The Future of BAO with BOSS, eBOSS, and DESI

Stephen Bailey
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Rencontres du Vietnam
2 August 2013

Thanks to:
BOSS Galaxy Clustering Group, and
Daniel Eisenstein, David Schlegel,
Nikhil Padmanabhan, David Kirkby, & J.P. Kneib

Astrophysics > Instrumentation and Methods for Astrophysics

The Tenth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the SDSS-III Apache Point Observatory Galactic Evolution Experiment

Christopher P. Ahn, Rachael Alexandroff, Carlos Allende Prieto, Friedrich Anders, Scott F. Anderson, Timothy Anderton, Brett H. Andrews, Éric Aubourg, Stephen Bailey, Fabienne A. Bastien, Julian E. Bautista, Timothy C. Beers, Alessandra Beifiori, Chad F. Bender, Andreas A. Berlind, Florian Beutler, Vaishali Bhardwaj, Jonathan C. Bird, Dmitry Bizyaev, Cullen H. Blake, Michael R. Blanton, Michael Blomqvist, John J. Bochanski, Adam S. Bolton, Arnaud Borde, Jo Bovy, Alaina Shelden Bradley, W. N. Brandt, Dorothée Brauer, J. Brinkmann, Joel R. Brownstein, Nicolás G. Busca, William Carithers, Joleen K. Carlberg, Aurelio R. Carnero, Michael A. Carr, Cristina Chiappini, S. Drew Chojnowski, Chia-Hsun Chuang, Johan Comparat, Justin R. Crepp, Stefano Cristiani, Rupert A.C. Croft, Antonio J. Cuesta, et al. (188 additional authors not shown)

(Submitted on 29 Jul 2013)

The Sloan Digital Sky Survey (SDSS) has been in operation since 2000 April. This paper presents the tenth public data release (DR10) from its current incarnation, SDSS-III. This data release includes the first spectroscopic data from the Apache Point Observatory Galaxy Evolution Experiment (APOGEE), along with spectroscopic data from the Baryon Oscillation Spectroscopic Survey (BOSS) taken through 2012 July. The APOGEE instrument is a near-infrared R~22,500 300-fiber spectrograph covering 1.514--1.696 microns. The APOGEE survey is studying the chemical abundances and radial velocities of roughly 100,000 red giant star candidates in the bulge, bar, disk, and halo of the Milky Way. DR10 includes 178,397 spectra of 57,454 stars, each typically observed three or more times, from APOGEE. Derived quantities from these spectra (radial velocities, effective temperatures, surface gravities, and metallicities) are also included.DR10 also roughly doubles the number of BOSS spectra over those included in the ninth data release. DR10 includes a total of 1,507,954 BOSS spectra, comprising 927,844 galaxy spectra; 182,009 quasar spectra; and 159,327 stellar spectra, selected over 6373.2 square degrees.

Astrophysics > Instrumentation and Methods for Astrophysics

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Released on Wednesday
~2x more BOSS data
First APOGEE data release
sdss3.org/dr10

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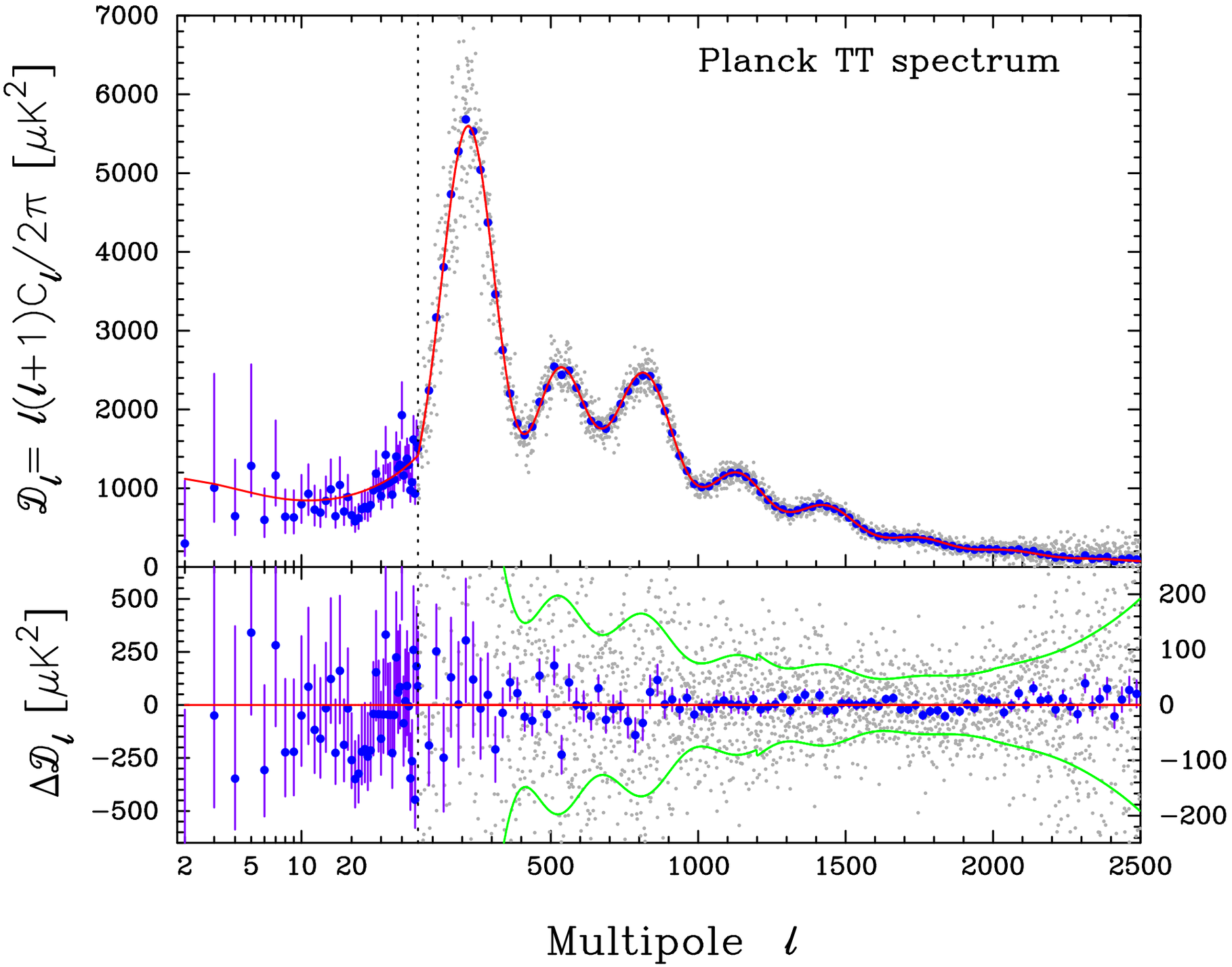
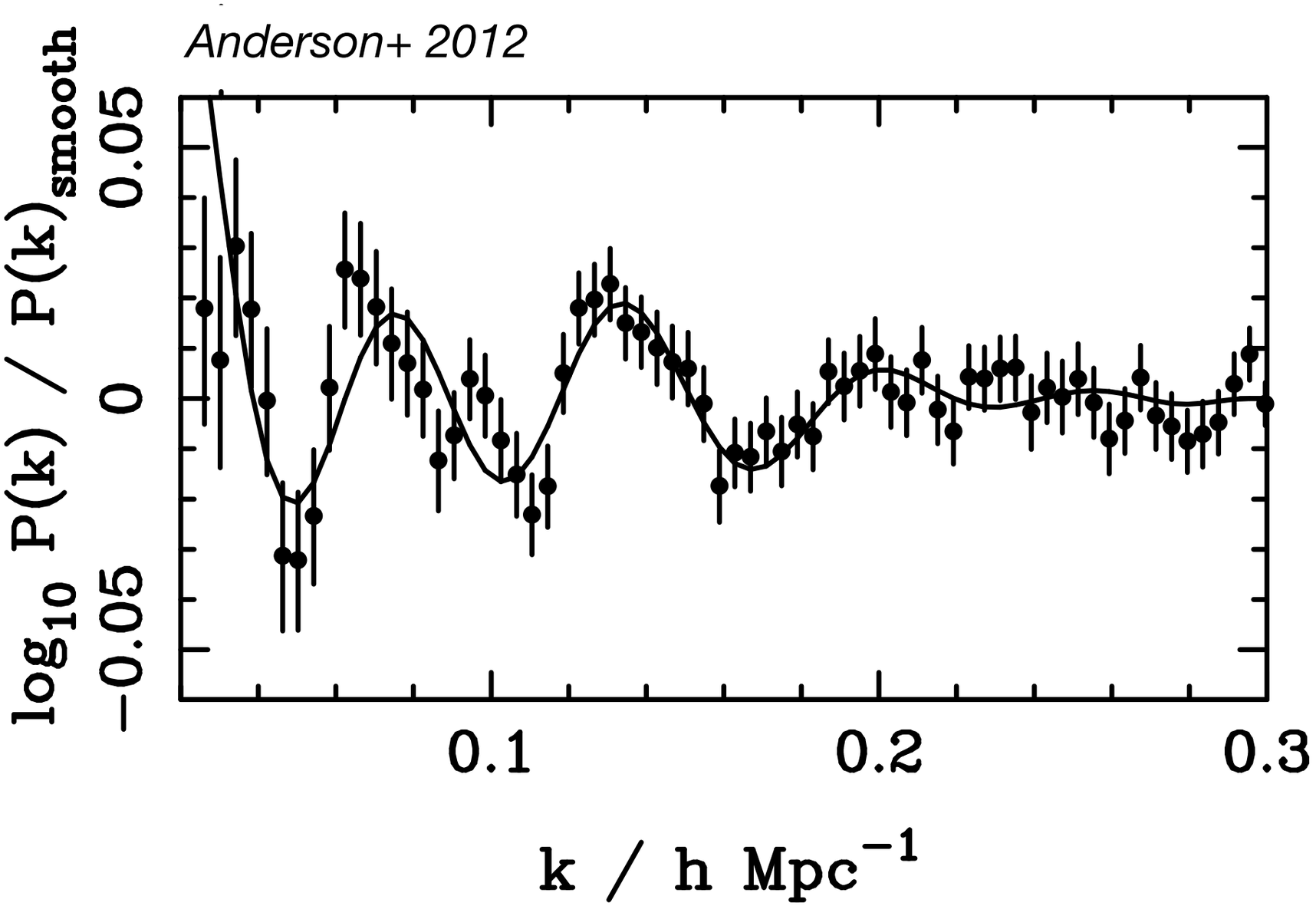
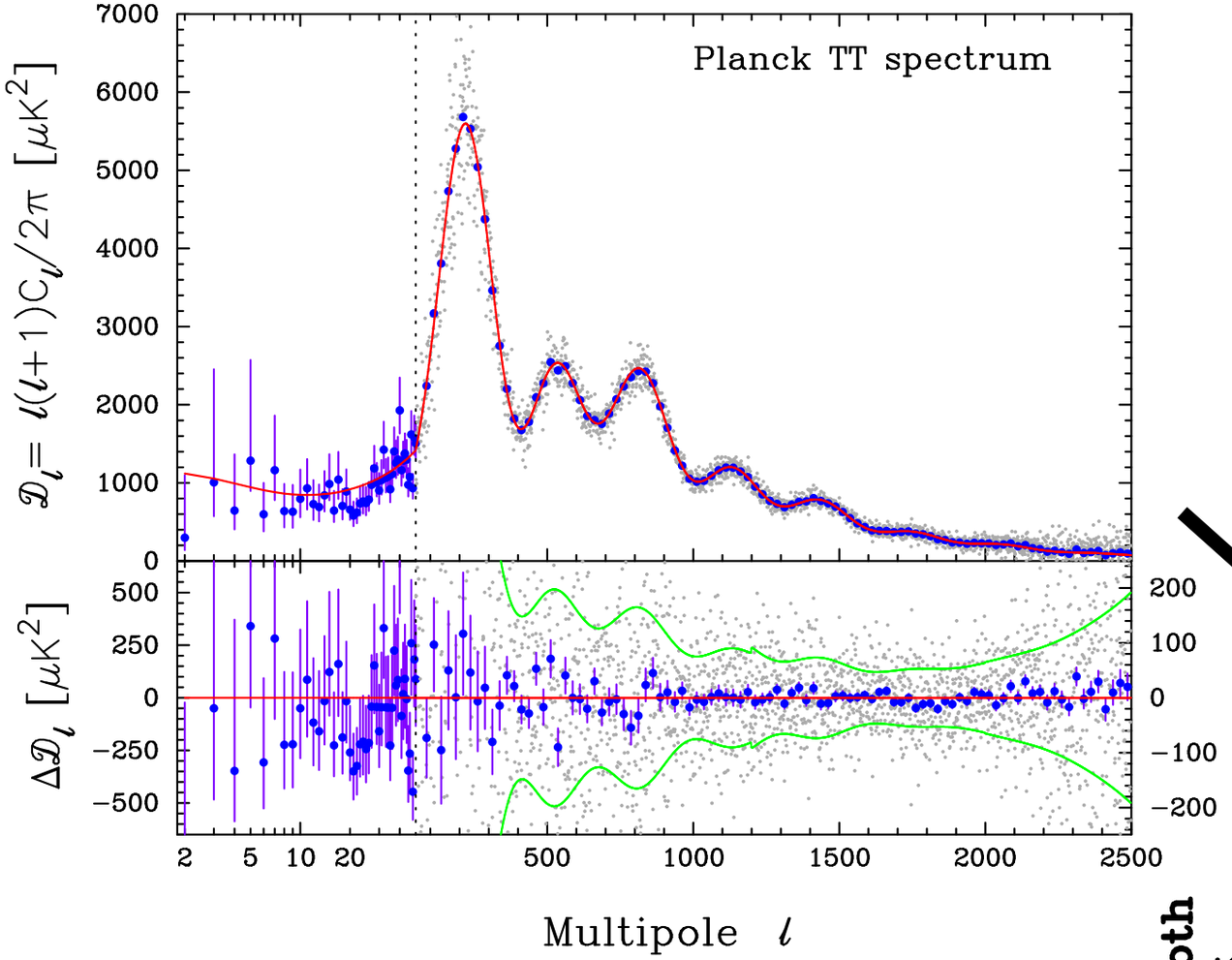
Planck 2013 @ z~1100

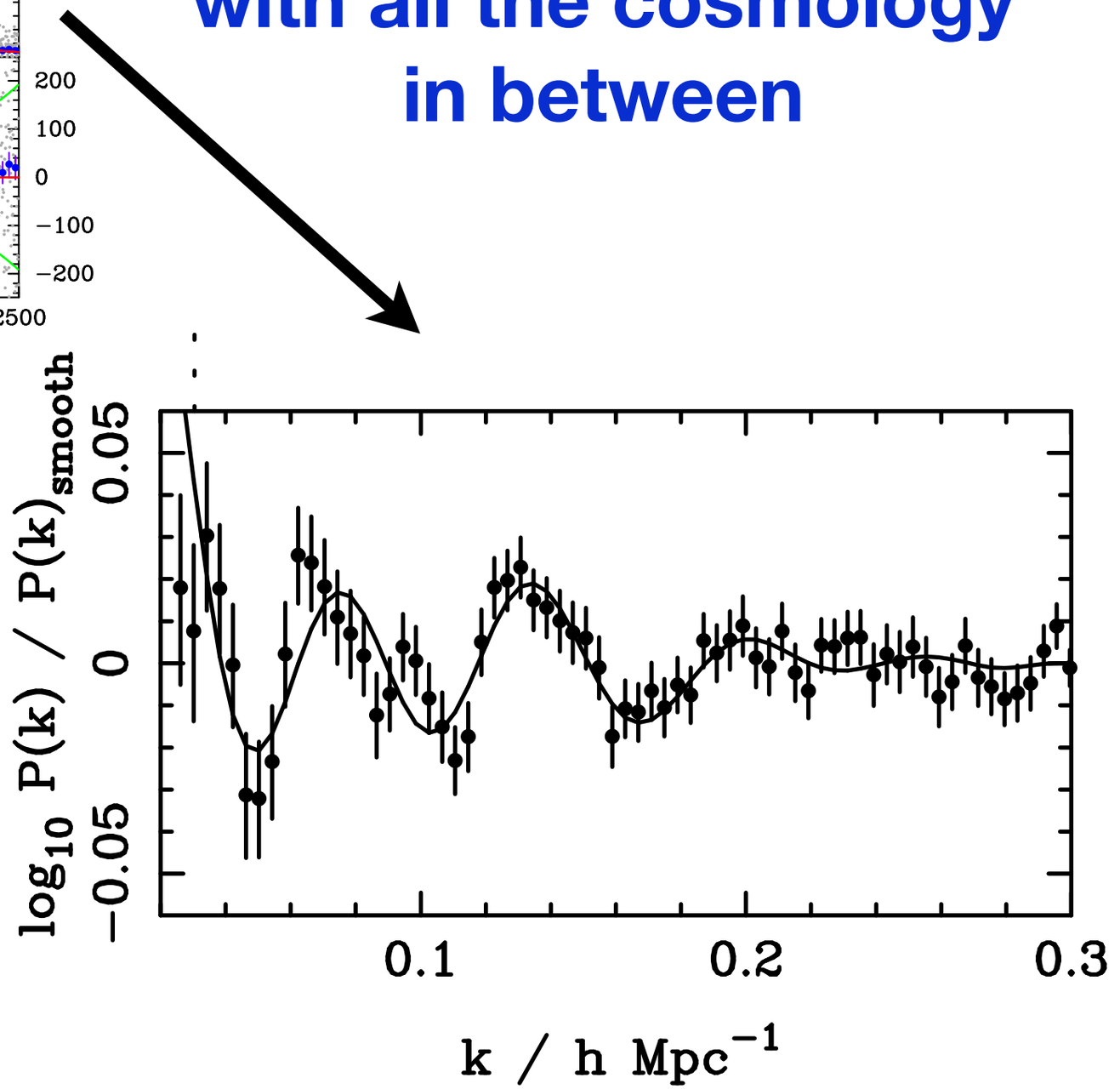


BOSS 2012 @ z~0.57





BAO connects the high-z and low-z universe, with all the cosmology in between



BOSS: Baryon Oscillation Spectroscopic Survey

3rd Generation of Sloan Digital Sky Survey

Spectra of:

- 1.5M galaxies
- 160k quasars

2.5m telescope at Apache Point Observatory

Improvements from SDSS-I & II

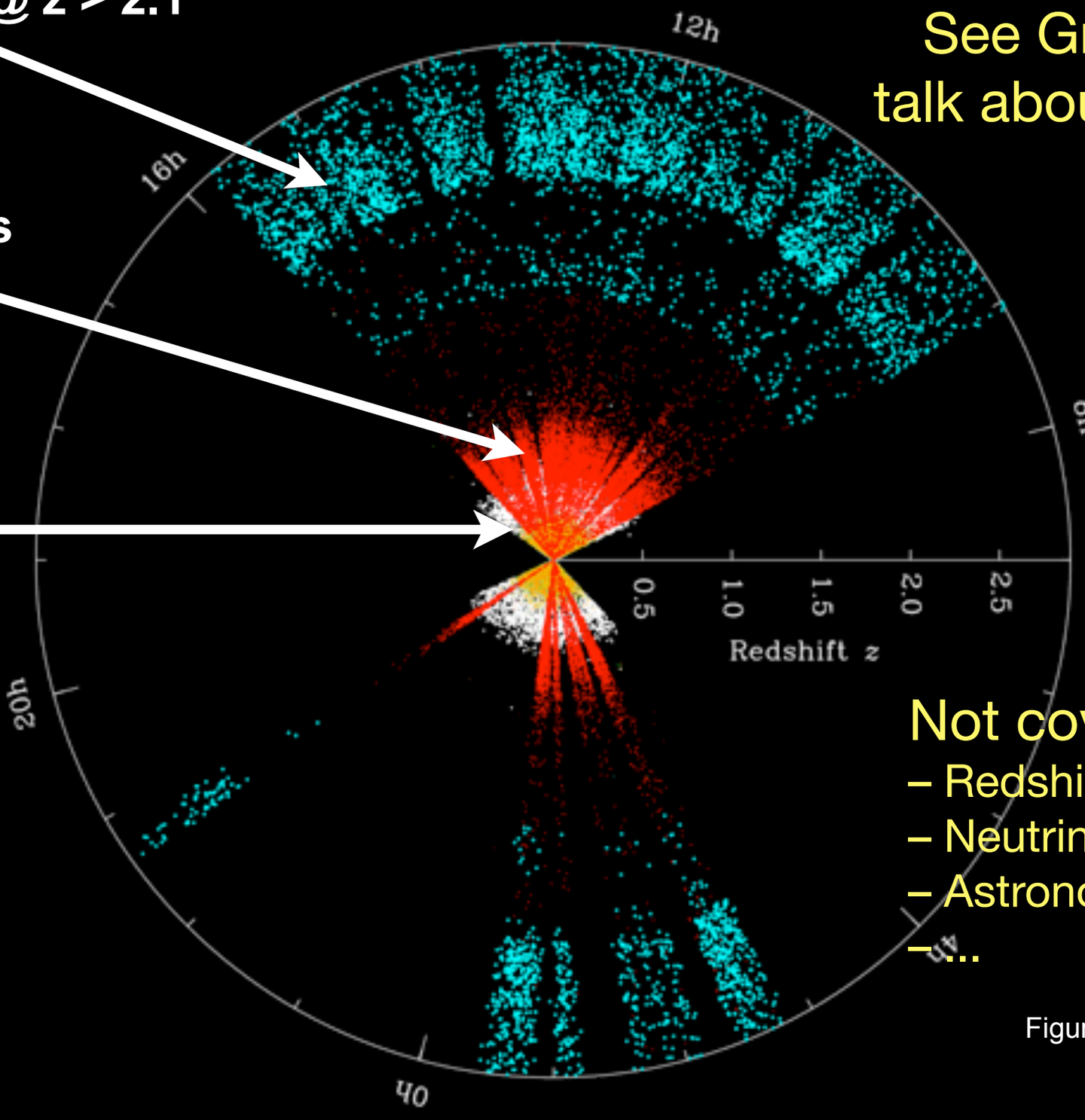
- More sky area (7600 → 10800 deg^2)
- Deeper redshifts ($z \sim 0.5 \rightarrow 0.7$)
- Better instrument throughput
- Denser sampling (640 →1000 spectra per exposure)

BOSS BAO Key Project

BOSS QSOs @ z > 2.1
160,000
(sparse map)

BOSS galaxies
1.5 million
(dense map)

SDSS DR7



See Graziano Rossi's talk about QSO/Lyα BAO

Not covered today:
– Redshift space distortions
– Neutrino masses
– Astronomy
–...

Figure: Michael Blanton

Plate Plugging

- 3° diameter FOV
- Each field has a unique plate drilled with target positions
- 1000 fibers per plate plugged by hand

Plates are mounted on carts & changed for each field

Up to 9 fields per night

~2200 fields in full survey

BOSS Data

1000 spectra at a time

- 500 per spectrograph, 2 channels covering 3600Å – 10000Å
- ~5 exposures x 15 minutes each
  - Repeat exposures until enough S/N

Quick extractions for quality control within a few minutes

- Dynamically adjust number of exposures to match conditions

Full extractions daily

- Raw data –> spectra –> classification, redshift
- Starts within 15 minutes of data arriving

SDSS Data Releases each year

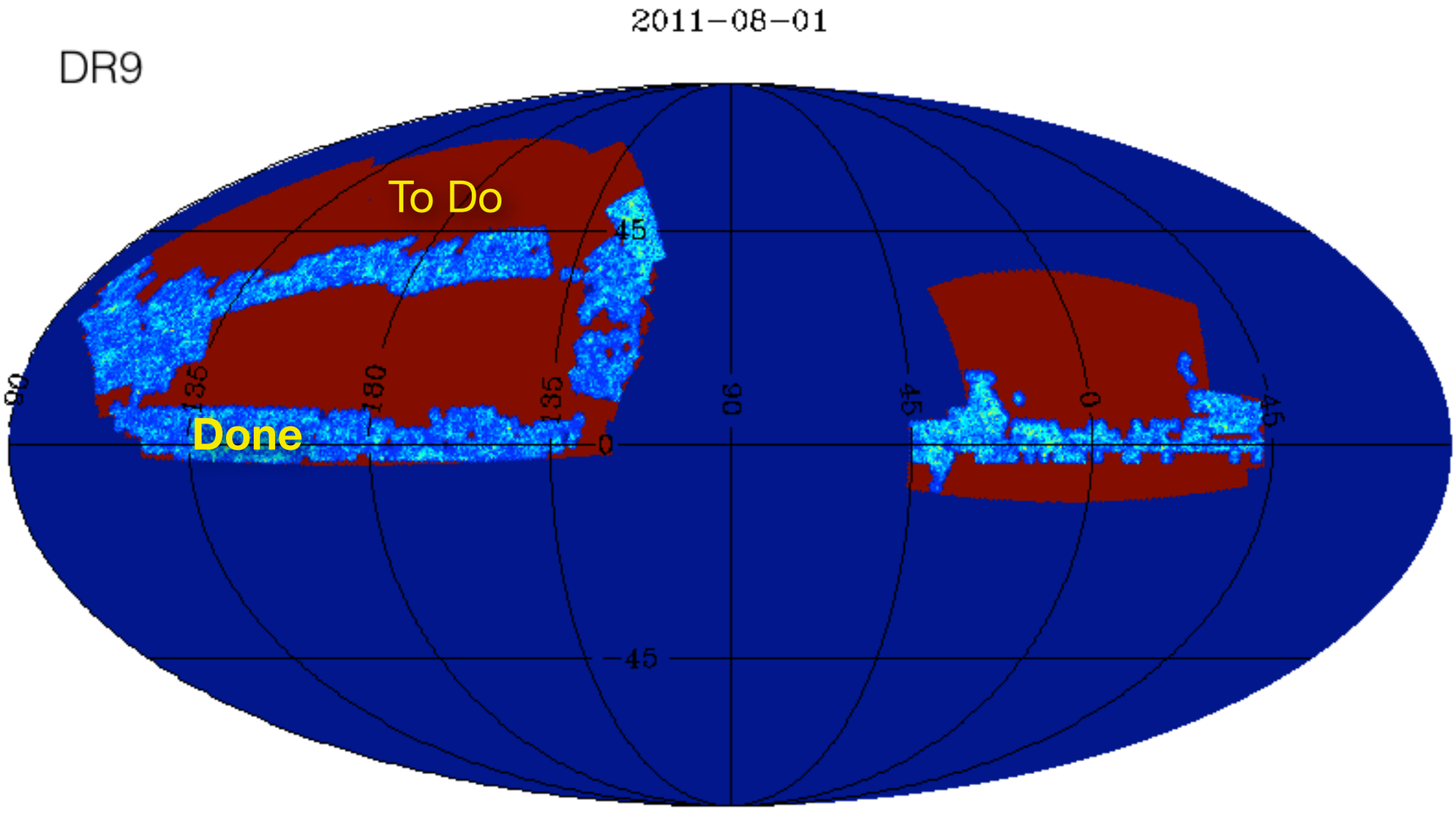
- DR9 : July 2012, ~1/3 of BOSS data
- DR10 : July 2013, ~2/3 of BOSS data
- DR11, DR12 : December 2014

~3/4 of papers on SDSS data are not from the SDSS collaboration. This is good!

sdss3.org/dr10

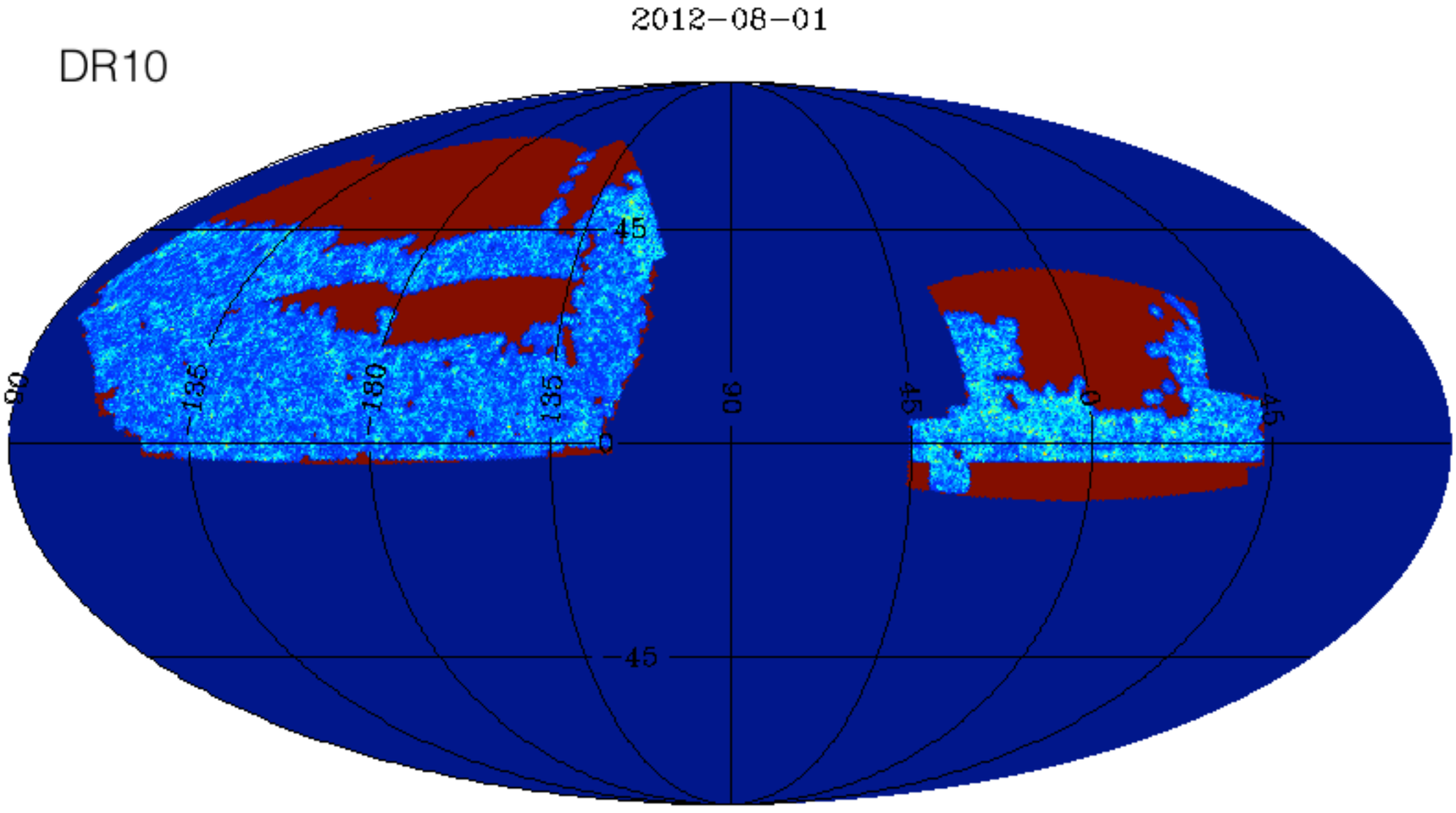
Data Release 9: July 2012

Current BOSS papers based upon this dataset



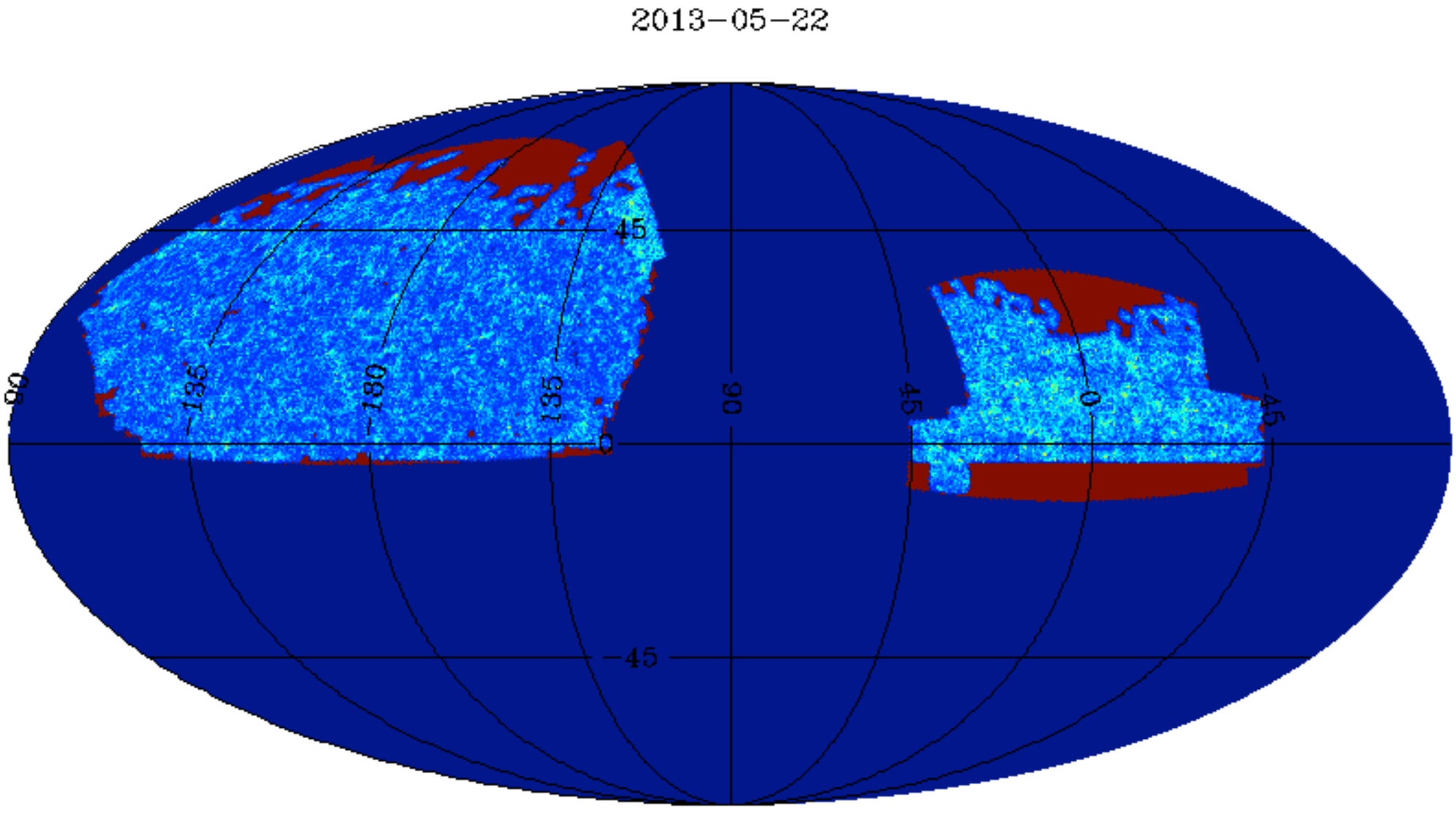
Data Release 10: July 2013

Data released 2 days ago;
still working on the science papers...



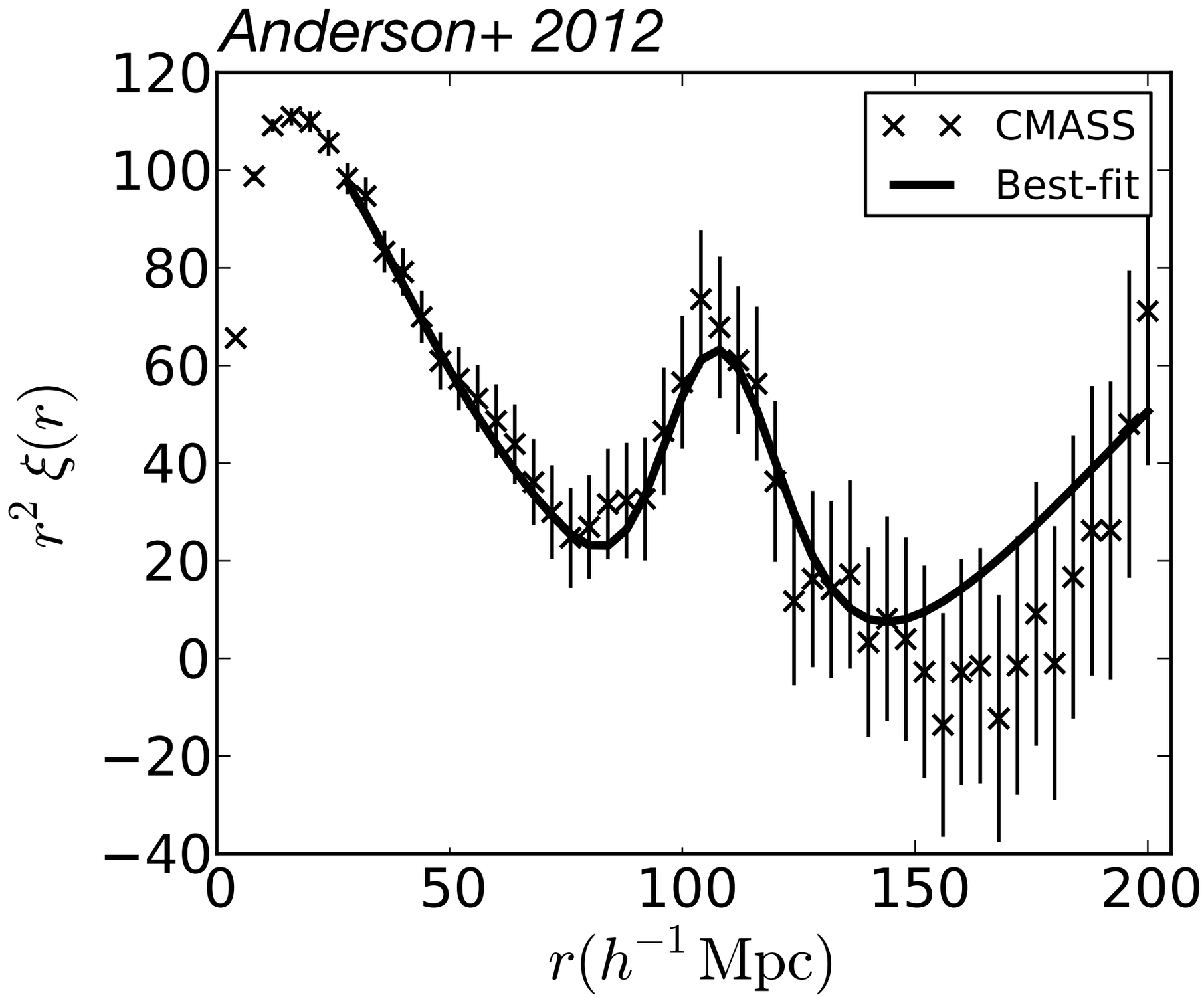
Data Release 11: Dec 2014

Data already taken and processed:
BOSS results this fall will be DR10+DR11 results



BOSS is on schedule to finish early (~Feb 2014)

~1/3 of BOSS Data



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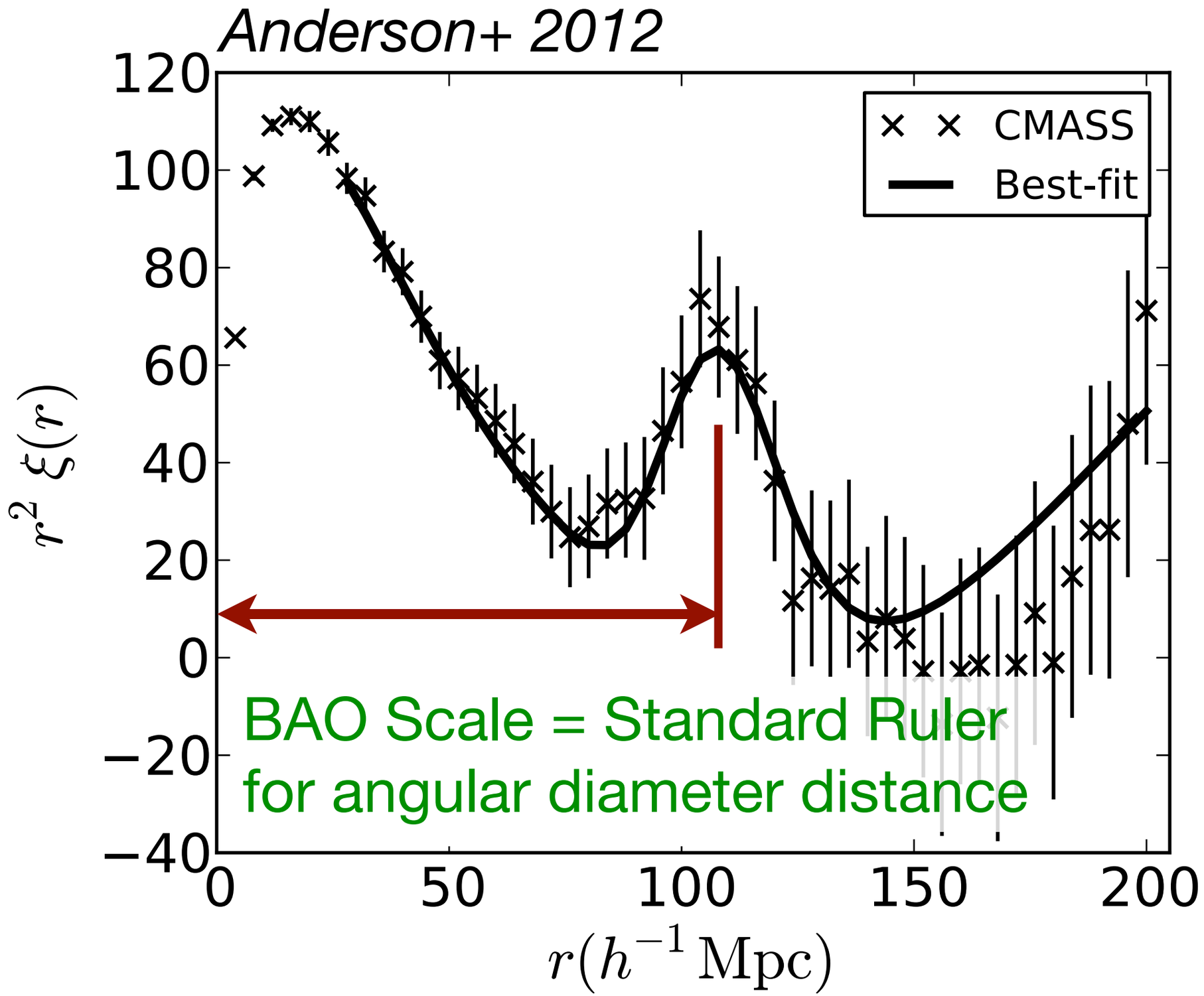
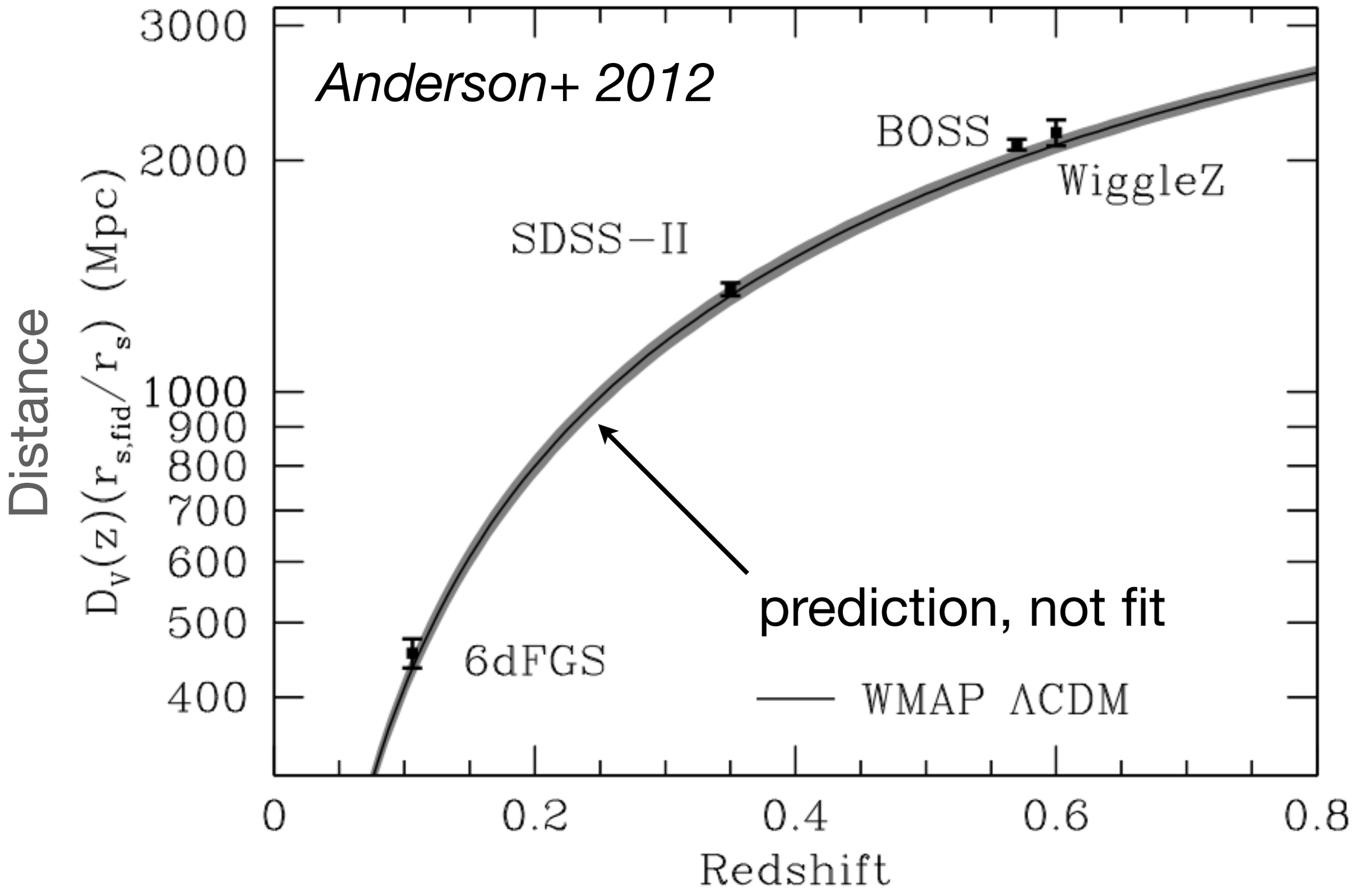
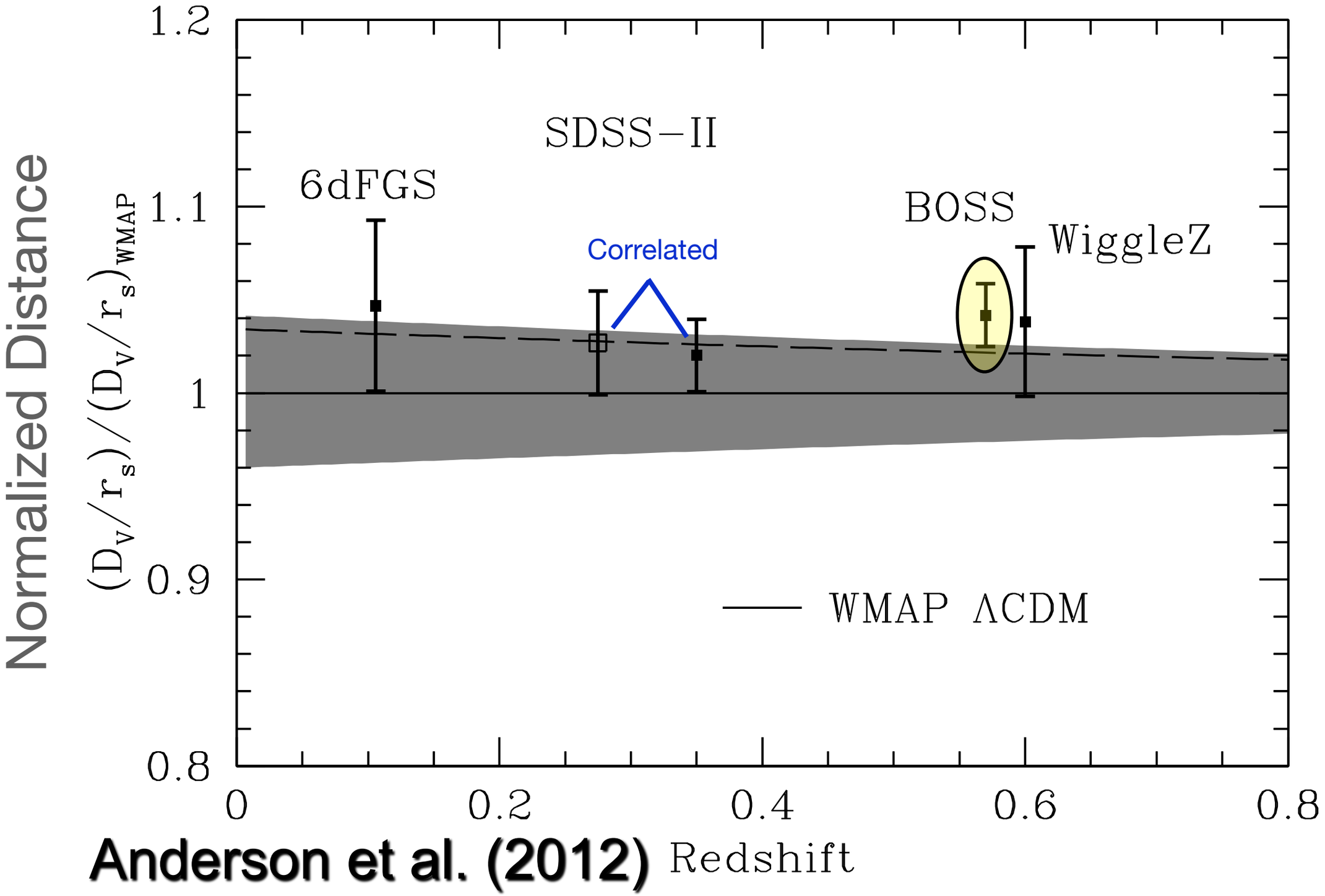


BAO Hubble Diagram



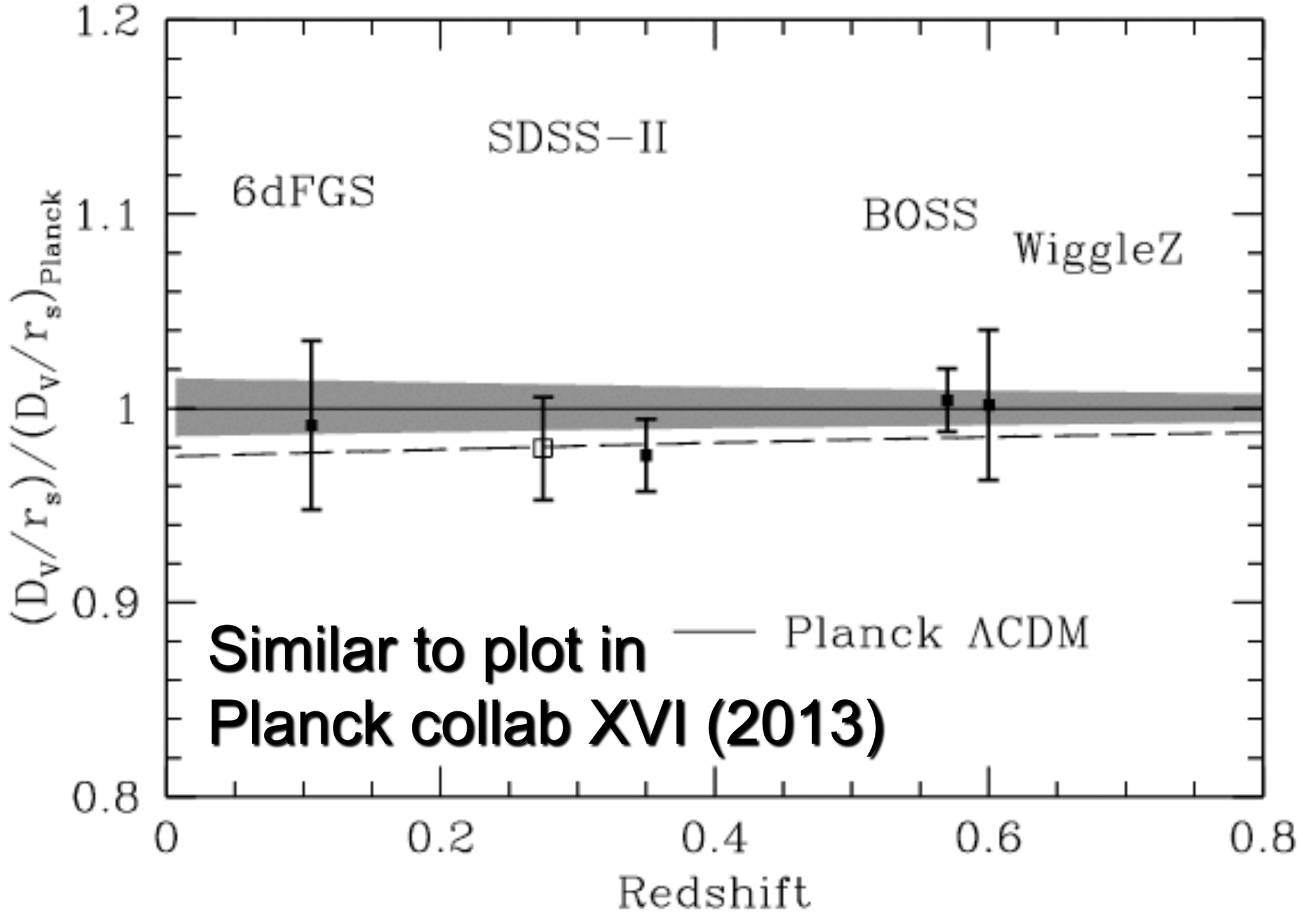
Slight Tension with WMAP



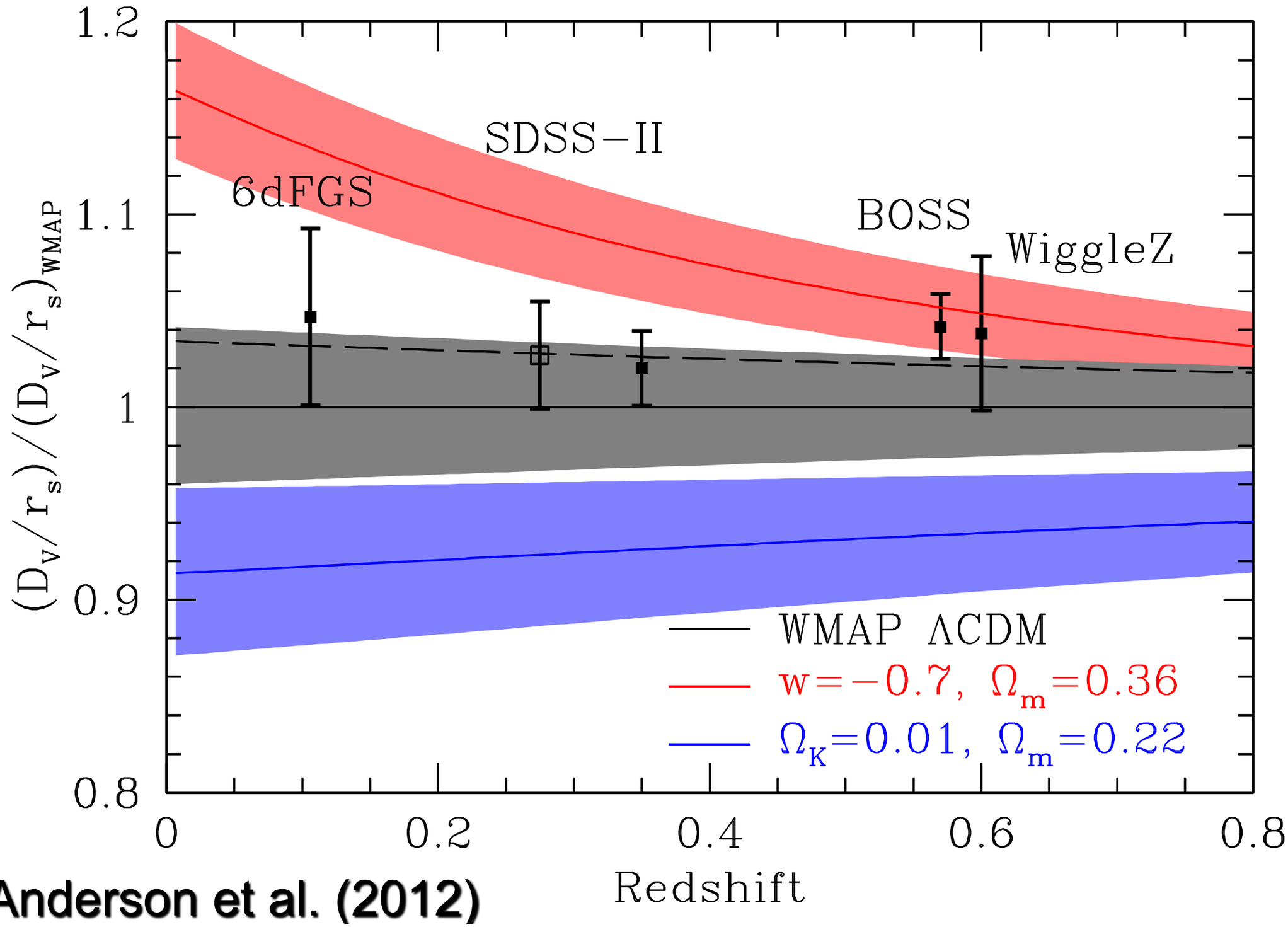
Anderson et al. (2012)

Excellent Agreement with Planck

(too bad...)



Cosmological Leverage



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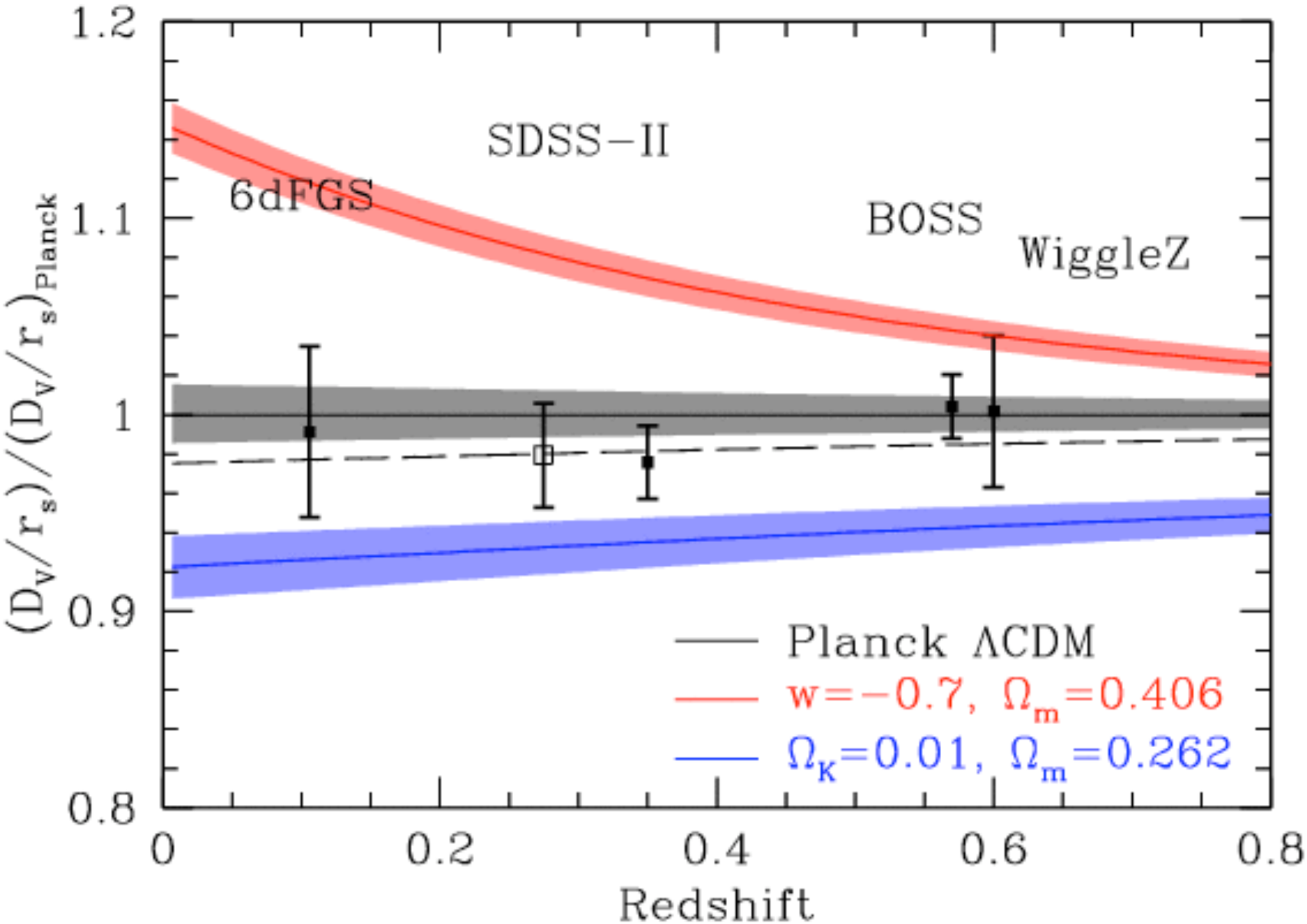
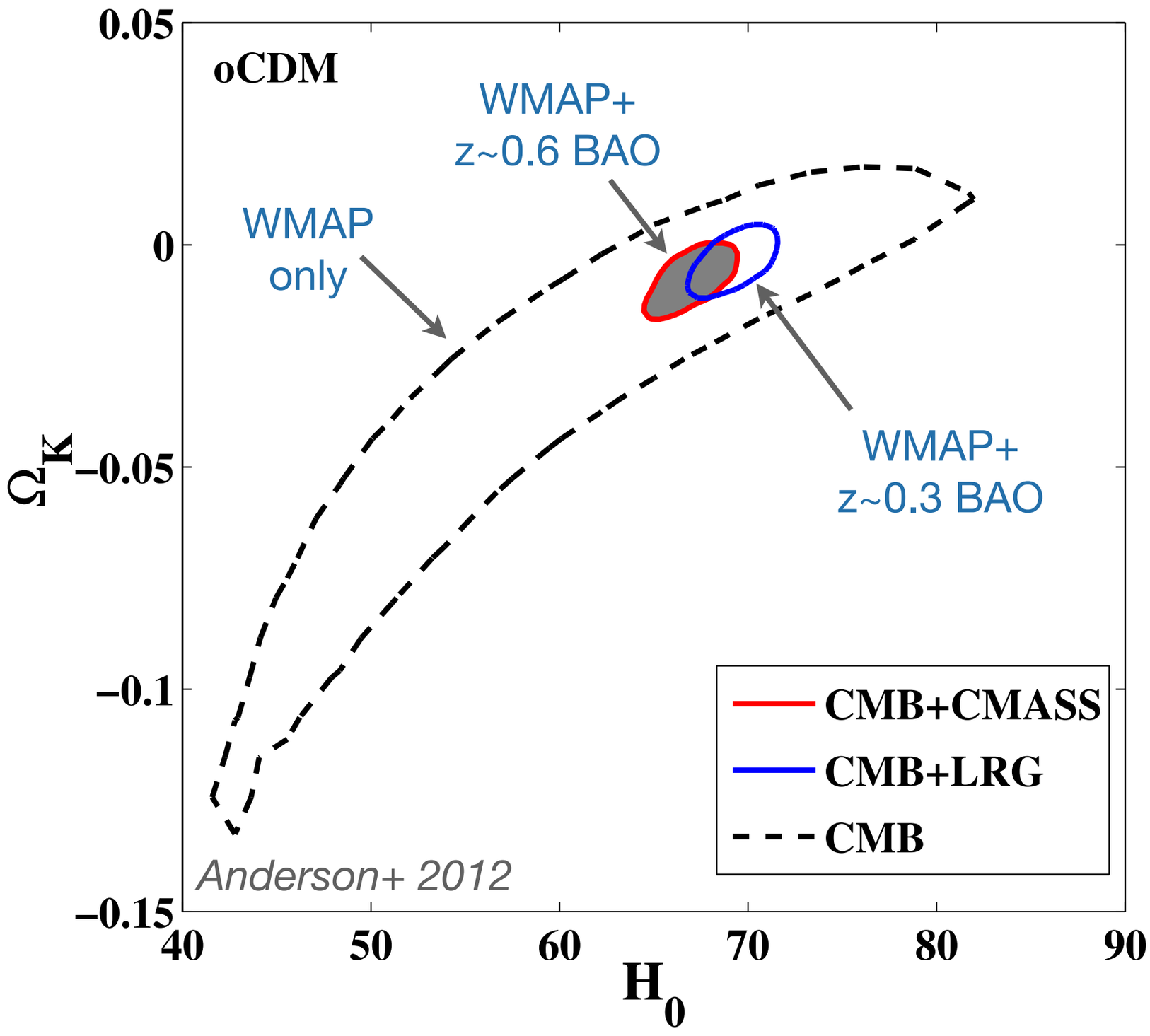


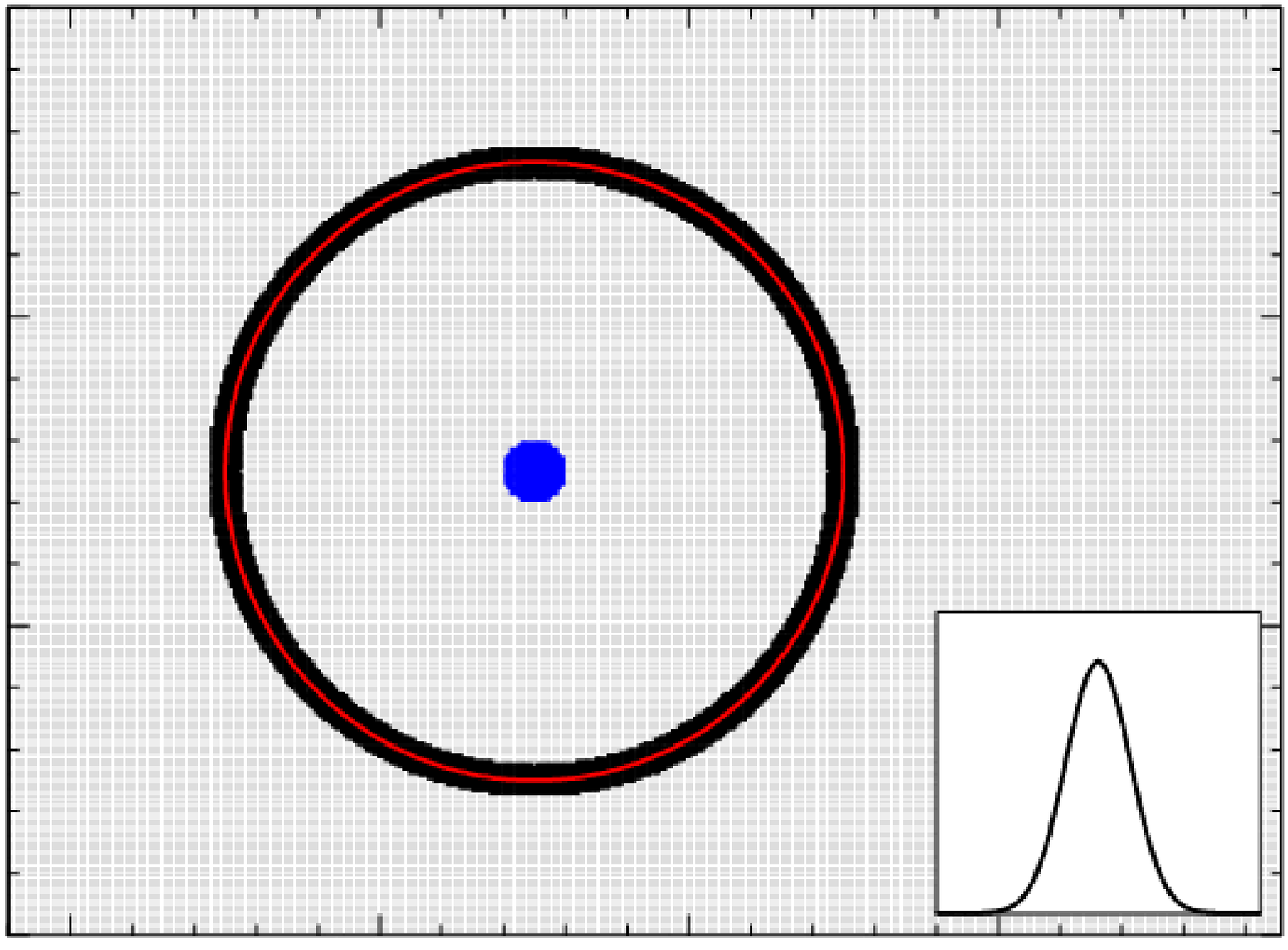
Cosmological Constraints



Only 1/3 of BOSS data

Reconstruction 101

Nikhil Padmanabhan



NP et al, 2012

Reconstruction 101

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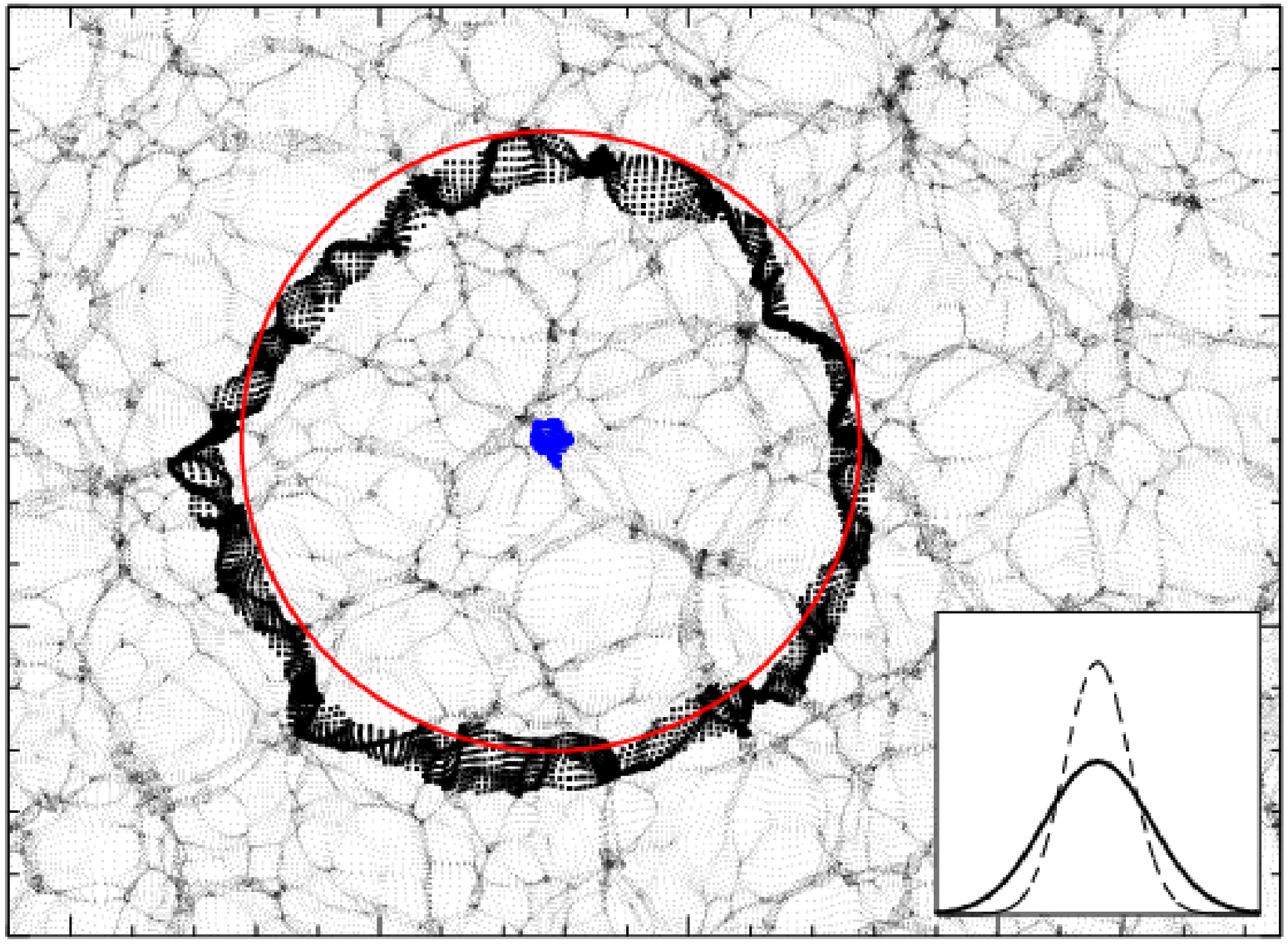

NP et al, 2012

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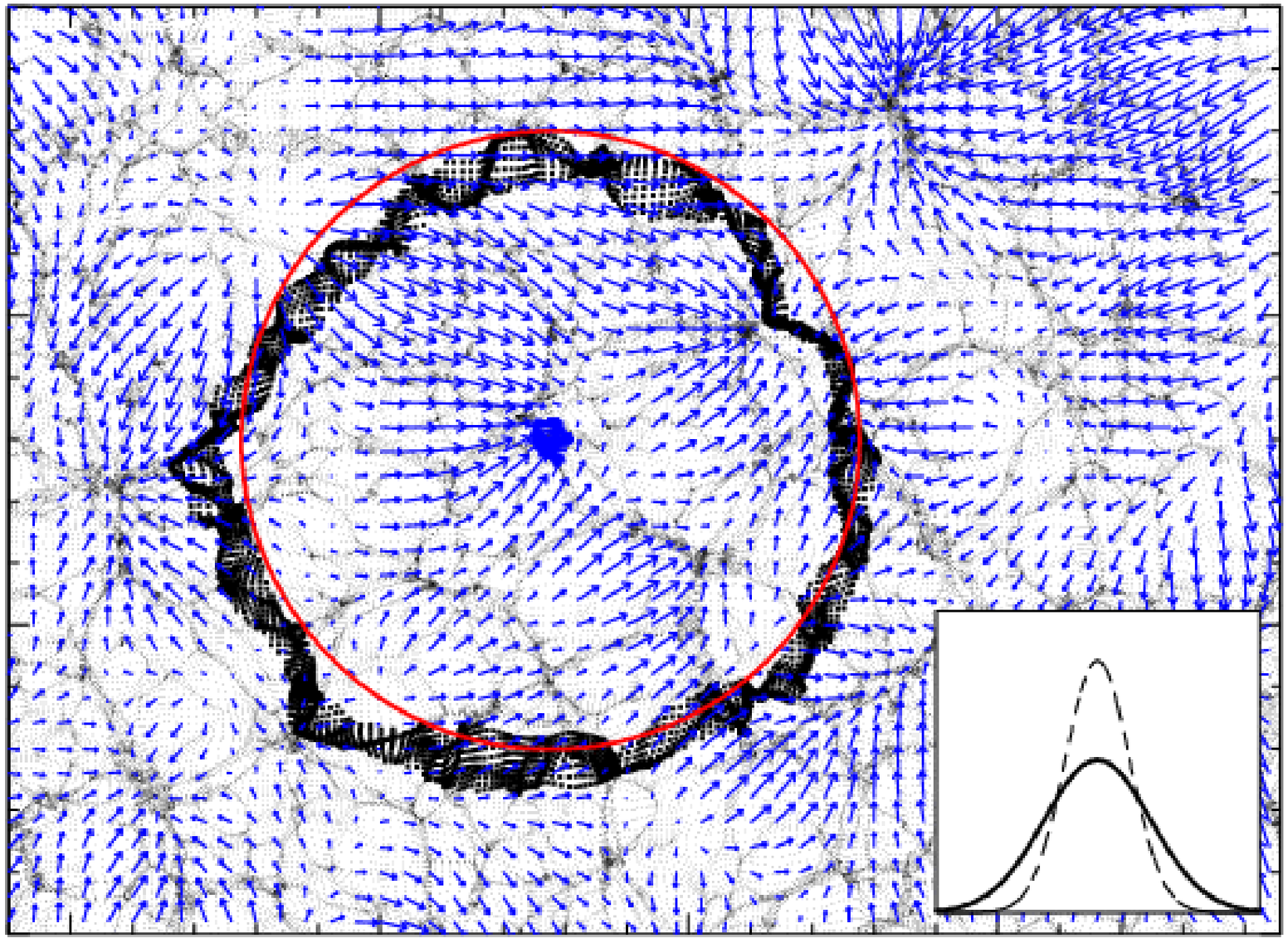

NP et al, 2012

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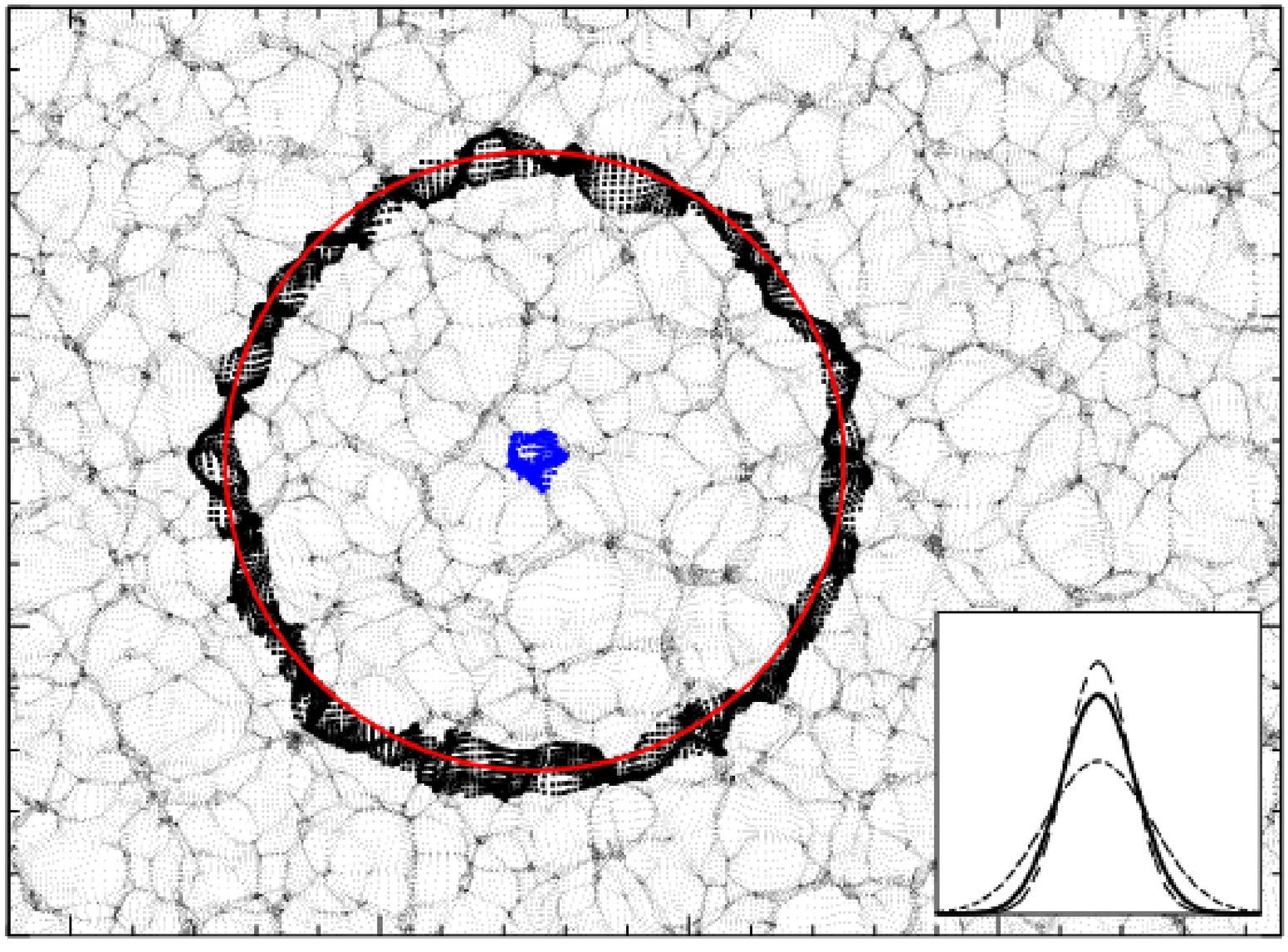
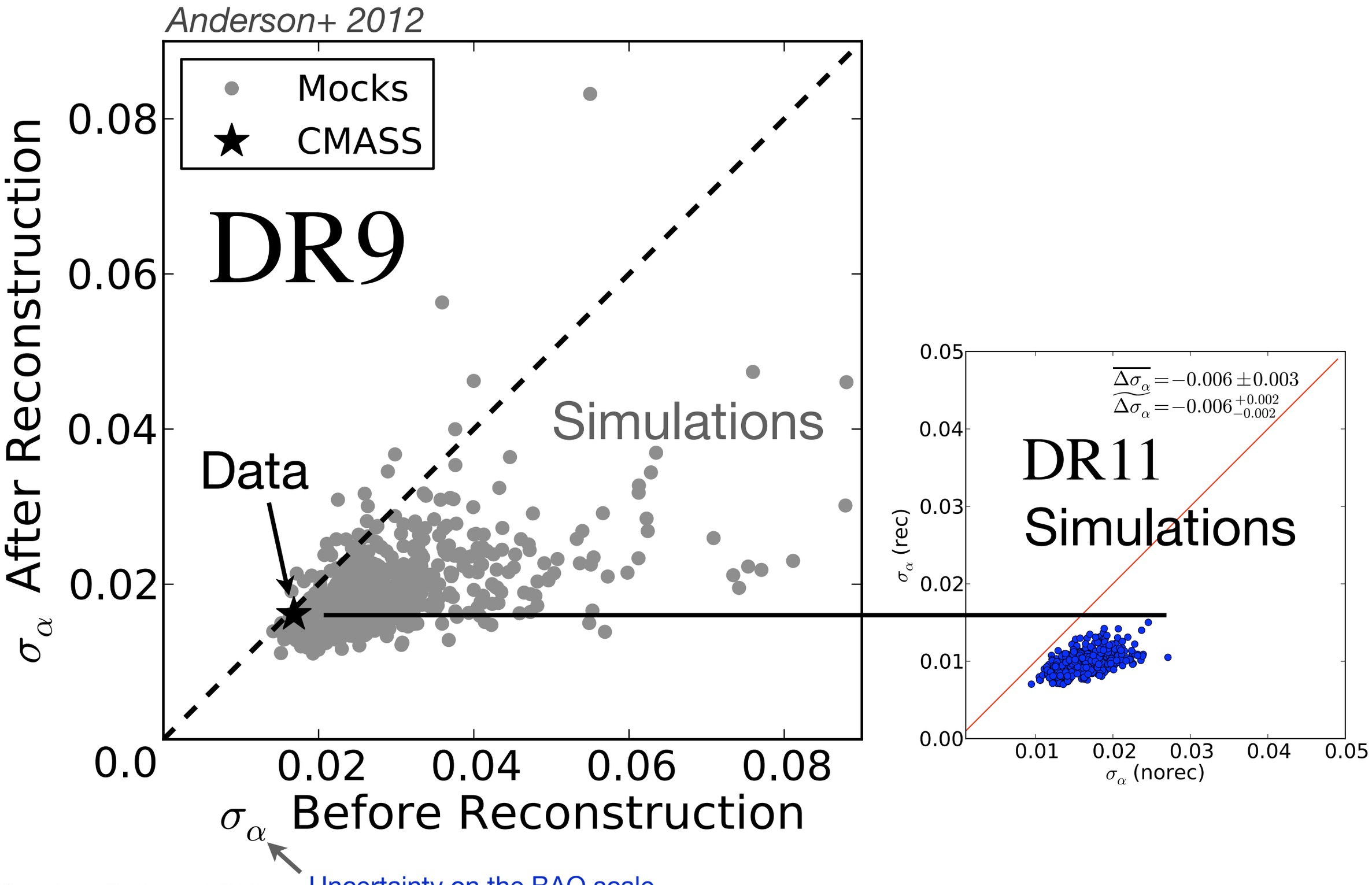


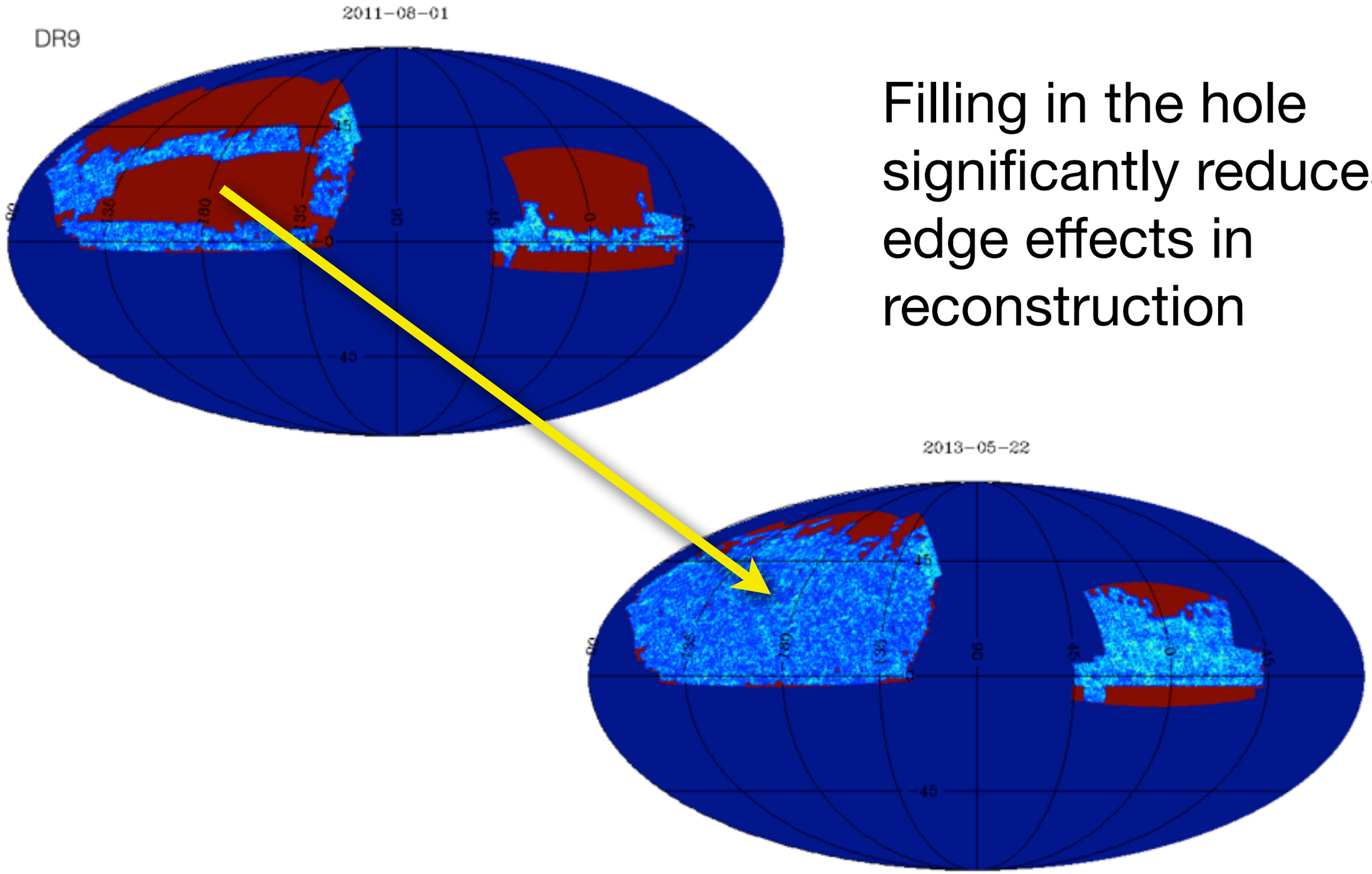
NP et al, 2012

BAO Reconstruction



Uncertainty on the BAO scale

Survey Geometry & Reconstruction



Filling in the hole significantly reduces edge effects in reconstruction

BAO Systematics

BAO famous as the method with lowest systematics

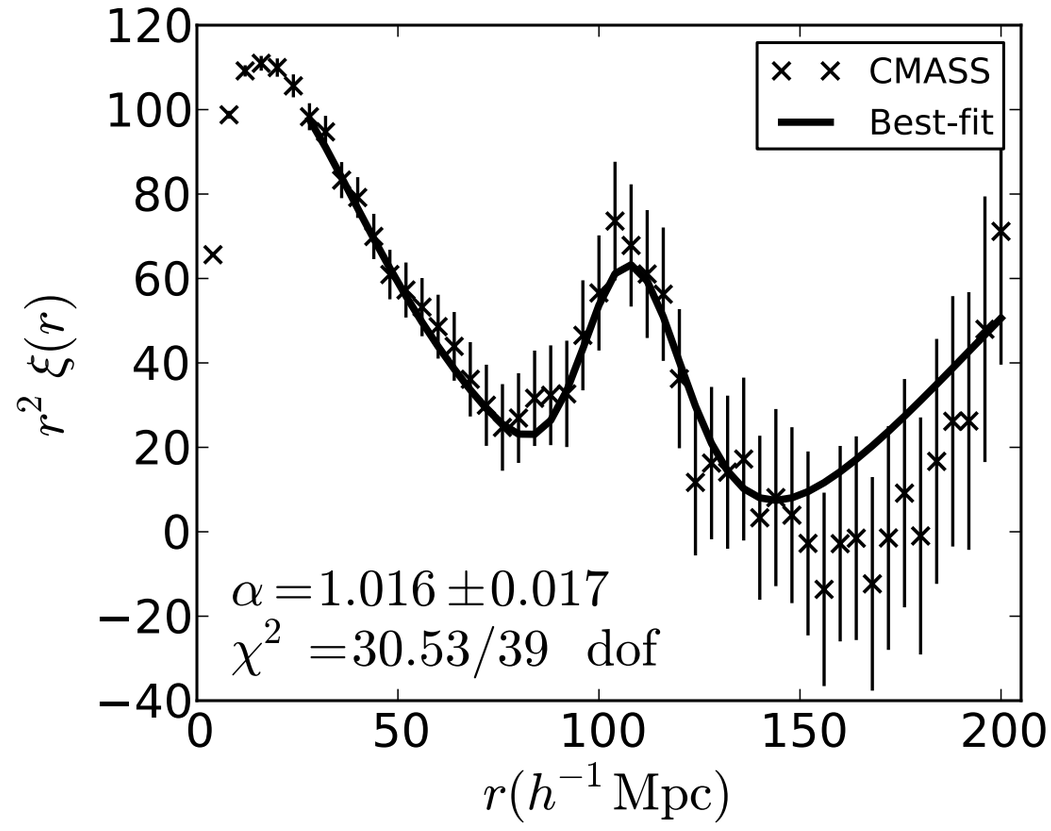
- Easy to mess up broadband shape, but
- Hard to make or move a bump

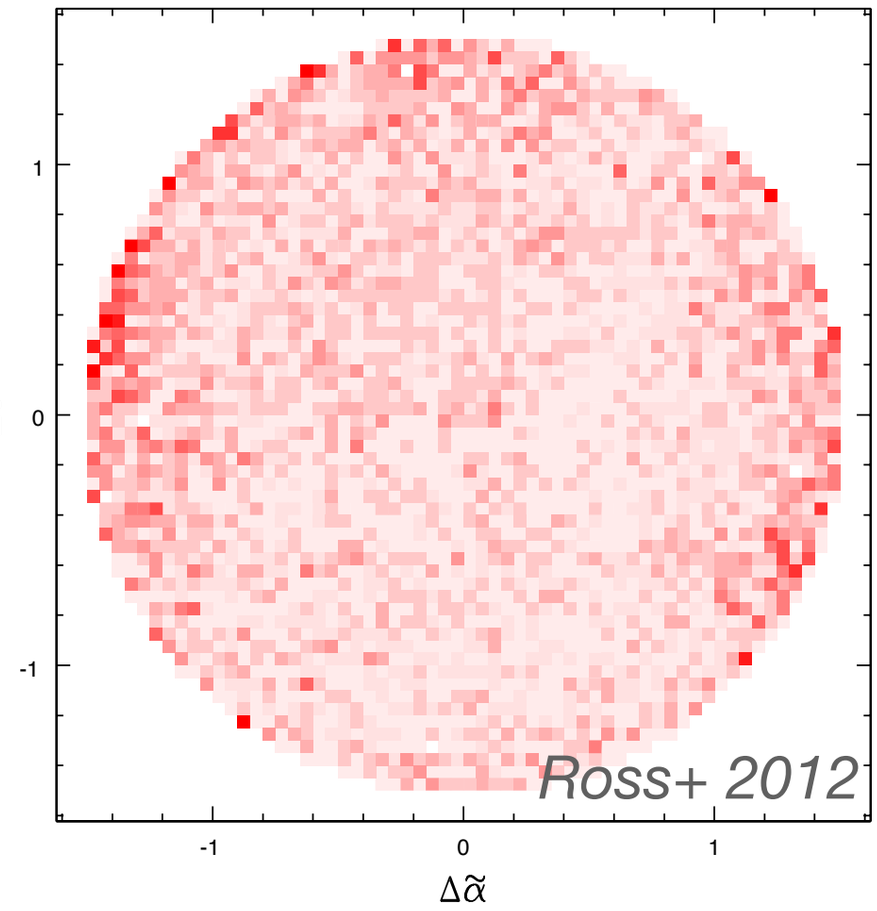
Good news: Systematics matter

- Measurements are getting so precise, systematics now matter!
- Reconstruction removes a ~0.5% bias
- Ross+ 2012 details many targeting & instrumental effects

Well under control, but require attention

Redshift failures vs.
focal plane location
(scale: 0 – 12%)



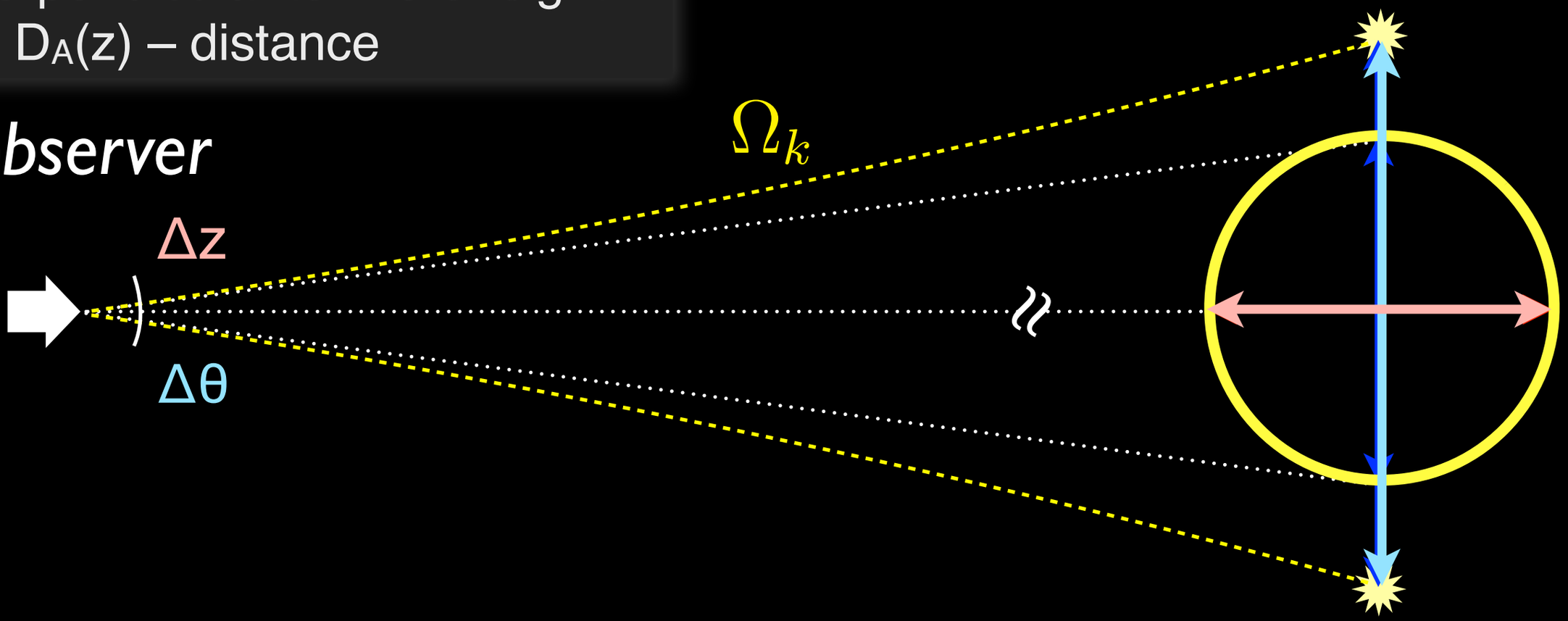


3D BAO

Parallel to line of sight:
H(z) – expansion of universe
Perpendicular to line-of-sight:
$D_A(z)$ – distance

$$\Delta r_{\parallel} = \frac{c}{H(z)}\,\Delta z$$

$$\Delta r_{\perp} = (1+z)\,D_A(z)\,\Delta\theta$$



$$r_{\parallel}(z) = \int_0^z \frac{c}{H(z')}\,dz'$$

Graphics compliments of D. Kirkby, UC Irvine

3D BAO

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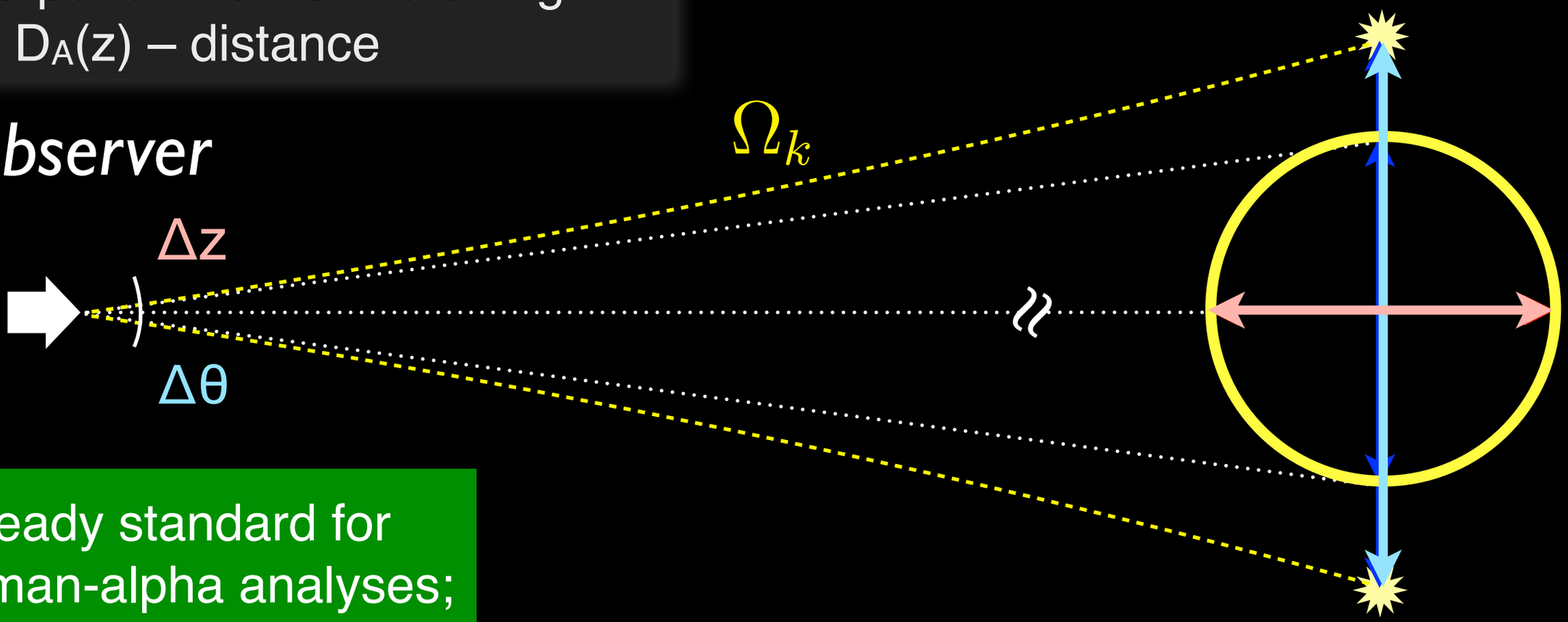


Already standard for Lyman-alpha analyses; Coming to the galaxy analyses this fall (?)

$$r_{\parallel}(z) = \int_0^z \frac{c}{H(z')}\,dz'$$

Graphics compliments of D. Kirkby, UC Irvine

BOSS Summary

On track to finish early (~Feb 2014)

- 1.5M galaxies
- 160k quasars

O(1%) BAO measurement at z=0.6

Analyses this fall on DR10 (2/3) and DR11 (90%)

- Galaxy BAO
  - Spherically averaged (like current results)
  - Full 3D fit to separate $d_A(z)$ from $H(z)$
- Lyman-alpha BAO
  - Fully 3D from the beginning
  - See Graziano Rossi's talk

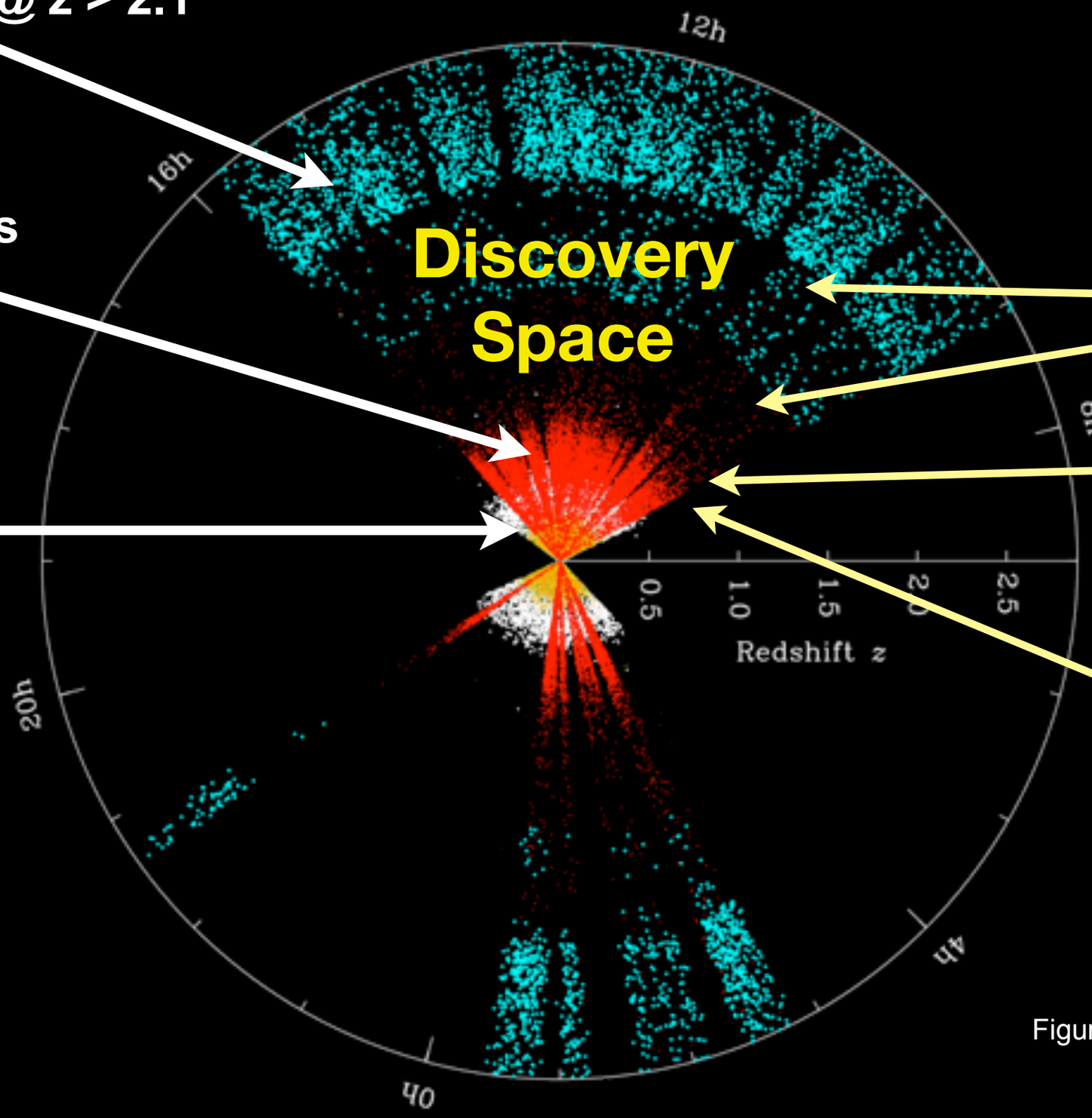
eBOSS: Extending BOSS 2014 – 2020

Same hardware, different targeting & survey strategy

BOSS QSOs @ z > 2.1
160,000
(sparse map)

BOSS galaxies
1.5 million
(dense map)
z<0.7

SDSS DR7



eBOSS:

690k QSOs
>2.1 Lyα
1 < z < 2

200k ELGs
0.6 < z < 1.0

350k LRGs
z < 0.8

Figure: Michael Blanton

Current & Future BAO experiments

x10

	BOSS (2009-2014)	e-BOSS (2014-2020)	DESI
Telescope	2.5m	2.5m	**4m @KPNO**
Imaging survey	SDSS	SDSS, DES	ZTF, DEcam, CFHT?
Redshift	0.2<z<0.7	0.6<z<3.5	0.2<z<3.5
Number density	150 deg^{-2}	180 deg^{-2}	**2800 deg^{-2}**
Exposure time	80 minutes	80 minutes	**10-15 minutes**
Sky coverage	10000 deg^2	7500 deg^2	**14000 deg^2**
Field-of-view	6.7 deg^2	6.7 deg^2	6.7 deg^2
Number of fibers	1000	1000	**5000**
Wavelength range	360-1000nm	360-1000nm	360-1000nm
Spectral resolution	1600-2600	1600-2600	**2300-5000**
Target galaxies	LRGs+Lya QSOs	LRGs+ELGs+QSOs	LRGs+ELGs+QSOs
FOM BAO gal.+Lya QSOs	21	~45	~140

Project Name Etymology

BOSS
Baryon Oscillation Spectroscopic Survey

2014: Same instrument, different targets

eBOSS
Extending BOSS

Proposal for 2018: New instrument, different telescope (Mayall)

BigBOSS

DES
Dark Energy Survey

Proposal for 2018: Photo –> Spectro Survey at Blanco

DESpec
Dark Energy Spectrograph

DOE merges, gives new name

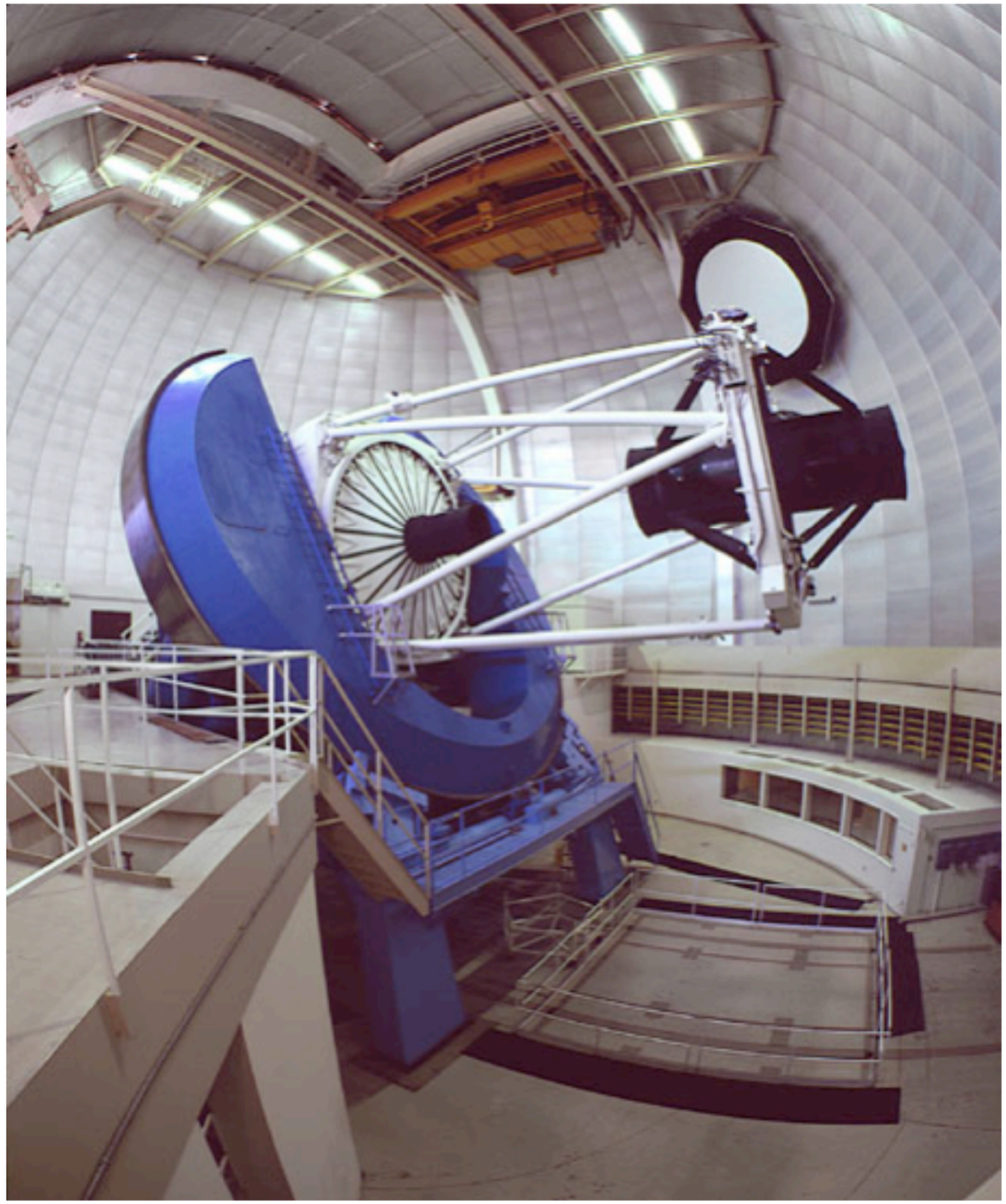
MS-DESI
Mid-Scale Dark Energy Spectroscopic Instrument

Easier to say

DESI
Dark Energy Spectroscopic Instrument

Mayall Telescope @ Kitt Peak

4-m primary



Mayall Telescope in 5 Years

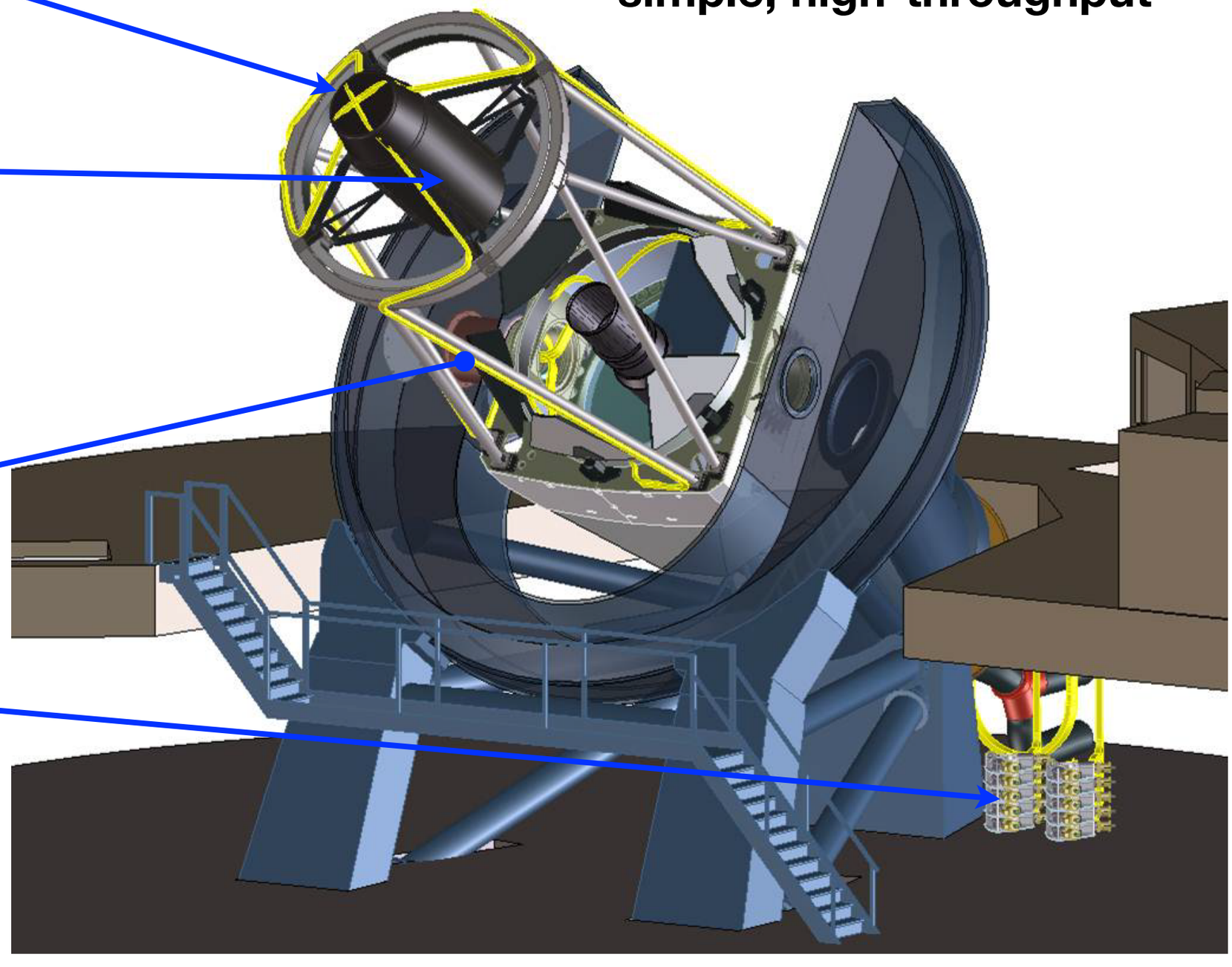
5000 fiber positioners on 1-m focal plane

Corrector lenses 3° FOV

5000 fibers

10 spectrographs X 3 channels each 3600 – 9800 Å

DESI Design is SDSS-inspired: simple, high-throughput



5000 fibers x 50 fields per night?

(vs 1000 x 9 fields for BOSS)

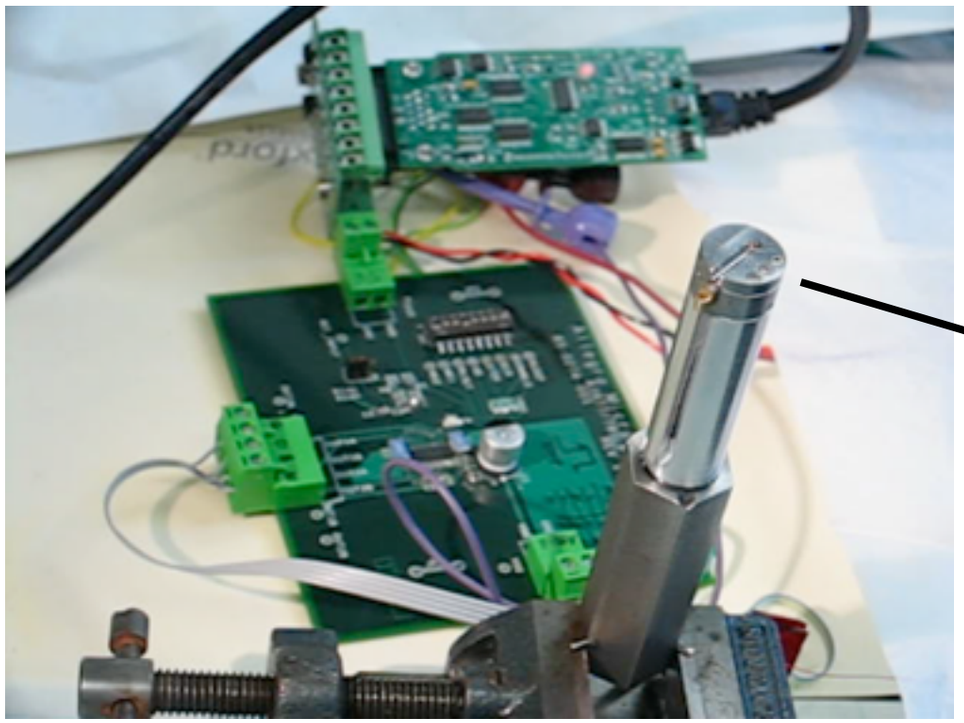
- Hand plugging custom drilled plates won't scale
- Need to move to robotic positioners

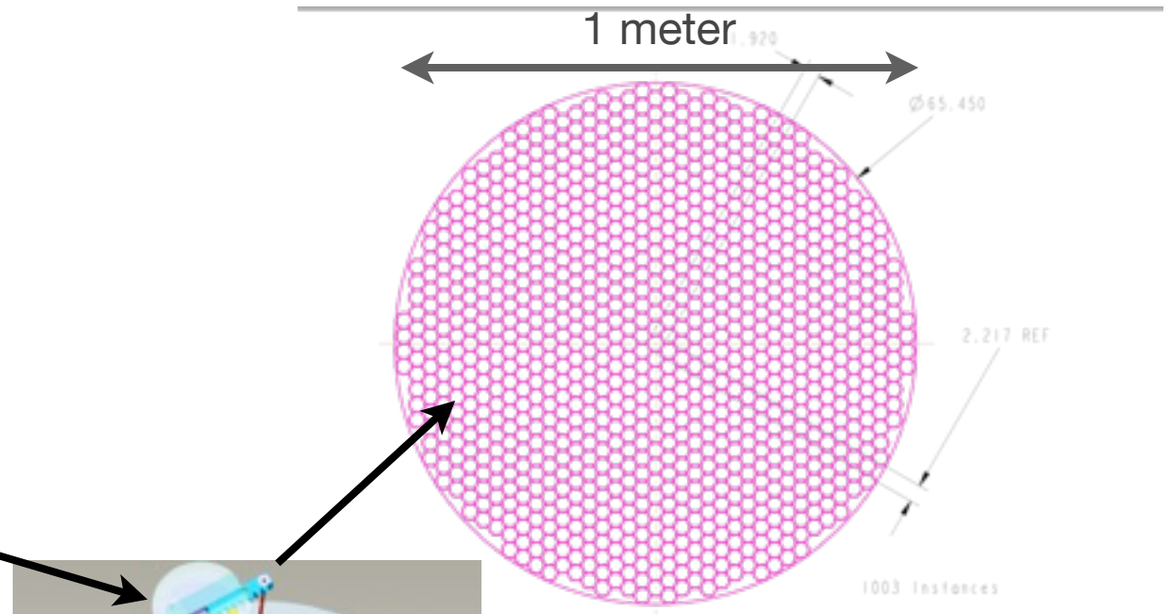
5000 Fiber Positioners

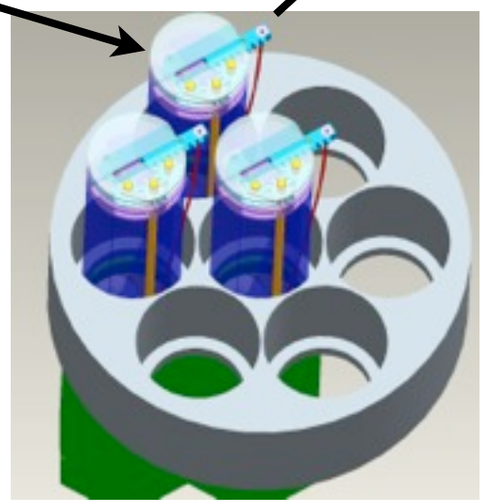
Multiple options under R&D

– UTSC (China), IAA Granada (Spain), AAT (Australia), LBNL (USA)

Comparison Testing @ LBNL

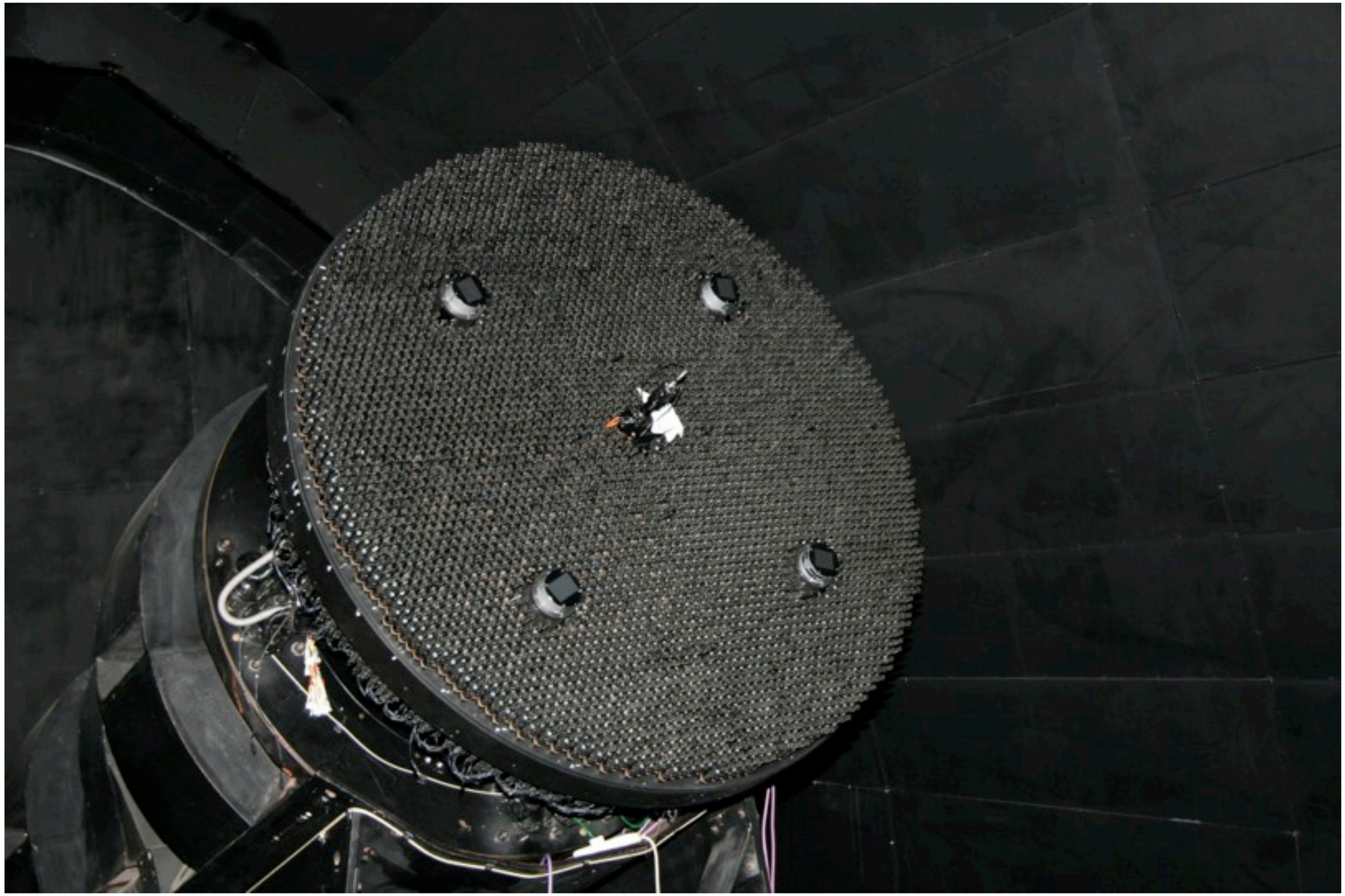




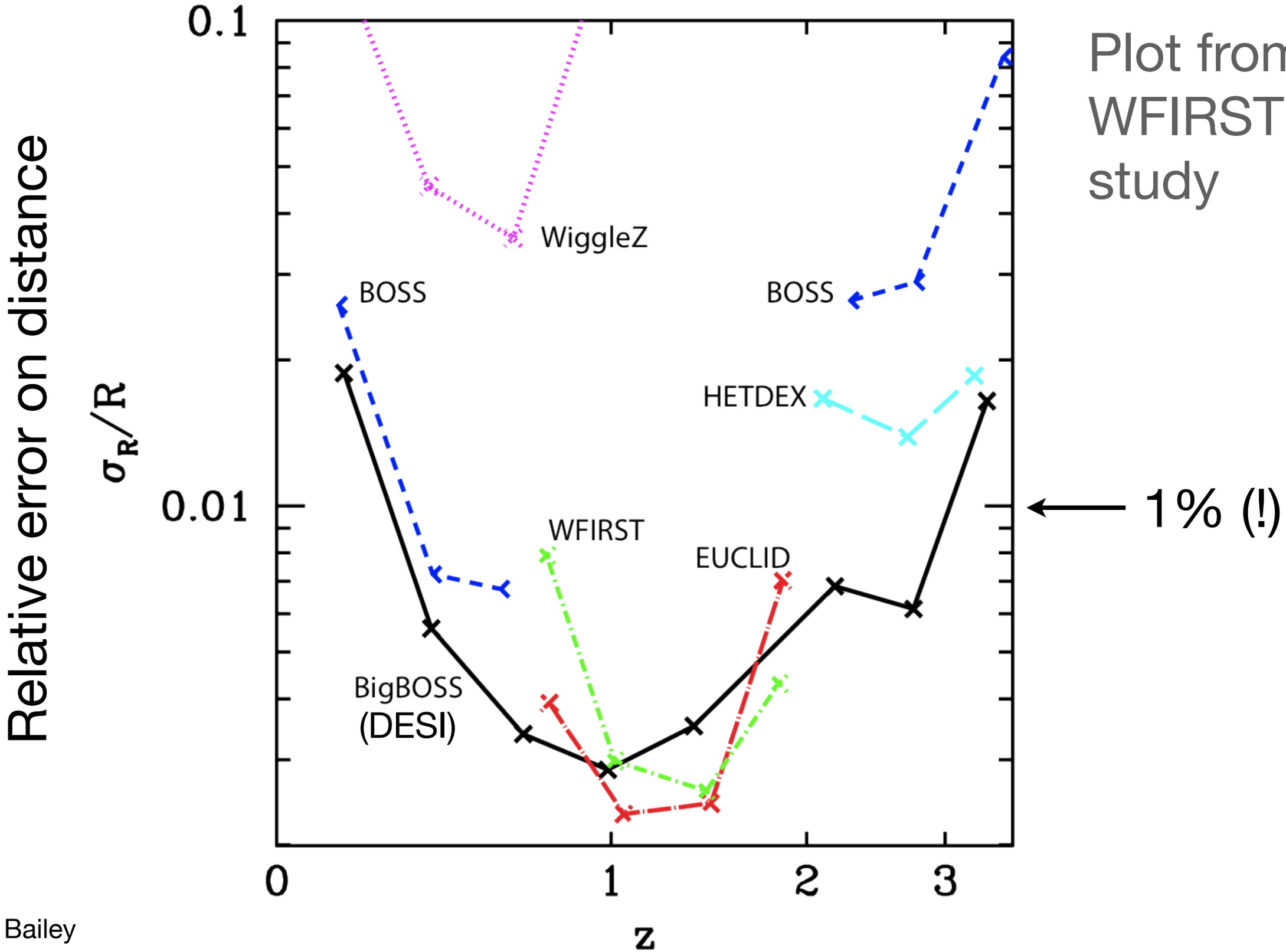


LAMOST 4000-fiber Positioner

Valuable lessons learned for developing 2nd generation fiber system



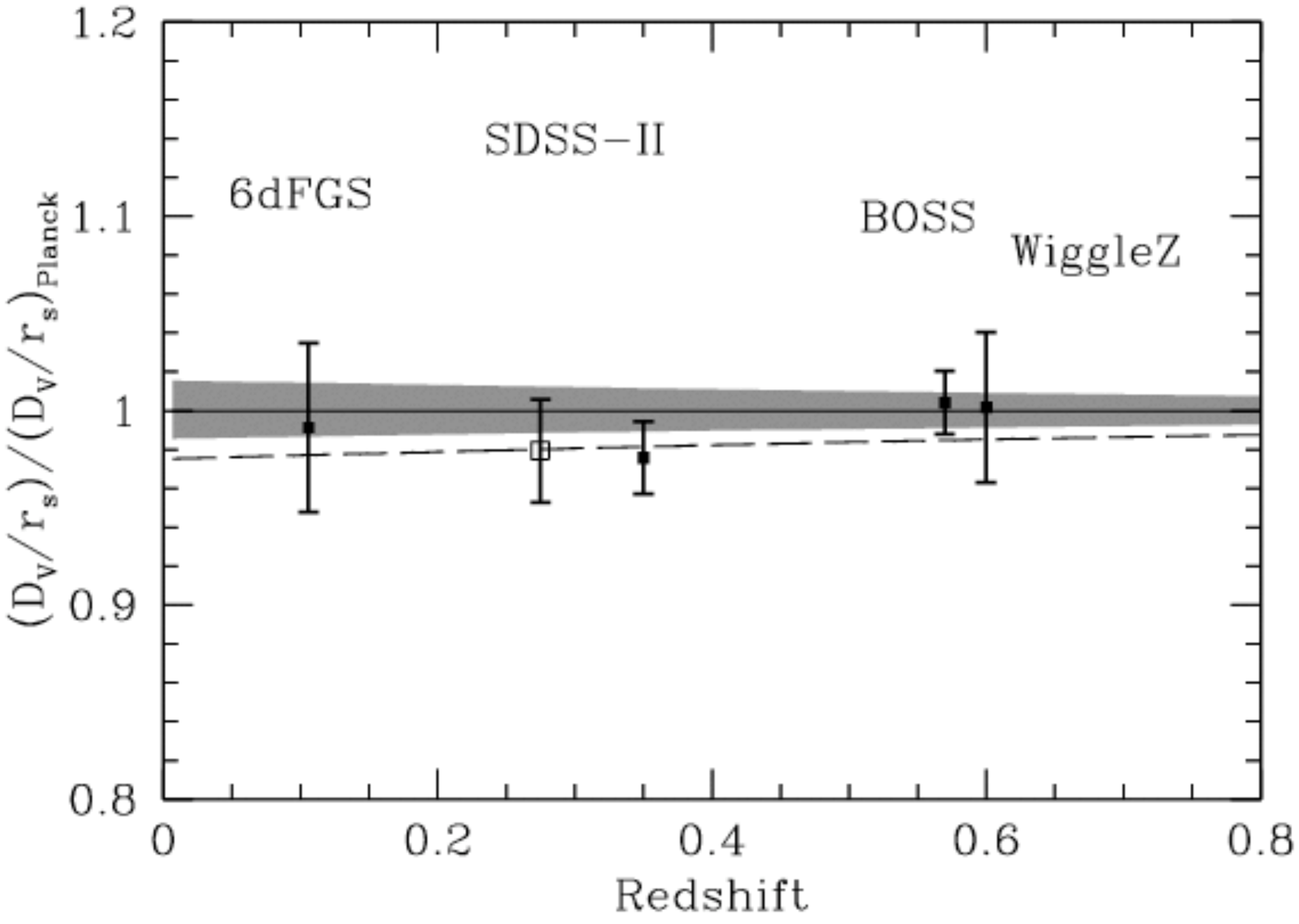
DESI Comparison to EUCLID+



Plot from WFIRST study

← 1% (!)

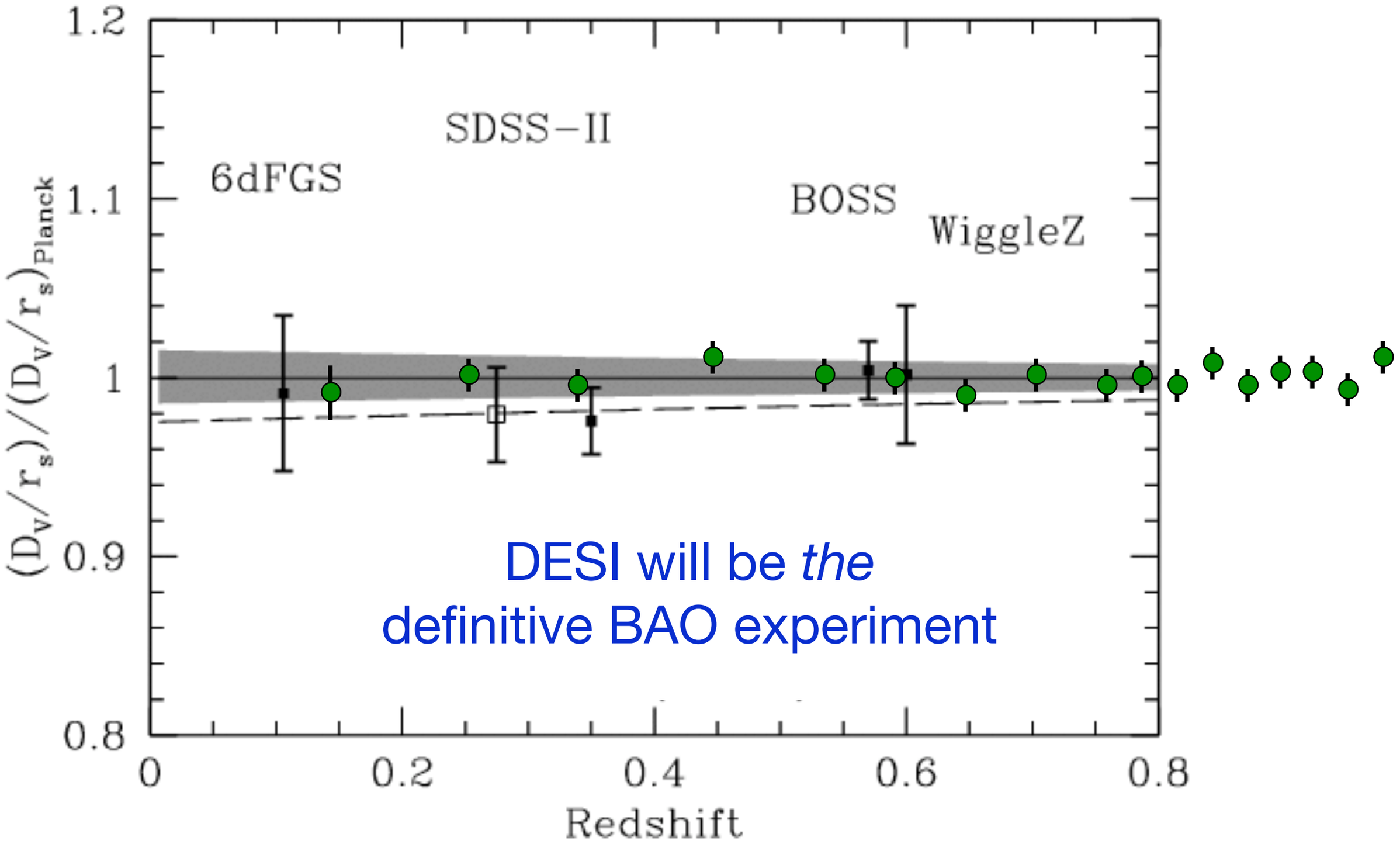
BAO Today



+BOSS LyA

BAO With DESI

~20 measurements better than 1% from 0.0 < z < 3.5



Step

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x10

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Imaging survey	SDSS	SDSS, DES	ZTF, DEcam, CFHT?
Redshift	0.2<z<0.7	0.6<z<3.5	0.2<z<3.5
Number density	150 deg^{-2}	180 deg^{-2}	**2800 deg^{-2}**
Exposure time	80 minutes	80 minutes	**10-15 minutes**
Sky coverage	10000 deg^2	7500 deg^2	**14000 deg^2**
Field-of-view	6.7 deg^2	6.7 deg^2	6.7 deg^2
Number of fibers	1000	1000	**5000**
Wavelength range	360-1000nm	360-1000nm	360-1000nm
Spectral resolution	1600-2600	1600-2600	**2300-5000**
Target galaxies	LRGs+Lya QSOs	LRGs+ELGs+QSOs	LRGs+ELGs+QSOs
FOM BAO gal.+Lya QSOs	21	~45	~140