The Chemical connection between Damped Lyman-alpha systems and dwarf galaxies

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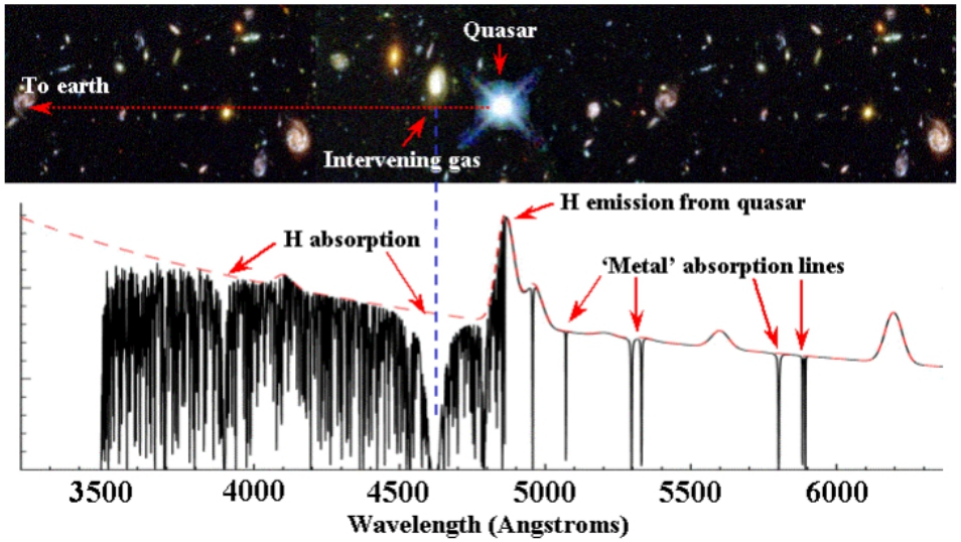
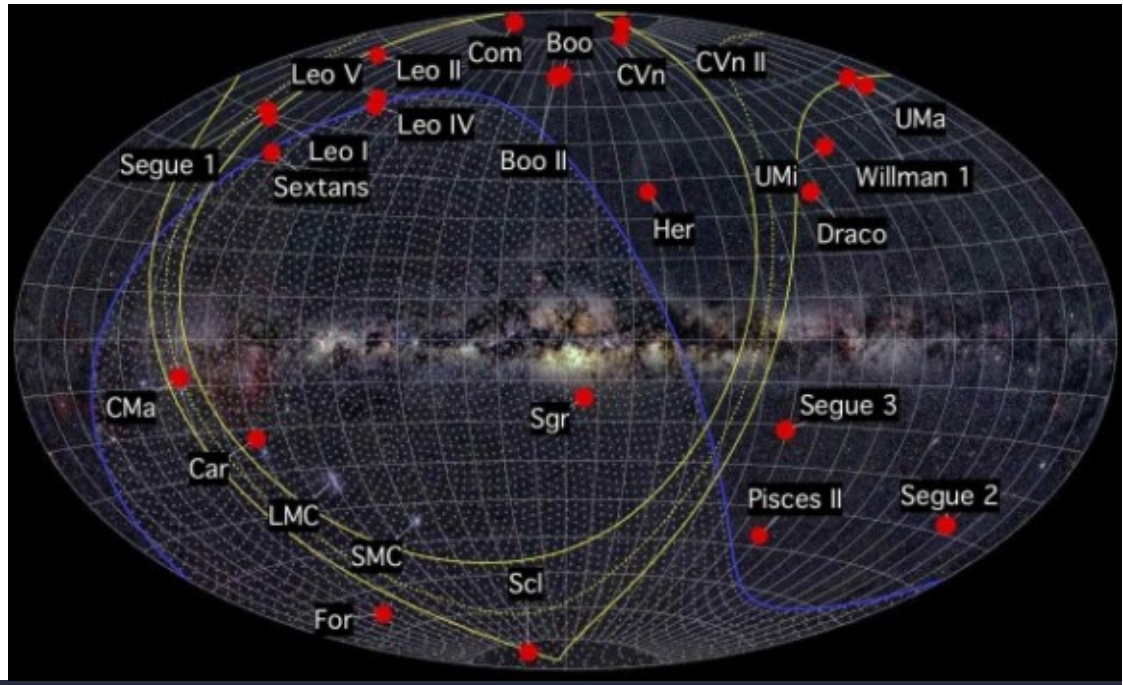
DLAs vs Local Dwarf Galaxies



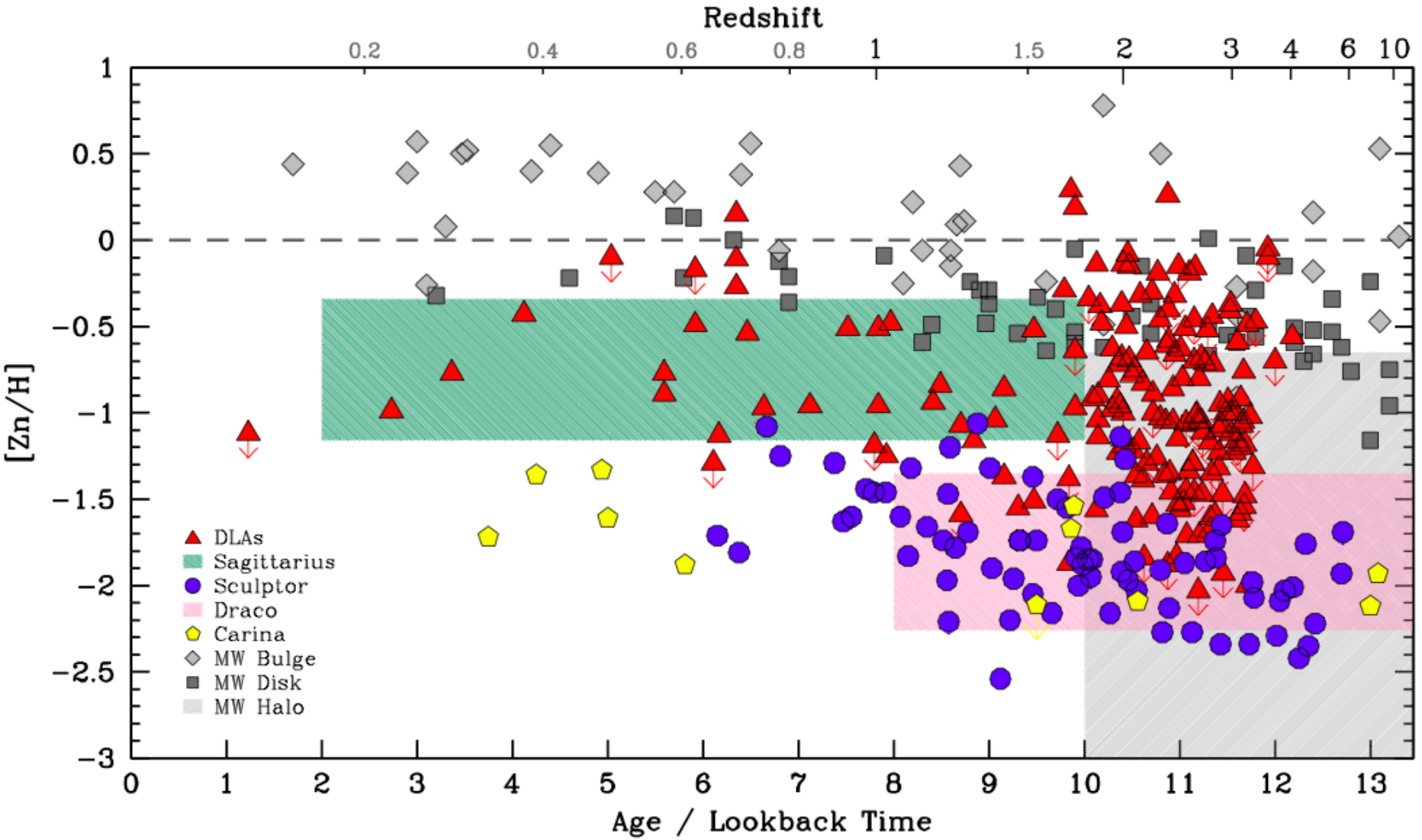
- DLA systems are reservoirs of neutral gas ($N(H\ I) \geq 2 \times 10^{20}\ cm^{-2}$), visible due to absorption.
- Dust depletion!
- Volatile elements such as S, Zn, O important.

- In the Local Group we are able to observe individual stars and get detailed chemical abundances.
- 50+ known dwarf galaxies around the Milky Way
- Stellar physics!



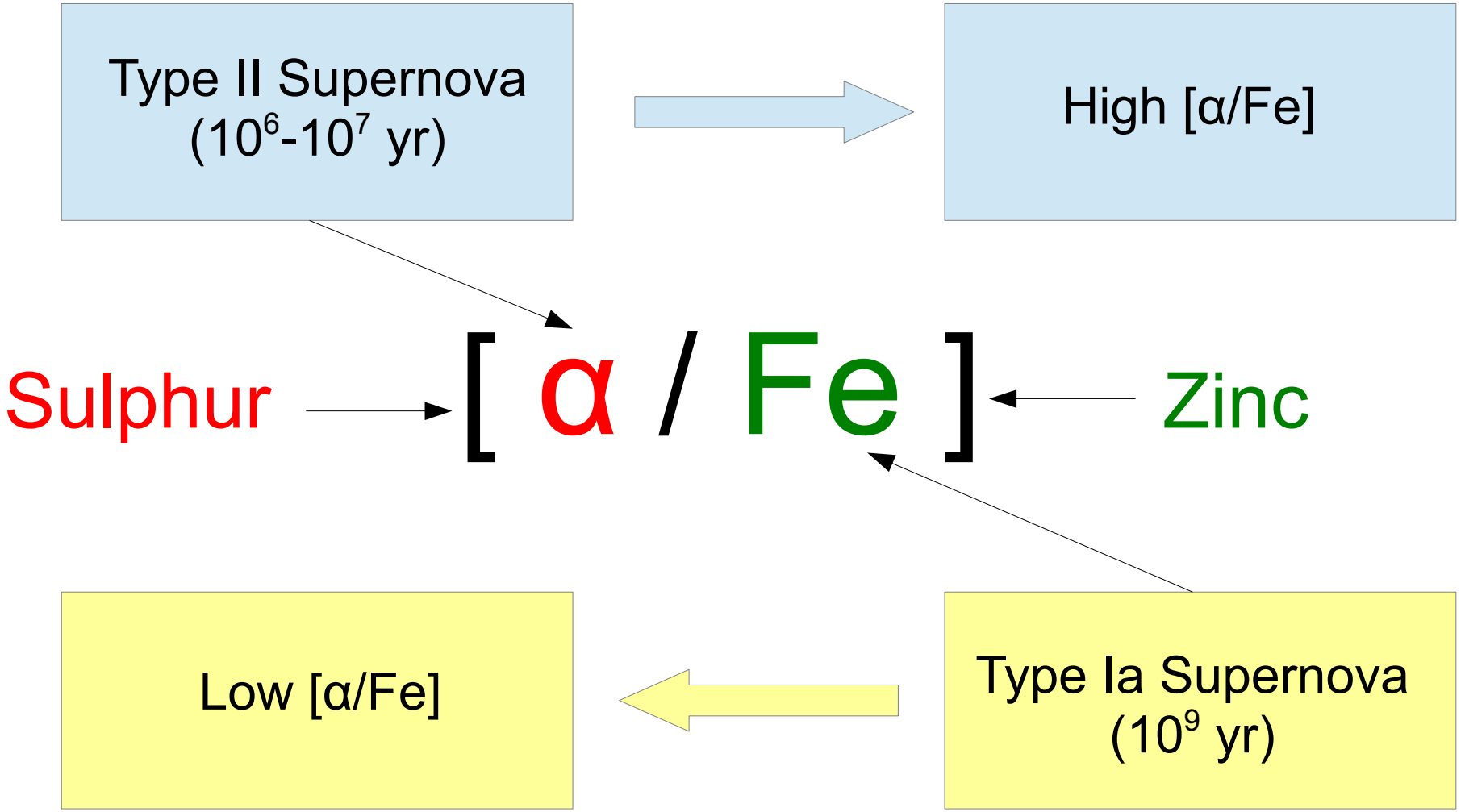
Right: H. Jerjen & Eso

Metallicity Comparison



DLAs: Quieret+16; Milky Way: Cayrel+04, Reddy+06, Nissen+07, Bensby+2013;
Sculptor: Skúladóttir+17, deBoer+12; Carina: Shetrone+03, Venn+12, Lemasle+12; Sagittarius: Sbordone+07.
Age models: Salvadori+10, Aparicio+11, Bellazzini+06, Siegel+07, deBoer+15

Abundance ratios



Abundance ratios

[α / Fe]

? ⬇ ?

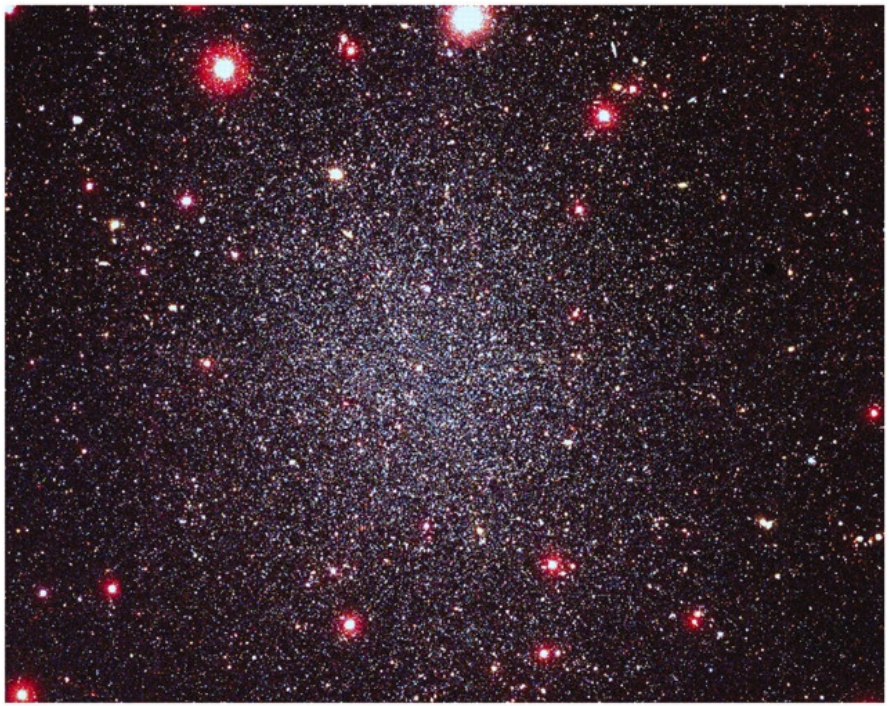
[S / Zn]

- Never been compared with stellar dwarf galaxy abundances
- **Now for the first time 80+ stars in Sculptor!**

  (Skúladóttir+ 2015b; 2017a)

The Sculptor dwarf spheroidal

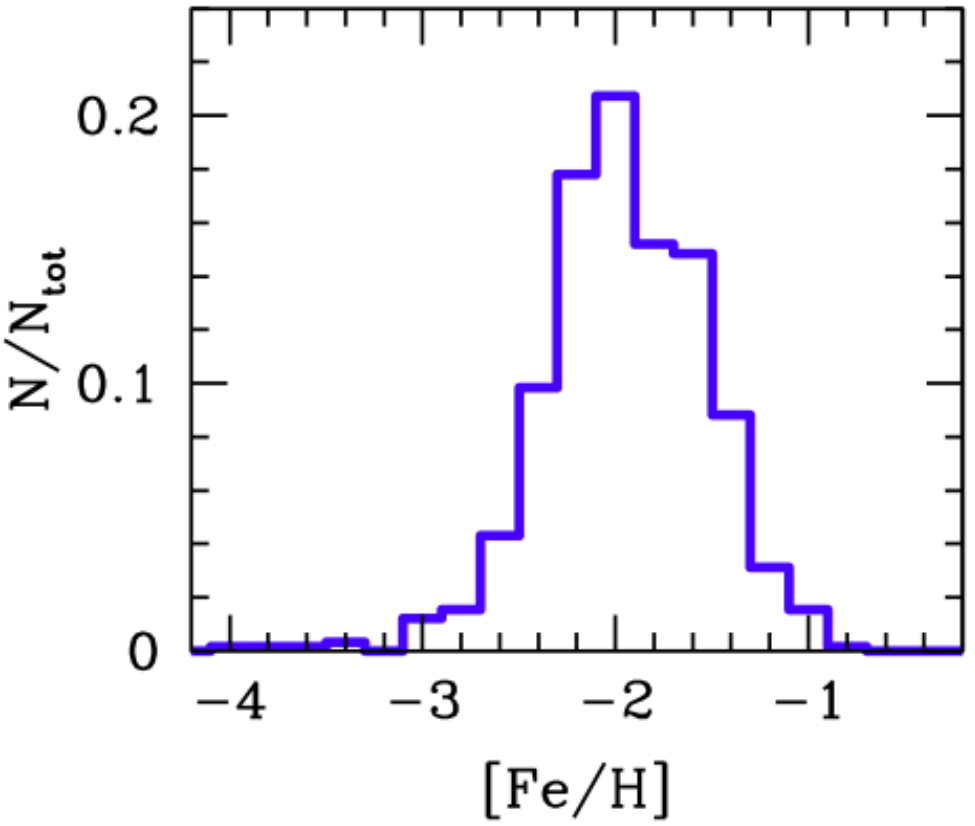
- Discovered in 1938
- $M_{tot} = 3.4 \times 10^8 M_\odot$
- $M_{stars} = 8 \times 10^6 M_\odot$
- Distance of 86±5 kpc
- At high Galactic latitude

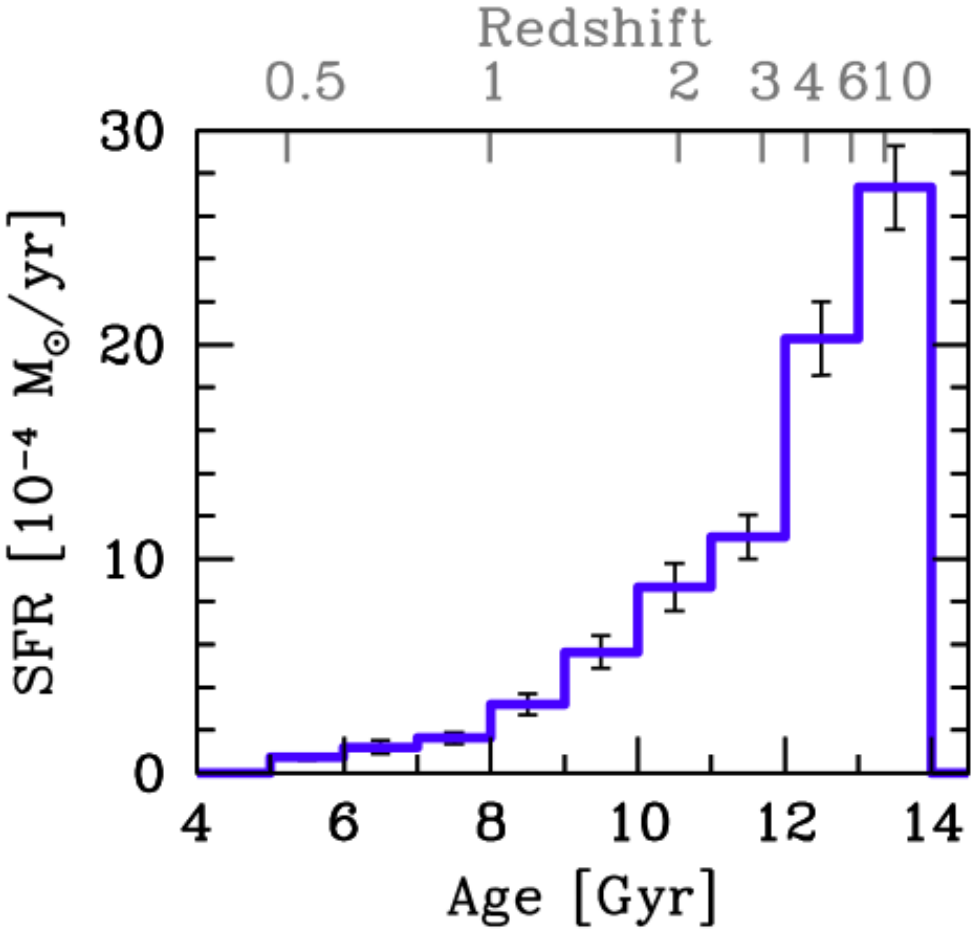


Shapley 1938, Battaglia et al. 2008b, de Boer et al. 2012, Pietrzyński et al. 2008

The stellar population in Sculptor

- Dominated by old stars (>10 Gyr old)

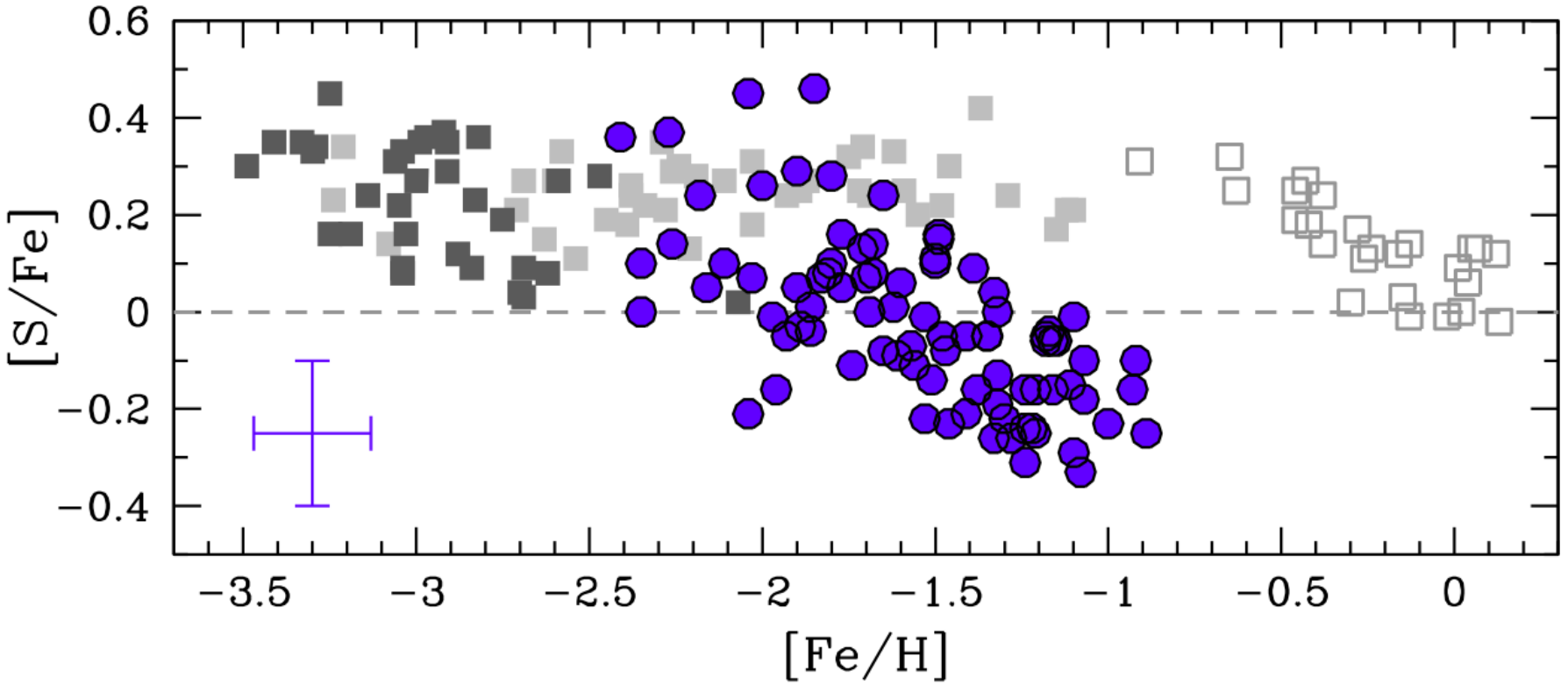




Metallicity Distribution Function
(Starkenberg et al. 2010)

Star Formation History
(de Boer et al. 2012)

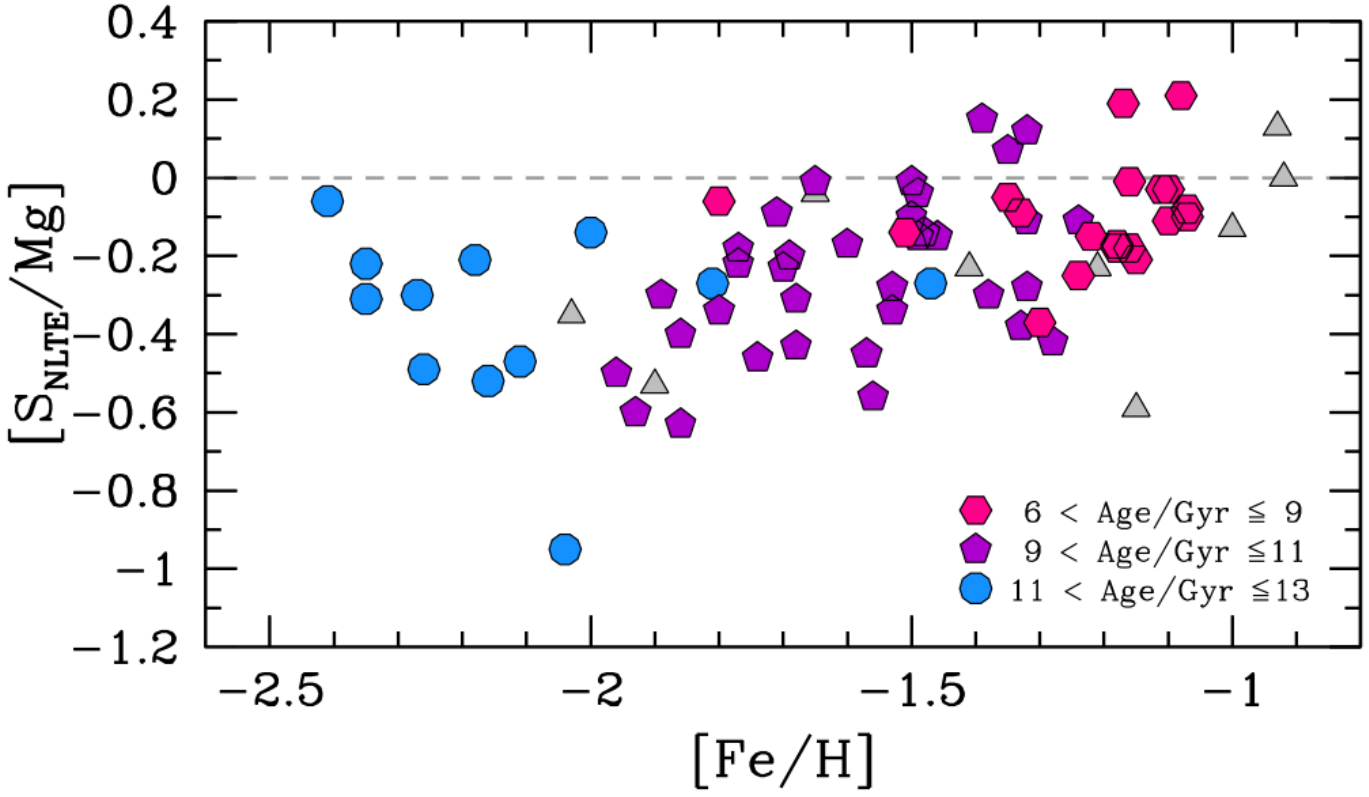
Closer Look - Sulphur



- The sulphur abundances in Sculptor show the same behaviour as other α-elements, consistent with a plateau at lower metallicities; with increasing [Fe/H], the ratio [S/Fe] declines, reaching negative values at the highest [Fe/H].

Sculptor: Skúladóttir et al. 2015b MW: Chen et al. 2002, Nissen et al. 2007, Spite et al. 2011

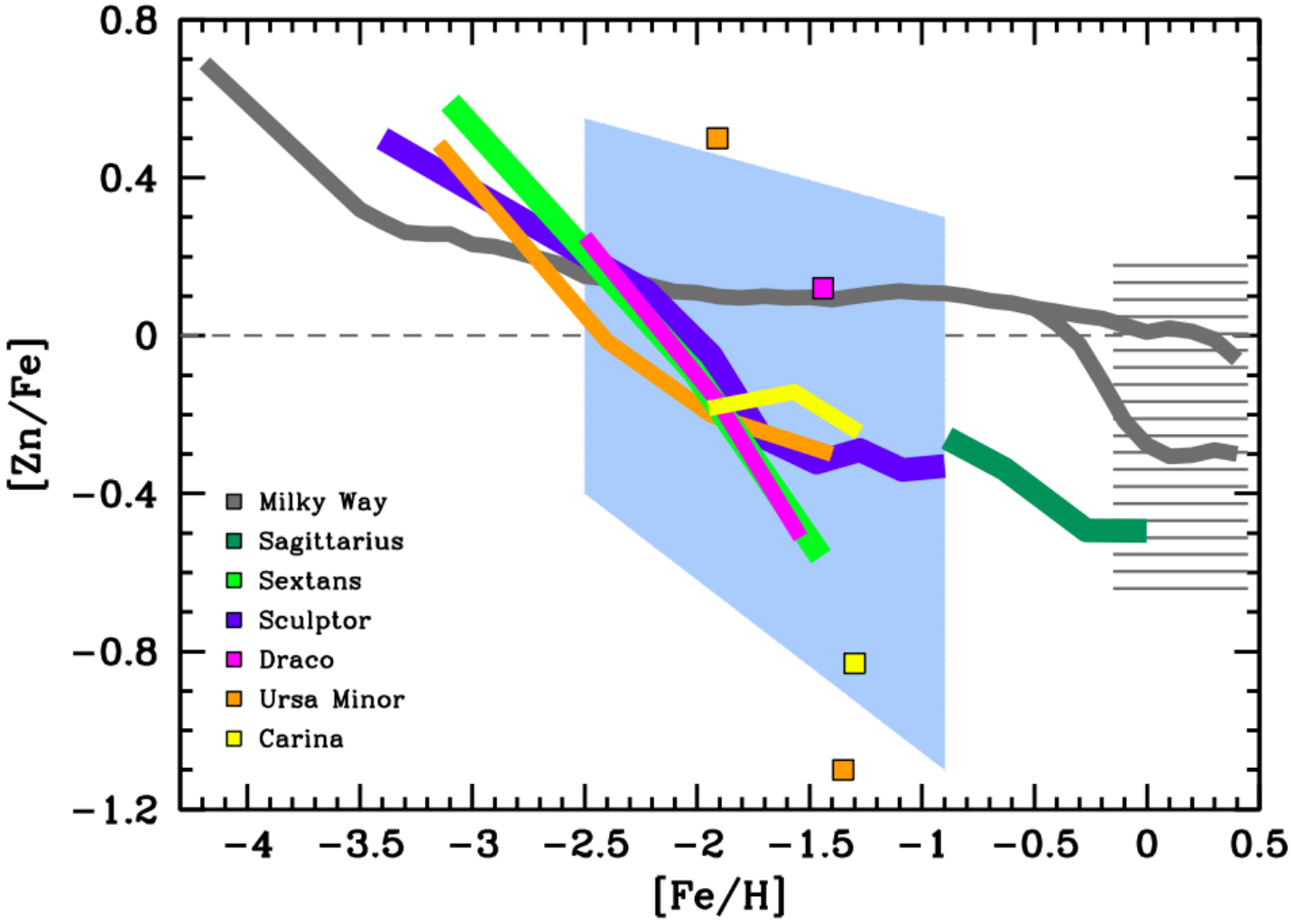
[S/α] in Sculptor



- The ratio of sulphur to magnesium increases with [Fe/H], consistent with **some production** of S in **Supernovae Type Ia**

Sulphur: Skúladóttir et al. 2015b Calcium: Hill et al. in prep Ages: Thomas de Boer et al. 2012

Closer Look - Zinc



⋆ **Zn behaves like an α-element! But with scatter!**

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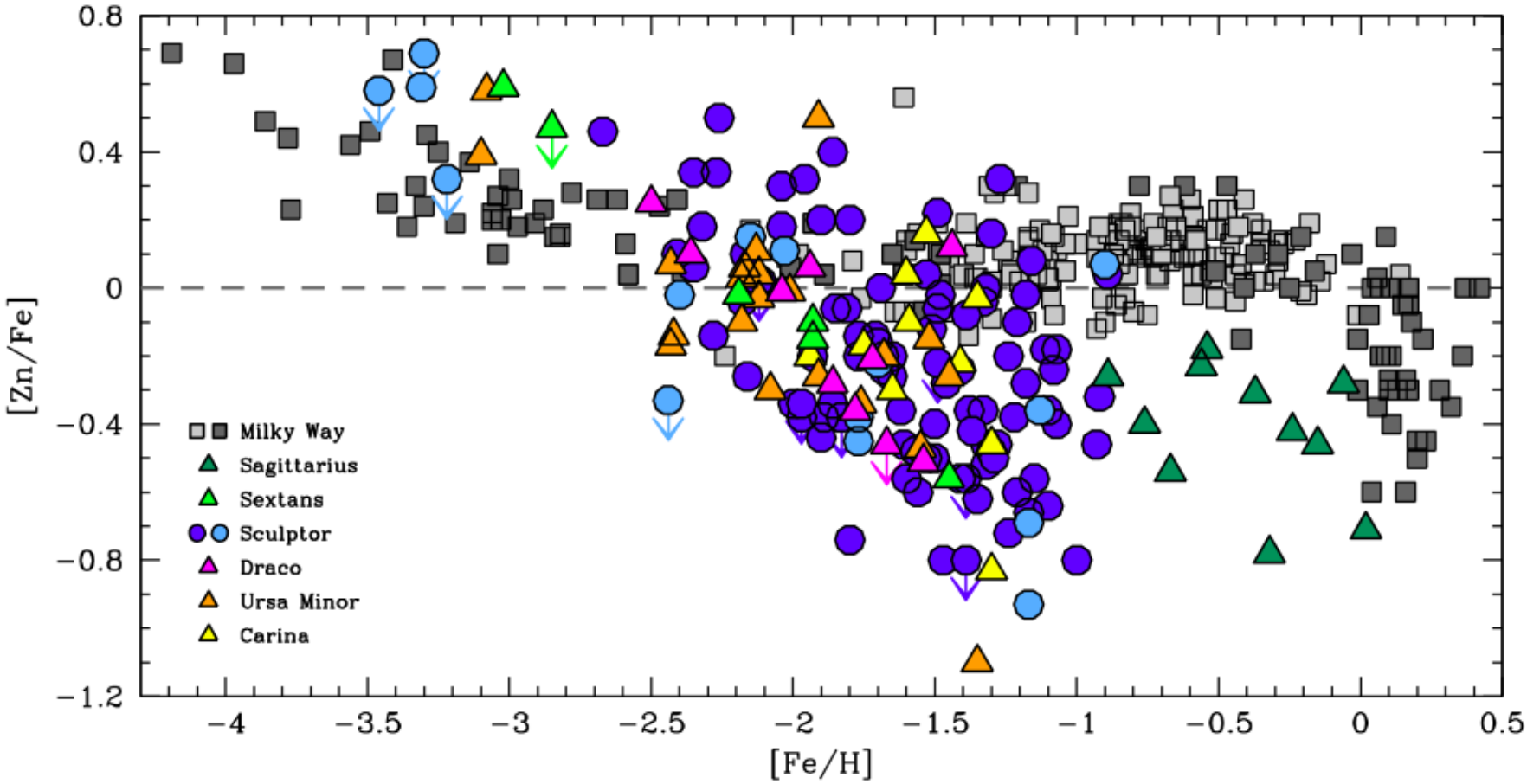
Closer Look - Zinc



References (Number of stars): *Sagittarius:* Sbordone et al. 2007 (11). *Sextans:* Shetrone et al. 2001 (5); Honda et al. 2011 (1). *Sculptor:* Shetrone et al. 2003 (1); Geisler et al. 2005 (1); Kirby & Cohen 2012 (1); Jablonka et al. 2015 (4 upper limits); Skúladóttir et al. 2015b (1); Simon et al. 2015 (1); Hill et al. in prep (6). *Draco:* Shetrone et al. 2001 (5); Cohen & Huang 2009 (5). *Ursa Minor:* Shetrone et al. 2001 (6); Sadakane et al. 2004 (3); Cohen & Huang 2010 (10); Ural et al. 2015 (2). *Carina:* Shetrone et al. 2003 (5); Venn et al. 2012 (5). *Milky Way:* Reddy et al. 2003, 2006; Cayrel et al. 2004; Nissen & Schuster 2011; Ishigaki et al. 2013; Bensby et al. 2014 (only including stars with errors $\delta_{[\mathrm{Zn/Fe}]} \leq 0.2$); Barbuy et al. 2015.

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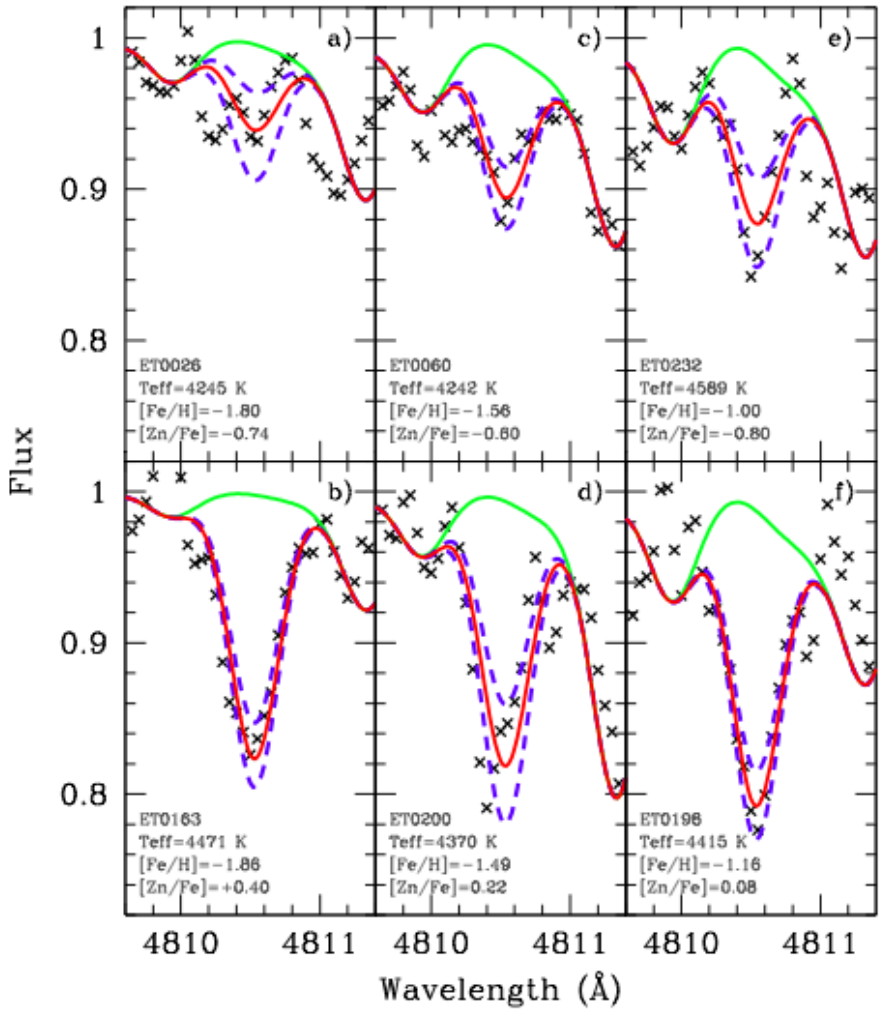
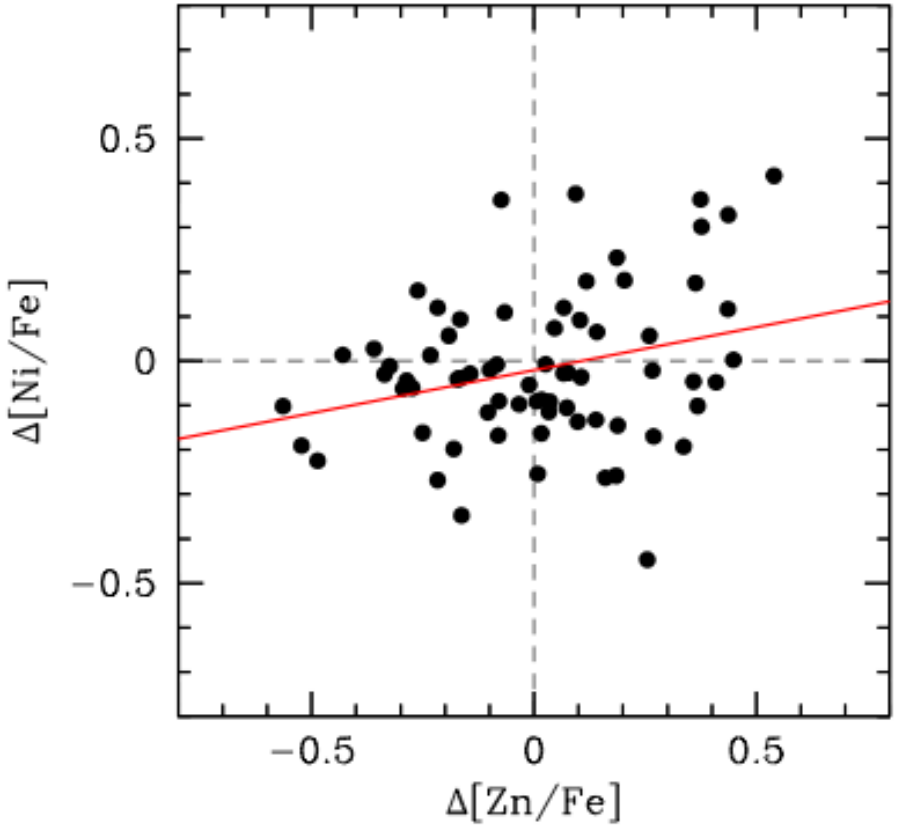
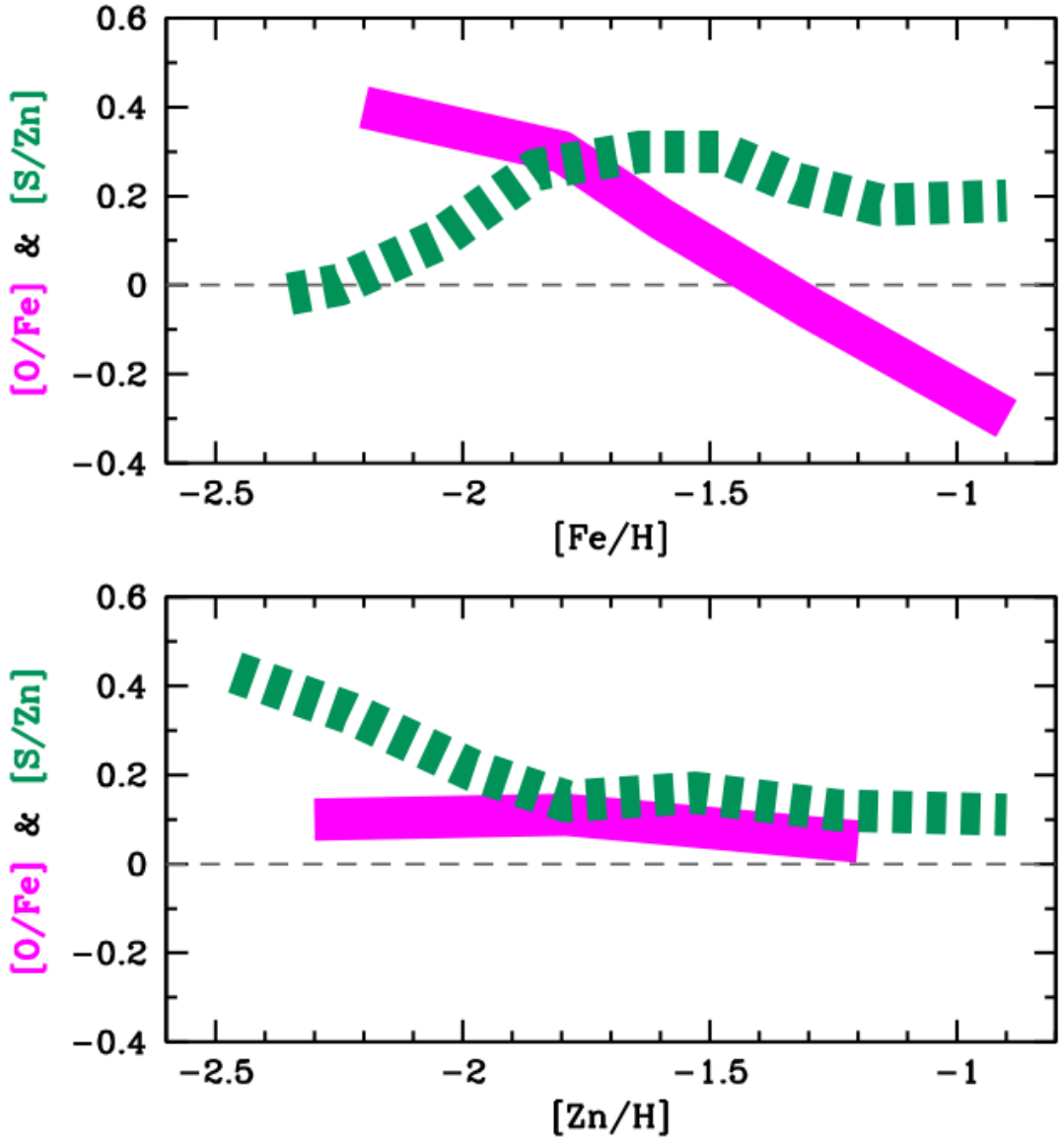
Scatter



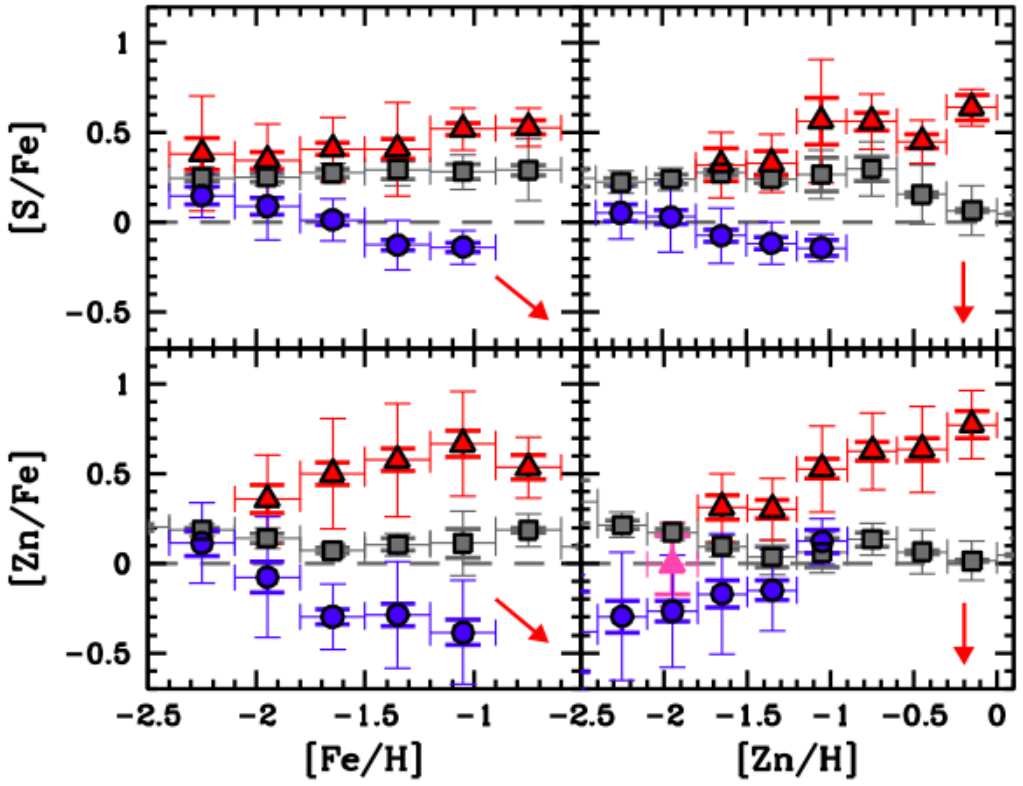
- Scatter in [Zn/Fe] correlated with Ni
- (but not: O, Na, Mg, Si, Ca, Ti, Sc, Cr, Mn, Fe II, Co, Ni, Ba, La and Nd)



[S/Zn] ≠ [α/Fe]



DLAs vs Sculptor



- Sculptor stars cover lower [Zn/H] compared to DLAs
- DLAs, Milky Way and Sculptor all different!
- Dust depletion of Fe complicates matter.
- In principle, DLAs could be like the Milky Way, or Sculptor, or neither depending on the level of dust depletion.

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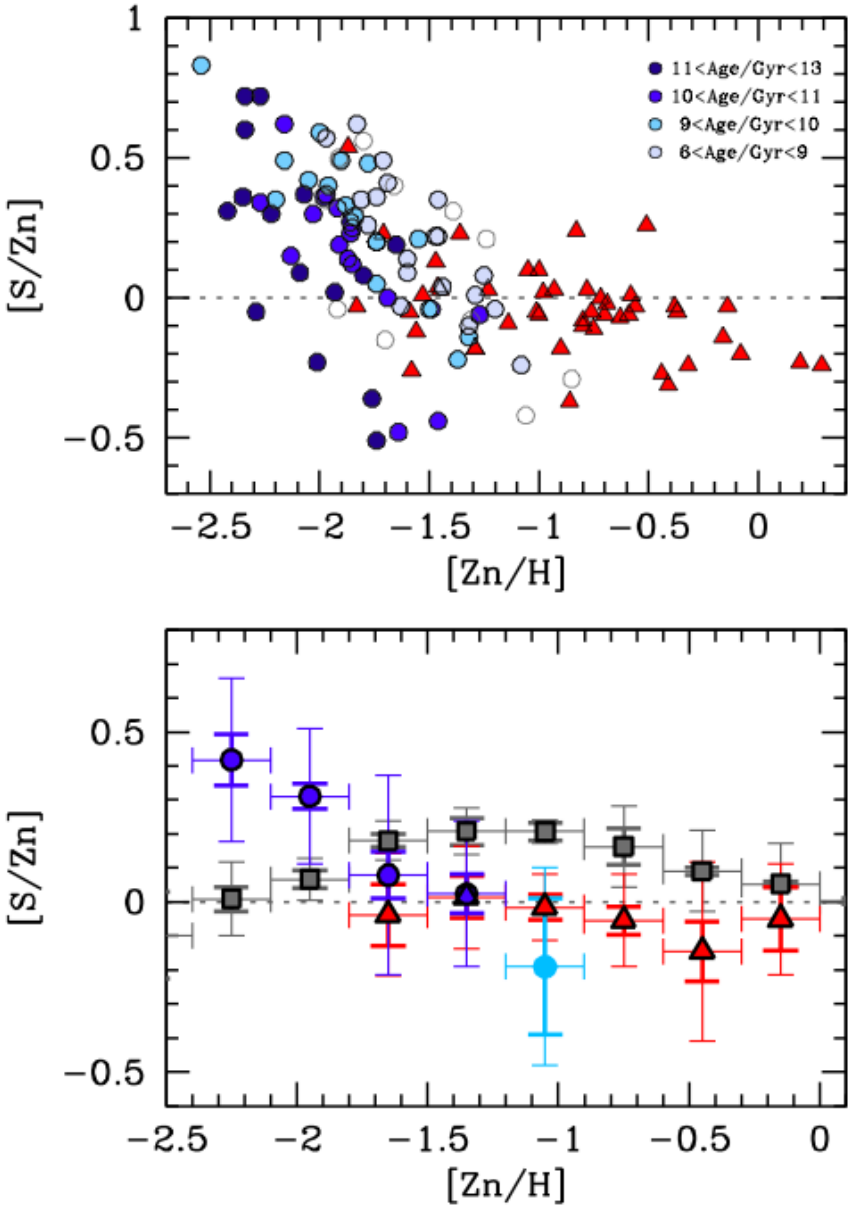
DLAs vs Sculptor



- [S/Zn] consistent in regions where they overlap!
- However: [Zn/H] is not a good tracer of the chemical evolution in Sculptor.
- Results difficult to interpret within the star formation history of Sculptor

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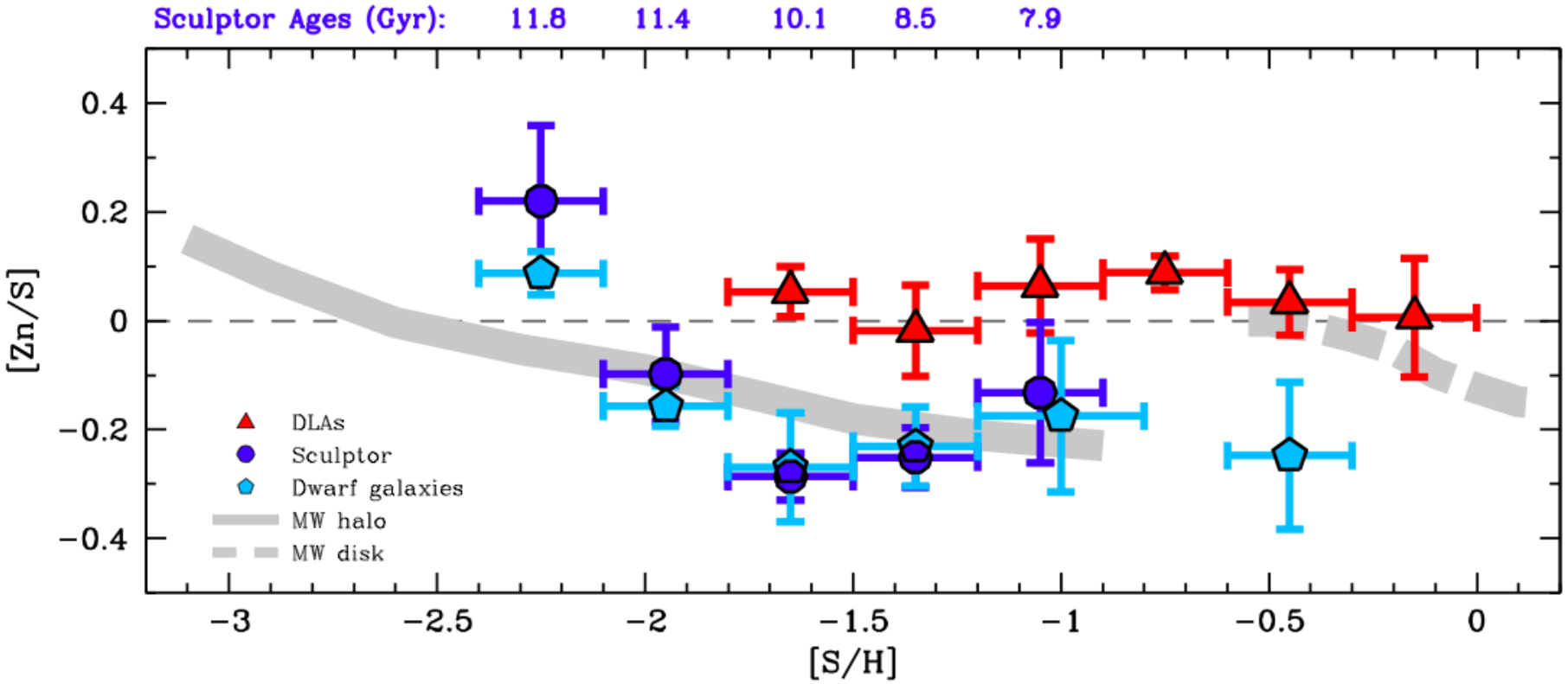
DLAs vs Sculptor



- Clear differences in abundance pattern!
- DLAs comparable to the early dwarf galaxy evolution, and the disk at higher metallicities.
- The plateau in DLAs a mystery!

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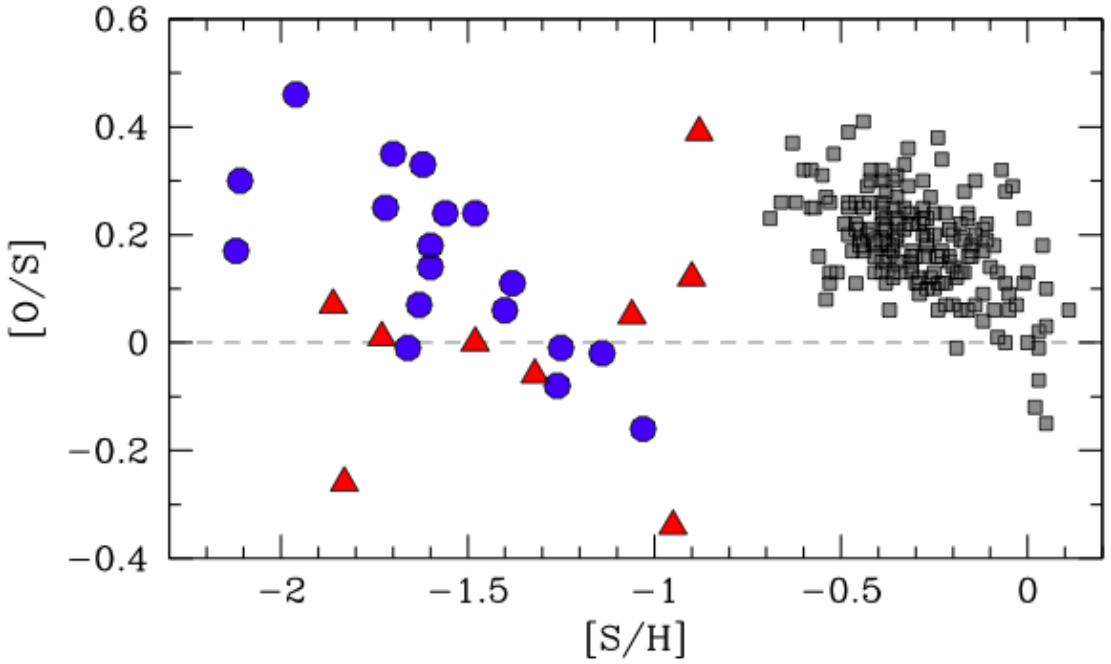
Alternative [α/Fe]: [O/S]



- Instead of [α/Fe] with [Fe/H] we propose the use of [O/S] with [S/H] as a measure of the relative contribution of SN Type II and Type Ia.
- Observationally challenging in DLAs.

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Conclusions

- **Zn is not Fe**
- Contrary to Fe, Zn is **not** significantly created in Supernova Type Ia.
- **[S/Zn] ≠ [α/Fe]**
- Zn is still not fully understood in the Local Group.
- S can be used as a metallicity tracer, created both by SN Type II and Ia.
- DLA abundance ratios of [Zn/S] consistent with earliest phases of dwarf galaxy evolution.
- Plateau of [Zn/S] in DLAs a mystery!