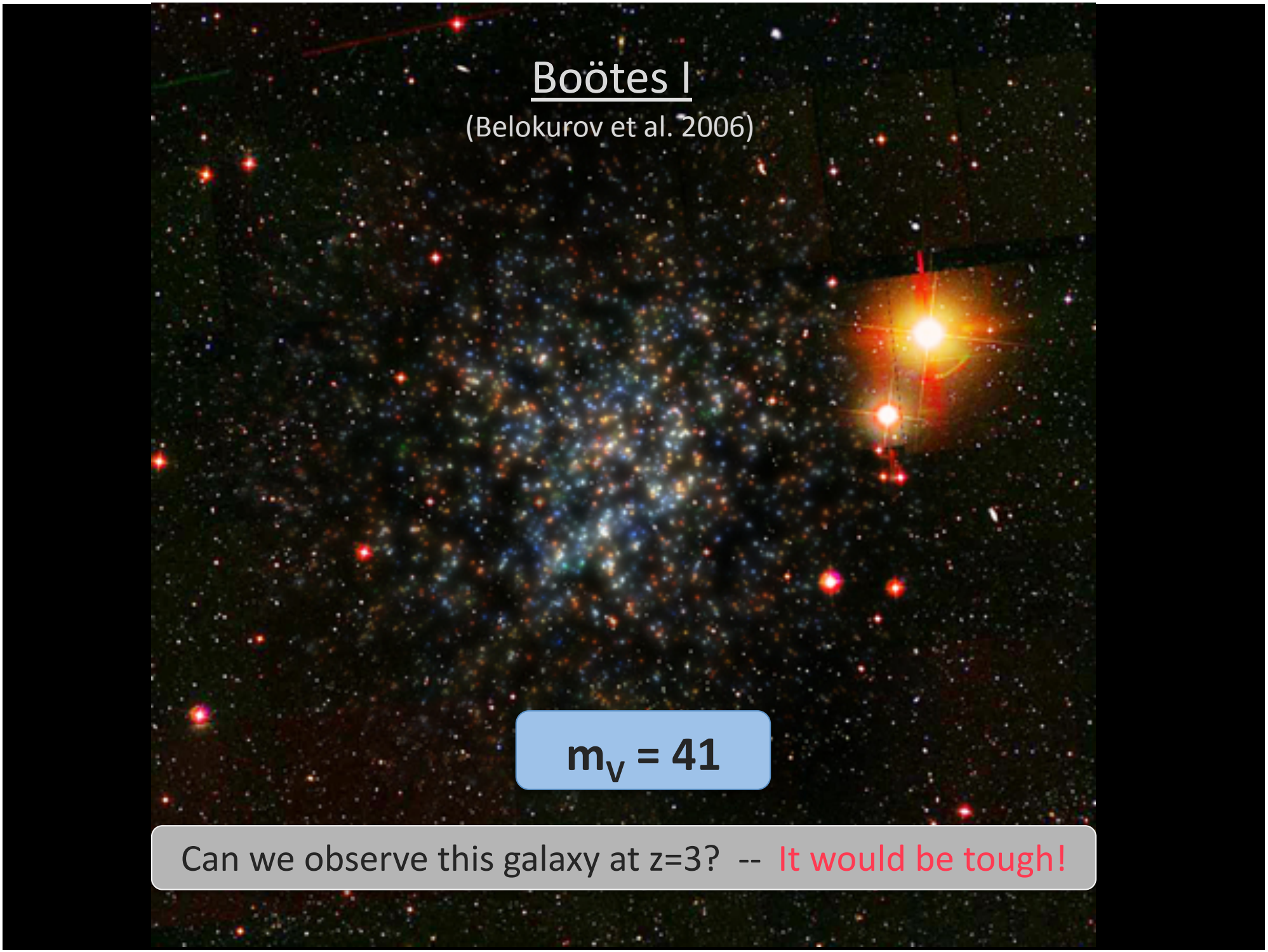
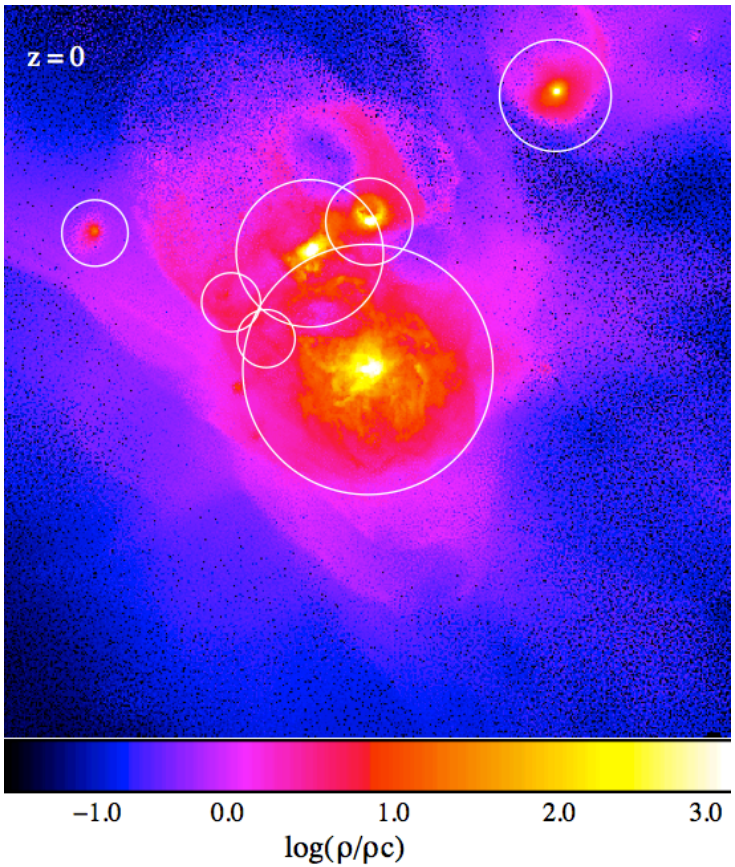
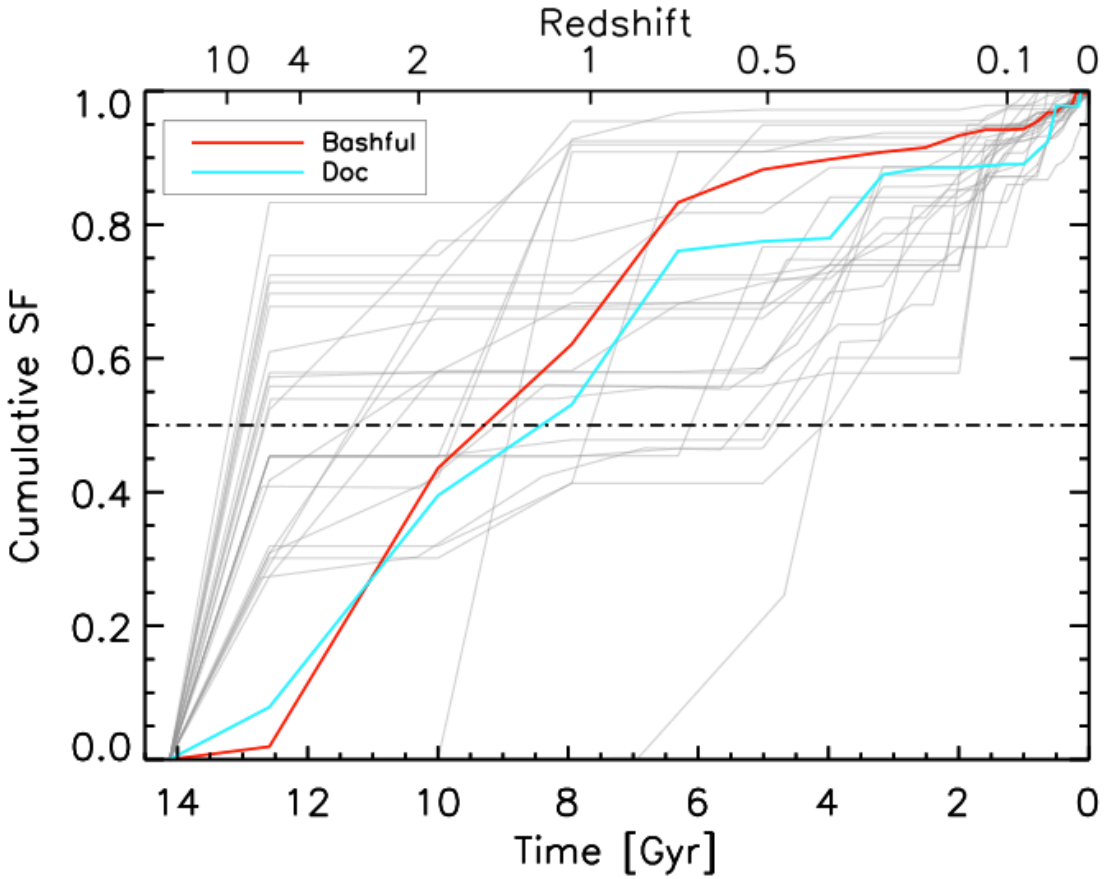

UNIVERSITY OF CALIFORNIA
SANTA CRUZ
IMAGE CREDIT: NASA/ESA
DWARF GALAXIES
AT HIGH REDSHIFT
Santa Cruz Galaxy Workshop
11th Aug 2014
Ryan Cooke (Hubble Fellow, UCSC)
Collaborators: Max Pettini (IoA, Cambridge), Regina Jorgenson (IfA, Hawaii)


Boötes I
(Belokurov et al. 2006)
$m_V = 41$
Can we observe this galaxy at z=3? -- It would be tough!

Simulated dwarf galaxies

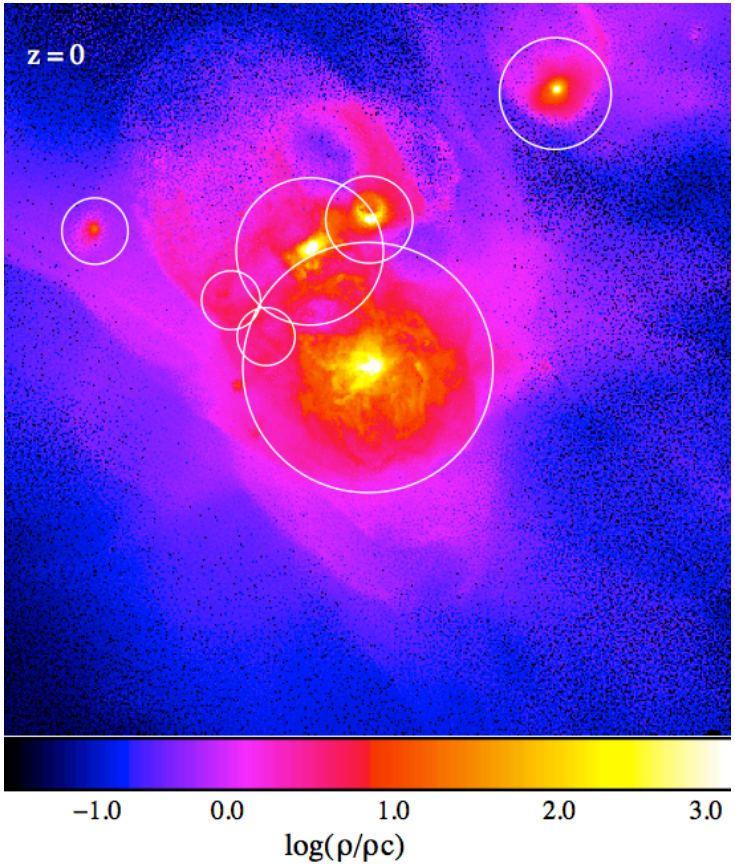
Shen et al. (2013)



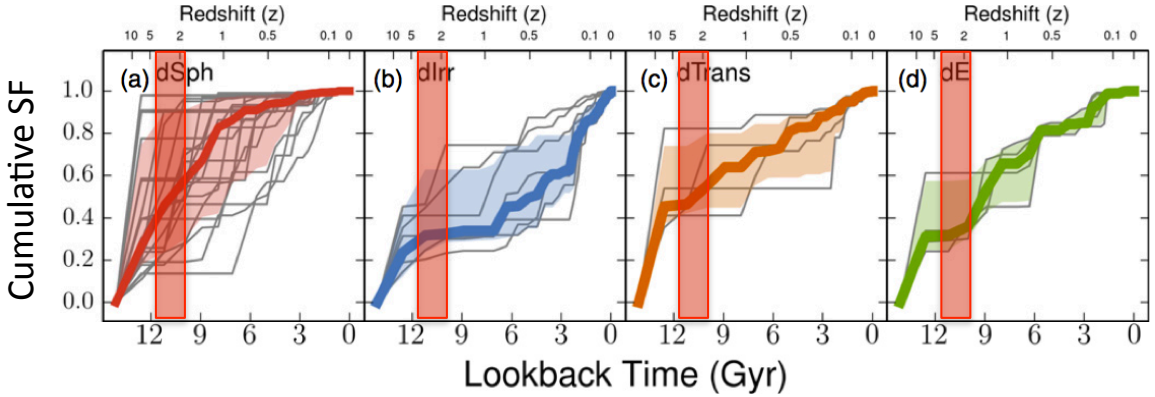


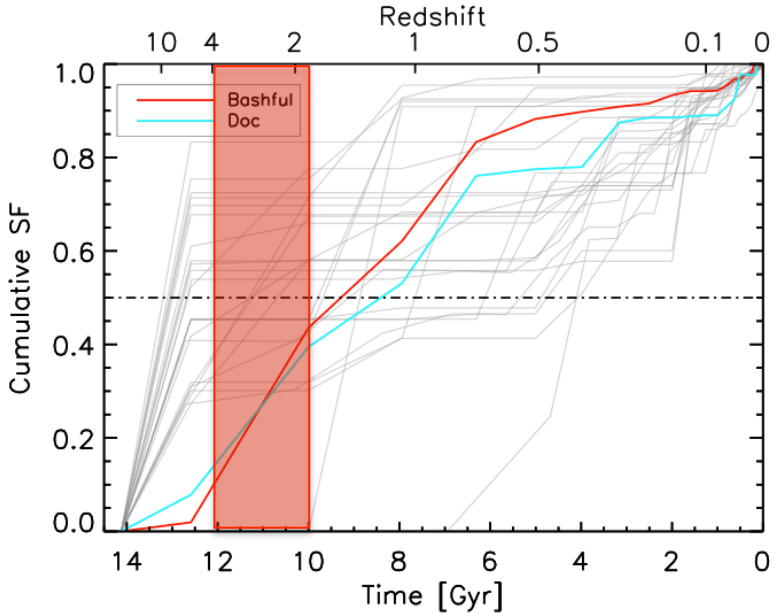
SFH of dwarf galaxies

Shen et al. (2013)



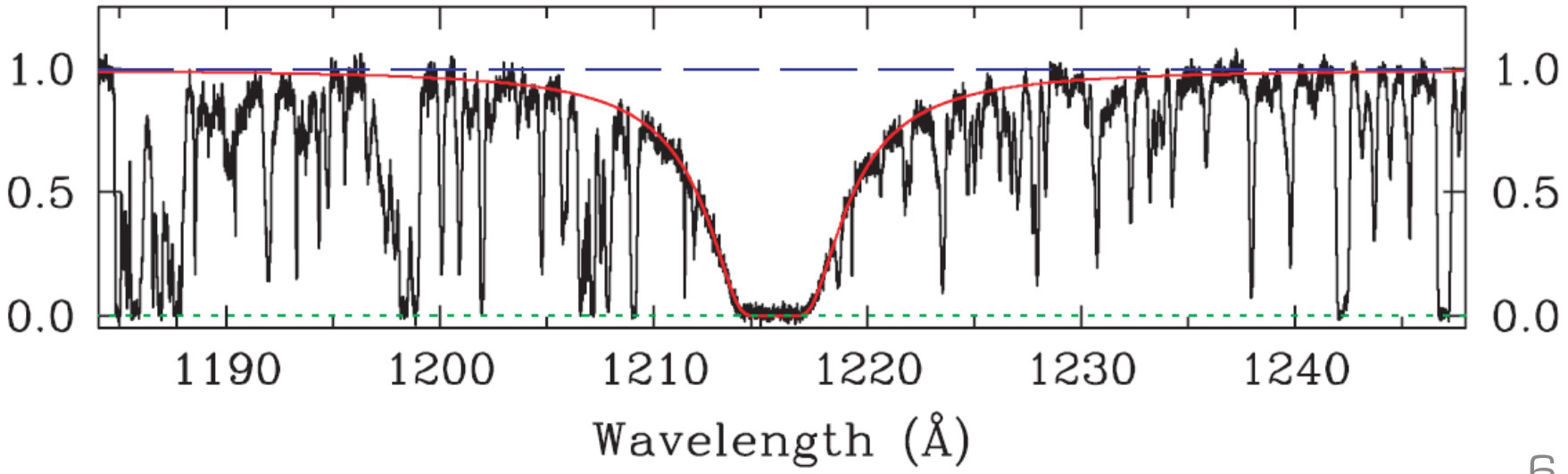
see also Weisz et al. (2011,2014)





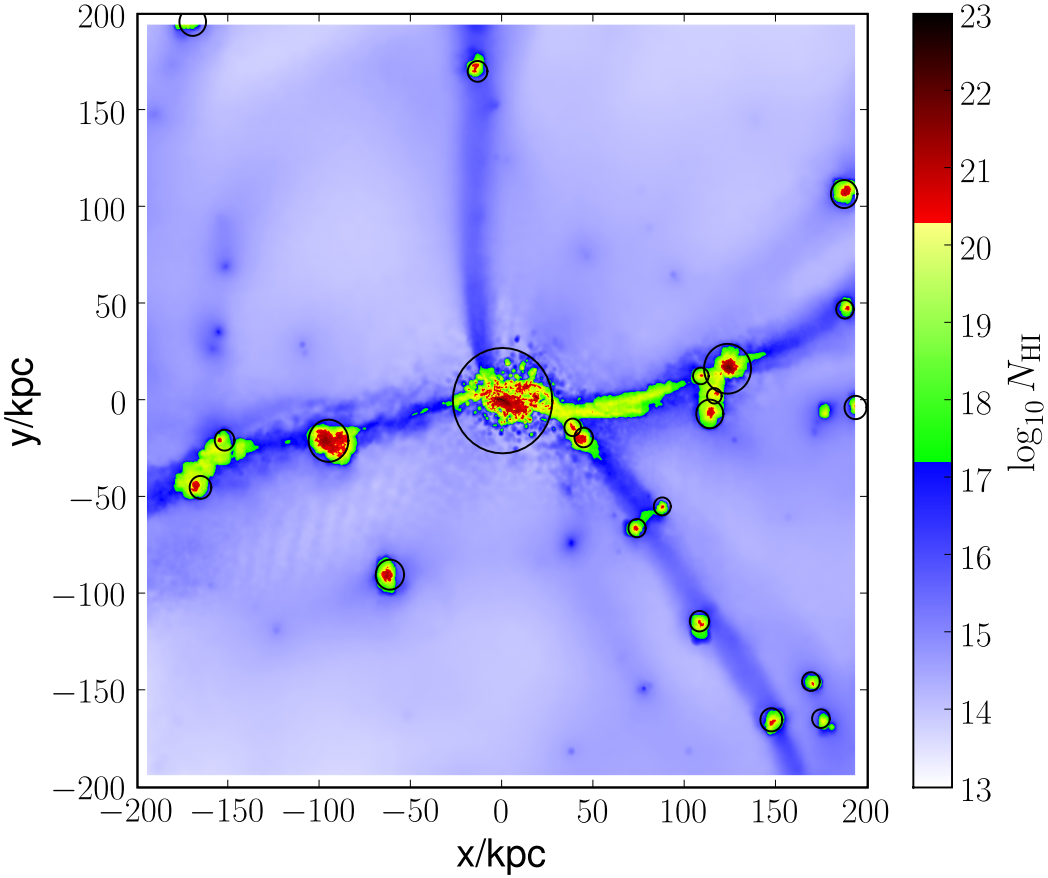
Damped Lyman alpha systems

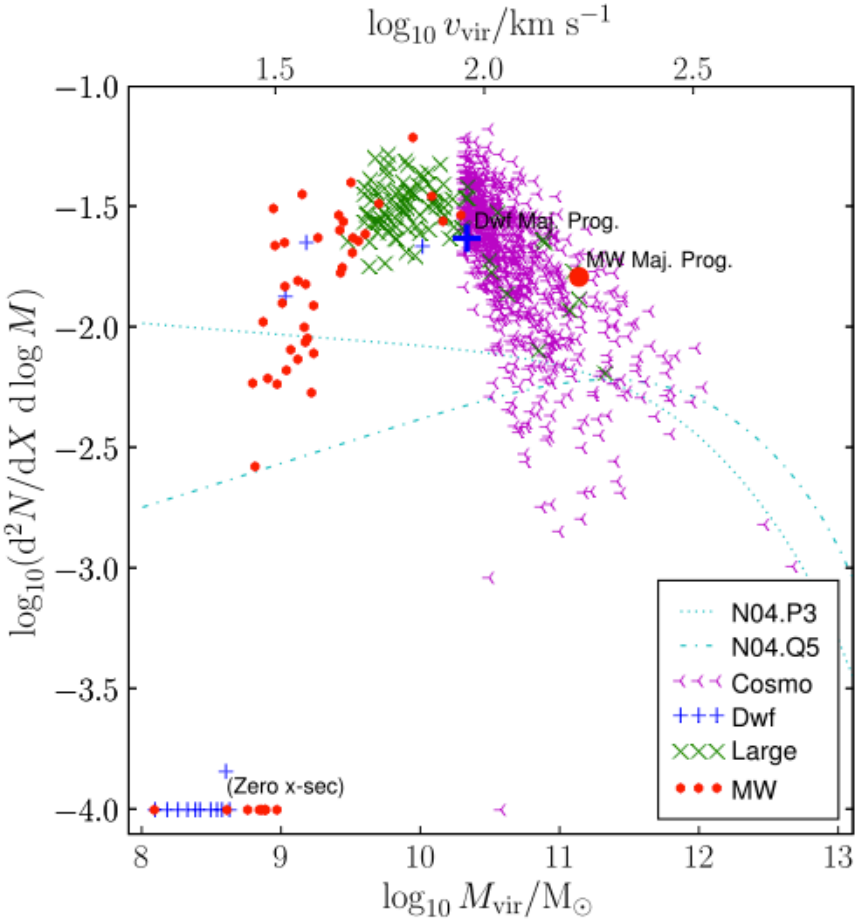
- log $N(\mathrm{H\,I})$ / cm^{-2} ≥ 20.3
- Characteristic damping wings
- Neutral gas reservoirs at high redshift
- Self-shielded



Simulated DLAs

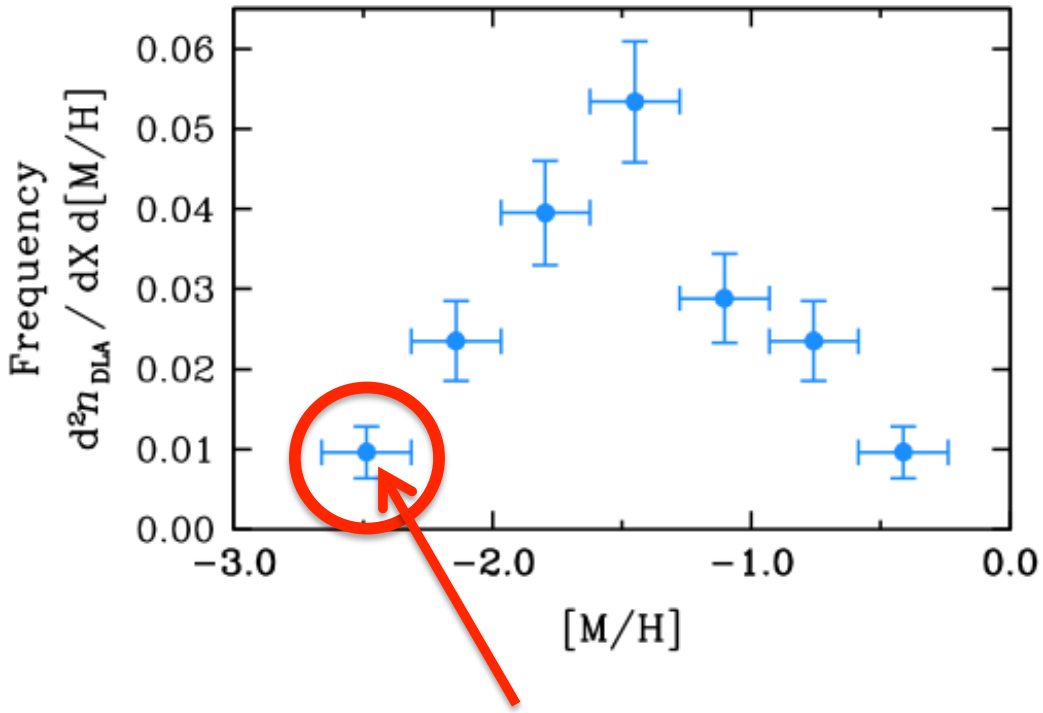
Pontzen et al. (2008)



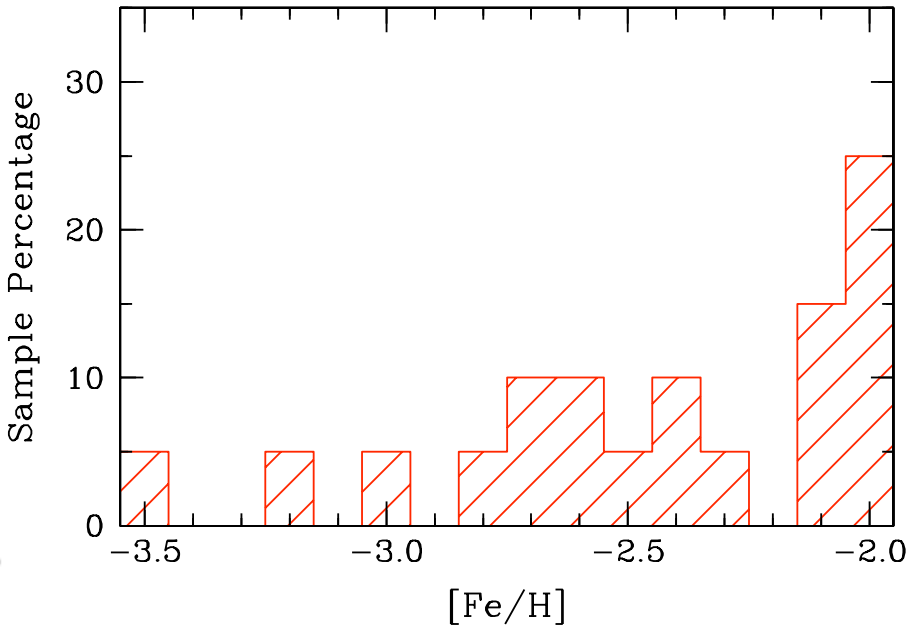


The Metal-poor DLAs Survey

Data from:
Rafelski et al. (2012), ApJ, 755, 89



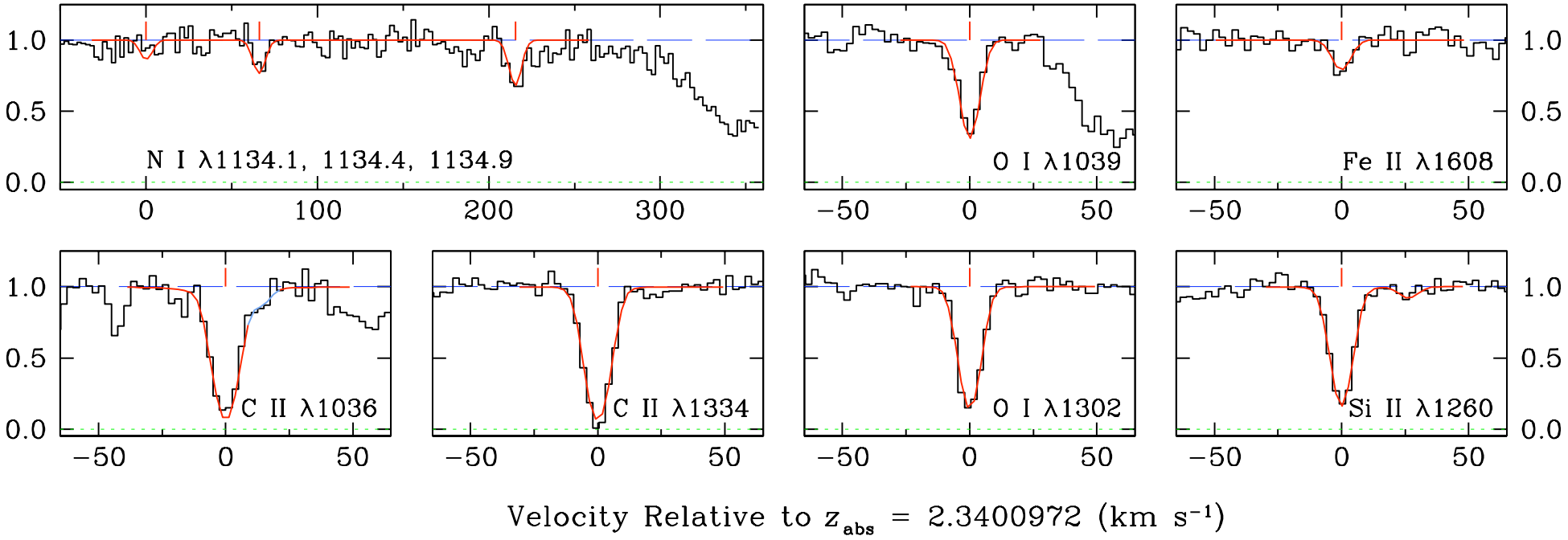
Cooke et al. (2011b) MNRAS, 417, 1534



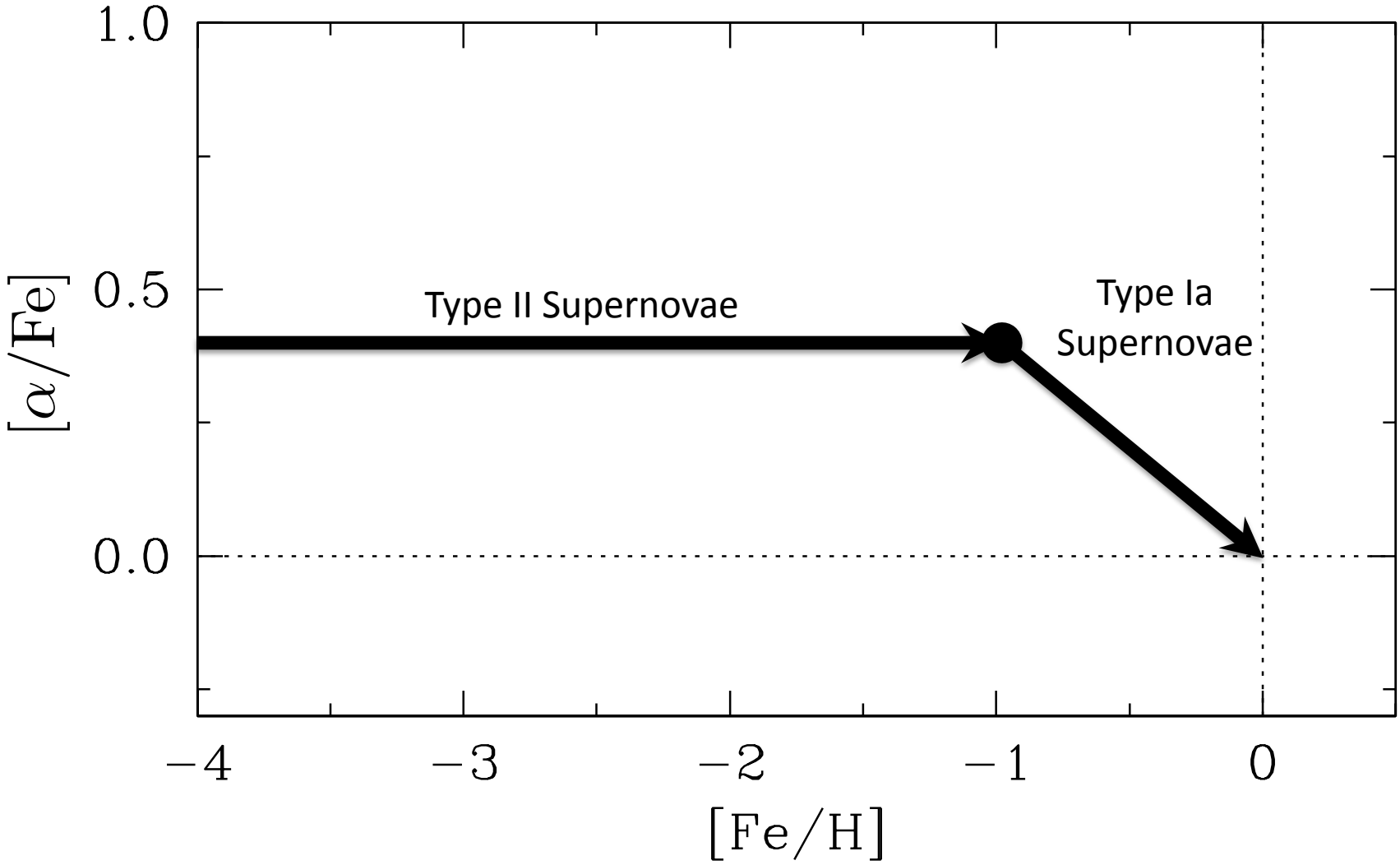
We want to find these DLAs!

The sample

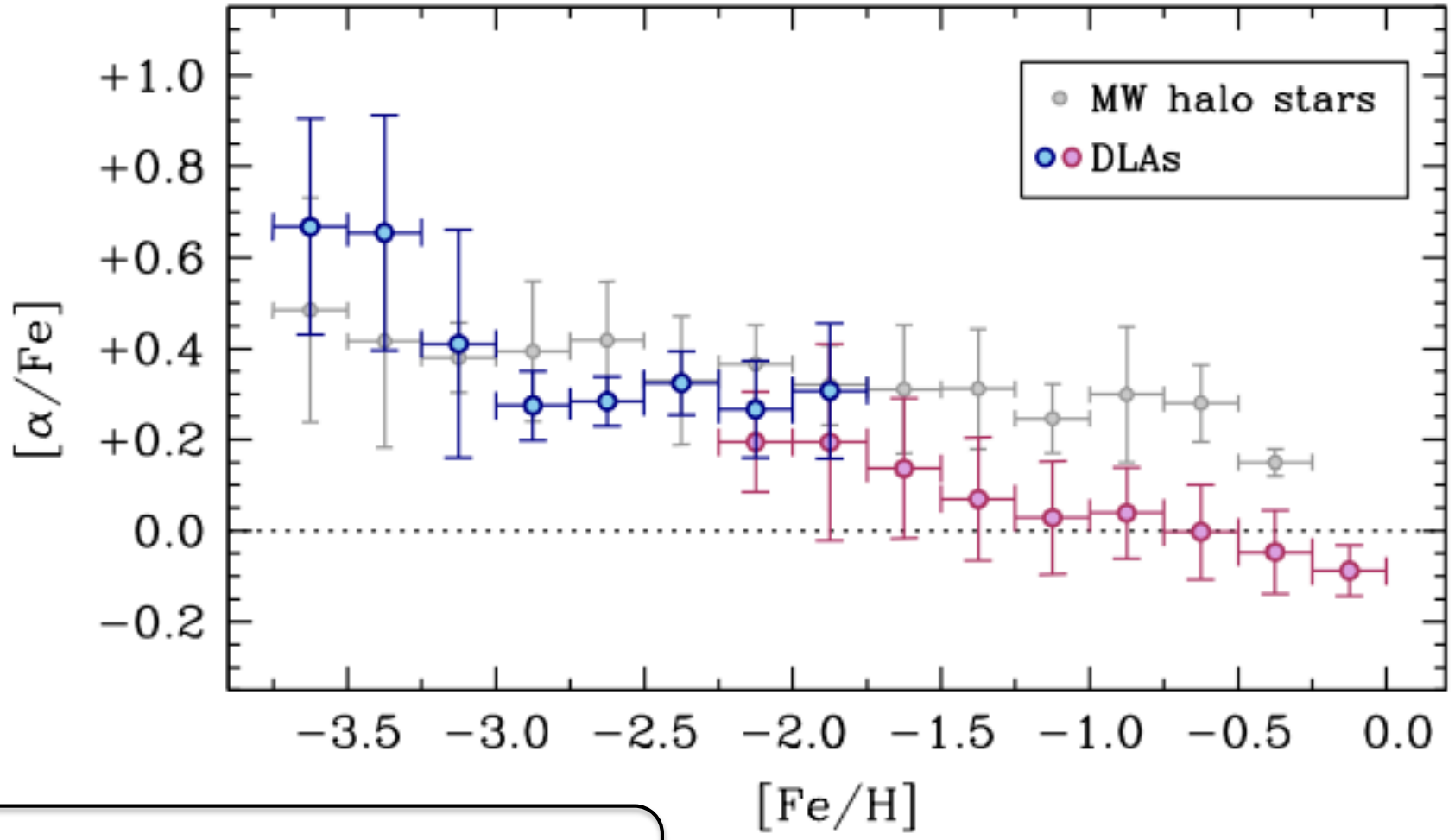
- 22 DLAs total (10 from the literature) --- z_{abs} = 2.3 – 3.7
- [Fe/H] < -2.0 --- "Very Metal-Poor"
- Observed with VLT+UVES & Keck+HIRES (R > 30,000)
- Exposure time ≈ 10 hrs → S/N ≈ 30



The [α/Fe] Ratio



Chemistry of DLAs and dwarf galaxies



Venn et al. (2004), AJ, 128, 1177

Vladilo et al. (2011), A&A, 530, A33

Cooke et al. (2014), arXiv: 1406:7003

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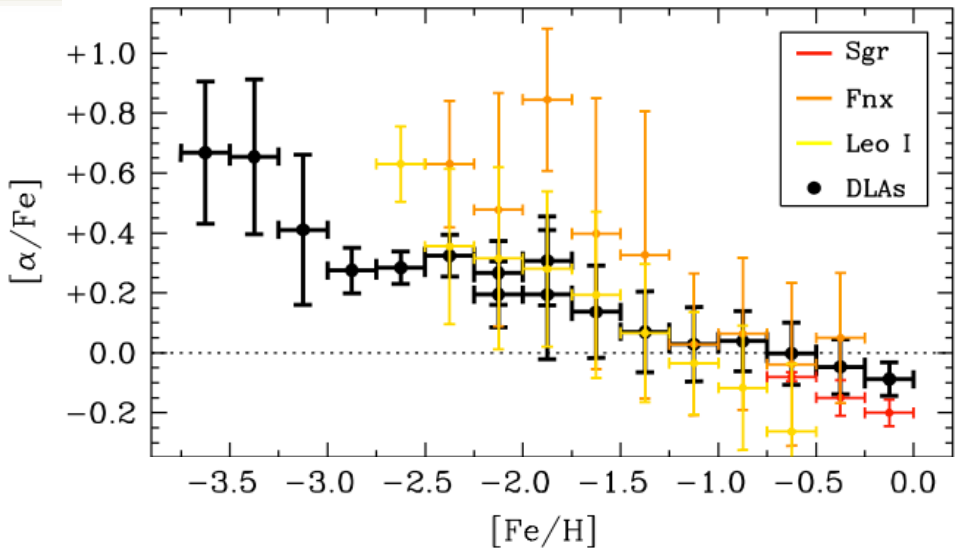
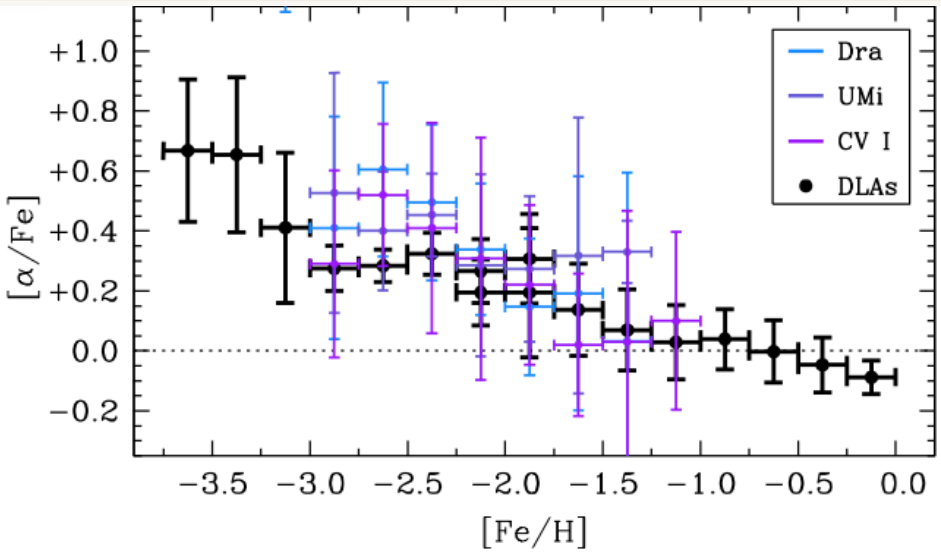
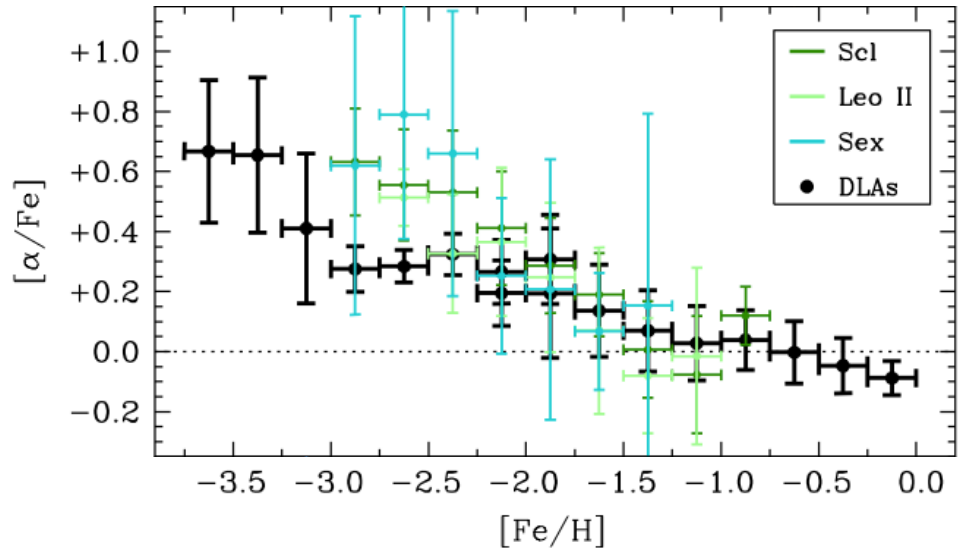
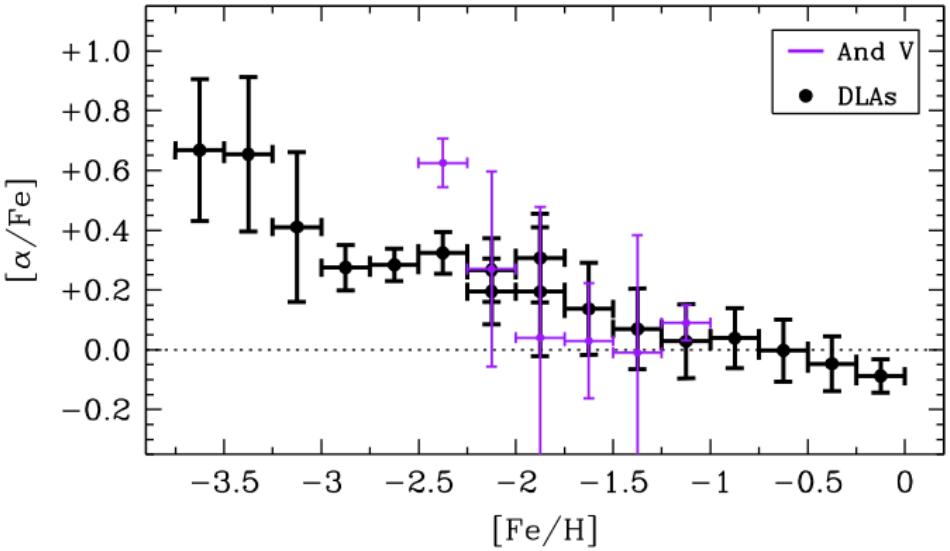




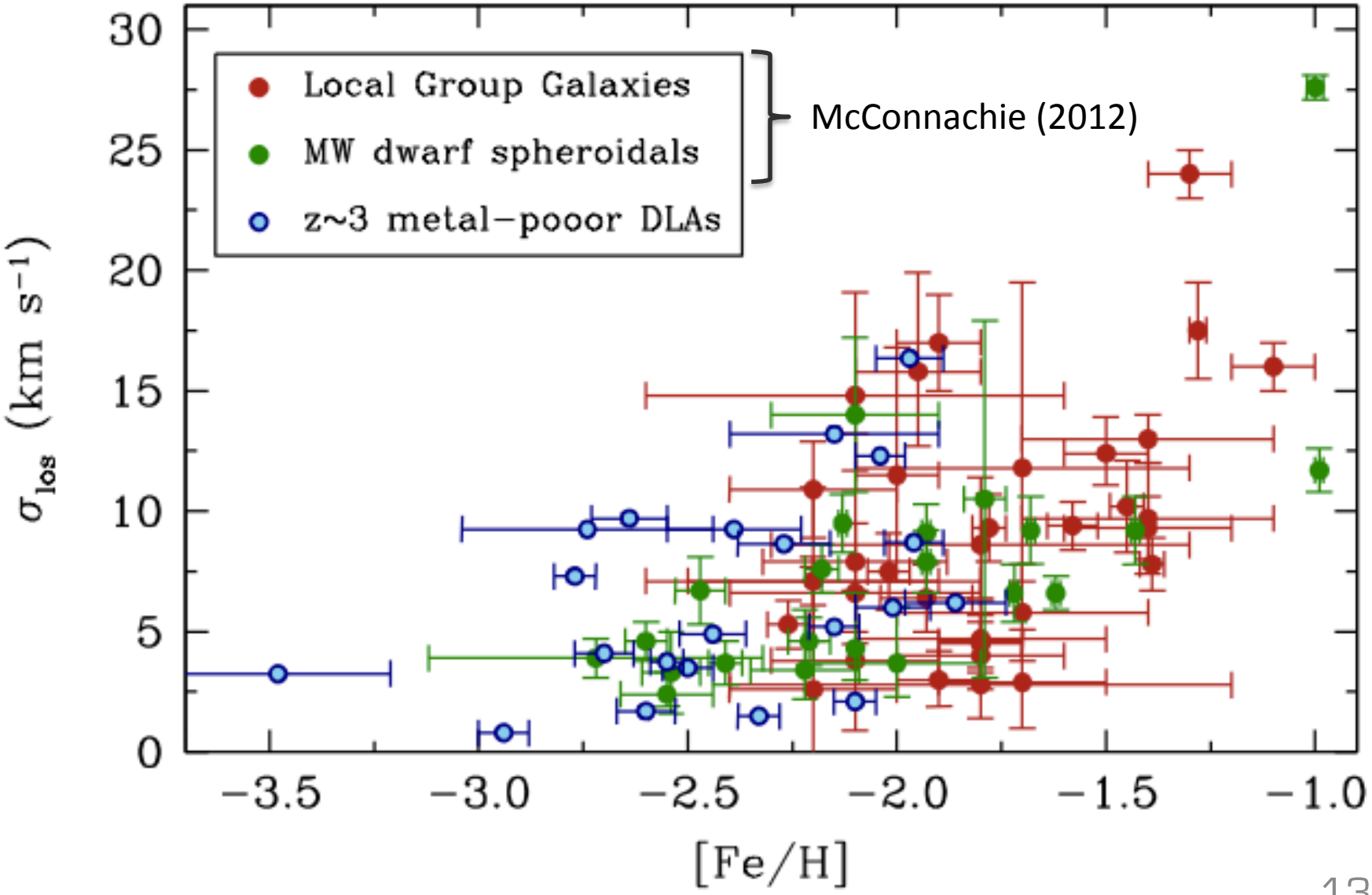




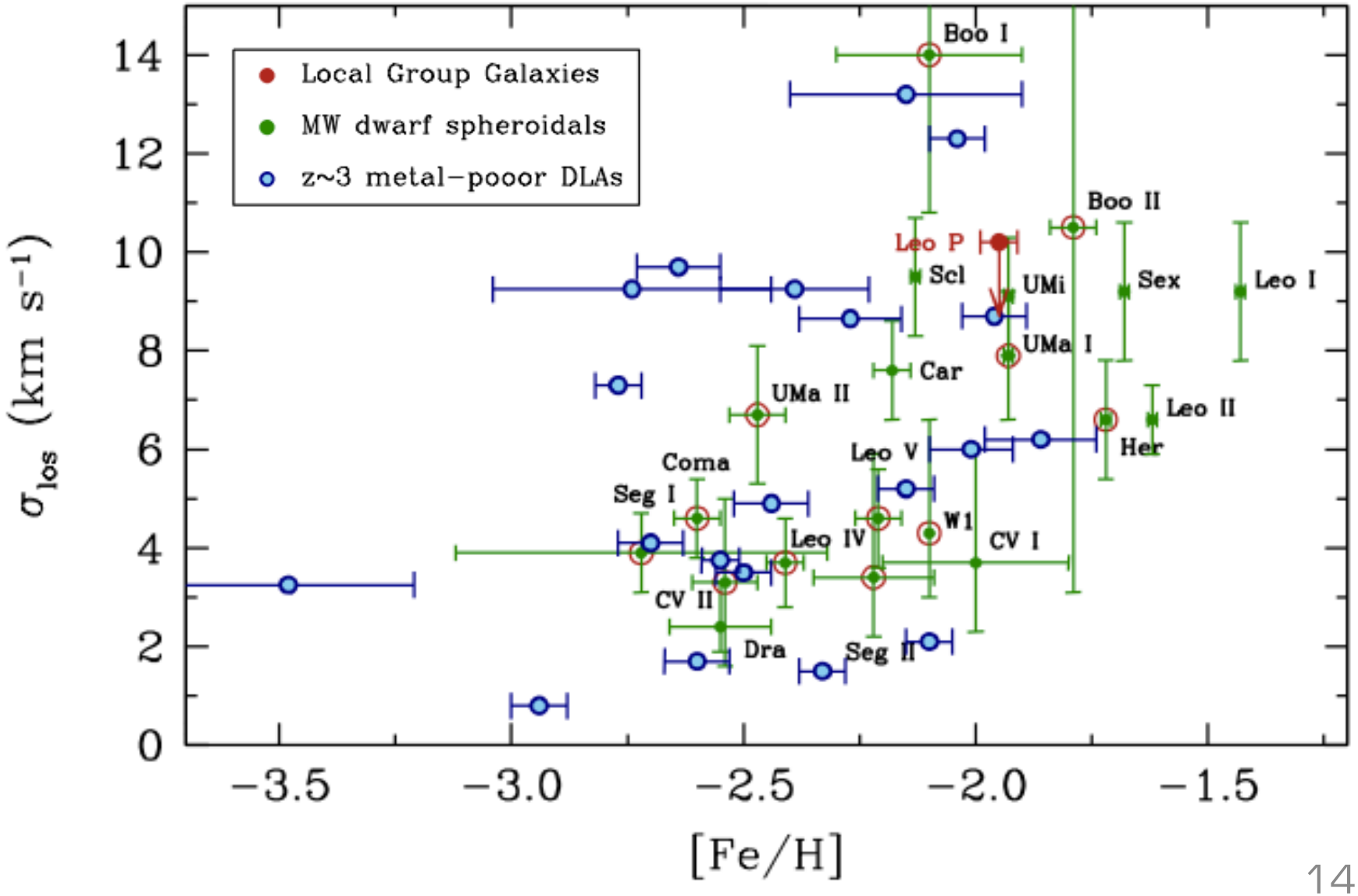
MW dwarfs: Kirby et al. (2011), ApJ, 727, 79

M31 dwarfs: Vargas et al. (2014), ApJ, 790, 73

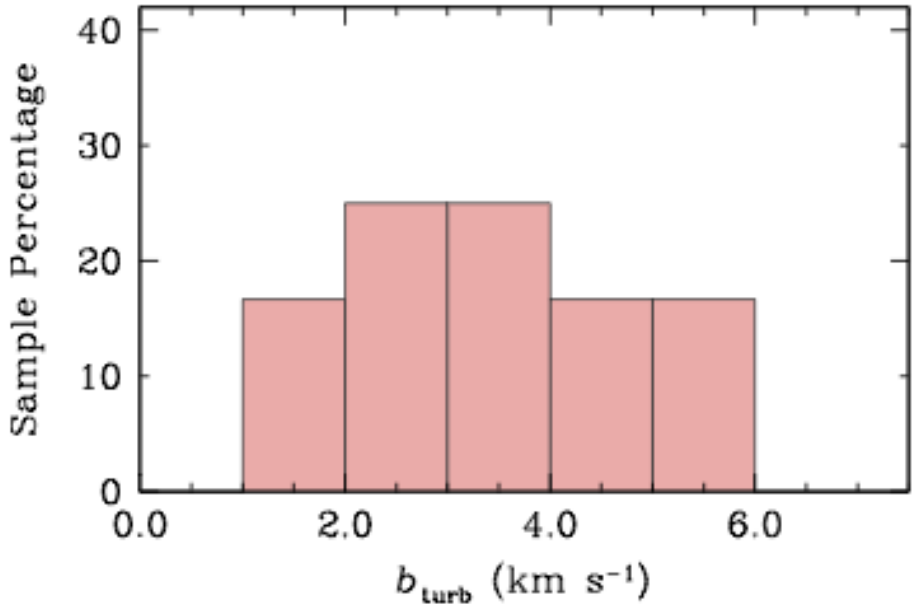
Kinematics of DLAs and dwarf galaxies

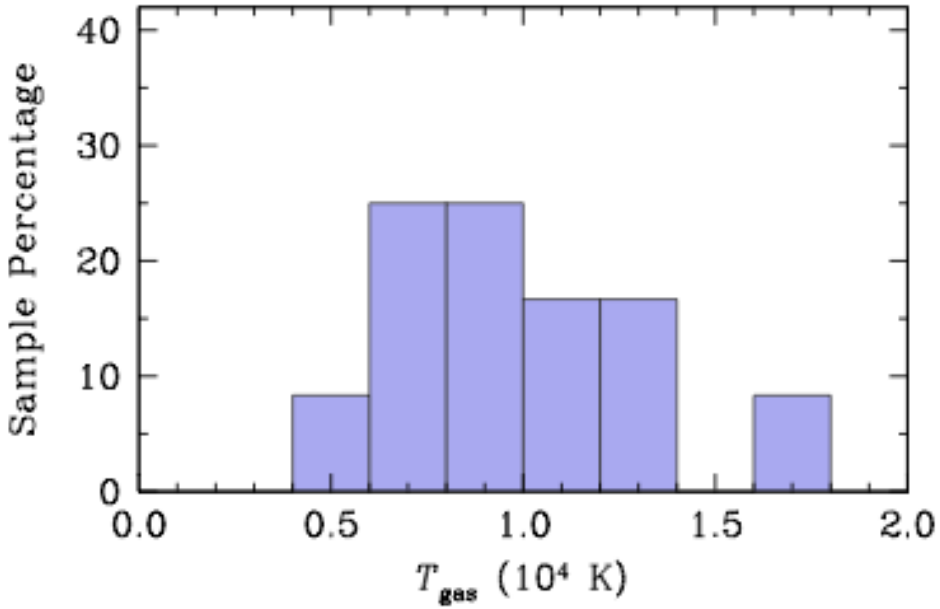


Kinematics of DLAs and the MW dwarfs



Birth clouds of the second stars





Typical metal-poor DLAs:

$\langle b_{\rm turb} \rangle = 3.5 \pm 1.1$ km s^{-1}

$\langle T_{\rm gas} \rangle = 9800 \pm 1200$ K

Typical MW ISM values:

$\langle b_{\rm turb} \rangle_{\rm MW} = 2.2 \pm 1.0$ km s^{-1}

$\langle T_{\rm gas} \rangle_{\rm MW} = 6700 \pm 1500$ K

Cooke et al. (2014), arXiv: 1406:7003

Redfield & Linsky (2004), ApJ, 613, 1004

Birth clouds of the second stars

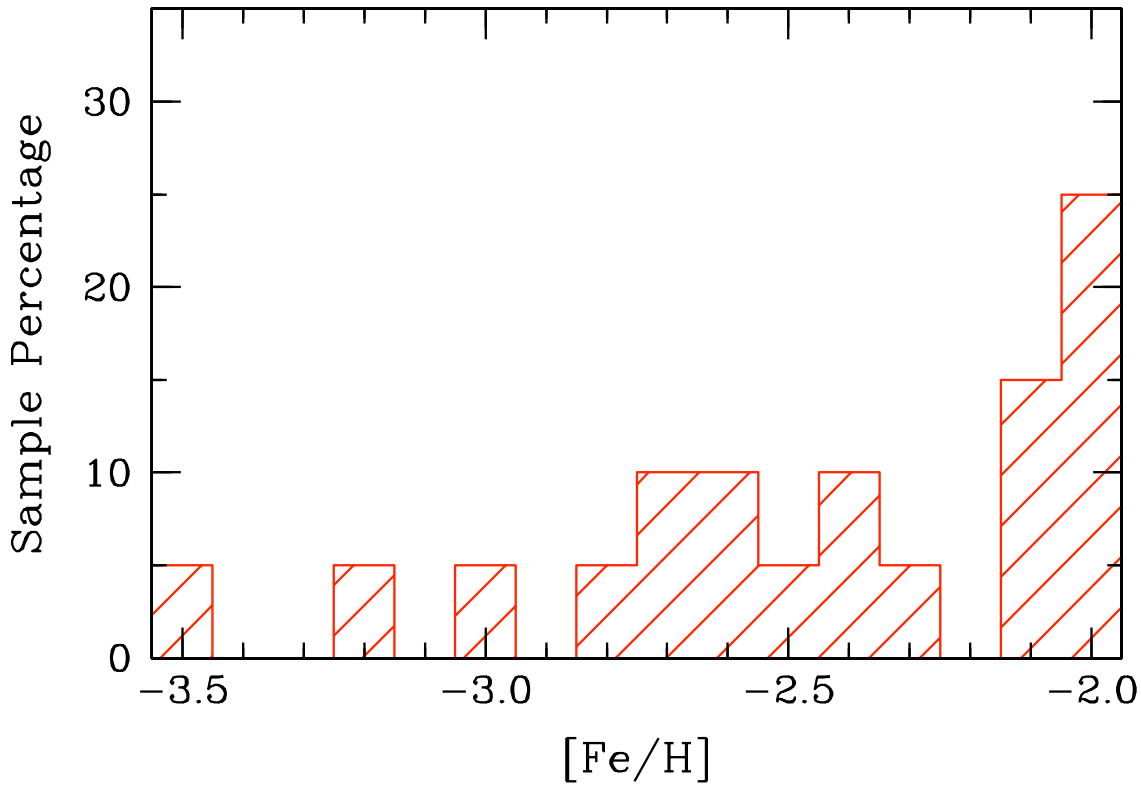
SUMMARY OF THE PHYSICAL PROPERTIES OF METAL-POOR DLAS

Property	Confidence Intervals
$b_{\rm turb}$ (km s^{-1})	$3.3^{+1.8}_{-1.5}$ (1σ) $^{+2.3}_{-2.4}$ (2σ)
$T_{\rm gas}$ (K)	9600^{+2500}_{-2600} (1σ) $^{+12200}_{-5000}$ (2σ)
$\log n({\rm H})/{\rm cm}^{-3}$	$-1.0^{+0.4}_{-0.3}$ (1σ) $^{+0.6}_{-0.7}$ (2σ)
$r_{\rm H\,I}$ (pc)	220^{+840}_{-130} (1σ) $^{+2200}_{-200}$ (2σ)
$\log M_{\rm WNM}/{\rm M}_\odot$	$5.4^{+1.9}_{-0.9}$ (1σ) $^{+2.5}_{-2.5}$ (2σ)
$P_{\rm th}/k_{\rm B}$ (K cm^{-3})	1050^{+1610}_{-450} (1σ) $^{+4150}_{-730}$ (2σ)
$P_{\rm turb}/k_{\rm B}$ (K cm^{-3})	130^{+330}_{-100} (1σ) $^{+630}_{-120}$ (2σ)
$c_{\rm s}$ (km s^{-1})	$8.0^{+1.0}_{-1.2}$ (1σ) $^{+4.1}_{-2.5}$ (2σ)
$\mathcal{M}_{\rm turb}$	$0.50^{+0.23}_{-0.24}$ (1σ) $^{+0.34}_{-0.36}$ (2σ)

Cooke et al. (2014), arXiv: 1406:7003

Summary and Conclusions

Conducted a survey to study the most metal-poor DLAs as probes of early stellar nucleosynthesis



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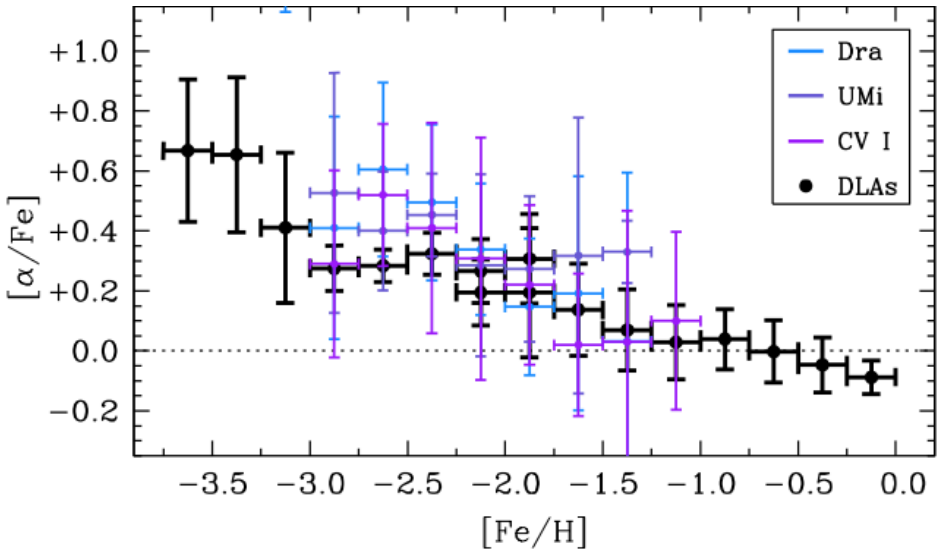

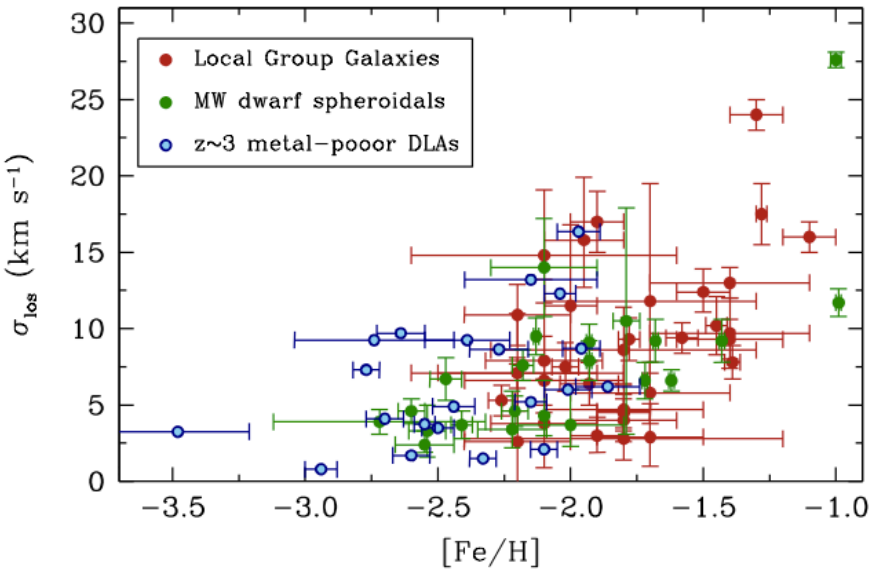

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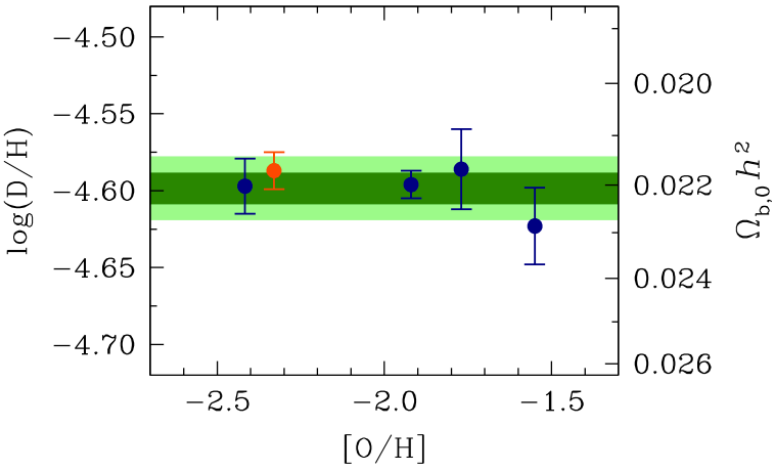
Such systems afford precise measures of the primordial element abundances

Cooke et al. (2014) ApJ, 781, 31



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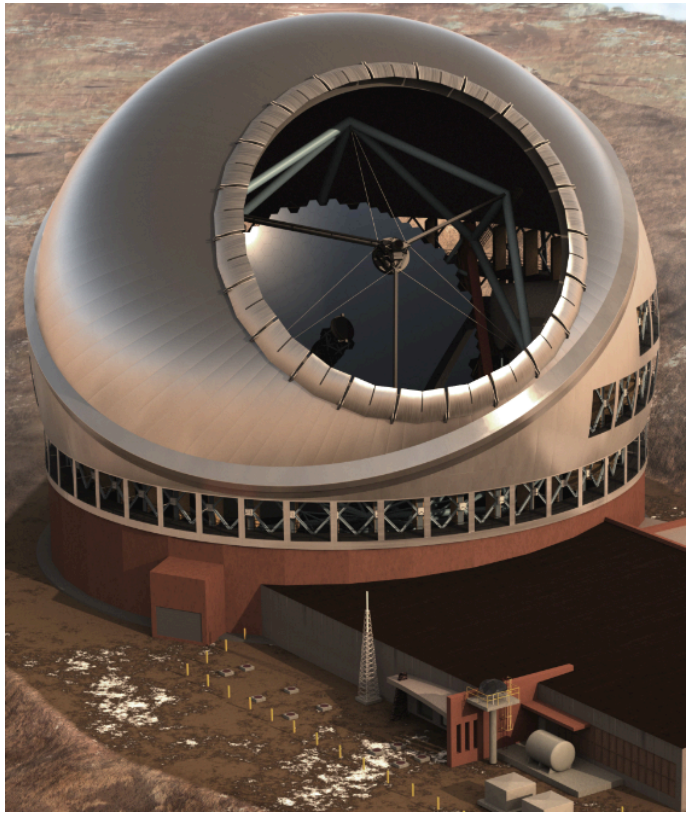

The most metal-poor DLAs are ideal environments to study early nucleosynthesis and the early evolution of dwarf galaxies