Clustering of Mg II absorbers

Dual degree project: 2017-18

H. S. Sunil Simha
PH13B011

Indian Institute of Technology, Madras
Guided by
Dr. L Sriramkumar
and
Dr. R Srianand, IUCAA, Pune

26^{th} November 2017

Contents

Mg II absorbers along QSO sightlines

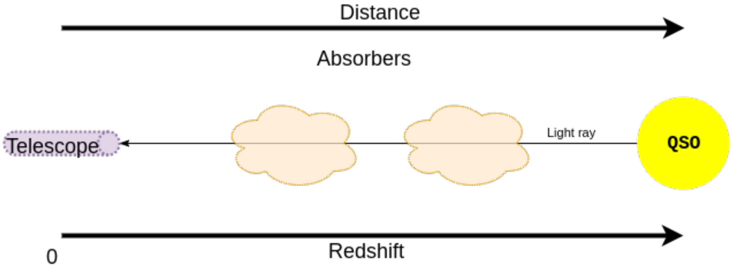

Figure: The absorption system

- Mg II ions have been known to be tracers of neutral gas.
- One of the strongest lines and thus easily spotted.
- Specifically looking at the doublet 2796-2803 Å

Goals of this project

- To study the distribution of Mg II absorbers in redshift space
- To model this distribution and hence make inferences on the distribution of dark matter halos

Understanding the relationship between cold gas and dark matter halos would help understand structure formation better.

Work to be done

Explaining the distribution of these absorbers using a dark matter halo model and a gas distribution.

Background universe

The cosmological principle

The universe is homogeneous and isotropic.

- True at large enough scales: Of the order of 100 MPc.
- Evolution governed by the FLRW equations.

$$\begin{aligned} H^2 &= H_0^2 \left[\frac{\Omega_{m0}}{a^3} + \frac{\Omega_{r0}}{a^4} + \Omega_{\Lambda 0} + \frac{1-\Omega_0}{a^2} \right] \\ \frac{\ddot{a}}{a} &= -\frac{H_0^2}{2}\left[\frac{3P}{\rho_{cr_0}} + \Omega\right] \end{aligned} \quad (1)$$

- The early universe being largely homogeneous and isotropic is reflected in the CMB.
- Temperature fluctuations are of the order of 10^{-5} of the average.

Cosmological perturbation theory

- Small fluctuations allow for a perturbative treatment.
- Since I am only interested in structures much smaller than the Hubble radius, **I can use Newtonian theory**.

Newtonian limit

The gravitational field obeys Poisson's equation. In terms of co-moving coordinates:

$$\nabla_x^2 \phi = 4\pi G a^2 \rho + 3a\ddot{a} \qquad (2)$$

Assuming the universe to be filled with fluid,

$$\frac{\partial \rho}{\partial t}_x + 3H\rho + \frac{1}{a}\nabla_x(\rho \mathbf{v}) = 0 \qquad \text{(continuity eqn.)}$$

$$\frac{\partial \mathbf{v}}{\partial t}_x + H\mathbf{v} + \frac{(\mathbf{v}.\nabla_\mathbf{x})\mathbf{v}}{a} = -\left(\frac{\nabla_x P}{\rho a} + \frac{\nabla_x \phi}{a}\right) \qquad \text{(Euler eqn.)}$$

Linear perturbation theory

Defining the density contrast as $\delta = \rho/\rho_b - 1$, and combining the Euler and continuity equations in a matter dominated universe, we get:

$$\partial_t^2\delta + 2H\partial_t\delta = \frac{\nabla^2 P}{\rho_b a^2} + \frac{1}{a^2}\nabla.(1+\delta)\nabla\phi + \frac{1}{a^2}\partial_i\partial_j[(1+\delta)v^i v^j] \tag{3}$$

Linear order: The Meszaros equation

$$\partial_t^2\delta + 2H\partial_t\delta = \frac{1}{a^2}(\frac{\nabla^2 P}{\rho_b} + 4\pi G\rho_b\delta) \tag{4}$$

Jean's length:

$$\lambda_J = \sqrt{\frac{\pi}{G\rho_b}}c_s \tag{5}$$

Perturbations of wavelength greater than this grow while the others die out.

Non-linear theory: Spherical collapse I

A spherically symmetric, uniformly overdense region is considered. By conservation of energy,

$$\frac{\dot{r}^2}{2} - \frac{GM}{r} = E \tag{6}$$

Starting from a point where $\dot{r}$ was nearly Hr, the region behaves as if it were a closed universe by itself.

$$r = X(1 - \cos\Theta), t + T = Y(\Theta - \sin\Theta), X^3 = GMY^2$$

Equation of a cycloid!

Non-linear theory: Spherical collapse II

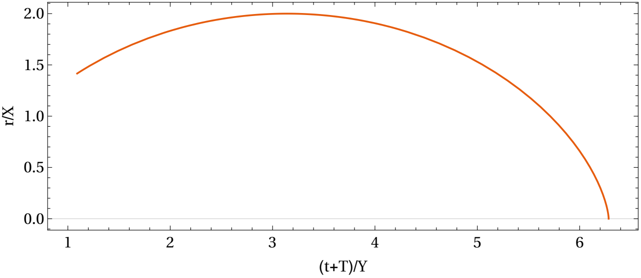

Figure: Evolution of a spherically overdense region.

Of course, collapse stops before $r = 0$ because of pressure generated by fluid. The system **virializes** and comes to a halt at $r = r_{max}/2$ with a density of $170\rho_b(t_{coll})$ in a matter dominated universe.

Press-Schechter formalism

The PS formalism estimates the number of objects collapsed within a mass range of $[M, M + \delta M]$ at a given redshift.

Press-schechter mass distribution

$$\frac{dn}{dM} = -\sqrt{\frac{2}{\pi}} \frac{\rho_m}{M} \frac{d\sigma}{dM} \frac{\delta_c}{\sigma^2} e^{\delta_c^2/2\sigma^2} \tag{7}$$

- ρ_m/M is the average number density of objects of mass M.
- σ is the variance of the linear power spectrum of density perturbations smoothed by a window function.
- δ_c is the initial critical over-density above which non-linear collapse happens. This is generally taken to be 1.686

Observed clustering

- Data of over 30,000 QSO sightlines taken from SDSS.
- Counted pairs along LoS in redshift space as a function of velocity separation.
- Calculated the expected histogram from current model of redshift space distribution.

Completeness correction

- Surveys tend to report less objects than there are simply because of sensitivity limitations.
- Used data from MC simulations by G.B. Zhu to correct for this.

Observed clustering

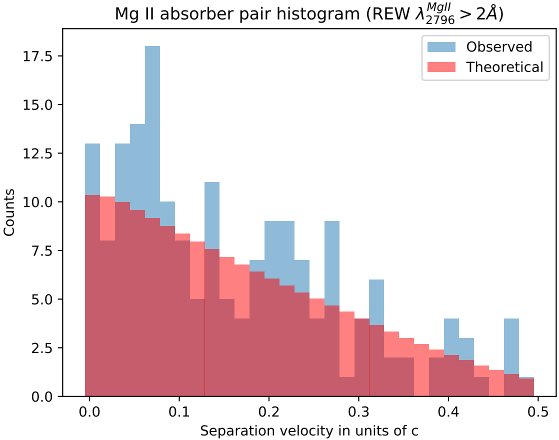

Figure: A comparison of theoretical and observed histograms of pairs of Mg II absorbers. The theoretical estimate has been obtained from the empirical distribution of absorbers in Zhu & Menard, The Astrophysical Journal, 770:130 (15pp), 2013 June 20

References

1. **Zhu, Menard**, *The JHU-SDSS Metal Absorption Line Catalogue*, The Astrophysical Journal, 770:130 (15pp), 2013 June 20
2. **Nestor, Turnshek & Rao**, *Mg II absorption systems in SDSS QSO spectra*, The Astrophysical Journal, 628:637654, 2005 August 1
3. **T. Padmanabhan**, *Structure formation in the universe*, Cambridge 1993
4. **Jim Peebles**, *Large Scale Structure of the Universe*, Princeton 1992
5. **Peter Schneider**, *Extragalactic Astronomy and Cosmology*, Springer 2006