The Via Lactea Project: A Glimpse into the Invisible World of Dark Matter

- “Via Lactea/GHALO Project”: some of the largest N-body simulations of MW-sized halos.
- CDM substructure on galaxy scales: some old and new blunders.
- The fossil remnants of the EoR in the halo of the MW.
- DM annihilation and GLAST.

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UMich: M. Zemp
IAS: M. Kuhlen
UZurich: B. Moore, D. Potter, J. Stadel

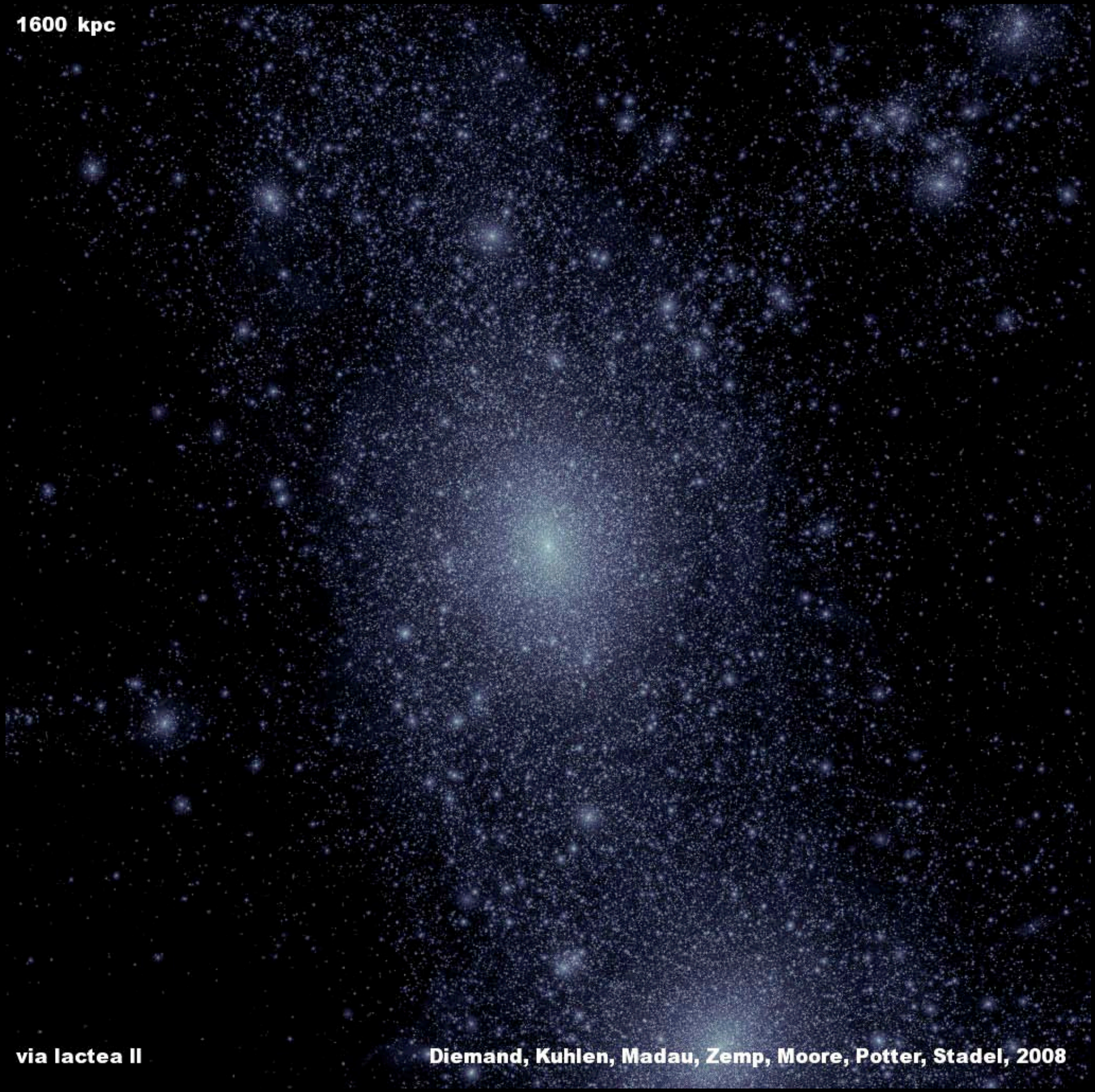
TASC

Via Lactea.

Aquarius.

Halo substructure

It is a unique prediction of ΛCDM that galaxy halos are lumpy. Subunits collapsing at high redshift have large central densities that allow them to resist the strong tidal forces.



Diemand, Kuhlen, Madau, Zemp, Moore, Potter, Stadel, 2008

Q: What fraction of these early subunits survive the hierarchical process as bound substructure?

collisionless ("pure N-body", DM only) simulations:
- simple physics: just gravity ⇨ good #CPU scaling ⇨ high resolution
- bad approximation in the center of large galaxies where baryons dominate, OK for dwarfs (M/L~2000) and smaller subunits.

The "VIA LACTEA Project"

A suite of the largest cosmological simulations of the assembly of the 2×10^{12} $M_\odot$ DM halo of the MW in ΛCDM/WMAP3

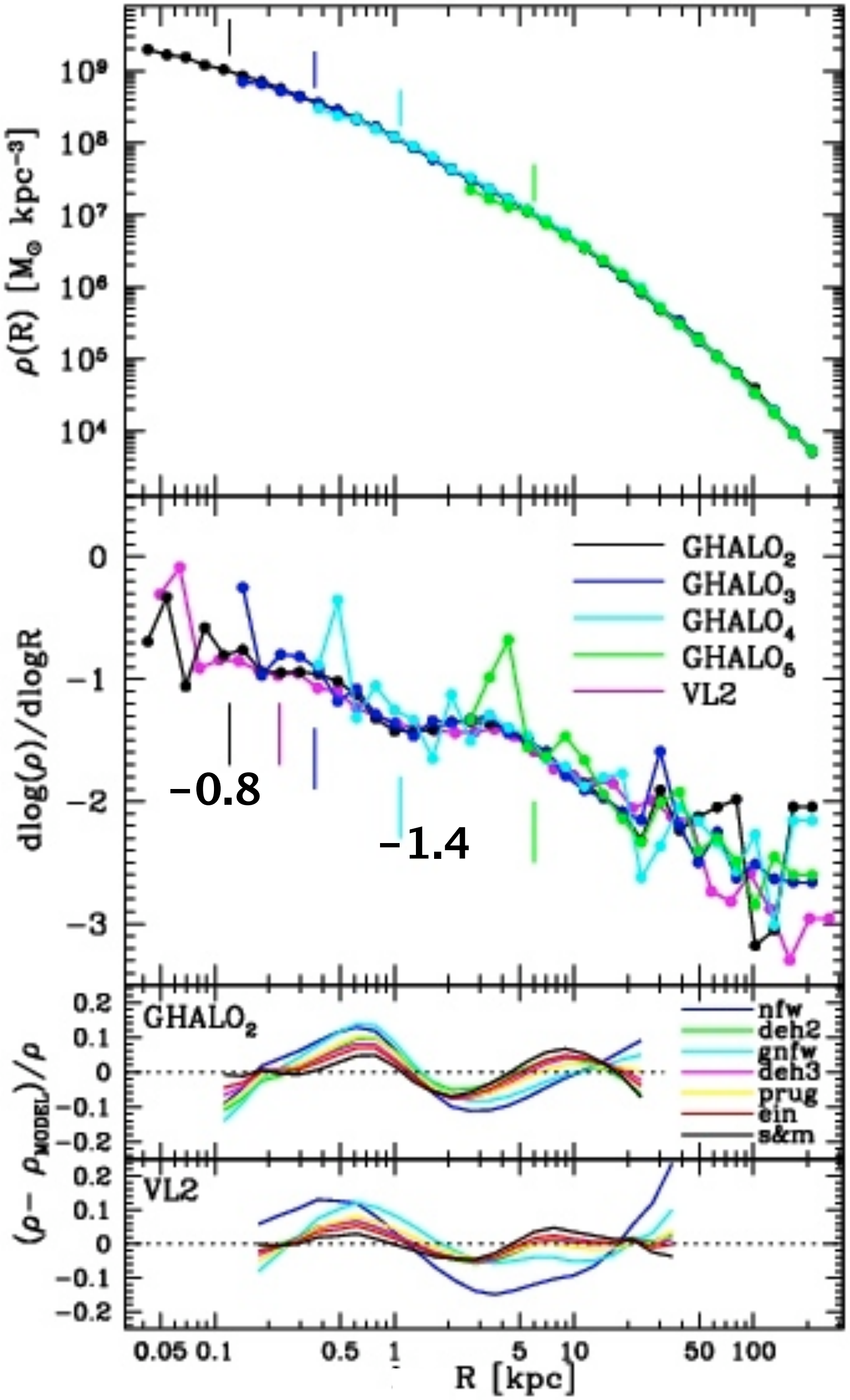
2007: VLI $N_{halo}=85M$ ($N_{tot}=213M$), $m_p=2.1e4$ $M_\odot$, $\varepsilon=90$ pc, 320K CPUh on Columbia @ NASA Ames

2008: VLII $N_{halo}=500M$ ($N_{tot}=1.1B$), $m_p=4100$ $M_\odot$, $\varepsilon=40$ pc, 1M CPUh on Jaguar @ ORNL 20TB

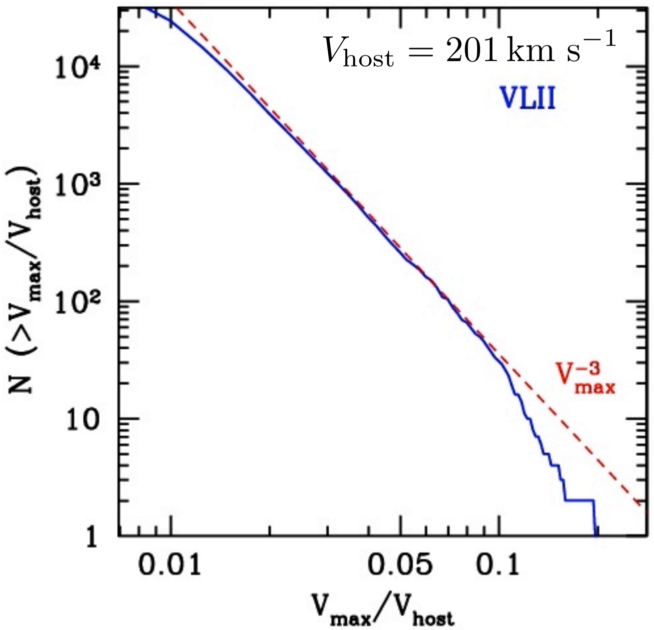
2008: $GHALO_{5,4,3,2}$ $N_{halo}=1.3B$ ($N_{tot}=3.1B$), $m_p=1000$ $M_\odot$, $\varepsilon=60$ pc, 2M CPUh on Marenostrum @ Barcelona

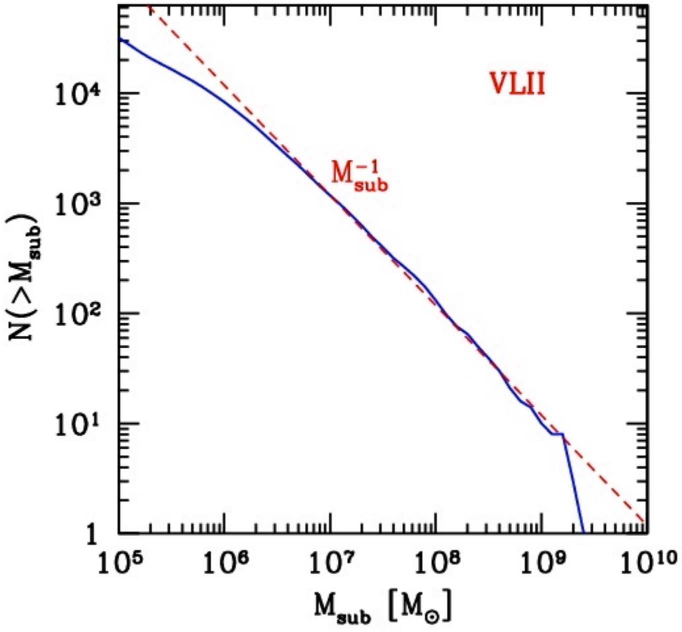
First cosmological simulations that resolve building blocks of massive galaxies down to z=0

Halo density profile

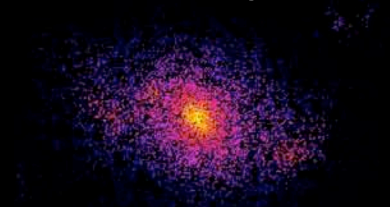


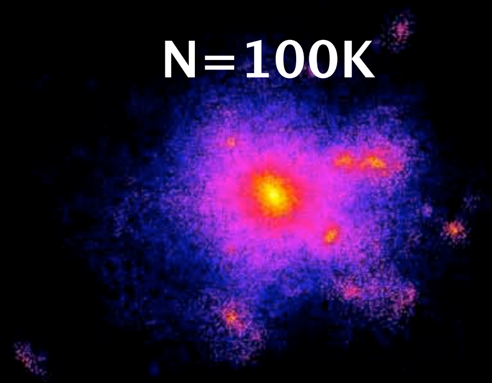
Substructure mass and velocity functions

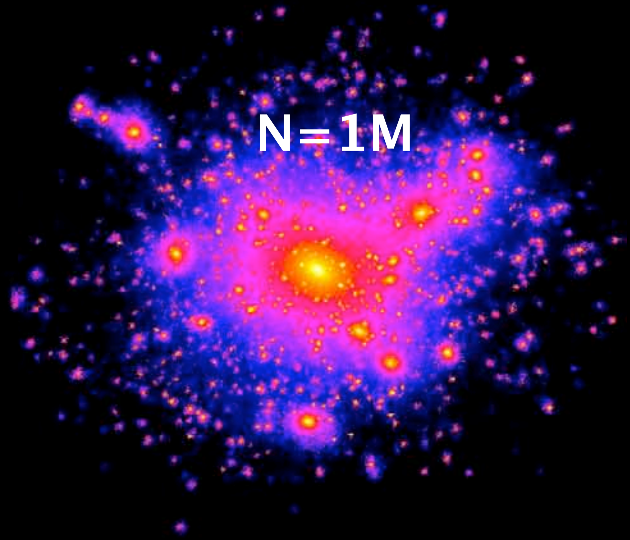


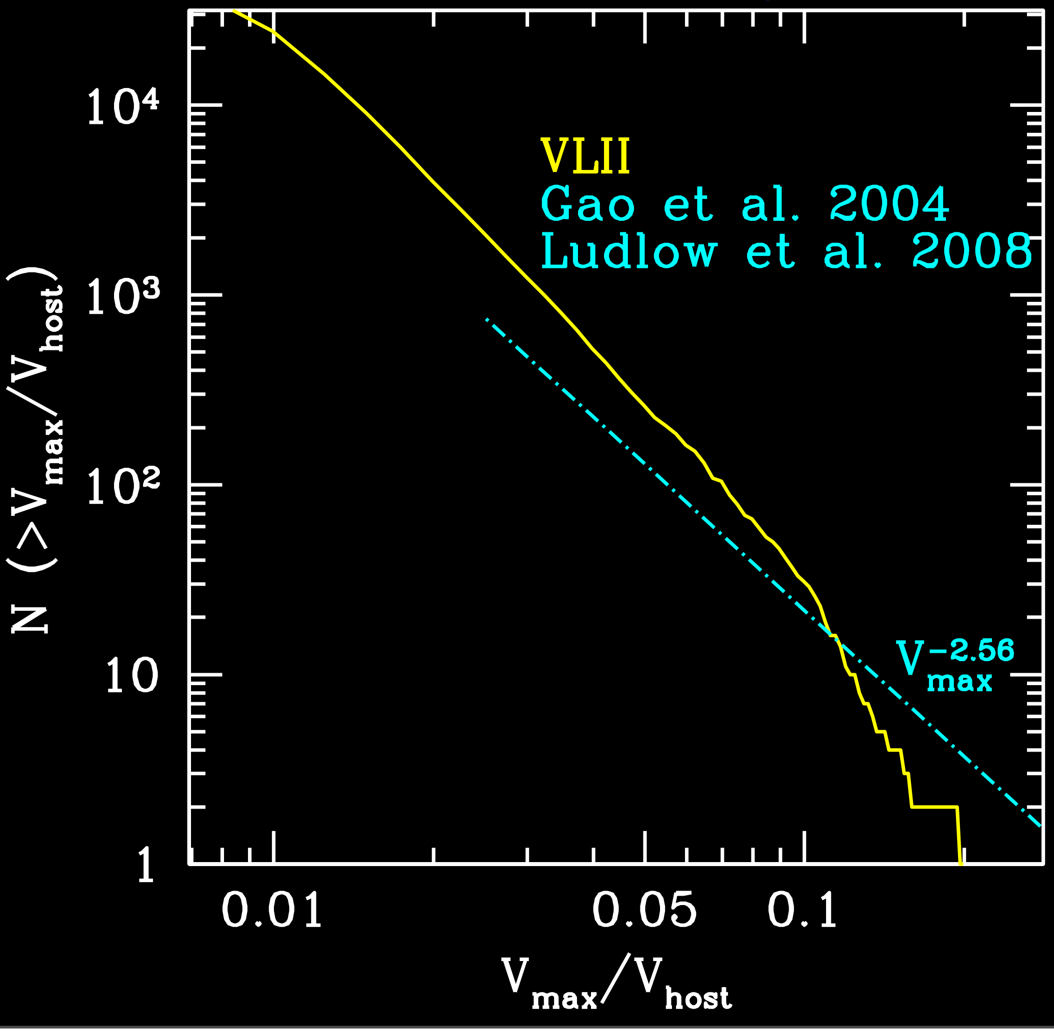


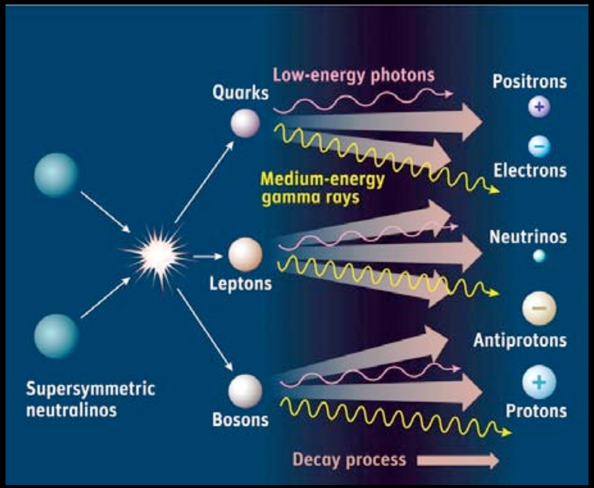
A brief history of N-body simulations







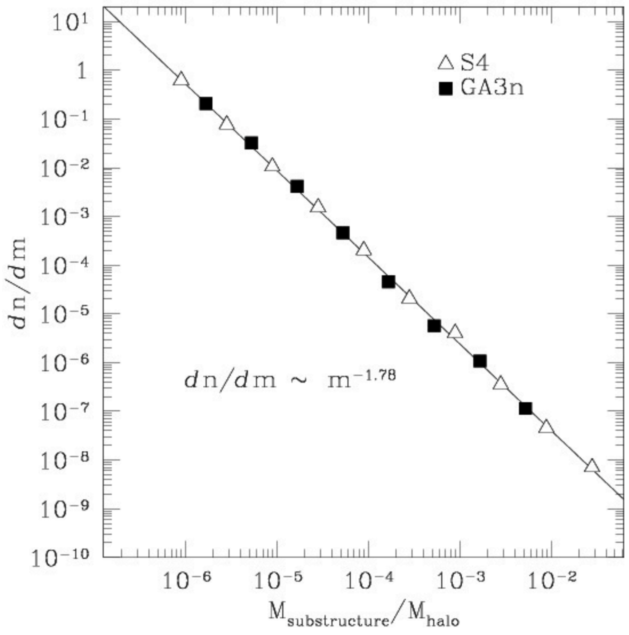


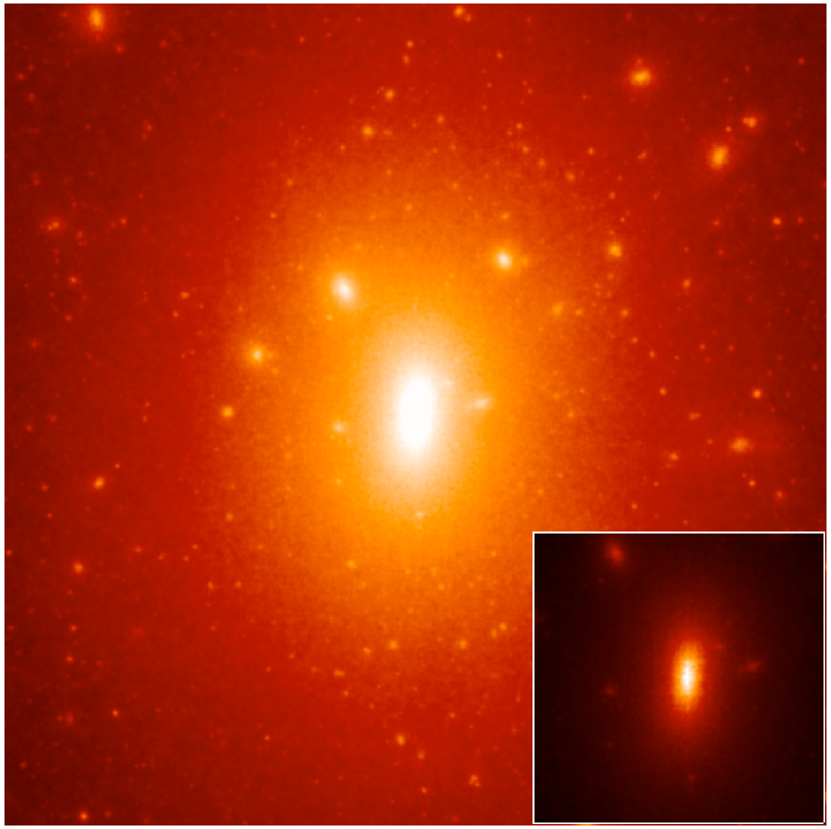


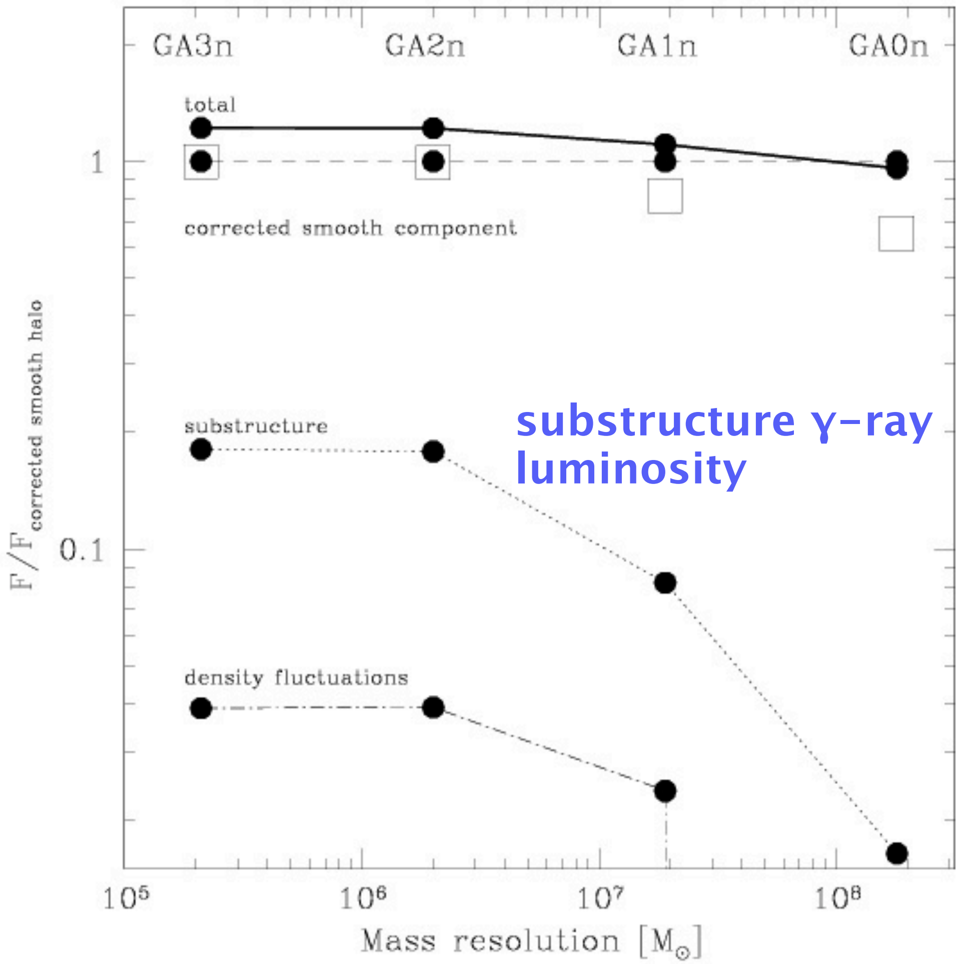
$$L_\gamma \propto \rho_s^2 r_s^3 \propto \frac{V_{\max}^4}{r_{\max}} \propto V_{\max}^3 \sqrt{\Delta_V}$$

$$N(V > V_{\max}) \propto V_{\max}^{-3}$$

Stoehr et al 2003

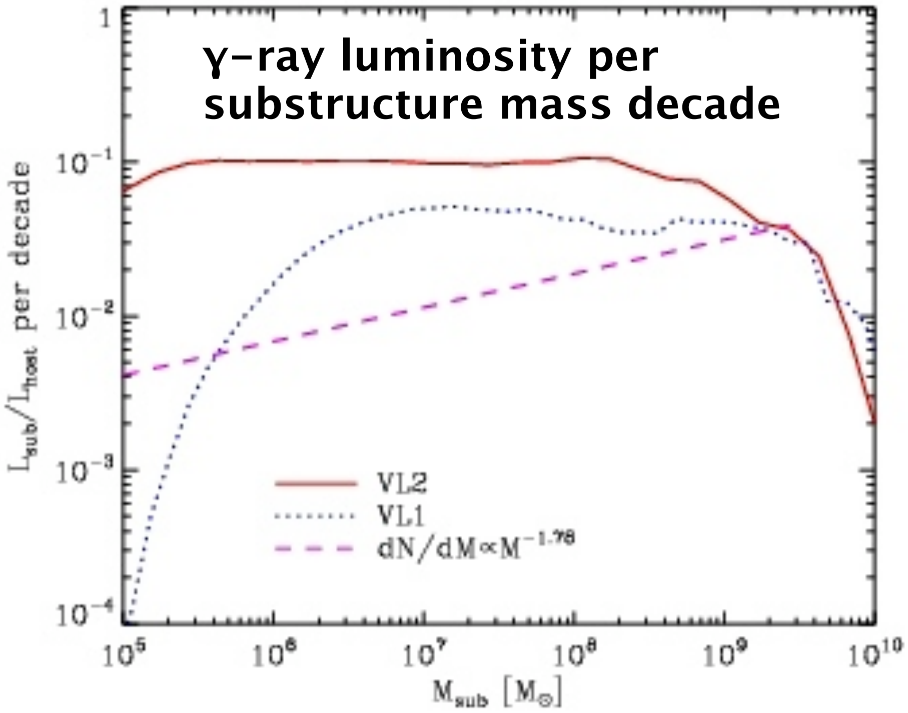




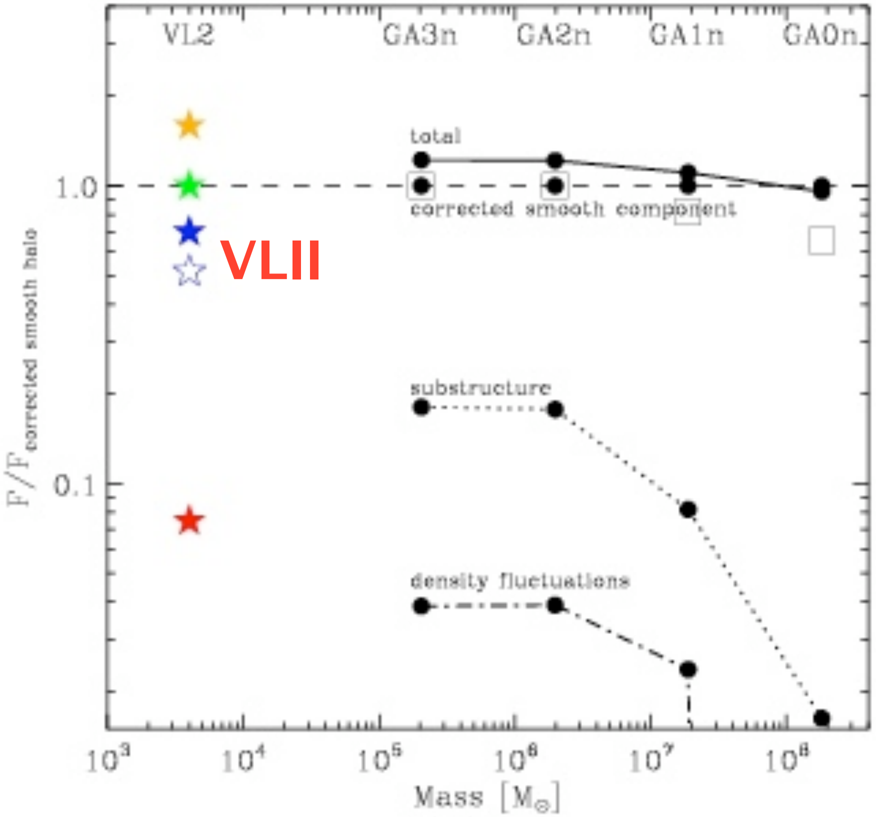


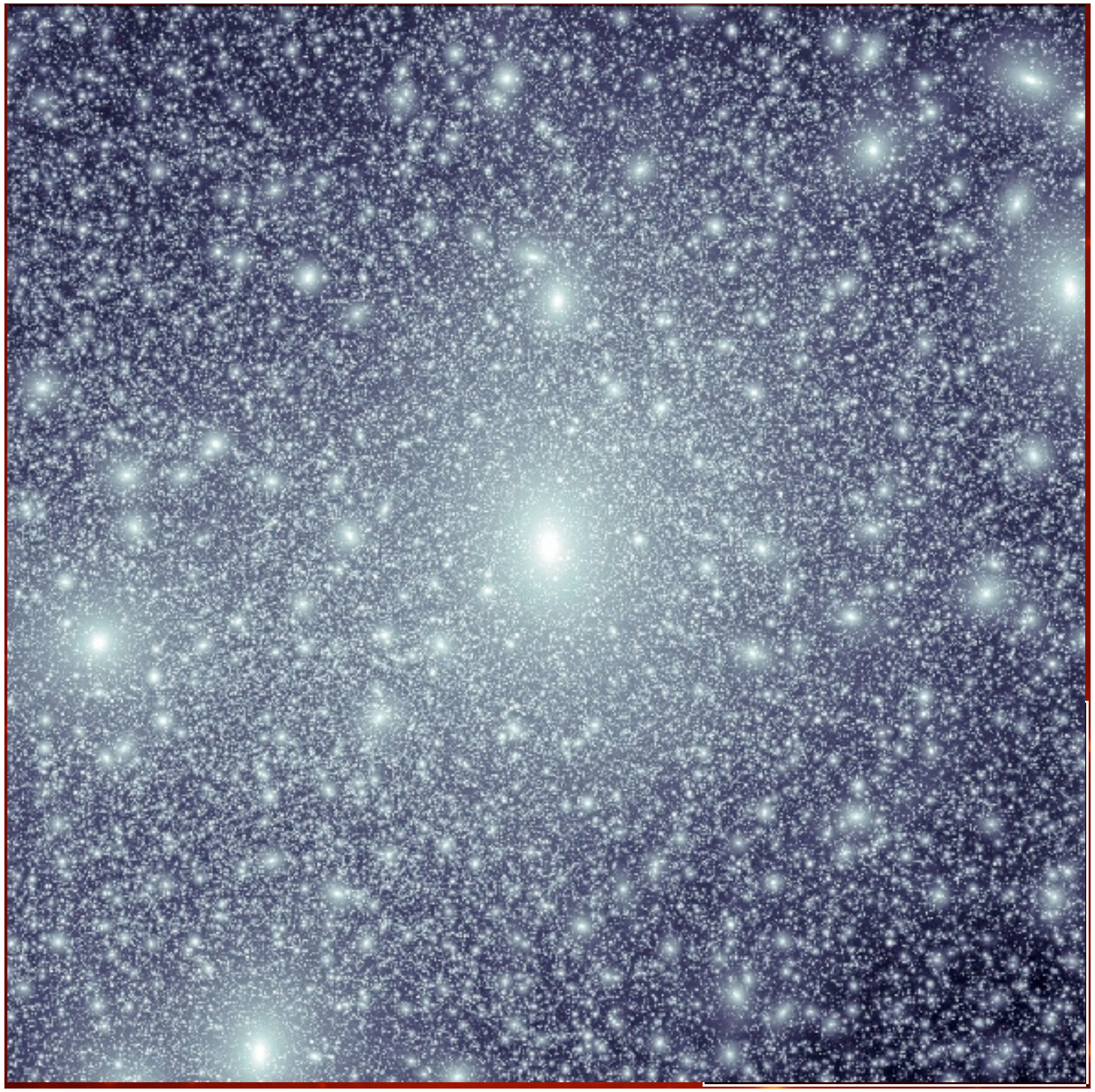
substructure γ-ray luminosity

"....the annihilation radiation from substructure within the Galactic halo is dominated by the most massive subhaloes..."

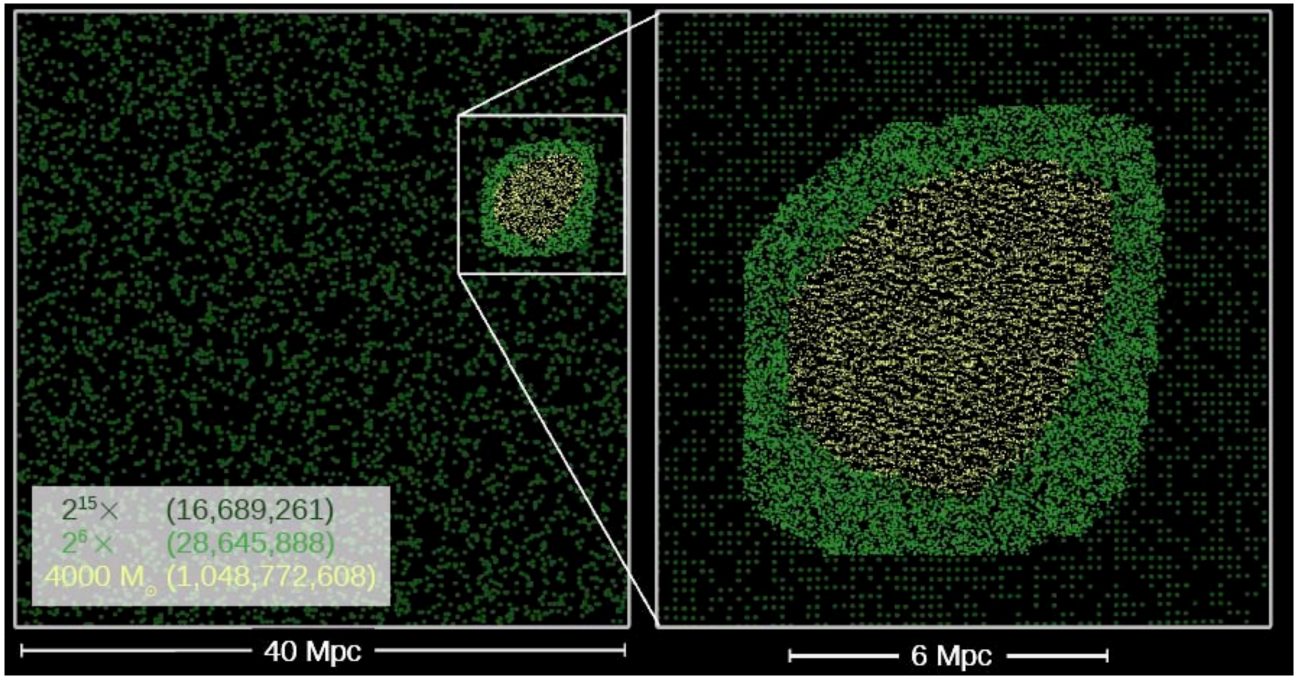


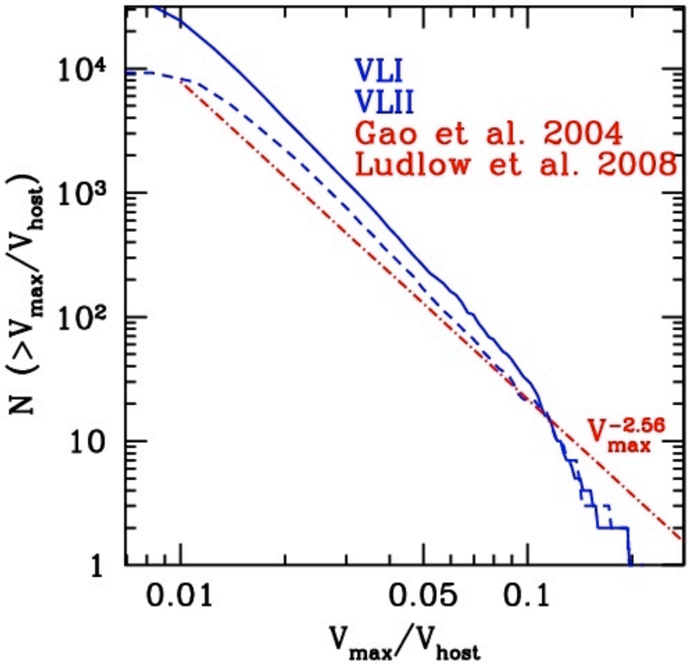
γ-ray luminosity per substructure mass decade

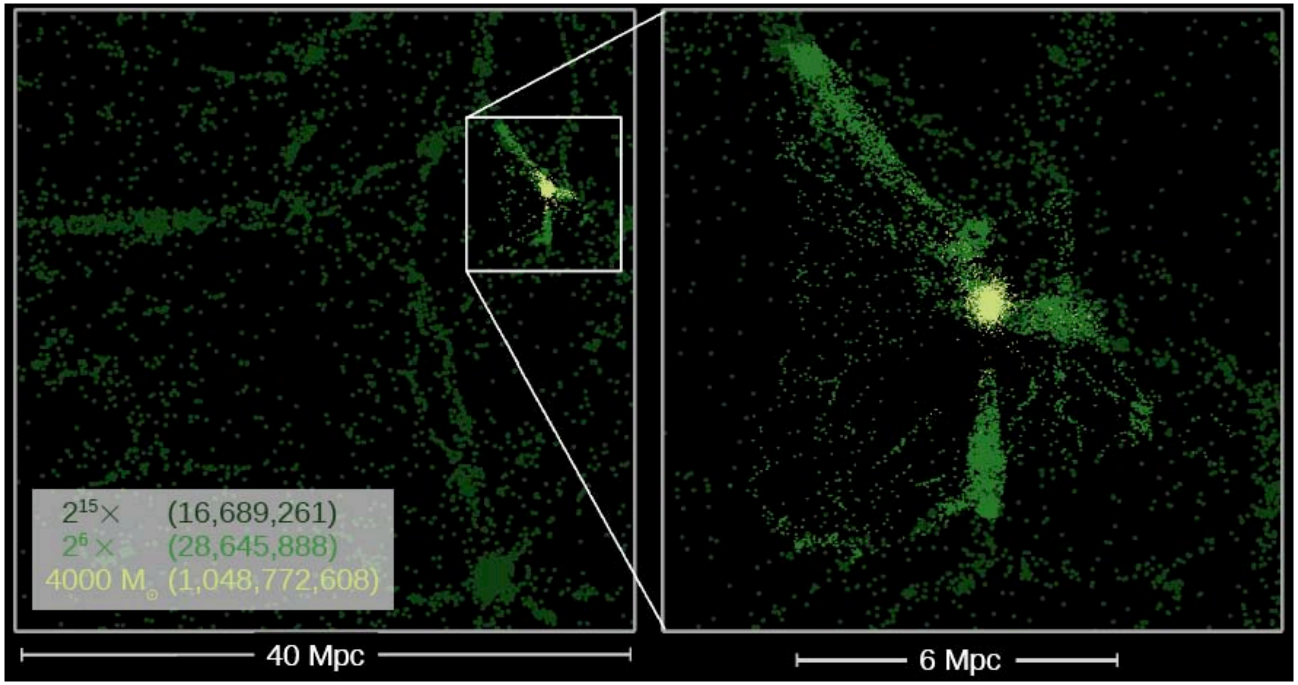


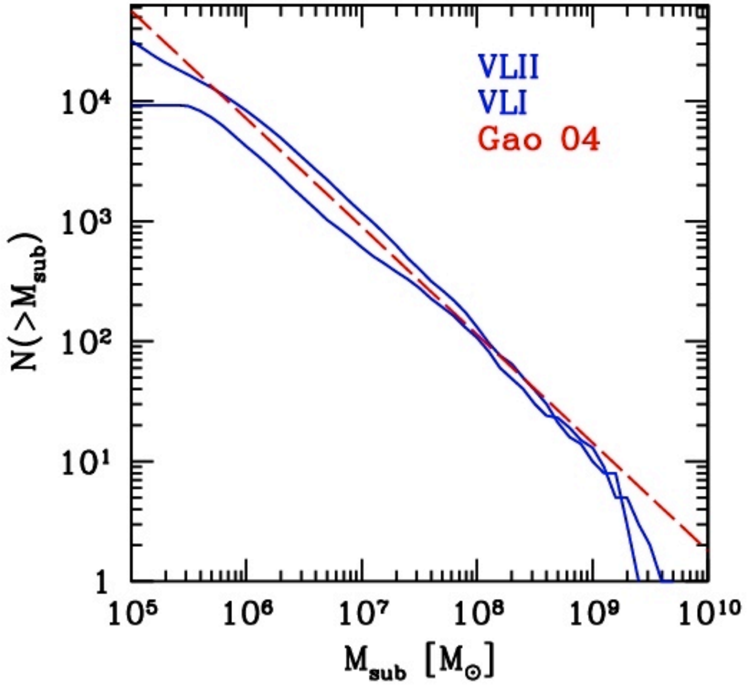


ICs with GRAPHIC2

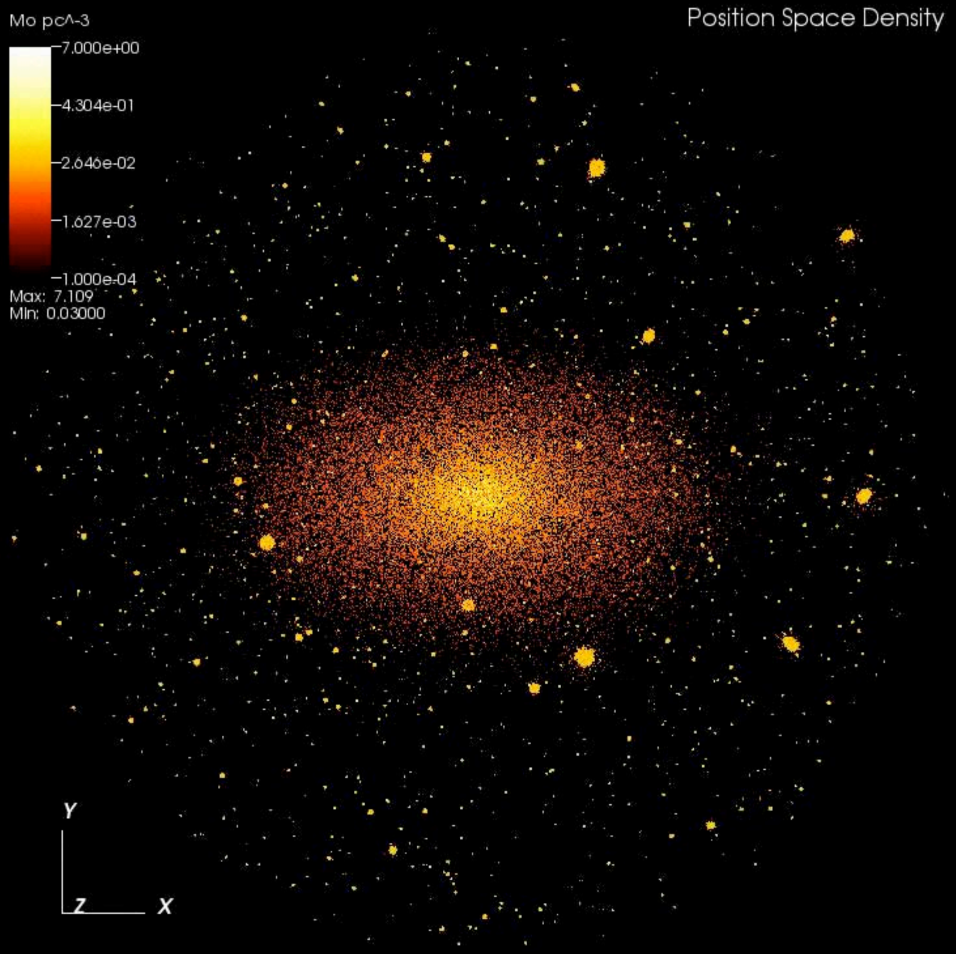


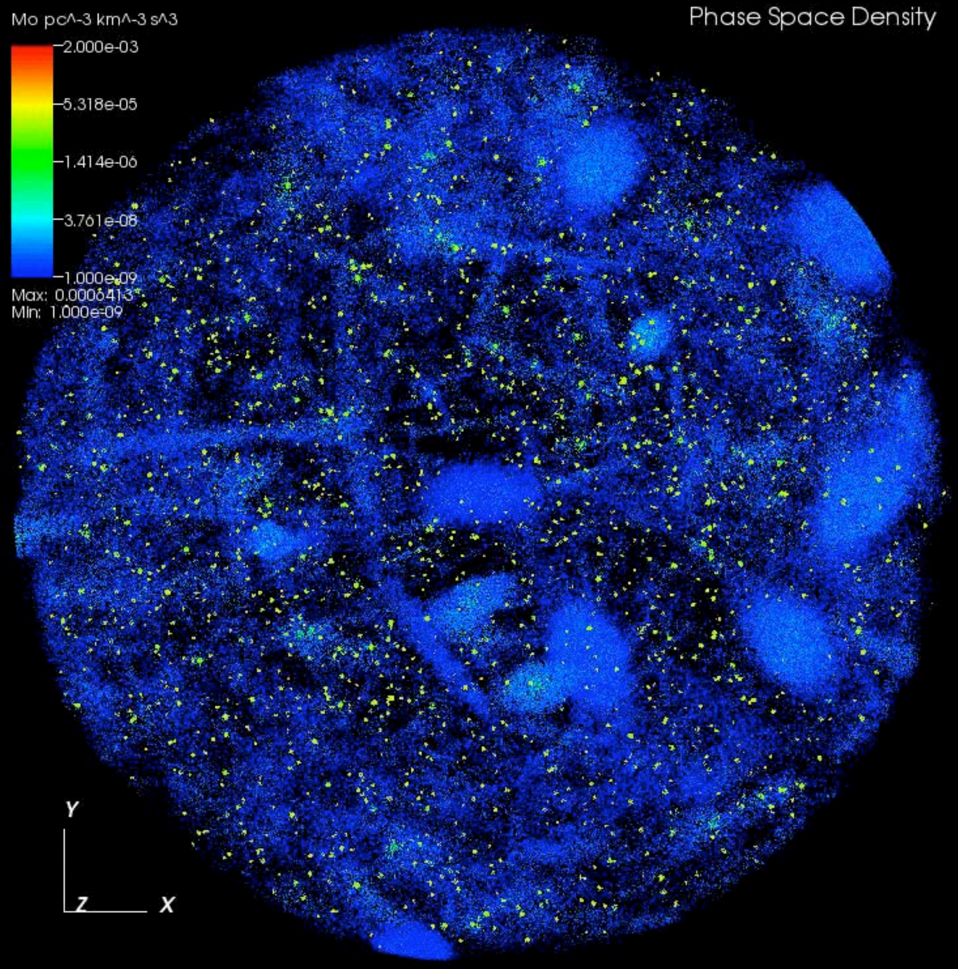




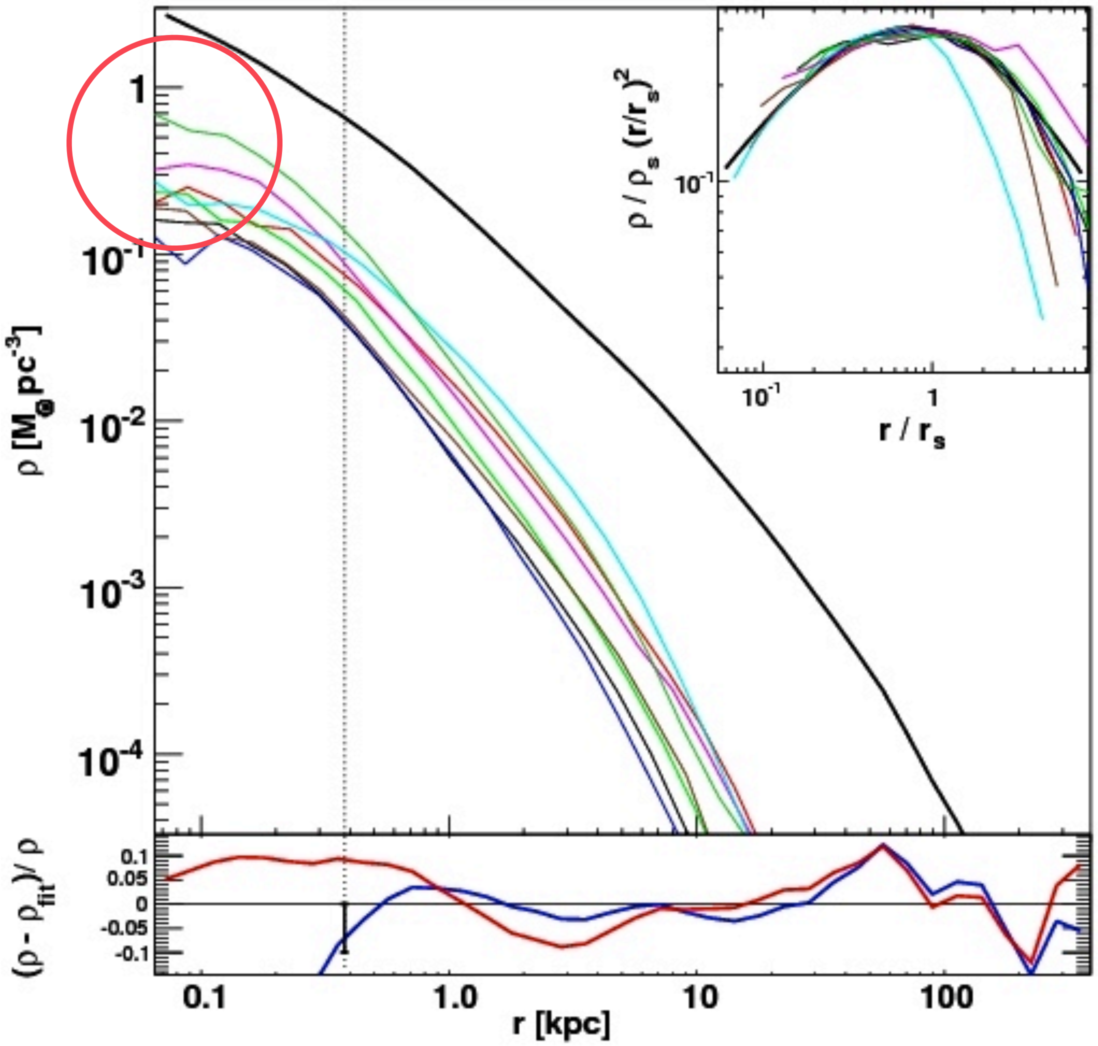


Phase-space substructure





coherent elongated features: streams that form out of material removed from accreted and disrupted subhalos. The visible streams are underdense relative to the surroundings but owing to their low velocity dispersion they manage to stand out in phase-space.



Kinematics of Ultra-Faint Milky Way Satellites

Simon & Geha 2007

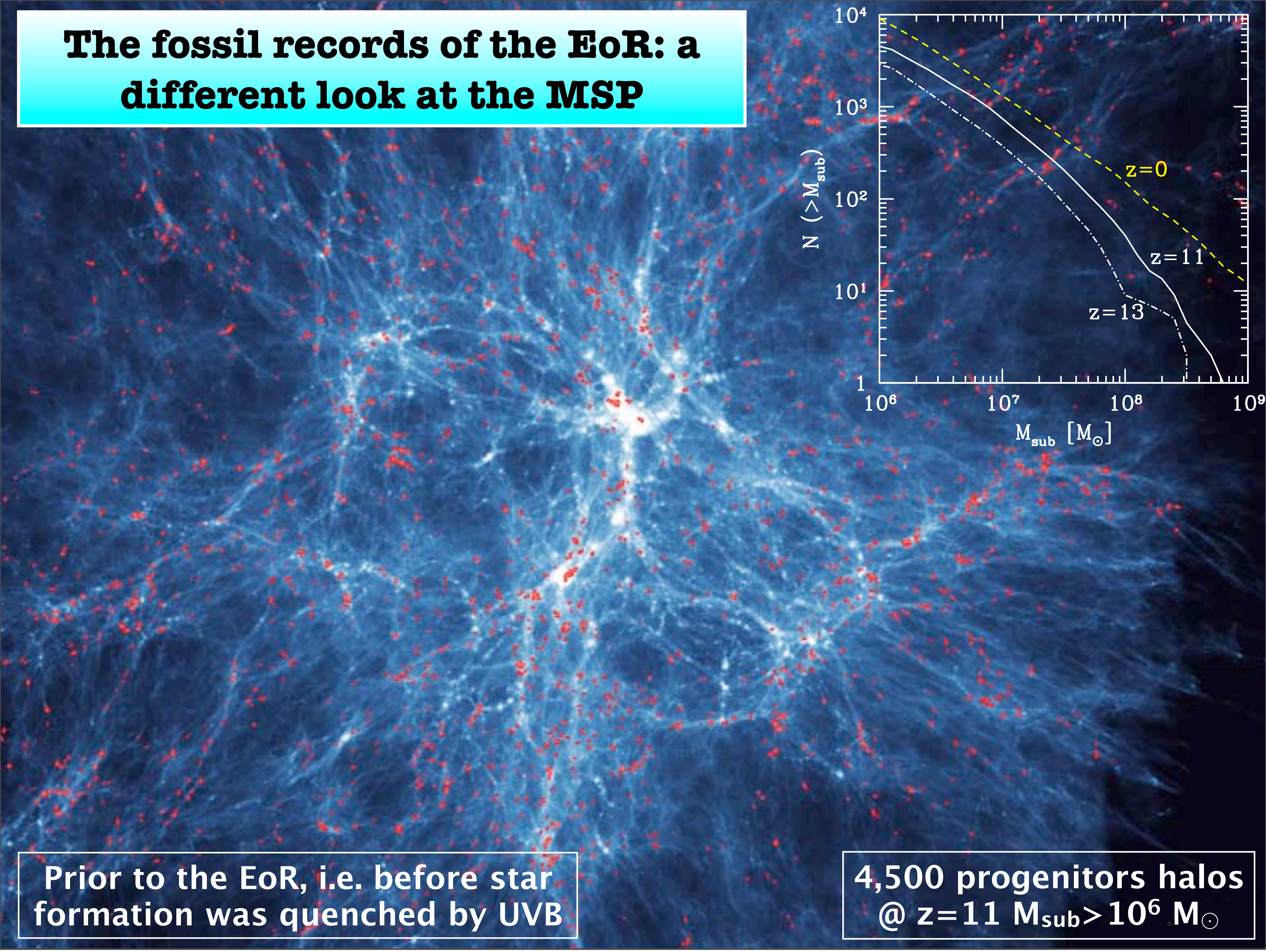
TABLE 5
PHYSICAL AND PHASE-SPACE DENSITIES

Galaxy	ρ_0 ($M_\odot$ pc^{-3})	$\bar{\rho}$ ($M_\odot$ pc^{-3})	Q ($M_\odot$ pc^{-3} [km s^{-1}]$^{-3}$)
Ursa Major II[a]	1.13 ± 0.60	0.27 ± 0.18	$3.7 \pm 3.1 \times 10^{-3}$
Leo T	0.79 ± 0.36	0.19 ± 0.10	$1.9 \pm 1.5 \times 10^{-3}$
Ursa Major I	0.25 ± 0.08	0.06 ± 0.02	$5.6 \pm 2.9 \times 10^{-4}$
Leo IV	0.19 ± 0.20	0.05 ± 0.05	$5.3 \pm 9.9 \times 10^{-3}$
Coma Berenices	2.09 ± 0.86	0.52 ± 0.24	$2.2 \pm 1.4 \times 10^{-2}$
Canes Venatici II	0.49 ± 0.25	0.12 ± 0.07	$5.1 \pm 4.1 \times 10^{-3}$
Canes Venatici I	0.08 ± 0.02	0.02 ± 0.01	$1.7 \pm 0.5 \times 10^{-4}$
Hercules	0.10 ± 0.04	0.02 ± 0.01	$7.7 \pm 5.2 \times 10^{-4}$

[a] UMa II may be a tidally disrupted remnant, which would artificially inflate its density.

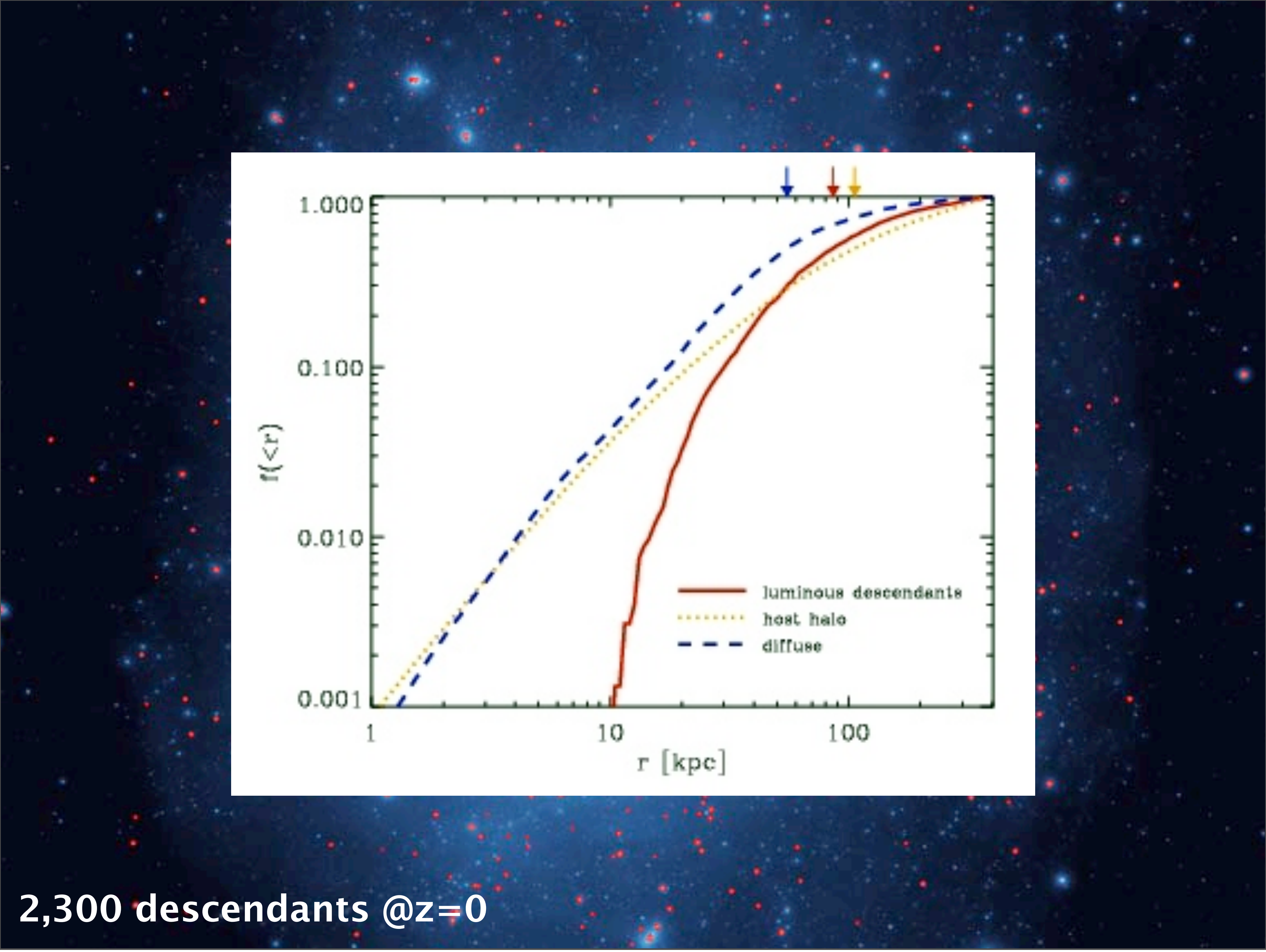
Our predicted subhalo central densities 0.4-2.5 $M_\odot$ pc^{-3} within 100 pc (7-46 $M_\odot$ pc^{-3} within 10 pc) as well as phase-space densities are in agrement with recent observations. The fact that CDM naturally predicts a small-scale DM distribution that matches the observations appears to be a real success of the model.

The fossil records of the EoR: a different look at the MSP



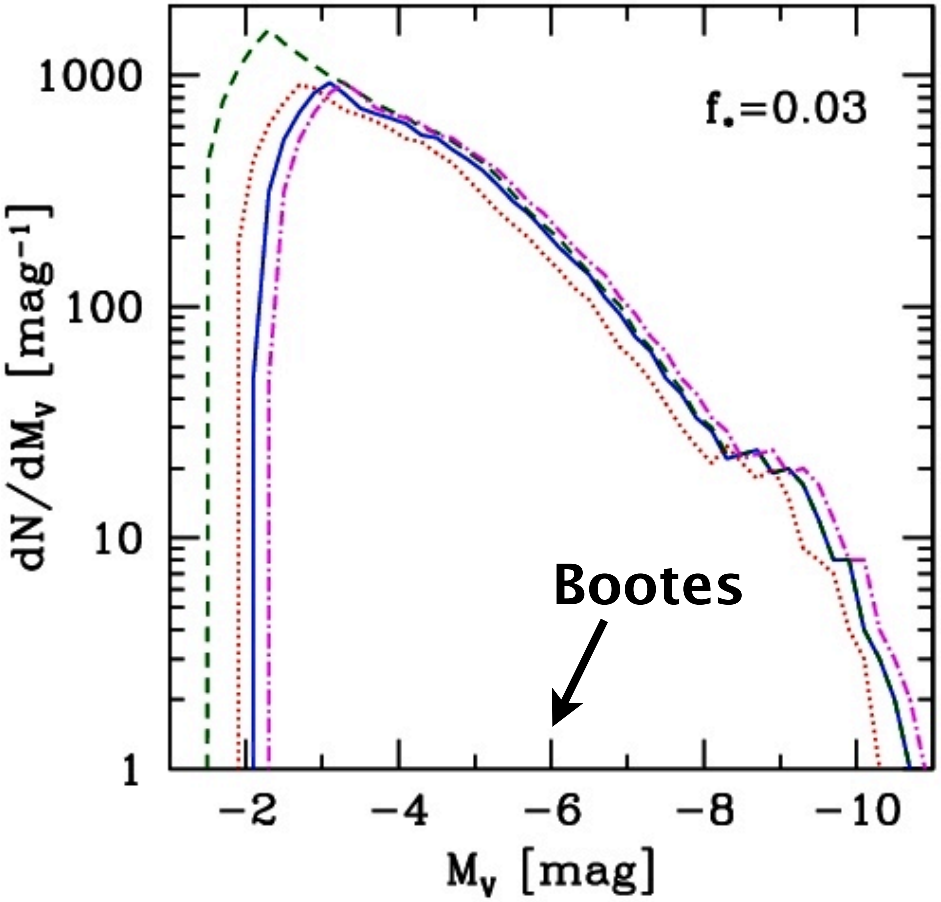
Prior to the EoR, i.e. before star formation was quenched by UVB

4,500 progenitors halos @ z=11 $M_{sub} > 10^6\ M_\odot$



2,300 descendants @z=0

The z=0 LF



SSP @ t=13.7 Gyr
$M_V=6.7^{mag}\ (M_\odot)^{-1}$

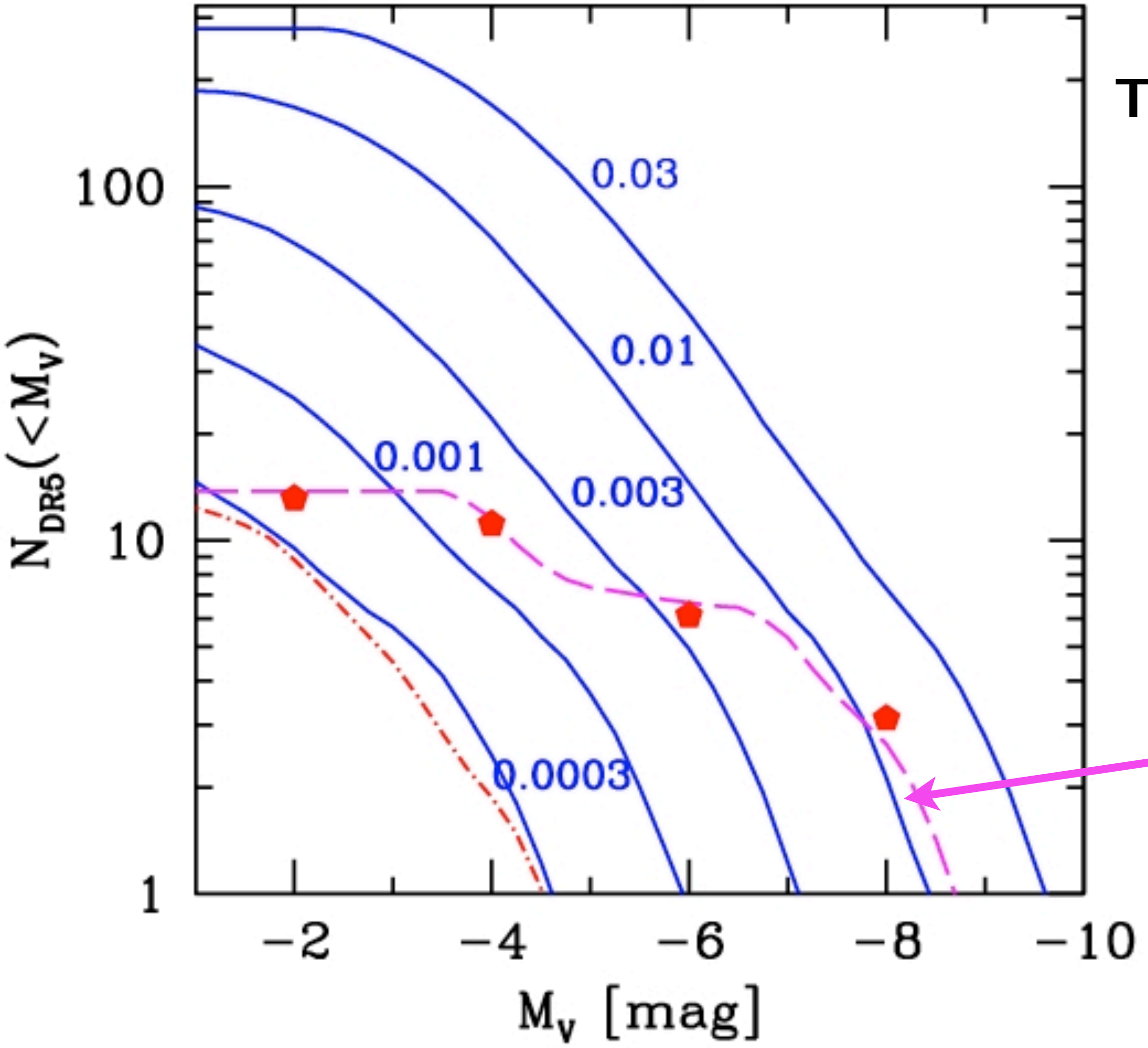
1) all progenitor hosts above 10^6 $M_\odot$ have $M_{gas}=(\Omega_b/\Omega_m)M_{sub}$.

2) @$z\gtrsim 11$ a fraction $f_* \neq f(M_{sub})$ of this gas is turned into very metal-poor stars with $Z=Z_\odot/200$ (the lowest metallicity allowed by BC03 population synthesis models) and a Salpeter IMF.

3) star formation is suppressed at later epochs in all progenitors and their descendants.

4) primordial stellar systems are deeply embedded in progenitor minihalos and remain largely unaffected by tidal stripping even if their hosts are not. The complete tidal disruption of a host, however, also destroys its stellar system.

Mock SDSS sample



$$r_{\rm max} = \left(\frac{3}{4\pi f_{\rm DR5}}\right)^{1/3} 10^{(-0.6M_V-5.23)/3}\ {\rm Mpc}$$

Tollerud et al 08, Koposov et al 08

mass-dependent
$f_*=(0.02,0.0025,0)$
$M_{sub}=(>7\text{x}10^7, 3.5\text{x}10^7\text{-}7\text{x}10^7, <3.5\text{x}10^7\ M_\odot)$

Low-mass stars did not form in significant numbers in halos below the atomic cooling mass threshold even before the EoR. Star formation at first light occurred either with an IMF lacking stars below $0.9M_\odot$, or was intrinsically very inefficient in hosts with $M_{sub}<10^8M_\odot$.

THE END