The Ultra-Faint Dwarf Galaxies

~~*Part 1: Kinematics*~~

Part 2: Abundances

Marla Geha

(Yale University)

Collaborators:

Josh Simon (Caltech)

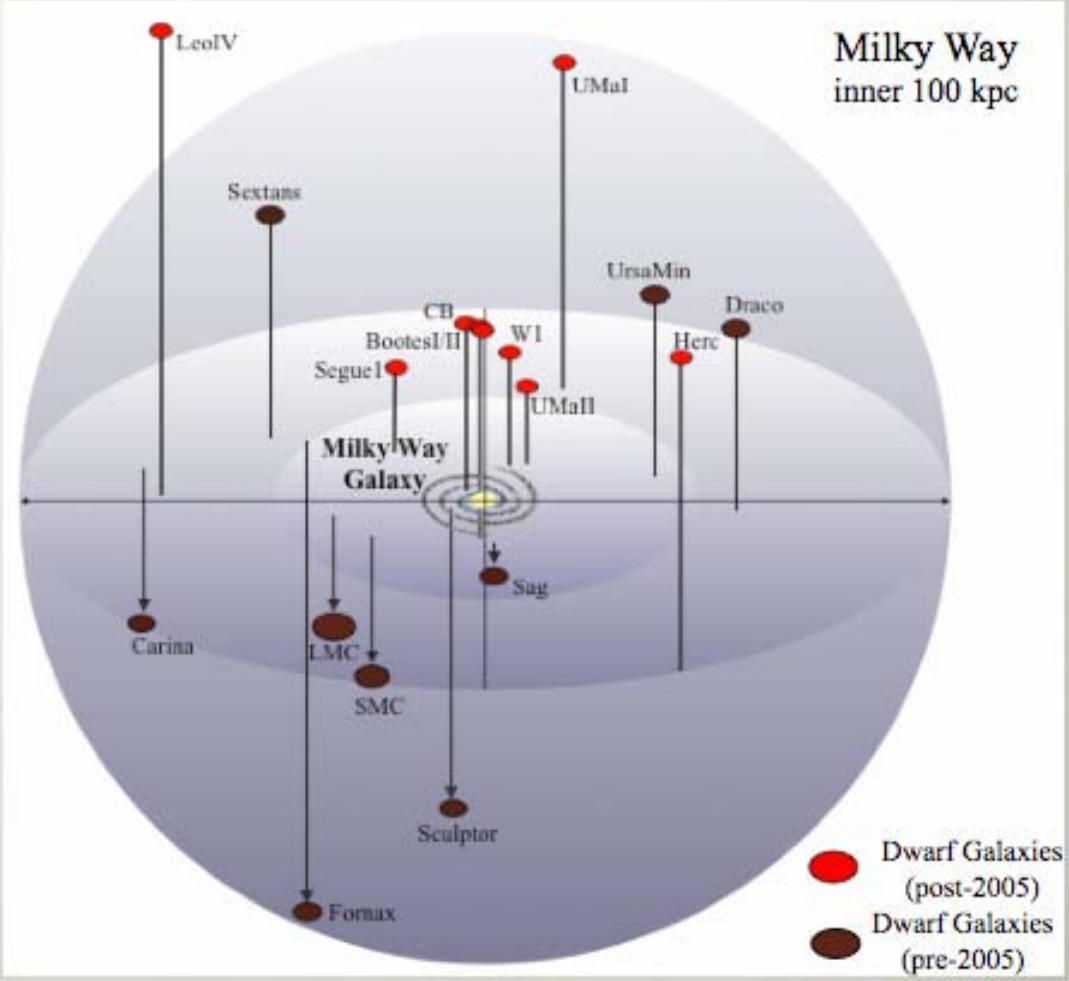
Beth Willman (CfA)

Evan Kirby (UCSC)

Anna Frebel (CfA)

~~Louie Strigari (Stanford)~~

~~James Bullock, Joe Wolf (UCI)~~

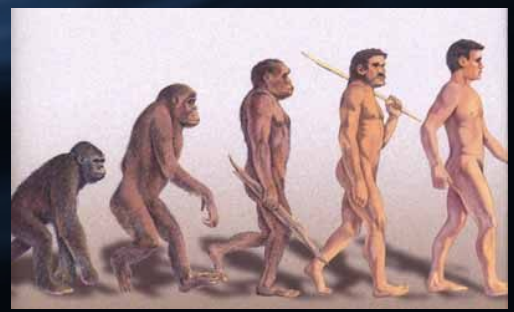


Chemical Abundances in the Least Evolved Dwarf Galaxies

Josh Simon
Caltech

Collaborators:

Marla Geha (Yale)
Evan Kirby (Santa Cruz)
Anna Frebel (Texas)
Beth Willman (Haverford)



Outline

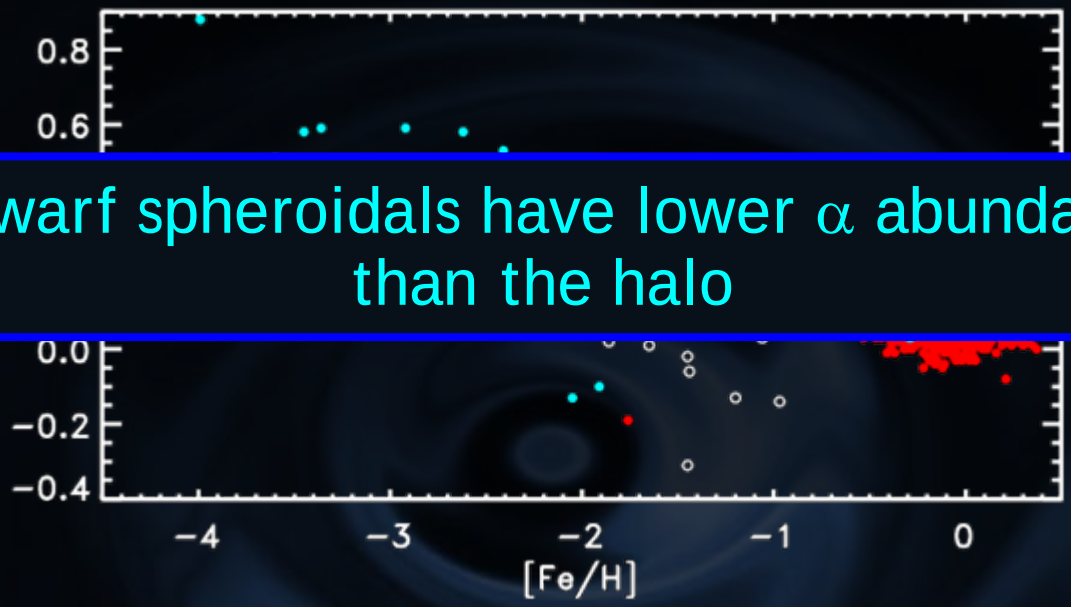
I. Motivation and background

II. Pros and cons of abundance measurement techniques

III. Metallicities in the ultra-faint dwarfs

IV. Is the halo chemically consistent with dwarf galaxies?

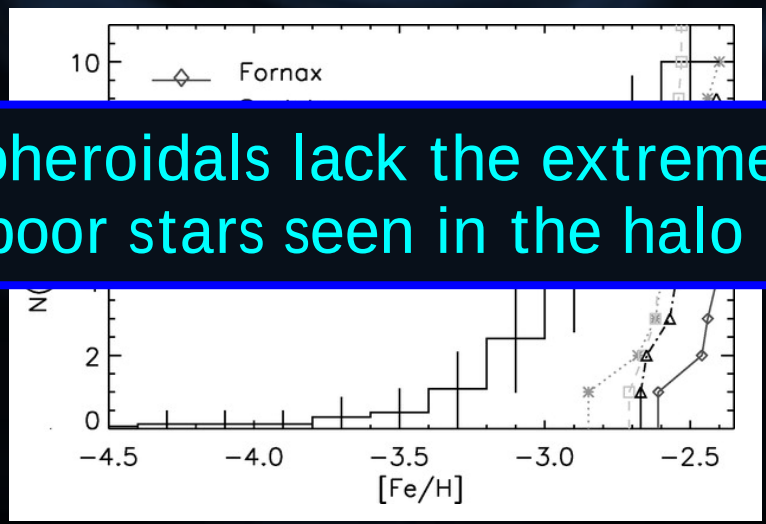
Where Did Halo Stars Come From?



• MW disk
alo

1) Dwarf spheroidals have lower α abundances than the halo

Venn et al. (2004)

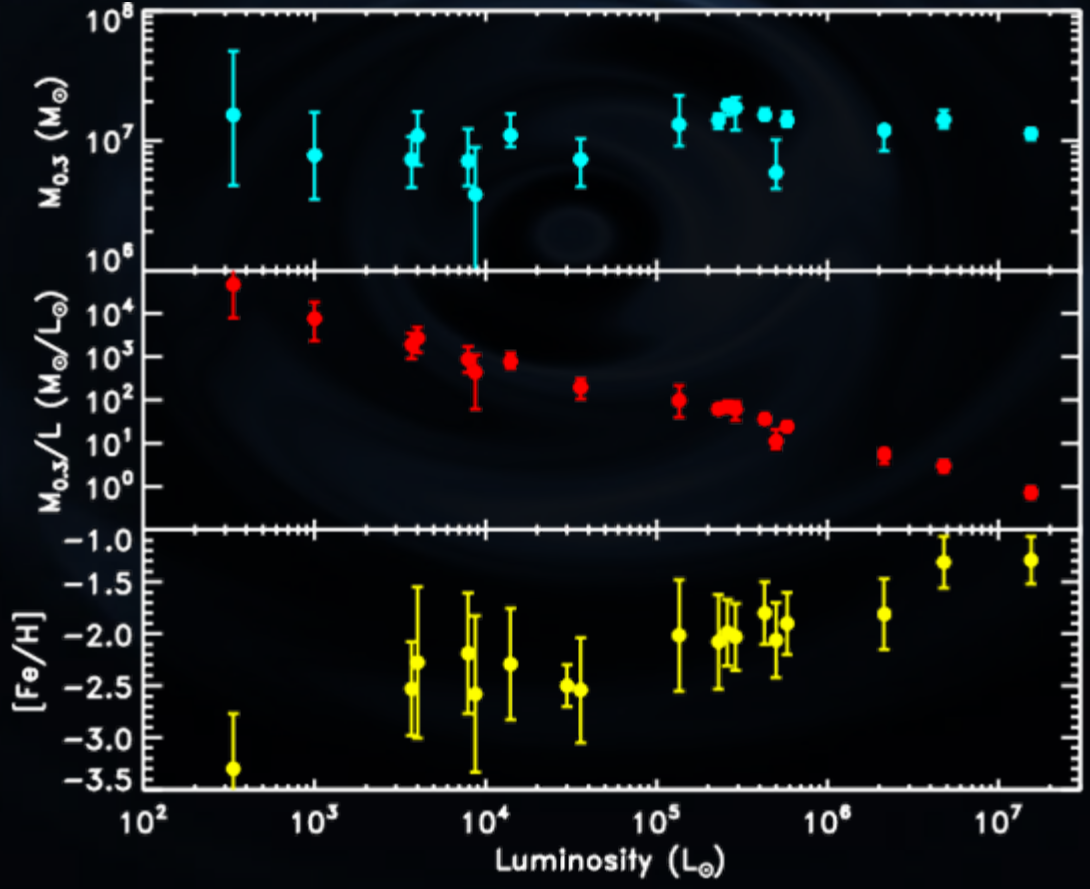


2) Dwarf spheroidals lack the extremely metal-poor stars seen in the halo

Helmi et al. (2006)

Why the Ultra-Faint Dwarfs?

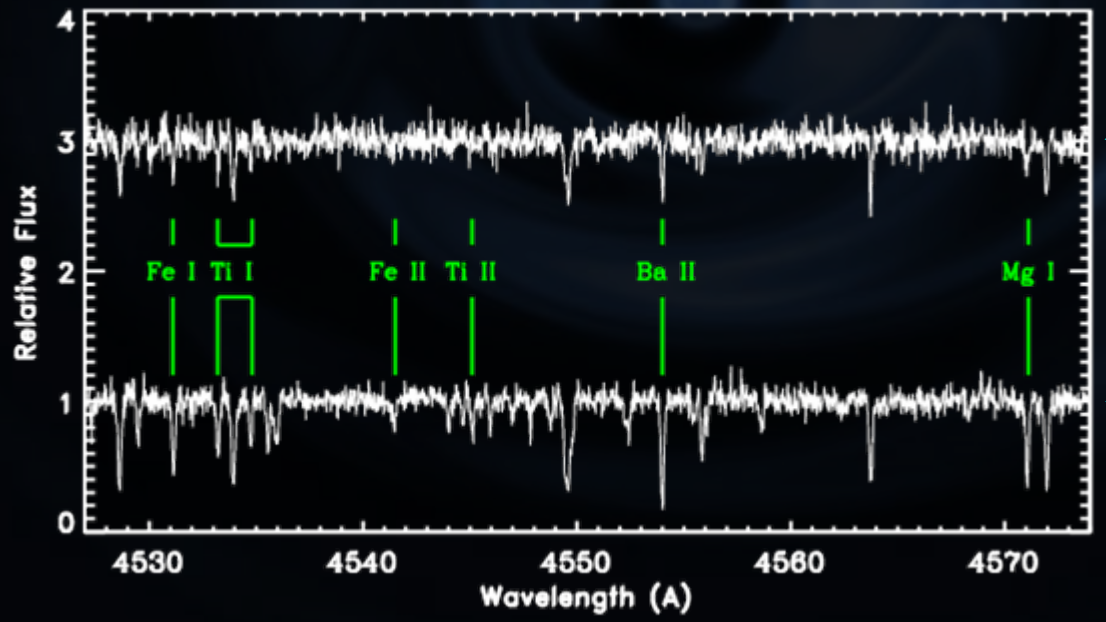
- They are where the action is!



Geha et al. (2008)

Techniques for Measuring Abundances

- **High-resolution spectroscopy**
  - Accurate abundances for many elements
  - Requires bright targets + long integrations



[Fe/H] = -3.24

V = 17.4, t_{exp} = 3 hr

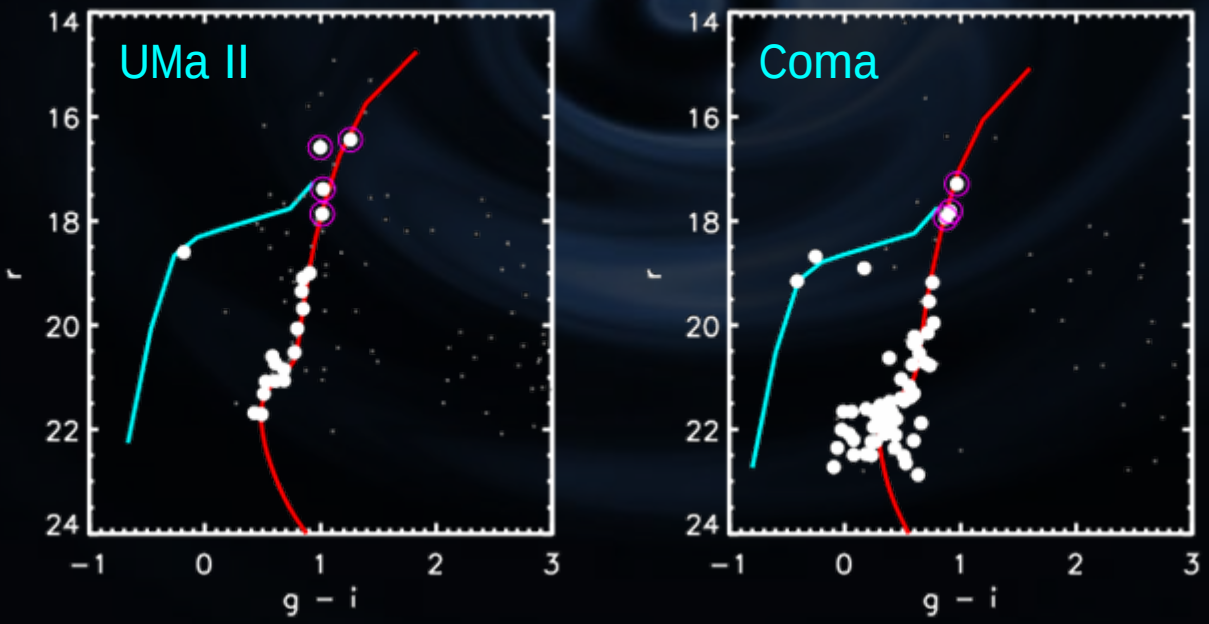
[Fe/H] = -2.34

V = 16.5, t_{exp} = 1 hr

Frebel et al., in prep.

Techniques for Measuring Abundances

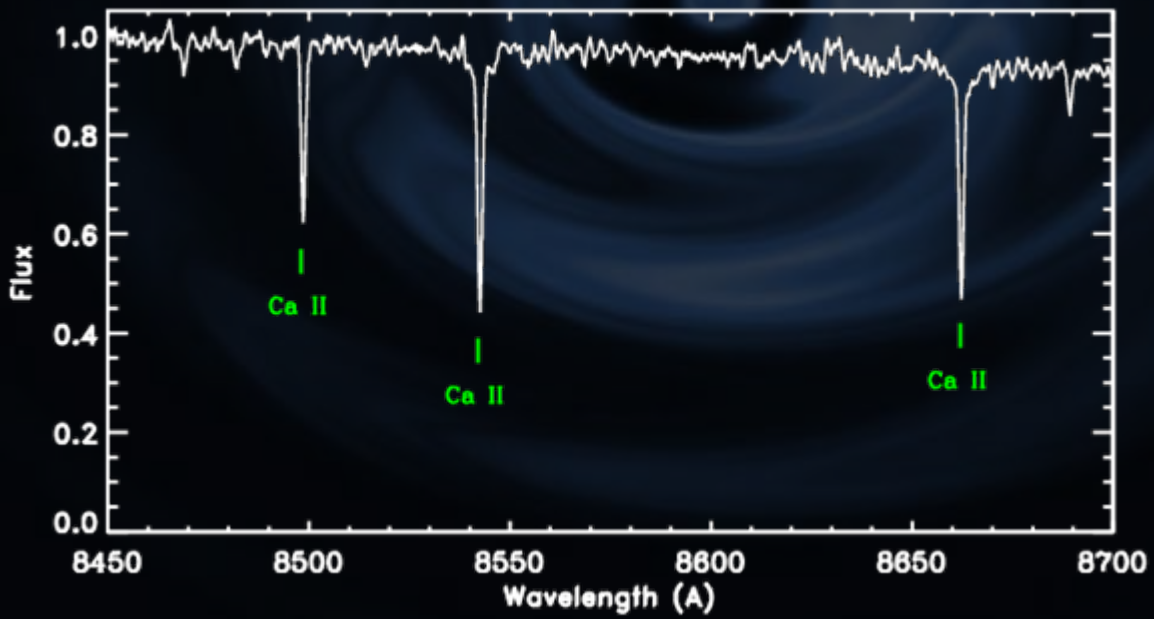
- **High-resolution spectroscopy**
  - Accurate abundances for many elements
  - Requires bright targets + long integrations



Frebel et al., in prep.

Techniques for Measuring Abundances

- **Ca triplet**
  - Requires only low/medium resolution spectroscopy
  - Can be used for much fainter stars!



e.g., Rutledge et al. (1997)

How Does the CaT Work?

- Empirical linear relationship between EW of the three lines and [Fe/H]:

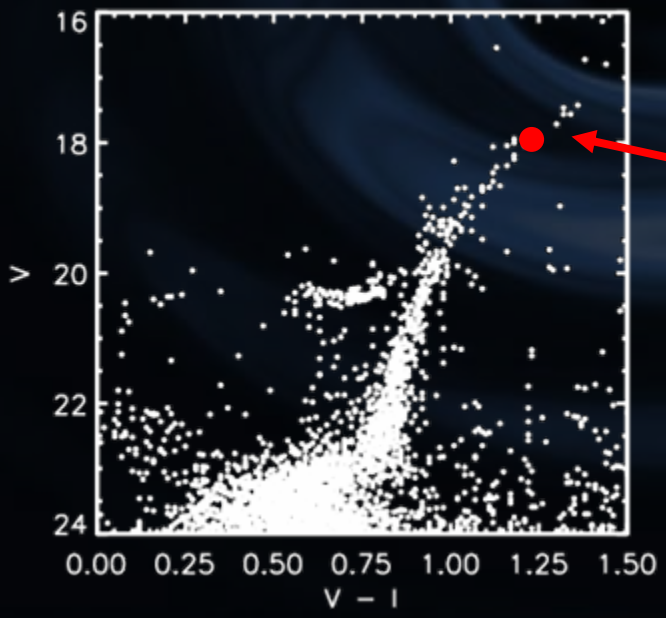
$$[Fe/H]_{CaT} = -2.66 + 0.42[\Sigma EW_{CaT} + 0.64(V - V_{HB})]$$

Rutledge et al. (1997)

How Does the CaT Work?

- Empirical linear relationship between EW of the three lines and [Fe/H]:

$$[Fe/H]_{CaT} = -2.66 + 0.42[\Sigma EW_{CaT} + 0.64(V - V_{HB})]$$



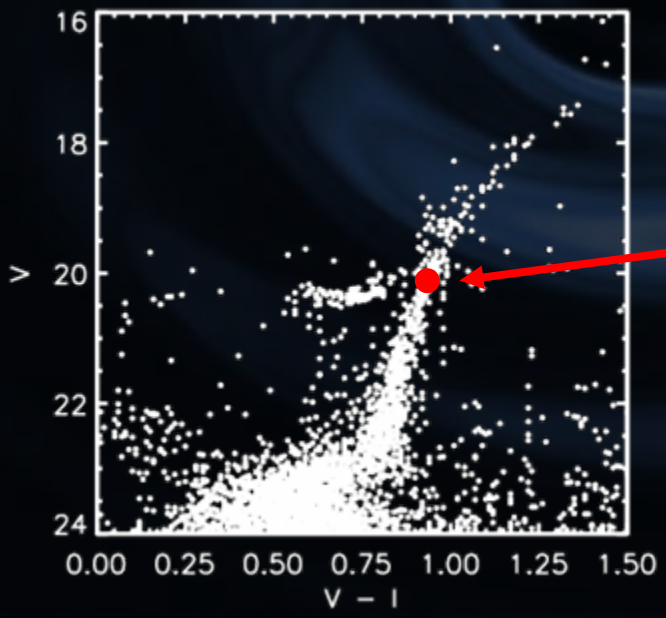
Can measure [Fe/H] down to -3.20

Rutledge et al. (1997)

How Does the CaT Work?

- Empirical linear relationship between EW of the three lines and [Fe/H]:

$$[Fe/H]_{CaT} = -2.66 + 0.42[\Sigma EW_{CaT} + 0.64(V - V_{HB})]$$



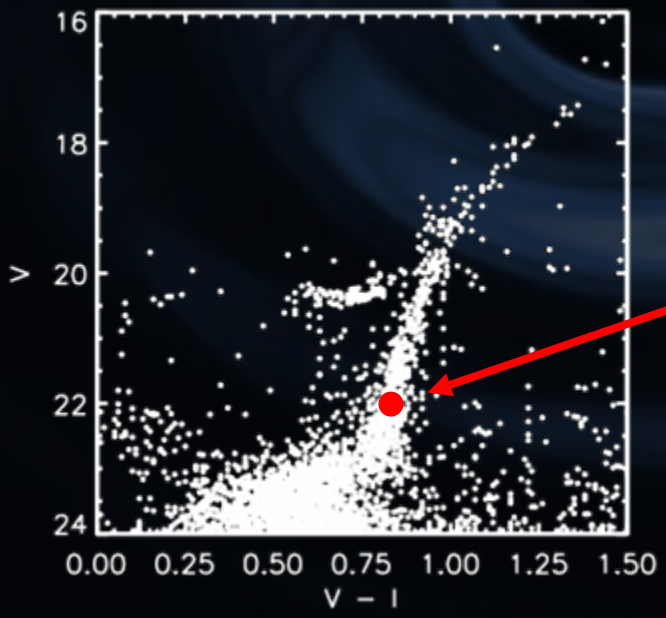
Can measure [Fe/H] down to -2.66

Rutledge et al. (1997)

How Does the CaT Work?

- Empirical linear relationship between EW of the three lines and [Fe/H]:

$$[Fe/H]_{CaT} = -2.66 + 0.42[\Sigma EW_{CaT} + 0.64(V - V_{HB})]$$

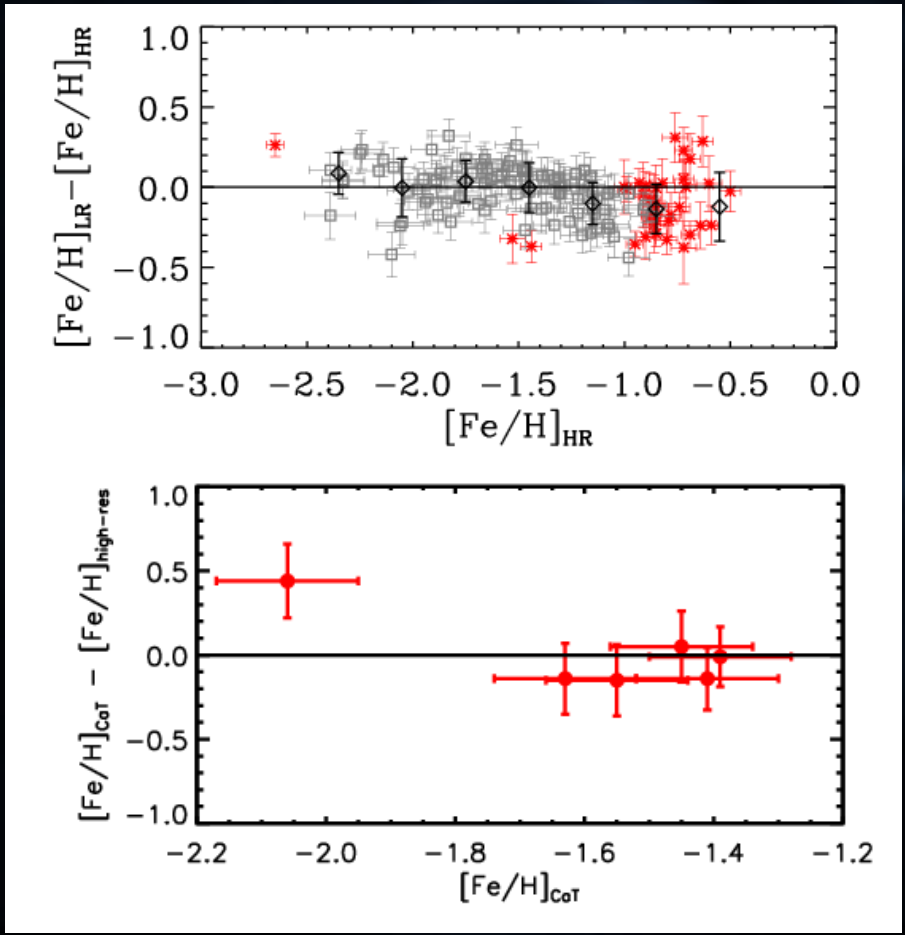


Can measure [Fe/H] down to -2.12

Rutledge et al. (1997)

How Does the CaT Work?

- Does it fail at low metallicities?

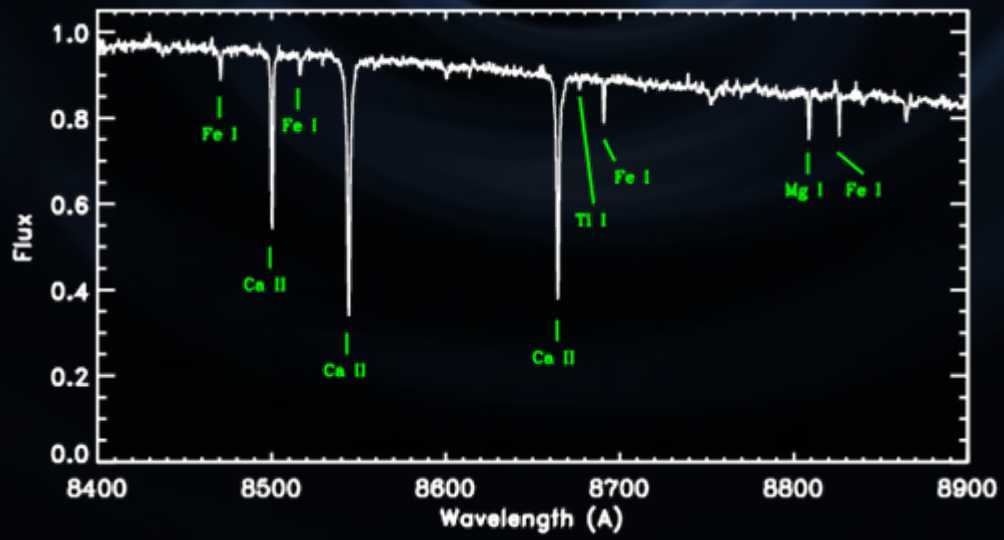


Battaglia et al. (2008)

Koch et al. (2008)

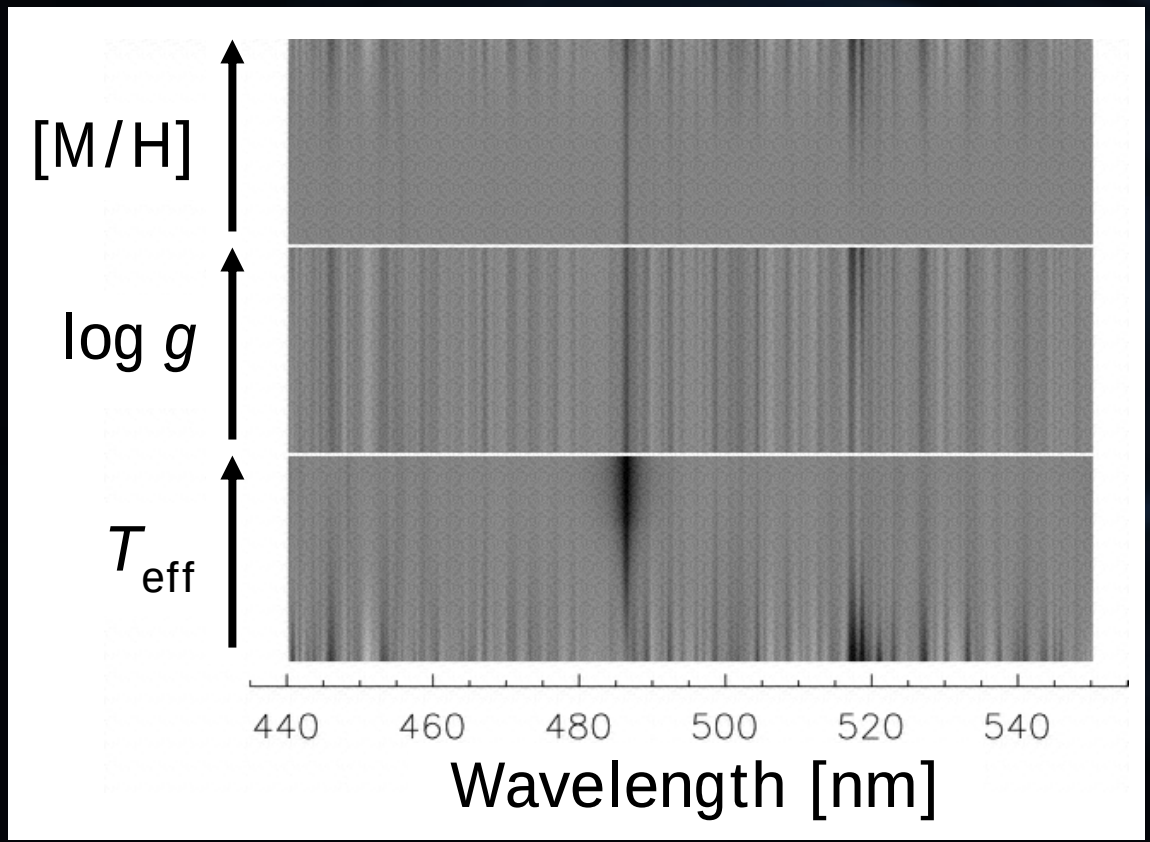
Techniques for Measuring Abundances

- Spectral synthesis with medium resolution spectroscopy
  - Lots of lines other than the CaT in R=6000 spectra



Kirby et al. (2008a)

Techniques for Measuring Abundances



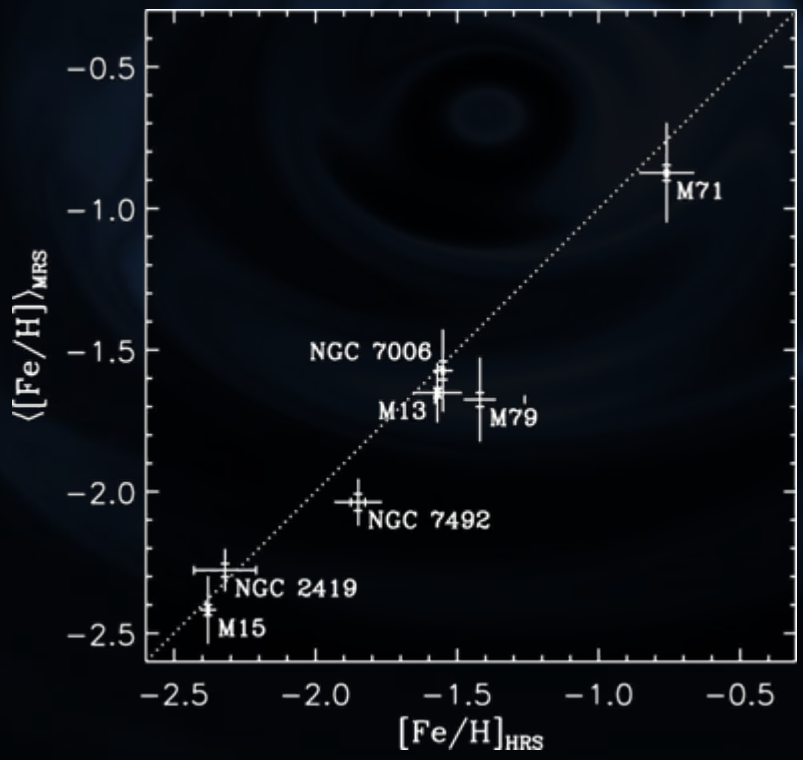
Allende Prieto et al. (2006)

- Construct grid of synthetic spectra over [Fe/H], [α/Fe], T_{eff}, log g
- Determine T_{eff} and log g from isochrones
- Find best-fitting spectrum!

Kirby et al. (2008a)

Techniques for Measuring Abundances

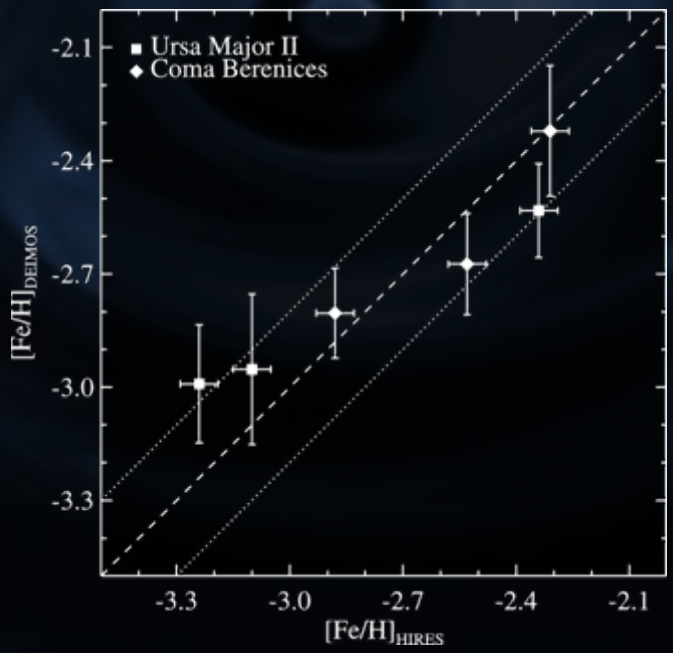
- Spectral synthesis with medium resolution spectroscopy



Kirby et al. (2008a)

Metallicities in the SDSS Dwarfs

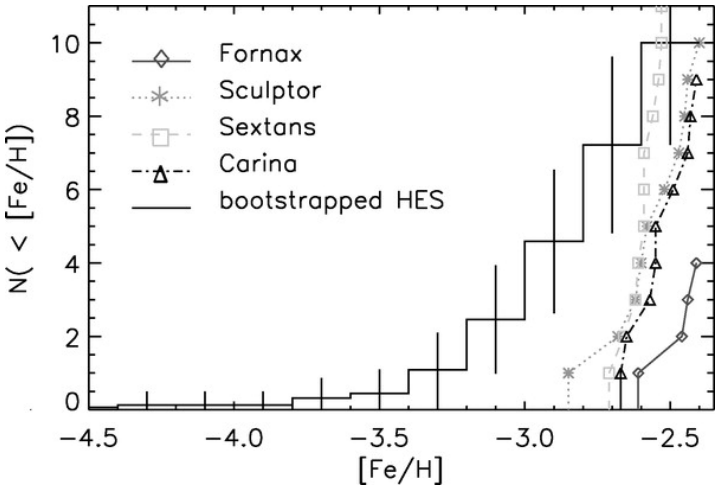
- Keck/DEIMOS spectra of 298 stars across 8 dwarfs
  (CVn I, CVn II, Coma Berenices, Hercules, Leo IV, Leo T, UMa I, UMa II)
  - R = 6000, S/N > 10 A^{-1}, wavelength coverage from 6500-9000 A



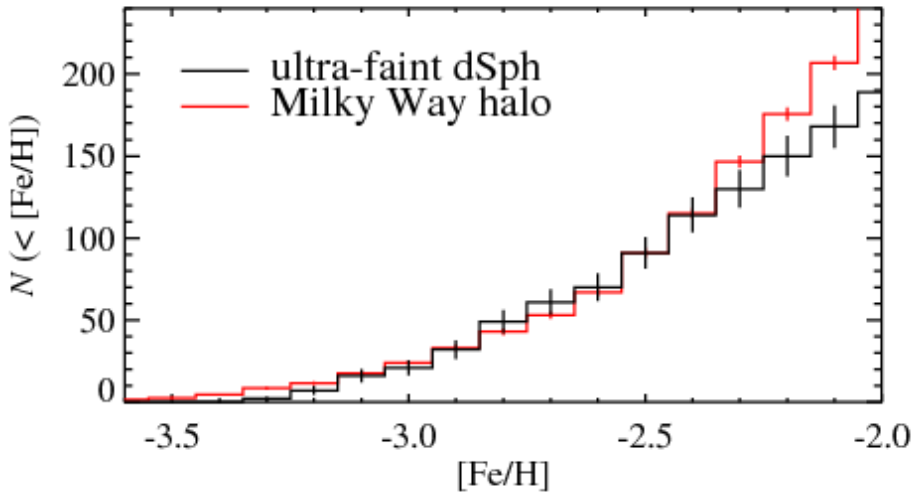
Kirby et al. (2008b)

Metallicities in the SDSS Dwarfs

- 15 out of 298 stars in the ultra-faint dwarfs have [Fe/H] < -3.0
- Ultra-faint dwarf MDF similar to halo . . .



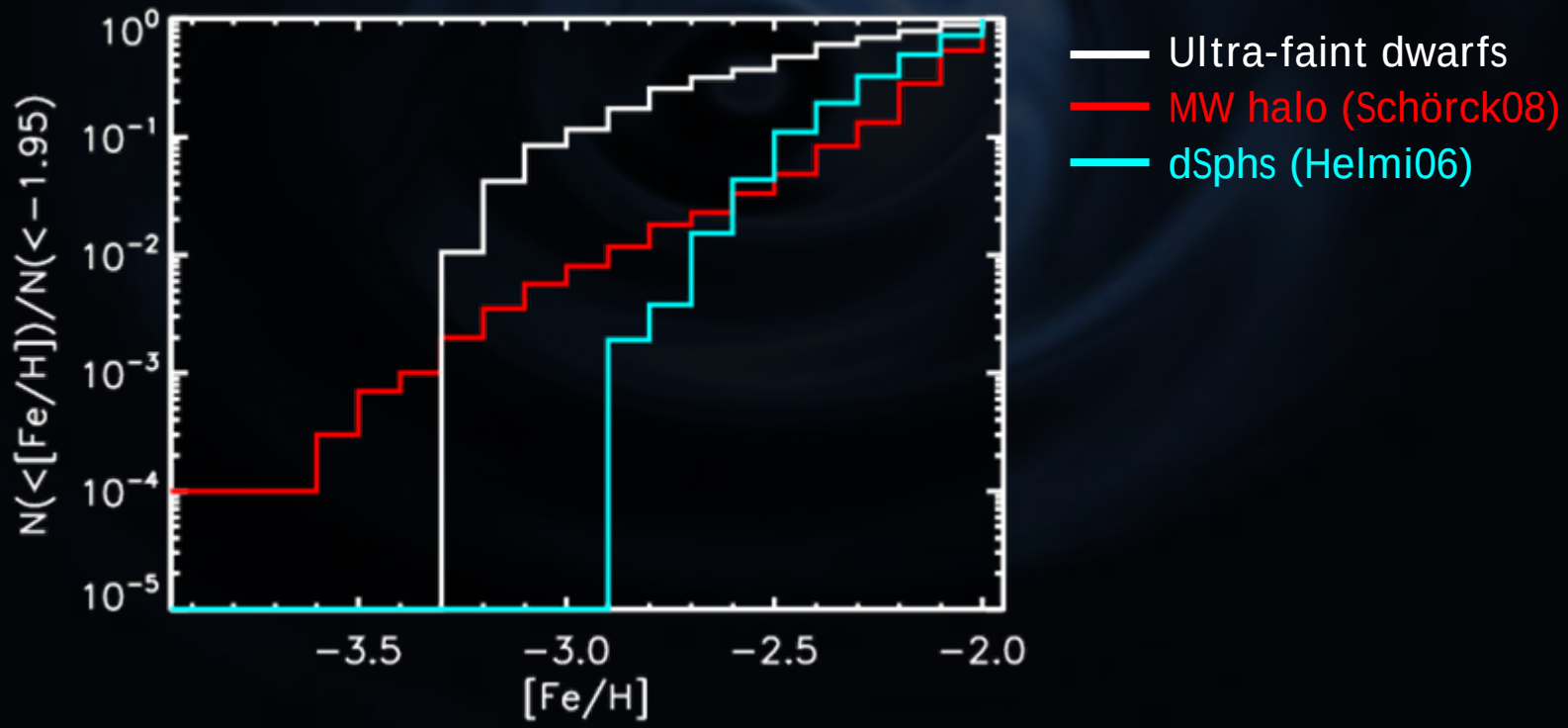
Helmi et al. (2006)



Kirby et al. (2008b)

Where Did the Halo Come From?

- Low-luminosity dwarfs appear to be more metal-poor than the halo

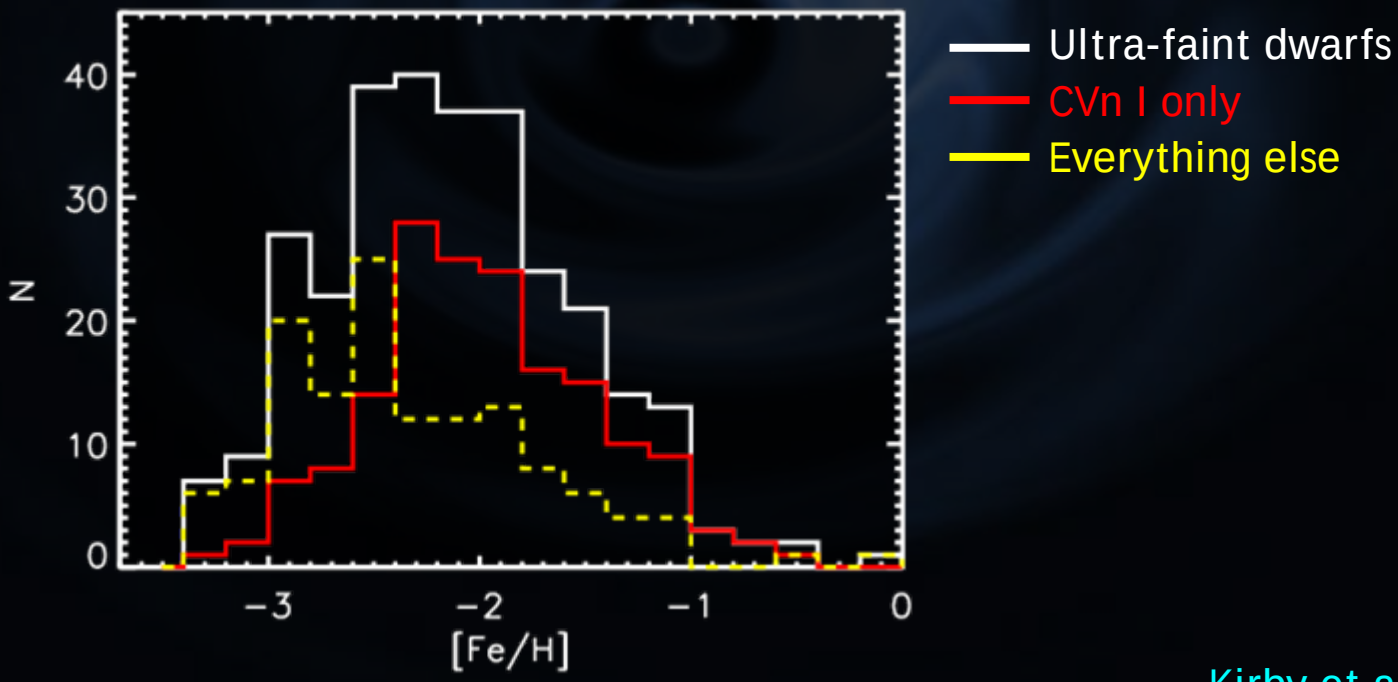


Where Did the Halo Come From?

- Presence of extremely metal-poor stars is not unique to the ultra-faint dwarfs:
  - 2 stars in Leo I at [Fe/H] < -3.0 (Kirby et al., in prep)
  - 1 star in Draco at [Fe/H] = -3.06, 2 stars in UMi at [Fe/H] ~ -3.1 (Cohen & Huang, in prep)
  - Possibly one star at [Fe/H] < -3.0 in Sculptor?

Metallicity-Luminosity Relation

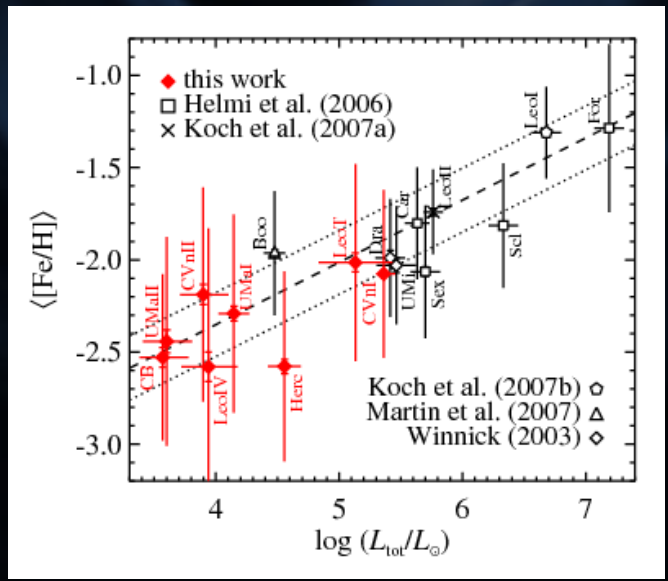
- Mean metallicity is correlated with luminosity



Kirby et al. (2008b)

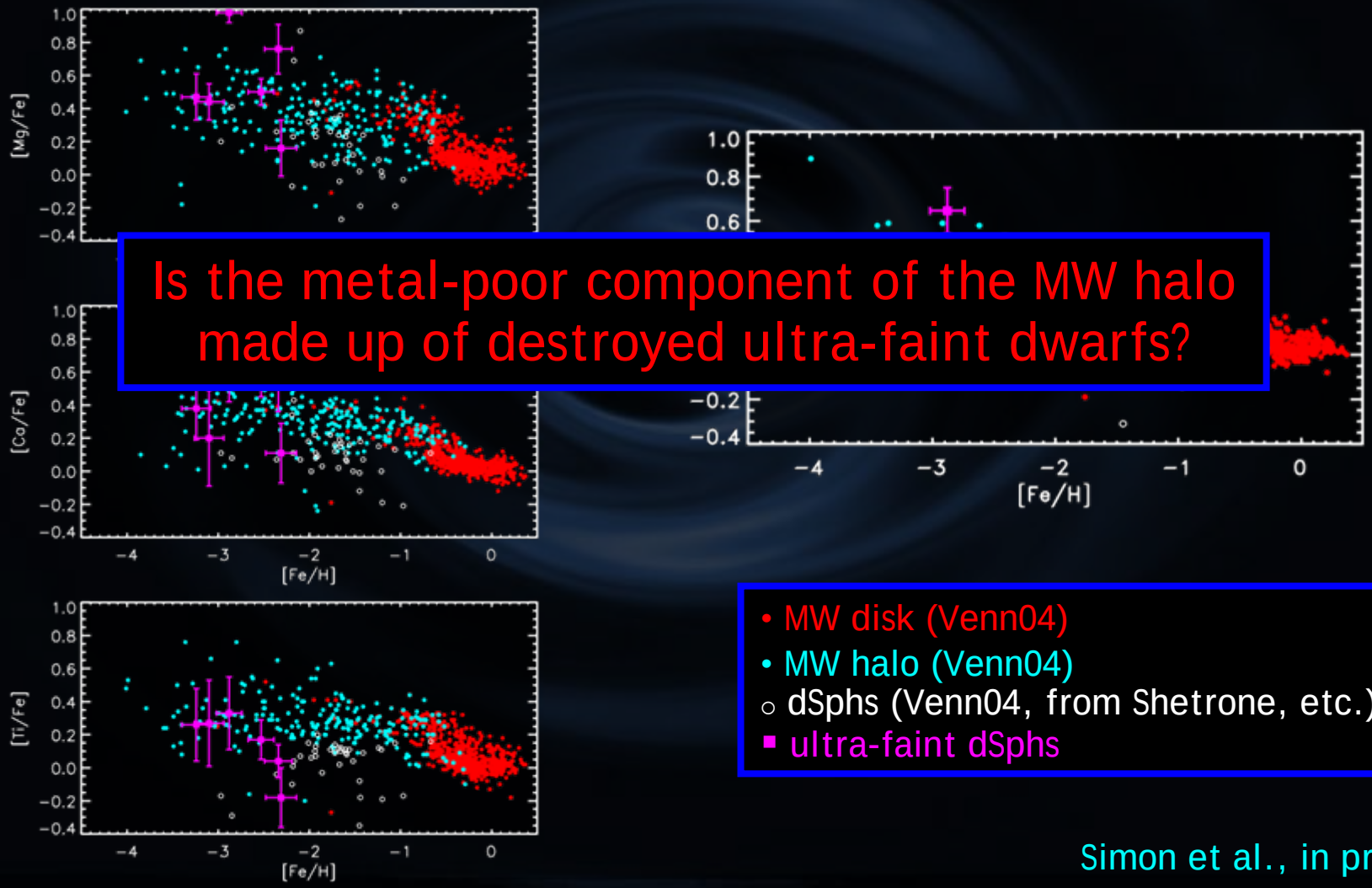
Metallicities in the SDSS Dwarfs

- **Metallicity-luminosity relation holds over 4 orders of magnitude in L**
- What does this say about the formation of ultra-faint dwarfs?



Kirby et al. (2008b)

Metallicities in the SDSS Dwarfs

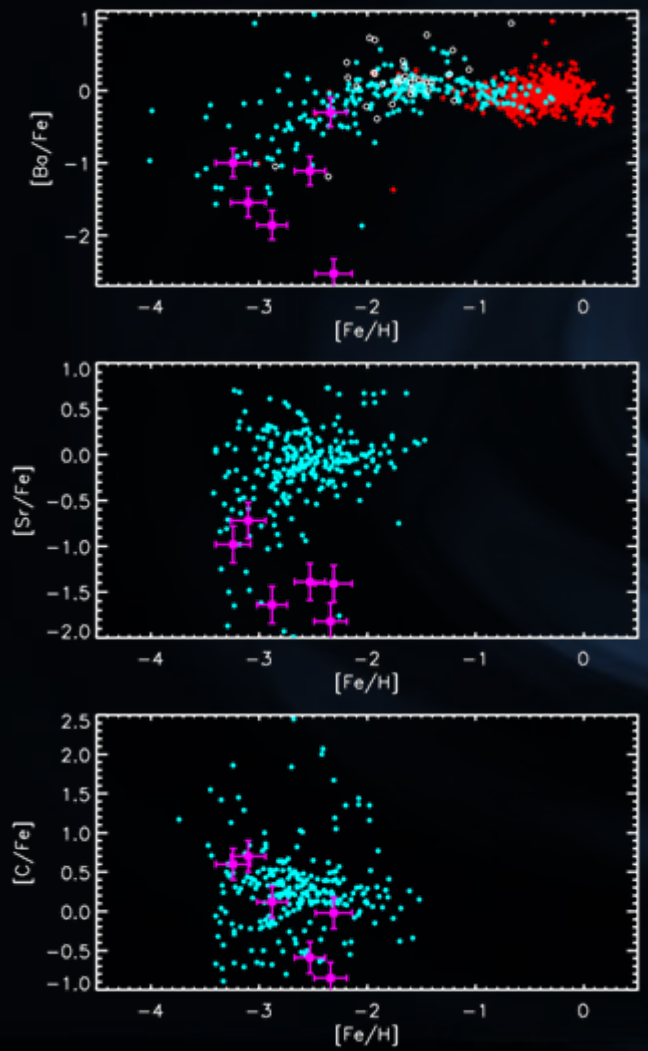


Is the metal-poor component of the MW halo made up of destroyed ultra-faint dwarfs?

- MW disk (Venn04)
- MW halo (Venn04)
- ○ dSphs (Venn04, from Shetrone, etc.)
- ▪ ultra-faint dSphs

Simon et al., in prep.

Metallicities in the SDSS Dwarfs



- Low abundances of neutron-capture species
- Large scatter within individual galaxies

(≠ age spread)

- MW disk (Venn04)
- MW halo (Venn04/Barklem05)
- dSphs (Venn04, from Shetrone, etc.)
- ultra-faint dSphs

Frebel et al., in prep.

Conclusions

- Complementary techniques for measuring abundances in Milky Way satellites
  - CaT may be biased at very low metallicities
  - Kirby et al. spectral synthesis method gives abundances independent of the CaT
- Ultra-faint dwarfs overturn some puzzles
  - They do contain stars with [Fe/H] < -3.0
  - (Ultra-faint) dwarf spheroidals are *more* metal-poor than unbiased HES halo sample
  - Alpha abundances agree with MW halo at [Fe/H] < -2.0