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

- At least one paper a day!

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

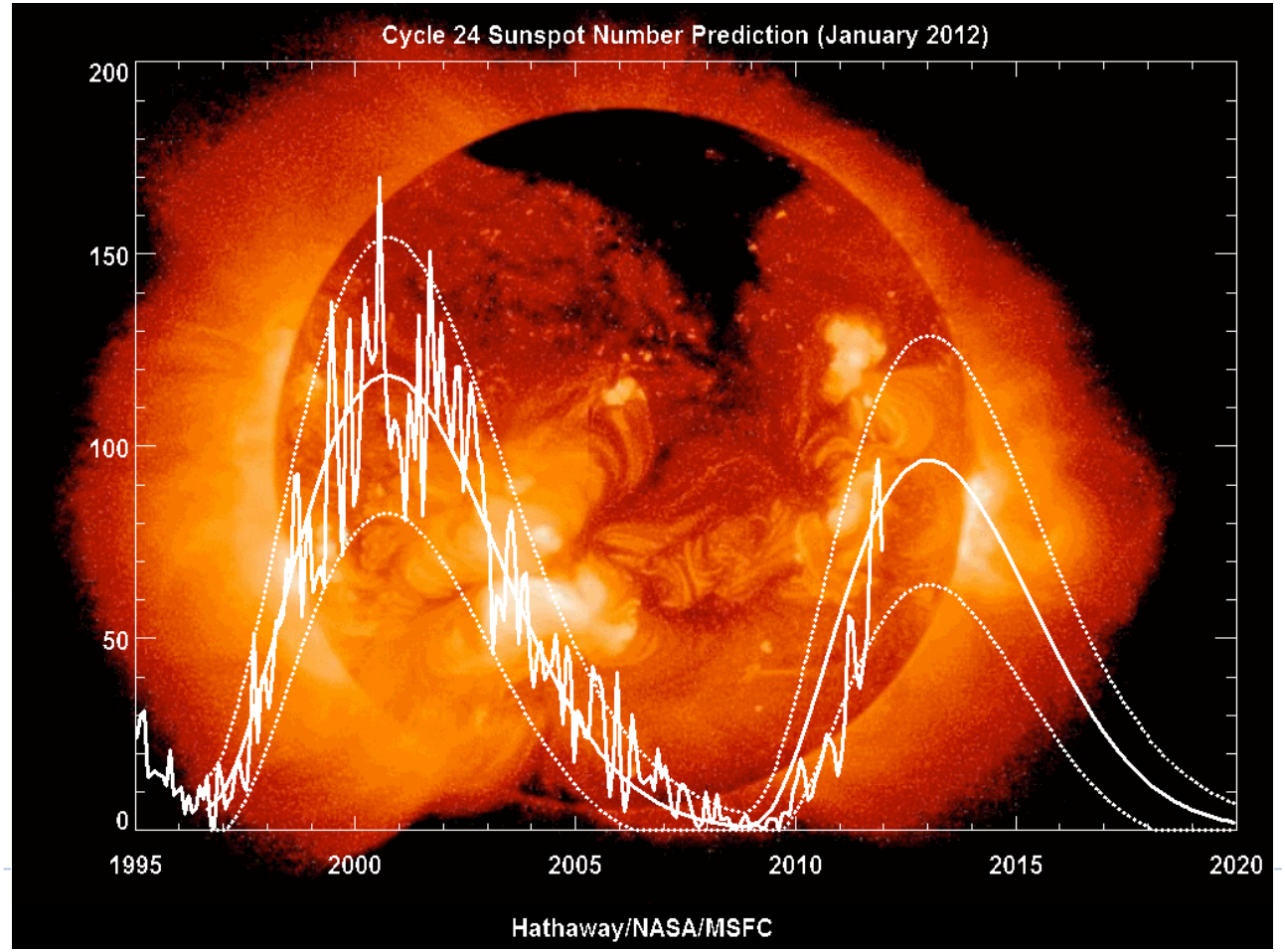
(Eisenstein et al. 2011)

- 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

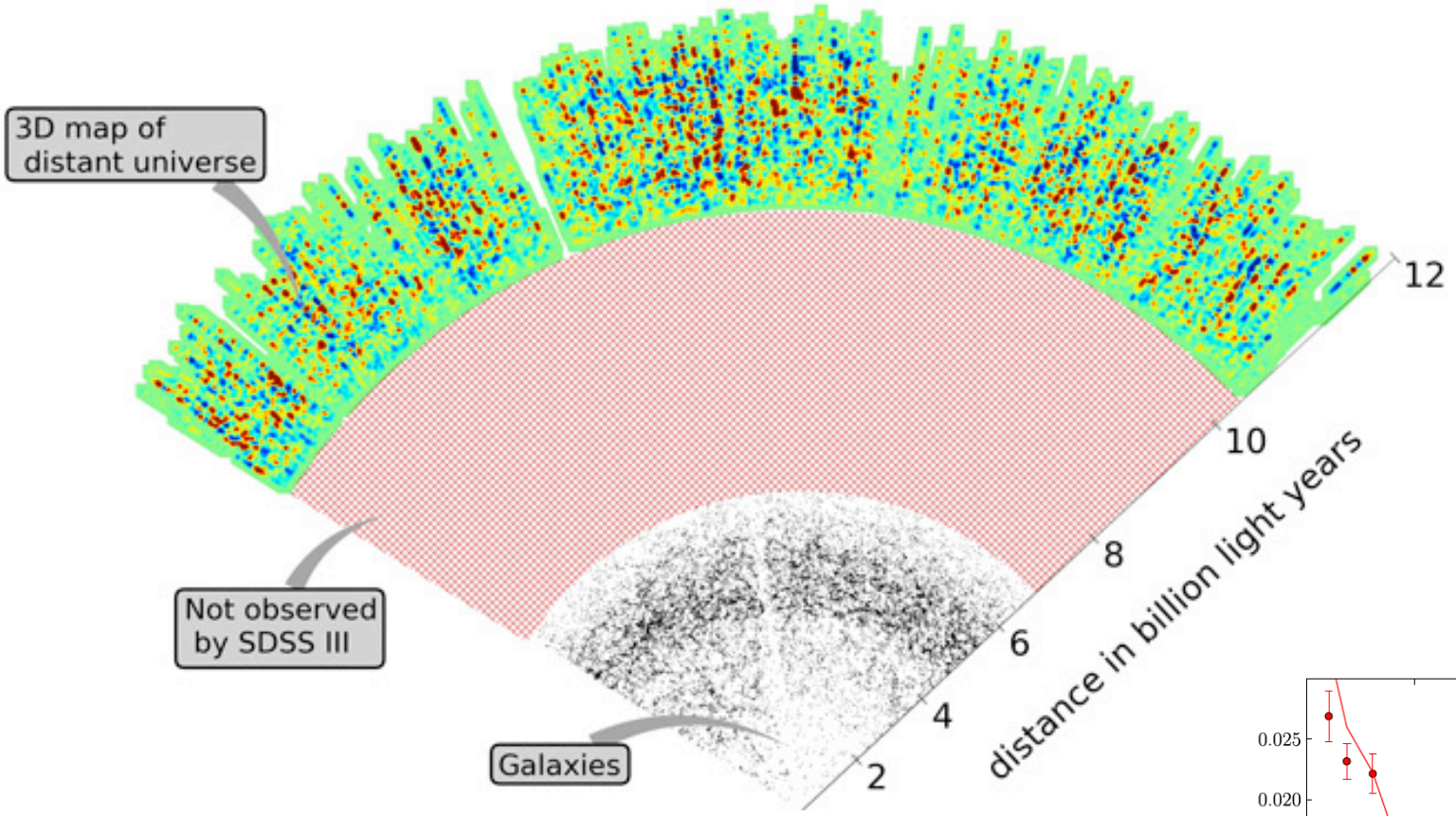
BOSS is over half done!

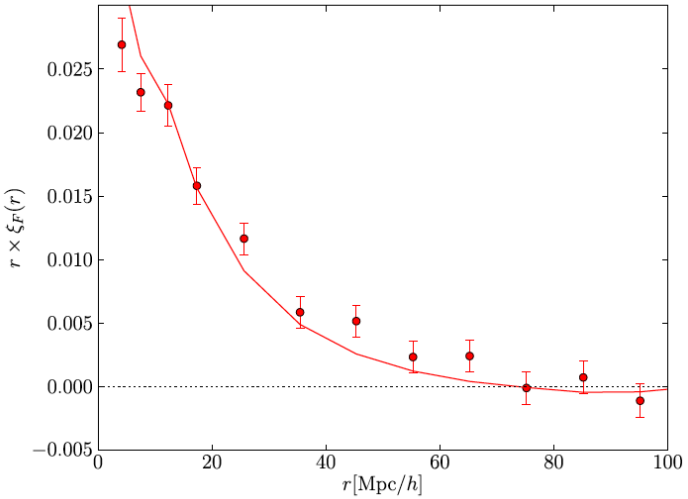
Over 1500 plates done (july 2012), or 1.515M spectra!
Only 2% of time lost to problems in 2011/12 season
Lower sky brightness



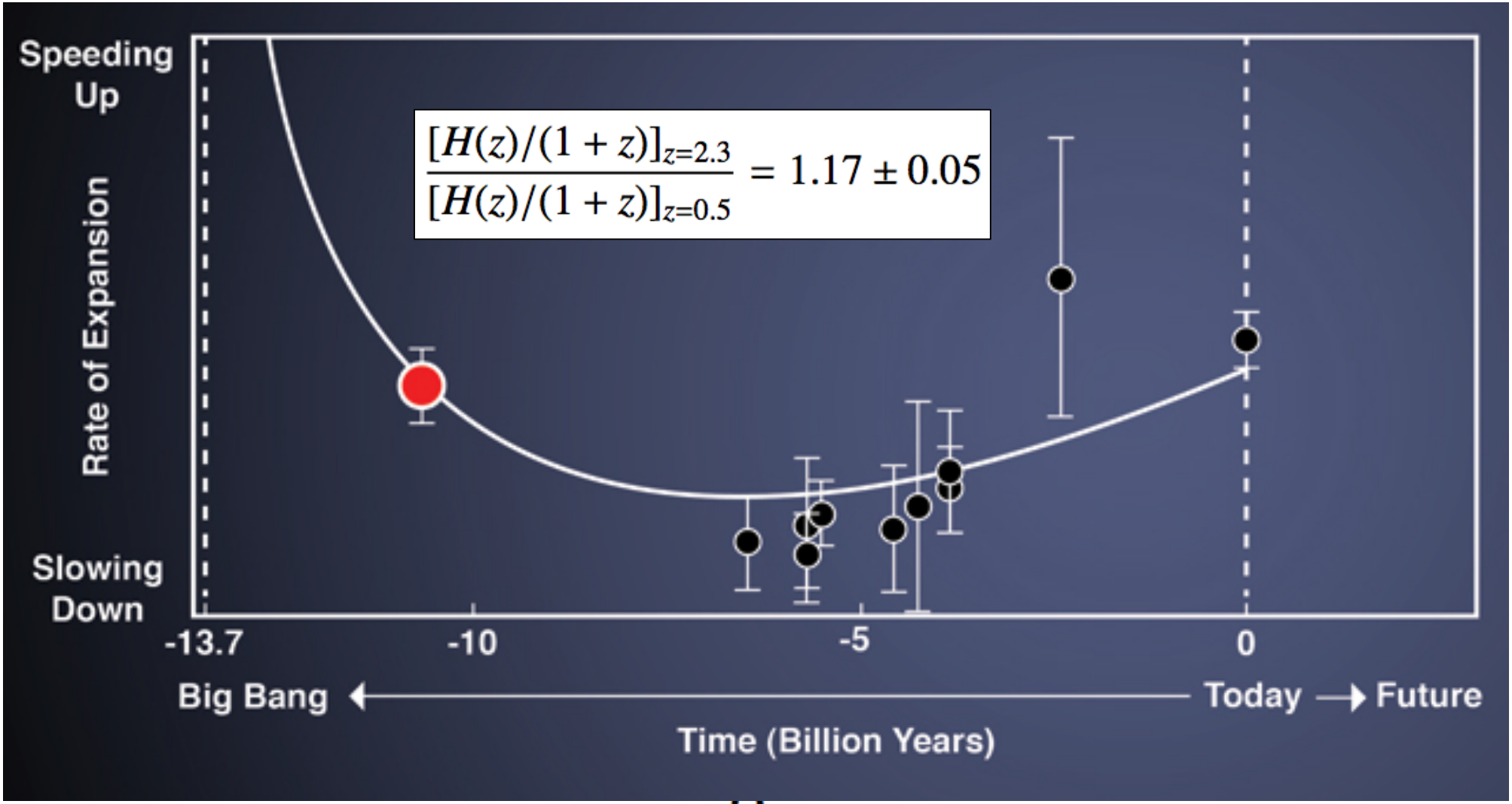
Schlegel

LSS at high z (Slozar et al. 2011)



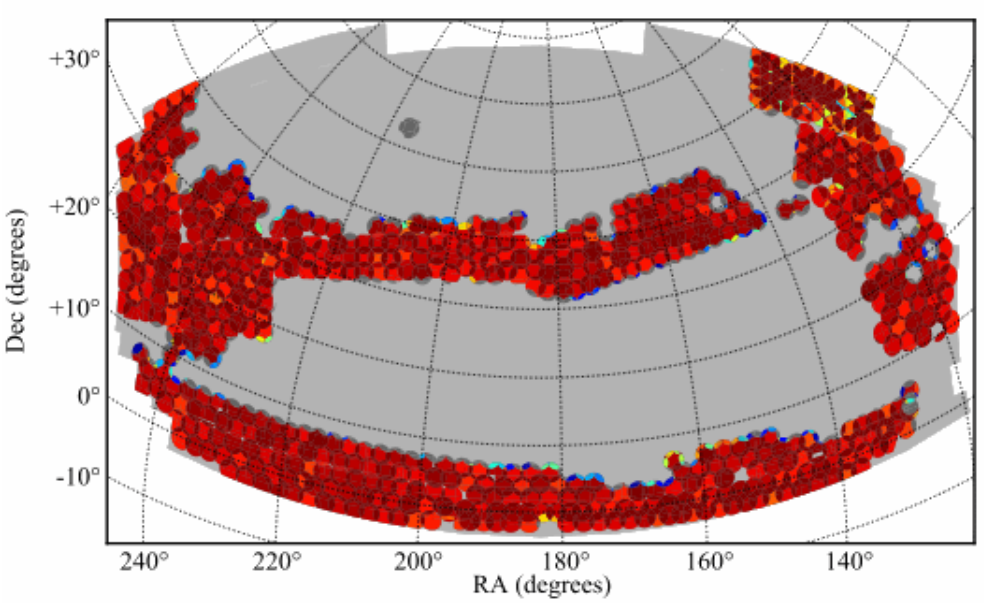


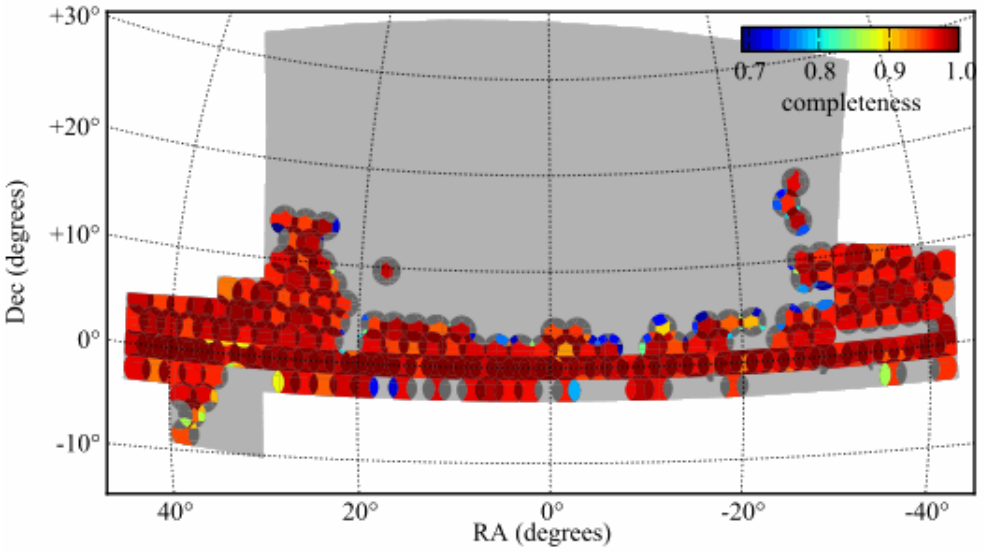
BAO at high z (Busca et al. 2012)

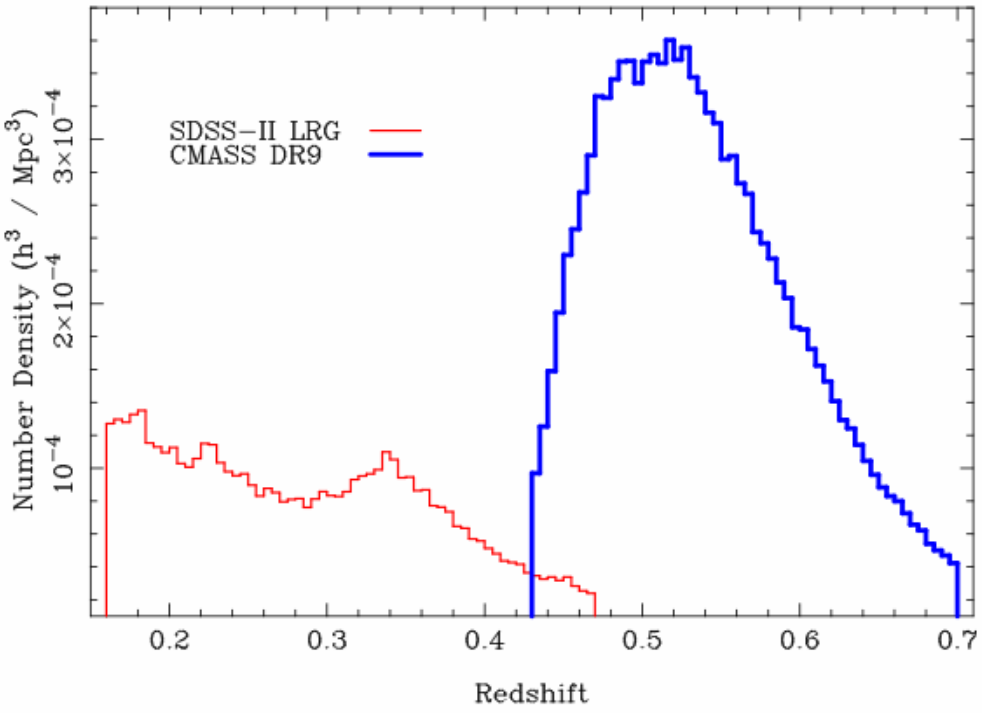


Ω_m

BOSS Galaxies (Anderson et al. 2012)

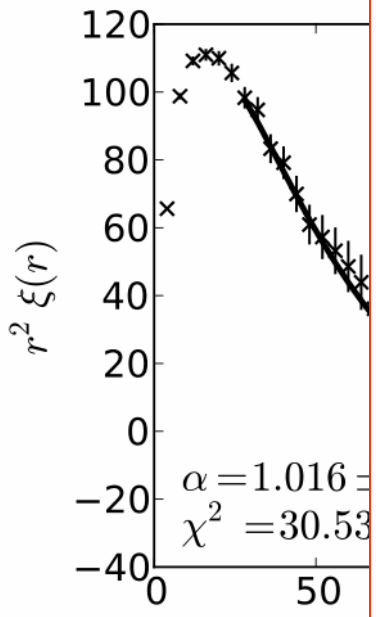


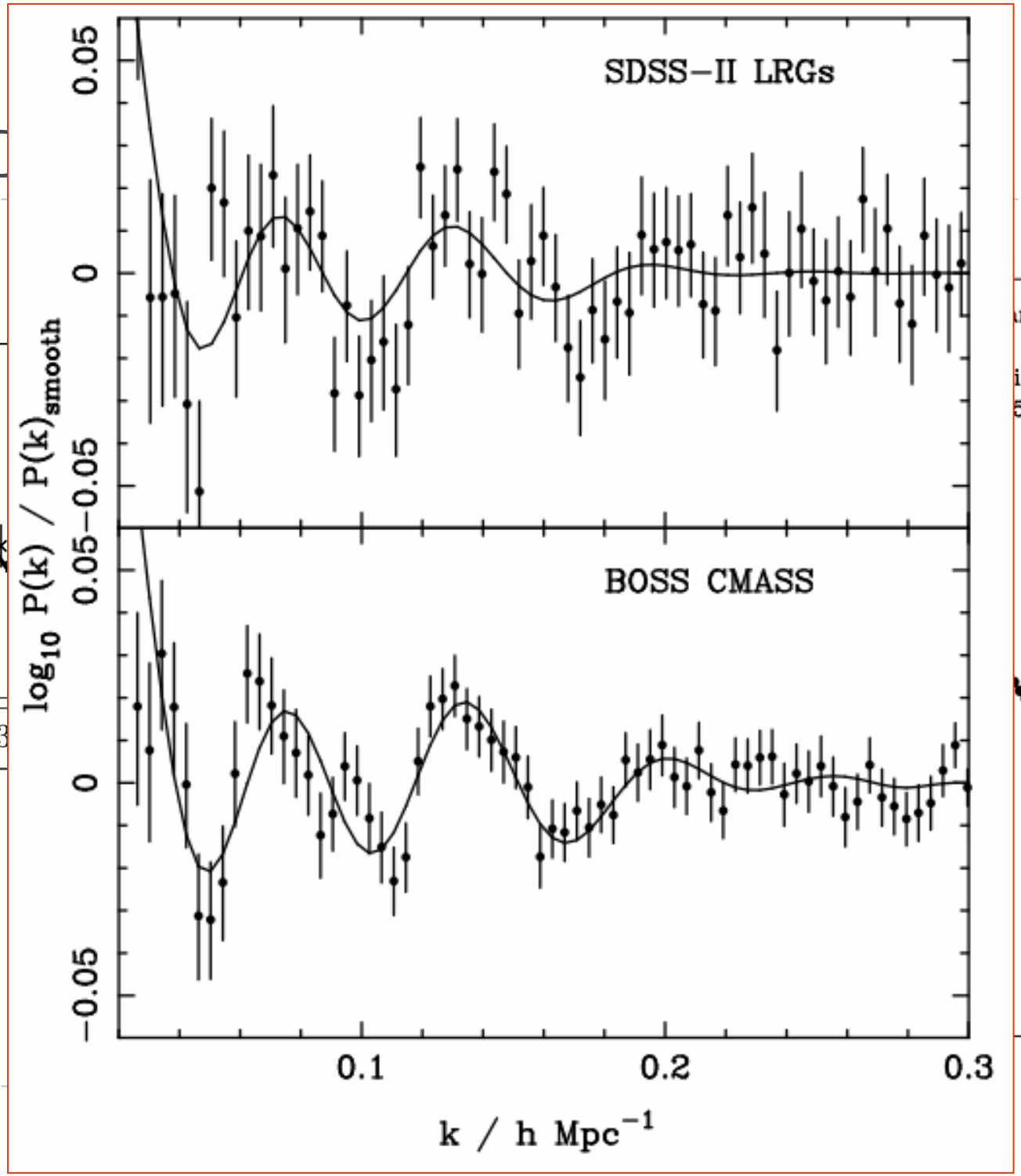


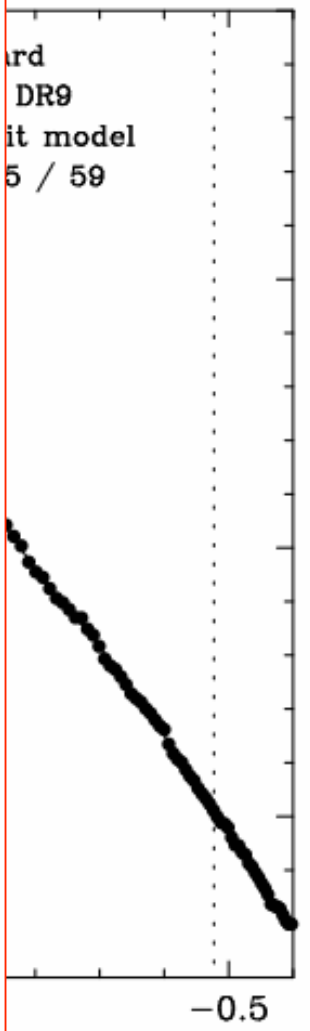


3275 deg²
264k redshifts
2.2Gpc³

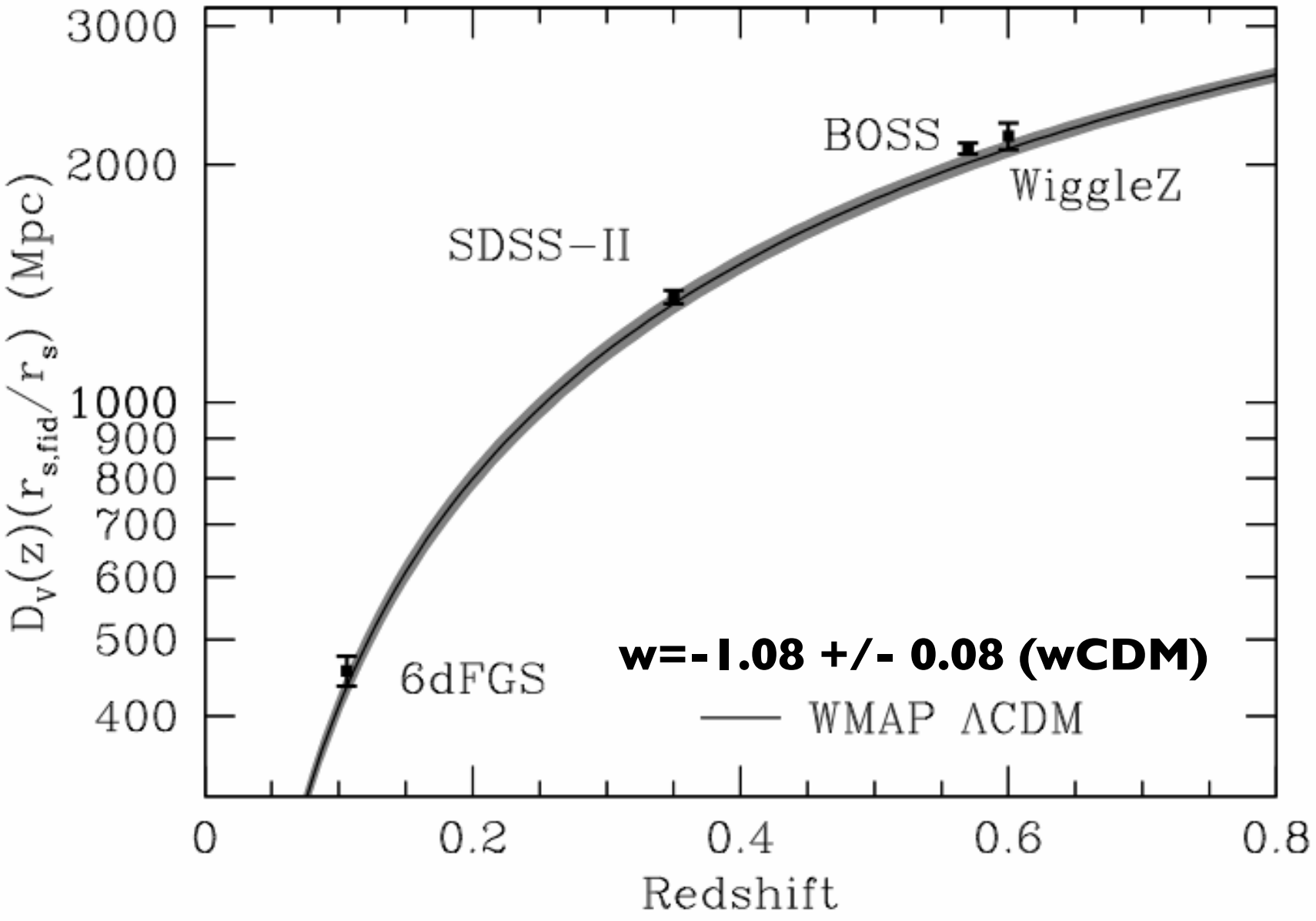
6.7σ D


120
100
80
60
40
20
0
−20
−40
0
50
$r^2\,\xi(r)$
$\alpha = 1.016 \pm$
$\chi^2 = 30.53$

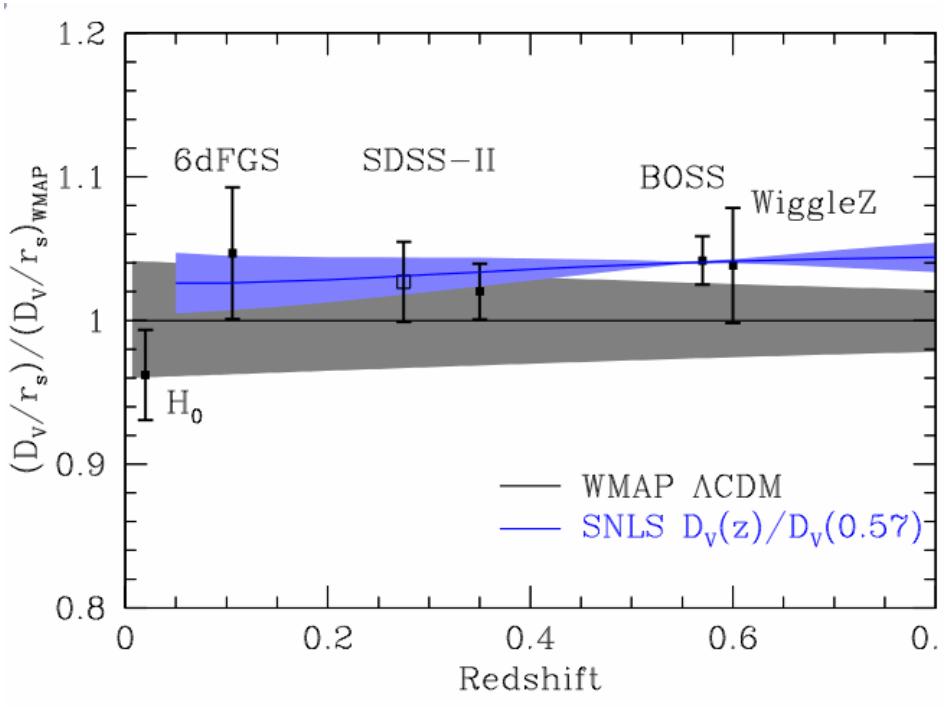

SDSS−II LRGs
BOSS CMASS
$\log_{10} P(k) / P(k)_{smooth}$
0.05
0
−0.05
0.05
0
−0.05
0.1
0.2
0.3
k / h Mpc^{-1}


rd
DR9
it model
5 / 59
−0.5

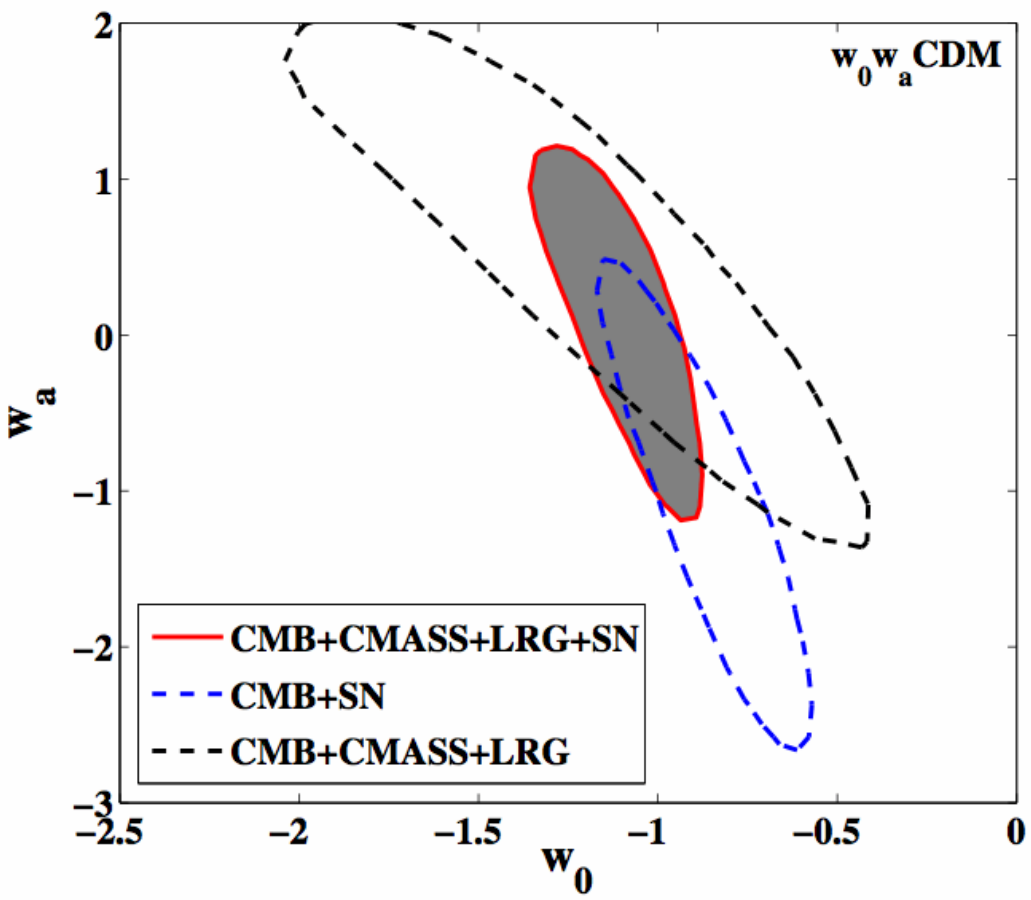
BAO Hubble Diagram



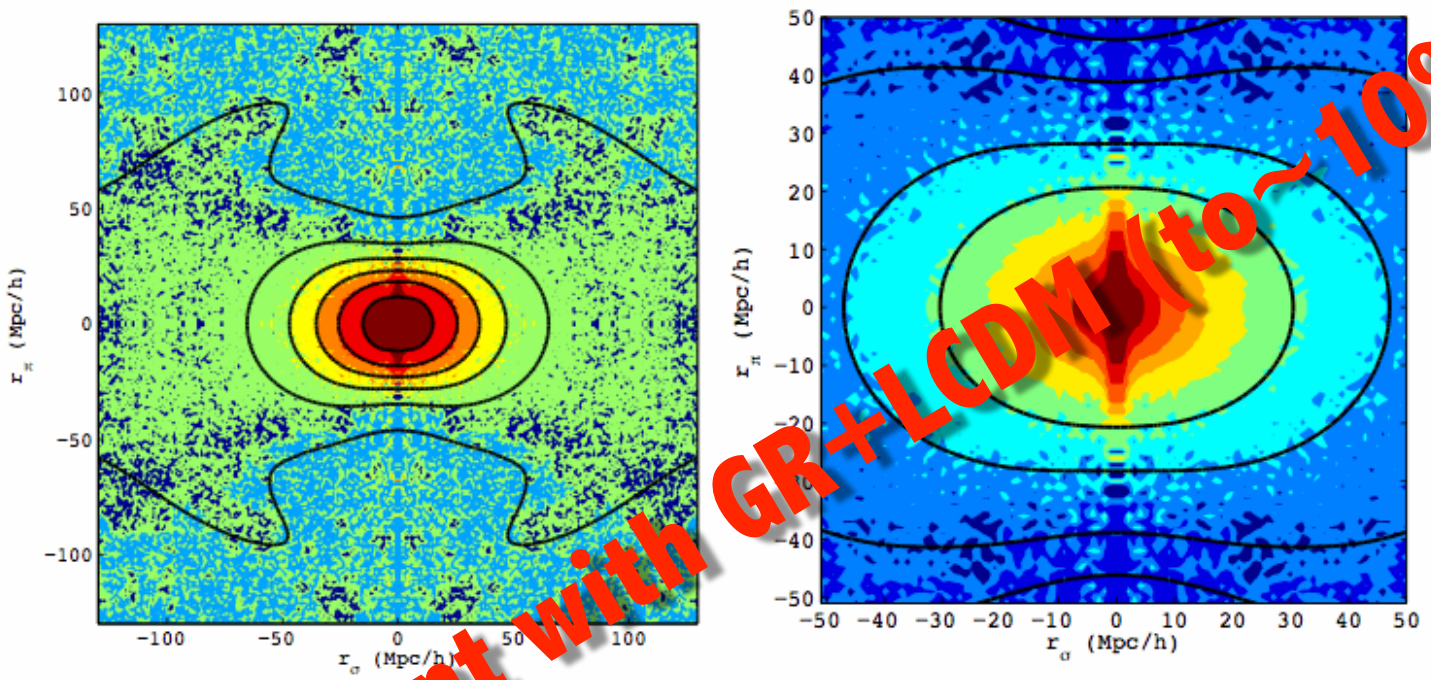
Still things to learn



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	$1.228^{+0.033}_{-0.032}$	$0.415^{+0.034}_{-0.033}$	-	-	-	-
Free Geometry	$1.246^{+0.043}_{-0.046}$	-	2076^{+42}_{-44}	$0.683^{+0.026}_{-0.025}$	2204 ± 44	$92.9^{+3.6}_{-3.3}$
Both free	$1.238^{+0.047}_{-0.050}$	$0.427^{+0.069}_{-0.063}$	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, $z_{\rm eff} = 0.57$.

BC

et al. 2011

$-w_a(1-a)$.

Ex	FoM
Pla	53.4
BC	87.4
BC	**102**
BC	188

N

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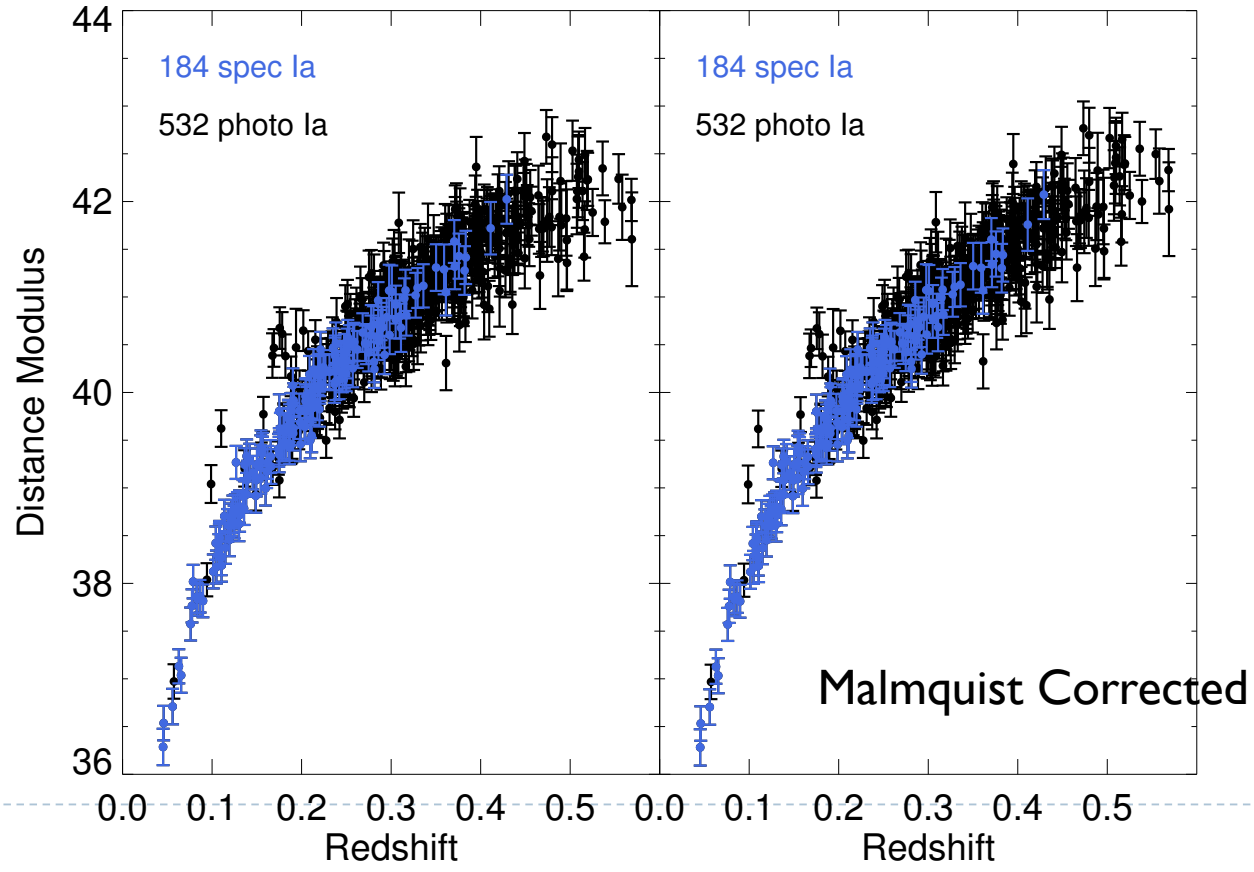
Ancillary Program (Dawson et al. 2012)

- High impact for relatively small fiber allocations
  - As powerful as SNLS without all the SN follow-up
- 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)
- WEAVE (2018)
- 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

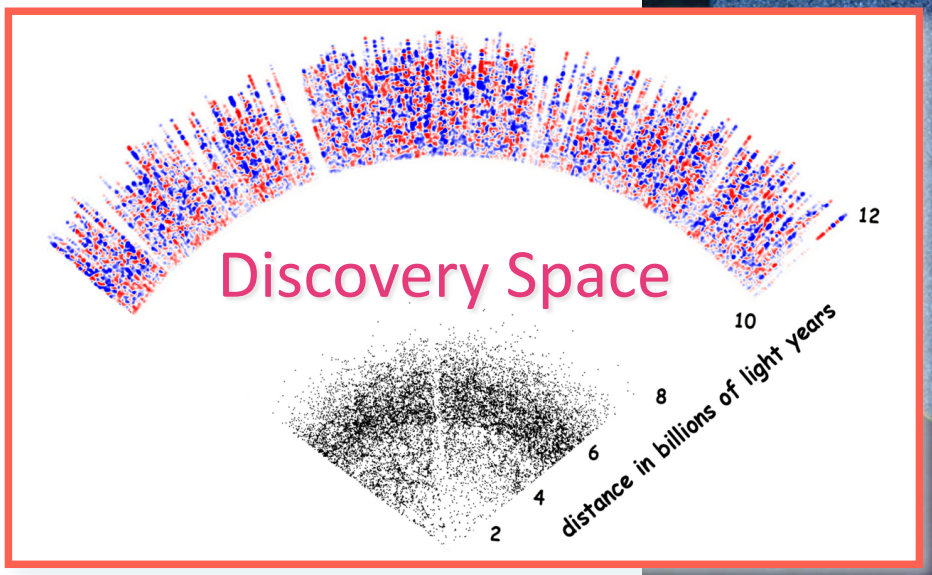
growing interest - you are welcome to join!

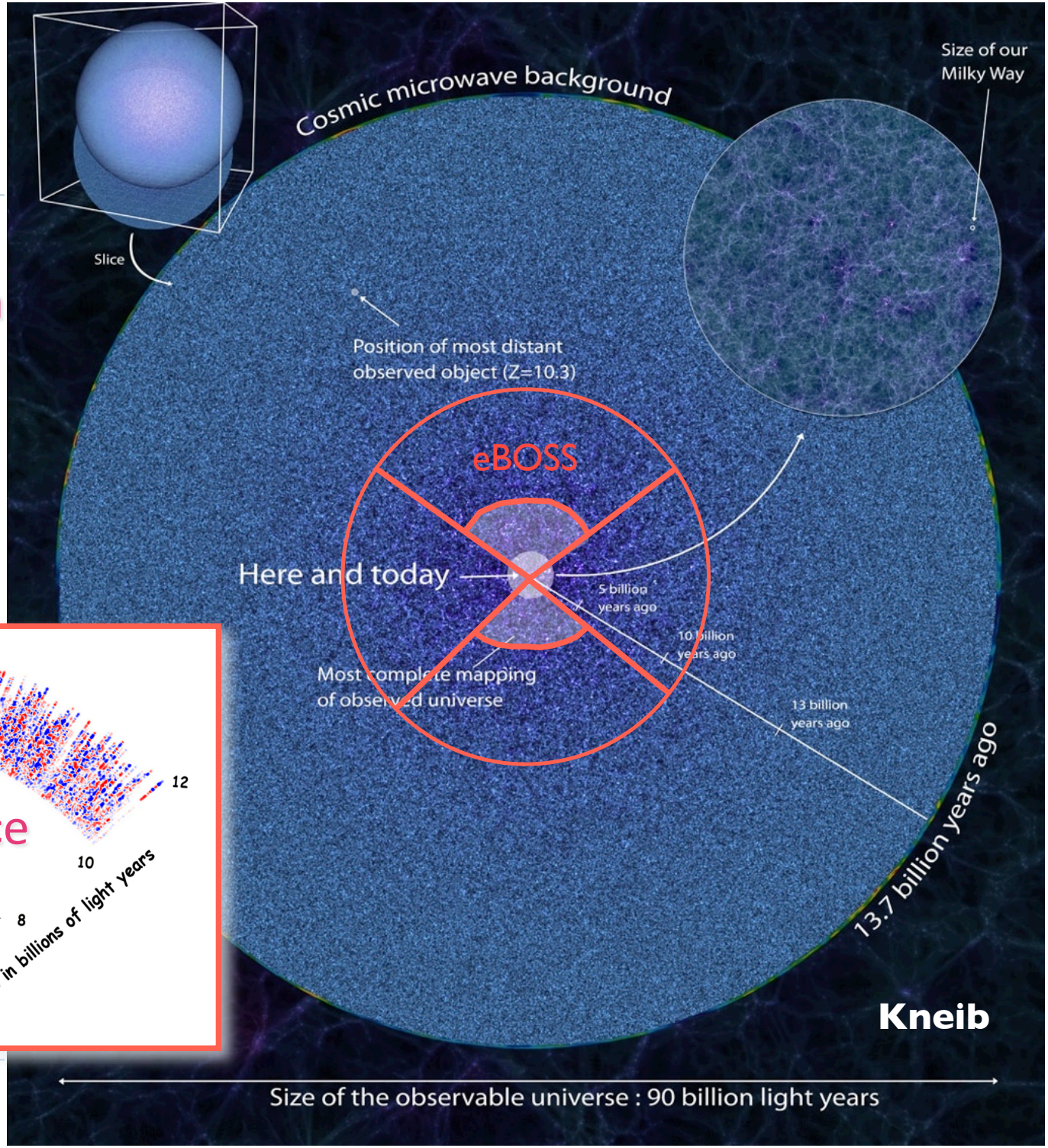
Talk to Mike Blanton!

Kneib

eBOSS:

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



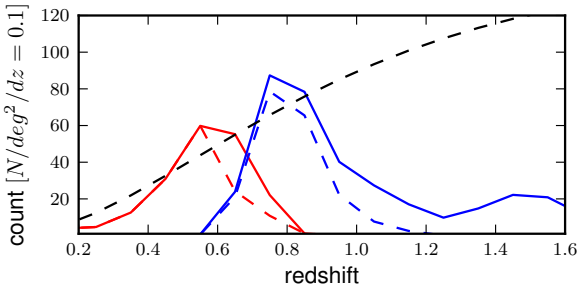


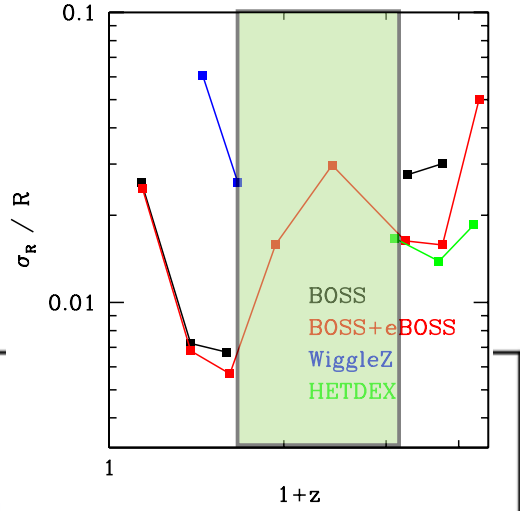
e-BOSS Summary

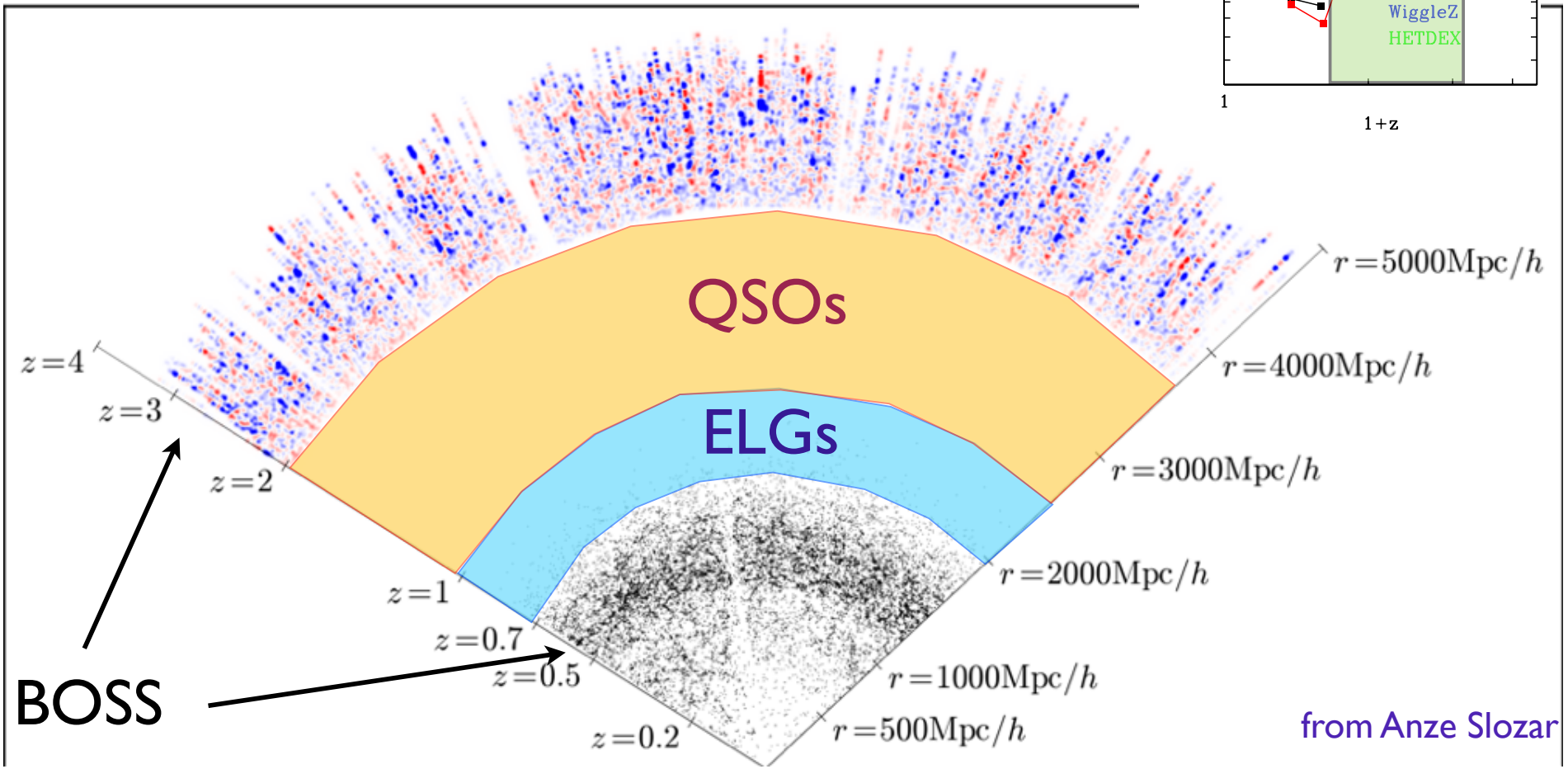
- **a new cosmology project that pushes the reach of the Sloan Telescope to *map the LSS beyond z=0.6 (BAO, RSD)*:**
  - **probe 0.6<z<~1.6 with Emission-Line-Galaxies (ELG)**
  - probe 0.6<z<0.8 with Luminous Red Galaxies (LRG)
  - **probe 1<z<~2.2 with QSOs**
  - increase the sample of z>2.2 QSOs for 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





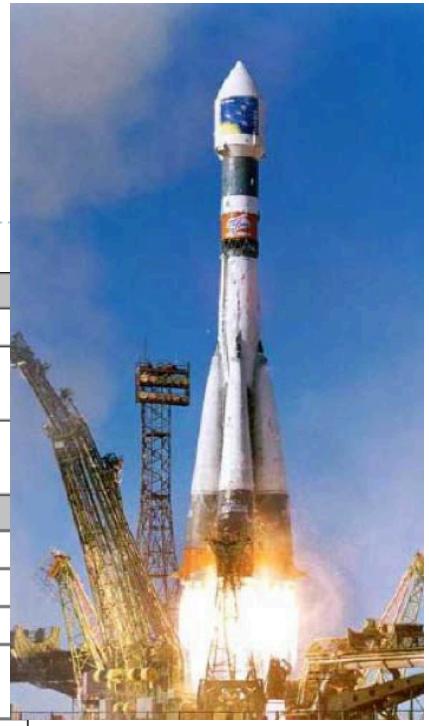


from Anze Slozar

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



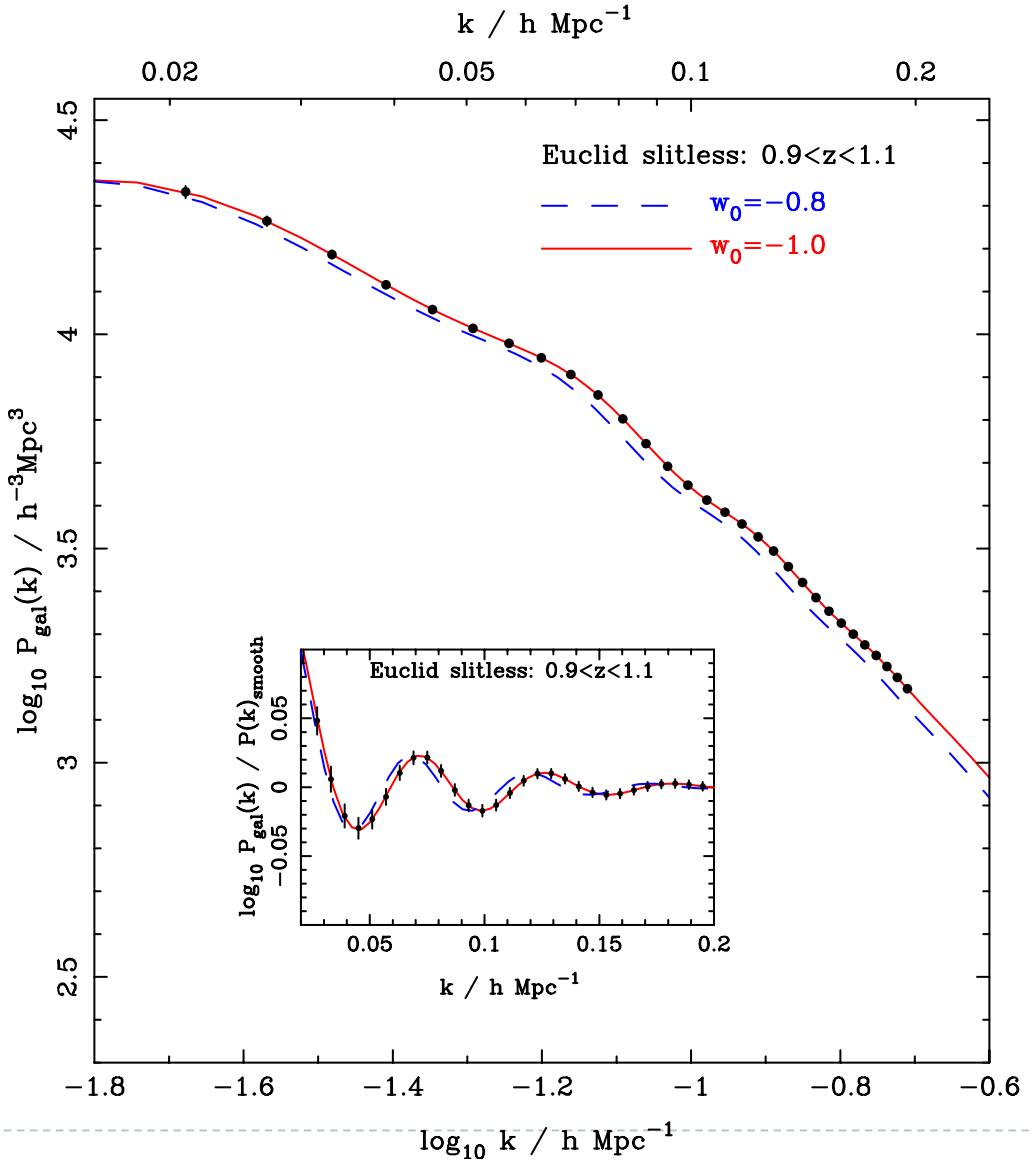
SURVEYS					
	Area (deg2)	Description			
Wide Survey	15,000 (required) 20,000 (goal)	Step and stare with 4 dither pointings per step.			
Deep Survey	40	In at least 2 patches of > 10 deg^2 2 magnitudes deeper than wide survey			
PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	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

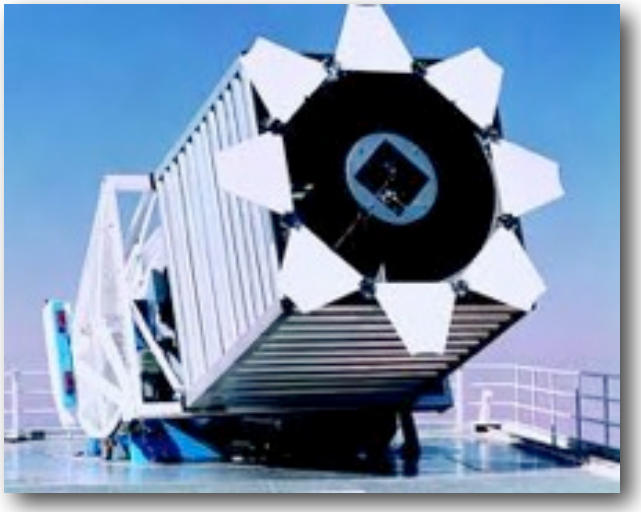


20% of the Euclid data, assuming the slitless baseline at z~1

Percival

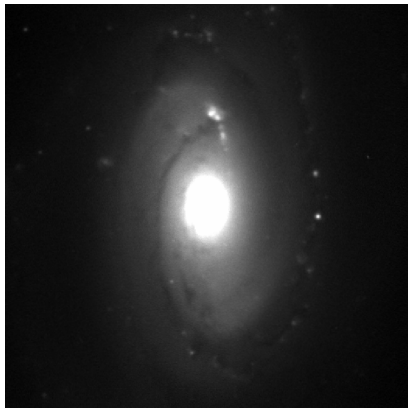
What is MaNGA?

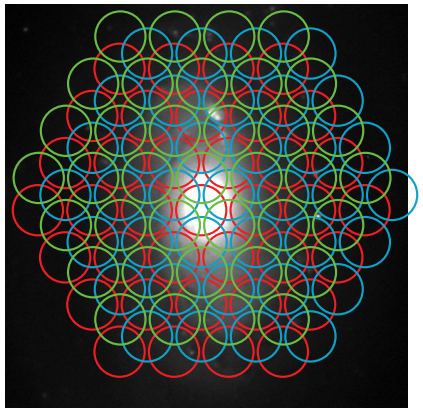
- One of three approved "After-SDSS-III" (AS3) surveys to begin on the Sloan 2.5m in September 2014
- AS3 = MaNGA, eBOSS, APOGEE-2
- MaNGA exploits the existing BOSS instrument (high throughput, pipeline)

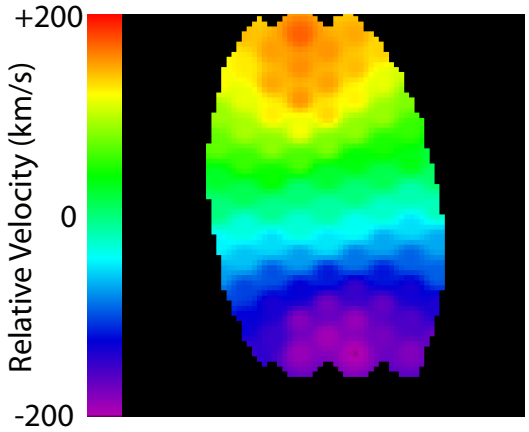


- MaNGA will bundle BOSS fibers to create 15-20 IFUs of various sizes
- IFU survey of ~10k nearby galaxies

From Kevin Bundy







MaNGA Key Questions:

LIFE

1. How does gas accretion drive the growth of galaxy disks?
2. What are the relative roles of stellar accretion, major mergers, and instabilities in forming galactic bulges?

DEATH

3. What quenches star formation?
4. How do external forces affect star formation in groups and clusters?

BIRTH

5. How was angular momentum distributed among baryonic and non-baryonic components as the galaxy formed?
6. How do baryons and stars trace and influence the shape of dark matter halos?
7. Does galaxy growth at low and high redshifts proceed in the same way?

Summary

- BOSS is over half way to Stage III
  - LyAF BAO is detected
  - LCDM + GR survives at 10% level
  - Suite of ancillary programmes (Dawson et al.)
- Push now towards Stage VI
  - eBOSS push to high redshift (greater volume) and better LyAF measurements – fill the gap
  - Imaging + eBOSS could deliver something quite unique by 2018 – novel tests of GR

The Dark Energy Survey

- Survey project using 4 complementary techniques:
  - I. Cluster Counts
  - II. Weak Lensing
  - III. Large-scale Structure
  - IV. Supernovae
- Multiband surveys:
  - 5000 deg^2 *grizY*
  - 1-2% photometry
  - 30 deg^2 repeat (SNe)
- Build new 3 deg^2 FOV camera and Data management system
  - Survey 2012-2017 (525 nights)

Blanco 4-meter at CTIO

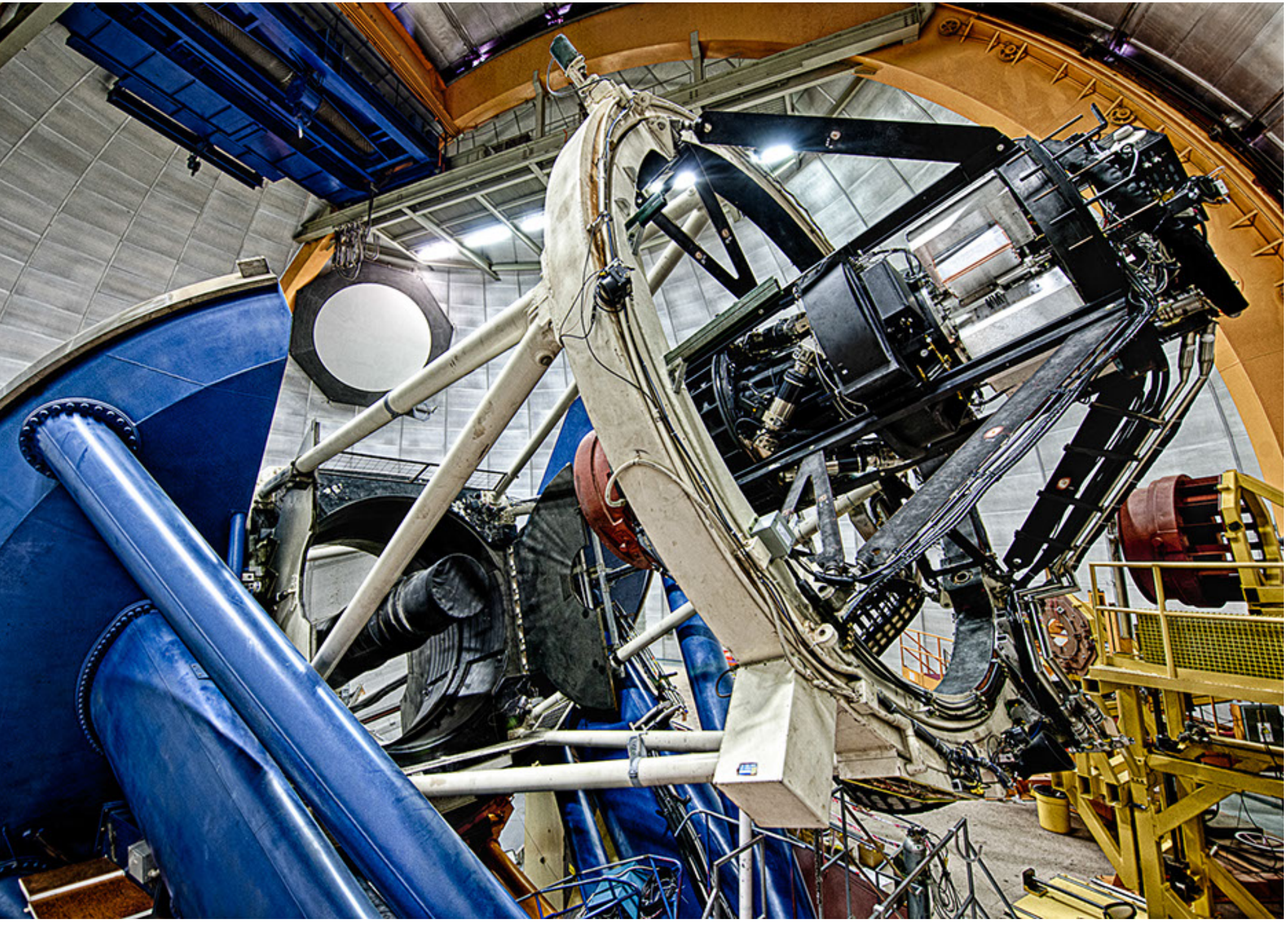
The DES Collaboration

Fermilab
University of Illinois at Urbana-Champaign/NCSA
University of Chicago
Lawrence Berkeley National Lab
NOAO/CTIO
DES Spain Consortium
DES United Kingdom Consortium
University of Michigan
Ohio State University
University of Pennsylvania
DES Brazil Consortium
Argonne National Laboratory
SLAC-Stanford-Santa Cruz Consortium
Universitats-Sternwarte Munchen
Texas A&M University
plus Associate members at: Brookhaven National Lab,
U. North Dakota, Paris, Taiwan

Over 120 members plus students & postdocs

Funding: DOE, NSF; UK: STFC, SRIF; Spain Ministry of Science, Brazil: FINEP, Ministry of Science, FAPERJ; Germany: Excellence Cluster; collaborating institutions

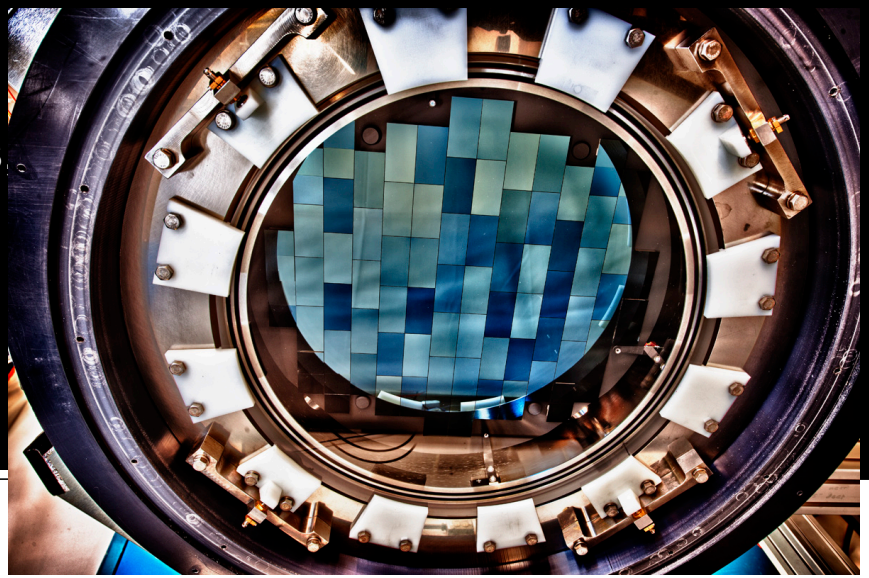
DES-Brazil
Dark Energy Survey

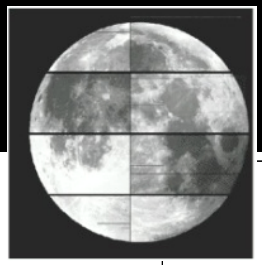


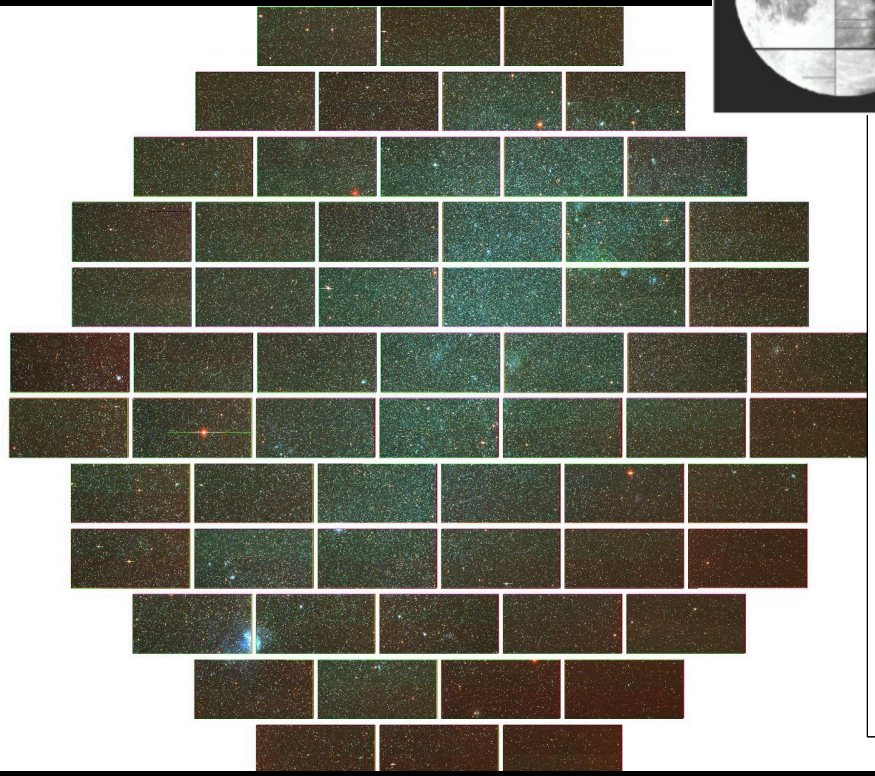

Sept 12th 2012 first light
November 9th Dedication
December 1st survey ops?

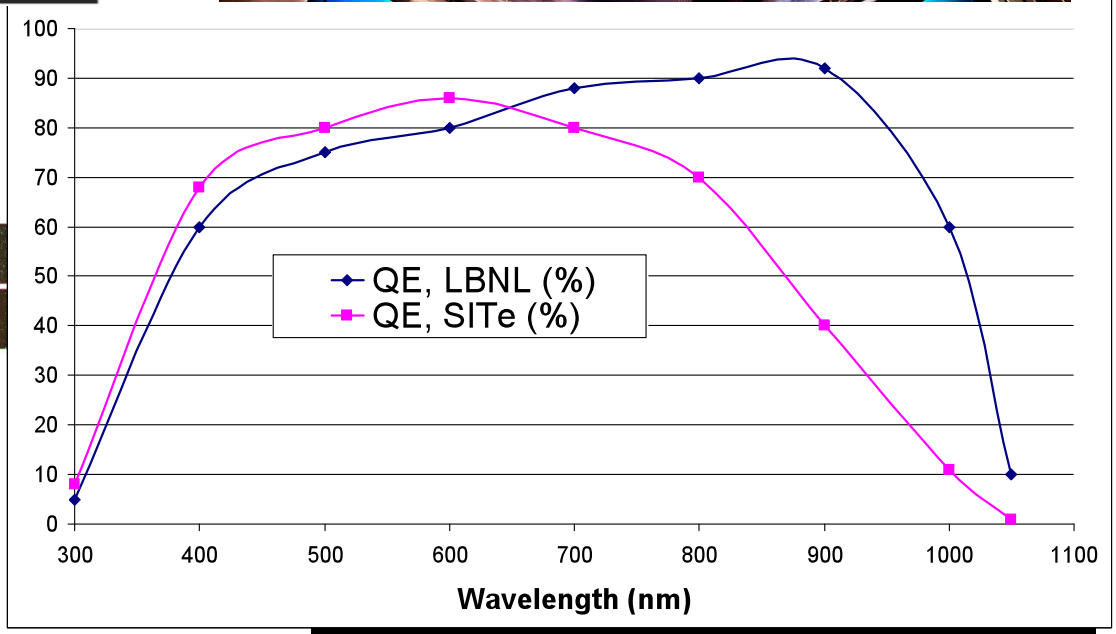
DECam CCDs

- 62 2kx4k fully depleted CCDs: 520 Megapixels
  250 micron thick, 15 micron (0.27”) pixel size
- 12 2kx2k guide and focus chips
- Excellent red sensitivity

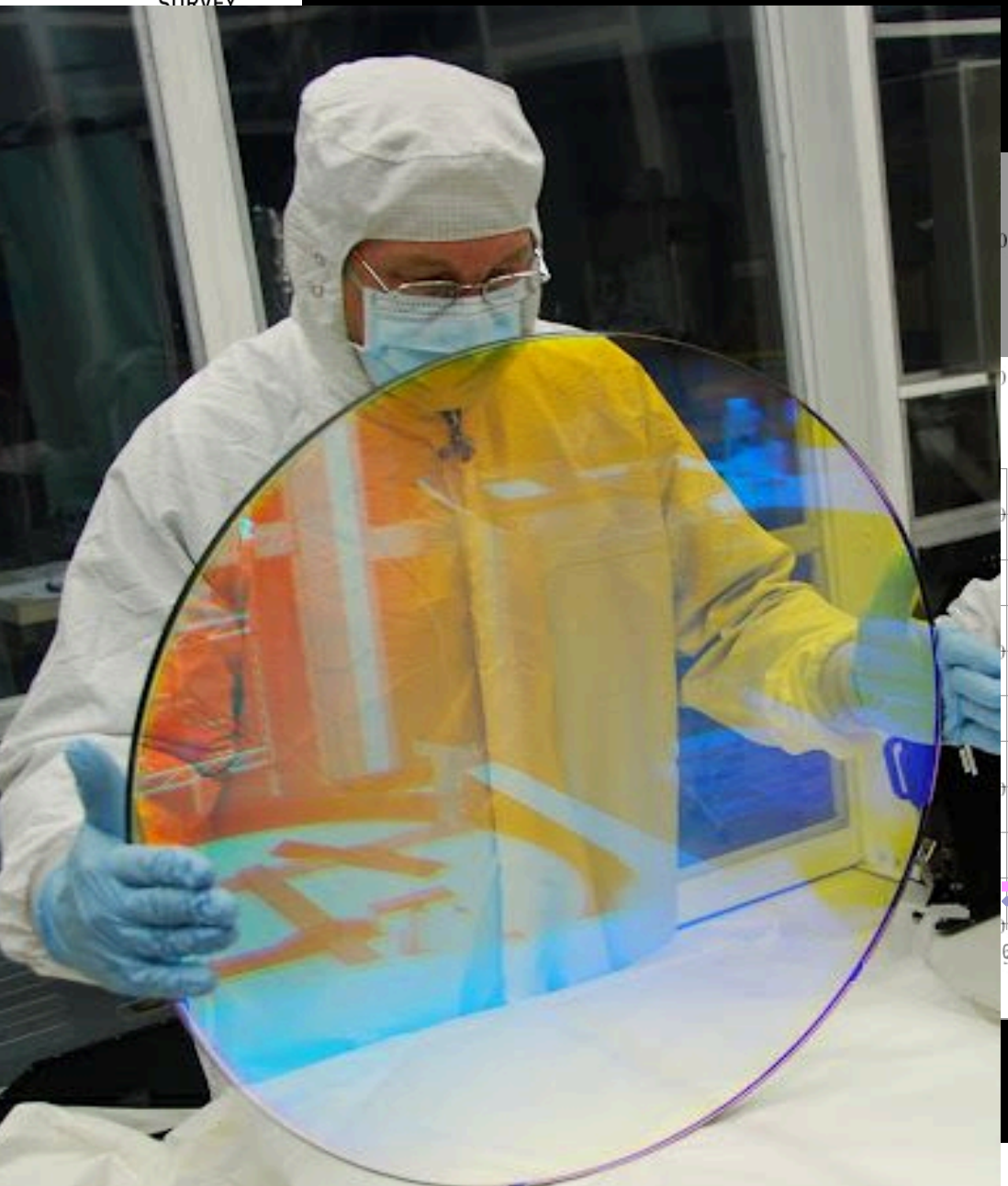


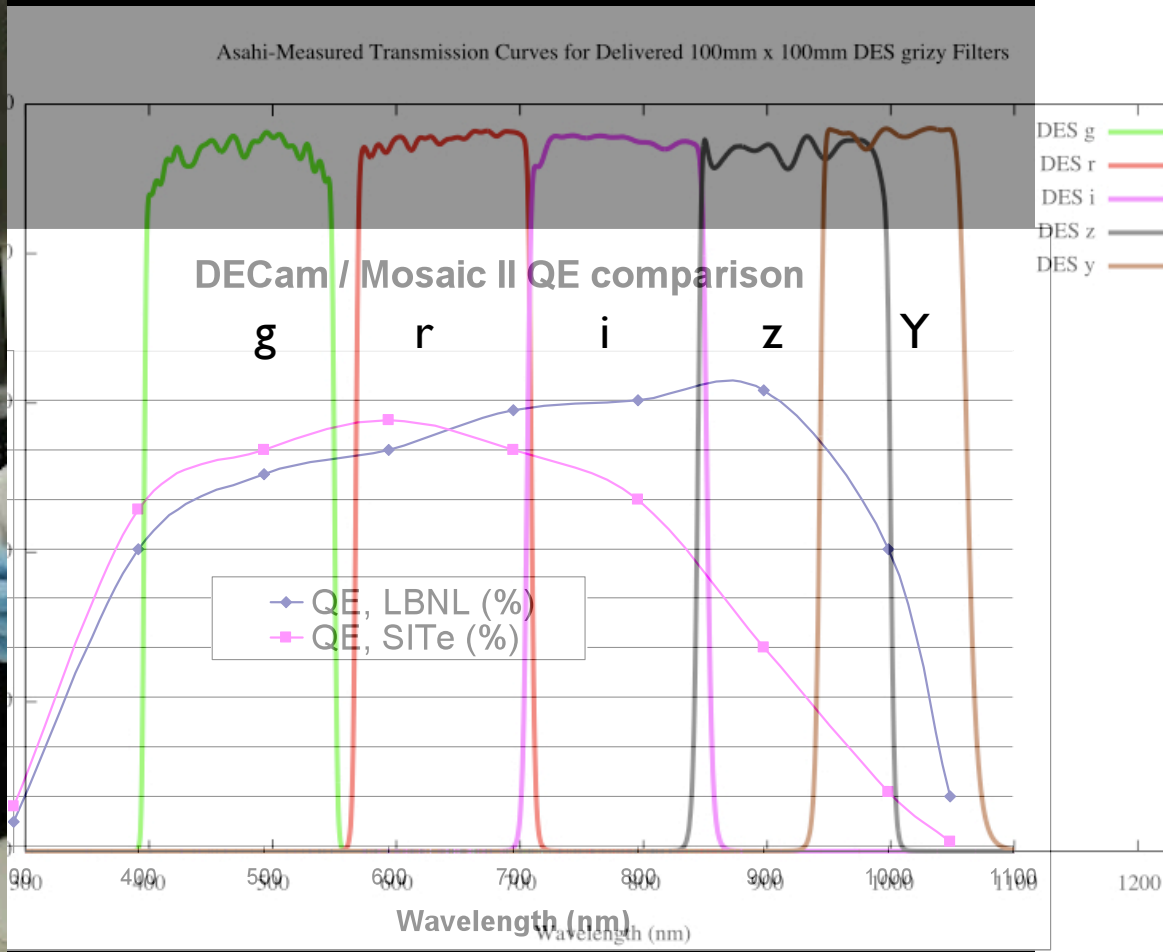






DECam CCDs




Asahi-Measured Transmission Curves for Delivered 100mm x 100mm DES grizy Filters
DES g
DES r
DES i
DES z
DES y
DECam / Mosaic II QE comparison
g
r
i
z
Y
QE, LBNL (%)
QE, SITe (%)
Wavelength (nm)

DESpec

• 4000 fibre spectrograph taking 10 million galaxy spectra on the DES footprint over ~350 nights, starting 2017-18.

• Blanco 4m telescope, CTIO, 3.8deg^2 FoV great seeing 0.65", many usable nights, 80% → fast & cheap survey

• DES provides target list, infrastructure & much more. Build on the DES legacy, Stage III -> Stage IV

• Spectral range 600-1000nm, R=3300 (red end)

• Hemisphere synergy with LSST, extend to ~15,000 deg2

DARK ENERGY SURVEY

DESpec White Paper

Astrophysics > Cosmology and Extragalactic Astrophysics

The Dark Energy Spectrometer (DESpec): A Multi-Fiber Spectroscopic Upgrade of the Dark Energy Camera and Survey for the Blanco Telescope

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(Submitted on 11 Sep 2012)

We describe an initiative to build and use the Dark Energy Spectrometer (DESpec), a wide-field spectroscopic survey instrument for the Blanco 4 meter telescope at Cerro Tololo InterAmerican Observatory (CTIO) in Chile. A new system with about 4000 robotically positioned optical fibers will be interchangeable with the CCD imager of the existing Dark Energy Camera (DECam), accessing a field of view of 3.8 square degrees in a single exposure. The proposed instrument will be operated by CTIO and available for use by the astronomy community. Our collaboration proposes to use DESpec to conduct a wide, deep spectroscopic survey to study Dark Energy. In a survey of about 350 nights, the DESpec collaboration proposes to obtain spectroscopic redshifts for about 8 million galaxies over 5000 square degrees selected from the Dark Energy Survey (DES). This Dark Energy Spectroscopic Survey will advance our knowledge of cosmic expansion and structure growth significantly beyond that obtainable with imaging-only surveys. Since it adds a spectroscopic third dimension to the same sky as DES, DESpec will enable increasingly precise techniques to discriminate among alternative explanations of cosmic acceleration, such as Dark Energy and Modified Gravity.

Comments: 57 pages, 28 figures
Subjects: **Cosmology and Extragalactic Astrophysics (astro-ph.CO)**; Instrumentation and Methods for Astrophysics (astro-ph.IM)
Report number: FERMILAB-TM-2547-AE

DARK ENERGY SURVEY