Near-Pristine Gas at High Redshifts: Prospects for the E-ELT
One approach: Galactic `archaeology'
[Fe/H] = 0.0
[Fe/H] = -1.6
[Fe/H] = -3.2
[Fe/H] = -5.4
Studying the First Stars

Grief et al. (2008)
`Damped Ly α systems’ (DLAs) ≡ neutral gas of high density.
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Ideal for accurate measures of physical properties.
'Damped Ly $\alpha$ systems' (DLAs) ≡ neutral gas of high density.

✓ Ideal for accurate measures of physical properties.

✓ Highly complementary to local stellar studies.
The metal-poor DLA survey

22 DLAs with $[\text{Fe/H}] < -2$

C, N, O abundances in the metal-poor regime

Cooke et al. 2011, 12
The metal-poor DLA survey

22 DLAs with $[\text{Fe/H}] < -2$

C,N,O abundances in the metal-poor regime

Cooke et al. 2011, 12
The “Oxygen Problem”

- OH UV: Suffers large 3D (+ not-LTE?) effects
- O I 777nm triplet: Suffers 3D + non-LTE effects
- OH IR: Suffers large 3D (+ not-LTE?) effects
- [O I] 6300 Å: Small 3D corrections, weak at low Z

[O/Fe] vs [Fe/H] graph:

- OH UV
- O I 777nm triplet
- OH IR
- [O I] 6300 Å

The graph illustrates the relationship between oxygen abundance ([O/Fe]) and metallicity ([Fe/H]).
[O/Fe] ≈ stellar IMF
The O/Fe ratio at low metallicity

For [Fe/H] < -2, halo stars and DLAs are indistinguishable in [O/Fe] when stellar [O/H] is measured from [O I] $\lambda$6300 line.
The O/Fe ratio at low metallicity

- DLAs exhibit surprisingly little dispersion
- \([\text{O/Fe}]\) in DLAs agree well with that from stars in the halo of our Galaxy.
- DLAs are helping to resolve this much debated trend below \([\text{Fe/H}] < -1.0\)

**Two main results:**

1) \([<\text{O/Fe}>] \approx +0.35\)
2) Tentative evidence for a slight increase in \([\text{O/Fe}]\) when \([\text{Fe/H}] < -3.0\)
CEMP STARS

CEMP-no STARS

Pop III SN

Pop II CEMP halo star
CEMP STARS

CEMP-no STARS

Cooke et al. 2011a

CEMP DLAs

Pop III SN

Pop II CEMP halo star
Nucleosynthesis of Nitrogen

N and O Abundances in H II regions and DLAs

\[ \log \left( \frac{N}{O} \right) \]

\[ \log \left( \frac{O}{H} \right) + 12 \]
1. $p \rightarrow n$
2. $p(n, \gamma)d$
3. $d(p, \gamma)^3\text{He}$
4. $d(d, n)^3\text{He}$
5. $d(d, p)t$
6. $t(d, n)^4\text{He}$
7. $t(\alpha, \gamma)^7\text{Li}$
8. $^3\text{He}(n, p)t$
9. $^3\text{He}(d, p)^4\text{He}$
10. $^3\text{He}(\alpha, \gamma)^7\text{Be}$
11. $^7\text{Li}(p, \alpha)^4\text{He}$
12. $^7\text{Be}(n, p)^7\text{Li}$
J1419+0829, z = 3.050, Fe/H = 1/200 solar
J1419+0829, $z = 3.050$, Fe/H = 1/200 solar
J1419+0829, z = 3.050, Fe/H = 1/200 solar
Spectral analysis tailored specifically to the determination of D/H and its error

Component 1

\[ \log N(\text{H I}) = 20.231 \]

\[ z_{\text{abs}} = 3.049840 \]

\[ b_{\text{turb}} = 5.26 \text{ km/s} \]

\[ T_{\text{DLA}} = 1.13e+04 \text{ K} \]

Component 2

\[ \log N(\text{H I}) = 19.880 \]

\[ z_{\text{abs}} = 3.049654 \]

\[ b_{\text{turb}} = 2.25 \text{ km/s} \]

\[ T_{\text{DLA}} = 9.98e+03 \text{ K} \]
\[(D/H)_{DLA} = (2.53 \pm 0.05) \times 10^{-5}\]

(Random + Systematic Error)
$100 \Omega_{b,0} h^2 (BBN) = 2.23 \pm 0.09$

(Random + Systematic Error)
$100 \Omega_{b,0} h^2 (\text{CMB}) = 2.22 \pm 0.042$
$N_\nu = 3.0 \pm 0.6$
Why the E-ELT?
Oldest stars
Oldest stars

Metal-poor DLAs
Oldest stars

Metal-poor DLAs

Light Elements
Oldest stars

Metal-poor DLAs

Light Elements

Photon Starved
QSO Luminosity Function

Glikman et al. 2011

$\Phi^*: 1.3^{+1.8}_{-0.2} \times 10^{-6}$

$\alpha: -3.3^{+0.2}_{-0.2}$

$\beta: -1.6^{+0.8}_{-0.6}$

$M^*: -24.1^{+0.7}_{-1.9}$
QSO Luminosity Function

$\Phi^*: 1.3^{+1.8}_{-0.2} \times 10^{-6}$

$\alpha: -3.3^{\pm 0.2}$

$\beta: -1.6^{+0.8}_{-0.6}$

$M^*: -24.1^{+0.7}_{-1.9}$

Glikman et al. 2011
Glikman et al. 2011

QSO Luminosity Function

\[ \phi(M_{1450}, \text{Mpc}^{-3} \, \text{mag}^{-1}) \]

\[ \phi^* = 1.3^{+1.8}_{-0.2} \times 10^{-6} \]

\[ \alpha = -3.3^{+0.2}_{-0.2} \]

\[ \beta = -1.6^{+0.8}_{-0.6} \]

\[ M^* = -24.1^{+0.7}_{-1.9} \]

Glikman et al. 2011
8 SDSS QSOs with $z \geq 2, r \leq 18$
~ 1000 SDSS QSOs with $z \geq 2, r \leq 21$
Here's an example:

$J153219.56+171734.4$, $m_r=19.8$, $z_{em}=2.6$, $\log N(H \ I)/cm^{-2}=20.1$

Velocity Relative to $z_{abs} = 2.483 \ (\text{km s}^{-1})$
Here's an example:

J153219.56+171734.4, $m_r = 19.8$, $z_{em} = 2.6$, $\log N(\text{H I})/\text{cm}^{-2} = 20.1$

Velocity Relative to $z_{abs} = 2.483$ (km s$^{-1}$)
Here's an example:

\[ J_{153219.56+171734.4}, \quad m_r = 19.8, \quad z_{em} = 2.6, \quad \log N(\text{H I})/\text{cm}^{-2} = 20.1 \]

Too faint for 8–10 m!
Full Chemical Fingerprints in MW Stars with [Fe/H] < -5
Full Chemical Fingerprints in MW Stars with $\text{[Fe/H]} < -5$

Fe-peak element ratios at $\text{[Fe/H]} < -3$
Full Chemical Fingerprints in MW Stars with [Fe/H] < -5

Fe-peak element ratios at [Fe/H] < -3

Significantly more precise measures of $\Omega_b(BBN)$
The Future