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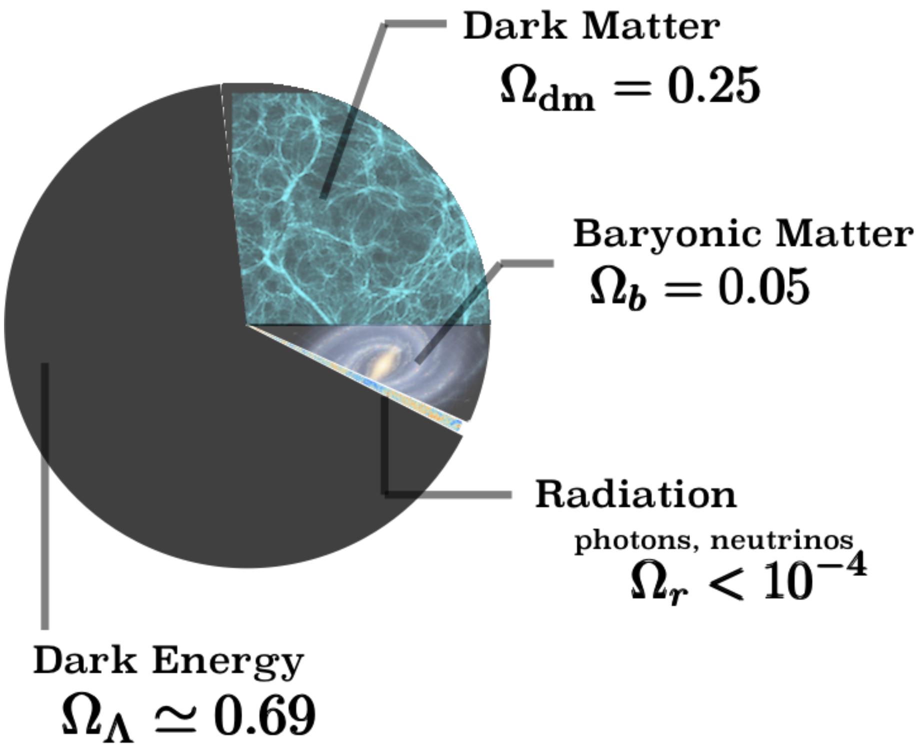
Clustering analysis with SDSS-IV eBOSS quasars

DEX XV meeting
Royal Observatory – Edinburgh
January 8th 2019

Introduction
The ΛCDM model

Today energy content



Unknown of interest

Unknown 1: Dark matter
Cold, very weakly interactive particles with broad mass range:

25% $10^{-22}eV < m_{DM} < 10\ M_\odot$

Baryonic matter
5% Also called ordinary matter
Stars, planets, dust, gaz, us...

Unknown 2: Dark energy
Assumed to be a cosmological constant Λ in the standard model

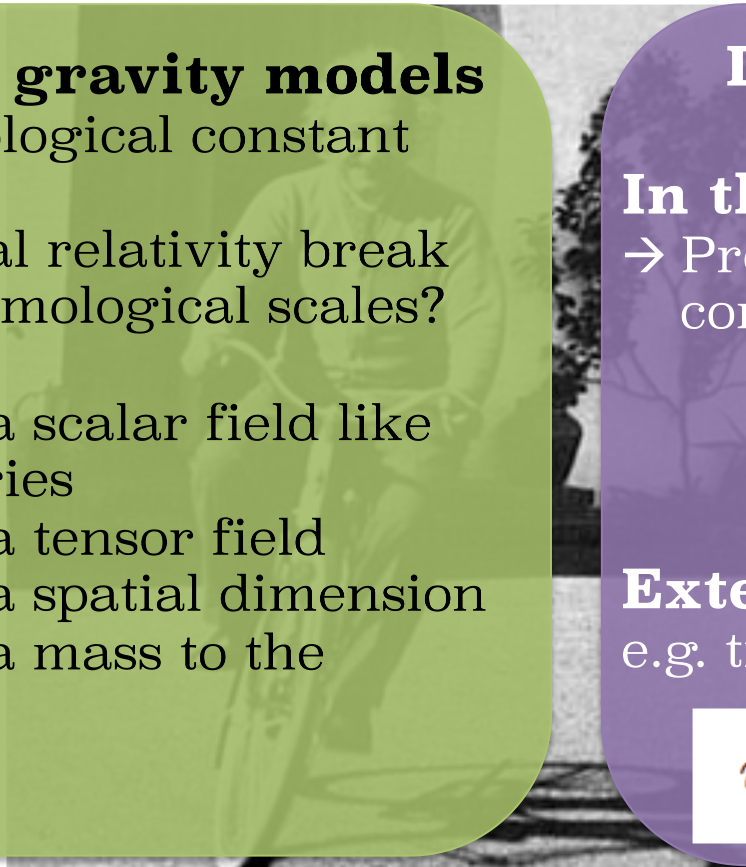
70% $$w = \frac{p_{DE}}{\rho_{DE}} = -1$$

Introduction
Dark energy or modifications of gravity?

Einstein 1915

Geometry — Energy content — Cosmological constant Λ

$$\boxed{R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R} = \frac{8\pi G}{c^4} \boxed{T_{\mu\nu}} + \boxed{\Lambda} g_{\mu\nu}$$



Modified gravity models
→ No cosmological constant

Does general relativity break down at cosmological scales?

- Can add a scalar field like ***f(R)*** theories
- Can add a tensor field
- Can add a spatial dimension
- Can add a mass to the graviton
- …

Dark energy models

In the ΛCDM model
→ Properties of dark energy are constant with time and space

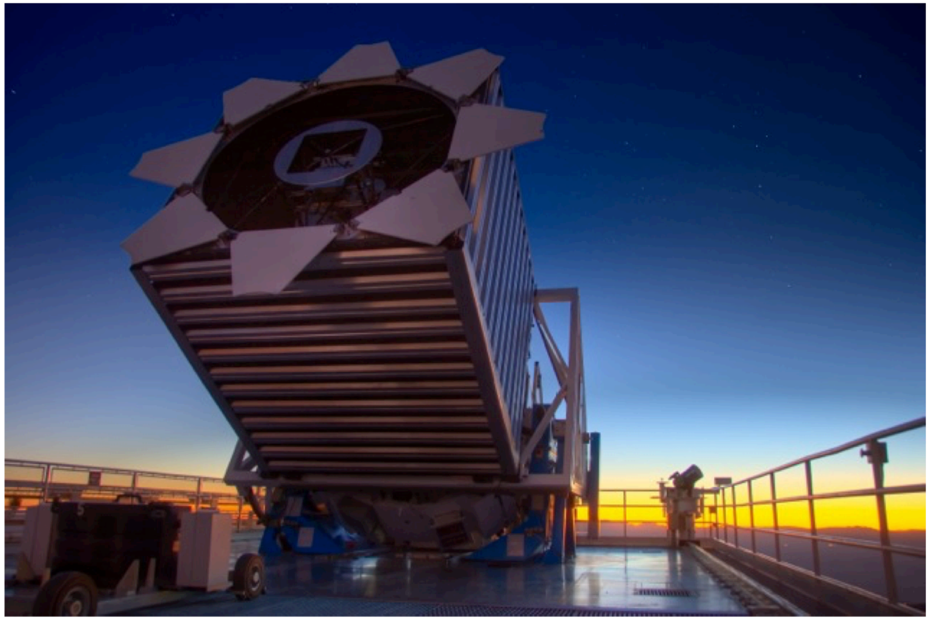
$$w = \frac{p_{DE}}{\rho_{DE}} = -1$$

Extensions to ΛCDM
e.g. time-dependent dark energy

$$w(a) = w_0 + w_a(1-a)$$

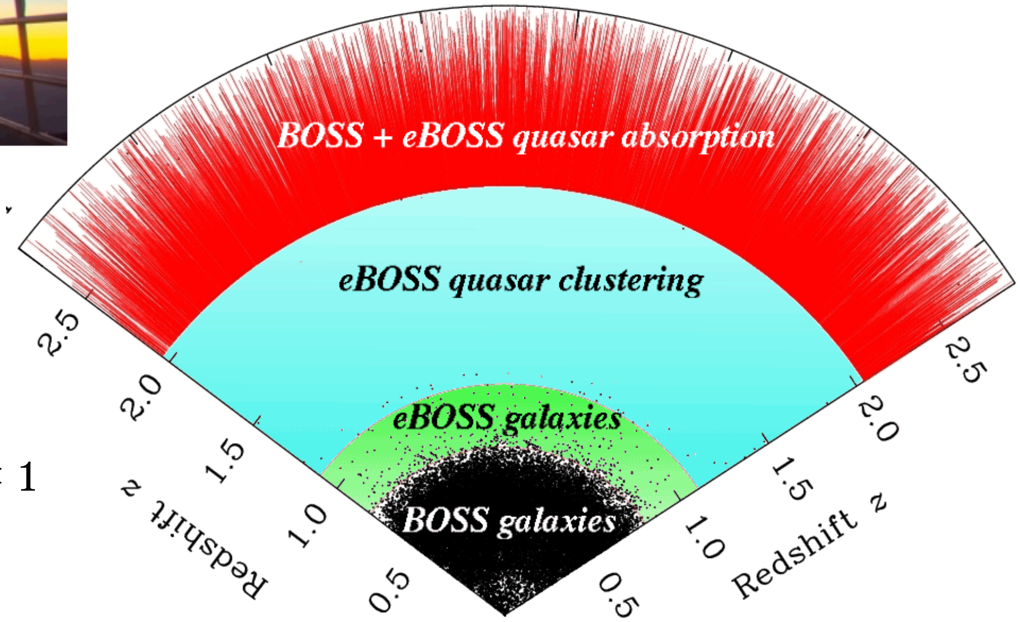
Clustering analysis

Data: The SDSS-IV eBOSS quasars



Sloan Digital Sky Survey (SDSS)

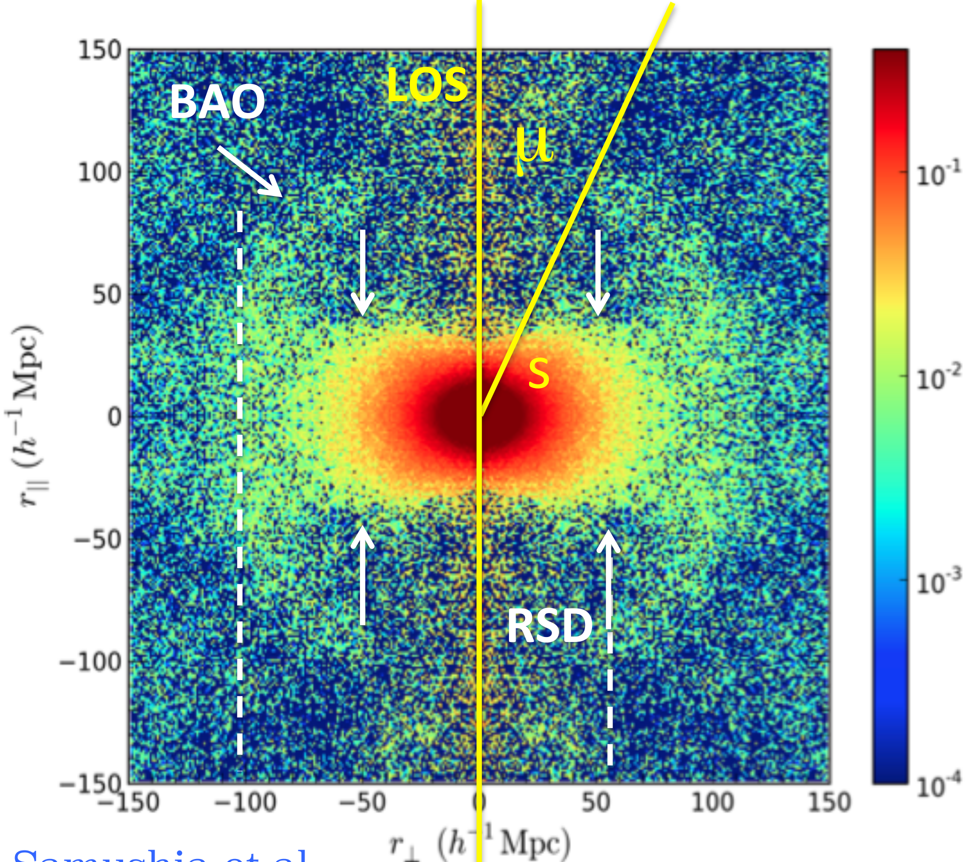
- 2.5 m telescope at Apache Point Observatory, USA
- Operating since 2000
- Baryon Oscillation Spectroscopic Survey (BOSS): 2008-2014
- **extended BOSS (eBOSS) 2014-2019**



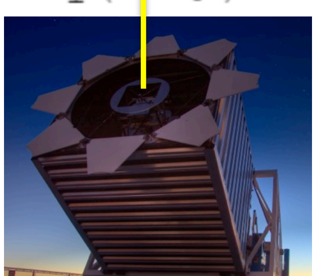
Tracers for eBOSS

- Luminous Red Galaxies between $0.6 < z < 1$
- Emission Line Galaxies (ELG, star-forming galaxies) between $0.6 < z < 1$
- **Quasars (active galaxies with SMBH) between $0.8 < z < 2.2$**

Clustering analysis
Observable: 2-point correlation function ξ(r)



Samushia et al. (2014)

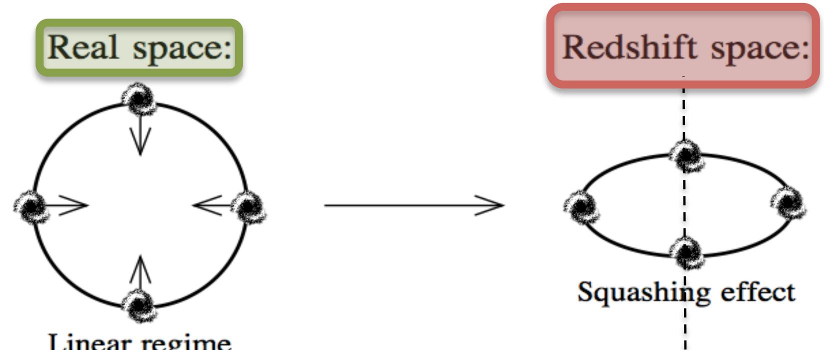


$$\xi(r) = \langle \delta(\mathbf{x})\delta(\mathbf{x}+\mathbf{r})\rangle$$

- **BAO** (Baryon Acoustic Oscillations): characteristic scale between 2 galaxies → **standard ruler: H, D_A**
- **RSD** (Redshift Space Distortions):

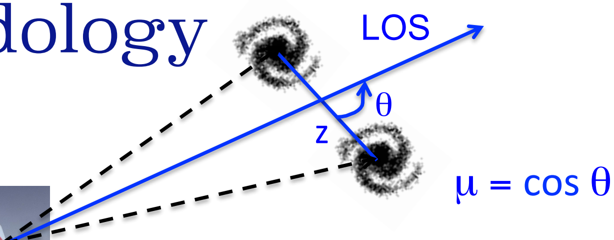
Peculiar velocity along the LOS

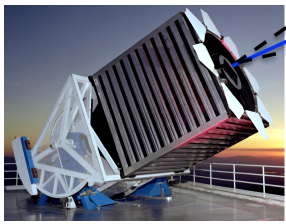
$$\boxed{\mathbf{s}} = \boxed{\mathbf{r}} + \boxed{u_z}(\mathbf{r})\hat{\mathbf{z}}$$



Direct test of GR: $\boxed{f(a) = \Omega_m(a)^{\gamma=0.55}}$

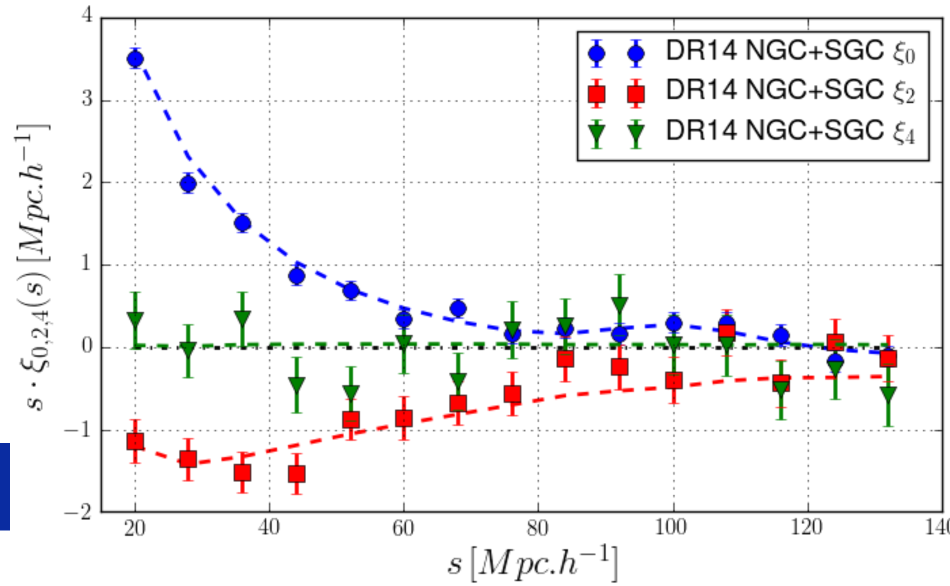
Clustering analysis
Methodology





I) Catalogue (ra, dec, z, weight)

II) Correlation function ξ(s,μ)



III) BAO-only analysis: $\xi_0(s)$

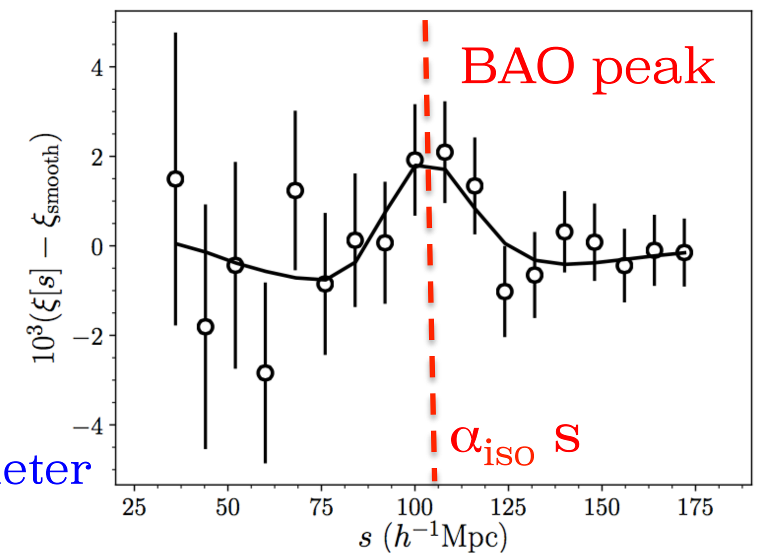
Isotropic shift: $\alpha_{\rm iso} = \dfrac{D_V(z) r_s^{\rm fid}}{D_V^{\rm fid}(z) r_s}$

Spherically-averaged BAO distance:

$$D_V(z) = \left[cz(1+z)^2 \boxed{H(z)}^{-1} \boxed{D_A^2(z)}\right]^{1/3}.$$

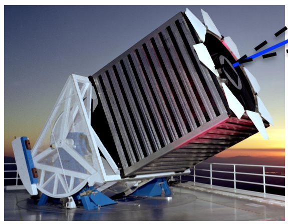
Expansion rate

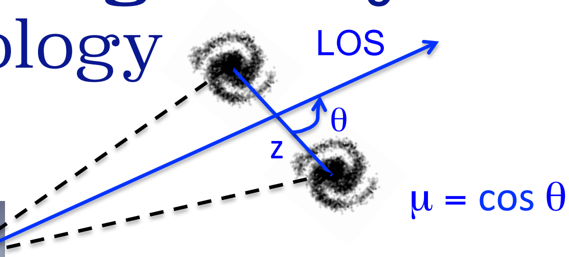
Angular diameter distance



Clustering analysis

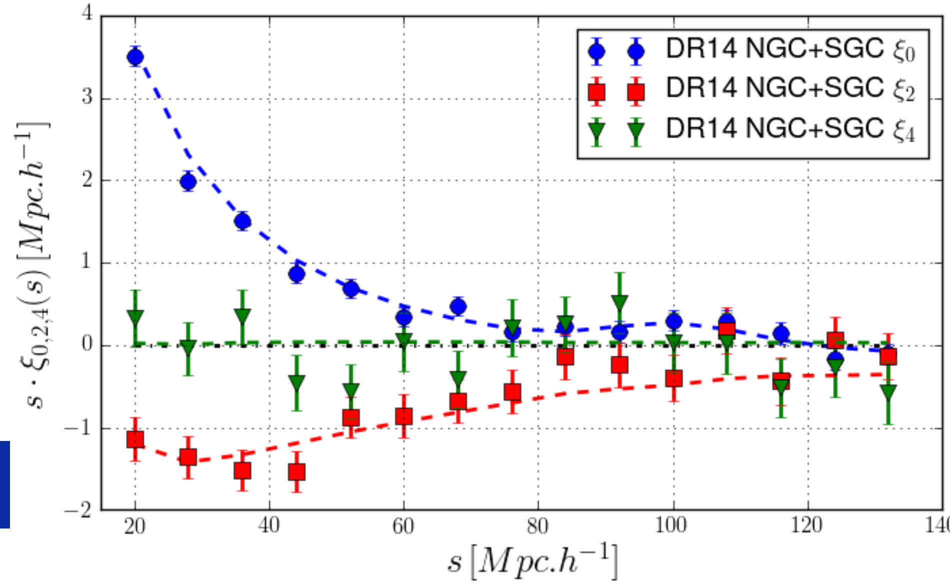
Methodology





I) Catalogue (ra, dec, z, weight)

II) Correlation function $\xi(s,\mu)$



III) BAO-only analysis: $\xi_0(s)$

III) Full-Shape analysis: $\xi_{0,2,4}(s)$

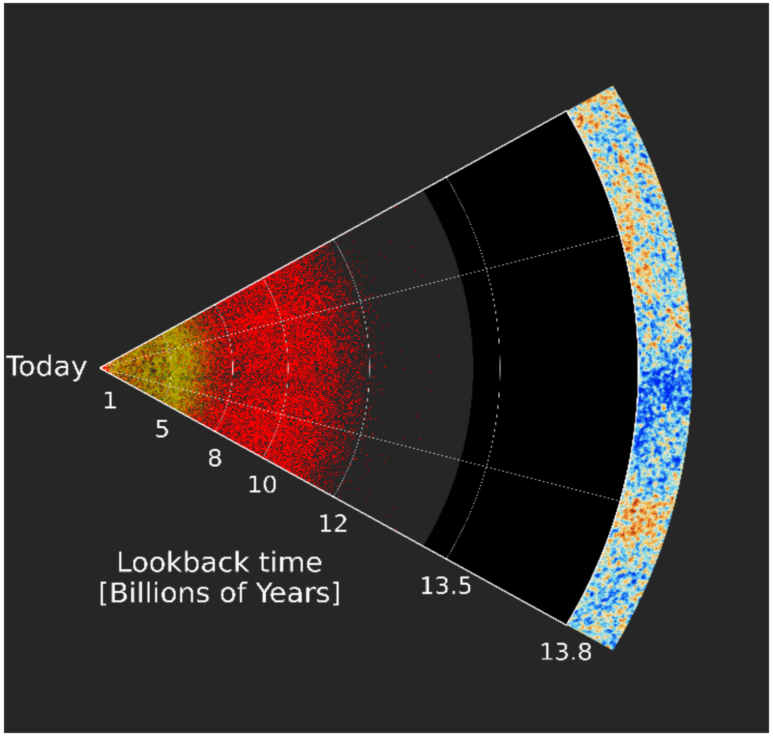
$$\alpha_{\parallel} = \frac{H^{\rm fid}(z) r_s^{\rm fid}}{H(z) r_s}, \qquad \alpha_{\perp} = \frac{D_{\rm A}(z) r_s^{\rm fid}}{D_{\rm A}^{\rm fid}(z) r_s}$$

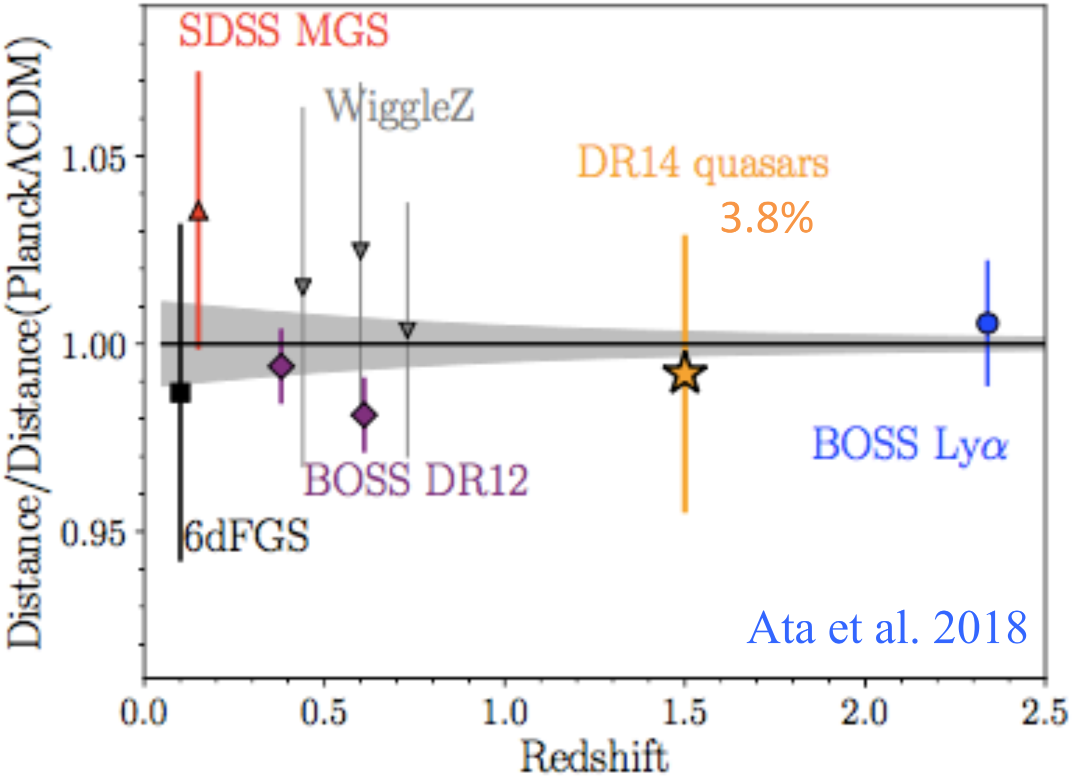
Growth rate of structures
$$f(a) = \Omega_m(a)^{\gamma=0.55}$$

BAO-only analysis

Results : 1st detection of BAO between $1 < z < 2$

+ SDSS Press release

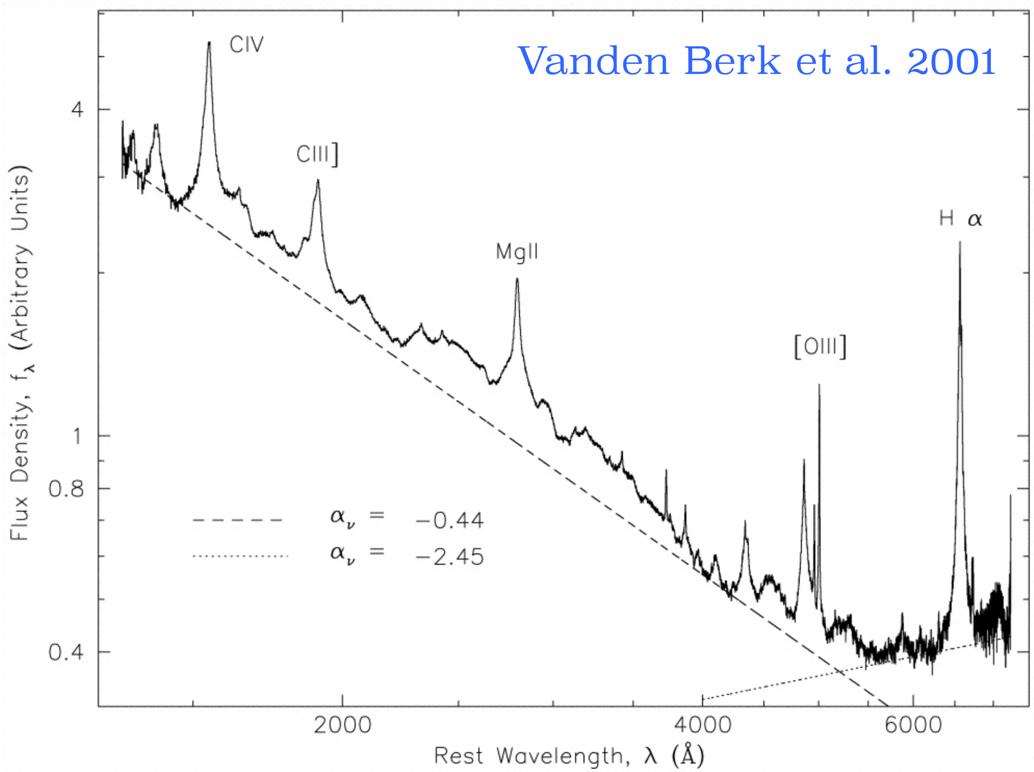




→ 3.8% precision on expansion rate of the universe at z=1.52
→ In agreement with ΛCDM model using Planck data

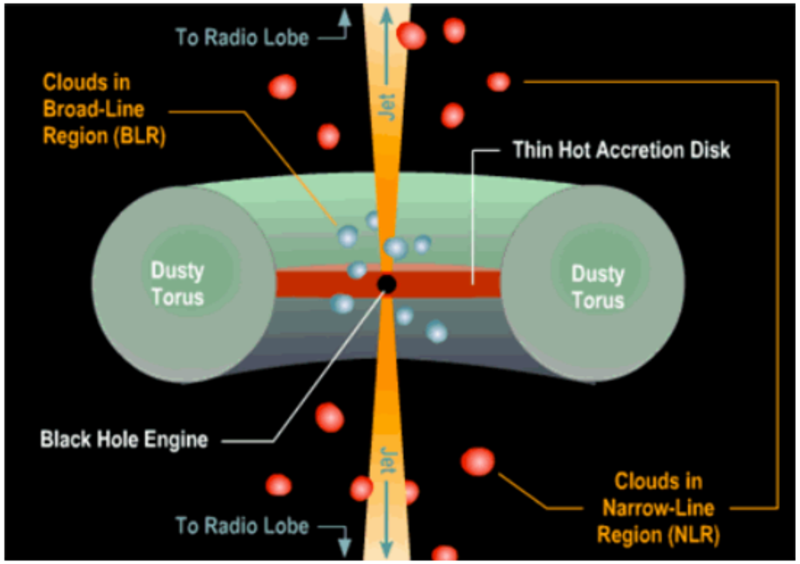
Full-shape analysus

Quasar redshift uncertainties



Quasar physics

- Continuum
- Broad emission line: MgII, CIV
- Narrow emission line: [O III], [O II]



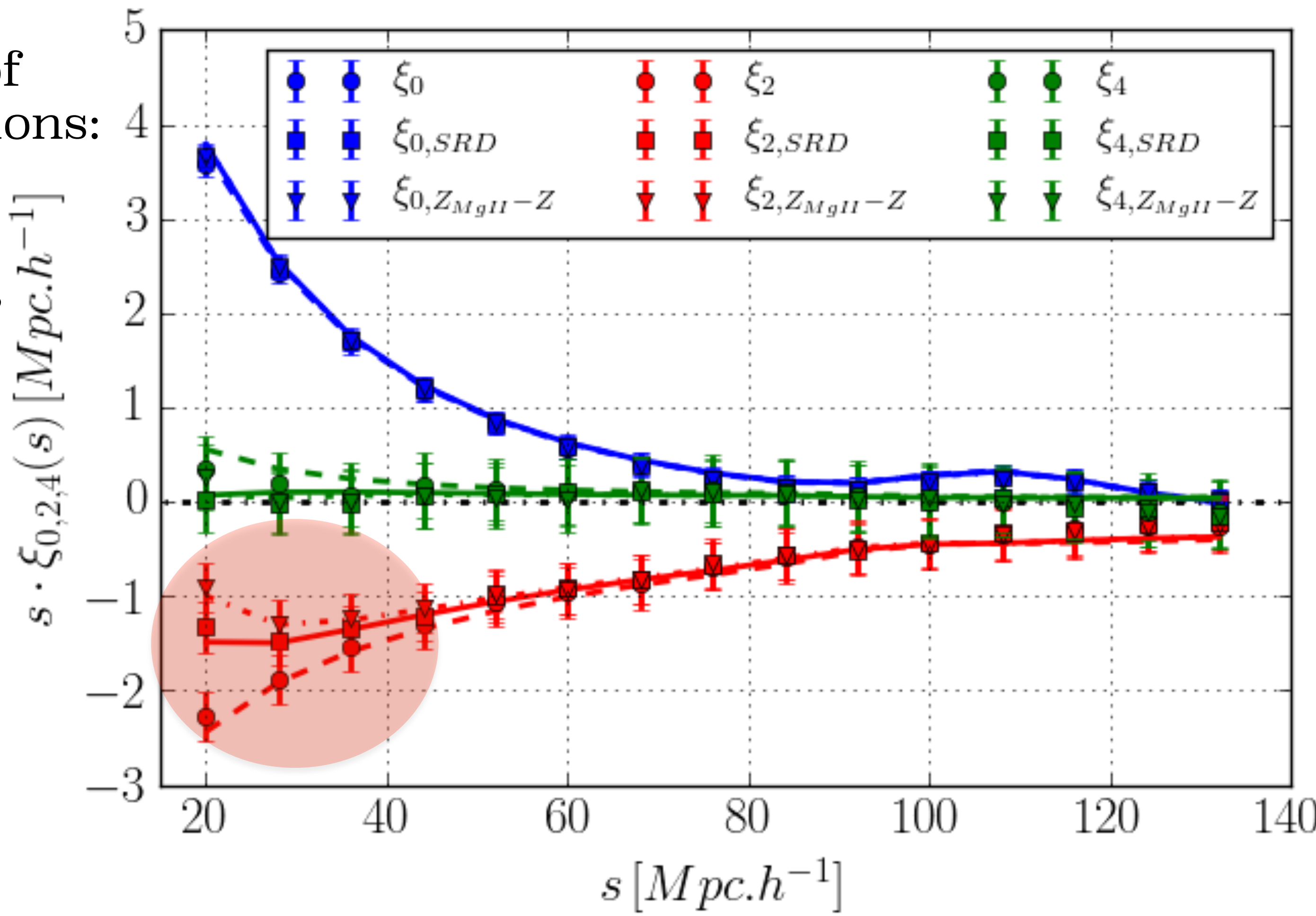
Redshift estimates in the DR14 quasar catalog

z_{temp} z_{VI} z z_{MgII}

→ Scatter 'z_{MgII} - z' gives an estimate of the pipeline redshift resolution

Full-shape analysis
Modeling systematics: quasar redshift uncertainties

- Implementation of redshift distributions:
  - ■ Gaussian SRD
  - ▼ Physical ‘z_{MgII} - z’



→ Quadrupole mainly affected on scales below 50 h^{-1}Mpc

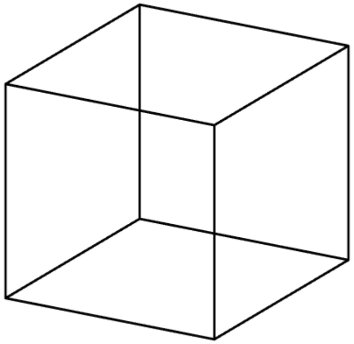
Full-shape analysis
Study of systematics

Statistical precision
$f\sigma_8$: 0.070
α_{par}: 0.070
α_{perp}: 0.050

Modeling systematics

Using mock catalogues from N-body simulation
→ Redshift uncertainties: 40% effect

$$\Delta f\sigma_8 = 0.033 \quad \Delta\alpha_{||} = 0.038 \quad \Delta\alpha_{\perp} = 0.006$$



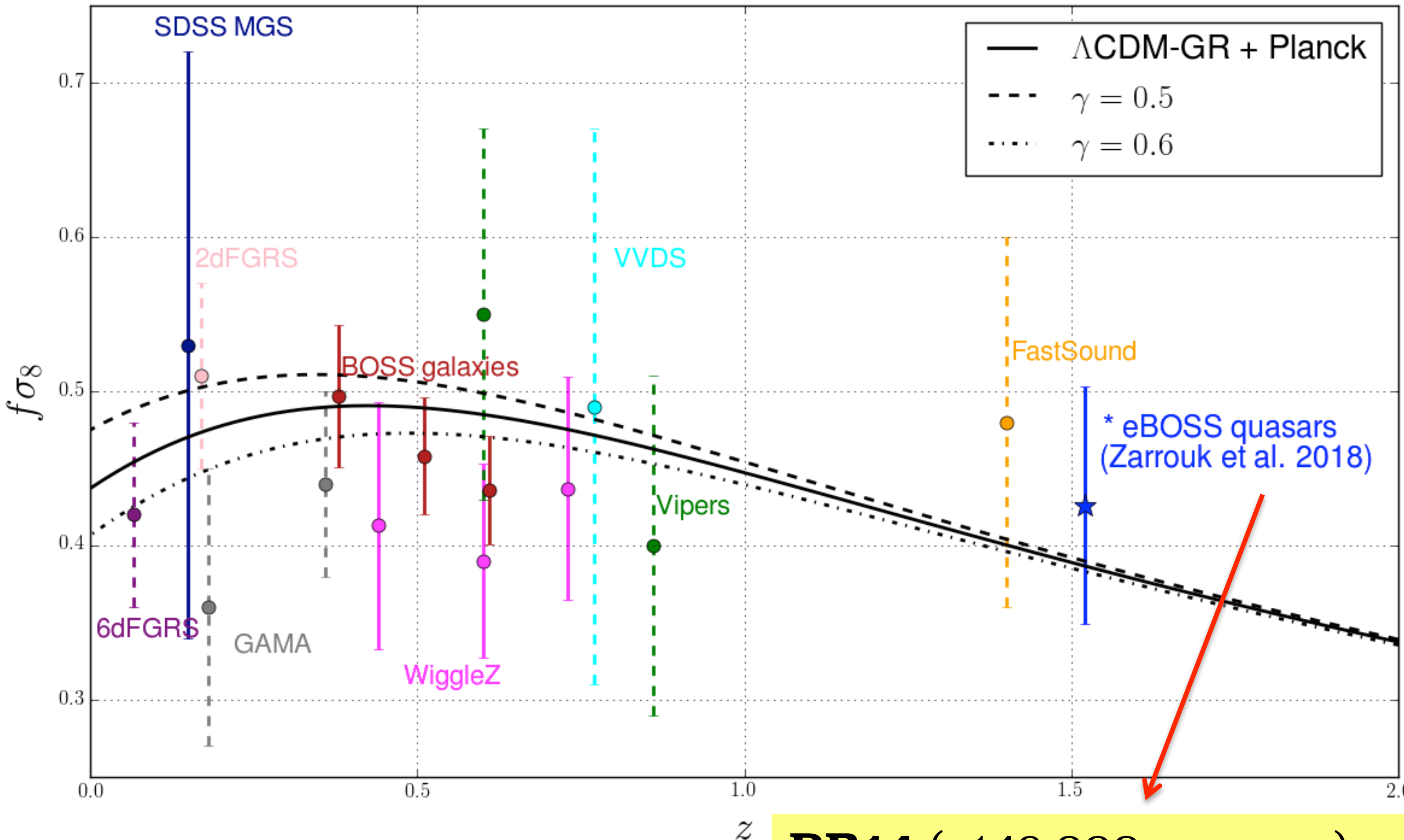
Dark matter halos hosting eBOSS quasars: $\mathbf{M_{mean} \sim 10^{12.5}\ h^{-1}M_{\odot}}$

Observational systematics

- Related to observing conditions (depth, Galactic extinction)
- Related to instrumental limitations (close-pairs and redshift failures)

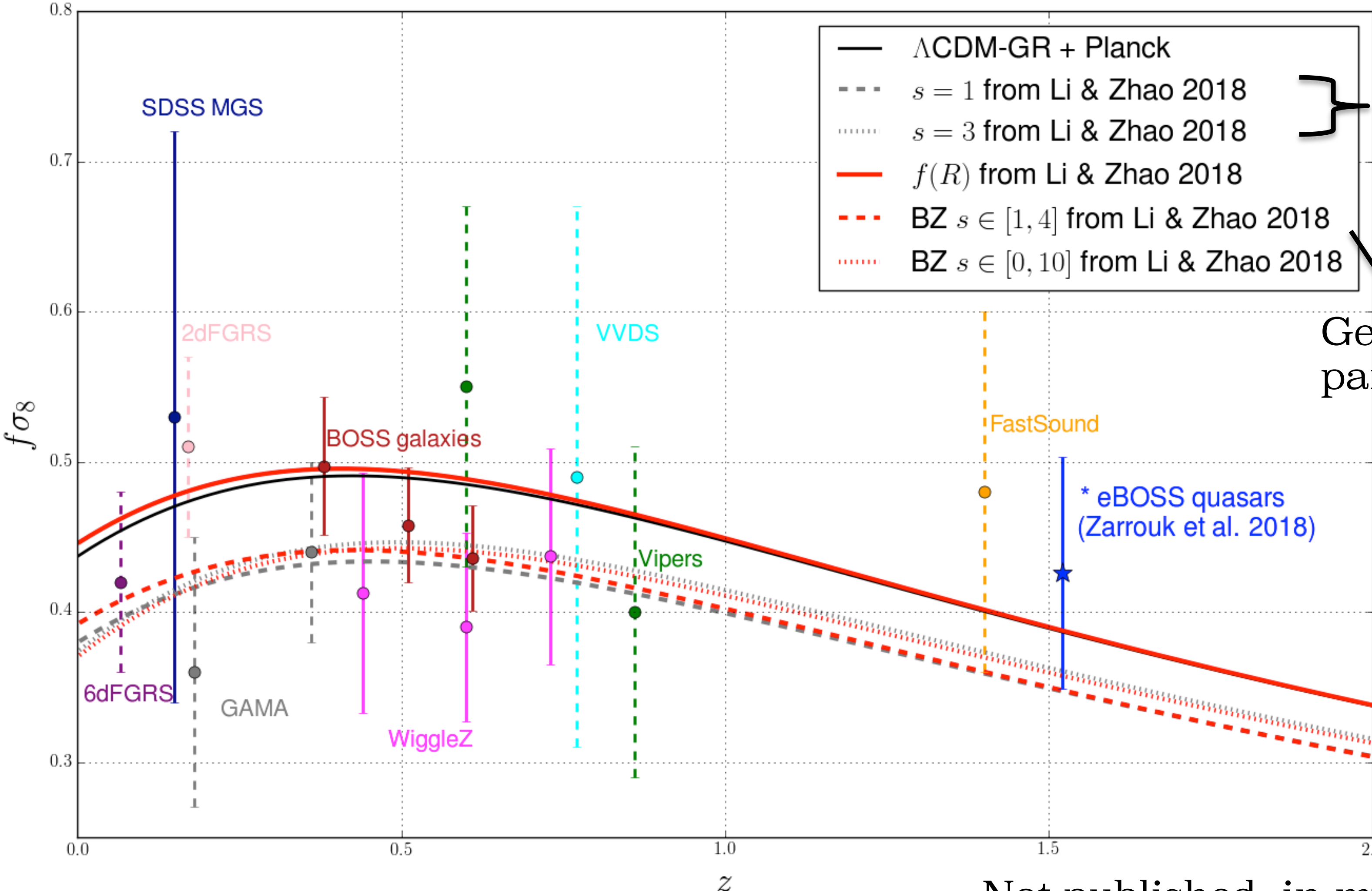
No additionnal systematic error budget thanks to an improved weighting scheme

Full-Shape analysis
Results : Structure growth at z > 1



DR14 (~149,000 quasars)
- Varying cosmology: 18%
- Fixing cosmology : 11%

Cosmological implications
Structure growth in scalar-tensor theories



Scale-independent

General parametrization

Not published, in my manuscript

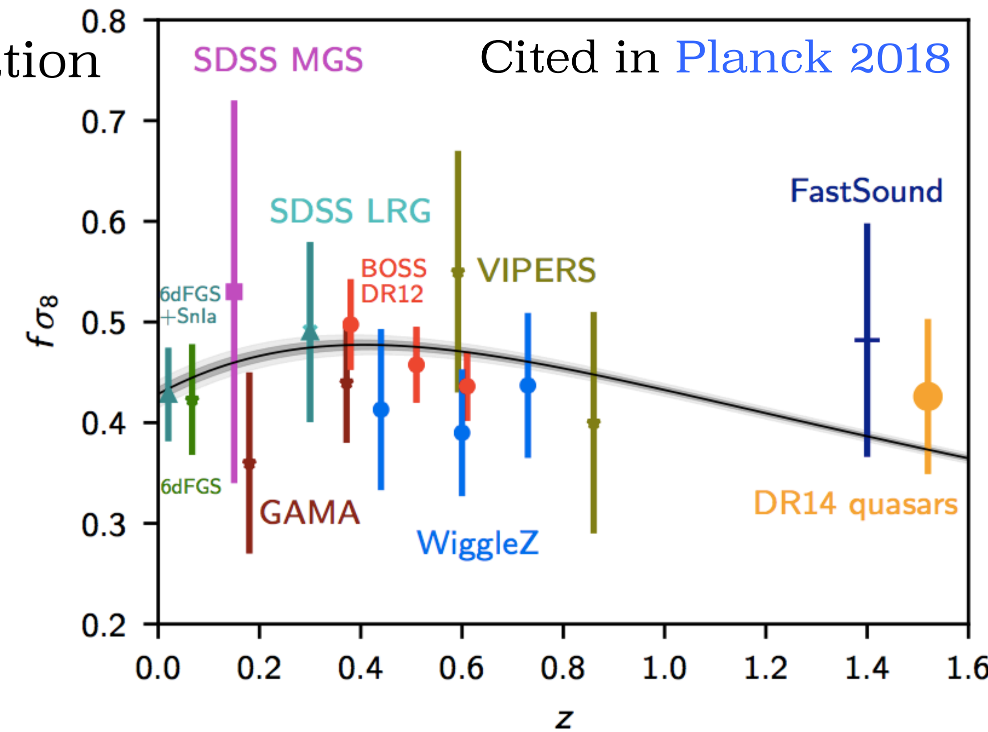
Conclusion of this work

- **Quasars** can be used as **tracers** of the matter field
Allows us to probe a redshift range almost unexplored to date

- **eBOSS DR14Q sample**
2 years of data taking, ~149,000 quasars between $0.8 \leq z \leq 2.2$ over 2113 deg²

- **1st BAO detection between 1 < z < 2** (eBOSS collaboration 2018)

- Full-shape analysis in configuration space (Zarrouk et al. 2018)
  - **BAO distances**:
    - 4.1% on $D_V(z_{eff}=1.52)$
    - 7.5% on $H(z_{eff}=1.52)$
    - 5.5% on $D_A(z_{eff}=1.52)$
  - **Growth rate of structure**:
    - 18% on $f\sigma_8(z_{eff}=1.52)$ with AP
    - Can be used to constrain modified gravity models



Prospects
Towards precision cosmology!