BARYON OSCILLATIONS

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Snowmass@SLAC, 3/6/2013

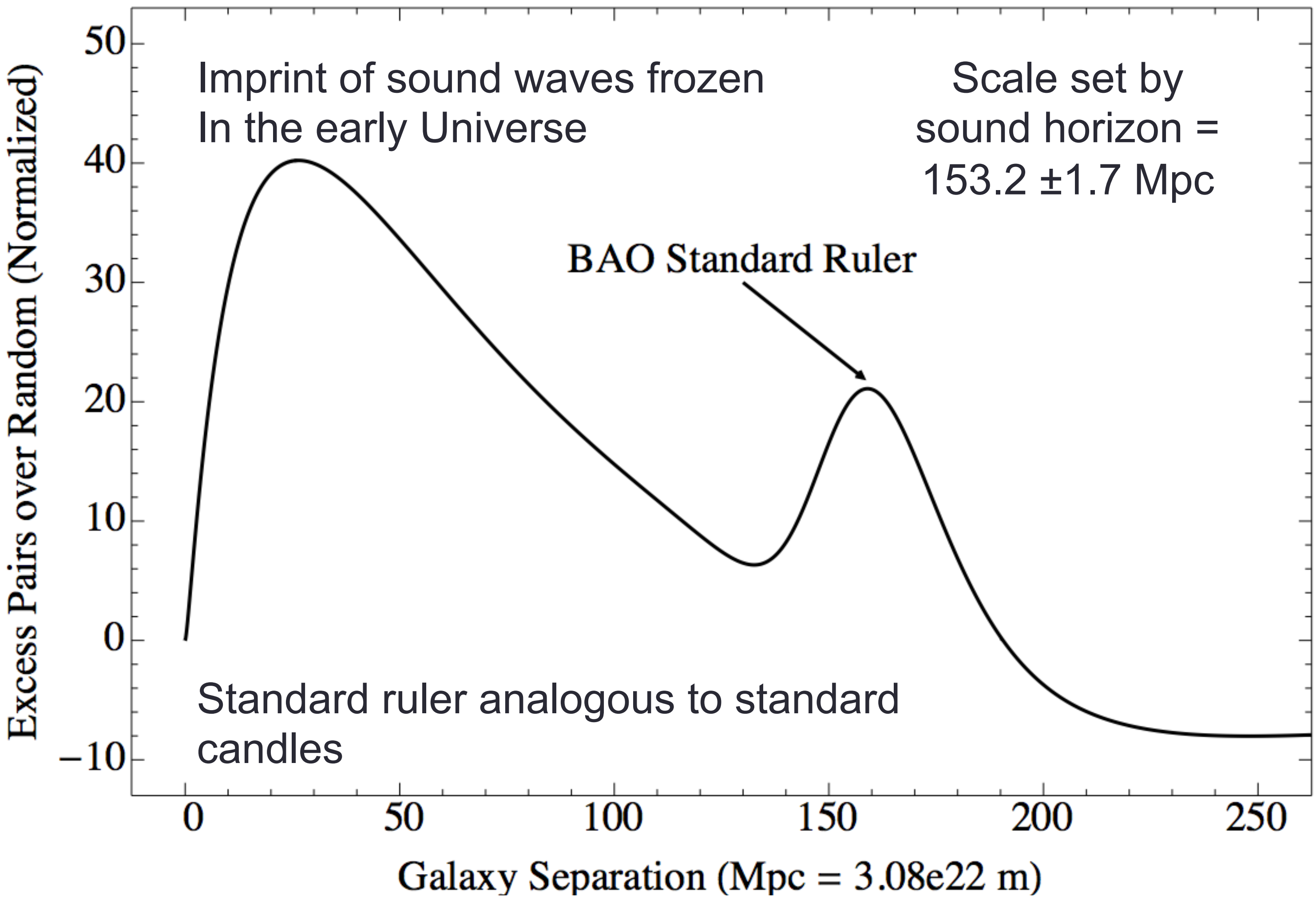
Questions

- Where are we today in BAO experiments?
  - BOSS, WiggleZ
- What is the current portfolio of planned BAO experiments?
  - Where will this leave us?
- What opportunities are there, both on short and long term timescales?
  - Our portfolio needs to include options for lower-cost and near-term experiments as well as larger/future ones →very important that we show our program has science results coming out in a regular schedule (Siegrist, CAA)

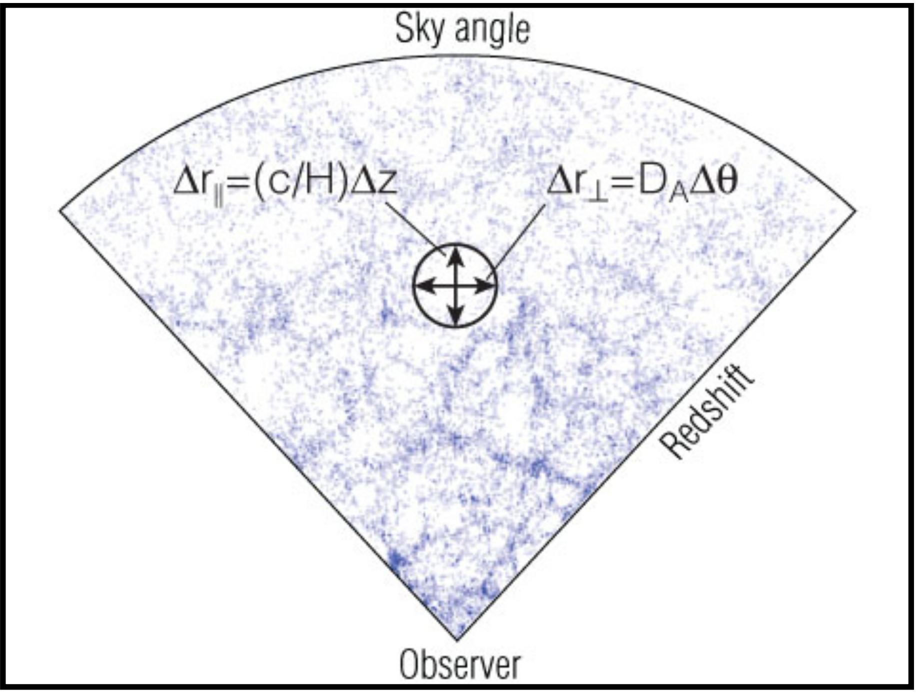
Next steps

- Projects
  - Redshift range
  - Probes
  - Eg. 21 cm intensity mapping
- Analysis techniques
  - Are we extracting all the information we can?
  - Error estimation (simulations)
- Systematics
  - Simulations

The Standard Ruler in the Galaxy Correlation Function



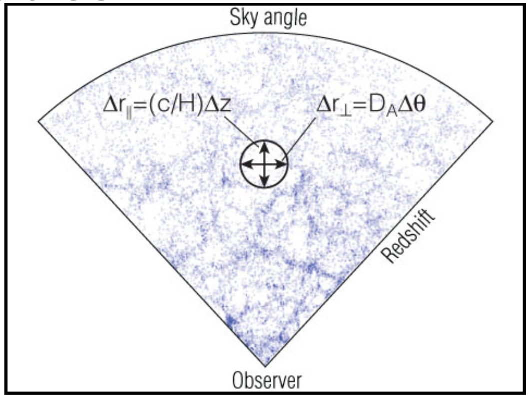
Measuring $d_A(z)$ and $H(z)$



- Transverse scale measures angular diameter distance
- Radial scale measures the Hubble constant
- Internal consistency tests
- H(z) unique amongst dark energy probes
- H(z) important to constrain dark energy at high redshifts

Observables

- Positions on the sky and redshifts
  - 3D map of the Universe
  - Precision redshifts require a spectroscopic survey
- Galaxy surveys are much more than just BAO
  - Redshift space distortions
  - Non-gaussianities
  - Cross-correlations
  - More than just the same survey, same observables



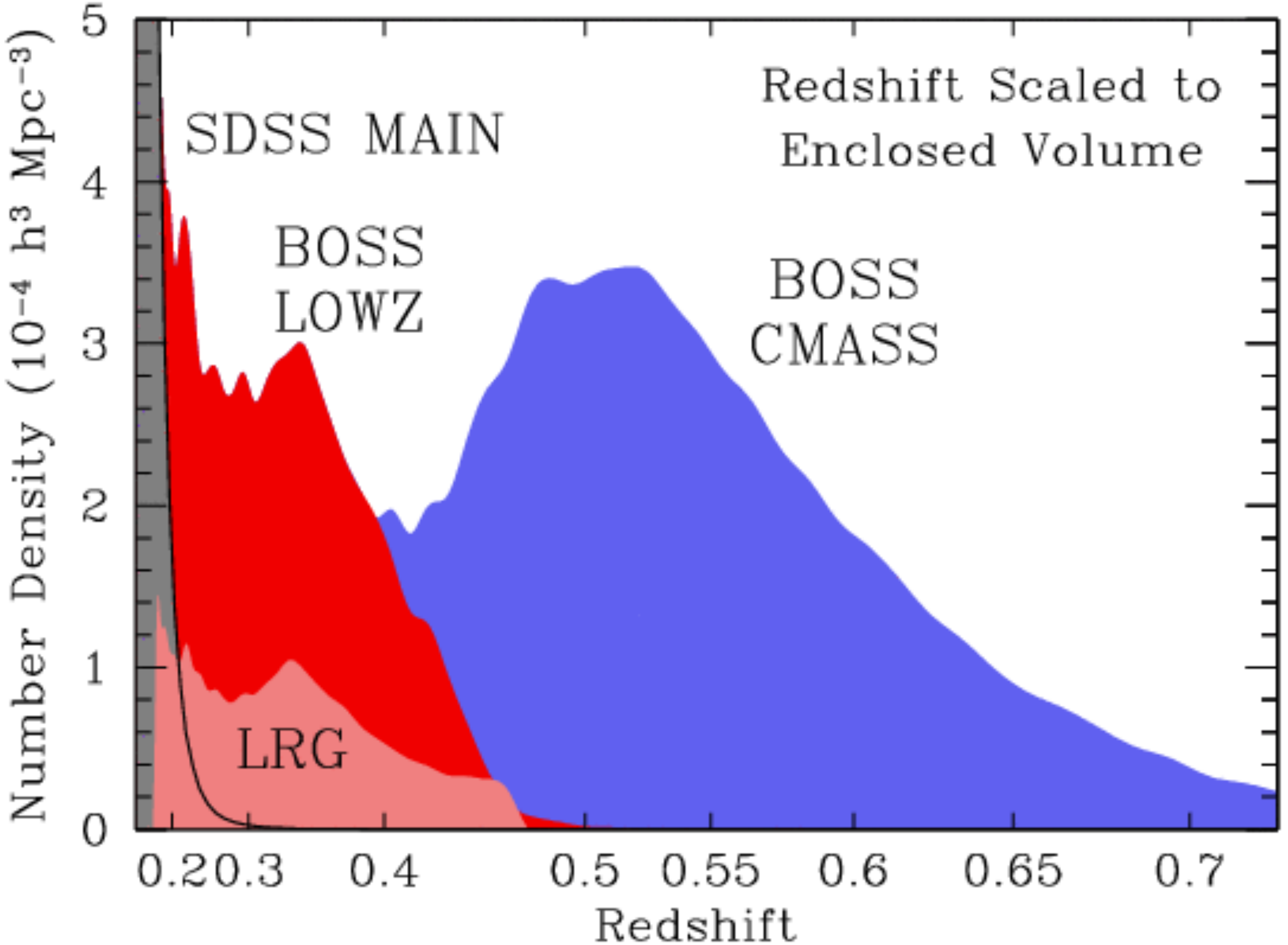
Why BAO?

- Simple measurement
  - Only requires positions
- Underlying theory is simple
  - Mostly linear physics (fluctuations are 1 part in 10^4)
  - Exquisitely calibrated by the CMB (~1% with WMAP, much better with Planck)
  - 3D feature (hard to mimic)
  - Very large scales >> scales of astrophysical complications
    - Can be treated perturbatively

What is BOSS?

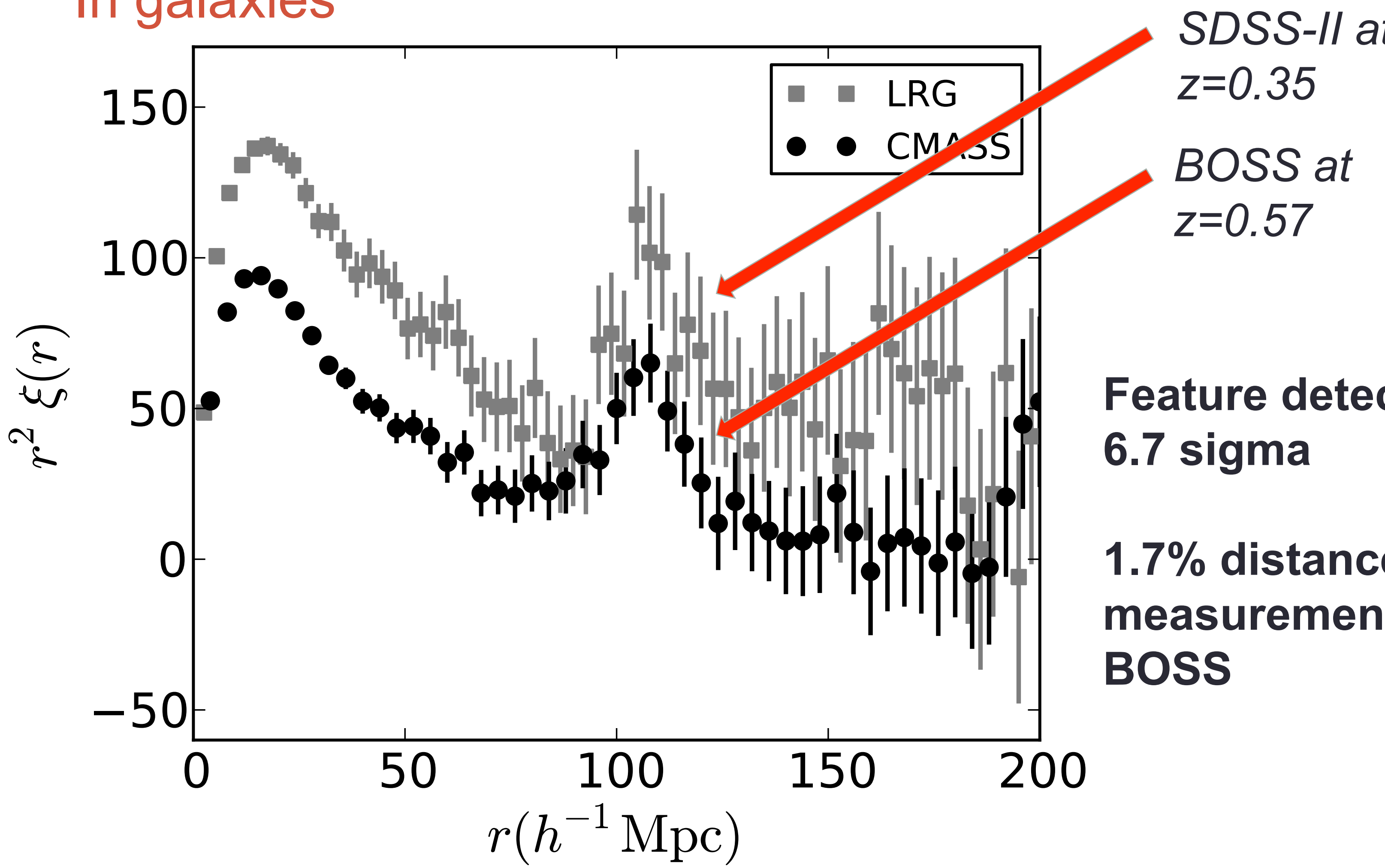
- Baryon Oscillation Spectroscopic Survey
- BAO with galaxies, Lyman-alpha forest
- On going dark energy experiment
  - Funded by DoE, NSF, Sloan Foundation and Participating Institutions
- The definitive low redshift BAO measurement
- 1% distance measurements at z=0.35, 0.6
- First results with 1/3 of the data out!

BOSS surveys a larger volume and redshift range



The BAO Feature clearly detected

In galaxies



Feature detected at 6.7 sigma

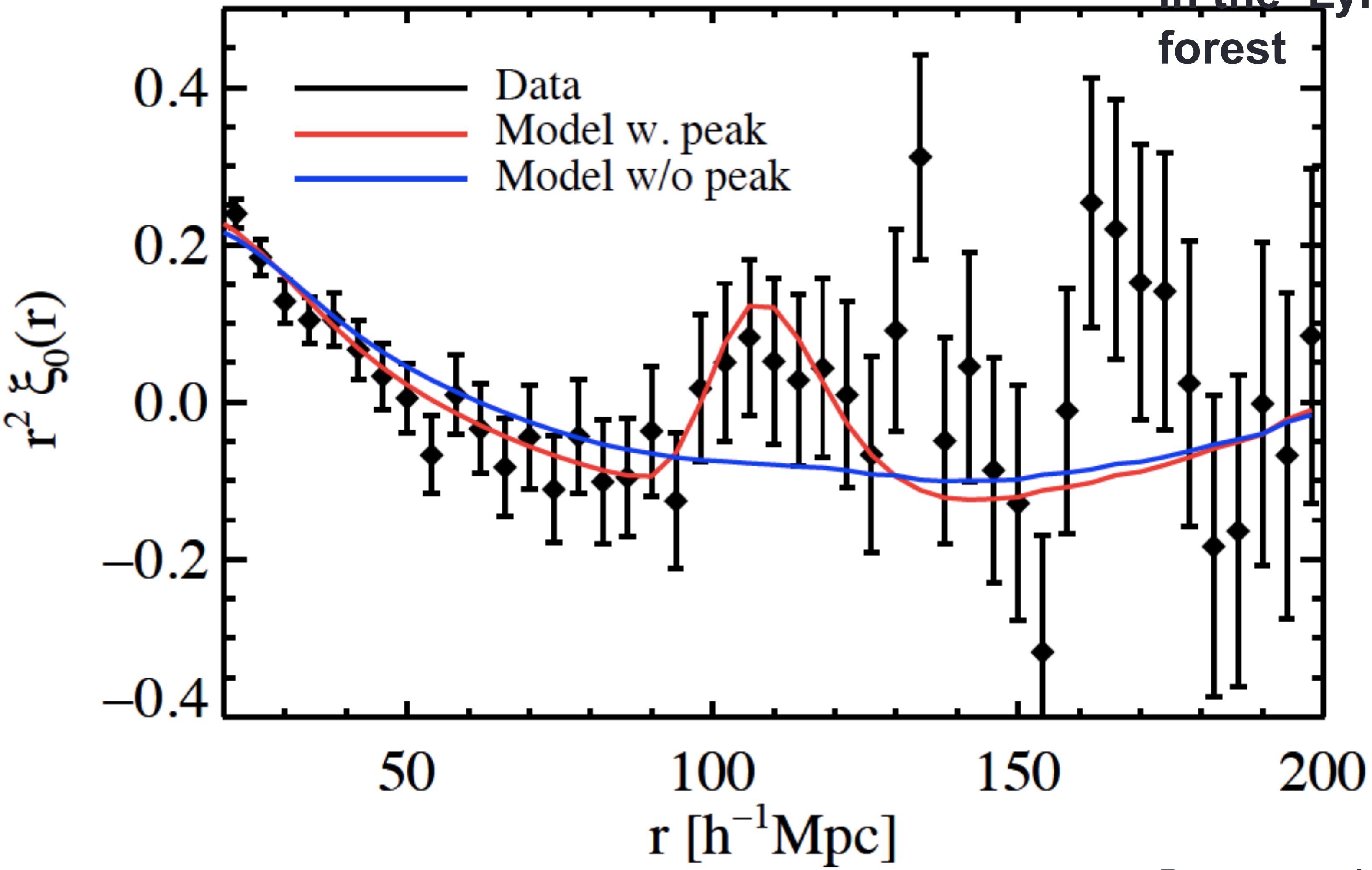
1.7% distance measurement from BOSS

Anderson et al, 2012

The BAO Feature clearly detected

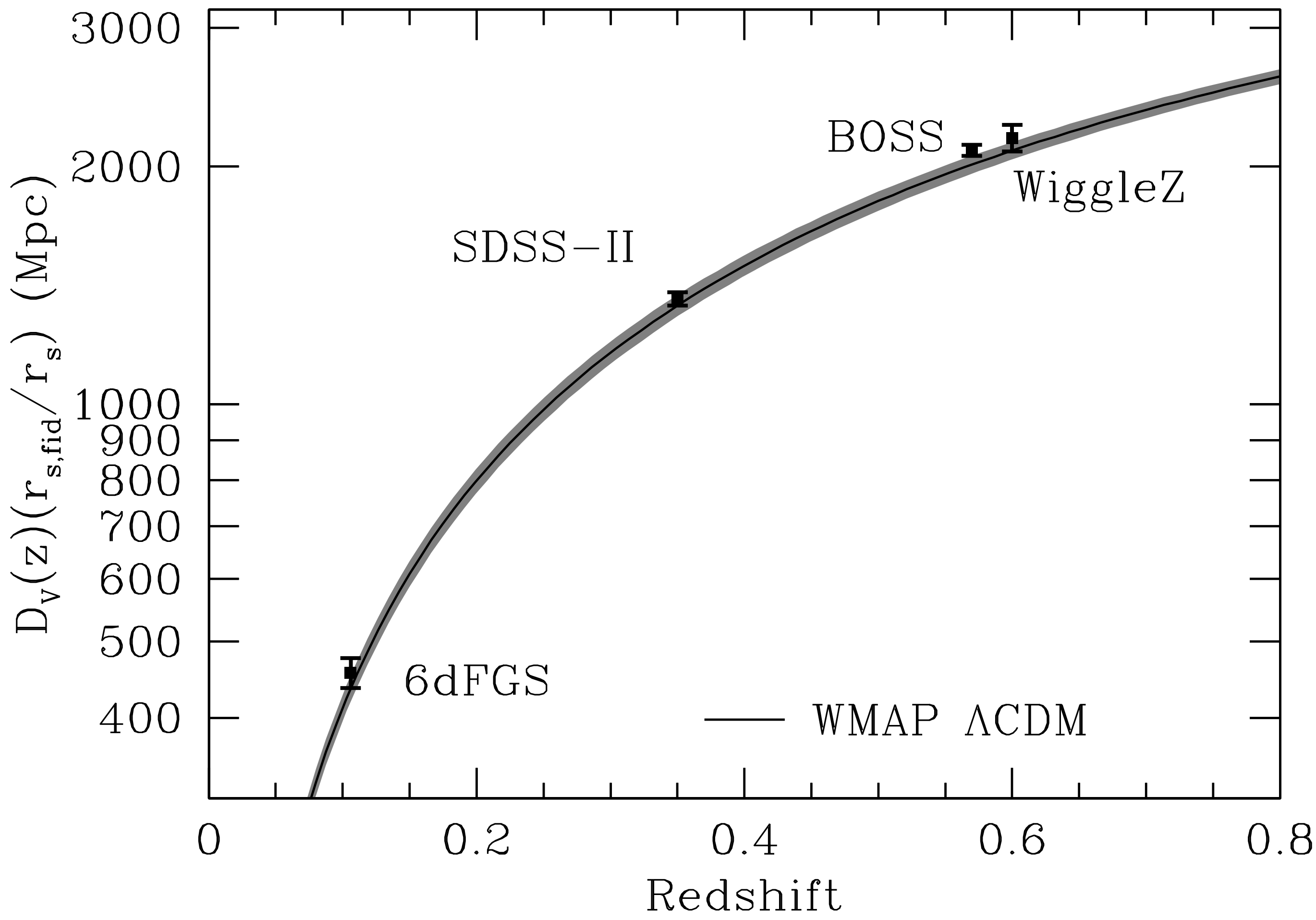
In Lyman-alpha forest

First BAO detection in the Lyman-alpha forest



Busca et al, 2012

BAO measure the expansion history



Anderson et al, 2012

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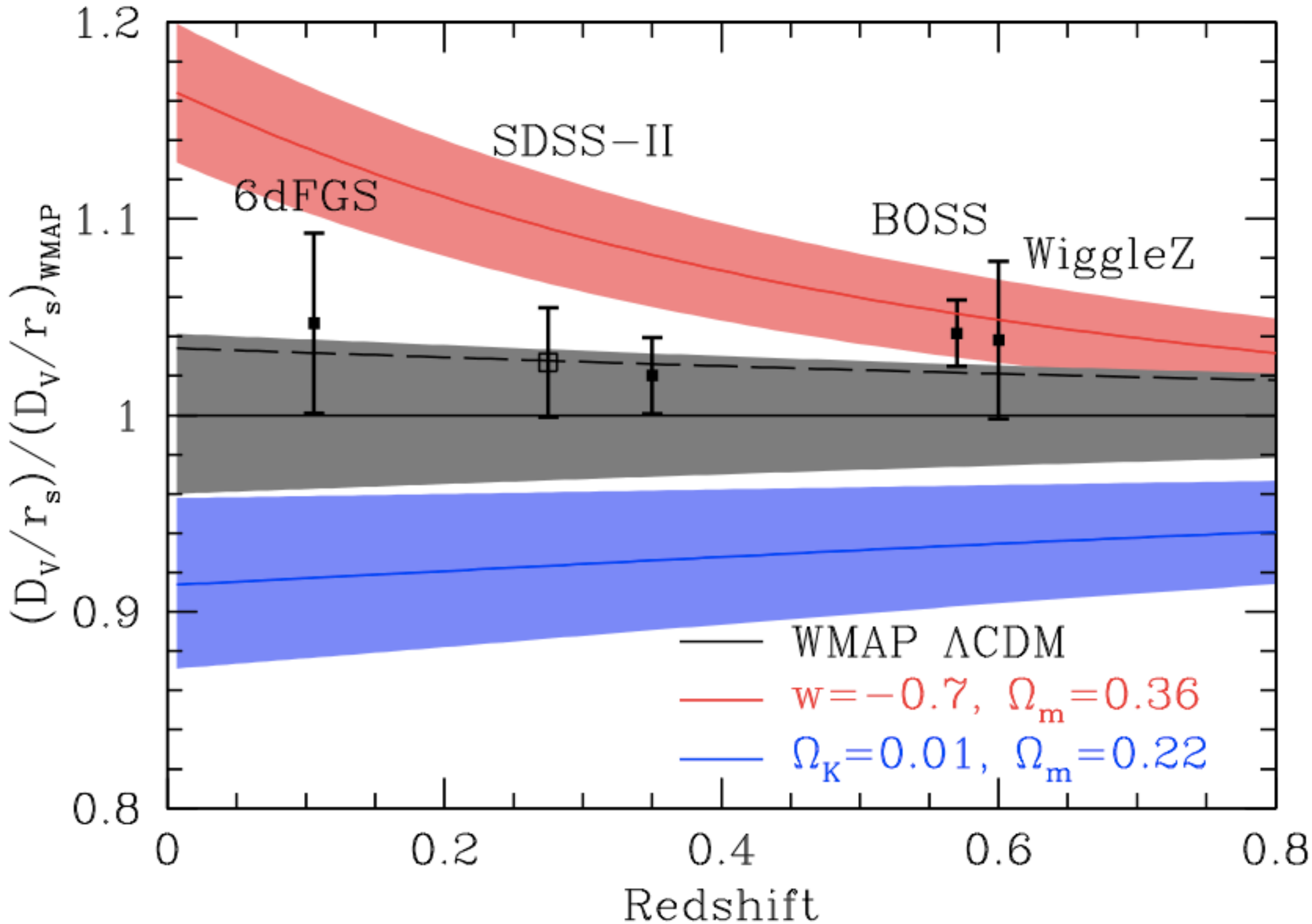

Anderson et al, 2012

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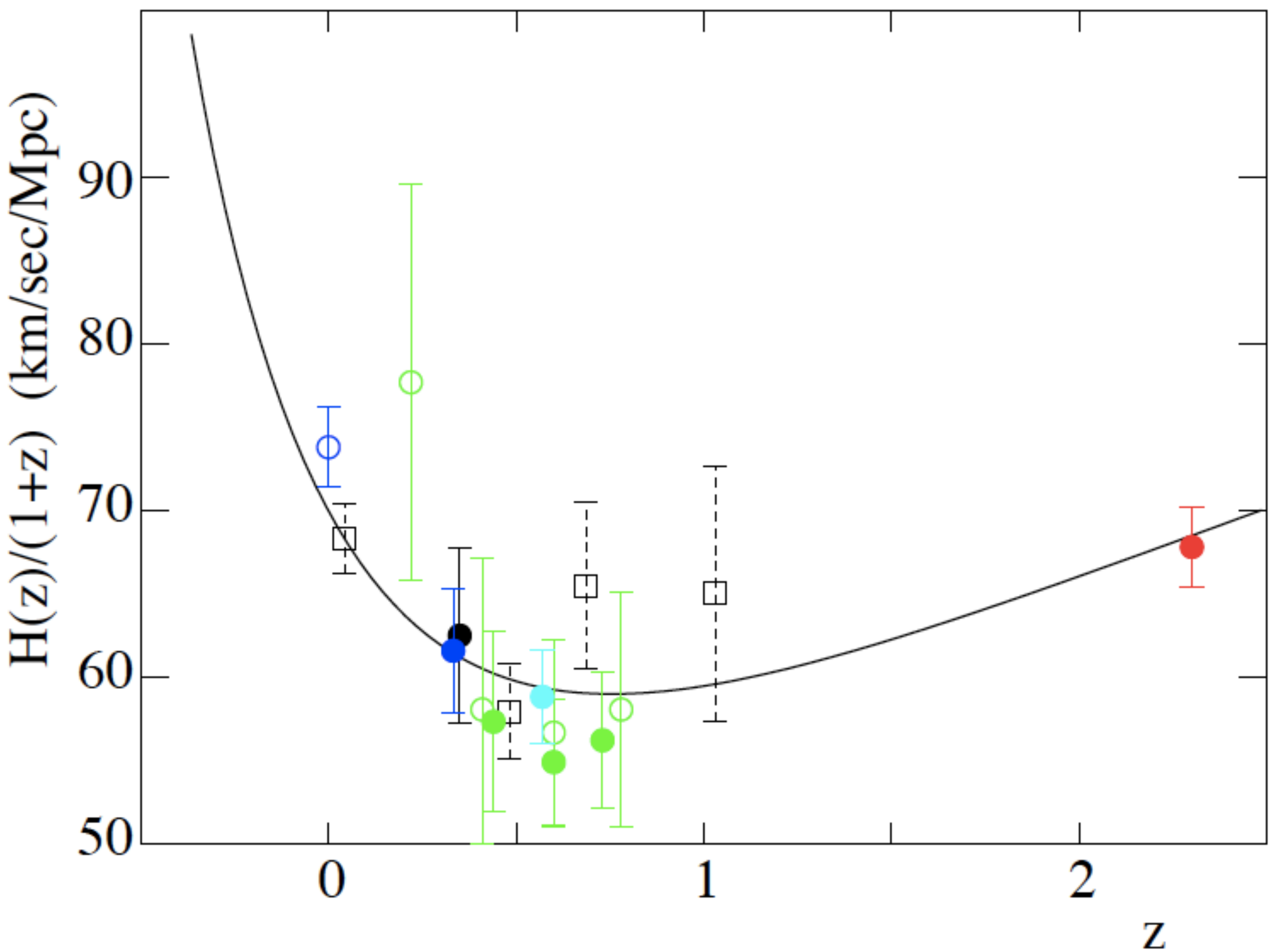
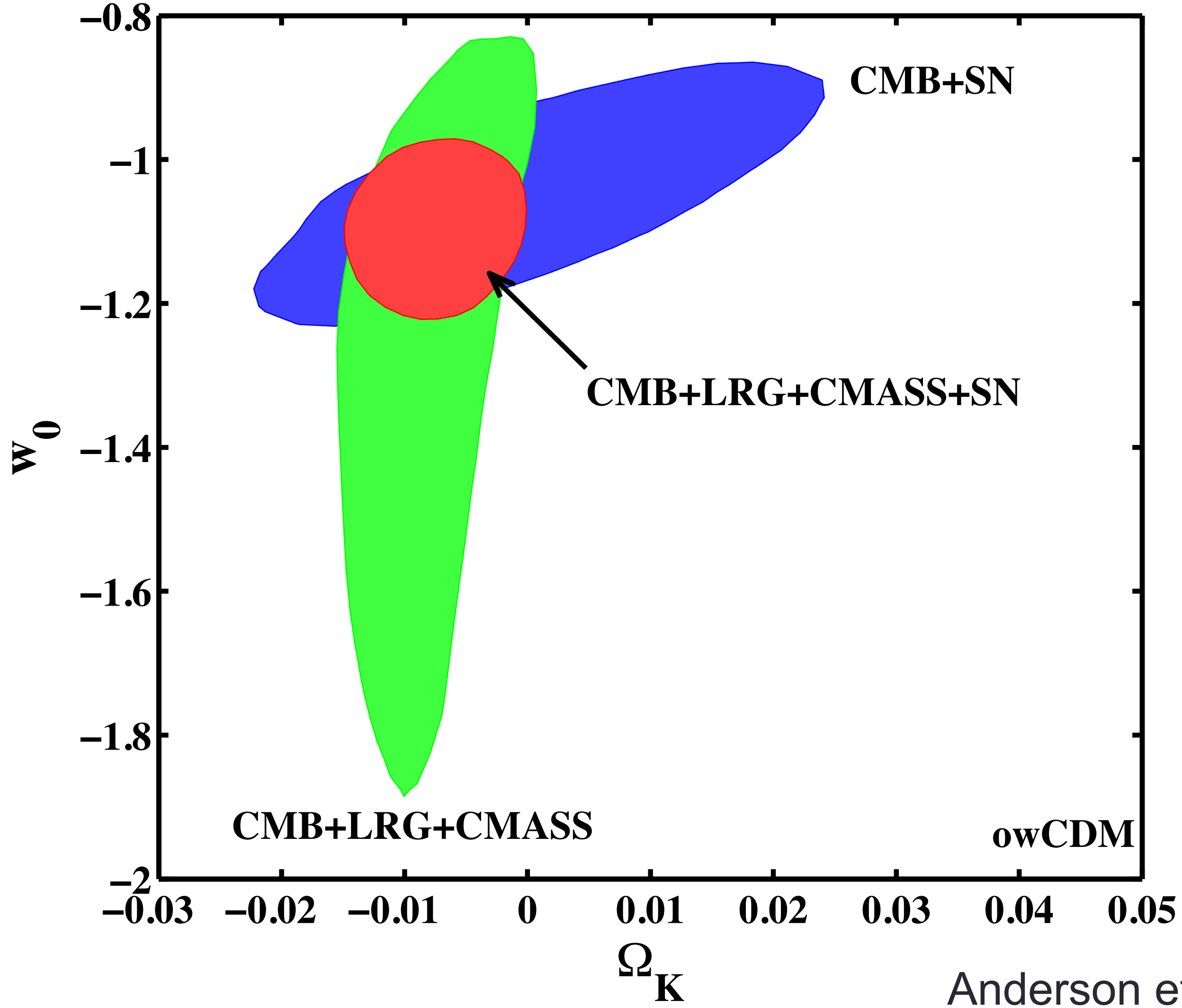


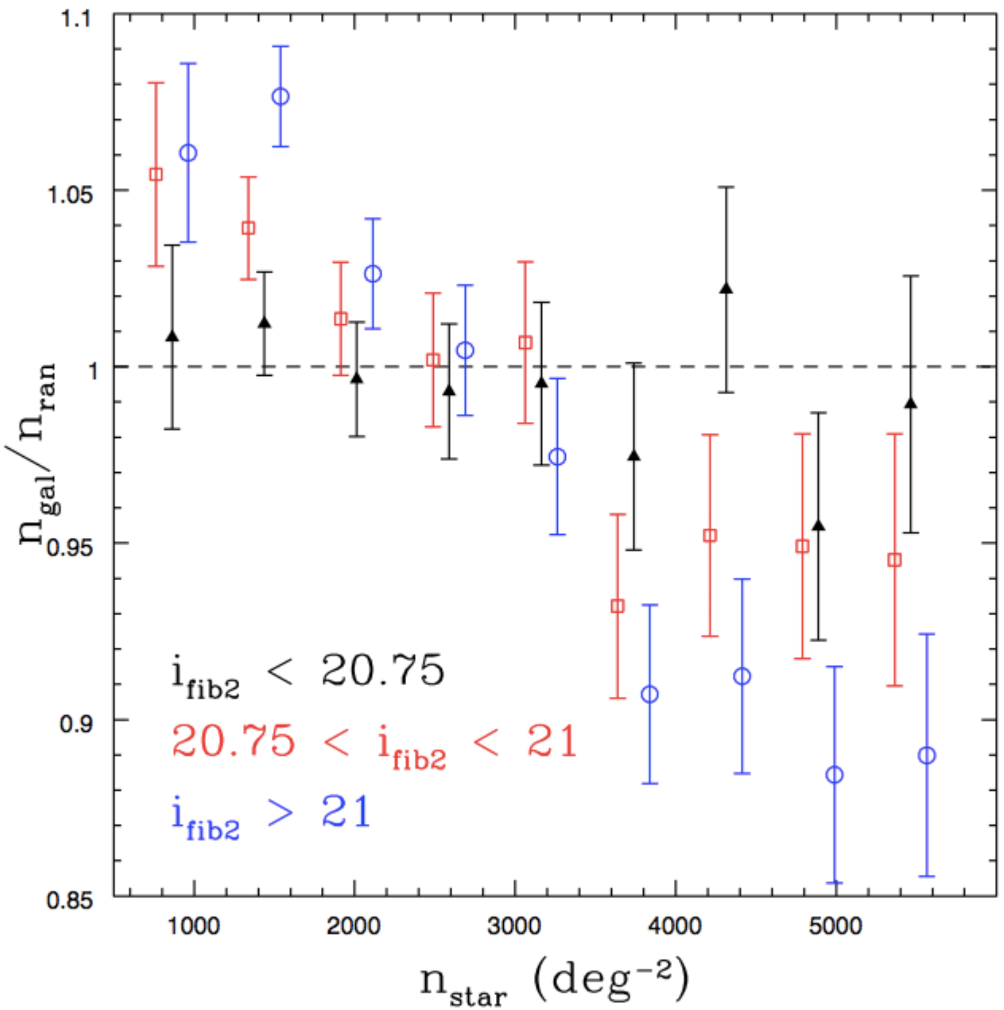
Busca et al, 2012

The complementarity of BAO and SN



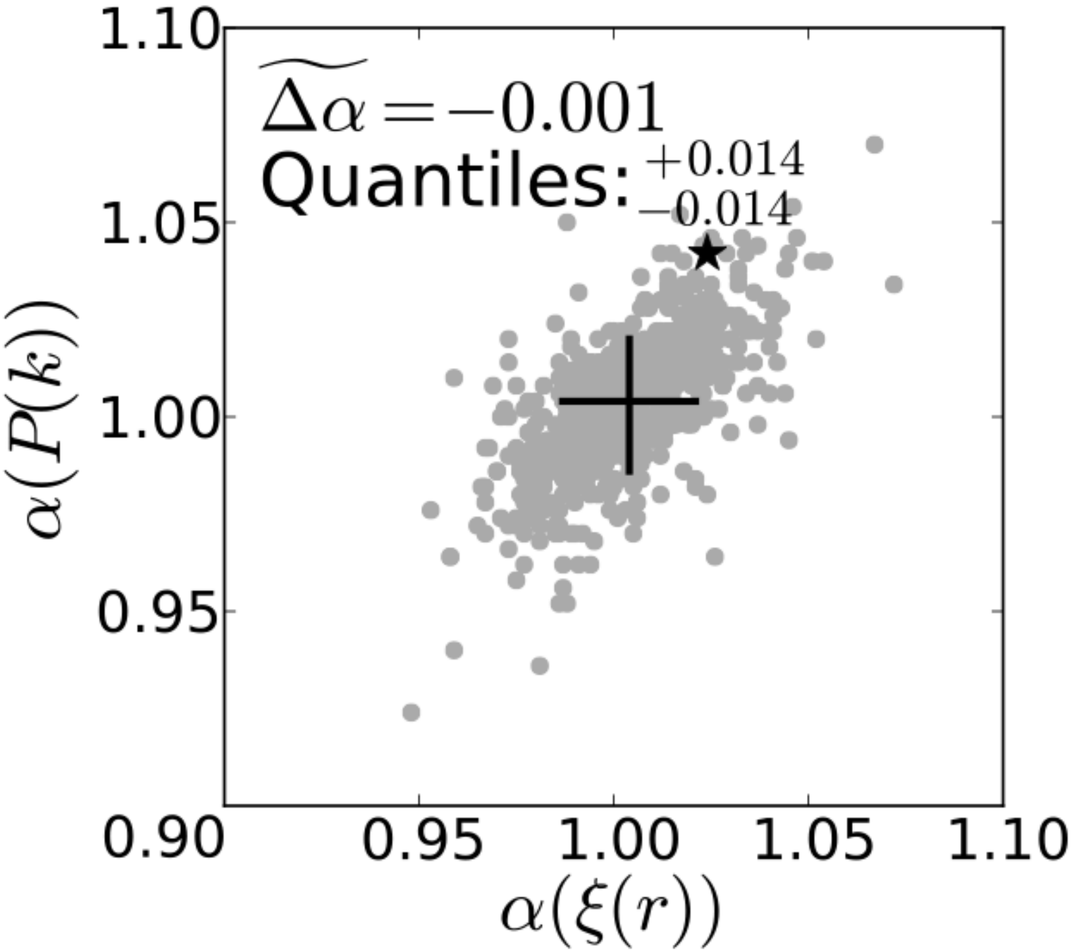
Anderson et al, 2012

BOSS as a precursor survey : Observational Systematics



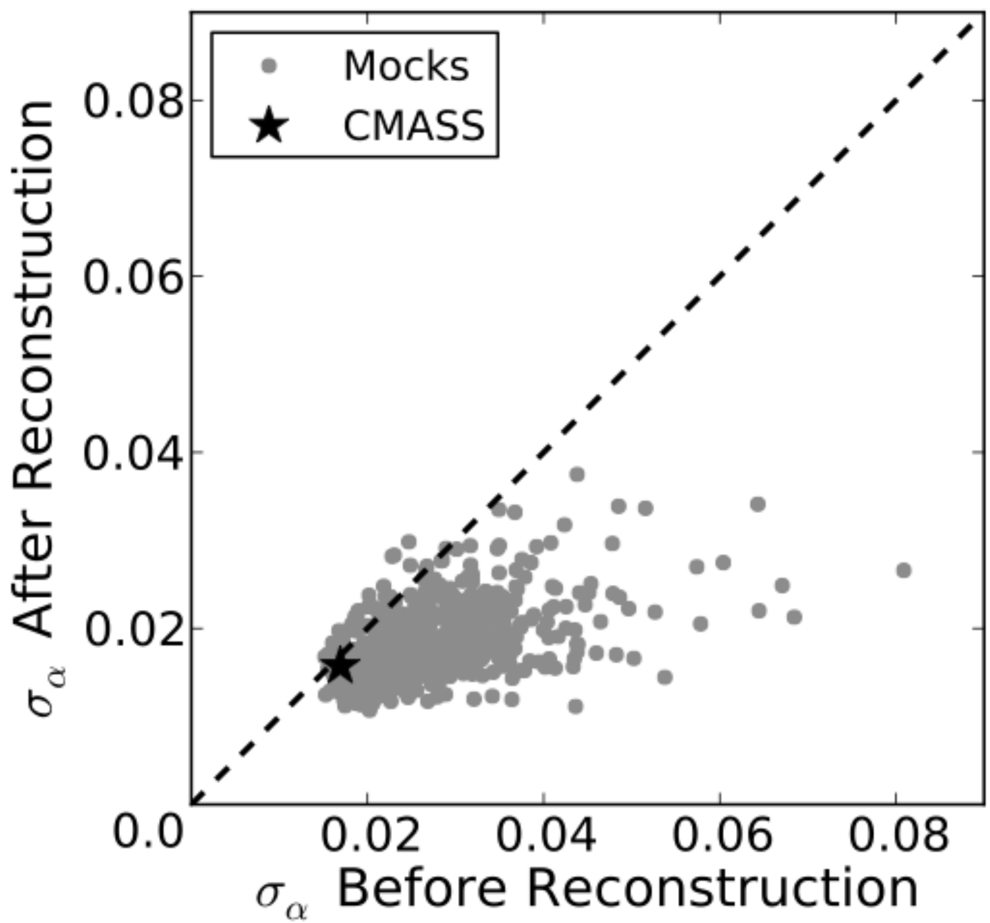
Ross et al, 2012

BOSS as a precursor survey : Analysis Techniques



Anderson et al, 2012

BOSS as a precursor survey : Analysis Techniques



Anderson et al, 2012

BAO Experiments : Past, Present and Future

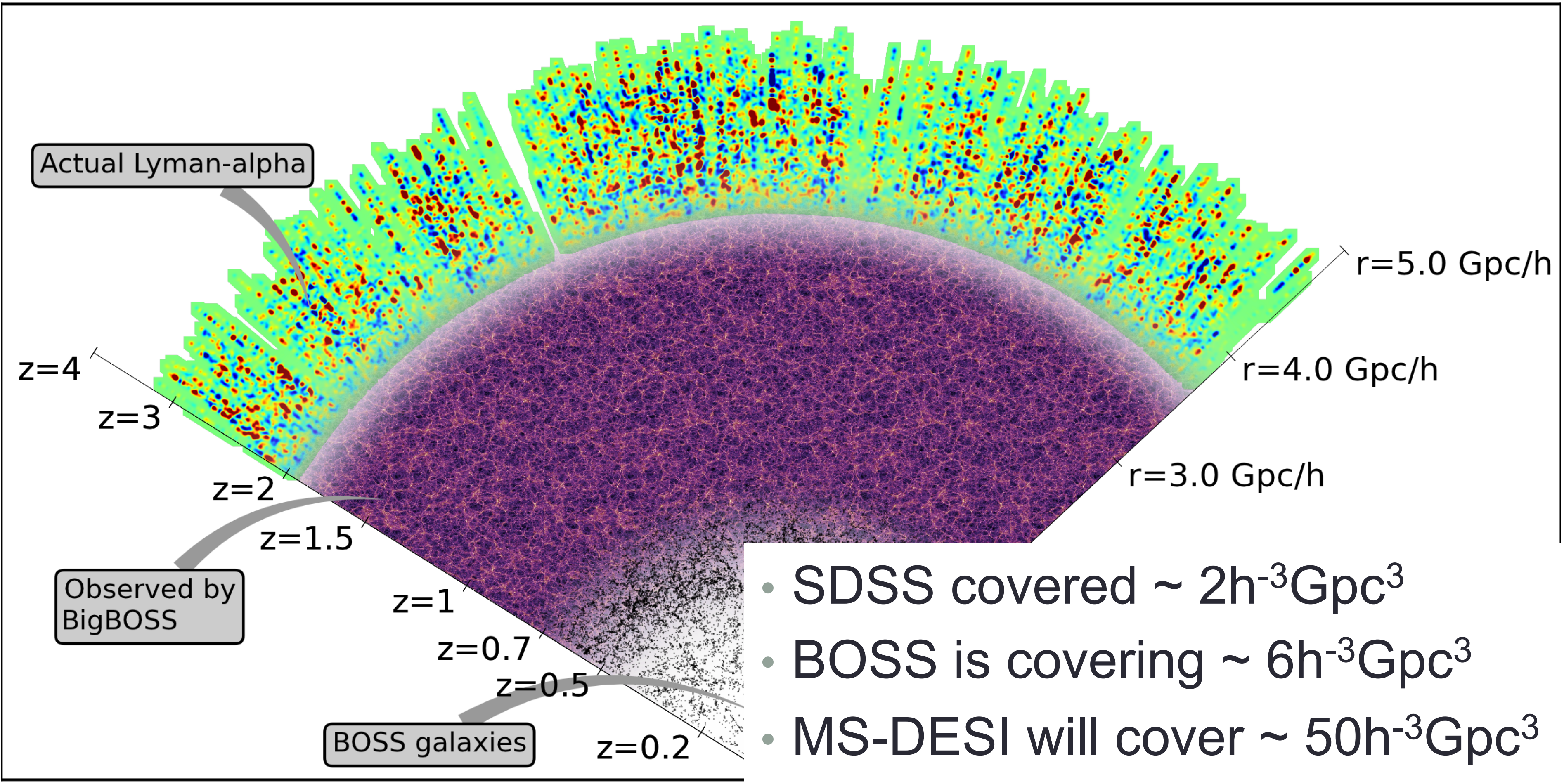
Survey	Redshift	Years	Precision
2dFGRS	0.2	Completed	detection
SDSS-I/II	**0.35**	**Completed**	**2%**
WiggleZ	0.7	Completed	4%
BOSS	**0.35, 0.55, 2.5**	**2009-2014**	**1.7% at z=0.57, 3.4% at z=2.3**
BOSS	0.35, 0.55, 2.5	2009-2014	1% (0.35, 0.55), 1.5% (2.5)
HETDEX	3.0	2013-2015	1%
eBOSS	0.6-1.0, 1-2, 2-	2014-2020	0.8%-2.0%, 1.5%,
Sumire PFS	0.6-2.4	2017	~1% (6 bins)
MS-DESI	0.2-1.7, 2-3.5	2018-	<1% (multiple bins)
WFIRST	1.5 – 2.5?	??	<1% (multiple bins)
Euclid	0.7 – 2.0	2021	<1% (multiple bins)

BAO Surveys : Future

	BOSS 2009-2014	e-BOSS 2014-2020	MS-DESI 2018-	SuMIRe PFS 2017-
Telescope	2.5m	2.5m	4m @KPNO or CTIO	8.2 Subaru Tel.
Imaging survey	SDSS	SDSS, WIRO, SCUSS, WISE	PTF, Pan-Starrs, DES?	Hyper SuprimeCam
Redshift	$0.2<z<0.7$	$0.6<z<2$	$0.2<z<2+z\sim2\text{-}3.5$ (Lya)	$0.6<z<2.4$ [OII]
Sky coverage	10000 deg^2	1500-7500 deg^2	14000 deg^2	~2000 deg^2
Field-of-view	6.7 deg^2	6.7 deg^2	6.7 deg^2	1.8 deg^2
Number of fibers	1000	1000	5000	2400
Wavelength range	360-1000nm	360-1000nm	340-1000nm	400-1300 nm
Spectral resolution	1600-2600	1600-2600	2300-5000	~3000
Target galaxies	LRGs	ELGs+QSOs	LRGs+[OII] emitters	LRGs+[OII] emitters

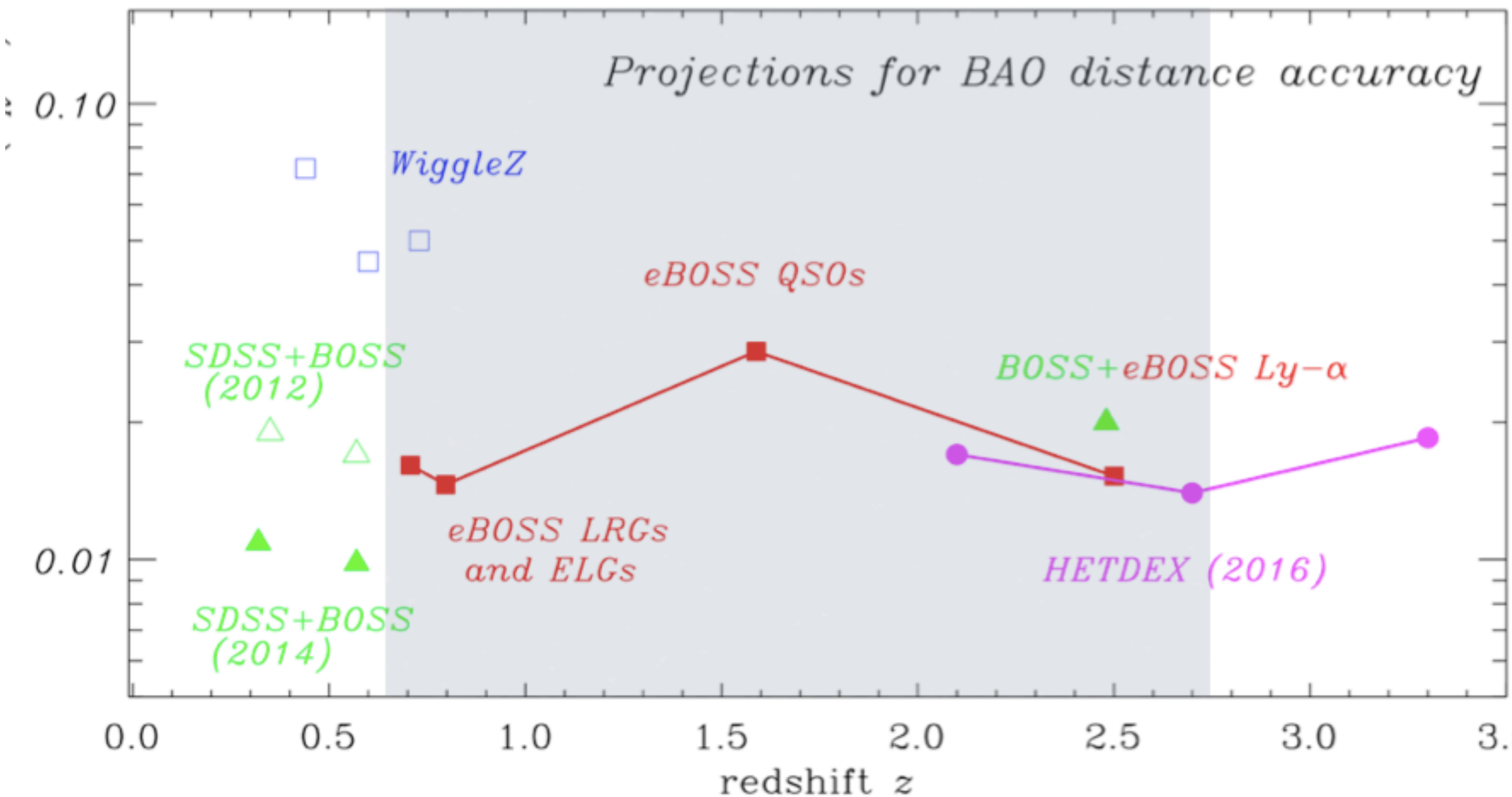
Kyle Dawson, priv. comm.

MS-DESI is BIG



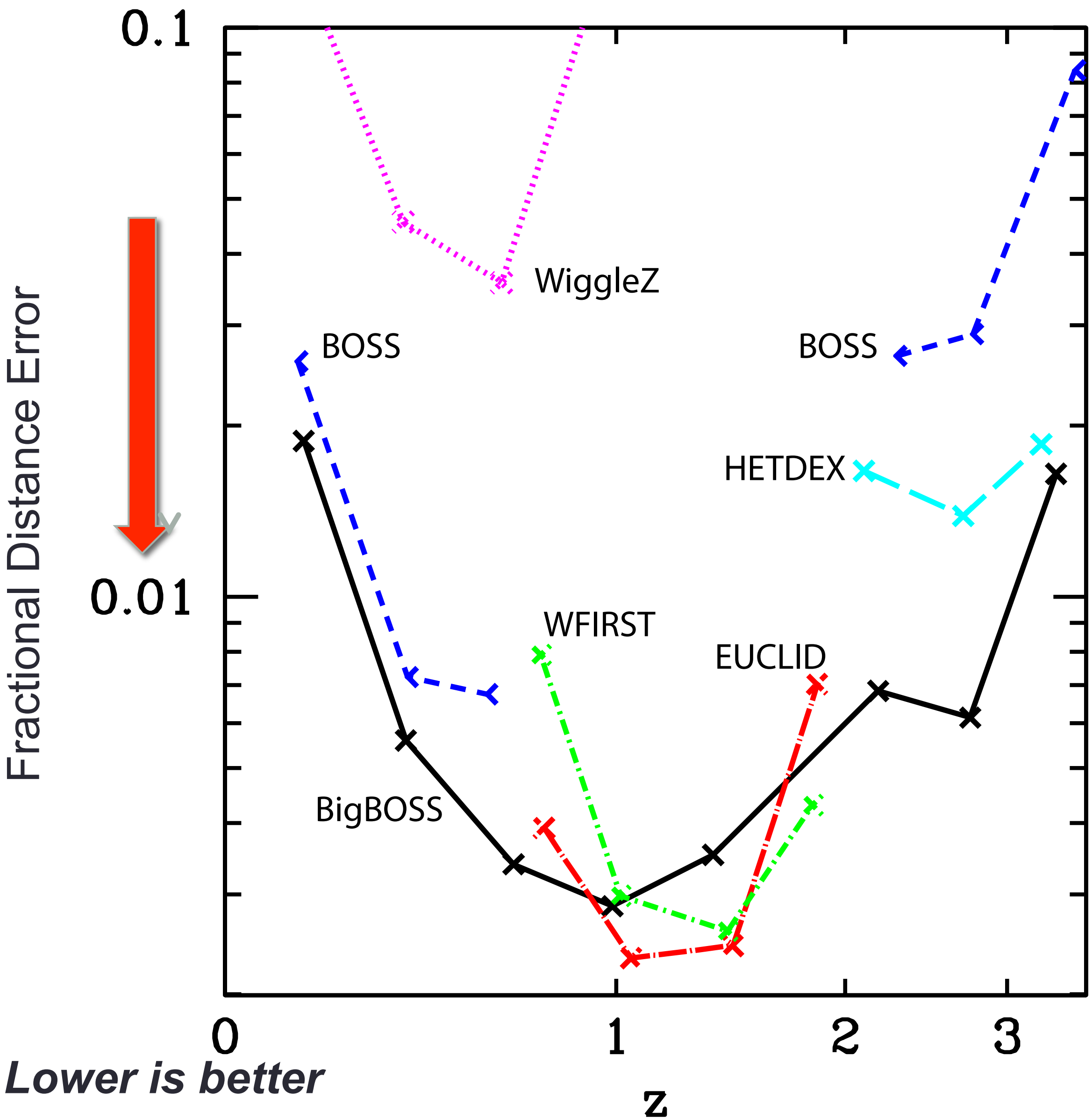
- SDSS covered ~ $2h^{-3}Gpc^3$
- BOSS is covering ~ $6h^{-3}Gpc^3$
- MS-DESI will cover ~ $50h^{-3}Gpc^3$
- unprecedented volume

Distance Constraints



Mike Blanton, priv. comm.

Distance constraints

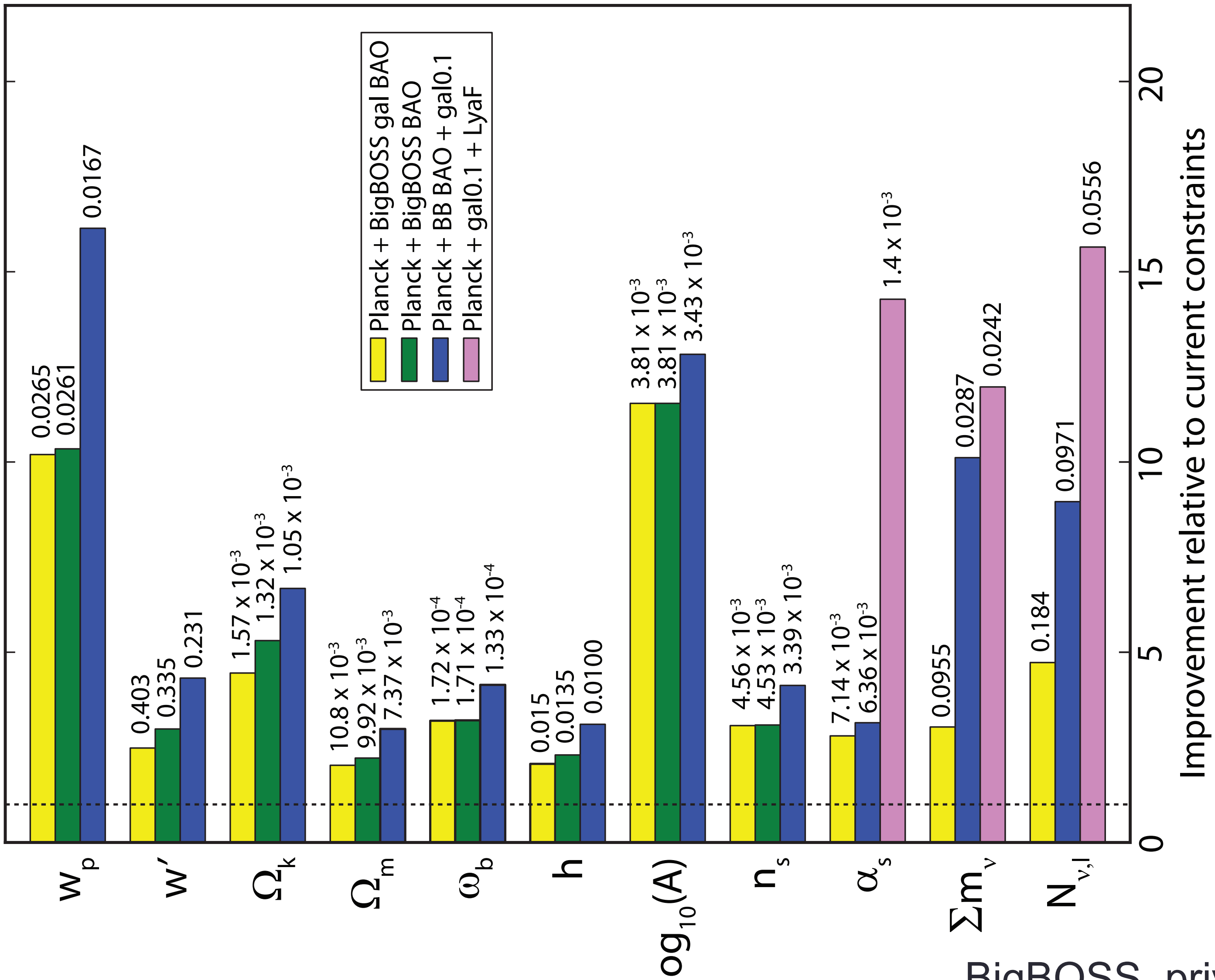


Lower is better

- MS-DESI has <1% distance errors
- Probe the expansion history over the widest redshift range

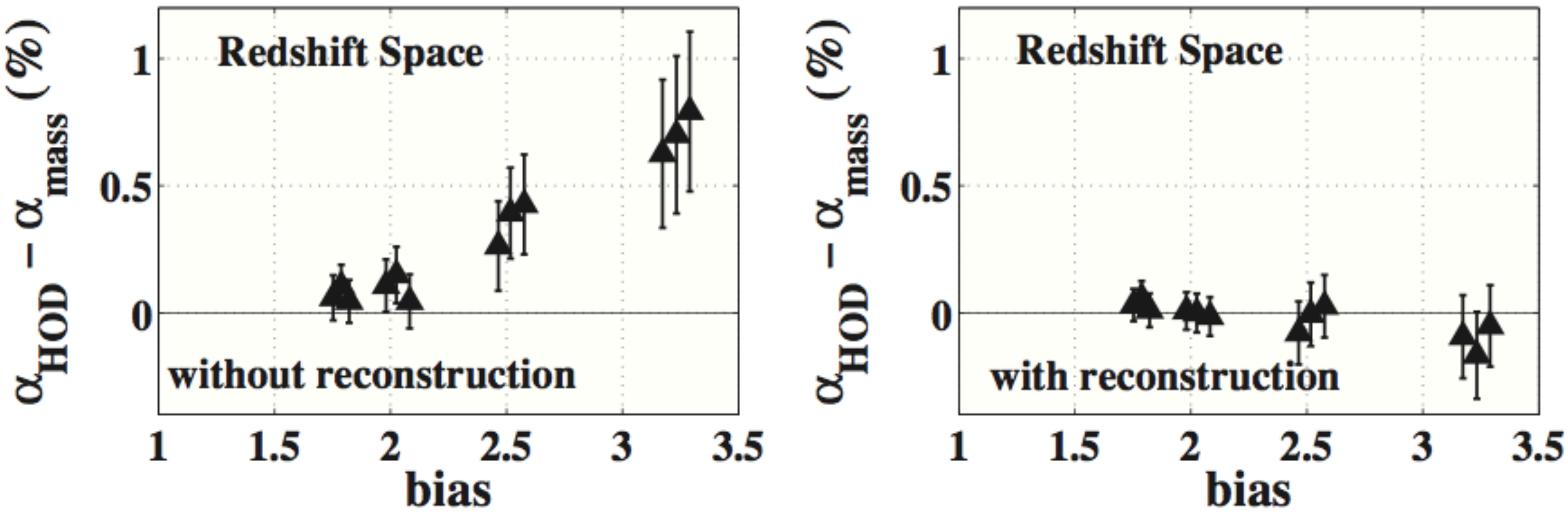
NASA WFIRST Science Definition Team

Beyond dark energy



BigBOSS, priv comm

Systematics



More work remains here – simulations

Mehta et al, 2010

Next steps

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