Empirical Constraints on the Cool Gas Content of Dark Matter Halos

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Great Lakes Cosmology Workshop
Chicago, 16 June 2010
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For lower-mass halos at low z, see poster by Jennifer Helsby

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Cold Gas Accretion on Dark Matter halos

Accretion of cool, T $\sim 10^4$ K gas, is inefficient in massive halo
Exploring the cool gas content of dark matter halos

(using QSO absorption line clustering)

• Taking advantage of the large data sample of SDSS
• Need a tracer/indicator of cool gas in halos: MgII absorbers in background QSO spectra
• Need a tracer of dark matter density field: Luminous Red Galaxies
MgII absorbers as a tracer of cool gas

- MgII λλ 2796, 2803 absorption doublet is commonly seen in QSO spectra

- Absorbers arise in photo-ionized gas of $T \sim 10^4$ K and trace high-column density HI clouds with $N(\text{HI}) \approx 10^{18} - 10^{22}$ (Bergeron & Stasínska 1986; Rao et al. 2006)

- Large HI column density suggests that MgII absorbers originate in halo gas around individual galaxies (Doyle et al. 2005).

- Many luminous galaxies have been found at projected distances $\rho = 50 - 100 \, h^{-1} \, \text{kpc}$ from known MgII absorbers. (Bergeron 1986; Lanzetta & Bowen 1990, 1992; Steidel et al. 1994; Zibetti et al. 2005, 2007; Nestor et al. 2007; Kacprzak et al. 2007).
LRGs are “red and dead” early-type massive galaxies. They constitute a homogeneous non-evolving population of galaxies. Luminous \( \rightarrow \) can be detected to high \( z \).

- known to inhabit massive halos and are good tracers of the large-scale cosmic structures.
- Their strong 4000Å break allows for reliable photometric redshift estimates.
Cool gas in massive halos: the clustering of MgII absorbers

Gauthier et al. (2009)

Cross-correlation MgII - LRGs at $z \sim 0.5$

see also Bouché et al. (2006) and Lundgren et al. (2009)
From the bias of LRGs to the bias of the absorbers hosts

1) compute the relative bias of your absorber hosts by computing the ratio between correlation functions on large scales

\[ \hat{b} \equiv \frac{b_a}{b_g} = \frac{w_{ag}}{w_{gg}}, \]

2) you know bias of LRGs from the HOD fit. You can obtain bias of absorbers hosts.
Clustering of MgII absorbers at $z \sim 0.5$

The main results of the clustering analysis

<table>
<thead>
<tr>
<th>$W_r(1-1.5)$</th>
<th>$W_r(1.5-5)$</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW</td>
<td>log $M_h$</td>
<td></td>
</tr>
<tr>
<td>$W_r(1-1.5)$</td>
<td>$13.0^{+0.4}_{-0.6}$</td>
<td>$12.6^{+0.4}_{-0.6}$</td>
</tr>
<tr>
<td>$W_r(1.5-5)$</td>
<td>$11.9^{+0.8}$</td>
<td></td>
</tr>
</tbody>
</table>

On average, stronger absorbers are unbiased. Weaker ones are preferentially found in more massive halos.
THE INCIDENCE OF COOL GAS IN $\sim 10^{13} \, \text{M}_\odot$ HALOS

Jean-René Gauthier$^{2,3}$, Hsiao-Wen Chen$^{2}$ and Jeremy L. Tinker$^{4}$

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Spectroscopic follow-up of LRGs around QSO sightlines

- 15 LRG spectra
- Isolated LRGs
- 5 physical MgII-LRG pairs ($\rho < 300$ kpc/h, $|\Delta v| < 350$ km/s)
- $\text{Wr}(2796) > 0.6$ Å
The incidence of cool gas in $\sim 10^{13} \, M_{\text{sun}}/h$

The 5 physical pairs

![Graph showing relative flux ($f_\lambda$) vs. wavelength (Å) for five physical pairs of LRGs and QSOs, with absorption lines and velocity separations marked.](image)

- **Relative Flux ($f_\lambda$)**: Y-axis from 0 to 1, showing the integrated flux levels.
- **Wavelength (Å)**: X-axis ranging from 6000 to 8000 Å.

**Key Features**:
- **Absorption Lines**: H$\alpha$, H$\beta$, [C II], [O III], Mg.
- **Velocity Separations**: Marked for each LRG-QSO pair with velocity differences indicated.
- **Sample B**:
  - SDSSJ142610.27+060748.6
  - SDSSJ113731.00+060748.6
  - SDSSJ160725.87+471221.7
  - SDSSJ003816.29-092550.5
  - SDSSJ083417.55+354833.5
- **Projected Distances**:
  - For each pair, the projected distance to the QSO sightline is listed.
  - E.g., 157 kpc/h (for SDSSJ142610.27+060748.6).
- **Redshifts**:
  - Indicated for each LRG-QSO pair, such as z=0.5409 (for SDSSJ142610.27+060748.6).

**Gauthier et al. (2010)**

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The thumbnail images are reproduced from the SDSS data archive to show the relative alignment and contaminating sky lines or artifacts.
The origin of cool gas in $\sim 10^{13} \, M_{\odot}/h$


A stellar population synthesis of the LRGs

$\text{MgII}$ absorber found at $\rho=287 \, kpc/h$ and $|\Delta v|=350 \, km/s$

$$\chi^2_i - \chi^2_{\text{min}})/2]$$

$L = \exp[-(\chi^2_i - \chi^2_{\text{min}})/2]$
Thank You!
The incidence of cool gas in $\sim 10^{13} \, M_{\odot}/h$

A search for MgII absorbers (within $\pm 3\sigma_{Zph}$) in the QSO spectra

**Upper limits on $\kappa$**

$W_r > 0.5 \, \text{Å}$

$W_r > 1.0 \, \text{Å}$

$\kappa_{\text{max}} (\rho | W_r)$

$\rho (h^{-1} \, \text{kpc})$
The incidence of cool gas in $\sim 10^{13} \, M_{\text{sun}}/h$

A search for MgII absorbers (within +/- 3$\sigma_{Zph}$) in the QSO spectra

- $\kappa \leq 7\%$ for $W_r(2796) > 1.0$ Å
- $\kappa \leq 18\%$ for $W_r > 0.5$ Å
- Cool gas cross-section from satellite galaxies seem to be insufficient
- Correlated structures (other galaxies in the surveyed volume) contribute $\sim 3\%$
- Where does the cool gas come from?

Gauthier et al. (2010)
The incidence of cool gas in $\sim 10^{13} \, M_{\text{sun}}/h$

**Absorption profiles**

- Sample A:
  - $z_{\text{LRG}}=0.5409$
  - SDSS J142609.74+594629.5
  - SDSS J161714.12+243255.6
  - SDSS J232448.00-095142.3

- Sample B:
  - $z_{\text{LRG}}=0.5240$
  - SDSS J211626.40-062437.4

Figure 2.— Absorption profiles of the five physical LRG–Mg II absorber pairs in our spectroscopic sample of LRGs. The first four objects belong to Sample A and the last one to Sample B. We included the associated Mg I $\lambda 2852$ and Fe II $\lambda 2600$ transitions. Zero velocity corresponds to the spectroscopic redshift of the associated LRG. Contaminating features are shown in gray.

Gauthier et al. (2010)
The incidence of cool gas in $\sim 10^{13} \, \text{M}_{\odot}/h$

**Absorption profiles**

Gauthier et al. (2010)
The incidence of cool gas in $\sim 10^{13} \, \text{M}_{\odot}/h$

**Absorption profiles**

![Absorption profiles of LRG-Mg II absorber pairs](image)

- **Sample A**
  - $z_{\text{LRG}} = 0.5409$
  - SDSS J142609.74+594629.5
  - SDSS J160726.77+471251.3
  - SDSS J161714.12+243255.6
  - SDSS J232448.00-095142.3

- **Sample B**
  - $z_{\text{LRG}} = 0.5240$
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Gauthier et al. (2010)
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Absorption profiles

Fig. 2.—Absorption profiles of the five physical LRG–Mg II absorber pairs in our spectroscopic sample of LRGs. The first four objects belong to Sample A and the last one to Sample B. We included the associated Mg I $\lambda 2852$ and Fe II $\lambda 2600$ transitions. Zero velocity corresponds to the spectroscopic redshift of the associated LRG. Contaminating features are shown in gray.

Absorption profiles of DLAs? (Rao, Turnshek & Nestor 2006)

Gauthier et al. (2010)
Origin of cool baryons in dark matter halos

Galactic interactions - stripping and tidal structures

150 kpc

See also Yun et al. (1994)

See also Stephan’s Quintet

Credit: Chynoweth et al., NRAO/AUI/NSF, Digital Sky Survey.
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Origin of cool baryons in dark matter halos

Formation of a $10^{11} \, M_{\odot}$ halo at $z \sim 3$

Stripped satellite material

Agertz, Teyssier & Moore (2009)
Origin of cool baryons in dark matter halos

Formation of a $10^{11} M_{\odot}$ halo at $z \sim 3$

Shock-heated halo gas

Stripped satellite material

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Formation of a $10^{11} \, M_{\odot}$ halo at $z \sim 3$

Cold Streams

Stripped satellite material

Agertz, Teyssier & Moore (2009)