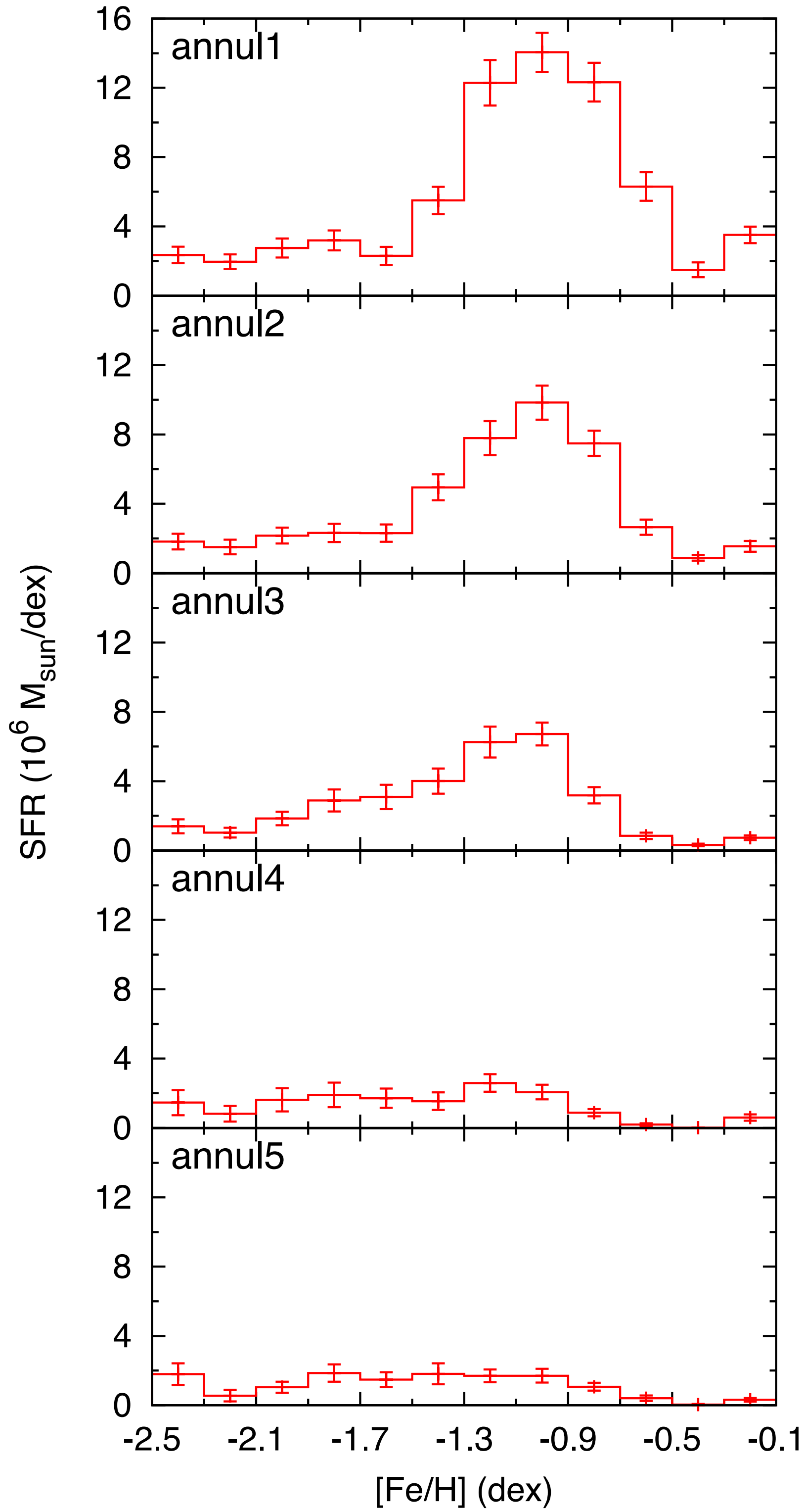
Fornax also displays radial gradients, similar to Sculptor

[Fe/H]=-2.45, [α/Fe]=0.4, age=14 Gyr (blue)
[Fe/H]=-1.0, [α/Fe]=0.0, age=4 Gyr (red)
[Fe/H]=-0.3, [α/Fe]=-0.2, age=0.3 Gyr (green)

(Battaglia et al. 2006, Starkenburg et al. 2010)

Radial SFH and CEH





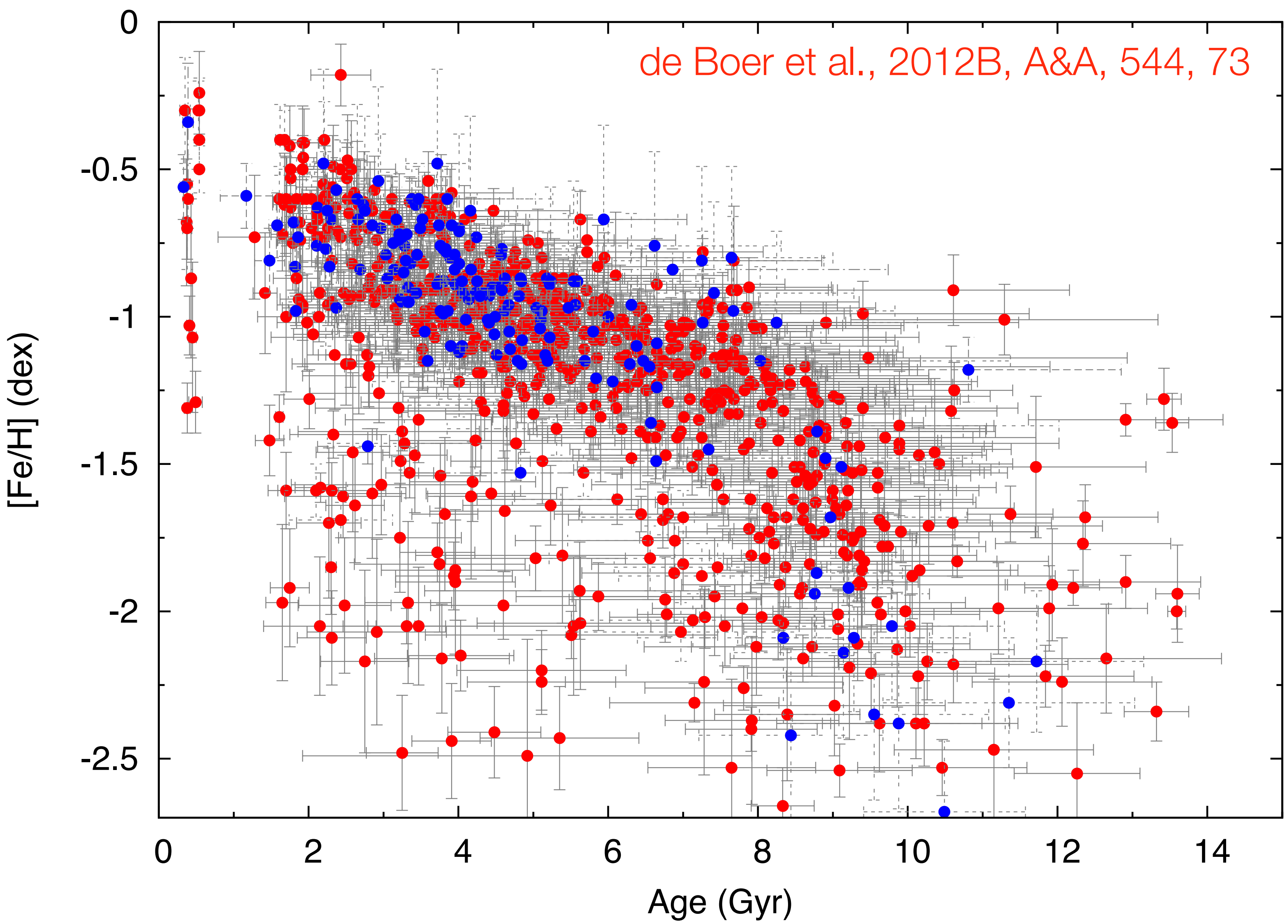
Extended period of SF
-> dominant intermediate age population
-> young stars only in centre

Radial gradient with age and metallicity
-> peak of SFH shifts

Distinct peaks in SFH at age ~4 Gyr and 8-10 Gyr
-> what fuels bursts?

Total stellar mass within R_{tidal}: 3.83×10^7 $M_\odot$

Fornax age-metallicity relation



AMR of individual RGB stars

-> clear effects of different stellar populations
-> rapid metal enrichment at old ages
-> subsequent narrow AMR at intermediate ages (3-8 Gyr)
-> hint of upturn at young ages (Pont 2004)

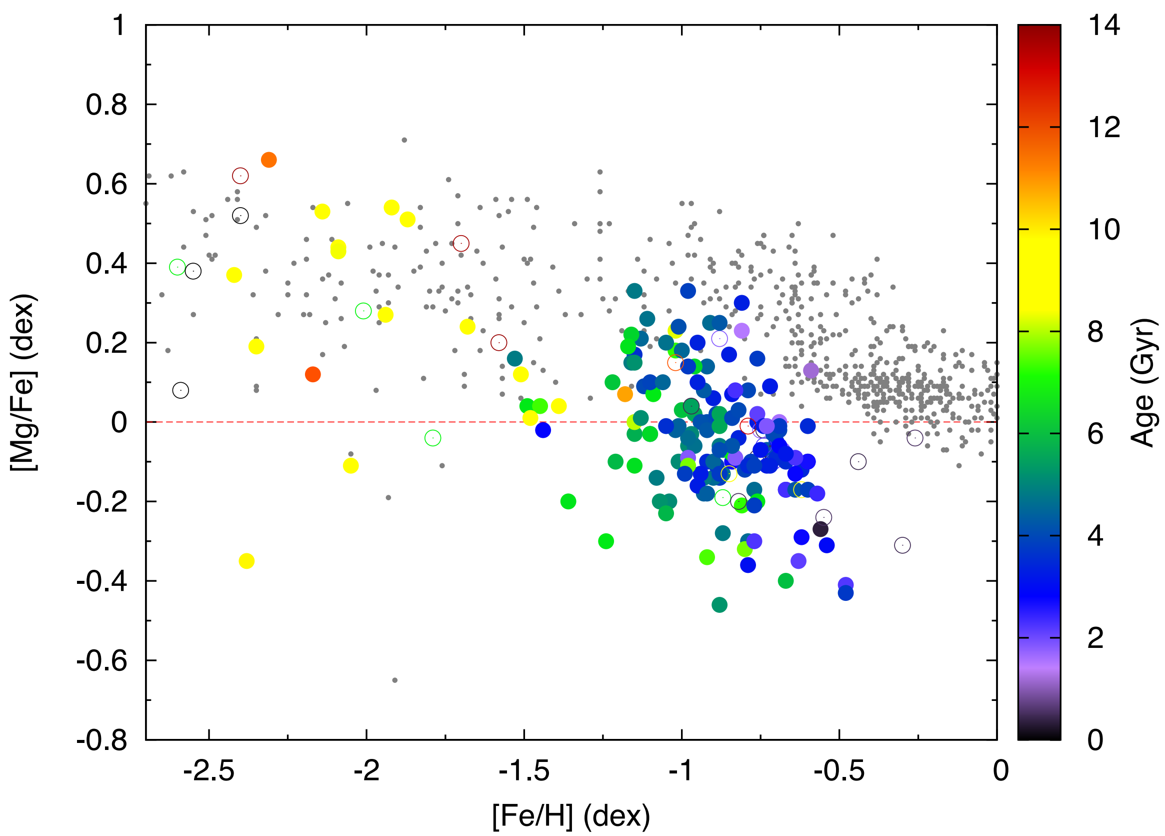
Changes of slope linked to bursts in SFH?

Continuous AMR

-> bursts can only be fueled by pre-enriched gas!

CaT spectroscopy for 870 stars (Battaglia et al. 2006, Starkenburg et al. 2010)
HR spectroscopy for ~100 stars in central 0.2 deg (Letarte et al. 2010, Kirby et al. 2010, Lemasle et al 2014)

Chemical evolution timescale

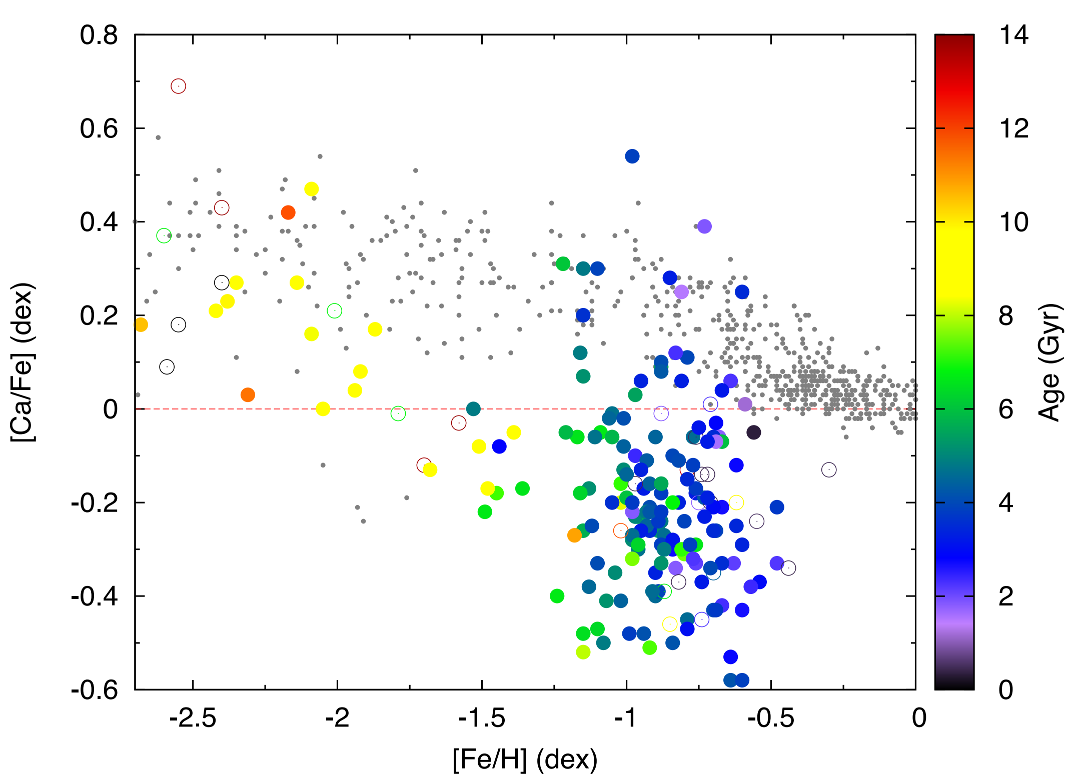


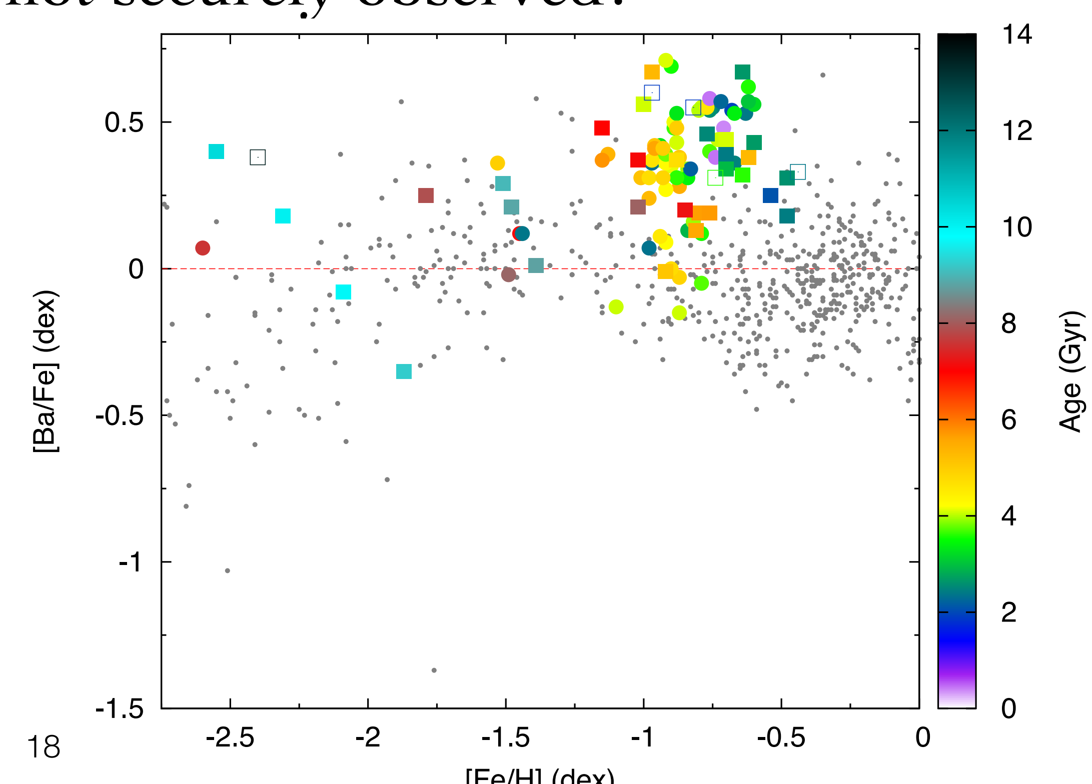
HR abundances coloured with age

Abundances at old ages similar to MW, departing below ~8 Gyr

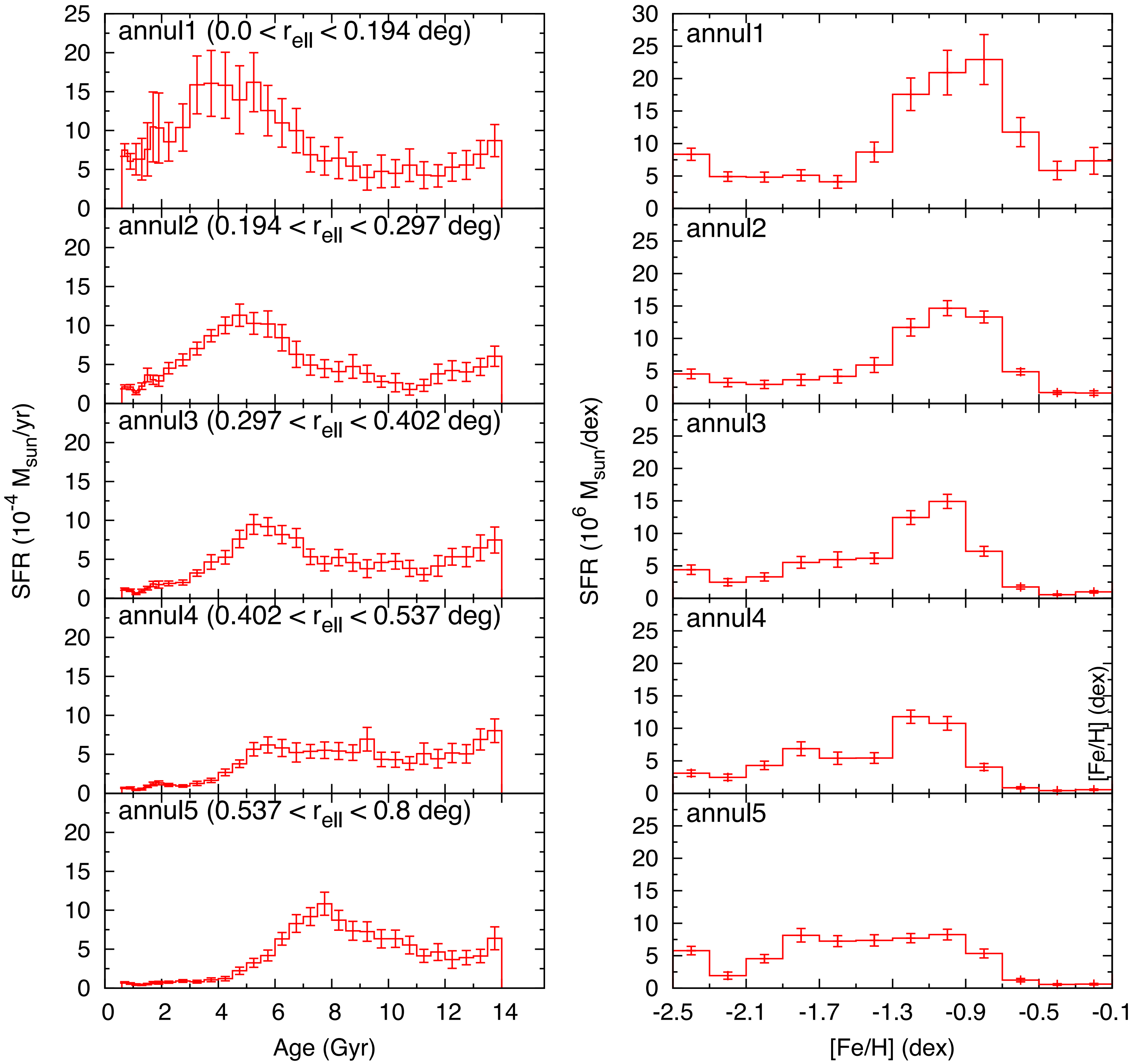
Clear trend with age in metal-rich populations, but missing intermediate metallicities

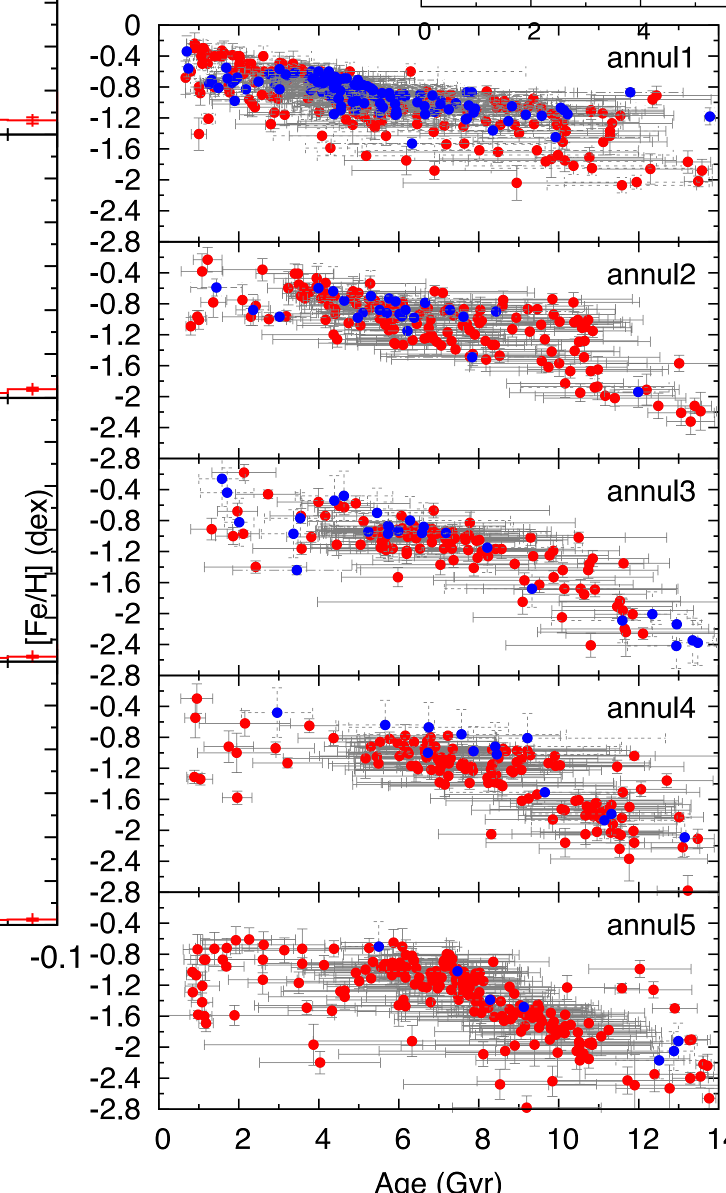
Steep decrease of α-elements suggests occurrence of 'knee'
->expected at 7-10 Gyr, [Fe/H]~ -1.5 dex, but not securely observed!

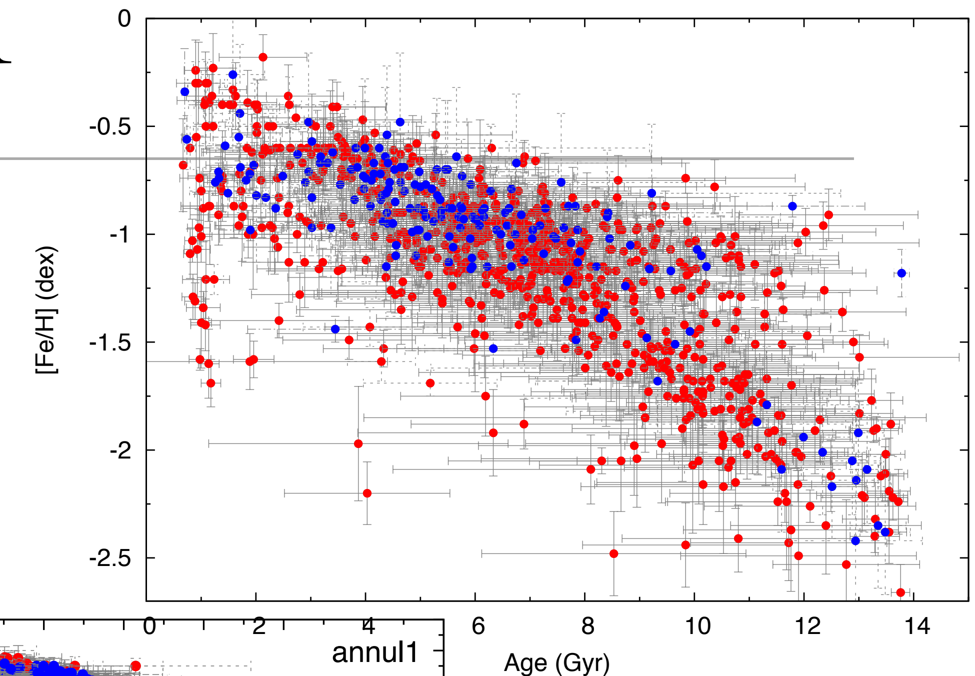




Fornax SFH revisited

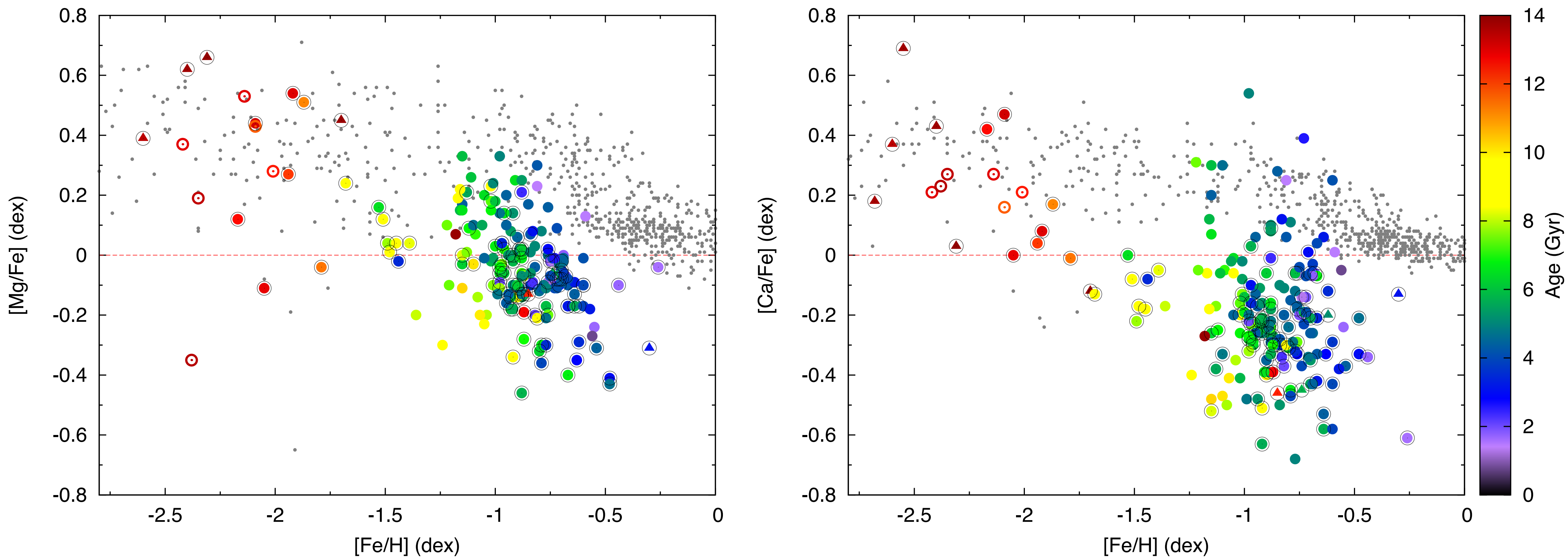


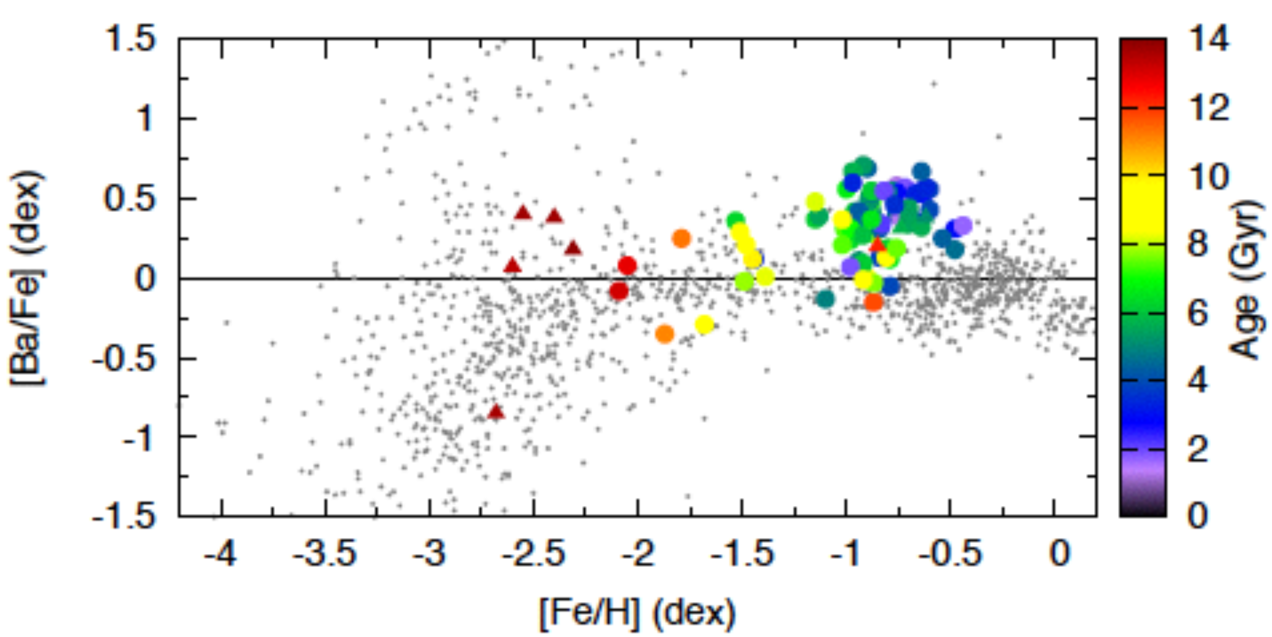


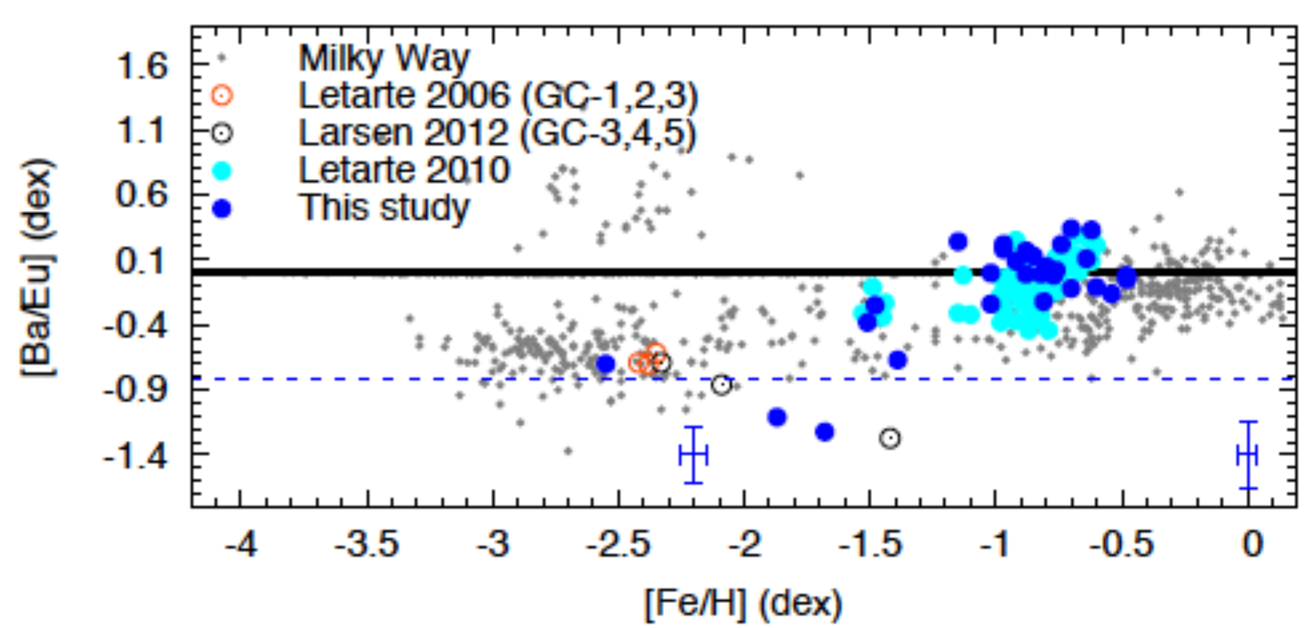


Chemical evolution timescale

Lemasle et al., 2014, submitted







Fornax conclusions

Fornax displays clear radial age and metallicity gradient

Multiple star formation episodes, dominated by bursts at ~4 Gyr and ~8 Gyr (linked to encounters?)

Detailed AMR shows clearly effect of different SF episodes

Chemical evolution timescale shows trend with age, with hints of different slope

Magnesium "knee" not observed, but predicted to occur at [Fe/H]~ -1.5 dex, 7-10 Gyr

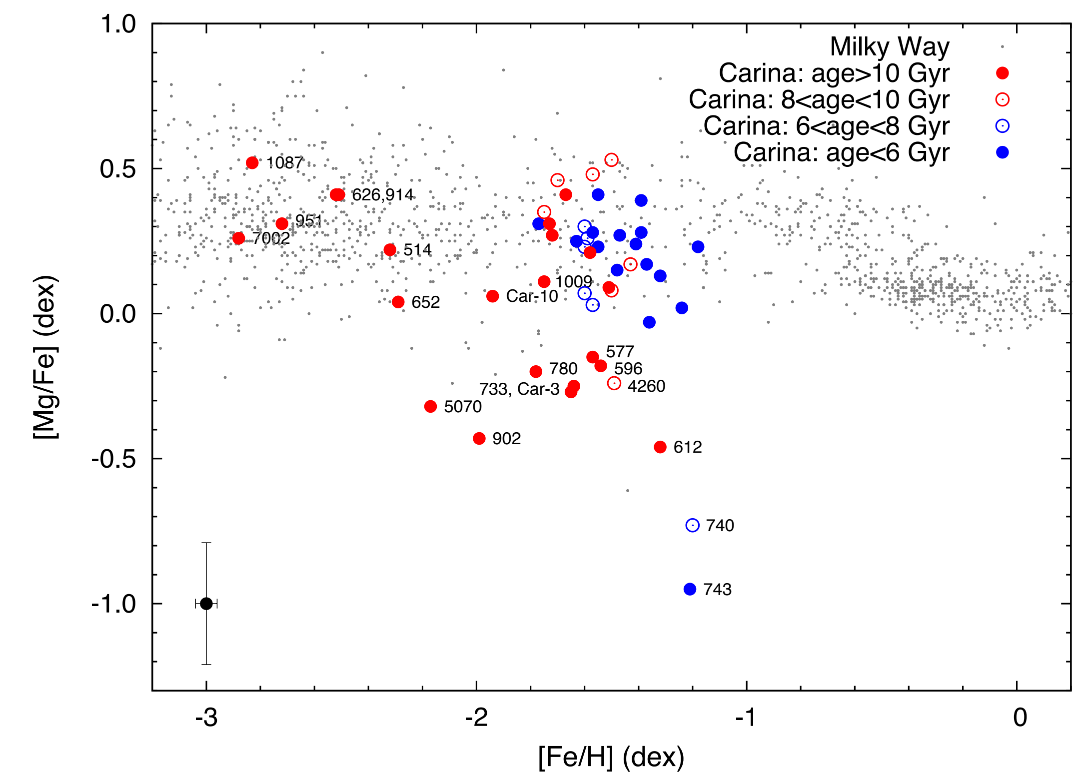
--> Hints for re-accretion of pre-enriched gas? kinematics?

Carina: episodic star formation

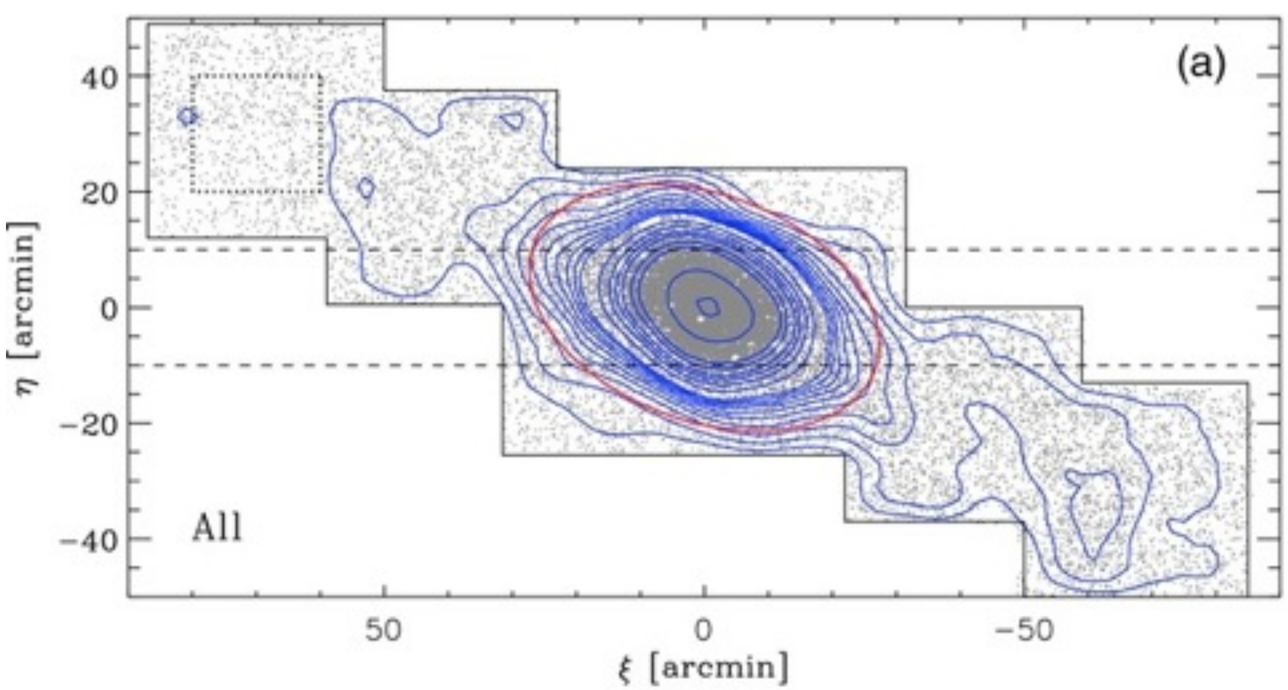
Clearly episodic star formation
-> distinct MSTOs

Thin RGB and small [Fe/H] range
-> different age, same metallicity?

Likely interacted with MW (Pasetto et al. 2011)
-> possible tidal tails
-> responsible for episodes?



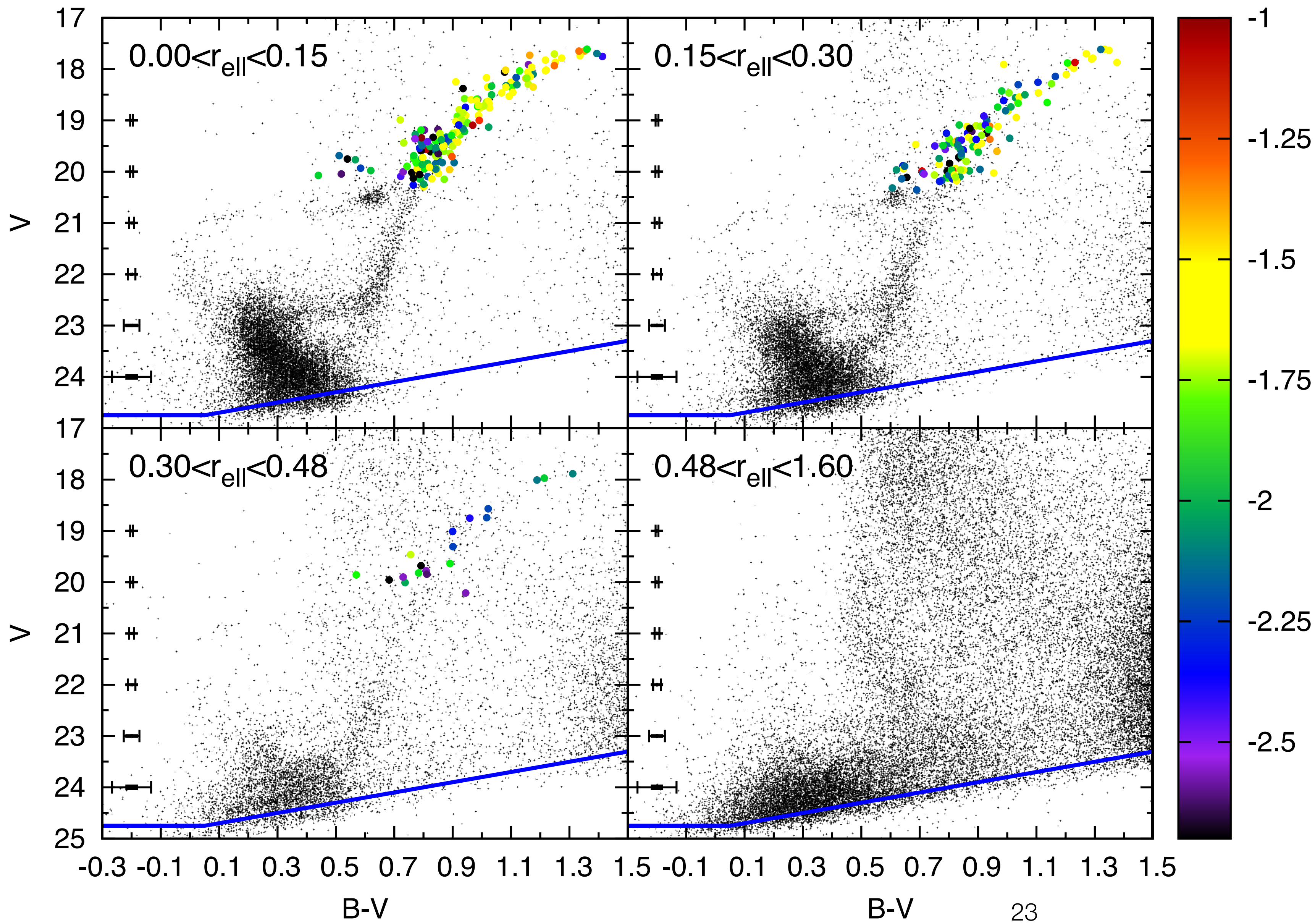
HR spectroscopy: Lemasle et al. 2012
-> no steady decline of [Mg/Fe] with age!
-> linked to episodes?



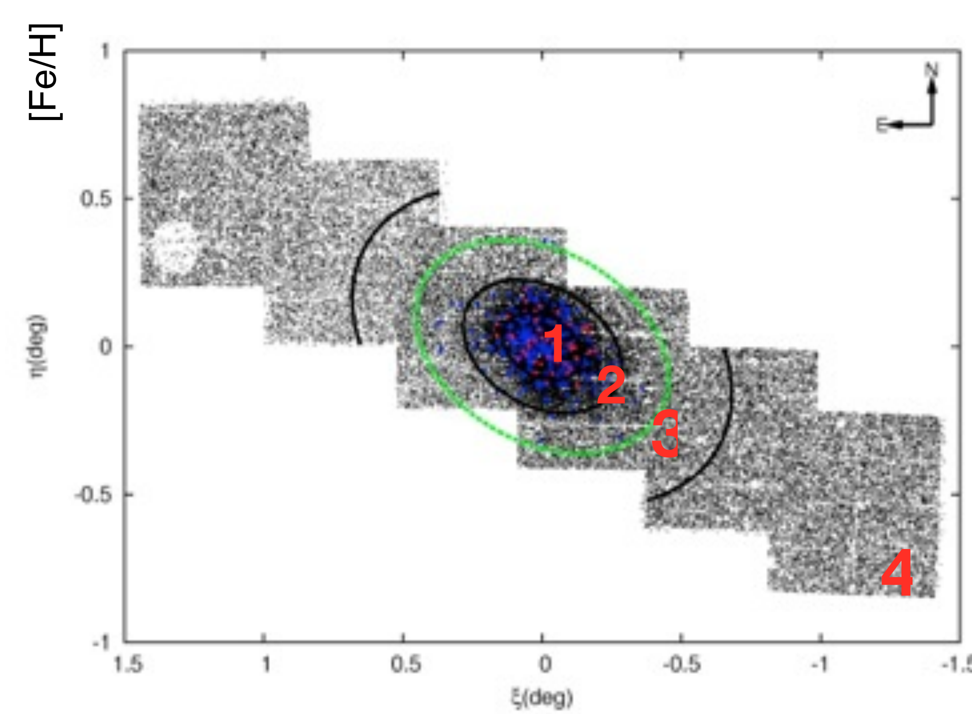
Battaglia et al. 2012

Carina CMDs: spatial variation

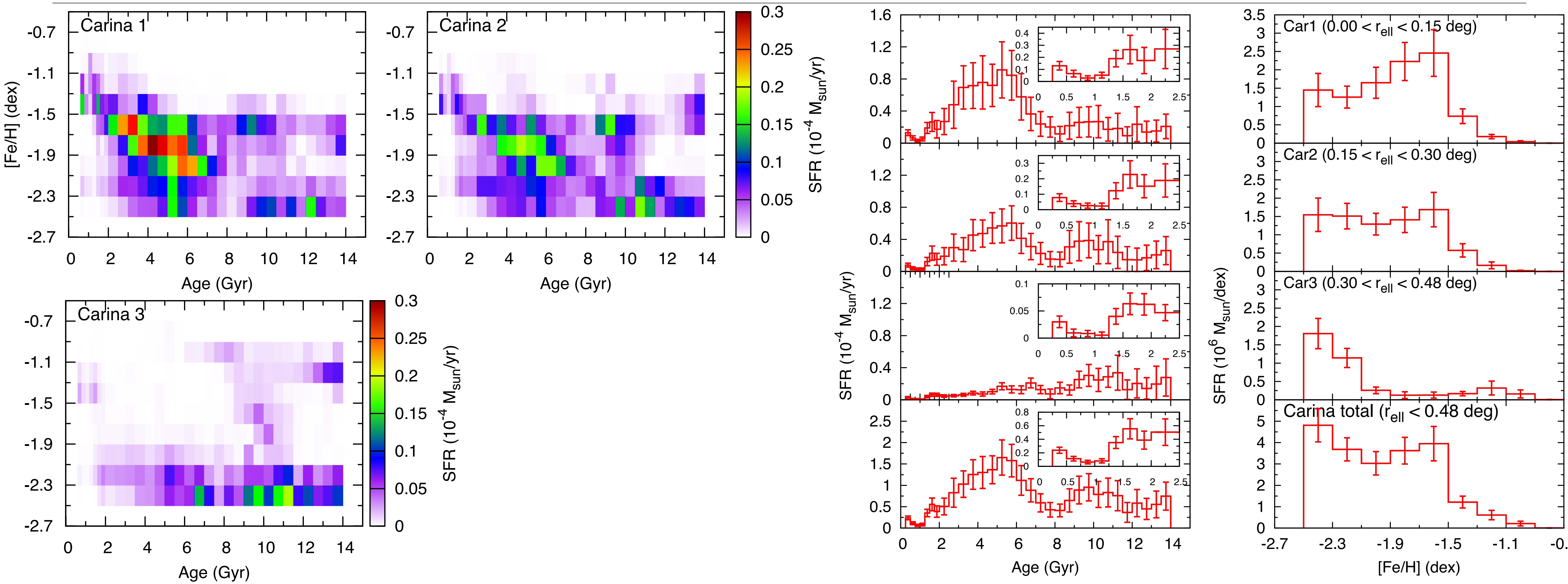
Deep B,V photometry + CaT spectroscopy (~320 stars)
-> range of metallicities across narrow RGB
-> clear change in SGB/MSTO strength with radius



Once again: age and metallicity gradient with radius from centre!



Spatially resolved SFH



SFH shows two distinct episodes, and radial age gradient

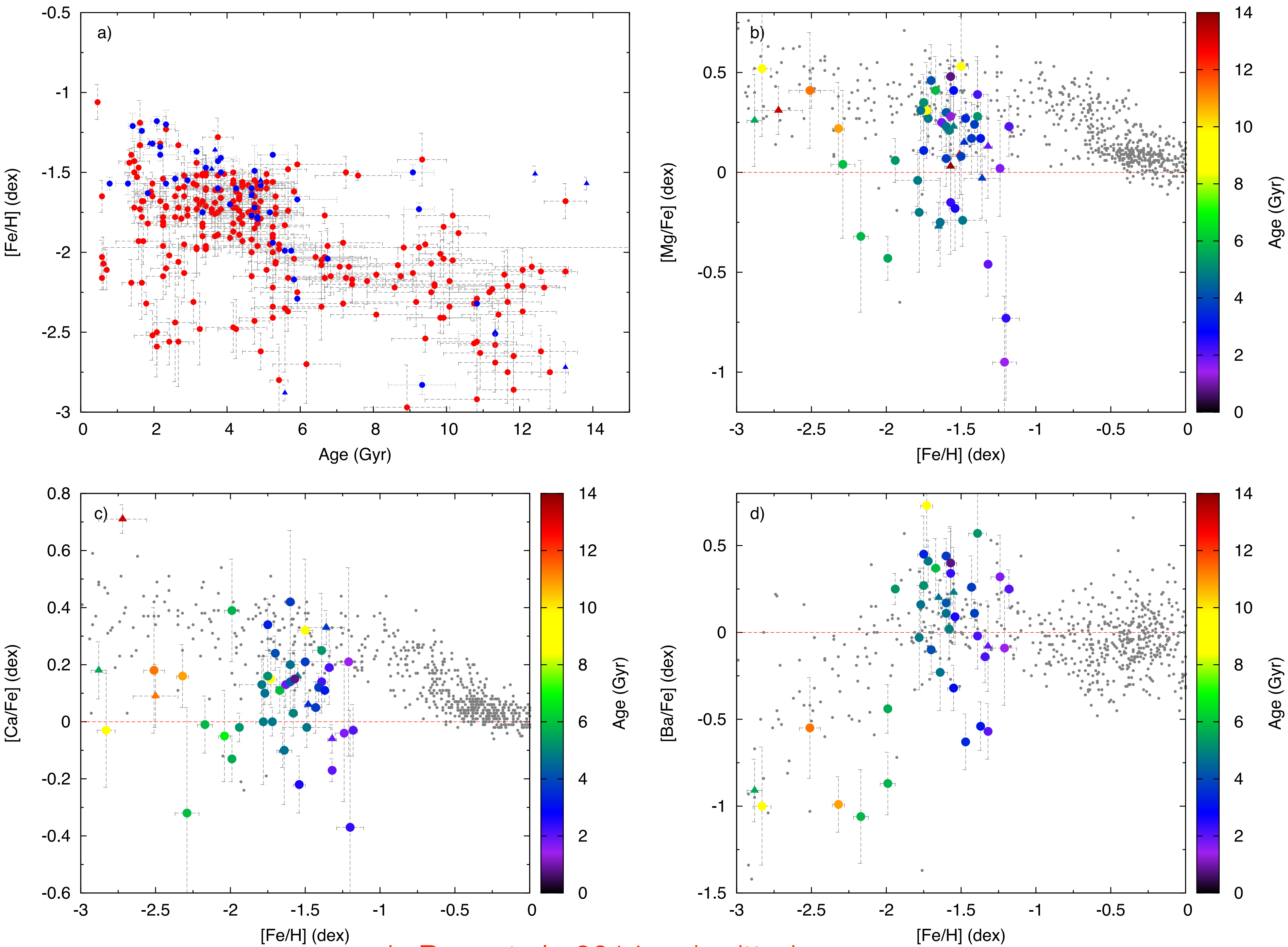
old episode (8-14 Gyr) everywhere: -> enrichment from [Fe/H]= -2.7 to -1.5 dex
intermediate episode (2-8 Gyr) in the centre: -> start at low [Fe/H] and enrich again!
possibly young episode as well in centre

Total stellar mass within R_{tidal}: $1.06 \pm 0.08 \times 10^6\, M_\odot$
Mass within R_{half}: $0.42 \pm 0.05 \times 10^6\, M_\odot$ -> M/L(stellar, $<R_{HL}$)=1.8±0.8 6

de Boer et al., 2014, submitted

Chemical abundances

Individual ages assigned to HR (35 stars) + CaT (300 stars)



de Boer et al., 2014, submitted

AMR split in two groups ->initial slow enrichment, followed by second enrichment (diff slope)

Accretion of fresh gas?
-> what else lowers abundances?

initial slow decrease of [α/Fe] with age
second episode starting from high [α/Fe] as well!

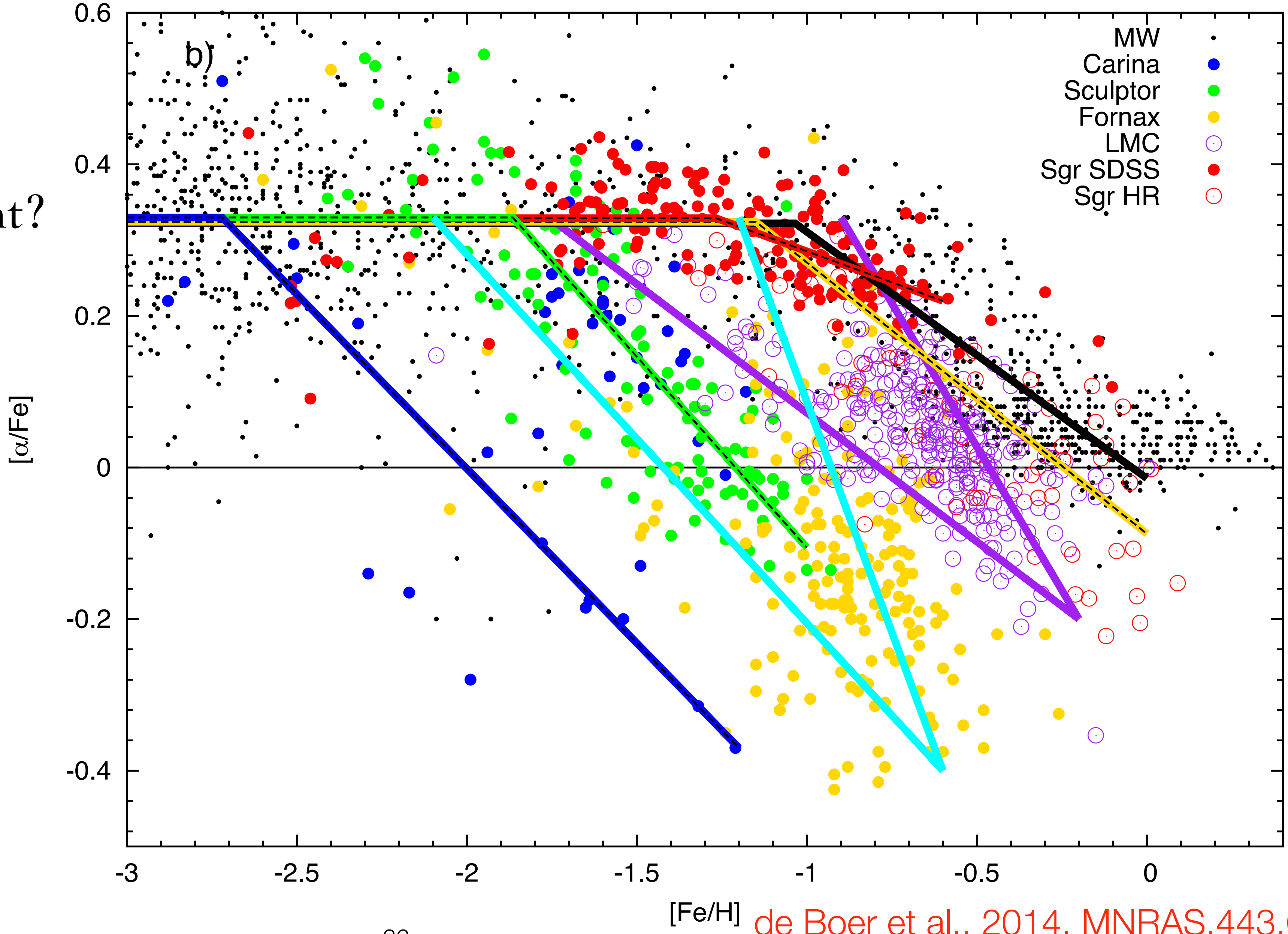
->Multiple [α/Fe] 'knees'? not clear
->old knee: >10 Gyr

Comparing the LG dwarfs

Overall enrichment behaviour of dSph similar, different timescales
->related to total mass? external effects?
->steepest slope in Fornax (stronger SF episodes-> more SN Ia?)

Is there bimodality in some larger systems?
-Fornax, LMC
-> function of environment?
-> or just larger scatter?

What drives slope?
-> similar slopes despite different mass?



de Boer et al., 2014, MNRAS,443,658

Conclusions

Sculptor, Fornax and Carina display radial age and [Fe/H] gradients

Sculptor:
-> SFH clearly dominated by ancient stars
-> extended period of star formation (over ~7 Gyr)
-> narrow AMR and clear magnesium "knee" at ~10.9±1.0 Gyr
--> benchmark for quiescent evolution

Fornax:
-> complex evolution with many episodes of star formation
-> AMR shows fast enrichment at old ages (able to retain more metals?)
-> magnesium abundance shows steep slope (effect of strong SF episodes?)
--> complexity related to greater mass?

Carina:
-> episodic SFH with large range of ages and small range of [Fe/H]
-> two phases of evolution, with enrichment on different timescale
--> accretion of fresh gas?

LG galaxies show similar overall evolution, but on different timescales

Thank you!