

Bullet Clusters in the MareNostrum Universe

Stefan Gottlöber
Astrophysical Institute Potsdam

KITP
March 18, 2011

- 1 Clusters in the MareNostrum Universe
- 2 Clusters in the MultiDark simulation
- 3 The MultiDark database at AIP

Collaborators

- Gustavo Yepes (UAM, Madrid)
- Jaime Forero (AIP, Potsdam)
- Federico Sembolini (UAM, Madrid) **Poster**
- The E-Science group at AIP
 - Kristin Riebe
 - Adrian Partl
 - Harry Enke
- Anatoly Klypin (NMSU, Las Cruces)
- Francisco Prada (IAA, Granada)

Clusters in the MareNostrum Universe

MareNostrum at chapel Torre Girona (BSC)

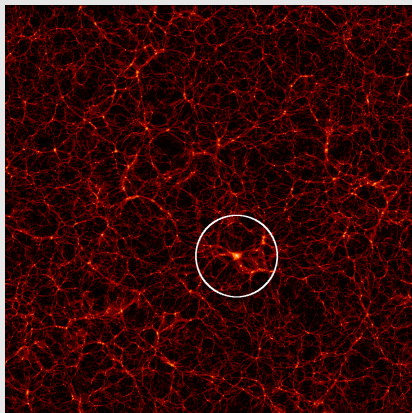


MareNostrum Numerical project

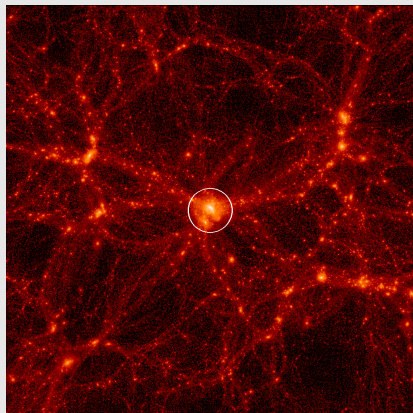
MareNostrum Universe

- A 2 billion particle non-radiative SPH simulation in a $500 h^{-1}$ Mpc box
- Concordance model
 - $\Omega_m = 0.3$
 - $\Omega_b = 0.045$
 - $\Omega_\Lambda = 0.7$
 - Hubble parameter $h = 0.7$
- web-page: <http://astro.ft.uam.es/marenostrum/>

The most massive cluster

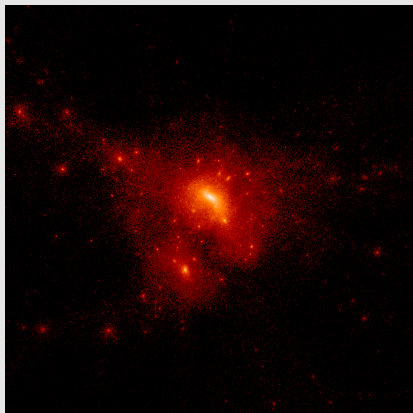


circle $100h^{-1}\text{Mpc}$

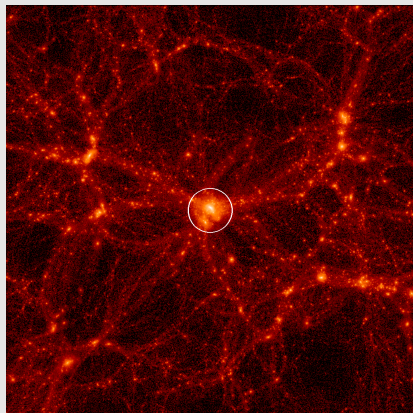


circle $20h^{-1}\text{Mpc}$

The most massive cluster



$$M_{\text{vir}} = 2.5 \times 10^{15} h^{-1} M_{\odot}$$



$$r_{\text{vir}} = 2.8 h^{-1} \text{Mpc}$$

Bullet Clusters in the MareNostrum Universe

Redshift z	# Selected Clusters	Most massive cluster ($10^{15} h^{-1} M_{\odot}$)
0	4063	2.5
0.3	2662	2.0
0.5	1826	1.3

Table: Analyzed redshifts z , number of selected clusters with $M > 10^{14} h^{-1} M_{\odot}$ and mass of the most massive cluster at the given redshift in the simulation volume

- J.E. Forero-Romero, SG, G. Yepes, ApJ 725 (2010), 604

Bullet Clusters in the MareNostrum Universe

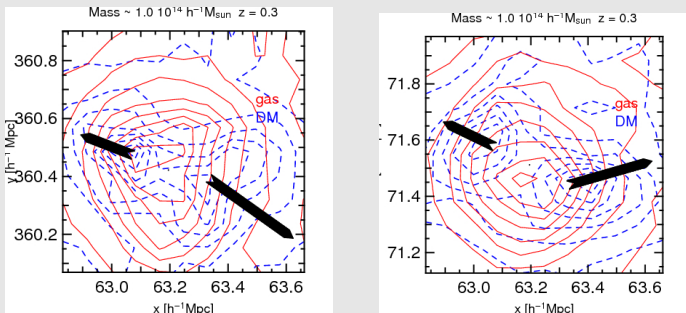
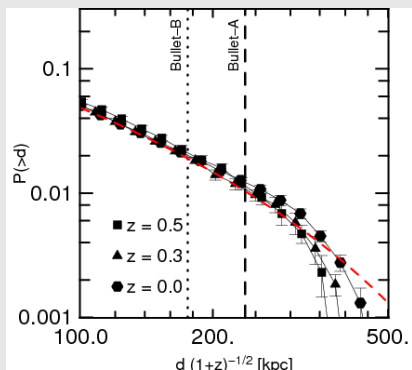


Figure: Linearly spaced surface density contours for the DM (dashed blue) and gas (continuous red) components of a cluster ($M = 1.0 \times 10^{14} h^{-1} M_{\odot}$ at redshift $z = 0.3$). The arrows are proportional to the velocities with respect to the center of the gas core, the relative velocity of the DM cores is 560 km/s.

Bullet Clusters in the MareNostrum Universe



Cumulative distribution of 2D physical displacements between dark matter and gas peaks at three redshifts: $z = 0$ (hexagons), 0.3 (triangles) and 0.5 (squares). The vertical lines indicate the measured displacements for the Bullet Cluster 1E0657—56 (Bullet-A) and the cluster MACS J0025.4-1222 (Bullet-B). Red dashed line ($P_0 = 0.04$, $d_* = 200$ kpc and $\alpha = -1.0$):

$$P_{2D} = P_0 \left(\frac{d_z}{d_*} \right)^\alpha \exp \left(-\frac{d_z}{d_*} \right),$$

Bullet Clusters in the MareNostrum Universe

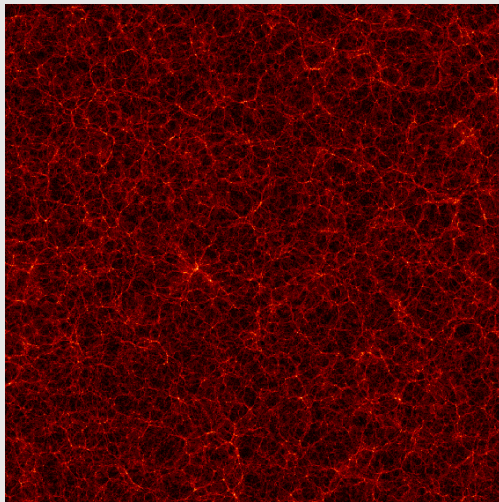
- large DM-gas displacements are fairly common in a Λ CDM cosmology
- around 1% to 2% of clusters with masses $M > 10^{14} h^{-1} M_{\odot}$ show DM-gas separations equal or larger than the observed in the Bullet Cluster
- J.E. Forero-Romero et al. ApJ 725 (2010), 604

Clusters in the MultiDark simulation

The MultiDark simulation

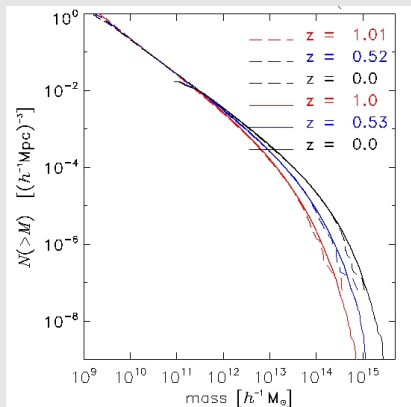
- 2048^3 particles
- ART simulation (NAS pleiades)
- the same parameters as Bolshoi
<http://astronomy.nmsu.edu/aklypin/Bolshoi/>
 - $\Omega_m = 0.27$
 - $\Omega_b = 0.0469$
 - $\Omega_\Lambda = 0.73$
 - $h = 0.7$
 - $\sigma_8 = 0.82$
 - $n = 0.95$
 - $z_{init} = 80$, $P(k)$: CAMB table

MultiDark - slice through the most massive cluster



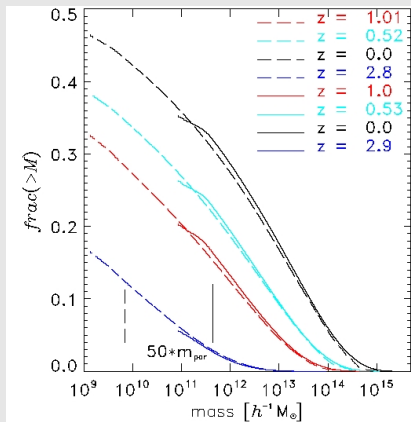
MultiDark resimulations

Mass function of MultiDark and Bolshoi



solid line (MultiDark), dashed line (Bolshoi)

Fraction of mass in bound objects



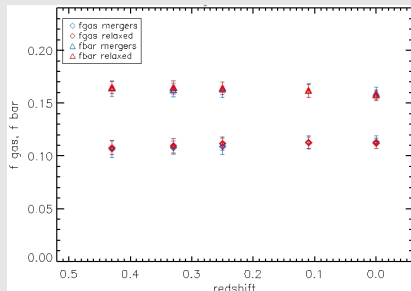
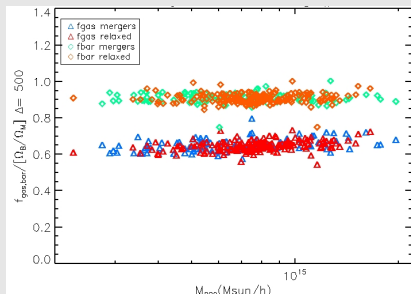
Cluster re-simulations (Gustavo Yepes)

- 283 cluster regions ($R = 6h^{-1}\text{Mpc}$)
- local resolution 4096^3 particles
- radiative SPH simulation (Springel-Hernquist)
- $m_{DM} = 8.1 \times 10^8 h^{-1} M_{\odot}$
- $m_{gas} = 1.9 \times 10^8 h^{-1} M_{\odot}$
- complete for $M_{cl} > 10^{15} h^{-1} M_{\odot}$ (105 clusters)
- total: 520 clusters with $M_{cl} > 10^{14} h^{-1} M_{\odot}$
- most massive cluster $M_{cl} = 2.7 \times 10^{15} h^{-1} M_{\odot}$

cluster1

Clusters in the MultiDark simulations (Federico Sembolini)

see also Federico's poster



Baryon and gas fractions in clusters (mergers and relaxed clusters) at overdensity 500

(*b* in Steven Allen's talk, Thursday afternoon)

Redshift evolution of the baryon and gas fraction (mergers and relaxed clusters)

The MultiDark database at AIP

MultiDark database

MultiDark Database

Welcome to the MultiDark Database

*** All data provided here are currently only in a pre-release state and **MUST NOT (yet) be used for SCIENTIFIC purposes!** ***

The MultiDark database provides results from cosmological simulations performed within the MultiDark project. This database can be queried by entering SQL statements directly into the [Query Form](#). The access to that form and thus access to the public & private databases is password protected - if you haven't done so, please register first.

More information on the simulations, the database, its design and the possibilities to access the data are described in the [Documentation](#), where we also provide a little tutorial on SQL ([SQL Step-by-Step](#)) and some [Frequently Asked Questions](#).



Registration

Access to the [Query Form](#) is password-protected - if you don't want to register, use the **public user**:

username: multidark_public

password: [none]

For gaining full access to all data in the database, registration via the [Registration Form](#), also linked at the [Registration](#) page of the [Documentation](#), is required.



Contact

For any comments, suggestions, help requests, bug reports etc., please don't hesitate to contact us by filling out our [Contact Form](#).



Status

The current status of the database and the web application is reported in the section [Status](#). This is the place to look for any news related to the simulations and the database.



Images & Movies

We have collected some images (and now also the first movies!) related to the MultiDark simulations at [Images & Movies](#). Feel free to use them for talks, posters or just enjoy them!

You have created a nice movie yourself and want to share it with other people? Excellent! Just fill out the [Contact Form](#) and send us a short description, where to find the movie/picture, what it shows and which data and code was used to produce it. We will then consider adding it to this web page.



Demo Video

For an easy start we created a little video on YouTube for you which demonstrates the basic usage of the web interface for accessing the MultiDark Database. Have a look at our section [Demos&Tutorials](#) or watch it directly on [YouTube](#).

Home
[Registration](#)
[Contact](#)
[Status](#)
[Images & Movies](#)

[Query Form](#)

[Credits](#)

[Documentation](#)



<http://www.multidark.org/MultiDark/>

Kristin Riebe, Adrian Partl, Harry Enke, Gerard Lemson(Millennium)

Project supported by MultiDark and the German Astrophysical Virtual Observatory (GAVO)

Input raw data: Bolshoi and MultiDark simulations

- Cosmology
 - $h = 0.70$
 - slope $n = 0.95$
 - normalization $\sigma_8 = 0.82$
 - $\Omega_\Lambda = 0.73$
 - $\Omega_{bar} = 0.0469$
- Initial conditions: $Z_{ini} = 80$, $P(k)$: CAMB table
- 2048^3 particles
- box: $250h^{-1}\text{Mpc}$ (Bolshoi) and $1000h^{-1}\text{Mpc}$ (MultiDark)
- Input: particles on a 1024^3 grid, four redshifts

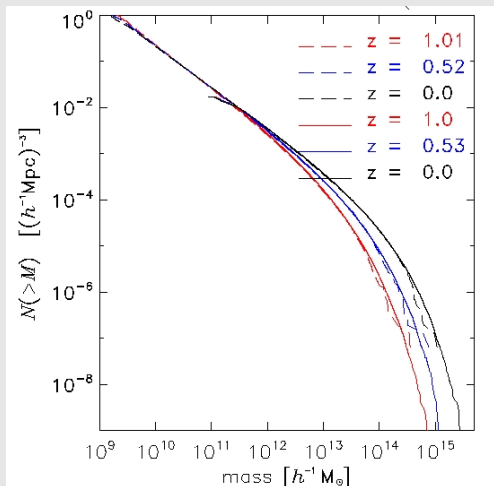
Input catalogs: FOF

- FOF
 - catalogs at 4 different linking lengths which correspond to different overdensities see the poster of Surhud More
 - FOF objects and subhalos
 - supercluster (and clusters within them)
 - particles per object (position, velocity)
 - merging tree (Jaime Forero)

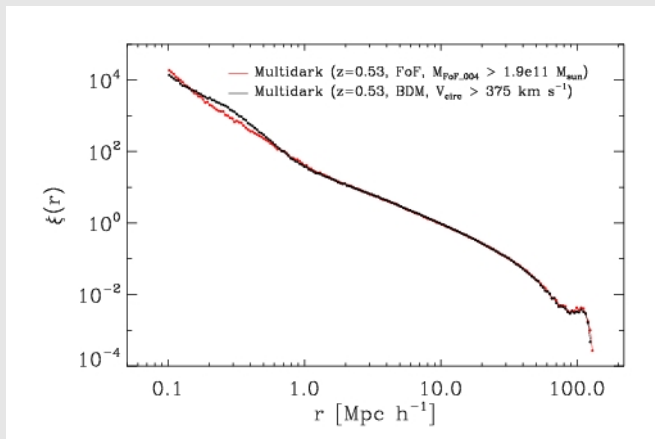
Input catalogs: BDM

- BDM (A. Klypin)
 - catalogs (halos and sub-halos)
 - profiles
 - galaxies

Output example: Bolshoi & MultiDark - mass functions



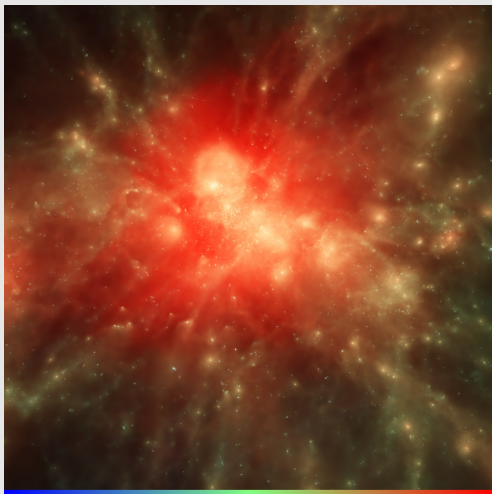
Output example: Halo correlation function



Input: Cluster re-simulations (Gustavo Yepes)

- 520 clusters with $M_{cl} > 10^{14} h^{-1} M_{\odot}$
- radiative SPH simulation (Springel-Hernquist)
- cluster properties
- profiles

The most massive cluster in MultiDark



Done with the SPLITCH software of Klaus Dolag.

The end: Thank you

Numerical simulations are a useful and necessary tool to get new insights into the evolution of the complex structure of the real Universe. A data base helps to explore the upcoming huge data sets from simulations.

<http://www.multidark.org/MultiDark/>