From current to future galaxy surveys

Will Percival

including work by the BOSS galaxy clustering working group

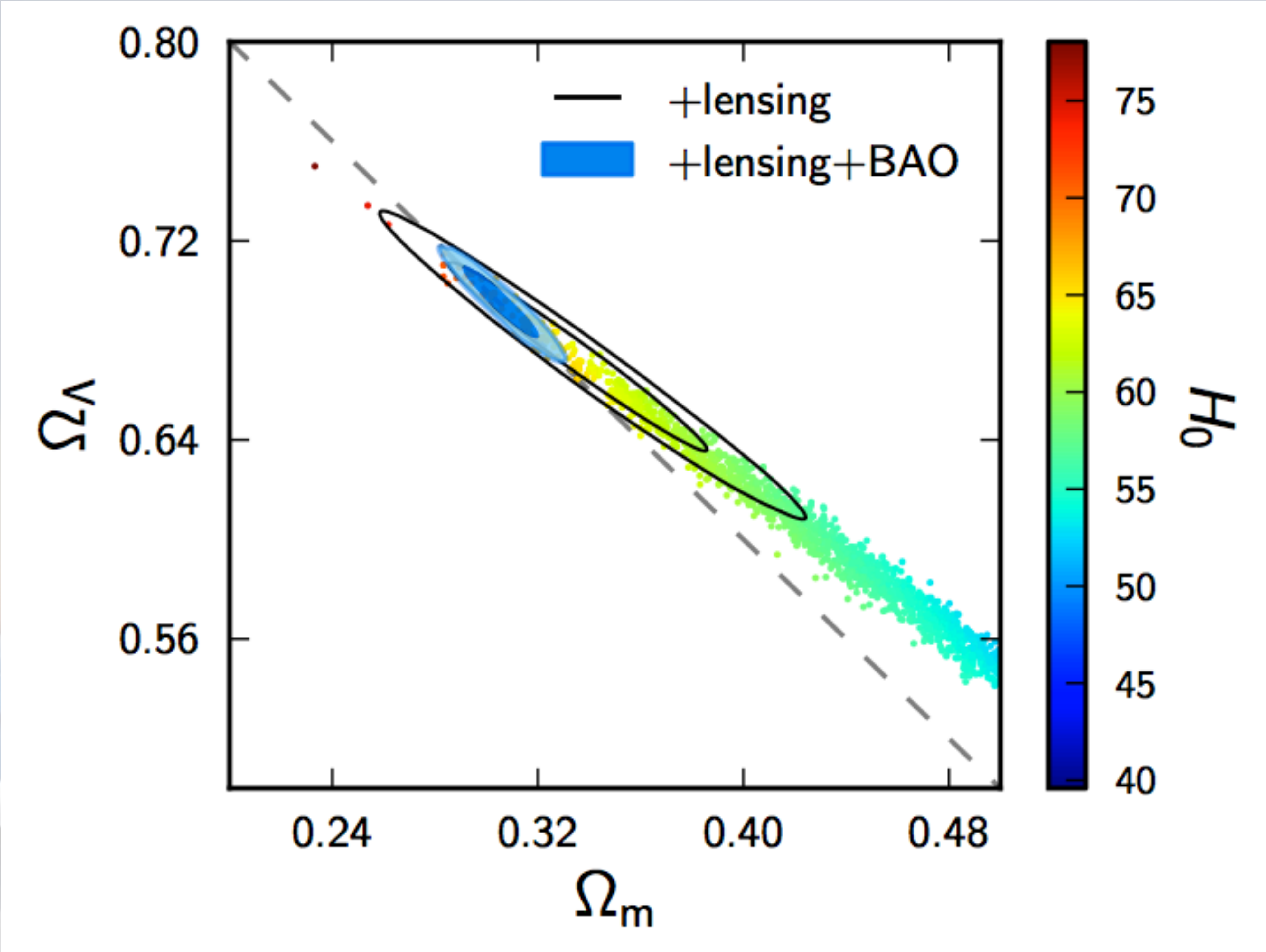
ICG Portsmouth

University of Portsmouth

Science & Technology Facilities Council

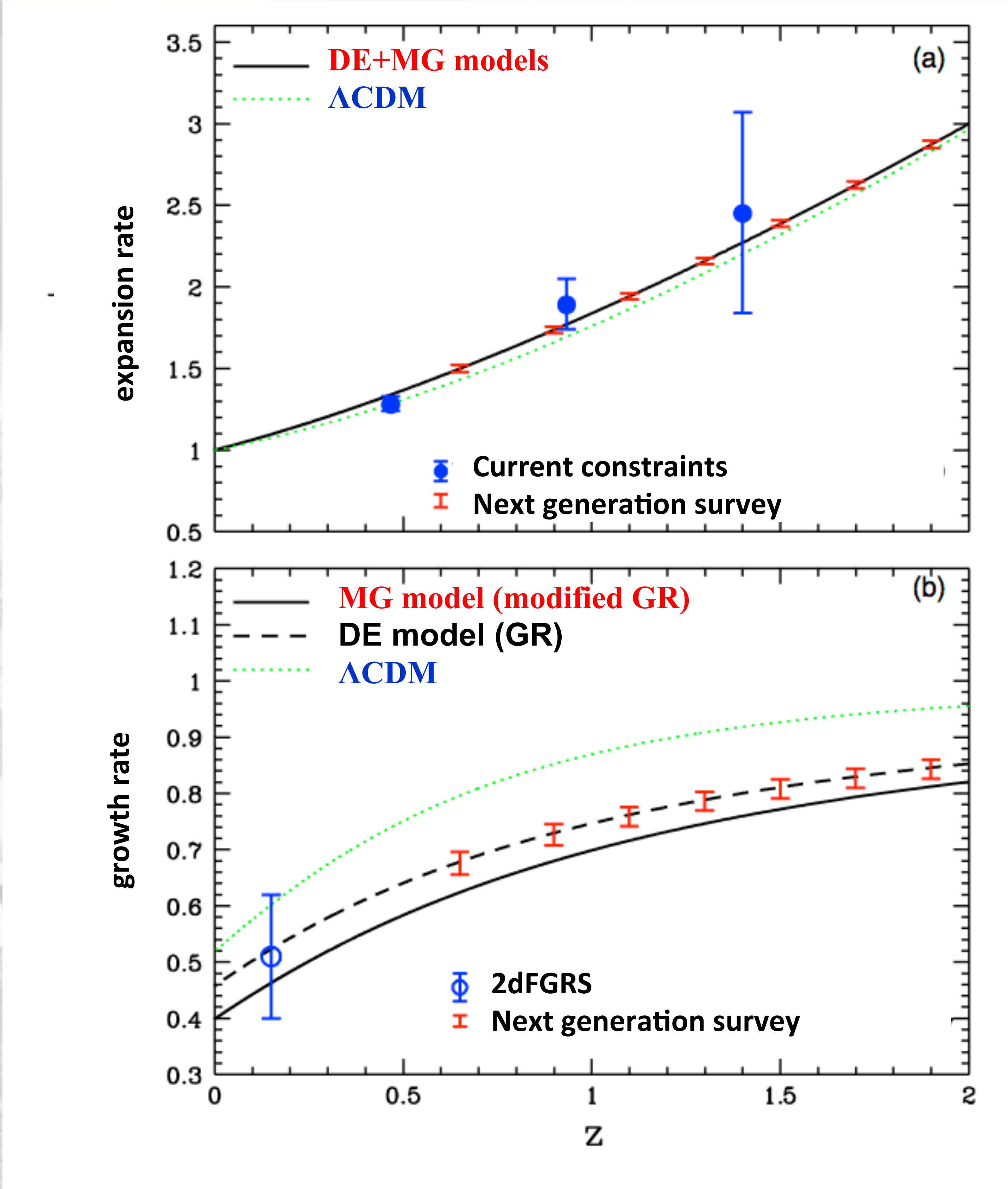
erc

Why BAO measurements are needed



Planck collaboration 2013; arXiv:1303.5076

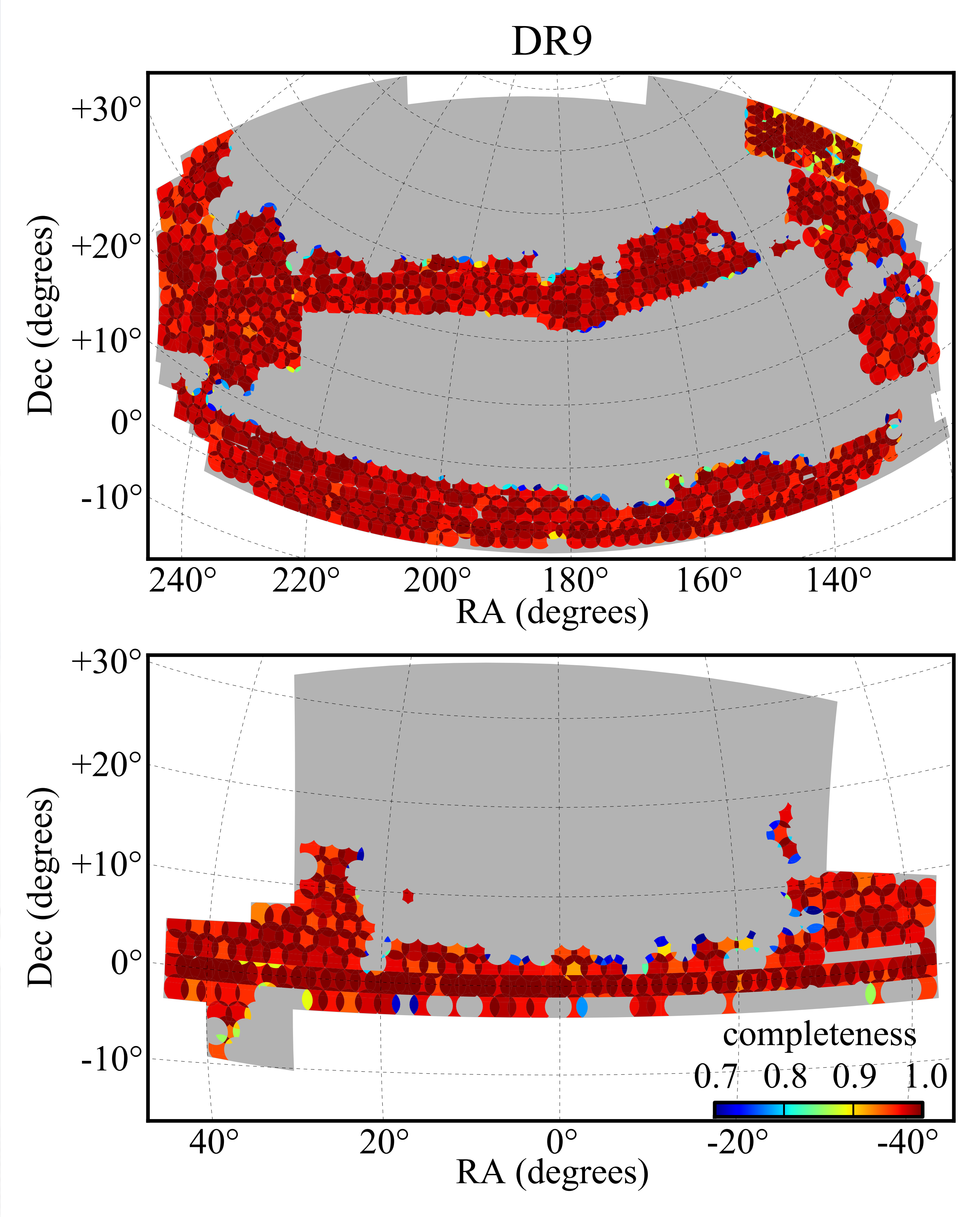
Why RSD measurements are needed



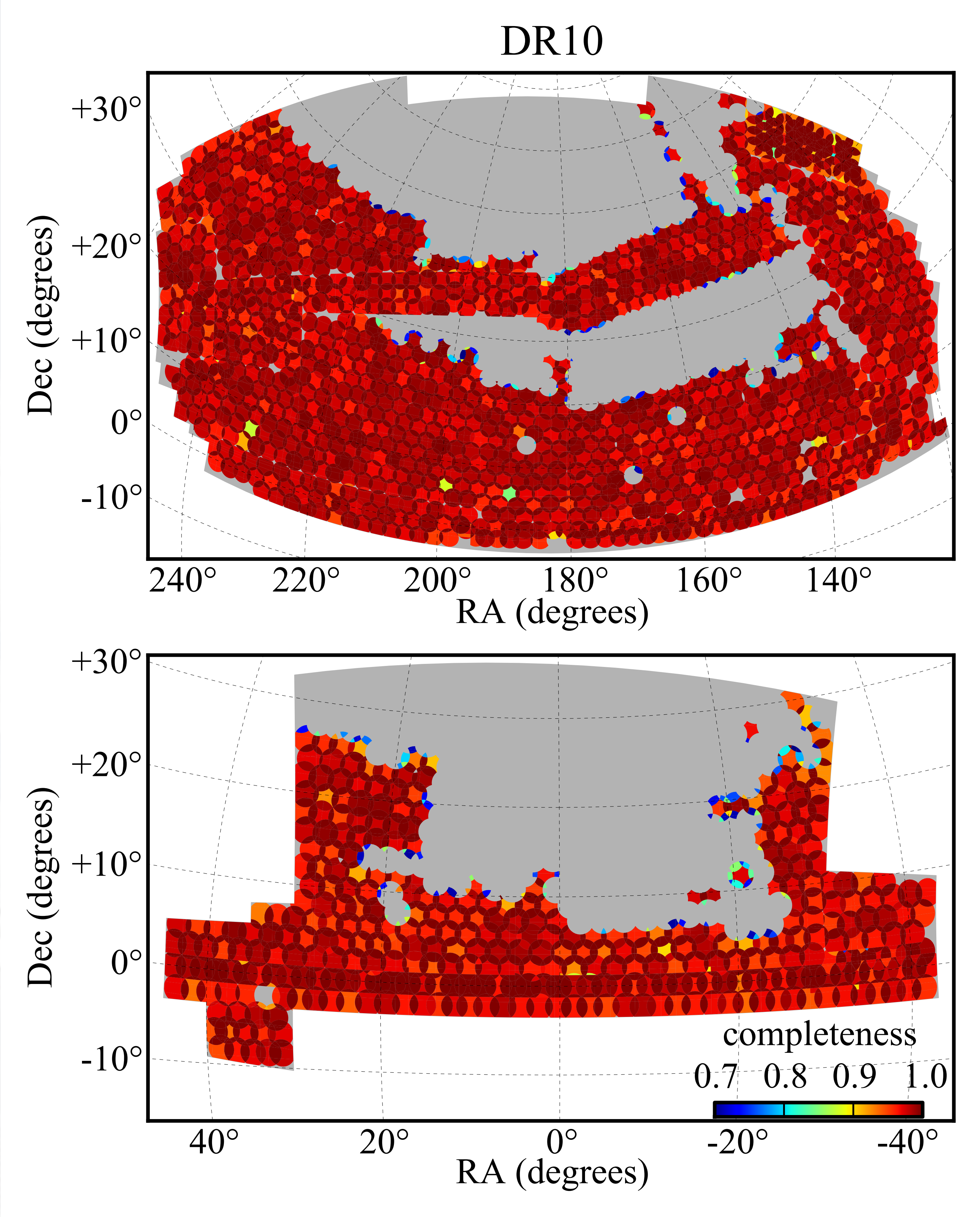
Wang 2008: JCAP, 05, 21

next 18 months

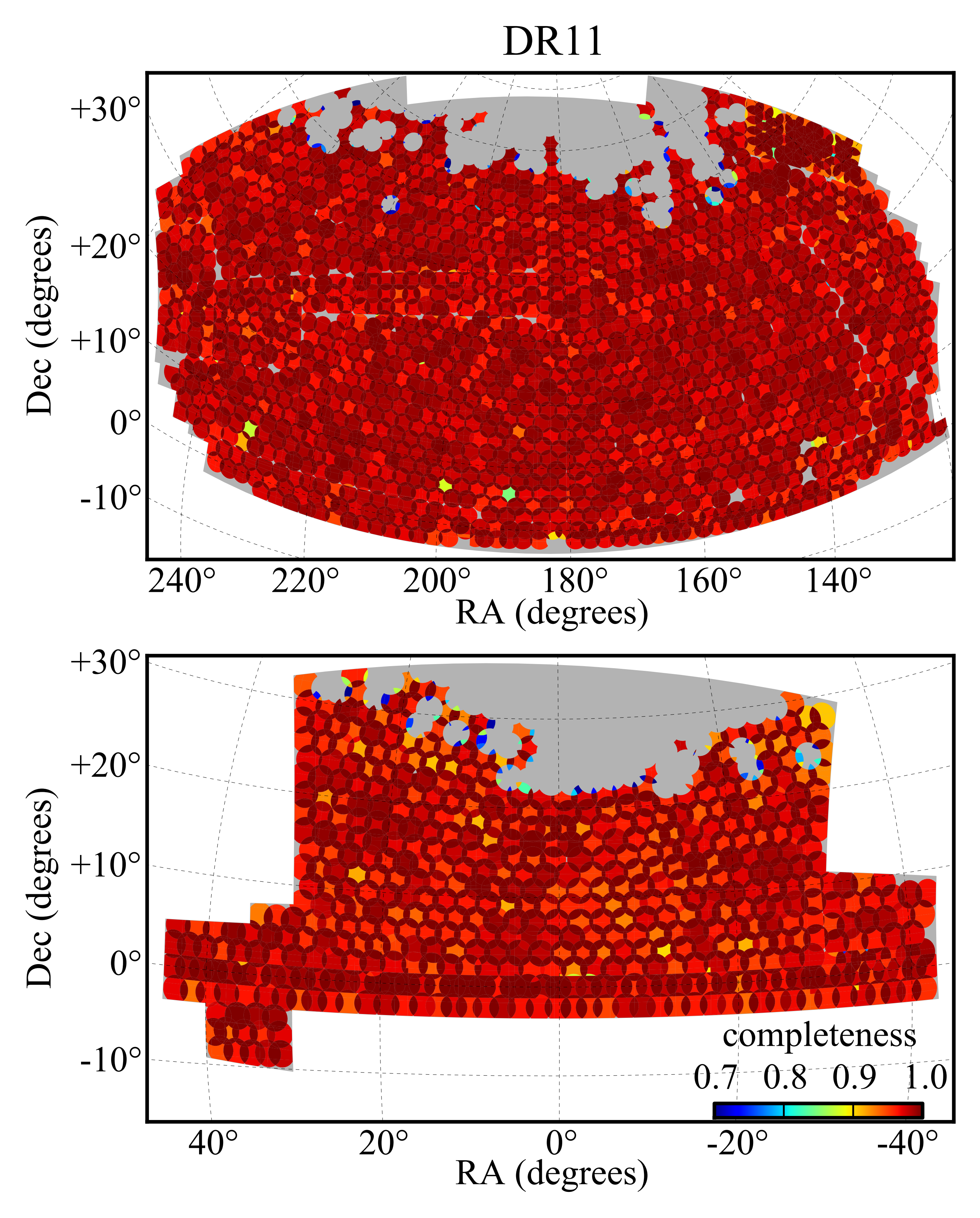
BOSS DR9 galaxies

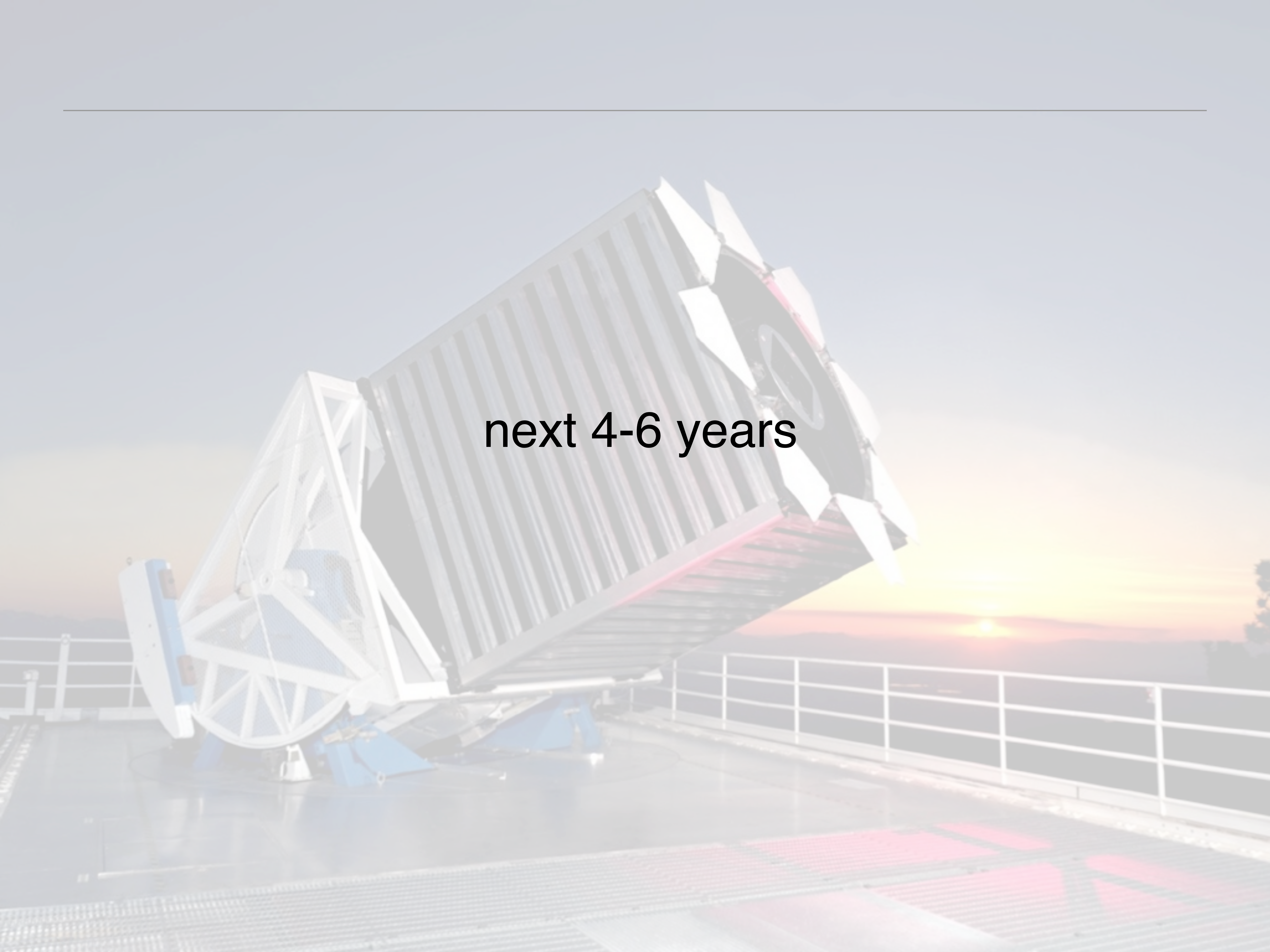


BOSS DR10 galaxies



BOSS DR11 galaxies

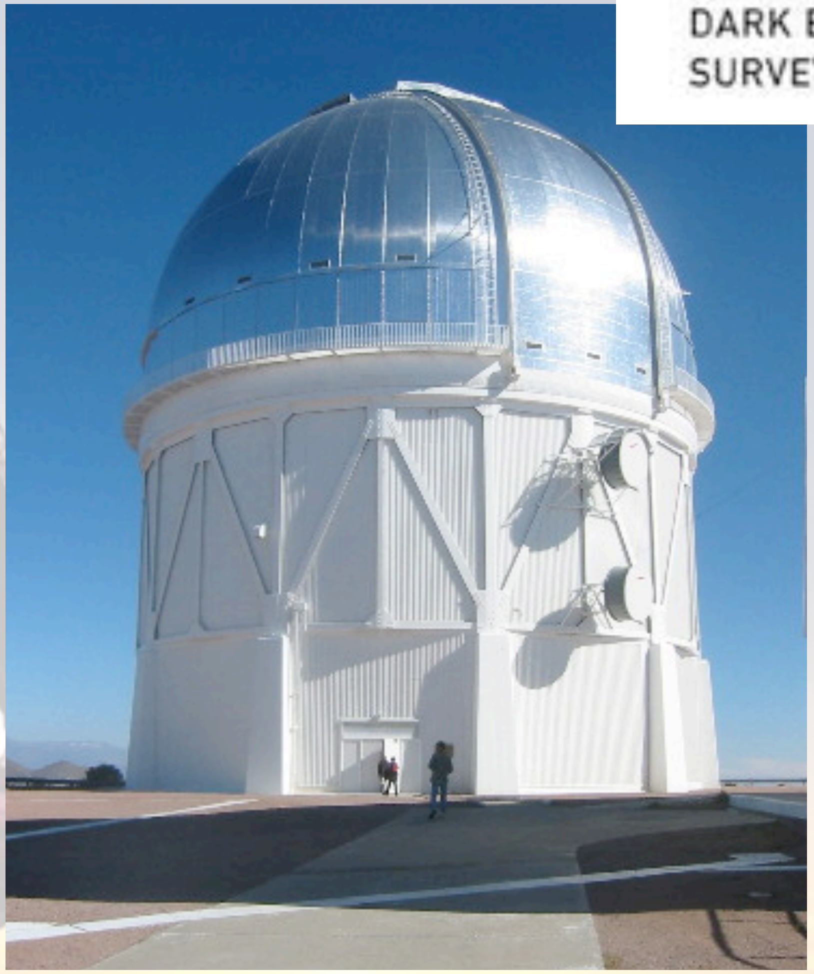


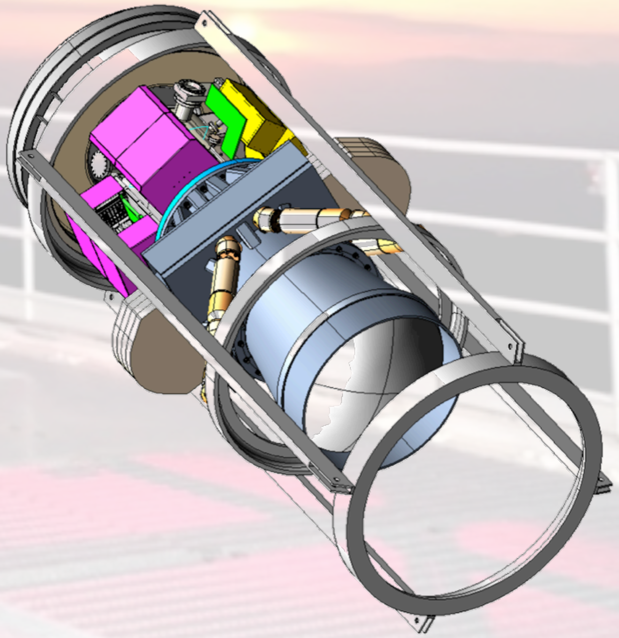


next 4-6 years

Dark Energy Survey (DES)

- New wide-field camera for the 4m Blanco telescope
- Commissioning currently finishing, Survey due to start September 2013
- $\Omega = 5{,}000\text{deg}^2$
- multi-colour optical imaging (g,r,i,z) with link to IR data from VISTA hemisphere survey
- 300,000,000 galaxies
- Aim is to constrain dark energy using 4 probes
  LSS/BAO, weak lensing, supernovae
  cluster number density
- Redshifts based on photometry
  weak radial measurements
  weak redshift-space distortions
- See also: Pan-STARRS, VST-VISTA, SkyMapper

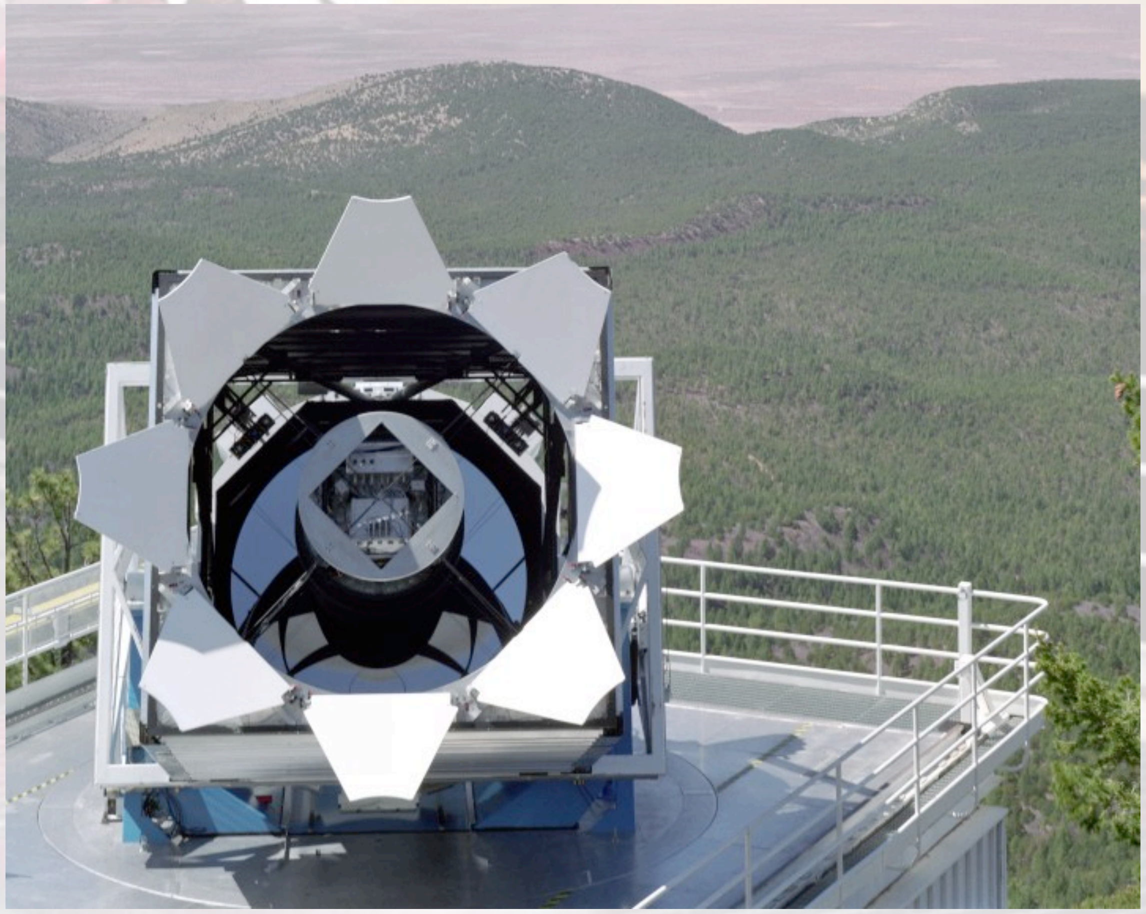




DARK ENERGY SURVEY

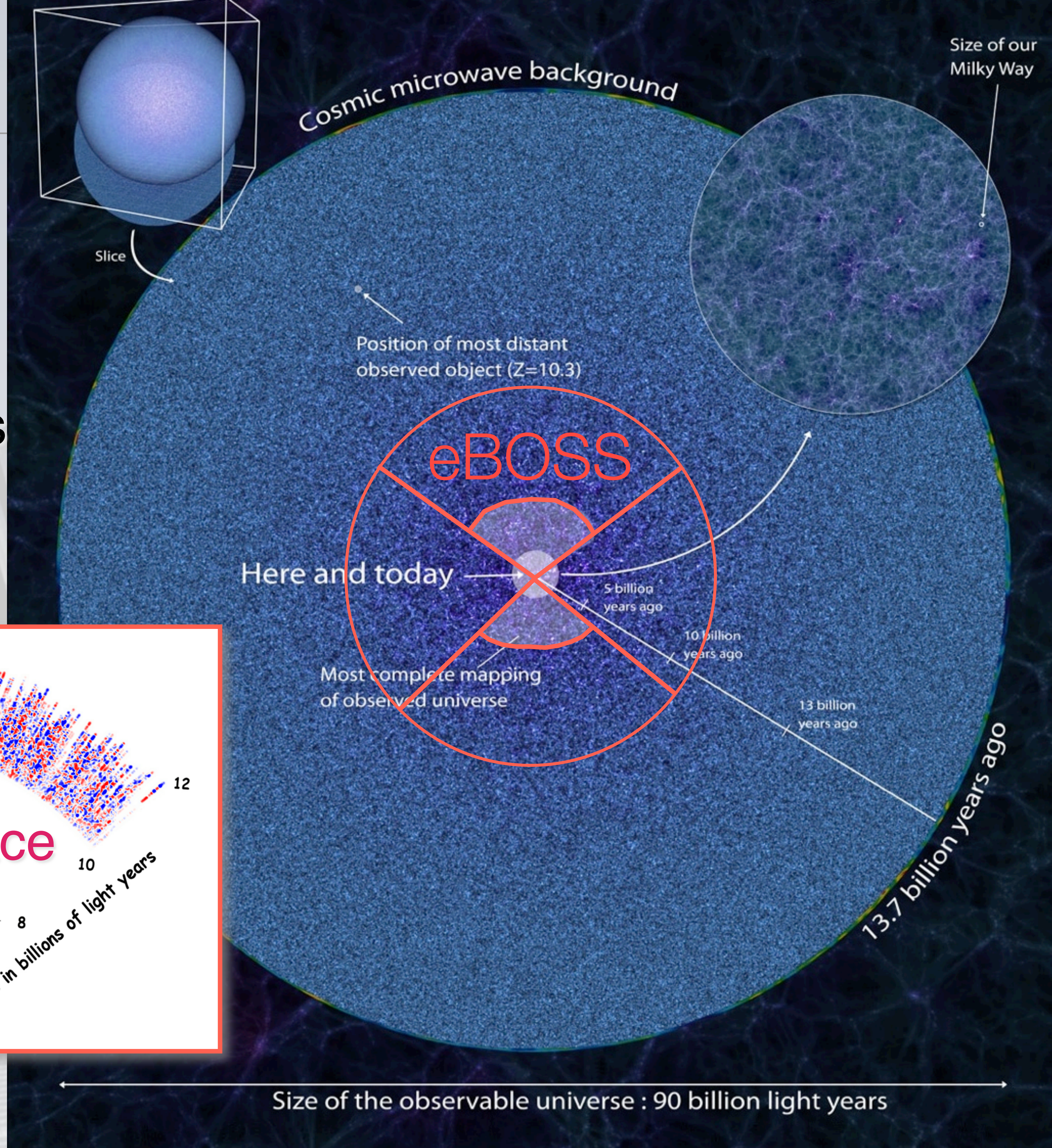
eBOSS / SDSS-IV

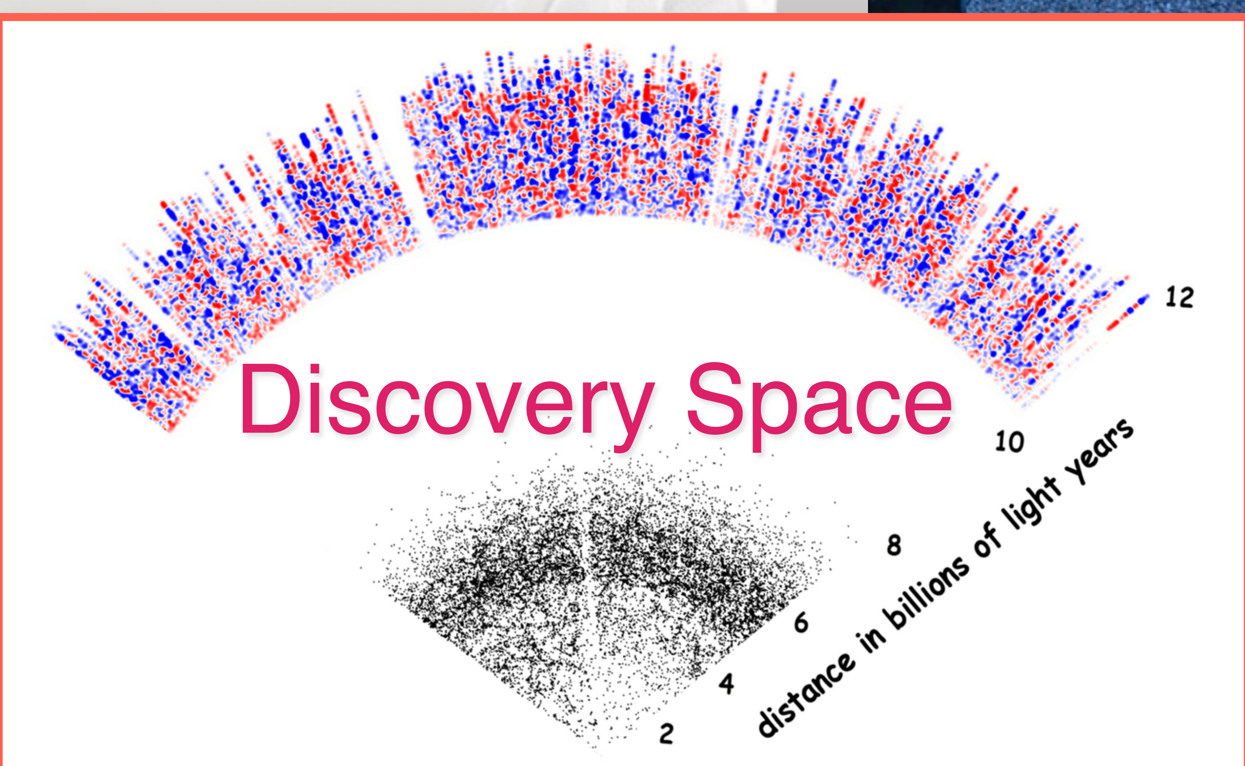
- The new cosmology project with SDSS
- Use the Sloan telescope and MOS to observe to higher redshift
- Basic parameters
  - Ω = 1,500deg^2 – 7,500deg^2
  - ~ 1,000,000 galaxies (direct BAO)
  - ~ 60,000 quasars (BAO from Ly-α forest)
- Distance measurements
  - 0.9% at z=0.8 (LRGs)
  - 1.8% at z=0.9 (ELGs)
  - 2.0% at z=1.5 (QSOs)
  - 1.1% at z=2.5 (Ly-α forest, inc. BOSS)
- Survey will start 2014, lasting 6 years
- Received $10M from Sloan foundation
  and significant funding from partners



eBOSS:

Measuring the Expansion History of the Universe between 7 and 11 billions of light years with Galaxies & Quasars





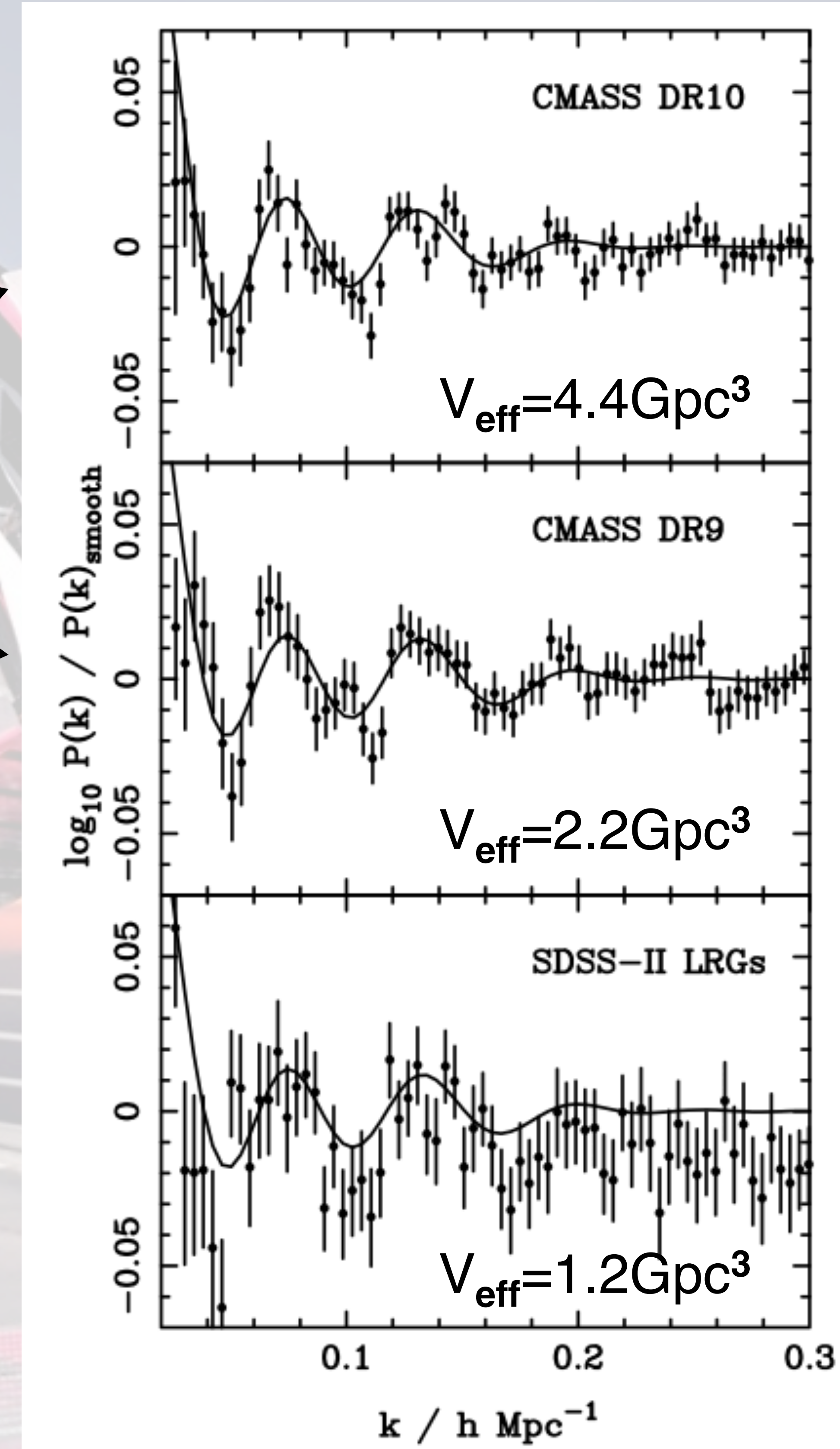
eBOSS targets

- LRGs – WISE+SDSS selected aiming for z~0.8 galaxies
- ELGs – SCUSS (u-band)+SDSS, South only (+DES over some area)
- QSOs – WISE+SDSS selected

Galaxies	Redshifts	Target sky density	Total area	Target success	Number of good redshifts	Distance precision	Effective volume
LRG	$0.7<z<0.9$	60deg^{-2}	7500deg^{2}	95%	430k	0.8%	4.7 Gpc^{3}
ELG	$0.6<z<1.0$	180deg^{-2}	1500deg^{2}	80%	216k	2.0%	2.3 Gpc^{3}
QSO	$0.9<z<2.3$ all	105deg^{-2}	7500deg^{2}	70% 90%	525k 700k	1.5%	6.6 Gpc^{3}
Lya QSO	$z>2.15$	5+22deg^{-2}	5000deg^{2}	30%	64k (+revisit)	-	-

eBOSS BAO measurements

Galaxies	Effective volume
LRG	4.7 Gpc^3
ELG	2.3 Gpc^3
QSO	6.6 Gpc^3
Lya QSO	-

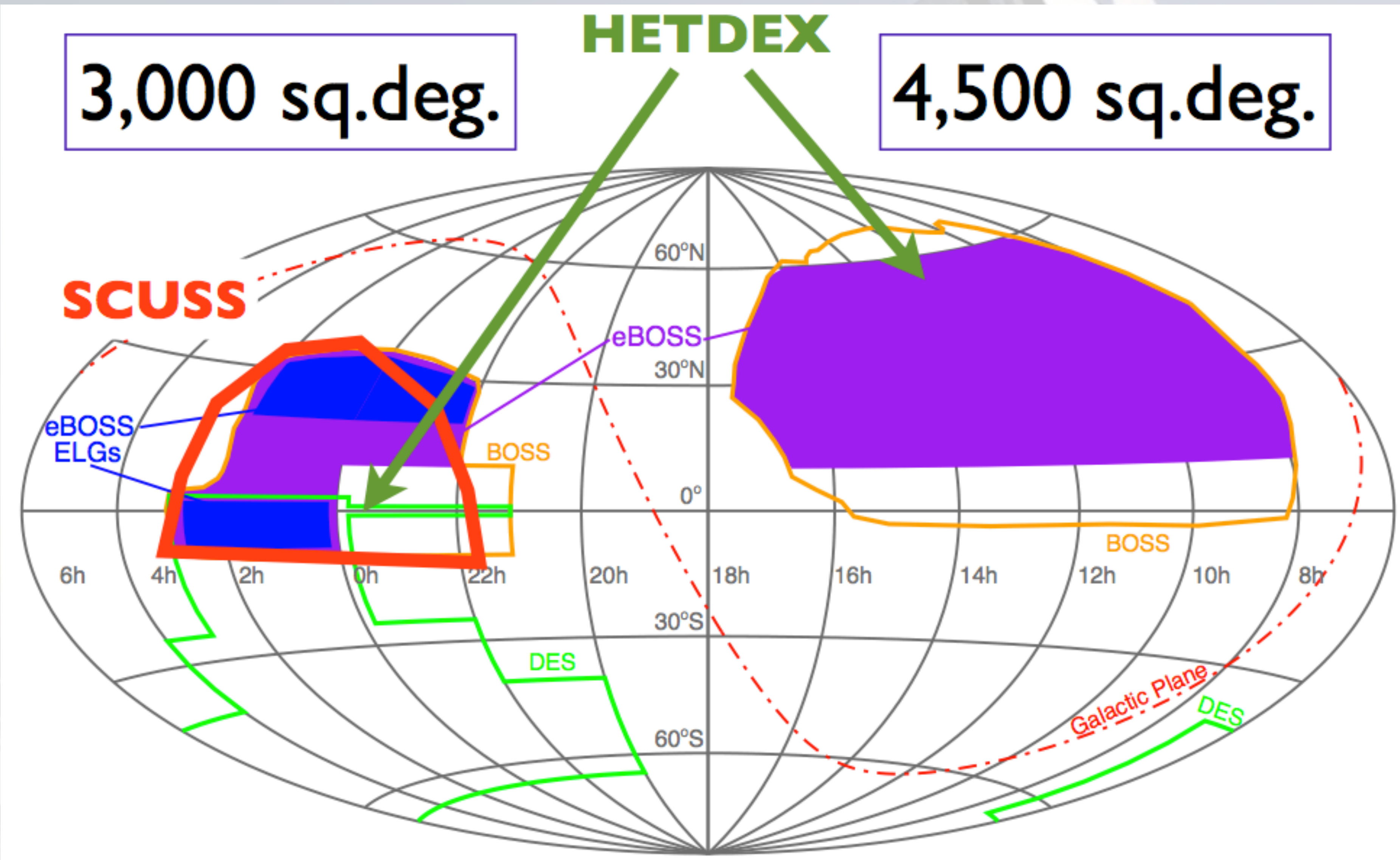


eBOSS further science

- DES – eBOSS overlap
  - ~500 deg^2 overlap with eBOSS in Southern sky
  - Synergy by “Cross-Correlation” of imaging and spectroscopic surveys for cosmological constraints (BAO+RSD+WL)
  - eBOSS will play a critical role allowing high-precision calibration of photo-z through cross-correlation

- eBOSS science will include many other cross-correlation opportunities
  - internally in eBOSS (LRG-ELG, LRG-QSO, ELG-QSO, CMASS-QSO, QSO absorbers-Galaxies ...)
  - U-band, WISE, Planck temperature, Planck lensing, eROSITA, DES, HSC, HETDEX ...

eBOSS strategy / timeline



Footprint depends on:

- SDSS-IV timeshare between projects
- DES coverage (500deg² overlap)
- SCUSS u-band survey on SGC (using Bok at Kitt-Peak)
- eROSITA (German sky) for additional follow-up program

Start date: summer 2014, but could be earlier!

Duration: 6 years

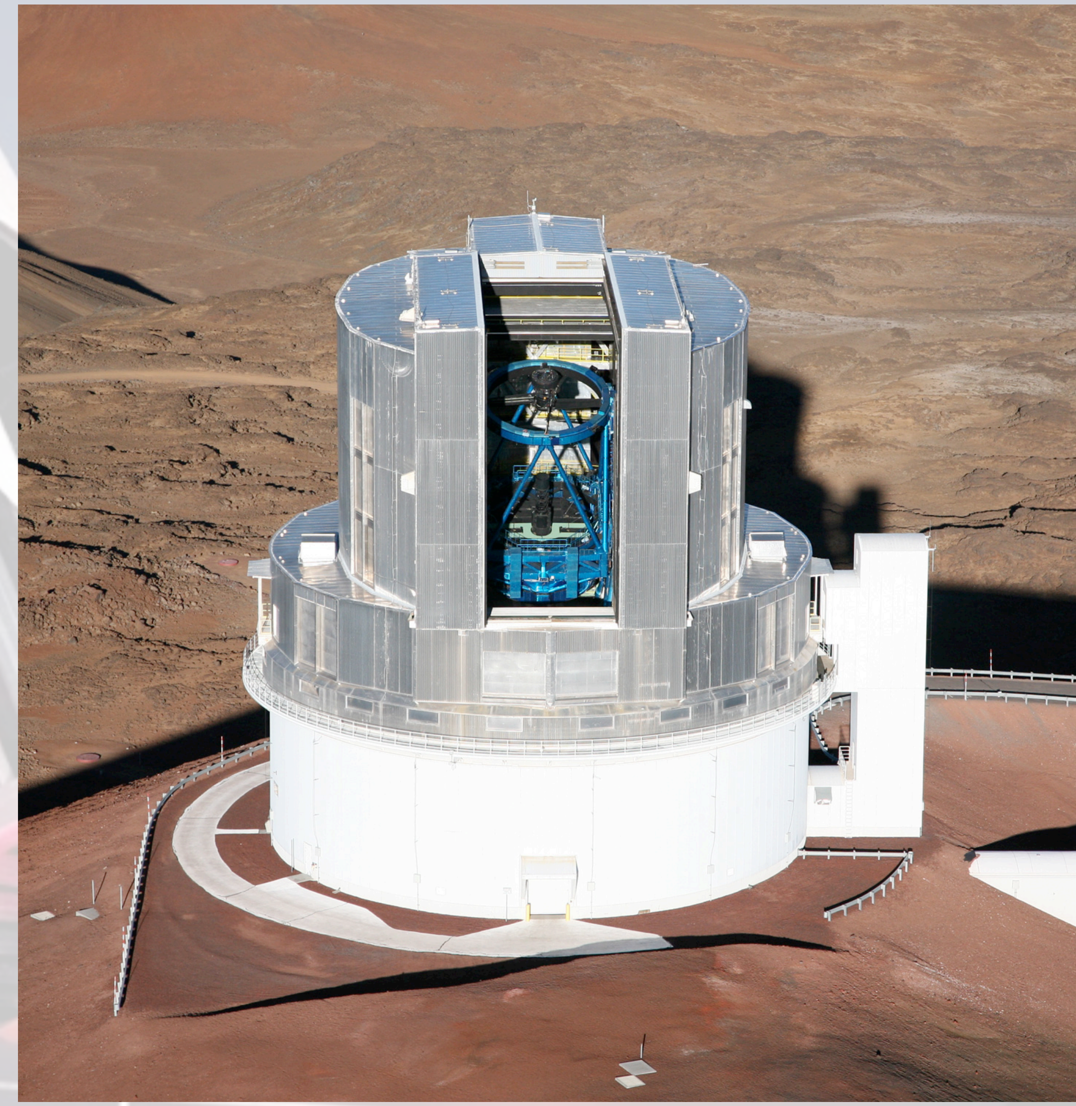
> 4 years

MOS on 4m-telescope

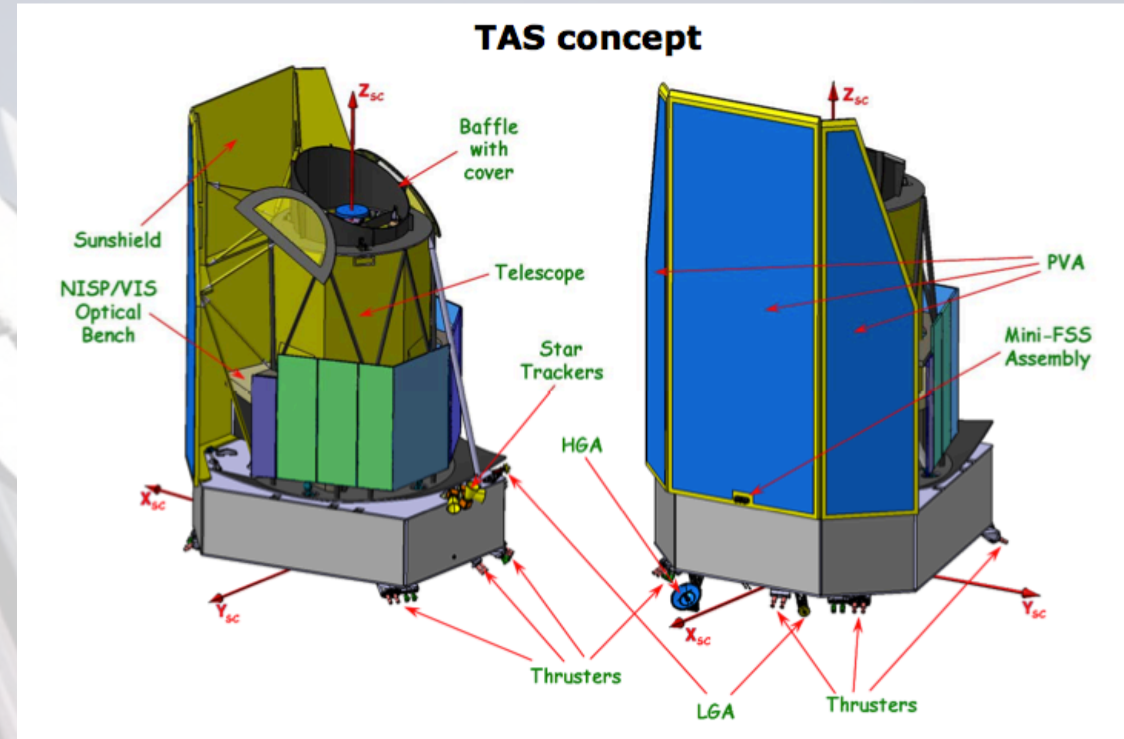
- New fibre-fed spectroscopes proposed
  for 4m telescopes
  - Mayall (BigBOSS) ⎫ DESi
  - Blanco (DESpec) ⎭ DESi
  - WHT (WEAVE)
  - VISTA (4MOST)
- Various stages of planning & funding
  - DESi now funded
  - 4MOST chosen by ESO, 1-year delay
  - WEAVE waiting for UK/Spain/Holland/France
- All capable of observing
  - Ω =5--14,000deg^2
  - 2--20,000,000 galaxies (direct BAO)
  - 1--600,000 quasars (BAO from Ly-α forest)
  - Cosmic variance limited to $z \sim 1.4$

MOS on 10m-telescope

- New fibre-fed spectroscopes proposed for 10m telescopes
  - Hobby-Eberly (HETDEX)
  - Subaru (PFS)
- Different baseline strategies
- HETDEX
  - 420deg^2 Ly-alpha emitters
  - 800,000 galaxies $1.9<z<3.5$
  - Greig, Komatsu & Wyithe, 2012, arXiv:12120977
- PFS
  - 1400deg^2 ELGs
  - 3,000,000 galaxies $0.6<z<2.4$
  - Ellis et al., 2012, arXiv:1206.0737



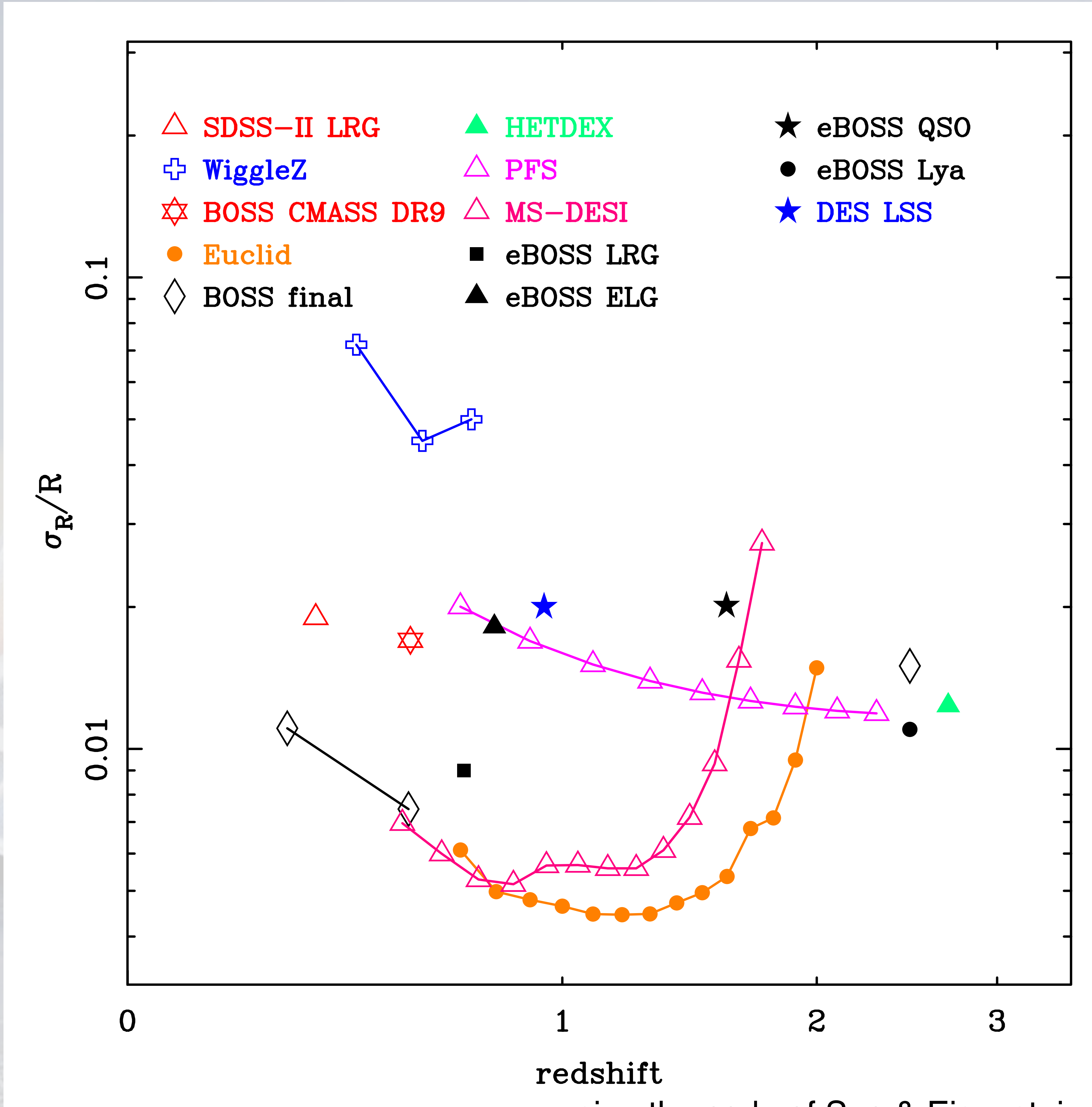
The Euclid spectroscopic survey



- Wide survey
  - 15,000deg²
  - 4 dithers
  - NIR Photometry
    - Y, J, H
    - 24mag, 5σ point source
  - NIR slitless spectroscopy
    - 1100-2000nm
    - 3×10^{-16}ergcm^{-2}s^{-1} 3.5σ line flux
    - 2 dispersion directions, 2 wavebands
    - 65M galaxies

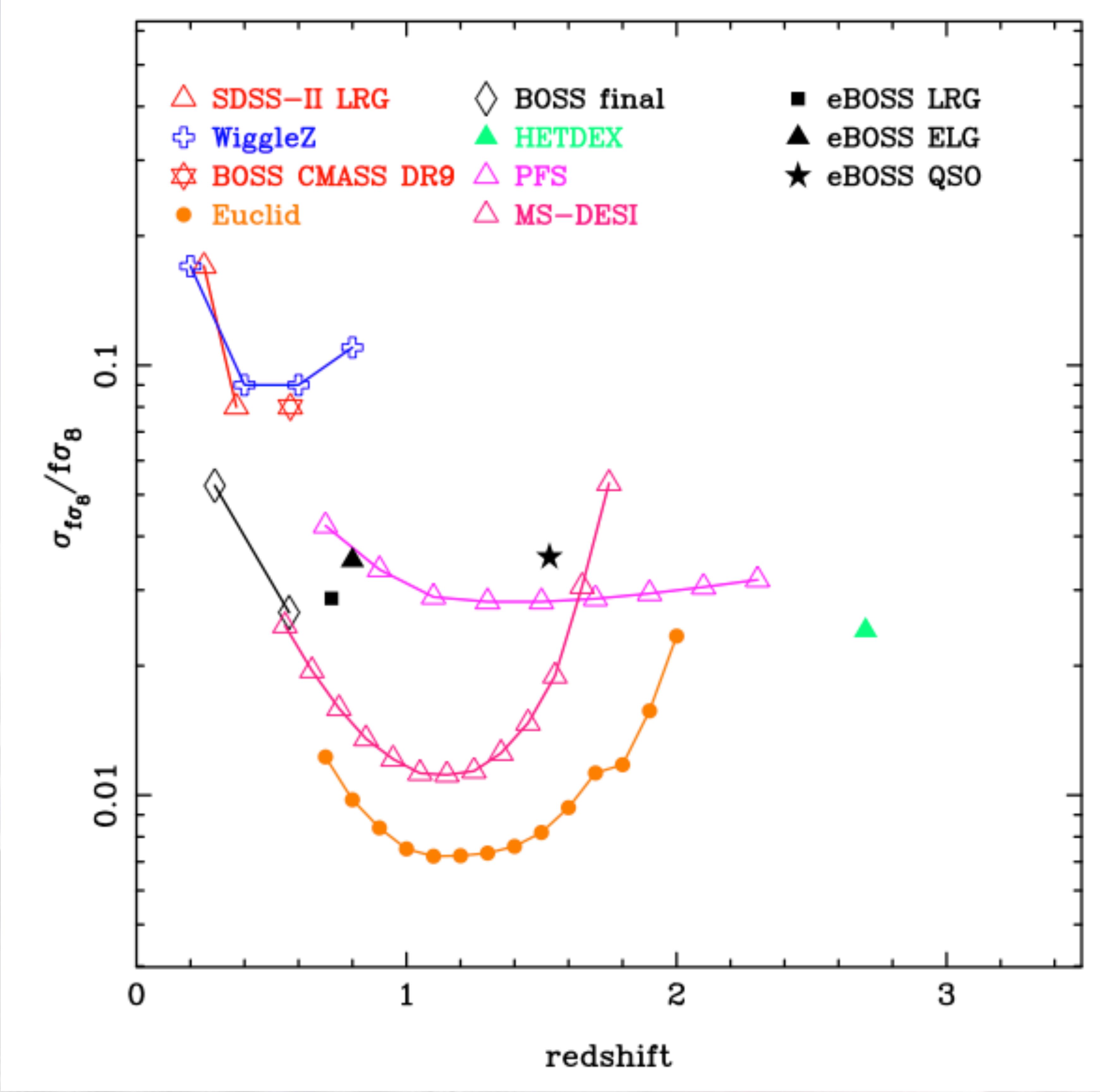
- Deep survey
  - 40deg²
  - 48 dithers
  - 12 passes, as for wide survey
  - dispersion directions for 12 passes >10deg apart

Distance measurements for future surveys



using the code of Seo & Eisenstein 2007, arXiv:0701079

RSD measurements for future surveys

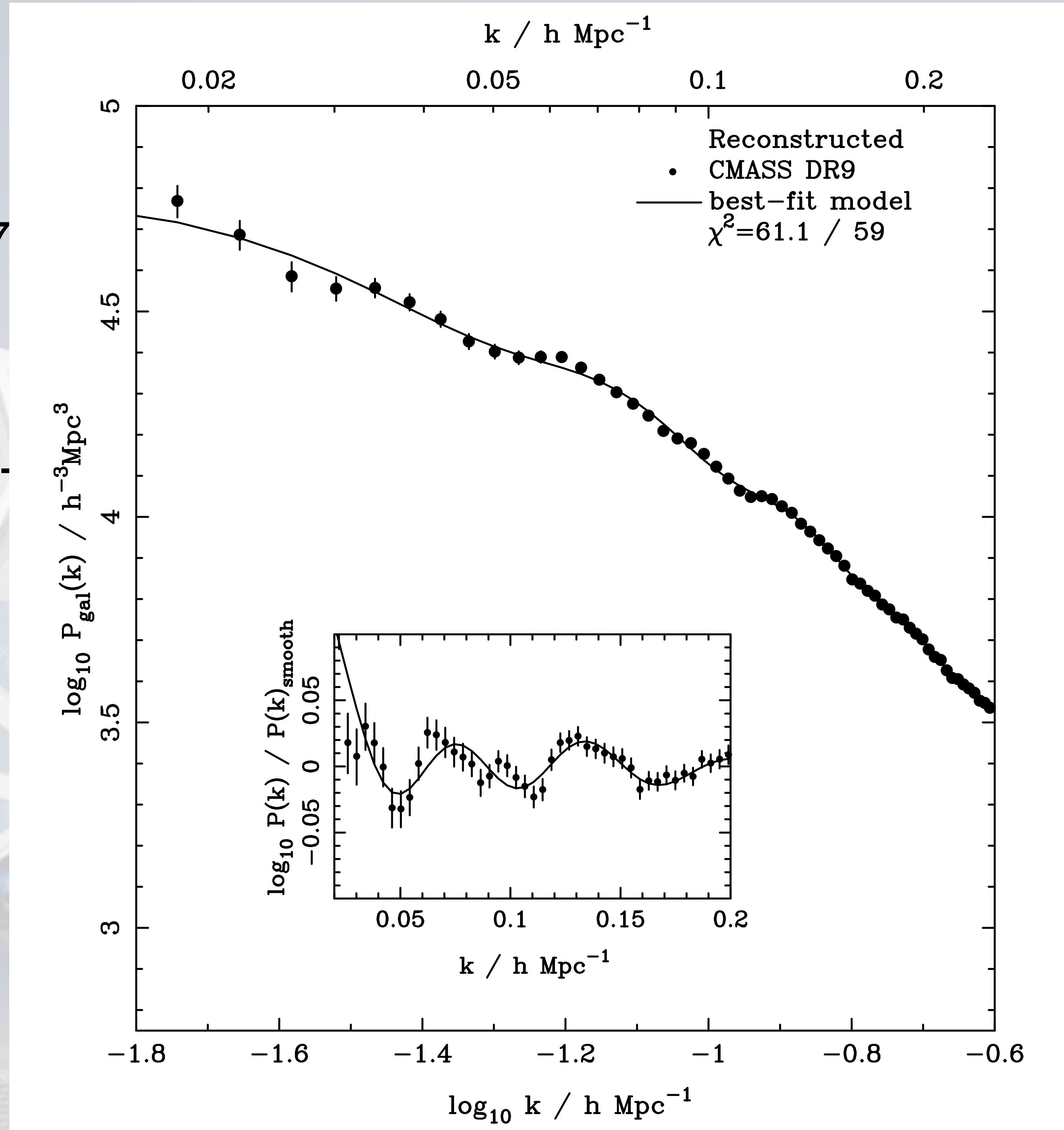


using the code of White et al. 2008, arXiv:0810.1518

BOSS CMASS DR9 galaxy clustering

BOSS CMASS galaxies at z~0.57

Total effective volume V_{eff} = 0.77 Gpc^3h^{-}

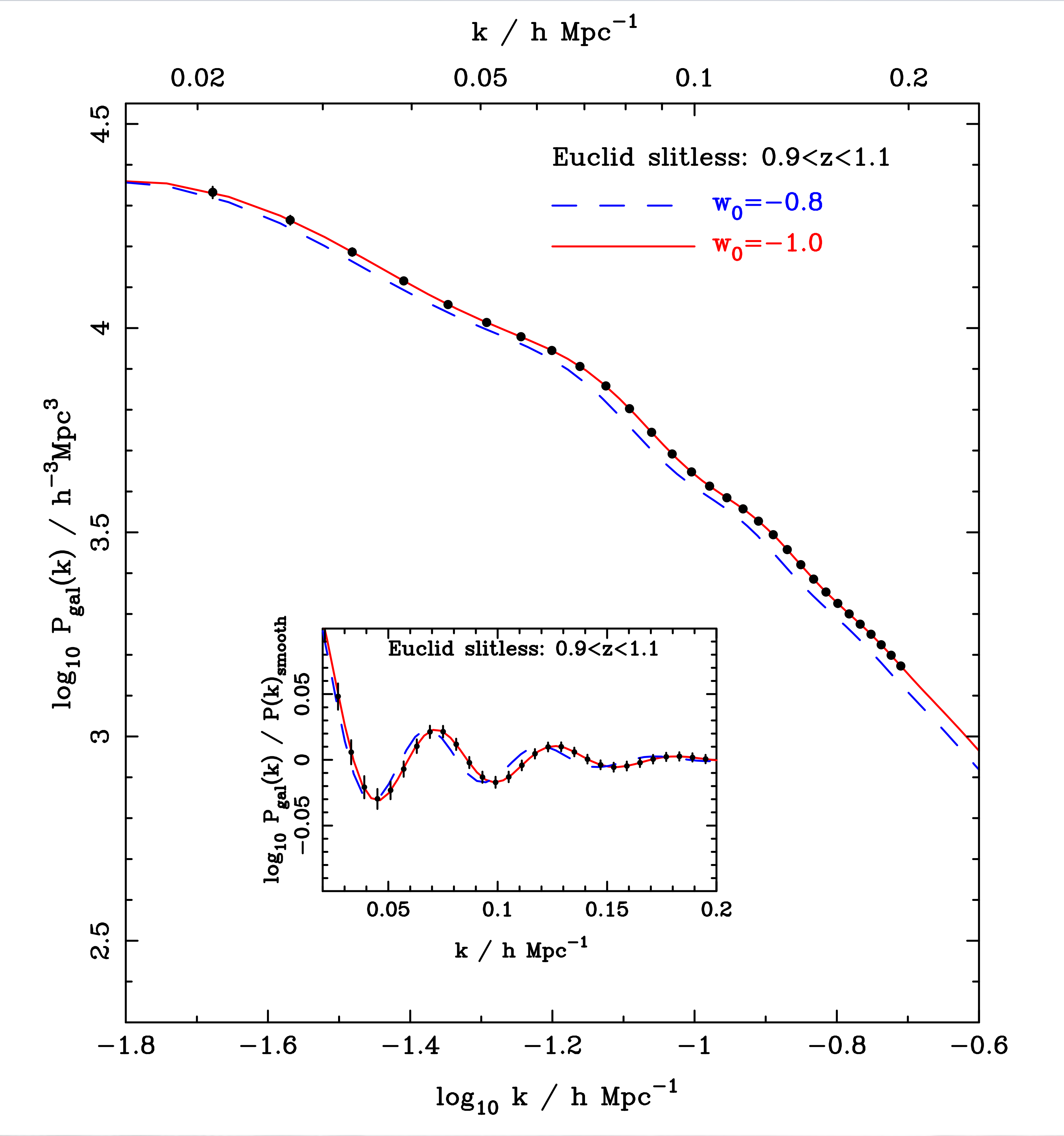


Anderson et al. 2012; arXiv:1203.6565

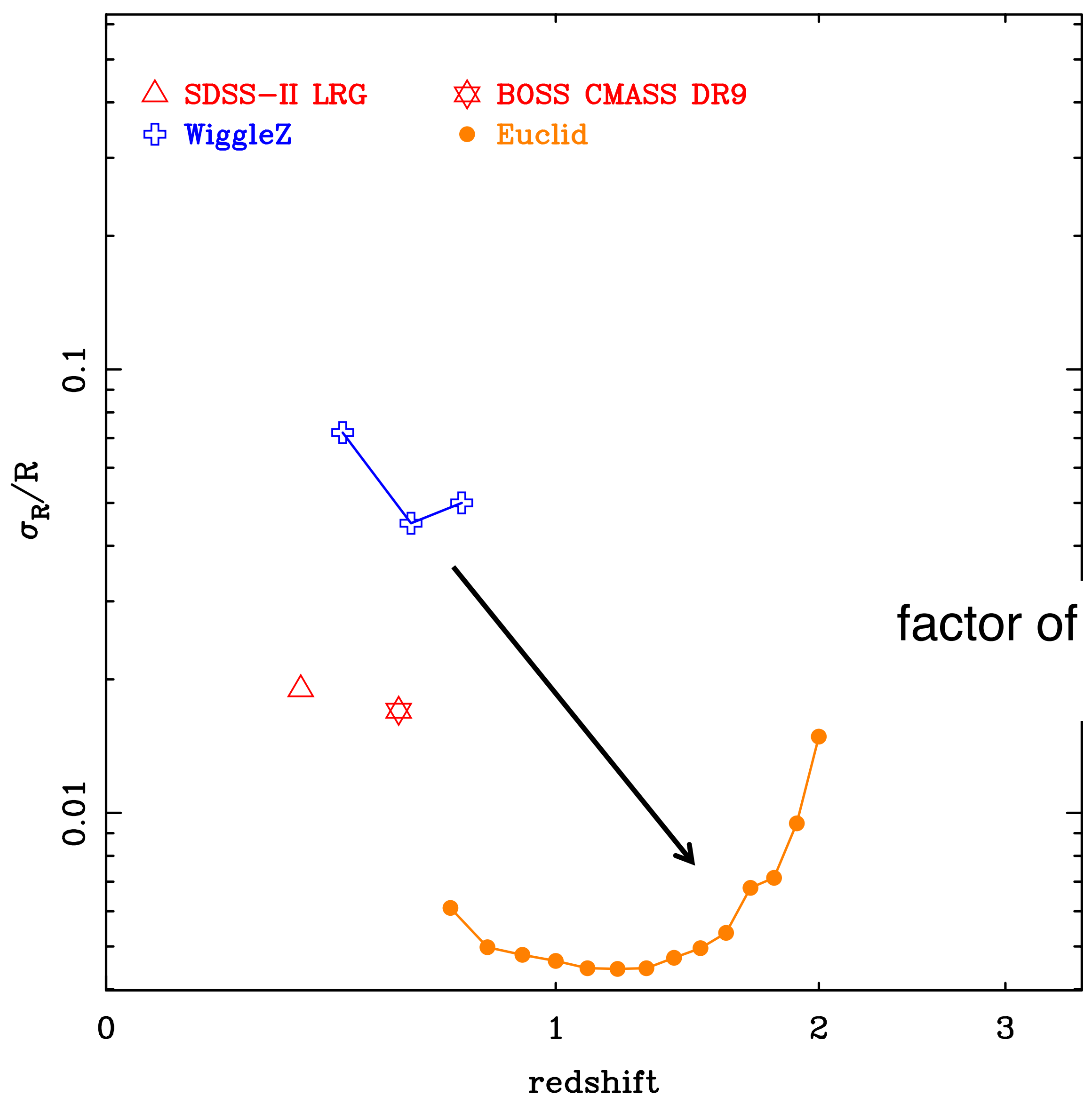
Predicted Euclid galaxy clustering

Redshift slice
0.9 < z < 1.1

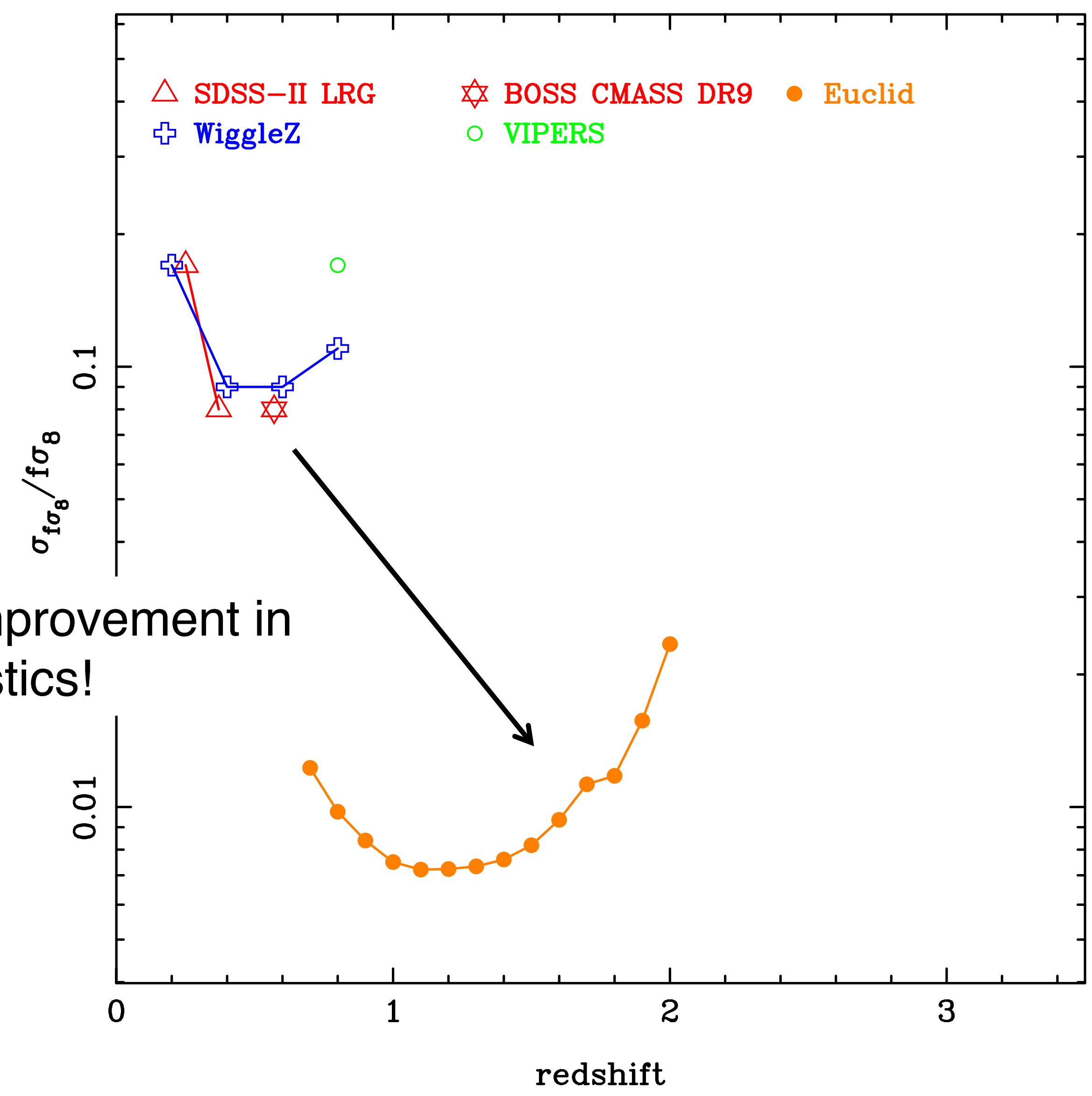
Total effective volume (of Euclid)
V_{eff} = 19.7 Gpc^3h^{-3}



Improvement in precision



factor of 30 improvement in statistics!

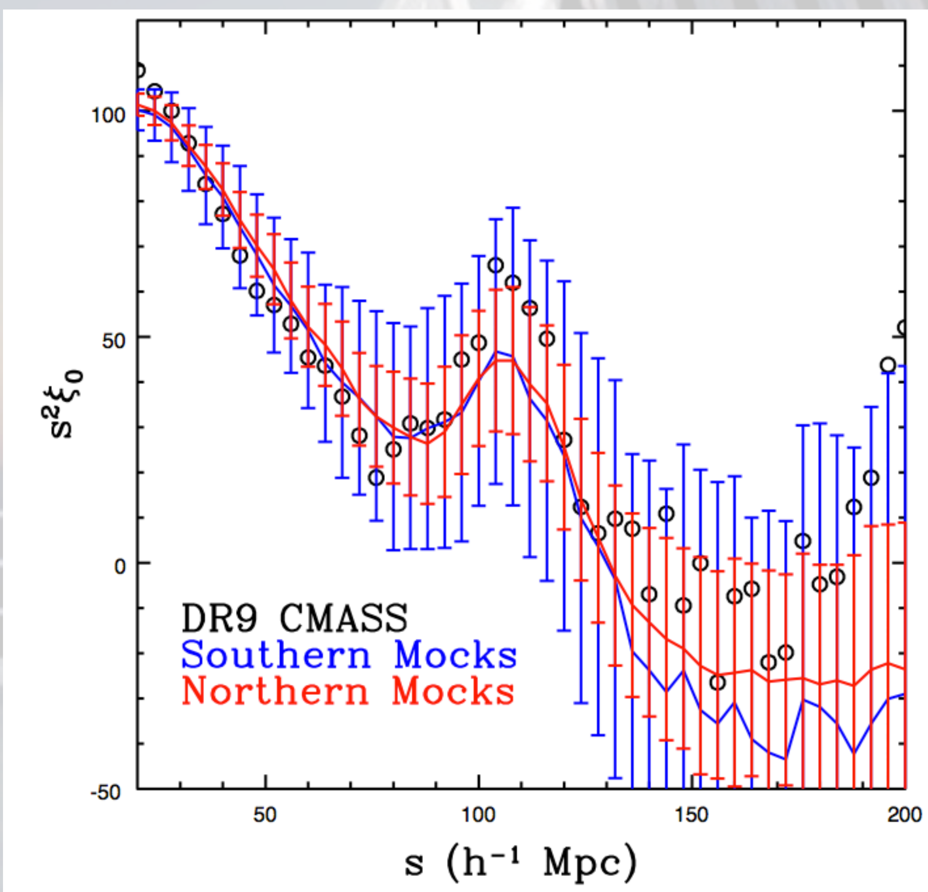


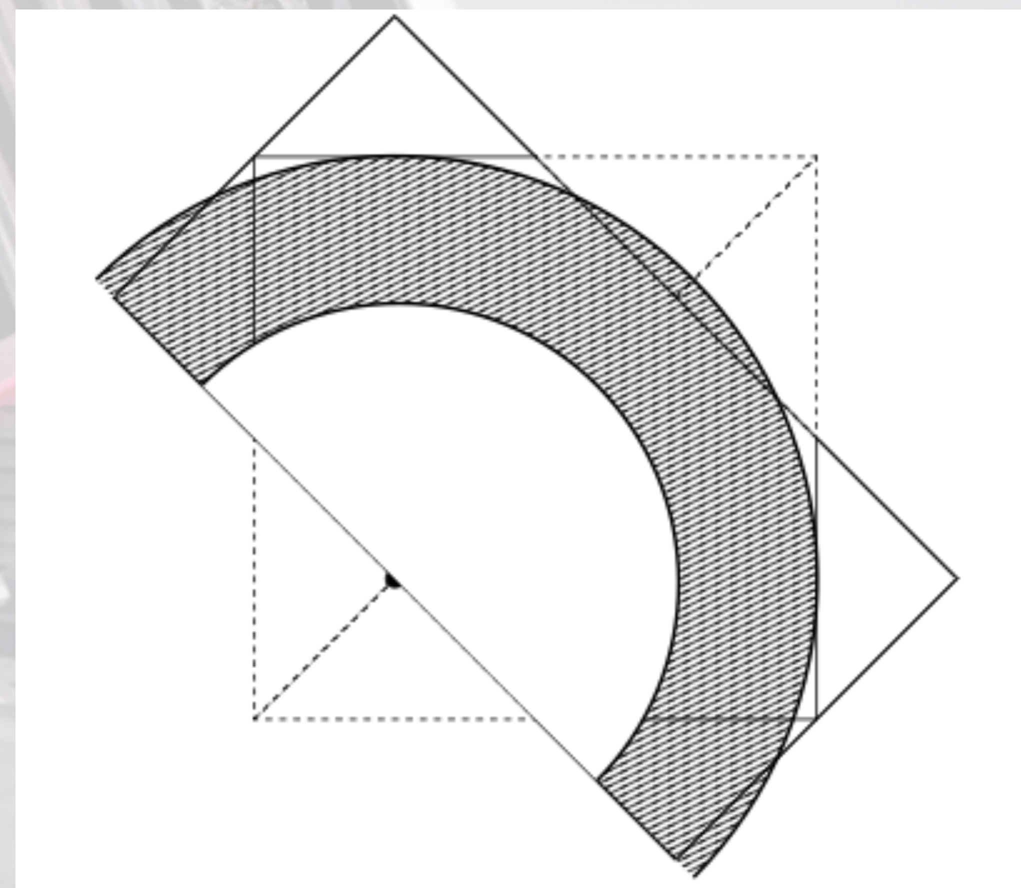
… but what about systematics? …

Testing using mock catalogues

Mock catalogues

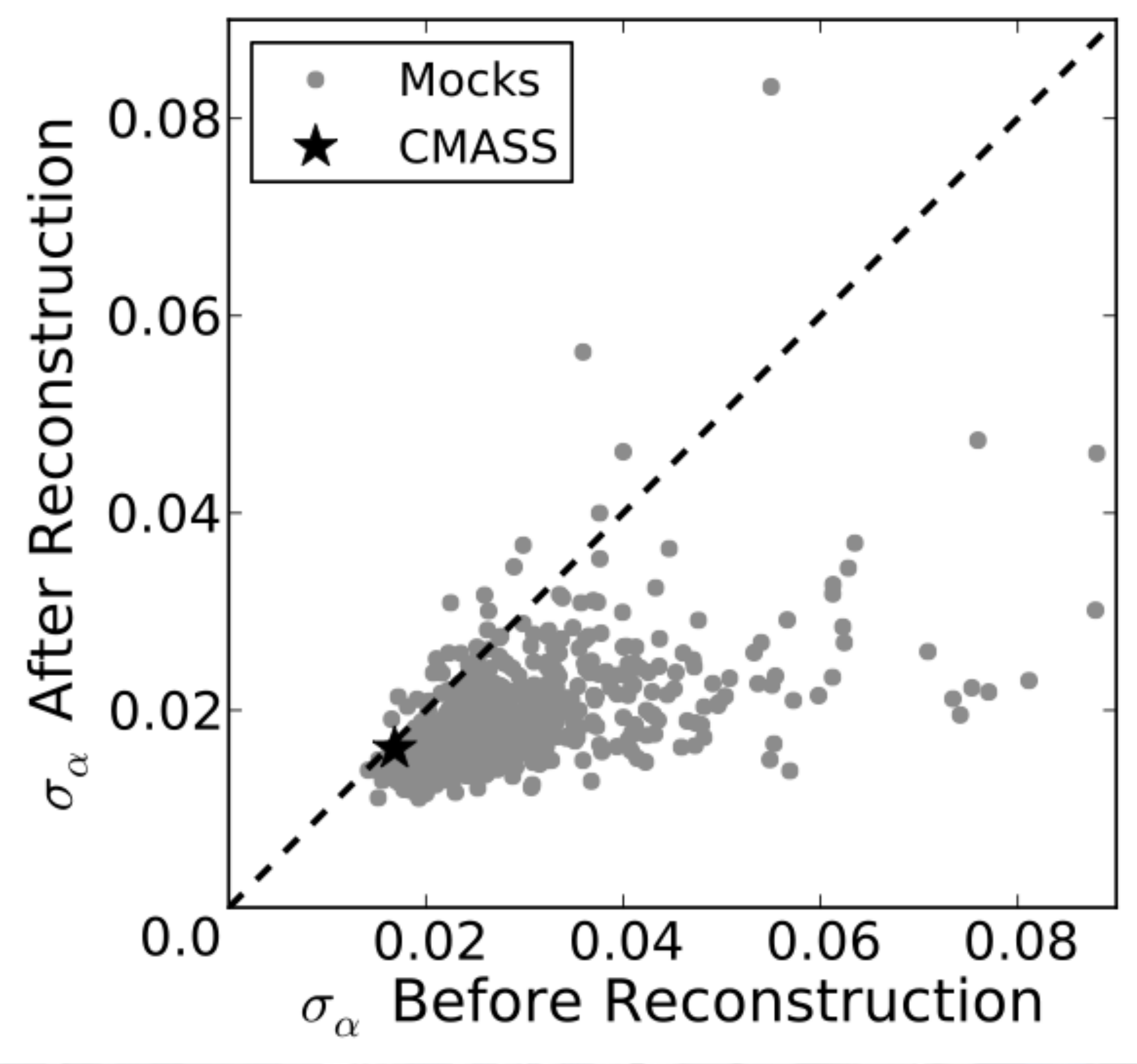
- 600 mocks created by populating 2LPT field using the CMASS HOD
- Redshift-space effects added based on 2LPT velocities
- Matches simulation large-scale clustering at 10% level
- Used to test method and estimate covariances





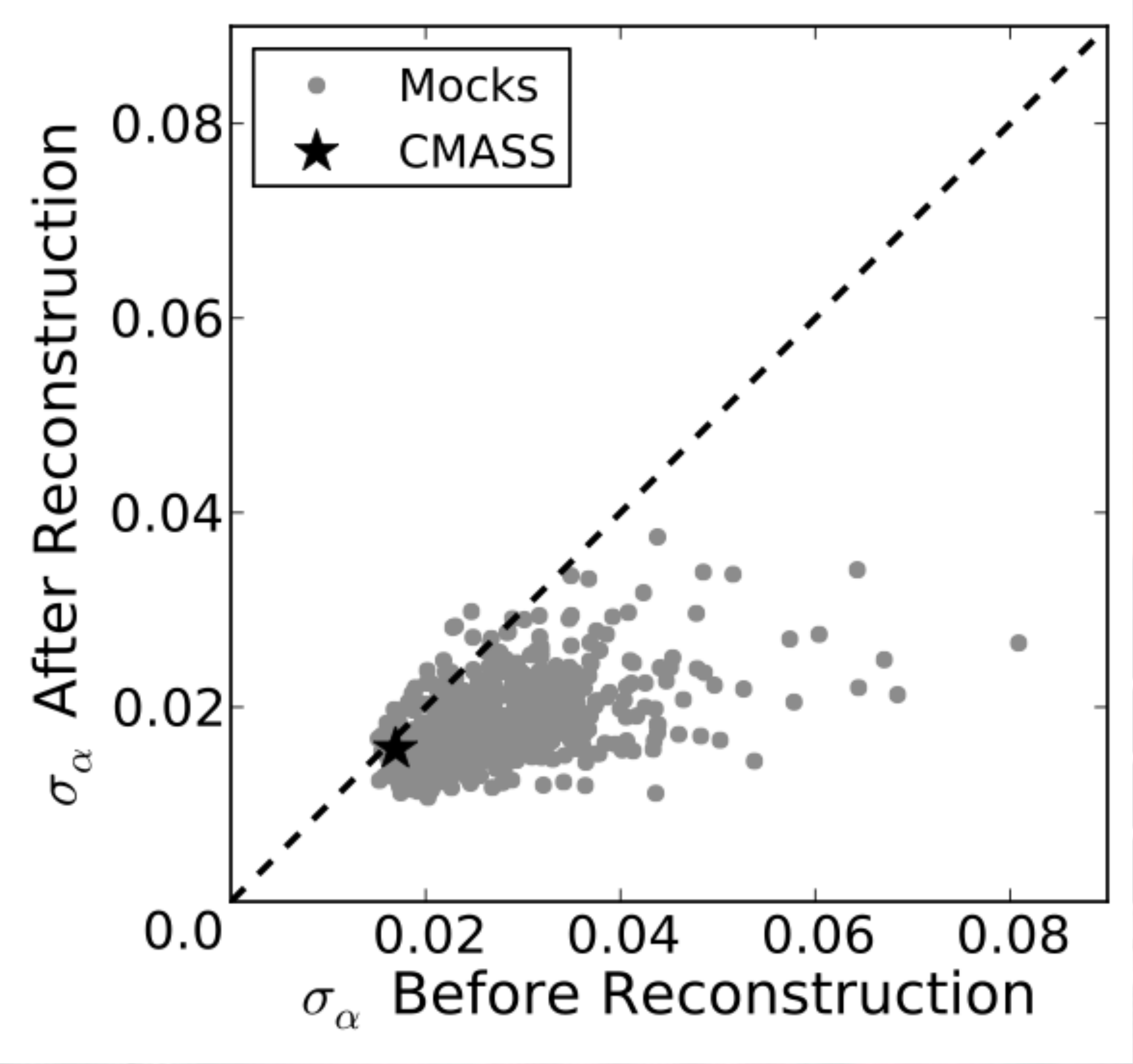
Manera et al. 2012; 1203.6609

Reconstruction: error on α



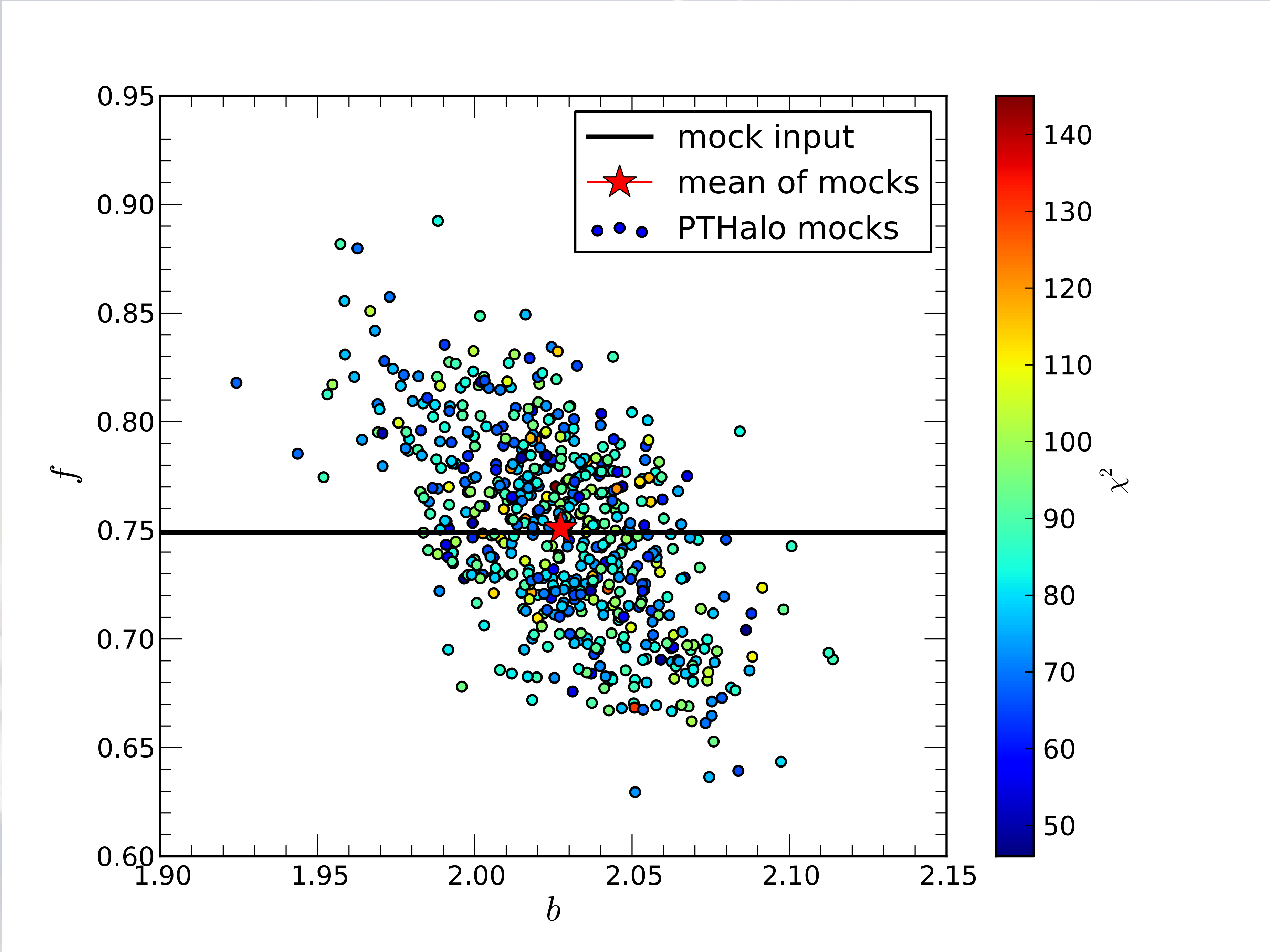
Correlation function

Power spectrum



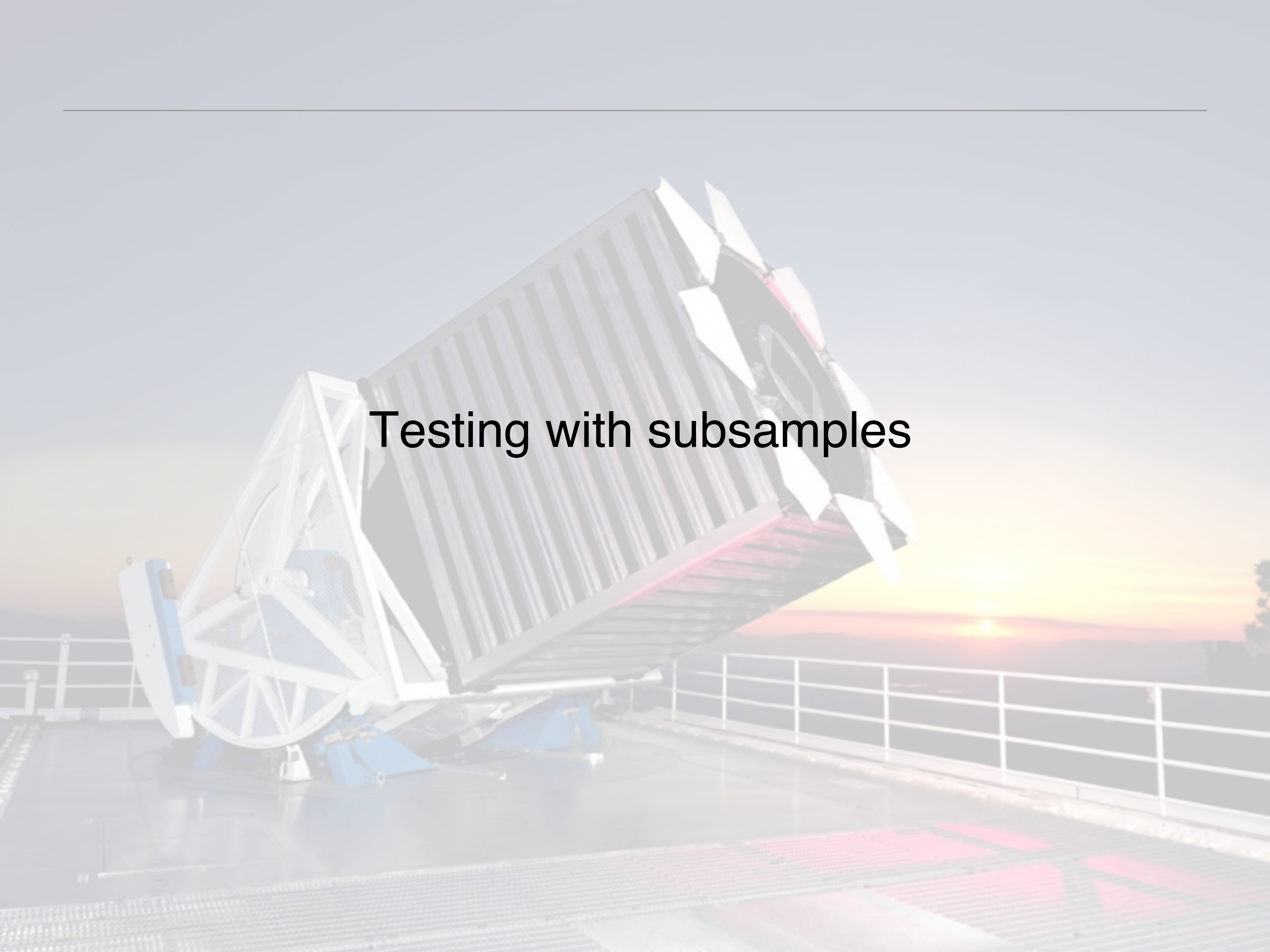
Anderson et al. 2012; arXiv:1203.6565

Using mocks to test DR11 RSD measurements

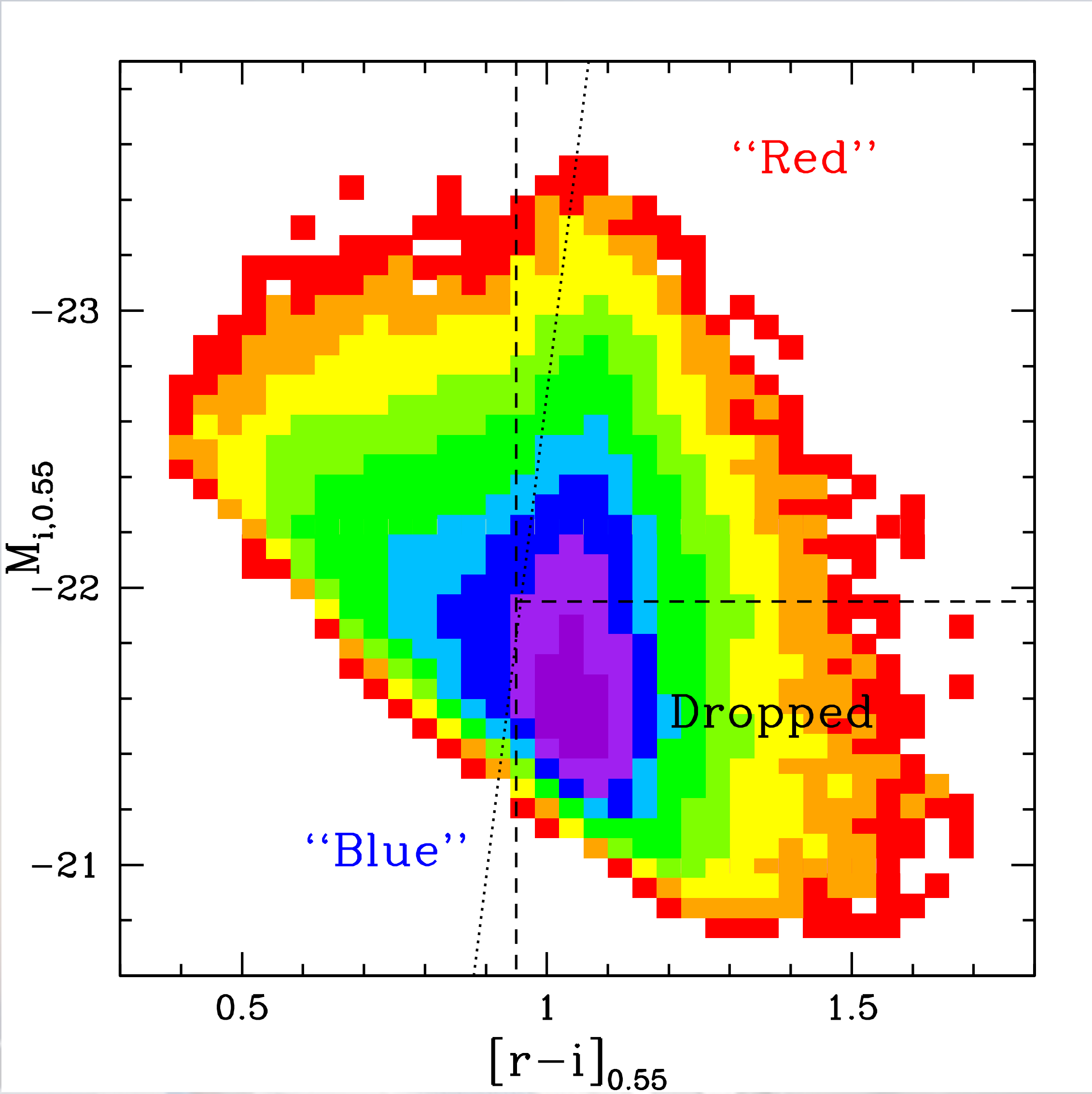


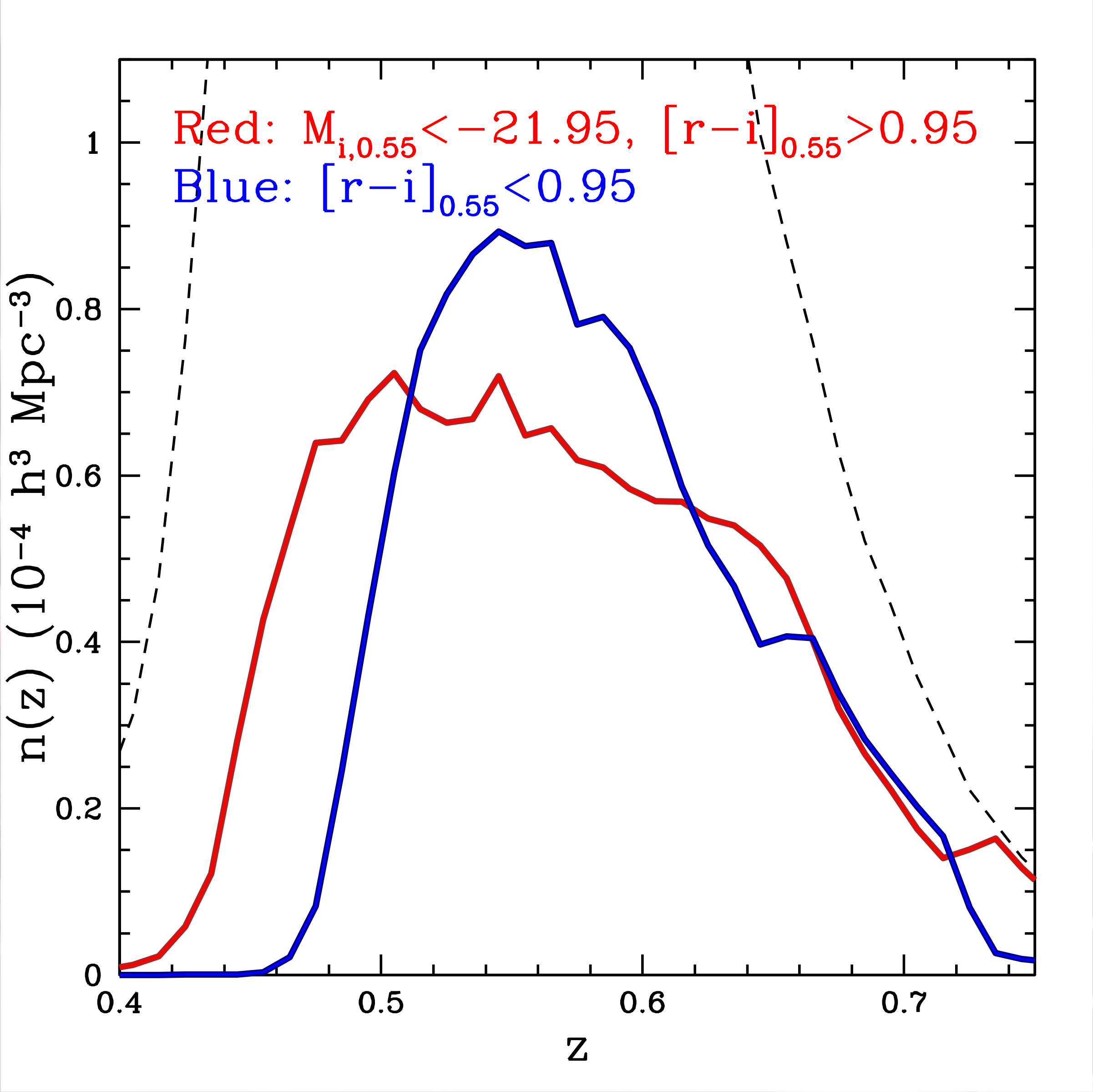
Samushia et al. 2012; in prep

Testing with subsamples



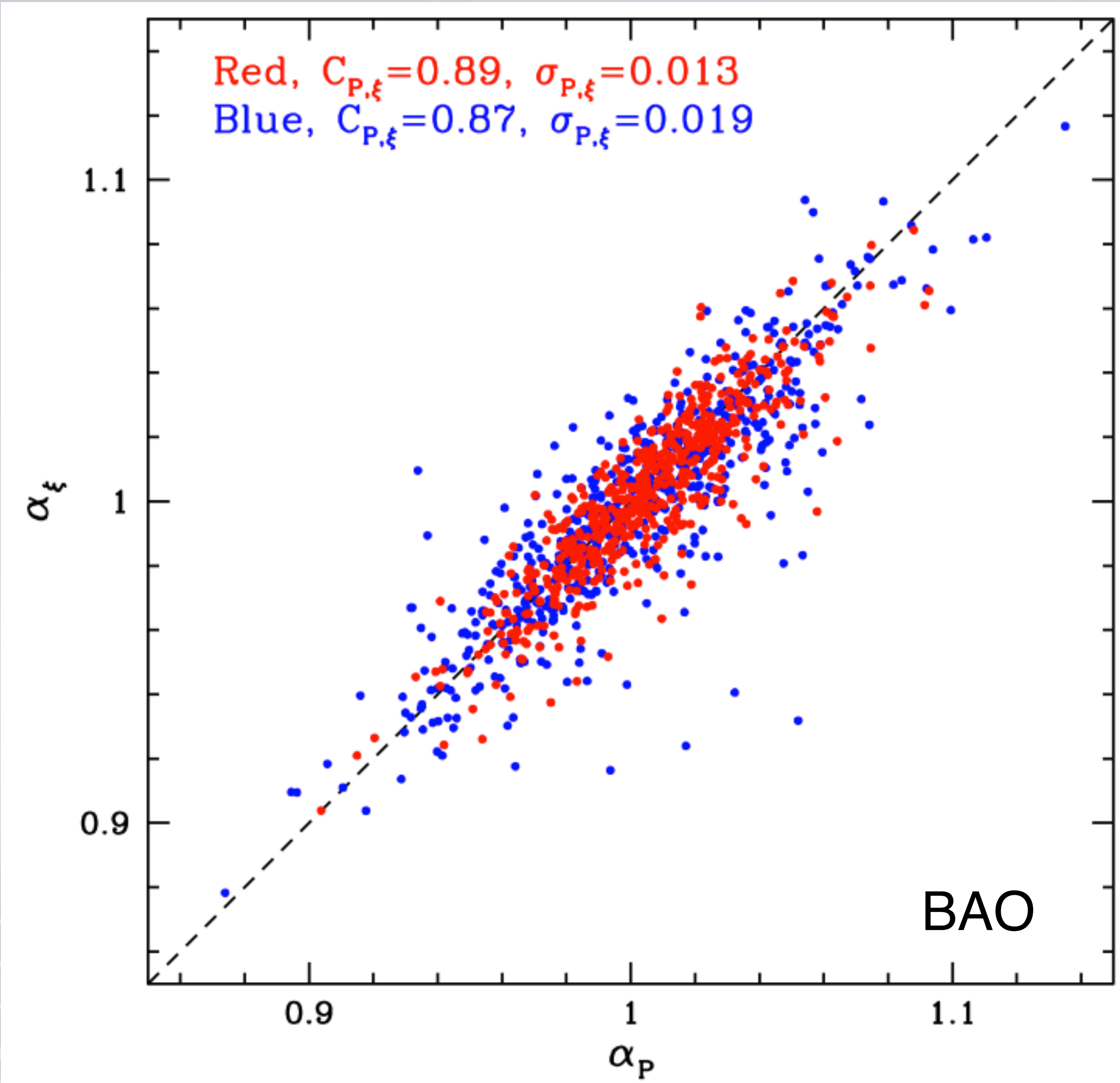
Testing with blue / red subsamples

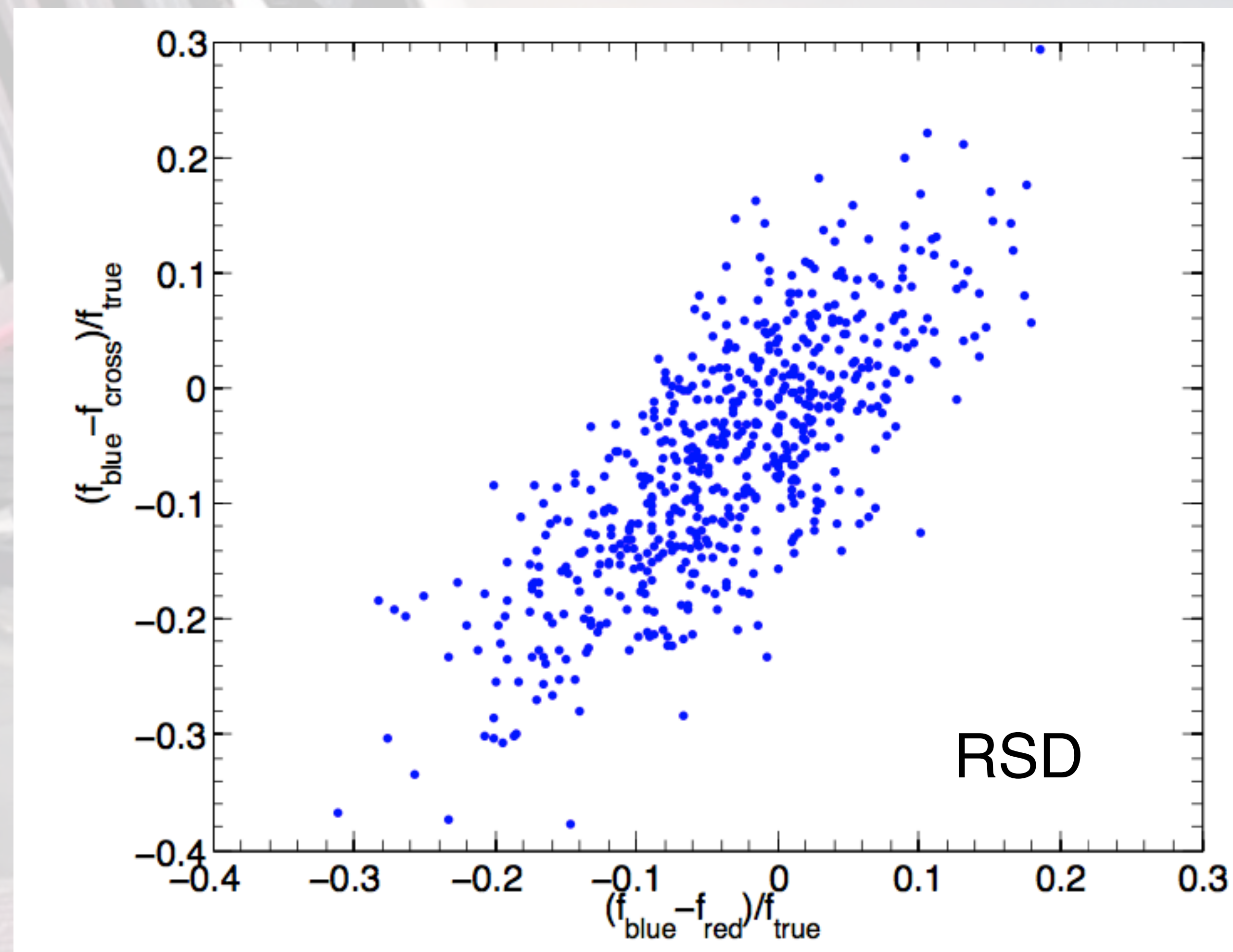




Ross et al. 2013, in prep

Testing with blue / red subsamples





The data also show no statistically significant change between red 7 blue samples

Ross et al. 2013, in prep

Getting the likelihood right

Getting the likelihood calculation 100% correct

The Likelihood under the standard assumption of a set of data drawn from a multi-variate Gaussian distribution is given by

$$\mathcal{L}(\mathbf{x}|\mathbf{p},\Psi^t) = \frac{|\Psi^t|}{\sqrt{2\pi}} \exp\left[-\frac{1}{2}\chi^2(\mathbf{x},\mathbf{p},\Psi^t)\right],$$

where $$\chi^2(\mathbf{x},\mathbf{p},\Psi^t) \equiv \sum_{ij} \left[x_i^d - x_i(\mathbf{p})\right] \Psi_{ij}^t \left[x_j^d - x_j(\mathbf{p})\right].$$

now suppose that the covariance matrix (size $n_{\mathbf{b}}$ x $n_{\mathbf{b}}$) has been calculated from $n_{\mathbf{s}}$ simulations

$$\mu_i = \frac{1}{n_s}\sum_s x_i^s \qquad C_{ij} = \frac{1}{n_s - 1}\sum_s (x_i^s - \mu_i)(x_j^s - \mu_j)$$

then an unbiased estimator of the inverse covariance matrix is

$$\Psi = \frac{n_s - n_b - 2}{n_s - 1} C^{-1}$$

Hartlap J., Simon P., Schneider P., 2007, A&A, 464, 399

Errors in the covariance matrix

Simply providing an unbiased estimator of the inverse covariance matrix is not enough

The inverse covariance matrix also has its own error

$$\langle \Delta\Psi_{ij} \Delta\Psi_{i'j'} \rangle = A \Psi_{ij} \Psi_{i'j'} + B(\Psi_{ii'} \Psi_{jj'} + \Psi_{ij'} \Psi_{ji'}),$$

$$A = \frac{2}{(n_s - n_b - 1)(n_s - n_b - 4)}$$

$$B = \frac{(n_s - n_b - 2)}{(n_s - n_b - 1)(n_s - n_b - 4)}$$

Strictly, we should form a joint likelihood

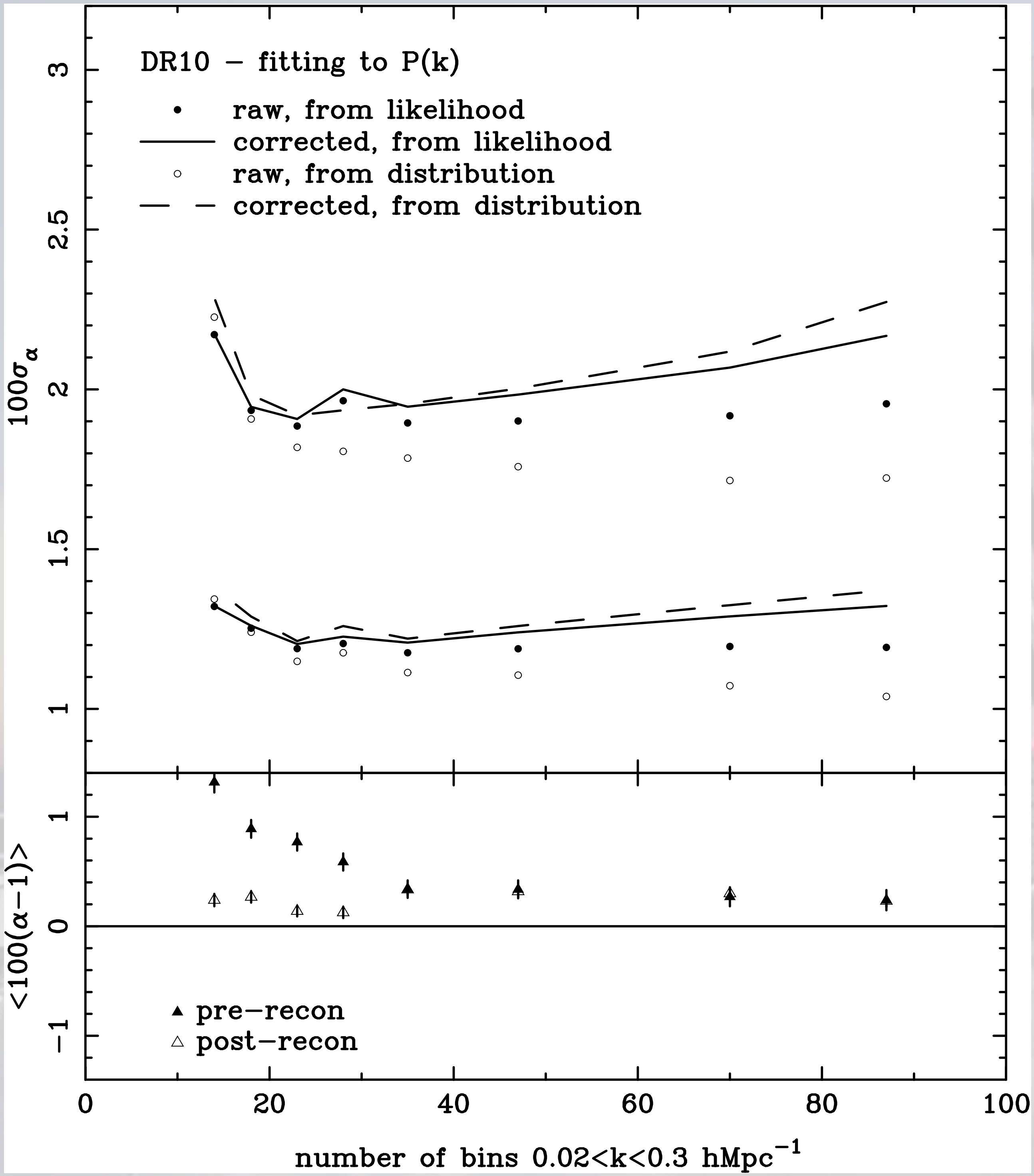
$$\mathcal{L}(\mathbf{x}, \Psi | \mathbf{p}, \Psi^t) = \mathcal{L}(\mathbf{x} | \mathbf{p}, \Psi) \mathcal{L}(\Psi | \Psi^t),$$

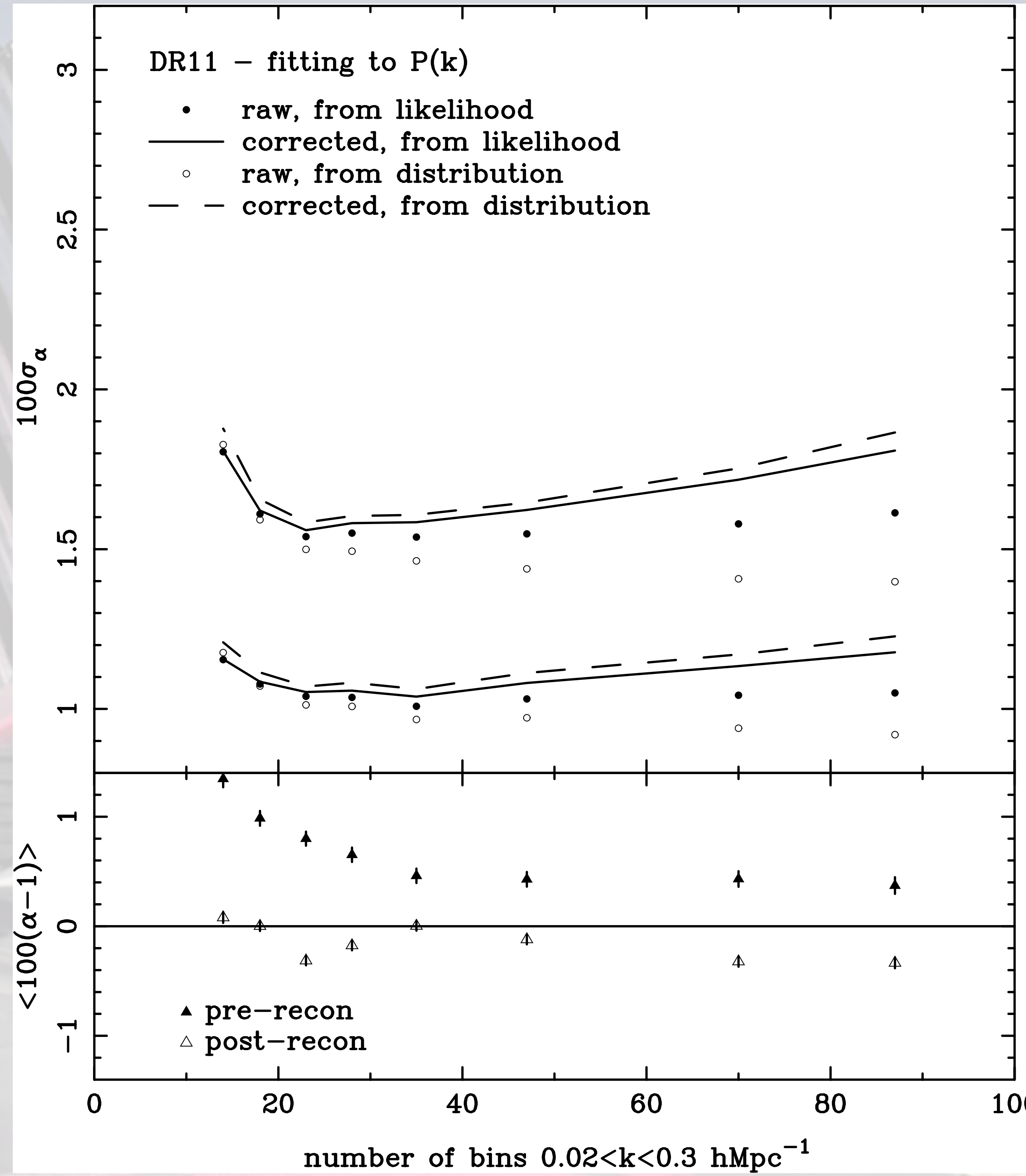
If we don't, this leads to an additional error on the $n_{\mathbf{p}}$ parameters being fitted

$$\langle p_\alpha p_\beta \rangle |_{s.o.} = B(n_b - n_p) F^{-1}_{\alpha\beta},$$

Taylor et al., 2012, arXiv:1212.4359; Dodelson & Schneider 2007, arXiv:1212.4359

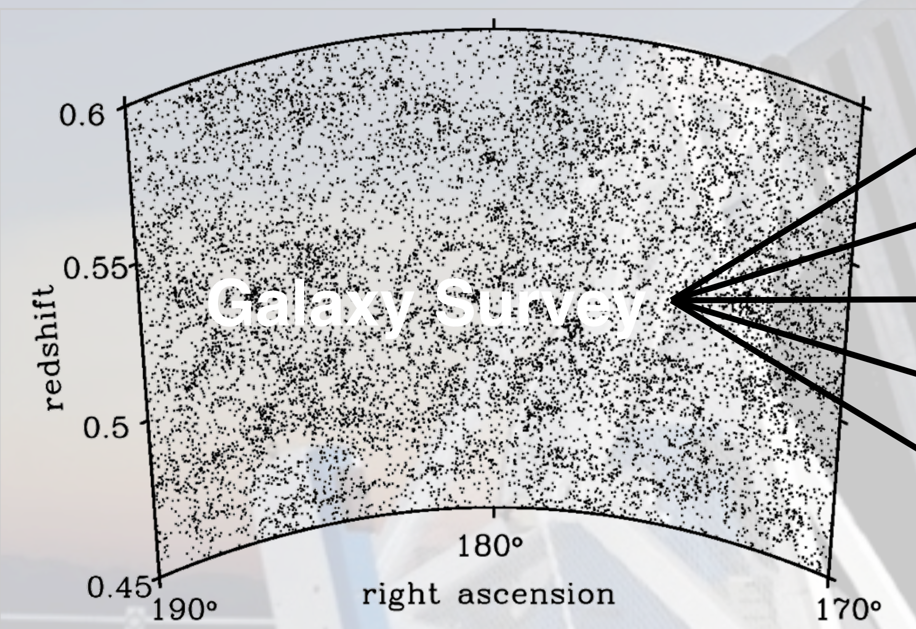
Application to BOSS





Percival et al., in prep

Cosmology from galaxy surveys



- Baryon Acoustic Oscillations → What is the expansion rate of the Universe? e.g. Anderson et al (2012)
- Alcock-Paczynski effect → What is the expansion rate of the Universe? e.g. Samushia et al (2012*)
- Redshift-Space Distortions → How does structure form within this background? e.g. Reid et al (2012)

→ Understanding Dark Energy

- Comoving clustering → What are the neutrino masses, matter density? e.g. Zhao et al (2012*) → Understanding energy-density
- large-scale density → What is f_{nl}, which quantifies non-Gaussianity? e.g. Ross et al. (2013*) → Understanding Inflation

Forthcoming surveys extremely exciting, but will require methodology development to reach statistical limit