Measuring the cosmic expansion rate at high redshift with DESI Lyman-α forests

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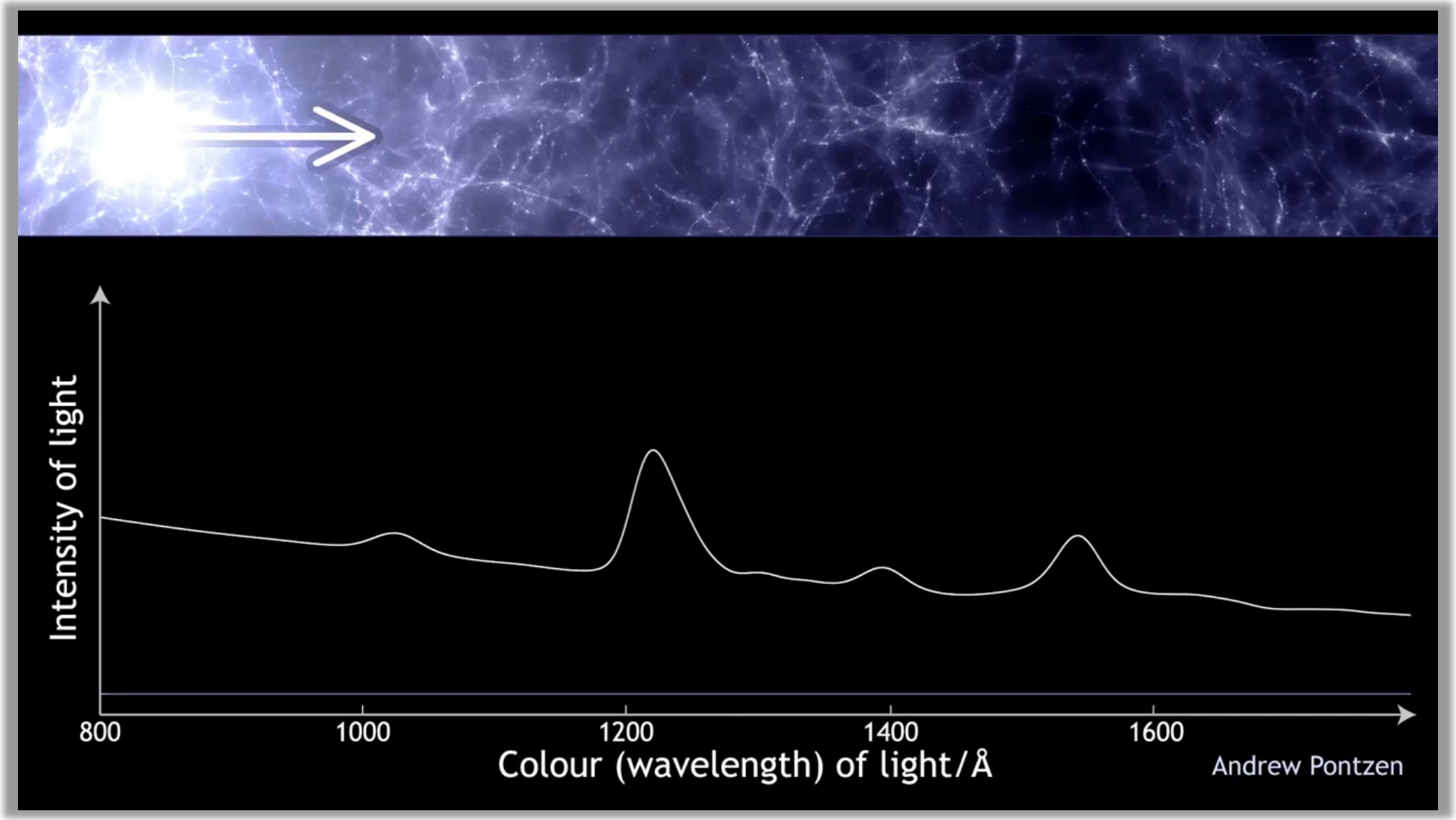
The Lyman-α forest



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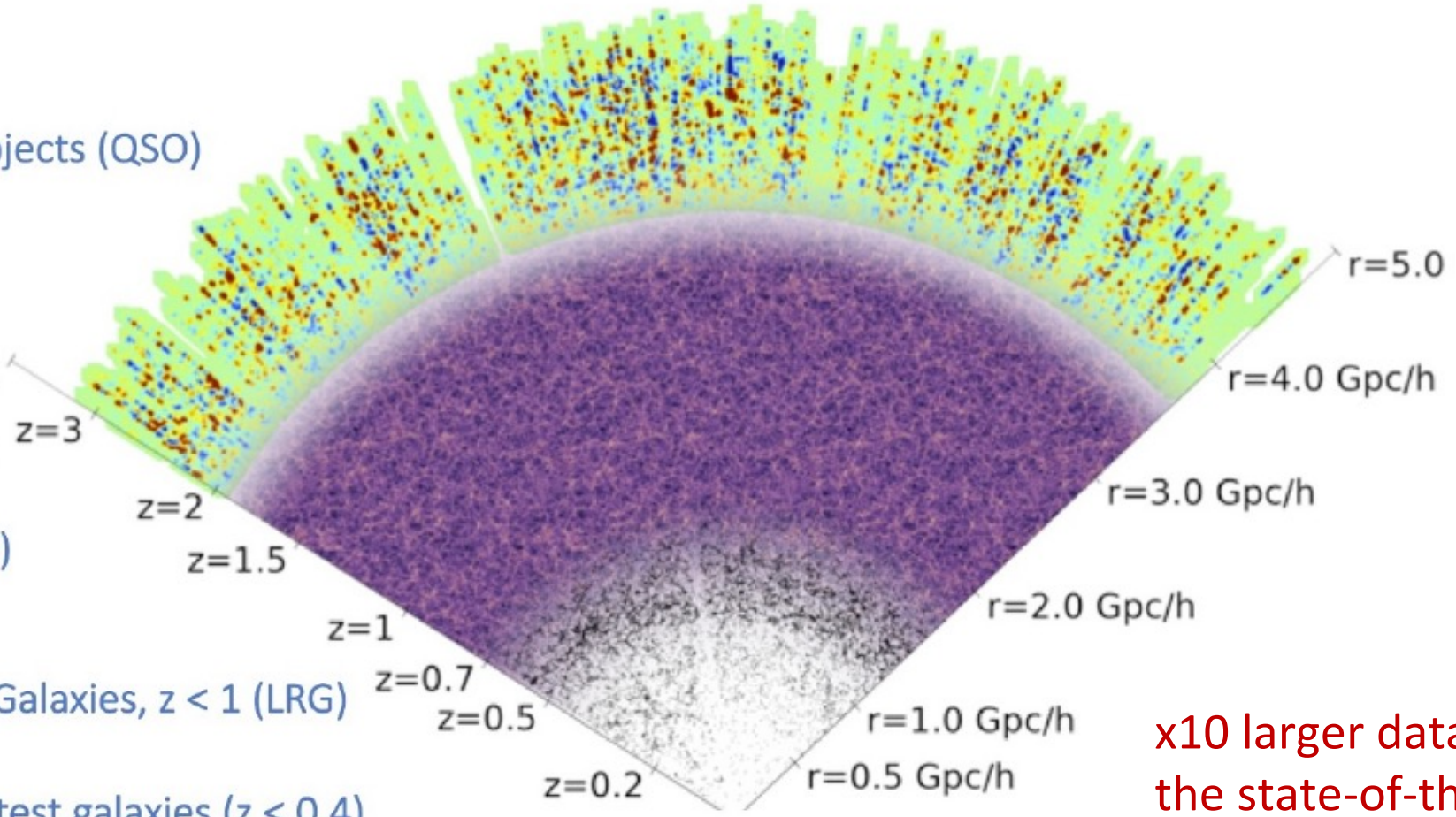
DESI is creating a 3D Map of the Universe

2.7 million
Quasi Stellar Objects (QSO)

13 million ELGs
(Emission Line
Galaxies, z < 1.8)

7.5 million LRGs
(Luminous Red Galaxies, z < 1 (LRG)

9 million brightest galaxies (z < 0.4)



x10 larger dataset than
the state-of-the-art (SDSS)

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Expansion and growth rate measurements from SDSS

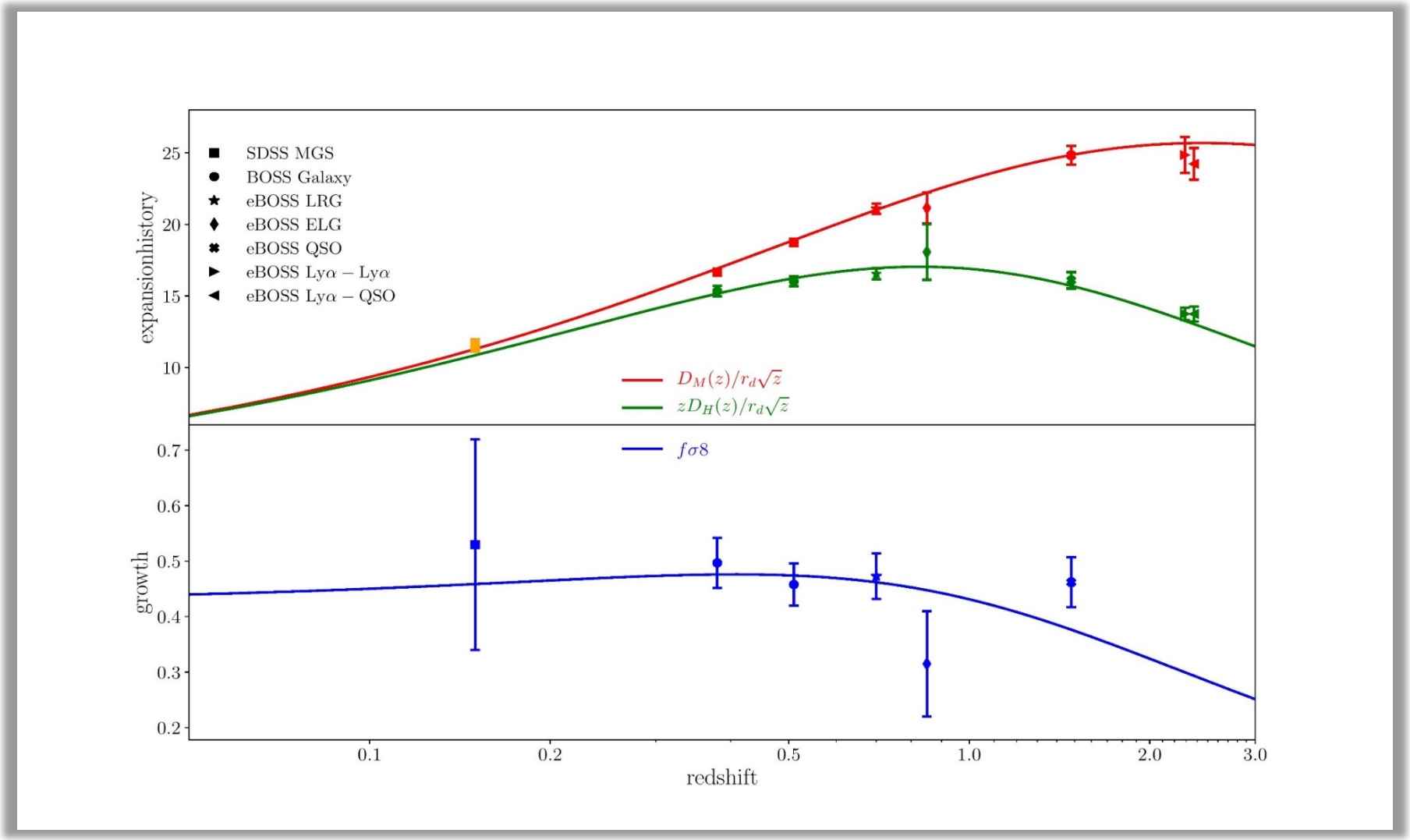

Figure from Alam et al. 2021 (2007.08991)

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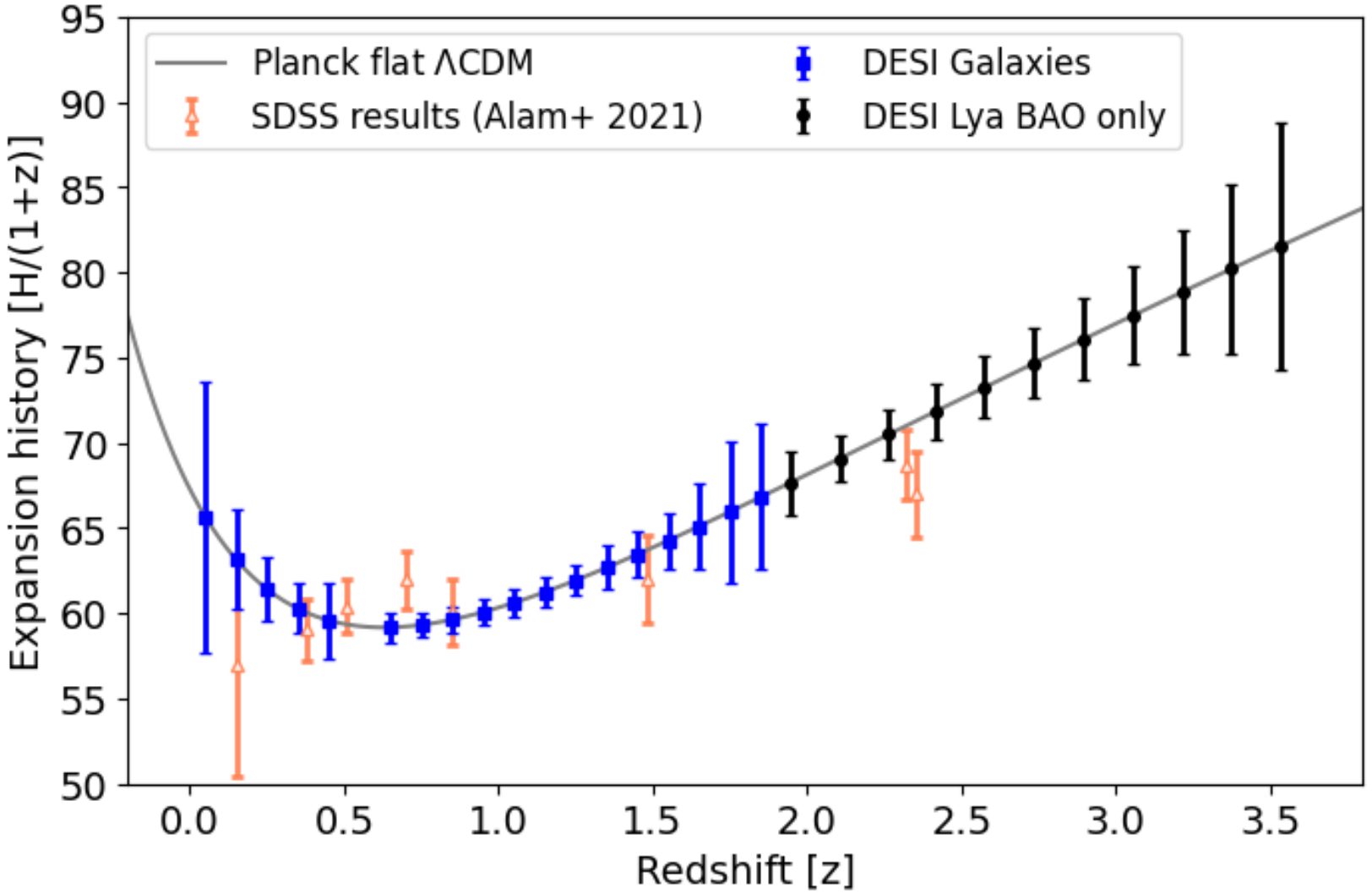
Expansion rate measurements with DESI



Based on Alam et al. 2021 (2007.08991) and DESI Collaboration et al. 2016 (1611.00036)

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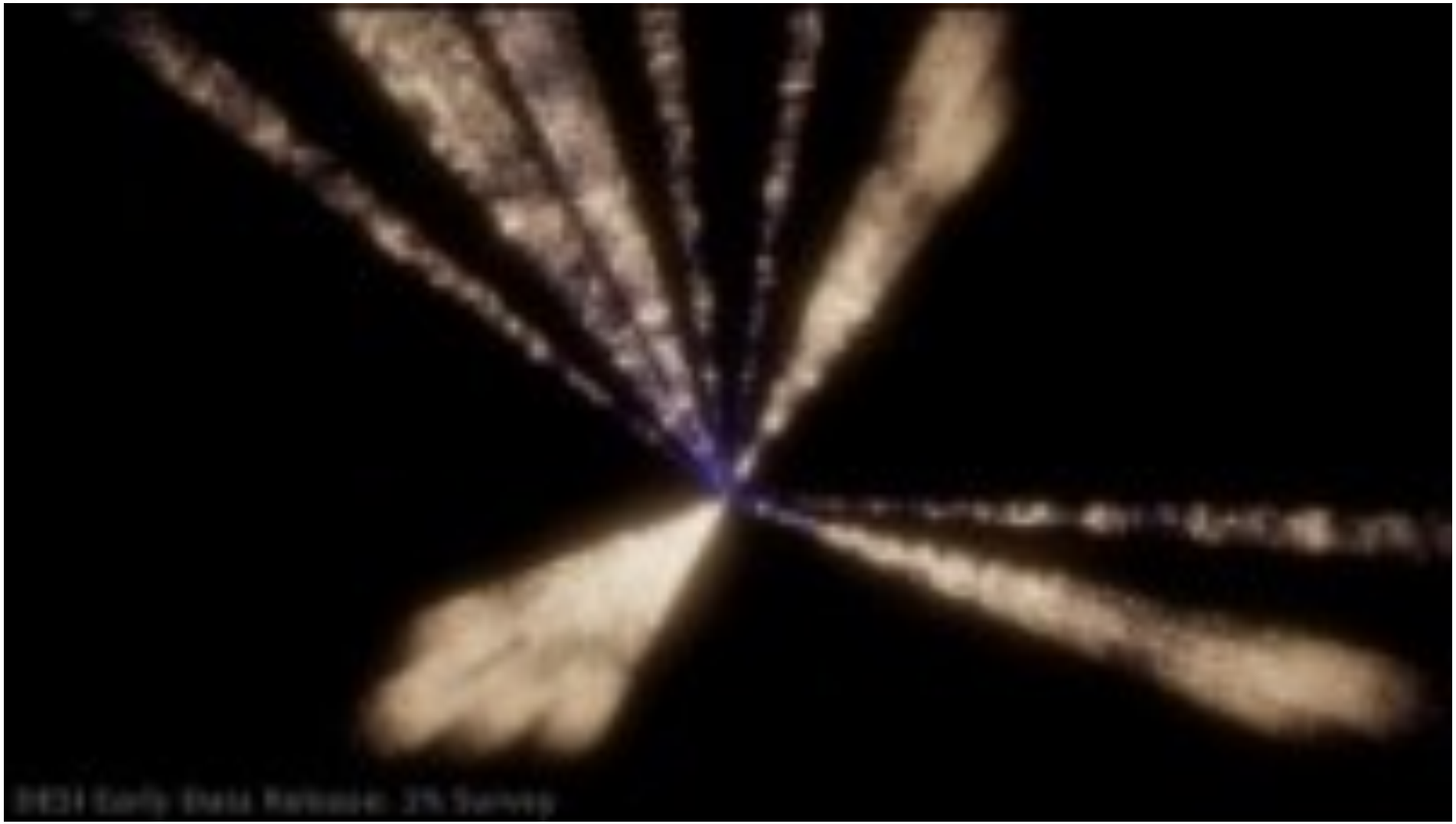
First measurements from DESI

Featured on Nature's Best Science Images of June 2023



Video credit: David Kirkby / DESI collaboration

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First measurements from DESI

DESI spectrum of Quasar at redshift $z = 2.495$

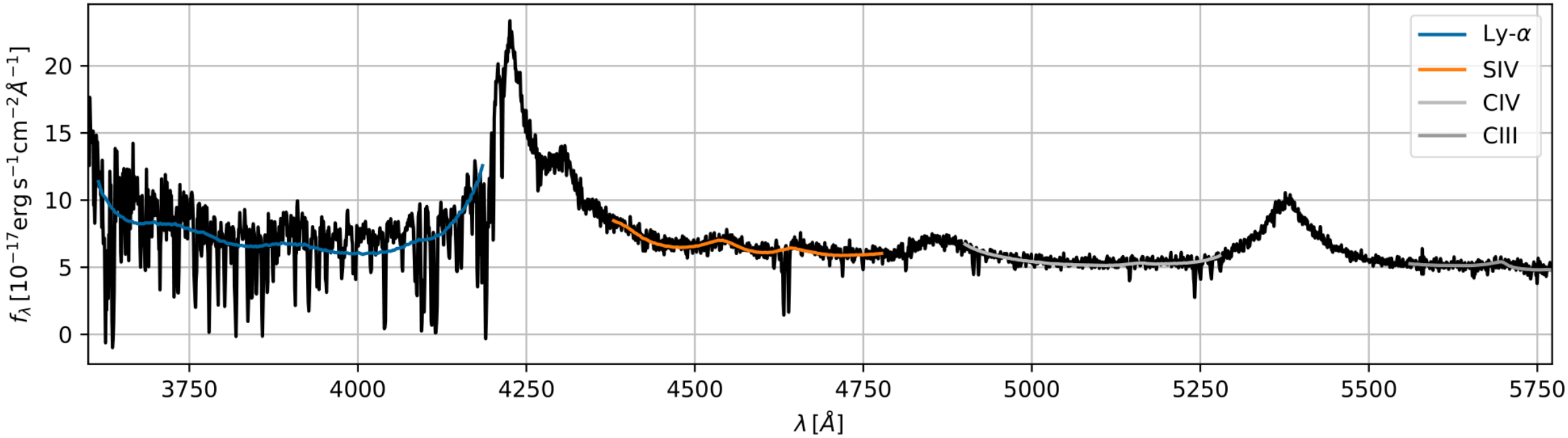

Figure from Ramírez-Pérez et al. 2023 (2306.06312)

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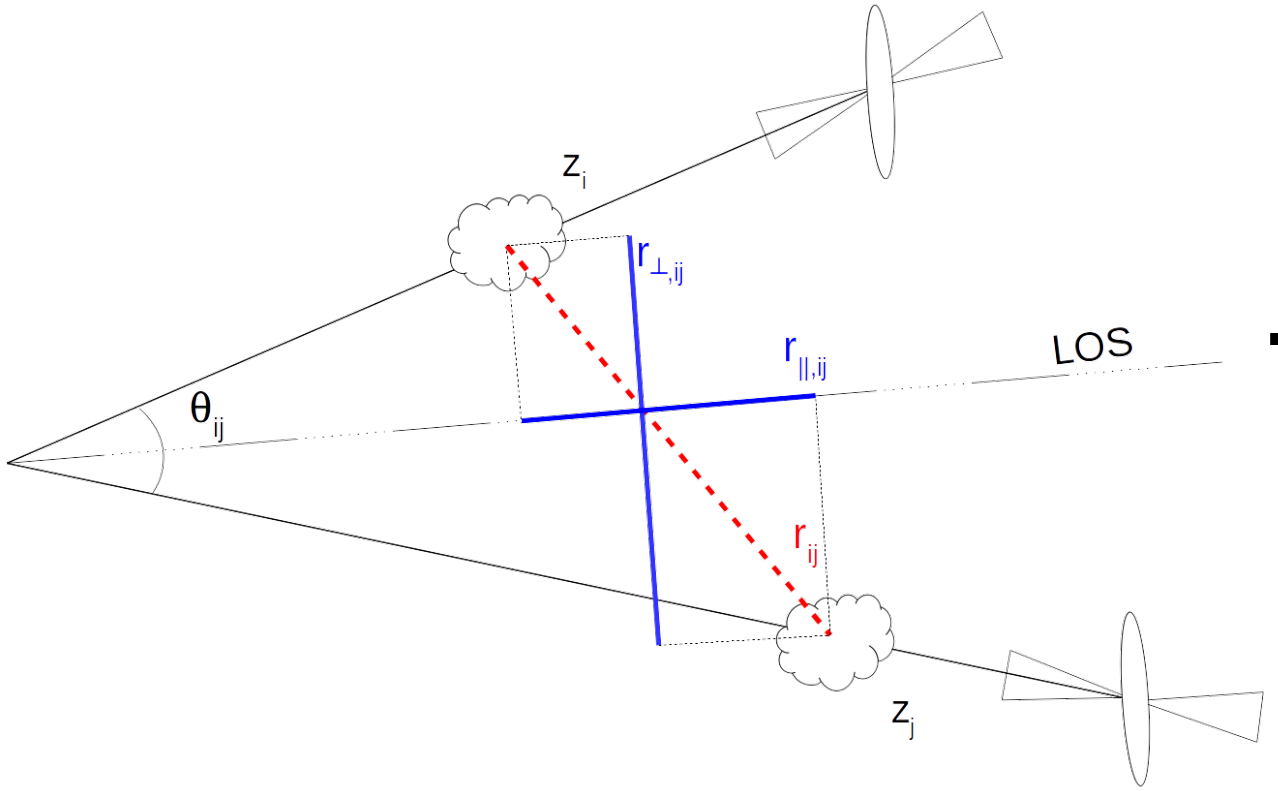
Lyman-α forest correlations



Lyα forest auto-correlation function

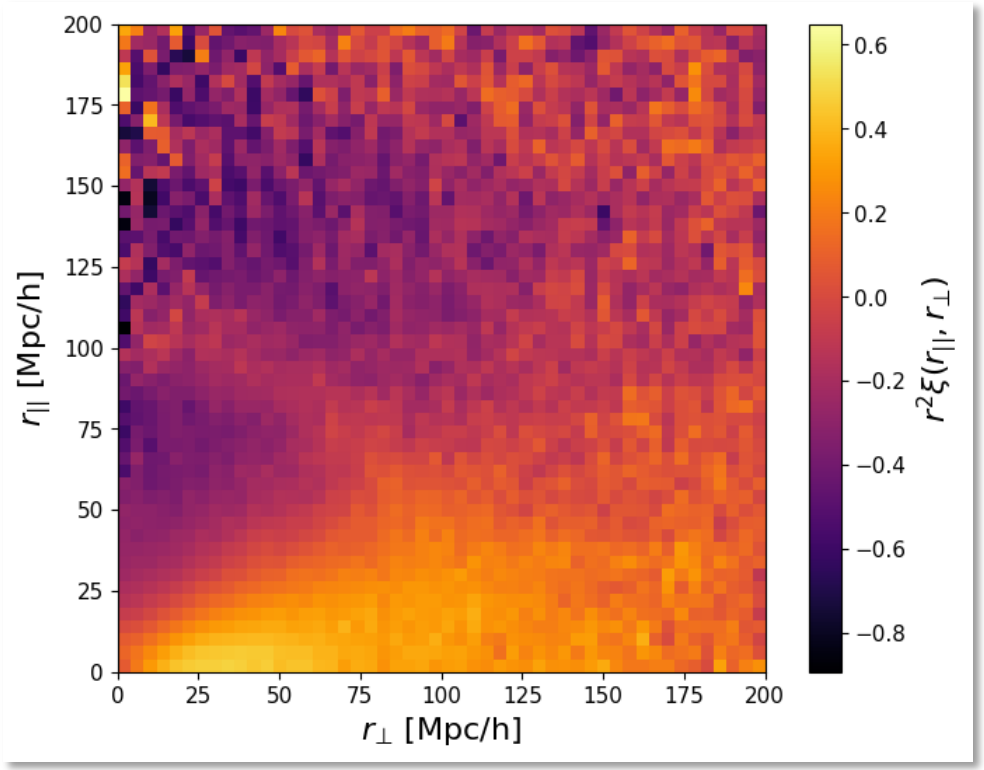


Figure from de Sainte Agathe et al. 2019 (1904.03400)

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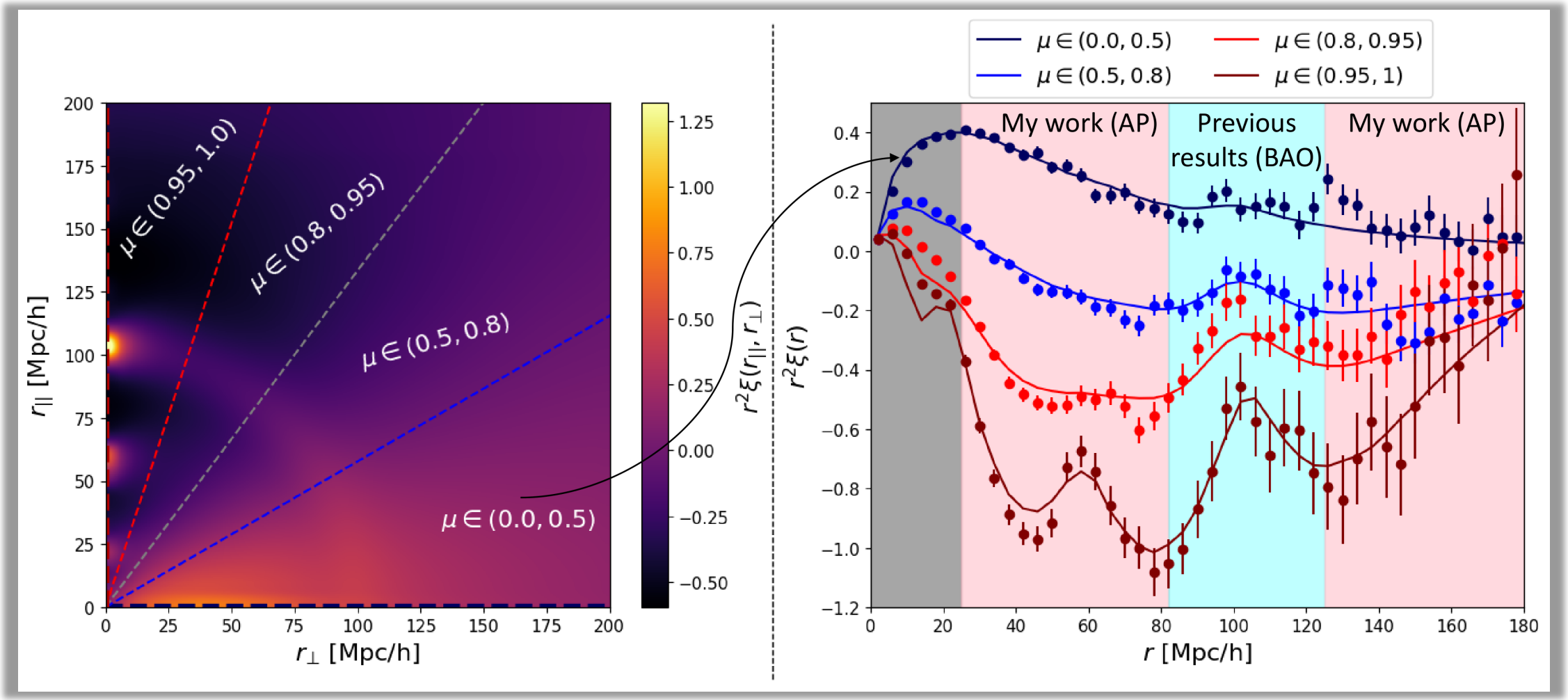
Compressing into wedges



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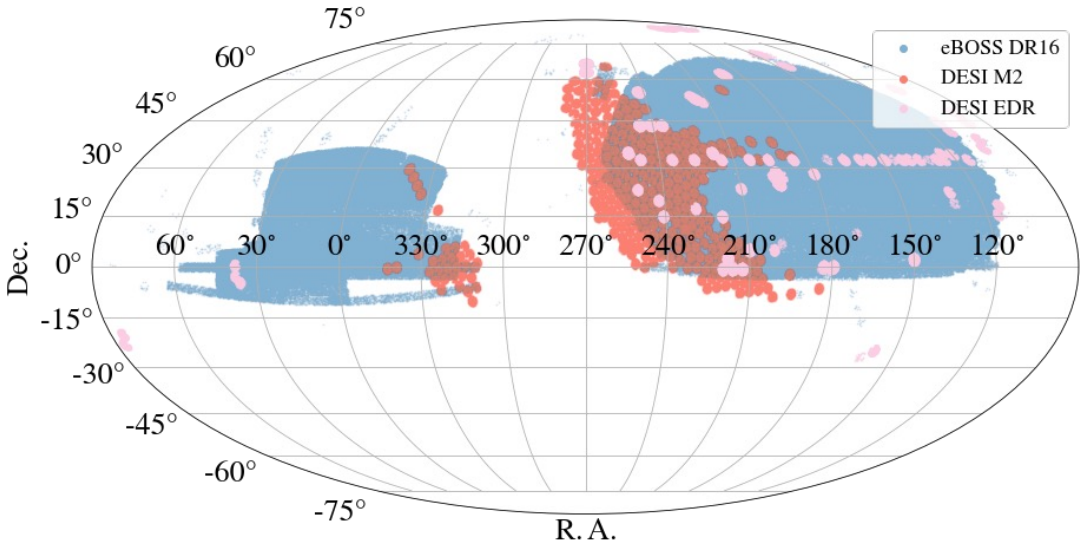
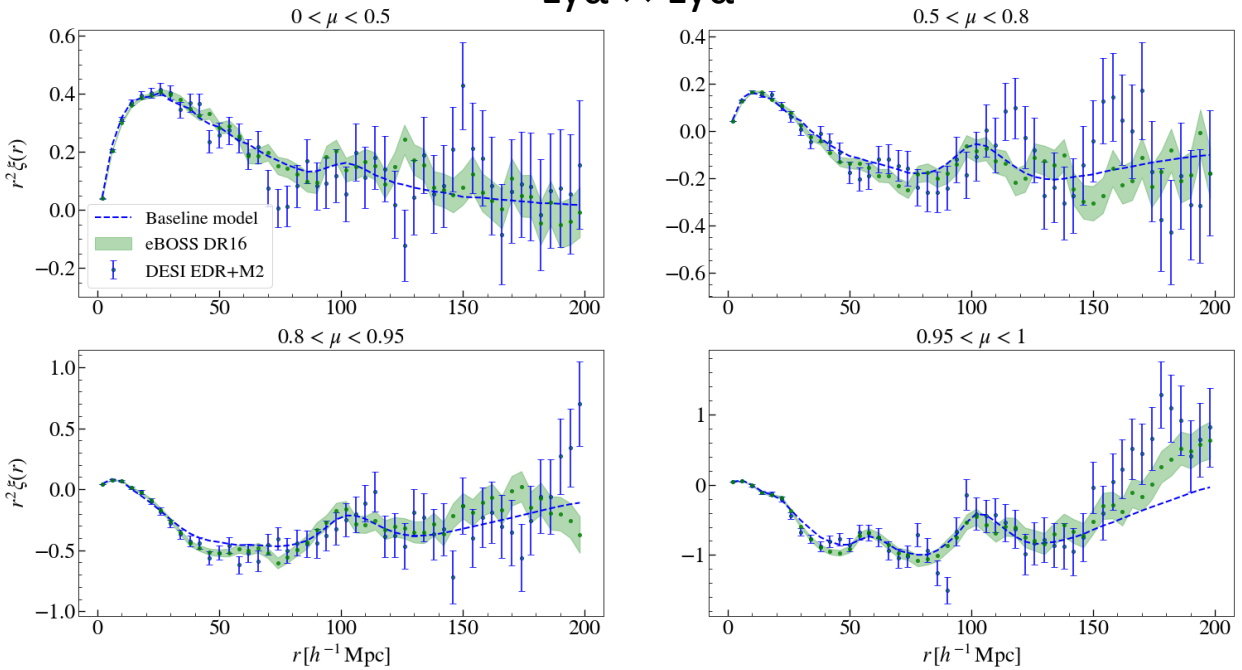
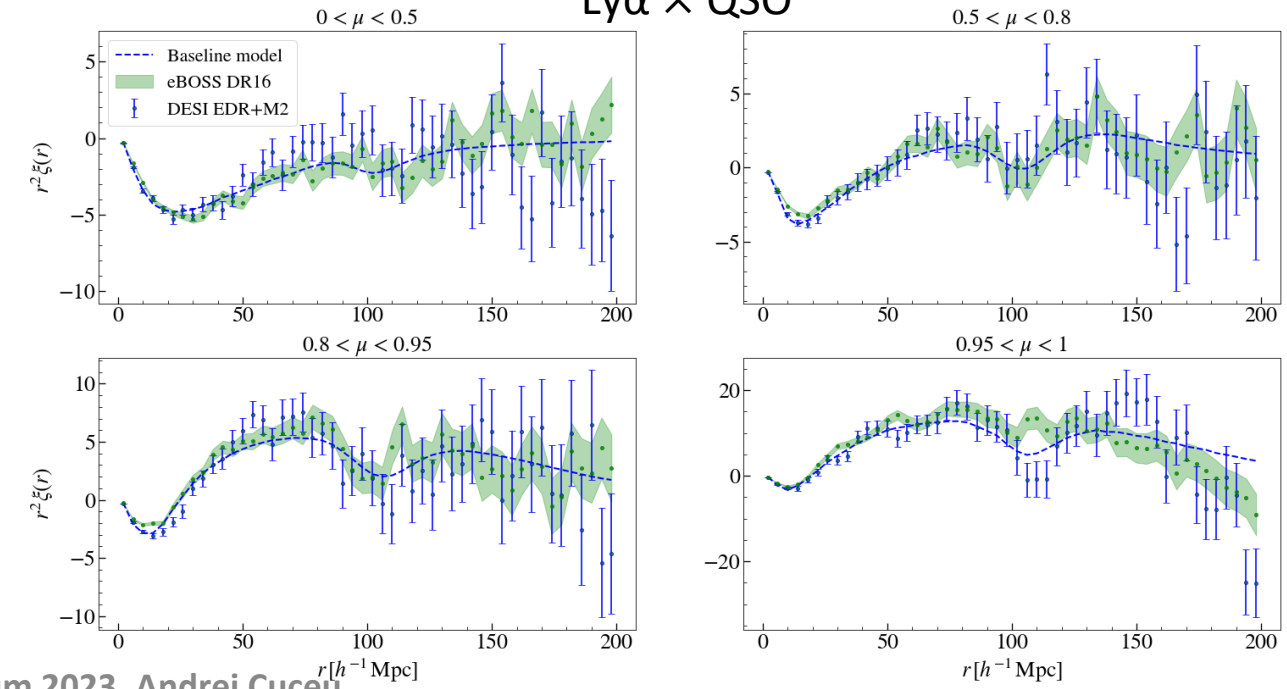
First measurements from DESI



Lyα × Lyα



Lyα × QSO



Figures from Gordon, Cuceu, et al. 2023 (2308.10950)

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Cosmology from the 3D Lyman-α forest

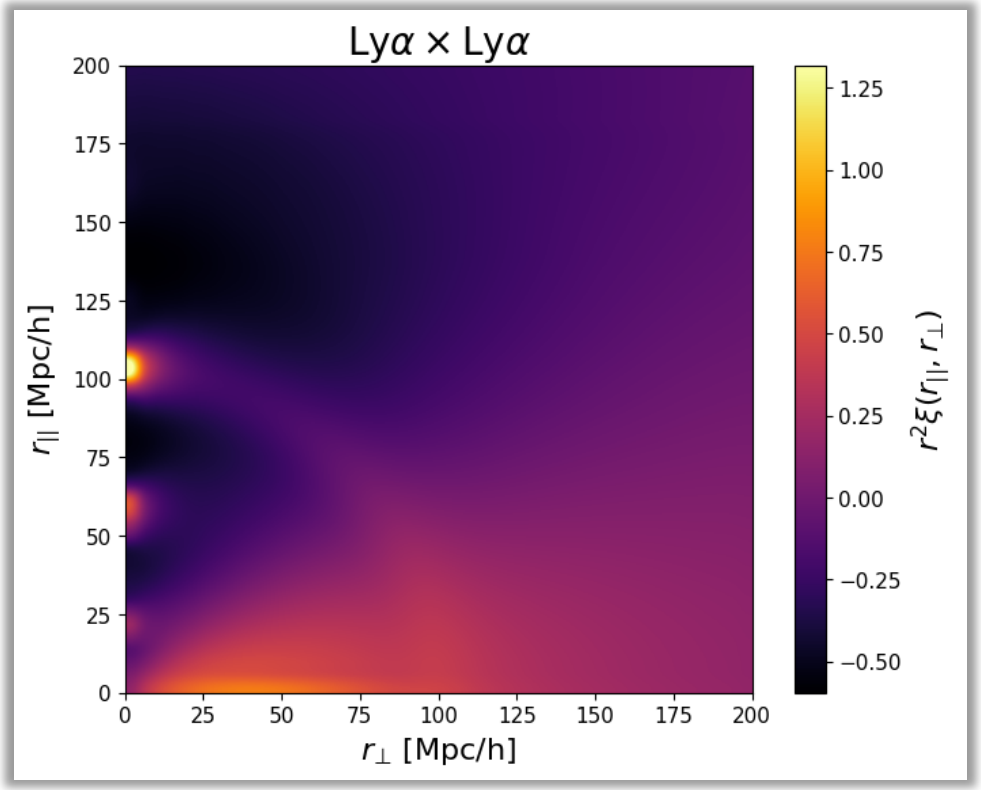
Expansion history:

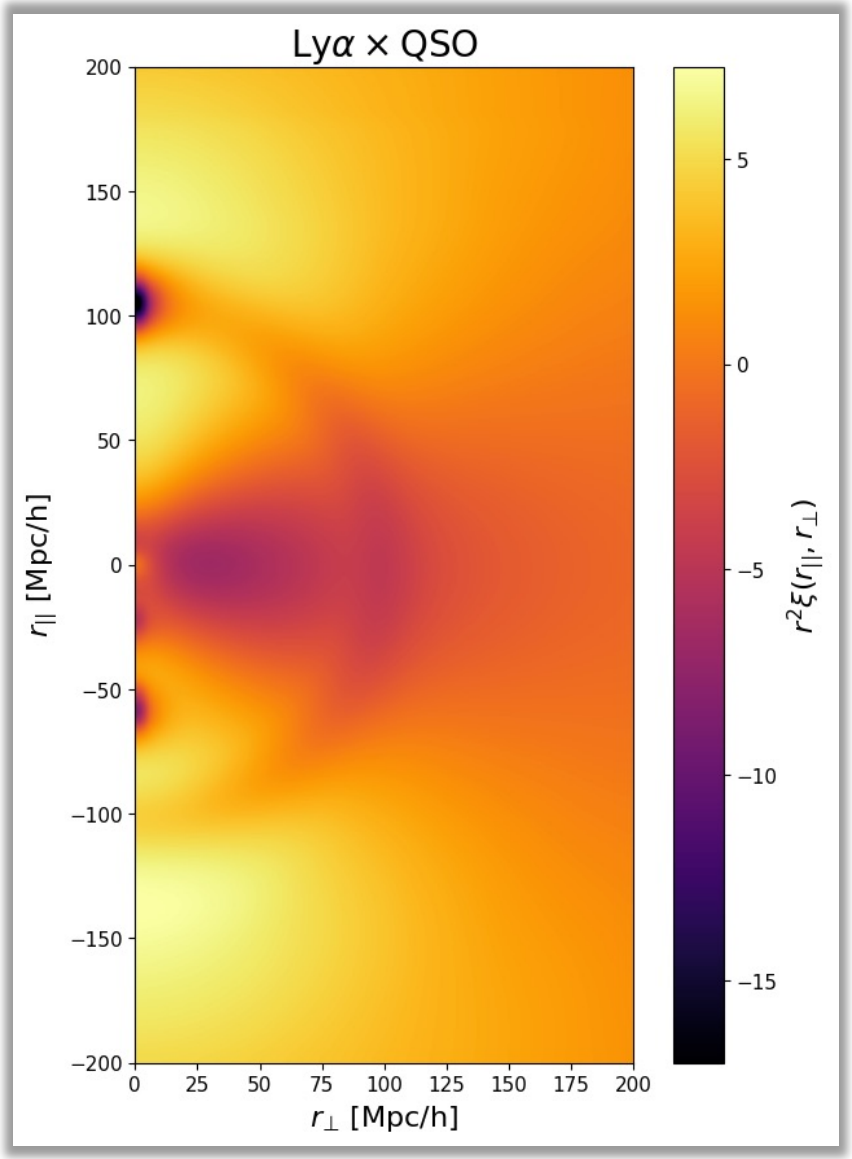
- BAO: circular feature at ~100 Mpc/h
- Alcock-Paczyński effect: Produces distinct anisotropy in the correlation function

Growth rate of structure:

- RSD: Main anisotropy present in the correlation functions

Model correlation functions
(no distortion)





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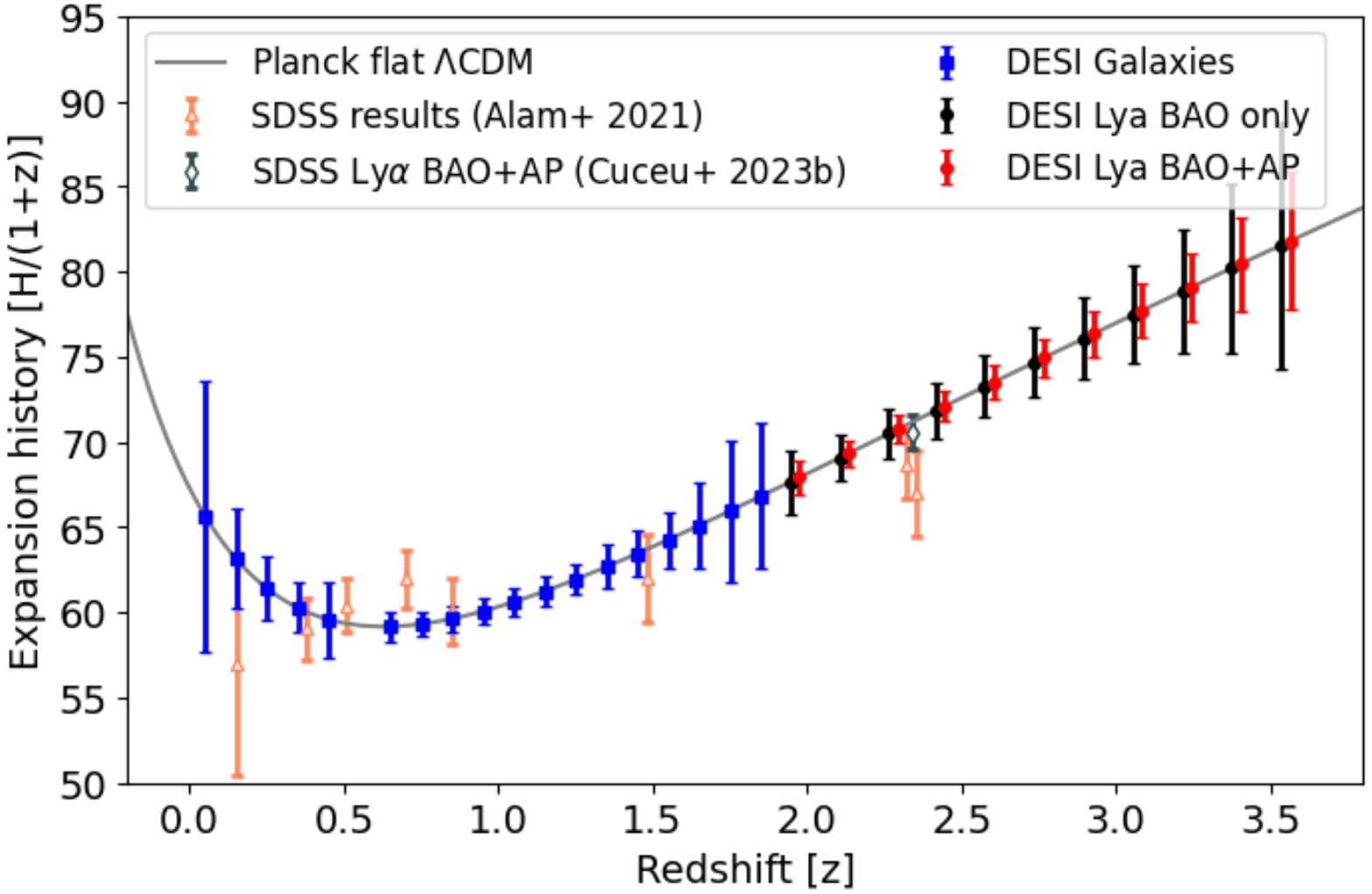
Cosmology from DESI Lyα forests

Forecast of DESI expansion history constraints



- DESI results from Survey Validation are out
- Currently working on analysing the first year of DESI data
- First cosmological measurements expected in 2024

Forecasts based on DESI Collaboration et al. (2016) and Cuceu et al. (2021), MNRAS, 506, 4, 2021

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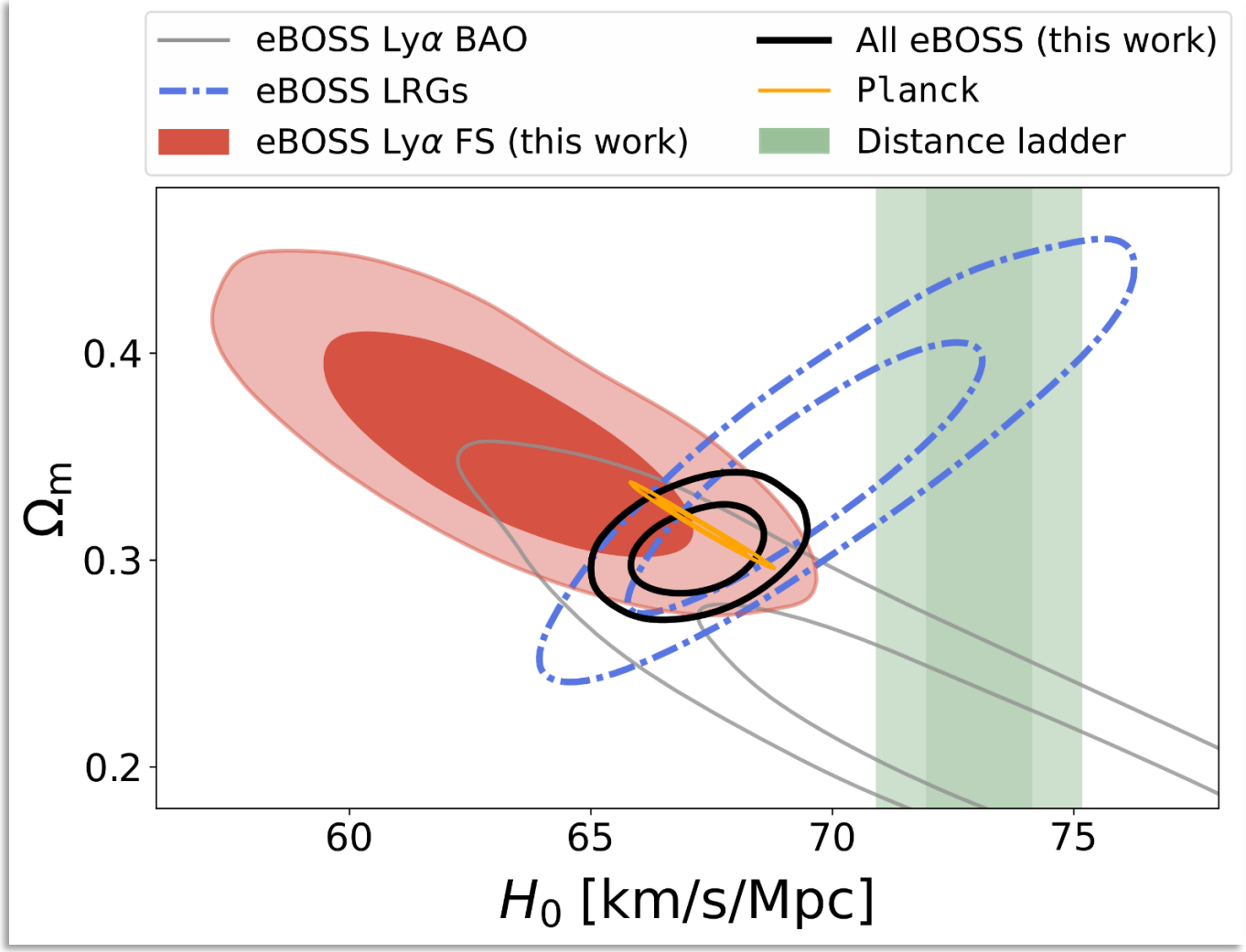
Measuring the Hubble constant



- In flat ΛCDM, Alcock-Paczynski → Ω_m
- Adding isotropic BAO → $H_0 r_d$
- Adding a prior on $\Omega_b h^2$ from Big Bang Nucleosynthesis (BBN) → H_0
- Lyα constraint: $H_0 = 63.2 \pm 2.5$ km/s/Mpc
- Full eBOSS: $H_0 = 67.2 \pm 0.9$ km/s/Mpc

From Cuceu et al. (2023b), PRL 130, 191003, 2023

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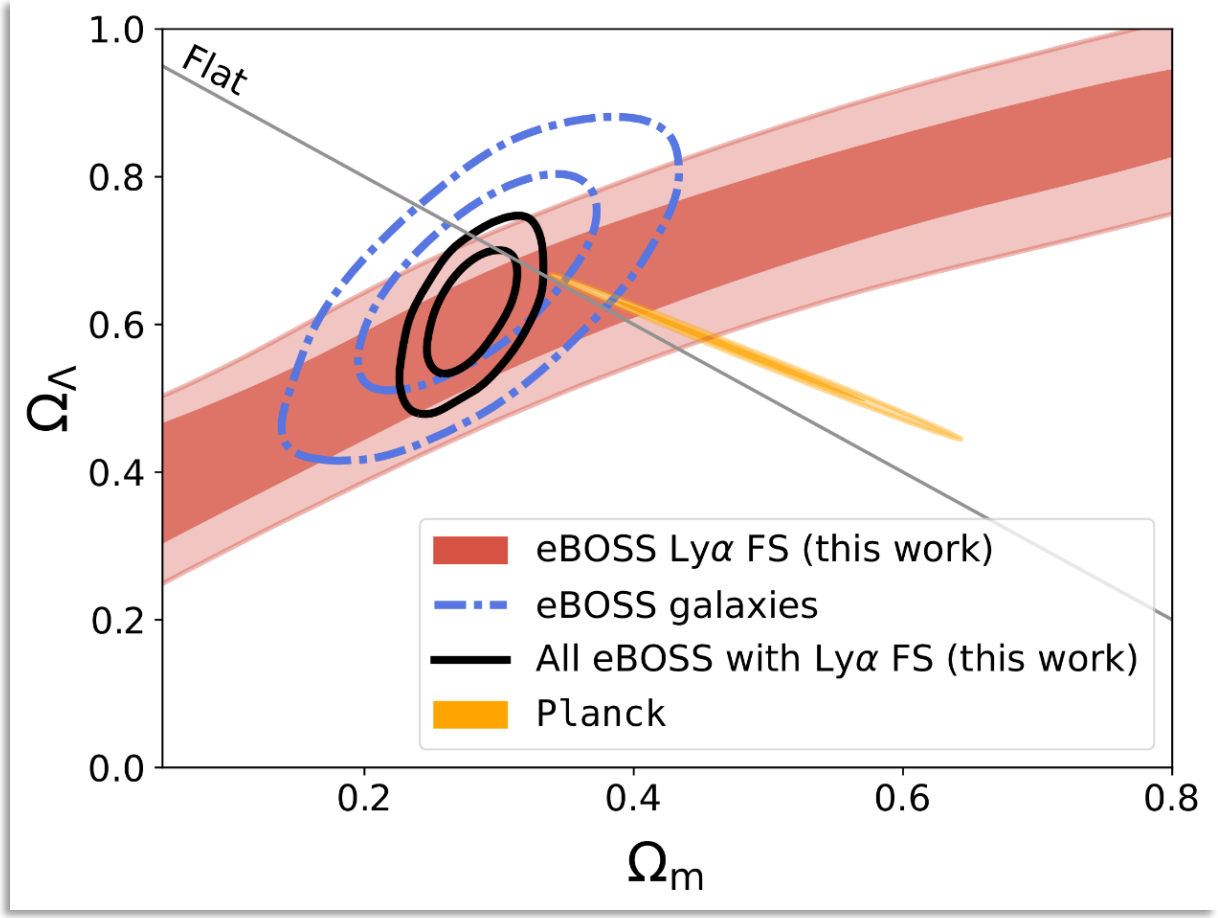
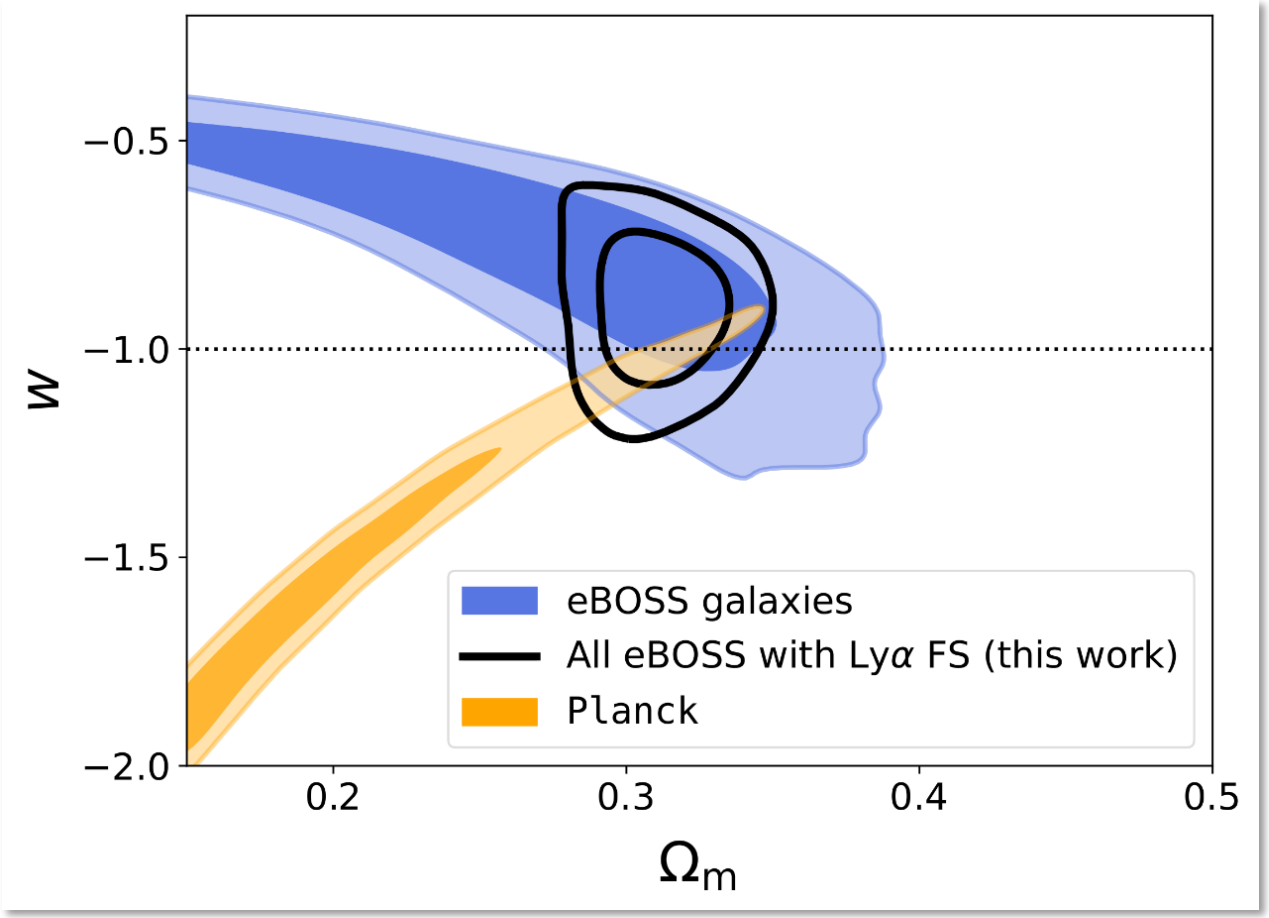
Measuring dark energy

Measuring dark energy with free curvature



Measuring dark energy equation of state



From Cuceu et al. (2023b), PRL 130, 191003, 2023

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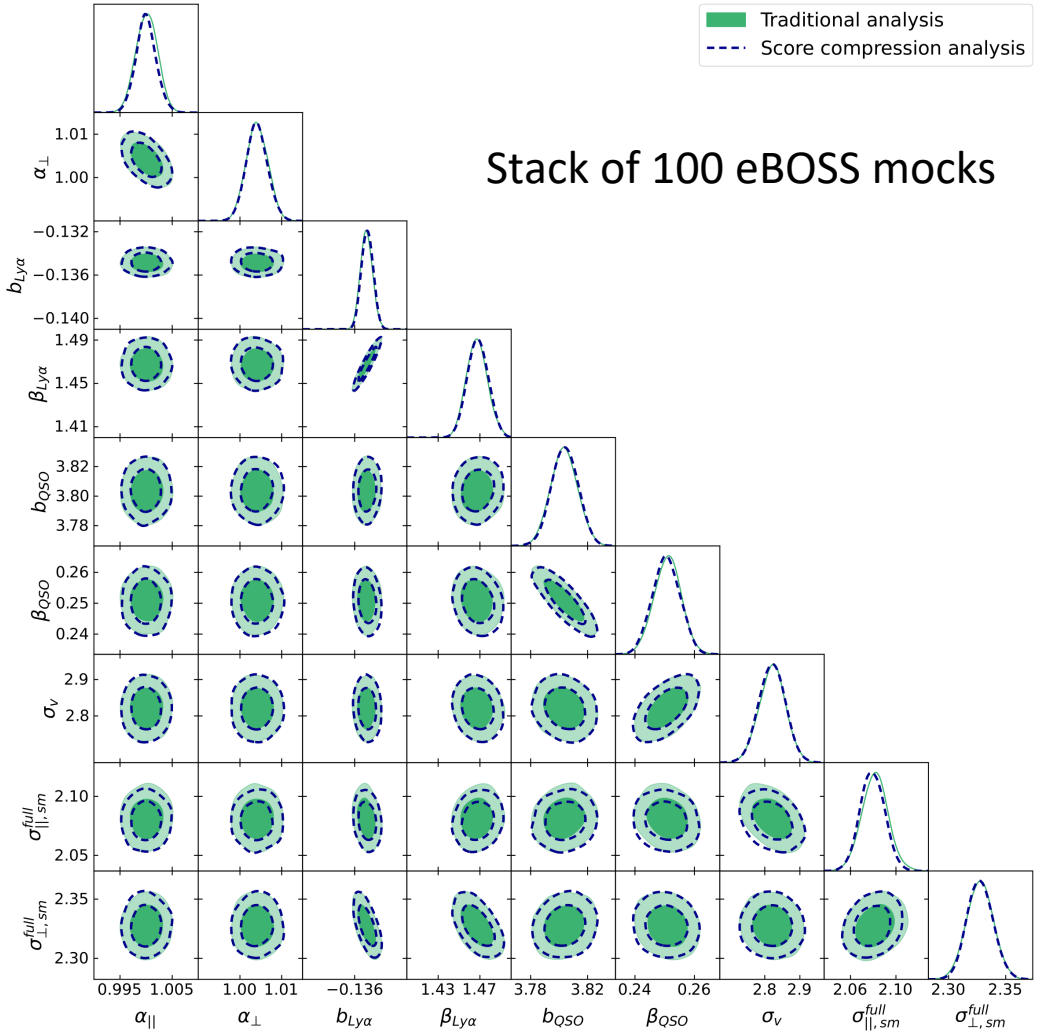
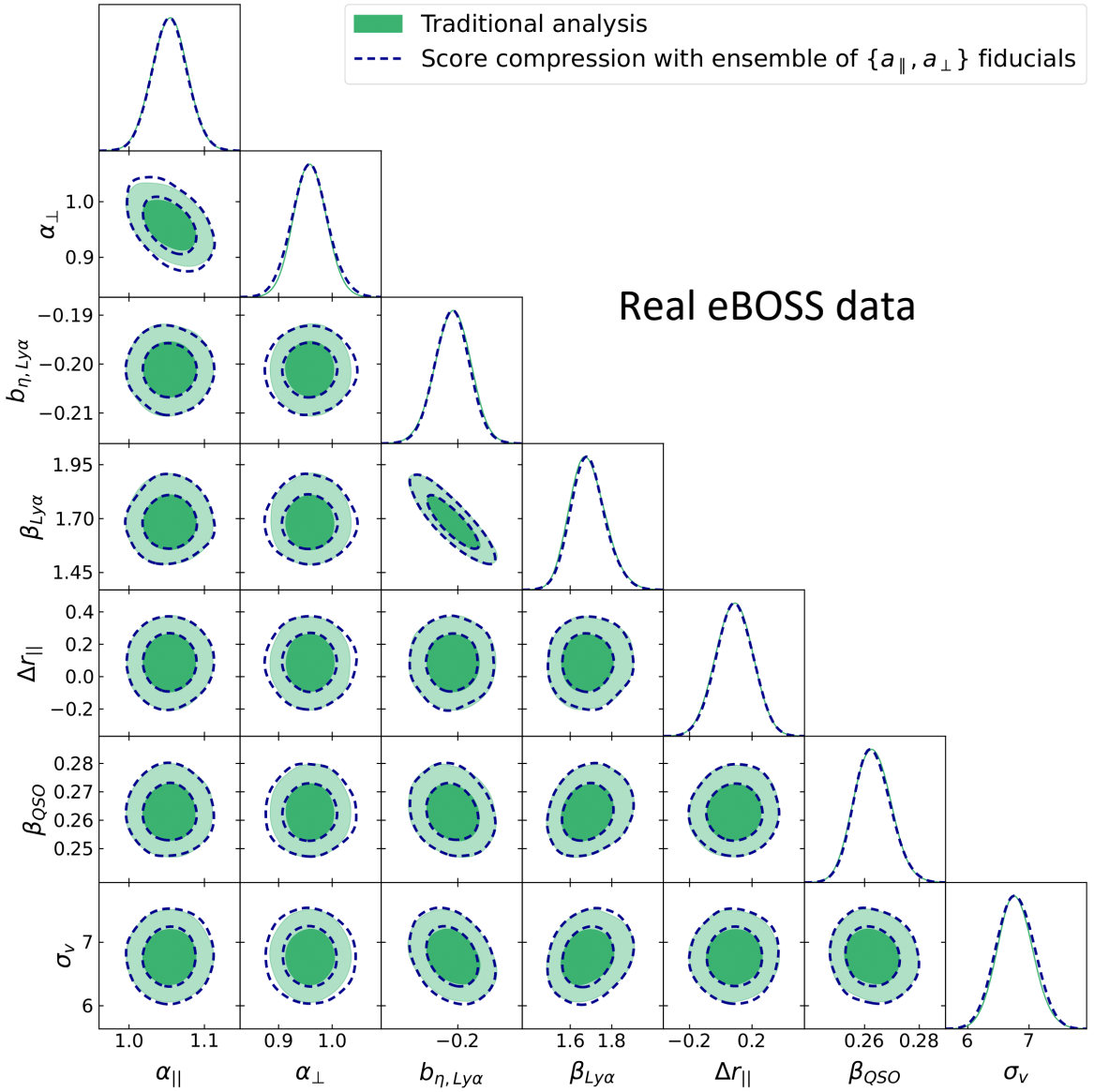
Optimal compression for Lyα forest analyses



Stack of 100 eBOSS mocks



Real eBOSS data

From Gerardi, Cuceu et al. 2023 (2309.13164)

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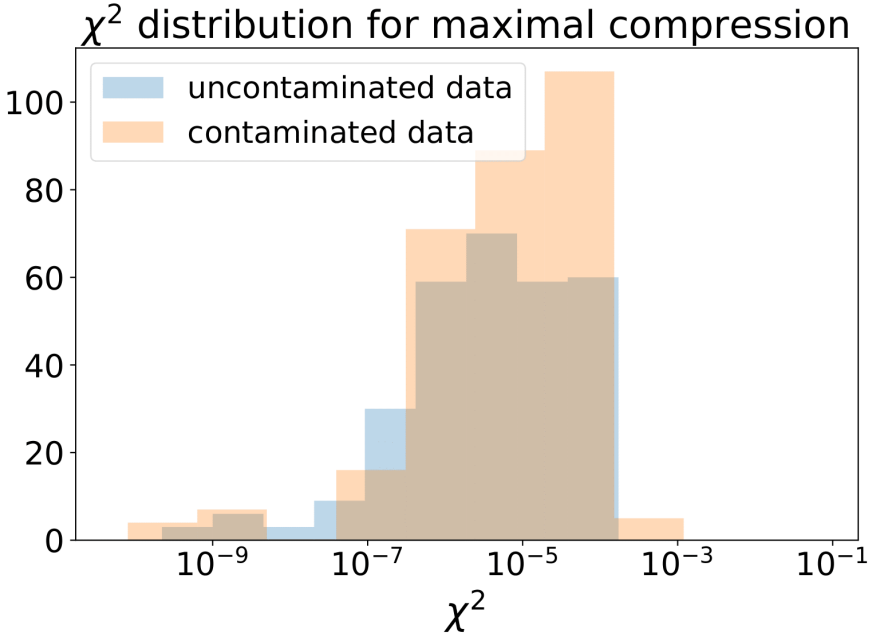
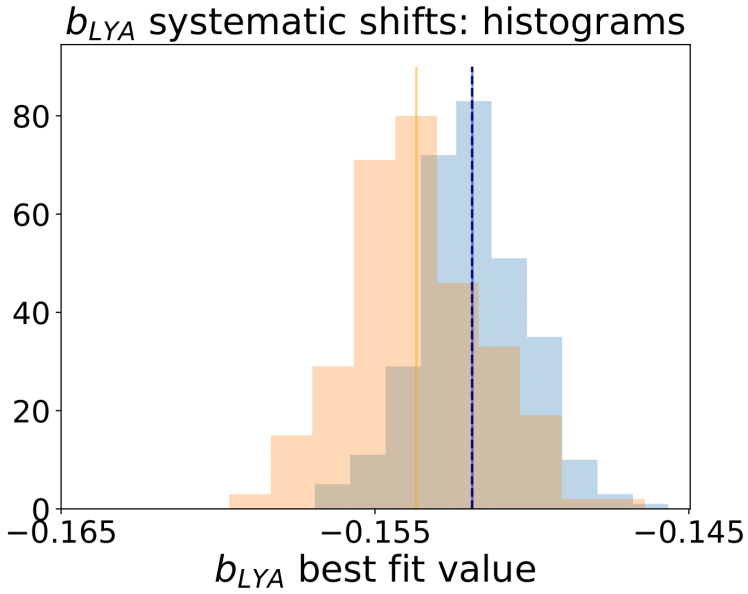
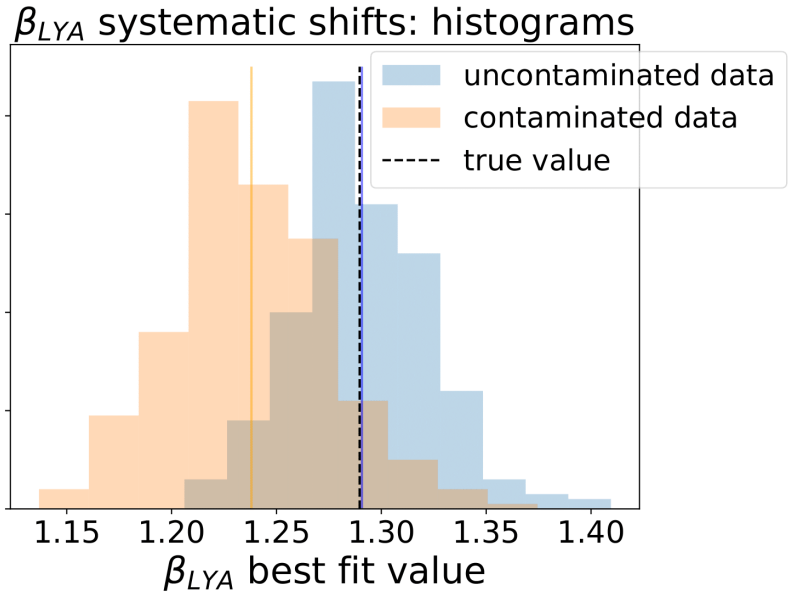
Optimal compression for Lyα forest analyses







- Compress data to a smaller subset of parameters that do not capture all effects present
- Bestfit χ^2 is identical!
- Instead, this shows up as a bias in measured parameters

From Gerardi, Cuceu et al. 2023 (2309.13164)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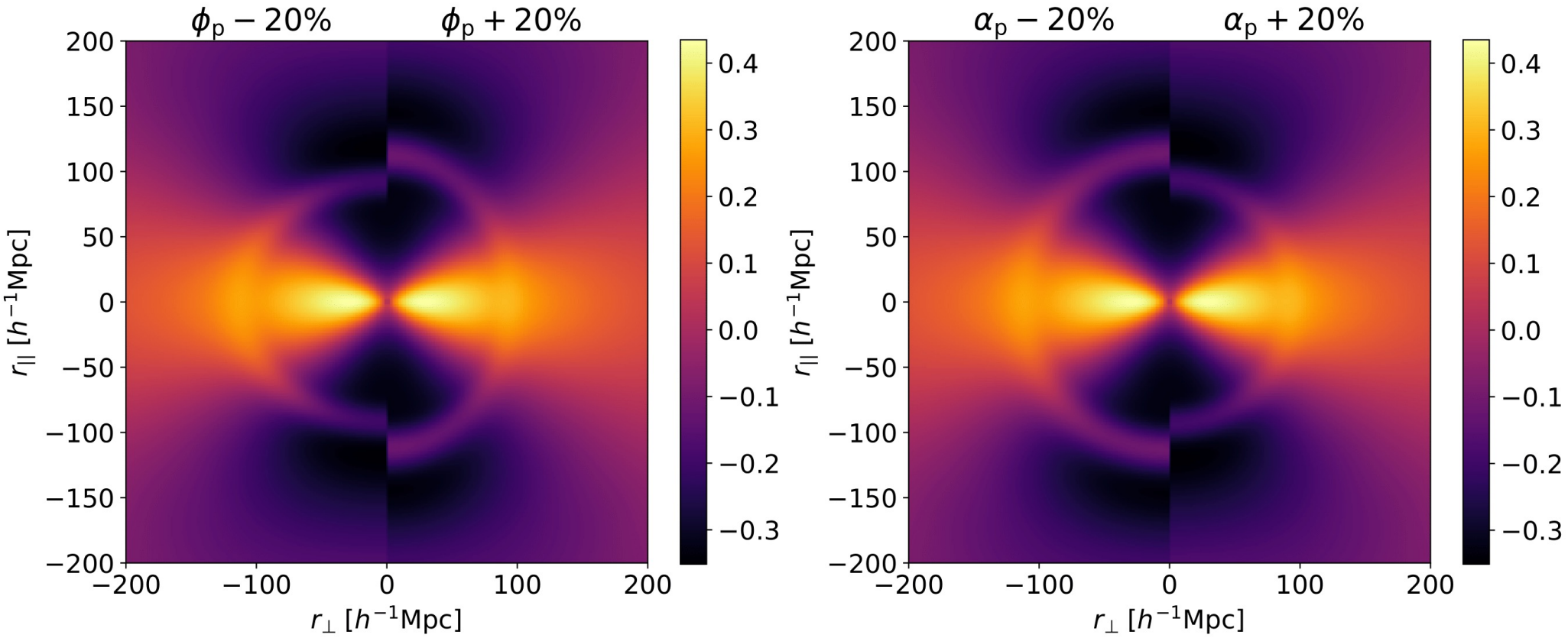
Rescaling the peak component



Cuceu et al. (2021), MNRAS 506, 4, 2021

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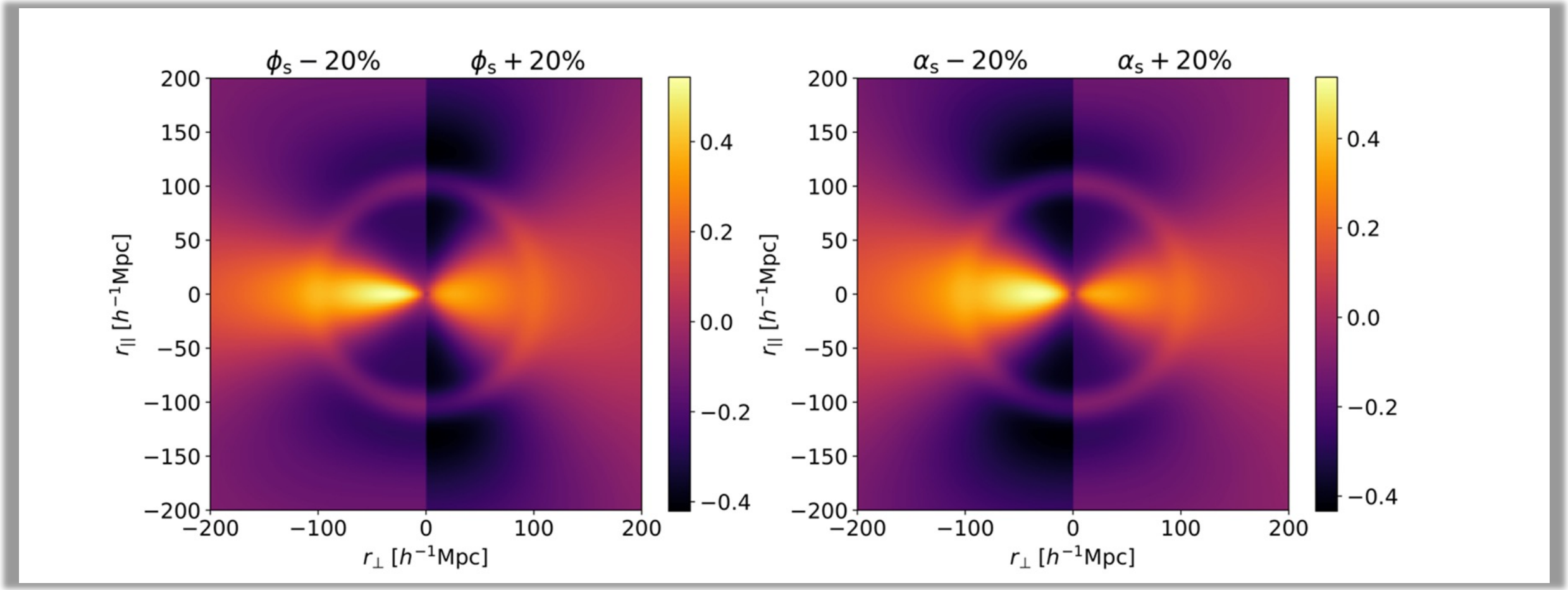
Rescaling the smooth component



Cuceu et al. (2021), MNRAS 506, 4, 2021

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Why no Lyα RSD measurement yet?

- Linear theory terms:

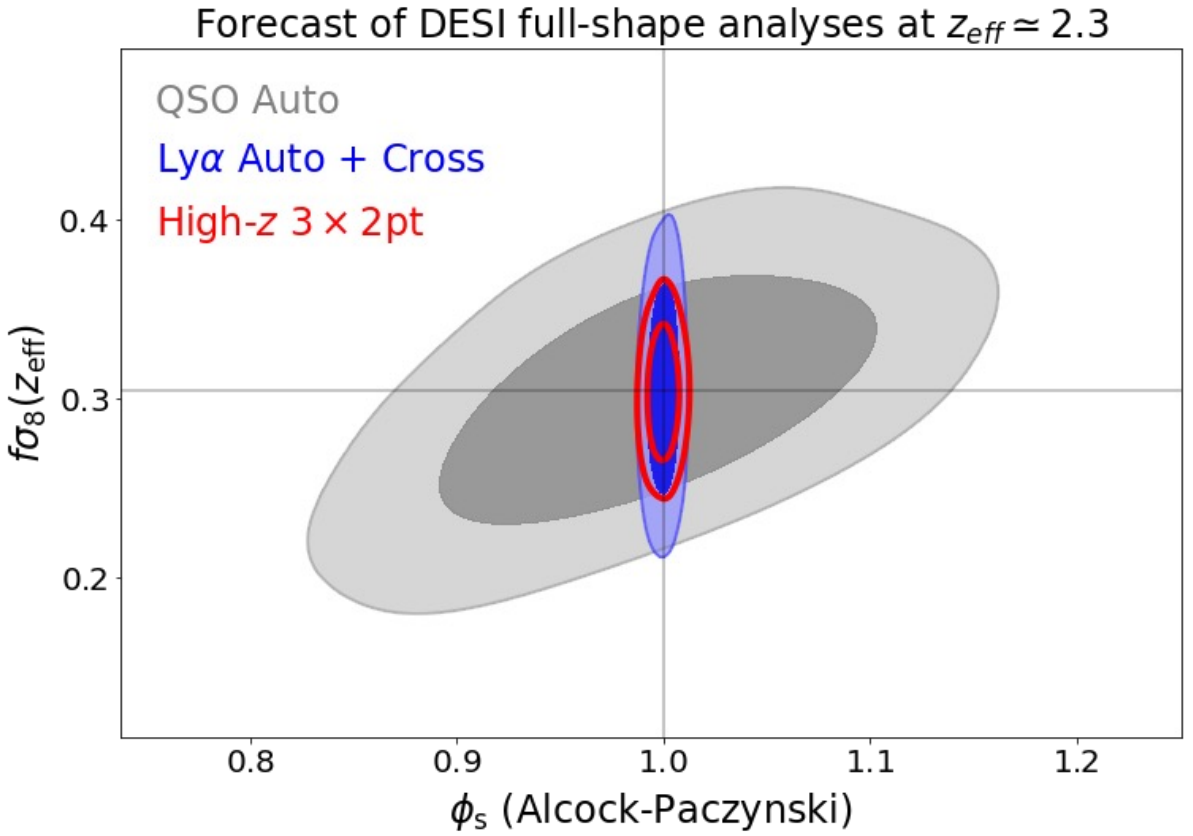
Lyα x Lyα: $P(k,\mu,z) = \left(b_F + b_{\eta,F} f\mu^2\right)^2 P(k,z)$

Lyα x QSO: $P(k,\mu,z) = \left(b_F + b_{\eta,F} f\mu^2\right)\left(b_Q + f\mu^2\right) P(k,z)$

QSO x QSO: $P(k,\mu,z) = \left(b_Q + f\mu^2\right)^2 P(k,z)$

- Lyα forest ⟶ growth rate (f) degenerate with unknown velocity divergence bias ($b_{\eta,F}$).
- Joint analysis of Lyα x Lyα and Lyα x QSO would be able to measure f.

High-z 3×2pt
- Lyα x Lyα
- Lyα x QSO
- QSO x QSO



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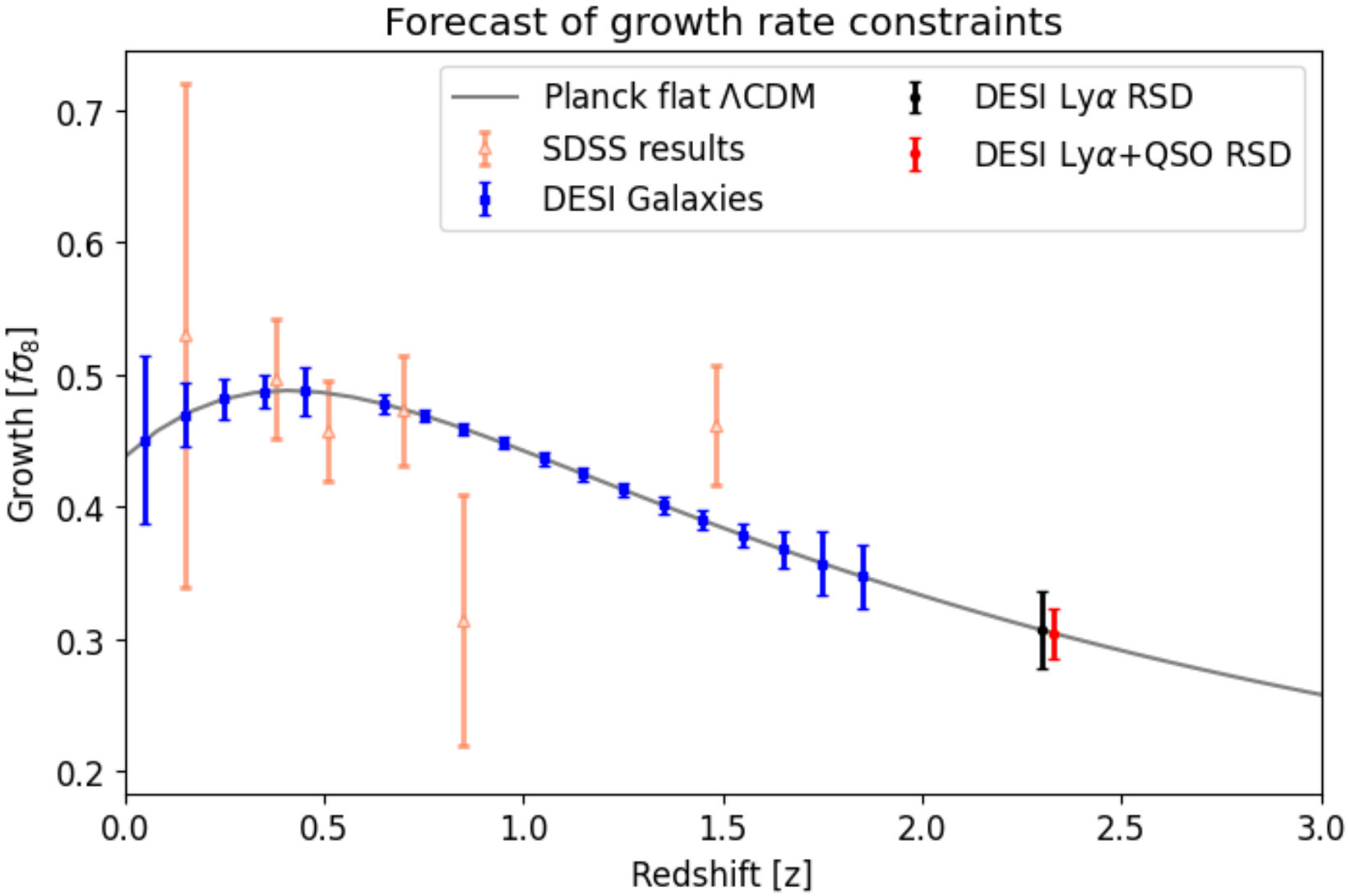
Cosmology from DESI Lyα forests



Forecasts based on DESI Collaboration et al. (2016) and Cuceu et al. (2021), MNRAS, 506, 4, 2021

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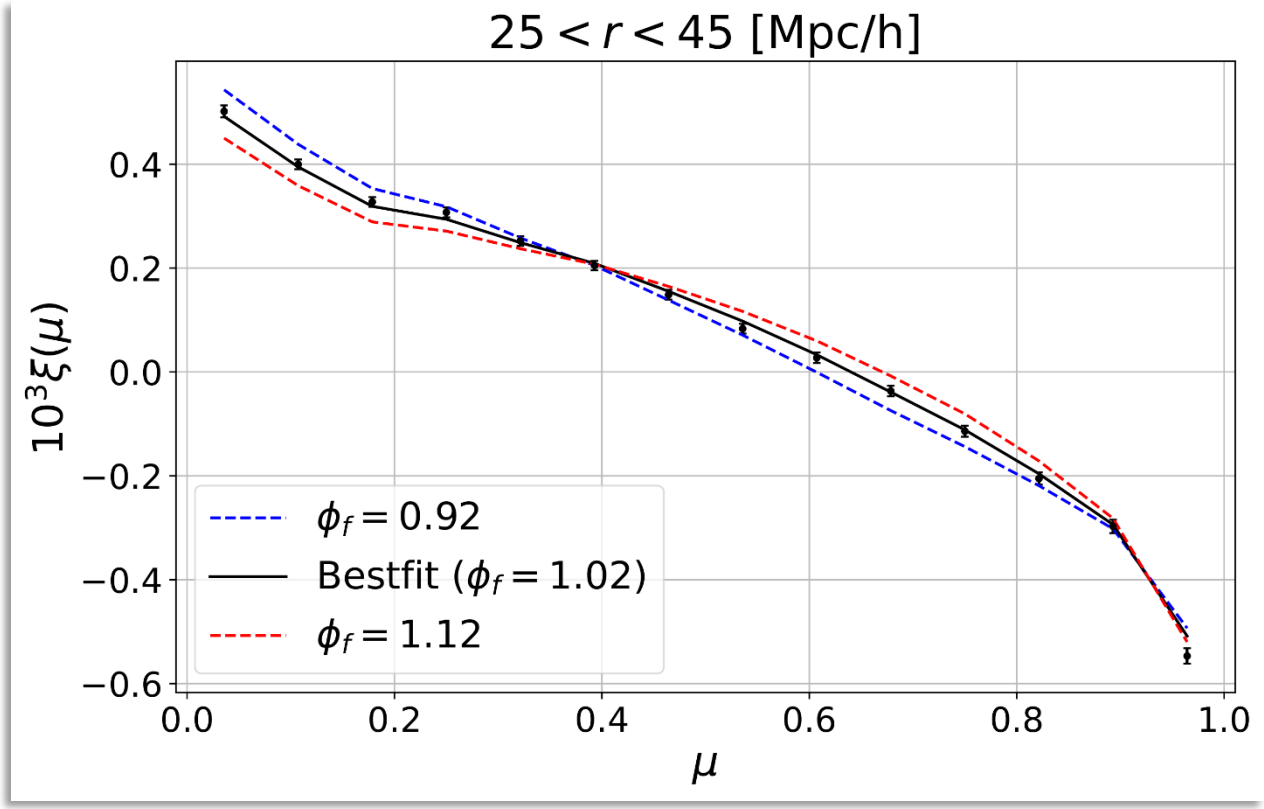
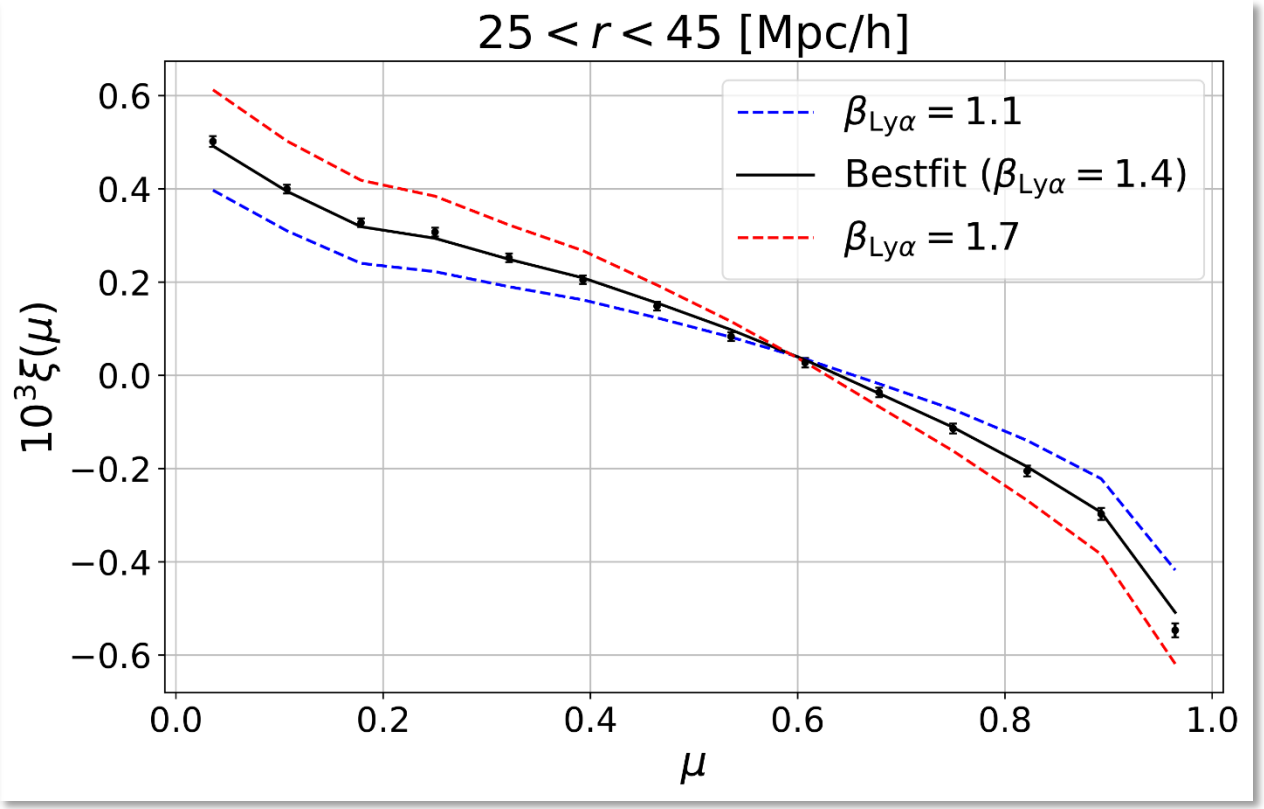
Alcock-Paczyński vs RSD

Changing Alcock-Paczyński



Changing RSD



Lyα auto-correlation function compressed into a shell in isotropic separation r, and shown as a function of the line-of-sight angle μ.

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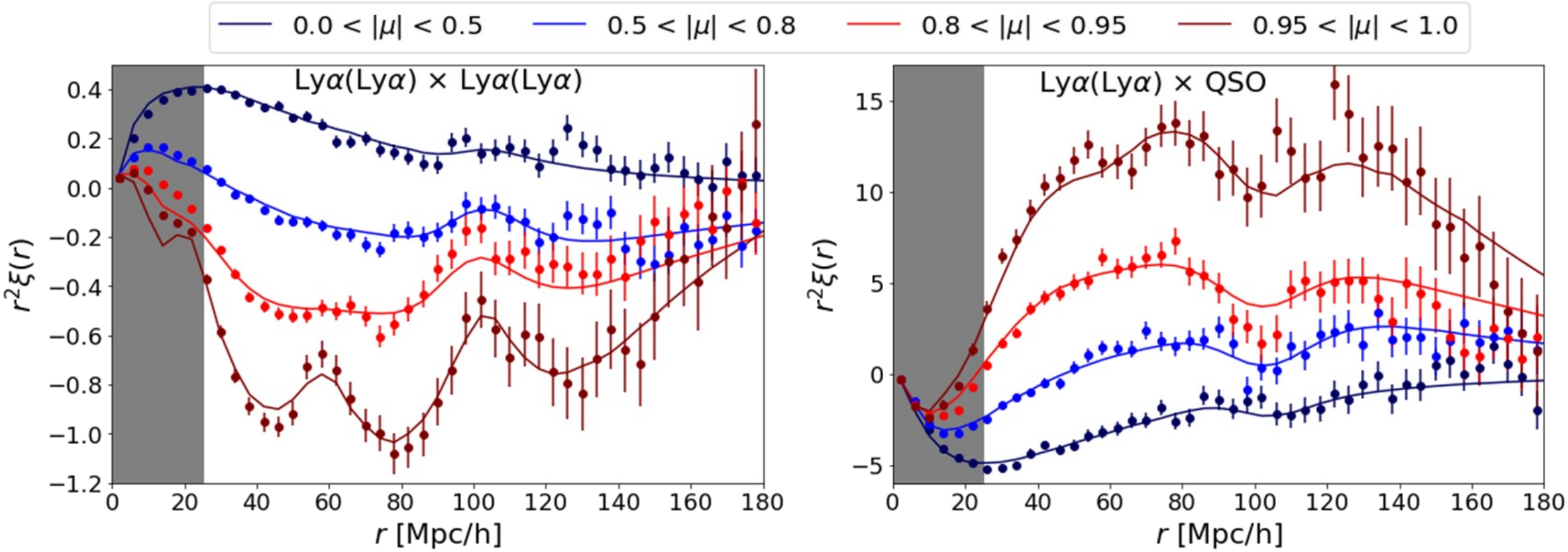
eBOSS data and best-fit model



From Cuceu et al. (2023b), PRL 130, 191003, 2023