Using DLAs to Study the Physical Conditions of Gas in High Redshift Galaxies

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IGM Workshop Heidelberg - June 17, 2014
Goal: To measure the temperature ($T$), electron density ($n_e$) and hydrogen density ($n_H$) of DLAs
Neutral gas in thermodynamic equilibrium will naturally divide itself into a cold neutral phase (CNM) and warm neutral phase (WNM) (Field+69)

CNM: $T < 500K$

WNM: $500K < T < 10^4K$

Understanding this picture at high $z$ requires measurements of $T$ and $n_H$
Previous Studies

21cm Absorption

\[ N_{\text{HI}} = C_0 \times T_s \times \int \tau_{21\text{cm}} \, dV \]

- Able to measure the spin temperature of the gas
- Result: gas in DLAs is mostly consistent with WNM, not CNM
- Drawbacks: only works for radio-loud quasars

Kanekar+14
Cl Fine-Structure lines

- Able to measure the spin temperature and density of the gas

- Result: gas from DLAs with Cl is almost all CNM.

- Drawbacks: only gives temperature of gas that shows Cl, which is not tracing the typical gas in a DLA
‘New’ Technique

Measure the fine structure column density of CII*, Sill*, and Sill

Ratios of these lines are determined by $T$, $n_H$, $n_e$

example case: J1417+4132
‘New’ Technique

Sill*/CII* technique

Assume that:

- The gas is in excitation equilibrium

then:

$$\sum_j n_j Q_{ji} = n_i \sum_j Q_{ij}$$

$$Q_{ij} = A_{ij} + B_{ij} u_{ij} + \Gamma_{ij} + \sum_k n^k q_{ij}^k$$

Under 30000K, both Si^+ and C^+ can be approximated by a two-level atom

$$\frac{n_2}{n_1} = \frac{B_{12} u_{\nu 12}(z) + \Gamma_{12} + \sum_k n_k \gamma_{12}^k}{A_{21} + B_{21} u_{\nu 12}(z) + \Gamma_{21} + \sum_k n_k \gamma_{21}^k}$$

$$\gamma_{12}^k \propto \gamma_{21}^k \exp\left(-kT_{12}/kT\right) \propto \Omega_{12}^k(T)T^{-1/2} \exp\left(-kT_{12}/kT\right)$$
‘New’ Technique

SII*/CII* technique

Assume that:

- The gas is in collisional excitation equilibrium
- Si$^+$ and C$^+$ trace the same gas

then:

$$\frac{n_2}{n_1} = \frac{B_{12} u_{v_{12}}(z) + \Gamma_{12} + \sum_k n_k \gamma_{12}^k}{A_{21} + B_{21} u_{v_{12}}(z) + \Gamma_{21} + \sum_k n_k \gamma_{21}^k}$$

holds for both Si and C, with same value of $z$, $T$, $n_H$, and $n_e$
‘New’ Technique

SII*/CII* technique

Assume that:
- The gas is in collisional excitation equilibrium
- Si\(^{+}\) and C\(^{+}\) trace the same gas
- \(\frac{N_2}{N_1} = \frac{n_2}{n_1}\)

\[
\frac{N_2}{N_1} \approx \frac{\int n_2 \, ds}{\int n_1 \, ds} = \frac{\int \frac{n_2}{n_1} \, n_1 \, ds}{\int n_1 \, ds}
\]

True if a DLA is a single uniform cloud
This is a swindle, or at least an oversimplification.
or is it?
'New' Technique

SiII*/CII* technique

Assume that:

- The gas is in collisional excitation equilibrium
- \( \text{Si}^+ \) and \( \text{C}^+ \) trace the same gas
- \( \text{N}^*/\text{N}=\text{n}^*/\text{n} \)
- The gas is neutral

\[
\frac{N_2}{N_1} = \frac{B_{12} u_{\nu 12}(z) + \Gamma_{12} + \sum_k n_k \gamma_{12}^k}{A_{21} + B_{21} * u_{\nu 21}(z) + \Gamma_{21} + \sum_k n_k \gamma_{21}^k}
\]
SiII*/CII* Technique

- Measure the column density ratios of fine structure lines of the ground state of Si$^+$ and C$^+$

- Explore the parameter space with MCMC code for acceptable solutions
The Sample

68 DLA\(s\) that have HIRES coverage of the two fine structure lines of both Si\(^+\) and C\(^+\)
The Sample

Quadruples the sample of known SiII$^*$ detections in QSO-DLAs
14 of the 68 DLAs have well-constrained $T$ and $n_H$
Data agrees very well with other methods for those DLAs for which $T$ and/or $n_H$ was measured.

<table>
<thead>
<tr>
<th>QSO</th>
<th>$z_{\text{abs}}$</th>
<th>T (K) (1–σ constraint)</th>
<th>C II* / Si II*</th>
<th>C I</th>
<th>21cm absorption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1157+014</td>
<td>1.9437</td>
<td>1023 (260-5500)</td>
<td></td>
<td></td>
<td>1015 (760-1270)</td>
</tr>
<tr>
<td>Q0336−01</td>
<td>3.0620</td>
<td>286 (28-5200)</td>
<td></td>
<td></td>
<td>&gt;8890</td>
</tr>
<tr>
<td>J0812+3208</td>
<td>2.6263</td>
<td>62 (25-178)</td>
<td>60 (32-88)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J2100−0641</td>
<td>3.0924</td>
<td>71 (30-171)</td>
<td>69 (10-251)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J2340−0053</td>
<td>2.0545</td>
<td>101 (36-375)</td>
<td>139 (55-200)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Results

Pressure

- \( \frac{P}{k_B} = nT \)

- Consistent with local pressures in the ISM (Jenkins+11)
Results

Absorption distances as small as 30 pc

Neeleman+ in prep
Is the neutral gas predominantly cold or warm in DLAs?

- 2 out of the 23 DLAs has significant fraction of CNM (Kanekar+14)
Results

Is the neutral gas predominantly cold or warm in DLAs?

- 2 out of the 23 DLAs has significant fraction of CNM (Kanekar+14)

- taking into account the bias in our sample we find that at least 10% of DLAs have significant fractions of CNM
Results

Fine-structure to low-ion ratios is similar for all components
Results

- Analysis of the individual components show little variation between the components.

- However, does show variation between individual DLAs
A new method was presented to measure the physical properties of DLAs which unlike other methods traces the bulk of the metals in DLAs.

Results:

- Pressures in DLAs are similar to those seen in the local ISM
- at least 10% of DLAs contain a large fraction of cold gas (T<500K)
- Clumps in DLAs can be as small as 30pc
- individual velocity components seem to have similar properties in a single DLA, but those properties can vary between DLAs