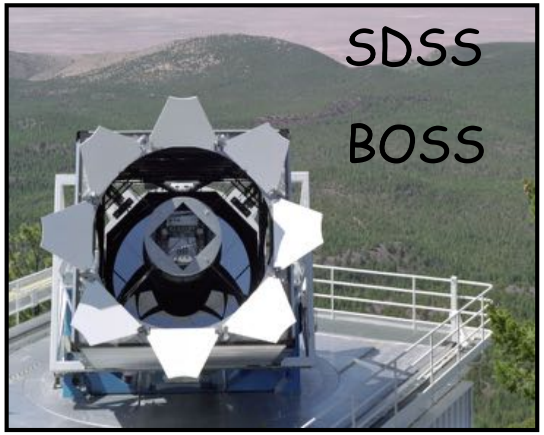
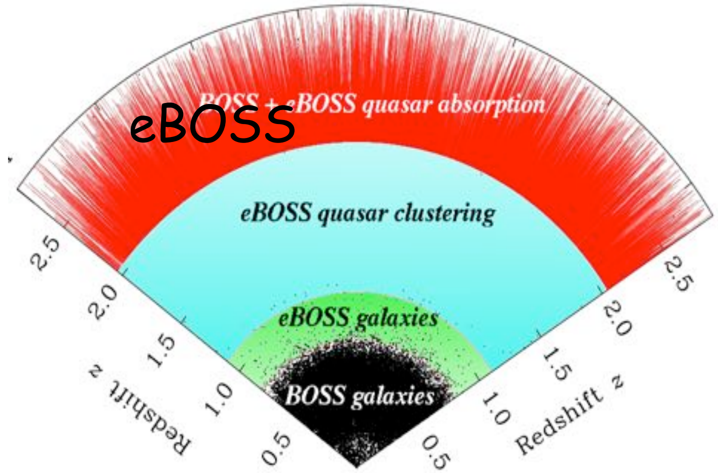
Clustering with quasar and galaxy surveys (e)BOSS - DESI

Ch. Yèche (CEA-Saclay Irfu)





Outline:

- Concepts : BAO and RSD
- SDSS-III: - BOSS/eBOSS results
- DESI: a future BAO and RSD survey

Colloque Dark Energy - Paris IAP – October 23, 2018

Concepts

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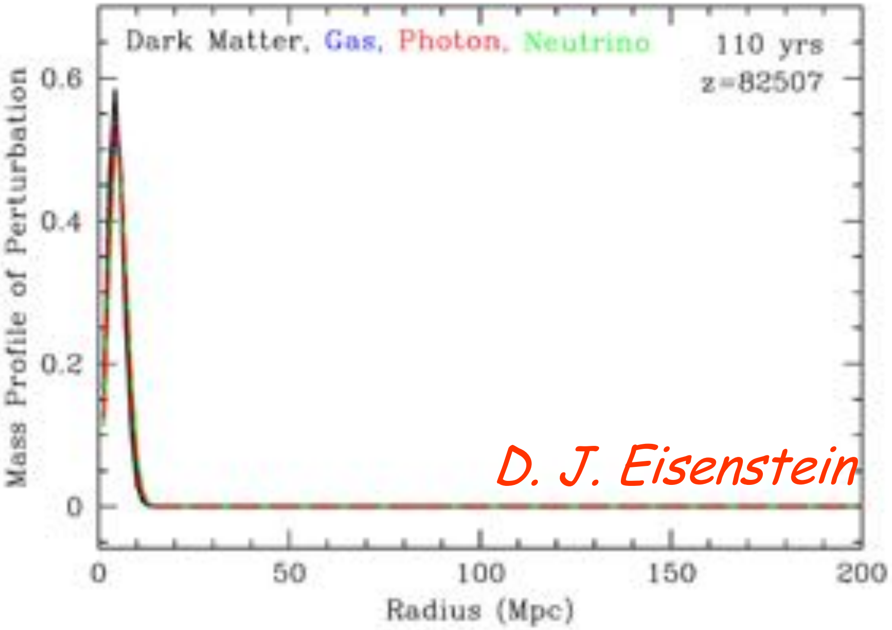
BAO and RSD

A probe for Dark Energy: Baryonic Acoustic Oscillations



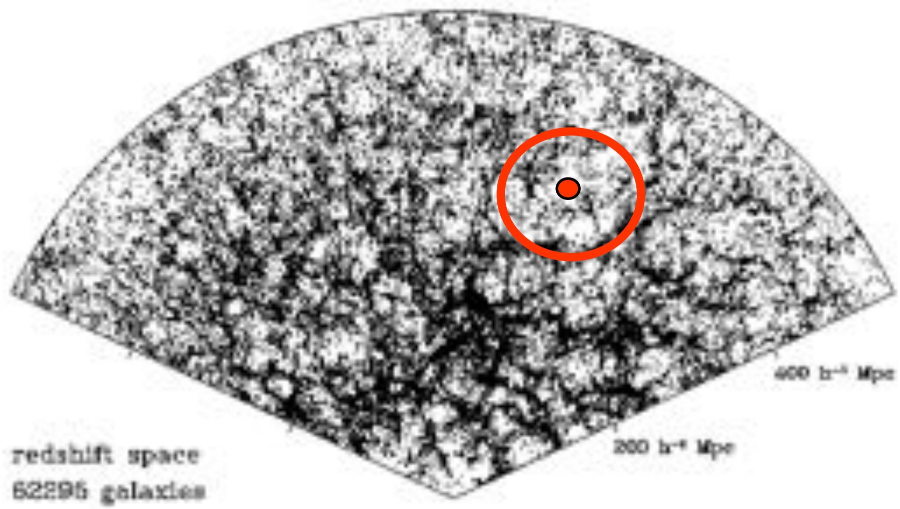
Acoustic propagation of an overdensity:

- Sound wave through relativistic plasma (baryons, electrons, photons).
- Baryon and photon perturbations travel together till recombination (z~1100).
- Then, the radius of the baryonic overdensity is frozen at 150 Mpc.

A special distance:

- Galaxies form in the overdense shells about 150 Mpc in radius.
- For all z, small excess of galaxies 150 Mpc (in comobile coordinates) away from other galaxies.

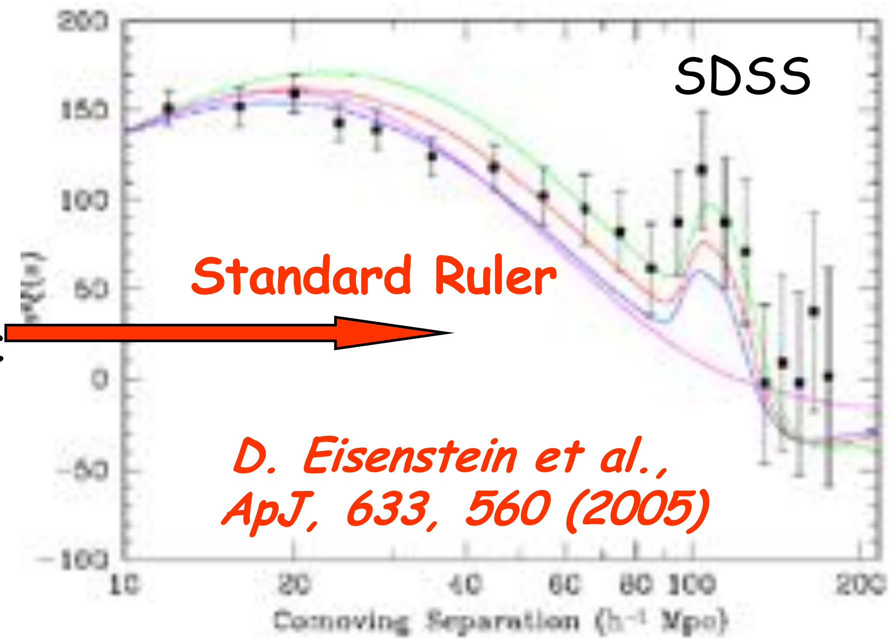
$\Rightarrow$ Standard Ruler

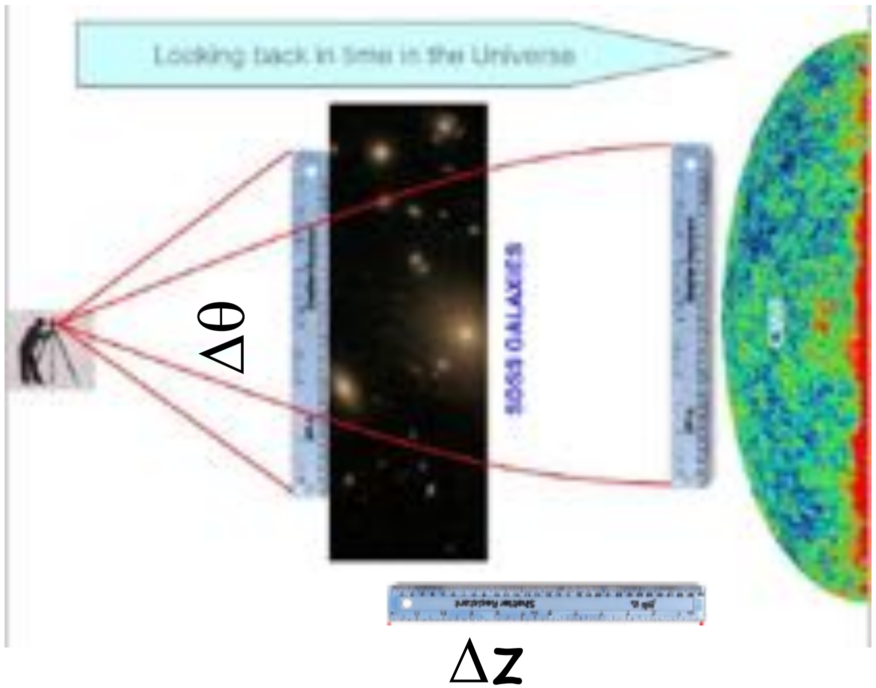


Observation of baryonic acoustic peak

First observation:

- In 2005: First observations of baryonic oscillations by 2 teams (2dFGRS and SDSS)
- SDSS observe a peak at ~150 Mpc
- SDSS: ~50 000 LRGs
  "Luminous Red Galaxies"
  <z> ~ 0.35





A 3D measurements:

- Position of acoustic peak ⇒ Size of the sound horizon r_s
- **Transverse direction:**

$\Delta\theta = r_s/(1+z)/D_A(z)$

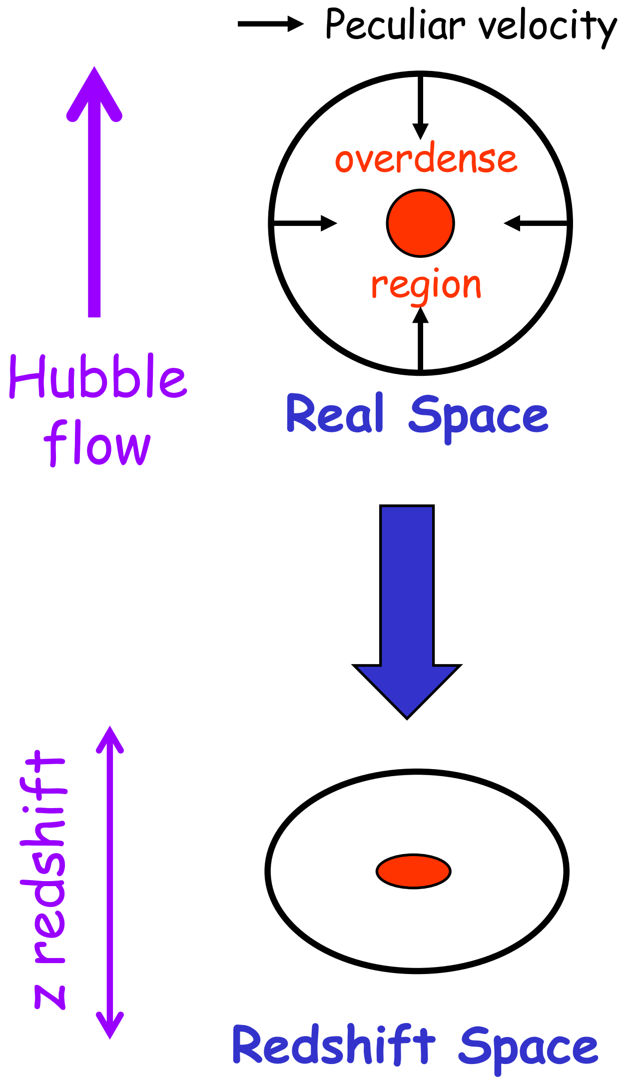
⇒ Sensitive to angular distance $D_A(z)$

- **Radial direction** (along the line of sight):

$\Delta z = r_s \cdot H(z)/c$

⇒ Sensitive to Hubble parameter $H(z)$.

Large-scale Redshift Space Distortions



- Acceleration toward overdense regions
- Flattening in radial direction from real space to redshift space (over tens Mpc)
- Allow us to measure action of gravity (5-40 Mpc) at cosmological distance (Gpc)

- Distortion are quantitatively measured by multi-poles decomposition

$$\boxed{\xi(r,\cos(\theta)) = \sum_{\ell=0,2,4...} b^2 C_\ell \xi(r) P_\ell(\cos(\theta))}$$

- *P_l: Legendre polynomials*
- *θ angle between pair vector and LoS*
- *b linear galaxy bias*

N. Kaiser, MNRAS 227, 1 (1987)

SDSS – BOSS

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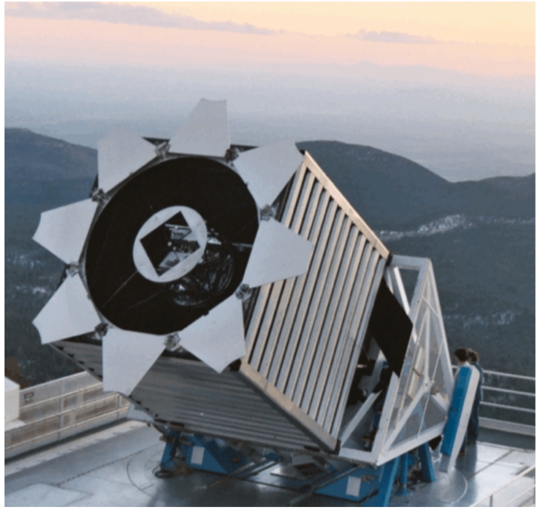
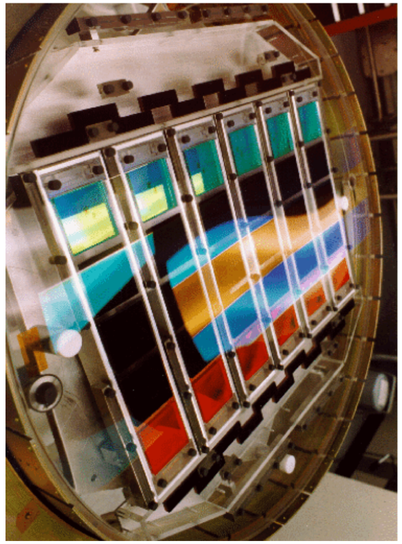
Final Results

BOSS 2009-2014



SDSS Survey

- 2.5m Sloan telescope with a wide FoV ~ 7 deg^2
- α,δ **positions:** 5 filter camera
- z **position:** Spectrograph ~1000 simultaneous spectra



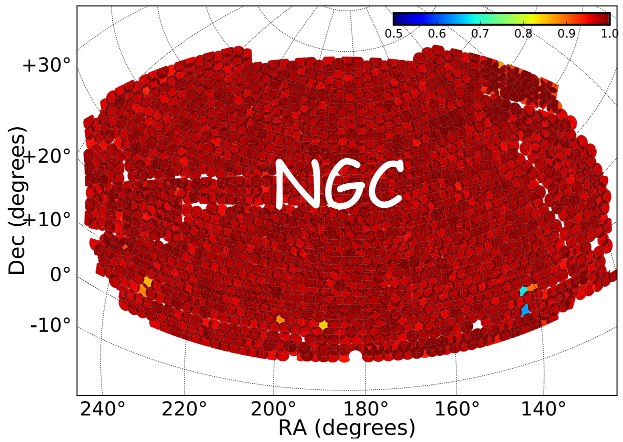
BOSS tracers

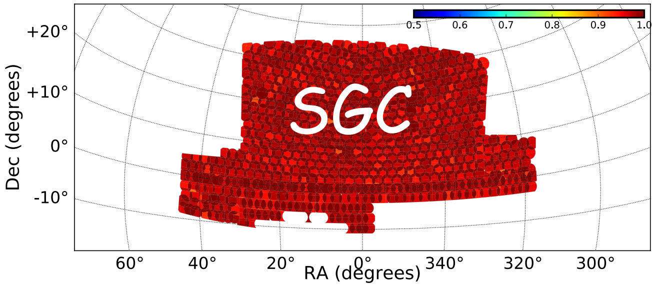
- 1.2 millions of Luminous Red Galaxies (light emitted 6 billions years ago, z~0.6)

- 170 000 quasars (light emitted 11 billions years ago, z~2.4)

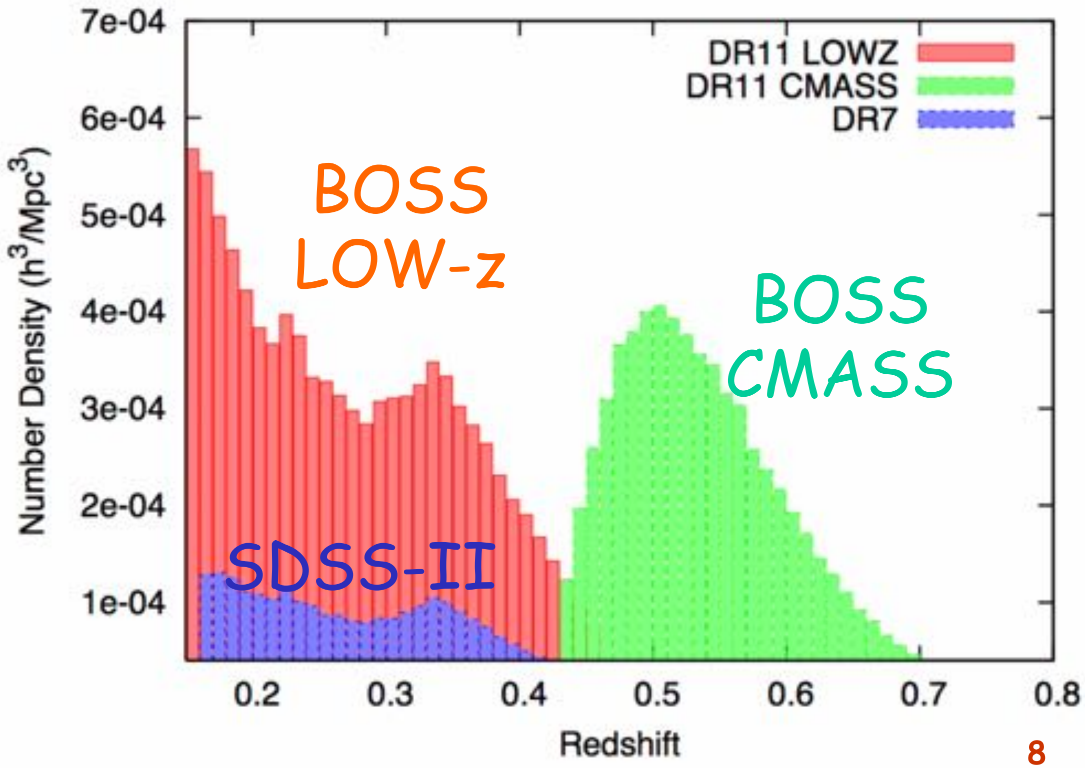
BOSS completed in spring 2014

Footprint
Galaxy Sample





- Final papers released in 2016
- Whole footprint with DR12
- ~10 000 deg^2

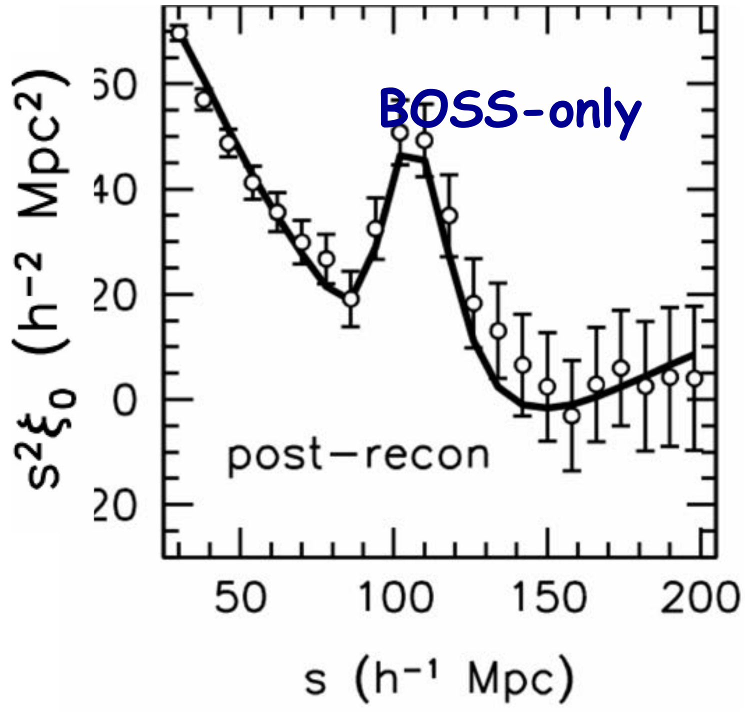


- Deeper and denser survey compare to SDSS-II
- Two tracers
  - LOW-z: $0.15<z<0.43$
  - CMASS: $0.43<z<0.7$
- Three overlapping redshift bins: 0.38, 0.51, 0.61

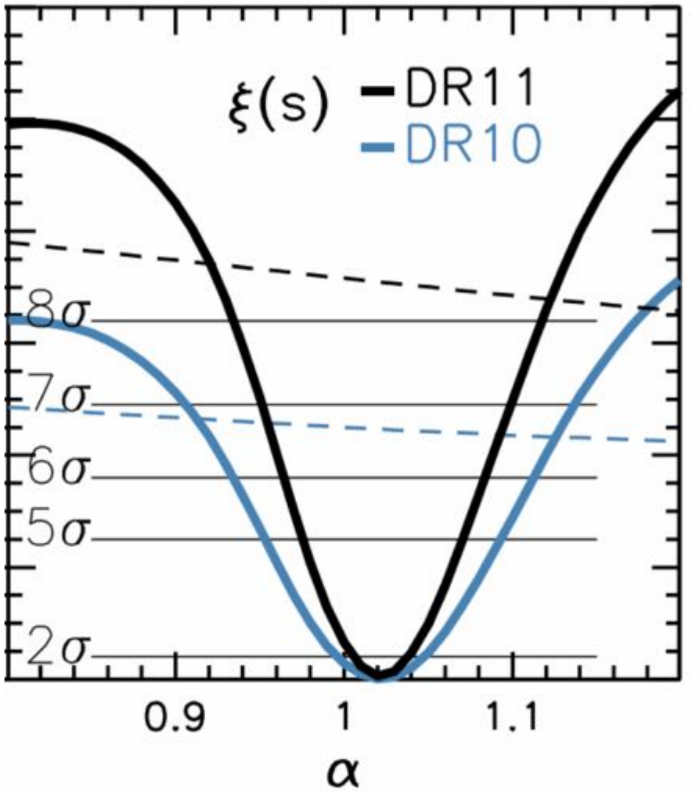
BAO in Correlation Function

- Use a fiducial model to compare against observed features in spherical average statistics.
- Departures quantified by dilatation scales α:

  ➡Fit of $\xi(\alpha r)$



BOSS-DR11. Anderson et al., 2014



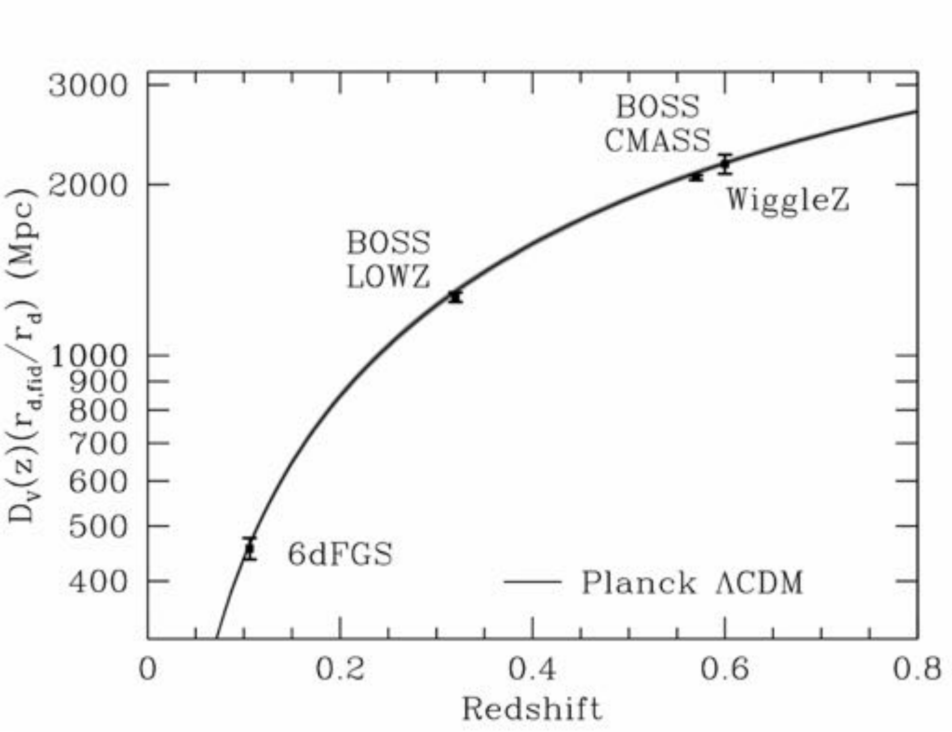
- BOSS-only 8-σ observation
- One percent measurement of BAO scale for CMASS-only !!!

  Low-z: α=1.018 ± 0.021

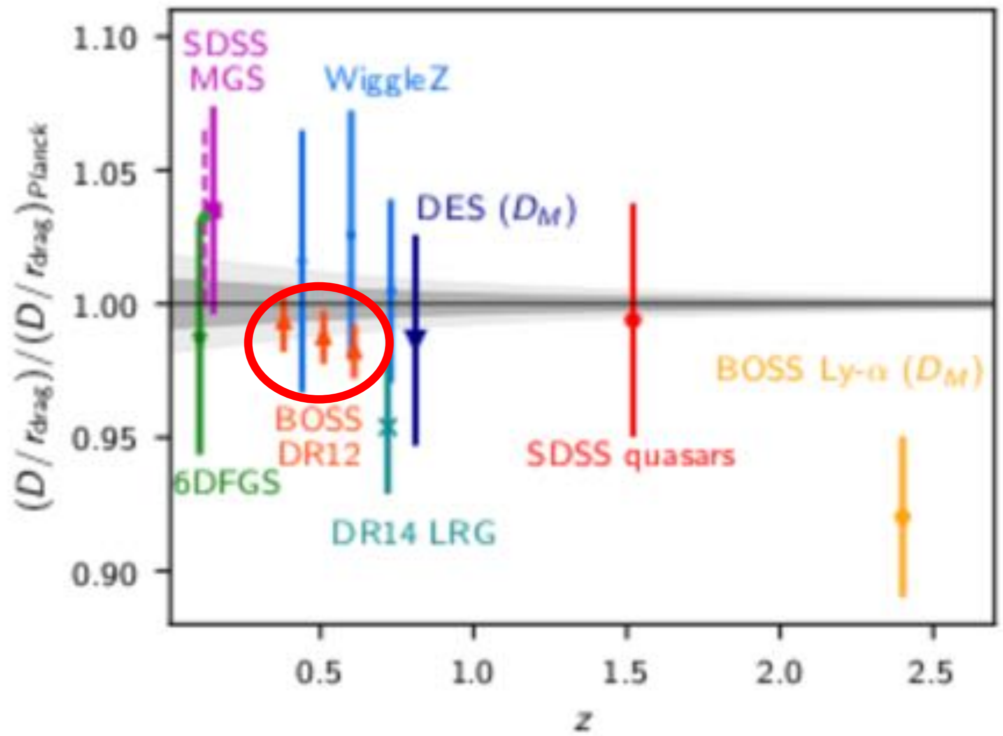
  CMASS: α=1.0144 ± 0.0098

Isotropic BAO results

- Combine transverse and longitudinal direction with
  $D_V = \left((1+z)^2 D_A(z)^2 \, . \, cz . H(z)^{-1} \right)^{1/3}$
- New "Hubble" diagram with BAO like SNIa with D_V/r_S
- BAO scales perfectly consistent with Planck 2018

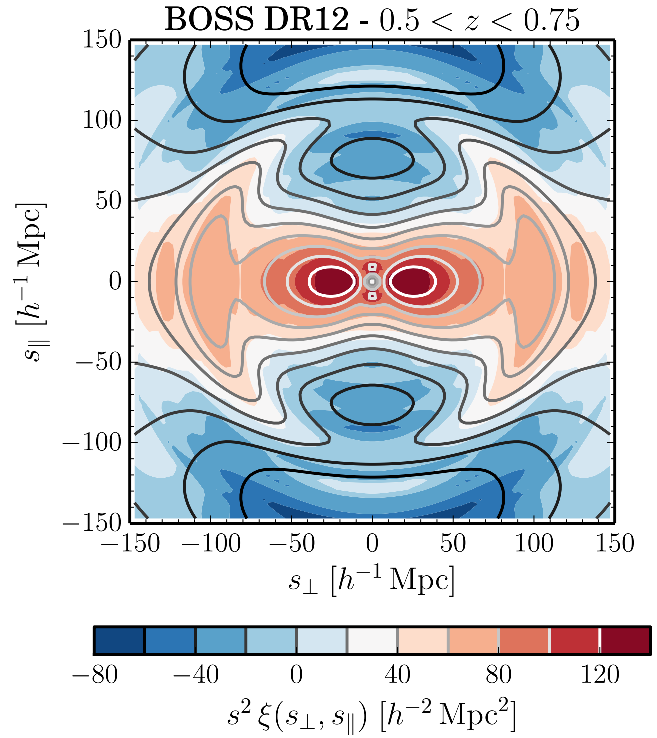


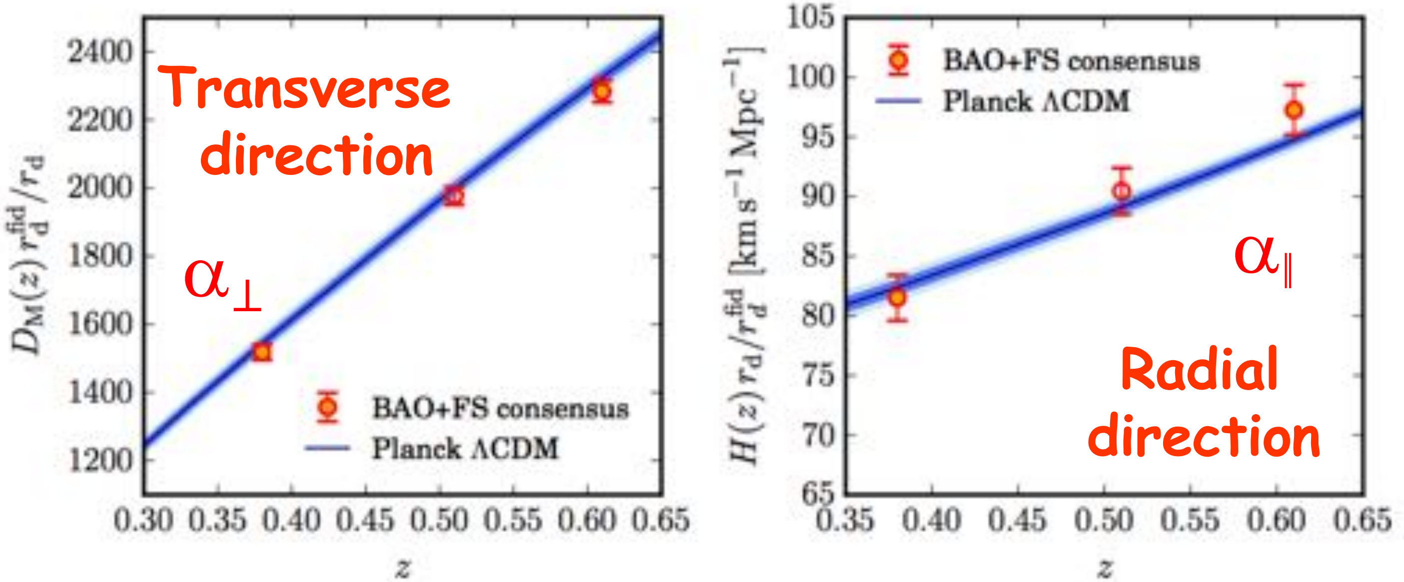
BOSS-DR11. Anderson et al., 2014



Planck 2018. VI. cosmological parameters

Anisotropic BAO results





- Redshift distortion clearly seen at <z>~0.6 in BOSS

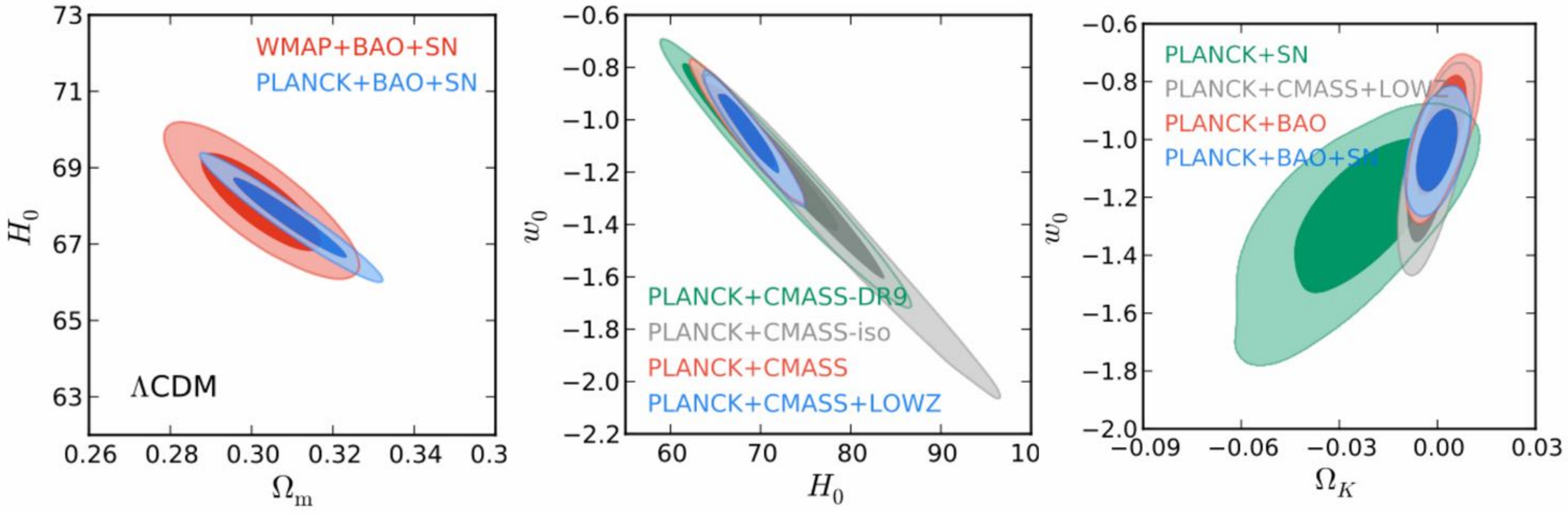
BOSS-DR12 Alam et al. (2016)

- Independent measurements of H(z) et $D_A(z)$
- No Alcock-Paczynski effect observed: $\alpha_\perp$ and $\alpha_\parallel$ are consistent
- FS= Full-shape fits with measurement of RSD ($f\sigma_8$)

Constraints on Friedman equation

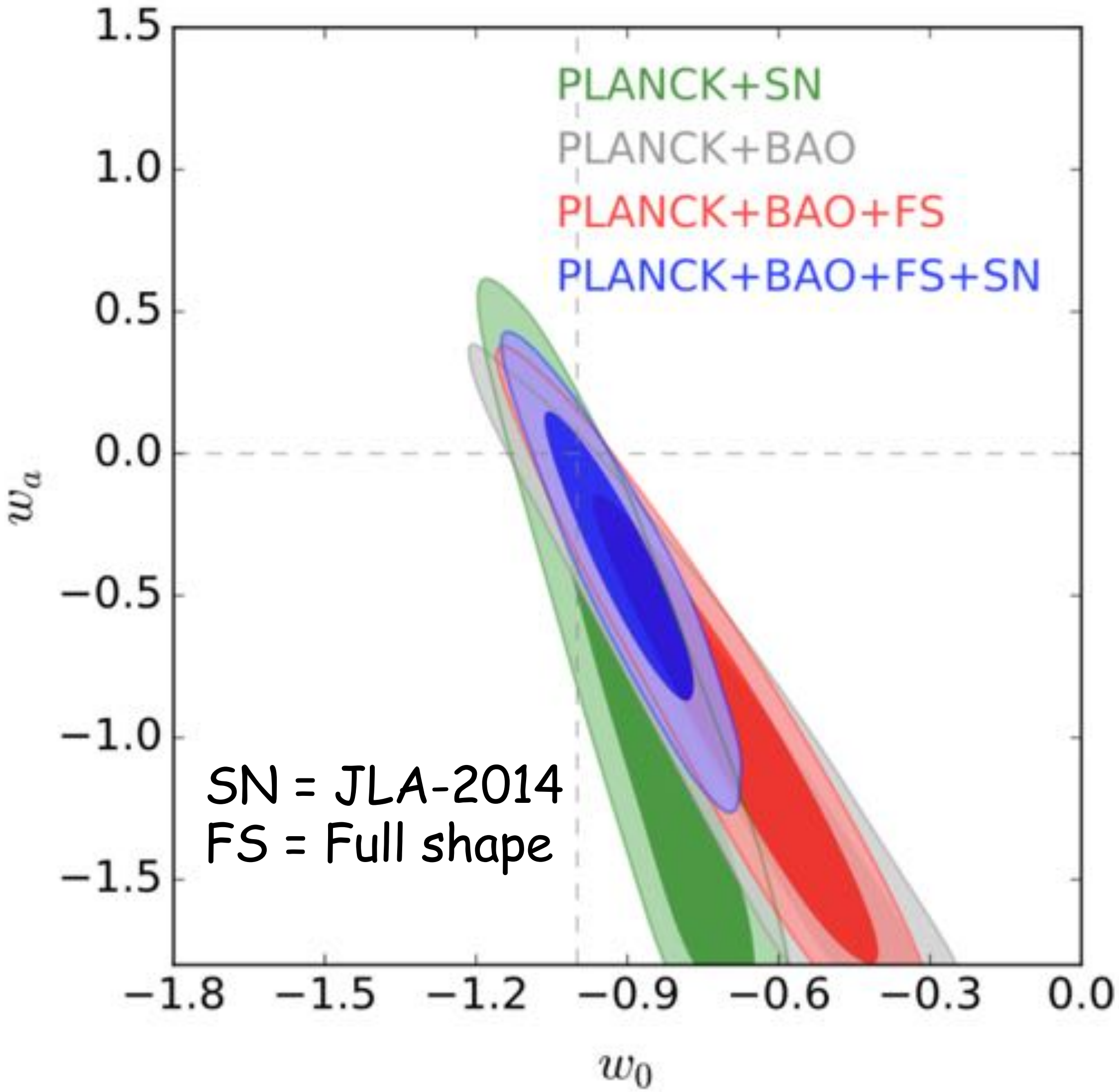
$$H^2(a) = H_0^2\Big[\Omega_R a^{-4} + \Omega_M a^{-3} + \Omega_k a^{-2} + \Omega_{DE} \exp\left\{3\int_a^1 \frac{da'}{a'}\left[1 + w(a')\right]\right\}\Big]$$

BOSS-DR11. Anderson et al., 2014



2-param. ΛCDM model	3-param. wCDM model	4-param. owCDM model

Dark Energy: Equation of state



BOSS-DR12 Alam et al. (2016)

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

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

- Planck+BAO:

  $w_0 = -0.63\pm0.20$

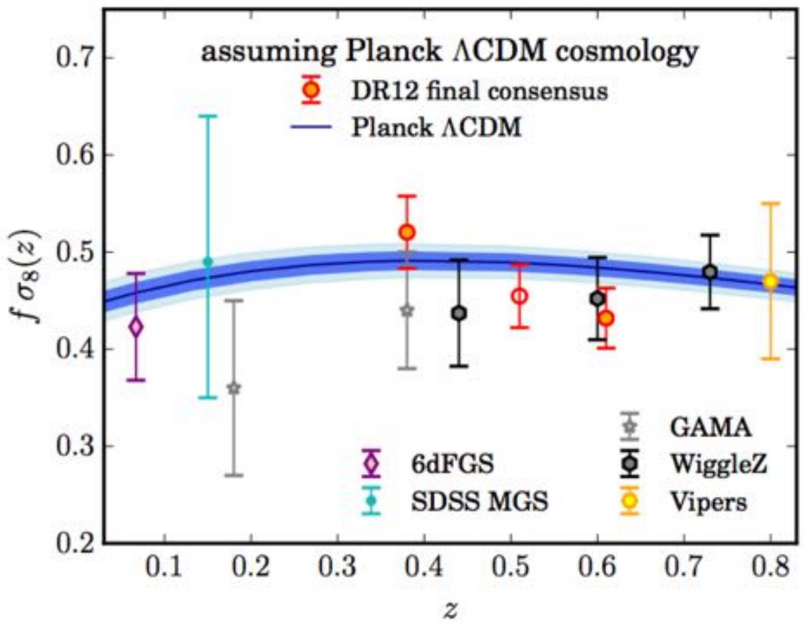
  $w_a = -1.16\pm0.55$

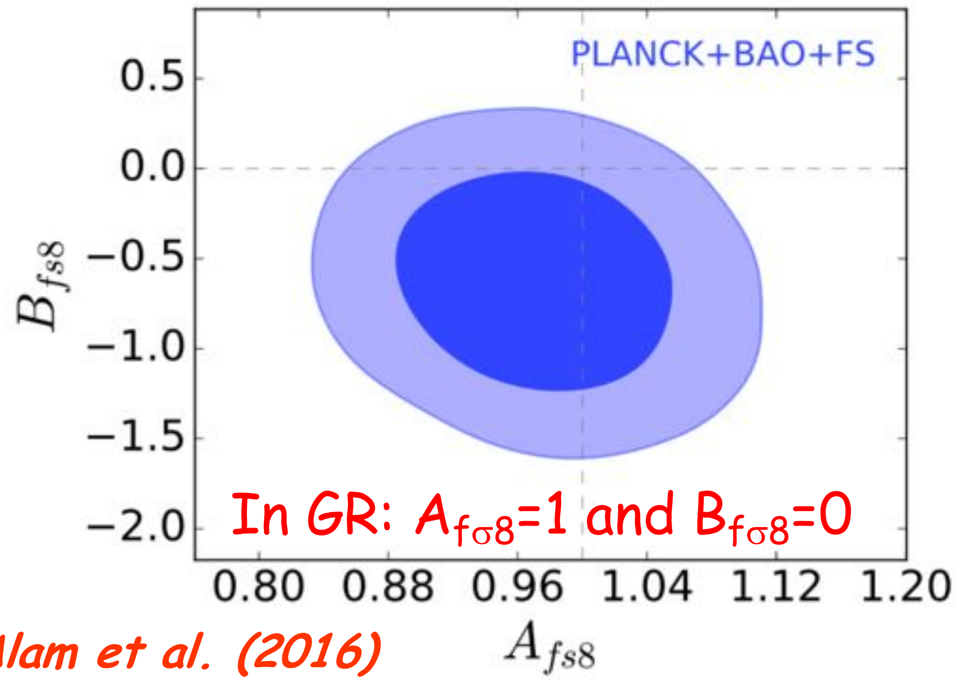
- Planck+BAO+FS+SN:

  $w_0 = -0.91\pm0.10$

  $w_a = -0.39\pm0.34$

Redshift Space Distortions





BOSS-DR12 Alam et al. (2016)

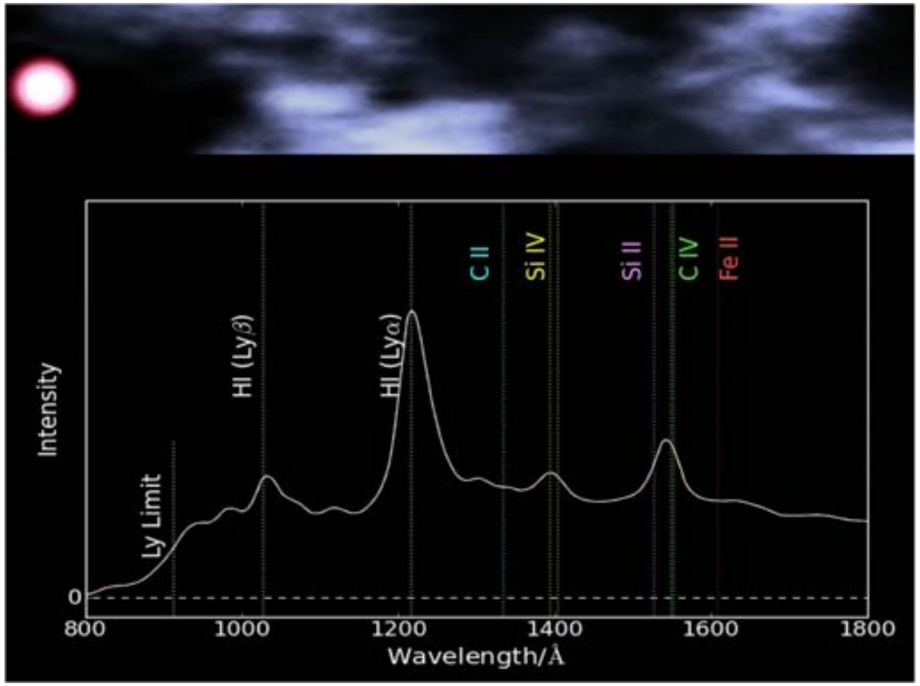
- Amplitude of the flattening gives a dependence on $f(z)\sigma_8(z) \propto dG/d\ln(a)$, where G is linear growth rate

- Test of GR with $f\sigma_8$ or γ where $f(z) \propto (\Omega_m(z))^\gamma$ in GR, $\gamma=0.554$

- Deviation from GR: $f\sigma_8 \rightarrow f\sigma_8\,[A_{f\sigma8}+B_{f\sigma8}.(z-z_p)]$

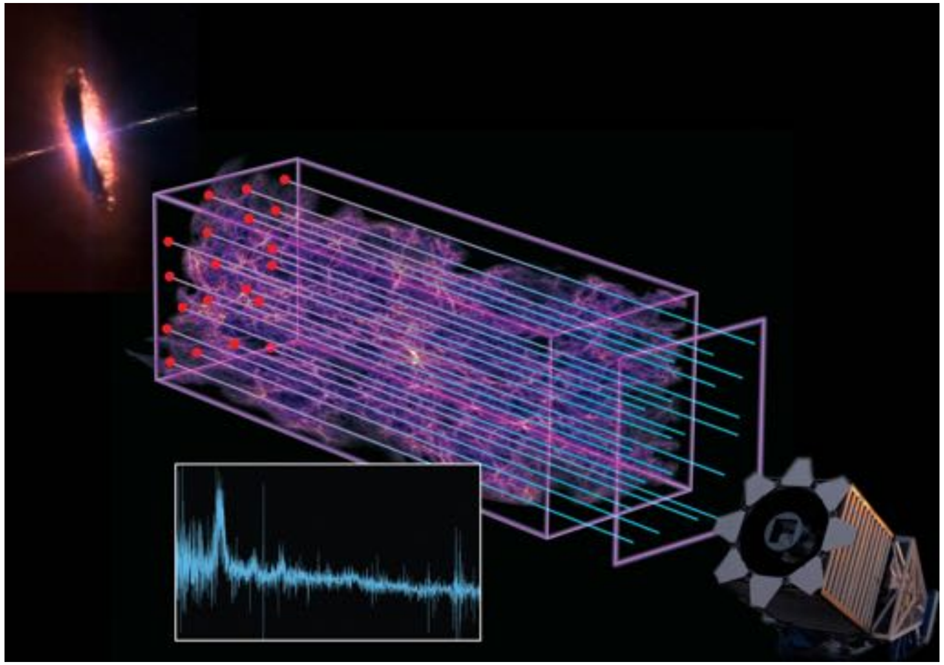
  $A_{f\sigma8}=0.96\pm0.06$ and $B_{f\sigma8}=-0.62\pm0.40$

BAO with Ly-α forests



Principles

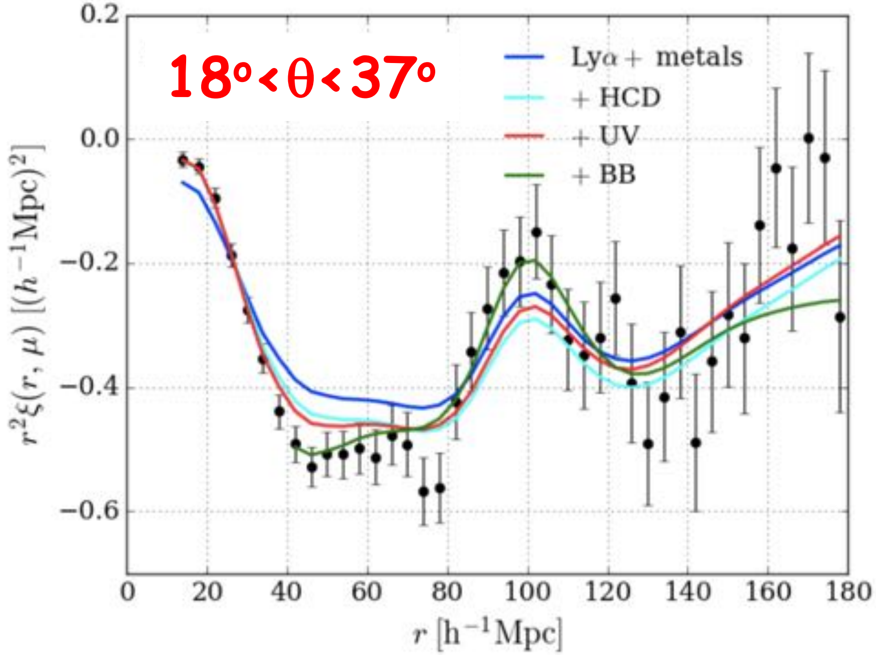
- Use Ly-α forests of quasars ($2.2<z<4$)
- HI absorption in IGM along the line of sight of QSOs
- We expect low density gas (IGM) to follow the dark matter density



Detection of BAO

- 3D BAO: Correlation between the different lines of sight
- BAO measurement for z~2.3 (11 billions years ago).
- Better precision in radial direction (H(z) measurement)

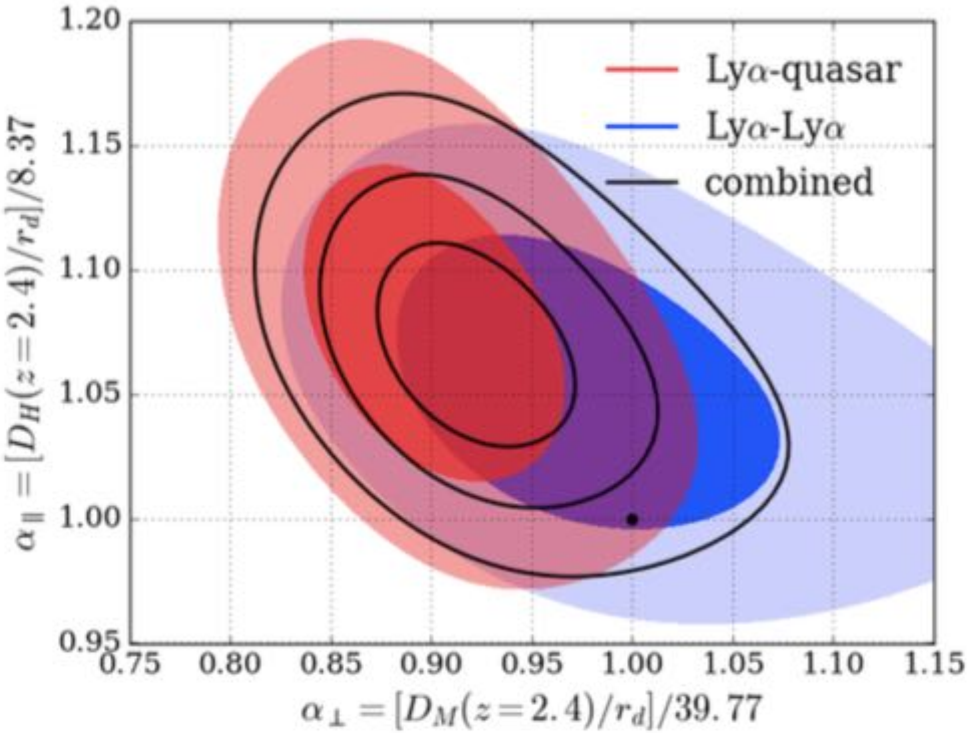
BAO in Ly-α



Bautista, J et al., (2016)
Du Mas des Bourboux et al. (2017)

- Consistent with QSO-Ly-α cross-correlation
- ~2.5σ tension with Planck 2015

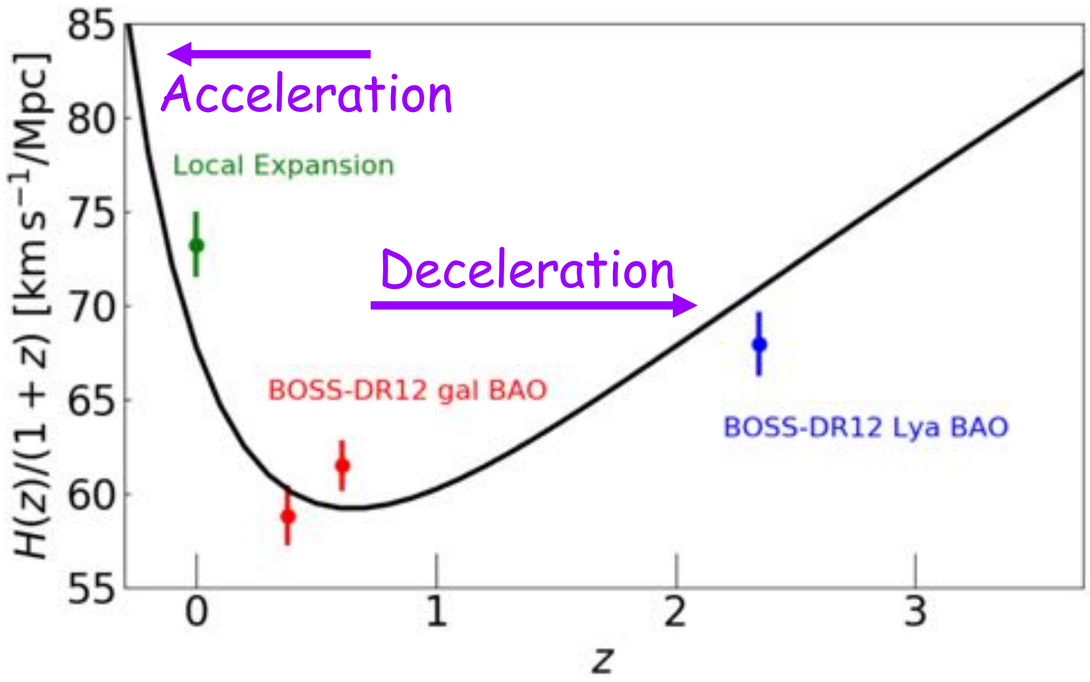
Correlation Ly-α – Ly-α
- 157 783 QSOs with 2.1<z<3.5
- Measurement of $D_A(z)$ at 6% and H(z) at 3% at z~2.3



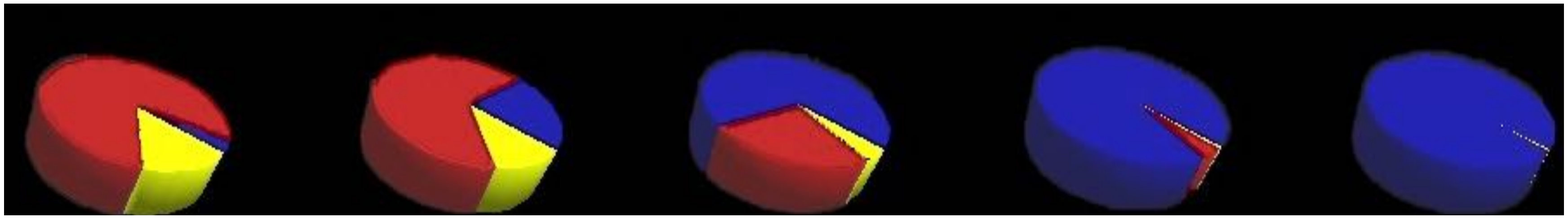
Decelerating Universe

Measurement of expansion

- First measurement of H(z) at z~2.3 (11 billions years from now)
- Deceleration of the expansion for z>0.8, when matter dominated
- Slight tension with Planck



Dark Matter Atoms - stars Dark Energy

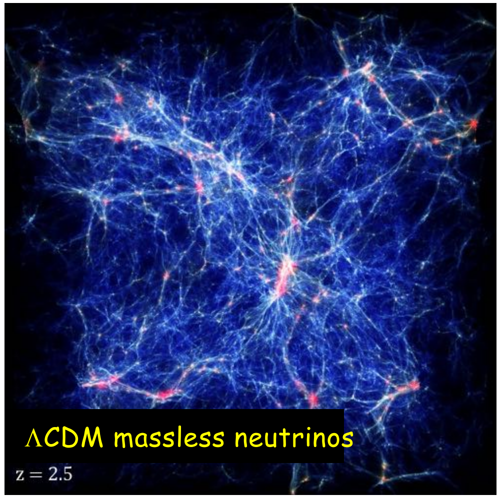


2 6 14 24 35

Age of Universe (Myears)

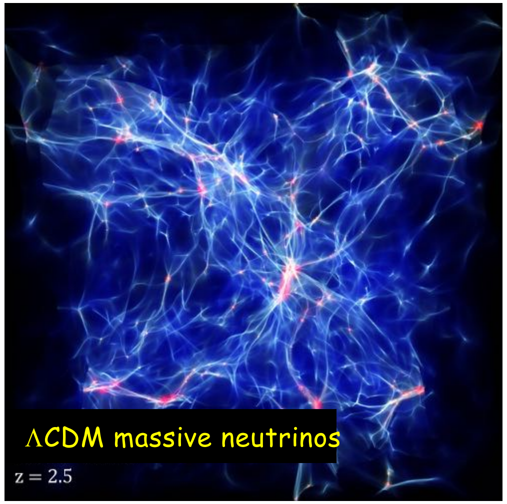
Quasars Today

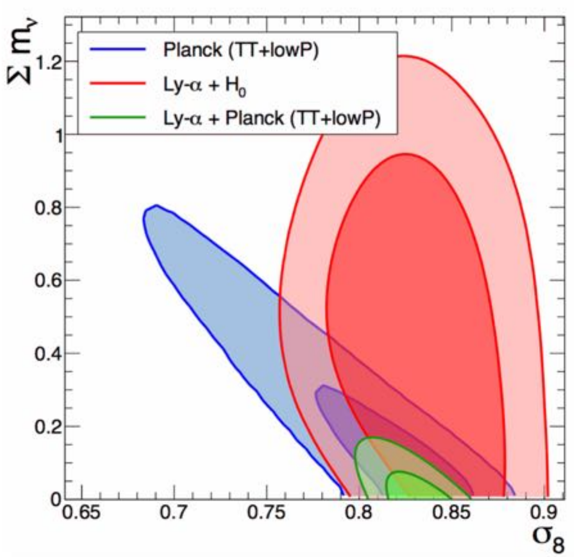
1D power spectrum: Neutrino masses



Suppression of the small scales

N-body hydro simulations of IGM





N. Palanque-Delabrouille et al. (2015)

Principle:

- Neutrino free-streaming: suppression of the structures at small scales (~1 Mpc) along the line of sight.

Limits:

- With Ly-α alone:
  $\Sigma m_\nu < 1.1$ eV @95%CL
- With Planck 2015 alone:
  $\Sigma m_\nu < 0.72$ eV @95%CL
- Combined with Planck 2015
  $\Sigma m_\nu < 0.12$ eV @95%CL

SDSS – eBOSS

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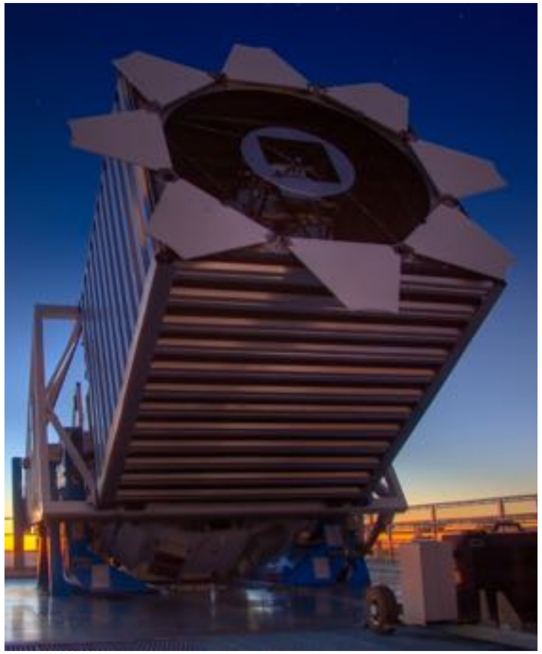
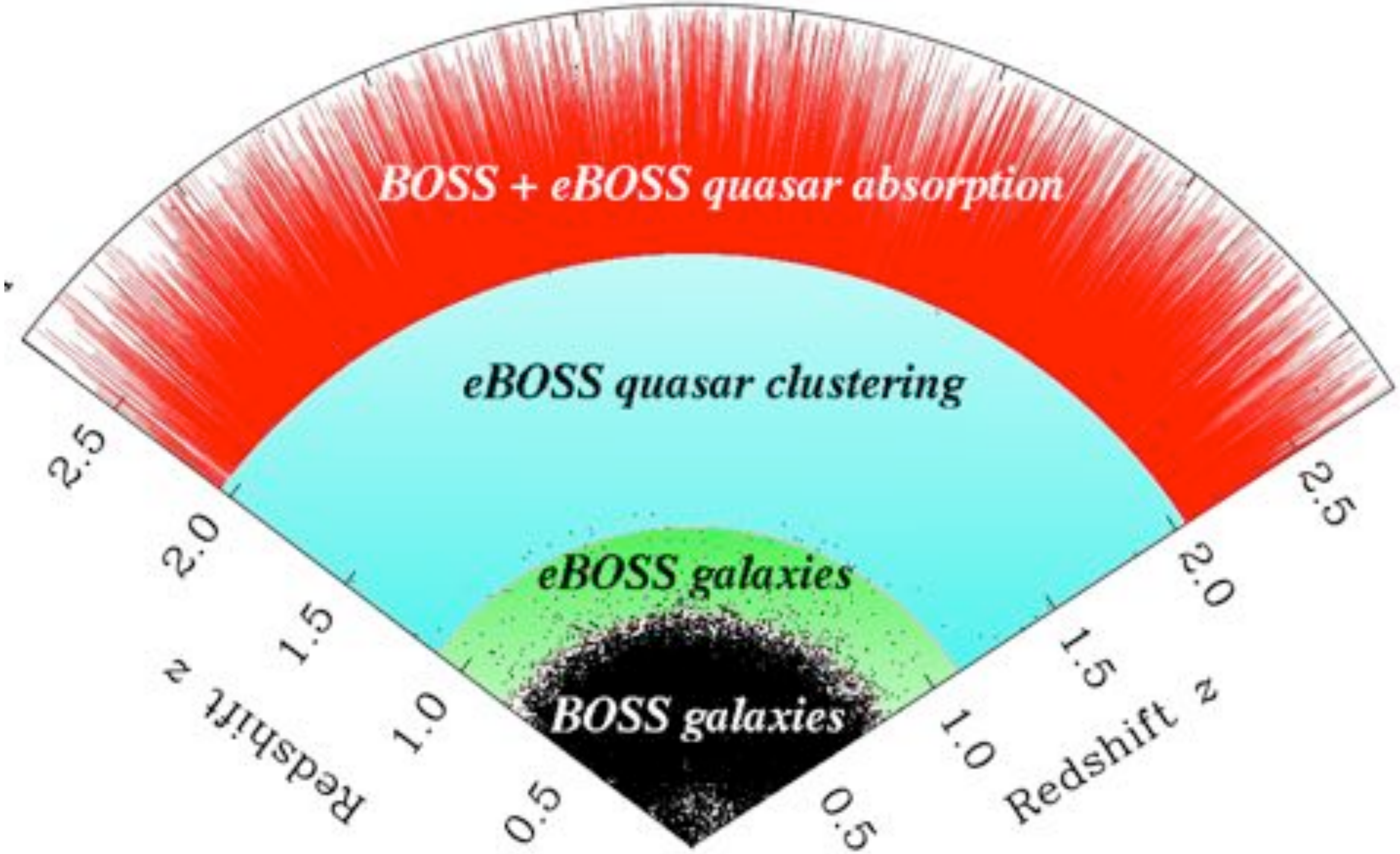
First Results

SDSS eBOSS 2014-2018





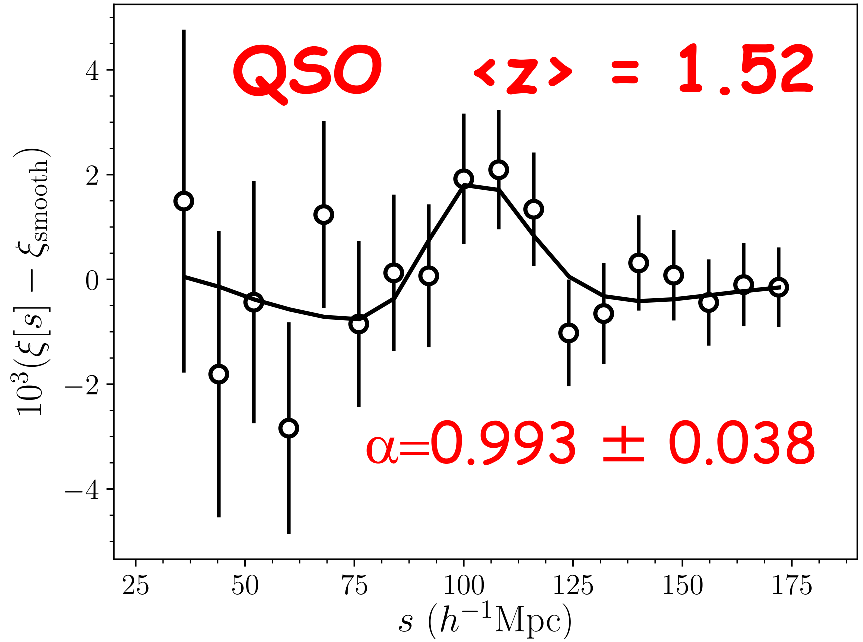
0.6<z<1.2
- LRG at z~0.7
- ELG: Emission line galaxies (stars forming)

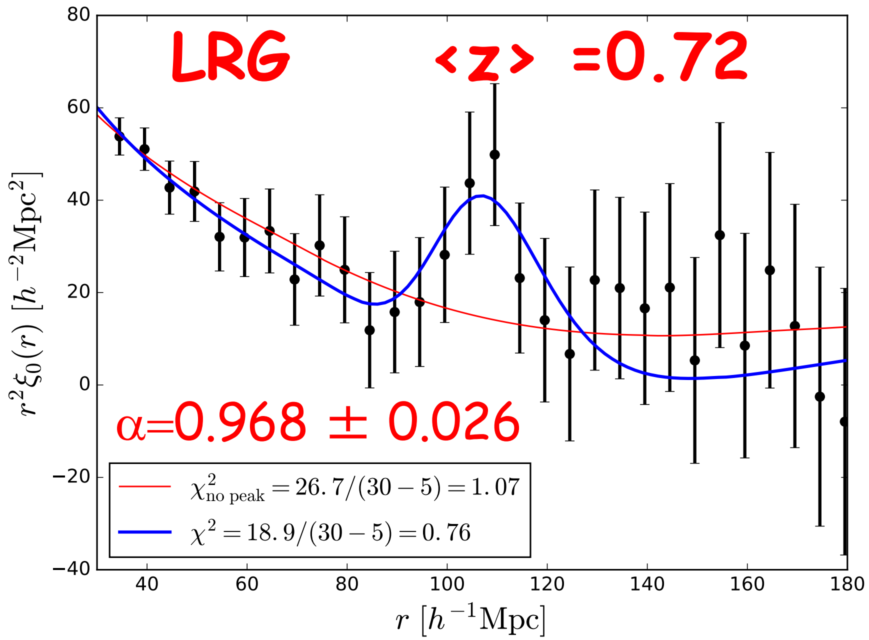
0.9<z<2.2 QSOs
- Tracers of cosmic structures
- Unexplored Universe

Ly-α QSOs, 2.2<z<5
- Improvement of selection
- ~17 deg^{-2} $\Longrightarrow$ ~30 deg^{-2}

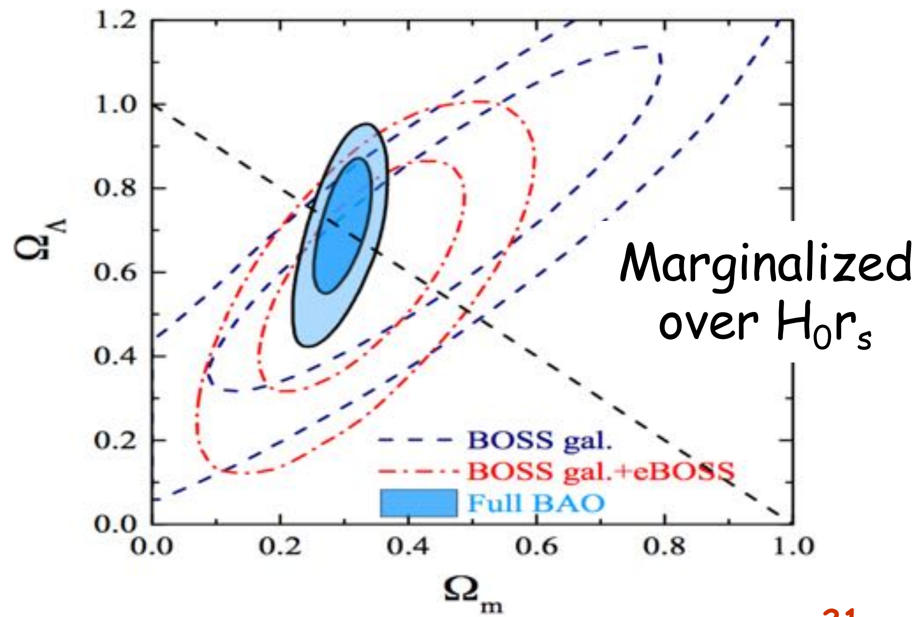
First results with BAO

- Use DR14 data: ~1/3 of the final dataset
- First observation with BAO with QSO tracers
- Ω_Λ>0 at 3.4σ only with galaxy and QSO tracers





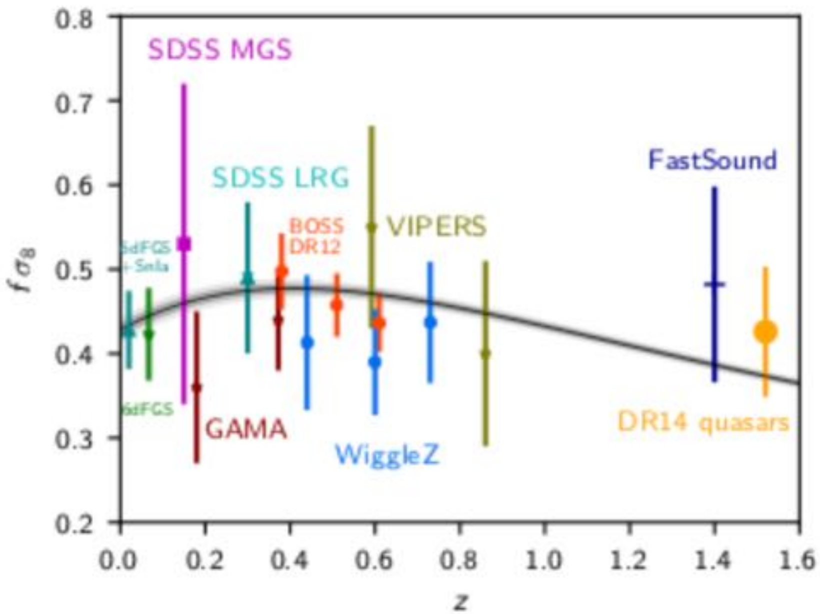
Bautista et al., 2017

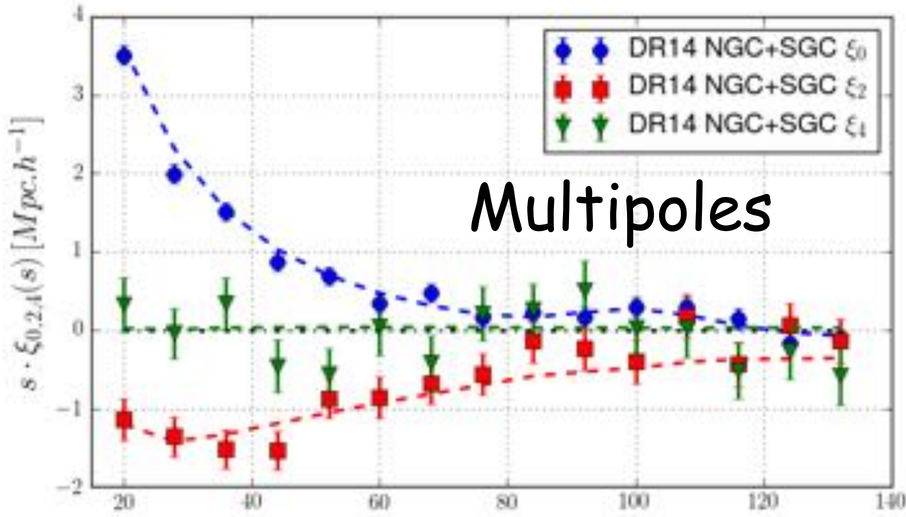


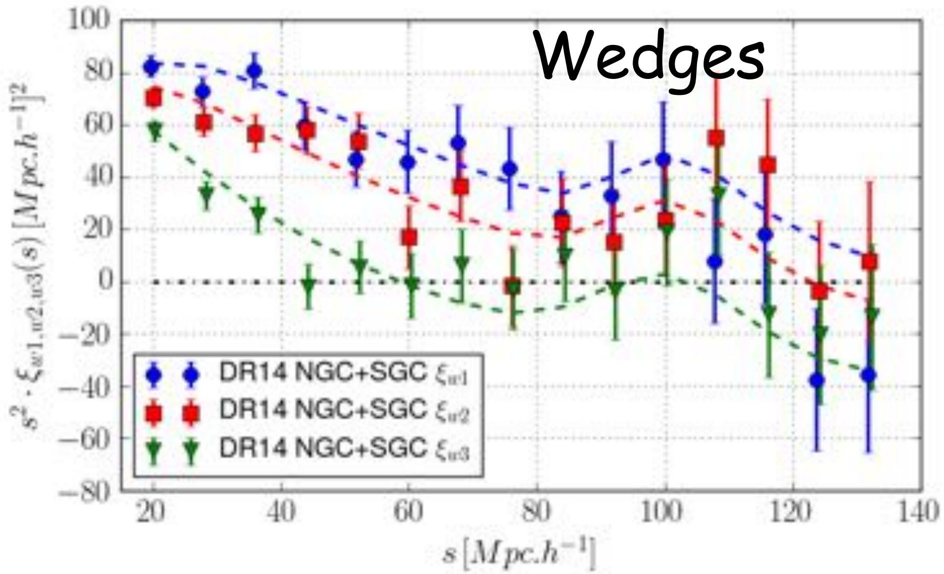
eBOSS-DR14 Ata et al., 2017

First results with RSD

- Use DR14 data: ~1/3 of the final dataset
- RSD clearly visible in the quadrupole
- First measurement of $f\sigma_8$ at z~1.5





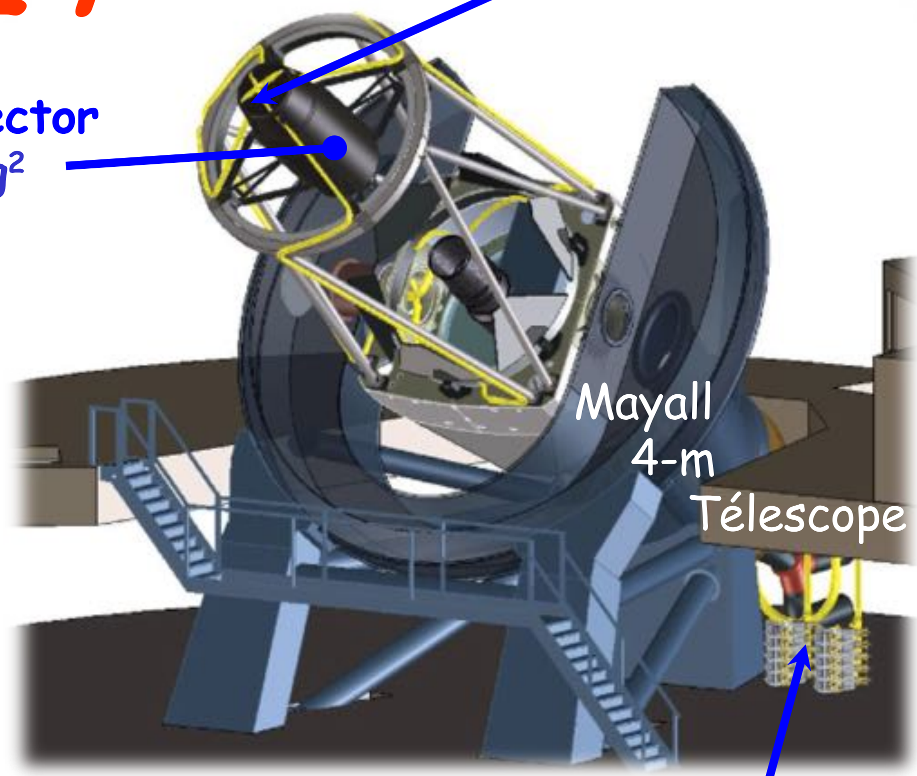


Planck 2018. VI. cosmological parameters

Zarrouk et al., (2018)

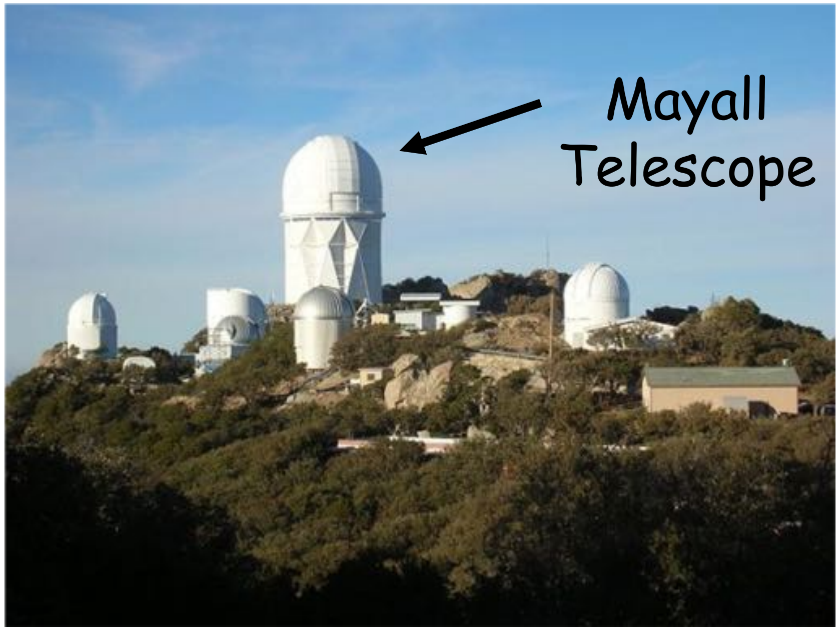
DESI

DESI 2019-2024



Scientific Project

- 14000 $\deg^2$ survey for $0.05<z<3.7$
- Main scientific goals : RSD and BAO
- International collaboration
- 74 institutions (46 non-US)
- 630 members
- ~40 French scientists and engineers



Instrument

- 4-m telescope at Kitt Peak (Arizona)
- Wide FoV (~ 7 $\deg^2$)
- Robotic positioner with 5000 fibers
- 10 spectrographs x 3 bands (blue, visible, red-NIR) → 360-1020 nm

DESI tracers of the Matter

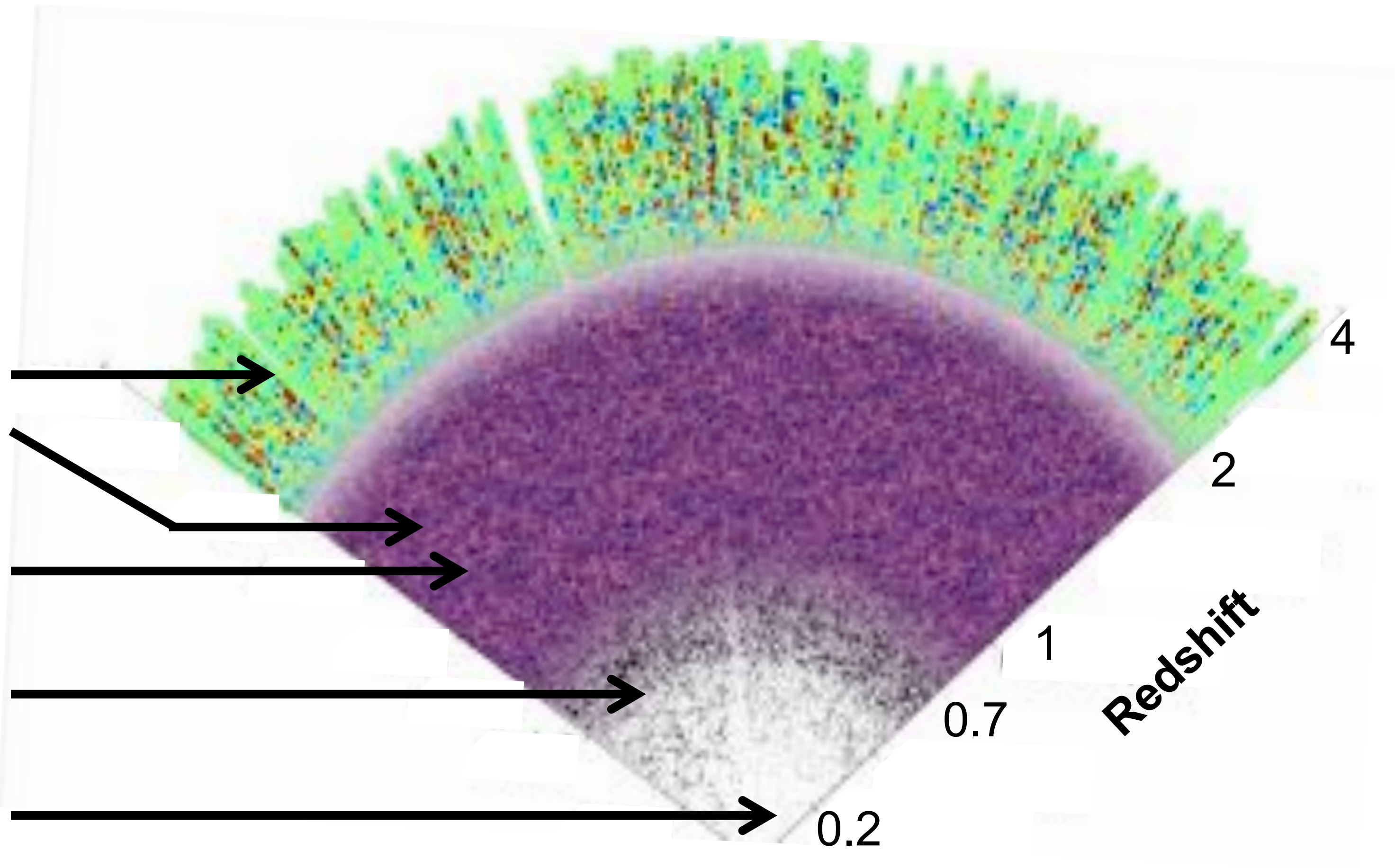
Five target classes spanning redshifts z=0.05 ➔ 3.7 for clustering
DESI will explore a x30 larger volume than the SDSS map
~35 million redshifts over 14,000 sq. degrees in five years

2.4 million QSOs
Lya z > 2.1
Tracers 1.0 < z < 2.1

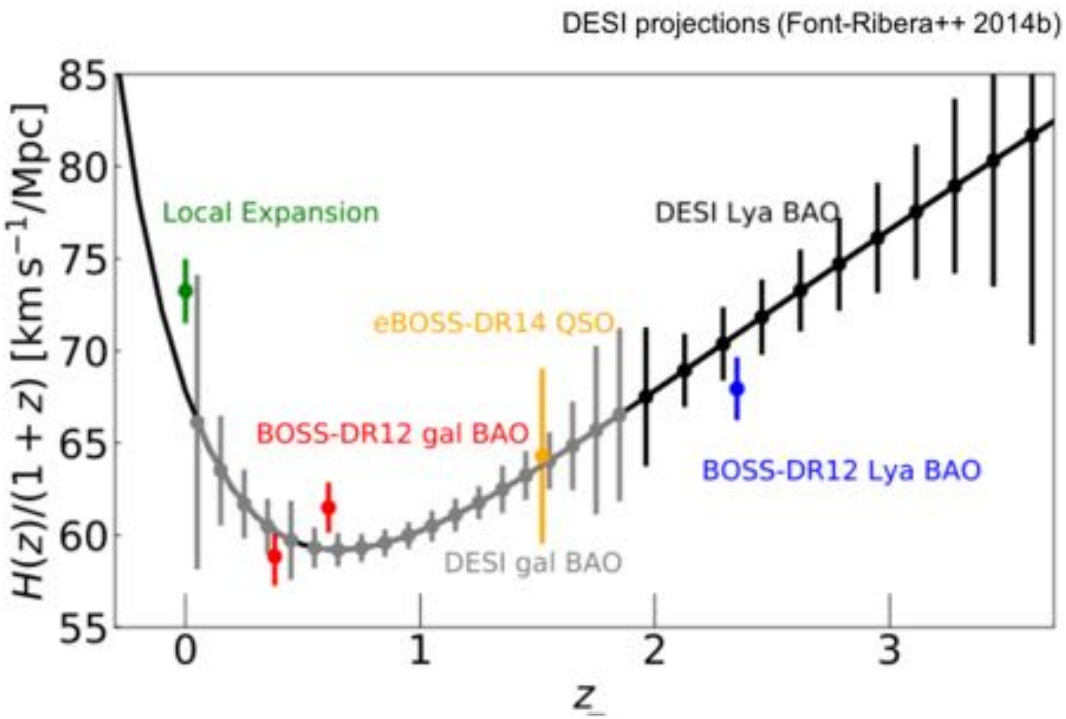
17 million ELGs
0.6 < z < 1.6

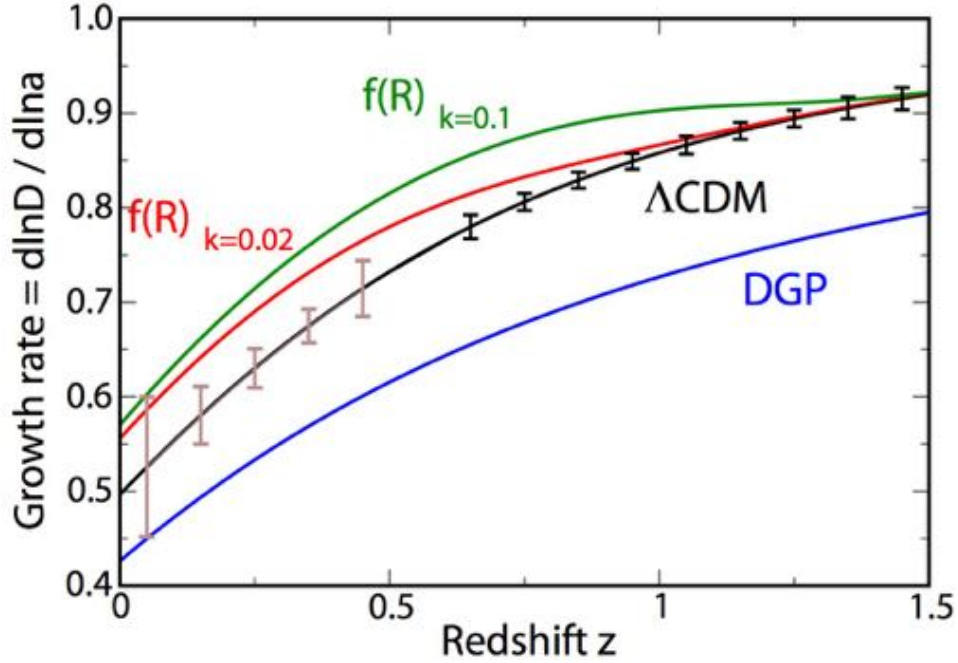
6 million LRGs
0.4 < z < 1.0

10 million brightest galaxies
0.05 < z < 0.4



Science with DESI





Improvements compared to SDSS

- **BAO:** 1 order of magnitude better $\sigma(\alpha)$ ~ 0.1%
- **RSD:** better than 1% over the full redshift range
- **Neutrino masses:** precision ~20-25 meV on Σm_ν
- **Non-gaussianity (inflation):** $\sigma(f_{NL})$ ~ 5 (DESI-only)

Status of Imaging Surveys

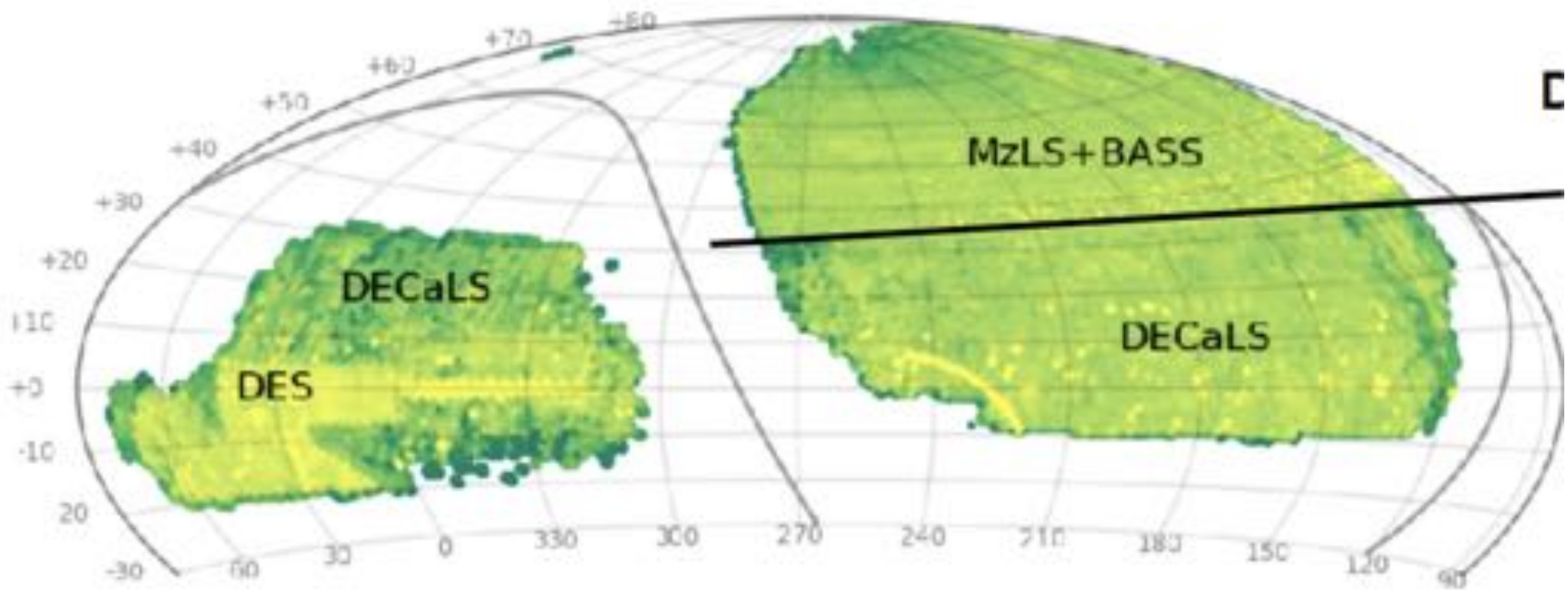
- The Target Selection is based on optical imaging developed specially for DESI
- Three optical bands (grz) + two NIR bands (W1-W2)

Three optical surveys

➢	**North**	**BASS** *gr*	95% completed
		MzLS *z*	100% completed
➢	**South**	**DECaLS** *grz*	91% completed

One infrared survey

- **All Sky WISE** (NASA)
  W_1 W_2. 100% completed

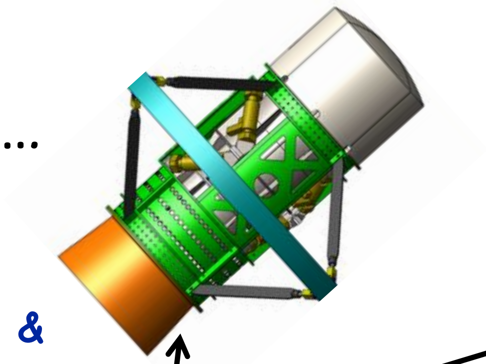


Status of DESI construction

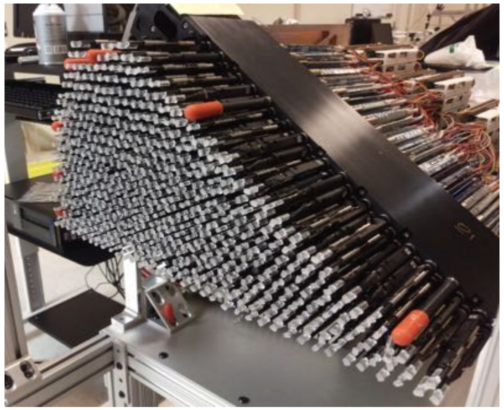
➢ Hardware Elements follows the path of a photon

Light bounces off the primary, then...

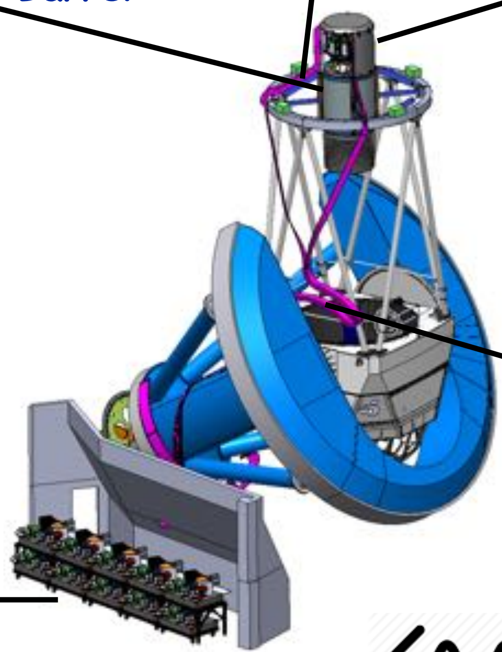
1.2 Corrector

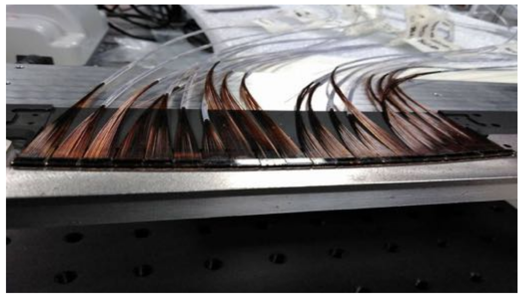


1.3 Cage & Barrel

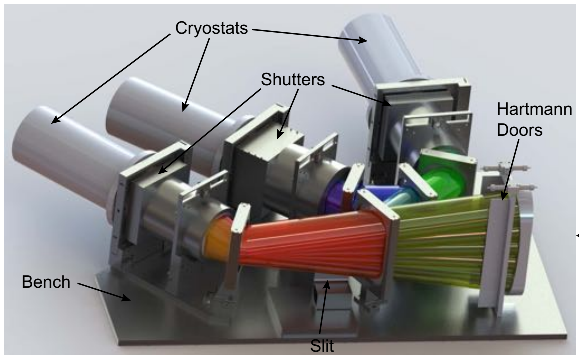


1.4 Focal Plane





1.5 Fiber System



1.6 Spectrograph

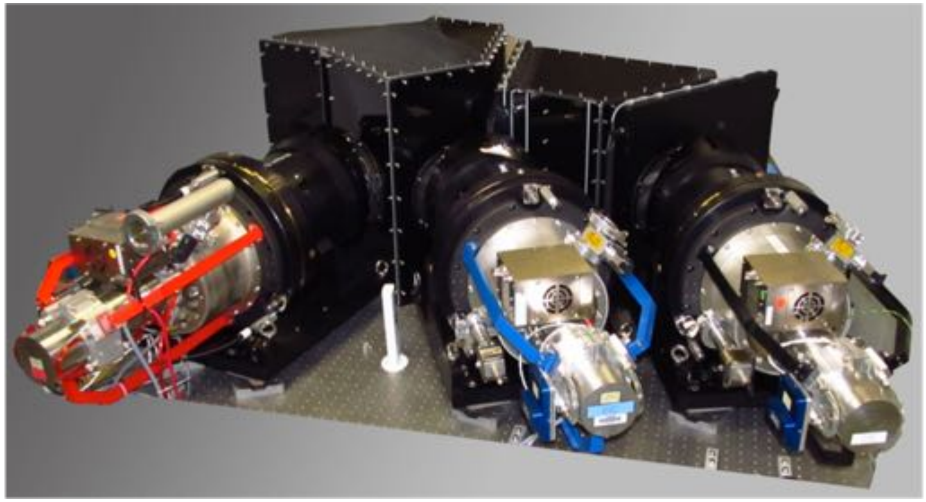
Corrector and Focal plane

Assembled corrector
at Kitt Peak

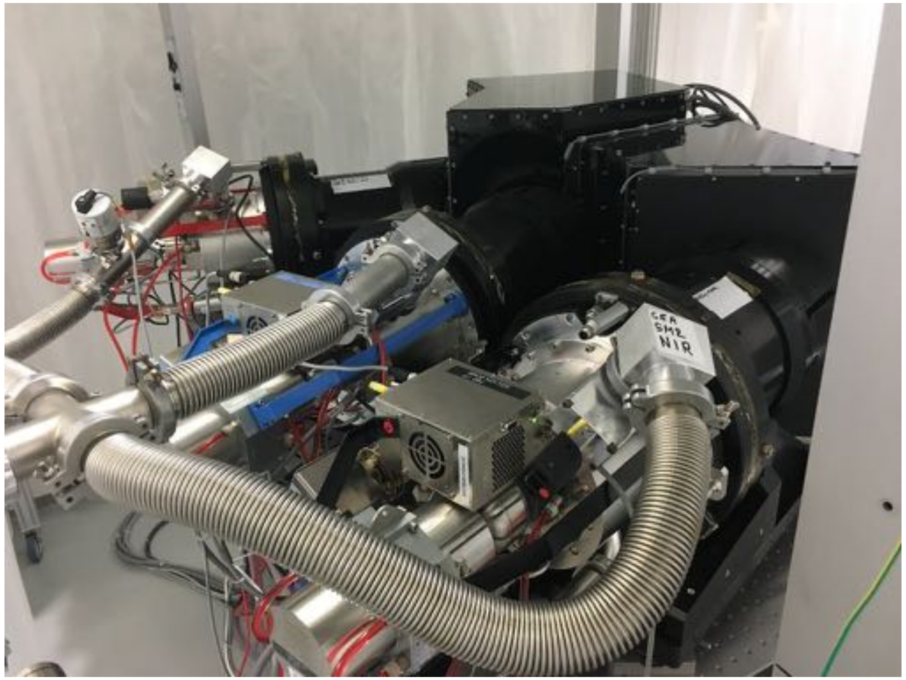
Commissioning instrument
with cameras installed

- Fall 2018: Installation of the corrector
- Feb. 2019: Commissioning of the corrector
- May 2019: Installation of focal plane with positioner

Spectrographs



First spectrograph delivered at Kitt Peak



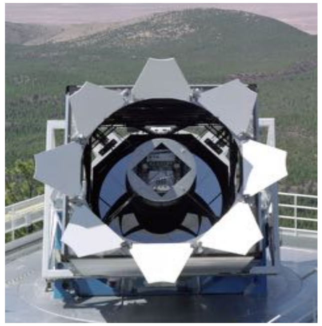
Test spectrograph #3 at Windlight

- 10 Spectrographs built in France (CEA-IN2P3-INSU)
- July 2019: Commissioning of DESI with spectrographs
- Nov. 2019: Survey Validation
- Feb. 2020: Science Survey

Summary

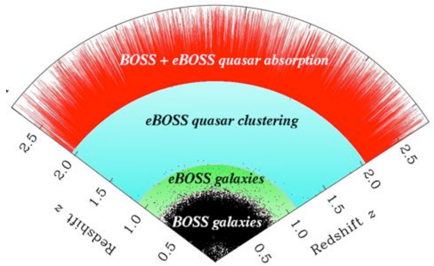
BOSS →2014

- BAO, a well established method with galaxies
- Demonstration of BAO with Ly-α forests



eBOSS 2014-2019

- Exploring unknown Universe:
  Dark matter → Dark energy
- DESI precursor (target selection,…)
- First results are very promising!



DESI 2020-2024

- BAO: one order of magnitude better
- First light next year
- Science survey will start
  in early 2020