Dwarf galaxies in the Local Group

- Chemical evolution with the E-ELT -

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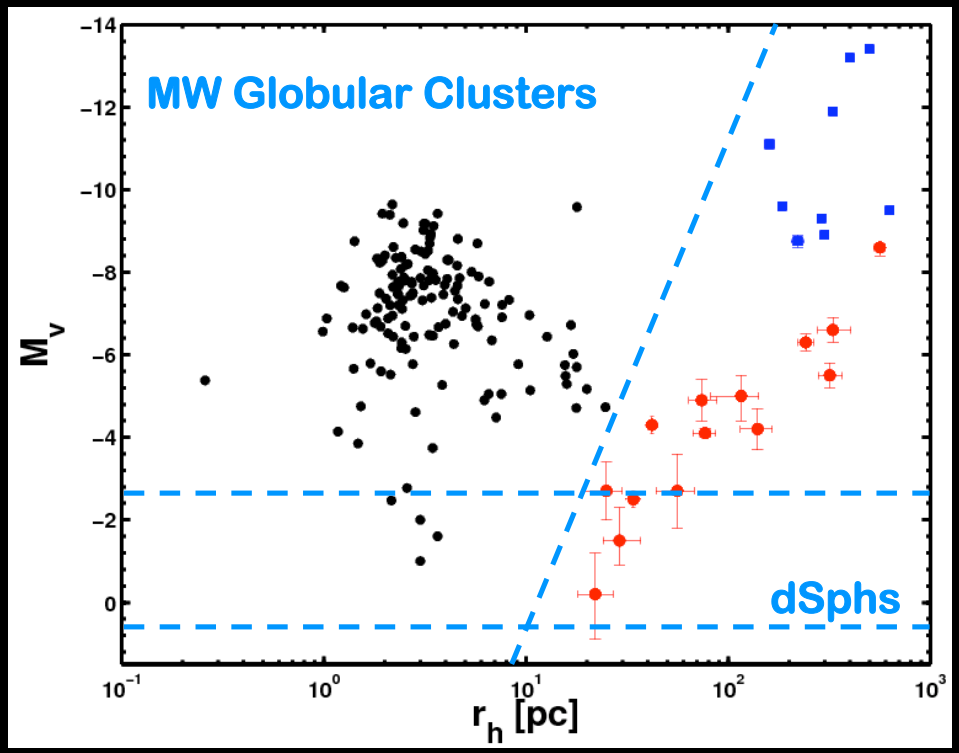
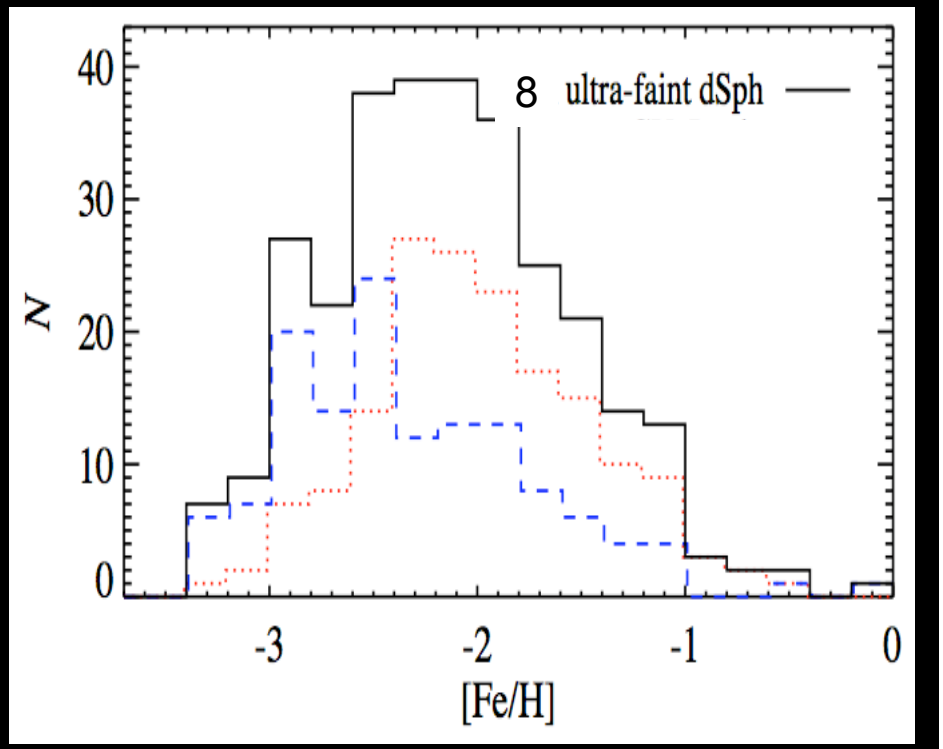
Smallest Scales

- dSphs: have long been known as *low* luminosity systems.
- Since ~2006: even *ultra*-faint dwarfs (Zucker et al. 2006; Belokurov et al. 2006,2007,2008; Walsh et al. 2007; Irwin et al. 2007).

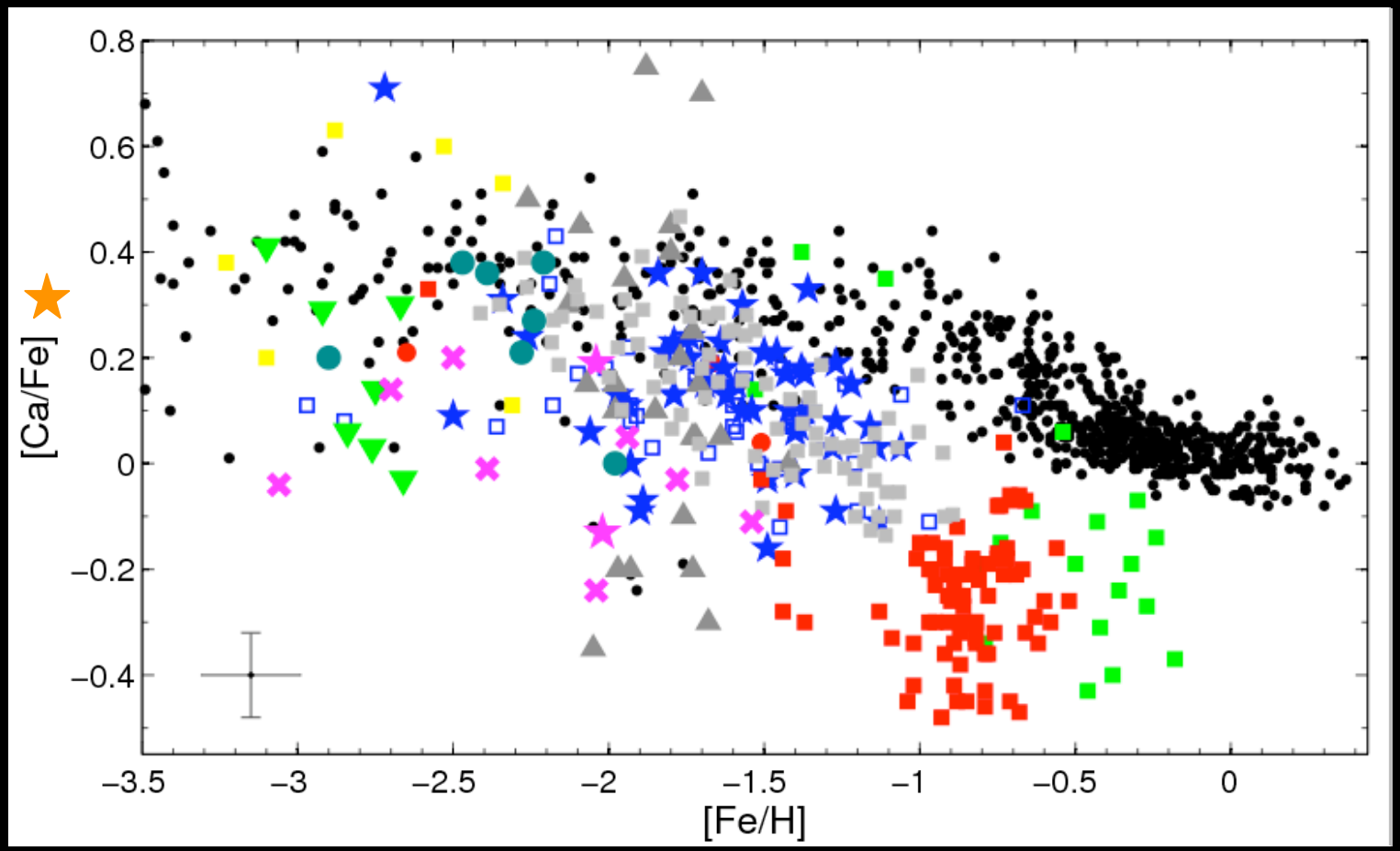


Martin et al. (2008); Koch 2009



Kirby et al. (2008)

dSphs vs. halo abundances



Shetrone et al. (2001, 2003): 5 dSphs

Sadakane et al. (2004): Ursa Minor

Monaco et al. (2005): Sagittarius

Koch et al. (2007, 2008, 2009): Carina

Letarte (2007): Fornax

Koch et al. (2008): Hercules

Frebel et al. (in prep.): Sculptor

Shetrone et al. (2008): Leo II

Frebel et al. (2009): Coma Ber, Ursa Major

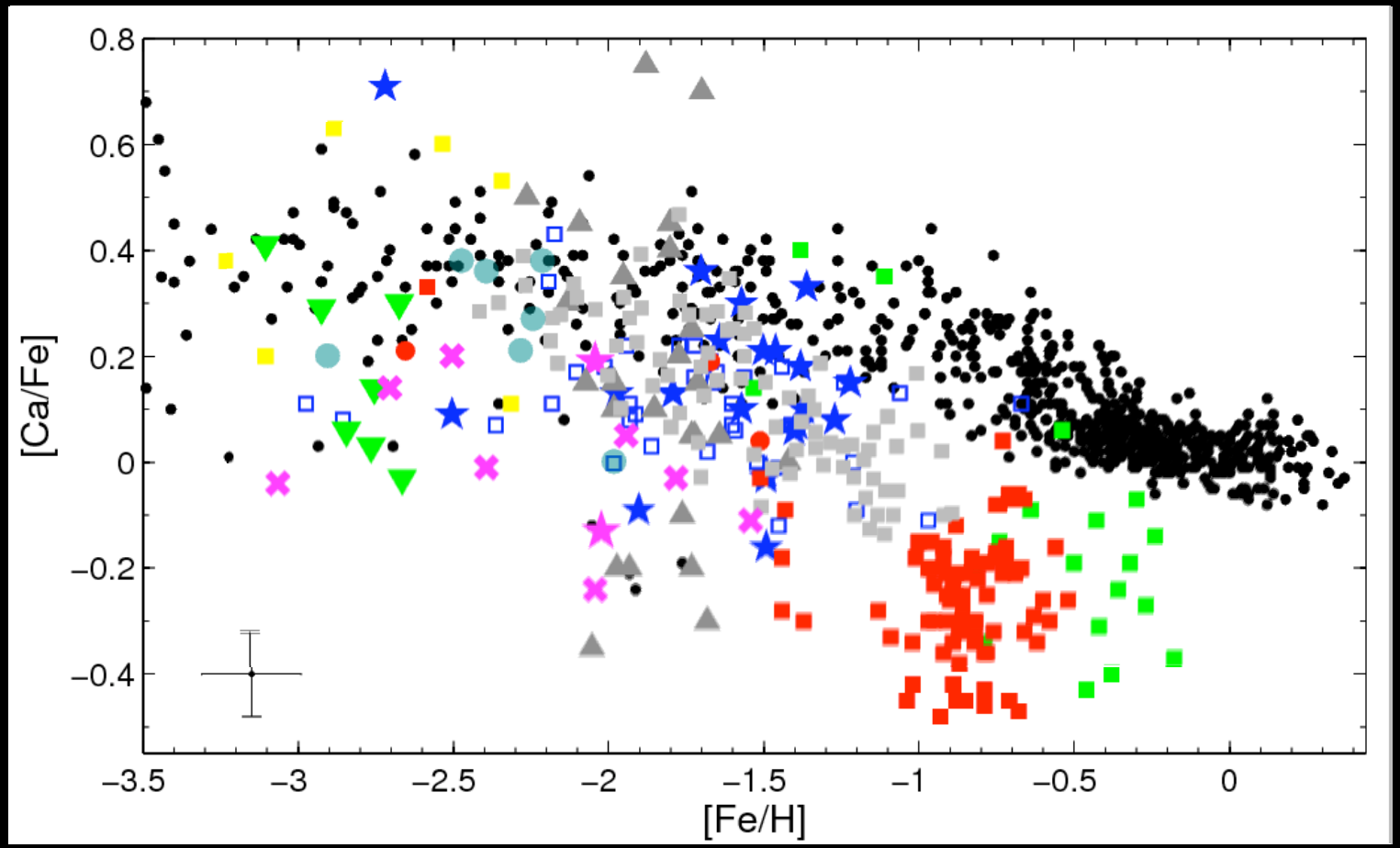
Aoki et al. (2009): Sextans

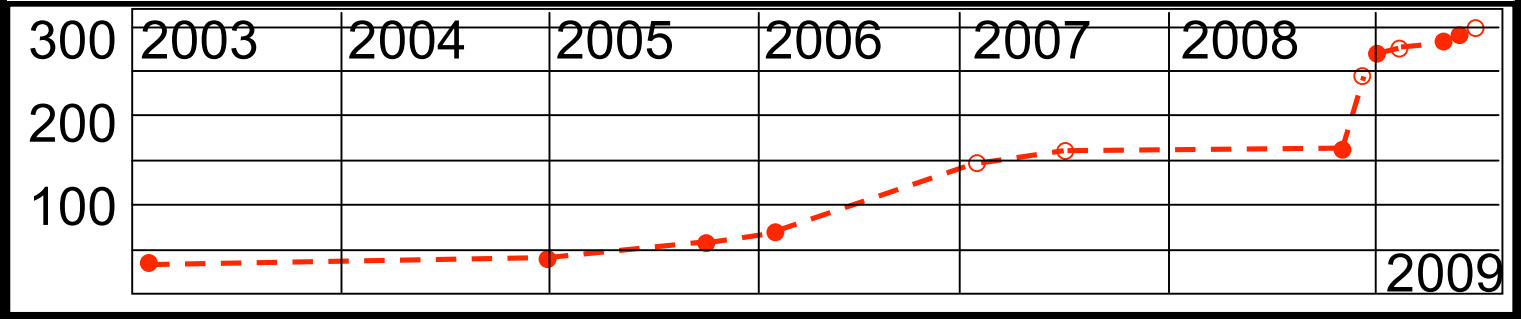
Tolstoy et al. (2009): Sculptor

Cohen & Huang (2009): Draco

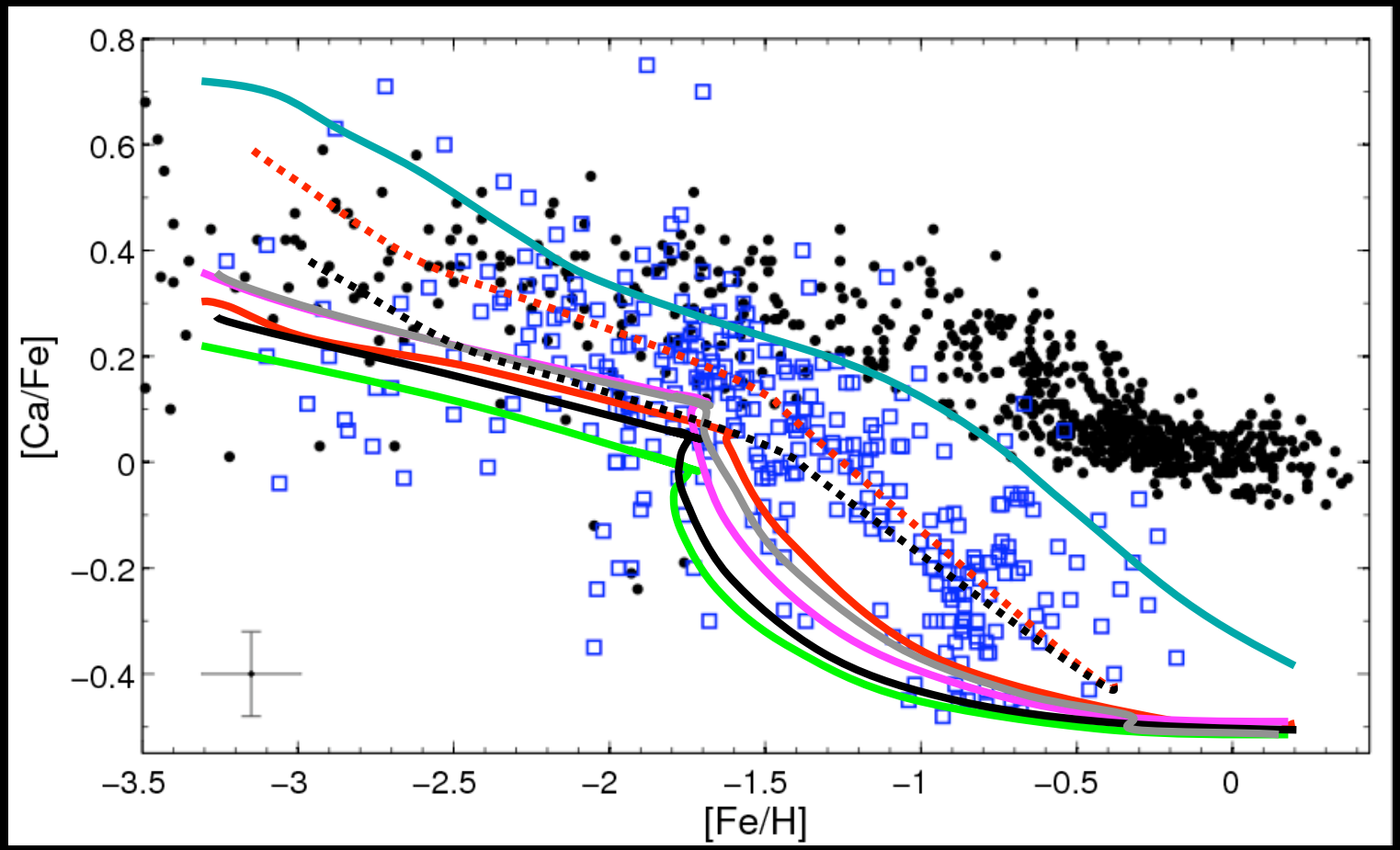
Feltzing et al. (2009): Boo I

dSphs vs. halo abundances





dSphs vs. halo abundances



Low star formation rate of dSphs compared to Galactic halo.

Note the increasing overlap at the metal poor halo. (Koch 2009, Rev. Mod. Ast., 21, 9)

Each galaxy is unique (in SFH and properties).

Lanfranchi & Matteucci (2004)

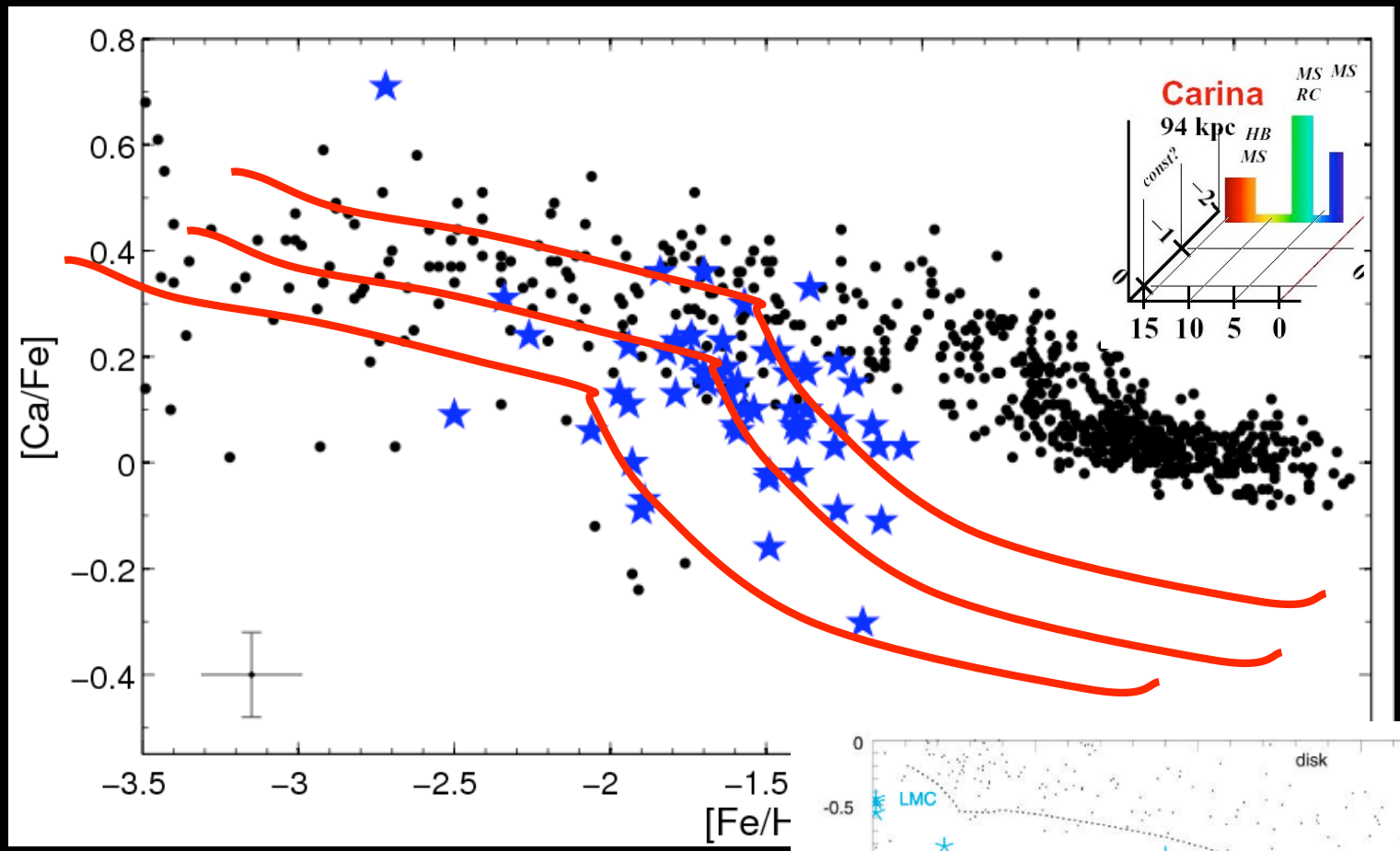
Carina
Draco
Sculptor

Sextans
Sagittarius
Ursa Minor

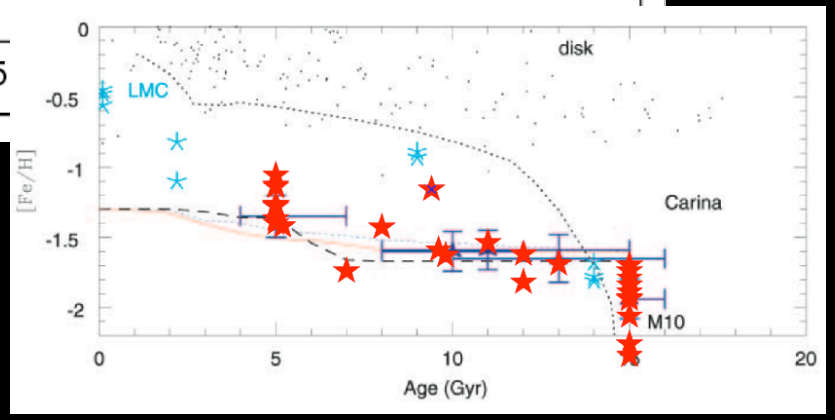
Fornax

Leo II

Carina abundances



Grebel 2002

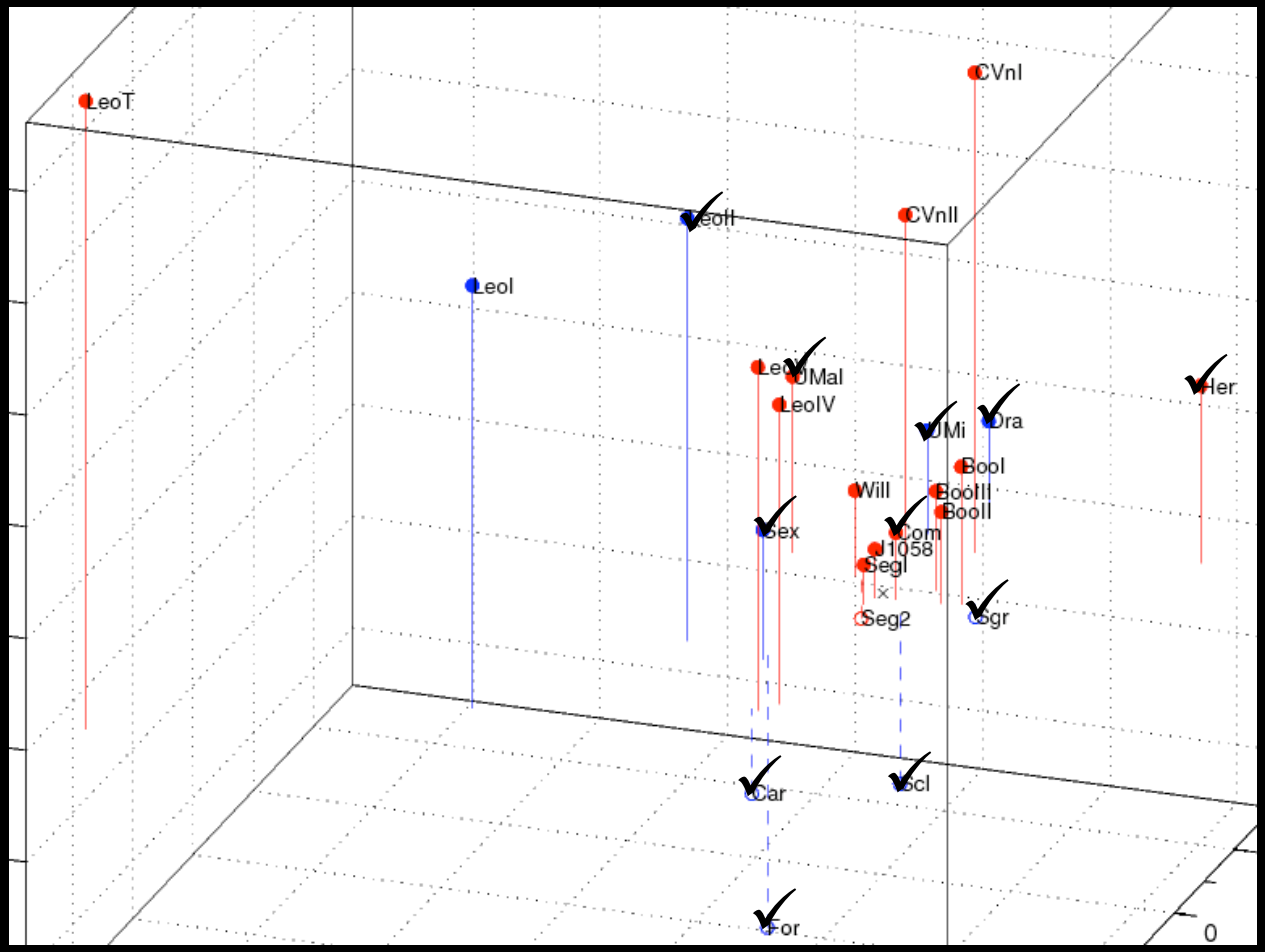


Need accurate abundances ($\Delta\varepsilon$~1-3%) AND ages (photometry).

(Model atmospheres to < 0.05 dex within next decade; B. Gustaffsson; IAUS-265)

Tolstoy et al. (2003)

dSphs with abundances

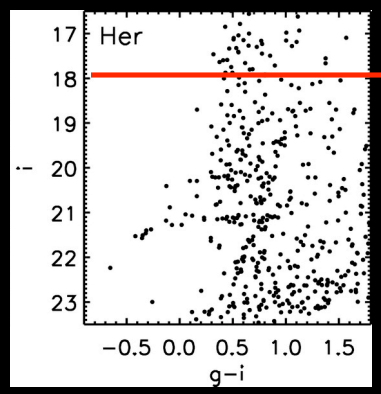


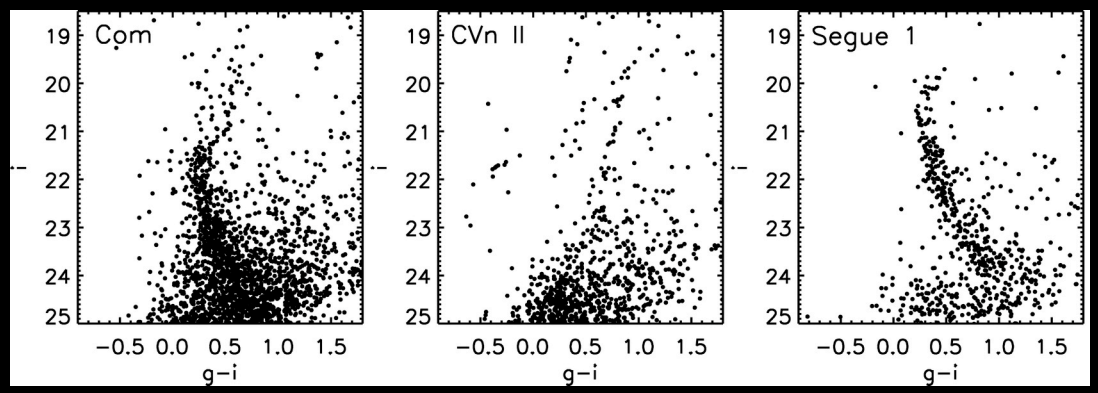
Targeted: 8 / 9 classical MW dSphs

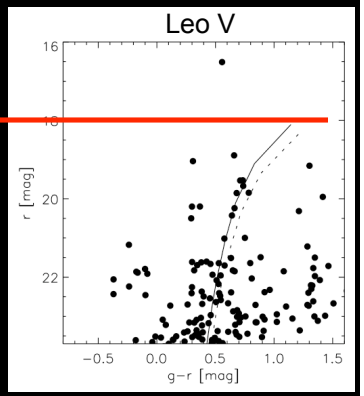
3 / 15 ultrafaint candidates

Faint dSphs' targets

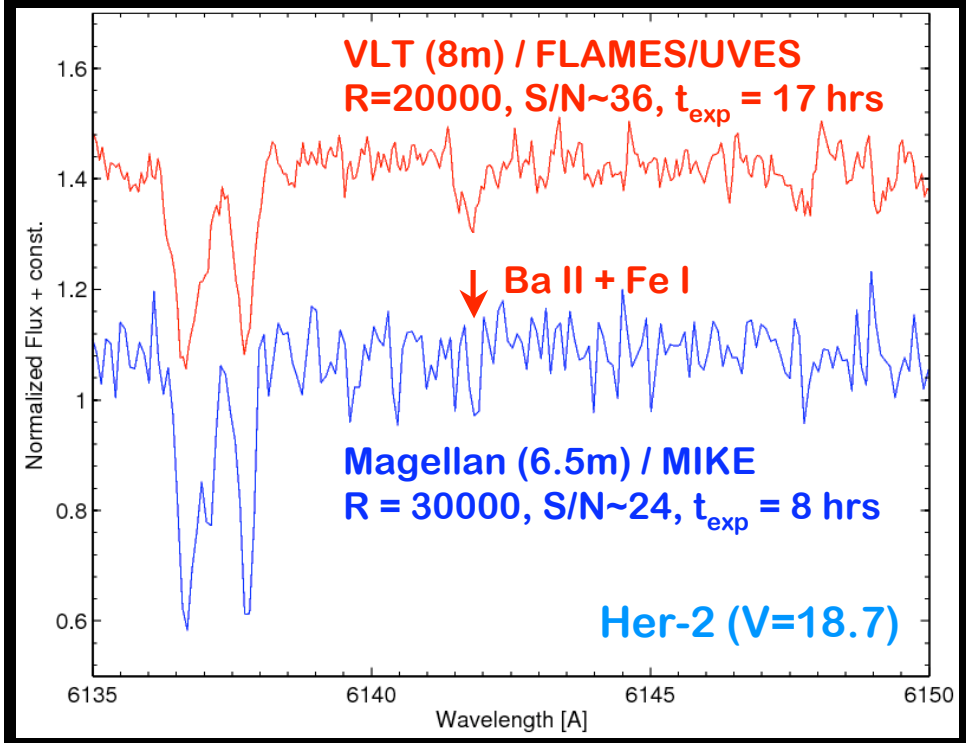
Belokurov et al. (2007, 2008)

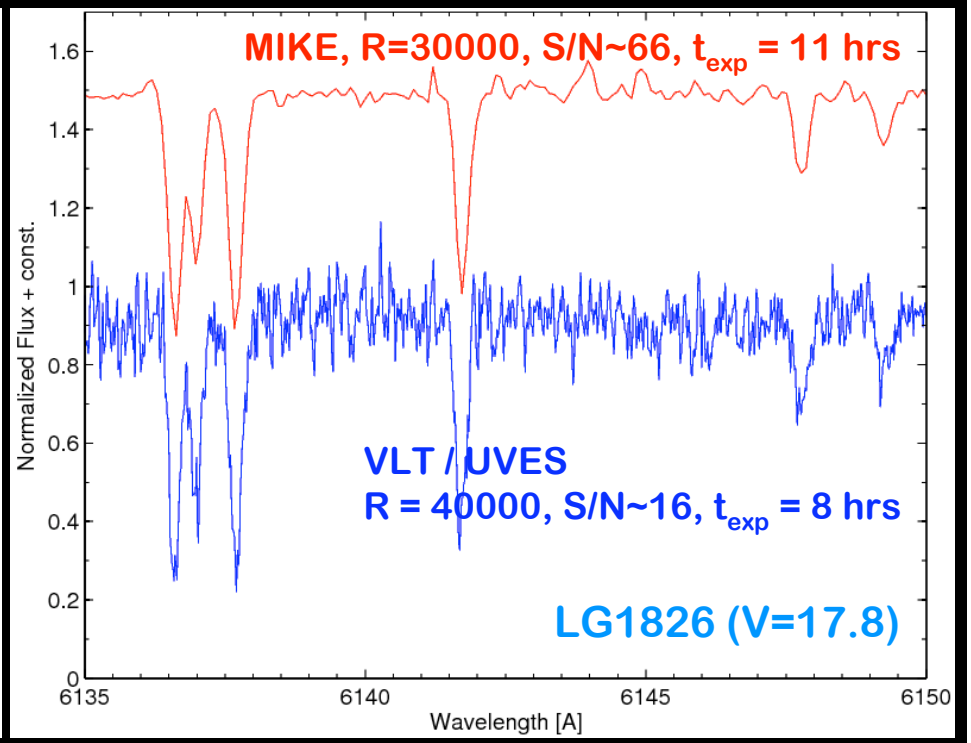






Faint dSphs' spectra





CODEX	High Resolution, High Stability Visual Spectrograph	0.37-0.72μm R = 115300 0.82"

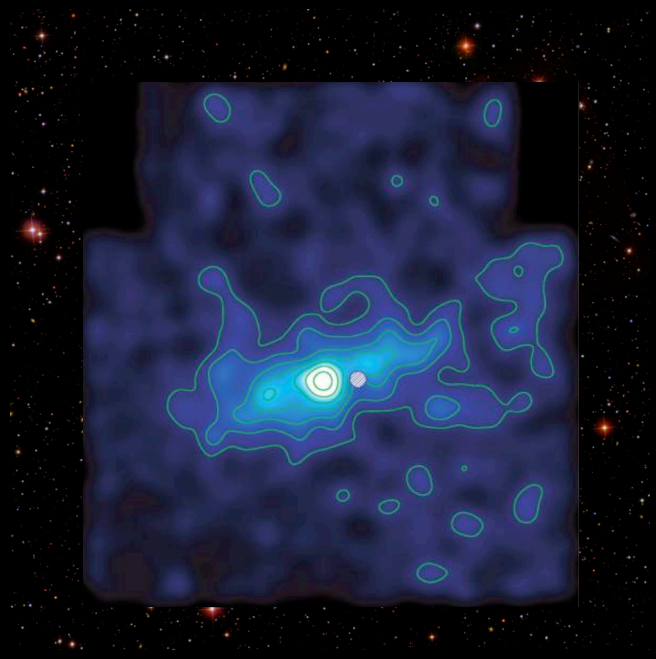
OPTIMOS	Wide Field Visual MOS
	0.37-1.7μm
	MOS: 5000 (for > 300 objects), 20000 (for > 80 objects), 40000 (for 25 objects) IFS: 5000
	MOS: 7' IFU: 2" x 3"

The Hercules dSph

- Ultrafaint dSph, discovered within SDSS (Belokurov et al. 2007); M_V=-6.6; d=132 kpc

- Low-mass (few x10^6 M_o)
  metal-poor ([Fe/H]~ -2.3 dex)
  broad range (-3.2 … -1.8 dex)
  elongated (one of the most elliptical LG dSphs)
  (Coleman et a. 2007; Martin et al. 2008; de Jong et al. 2008; Kirby et al. 2008 ; Adén et al. 2009)

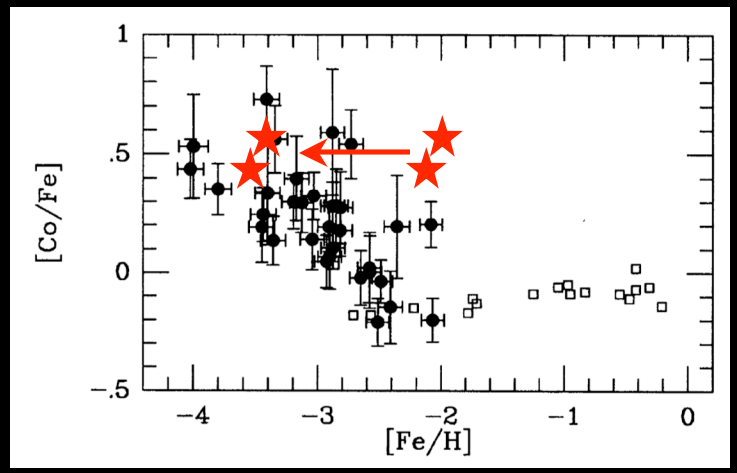
- "Low mass" also manifests in peculiar abundances.
  (Koch, McWilliam, Grebel, et al. 2008)

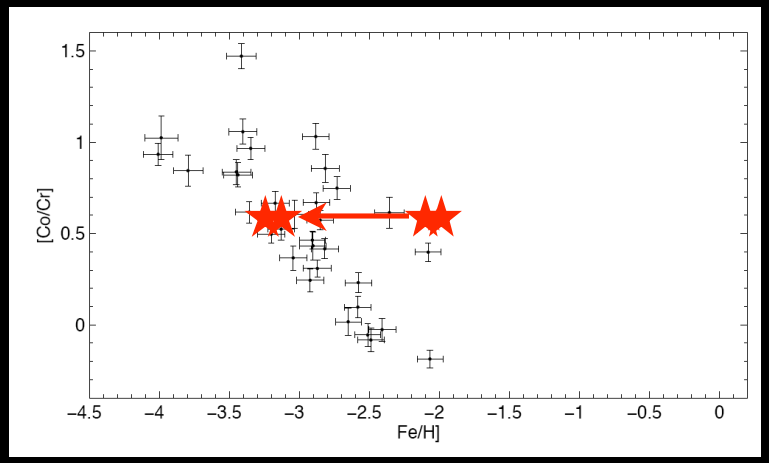


SDSS DR6; 30'x30' (ca. 4xr_h)

Hercules - puzzling enrichment

Low [Ba/Fe], high [Co/Fe], low [Cr/Fe] similar to Galactic halo stars at [Fe/H] < -3.





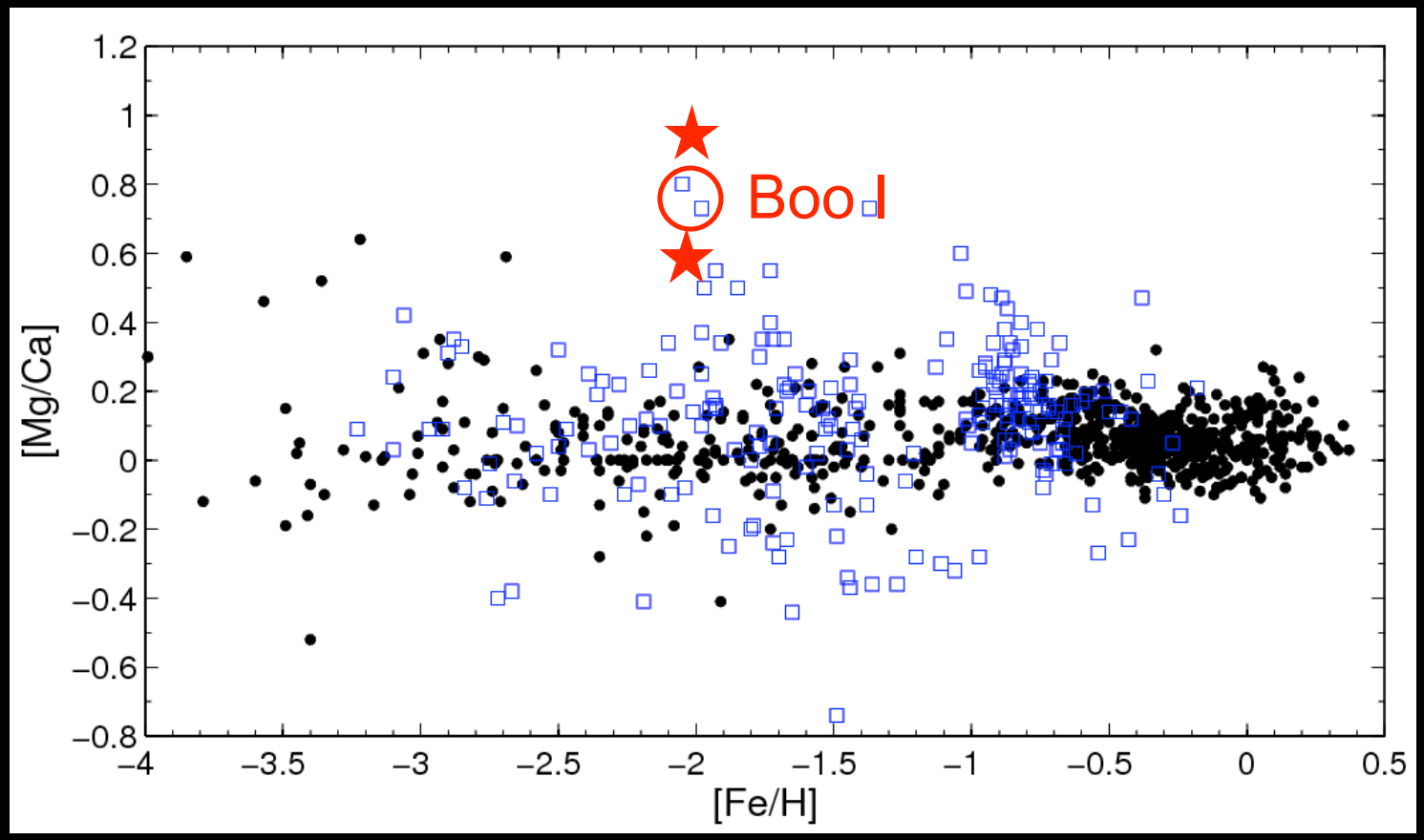
Koch et al. 2008;
McWilliam et al. 1995

Why at "high" [Fe/H] ?

- Standard-composition gas was diluted with primordial *Population III* ejecta ?!
- Ultrafaints may be sites of first stars

Hercules – SNe enrichment

Models for high-mass SNe II predict very high Mg yields w.r.t. Ca. The high [O, Mg, Si / Ca, Ti] in Her implies $M_{prog} \sim 35 - 50\ M_{\odot}$ (Heger & Woosley 2008).



Stochastical Star Formation

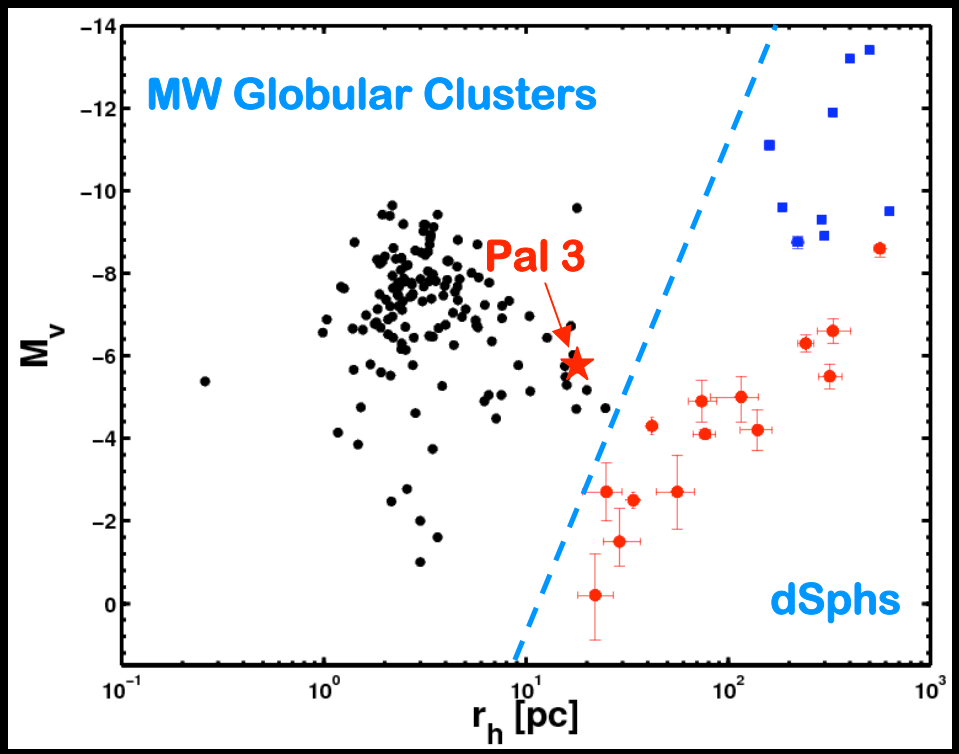
- $M_{tot} \sim 7 \times 10^6\ M_\odot$ and M/L ~ 300 implies $M_* \sim 40000\ M_\odot$ (Adén et al. 2009; Martin et al. 2008)
- Incomplete sampling of high-mass end of IMF (stochastical SF): 1-3 massive SNe II alone can reproduce the high [Mg/Ca] in Her.
- Inhomogeneous pollution & incomplete mixing ("SNe pockets") (Marcolini et al. 2008)

Studying the *outer* halo

- Clear dichotomy in MW (Carollo et al. 2007) and M31 (Koch, Rich, et al. 2008) halo field stars.
- Lack of [Fe/H]-gradient of outer halo GC system.
- 2nd-parameter problem in OHGCs; broad age range at same metallicities.
- All that prompted accretion origin of Galactic halos (Searle & Zinn 1978)
- Thus: are OHGCs similar to the dSphs?

The faint OHGC Pal 3

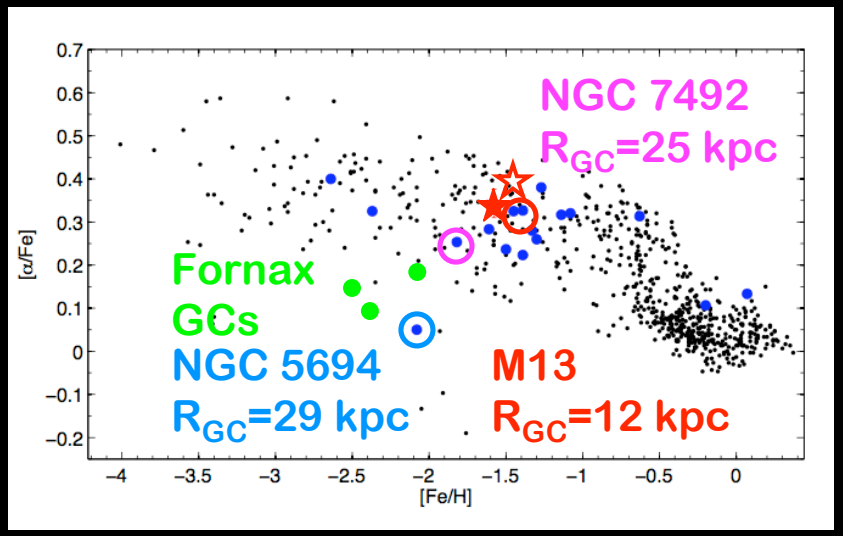
- Remote (R_{GC} ~100 kpc)
- Faint (M_V ~ -5)
- Extended (r_h ~ 20 pc)

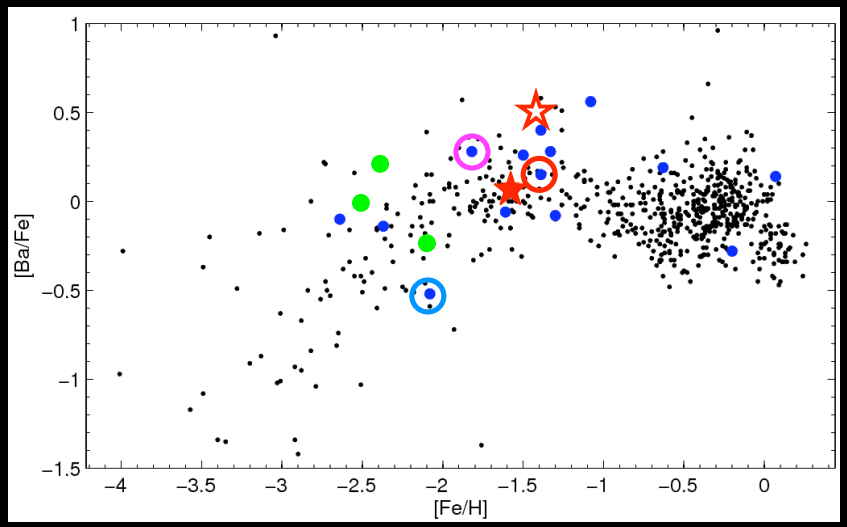


Martin et al. (2008); Koch 2009

- PM consistent with bound and unbound orbit (to MW)
- 1-2 Gyr younger than other GCs at same [Fe/H]
- Related to dSphs ?

The boring OHGC Pal 3





MIKE and HIRES spectra (19 stars)

- [α/Fe] ~ 0.4
- Fe-peak elements ~Solar
- Negligible abund. spread

Chemical history of outermost halo (GCs) is comparable to inner halo (GCs). Dissimilar from dSph stars.

Pal 4 : AK & P. Côté, in prep.

Cohen & Melendez (2005a)
Lee et al. (2006)
Letarte et al. (2006)
Cohen & Melendez (2005b)

AK, Côté & McWilliam (2009), A&A in press (astro-ph/0908.2629)

Summary

- *Ultra*faint dSphs: Very metal poor; huge [Fe/H] spread
- Peculiar halo stars may originate in ultrafaint dSph-like systems. There *is* overlap of halo and dSphs abundances.
- Different modes of SF: incomplete sampling of high-mass (>30 $M_{\odot}$) end of IMF due to extremely low stellar masses. The ultrafaints may host the first stars.
- Outer halo GCs appear similar to inner halo GCs and dissimilar to dSphs.
- Many (!) faint puzzling targets left to study (ultrafaints, outer halo GCs, M31 satellites, beyond LG...)