First Stars from Abundance Patterns in Dwarf Spheroidal Galaxies

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The DART-eam

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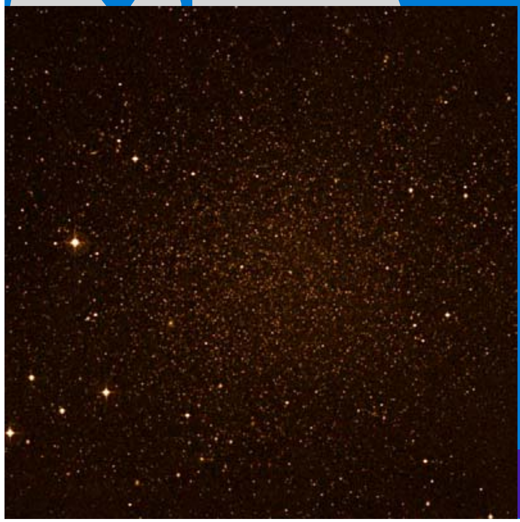


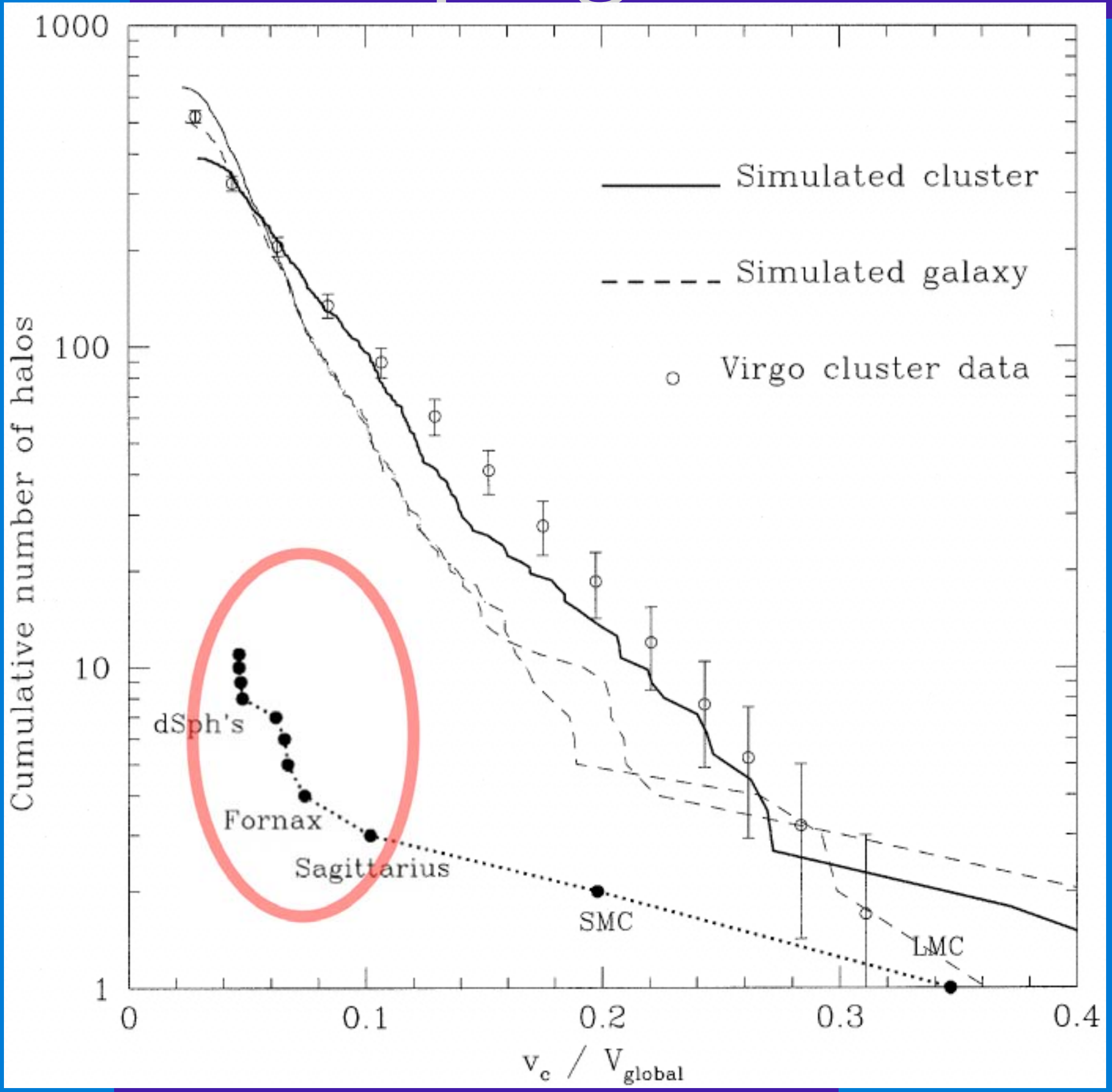
Talk Outline

1. Why look for First stars relics in dSph galaxies ?
2. DART: a chemo-dynamical survey of nearby dSph galaxies
3. Metal-poor stars in dSph galaxies: how metal-poor can we go ?
4. Metal-poor stars in dSph galaxies: abundance patterns compared to the Milky-Way halo counterparts

1. First stars in dSph ?

- Hierarchical galaxy formation: small blocks form first
- dSph are the smallest galaxies directly observable in details
- Could be formed prior to reionization (Gnedin & Kravtsov 2006) ? First stars in them could be responsible for (part of) the reionization and the IGM metal-enrichment (lost through efficient winds) ?
- Even though the present-day nearby dSph might have evolved since the first star formation episodes, the relics (low-mass stars) of the first epochs are still observable.

1. dSph galaxies: the smallest units

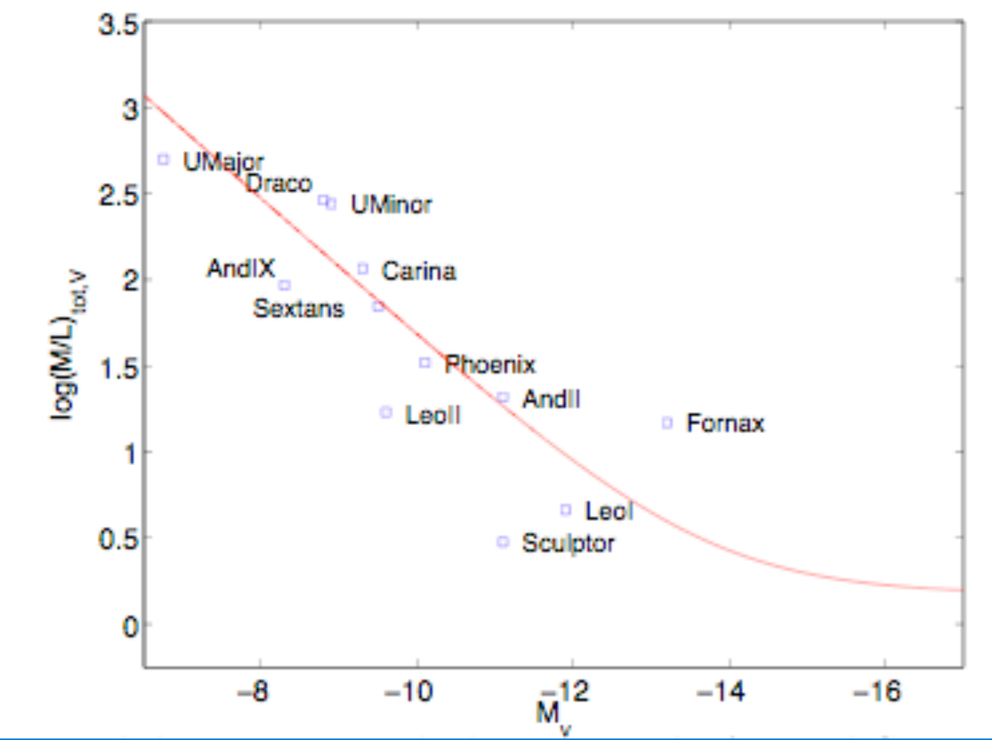


CDM predictions ok at large scales, not so well at the smallest scales

What relation do dSph have to building blocks ?

Moore et al. 1999

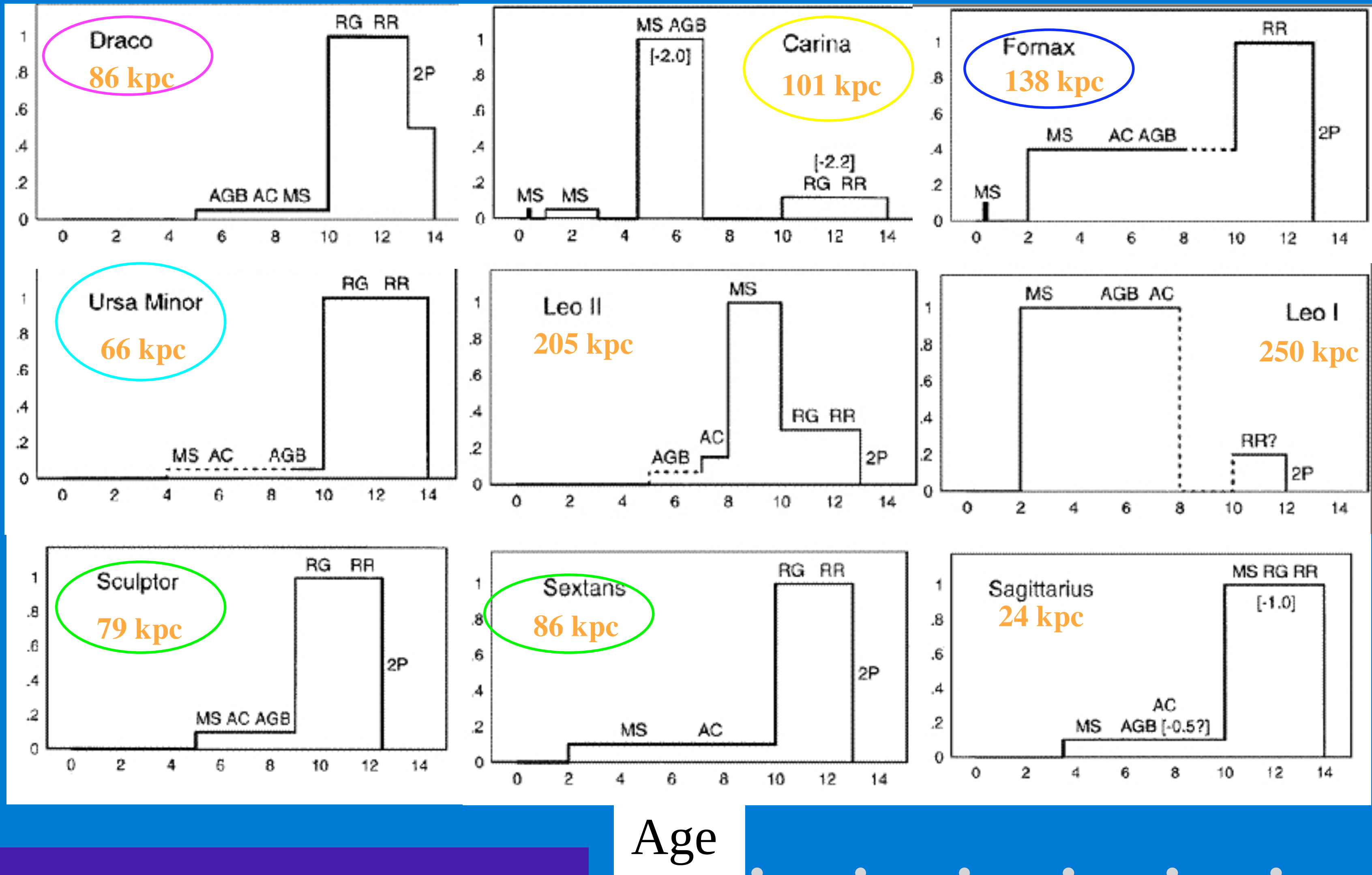
1. Smalest units: Mv, M, M/L



Consistent with a constant Mass ~ a few 10^8 M_o

(Wilkinson 2006)

1. Various evolutionary paths



2. DART

Dwarf Galaxy Abundances and Radial Velocities Team

Sculptor, Fornax, Sextans, (Carina)

FLAMES multiobject spectrograph @ ESO/VLT

• HR abundances in central regions for detailed abundance analysis :
50- 100* per galaxy

• LR abundances over the whole galaxy for a wider view of metallicities and kinematics of the entire system using the IR Ca triplet:
200 - 900* per galaxy

• WFI imaging over entire area of galaxies: looking for large scale spatial variations in stellar populations, and to provide spectro targets.

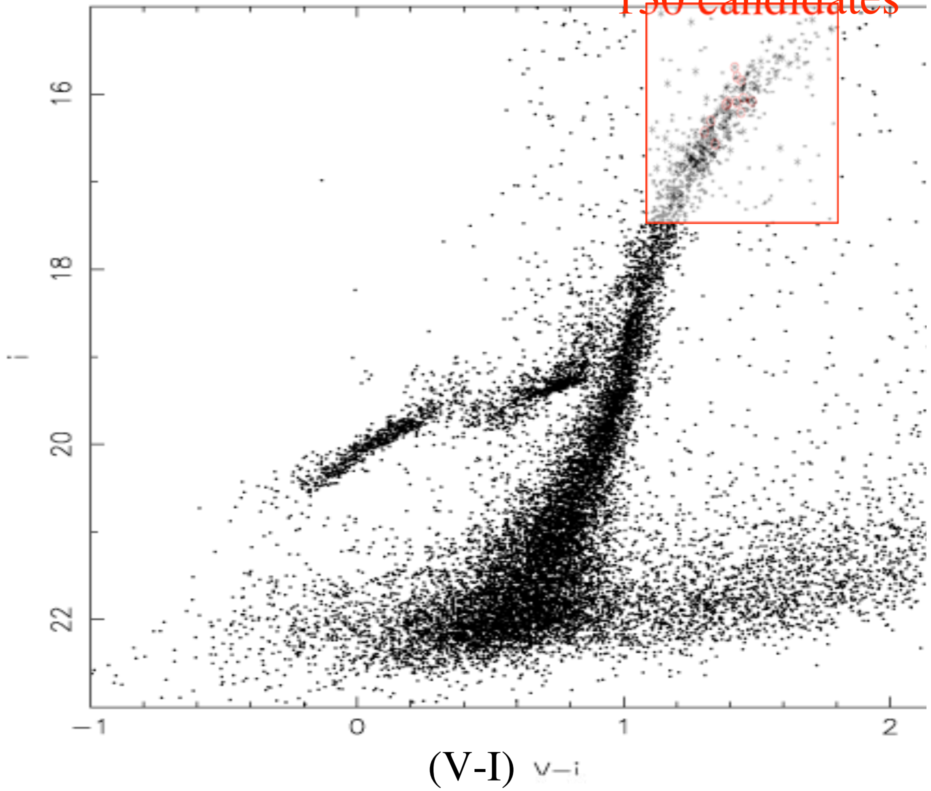
Sculptor: Tolstoy et al. 2004 (LR) and Hill et al. 2007 in prep (HR)

Fornax: Battaglia et al. 2006 (LR) and Letarte PhD thesis 2007 (HR)

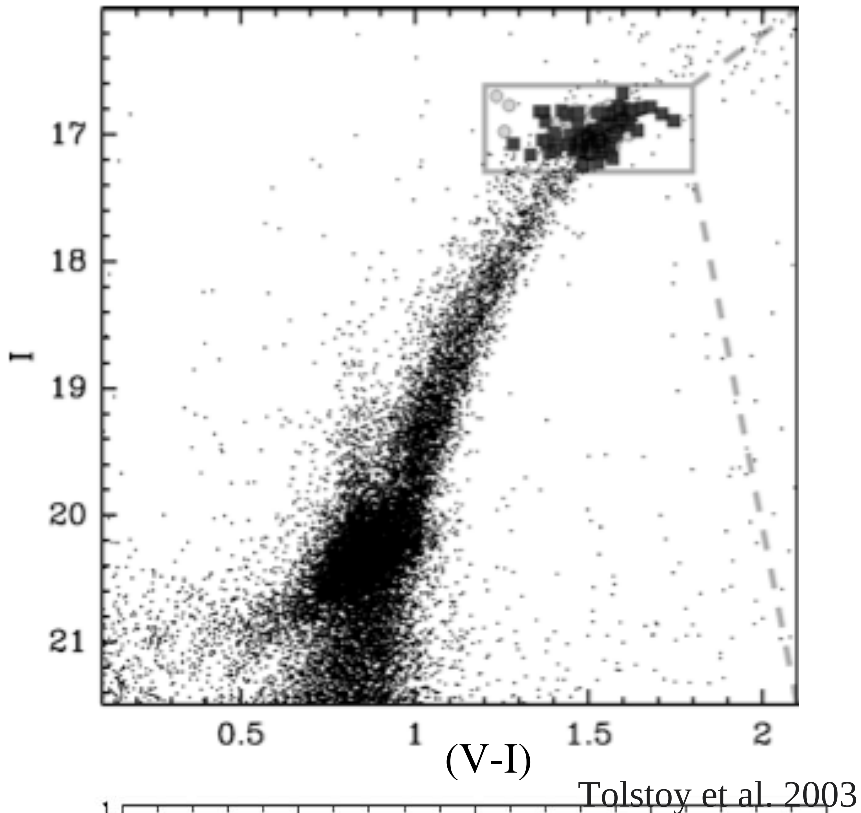
HR abundances: Hill et al. 2007 in prep.

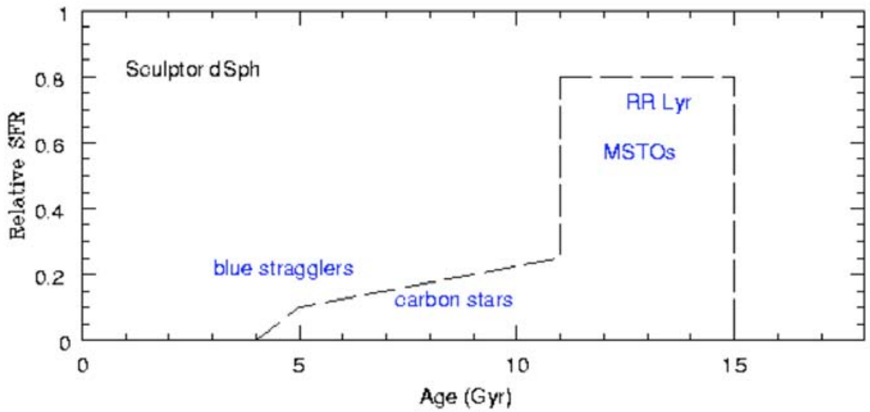
HR abundances: Letarte PhD thesis 2007

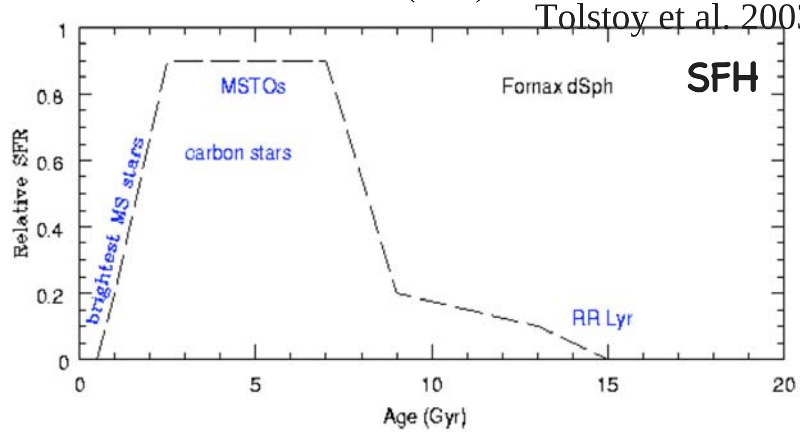
Sculpteur

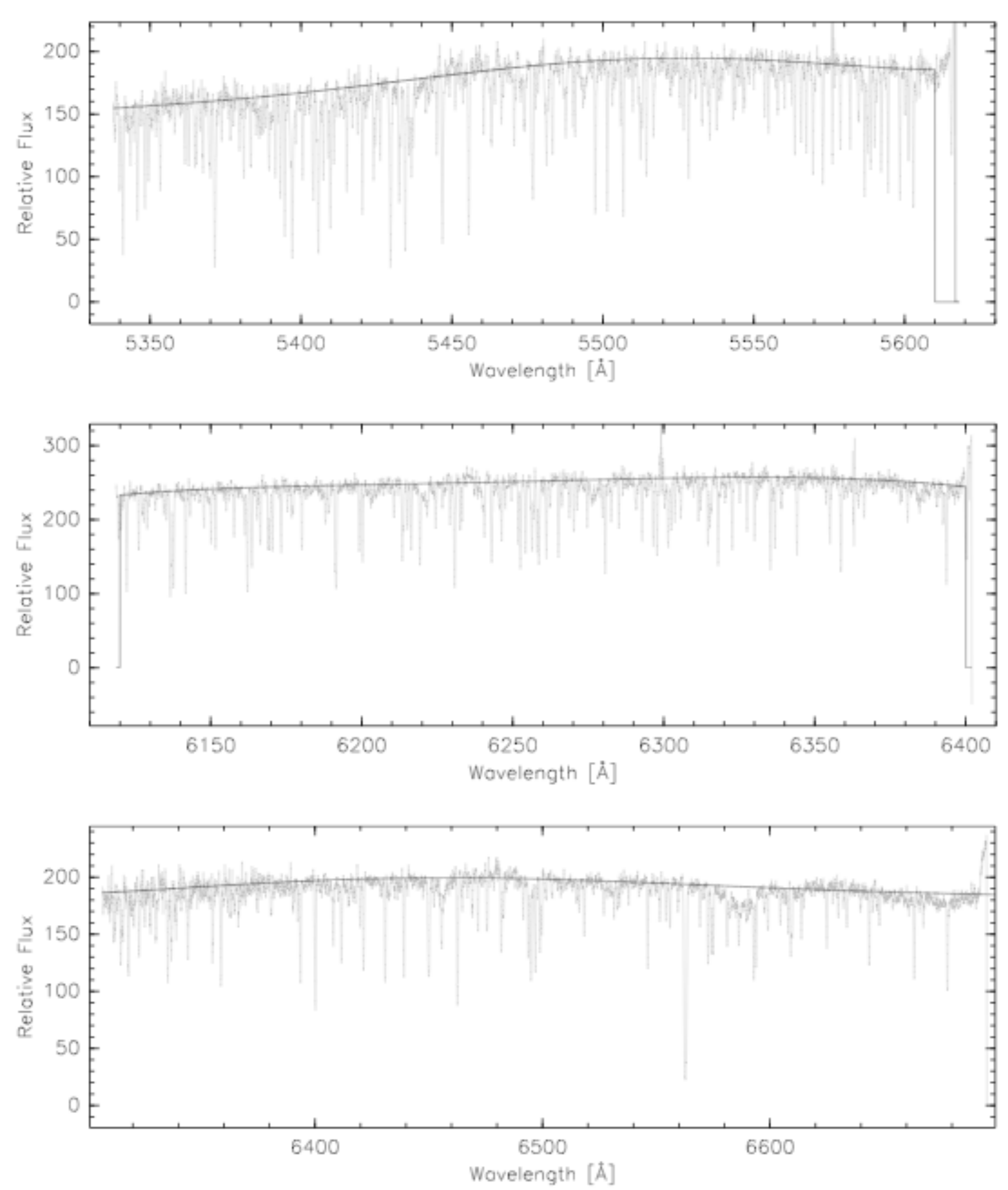


Fornax









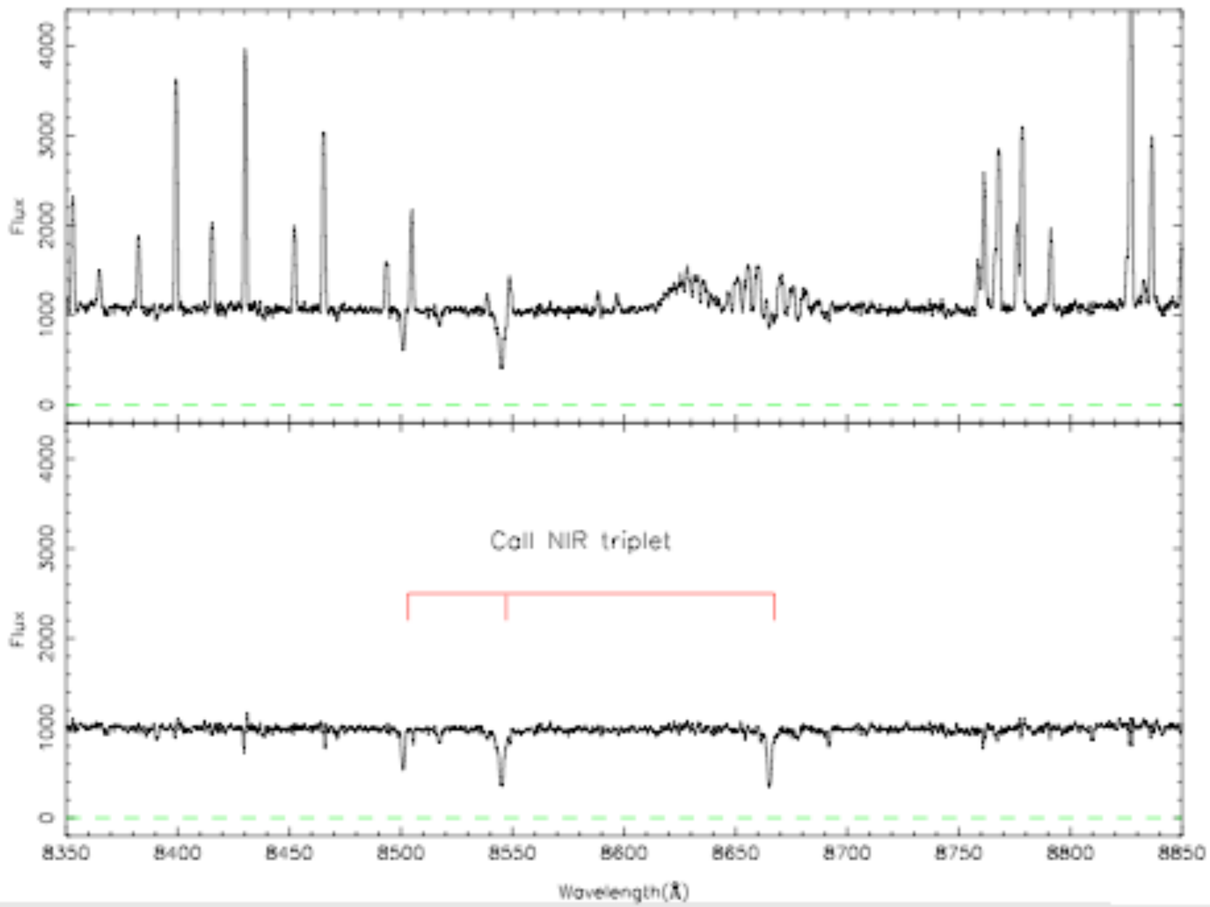
2. GIRAFFE HR

- P=20000 Δλ : 3x 20nm
- Measure hundred(s) of lines

+model atmosphere

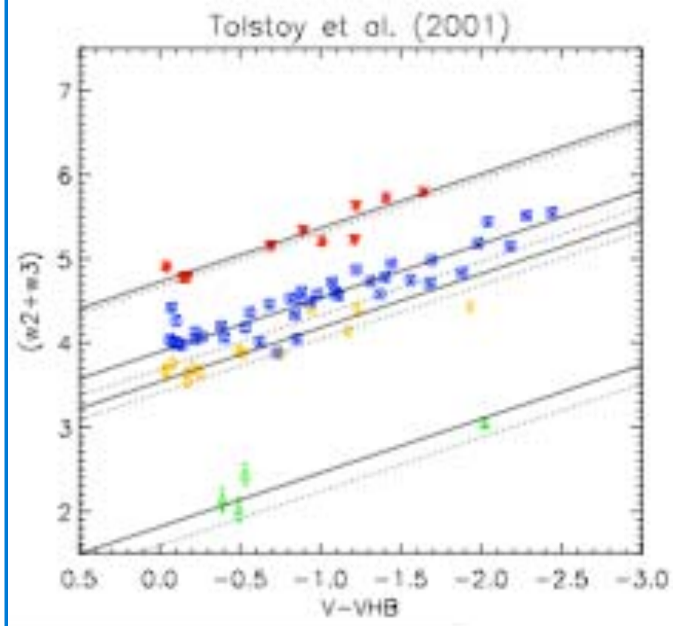
➞ Abundances of ~15 elements, incl. Fe, alpha-elements, neutron capture elements.

2. GIRAFFE LR: CaII NIR triplet

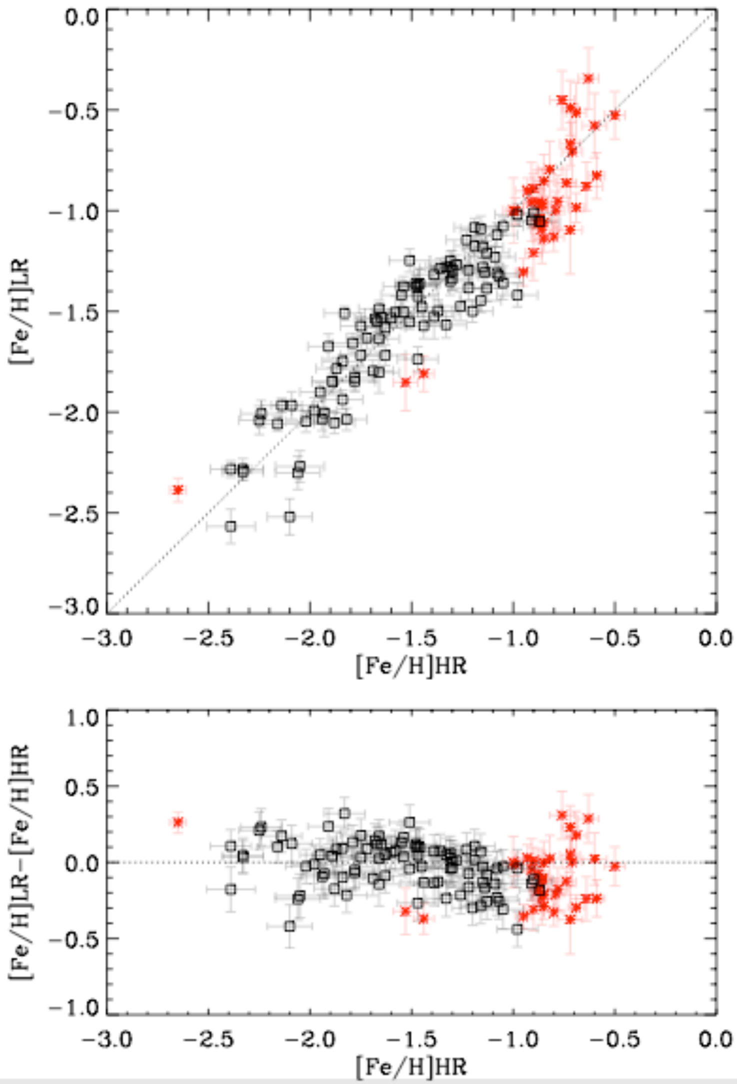


- R=6000 2 CaII lines + calibration to $(V-V_{HB})$

→ [Fe/H] estimate



2. Comparison LR - HR

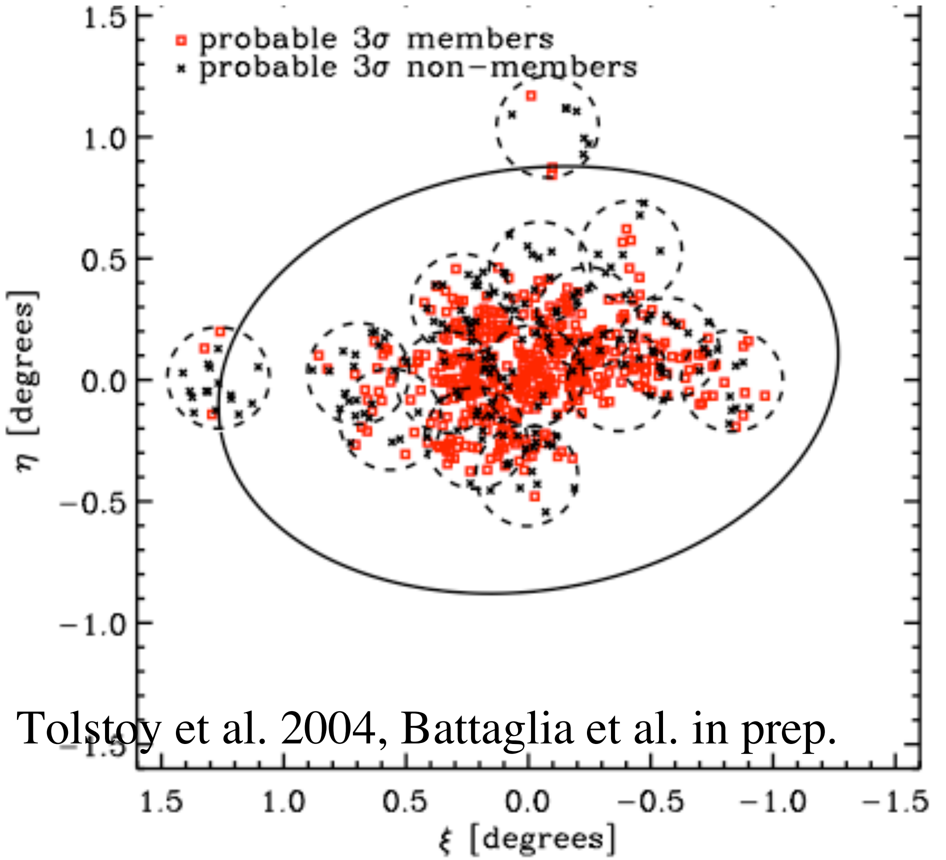


- rms ok: ~0.15-0.2dex
- Slight systematics:
  - -0.2 at the high-metallicity end (above [Fe/H]~-1) ? Or simply an increase of the dispersion… Can be expected from the age-dependency of the method.
  - +0.1 at the low-metallicity end ?

Battaglia et al. 2007 in preparation

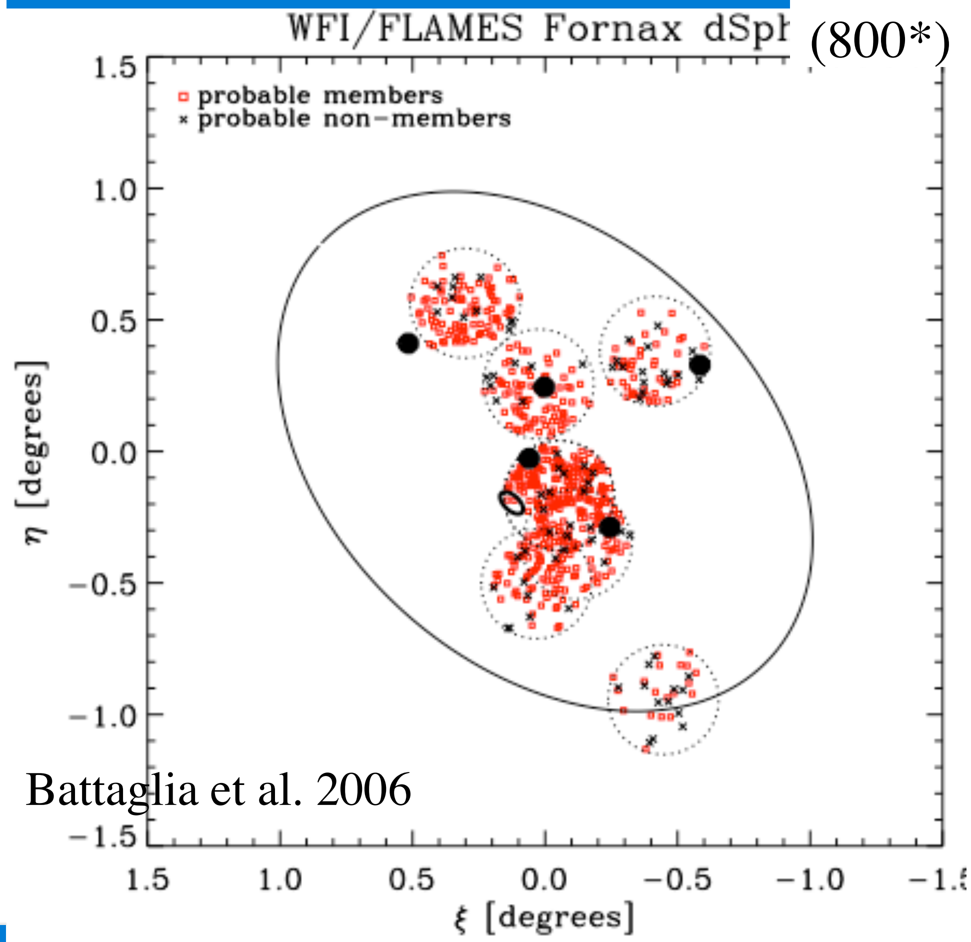
3. Looking for low-Z: extent

WFI/FLAMES Sculptor dSph (650*)



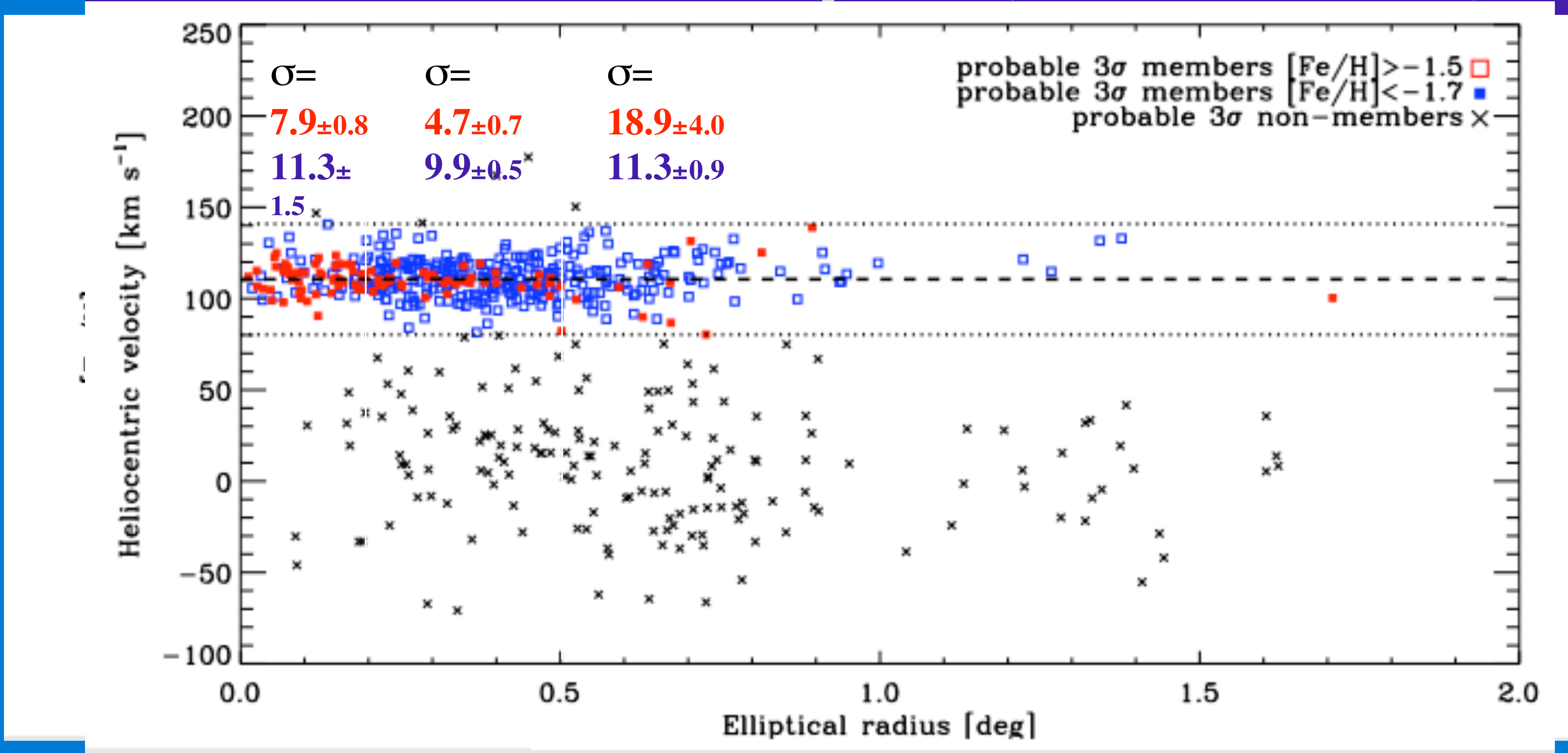
Tolstoy et al. 2004, Battaglia et al. in prep.

(800*)



Battaglia et al. 2006

Sculptor (470 confirmed members)



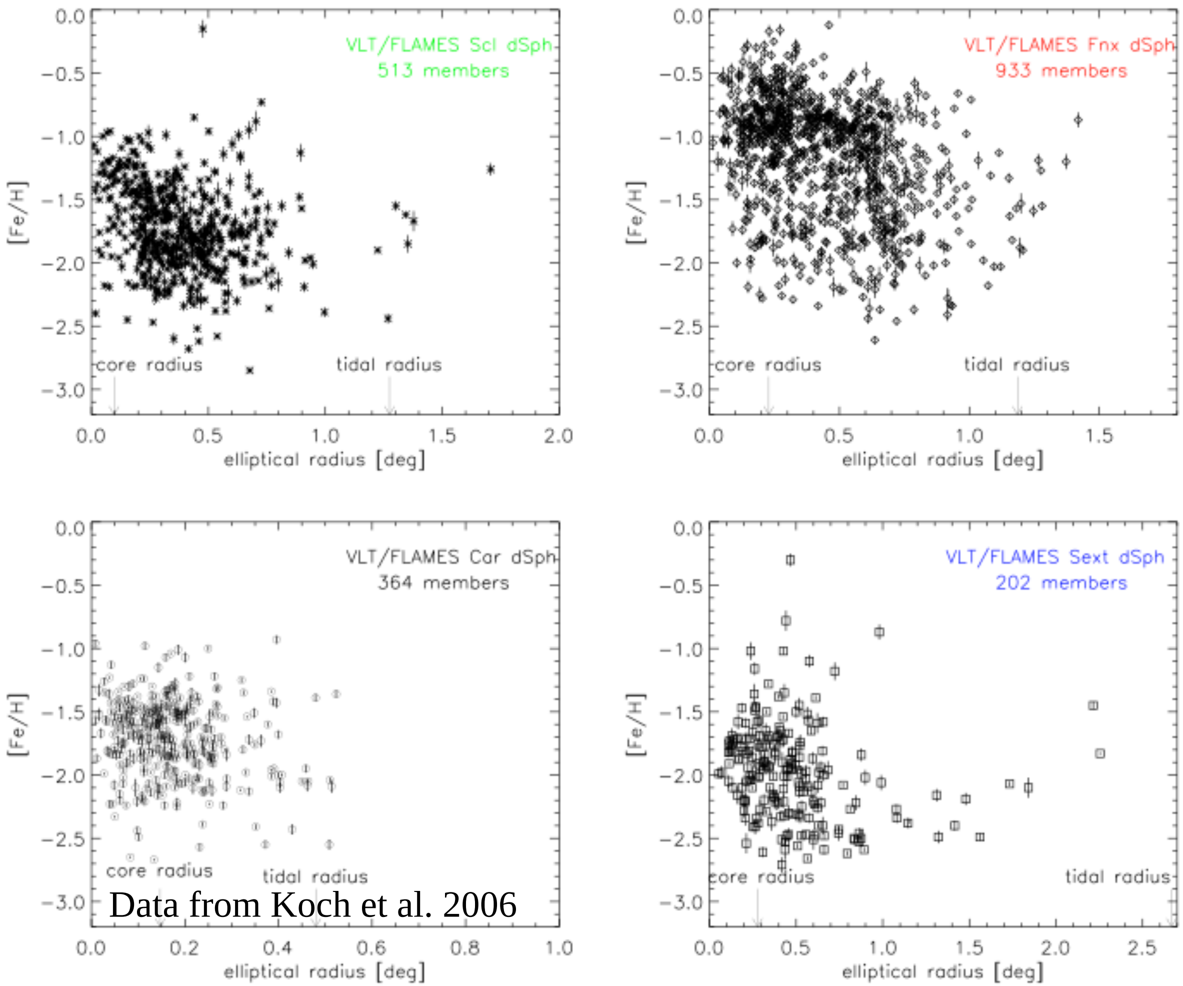
Battaglia et al. 2007 in prep.

Tolstoy et al. 2004 ApJL

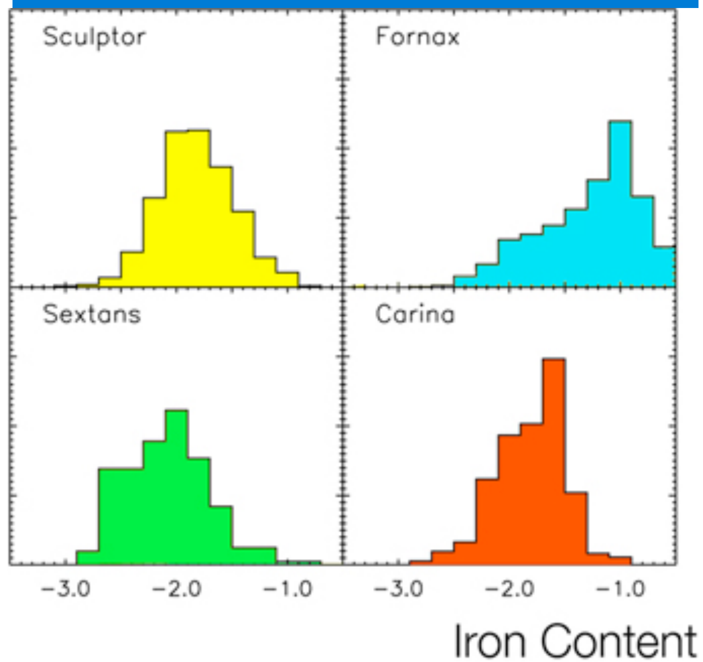
Metallicity distribution variation...

Associated with different kinematics

3. Ubiquitous low-Z component

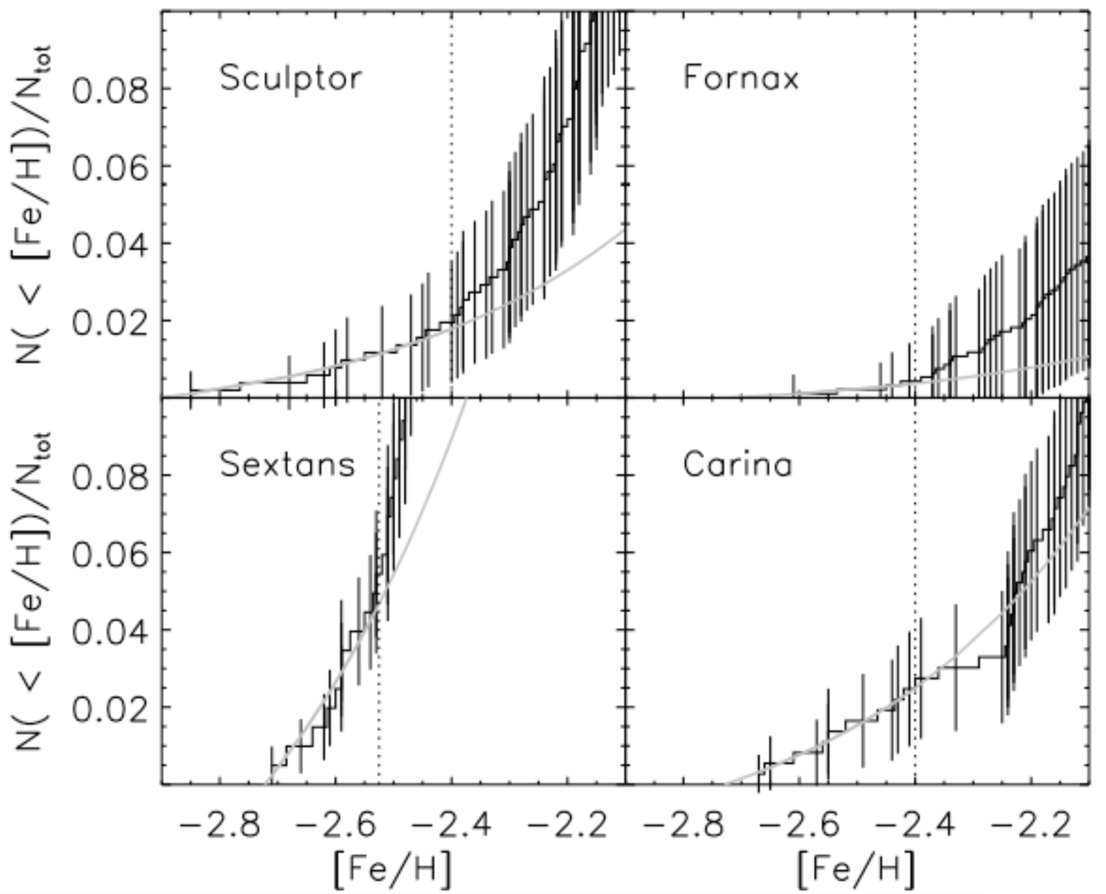


Data from Koch et al. 2006



- Various SFH and therefore MDFs, but low-Z component is ubiquitus

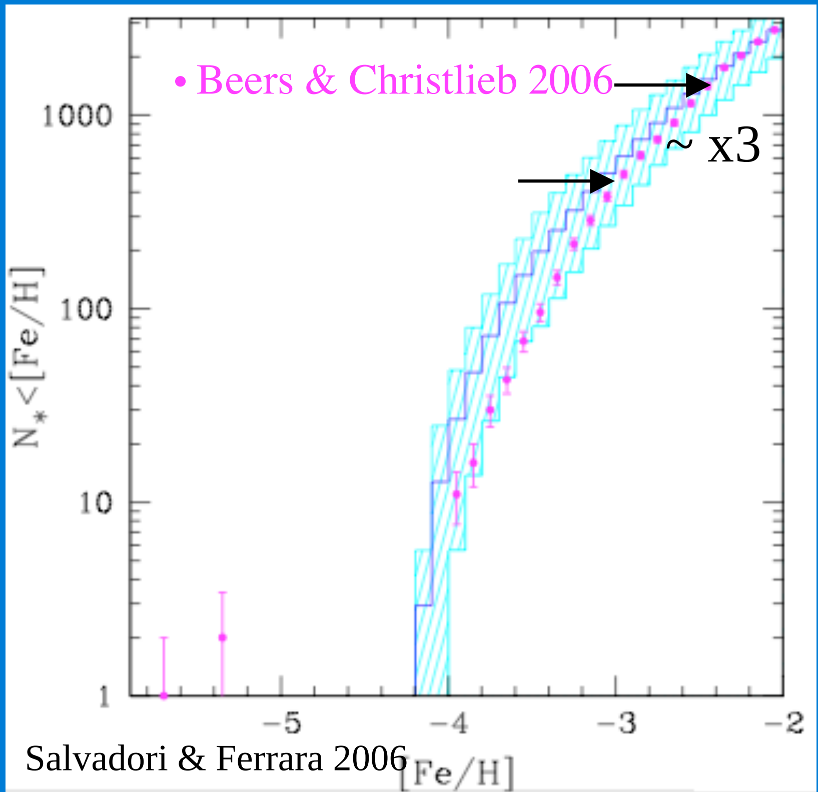
3. Similar low-Z tails



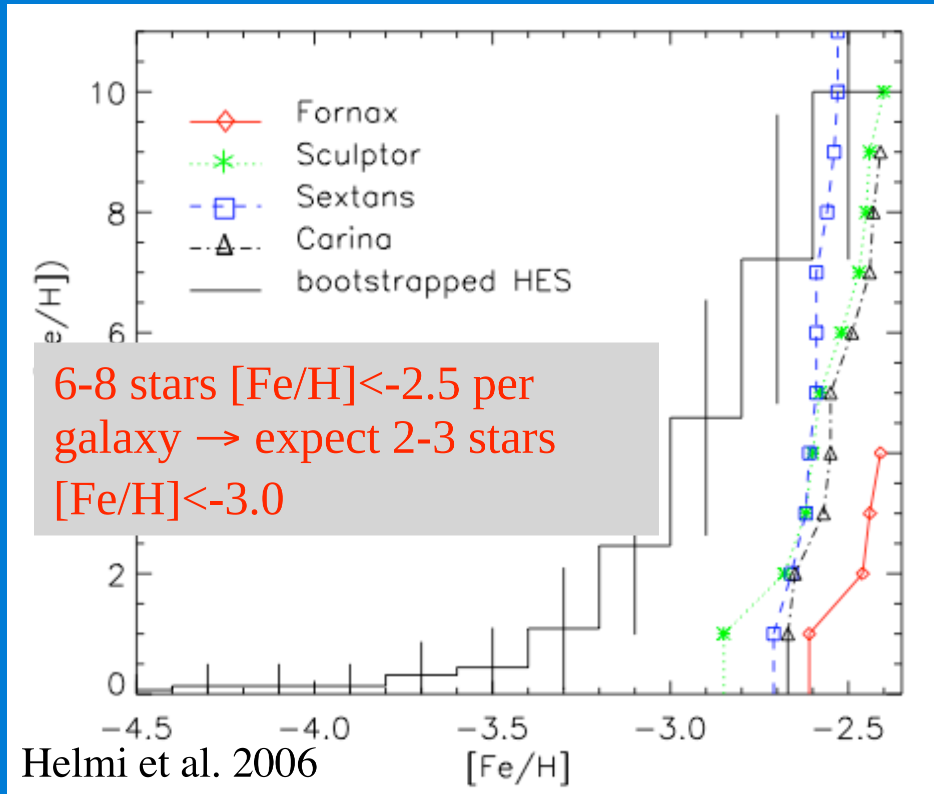
$$N\ (< [Fe/H]) = a\ 10^{[Fe/H]} + b$$

galaxy	$[Fe/H]_0$	χ^2	*prob*	N_{stars}
Sculptor	−2.90± 0.21	1.02	0.998	10
Fornax	−2.68± 0.35	0.86	0.931	6
Sextans	−2.72± 0.14	2.0	0.991	11
Carina	−2.73± 0.19	0.44	0.999	9

3. dSph lack the lowest-Z tail ?



Salvadori & Ferrara 2006



6-8 stars [Fe/H]<-2.5 per galaxy → expect 2-3 stars [Fe/H]<-3.0

Helmi et al. 2006

Milky-Way: "-4 desert"

+ 2 [Fe/H]<-5 stars with very high CNO

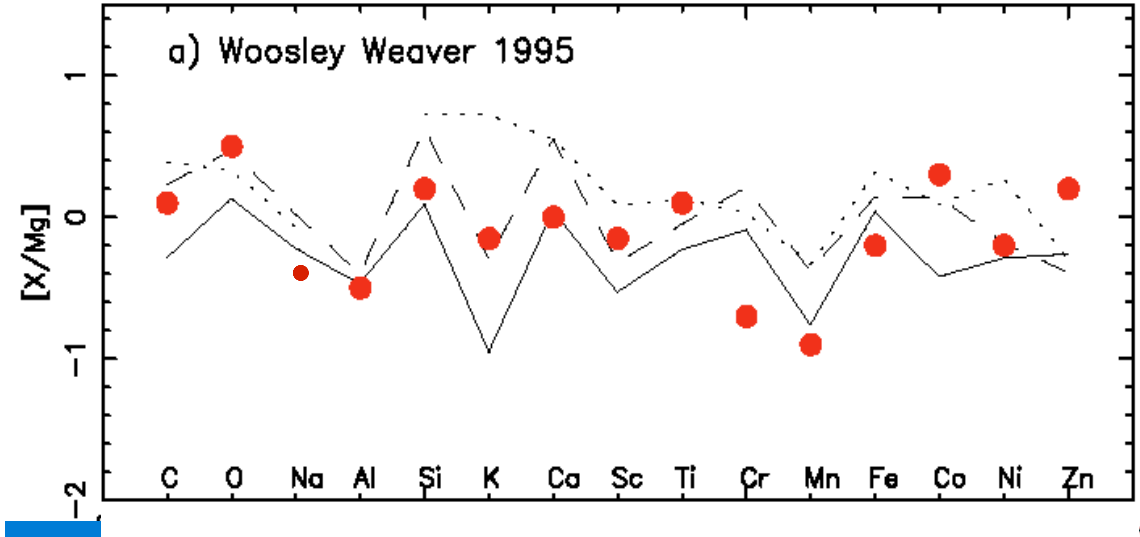
Dwarf spheroidals: "-3 desert"

3. Interpretation and Caveats

1) The MW building blocks formed from high-σ density peaks (Diemand et al. 2005), while dSph can arise from low-σ peaks (predicted to collapse on average at lower z: e.g., 1-σ peak of mass 10^8 M collapses at z~4, Qian & Wasserburg 2004). dSph could then be formed in pre-enriched gas (cf IGM metallicity of [Fe/H]~ −3 dex, Cowie & Songaila 1998)
2) The IMF could have behaved differently in Galactic building blocks and dSph at the earliest times. Ex: with a bimodal IMF, low-mass stars can form even from zero metallicity gas (Nakamura & Umemura 2001). This would then be favoured when then initial density of the gas is sufficiently large, and so this would be favoured in high-σ peaks collapsing at very early times.

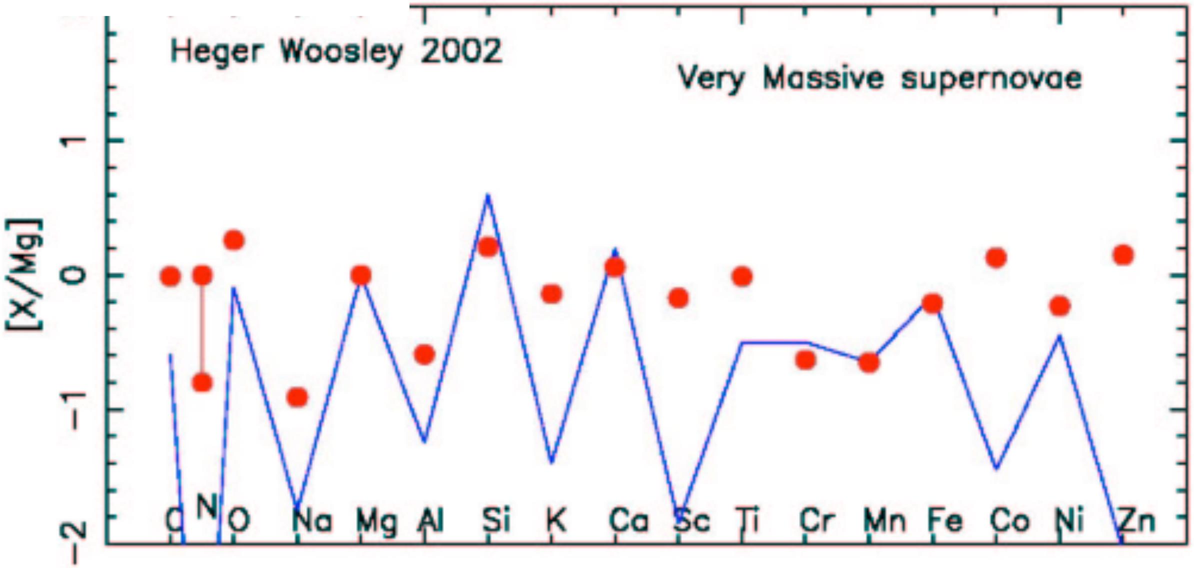
- However:
  - CaT metallicities are extrapolated below -2.5
  - Samples are still small….

4. High resolution abundances

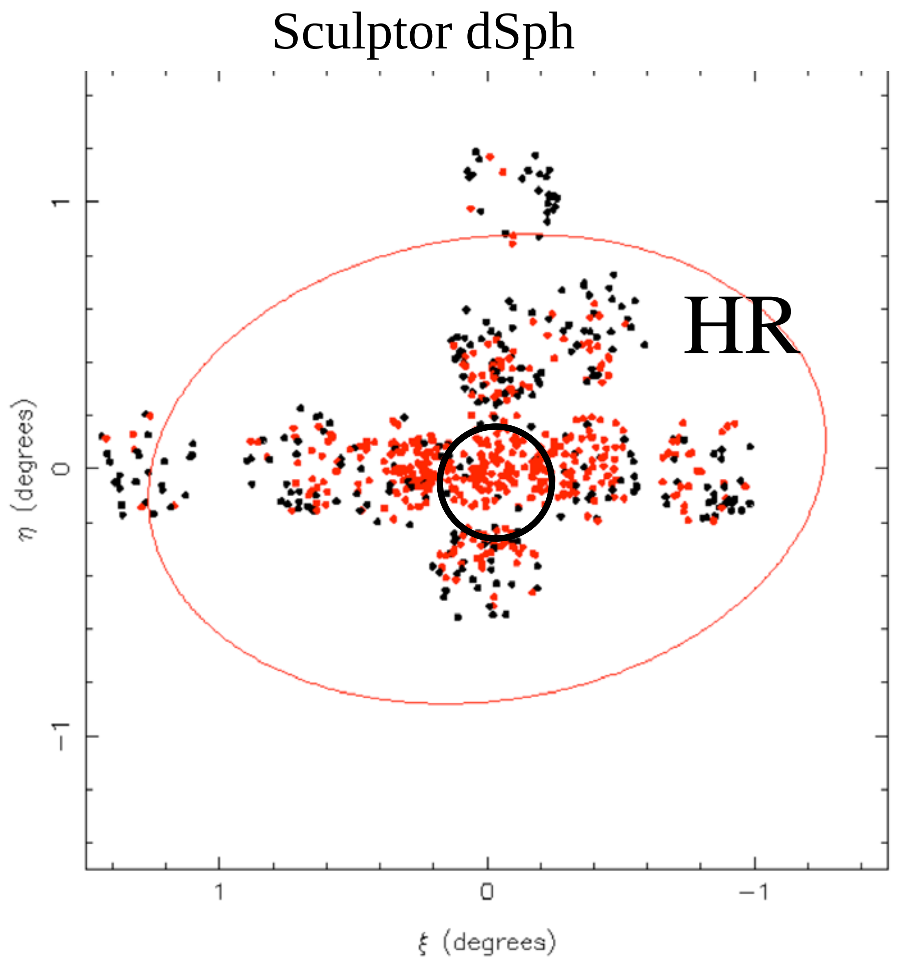


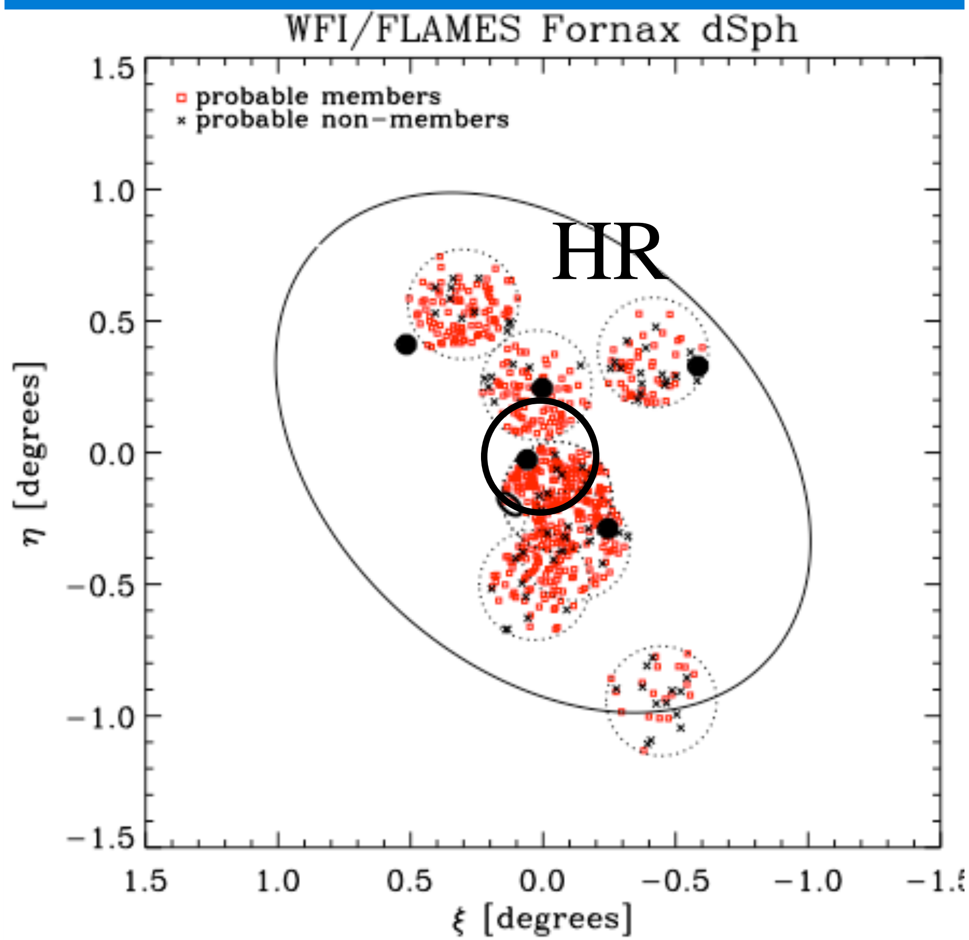
Abundance patterns are powerful to discriminate progenitors (polluters): masses, …

Cayrel et al. 2004 +
Spite et al. 2007 in prep:
~50 EMPS stars in the galactic halo



4. Abundance patterns in dSphs ?

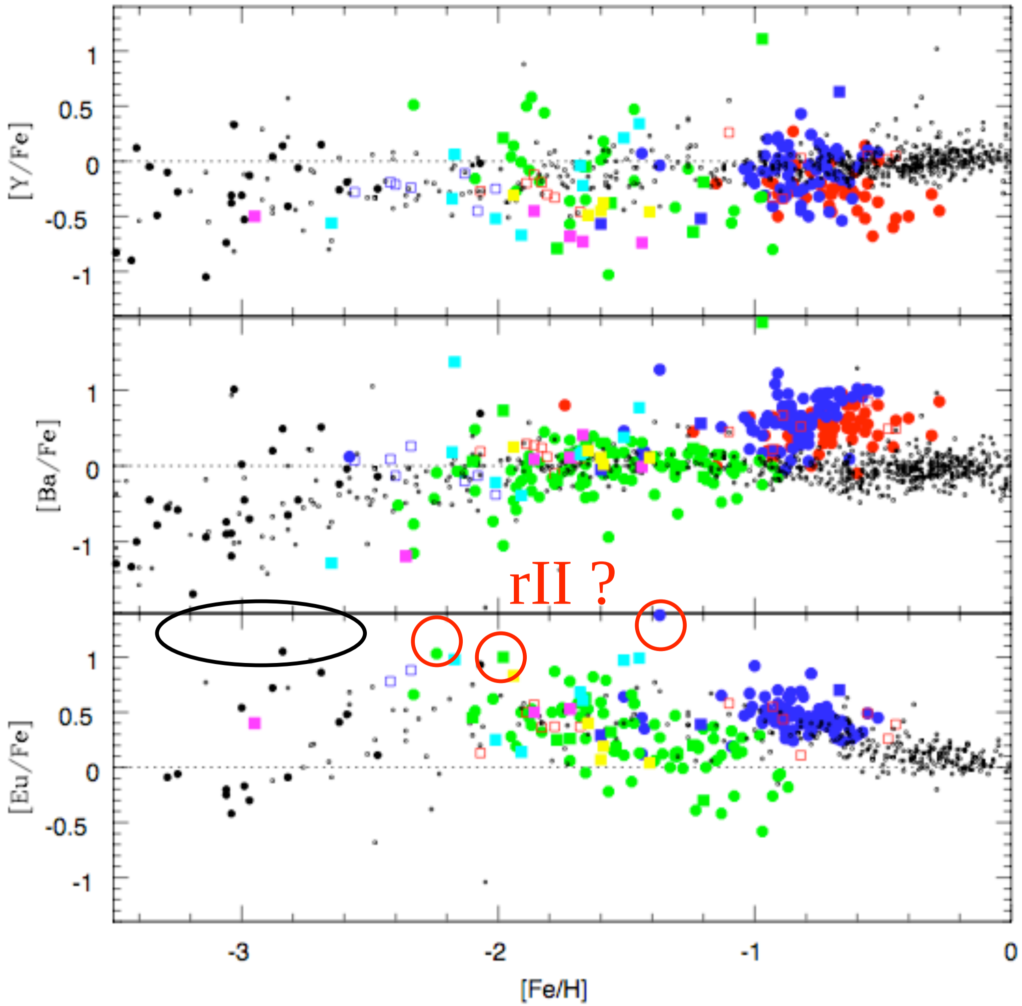




HR samples (also in the litterature) in the center: miss the low-Z tail

LMC Pompeia, Hill et al. 2006 subm.
Fornax Letarte PhD thesis, Shetrone et al. 2003
Sculptor Hill et al. in prep, Shetrone et al. 2003, Geisler et al. 2005
Uminor Shetrone et al. 2001, Sadakane et al. 2004
Draco Shetrone et al. 2001, Fulbright et al. 2004

n-capture elements



- Y,Ba: s-process (TP AGB) +r process
- Eu: r-process, massive stars (SNII)

At hight Z:

Ba/Fe follows distinct path: s- process very efficient in galaxies with strong SFR at younger ages (<5Gyrs): Fnx > LMC > Scl

At low Z ([Fe/H]<-2):

- r-process dominates in dSph and MW
- Ba rise happens at higher Fe/H in dSph
- Occurrence of rII stars also at higher Fe/H ?

Milky-Way:

. Compilation by Venn et al. 2004
- Francois et al. 2007 (subm.)

Conclusions

1. CaT metallicities of large sample of stars in Sculptor Fornax Sextans and Carina show that:
   a) dSph seem to lack the most metal-poor stars found in the MW halo ([Fe/H]<-3). IMF ? Late formation of dSph from pre-enriched (IGM) gaz ?
   b) Two distinct old stellar populations, chemically and kinematically
2. Abundance patterns of *very metal poor* stars ([Fe/H]<-2) in dSph are still very scarce, but we show that:
   a) Very Metal poor stars abundances in dSph are not significantly different from those of the metal-poor halo of the MW.
   b) The onset of the r-process might have happened at higher metallicities in dSph:
      - ✓ if r-process is a clock, then it would mean that dSph enrich faster to a metallicity of -2;
      - ✓ alternatively, if r-process is a baryometer, it would mean that the IMF favours lower-mass SNII in dSph)
3. Subsequent chemical evolution is distinct in each distinct galaxy (as strikingly shown by the new large samples in Sculptor and Fornax)

(near) Future work

- Obtain precise abundances in all the most metal-poor stars detected to date in dSph (in progress, using VLT/UVES, Subaru/HES, Magellan/MIKE).
- Continue CaT surveys to probe the (or the lack of) [Fe/H]<-3 stars.