Distribution of Mg II absorbers in along QSO lines of sight

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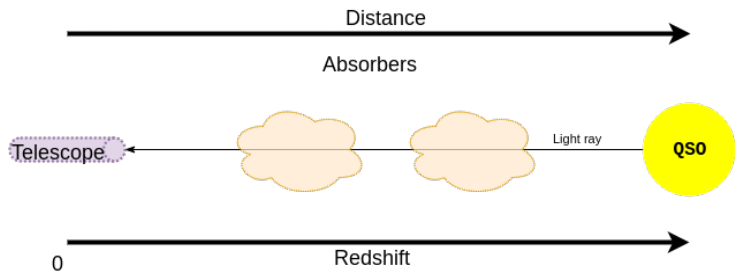
Contents

Mg II absorbers along QSO sightlines I

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
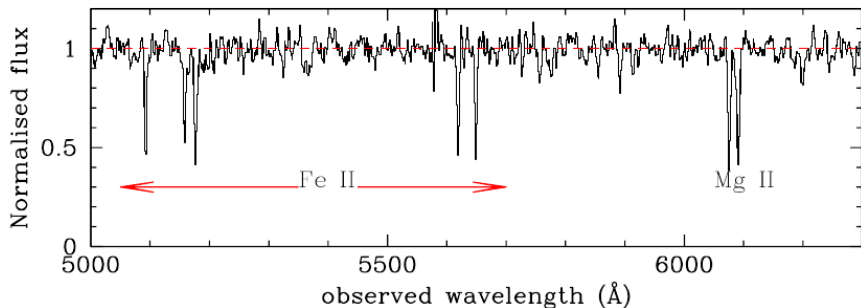
Mg II absorbers along QSO sightlines II

Figure: Mg II absorbers in QSO spectrum. Note the wavelength of the Mg II lines. They have been redshifted to nearly 6100 Åfrom their rest wavelength of 2800 Å. *Source: R. Srianand, private communication*
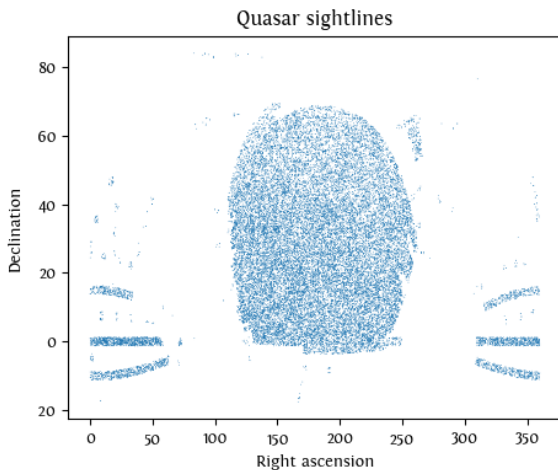
QSO sightlines

Figure: All QSO sightlines considered

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 in progress

Modelling the distribution of absorbers. i.e. The number density dN/dz

Work to be done

Modelling the **clustering** of absorbers as well. i.e. Distribution of pairs as a function of velocity/redshift separation.

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.

$$H^2 = H_0^2 \left[\frac{\Omega_{m0}}{a^3} + \frac{\Omega_{r0}}{a^4} + \Omega_{\Lambda 0} + \frac{1 - \Omega_0}{a^2} \right]$$

$$\frac{\ddot{a}}{a} = -\frac{H_0^2}{2} [\frac{3P}{\rho_{cr_0}} + \Omega]$$

(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:

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

Assuming the universe to be filled with fluid,

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

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

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:

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

Linear order: The Meszaros equation

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

Jean's length:

$$\lambda_J = \sqrt{\frac{\pi}{G\rho_b}}c_s \qquad (5)$$

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!

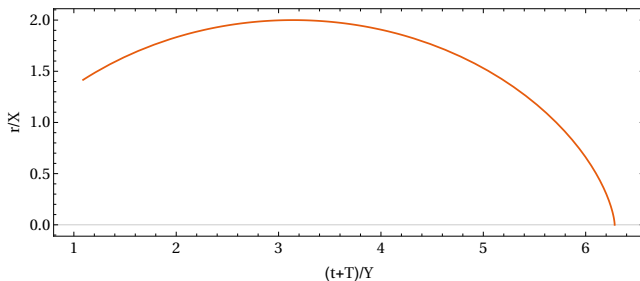# Non-linear theory: Spherical collapse II

Figure: Evolution of radius of a spherically overdense region. The region by itself behaves like a closed universe.

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.

Halo mass function: Beyond Press-Schechter

The Millennium simulations showed the errors in the Press-Schechter halo mass function (HMF). A general HMF could be defined as

Sheth-Tormen Fitting function

$$\frac{dn}{dM} = -f(\sigma)\frac{\rho_m}{M}\frac{d\log\sigma}{dM}$$

$$f(\sigma) = A\left[\left(\frac{\sigma}{b}\right)^{-a} + 1\right]e^{-c/\sigma^2} \quad (7)$$

- ρ_m: Mean background density
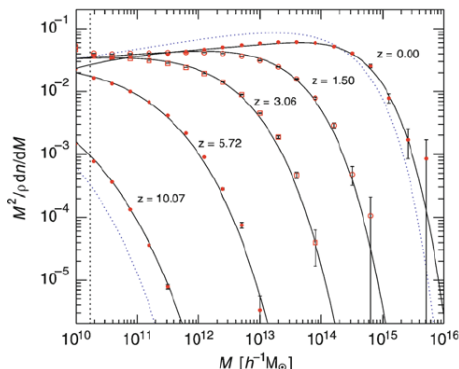
- σ: Std. dev. of linear power spectrum

Figure: Results from the Millennium simulation. The dotted line represents Press-Schechter. *Source: Springel et al. 2005, Nature 435, 629, Fig. 2*
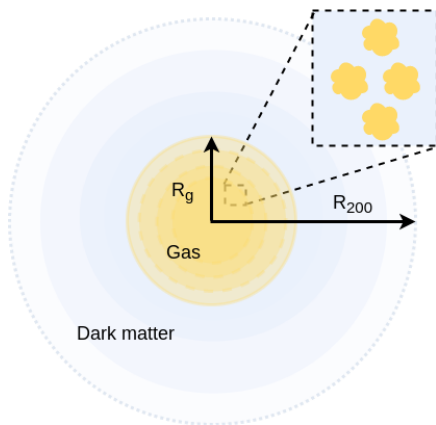
Halo-Absorber model: Tinker & Chen 2008

Halo-Absorber model

Halo: Has **NFW mass** profile.
Radius defined through:

$$M = 200\rho_m \frac{4}{3}\pi R_{200}^3$$

Gas: Arranged in clumps within R_g.
Distribution of clumps is of the form:

$$\rho_g = f_g G_0/(r^2 + a_h^2)$$

$$G_0 = \frac{M(<R_g)/4\pi}{R_g - a_h \arctan(R_g/a_h)}$$
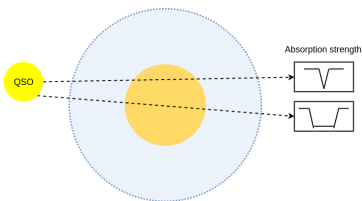
Probability density of REW I

Figure: Absorption strength depends on impact parameter and gas distribution properties

REW vs impact parameter

$$W_r(s|M) = \frac{W_0 \sigma_{cl} f_g}{M_{cl}} \frac{2G_0}{\sqrt{s^2 + a_h^2}} \times$$

$$\arctan \frac{R_g^2 - s^2}{s^2 + a_h^2}$$

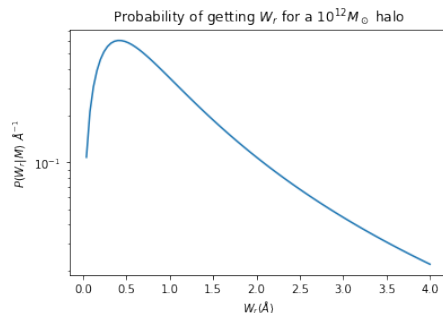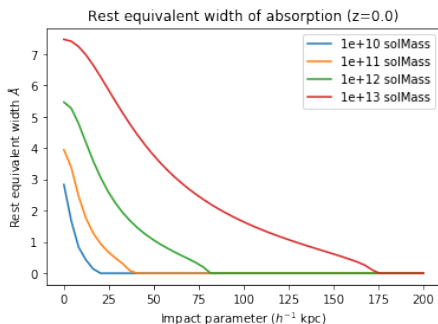$$= A_w \frac{2G_0}{\sqrt{s^2 + a_h^2}} \arctan \frac{R_g^2 - s^2}{s^2 + a_h^2}$$

- s: Impact parameter
- $\sigma_{cl}, M_{cl}, W0$: Clump characteristics

Probability density of REW II

Probability of W_r given M

$$P(W_r|M)dW_r = \kappa_g(M)P(s|M)ds$$

$$P(W_r|M) = \kappa_g(M)\frac{2s(W_r|M)}{R_g^2}\frac{ds}{dW_r} \tag{8}$$

Rest equivalent width of absorption (z=0.0)

Probability of getting W_r for a $10^{12}M_\odot$ halo

Number density of absorbers

Absorber distribution

$$\frac{d^2N}{dW_r dl} = \int dM \times \text{Number density of halos}$$

$$\times \text{Total cross section}$$

$$\times P(W_r|M)$$

(9)

$$\frac{d^2N}{dW_r dl} = \int dM \frac{dN}{dM} \pi R_g^2 P(W_r|M)$$

$$\frac{dN}{dz} = \frac{dl}{dz} \int dW_r \frac{d^2N}{dW_r dl}$$

Current state of work

- Speeding up the integral for $d^2N/dW_r dl$
- Checking for numerical errors

Currently, computed dN/dz is a decreasing function of redshift, unlike Zhu-Menard's observations.
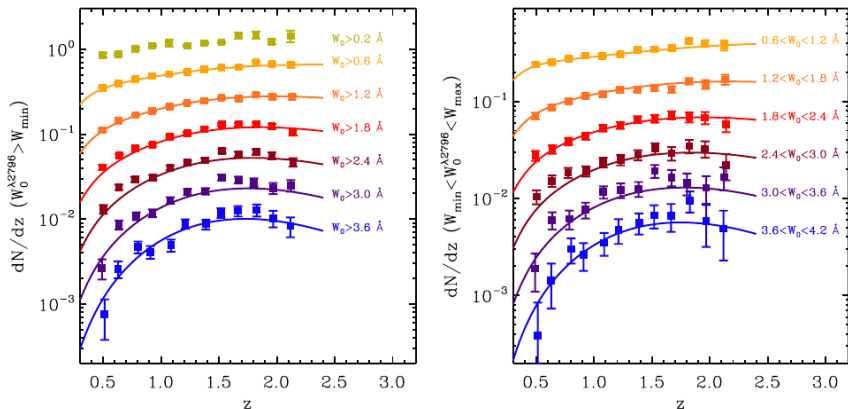
Observed distribution

Figure: Cumulative (left) and differential (right) incidence rates dN/dz of Mg II absorbers. The solid lines show the best-fit parametrisation. The redshift evolution is much stronger for stronger absorbers. *Source: Zhu-Menard 2013, ApJ 770:130*

Summary

- The ultimate aim of this project is to model the distribution of Mg II absorbers and their clustering in redshift space.

- Currently trying to create a model which can capture the number density of absorbers observed.

- Preliminary results show that gas radius needs to increase with increasing redshift (or some such scaling in some model parameter should exist) so as to account for a rising dN/dz.

- Future work would involve modelling the observed clustering of absorbers around a separation of 5000 km/s.

References

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2. **Tinker, Chen**, *On the Halo Occupation of Dark Baryons*, The Astrophysical Journal, 679:1218-1231, 2008
3. **T. Padmanabhan**, *Structure formation in the universe*, Cambridge 1993
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