Ca II Absorbers in the Sloan Digital Sky Survey Data Release 9

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Outline

I. Introduction/Motivation
II. Survey Details
III. Statistics
IV. Imaging
V. Summary
I. Search for Ca II in the SDSS

In an SDSS spectrum:
Motivation

• Ca II $\lambda\lambda$ 3934,3969 Å gives access to the very low redshift Universe.
• It is a rare class of absorber— under-utilized, under represented and under-studied.
• Ca II absorber regions exhibit higher SFRs than other absorber regions (Zych et al 2008, Zhu & Menard 2013)
• Host galaxies as faint as $\sim0.01L^*$ can be studied with SDSS images
Search for Ca II in SDSS

1. SDSS DR9 spectroscopic QSOs brighter than $i = 20$.
2. $z_{\text{QSO}} > 0.1$
3. Exclude BAL QSOs
   (Paris et al. 2012, Shen et al. 2011)
4. Searched a total of roughly 95,000 QSOs
5. Search excludes the Ly-alpha forest
Search for Ca II in SDSS: Data Reduction Pipeline

Spectrum: wavelength, flux, error

Fit Continuum: Splines and Gaussians

Linefinder to find candidate CaII absorbers, separated \( z_{\text{QSO}} \) & \( z = 0 \) by at least 6,000 km/s

Visual inspection to remove spurious systems. Apply significance & doublet ratio cuts

= 441 candidates
Observed Redshift and Rest Equivalent Width Distributions

Stats:
Cuts: $W_0^{\lambda 3934} \geq 5\sigma$, $W_0^{\lambda 3969} \geq 2.5\sigma$,
$1-\sigma_{DR} \leq DR \leq 2+\sigma_{DR}$
Number of systems = 441

$DR = \frac{W_0^{\lambda 3934}}{W_0^{\lambda 3969}}$
Survey Sensitivity Function

\[ g(W_{0\lambda3934}, z) = \sum_{i=1}^{N_{LOS}} H(z - z_{min(i)})H(z_{max(i)} - z)H[W_{0\lambda3934} - 5\sigma_0]H[W_{0\lambda3969} - 2.5\sigma_0] \]
The Corrected Equivalent Width Distribution

Maximize Likelihood of the distribution:

\[
p(W_i; \theta) = \frac{g(W_i) f(W_i; \theta)}{\int_{W_{\min}}^{W_{\max}} g(W) f(W; \theta) dW}
\]
Corrected Rest Equivalent Width Distributions

\[
\frac{dn}{dW_0^{\lambda3934}} = \frac{N^*_{\text{weak}}}{W^*_{\text{weak}}} \exp \left( - \frac{W_0^{\lambda3934}}{W^*_{\text{weak}}} \right) + \frac{N^*_{\text{strong}}}{W^*_{\text{strong}}} \exp \left( - \frac{W_0^{\lambda3934}}{W^*_{\text{strong}}} \right)
\]

MLE Parameters:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weak</th>
<th>Strong</th>
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</thead>
<tbody>
<tr>
<td>N^*</td>
<td>0.229 ± 0.032</td>
<td>0.022 ± 0.014</td>
</tr>
<tr>
<td>W^*[A]</td>
<td>0.146 ± 0.017</td>
<td>0.359 ± 0.055</td>
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Ca II Equivalent Width Distribution
vs Mg II & C IV

\[ \log_{10}(\partial N/\partial W_0) \]

\[ W_0 [\text{Å}] \]
Evolution?

\[
\ln\left(\frac{\delta N}{\delta W_0^{\lambda 3934}}\right)
\]

Number

\[z_{\text{range}} = [0.03, 0.42)\]
\[z_{\text{range}} = [0.42, 0.72)\]
\[z_{\text{range}} = [0.72, 1.34]\]

\[
W_0^{\lambda 3934} [\text{Å}]
\]
$\log_{10}(\partial N/\partial W_0)$ vs. $W_0 [Å]$
Redshift Number Density

\[ W_0^{\text{lim}} \geq 0.3\text{Å} \]

\[ W_0^{\text{lim}} \geq 0.6\text{Å} \]

\[ W_0^{\text{lim}} \geq 1.0\text{Å} \]

\[ W_0^{\text{lim}} \geq 1.5\text{Å} \]

\[ \text{NEC} \]
Redshift Number Density: CaII vs MgII

Lookback Time, Gyr

Redshift

Lookback Time, Gyr

Redshift

Lookback Time, Gyr

Redshift
Absorber – Galaxy Connection

1. Find the average number density of galaxies around Ca II-absorbing QSOs from SDSS images as a function of angular distance, redshift and limiting magnitude

2. At $z = 0.15$, the limiting magnitude of SDSS corresponds to $L \sim 0.03L^*$

3. Background is determined from non-CaII absorbing QSOs
Lines of Sight with Absorbers

$z = [0.02, 0.05)$
Brighter than $r_{\text{SDSS}} < 19.3$

$z = [0.05, 0.08)$
Brighter than $r_{\text{SDSS}} < 20.6$

$z = [0.08, 0.11)$
Brighter than $r_{\text{SDSS}} < 21.3$

$z = [0.11, 0.12)$
Brighter than $r_{\text{SDSS}} < 21.5$

$z = [0.12, 0.14)$
Brighter than $r_{\text{SDSS}} < 21.9$

$z = [0.14, 0.15)$
Brighter than $r_{\text{SDSS}} < 22.0$
Some Ca II absorbers are Associated with very Luminous, Low-Impact Parameter Galaxies

- $z_{\text{abs}} = 0.047$
- $z_{\text{abs}} = 0.114$
- $z_{\text{abs}} = 0.113$
- $z_{\text{abs}} = 0.242$

- $L = 1.3L^*$
- $L = 1.4L^*$
- $L = 9.5L^*$

$\theta = 5''$

$\theta = 8 kpc$
$\theta = 21 kpc$
$\theta = 25 kpc$
Are all Ca II absorbers associated with moderately luminous, low-impact parameter galaxies?

No.
Cases with the Lowest Redshifts:

$z_{\text{abs}} < 0.08$

- Brighter than $0.01L^*$
- Number of Detections vs. Minimum Impact Parameter [Arcsec]

- Nearest Neighbor Luminosity [$L^*$]
- Brighter than $0.01L^*$

- Mean Luminosity = $0.15L^*$
- Median Luminosity = $0.04L^*$
- Minimum Luminosity = $0.01L^*$
- Maximum Luminosity = $1.35L^*$

- Minimum Impact Parameter [kpc]
- Brighter than $0.01L^*$

Number of Detections vs. Minimum Impact Parameter [kpc]
Ca II at $z_{abs} = 0.0655$: Where is the absorbing galaxy?

CaII Absorption Spectrum

SDSS r-band image

$S$: star-like

Arrows:
- Blue – QSO
- Red – “Galaxy”

Spectrum:

$W_{0}^{3934} = 1.1 \pm 0.2$

$W_{0}^{3969} = 0.5 \pm 0.2$

At minimum $b$:

$b_{\text{min}} \sim 43''$

$r(b_{\text{min}}) = 21.0$

$b_{\text{min}} \sim 53$ kpc

$L(b_{\text{min}}) \sim 0.03 L^*$
Ca II at $z_{\text{abs}} = 0.0636$: Where is the absorbing galaxy?

**CaII Absorption Spectrum**

- **Spectrum:**
  - $W_0^{3934} = 0.25 \pm 0.05$
  - $W_0^{3969} = 0.26 \pm 0.05$

- **At minimum $b$:**
  - $b_{\text{min}} \sim 74.6''$
  - $b_{\text{min}} \sim 90.2$ kpc
  - $r(b_{\text{min}}) = 20.7$
  - $L(b_{\text{min}}) \sim 0.04L^*$

**SDSS r-band image**

$z = 0.0636$
Summary

• Conducted a search of Ca II λλ 3934,3969 AA doublet from ~95,000 quasars in SDSS DR9.

• Rest equivalent width distribution is fit very well by a double power-law model, with little or no evolution with redshift.

• The redshift number density is consistent with the no evolution curve at > 99%, and at least an order of magnitude smaller than Mg II.

• Very few Ca II absorbers are associated with bright, low-impact parameter galaxies.

• In some cases, there is no evidence for “plausible” absorbing galaxies.