Cosmo-club (SPP – SAP)

Towards physics responsible for large-scale Lyman-α forest bias Parameters

(arXiv:1509.07875)

[with Jim’s help]

Introduction to large scale correlation parameters

Matter auto-correlation parameters

- There are 4 important parameters when measuring the large scale matter auto-correlation (or power-spectrum) from objects.
- $(\alpha_{||}, \alpha_{\perp}, b\sigma_8, f\sigma_8)$
- Another set is :

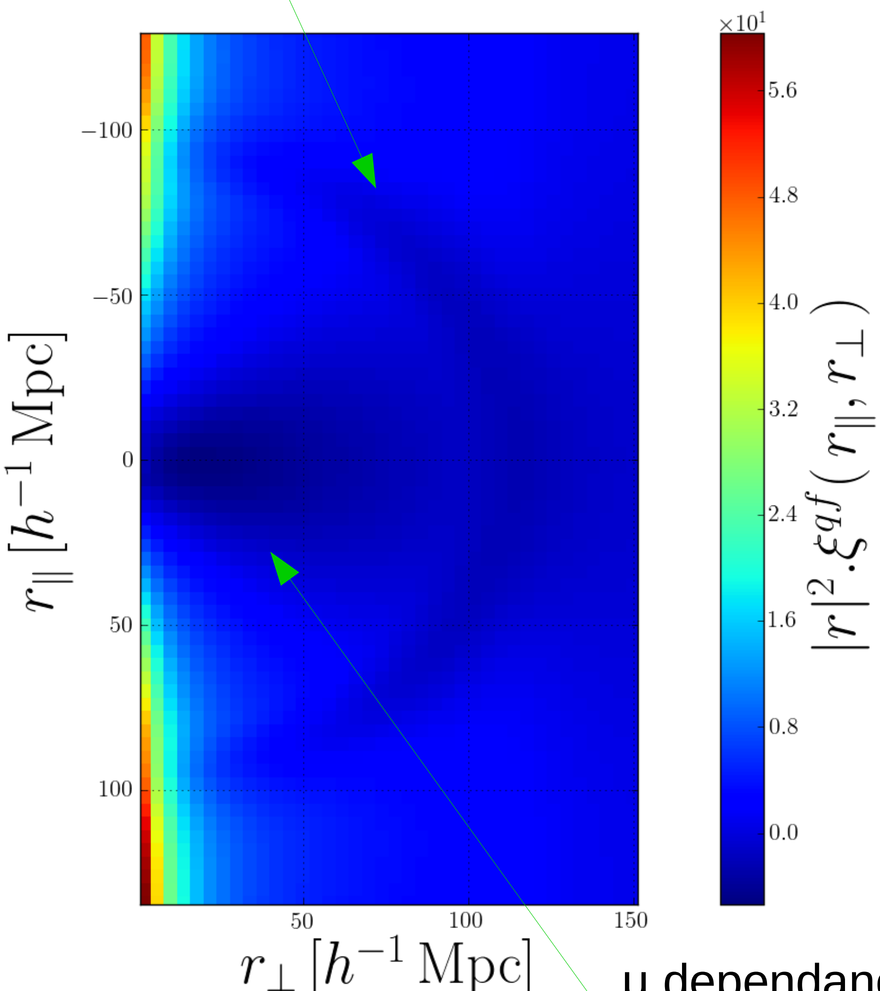
  $(\alpha_{||}, \alpha_{\perp}, b, \beta)$

- $P_{Observed} = b^2(1 + \beta\mu^2)^2 P_{lin}$

Effect of the parameters

Ring to ellipsis

Value of the correlation

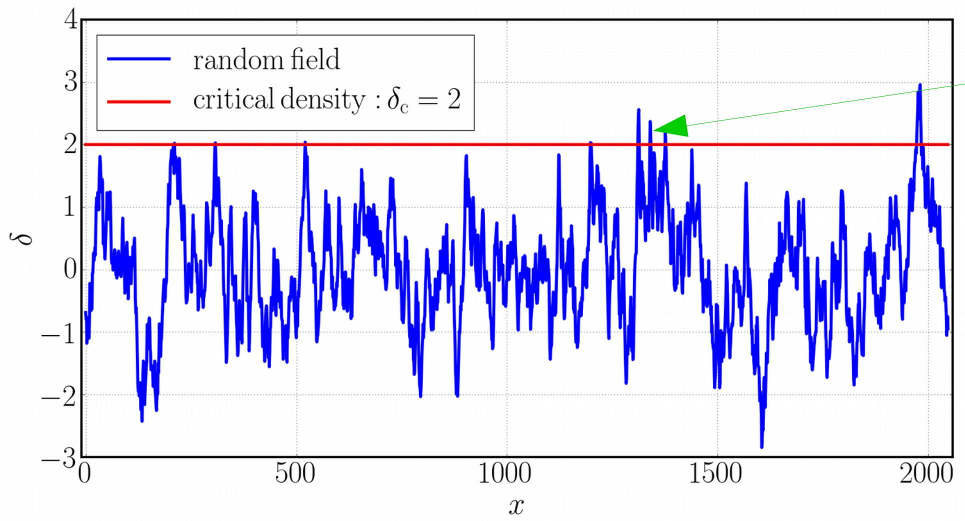


μ dependance

- The effect of both α is to change the bao form from a ring to an ellipsis
- The bias is a multiplicative value to the overall correlation
- The β introduces a dependance on μ = cos(θ), the angle with the line of sight.

Physical meaning for objects

- Here objects are : quasars, galaxies, clusters, ...
- The pysical meaning of b and β is different for objects and for Lyman-α pixels.



Where do objects form

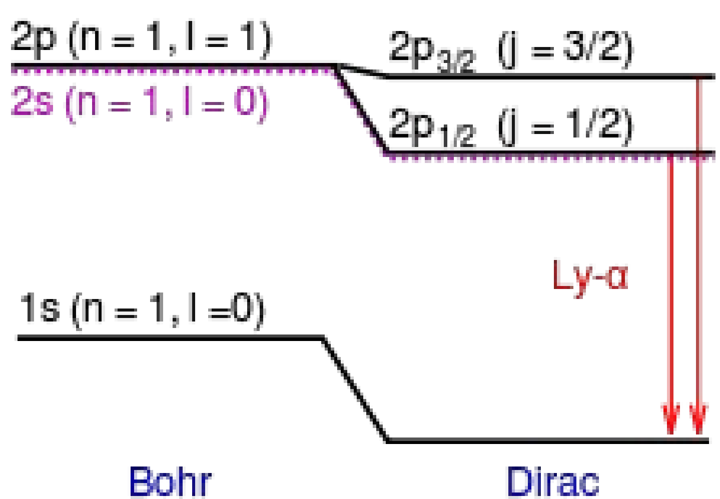
$$b(z) \times \beta(z) = f(z)$$

What growth of structure

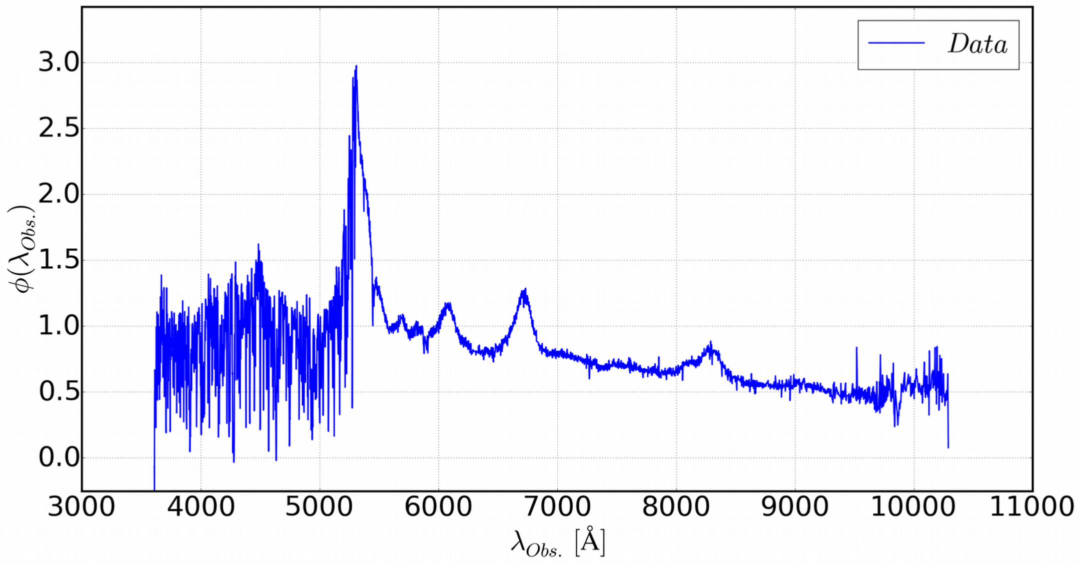
Introduction to Lyman-α

What is the Lyman-α forest

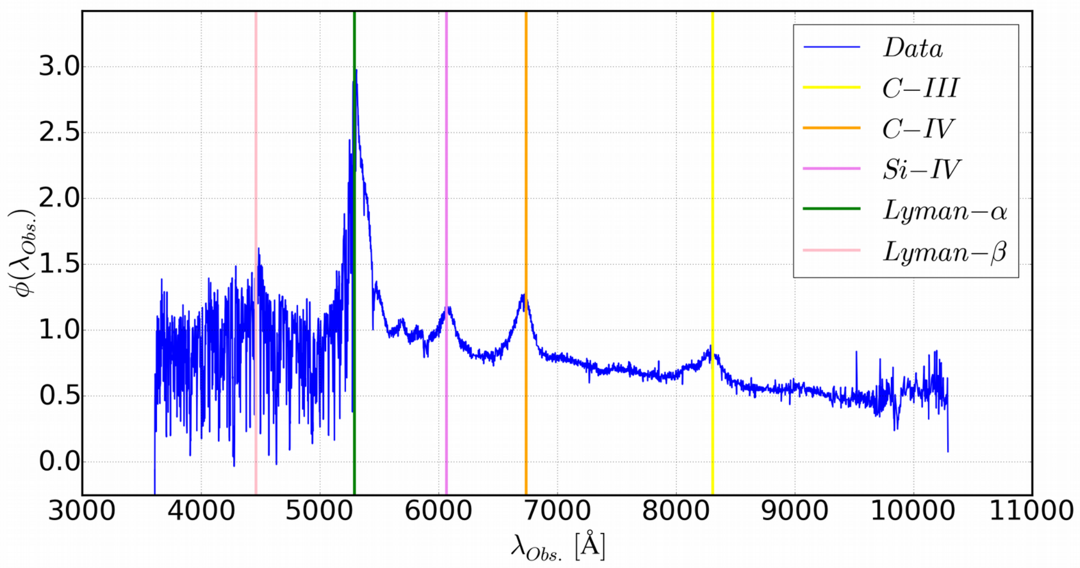
- Desexcitation radiation from going to the first excitation state of Hydrogene atom to ground state
- Lyman-alpha emission only for neutral Hydrogen.



What is the Lyman-α forest

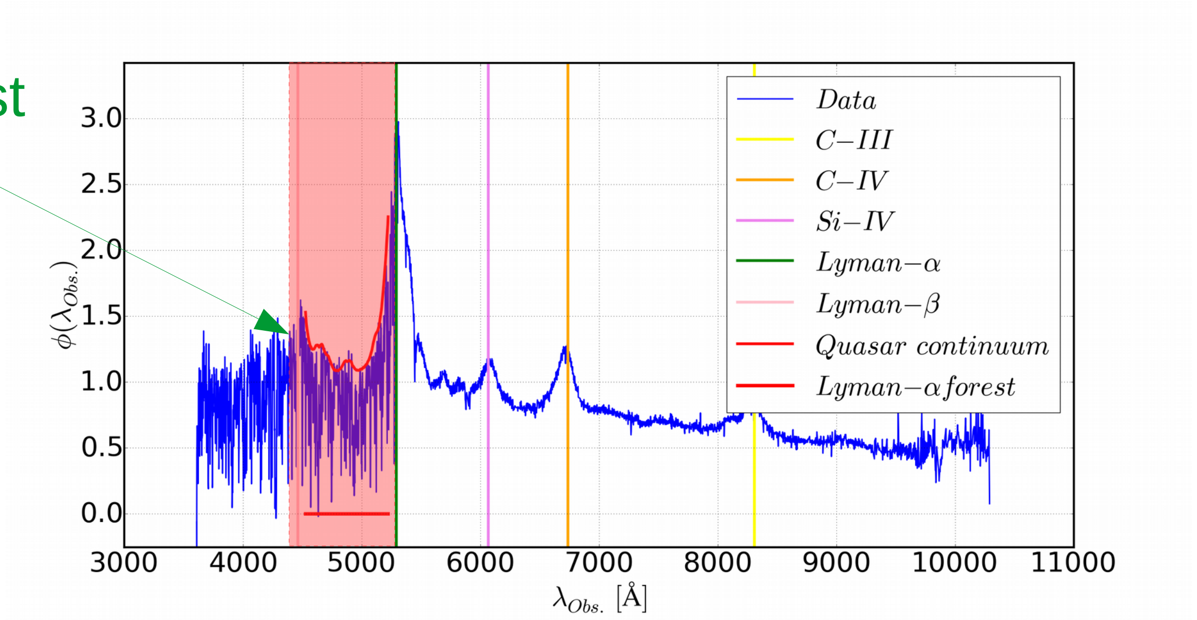


What is the Lyman-α forest



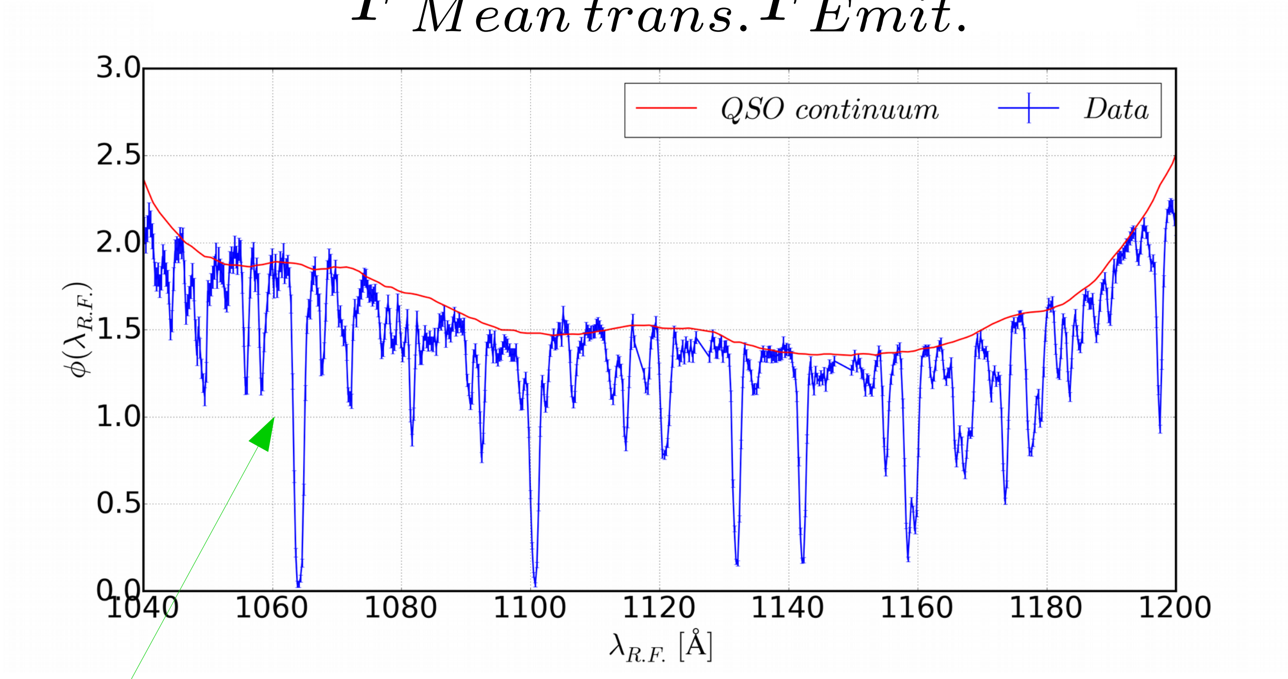
What is the Lyman-α forest

Lyman-α forest



What is the Lyman-α forest

$$\delta_F = \frac{F_{Obs.}}{\overline{F}_{Mean\,trans.} F_{Emit.}} - 1,$$



We see the fluctuation of flux absorption
by mostly neutral Hydrogen atom

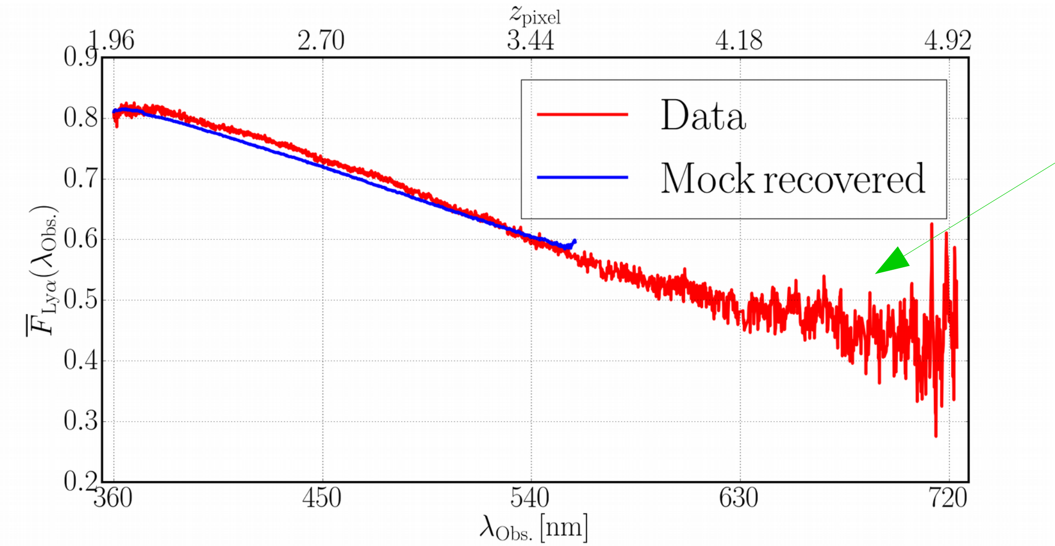
What part of the Universe

This method is therefore sensitive to low gas densities, serving as a tracer of the large scale matter distribution between the redshifts of 1.7 (below which the gas becomes fully ionised while at the same time the UV light continuum becomes redshifted to wavelengths absorbed by the atmosphere) and redshifts 4-5 (above which the forest becomes opaque).

- z \in [1.7, 5]

$$\delta_F = \frac{e^{-\tau}}{< e^{-\tau} >} - 1$$

Transmitted flux fraction



Traces the matter density fluctuations

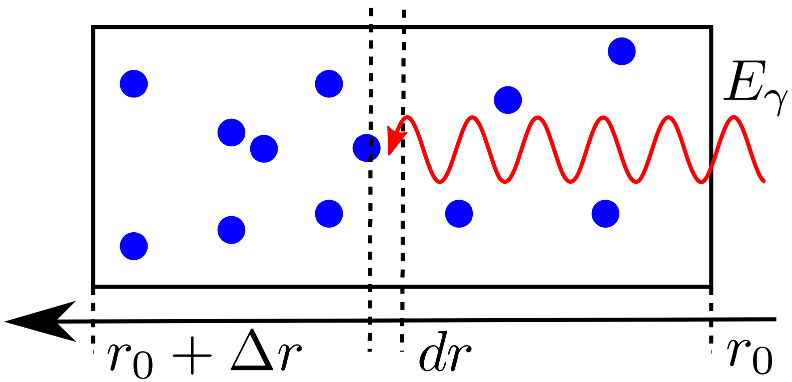
Matter density tracer

The relationship between the measured Lyman-α forest flux and the underlying matter is highly nonlinear, but the physics is thought to be well-understood. Underlying neutral

- Definition of fluctuation of transmitance :
  - $$\delta_F = \frac{F_{Obs.}}{\overline{F}_{Mean\,trans.} F_{Emit.}} - 1,$$
- Optical depth definition gives :
  - $$F_{Obs.} = e^{-\tau} F_{Emit.}.$$
- We then have :
  - $$\delta_F = \frac{e^{-\tau}}{< e^{-\tau} >} - 1$$

The relationship between the measured Lyman-α forest flux and the underlying matter is highly nonlinear, but the physics is thought to be well-understood. Underlying neutral hydrogen gas is related to this measured flux via the optical depth, $\tau = -\ln F$, which is proportional to the Lyman-α absorption cross section and the number of neutral hydrogen atoms along the line of sight (los). If photoionization equilibrium at these redshifts is assumed, the

- The optical depth can be seen as the probability of flux absorption, it is given by the Beer-Lambert law :
  - $d\tau = n_H \sigma_1 dr$



  - $\sigma_1 = \begin{cases} \sigma_{Ly\alpha} & \text{, si } \mathrm{E}_\gamma(1 - \frac{\mathrm{v}_\parallel(\mathrm{r})}{\mathrm{c}}) = \mathrm{E}_{\mathrm{Ly}\alpha} \\ 0 & \text{, sinon} \end{cases}$

- Results for optical depth

$$\tau = \int_{r_0}^{r_0+\Delta r} \sigma_{Ly\alpha} n_H f \left[E_\gamma (1 - \frac{v_\parallel(r)}{c}) - E_{Ly\alpha} \right] dr$$

$$\tau = \sigma_{Ly\alpha} \int_{v_\parallel(r_0)}^{v_\parallel(r_0+\Delta r)} \frac{n_H}{v'_\parallel} f \left[E_\gamma (1 - \frac{v_\parallel}{c}) - E_{Ly\alpha} \right] dv_\parallel$$

- What is important is not the velocity but the velocity gradient
- Need to know the value of Hydrogen density

along the line of sight (los). If photoionization equilibrium at these redshifts is assumed, the amount of neutral hydrogen is related in a temperature-dependent way to the total number of hydrogen atoms, which in turn traces the underlying matter density. Additionally, assuming

- There is a balance between two proceses :
  - $\gamma + H \rightleftharpoons e^{-} + p$
  - $\Gamma_{\gamma\, H} = \Gamma_{e^{-}\, p}$

- The ionization process gives :
  - $\Gamma_{\gamma\, H} = n_{\gamma_{UV}} n_H \sigma_{Ioni.} \dfrac{c+v}{\sqrt{1-\frac{v}{c}}}$
  -
  - $\Gamma_{\gamma\, H} = c n_{\gamma_{UV}} n_H \sigma_{Ioni.}$

- The combinaison
  - (by electroneutrality : n_e = n_p):

$$\Gamma_{e\,p} = n_b^2 \sigma_{ep} \sqrt{\frac{2k_b T}{m_e}}$$

- We thus get the following expression for the density of Hydrogen :
  -

$$n_H = \left(\frac{\sigma_{ep}\sqrt{\frac{2k_b}{m_e}}}{c\sigma_{Ioni.}} \right) \frac{n_b^2 \sqrt{T}}{n_{\gamma_{UV}}}$$

Summary

- The optical depth is given by :

$$\tau = \left(\frac{\sigma_{Ly\alpha}\sigma_{ep}\sqrt{\frac{2k_b}{m_e}}}{c\sigma_{Ioni.}} \right) \int_{v_{\parallel}(r_0)}^{v_{\parallel}(r_0+\Delta r)} \frac{n_b^2\sqrt{T}}{v'_{\parallel} n_{\gamma_{UV}}} f \left[E_\gamma (1 - \frac{v_{\parallel}}{c}) - E_{Ly\alpha} \right] dv_{\parallel}$$

$$\delta_F(z) = \frac{A(n_b, T, v'_{\parallel}, n_{\gamma_{UV}})}{B(z)} - 1$$

- With an expansion :

$$\delta_F = b_\delta \delta + b_\eta \eta + b_\Gamma \delta_\Gamma + \epsilon$$

- The RSD parameter is now :
  - $$\frac{\beta_{Ly\alpha}(z) b_{\delta}(z)}{b_{\eta}(z)} = f(z)$$

The Fluctuating Gunn Peterson Approximation (FGPA)

- We can model the optical depth by :
  - $$\tau = A(1+\delta)^{\alpha}$$
  - $$\alpha = 2 - 0.7(\gamma - 1)$$
  - $$\gamma - 1 = \frac{dln\rho}{dlnT}$$

Summary

- The delta field fluctuation of the Lyman-α forest flux is simply the variation of absorption.
- It is related to the matter density, the velocity gradient, the photo-ionization rate.
- The proof uses the simple law of Beer-Lambert, the suposition of equilibrium in the photo-ionization.