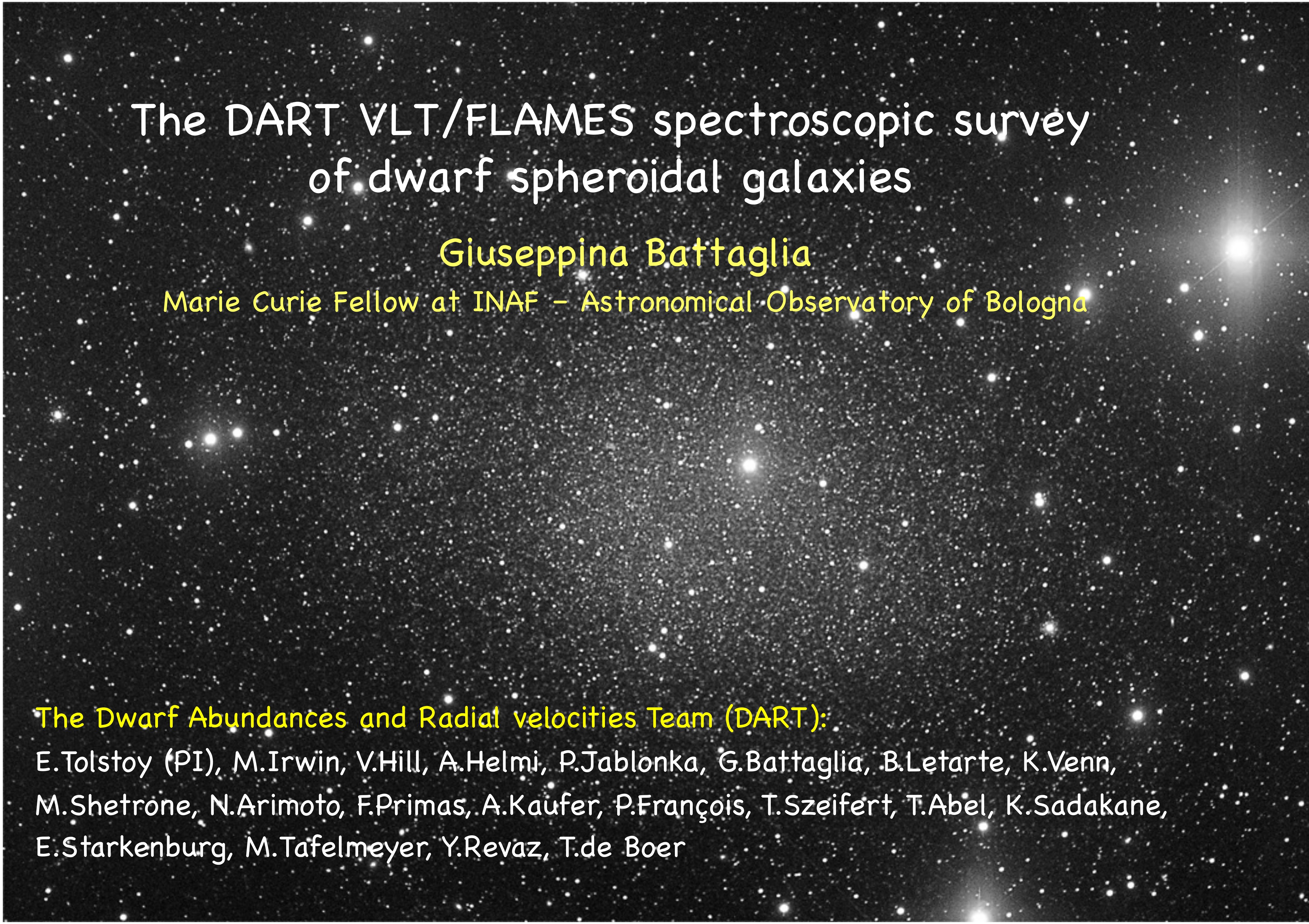

The DART VLT/FLAMES spectroscopic survey of dwarf spheroidal galaxies

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The Dwarf Abundances and Radial velocities Team (DART):

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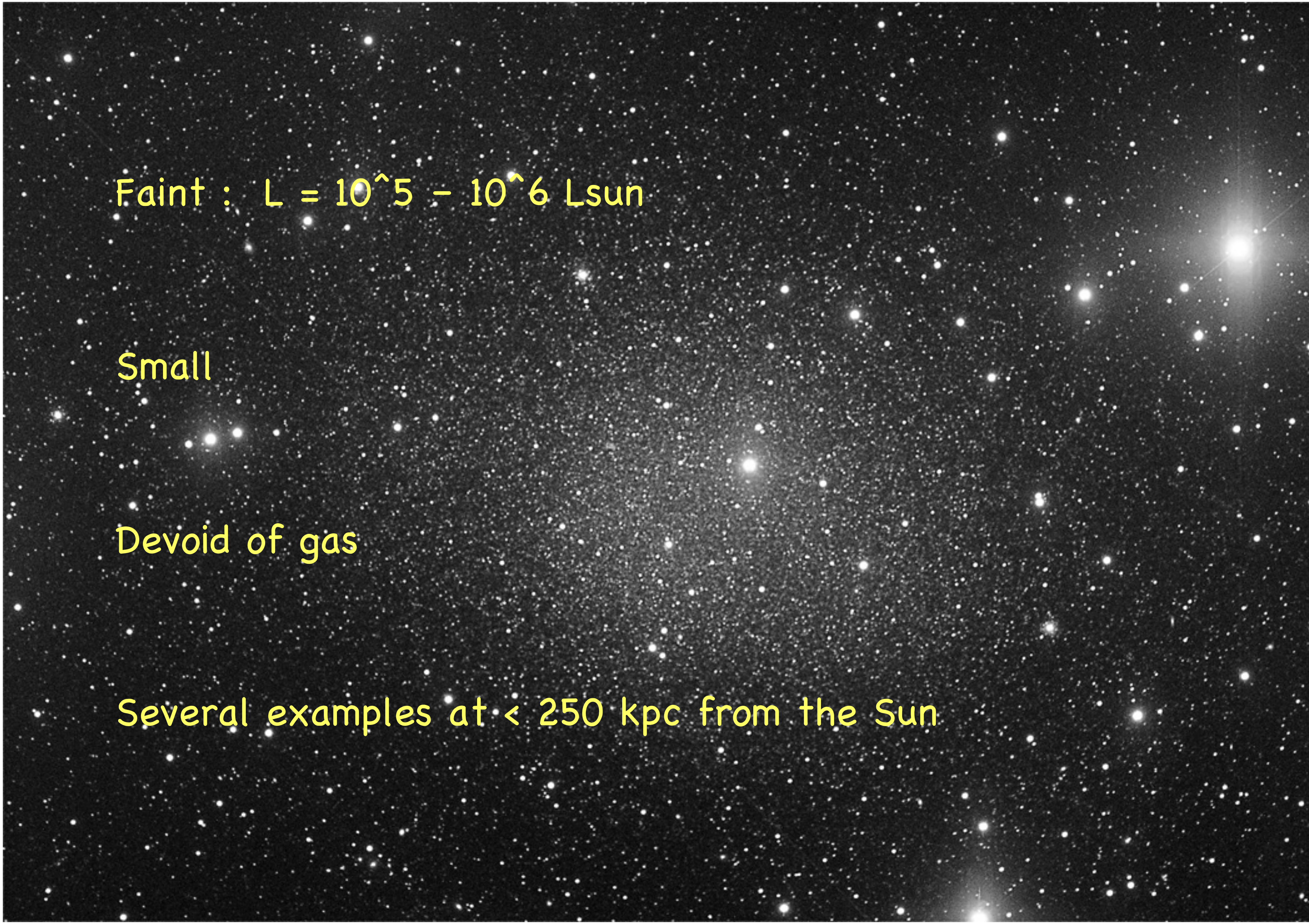

Faint : L = 10^5 - 10^6 Lsun
Small
Devoid of gas
Several examples at < 250 kpc from the Sun

Motivation

- Most dark-matter dominated galaxies -> potentially very good targets for testing different dark matter theories

- Possible role in the build-up of larger galaxies

- Most numerous galaxy population

- Close-by and small -> they can be studied in great detail

dSphs: historical view mostly from observations restricted to central regions (e.g. review from Mateo 1998)

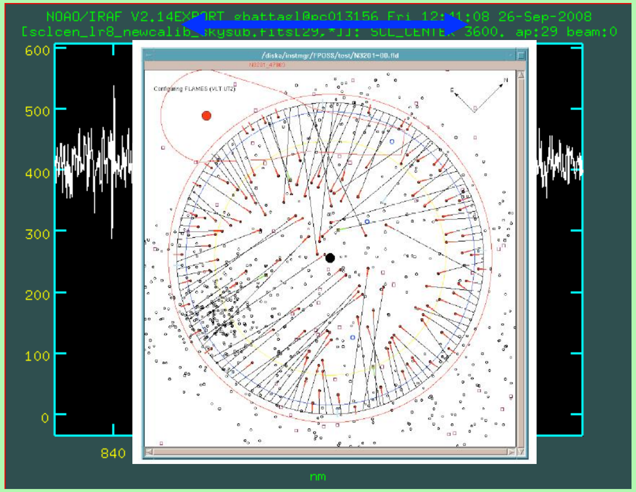
- Prolonged and diverse SFHs
- Hints of spatial variations in stellar population mix
- Metal poor (<[Fe/H]> < -1); spreads of about 0.2-0.3 dex
- Completely supported by velocity dispersion (no rotation)
- Dynamical M/L up to 10 s-> dark matter dominated (no info on dark matter density PROFILE)

Time [Gyr]

Grebel, Gallagher & Harbeck 2007

The DART LP (PI: E.Tolstoy) & follow-up programs (2003-2012)

130 fibres over 25 arcmin



- SAMPLE

Milky Way dSphs: Sextans, Fornax, Sculptor (80 kpc < d < 140 kpc)

- DATA

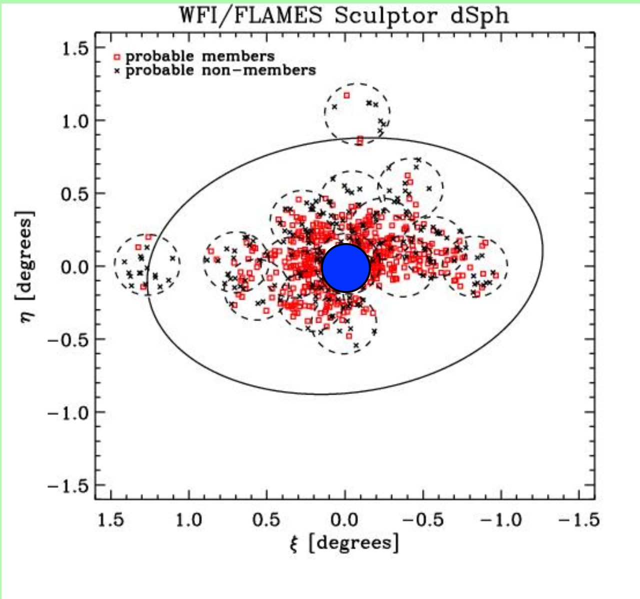
-ESO/WFI V and I photometry

-VLT/FLAMES spectroscopy of Red Giant Branch stars:

1) Low Resolution around CaII triplet

(R ~ 6500, 8000-9000 Å; V=16-19.5)

2) High Resolution (R ~ 20000, HR10/13/14; V<18-18.5)



CaT [Fe/H] (±0.15dex) and l.o.s.velocities (±2 km/s) for hundreds probable members over a large area

Abundances (Ca, Mg, Ti, etc) and l.o.s.velocities (±0.5 km/s) for ~ 80 members in the centre

Velocity gradients (rotation?) found in

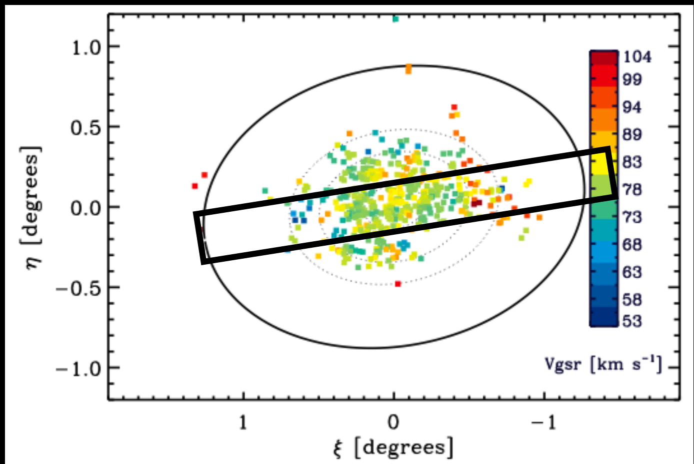
Sculptor & Sextans

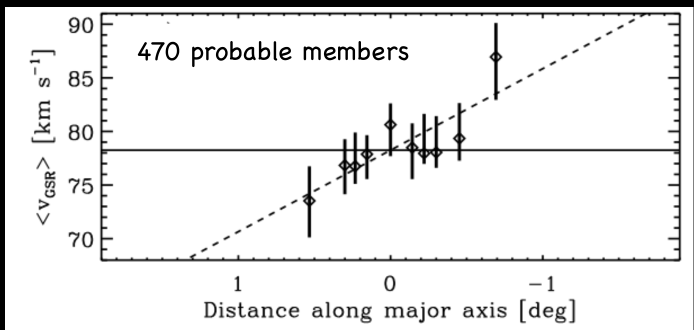
7.6$^{+3.3}_{-2.2}$ km/s/deg along projected major axis.

V/σ= 0.6

8.4 ± 1.0 km/s/deg along projected major axis.

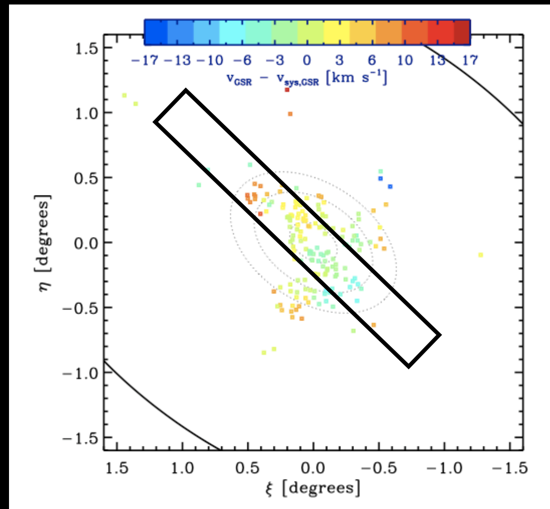
V/σ = 0.7

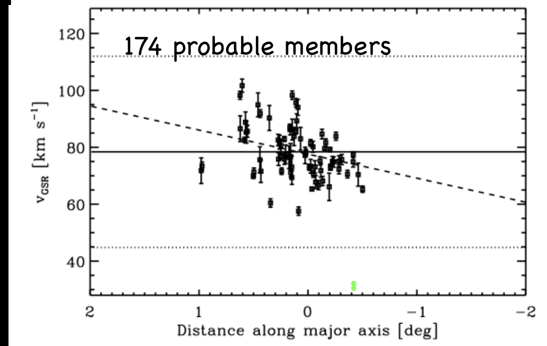




Battaglia et al. 2008, ApJL, 681, 13

Velocities are corrected for the Local Standard of Rest and Sun motions





Battaglia et al. 2011

Gradient confirmed from further 150 members in the outer parts

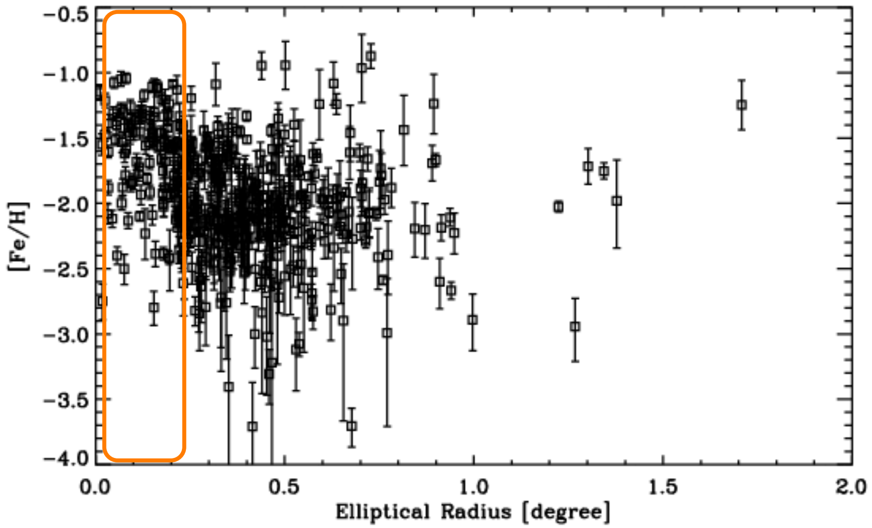
Mock data-sets give as large a gradient 0.4% of the times (10^4 realizations)

Confirmed by independent studies (Walker et al. 2009, Breddels et al. 2012)

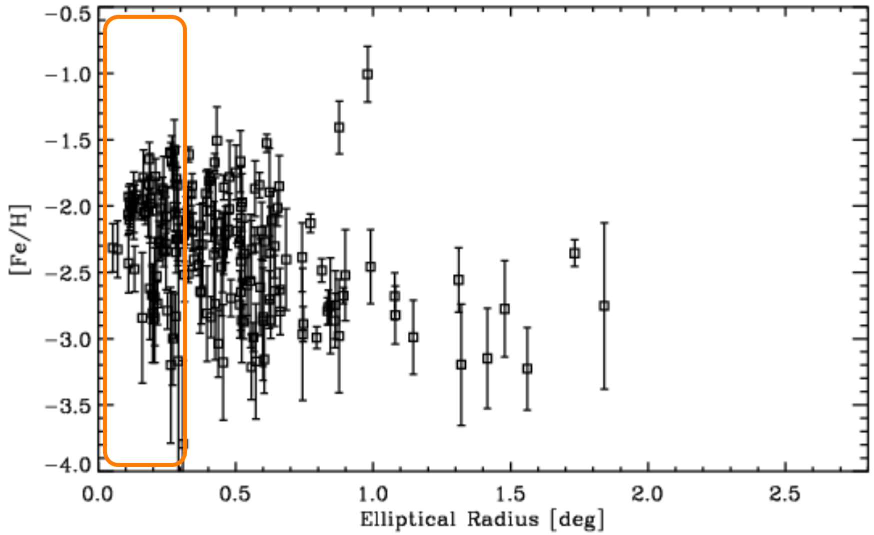
Spatial variations of metallicity properties

[Fe/H] from CaT lines calculated using the calibration from Starkenburg et al. 2010

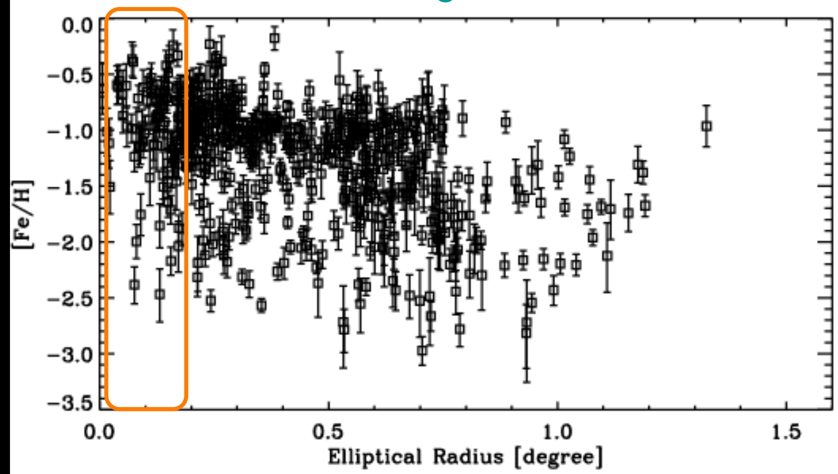
Sculptor (Tolstoy et al. 2004)



Sextans (Battaglia et al. 2011)



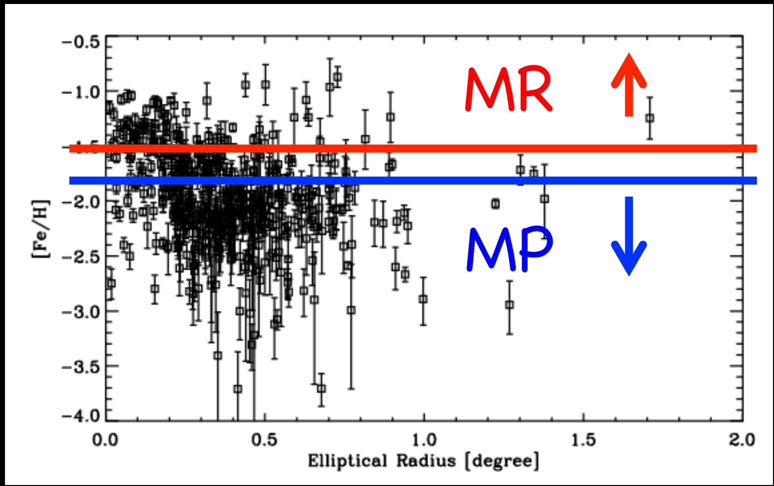
Fornax (Battaglia et al. 2006)



Wide range of [Fe/H] values within each galaxy (more than 2 dex in Scl and Fnx)

Multiple stellar components & dark matter: Sculptor

(found also in Fornax and Sextans)

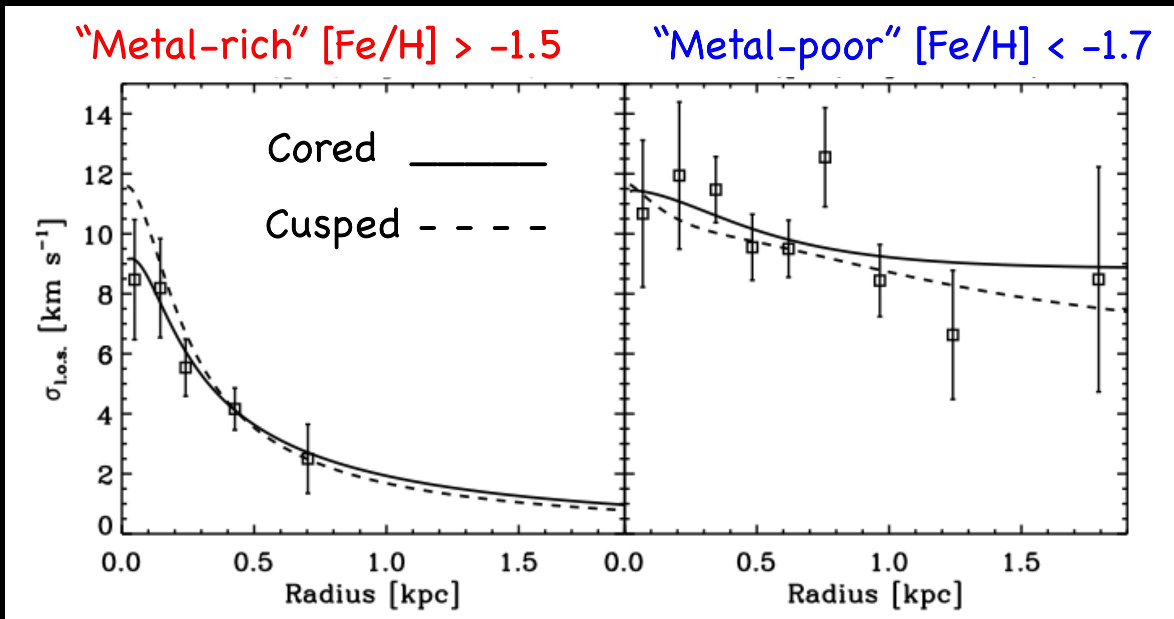


-Kinematics of multiple stellar components prefer a cored profile to a cuspy one (Battaglia et al. 2008)

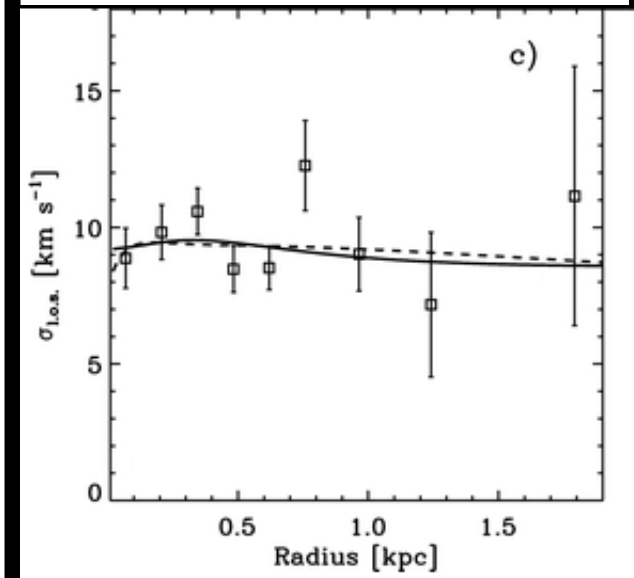
-Not possible to make a distinction when treating the stars as 1 component

-Results confirmed by other groups (Walker & Peñarrubia 2011; Amorisco & Evans 2012)

Line-of-sight velocity dispersion profiles:



No selection in [Fe/H]



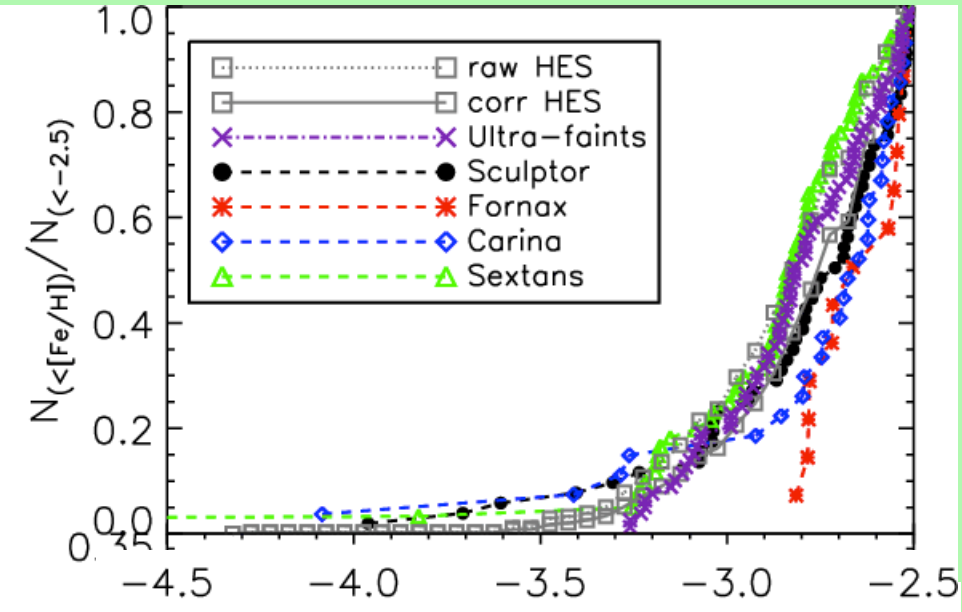
Battaglia et al. (2008)

Presence of Extremely Metal Poor stars ([Fe/H] < -3) & Comparison to the Milky Way (halo) stars

Found EMP stars in each of the 3 galaxies;

in Sculptor, the most metal-poor extra-galactic star [Fe/H]=-3.96±0.06

(Starkenburg et al. 2010, Tafelmeyer et al. 2010, Aoki et al. 2009)



Starkenburg et al. (2010)

α-elements, (*a*) Mg and (*b*) Ca, in four nearby dwarf spheroidal galaxies: Sgr (*orange*: McWilliam & Smecker-Hane 2005, Monaco et al. 2005, Sbordone et al. 2007), Fnx (*blue*: Shetrone et al. 2003, Letarte 2007), Scl (*green*: V. Hill & DART, in preparation, Shetrone et al. 2003, Geisler et al. 2005), and Carina (*purple*: Shetrone et al. 2003, Koch et al. 2008a). Open symbols refer to single-slit spectroscopy

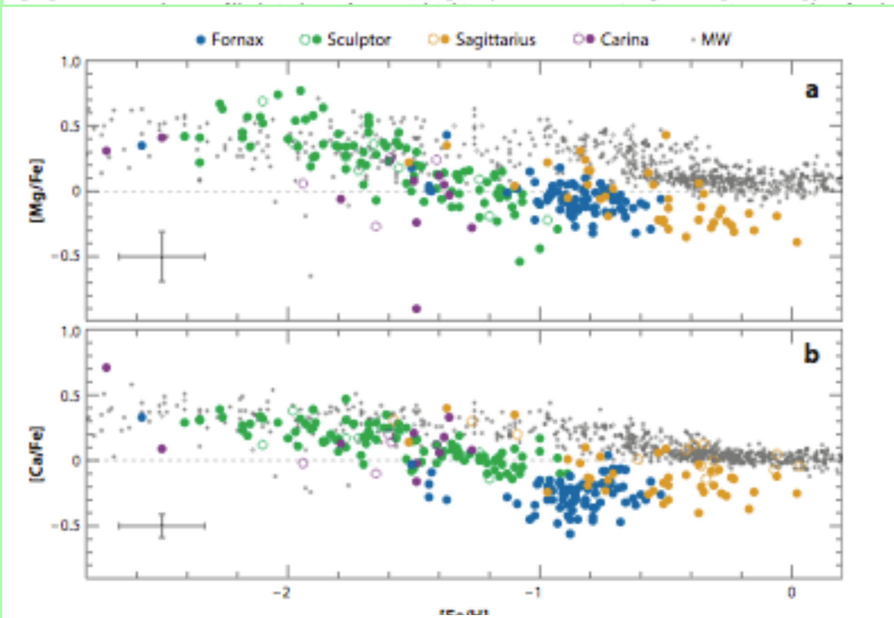
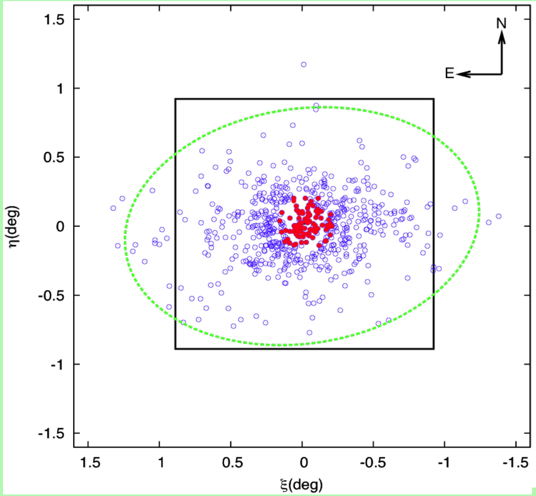
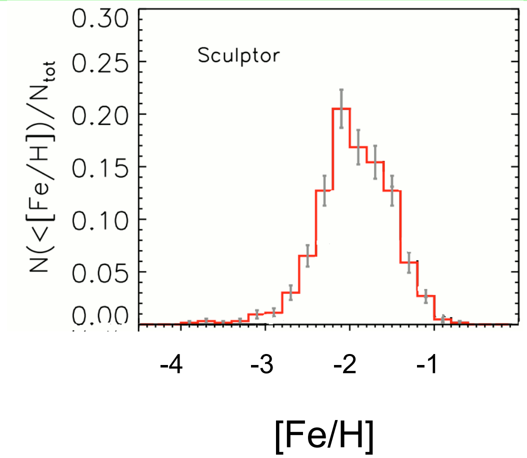


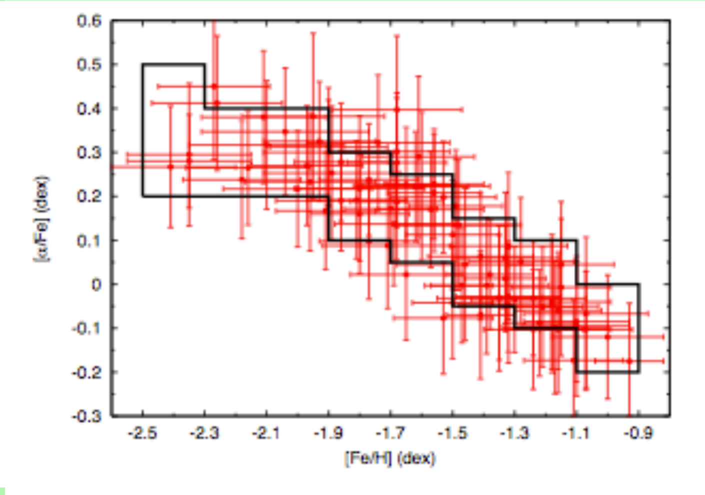
Figure from Tolstoy, Hill & Tosi (2009) review

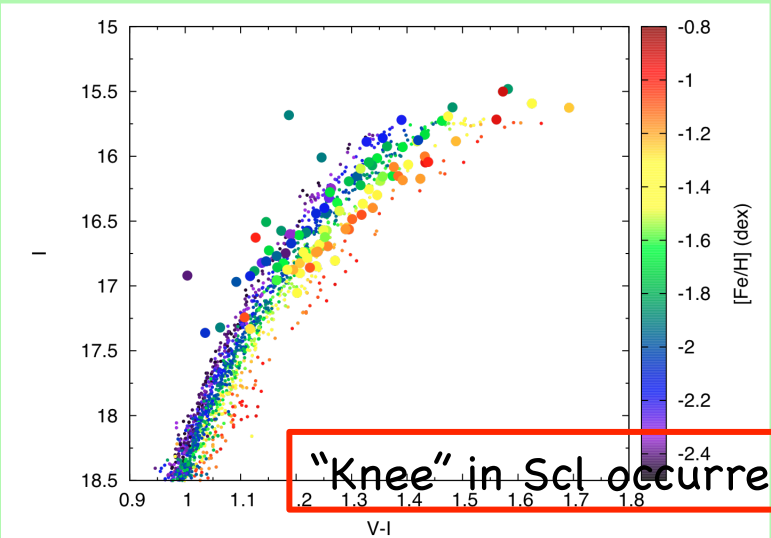
Combining star formation history and chemical abundances for Sculptor (de Boer et al. 2011, 2012)

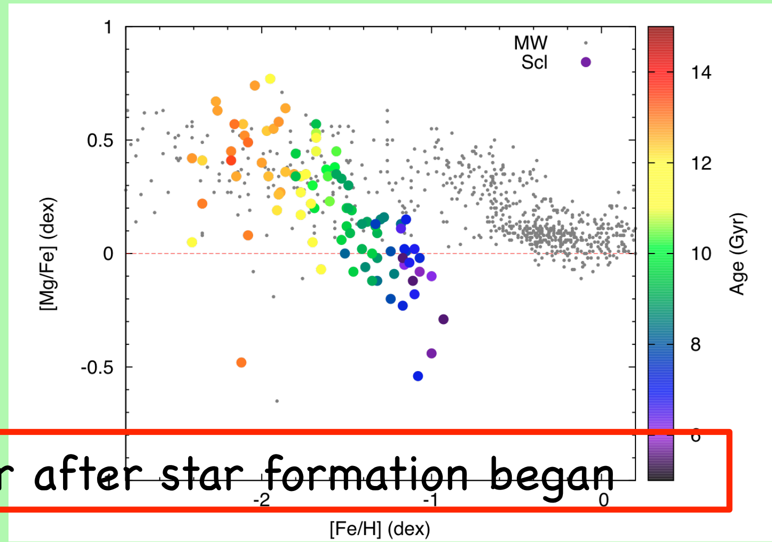




Starkenburg et al. 2010







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

Lack of C-rich stars & larger scatter in [α/Fe]?

Starkenburg et al. (2012), Venn et al. (2012), Lemasle et al. (2012)

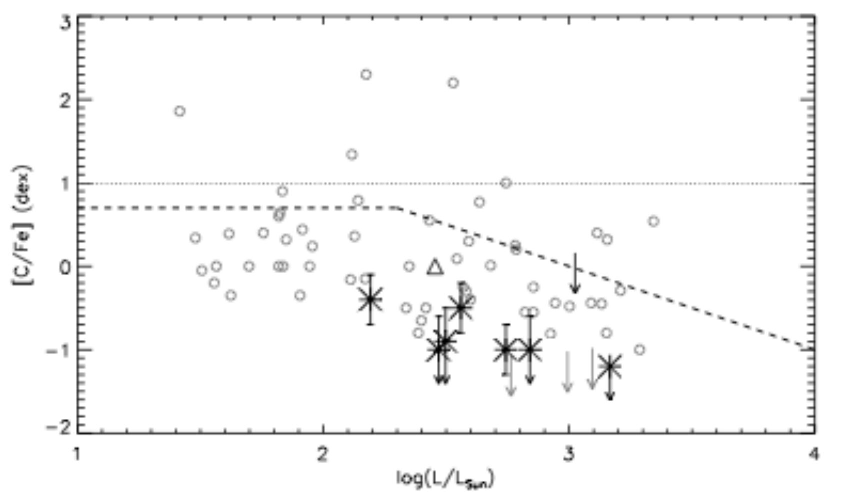
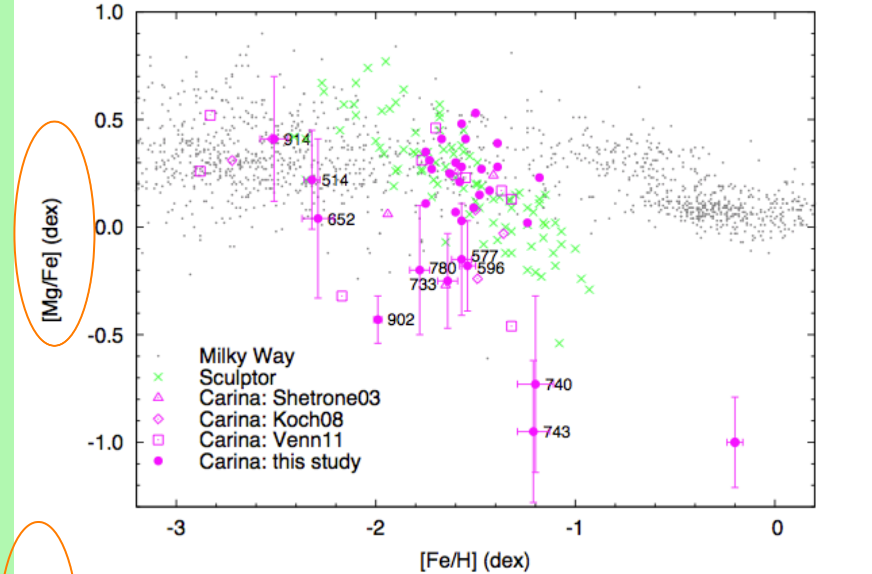
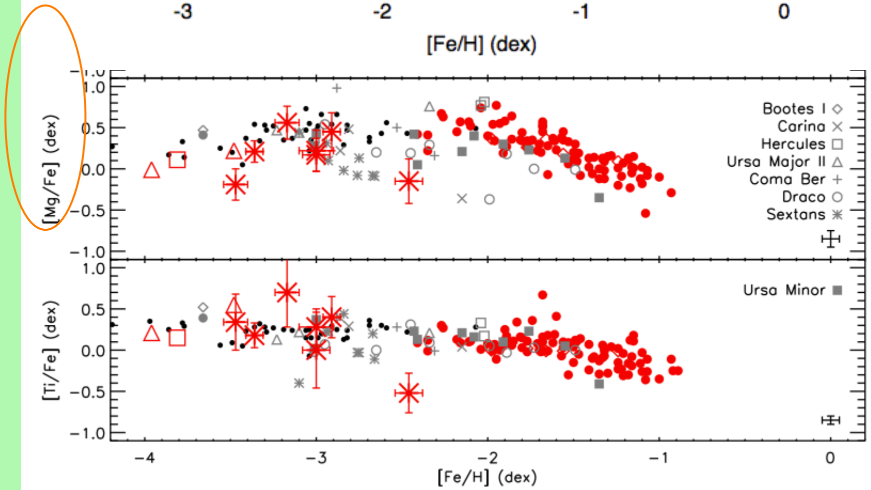


Fig. 7. [C/Fe] versus the bolometric luminosity of the target stars (black asterisks). Both the classical definition for carbon-rich ([C/Fe]>1, horizontal dotted line) and the definition from Aoki et al. (2007) taking into account mixing on the red giant branch (dashed line) are indicated. One Sculptor star from Tafelmeyer et al. (2010) is shown as a large black open triangle, the upper limit for the Sculptor star of Frebel et al. (2010a) is shown as a black arrow and upper limits for Carina stars from (Venn et al. 2012) are shown as gray arrows. Stars from other dwarf galaxies are shown as open gray circles (Fulbright et al. 2004; Cohen & Huang 2009; Tafelmeyer et al. 2010; Norris et al. 2010,a; Honda et al. 2011; Lai et al. 2011).





from other studies. Red symbols indicate Sculptor stars from Hill et al., in preparation, Shetrone et al. (2003), Tafelmeyer et al. (2010) and Frebel et al. (2010a). The black small circles are the halo stars from the Cayrel et al. (2004) sample. A typical error bar for this sample is shown in the lower right corner of each panel. The Mg values are taken as updated by Bonifacio et al. (2009). A sample of very and extremely metal-poor stars from other galaxies are plotted as gray symbols. We show all literature values for stars in ultra-faint galaxies and stars with [Fe/H]<−2.5 dex in the classical dwarf spheroidals. Frebel et al. (2010b) for Ursa Major II and Coma Berenices, Tafelmeyer et al. (2010) for Fornax, Tafelmeyer et al. (2010) and Aoki et al. (2009) for Sextans, Venn et al. (2012), and Lemasle et al. (2012), for Carina, Koch et al. (2008) for Hercules, Cohen & Huang (2009) and Fulbright et al. (2004) for Draco, Cohen & Huang (2010) for Ursa Minor and Norris et al. (2010b) for Bootes I. For Ti, Ti II

In the MW halo, the fraction of C-rich stars is 14-32%

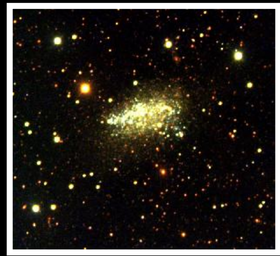
Conclusions

- **Velocity gradients found in dSphs:** if due to rotation, it changes our view of dSphs and makes them more similar to the other main type of dwarfs.
- **Metallicity gradients** present **and large range of [Fe/H] (1-2dex)**: capable to retain their metals, should say about their potential well
- Multiple kinematic components allow to place stronger constraints on the dark matter mass and distribution **-> CORES favoured over CUSPS**
- **Difficult to make the whole MW halo out of low luminosity dSphs**; even making the low metallicity part may present difficulties (timescale, scatter at similar [Fe/H])

Important to be able to efficiently look at MANY stars at once

And the rest of Local Group dwarf galaxies?

dIrrs



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dSphs

Metallicity properties	From gas and/or O-B stars (end point of metallicity evolution)	From RGB stars (wide age range)
Internal kinematics	From the gas (rotating in dIrrs, disordered in dTs)	From RGB stars

They can already be studied at intermediate resolution with VLT/FORS, Keck/DEIMOS, but several hours of integration needed to achieve s/n > 10-15/Å ($I_{TIP,RGB} \sim 21$ at d= 1Mpc)

A wider area, with larger MOS capabilities instrument on a 8m-10m class telescope would help (e.g. MOONS, ngCFHT...)