Title: Cosmology from the SDSS

Speakers: Will Percival

Series: Cosmology & Gravitation

Date: July 28, 2020 - 11:00 AM

URL: http://pirsa.org/20070028

Abstract: On Monday July 20th, we announced the final results from extended Baryon Oscillation Spectroscopic Survey (eBOSS), the last large-scale structure galaxy survey to be undertaken within the umbrella of the Sloan Digital Sky Survey (SDSS). This marks the culmination of 20 years of galaxy surveys undertaken using the Sloan Foundation Telescope. In this seminar I will summarise the measurements presented in the 23 scientific papers that were released last Monday, and present the impact of the measurements from eBOSS and previous SDSS galaxy surveys on the development of the standard cosmological model.

PowerPoint Slide Show – [PI-eBOSS 28-07-20]

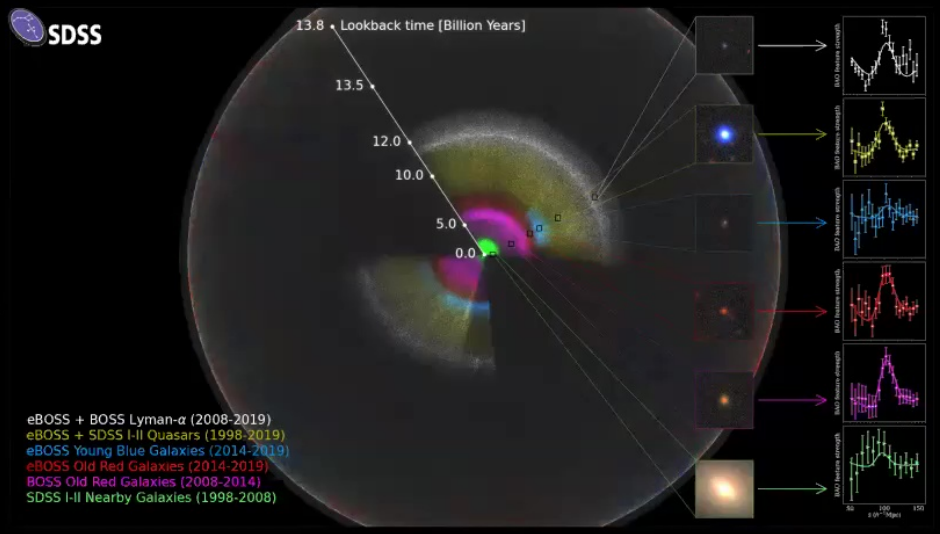
Final Cosmology from SDSS redshift surveys

Will Percival

Waterloo Centre for Astrophysics

University of Waterloo / Perimeter Institute

eBOSS Survey Scientist



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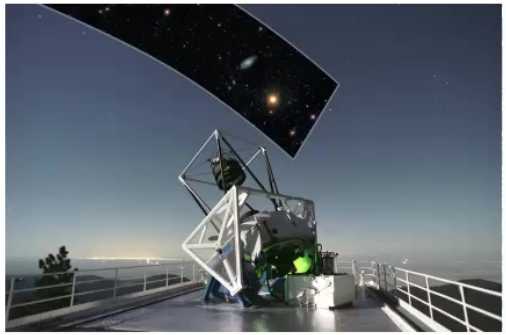
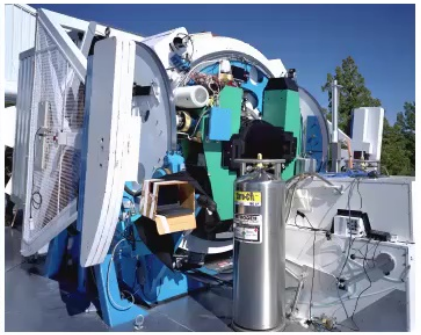
The Sloan Foundation Telescope 1998-2020



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The SDSS large-scale structure galaxy surveys

- **1999-2009 The SDSS-I and -II** gave us the Main Galaxy Sample (out to z<0.2), and some LRGs subsequently subsumed into later surveys
- **2009-2014 SDSS-III** included the BOSS experiment which observed luminous (mainly red) galaxies, and quasars for Ly-α forest measurements
- **2014-2019 SDSS-IV** included the eBOSS experiment, which observed
  - Luminous red galaxies (LRG)
  - Emission line galaxies (ELG)
  - Quasars used as direct tracers
  - Quasars for Ly-α forest measurements
- Baryon Acoustic Oscillations (BAO) were observed in each sample. The aggregate precision of the expansion history measurements is 0.70% at redshifts $z < 1$ and 1.19% at redshifts $z > 1$,
- The aggregate precision of redshift space distortions (RSD) based growth measurements is 4.78% over the redshift interval $0 < z < 1.5$.
- With this redshift coverage and sensitivity, the SDSS experiment is unparalleled in its ability to explore models of cosmology.

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The SDSS large-scale structure galaxy samples

Parameter	Main Galaxy Sample (MGS)	BOSS Galaxy	BOSS Galaxy	eBOSS LRG	eBOSS ELG	eBOSS Quasar	Lyα-Lyα	Lyα-Quasar
Imaging, Target Selection, and Spectroscopic Properties of Each Sample								
Imaging for Target Selection	SDSS	SDSS	SDSS	SDSS + WISE	DECaLS	SDSS + WISE	SDSS + WISE + MISC	SDSS + WISE + MISC
Target Selection	g,r	g,r,i	g,r,i	g,r,i,z,W1	g,r,z	u,g,r,i,z,W1,W2	misc	misc
Spectroscopic Program	SDSS-I and -II	BOSS	BOSS	BOSS and eBOSS	eBOSS	primarily eBOSS	BOSS and eBOSS	BOSS and eBOSS
redshift range	0.07 < z < 0.20	0.2 < z < 0.5	0.4 < z < 0.6	0.6 < z < 1.0	0.6 < z < 1.1	0.8 < z < 2.2	z > 2.1	z > 1.77
Number of Tracers	63,163	604,001	686,370	377,458	173,736	343,708	210,005	341,468
Effective Redshift	0.15	0.38	0.51	0.70	0.85	1.48	2.33	2.33
Effective Volume (Gpc^3)	0.24	3.7	4.2	2.7	0.6	0.6		
Clustering Catalog Documentation	Ross et al. (2020)	Reid et al. (2016)	Reid et al. (2016)	Ross et al. (2020)	Raichoor et al. (2020)	Ross et al. (2020), Lyke et al. (2020)	du Mas des Bourboux et al. (2020), Lyke et al. (2020)	du Mas des Bourboux et al. (2020), Lyke et al. (2020)
N-body and Mock Catalogs		Kitaura et al. (2016)	Kitaura et al. (2016)	Zhao et al. (2020), Rossi et al. (2020)	Zhao et al. (2020), Lin et al. (2020), Alam et al. (2020)	Zhao et al. (2020), Smith et al. (2020)	Farr et al. (2020)	Farr et al. (2020)

From https://www.sdss.org/science/final-bao-and-rsd-measurements/

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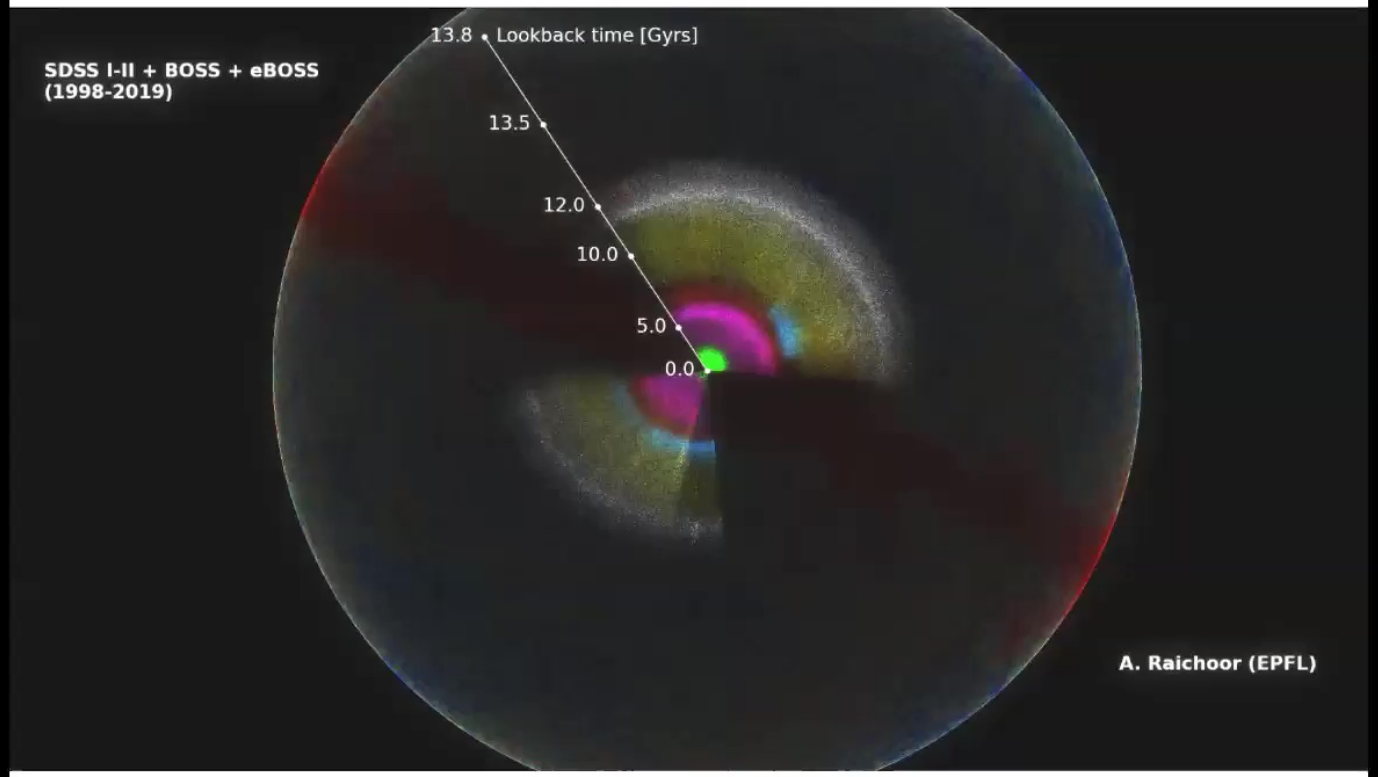
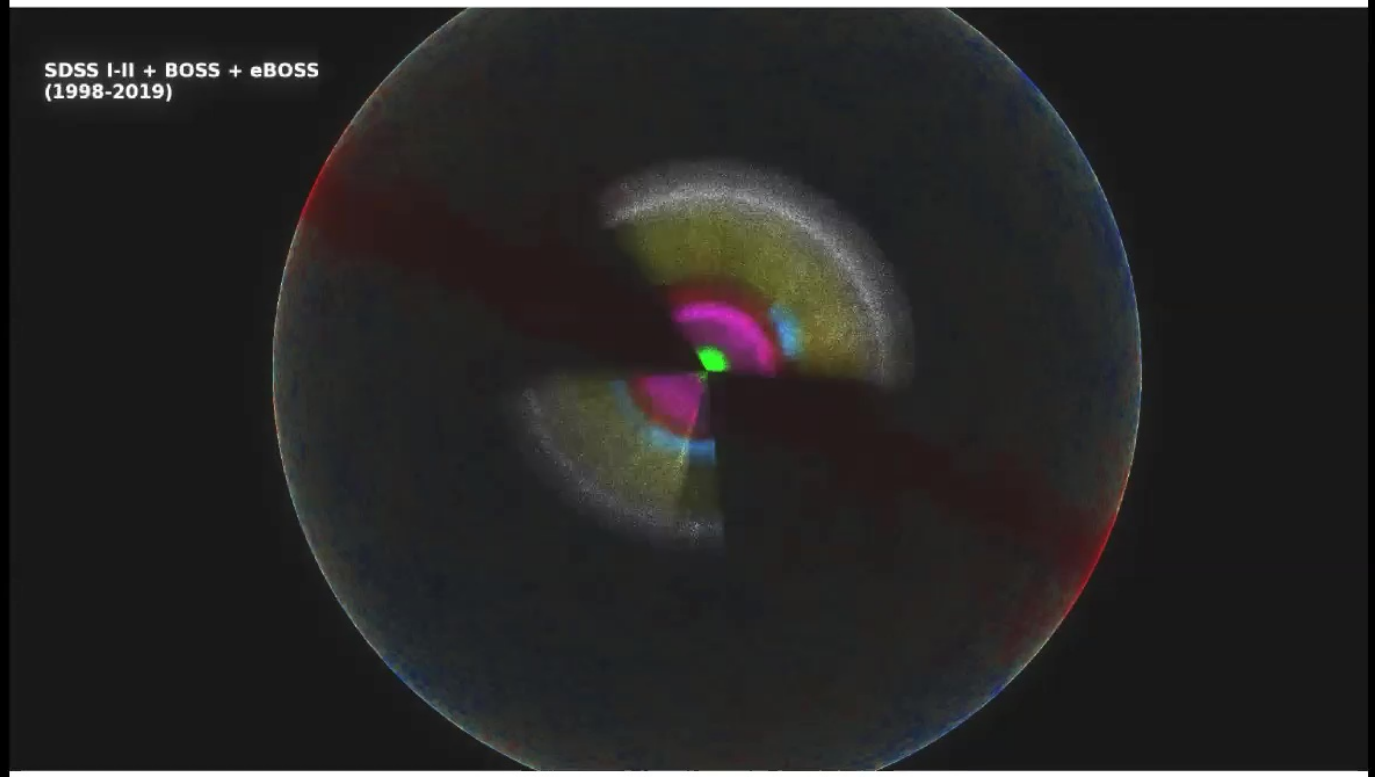
The SDSS galaxy surveys



PowerPoint Slide Show – [PI-eBOSS 28-07-20]

The SDSS galaxy surveys



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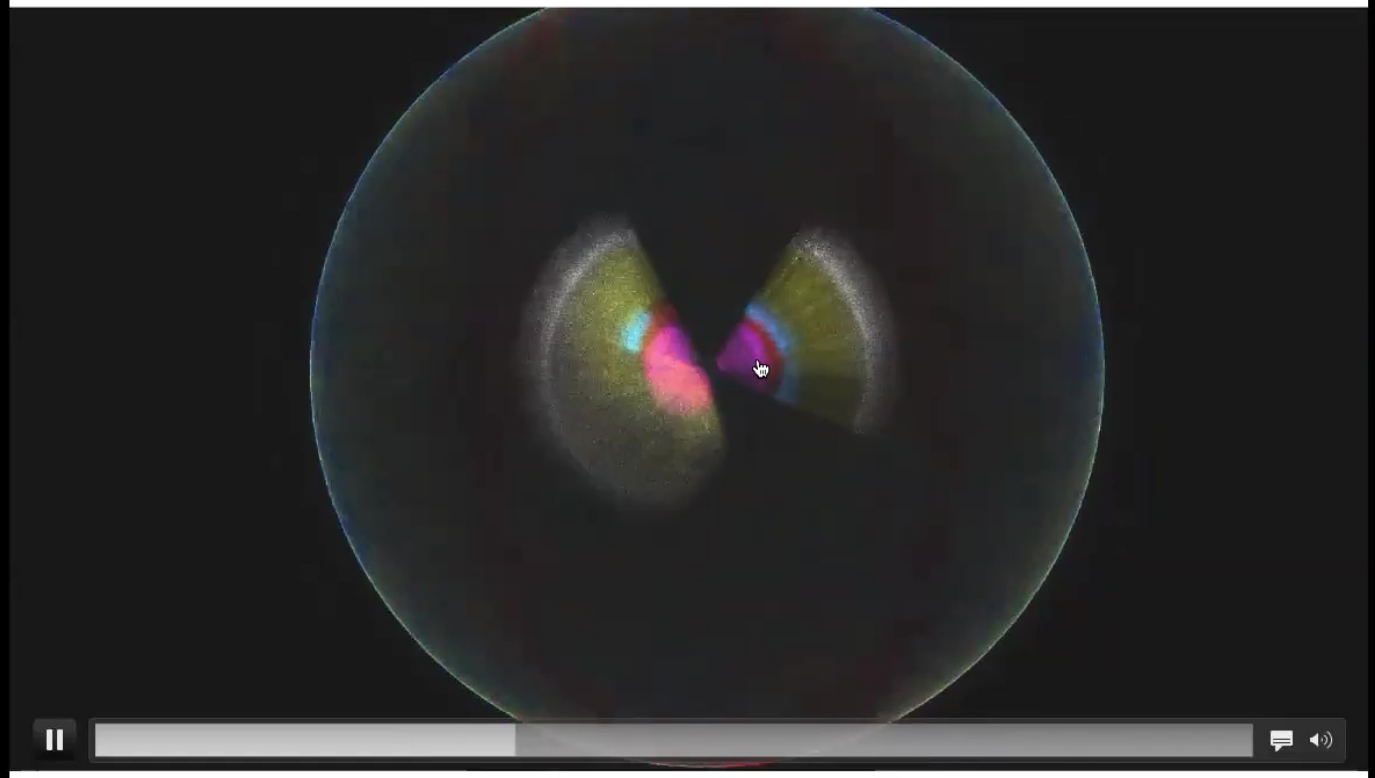
The SDSS galaxy surveys



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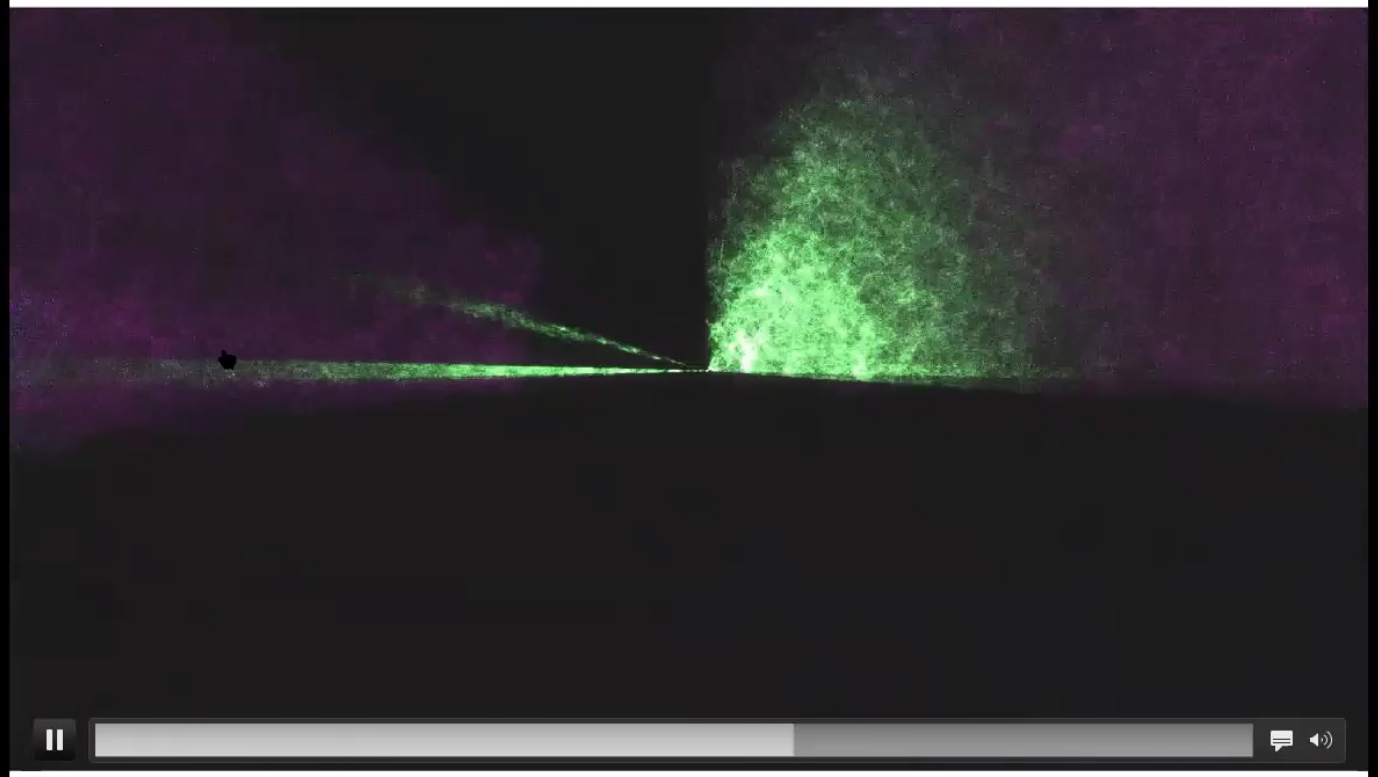
The SDSS galaxy surveys



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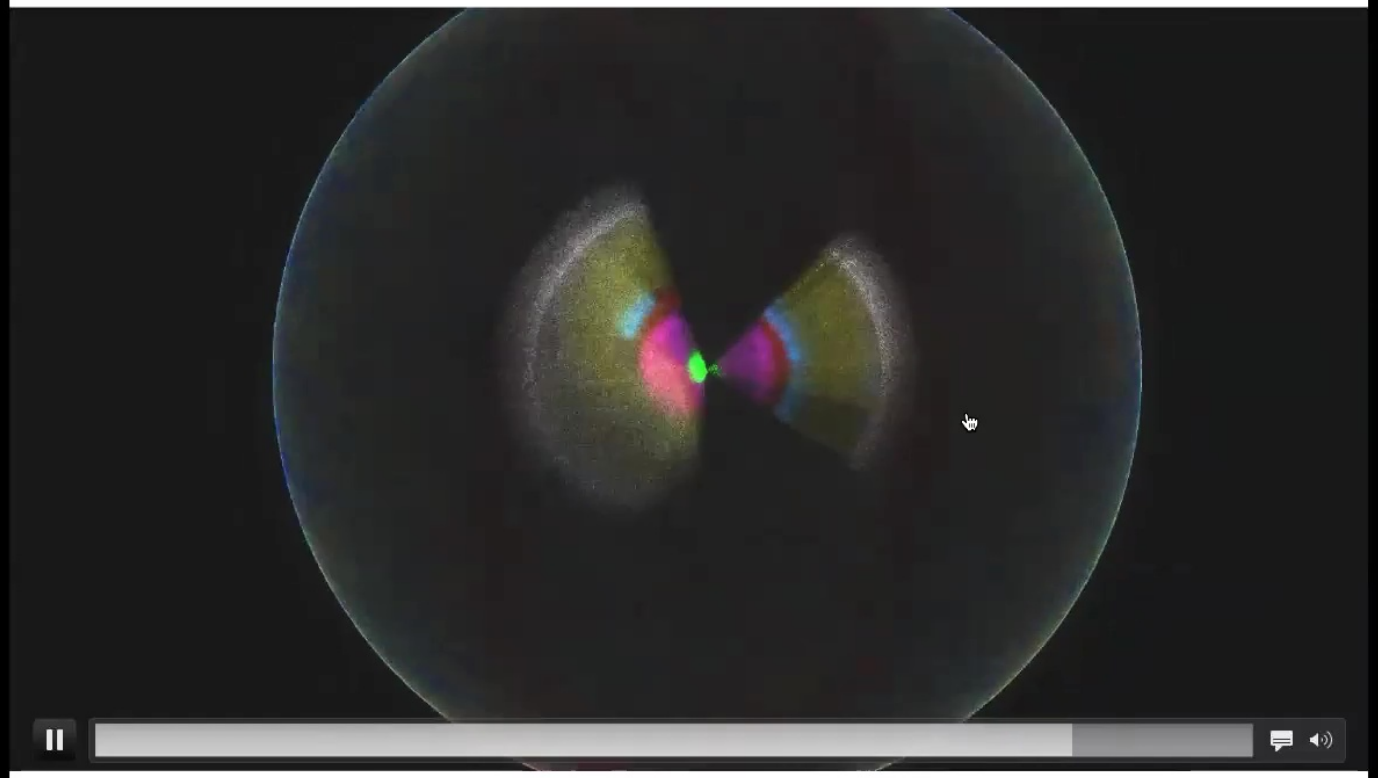
The SDSS galaxy surveys



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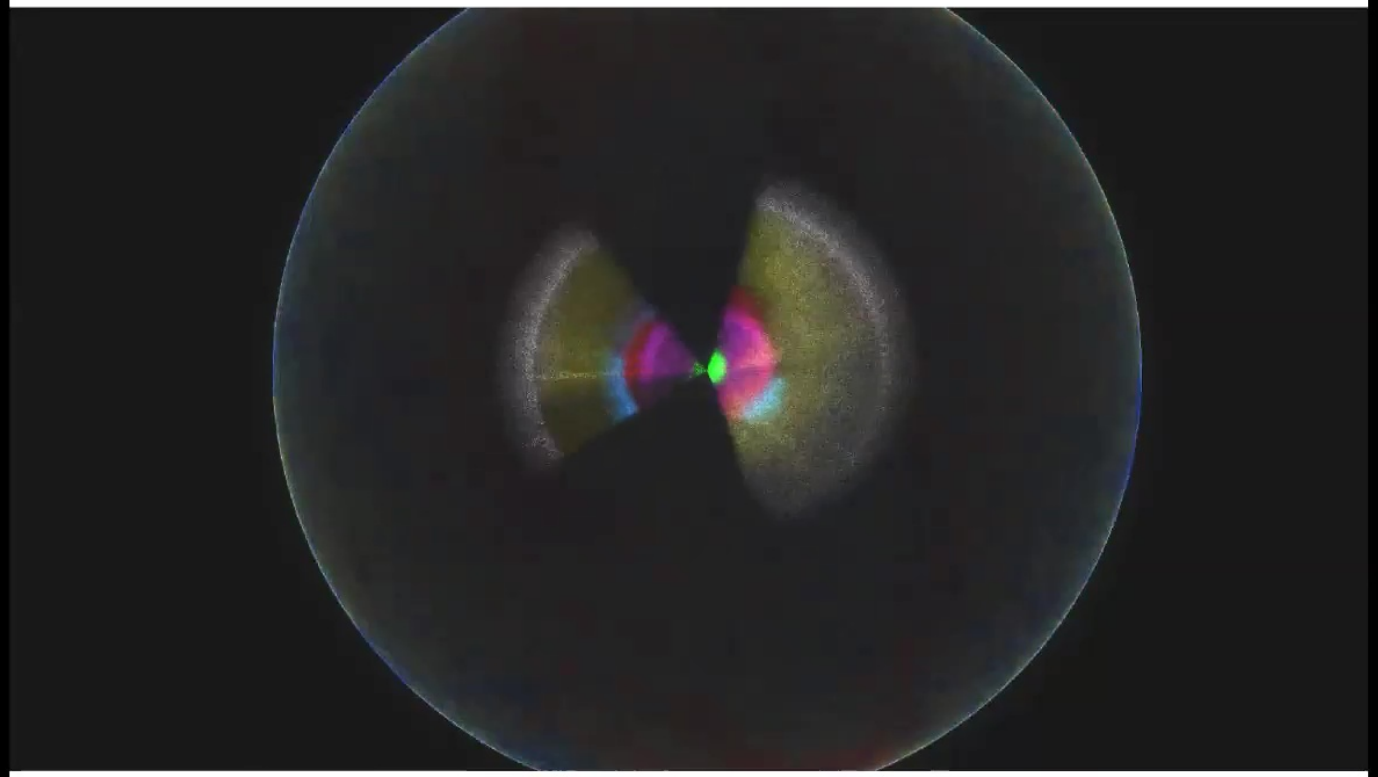
The SDSS galaxy surveys



eBOSS – the end of an era

- SDSS-V will not perform a LSS redshift survey

- eBOSS announcement last week was last using a galaxy redshift survey from SDSS
- Out with a bang! – 23 papers on the archive last Monday
- 4 promotional videos (2 with ~300k hits)
- press releases (with local variations around the world)
- Many articles in the news, including some that were accurate and well written!
- The end of an era ...

- This seminar – hastily put together review of eBOSS and those 23 papers.

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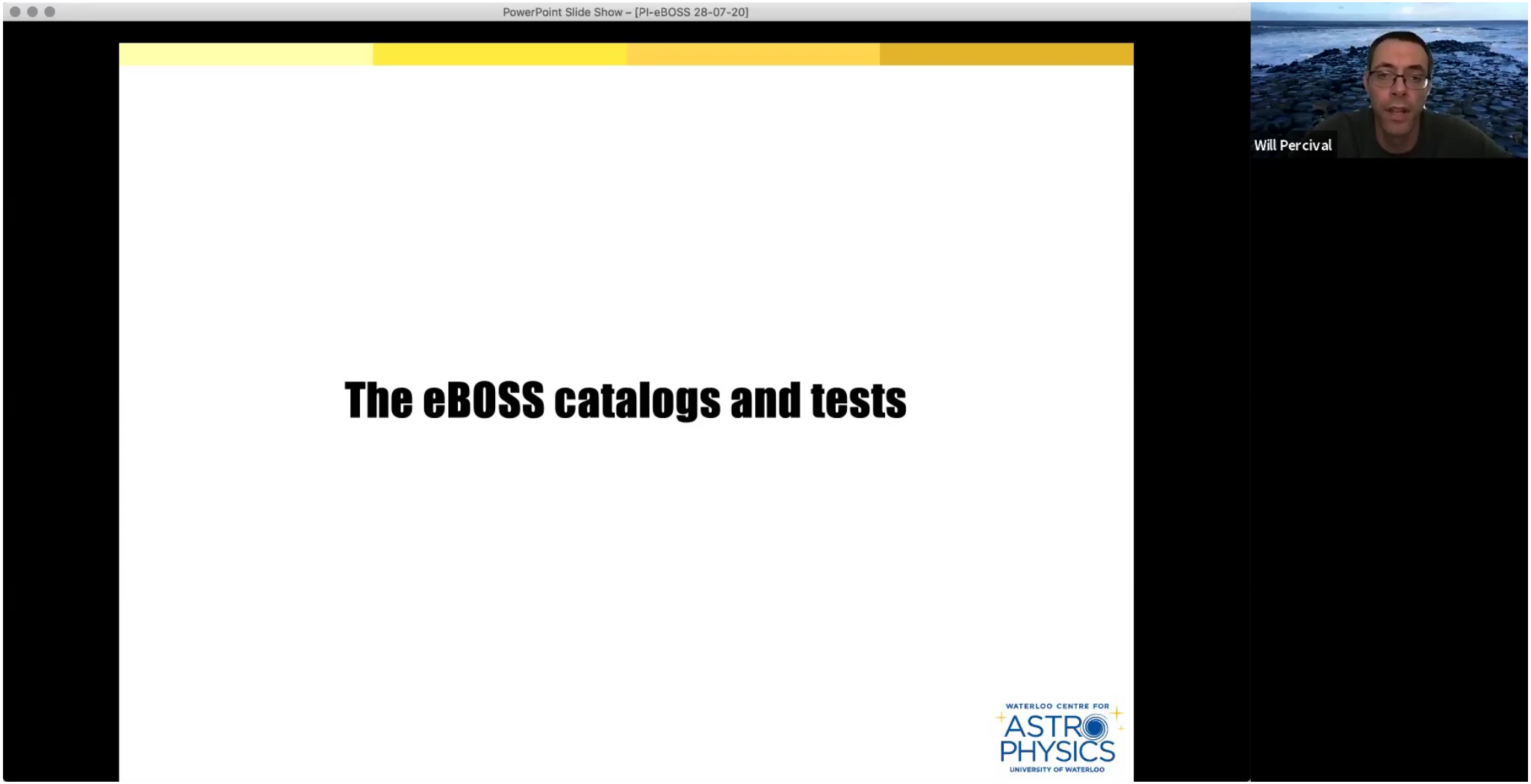
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Will Percival
The eBOSS catalogs and tests
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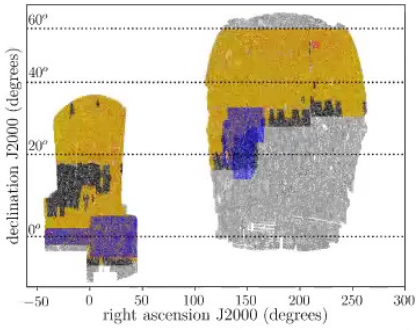
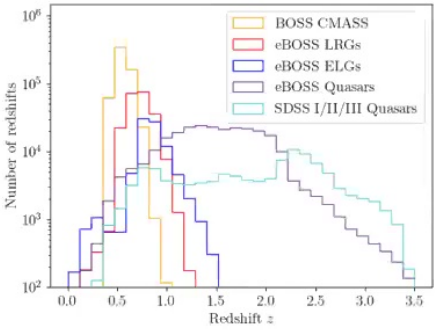
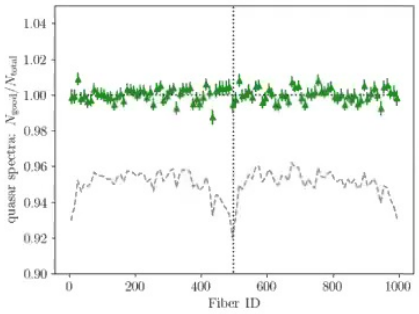
LRG & QSO clustering catalogs





Turned the raw data into well-understood catalogs of objects and their expected density



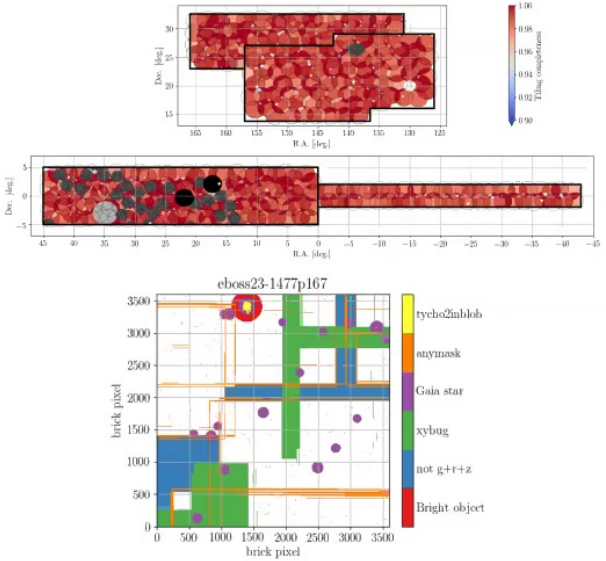
Quasar redshift efficiency versus fiber – before and after correction

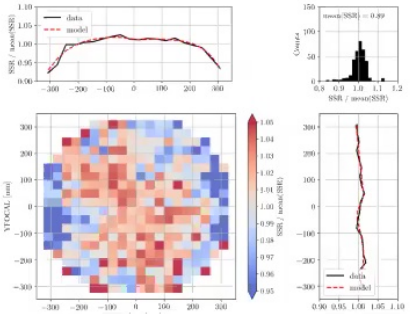
Results of LRG target spectroscopic observations

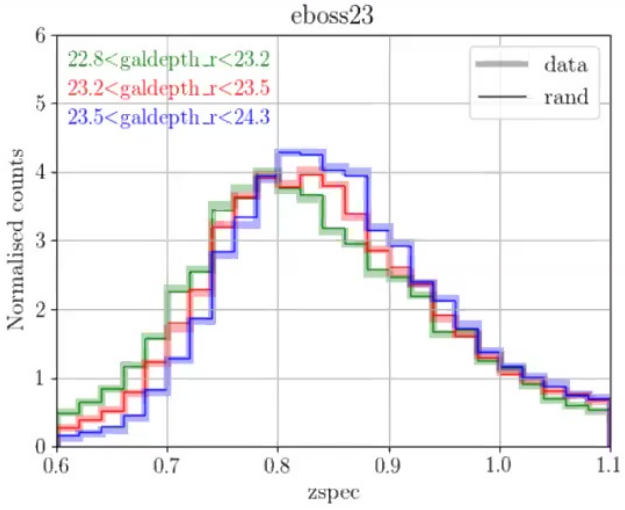
	SGC	NGC	Total
$N_{\rm eff}$	87,607	134,695	222,302
$N_{z,\rm tot}$	82,607	127,287	209,894
$N_{\rm zfail}$	2,205	3,019	5,224
$N_{\rm cp}$	3,436	4,950	8,386
$N_{\rm QSO}$	1,254	1,635	2,889
$N_{\rm star}$	10,749	10,017	20,766
after $C_{\rm eBOSS} > 0.5, C_z > 0.5$ cuts:			
$N_{\rm eff}$	86,511	133,540	220,051
$N_{z,\rm tot}$	81,600	126,230	207,830
$N_{\rm eff}, 0.6 < z < 1.0$	71,427	113,868	185,295
$N_{z,\rm tot}, 0.6 < z < 1.0$	67,316	107,500	174,816
Area post-veto (deg^2)	1,676	2,566	4,242
Weighted area post-veto (deg^2)	1,627	2,476	4,103

Ross et al. (2020), arXiv:2007.09000

ELG clustering catalog



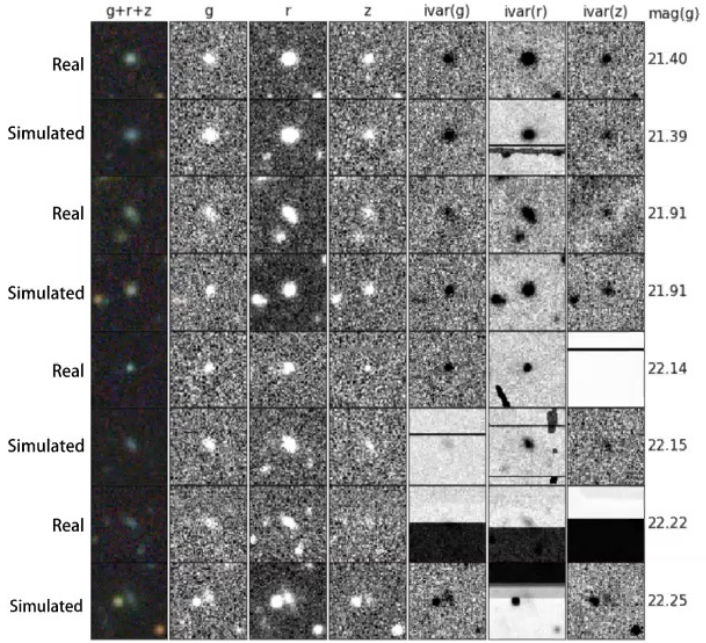




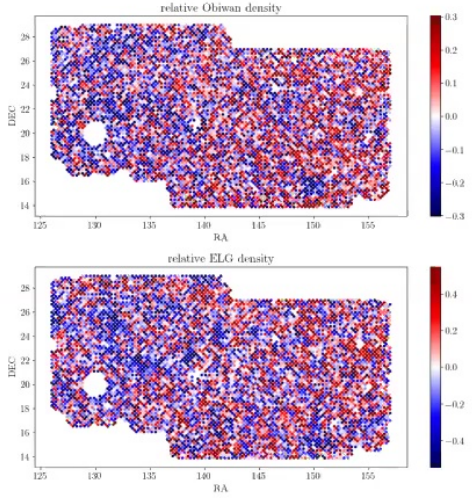
Turned the raw data into well-understood catalogs of objects and their expected density

Raichoor et al. (2020), arXiv:2007.09007

Testing ELG target selection

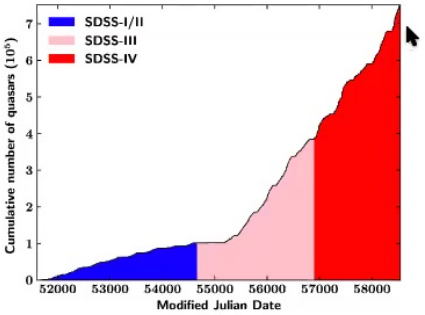


Used software called Obiwan to inject fake ELGs into the imaging data used for targeting and checked for large-scale systematics

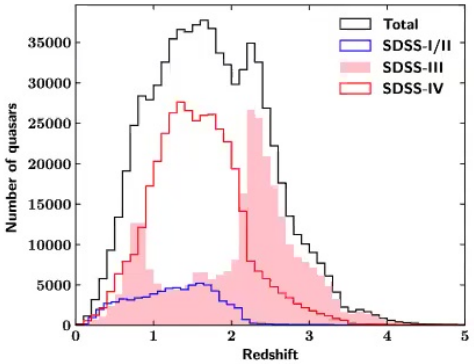


Kong et al. (2020), arXiv:2007.08992

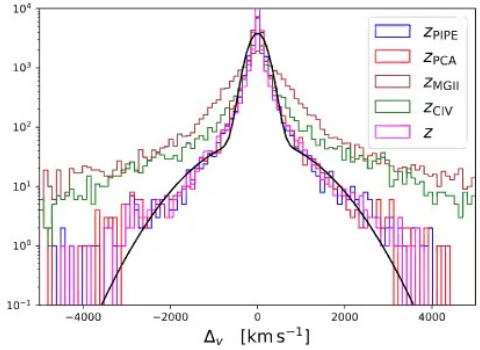
Quasar catalog



eBOSS primarily filled in the gap 1<z<2, between low-redshift quasars and Ly-α quasars at high redshift



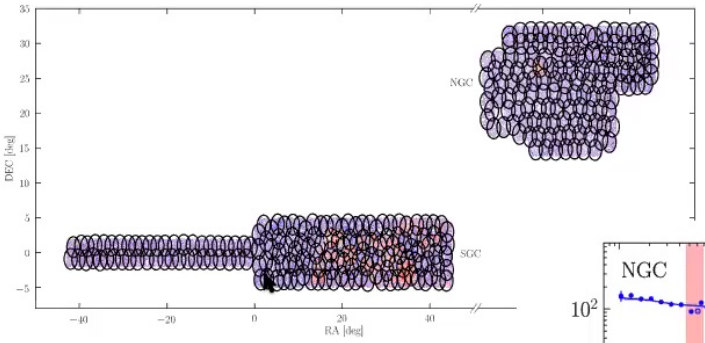
Tradition in SDSS to release a catalogue of all quasars observed, not just those whose expected clustering can be understood (the large-scale structure catalog)



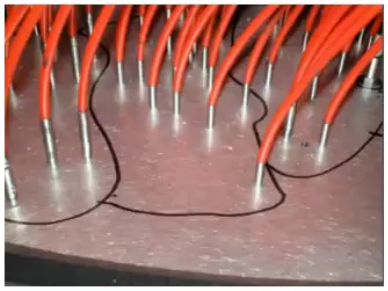
Redshift measurement for quasars is more complicated than other objects due to outflows

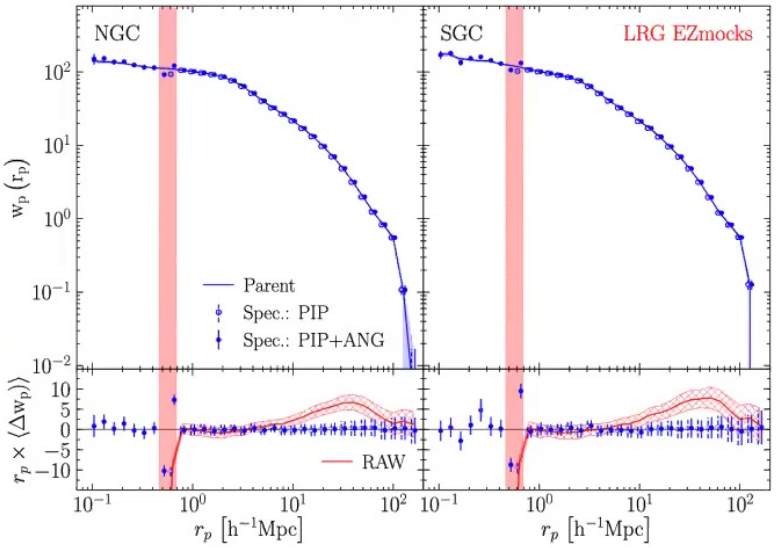
Lyke et al. (2020), arXiv:2007.09001

Dealing with fiber collisions



Created weights for each pair in the LRG, ELG and QSO catalogues to correct for fiber collisions and get the correct small-scale clustering





Mohammad et al. (2020), arXiv:2007.09005

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The eBOSS mock catalogs

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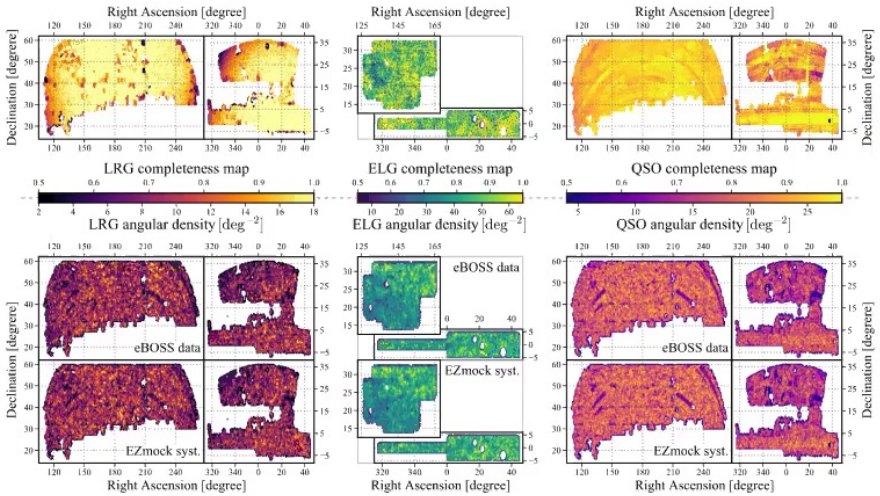
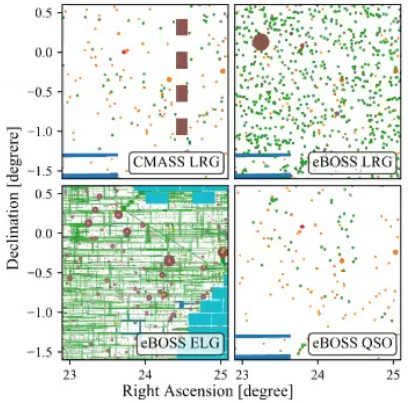
ELG-LRG-QSO approximate mocks

Created 1000 perturbation-theory based mocks, samples by each galaxy type, and turned into overlapping mock surveys

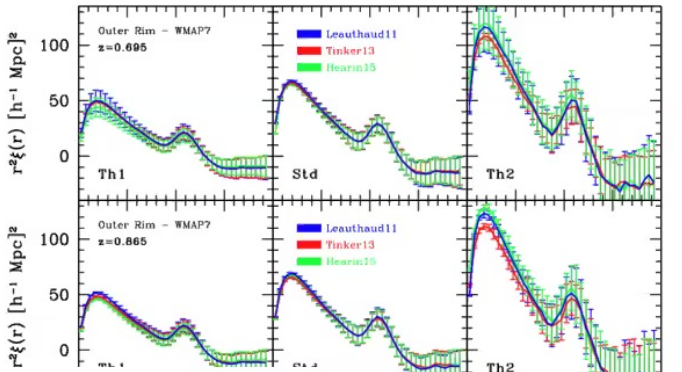


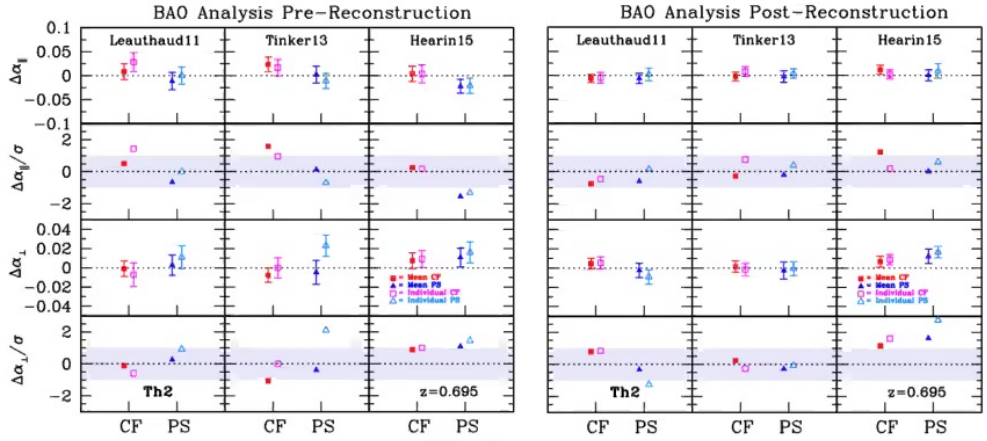


Zhao et al. (2020), arXiv:2007.08997

LRG mock challenge

Carried out internal mock challenge, where groups fit mock samples and try to recover unknown cosmological parameters – this analysis focussed particularly on the effect of small scales through the HOD used to populate the Outer Rim simulation.

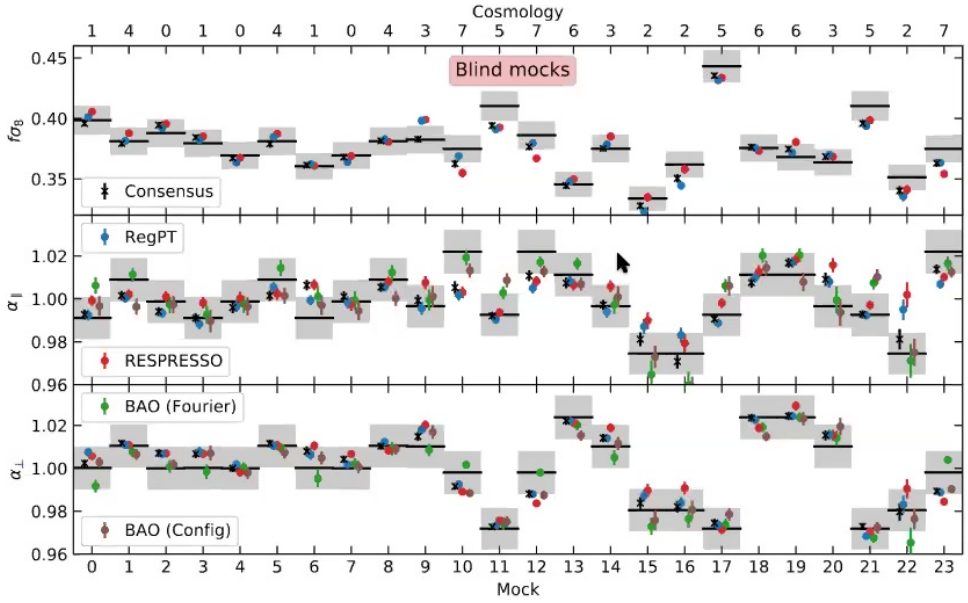




Rossi et al. (2020), arXiv:2007.09002

QSO mock challenge

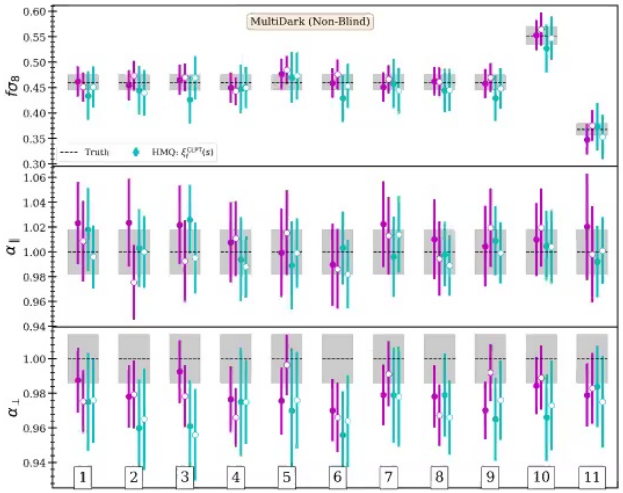
Blind tests on the recovery of cosmological parameters using QSO mocks with different cosmologies and HOD

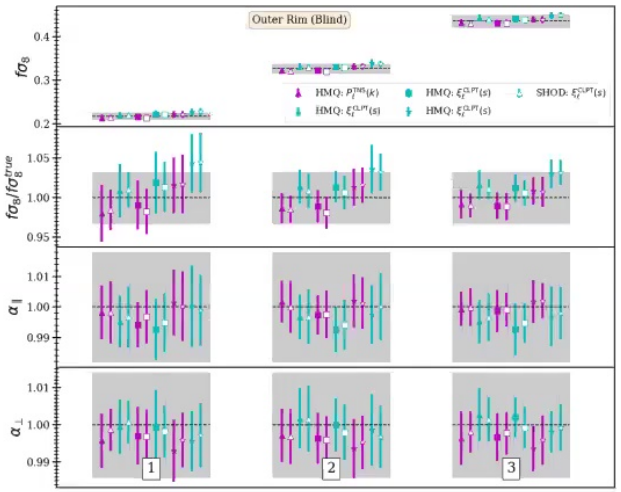


Smith et al. (2020), arXiv:2007.09003

ELG mock challenge

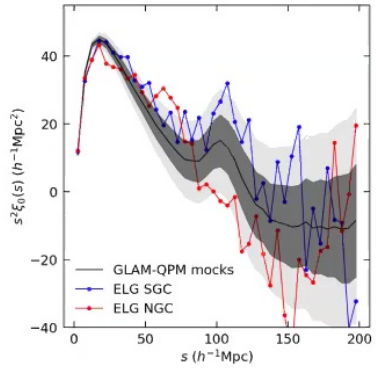
Blind tests on the recovery of cosmological parameters using ELG mocks with different cosmologies and HOD

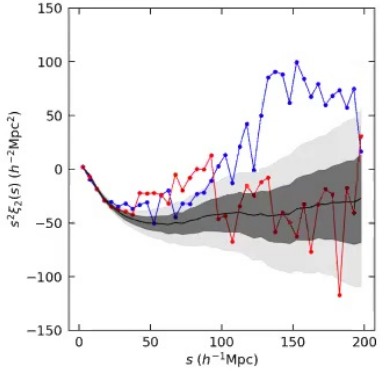




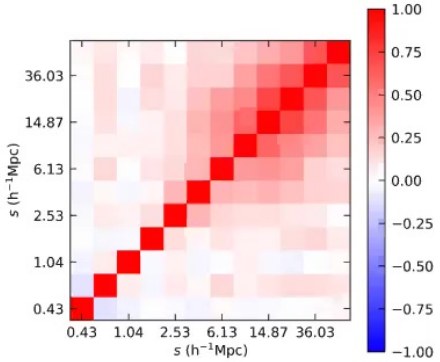
Alam et al. (2020), arXiv:2007.09004

ELG GLAM-QPM mocks





Ran 200 large GaLAxy Mocks (GLAM) N-body simulations, and placed haloes with a local density matching algorithm. Galaxies placed using Gaussian HOD. Used to test ELG modelling on small scales.



Lin et al. (2020), arXiv:2007.08996

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Baryon Acoustic Oscillations

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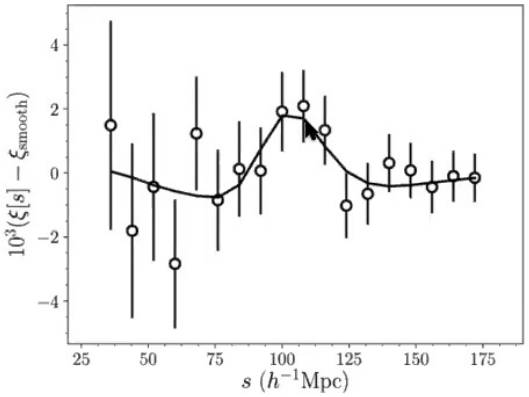
BAO as an absolute ruler



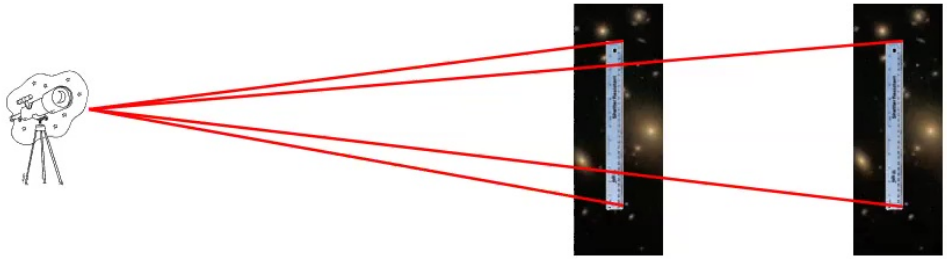
eBOSS DR14 quasars at z=1.52
Ata et al. 2017; arXiv:1705.06373

Radial direction

$$\alpha_{\parallel} \propto H(z) r_d$$

Angular direction

$$\alpha_{\perp} \propto \frac{D_A(z)}{r_d}$$



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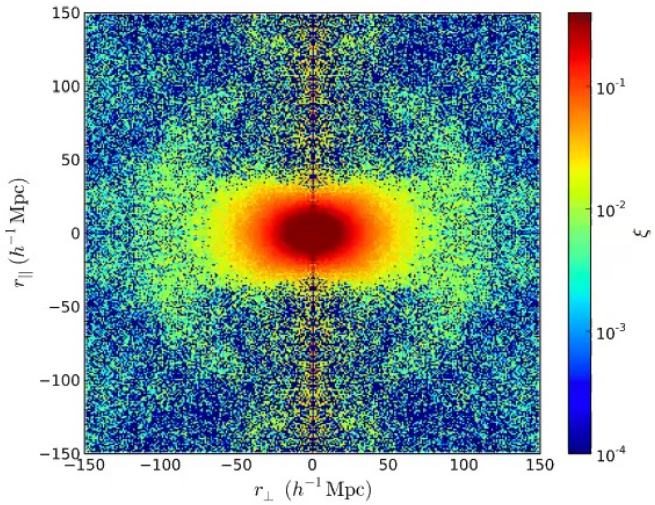
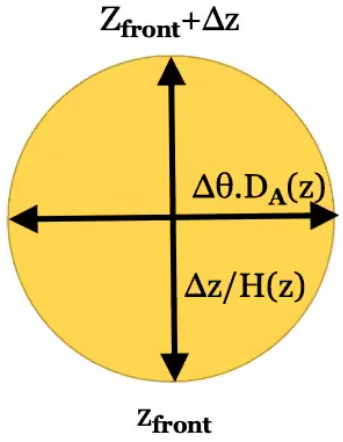
Relative BAO: position vs line-of-sight

Samushia et al. 2013; MNRAS, 439, 3504



$$\frac{\alpha_\parallel}{\alpha_\perp} \propto H(z) D_A(z)$$

The Alcock-Paczynski effect



STANDARD SHAPE
[Minimum scale – cosmological expansion can still be recovered]

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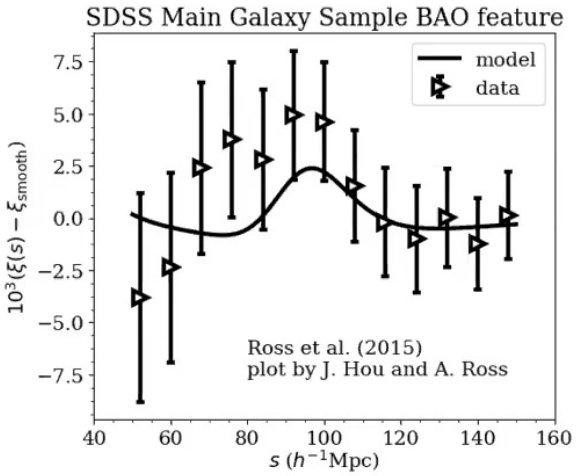
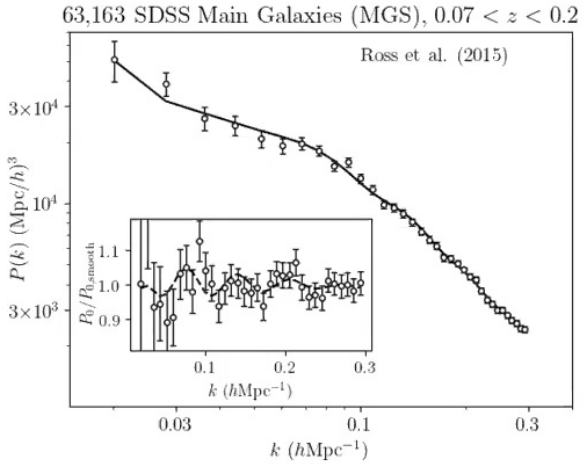
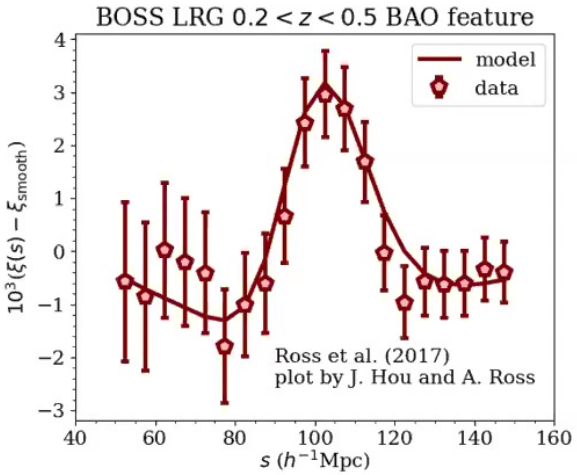
BAO from SDSS Main Galaxy Sample (0.07<z<0.2)

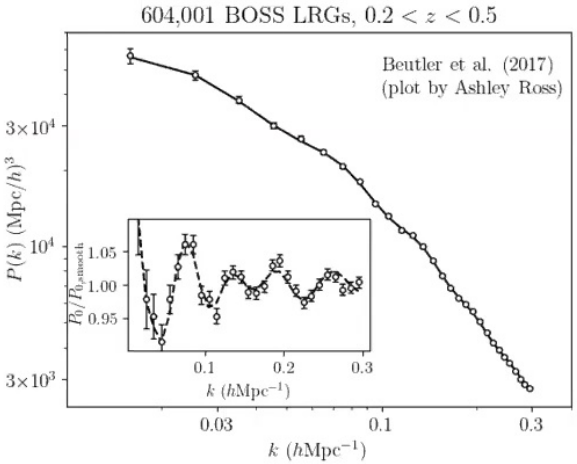




Ross et al. (2015), MNRAS 449, 835

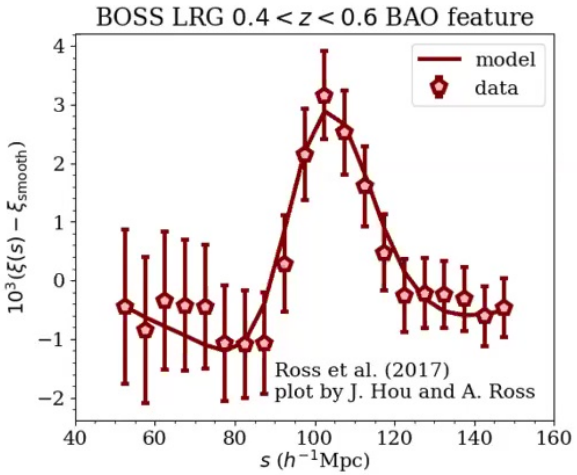
BAO from BOSS low-redshift bin (0.2<z<0.5)

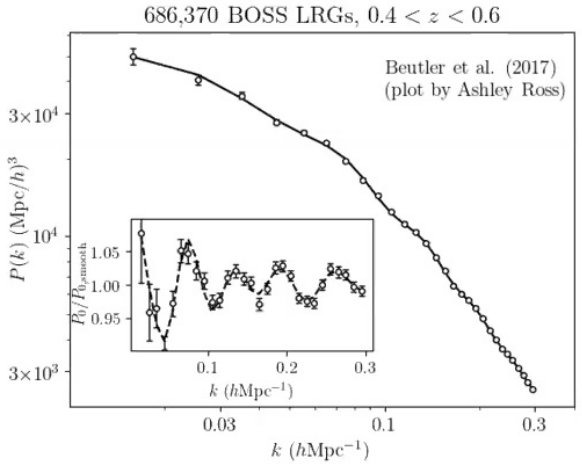




Alam et al. (2017), MNRAS 470, 2617

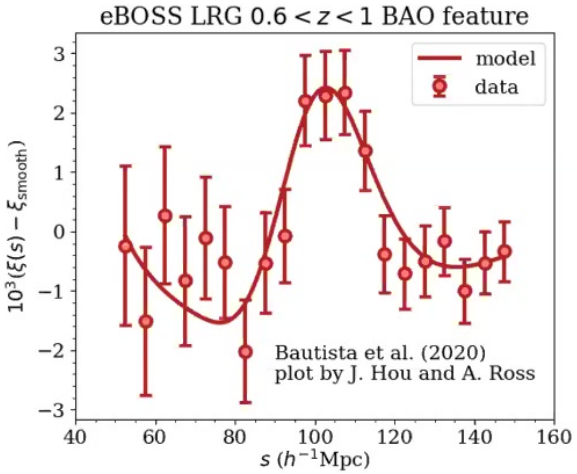
BAO from BOSS high-redshift bin (0.4<z<0.6)

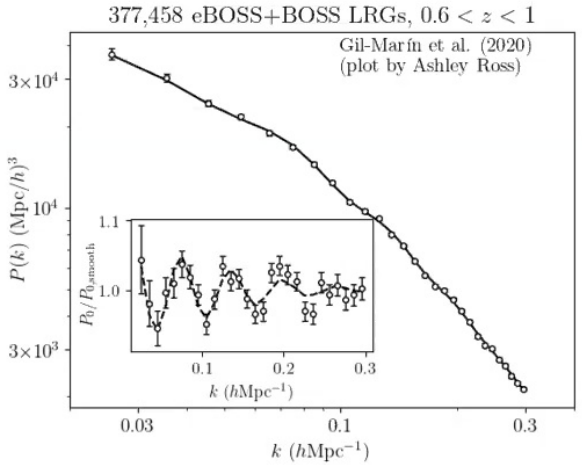




Alam et al. (2017), MNRAS 470, 2617

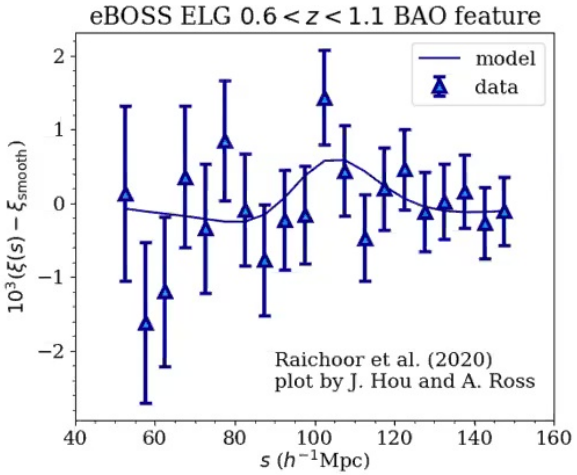
BAO from BOSS+eBOSS LRG (0.6<z<1.0)

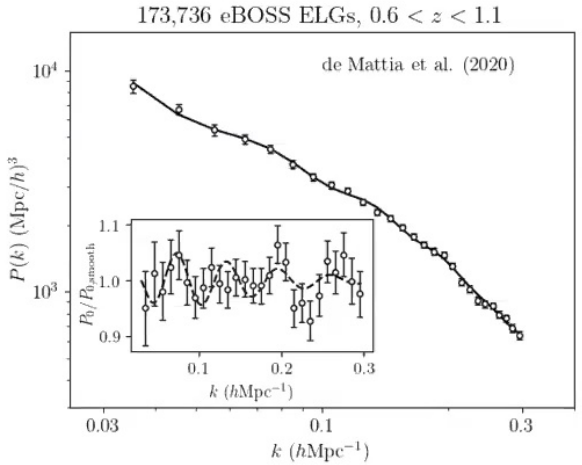




Bautista et al. (2020), arXiv:2007.08993; Gil-Marin et al. (2020), arXiv:2020.08994

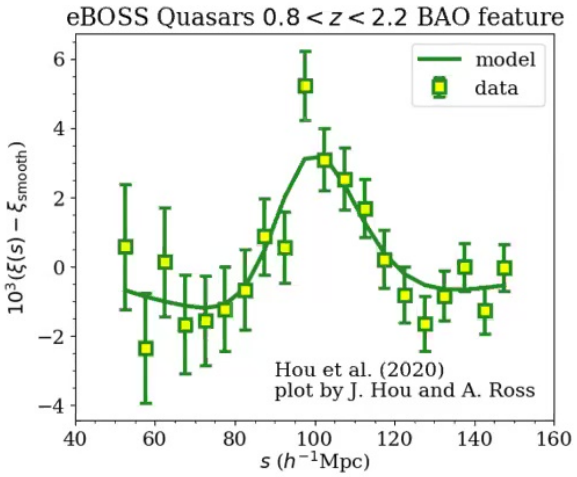
BAO from eBOSS ELG (0.6<z<1.1)

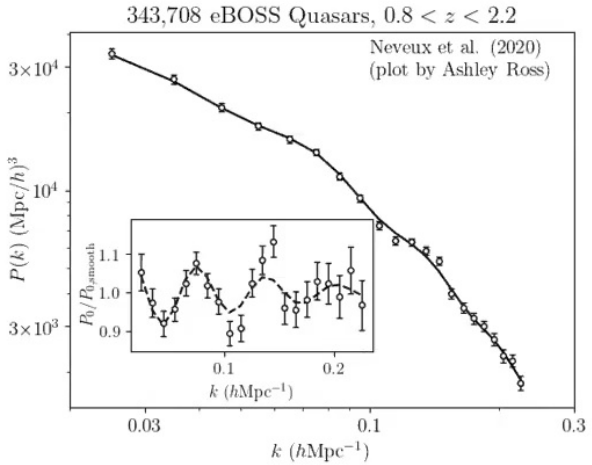




Raichoor et al. (2020), arXiv:2020.09007; de Mattia et al. (2020), arXiv:09008

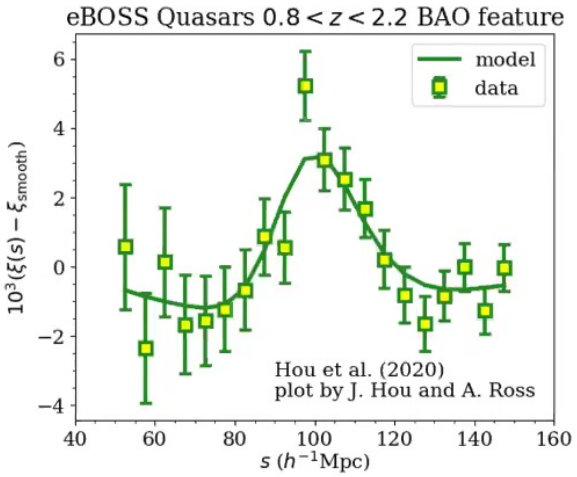
BAO from eBOSS QSO (0.8<z<2.2)

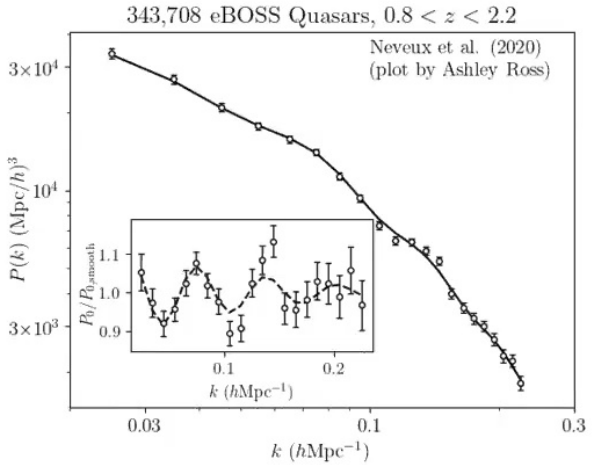




Hou et al. (2020), arXiv:2020.08998; Neveux et al. (2020), arXiv:08999

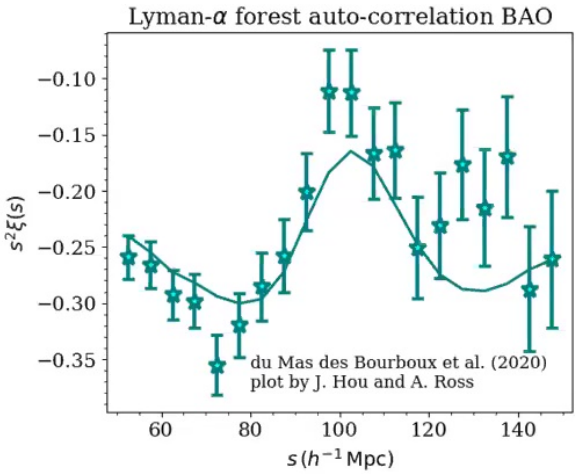
BAO from eBOSS QSO (0.8<z<2.2)

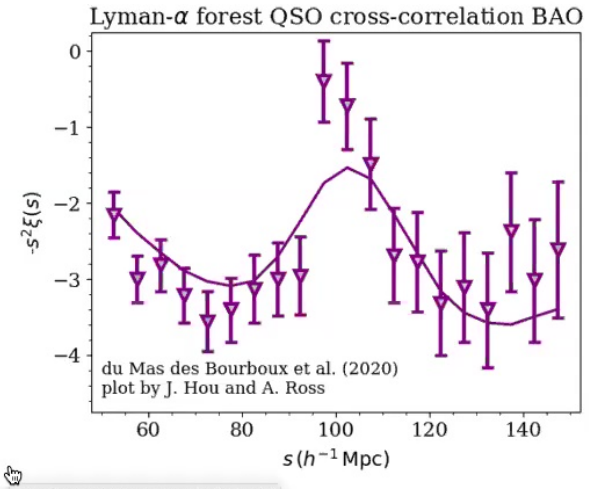




Hou et al. (2020), arXiv:2020.08998; Neveux et al. (2020), arXiv:08999

BAO from BOSS + eBOSS Ly-α





https://www.sdss.org/wp-content/uploads/2020/07/xiw_Lyaxcf_z_0_10_mu950.png

des Mas du Bourboux et al. (2020), arXiv:2020.08995

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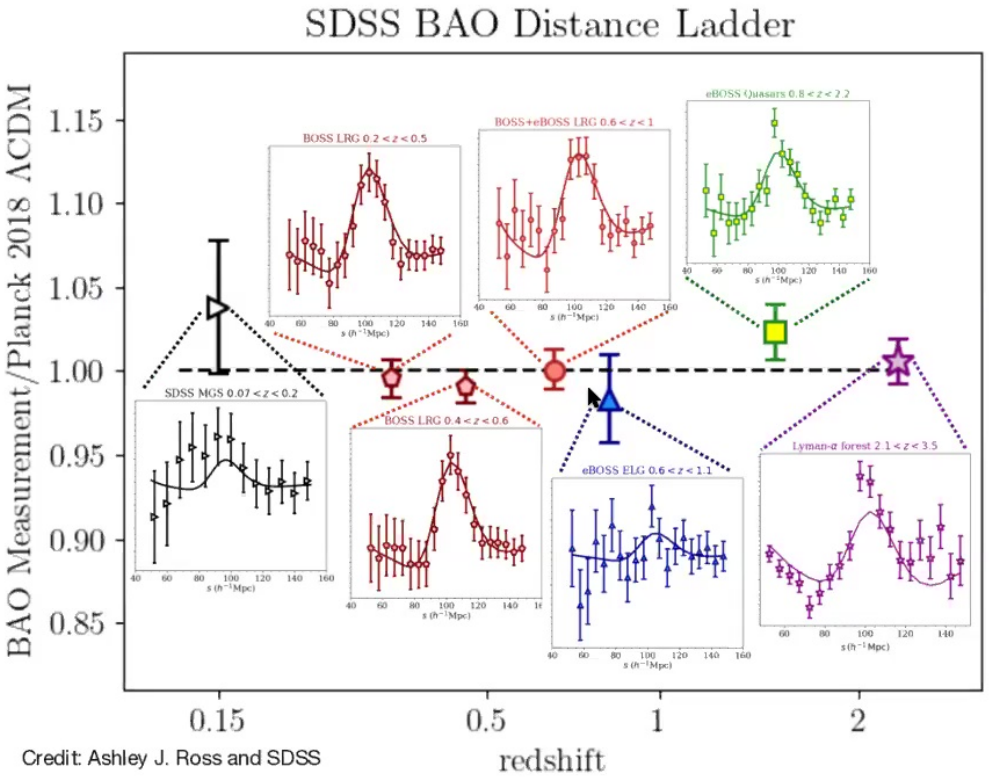
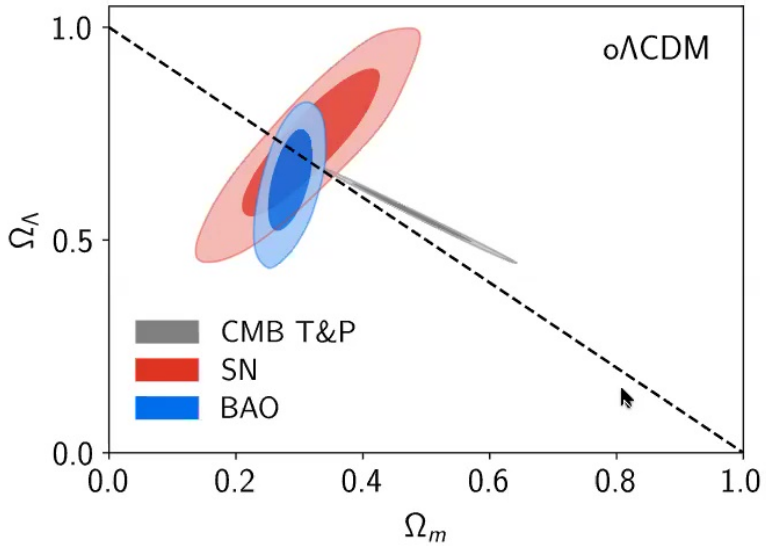
SDSS BAO Distance Ladder



Credit: Ashley J. Ross and SDSS

1. Detecting dark energy with BAO



Constraints on the matter and dark energy components of the Universe while allowing for free curvature allow us to assess the impact of the SDSS BAO measurements. BAO measurements alone lead to a constraint on the dark energy density with an **8σ confidence detection**.

Mueller et al. (2020), arXiv:2007.08991

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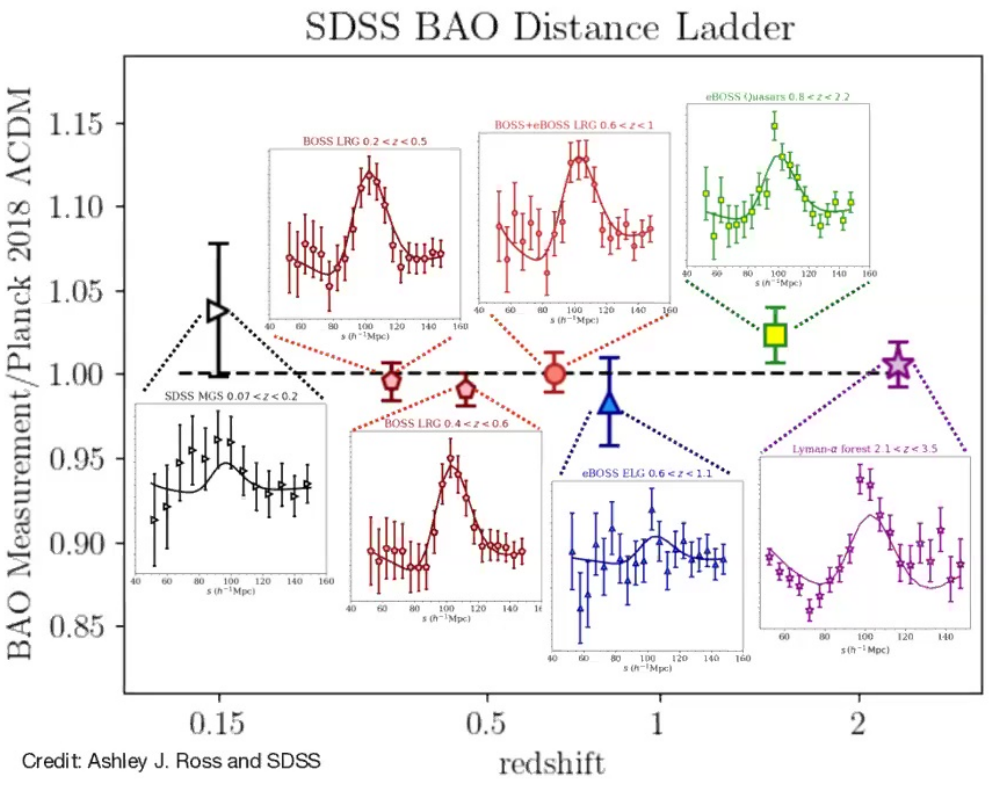
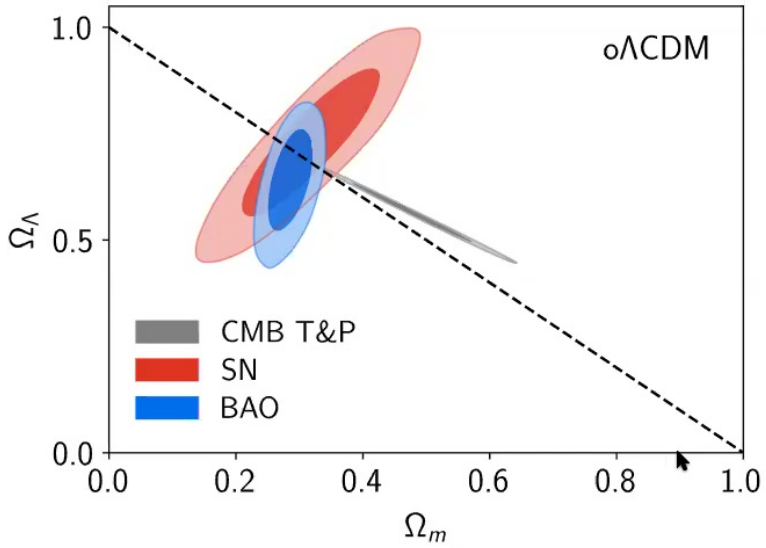
SDSS BAO Distance Ladder



Credit: Ashley J. Ross and SDSS

1. Detecting dark energy with BAO



Constraints on the matter and dark energy components of the Universe while allowing for free curvature allow us to assess the impact of the SDSS BAO measurements. BAO measurements alone lead to a constraint on the dark energy density with an **8σ confidence detection**.

Mueller et al. (2020), arXiv:2007.08991

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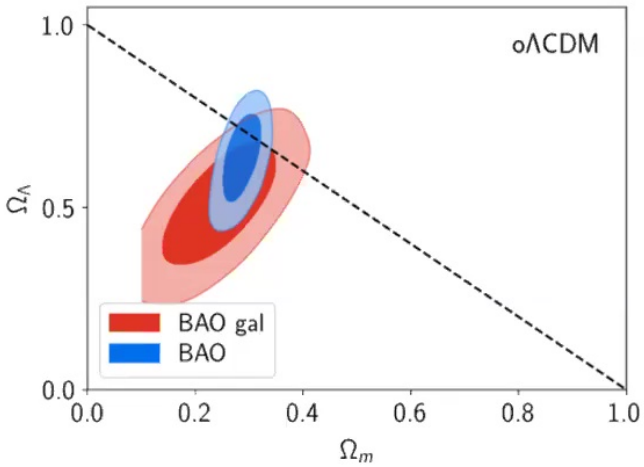
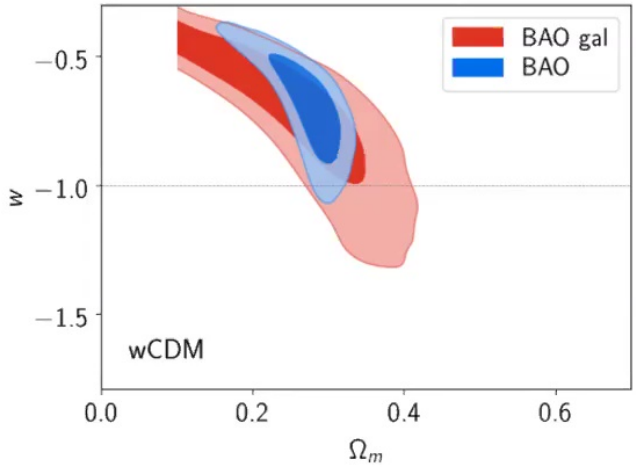
2. Low-z and high-z BAO





SDSS offer a unique combination of galaxy and quasar BAO at z<=1.5 along with the Lyman-alpha forest BAO at z=2.33. With complementary degeneracy directions, low and high redshift measurements, when combined, allow precise constraints on both the matter density and the dark energy density.

Mueller et al. (2020), arXiv:2007.08991

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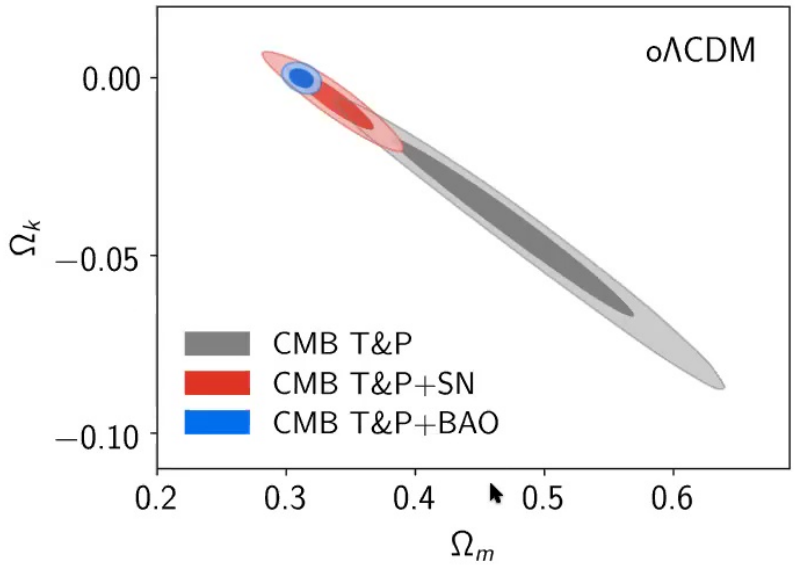
3. The curvature of space from BAO



When combined with Planck temperature and polarization data, SDSS BAO measurements allow an order of magnitude improvement on curvature constraints compared to Planck data alone. The BAO data provide strong evidence for a nearly flat geometry and constraints on curvature that are now roughly one order of magnitude within the fundamental limits.

Mueller et al. (2020), arXiv:2007.08991

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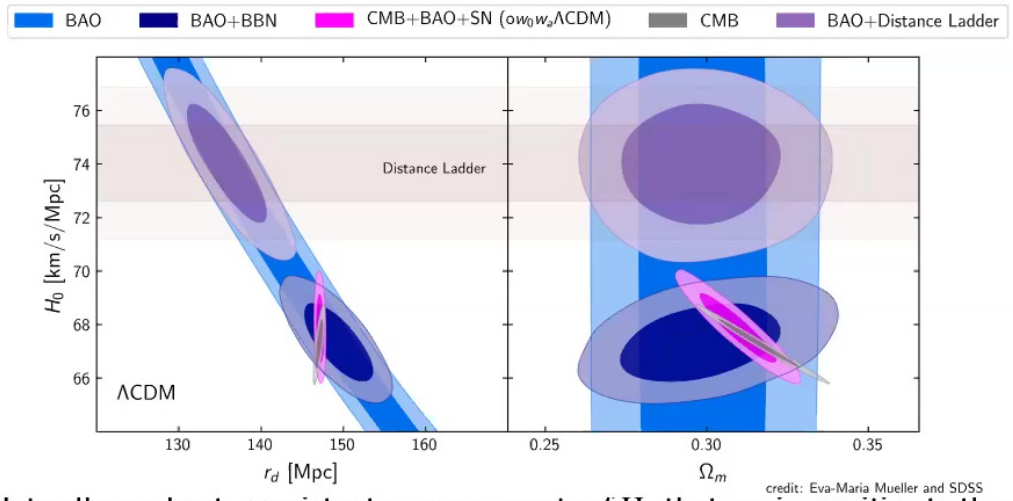
4. Local expansion history estimates



credit: Eva-Maria Mueller and SDSS

The BAO data allow robust, consistent measurements of H_0 that are insensitive to the strict cosmological priors in CMB-only estimates. BAO estimates are insensitive to the use of CMB anisotropies altogether under the assumption of a ΛCDM cosmology and including the Big Bang Nucleosynthesis constraints from primordial deuterium abundance. Under all assumptions, the H_0 values from BAO are roughly 10% smaller than those from the Cepheid distance ladder and strong-lensing time delays, and geometric distance to MASERs. The consistency of the BAO results highlights that the `H_0 tension' can not be restricted to systematic errors in Planck or to the strict assumptions of the ΛCDM model.

Mueller et al. (2020), arXiv:2007.08991

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Redshift-Space Distortions

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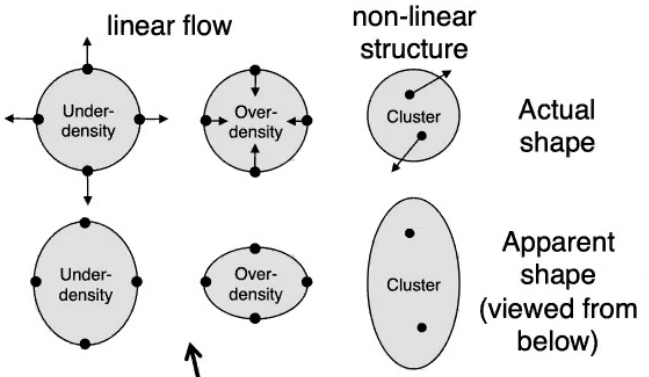
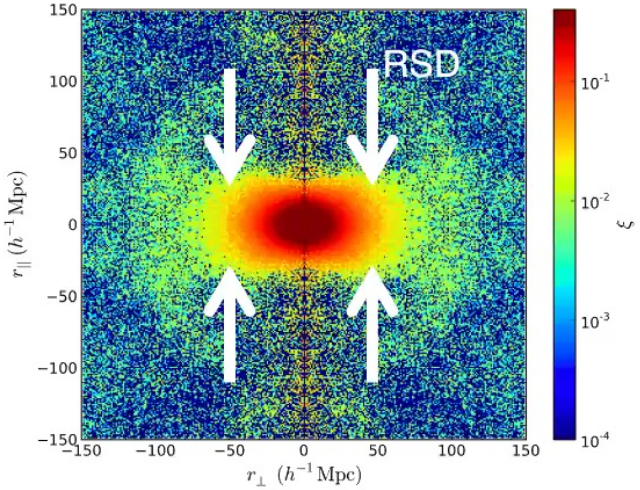
Redshift Space Distortions (RSD)



Boost to radial clustering depends on $f\sigma_8$



Samushia et al. 2013; MNRAS, 439, 3504;
Alam et al. 2016, arXiv:1607.03155

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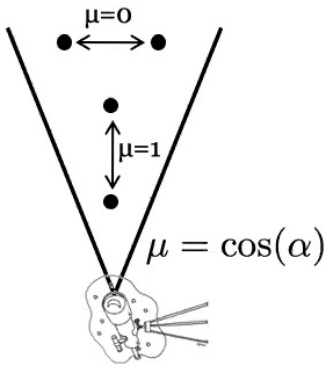
Moments of the clustering signal



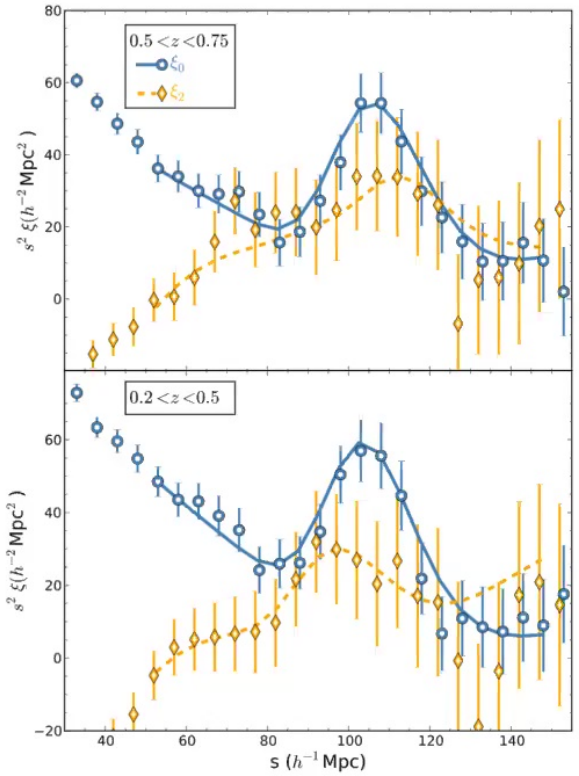
Define moments of the clustering signal

$$P_F(k) = \int_0^1 d\mu\, F(\mu) P(k,\mu)$$

$$\xi_F(r) = \int_0^1 d\mu\, F(\mu) \xi(r,\mu)$$

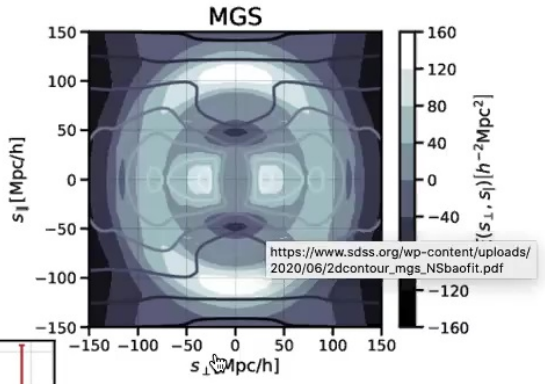
Monopole F(μ)=1,
Quadrupole F(μ)=½(3μ²-1),
Hexadecapole F(μ)=⅛(35μ⁴-30μ²+3)

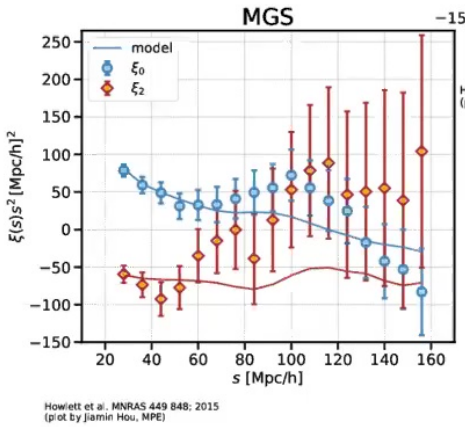
RSD = non-zero quadrupole



Ross et al. 2016, arXiv:1607.03145

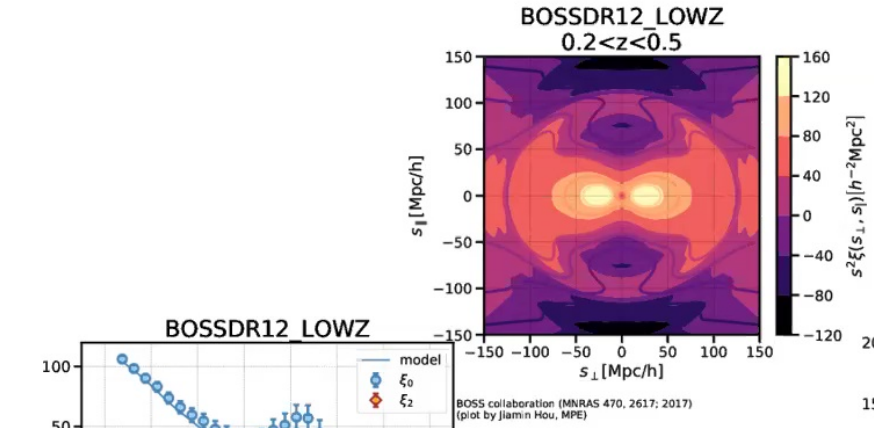
RSD from SDSS Main Galaxy Sample (0.07<z<0.2)

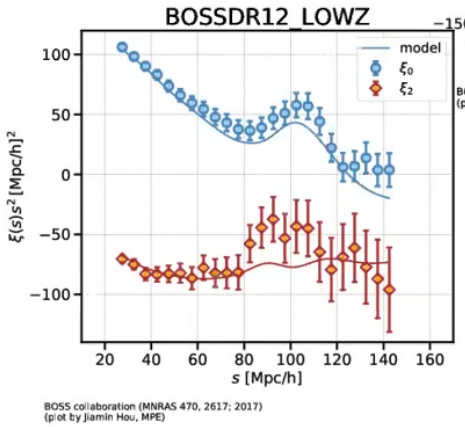


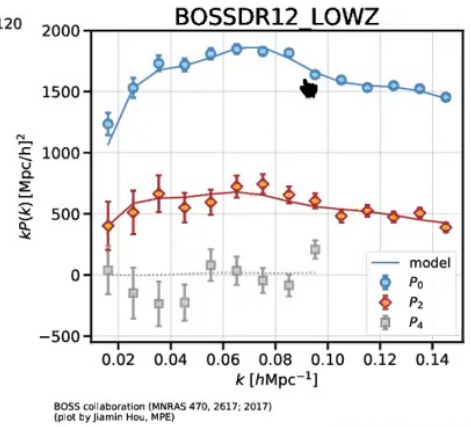


Howlett et al. (2015), MNRAS 449, 848

RSD from BOSS low-redshift bin (0.2<z<0.5)

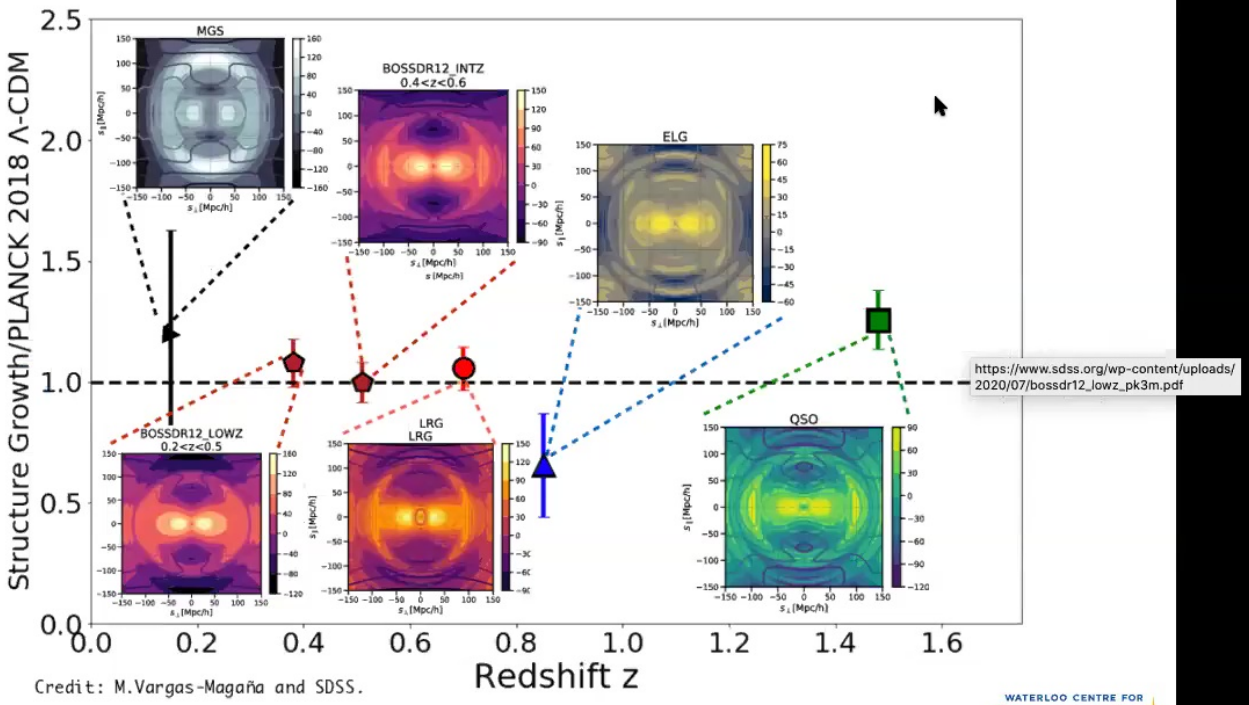






Alam et al. (2017), MNRAS 470, 2617

RSD measurements from SDSS



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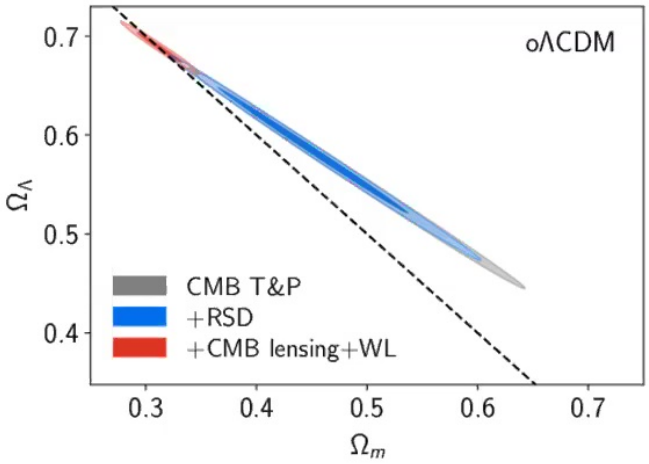
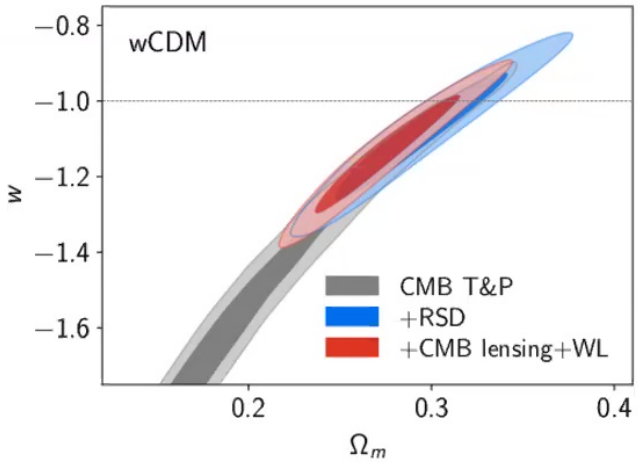
5. Dark Energy constraints from growth





RSD growth measurements provide 2-3X improvements on the precision in extended ΛCDM models when compared to CMB temperature and polarization data alone. Weak lensing data instil a preference for a flat geometry while RSD instil a preference for a cosmological constant.

Mueller et al. (2020), arXiv:2007.08991

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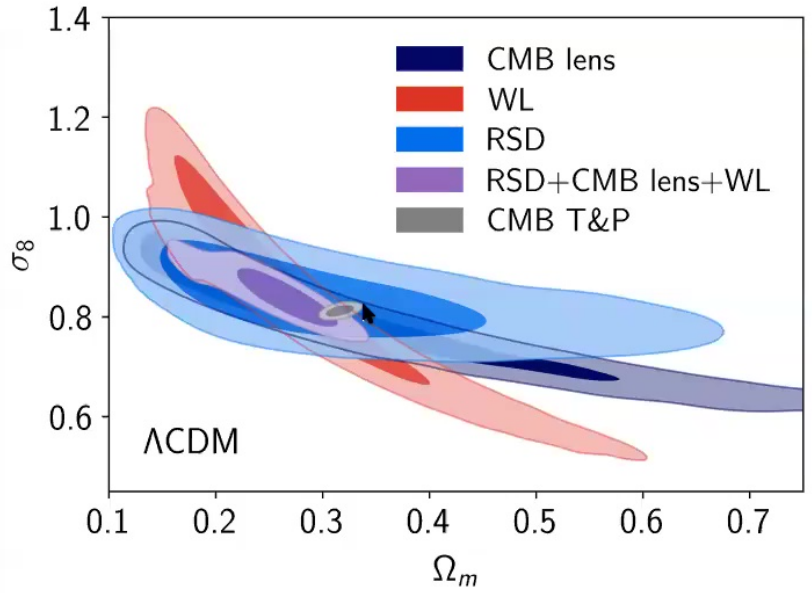
6. Consistency of General Relativity (GR) in predicting the rate of structure formation



RSD and weak lensing allow us to estimate the current amplitude of matter fluctuations. We find a picture of structure growth that is consistent with extrapolations of the amplitude of the measured CMB power spectrum under a GR model for gravity and a ΛCDM model for cosmic expansion.

Mueller et al. (2020), arXiv:2007.08991

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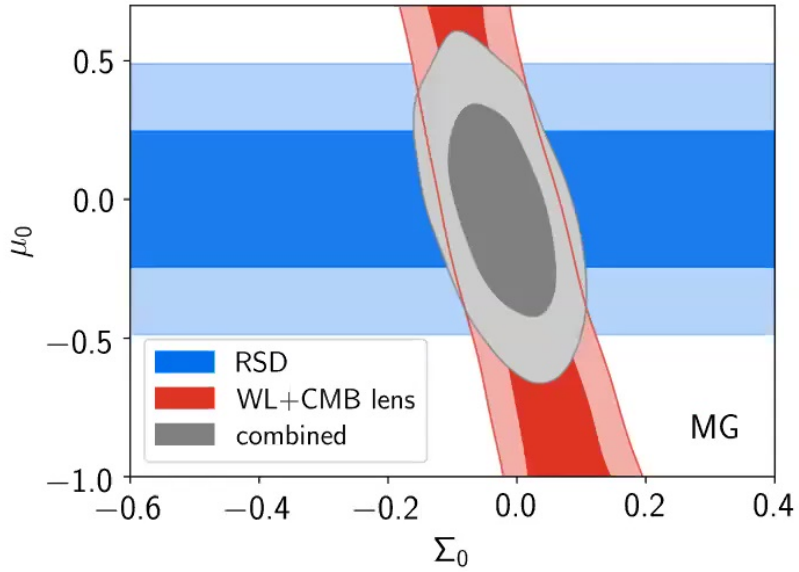
7. Testing GR predictions for matter and light



RSD measurements probe the gravitational response of matter while weak lensing measurements probe that of photons. These combined growth measurements provide evidence in support of the GR assumption that matter and photons follow the same interactions with a gravitational potential.

$$ds^2 = a^2(\tau)[(1+2\Psi)d\tau^2 - (1-2\Phi)\delta_{ij}dx_i dx_j]$$

$$k^2\Phi = -4\pi G a^2(1+\mu(a))\rho\delta$$

$$k^2(\Psi+\Phi) = -8\pi G a^2(1+\Sigma(a))\rho\delta$$

Mueller et al. (2020), arXiv:2007.08991

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BAO + RSD

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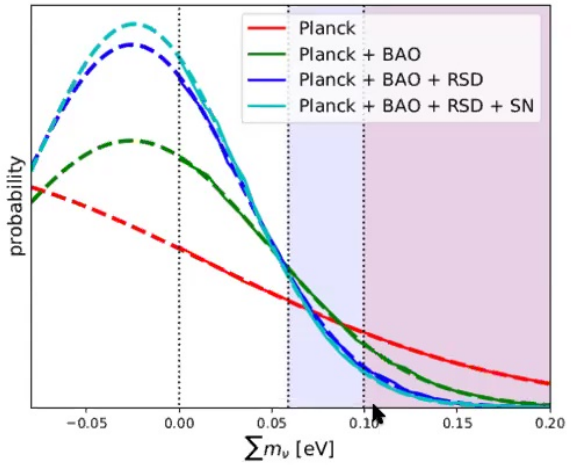
8. Bounds on neutrino mass



The combined analysis allows very tight constraints on the summed mass of the three neutrino species, with an uncertainty that is almost equal to the lower bound of 60 meV allowed by neutrino oscillation experiments. Using the Planck data as a baseline, the largest improvement in precision comes from the addition of the SDSS BAO measurements, while the RSD improve the precision by another 23%.

Data	95% upper limit [eV]	$P_{\rm inv}/P_{\rm norm}$	$P_{\rm unphy}$	Gaussian fit [eV]
Planck	0.252	0.64	0.43	
Planck + BAO	0.129	0.36	0.64	-0.026 ± 0.074
Planck + BAO + RSD	0.102	0.24	0.76	-0.026 ± 0.060
Planck + SN	0.170	0.49	0.56	-0.076 ± 0.106
Planck + BAO + RSD + SN	0.099	0.22	0.78	-0.024 ± 0.057
Planck + BAO + RSD + SN + DES	0.111	0.27	0.71	-0.014 ± 0.061
Planck + BAO + RSD + SN (νwCDM)	0.139	0.40	0.61	-0.033 ± 0.082
Planck + BAO + RSD + SN + DES (νwCDM)	0.161	0.48	0.56	-0.048 ± 0.097

Mueller et al. (2020), arXiv:2007.08991

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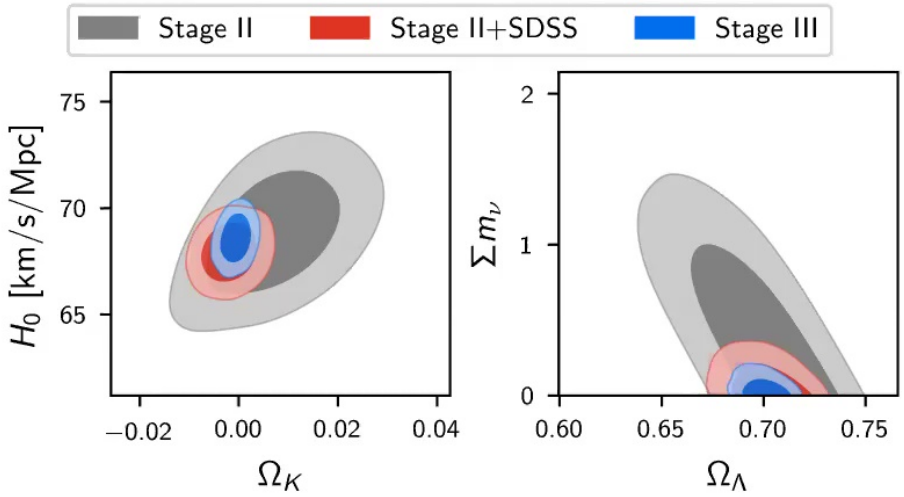
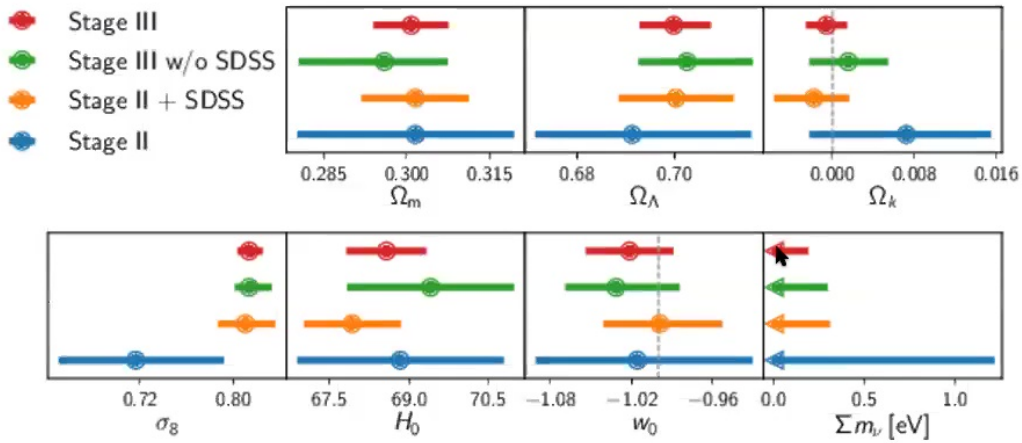
9. Role of SDSS in cosmology over the last decade



Model with free curvature, neutrino mass, and constant equation of state for dark energy. Stage-II: WMAP, JLA Supernovae, and low redshift measurements of the baryon acoustic oscillations. The posterior volume spanned by w, curvature (Ω_k), H_o, fluctuation amplitude (σ_8), and neutrino mass decreases by a factor of 40 when adding the SDSS BAO and RSD data to Stage-II experiments. The biggest impact from SDSS is in improved constraints on Ωk, H0, and neutrino mass. The volume decreases by another factor of 25 when adding Planck, Pantheon SNe Ia, and DES data, for a total improvement of three orders of magnitude in the precision in this 5D parameter space.

Mueller et al. (2020), arXiv:2007.08991

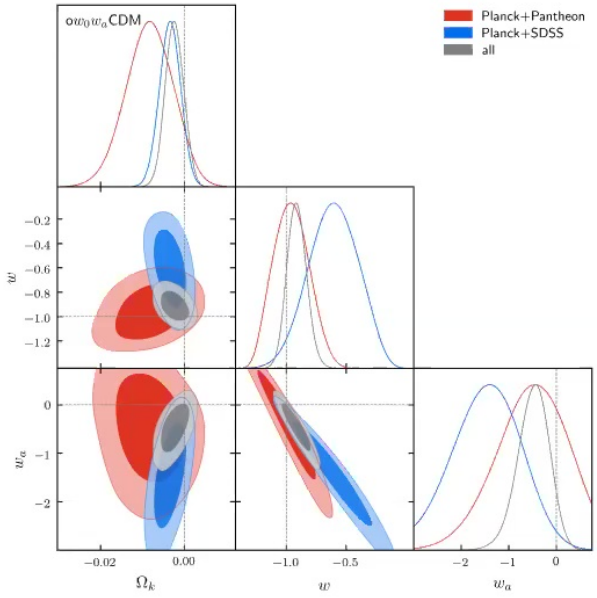
9. Role of SDSS in cosmology over the last decade



Model with free curvature, neutrino mass, and constant equation of state for dark energy. Stage-II: WMAP, JLA Supernovae, and low redshift measurements of the baryon acoustic oscillations. The posterior volume spanned by w, curvature (Ω_k), H_o, fluctuation amplitude (σ_8), and neutrino mass decreases by a factor of 40 when adding the SDSS BAO and RSD data to Stage-II experiments. The biggest impact from SDSS is in improved constraints on Ωk, H0, and neutrino mass. The volume decreases by another factor of 25 when adding Planck, Pantheon SNe Ia, and DES data, for a total improvement of three orders of magnitude in the precision in this 5D parameter space.

Mueller et al. (2020), arXiv:2007.08991

10. Summary cosmological model



The tightest constraints on the cosmological model are found when combining current measurements of the expansion history, CMB, and growth of structure. This combination reveals a dark energy density measured to 0.7% precision under an assumed ΛCDM model. We find ~1% precision estimates on the dark energy density (Ω_Λ), H_0, and σ_8 regardless of cosmological model, with a preference for a cosmological constant and a flat Universe under all models explored. The complementarity of BAO and SNe Ia data allow tight constraints of curvature and the dark energy equation of state, resulting in a Dark Energy Task Force Figure of Merit of 92.

Mueller et al. (2020), arXiv:2007.08991

PowerPoint Slide Show – [PI-eBOSS 28-07-20]

Other measurements

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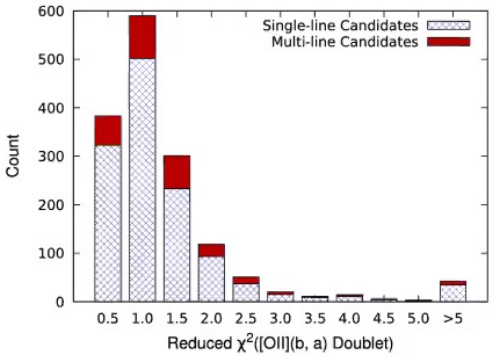
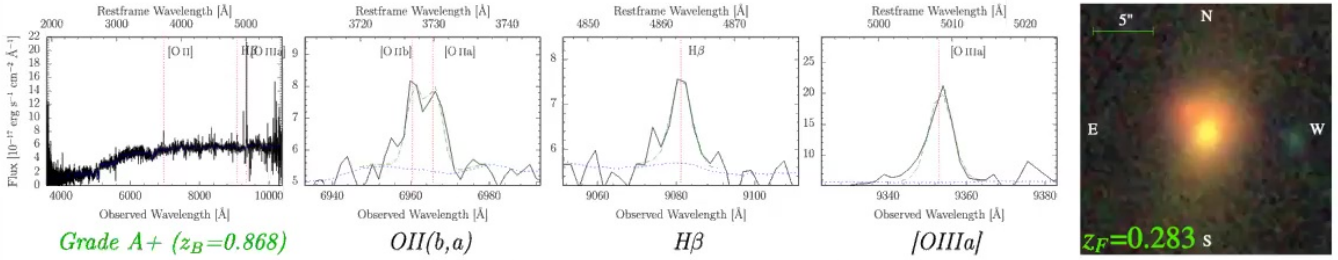
Strong lens catalog



Looked for strong lens candidates by subtracting galaxy model from spectrum and looking for background emission lines: 838 likely, 448 probably, 265 possible



(1) SDSS J0213-0347 (Target Image from DeCALS DR7)

Talbot et al. (2020), arXiv:2007.09006

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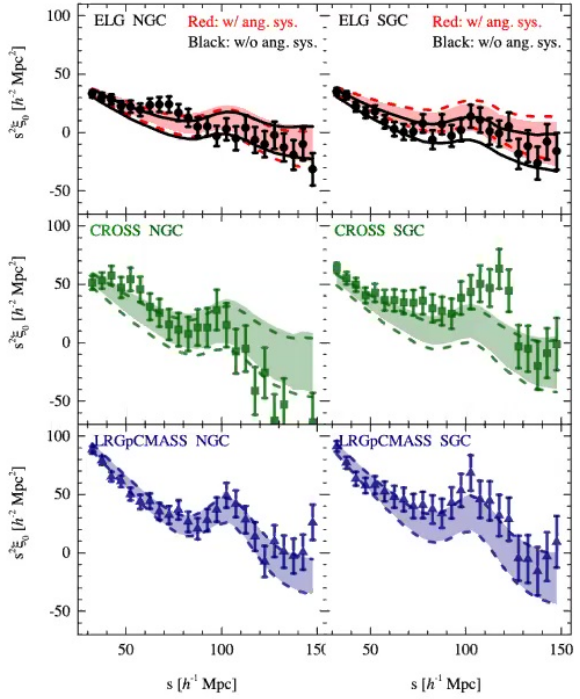
Multi-tracer analyses

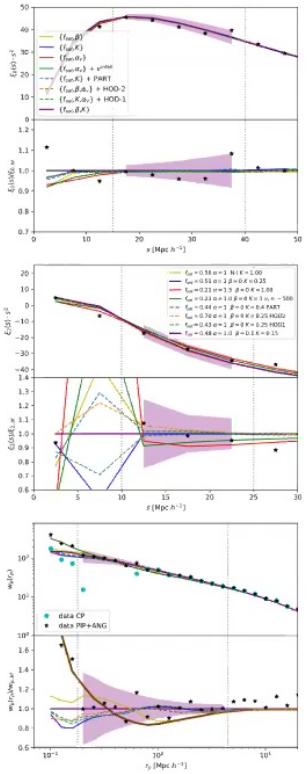


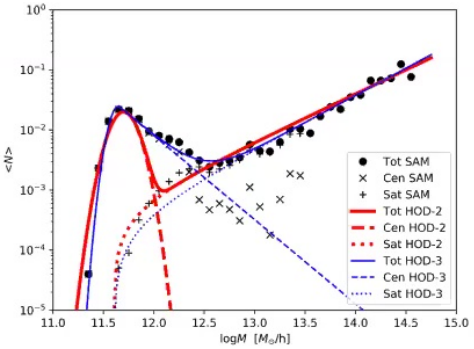
Use angular overlap between ELG and LRG samples to make "sample variance-free" measurements of ratios: 18% improvement on $f\sigma_8$.

Samples	$\alpha_\perp$	$\alpha_\parallel$	$f\sigma_8$	χ^2/dof
ELG	$1.097^{+0.374}_{-0.236}$	$1.173^{+0.248}_{-0.219}$	$0.432^{+0.135}_{-0.149}$	169/138
ELG, SGC	$1.033^{+0.071}_{-0.130}$	$1.127^{+0.095}_{-0.163}$	$0.431^{+0.104}_{-0.132}$	92/67
ELG	fixed	fixed	0.433 ± 0.045	169/140
LRGpCMASS	1.016 ± 0.021	1.007 ± 0.028	0.472 ± 0.043	161/138
LRGpCMASS	fixed	fixed	0.448 ± 0.032	161/140
CROSS	0.949 ± 0.040	1.118 ± 0.118	0.342 ± 0.085	147/138
CROSS	fixed	fixed	0.443 ± 0.050	148/140
ELG+LRGpCMASS	1.004 ± 0.020	1.020 ± 0.028	0.435 ± 0.037	309/279
ELG,SGC +LRGpCMASS	1.013 ± 0.021	1.014 ± 0.028	0.451 ± 0.041	232/208
ELG+CROSS	0.970 ± 0.037	1.044 ± 0.072	0.402 ± 0.062	290/279
CROSS+LRGpCMASS	1.006 ± 0.021	1.016 ± 0.029	0.444 ± 0.041	298/279
Joint ($N_p = 10$)	1.003 ± 0.020	1.018 ± 0.030	0.439 ± 0.039	416/422
Joint ($N_p = 10$, w/ AP fixed)	fixed	fixed	0.444 ± 0.029	414/424
Joint ($N_p = 12$)	1.005 ± 0.020	1.016 ± 0.028	0.445 ± 0.038	416/420
Joint ($N_p = 12$, w/ AP fixed)	fixed	fixed	0.446 ± 0.029	414/422

Wang et al. (2020), arXiv:2007.09010, Zhao et al. (2020), arXiv:2007.09011 (similar with P(k))

ELG HOD





ELGs trace halos in a complicated way (compared to LRGs) as they have more satellites and hence a more complicated HOD. This project fits models to the data, including small-scales using PIP weights.

Mock	HOD	$f_{\rm sat}$	β	K	α_v	profile	$v^{\rm infall}$	χ^2_{wp}	χ^2_2	χ^2_0	$\chi^2_{\rm tot}$ (bins: 14+3+5)
0	HOD-3	**0.22**	0	1	1	NFW	0	21.7	1.1	5.0	31.3
1	HOD-3	**0.56**	**N-I**	1	1	NFW	0	17	0.3	4.7	24
2	HOD-3	**0.51**	0	**0.25**	1	NFW	0	7.2	0.3	5	12.7
3	HOD-3	**0.21**	0	1	**1.5**	NFW	0	22	0.5	5.3	28.3
4	HOD-3	**0.21**	0	1	**1.0**	NFW	-500	22	0.5	5.0	28
5	HOD-3	**0.36**	**0.0**	1	1	PART	0	15.5	0.7	4.7	23
6	HOD-3	**0.44**	0	**0.4**	1	PART	0	8	0.3	4.6	13.5
7	HOD-3	**0.26**	0	1	**1.2**	PART	0	15	0.2	4.6	21.4
8	HOD-3	**0.26**	0	1	**0.8**	PART	-500	16	0.9	4.3	21.2
9	HOD-3	**0.48**	**0.10**	**0.15**	1	NFW	0	6	0.3	4.9	10.9
10	HOD-3	**0.21**	**0.0**	1	**1.5**	NFW	0	22	0.5	5.3	28.3
11	HOD-3	**0.51**	0	**0.25**	**1.0**	NFW	0	7.2	0.3	5	12.7
12	HOD-1	**0.40**	**N-I**	1	1	NFW	0	17.9	0.3	4.7	25
13	HOD-1	**0.43**	0	**0.25**	1	NFW	0	7	0.3	5.0	12.4
14	HOD-1	**0.18**	0	1	**1.6**	NFW	0	22	0.3	5.5	28.6
15	HOD-2	**0.70**	**N-I**	1	1	NFW	0	21	0.3	4.9	28.4
16	HOD-2	**0.70**	0	**0.25**	1	NFW	0	8.1	0.3	4.8	13.8
17	HOD-2	**0.22**	0	1	**1.5**	NFW	0	22	0.2	5.4	29.1

Avila et al. (2020), arXiv:2007.09012

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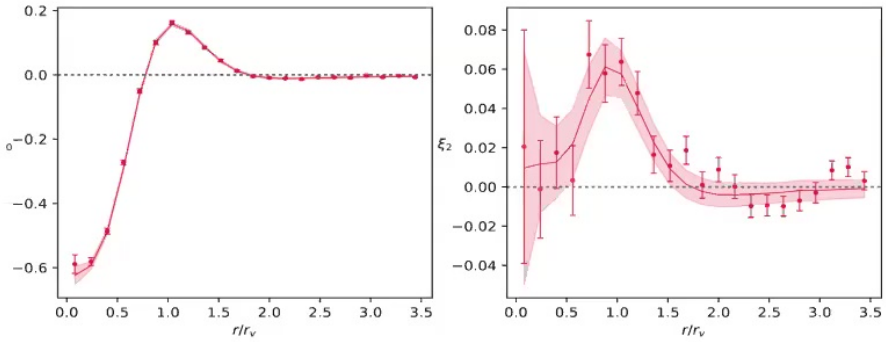
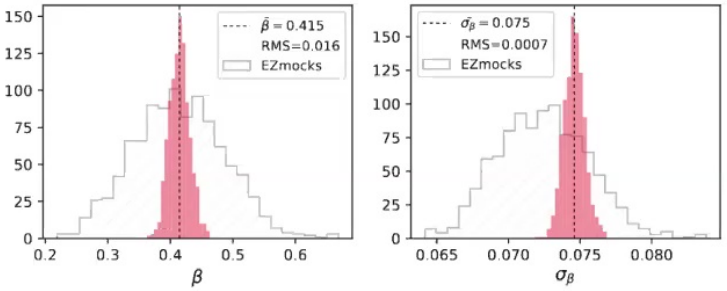
Voids



Simple RSD measurements from the growth of voids.



Aubert et al. (2020), arXiv:2007.09013

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Discussion

- Still to come
  - f_{NL} analyses from large-scale clustering of QSOs
  - RSD + AP void analyses (draft in review)
  - Small-scale RSD measurements
  - More cosmological tests (for example E_G statistic draft in review)
- Resources
  - https://www.sdss.org/science/final-bao-and-rsd-measurements/
  - https://www.sdss.org/science/cosmology-results-from-eboss/
  - https://arxiv.org/abs/2007.08991 ... https://arxiv.org/abs/2007.09013

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