EPFL - LABORATOIRE D'ASTROPHYSIQUE

Cosmology with recent and future massive spectroscopic surveys:

SDSS

SDSS/eBOSS and 4MOST/CRS

eBOSS

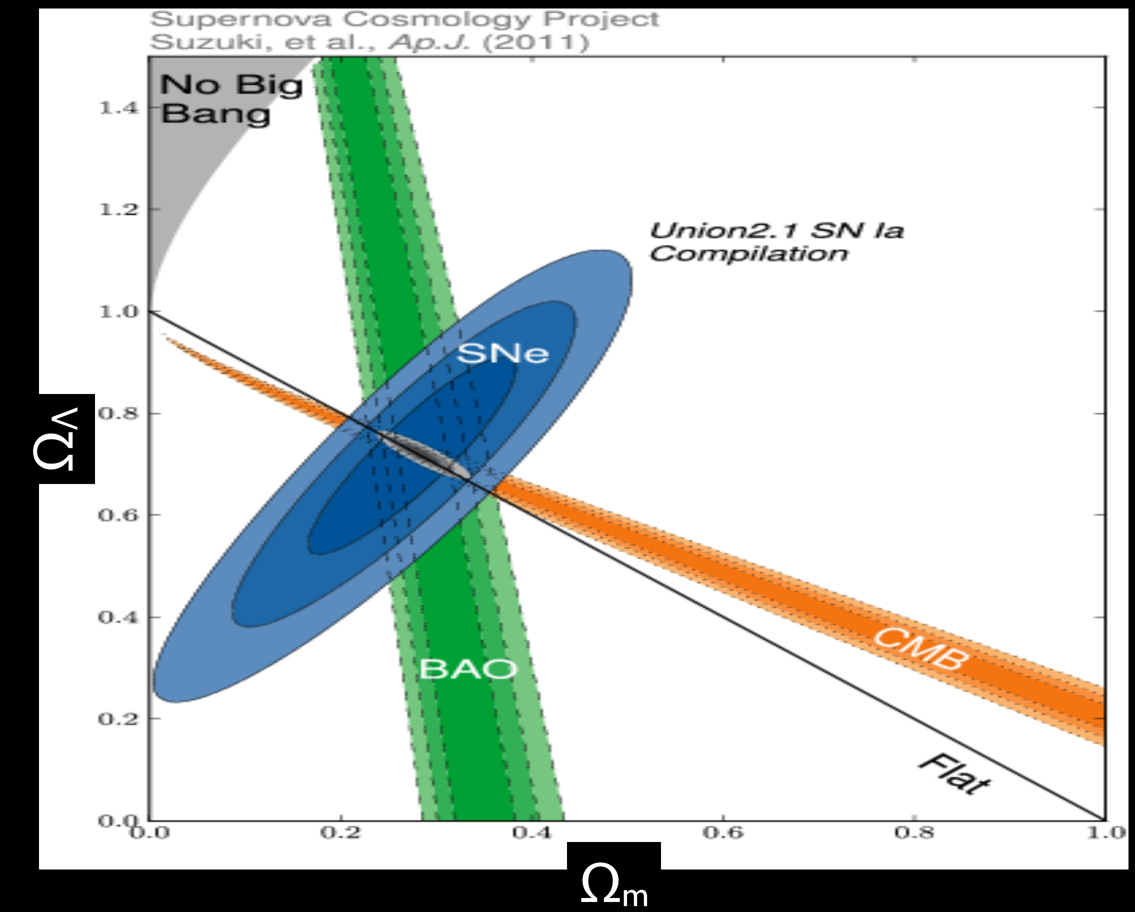
4MOST

A. Raichoor
(EPFL, anand.raichoor@epfl.ch)
on behalf of the SDSS/eBOSS and 4MOST/CRS teams

Cosmology with LSS surveys

Current state

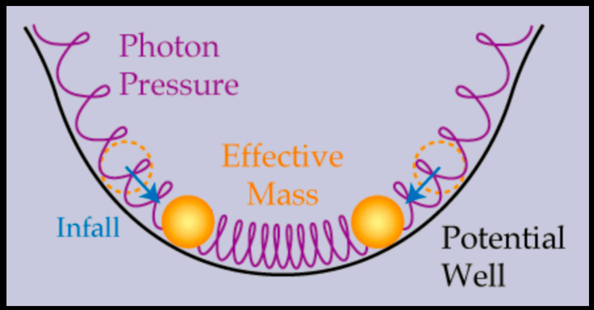
- cosmological probes
  - geometry of the Universe : CMB, SNIa, BAO
  - growth of structures: RSD, WL, galaxy clusters
- observations show
  - Universe is flat (CMB)
  - the expansion of the Universe is accelerating
- theoretical framework
  - ΛCDM standard model with ~75% dark energy
  - modification of the General Relativity on cosmological scales



Baryon Acoustic Oscillations (BAO)

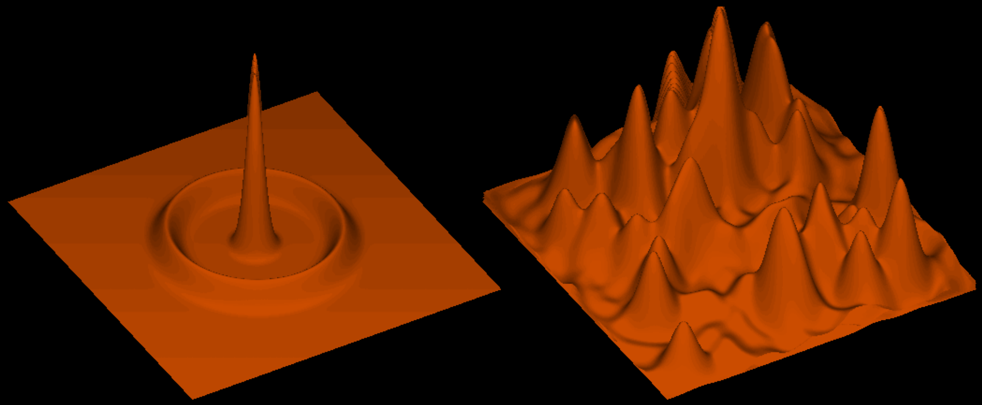
Before z~1100

- baryonic matter and radiation coupled
- oscillations due to radiation pressure
- acoustic waves propagating



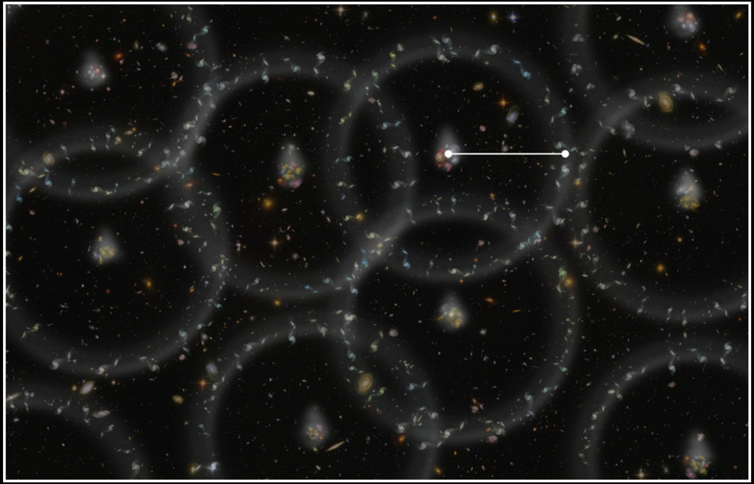
At z~1100 (age~0.4 Myr)

- baryonic matter and radiation decouple
- acoustic waves stop propagating
- distinct imprint: spherical peak at a specific scale, r_s
- CMB → r_s = 150 Mpc ~ 105 Mpc/h



After z~1100

- BAO = overdensity of baryonic matter separated by 105 Mpc/h
- parallel to l.o.s.: $\Delta z = r_s / D_H(z)$, $D_H(z) = c/H(z)$ → expansion rate
- perpendicular to l.o.s.: $\Delta\theta = r_s / [(1+z) \times D_A(z)]$ → angular diameter distance

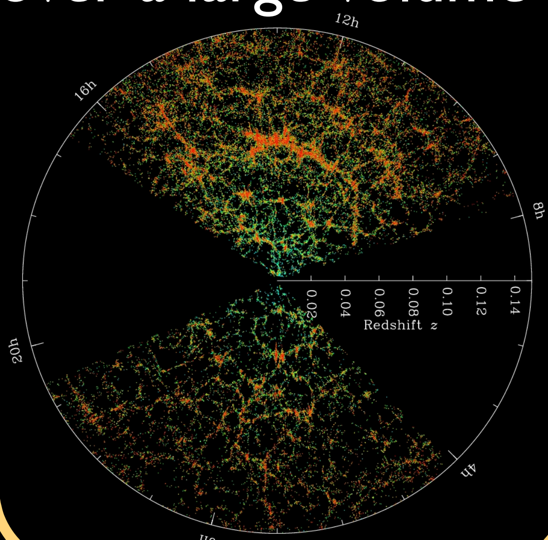


Baryon Acoustic Oscillations (BAO)

Typical BAO analysis flow

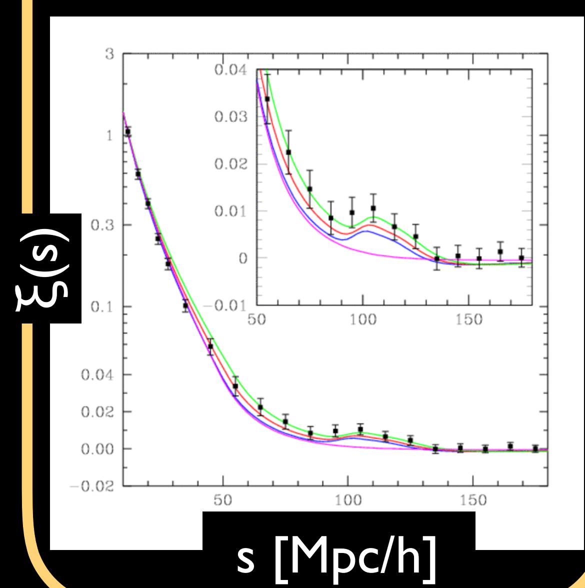
step 1

obtain redshift of galaxies over a large volume



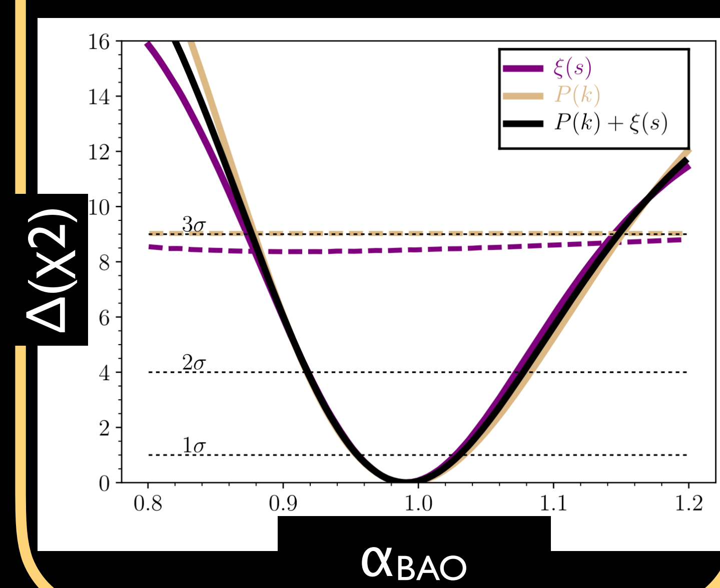
step 2

compute 2-point, 3D-position clustering



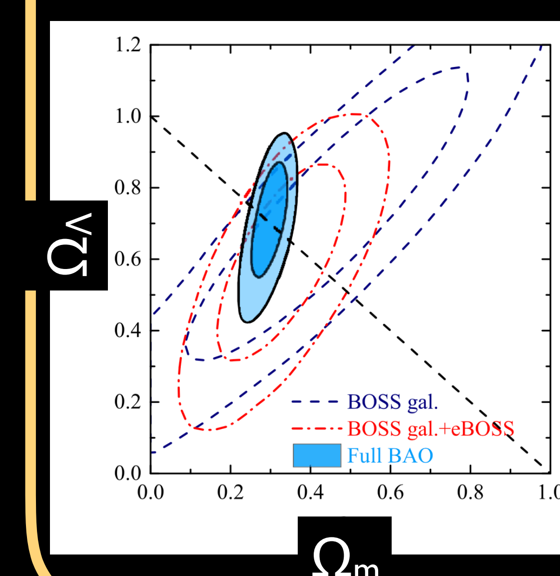
step 3

measure BAO position



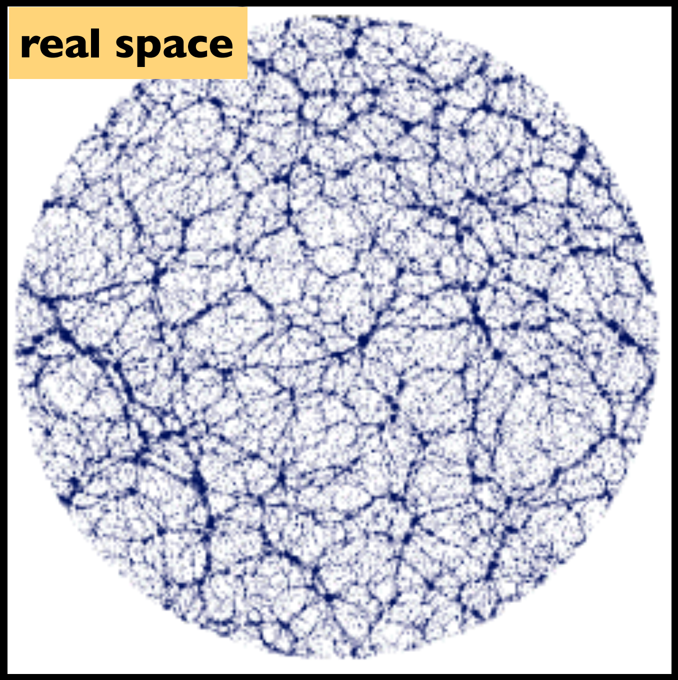
step 4

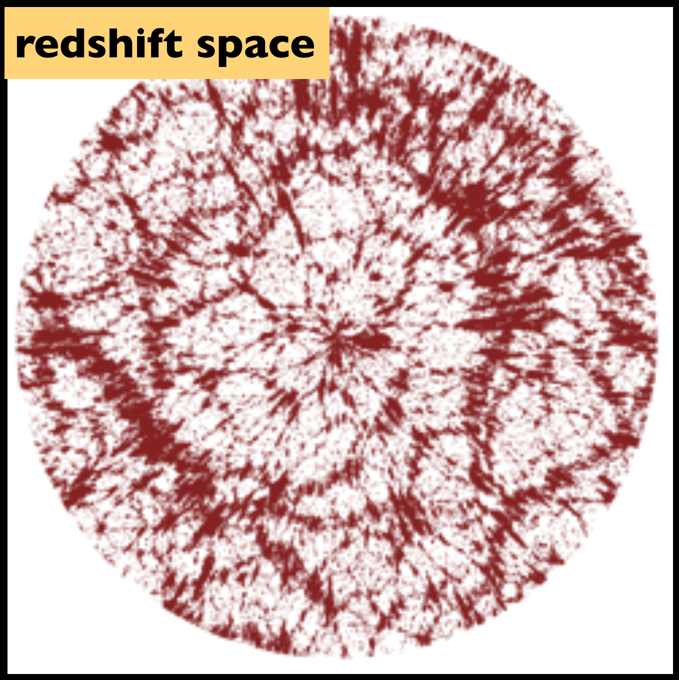
constrain the models

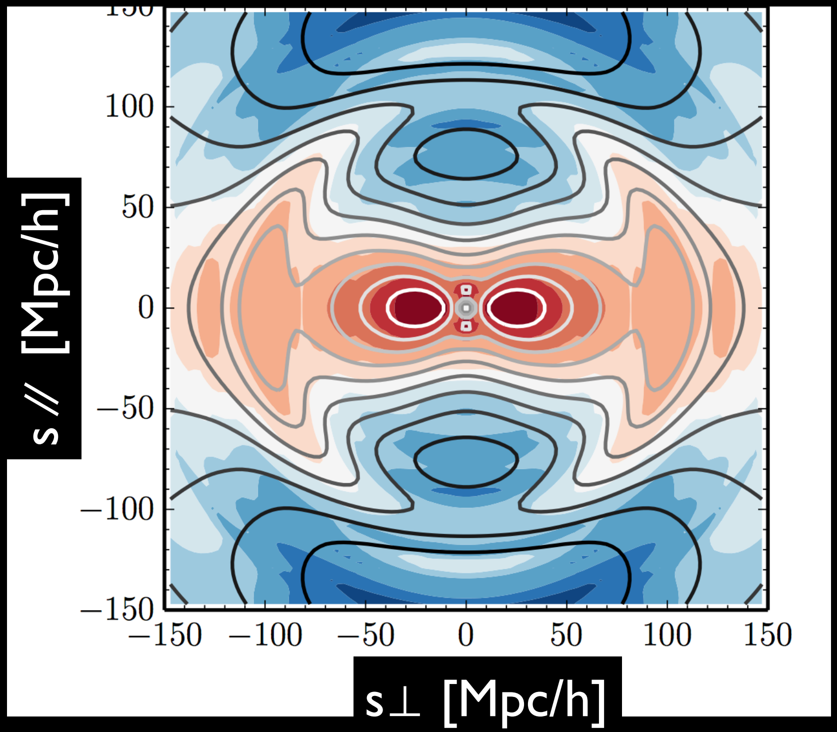


Anisotropic clustering in redshift space

- zobs = Hubble recession + peculiar velocity along line of sight
- large scales (linear): coherent infall on clusters → flattening
- small scales (non-linear): random motion → elongation



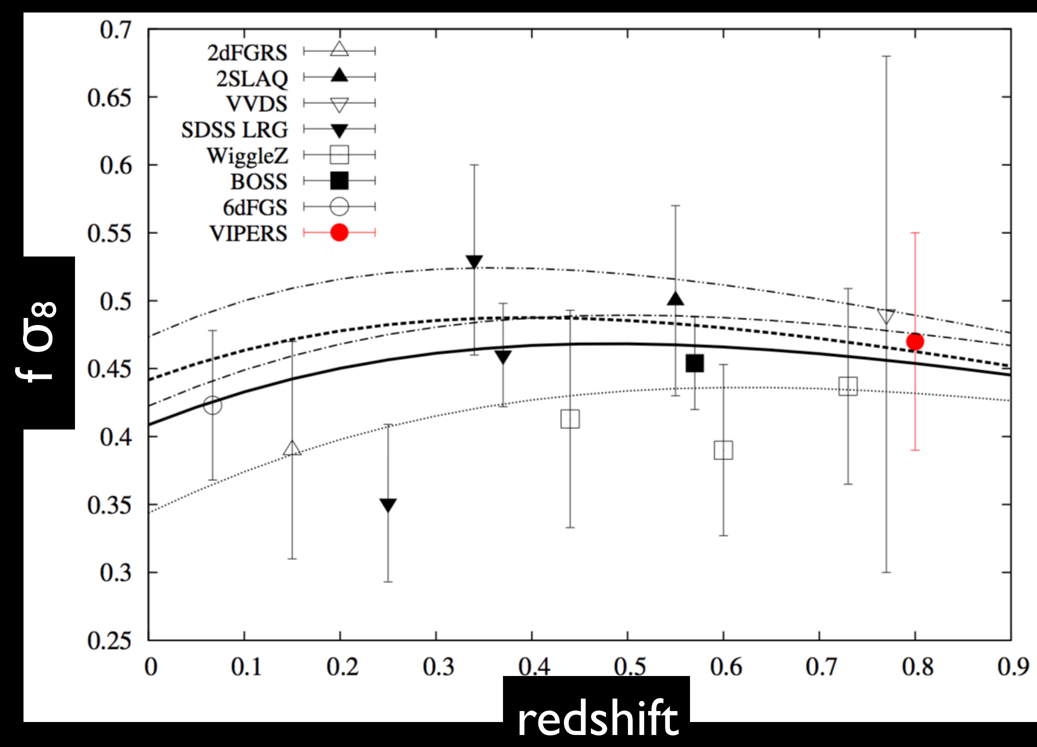


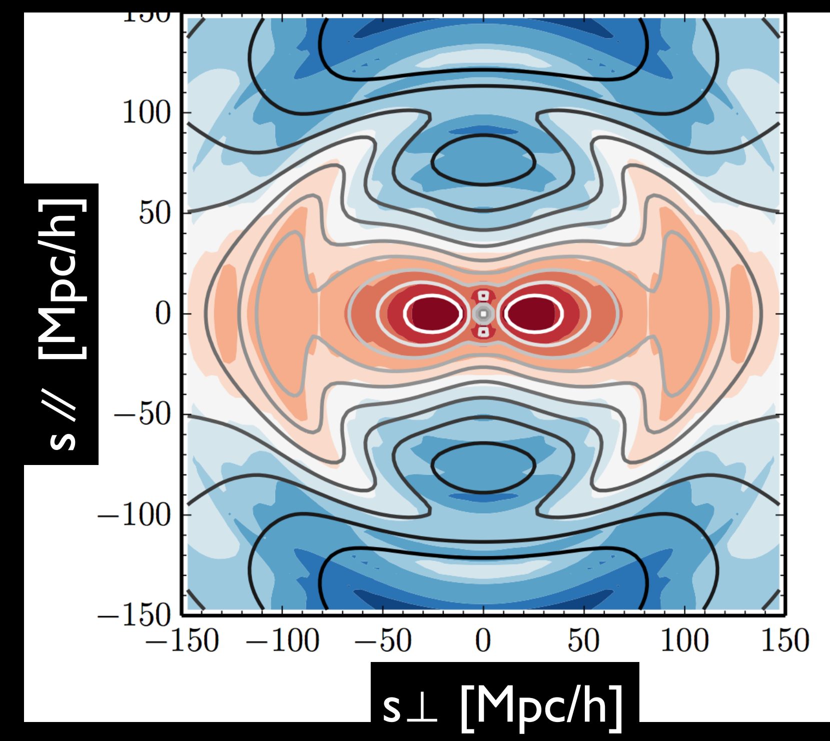


Redshift Space Distortions (RSD)

Constraining cosmology and General Relativity

- $\sigma_8(z)$: amplitude of clustering
- degree of anisotropy depends on the rate of change of $\sigma_8(z)$
- $f \cdot \sigma_8 = \partial\sigma_8 / \partial \ln a$
- General Relativity : $f(z) \sim \Omega_m(z)^{0.55}$





Modelling of the RSD

- constraints on gravity stronger at small scales
- linear regime (s>80 Mpc/h) modelling well understood
- challenge to model:
  - quasi-linear (30<s<80 Mpc/h)
  - non-linear regimes (s<30 Mpc/h)

BAO surveys with the SDSS

SDSS telescope

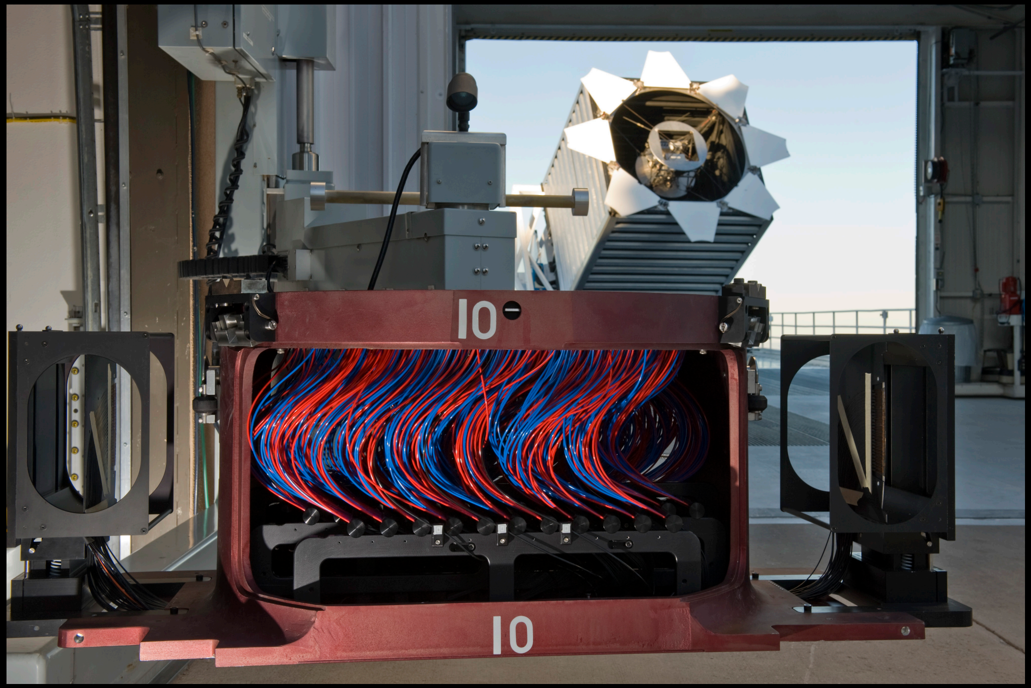
- 2.5-meters, New Mexico
- 1000 fibers, field of view of 7 deg2
- 2005: (co-)first BAO measurement at z~0.3 with ~50k LRGs

SDSS/BOSS (2008-2014)

- 1.5M spectra over 10k deg2

SDSS/eBOSS (2014-2019)

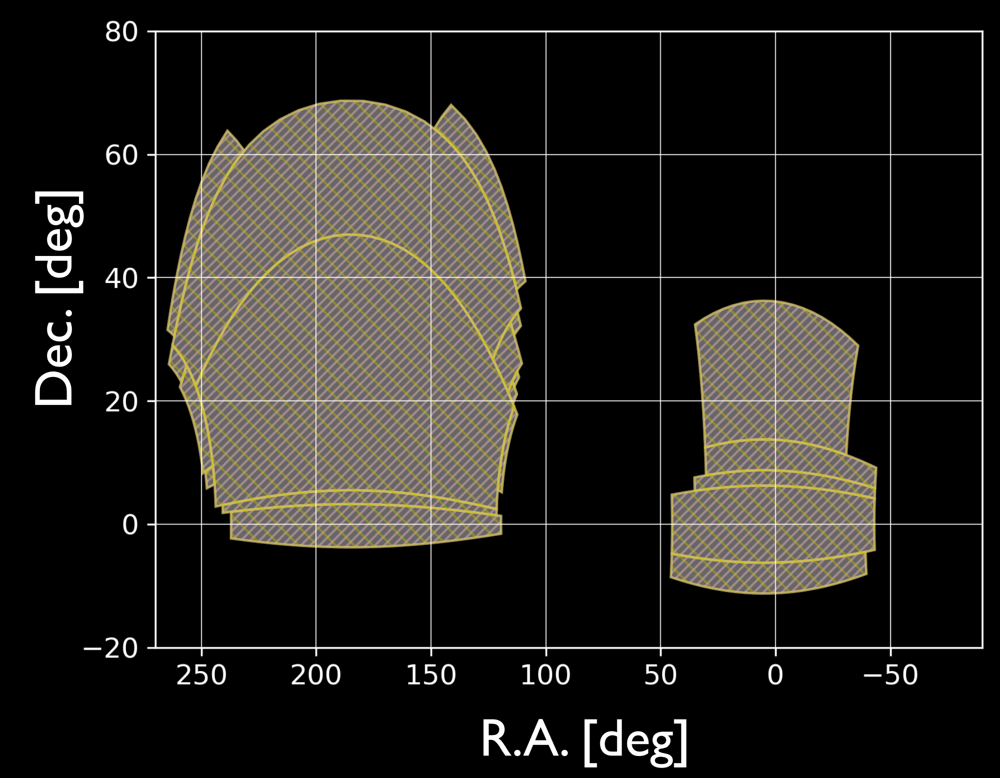
- extension of SDSS/BOSS to 0.6<z<2.2 + new tracer (ELG)
- BAO distance measurement
- test of General Relativity on cosmological scales with RSD
- bonus: constraint on the sum of the neutrino masses

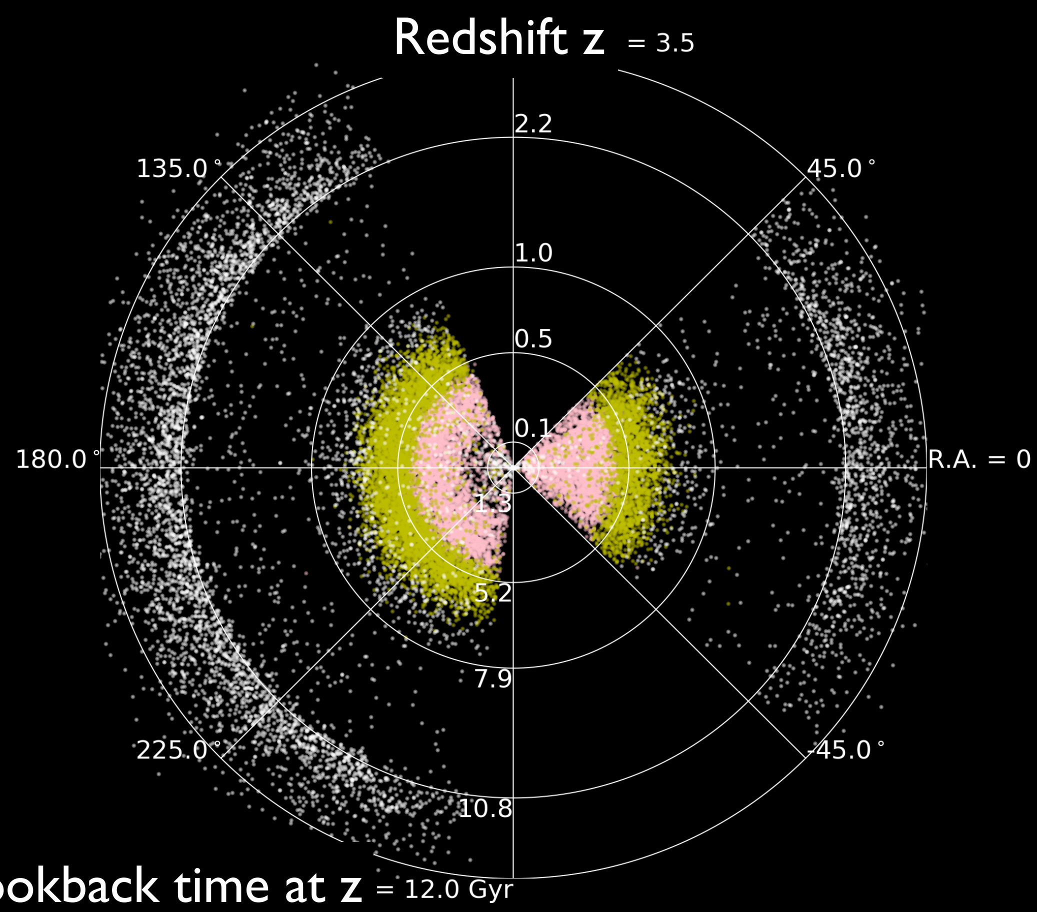


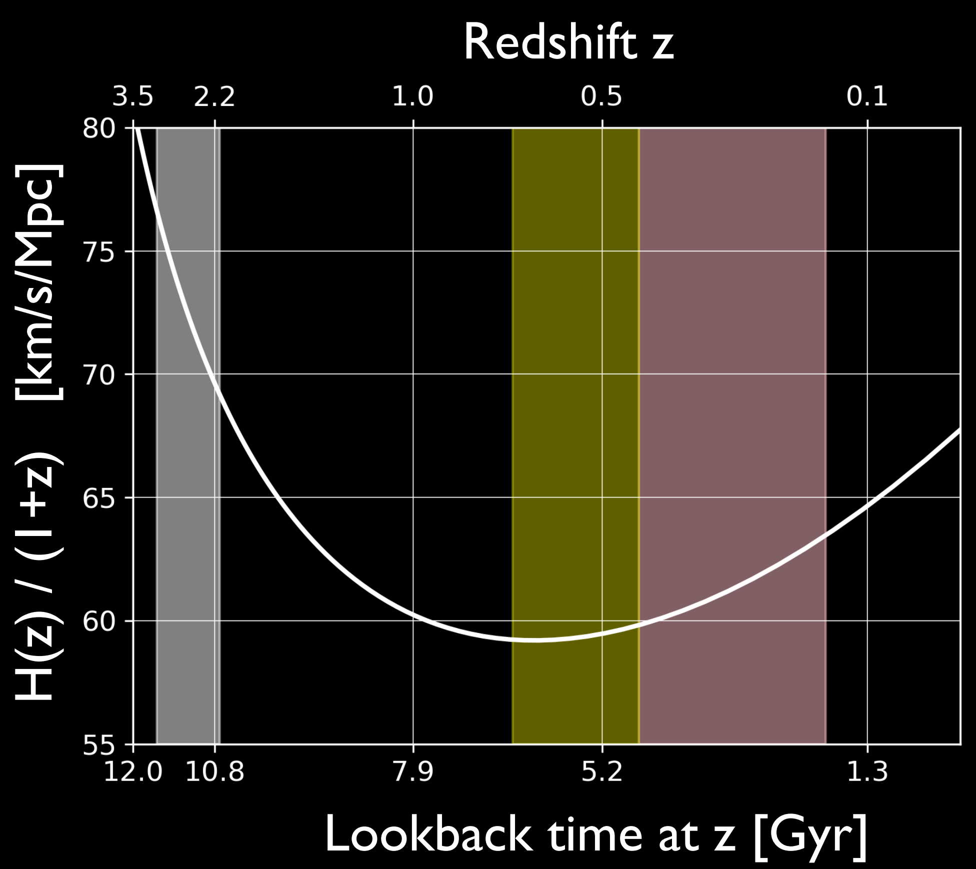
SDSS/BOSS survey

BOSS (2008-2014, 1.5M spectra)

- LOWZ [30 deg^{-2}]
- CMASS [120 deg^{-2}]
- Lyα [35 deg^{-2}]



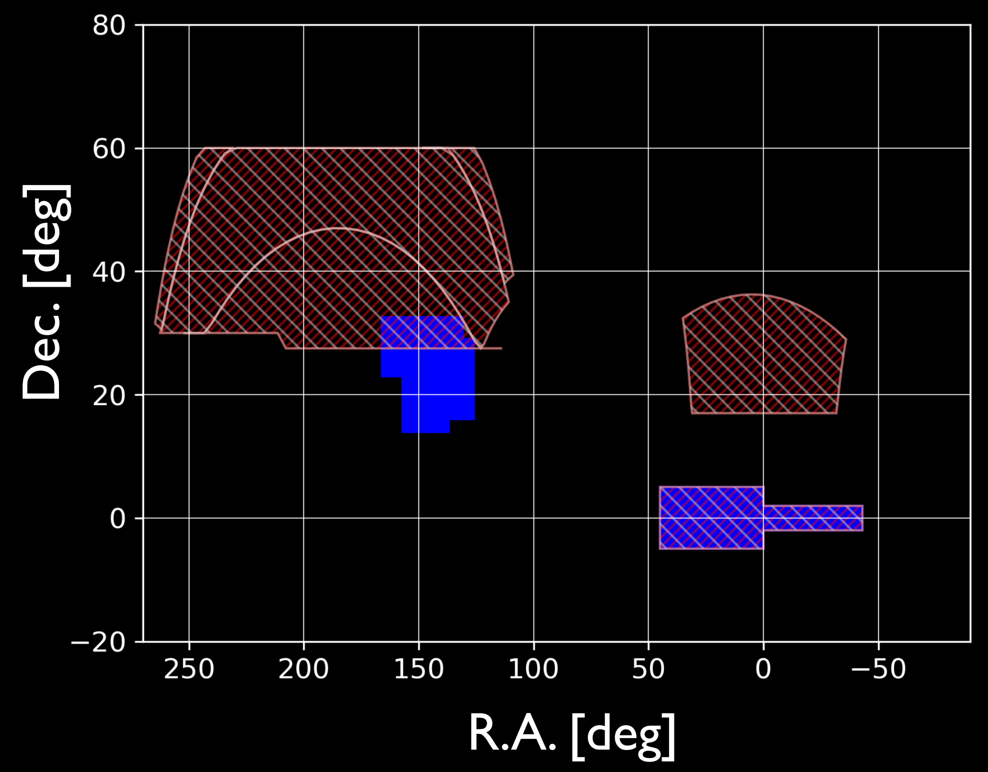


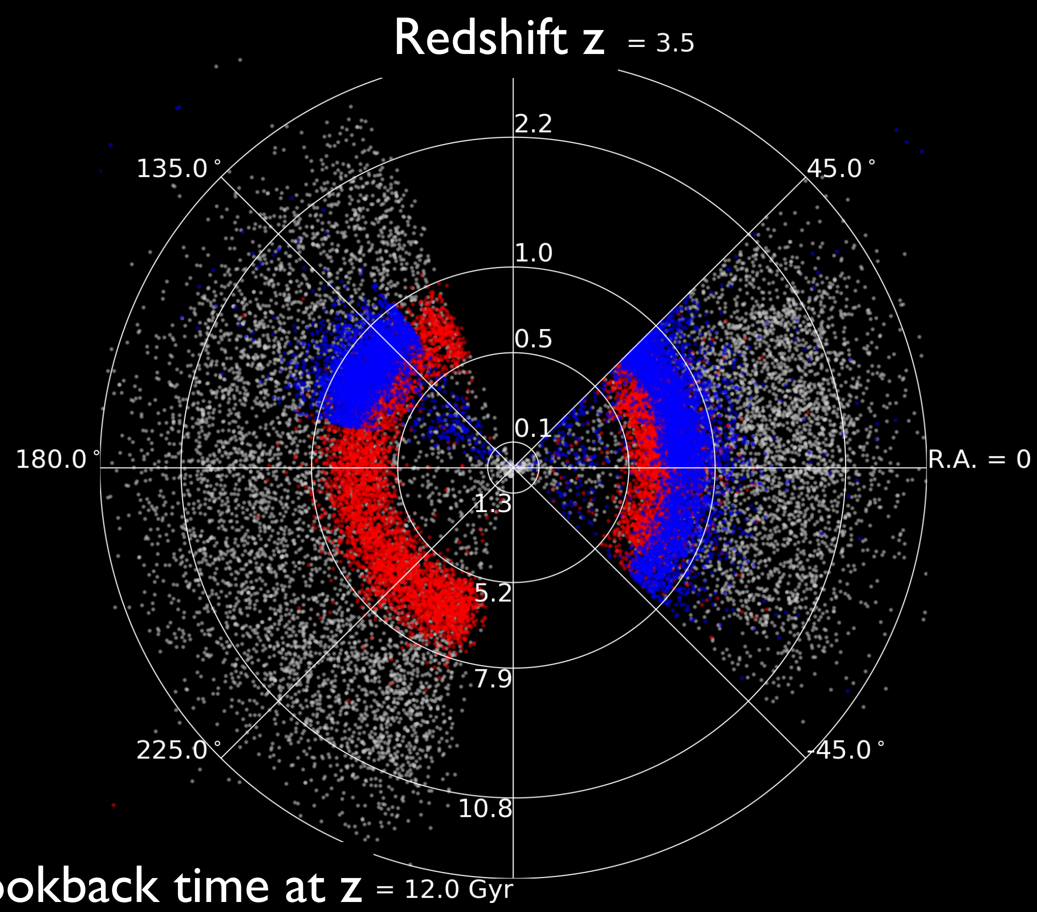


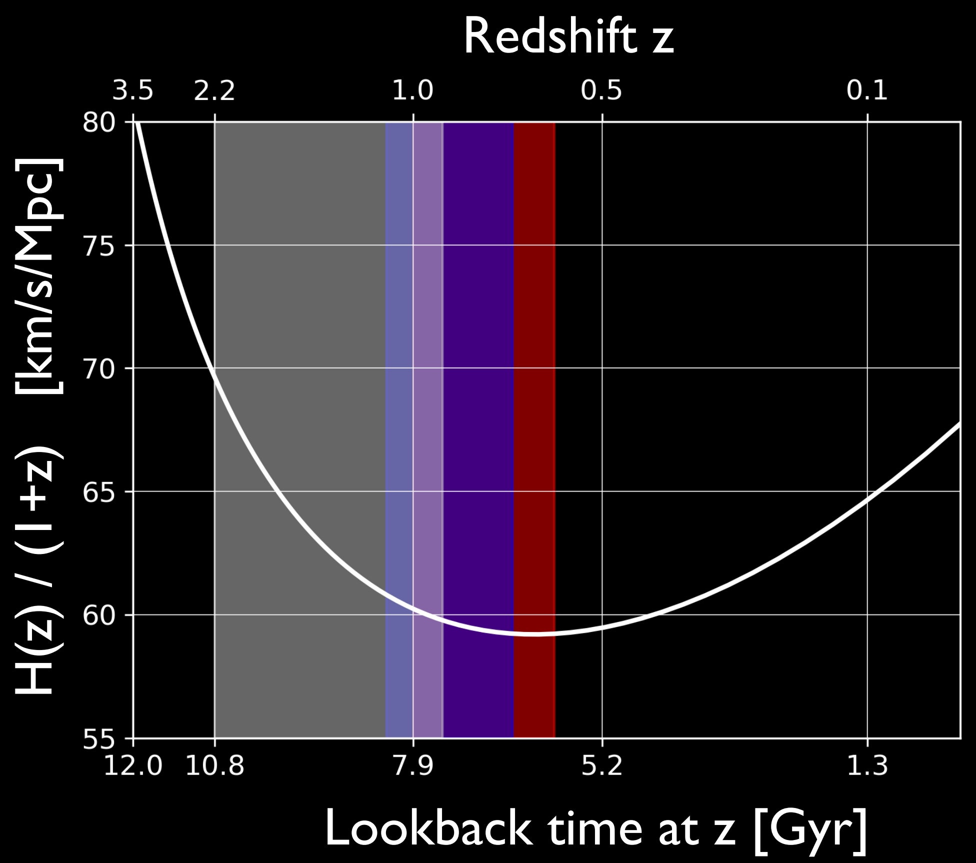
SDSS/eBOSS survey

eBOSS (2014-2019, 1M spectra)

- LRG [60 deg^{-2}]
- ELG [230 deg^{-2}]
- QSO+Lyα [140 deg^{-2}]







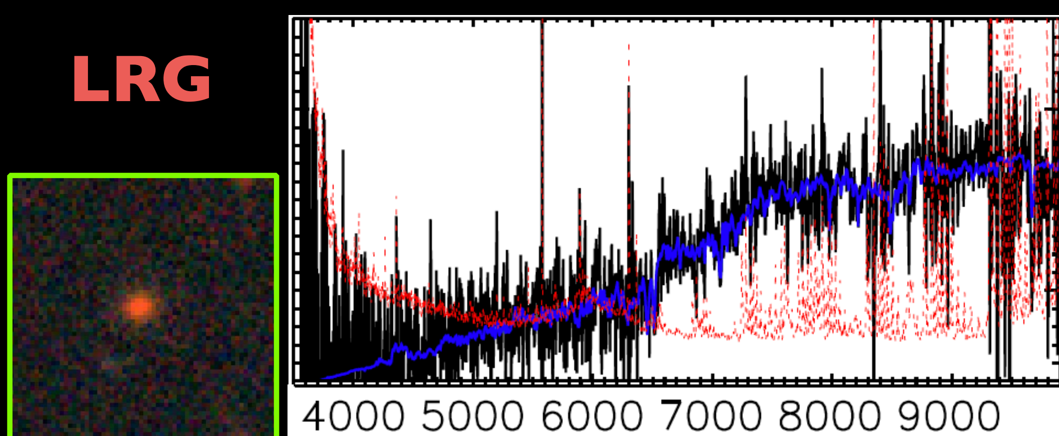
SDSS/eBOSS survey

eBOSS tracers

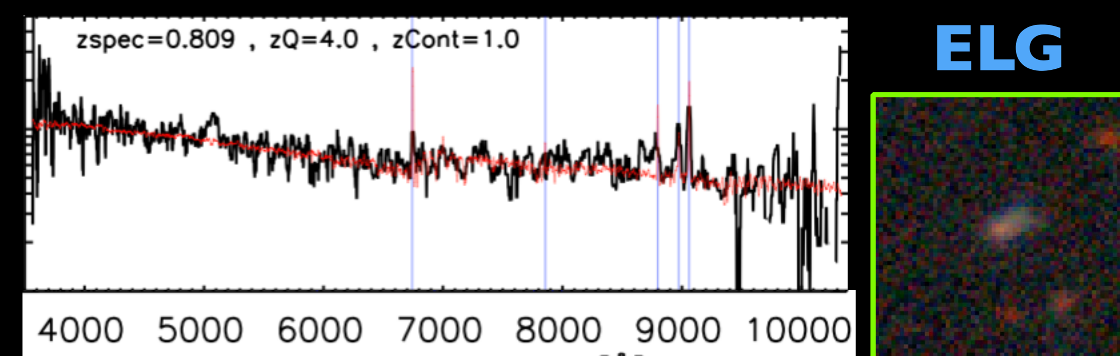
- principle: for each redshift range, choose the « easiest » objects to observe

	redshift	nb spectra
Luminous Red Galaxies (LRG)	$0.6 < z < 1.0$	0.25 M
Emission Line Galaxies (ELG)	$0.7 < z < 1.1$	0.20 M
Quasars (QSO)	$0.9 < z < 2.2$	0.50 M
Lyα-quasars (Lyα)	$2.2 < z < 3.5$	0.12 M

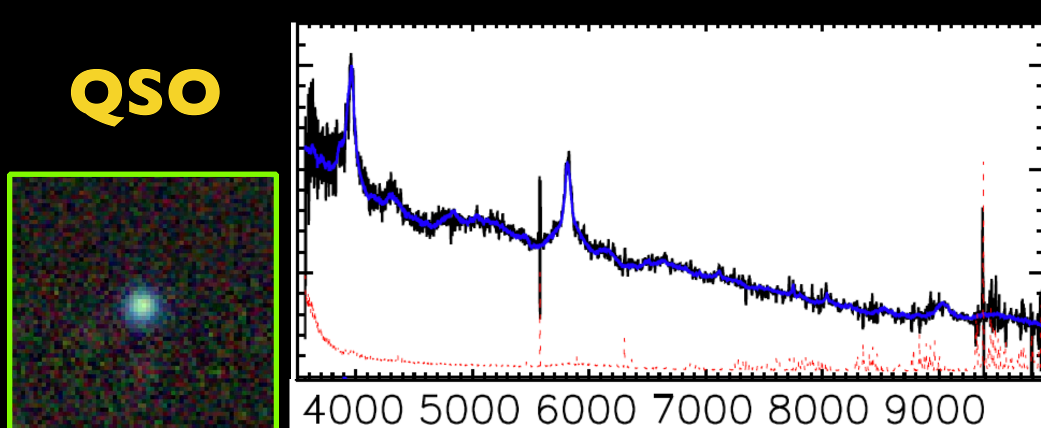
LRG



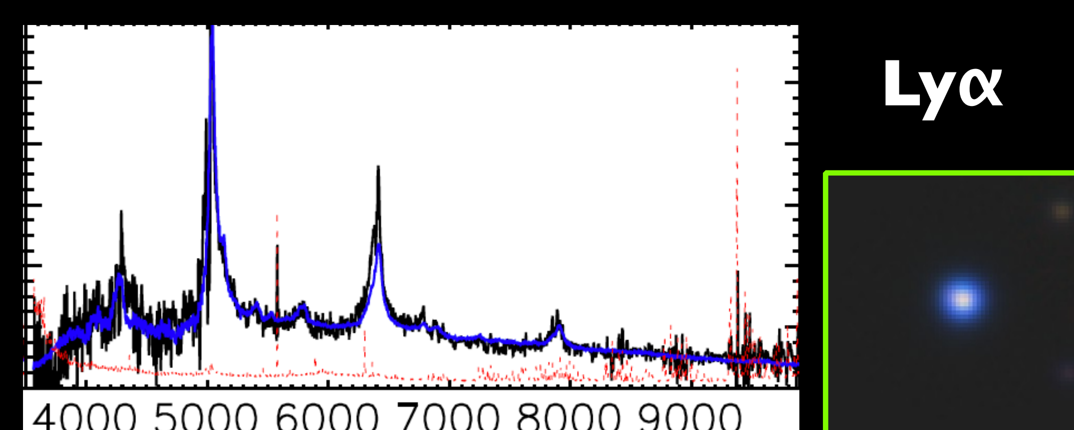
ELG



QSO



Lyα



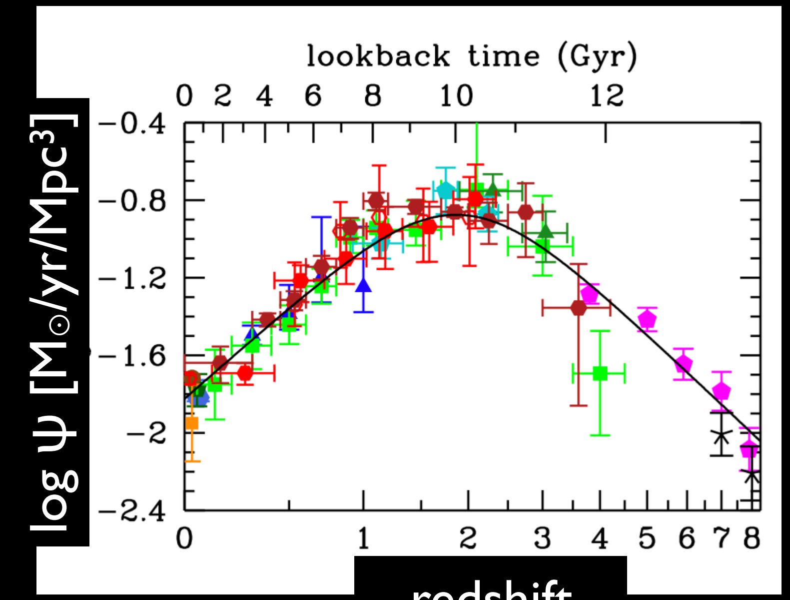
observed wavelength [Å]

observed wavelength [Å]

ELG principle

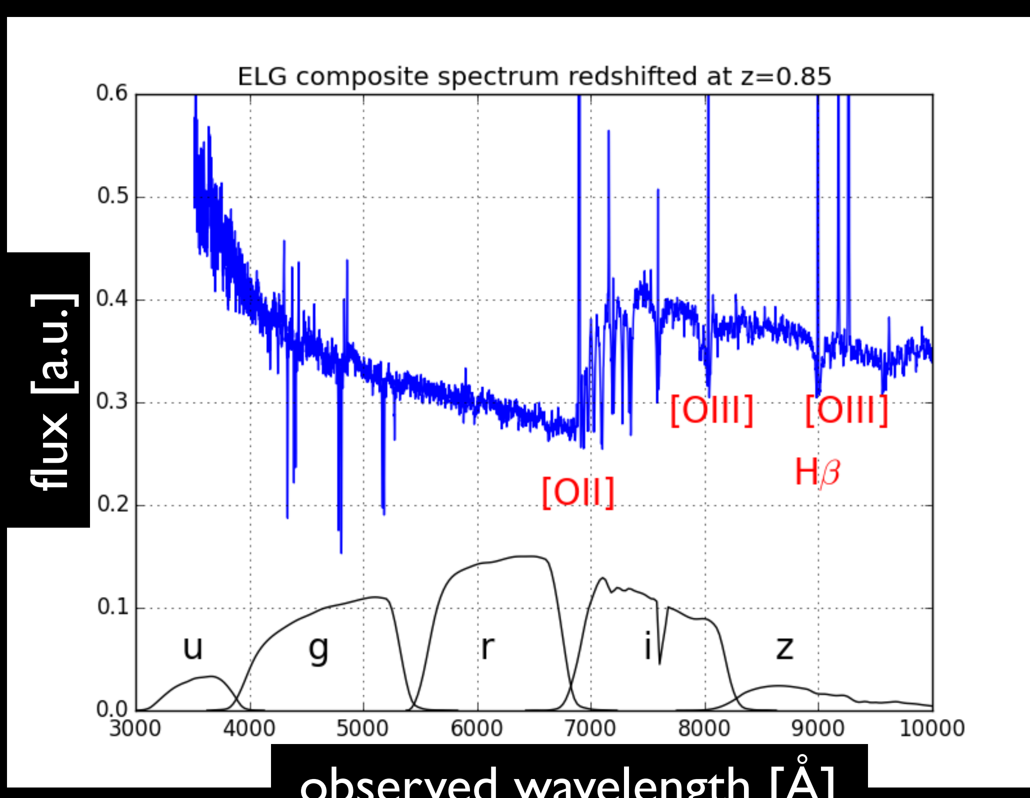
Why ELGs?

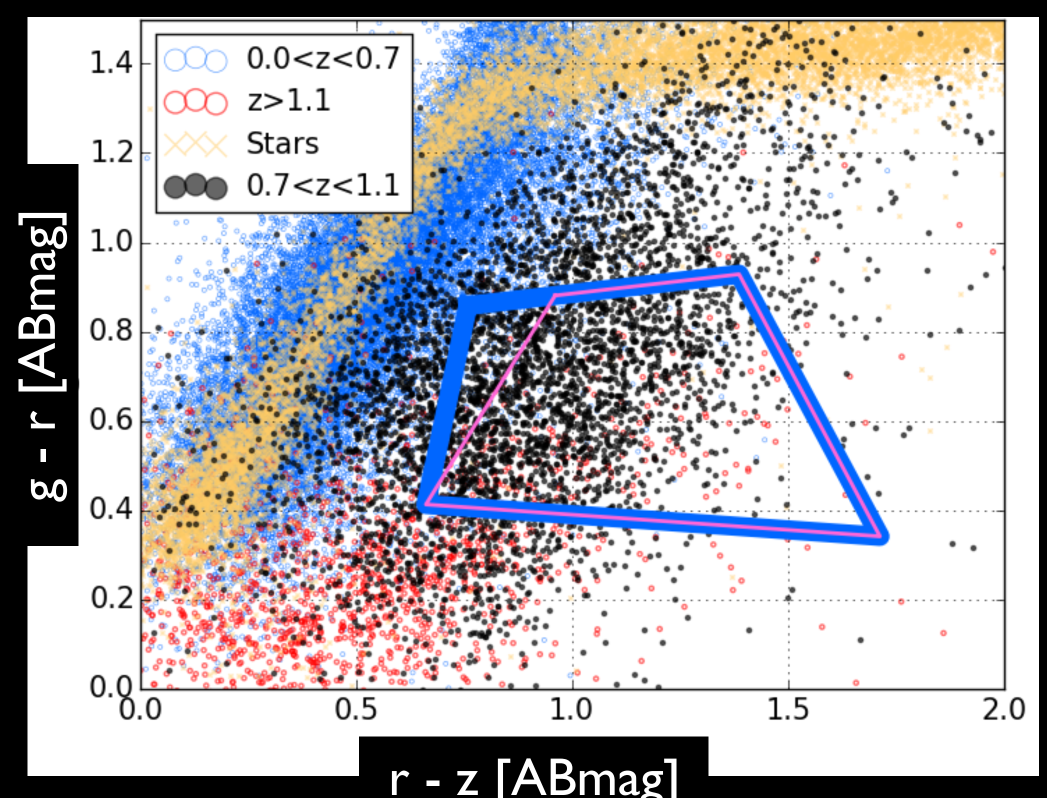
- emission lines ([O_{II}] 3727 Å) permits quick zspec measurement
- abundant at z~0.85
- key for future BAO surveys (DESI, *Euclid*, 4MOST)



How to select ELGs at z~0.85?

- star-forming → « blue » cut in (g-r)
- Balmer break → « red » cut in (r-z)
- [O_{II}] flux correlates with g-mag → « bright » cut in g-mag





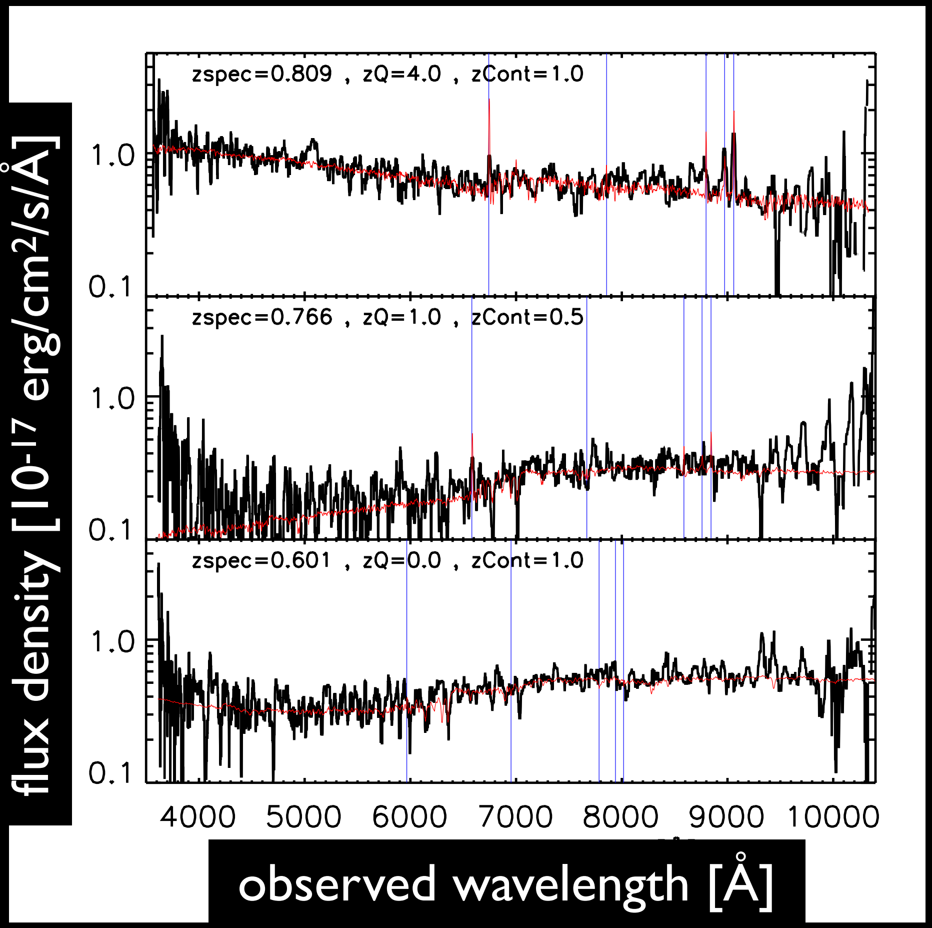
ELG spectra

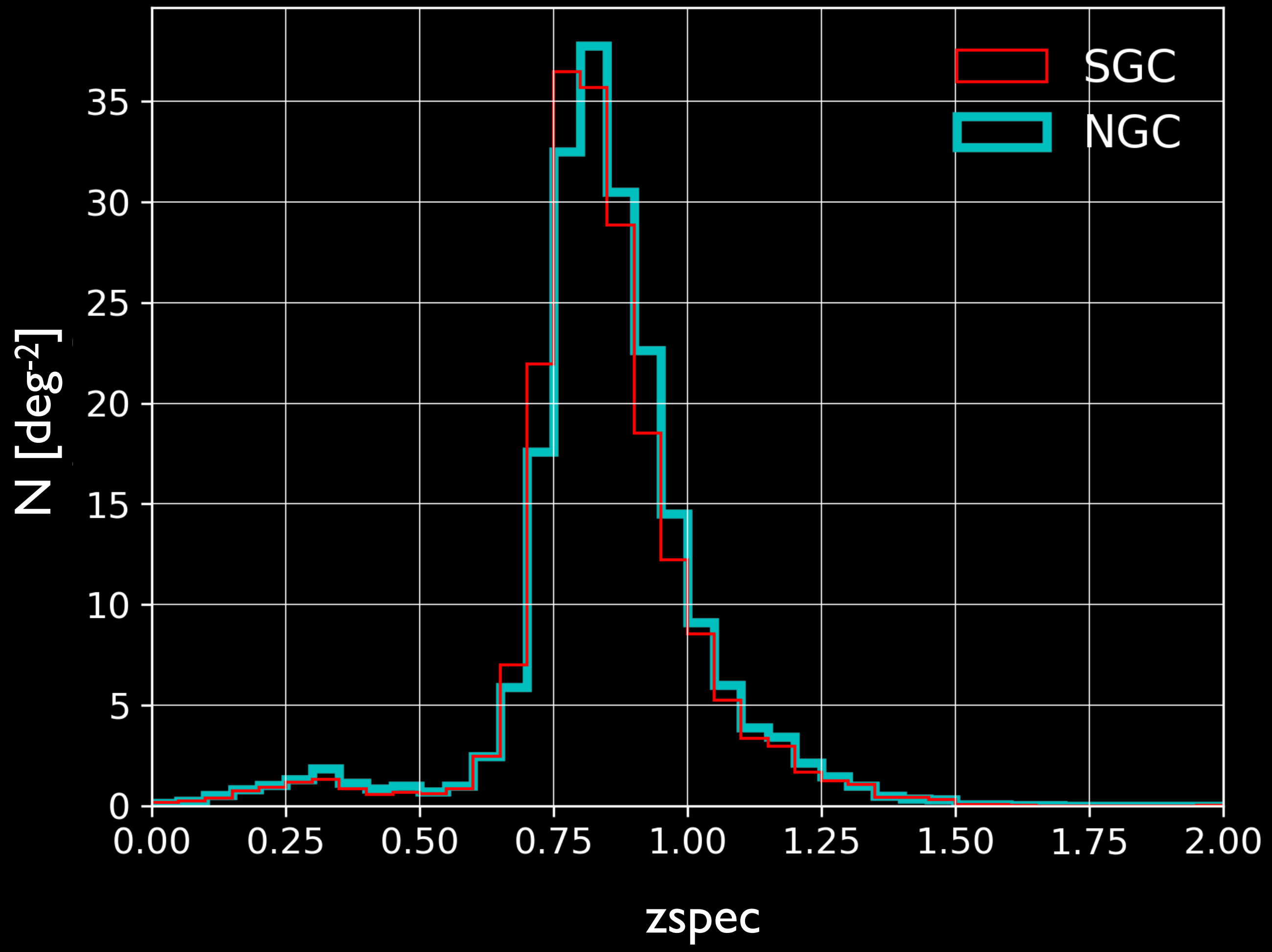
Spectroscopic redshift measurement

- rather low SN
- SDSS spectroscopic pipeline not optimised for ELGs
- a posteriori flags quantifying the SN in continuum/emission lines
- visual inspection → ~1% catastrophic redshifts

eBOSS/ELG status

- n(z) as expected, peaking at z~0.85
- full data observed, analysis on-going
- first cosmological results this summer





eBOSS results: BAO with QSOs

Ata et al.2018

Data

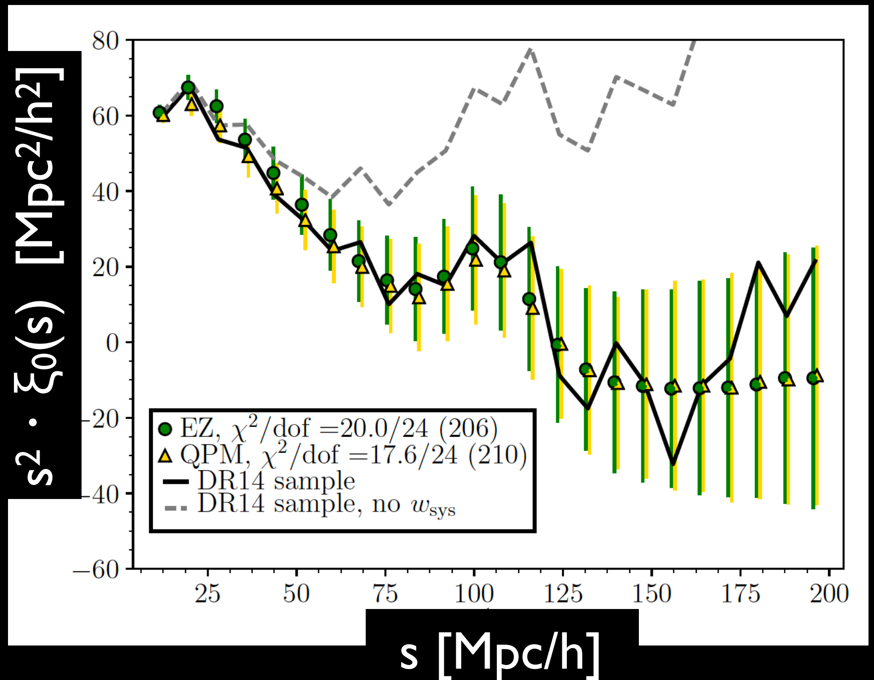
- 150k QSOs with 0.9<z<2.2 (DR14, 2-years sample)

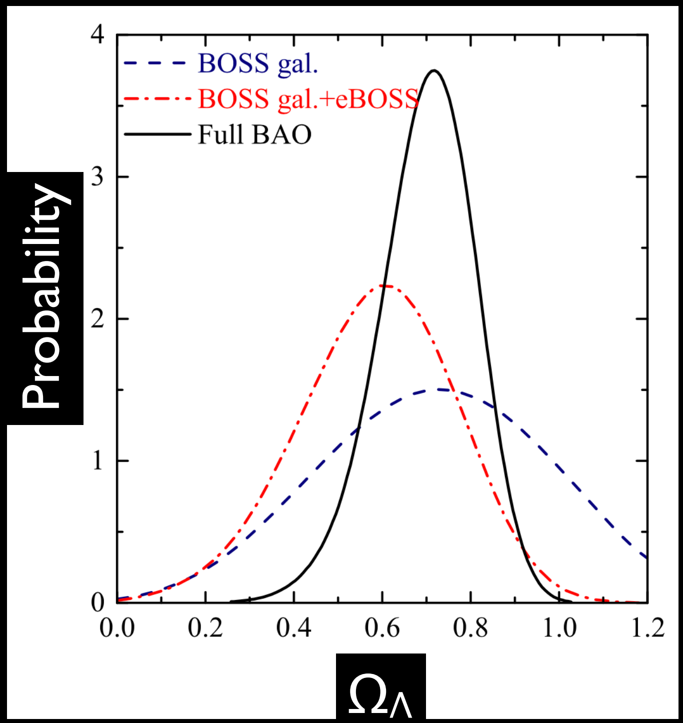
Analysis development

- new redshift classification (not visual)
- high-fidelity QSO mock catalogues
- improved weighted schemes to account for redshift failure patterns

First BAO measurement at z~1.5

- 4.4% precision on the distance scale
- strong leverage thanks to the sample high-redshift (already improves BOSS galaxy BAO measurement)
- combining BAO measurements → non-zero Λ preferred at 6.5σ





eBOSS results: RSD with QSOs

Gil-marin et al. 2018
Hou et al. 2018
Ruggeri et al.2018
Zarrouk et al. 2018
Zhao et al. 2018a,2018b
Zhu et al. 2018

Data

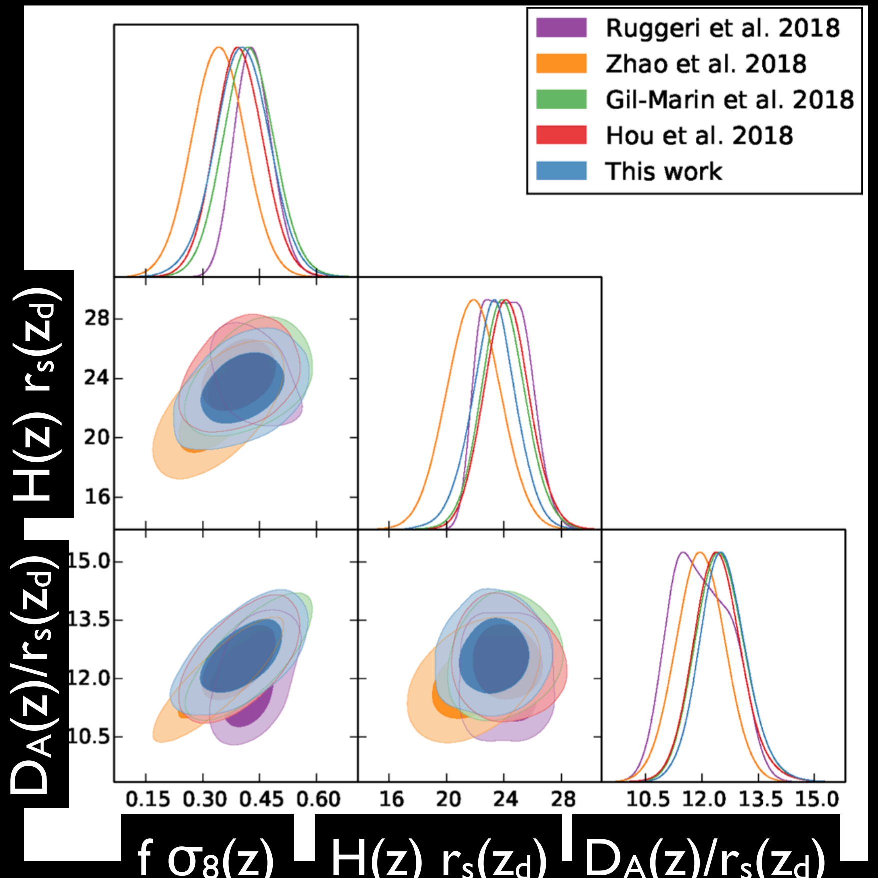
- 150k QSOs with 0.9<z<2.2 (DR14, 2-years sample)

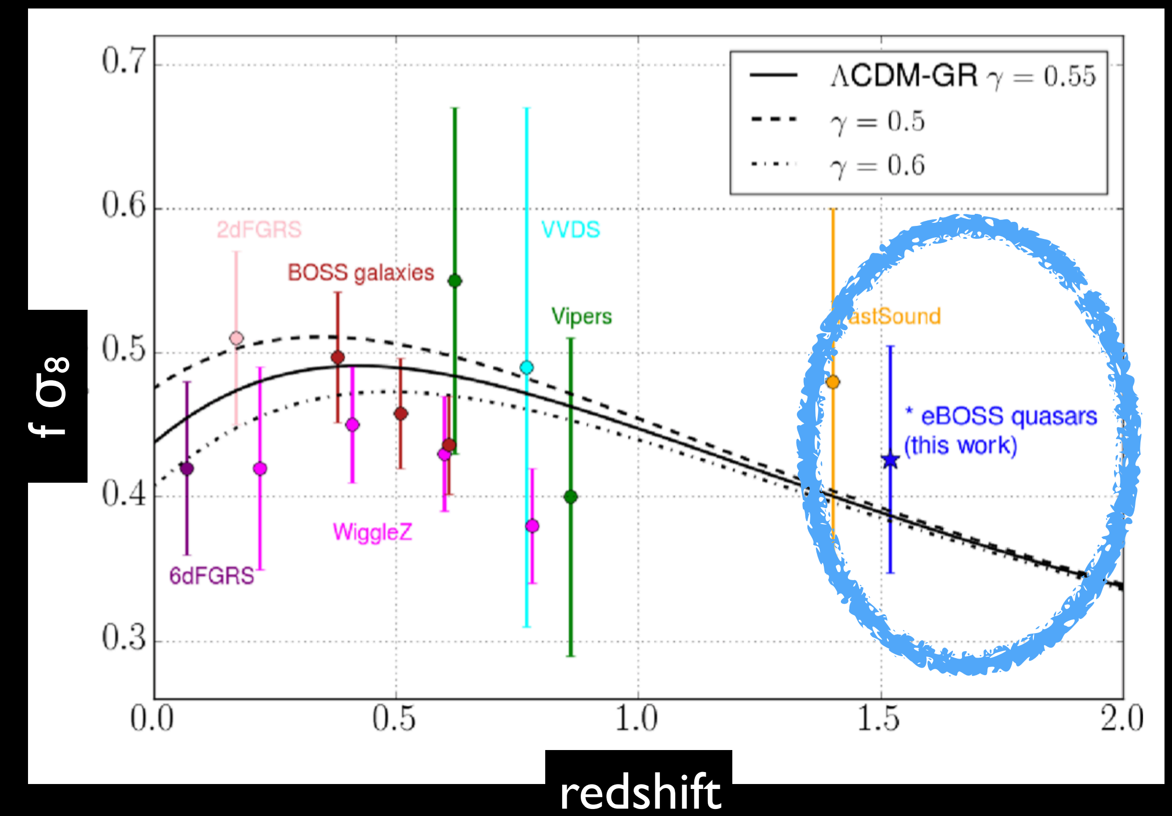
Analysis development

- different weighting techniques
- decomposition of BAO and RSD measurements into multiple redshift bins
- different models of non-linear matter clustering in configuration space
- measurements of RSD in the matter power spectrum

Anisotropic clustering, RSD measurement at z~1.5

- $f \cdot \sigma_8$, $H(z) \cdot r_s$, $D_A(z) \cdot r_s$ full shape analysis
- precision: $f \cdot \sigma_8$ =18%, $H(z) \cdot r_s$ = 7.5%, $D_A(z) \cdot r_s$= 5.5%





eBOSS results: BAO with LRGs

Bautista et al. 2017
Zhai et al. 2017

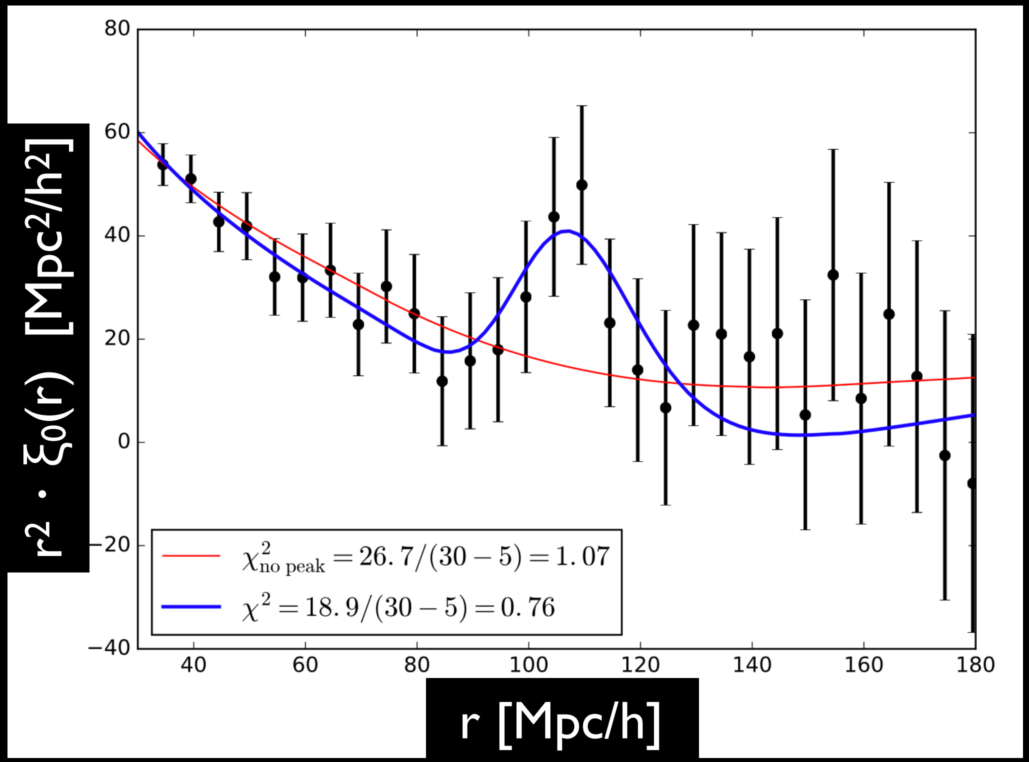
Data

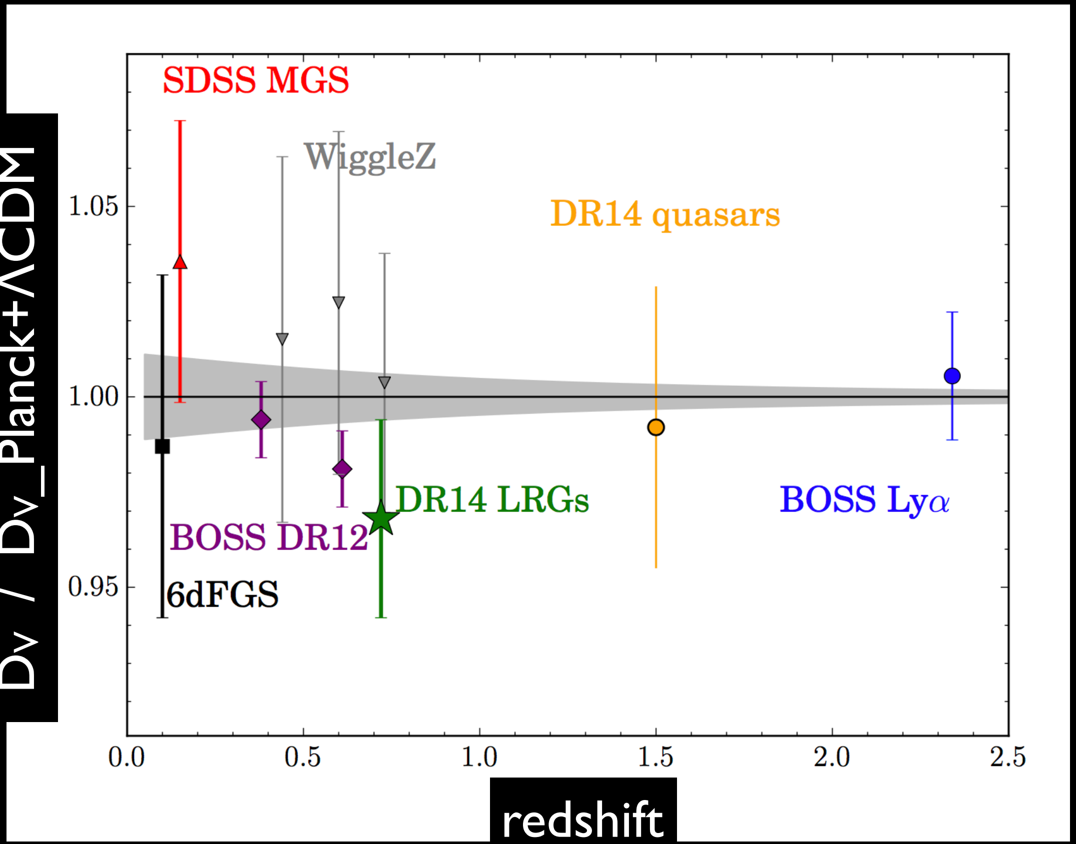
- 80k LRGs with 0.6<z<1.0 (DR14, 2-years sample)

Analysis development

- optical+NIR target selection
- data reduction improvement (extraction, calibration, redshift fitter)
- new forward-modeling scheme to account for sources of incompleteness

2.6% BAO measurement at z~0.7





eBOSS results: QSO-CIV cross-correlation

Blomqvist et al. 2018

Data

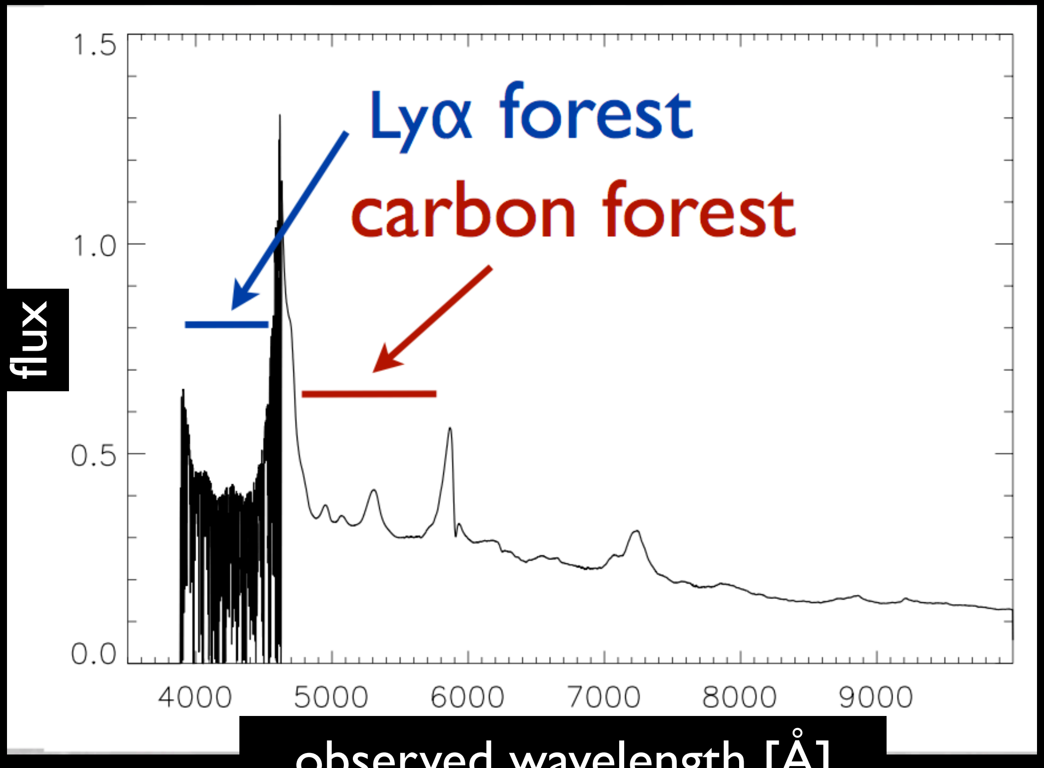
- 30k new Lyαs in DR14 (2-years sample)
- 290k CIV forest quasars in 1.4<z<3.5, 390k tracer quasars in 1.2<z<3.5

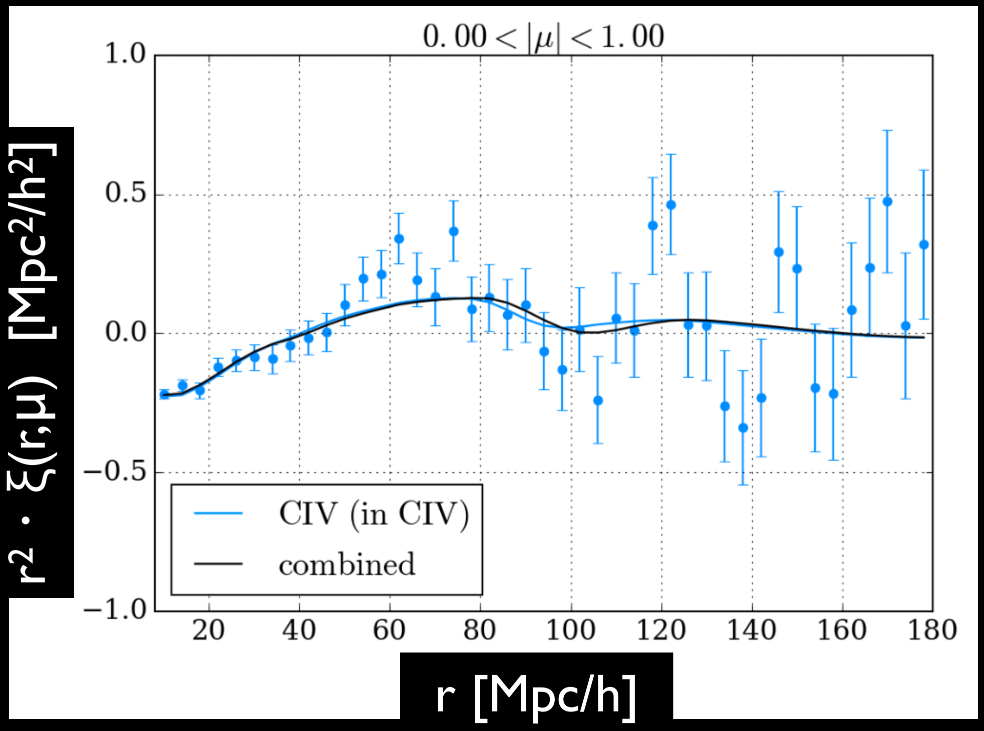
New idea

- use CIV forest instead of Lyα forest
- weaker than Lyα, but:
  - can be used down to z=1.3 (w.r.t. z=2.1 for Lyα)
  - high density of quasars at z<2

Analysis development

- first measurement of QSO-CIV cross-correlation at large scales
- CIV absorption has the potential to be used as a new probe of BAO

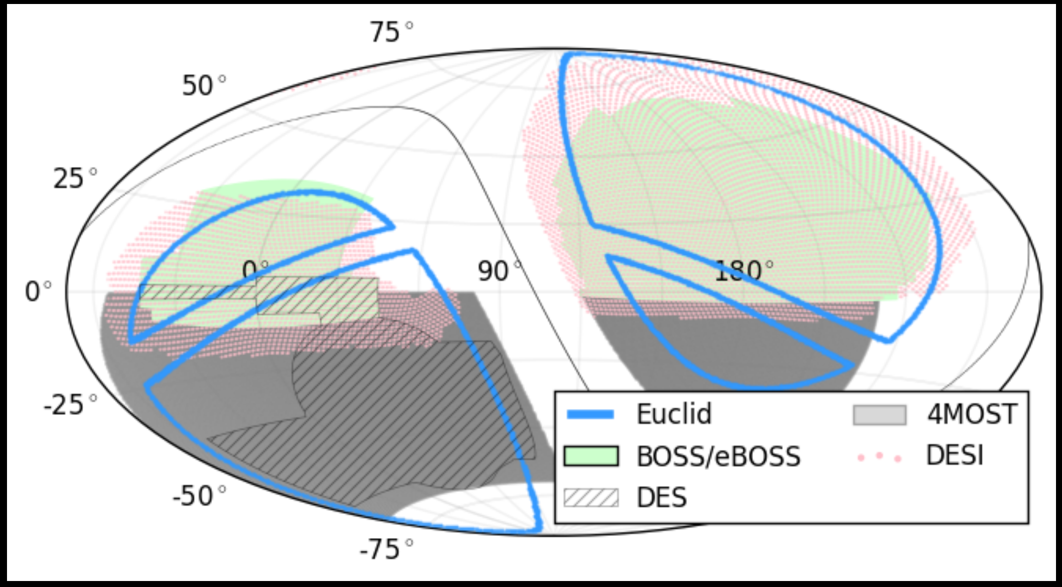




Future LSS surveys

DESI (2020-2025)

- 5000 fibers spectrograph at KPNO/Mayall telescope
- 35M spectra over 14k deg2
- precise BAO/RSD measurement from z~0.1 to z~3.5

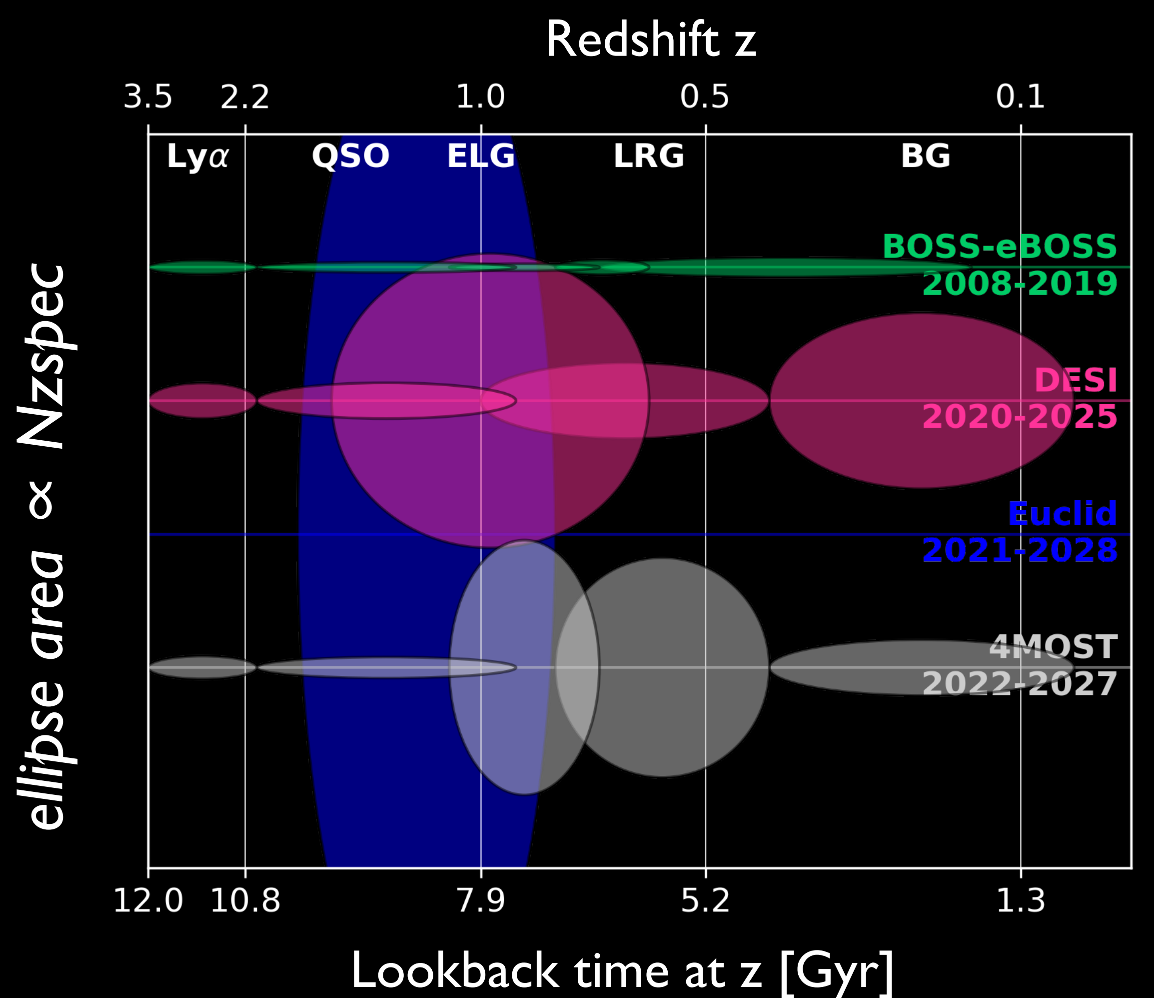


4MOST/CRS (2022-2027)

- 2430 fibers spectrograph at VISTA telescope
- Cosmological Redshift Survey (CRS)
  - one of the 4MOST Consortium Surveys
  - 20M spectra over 12k deg2
  - combine with other surveys

Euclid (2021-2028)

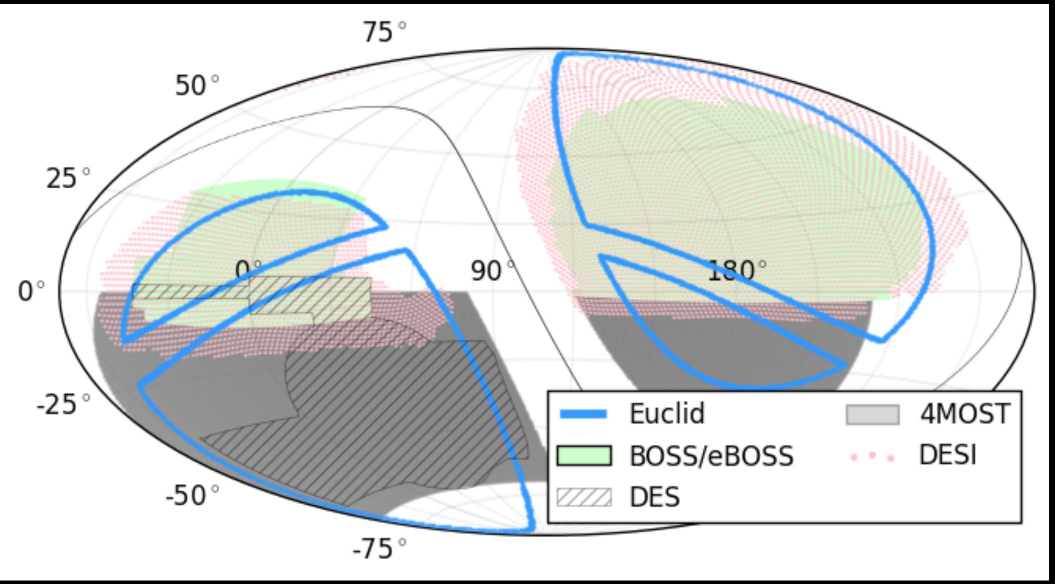
- grism spectroscopy with satellite
- 50M spectra over 15k deg2



4MOST/CRS survey

Science goals

- test gravitational physics
  - complementary imaging: KiDS, DES, LSST
  - galaxy-galaxy lensing x RSD
- synergy with CMB experiments
  - CMB-S4 in the Southern Sky
  - kinetic Sunyaev-Zel'dovich (kSZ) effect
  - weak gravitational lensing of the CMB
- Ly-α forest clustering
  - high spectral resolution, good seeing
  - constraint on small- and large-scale cosmology
- BAO
- source redshift distributions via cross-correlations
  - use clustering properties to estimate source n(z)
  - primordial for weak-lensing analysis: KiDS, DES, LSST, *Euclid*



Conclusions

SDSS/eBOSS DR14 results

- results in agreement with ΛCDM + GR framework
  - LRG @ z~0.7: 2.6% BAO distance measurement
  - QSO @ z~1.5: first BAO measurement + RSD measurements
- new BAO tracer with QSO x CIV @ z~1.9

SDSS/eBOSS/ELG

- full data observed
- first cosmological results @z~0.9 this summer

Future LSS surveys

- DESI, 4MOST, *Euclid* starting in the coming years
- eBOSS experience crucial

4MOST/CRS survey (2022-2027)

- ~20M spectra over the Southern Sky
- will enable broad range of cosmological analysis
- strong synergy with other surveys (WL, CMB)
- will be the reference spectroscopic survey over the Southern Sky