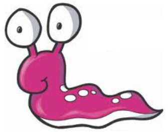
Predicting Large-Scale Lyman-α Forest Statistics from the Dark Matter Density Field

Sébastien Peirani (IAP)

Lyman-α Mass Association Scheme

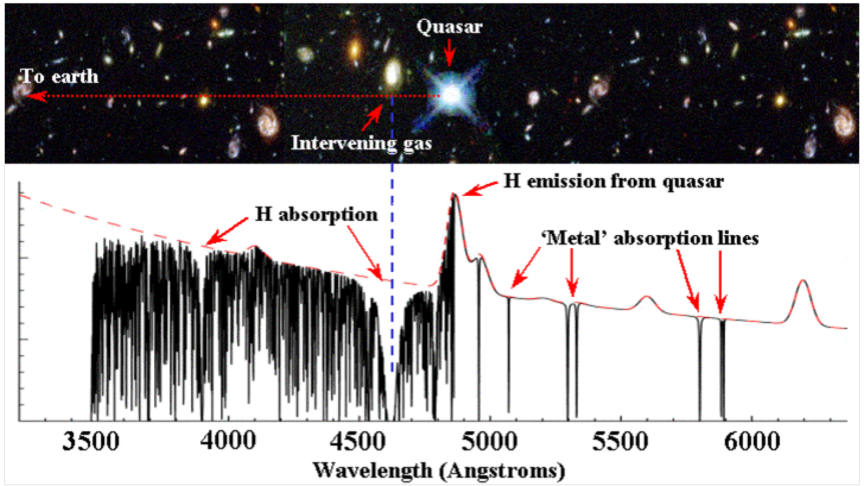
Peirani, Weinberg, Colombi, Blaizot, Dubois & Pichon - ApJ 2014, 427, 2625

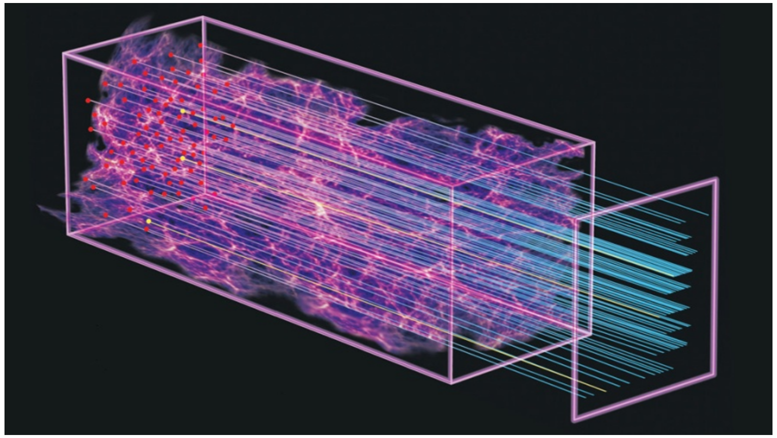
Plan



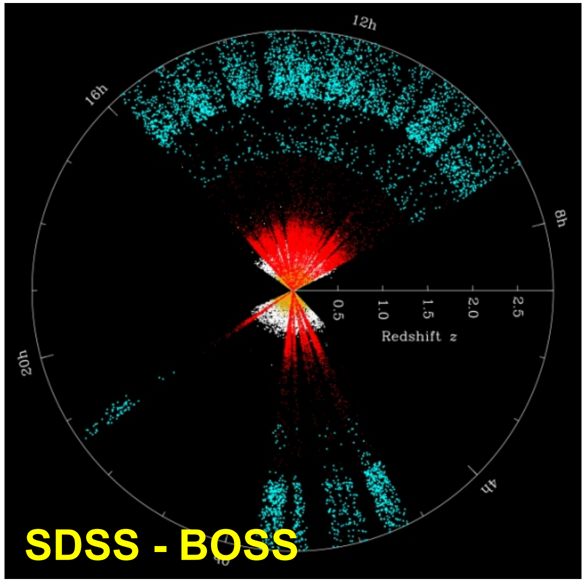
1. Introduction
2. LyMAS scheme
3. Application to large N-body simulations
4. Ongoing works
5. Next

Lyα-forest clustering





Light from distant quasars is partially absorbed as it passes through clouds of hydrogen gas



➡ Bao, lyα-forest clustering : need huge volume (> 1 Gpc/h) while capturing the physics on small scales (< 0.3 Mpc/h)

Construction of Mock Ly-α spectra for large surveys

Existence of a tight correlation between density and temperature

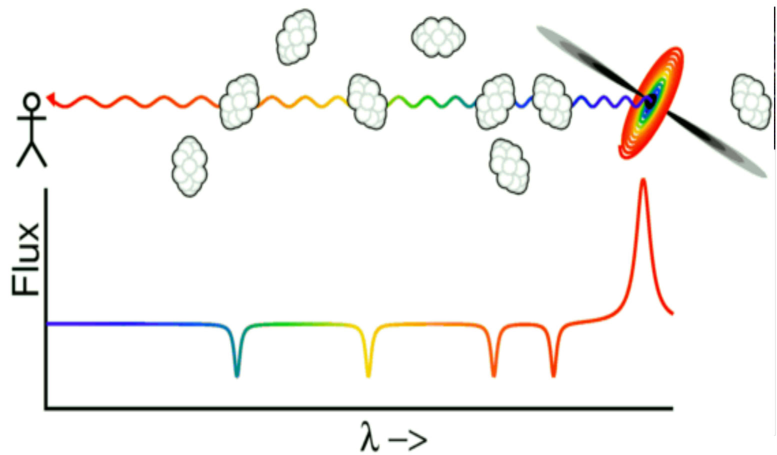
(Katz, Weinberg & Hernquist 1996; Hui & Gnedin 1997)

↓

"Fluctuating Gunn-Peterson Approximation"

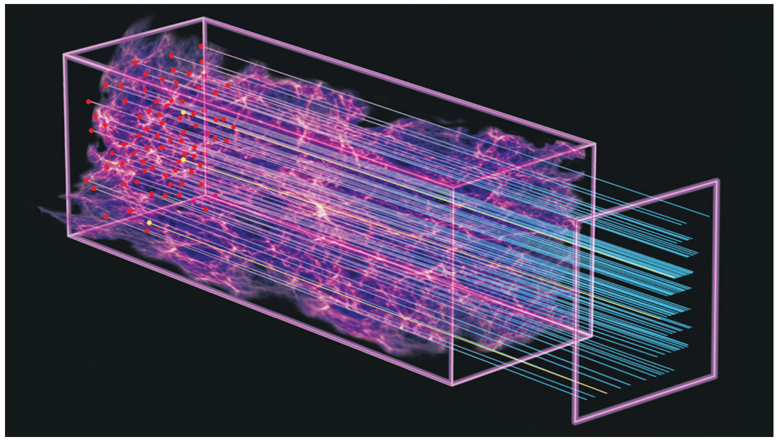
Lyα Optical depth τ ⟺ DM overdensity Δ

(FGPA, Katz, Weinberg & Hernquist 1998; Croft et al. 1998)



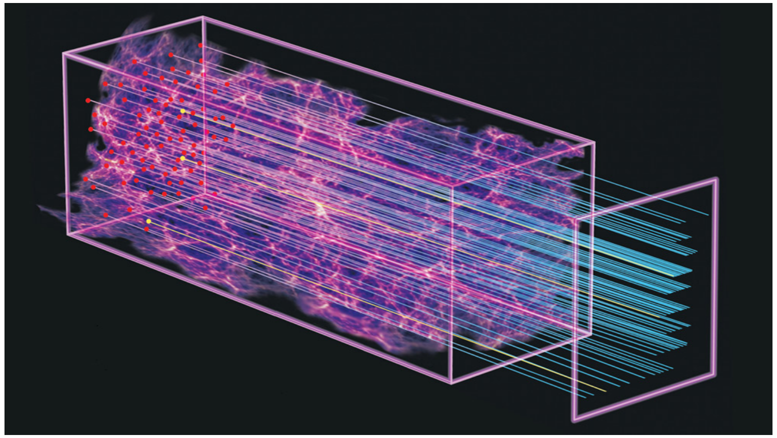
Mock Ly-α : log-normal density field + FGPA

Log-normal density field
- Gaussian initial conditions
- DM density field from N-body simulation



Construction of Mock Ly-α spectra for large surveys

Mock Ly-α : log-normal density field + FGPA



Log-normal density field
- **Gaussian initial conditions**
- **DM density field from N-body simulation**

Problems of this approach:

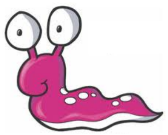
- **Model Gpc^3 volume while retaining good resolution on the gas Jeans scale**
- **The choice of the smoothing scale for DM produces ambiguity in the predictions**
- **The FGPA assumes a deterministic relation between ρ and *F=e$^{-\tau}$***

$$F = e^{-A\left(\frac{\rho}{\bar{\rho}}\right)^{2-0.6(\gamma-1)}}$$

γ-1 : index of the gas temperature-density relation

A : normalization constant

Plan



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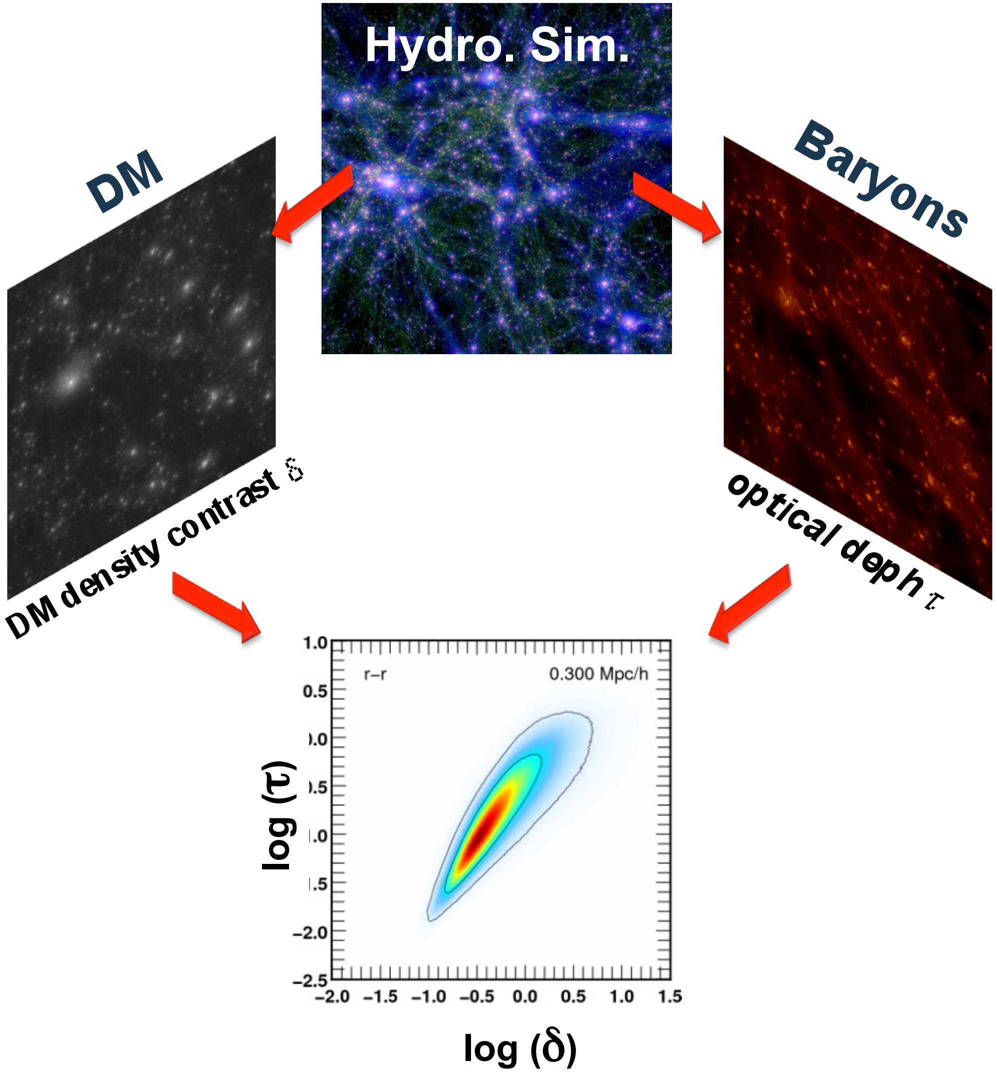
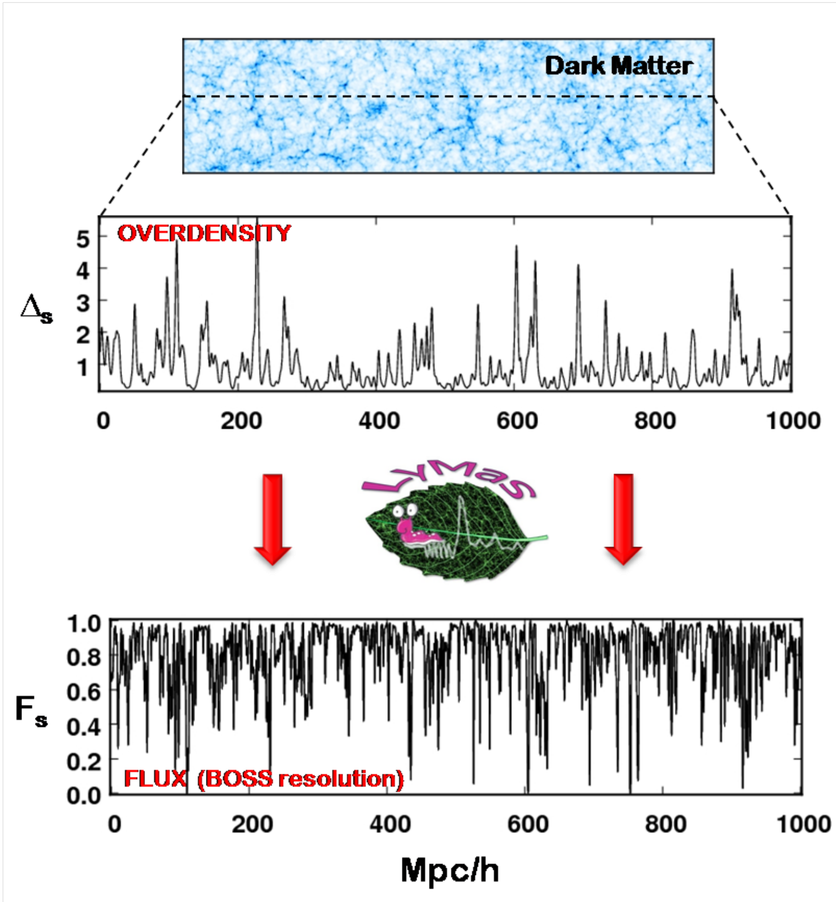
LyMAS: Lyα Mass Association Scheme



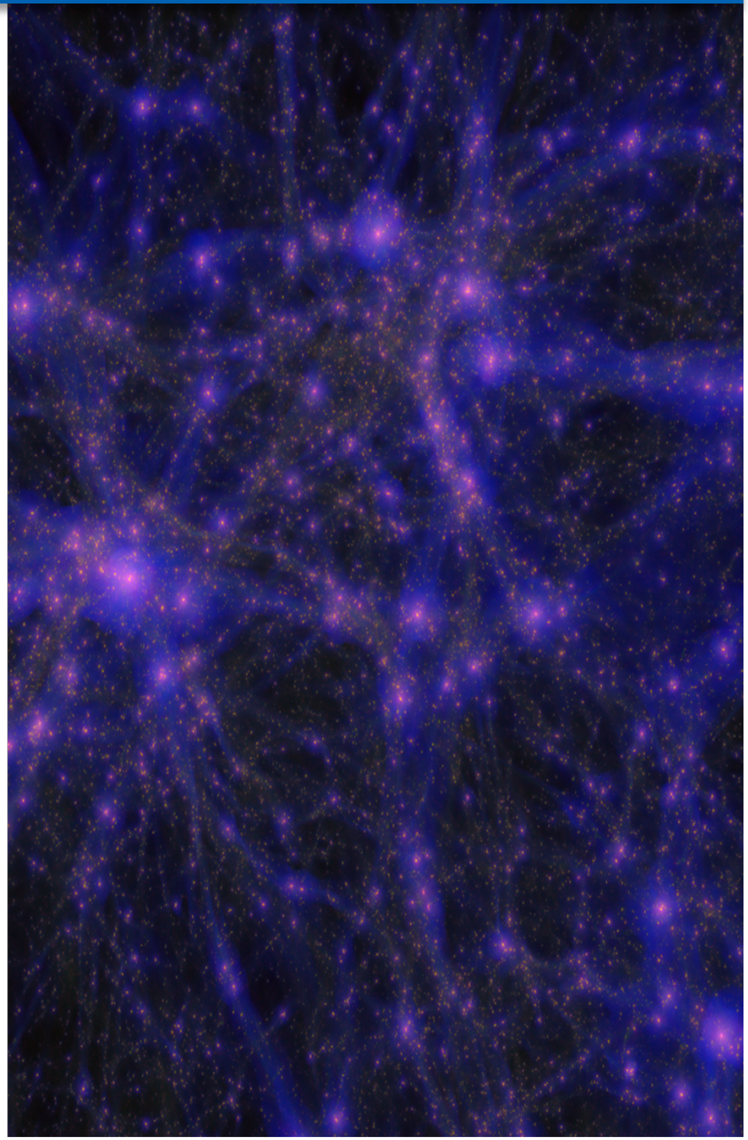


MareNostrum (2006)

- Horizon-MareNsotrum simulation

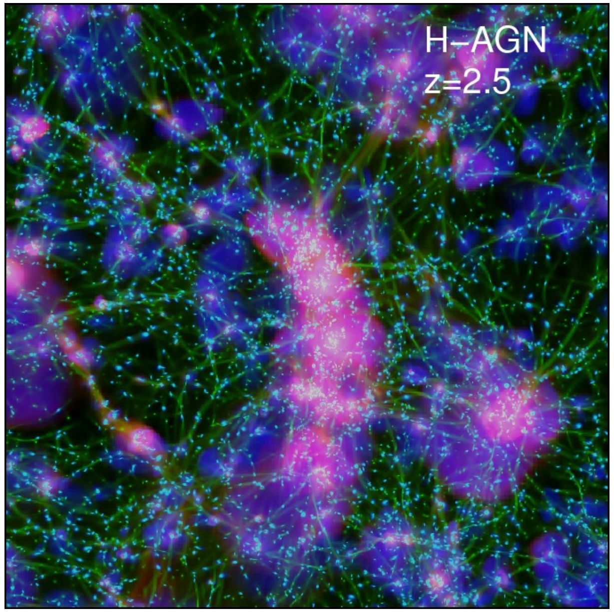
  (PI J. Devriendt, R. Teyssier, G. Yepes)

  - L_{box}=50 Mpc/h
  - 1024^3 DM particles $M_{DM,res}=8x10^6\ M_{sun}$
  - Finest cell resolution dx=1 kpc (-1 level of refin.)
  - Gas cooling & UV background heating
  - Low efficiency star formation
  - Stellar winds + SNII + SNIa
  - O, Fe, C, N, Si, Mg, H metals w/ solar composition
  - AGN feedback radio/quasar
- Outputs
  - Simulation outputs
  - Lightcones (1°x1°) performed on-the-fly
    - Dark Matter (position, velocity)
    - Gas (position, density, velocity, pressure, chemistry)
    - Stars (position, mass, velocity, age, chemistry)
    - Black holes (position, mass, velocity, accretion rate)
- z=1.5 using 1.3 Mhours using 2048 cores

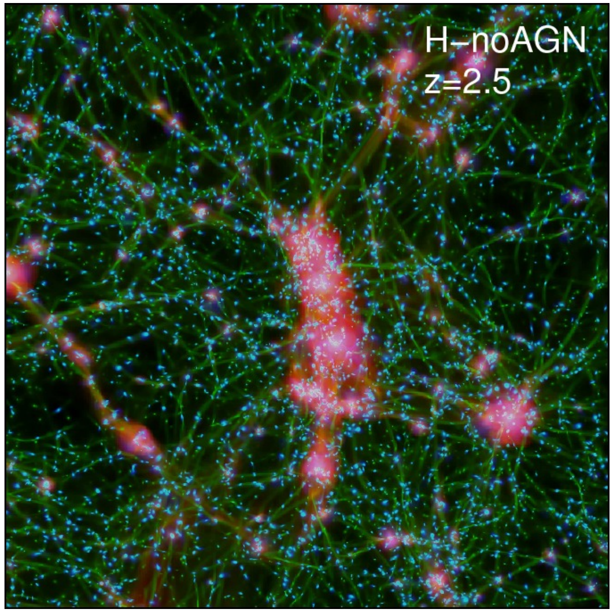


Horizon-AGN – Horizon-noAGN (2014)

Horizon-AGN (Dubois)



Horizon-noAGN (Peirani)



Gas density

Gas temperature

Gas metallicity

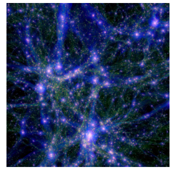
- L_{box}=100 Mpc/h
- 1024^3 DM particles $M_{DM,res}=8\times10^7\,M_{sun}$
- Finest cell resolution dx=1 kpc (-1 level of refin.)
- Gas cooling & UV background heating

- Low efficiency star formation
- Stellar winds + SNII + SNIa
- O, Fe, C, N, Si, Mg, H
- AGN feedback radio/quasar

Extracting Lyα spectra

For a given los, the opacity at observer-frame frequency υ_{obs}:

$$\tau(\upsilon_{obs}) = \sum_{cells} n_{HI}\sigma(\nu_{obs})dl$$



Grid of density transmitted Flux (1024^3 pixels)

n_{HI} : numerical density of neutral H atoms in each cell

dl : physical cell size

$\sigma(\nu_{obs})$: the cross section of Hydrogen to Lyα photons

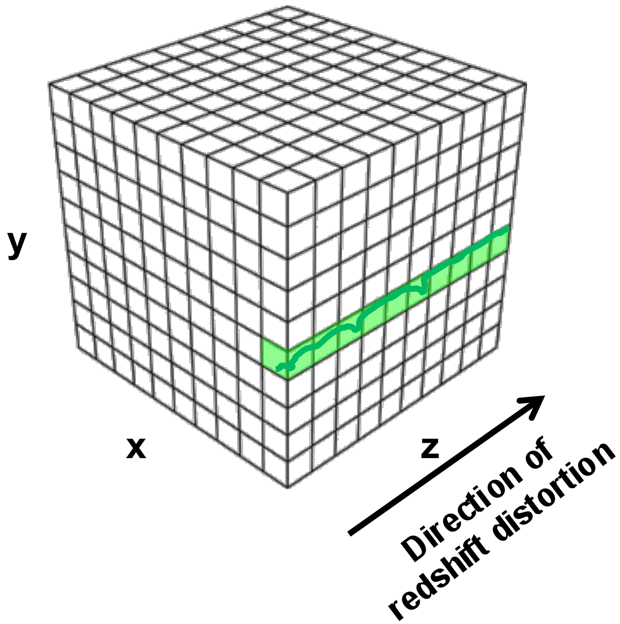
$$\sigma(\upsilon_{obs}) = f_{12}\frac{\pi e^2}{m_e c}\times\frac{H(a,x)}{\sqrt{\pi}\Delta\nu_D}$$

$f_{12} = 0.4162$: Lyα oscillator strength

$$\Delta\upsilon_D = (2k_B T/m_H)^{1/2}\times\nu_\alpha/c$$

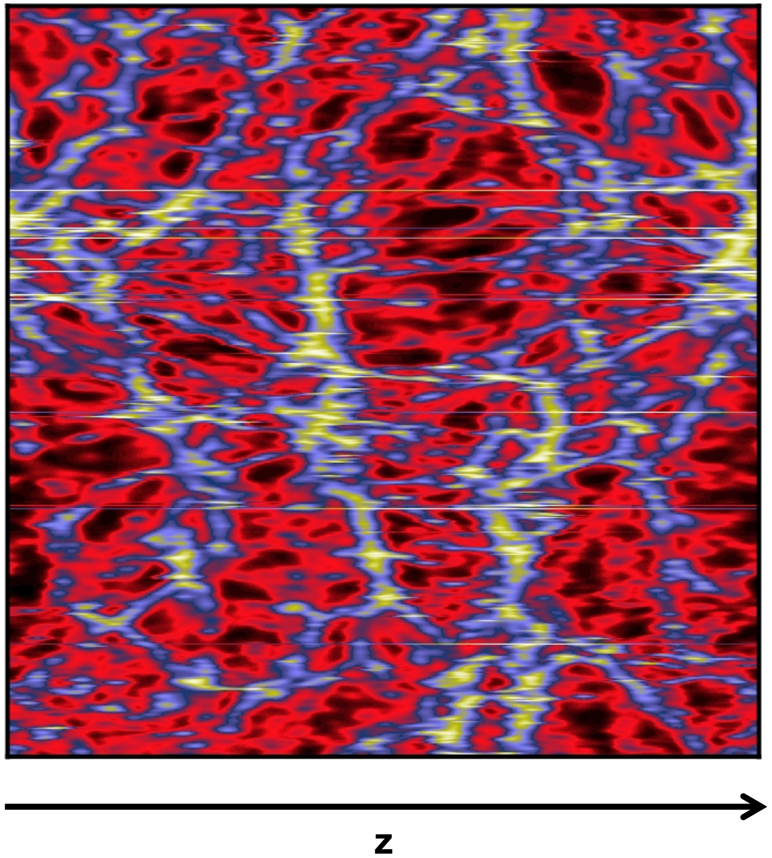
$$a = \Delta\upsilon_L/(2\Delta\upsilon_D) \qquad \Delta\upsilon_L \approx 9.9\,10^7 s^{-1}$$

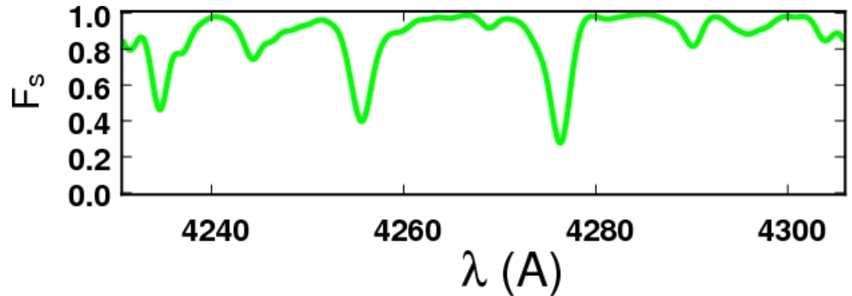
$$H(a,x) = \frac{a}{\pi}\int_{-1}^{1}\frac{e^{-y^2}}{a^2+(x-y)^2}dy$$: the Hjerting function

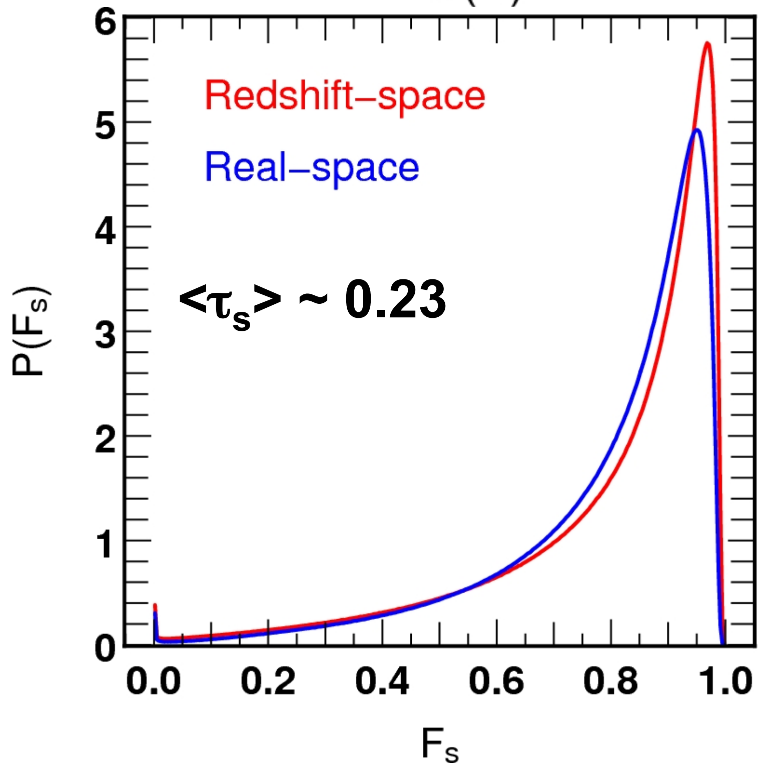


Extracting Lyα spectra

Slice







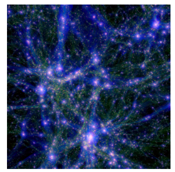
1-d smoothed at the BOSS resolution

Extracting Dark matter skewers

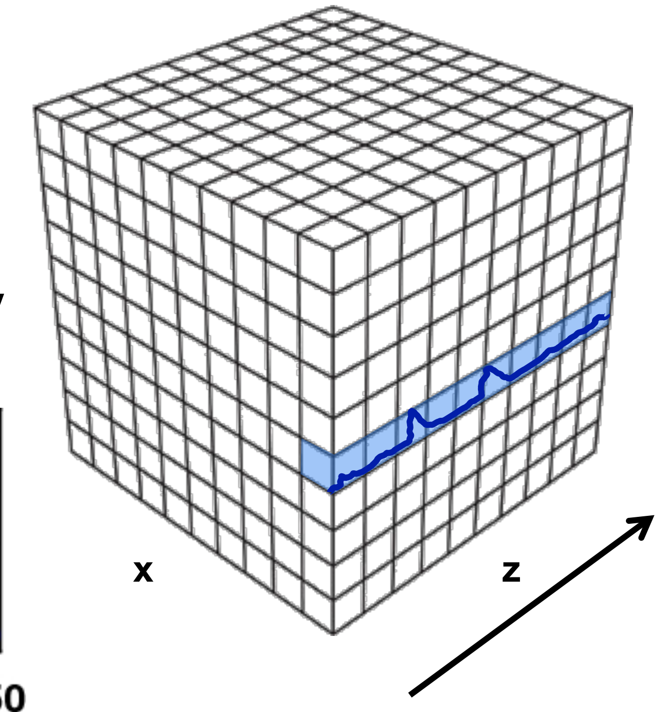
1. Adaptive interpolation of the DM particle distribution on a high resolution grid.

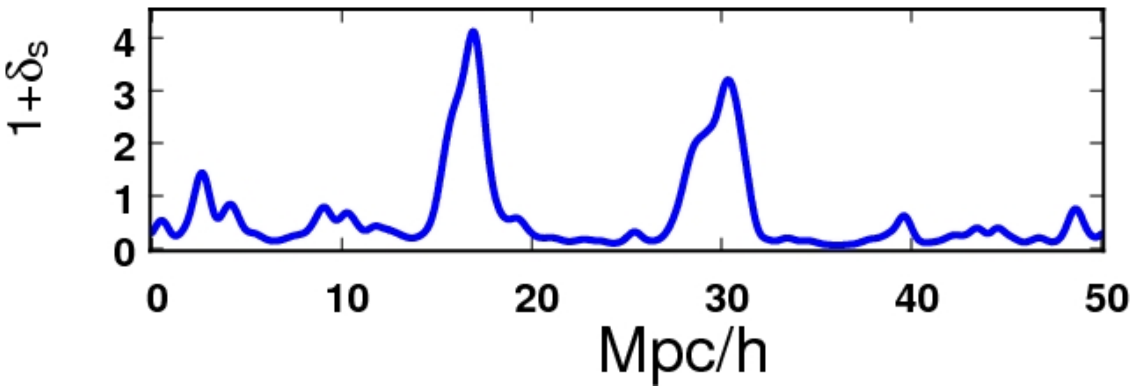
2. Smoothing with a Gaussian window in Fourier space

3. Extraction of the skewers from a grid of lines of sight aligned along the z axis



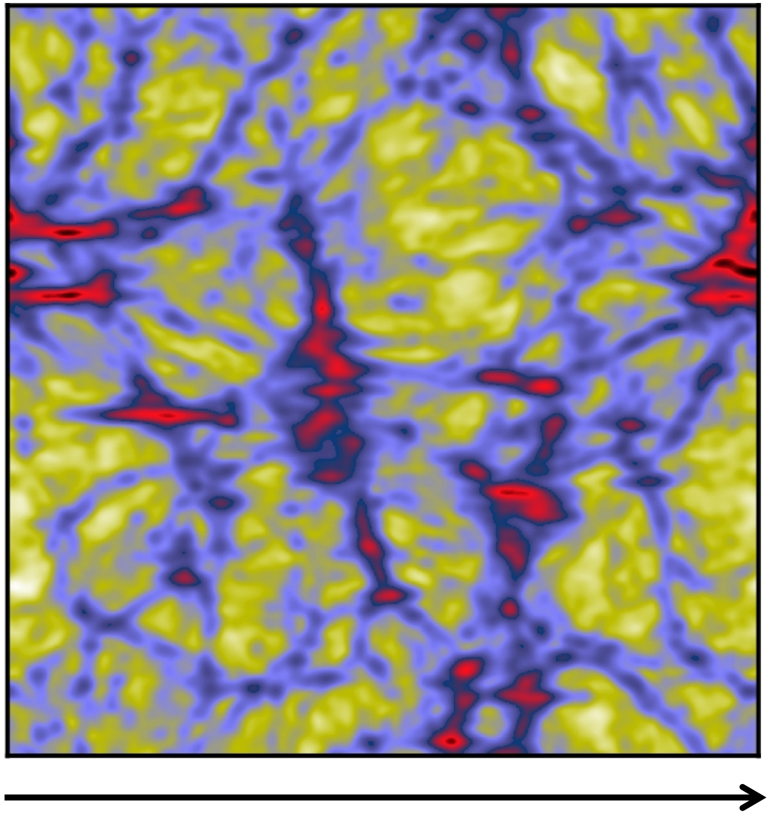
Grid of density fied 1+δ (1024^3 pixels)





Extracting Dark matter skewers

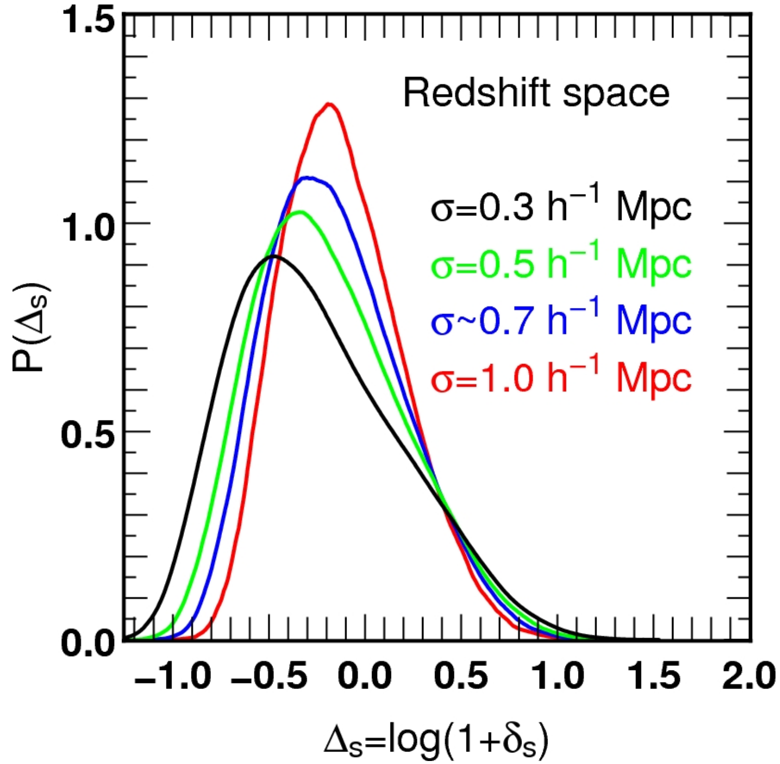
Slice



z

3-d smoothed at different scales

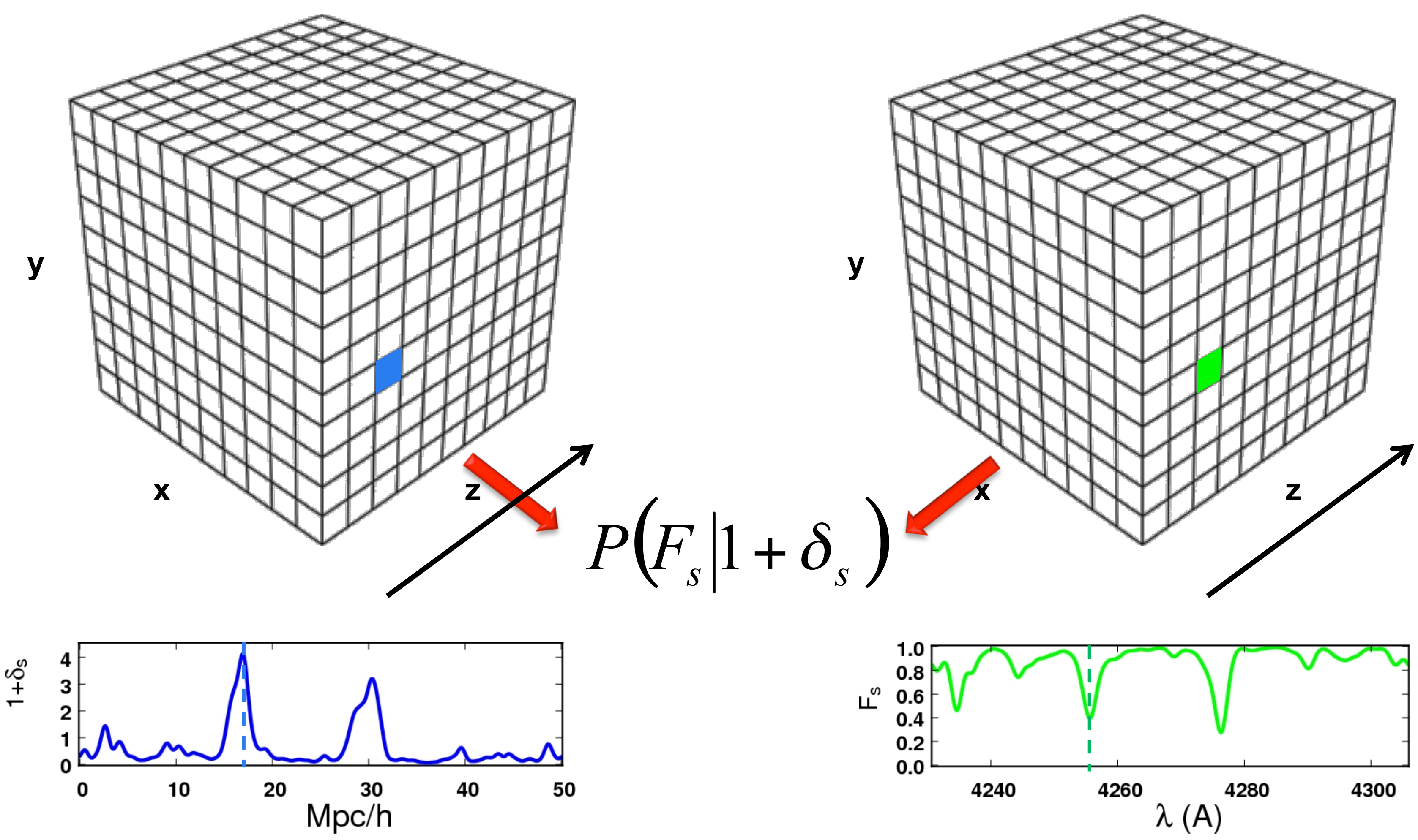
PDF



Predicting conditional Flux distributions

Grid of density contrast 1+ δ_s
1024^3 pixels

Grid of transmitted flux F_s
1024^3 pixels



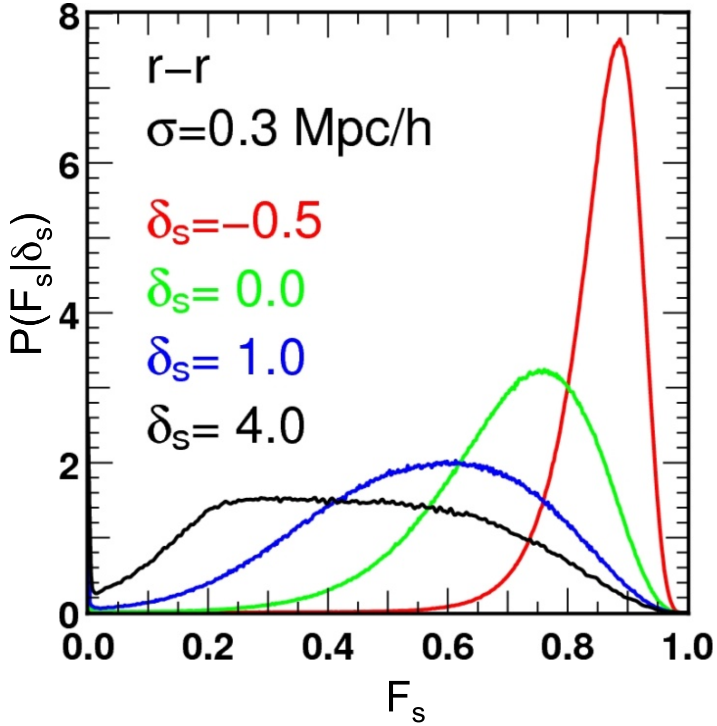
Predicting conditional Flux distributions

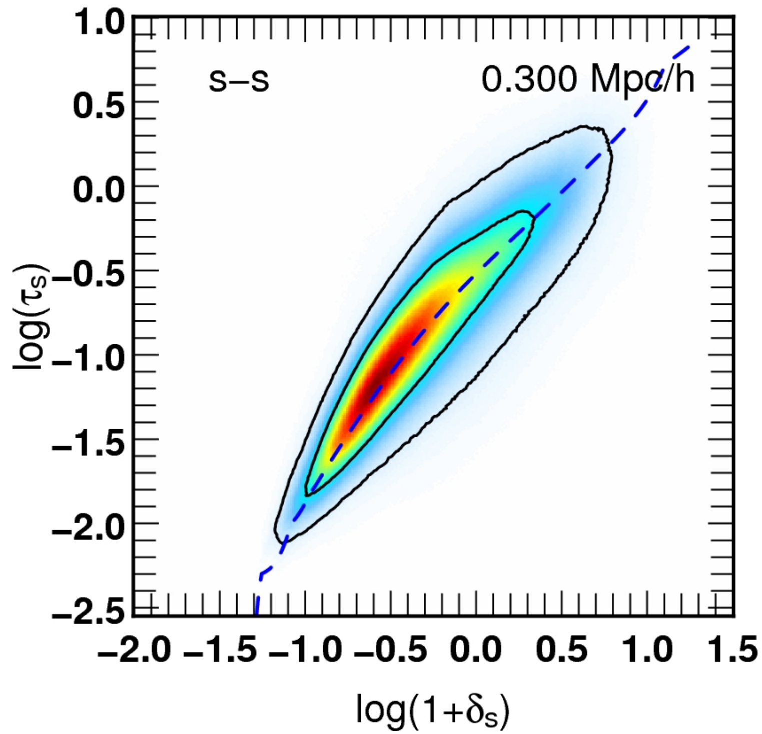
$$P\left(F_s \middle| 1+\delta_s\right)$$

Optical depth: $\tau_s = -\ln F_s$

$$P\left(\tau_s \middle| 1+\delta_s\right)$$

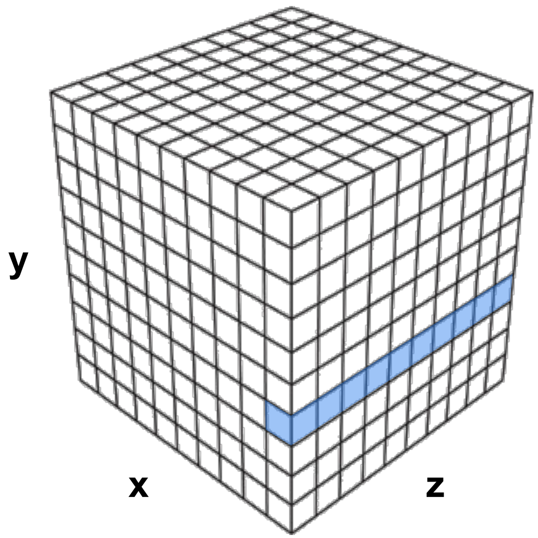
Ex:



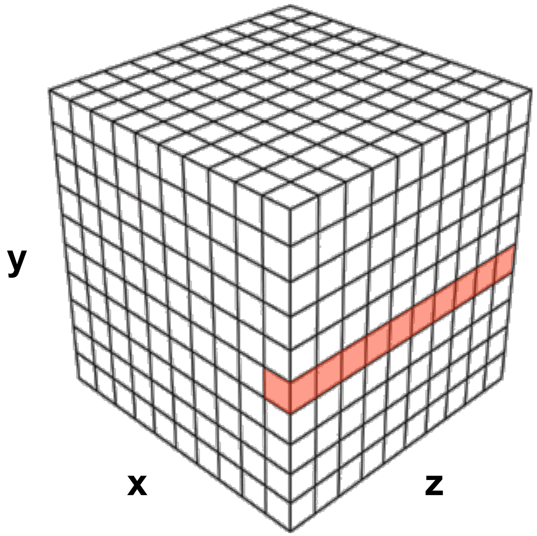


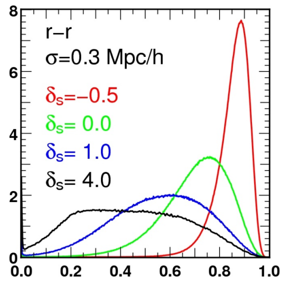
Probabilistic mapping

Grid of DM density contrast $1+\delta_s$
1024^3 pixels

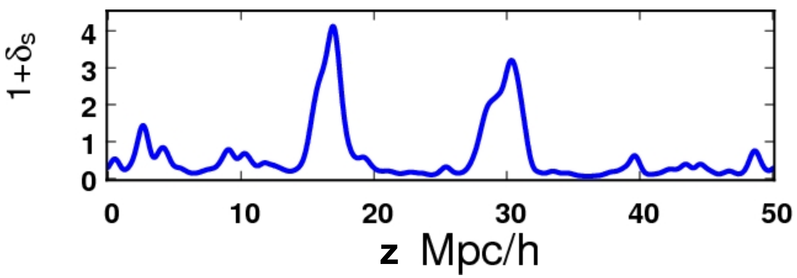


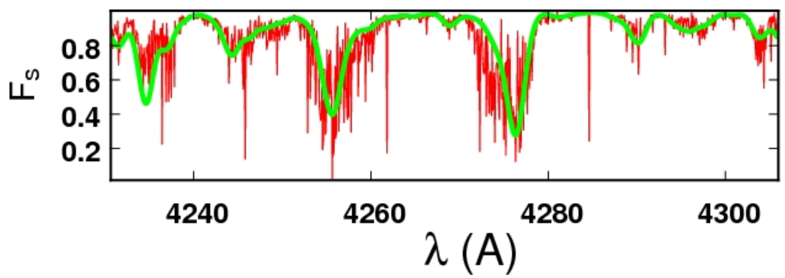
Grid of predicted transmitted flux F_s
1024^3 pixels



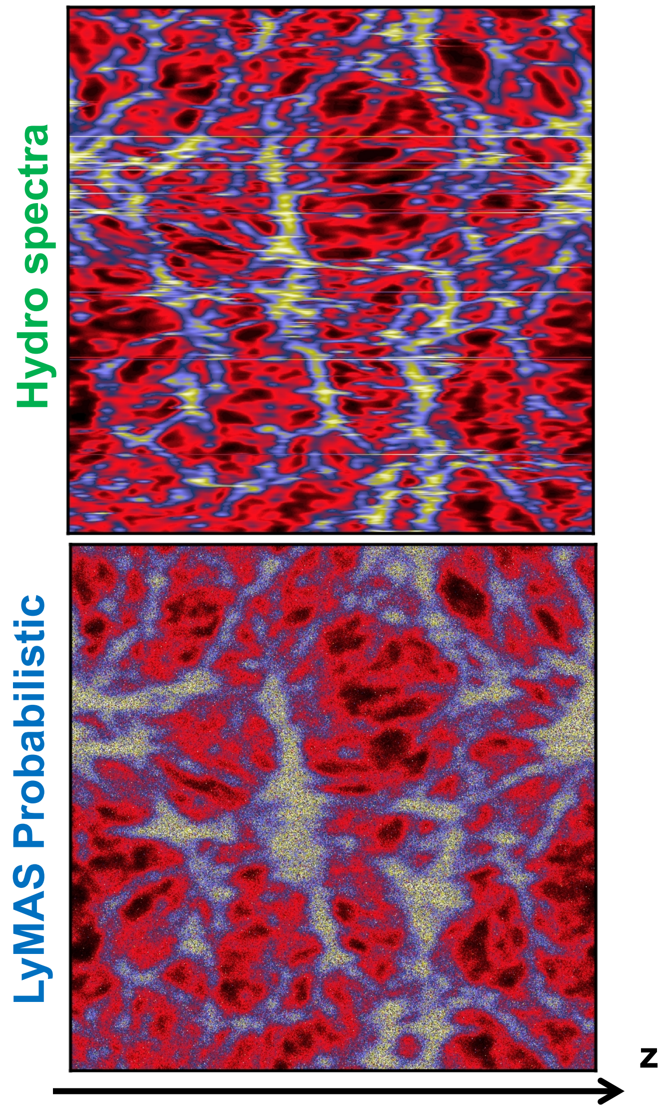


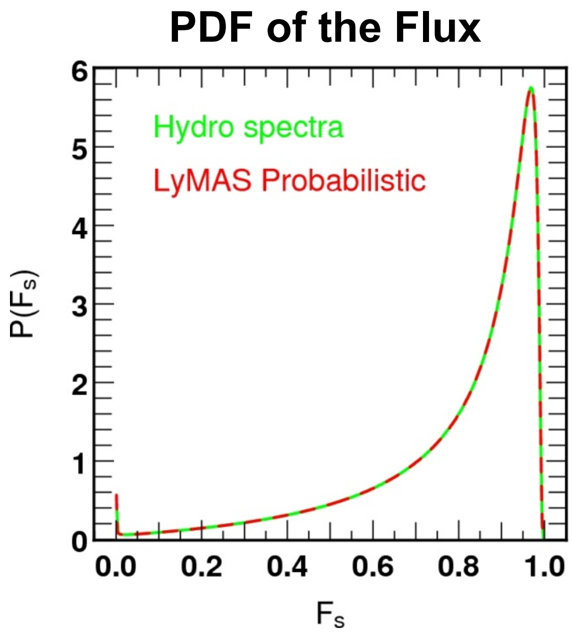
$$P\left(F_s \middle| 1+\delta_s\right)$$

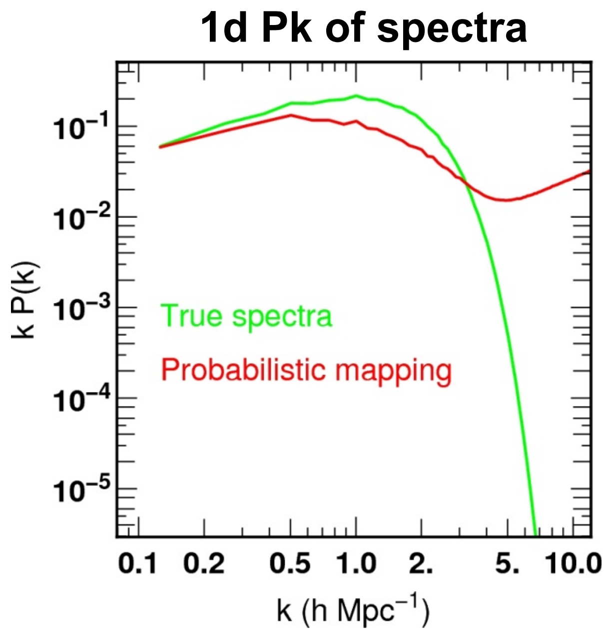


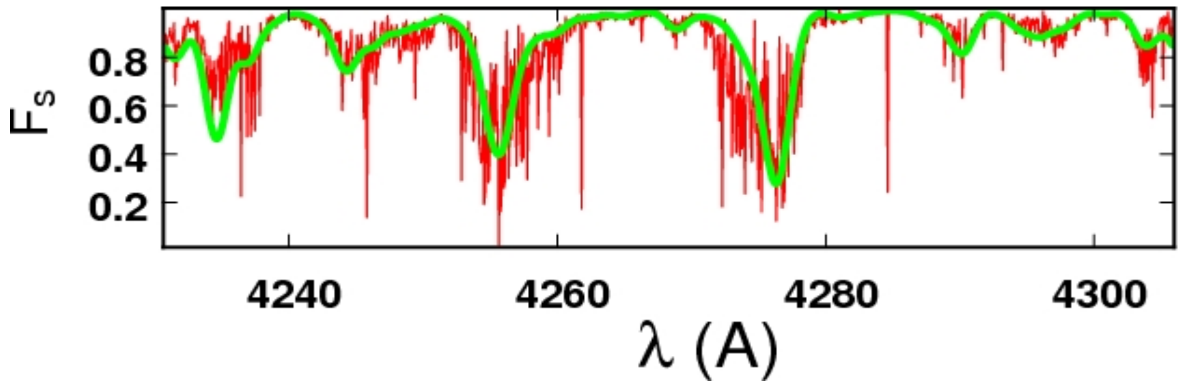


Probabilistic mapping

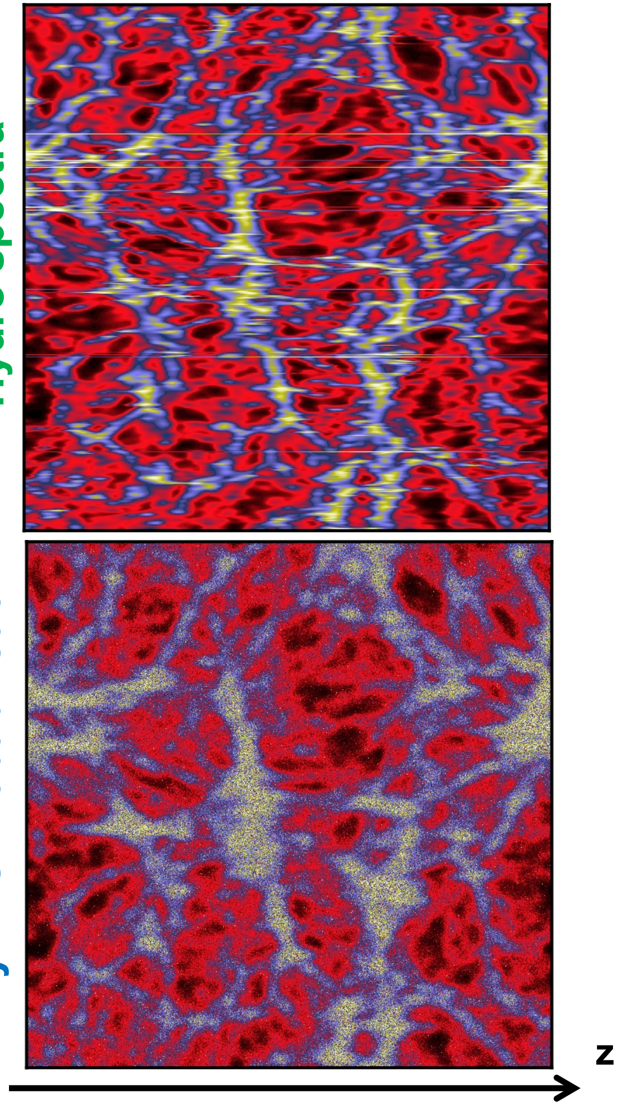


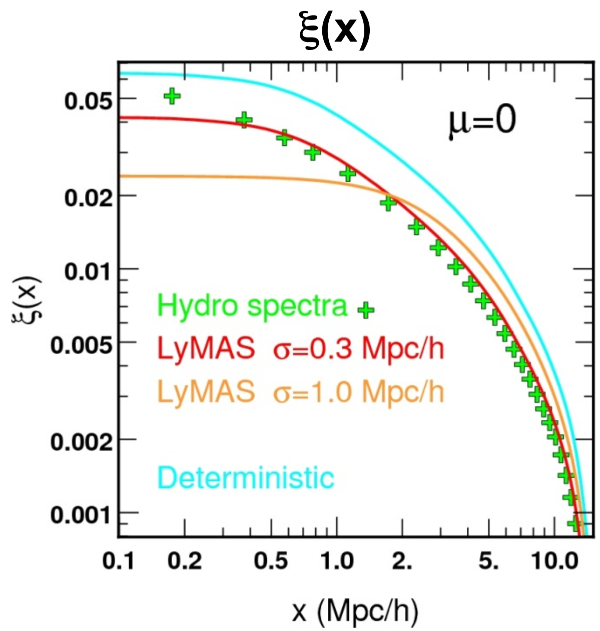


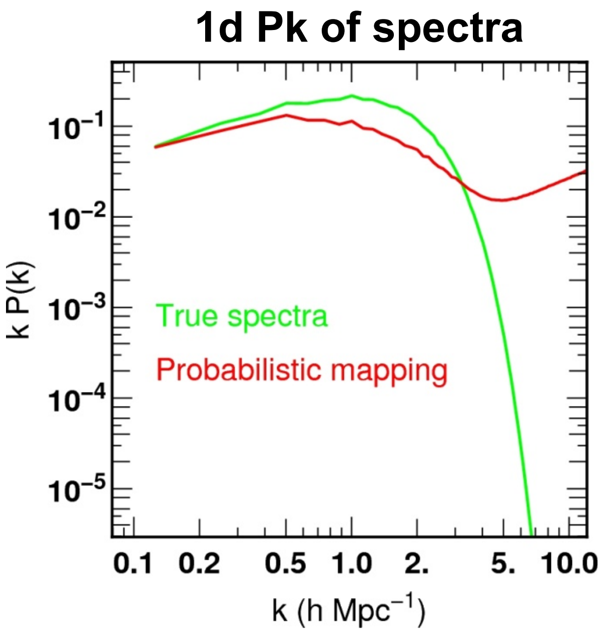


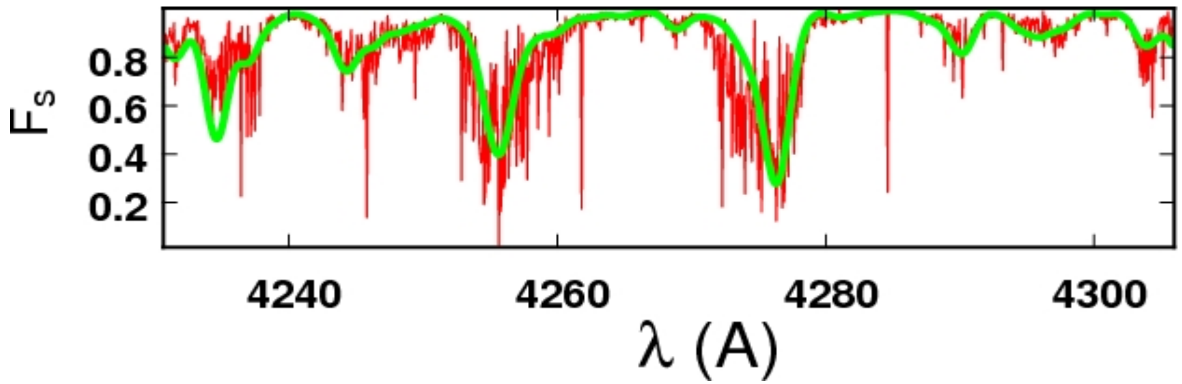


Probabilistic mapping



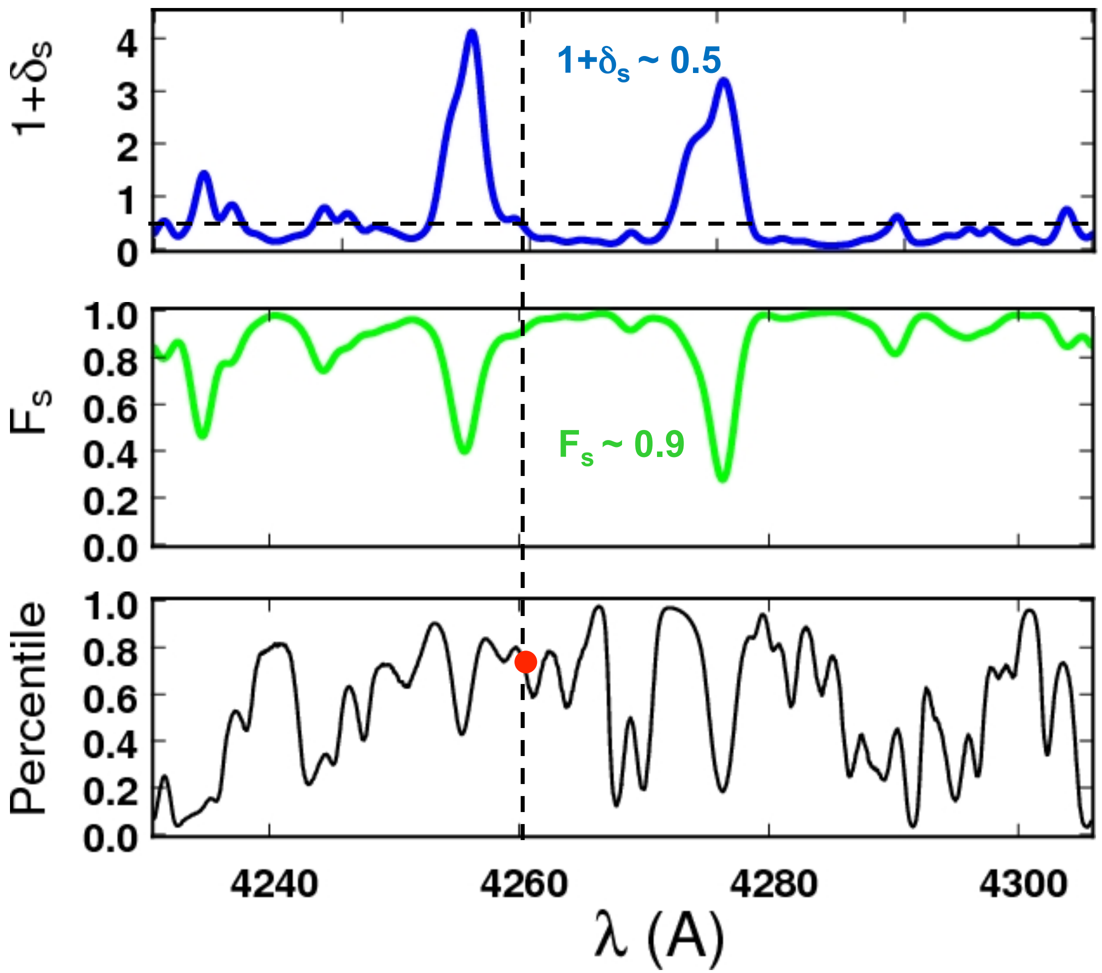


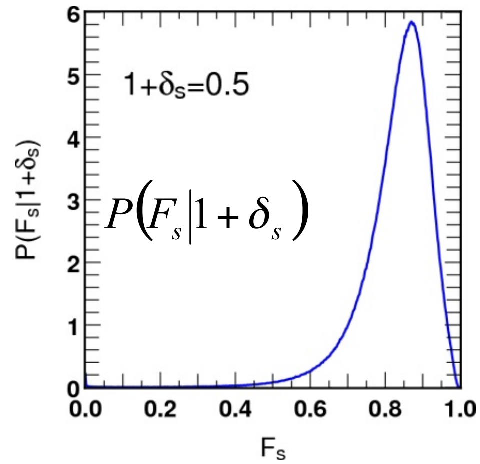




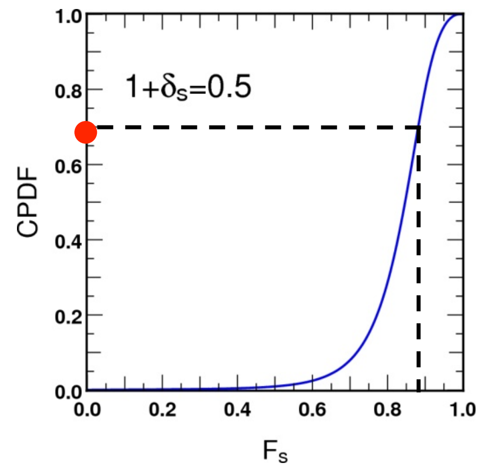
Coherent mapping

1. Construction of "percentile spectra": $Per(F_S, \delta_S) = \int_0^{F_S} P(F_S' | \delta_S)\, dF_S'$





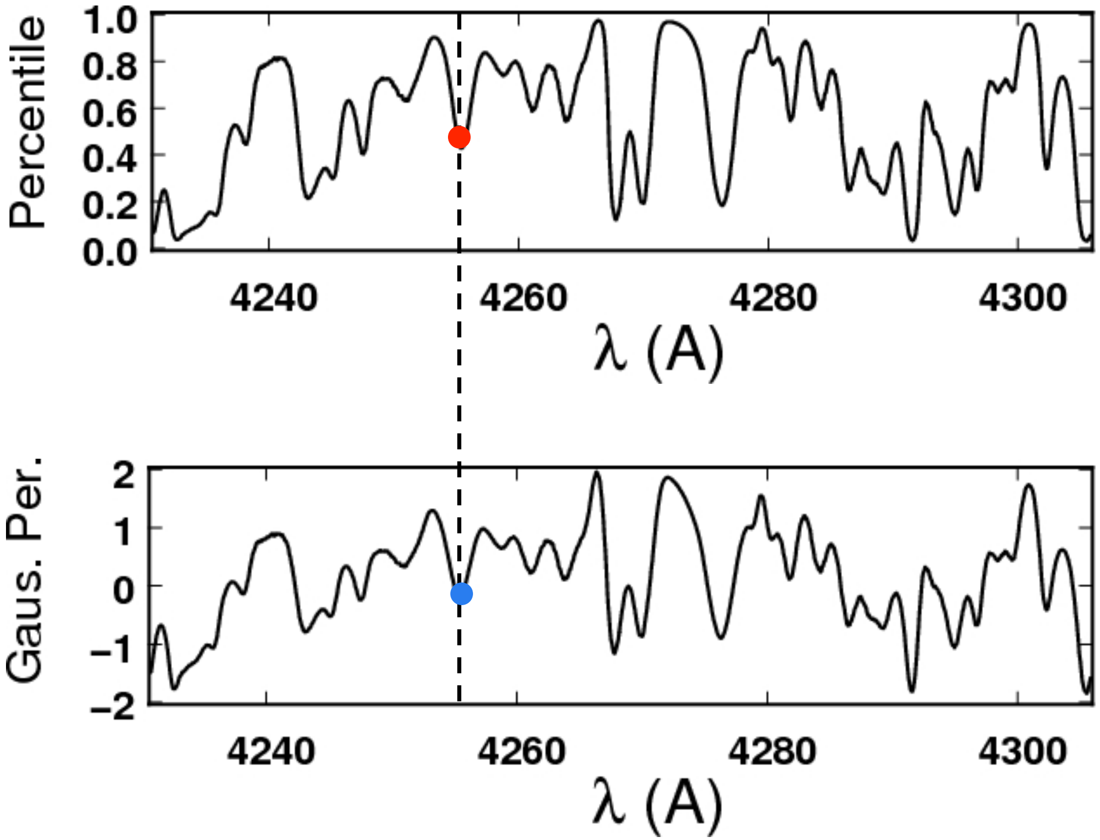
Cumulative PDF



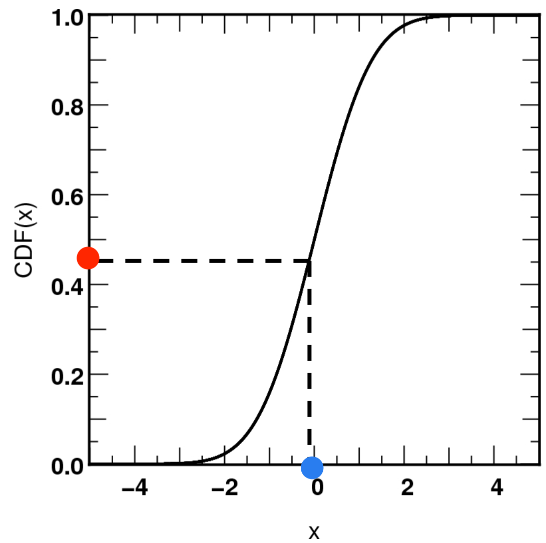
Coherent mapping

2. Construction of "Gaussianized" percentile spectra:

$$G_{Per}(x) = y \qquad (2\pi)^{-1/2}\int_{-\infty}^{y} e^{-\frac{z^2}{2}}\,dz = Per(x)$$



Cumulative PDF of Gaussian function



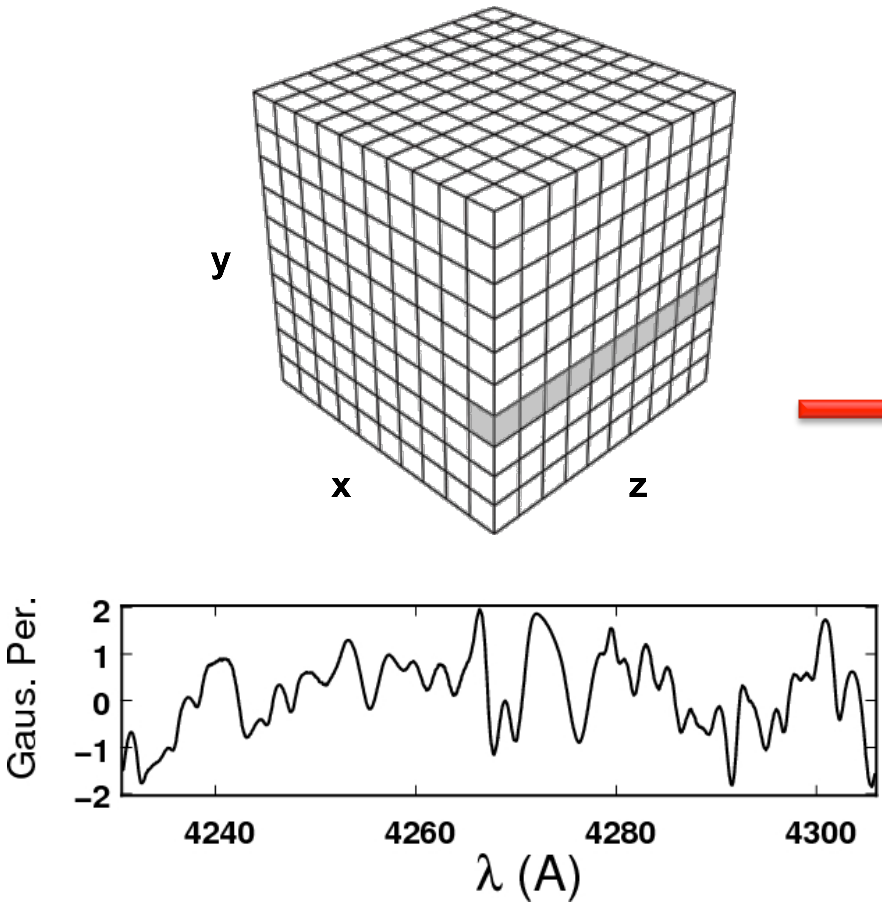
$$CDM(x) = \frac{1}{2}\left[1 + erf\left(\frac{x-\mu}{\sqrt{2\sigma^2}}\right)\right]$$

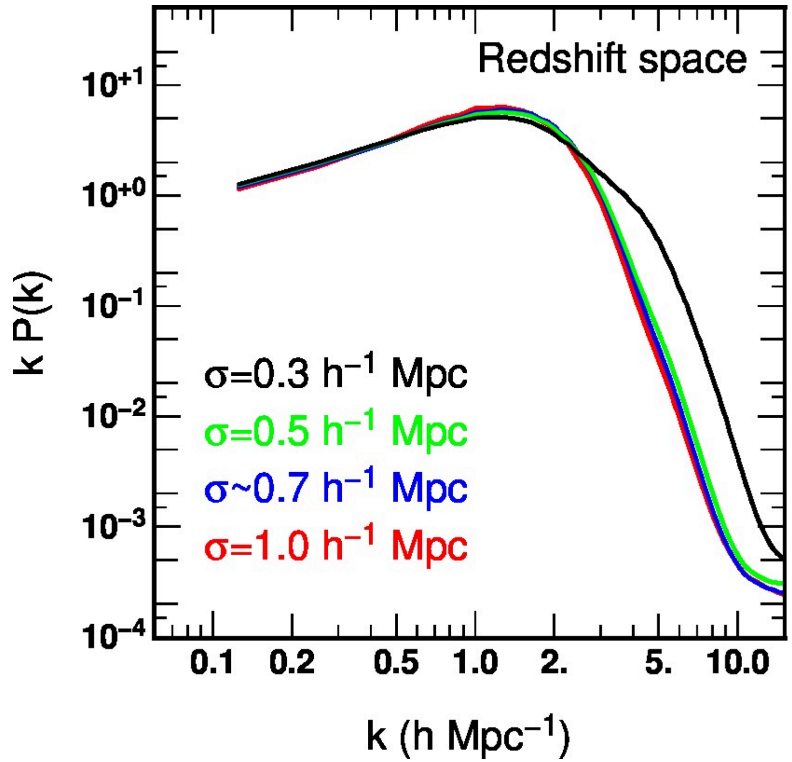
$$\mu = 0$$

$$\sigma^2 = 1$$

Coherent mapping

3. Derive the 1d power spectrum of the "Gaussianized percentile spectra":



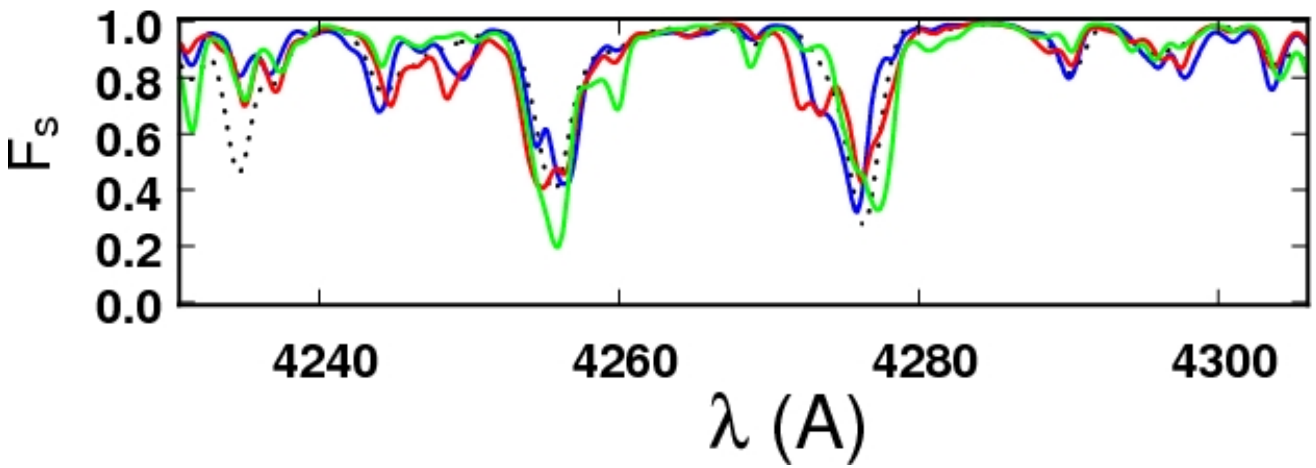


Coherent mapping

1. For each DM skewer, create a realization of G.Per(x) of the 1-d gaussian field

2. Get a realization of Per(F) by “degaussianization”

3. Get the flux field by drawing the flux at each pixel from the location of in $P(F_s|1+\delta_s)$ implied by the value of Per(F)

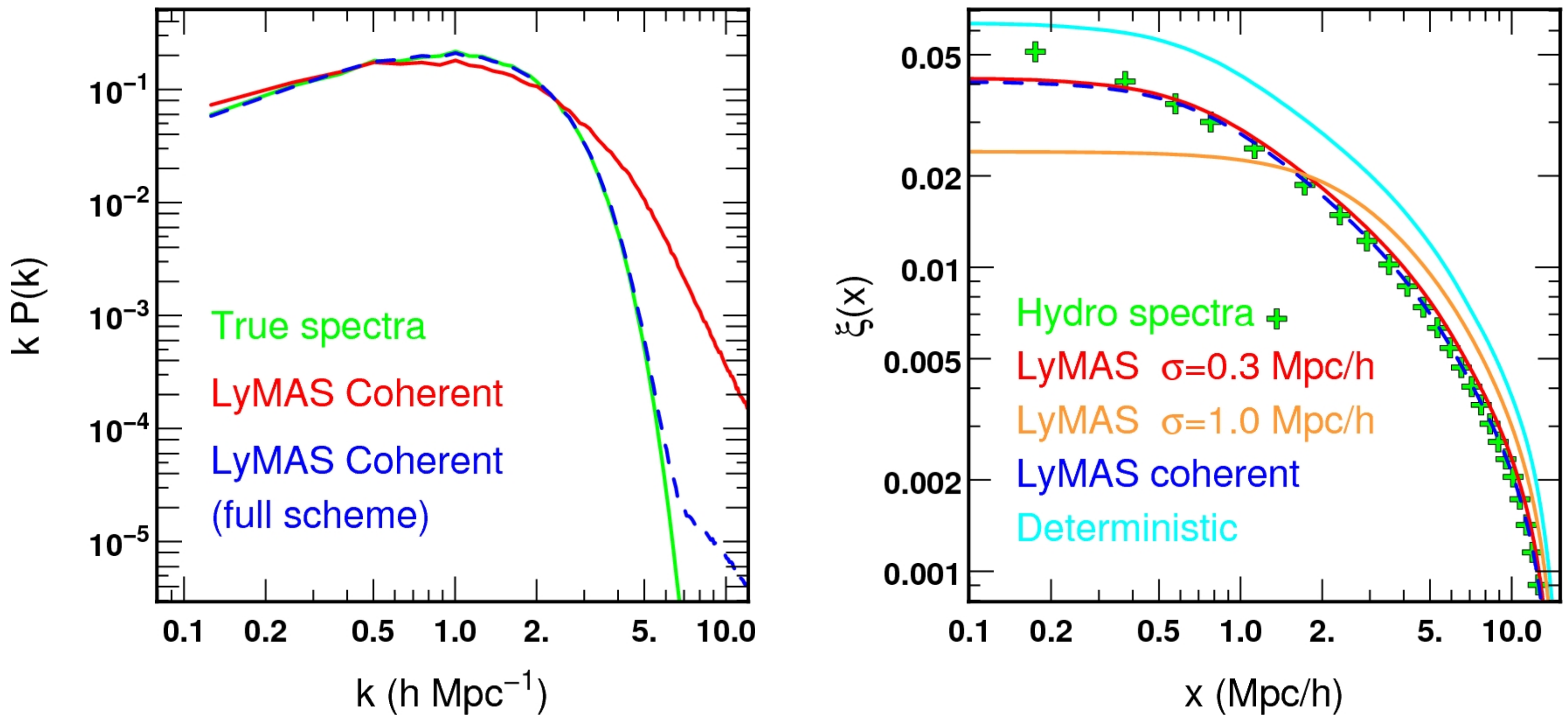


4. One iteration:

- Pk rescaling: multiply each Fourier components by the ratio $[P_F(k)/P_{PS}(k)]^2$
- Flux rescaling

Coherent mapping

4. Iteration on F_s:



Mapping

Hydro Spectra F_s

1d P_k

PDF(F_s)

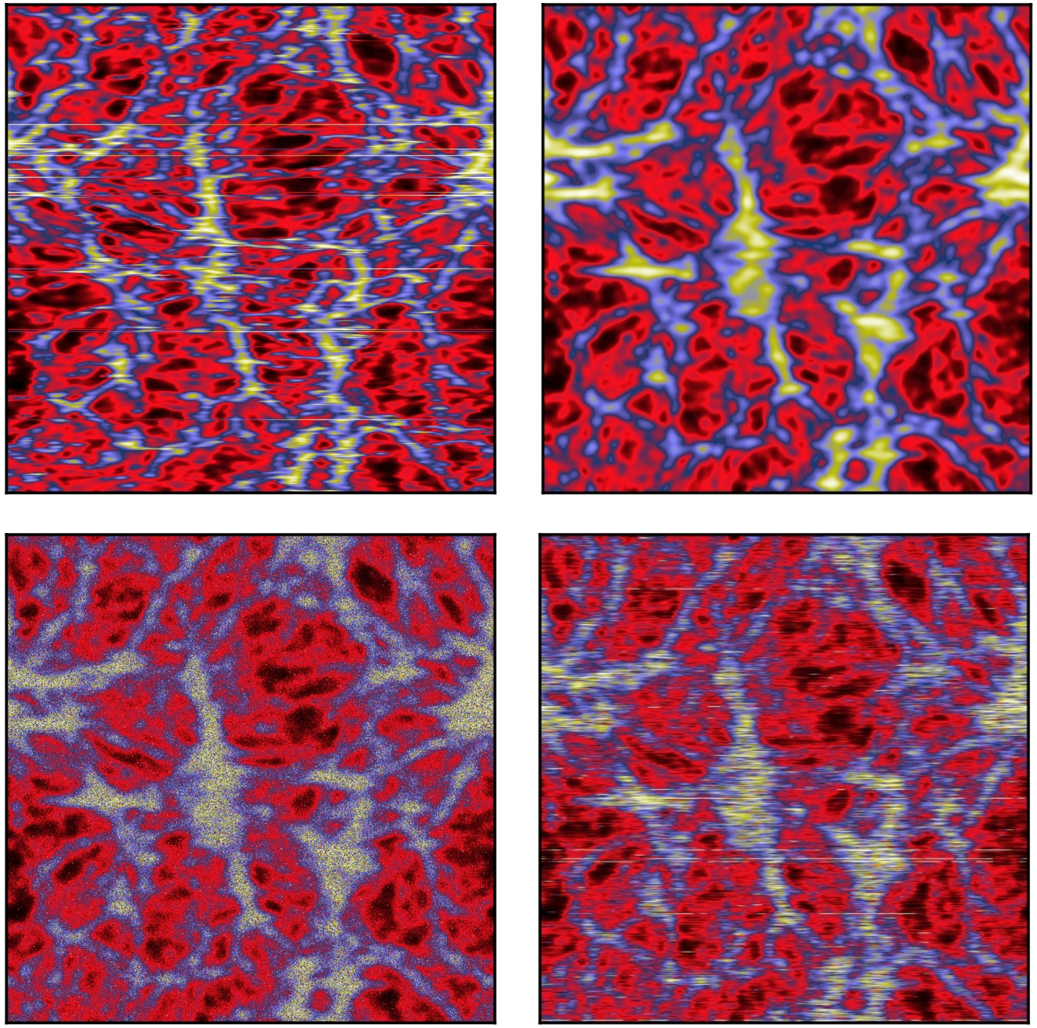
ξ(x)

Deterministic mapping

~~**1d P_k**~~

PDF(F_s)

~~**ξ(x)**~~



LyMAS probabilistics

~~**1d P_k**~~

PDF(F_s)

ξ(x)

LyMAS coherent

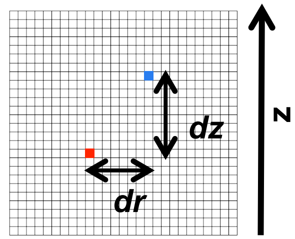
1d P_k

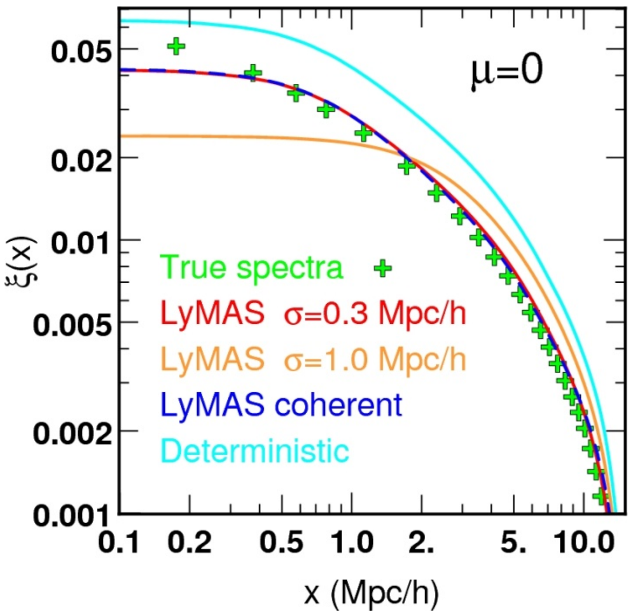
PDF(F_s)

ξ(x)

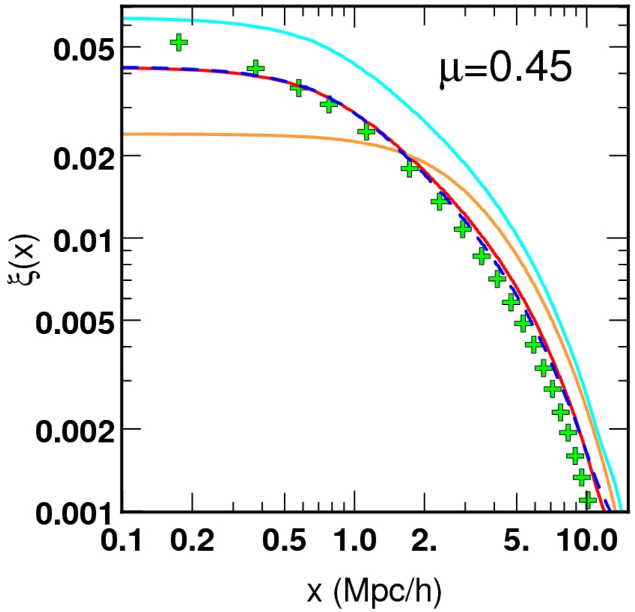
Correlation function

$$\zeta = \frac{\langle F_1(r,z) F_2(r+dr, z+dz) \rangle}{\langle F \rangle^2} - 1$$

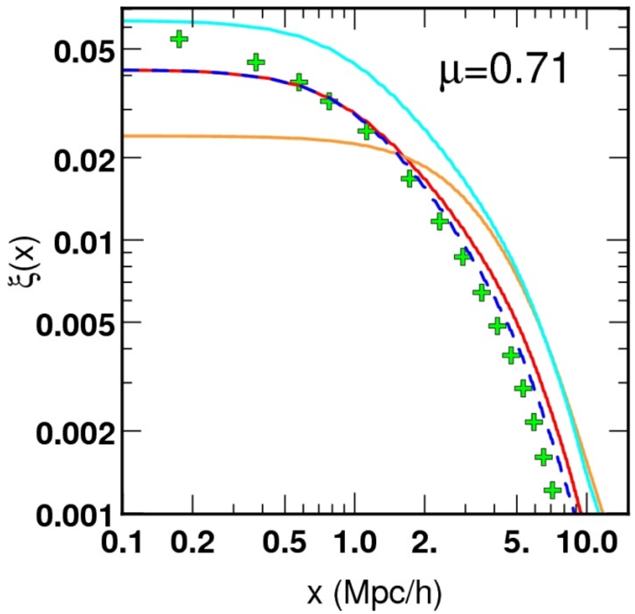




$dz = 0$

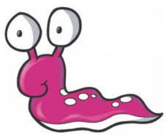


$dr = 0.5dz$



$dr = dz$

Plan



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Application to large cosmological DM simulations

Gadget2 (Springel 2005)

2013:

300 Mpc/h - 1024^3 particles
WMAP1 - σ_{DM}=0.3 Mpc/h

1.0 Gpc/h - 1024^3 particles
WMAP1 - σ_{DM}=1.0 Mpc/h

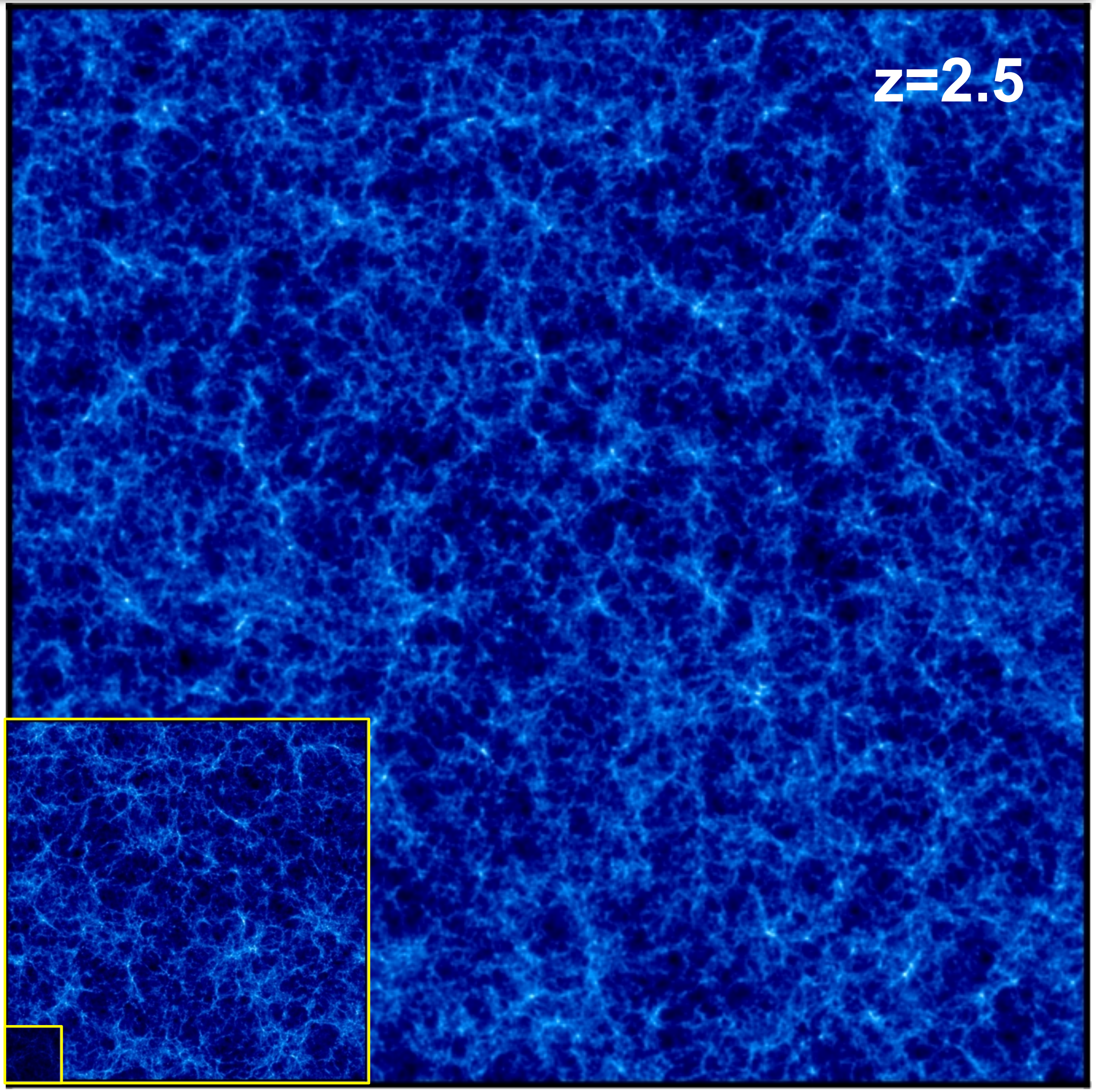
(z=2.5)

2014:

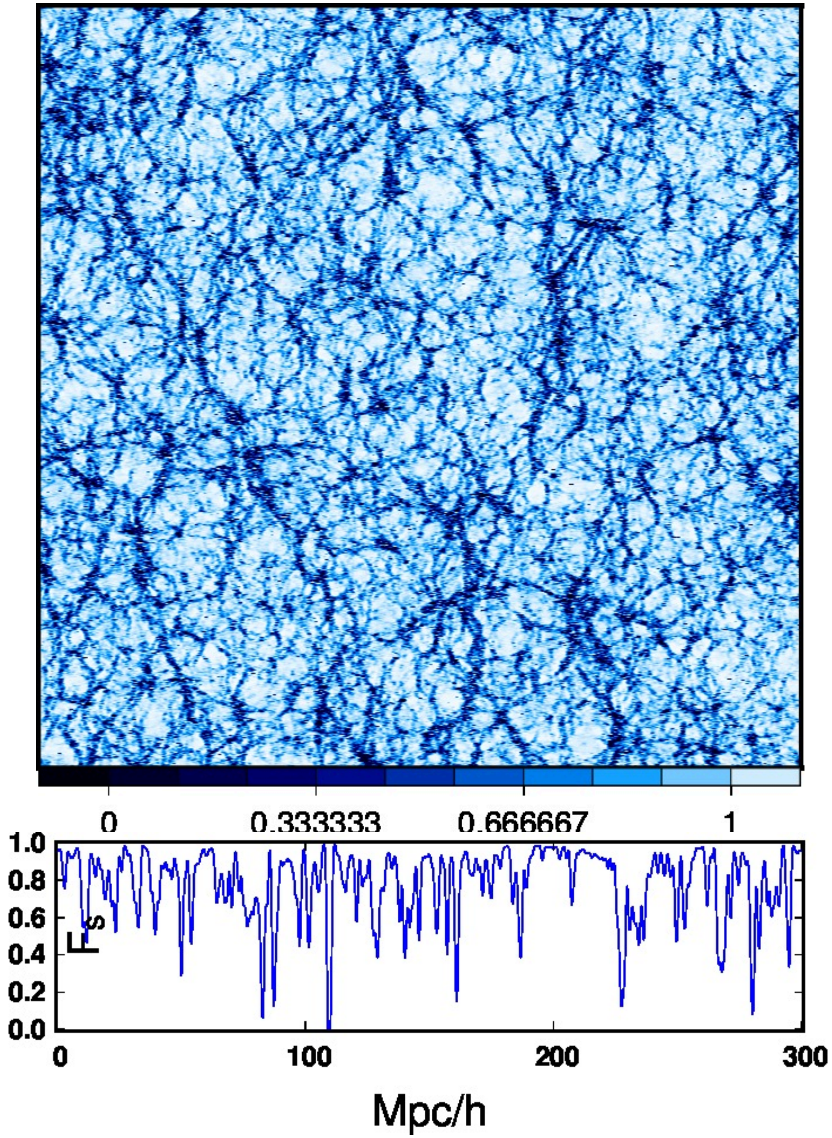
300 Mpc/h - 1024^3 - 2048^3 parts.
WMAP7 - σ_{DM}=0.3 Mpc/h

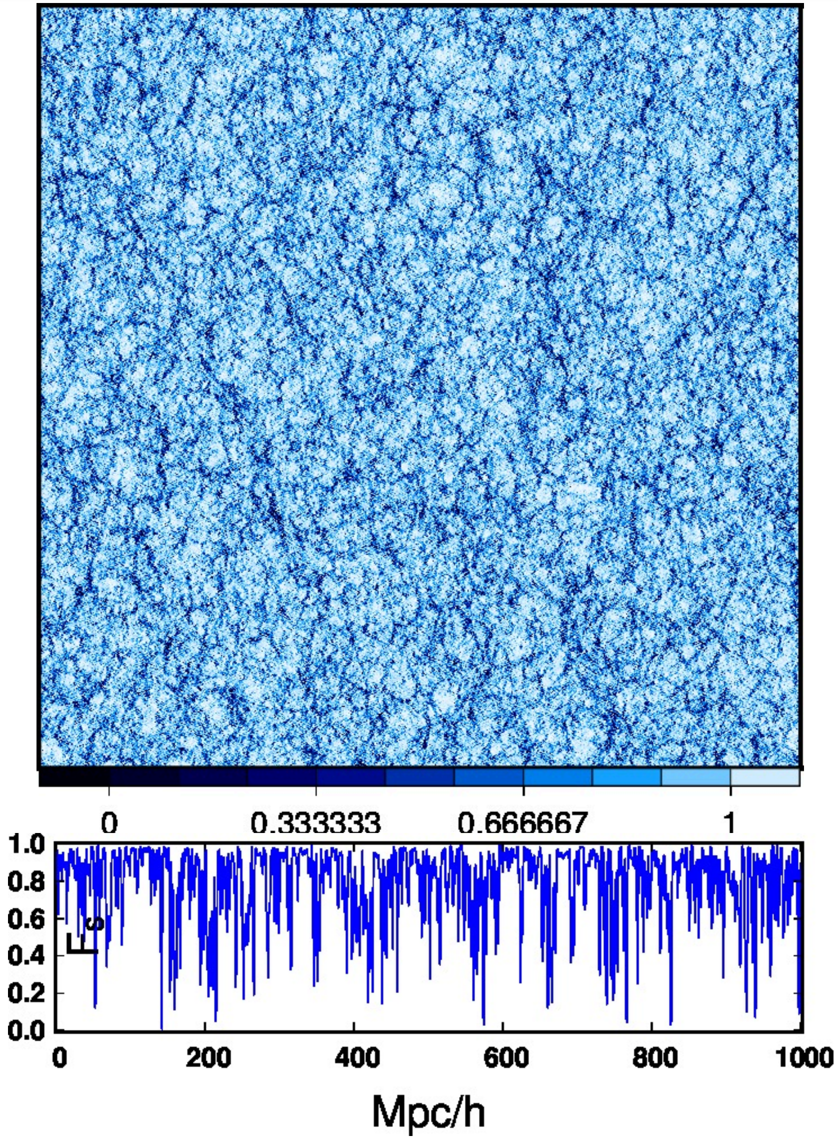
1.0 Gpc/h – 1024^3 - 2048^3 parts.
WMAP7 - σ_{DM}=0.5 ou 1.0 Mpc/h

(z=3.0, 2.5, 2.1)

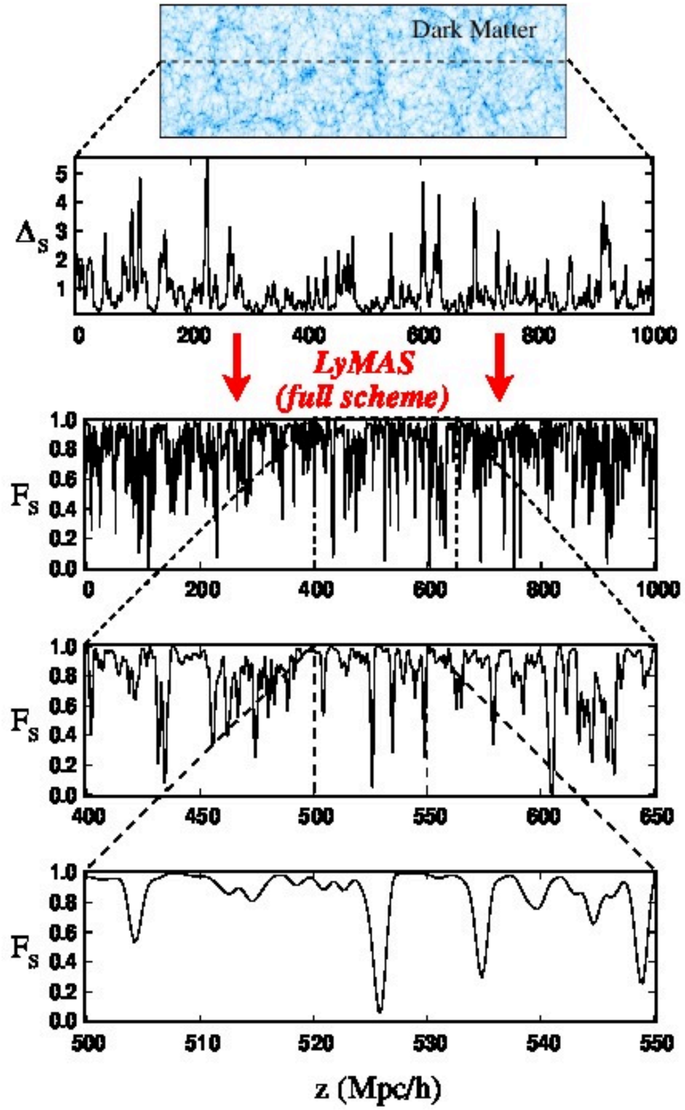


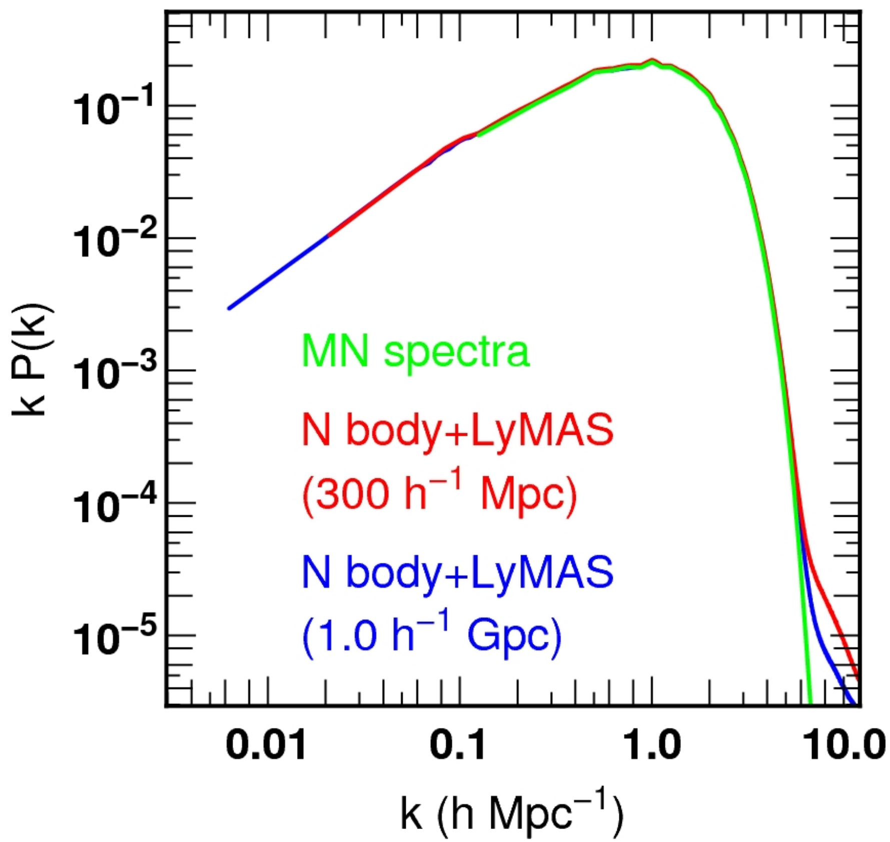
Application to large cosmological DM simulations





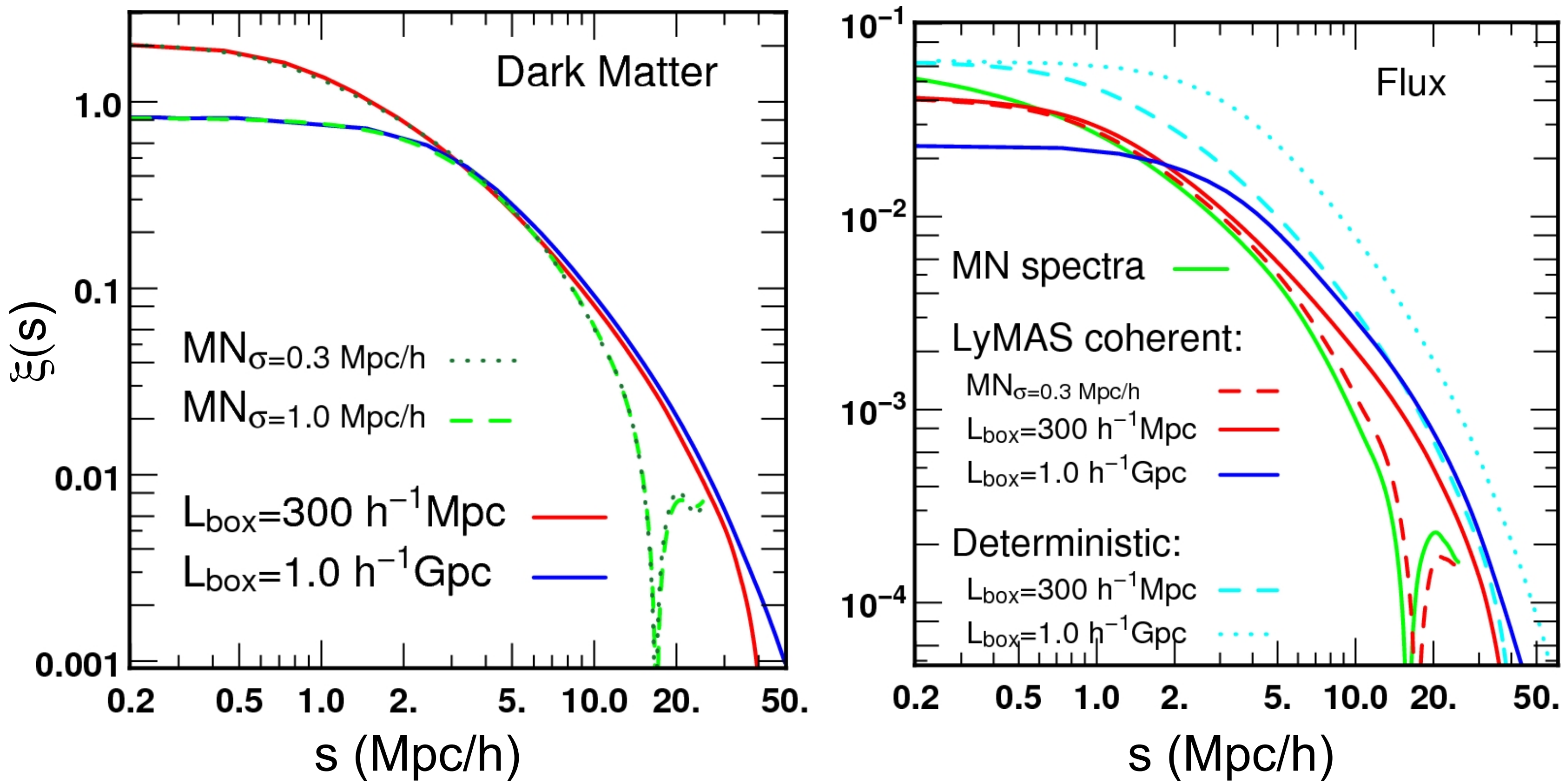
Application to large cosmological DM simulations





Application to large cosmological DM simulations

Correlation function:

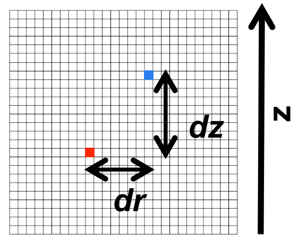


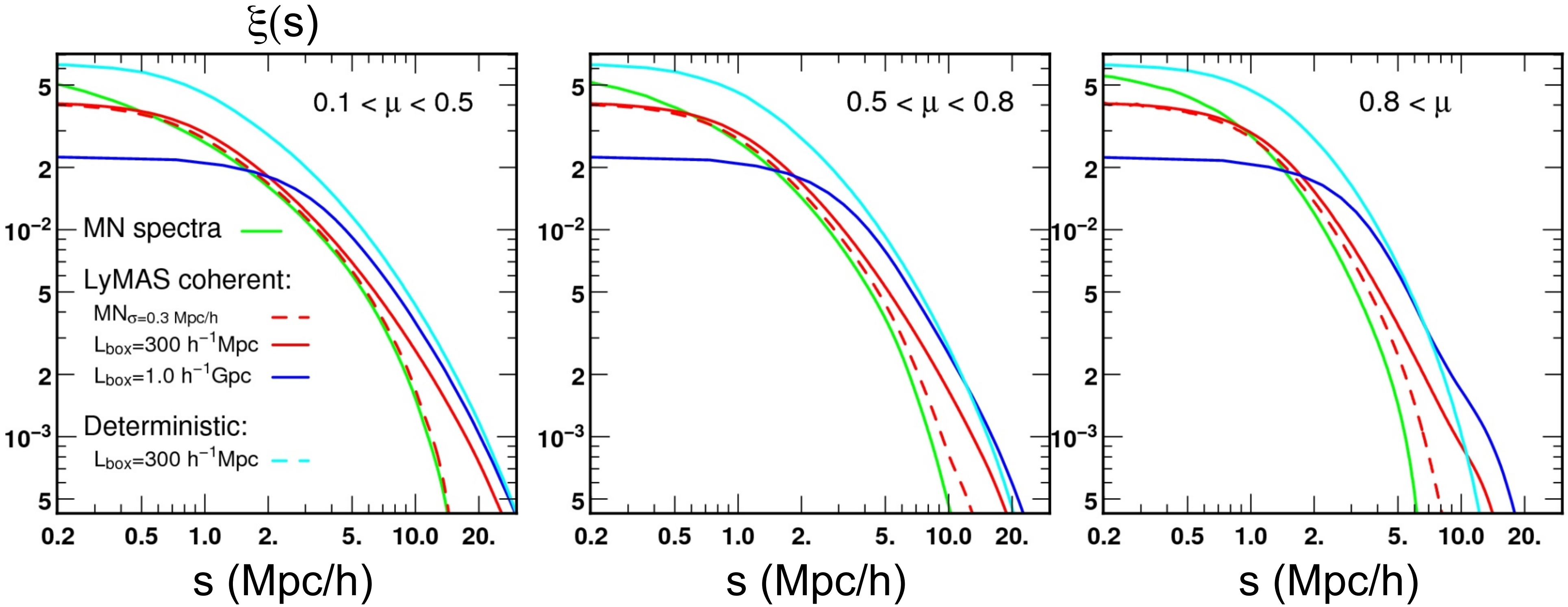
Application to large cosmological DM simulations

Correlation function:

$$\mu = \frac{dz}{\sqrt{dr^2 + dz^2}}$$

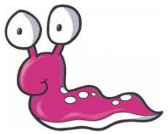
$$s = \sqrt{dr^2 + dz^2}$$





Plan

1. Introduction
2. LyMAS scheme
3. Application to large N-body simulations

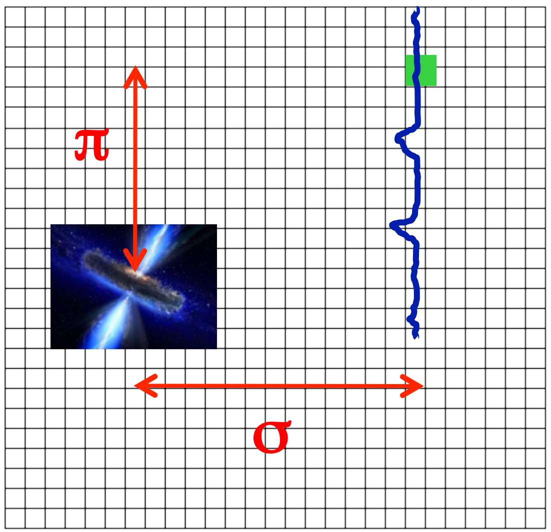


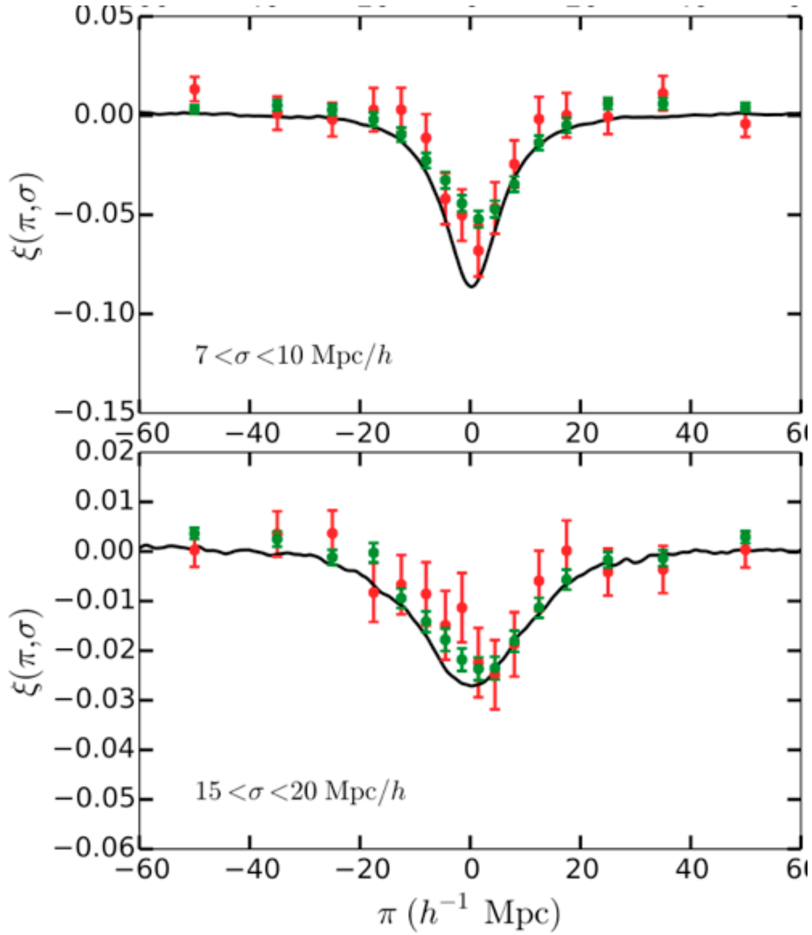
4. Ongoing works
5. Next

Cross correlation quasar Lyα in BOSS survey

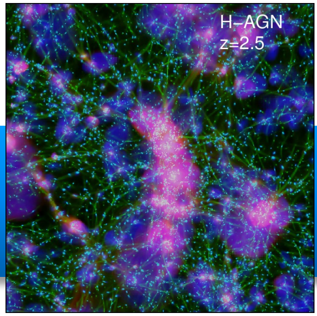
Font-Ribera et al. (2013)

(SDSS DR9)

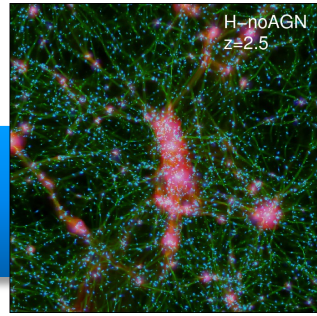


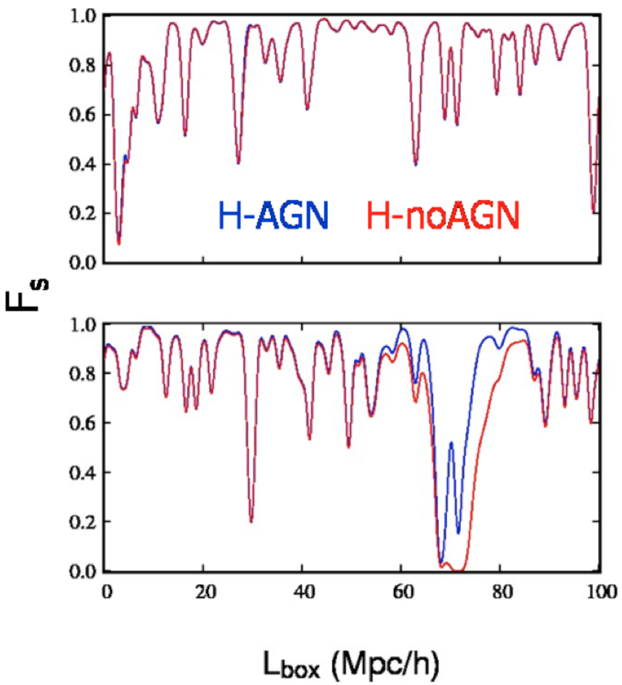


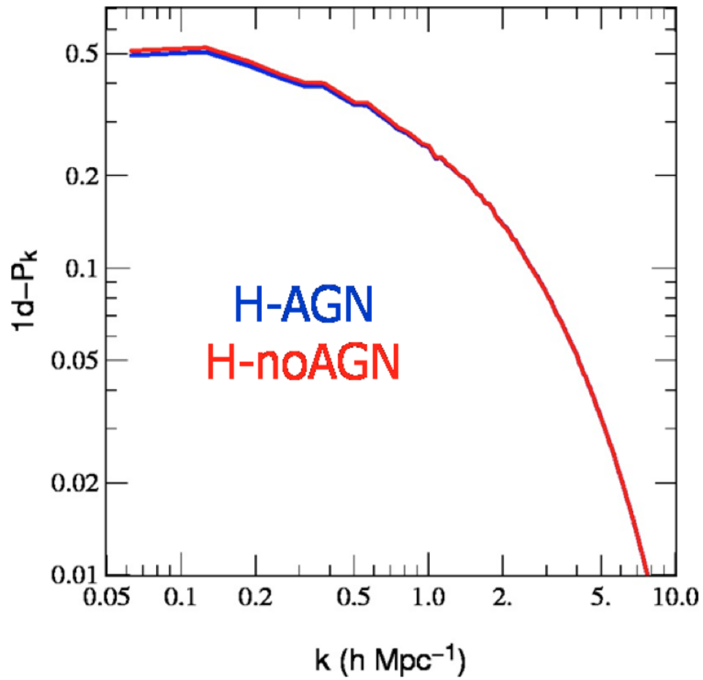
"Modelling the Lya forest cross correlation with LyMAS"
Lochhass, Weinberg, Peirani et al., to be submitted



AGN vs noAGN



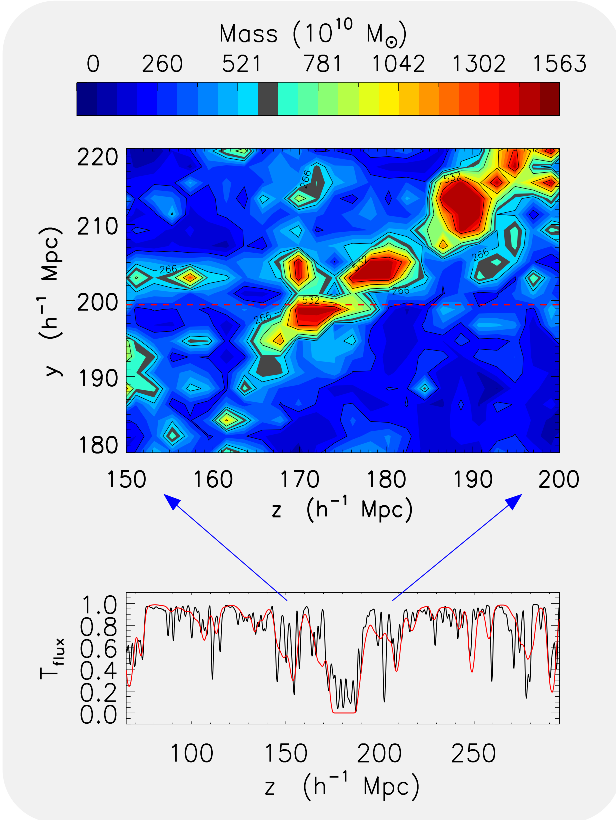




“The effect of AGN feedback on the Lya forest clustering”
Peirani et al., in prep

MAMMOTH + LyMAS

MApping the Most Massive Overdensity Through Hydrogen



"MApping the Most Massive Overdensity Through Hydrogen (MAMMOTH): I – Cai, Fan, Bian, Peirani, Frye, McGreer, White & Ho, to be submitted

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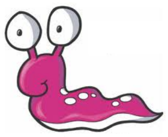


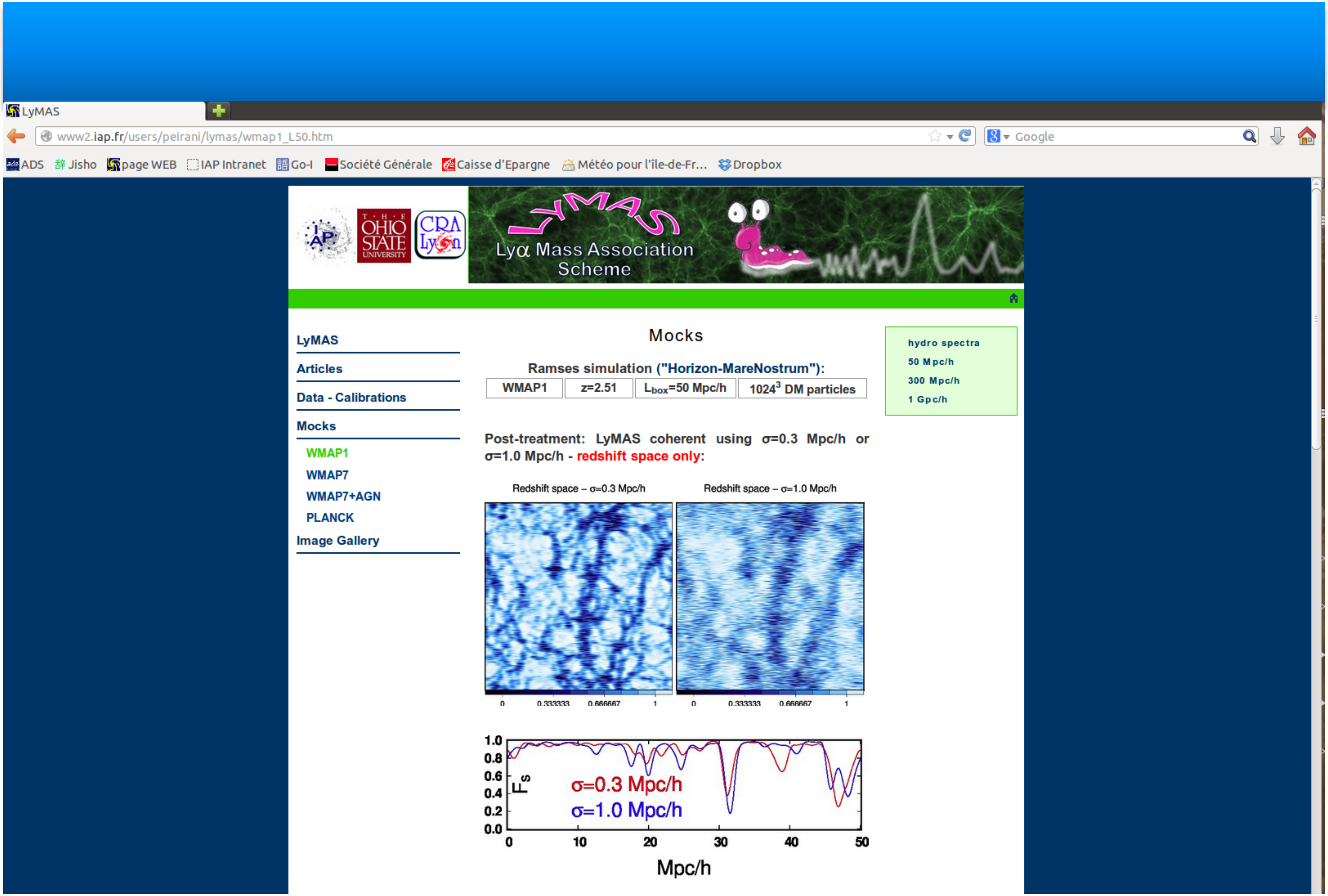
5. Next

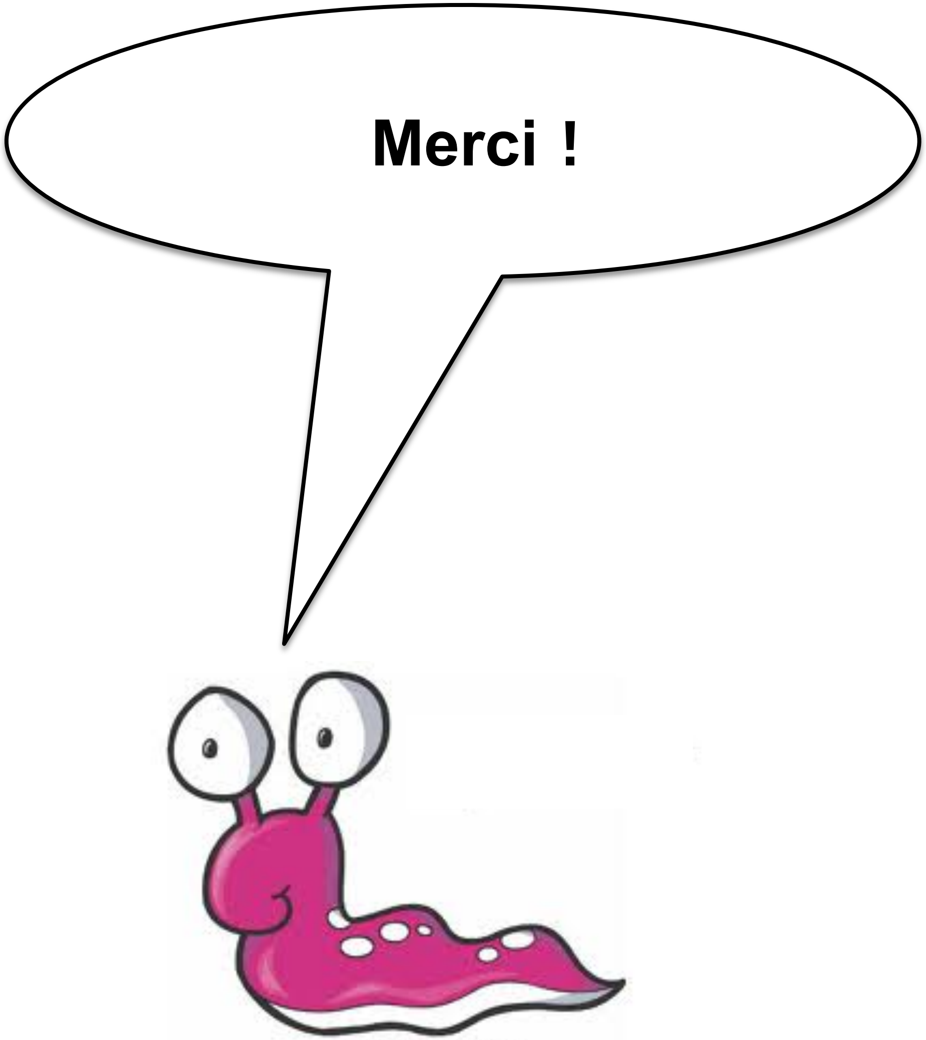
Numerical modeling improvements

1. Algorithms
   - QSO continuum
   - Redshift evolution
   - noises
   - Non constant spectral resolution
   - Etc…

2. Simulations and more realistic catalogs of spectra
   - N-body simulations : $\geq$ 2 Gpc/h (BAO study)
   - Light cones
   - Hydro simulations (planck, WDM…)
   - Etc…

Web : www2.iap.fr/users/lymas/lymas.htm




Merci !