Simulations for the Lyman-alpha forest

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Mock Córdoba, April 2019

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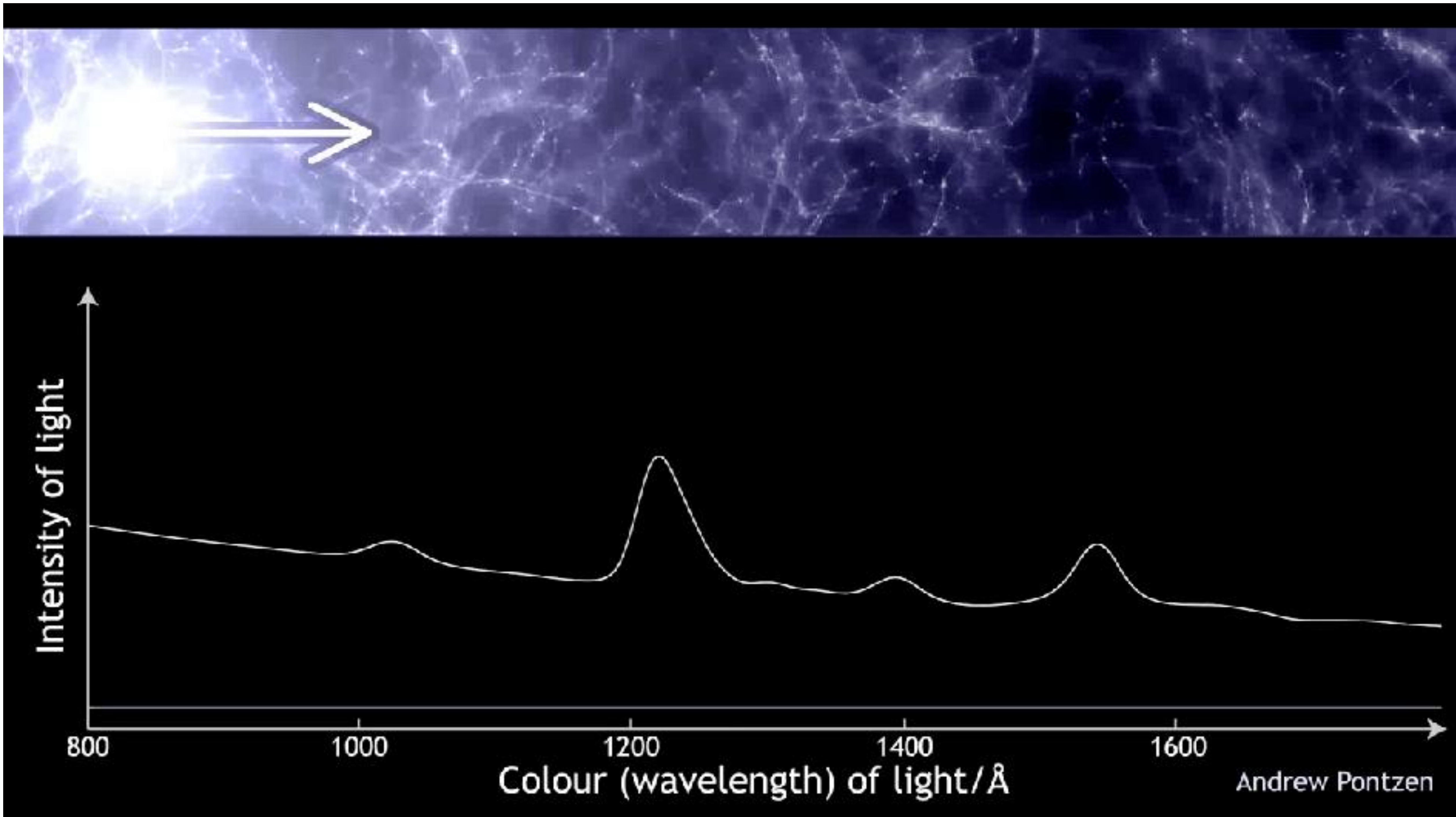
SDSS

- A forest survey versus a galaxy survey
- Dark energy and neutrino masses
- Overview of current (eBOSS) measurements
- Overview of used simulations and modelling
- Ideas for future

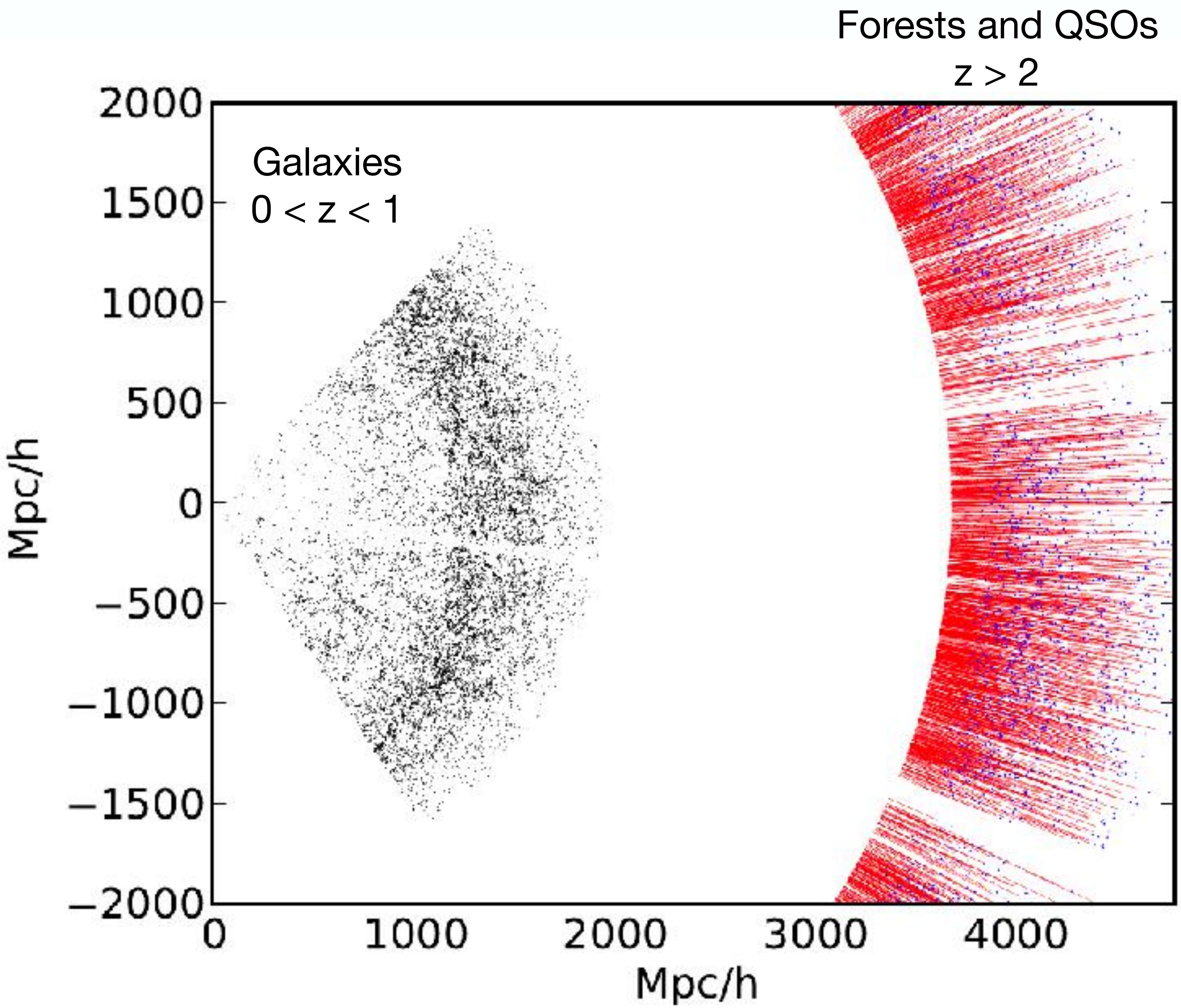
Forest survey vs Galaxy survey

The Lyman-alpha forest



One spectrum = hundreds of density estimates

Forest survey vs Galaxy survey



Forest survey vs Galaxy survey

Access to:

- higher redshift Universe ($z > 2$)
- low bias tracer
- larger volumes
- models of clustering on small-scales
- physics of the intergalactic medium (IGM)
- proto-galaxies via high column density systems

Cosmology with forests

BAO, Dark Energy

Three-dimensional
or across different lines-of-sight

Large-scale correlations

Configuration-space

Hundreds of survey-volume
mock catalogs

Analytic models

Neutrino masses

One-dimensional
or line-of-sight

Small-scale correlations

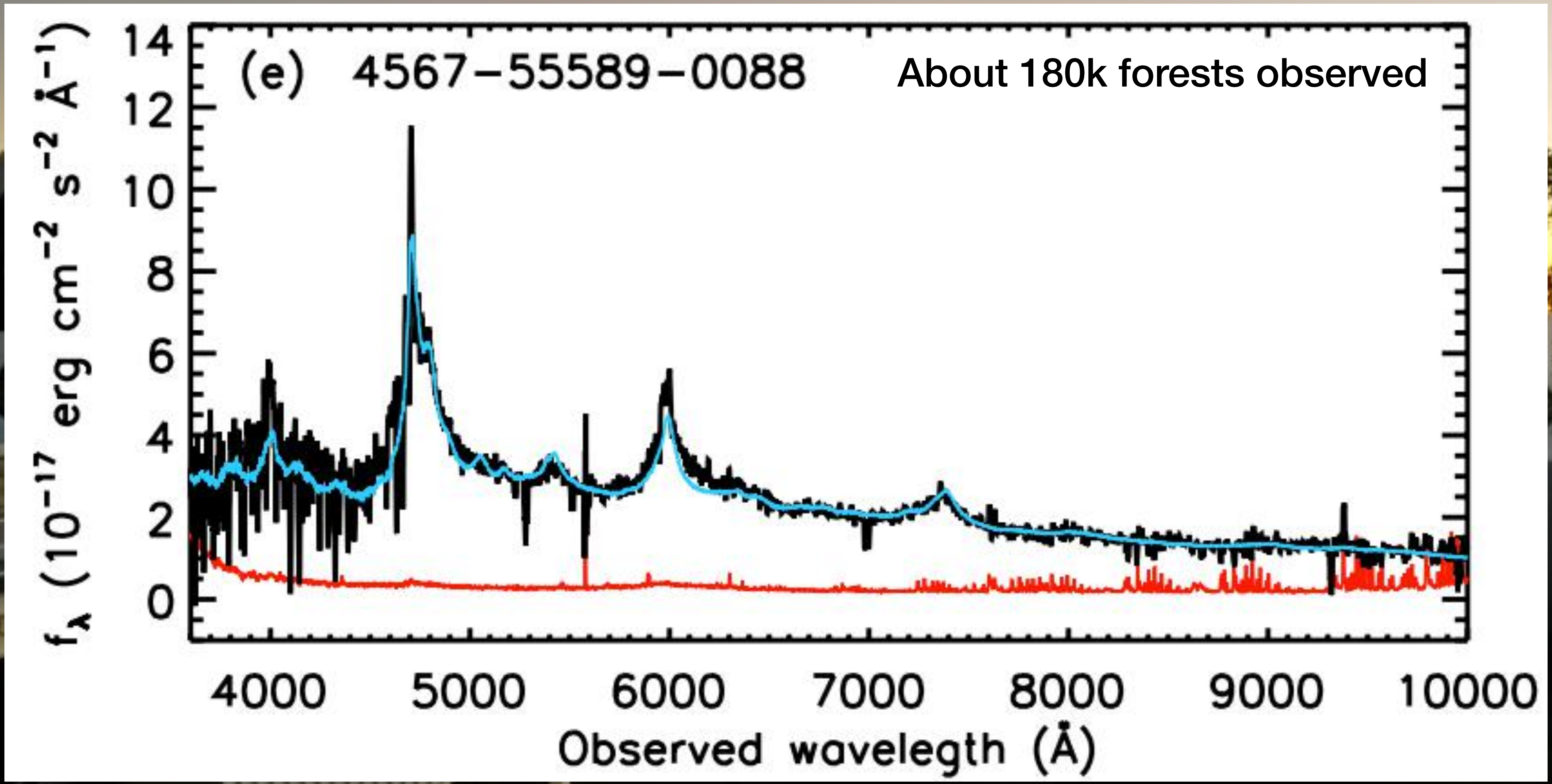
Fourier-space

N-body hydrodynamic **simulations**

I will illustrate these with the last up-to-date measurements

(e)BOSS

(Extended) Baryon Oscillation Spectroscopic Survey



SDSS Telescope @ Apache Point Observatory, New Mexico, USA

BAO with forests

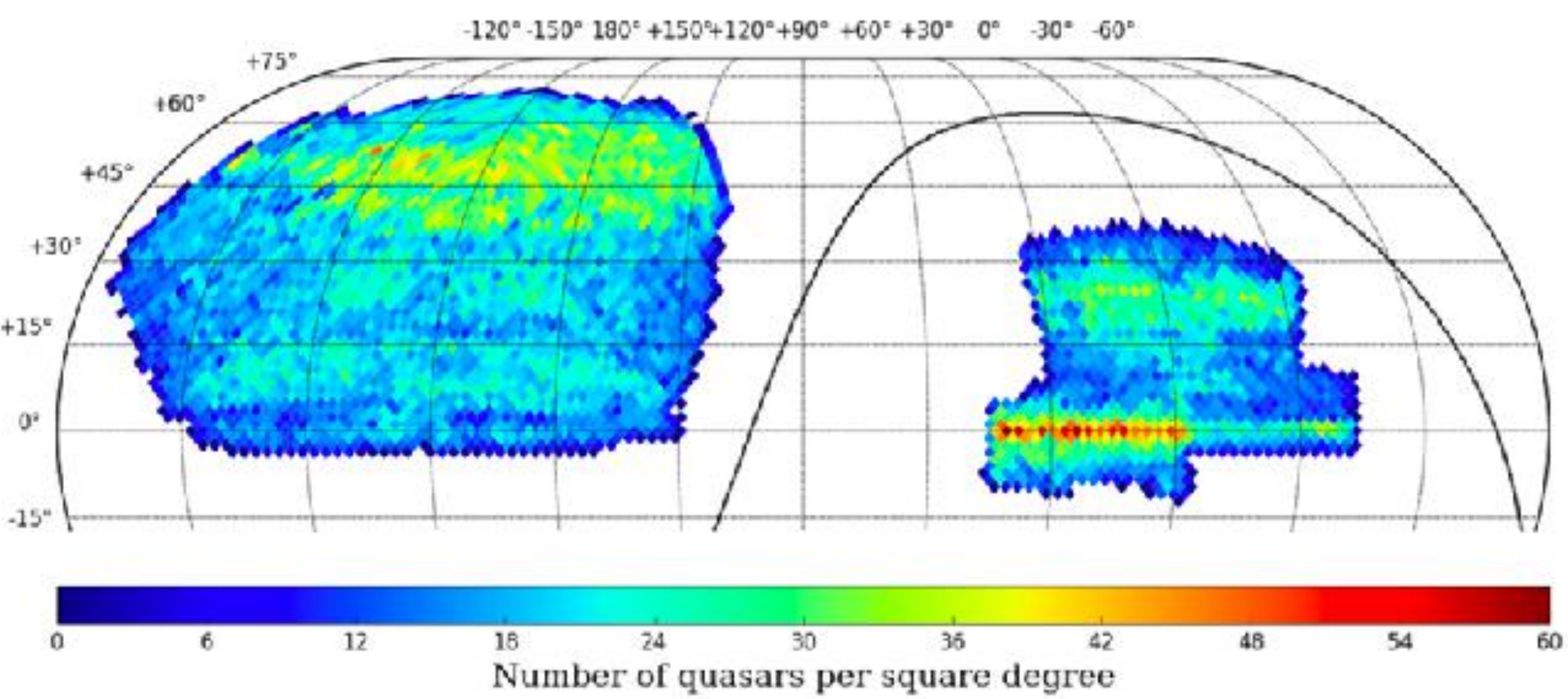
First BAO detection: Busca et al. 2013, Slosar et al. 2013, Kirkby et al. 2013

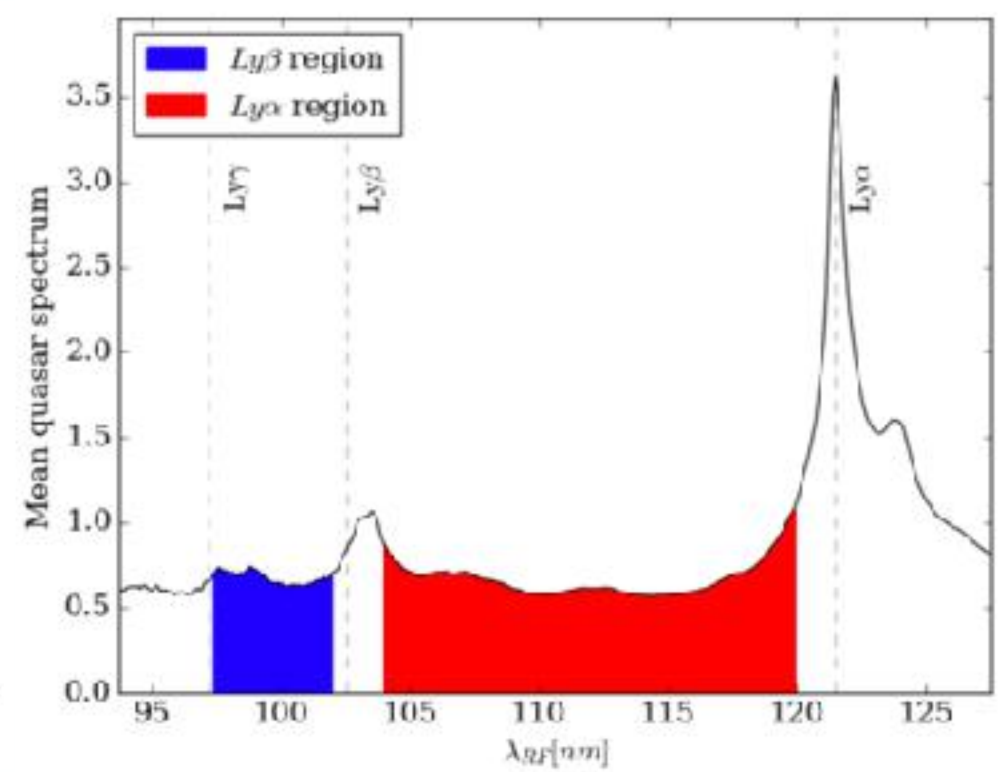
Final BOSS measurements: Bautista et al. 2017, du Mas des Bourboux et al. 2017

First eBOSS update with 2 year data: de Sainte Agathe et al. 2019, Blomqvist et al. 2019

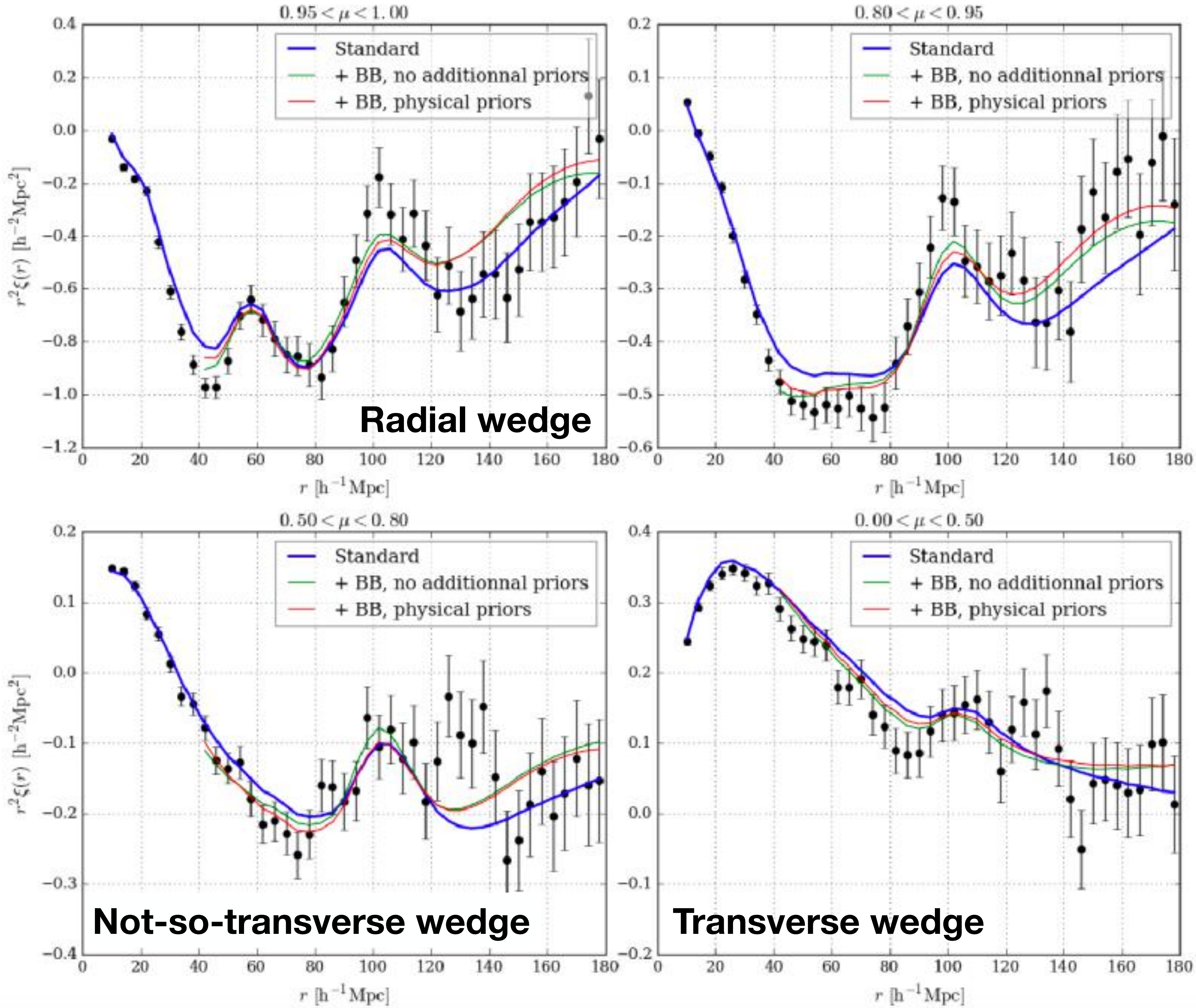
Today on the arXiv!
1904.03400 & 1904.03430

Use of Lyman-beta forest

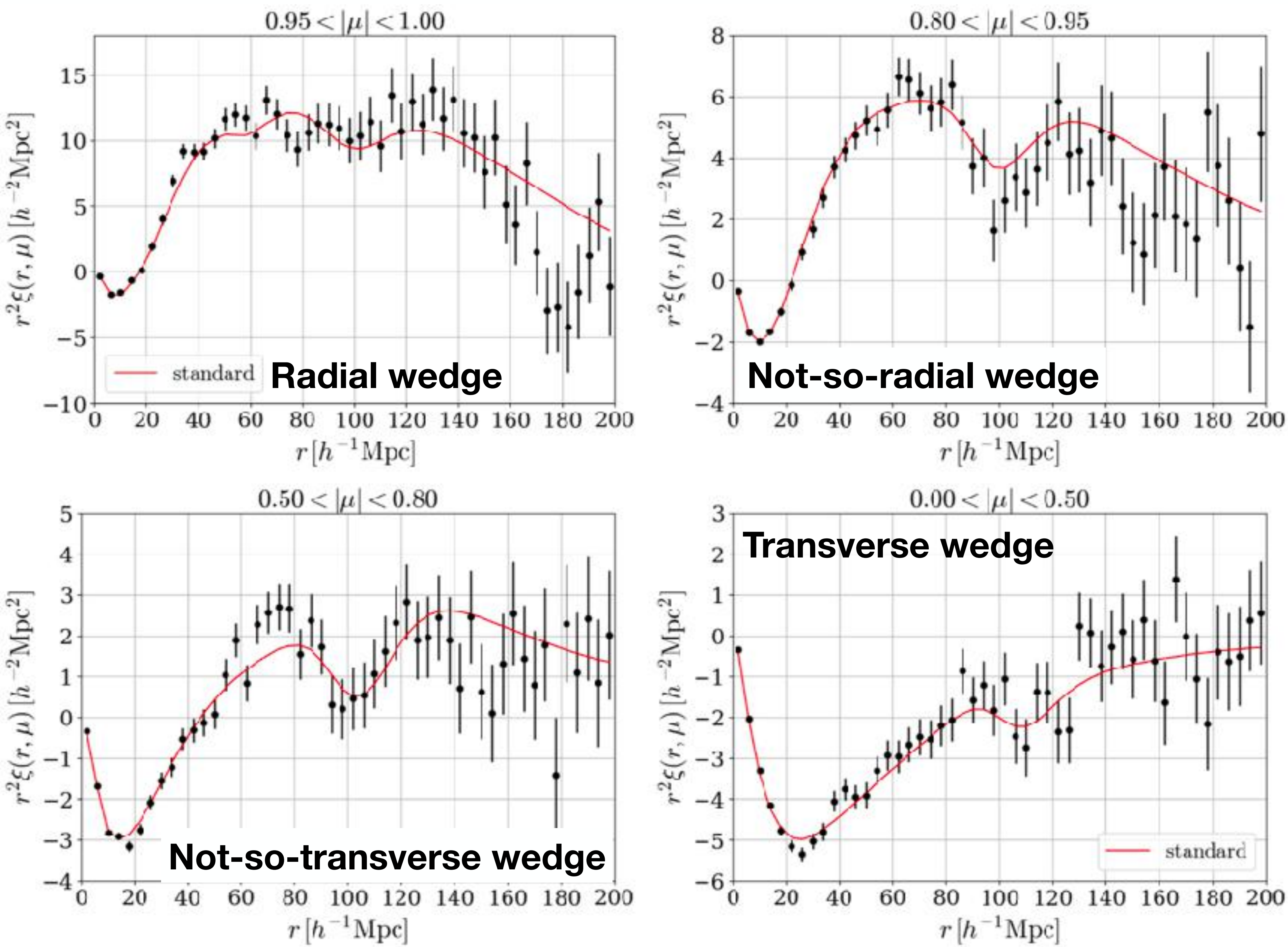




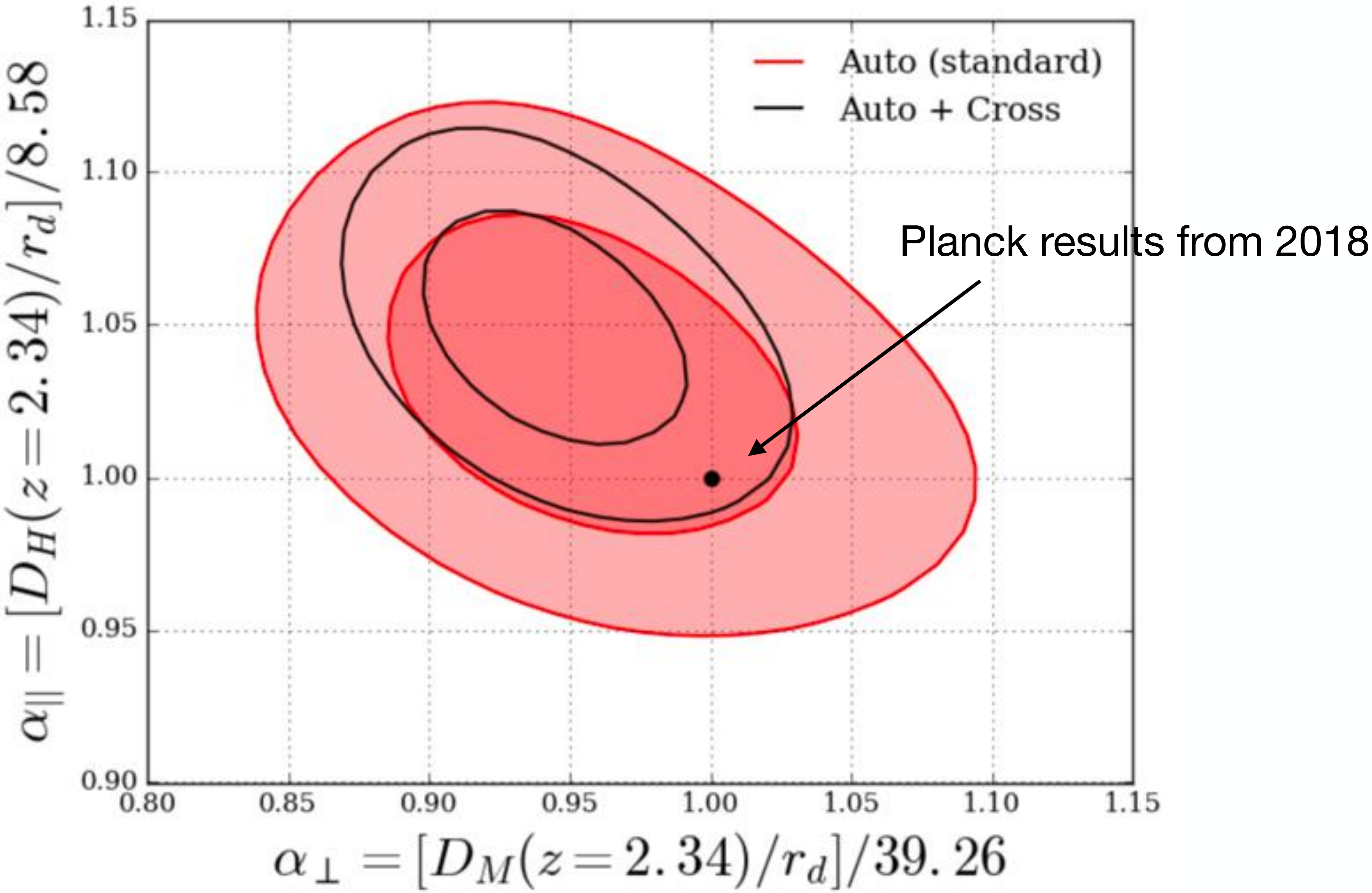
Auto-correlation (de Sainte Agathe et al. 2019)



Cross-correlation with QSOs (Blomqvist et al. 2019)



Auto-correlation BAO constraints



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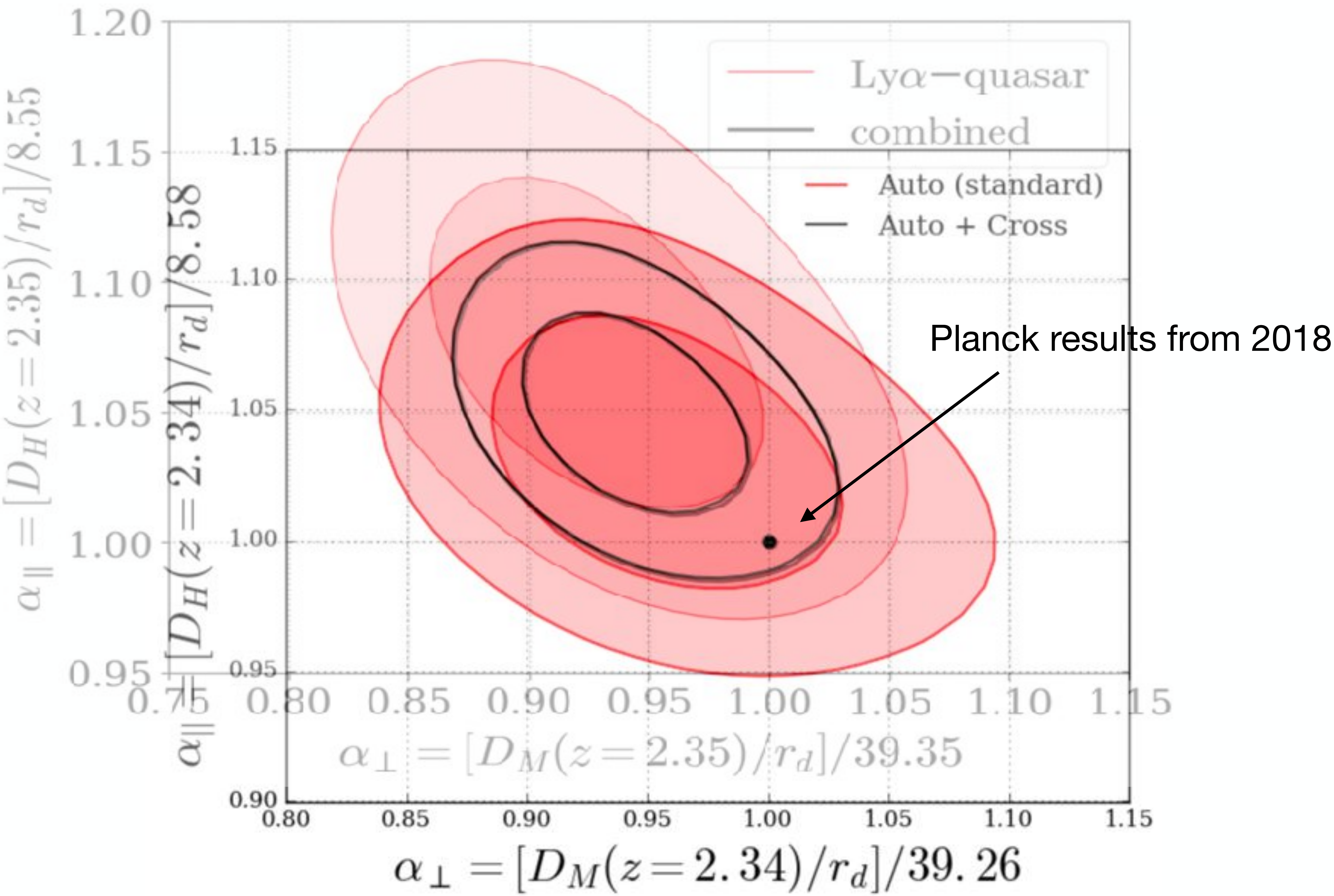

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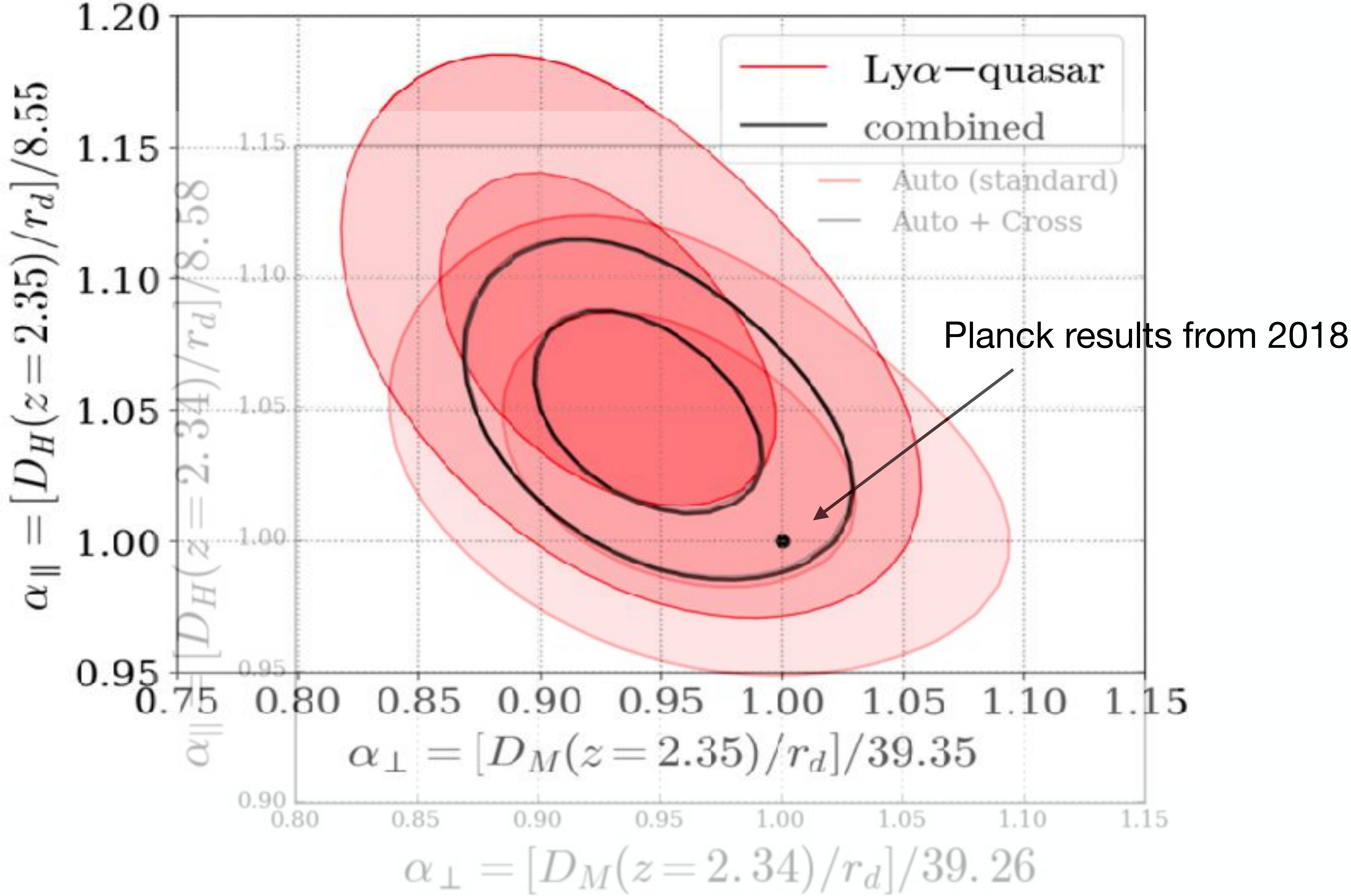

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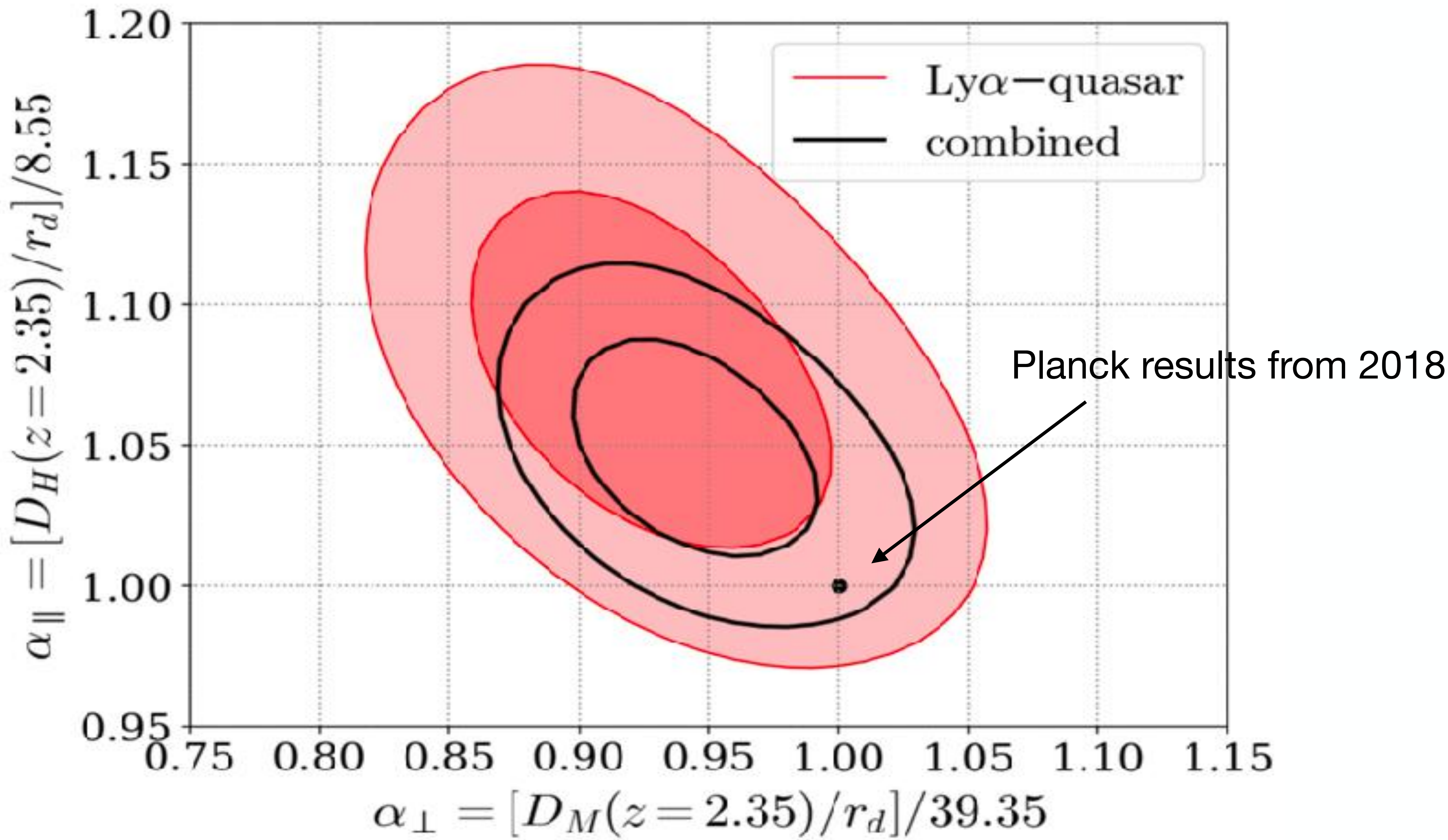
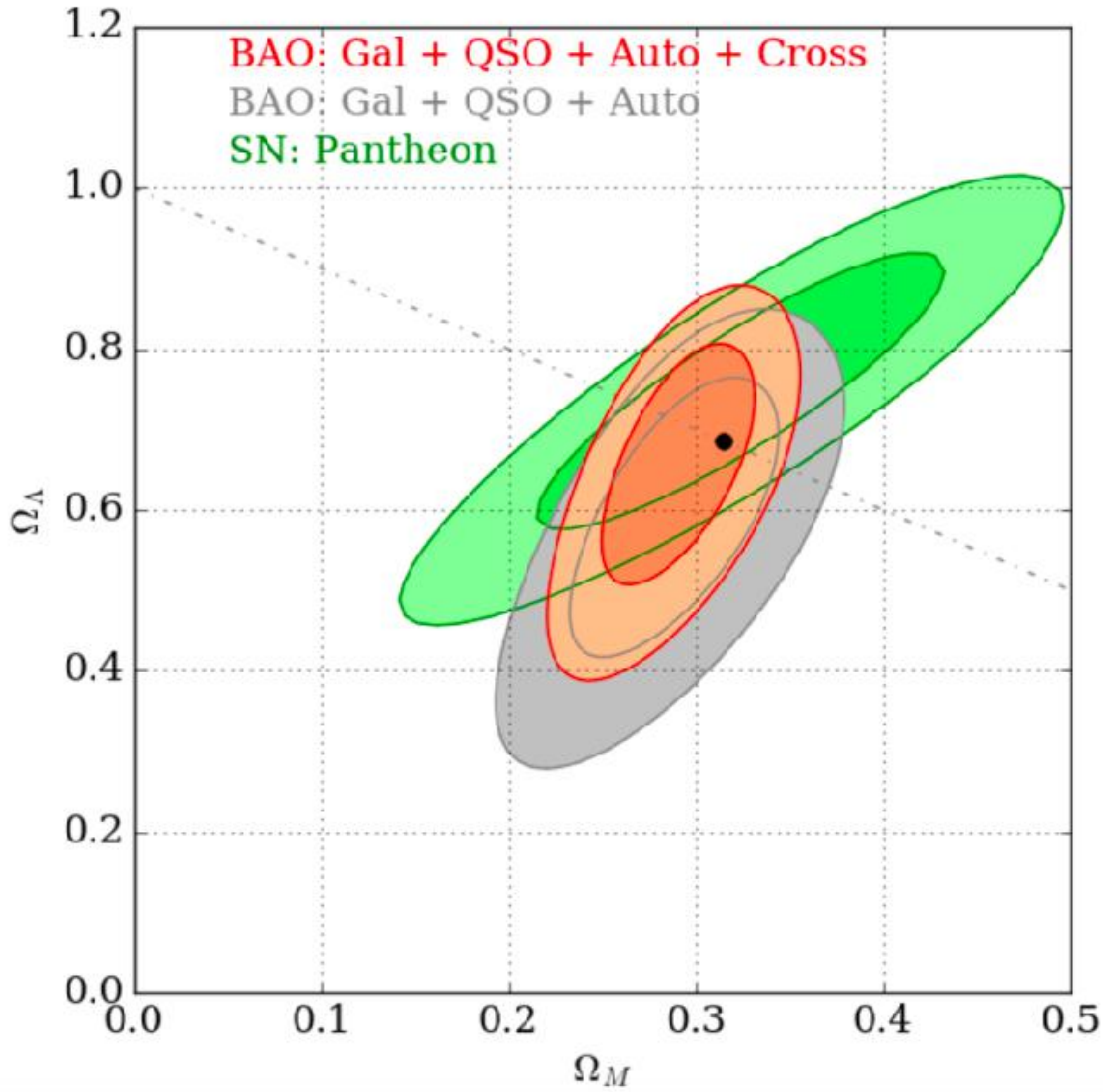
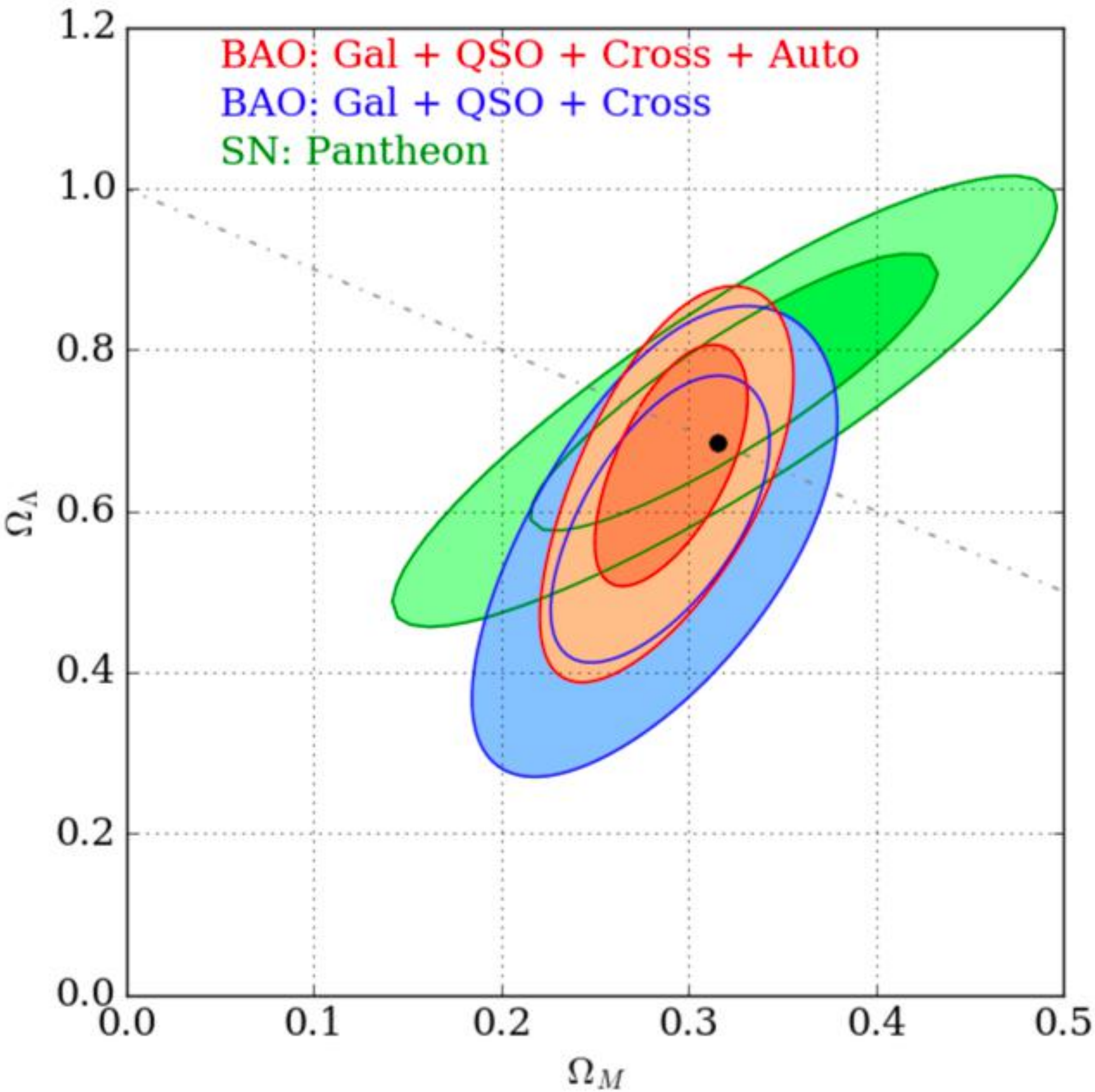


Tension with Planck reduced from 2.3 sigma to 1.7 sigma

BAO with forests



BAO with forests



Mock forests for BAO

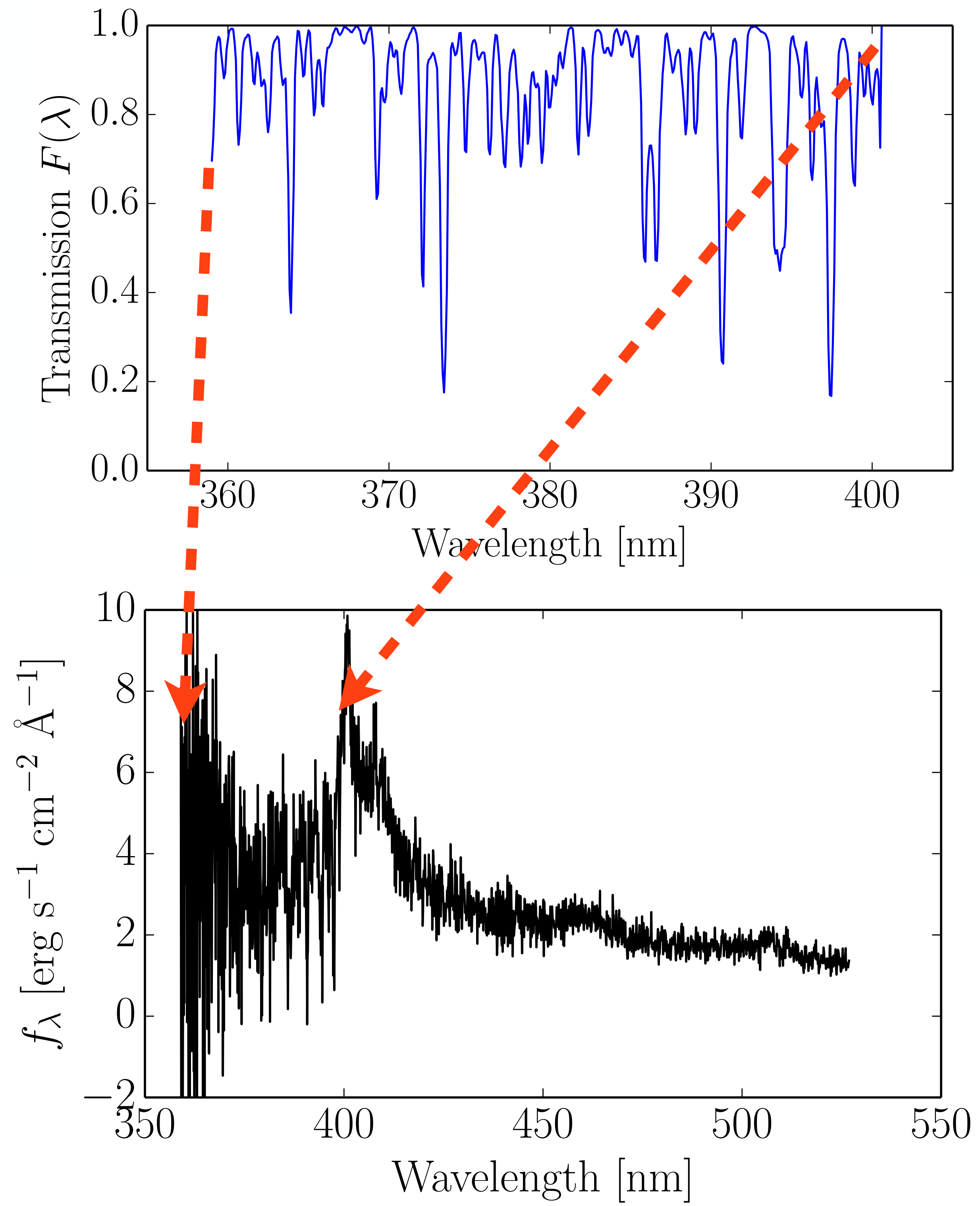
In order to cover both **large** volumes and **small** scale fluctuations:

Log-normal absorption field following an input P(k)

Font-Ribera et al. 2012

eBOSS-like quasar spectra including noise, continuum, resolution, instrumental and astrophysical systematics

Bautista et al. 2015



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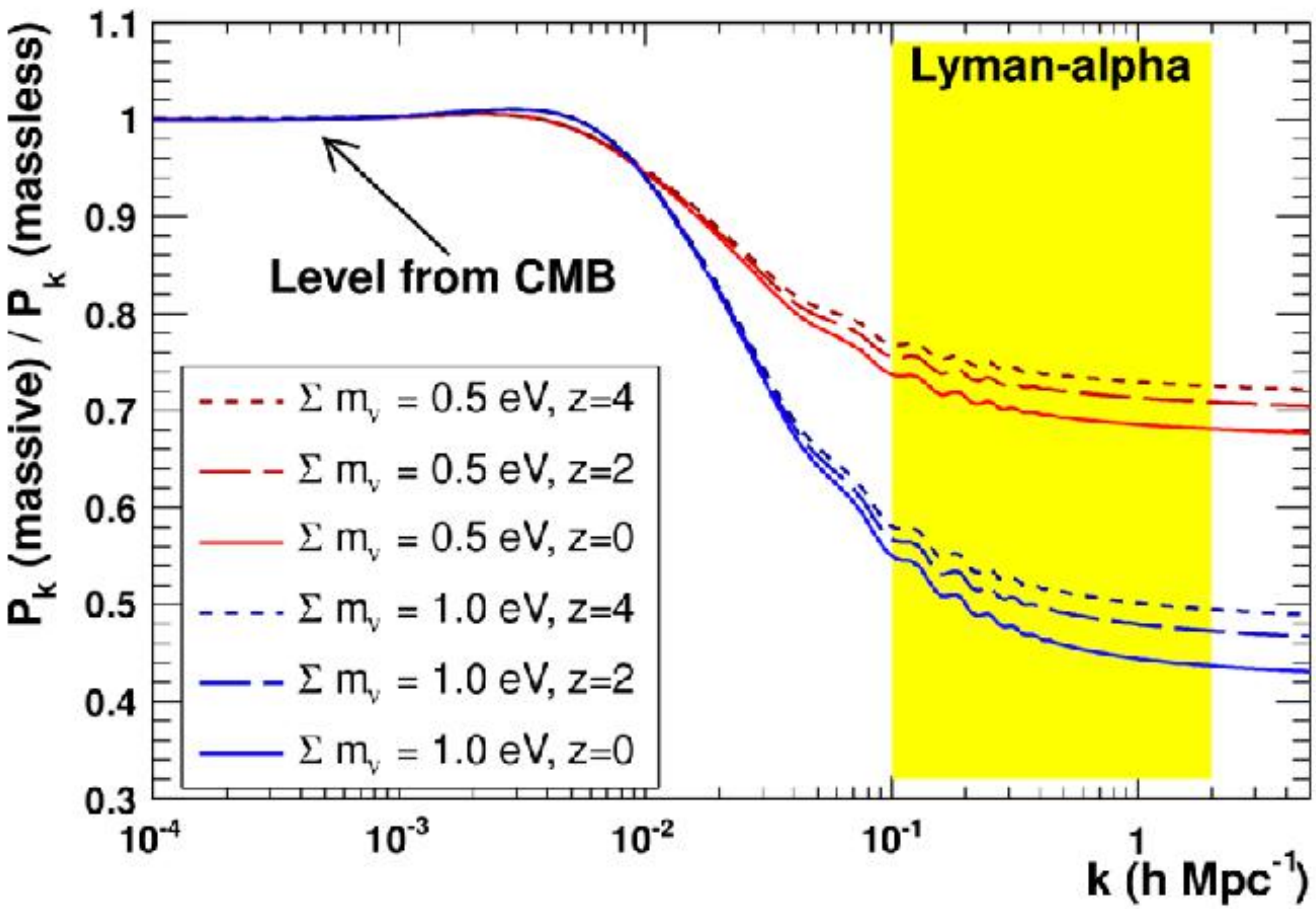
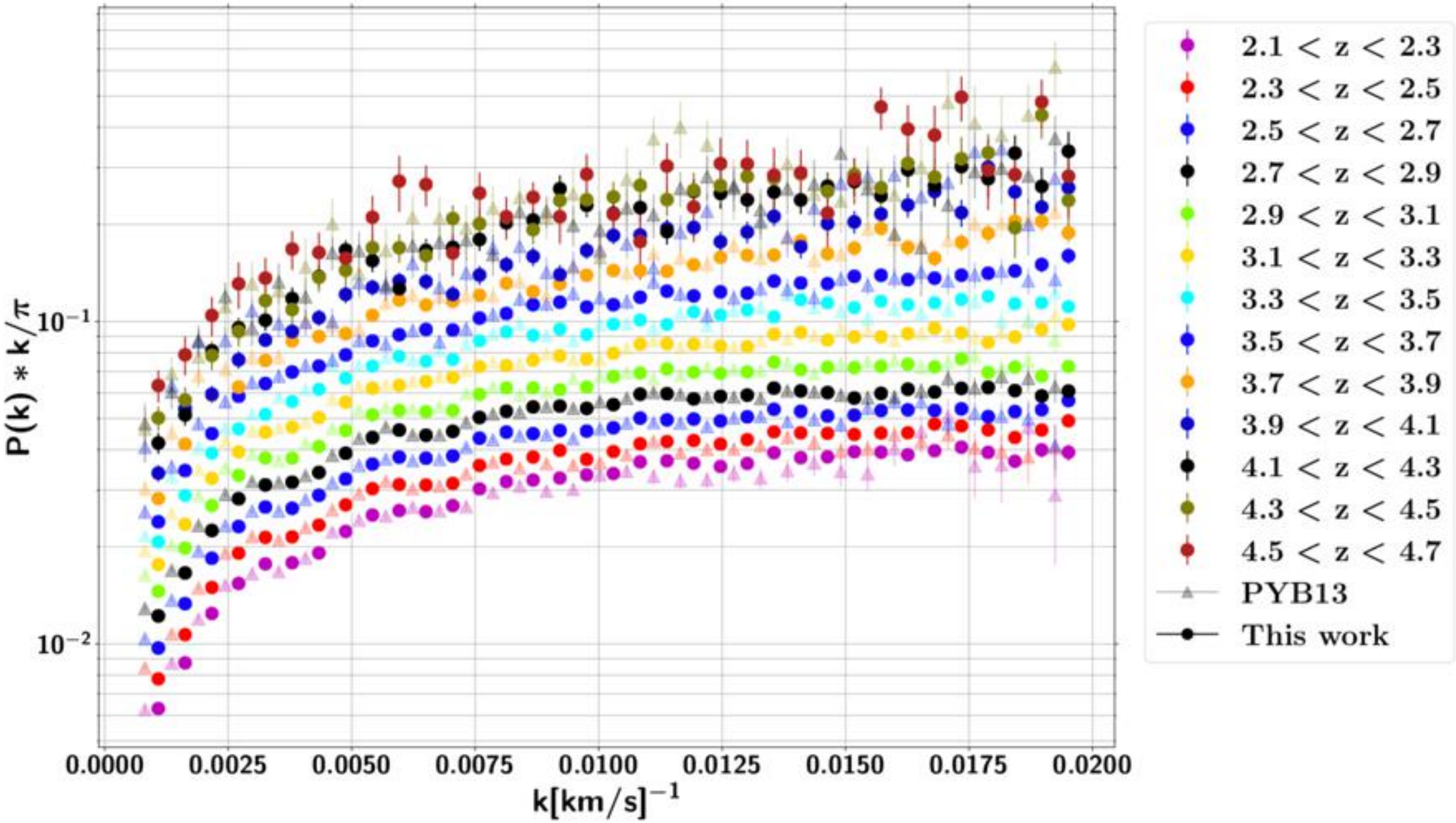
Neutrino masses with forests

Impact on linear matter power-spectrum
Palanque-Delabrouille et al. 2014



One-dimensional power spectrum

BOSS+eBOSS data: 43k forests
Chabanier et al. 2018



units: $\Delta v = c\dfrac{\Delta\lambda}{\lambda}$ [km/s] $\quad k \equiv \dfrac{2\pi}{\Delta v}$ [s/km]

Pixel size: 69 km/s ~ 0.3 Mpc/h at z ~ 3
k^{max} ~ 0.09 [s/km]

Hydro-simulations to model the signal

Suite of 48 hydro-sims (Gadget-3) for several values of
both cosmological and IGM parameters, and resolutions for "splicing"
Borde et al. 2014, Rossi et al. 2014

Parameter	Value	
$\sigma_8(z=0)$	0.83	± 0.05
n_s	0.96	± 0.05
H_0 [km s^{-1} Mpc^{-1}]	67.5	± 5.0
Ω_m	0.31	± 0.05
Ω_b	0.044	
Ω_Λ	0.69	
$T_0(z=3)$[K]	15 000	± 7000
$\gamma(z=3)$	1.3	± 0.3
Starting redshift	30	

100 Mpc/h 768^3
25 Mpc/h 768^3
25 Mpc/h 192^3

Adiabatic cooling

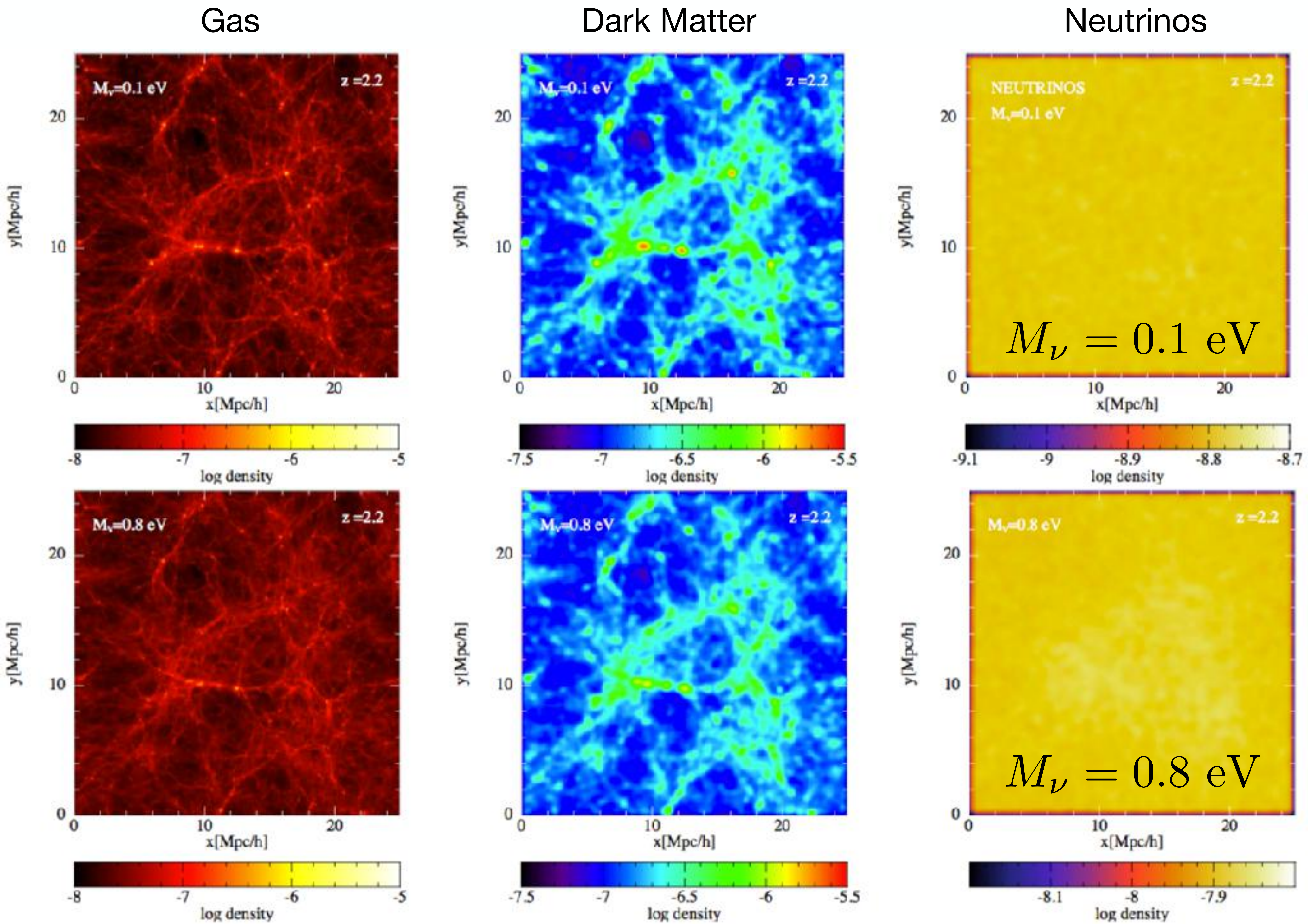
Ultraviolet background ionization heating

Compton and recombination cooling

Feedback from star formation and AGNs

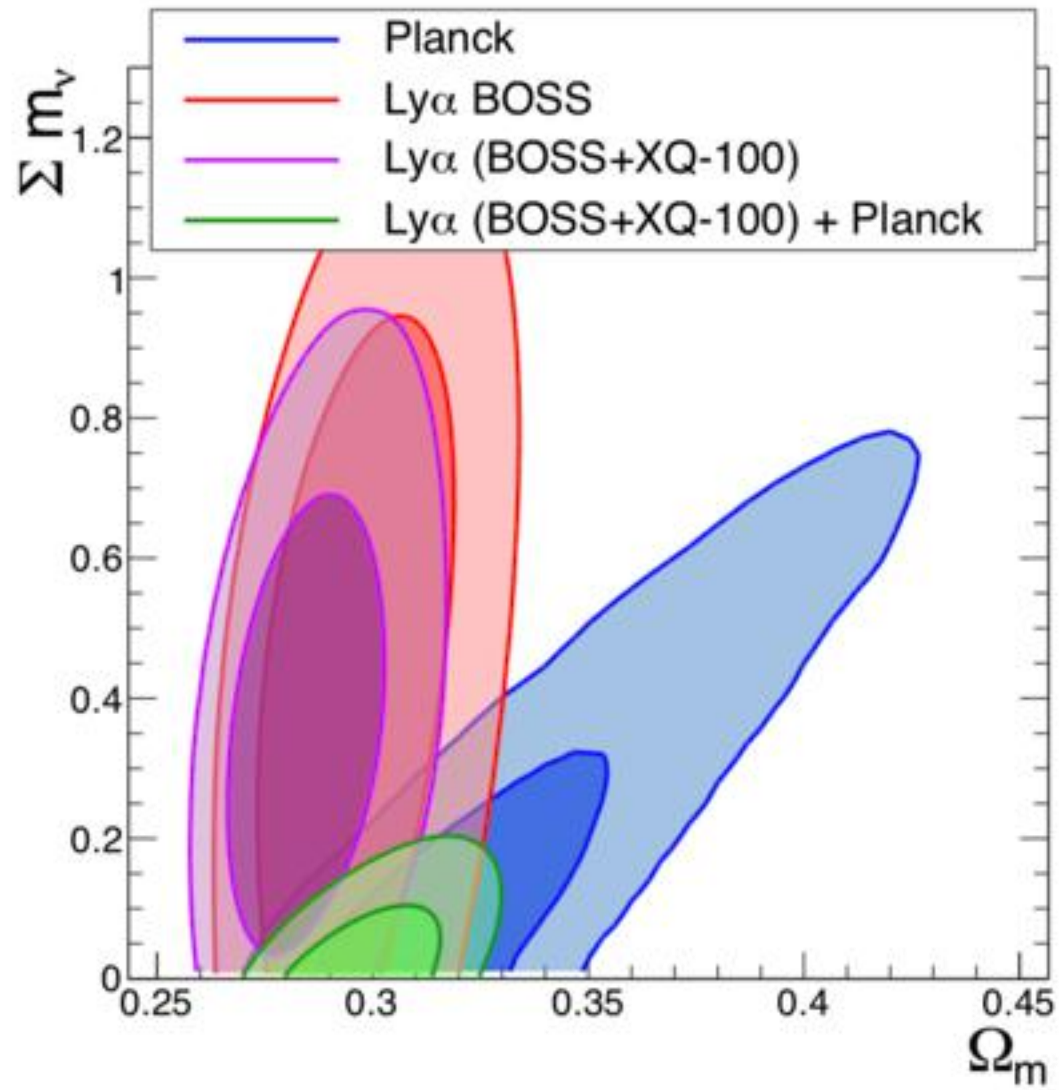
Particle based neutrino implementation

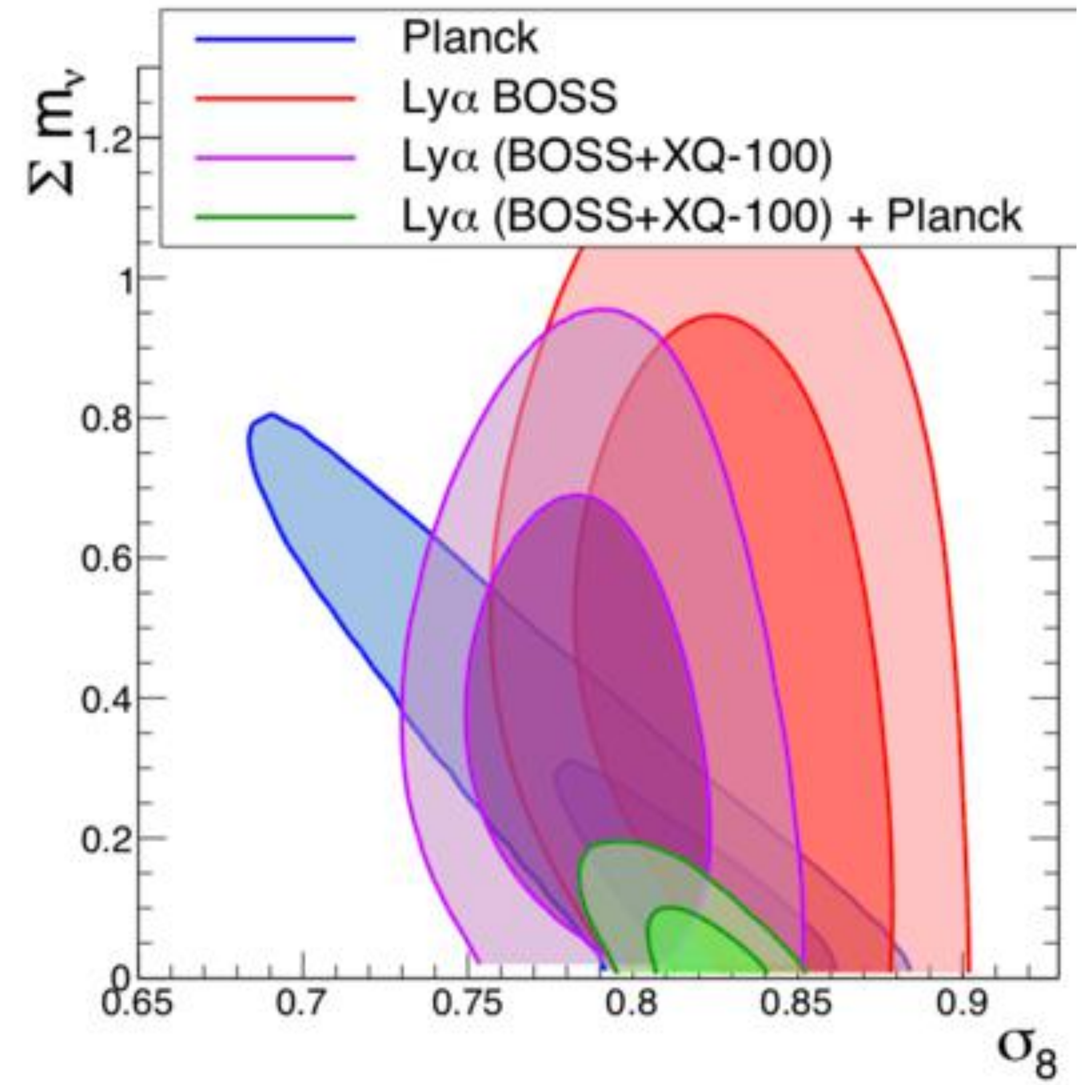
+ neutrino masses: $M_\nu = 0.1, 0.2, 0.3, 0.4,$ and 0.8 eV



Rossi et al. 2014

Constraints on neutrino mass





Constraints on n_s, σ_8 , warm dark matter and **neutrino masses**

McDonald et al. 2006, Palanque-Delabrouille et al. 2014, **Yèche et al. 2017 (shown)**

$$\sum m_\nu < 0.15\text{eV} \ (95\%)$$ Forests + CMB

Other simulations

Dedicated to Lyman-alpha forest

NIX code

Eulerian

Almgren et al. 2013,
Lukic et al. 2015

MP-Gadget2

Feng et al. 2015
Rogers et al. 2018

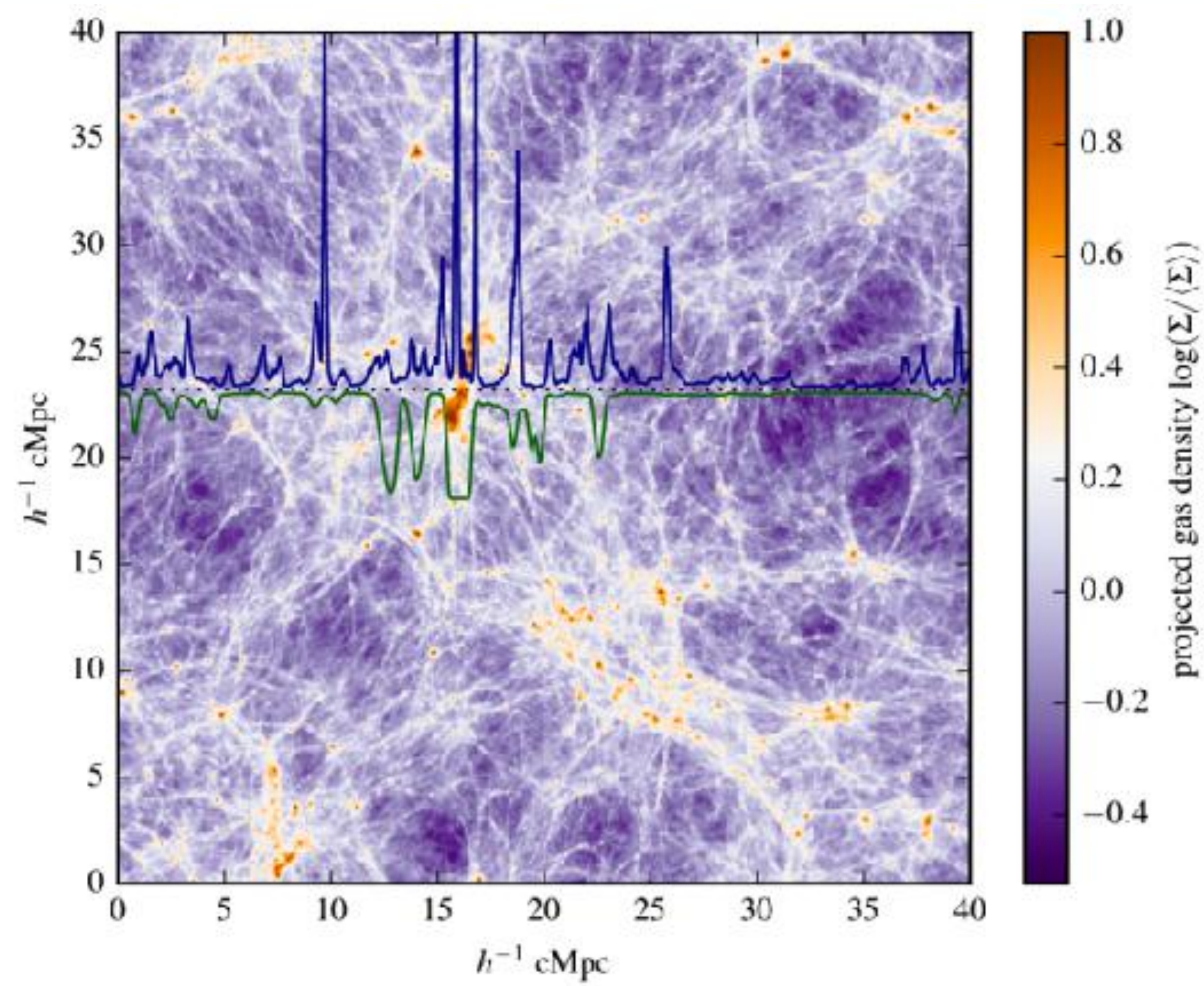
Sherwood Suite

P-Gadget3
(10 - 160 Mpc/h)^3

Bolton et al. 2017

Illustris & IllustrisTNG

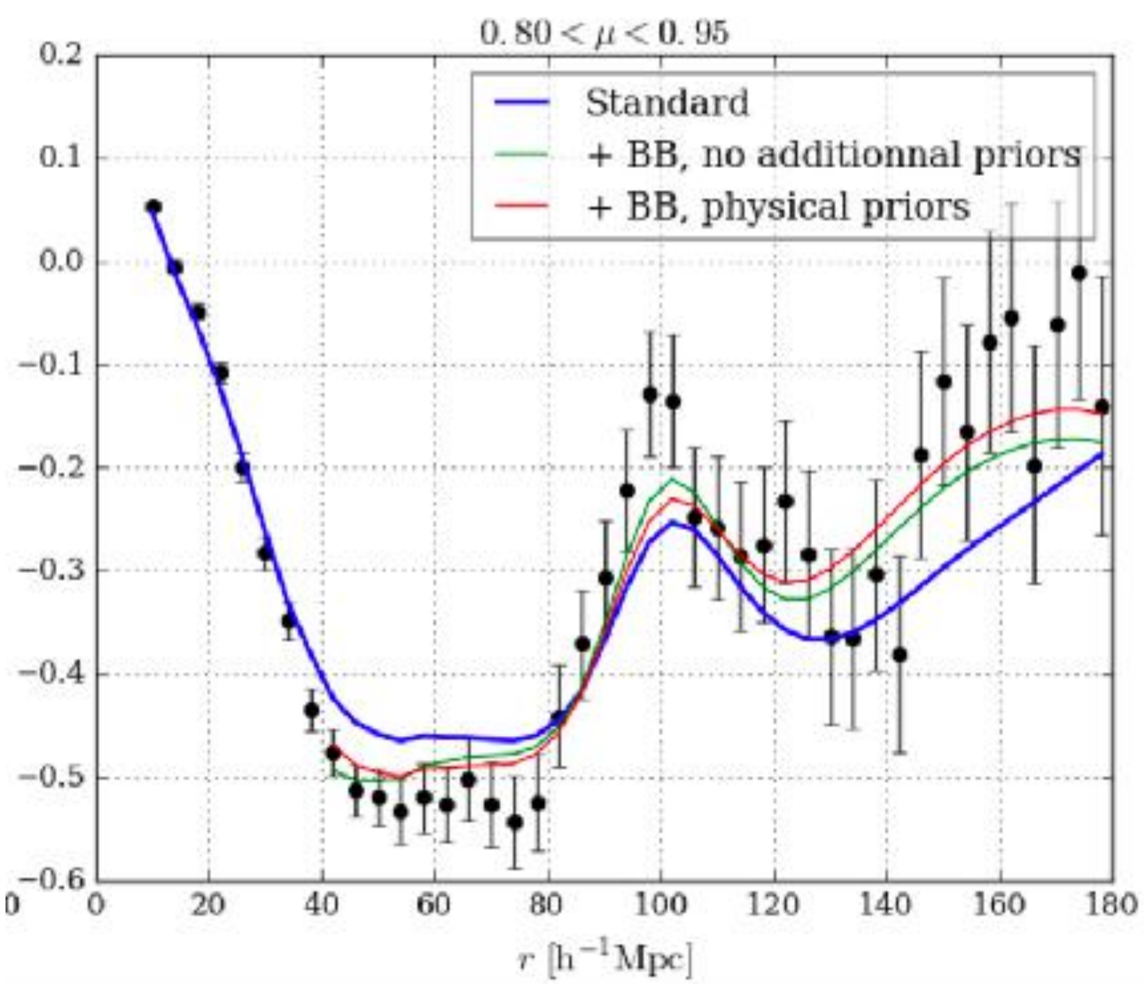
EAGLE



And the list goes on...

What do we need?

Discrepancies on intermediate-scales?



Is this enough for neutrino masses?

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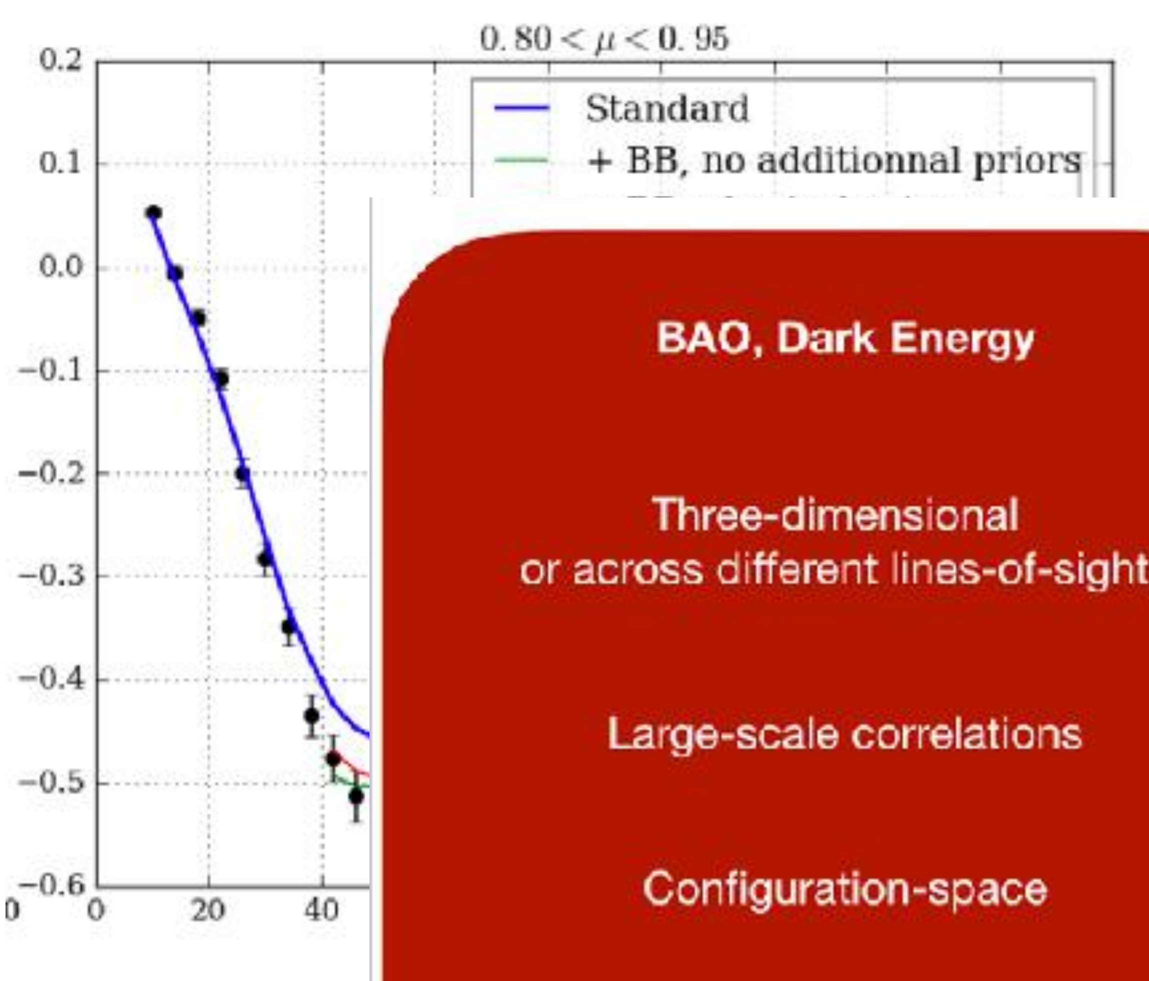

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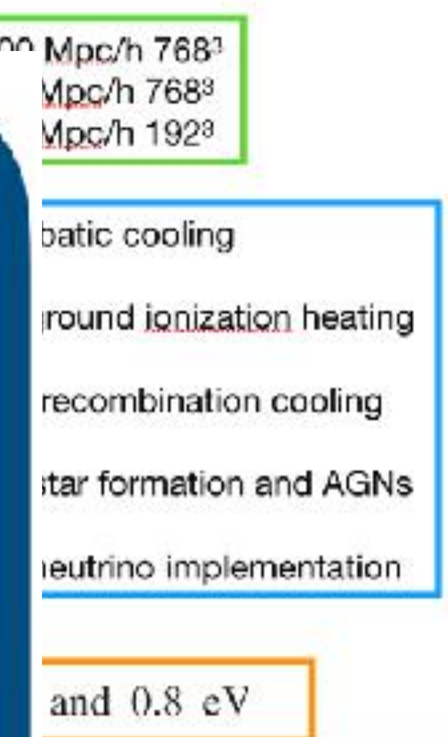

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Common framework for both analyses?

Conclusion

- Lyman-alpha forest surveys are now main component of future spectroscopic surveys

- eBOSS new BAO measurements with Lyman-alpha forest are now 1.7 sigma away from Planck 2018 prediction

- Neutrino masses upper bound from forests+CMB is below 0.15 eV (95% C.L.)

- Simulations are an essential tool in these analyses. Challenges are to simulate huge volumes (Gpc) and small scale fluctuations (tens of kpc). How to increase realism and precision for cosmology?