The cool CGM in SDSS galaxies

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Abstract

In order to study the circumgalactic medium (CGM) of galaxies we develop an automated pipeline to estimate the optical continuum of quasars and detect intervening metal absorption line systems with a matched kernel convolution technique and adaptive S/N criteria. We process $\sim$ 1 million quasars in the latest Data Release 16 (DR16) of SDSS and compile a large sample of $\sim$ 160,000 Mg II absorbers, together with $\sim$ 70,000 Fe II systems, in the redshift range $0.35 < z_{abs} < 2.3$. Combining these with the SDSS DR16 spectroscopy of ~ 1.1 million luminous red galaxies (LRGs) and $\sim 200,000$ emission line galaxies (ELGs), we investigate the nature of cold gas absorption at $0.5 < z < 1$. These large samples allow us to characterize the scale dependence of Mg II with greater accuracy than in previous work. We find that there is a strong enhancement of Mg II absorption within ~ 50 kpc of ELGs, and the covering fraction within $0.5r_{\rm vir}$ of ELGs is 2-5 times higher than for LRGs. Beyond 50 kpc, there is a sharp decline in Mg II for both kinds of galaxies, indicating a transition to the regime where the CGM is tightly linked with the dark matter halo. The Mg II covering fraction correlates strongly with stellar mass for LRGs, but weakly for ELGs, where covering fractions increase with star formation rate. Our analysis implies that cool circumgalactic gas has a different physical origin for star forming versus quiescent galaxies.

Introduction & Motivation

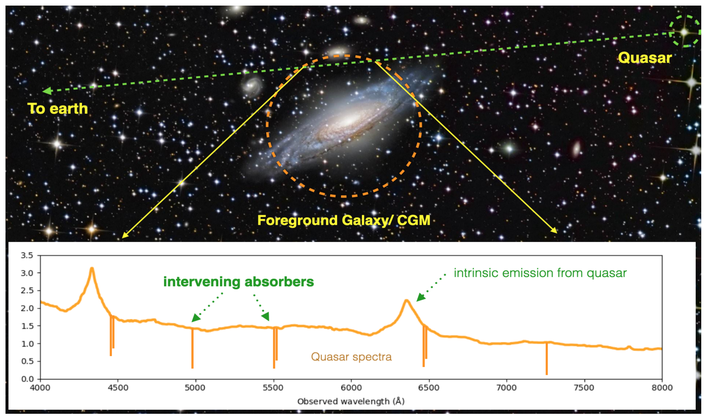

Figure 1. Basic setup of an absorber-galaxy cross-correlation study, where the CGM is observed in absorption against a bright background quasar.

- **Quasar absorption lines:** The invisible circumgalactic medium (CGM) can be probed in absorption against a bright background source such as a quasar. These absorption lines provide direct observational constraints on the gas flows around galaxies at different epochs. For e.g., Mg II (Mg+) traces cool ($\sim 10^4$ K) CGM and C iv (C^{3+}) traces warm phase ($\sim 10^5$ K) of the CGM (Tumlinson et al. 2017, Zhu et al. 2014).
- **Our Goal:** In this paper (Anand et al. 2021), we develop an automated continuum estimation and absorption detection pipeline. Using metal absorbers and connecting them with galaxies we measure the physical properties of CGM gas as a function of galaxy mass, star formation activity, impact parameter, and redshift.

Quasar and Galaxy Samples

- **Quasar sample:** The quasar sample is taken from SDSS DR16. It includes $\sim 900,000$ objects identified as quasars with $0 < z < 7$ (Ahumada et al. 2020).
- **Luminous Red Galaxies (LRGs):** LRGs from the Wisconsin PCA-based catalogue which contains a total of ~ 1.1 million galaxies with $z > 0.4$ (Chen et al. 2012).
- **Emission Line Galaxies (ELGs):** ELGs are available as part of SDSS DR16 VAC. It contains a total of $\sim 200,000$ galaxies with $z > 0.4$ (Raichoor et al. 2021).

Automated Absorber Detection Pipeline

Quasar Continuum
(estimated using Nonnegative matrix factorization, NMF technique)

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Metal absorber detection
(based on a matched kernel convolution technique and adaptive S/N criteria)

- **MgII Absorber Catalogue:** We run our pipeline on ~ 1 million quasars from the Data Release 16 (DR16) of SDSS and have compiled the largest metal absorber catalog to date consisting $\sim 160,000$ Mg ii absorbers and $\sim 70,000$ Fe ii systems. The catalogue is publicly available at `https://wwwmpa.mpa-garching.mpg.de/SDSS/MgII/`
- **Completeness and Purity of Catalogue:** The completess and purity both are high ($\sim 90\%$) for our catalogue.

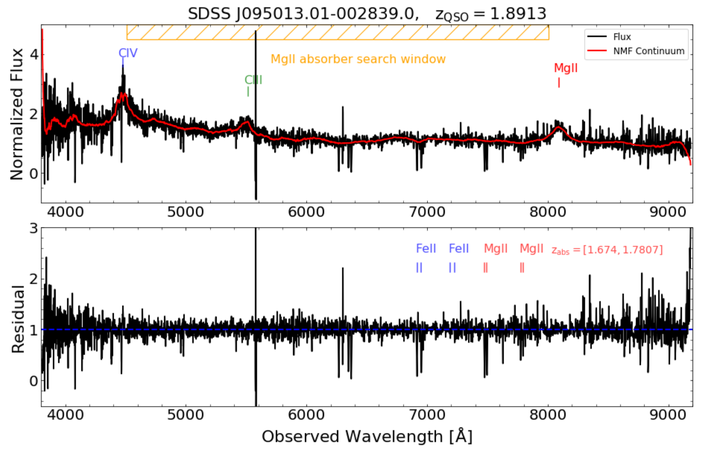

Figure 2. Quasar spectra with continuum and detected metal absorbers.

The Nature of cool CGM in Galaxies

- **Galaxy-MgII cross-correlation:** To study these gas flows, we connect Mg II absorbers with LRGs and ELGs and investigate the nature of cold gas absorption at $0.5 < z < 1$ for star-forming and passive galaxies.
- **MgII Covering Fraction:** Our large samples allowed us to characterize the scale dependence of MgII with greater accuracy than in previous work (Lan et al. 2014, Lan & Mo 2018). There is a strong enhancement of Mg ii absorption within ~ 50 kpc of ELGs (blue) relative to LRGs (red) (Fig 3, top left). For ELGs, covering fraction also correlates strongly with SFR (Fig 3, top right), indicating that cold gas is mostly associated with stellar outflows. Our analysis also shows that massive haloes have less cool gas in their CGM (Fig 3, bottom).

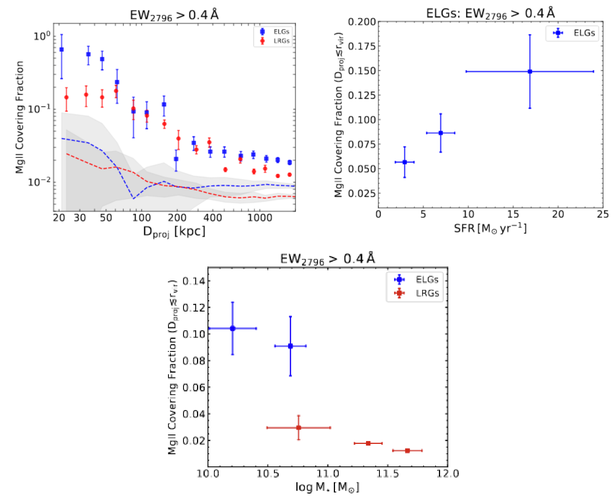

Figure 3. **Top left:** MgII covering fraction around ELGs and LRGs. Dashed lines denote the random expectations. **Top right:** MgII covering fraction within virial radius of ELGs as function of star formation rate (SFR). **Bottom**: MgII covering fraction within galactic halo as a function of stellar mass.

Future Aspects

- Currently, we are working trying to understand the nature of MgII absorbers in the intracluster medium (ICM) to understand how cold gas can arise and survive in hot ICM.
- Preliminary results show a non-zero covering fraction (3 - 4 %) of MgII absorbers inside the halo (< 1 Mpc) of galaxy clusters.
- Trying to understand, if the cold gas traced by MgII absorbers in the ICM is due to stripping of gas from the satellite galaxies?

References

Anand A., Nelson D., Kauffmann G., 2021, MNRAS, 504, 65
Ahumada R., et al., 2020, ApJS, 249, 3
Chen Y.-M., et al., 2012, MNRAS, 421, 314
Lan T.-W., Mo H., 2018, ApJ, 866, 36
Raichoor et al. 2021, MNRAS, 500, 3254
Tumlinson J., Peeples M. S., Werk J. K., 2017, ARA&A, 55, 389
Zhu G., et al., 2014, MNRAS, 439, 3139