Is there a hope of discovering new physics in the Euclid era?

Francisco Prada
Instituto de Física Teórica UAM-CSIC, Madrid
IAA-CSIC, Granada

ESAC, October 15th, 2015

Our view of the distant Universe:

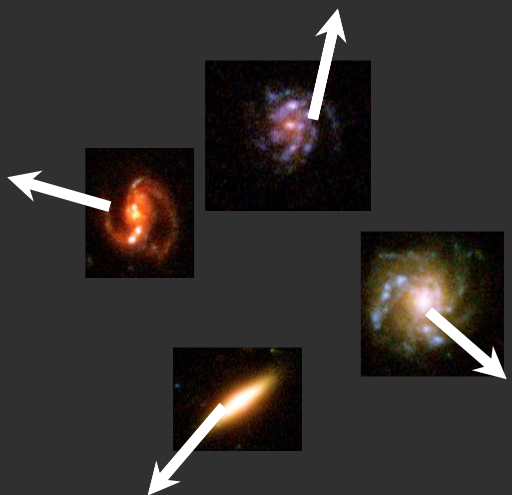
Hubble Ultra-deep Field

Is the visible material all there is?

Dark Cosmology

Much more gravity than we would expect:

➡ Dark Matter (27%)



Galaxies moving apart faster and faster:

➡ Dark Energy (68%)

New Physics, beyond the Standard Model

Observation and Theory interplay

Dark matter and dark energy have predictable effects on:

- Cosmic Microwave Background
- Patterns of galaxies
- Bending of light in Universe
- Brightness of supernovae  **The Nobel Prize in Physics 2011**

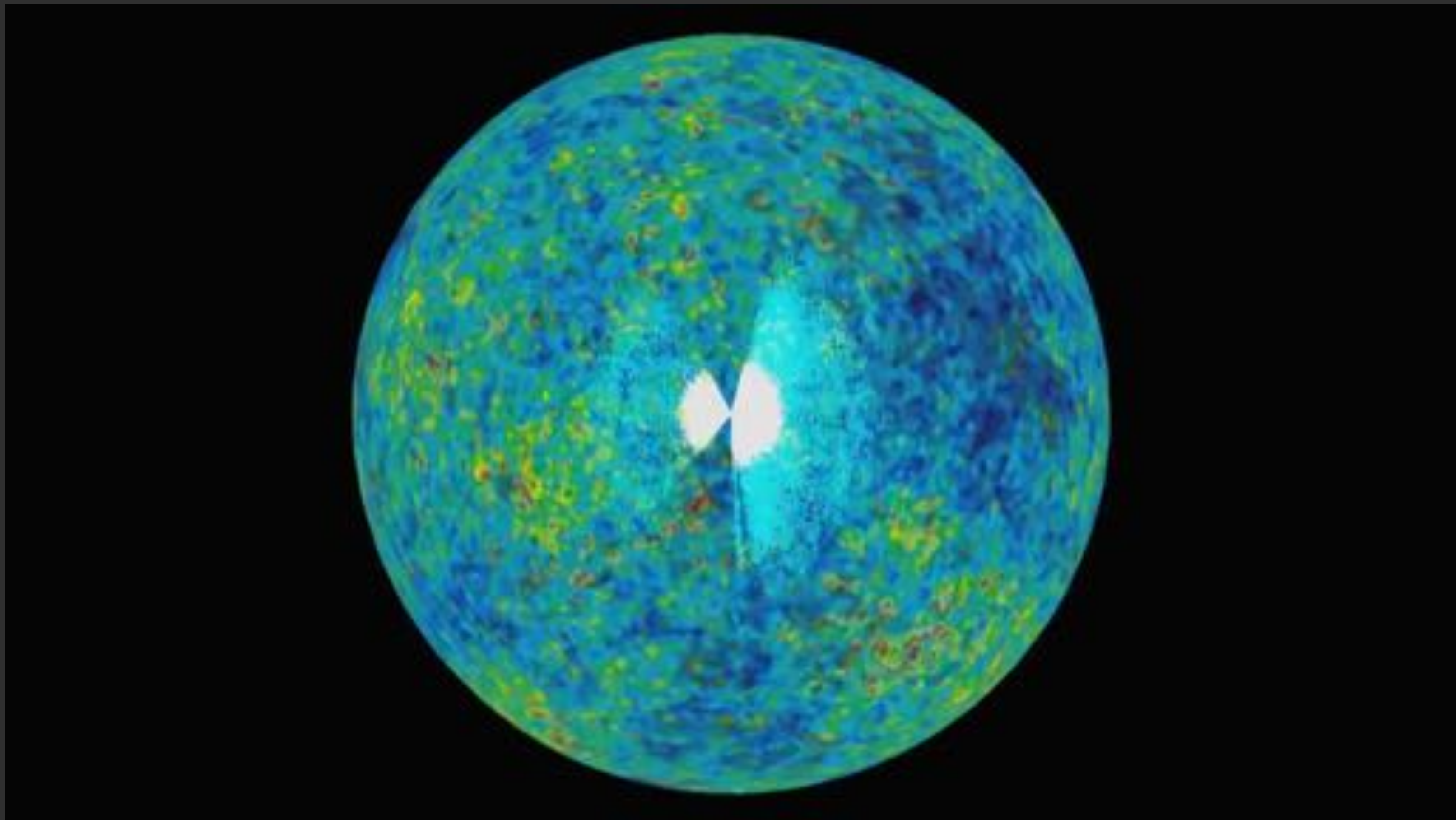
➡ Measure these effects in our large surveys

➡ Compare with theories and simulations containing dark Physics

Ptolomeo’s Map

Building 3D Maps of the Universe

“Nearly 2,000 years later still we make maps. To avoid getting lost and because we want to discover new things. The ambition and intent of accuracy are the same as then …”



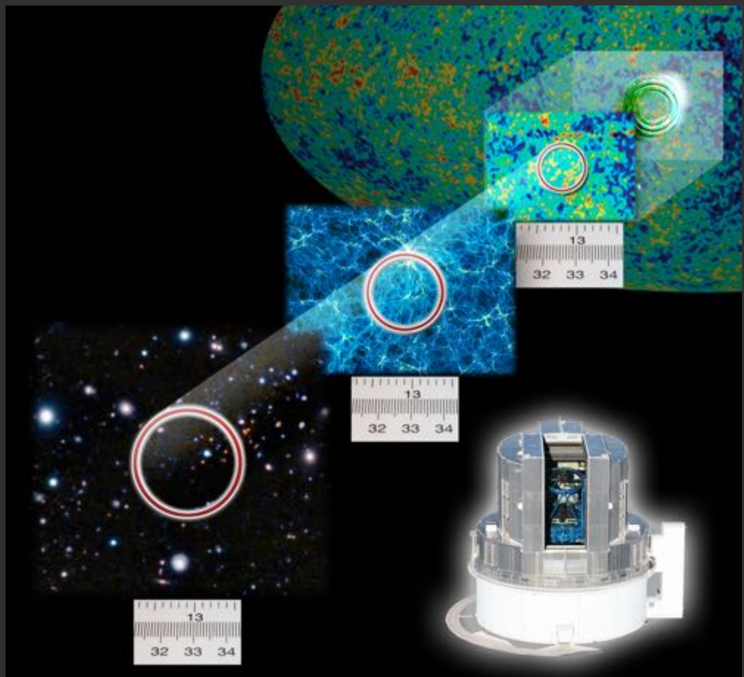
Only 1% of the Universe is known!

From surveys to measurements of dark physics

- ➡ Measure statistics of galaxy properties in large surveys
- ➡ Compare with predictions for particular dark energy physical values

e.g. Baryonic Acoustic Oscillations (BAO):

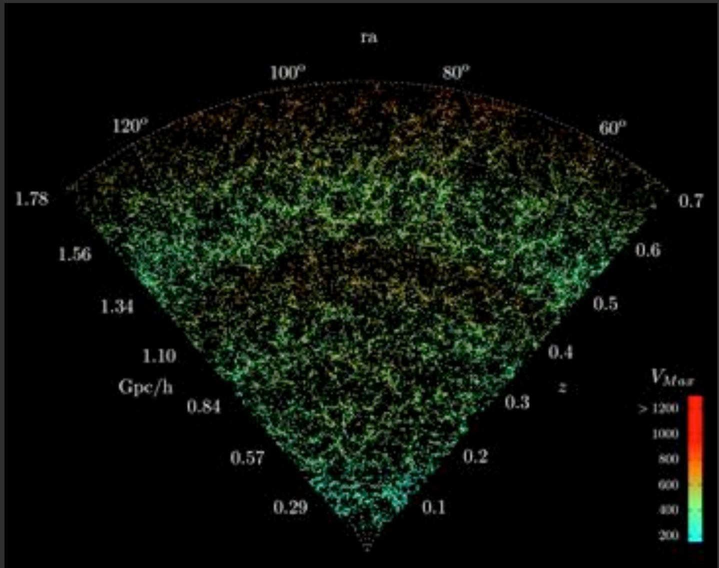
Measure correlation function of galaxy positions – BAO peak is found at a physical scale that depends on dark energy!

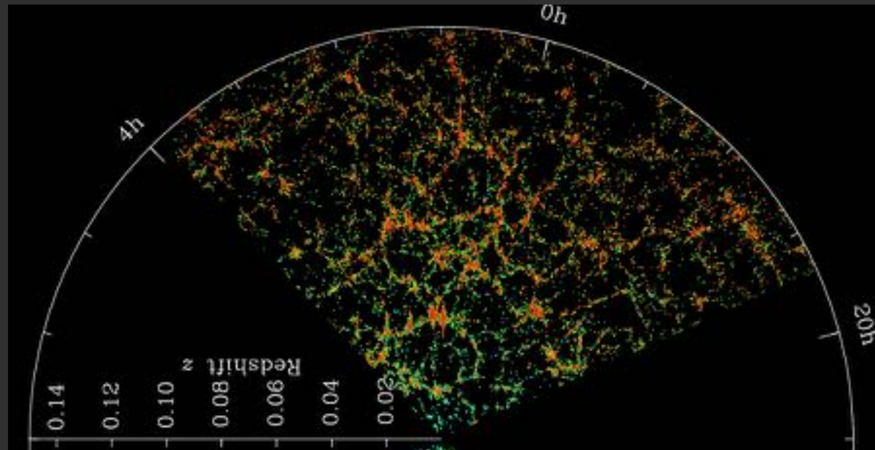


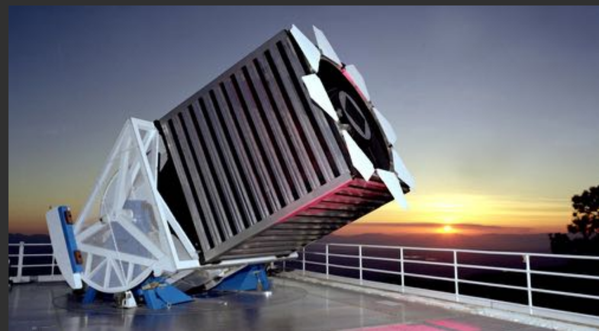
Simulations calculate consequences of dark physics

PARTNERSHIP FOR ADVANCED COMPUTING IN EUROPE

SDSS III





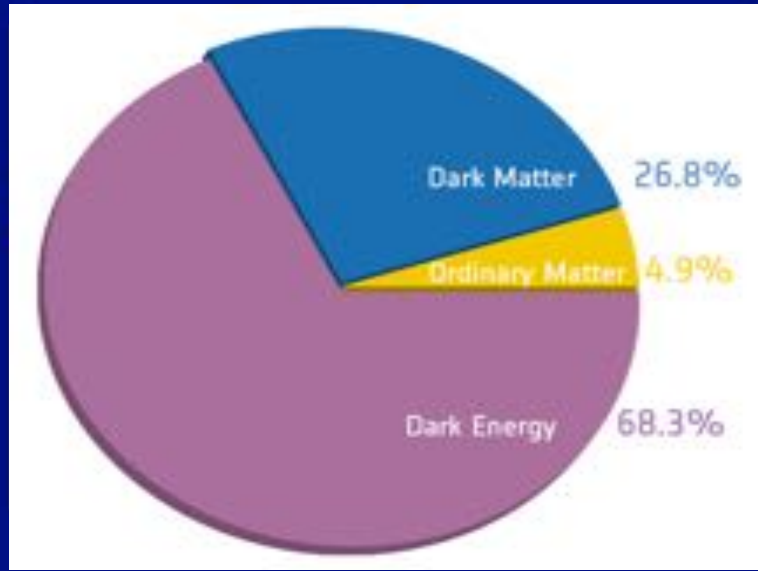


Europe is leading the effort in providing large numerical simulations for cosmological large surveys.

Top Scientific Objectives

Physics of the Universe

Understanding Scientific Principles



The two highest level questions in the field are the following:

- Is cosmic acceleration caused by a breakdown of Einstein General Relativity on cosmological scales, or is it caused by a new energy component with negative pressure ("dark energy") within General Relativity?

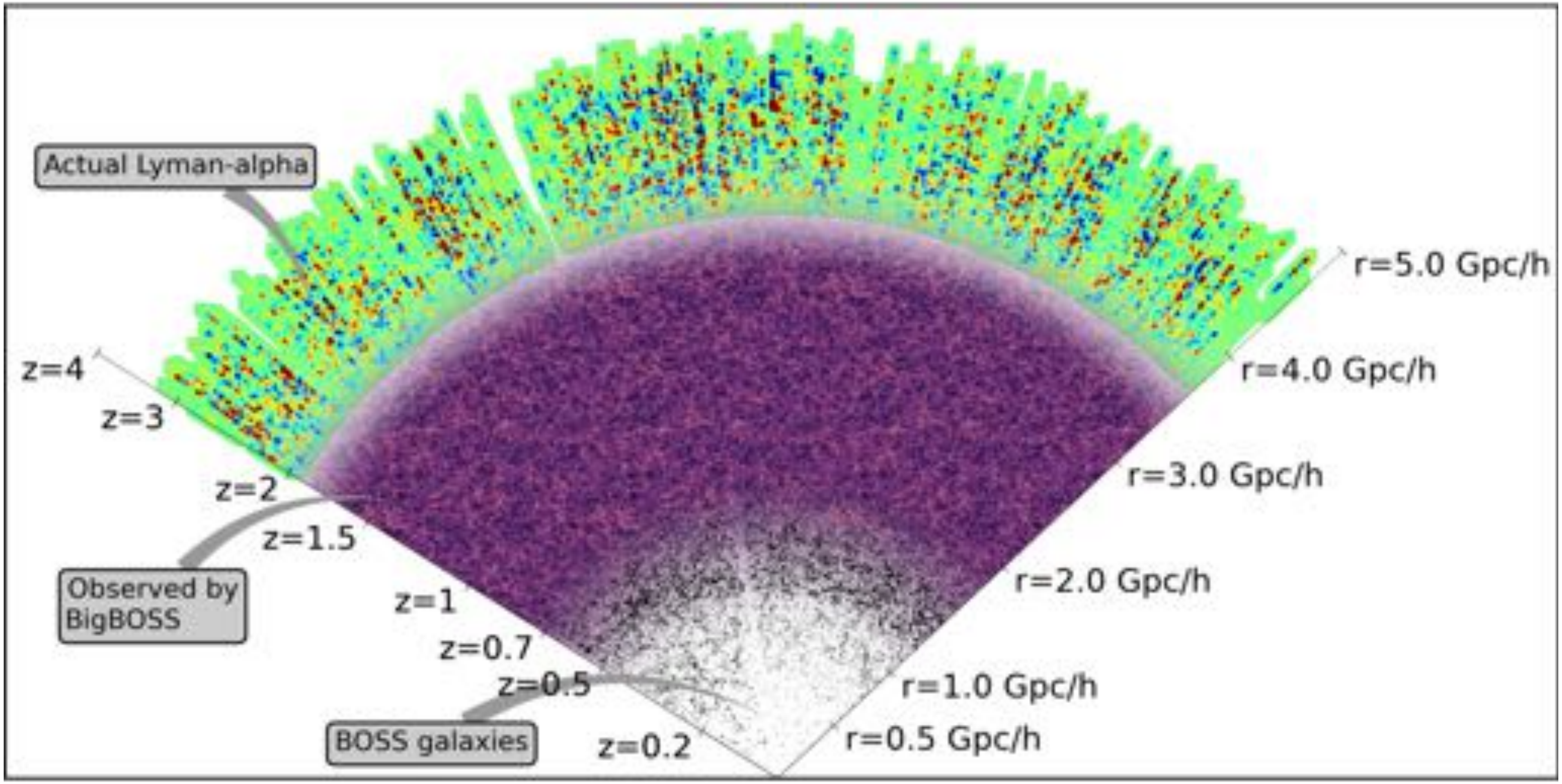
- If the acceleration is caused by "dark energy," is its energy density constant in space and time and thus consistent with quantum vacuum energy or does its energy density evolve in time and/or vary in space?

Dark Energy Experiments

Table B2.1: **[S]** designates a spectroscopic redshift survey, **[I]** an imaging survey and **[R]** a radio survey.

Projects	Status	Ref.
[S] VIPERS	2009-2015	http://vipers.inaf.it/
[S] SDSS-III/BOSS	2009-2014	http://www.sdss3.org/surveys/boss.php
[I] DES	2012-2017	http://www.darkenergysurvey.org/
[I] VST/KIDS	2011-2016	http://kids.strw.leidenuniv.nl/
[I] eROSITA	2015-2020	http://www.mpe.mpg.de/erosita/
[S] HETDEX	2015-2017	http://hetdex.org/
[S] SDSS-IV/eBOSS	2014-2020	http://www.sdss3.org/future/eboss.php
[I+S] Euclid	2020-2027	http://sci.esa.int/euclid/
[S] DESI	2018-2022	http://desi.lbl.gov/
[I] J-PAS	2015-2020	http://j-pas.org/
[S] 4MOST	2019-2024	http://www.4most.eu/
[I] VISTA-VHS	2010-2017	http://www.vista-vhs.org/
[I] iPTF	2013-2015	http://ptf.caltech.edu/iptf/
[I] ZTF	2016-2020	-
[I] LSST	2023-onwards	http://www.lsst.org/
[R] LOFAR	2013-2018	http://www.lofar.org/
[R] Meerkat SKA-Pathfiner	2016-onwards	http://www.ska.ac.za/meerkat/
[R] SKA	2019-onwards	http://www.skatelescope.org/
[R] CMB (COrE/PRISM)	Proposal	http://www.prism-mission.org/
[R] PLANCK	2009-2014	http://sci.esa.int/planck/

Large Scale Structure Spectroscopic Surveys



The clustering of galaxies at z=0.5 in the BOSS-CMASS DR12

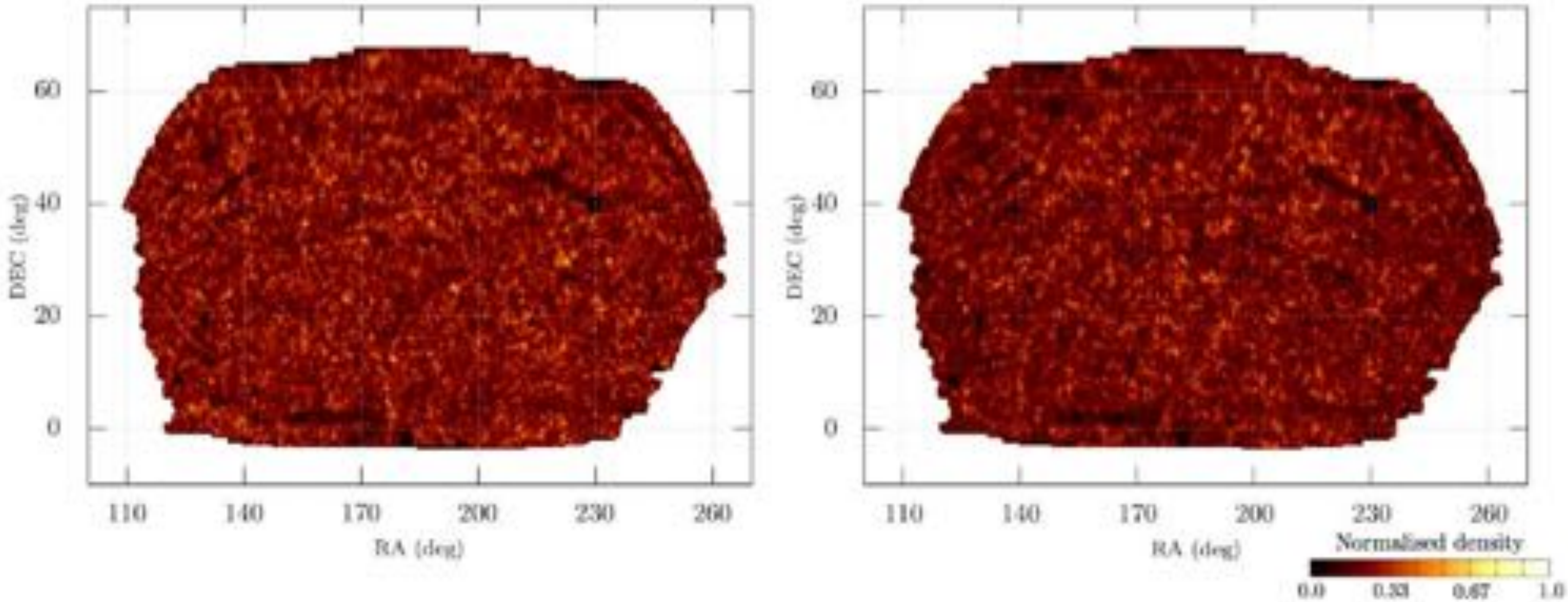


Figure 1. *Left panel*: Sky area covered by the BigMD-BOSS light-cone. This region includes the BOSS CMASS DR12 geometry and veto masks. *Right panel*: Sky area covered by the BOSS-CMASS DR12 sample. Colors indicate the angular number density, which is normalised by the most dense pixel. Each pixel has an angular area of 1 deg^2. BigMD-BOSS light-cone uses the same mask as the BOSS CMASS data release 12, including angular completeness and veto masks.

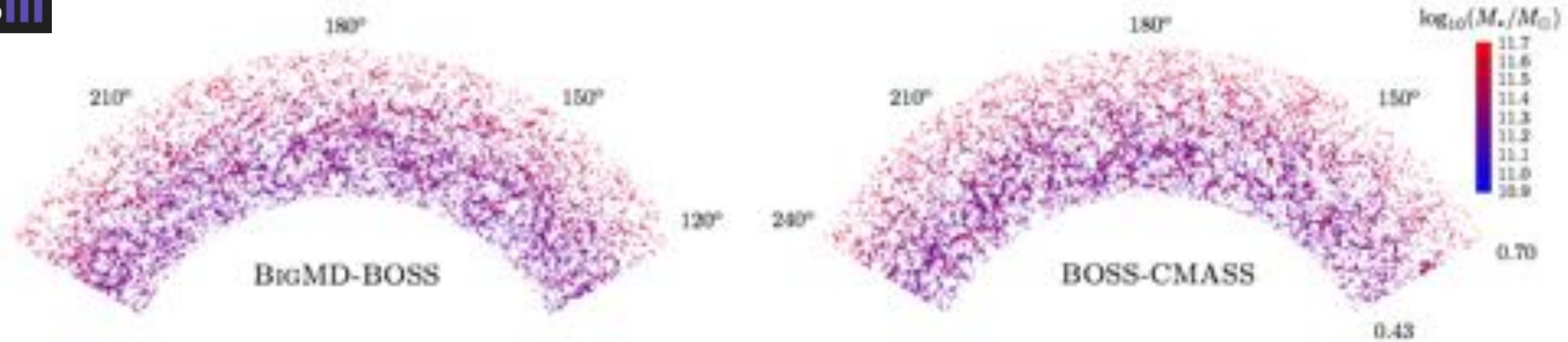


Figure 2. Pie plot of the BigMD-BOSS light-cone (left panel) and the BOSS-CMASS DR12 data (right panel). Both figure were made with 2deg of thickness (DEC coordinate).

Rodríguez-Torres et al. 2015

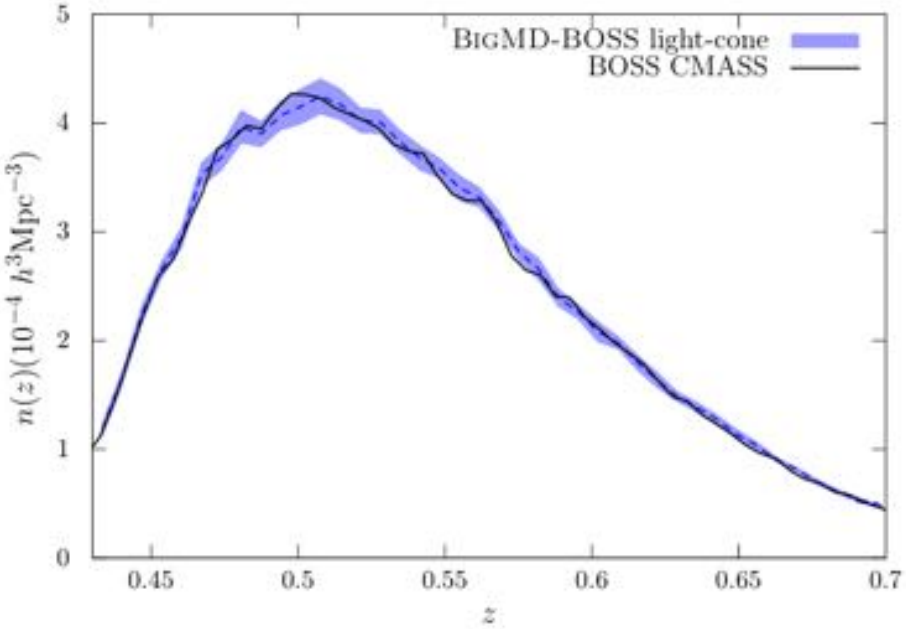


Figure 4. The comoving number density of BOSS-CMASS DR12 North Galactic Cap (black line) compared to the comoving number density of the BigMD-BOSS light-cone (Dashed line). Shaded area comes from 100 MD-PATCHY Mocks.

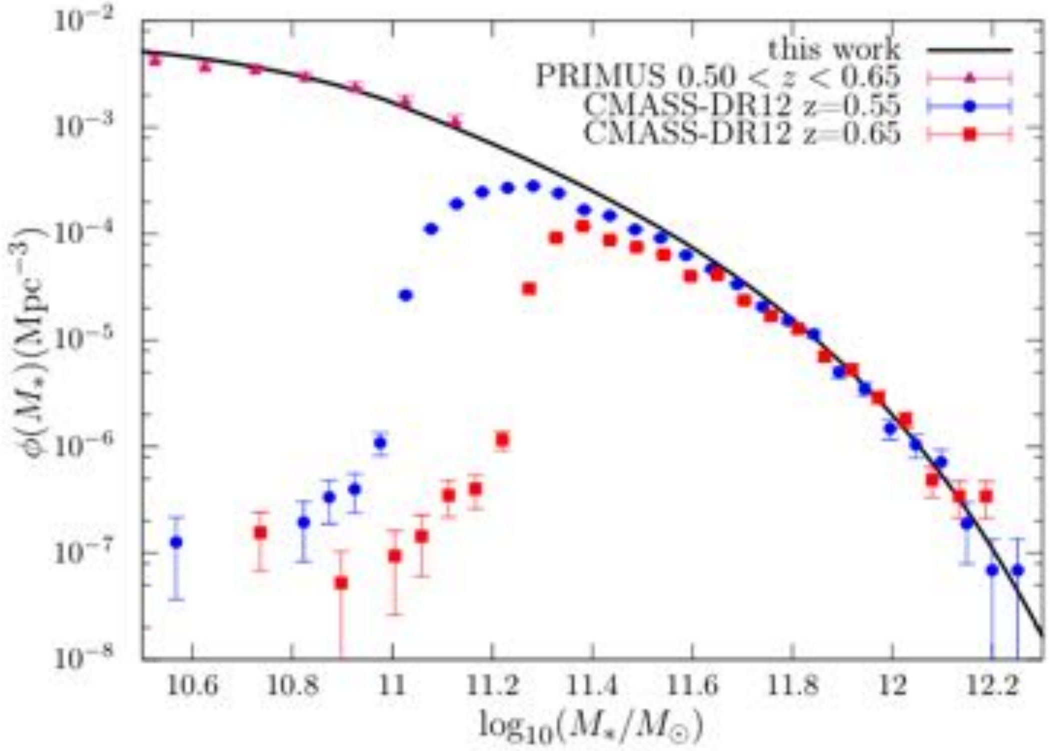


Figure 3. Stellar mass function from BOSS CMASS DR12 sample. Circles and squares show the stellar mass distribution for two redshift bins from the Portsmouth DR12 catalogue. Poissonian errors are included. Triangles represent the PRIMUS SMF for the redshift range 0.5 to 0.65, and solid line shows the estimate of the SMF for this work, which is constructed combining the high mass end of the BOSS sample and Guo et al. 2010 for the low mass range ($\log_{10} M* < 11.0$). Our model agrees at low masses with the PRIMUS mass function.

Rodríguez-Torres et al. 2015

Modeling CMASS clustering

- Haloes identified using BDM (Klypin & Holtzman 1997).
- Identifies distinct (central) and sub-halos (satellites).
- We match halo abundances according to

$$V_{\max}^2 = \max\left[\frac{GM(<r)}{r}\right]$$

- Measures the depth of the potential well of the halo.
- Good to relate halos with the galaxies they host.

The New Suite of MultiDark Simulations for Large Surveys

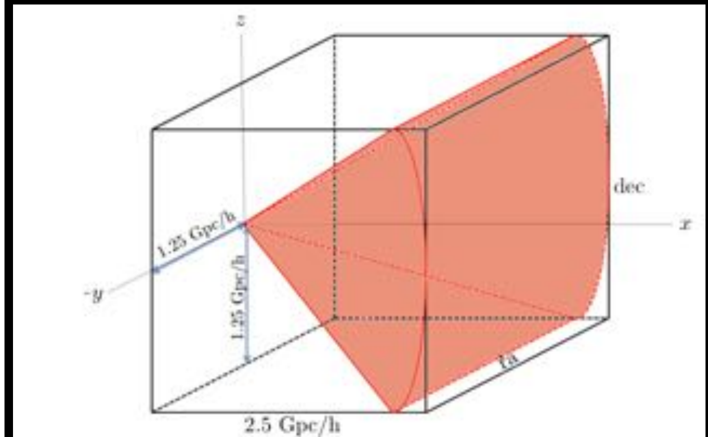
>> The BigMD Project <<

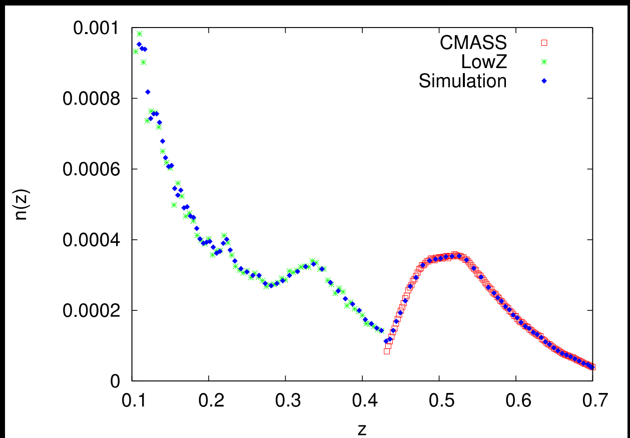
MultiDark Database

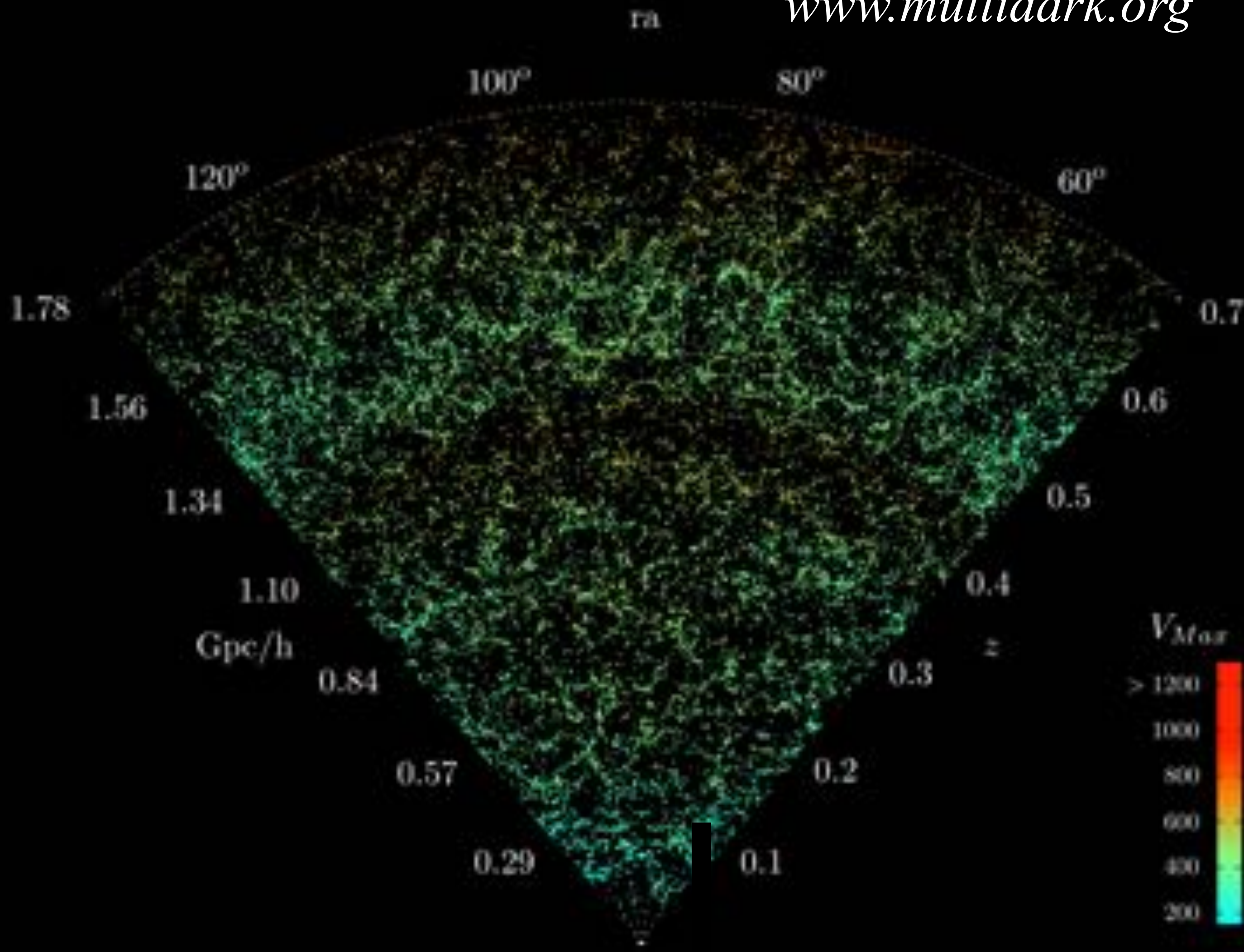
www.multidark.org

Products:

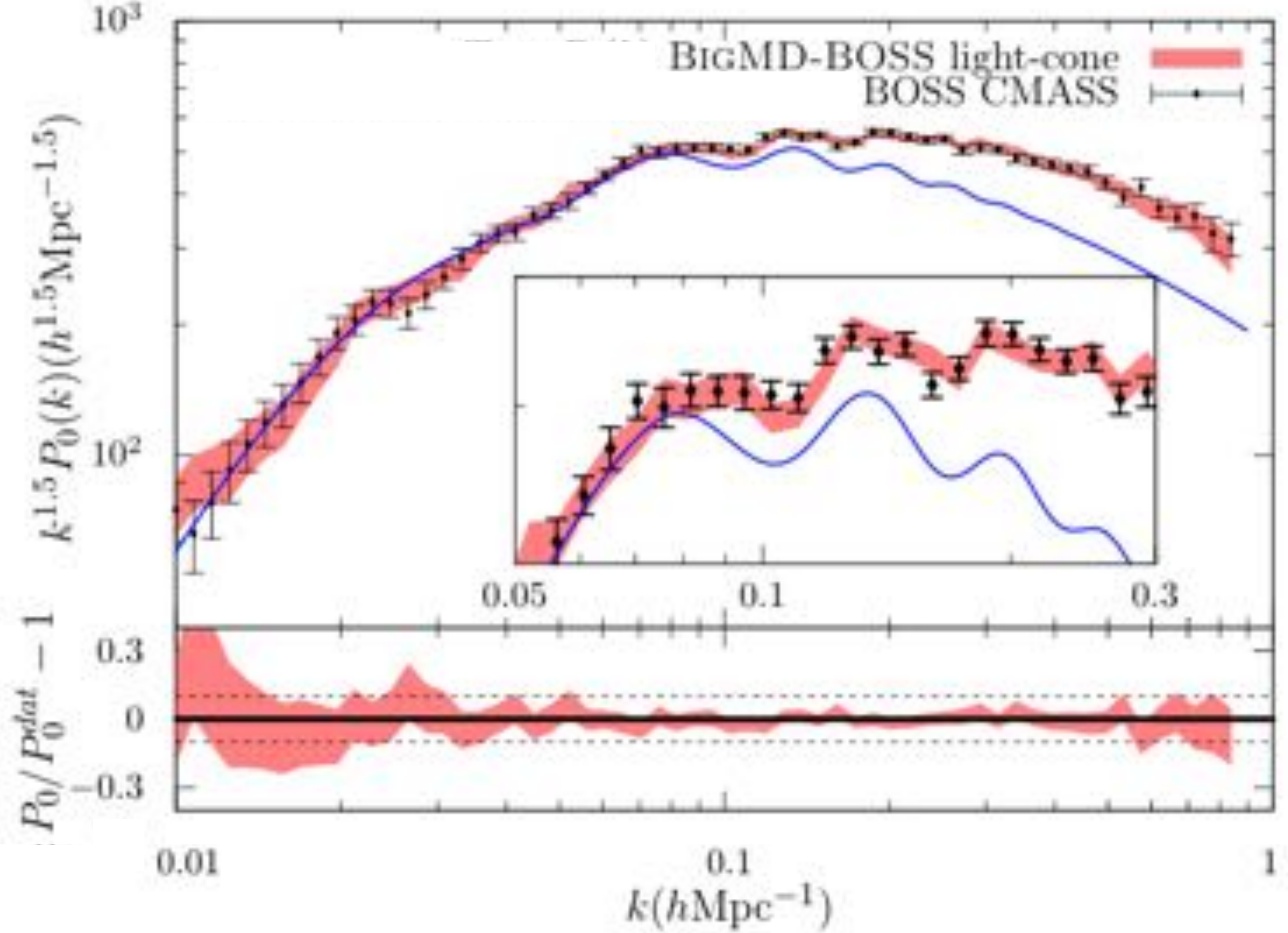
- Row particle data
- FOF & BDM halo catalogs
- (sub)Halo profiles
- Merging Trees
- **BOSS galaxy light-cones**
- “Add to Wish List”







Simulation	box	particles	m_p	ϵ
BigMDPL	2.5	3840^3	2.4×10^{10}	10.0
BigMDPLnw	2.5	3840^3	2.4×10^{10}	10.0



Rodríguez-Torres et al. 2015

Figure 11. Monopole of power spectrum from the BigMD-BOSS light-cone and the CMASS DR12 sample. *Top Panel*: The true

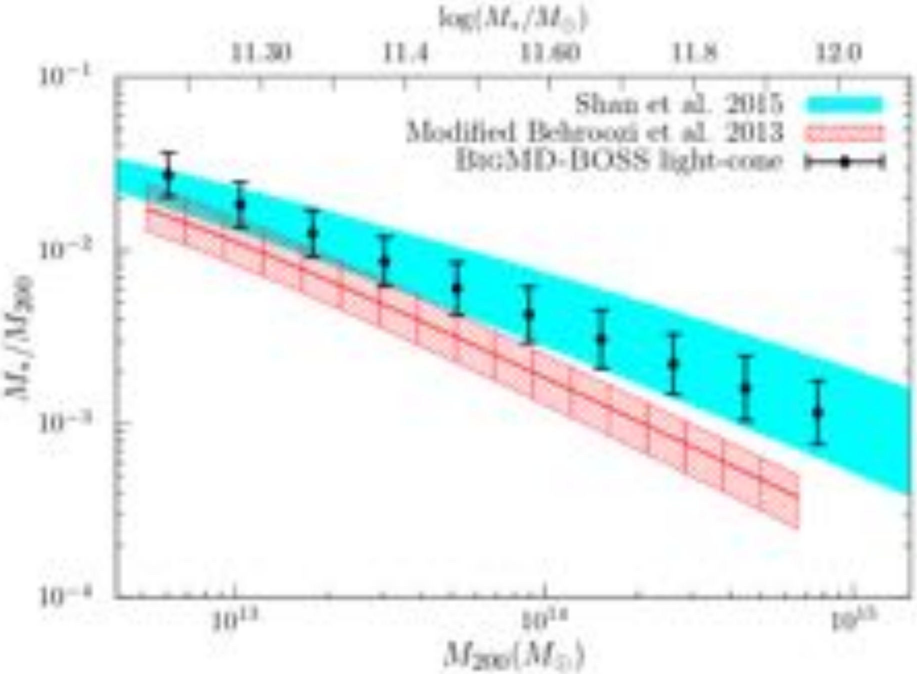


Figure 13. Halo-to-stellar mass ratio. The shaded blue area represents the best fit of the stellar to halo mass relation measured using weak lensing in the CFHT Stripe 82 Survey (Shan et al. 2015). The red area represent previous HAM result from Behroozi et al. 2013c. The analysis in Behroozi et al. 2013c was modified using the Planck cosmology parameters and changing the definition of the halo mass. Black dots are the prediction frome the Halo Abundance Matching - BigMD-BOSS light-cone. Differences between our model and Behroozi et al. 2013c. are mainly due to the SMF adopted in both works. Scatter between M_{200} and M_* is similar between the data and our model. We adopted constant scatter while observed data suggests a dependency of the scatter with the stellar mass.

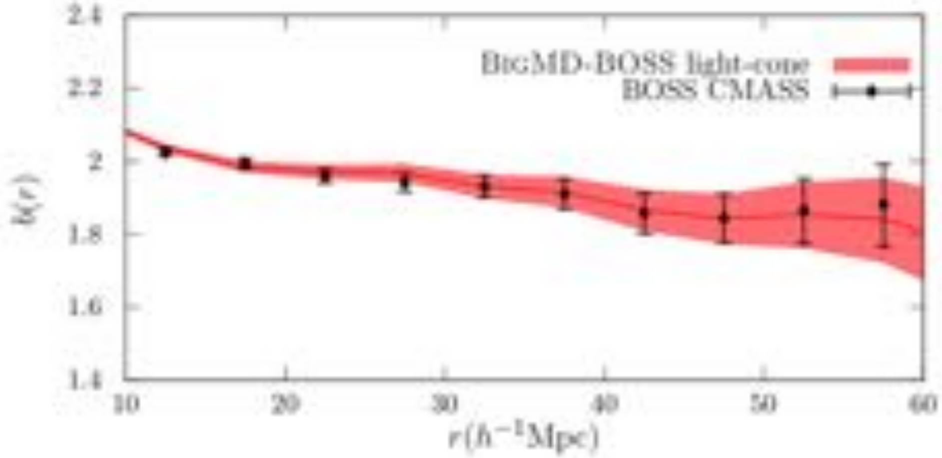
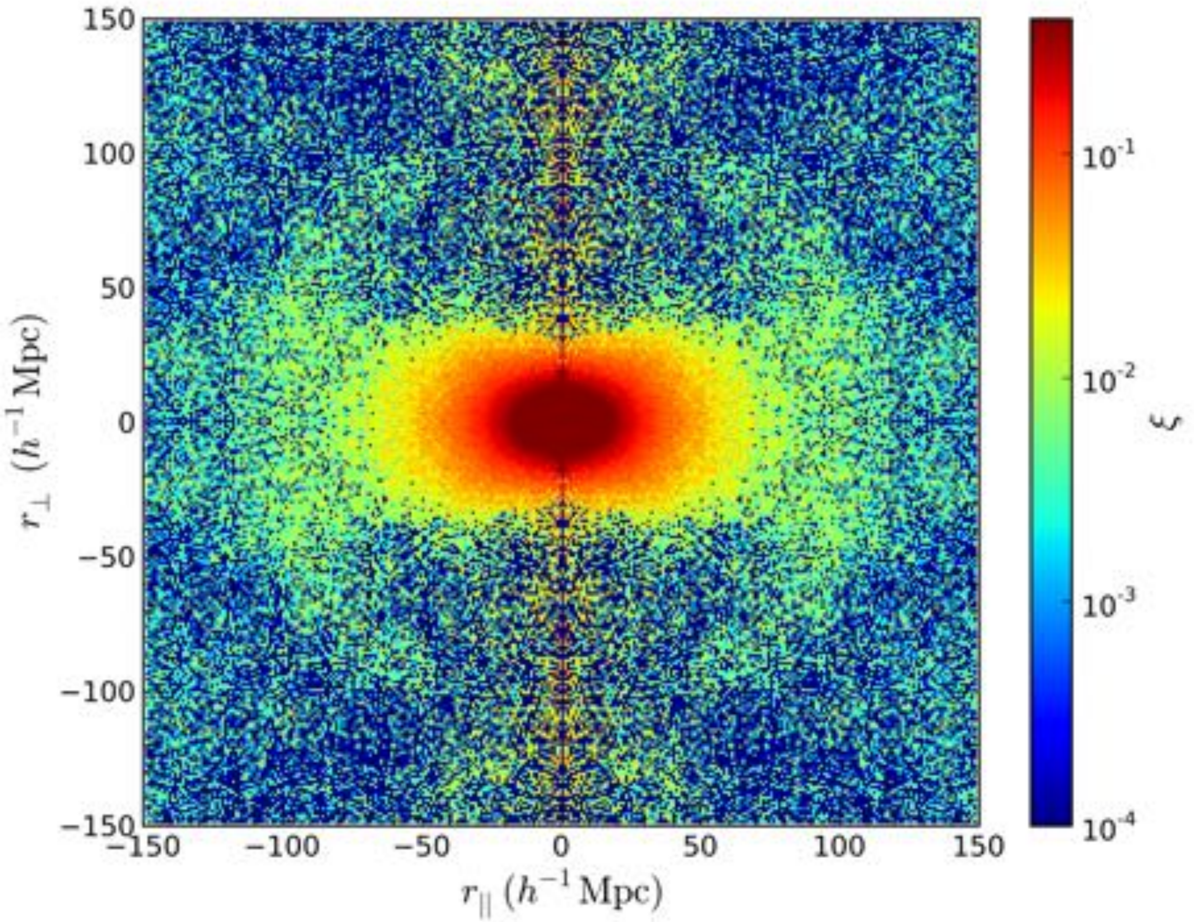


Figure 14. Scale-dependent galaxy bias from the model presented in this work. We measure the bias with respect to the correlation function of dark matter in the BigMultiDark light-cone for the data and the model. There is an excellent agreement between the CMASS observations and the predictions of the HAM-BigMD-BOSS light-cone.

Rodríguez-Torres et al. 2015

Baryonic Acoustic Oscillations



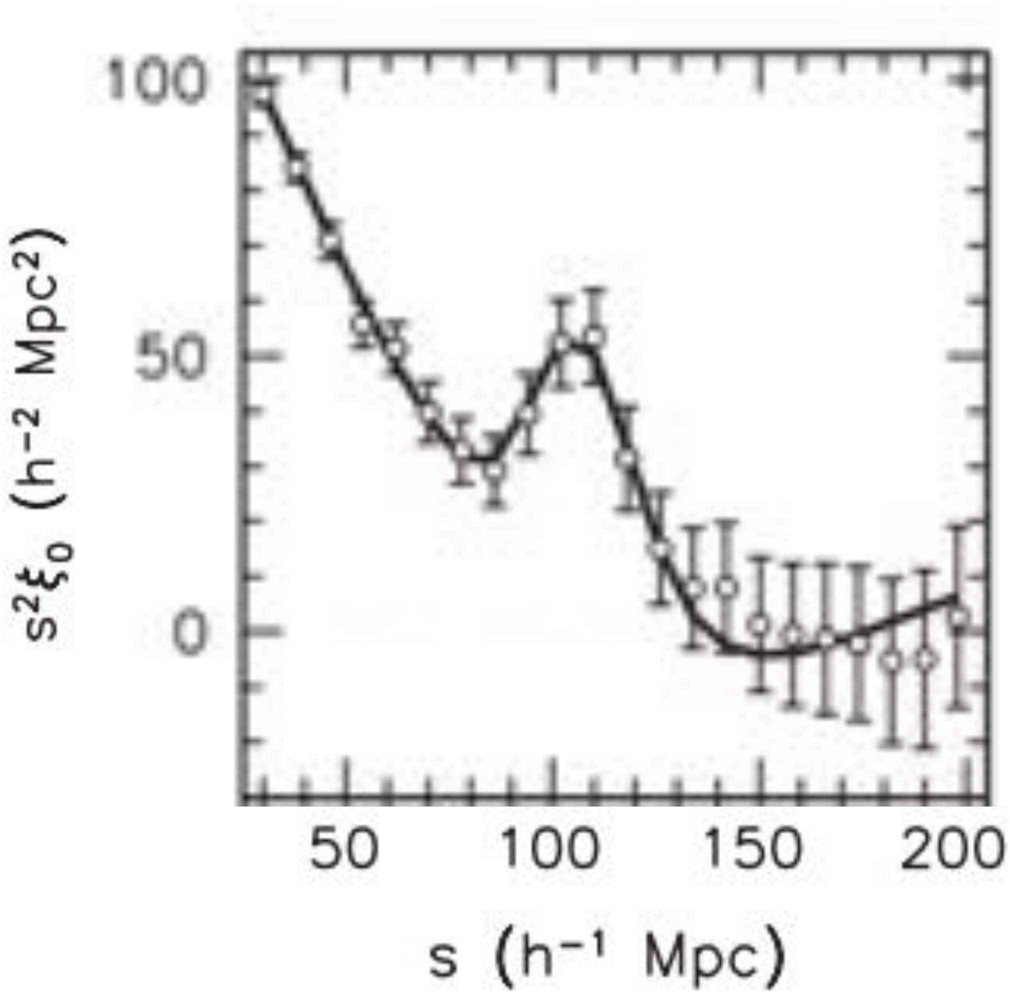
Two-dimensional correlation function of DR11 CMASS galaxies in BOSS. Colors indicate amplitude of the correlation function (Samushia et al. 2013)

BAO feature in both the transverse and line-of-sight directions. These shifts are typically parameterised by

$$\alpha_\perp = \frac{D_A(z) r_d^{\rm fid}}{D_A^{\rm fid}(z) r_d}, \quad \alpha_\parallel = \frac{H^{\rm fid}(z) r_d^{\rm fid}}{H(z) r_d}$$

Together, they allow us to measure the angular diameter distance (relative to the sound horizon at the drag - photon decoupling - epoch r_d) $D_A(z)/r_d$, and the Hubble parameter $H(z)$ via $cz/(H(z)\ r_d)$ separately.

SDSS-III/BOSS Galaxy Clustering results



The observed BAO position depends simply on the scale dilation parameter

$$\alpha \equiv \frac{D_V(z) r_{d,\mathrm{fid}}}{D_V^{\mathrm{fid}}(z) r_d}$$

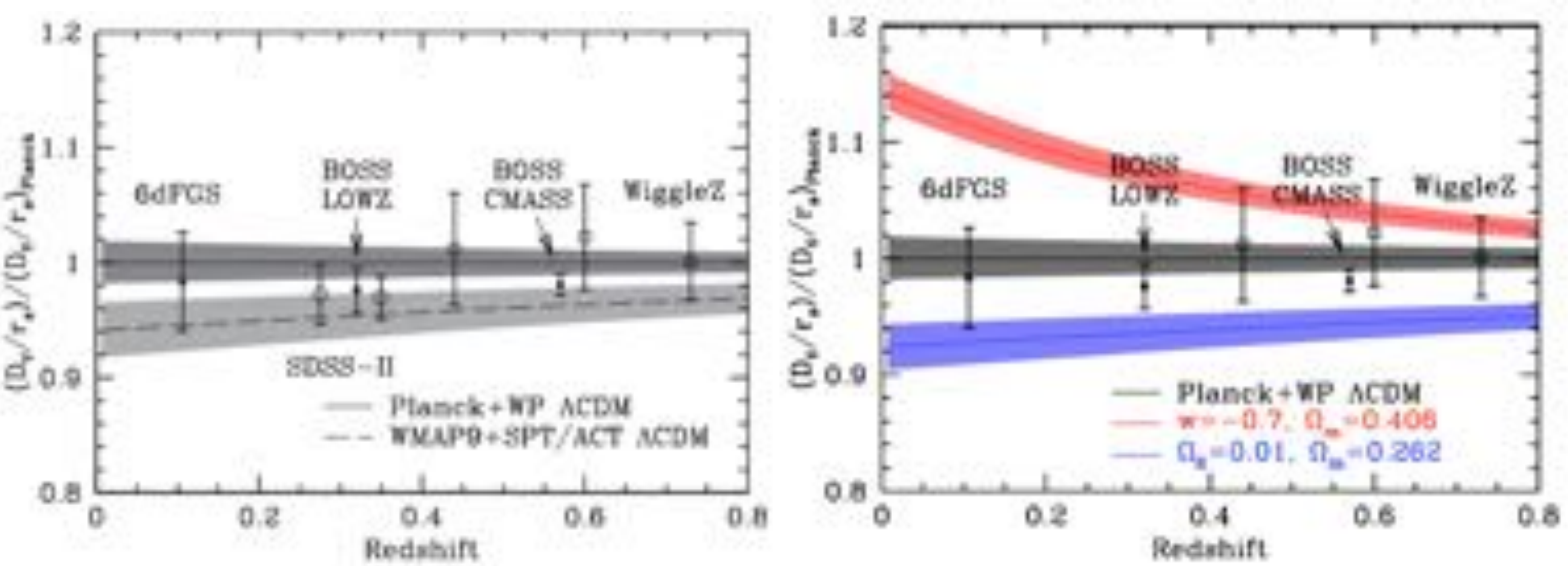
which measures the relative position of the acoustic peak in the data versus the model, thereby characterizing any observed shift.
If $\alpha > 1$, the acoustic peak is shifted towards smaller scales, and $\alpha < 1$ shifts the observed peak to larger scales.

alpha = 1.0144 +− 0.0098

Measurement of the correlation function monopole from the BOSS DR11 CMASS galaxy sample, compared to the best-fitting BAO model given the the solid line (Anderson et al. 2014).

BOSS DR11 cosmology results

Anderson et al. (2014)



The distance-redshift relation from the BAO method on galaxy surveys. This plot shows $DV(z)/r_d$ versus z measured from from galaxy surveys, divided by the best-fit flat LCDM prediction from the Planck data.

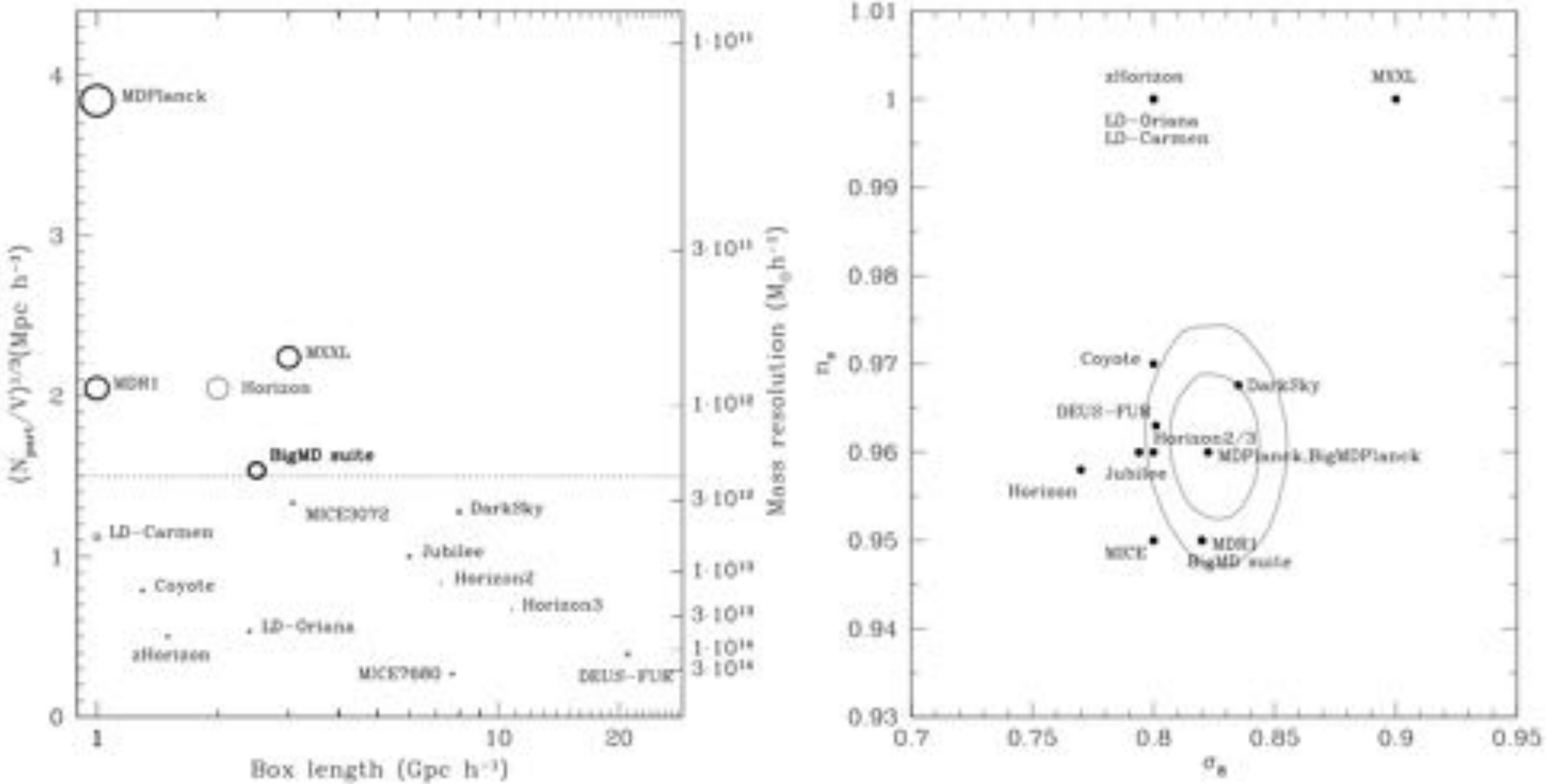


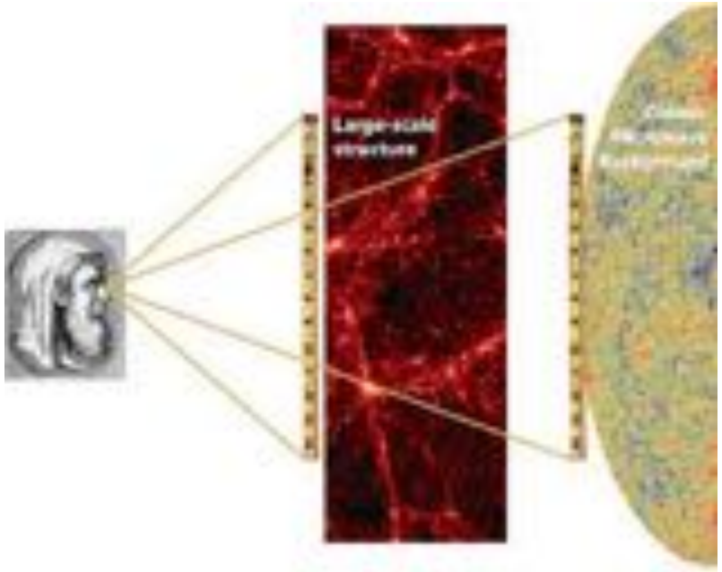
Figure 1. Left: Compilation of the basic numerical parameters adopted in large N-body cosmological simulations used in recent years for galaxy clustering and bias studies. The number of particles per unit comoving distance (and mass resolution for halos with at least 100 particles) is shown as a function of the box length for each simulation. The size of the circles is inversely proportional to the softening parameter ϵ used in the gravitational force. Our new suite of BigMultiDark simulations have been designed to meet all science requirements needed to interpret the galaxy clustering in the BOSS survey (dotted line). Right: n_s versus σ_8 (right) cosmological parameters adopted for each simulation. Contours show 68% and 95% confidence levels from Planck assuming a flat ΛCDM Planck cosmology. In this work we are using the BigMD Planck simulations.

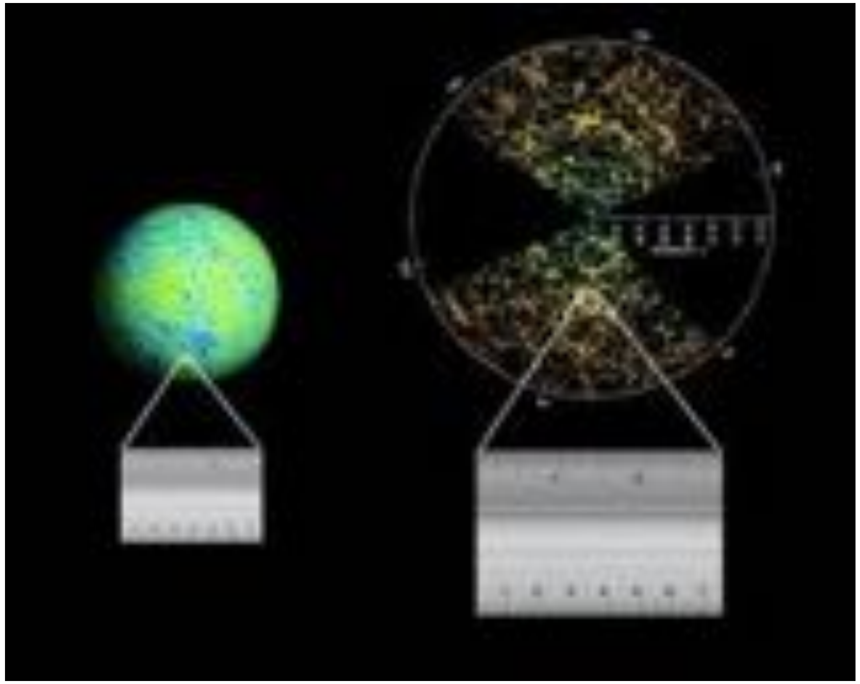
Prada et al. 2014

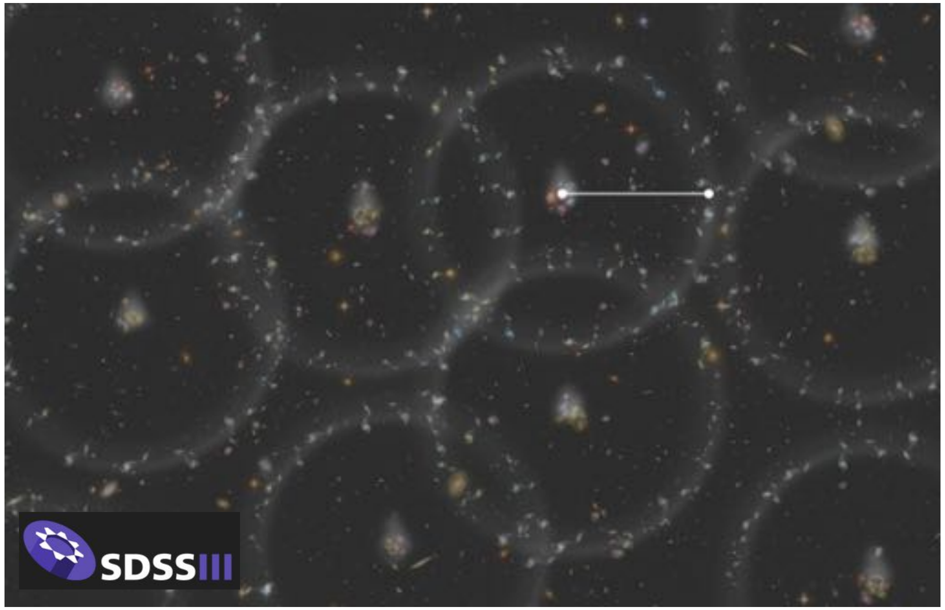
How to measure Dark Energy?

Baryonic Acoustic Oscillations as standard ruler

The propagation of sound waves through the primordial plasma in the early universe gives rise to a characteristic scale in the distribution of perturbations corresponding to the distance travelled (150 Mpc) by the wave before recombination.

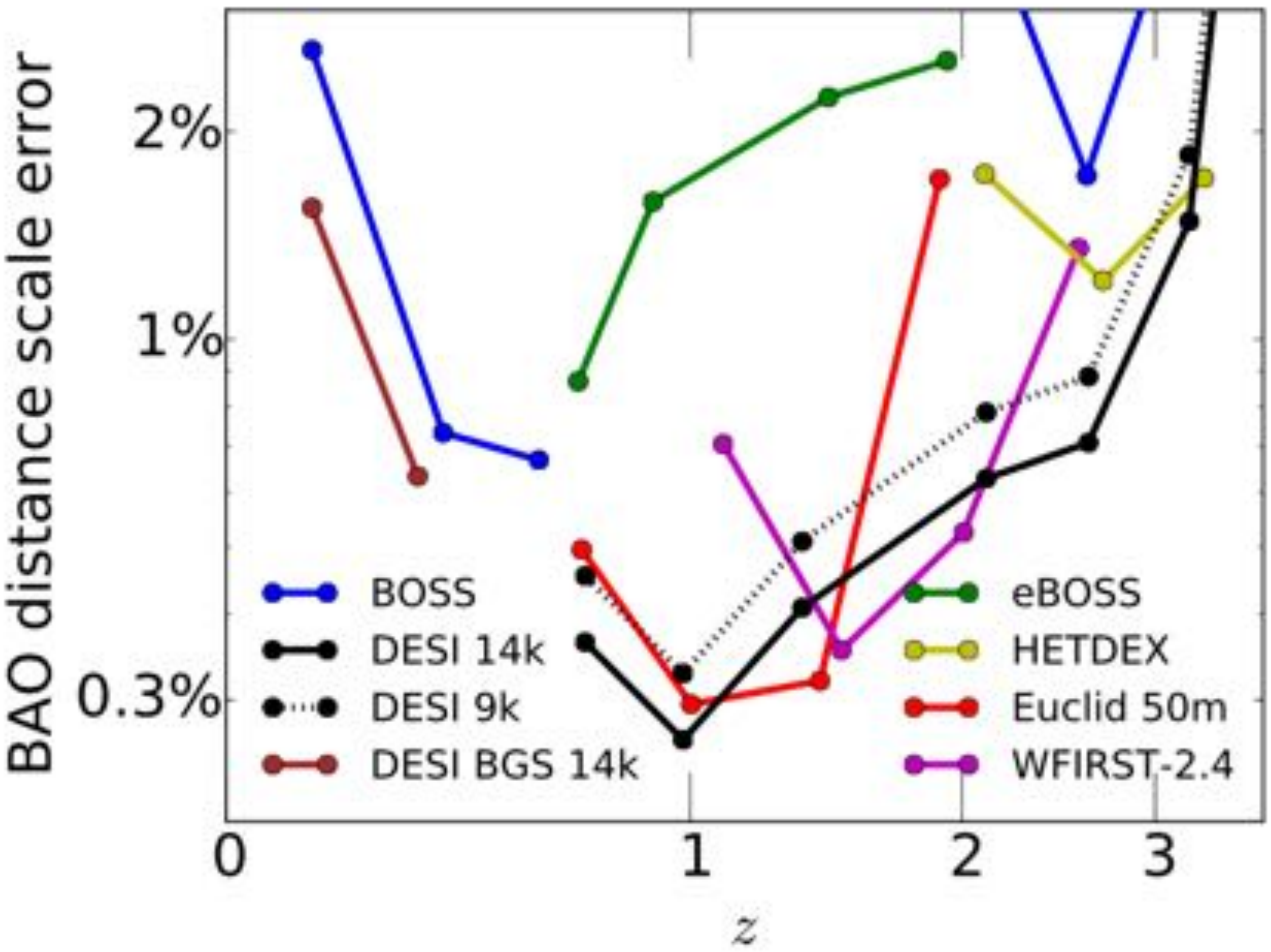




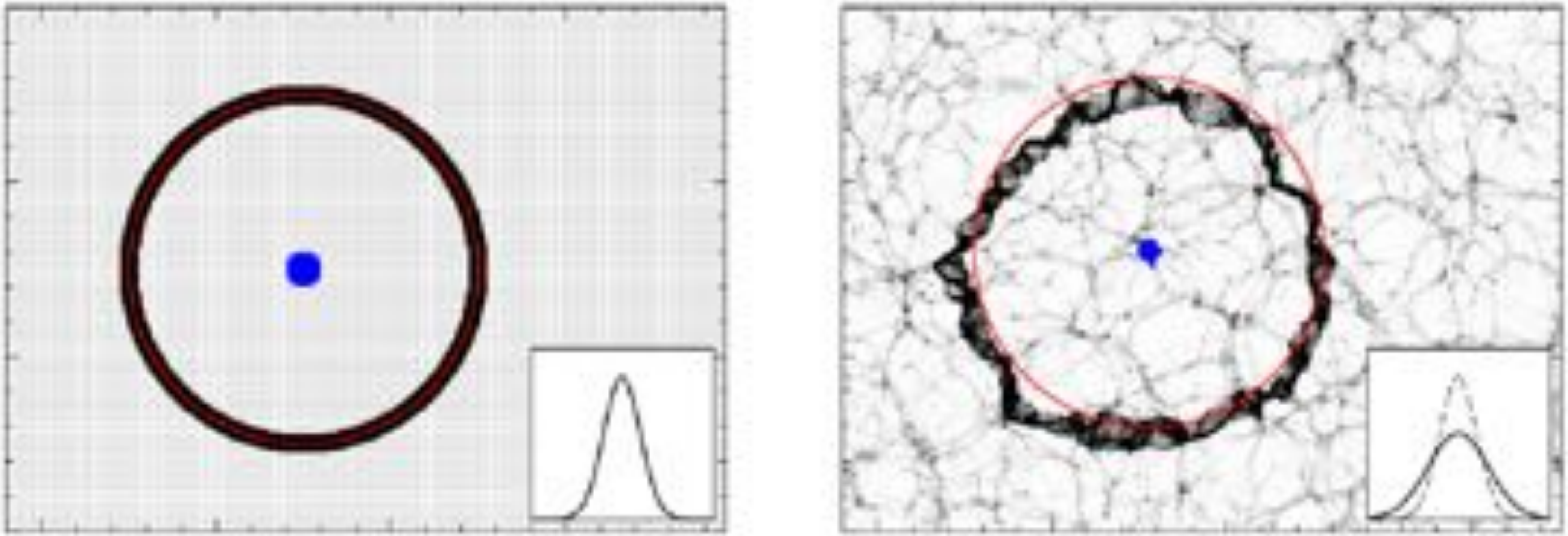


LSS galaxy surveys provides a picture of the distribution of matter such that one can search for a BAO signal by seeing if there is a larger number of galaxies separated at the sound horizon.

BAO forecast

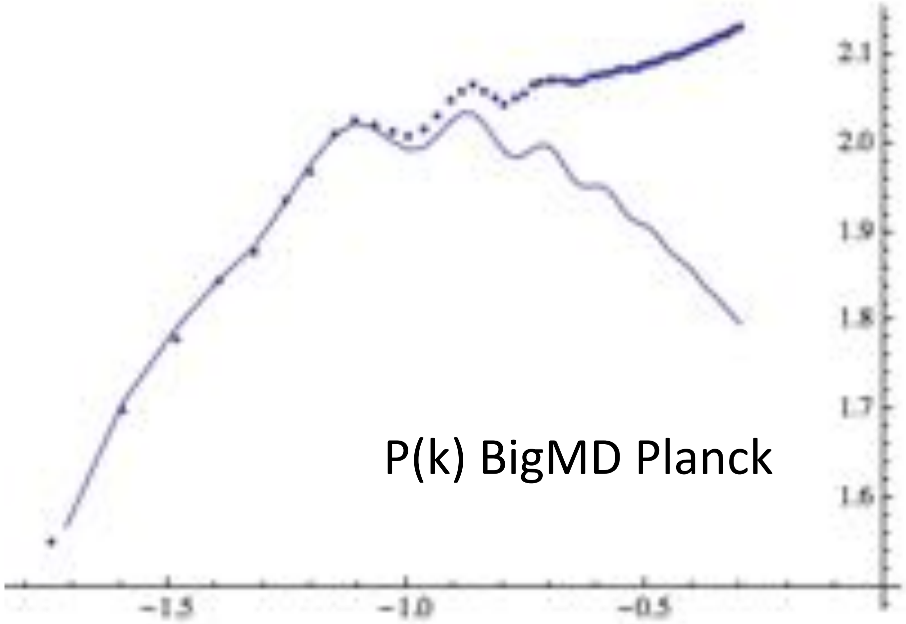


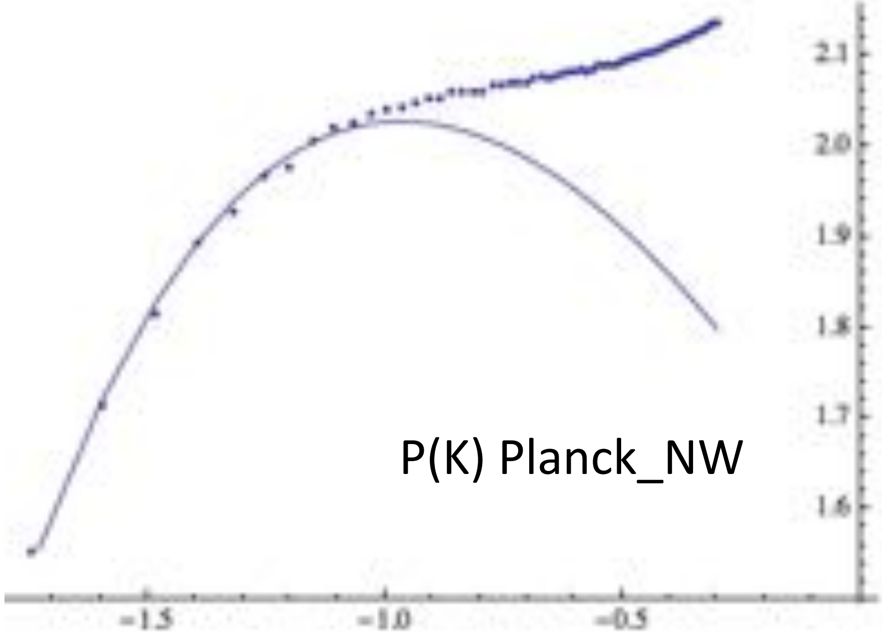
Physics of BAO



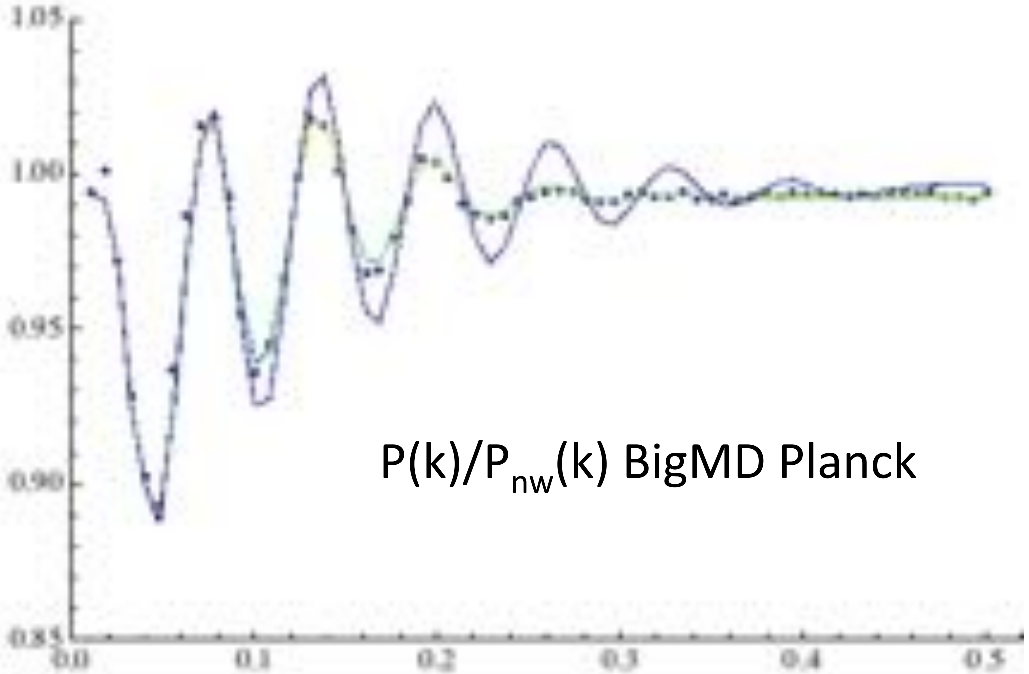
A pictorial explanation of how the BAO shifts and broadened since the early universe to the present day. In each panel, we show a thin slice of a simulated cosmological density field. (top left) In the early universe, the initial densities are very smooth. We mark the acoustic feature with a ring of 150 Mpc radius from the central points. A Gaussian with the same rms width as the radial distribution of the black points from the centroid of the blue points is shown in the inset. (top right) We evolve the particles to the present day, here by the Zel'dovich approximation. The red circle shows the initial radius of the ring, centered on the current centroid of the blue points. The large-scale velocity field has caused the black points to spread out; this causes the acoustic feature to be broader (Padmanabhan 2012).

Accurate measurement of the BAO shift and damping



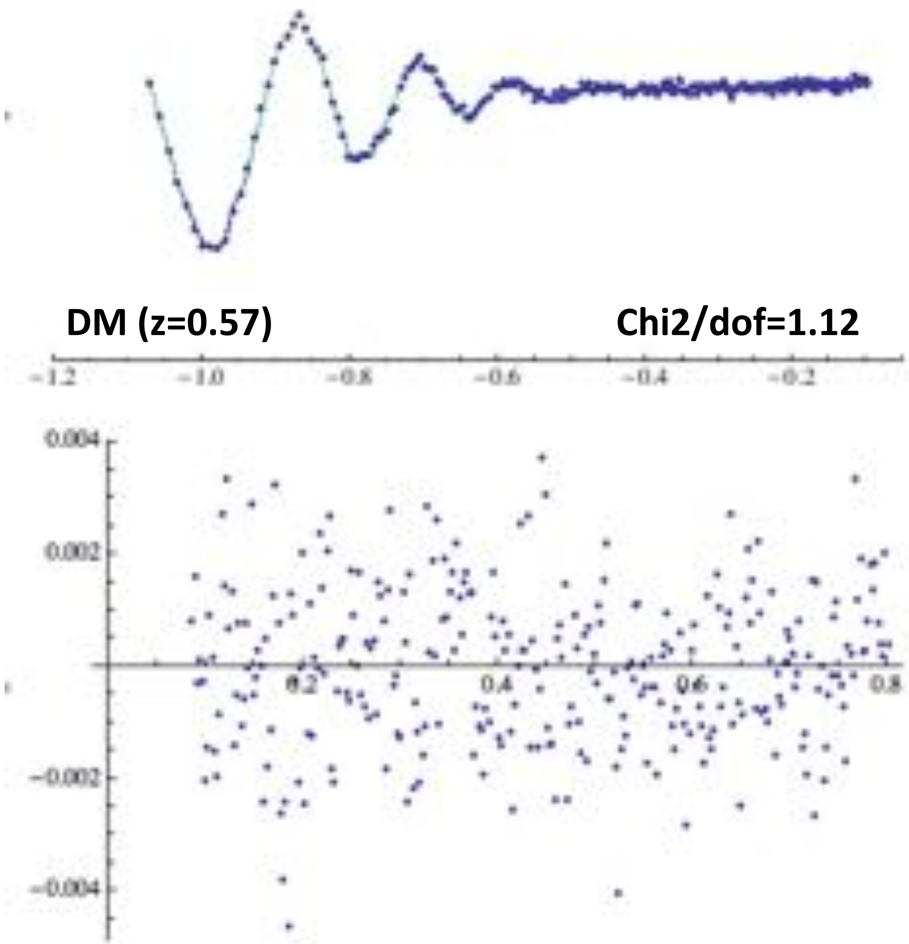


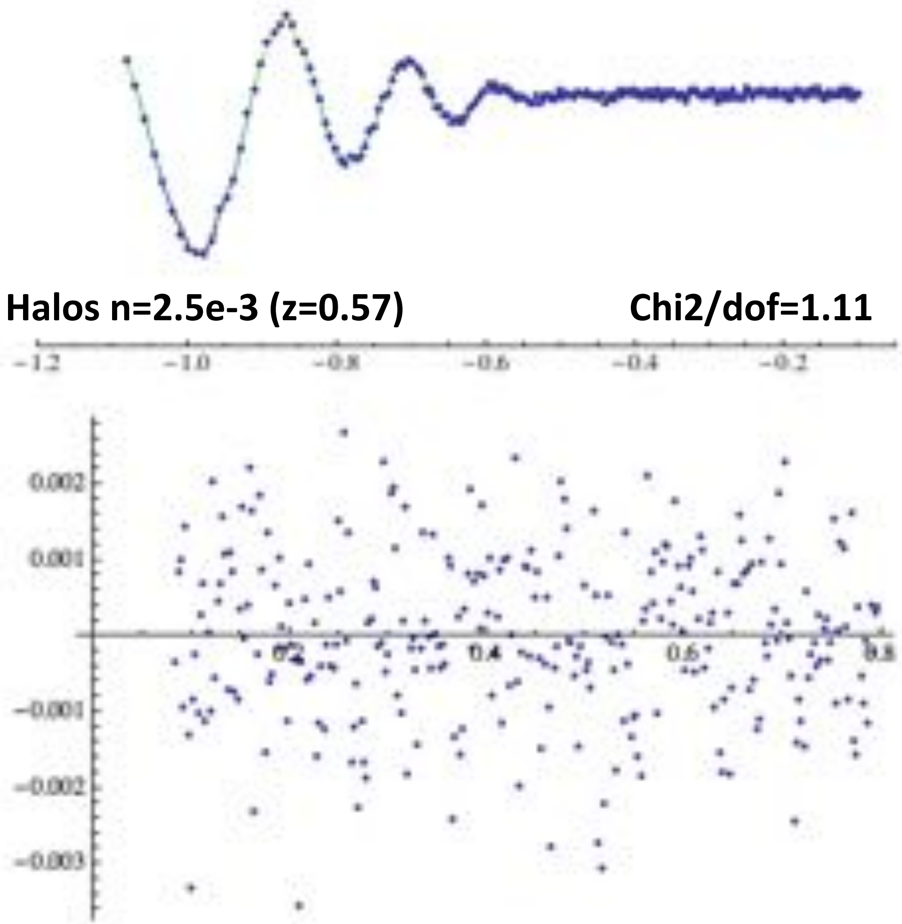
Simulation	box	particles	m_p	ϵ
BigMDPL	2.5	3840^3	2.4×10^{10}	10.0
BigMDPLnw	2.5	3840^3	2.4×10^{10}	10.0



Prada et al. 2015

$P(k)/P_{nw}(k)$ for DM & Halos in BigMD Planck





Very accurate measurement of the BAO shift & damping

$$\frac{P}{P_{nw}}(k) = [\left(\frac{P^{lin}(k/\alpha)}{A(k)\cdot P^{lin}_{nw}(k/\alpha)} - 1\right)\cdot \exp\left(-k^2\Sigma^2_{nl}/2\right) + 1]\cdot C(k)$$

BAO shift & damping in the Planck Cosmology

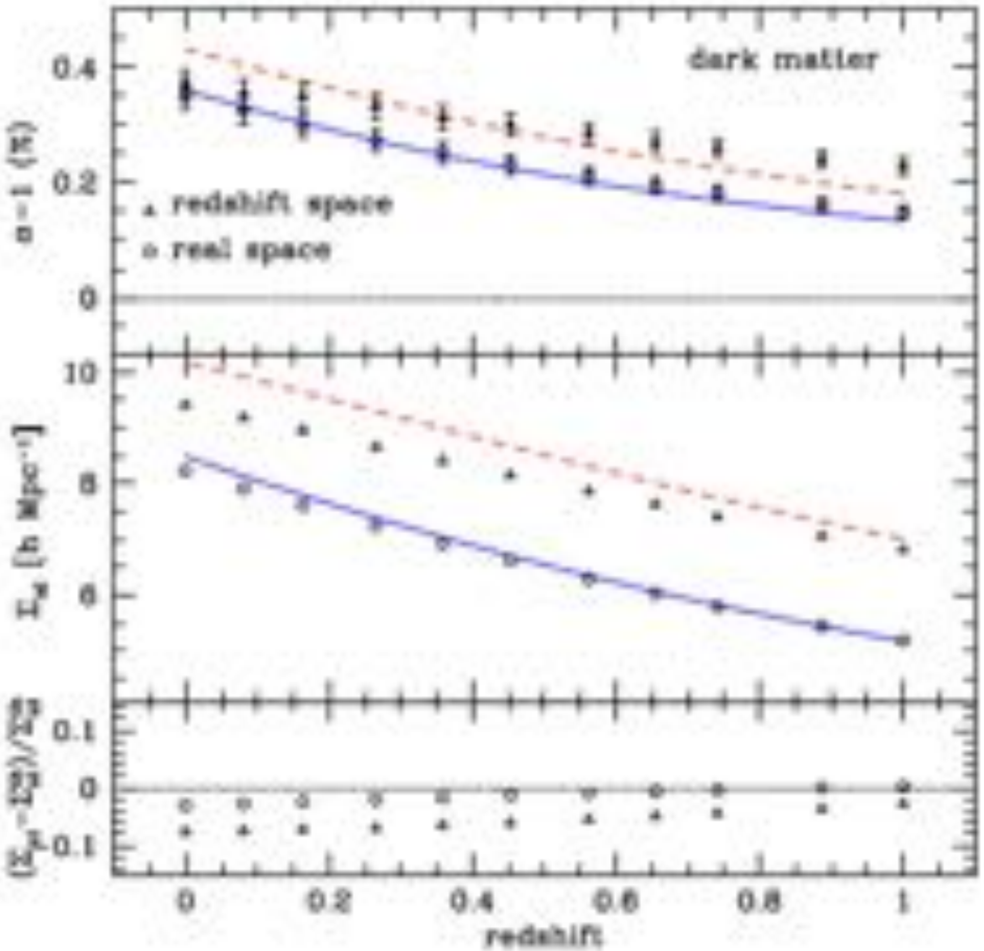


Figure 5. Nonlinear evolution of the BAO shift and damping with redshift for dark matter in real- and redshift-space (circles and triangles respectively). The solid line in the top and middle panel are our best fit to $\alpha(z) - 1 \propto [D(z)/D(0)]^2$ and the linear theory estimate of the damping given by Eq. 3 respectively. Errors for the damping measurements are smaller than the size of the symbols. The dashed lines correspond to redshift-space predictions. The bottom panel shows the relative ratio of the damping measurements as compared to linear theory.

redshift	$\alpha - 1(\%)$	Σ_{nl} (Mpc/h)	Σ_{nl}^{th} (Mpc/h)	$\chi^2/d.o.f.$
1.000	$0.1483^{+0.0114}_{-0.0108}$	$5.1846^{+0.0147}_{-0.0147}$	5.1711	1.004
0.887	$0.1611^{+0.0121}_{-0.0120}$	$5.4400^{+0.0148}_{-0.0160}$	5.4378	1.025
0.741	$0.1820^{+0.0134}_{-0.0137}$	$5.7946^{+0.0162}_{-0.0170}$	5.8164	0.992
0.655	$0.1943^{+0.0141}_{-0.0142}$	$6.0238^{+0.0170}_{-0.0167}$	6.0621	1.027
0.562	$0.2121^{+0.0143}_{-0.0162}$	$6.2878^{+0.0178}_{-0.0172}$	6.3449	1.049
0.453	$0.2305^{+0.0170}_{-0.0161}$	$6.6175^{+0.0194}_{-0.0178}$	6.7026	1.019
0.358	$0.2513^{+0.0183}_{-0.0175}$	$6.9226^{+0.0198}_{-0.0191}$	7.0355	1.029
0.265	$0.2732^{+0.0207}_{-0.0191}$	$7.2418^{+0.0207}_{-0.0210}$	7.3840	1.008
0.164	$0.3006^{+0.0232}_{-0.0211}$	$7.6053^{+0.0227}_{-0.0225}$	7.7886	1.012
0.081	$0.3270^{+0.0249}_{-0.0254}$	$7.9156^{+0.0244}_{-0.0244}$	8.1347	1.013
0.000	$0.3530^{+0.0272}_{-0.0263}$	$8.2308^{+0.0249}_{-0.0275}$	8.4859	1.011

Real-space

$$\Sigma_{nl}^{th} = \left[\frac{1}{3\pi^2}\int P_{lin}(k)dk\right]^{1/2}$$

Prada et al. 2015

Halo Tracers

BAO shift & damping as a function of bias

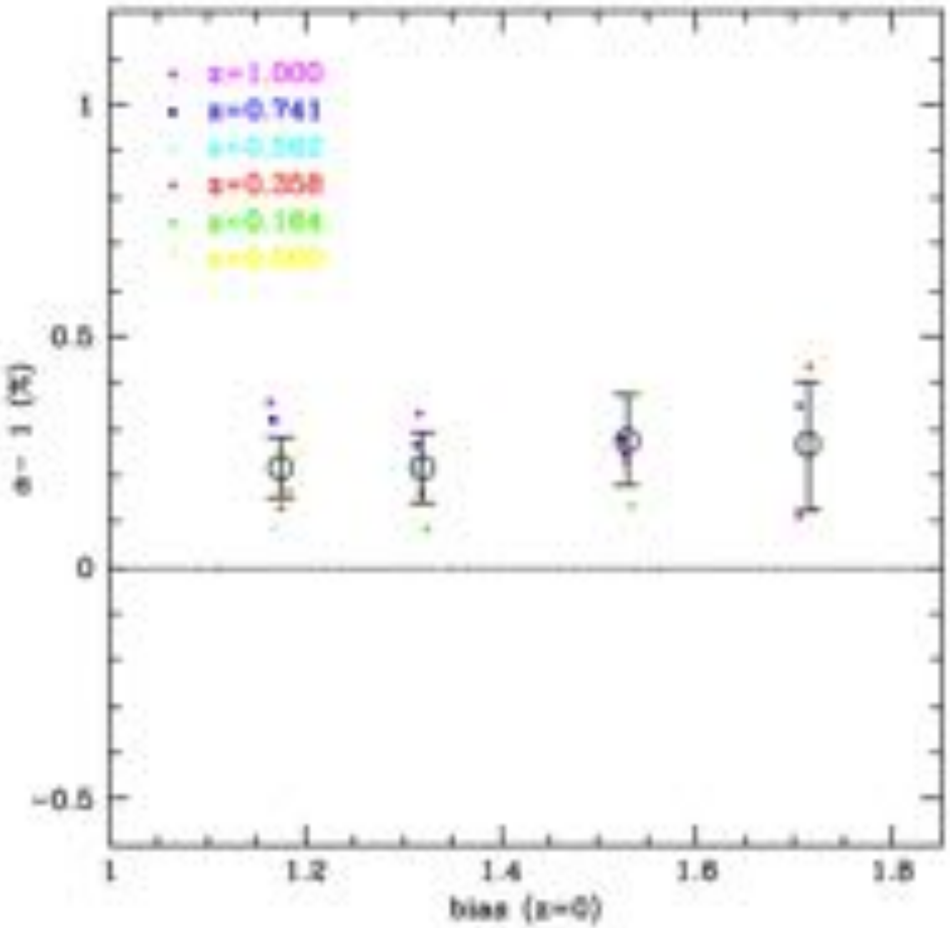


Figure 6. Measurements of the BAO shift as a function of halo bias for our BigMD Planck data. Each of the individual shift estimates are shown with tiny solid symbols for the different redshifts (color coded). Large open circles shows the mean values for the four bias bins, and 1σ error bars correspond to the errors of the mean.

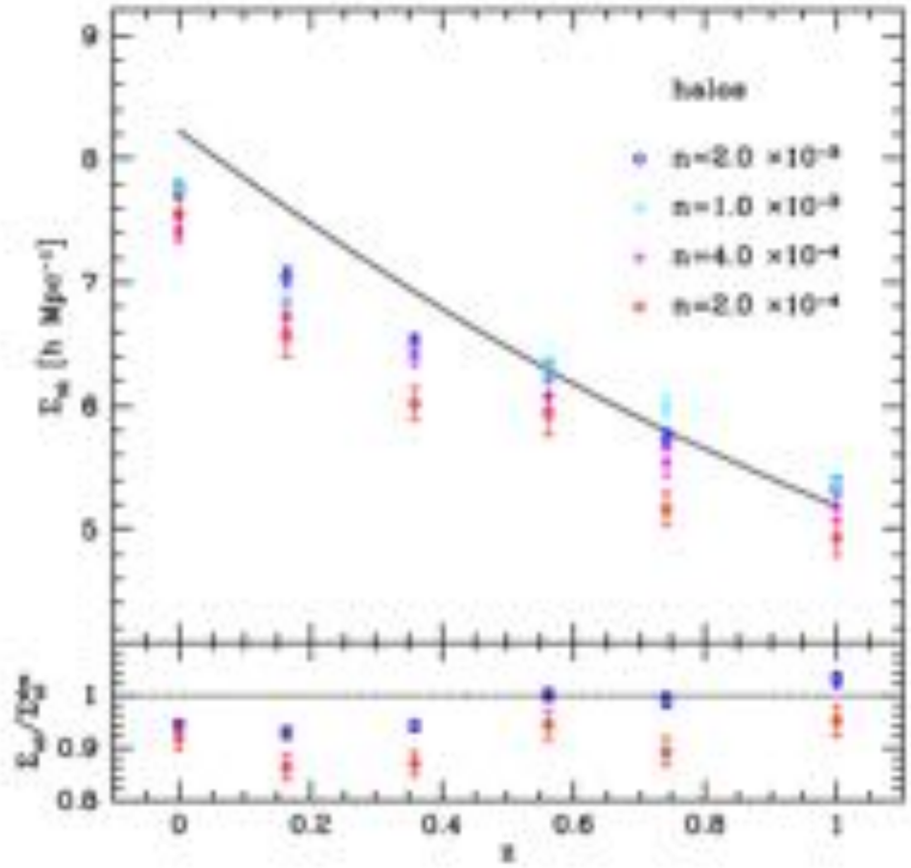
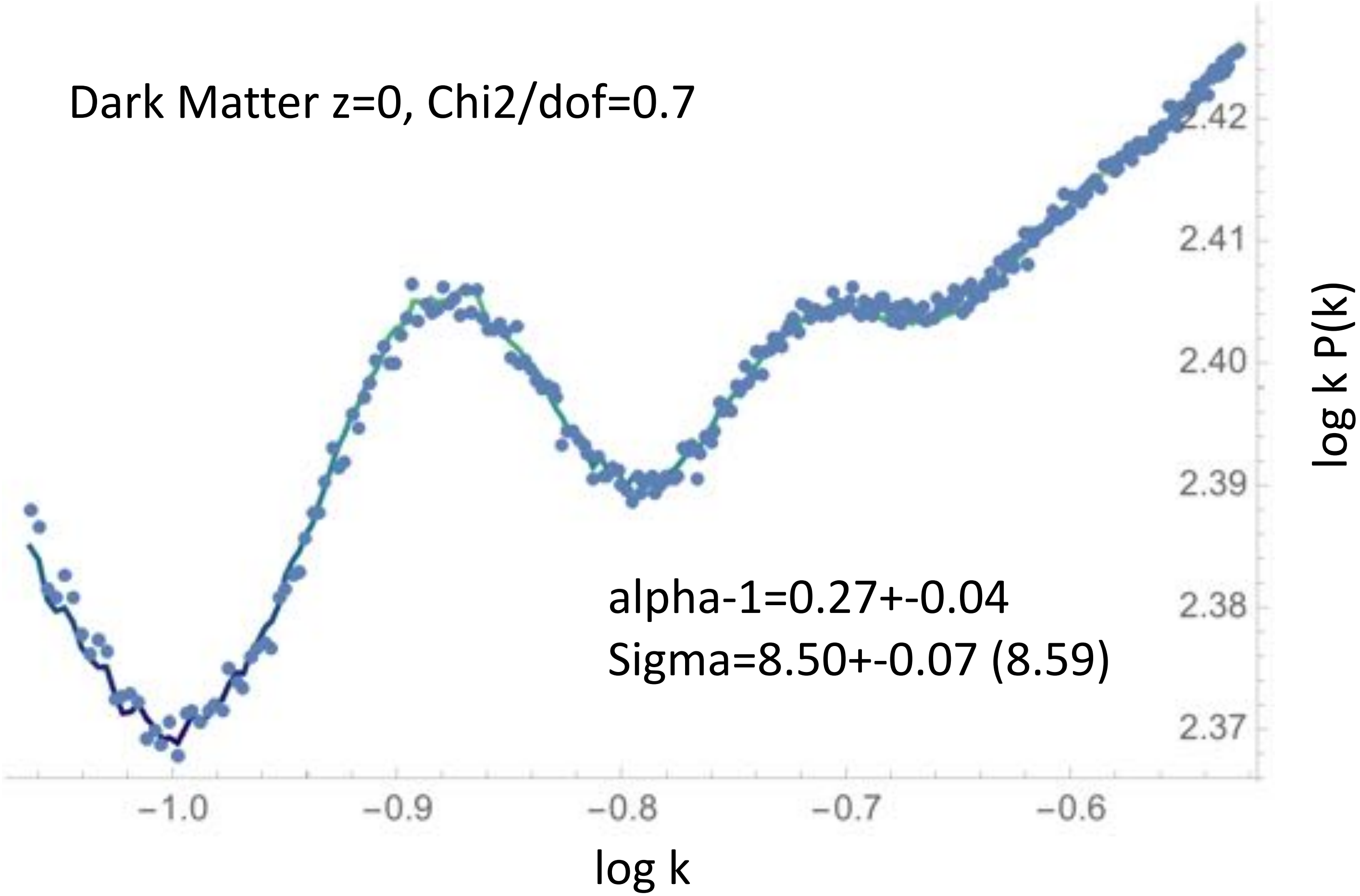


Figure 7. Nonlinear evolution of the BAO damping with redshift, in real space, for our four different halo samples (open symbols). The solid line connects the measurements for the dark matter tracer provided in Table 1 and shown in Figure 7. The acoustic feature suffers less damping due to nonlinear effects as compare to dark matter towards lower redshift and also for more sparse halo samples at a given redshift.

Prada et al. 2015

DarkSky preliminary results



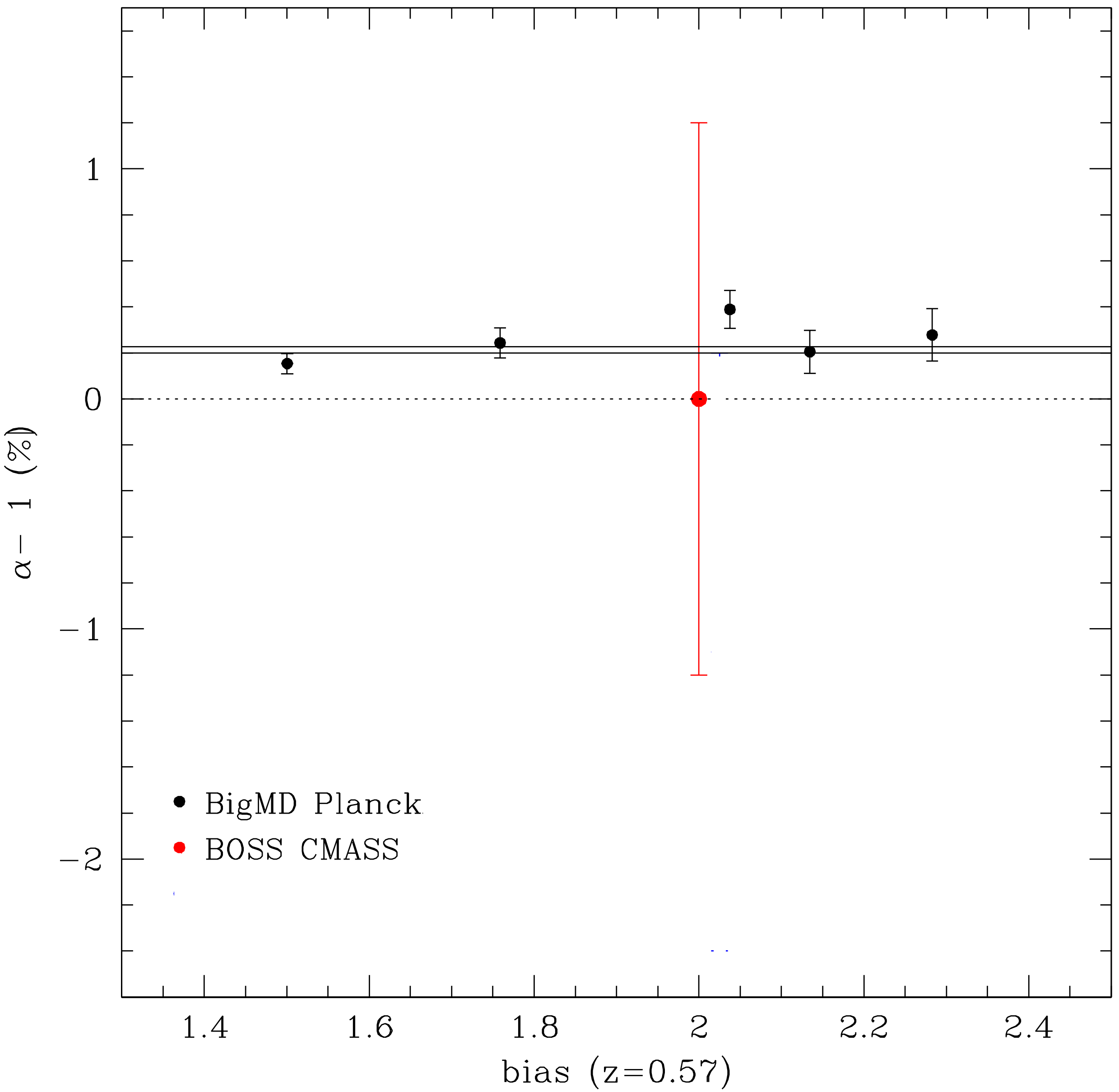
10240^3, (8 Gpc/h)^3

Skillman et al.

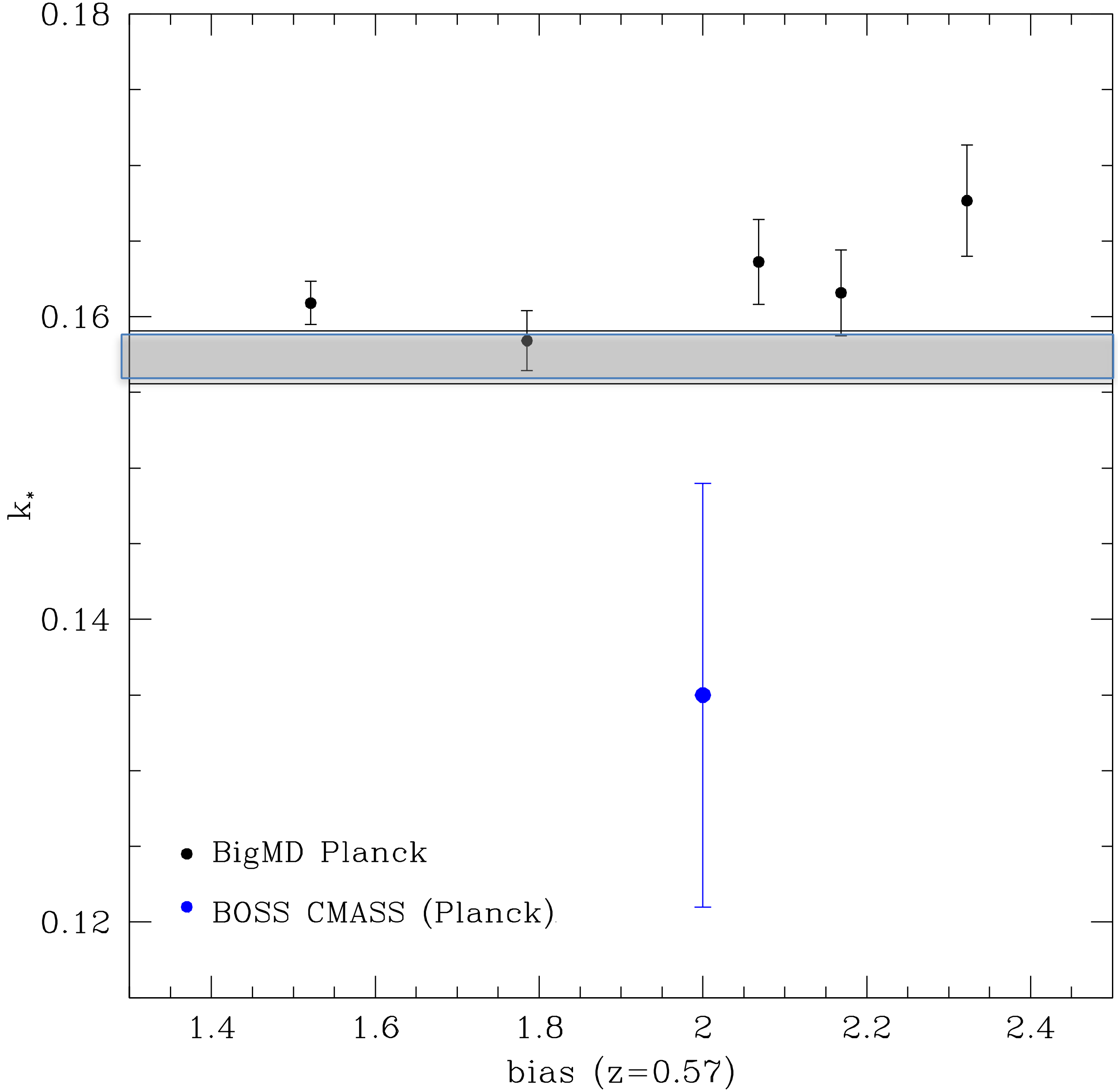
$$P_{\rm obs}(k) = B(k) P_m(k/\alpha)$$

$$P_m(k) = [P_{\rm lin}(k) - P_{\rm nw}(k)] \exp\left[-k^2 \Sigma_{\rm m}^2/2\right] + P_{\rm nw}(k),$$

BAO shift as a function of bias



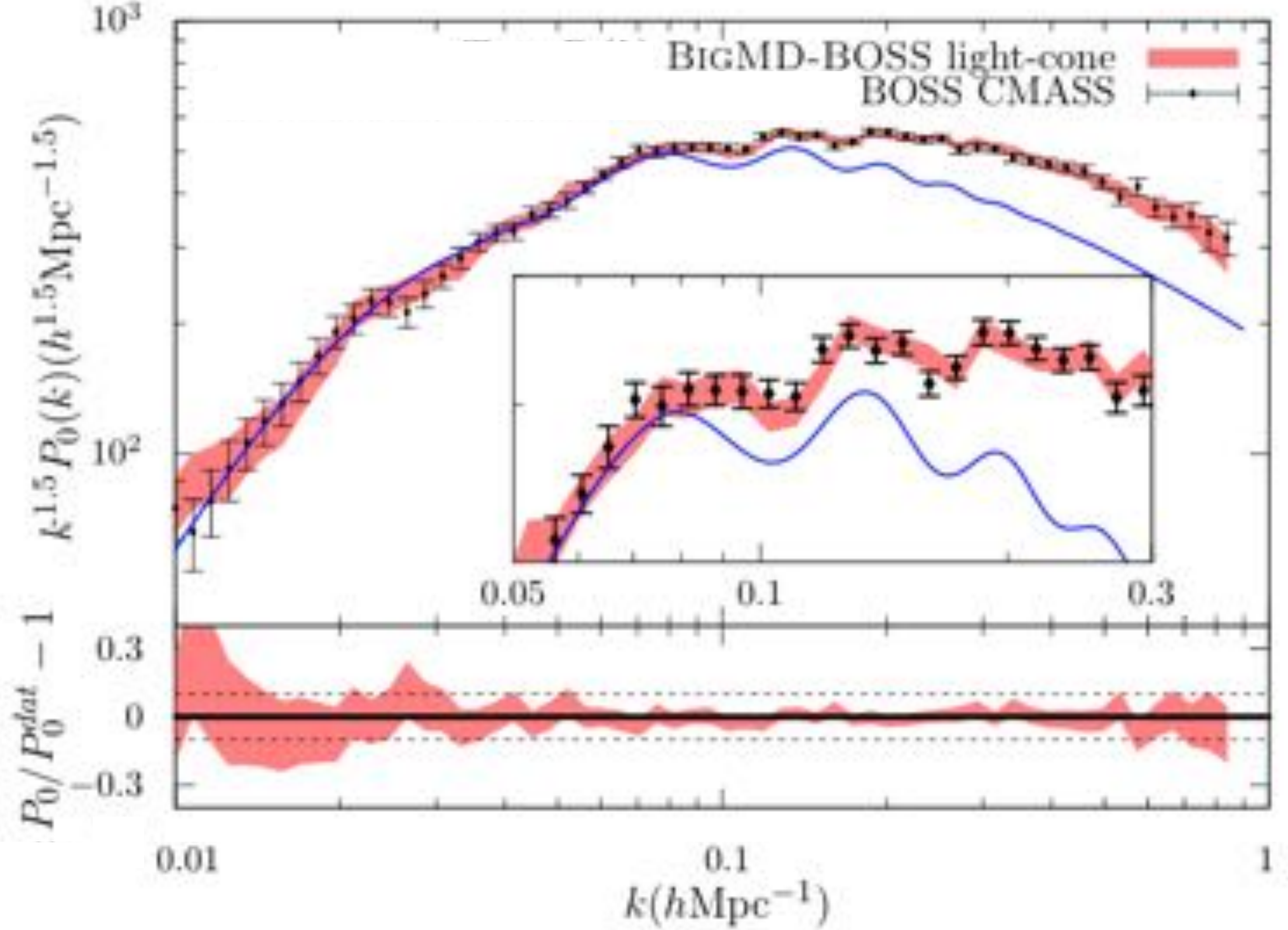
BAO damping as a function of bias



Remarks

- The new suite of BigMD simulations is being uploaded in the MultiDark Database: *www.multidark.org*
- BigMD is designed to study LSS and BAO systematics
- BAO shift & damping scale, and their evolution with redshift, has been studied both for dark matter and different halo number densities
- Level of BAO systematics in halos and dark matter tracers seems different, and about the same level than observational statistical errors from the new planned surveys such as DESI, Euclid, 4MOST …
- It remains to be understood the impact of this study on the BAO modelling and reconstruction

Is there a HOPE for discovering NEW Physics in the Euclid Era?



Rodríguez-Torres et al. 2015

Figure 11. Monopole of power spectrum from the BIGMD-BOSS light-cone and the CMASS DR12 sample. *Top Panel*: The true

Conclusions

- Future is BRIGHT!
- Need to be critical and motivated

Thank YOU!