BOSS & eBOSS

(on behalf of many SDSS colleagues)

Bob Nichol (ICG Portsmouth)

Building on the legacy of SDSS

Still a highly competitive wide-field spectroscopic capability

SDSS-III

- BOSS
- SEGUE-II
- APOGEE
- MARVELS

Funded for operation from 2008 to 2014

BOSS in a nutshell

8,000 deg^2 footprint in Spring
3,000 deg^2 footprint in Fall

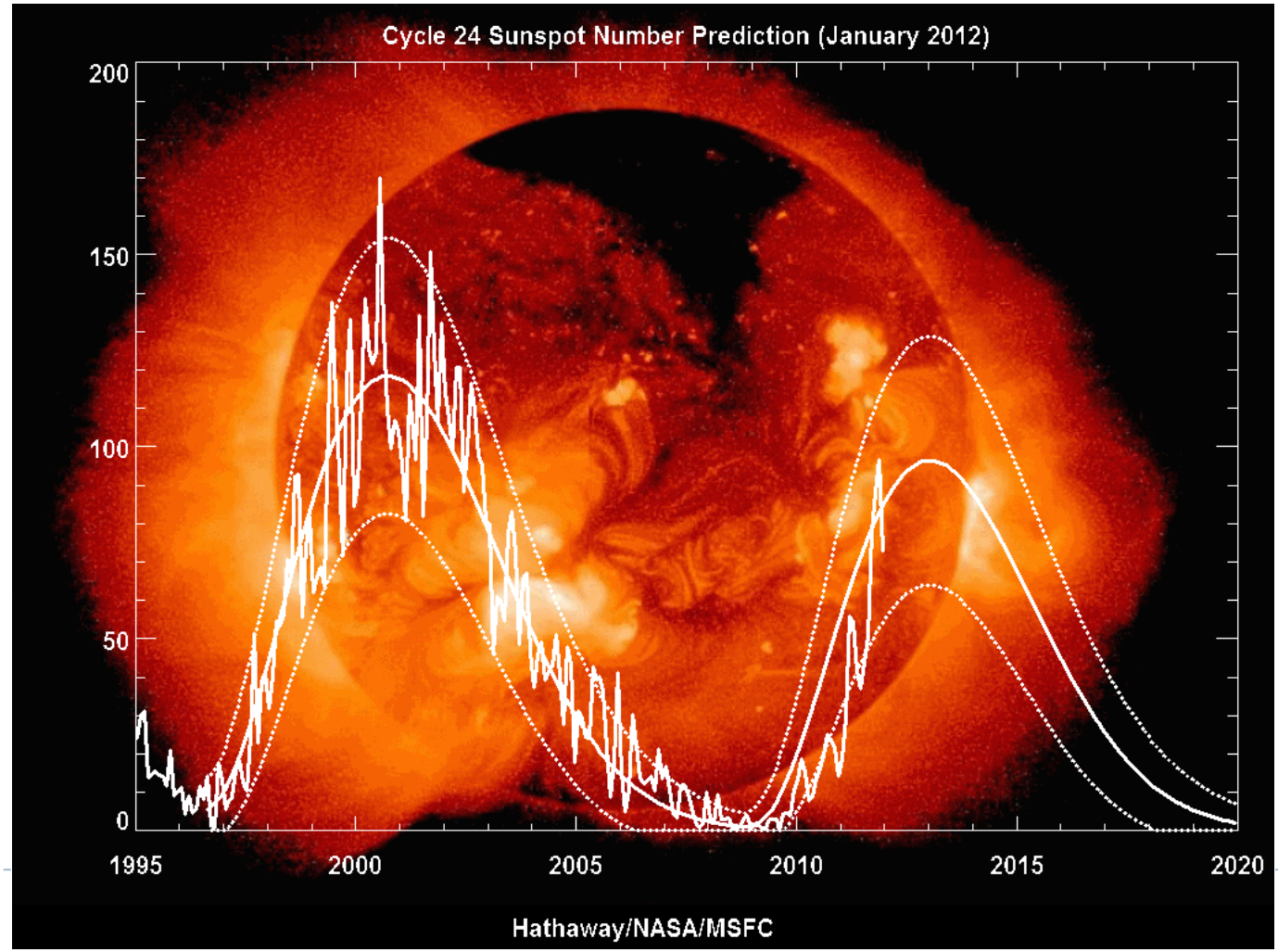
(Eisenstein et al. 2011)

- Upgraded spectrographs (with better throughput)
  - 1000x 2-arcsec fibers in cartridges
  - Increase wavelength range to 3600-10,000A (R=1500-2600)
- Finished ~3,000 deg^2 southern imaging in Fall 2008.
  - Released as part of DR8, published in ApJS (2011).
- Currently doing only spectroscopy
  - 1.5 million galaxies, i<19.9, z<0.8, over 10,000 deg^2
  - 150,000 QSOs, g<22, 2.3<z<3, over 8,000 deg^2

Blanton

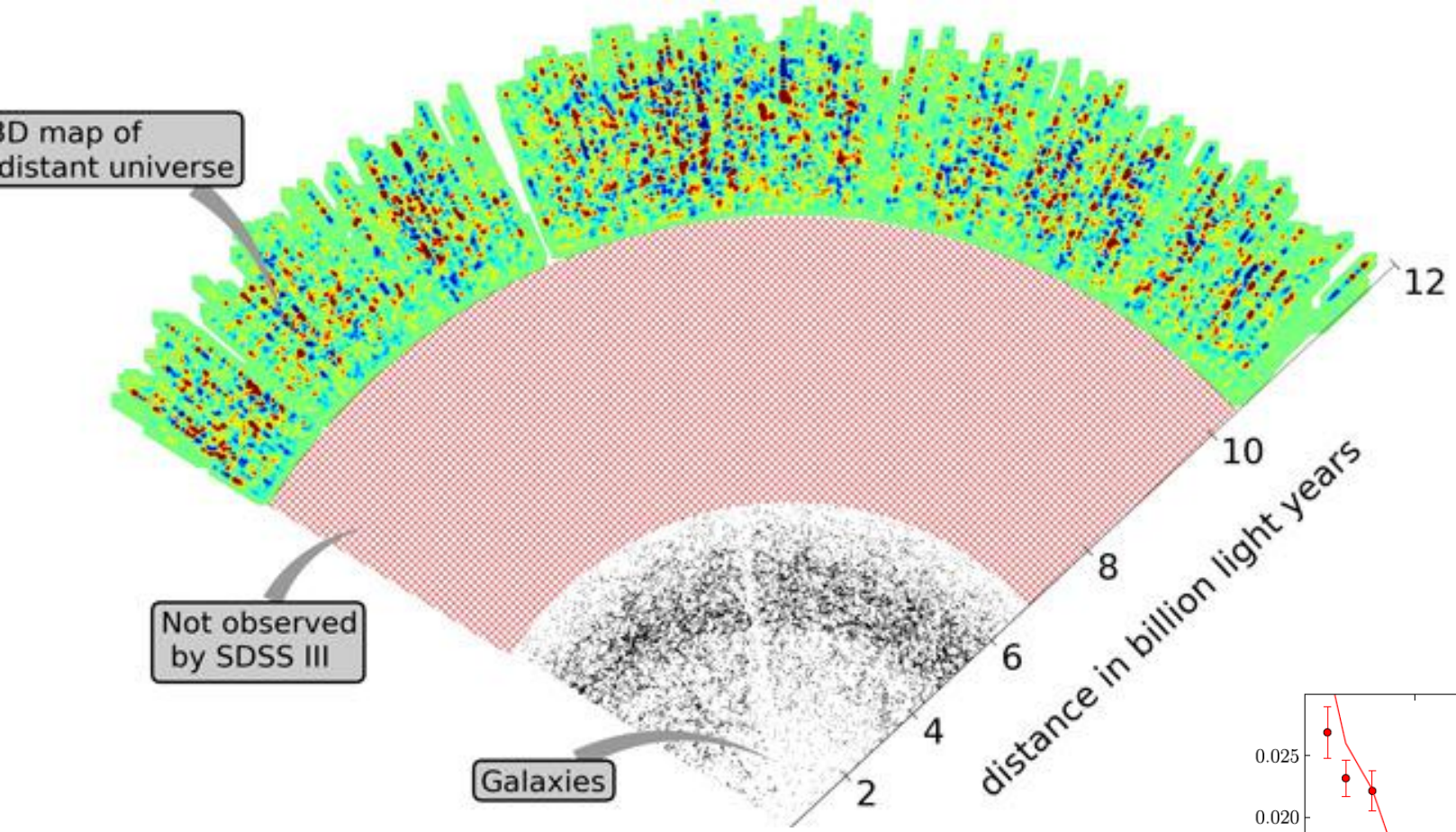
BOSS is over half done!

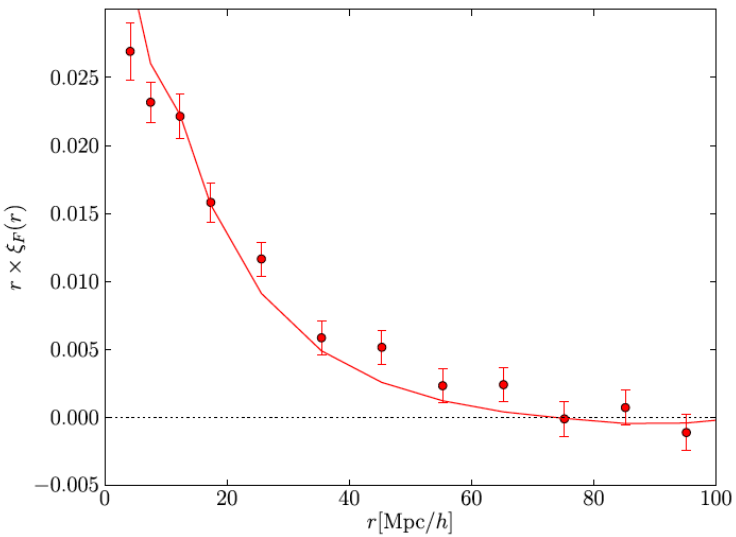
Over 1000 plates done, each with 1000 targets – million spectra!
Only 27% of time lost to weather and problems
Lower sky brightness



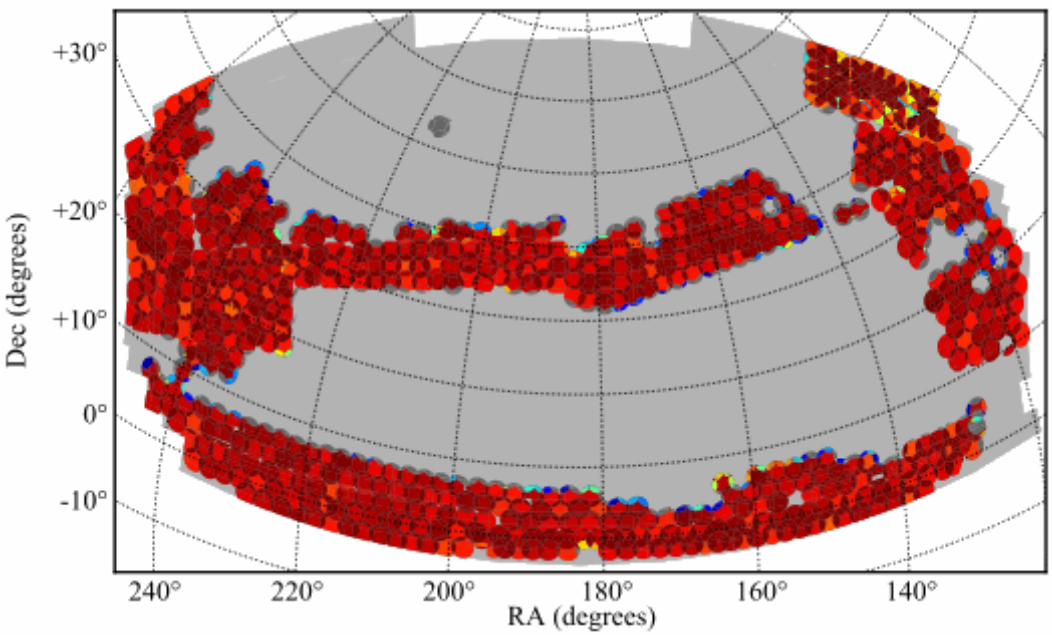
Schlegel

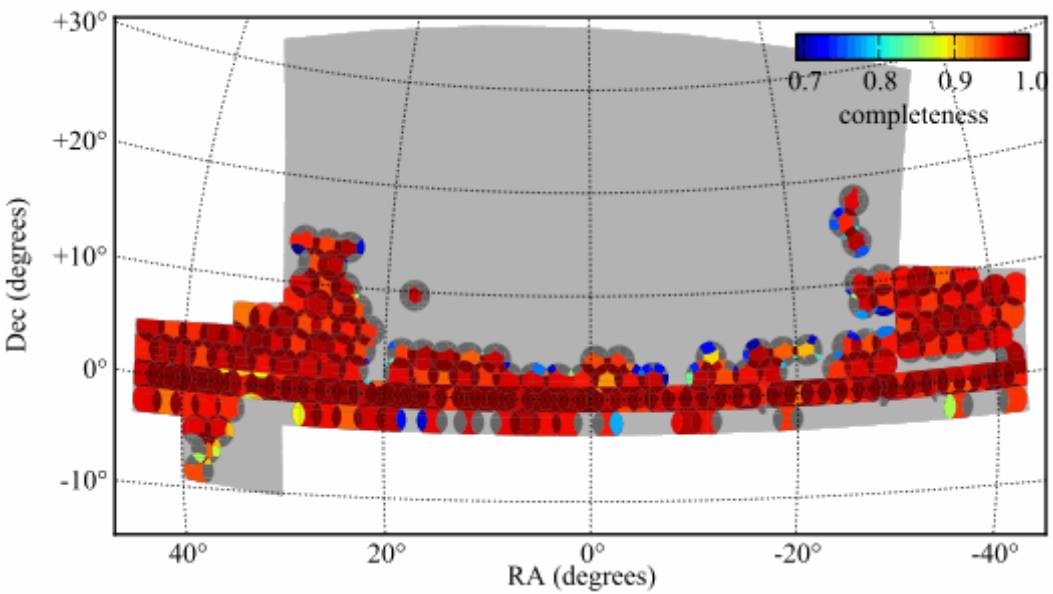
LSS at high z (Slozar et al. 2011)

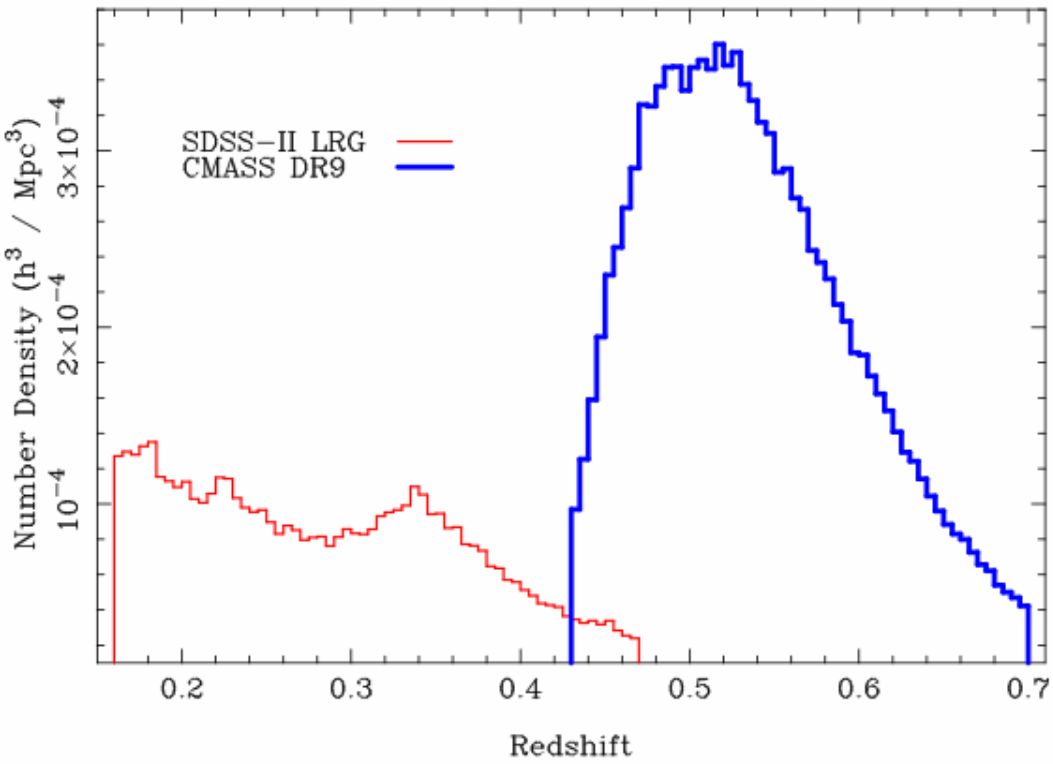




BOSS 2012 (Anderson et al. 2012)

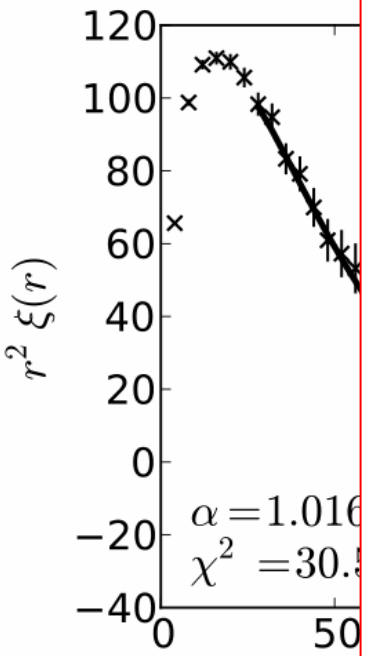


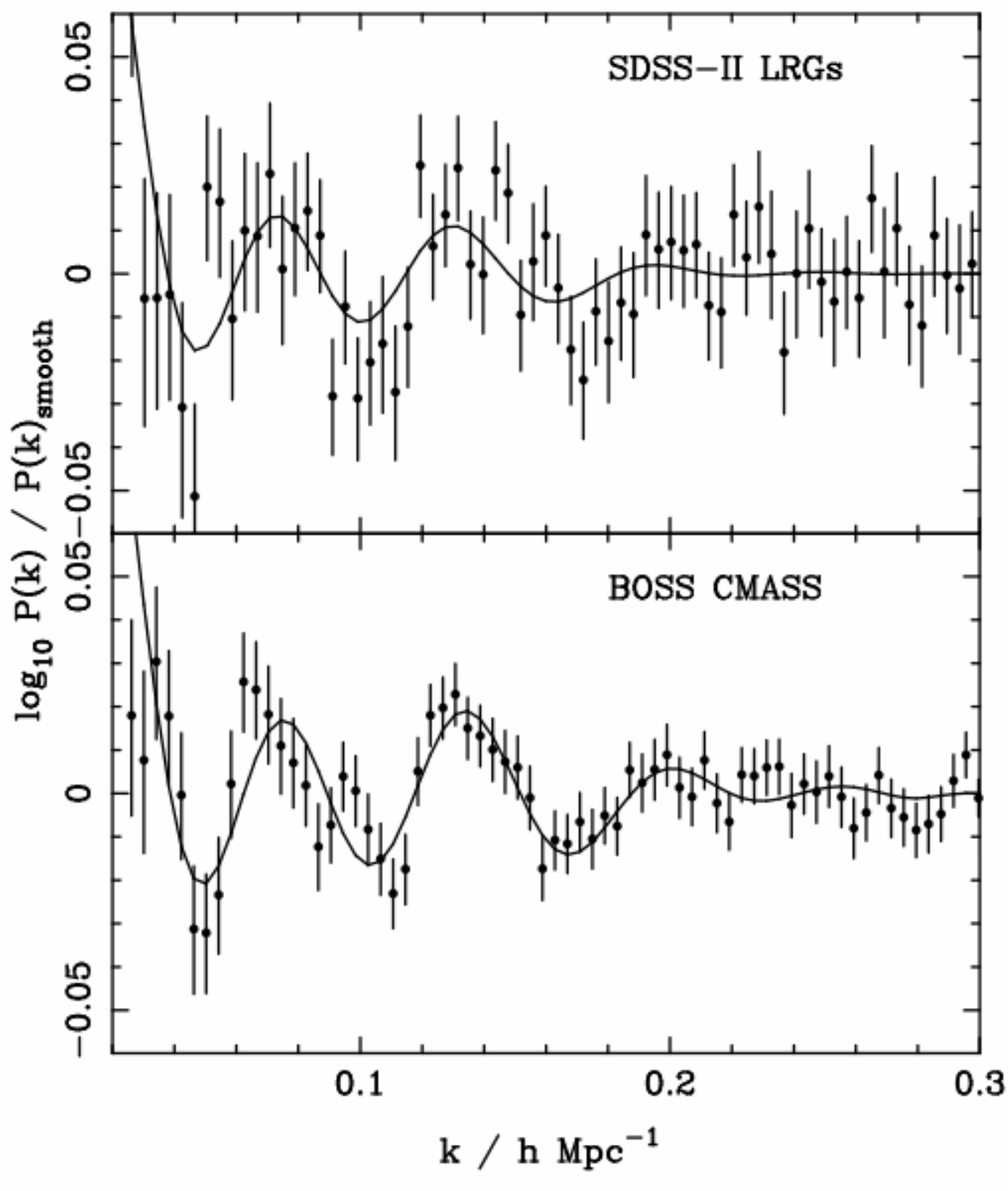


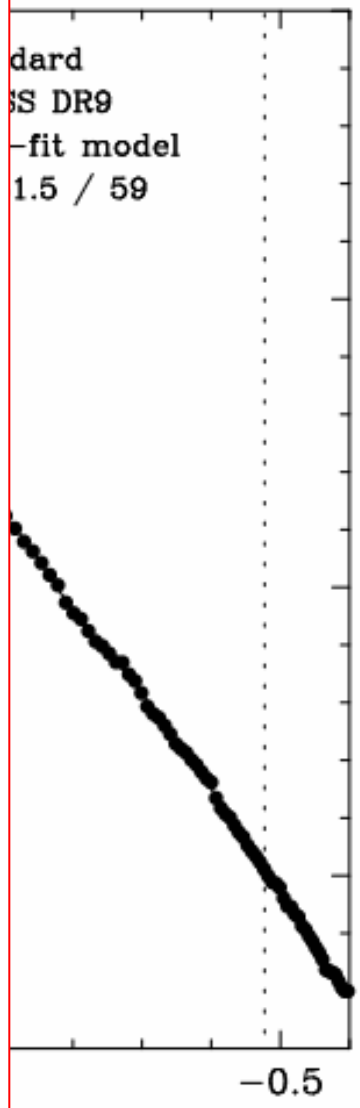


3275 deg²
264k redshifts
2.2Gpc³

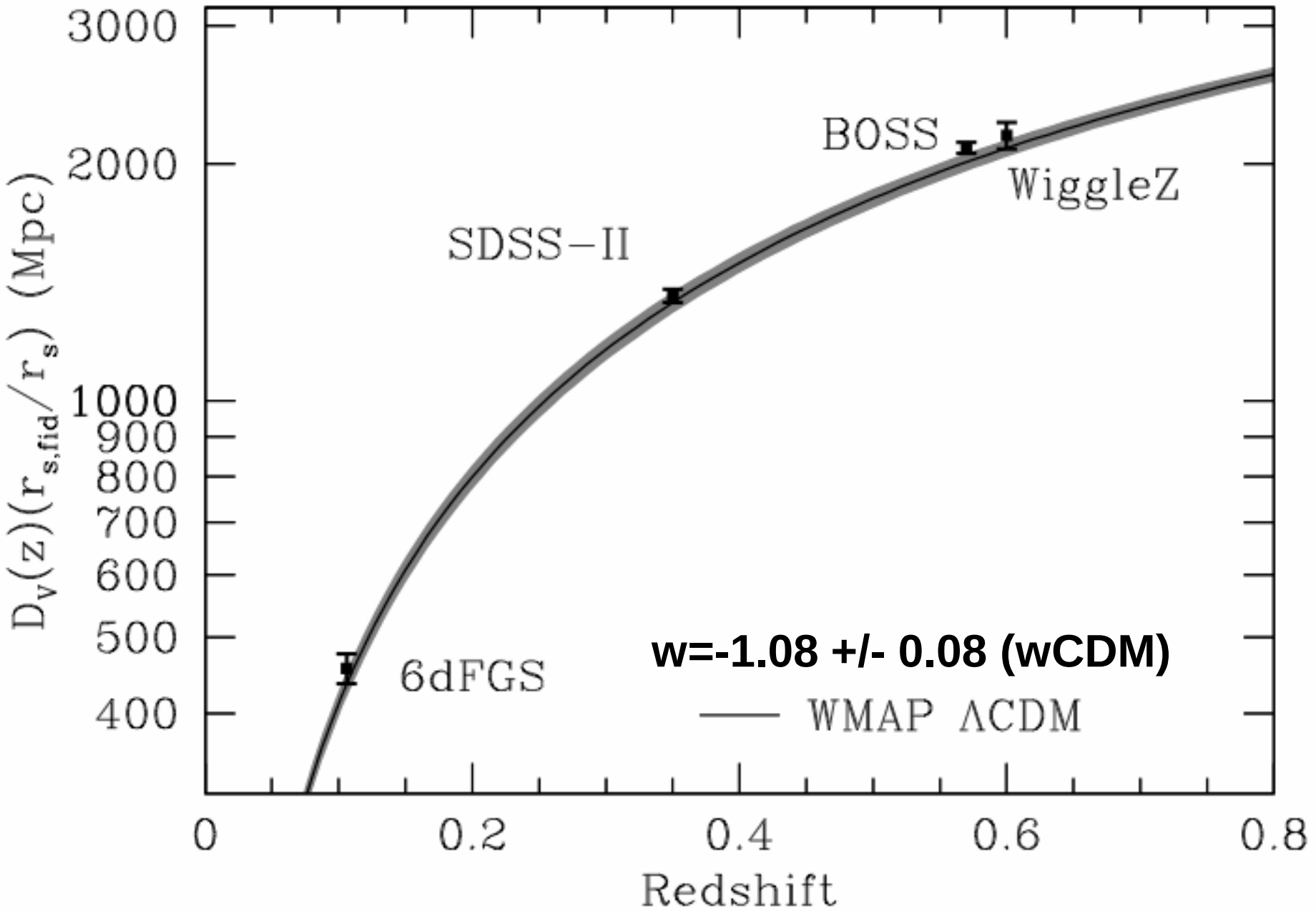
6.7σ


120
100
80
60
40
20
0
−20
−40
0
50
$r^2\,\xi(r)$
$\alpha = 1.016$
$\chi^2 = 30.5$

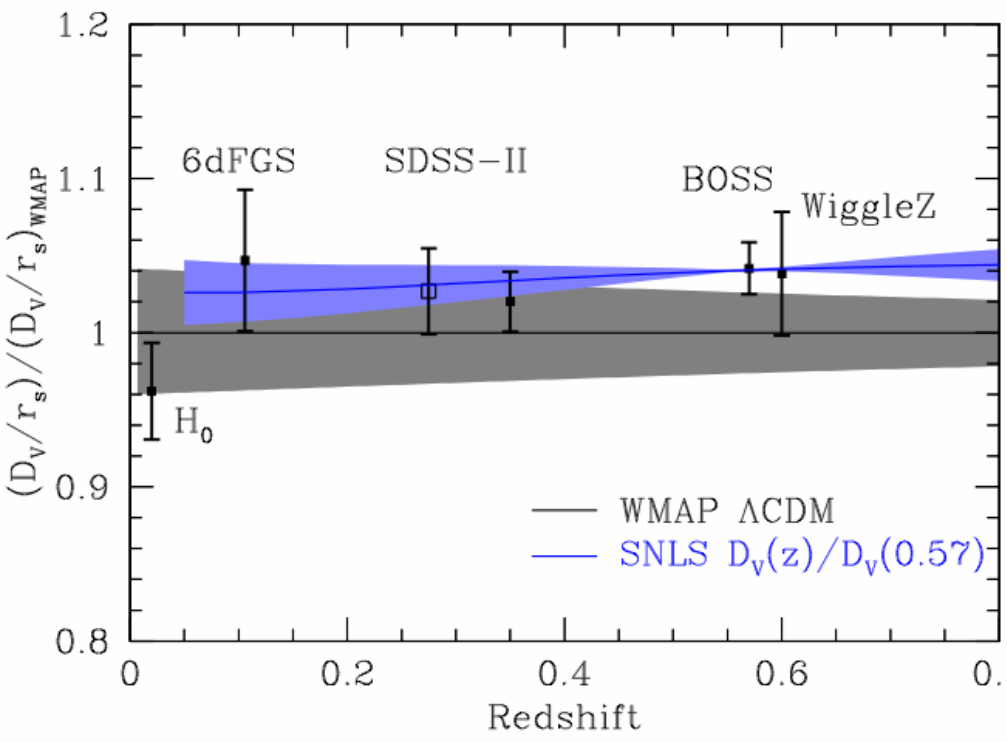

SDSS−II LRGs
BOSS CMASS
$\log_{10} P(k) / P(k)_{smooth}$
0.05
0
−0.05
0.1
0.2
0.3
k / h Mpc^{-1}


dard
S DR9
-fit model
1.5 / 59
−0.5

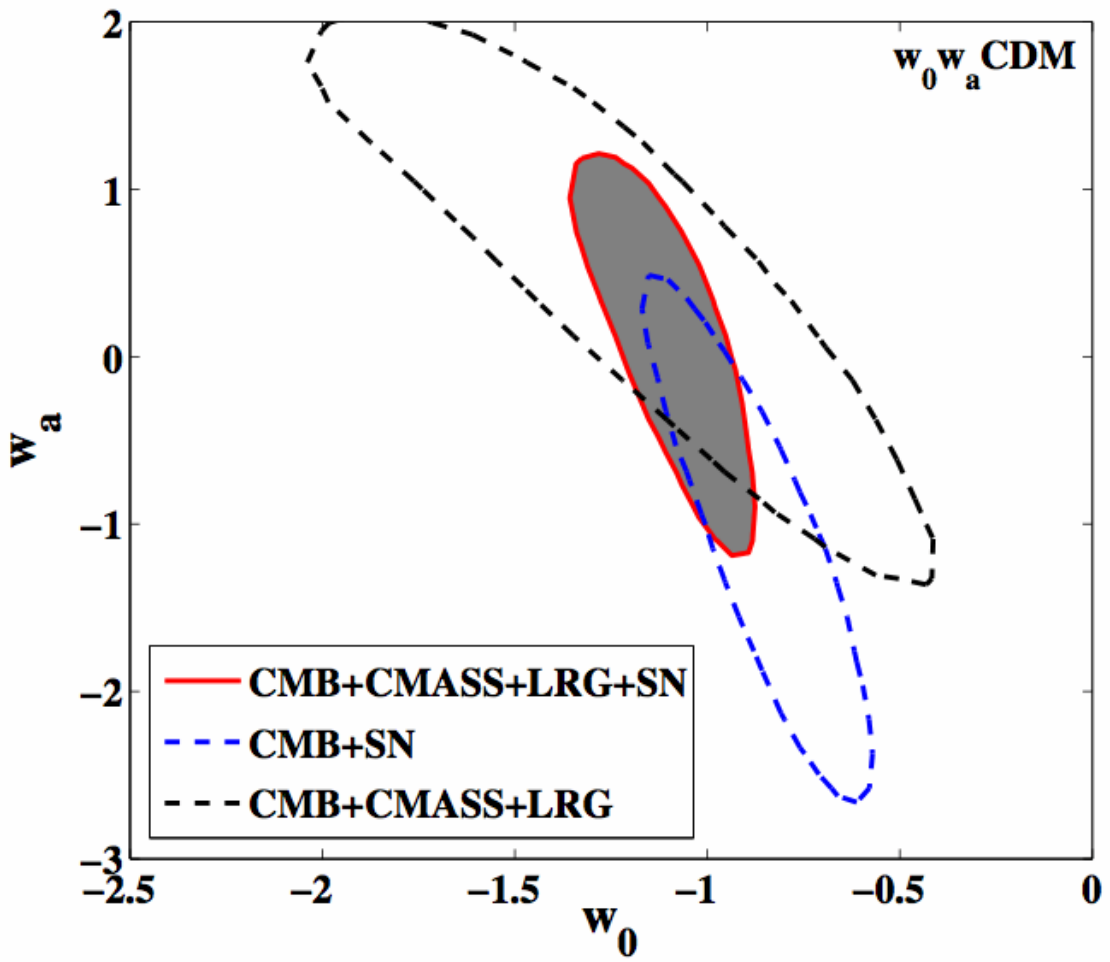
BAO Hubble Diagram



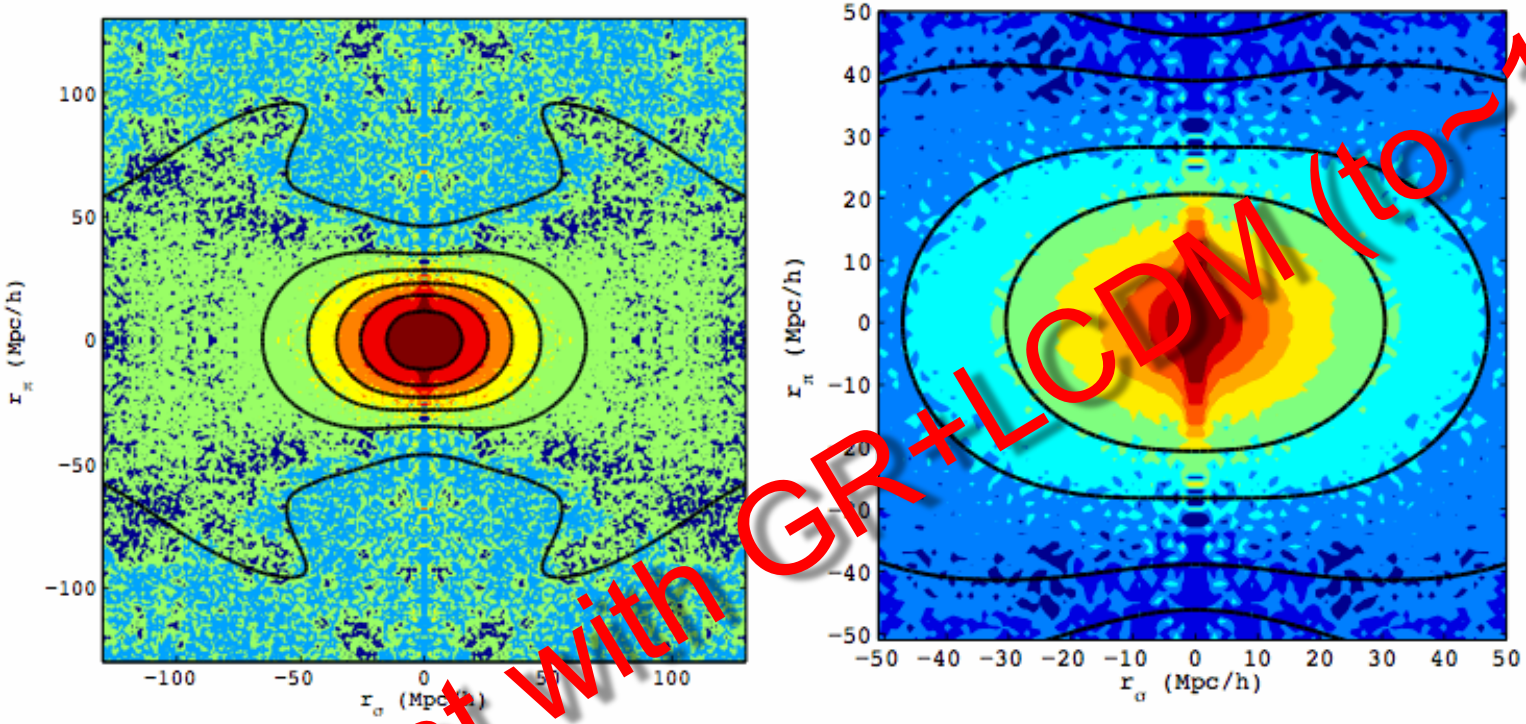
Still things to learn



FoM=14



Other Cosmologies (Reid et al. 2012)



All consistent with GR+LCDM (to ~10%)

Figure 3. *Left panel*: Two-dimensional correlation function of CMASS galaxies (color) compared with the best fit model described in Section 6.1 (black lines). Contours of equal ξ are shown at [0.6, 0.2, 0.1, 0.05, 0.02, 0]. *Right panel*: Smaller-scale two-dimensional clustering. We show model contours at [0.14, 0.05, 0.01, 0]. The value of ξ_0 at the minimum separation bin in our analysis is shown as the innermost contour. The $\mu \approx 1$ "finger-of-god" effects are small on the scales we use in this analysis.

Model	$b\sigma_8$	$f\sigma_8$	D_V [Mpc]	F	$(1+z_{\rm eff})D_A$ [Mpc]	H [km s^{-1} Mpc^{-1}]
Free growth 2	$1.228^{+0.033}_{-0.032}$	$0.415^{+0.034}_{-0.033}$	-	-	-	-
Free Geometry 3	$1.246^{+0.043}_{-0.046}$	-	2076^{+42}_{-44}	$0.683^{+0.026}_{-0.025}$	2204 ± 44	$92.9^{+3.6}_{-3.3}$
Both free 4	$1.238^{+0.047}_{-0.050}$	$0.427^{+0.069}_{-0.063}$	2070^{+43}_{-46}	$0.675^{+0.042}_{-0.038}$	2190 ± 61	$92.4^{+4.5}_{-4.0}$
WMAP7 ΛCDM	-	0.451 ± 0.025	2009 ± 42	$0.6635^{+0.0084}_{-0.0073}$	2113^{+53}_{-52}	$94.2^{+1.4}_{-1.3}$

Table 1. The median and 68.3 per cent confidence level intervals on parameters $b\sigma_8$, $f\sigma_8$, absolute distance scale D_V (Eqn. 15), Alcock-Paczynski parameter F (Eqn. 16), as well as derived parameters, comoving angular diameter distance ($(1+z_{\rm eff})D_A$) and expansion rate (H). To obtain these constraints, we marginalize over $\sigma^2_{\rm FoG}$ and power spectrum shape parameters $\vec{p}_s = \{\Omega_b h^2, \Omega_c h^2, n_s\}$ for Models 2-4, as described in Section 5.2. We interpret our measurements at the effective redshift of our galaxy sample, $z_{\rm eff} = 0.57$.

BOSS 2014 ("Stage III")

Eisenstein et al. 2011

$w(z)=w_0+w_a(1-a)$.

TABLE 5
BOSS Parameter Constraint Forececasts

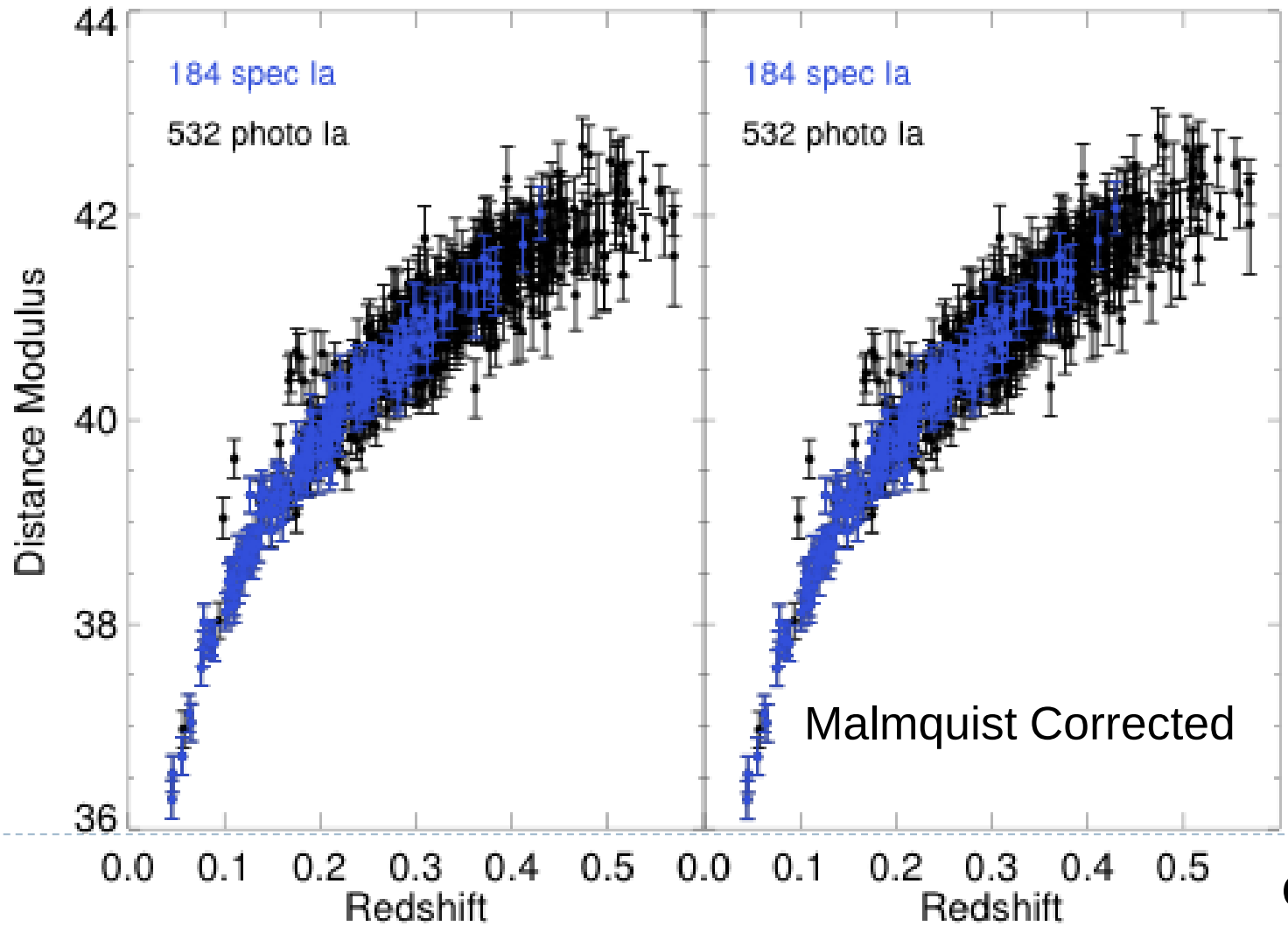
Expt.	h	Ω_K	w_0	w_p	w_a	FoM
Planck+Stage II	0.019	0.0031	0.115	0.036	0.524	53.4
BOSS LRG BAO	0.009	0.0027	0.090	0.031	0.365	87.4
BOSS LRG BAO+LyaF BAO	0.009	0.0019	0.083	0.030	0.320	**102**
BOSS LRG broad-band+LyaFBAO	0.007	0.0018	0.074	0.019	0.284	188

Note. — All constraints assume Planck and the DETF forecasts for "Stage II" experiments. BAO constraints include only the acoustic scale information and are therefore conservative; the final line shows the BOSS forecast that also incorporates broad-band galaxy power information.

d_A of 1.0% at z = 0.35 & 0.6, 4.5% at z = 2.5, H(z) to 1.8%, 1.7% and 2.6% respectively

Ancillary Program!

- High impact for relatively small fiber allocations
- Lots of community support



Campbell et al.

“Stage VI” experiments

We have a decade of surveys:

- eBOSS (2014)
- DESpec (2018)
- BigBOSS (2018)
- WEAVE (2018)
- SuMIRE (2018)
- Euclid (2019)
- LSST (2020)
- WFIRST (2022)
- SKA (2023)

“Stage VI” experiments

We have a decade of surveys:

- eBOSS (2014) – *4 years to exploit SDSS wide-field!*
- DESpec (2018)
- BigBOSS (2018)
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- SuMIRE (2018)
- Euclid (2019)
- LSST (2020)
- WFIRST (2022)
- SKA (2023)

e-BOSS: Extending BOSS

The novel Sloan legacy cosmological survey

Selected for AS3 end 2011 - survey will start mid 2014

J.-P. Kneib, F. Abdalla, J. Annis, E. Aubourg, D. Bacon, S. Bailey, G. Bernstein, A. Bolton, N. Brandt, J. Brownstein, Y. Cai, F. Castander, J. Cepa, J. Comparat, R. Croft, F. Courbin, J.-G. Cuby, S. Das, L. Da Costa, A. Dey, A. Ealet, S. Escoffier, J. Frieman, S. Ho,, R. Kron, O. Lahav, J.-M. Le Goff, O. Le Fèvre, M. Limousin, C. Magneville, M. Maia, M. Makler, G. Meylan, P. McDonald,, N. Mostek, A. Myers, J. Newman, B. Nichol, N. Padmanabhan, N. Palanque-Delabrouille, J. Peacock, W. Percival, C. Peroux, P. Petitjean, M. Pieri, F. Prada, J. Rich, E. Rollinde, E. Rozo, E. Rykoff, V. Ruhlmann-Kleider, M. Sako, B. Santiago, C. Schimd, D. Schlegel, D. Schneider, U. Seljak, A. Slosar, M. Takada, C. Tao, L. Tasca, R. Tojeiro, L. Verde, M. White, C. Yèche, and I. Zehavi

66 co-Is, from 29 institutes signed the proposal

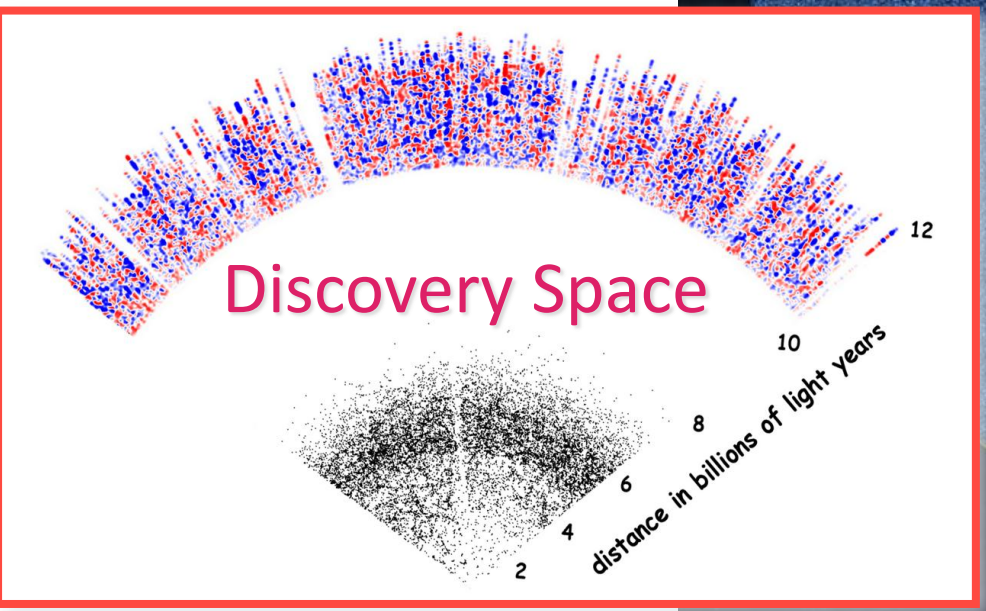
growing interest - you are welcome to join!

Talk to Mike Blanton!

Kneib

eBOSS:

Measuring the Expansion History of the Universe between 7 and 11 billions of Light-Year with Galaxies & Quasars



Cosmic microwave background

Size of our Milky Way

Slice

Position of most distant observed object (Z=10.3)

eBOSS

Here and today

5 billion years ago

10 billion years ago

13 billion years ago

13.7 billion years ago

Most complete mapping of observed universe

Size of the observable universe : 90 billion light years

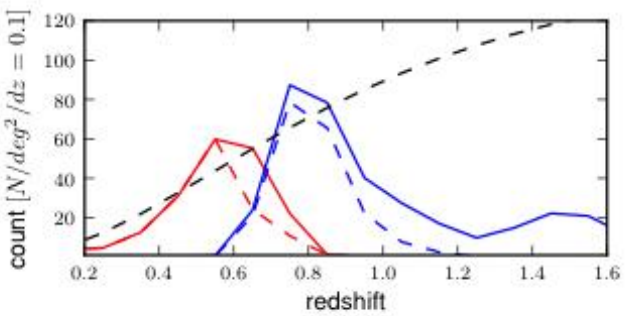
Kneib

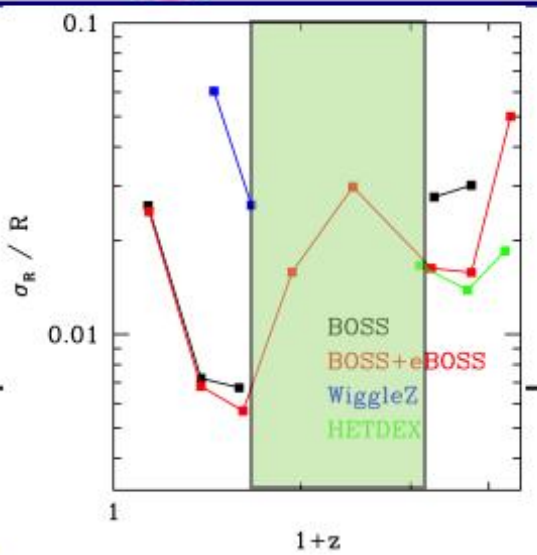
e-BOSS Summary

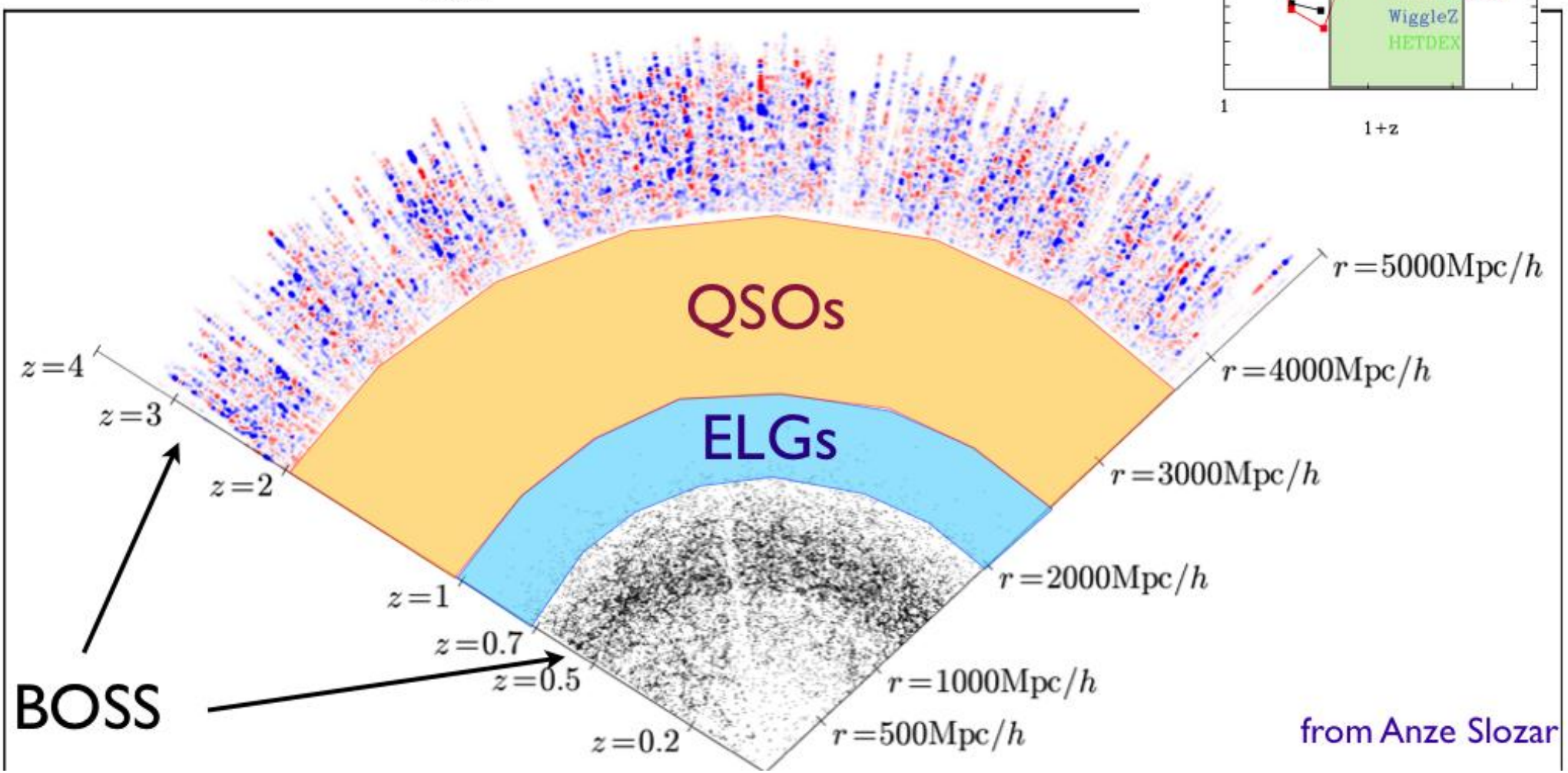
- **a new cosmology project that pushes the reach of the Sloan Telescope to *map the LSS beyond z=0.6 (BAO, RSD)*:**
  - **probe 0.6<z<~1.6 with Emission-Line-Galaxies (ELG)**
  - probe 0.6<z<0.8 with Luminous Red Galaxies (LRG)
  - **probe 1<z<~2.2 with QSOs**
  - increase the sample of z>2.2 QSOs for Ly-forest survey
  - **accomodate TDSS (Variability) and SPIDERS (eROSITA) targets**
- **provide new competitive BAO+RSD+WL Dark Energy constraints in the footprint of new WL/cluster DE survey [e.g. DES, KIDS, Scube]:**
  - double the signal in the Ly-alpha forest compared to BOSS
  - a factor of ~2+ improvement in DETF-FOM for BAO compared to BOSS.
  - **develop synergy with the new WL and cluster DE probes.**
- **provide a *wealth of ancillary sciences*:**
  - Galaxy Evolution and Quasar/IGM sciences
  - Lensing (photo-z calibration and tracing clusters/groups, strong lensing)
  - Multi-wavelength science using synergy with other very wide field survey

Kneib

e-BOSS LSS mapping







e-BOSS numbers

- **Survey Strategy:**
  - ~2,500 sq.deg.
  - survey area *visited 3 times over the project* (finish before BigBOSS starts), ~1h exposures (similar to BOSS)
    - *~400k ELGs*
    - *~200k LRGs (at z>0.6)*
    - *~350k QSOs* (100k at z>2.2)
    - ~100k targets from TDSS & SPIDERS (variability+AGN)
  - *repeat observations on some targets (Ly-alpha QSOs, hi-z LRGs, time-variability spectroscopy), and observation of close objects closer than the fiber collision limit (galaxy pairs, galaxy members in a cluster, galaxy-quasar close pairs ...) offer new science topics!*

Euclid

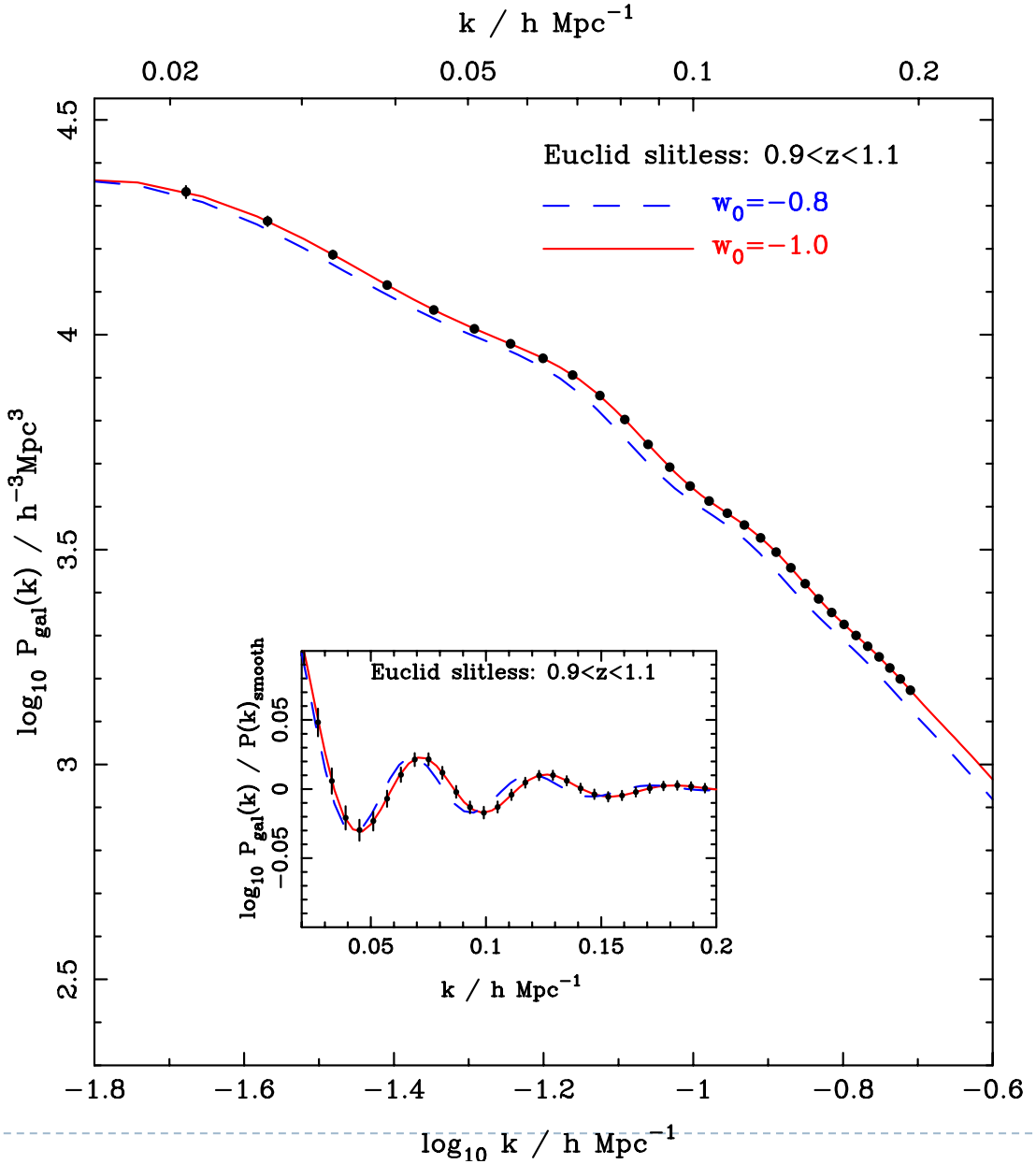
SURVEYS					
	Area (deg2)	Description			
Wide Survey	15,000 (required) 20,000 (goal)	Step and stare with 4 dither pointings per step.			
Deep Survey	40	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey			
PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg^2	0.763×0.722 deg^2			
Capability	Visual Imaging	NIR Imaging Photometry			NIR Spectroscopy
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	3 10^{-16} erg cm-2 s-1 3.5σ unresolved line flux
Detector Technology	36 arrays 4k×4k CCD	16 arrays 2k×2k NIR sensitive HgCdTe detectors			
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec			0.3 arcsec R=250
SPACECRAFT					
Launcher	Soyuz ST-2.1 B from Kourou				
Orbit	Large Sun-Earth Lagrange point 2 (SEL2), free insertion orbit				
Pointing	25 mas relative pointing error over one dither duration 30 arcsec absolute pointing error				
Observation mode	Step and stare, 4 dither frames per field, VIS and NISP common FoV = 0.54 deg^2				
Lifetime	7 years				
Operations	4 hours per day contact, more than one ground station to cope with seasonal visibility				

Science summary

- Two primary probes: new physics and systematics
- Weak lensing and galaxy clustering

	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν/eV	f_{NL}	w_p	w_a	FoM
Euclid Primary	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>50**	**>300**

Euclid clustering measurements



20% of the Euclid data, assuming the slitless baseline at z~1

Percival

Summary

- BOSS is half way to Stage III
  - LCDM + GR survives at 10% level
- Push now towards Stage VI
  - DES + eBOSS could deliver something quite unique by 2018
- Euclid should be adopted in June!