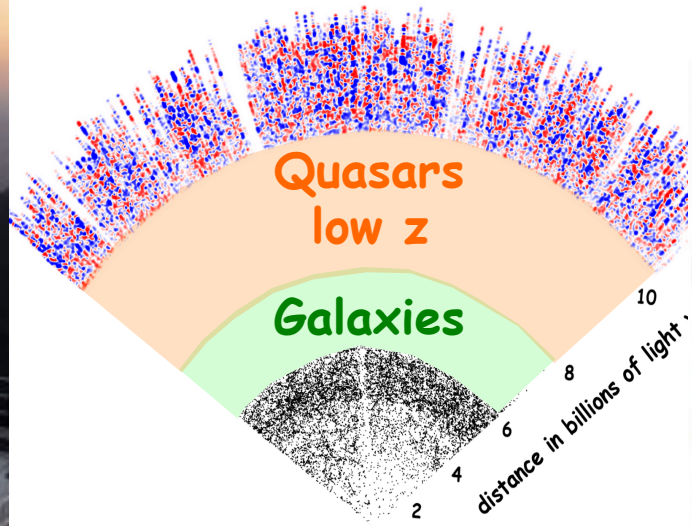
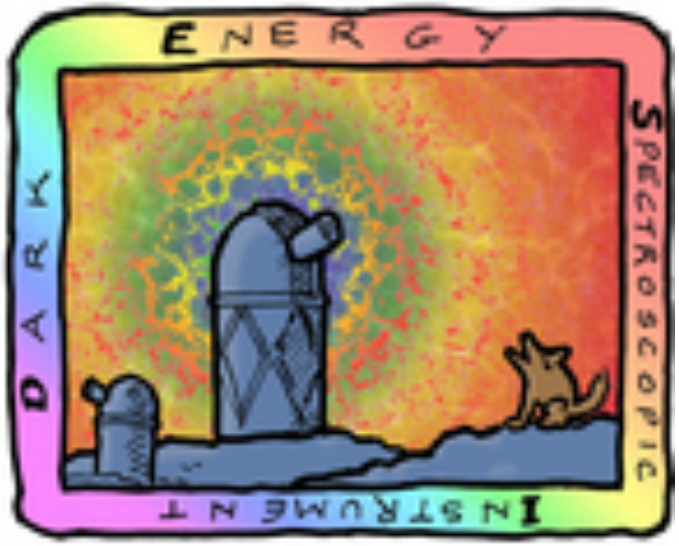
Dark Energy and Neutrinos

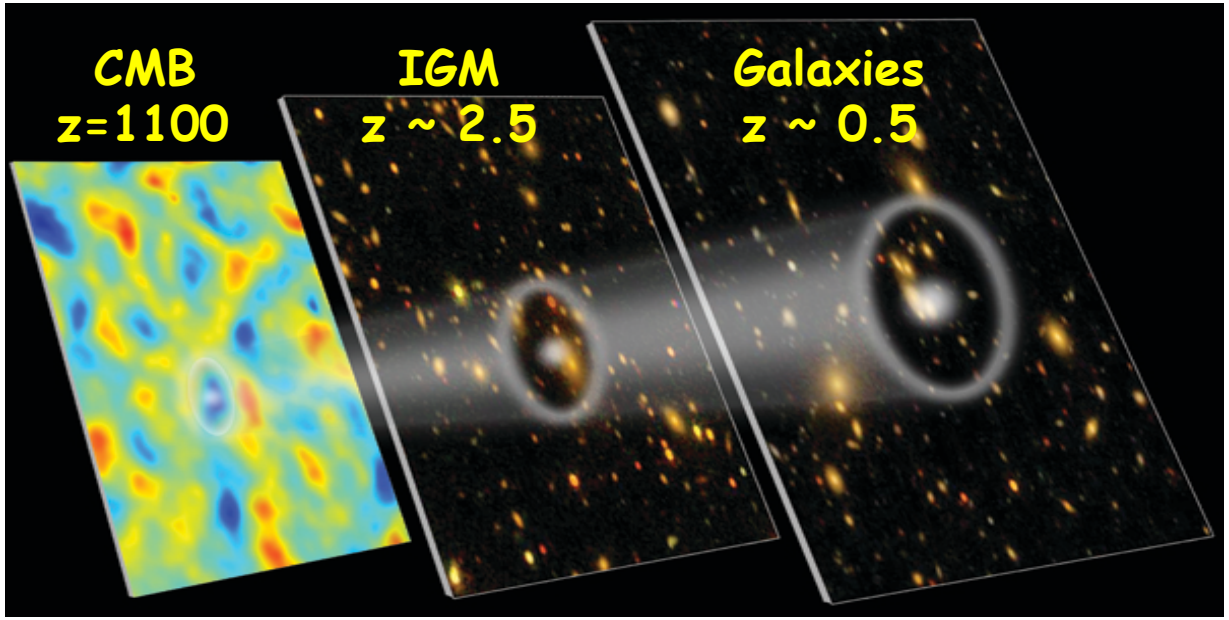




BOSS **eBOSS** **DESI**

Nathalie Palanque-Delabrouille
CEA-Saclay + LBNL

Dark Energy with BAO



3D observation of density excess

- **Transverse direction** (perp. to line of sight)
  $\Delta\theta = s/(1+z)/D_A(z)$
  ⇒ Sensitive to angular distance $D_A(z)$
- **Radial direction** (along line of sight)
  $\Delta z = s \cdot H(z)/c$
  ⇒ Sensitive to Hubble parameter $H(z)$

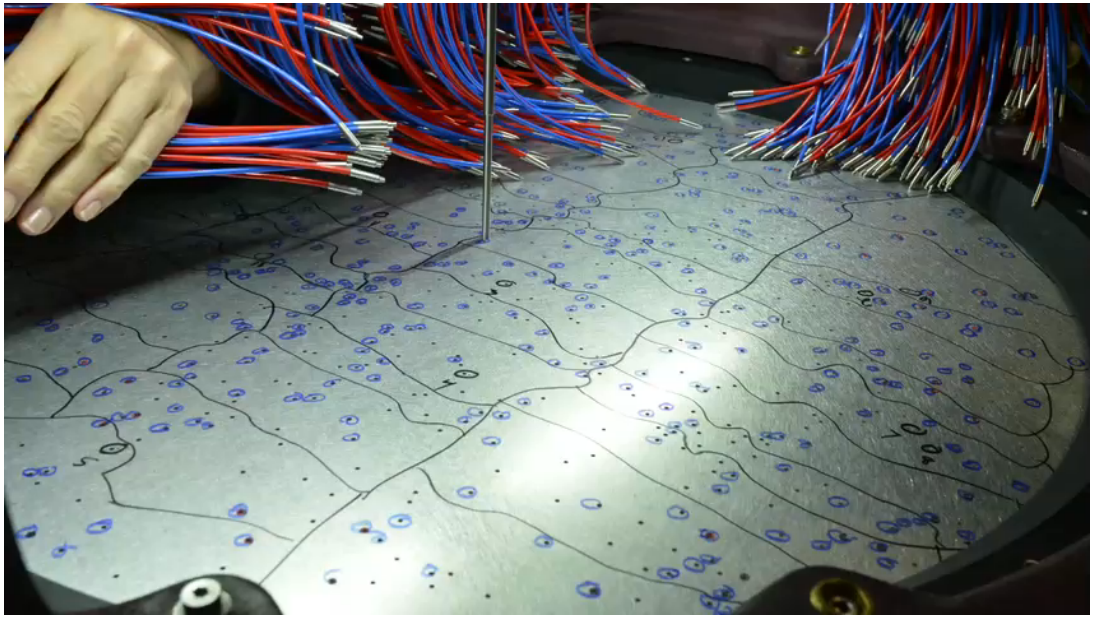
Isotropic measurement

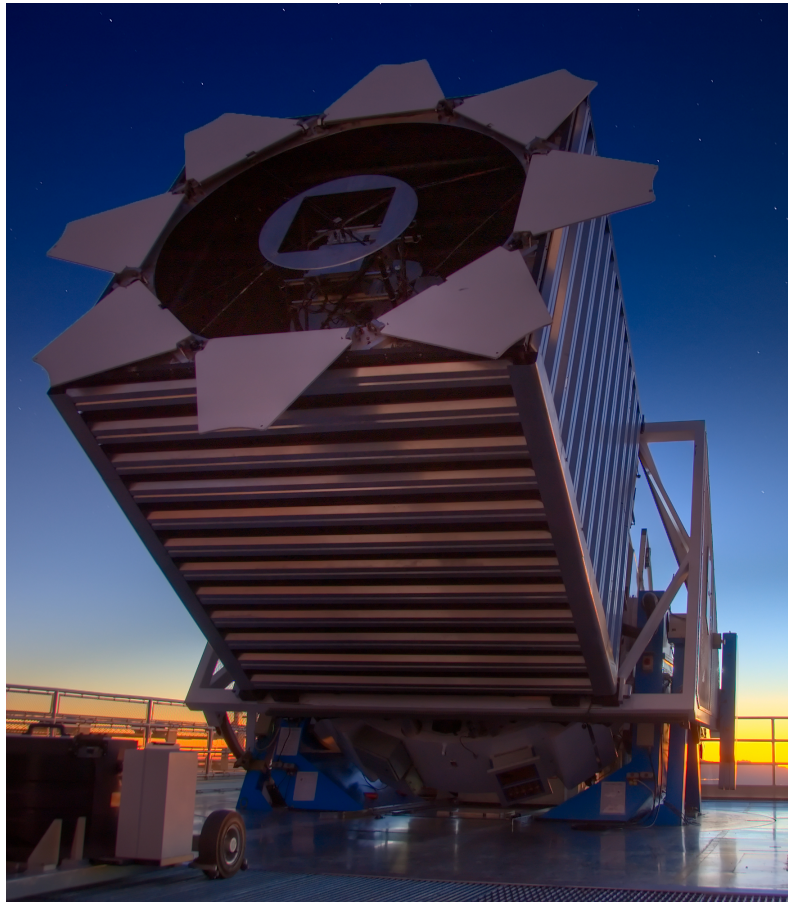
$$D_V = \left[\frac{cz}{H(z)} . (1+z)^2 D_A^2(z) \right]^{1/3}$$

BOSS in SDSS-III

SDSS-III spectroscopic survey

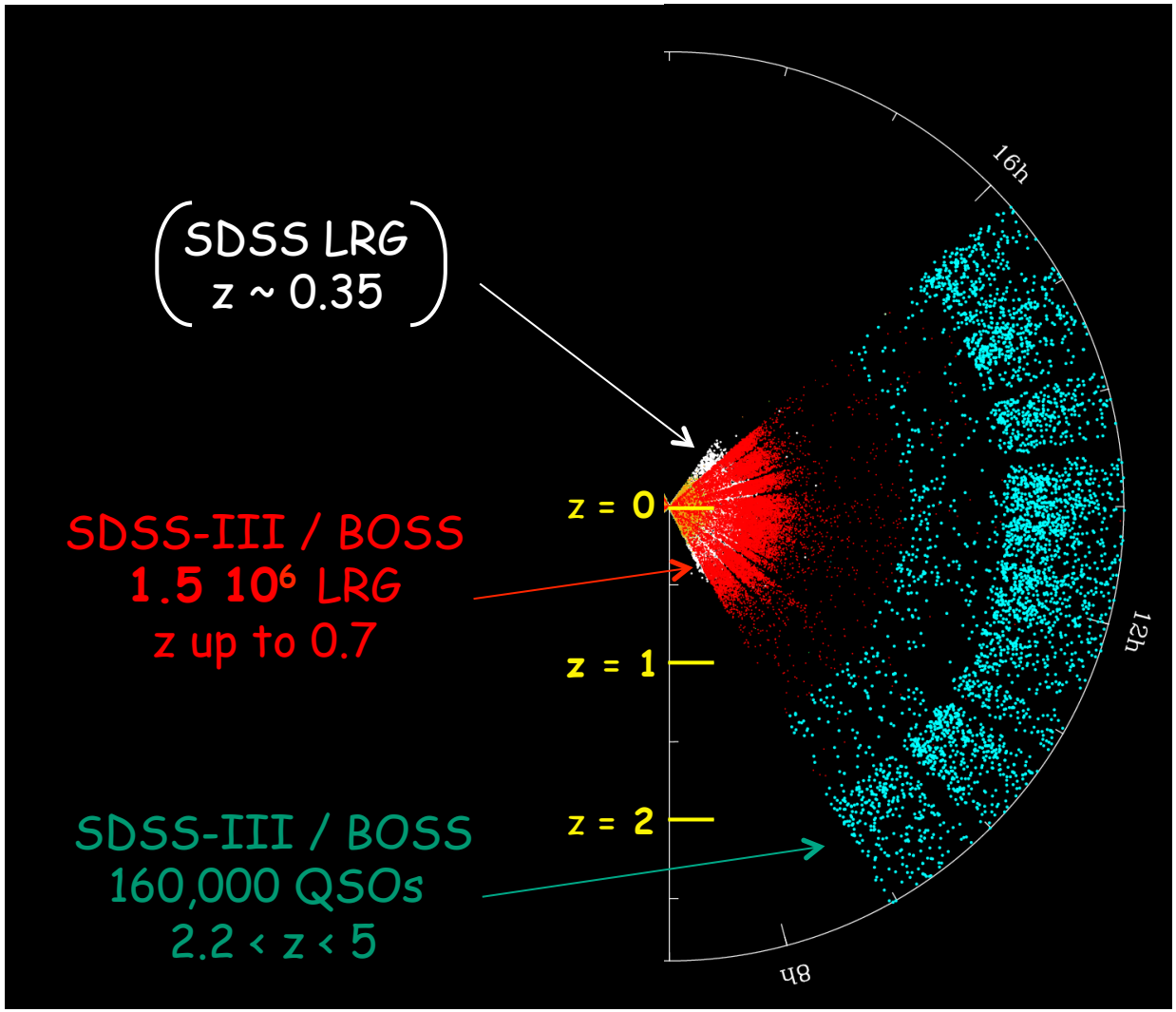
- 2.5 m Sloan telescope (New Mexico)
- Total survey area: 10,000 deg^2
- 1000 fibers



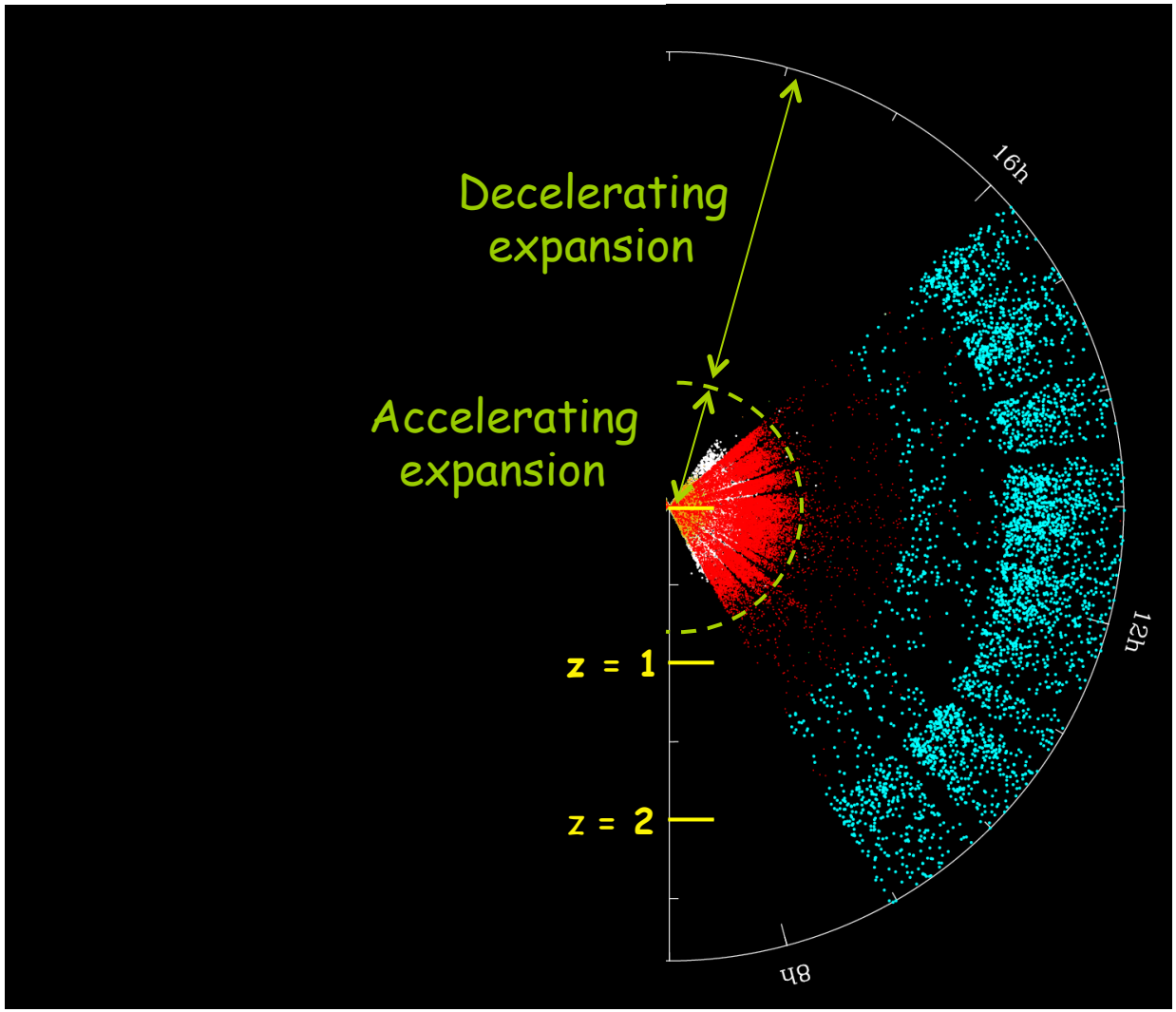


Data taking 2009-2014

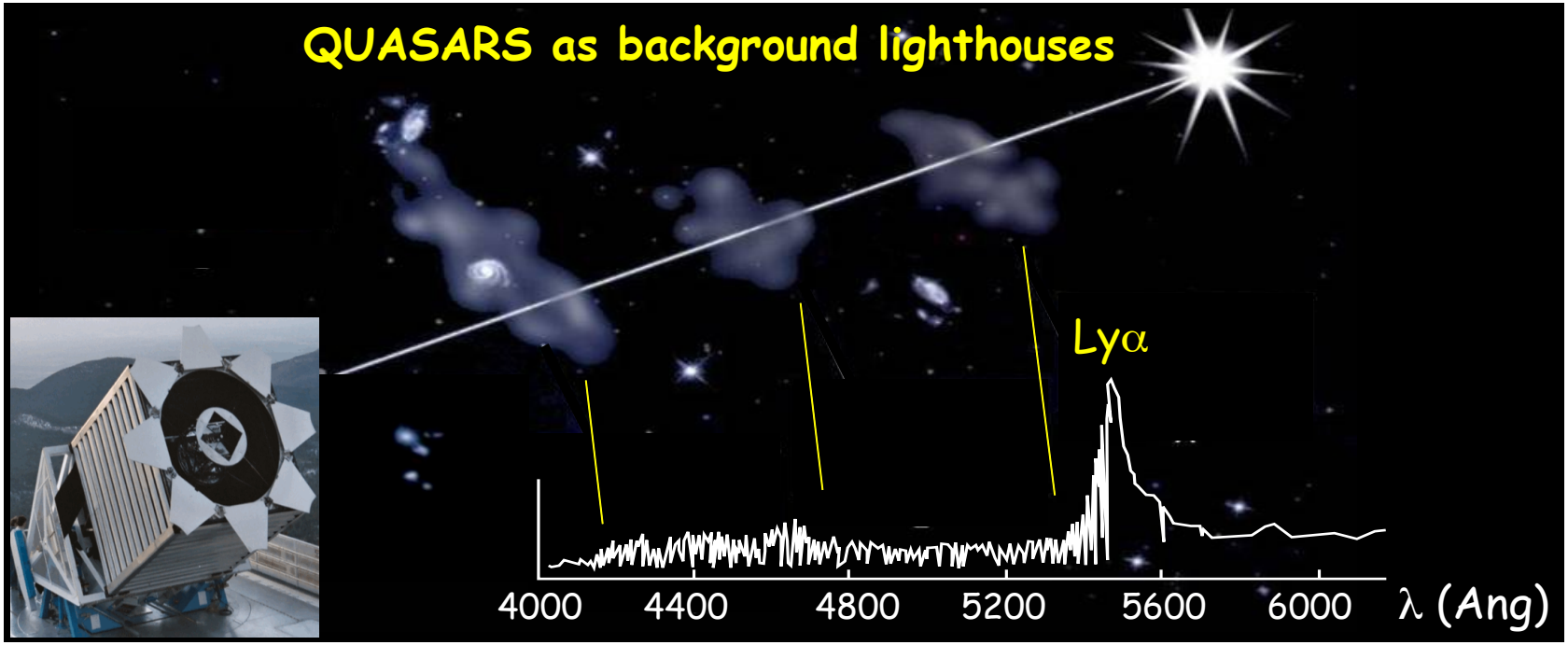
BOSS in SDSS-III



BOSS in SDSS-III



IGM probe



- **Ly-α forests** of quasars (2.2<z<4 → visible range)
  Transmitted flux fraction ∝ exp(-τ) where $\tau \propto n_{HI}$

- Low density gas (**IGM**) expected to **follow dark matter density**

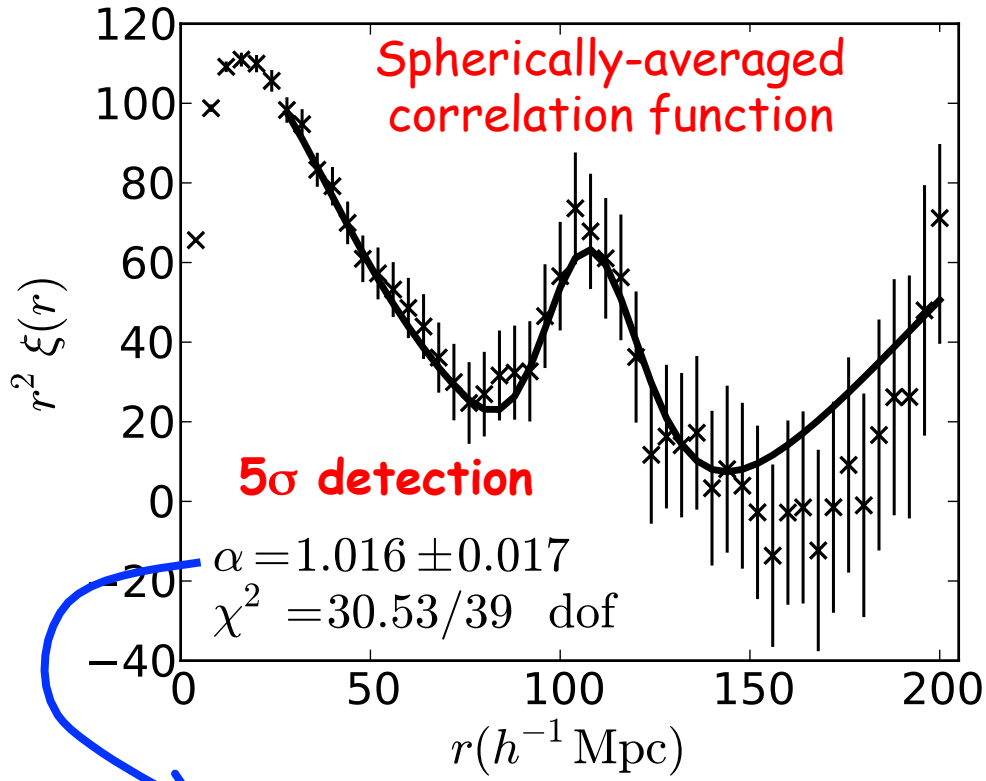
BOSS

Dark Energy Results

BOSS DR9 galaxies (isotropic approach)

1/3 of total BOSS:
330,000 galaxies over 3300 deg^2
<z> = 0.57

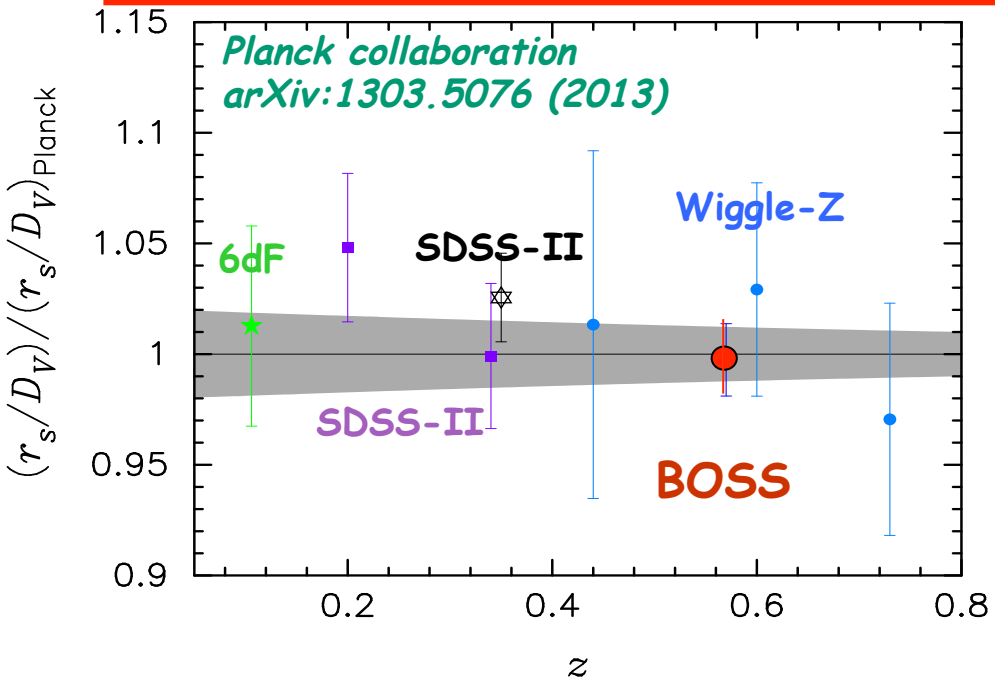
- **Use of fiducial model ($\theta \rightarrow r$)**
- **Departures quantified by dilation scale α**
  $\rightarrow$ Fit of $\xi(\alpha r)$



consistent with Planck ΛCDM

L. Anderson et al., MNRAS 427, 3435 (2012)

Dark Energy Results (isotropic approach)



- Combine transverse and longitudinal direction with

  $D_V=(cz.H(z)^{-1}.(1+z)^2D_A(z)^2)^{1/3}$

- "Hubble" diagram with D_V/r_S

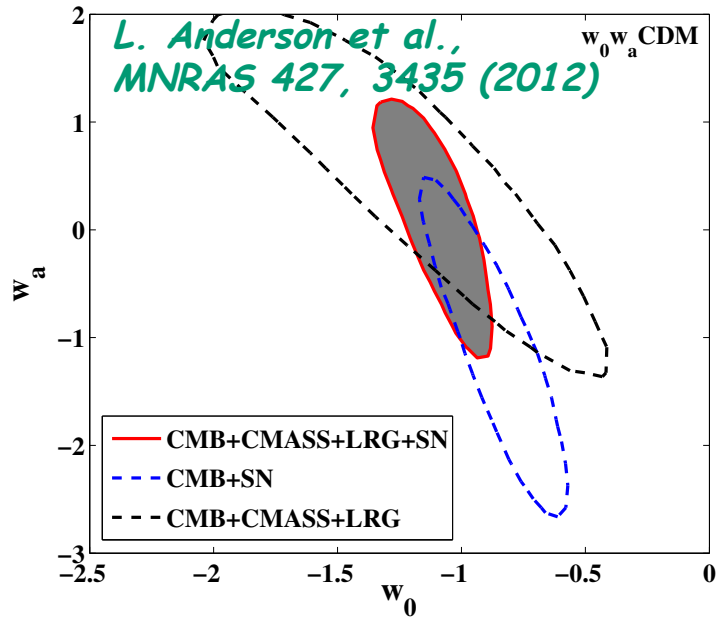
- Eq. of state: $w=p/\rho$

  $w(z)=w_0+z/(1+z).w_a$

- WMAP+BAO+SN:

  $w_o = -1.08\pm0.15$

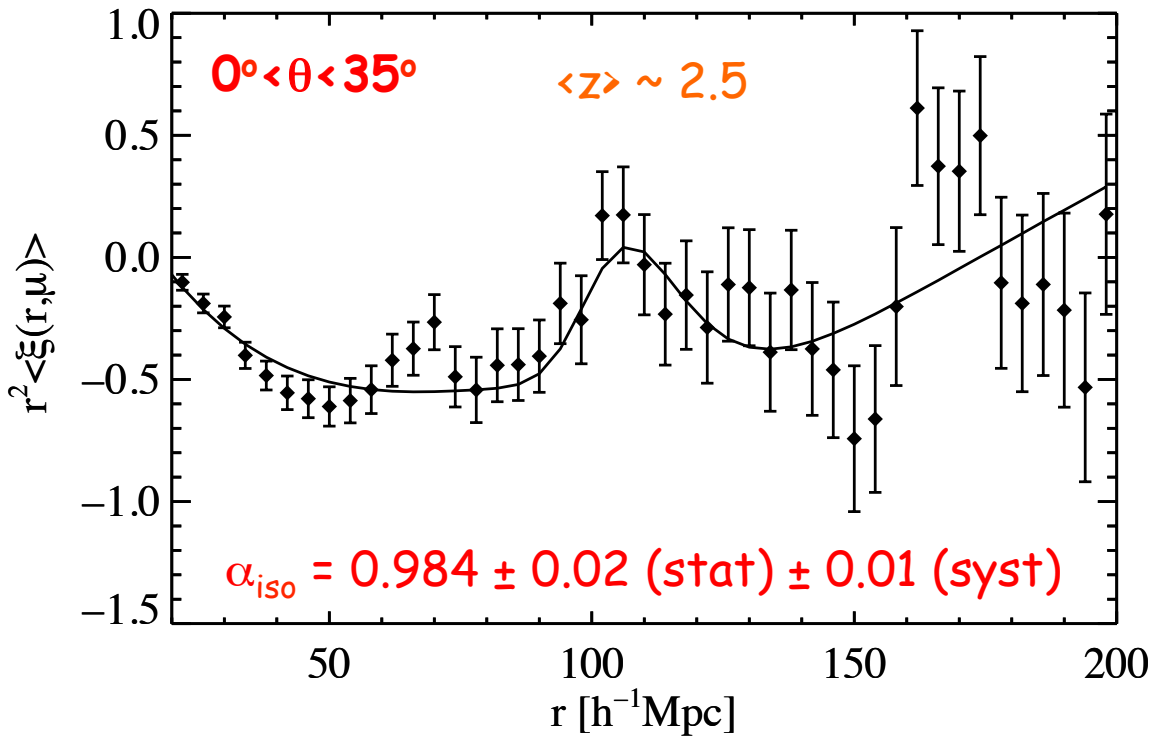
  $w_a = 0.10\pm0.87$

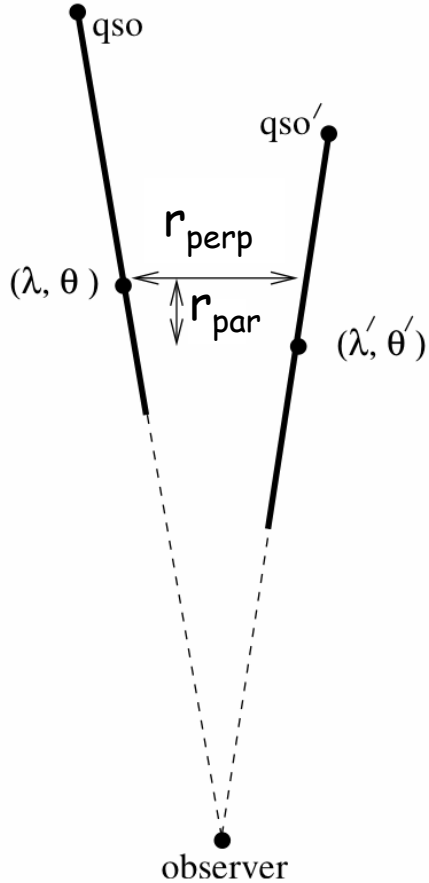


Lyman-α BAO

Transmitted flux fraction $\delta_F \equiv \frac{F}{\overline{F}} - 1$

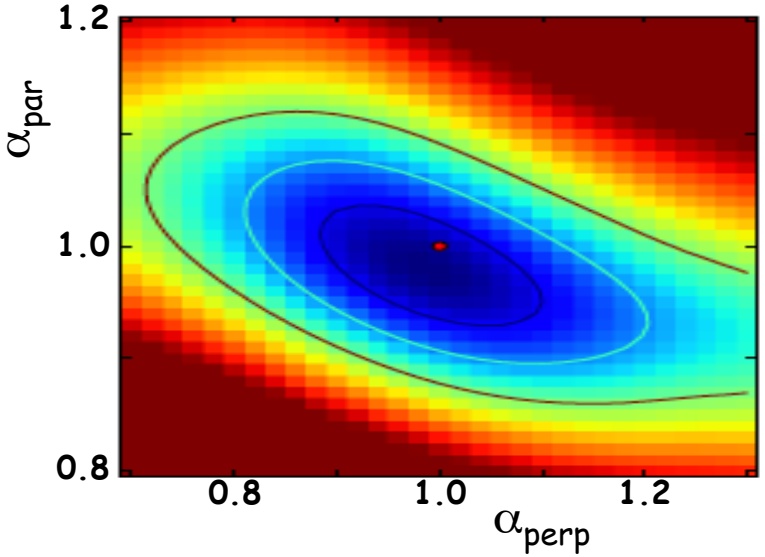
Correlation function $\xi_F(\vec{r}) = \langle \delta_F(\vec{x}) \cdot \delta_F(\vec{x} + \vec{r}) \rangle$





6 orders of mag. between galaxy & IGM $\delta\rho/\rho$

Lyman-α BAO



2D Fit

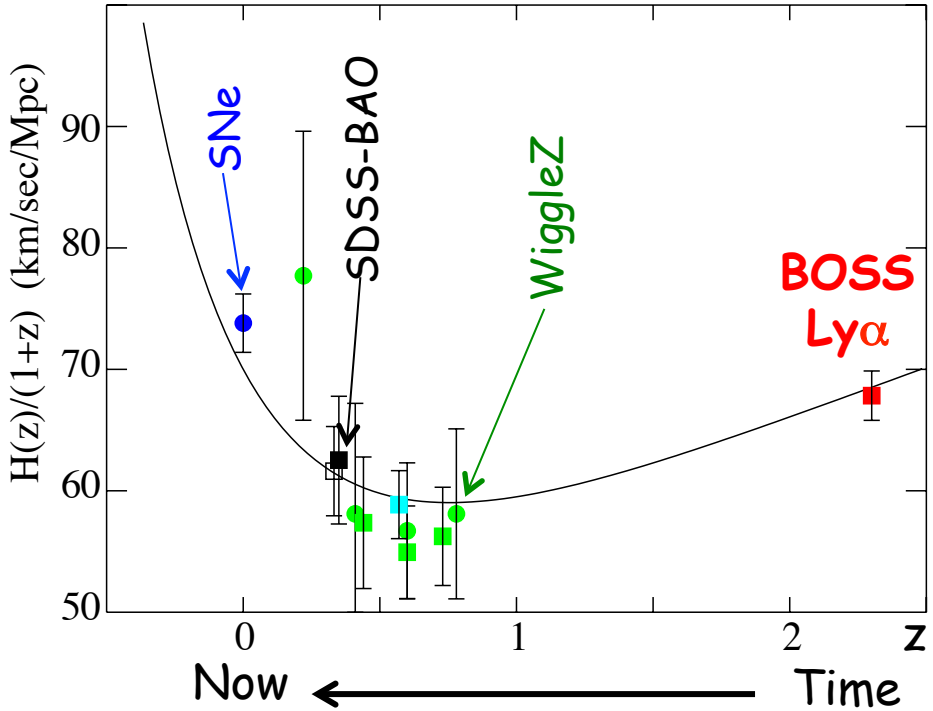
Slosar et al., JCAP 04, 026 (2013)

- Two dilatations scales: radial (α_{par}) and transverse (α_{perp})
- α_{par} much more precisely measured

Cosmological implication

- First measurement of H at z~2.3 (11 Gyrs from now)
- Deceleration of expansion of Universe for z>0.8 !!!

Busca et al., A&A 552, A96 (2013)



BOSS

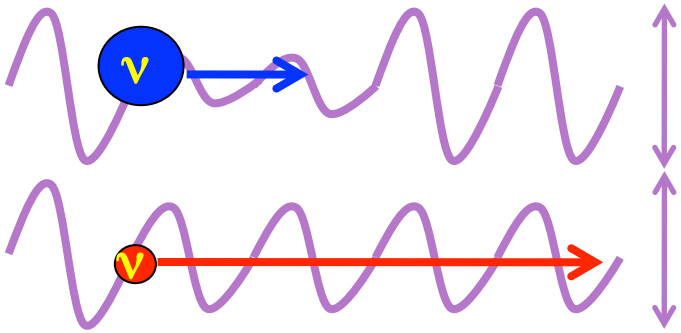
Neutrino Results

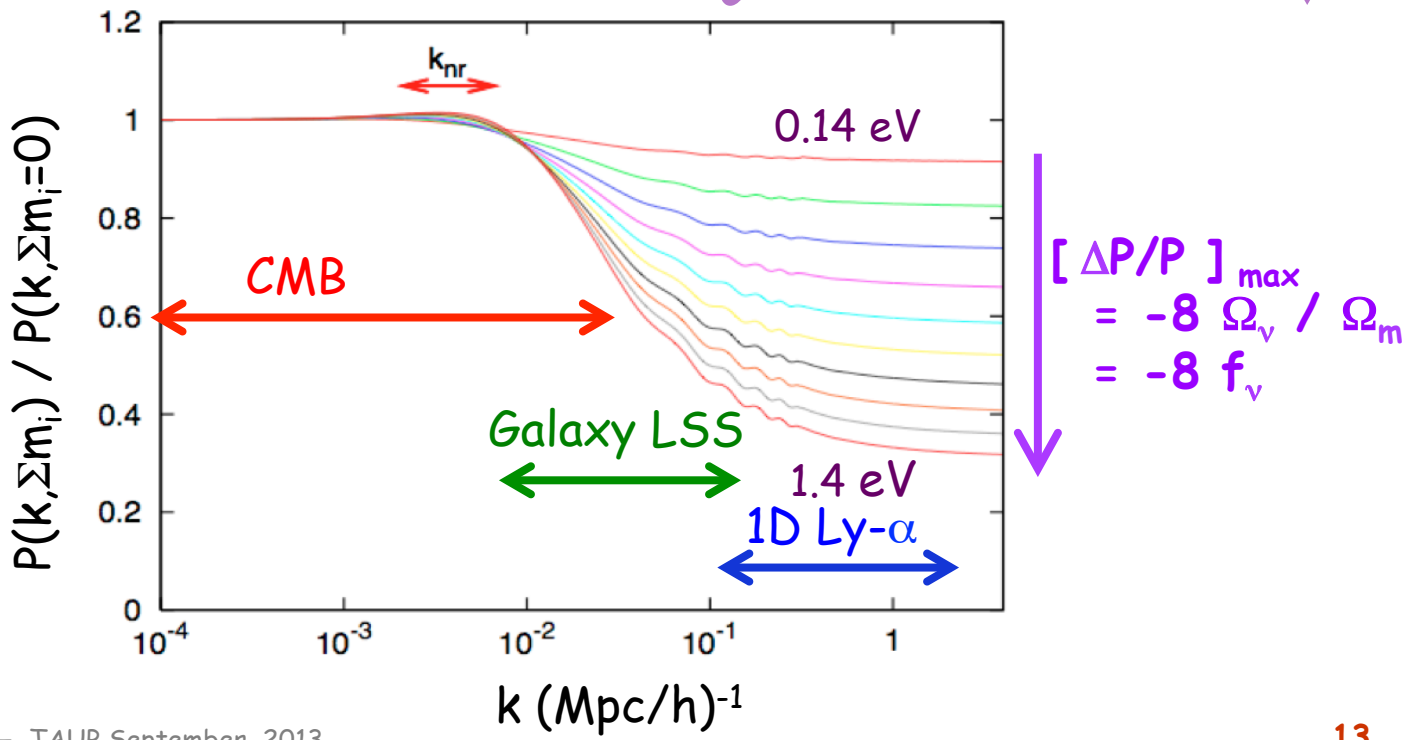
Large-scale structures and neutrinos

Growth of potential wells suppressed on small scales by free-streaming ν

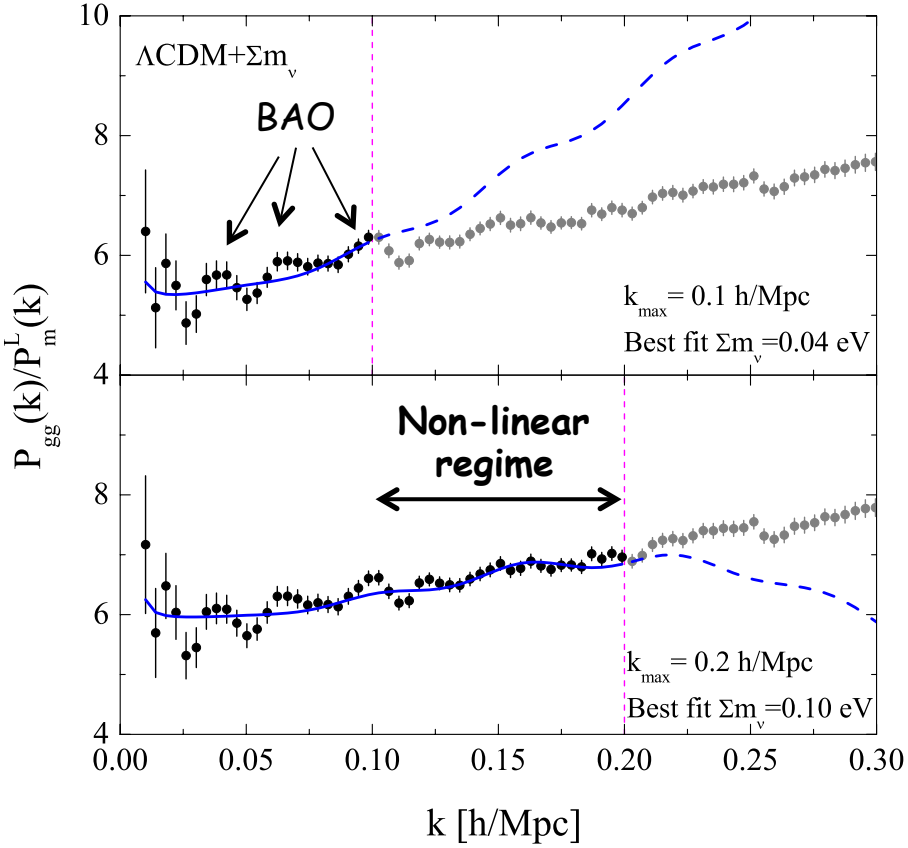
- **Heavy neutrinos:**
  Strong suppression over short range

- **Light neutrinos:**
  Weak suppression over long range

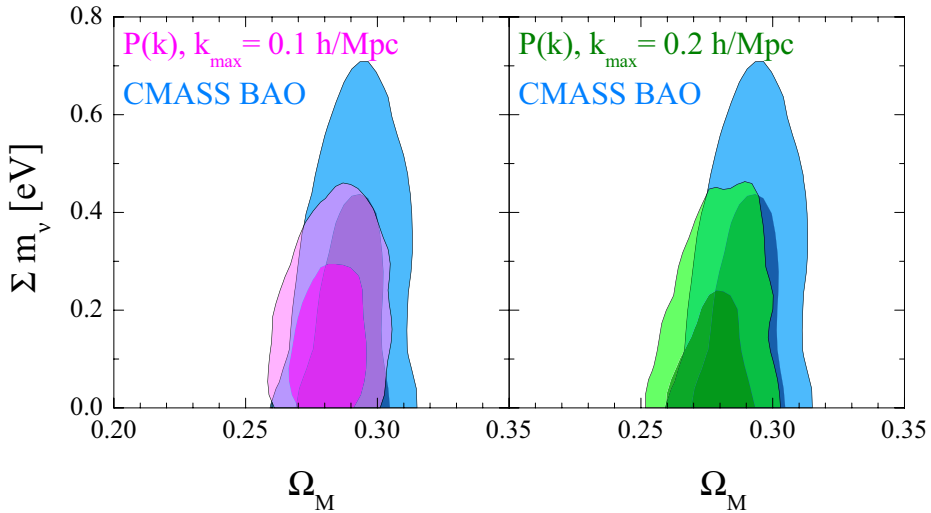




Galaxy power spectrum



Higher k_{max}
→ More non-linearities
→ Less reliability



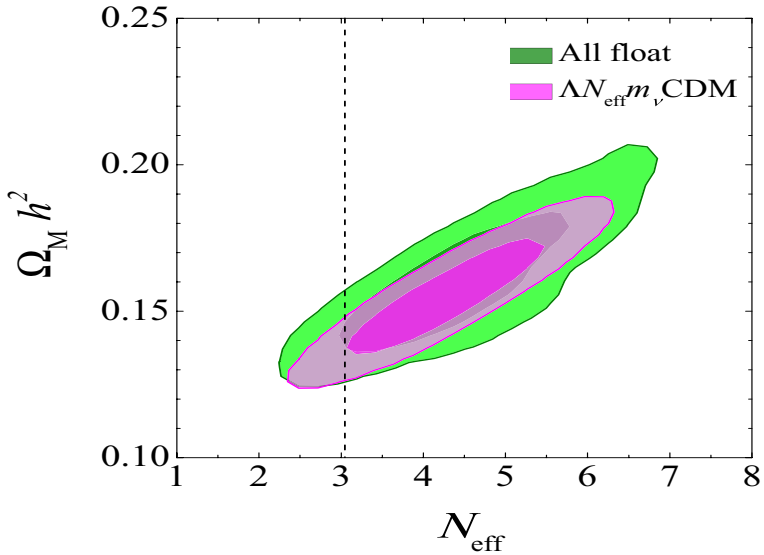
Σm_ν < 0.34 eV whatever k_{max}

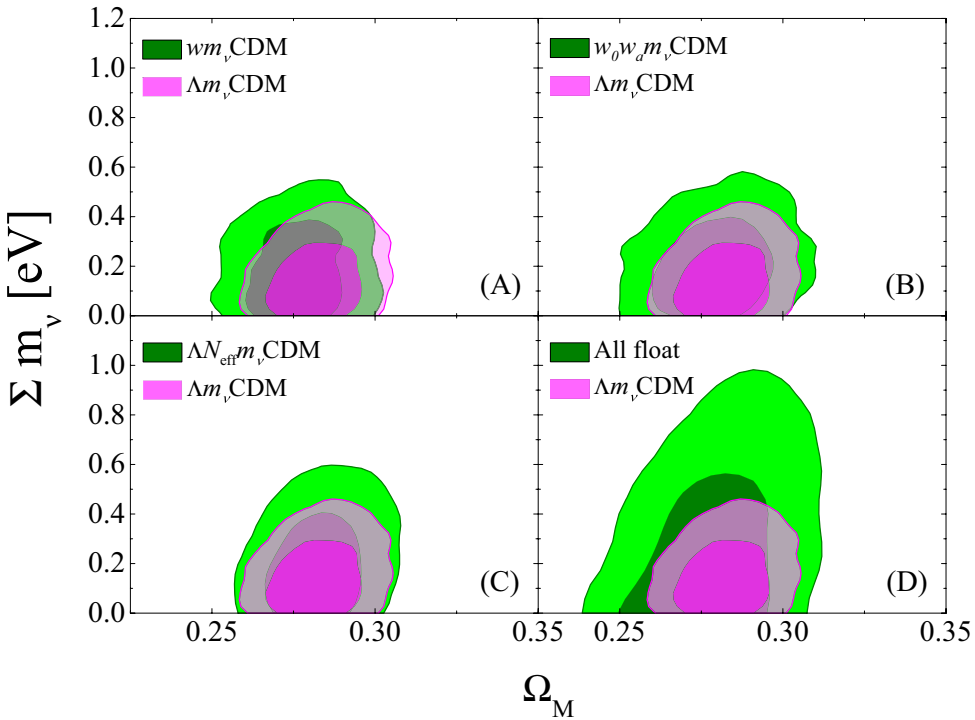
Zhao et al., arXiv:1211.3741

Relaxing additional parameters

- N_{eff} = 4.31 ± 0.79 ($\Lambda N_{eff} m_\nu$CDM)
  N_{eff} = 4.41 ± 0.87 (all float)

  consistent with N_{eff} = 3.046 at 1.6σ



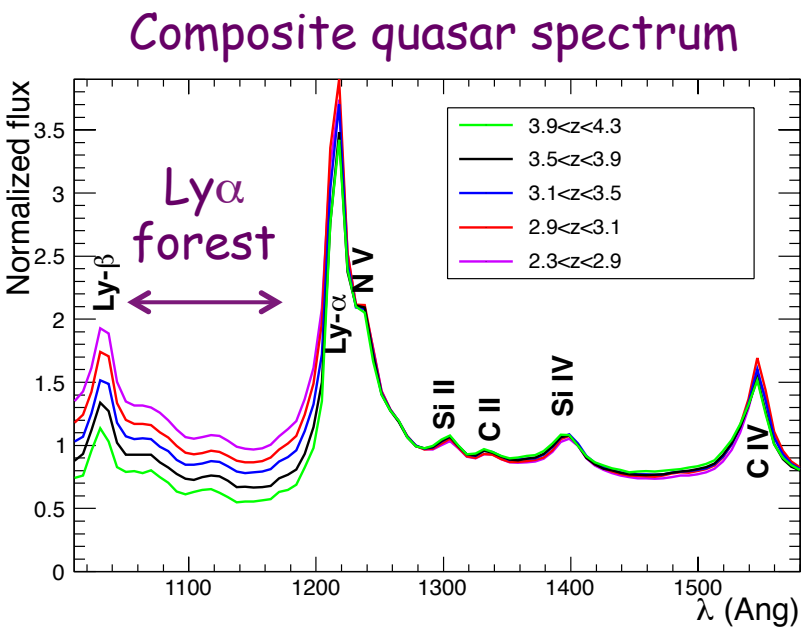


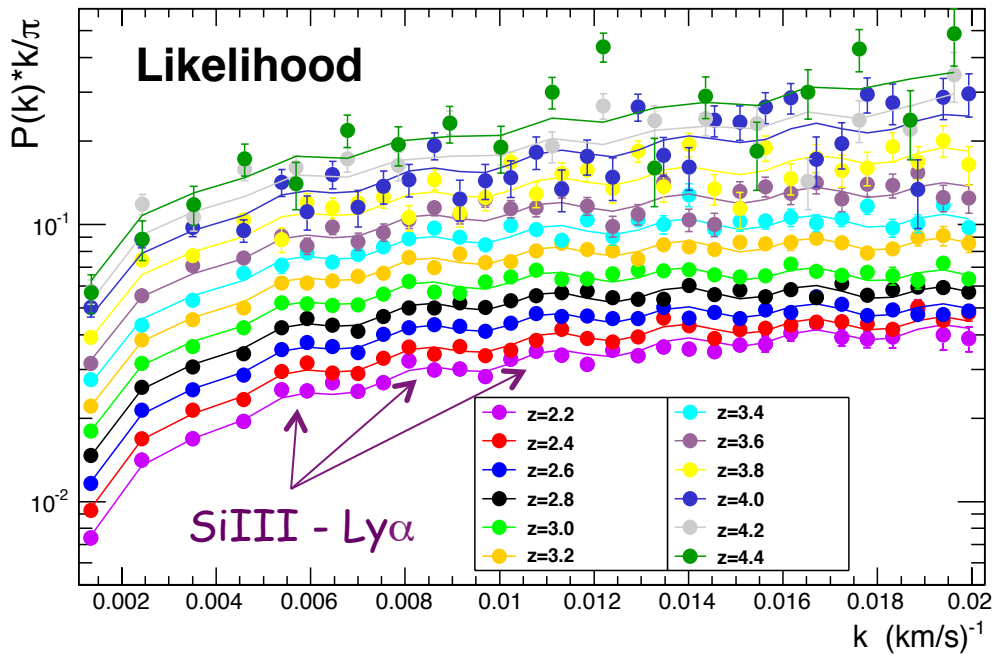
- No surprise on DE parameters

- Σm_ν < 0.340 eV (95% CL, Λm_νCDM)
  Σm_ν < 0.821 eV (95% CL, all float)

Zhao et al., arXiv:1211.3741

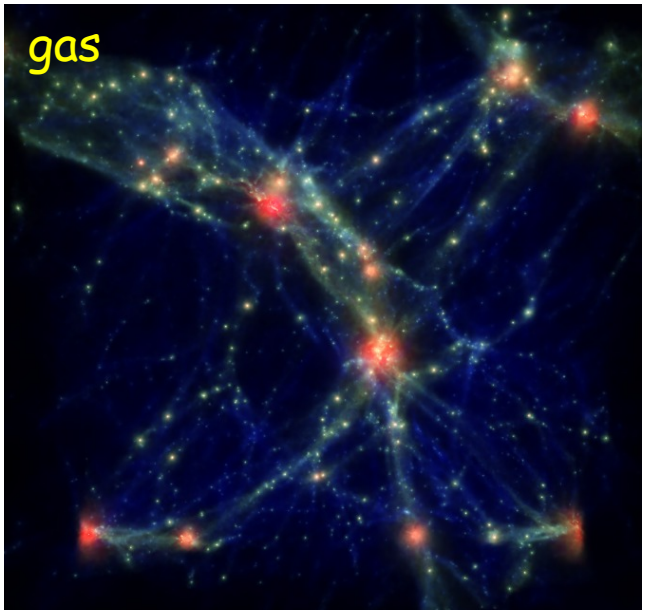
Lyman-α forest

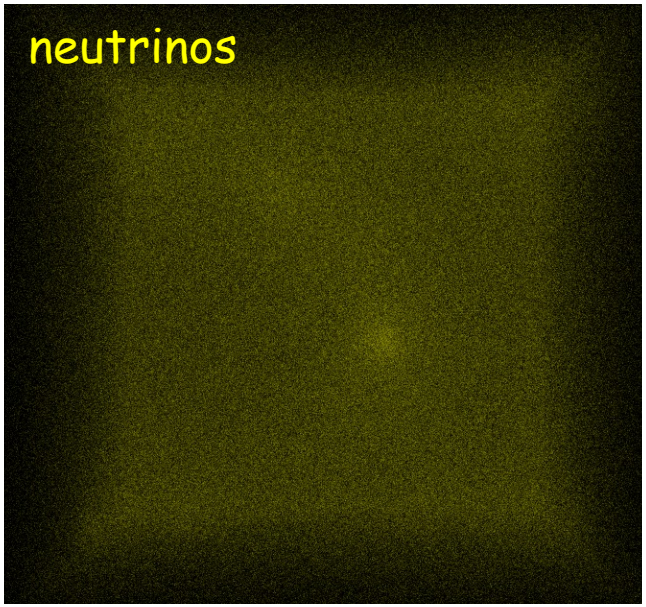




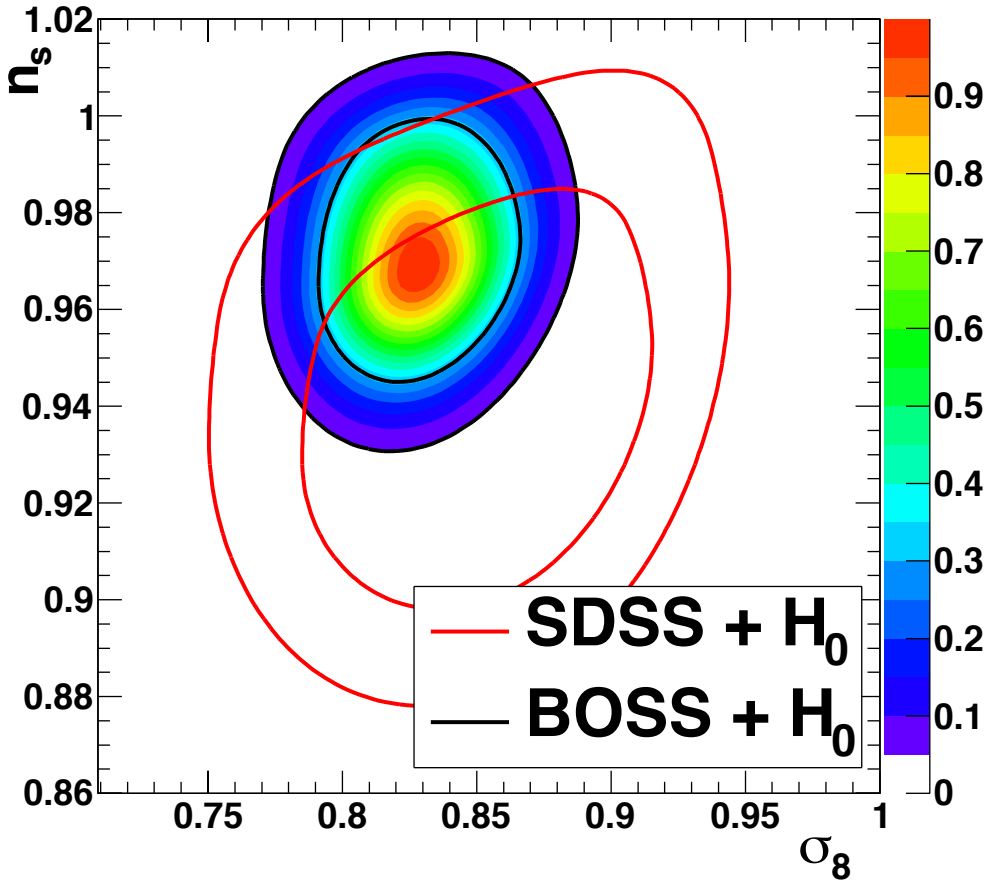
Palanque-Delabrouille et al., arXiv:1306.5896 (2013)

Lyman-α forest



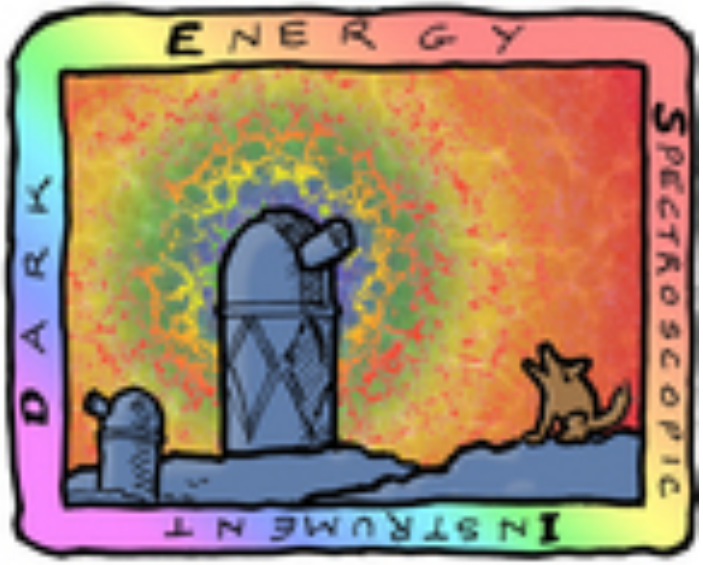


Cosmological interpretation
with hydrodynamical simulations



Palanque-Delabrouille et al., arXiv:1306.5896 (2013)

eBOSS
(2014-2018)

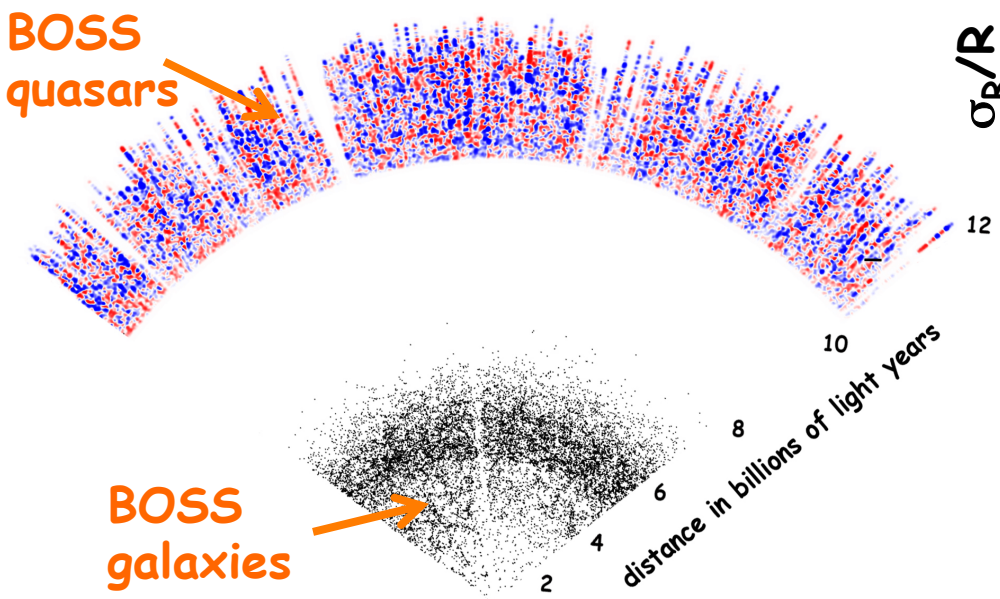


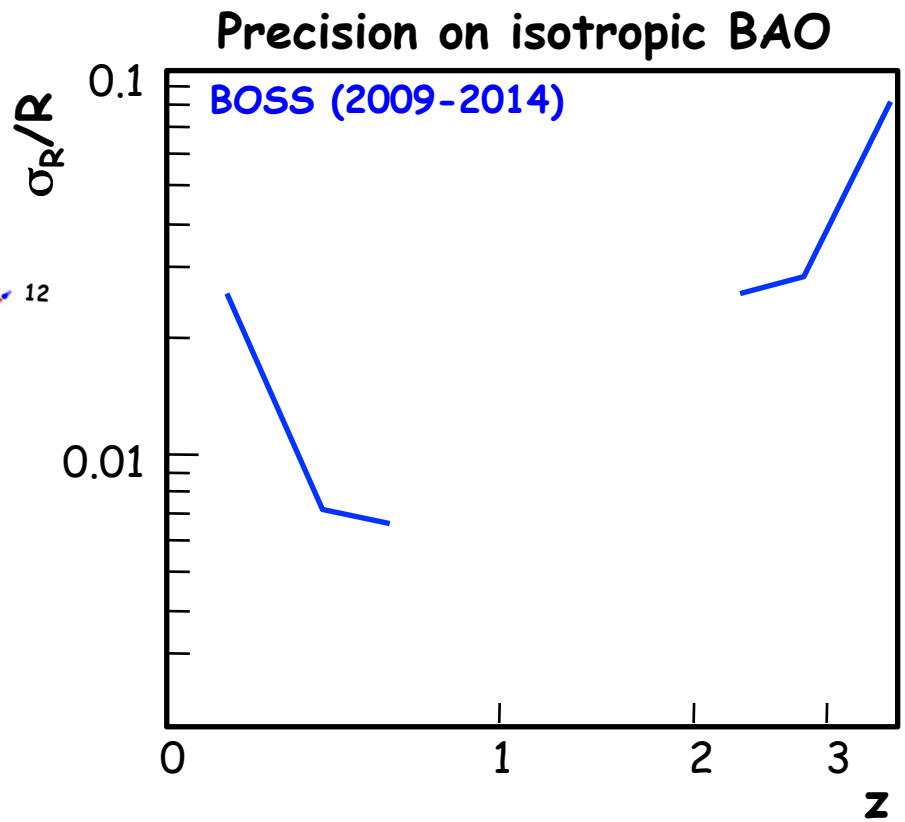
DESI
(2018-2023)

Prospects

From BOSS to eBOSS & DESI

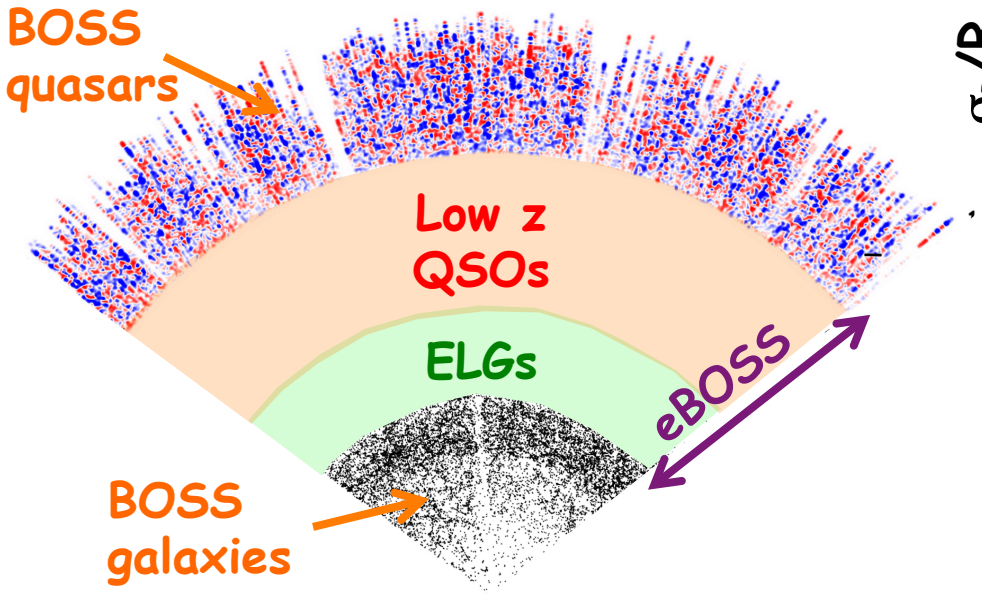
BOSS: 17 deg^{-2} Lyα QSOs
135 deg^{-2} LRGs

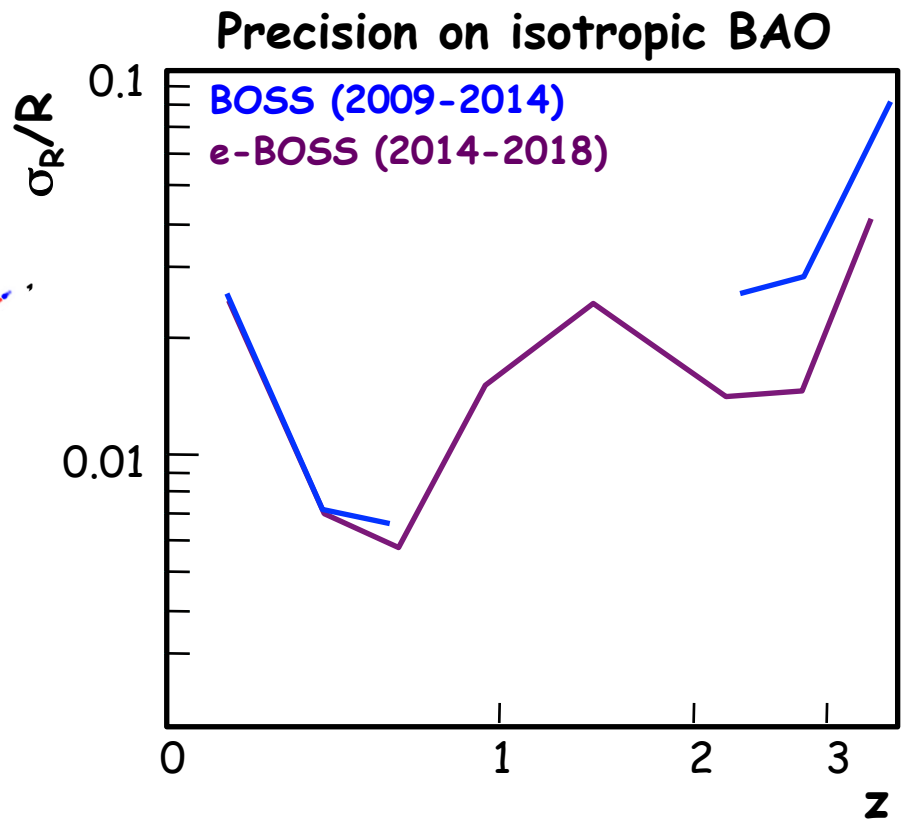




From BOSS to eBOSS & DESI

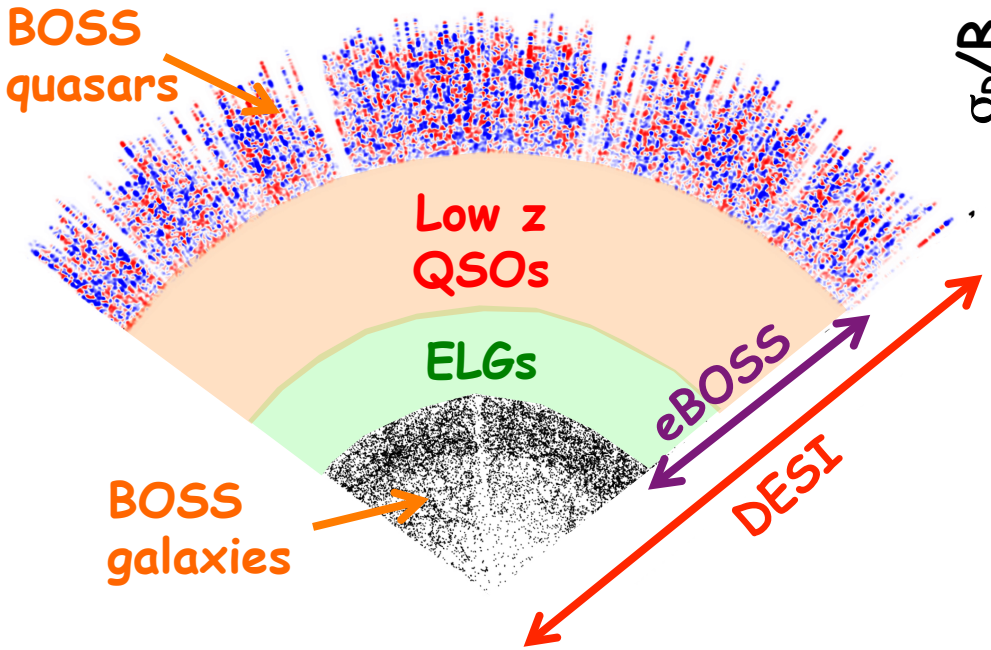
eBOSS: 60 deg^{-2} 1<z<2 QSOs, 23 deg^{-2} Lyα QSOs
150 deg^{-2} ELGS, 180 deg^{-2} LRGs

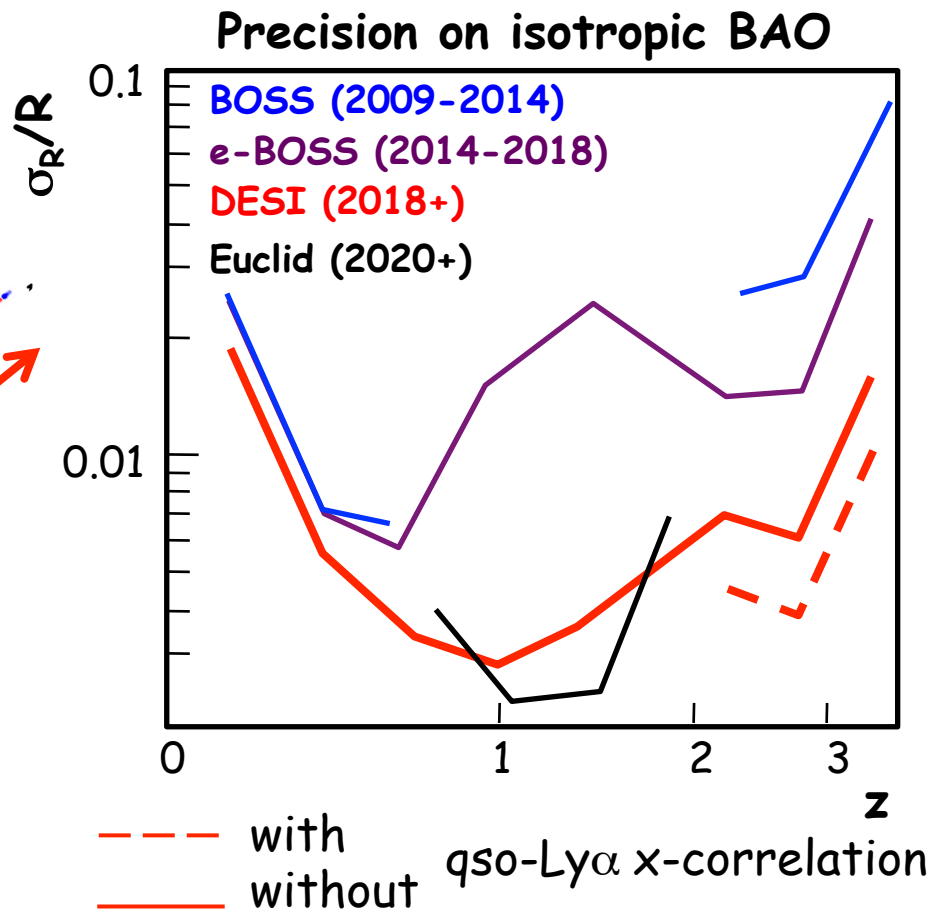




From BOSS to eBOSS & DESI

DESI: 100 deg^{-2} 1<z<2 QSOs, 60 deg^{-2} Lyα QSOs
2400 deg^{-2} ELGS, 400 deg^{-2} LRGs





Conclusions

From BOSS to DESI:
Significant increase in number & z-coverage of targets
Galaxies: 400 deg^{-2} LRGs ($0.5<z<1.0$), 2400 deg^{-2} ELGs ($0.5<z<1.6$)
QSOs: 100 deg^{-2} Low-z ($1<z<2.3$), 60 deg^{-2} Lyα ($z>2.2$)

- 1% measurement in 20 z-bins from $0 < z < 3.5$

  - Lyα BAO with gain ~5 over BOSS
    $\sigma R/R$ (DESI) ~ 0.006
  - QSO clustering
    $\sigma R/R$ (DESI) ~ 0.003

- Neutrino mass
  $\sigma(\Sigma m_\nu)$ (DESI) ~ 0.024 eV

Complementary to other probes of neutrino mass (CMB lensing …)