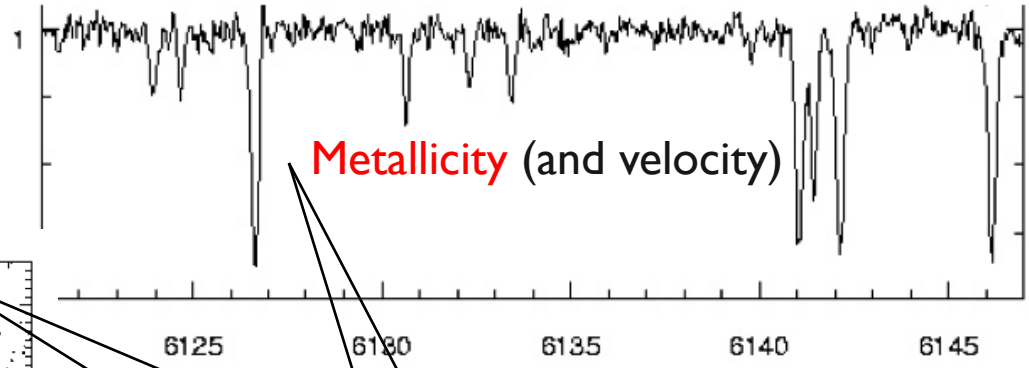
Dwarf galaxies and resolved stellar populations

ESO Fellow 1998-2000

Eline Tolstoy
Kapteyn Institute
University of Groningen
the Netherlands

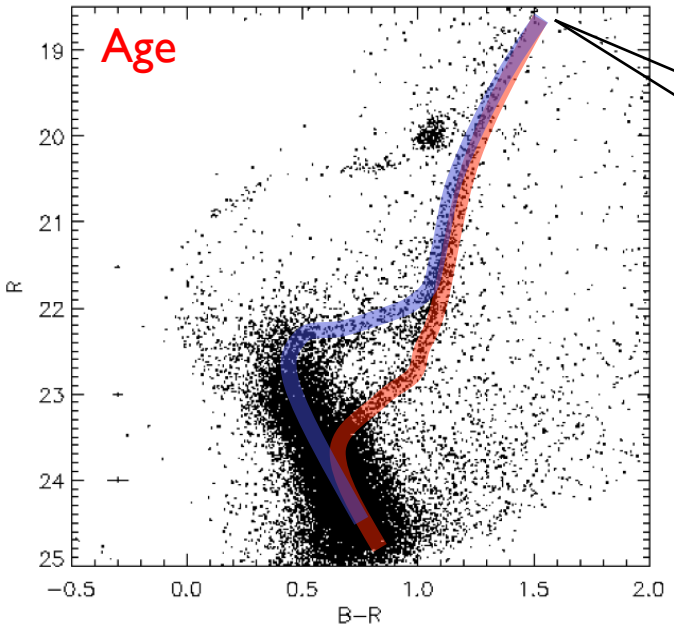
Resolved Stars

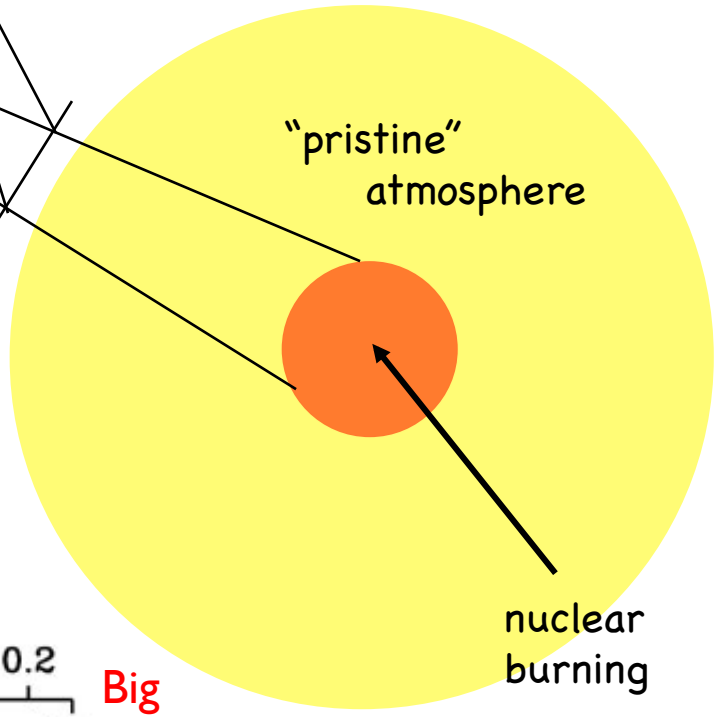
Spectroscopy

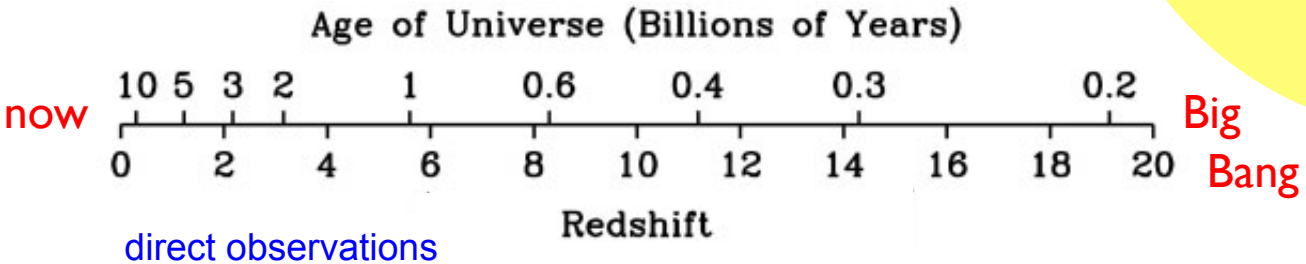


Metallicity (and velocity)

Imaging





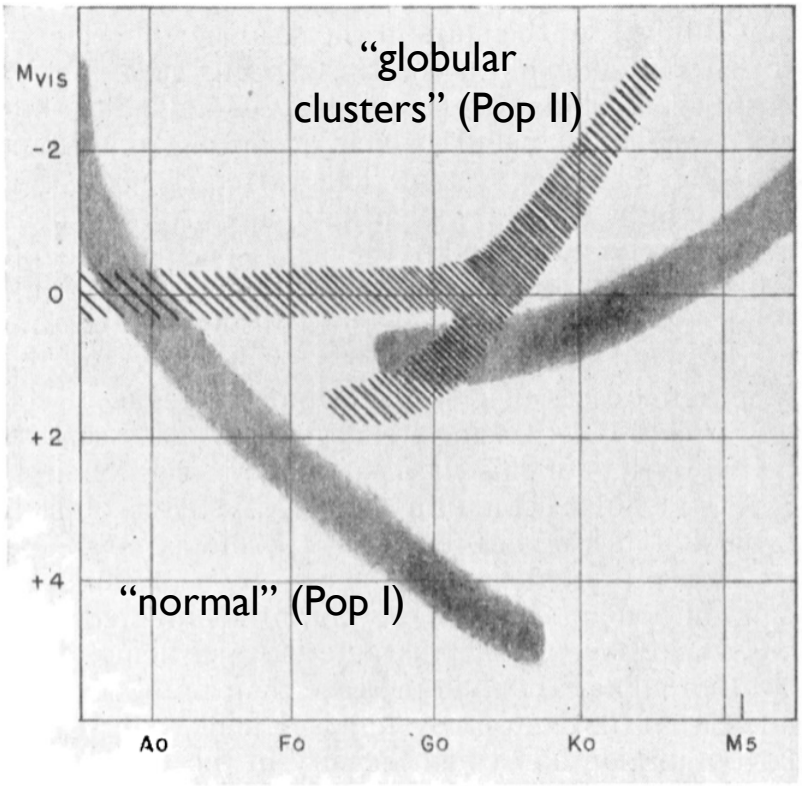


direct observations of galaxies

Low mass stars < $1M_{\odot}$

Foundations of stellar population research

Walter Baade (1893-1960)



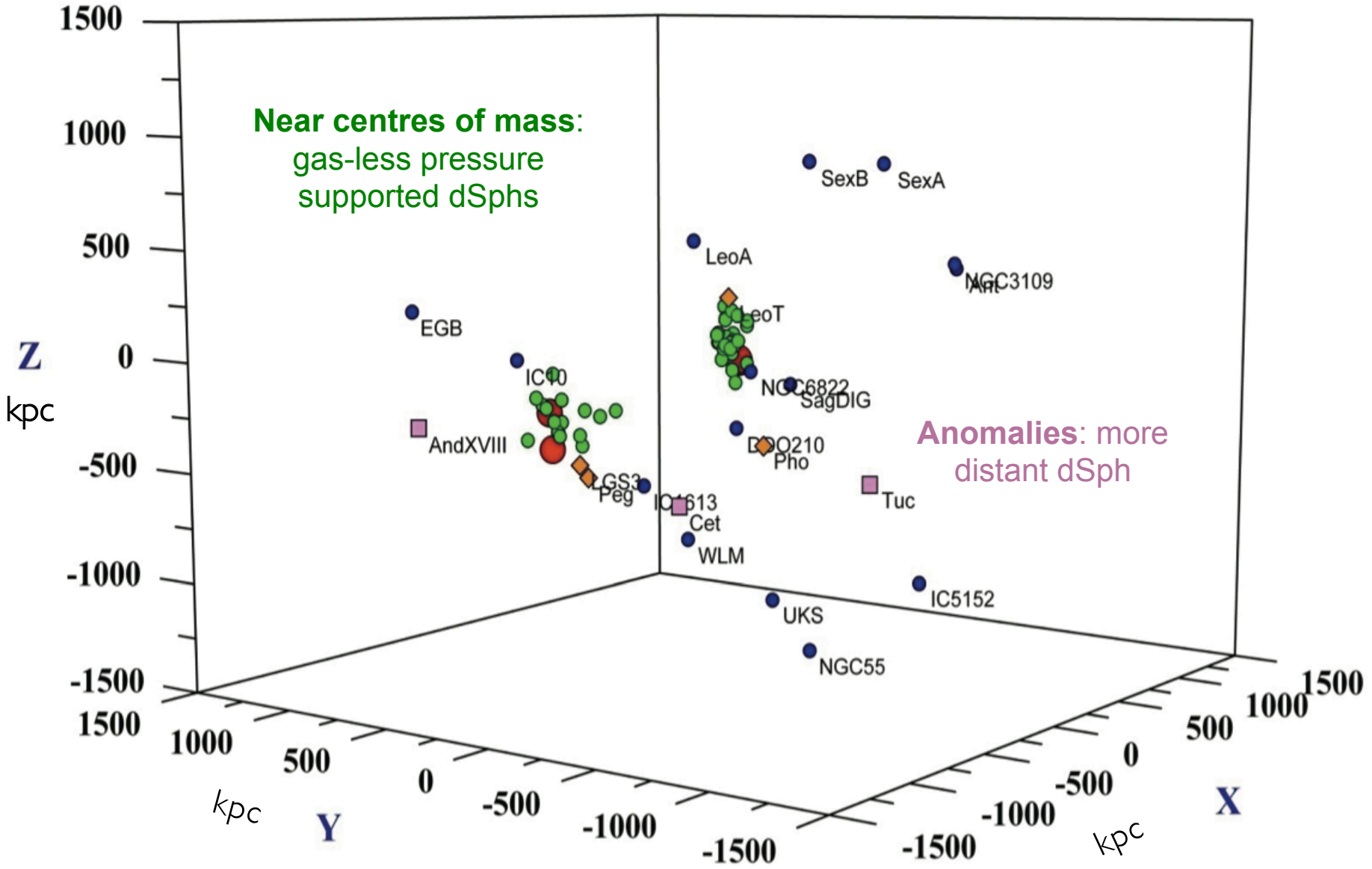
stars fall into two distinct populations:
Pop I and Pop II

In the spring of 1953, I witnessed Walter Baade and Jan Oort dreaming aloud about European astronomers' creating a powerful joint observatory—the dream that became the European Southern Observatory (ESO).

Adriaan Blaauw (2004) ARAA, 42, 1

Baade 1944a ApJ, 100, 137
Baade 1944b ApJ, 100, 147

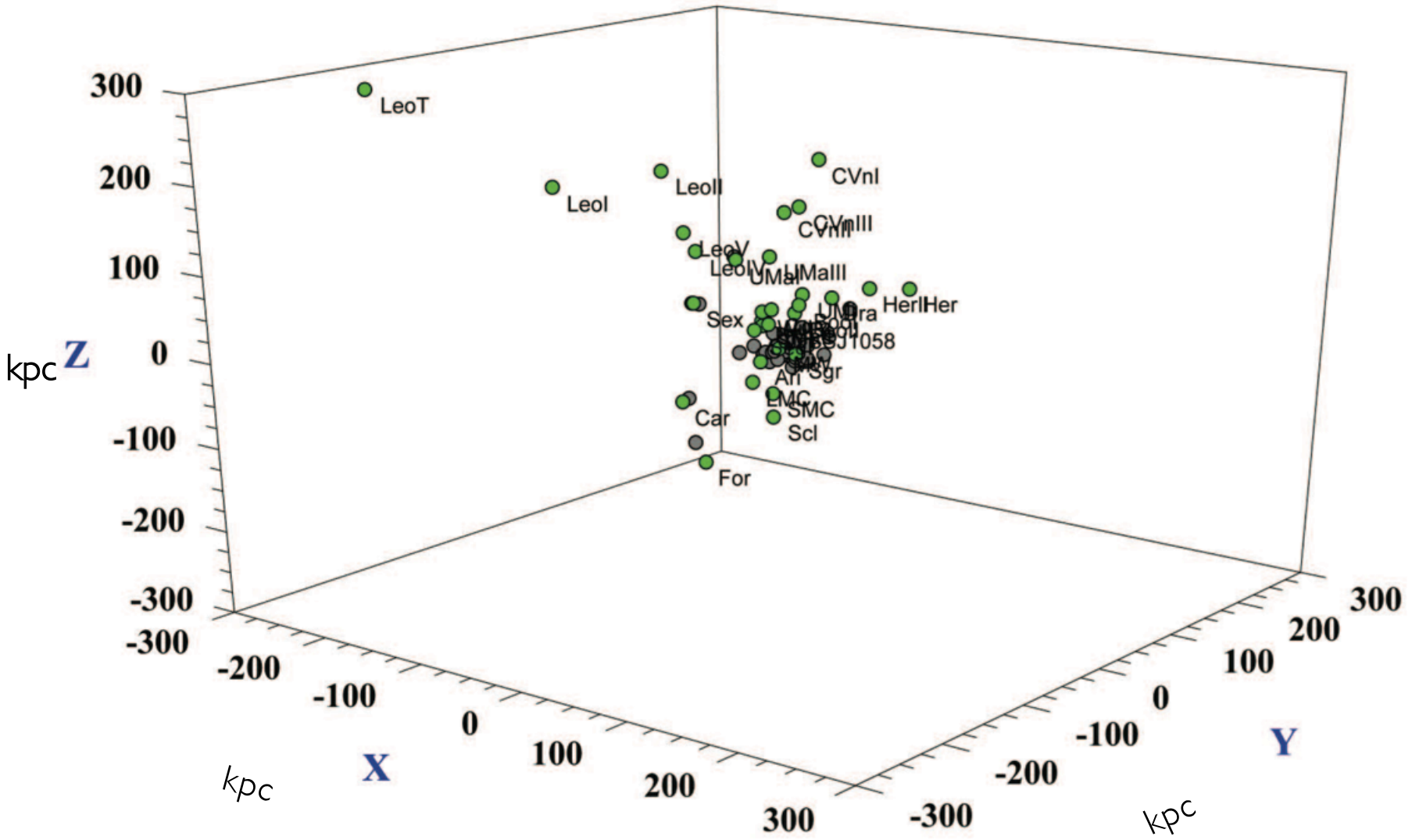
The Local Group



Outer regions: dominated by gas rich quiescently evolving dwarf irregulars

Mateo 2008, Garching workshop

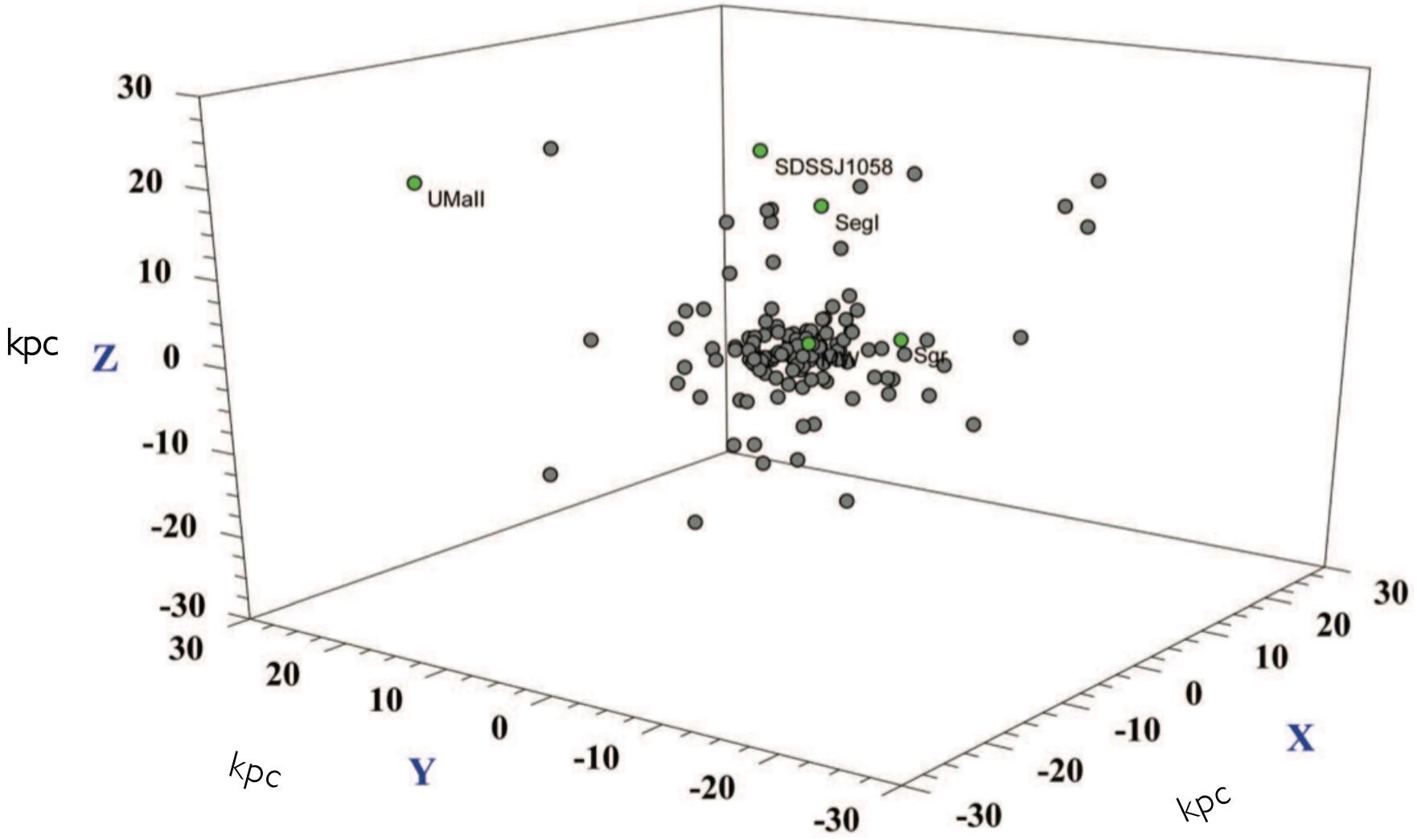
The Milky Way Halo



Mateo 2008, Garching workshop

Globular Clusters

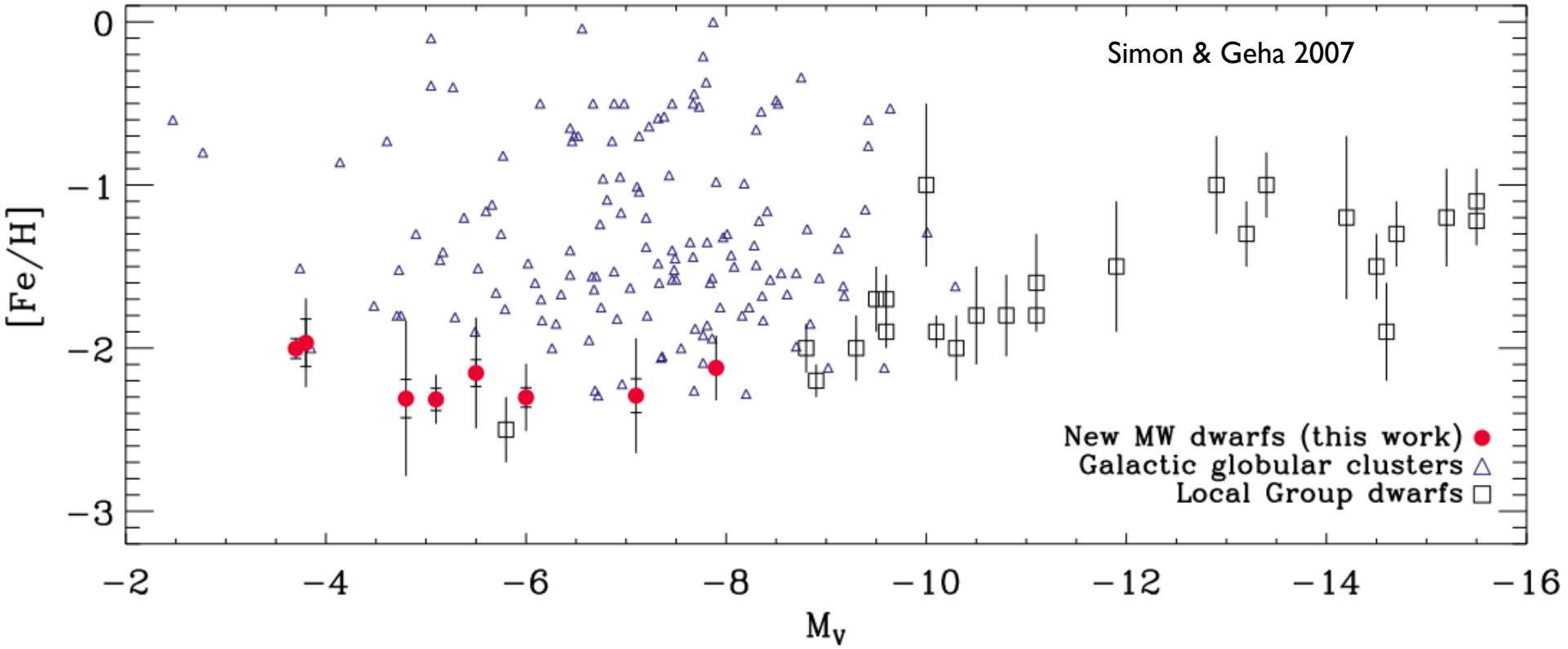
(and a few ultra-faints)



~140 globular clusters, 65% <8kpc from centre

Mateo 2008, Garching workshop

Global Properties: luminosity & size



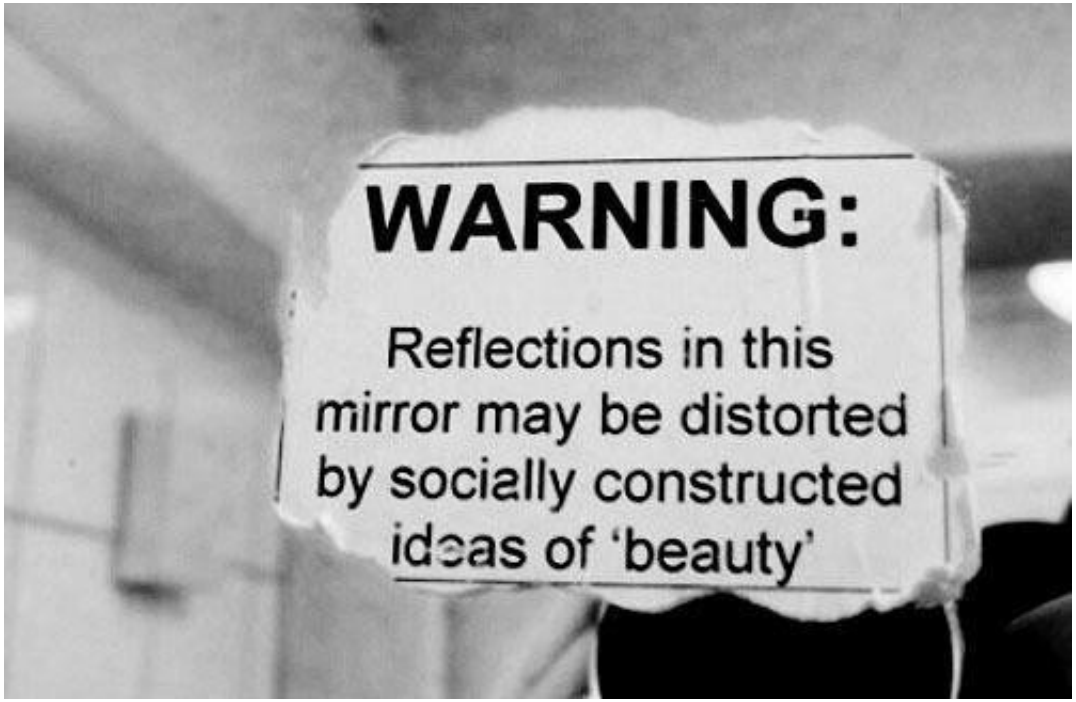
- Wide Field Imaging down to oldest MSTOs (Star formation histories, structure, ages)

- LR metallicities and velocities over wide field ([Fe/H], kinematics & mass modeling)

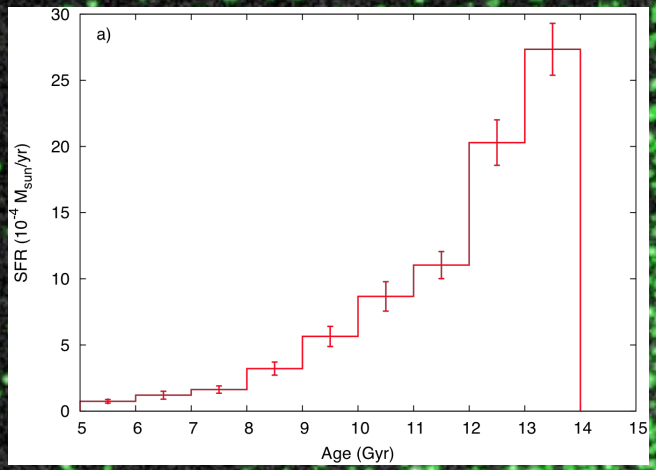
- Follow up: looking for rare objects, like extremely metal poor stars

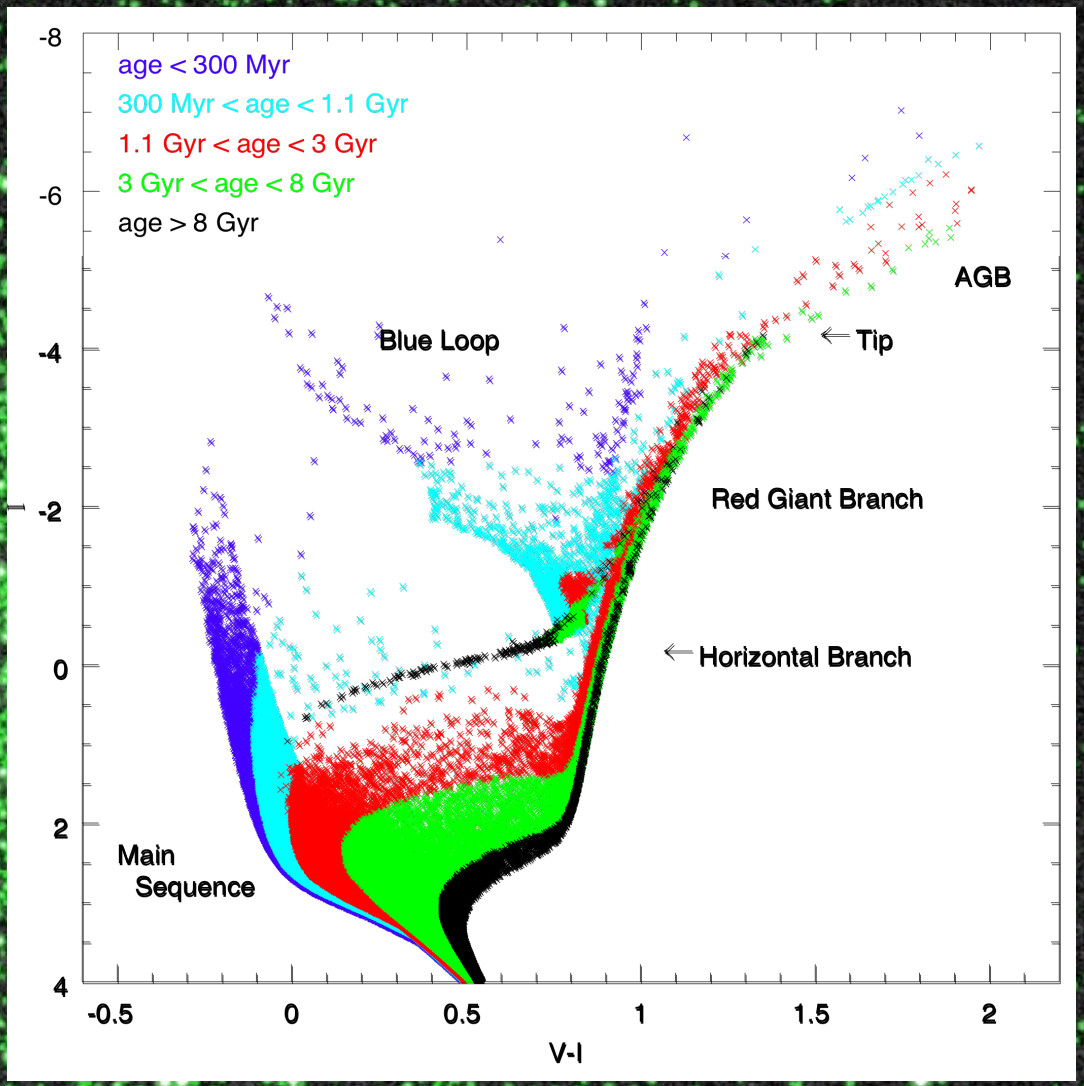
-HR abundances (numerous chemical elements, e.g., Fe, Mg, Ca, Ba, Ni etc.)

Imaging


WARNING:
Reflections in this mirror may be distorted by socially constructed ideas of 'beauty'

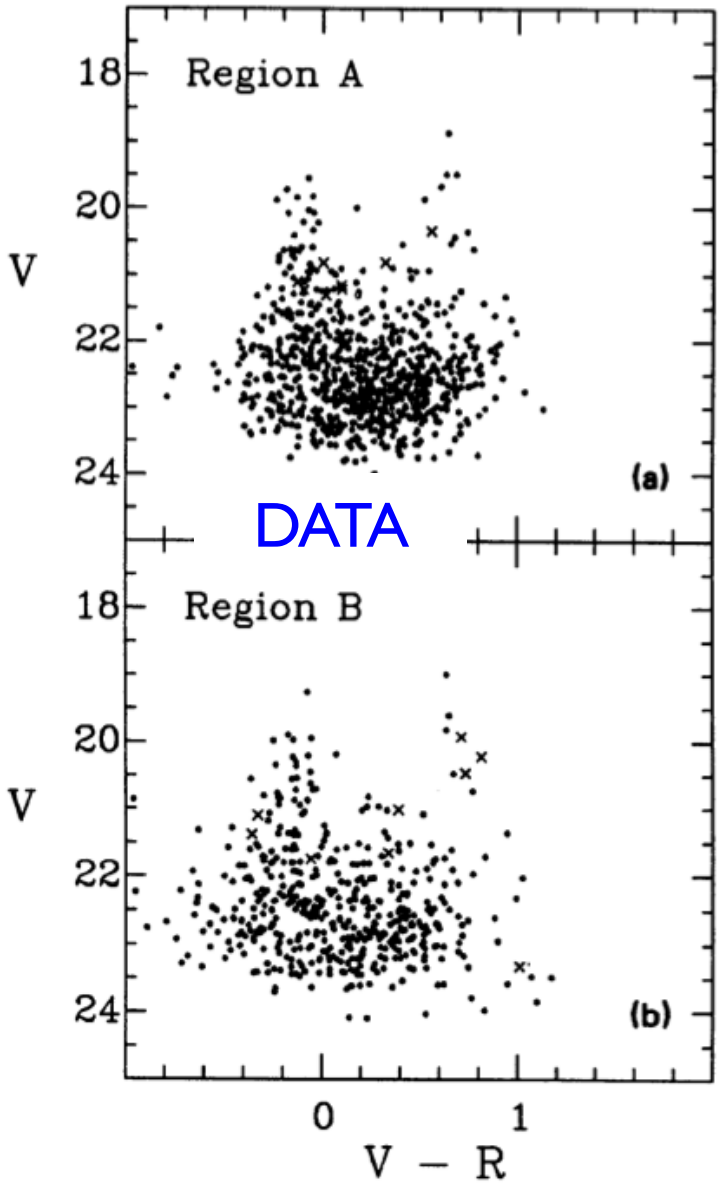
RESOLVED STELLAR POPULATIONS





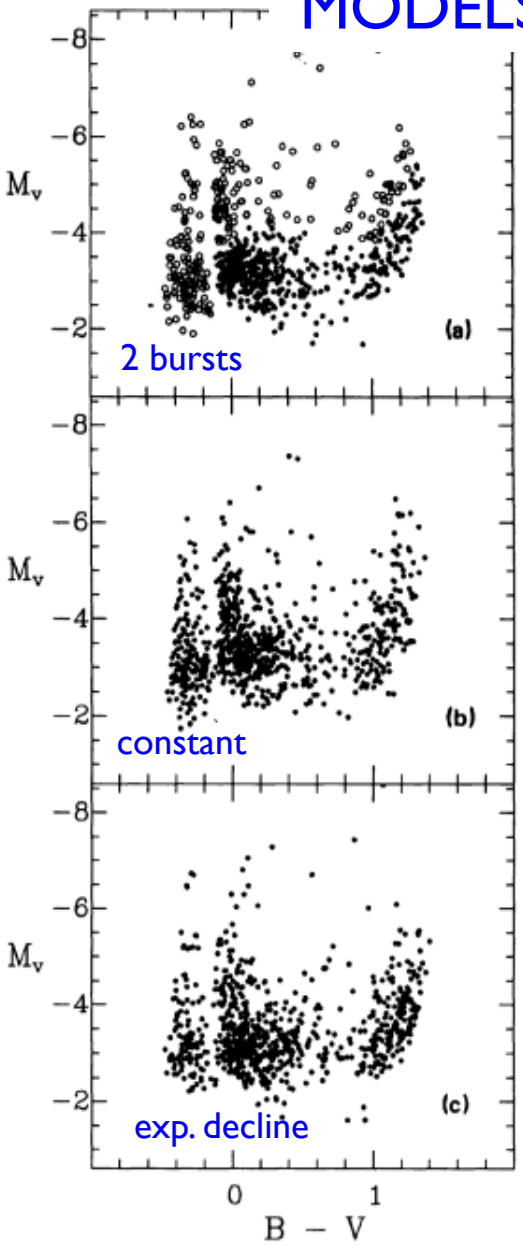
Synthetic CMD modelling

SEXTANS B: ESO/MPI 2.2m, March 1988



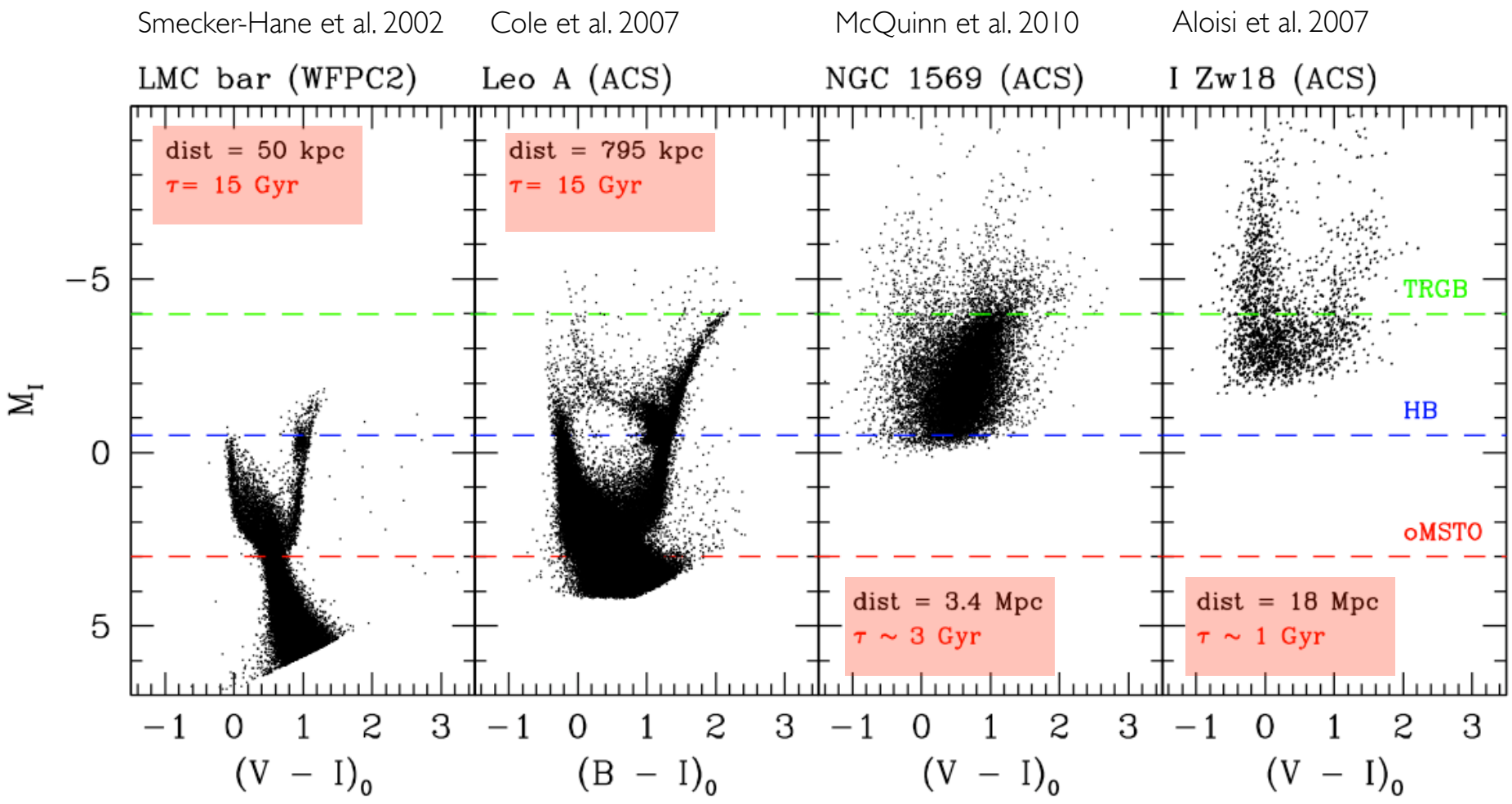
DATA

MODELS



Tosi et al. 1991 AJ, 102, 951

Probing Different Environments



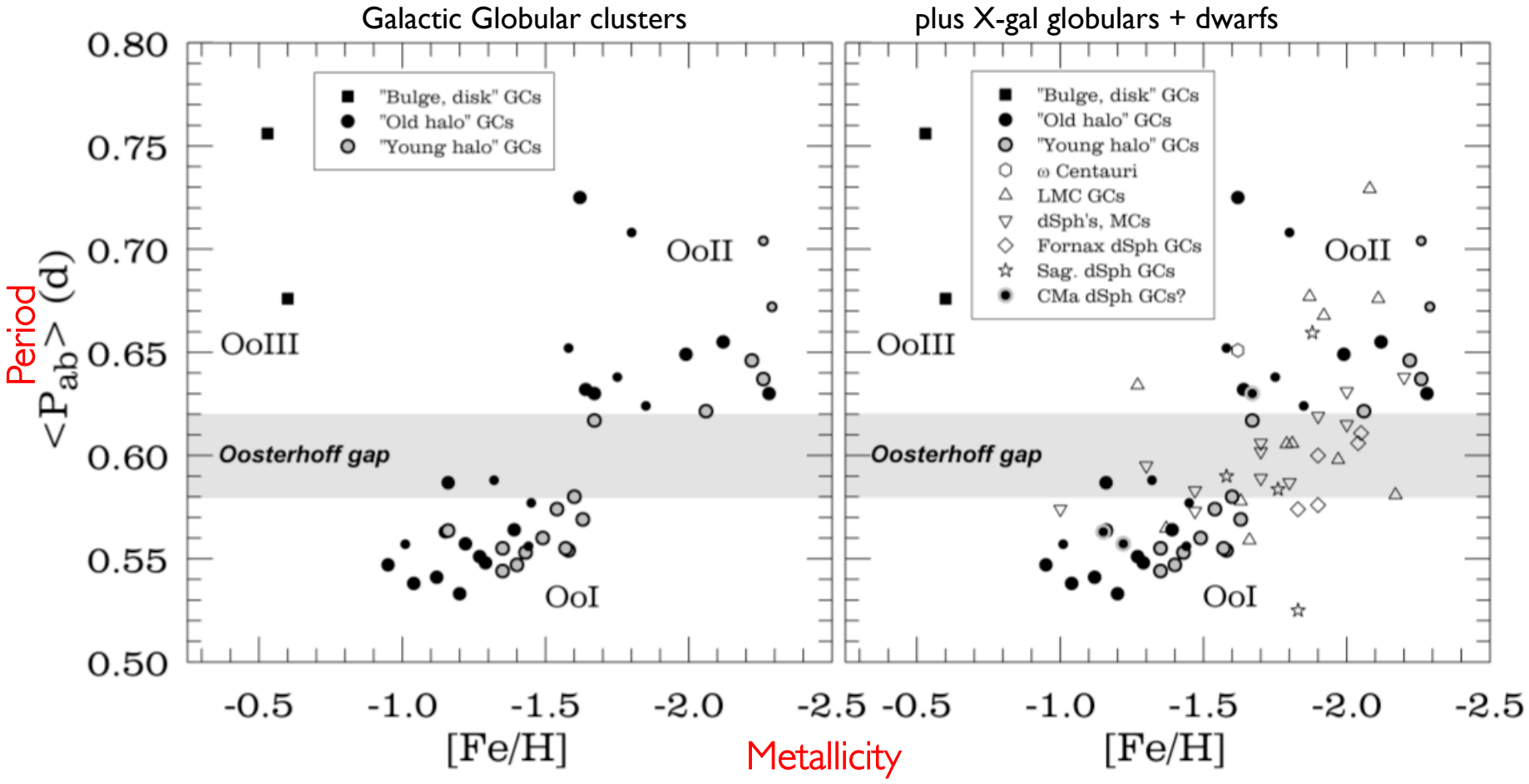
We can't study all galaxies with the same detail and beyond the Local Group it becomes particularly difficult with current facilities.

RR Lyr Variable Stars

Oosterhoff Dicotomy

Oosterhoff (1939)

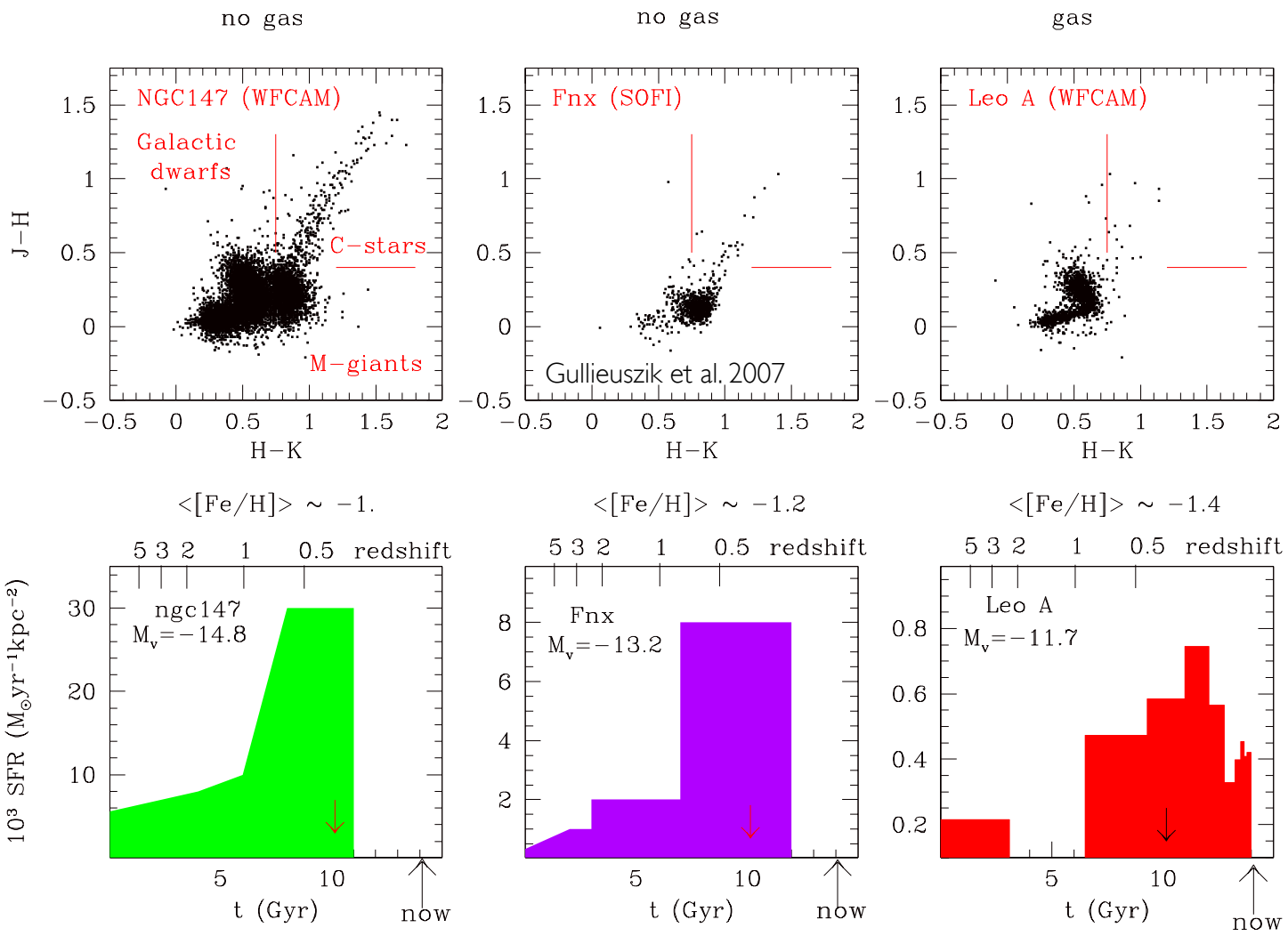
Galactic GCs can be divided into two groups according to the mean periods of their RR Lyrae stars.



Dichotomy also present in field stars….

Catelan 2009

IR Imaging: E-AGB stars

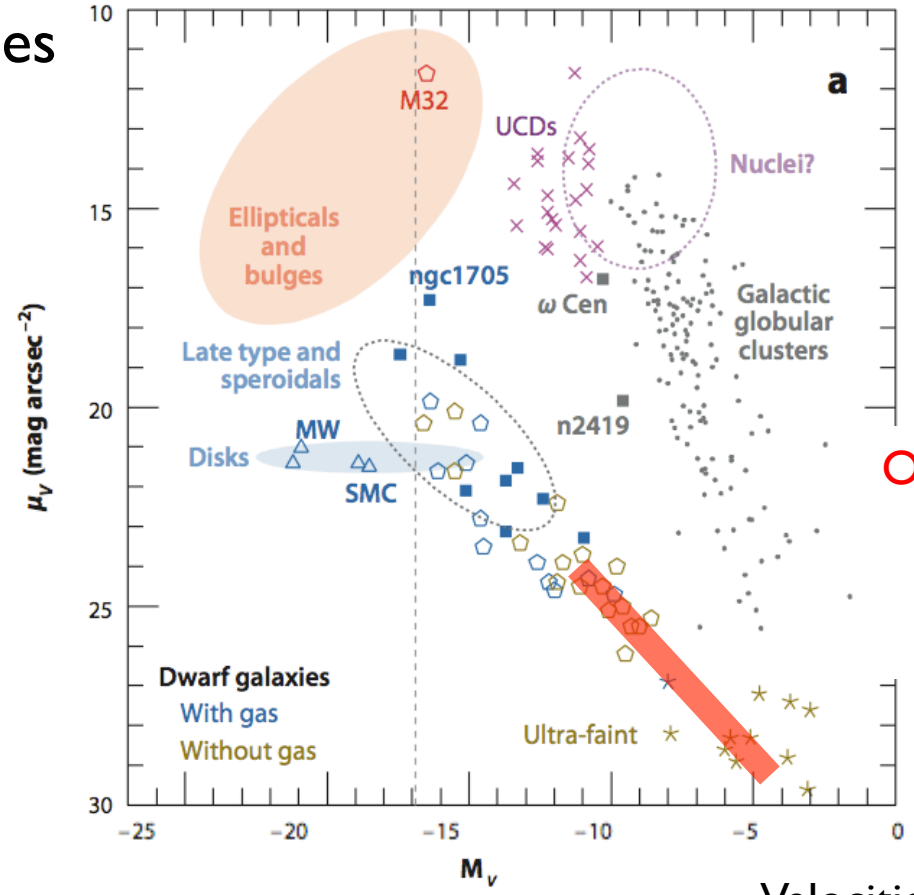


Tolstoy 2010

Spectroscopy

- Velocities
- Metallicity
- Abundances

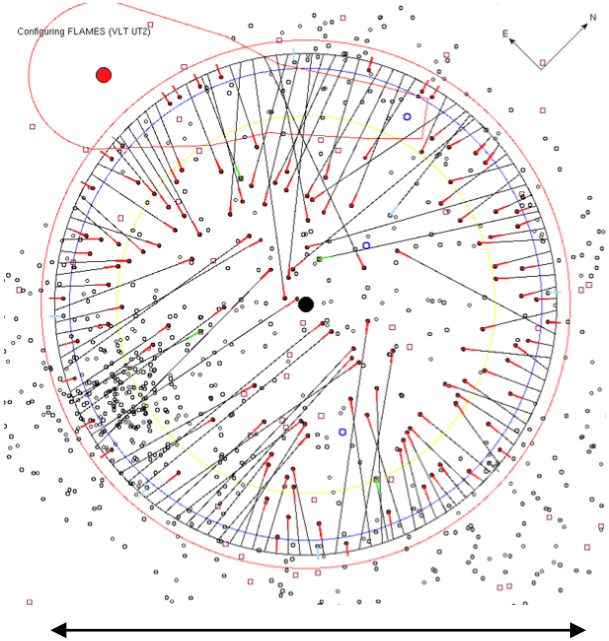
More distant studies of massive stars in star-forming system



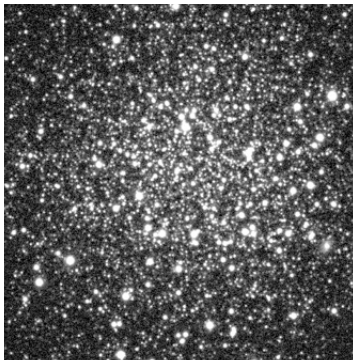
Only the very closest galaxies can be subjects of detailed abundance studies of old (RGB) stars: dSph+UFD

Velocities can be measured over a larger range of distance

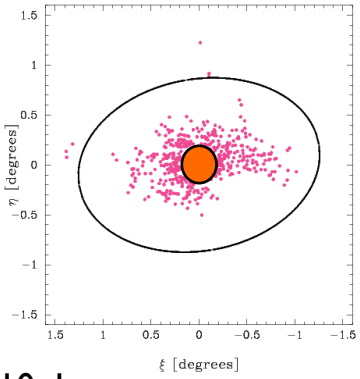
GIRAFFE



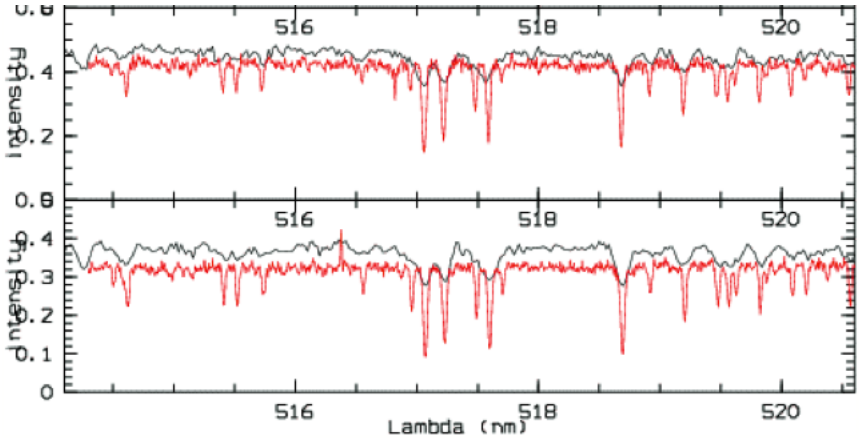
25 arcmin



Well suited to nearby dSph

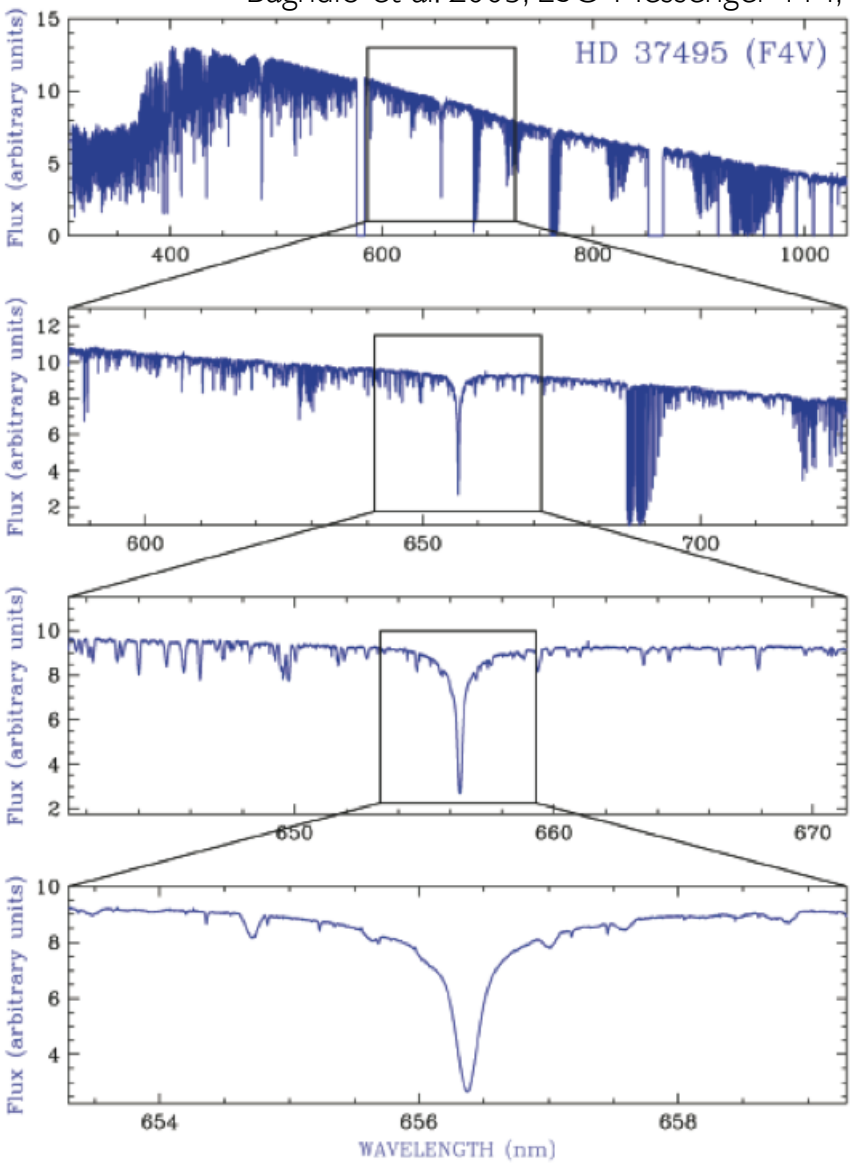


Pasquini et al. 2002, ESO Messenger 110, 1



UVES

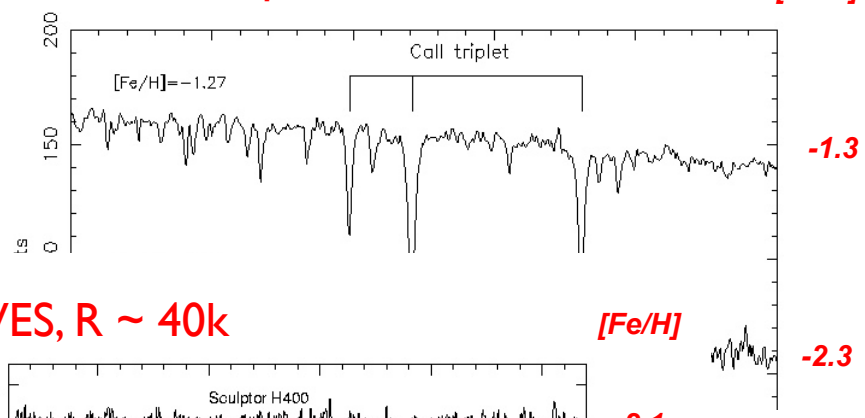
Bagnulo et al. 2003, ESO Messenger 114, 10

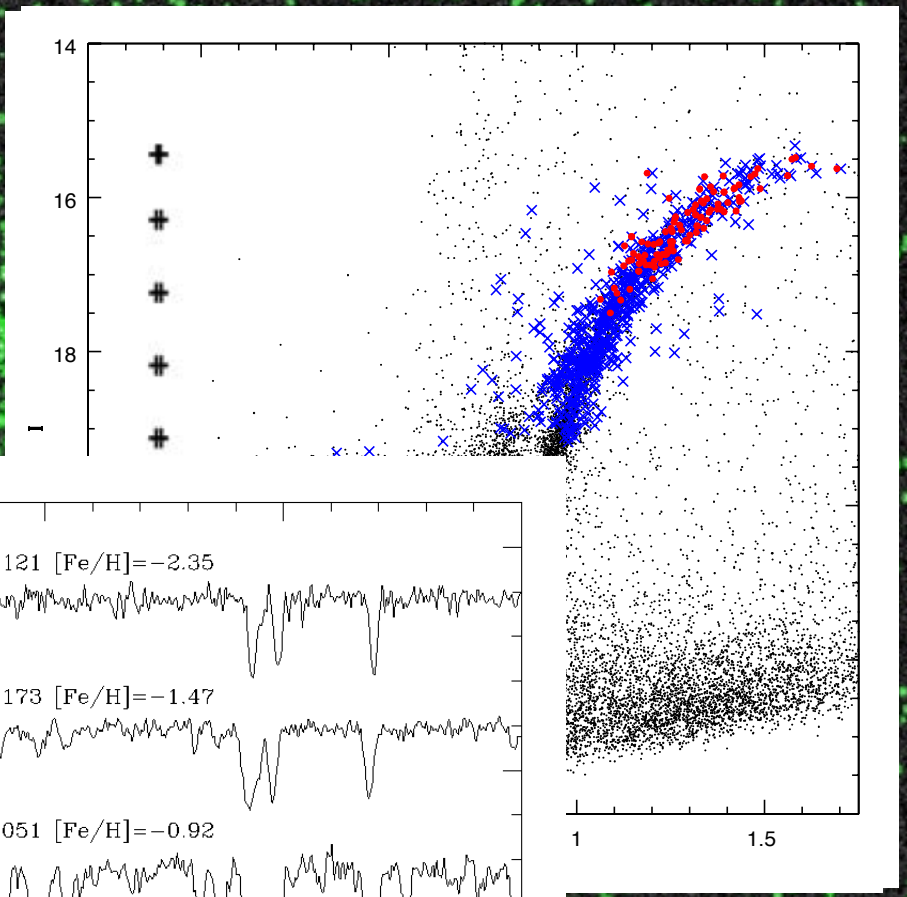


Dekker et al. 2000, SPIE, 4008, 534

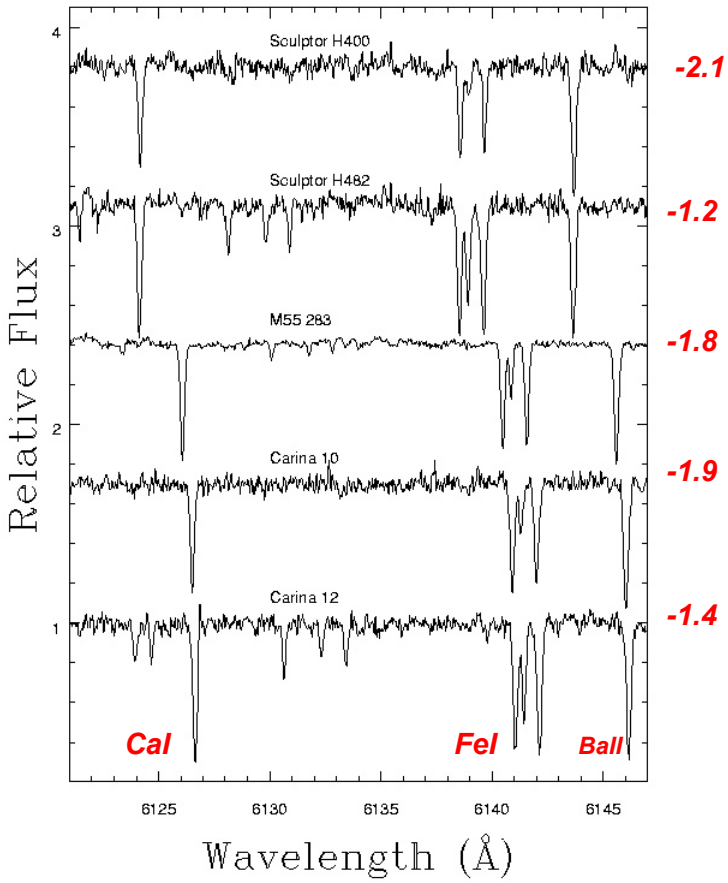
RESOLVED STELLAR POPULATIONS

Ca II Triplet R~6000

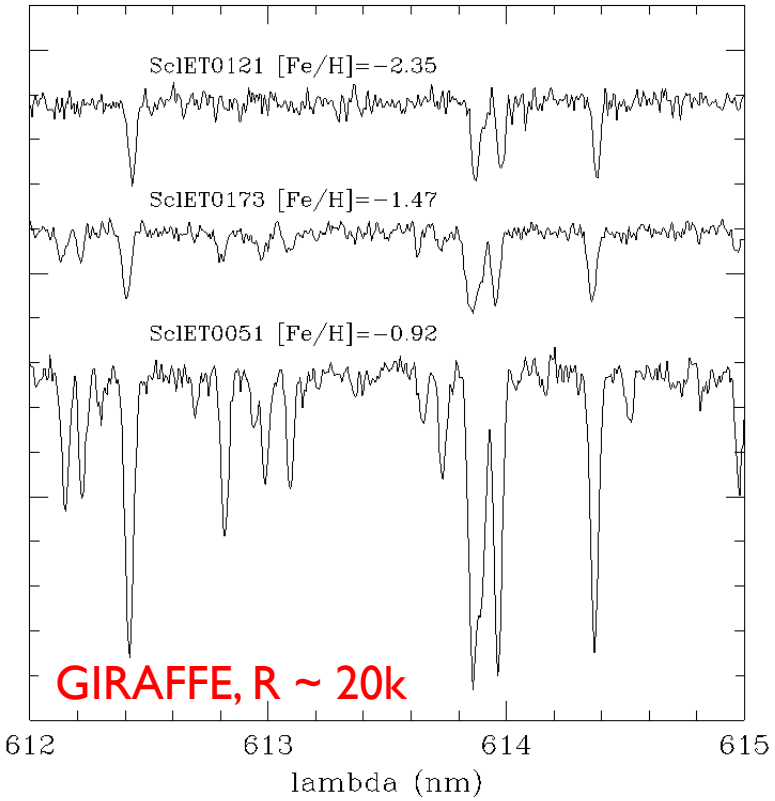




UVES, R ~ 40k



GIRAFFE, R ~ 20k



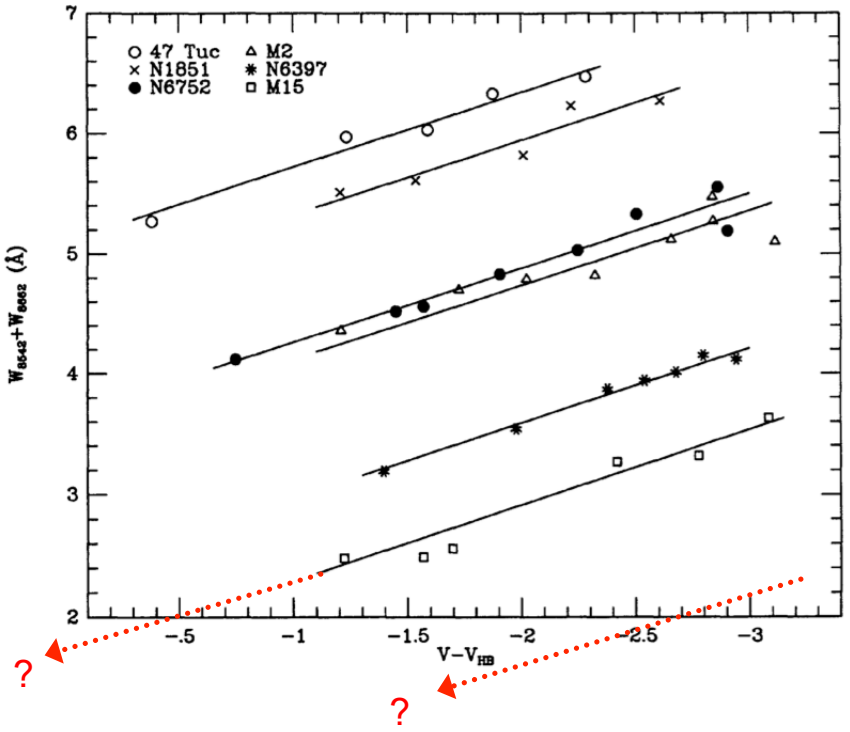
Metallicity Indicators

American Science and Engineering Inc, (AS&E)

Ca II triplet

Only valid for RGB stars!!

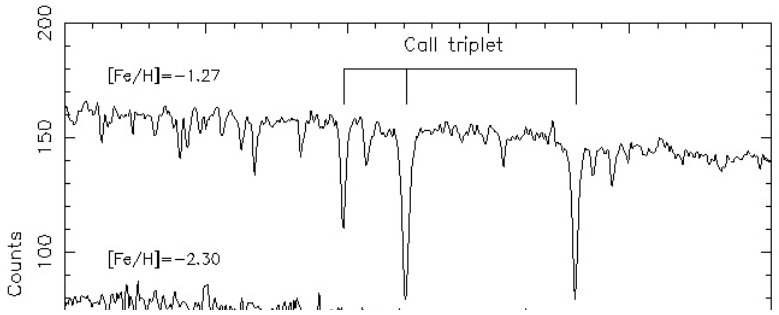
Armandroff & da Costa 1991



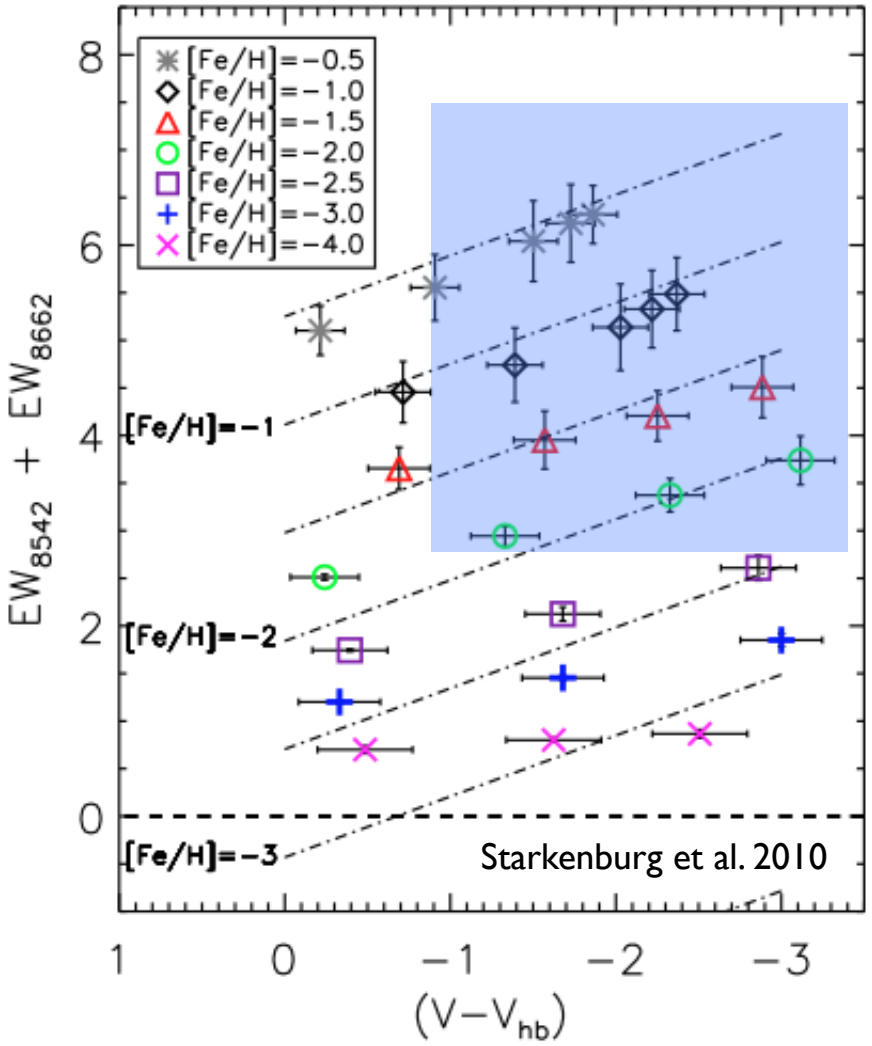
The slope has to change or the relation will become unphysical around [Fe/H] ~ -3

R~6000

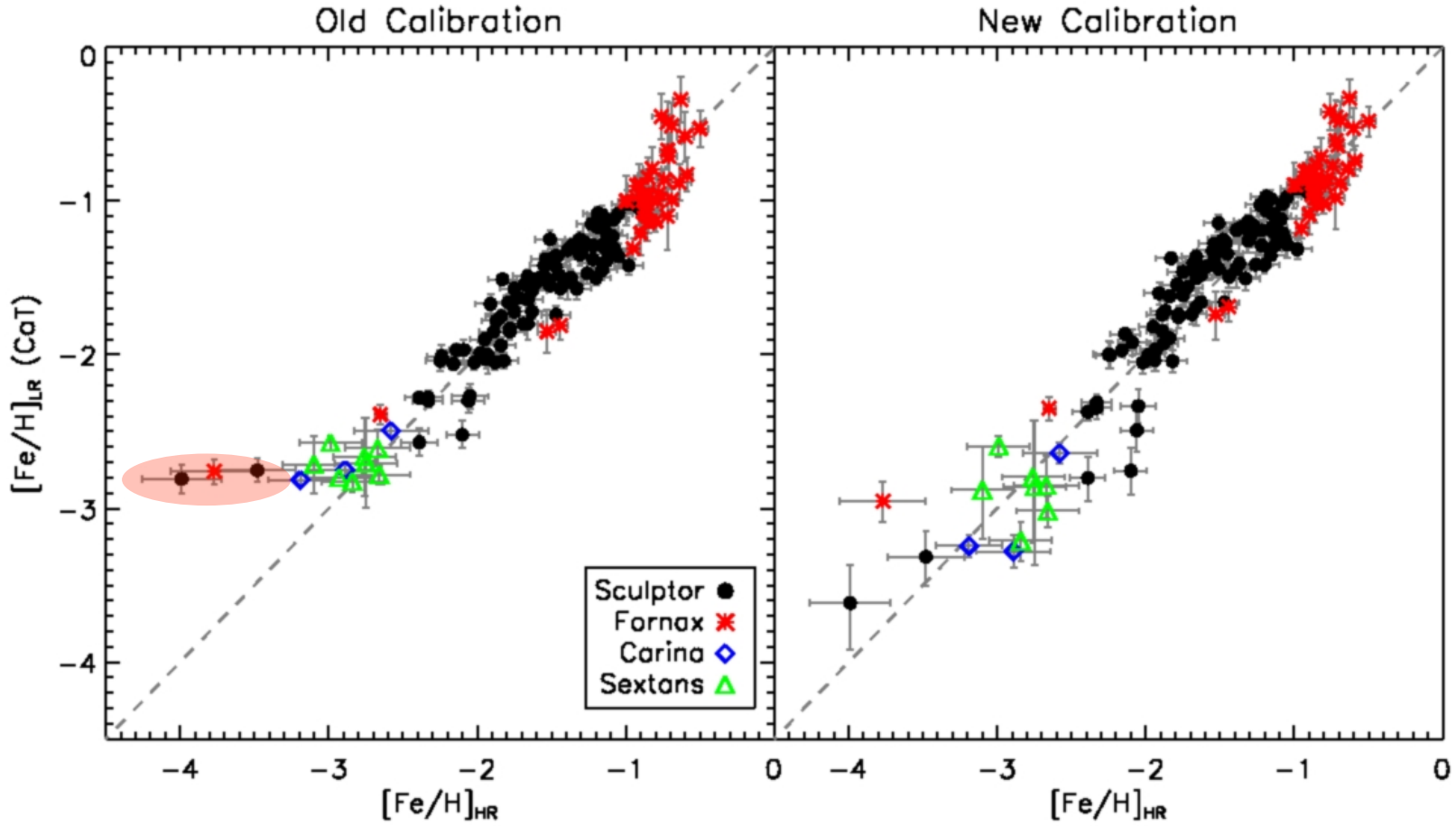
[Fe/H]



-1.3



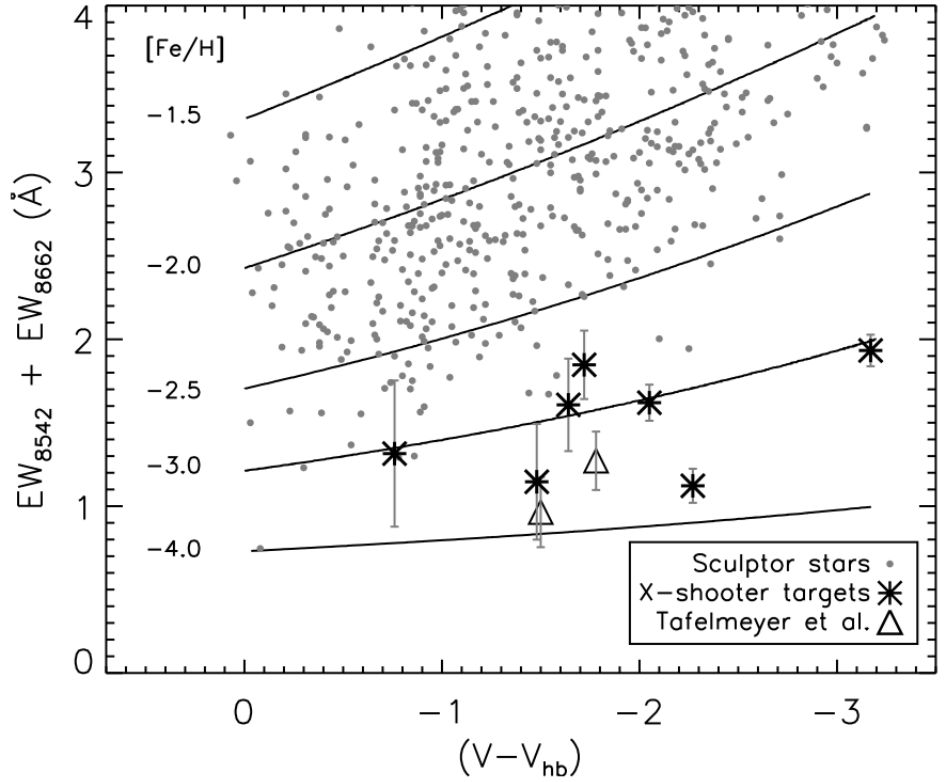
Ca II triplet recalibration

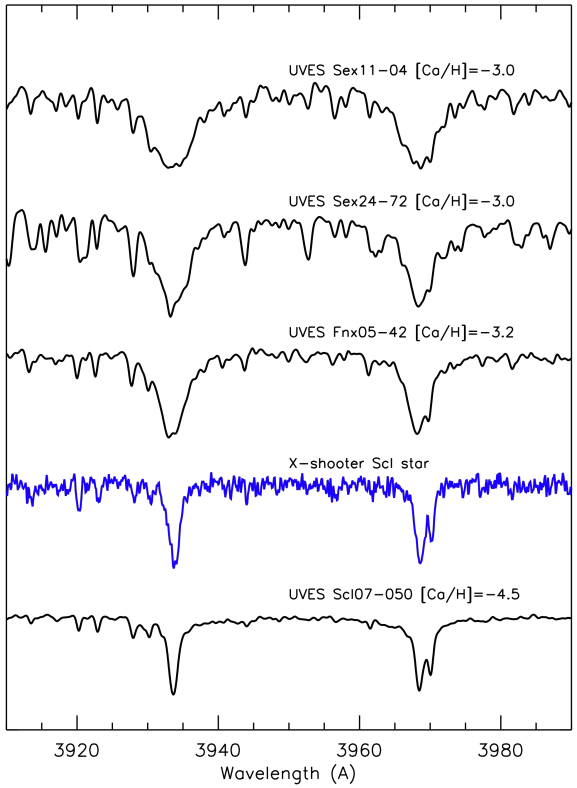


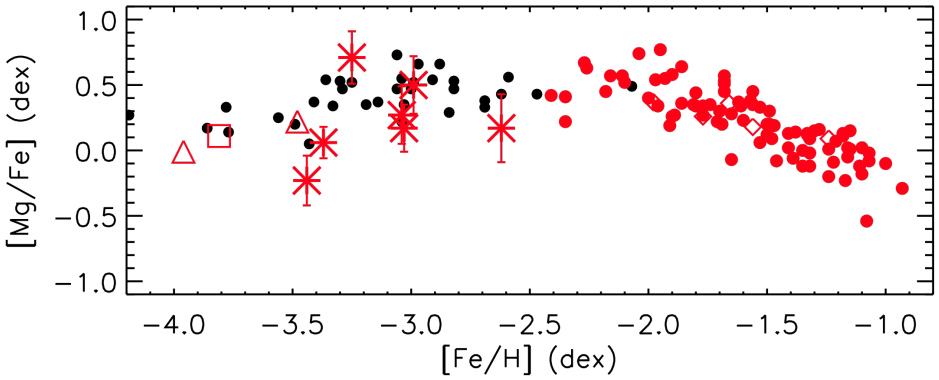
Tafelmeyer et al. 2010
Venn et al. 2012
Aoki et al. 2009 A&A
Battaglia et al. 2008

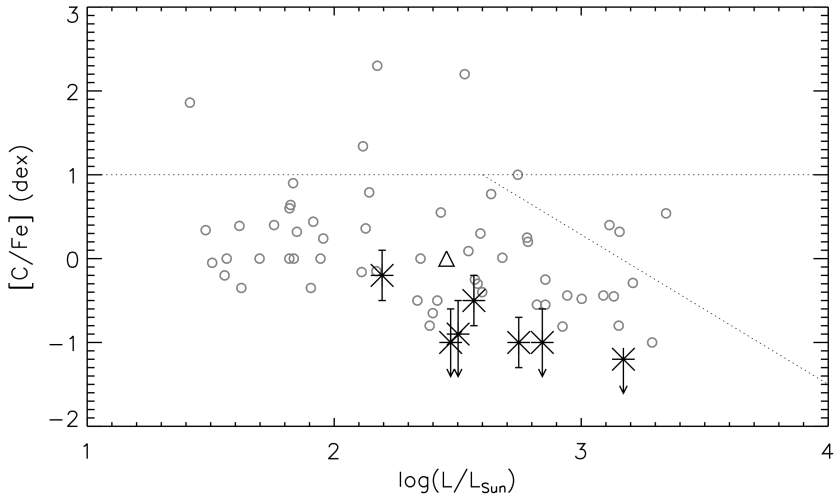
Starkenburg et al. 2010

X-shooter follow-up





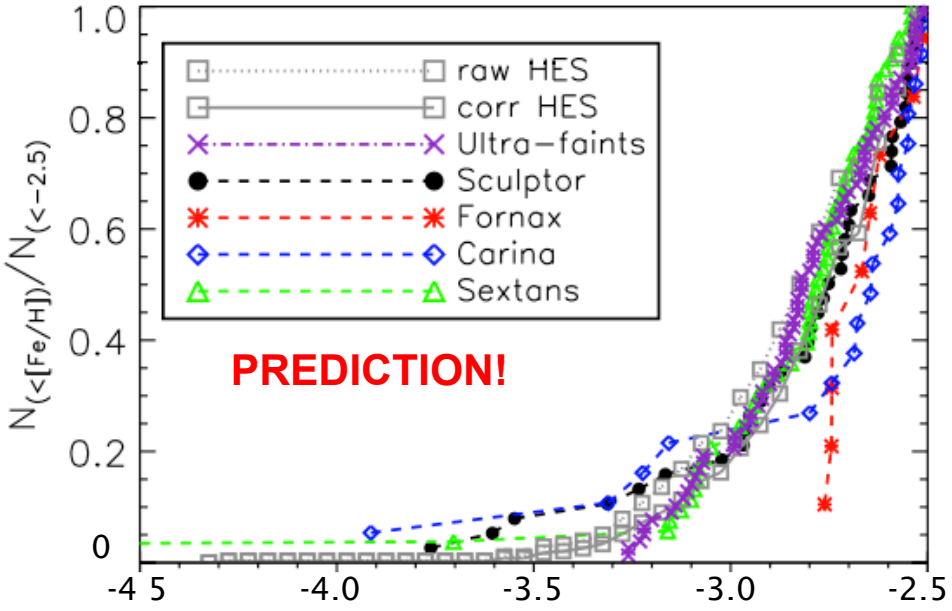


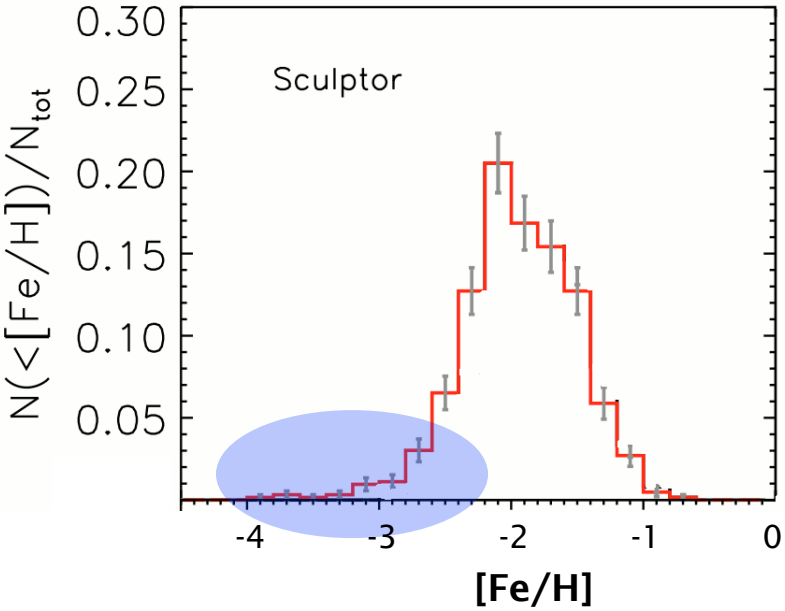


Starkenburg et al. 2012 submitted (Dutch GTO)

Metal Poor tails...

Starkenburg et al. 2010

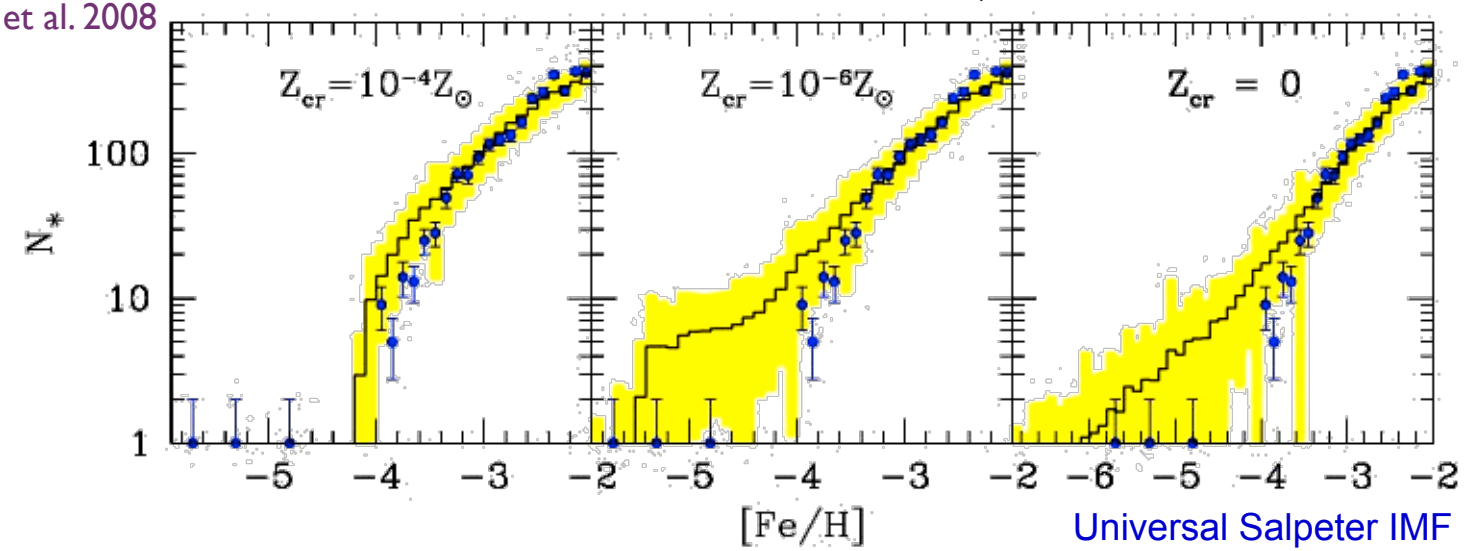




MW halo: Schörck et al. 2009

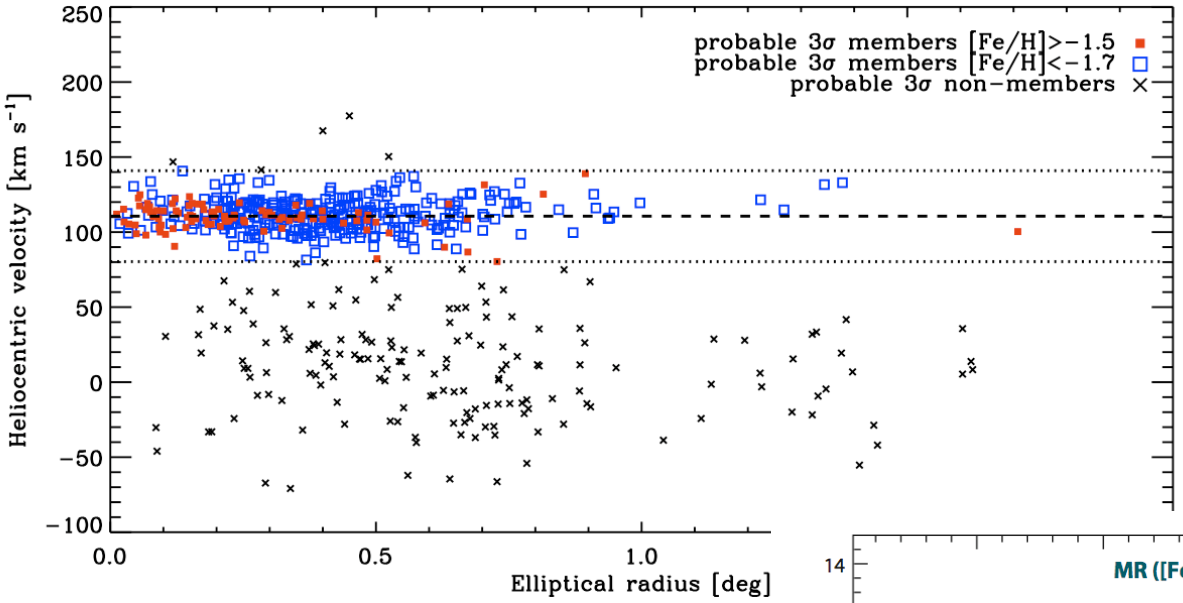
Ultrafaints: Kirby et al. 2008

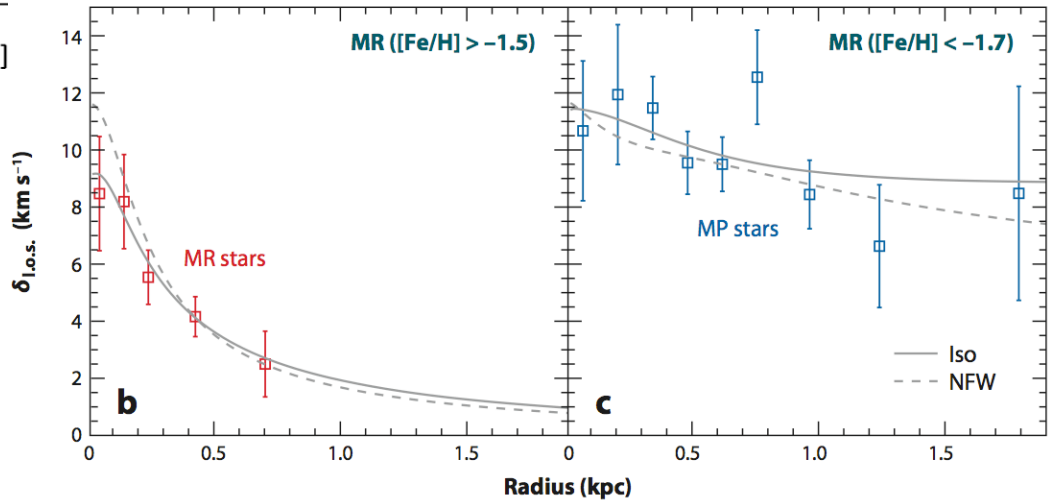
Salvadori, Schneider & Ferrara 2007



Universal Salpeter IMF

Kinematics & Chemistry



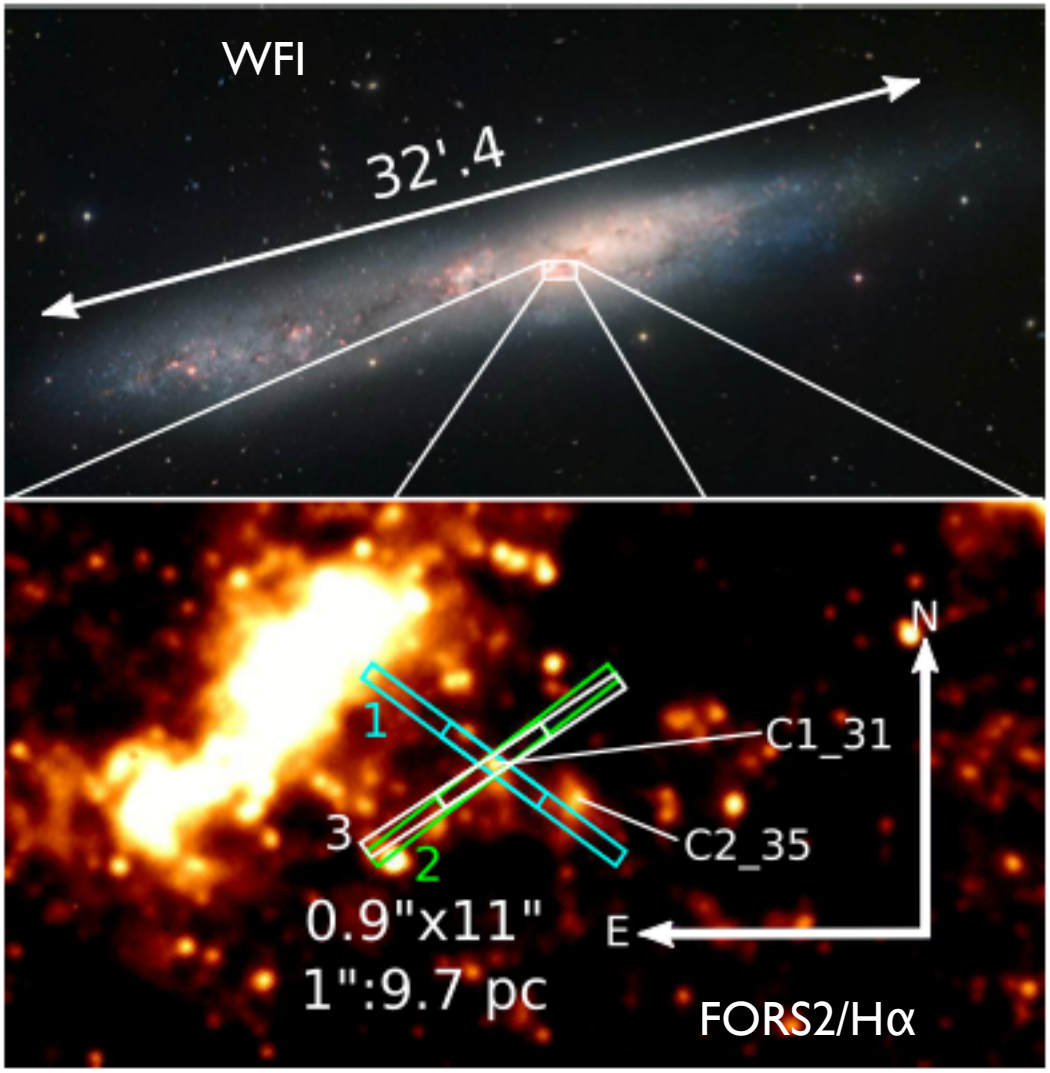


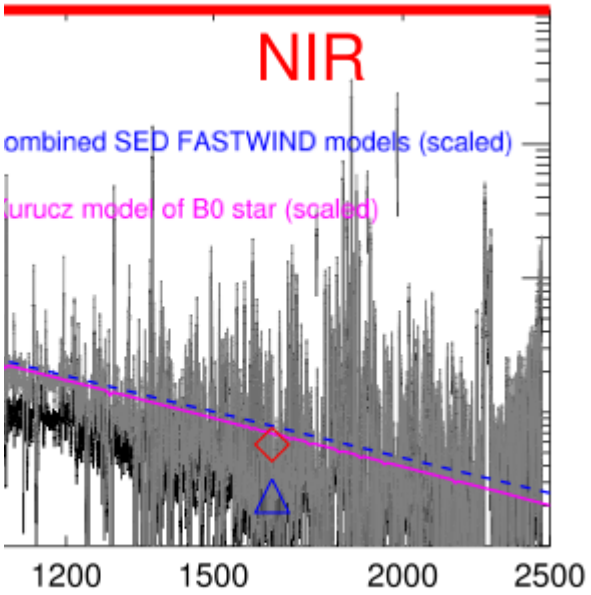
Tolstoy et al. 2004
Battaglia et al. 2008, 2009, 2011

M/L~160; M=3x10^{8}M$_\odot$

Distant Early Type Stars

NGC55





Distance ~ 2 Mpc

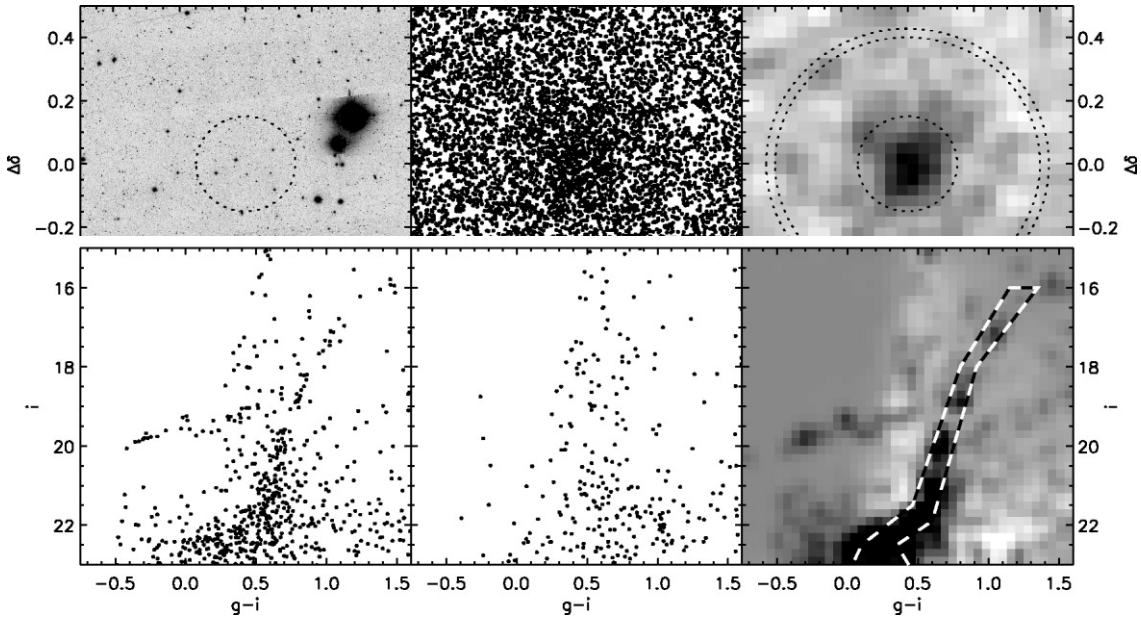
Hartoog et al. 2012 MNRAS

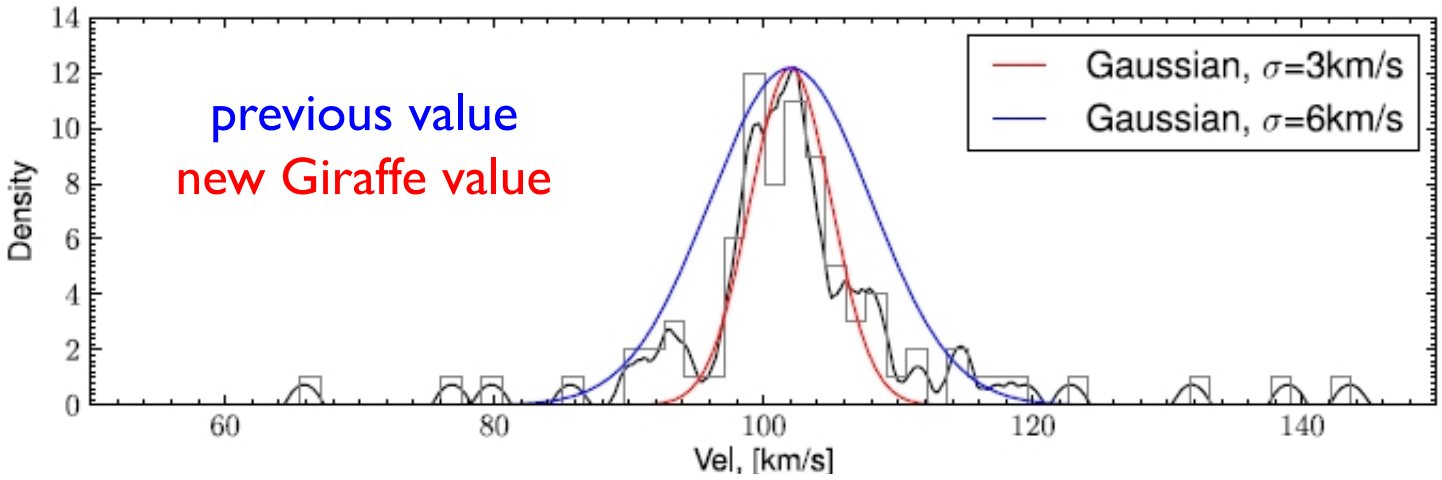
Boötes I

D ~ 60kpc

M_V ~ -5.8

R_h ~ 220pc





FLAMES/Giraffe velocities are both precise and reliable ➔ taking dSph kinematics to the most extreme ultra-faints.

Koposov et al. 2011, ApJ, 736, 146

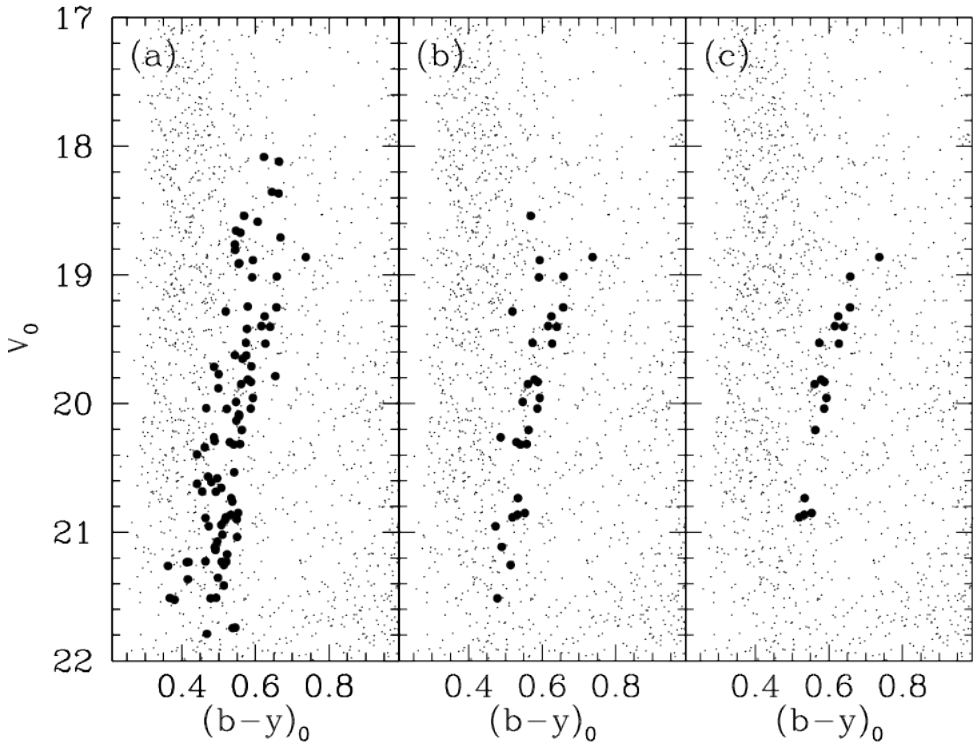
Belokurov et al. 2006, ApJL, 647, 111

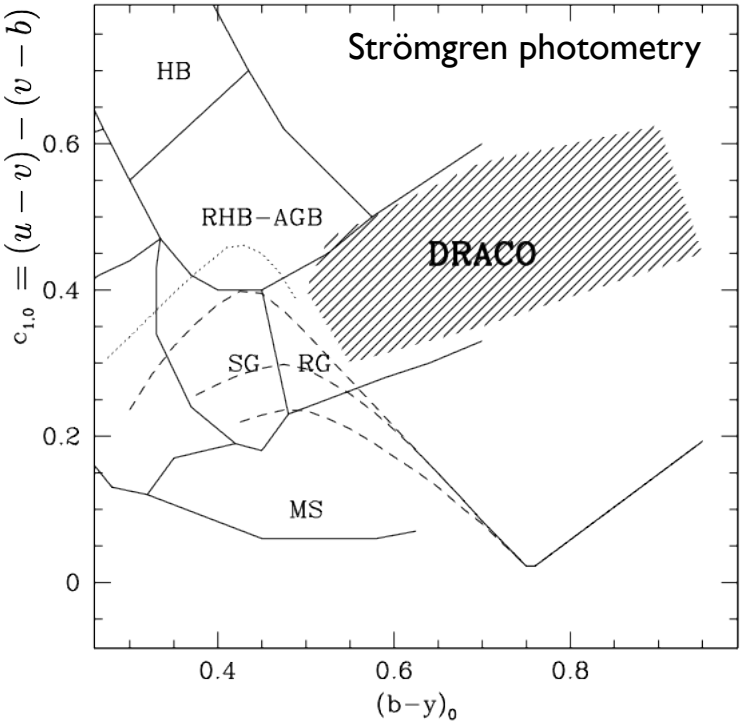
Hercules

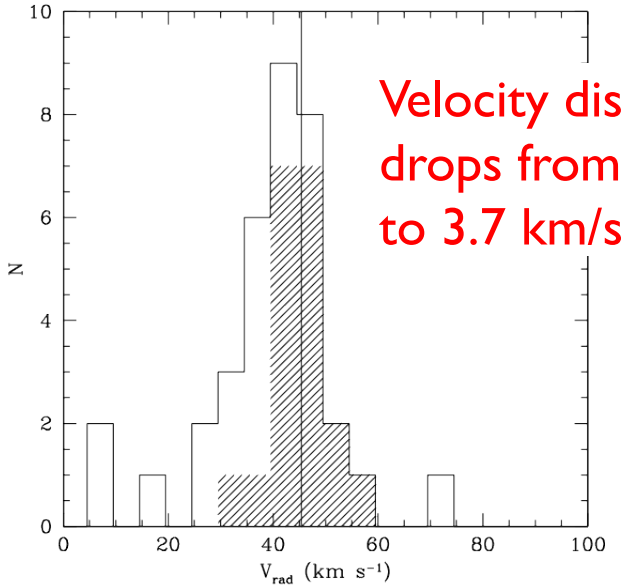
D ~ 150kpc

M_V ~ -6.6

R_h ~ 300pc







Velocity dispersion drops from >7 km/s to 3.7 km/s

Adén et al., 2009 A&A, 506, 1147

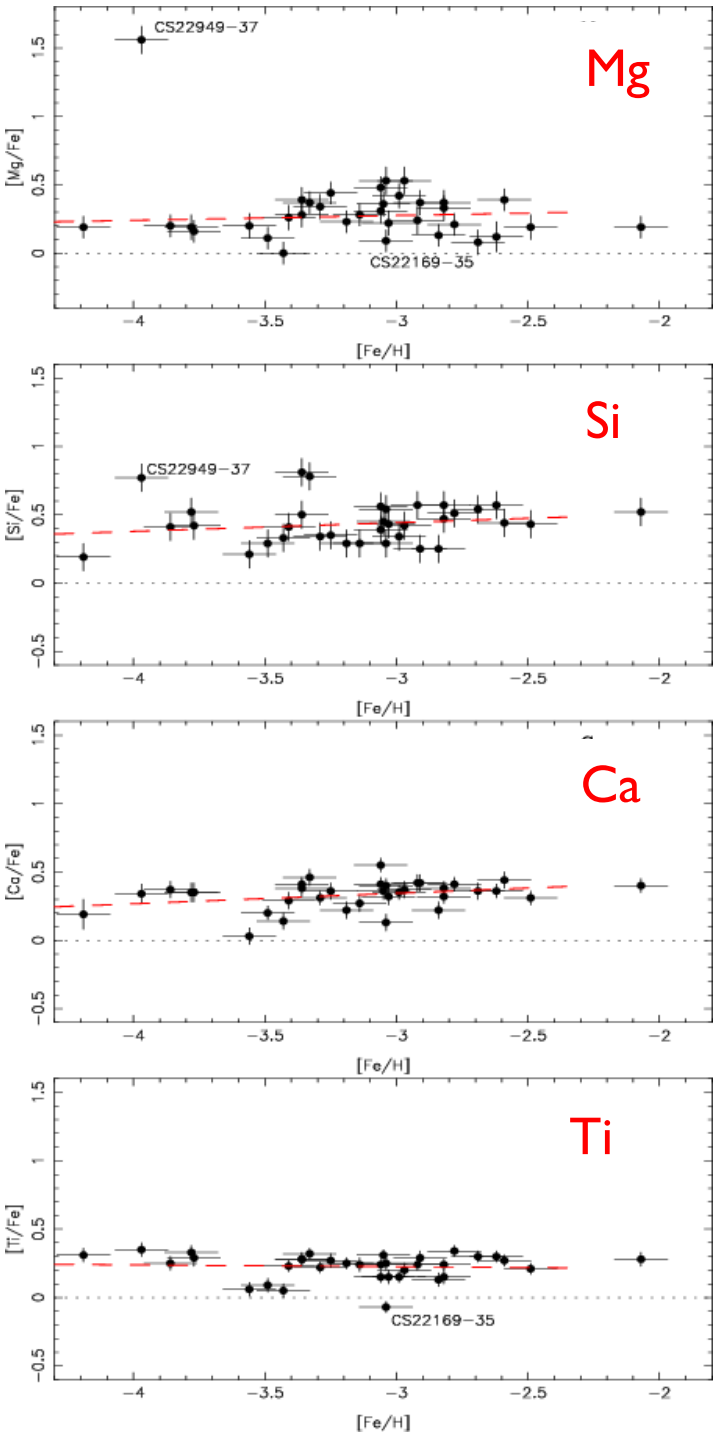
Detailed Abundances

EMPS in Galactic halo

ESO Large Programme:
"The First Stars"
30 giants:

-4.1 < [Fe/H] < -2.7

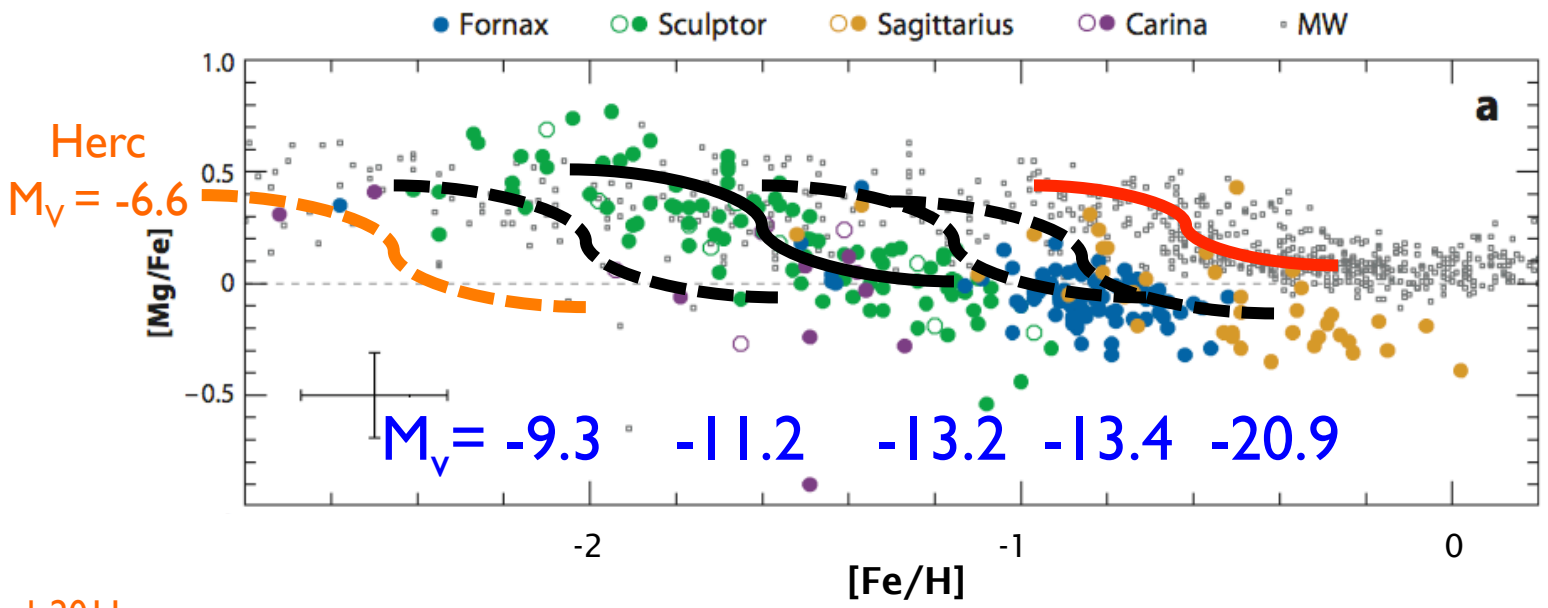
The absence of significant star-to-star scatter – given that these stars likely boast in the mean only ~ one progenitor implies a robust nucleosynthesis mechanism and/or a narrow mass range of (massive) star zero-metallicity progenitors.



Cayrel et al. 2004
A&A, 416, 1117

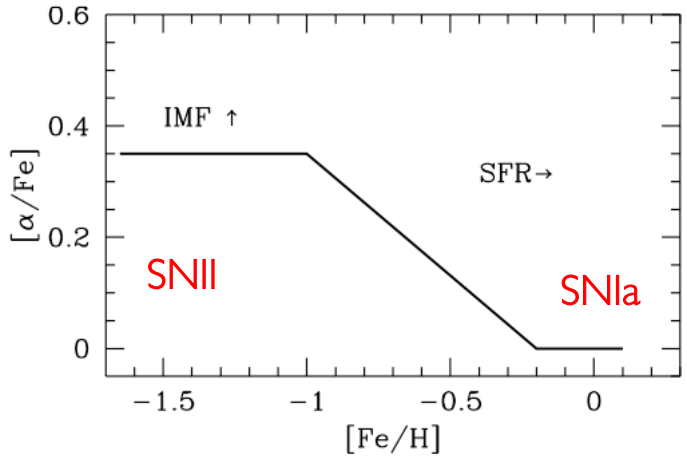
Alpha element abundances in dSph

"The Knee"



Adén et al. 2011

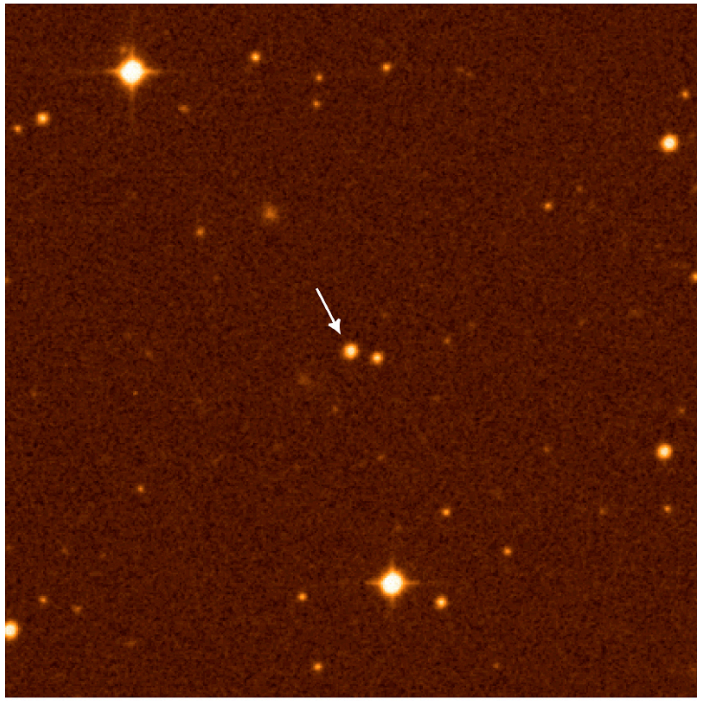
Hill et al. 2012, in prep.
Geisler et al. 2005
Shetrone et al. 2003 AJ
Letarte et al. 2010 A&A
Koch et al. 2008
Venn et al. 2012 ApJ
Lemasle et al. 2012 A&A
Sbordone et al. 2007
Venn et al. 2004



Tolstoy, Hill & Tosi 2009

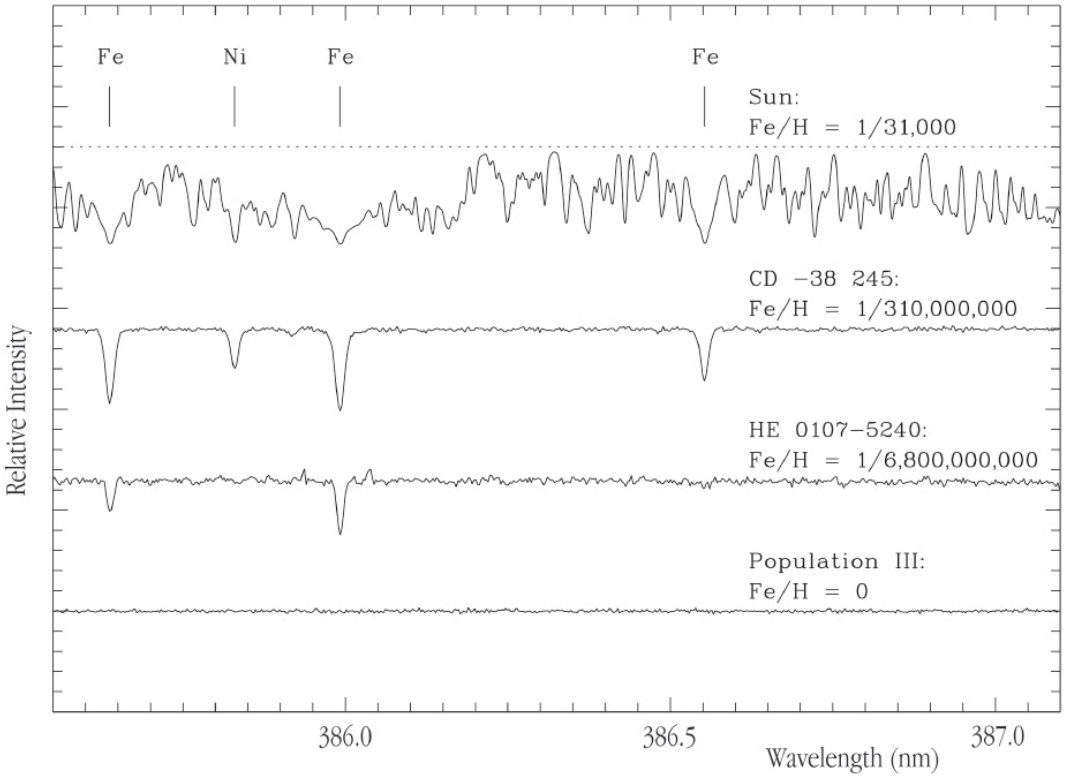
Christlieb star...

HE 0107-5240



The Very Metal-Deficient Star HE 0107-5240

ESO PR Photo 25a/02 (30 October 2002)



Spectra of Stars with Different Metal Content

ESO PR Photo 25b/02 (30 October 2002)

[Fe/H] = -5.4

$Z \leq 10^{-3.5} Z_{\odot}$

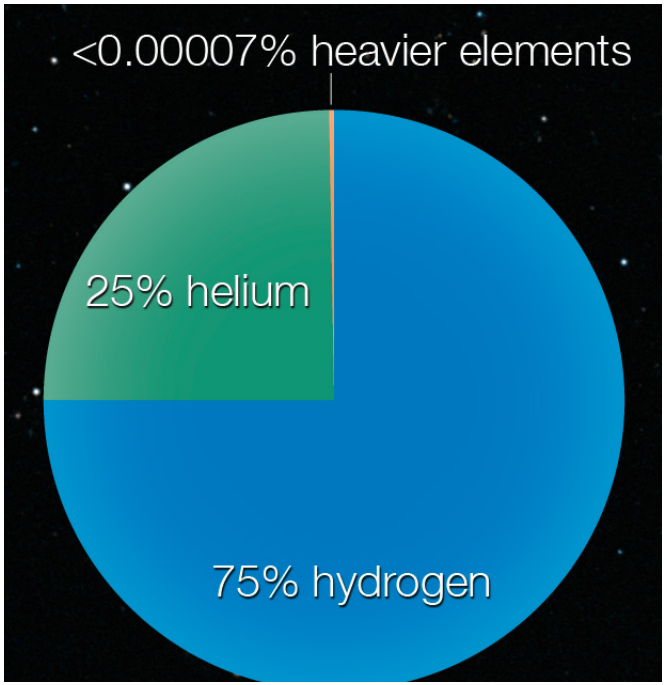
Christlieb et al. 2002 Nature, 419, 904

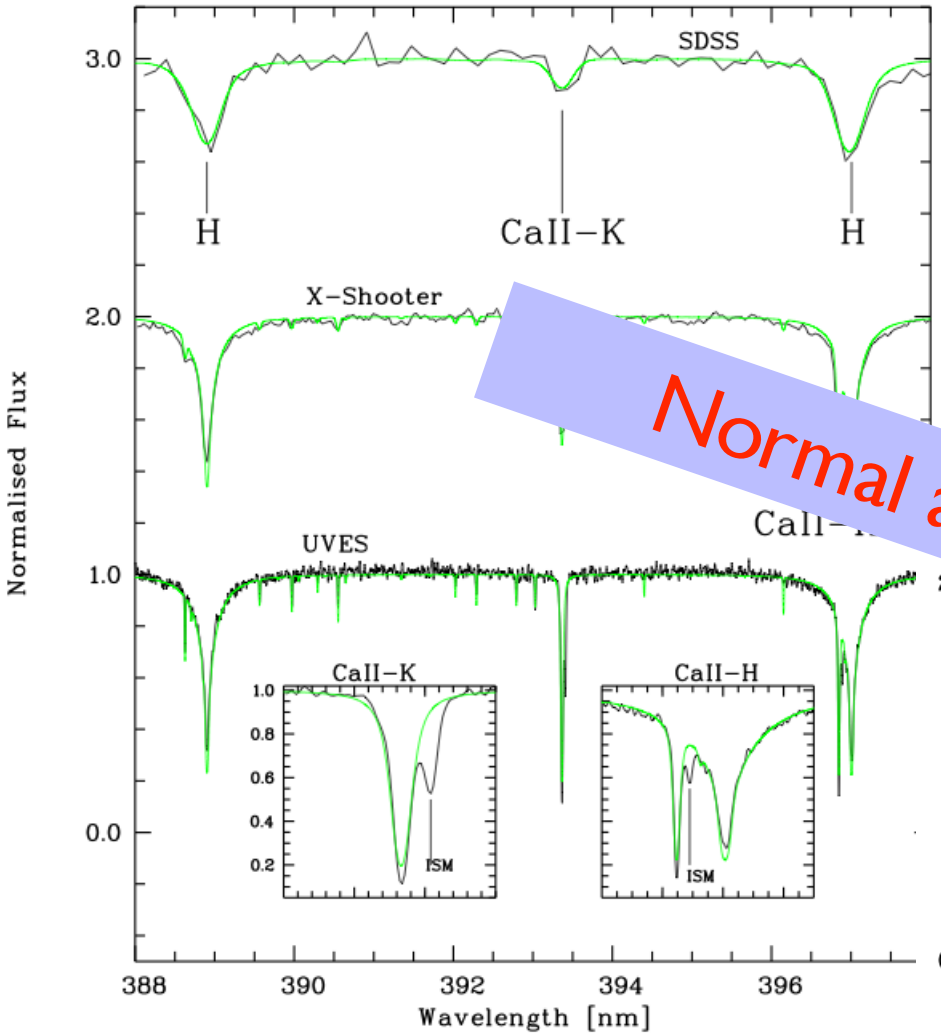
Caffau star

SDSS J102915+172927

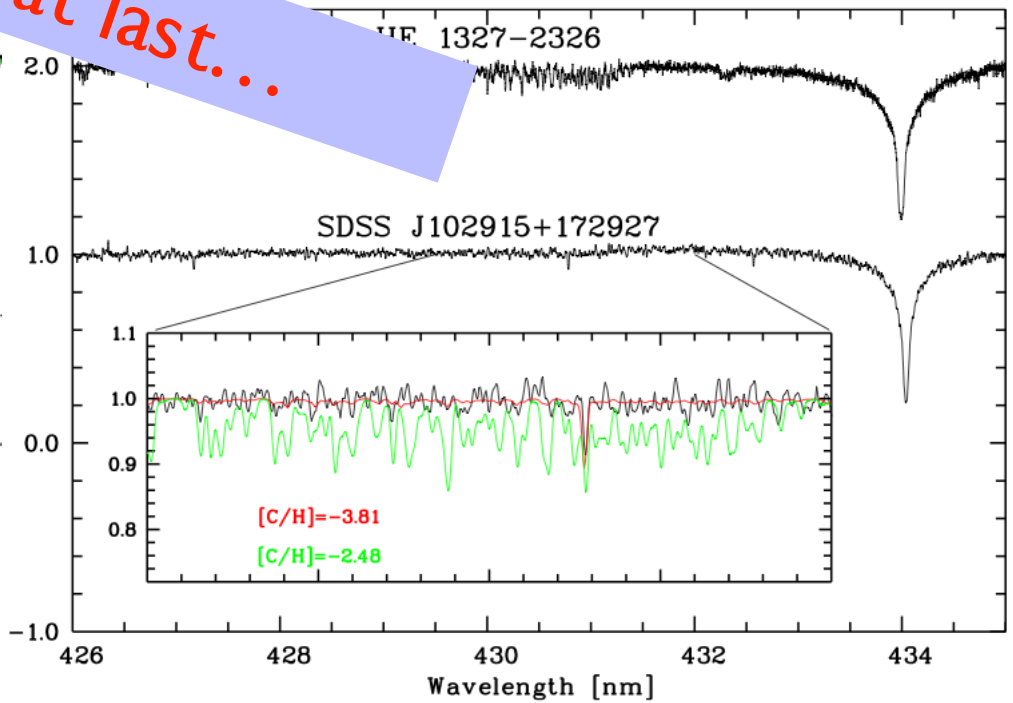
[Fe/H] = -4.9

$Z \leq 10^{-4}\, Z_{\odot}$





Normal at last...

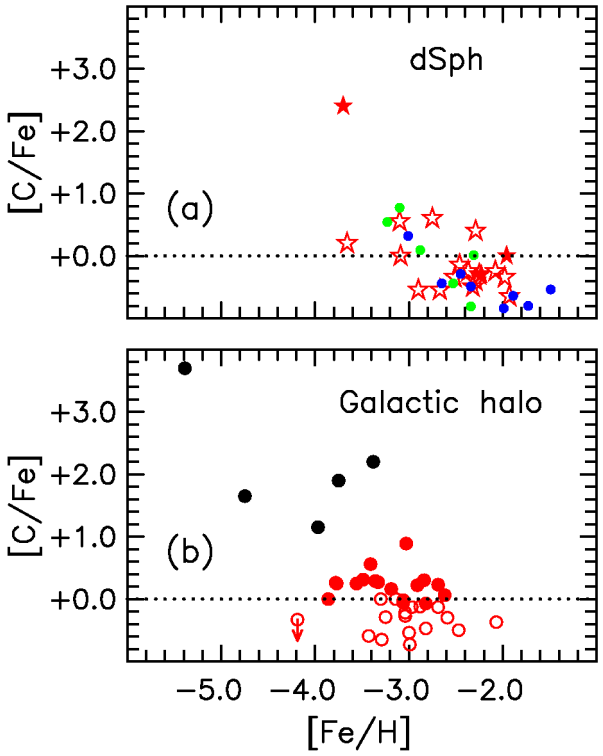


Caffau et al. 2011 Nature, 477, 67

Caffau et al. 2012 A&A, 542, A51

Carbon-Rich stars

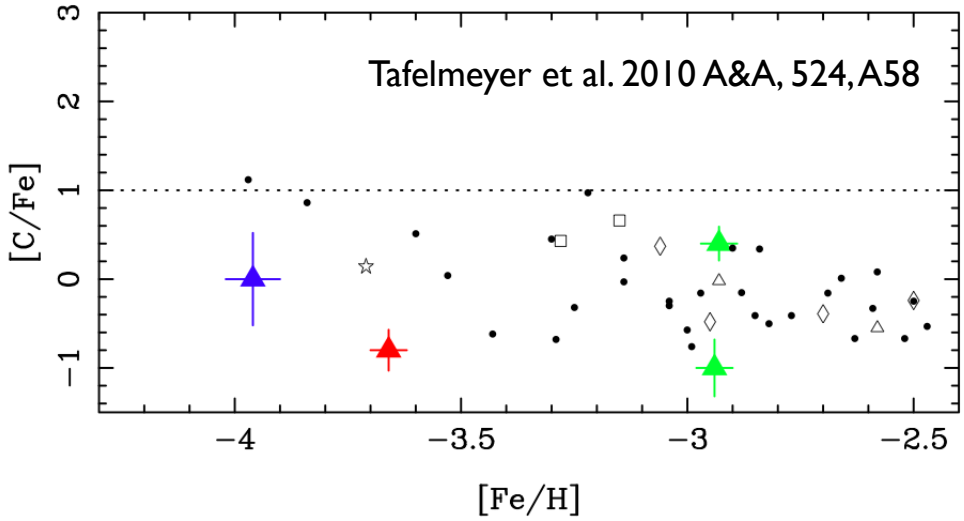
Norris et al. 2010 ApJ, 723, 1632



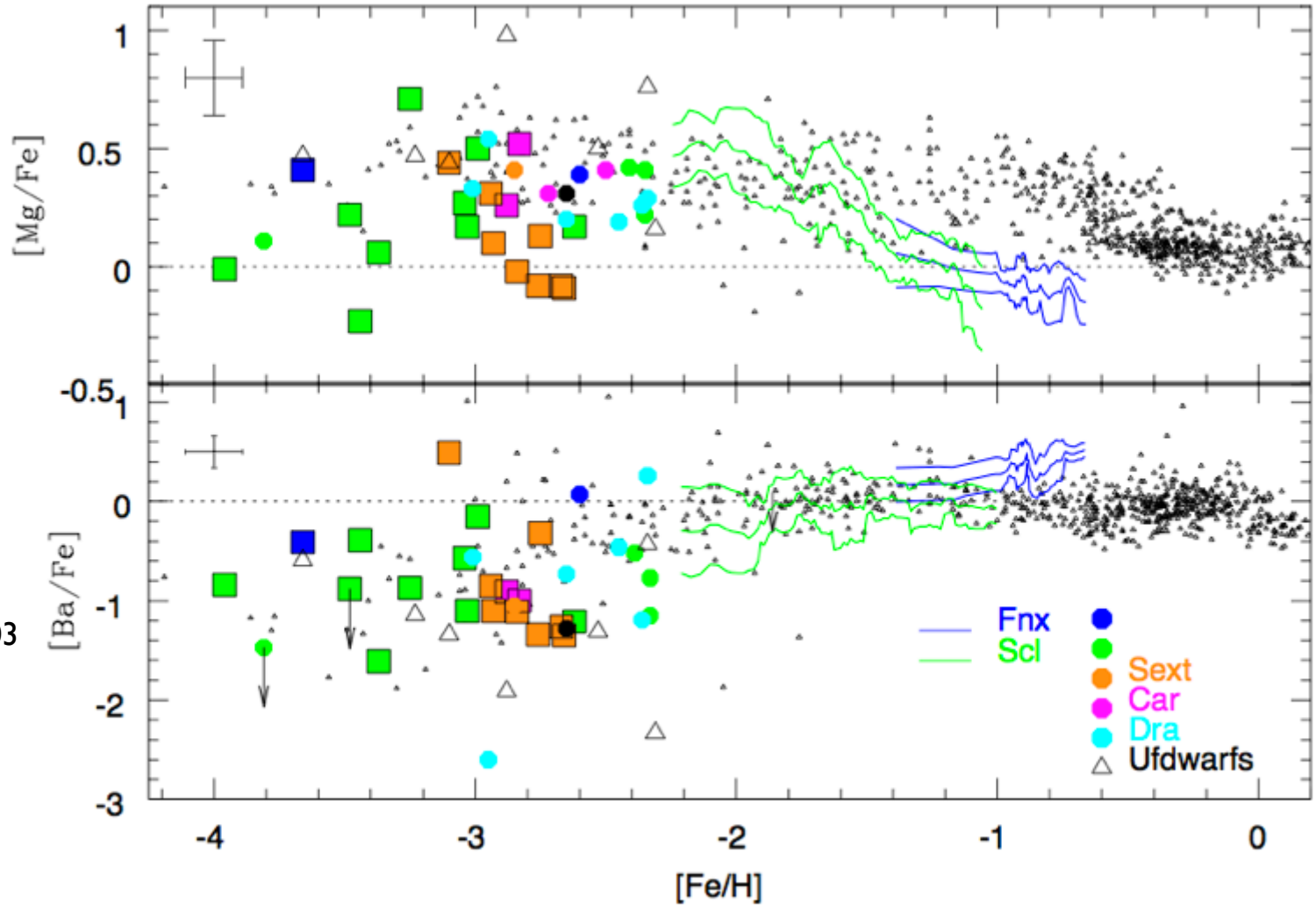
Boötes I (open red stars), Norris et al. 2010
Segue I (red closed stars), Norris et al. 2010
UMa II, Com (green dots), Frebel et al. 2010
Draco (blue dots), Cohen & Huang 2009

Open & filled red dots – mixed & unmixed,
Spite et al. 2005

Black dots, C-rich EMP giants

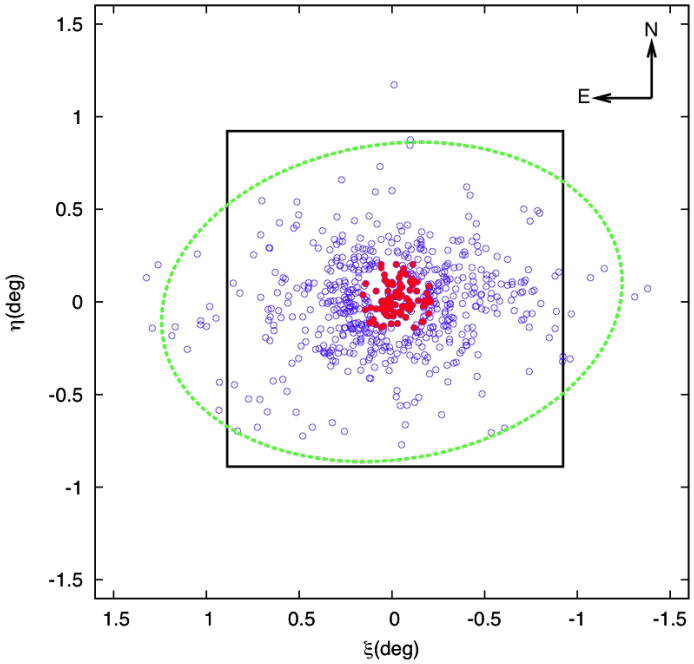


Extremely Metal Poor stars: clues to galaxy formation

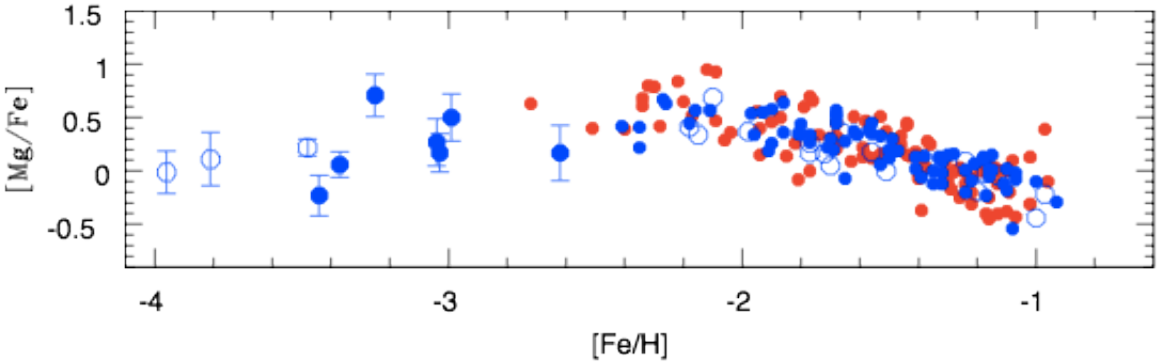


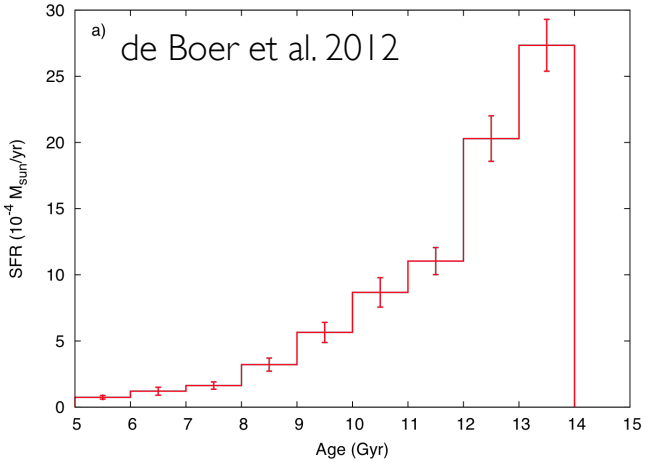
Starkenburg et al. 2012
Tafelmeyer et al. 2010
Shetrone et al. 2001, 2003
Frebel et al. 2010
Aden et al. 2011
Koch et al. 2008
Aoki et al. 2009
Letarte et al. 2010
Hill et al. 2012

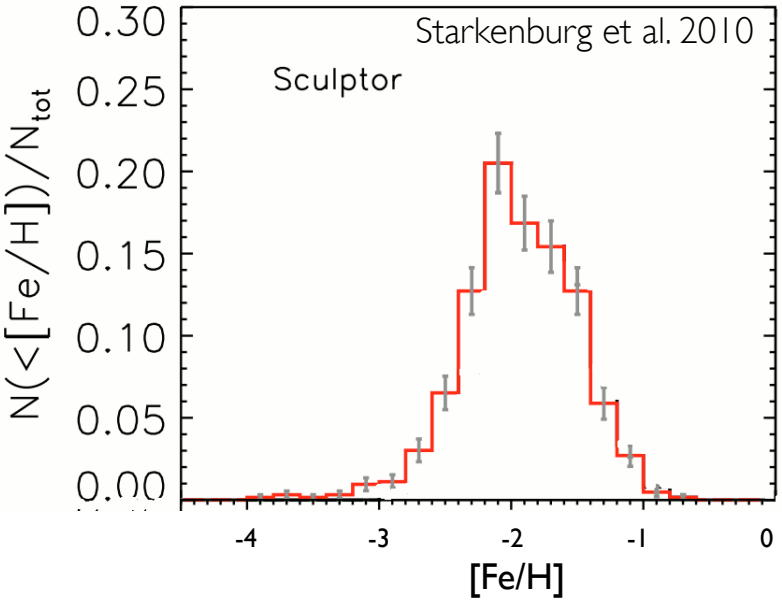
Combining SFH & abundance analyses for Scl



Starkenburg et al. 2012, Hill et al. 2012; Kirby et al. 2010

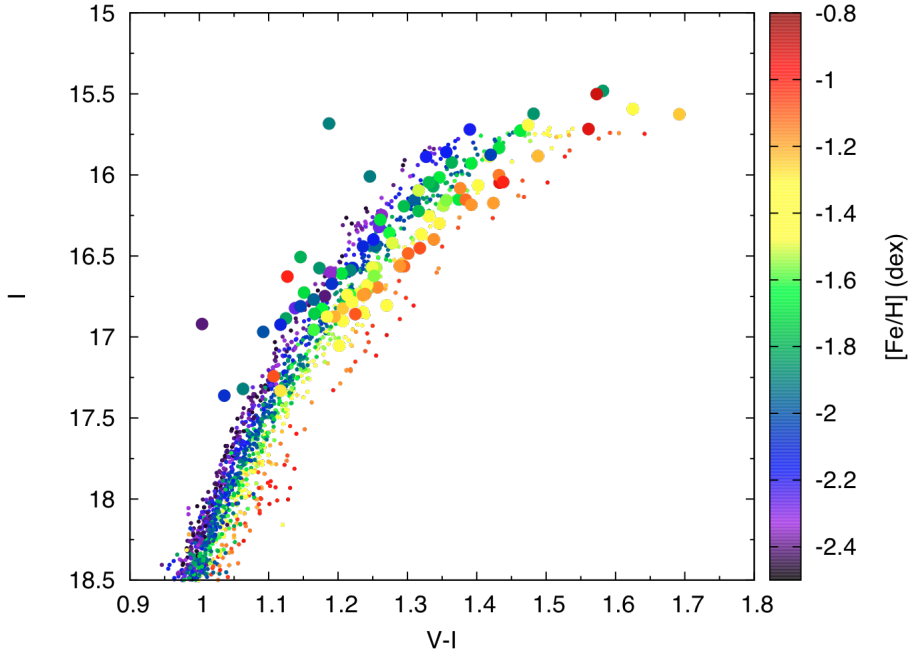


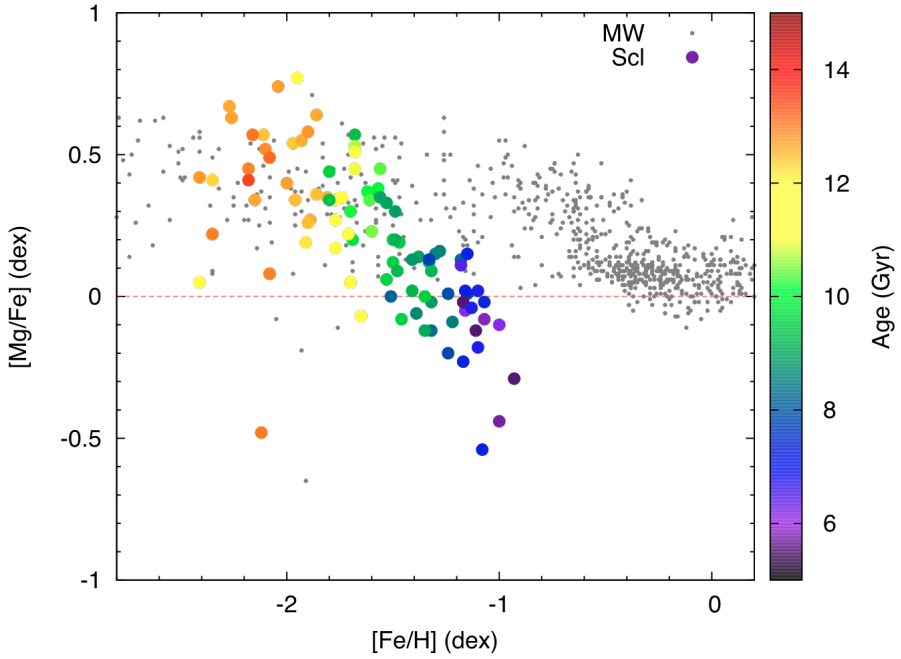




de Boer et al. 2011 A&A, 528A, 119; de Boer et al. 2012 A&A, 539A, 103

Measuring the timescale for chemical evolution in Scl





Knee in Scl occurred ~2±1 Gyr after star formation began

de Boer et al. 2012, A&A, 539A, 103

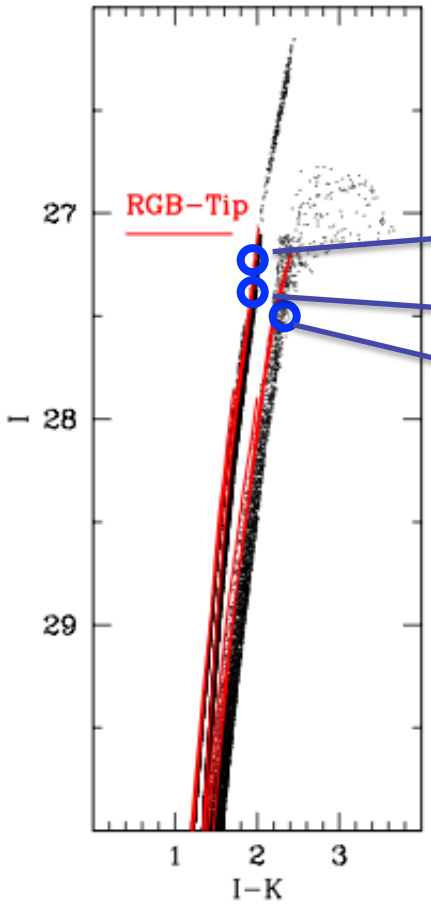
Resolved Stellar Populations in Dwarf Galaxies:

- can allow an unobscured look back into the earliest epoch of galaxy formation.
- are particularly sensitive to physical processes, such as feedback.
- are the most dark matter dominated objects we know of.
- there are several of them nearby enough for detailed study (but need to extend...)

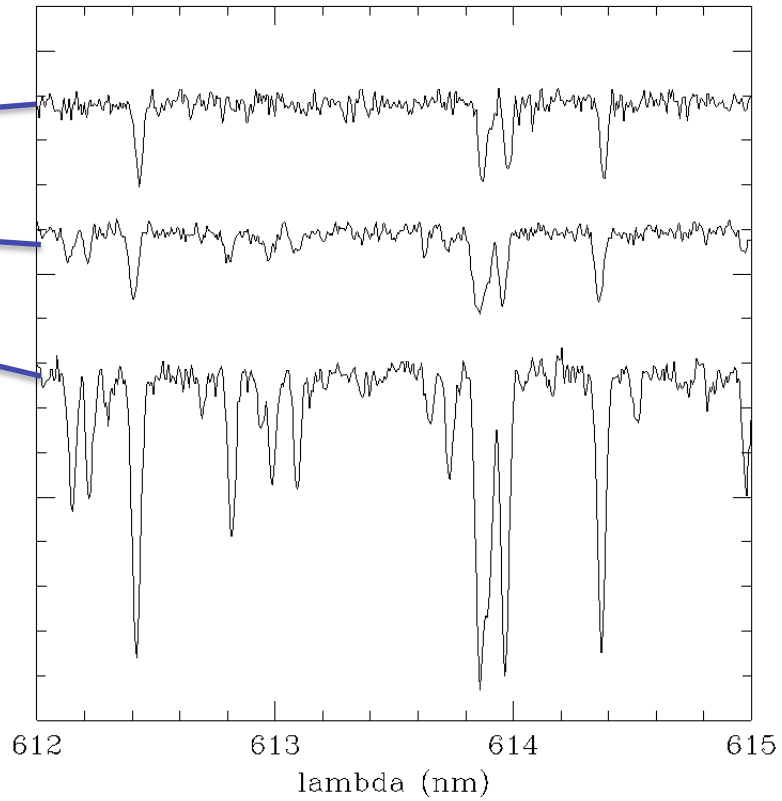
The FUTURE:

ELT/MICADO + HARMONI

galaxy @ 15 Mpc



HR spectra of individual stars



fin