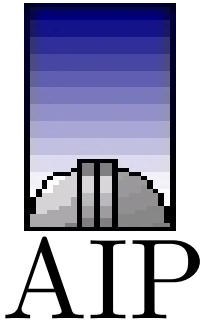

ASTROPHYSIKALISCHES INSTITUT
POTSDAM

Dark and baryonic matter in the MareNostrum Universe

Stefan Gottlöber
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MareNostrum

MareNostrum at BSC Barcelona
4812 PowerPC970 FX processors (dual)
4 GB memory per node (total: 9.6 Tb main memory, 233 Tb disk)

MareNostrum

TOP500 BSC Certificate

TOP500 CERTIFICATE

MareNostrum, an IBM eServer BladeCenter JS20 System at the Barcelona Supercomputing Center, Spain

is ranked

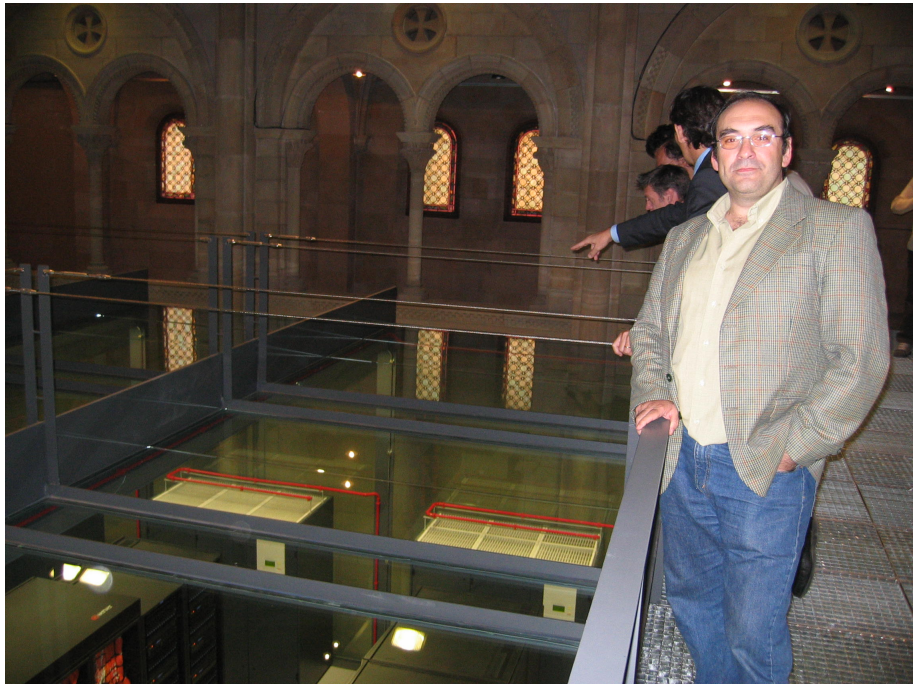
No. 1 in Europe

among the World's TOP500 Supercomputers
with 27.9 TFlop/s Linpack Performance
on the TOP500 List published at the ISC2005 Conference, June 22, 2005.

Congratulations from the TOP500 Editors

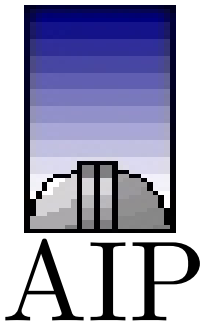
Hans Meuer, University of Mannheim
Erich Strohmaier, NERSC/Berkeley Lab
Jack Dongarra, University of Tennessee
Horst Simon, NERSC/Berkeley Lab

MareNostrum Universe



- initial number for random phases

- three weeks on 512 CPUs
- 29 CPU-years
- output: 8600 Gbyte



ASTROPHYSIKALISCHES INSTITUT POTSDAM

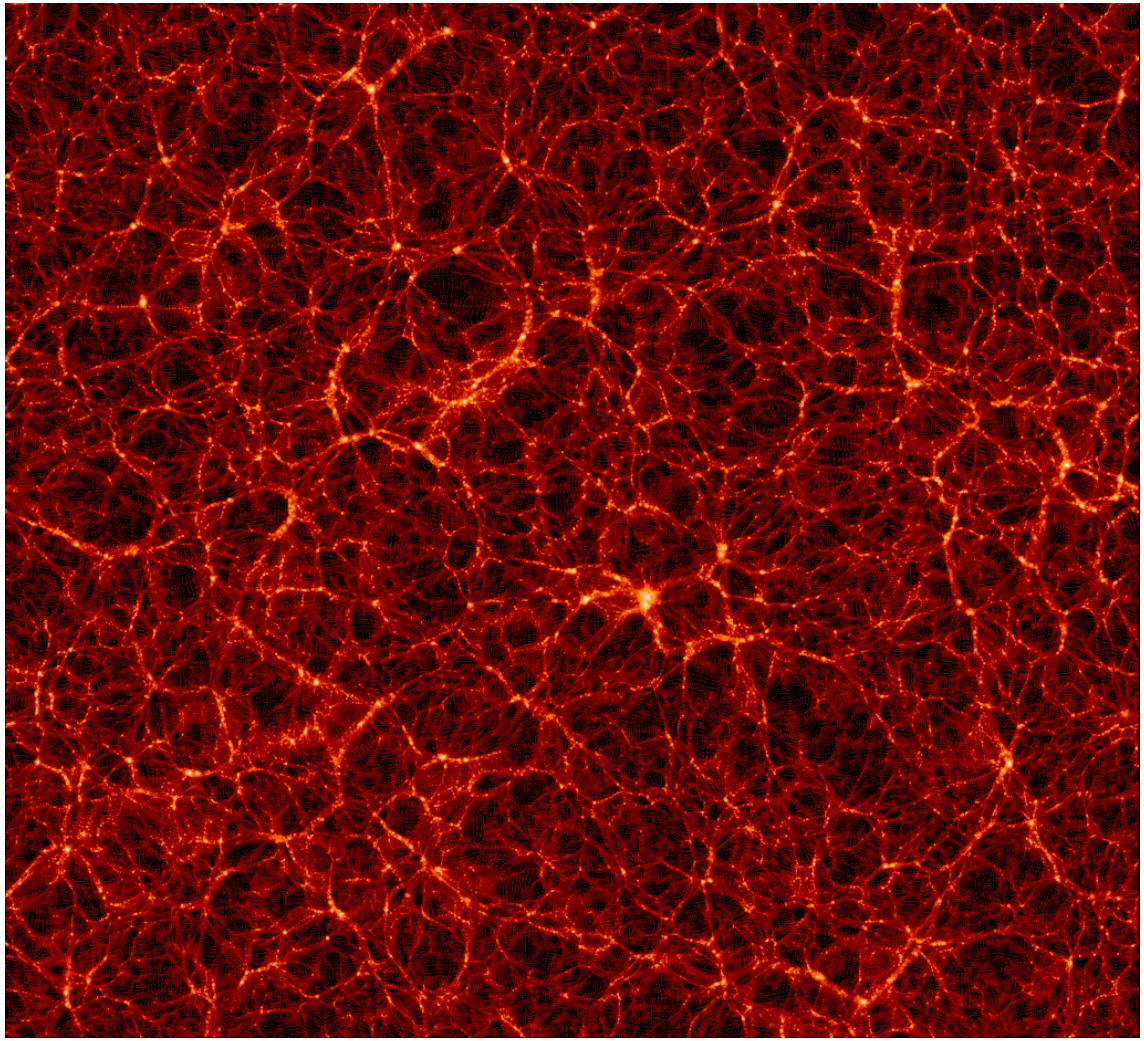
The Large Scale Structure of the MareNostrum Universe

Stefan Gottlöber

Collaborators

Gustavo Yepes (UAM, Madrid)
Matthias Hoeft (IU Bremen)
Massimo Meneghetti (ZAH, Heidelberg)
Christian Wagner (AIP, Potsdam)
Raul Sevilla (UAM, Madrid)
Armen Khalatyan (AIP, Potsdam)
Victor Turchaninov (IAM, Moscow)

The simulation

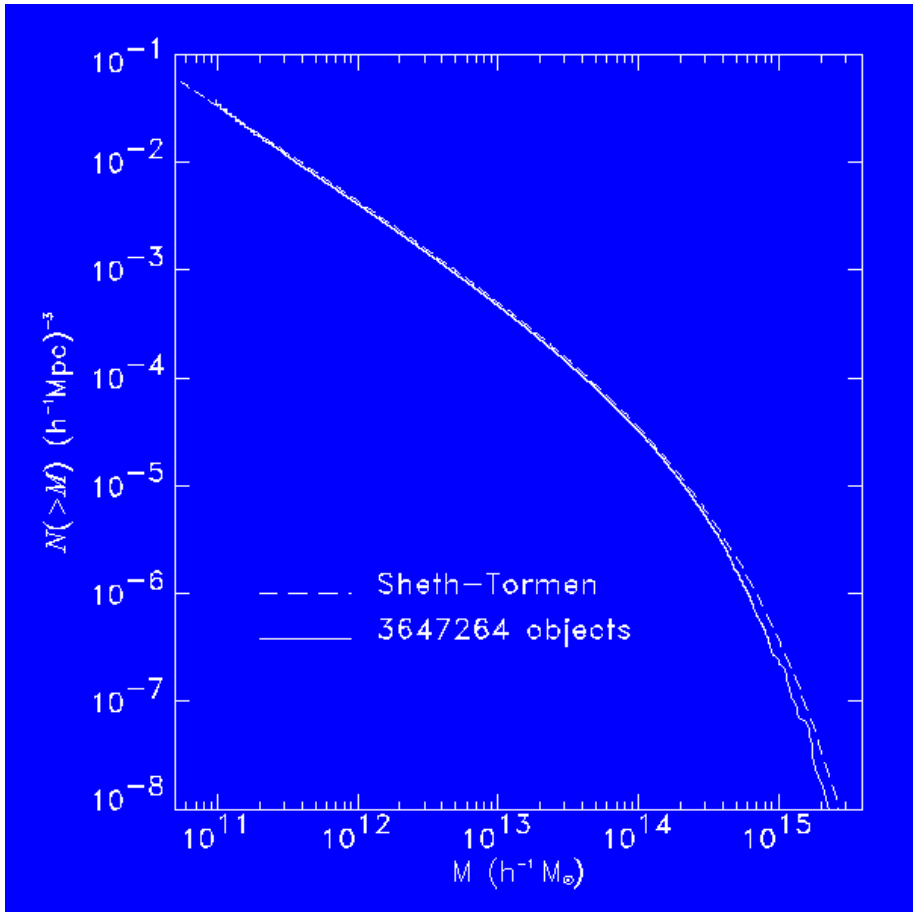


- 500 h^{-1}Mpc box
- 1024^3 DM particles, 1024^3 gas particles,
- GADGET II (Volker Springel)
- adiabatic simulation
- force resolution: 15 kpc
- now finding halos .....

MST and hierarchical FOF

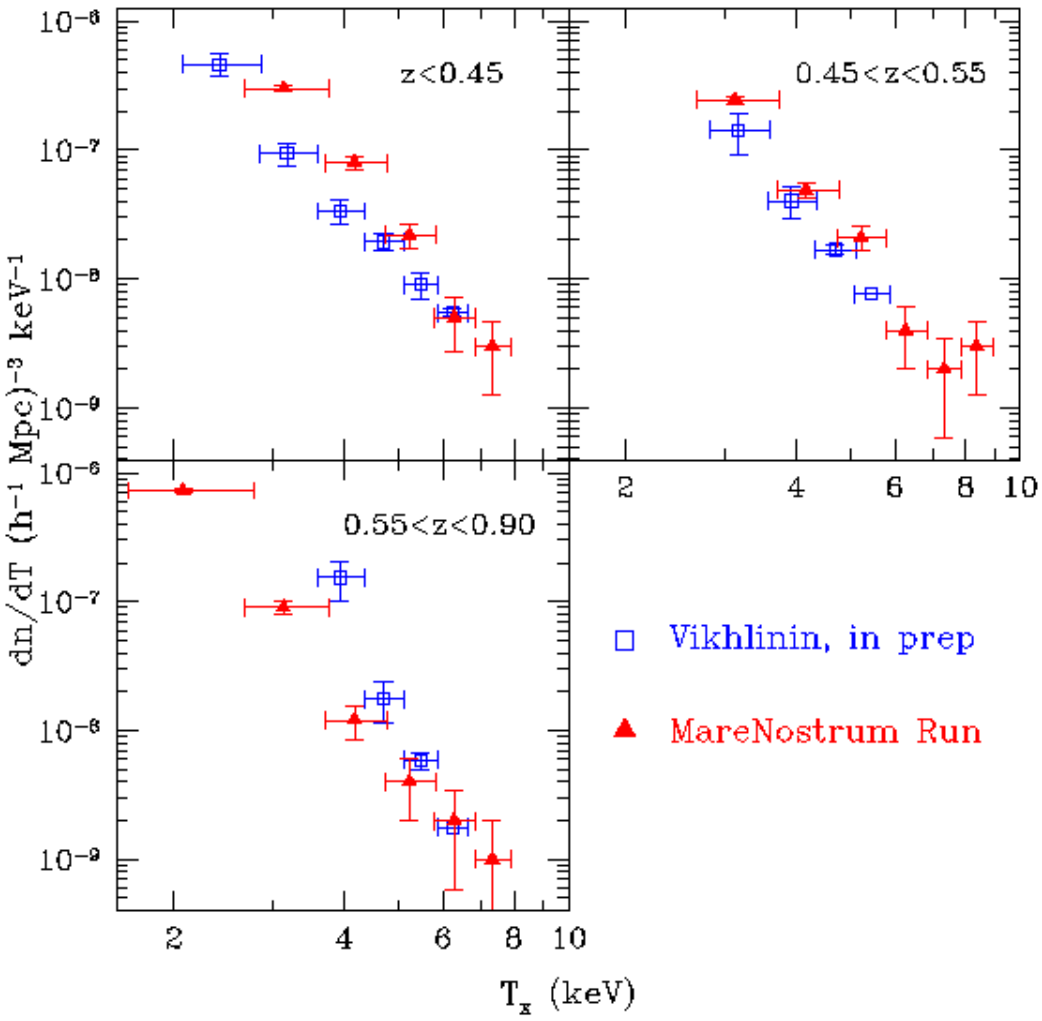
- Minimum spanning tree (MST) of n points contains $N-1$ connections
- sorting of particles in a cluster-ordered sequence $P = \{p_1, p_2, ..., p_n\}$
- any cluster is a segment of the sequence P: $p_i, p_{i+1}, ..., p_j$
- neighboring clusters are neighboring segments
- $p_i, p_{i+1}, ..., p_j$ and $p_{j+1}, p_{j+2}, ..., p_k$ merge by $r_{j+1/2}$
- The sequences P and R are sufficient for deriving the complete list of clusters at any linking length r.
- hierarchical Friends of Friends analysis delivers structures at virial overdensity and all substructures
- mass, shape, orientation, angular momentum, list of particles of the given object (from P), ...
- timing: analysis of 1024^3 particles in 4 hours using 32 CPUs

Halo mass function

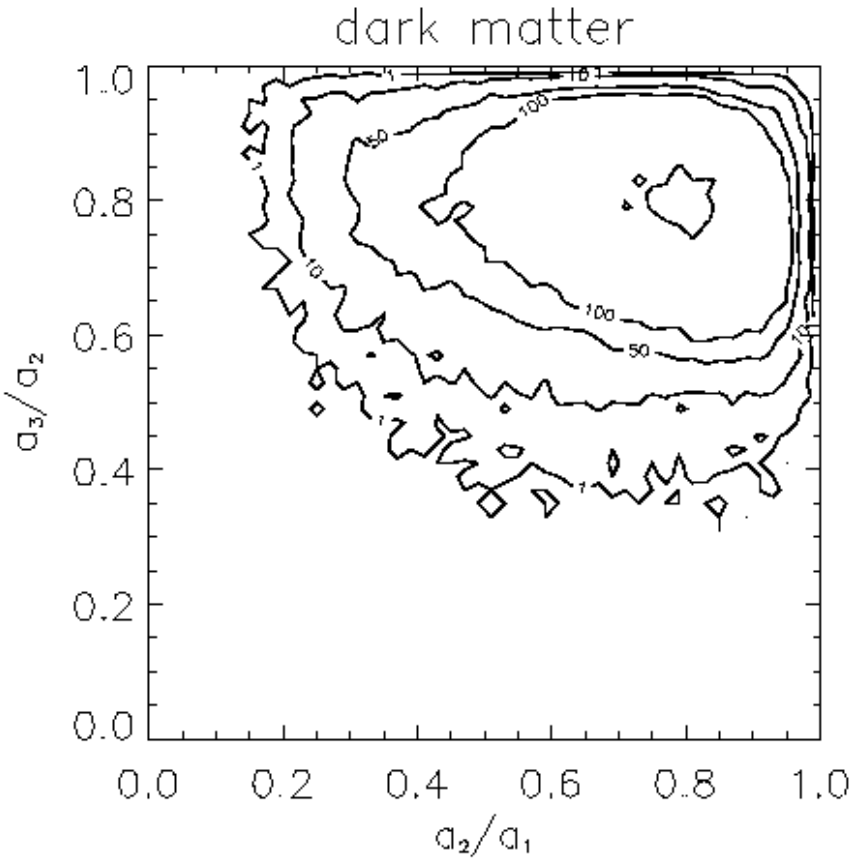


4063 clusters with $m_{cl} > 10^{14} h^{-1}\mathrm{M}_\odot$
58167 groups + clusters with $m > 10^{13} h^{-1}\mathrm{M}_\odot$
506000 objects with $m > 10^{12} h^{-1}\mathrm{M}_\odot$ (100 gas + 100 DM particles)
1 million objects with more than 100 particles

X-ray temperature function at different redshifts



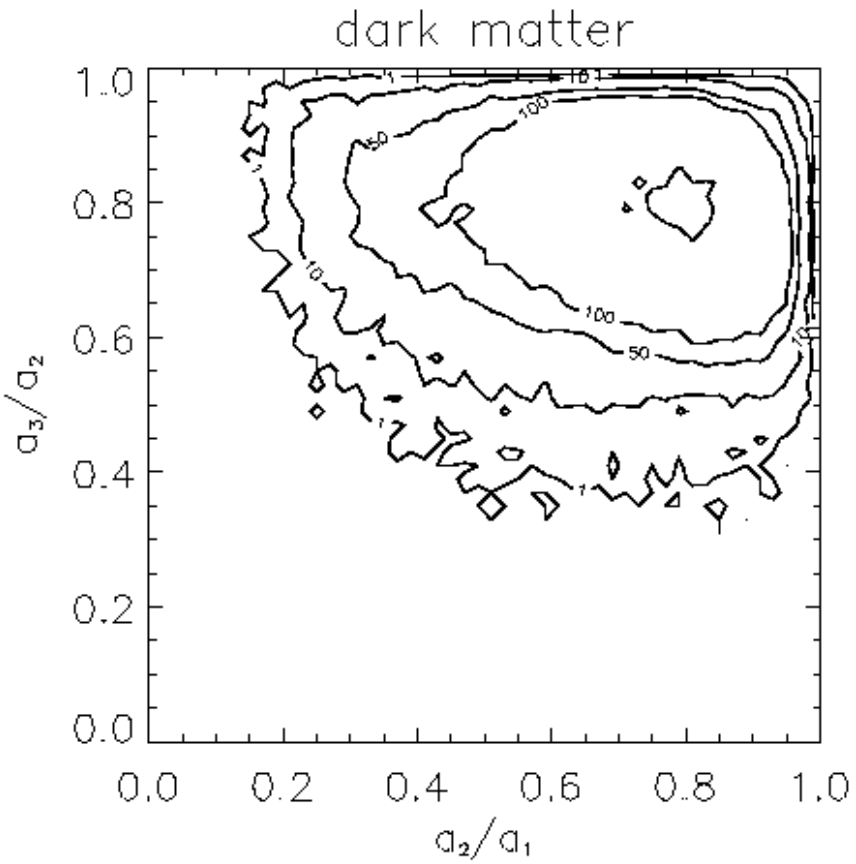
Shape of the halos



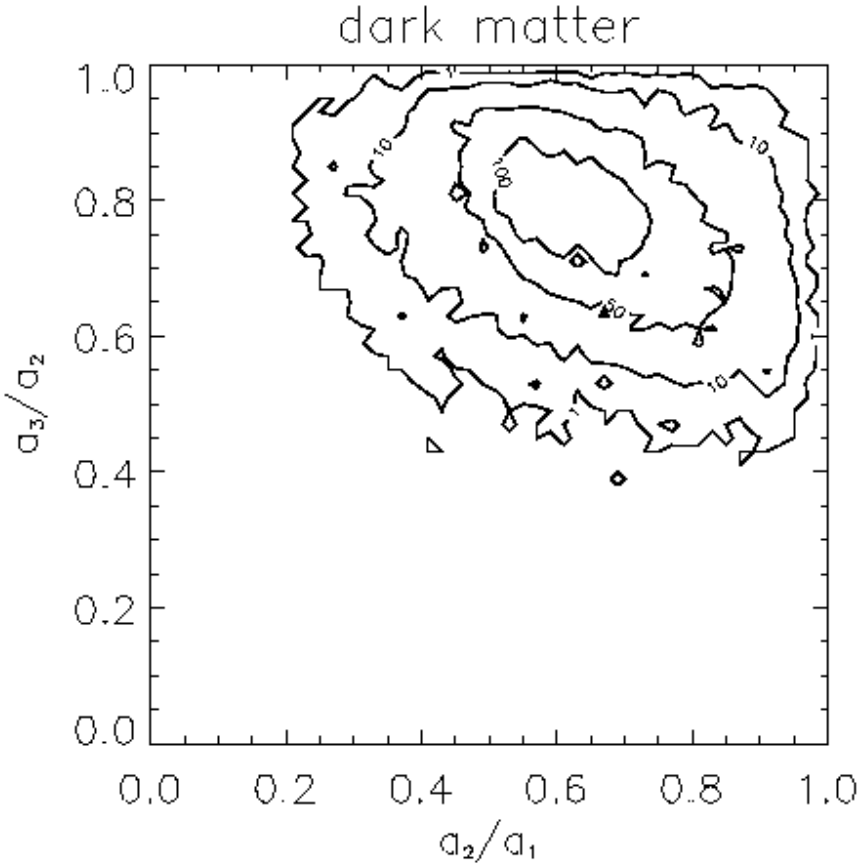
shape of the dark matter distribution
at virial overdensity
halos with more than 500 particles

- main axii $a_1 > a_2 > a_3$
- halos concentrated around $a_2/a_1 \approx 0.8$, $a_3/a_2 \approx 0.8$,

Shape of the halos

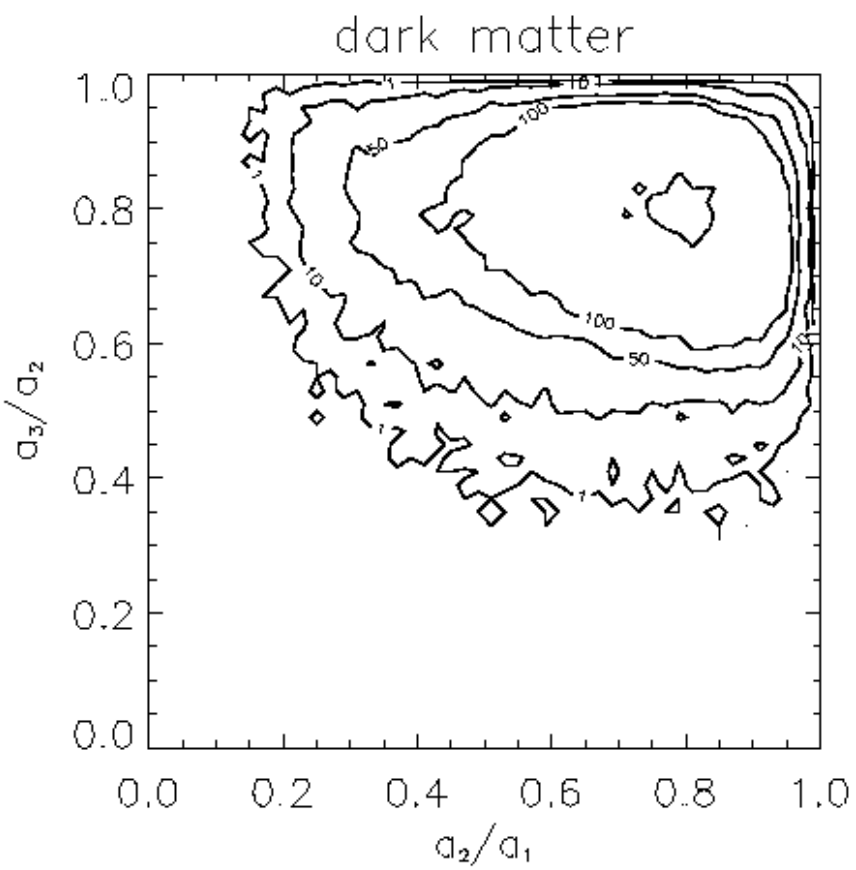


shape of the dark matter distribution at virial overdensity

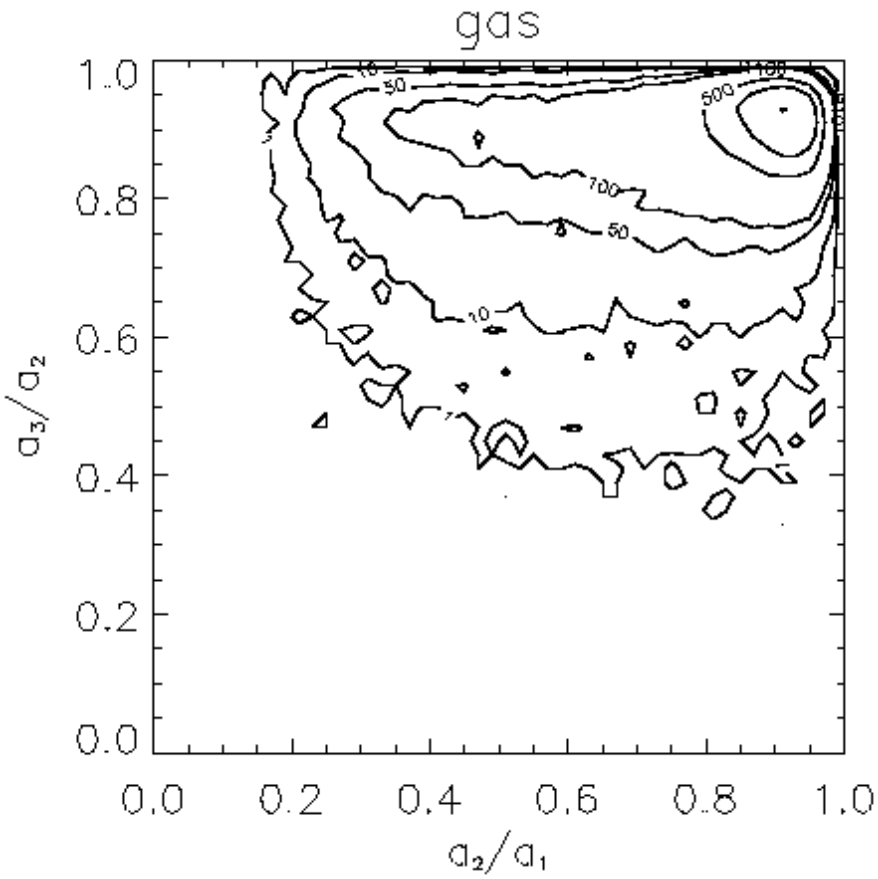


shape of the dark matter distribution at 64× virial overdensity

Shape of the halos

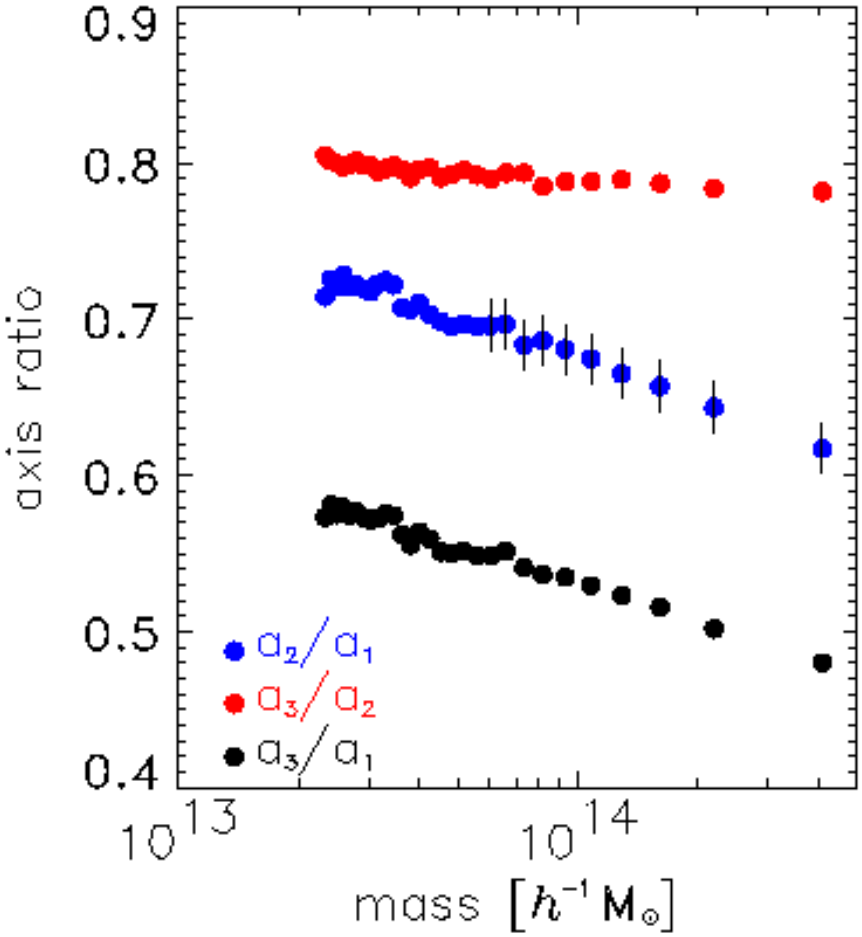


shape of the dark matter distribution at virial overdensity

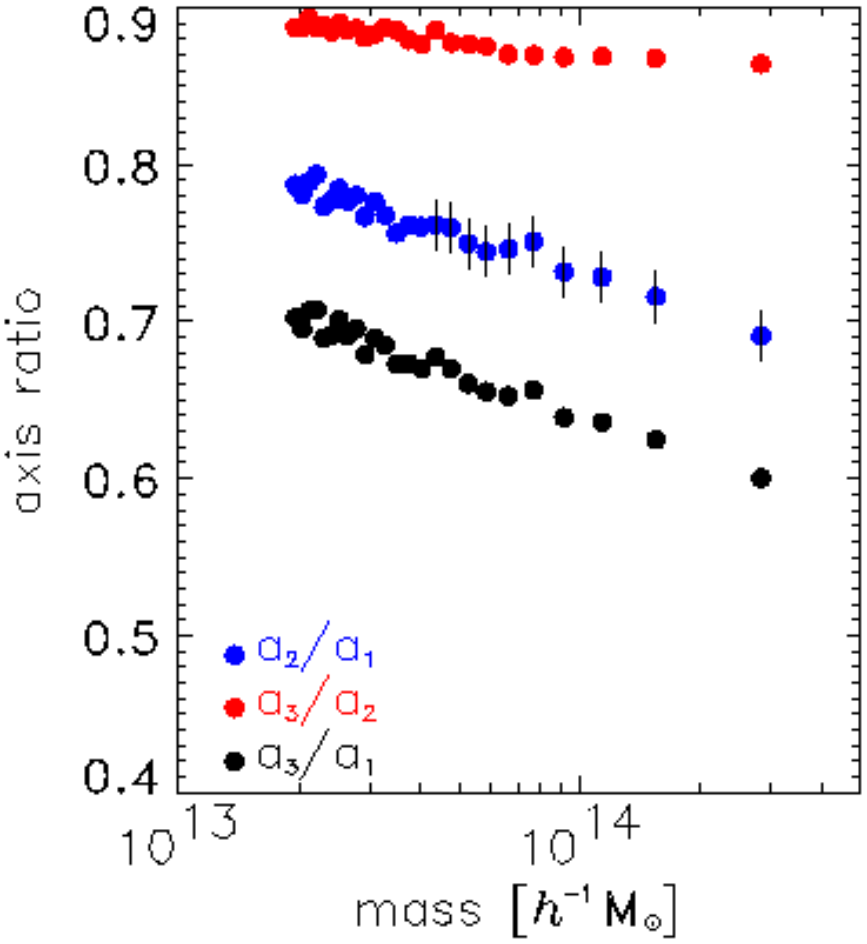


shape of the corresponding gas distribution

Shape depends on mass

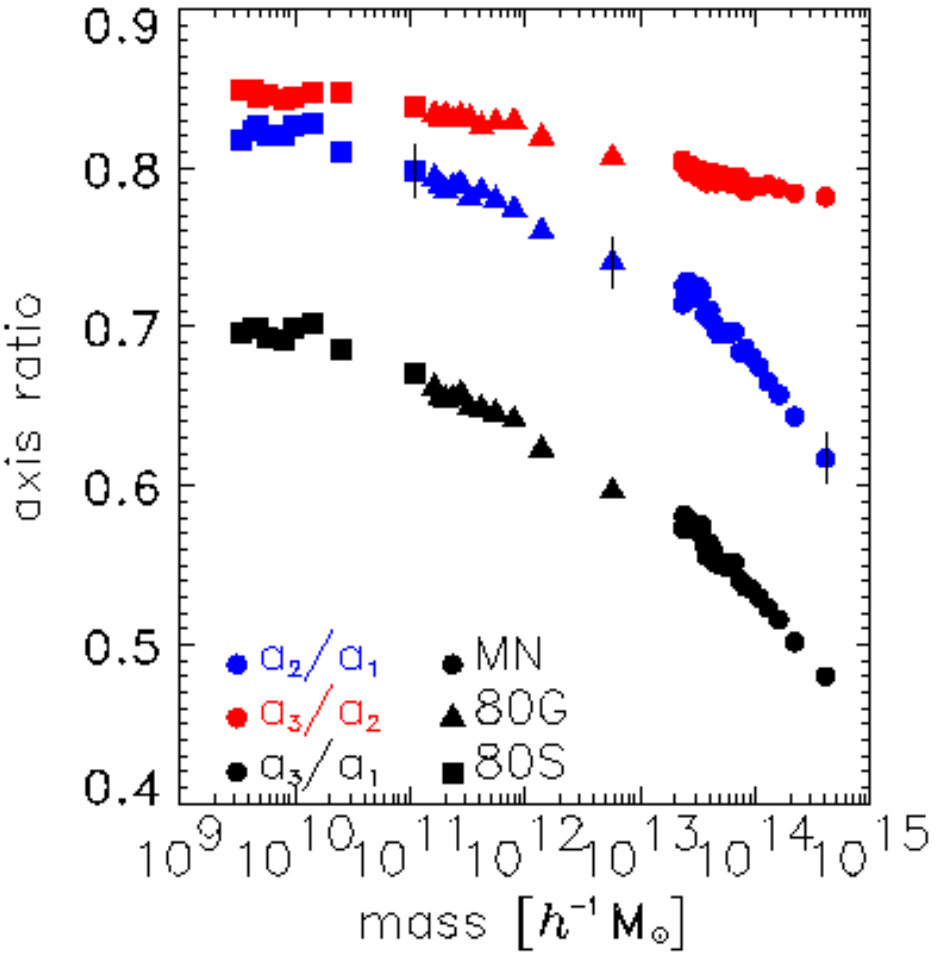


dark matter distribution



gas distribution

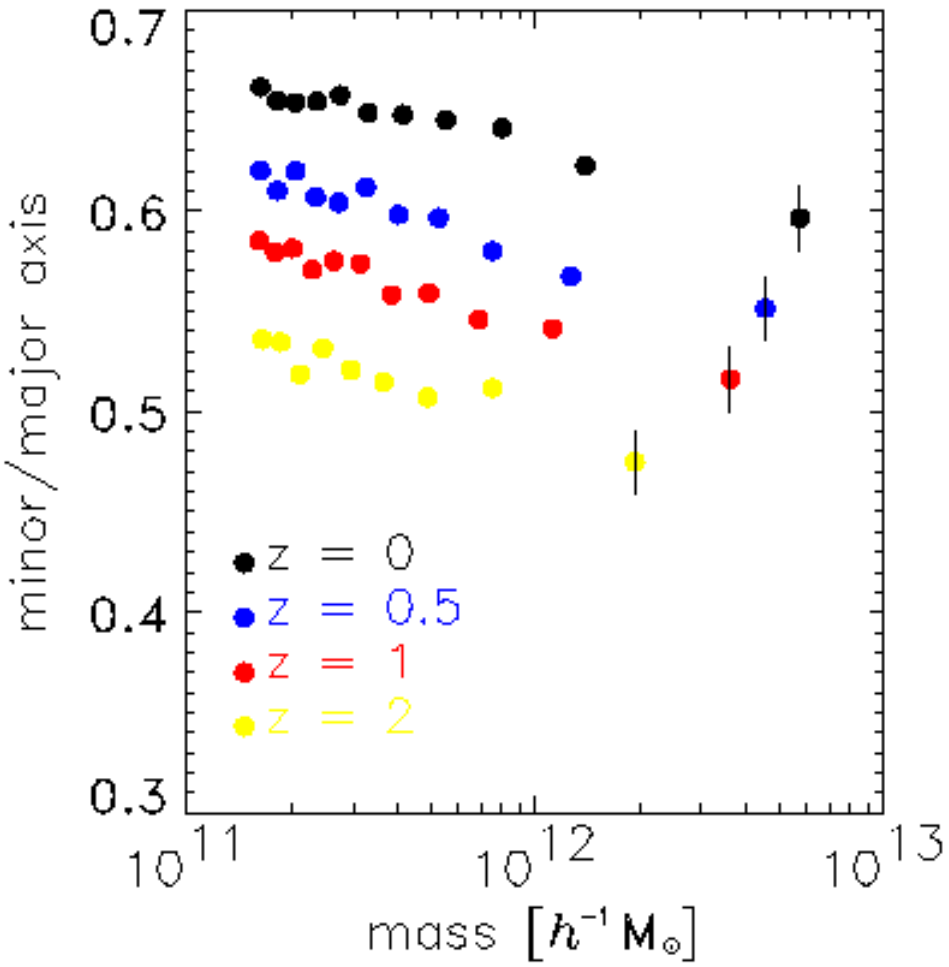
Shape depends on mass



- MN: MareNostrum simulation
- 80G: DM simulation,
  boxsize $80h^{-1}$Mpc, 500^3 particles
- 80S: DM simulation,
  boxsize $80h^{-1}$Mpc, 2048^3 particles

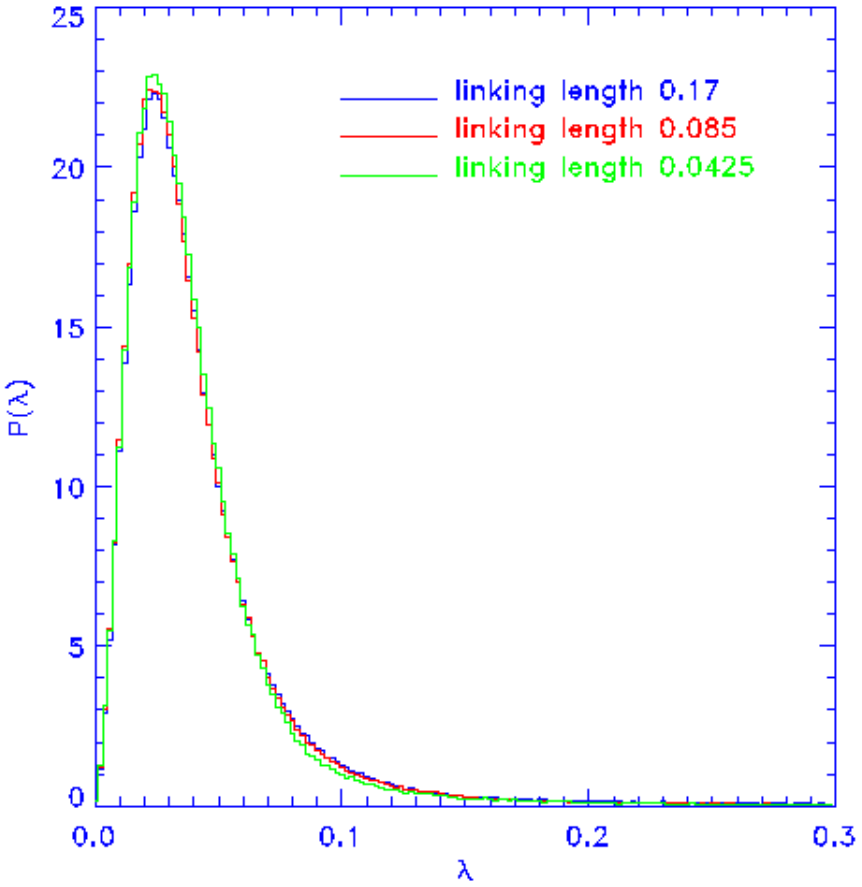
dark matter distribution

Shape depends on time



- 80G: DM simulation, boxsize $80h^{-1}$Mpc, 500^3 particles
- redshift z = 0, 0.5, 1, 2

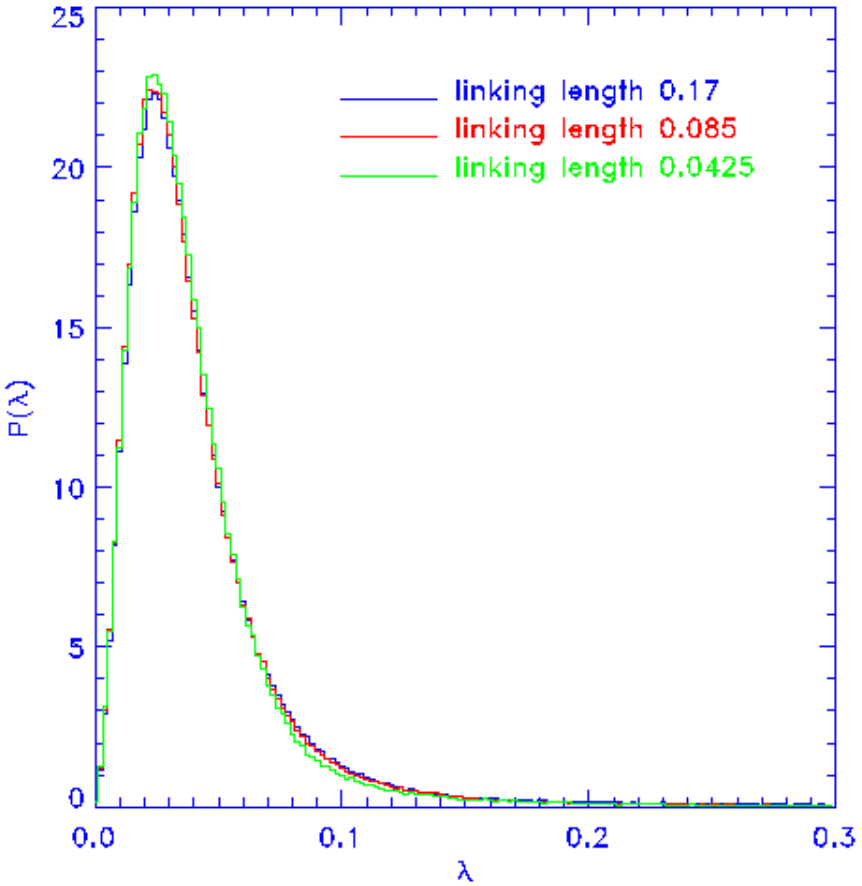
Spin of the halos



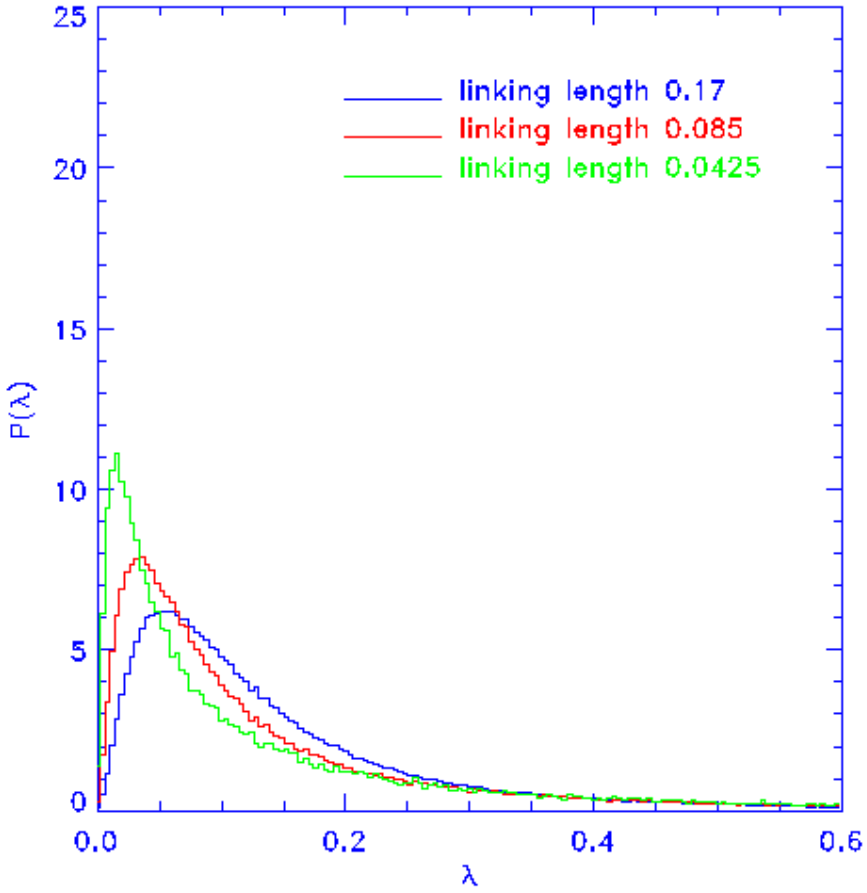
spin of the "dark matter halos"

- $\lambda_0 = 0.023$ for all overdensities
- no hint that substructures have a different spin distribution

Spin of the halos

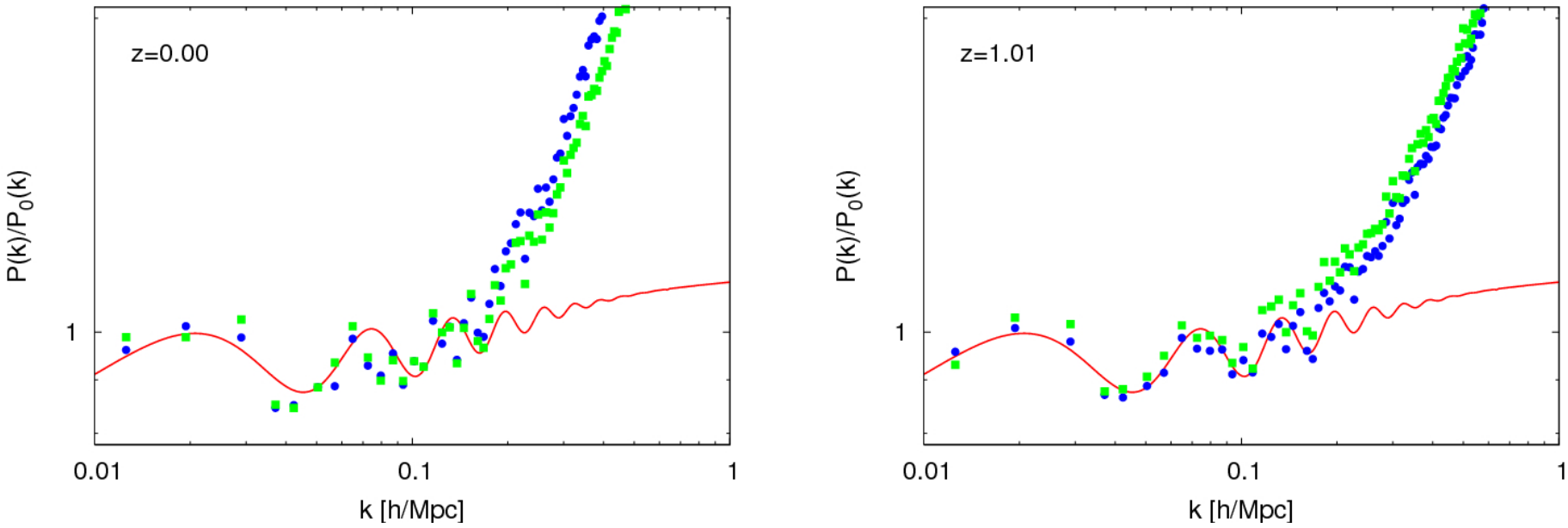


spin of the "dark matter halos"



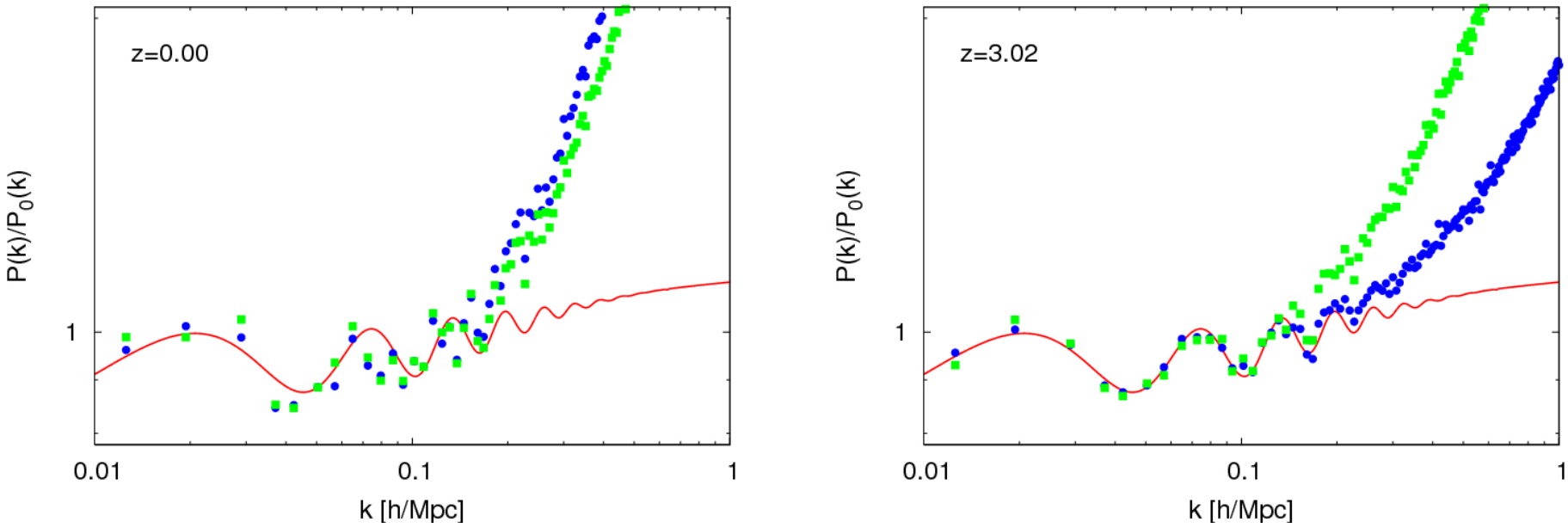
spin of the "gas halos"

Power spectrum with baryonic oscillations



- green quadrates: halos
- blue circles: dark matter particles
- bias: 0.94^2, 1.28^2, 2.78^2 for $z = 0, 1, 3$ resp.
- correction: according to deviation of the start realization from input power spectrum

Power spectrum with baryonic oscillations



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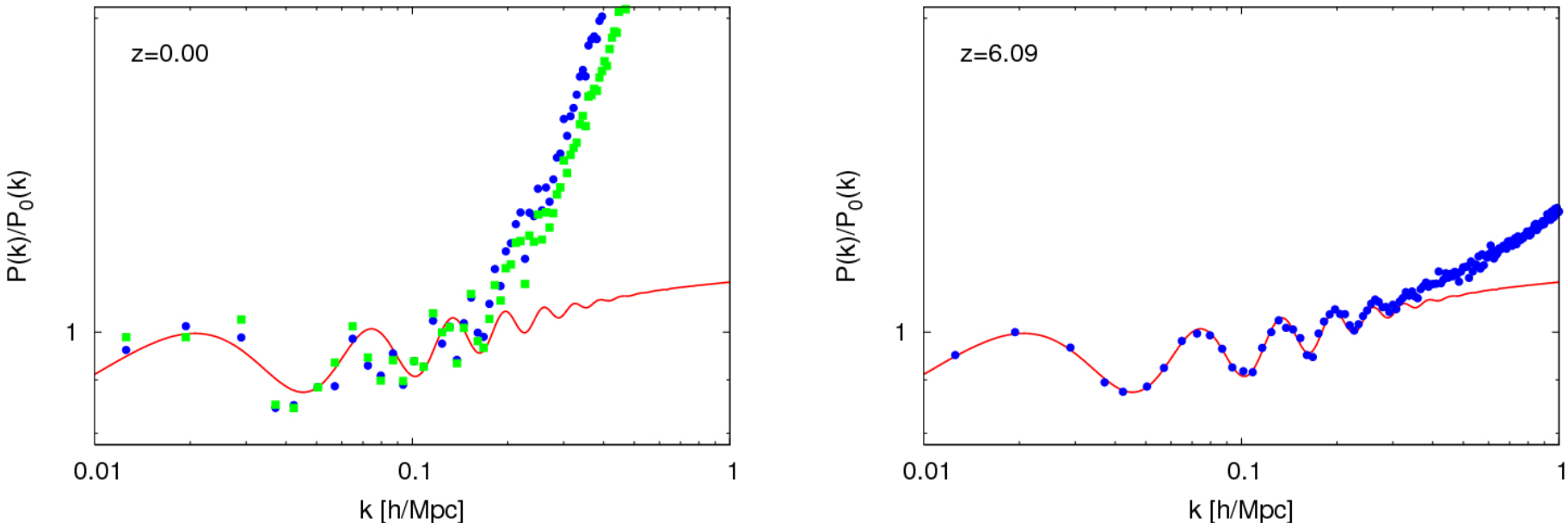
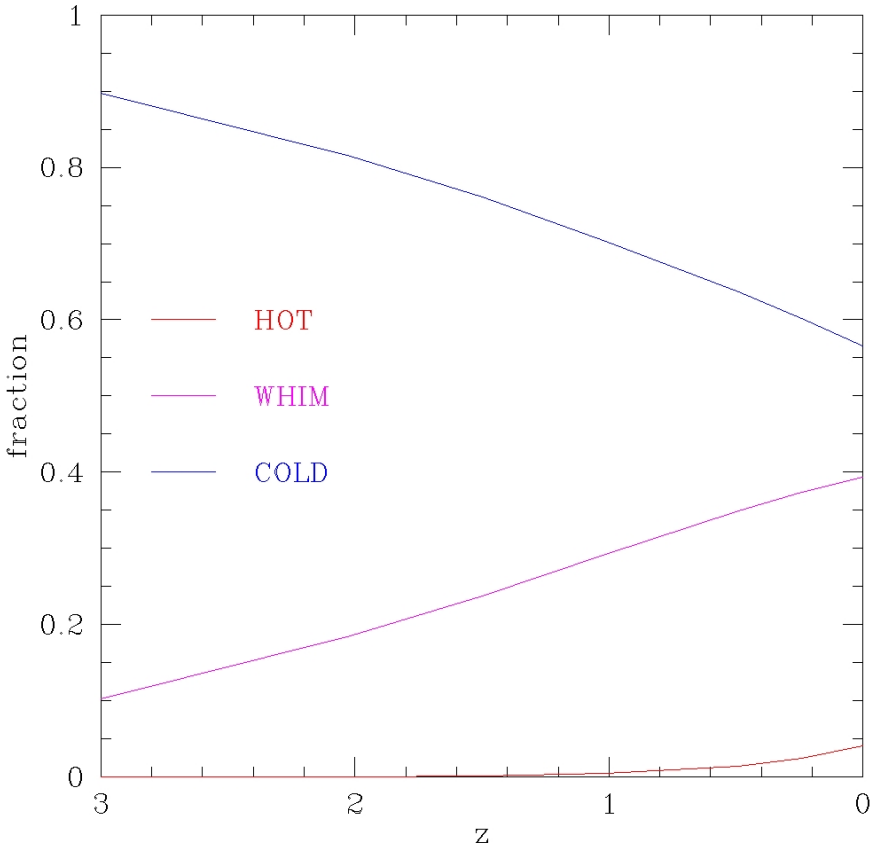
Power spectrum with baryonic oscillations



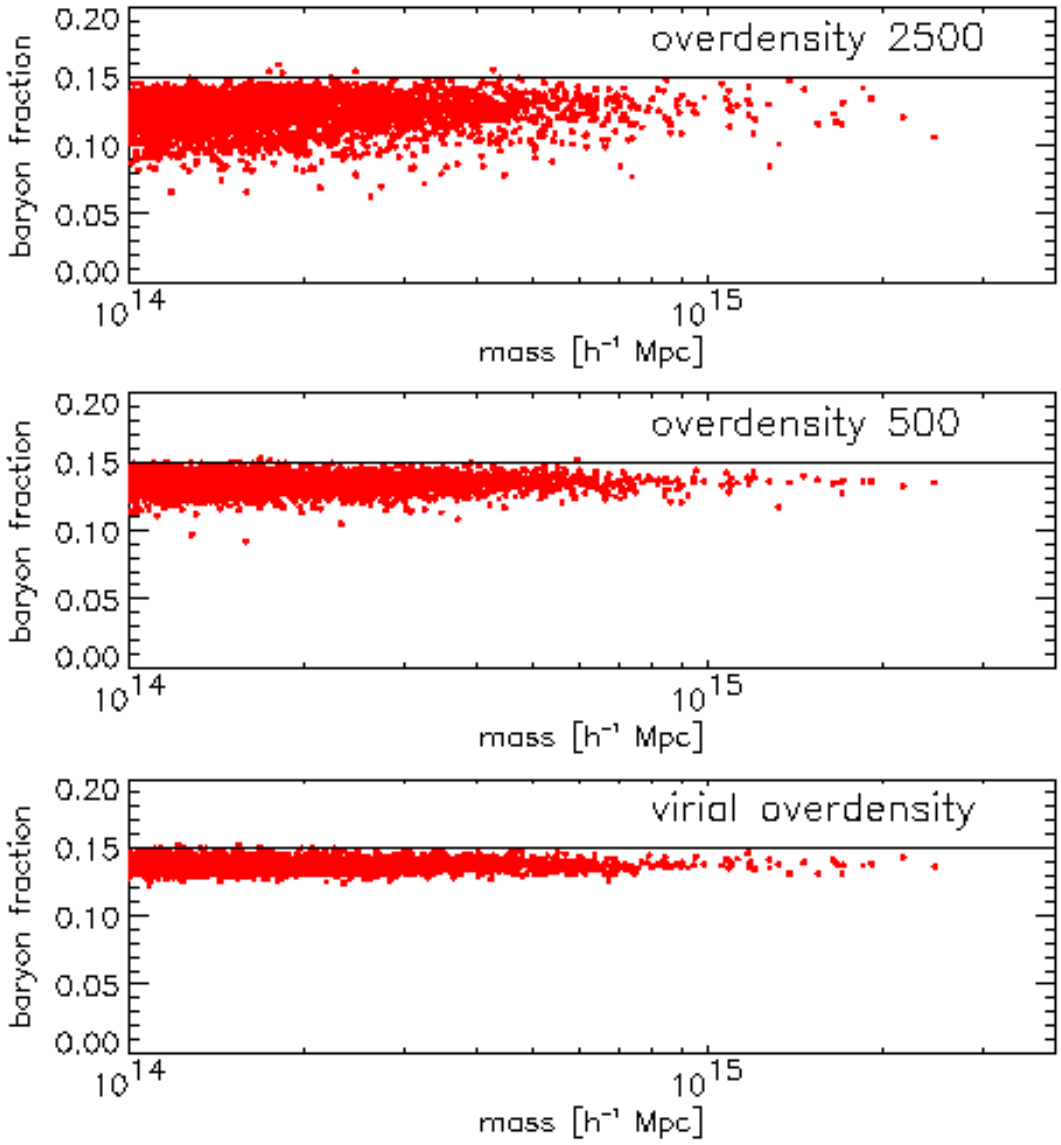
- green quadrates: halos
- blue circles: dark matter particles
- bias: 0.94^2, 1.28^2, 2.78^2 for $z = 0, 1, 3$ resp.
- correction: according to deviation of the start realization from input power spectrum

Evolution of gas temperature distribution

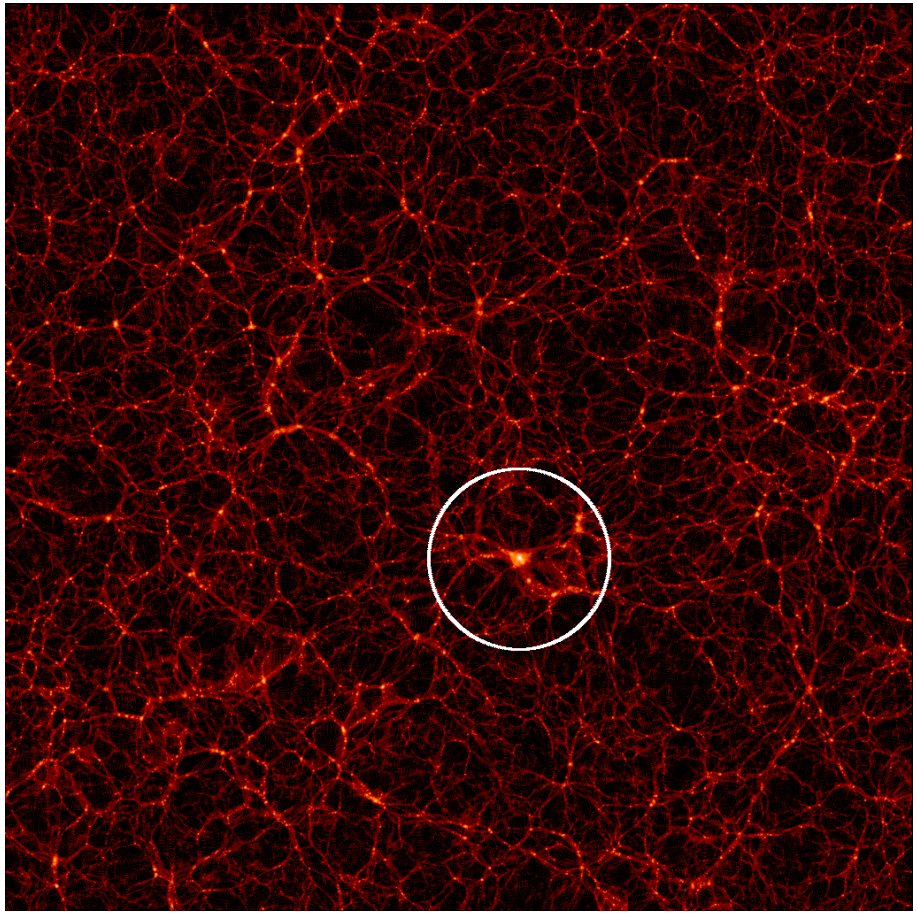


- hot: $T > 10^7$ K
- WHIM: 10^5K$< T < 10^7$ K
- cold: $T < 10^5$ K

Gas fraction in clusters

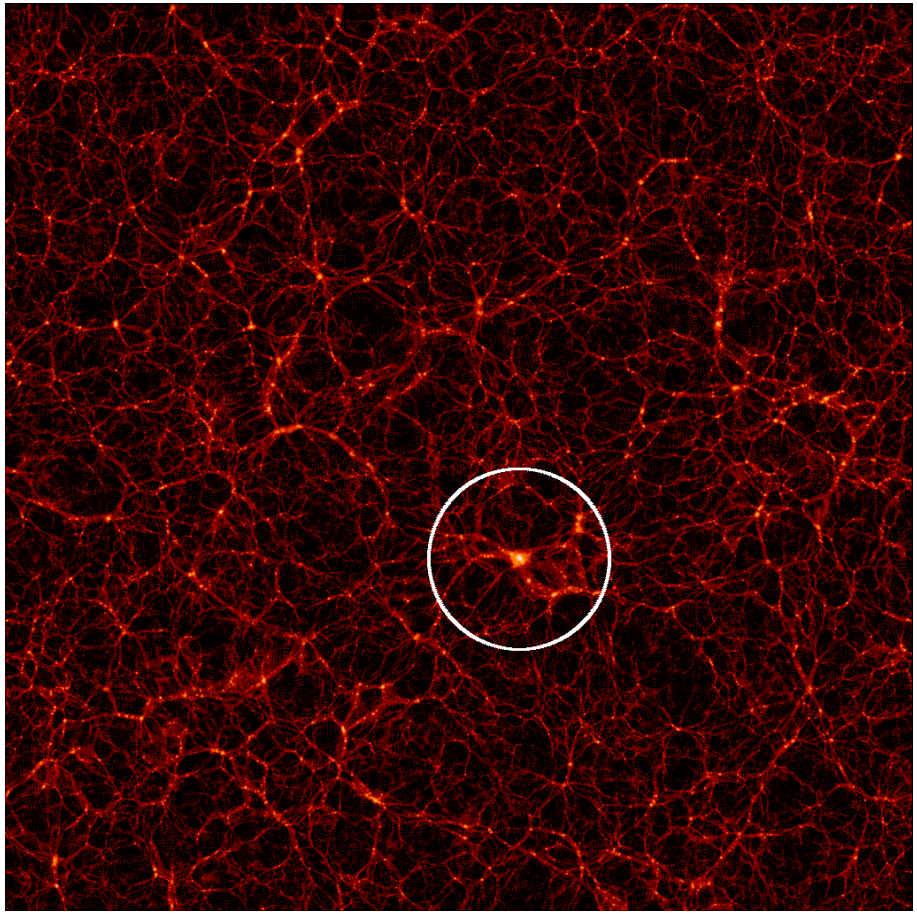


Clusters of galaxies

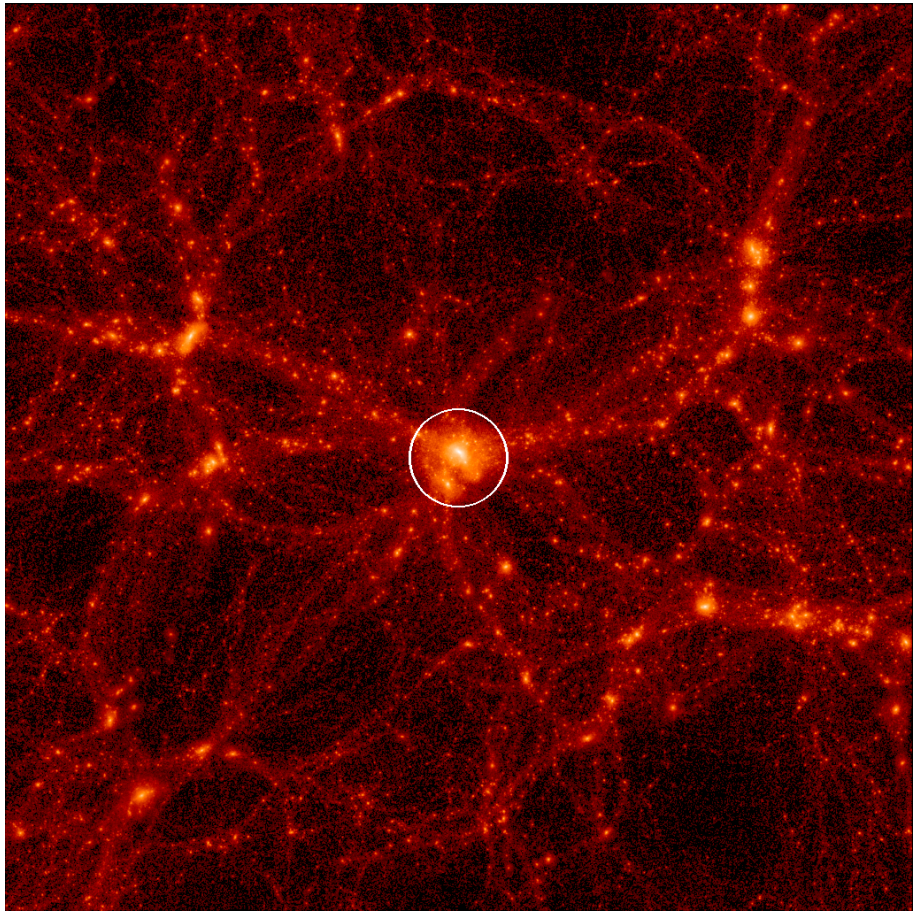


- 30 clusters with $M_{vir} > 10^{15} h^{-1} \mathrm{M}_{\odot}$
- 4000 clusters with $M_{vir} > 10^{14} h^{-1} \mathrm{M}_{\odot}$

The most massive cluster

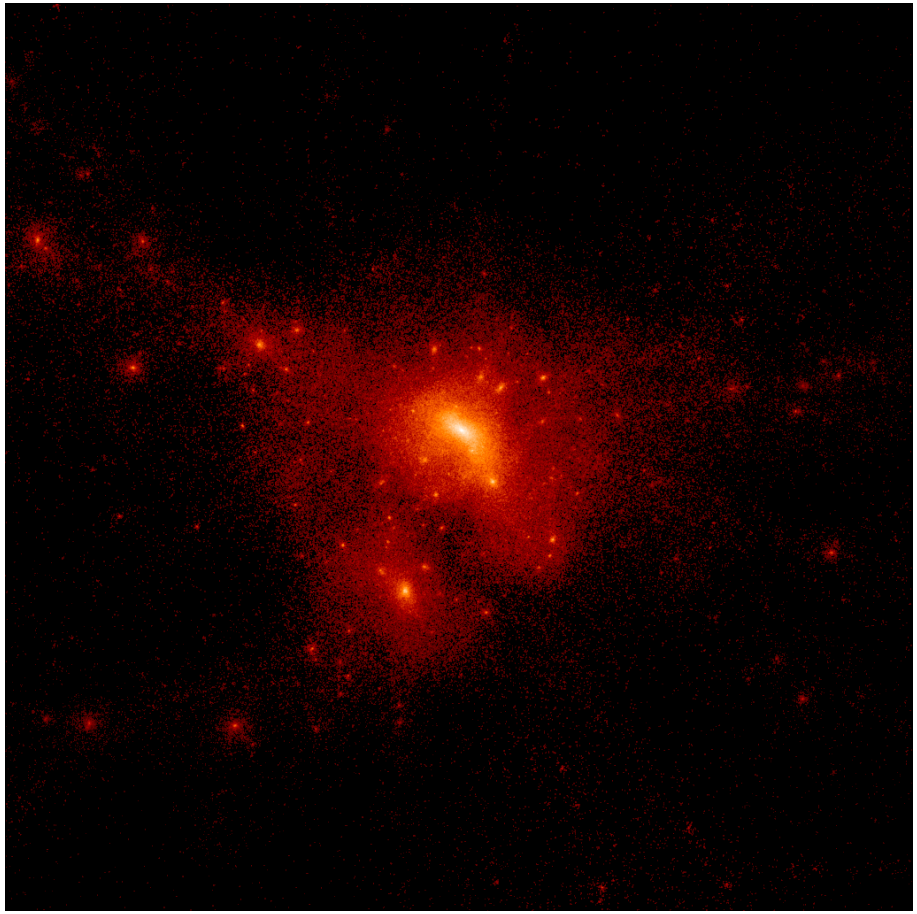


circle $100h^{-1}$Mpc

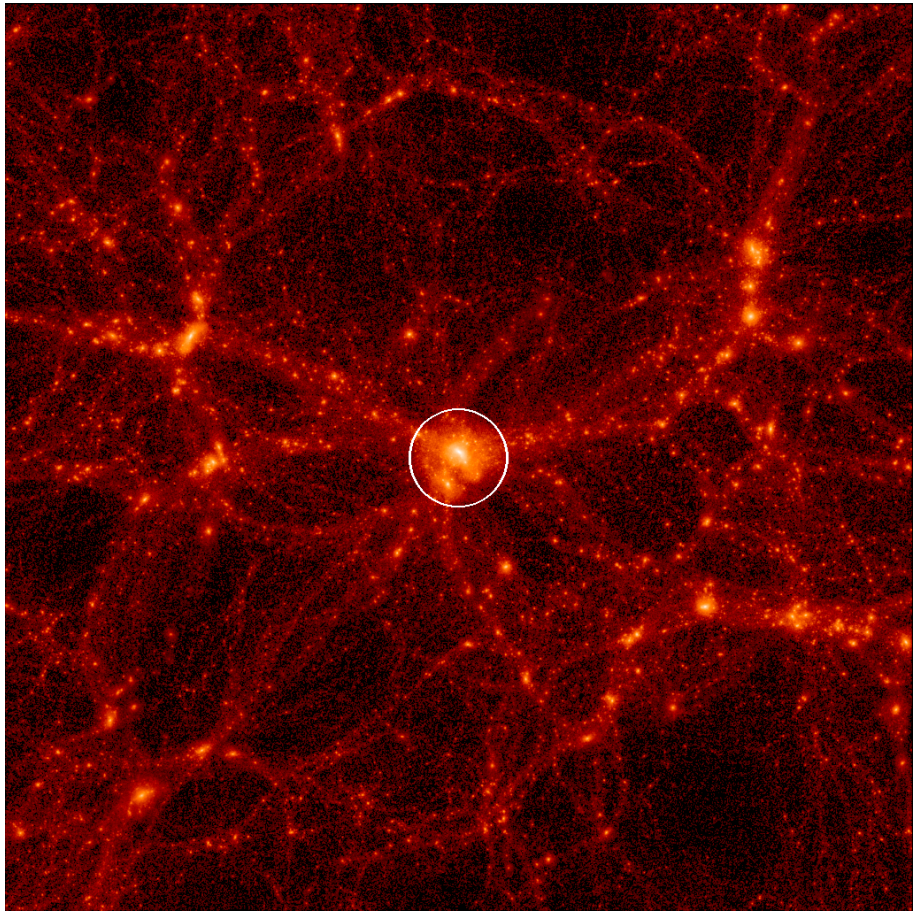


circle $20h^{-1}$Mpc

The most massive cluster

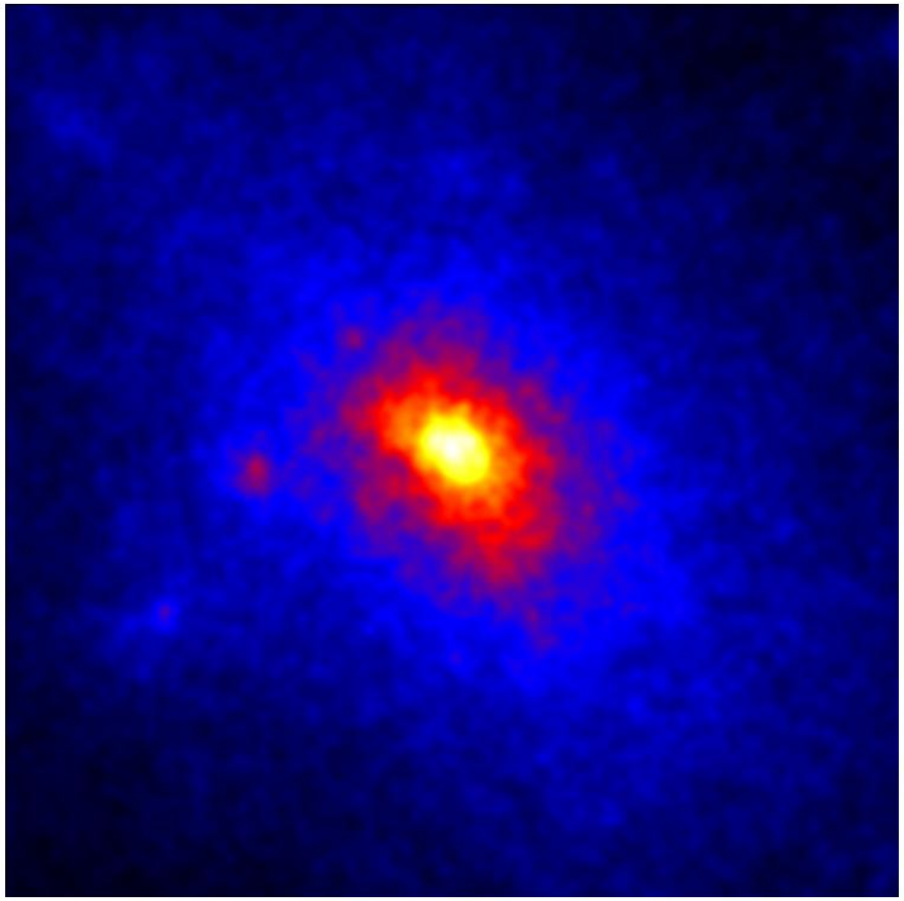


$M_{vir} = 2.5 \times 10^{15} h^{-1} \mathrm{M}_{\odot}$
$r_{vir} = 2.8 h^{-1} \mathrm{Mpc}$

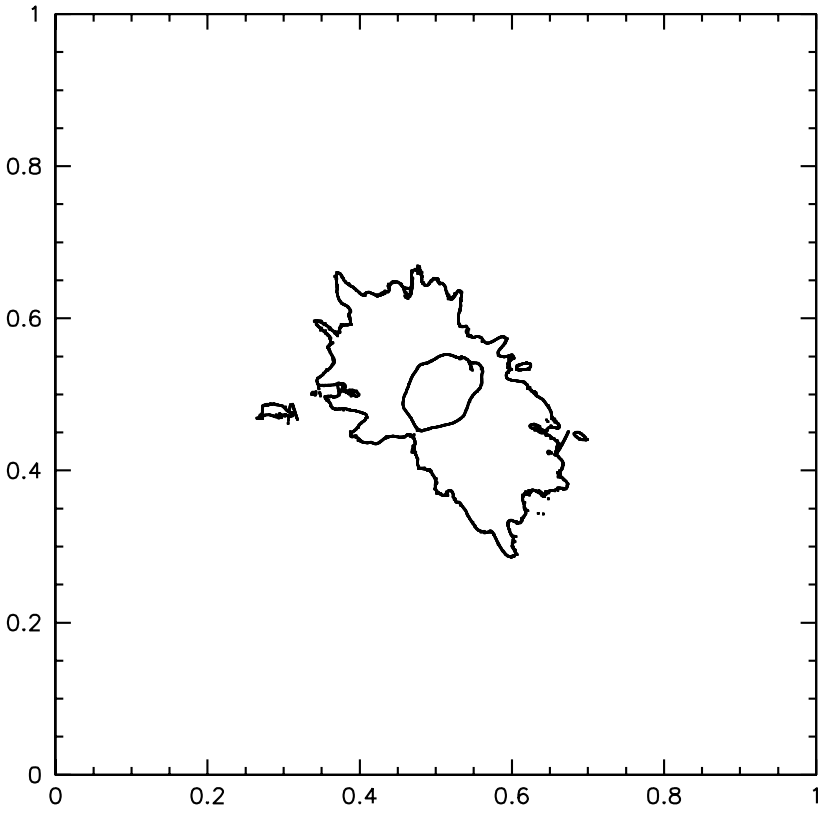


circle $20 h^{-1} \mathrm{Mpc}$

Lensing with clusters

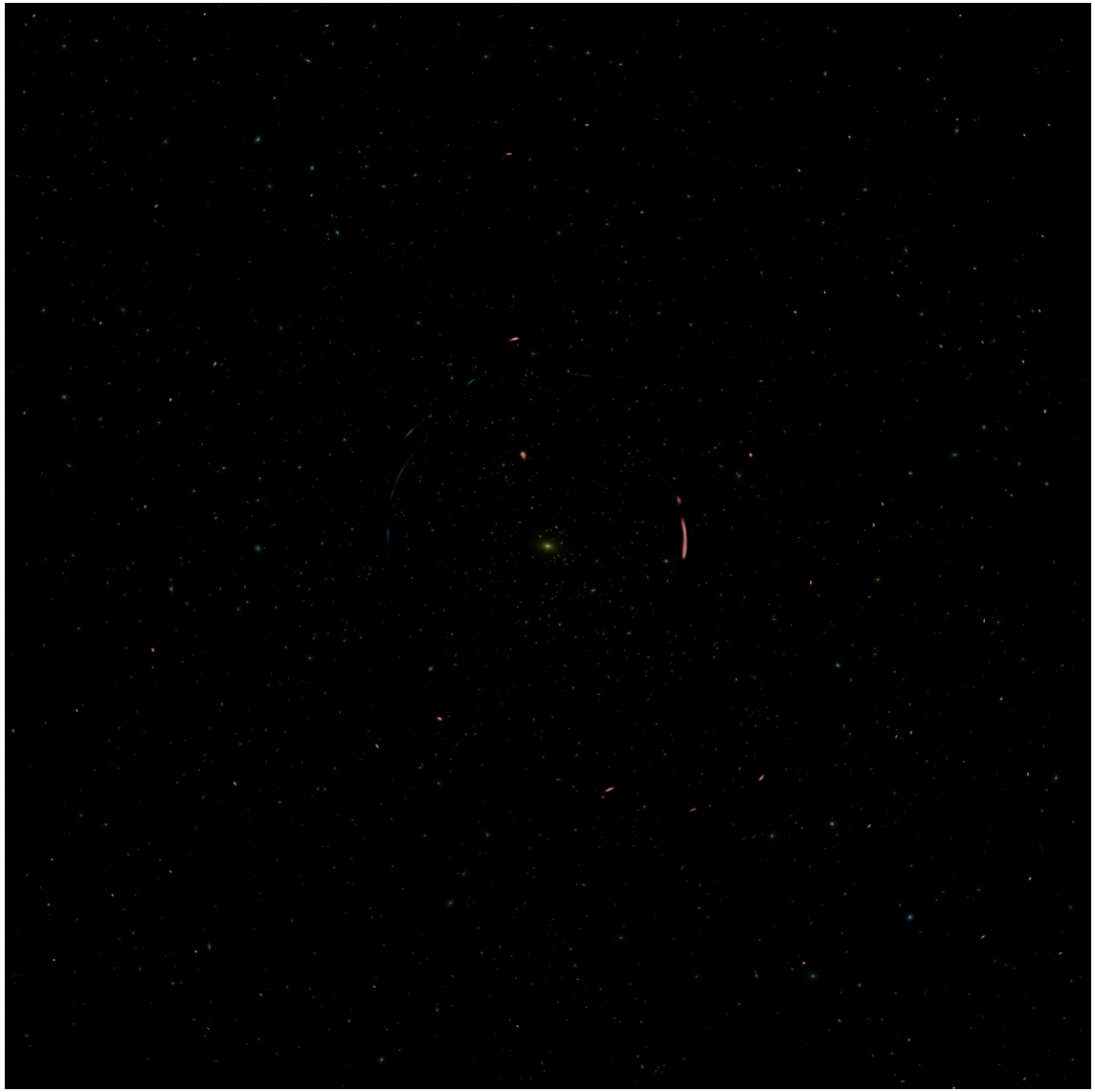


$M_{vir} = 2.5 \times 10^{15} h^{-1} \mathrm{M}_{\odot}$



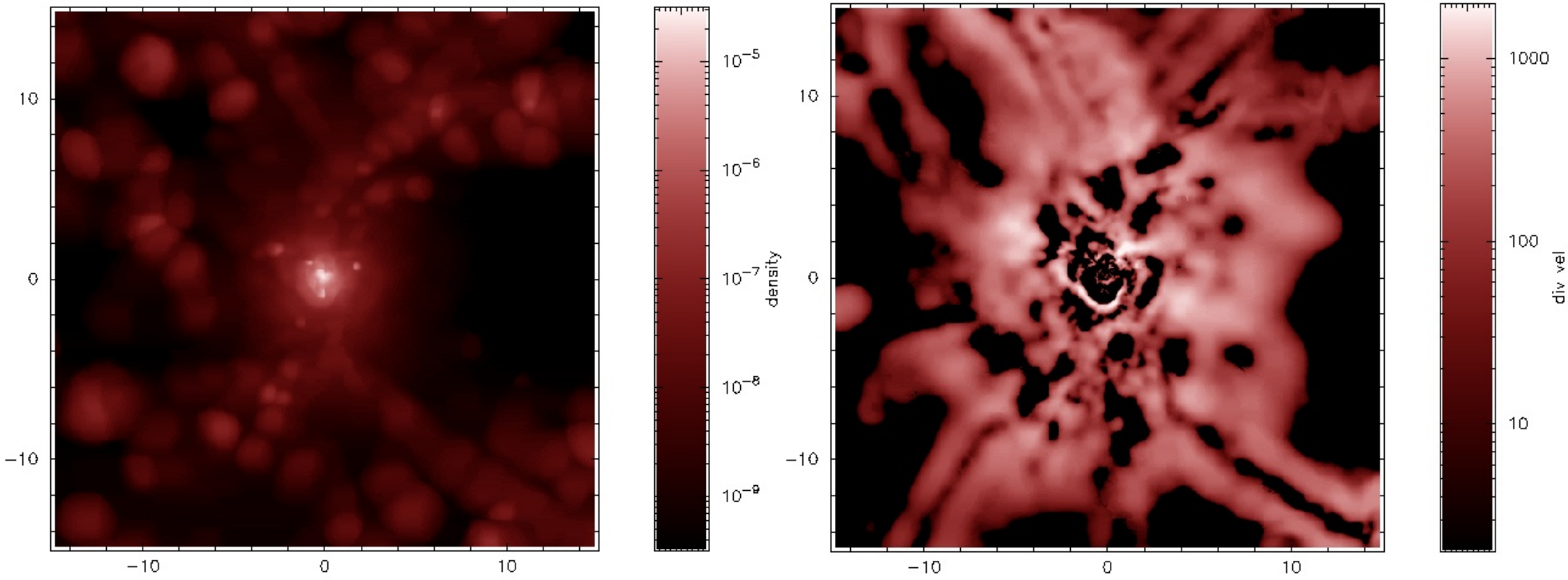
critical lines of the lens
(tangential: outer closed line,radial: inner closed line)

Observing our most massive cluster from space

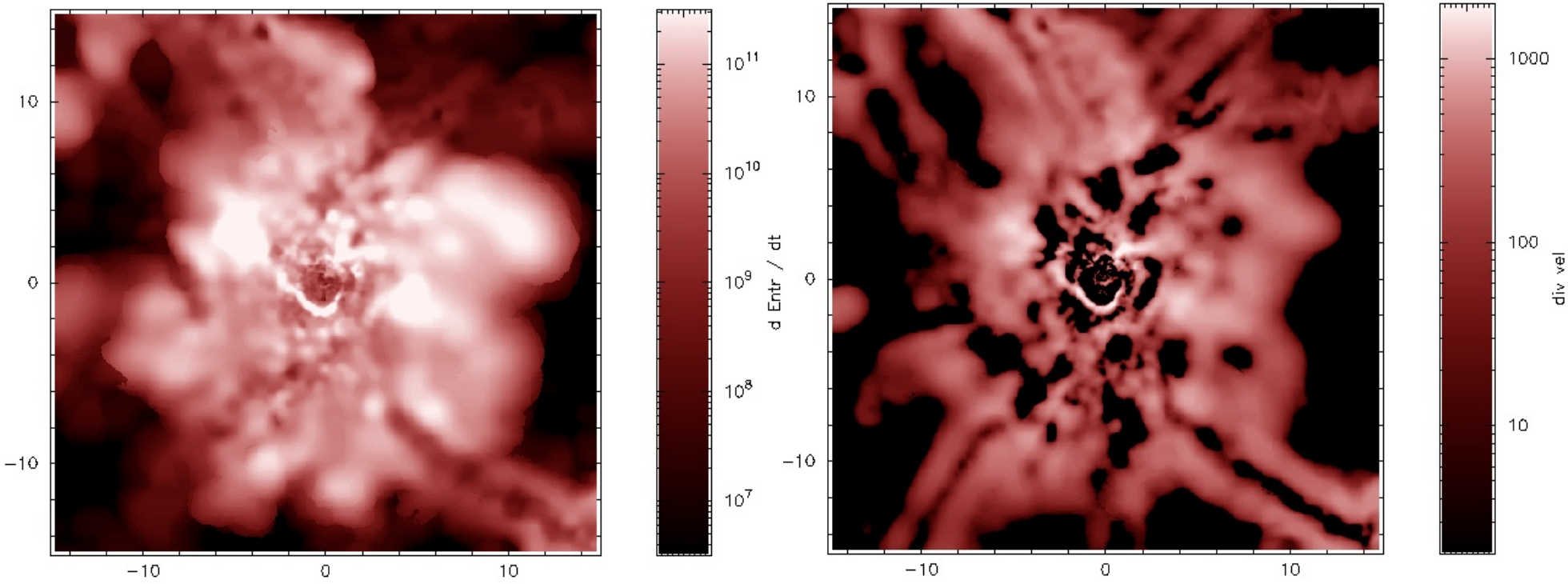


- ray tracing simulation (including sky brightness, photon noise)
- composite U,B,V observation of the cluster taken from the space
- typical morphological type distributions in the field and cluster

Streaming velocity in clusters



Streaming velocity in clusters



Outlook

- Where are the most powerful computers in this world?

Summary

Using a billion of gas particles and another billion of DM particles we have performed on MareNostrum (Barcelona) one of largest simulations of the evolution of large scale structure in the universe. We discussed the identification of halos in that simulation, their internal properties and the baryonic oscillations found in the large scale distribution of halos.