Large-scale cosmological N-body simulations

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New requirements and new simulations

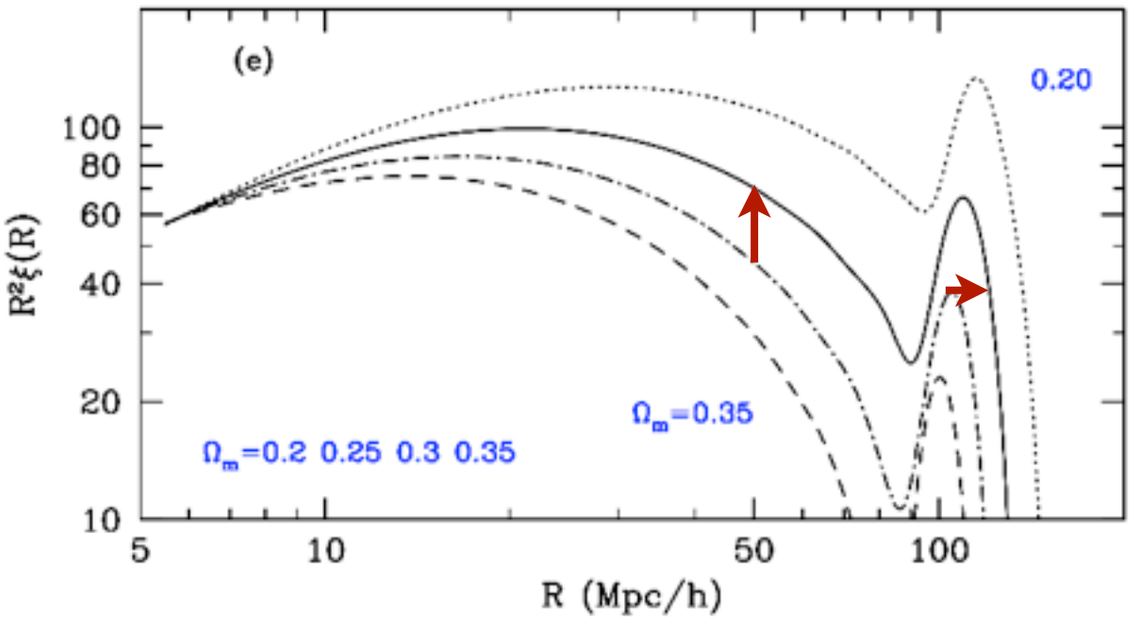
- The field of large-scale simulation is driven by ever increasing need for very accurate theoretical predictions.

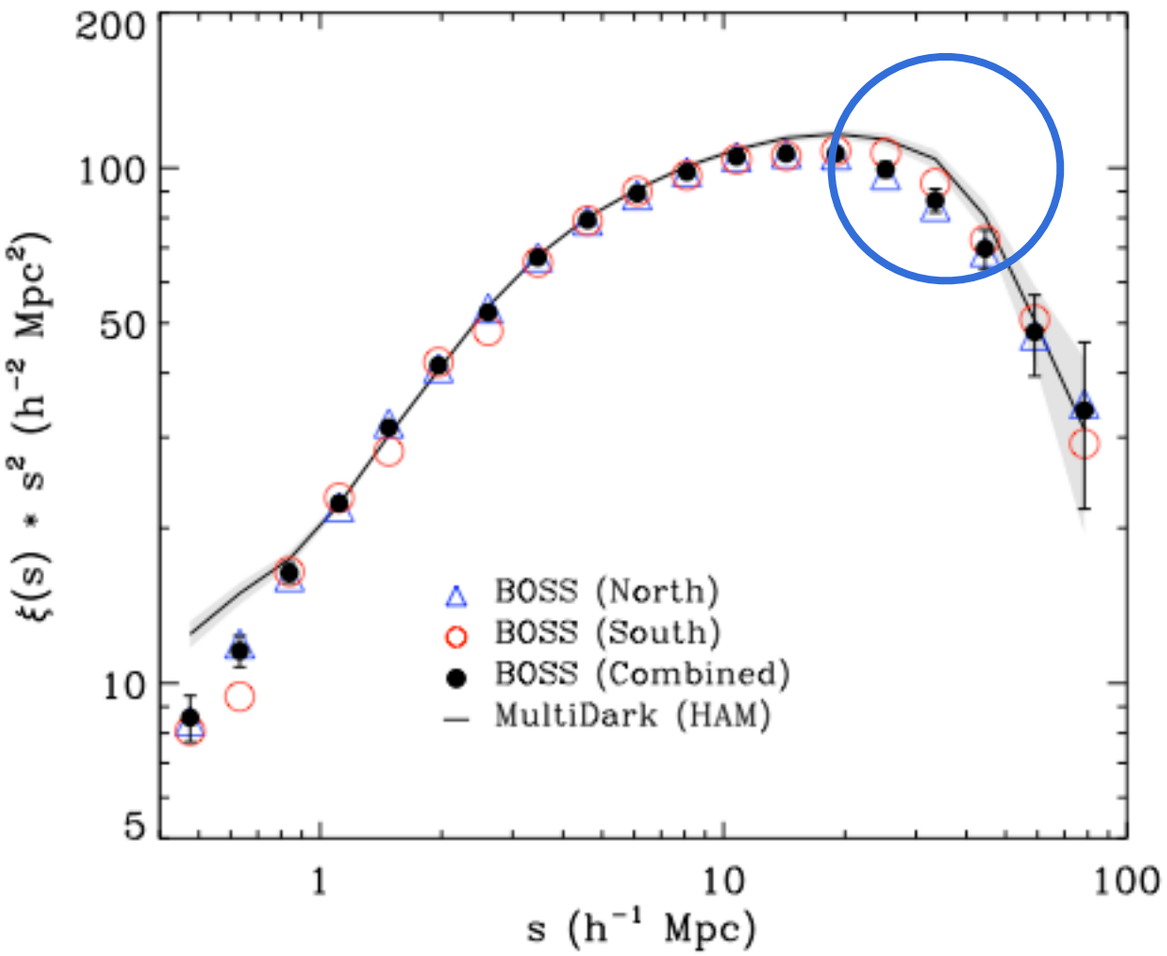
- For surveys such as BOSS, DES, LSST, Euclid we need to predict clustering properties and lensing for many millions of galaxies in large cosmological volumes. Requirements at present: one percent for accuracy of power spectrum and correlation function of galaxies from 100 kpc to 100 Mpc. The same accuracy for weak lensing signal on 100 kpc - 20 Mpc scales.

- Connecting dark matter with galaxies: Halo Abundance Matching and Halo Occupation Distribution

More accurate predictions: more physics

- High resolution and accuracy means more physics and fewer assumptions
- 15% difference in correlation function at 50Mpc is equivalent of changing Om from 0.27 to 0.3

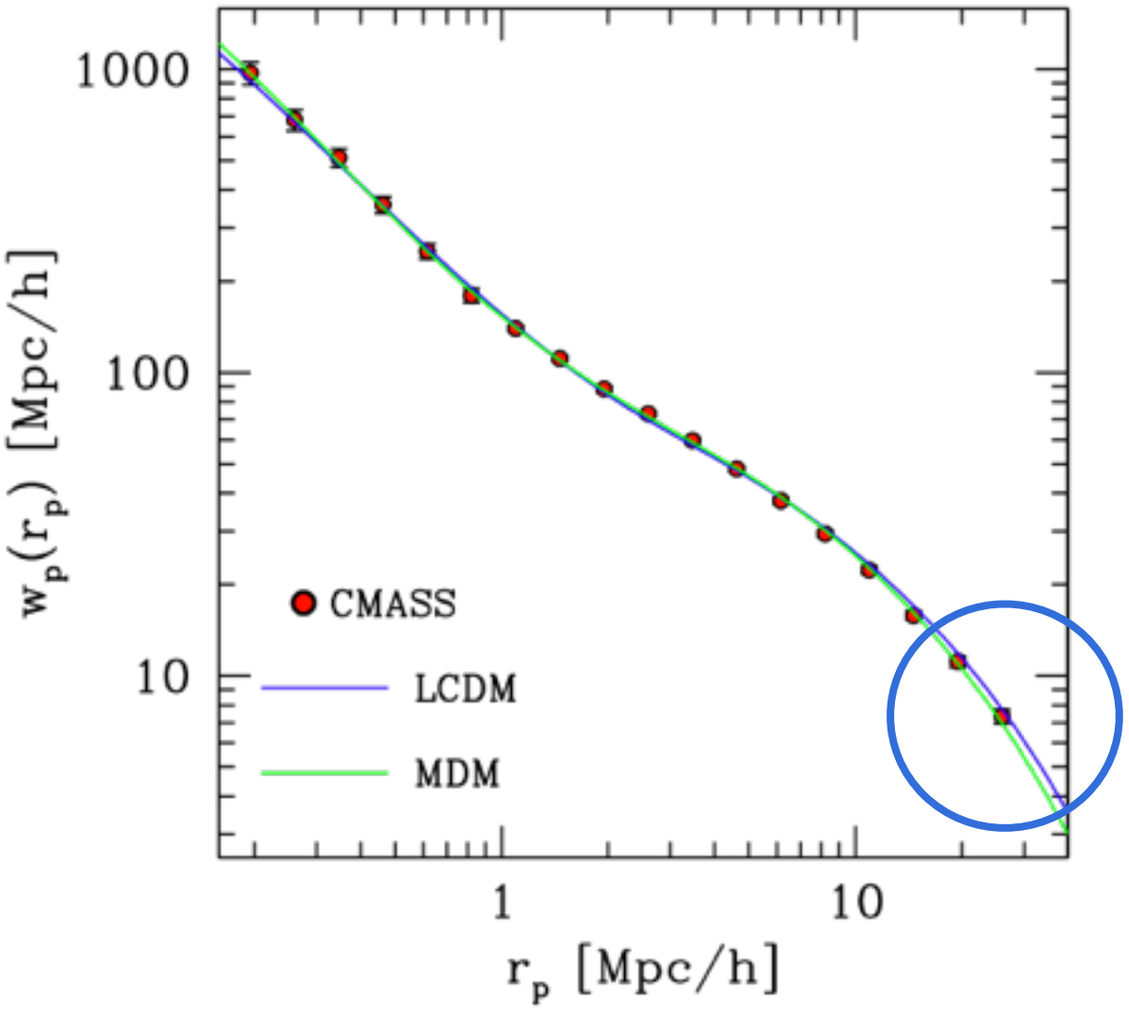




Nuza et al 2012: BOSS vs Om=0.27

New requirements and new simulations

- High resolution and accuracy means more physics and fewer assumptions
- 2% difference in correlation function at 20Mpc is detection of 0.4eV neutrino



Tinker, Hasenkamp et al 2014

New Simulations: Multi Dark and Bolshoi

Box	σ_8	h	Np	m_p	Ω_m	resolution
2500	0.82	0.70	57G	2.07×10^{10}	0.27	10kpch
2500	0.82	0.70	57G	2.22×10^{10}	0.29	10kpch
2500	0.82	0.70	57G	2.36×10^{10}	0.31	10kpch
2500	0.82	0.68	57G	2.35×10^{10}	0.31	10kpch
1000	0.82	0.68	57G	1.5×10^{9}	0.31	5kpc
400	0.82	0.68	57G	0.96×10^{8}	0.31	1kpc
250	0.82	0.68	8G	1.5×10^{8}	0.31	1kpc

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New Simulations: Multi Dark and Bolshoi

20 M cpu hrs 3e11 particles 5 PTb of stored data

Gadget and ART codes

5 trillion halos at different redshifts z=0-10

with properties such as :

mass, concentration, circular velocity shape, rotation

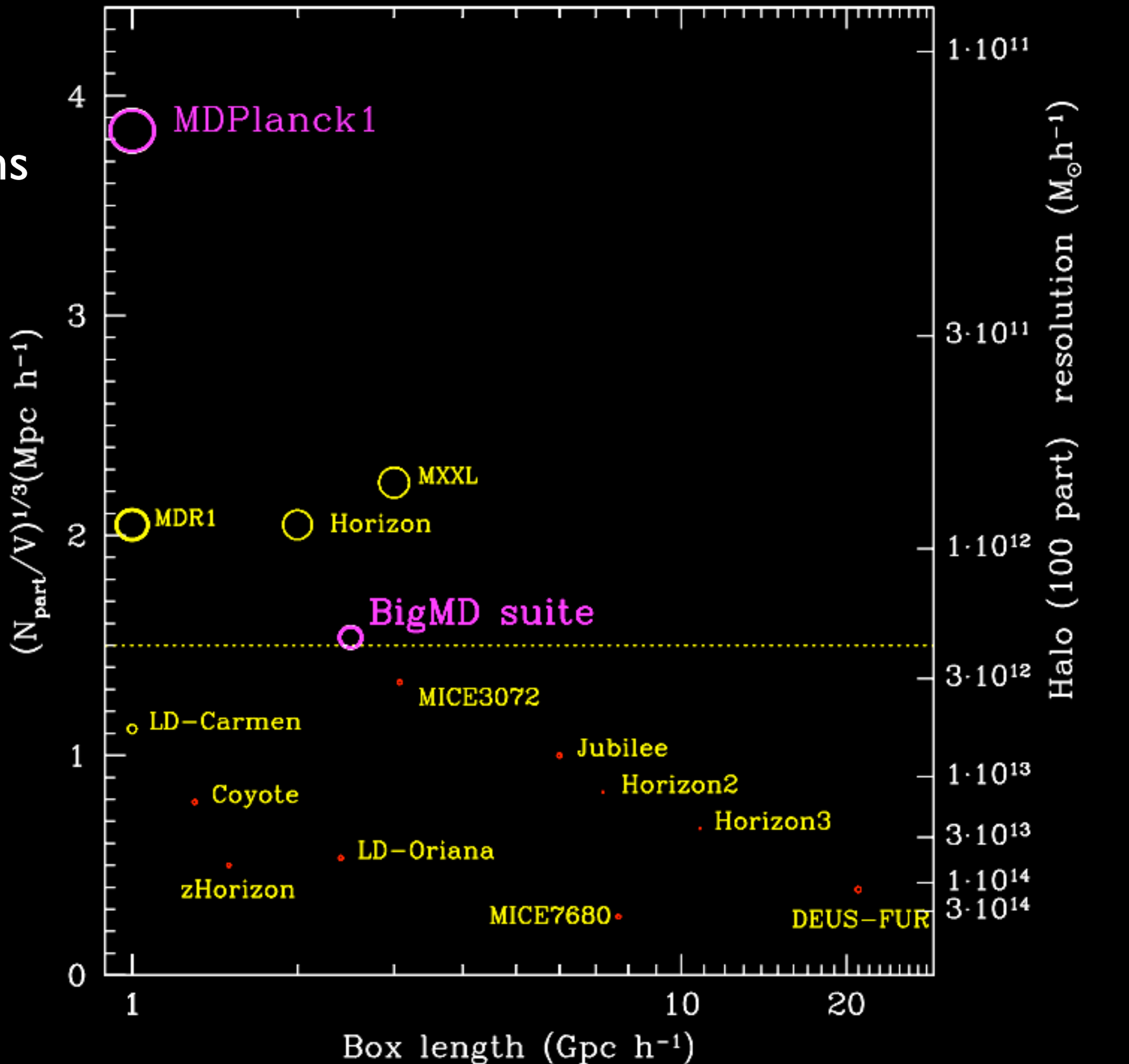
Spherical Overdensity (BDM and RockStar) and FoF

Halos and some snapshots are publicly available

Comparison of different large volume simulations

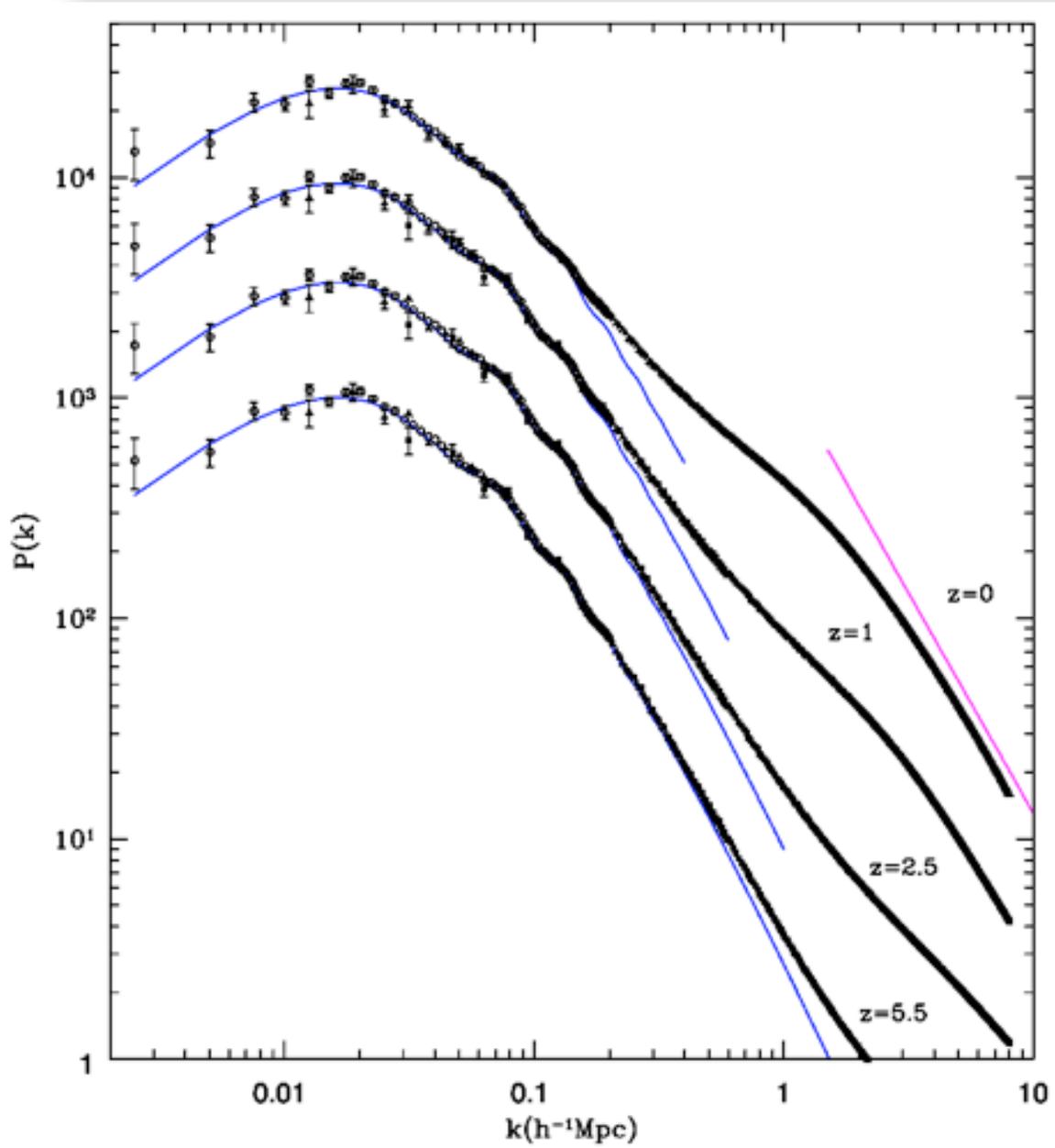
Size of circles indicates force resolution: the bigger the better

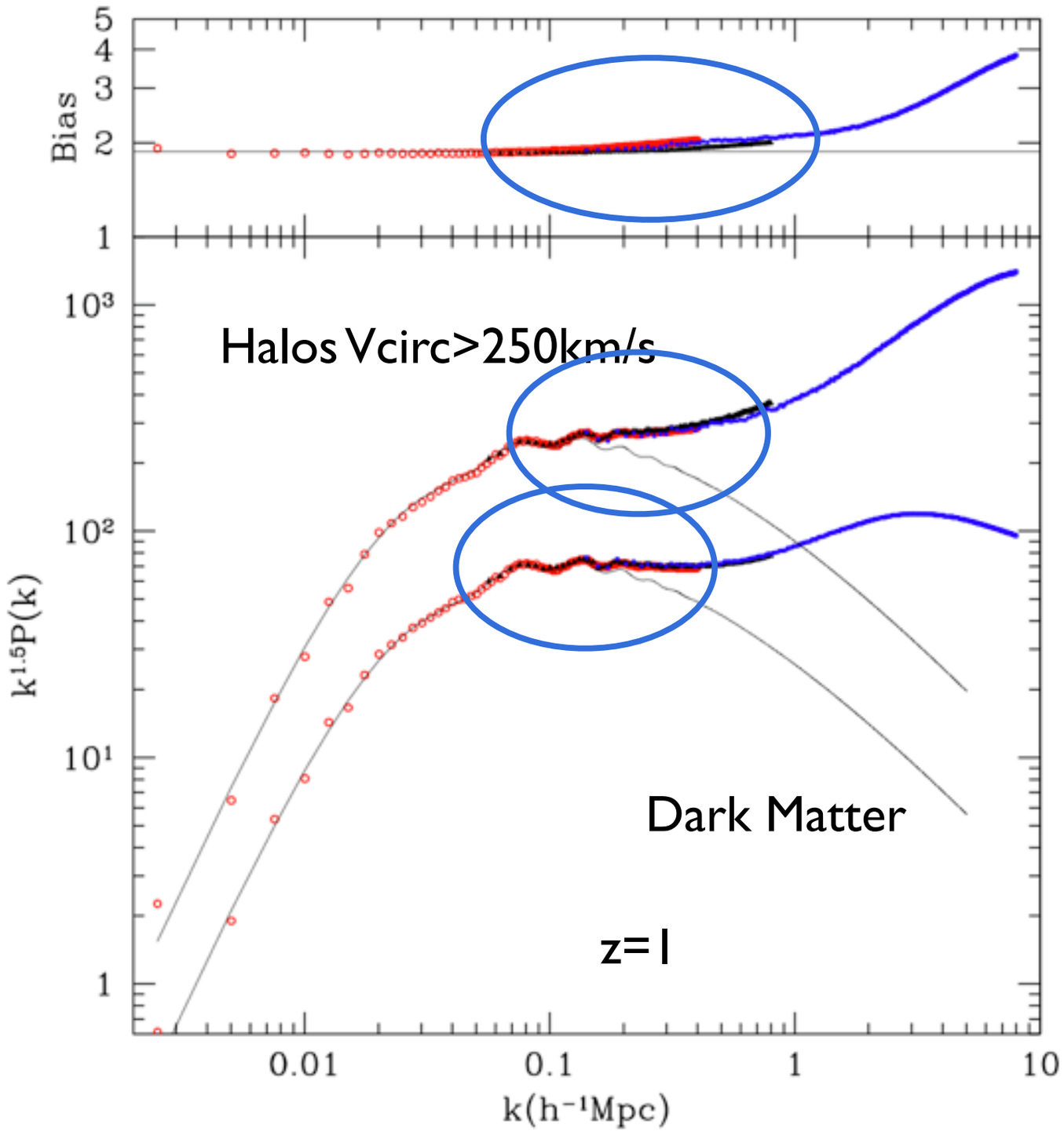
Dotted line: minimum mass resolution to resolve galaxy-size halos



Testing Accuracy

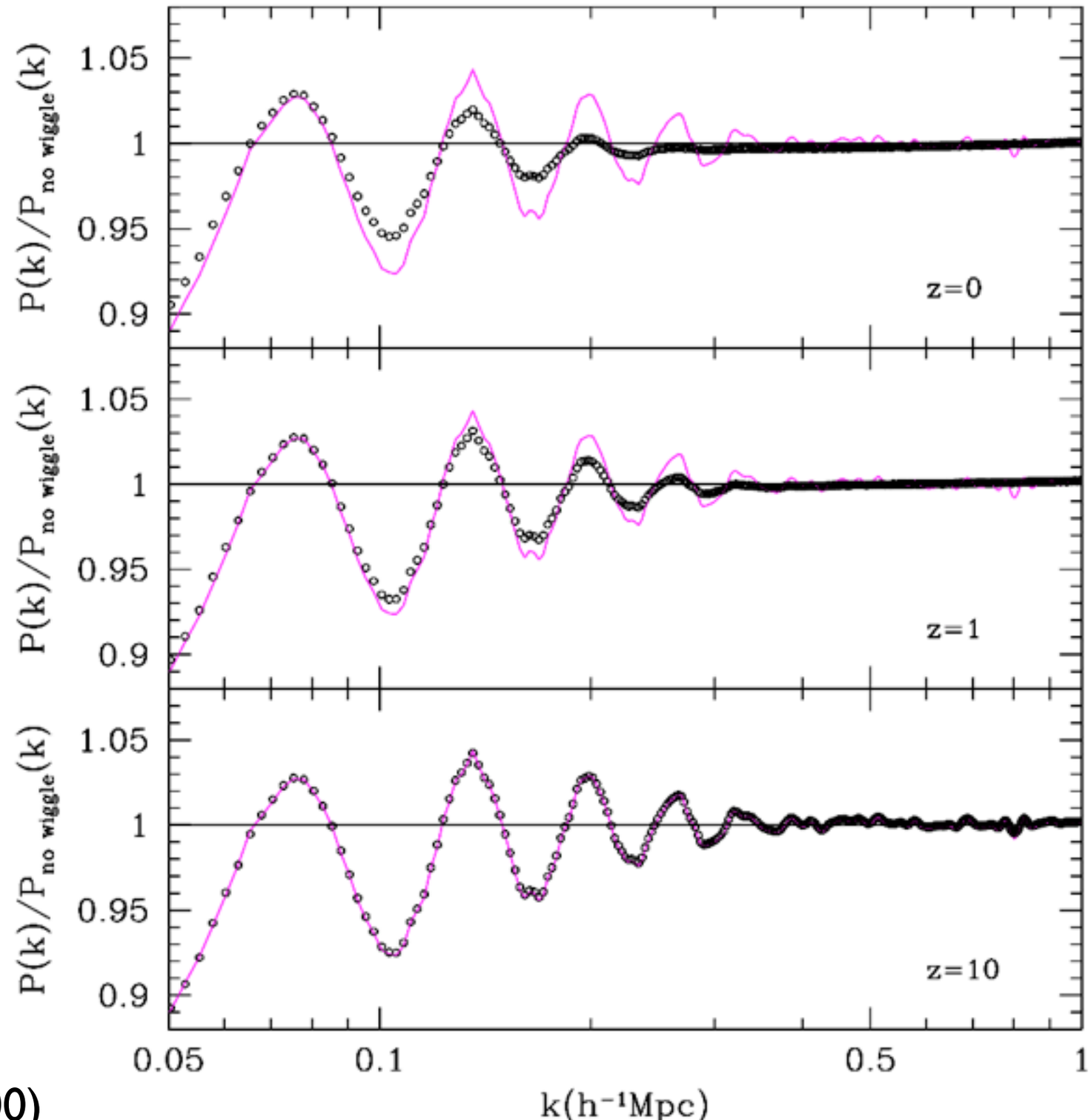
Convergence of power spectrum and bias





Testing Accuracy

Dumping of BAO peaks due to non-linear effects



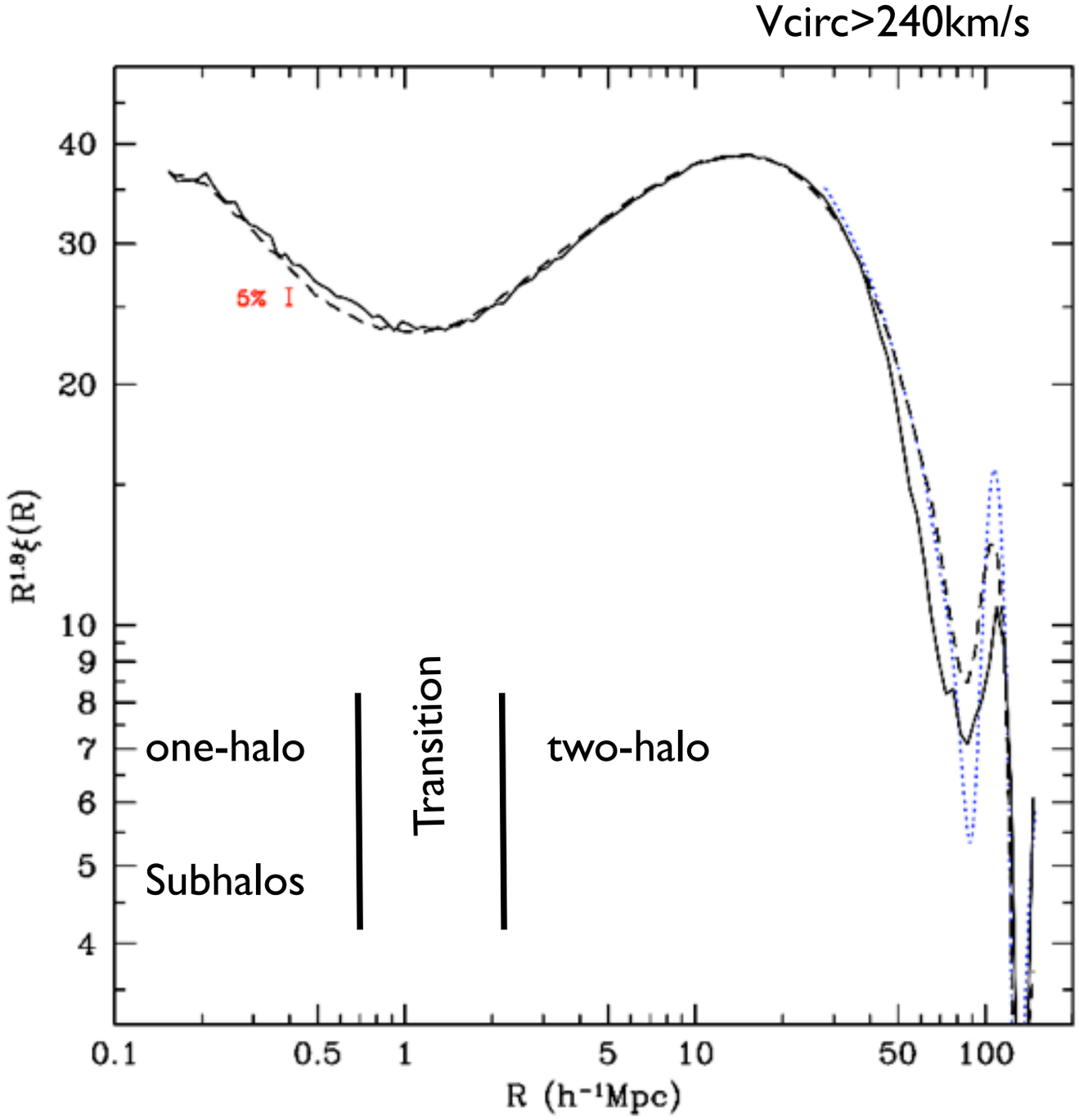
Magenta: initial conditions (z=100)

Testing Accuracy of simulations

Comparison of correlation functions of halos with the same Vcirc limits

Dash - bigMD (2.5Gpch)
Full - MultiDark (1Gpc)
blue dots - linear xi
Cosmic variance on scales > 50Mpch

Convergence for 120-150 particles on scales 100kpc to 50 Mpch



Testing Accuracy

Convergence of our results. ART and GADGET

MultiDark:

Vmax =180km/s =>

M=10^{12}Msunh

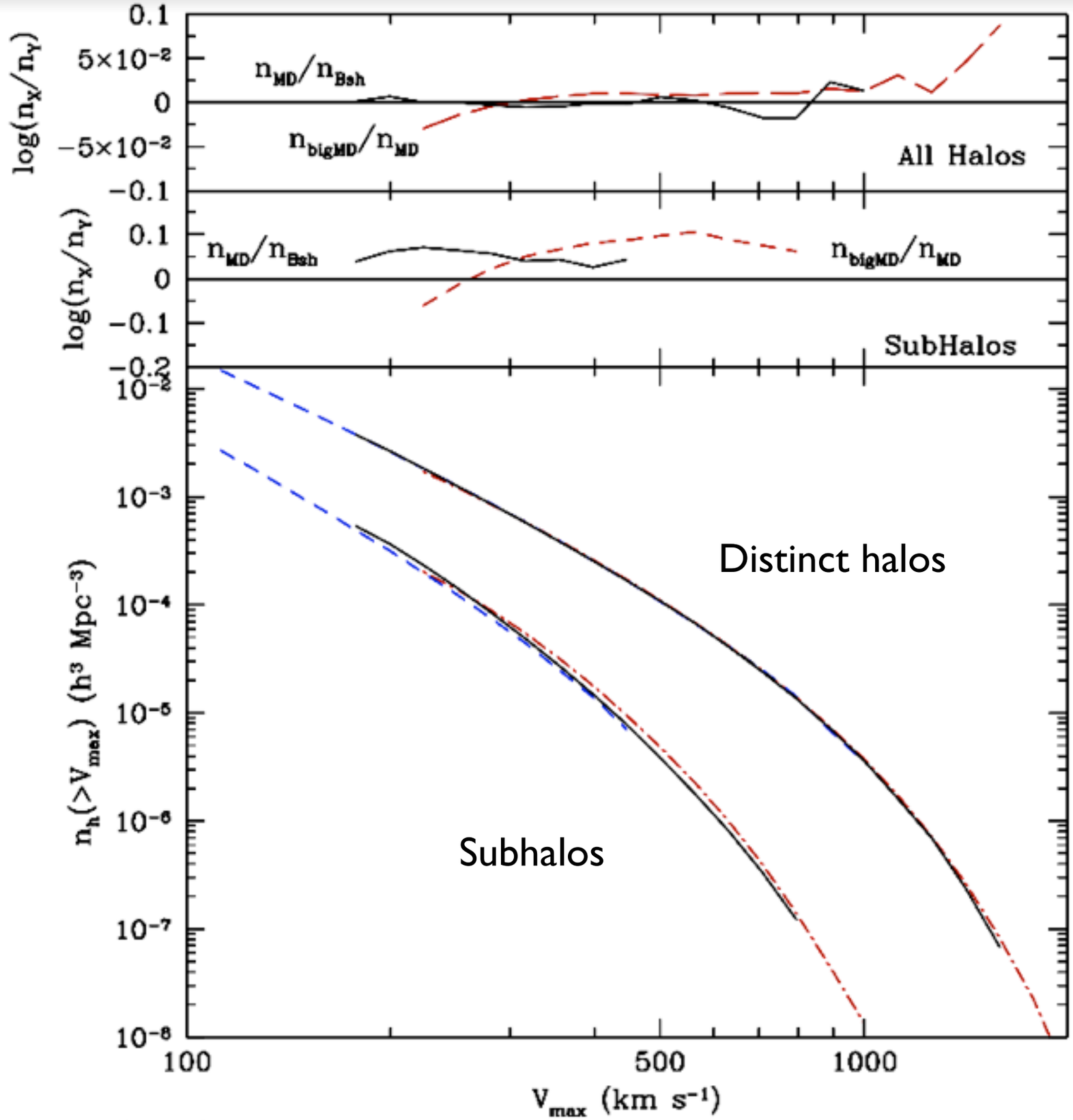
=> 120 particles

bigMultiDark:

Vmax =235km/s =>

M=2.8x10^{12}Msunh

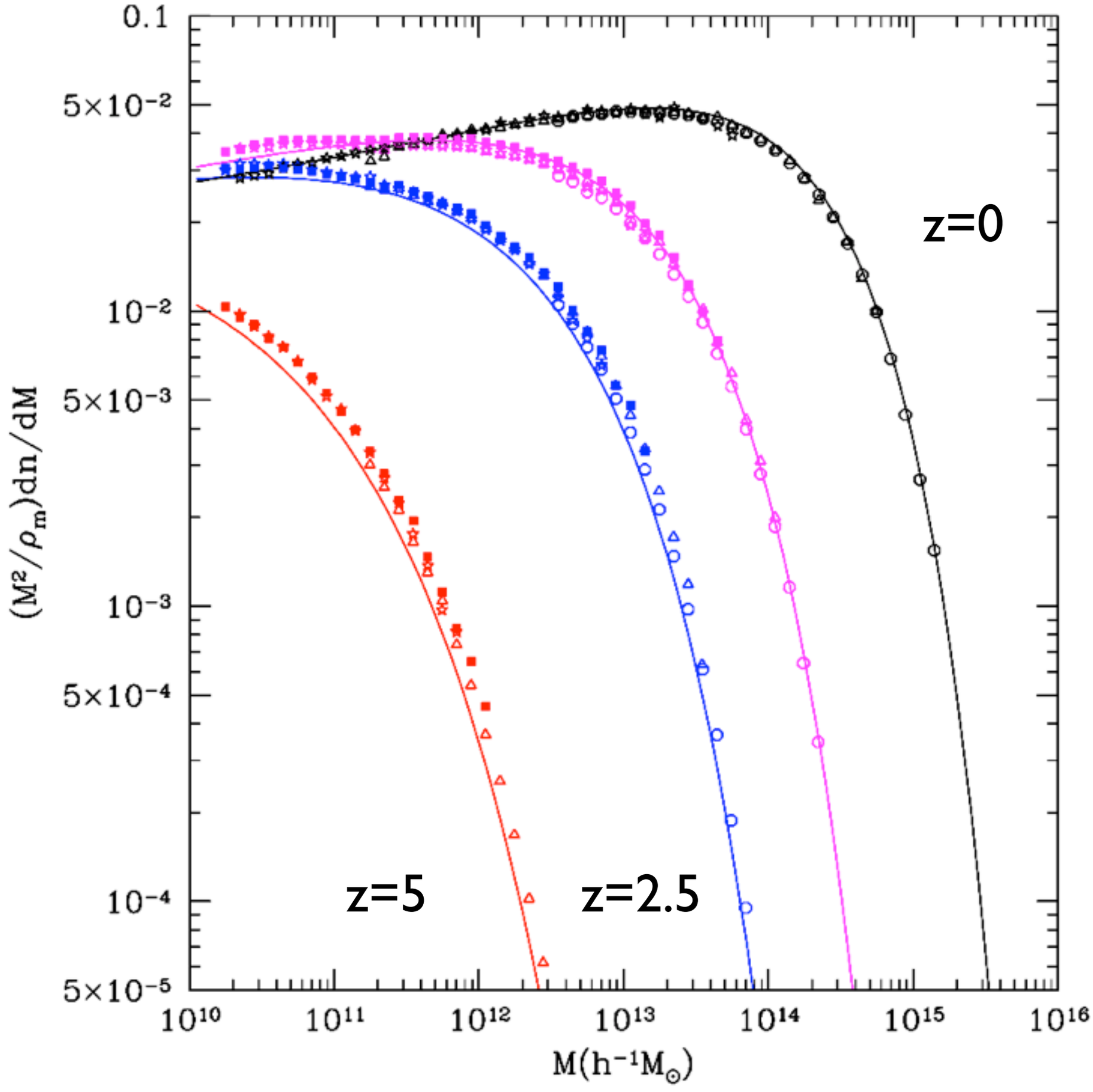
=> 140 particles



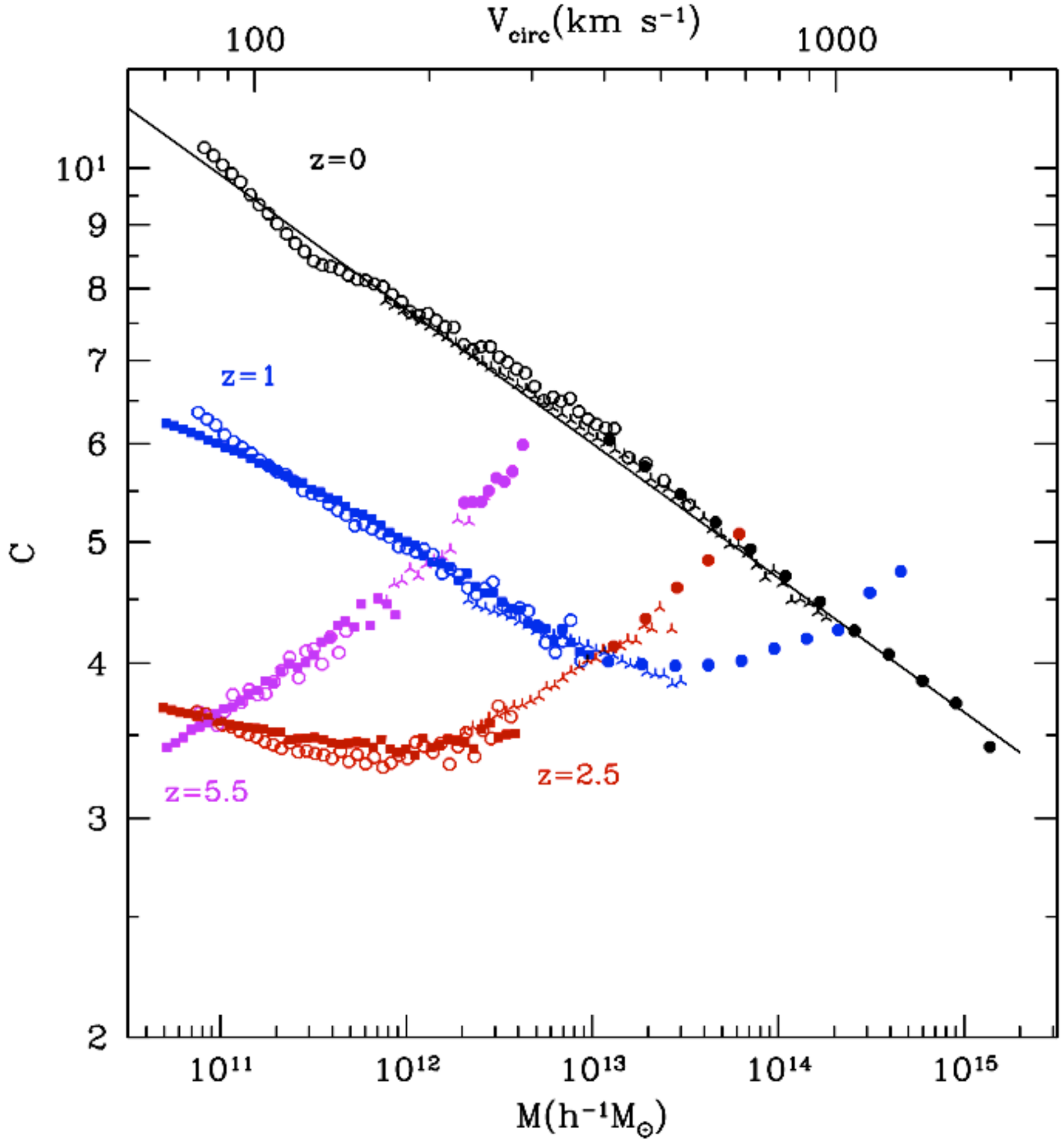
20 times better than in Millennium Simulations

Halo Mass Function:

Comparison with Tinker et al 2008



Halo Concentration



DATA products

- Halo properties: z= 0-10
- Subhalos
- DM density profiles for distinct halos
- Halo Abundance Matching => Stellar masses
- Fraction of DM particles for large number of snapshots
- Full set of DM particles for few snapshots: 1.7TB/snap
- Merging trees: in works
- Routines to read data in parallel.

Final Points: Codes and Analysis

- It is easy to make useless very large simulations. Gadget can produce good quality simulations, but not with the standard (recommended) parameters.

- There are other accurate codes: e.g. 2HOT (Warren), HACC (Habib), RAMSES (Tessier), ART (Kravtsov).

- It does not matter what code to use: as long as it runs, run it. We compared ART and Gadget: produce the same results once gadget parameters are tuned.

- Most of effort and problems is in data analysis, not cpu

Final Points: DATA access

- There are some very good and very useful simulations done by different groups.
- As a community we are failing when it comes to dissemination and access to results of simulations. Very little is available for public.
- Only two groups provide access to their results: MultiDark and Millennium. Only MultiDark gives access to raw data.
- MultiDark.org is based at AIP, Potsdam. Hosts MultiDark +Bolshoi simulations. About 100TB of data mostly in SQL database.
- We need a center where users can access 'catalogs' of galaxies and raw data. It is not enough to upload data on a server. There should be staff, who looks at the data, tracks completeness, consults users, looks after the center. If planetary community can have a center, why cannot we?
- Very little hope that this will ever happen.

Halo profiles of relaxed halos