Bullet Clusters in the MareNostrum Universe

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Collaborators

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- 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

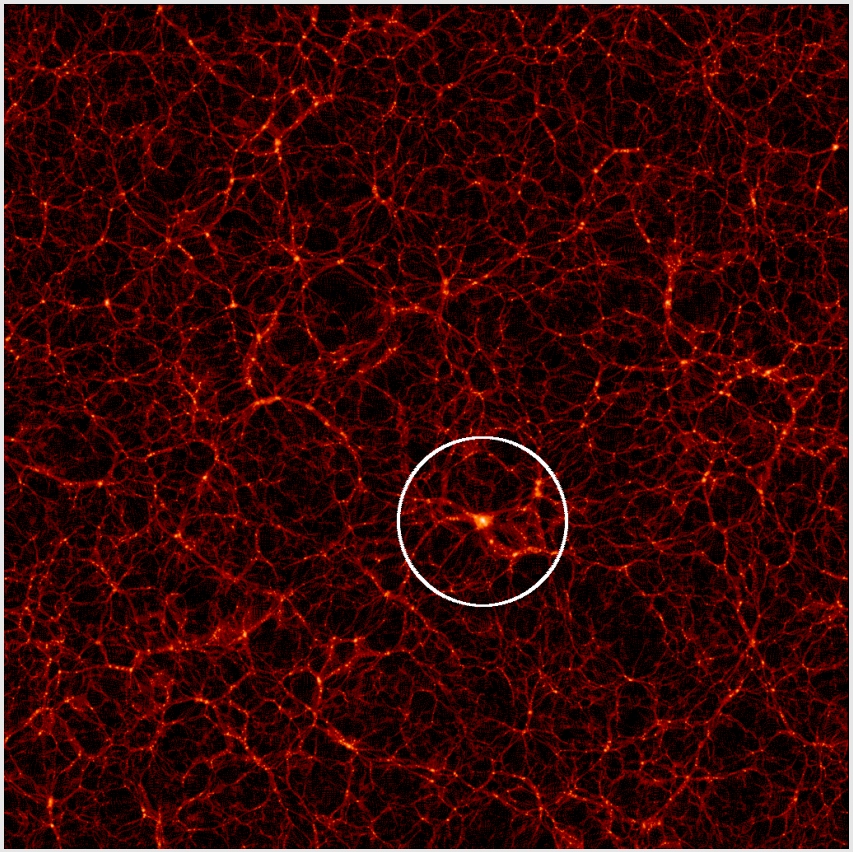
MareNostrum at chapel Torre Girona (BSC)

MareNostrum Numerical project

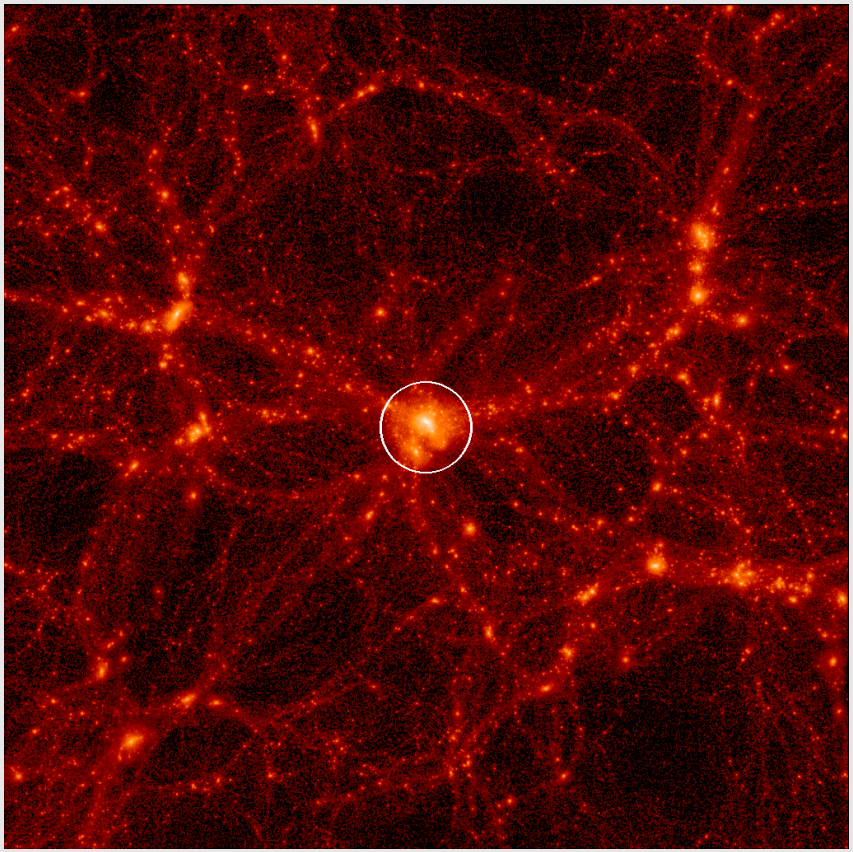
MareNostrum Universe

- 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

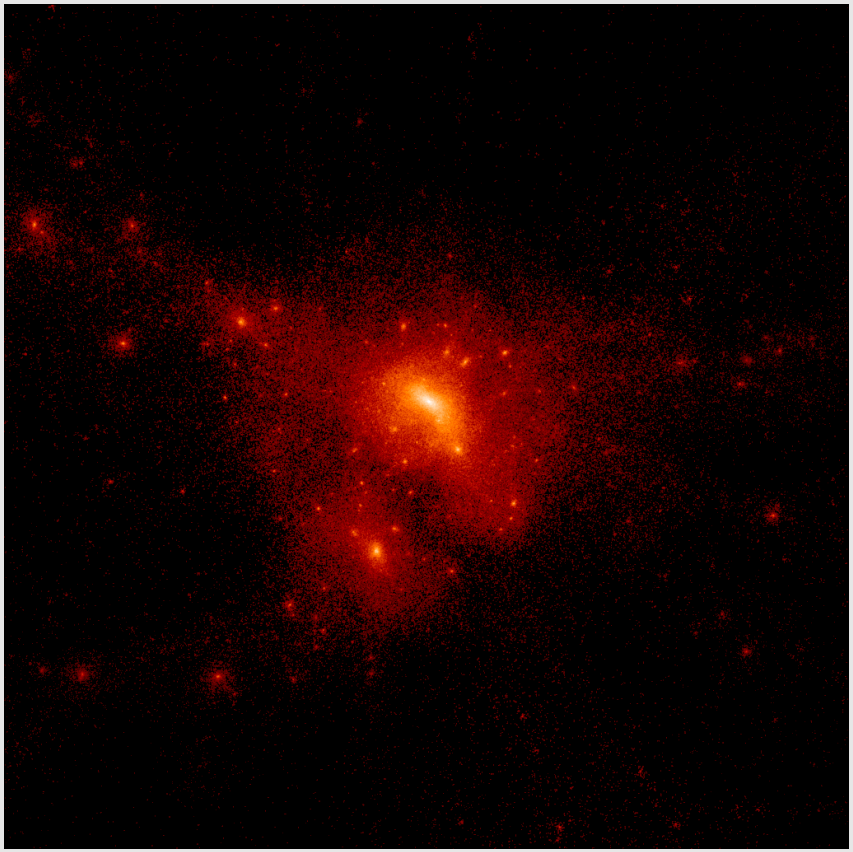


circle $100h^{-1}\mathrm{Mpc}$

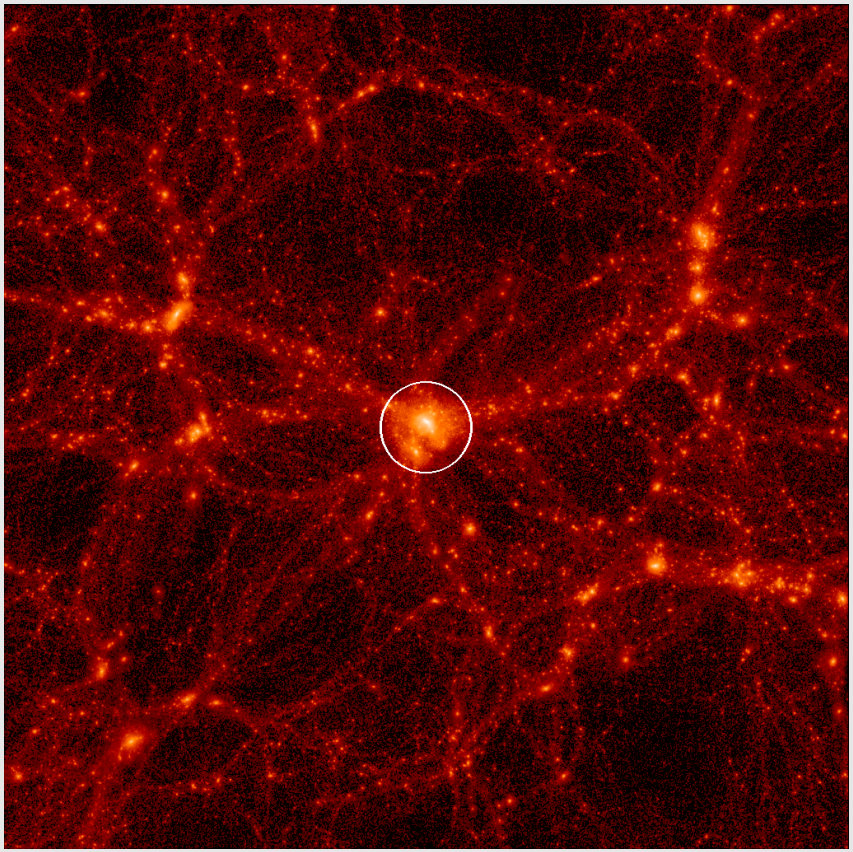


circle $20h^{-1}\mathrm{Mpc}$

The most massive cluster



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



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

Bullet Clusters in the MareNostrum Universe

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

Table: Analyzed redshifts z, number of selected clusters with $M > 10^{14} h^{-1}\mathrm{M}_{\odot}$ 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

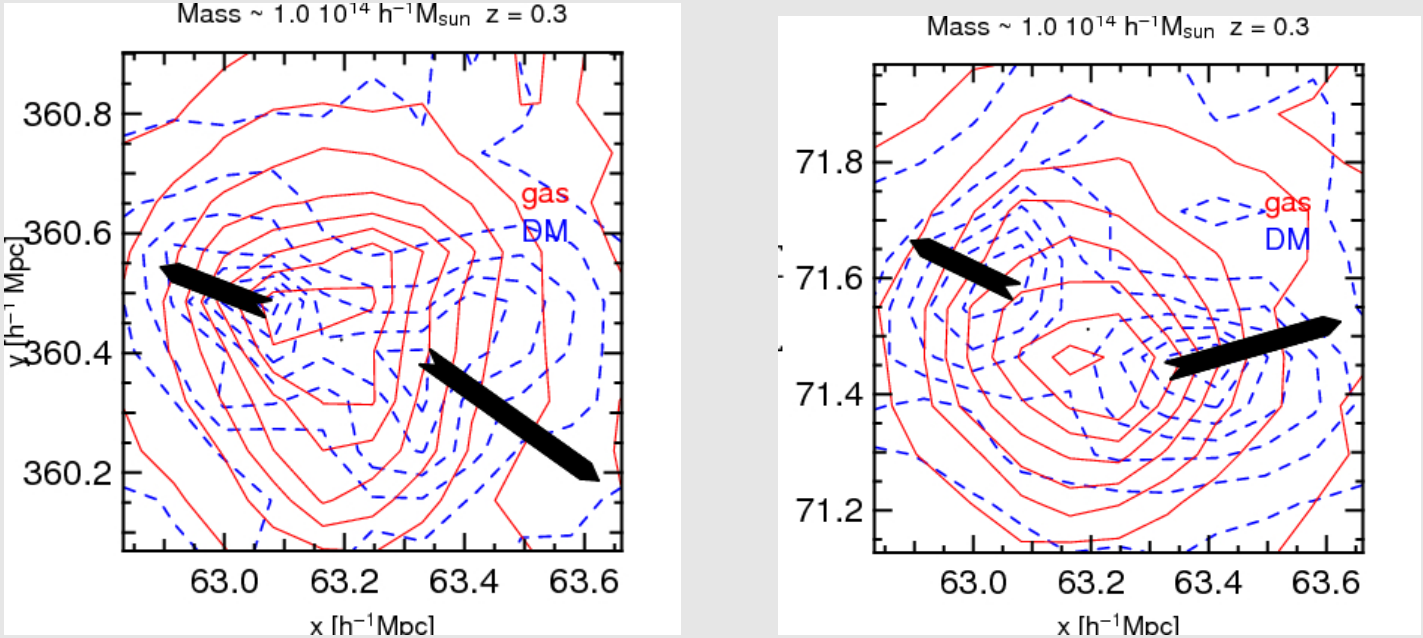
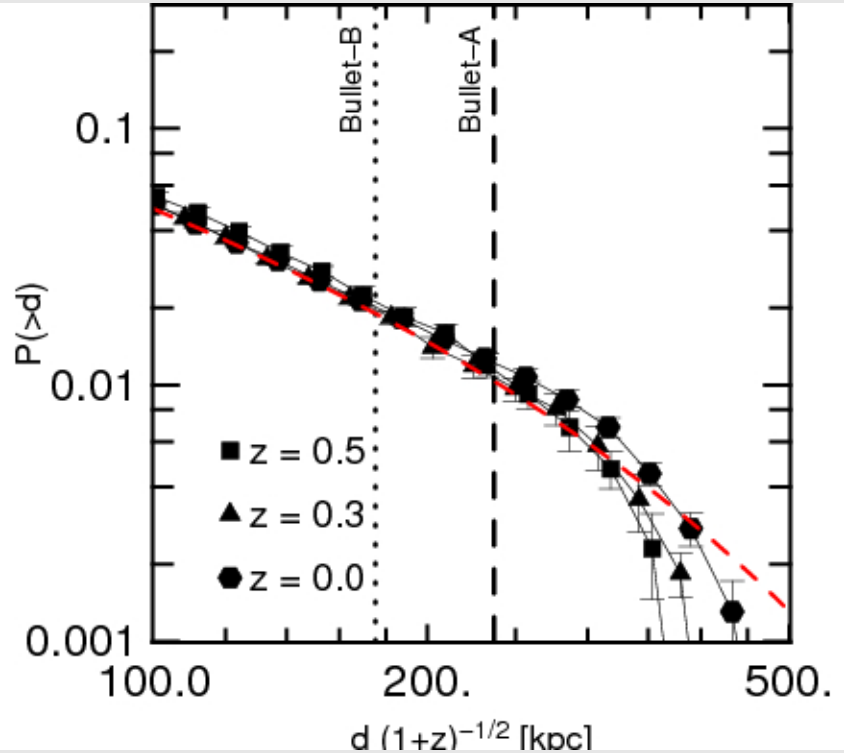


Figure: Linearly spaced surface density contours for the DM (dashed blue) and gas (continuous red) components of a cluster ($M = 1.0 \times 10^{14} h^{-1} \mathrm{M}_{\odot}$ at redshift $z = 0.3$). The arrows are proportional to the velocities with respect to the center of the gas core, the relative 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 ($P_0 = 0.04$, $d_\star = 200$ kpc and $\alpha = -1.0$):

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

Bullet Clusters in the MareNostrum Universe

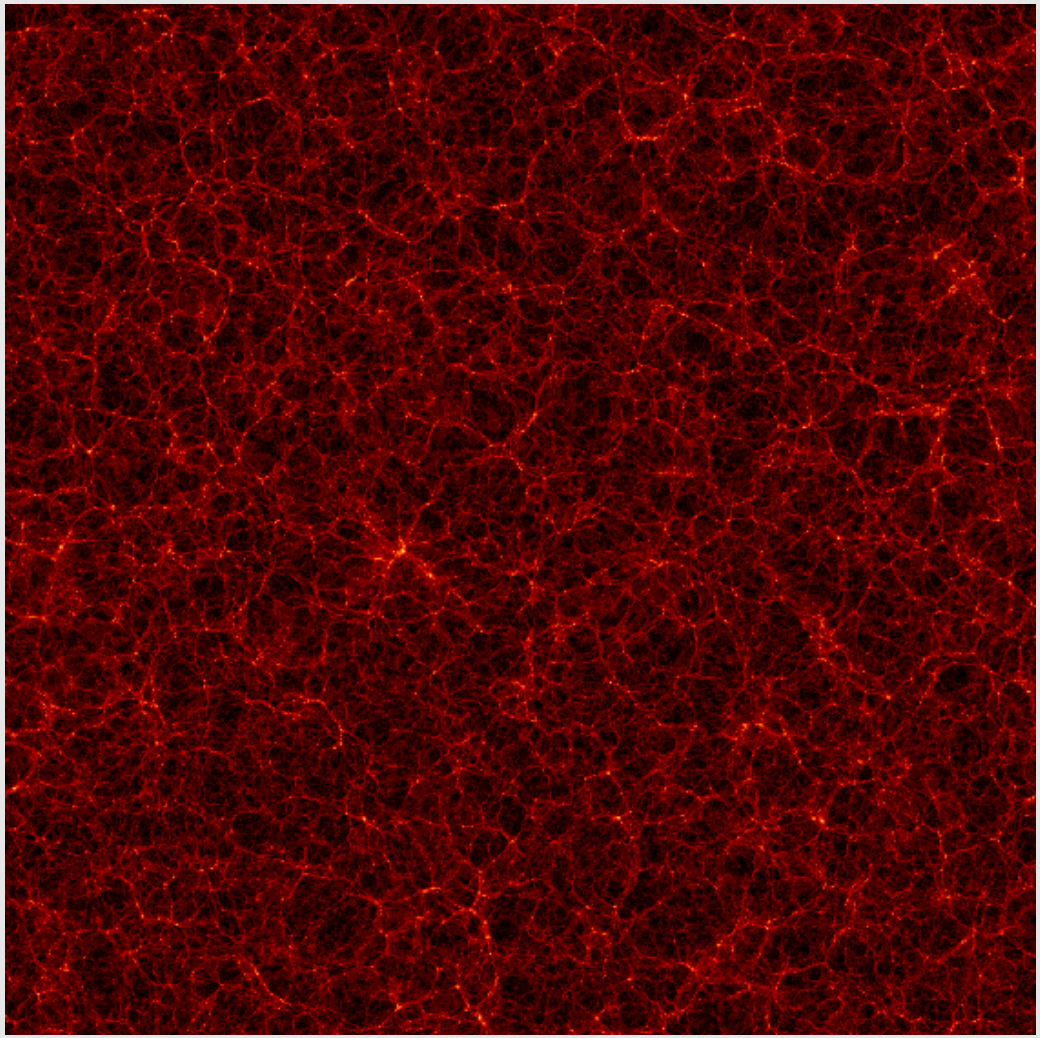
- large DM-gas displacements are fairly common in a ΛCDM cosmology
- around 1% to 2% of clusters with masses $M > 10^{14} h^{-1} \mathrm{M}_{\odot}$ show DM-gas separations equal or larger than the observed in the Bullet Cluster
- J.E. Forero-Romero et al. ApJ 725 (2010), 604

Clusters in the MultiDark simulation

The MultiDark simulation

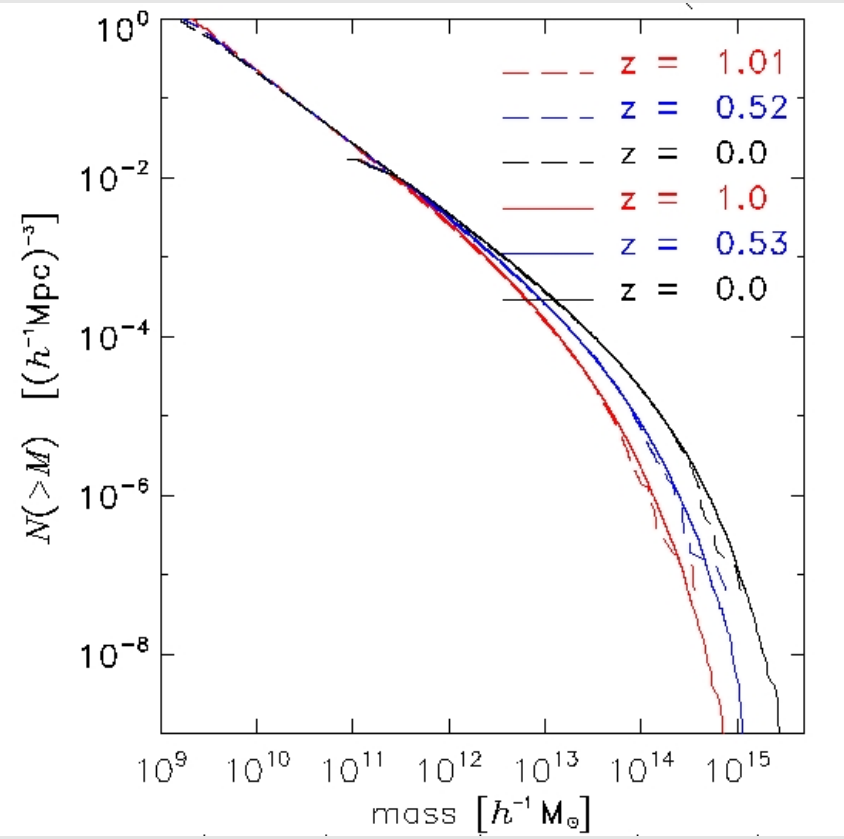
- 2048^3 particles
- ART simulation (NAS pleiades)
- the same parameters as Bolshoi http://astronomy.nmsu.edu/aklypin/Bolshoi/
  - $\Omega_m = 0.27$
  - $\Omega_b = 0.0469$
  - $\Omega_\Lambda = 0.73$
  - $h = 0.7$
  - $\sigma_8 = 0.82$
  - $n = 0.95$
  - $z_{init} = 80$, $P(k)$: CAMB table

MultiDark - slice through the most massive cluster

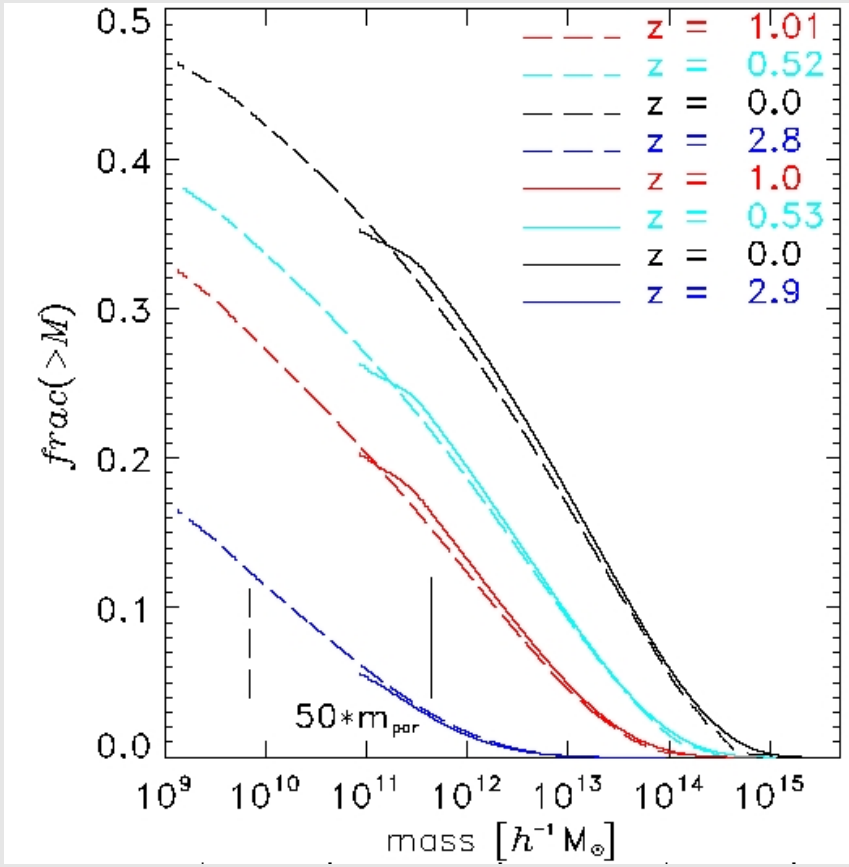


MultiDark resimulations

Mass function of MulitDark and Bolshoi



Fraction of mass in bound objects



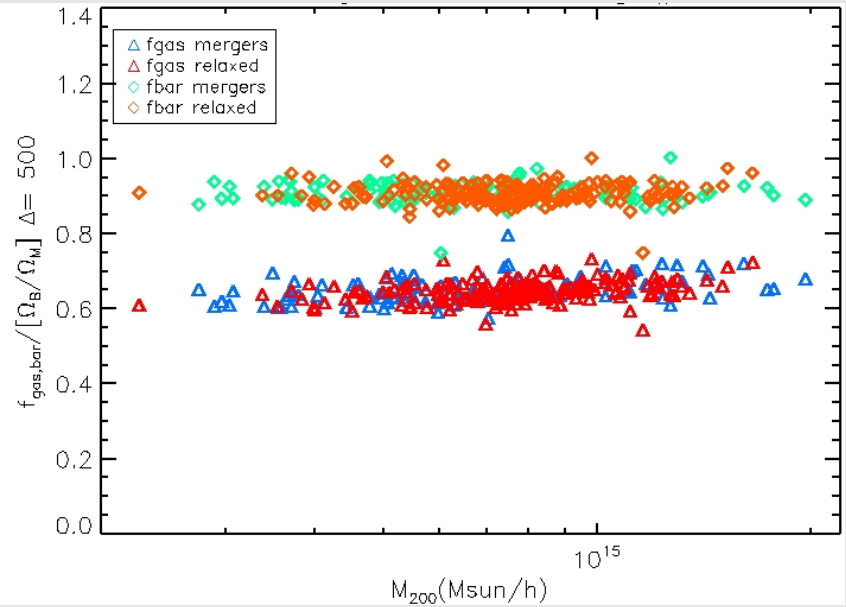
solid line (MultiDark), dashed line (Bolshoi)

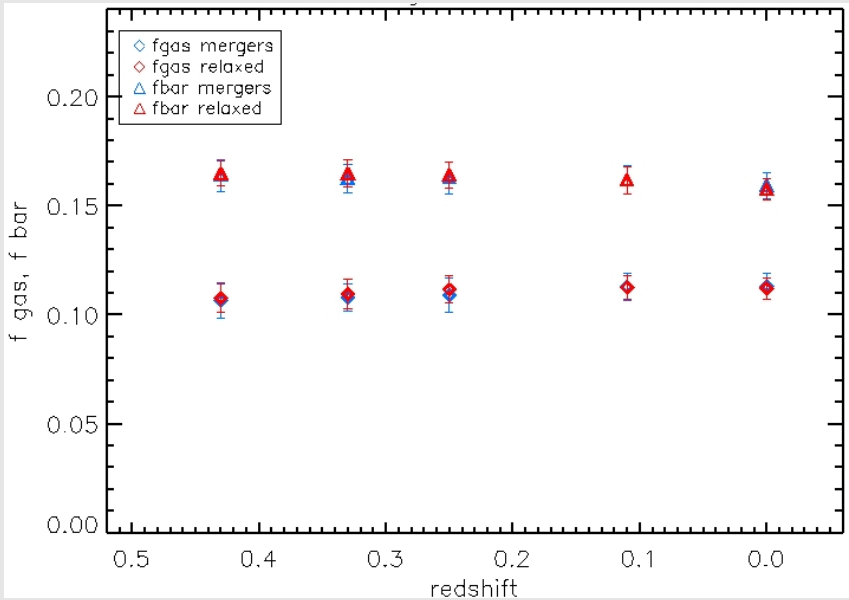
Cluster re-simulations (Gustavo Yepes)

- 283 cluster regions ($R = 6h^{-1}\mathrm{Mpc}$)
- local resolution 4096^3 particles
- radiative SPH simulation (Springel-Hernquist)
- $m_{DM} = 8.1 \times 10^8 h^{-1}\mathrm{M}_\odot$
- $m_{gas} = 1.9 \times 10^8 h^{-1}\mathrm{M}_\odot$
- complete for $M_{cl} > 10^{15} h^{-1}\mathrm{M}_\odot$ (105 clusters)
- total: 520 clusters with $M_{cl} > 10^{14} h^{-1}\mathrm{M}_\odot$
- most massive cluster $M_{cl} = 2.7 \times 10^{15} h^{-1}\mathrm{M}_\odot$ cluster1

Clusters in the MultiDark simulations (Federico Sembolini)

see also Federico's poster





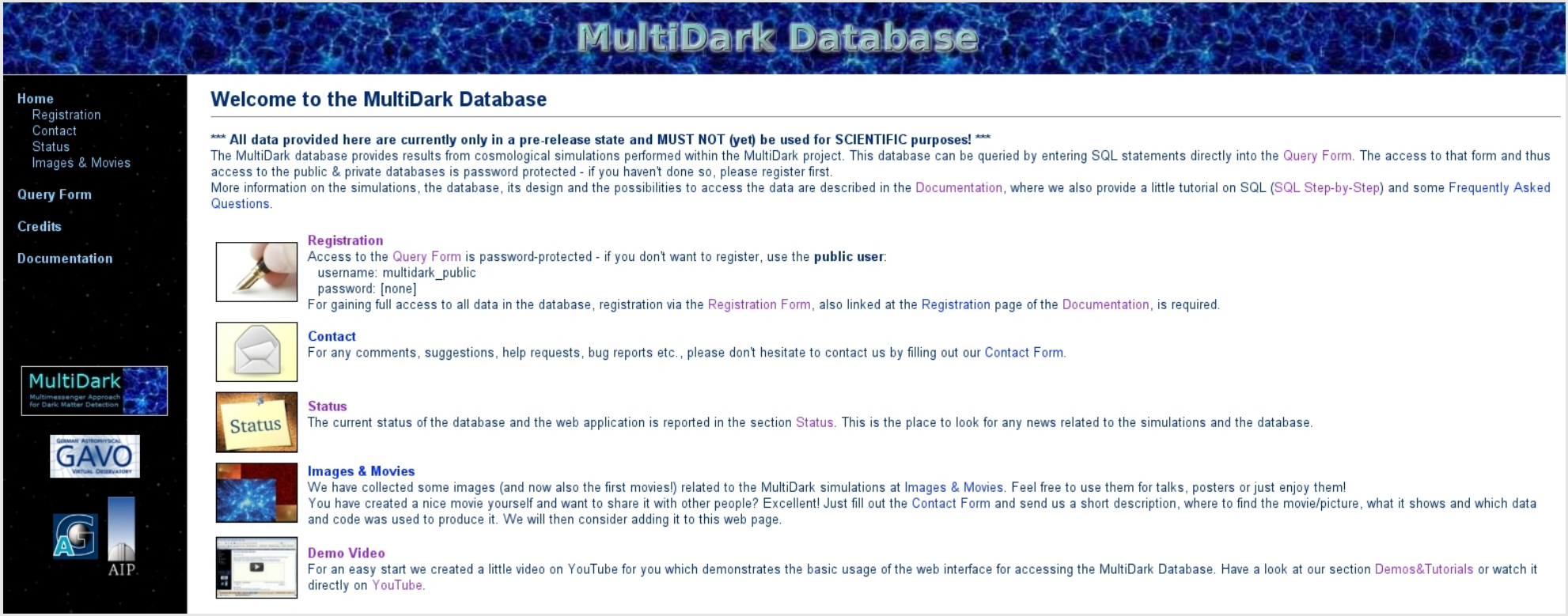
Baryon and gas fractions in clusters (mergers and relaxed clusters) at overdensity 500

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

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

The MultiDark database at AIP

MultiDark database



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

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

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: $250h^{-1}\mathrm{Mpc}$ (Bolshoi) and 1000 $h^{-1}\mathrm{Mpc}$ (MultiDark)
- Input: particles on a 1024^3 grid, four redshifts

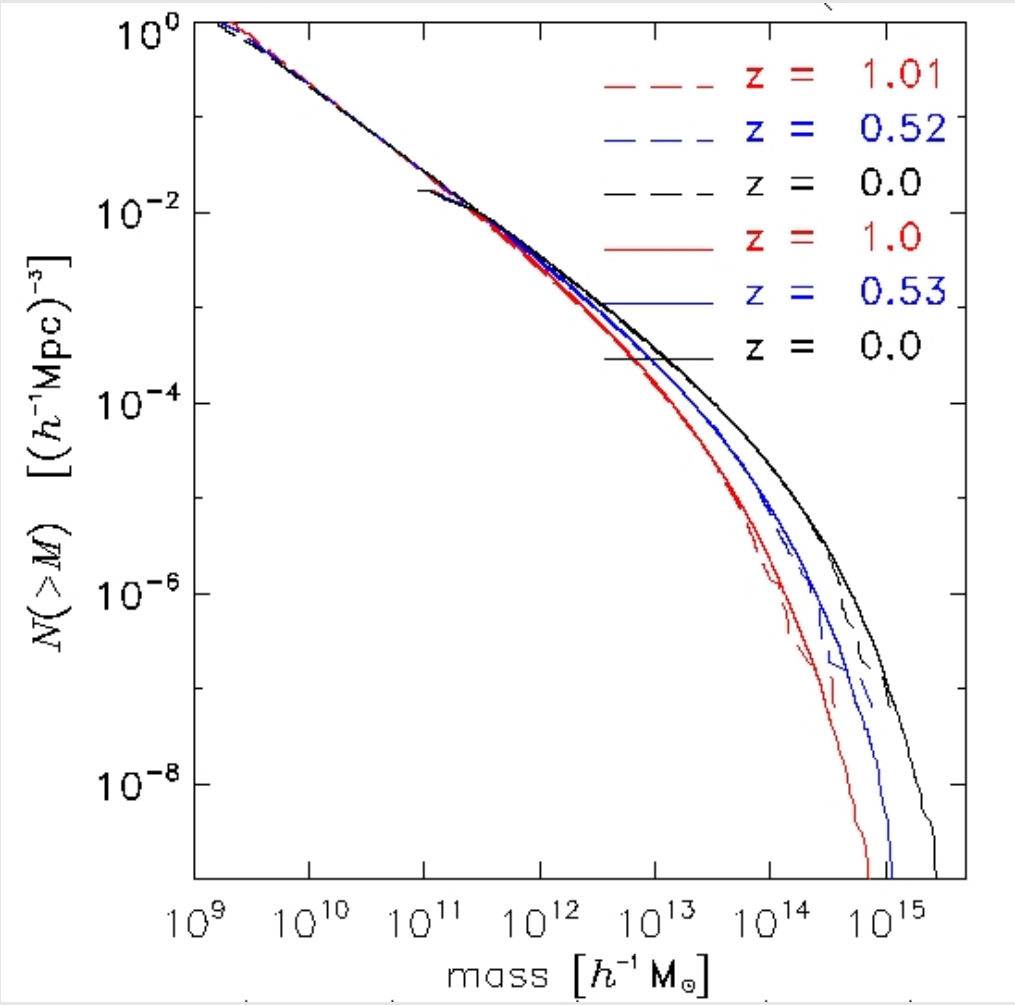
Input catalogs: FOF

- 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)

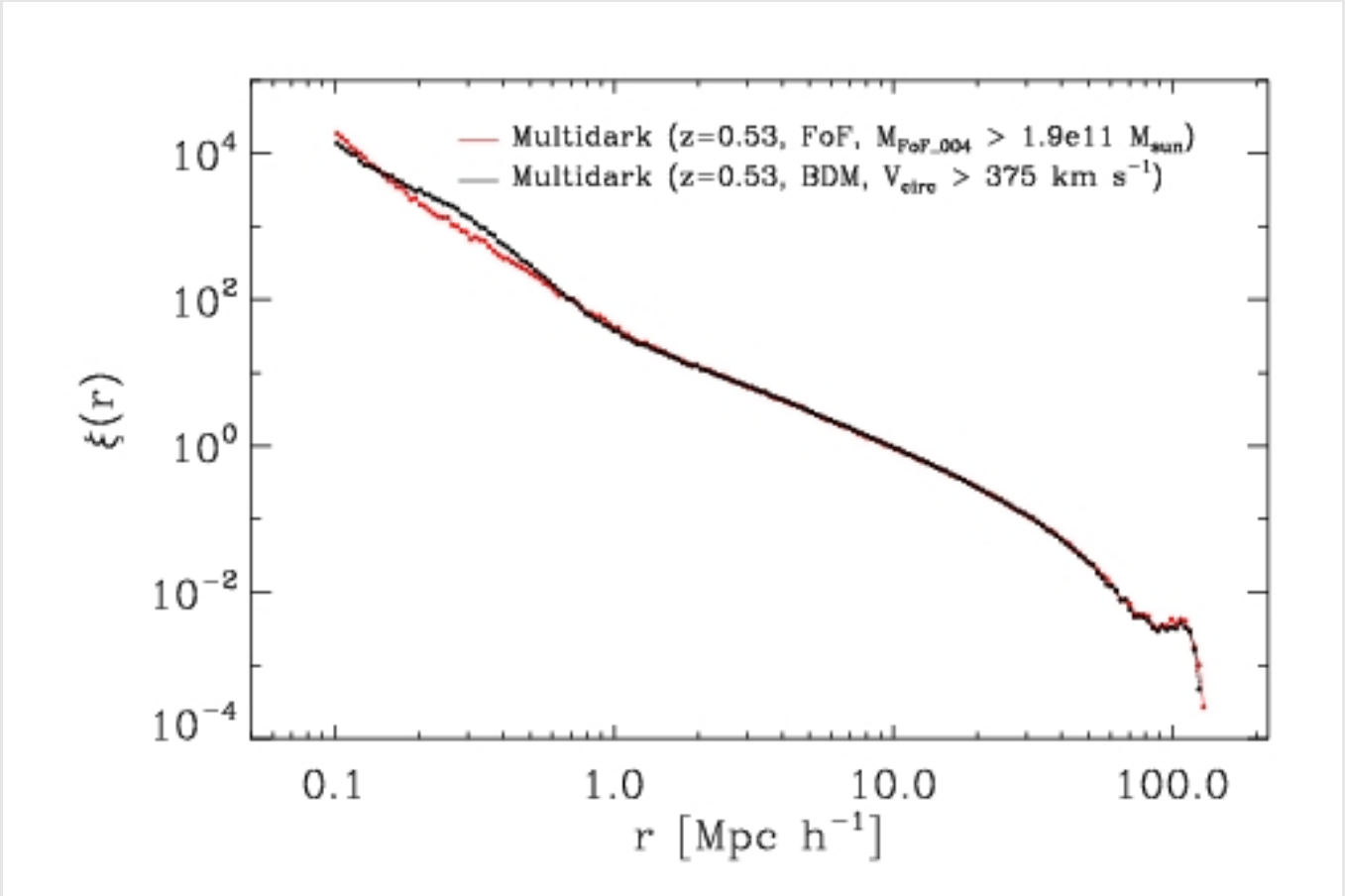
Input catalogs: BDM

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

Output example: Bolshoi & MultiDark - mass functions



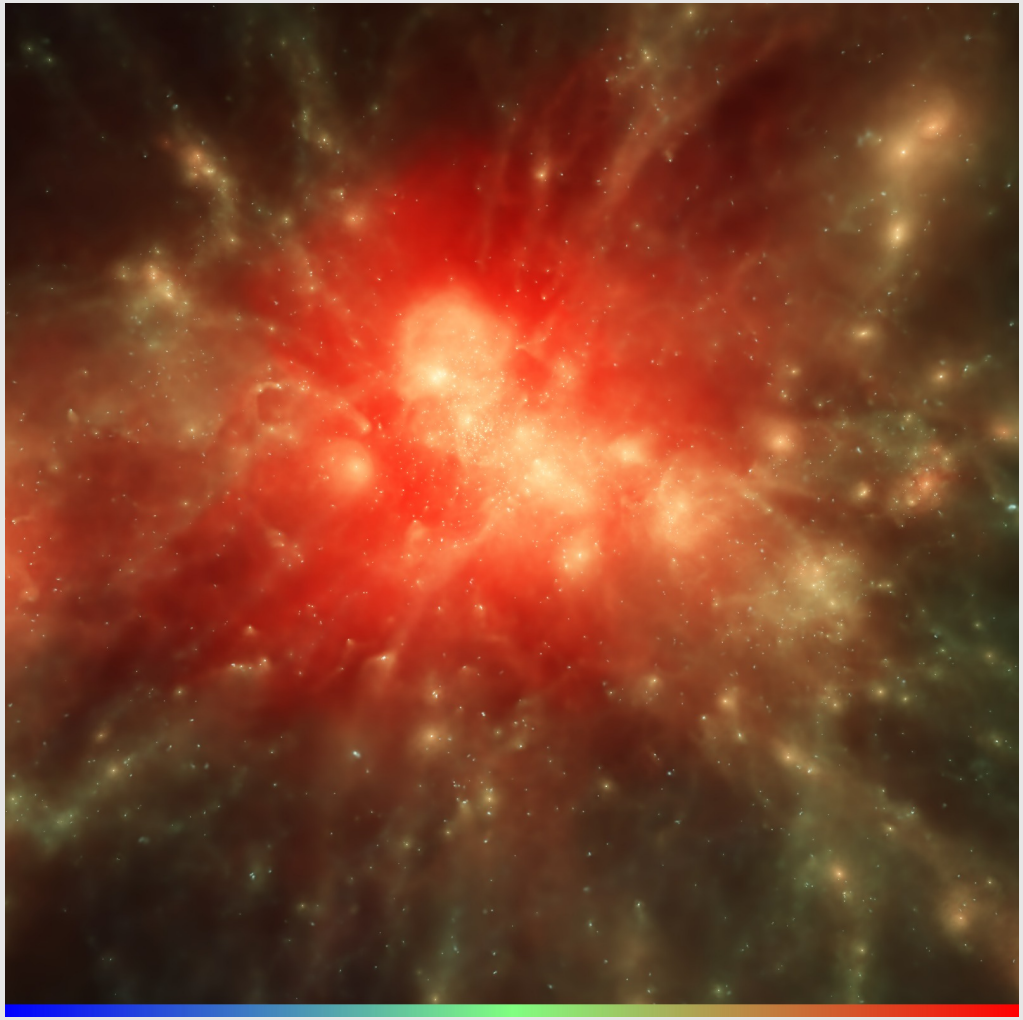
Output example: Halo correlation function



Input: Cluster re-simulations (Gustavo Yepes)

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

The most massive cluster in MultiDark



Done with the SPLOTCH 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/