KITP GALAXY-IGM Workshop 2004

HIGH and ULTRA-HIGH RESOLUTION SPH SIMULATIONS OF CLUSTERS AND VOIDS

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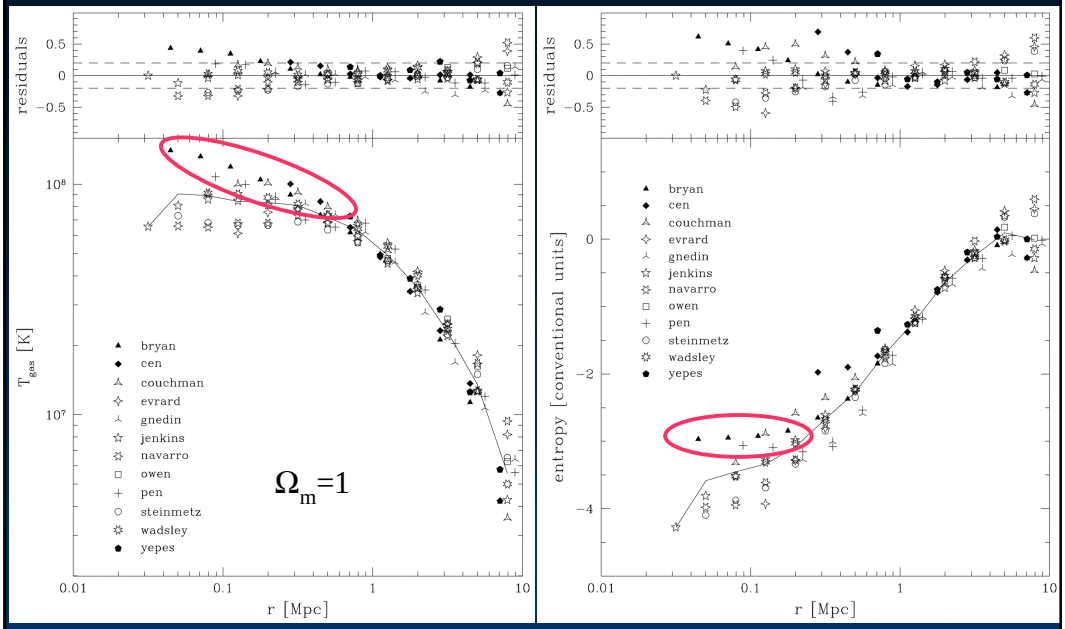
MOTIVATIONS

- **Study the processes of galaxy formation in different environments:**
  - **The most violent ones (clusters) and the most peaceful ones (voids).**
- **Not possible without our *beloved* baryons:**
- **Two ways of dealing with them:**
  - **N-body + Semianalytical modelling**
  - **N-body + Hydro simulations + extra baryonic physics**

METHODOLOGY

- Two steps:
  - Numerical convergence :
    gravitation and gasdynamics
  - Incorporate non-adiabatic effects: radiative cooling, heating, magnetic fields, thermal conductivity, etc.

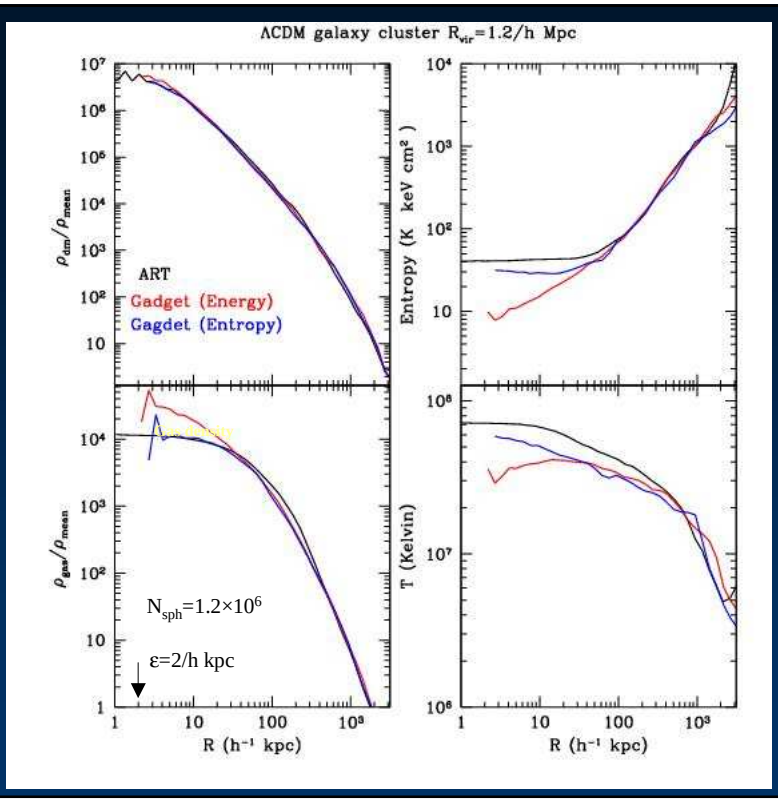
SANTA BARBARA CLUSTER COMPARISON



COMPARISON OF AMR AND SPH RESULTS FROM HIGH-RESOLUTION CLUSTER SIMULATIONS

(Yago Ascasibar's Ph D Thesis)

- Comparison of results from ART-Hydro (Kravtsov 2002) and GADGET (Springel, Yoshida, White 2001) of profiles for the Sbarbara cluster for different mass and spatial resolutions. (Yago's Thesis).
- Comparison of results for a highly resolved cluster in a ΛCDM simulation from:
  - ARTH
  - GADGET (with standard SPH implementation)
  - GADGET (with entropy conservation SPH)



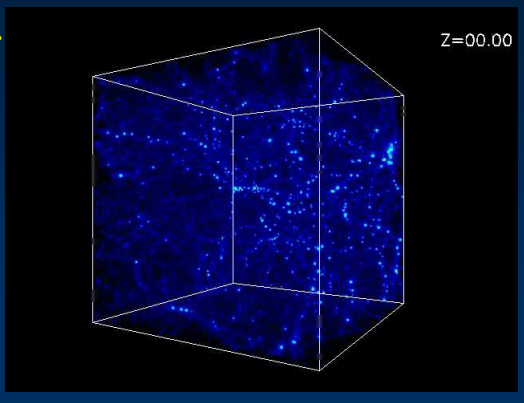
ΛCDM CLUSTER SIMULATIONS

- Ω_m=0.3; Ω_Λ=0.7, h=0.7; σ_8=0.9
- **80/h Mpc box size.** (Initial P(k) for 1024^3)
- **Resample to 128^3 particles.**
- **Identify clusters for** resimulation

Two N-body codes:

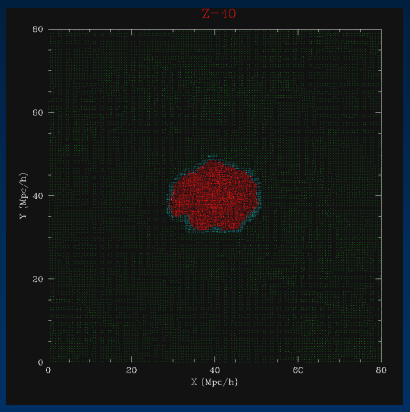
ART (1/h kpc)

GADGET (2-5 kpc)



HIGH RESOLUTION ΛCDM CLUSTER SIMULATIONS

- **Multi-mass technique to achieve high resolution**
- **15+2 Re-Simulated clusters**
  - **2-5 /h kpc smoothing**
  - **~2.5 million particles in high-res area (512^3 effective)**
  - **4.4 Million in whole box**
  - **$M_{sph}=4\times10^7\ M_\odot$**
  - **$M_{dm}=2.76\times10^8\ M_\odot$**



- **Parallel GADGET (entropy conserving version)**
- **Results from these clusters are shown in**
  - **Yago's PhD Thesis. (2003) `astro-ph/0305250`**
  - **Ascasibar et al 2003**
    - **MNRAS 2003, 346, 731**
    - **astro-ph/0312221**
  - **Hoeft, Brugger, Yepes (MNRAS, 2004)**

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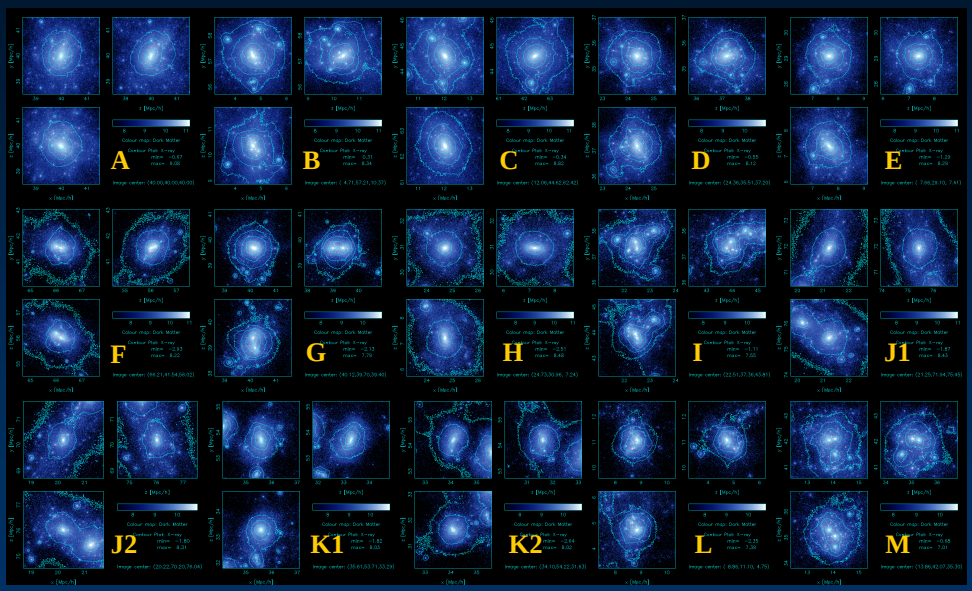
ATLAS OF SIMULATED CLUSTERS



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RESULTS FROM THESE SIMULATIONS

- DARK MATTER:
  - UNIVERSAL PROFILES
  - PHASE SPACE DARK MATTER STRUCTURE
  - ORIGIN OF UNIVERSAL DM PROFILE FROM SPHERICAL COLLAPSE MODEL+ ANGULAR MOMENTUM
- BARYONS:
  - UNIVERSAL GAS AND TEMPERATURE PROFILES.
  - SCALING RELATIONS
  - DYNAMICS OF GALAXY CLUSTER MERGERS
    - **Merger Shocks as origin of Radio Relics in clusters (`astro-ph/0302185`) (with M. Hoeft and M. Brugger)**
    - **Comparison of merger clusters with X-Ray vs optical distributions (with M. Plionis)**

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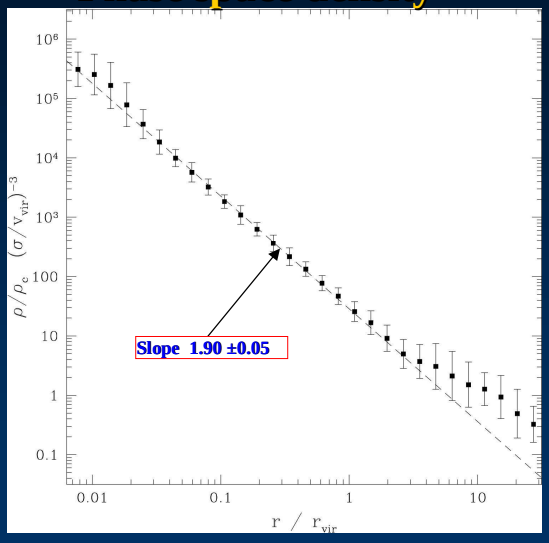
Dark Matter structure

- **Phase space density**



Four orders of magnitude in mass:

From galactic size halos to clusters of galaxies.

Ascasibar, Yepes, Gottlober, Muller, MNRAS, 352,1109 (2004)

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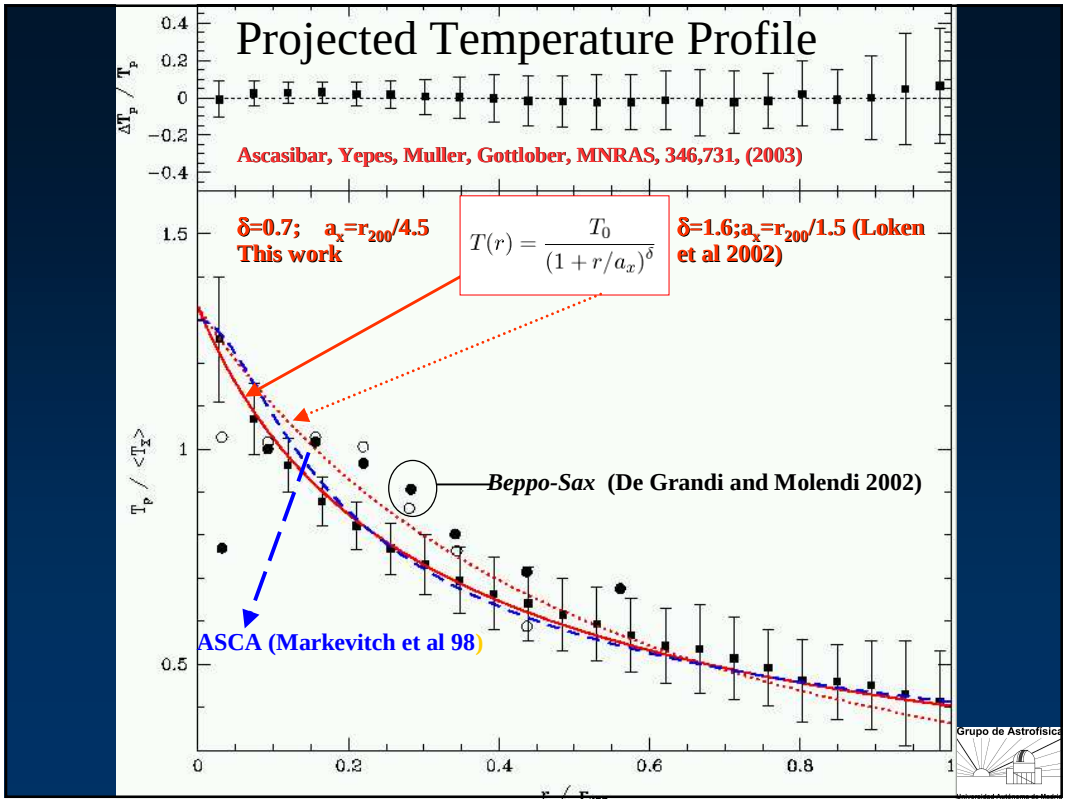


SCALING RELATIONS

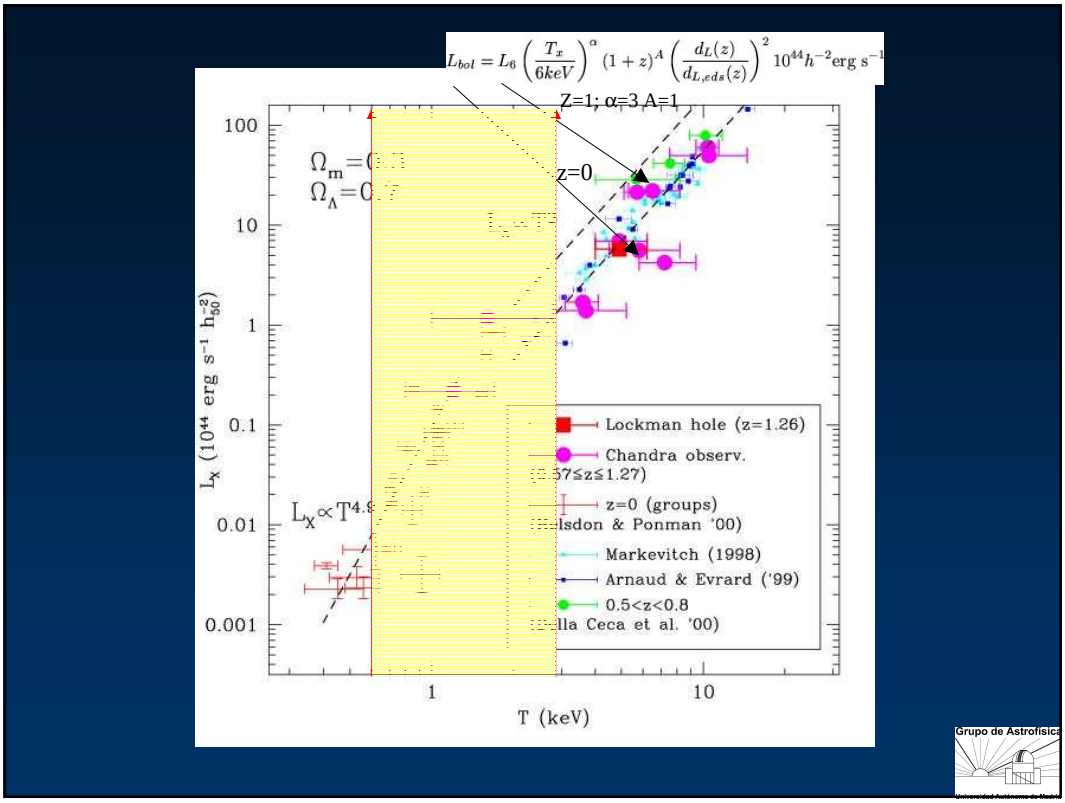
$M\text{-}T_X$

$L_X\text{-}T_X$

STATISTICAL FUNCTIONS

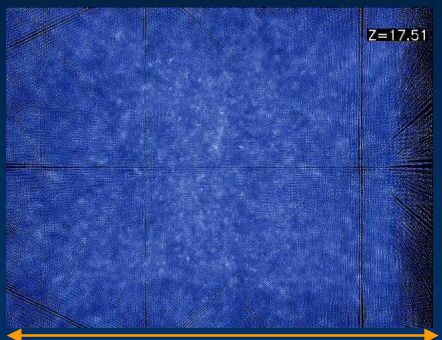
XTF

XLF

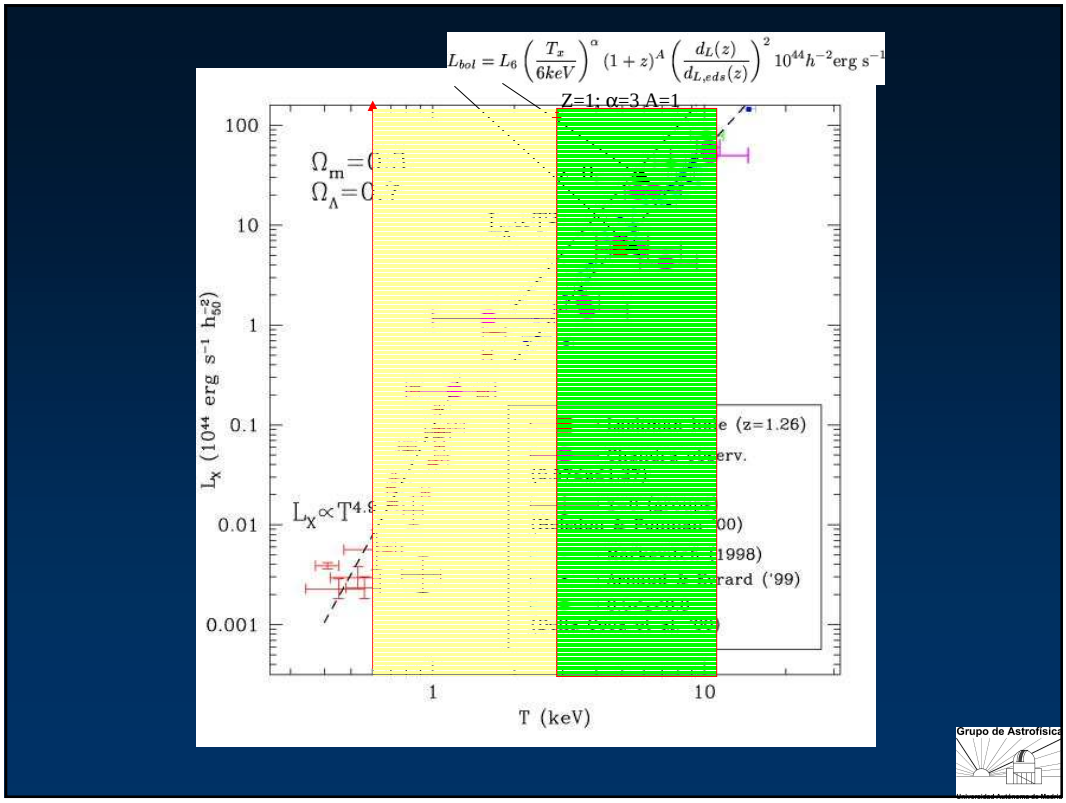


LARGE-SCALE SPH SIMULATIONS

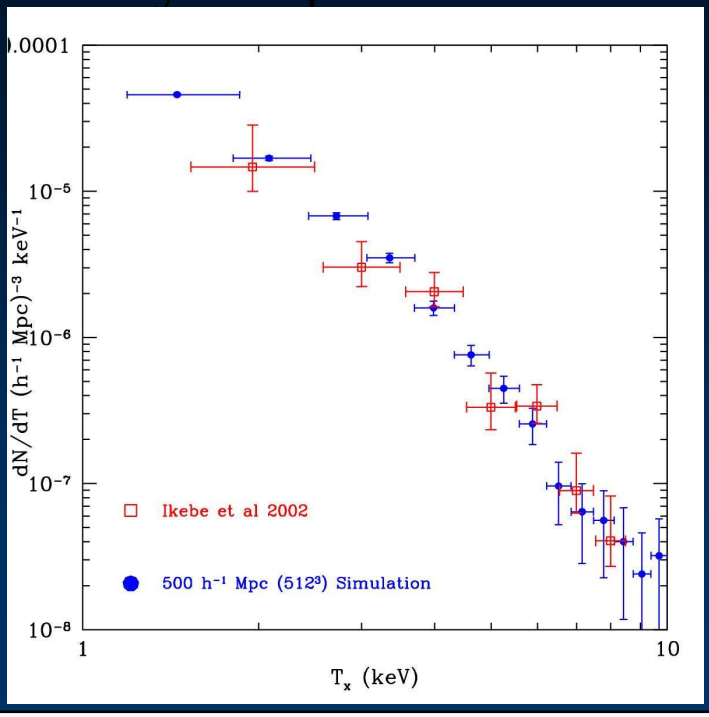
- Ω_m=0.3; Ω_Λ=0.7, h=0.7; σ_8=0.9, Ω_b=0.045
- **500/h Mpc box size**. (Initial P(k) for **2048^3**)
- **Runs with up to 512^3 particles.**
  - **# Halos=4×10^5 ($M>10^{12}\ M_\odot$)**
  - **M_{dark}= $7\times10^{10}\ M_\odot$**
- **Identify clusters for** resimulation with 128^3
- **Mass of clusters**
  - $M_{cluster} \leq 2.5\times10^{15}\ M_\odot$
  - Same resolution than previous simulations

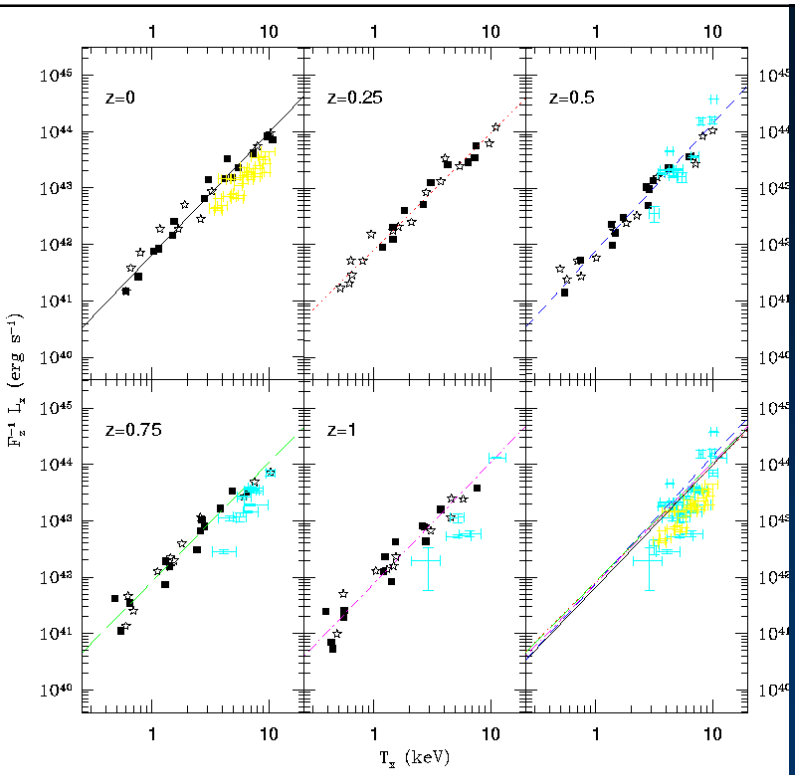


500 h^{-1} Mpc



X-ray Temperature Function

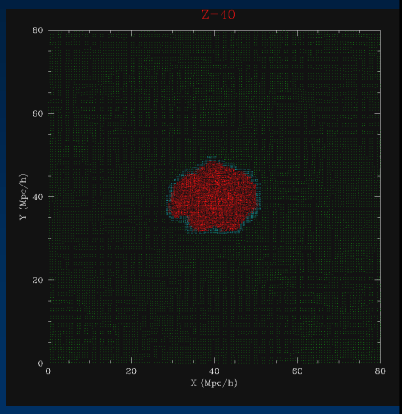




HAVE WE REACHED CONVERGENCE OF RESULTS IN TERMS OF RESOLUTION?

ULTRA-HIGH RESOLUTION SPH CLUSTER SIMULATION

- Open another level of mass refinement to achieve very high resolution (1024^3)
- One Re-Simulated cluster
  - 500/h pc smoothing
  - ~ 20 million particles in high-res area (1024^3 effective)
  - 25 Million in whole box
  - $M_{sph}=5\times10^6\ M_\odot$
  - $M_{dm}=3\times10^7\ M_\odot$
- Parallel GADGET-2 (entropy conserving version+ TREE-PM)
- 32 CPU itanium-2 –cluster
- CPU Time: 5×10^6 secs ~ 60 CPU days



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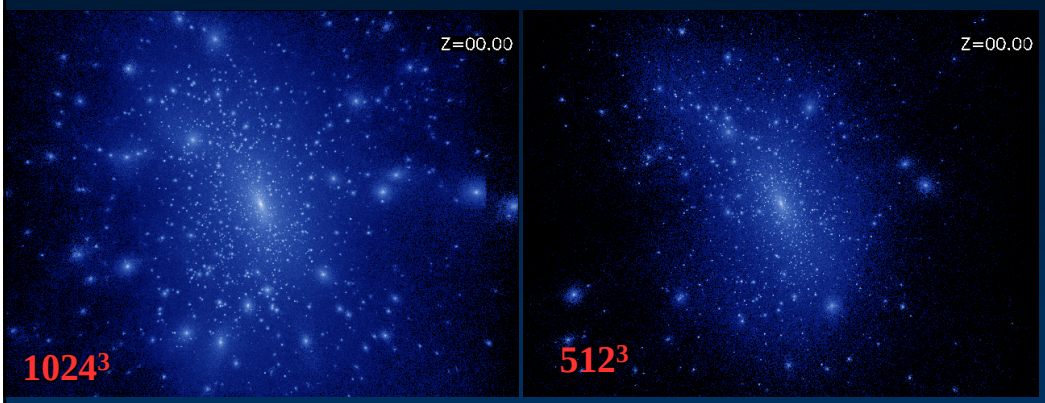
ULTRA-HIGH RESOLUTION SPH CLUSTER SIMULATION



DARK MATTER

2/h Mpc volume centered in the CM of this cluster.

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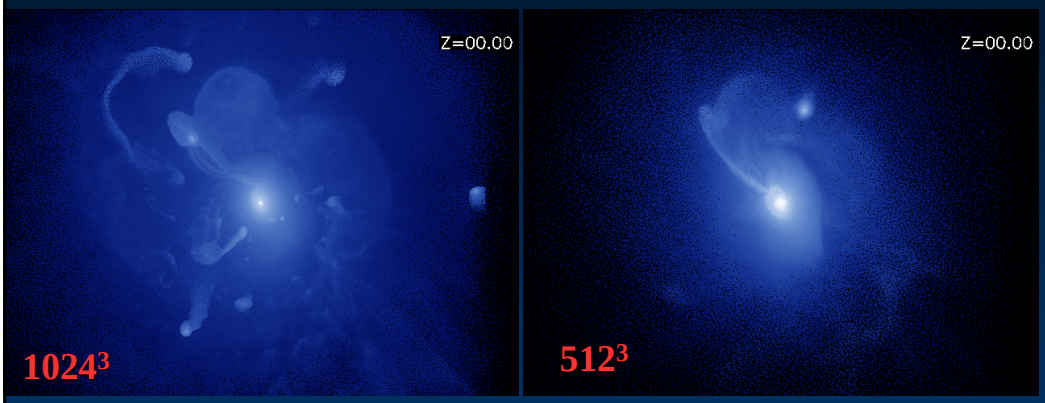
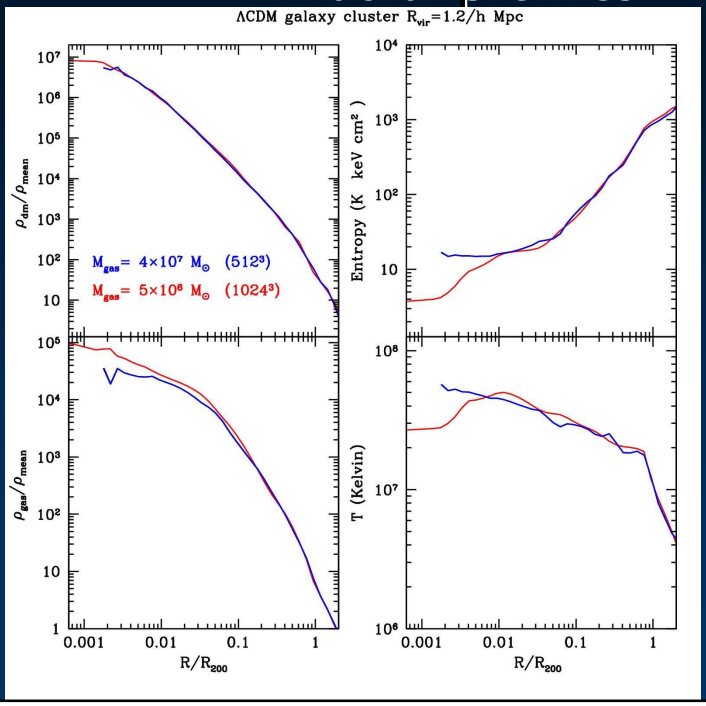
ULTRA-HIGH RESOLUTION SPH CLUSTER SIMULATION



GAS DENSITY

2/h Mpc volume centered in the CM of this cluster.

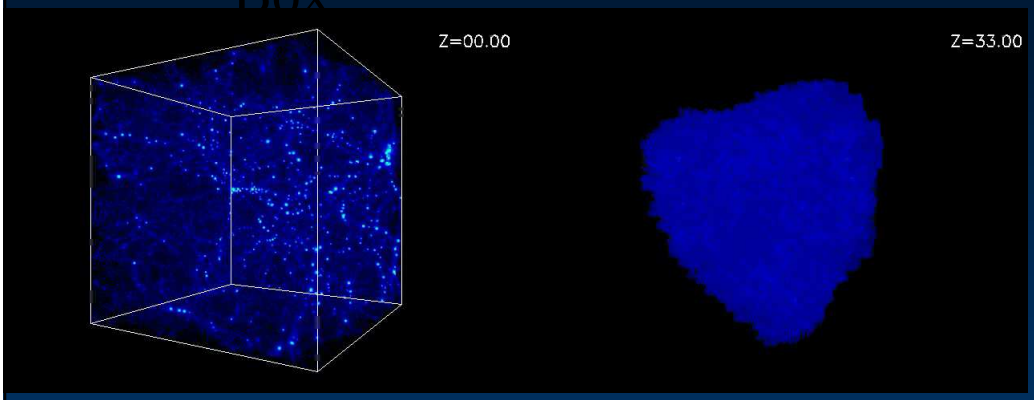
Radial profiles



SPH SIMULATIONS OF VOIDS

M. Hoeft, G. Yepes, S. Gottlober and V. Springel

VOIDS FROM A 80/h Mpc Box



Simulations done with GADGET2
- Primordial Cooling
- Photoionization
- Multiphase medium
- Star formation
- Feedback
  - Thermal
  - Kinetic (Winds)

10/h Mpc

1024^3 effective particle in void region

$M_{gas} = 5.5 \times 10^6 M_\odot$

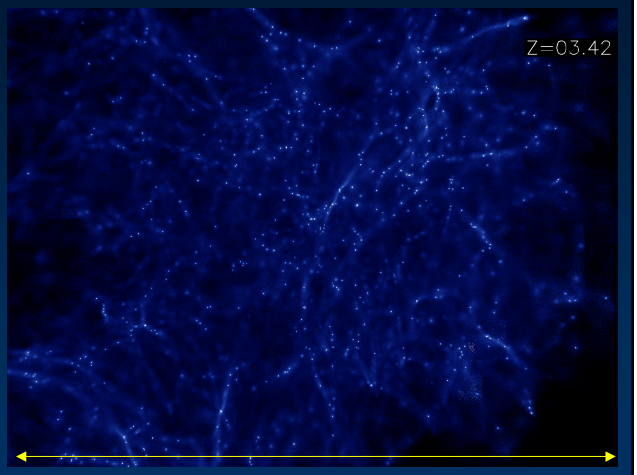
$M_{dark} = 3.4 \times 10^7 M_\odot$

Smoothing= 2-0.8 kpc

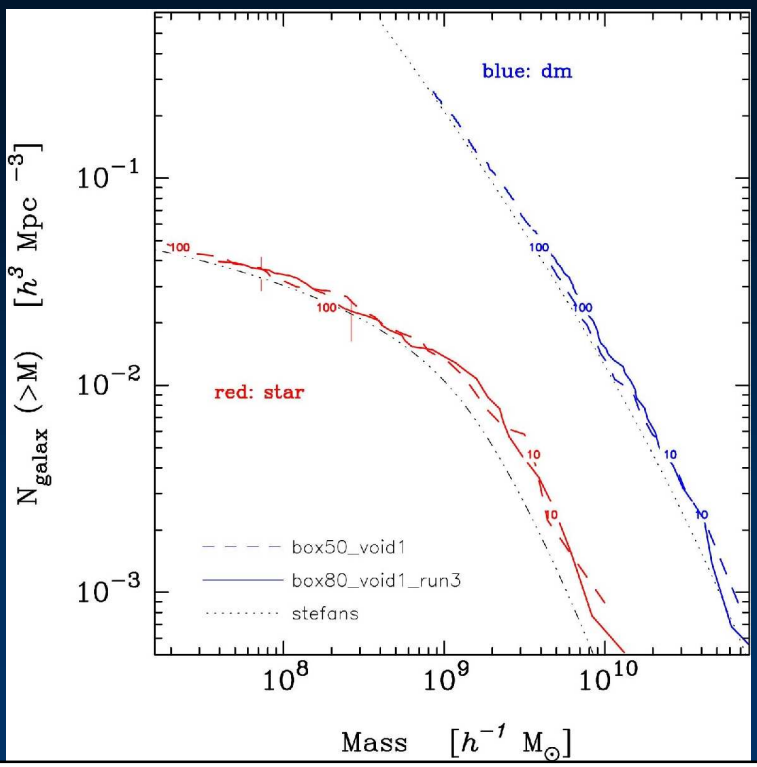
VOIDS FROM A 50/h Mpc Box

- **2048^3 effective particles**
- **RUN with 1024^3**
  - **M_{gas} = $1.5\times10^6 M_\odot$**
  - **M_{dark}= $8.2\times10^6 M_\odot$**

  Spatial smoothing= 2 kpc
- **Same void is resimulated with full resolution 2048^3**
  - **$M_{gas} \approx 2\times10^5 M_\odot$**
  - **$M_{dark} \approx 10^6 M_\odot$**
  - **Spatial smoothing= 0.5 kpc**

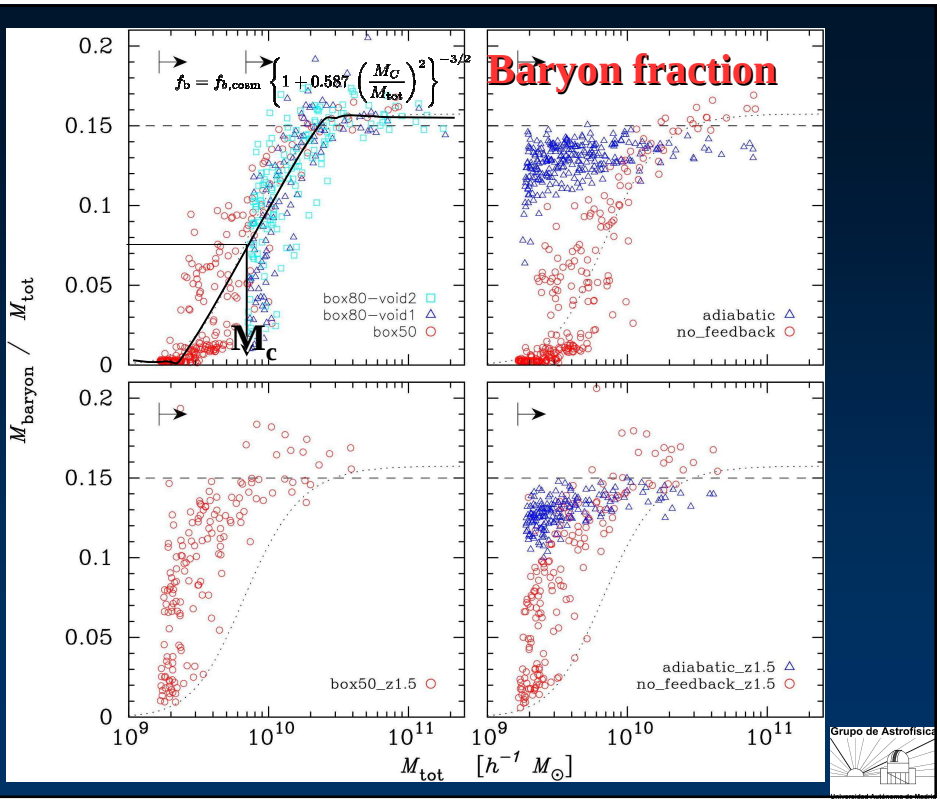


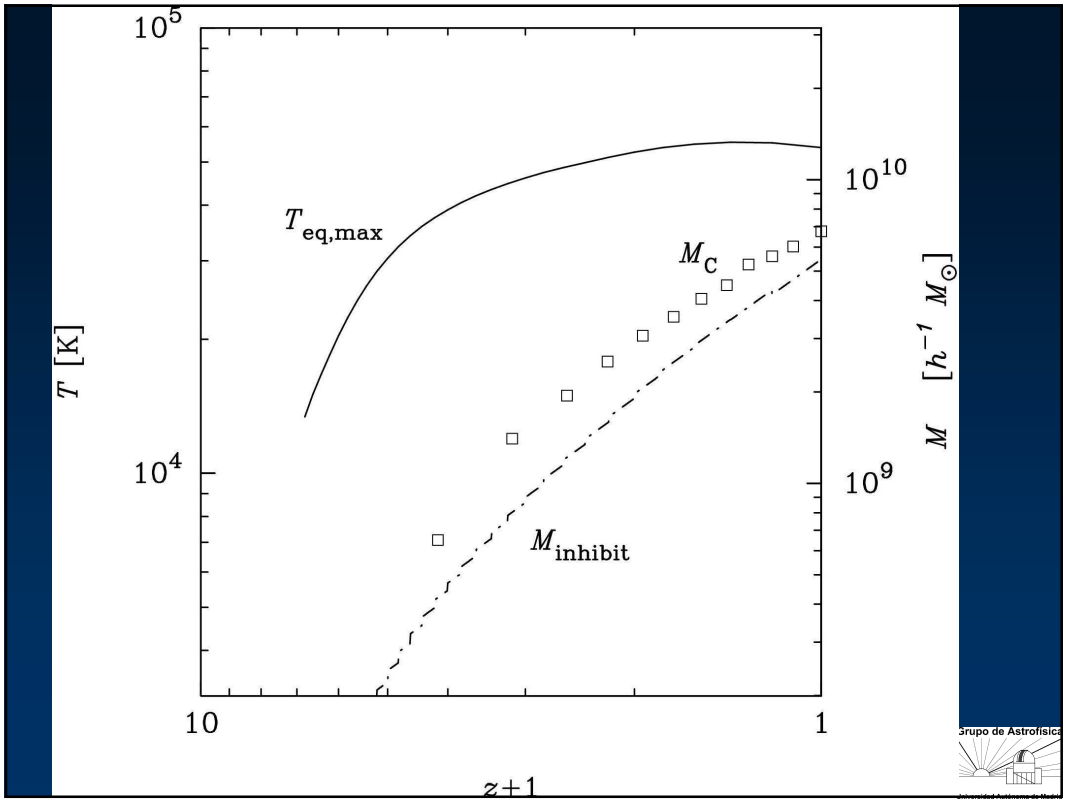
10/h Mpc

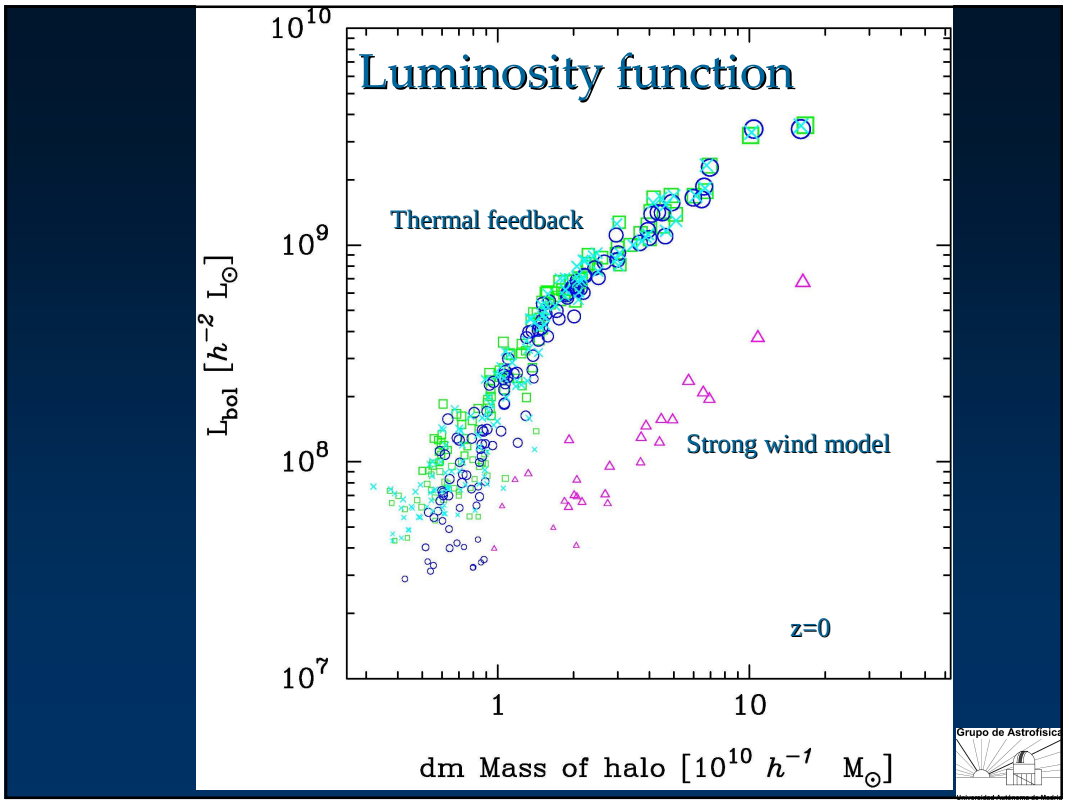


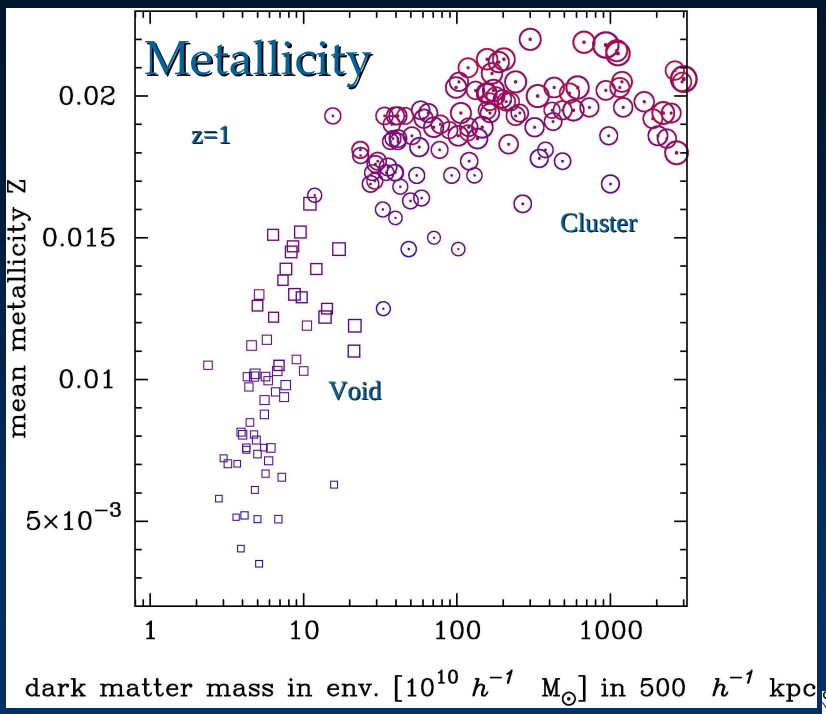
The missing dwarf galaxy problem in VOIDS

- **No galaxies brighter than M_b=-15 found.**
- **What happens with baryons of small halos in voids?**
  - **Are they visible but faint?. Magnitude, colors. (Red Dwarfs)**
  - **Are they just baryonless dark halos?**
- **What are the physical mechanism**
  - **Gas evaporation by UV photoionization**
  - **Supernova feedback (e.g Dekel & Silk)**
- **What is the typical halo mass for this to happen?**




10^5
10^4
T [K]
$T_{eq,max}$
M_C
$M_{inhibit}$
10^{10}
10^9
M $[h^{-1}\ M_\odot]$
10
1
$z+1$


Luminosity function
Thermal feedback
Strong wind model
z=0
10^{10}
10^9
10^8
10^7
L_{bol} $[h^{-2}\ L_\odot]$
1
10
dm Mass of halo $[10^{10}\ h^{-1}\ M_\odot]$



SOME CONCLUSIONS ABOUT GALAXIES IN VOIDS

- Halos below M_{lim} $7x10^9$ $M_\odot$ are photo-evaporated and have almost no baryon content, either cold gas or stars. This mass scale decreases with redshift.
- Thermal feedback does not play a significant role in keeping gas out of halos.
- Kinetic feedback (winds) is very efficient in inhibitting star-formation:
- UV photionization can explain the missing dwarfs in voids.