THE MOST METAL-POOR DLAs AND EARLY NUCLEOSYNTHESIS

Galaxy Formation Workshop
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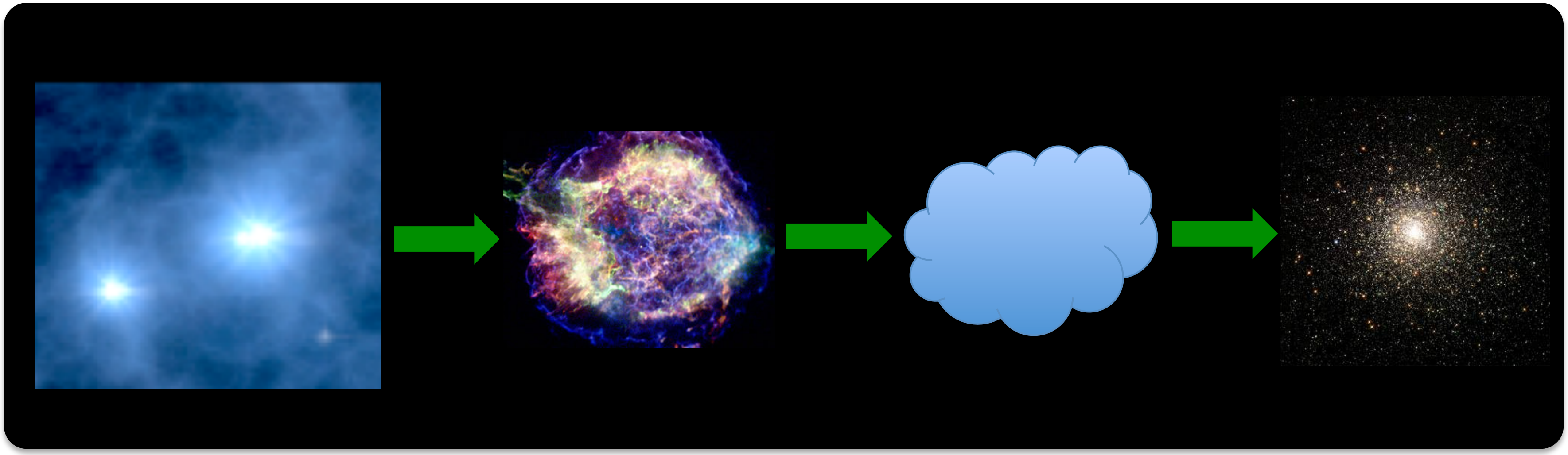
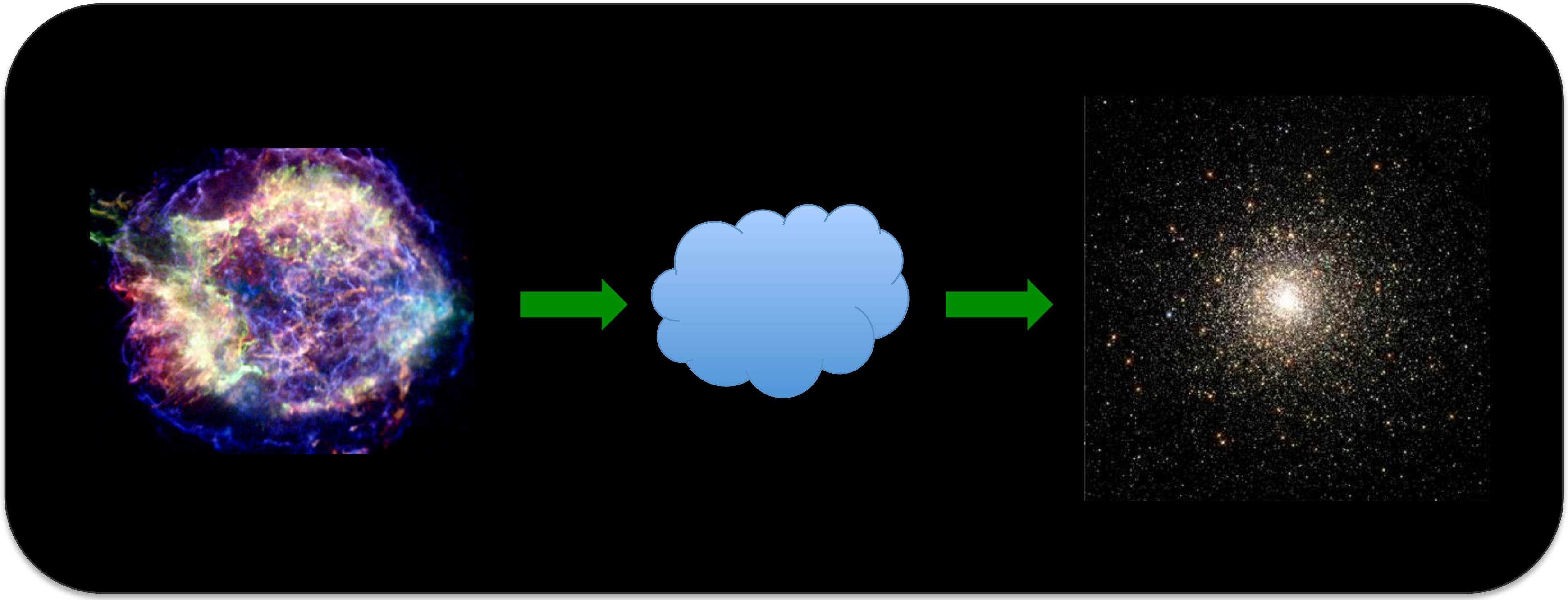
Studying Early Nucleosynthesis



Near-pristine clouds of gas



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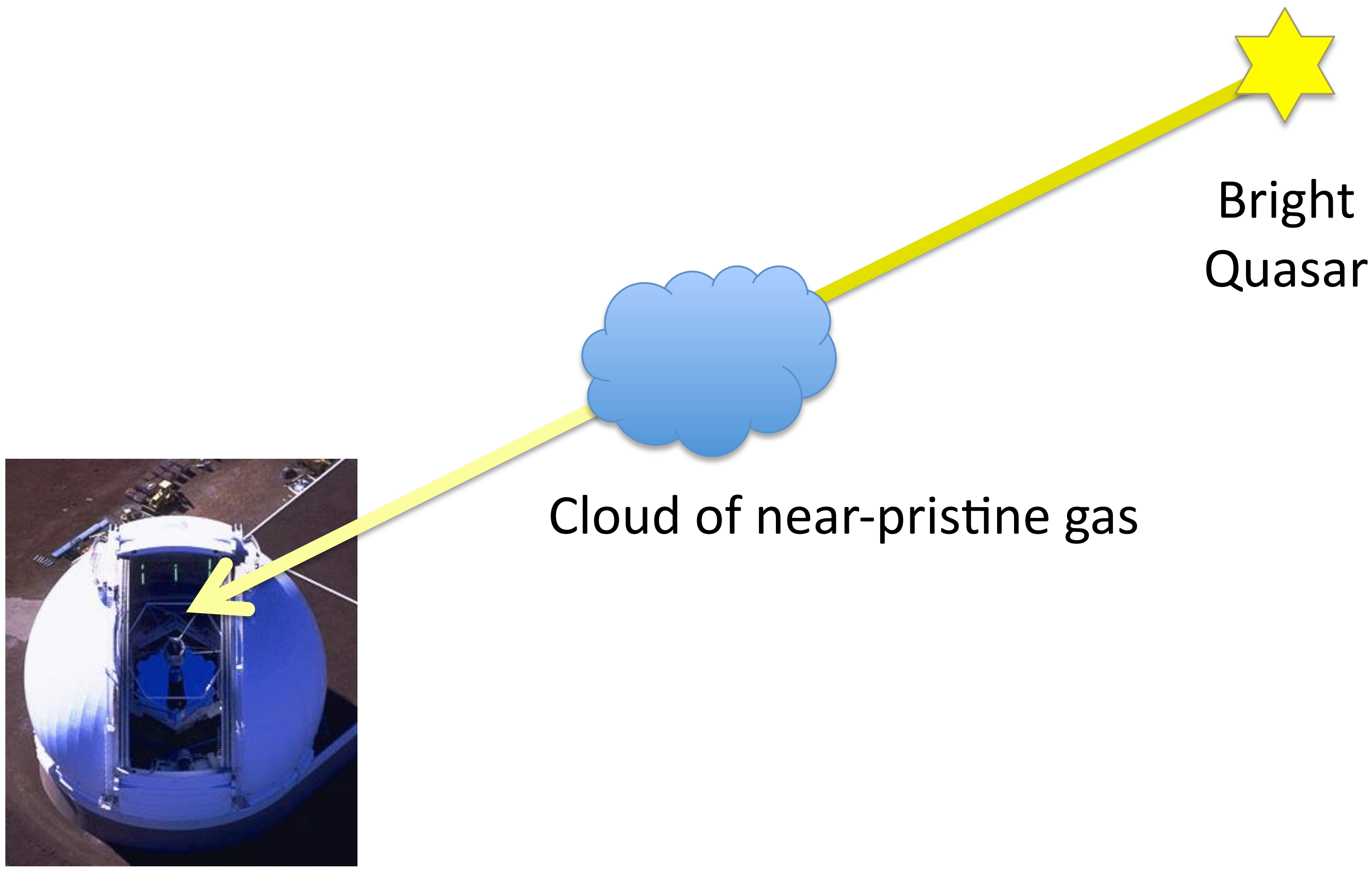
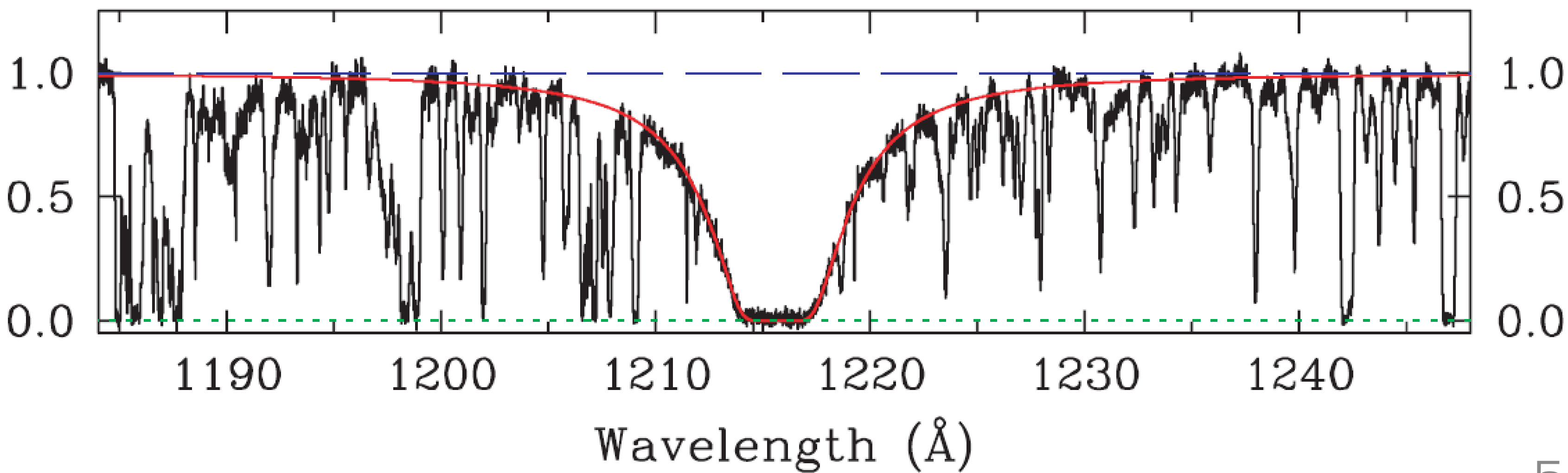


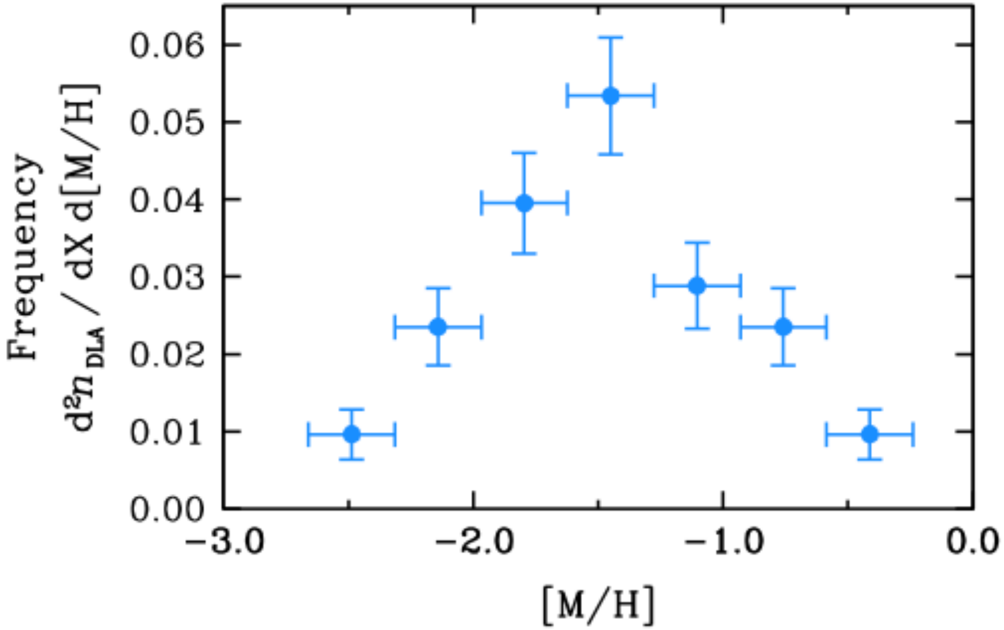
Damped Lyman alpha systems

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

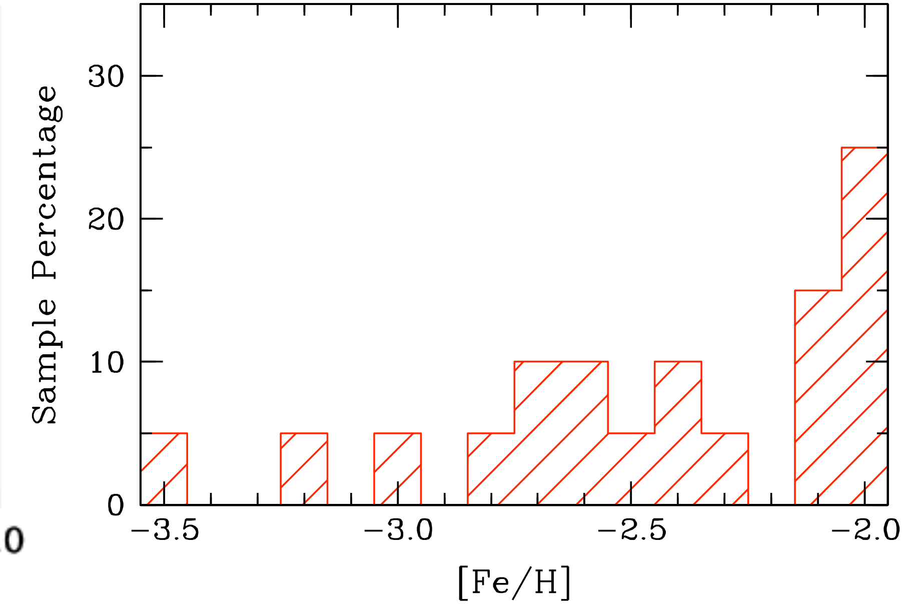


The Metal-poor DLAs Survey

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

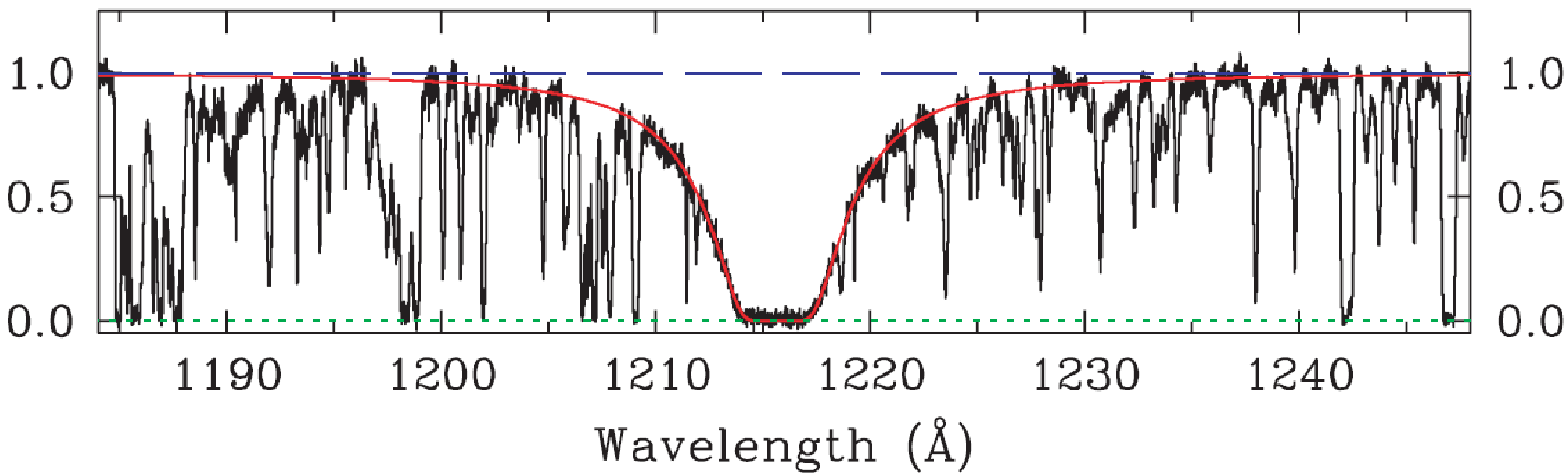


Cooke et al. (2011b) MNRAS, 417, 1534



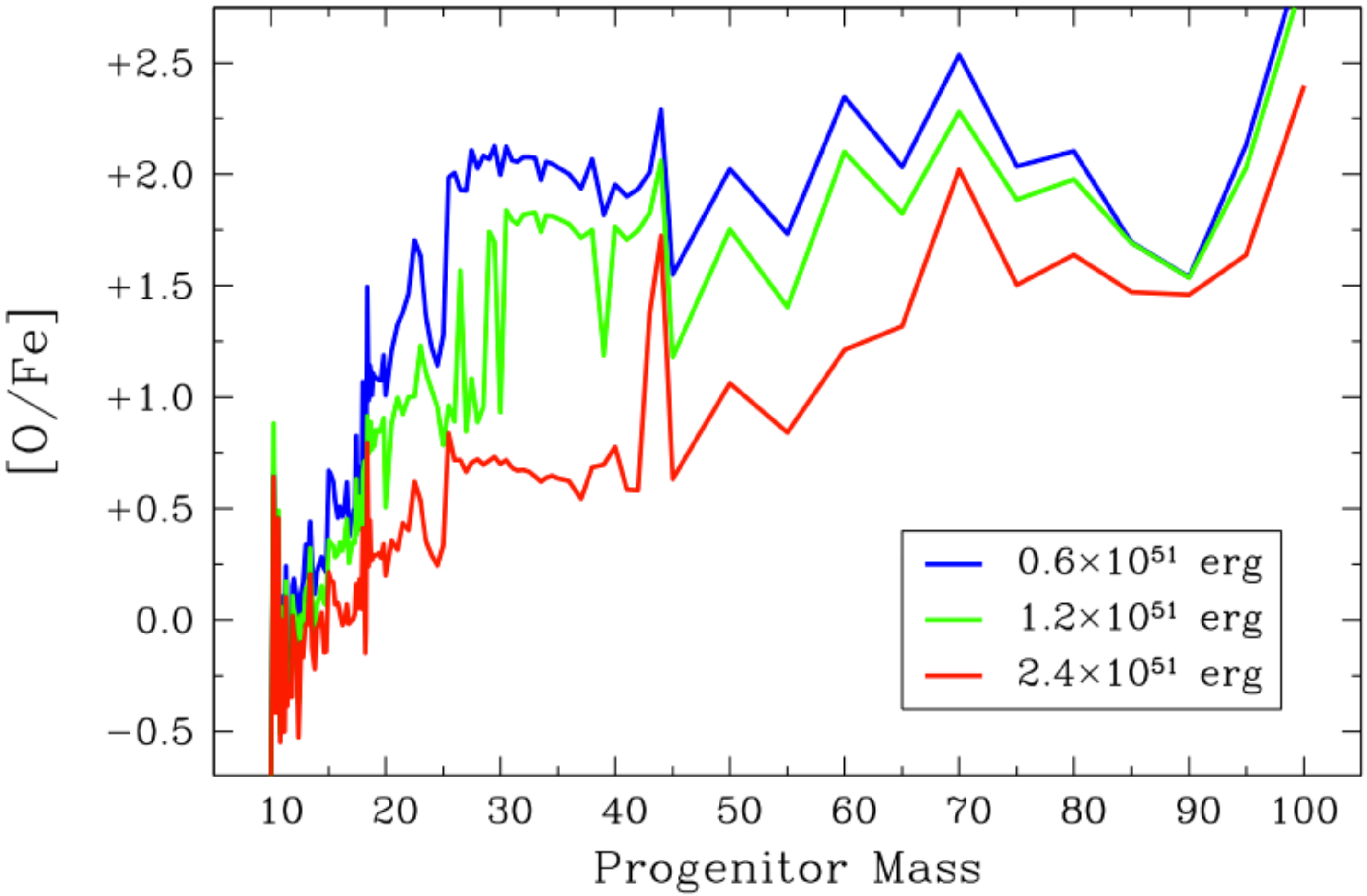
Science Highlights

- The oxygen problem
- Indications of nucleosynthesis from the first stars
- Explosion energy of metal-poor Type-II supernovae
- Precision measures of primordial nucleosynthesis

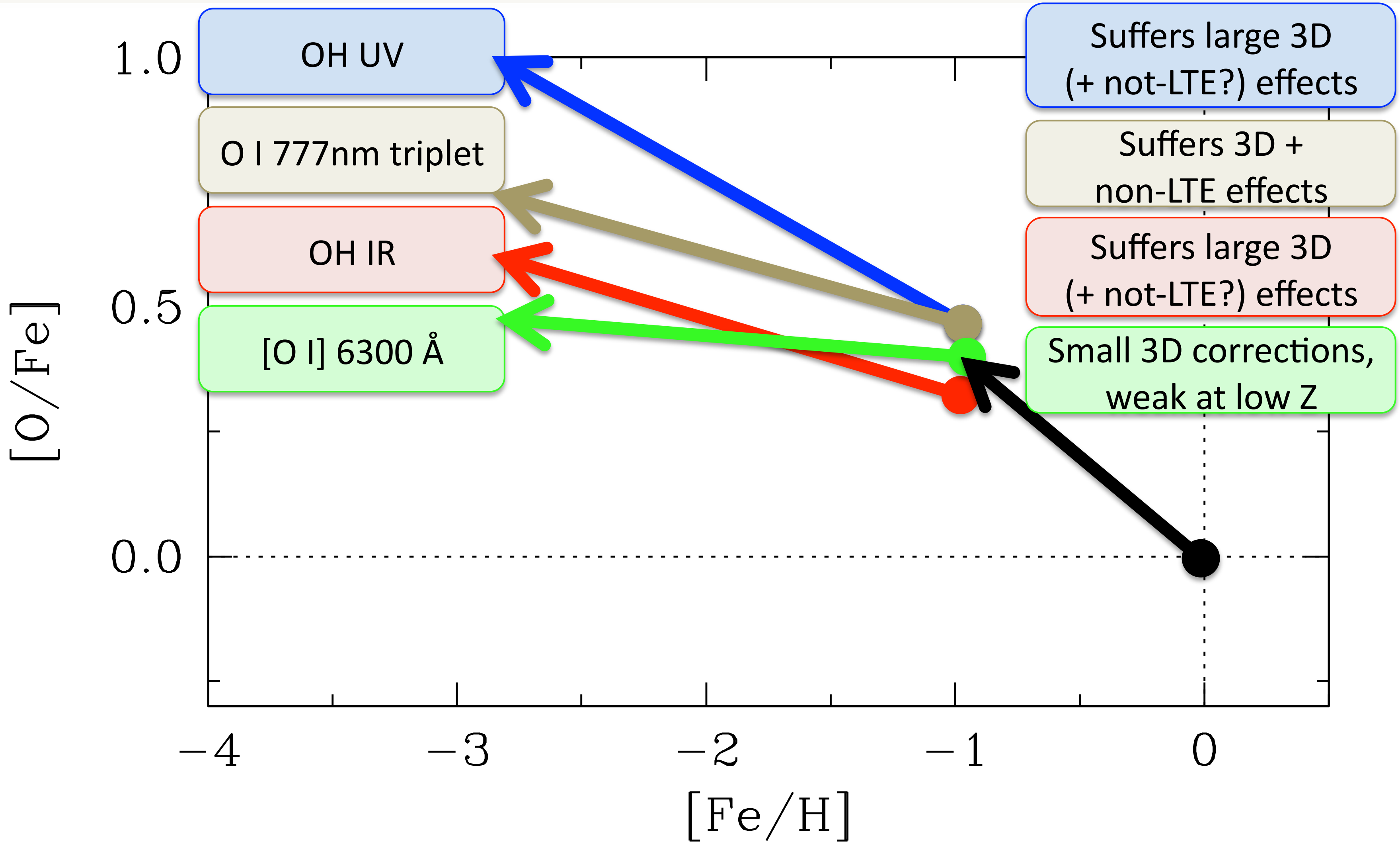


[O/Fe] ≈ stellar initial mass function

Yields from:
Heger & Woosley (2010) ApJ, 724, 341

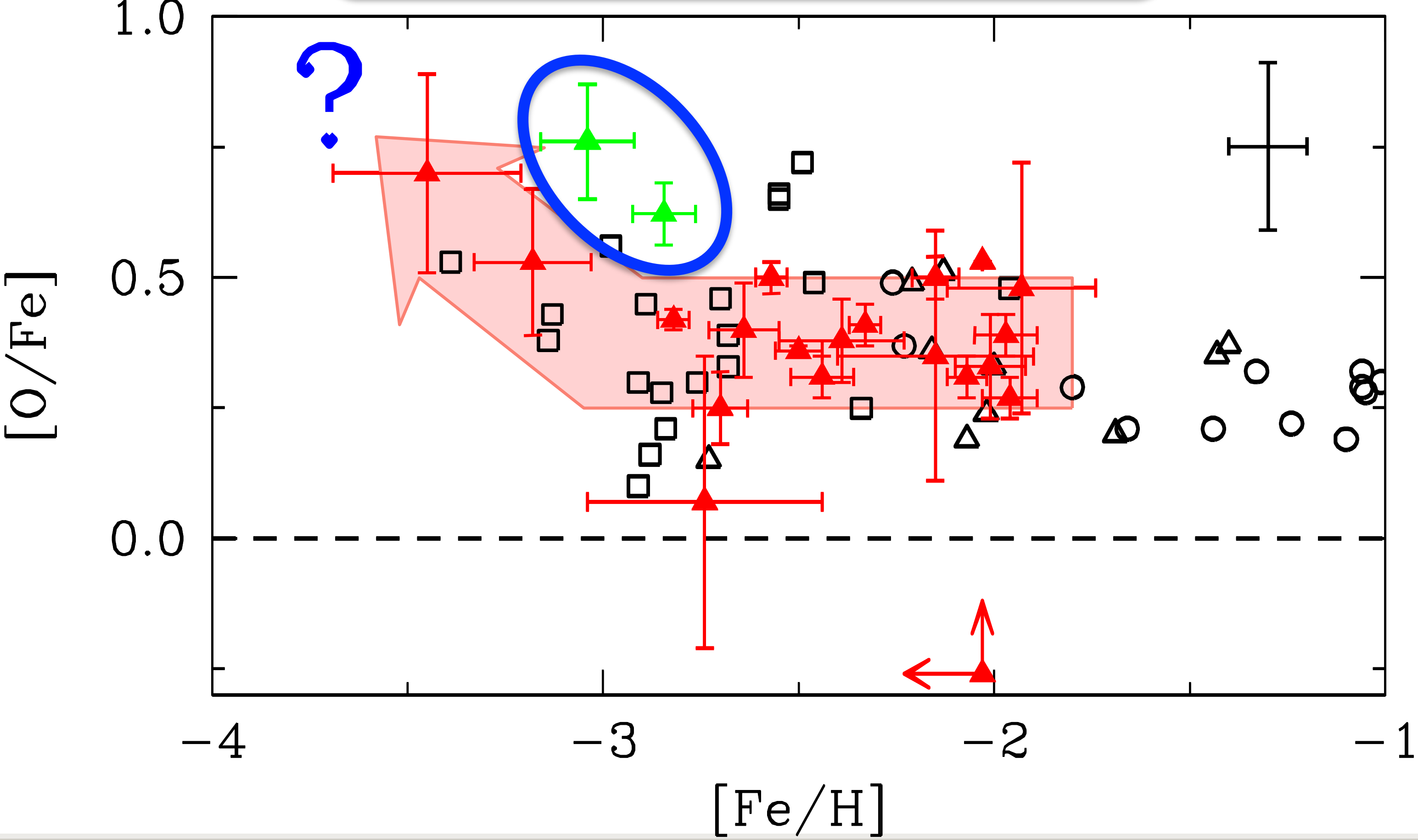


The Oxygen Problem



The [O/Fe] ratio at low metallicity

- ○ Nissen et al. (2002) A&A, 390, 235
- △ Garcia-Perez et al. (2006) A&A, 451, 621
- □ Cayrel et al. (2004) A&A, 416, 1117
- ▲ Cooke et al. (2011) MNRAS, 417, 1534

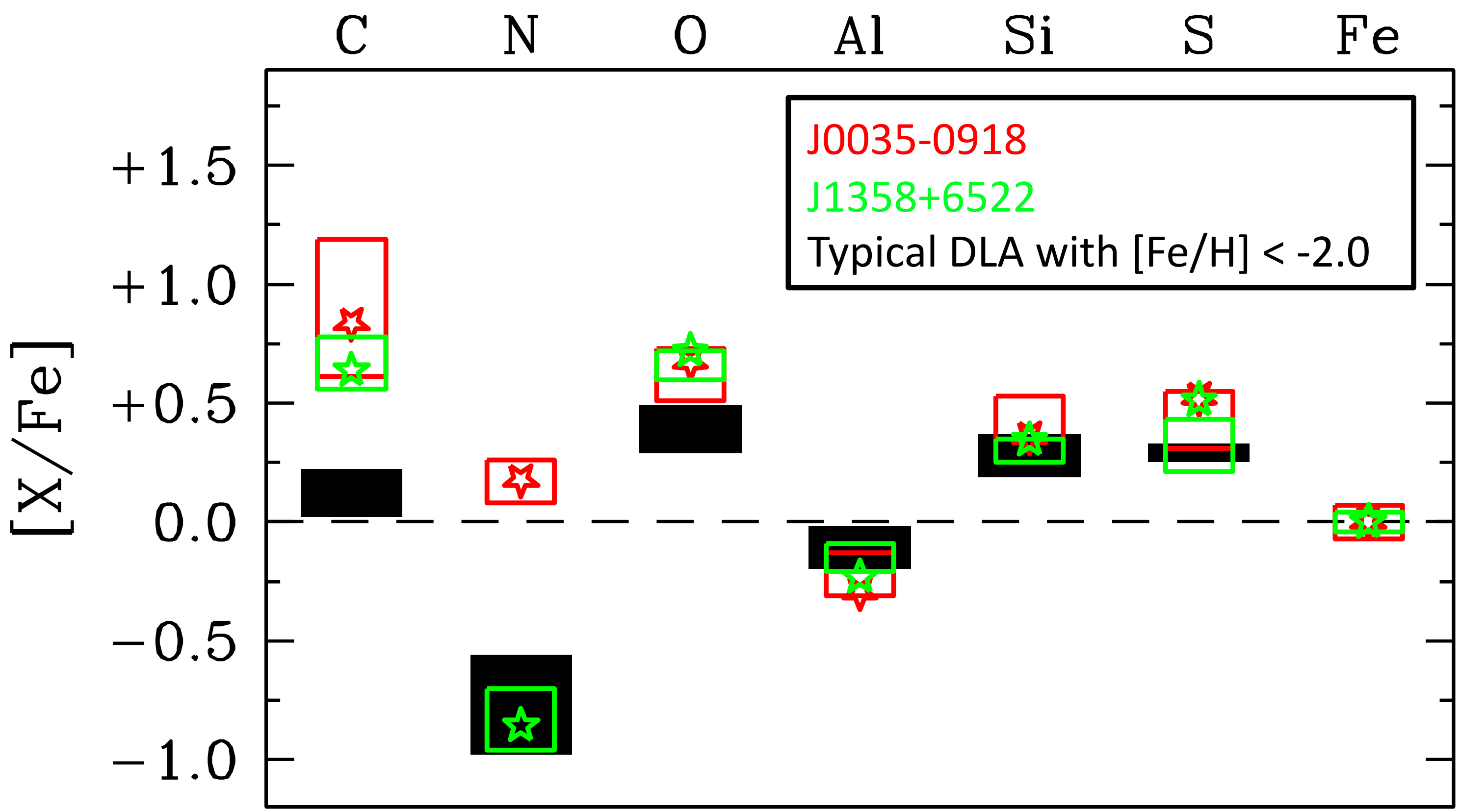


2 DLAs enhanced in C/Fe and O/Fe
Comparison with Population III star models

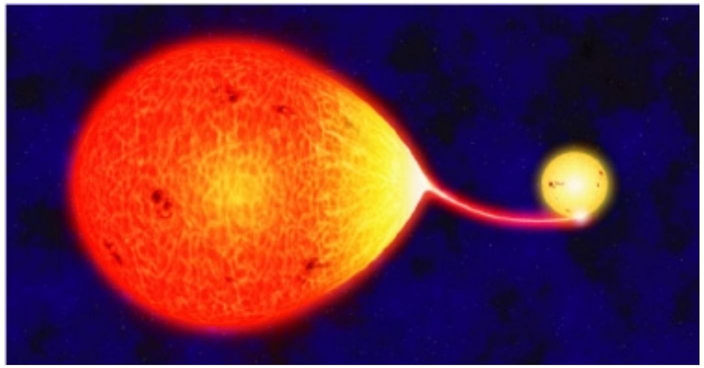
15 $M_{\odot}$ --- 1.2×10^{51} erg

17 $M_{\odot}$ --- 1.4×10^{51} erg

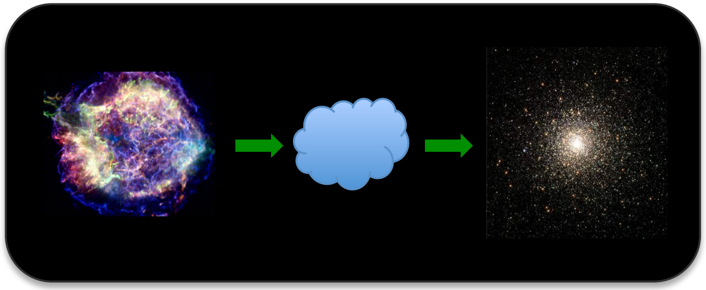
Heger & Woosley (2010) ApJ, 724, 341



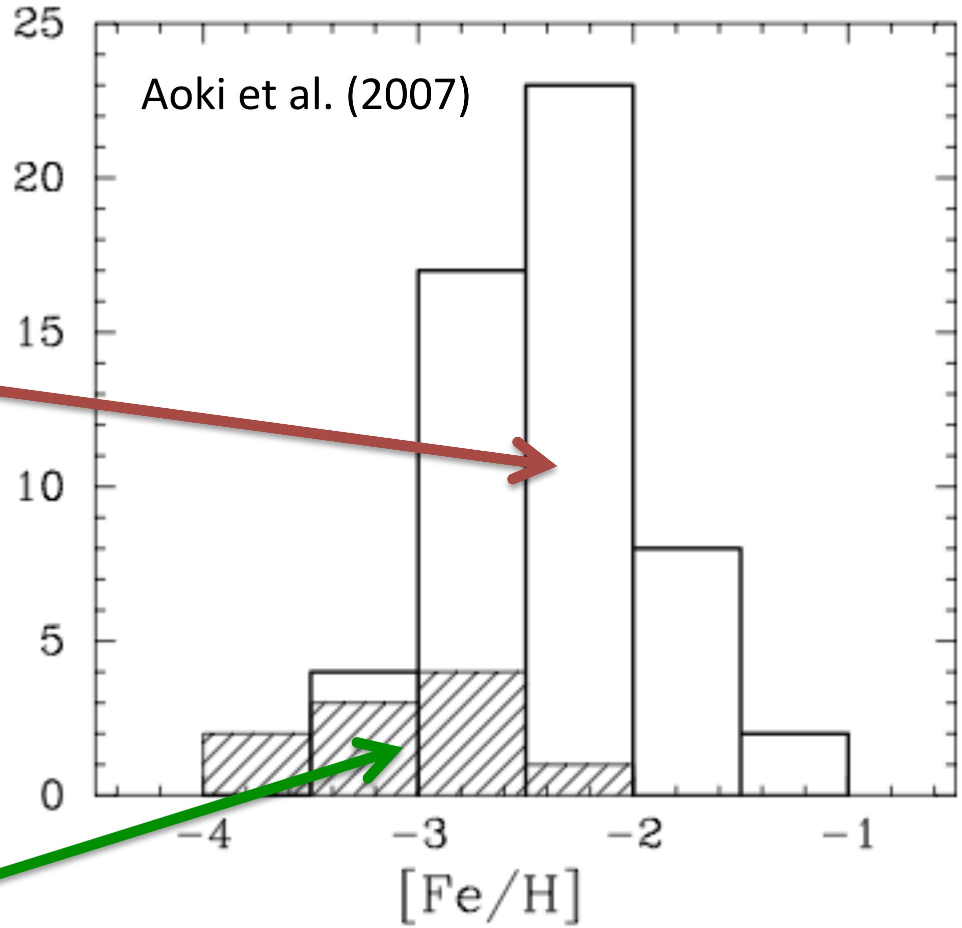
The link to
Carbon-Enhanced Metal-Poor (CEMP) stars



Also enhanced in s-process elements



No enhancement of s-process elements



Energy released by early Type II supernovae

Cooke et al. (2013), MNRAS, 431, 1625

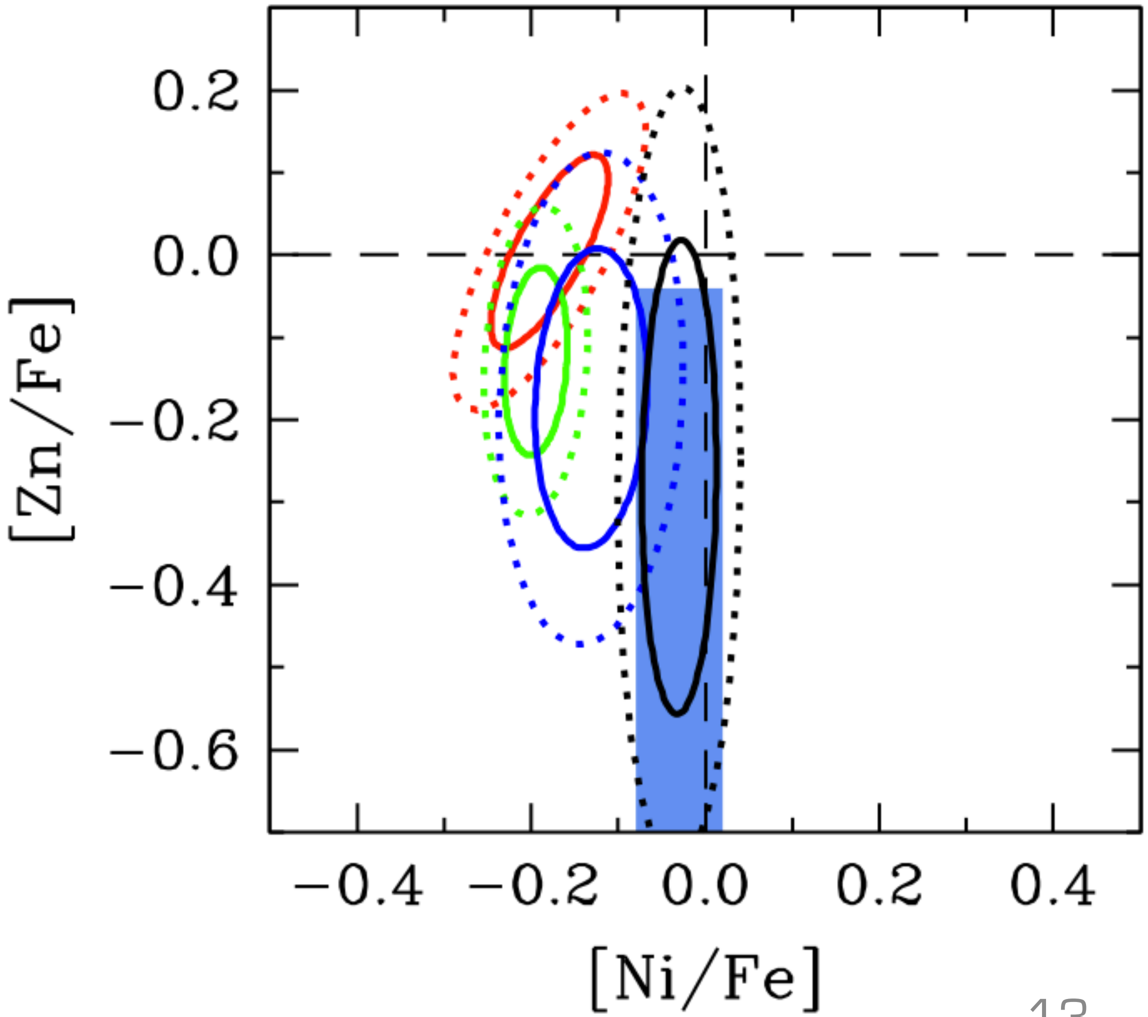
= Hypernovae

= High energy

= Typical

= Low energy

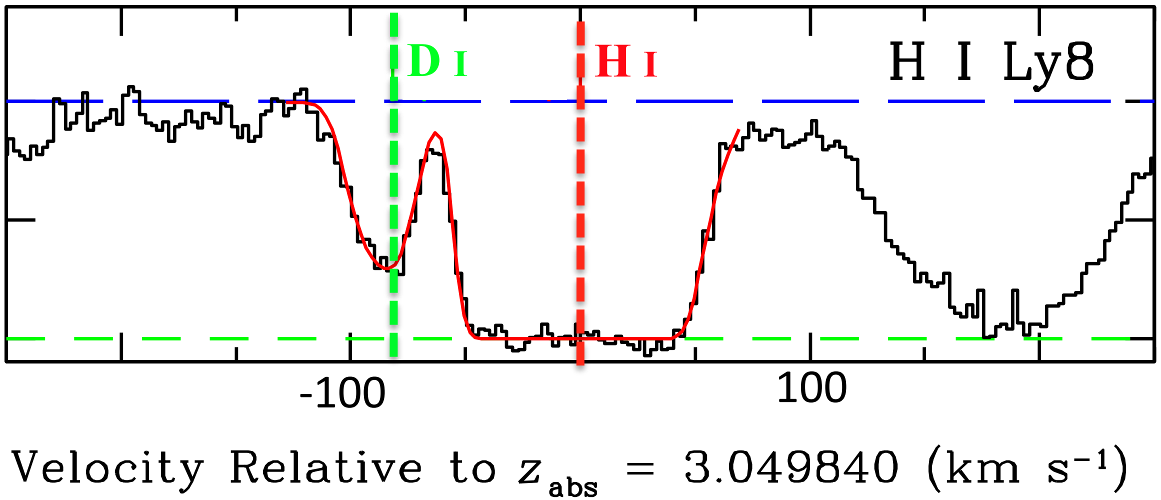
= Observations



Precision estimates of D/H

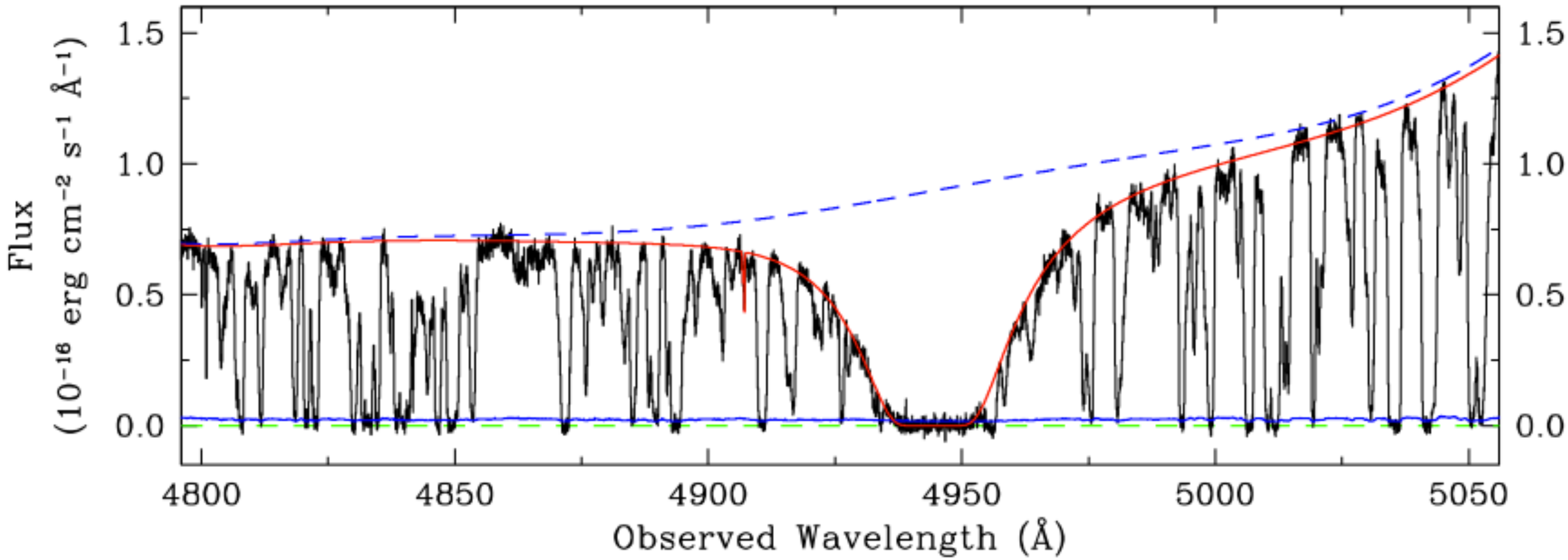
Potentially the best systems are the most metal-poor DLAs

- Ease of measuring the H I column density from the wings of the damped Lyman-α line.
- Many transitions available for the D I Lyman series to measure deuterium column density
- Low metallicity implies negligible D astration
- Quiescent kinematics help to resolve the 82 km/s isotope shift



A new system with D/H

Cooke et al. (2013) ApJ submitted (arXiv: 1308.3240)



log N(H I)/cm^{-2} = 20.49 ± 0.01

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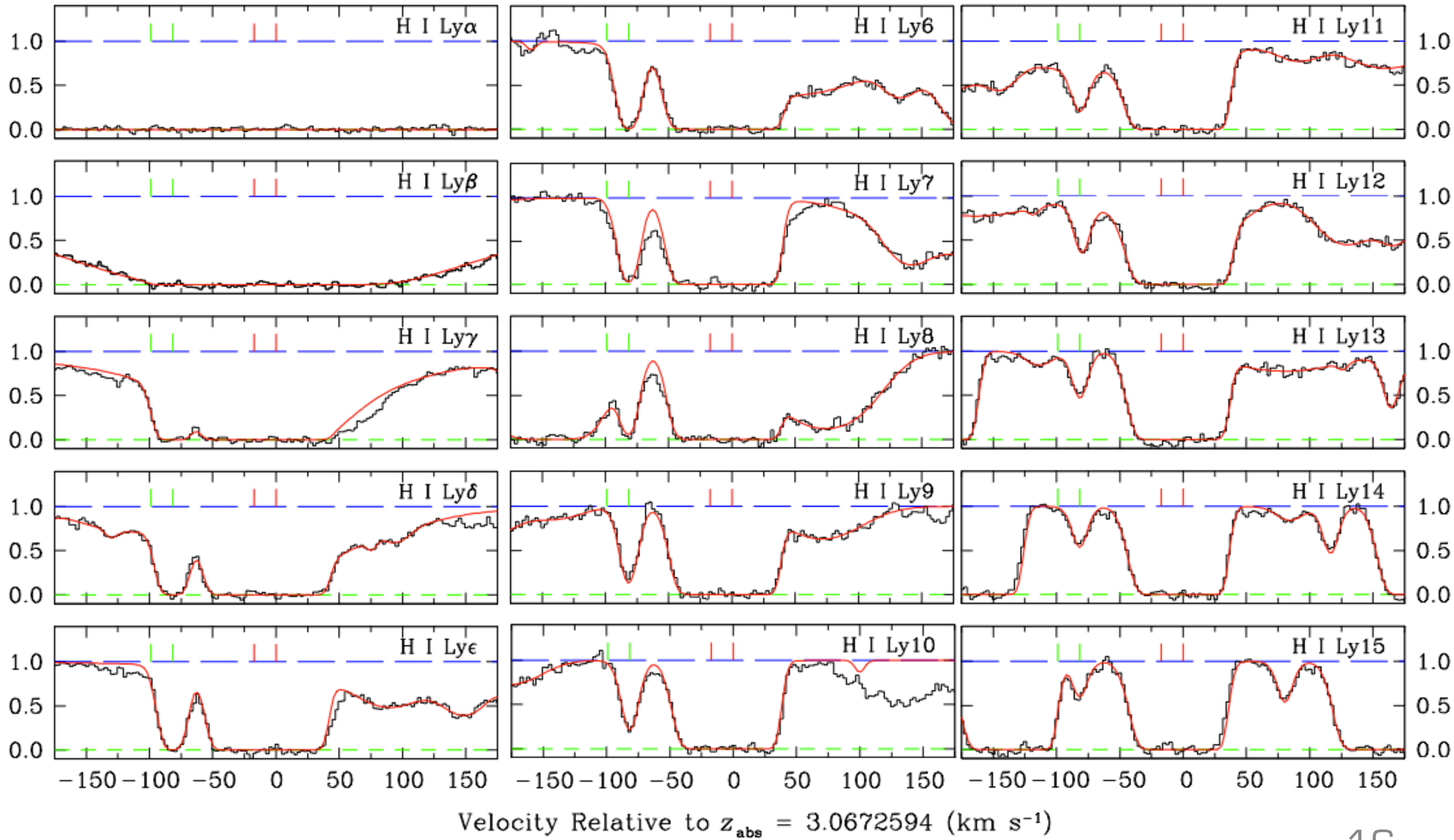
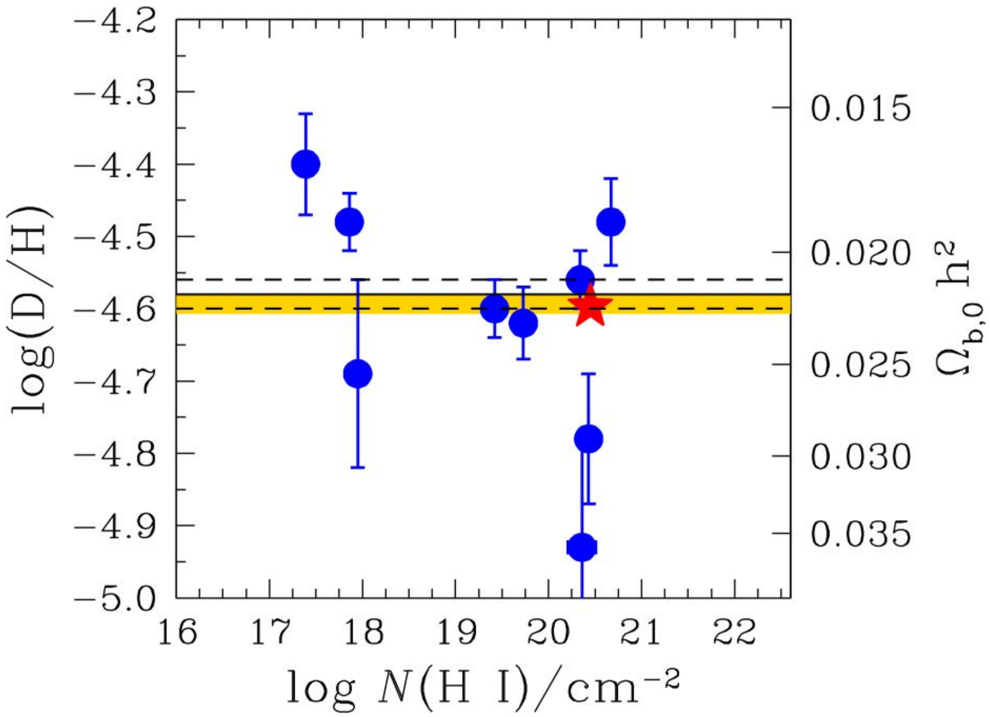


Precision Estimates of D/H

Why is there an excess dispersion in D/H measures?

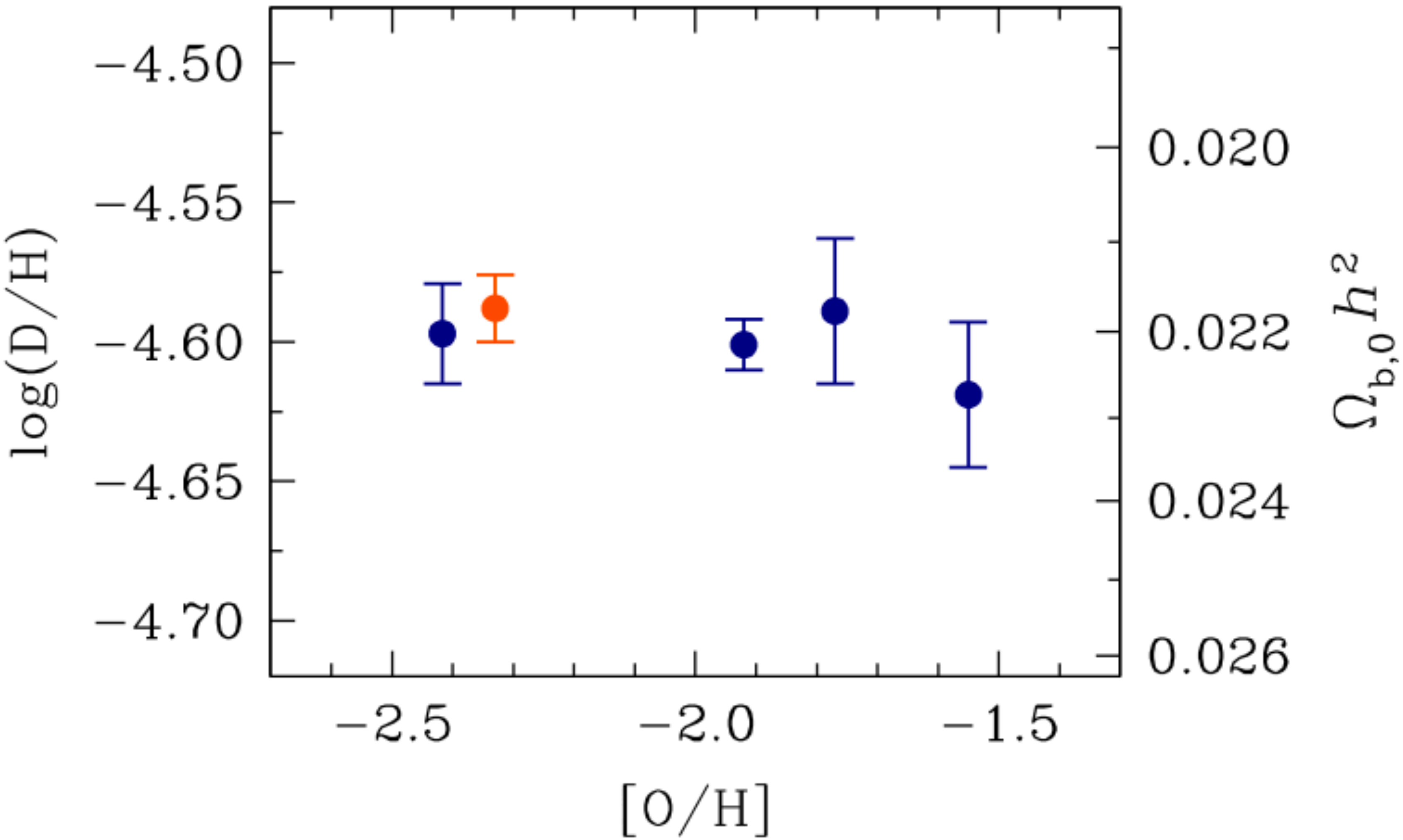
- Careful modeling of the QSO continuum+emission lines
- Blind analysis technique
- Full accounting of the dominant systematics
- Simultaneous fit all of the important parameters



ALIS – Absorption LIne Software

- Simultaneously fit emission and absorption lines
- Fits D/H directly
- Chi-squared minimization
- Calculates the systematic uncertainties in zero-level and continuum choice
- Multiprocessed

Precision Measures of D/H



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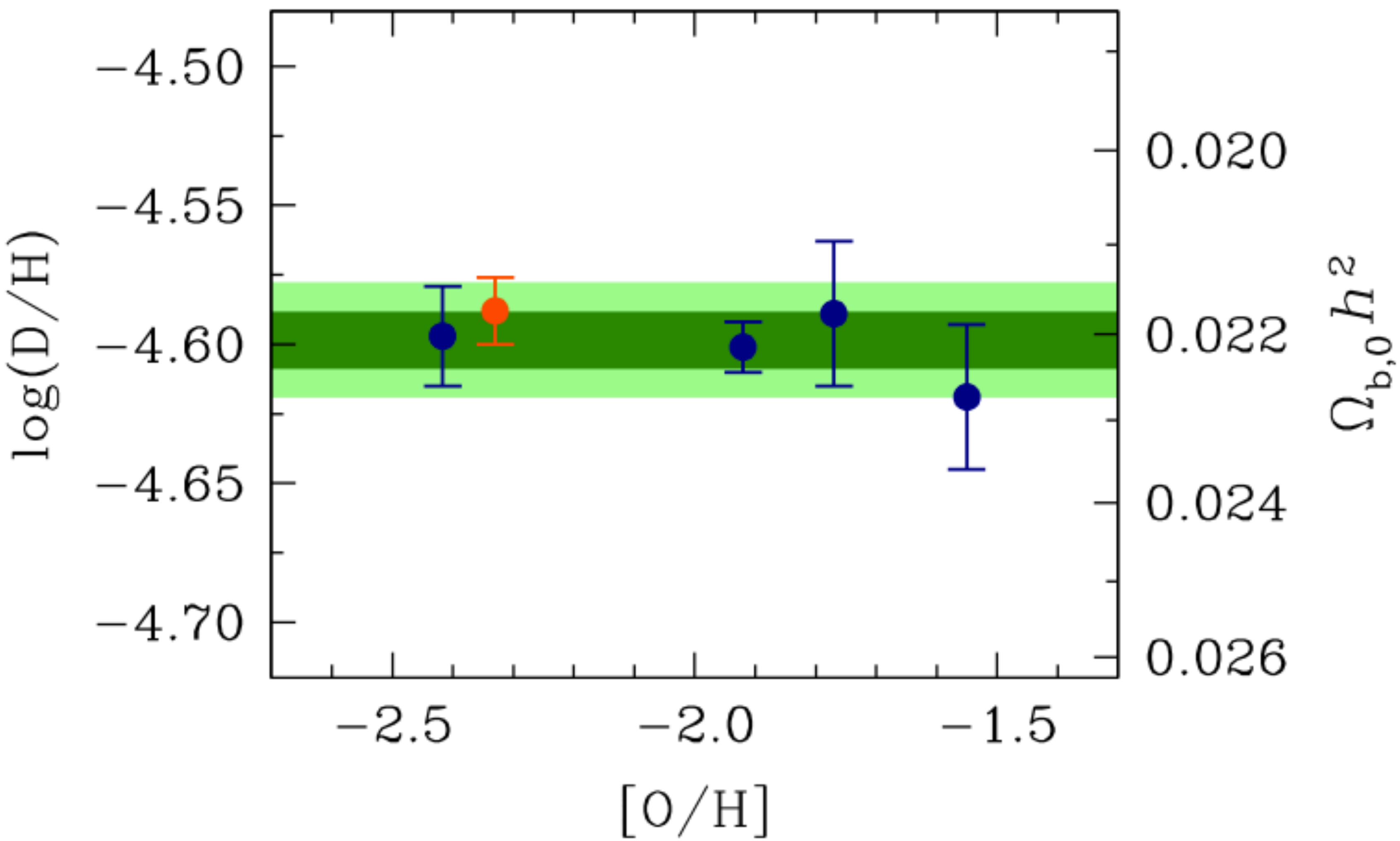
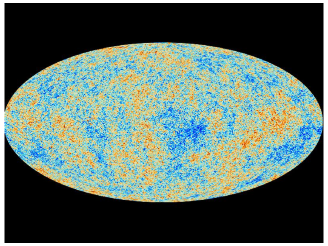


The baryon density

ASSUMING STANDAND BIG BANG NUCLEOSYNTHESIS

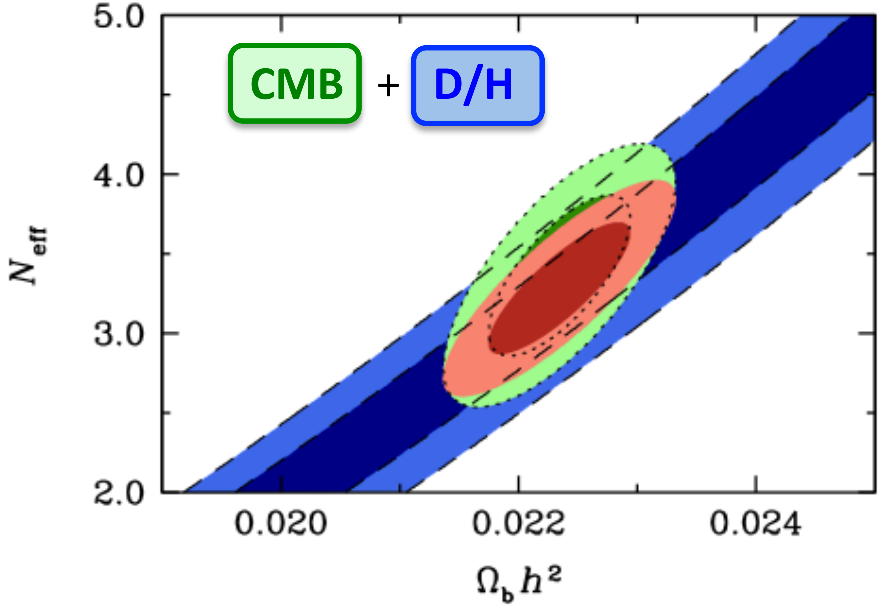
$$100\ \Omega_{b,0}\, h^2(\mathrm{BBN}) = 2.202 \pm 0.045$$

$$100\ \Omega_{b,0}\, h^2(\mathrm{CMB}) = 2.205 \pm 0.028$$

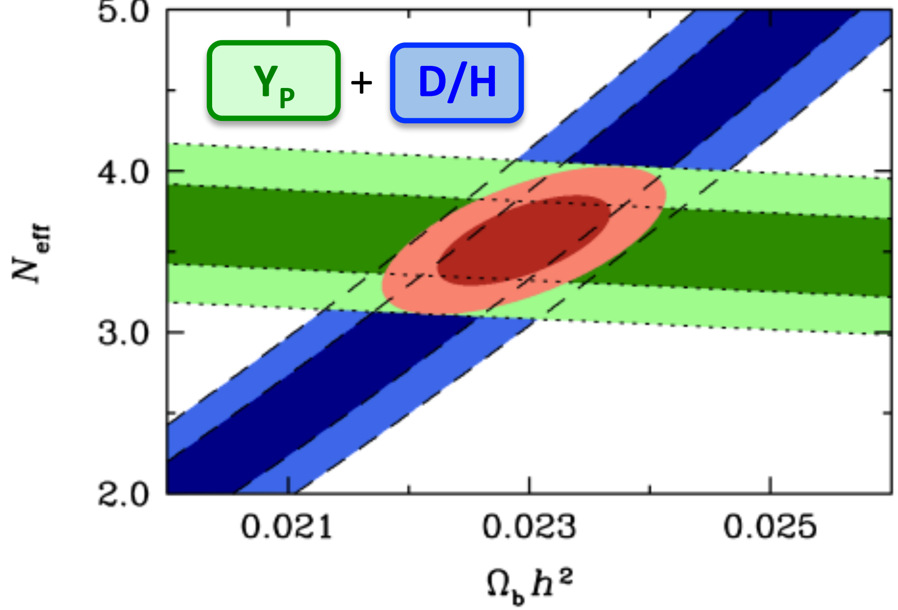


New physics?

CMB+BBN



BBN only

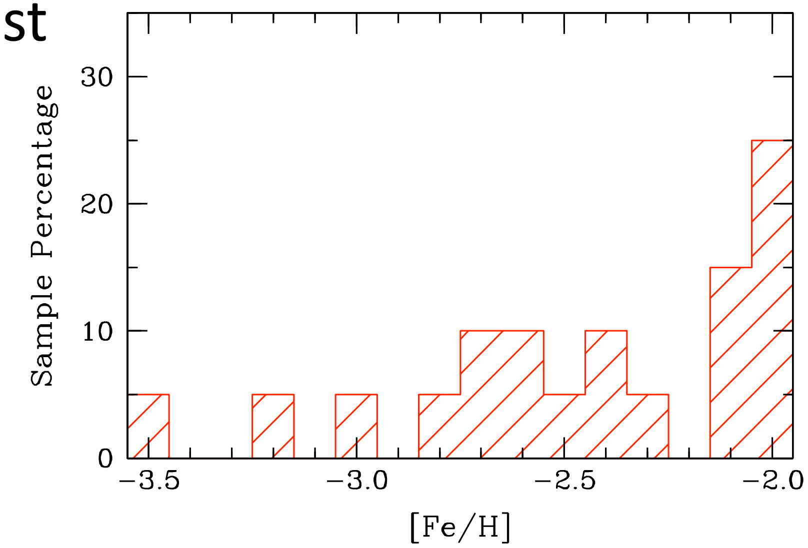


$$N_{eff} = 3.28 \pm 0.28$$

$$N_{eff} = 3.57 \pm 0.18$$

Summary and Conclusions

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



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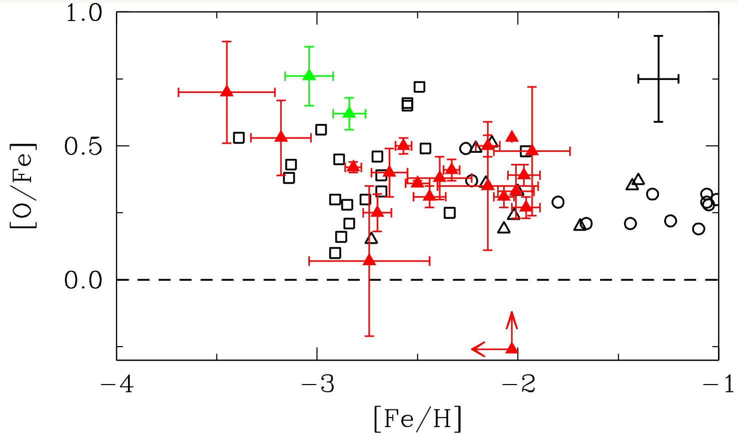

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- [O/Fe] exhibits a flat plateau of +0.40

  - New light on the much-debated trend of [O/Fe] in the low metallicity regime
  - Stars and DLAs are in good agreement when [Fe/H] < -1.0
  - Tentative evidence for an increase in [O/Fe] when [Fe/H] < -3.0

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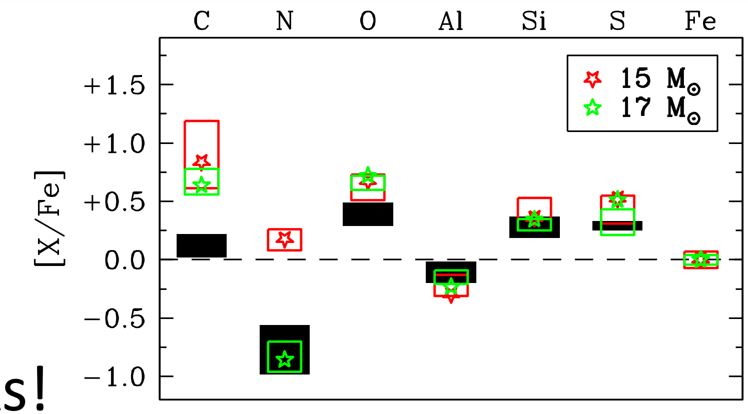
- Reported the discovery of CEMP DLAs!



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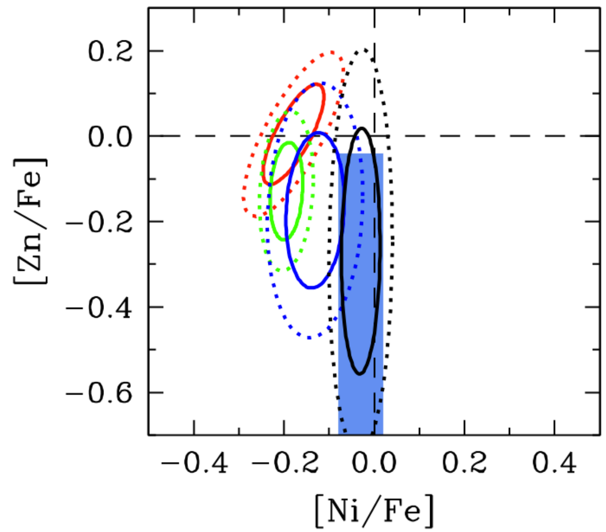

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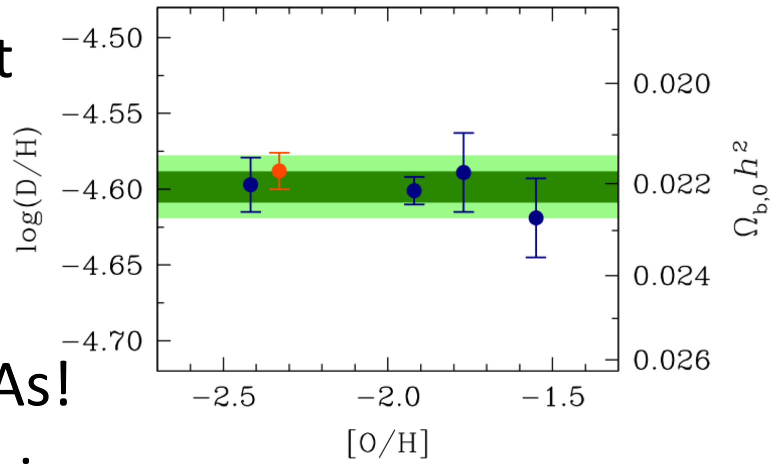

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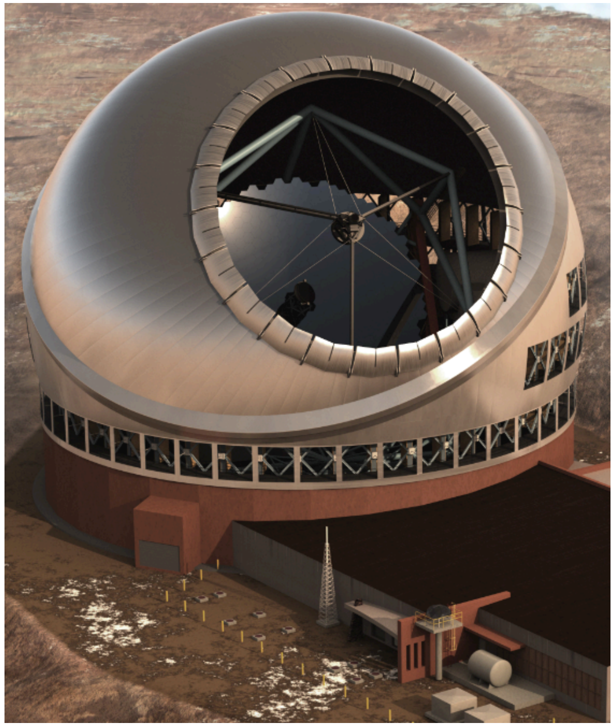

- The most metal-poor DLAs are ideal environments to probe early nucleosynthesis at the lowest metallicities