

Title: Optical Surveys of Large-Scale Structure

Date: Apr 28, 2010 10:15 AM

URL: <http://pirsa.org/10040091>

Abstract: TBA

Optical Surveys of Large-Scale Structure

Jeffrey Newman
University of Pittsburgh



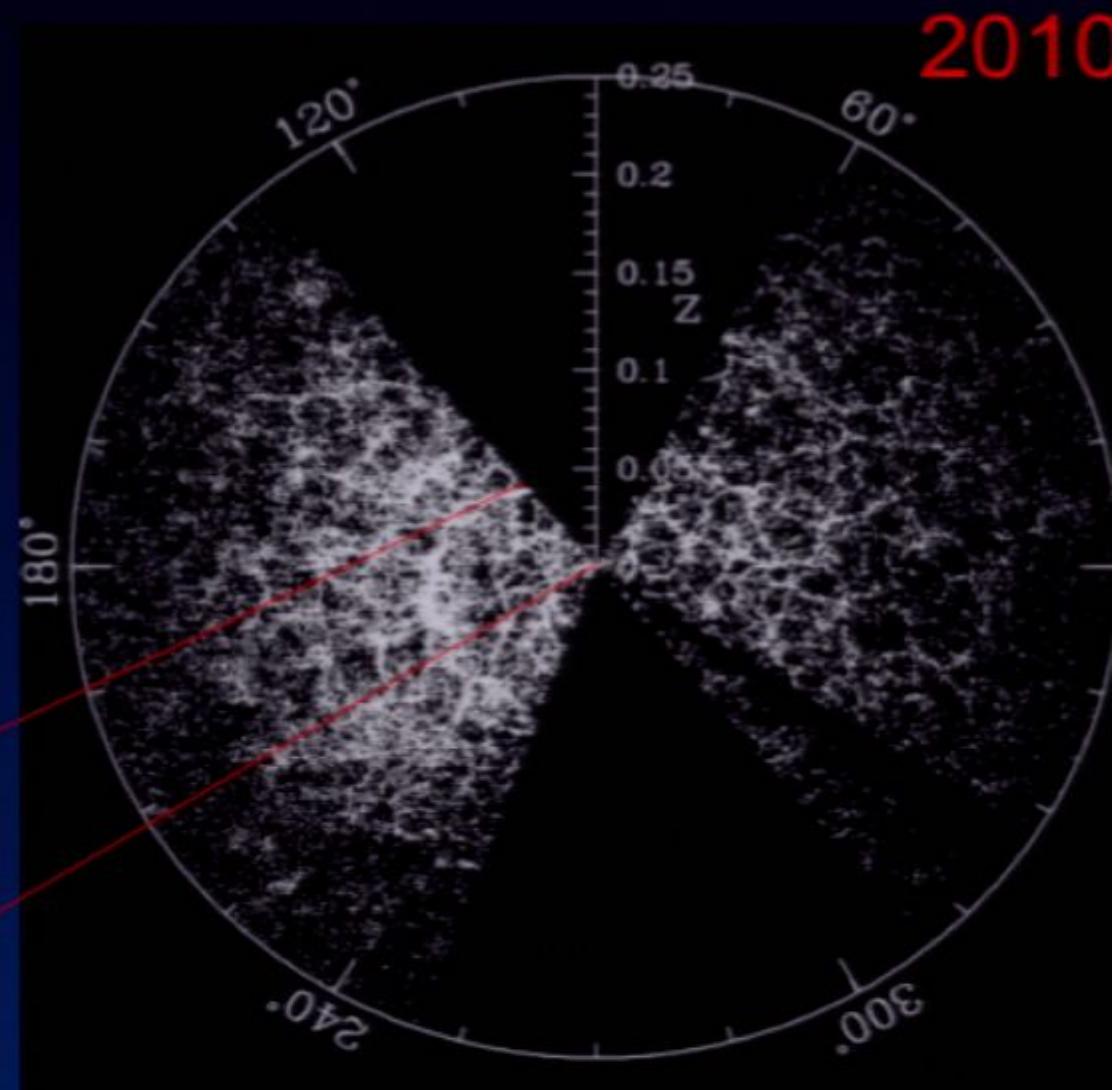
Outline

- I. Be ready (for new data from ongoing surveys)
- II. Be careful (of systematics)
- III. Be creative (in testing fundamental physics)
- IV. Be optimistic!

Large redshift surveys

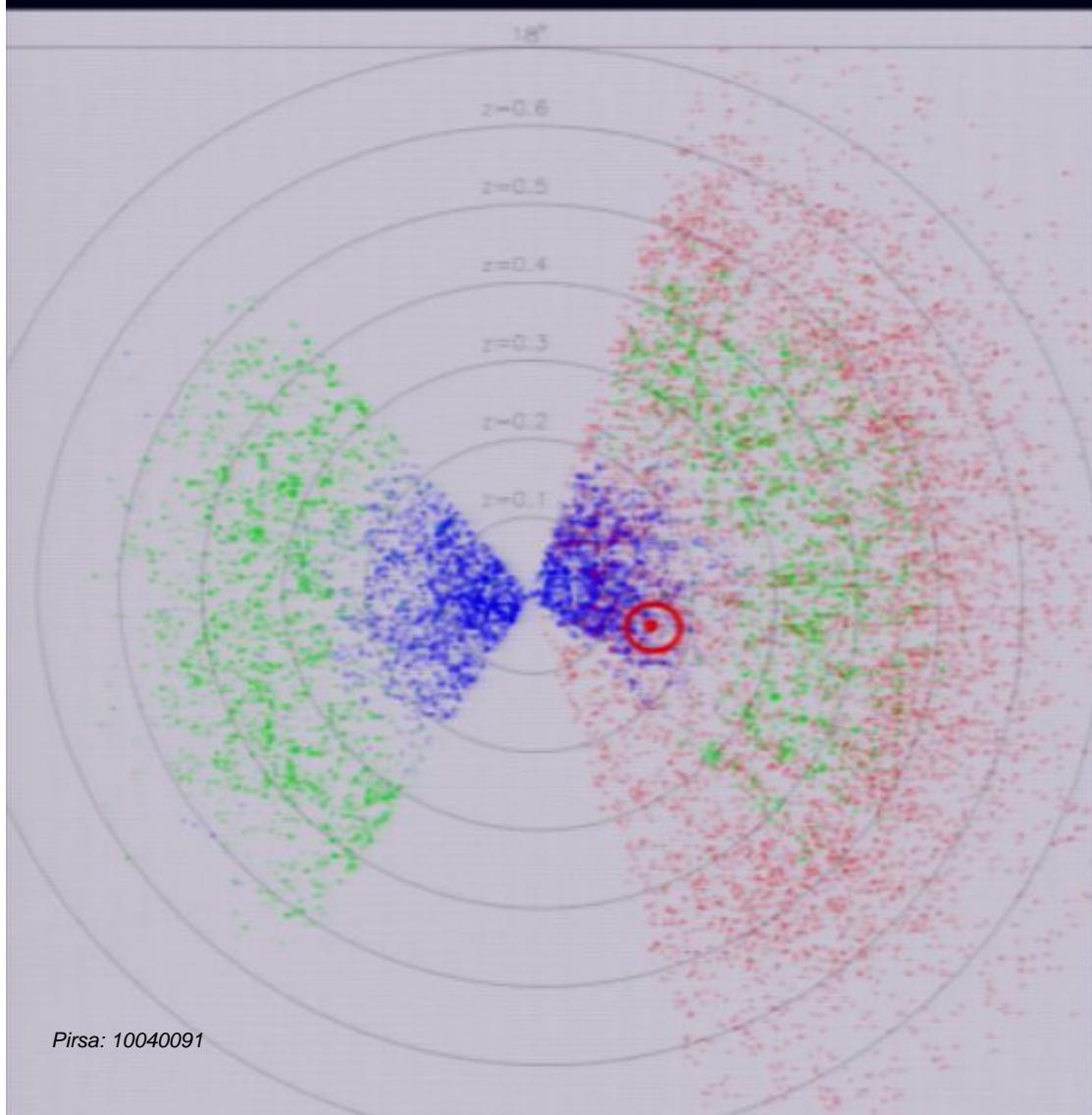
Over the past ~25 years, surveys of the local Universe have progressed from mapping out 2500 galaxies in a thin slice of sky (Davis et al.'s CfA1) to $\sim 10^6$ over one-fourth of the sky (Sloan Digital Sky Survey)

1982



A new generation of surveys

Example: BOSS



SDSS main galaxy survey
~1 million galaxies
Too little volume for BAO

SDSS luminous red galaxies (LRGs)
Sparse sampled, 10^4 galaxies/Mpc
80,000 galaxies, 8000 deg^2

BOSS (SDSS-III) red galaxies
1,300,000 galaxies, $10,000 \text{ deg}^2$

5x sample density vs. SDSS LRG's
(shot noise)
2x volume

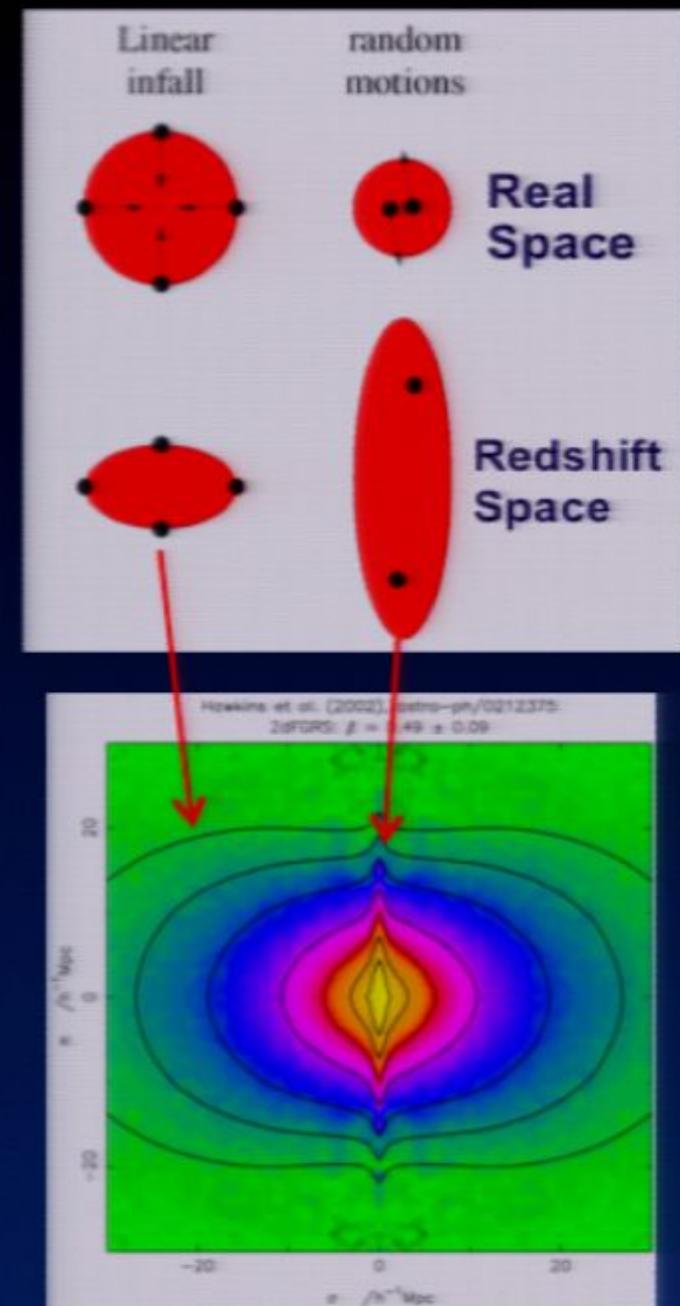
Currently ongoing surveys

Survey	# targets	z range	Area (square degrees)	#/sq. deg.
GAMA	250,000	$0 < z < 0.5$	240	1000
BOSS	1,300,000	$0.2 < z < 0.7$	10,000	130
WiggleZ	340,000 targets (240k secure z's)	$0.2 < z < 1$	1000	240
VIPERS	~100,000 targets (~40k secure z's)	$0.5 < z < 1.2$	24	1666

- In the next couple of years: FastSound (Subaru/FMOS near-IR)
DES (4000 sq. deg. photometric survey to $z \sim 1$)

Redshift-space Distortions

- Measure excess of galaxy pairs due to clustering as a function of separation in plane of sky (r_p) and along line of sight (π): $\xi(r_p, \pi)$
- Intrinsically isotropic in real space
- Gravity causes structures to appear compressed along line of sight ("Kaiser infall")
- Random relative velocities perturb redshifts along line of sight (FoG)



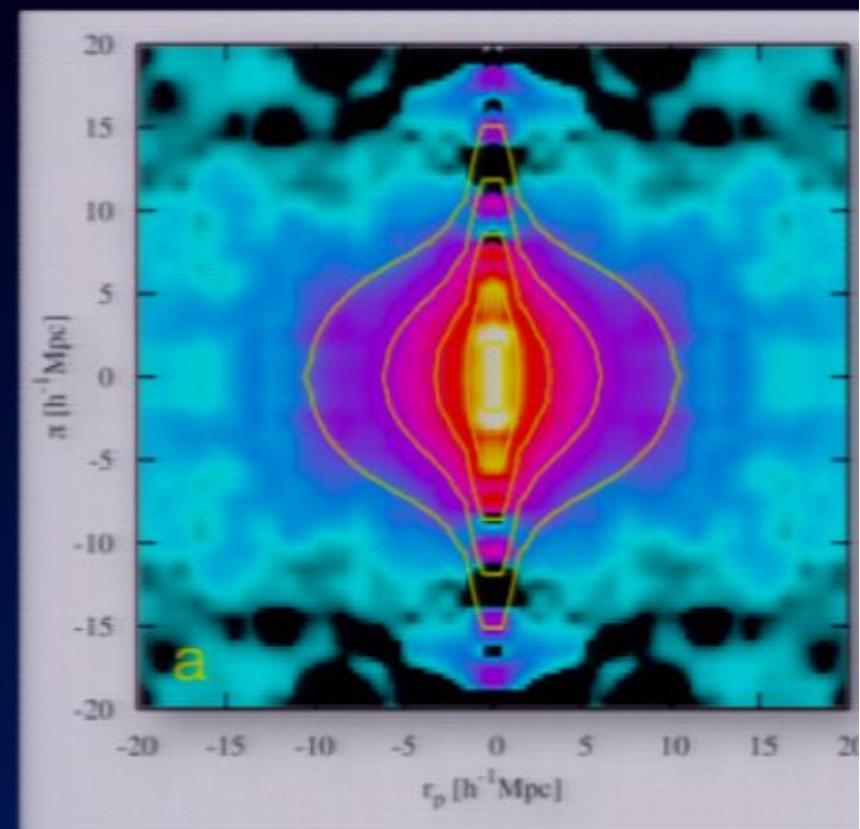
Measuring growth of structure with redshift-space distortions

- Strength of infall depends on growth rate of structure: proportional to $\beta = f/b = f\sigma_8$, with:

$$f = \frac{d \ln D}{d \ln a} \approx \Omega_m^\gamma$$

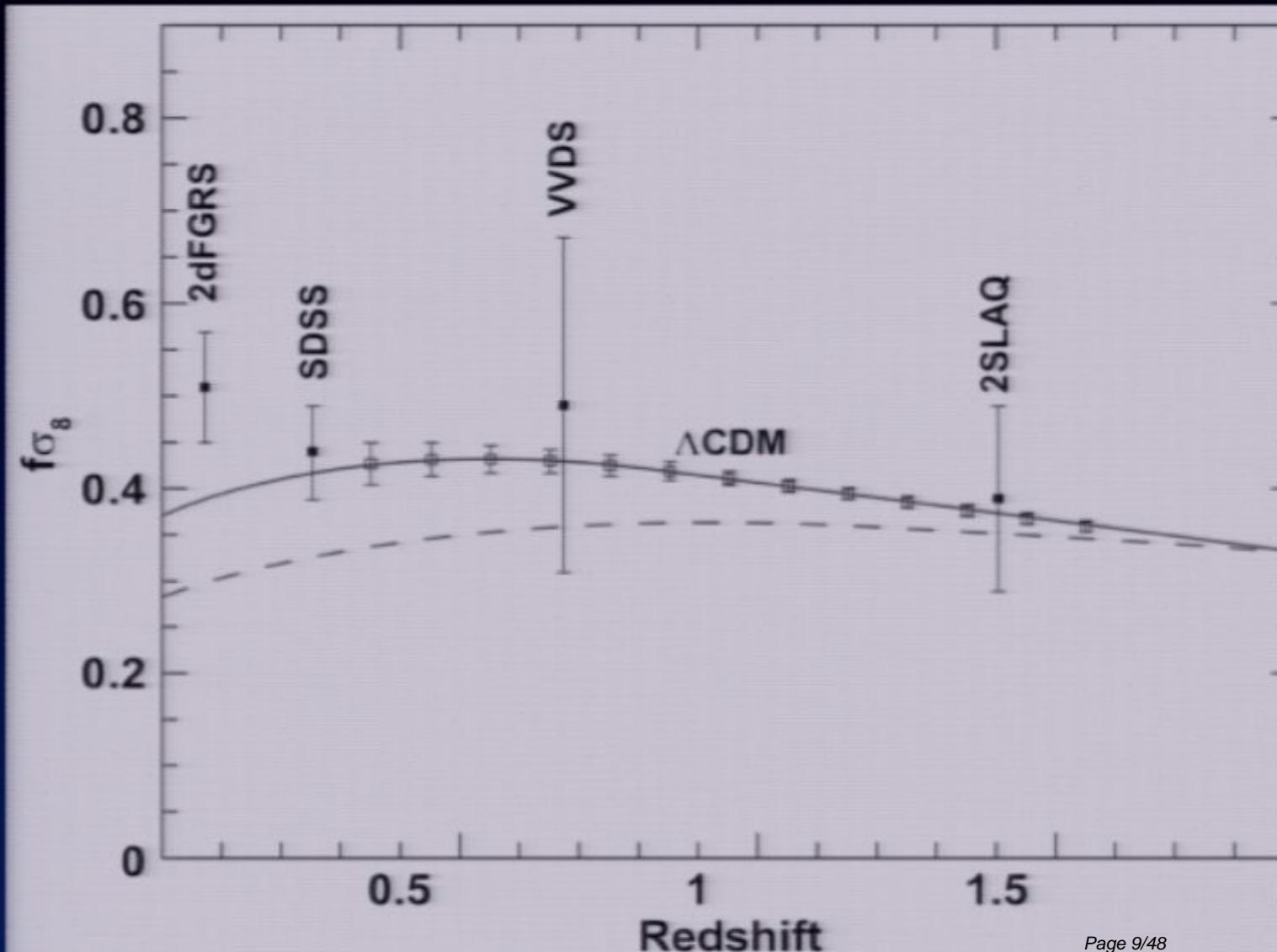
- $\gamma \approx 0.55$ for GR; 0.68 for DGP; etc.
- Guzzo et al. 2008: used 6000 galaxies in ~ 6 sq. deg from VVDS, found $\beta = 0.70 \pm 0.26$

Guzzo et al. 2008



Current measurements

VIPERS goal:
~3x smaller
errors than
VVDS



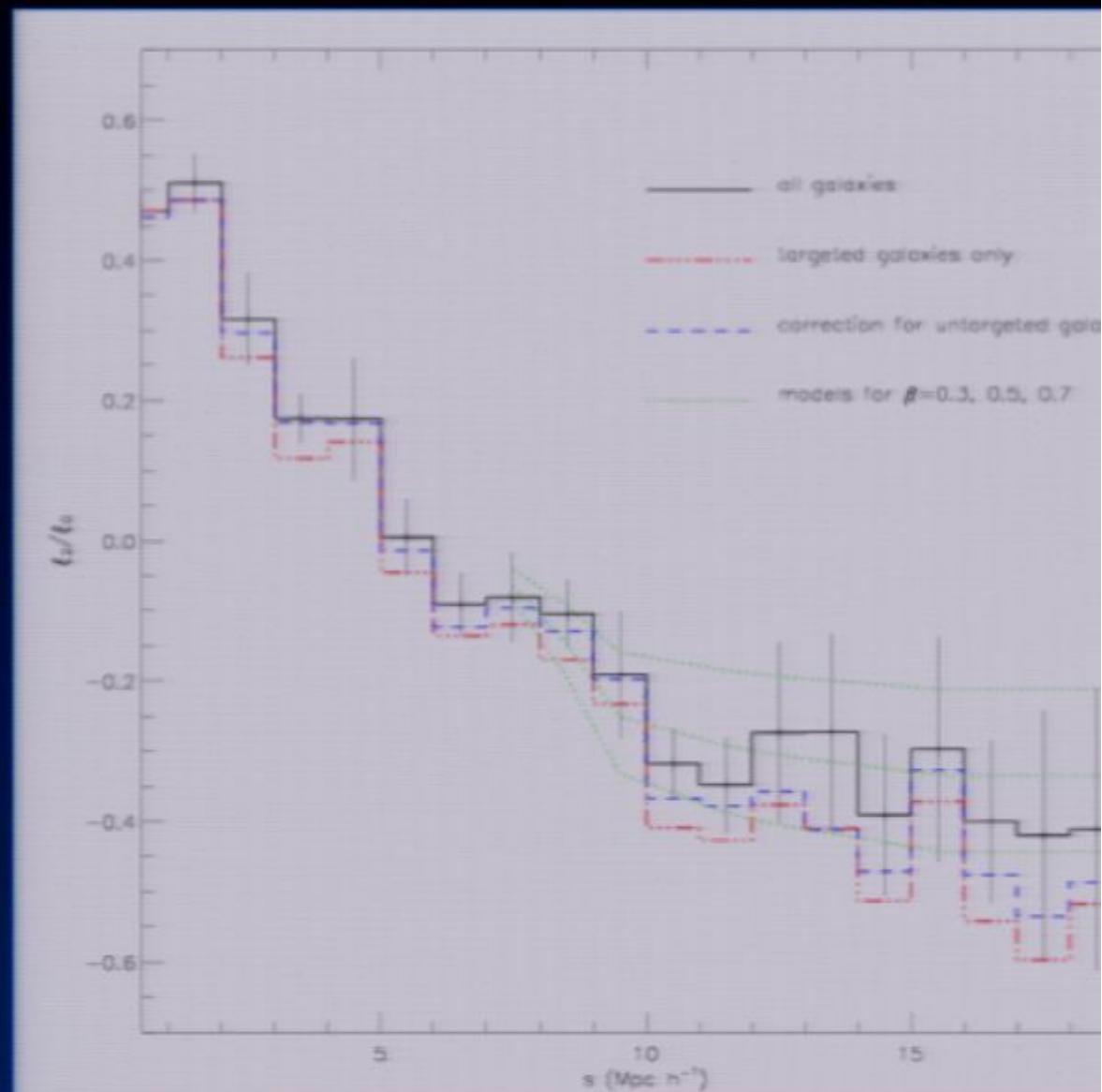
A cautionary tale

One goal for DEEP2 was constraining bias and Ω_m using redshift-space distortions at $z \sim 1$

> 30,000 secure redshifts in 3 square degrees, focused on $0.7 < z < 1.4$: predicted statistical error in β is ~ 0.10 (3x smaller than VVDS, similar to VIPERS)

Had difficulty robustly recovering known, true β in GIF simulations

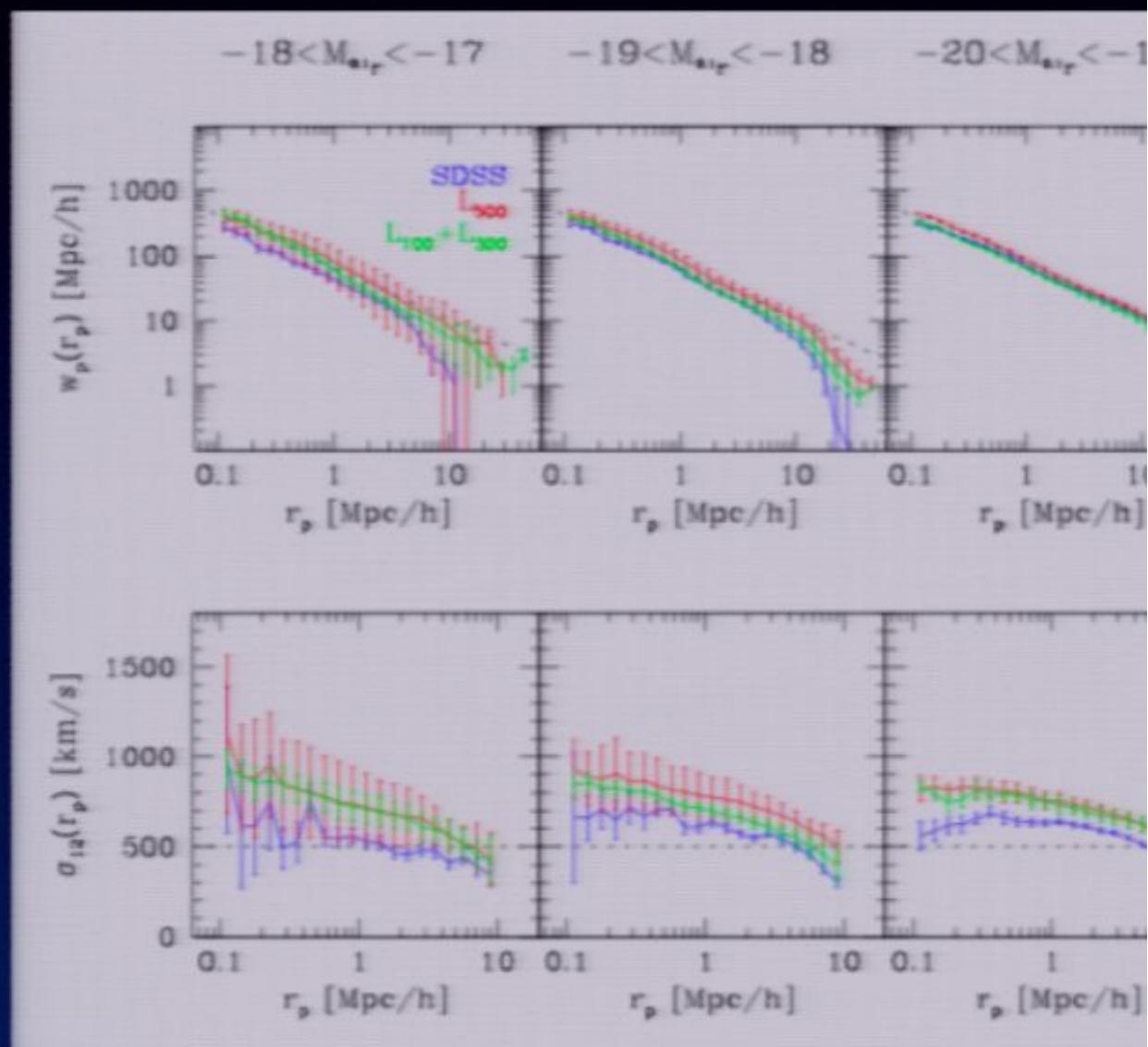
Guzzo et al.: systematic offset of 0.03 in β in Millennium simulation



Some targets for future work

Some issues to think about:

- testing methods with more accurate & greater variety of simulations
- constraining pairwise velocity, $\sigma_{12}(r_p)$, when redshift error is comparable to signal (VIPERS, Euclid)
- End-to-end halo model for $\xi(r_p, \pi)$, not just fixed $\sigma_{12}(r_p)$ & assuming linear bias
- Simultaneous fitting for Alcock-Paczynski effect
- Effects of changing selection effects with z



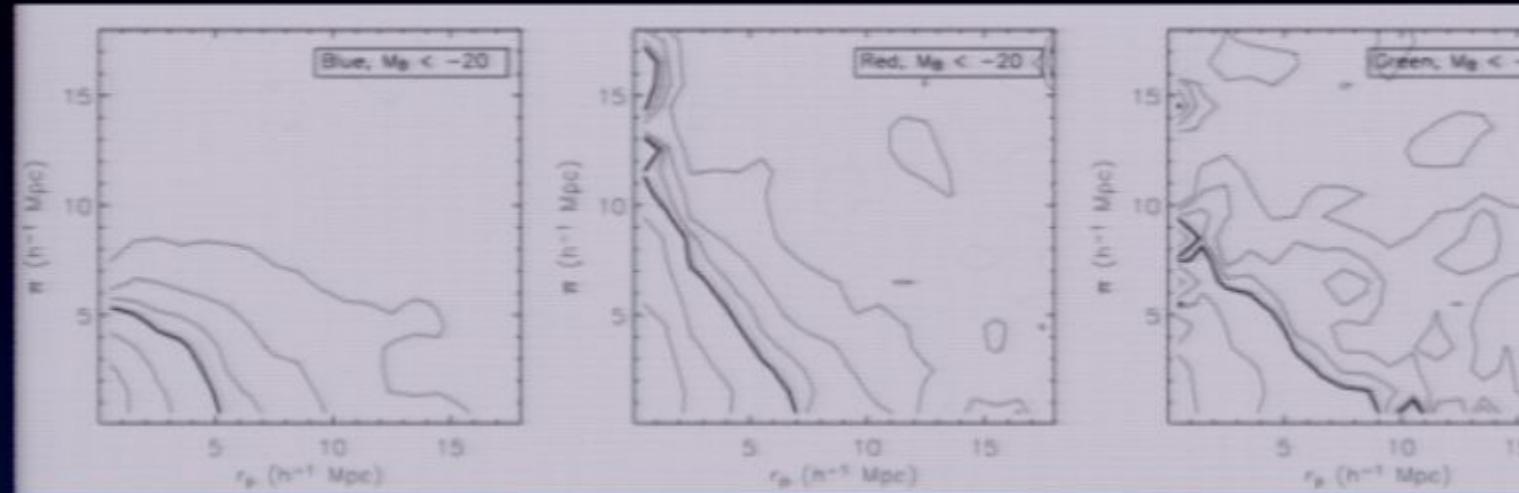
An iron test

SD depends on
 f/b

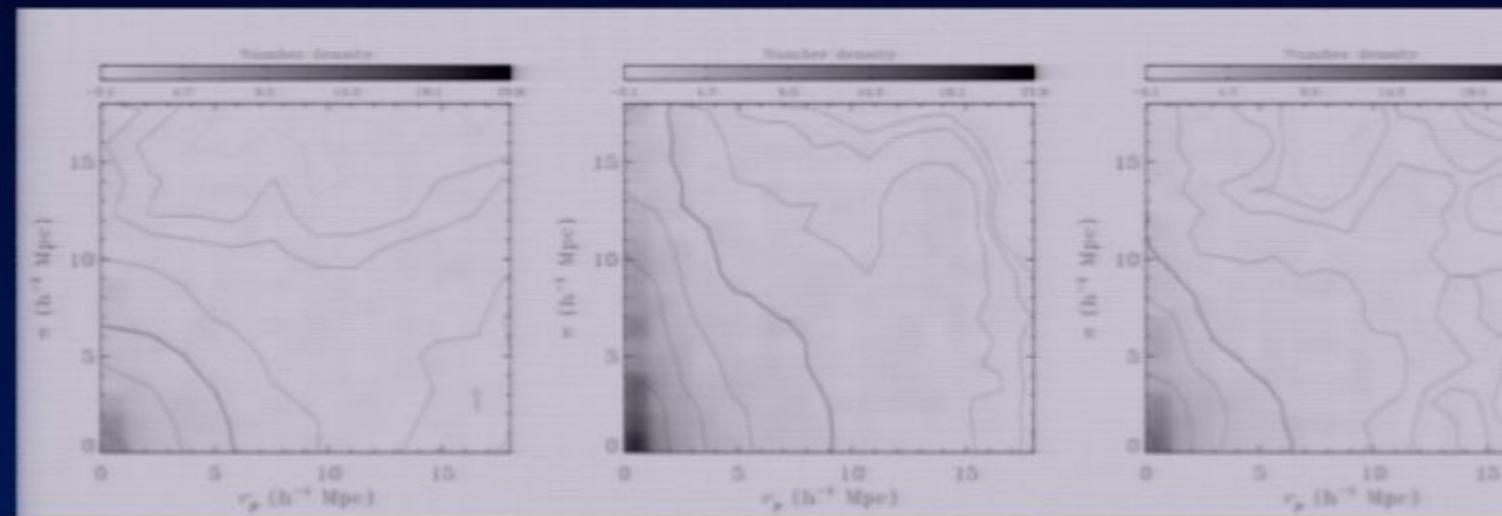
Galaxies of different properties have different biases, but all are found in the same Universe...

ence they give different degrees of RSD, but should yield the same value for f if methods work

Alternatively: use to cancel out sample variance (McDonald & Seljak)



DEEP2: Coil, JN et al. 2007

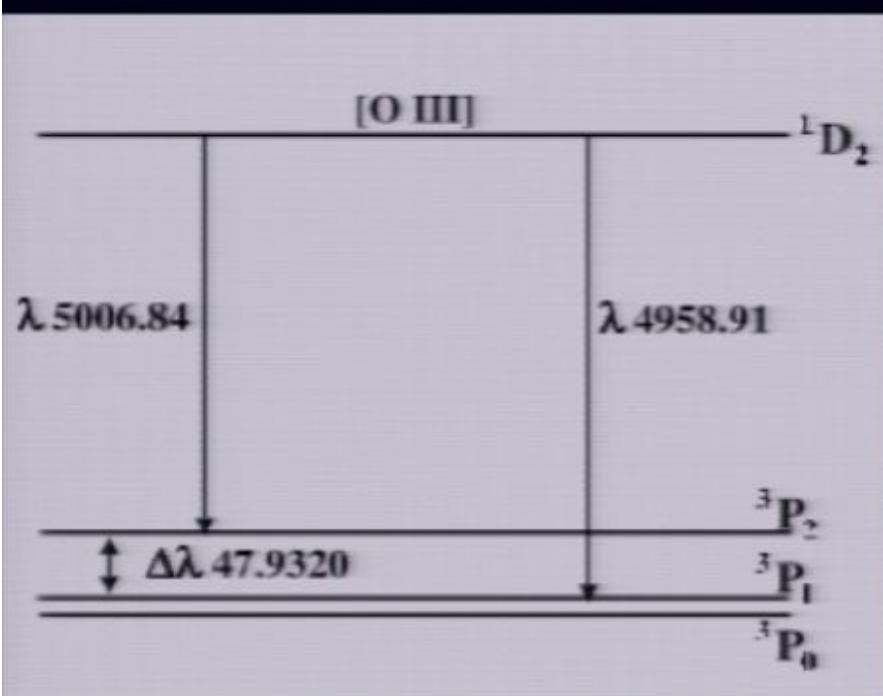


SDSS+GALEX: Loh et al. 2010

Look for free byproducts: e.g. Testing for changes in α

- α provides one of the easiest ways to test the universality of physical laws.
- Temporal and/or spatial variation in α is predicted by some theories with large extra dimensions and dark energy scenarios.
- There have been recent claims that significant evolution has been detected.
- Most methods of testing for evolution in α are likely dominated by unknown systematics (e.g. different groups get significantly different results using the same basic method).

Testing for variation using [OIII]



- Twice-ionized oxygen will randomly emit a photon of wavelength either 4959 or 5007 Å. Because the transition is forbidden, absorption has negligible probability.

Hence [OIII] 4959 & 5007 Å emission lines must have line profiles proportional to each other, unlike absorption line tests.

To $<\sim 1\%$, $\alpha^2 \propto (\lambda_2 - \lambda_1)/(\lambda_2 + \lambda_1)$ for these lines, as the splitting arises from fine structure directly.

Vital statistics of DEEP2

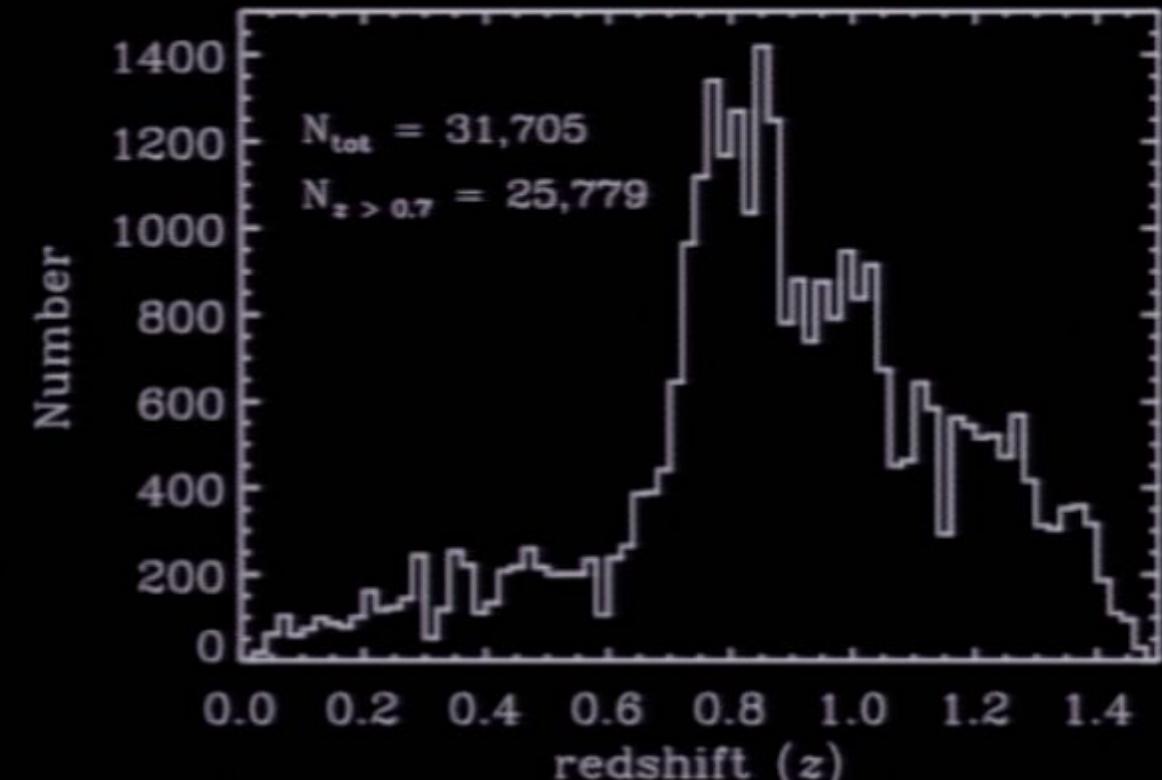
- **Observational details:**

- ~3 sq. degrees
- 4 fields ($0.5^\circ \times <2^\circ$)
- RAB ≤ 24.1
- 80+ Keck nights
- >33,000 redshifts
- primarily $0.7 < z < 1.4$

- (pre-selected using BRI photometry)

- 1200 l/mm: $\sim 6400\text{-}9200\text{\AA}$ ($R \sim 5000$)

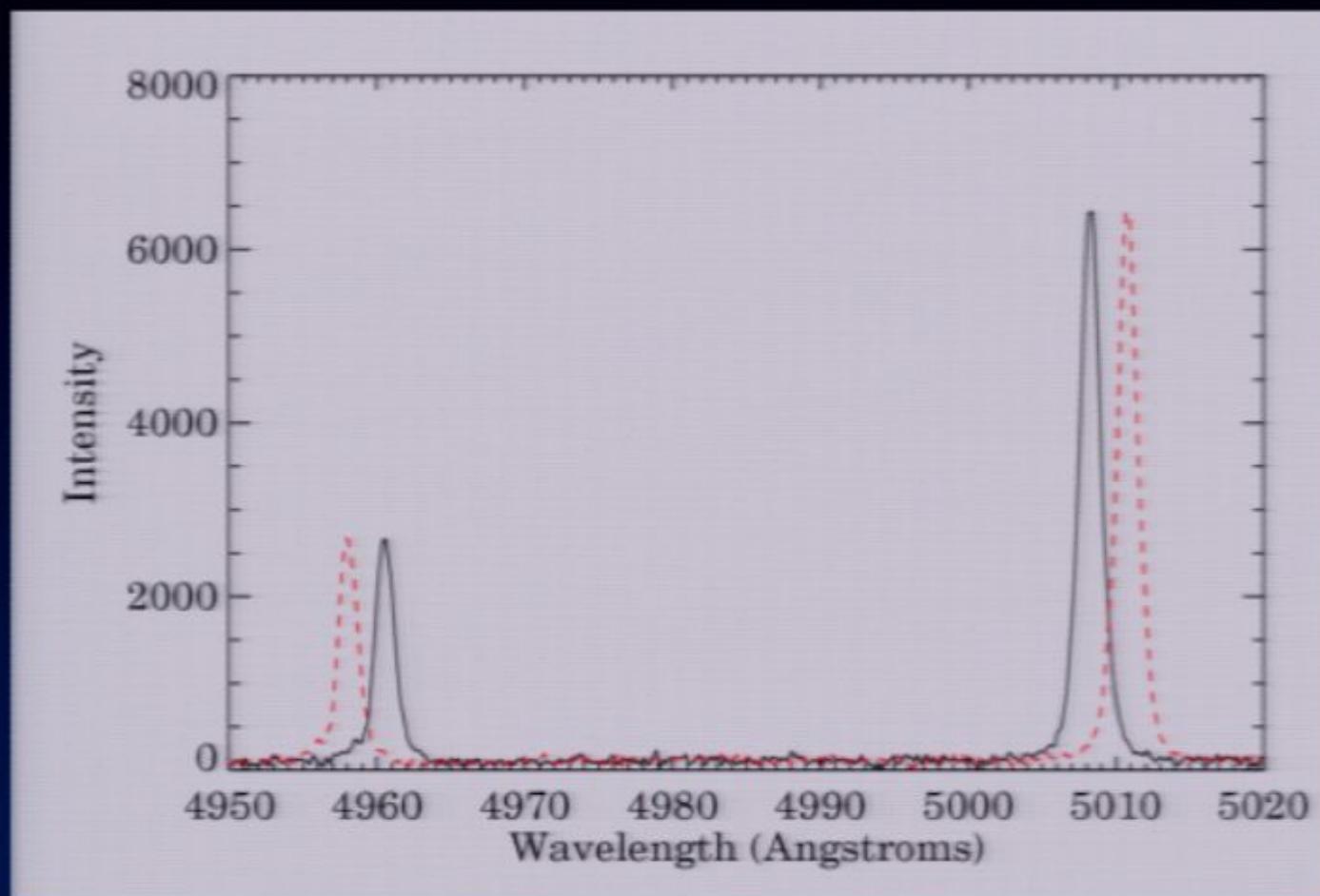
- 1.0" slits: FWHM ≈ 68 km/s



All DEEP2 data have been released!

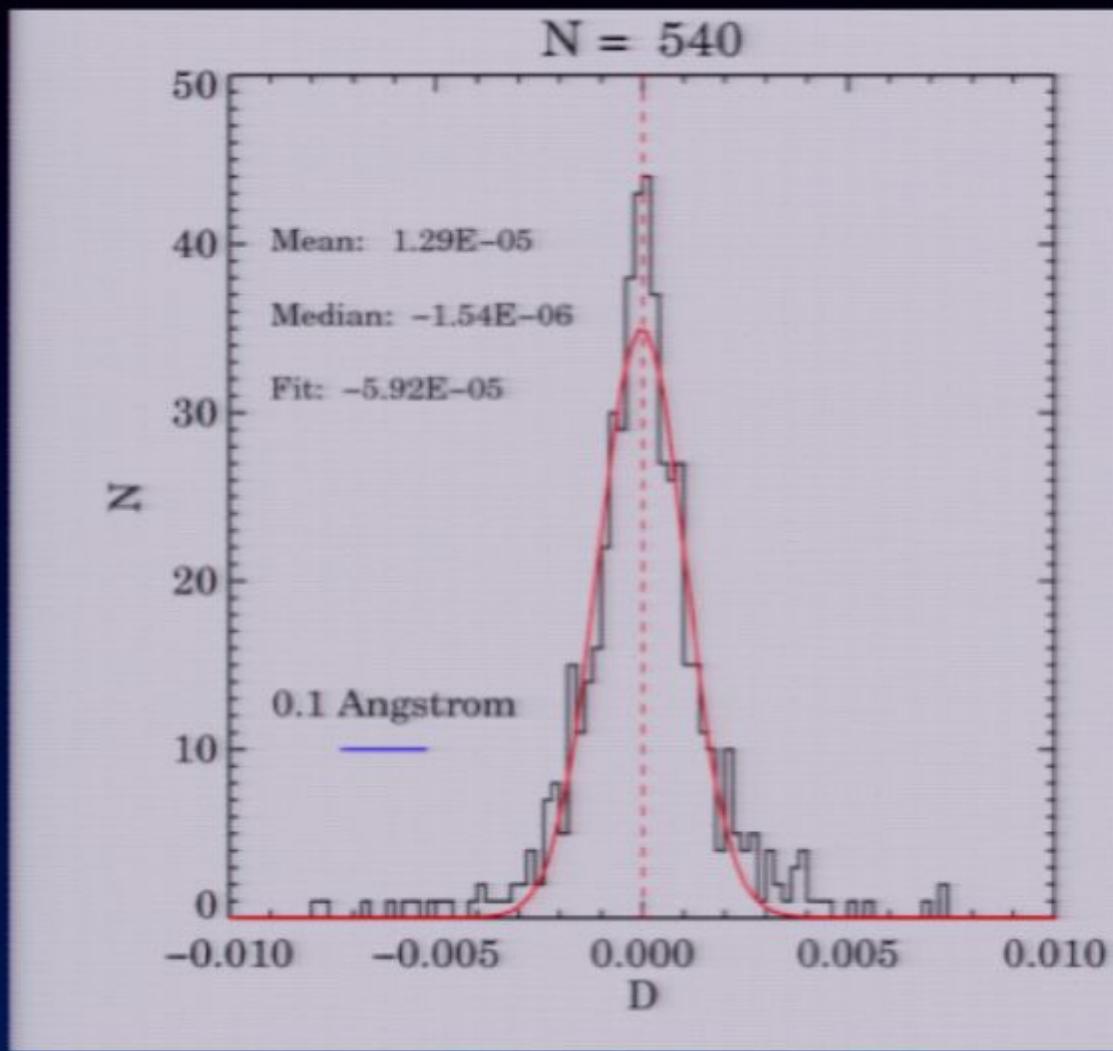
<http://deep.berkeley.edu/DR3>

Effect of changing α



shown is the effect of a 5% change in α applied to an actual spectrum - in DEEP2 data, we can detect evolution $\sim 1/800$ this large

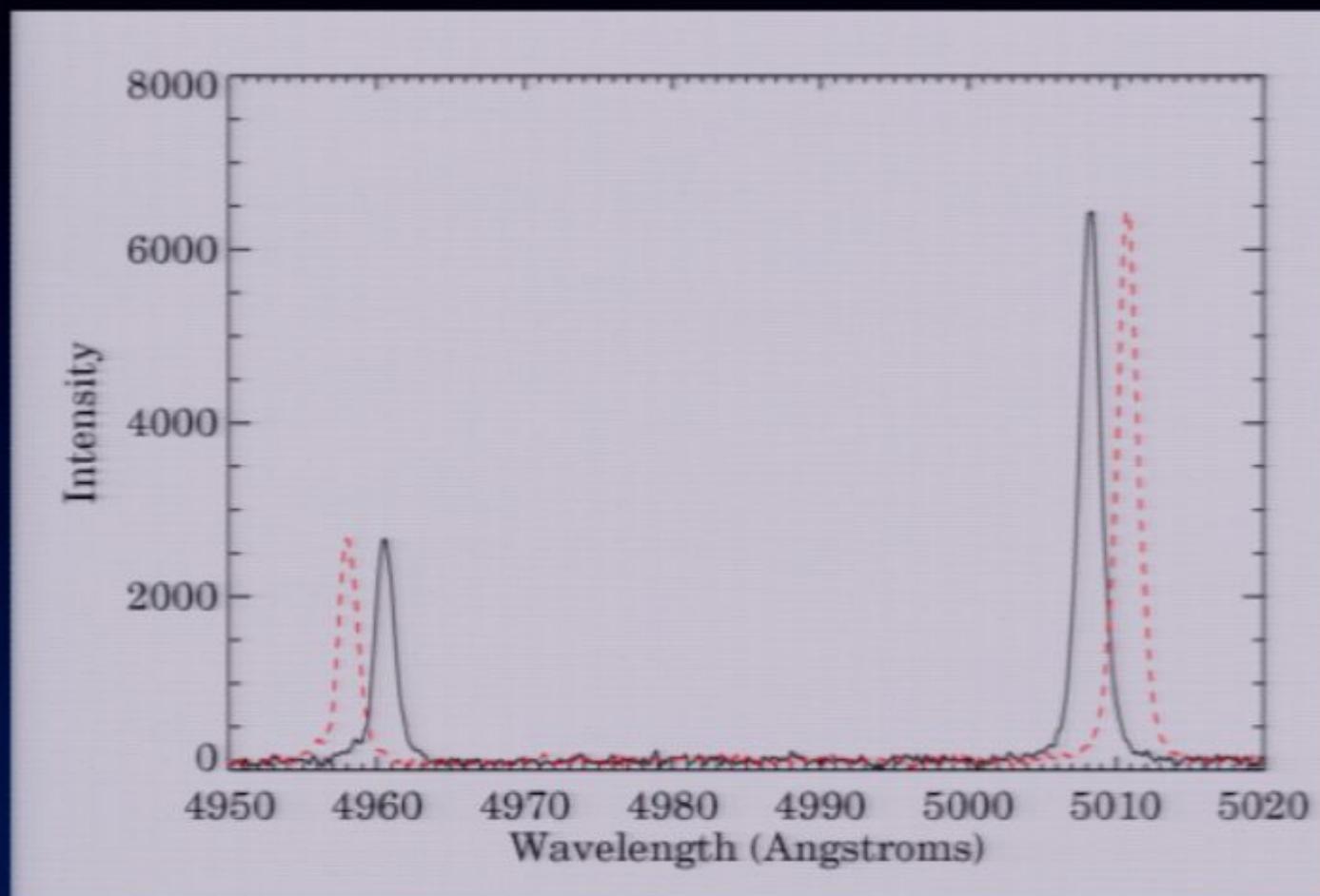
We detect no change in α from $z=0$ to $z=0.7$



- Hard part is bringing down wavelength calibration systematics (done)
- Simplest test: combine all galaxies with $z > 0.6$ into one bin, and measure $\langle D \rangle = \langle \Delta \alpha^2 / \alpha^2 \rangle$.

Newman et al.
2010, *in prep.*

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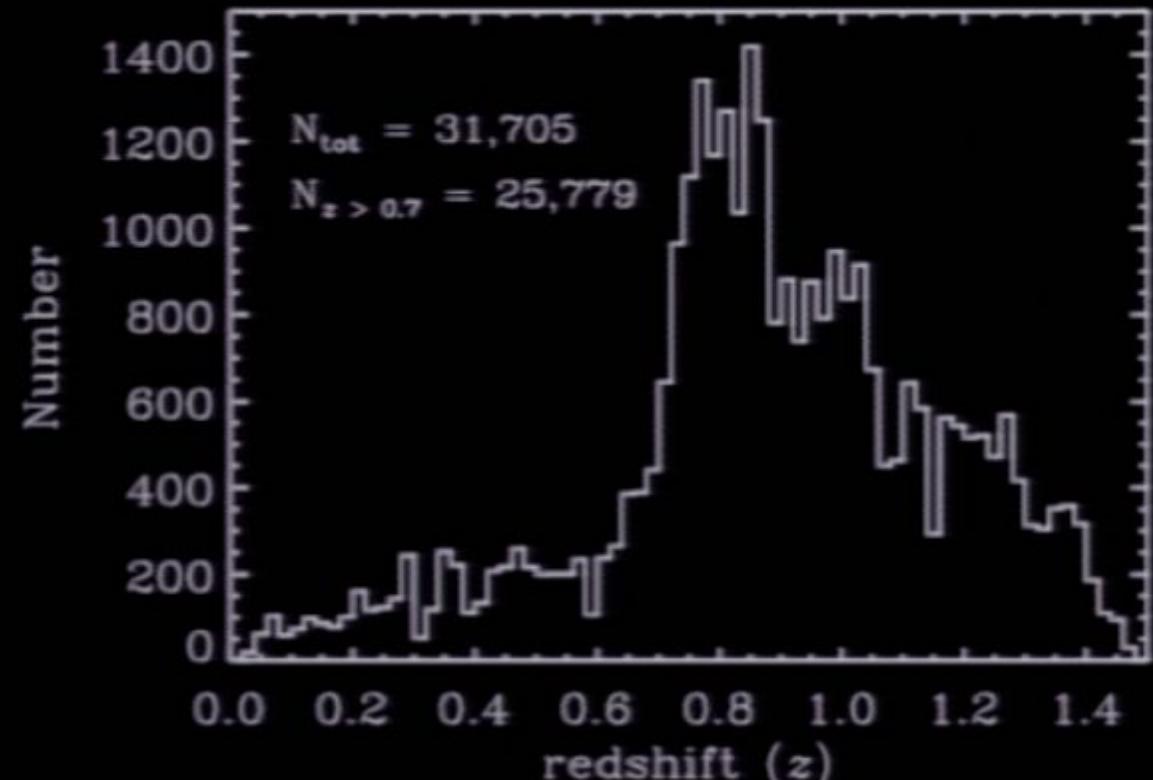
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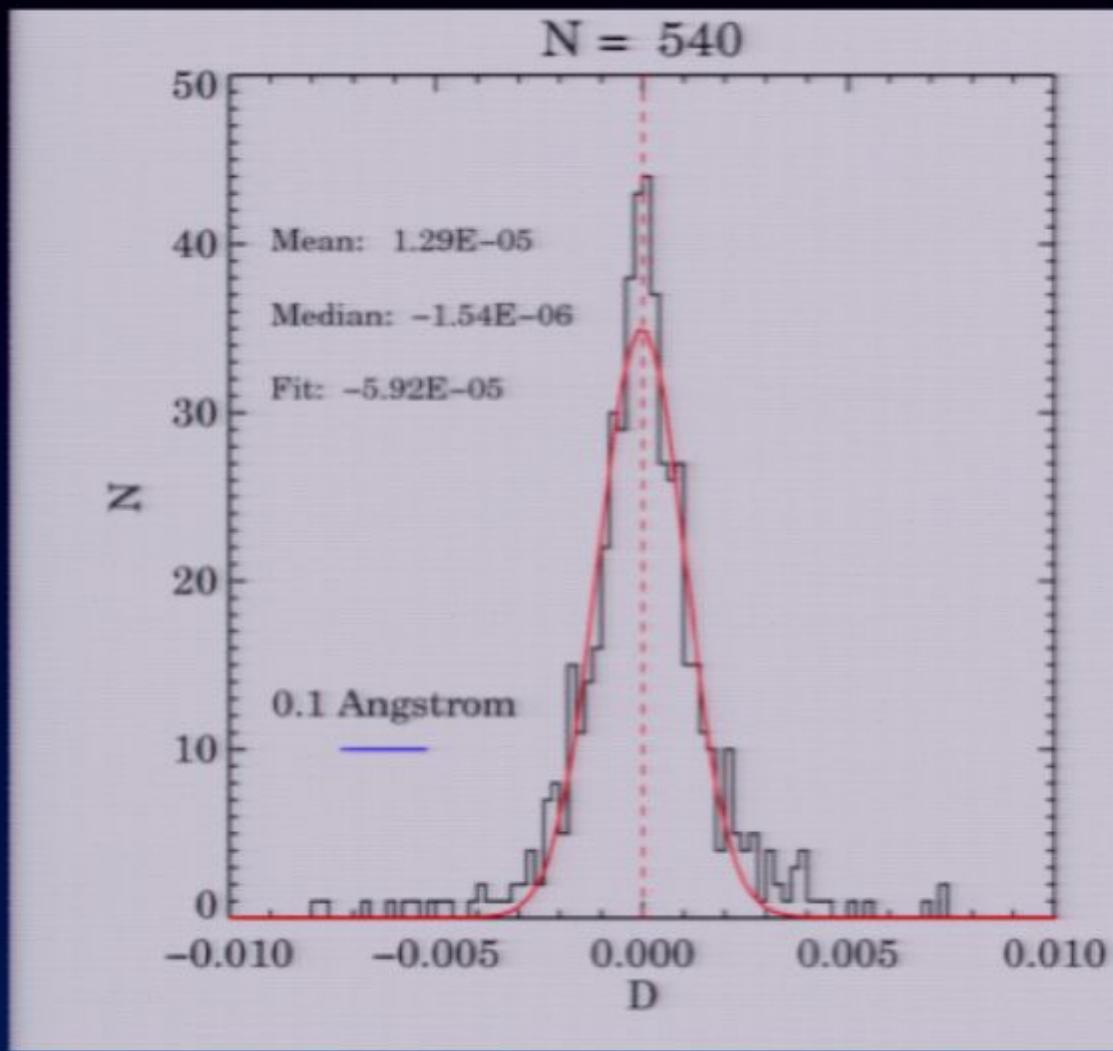
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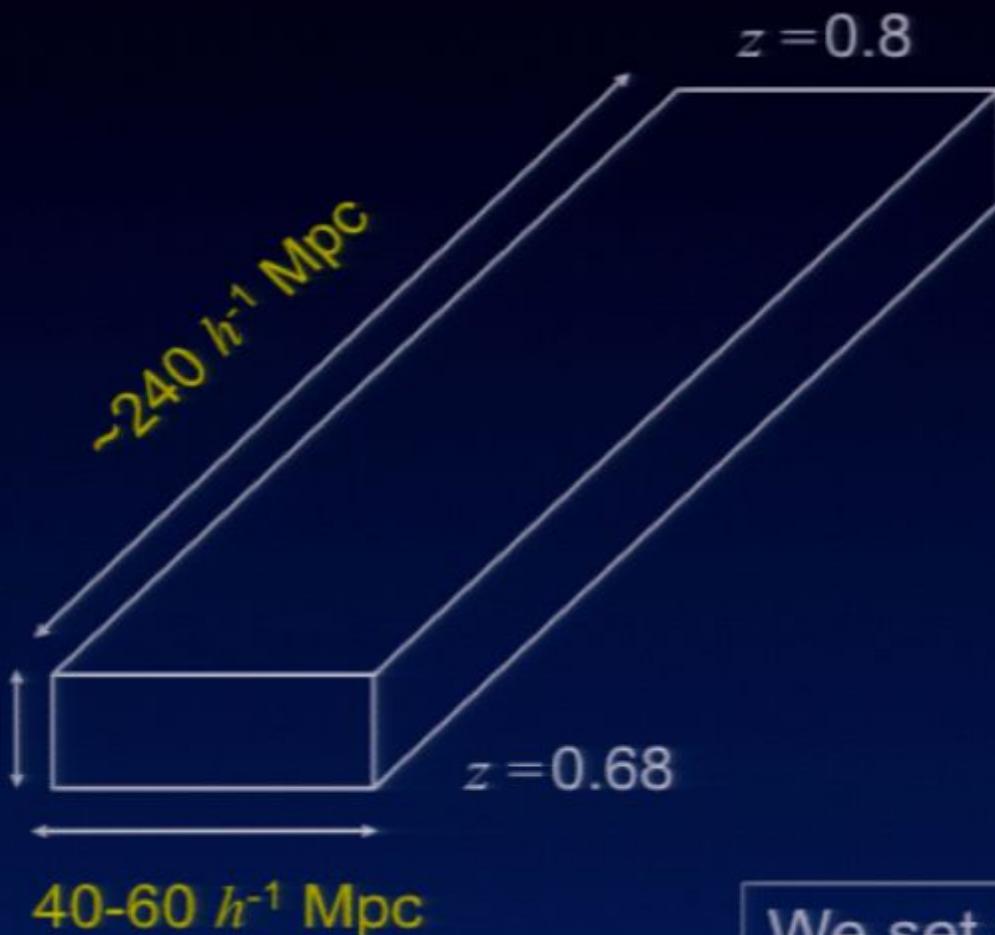
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DEEP2 vs. previous measurements

Sample	Method	Median z	$d\alpha/dt/\alpha$ (year $^{-1}$)	$\sigma(d\alpha/dt/\alpha)$
Webb et al. 2001	Many-multiplet	~1.5	1.14E-15	2.9E-16
Murphy et al. 2004	Many-multiplet	1.75	6.40E-16	1.4E-16
Quast et al. 2004	Many-multiplet	1.15	5.08E-17	4.2E-16
Srinand et al. 2004	Many-multiplet	1.55	-6.50E-17	6.2E-17
Tzanavaris et al. 2004	MM + 21cm	0.5	-1.30E-15	1.5E-15
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Levshakov et al. 2005	Fe absorption	1.839	-3.73E-17	5.9E-17
Prestage et al. 1995	Lab measurement	0 (140d)	3.70E-14	Upper limit
Fujii et al. 2003	Oklo natural reactor	~0.1	-4.40E-17	4.0E-18
Lamoreaux & Torgerson	Oklo natural reactor	~0.1	-2.25E-17	5.5E-18
Darling 2004	OH 18cm lines	0.247	4.98E-16	1.3E-15
Bahcall et al. 2003	Oxygen emission	0.37	-2.99E-14	1.7E-14
This work (slope)	Oxygen emission	0.72	9.55E-15	2.6E-14
This work (vs. z=0)	Oxygen emission	0.72	-1.35E-15	3.2E-15

Nominal precision does not approach QSO absorption-line measurements. However, [OIII] method is much simpler and should be more robust.

Testing for spatial variation



Large surveys provide a unique opportunity: We can test for **spatial variation** in α by measuring the differences in $\langle \Delta\alpha^2/\alpha^2 \rangle$ amongst **similar volumes** in the 4 DEEP2 fields **at the same redshifts**.

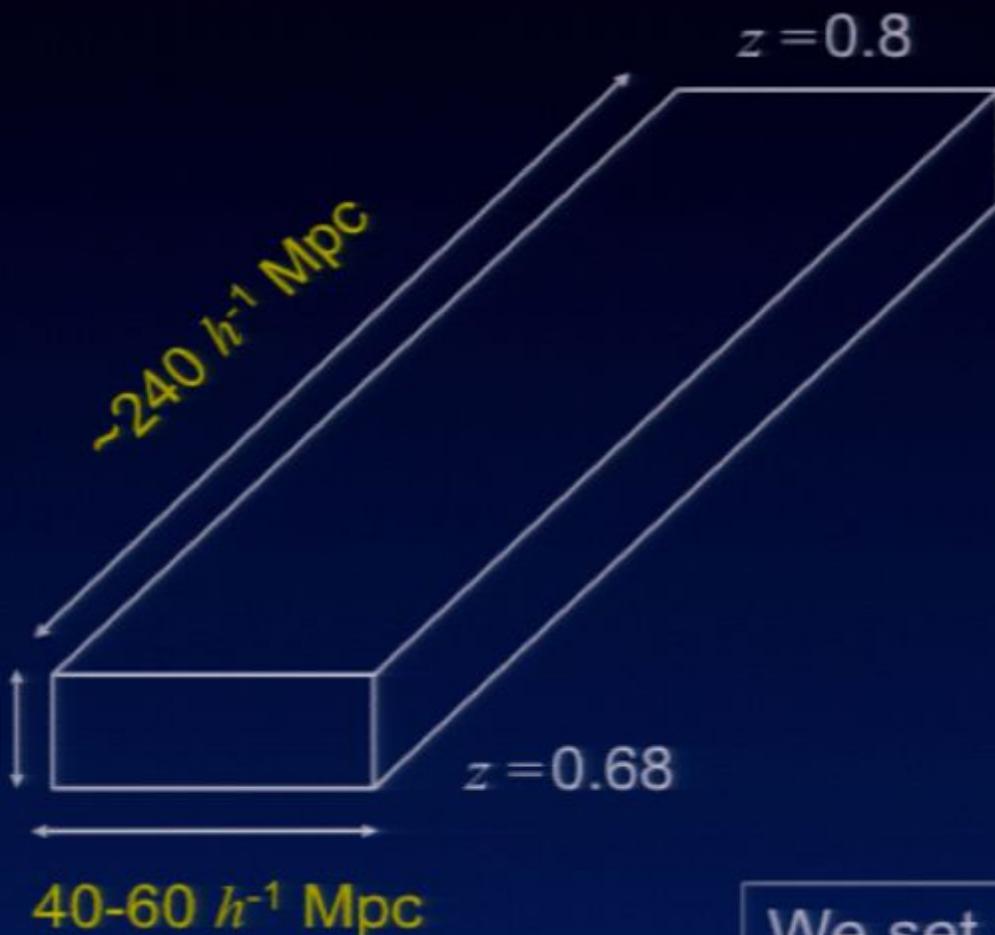
We set a 95% upper limit on Gaussian spatial fluctuations at $\sim 1000-3000 \text{ Mpc}$ separations: $\sigma(\Delta\alpha/\alpha) < 9.0 \times 10^{-5}$

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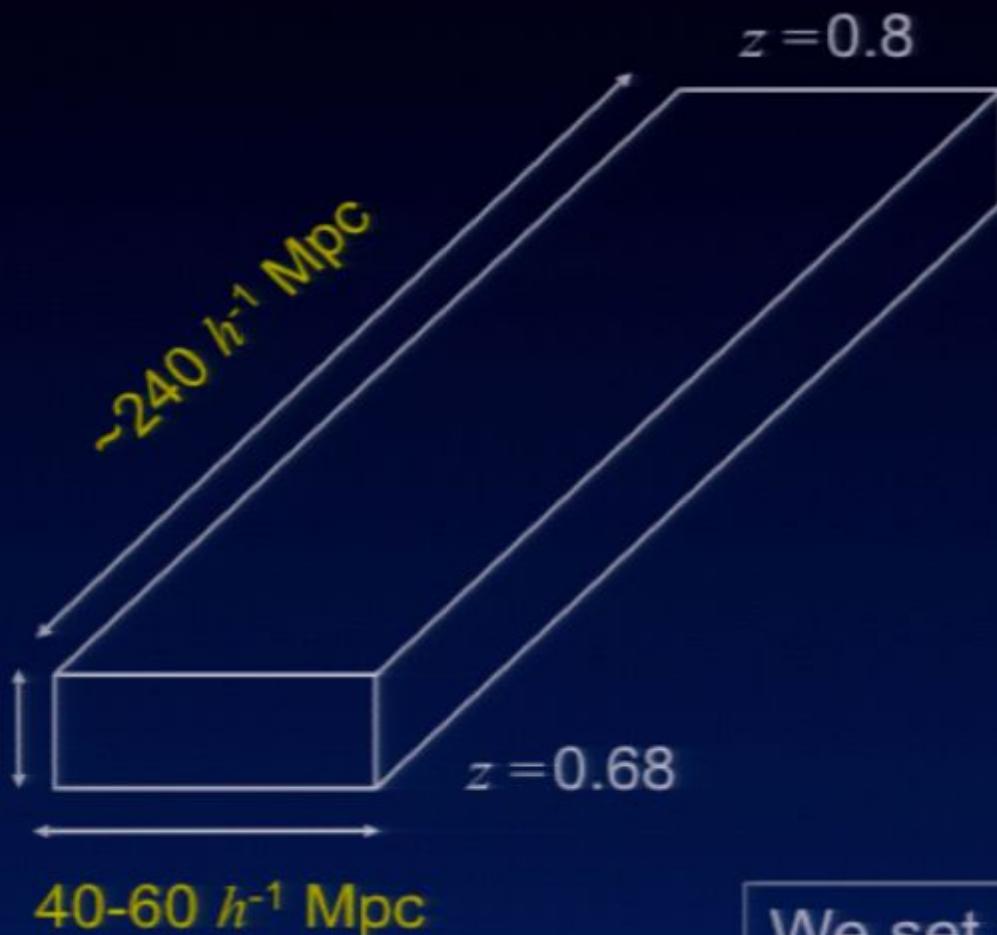
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Future Applications

Number of [OIII]-emitting galaxies needed to rule out (or confirm) the claimed many-multiplet detections at 99% confidence:

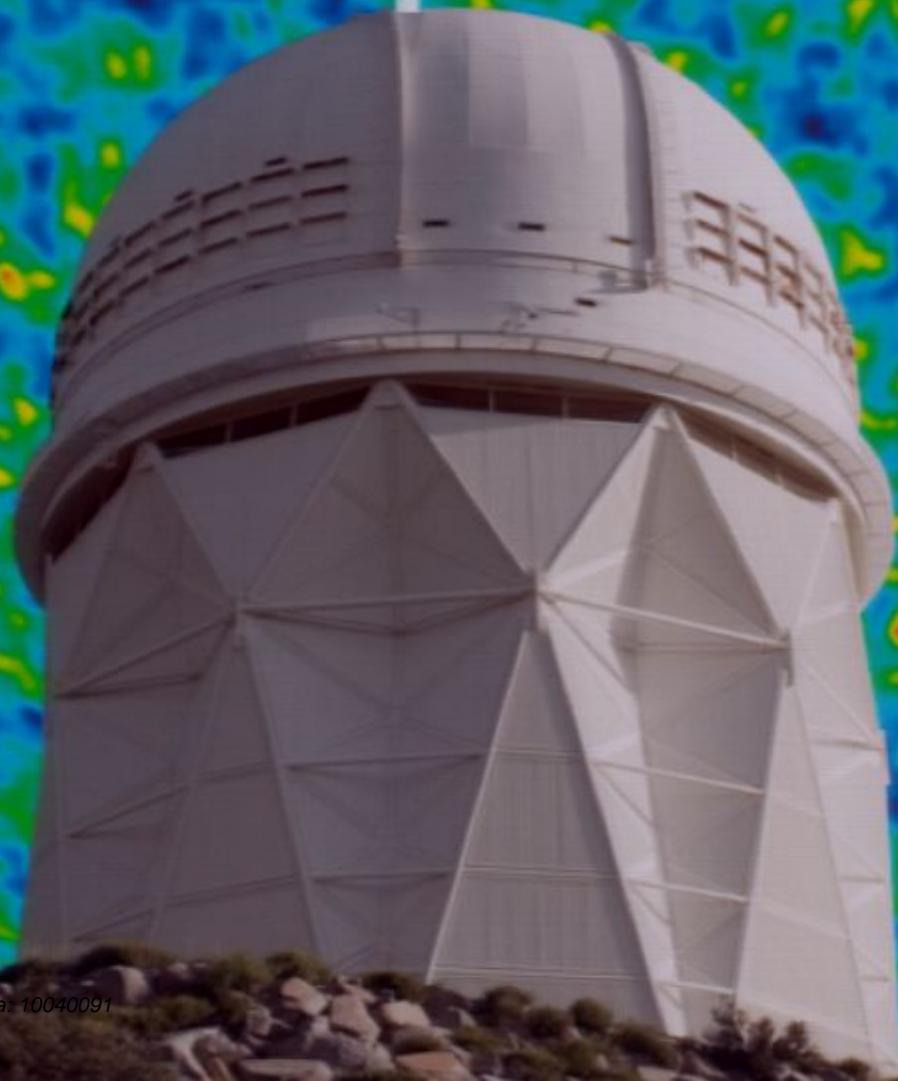
[OIII] Photons per galaxy →	1 x DEEP2	3 x DEEP2	10 x DEEP2
Resolution ↓			
2500 (0.5xDEEP2)	192000	64000	19200
5000 (1xDEEP2)	96000	32000	9600

Cf. 540 objects (~1% of full sample) in DEEP2 measurement (due to limited z range where we cover [OIII]). Ongoing/ future BAO surveys target bright emission-line galaxies around the ideal redshift range!

[BigBOSS sample: equivalent to ~10⁶ DEEP2 galaxies: 50x smaller errors on $\Delta\alpha/\alpha$)

BigBOSS: The Ground-Based Stage IV BAO Experiment

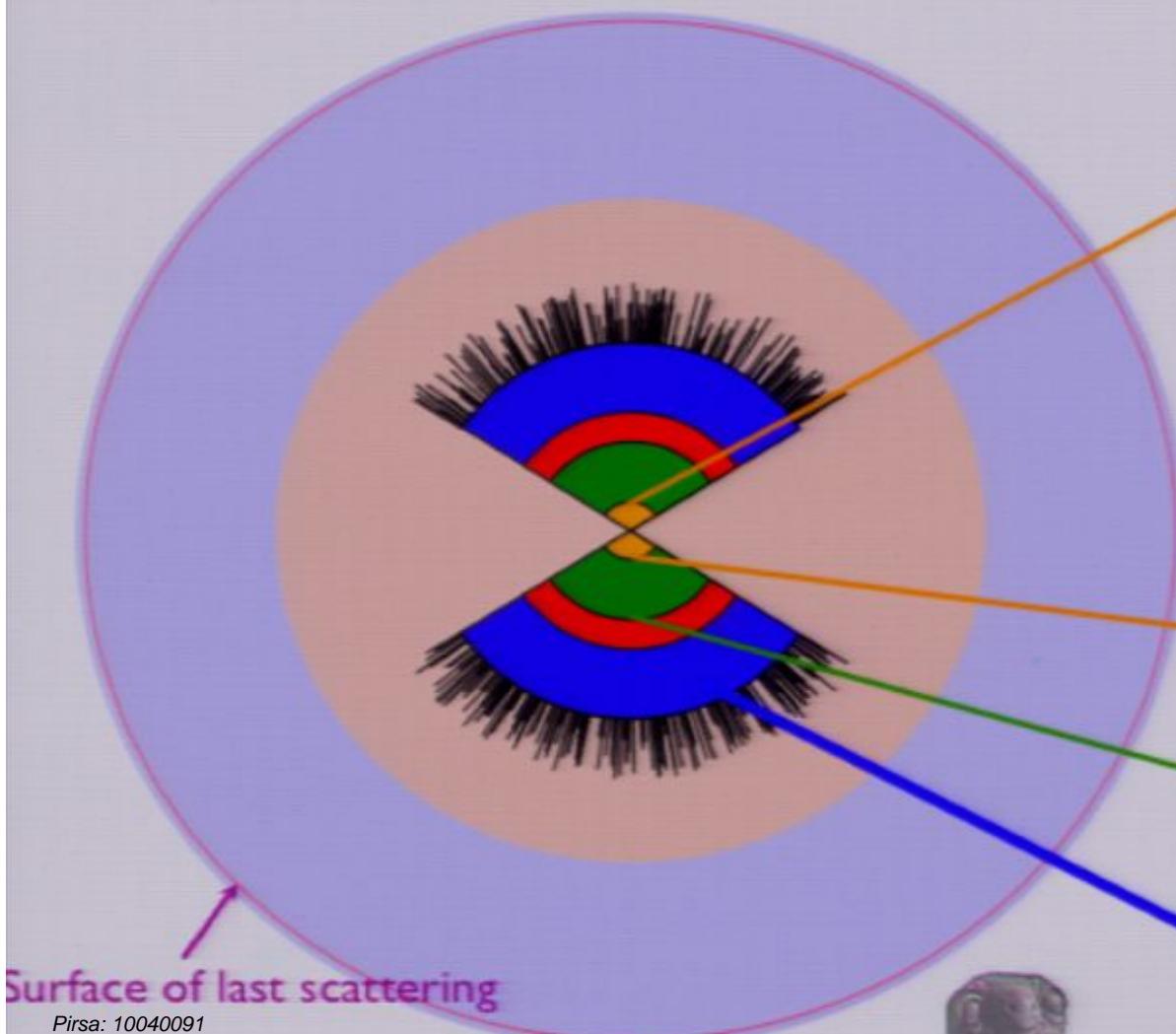
Submitted to Astro2010
April, 2009



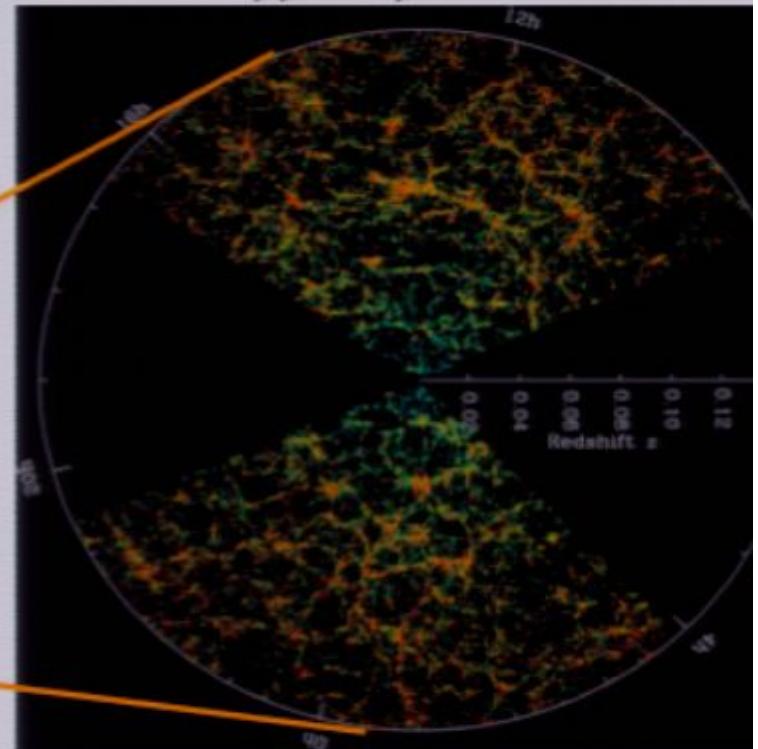
Science Goals: 50 million redshifts

Sensitivity to new physics scales as volume (# of modes)

Our observable Universe



Volume mapped by SDSS + SDSS-II



Volume to be mapped by SDSS-III/BOSS
(ca. 2015)

BigBOSS @NOAO

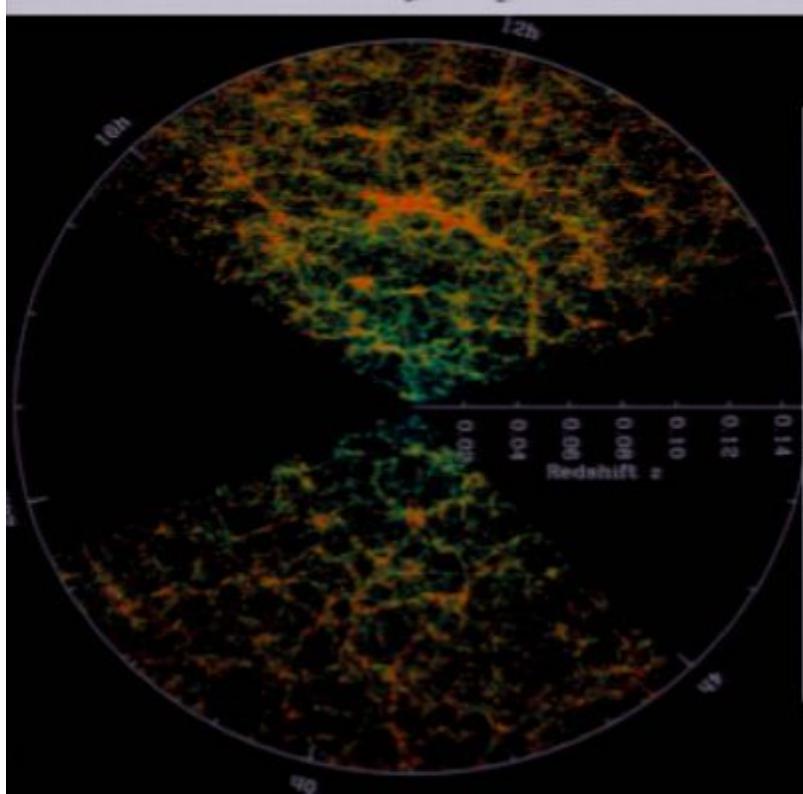
Science Goals: 50 million redshifts

Simultaneous spectroscopic surveys from 2015-2025

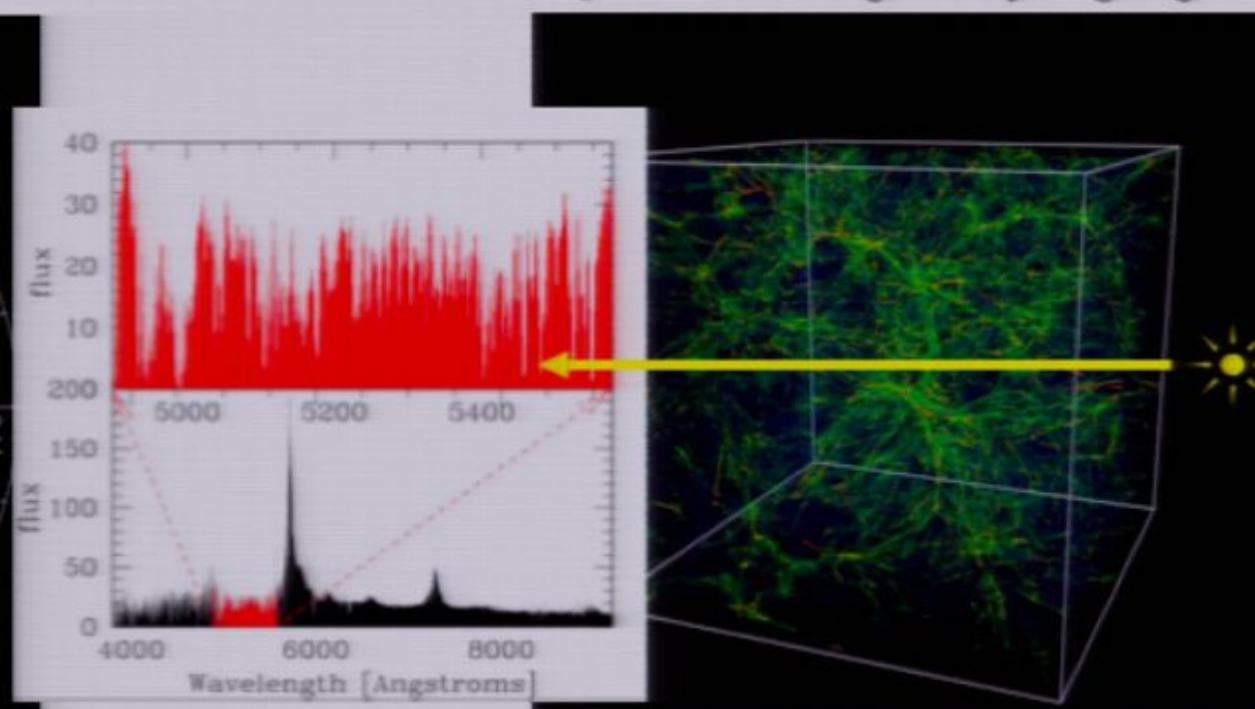
→ BAO from 50 million galaxies at $0.2 < z < 2.0$

→ BAO from 1 million QSOs at $1.8 < z < 3$

Galaxy map



QSOs as back-light to hydrogen gas



Science Goals: BAO and dark energy

	BOSS (Stage III)	BigBOSS- North (Stage IV)	JDEM (Stage IV)	BigBOSS-N+S (Stage IV)
Redshift range	$0 < z < 0.7$	$0 < z < 3.5$	$0.7 < z < 2.0$	$0 < z < 3.5$
Sky Coverage	10000 deg ²	14000 deg ²	20000 deg ²	24000 deg ²
Wavelength Range	360-1000 nm	340-1130 nm	1100–2000 nm	340nm–1130 nm
Spectral Resolution	1600-2600	2300-6100	200	2300-6100
DETF FoM	57	175	250	286
DETF FoM w/Stage III	107	240	313	338



**BigBOSS has same science reach as \$1.7B JDEM satellite
if fielded on both KPNO 4m + CTIO 4m**

Science Goals: Summary

- **“Stage-IV” dark energy experiment from the ground**
 - Higher performance than JDEM-BAO satellite
 - Lower risk + greater flexibility
- **Physics beyond the standard model**
 - More linear modes than CMB == higher sensitivity to non-gaussianity from inflation
- **Enhances future imaging surveys (DES, LSST)**
 - Adds spectroscopic capability, eg. for SNe follow-up
 - Calibrates LSST photo-z's for WL
- **Requires only 4-m telescope time**
 - North: Kitt Peak (4m)
 - South: CTIO (4m)

Instrument: Telescope

Kitt Peak 4-m (Mayall) at Kitt Peak, Arizona

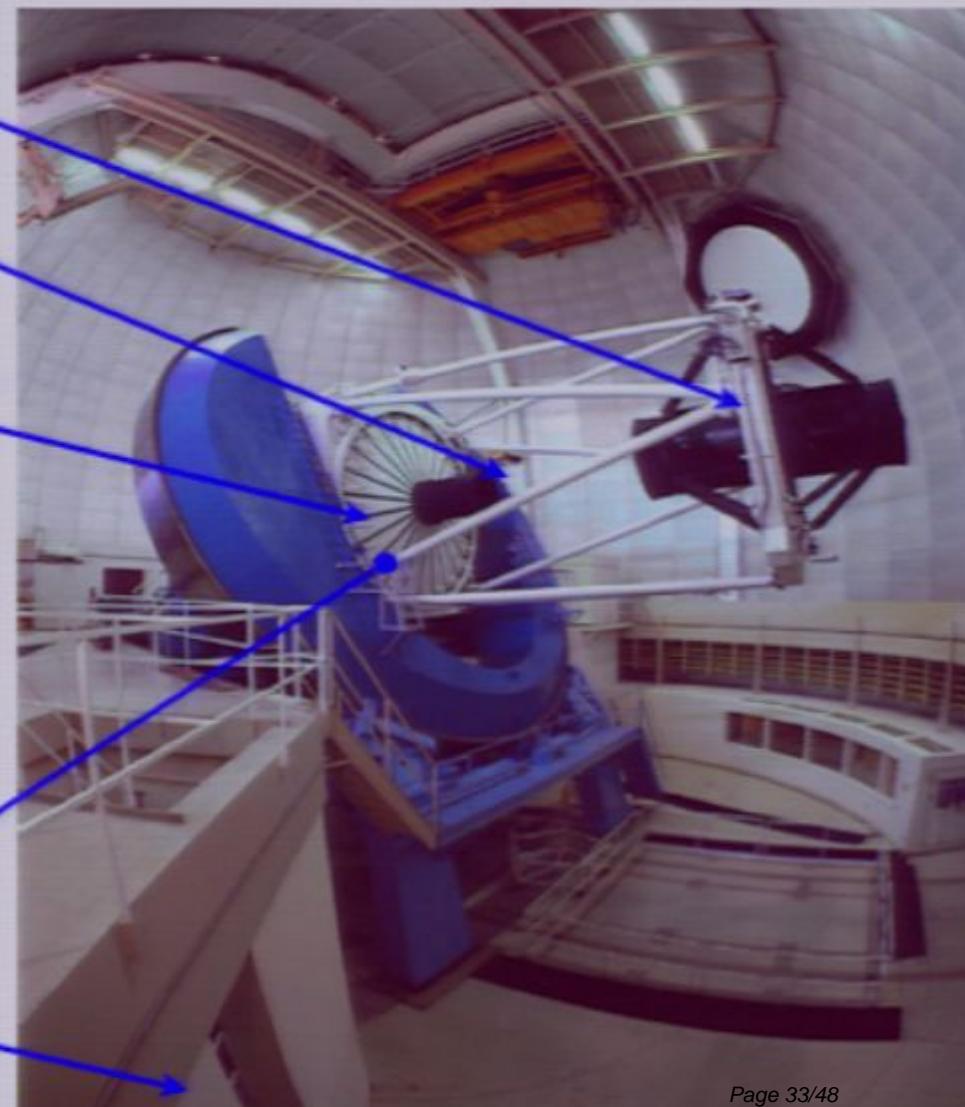
1.5-m f/5 secondary
enables 3° FOV

3-element corrector

5000 fiber positioners on
99-cm focal plane

Fiber run (bare fibers)

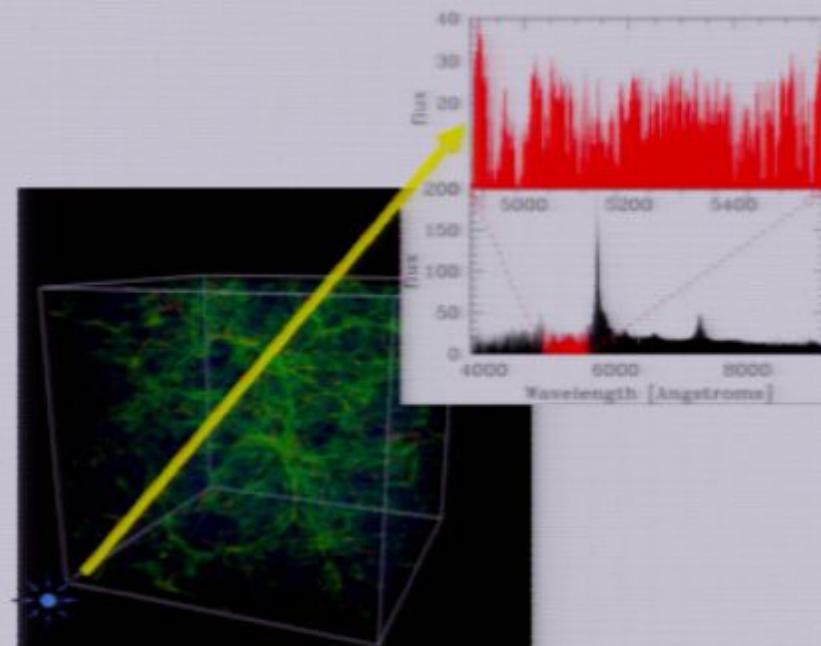
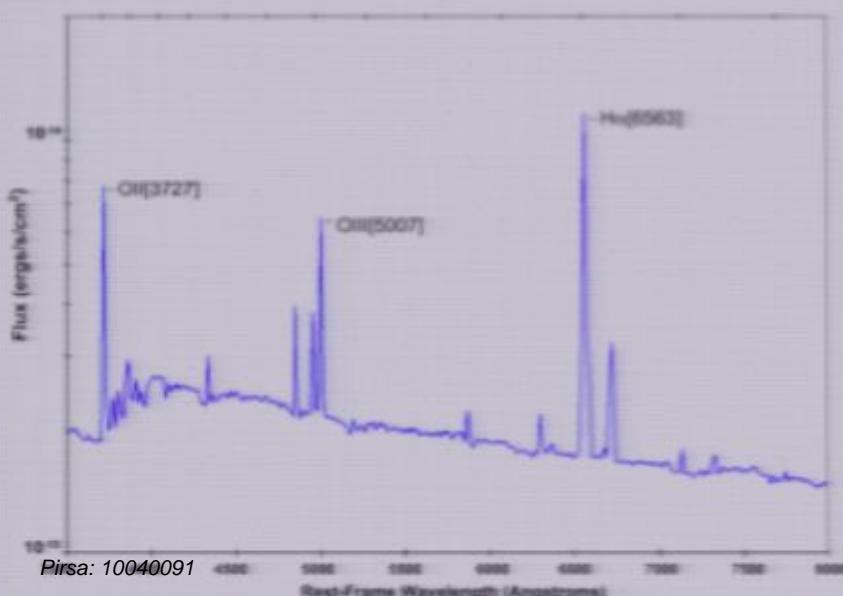
10 spectrographs



Targets:

3 samples

- Luminous Red Galaxies (LRGs):
 - Selected to $z \sim 1$
 - Efficient BAO tracers due to large bias
- Emission-line galaxies:
 - Selected $0.7 < z < 2.0$ at source density of $dn/(dz \text{ deg}^2) = 2000$ (\approx VIPERS)
 - Redshifts from [O II], [O III] emission lines, $R \sim 5000$
- QSOs:
 - Selected $2 < z < 3.5$
 - 3-D density map from Ly-alpha forest



BigBOSS

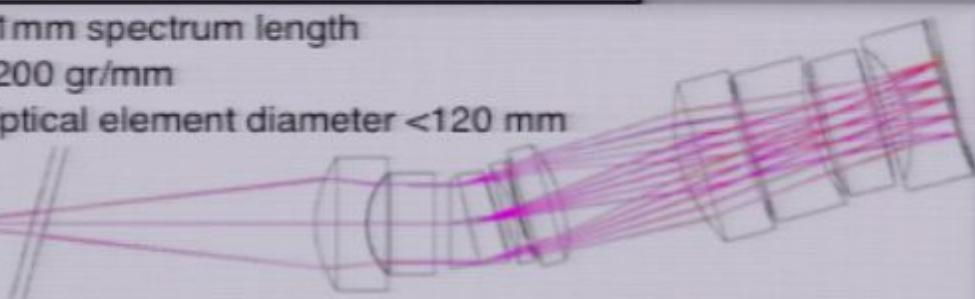
Instrument: Spectrographs

Blue “QSO Ly α channel”
3400-5800 Å at R~3000
e2v CCDs

- 61mm spectrum length

- 1200 gr/mm

- Optical element diameter <120 mm



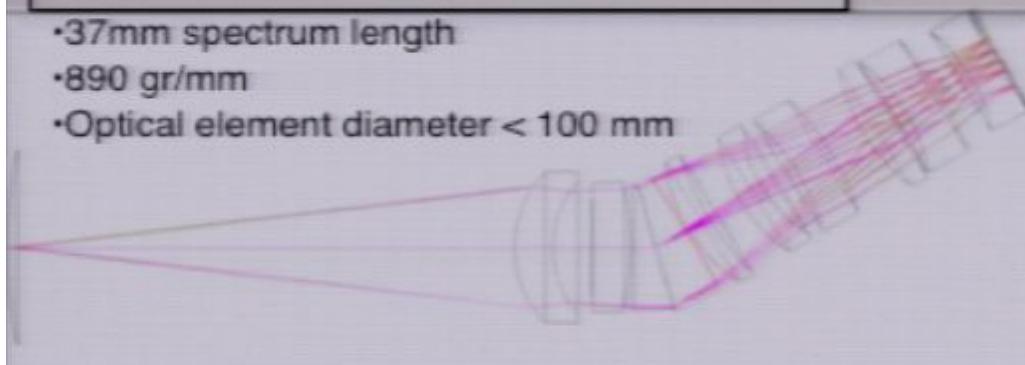
Red “galaxy channel”
8200-11,000 Å at R~5500

LBNL CCDs

- 37mm spectrum length

- 890 gr/mm

- Optical element diameter < 100 mm



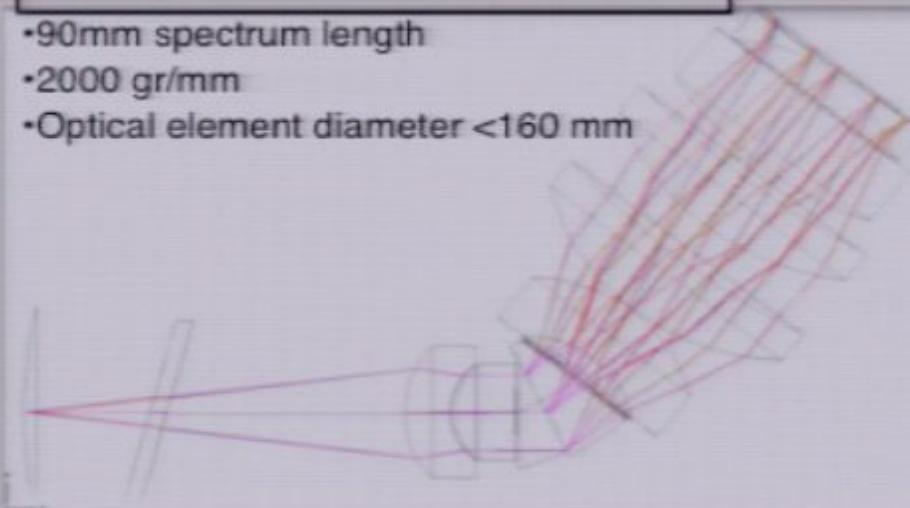
Conceptual design, Eric Prieto (LAM)

Visible “supernova channel”
5400-8600 Å at R~3500
LBNL CCDs

- 90mm spectrum length

- 2000 gr/mm

- Optical element diameter <160 mm



Instrument: Spectrographs x 10

Instrument designed to be a “BAO spectrograph”

Detect emission-line galaxies at $z=0.6 \rightarrow 2.0$

Observed
Spectrum



Sky-Subtracted
Spectrum

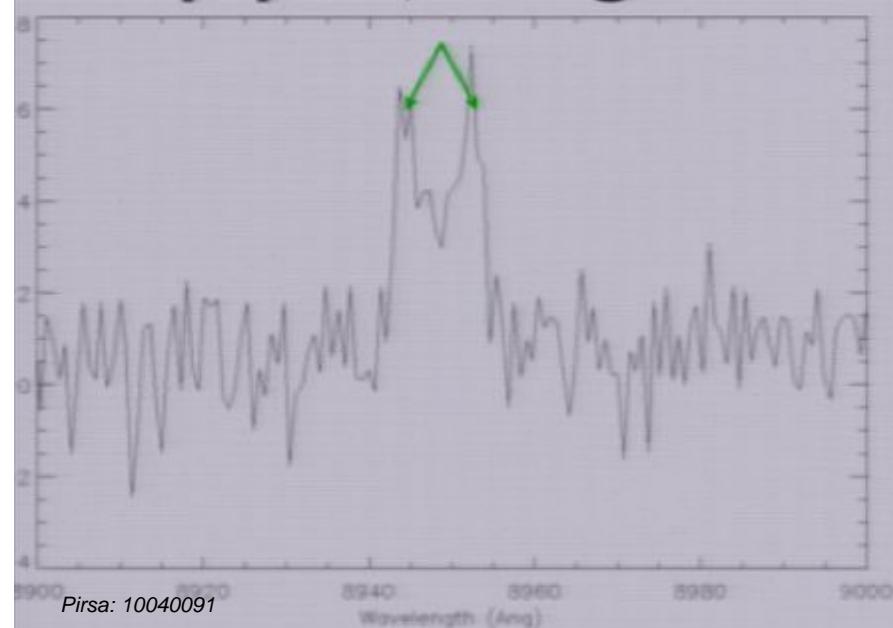


λ —————→



[OII]

[OII] $\lambda 3726, \lambda 3729 @ z=1.4$

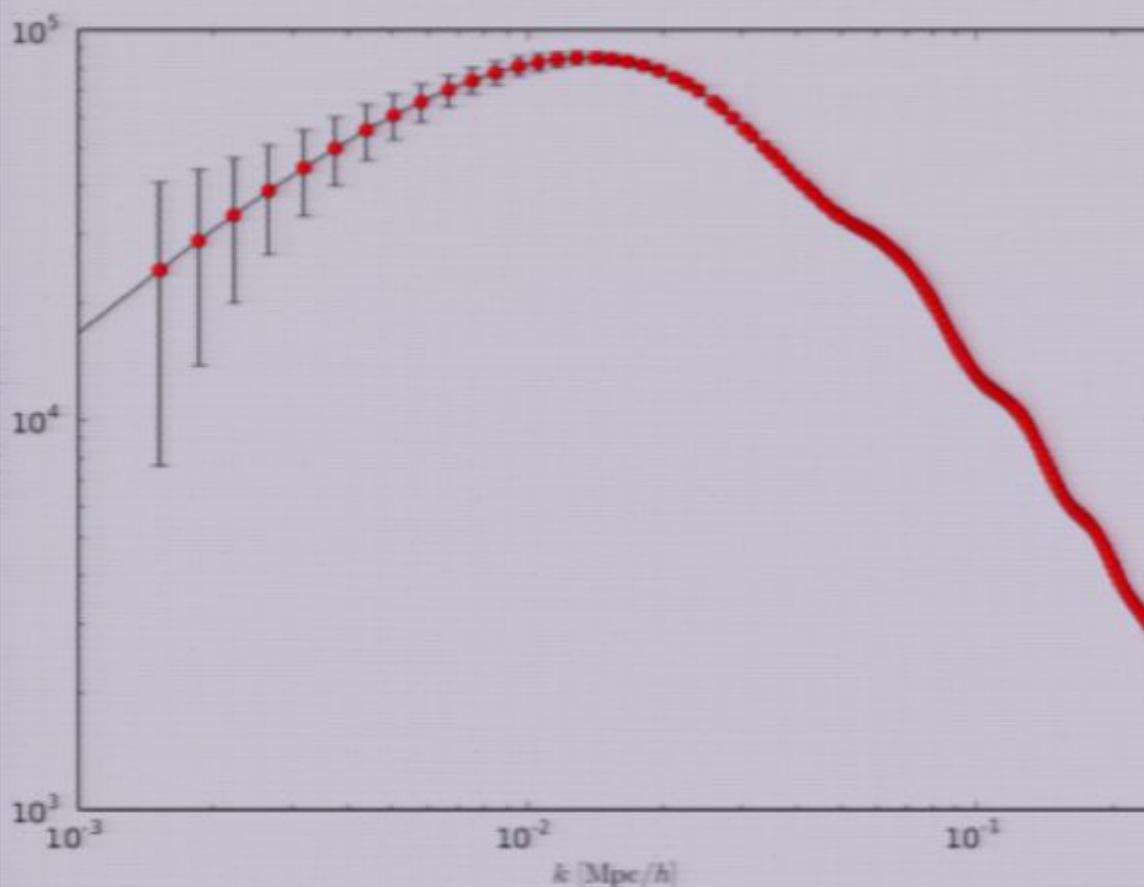


- Advantage 1:** $R > 5000$ allows working between night sky lines
- Advantage 2:** High resolution splits the [OII] doublet

BigBOSS:

Linear power spectrum

Courtesy: Anze Slosar



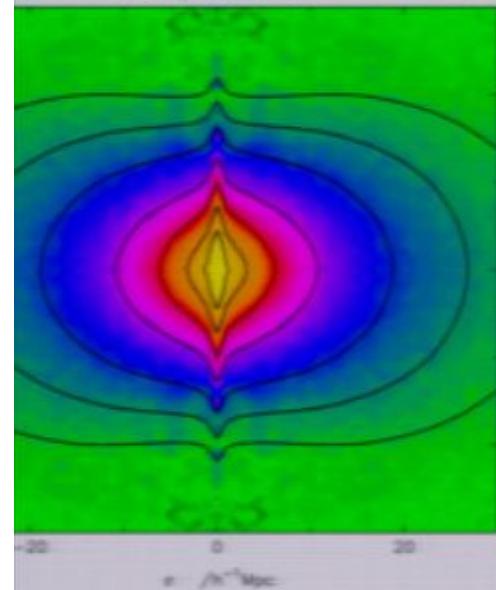
Preliminary:
Errors assume Gaussianity and no systematics

Pirsa: 10040091

- Significant improvements in cosmological parameters from the shape of the linear power spectrum

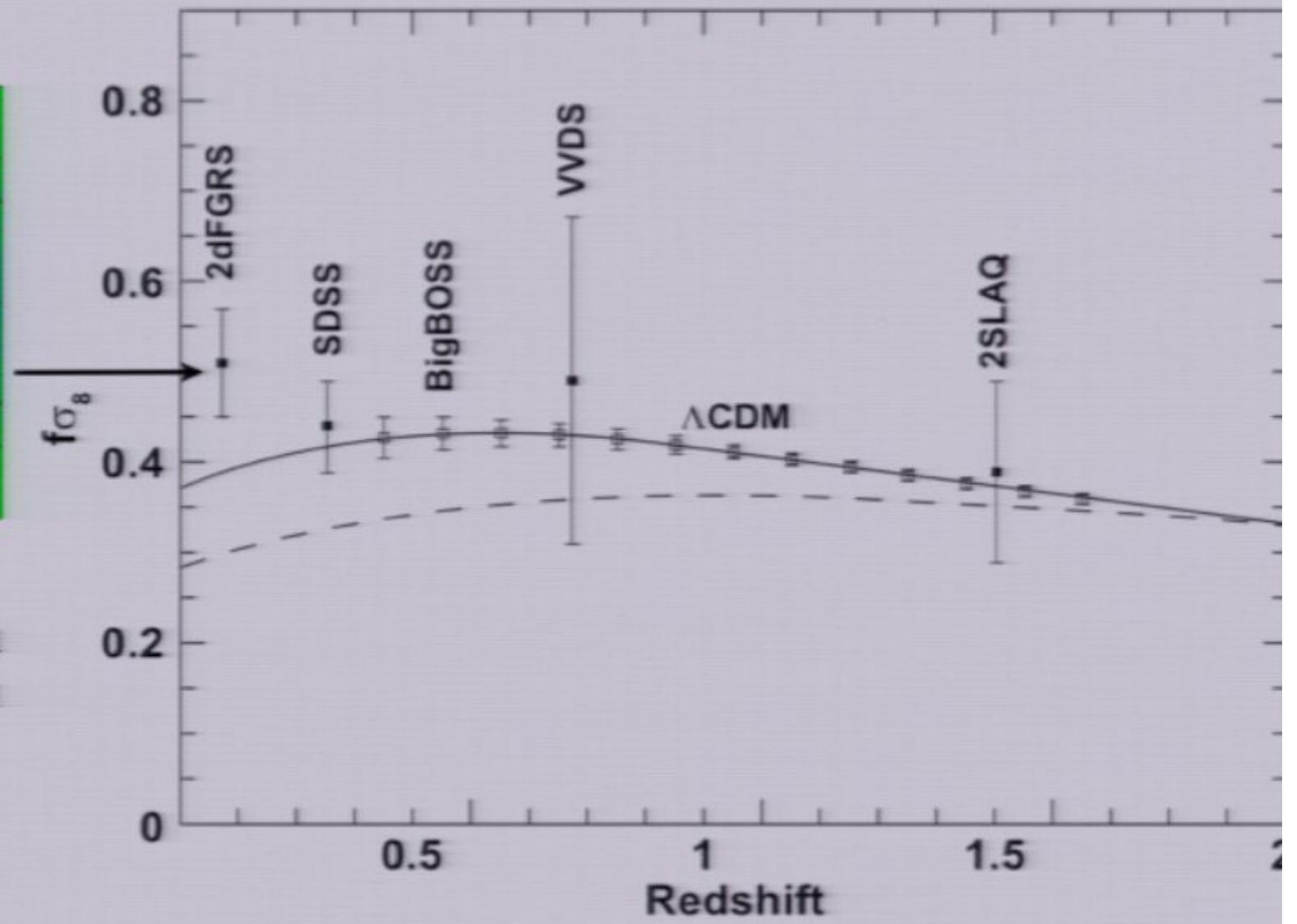
Neutrino mass	0.019 eV 0.018 eV for JDEM (current knowledge >0.05 eV)
Number of relativistic species	0.12 0.11 for JDEM
Curvature	0.0006 Factor 10 better than Planck 0.0005 for JDEM
Spectral index / running	0.0030/0.0018 Factor 6 better than Planck 0.0028/0.0017 for JDEM

Hawkins et al. (2002), astro-ph/0212375
 2dFGRS: $\beta = 0.49 \pm 0.09$



Giant volume, high resolution and high density yields strong RSD measurements

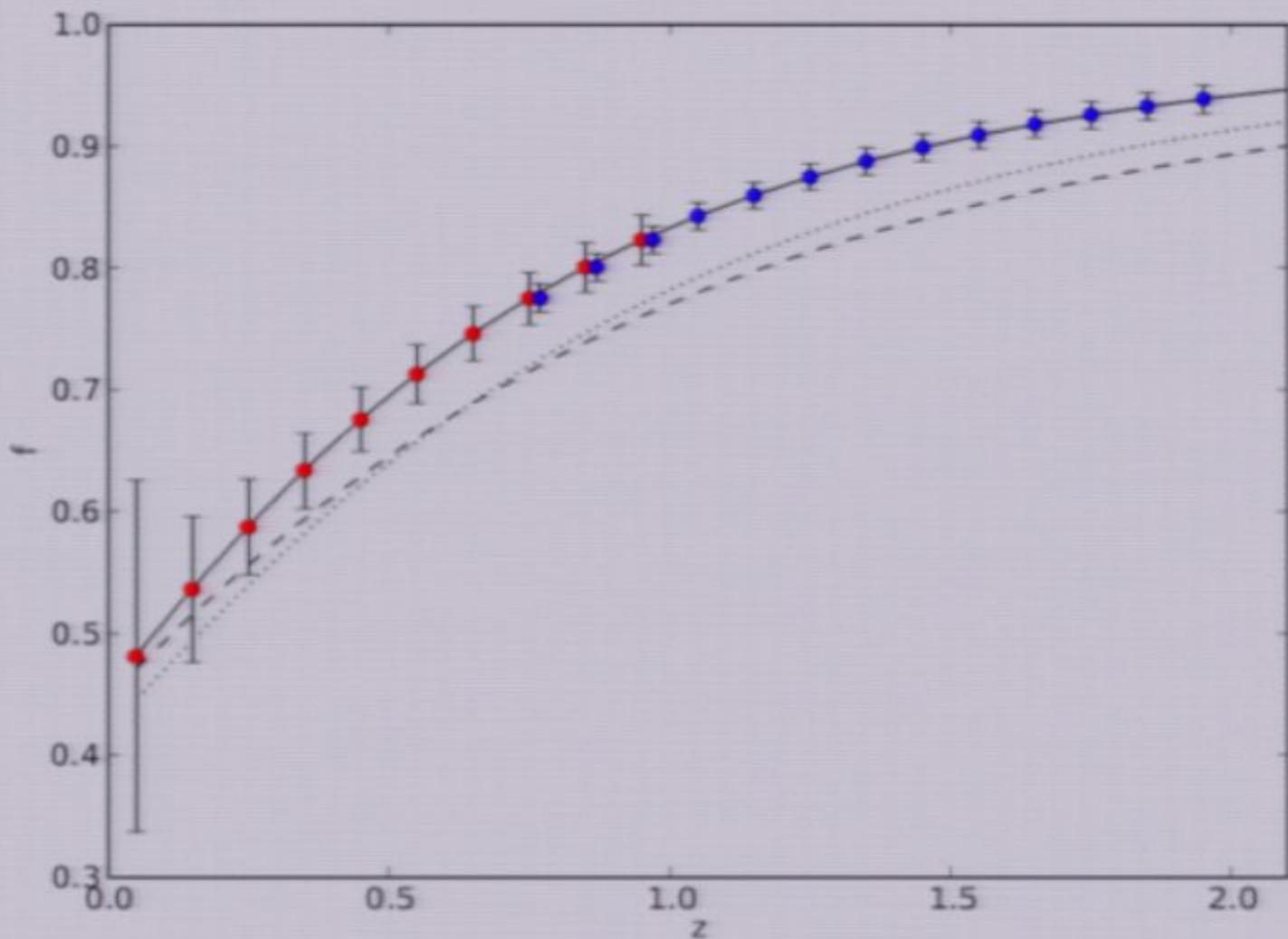
Redshift-space distortions: a new domain



Courtesy: M. White

Redshift-space distortions: a new domain

Multiple samples
(LRGs and
emission line
galaxies) allow for
cross-checks



Courtesy: Anze Slosar, Shirley Ho, Thibaut Louis

BigBOSS:

Non-gaussianity and f_{NL}

BigBOSS inflation constraints beat CMB!

parameterize how much non-linear corrections are there to the potential

$$\Phi = \phi + f_{NL} \Delta\phi^2$$

Primordial potential (assumed to be gaussian random field)

Non-Gaussianity from Inflation

$f_{NL} \sim 0.05$ canonical inflation (single field, couple of derivatives)

(Maldacena 2003, Acquaviva et al 2003)

$f_{NL} \sim 0.1 - 100$ higher order derivatives

DBI inflation (Alishahiha, Silverstein and Tong 2004)

UV cutoff (Craminelli and Cosmol, 2003)

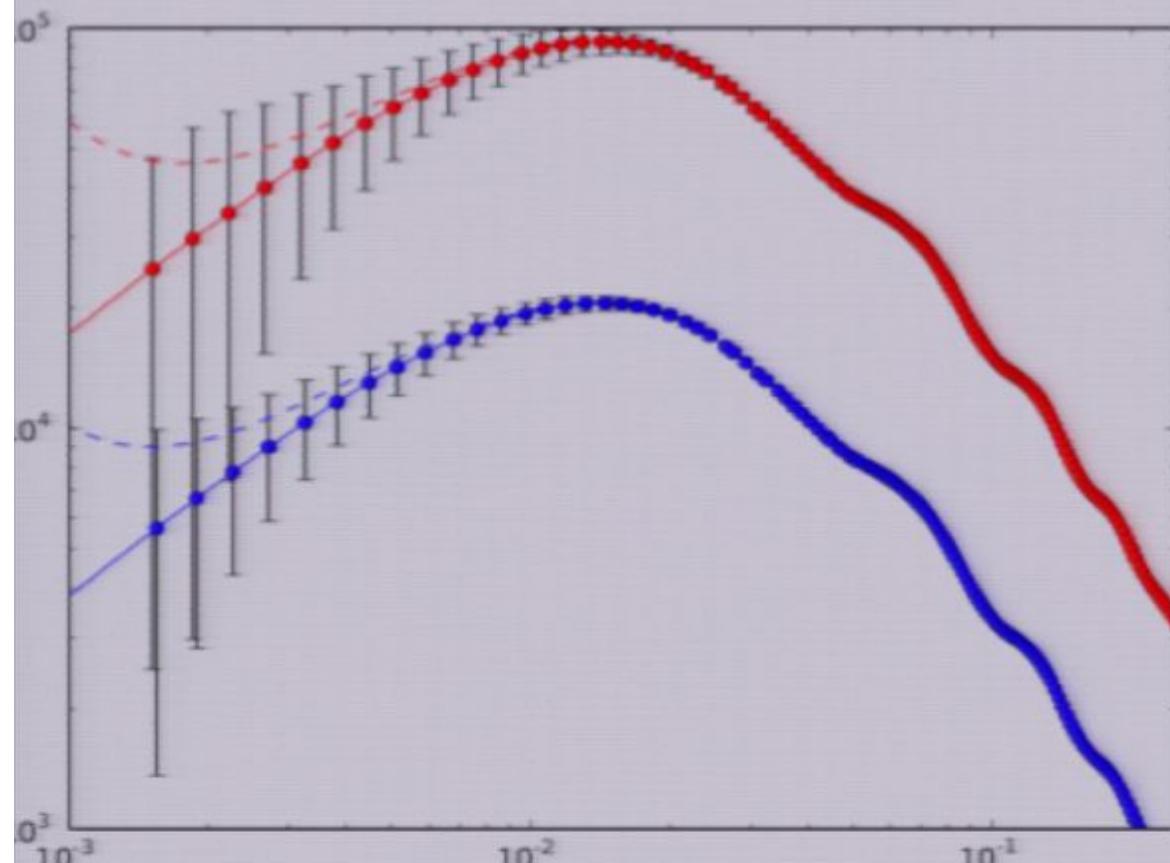
$f_{NL} > 10$ curvaton models (Lyth, Ungarelli and Wands, 2003)

$f_{NL} \sim 100$ ghost inflation (Arkani-Hamed et al., Cosmol, 2004)

Courtesy: Anze Slosar

BigBOSS:

Non-gaussianity and f_{NL}



Courtesy: Anze Slosar

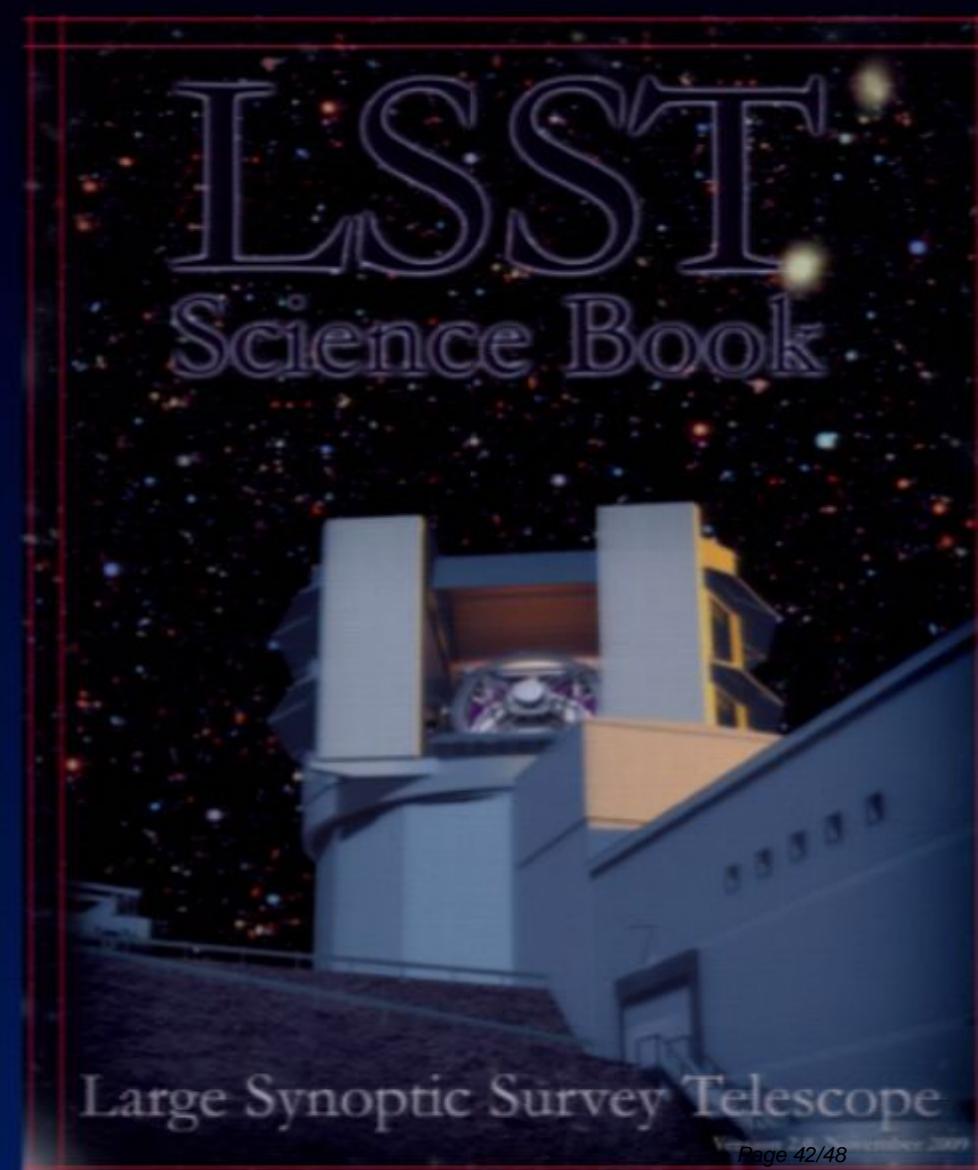
- f_{NL} induces scale-dependent bias
- Big Volume helps!
- Interesting region around $f_{NL} = 1$
- Dashed lines: predictions for $f_{NL} = 5$
- Systematics controlled by having multiple samples with different biases
- Selection function under control

BigBOSS allows systematics checks w/ multiple samples
JDEM-BAO satellite lacks this

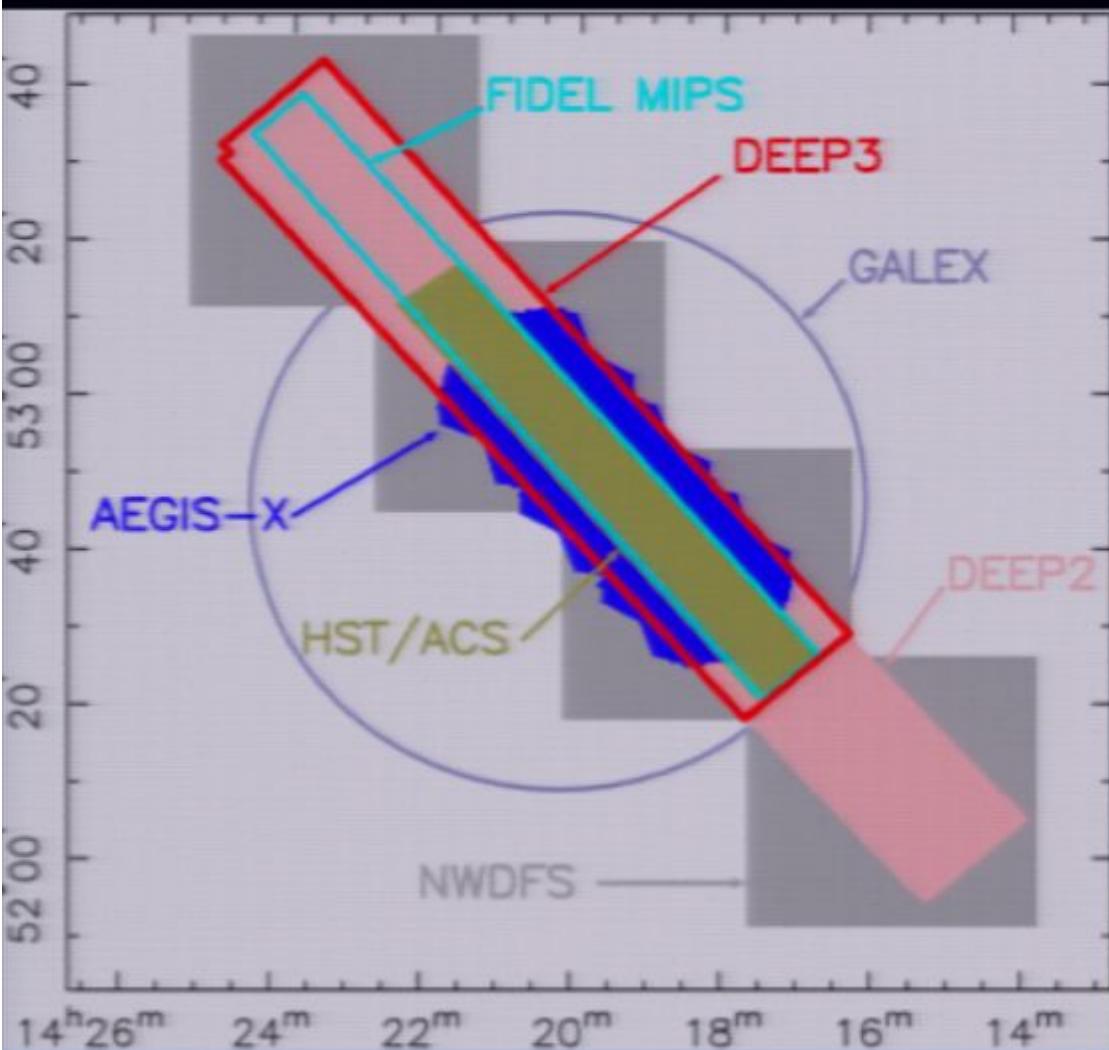
Chapters in the Science Book

- Introduction
- LSST System Design
- System Performance
- Education and Public Outreach

- The Solar System
- Stellar Populations
- Milky Way and Local Volume Structure
- The Transient and Variable Universe
- Galaxies
- Active Galactic Nuclei
- Supernovae
- Strong Lenses
- Large-Scale Structure
- Weak Lensing
- Cosmological Physics



DEEP3



- 18k new spectra, EGS only
- Target the 40% of $R_{AB} < 24.1$ objects DEEP2 missed, plus:
 - All FIDEL *Spitzer* 70 μ m sources
 - All *Chandra* sources down to $R_{AB} \sim 24.5$
 - “Faint extension” of star-forming galaxies down to $R_{AB} \sim 25.5$
- Granted 23 nights & long-term status from UC TAC

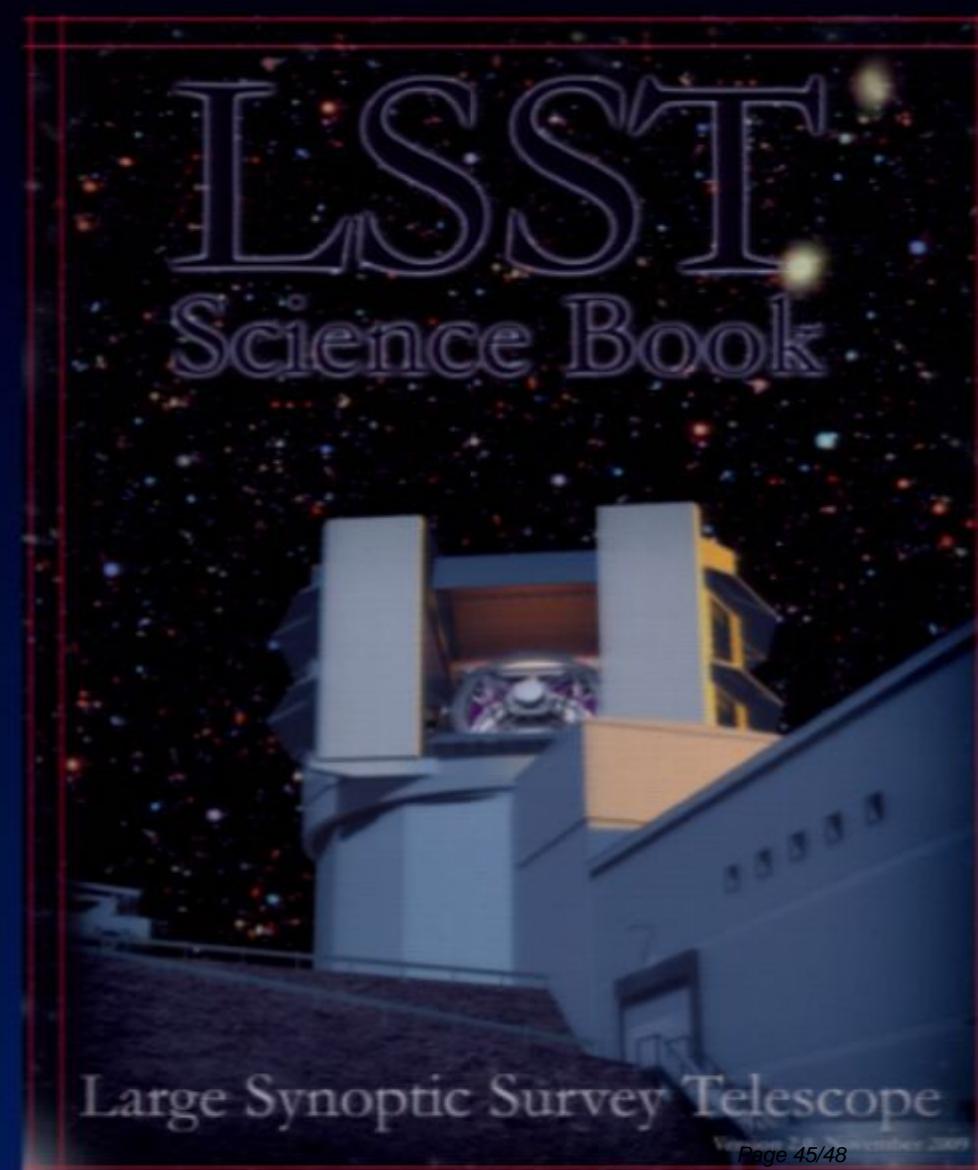
Conclusions

- Be ready: A new generation of LSS surveys are now taking data
- Be careful: these new surveys are entering the domain where systematics are important
- Be creative: these same surveys may be used to constrain fundamental physics in novel ways, e.g. testing for fine structure constant variation
- Be optimistic: LSST & BigBOSS will bring us close to the sample/cosmic variance to $z \sim 2.5$
- If you're interested in galaxy evolution, ask me about DEEP3, AEGIS, or CANDELS...

Chapters in the Science Book

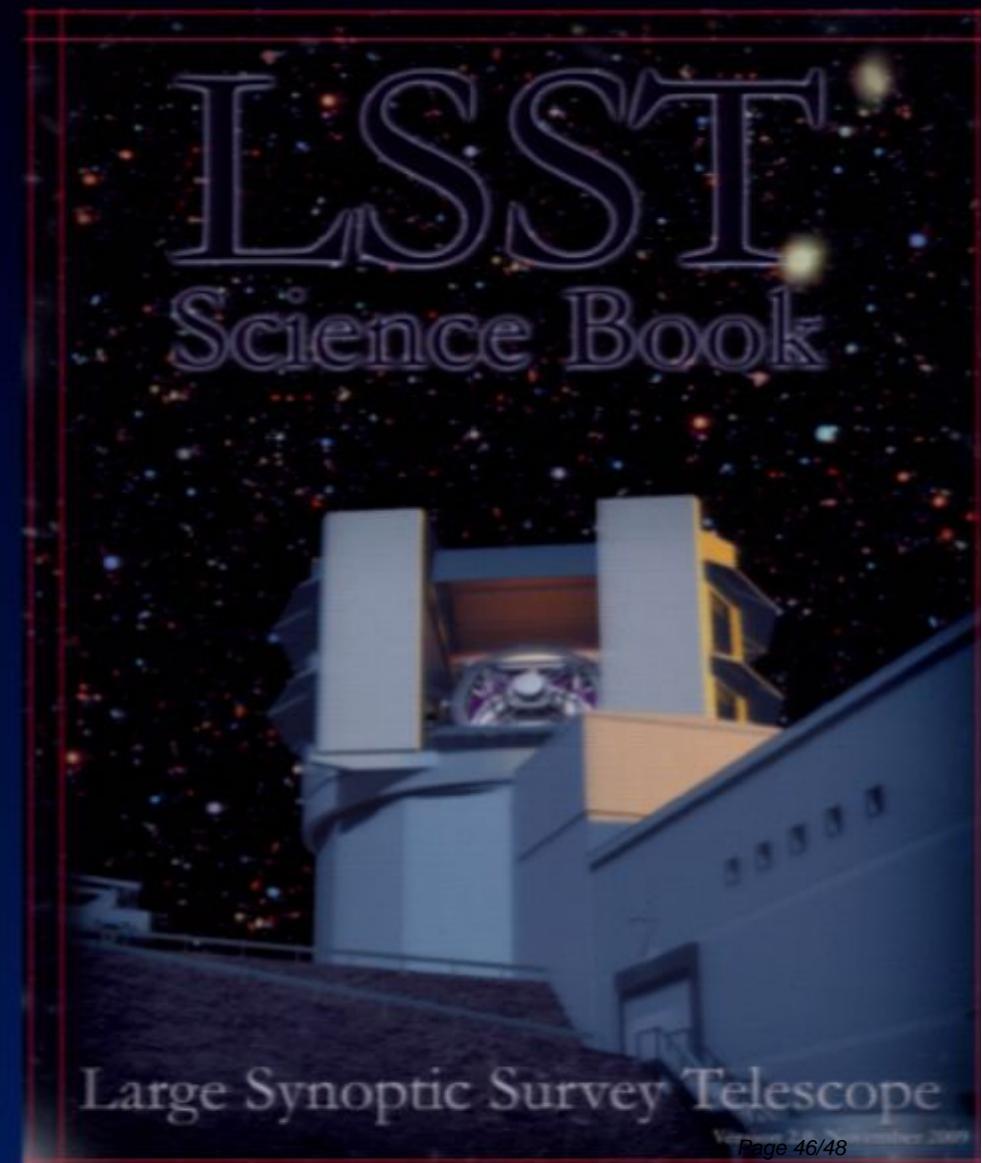
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LSST Update

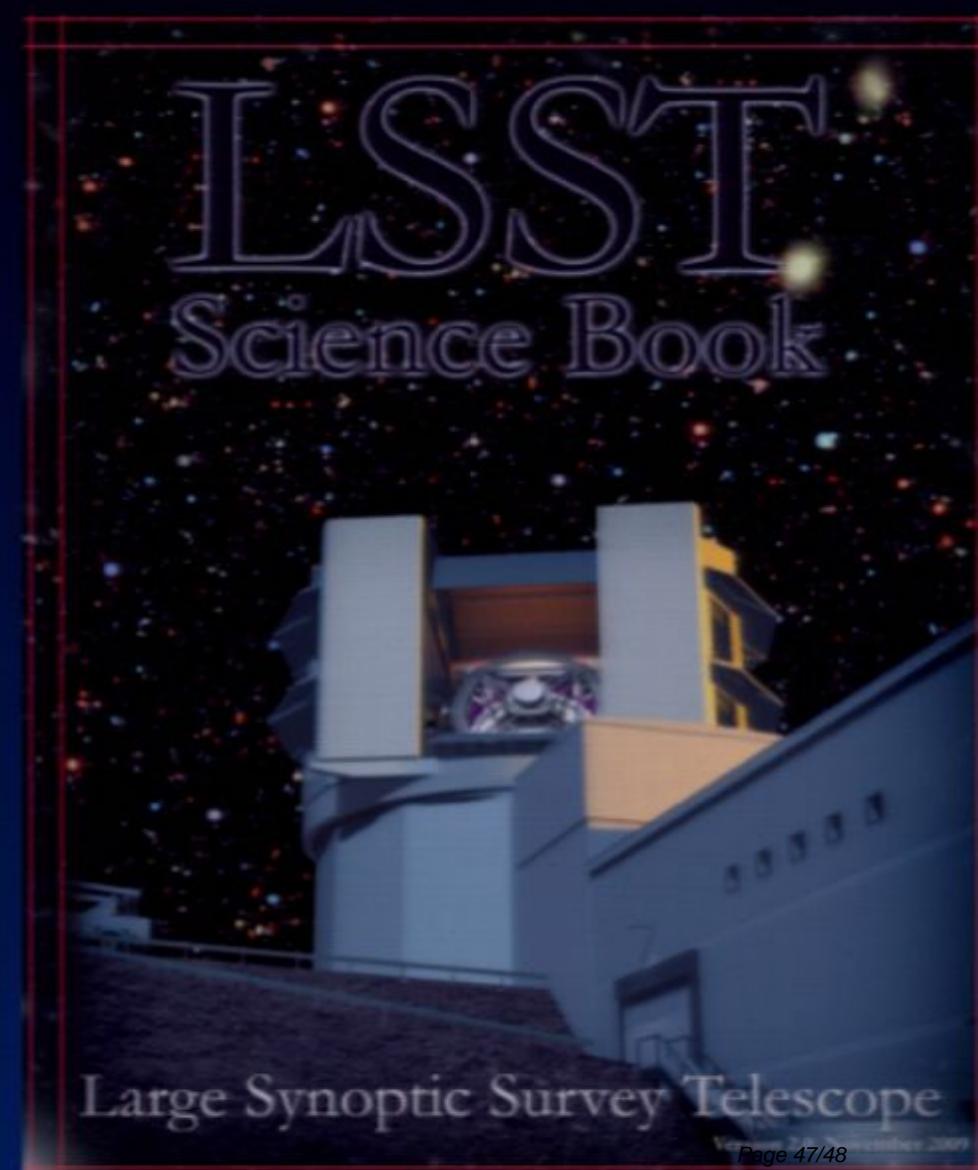
- LSST Science Book:
 - 245 authors
 - 598 pages
 - Living document
(on lsst.org)



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LSST timeline

