Metals in the Low-redshift Universe:
From Galaxies to the Intergalactic Medium

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Science Driver: Enrichment of IGM

- **CIV in z < 1 IGM**
  - Measure $\Omega_{\text{CIV}}$

- IGM-galaxy connection
  - Compare abundances

(Plotted points normalized to same $H_0$)
CIV Sample

- 48 lines of sight
- Blind CIV search
  - Ultimately, $W_r \geq 3\sigma$ for both lines
  - $dN/dX = 4.2$
  - $(W_{r,\text{CIV 1548}} \geq 52 \text{ mÅ})$

<table>
<thead>
<tr>
<th>Group</th>
<th>$N$</th>
<th>$W_r \geq 3\sigma$</th>
<th>Unsat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Definite</td>
<td>49</td>
<td>42</td>
<td>27</td>
</tr>
<tr>
<td>Likely</td>
<td>19</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>68</td>
<td>47</td>
<td>32</td>
</tr>
</tbody>
</table>

- Danforth & Shull 2008
- Frye+ 2003
Example CIV: Consensus at $z \leq 0.1$

- Agree with Frye+ 2003 and Danforth & Shull 2008
Example CIV: Consensus at $z > 0.4$

- Agree with Milutinovic+ 2007
Example CIV: New at $z < 1$

- Sightlines not in other studies at $z < 1$
Example CIV: GHRS Detections

However, CIV 1550 < 3σ

(See e.g., Thom & Chen 2006 or poster 482.07)
Lyα Contamination

- Fraction of CIV sample that are coincident Lyα forest lines

(Compliments of Chris & Hsiao-Wen)
Frequency Distribution

- $\alpha \approx -1.5$ for $z < 1$
  - Fit to 27 definite C\textsc{iv} (red) and 32 total (gray)

- $\alpha = -1.7$ for $z < 0.6$
  - Similar to Danforth & Shull 2008 ($\alpha = -1.79$)

- $\alpha = -1.3$ for $z \geq 0.6$
  - Lower than high-z studies ($\alpha \approx -1.44$)
CIV Mass Density: Over Redshift

(Plotted points normalized to same $H_0$)
CIV Mass Density: Over Time

(Plotted points normalized to same $H_0$)
IGM-Galaxy Connection

- Galaxies close to LOS
  - ρ < 150 kpc; |δv| < 500 km/s
- Follow-up LRIS spectra
  - 3 galaxies close to 2 published log N_{HI} > 15 metal-line systems
- Measure IGM and galaxy abundances
  - IGM: CLOUDY
  - Galaxy: EZ_Ages

Inset: ACS image (Jenkins et al 2005)

Blue: FJ2155-092: galaxies with |δv| < 500 km/s of z_{LLS} = 0.08092
IGM-Galaxy Metals Connection?

FJ2155: $z_{\text{LLS}} = 0.08092 \log N_{\text{HI}} = 18$

PG1116: $z_{\text{abs}} = 0.13847 \log N_{\text{HI}} = 16.2$
Summary

- $\Omega_{\text{CIV}}$ at $z < 1$ consistent with $z > 1.5$
- $[\text{C/N}]_{\text{gal}}$ mimic $[\text{C/N}]_{\text{IGM}}$ in one system

(Plotted points normalized to same $H_0$)
CIV without Ly\(\alpha\)

- Purpose of blind survey
- Are these believable?
## Galaxy Metallicities

<table>
<thead>
<tr>
<th></th>
<th>PG1116: log $N_{\text{HI}} = 16.2$</th>
<th>FJ2155: log $N_{\text{HI}} = 18$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho$ (kpc)</td>
<td>129</td>
<td>100</td>
</tr>
<tr>
<td>Age (Gyr)</td>
<td>$8.8 \pm 2.9$</td>
<td>$15.1 \pm 3.4$</td>
</tr>
<tr>
<td>$[\text{Fe/H}]$</td>
<td>$-0.03 \pm 0.11$</td>
<td>$-0.31 \pm 0.08$</td>
</tr>
<tr>
<td>$[\text{C/N}]$</td>
<td>$0.17 \pm 0.21$</td>
<td>$0.36 \pm 0.27$</td>
</tr>
</tbody>
</table>

(z thanks to Arjen van der Wel)

(Beware: AGN!)