Mocking the Universe: The Jubilee cosmological simulations

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on behalf of Gustavo Yepes (UAM)

Deep galaxy surveys, large-scale structure and dark energy. Spanish participation in future projects, Valencia, 29-30 March 2012

JUBILEE

JÜLICH
FORSCHUNGSZENTRUM

Juropa Hubble Volume Simulation Project

216 Billion particle N-body simulation in 6/h Gpc box

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Why do we need large particle simulations?

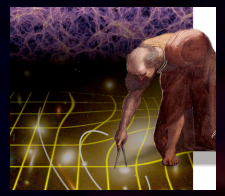
Large Volume Galaxy Surveys
DES, KIDS, BOSS, JPAS, LSST,
BigBOSS, Euclid

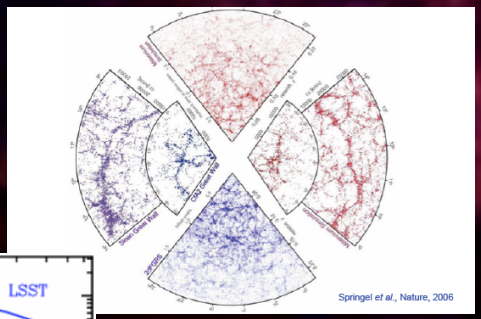
They will probe 10-100 Gpc^3 volumes

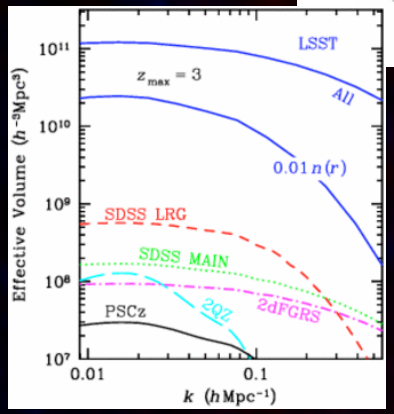
- Need to resolve halos hosting the faintest galaxies of these surveys to produce realistic mock catalogues. Higher z surveys imply smaller galaxies and smaller halos->more mass resolution.

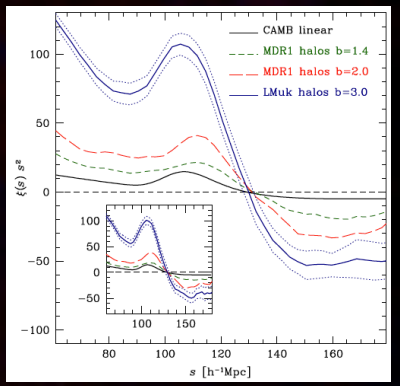
- Fundamental tool to compare clustering properties of galaxies with theoretical predictions from cosmological models at few % level. Not possible only with linear theory. Must do the full non-linear evolution for scales 100+ Mpc (BAO, zero crossing)

Galaxy Biases: Large mass resolution is needed if internal sub-structure of dm halos has to be properly resolved to map halos to galaxies.
e.g. Using the *Halo Abundance Matching* technique (e.g. Trujillo-Gómez et al 2011, Nuza et al 2012)

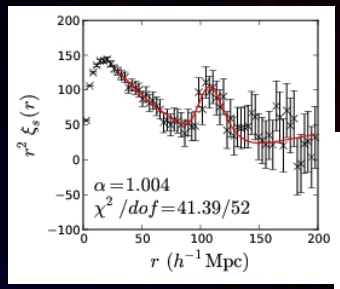




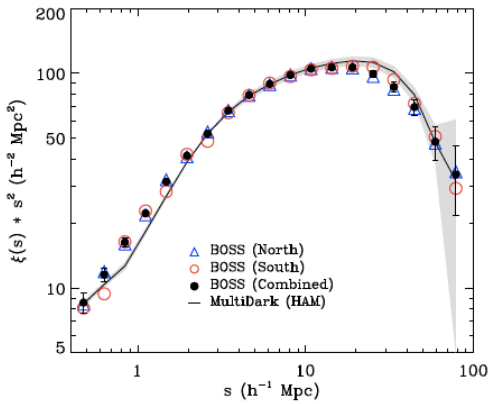




Zero crossing of CF. 130Mpc
Prada et al 2012



BAO in BOSS,
100Mpc scale



We will need trillion+ particle simulations

Large Volume Galaxy Surveys

A typical example: BOSS (z=0.1..0.7)

Box size to host BOSS survey : 3.5 h^-1 Gpc

BOSS completed down to galx with V_{cir} >350 km/s - > M_{vir} ~5x10^12 Msun.

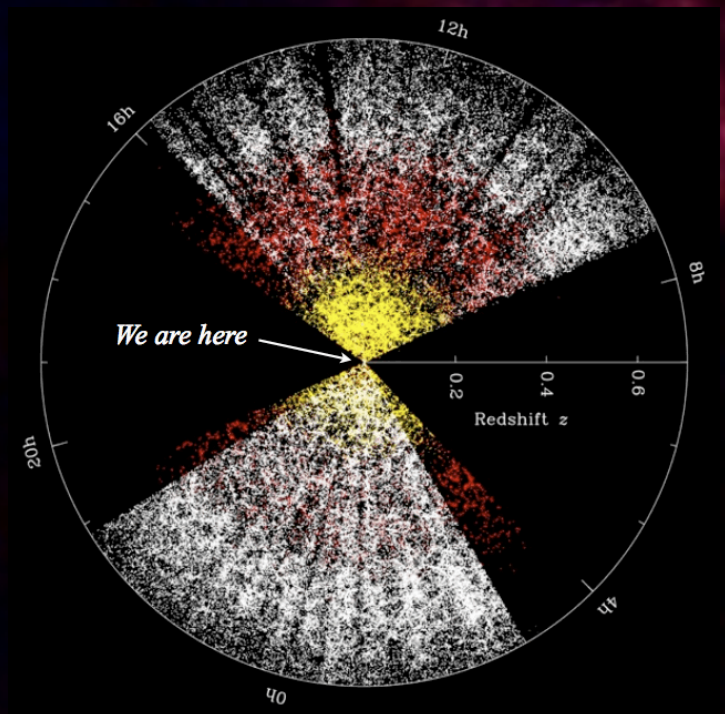
To properly resolve the peak of the Vrot in a dark matter halo we need a minimum of 500-1000 particles.

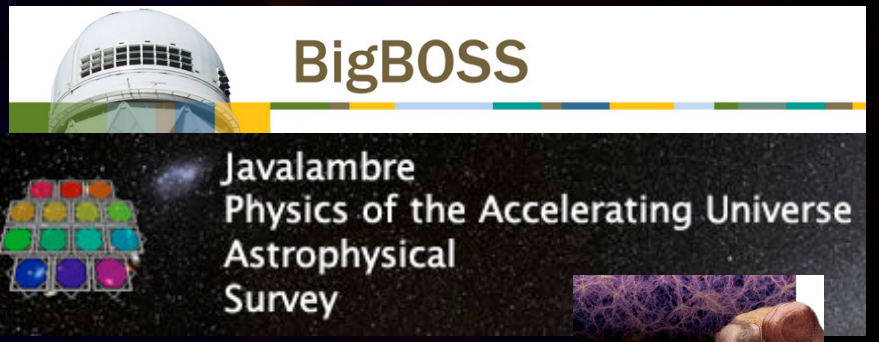
Then, a proper representation N-body realization of a BOSS survey will need > 7000^3 particles.

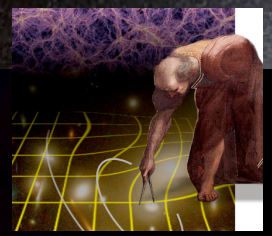
BigBOSS, Euclid ,LSST JPAS will go to z>1.5

Larger Boxes: > 6/h Gpc

Npart > 10,000^3







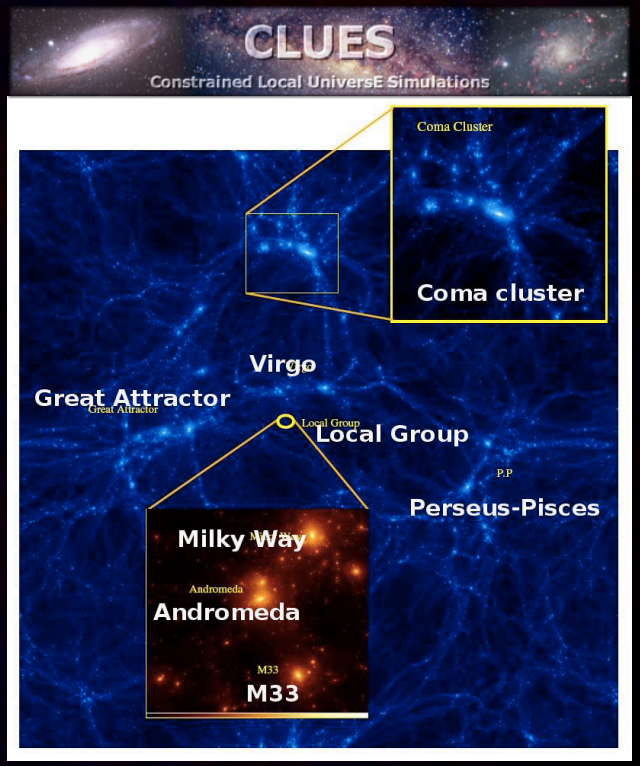
We will need trillion+ particle simulations

LSS structure formation in the cosmic reionization epoch
(e.g. Iliev et al 2006, 2010).

Large cosmological volumes with huge dynamical range to resolve the tiny CDM mini-halos that host the first population of stars. (~1-5x10^5 Msun).
Not-full RT treatment of course. Only DM simulations to find sources of UV radiation. Then RT is done as a postprocessing

Fortunately, only have to integrate in time up to z=6.

An example: Reionization of the Local group (Iliev et al 2011) we used a 64 Mpc box with 1024^3 particles.
Resolving only ~10^9 Msun halos.
Desired resolution: 3x10^5 Msun minihalos:10,000^3
A trillion particles…



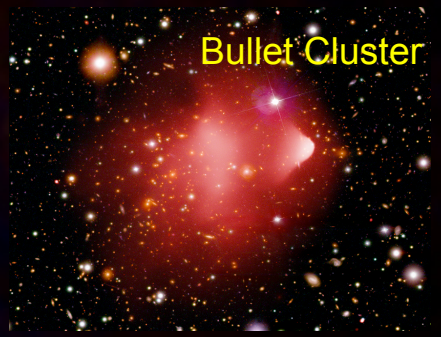
We will need trillion+ particle simulations

Cosmic Abundance of extreme rare objects

In LCDM Need very large computational volumes to find one of the extreme interacting objects recently found in SZ or X-rays + Lensing data: e.g Bullet cluster, El Gordo.

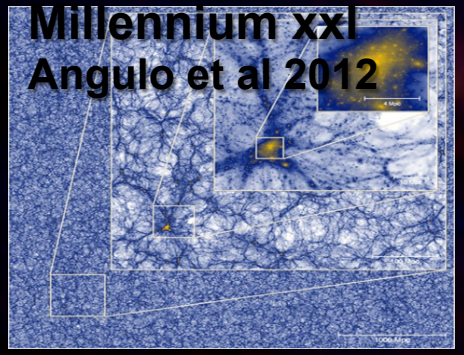
For a Bullet-like object, assuming that pairwise velocity is >3000 km/s then volumes typical of 5Gpc and above are needed but with moderate number of particles ~3000^3 . (Thomson & Nagamine 2012) .

For EL Gordo, at z=0.87, considerable much larger volumes need to be simulated. More than 6 Gpc and > 7000^3 particles



Current S.o.A Cosmological Simulations

The MILLENNIUM TRILOGY



The Bolshoi Ballet

Millennium I	(WMAP1)-GAD:	500 /h Mpc	10 billion particles
Millennium II	(WMAP1 -GAD	100/h Mpc	10 billion particle
Millenium XXL	(WMAP1-GAD:	3 /h Gpc	303 billion particles
Bolshoi	(WMAP7-ART)	250/h Mpc	8 billion particles
Multidark	(WMAP7.ART)	1 /h Gpc	8 billion particles
MICE	(WMAP5-GAD)	7 /h Gpc	8 billion particles
Horizon (FR)	(WMAP3-RAMSES)	2 /h Gpc	68 billion particles
Horizon (KR)	(WMAP5-GOTPM)	10.7 /h Gpc	372 billion.
JUBILEE	*(WMAP7-CP3M)*	*6/h Gpc*	*216 billion particles*

The Jubilee Simulation

A Coherent Hubble Volume Simulation for All-Sky ISW predictions and Large Scale Surveys

The JUBiLEE (JUropa huBbLE volumE) project

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One of the largest simulated volumes in the current most favored cosmology.

- **6/h Gpc** = 20 billions light-years
- Second largest number of particles
  - **6000^3** ~ 216 billion particles
  - **$12{,}000^3$**~1.6 trillion mesh for PM
- Covers all the universe from z=1
- N-body simulation CUBEP^{3}M code
- Use 8000 nodes of Juropa:
  - Node=8 Cpus and 24 Gbytes
- Each snapshot = 6 Tbytes. More than 30 snapshots stored
- Scientific results:
  - Measuring of ISW
  - Cross correl. ISW -LSS from LRG.
- Halos finding: AHF
- ISW from potential in a 12000^3 mesh
- Starting z=100.

JUBILEE

Abstract

We propose to run a large N-body cosmological simulation with a volume of $V = (6h^{-1}\mathrm{Gpc})^3$ and a number of particles $N_p = 6000^3$. The simulation will be used primarily to compute an all-sky map of the Integrated Sachs-Wolfe effect (or ISW) but also to produce catalogues of luminous red galaxies (or LRG), radio and IR galaxies as well as all sky maps of the Sunyaev-Zel'dovich (or SZ) and lensing effects. All these products will be made publicly available and can be used to test algorithms and to check for systematics in upcoming surveys. Future data sets like Planck and surveys like Pan-STARRS, DES, EUCLID, BigBoss, and J-PAS will require coherent simulated data derived from very large N-body simulations that include the above effects and a catalogue of simulated galaxies. A large volume is needed in order to properly simulate the largest scales of the ISW and also to study the impact of cosmic variance on future LSS surveys. In this project we propose to do a coherent simulation over a very large volume with enough resolution to be able to resolve individual LRGs.

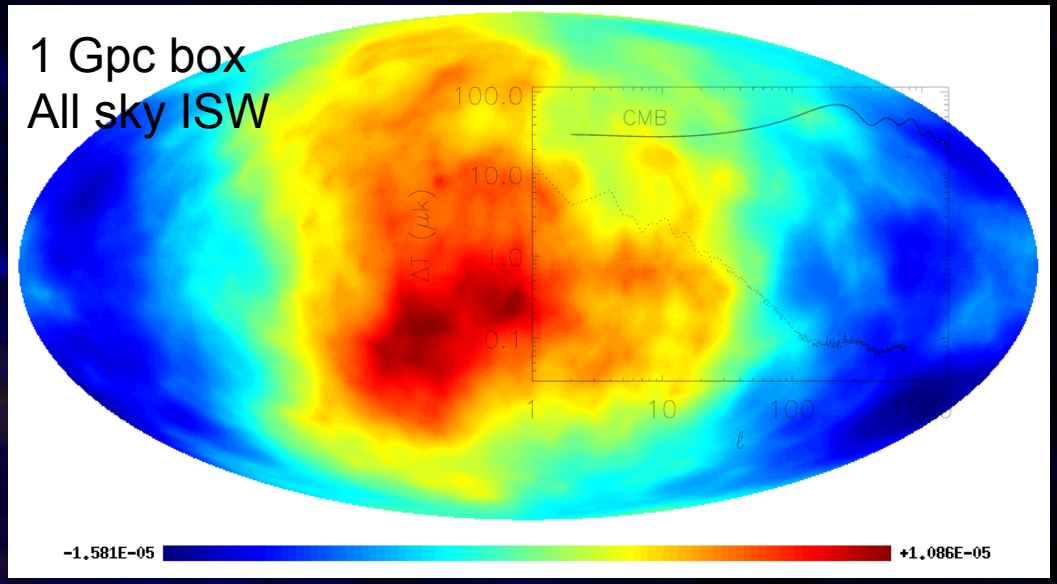
GOAL: Measure all sky maps of ISW over the hubble volume and derive realistic galaxy catalogs in the same computational volume.

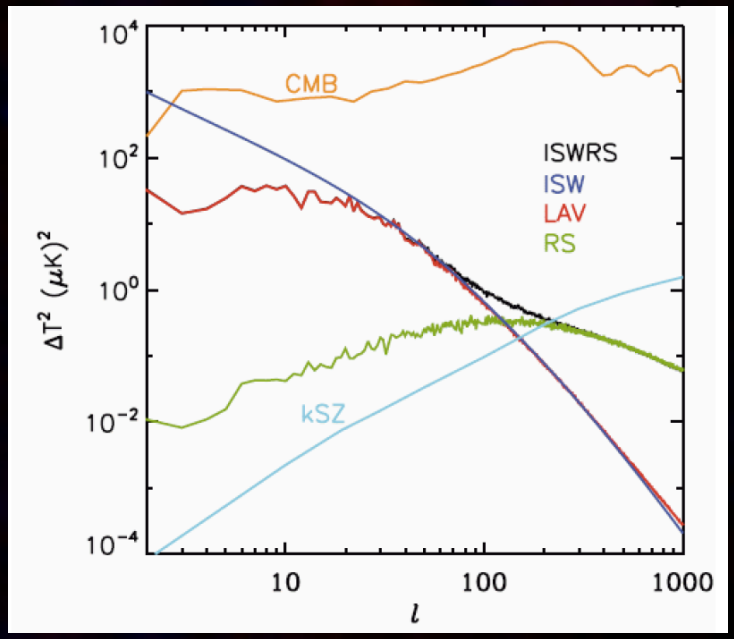
JUBILEE DELIVERABLES

1. All sky ISW maps and systematics
2. Population of high-z clusters.
3. Mock galaxy catalog productions
4. Correlation analyses of LRG (BAOS, Zero crossing)
5. Cosmic variance error estimates
6. Redshift distortions
7. Lensing maps

JUBILEE ISWRS

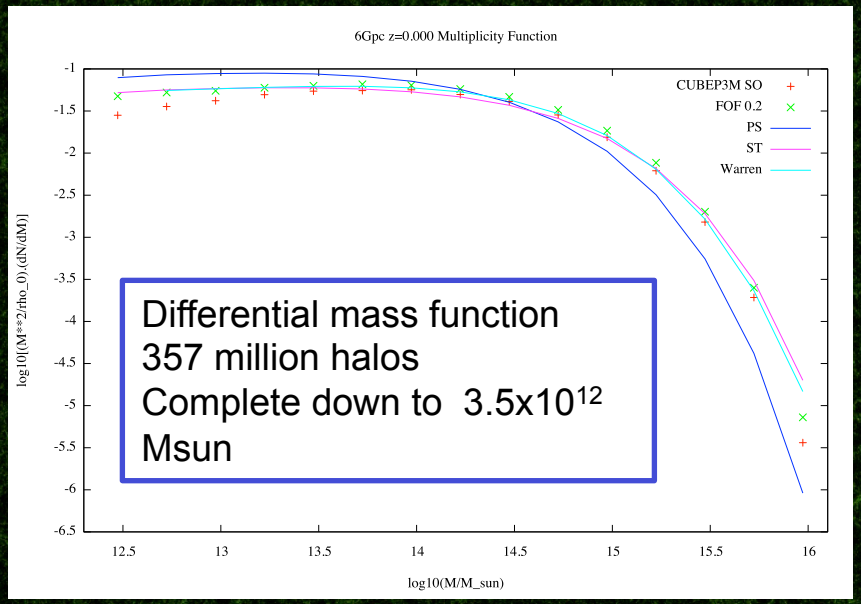
The ISW is an important probe of the content of dark energy.
Need of large cosmological volumes because the correlation length of gravitational potentials is very large. Otherwise, lack of power at large scales
Cai et al 2010

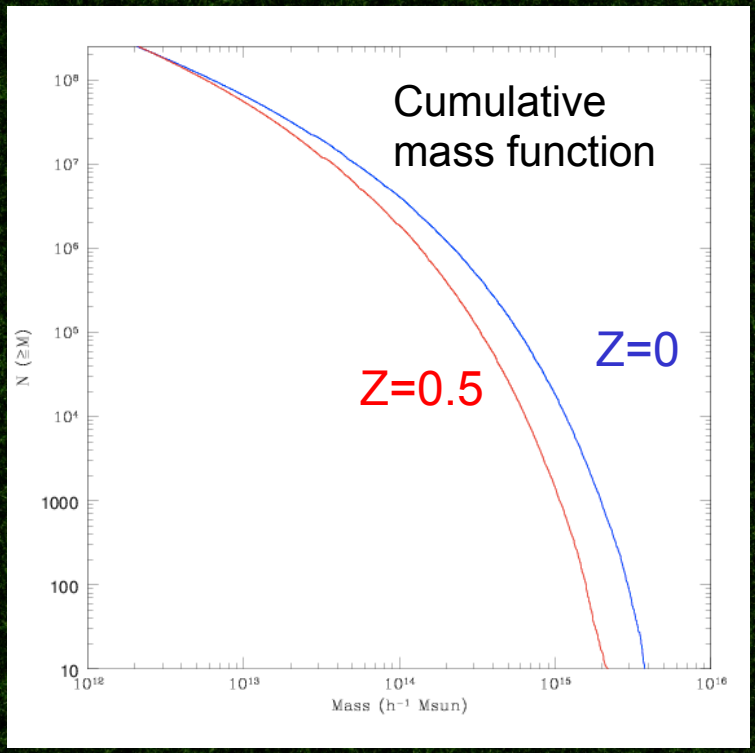


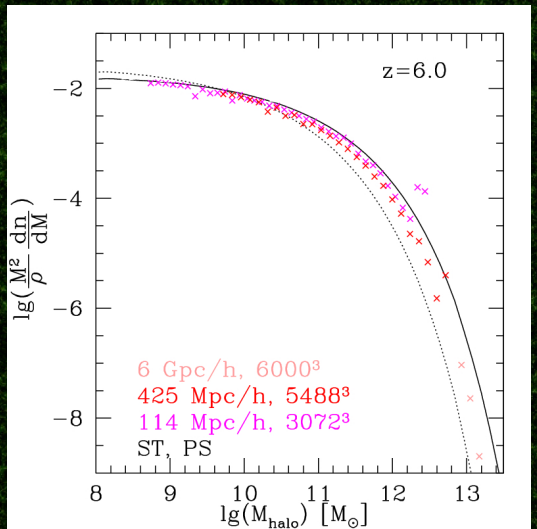


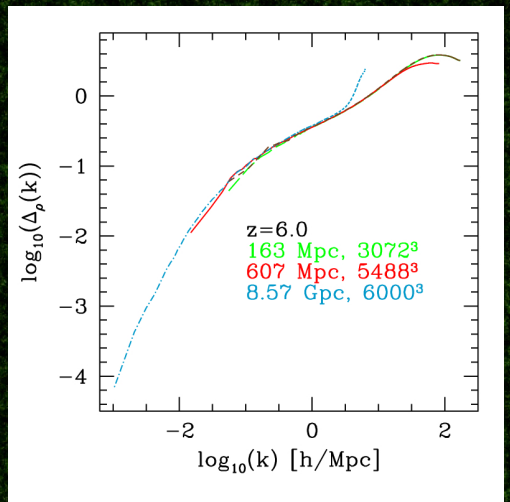
If not enough volume, then the replication of the box gives rise to an effective filtering of the lower modes . According to the studies of Cai et al 2010, most of the power of the ISW comes from $z < 1.5$ (D ~3000 Mpc)

JUBILEE HALO ABUNDANCE

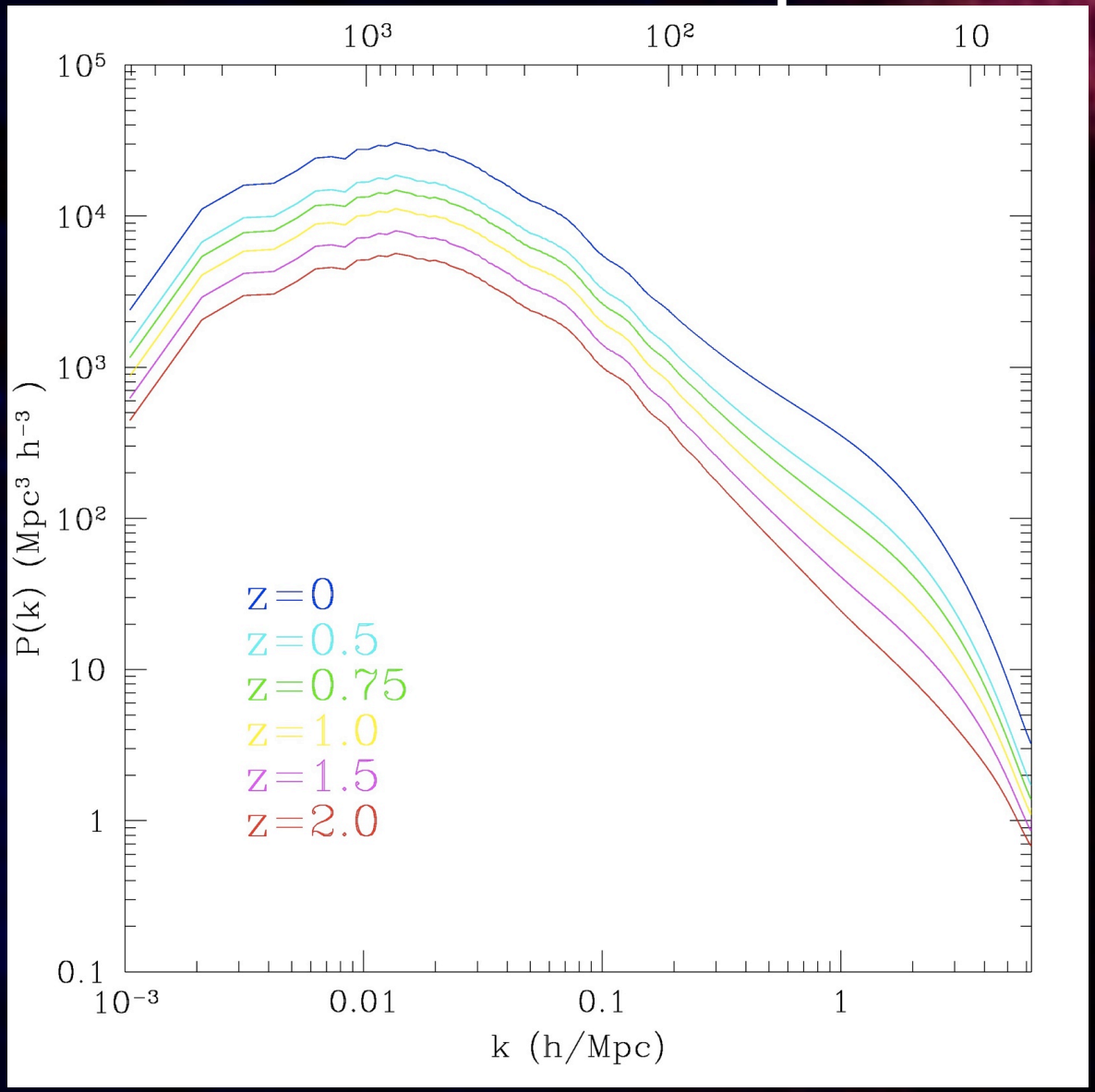








JUBILEE Matter Power Spectrum



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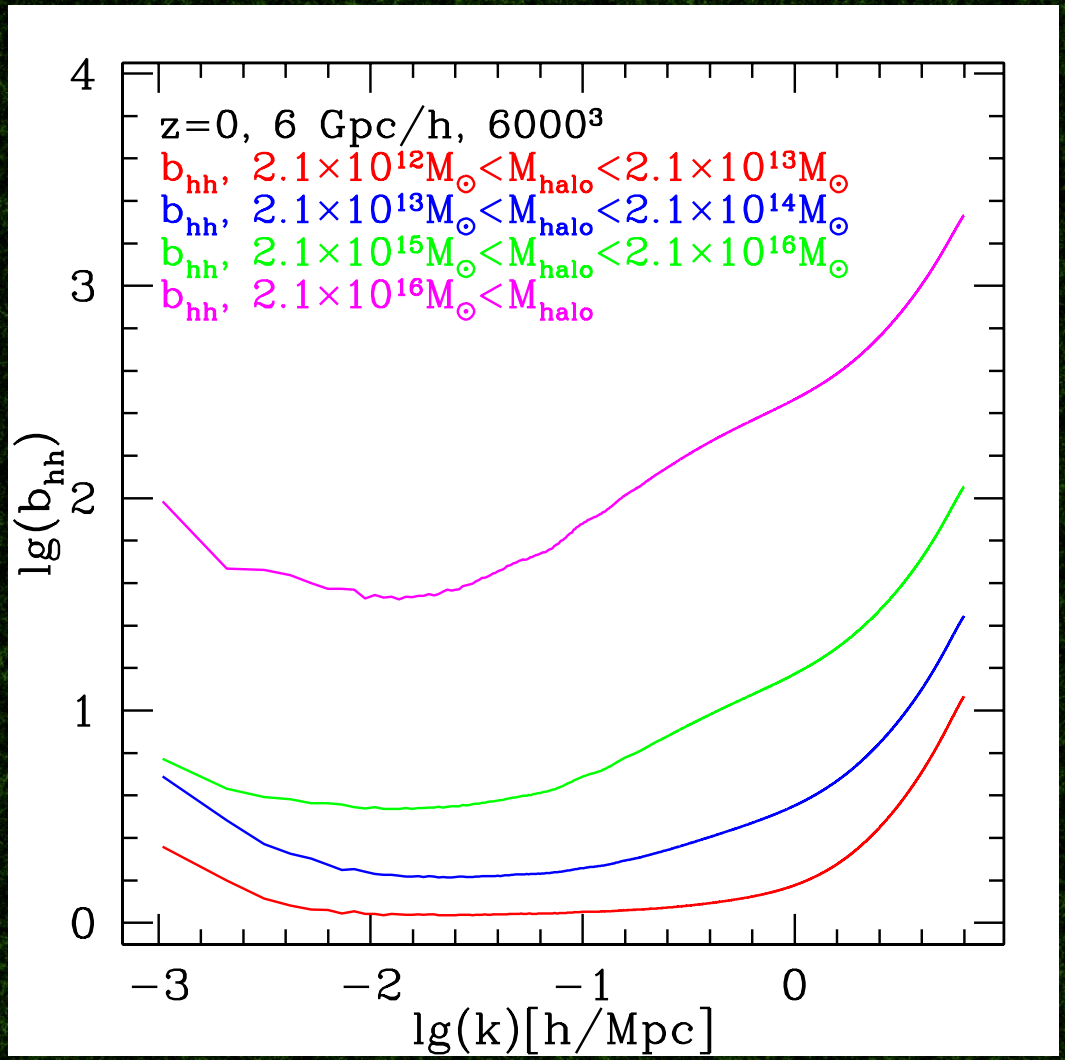

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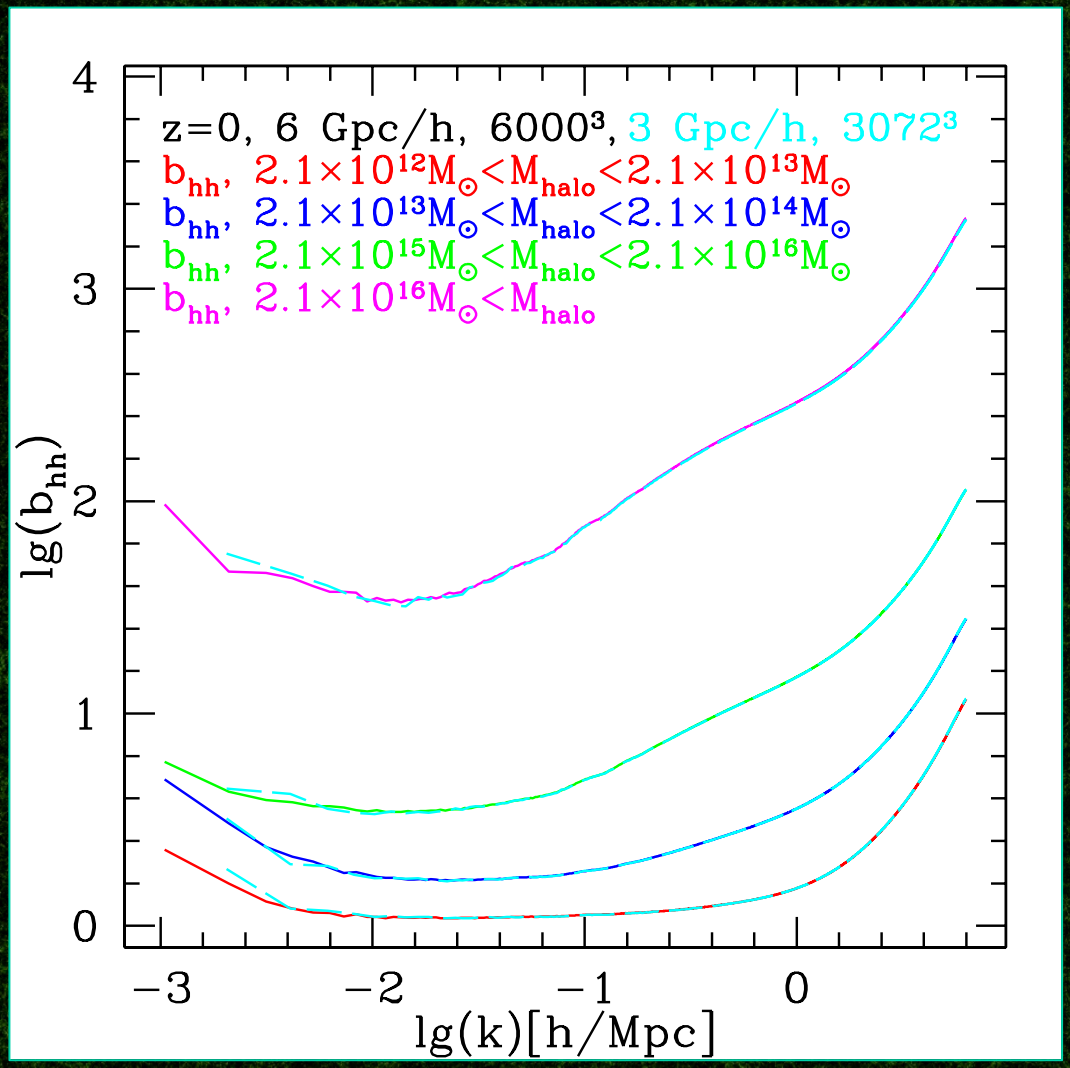

Things to do

Generate mock galaxy catalogues:

- Apply semi-analytic modeling (merger trees)
- Halo Occupation Distribution (HOD, FoF halos)
- Halo Abundance Matching (Vmax halos, subhalos

Generate all sky maps of the ISWRS.

Public release of Jubilee database

http://Jubilee-project.org

CONCLUSIONS

- LSS N-body simulations for different cosmological settings are required for current and upcoming galaxy redshift and photometric surveys.
- It would be necessary to coordinate efforts among the different collaborations and not repeating same big runs again and again (e.g. Euclid SWG).
- So far the SC centers have not paid attention to the data managements of simulated results. Some sort of central repository for simulation datasets could be an ideal solution. This might be another big HPC infrastructure.
- Some kind of standarization of the analysis and format of data has to be done.
- Same kind of problems than the observed data mining