Stellar chemistries in dwarf Spheroidal galaxies and the Magellanic Clouds

Vanessa Hill

1. Stellar chemistries - chemical evolution:
    1. Commonalities and peculiarities in dSph (and LMC)
    2. Rôle of AGBs
    3. Extremely low metallicity stars in dSph

The standard picture (seminal)

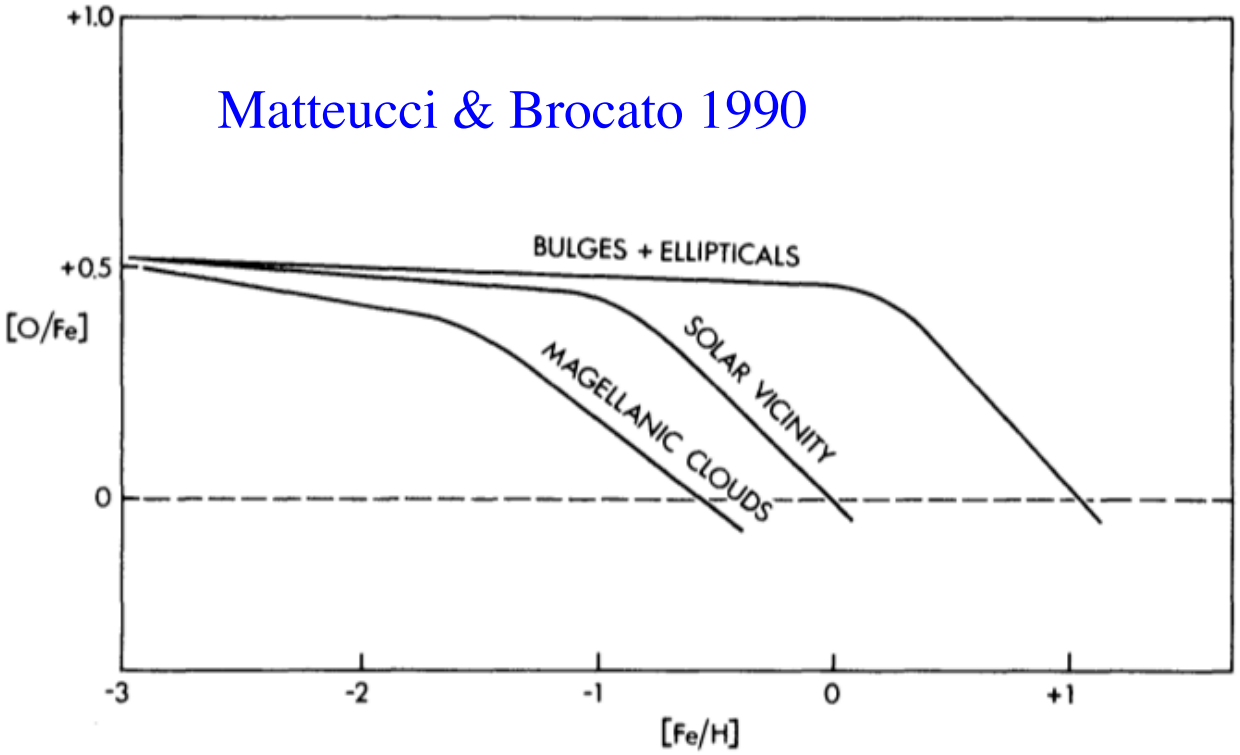
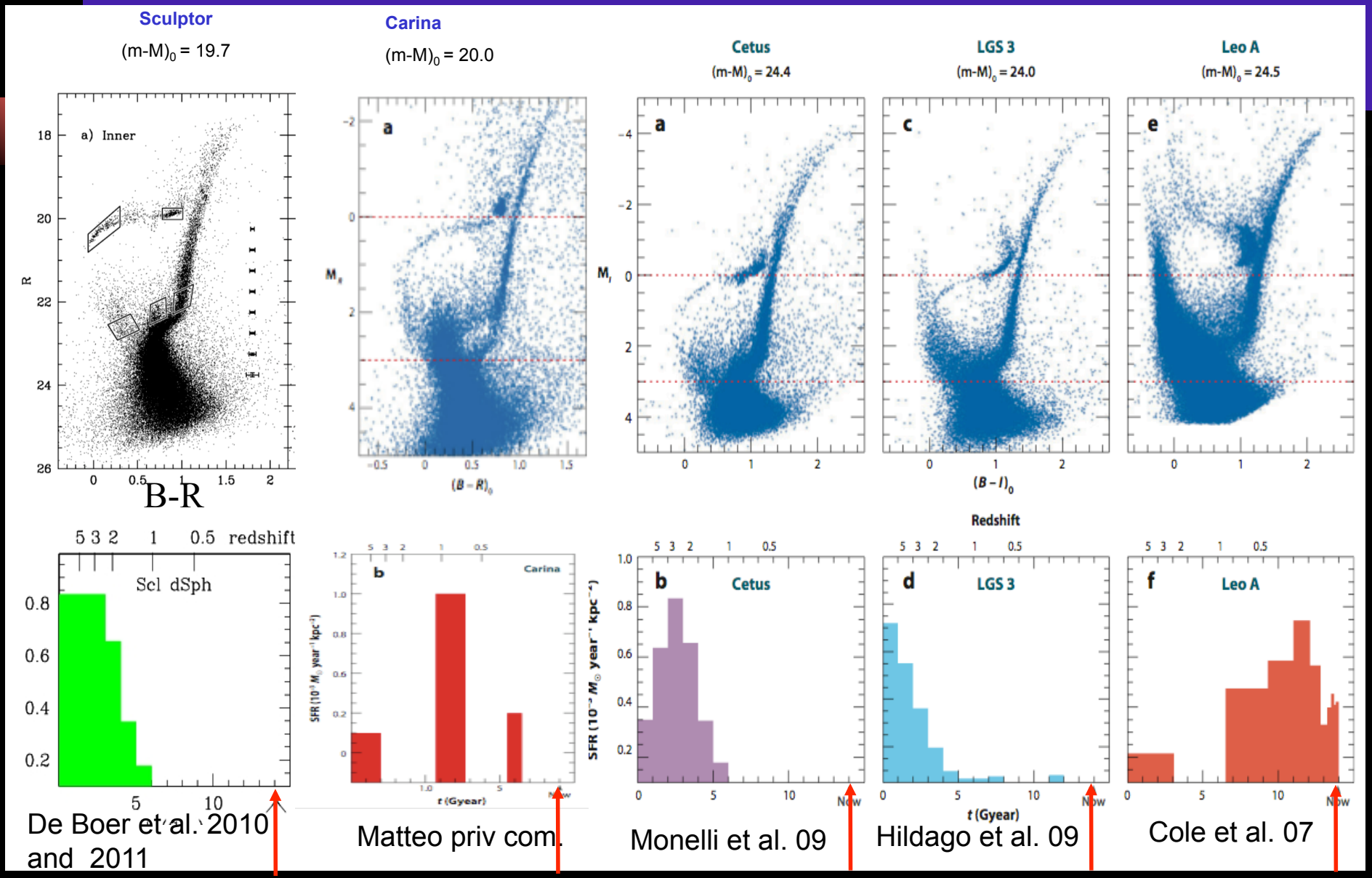


FIG. 4.—A sketch of the predicted [O/Fe] vs. [Fe/H] relations in different systems as a consequence of their different [Fe/H]-*t* relations.

Star formation histories



De Boer et al. 2010 and 2011

Matteo priv com.

Monelli et al. 09

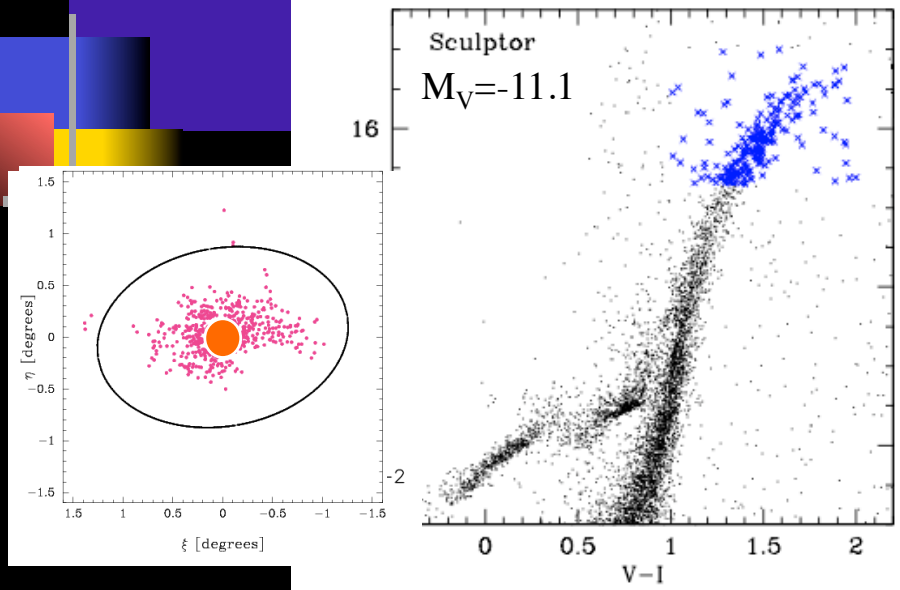
Hildago et al. 09

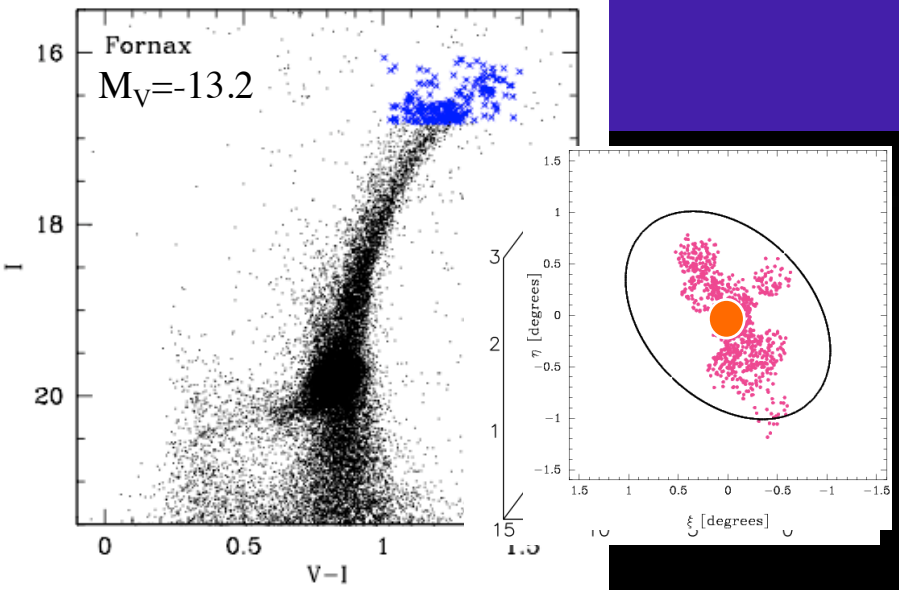
Cole et al. 07

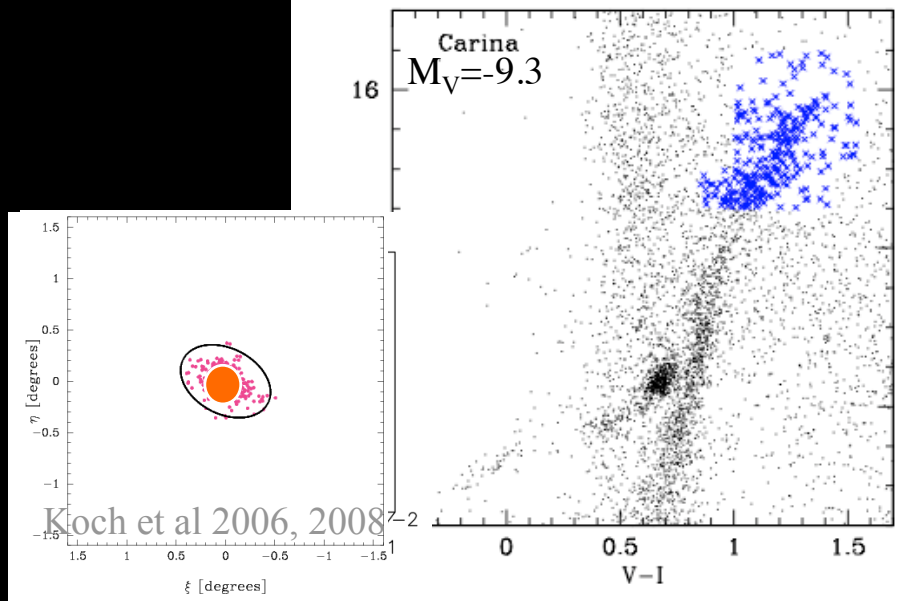
NOW

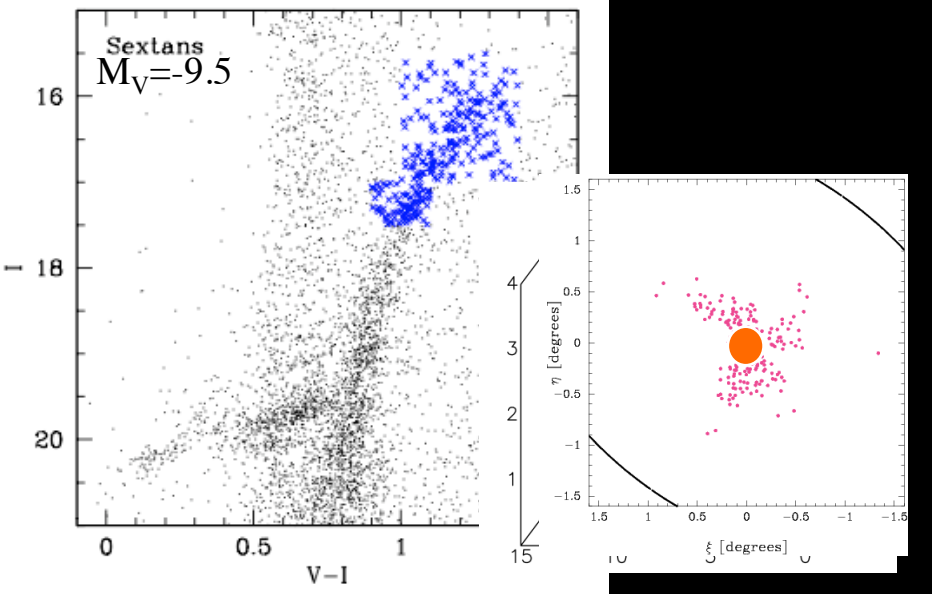
Tolstoy, Hill & Tosi ARAA 2009

DART samples



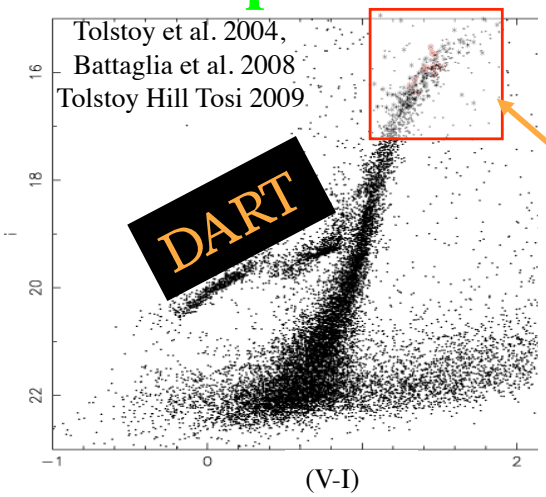


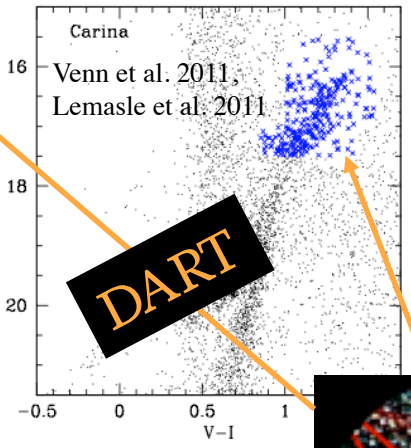


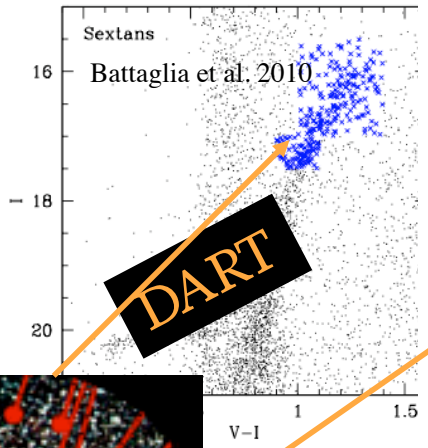


Koch et al 2006, 2008

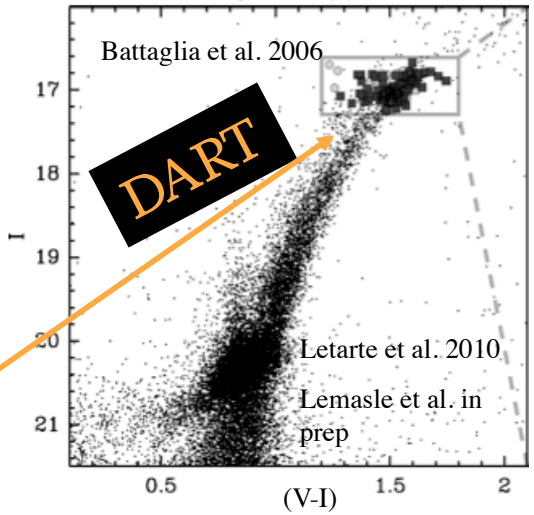
Sculptor

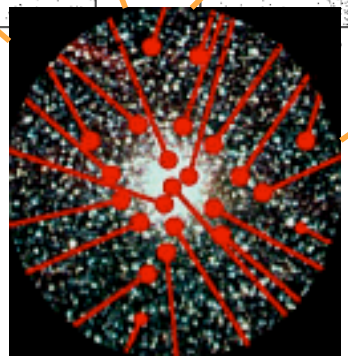






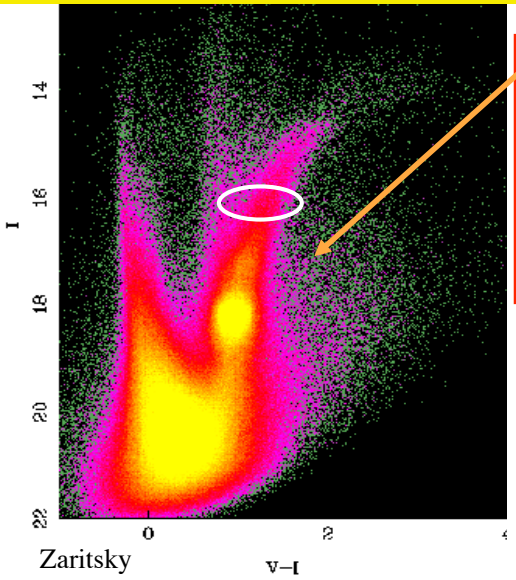
Fornax

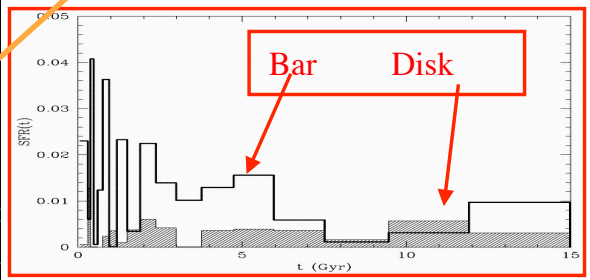




LMC

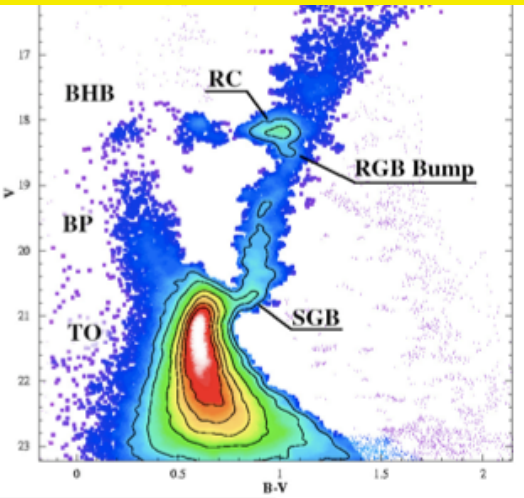
Van Der Swaelmen et al. 2013 & PhD: 160 *





Sagittarius

see talk by A. McWilliam

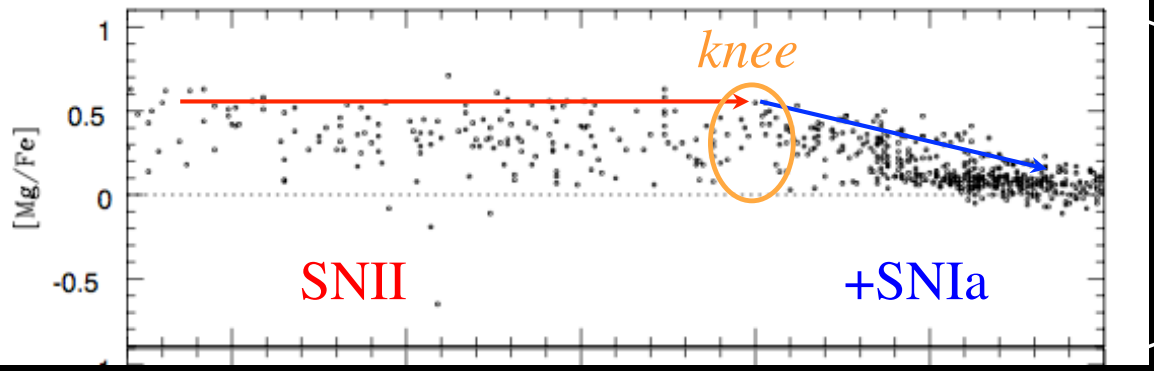


Sgr: (Bellazzini et al. 2006)

12%	old (>10Gyrs)
>80%	5.5-9Gyrs
~6%	younger stars (BP)

The standard picture

Milky-Way Venn et al. 2004



α-elements

SNII: [α/Fe] ~0.4
(fast enrichment)

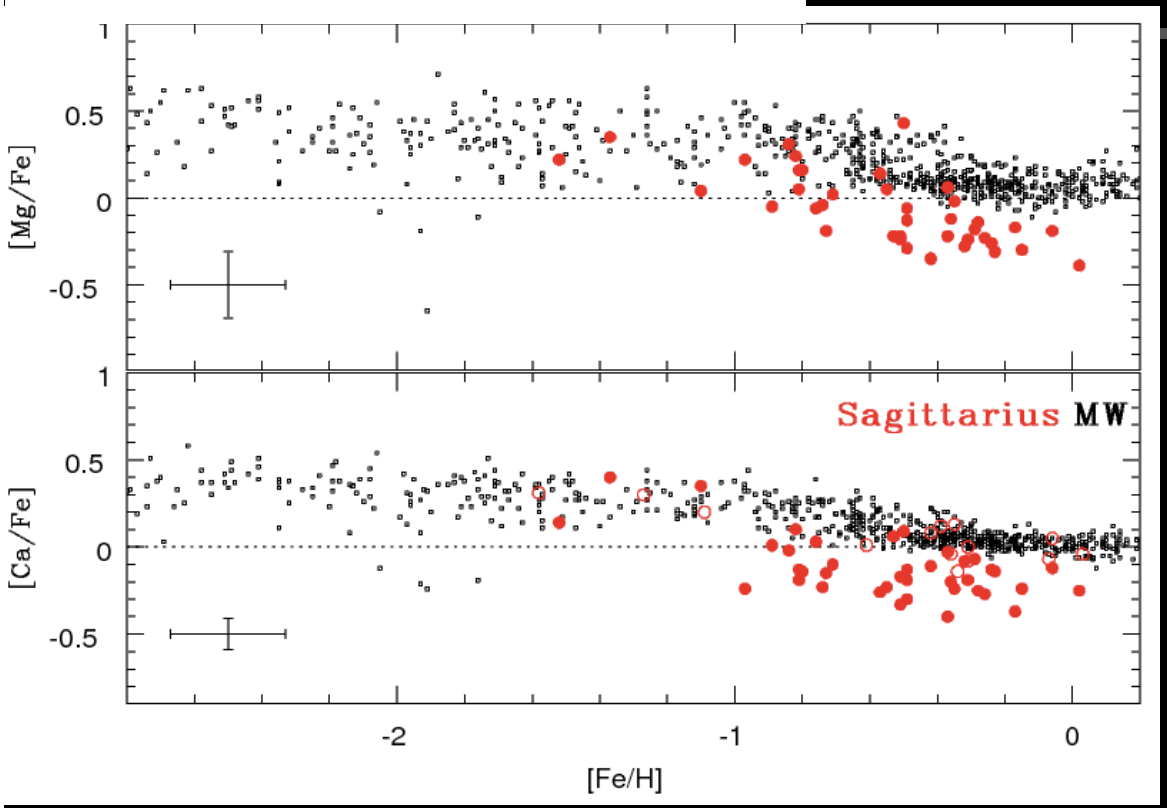
SNIa:: Fe, no α
(delayed enrichement)

Sgr

Sbordone et al. 2007
+ McWilliam et al. 2005

Milky-Way Venn et al. 2004

Distinct evolution

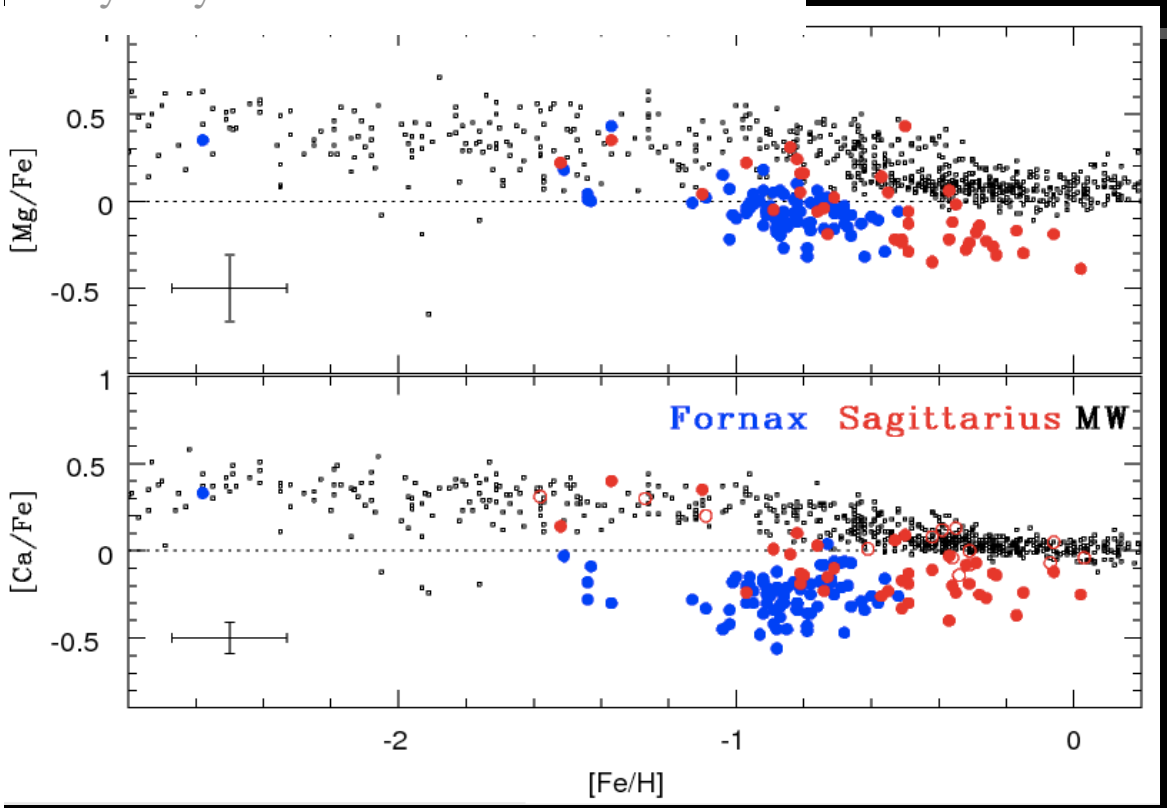


Distinct evolution

Sgr Sbordone et al. 2007 + McWilliam et al. 2005

Fornax Letarte et al. 2010

Milky-Way Venn et al. 2004



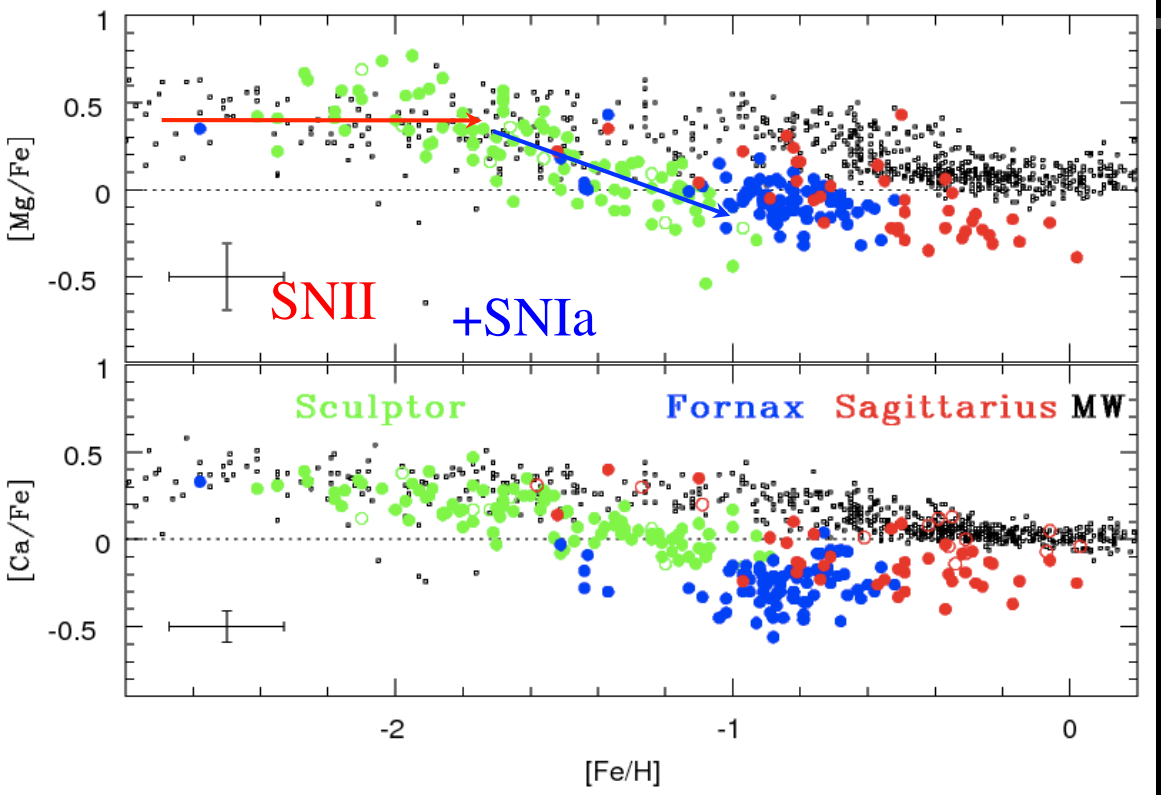
Distinct evolution

Sgr Sbordone et al. 2007
+ McWilliam et al. 2005

Fornax Letarte et al. 2010

Sculptor Tolstoy Hill Tosi 2009 & Hill et al. in prep)
+ Shetrone et al. 2003& Geisler et al. 2005

Milky-Way Venn et al. 2004



- Each galaxy occupies a different locus - evolutionary track
- [α/Fe] « knee » metallicity: according to the ability of the galaxy to retain metals
  - **Sgr : [Fe/H]knee >-1.2**
  - Fnx: [Fe/H]knee <-1.5? (Lemasle et al. in preparation for an outer field cover nicely -1.0<[Fe/H]<-2.7 dex)
  - **Scl: [Fe/H]knee ~ -1.8**
- in accordance to total L of the galaxy
- reflected on mean metallicity
- linked to SFH (gas availablility?)

- Dispersion: none detected in **Scl, Fnx, Sgr**
- Abundance pattern in the metal-poor stars everywhere undistinguishable ? -> IMF

Distinct evolution

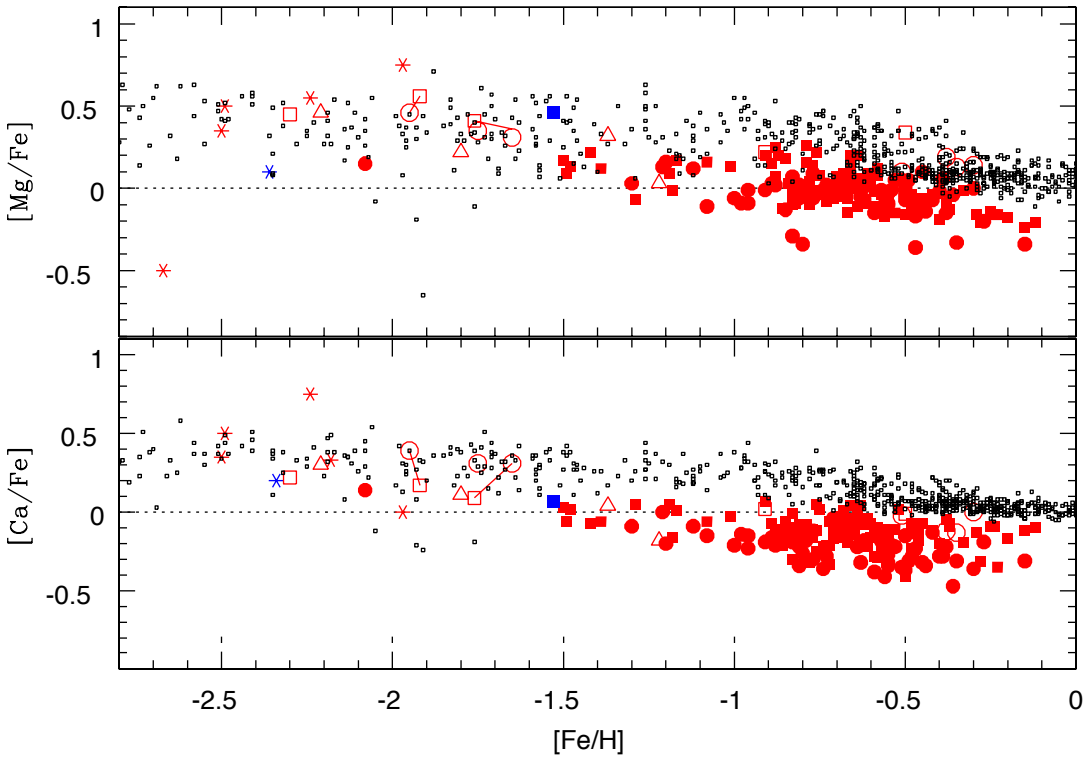
LMC field Pompeia, Hill et al. 2008, Van der Swaelmen, Hill et al. 2012

clusters Hill et al. 2000, and 2009; Johnson et al. 2006; Mucciarelli et al. 2008, 2010

SMC cluster Hill et al. in prep;

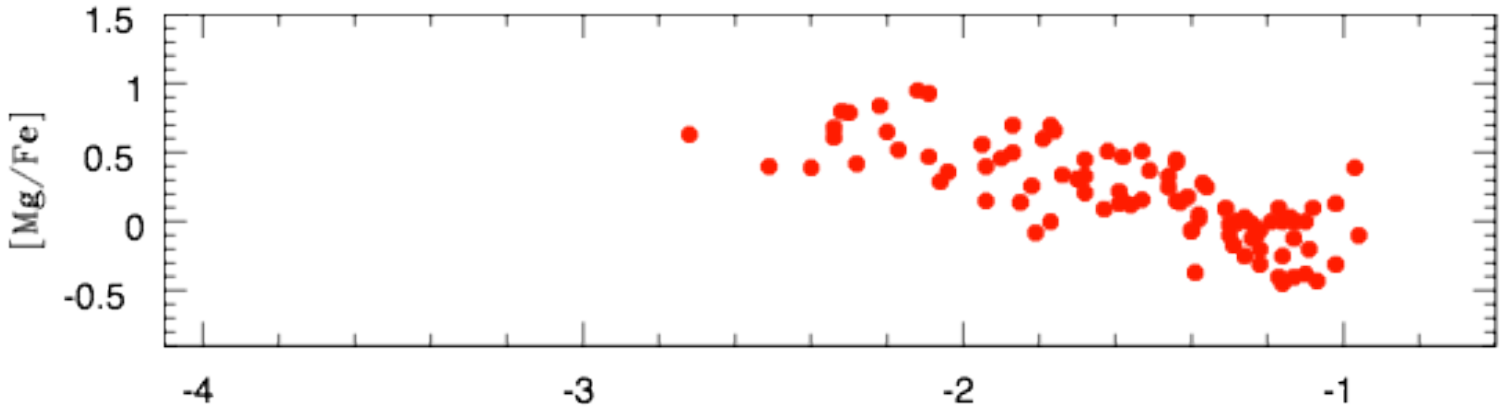
RR Lyrae stars Haschke et al. 2012

Milky-Way Venn et al. 2004

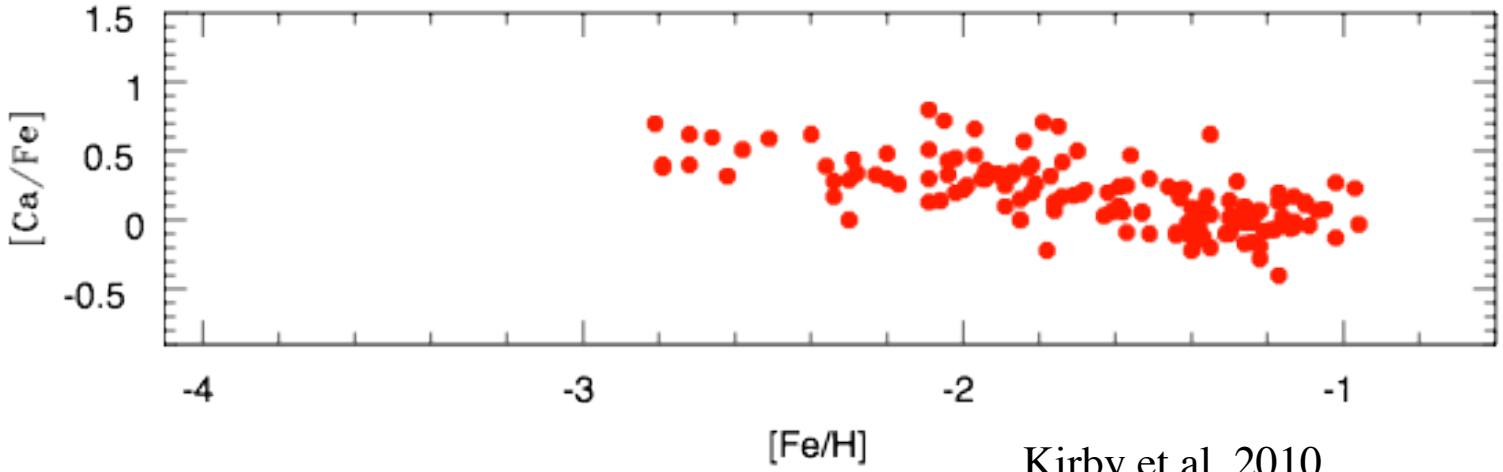


- In the common metallicity regime, clusters and field stars agree.
- alpha elements are depleted compared to the MW disk, as expected from:
  - slower SF (e.g. Matteucci & Brocato 1990, Pagel & Tautvaisiene1998)
  - Bursts of star formation (Wyse 1996, Pagel & Tautvaisiene1998)
  - Galactic winds (e.g. Freitas Pacheco 1998; Lehner 2007 evidence of outflow)
- The position of the « knee » in [α/Fe] is ill-defined, because of the lack of metal-poor field stars…
- Old and metal-poor GCs resemble the galactic halo. No evidence for a different massive star IMF

Is there truely a *knee* in Scl ?

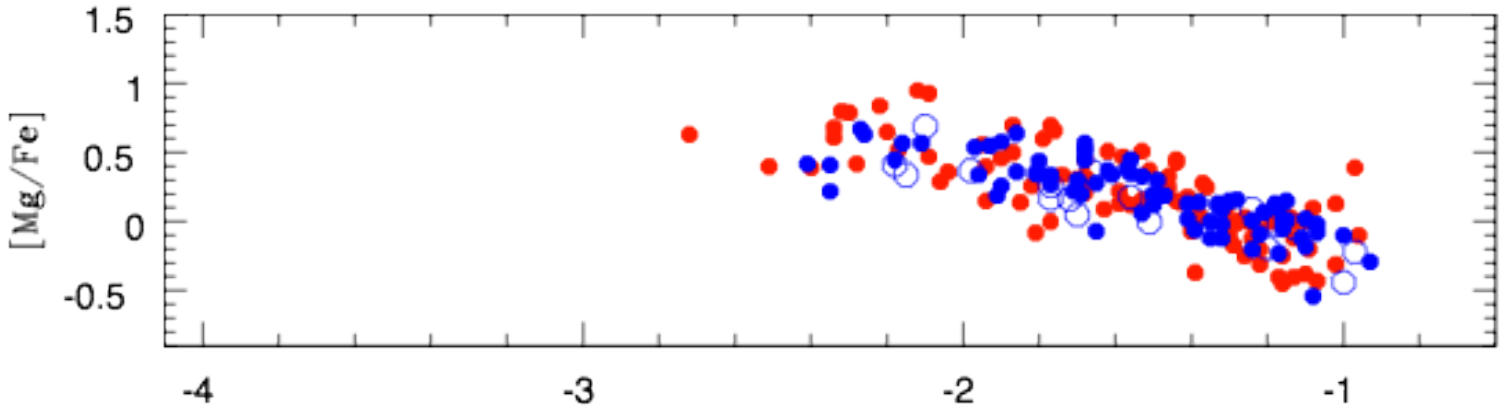


MRS data: sorted by errors



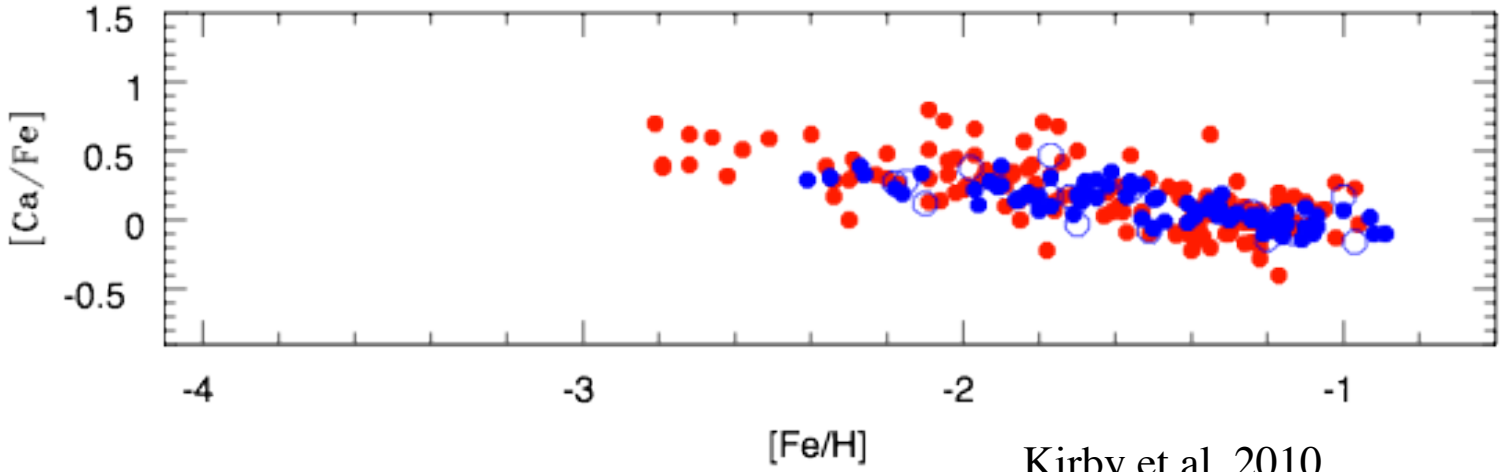
Kirby et al. 2010

Is there truely a *knee* ?



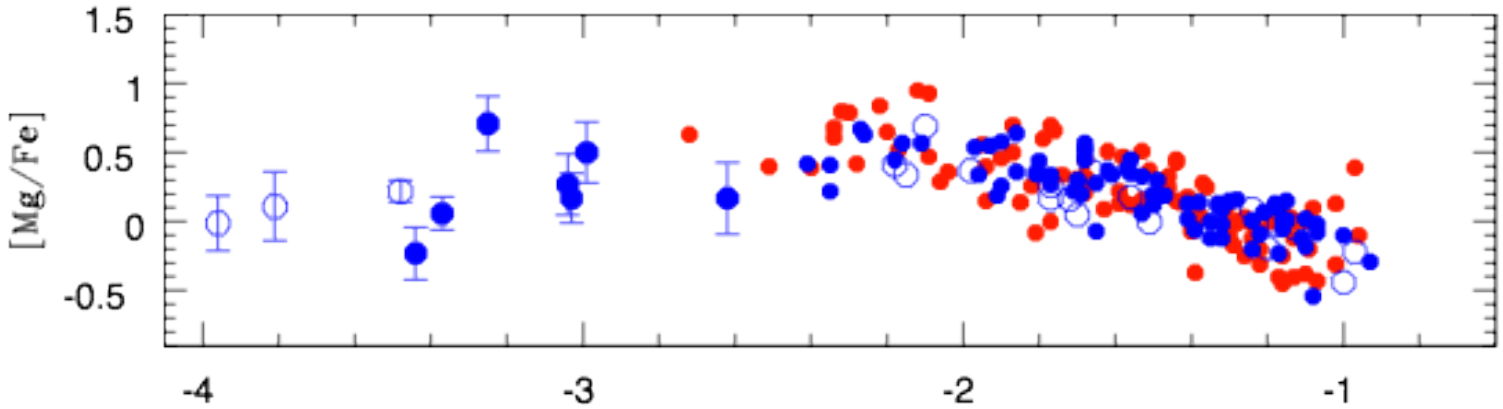
MRS data: sorted by errors

DART data

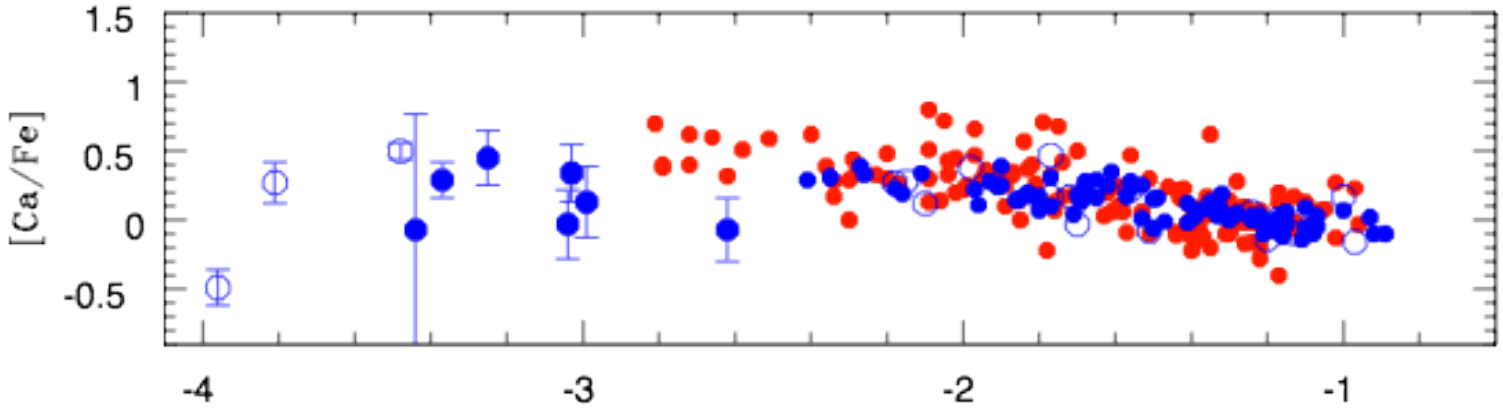


Kirby et al. 2010

There is a true *plateau (and a knee)*



MRS data: sorted by errors [Fe/H] DART data

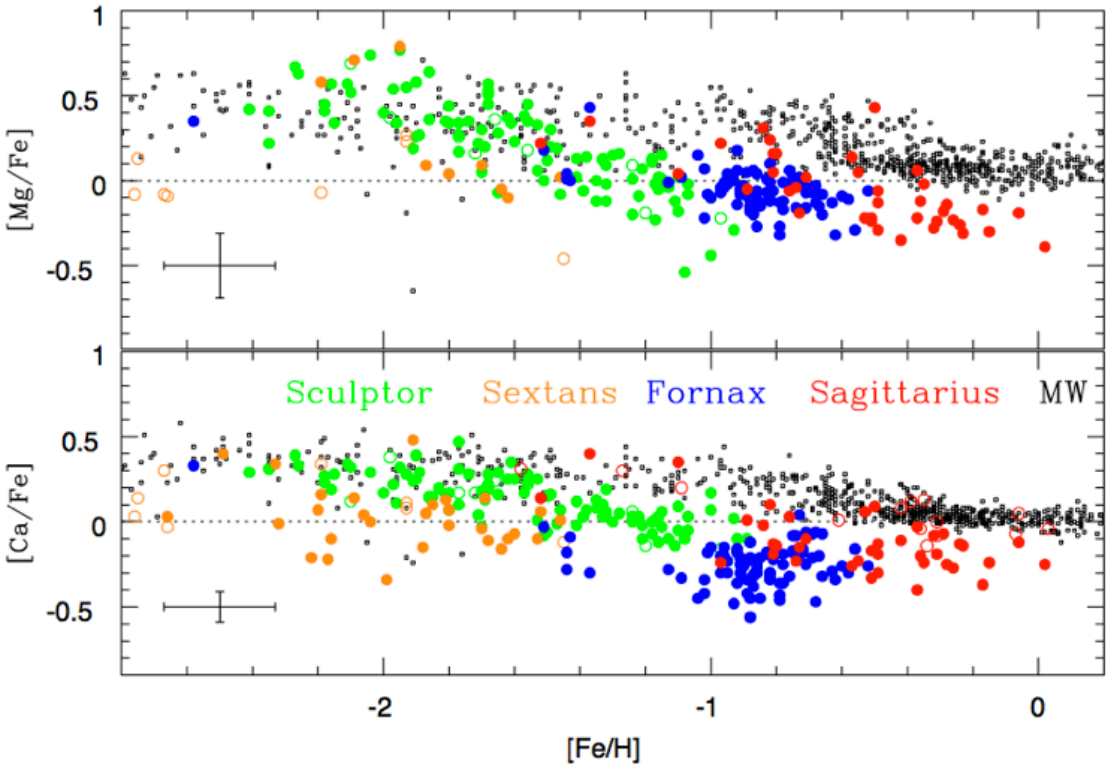


Low Z stars in Scl:

Starkenburg et al. 2012 (Xshooter); Tafelmayer et al. 2010 (UVES) + 1 star Frebel et al. 2010

Sgr Sbordone et al. 2007
+ McWilliam et al. 2005
Fornax Letarte et al. 2010
Sculptor Tolstoy Hill Tosi 2009 & Hill et al. in prep)
+ Shetrone et al. 2003& Geisler et al. 2005
Sextans Kirby et al. 2010
+Shetrone et al. 2003+Aoki et al 2009
Milky-Way Venn et al. 2004

Distinct evolution

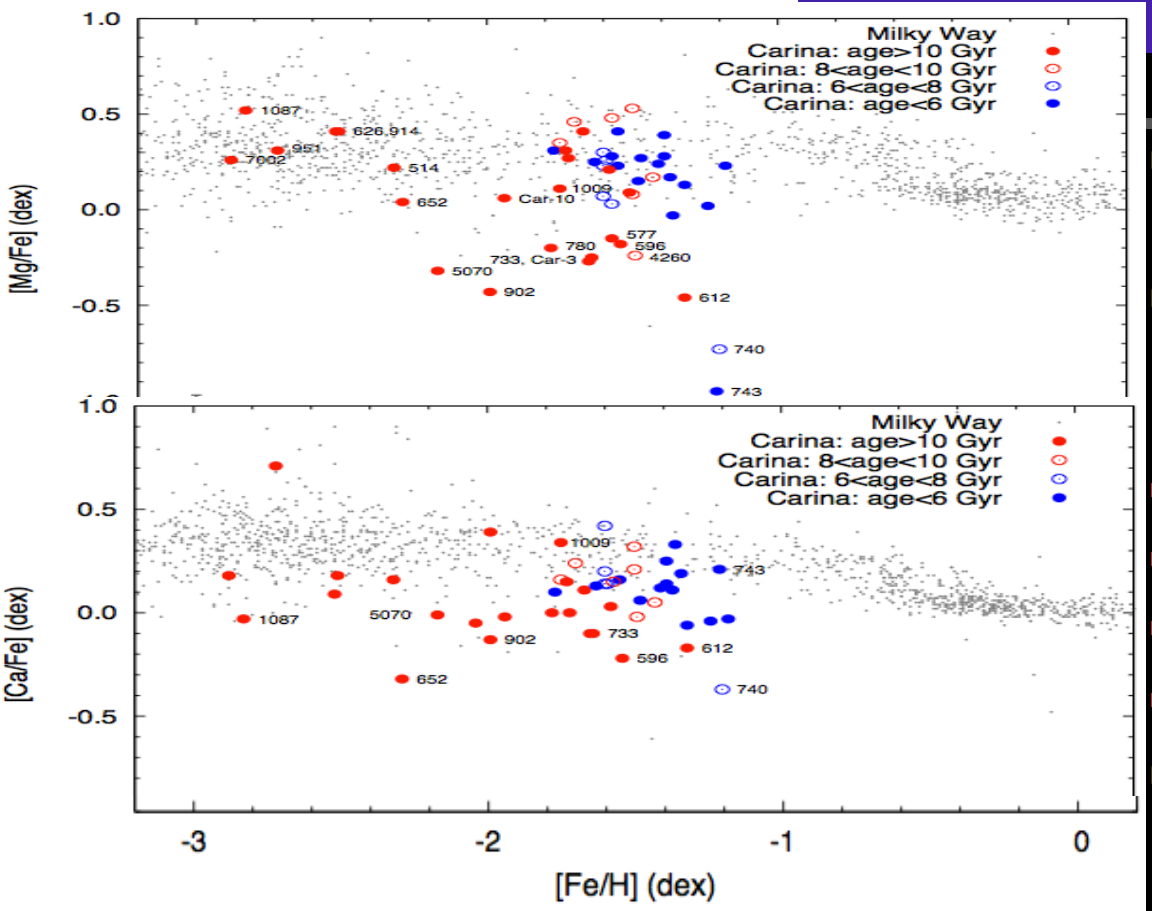


- Each galaxy occupies a different locus - evolutionary track
- [α/Fe] « knee » metallicity: according to the ability of the galaxy to retain metals
- Sgr : [Fe/H]knee >-1.2
- **Fnx: [Fe/H]knee <-1.5? (Lemasle et al. in preparation for an outer field cover nicely -1.0<[Fe/H]<-2.7 dex)**
- Scl: [Fe/H]knee ~ -1.8
- Sextans: knee ?????
- in accordance to total L of the galaxy (& mean metallicity)

- Dispersion: probably present in Sextans (at all metallicities ?) -> inhomogeneous

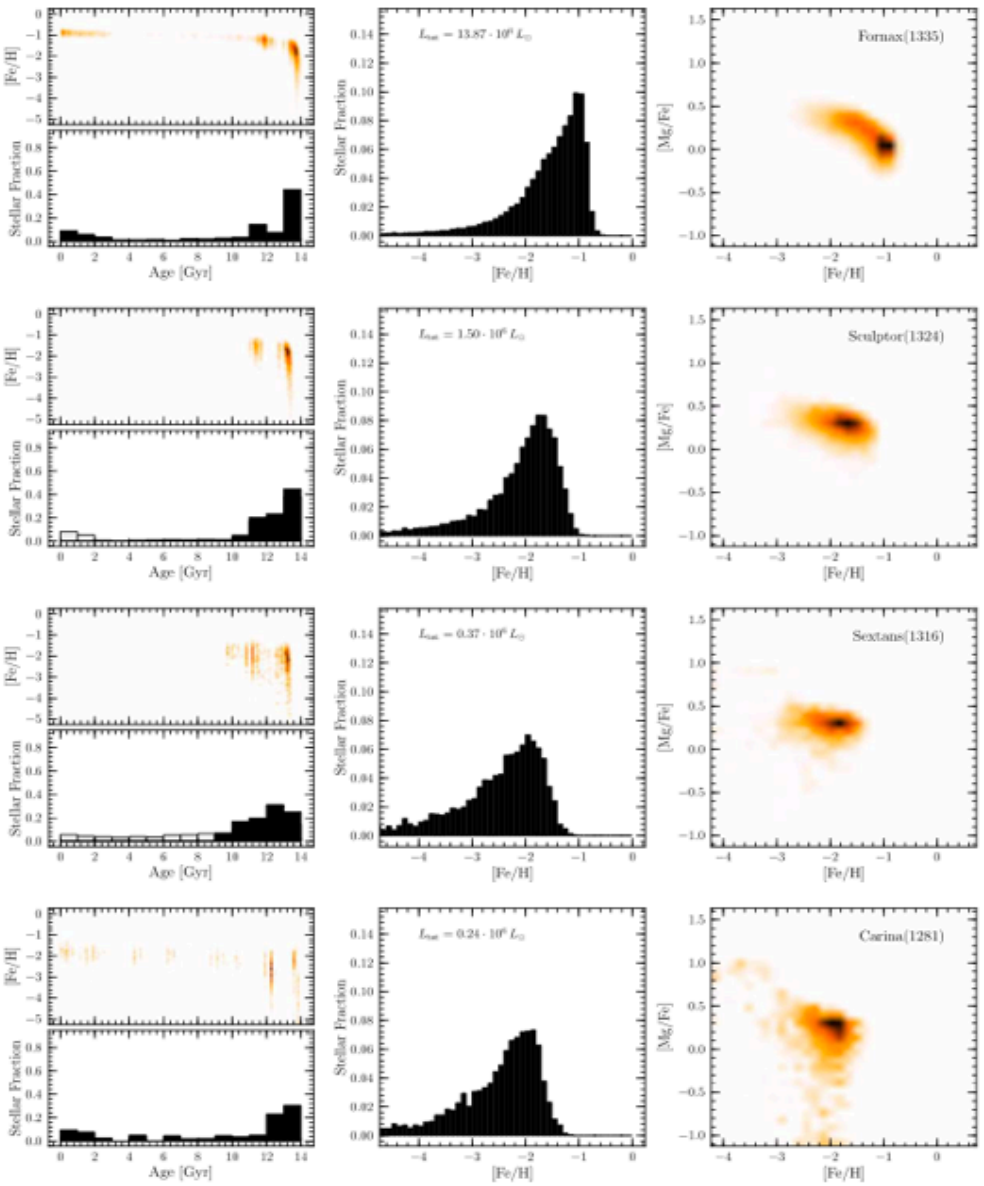
Distinct evolution

Carina Venn et al. 2011, Lemasle etal. 2011
+Koch et al. 2008 + Shetrone et al. 2003
Milky-Way Venn et al. 2004



- Each galaxy occupies a different locus - evolutionary track
- [α/Fe] « knee » metallicity: according to the ability of the galaxy to retain metals
- Sgr : [Fe/H]knee >-1.2
- **Fnx: [Fe/H]knee <-1.5?**
- Scl: [Fe/H]knee ~ -1.8
- Carina: no knee, dispersion !
- in accordance to total L of the galaxy (& mean metallicity)

- Dispersion: Detected in Carina -> bursty SFH + inhomogeneous
  Probably present in Sextans (at all metallicities ?) -> inhomogeneous
- At the lowest metallicities (EMPS), inhomogeneities or smooth as in MW halo ?



Revaz, Jablonka (2009, 2012)

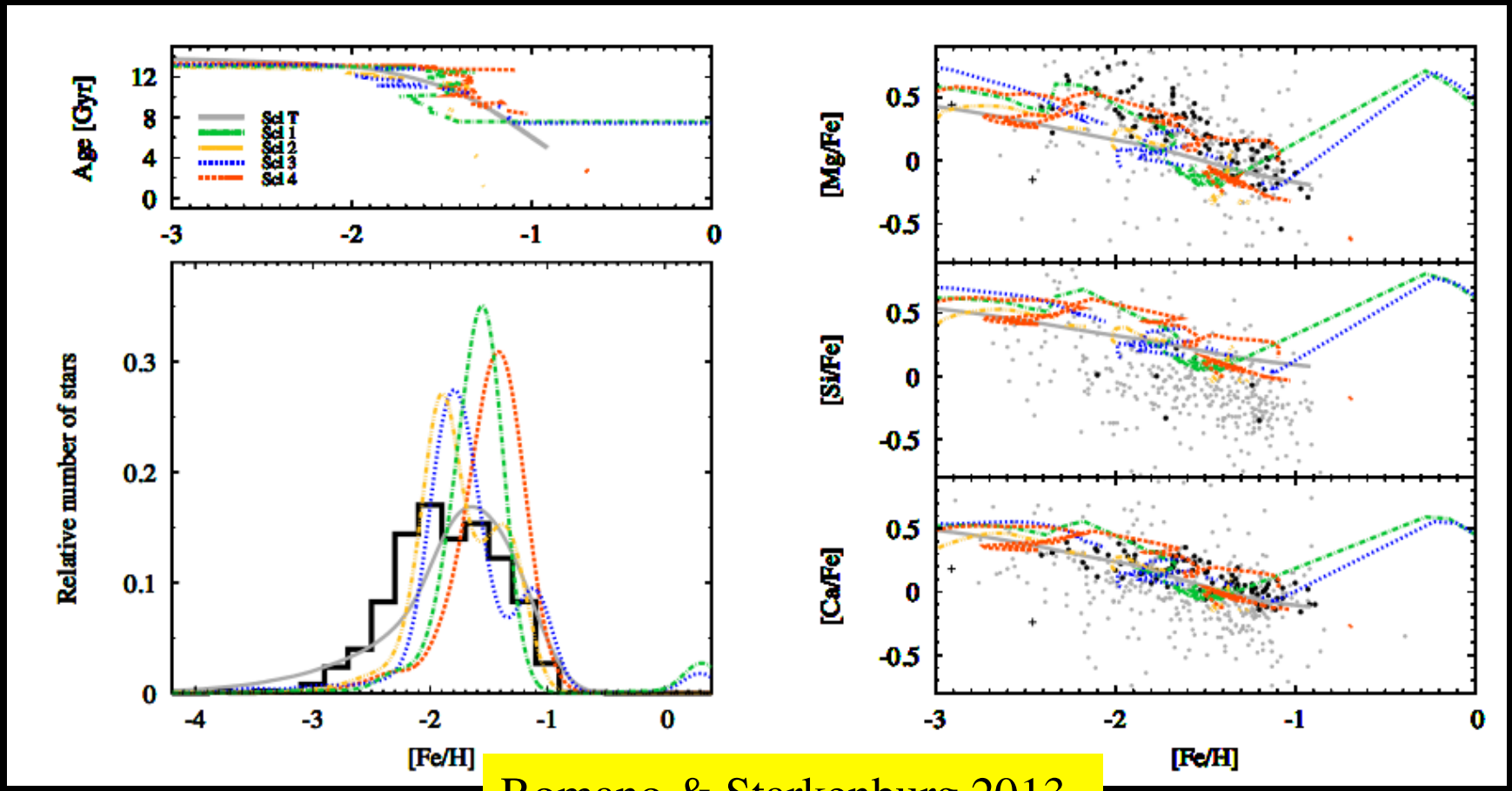
dSph	L_V [10^6 $L_\odot$]	⟨[Fe/H]⟩	M/L	r_t [kpc]	σ [km/s]
Fornax	14	−1.17	12	2.08	11.7
Sculptor	1.4	−1.96	158	1.33	9.2
Sextans	0.41	−2.26	19	3.10	7.9
Carina	0.24	−1.86	88	0.58	6.6

Nbody-Tree-SPH code with simple chemistry (Mg, Fe): cosmologically motivated initial conditions, isolated galaxies, feedback treated with care.

- varying Mtot, ϱ_g, r_{max}, c_*, (ε_{SN},t_{ad})
- reproduces L-metallicity and M/L-L relations

dSphs	#	M_{tot} 10^8 $M_\odot$	$\rho_{c,gas}$ m_H/cm^3	r_{max} kpc	$c_\star$ -	ϵ_{SN} -	t_{trunc} Gyr	L_V 10^6 $L_\odot$	⟨[Fe/H]⟩	r_t kpc	$\sigma_\star$ km/s	σ_{DM} km/s	M_{gas} 10^7 $M_\odot$	M_{stars} 10^7 $M_\odot$	M_{halo} 10^7 $M_\odot$
Fornax	1335	7	0.059	7.1	0.05	0.03	-	13.9	−1.01	1.98	9.4	15.0	2.4	1.35	8.80
Sculptor	1324	5	0.029	9.6	0.05	0.03	9.1	1.50	−1.75	2.93	6.4	11.7	1.9	0.34	4.45
Sextans	1316	3	0.022	8.0	0.05	0.03	4.7	0.37	−2.09	1.58	4.2	9.7	0.5	0.07	1.04
Carina	1281	1	0.022	3.5	0.1	0.03	-	0.24	−1.93	0.76	3.1	7.2	0.2	0.02	0.63

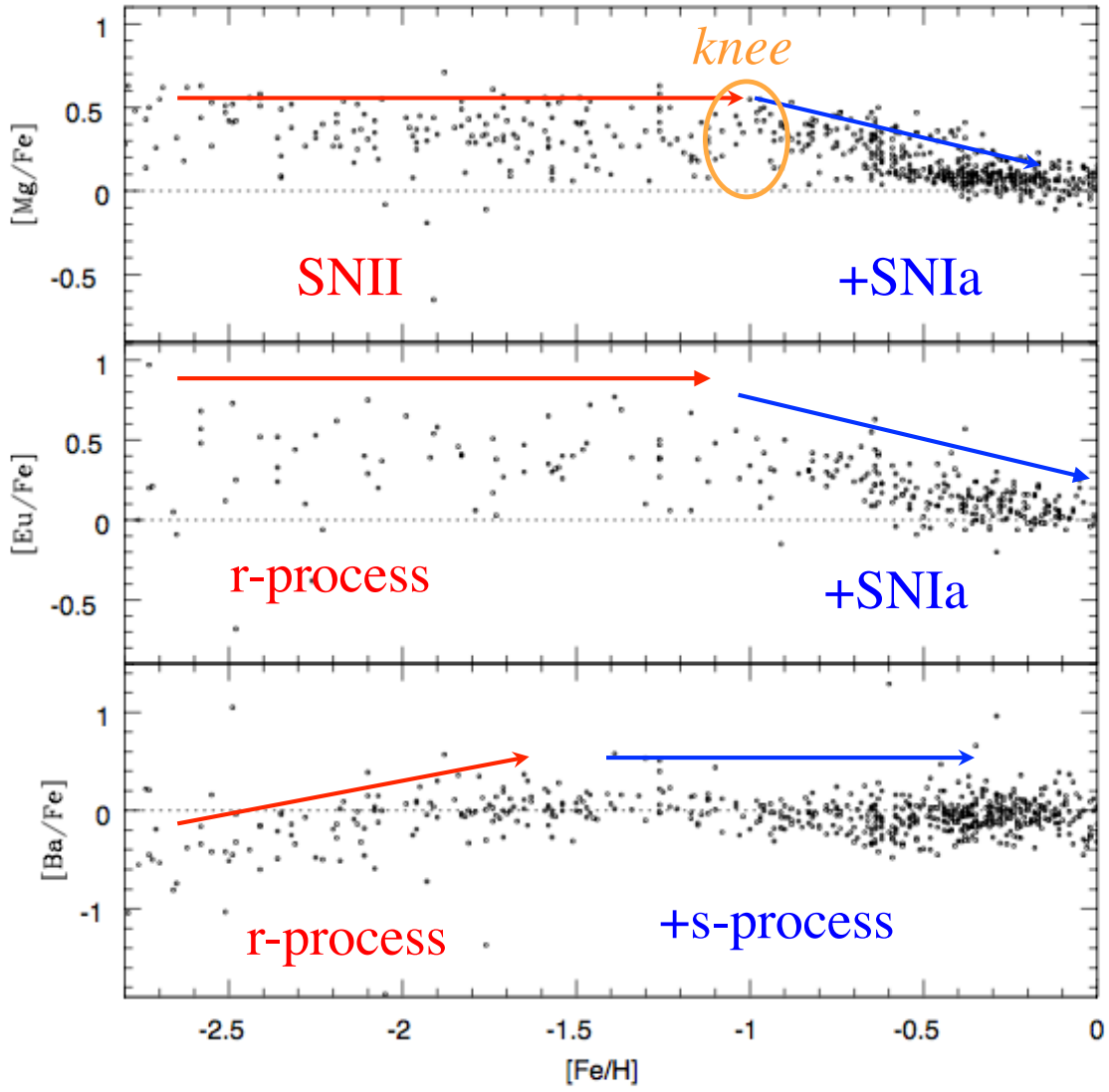
Modelling Scl in a cosmological contexte



Romano & Starkenburg 2013

The standard picture

Milky-Way Venn et al. 2004



α-elements

SNII: [α/Fe] ~0.4
(fast enrichment)

SNIa:: Fe, no α
(delayed enrichement)

Neutron-capture element

R- process: massive stars
(fast enrichment)

S-process: AGB stars
(slower enrichement)

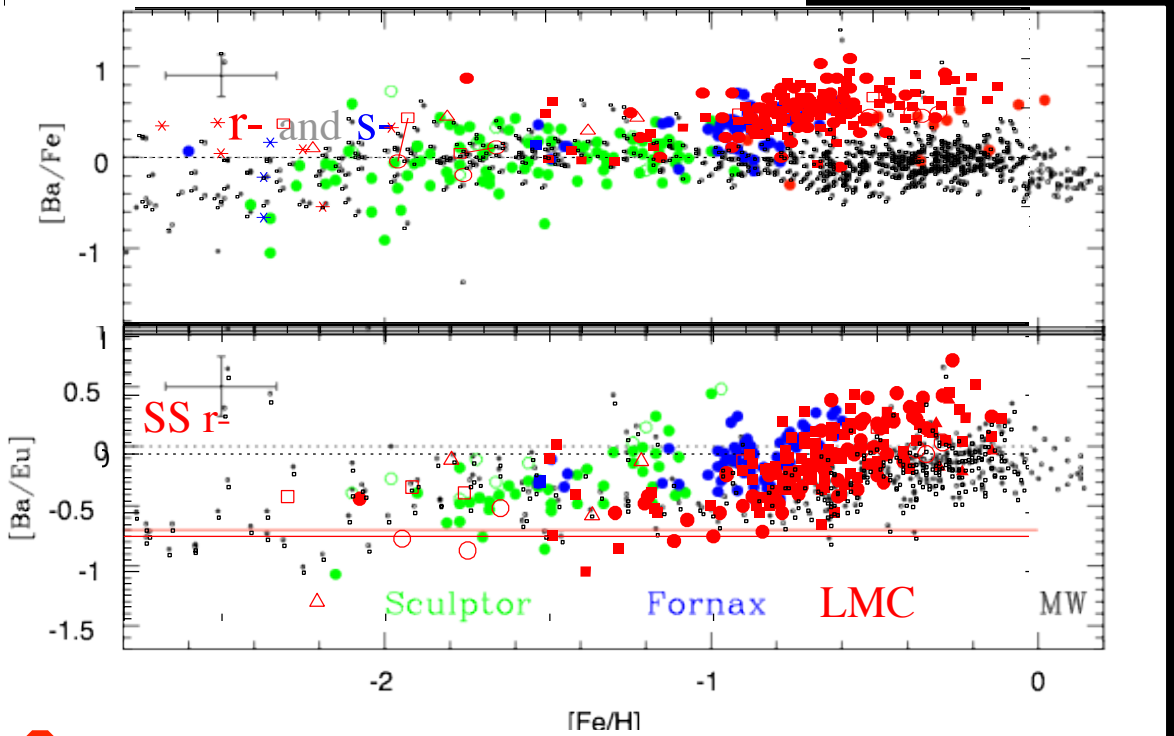
N-capture elements

Sgr Sbordone et al. 2007, + McWilliam et al. 2005

Fornax Letarte et al. 2010

Sculptor Tolstoy Hill Tosi 2009 & Hill et al. in prep) + Shetrone et al. 2003& Geisler et al. 2005

Milky-Way Venn et al. 2008



LMC field Van der Swaelmen, Hill et al. 2012

clusters Hill et al. 2000, and 2009; Johnson et al. 2006; Mucciarelli et al. 2008, 2010

RR Lyrae stars Haschke et al. 2012

- 2nd peak r- and s- process elements (Ba, La, ..) similar to MW in Scl:
  - Dominated by r- process at the lowest metallicities (all galaxies)
  - Mix of r- and s- process [Fe/H]> -2
- In Fornax, Sgr and the LMC, the s-process displays a strong enhancement at the highest metallicities (younger ages): AGBs
- s-process yields are metallicity-dependent (seeds), favoring high-A over low-A elements (Ba/La over Y/Zr), and Y or Zr are observed not to be enhanced in Fnx/Sgr/LMC.

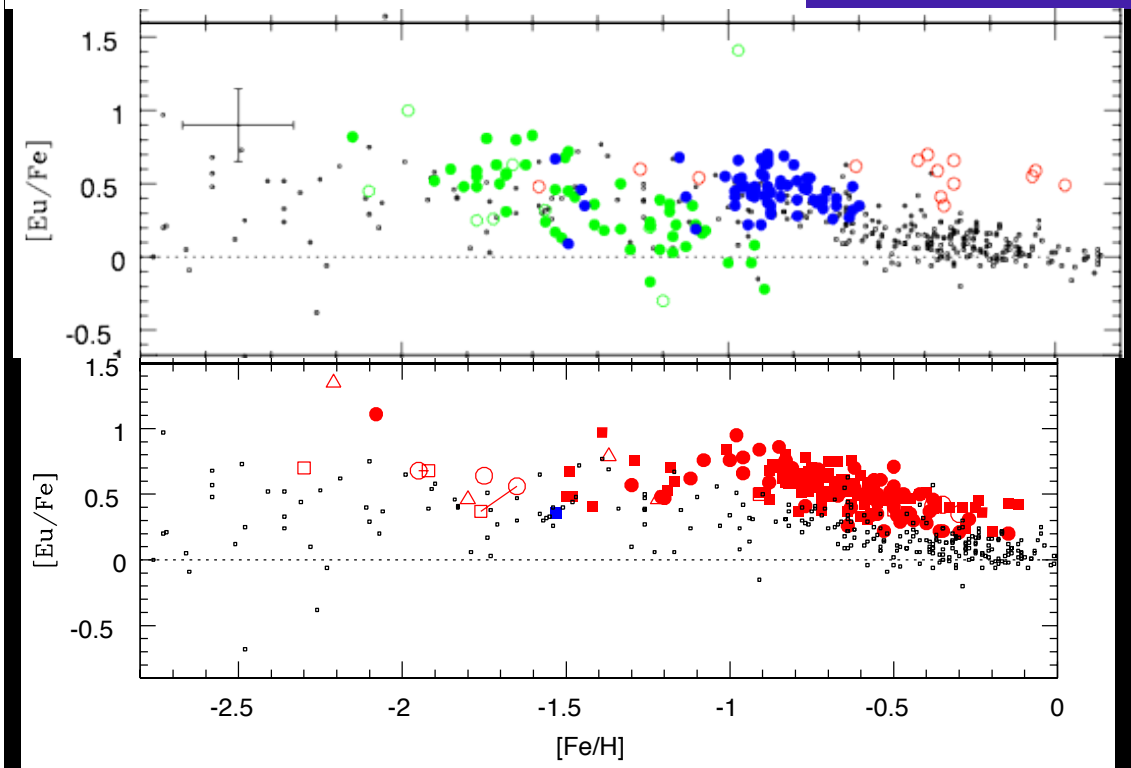
→ Points towards low-metallicity AGB pollution

→ Models: Lanfranchi et al. (dSph); Tsujimoto & Bekki (LMC)

→ Should be seen in Carbon ?

Europium

Sgr McWilliam et al. 2005
Fornax Letarte et al. 2010
Sculptor Tolstoy Hill Tosi 2009 & Hill et al. in prep)
+ Shetrone et al. 2003& Geisler et al. 2005
Milky-Way Venn et al. 2008



LMC field Van der Swaelmen, Hill et al. 2012

clusters Hill et al. 2000, and 2009;
Johnson et al. 2006;
Mucciarelli et al. 2008, 2010

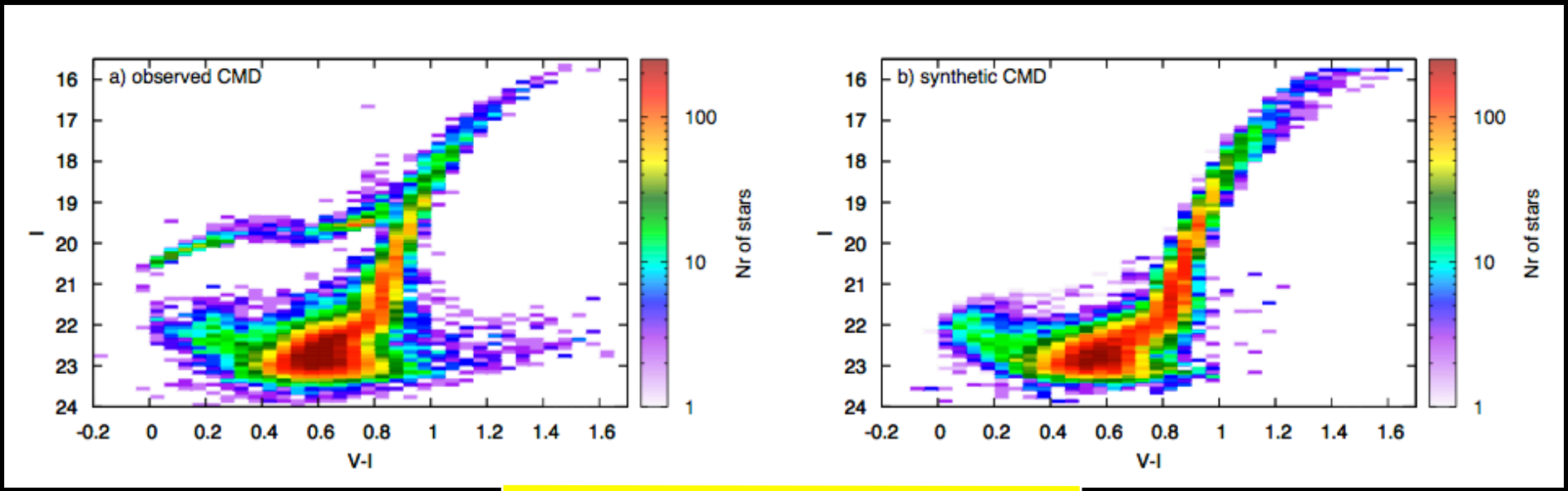
RR Lyrae stars Haschke et al. 2012

- The "pure" r-process element Eu (>93% in the Sun): should behave like an α−elements
- Eu follows α as expected in Scl
- On the contrary, Eu (and but [Eu/α]) is significantly enhanced in the metal-rich part of Sgr, Fnx and the LMC, i.e. in the galaxies with also strong AGB contributions → Tempting to suggest an AGB contribution to Eu…. (also CEPM-sr stars). But see A. McWilliam's talk.

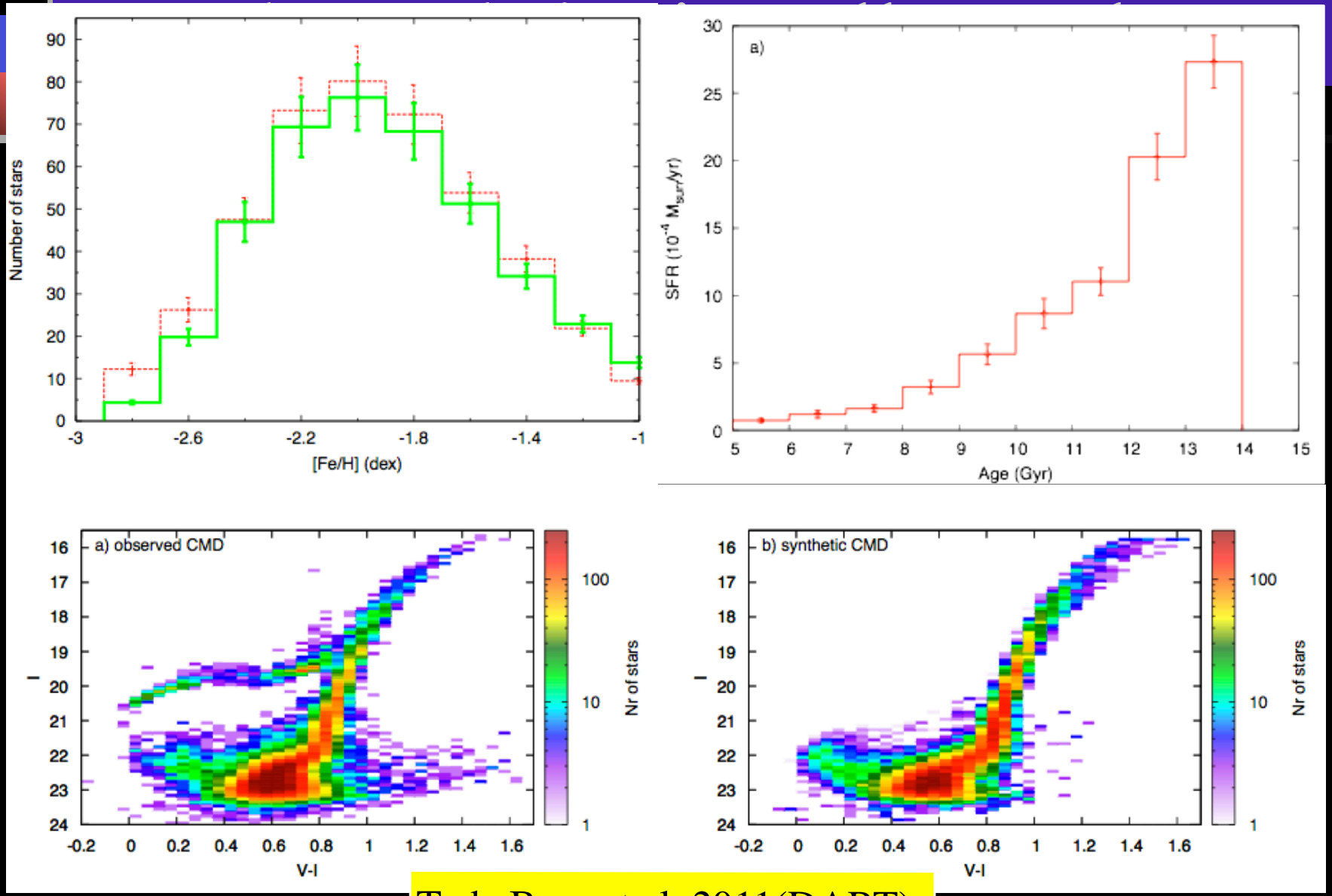
Sculptor: bringing all together

Fitting wide field & deep CMD simultaneously with the MDF:

- beats the age-metallicity degeneracies
- overall fit of CMD (x2) not necessarily better, but builds a self-consistent picture

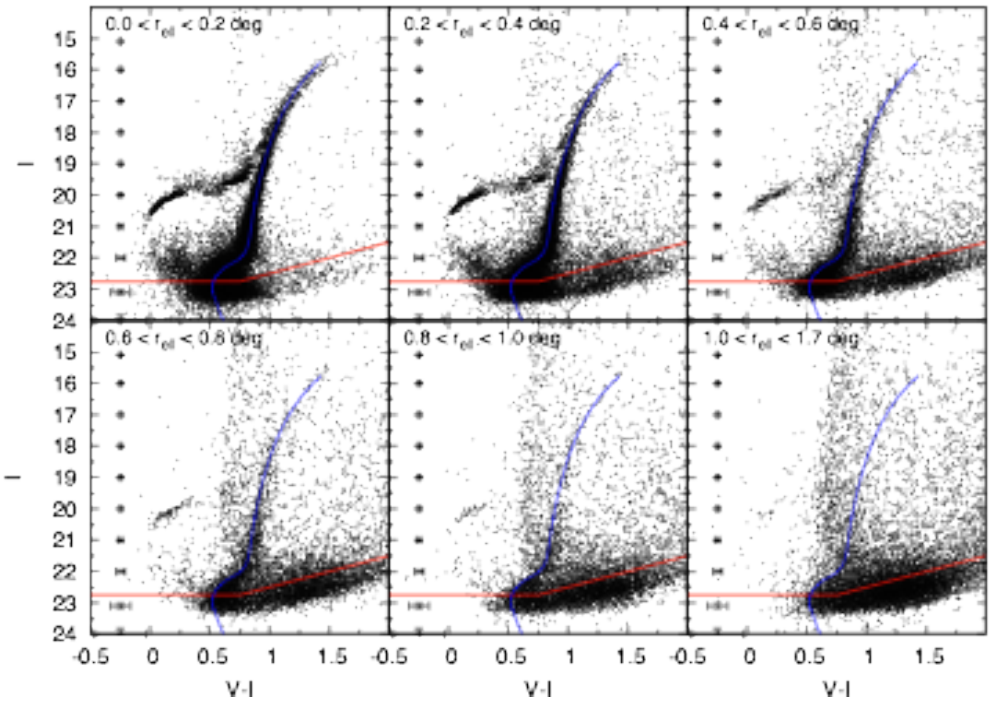


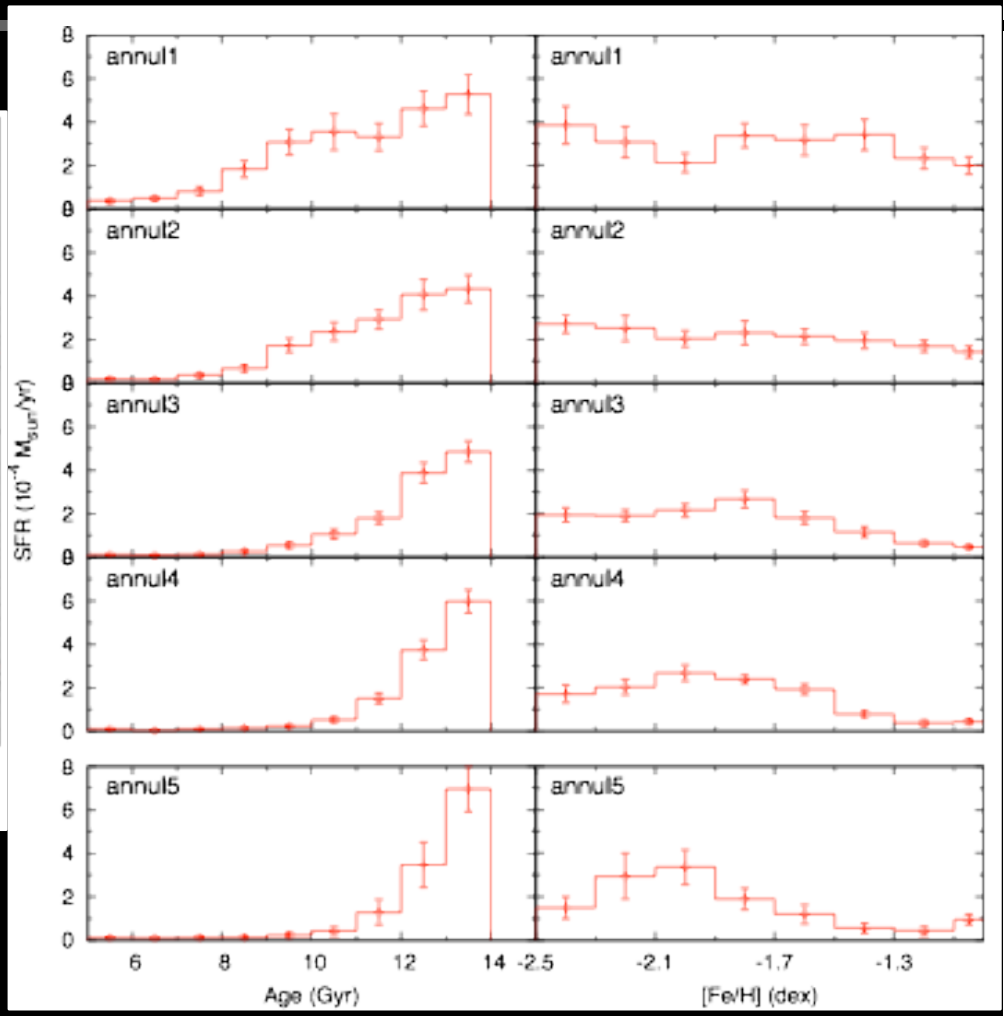
T. de Boer et al. 2011(DART)



T. de Boer et al. 2011(DART)

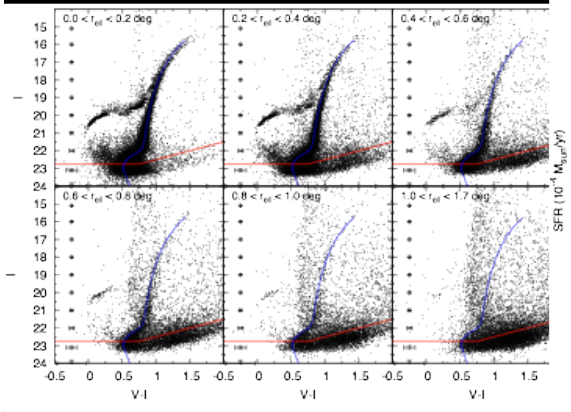
Sculptor: spatial variations

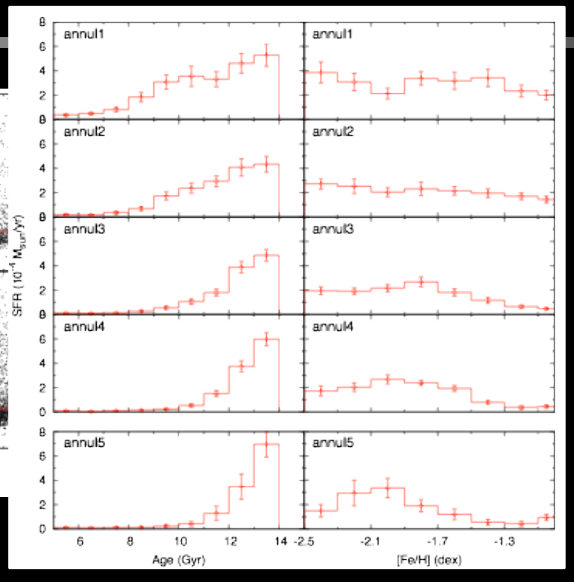


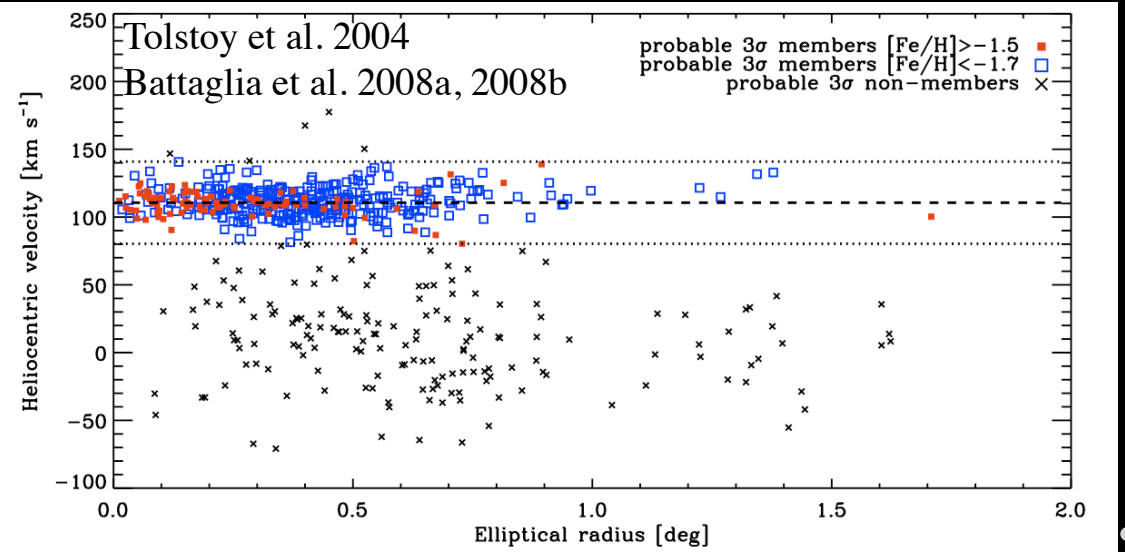


T. de Boer et al. 2011(DART)

Sculptor: spatial variations

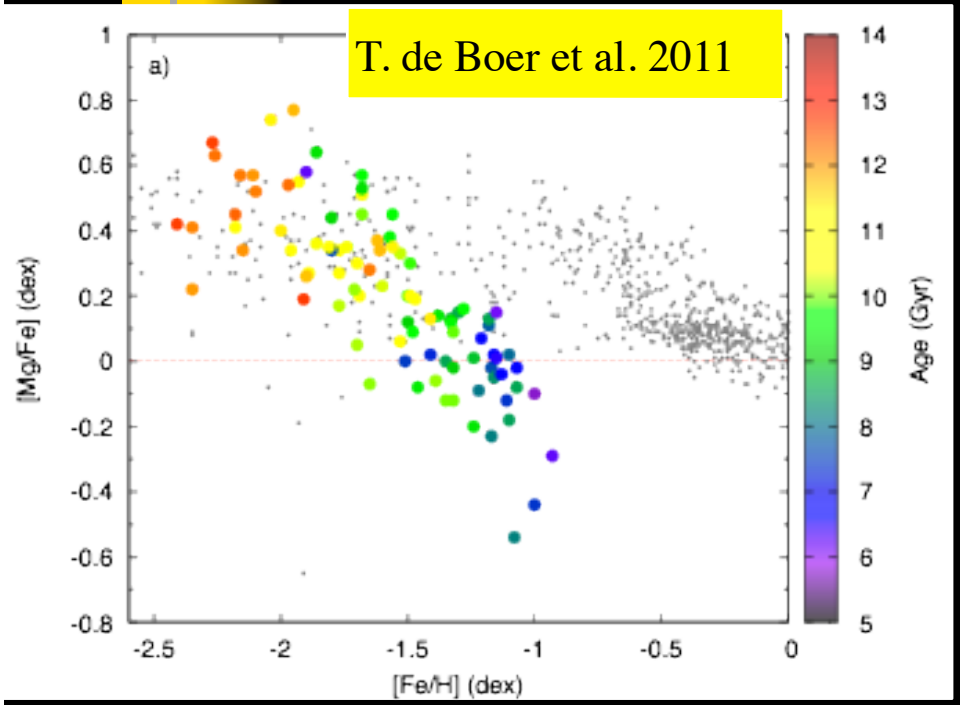






- Sculptor is not only case (Sextans: Battaglia et al. 2010, ...)
- linked to environment ? (seems not to be seen in *isolated* dSph)
- ! Caution when interpreting MDFs derived in the center only (bias towards younger, metal-rich)

Sculptor: bringing all together



- The SFH can conversely be used to constrain solutions to derive more robust ages on the RGB
- The SNIa (knee) in Scl occurred 2Gyrs after the start of SF
- Presumably no SNIa pollution will be observed in Scl outskirts (no data yet).

- A self-consistent model (reproducing SFH, chemical enrichment timescale) for the two populations (incl. kinematics) is yet to be produced. (e.g. Revaz & Jablonja 2011 could not reproduce population gradients)

Summary

- Chemical evolution consistent with a less efficient enrichment (SN Ia contributions at lower Fe than in MW)

➔ The position of the *knee* seems to correlate with the galaxy L or <[Fe/H]> or Mv

➔ Expected if lowest mass systems loose easily their gas (less efficient enrichment)

➔ When star formation is extremely low & bursty, dispersion may prevails at all metallicities (Carina?, Sextans?)

- Very high s-process element content of the metal-rich populations in Fornax, Sagittarius and the LMC (but NOT in Sculptor, Carina, Draco), result from a strong pollution by metal-poor AGBs.
- dSph do host some extremely metal poor stars (<-3), although in small numbers
- *Metal poor* stars abundances are not (yet) very significantly different from those of the metal-poor halo (but see M. Shetrone's talk about C)
- Many modelling efforts ongoing….