The SDSS / eBOSS survey
recent results and prospects

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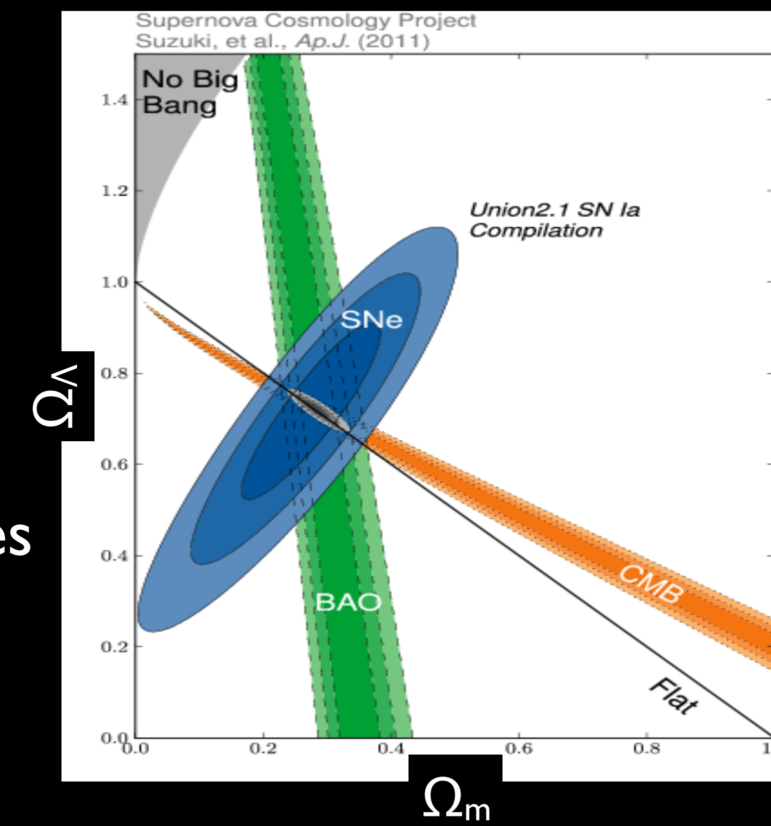
on behalf of the eBOSS team

- LSS surveys
- eBOSS results with the 2-years sample
- eBOSS/ELG analysis
- future LSS surveys

Cosmology with LSS surveys

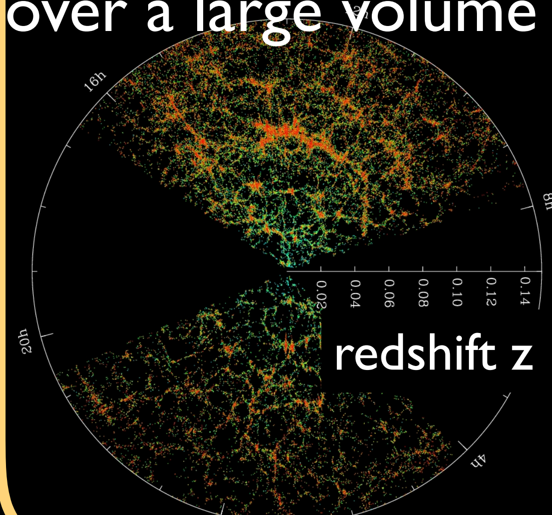
Current state

- 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
- cosmological probes
  - geometry of the Universe : CMB, SNIa, BAO
  - growth of structures: RSD, WL, galaxy clusters

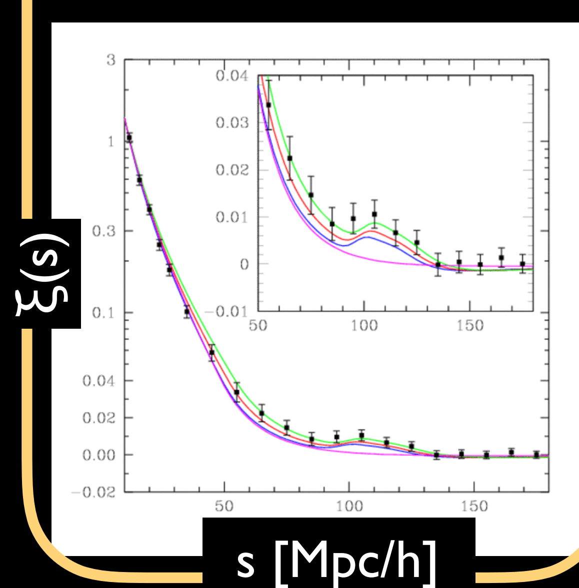


Large-scale structure surveys

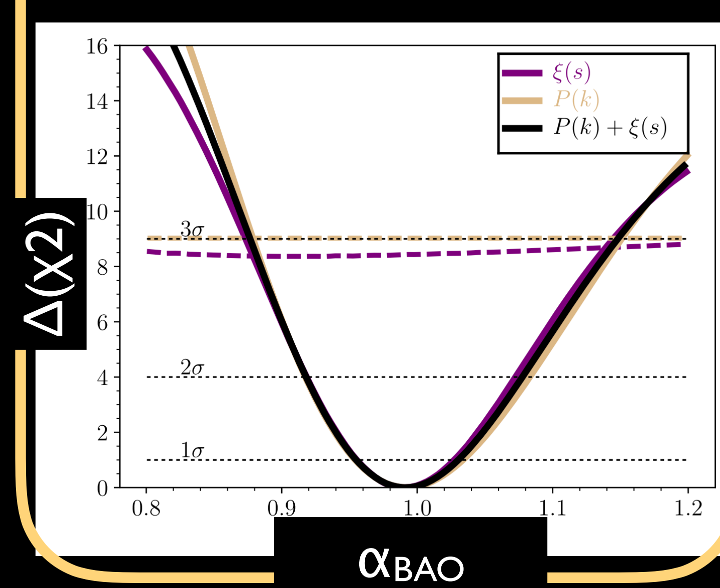
step 1
obtain redshift of galaxies over a large volume



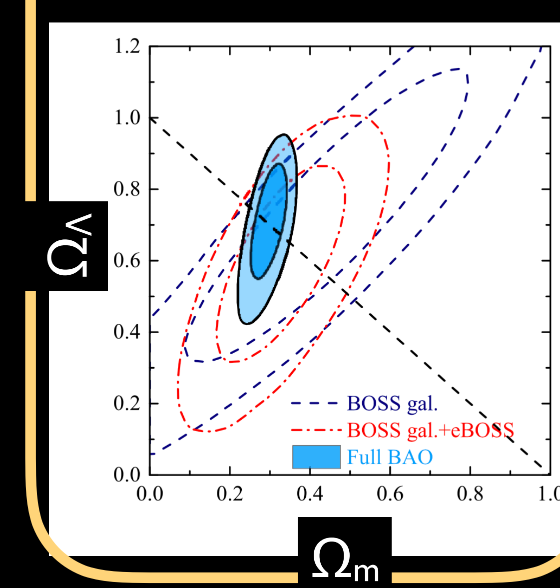
step 2
compute 3D-position clustering



step 3
measure BAO / RSD



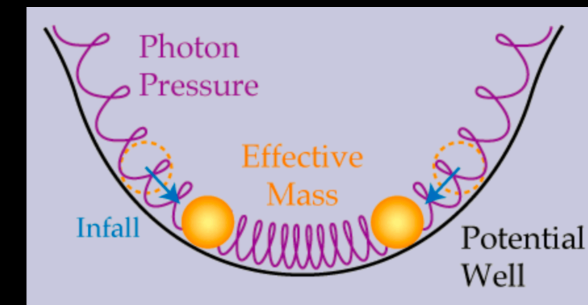
step 4
constrain the models



Baryon Acoustic Oscillations

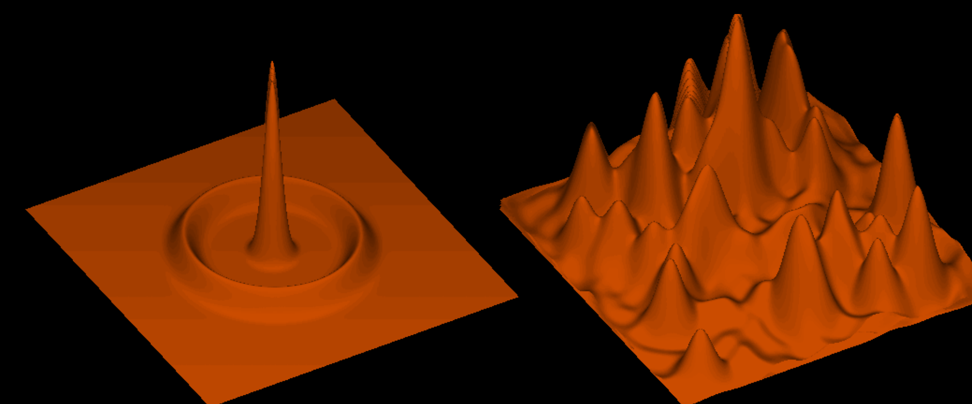
Before z~1100

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



At z~1100

- 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



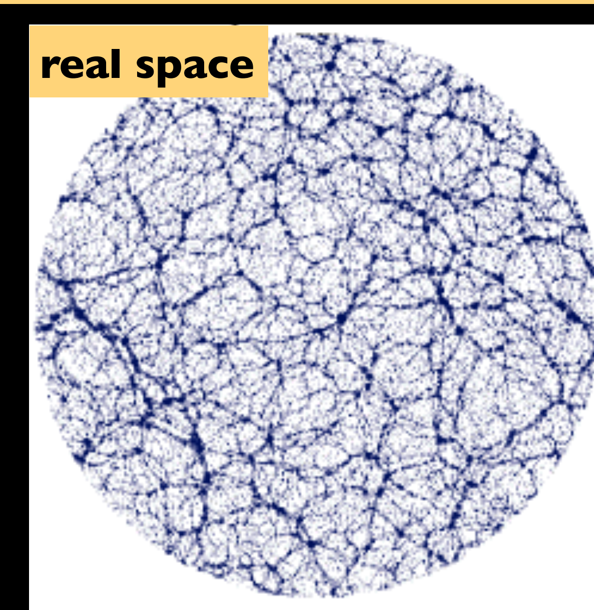
After z~1100

- BAO = overdensity of galaxies 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

Redshift Space Distortions

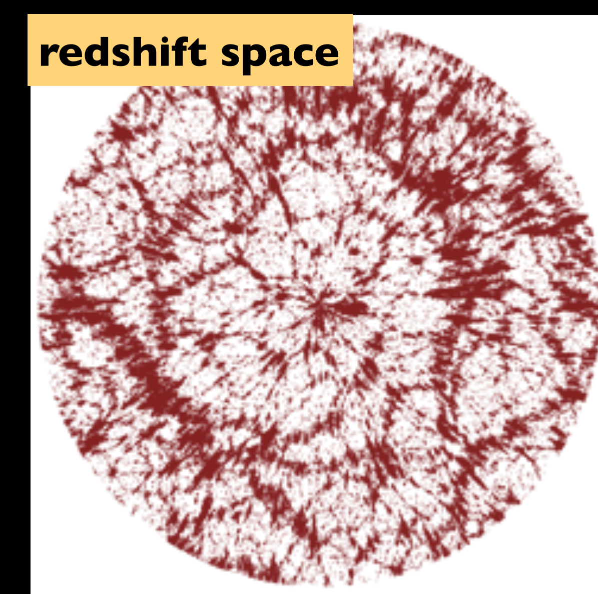
Anisotropic clustering in redshift space

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



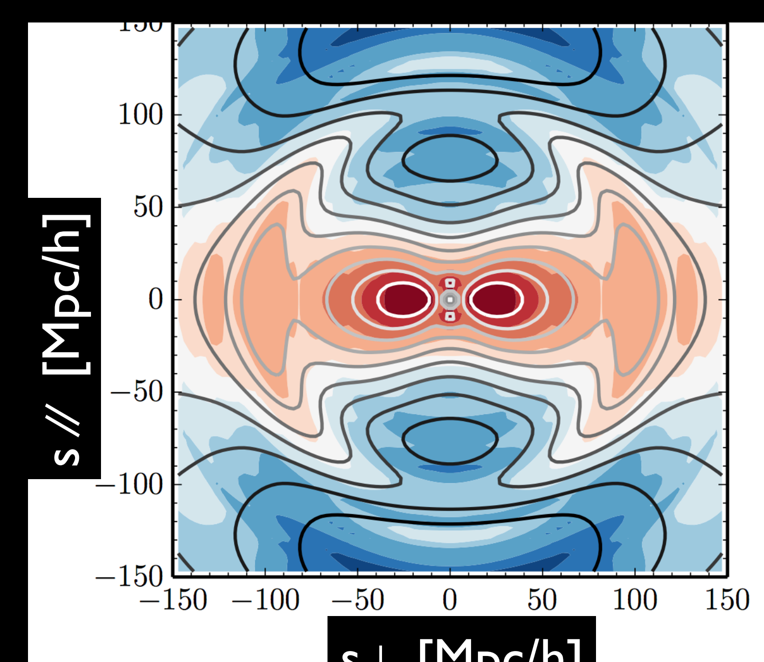
Constraining cosmology and General Relativity

- $\sigma_8(z)$: 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

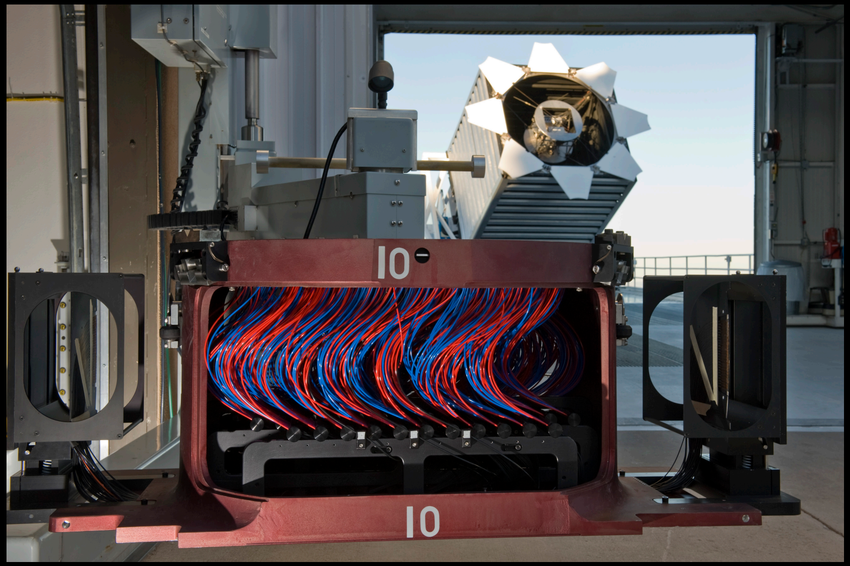
- constraints on gravity stronger at small scales
- linear regime (s>80 Mpc/h) modelling well understood
- challenge to model:
  - quasi-linear (30<s<80 Mpc/h)
  - non-linear regimes (s<30 Mpc/h)
- current 40 < s < 80 Mpc/h
- some models (CLPT) down to ~25-30 Mpc/h



BAO surveys with the SDSS

SDSS telescope

- 2.5-meters, New Mexico
- 1000 fibers, field of view of 7 deg2
- ~1h exposure per plate
- 2005: (co-)first BAO measurement at z~0.3 with ~50k LRGs
- 2008-2014: BOSS, 1.5M spectra over 10k deg2

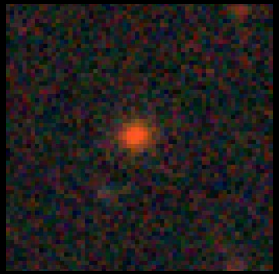


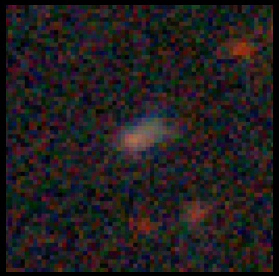
eBOSS (2014-2019)

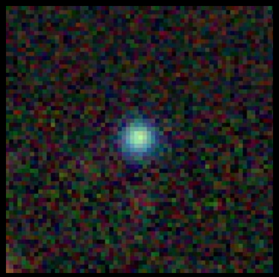
- extension of BOSS to 0.6<z<2.2 + new tracer (ELG)
- BAO distance measurement
- test of General Relativity on cosmological scales with RSD
- bonus: constraint on the sum of the neutrino masses

eBOSS tracers

	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**



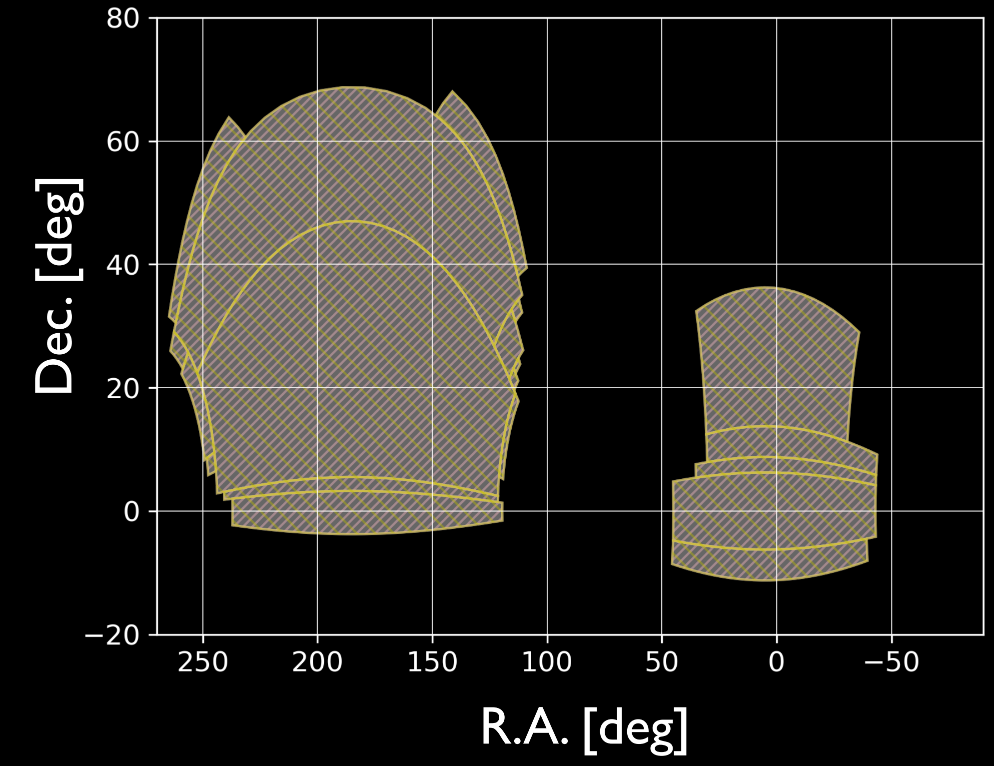


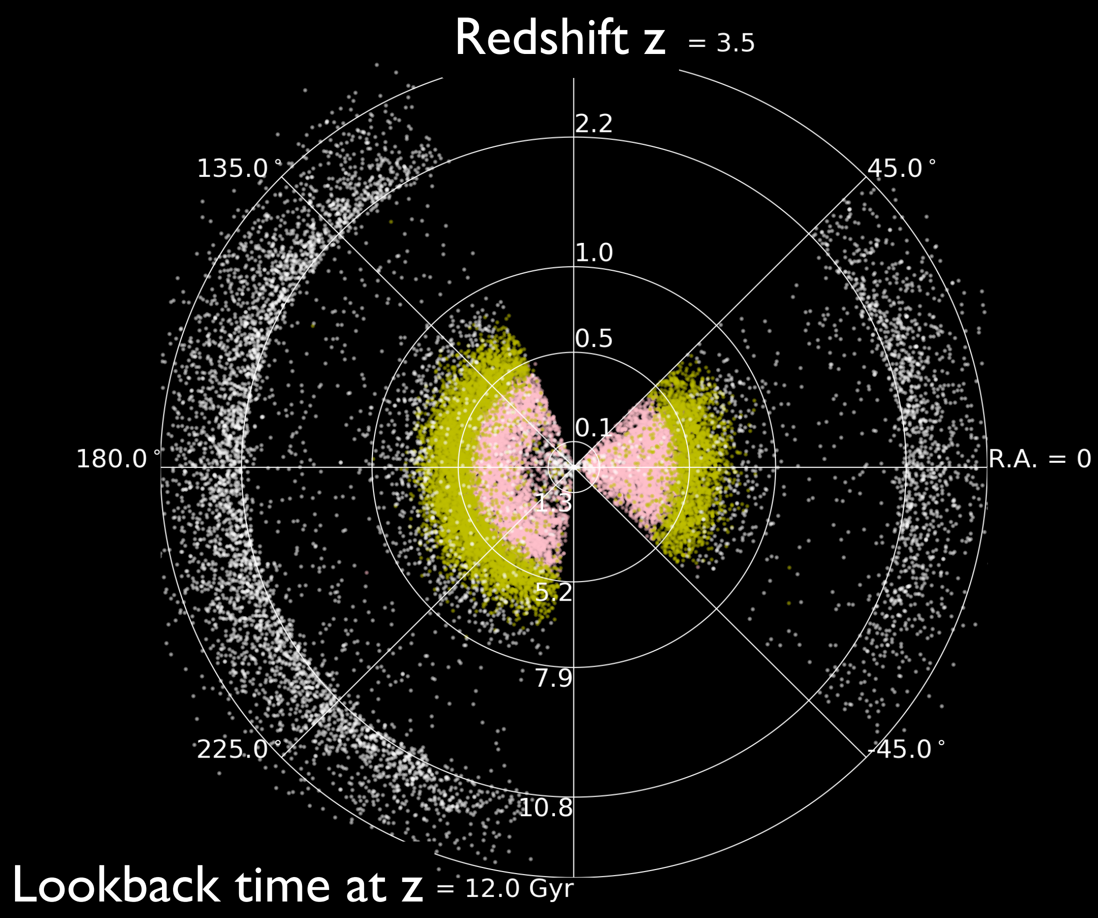


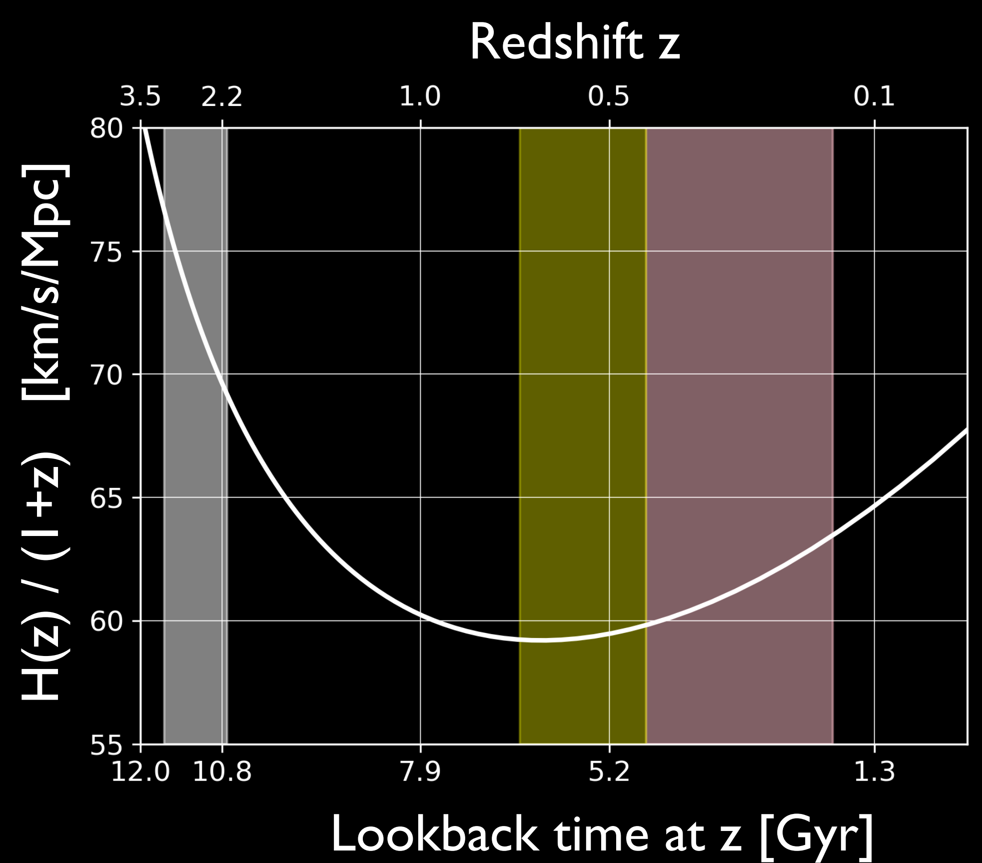
SDSS/BOSS survey

BOSS (2008-2014, 1.5M spectra)

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



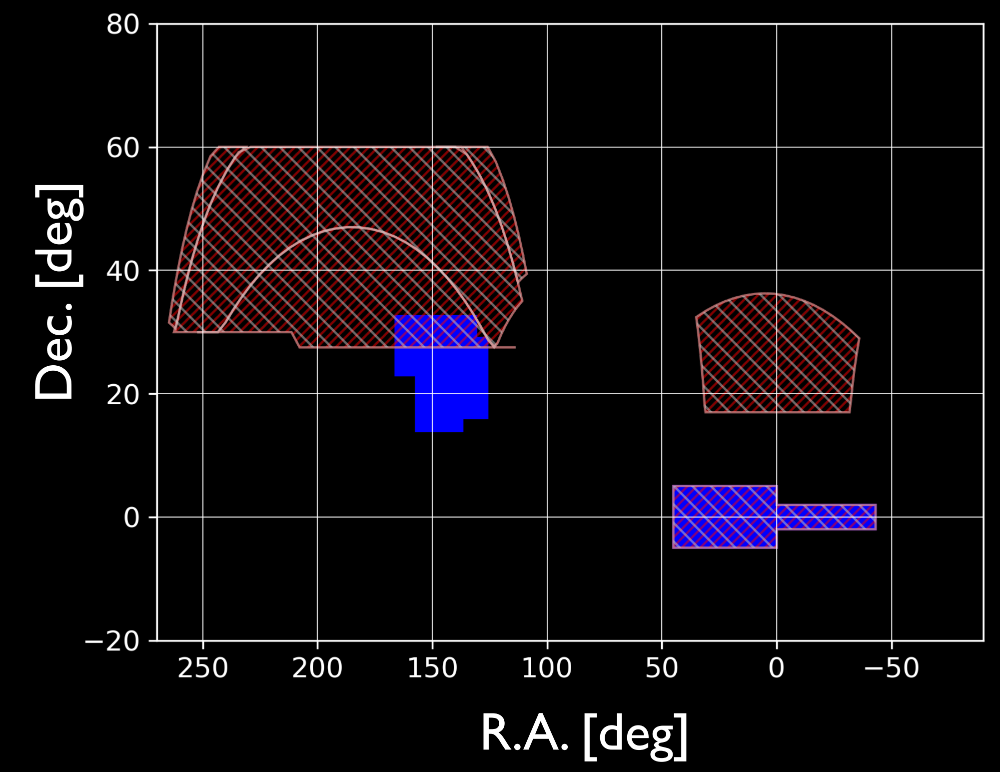


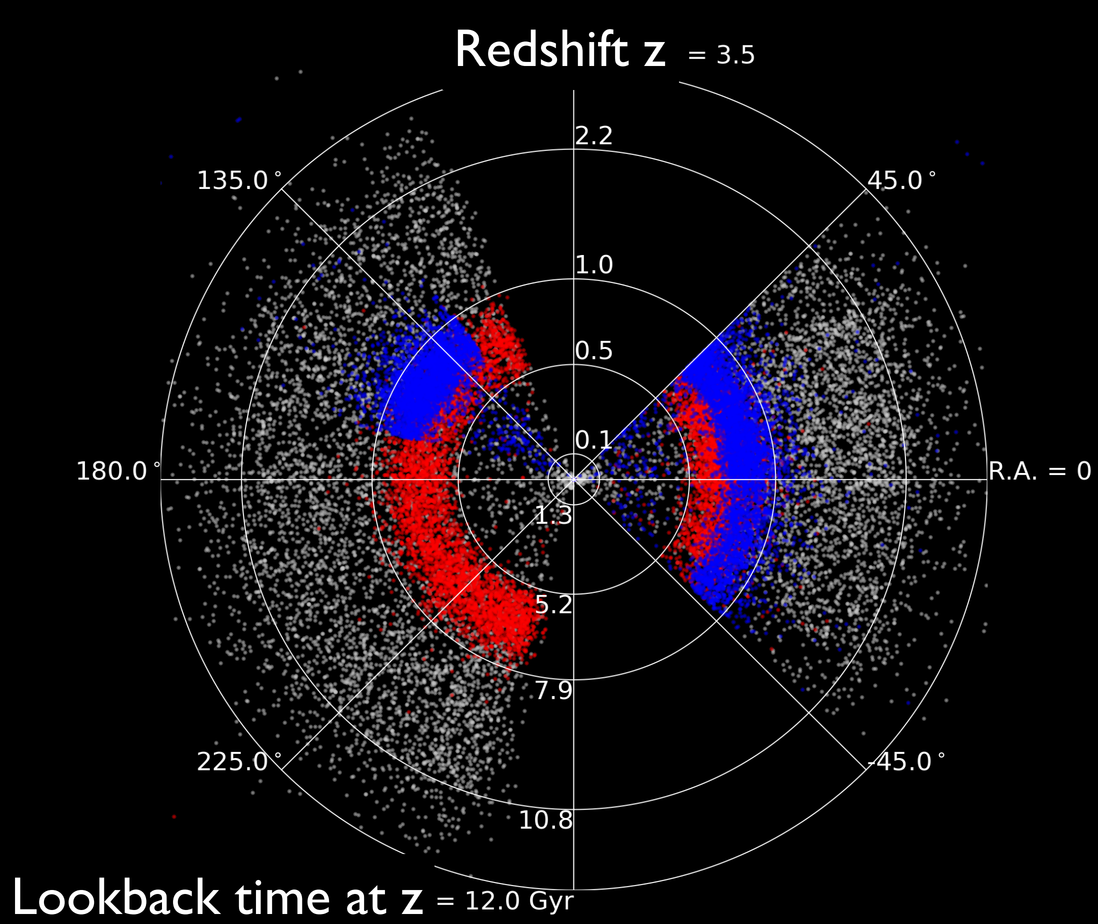


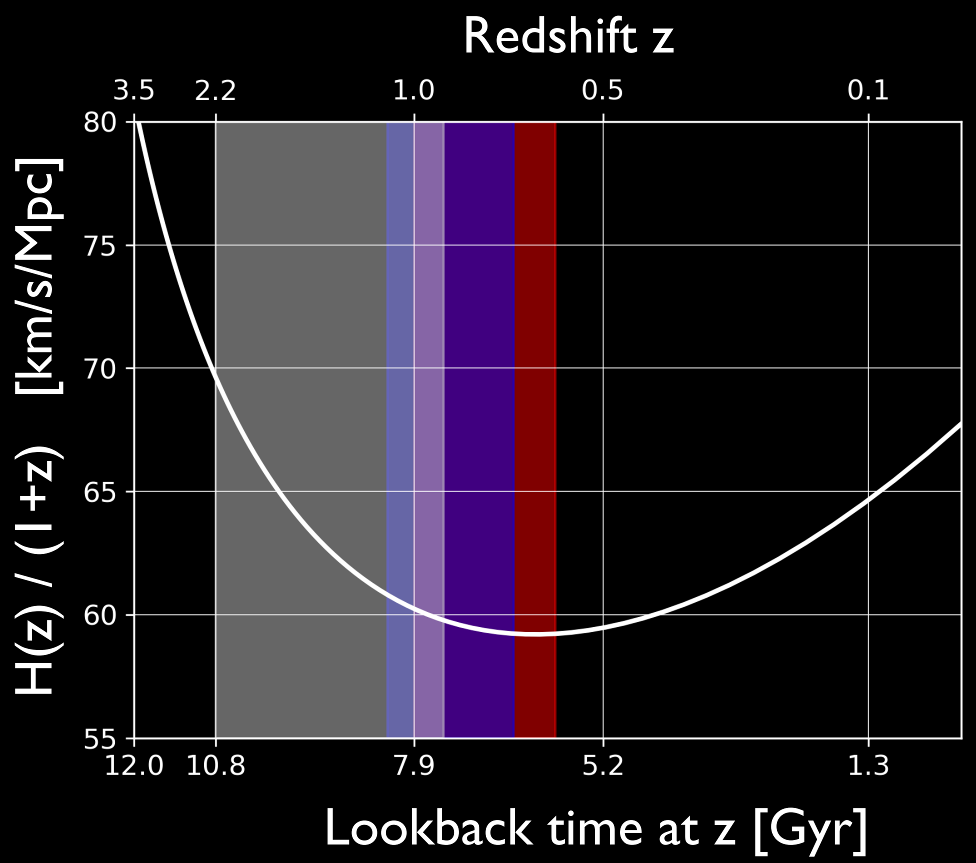
SDSS/eBOSS survey

eBOSS (2014-2019, 1M spectra)

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







eBOSS results: BAO with QSOs

Ata et al.2018

Data

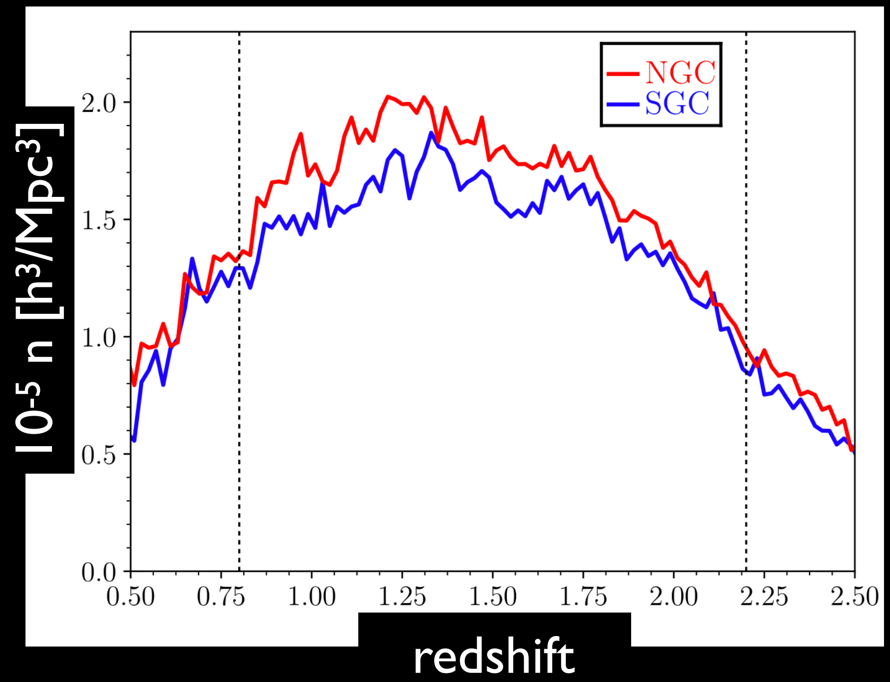
- 150k QSOs in DR14 (2-years sample)

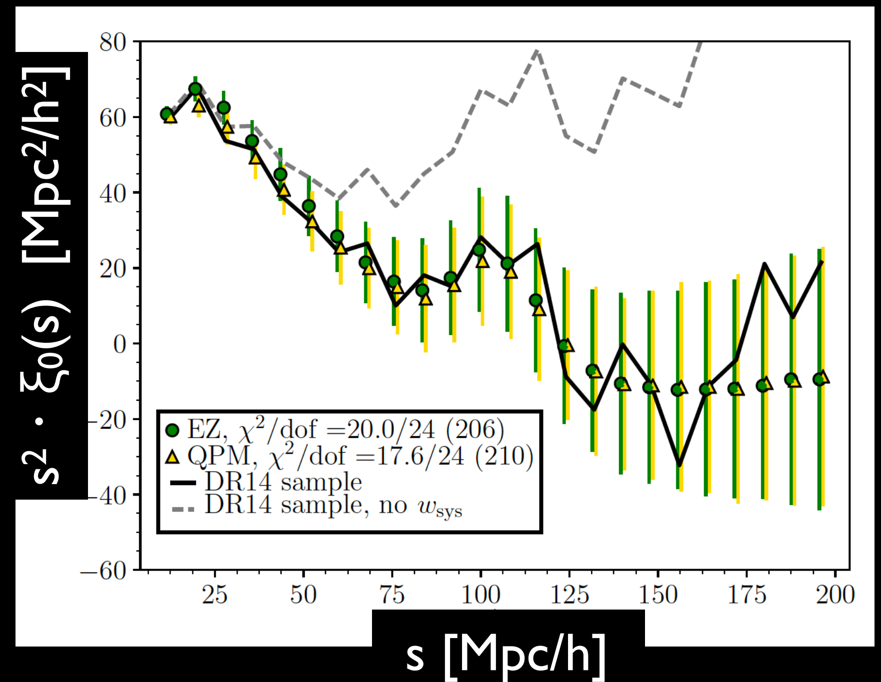
Analysis development

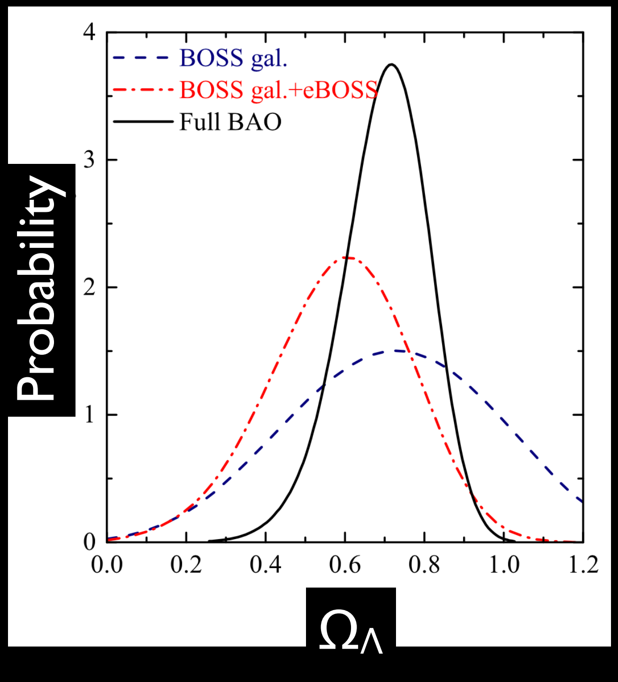
- new redshift classification (not visual)
- high-fidelity QSO mock catalogues
- improved weighted schemes to account for redshift failure patterns

First BAO measurement at z~1.5

- QSO properties in agreement with what was expected
- 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

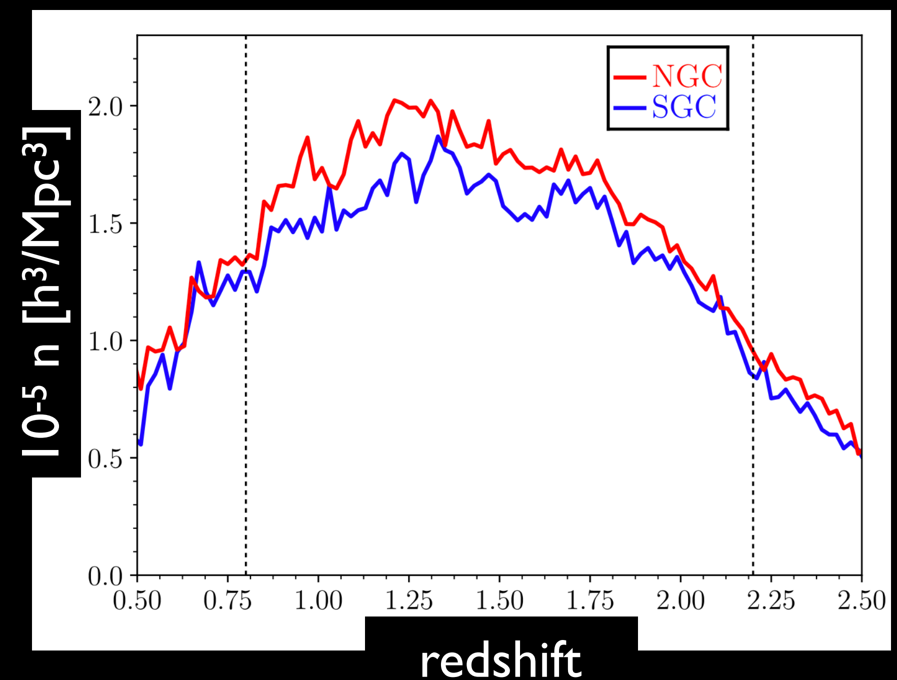
- 150k QSOs in DR14 (2-years sample)

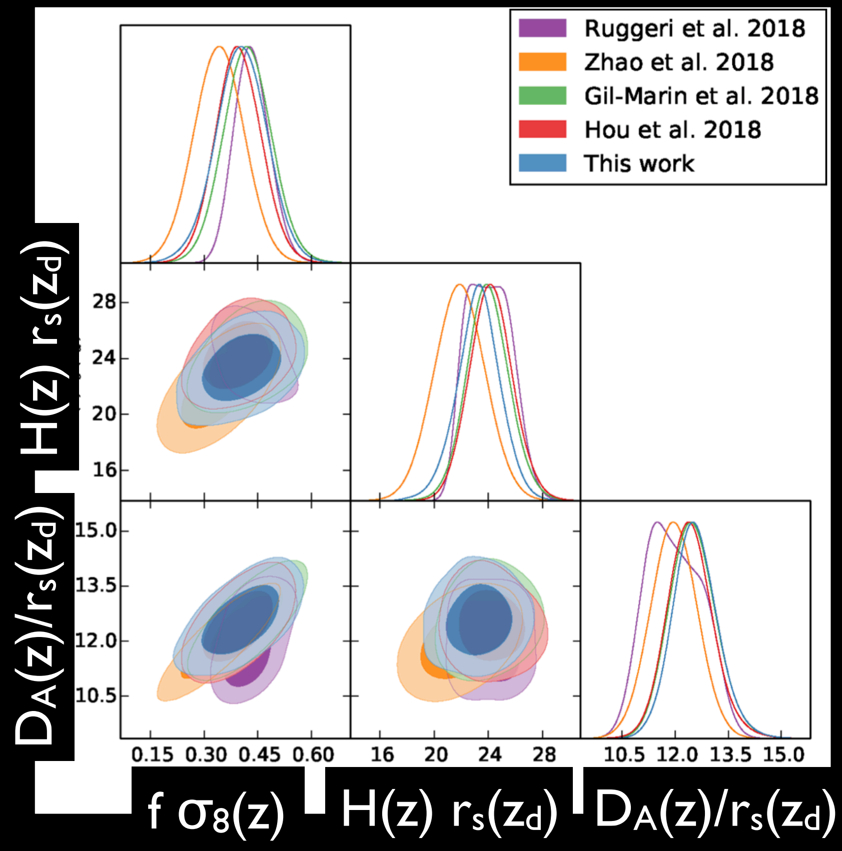
Analysis development

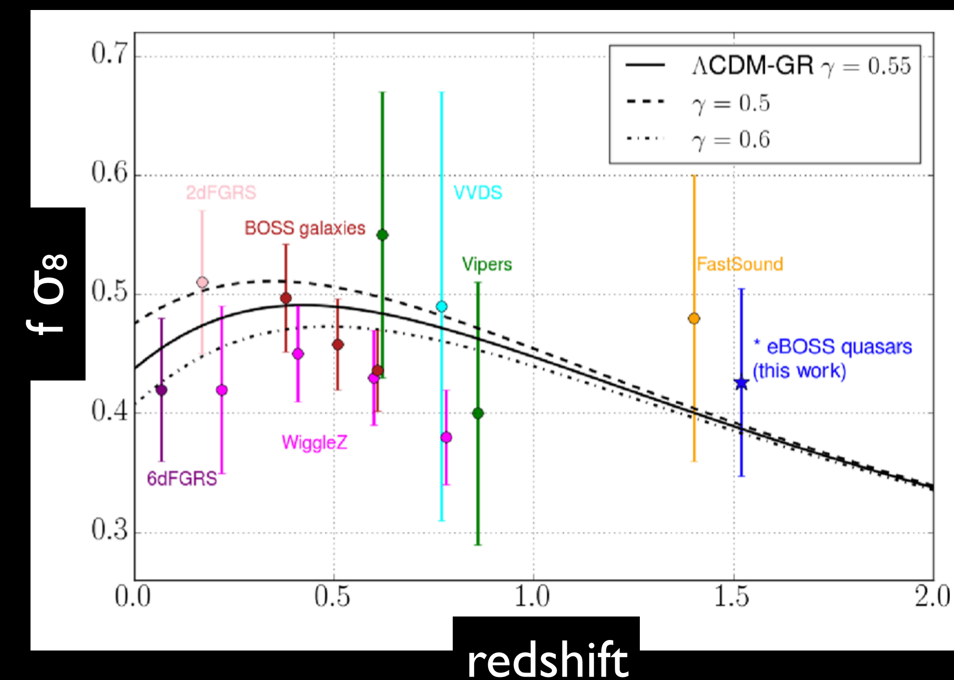
- different weighting techniques
- decomposition of BAO and RSD measurements into multiple redshift bins
- different models of non-linear matter clustering in configuration space
- measurements of RSD in the matter power spectrum

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 in DR14 (2-years sample)

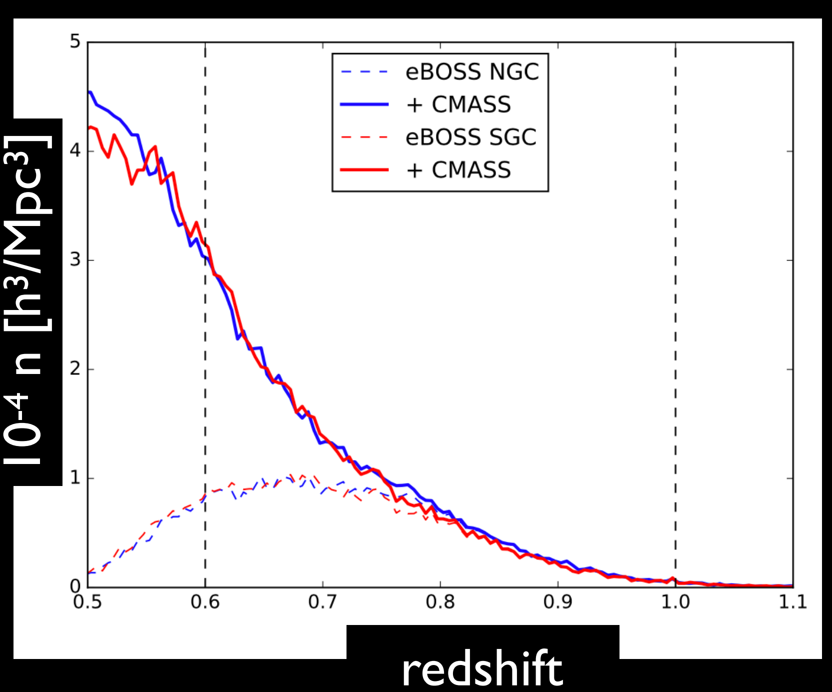
Analysis development

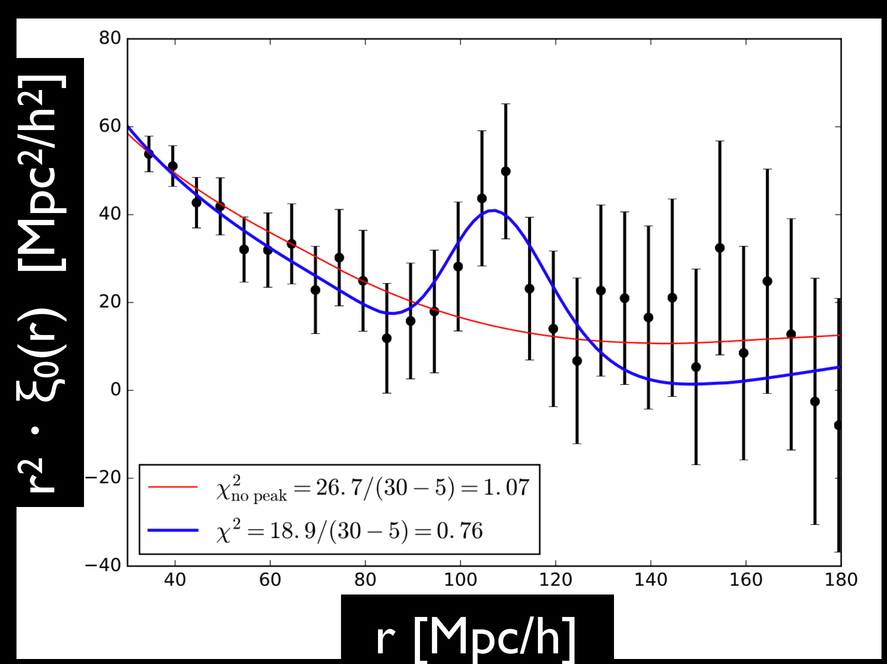
- optical+NIR target selection
- data reduction improvement (extraction, calibration, redshift fitter)
- new forward-modeling scheme to account for sources of incompleteness

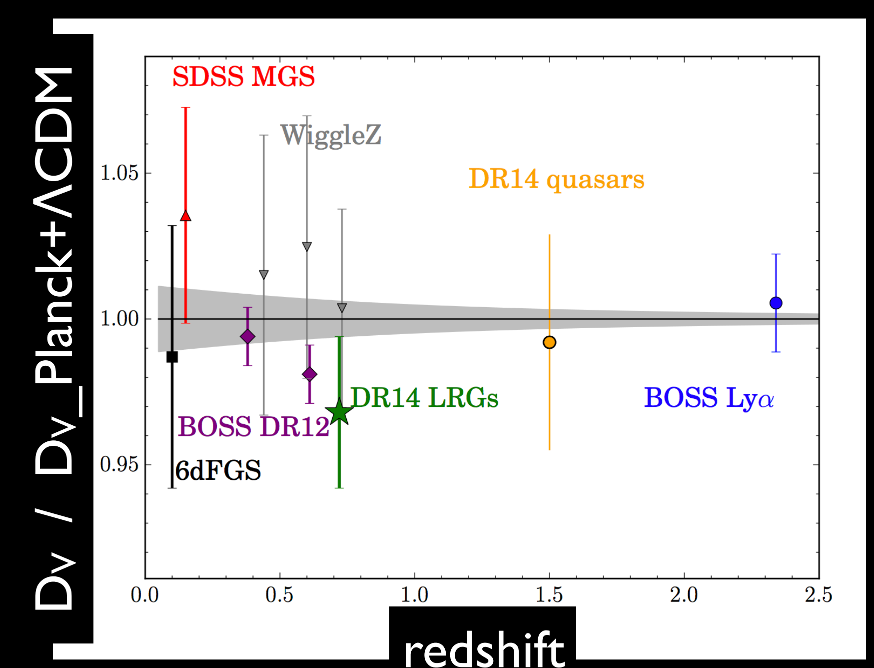
Small/intermediate-scale clustering

- bias measurement / satellite fraction / mean halo mass
- in agreement with what expected

2.6% BAO measurement at z~0.7







eBOSS results: QSO-CIV cross-correlation

Blomqvist et al. 2018

Data

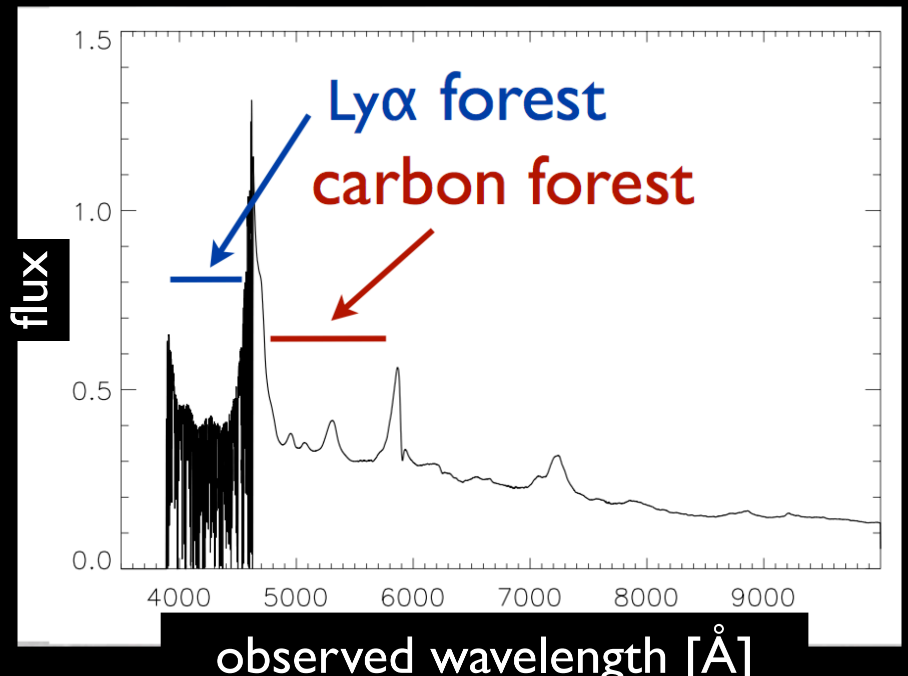
- 30k new Lyαs in DR14 (2-years sample)
- 290k CIV forest quasars in 1.4<z<3.5, 390k tracer quasars in 1.2<z<3.5

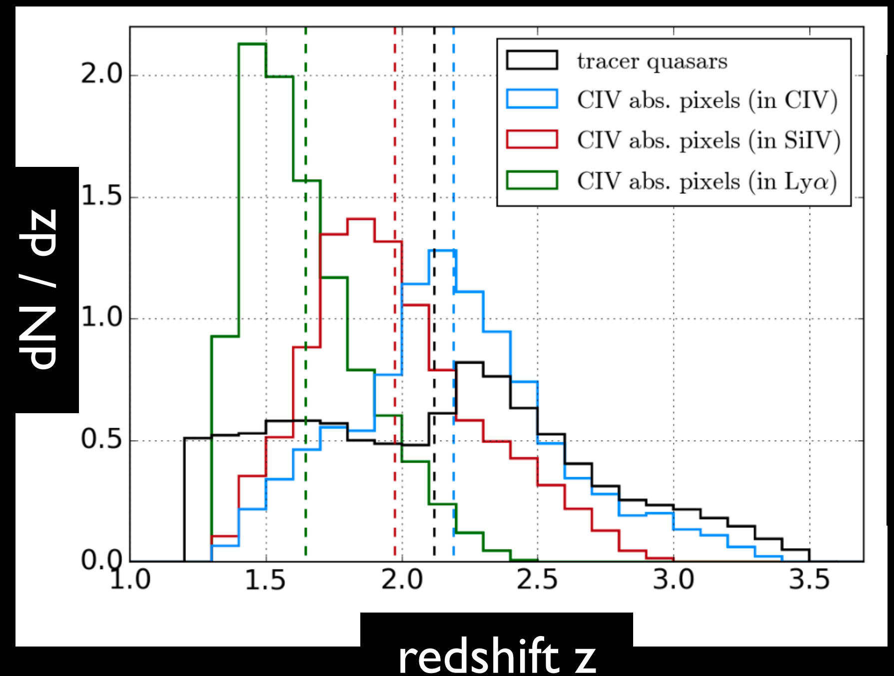
New idea

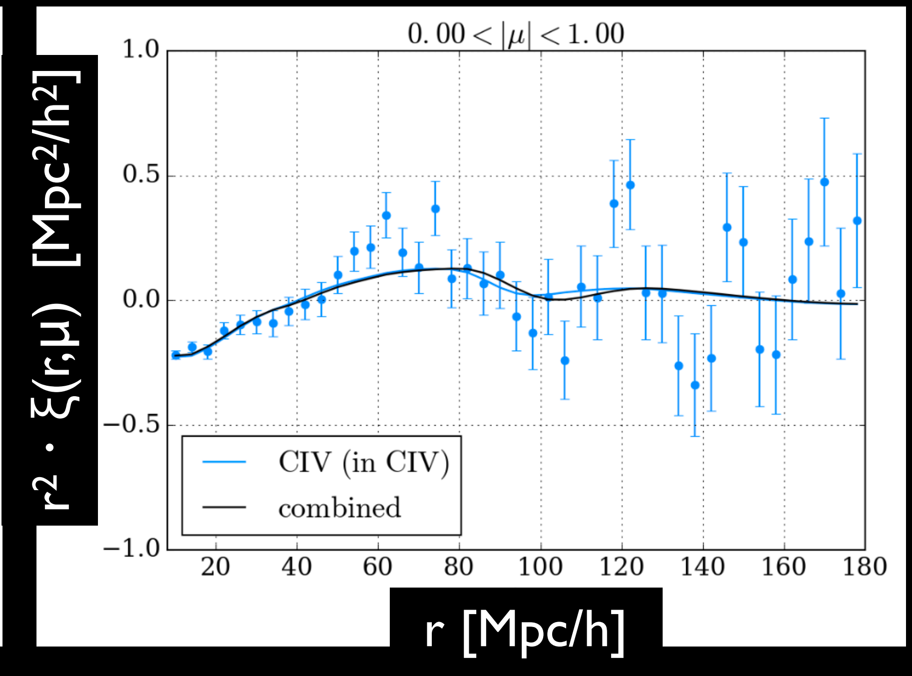
- use CIV forest instead of Lyα forest
- weaker than Lyα, but:
  - can be used down to z=1.3 (w.r.t. z=2.1 for Lyα)
  - high density of quasars at z<2

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



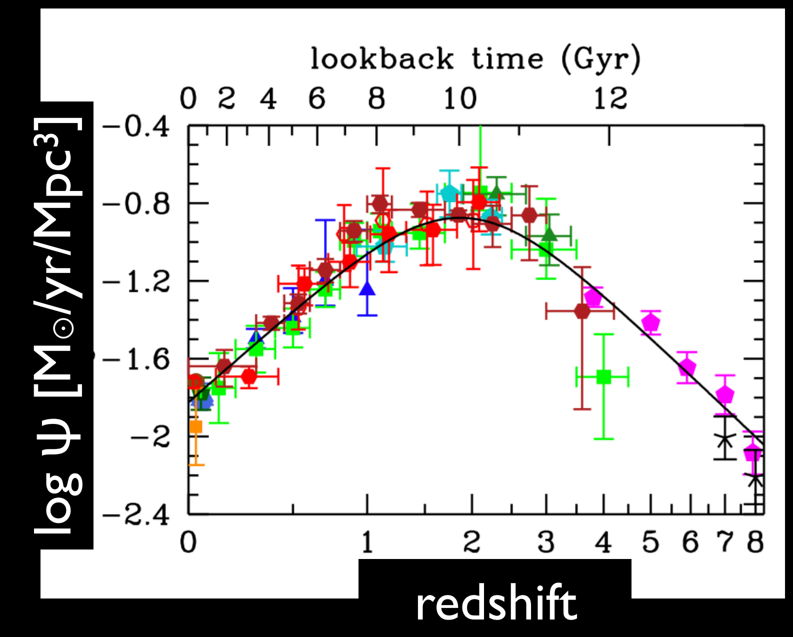




ELG principle

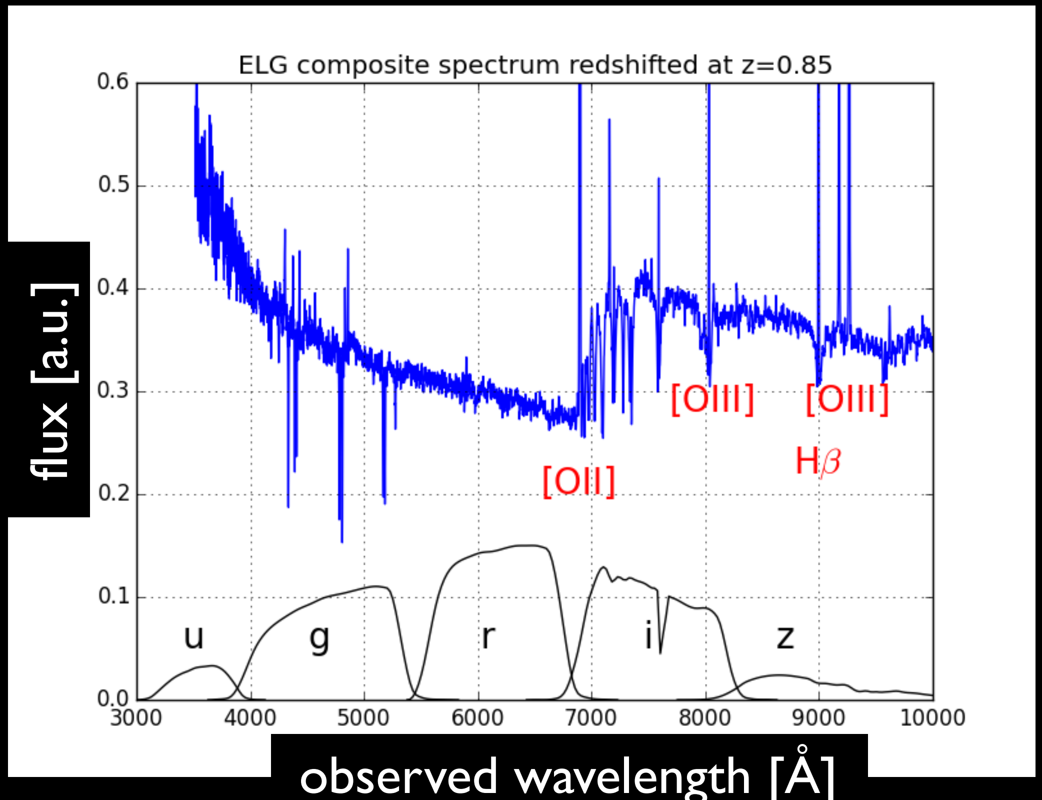
Why ELGs?

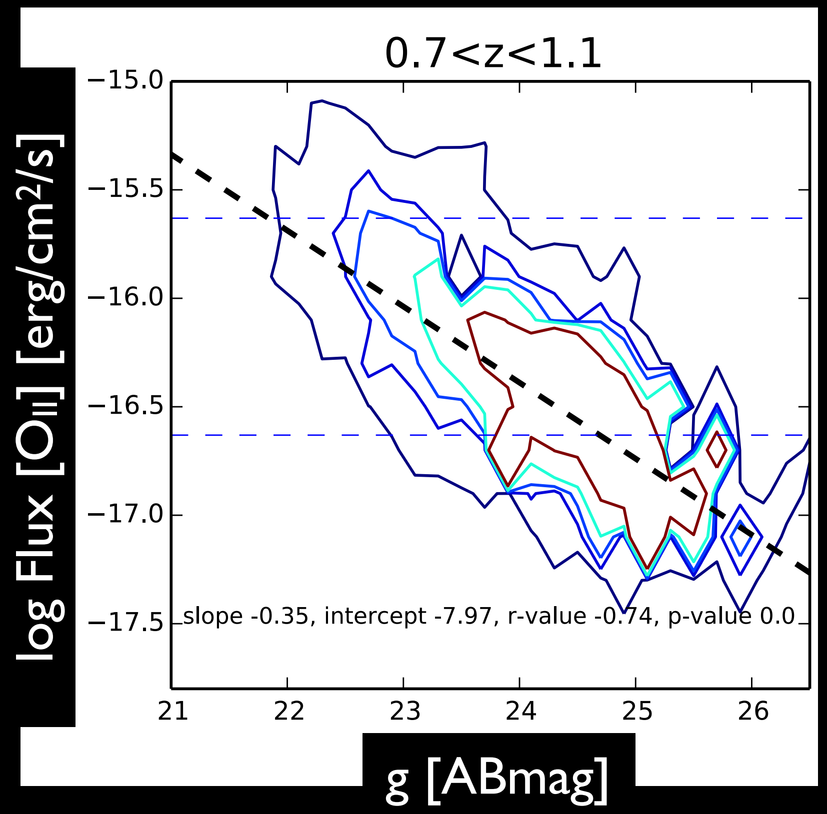
- emission lines ([O_{II}] 3727 Å) permits quick zspec measurement
- abundant at z~0.85
- key for future BAO surveys (DESI, *Euclid*, 4MOST)



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

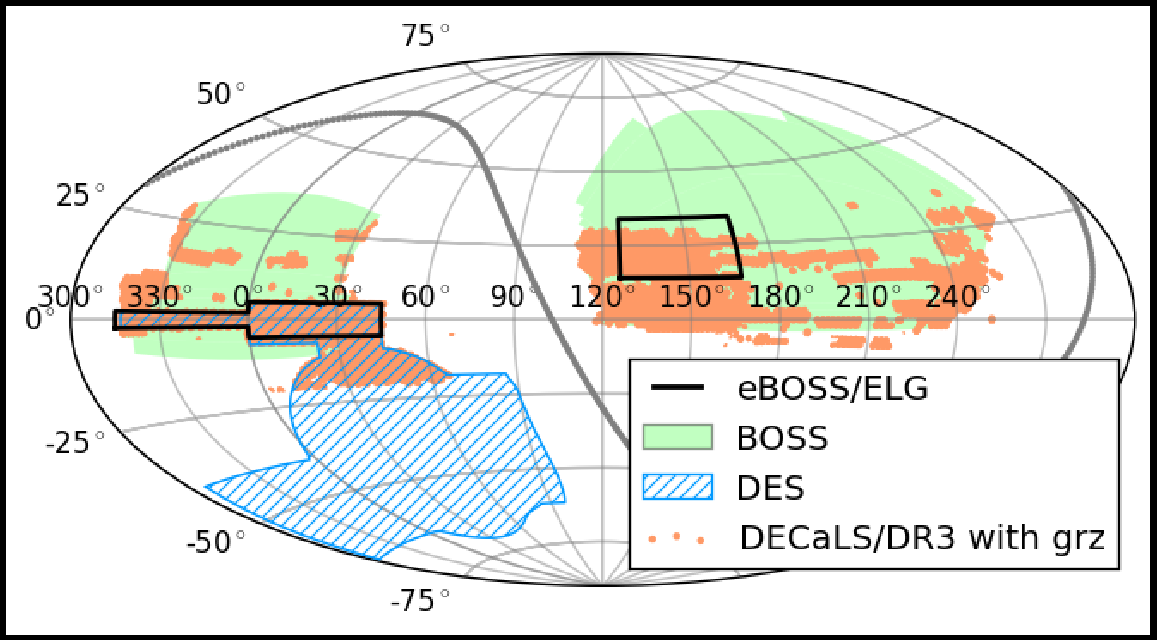




ELG target selection

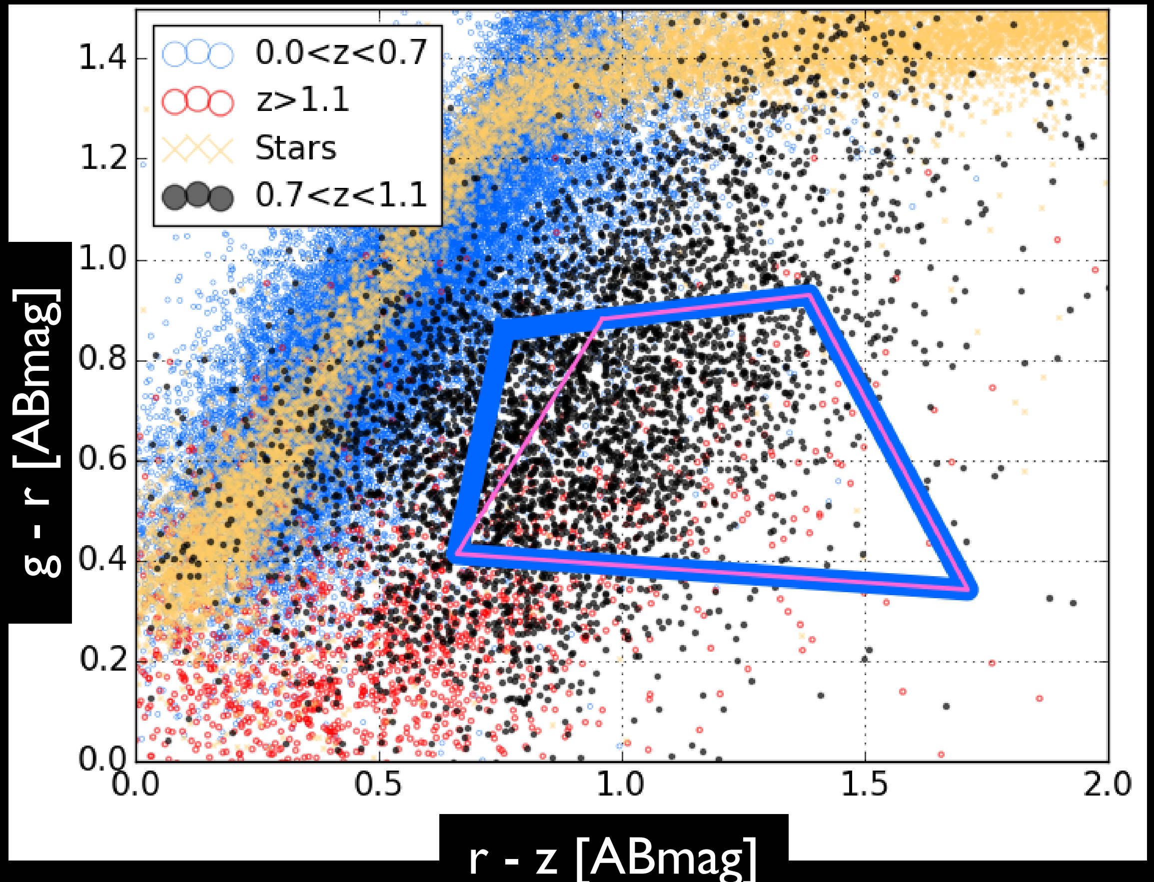
DECaLS imaging

- DECam @ CTIO/Blanco
- DESI main imaging
- grz coverage over ~9k deg2
- ~2 mag deeper than SDSS imaging



eBOSS/ELG target selection

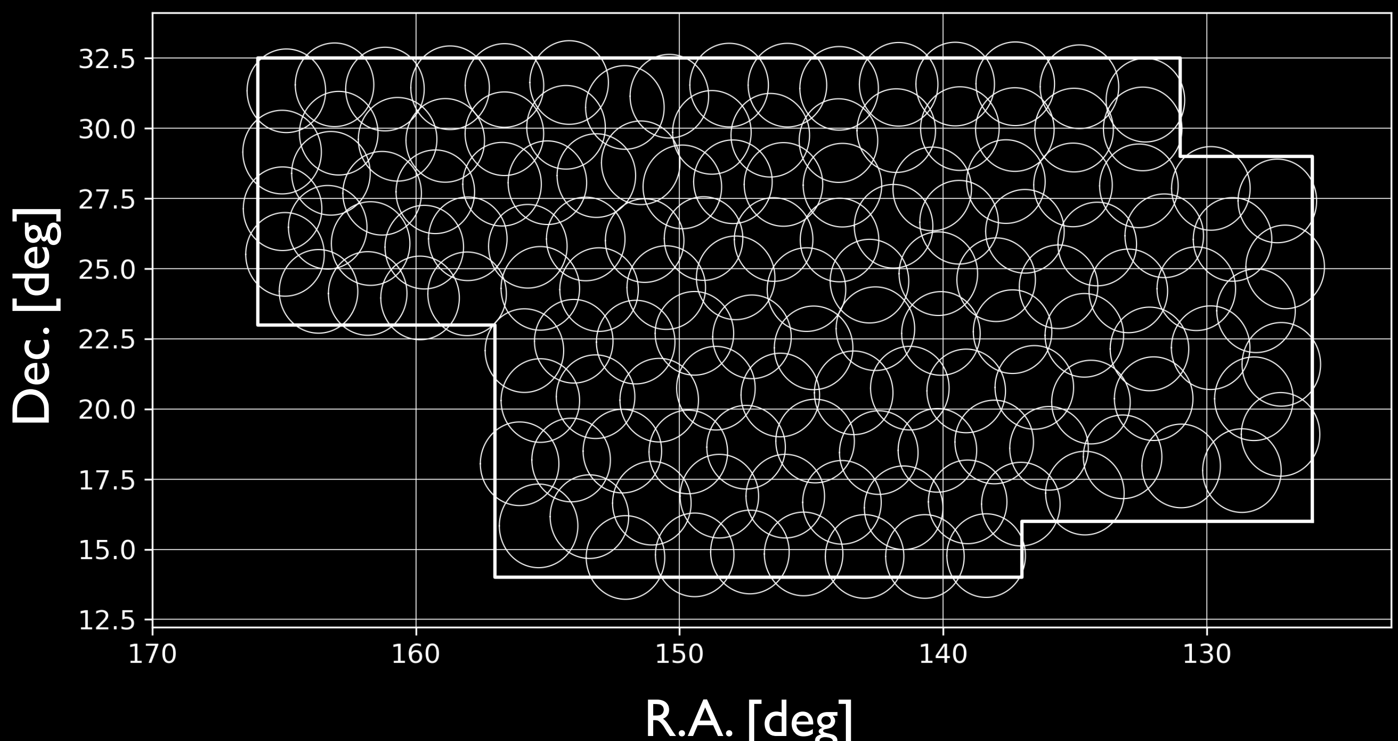
- 270k targets over 2 x 600 deg2 (~230/deg2)
- g-cut + grz colour-colour cut

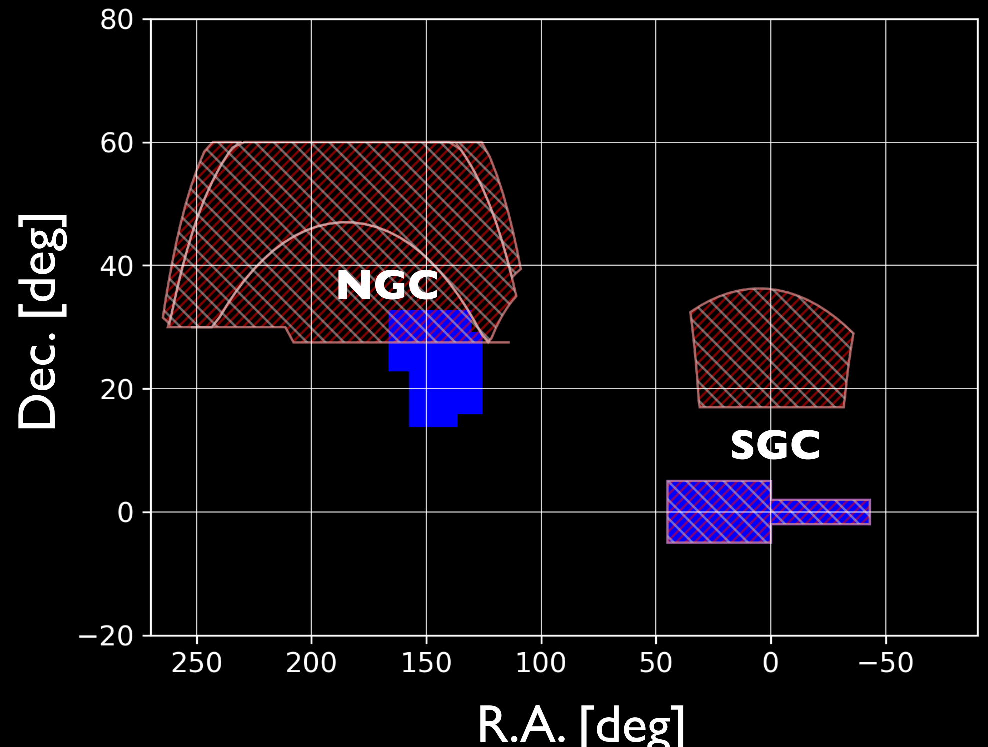


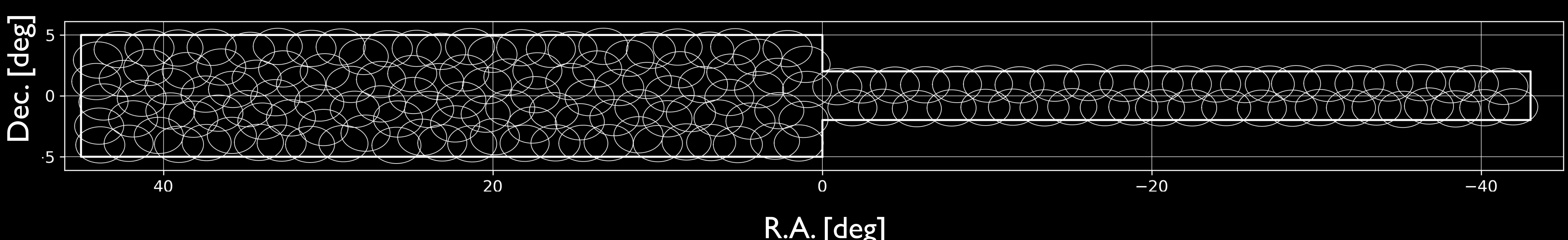
ELG observations

Observations

- 300 plates split between SGC and NGC
- ~850 ELGs per plate
- observations: started in 2016, Sep. and completed in 2018, Mar.
- **on-going analysis**







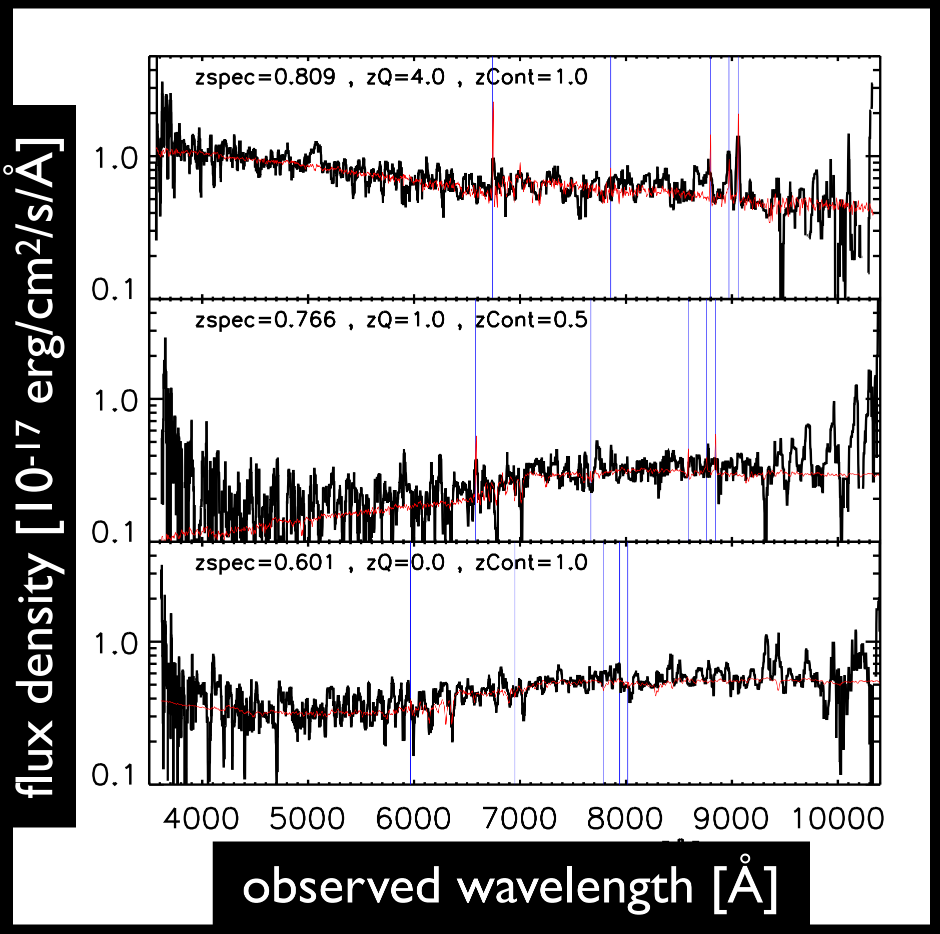
ELG spectra

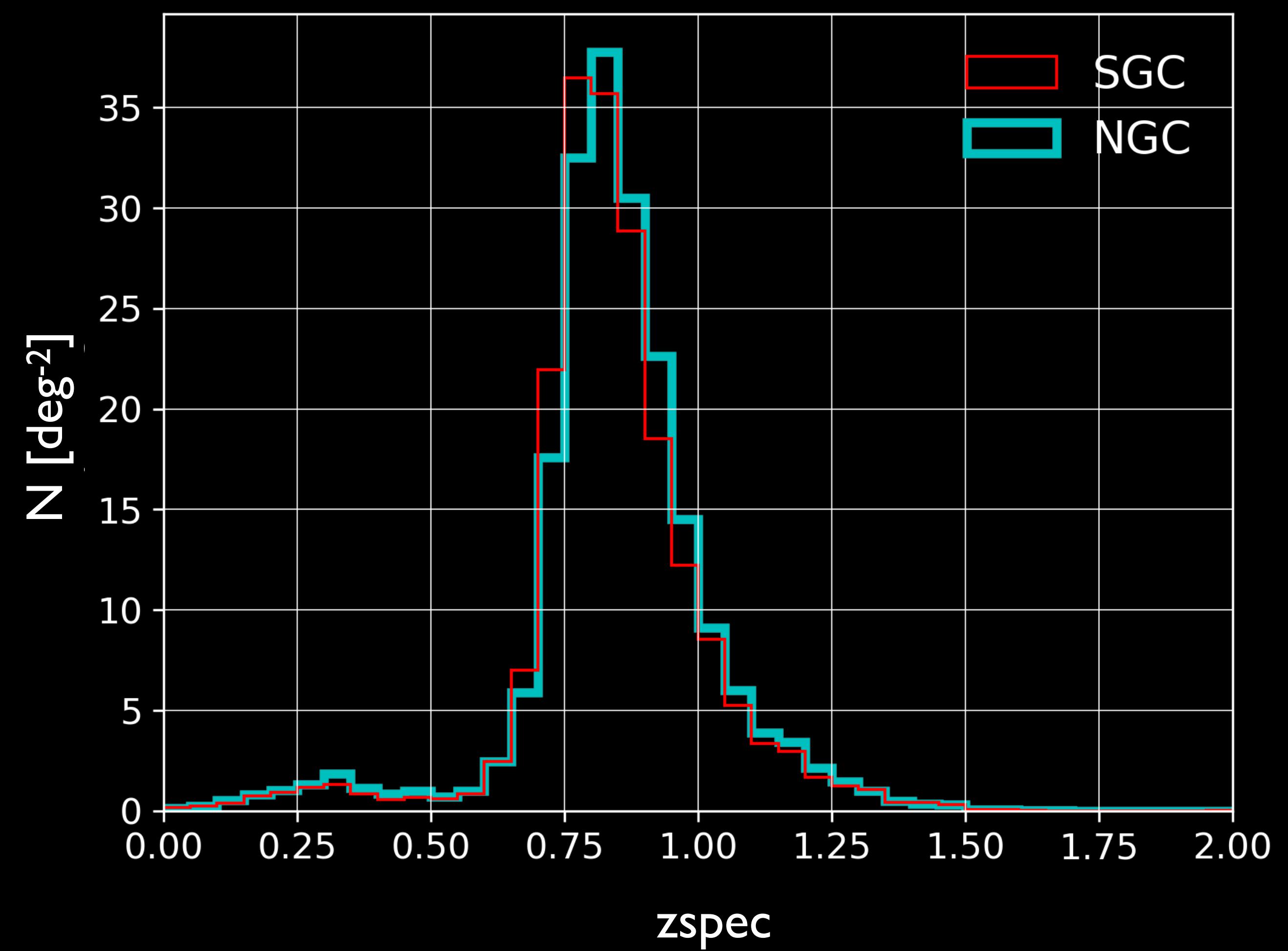
Spectroscopic redshift measurement

- 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

Spectroscopic redshift properties

- n(z) as expected, peaking at z~0.85
- ~80% with reliable zspec
- ~70% with 0.7<zreliable<1.1

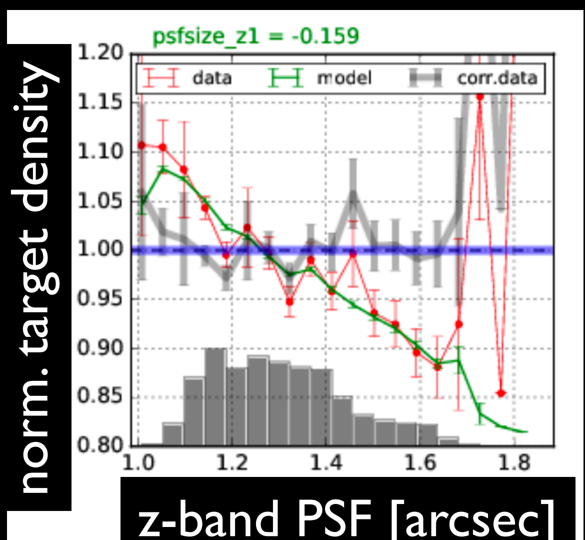


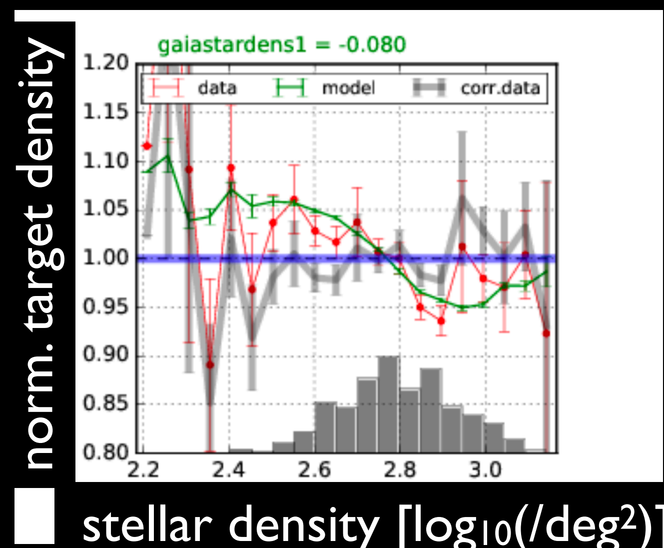


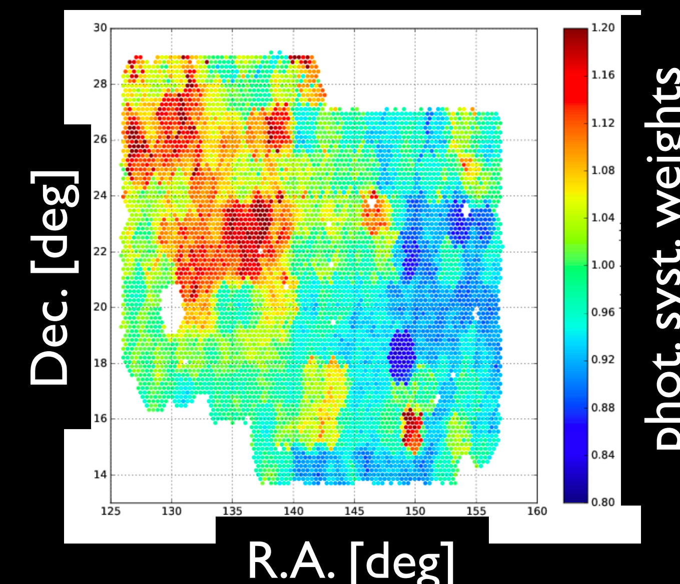
ELG weights

Photometric weights

- account for target density variations with imaging properties
- first use of the DECaLS imaging

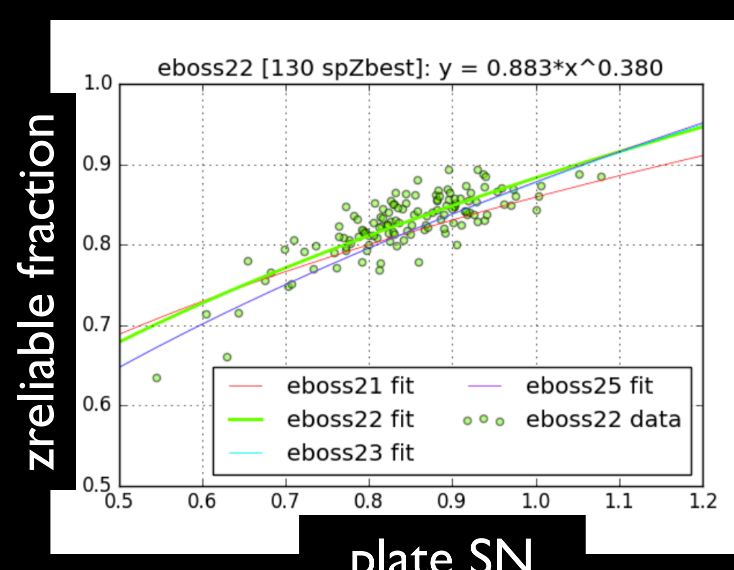


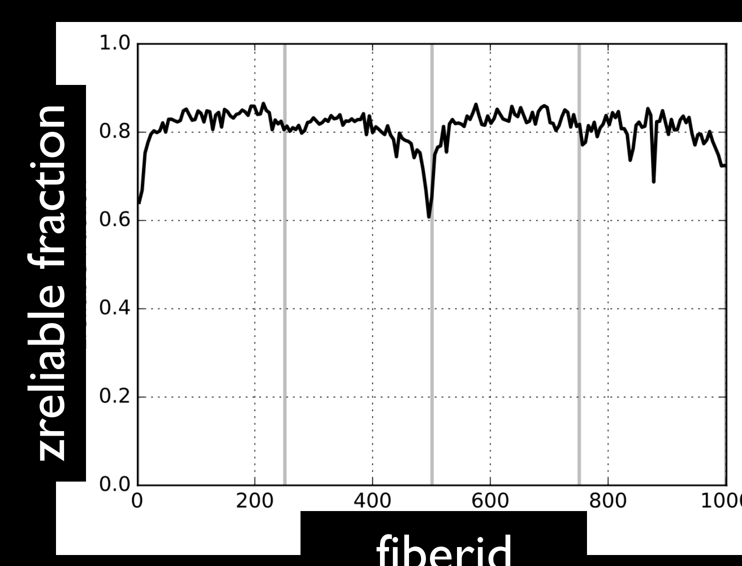




Redshift failure weights

- account for galaxies which were observed but did not succeed in a reliable zspec
- plate-to-plate variations (zreliable fraction can range from 0.7 to 0.9)
- fiberid dependence





Future LSS surveys

DESI (2020-2025)

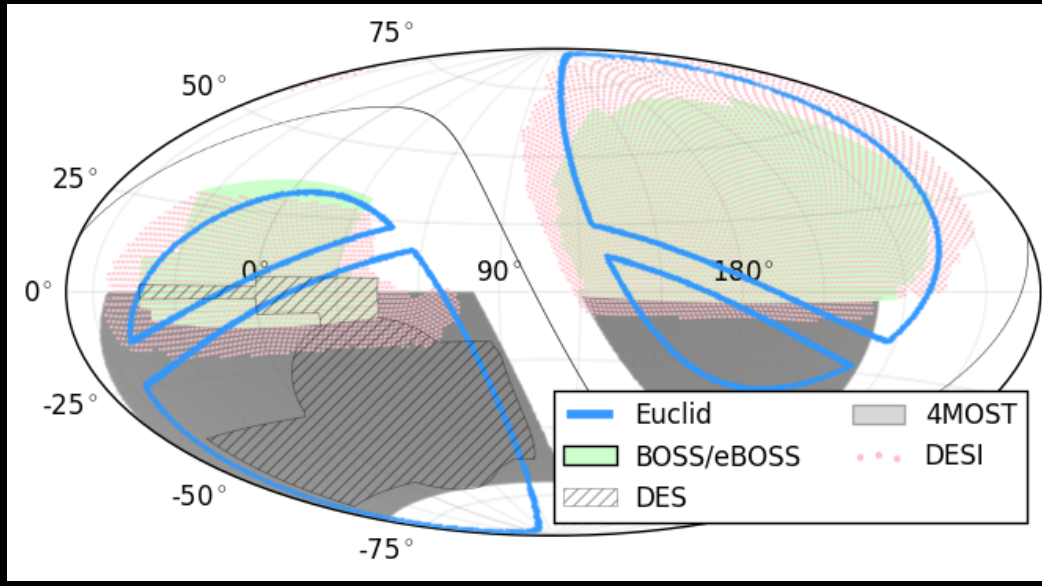
- DECaLS + BASS/MzLS imaging
- 5000 fibers spectrograph at KPNO/Mayall telescope
- 35M spectra over 14k deg2
- precise BAO/RSD measurement from z~0.1 to z~3.5

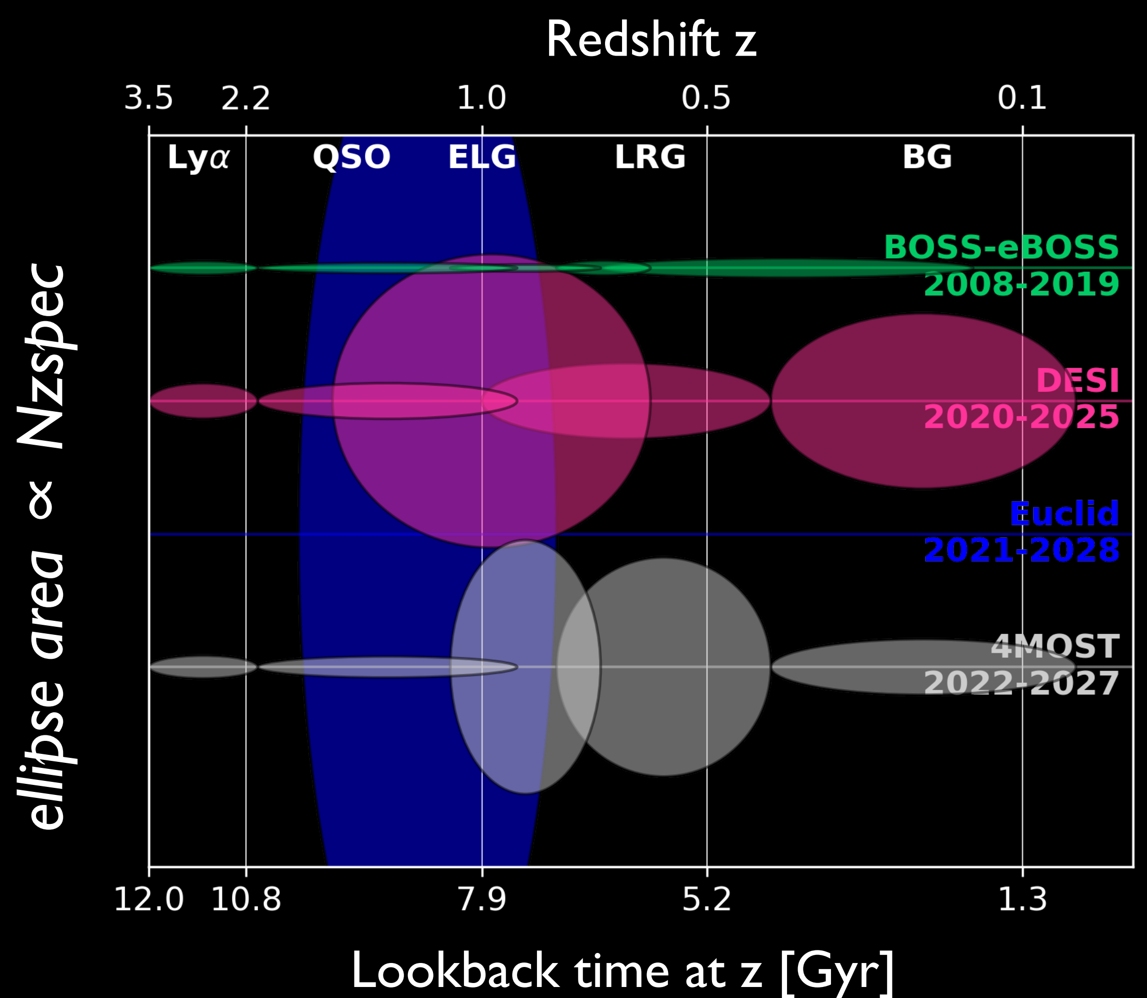
4MOST (2022-2027)

- DES and VHS imaging
- 2430 fibers spectrograph at VISTA telescope
- 20M spectra over 12k deg2
- combine with other surveys (lensing, CMB, radio)

***Euclid* (2021-2028)**

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





Conclusions

eBOSS 2 yrs sample

- 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

eBOSS/ELG

- full data observed
- first cosmological results this summer

eBOSS prospects

- all data taken by early 2019, public DR and final results by end 2019
- $f \cdot \sigma_8$, $H(z) \cdot r_s$, $D_A(z) \cdot r_s$ with all tracers
- BAO + RSD with BOSS+eBOSS
- neutrino masses

Future LSS surveys

- DESI, 4MOST, *Euclid*
- eBOSS experience crucial