The Chemical Evolution of Milky Way Satellite Galaxies from Keck Spectroscopy

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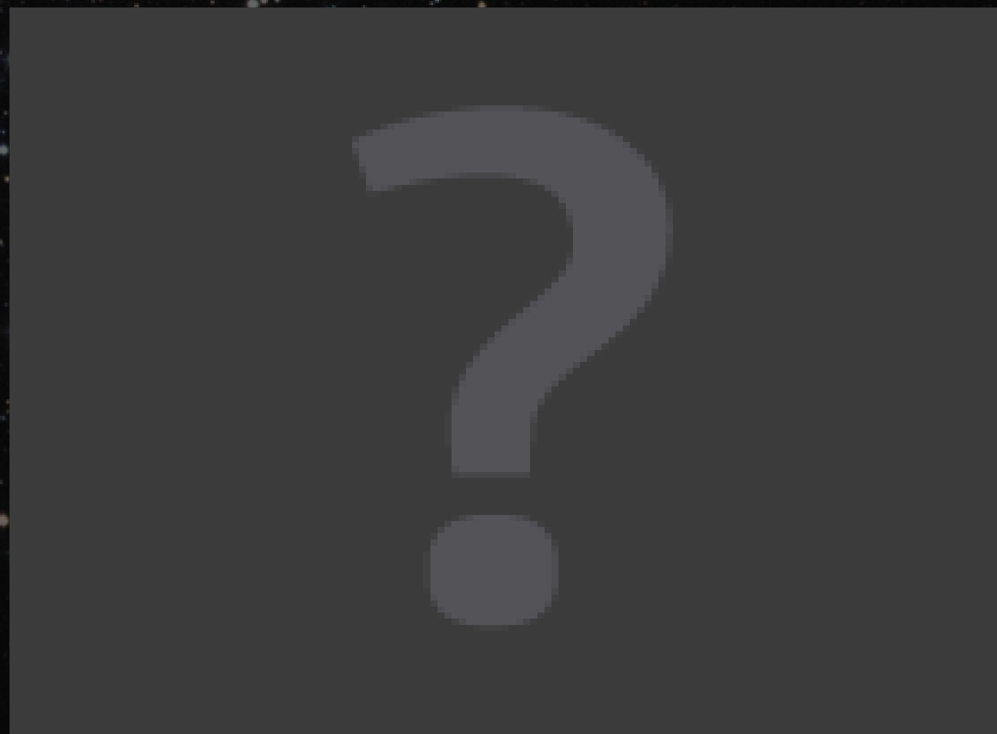
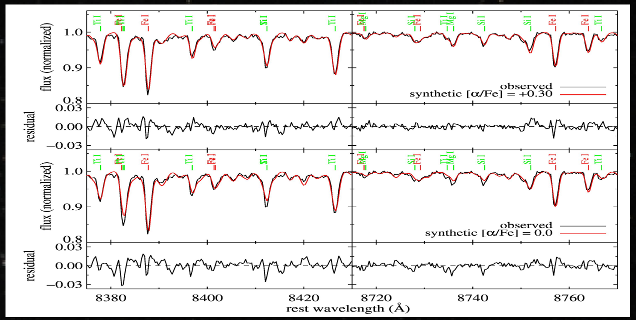
Ursa Minor dwarf spheroidal (Capella Observatory)

The precursors to today's dSphs may have built the MW halo.

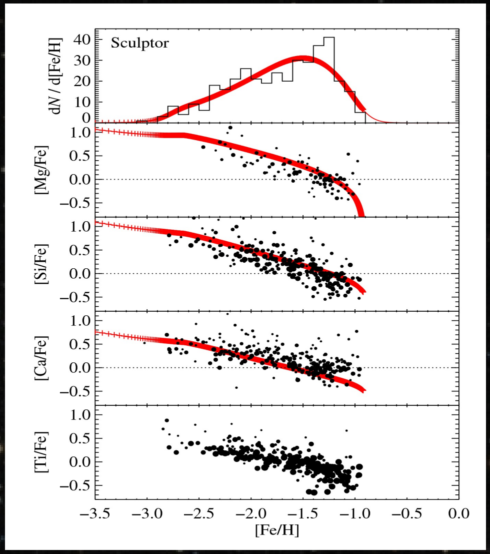


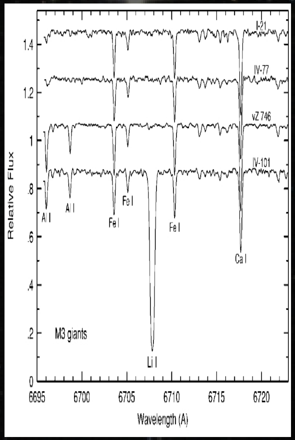
Diemand et al. 2008, Nature, 454, 735

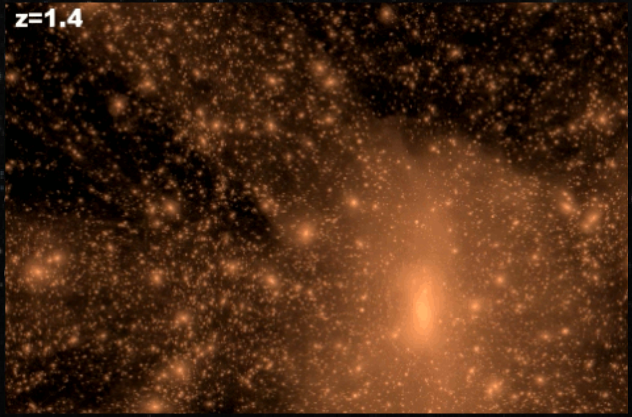
The Chemical Evolution of Milky Way Satellite Galaxies



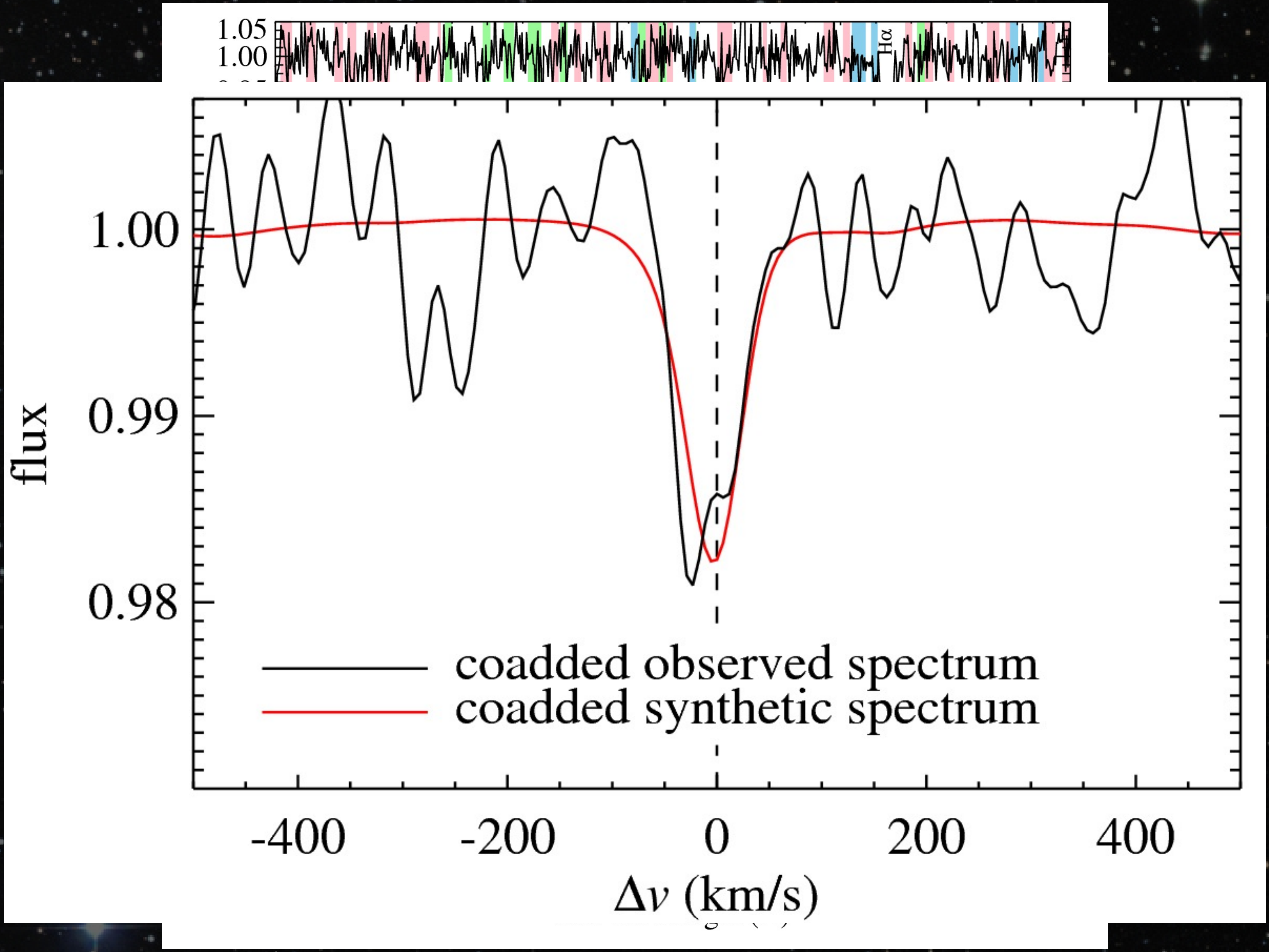
- Method for measuring abundances
- Chemical evolution
  - Metallicity distributions
  - [α/Fe] distributions
- The construction of the halo
- Lithium in evolved red giants







Detailed abundances may be measured from med-res spectra.



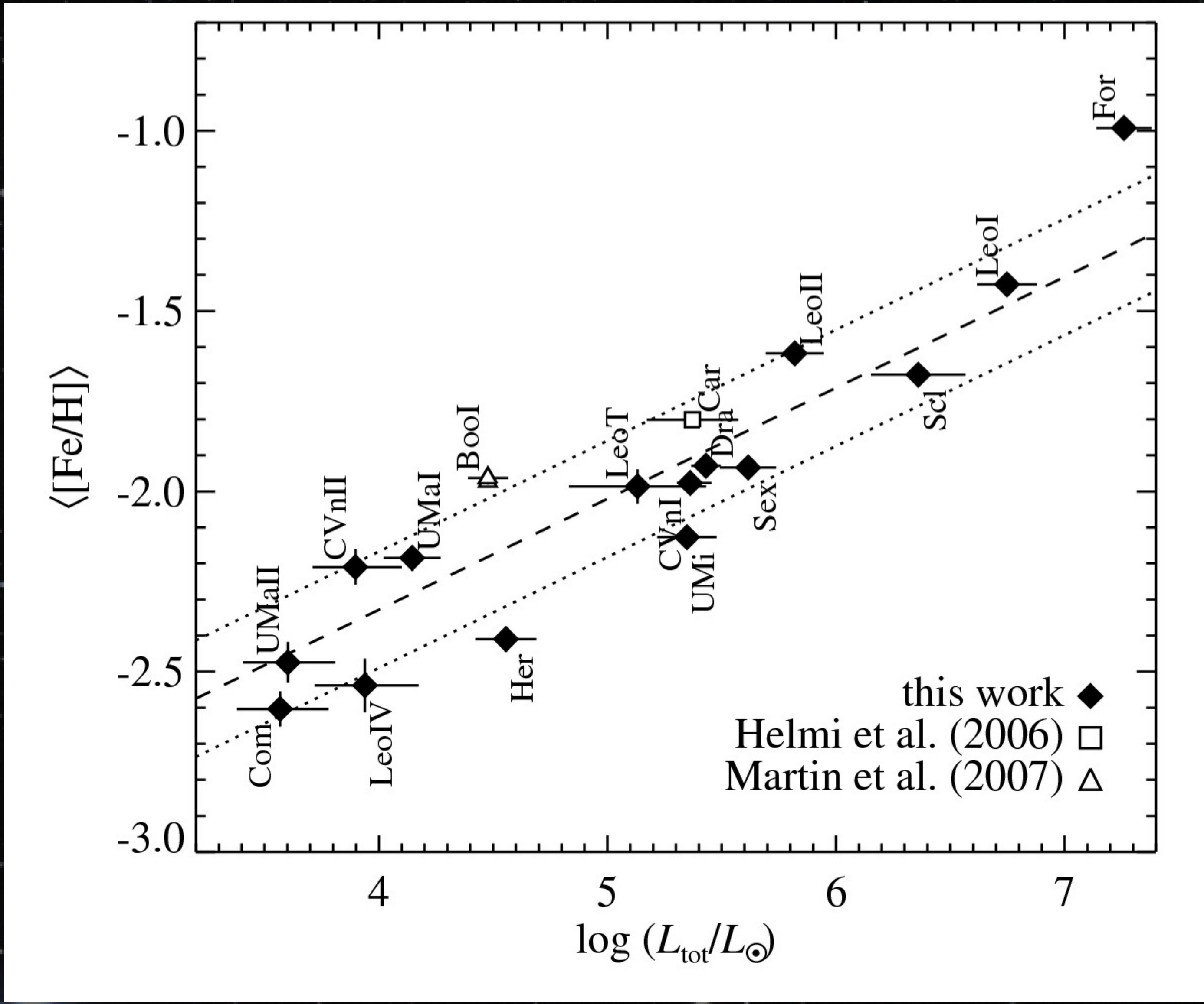
EK et al. 2009, ApJ, 705, 328
Frebel, EK, & Simon 2010, Nature, 464, 72

A catalog of multi-element abundances in MW dSphs

dSph	N	t_{exp} (hours)
Fornax	675	4.1
Leo I	827	15.5
Sculptor	376	3.3
Leo II	258	5.3
Sextans	141	5.8
Draco	298	6.0
Canes Venatici I	174	6.2
Ursa Minor	212	5.1
Total	2961	51.2

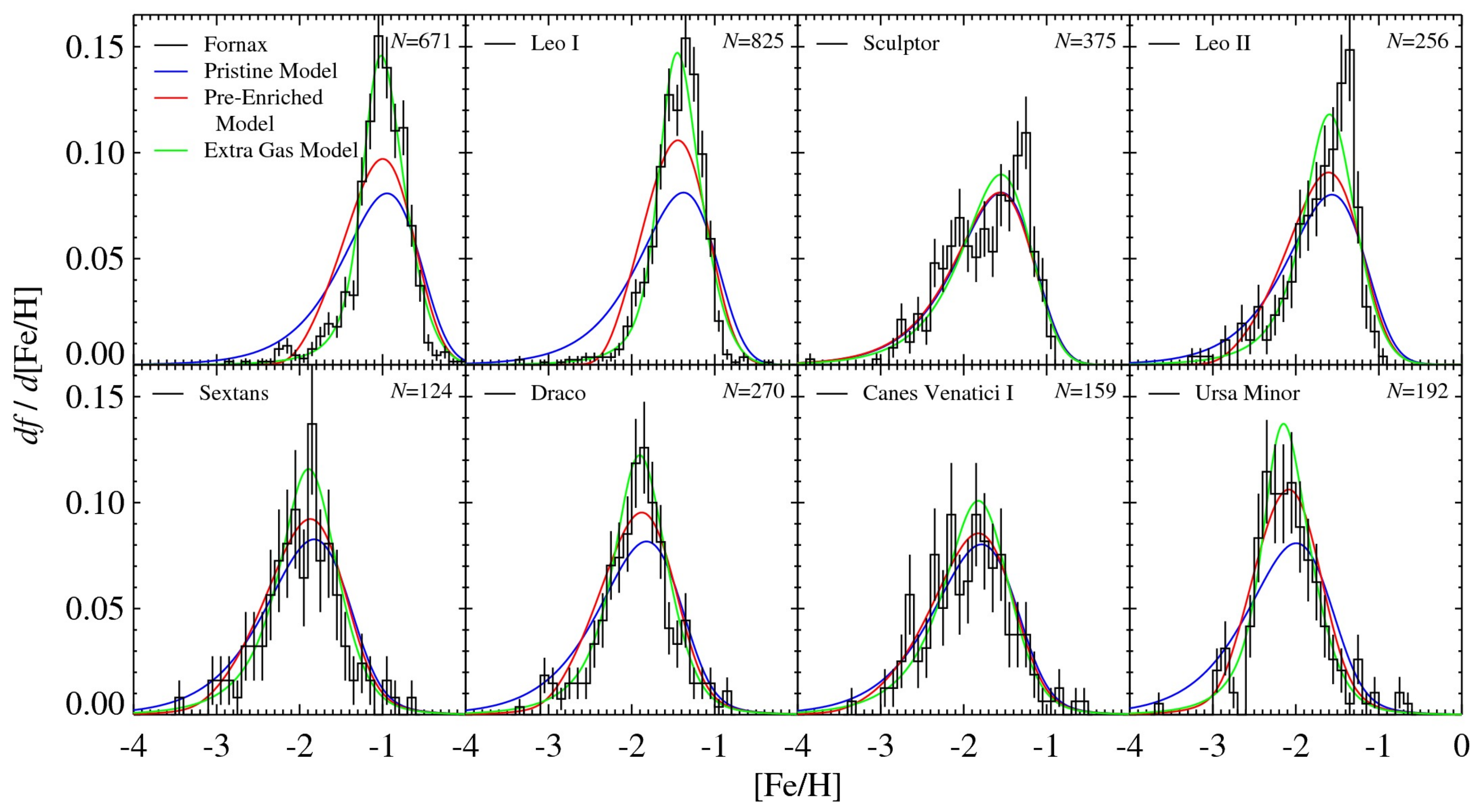
EK et al. 2010, ApJS, 191, 352

The dependence of metallicity on luminosity may indicate gas outflow.



EK et al. 2008, ApJL, 685, L43
EK et al. 2011a, ApJ, 727, 78

The metallicity distributions of dwarf galaxies evolve with luminosity.



EK et al. 2011a, ApJ, 727, 78

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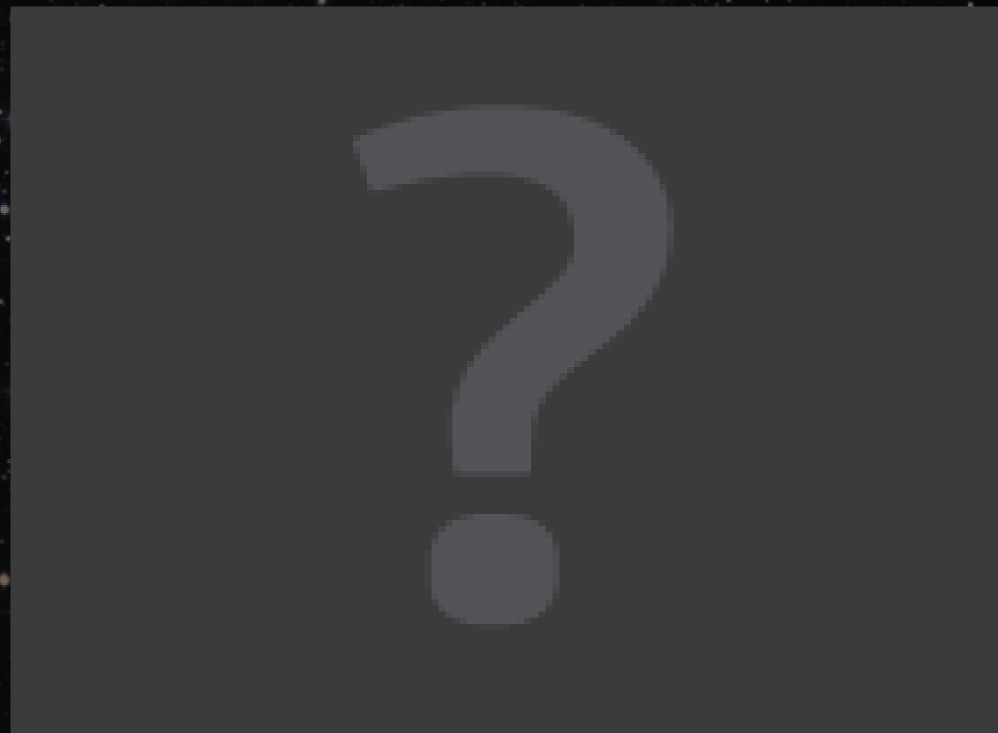
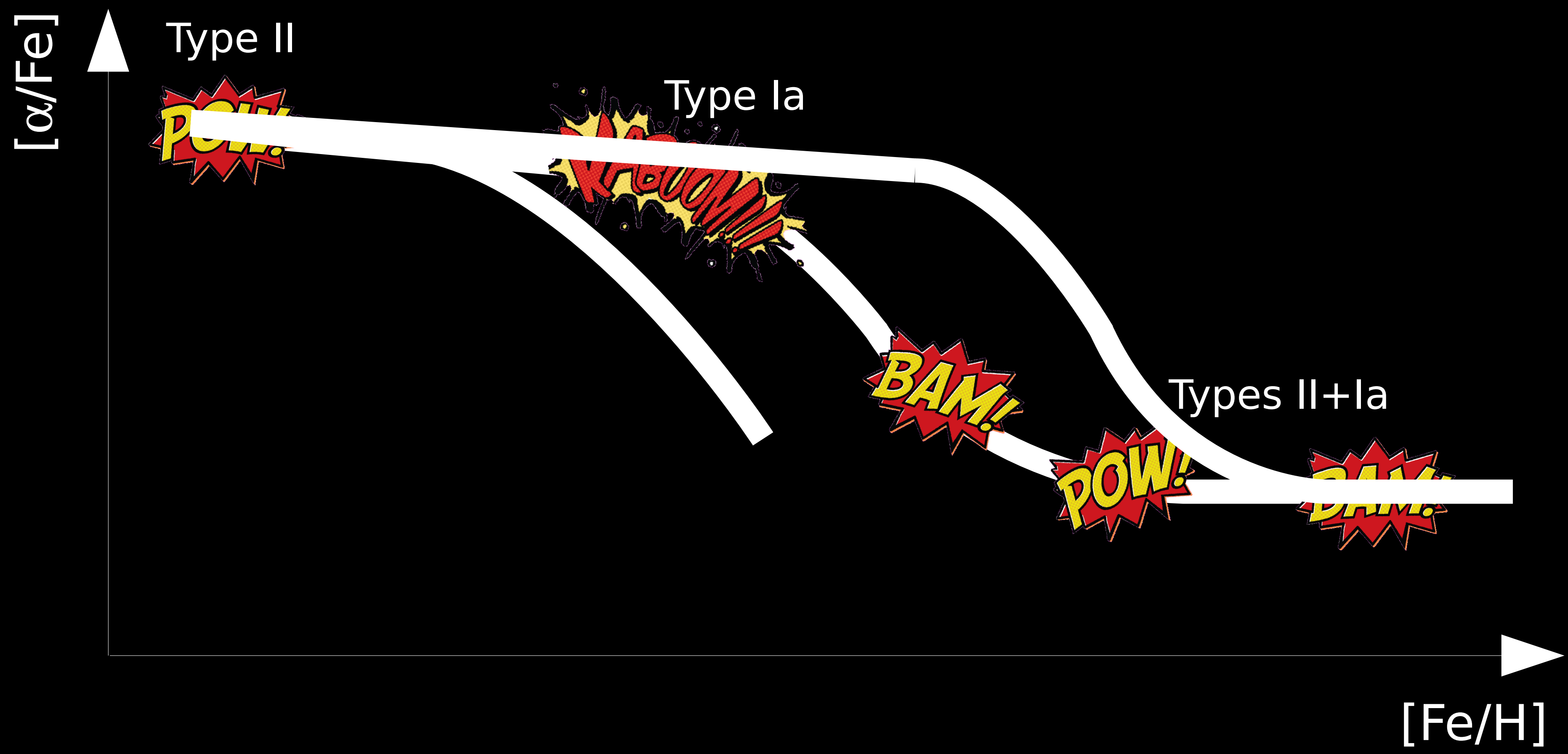


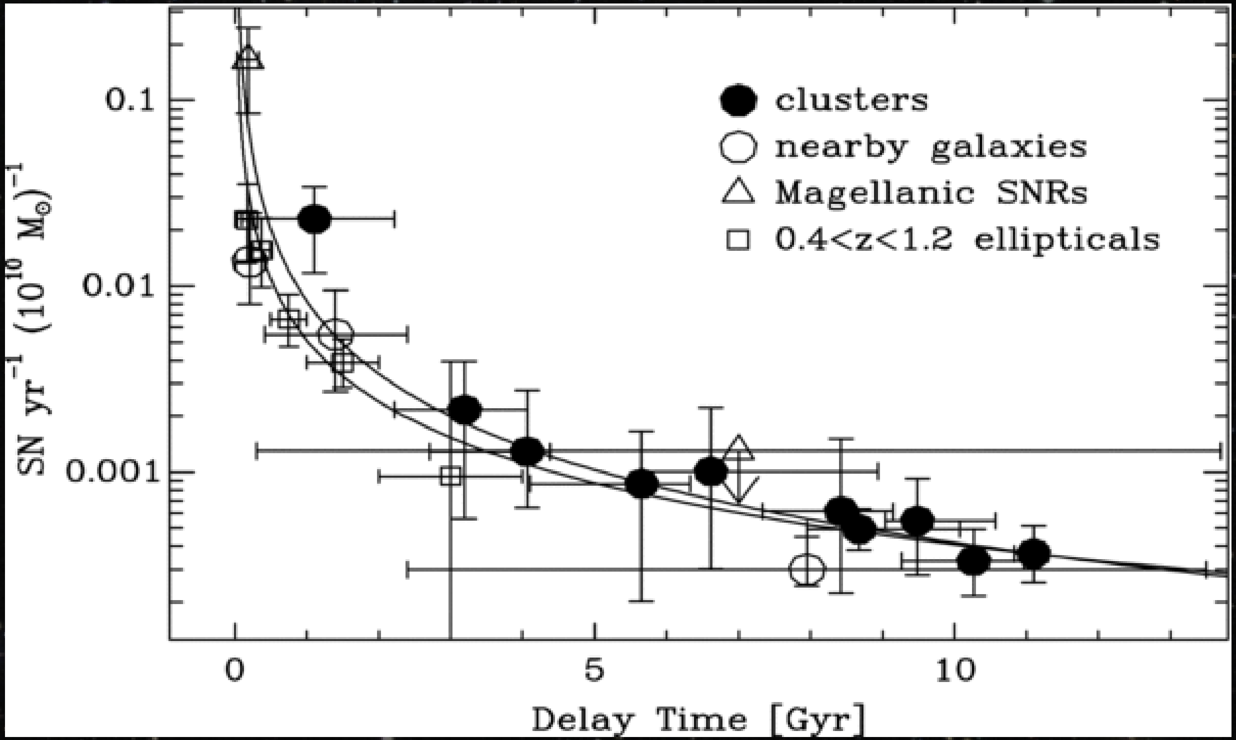
The [α/Fe] ratio indicates the star formation timescale.



A numerical model describes the evolution of the elements.

$$\mathrm{SFR} = A_* (M_{gas})^{\alpha}$$

$$M_{gas}(t) = M_{gas}(0) + A_{in}\, t\, e^{-t/\tau} - A_{out}\,(R_{Ia} + R_{II}) - \mathrm{SFR}$$

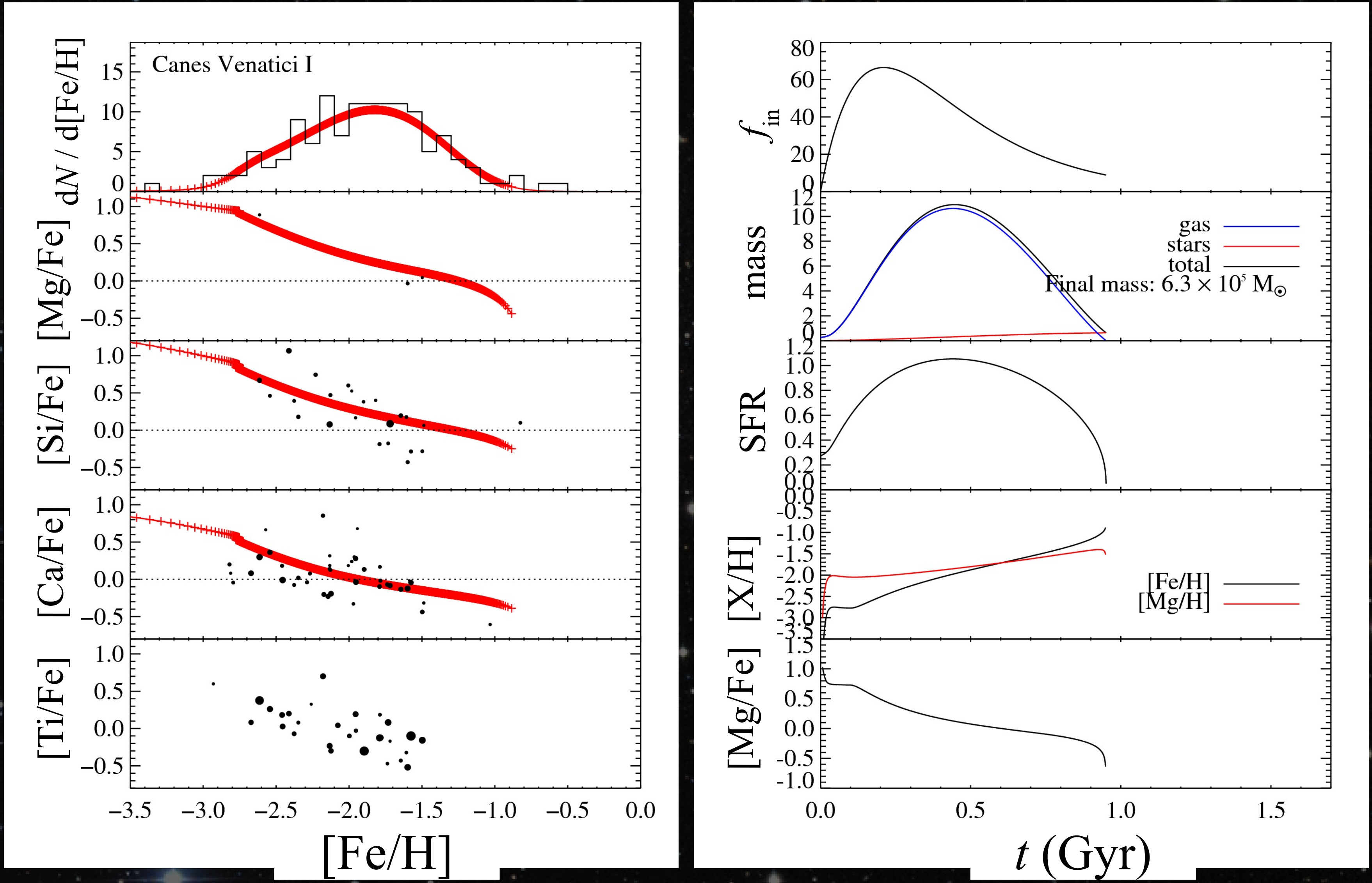


Maoz et al. 2010, ApJ, 722, 1879

Nucleosynthetic yields:

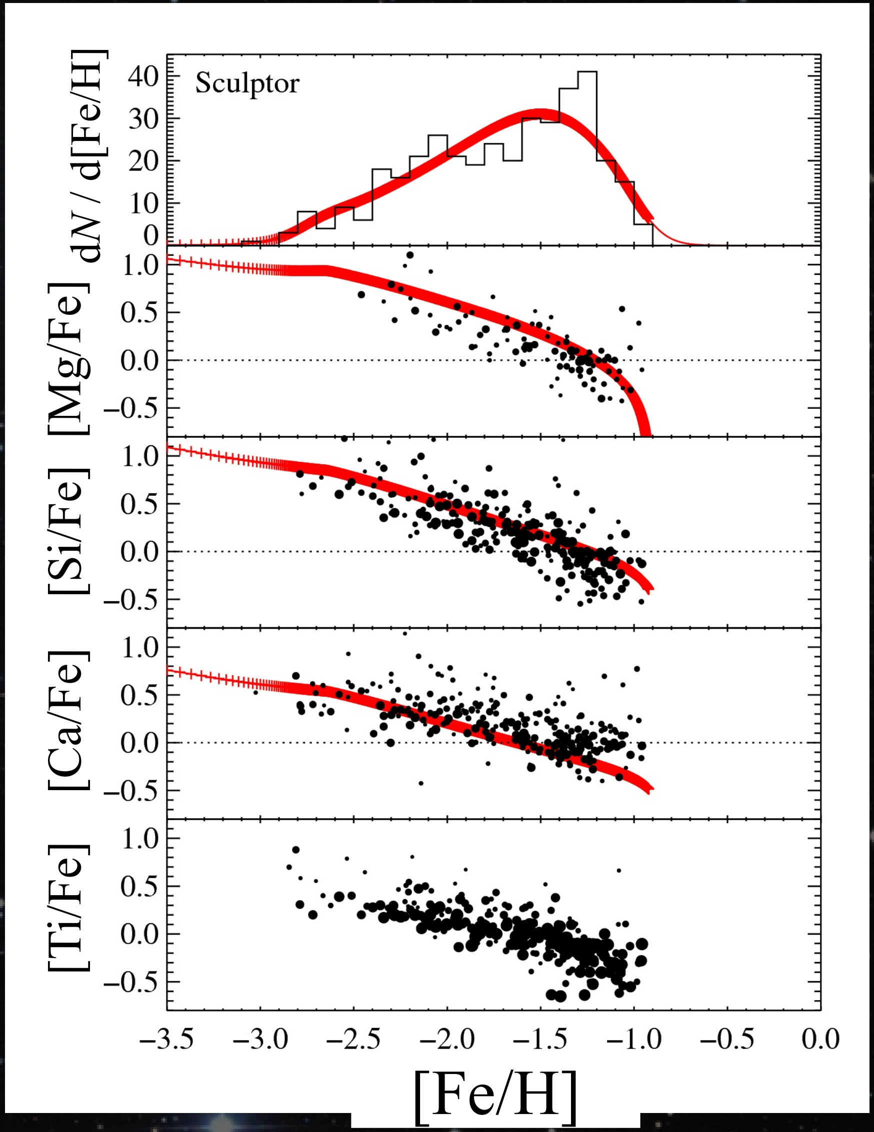
- Type II Sne: Nomoto et al. 2006, NuPhA, 777, 424
- Type Ia Sne: Iwamoto et al., 1996, ApJS, 125, 439
- AGB stars: Karakas 2010, MNRAS, 403, 1413

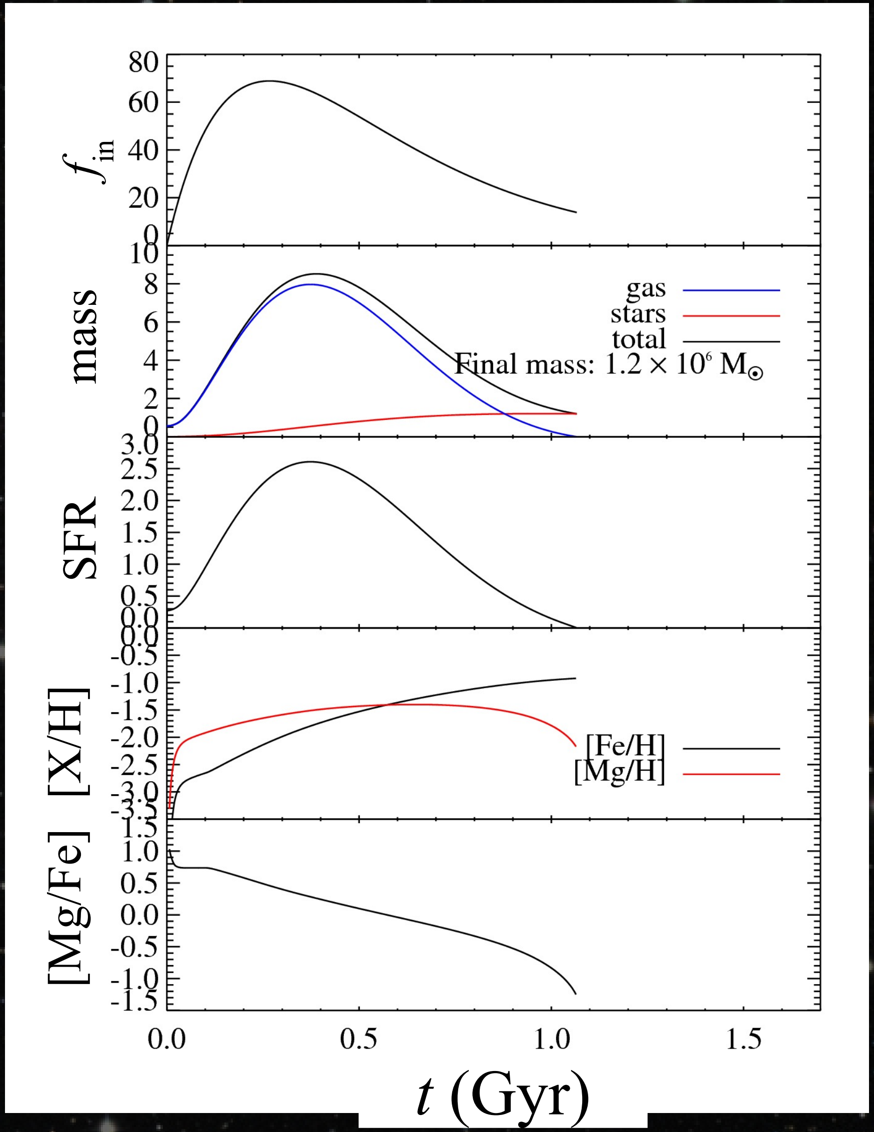
Low-*L* galaxies lost a lot of gas.



EK et al. 2011b, ApJ, 727, 79

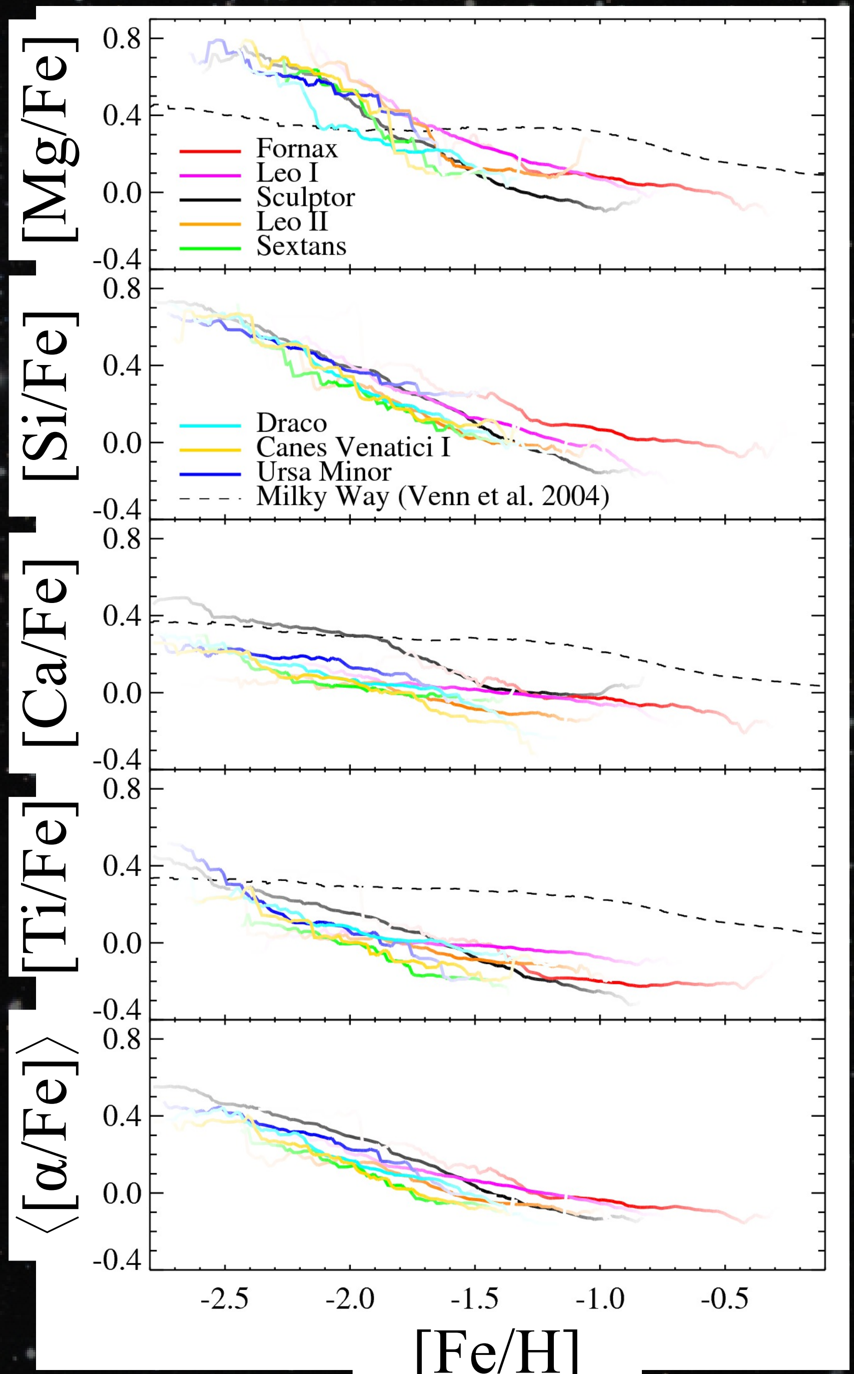
Gas accretion shaped the MDFs of higher-*L* galaxies.





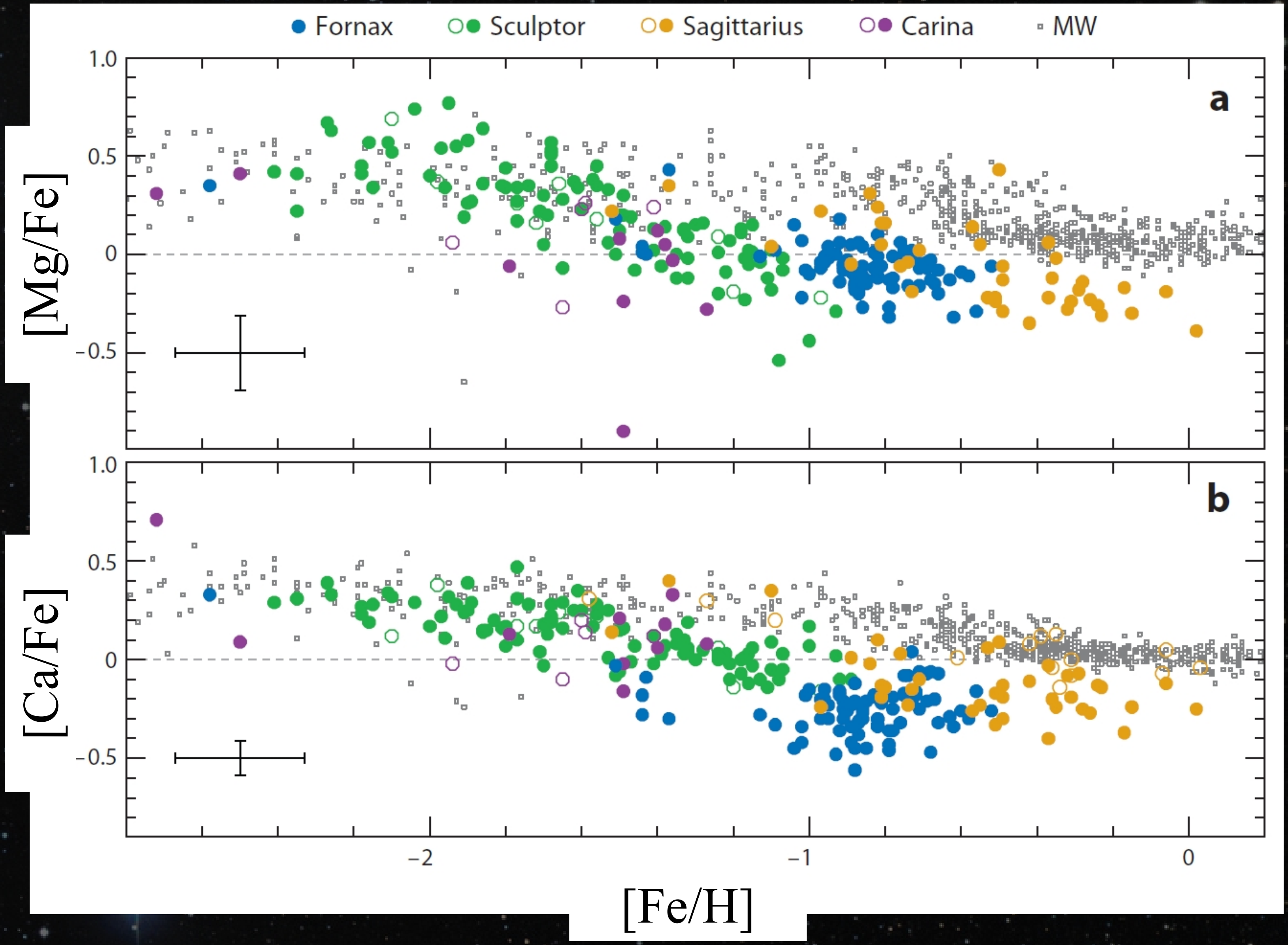
EK et al. 2011b, ApJ, 727, 79

[α/Fe] follows a very similar path in all dSphs.



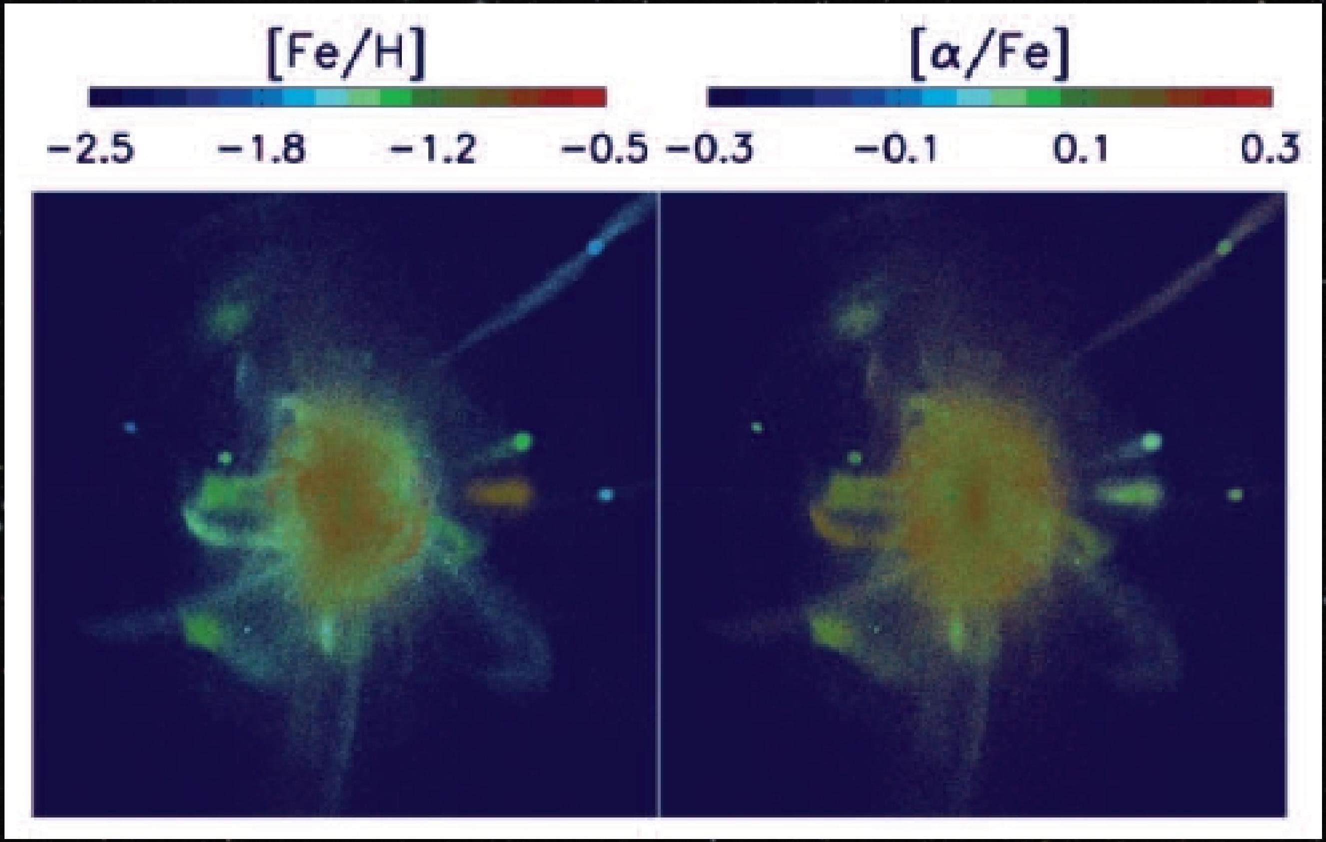
EK et al. 2011b, ApJ, 727, 79

Alpha elements in dwarf galaxies show different patterns than in the halo.



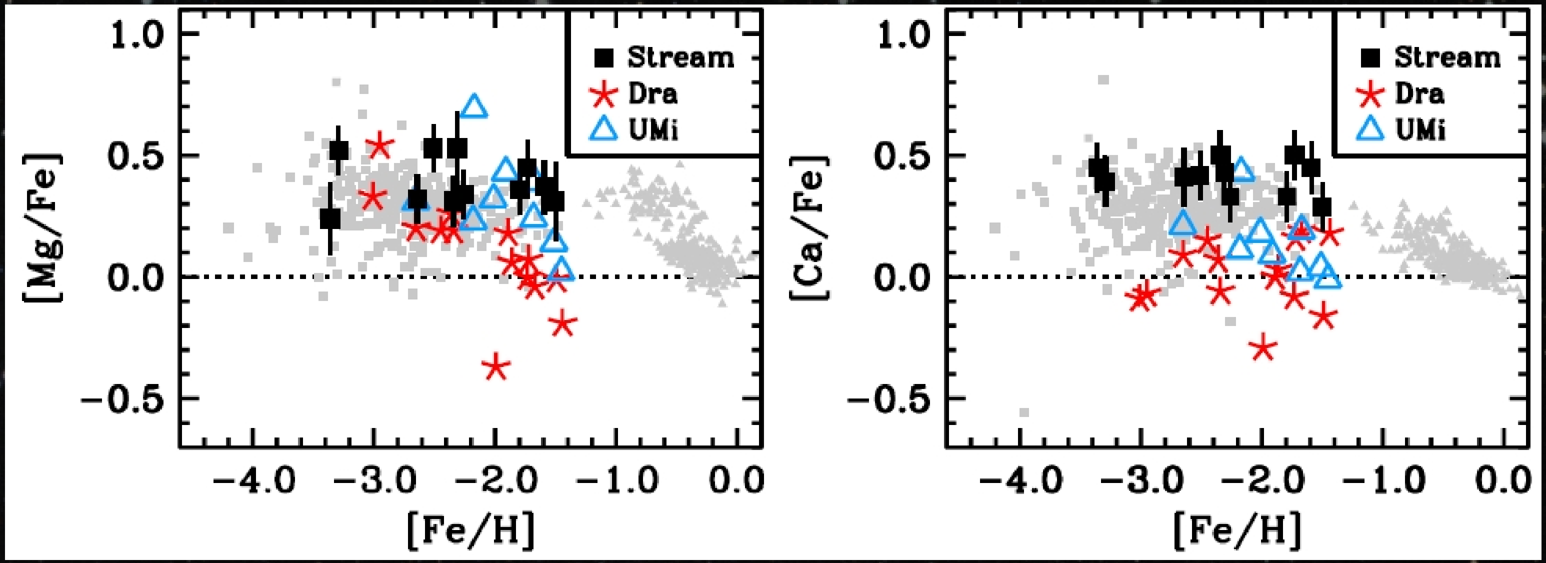
Tolstoy, Hill, & Tosi 2009, ARA&A, 47, 371
and many references therein

“The halo” is an ill-defined structure.

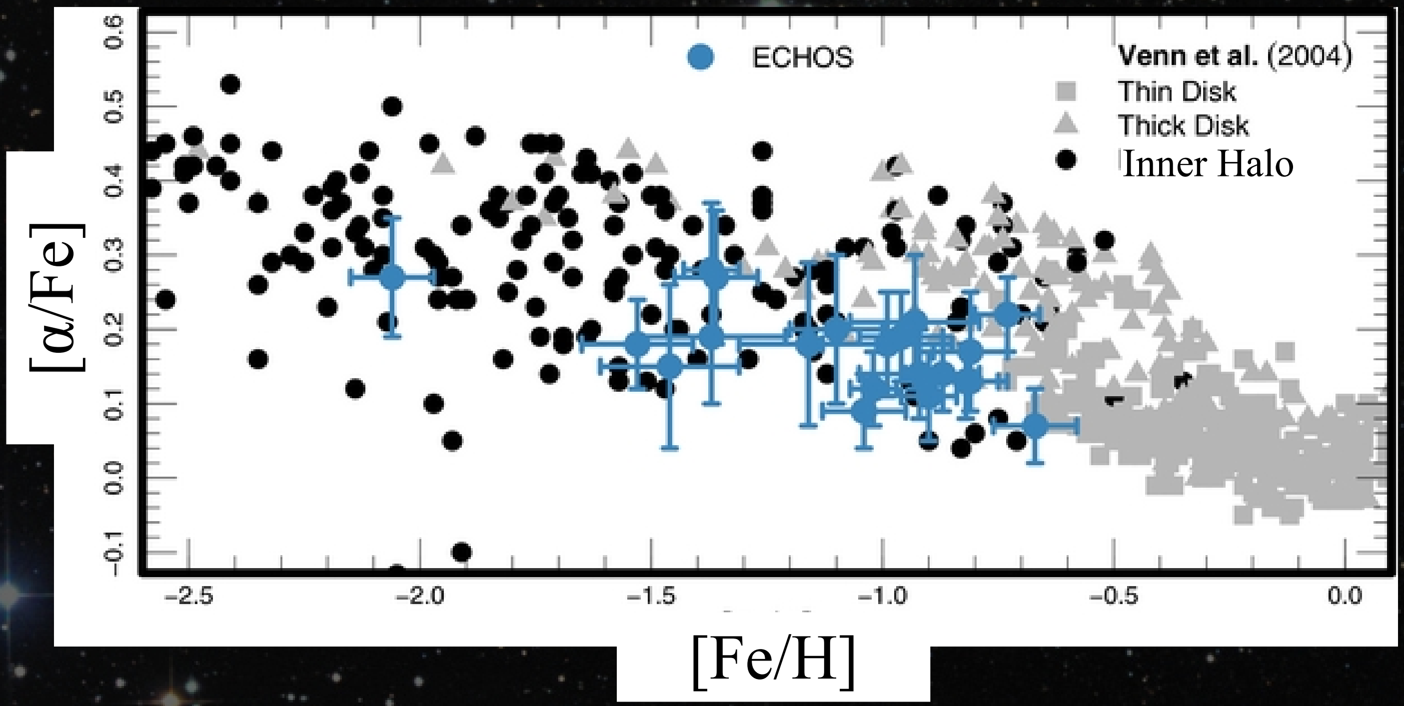


Font et al. 2006, ApJ, 646, 886

Smoother substructure has abundances more consistent with the halo.

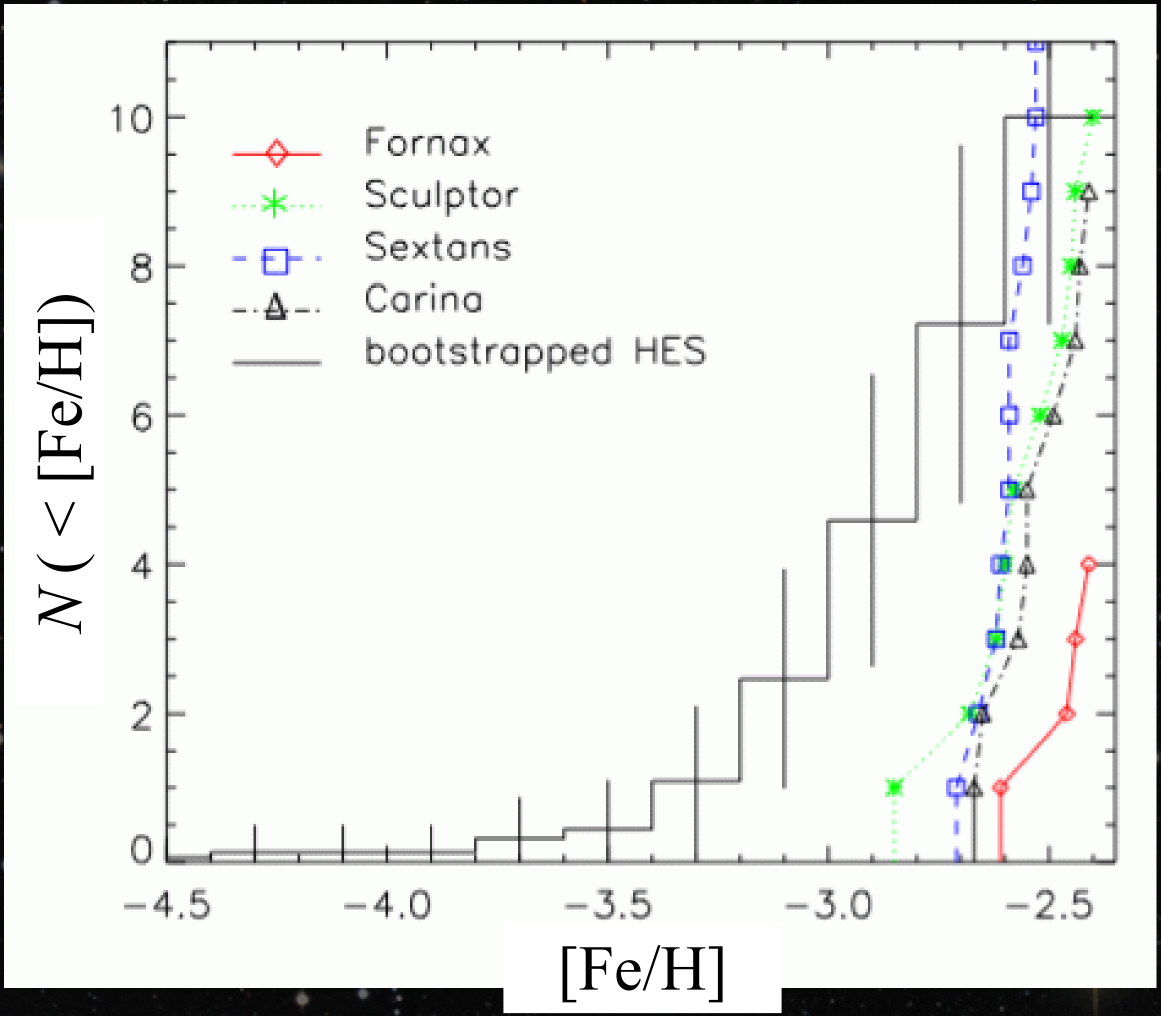


Roederer et al. 2010, ApJ, 711, 573



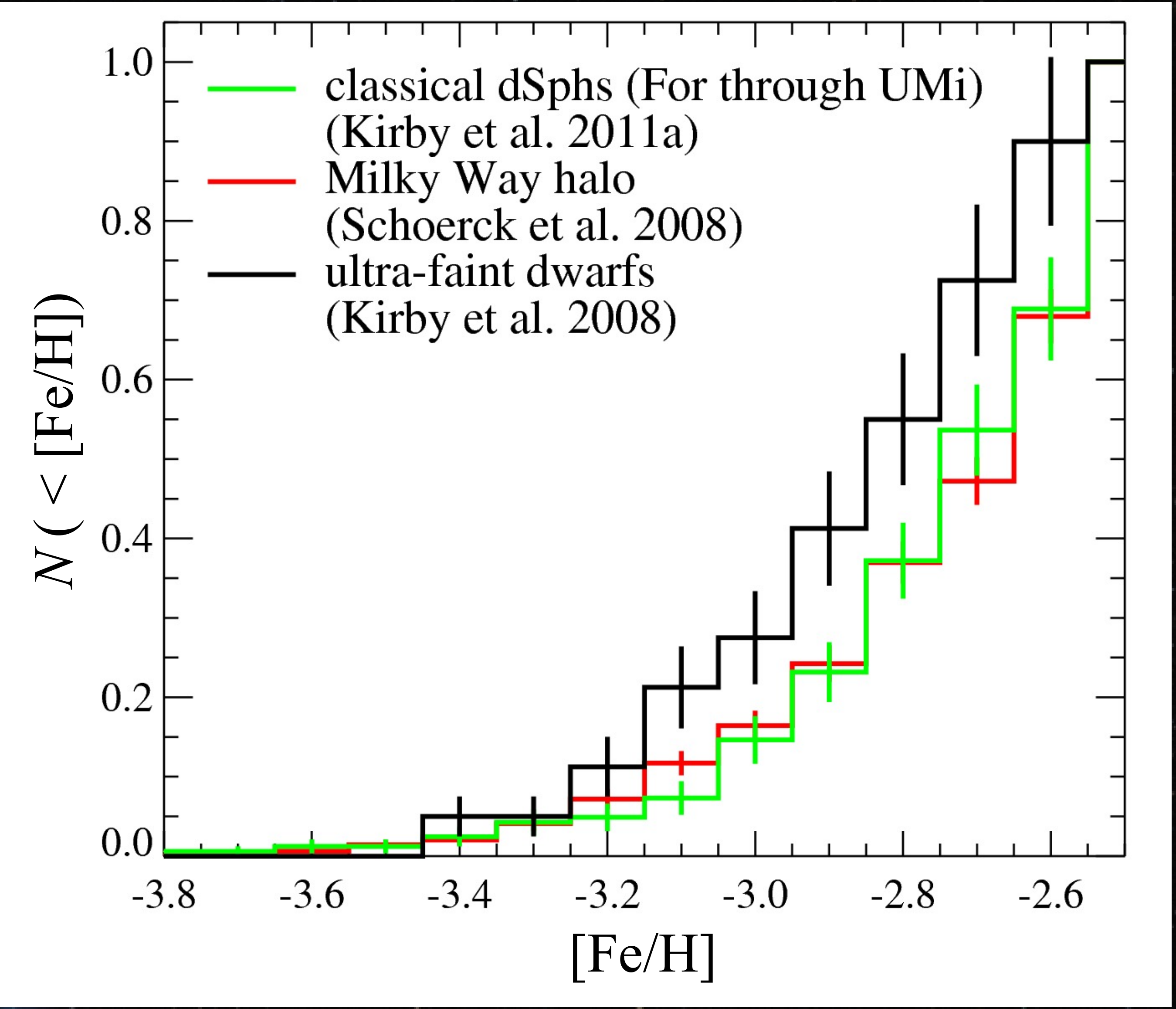
Schlaufman et al. 2011, ApJ, 734, 49

Dwarf galaxies seemed not to contain extremely metal-poor stars.



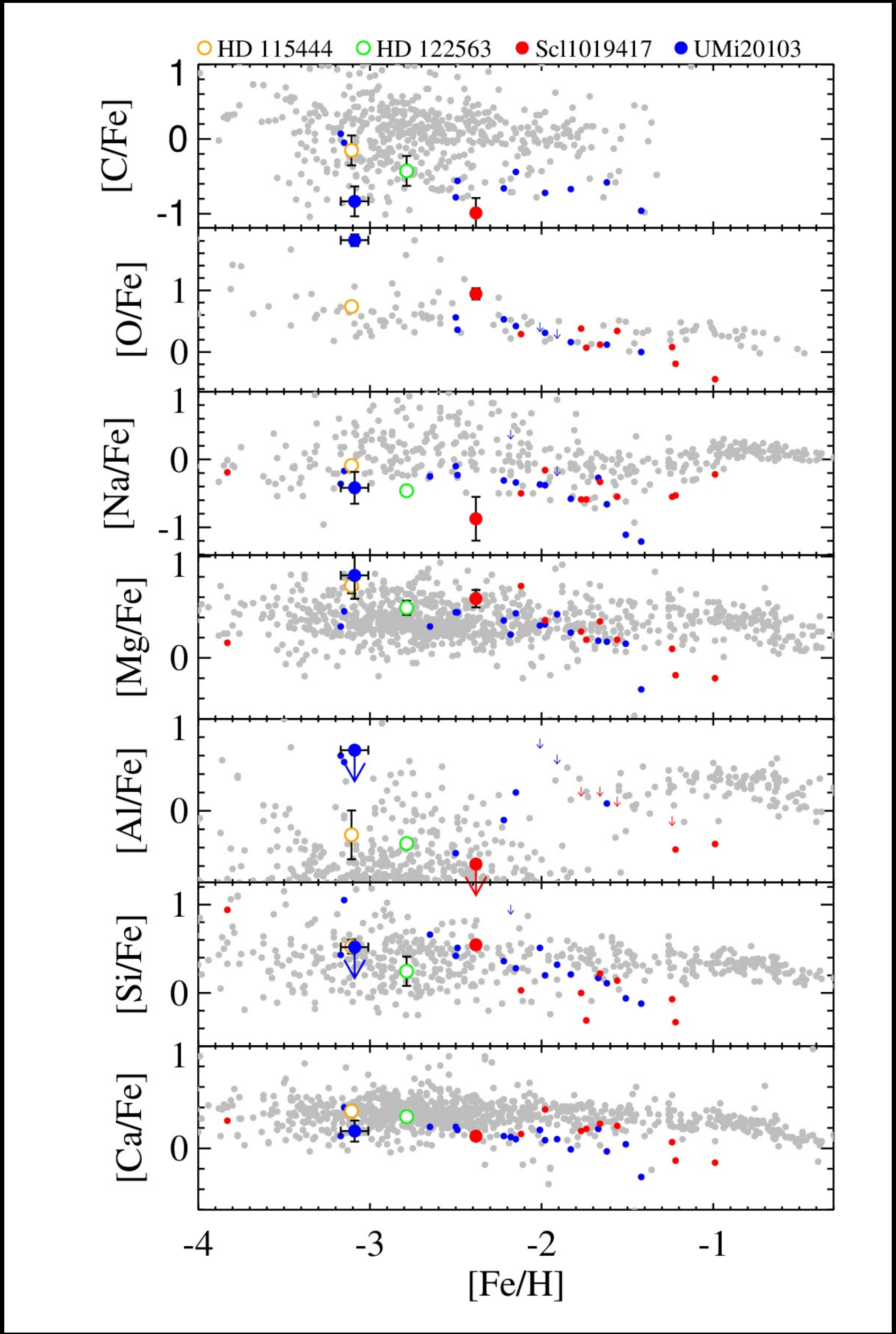
Helmi et al. 2006, 651, L121

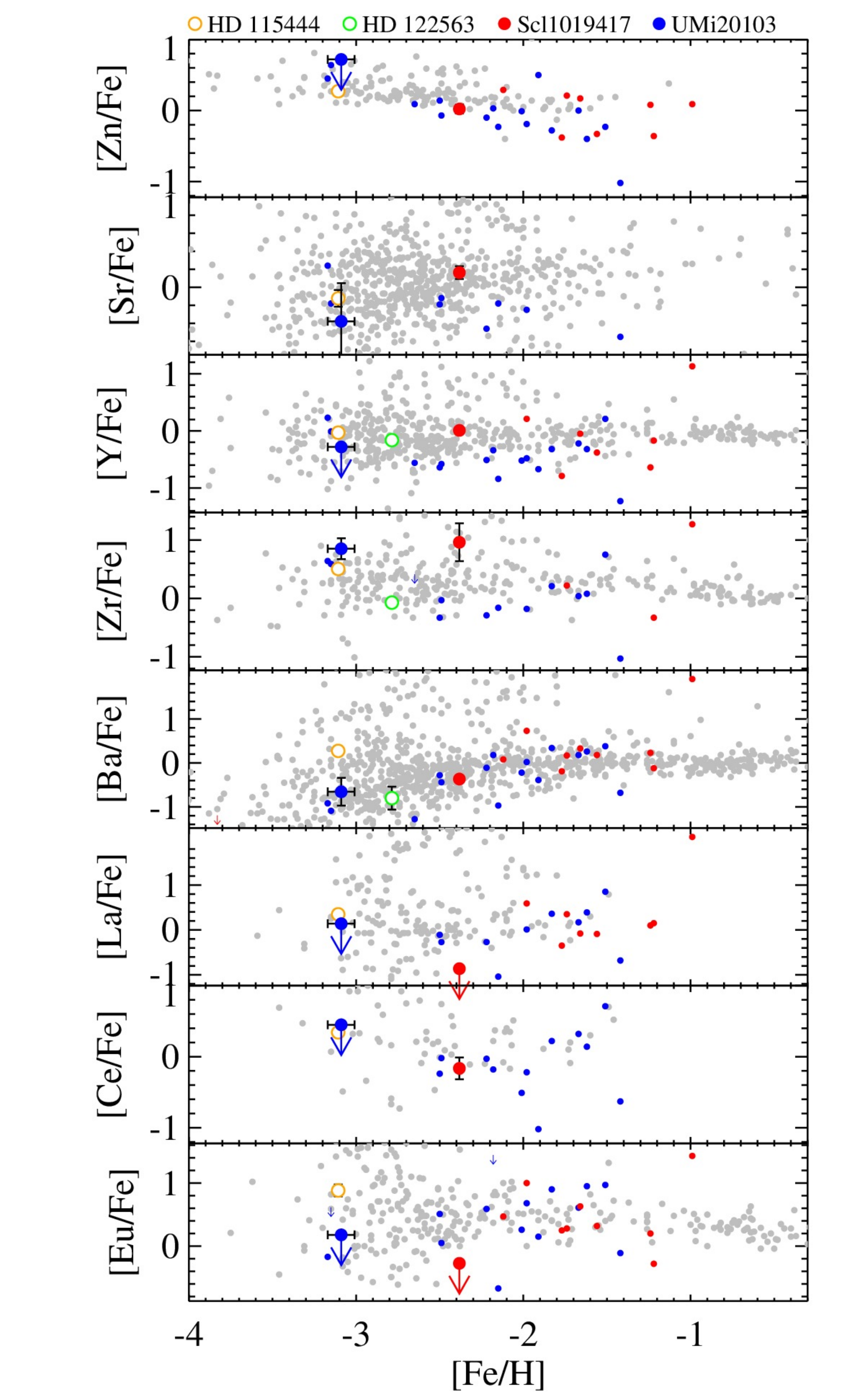
Dwarf galaxies *do* contain extremely metal-poor stars.



EK et al. 2008, ApJL, 685, L43
EK et al. 2011a, ApJ, 727, 78

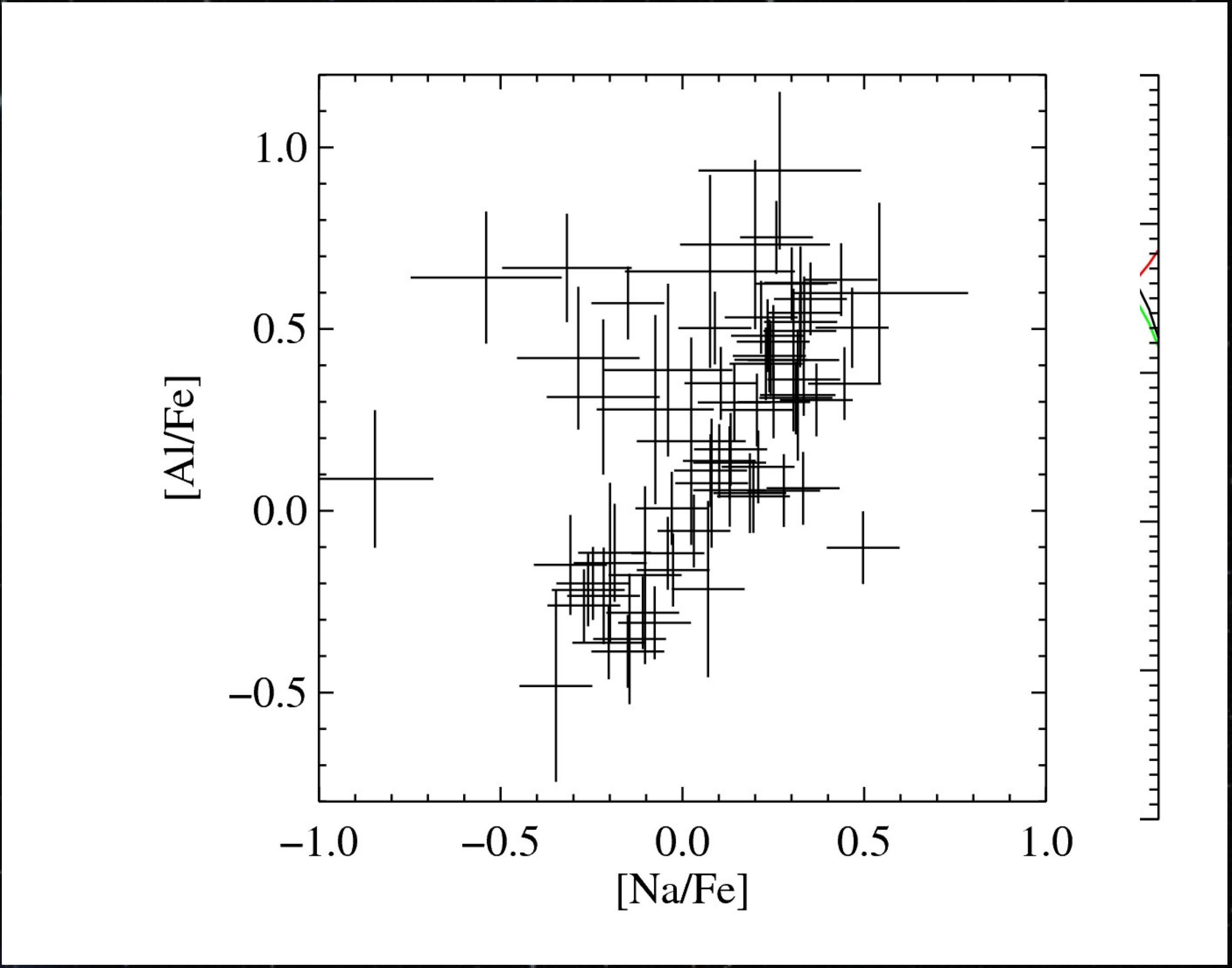
Even very metal-poor show halo-dSph discrepancies.





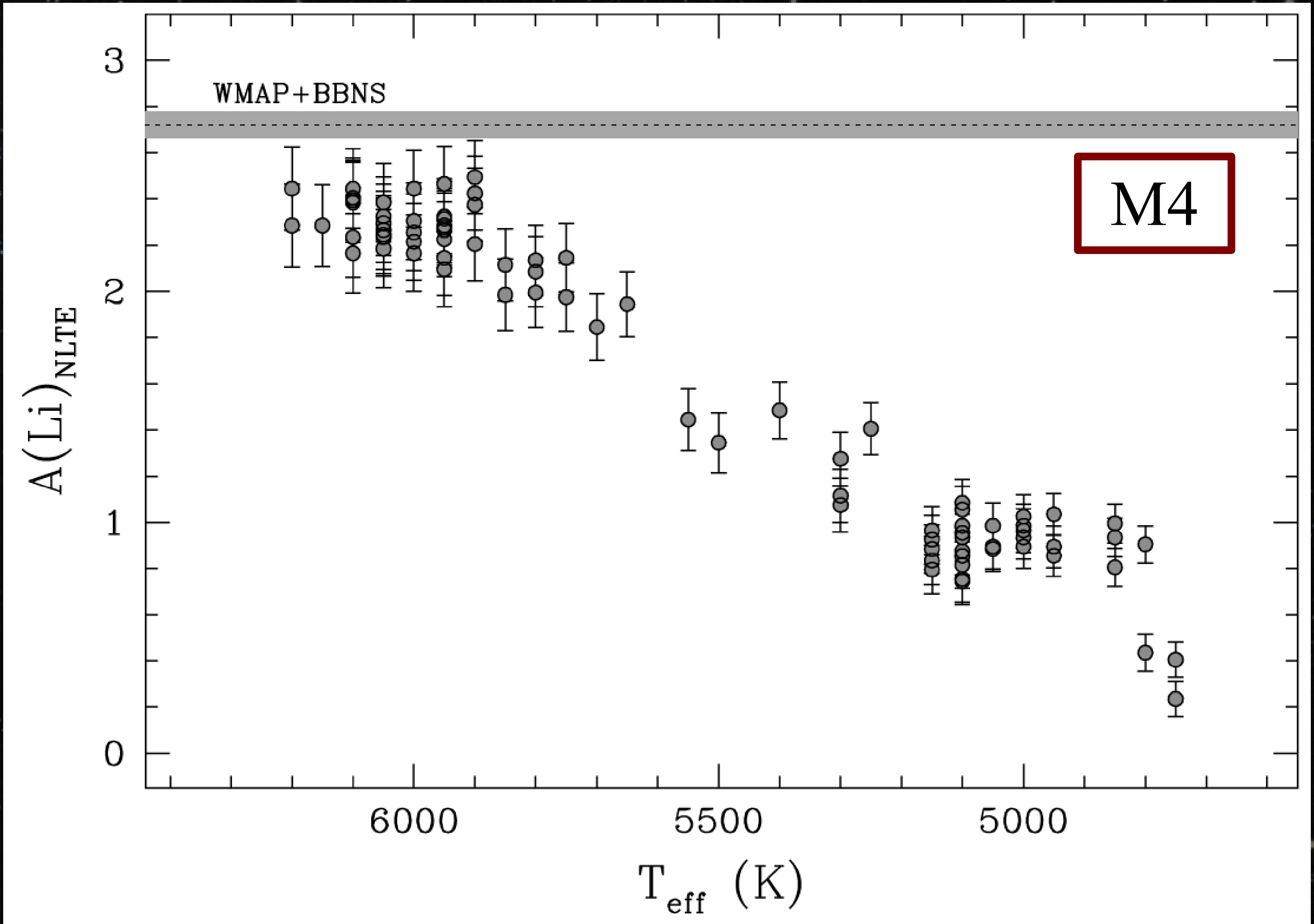
EK & Cohen, AJ, submitted

Other elements are also acessible to DEIMOS.



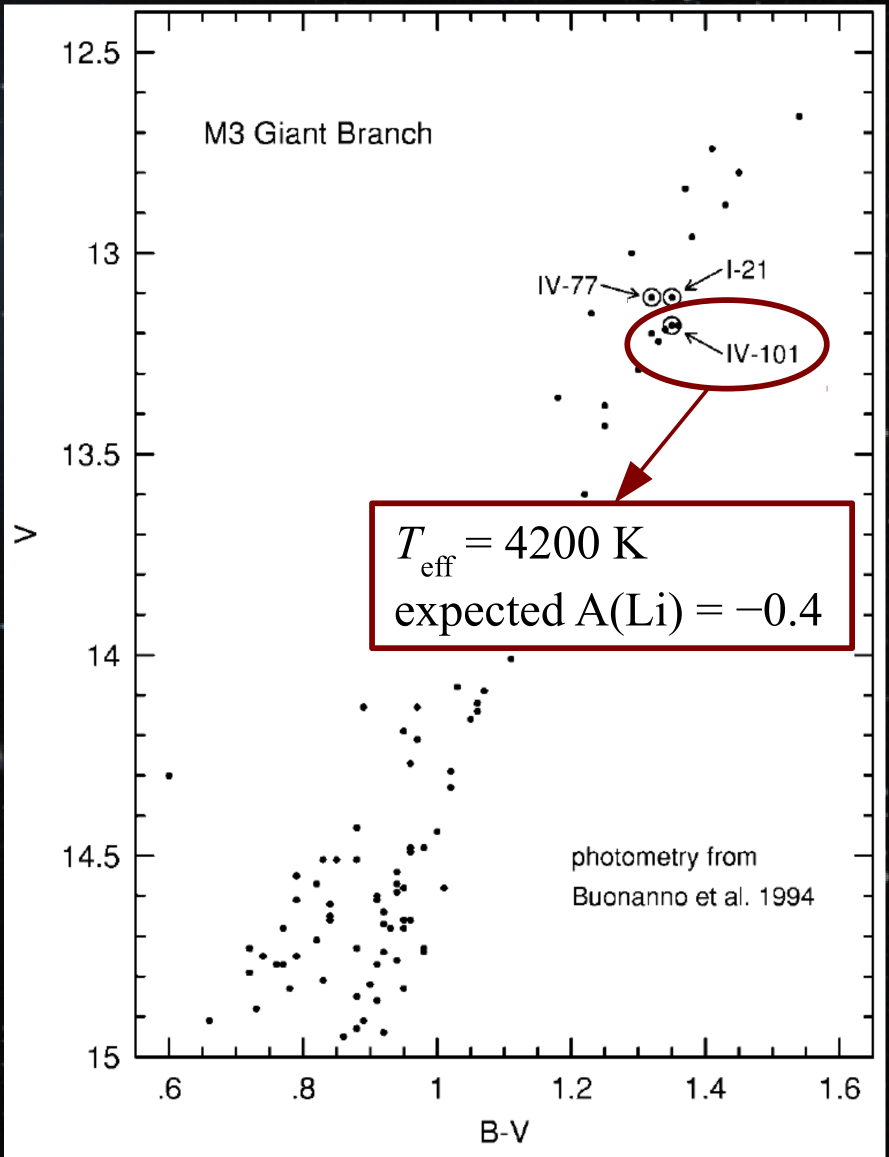
Keck PI: Bob Kraft

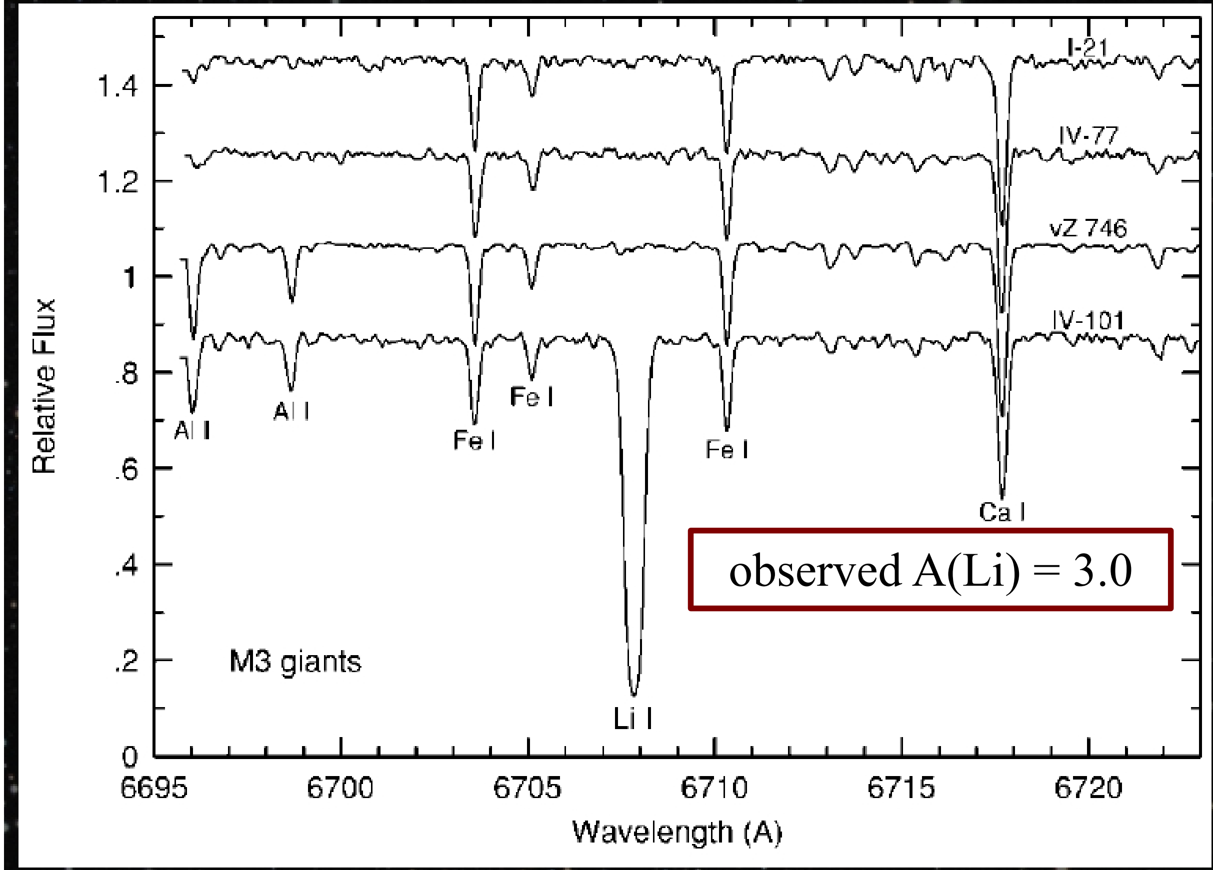
Lithium is depleted with increasing temperature in red giants.



Mucciarelli et al. 2011, MNRAS, 412, 81

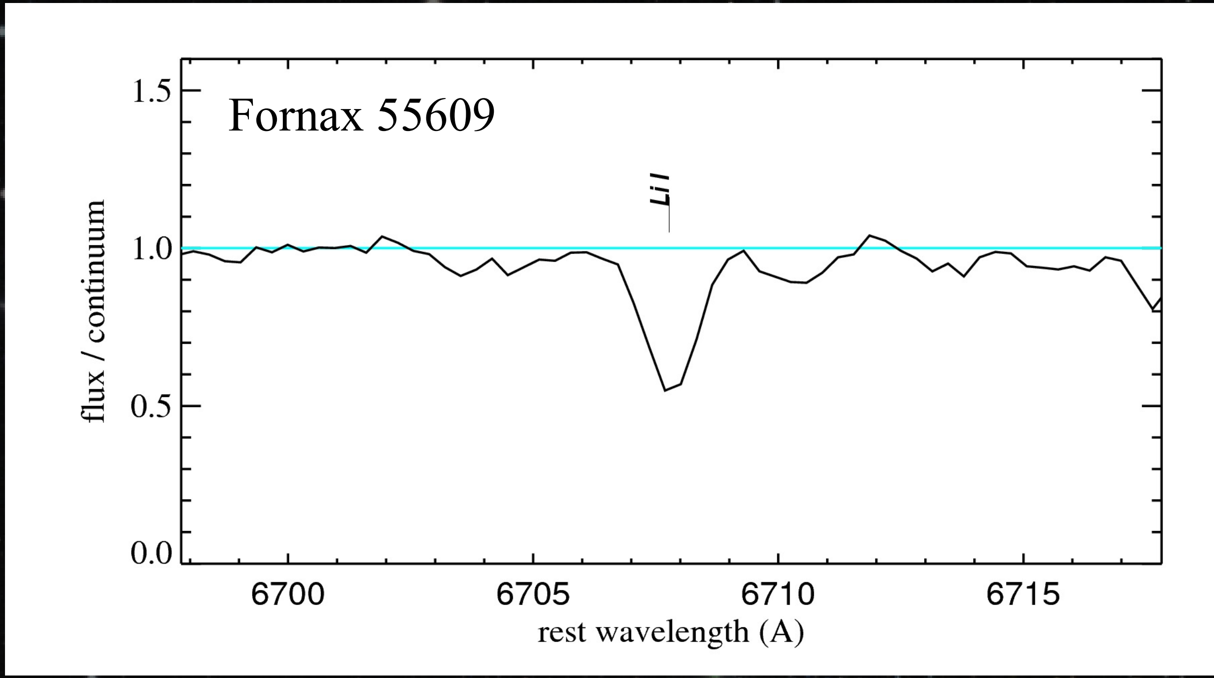
Sometimes Li is seen in red giants with no business in having Li.

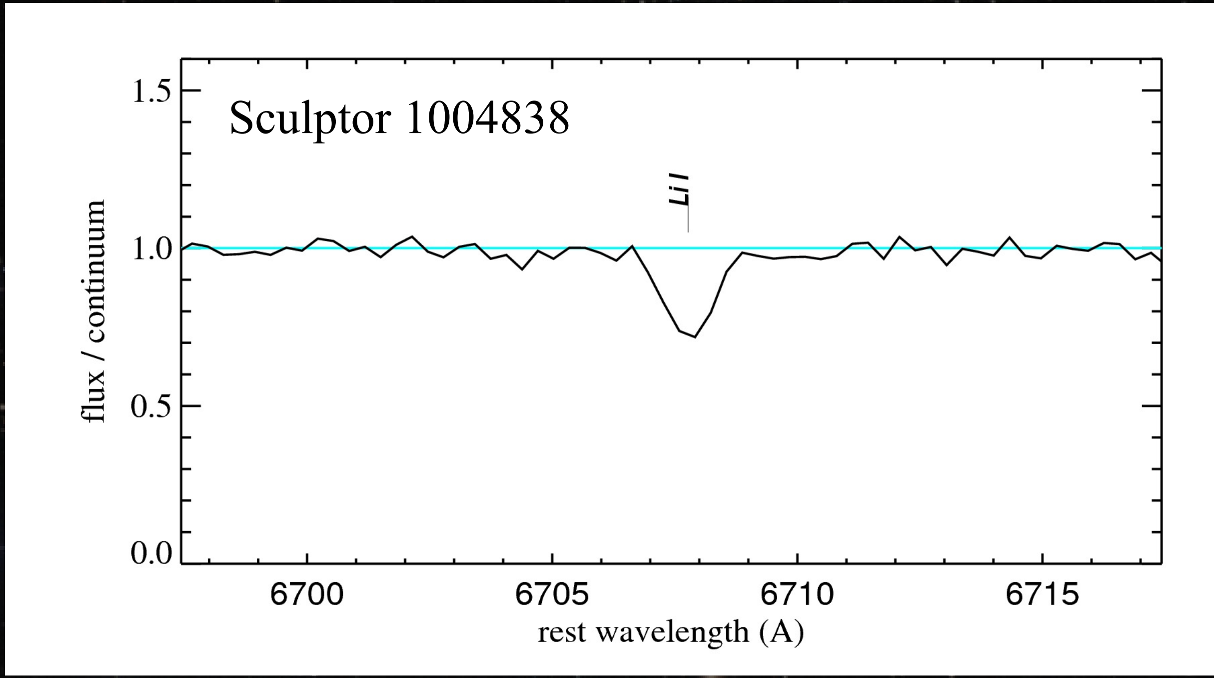




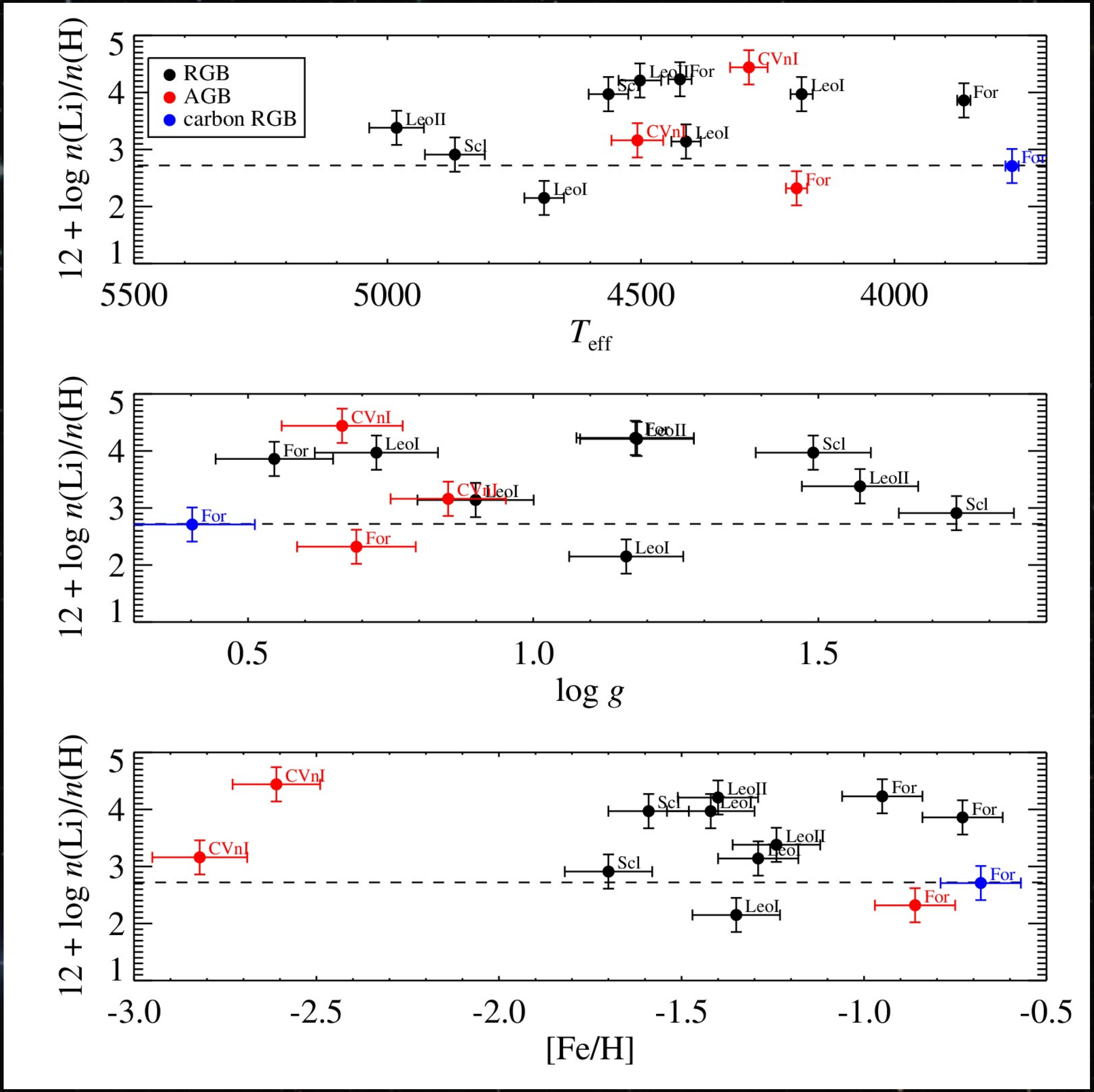
Kraft et al. 1999, ApJL, 518, L53

Lithium detected in 0.5% of dSph red giants.



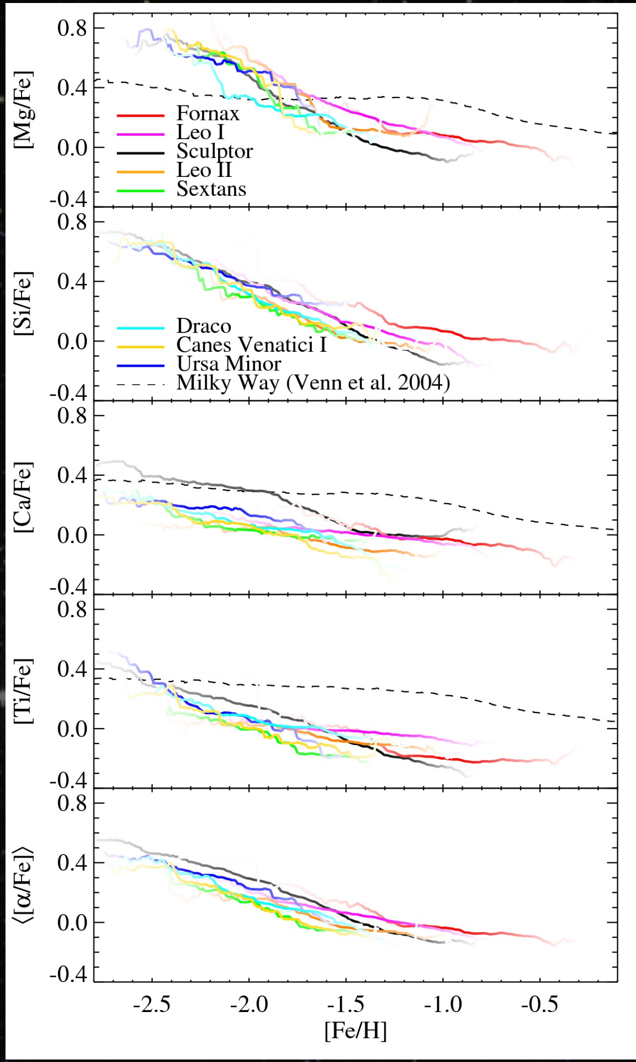


The giants show no correlation with evolutionary state.



Conclusions

- **Medium-resolution spectroscopy** is an efficient way to measure multi-element abundances in nearby galaxies.
- **Metallicity distributions** suggest that more luminous dSphs experienced more complex gas dynamics.
- **Element ratios** show that early star formation proceeded at the same rate in all dSphs.
- The **outer halo** could be composed of dSph predecessors.
- How does **a ton of lithium** get into the photosphere of evolved red giants?



Kirby et al. 2011b, ApJ, 727, 79