InterGalactic Medium - based Cosmology: from BOSS to DESI

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Outline

- Intergalactic Medium - based Cosmology :
  - **What is it ?**

- The SDSS-III Baryon Oscillation Spectroscopic Survey
  - Main cosmological results
  - Corrections
  - Adjacent science

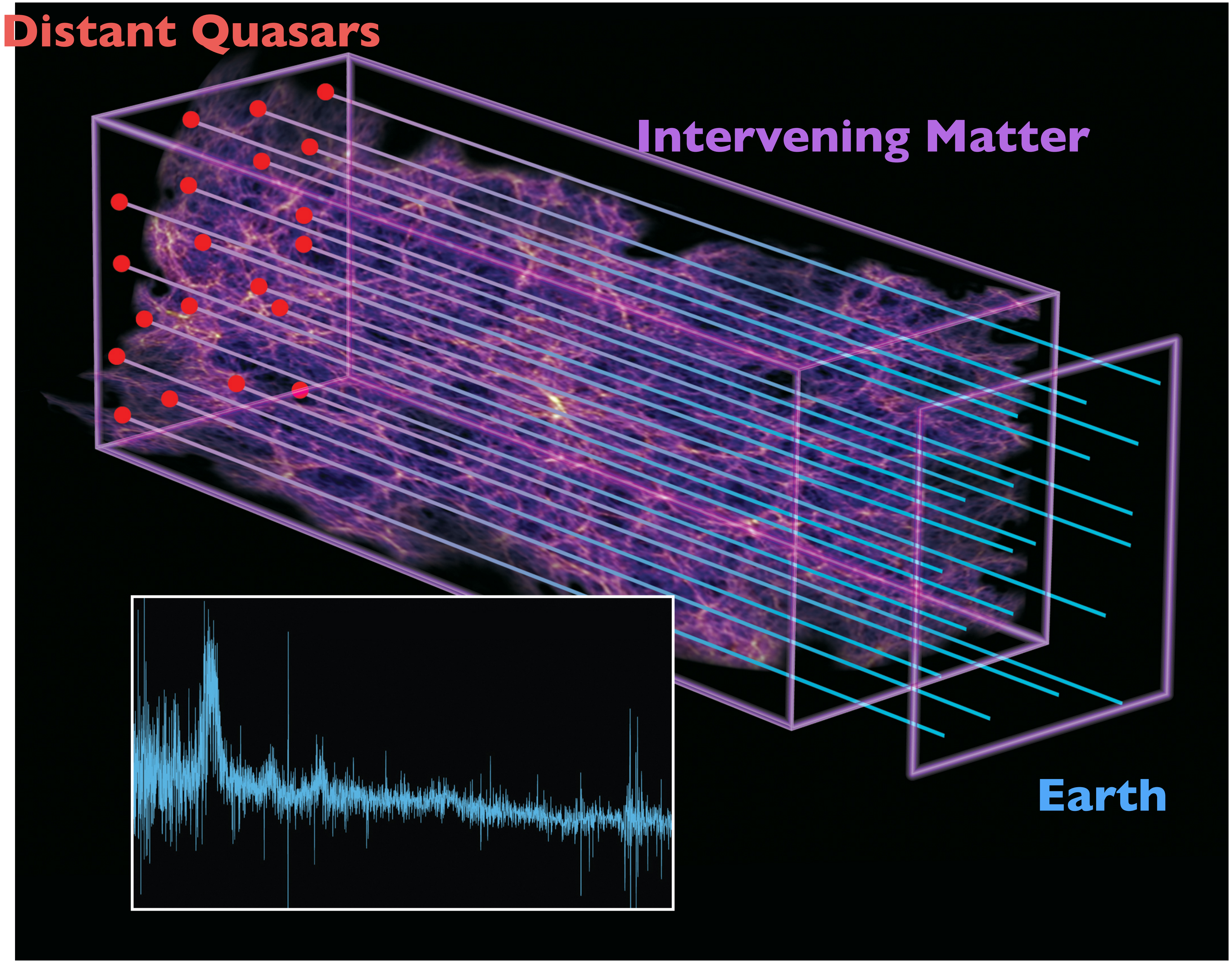
- The Dark Energy Spectroscopic Instrument
  - BOSS vs DESI
  - BAO forecasts for DESI Lyα
  - Opportunities
  - Statistical challenges

Quasars

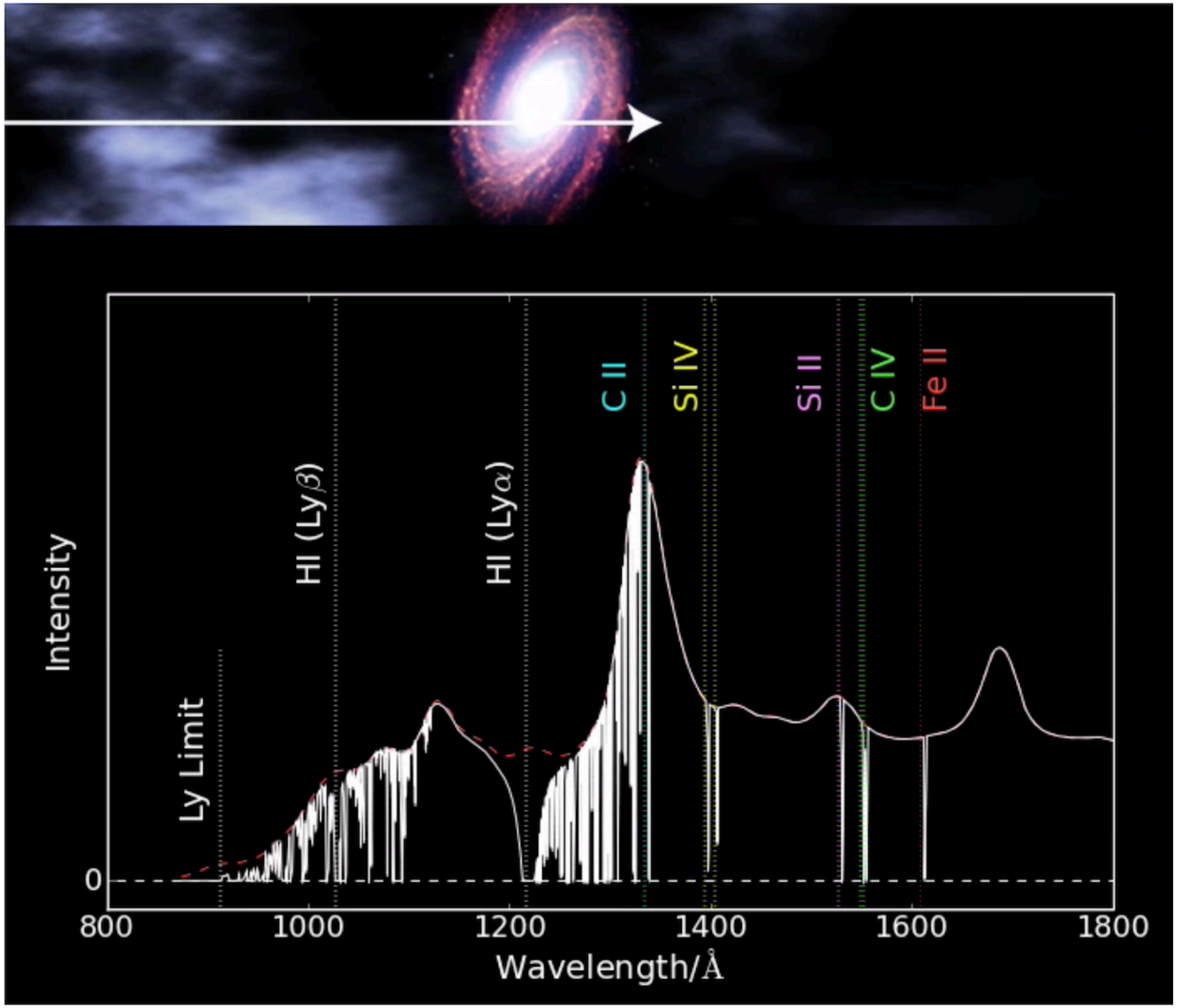
- Brightest objects in the Universe powered by accretion disk of a SMBH
- Emit across the EM spectrum and can be observed in radio, IR, visible, UV and X-ray
- Reach maximum luminosity in UV at 1216 Å (the Lyα e- transition of HI)
- Can be found on a broad range of distances: $0.1 < z < 7$
- More abundant in the early Universe than today ; higher density of quasars at redshift $z = 2 — 3$
- Provide an uncalibrated broadband backlight

… *what does that mean ?*

Quasars as backlight

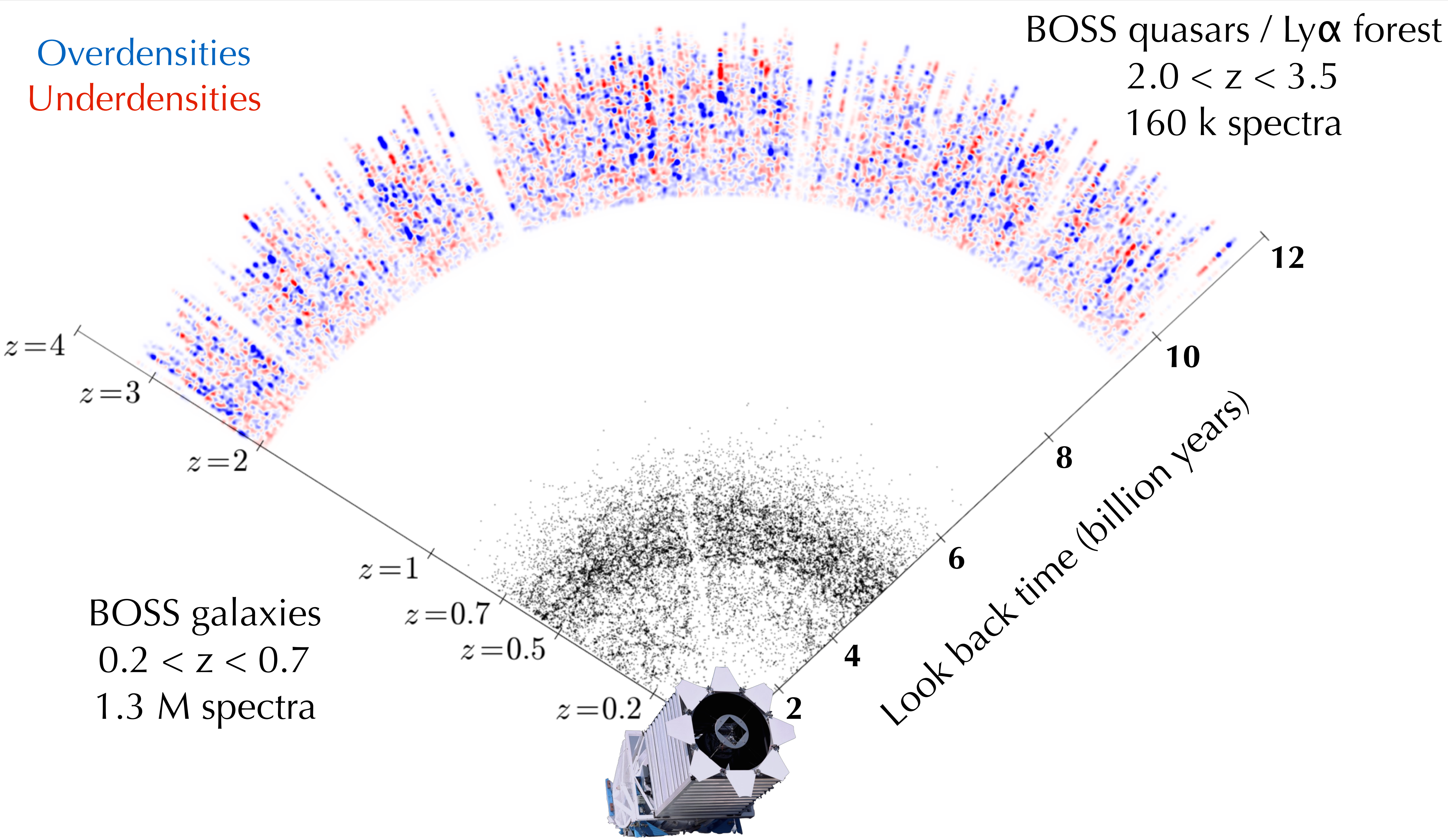


Quasars as backlight

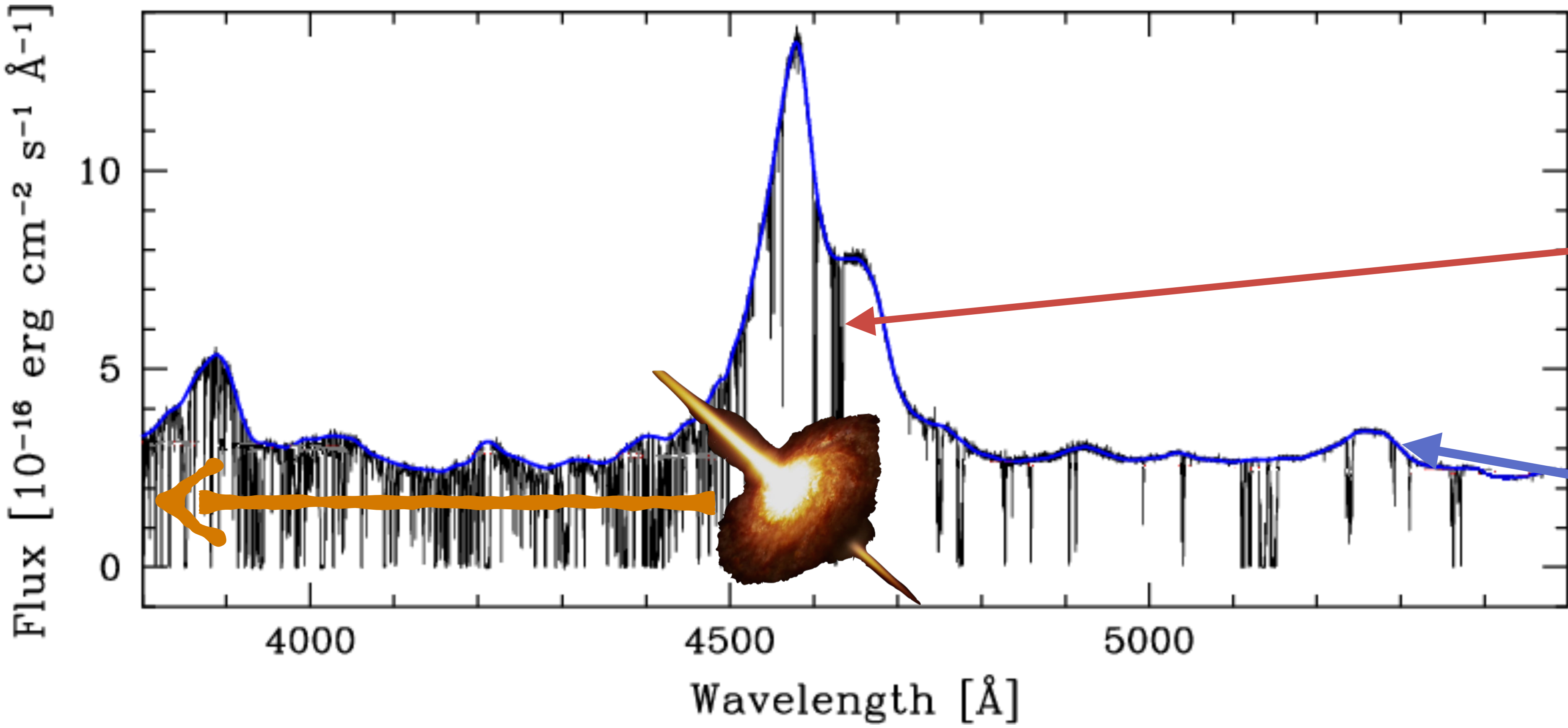


Credit : Pontzen, UCL

- Sloan Digital Sky Survey IIIrd Generation
- Baryon Oscillation Spectroscopic Survey
- 2009 - 2014
- 2.5 m Telescope at Apache Point Observatory, Cloudcroft, New Mexico
- 2 optical spectrographs : 3600 Å - 10400 Å
- Cover 10 000 sq. degres => ~1/4 of the sky
- 2370 plates ; 1000 targets per plate
- 3° diameter field of view


Overdensities
Underdensities
BOSS quasars / Lyα forest
2.0 < z < 3.5
160 k spectra
z = 4
z = 3
z = 2
z = 1
z = 0.7
z = 0.5
z = 0.2
BOSS galaxies
0.2 < z < 0.7
1.3 M spectra
2
4
6
8
10
12
Look back time (billion years)

Observed Flux to Cosmological Fluctuations



Transmitted flux fraction

Observed flux

$$F(\lambda) = \frac{f(\lambda)}{C(\lambda)}$$

Quasar continuum

Observed Wavelength

Absorption Redshift

$$\lambda = \lambda_{\alpha,c}(1 + z_{\alpha,c})$$

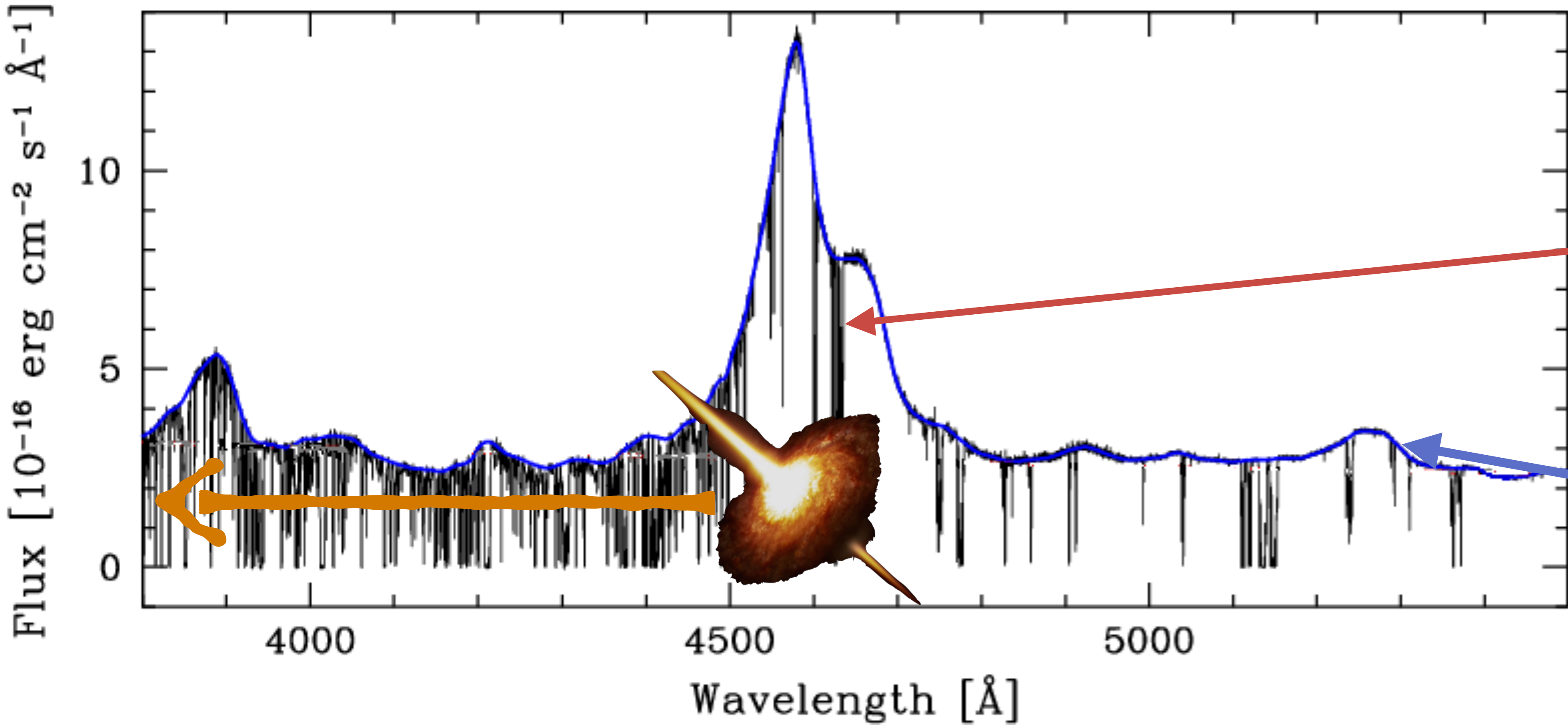
Lyman Alpha wavelength : 1216 Å

Triply ionized Carbon wavelength : 1550 Å

As a result, for an observed wavelength of 4000 Å :

$z_{\alpha} = 2.29$ while $z_c = 1.58$

Observed Flux to Cosmological Fluctuations



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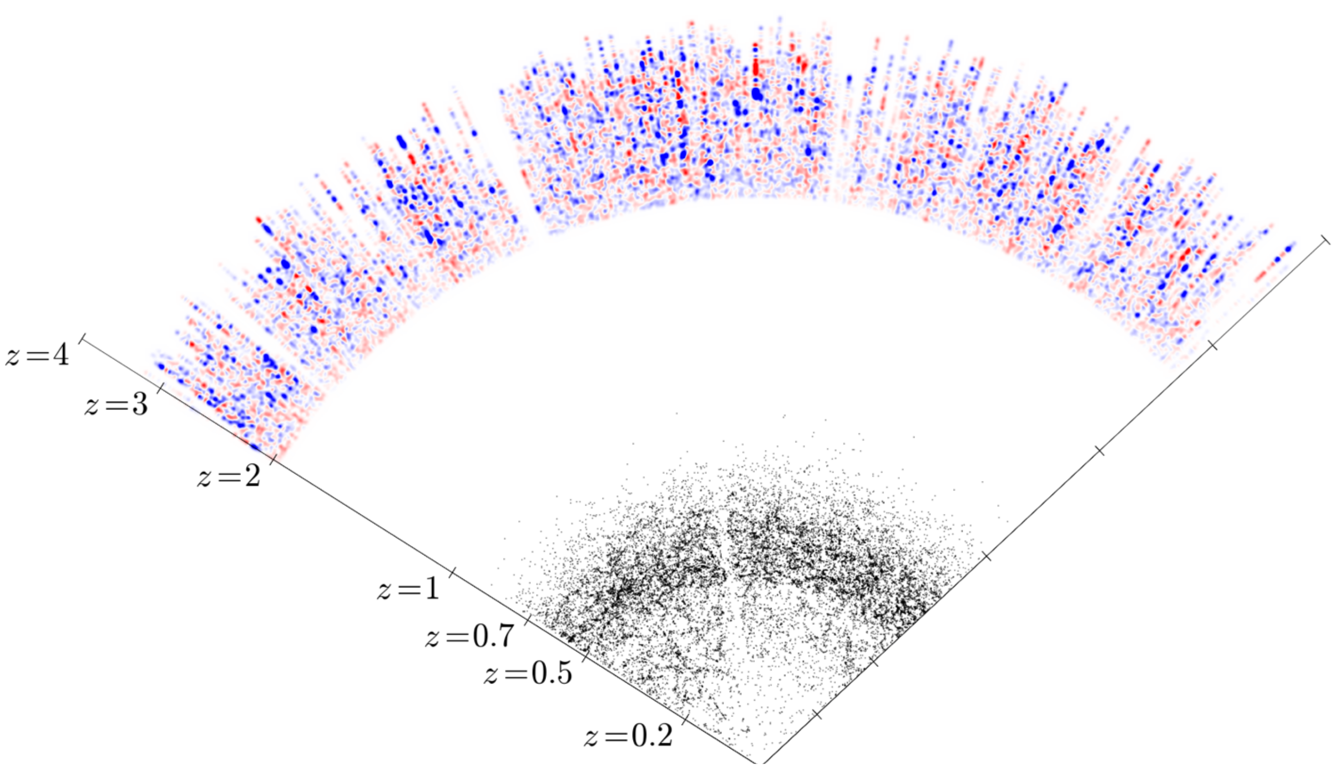

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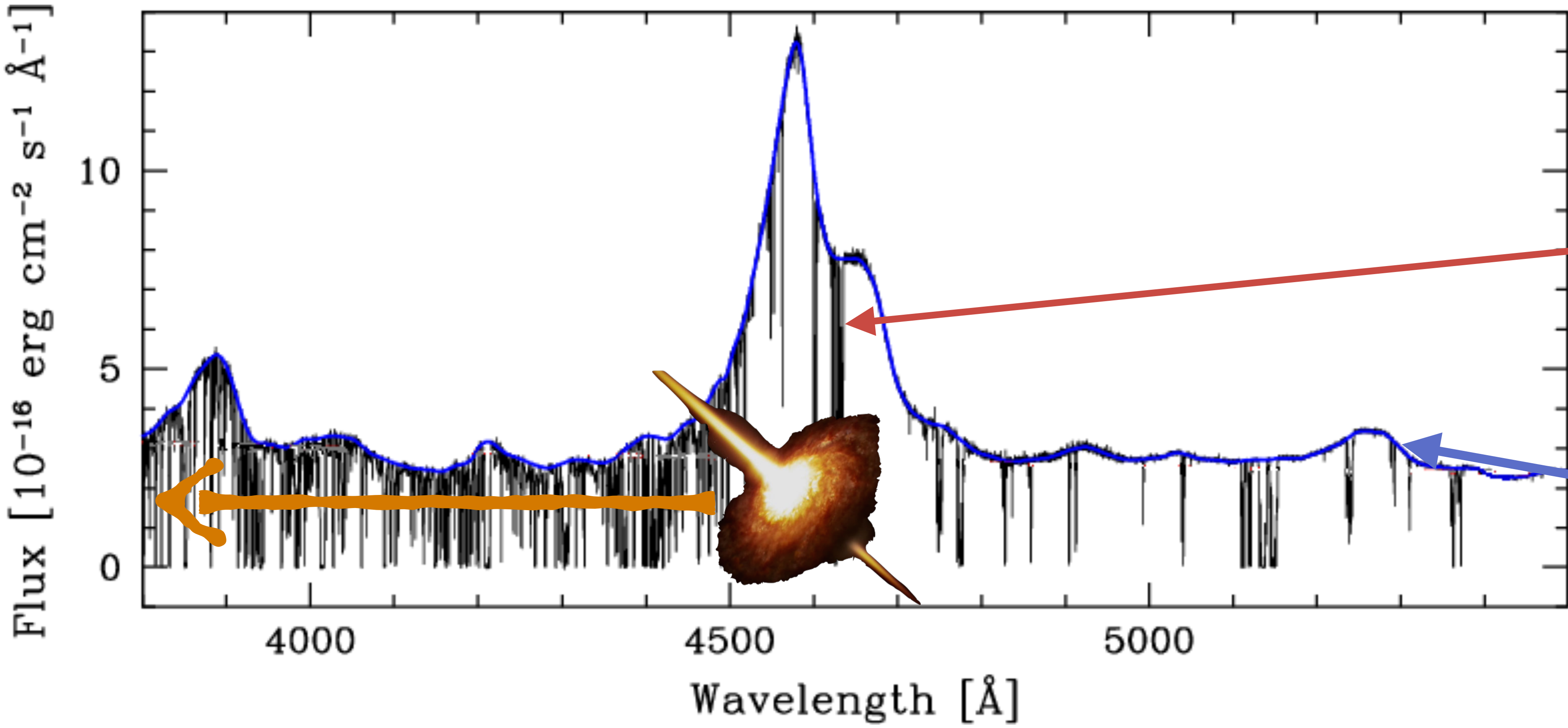
Observed Flux to Cosmological Fluctuations



Transmitted flux fraction

Observed flux

$$F(\lambda) = \frac{f(\lambda)}{C(\lambda)}$$

Quasar continuum

$$\delta_F(x) = \frac{F(x) - \bar{F}}{\bar{F}}$$

Flux fluctuations in pixels trace the **density** along the line of sight to the quasar

$$\delta_F = b_F \delta$$

bias

Observed Flux to Cosmological Fluctuations

Measurement of the two-point correlation function of Hydrogen clouds, assuming a linear bias, **gives us access to the dark matter distribution** :

$$\xi_F(r) = b_F^2 \langle \delta(\vec{x})\delta(\vec{x}+\vec{r})\rangle = b_F^2 \xi(r)$$

The two-point correlation function is the Fourier transform of the power spectrum :

$$\xi_F(r) = \frac{1}{(2\pi)^3} \int \mathcal{P}_F(k) e^{-i\vec{k}\cdot\vec{r}} d^3k$$

Measured from observation

Flux 3D power spectrum

The two-point correlation function is the Fourier transform of the power spectrum :

$$\xi_F(r) = \frac{1}{(2\pi)^3} \int \mathcal{P}_F(k) e^{-i\vec{k}\cdot\vec{r}} d^3k$$

Measured from observation

Flux 3D power spectrum

In redshift space, the **Kaiser effect** describes the **redshift space distortions** resulting from peculiar velocities :

$$\mathcal{P}_F(k) = b_F^2 (1 + \beta\mu_k^2)^2 \mathcal{P}_L(k)$$

bias

redshift distortion parameter

Predicted by cosmological models

BAO

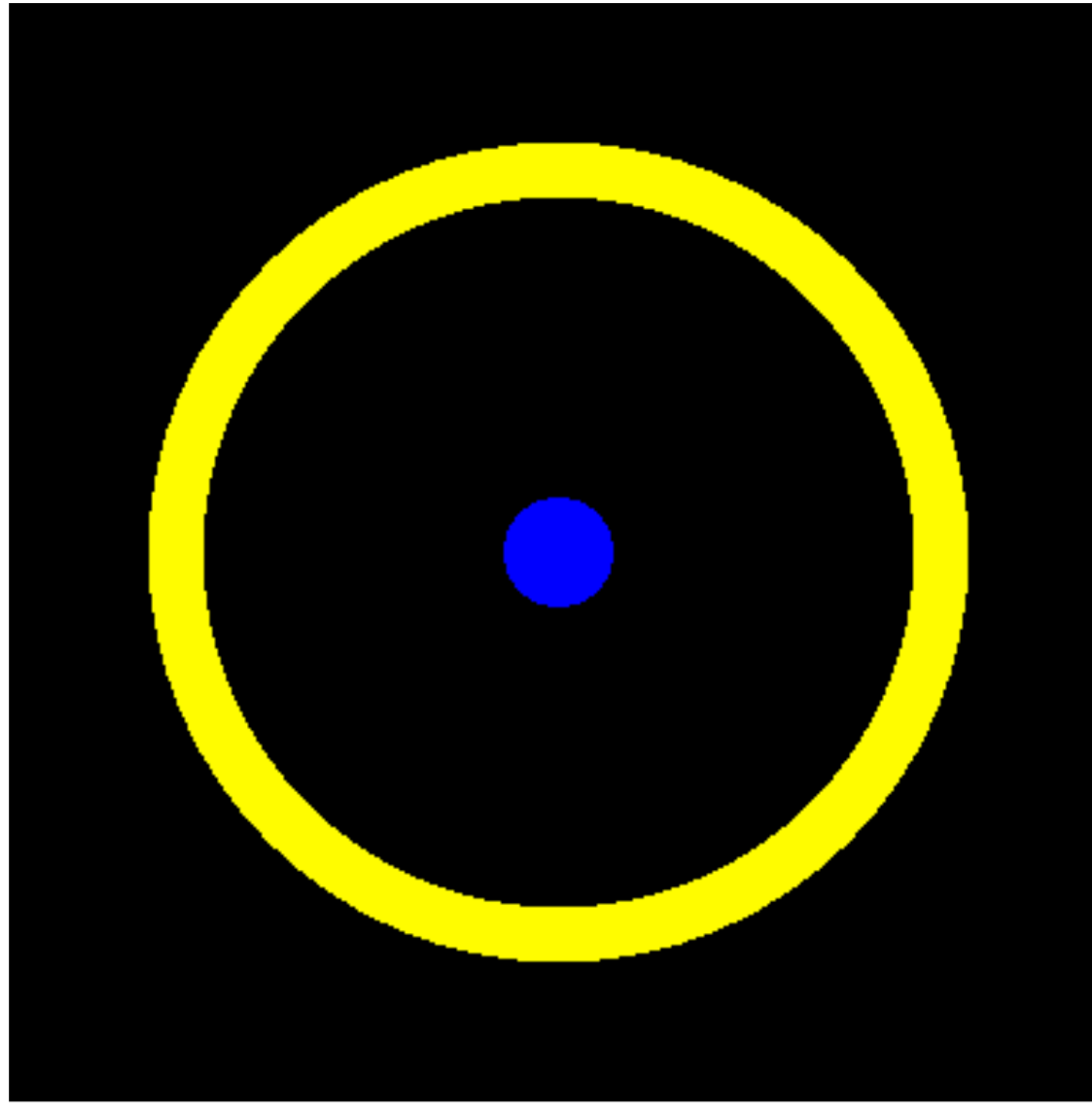
Sound wave imprint a signature into the distribution of matter at large-scale:

Baryon Acoustic Oscillations (BAO)

Dark Matter

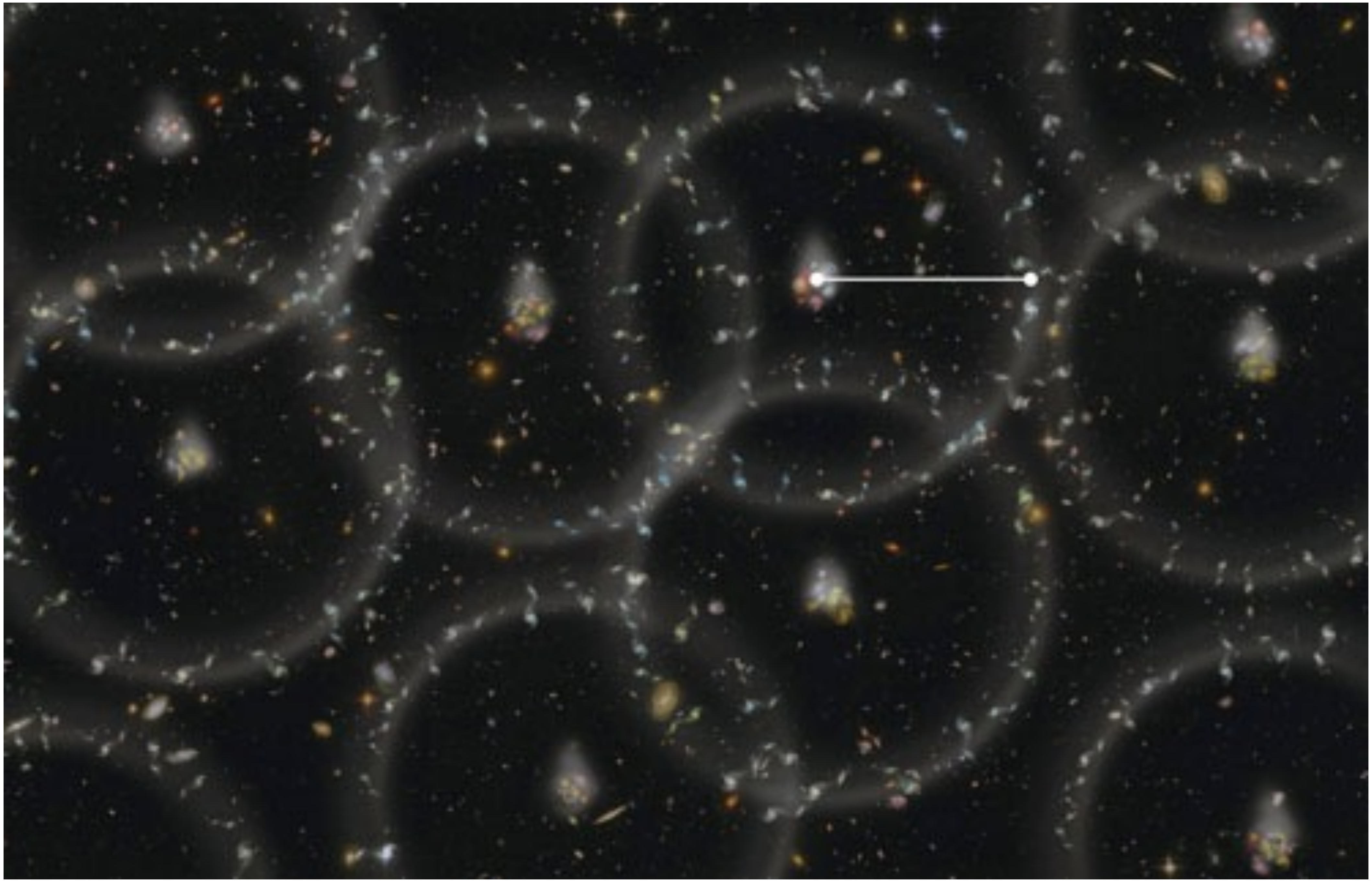
Baryon-photon fluid (before recombination)

Baryons



Credit : Wright, UCLA

BAO



Credit : BOSS collaboration

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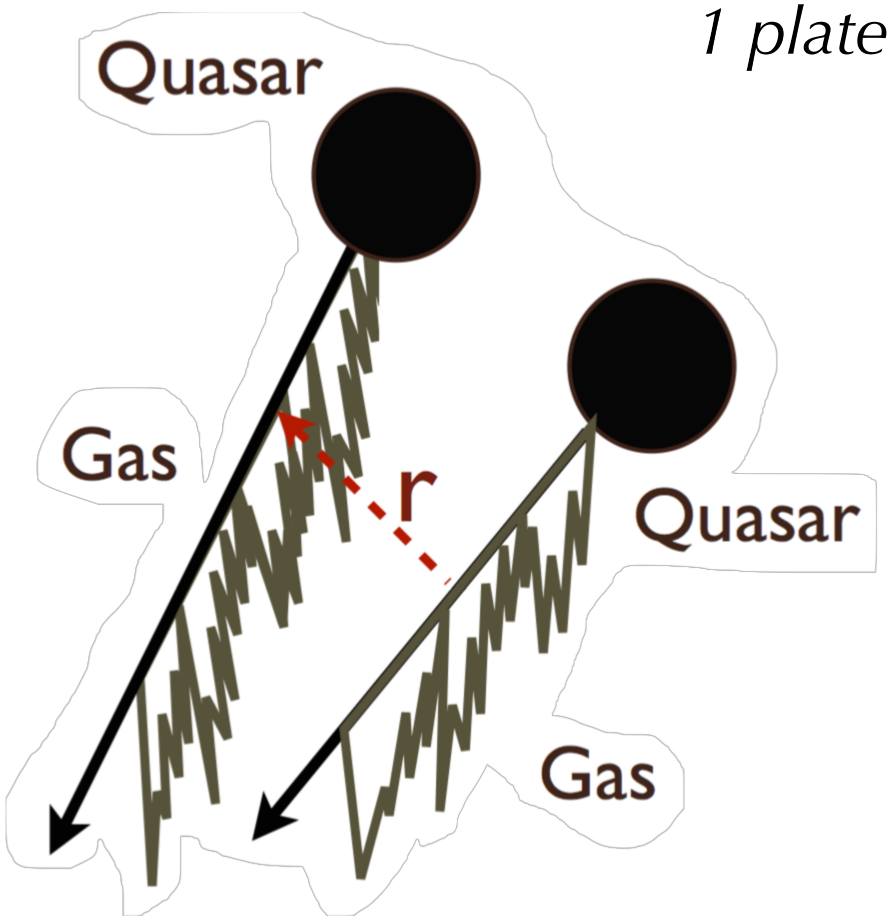
BAO from BOSS Lyα

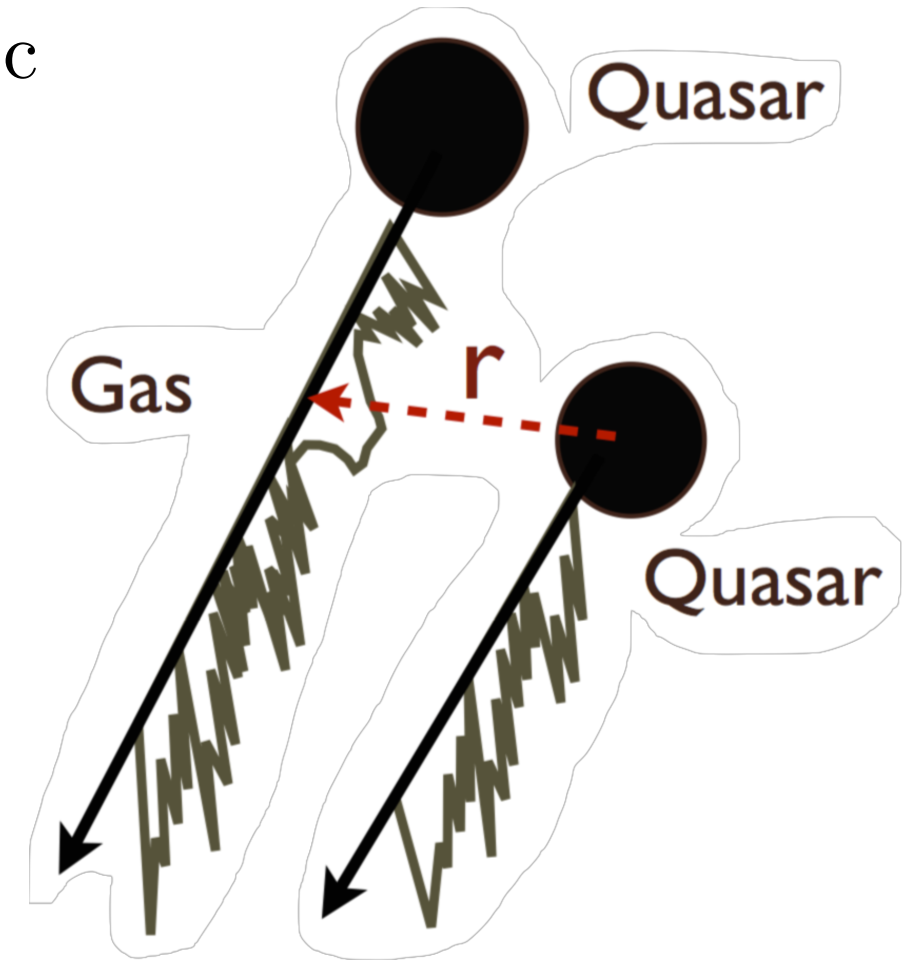
Two independent ways of measuring the BAO scale :

1 analysis pixel : $1\text{Å} \sim 70\text{kms}^{-1} \sim 0.7h^{-1}\text{Mpc}$

1 plate : $3\ \text{deg} \sim 210\, h^{-1}\text{Mpc}$



Lyα auto-correlation
Bautista et al. (2017)

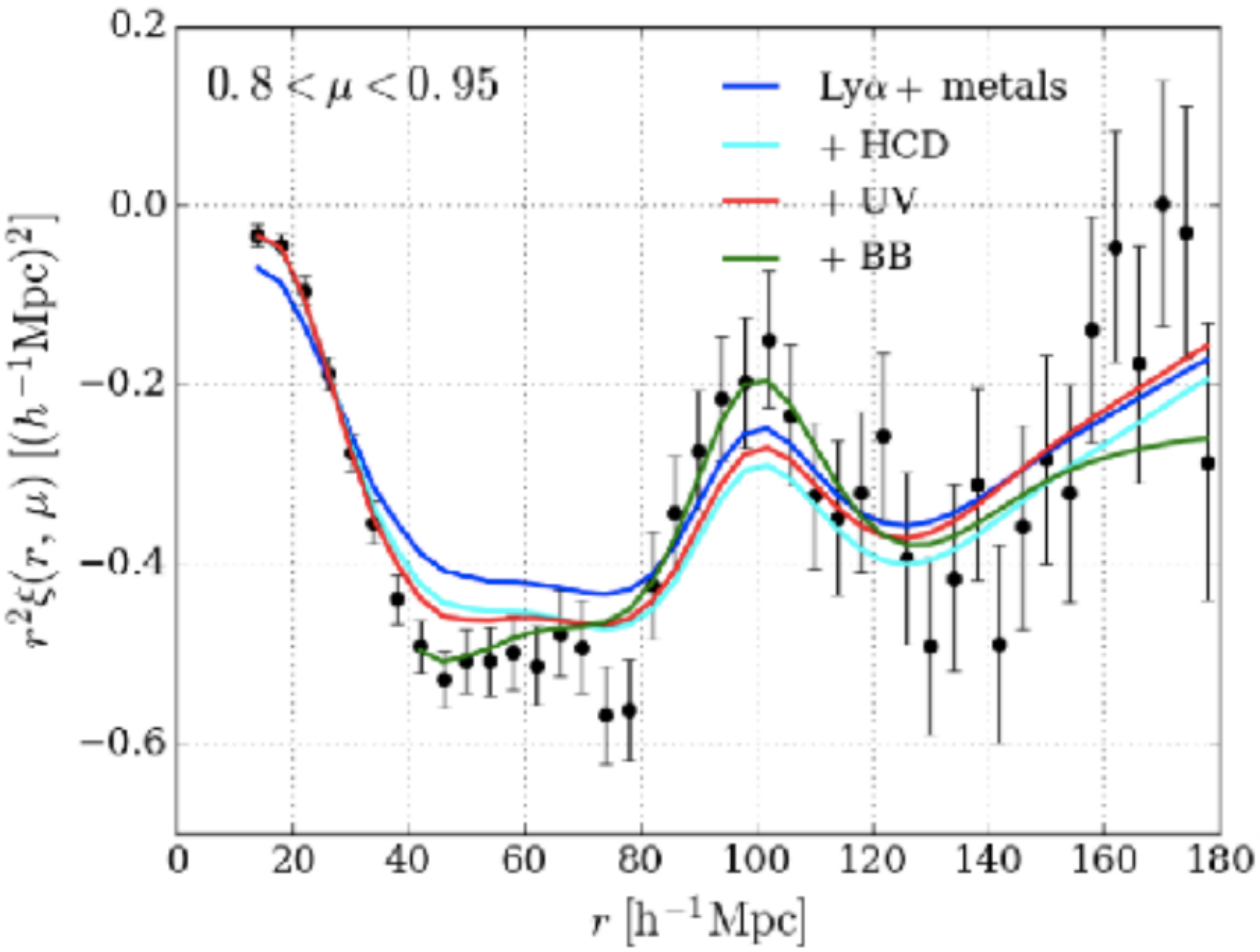


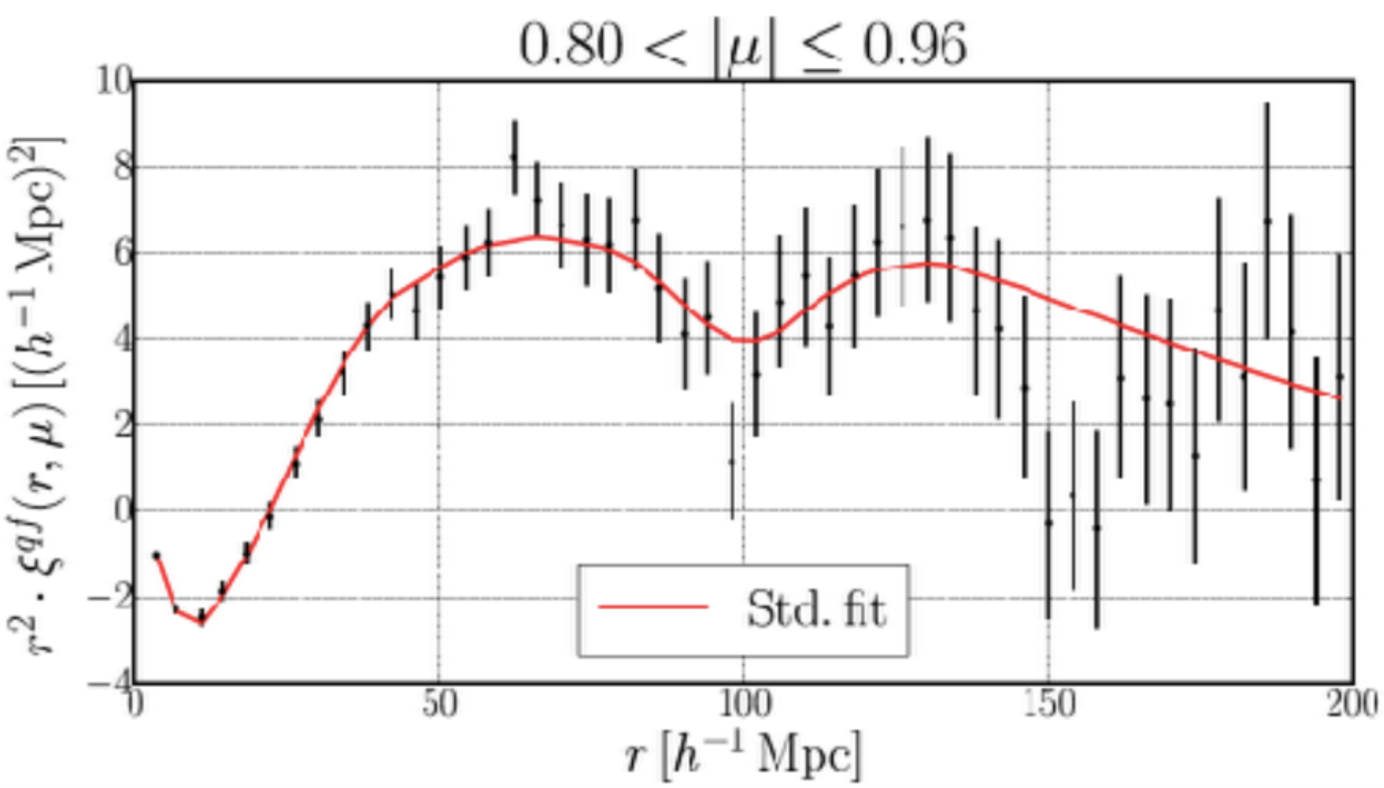
Lyα x Quasars cross-correlation
du Mas des Bourboux et al. (2017)

SDSS-III/BOSS DR12

BAO from BOSS Lyα

Two independent ways of measuring the BAO scale :





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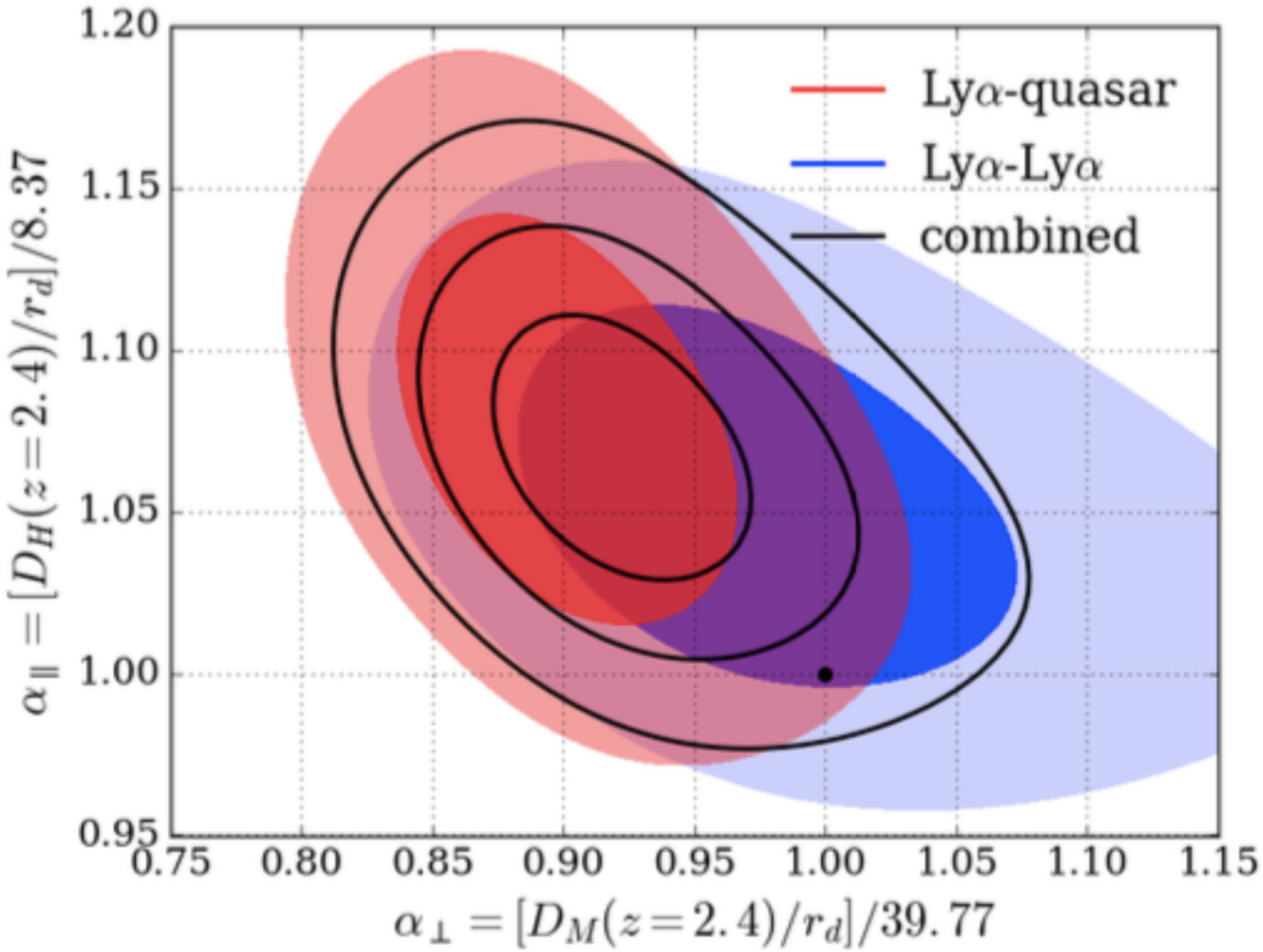

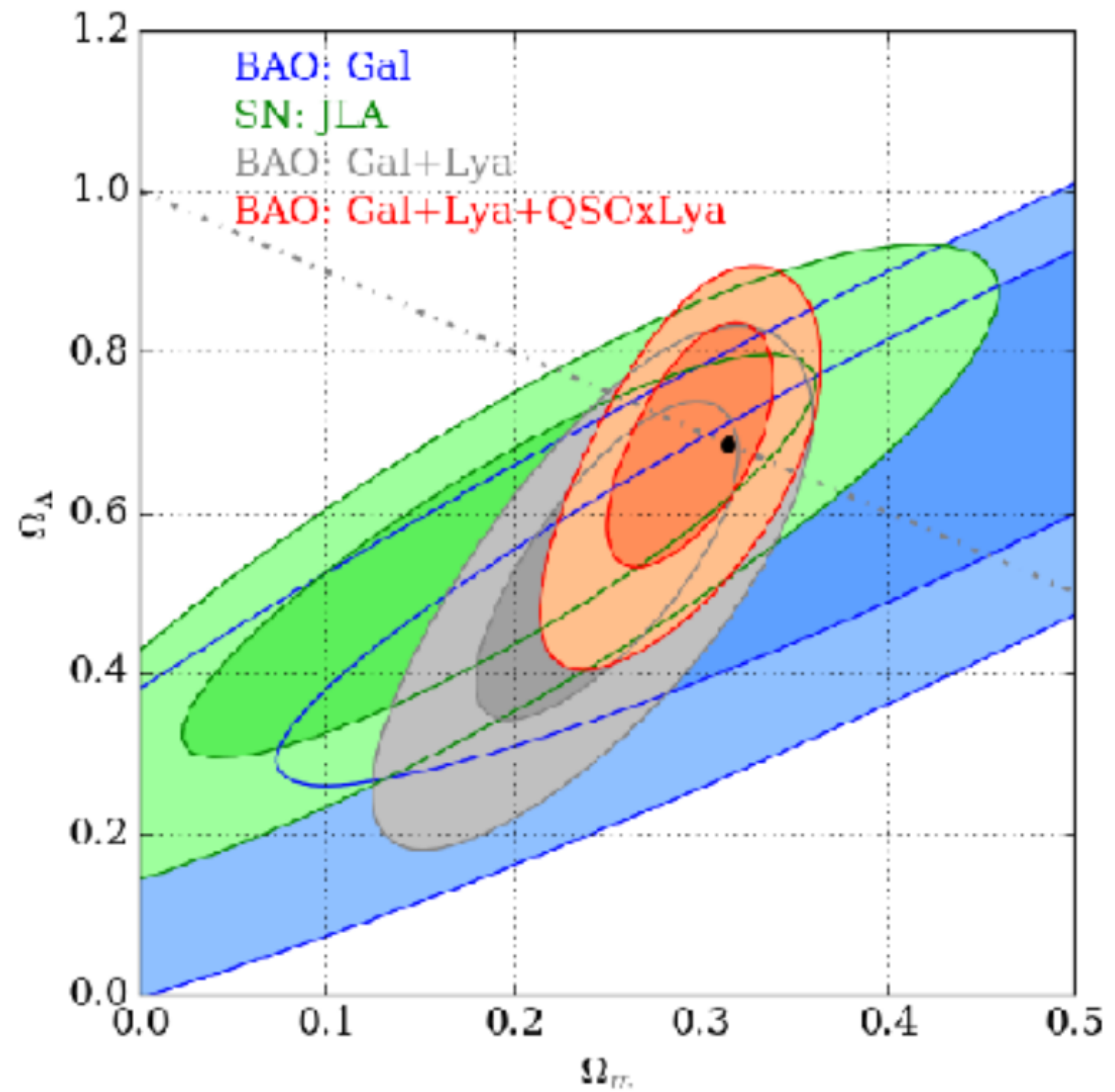

In a flat ΛCDM model :

$$\Omega_m = 0.292 \pm 0.019$$ BAO (BOSS)

$$\Omega_m = 0.315 \pm 0.017$$ CMB (PLANCK)

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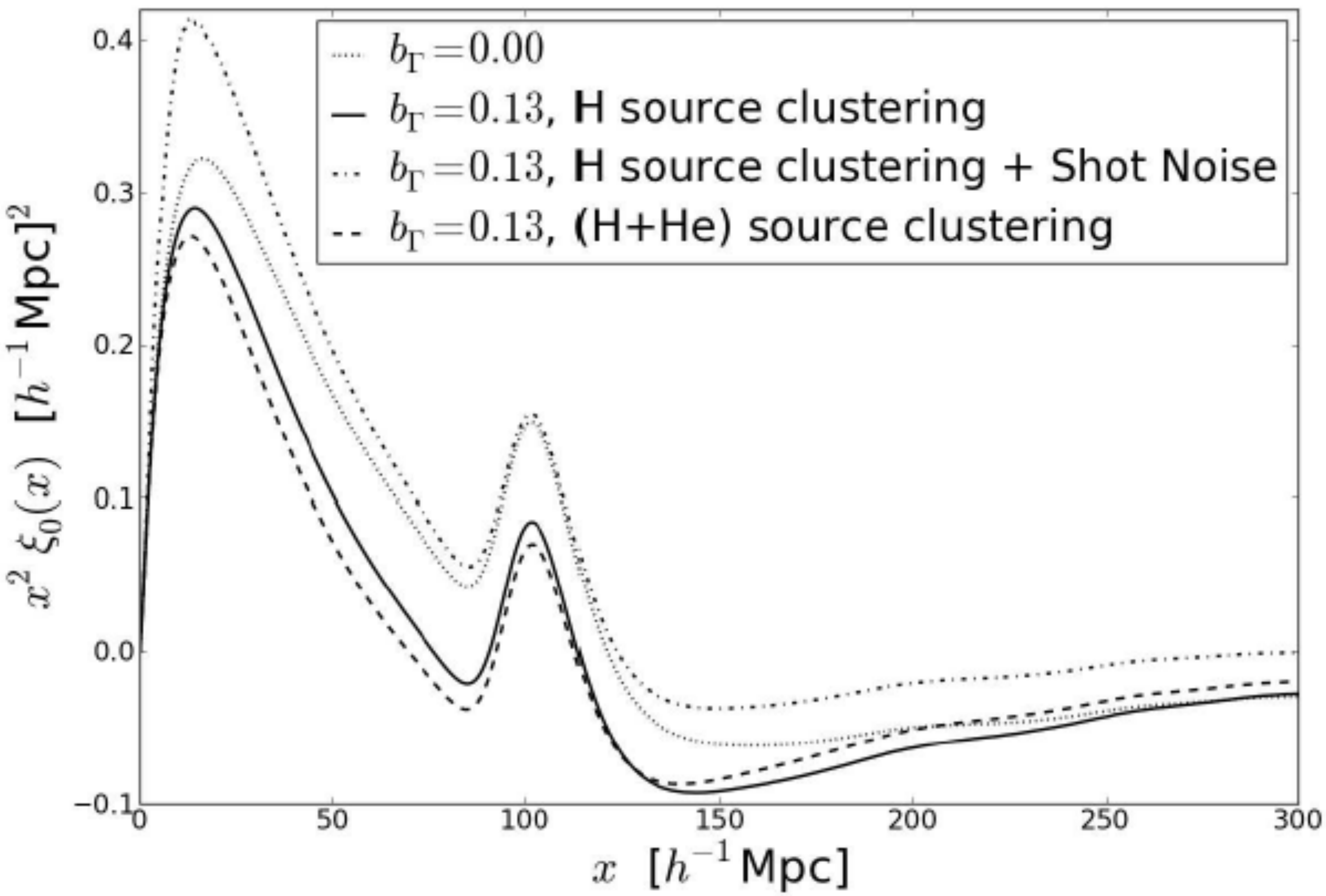
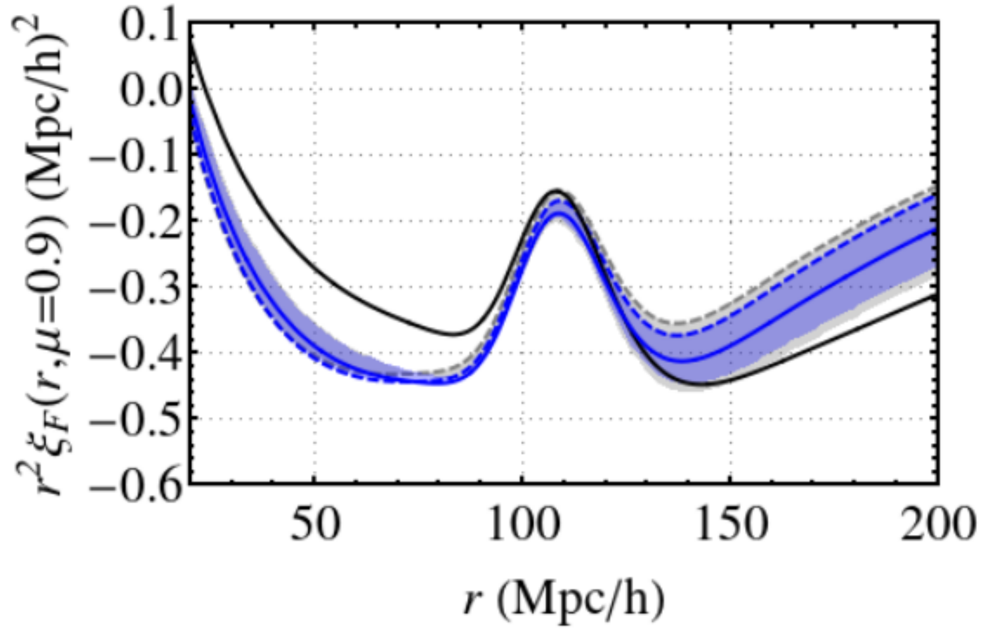
Corrections

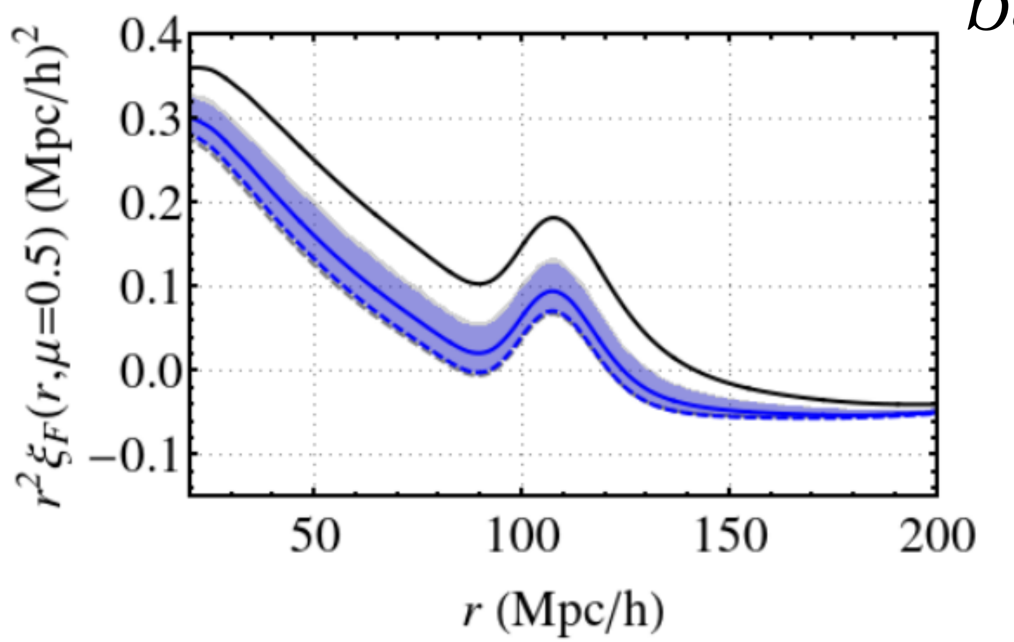
- Fluctuations of the ionizing background — **Gontcho A Gontcho et al. (2014)**



Corrections

- Fluctuations of the ionizing background — **Gontcho A Gontcho et al. (2014)**
- Broadband distortions — **Blomqvist et al. (2015)**





solid black *: undistorted*
solid blue *: distorted*
bands : different nlc considerations

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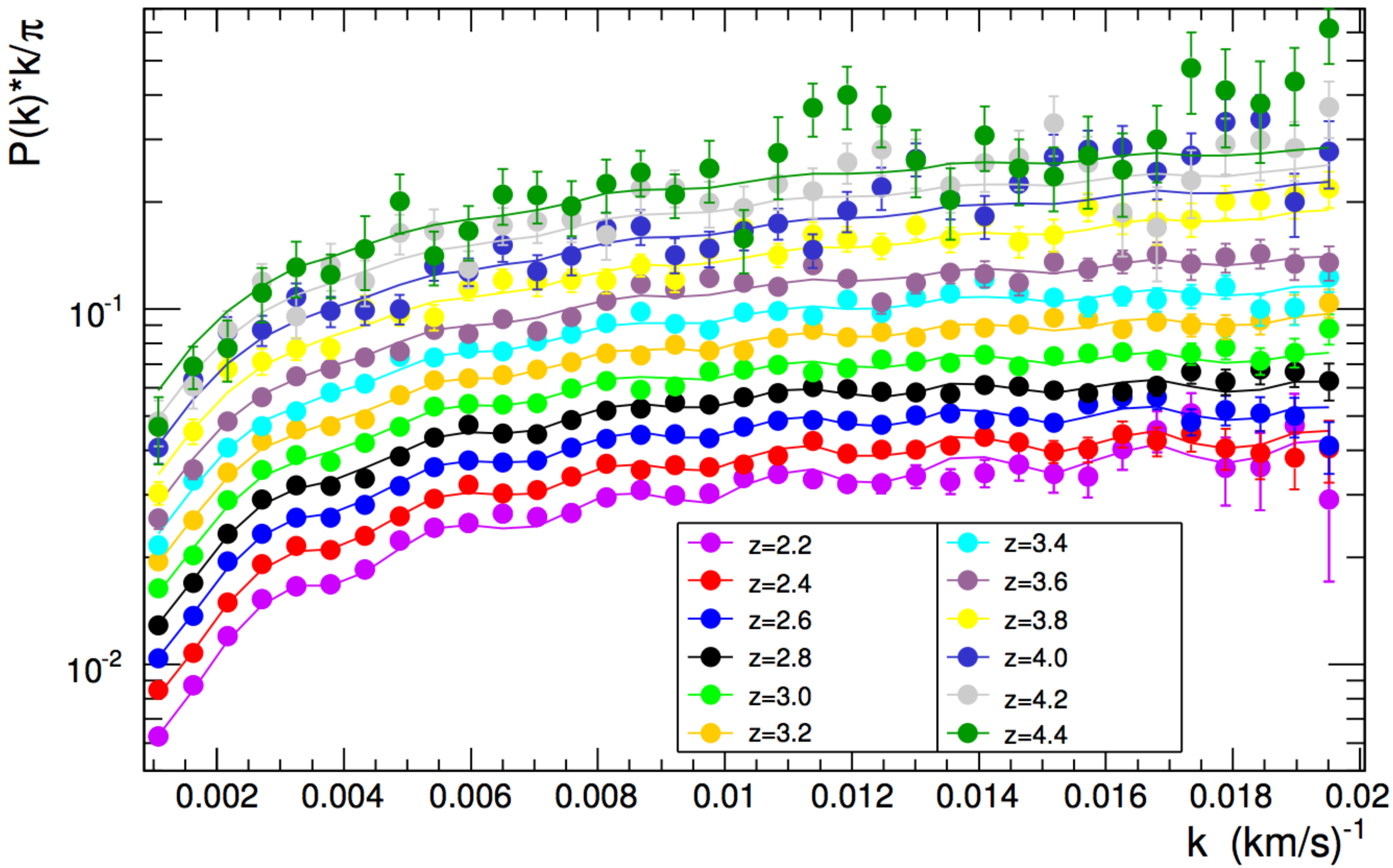
Adjacent Science

- P1D from Lyα forest — **Palanque-Delabrouille et al. (2013)**

1D correlations, one skewer at the time



~ 0.1 h/Mpc Line of sight (1D) wavenumber ~ 2 h/Mpc

state of the art. opportunity for precision cosmology

Adjacent Science

- P1D from Lyα forest — **Palanque-Delabrouille et al. (2013)**
- Constrains on Σmν from Lyα P1D — **Palanque-Delabrouille et al. (2015)**

$\sum m_\nu < 0.12$ eV (95% C.L.) SDSS-III/BOSS DR9 + Planck 2013

Adjacent Science

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- Constrains on Σmν from Lyα P1D — **Palanque-Delabrouille et al. (2015)**
- Non Linearities — **Arinyo-i-Prats et al. (2015)**

$$P_{3D,\alpha}(k,\mu) = P_L(k) b_\alpha^2 \left(1+\beta_\alpha \mu^2\right)^2 D_{NL}(k,\mu)$$

Parametrization of non linearities from Hydrodynamical Simulations

Redshift Space Distortions
Kirkby et al. (2013)
Kaiser (1987)

Adjacent Science

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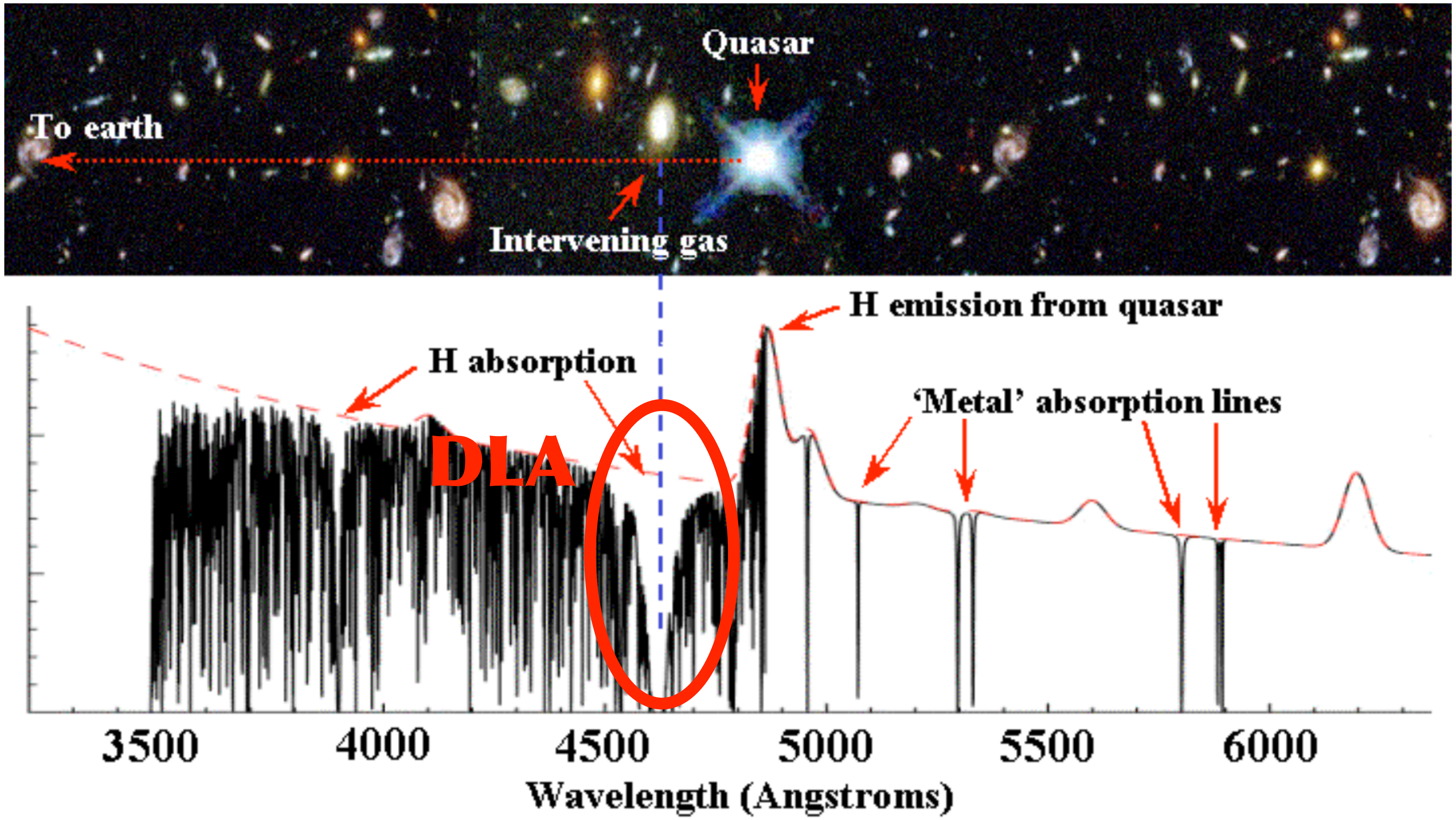
- Non Linearities — **Arinyo-i-Prats et al. (2015)**
- DLA x Lyα forest — **Pérez-Ràfols et al. (2017)** ⟶ b_{DLA}



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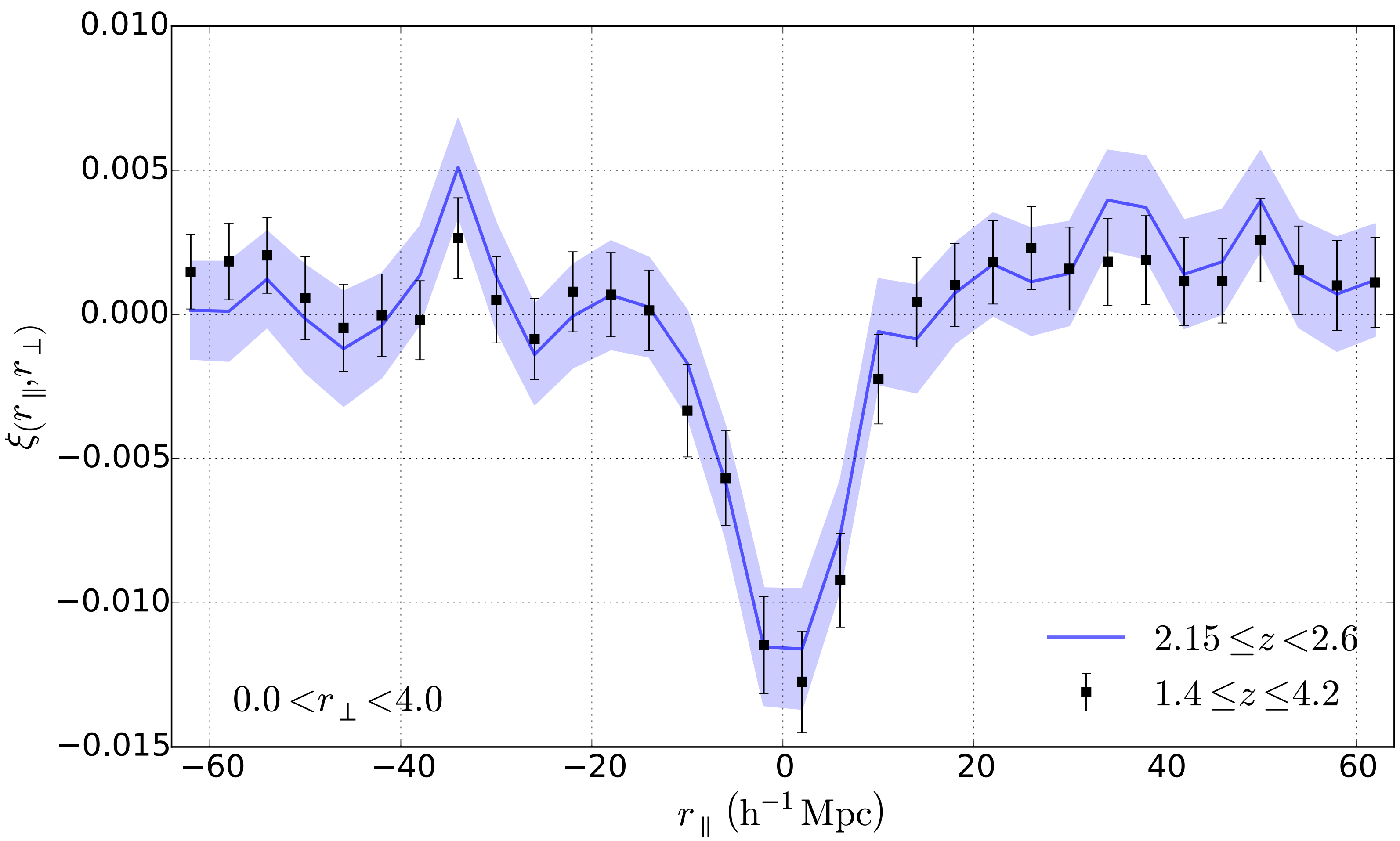
- DLA x Lyα forest — **Pérez-Ràfols et al. (2017)**
- CIV Forest x Quasars — **Gontcho A Gontcho et al. (2017))**



First measurement of the transmission bias of CIV forest

→ b_c

LyA Working Group

People that haven't been mentioned so far but that were **instrumental** in the Lyα working group and all resulting papers over the course of BOSS:

Nicolas Busca (*Paris 6*)
Andreu Font-Ribera (*UCL*)
Julien Guy (*LBNL*)
Jean-Marc Le Goff (*Saclay*)
Jordi Miralda-Escudé (*Barcelona*)
James Rich (*Saclay*)
Anže Slosar (*BNL*)
Christophe Yèche (*Saclay*)
…
+
Isabelle Pâris (Mention d'honneur !)

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BOSS vs DESI

The Dark Energy Spectroscopic Instrument : Mayall (3.7 m) at Kitt Peak, AZ

- Mirror area **x 2.4**
- Number of fibers **x 5**
- Telescope throughput **x 1.6**

- Resolution **x 2.3** at 7000 Å (for ELGs OII doublet detection, but higher S/N for all lines)

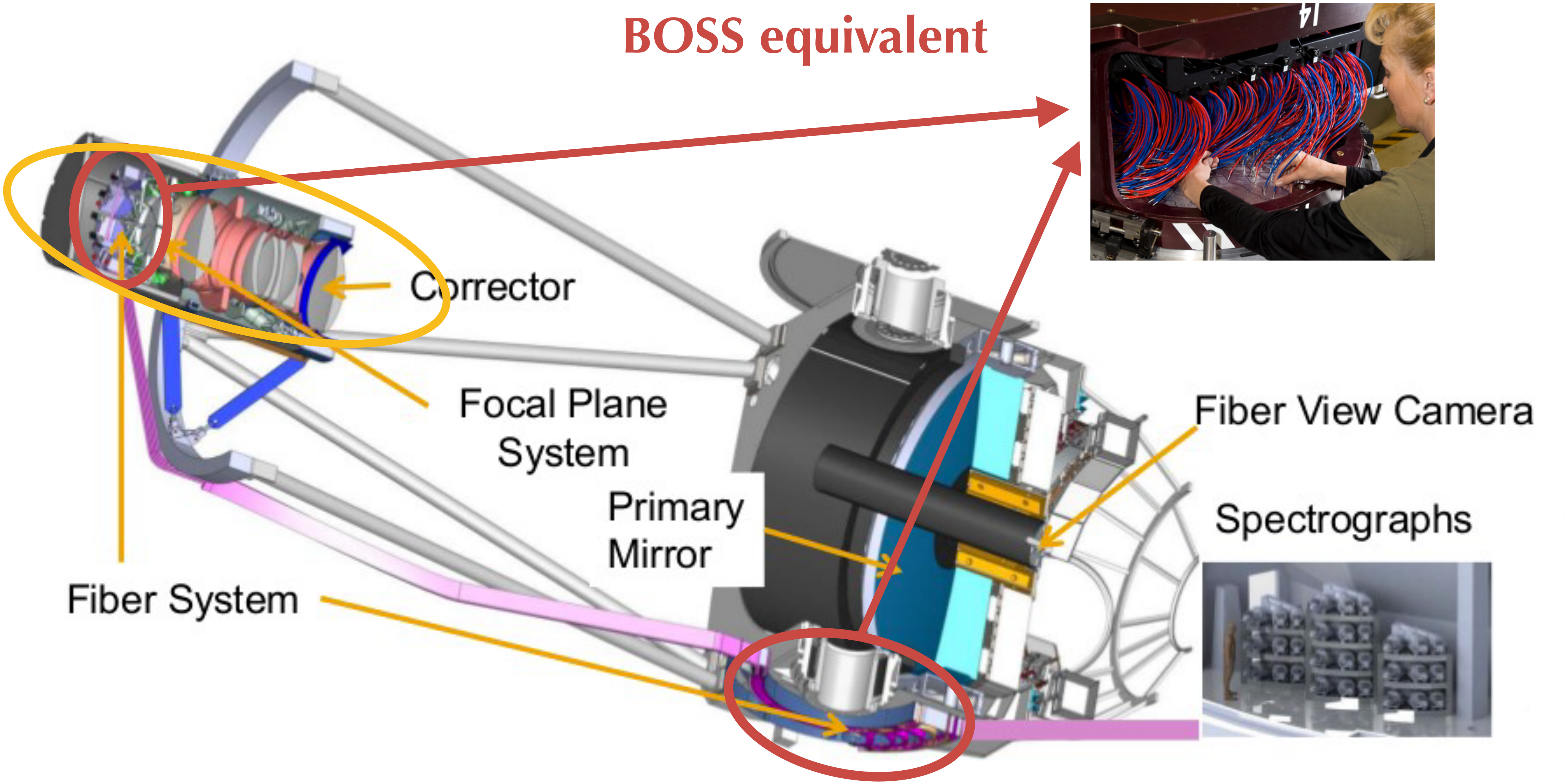
- Fiber positioners instead of drilled plates : more flexibility/science
- Stable spectrographs : smaller sky systematic residuals
- Atmospheric Dispersion Compensator : smaller fiber aperture losses

- DESI can an detect an emission line **3 times fainter** than BOSS in the same exposure time
- …or detect the same galaxy **9 times faster**

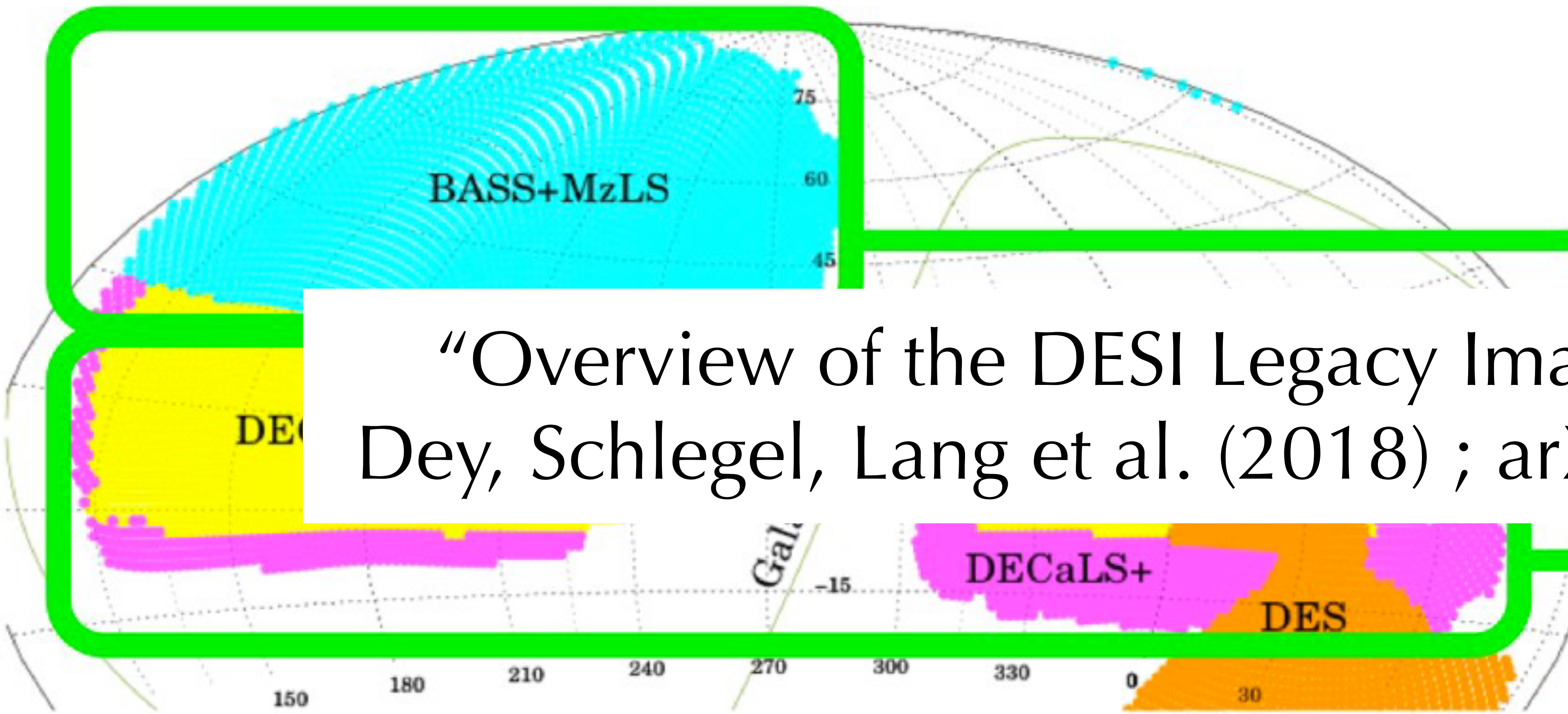
- and so **DESI can measure redshifts 45 times faster than BOSS for ELGs and 20 times faster for QSOs** (no resolution gain)

Thank you Julien Guy for this on point comparison !

BOSS vs DESI


BOSS equivalent
Corrector
Focal Plane
System
Primary
Mirror
Fiber View Camera
Spectrographs
Fiber System

- 14,000 sq. degree footprint defined by low Galactic and atmospheric extinction
- DESI targeting requires new imaging over this area



"North cap":
Accessible from Northern

"Overview of the DESI Legacy Imaging Surveys"
Dey, Schlegel, Lang et al. (2018) ; arXiv: 1804.08657

"Equatorial":
Accessible from
Northern or Southern
telescopes

DECam, including DECALS project started August 2014

(slide from R.Weschler)

BOSS vs DESI

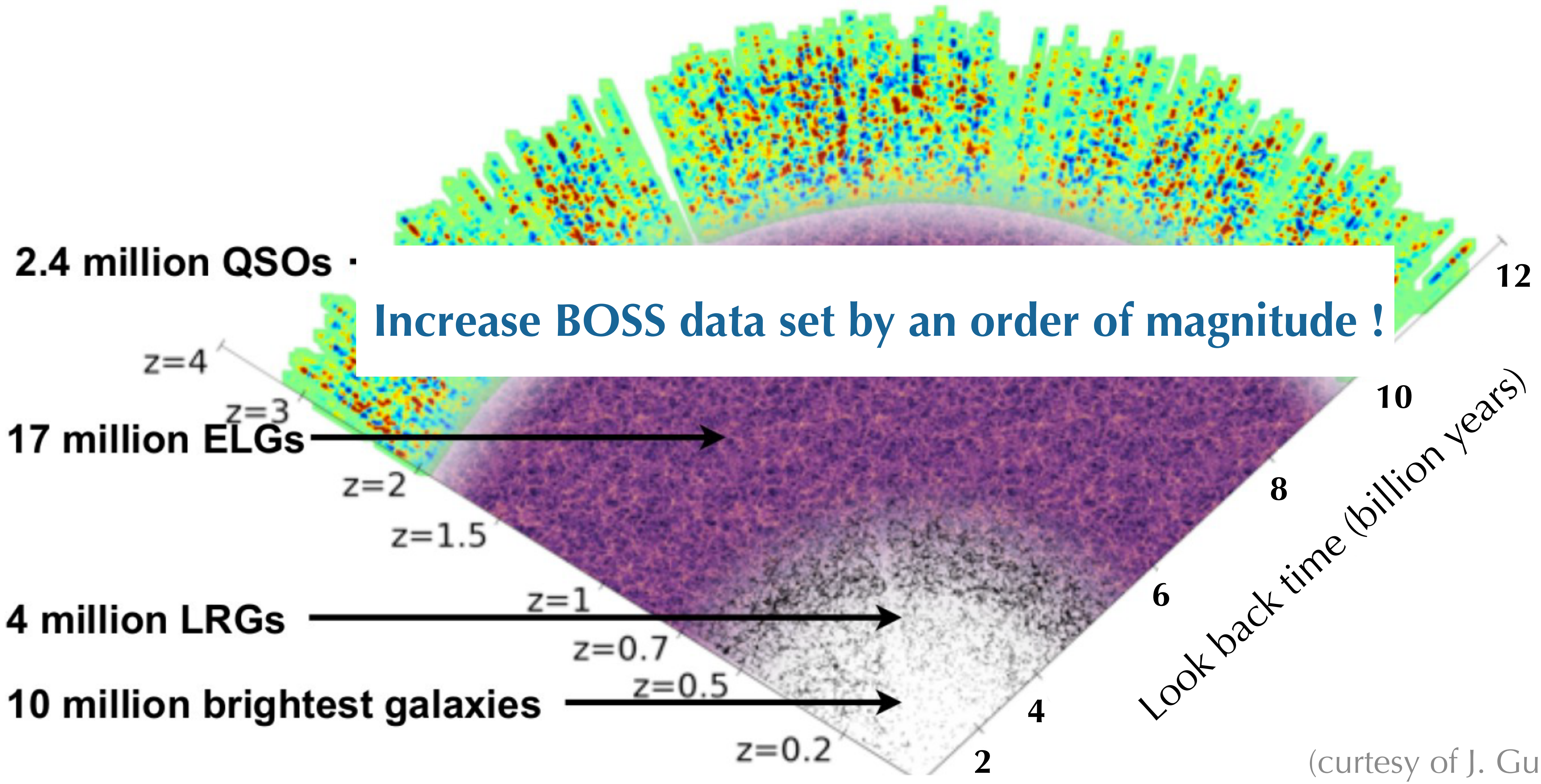
End of DESI imaging : early -2019

On sky commissioning starts : mid-2019

6 months Science Verification starts :end-2019…
…followed by 5 years survey

BOSS vs DESI

SDSS ~2h^{-3}Gpc^3 ⇨ BOSS ~6h^{-3}Gpc^3 ⇨ DESI 50h^{-3}Gpc^3



(curtesy of J. Guy)

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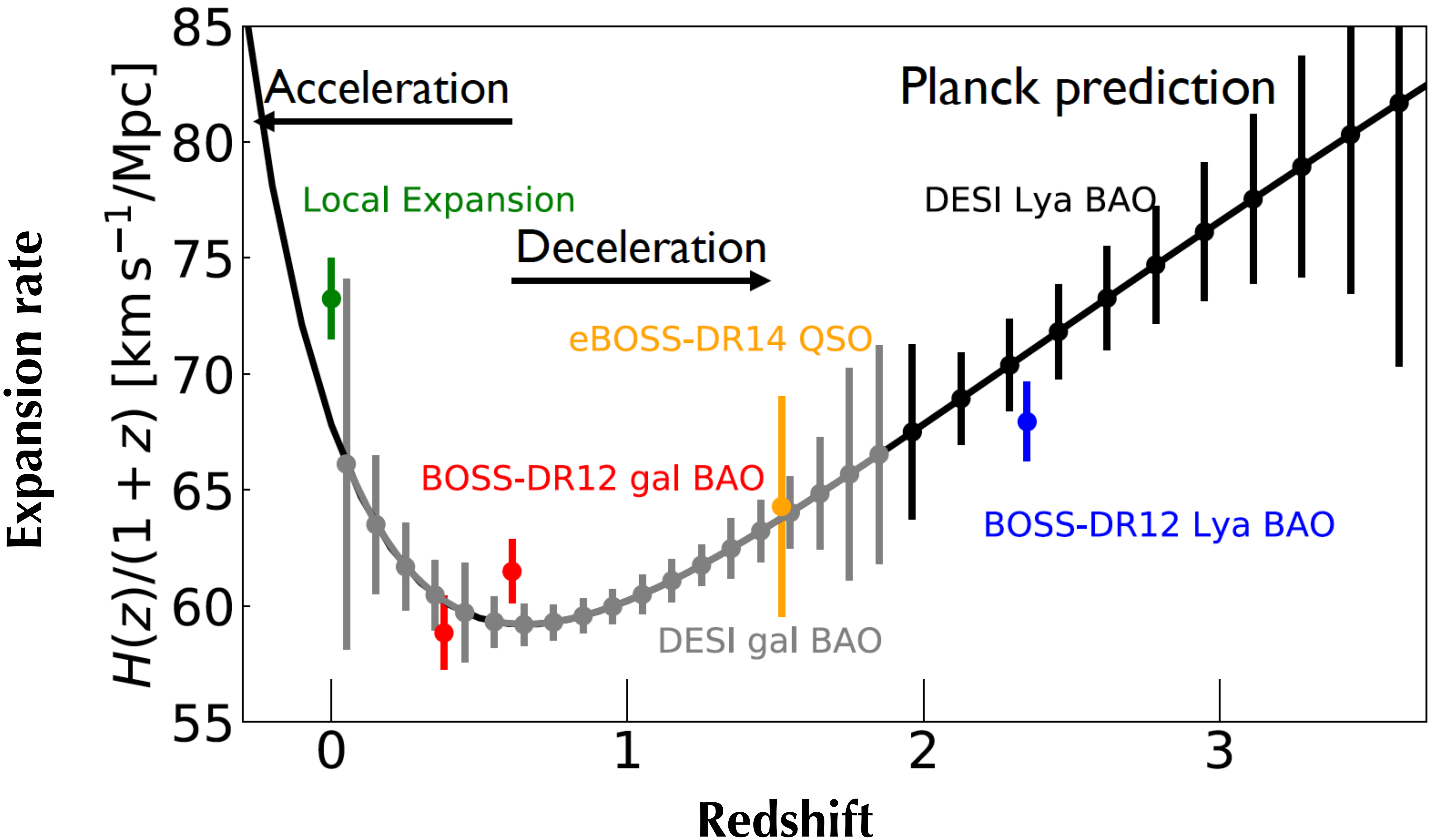
Forecasts

DESI projections, **Font-Ribera et al. (2014b)**



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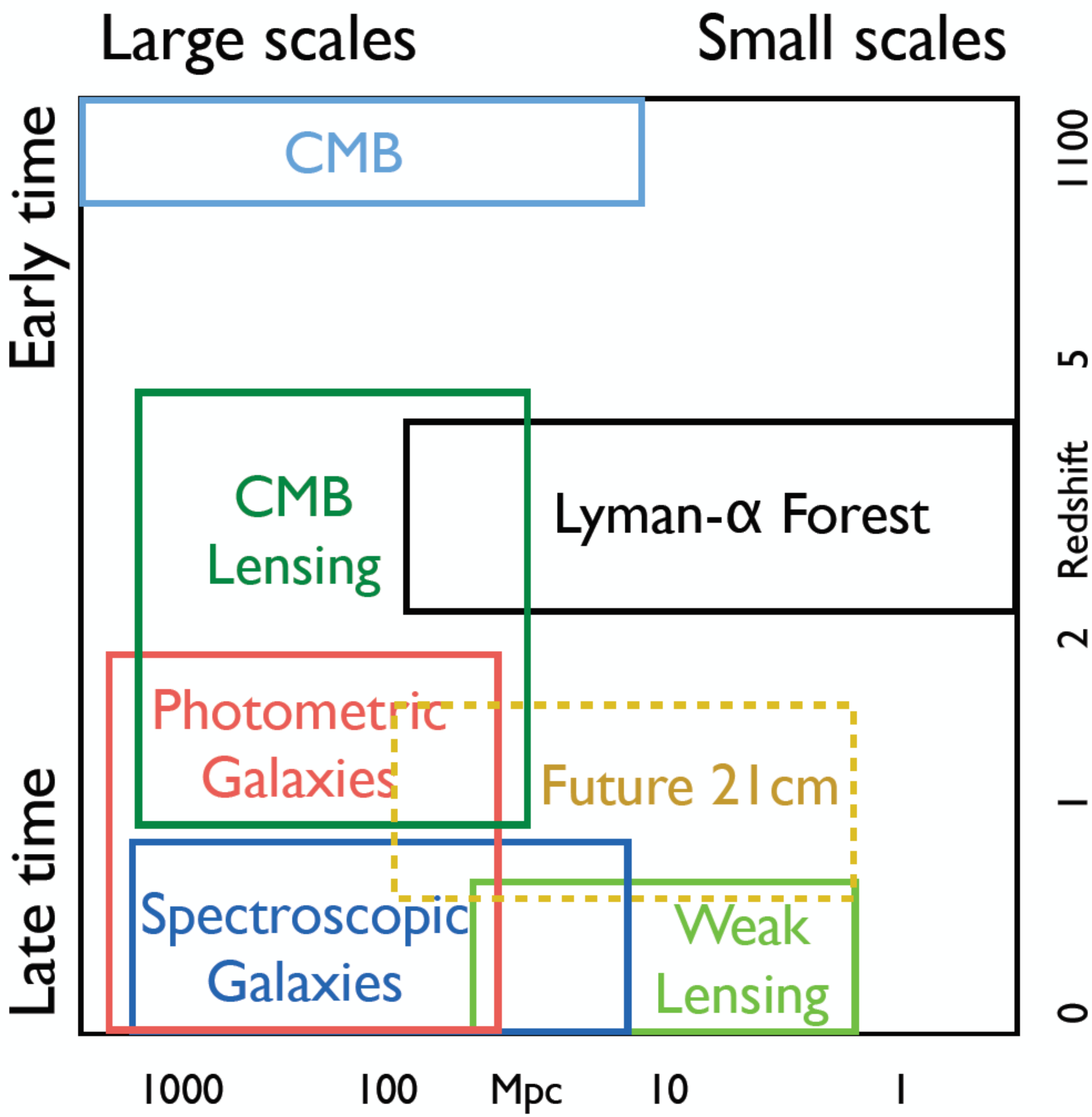
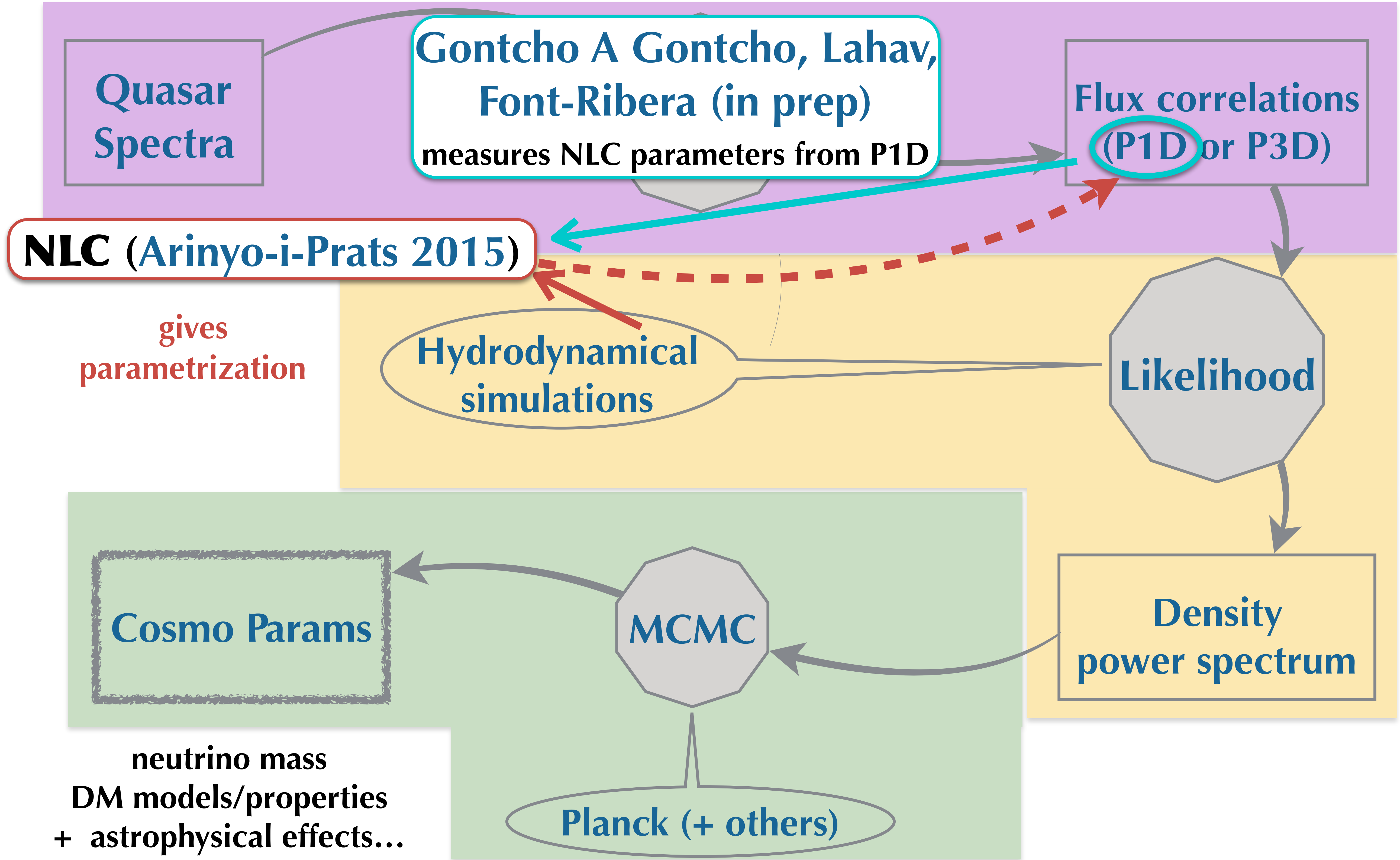
Small scale clustering of Lyα forest



Combined with CMB it allows us to study:

- shape of primordial P(k)
- dark matter properties
- neutrino mass



neutrino mass
DM models/properties
+ astrophysical effects…

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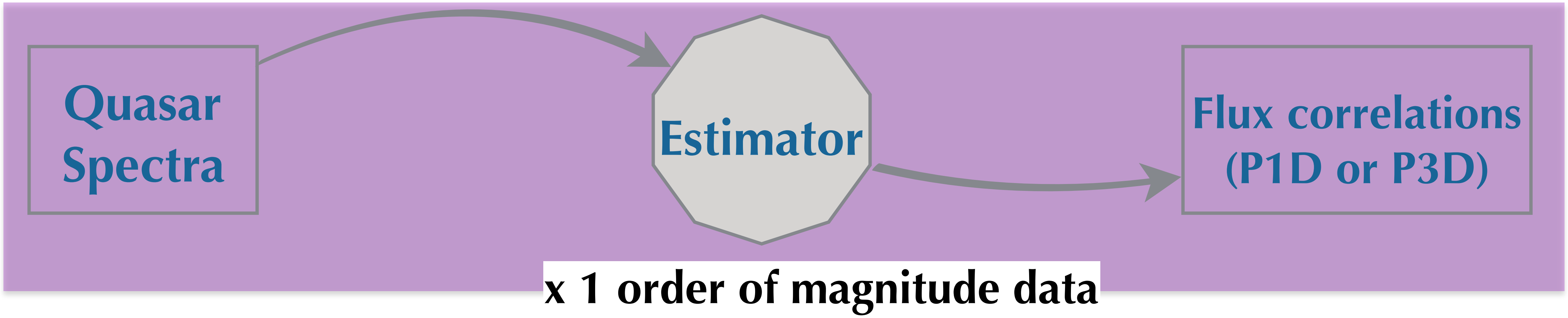
3D P(k) estimators



Motivations :

- alternative way to study BAO
- constrain cosmology from Lyα clustering beyond BAO
  - DESI forecast dominated by P3D, not P1D

Current status :

- 1D analyse ... FFT / pseudo-Cl and Maximum likelihood
- 3D studies

Brute force is no longer enough: 1 billion pixels correlated with each other

3D P(k) estimators

Possible ways to go :

Font-Ribera, McDonald, Slosar (2018) : controlled approximations pertaining to LyA forest.

- formalism that allows for a unified P1D + P3D likelihood (definition of a cross-spectrum) and shows encouraging results
- … next step is to incorporate more systematics to test on more realistic data

Demina et al. (2017) : developed a fast algorithm to calculate the Galaxy two - point correlation — ***computation time reduced by an order of magnitude !***

- up to now : contrasting the observed distribution of gala[illegible] with that of a uniformly populated random cata[illegible]
- this fast algorith[illegible] [illegible]ution of [illegible] [illegible]dent of angular position allows [illegible] pairwise combinatorics with fast integration over probability maps.

To what extent can this technique be adapted for use on Lyman-α forest analyses ?

Summary

The SDSS-III Baryon Oscillation Spectroscopic Survey

- 2% measurement at z~2.3 (quasars and the Lyman-α forest)
- BOSS Ly-α showed the forest is ready for precision cosmology

The Dark Energy Spectroscopic Instrument

- DESI will represent an order of magnitude jump in precision
- Lyα offers a unique window to small scales
- Strong constraints on warm dark matter, neutrinos or running
- Several statistical and computational challenges…

That's all about the science…. but hold on !

THE SUPERNOVA FOUNDATION
Mentoring For Women In Physics

Why the need for such a program ?

Gender gap in STEM is a serious international societal problem which needs to be addressed.
Particularly in developing countries — but not only,
the environment for women in STEM is often challenging with little to no support system.

The Supernova Foundation…

…Seeks to connect female undergraduate students to established female physicists

…Provides support as they transition to postgraduate studies, in the form of personal mentoring

…brings together 46 international mentors

… received 100+ applications for the second year of the program

Please consider being a **Mentor**, referring a **Mentee** or advertising this program :

http://supernovafoundation.org/apply/