MultiDark

Multimessenger Approach for Dark Matter Detection

Instituto de Física Teórica UAM-CSIC

Clustering and Bias in the Planck Cosmology

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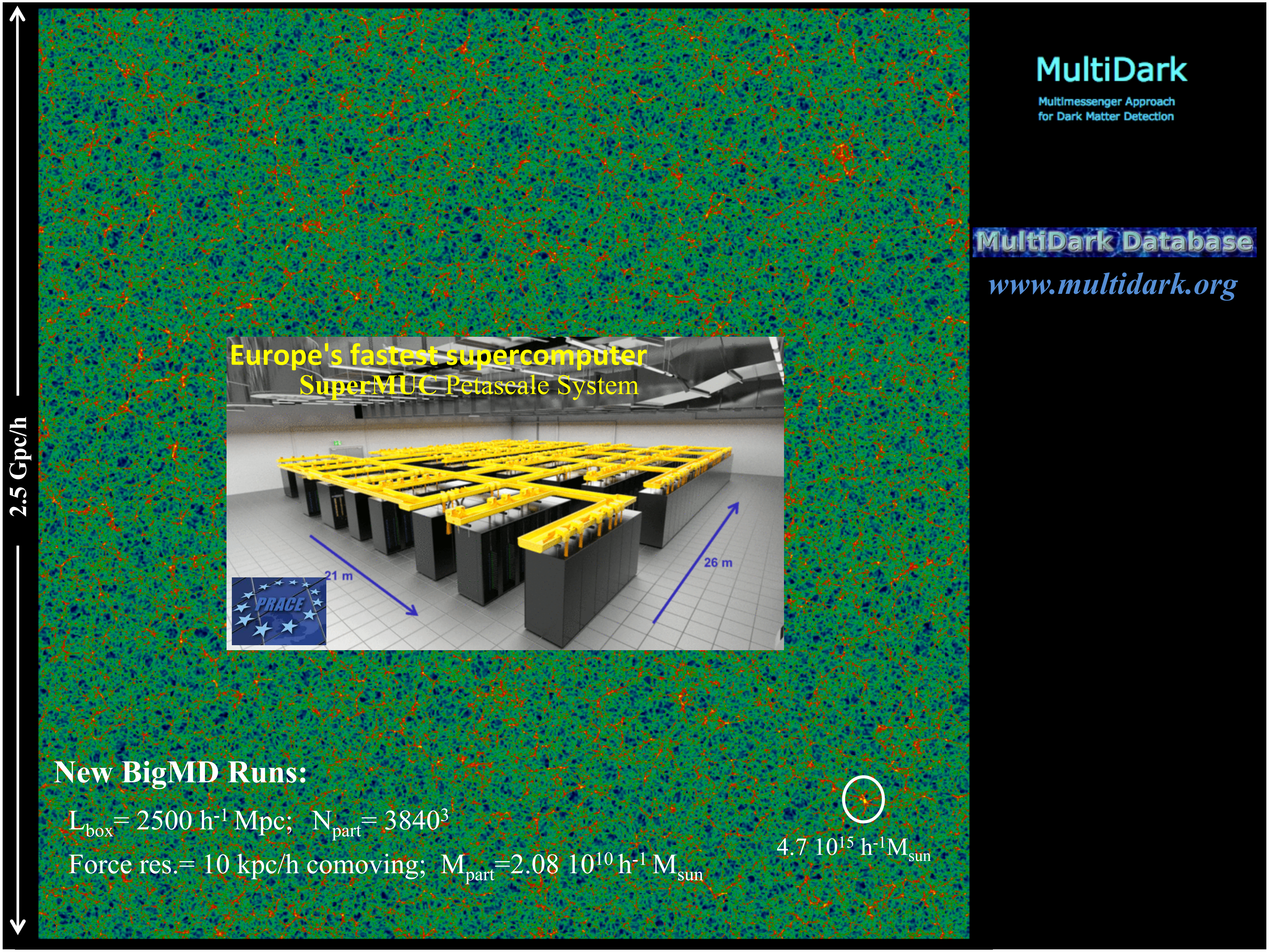
Durham, July 26th, 2013

Motivation

- Modeling non-linearity and galaxy bias to use BAO, RSDs, weak-lensing and the power spectrum broad-band shape at the 0.1-1% level.
- Using Halo Abundance Matching for accurate modeling of galaxy bias
- Providing clustering and bias model useful to compare with perturbation theory predictions to facilitate the massive production of mock galaxy catalogs.
- In particular, studying BAO systematics: shift and damping for biased tracers.



2.5 Gpc/h
Europe's fastest supercomputer
SuperMUC Petascale System
21 m
26 m
PRACE
New BigMD Runs:
L_{box}= 2500 h^{-1} Mpc; N_{part}= 3840^3
Force res.= 10 kpc/h comoving; M_{part}=2.08 10^{10} h^{-1} M_{sun}
4.7 10^{15} $h^{-1}M_{sun}$
MultiDark
Multimessenger Approach
for Dark Matter Detection
MultiDark Database
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The New Suite of MultiDark Simulations for Large Surveys

>> The BigMD Project <<

1.2 : Simulations

The MultiDark Database eventually contains data from different simulations, with a separate database for each simulation. Here, we provide the main parameters of the simulations for comparison. A click on the simulation name leads to the corresponding section of the Databases chapter, with a more detailed description of the simulation parameters and the database tables.

Simulation overview

Name	Cosmology	Ω_m	Ω_Λ	Ω_b	σ_8	n_s	Box [Mpc/h]	Particles	Mass range (min/max halo mass, $[M_{sun}/h]$)	Force resolution	Data in DB
Bolshoi [Query]	WMAP 5	0.27	0.73	0.047	0.82	0.95	250	2048^3	$2.7*10^{8} – 8*10^{14}$	1.0 kpc/h	BDM, FOF, Profiles, Particles, Density
MDR1 [Query] (MDark_2048_om0.27)	WMAP 5	0.27	0.73	0.047	0.82	0.95	1000	2048^3	$1.7*10^{11} – 1.6*10^{15}$	7.0 kpc/h	BDM, FOF, Profiles, Particles, Mtree, Substructure, Density
MDPL [in progress] (MD_3840_Planck1)	Planck 1	0.31	0.69	0.048	0.82	0.96	1000	3840^3	$3.0*10^{10} – 4.2*10^{15}$	13 kpc/h (for high z) – 5 kpc/h (low z)	BDM, FOF
BigMDPL [coming soon] (BigMD_3840_Planck1)	Planck 1	0.31	0.69	0.048	0.82	0.96	2500	3840^3	$4.7*10^{11} – 6*10^{15}$	30 kpc/h (high z) – 10 kpc/h (low-z)	[nothing yet]
BigMDPLnw [coming soon] (BigMD_3840_Planck1_NW, no baryonic wiggles)	Planck 1	0.31	0.69	0.048	0.82	0.96	2500	3840^3	$4.7*10^{11} – 6*10^{15}$	30 kpc/h (high z) – 10 kpc/h (low-z)	[nothing yet]
BigMD27 [coming soon] (BigMD_3840_om0.27)	WMAP 5	0.27	0.73	0.047	0.82	0.95	2500	3840^3	$4.2*10^{11} – 5.5*10^{15}$	30 kpc/h (high z) – 10 kpc/h (low-z)	[nothing yet]
BigMD29 [coming soon] (BigMD_3840_om0.29)	–	0.29	0.71	0.047	0.82	0.95	2500	3840^3	$4.4*10^{11} – 5.6*10^{15}$	30 kpc/h (high z) – 10 kpc/h (low-z)	[nothing yet]
BigMD31 [coming soon] (BigMD_3840_om0.31)	–	0.31	0.69	0.047	0.82	0.95	2500	3840^3	$4.1*10^{11} – 5.8*10^{15}$	30 kpc/h (high z) – 10 kpc/h (low-z)	[nothing yet]

MultiDark Database

MultiDark
Multimessenger Approach for Dark Matter Detection

German Astrophysical GAVO Virtual Observatory

AIP

PRACE

www.multidark.org

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MultiDark Database

- Home
- Query Form
- Credits
- Very useful queries
- Codes
- Documentation

Databases
- Bolshoi
- MDR1
- miniMDR1
- Sp3D

Private (MyDB) Databases
- fprada_db (rw) (context)

Logout

MultiDark
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GAVO

Query the MultiDark Database

4.11.2011 - Bolshoi Halo profiles now available for all snapshots. For an overview, consult the status page.

Welcome Francisco Prada! Logout

Place your SQL statement directly in the text area below and submit your request by pressing one of the 'Query' buttons.
Please note, that there is a timeout and row limit for each query:
Streaming queries: return unlimited number of rows in CSV format. They are cancelled after 1400 seconds.
Browser queries: return a maximum of 1000 rows in HTML format. They are cancelled after 30 seconds.

```
with massive_halo as (
  select top 1 x,y,z from miniMDR1..FOF where snapnum=85 order by np desc
)
select f.* from massive_halo mh, miniMDR1..FOF f
where f.snapnum = 85
 and  f.x between (mh.x - 2) and (mh.x + 2)
 and  f.y between (mh.y - 2) and (mh.y + 2)
 and  f.z between (mh.z - 2) and (mh.z + 2)
```

Query (stream) Query (browser) Maximum number of rows to return: 30

Help Clear Text

Previous queries

Show all previous queries for current user (max. 1000) with additional information in a new window:

Advanced query history

>> The BigMD Project <<

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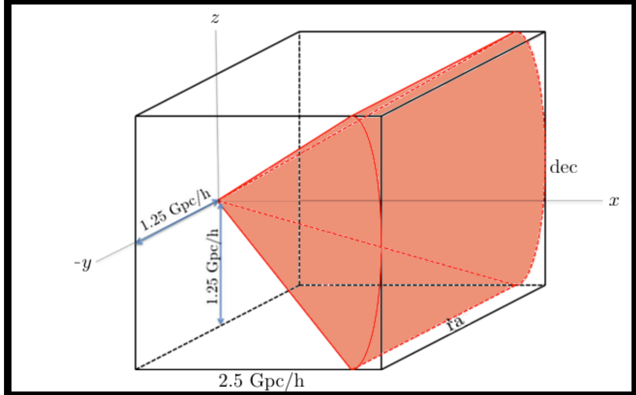
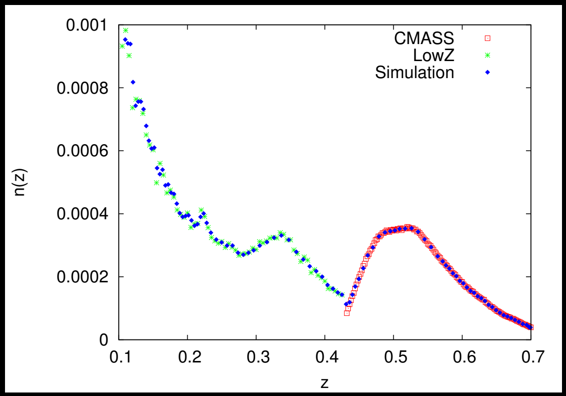
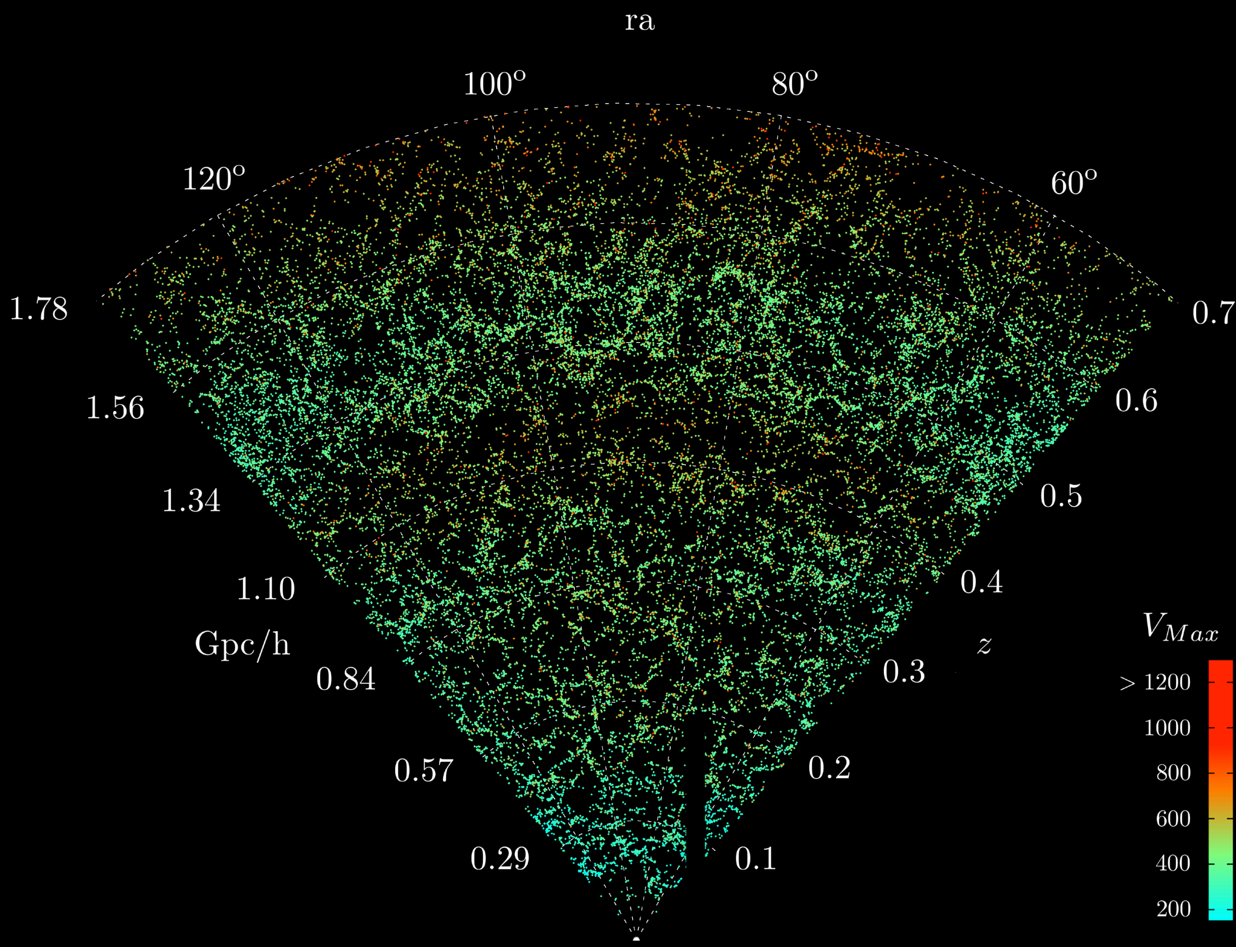
Products:

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







>> The BigMD Project <<

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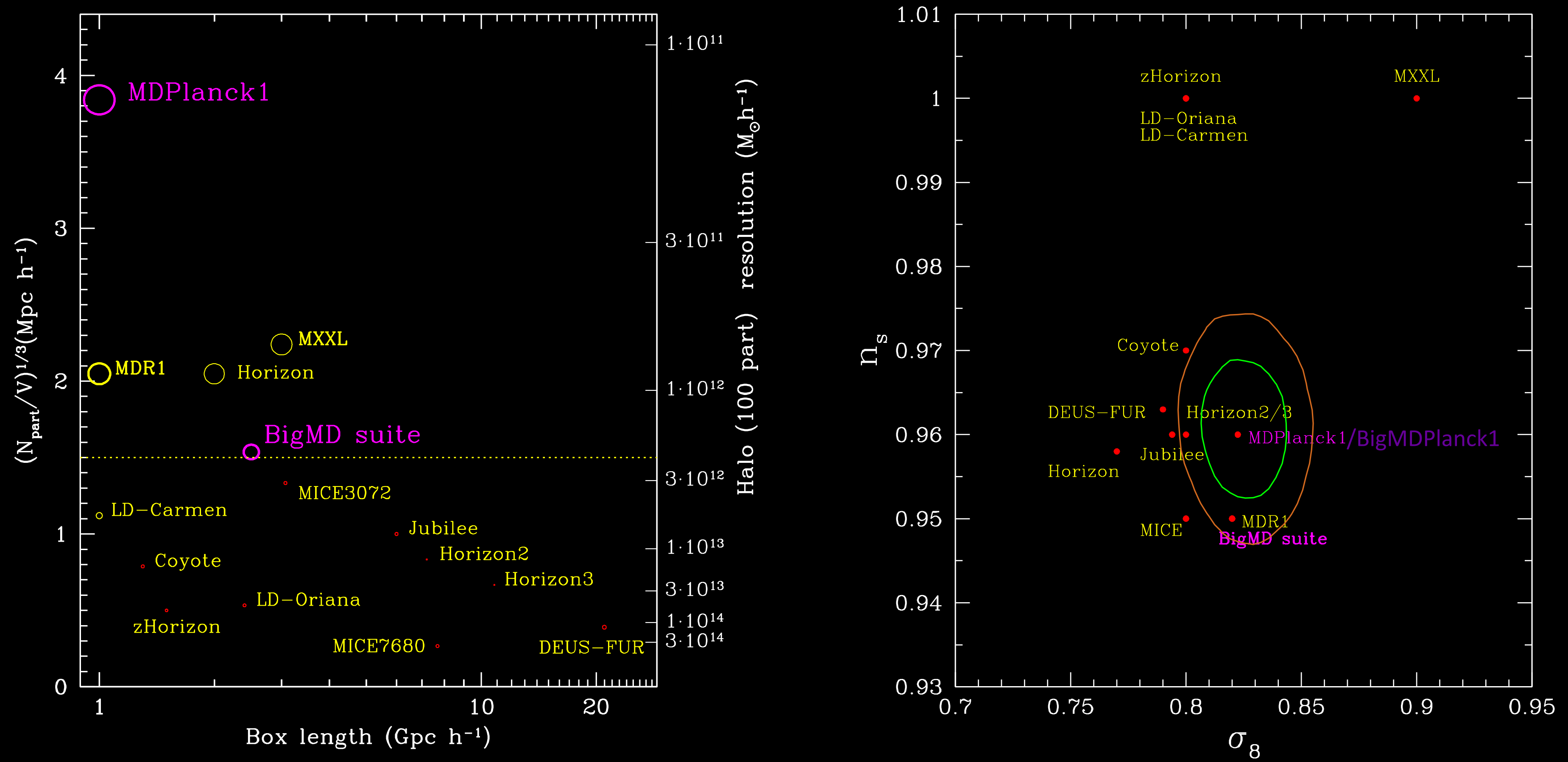
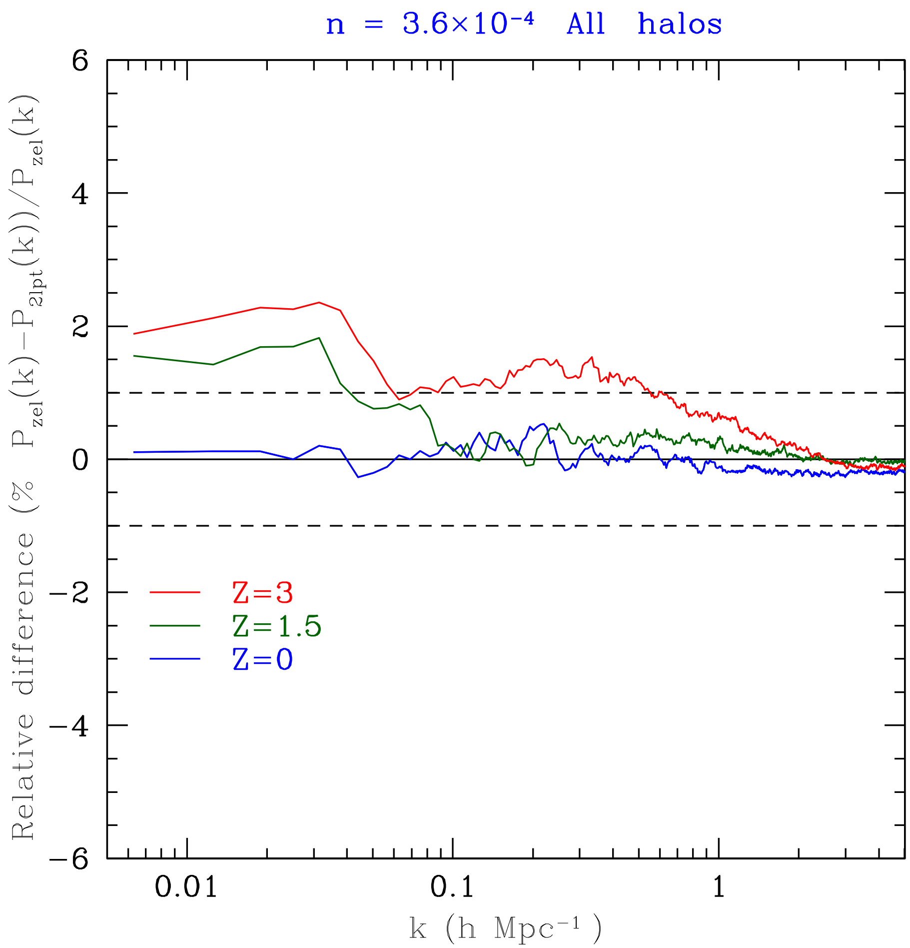
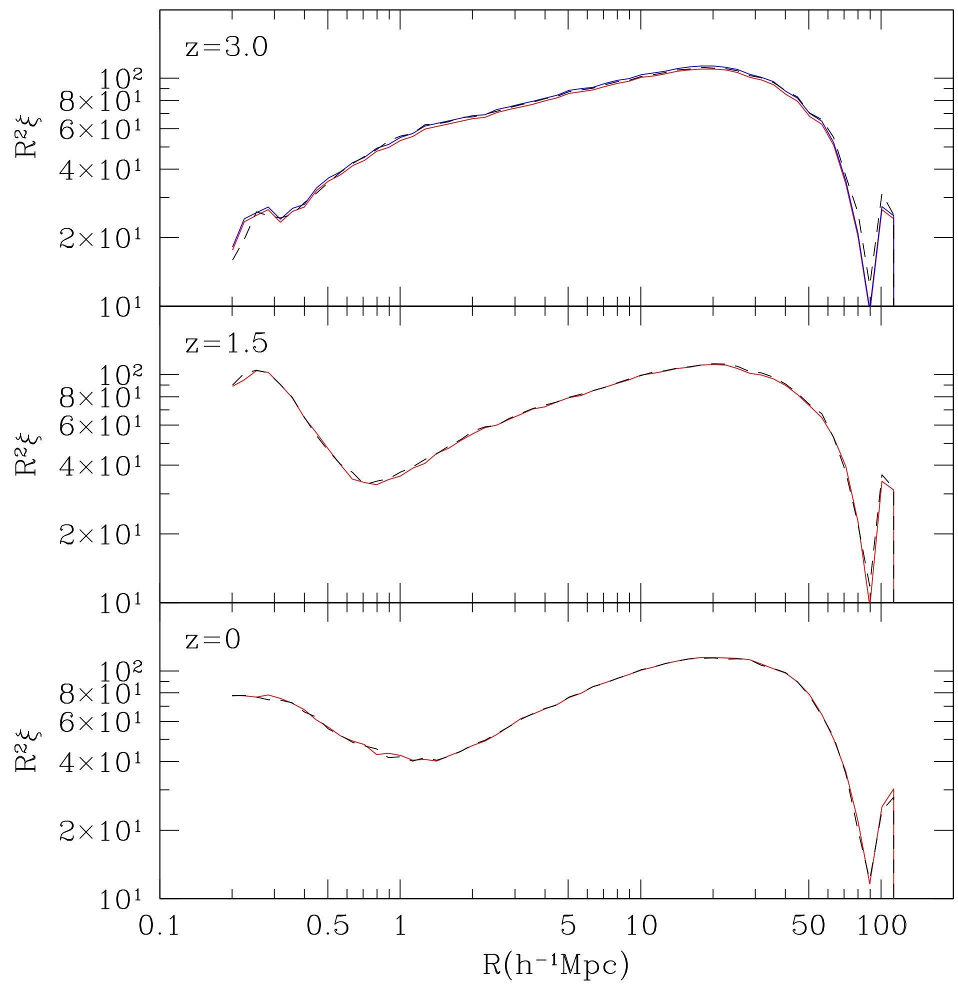


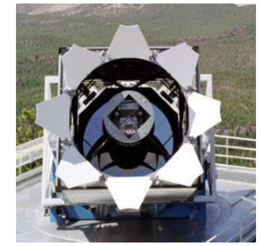
Simulation and Cosmological parameters of our MultiDark boxes in comparison with other large simulations run by different groups. The size of the circles shown in the left panel corresponds to the inverse of the force resolution adopted for each simulation. The contour levels in the right panel correspond to the 68% and 95% CL from Planck.

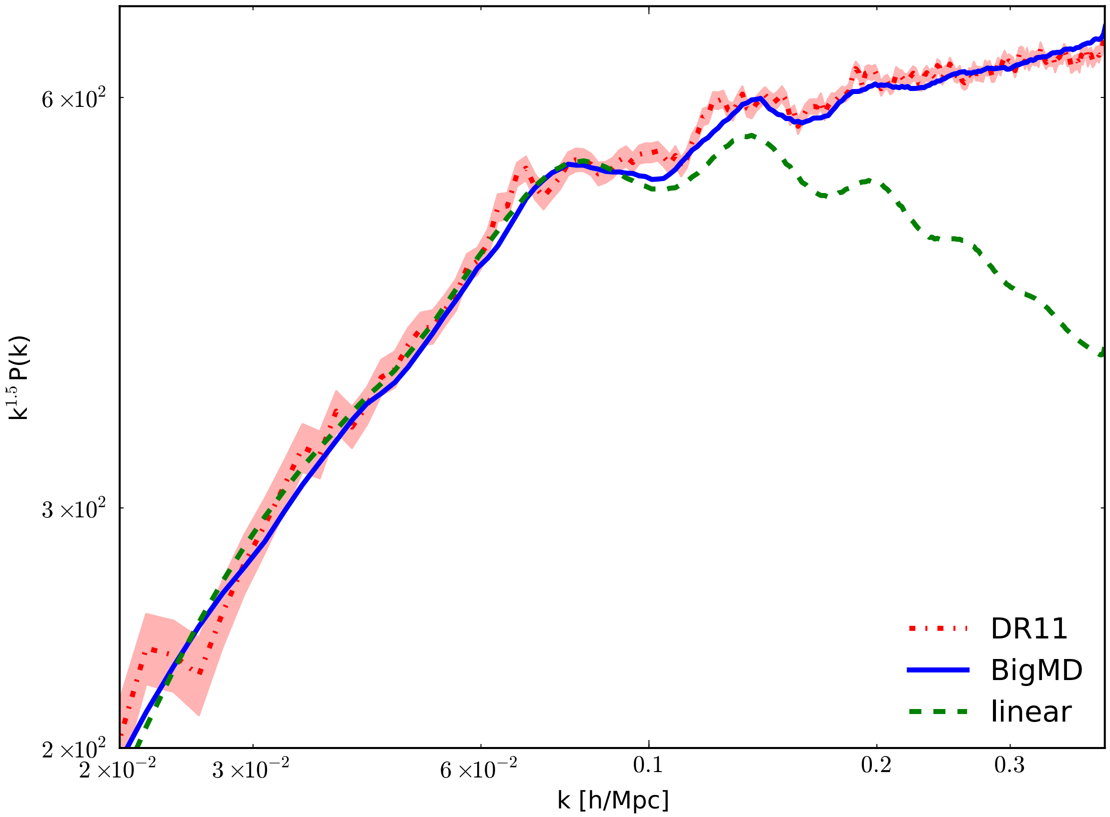
Zeldovich vs. 2LPT Initial Conditions



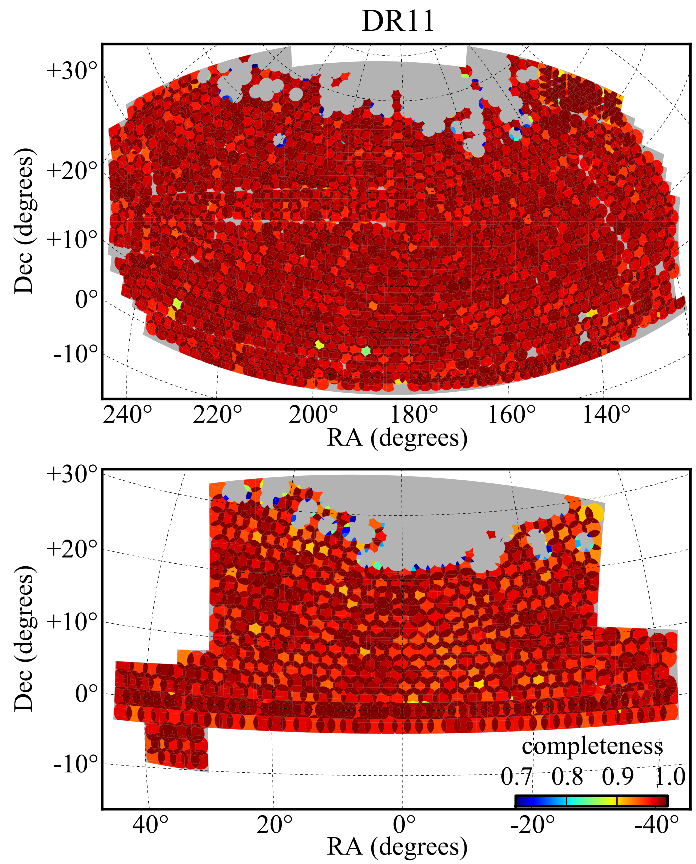


Large-scale Galaxy Clustering and Bias
BAO systematics study





BOSS-CMASS galaxy power spectrum compared to BigMD-SHAM prediction for n=3e-4 at z=0.57 (*courtesy of Francesco Montesano*)



BOSS-CMASS DR11:
North: 520,806
South: 170,407
total: 691,213

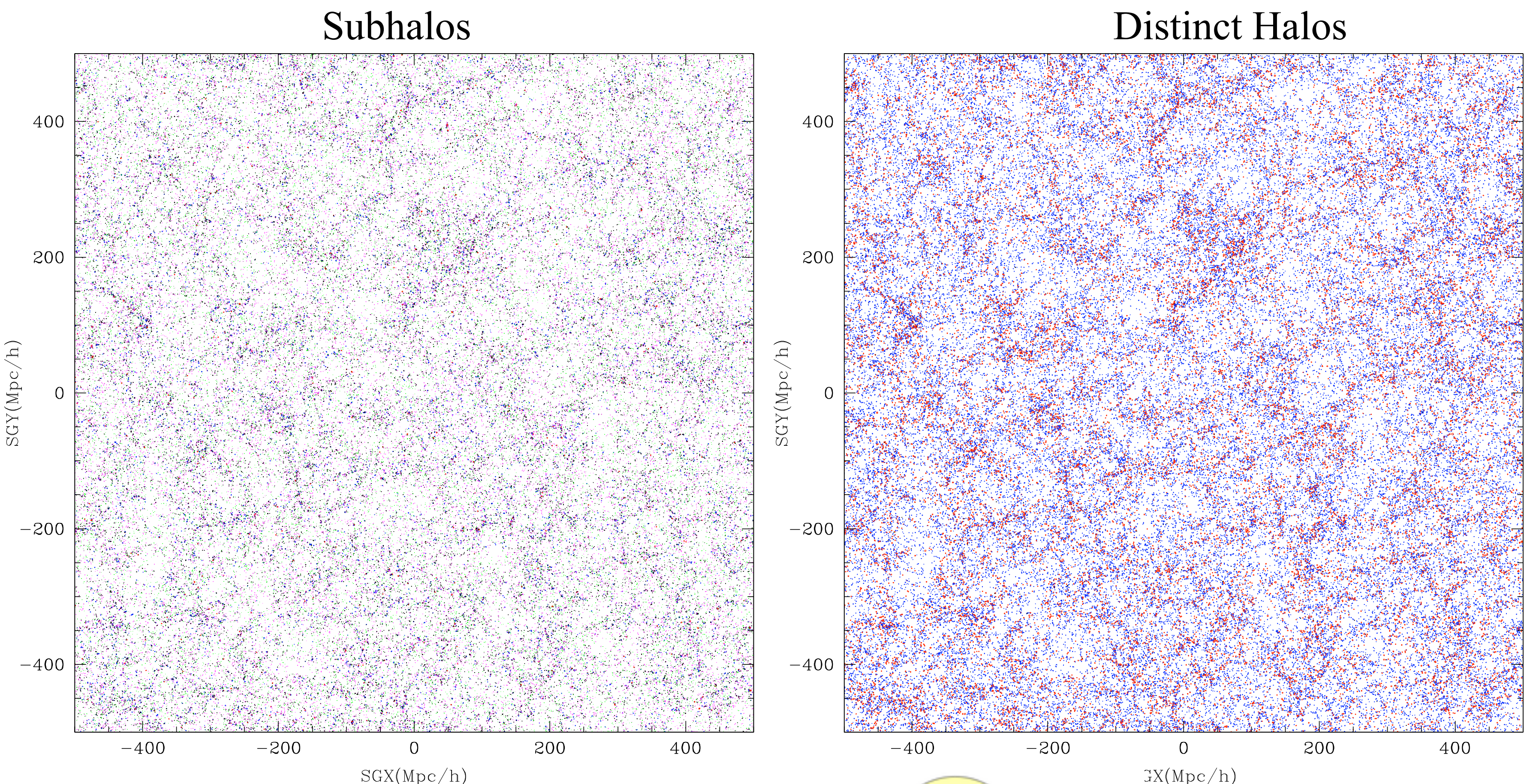
Modeling CMASS clustering

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

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

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

Dark Matter Halos in the MultiDark simulations



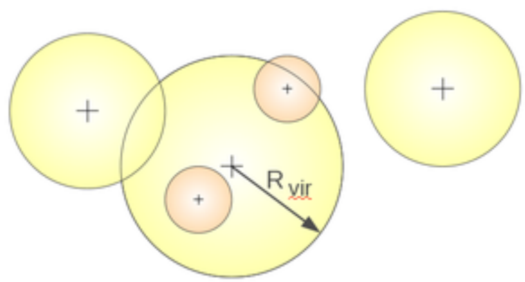
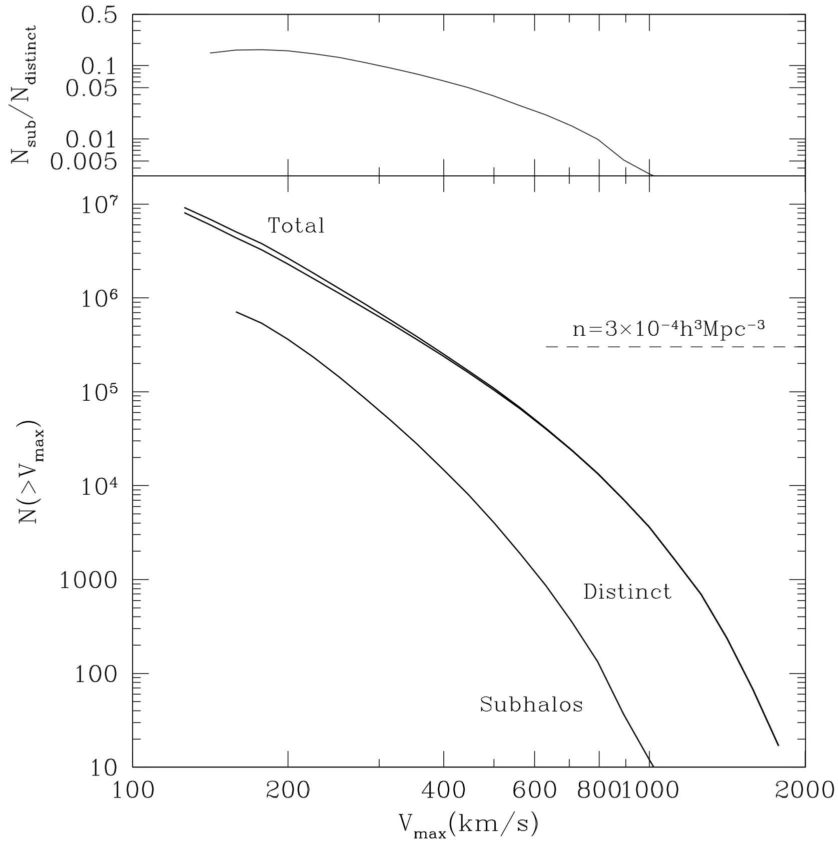


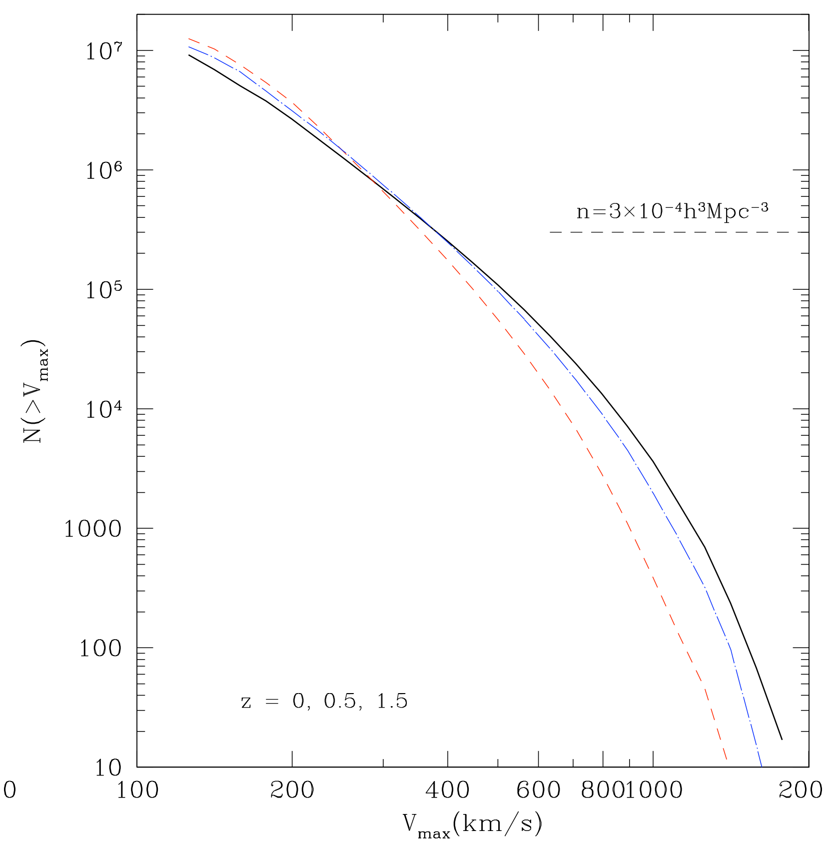
Figure 1: Distinct BDM halos (yellow) and subhalos (orange): The centers of distinct halos do not lie within the virial radius (R_{vir}) of a larger halo, in contrast to subhalos. This still allows that halos and subhalos overlap.

Velocity functions for Subhalos and Distinct Halos

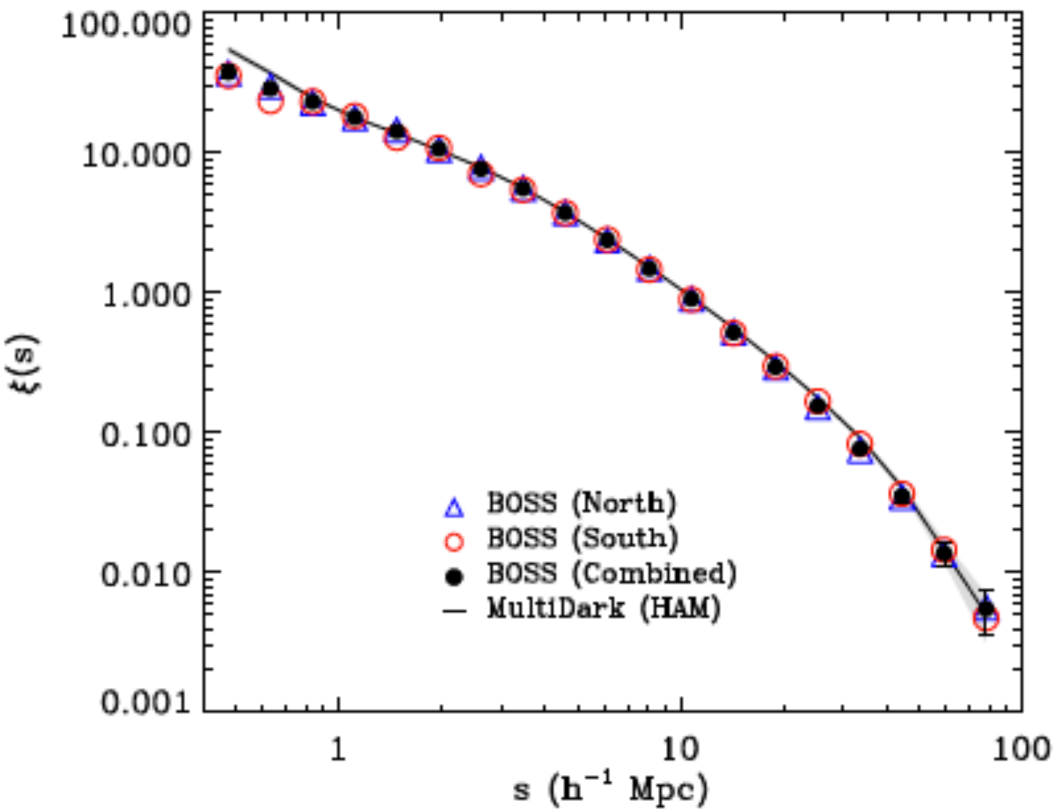
MultiDark @ z=0



Evolution



V^2_{max}=max[GM(<r)/r] is the maximum of the halo circular velocity profile



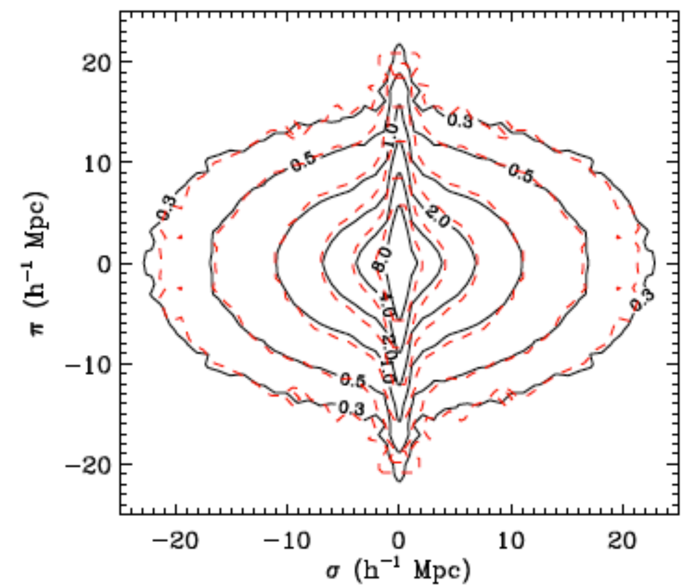


Figure 5. Contours of the two-dimensional correlation function $\xi(\sigma, \pi)$ estimated from the DR9 BOSS-CMASS north galaxy sample (dashed contours) at $0.4 < z < 0.7$ and for our MultiDark halo catalogue constructed using the HAM technique at $z = 0.53$ (solid contours).

Nuza et al. 2013

The effect of small-scale clustering on the large-scale tail of the power spectrum

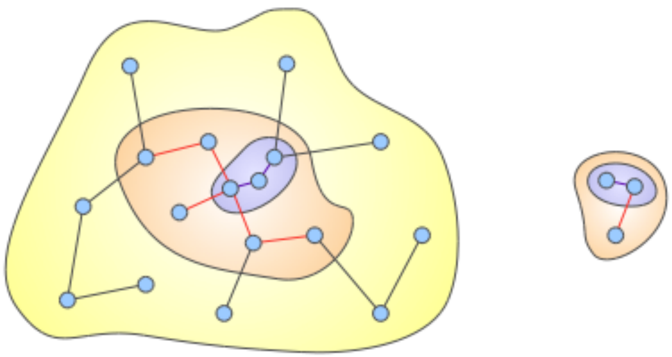
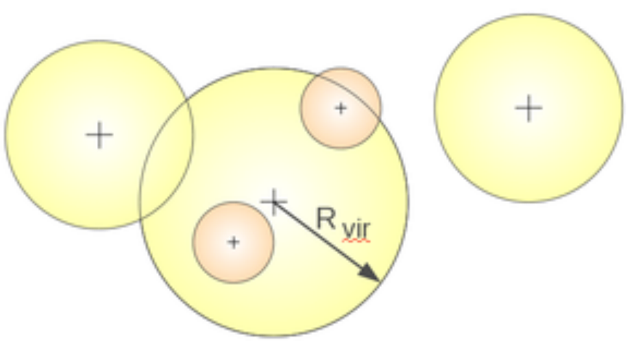


Figure 2: FOF groups with different linking lengths (yellow, orange, violet): substructures are defined as FOF groups which have a smaller linking length and lie inside a larger host halo. By definition, they always lie completely within their host.



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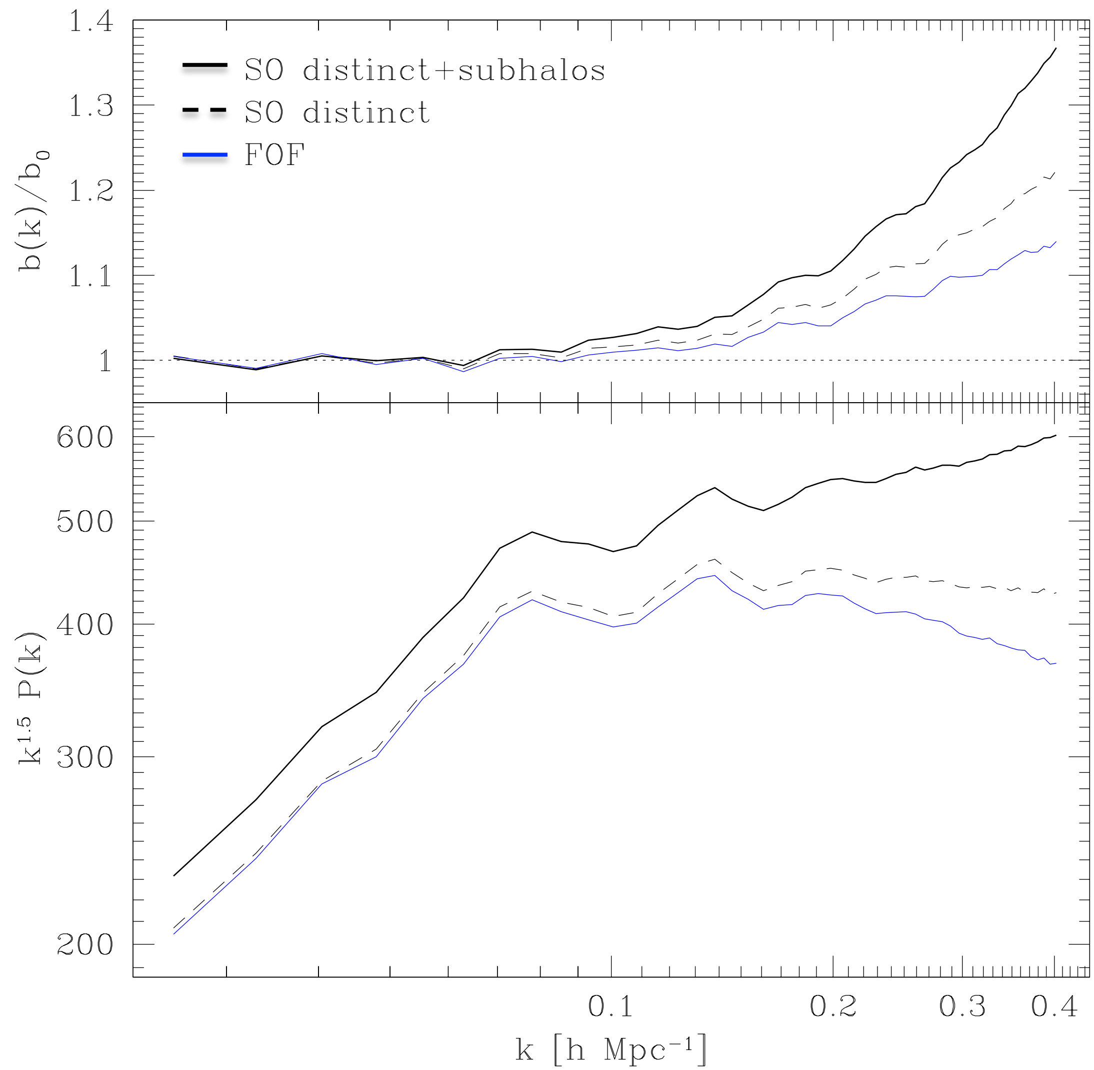


The power spectrum and bias of SO and FOF (sub)halos with $3.5\ 10^{-4}$ number density taken from BigMultiDark Planck1 box

The effect of small-scale clustering on the large-scale tail of the power spectrum

After all, why clustering at large scales should be affected by inclusion of subhalos at much smaller scales? However, there are two effects:

- The first one, is rather simple. There are more subhalos of given mass (or circular velocity) in each massive distinct halo as compared with less massive halo. When subhalos are included, larger halos give proportionally larger contribution to the estimate of the power spectrum. Because larger halos are more biased, the power spectrum and the correlation function are larger on all scales. In practice, this effect results in almost scale-independent bias.

- The second effect is more subtle. There is a change – a boost due to subhalos – in the power spectrum even when there is no change in the large-scale correlation function. This happens because the power spectrum and the correlation function are connected through an integral relation. This effect results in a scale-dependent bias and its effect gets progressively small for small wavenumbers k.

The effect of small-scale clustering on the large-scale tail of the power spectrum

We can compare our theory estimates with the results for the observed power spectrum of BOSS CMASS sample. For BAO oscillations at $k < 0.2\ h\ \mathrm{Mpc}^{-1}$ the effect of subhalos is quite small, but potentially measurable. For example, at $k = 0.2\ h\ \mathrm{Mpc}^{-1}$, we have estimated $P=370\ h^{-3}\ \mathrm{Mpc}^3$ from the 1-halo term of the correlation function. Measured power is $P \approx 5000\ h^{-3}\ \mathrm{Mpc}^3$. Thus, subhalos contribute about 10% to the clustering signal. Yet, this change both the amplitude and the shape of the spectrum, and, thus, they substantially affect the shape and the value of the bias.

$$\xi(r) = \begin{cases} \left(\frac{r}{r_0}\right)^{-\alpha} & \text{if } r < r_{1h} \\ 0 & \text{otherwise.} \end{cases} \qquad (2)$$

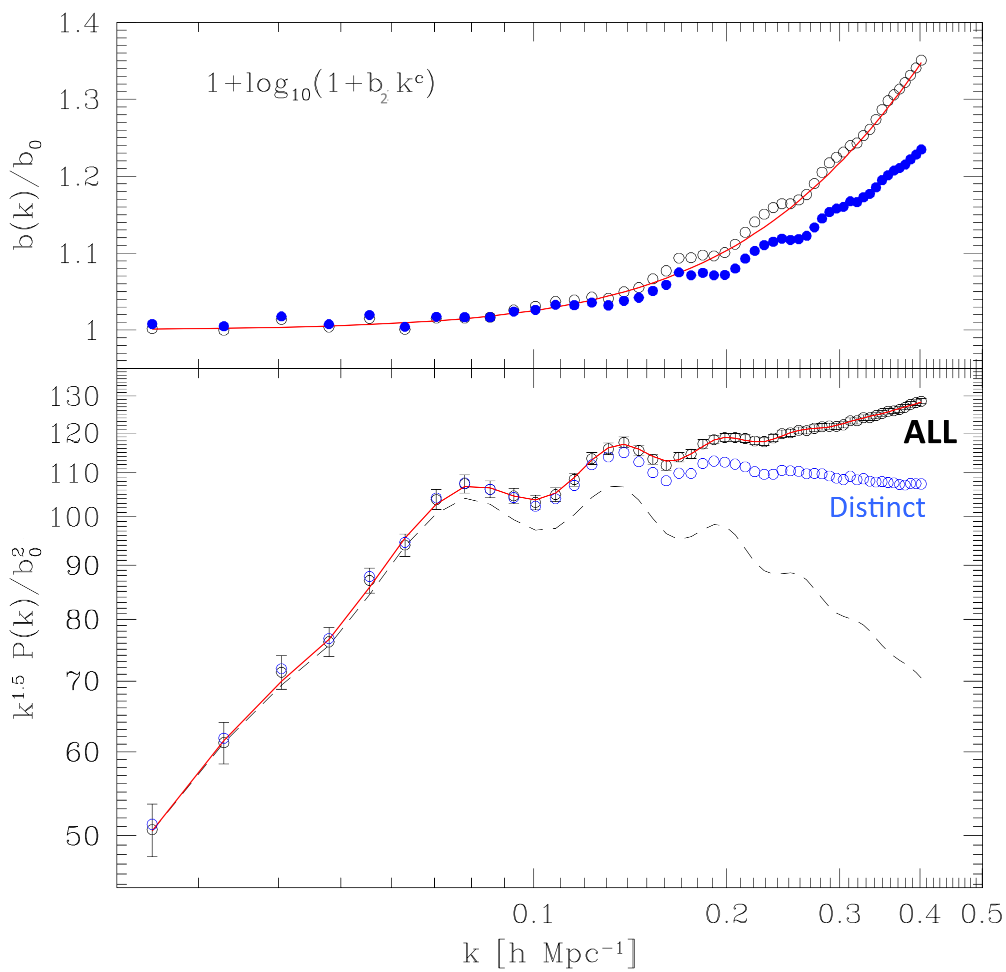
It is convenient to re-write this in the following form:

$$P(k) = 4\pi r_{1h}^3 \left(\frac{r_{1h}}{r_0}\right)^{-\alpha} (kr_{1h})^{-(3-\alpha)} \int_0^{kr_{1h}} x^{1-\alpha} dx \sin(x). \qquad (3)$$

For $\alpha < 3$ and $kr_{1h} \ll 1$ we can use the Taylor expansion:

$$P(k) \approx \frac{4\pi}{(3-\alpha)} r_{1h}^3 \left(\frac{r_{1h}}{r_0}\right)^{-\alpha} \left(1 - \frac{(3-\alpha)(kr_{1h})^2}{(5-\alpha)3!} + \frac{(3-\alpha)(kr_{1h})^4}{(7-\alpha)5!} + \dots\right) \qquad (4)$$

Modeling halo clustering and bias



First, we adopt the cold dark matter model and the simplest inflation model (adiabatic initial condition). Thus, we can compute the linear matter power spectra, $P_{lin}(k)$, by using CAMB (Code for Anisotropies in the Microwave Background, Lewis, Challinor, & Lasenby 2000). The linear power spectrum can be decomposed into two parts:

$$P_{lin}(k) = P_{nw}(k) + P_{BAO}^{lin}(k), \quad (2)$$

where $P_{nw}(k)$ is the "no-wiggle" or pure CDM power spectrum calculated using Eq.(29) from Eisenstein & Hu (1998). $P_{BAO}^{lin}(k)$ is the wiggled part defined by the equation itself. The nonlinear damping effect of the "wiggled" part, in redshift space, can be well approximated following Eisenstein, Seo, & White (2007) by

$$P_{BAO}^{nl}(k,\mu_k) = P_{BAO}^{lin}(k)\cdot\exp\left(-\frac{k^2}{2k_\star^2}[1+\mu_k^2(2f+f^2)]\right), \quad (3)$$

where μ_k is the cosine of the angle between **k** and the LOS, f is the growth rate, and $k_\star$ is computed following Crocce & Scoccimarro (2006); Matsubara (2008) by

$$k_\star = \left[\frac{1}{3\pi^2}\int P_{lin}(k)dk\right]^{-1/2}. \quad (4)$$

The dewiggled power spectrum is

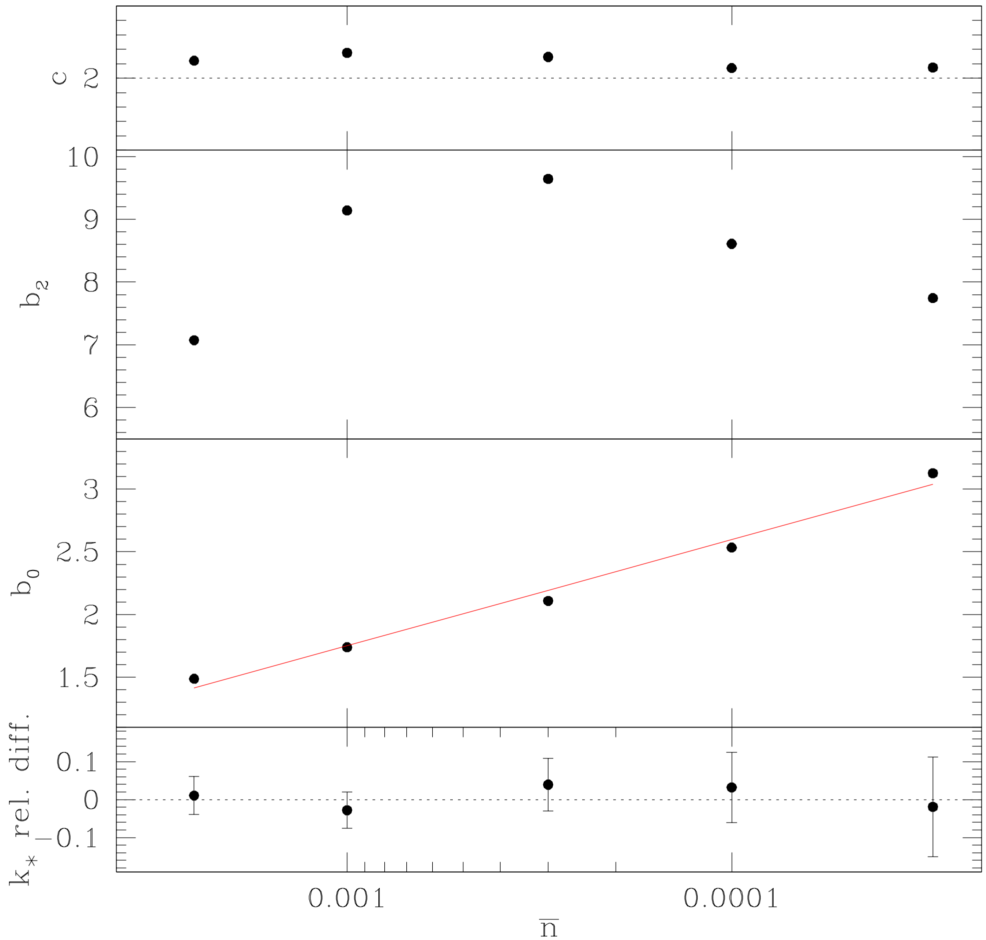
$$P_{dw}(k,\mu_k) = P_{nw}(k) + P_{BAO}^{nl}(k,\mu_k). \quad (5)$$

Scale-dependent bias
$b^2(k)=P(k)/P_{lin}(k)$

Large-scale halo power spectrum model:

$$P(k) = \left(\mathrm{PEH}[k] + (\mathrm{Pklineal}[k] - \mathrm{PEH}[k]) * e^{-k^2/(2.*k_s^2)}\right) * b_0^2 * (1 + \mathrm{Log10}[1 + b_2 * k^c])^2$$

BAO damping & scale-dependent bias as a function of halo number density

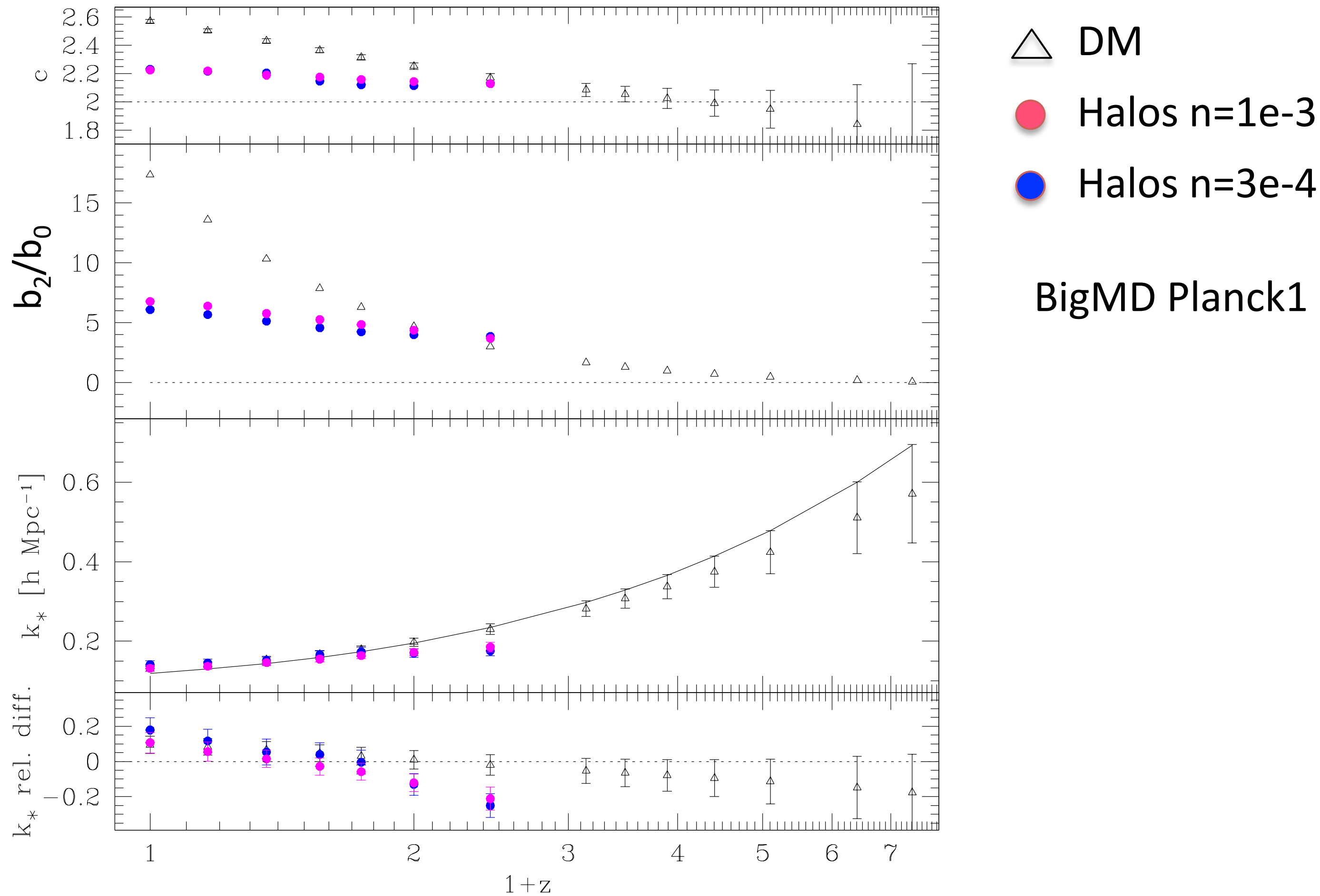


z=0.57
BigMD Planck1

Large-scale halo power spectrum model 0.02 < k < 0.4:

$$P(k, n) = \left(\mathrm{PEH}[k] + (\mathrm{Pklineal}[k] - \mathrm{PEH}[k]) * e^{-k^2/(2.*k_s^2)}\right) \underbrace{* b_0^2 * \left(1 + \mathrm{Log10}[1 + b_2 * k^c]\right)^2}_{b^2(k,\, n)}$$

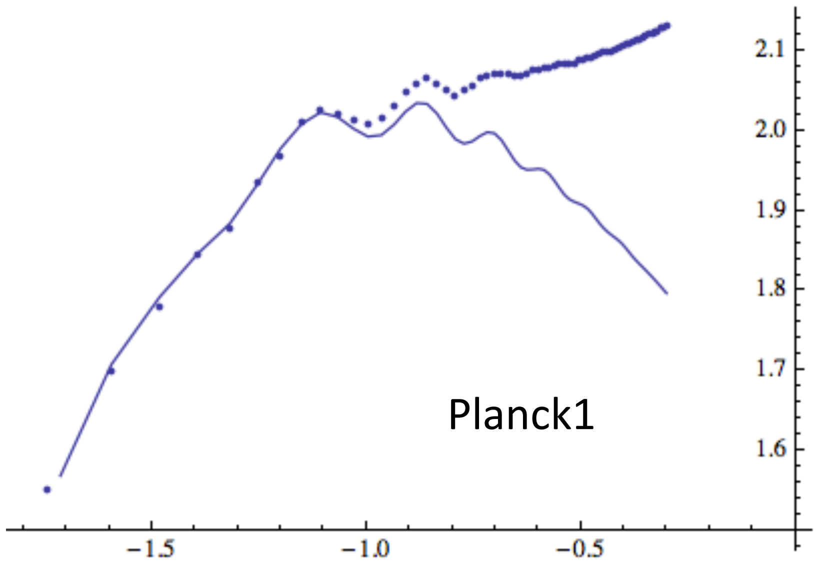
BAO damping & scale-dependent bias as a function of redshift

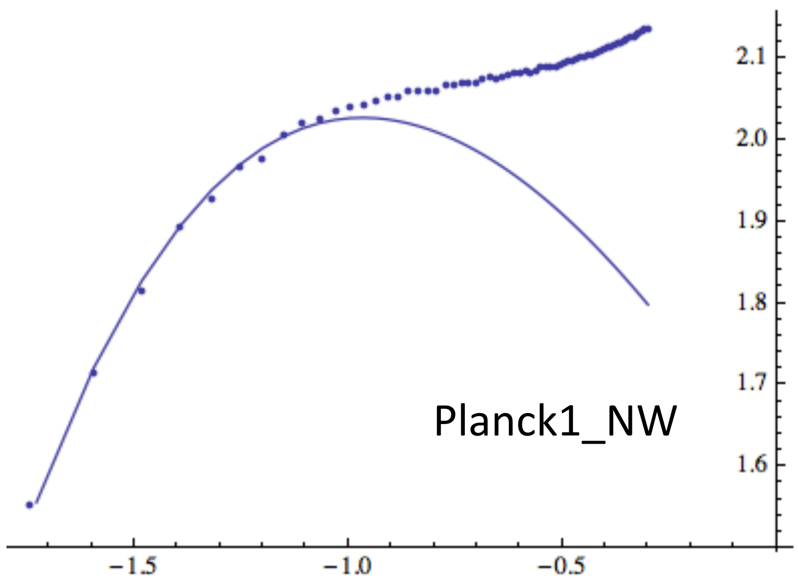


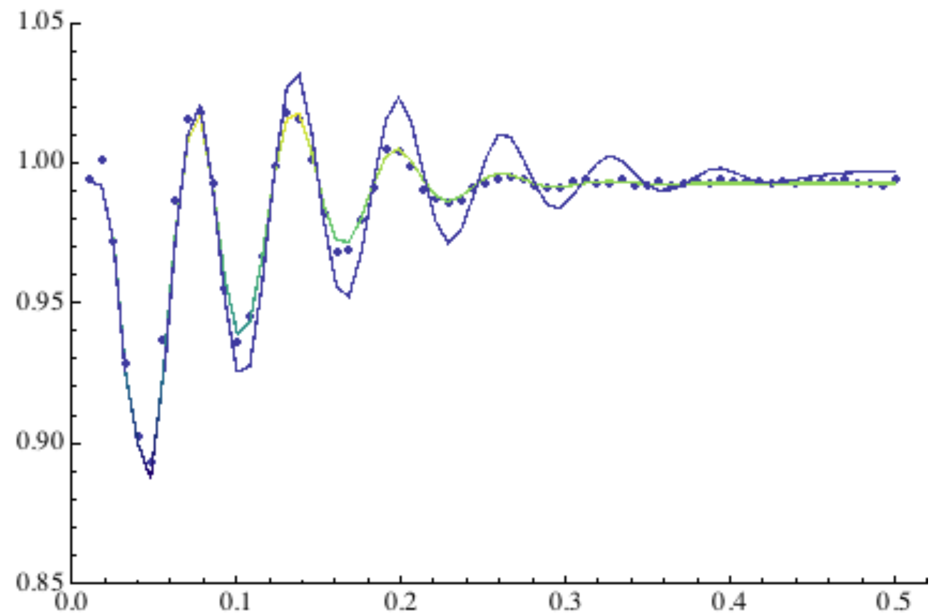
Large-scale halo power spectrum model 0.02 < k < 0.4:

$$P(k, n) = \left(\mathrm{PEH}[k] + (\mathrm{Pklineal}[k] - \mathrm{PEH}[k]) * e^{-k^2/(2.*k_s^2)}\right) \underbrace{* b_0^2 * \left(1 + \mathrm{Log10}[1 + b_2 * k^c]\right)^2}_{b^2(k,\,n)}$$

$P(k)/P_{nw}(k)$ for halos in BigMD Planck1



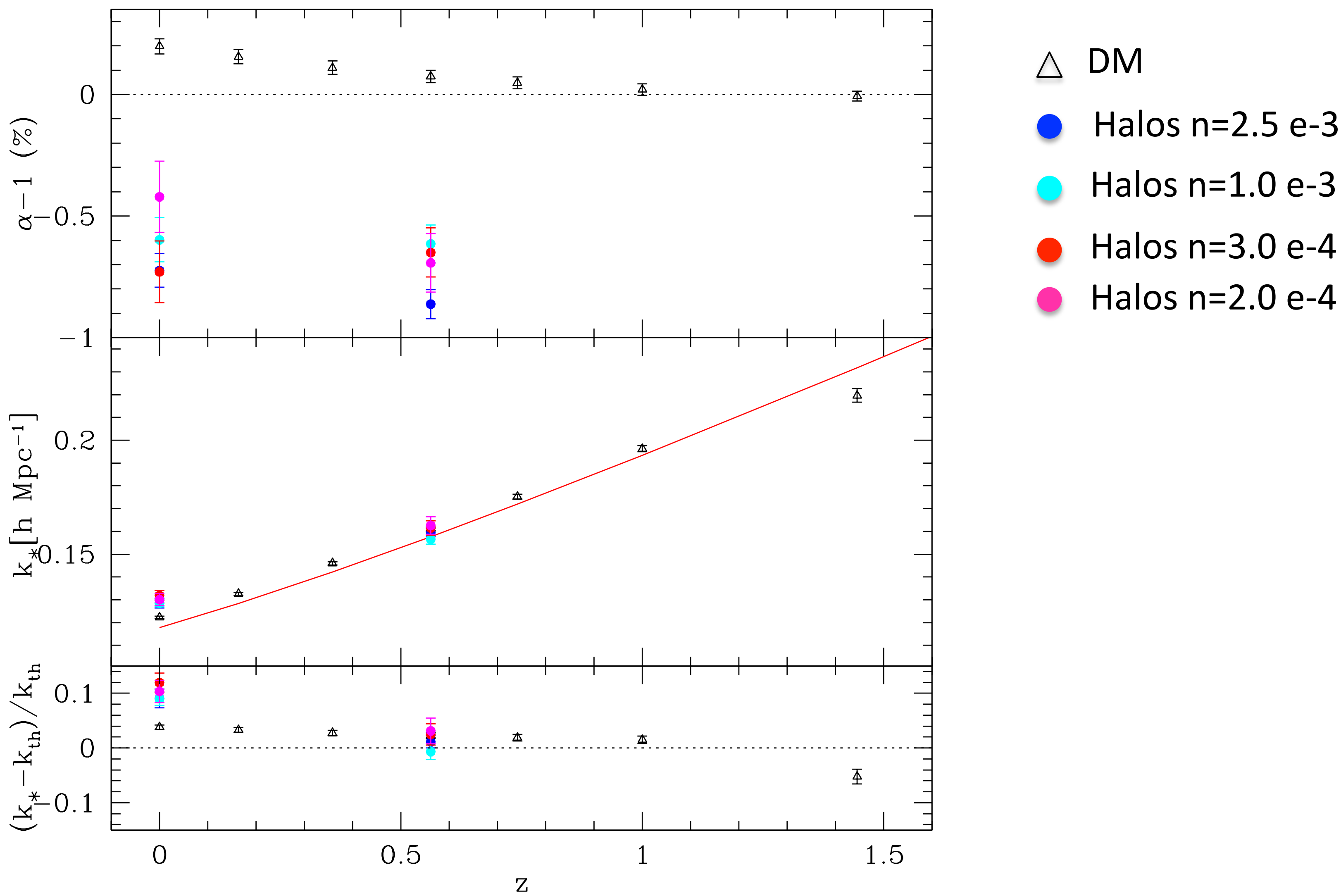




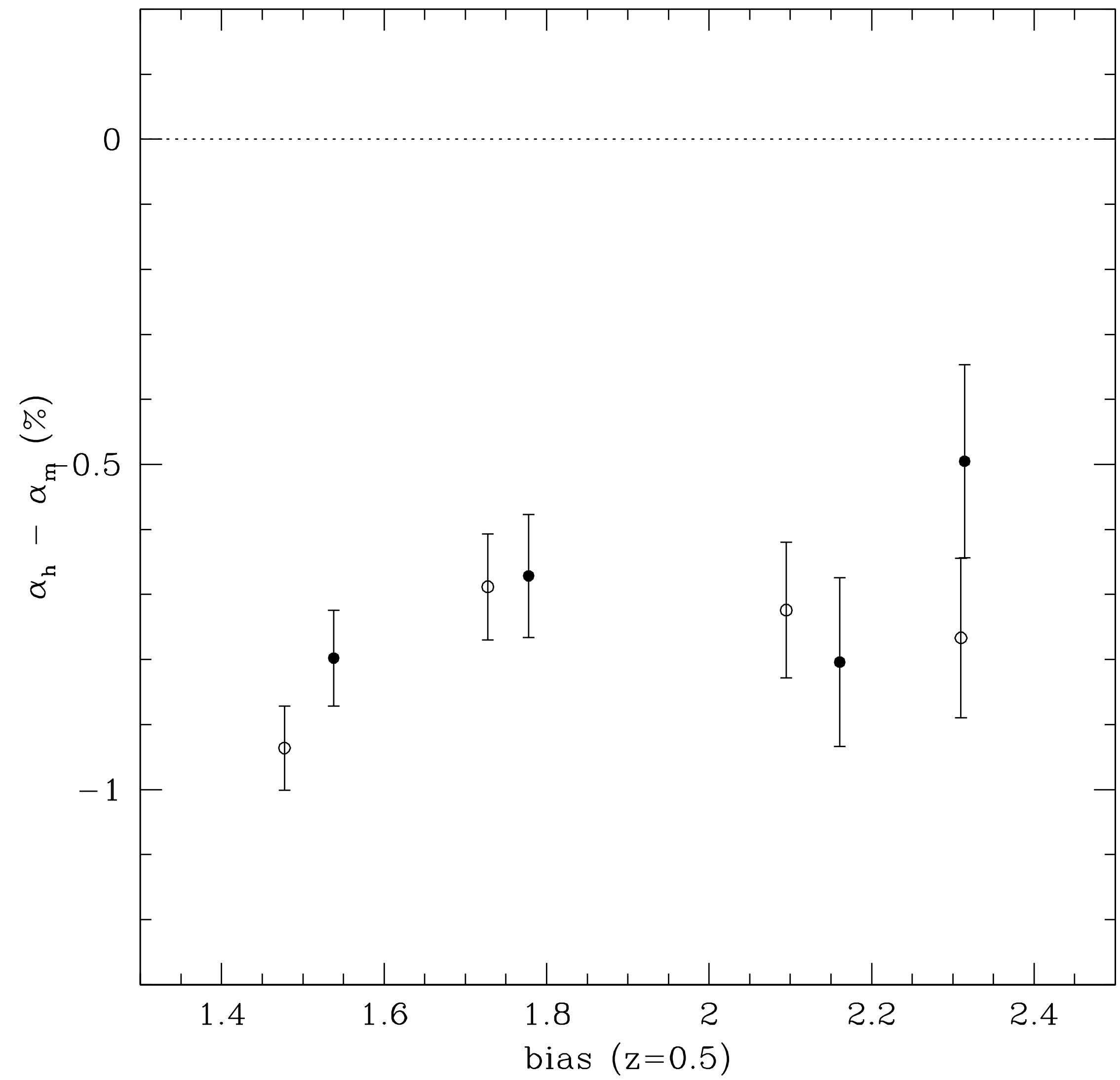
Very accurate measurement of BAO shift & k_* damping

$$\mathbf{Pk} / \mathbf{PkNW} = \left(\left(\left(\mathbf{Pklineal}[k/\alpha] / \mathbf{PklinealNW}[k/\alpha] \right) - 1. \right) * e^{-(k/\alpha)^2 / \left(2. * (ks/\alpha)^2\right)} \right) + 1.$$

BAO shift & k_* damping in the Planck Cosmology



BAO shift as a function of bias in the Planck Cosmology



Modeling Baryon Acoustic Oscillations with Perturbation Theory and Stochastic Halo Biasing

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15 July 2013

ABSTRACT

In this work we investigate the generation of mock halo catalogs based on perturbation theory and nonlinear stochastic biasing with the novel PATCHY-code. In particular, we use Augmented Lagrangian Perturbation Theory (ALPT) to generate a dark matter density field on a mesh starting from Gaussian fluctuations. ALPT is based on a combination of second order LPT (2LPT) on large scales and the spherical collapse model on smaller scales. We account for the systematic deviation of perturbative approaches from N-body simulations together with halo biasing adopting an exponential bias. We then account for stochastic biasing by defining three regimes: a low, an intermediate and a high density regime, using a Poisson distribution in the intermediate regime and the negative binomial distribution including an additional parameter to model over-dispersion in the high density regime. Since we focus in this study on massive halos, we suppress the generation of halos in the low density regime. The various nonlinear biasing parameters, stochastic biasing parameter and density thresholds are calibrated with the large BigMultiDark N-body simulation to match the power spectrum of the corresponding halo population. Our model effectively includes only 4 parameters, as they are additionally constrained by the number density. Our mock catalogues show power spectra which are compatible with N-body simulations within about 2% up to $k \sim 1\,h$ Mpc^{-1} at redshift $z = 0.577$ for a sample of halos with the typical BOSS CMASS galaxy number density. The corresponding correlation functions are compatible down to a few Mpc. We also find that neglecting over-dispersion in high density regions produces power spectra with deviations of 10% at $k \sim 0.4\,h$ Mpc^{-1}. These results indicate the need to account for an accurate statistical description of the galaxy clustering for precise studies of large-scale surveys.

Key words: (cosmology:) large-scale structure of Universe – galaxies: clusters: general – catalogues – galaxies: statistics

PATCHY vs. BigMultiDark

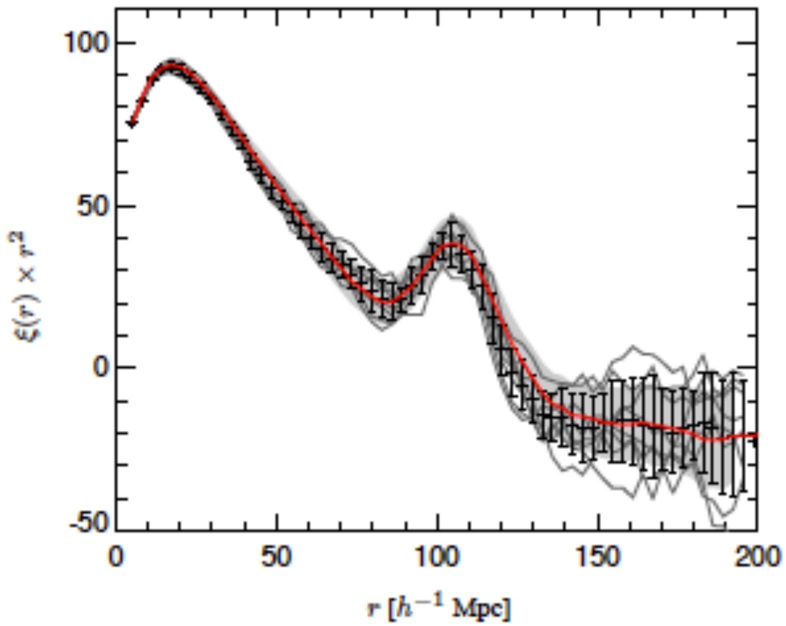


Figure 4. Correlation functions of the PATCHY simulations vs the BigMultiDark N-body simulations. The red line corresponds to the mean of 50 PATCHY realization with the corresponding 1-sigma region in grey. Black crosses: mean over 8 sub-volumes of the BigMultiDark simulation. The error bars indicate 1-sigma regions for the N-body case. Each of the 8 sub-volumes from the N-body simulation is represented by a dashed line.

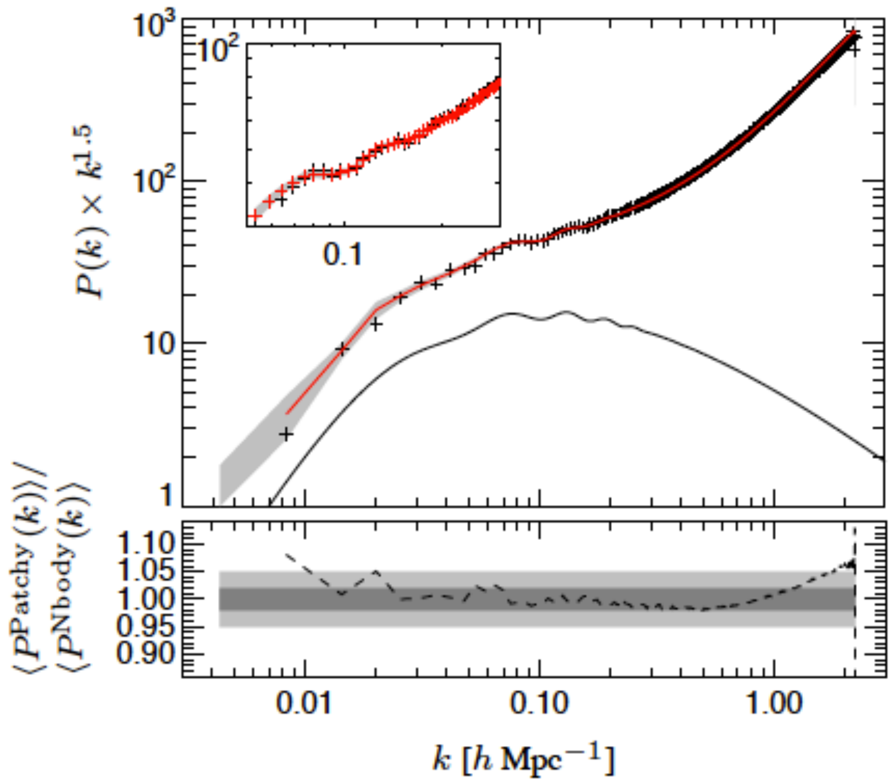


Figure 3. Power spectra obtained with PATCHY vs. BigMultiDark at $z = 0.577$ for a halo sample with number density 3.6×10^{-4} Mpc^{-3} h^3. The red line corresponds to the mean of 50 PATCHY realizations with the corresponding 1-sigma region in grey. The linear power spectrum is also shown (solid black line) as well as the mean over 8 sub-volumes of the BigMultiDark simulation.

Conclusions

- 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
- Clustering at large-scales should be affected by inclusion of subhalos at much smaller scales. This change both the amplitude and the shape of the spectrum, and, thus, they substantially affect the shape and the value of the bias.
- Scale-dependent bias at BAO scales $k<0.4$ can be modeled by simple function, i.e. $b(k)=b_0\ (1+\log_{10}[1+b_2\,k^{2.15}]$
- BAO damping scale k_* and its evolution has been studied both for dark matter and different halo number densities and compared to perturbation theory prediction using *PATCHY*
- It remains to be understood the impact of this study on the BAO modeling and reconstruction

SO vs. FOF halo clustering

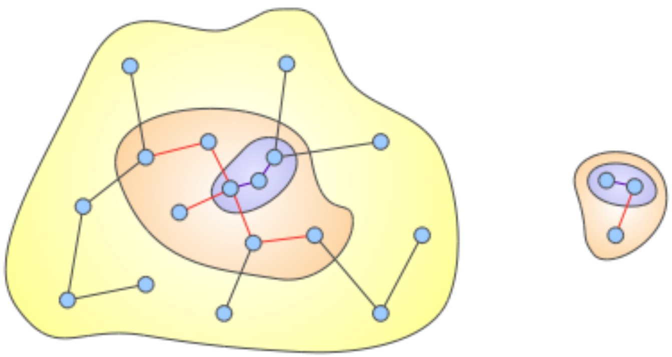


Figure 2: FOF groups with different linking lengths (yellow, orange, violet): substructures are defined as FOF groups which have a smaller linking length and lie inside a larger host halo. By definition, they always lie completely within their host.

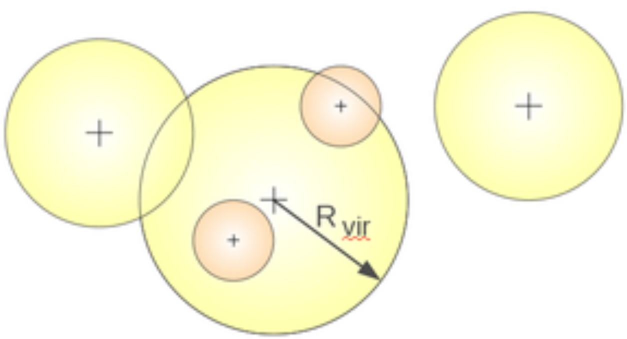
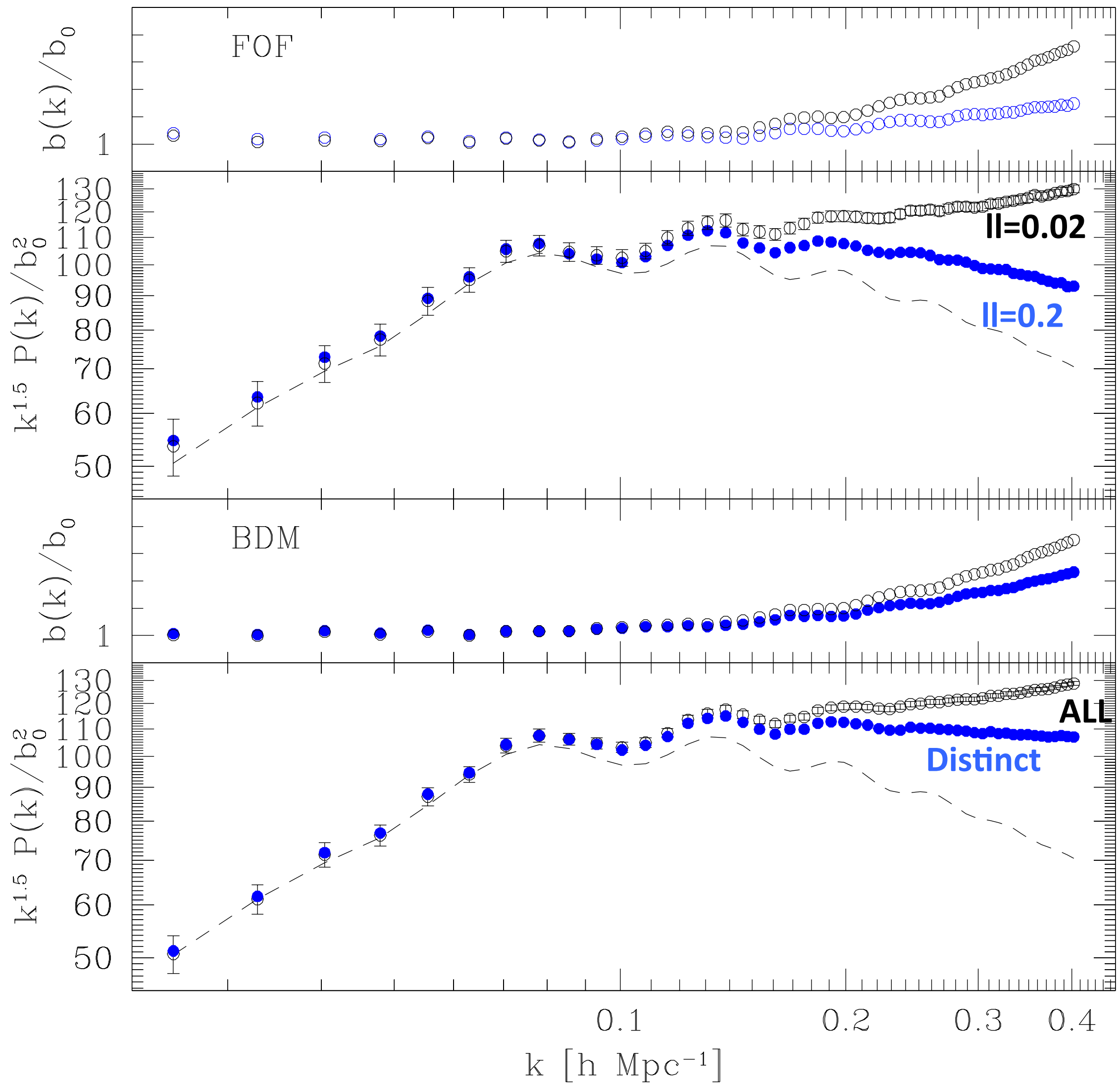


Figure 1: Distinct BDM halos (yellow) and subhalos (orange): The centers of distinct halos do not lie within the virial radius (R_{vir}) of a larger halo, in contrast to subhalos. This still allows that halos and subhalos overlap.



The power spectrum and bias of BDM and FOF (sub)halos with Number den3.5 10^{-4} taken from the BigMultiDark Planck1 box