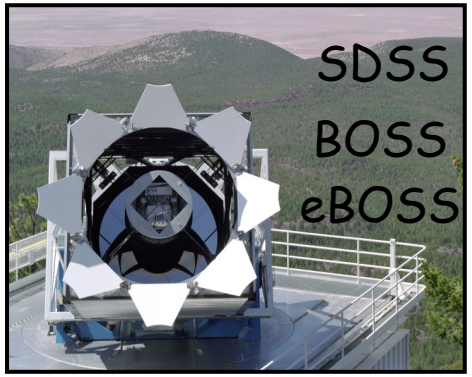
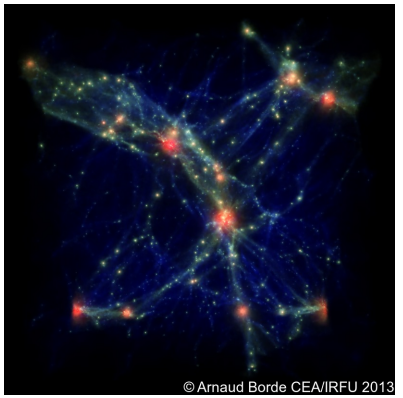
Quasar and galaxy clustering and simulations

Ch. Yèche (CEA-Saclay Irfu)





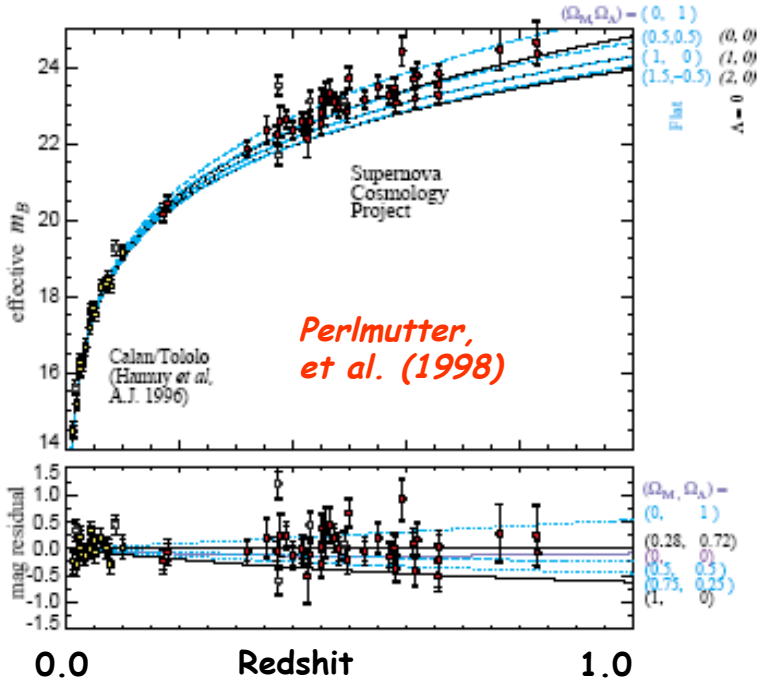
Outline:

- Concepts : BAO and RSD
- BAO and RSD surveys
- Simulations and HPC

HPC meeting at Irfu - Saclay – May 25, 2016

BAO and RSD
–
Concepts

Dark energy



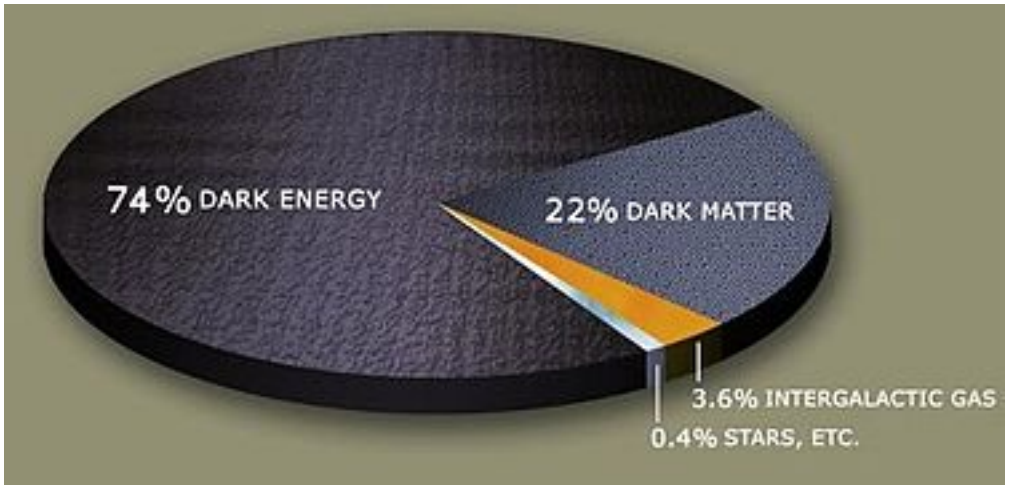
Acceleration of Universe expansion

- In 1998 revolution of cosmology with standard candles, SNIa
- SNIa were dimmer (~0.2 mag), ~10% further away than expected with Ω_m =1

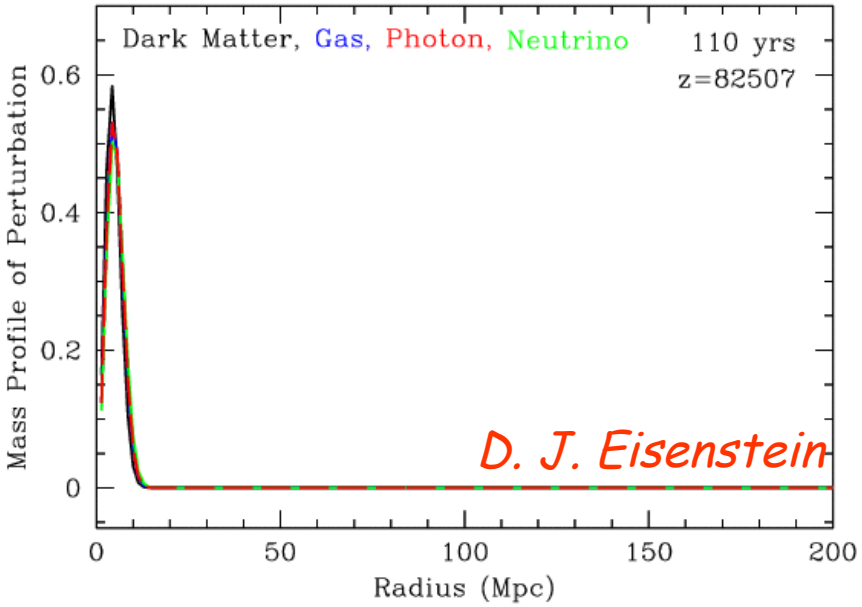
Concordance Model

- ΛCDM with GR
- Study of the nature of DE

$$w=P_{DE}/\rho_{DE}=w_0+w_a z/(1+z)$$



A probe for Dark Energy: Baryonic Acoustic Oscillations



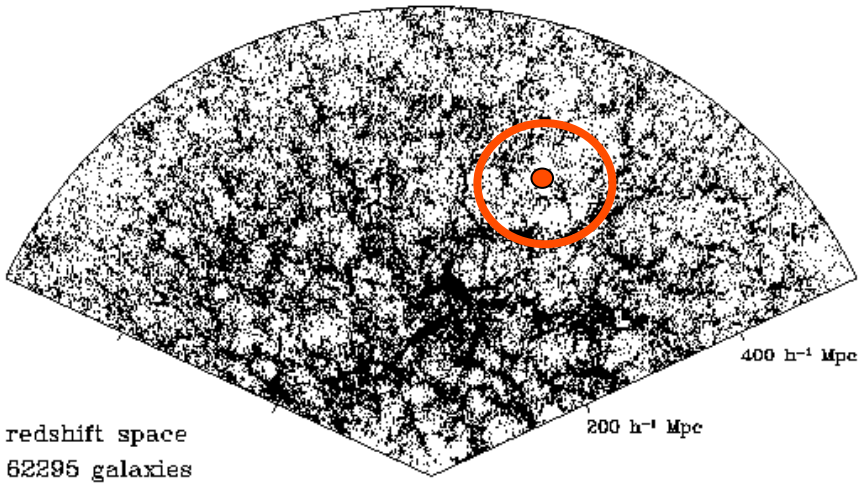
Acoustic propagation of an overdensity:

- 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.

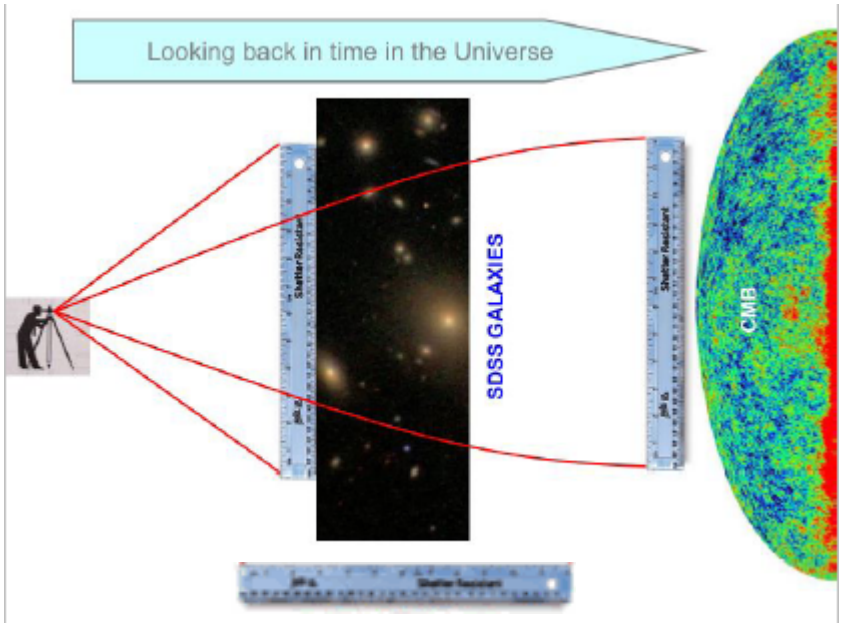
⇒ **Standard Ruler**



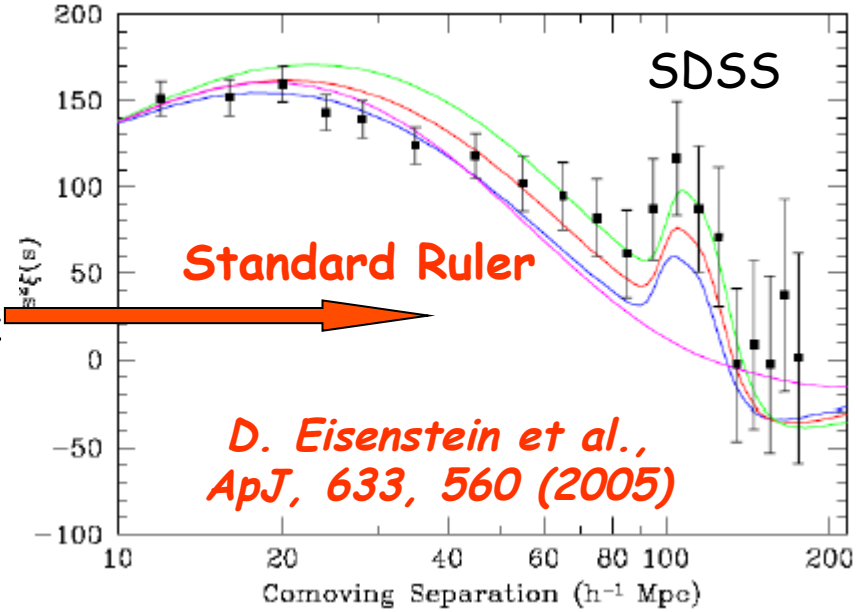
Observation of baryonic acoustic peak

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



H(z)



A 3D measurements:

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

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

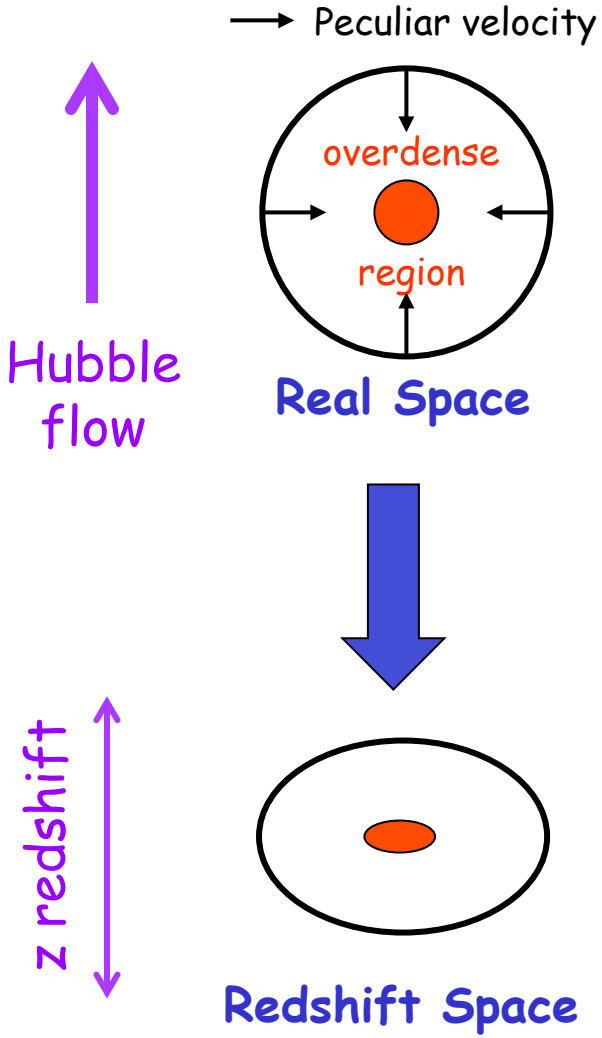
⇒ Sensitive to angular distance $D_A(z)$

- **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 gravitation (5-40 Mpc) at cosmological distance (Gpc)

- Distortion are quantitatively measured by multi-poles decomposition

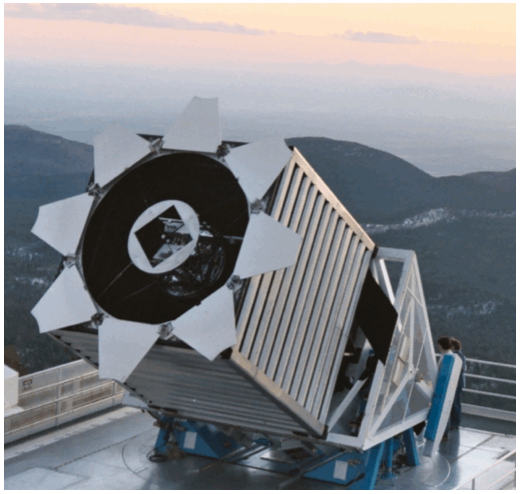
$$\xi(r,\cos(\theta)) = \sum_{\ell=0,2,4...} b^2 C_\ell \xi(r) P_\ell(\cos(\theta))$$

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

N. Kaiser, MNRAS 227, 1 (1987)

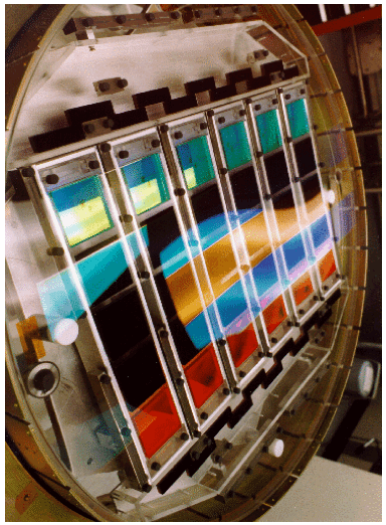
BAO and RSD Surveys

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

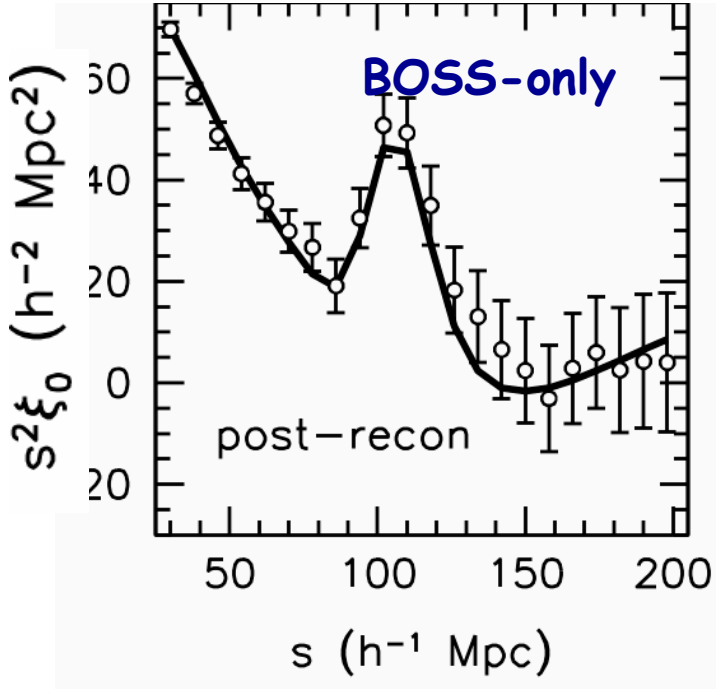
- 1.2 millions of Luminous Red Galaxies (light emitted 6 billions years ago, z~0.6)

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

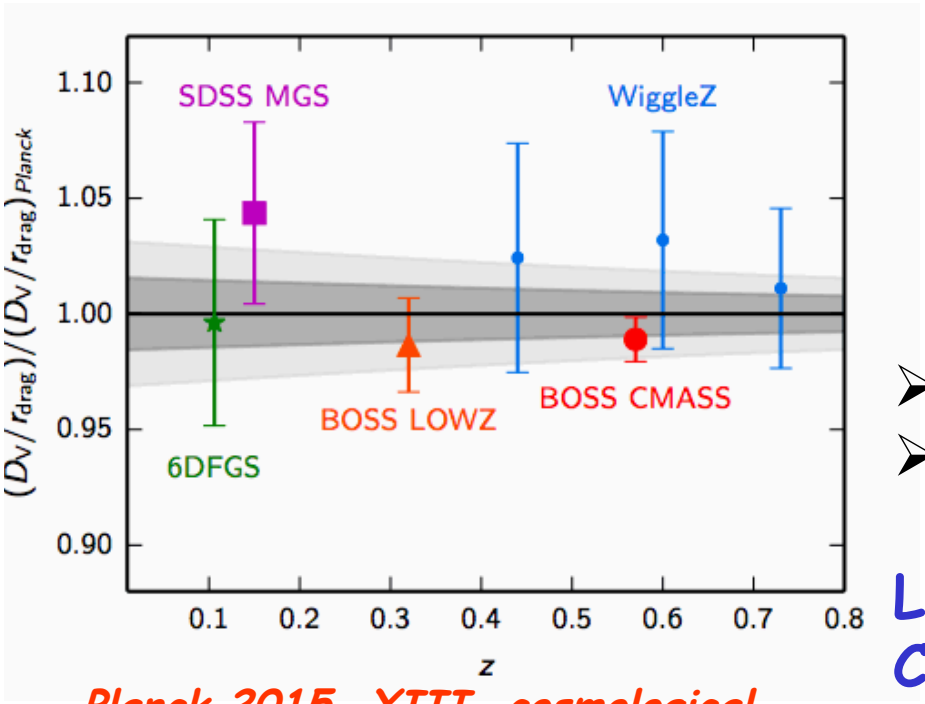
BOSS completed in spring 2014

BAO in Correlation Function

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



L. Anderson (alphabetical) et al., MNRAS 441, 24 (2014)



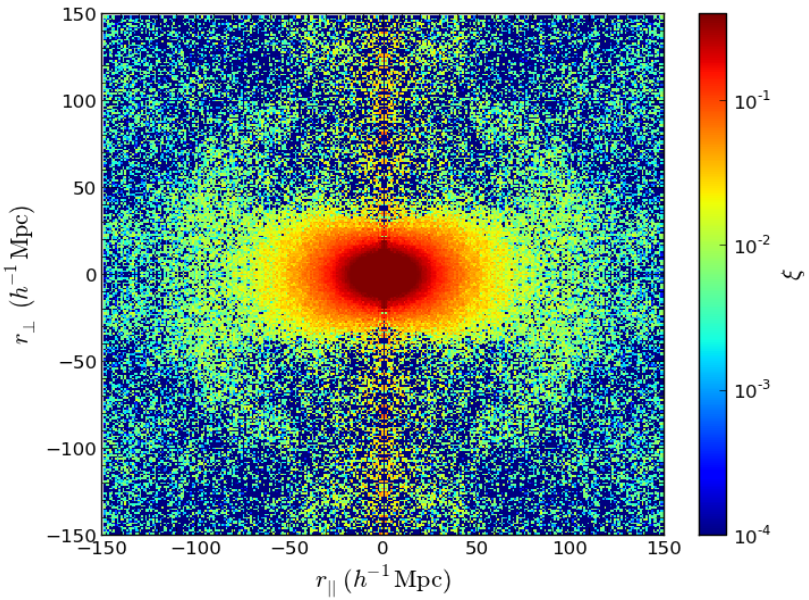
Planck 2015. XIII. cosmological parameters.

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

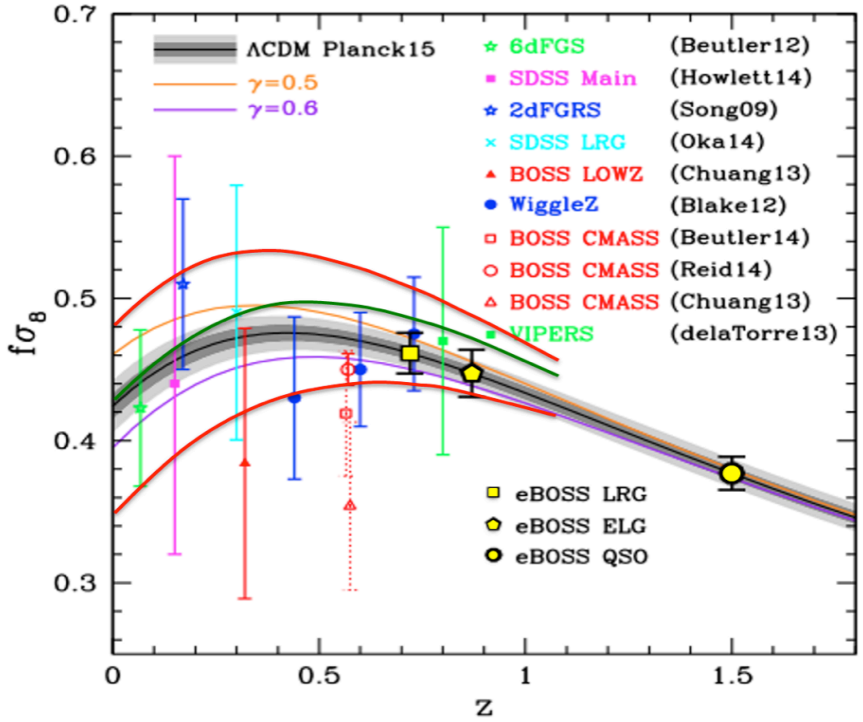
Low-z (0.15<z<0.43) : α=1.018 ± 0.021

CMASS (0.43<z<0.7) : α=1.0144 ± 0.0098

Redshift Space Distortions



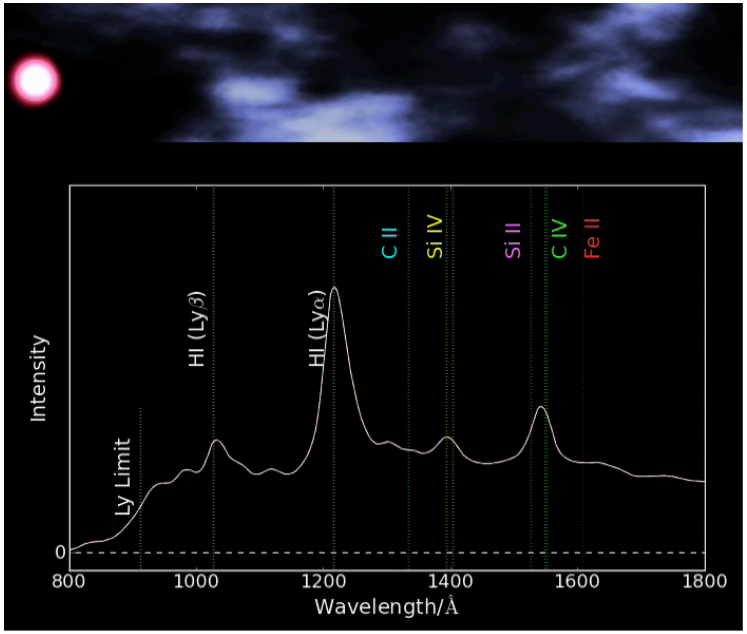
L. Samushia et al., MNRAS 439, 3504 (2014)



- 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, γ=0.554

BAO with Ly-α forests

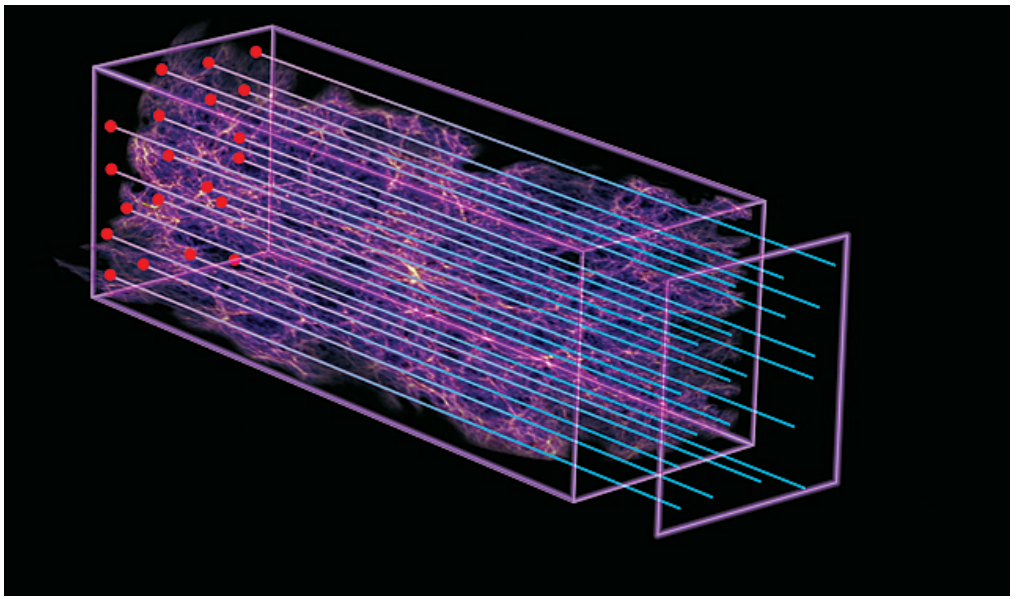


Principles

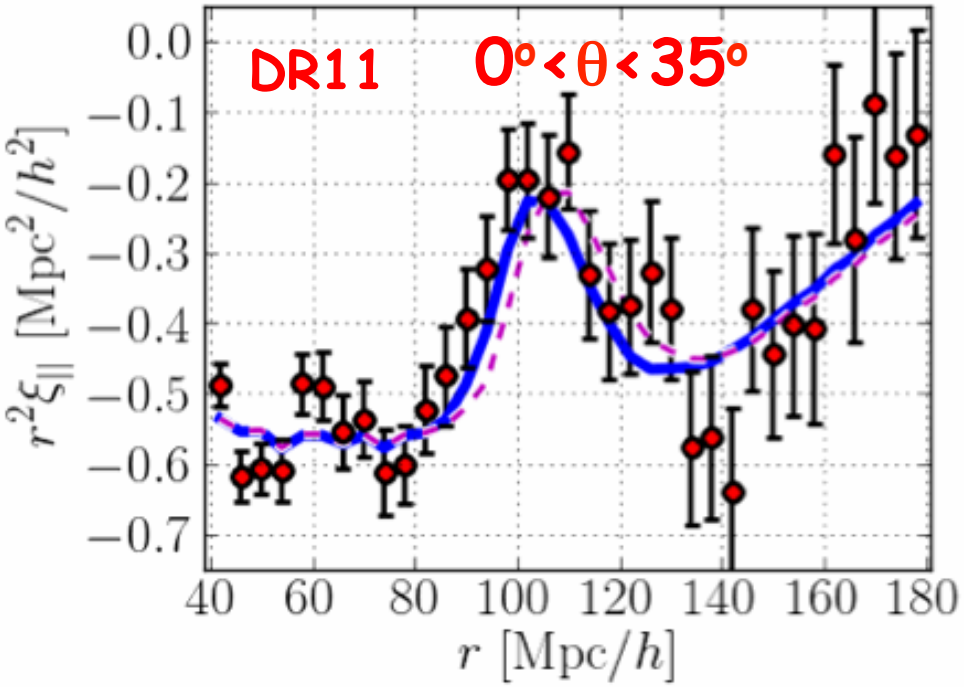
- Use Ly-α forests of quasars (2.2<z<4)
- HI absorption in IGM along the line of sight of QSOs
- We expect low density gas (IGM) to follow the dark matter density

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

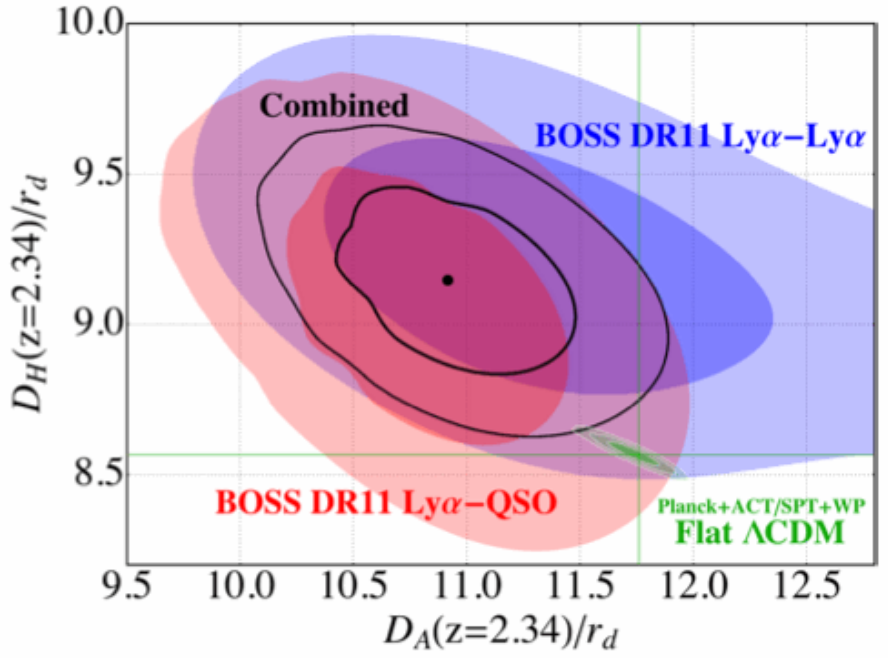


T. Delubac et al., A&A, 574, A59 (2015)

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

Correlation Ly-α – Ly-α

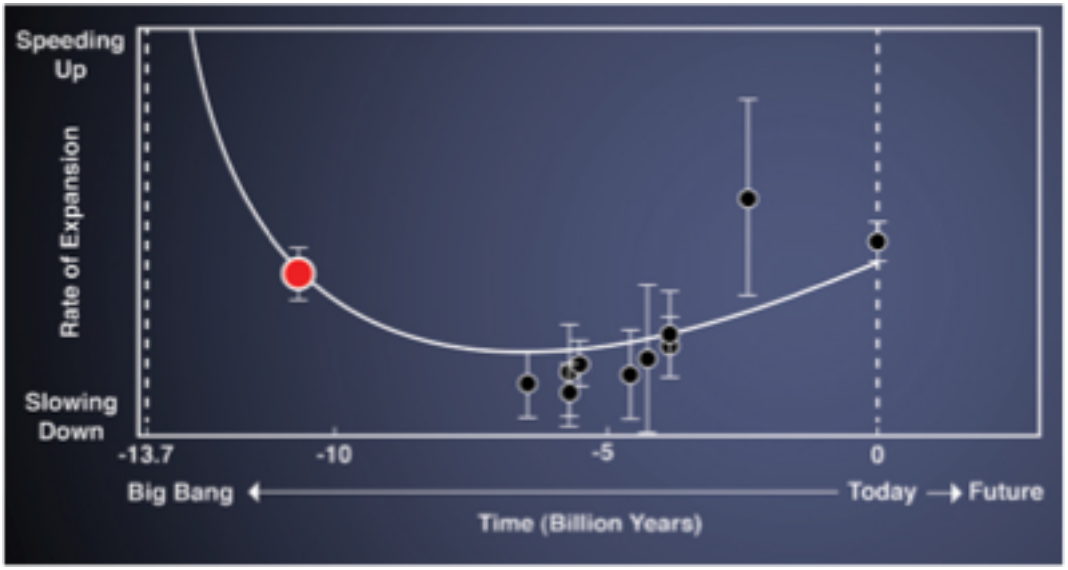
- ~90% of the final survey (DR11)
- 137 532 QSOs with 2.1<z<3.5
- Measurement of $D_A(z)$ at 6% and H(z) at 3% at z~2.3



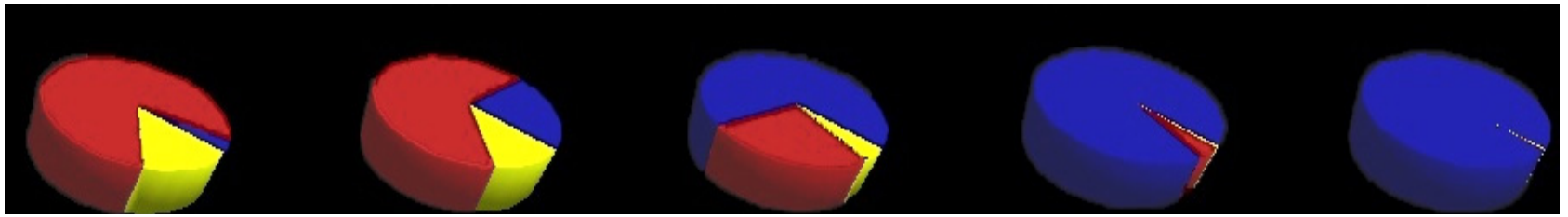
Decelerating Universe

Measurement of expansion

- First measurement of H 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

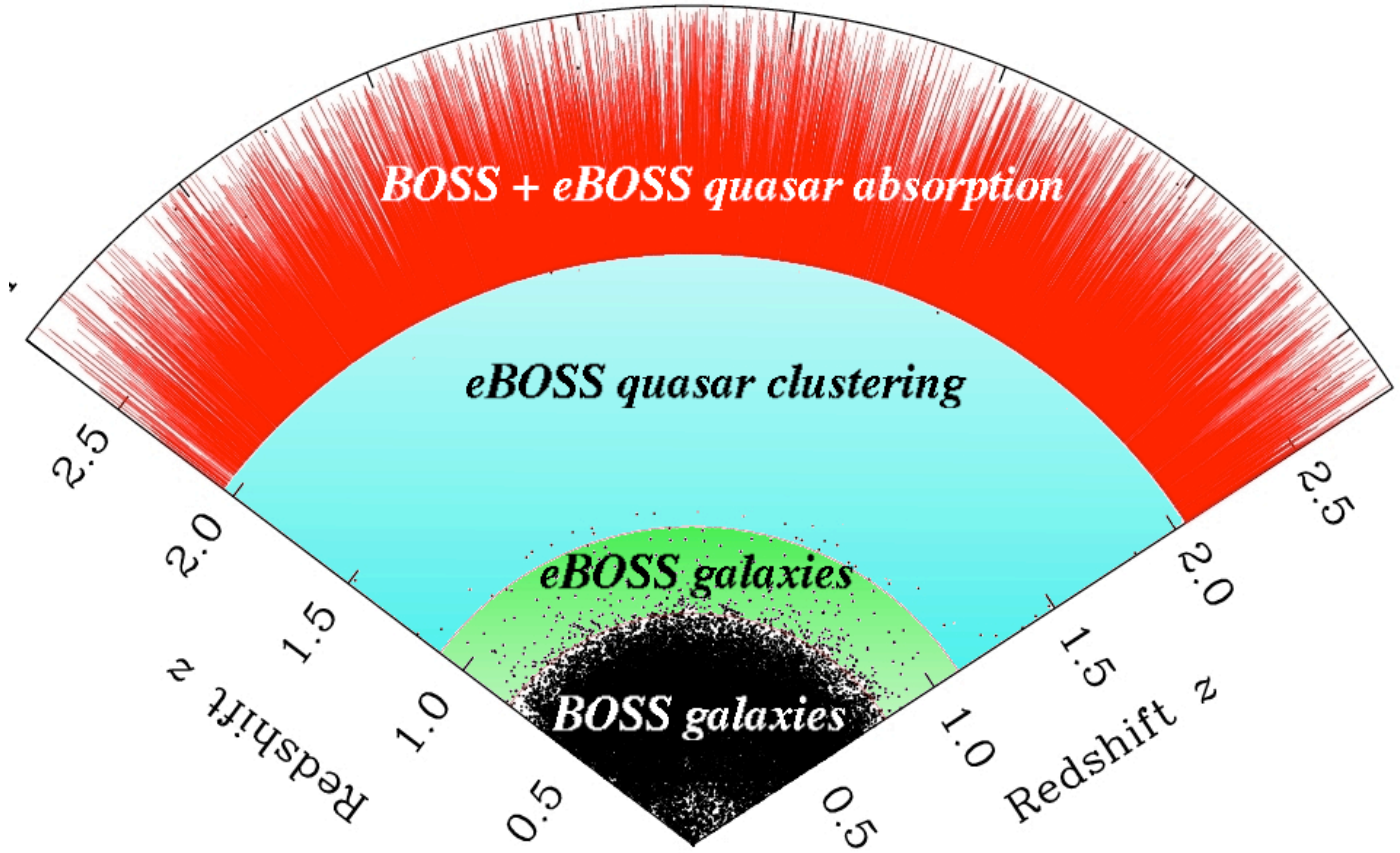


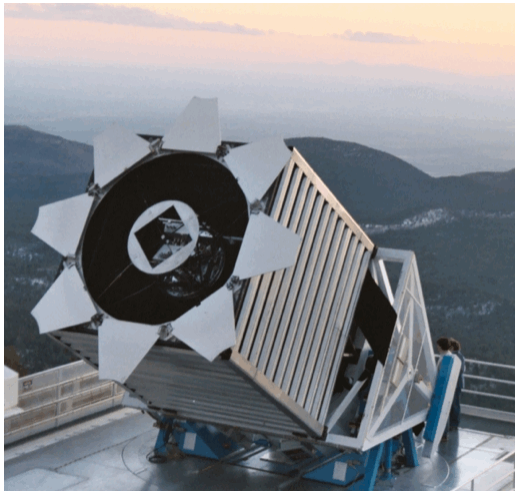
2 6 14 24 35

Age of Universe (Myears)

Quasars Today

eBOSS 2014-2020





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

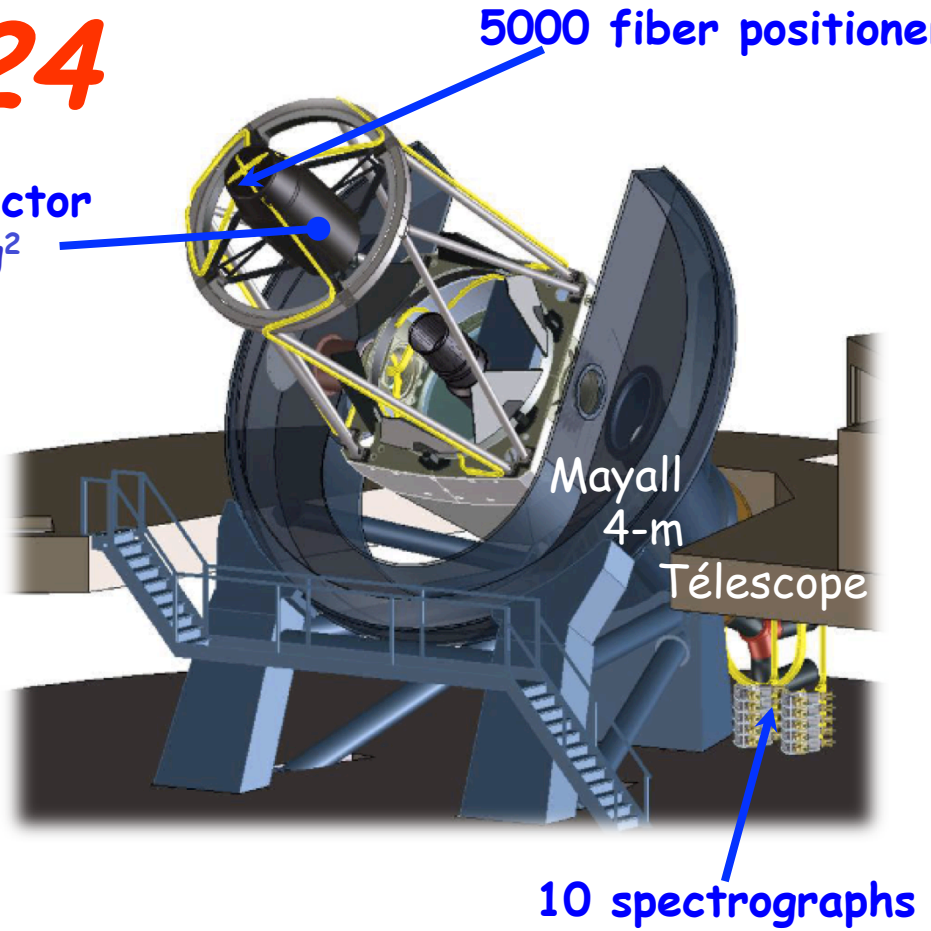
0.9<z<2.2 QSOs
- Tracers of cosmic structures
- Unexplored Universe

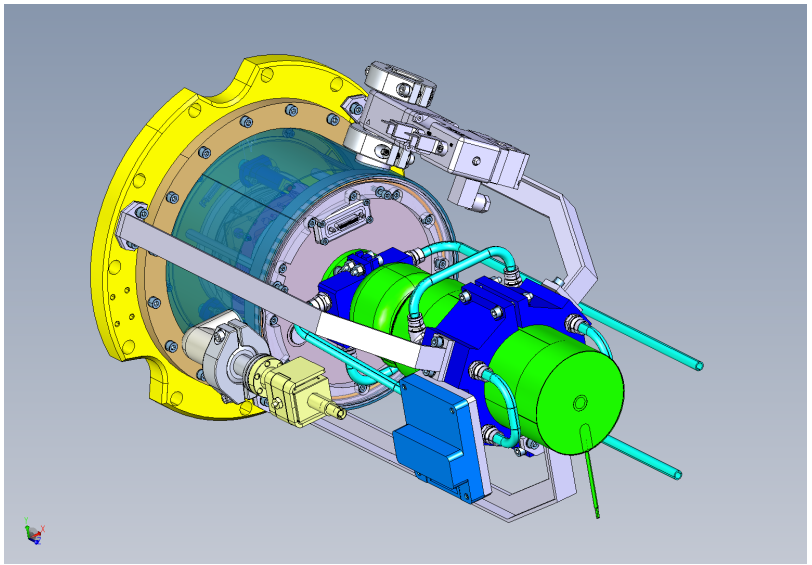
Ly-α QSOs, 2.2<z<5
- Improvement of selection
- ~17 deg^{-2} ⟹ ~30 deg^{-2}

DESI 2019-2024

Instrument

- 4m.telescope at Kitt Peak
- Wide FoV (~ 7 deg^2)
- Robotic positioner with 5000 fibers
- 10 spectrographs x 3 bands (blue, visible, red-NIR)
  →360-1020 nm
- **30 cryostats (built by Irfu)**

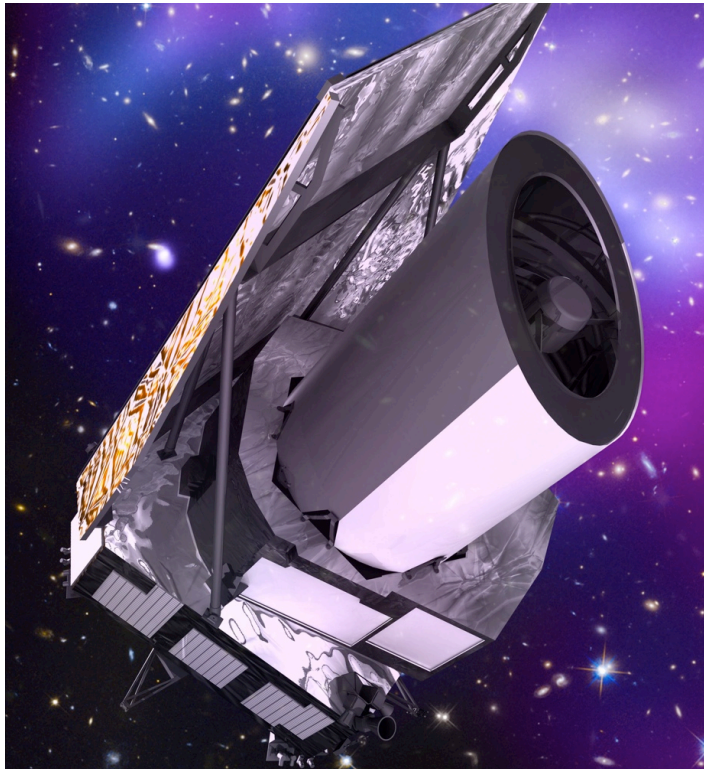




Scientific Project

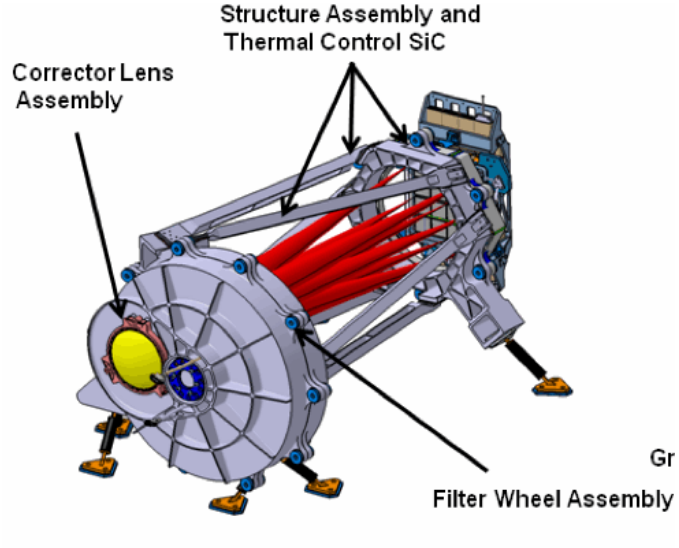
- International Collaboration steered par Berkeley (DOE)
- 14000 deg^2 survey for 0.3<z<4.5
- 20M galaxies and quasars (R~4000)

Euclid 2021-2027



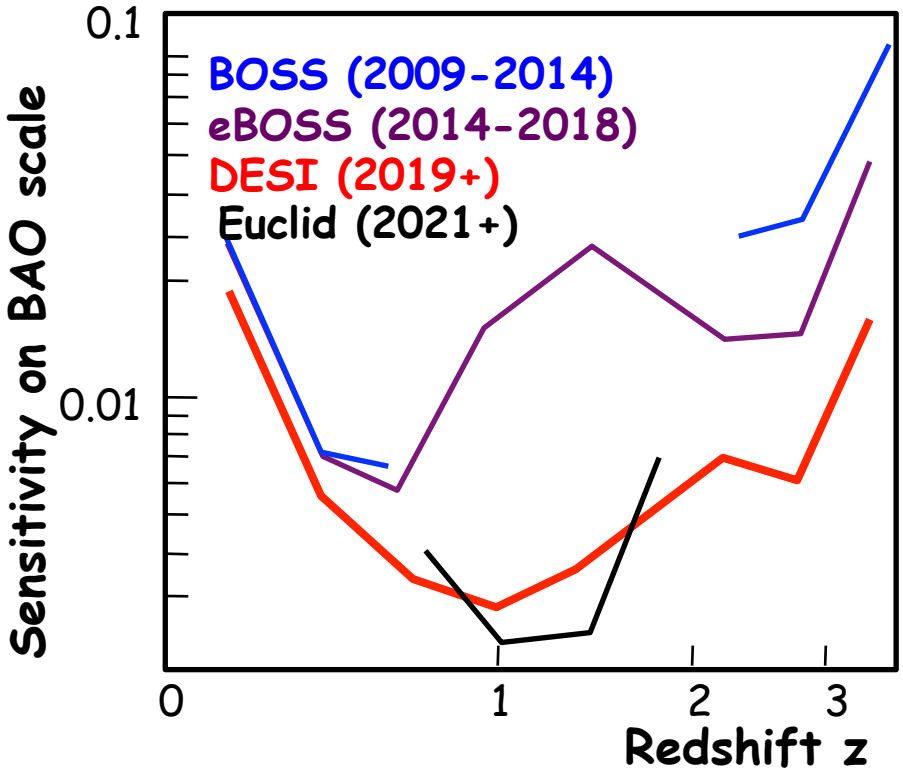
Instrument

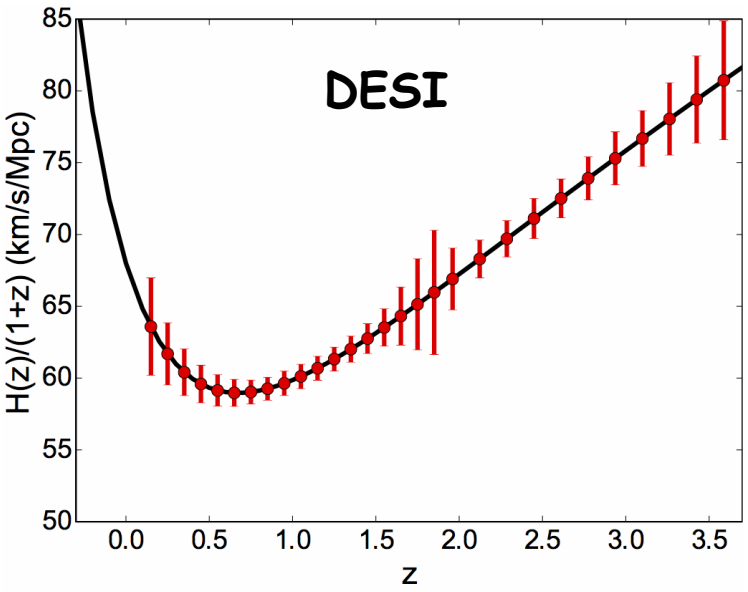
- ESA Satellite (launch in 2020) at L2
- 6 year program
- 14 countries + 1100 members
- 1.2m telescope with 0.5 deg^2 FoV
- Two instruments (VIS, NISP)
- Slitless NIR spectrograph (1 blue and 3 red grisms) →1000-2000 nm
- **Strong contributions of Irfu/SAP and IAS to VIS and NISP**



Scientific Project

- WL (not in this talk)
- 15000 deg^2 survey for 0.9<z<1.85
- For BAO and RSD: 50M galaxy spectra with R~250
- Redshift determined with Hα line





Forecasts

Improvements with eBOSS

- Continuous measurement of BAO for $0.3<z<4.0$.
- Exploration of unknown area: Dark matter → Dark energy

Improvements with DESI

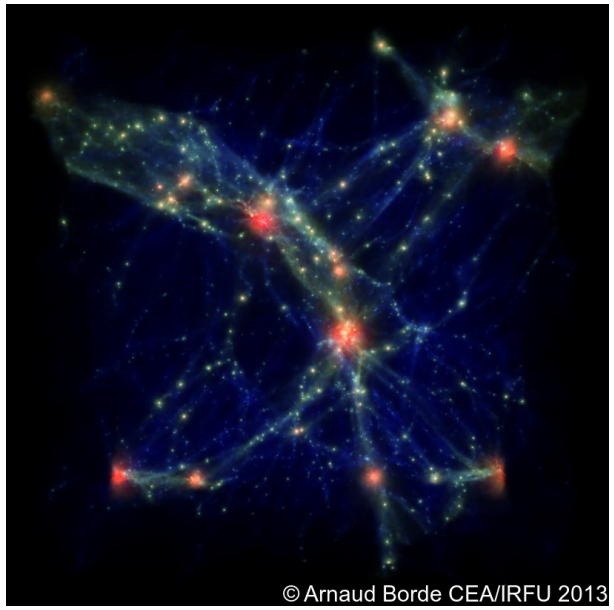
- **BAO:** 1 order of magnitude
- **Neutrino masses:** accuracy ~20-25 meV on Σm_ν

Improvements with Euclid

- For BAO in the $1<z<1.6$ region
- Much impressive gain for RSD (50M galaxies to compare to ~20M for DESI)

Simulations and HPC

Current status of simulations

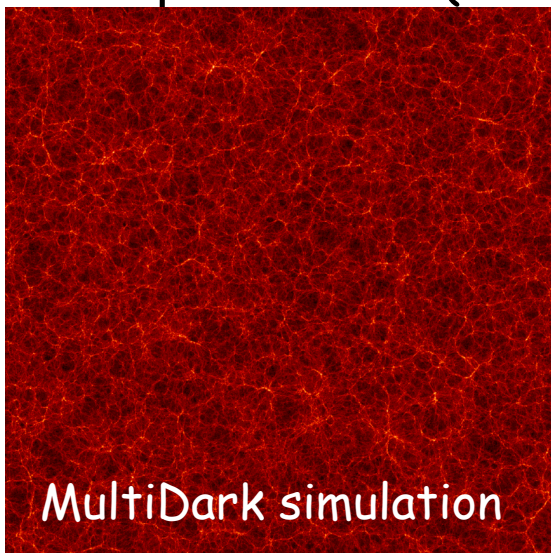


Ly-α forests

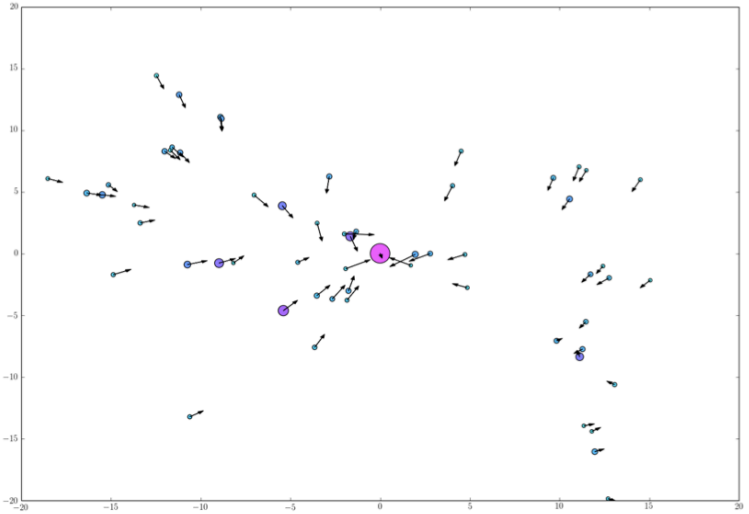
- 1D power spectrum:
  - N-body with full-hydro simulation (see Nathalie's talk)
  - Two PRACE projects : ~15 M hours
  - Particle mass: a few 10^5 $M_\odot$
- 3D (BAO):
  - N-body Hydro simulation too CPU-time consuming for BAO
  - Gaussian random field with simulation of the absorption in HI (J-M Le Goff)

Galaxy and quasar clustering

- N-body simulations of pure DM
- Why simulations?
  - Covariance matrix
  - Tuning of RSD parameterization
- Typical simulations for BOSS, (QPM)
  - Box size: 2.5 Gpc/h
  - Resolution: $(1280)^3$ particles
  - Particle mass: 6.10^{10} $M_\odot$

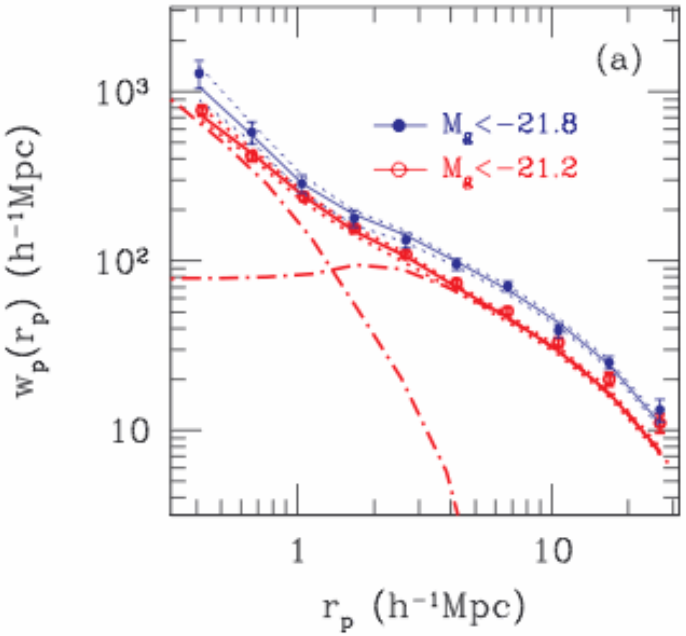


Simulations for BAO

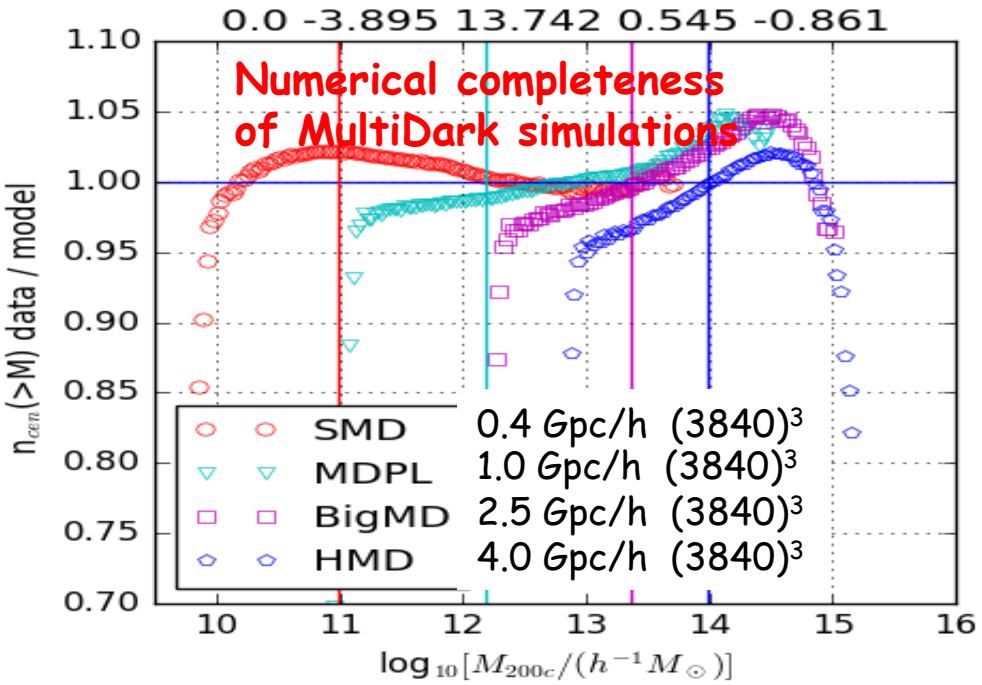


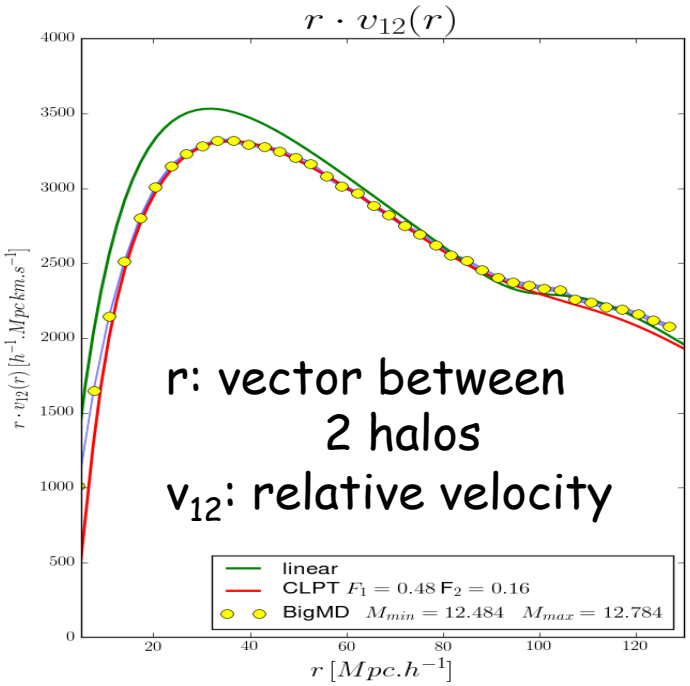
How to use simulations?

- Halo of DM
- HOD: Halo of DM by comparing to data
  - LRG ~ 2.10^{13} $M_\odot$
  - Quasar ~ $2.5\ 10^{12}$ $M_\odot$
- Optimization of the simulations
- Use QPM simulations from (Berkeley and NYU) and MultiDark from a Spanish consortium



Zheng et al., (2009)





r: vector between 2 halos

v_{12}: relative velocity

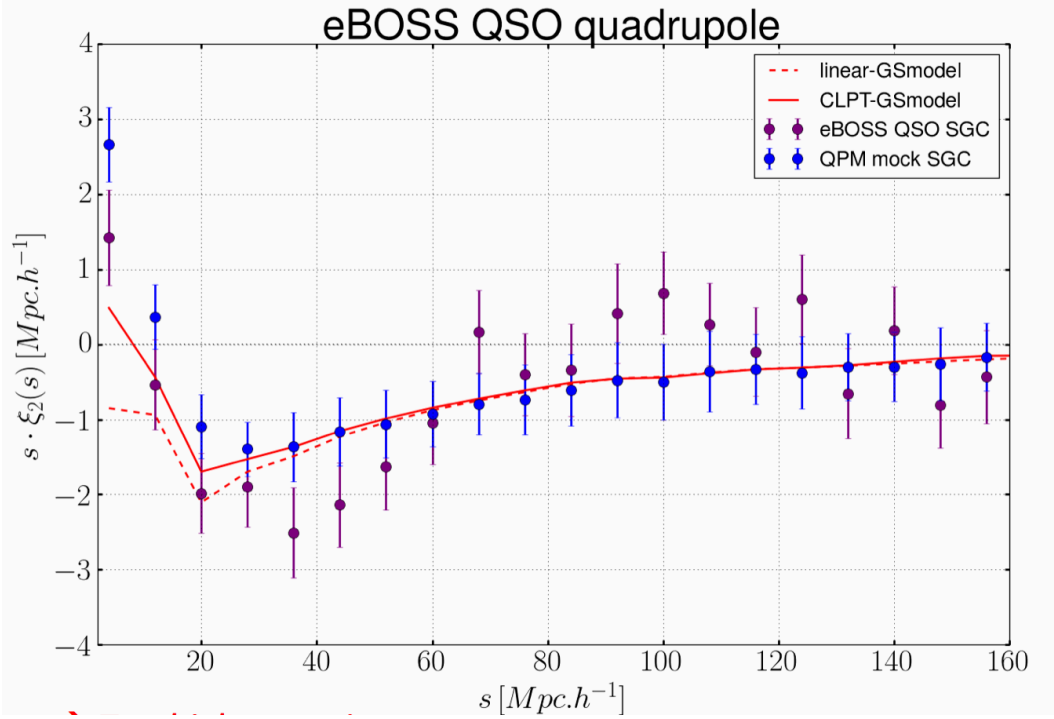
Modeling of RSD

Why simulations?

- For BAO just used for the covariance matrix
- For RSD, science cannot be extracted without comparison with simulations
- Modeling of the CLPT (Convolution Lagrangian Perturbation Theory)

Example with eBOSS QSO?

- E. Burtin and P. Zarrouk tuned CLPT over BigMultiDark
- Fit to the data with the modeled CLPT
- Extraction of $f\sigma_8$



Strategy for simulations

Simulations for Ly-α forests

- For 1D, continue to produce our own simulations
- Risk: depend on success to PRACE, GENCI calls…
- For 3D (BAO), full hydro + N-body might become conceivable for DESI…

Simulations for galaxy and quasar clustering:

- Use simulations produced by the collaborations (SDSS, DESI or Euclid)
- No more real expertize in big cosmological simulation
- 2-3 FTE per year + CPU time to get this experience
- Huge MultiDark
  - Size 4 Gpc/h, $(3840)^3$ particles
  - 80M CPU-hours, storage: 1Pb
- Risk: no ability to generate simulations with exotic gravity (Galileon…) to test our models