Copernicus Complexio:

The Milki-Way, the Cosmic Web and the satellites

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Collaborators:

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The outline

- Copernicus Complexio - COCO
- The Cosmic Web and the dwarfs
- The MW satellites & the halo mass
- Conclusions

The Copernicus Complexio: COCO simulation suite

A zoom-in set-up:

$Np = \sim 2400^3$

$Mp = 1.135 \times 10^5\ M_\odot/h$

$\varepsilon = 230pc/h$

L=100 Mpc

$V_{hr} = \sim 36200\ Mpc^{3s}$

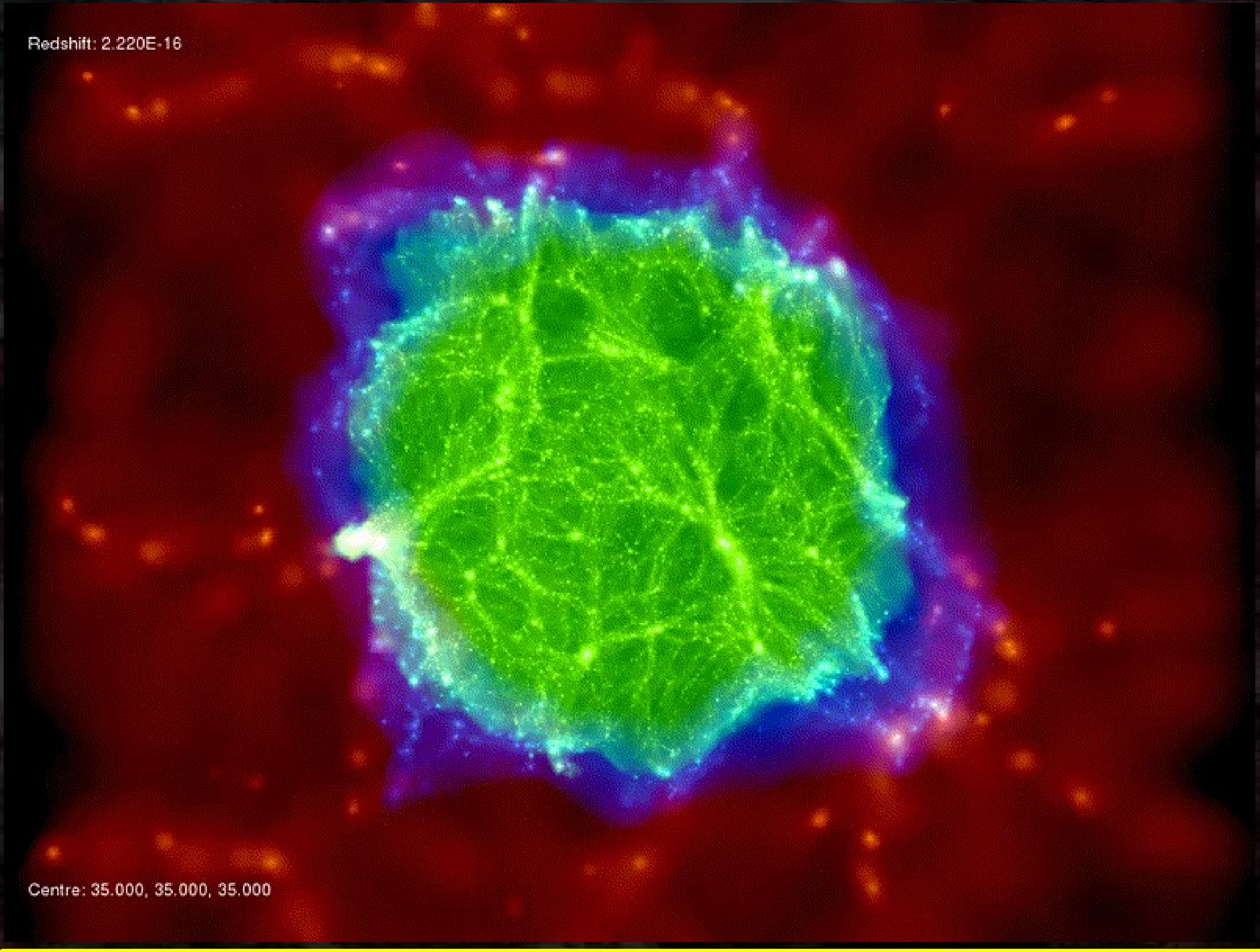
2 flavours:

COLD and

WARM(~3.5keV line TRMEP equivalent)

IC's set at $z_{ini}=127$ with 2LPT

The overall resolution is close to Aquarius lvl-3



The initial P(k) normalisation is chosen to be WMAP7

$\Omega_m=0.272$, $\Omega_\Lambda=0.728$, $\sigma_8=0.809$, $n_s=0.968$, $h=0.704$

The Copernicus Complexio: COCO simulation suite

Why the name?

The scientific motivation:

- **testing the CDM on galaxy scales,**
- **obtaining statistical insights into dwarf/galaxy CDM riddles: TBTF, missing satellites, core/cusp, satellites orbits, tidal debris, etc. (and many more – the sky is the limit)**

Is the MW a very unusual galaxy within the LCDM picture? Do we really need to "break" (weaken) our Copernican Principle to accept current cosmological paradigm?

The Copernican Principle:
"WE ARE NOT PRIVILEDGED OBSERVERS OF THE UNIVERSE"

The Copernicus Complexio: COCO simulation suite

The Copernicus Complexio: COCO simulation suite

The main goal was to obtain a census of ~50 MW mass host with subhaloes resolved down to v_{max}~10-15km/s

To save cpu time we picked a region with no cluster closer than 5Mpc/h to the zoom-in boundary keeping MF as close as possible to the universal one.

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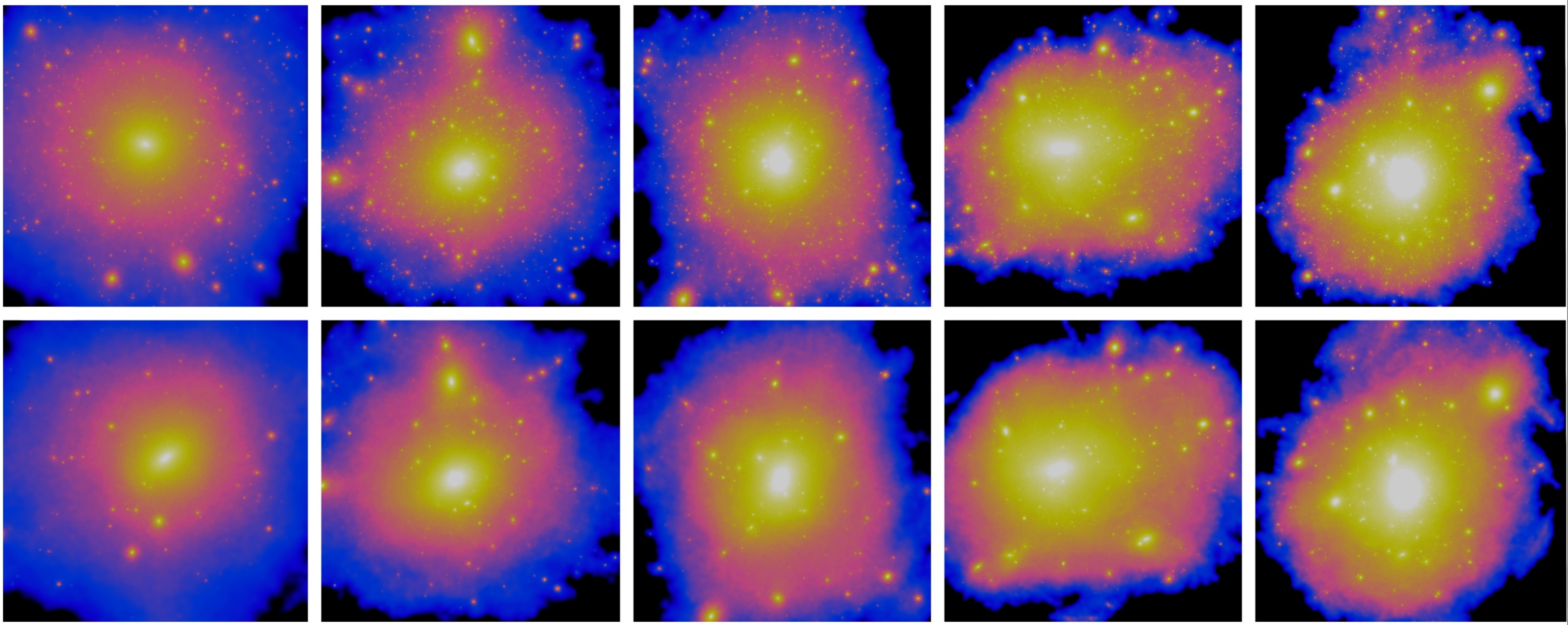
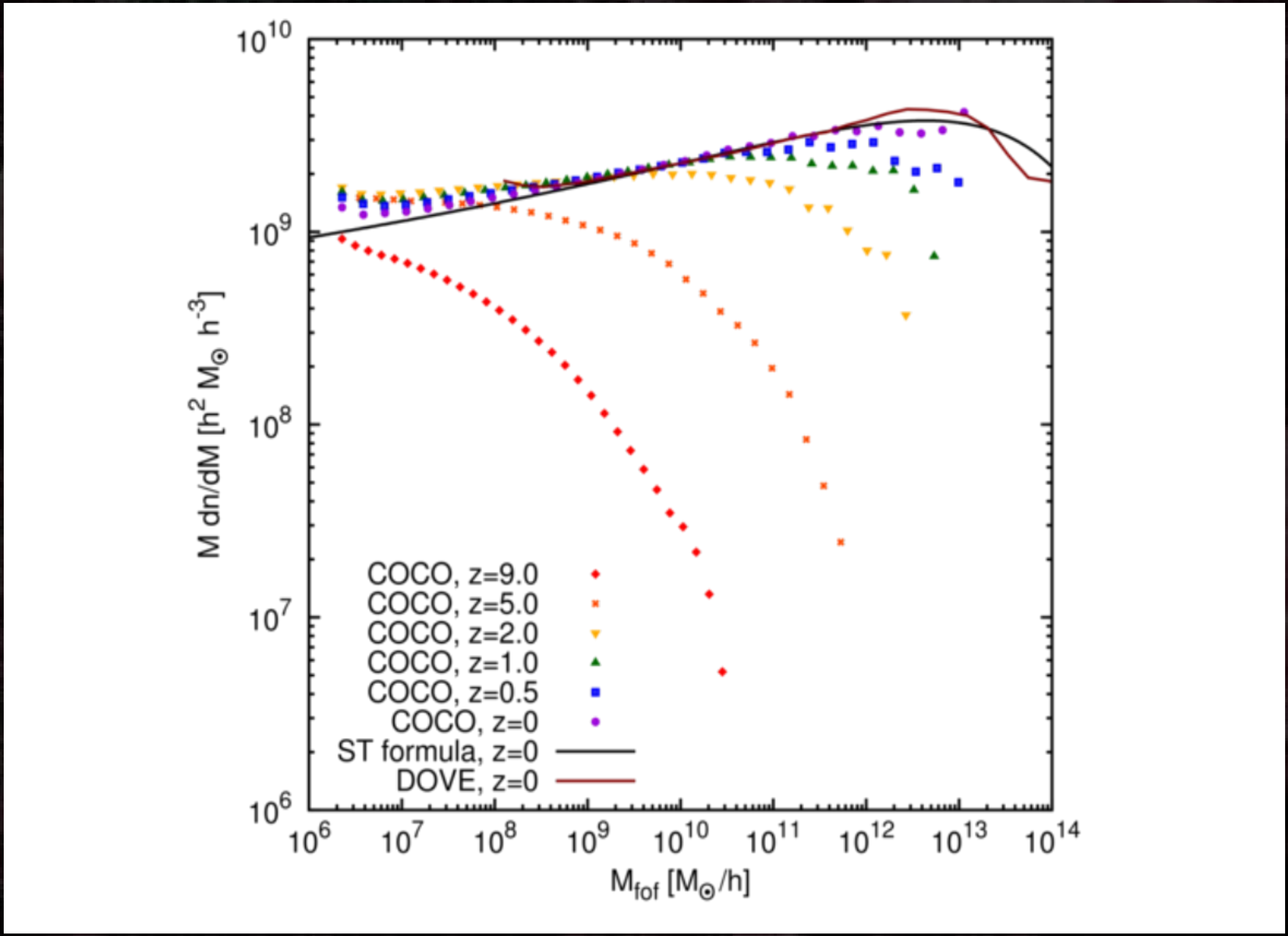
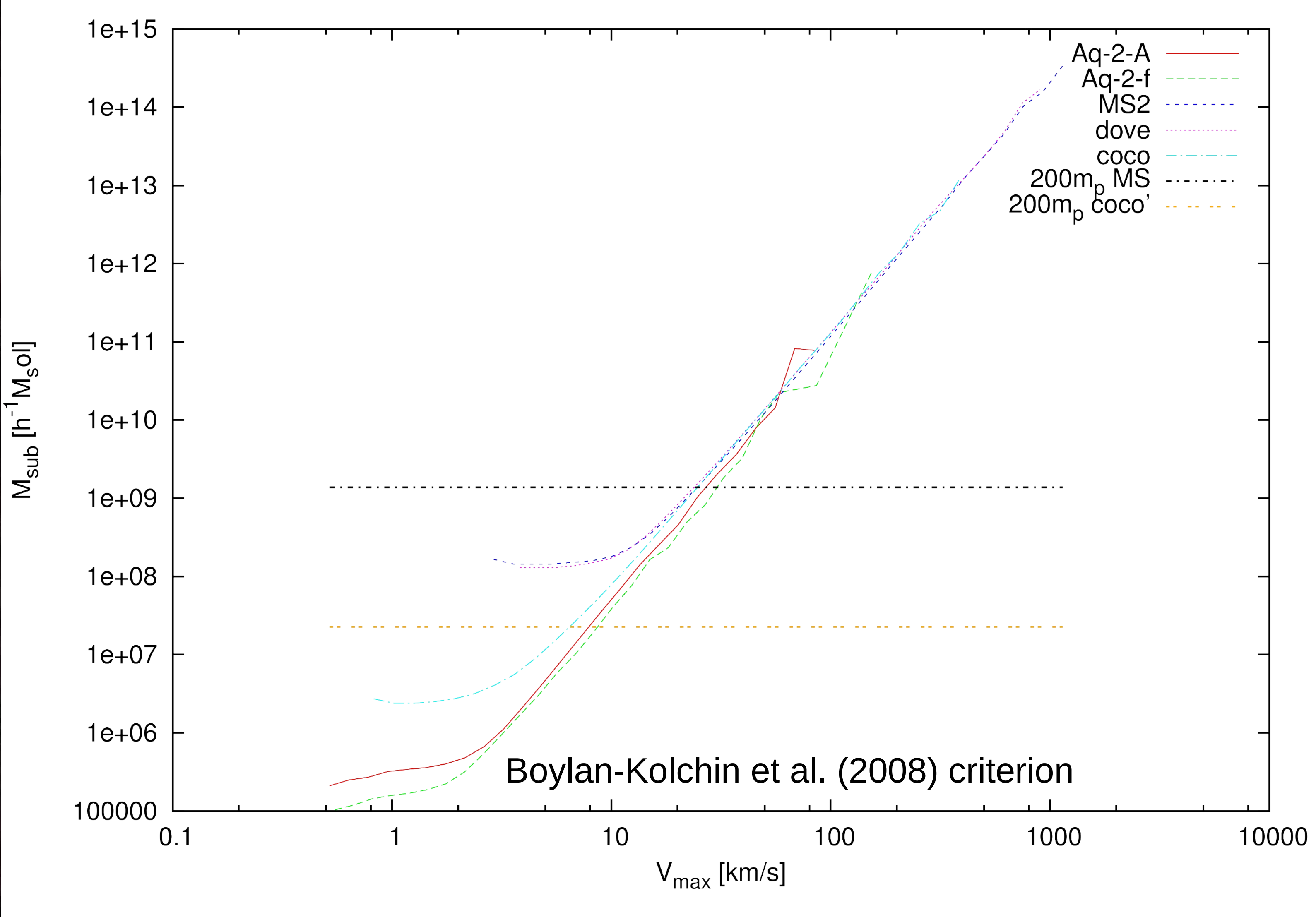


The Copernicus Complexio: some basic results



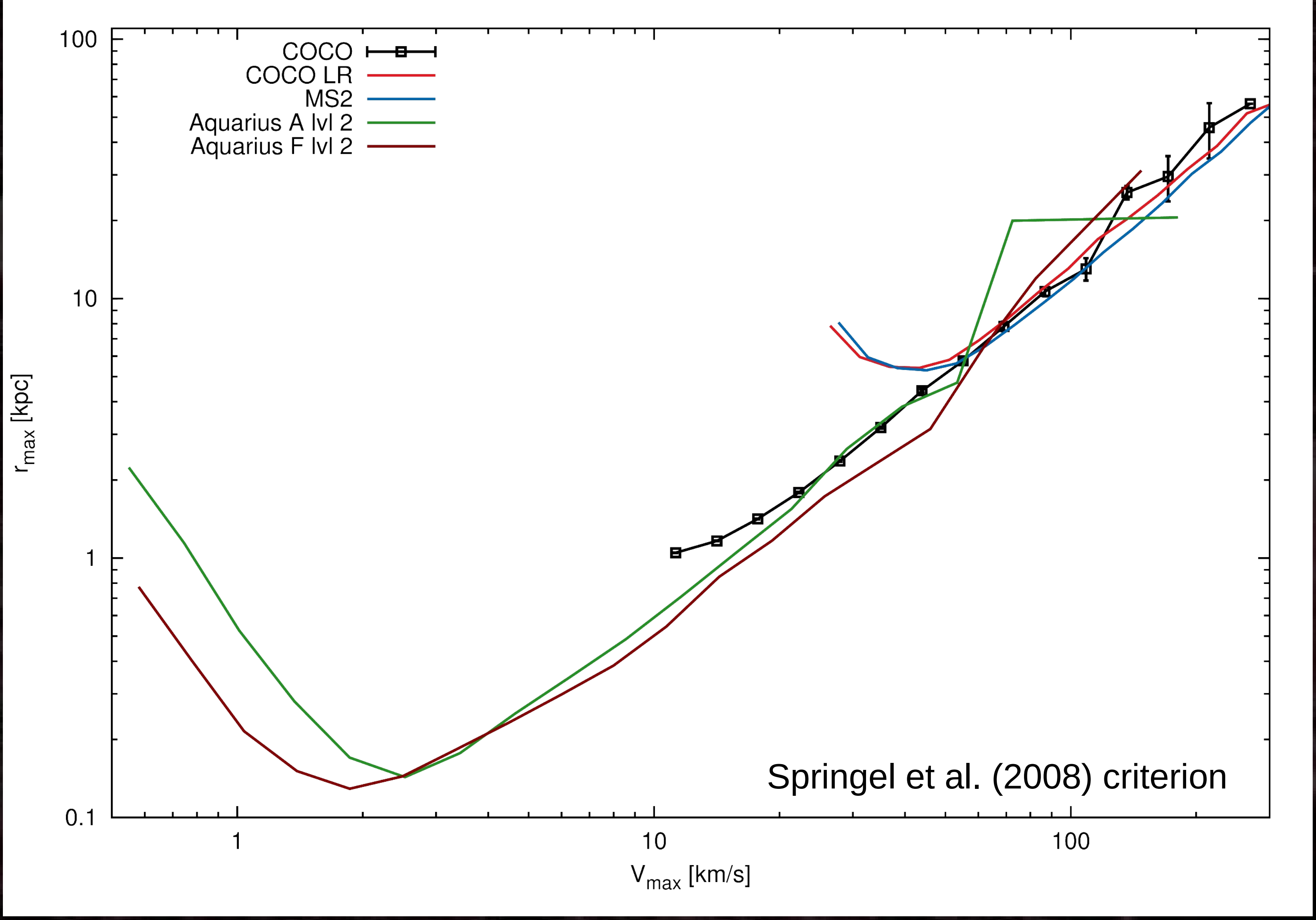
The redshift evolution of the halo mass function

The Copernicus Complexio: some basic results



The convergence and the attained resolution

The Copernicus Complexio: some basic results



The convergence and the attained resolution

THE COSMIC WEB

The key aspects of the Cosmic Web related to the processes that shape the LSS:

Hierarchical structure formation

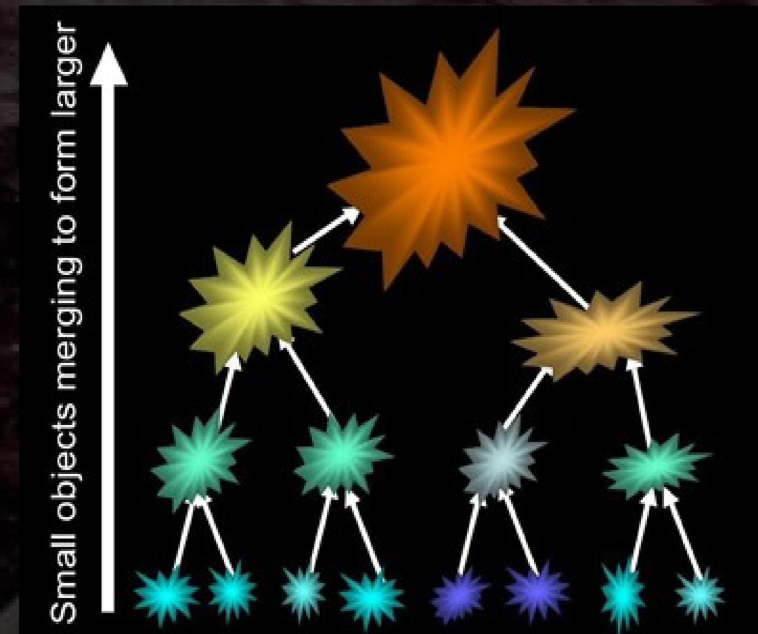
➡ **Multi-scale character**

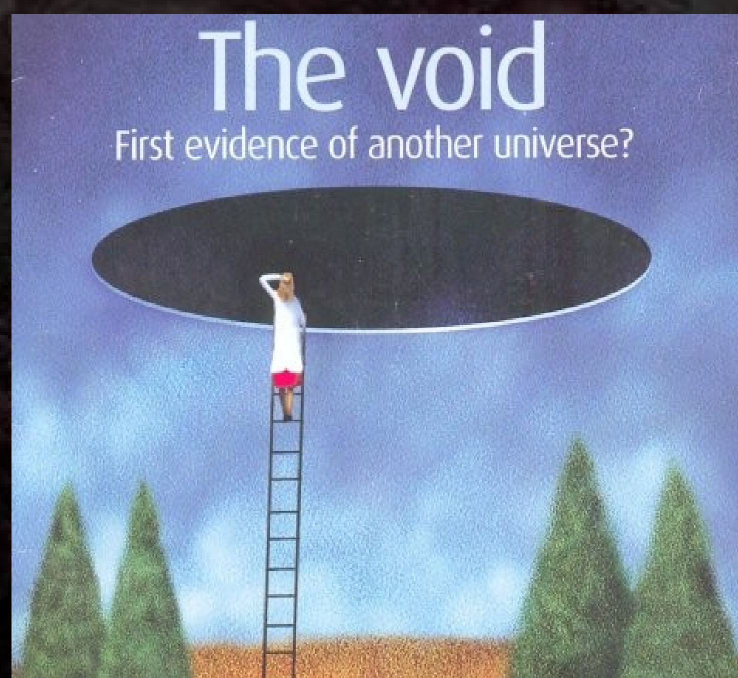
Anisotropic collapse

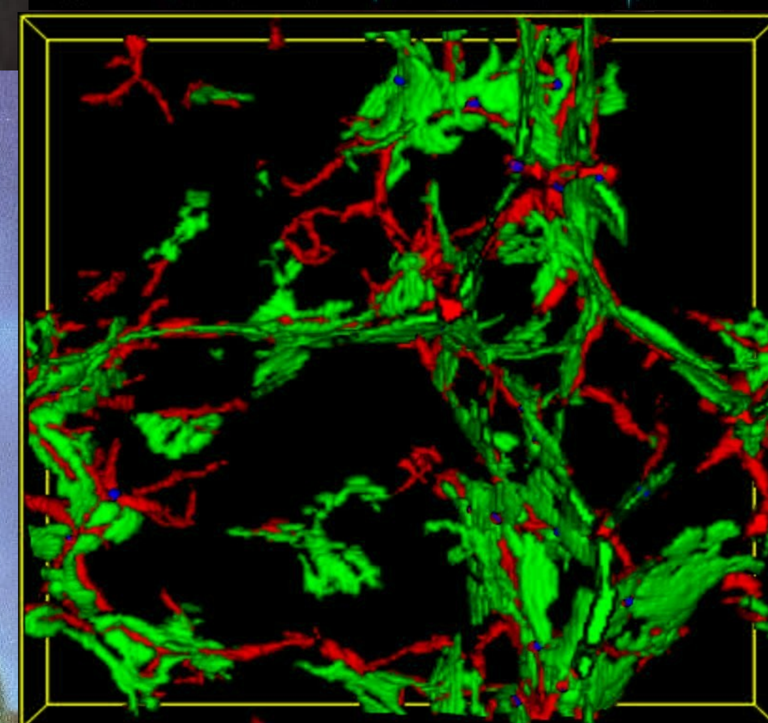
➡ **Web-like network of walls, filaments & voids**

skewness of the density distribution

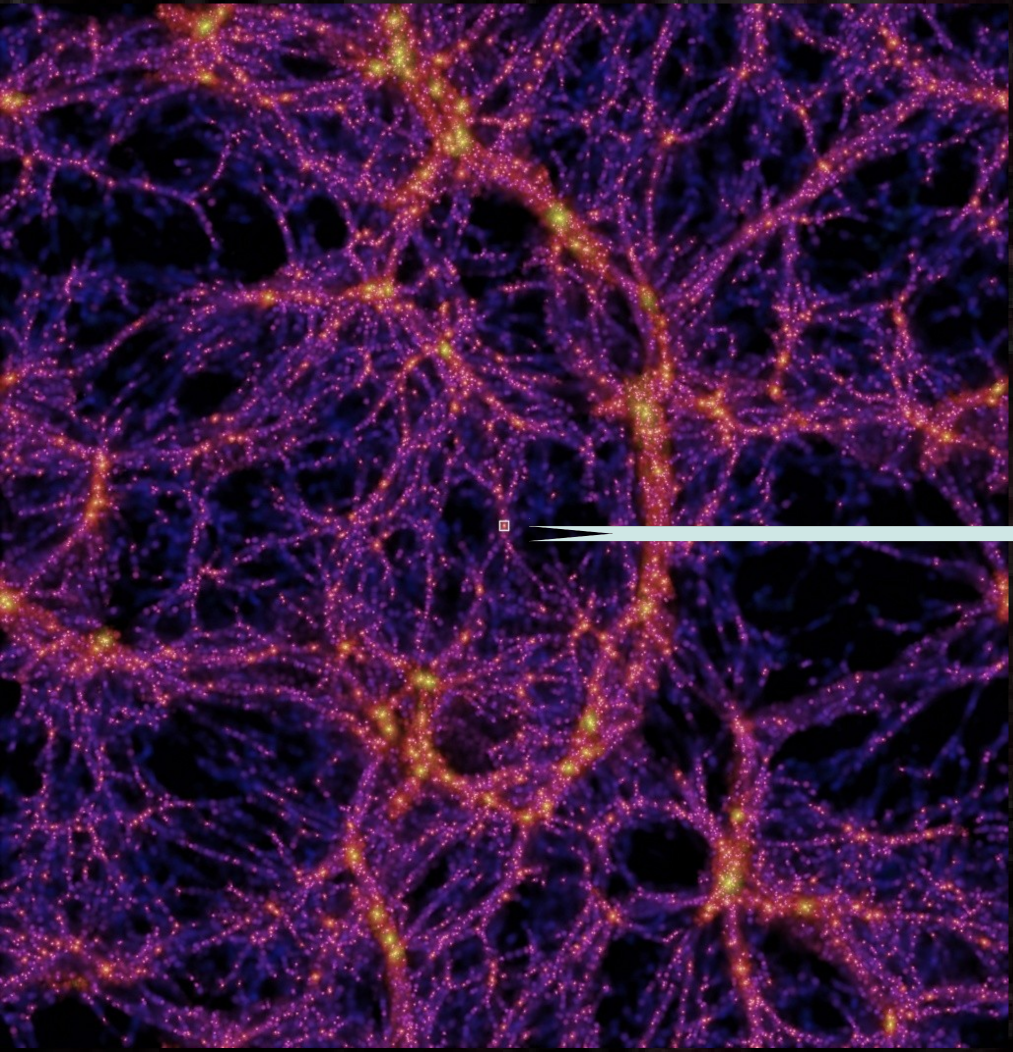
➡ **Volume dominance of voids**







THE COSMIC WEB
a home for haloes and galaxies woven within

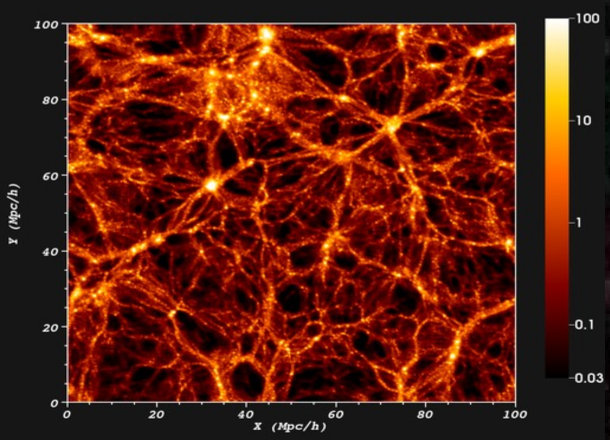


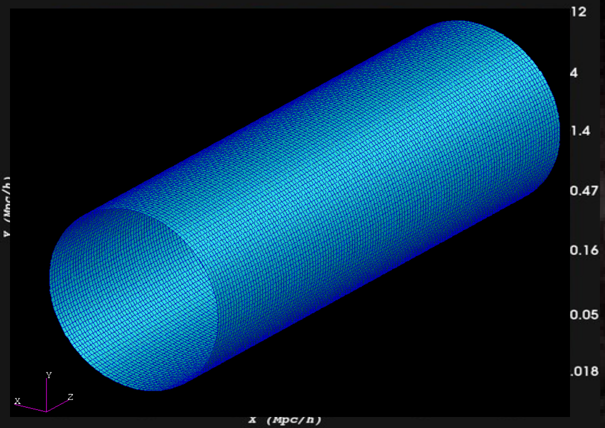
Aquarius simulation

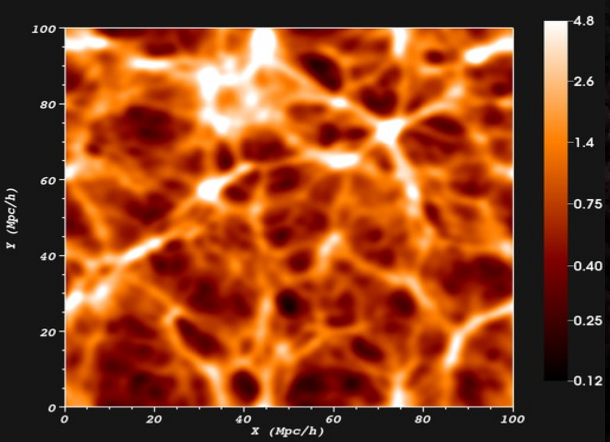
THE NEXUS+ algorithm (bowdlerized)

Cautun et al. (2012)

Logarithmic Gaussian filtering







$$\mathcal{S} = \mathcal{I} \times \begin{cases} |\lambda_3| \; \theta(-\lambda_1)\theta(-\lambda_2)\theta(-\lambda_3) & \text{cluster} \\ |\lambda_2| \; \theta(-\lambda_1)\theta(-\lambda_2) & \text{filament} \\ |\lambda_1| \; \theta(-\lambda_1) & \text{wall,} \end{cases}$$

And the response function

Compute the env strength function

$$\mathcal{I} = \begin{cases} \left|\frac{\lambda_3}{\lambda_1}\right| & \text{cluster} \\ \left|\frac{\lambda_2}{\lambda_1}\right| \Theta\left(1 - \left|\frac{\lambda_3}{\lambda_1}\right|\right) & \text{filament} \\ \Theta\left(1 - \left|\frac{\lambda_2}{\lambda_1}\right|\right) \Theta\left(1 - \left|\frac{\lambda_3}{\lambda_1}\right|\right) & \text{wall} \end{cases}$$

Find and sort the eigenvalues at every point

Structure	Soft constraints	Strict constraints
cluster	$\lvert\lambda_1\rvert \simeq \lvert\lambda_2\rvert \simeq \lvert\lambda_3\rvert$	$\lambda_1 < 0$; $\lambda_2 < 0$; $\lambda_3 < 0$
filament	$\lvert\lambda_1\rvert \simeq \lvert\lambda_2\rvert \gg \lvert\lambda_3\rvert$	$\lambda_1 < 0$; $\lambda_2 < 0$
wall	$\lvert\lambda_1\rvert \gg \lvert\lambda_2\rvert$; $\lvert\lambda_1\rvert \gg \lvert\lambda_3\rvert$	$\lambda_1 < 0$

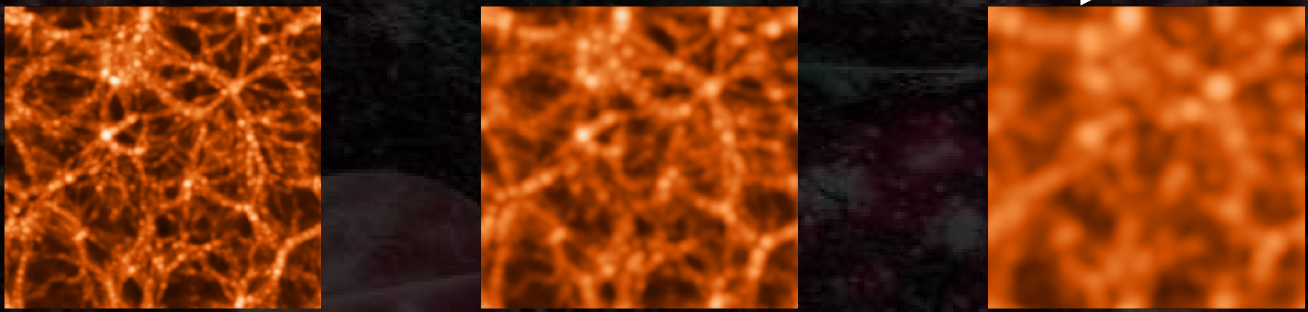
$$H_{ij,R_n}(\mathbf{x}) = R_n^2 \, \frac{\partial^2 f_{R_n}(\mathbf{x})}{\partial x_i \partial x_j},$$

Compute the Hessian for the input field

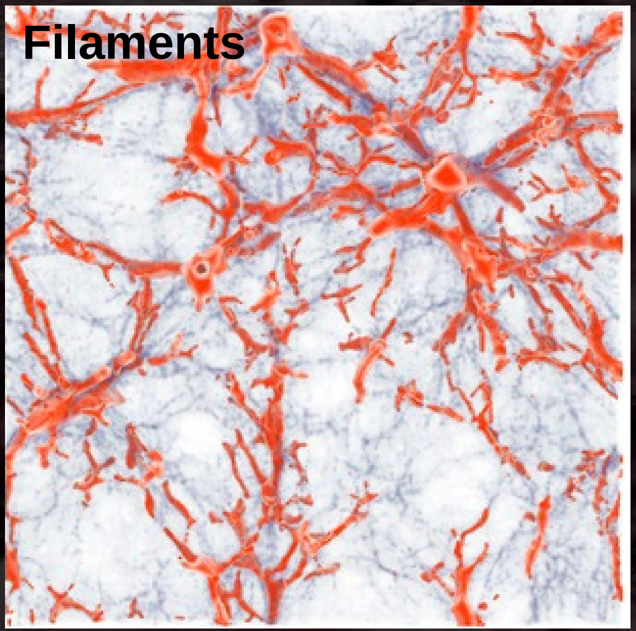
THE NEXUS+ algorithm (bowdlerized)

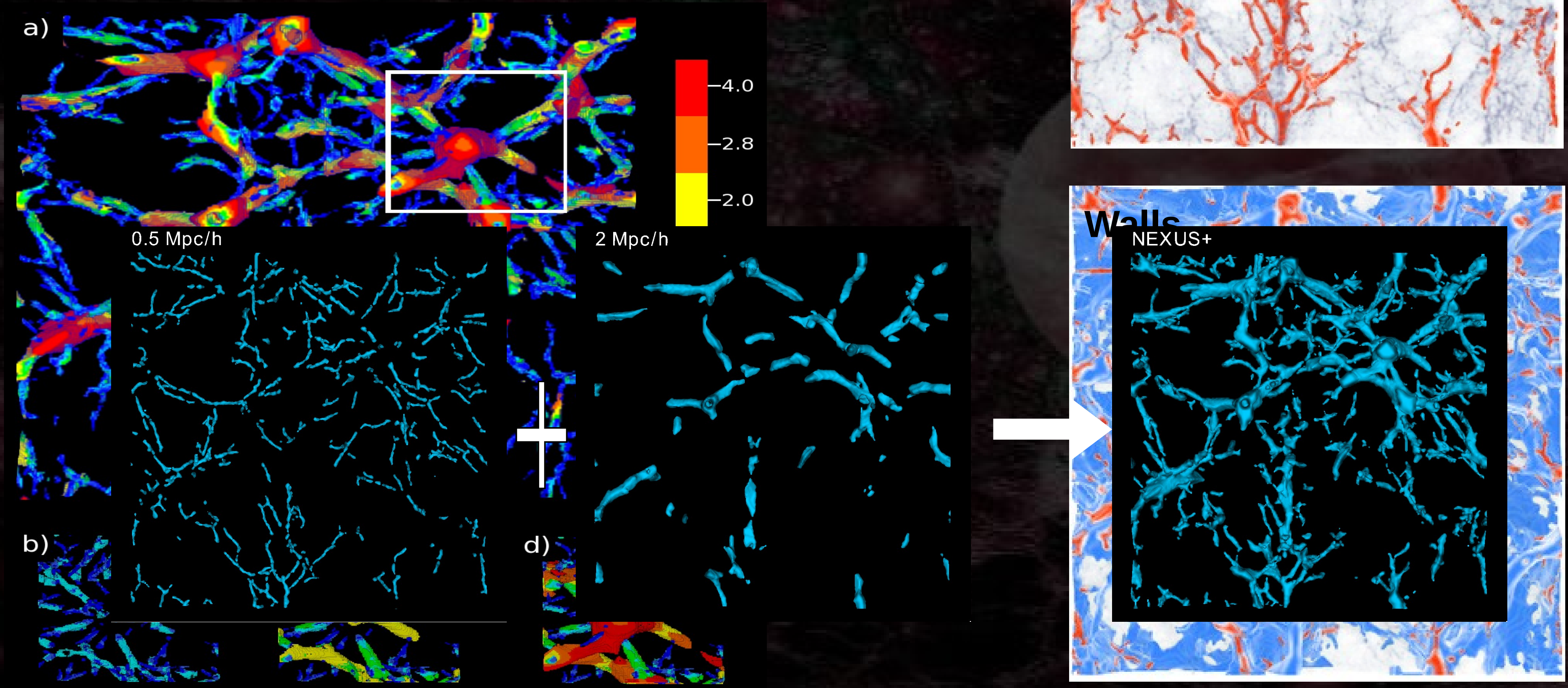
Cautun et al. (2012)

increasing filter size

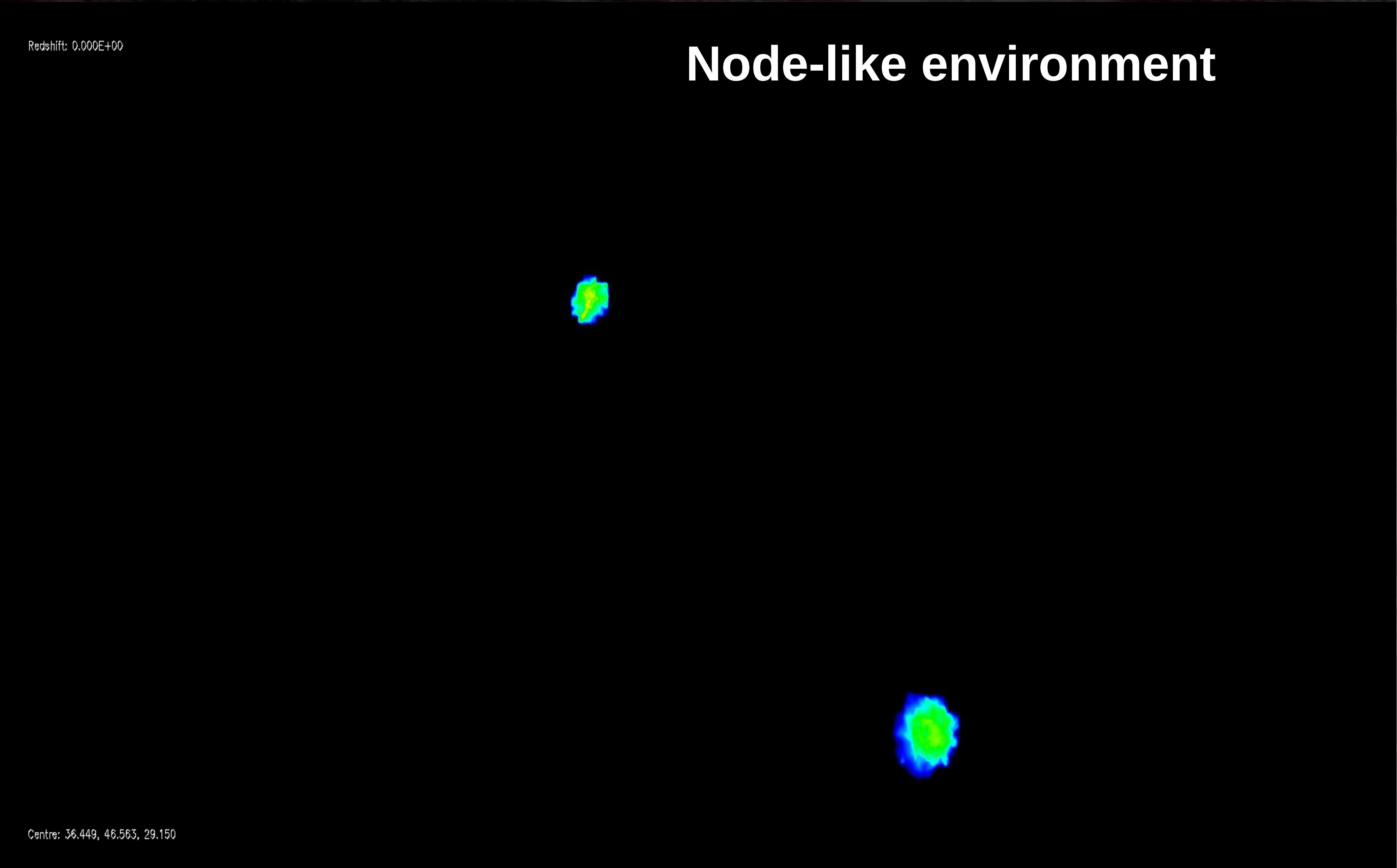


Iterate for a range of smoothing scales





COCO Cosmic Web: the results



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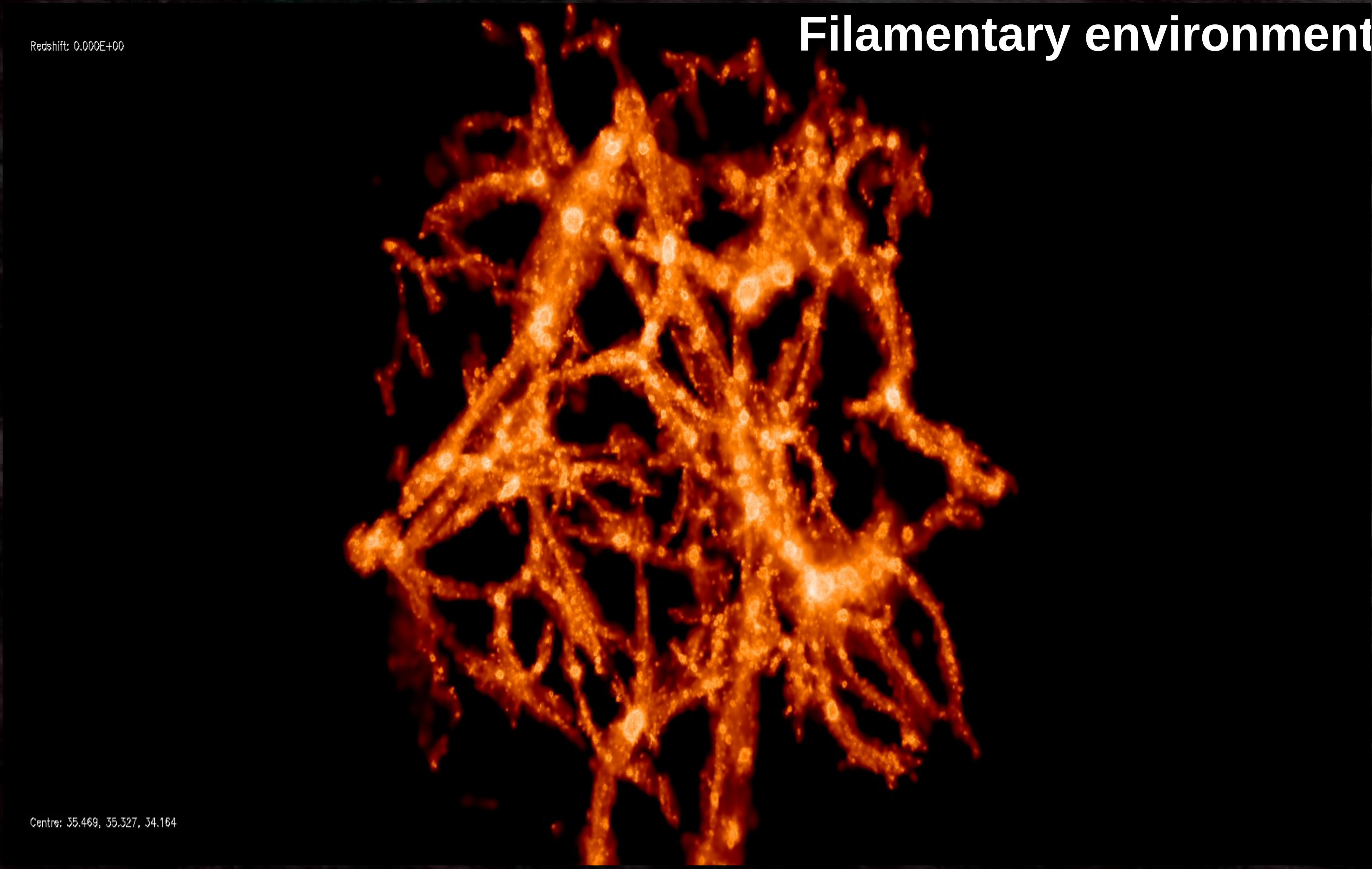

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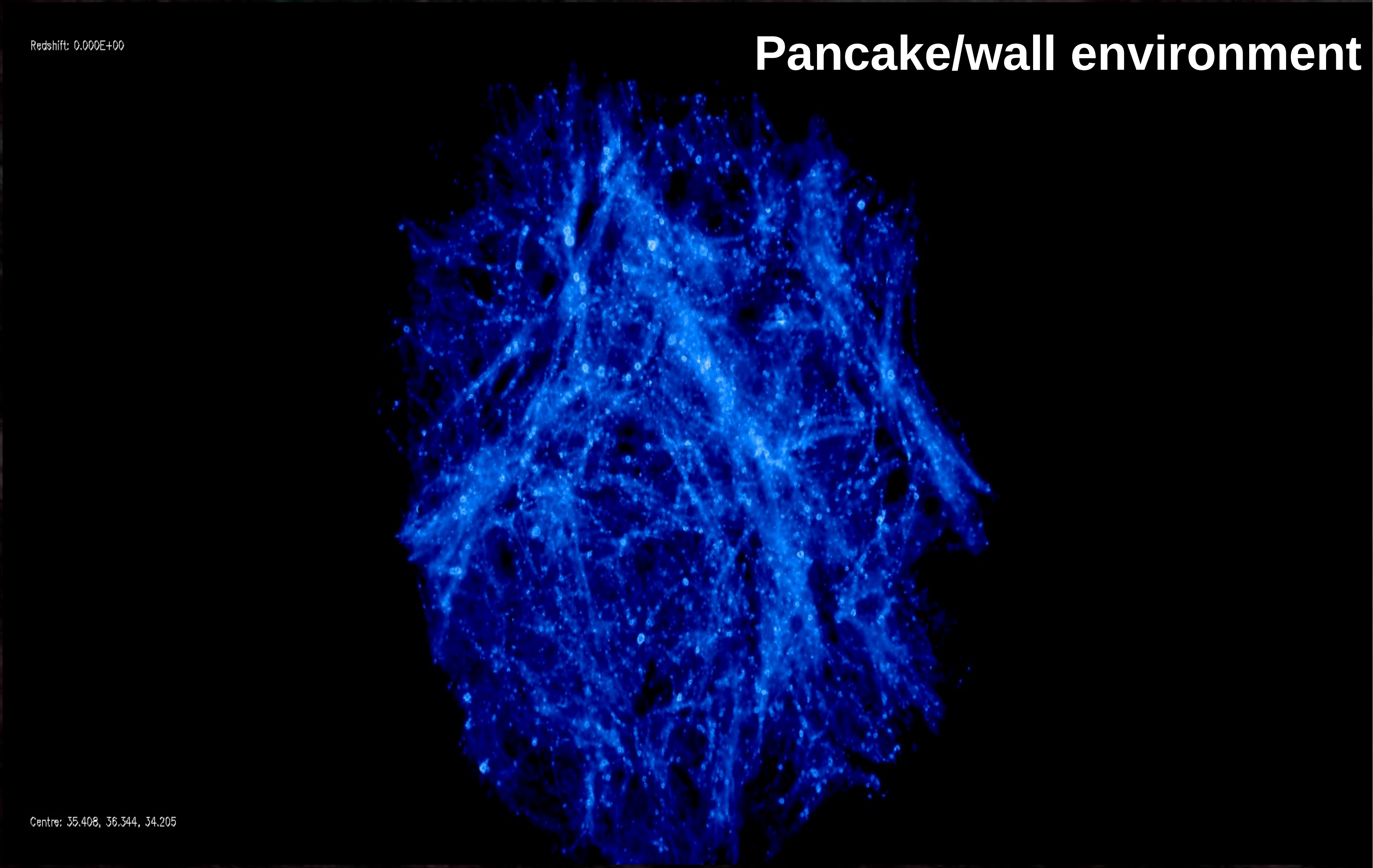

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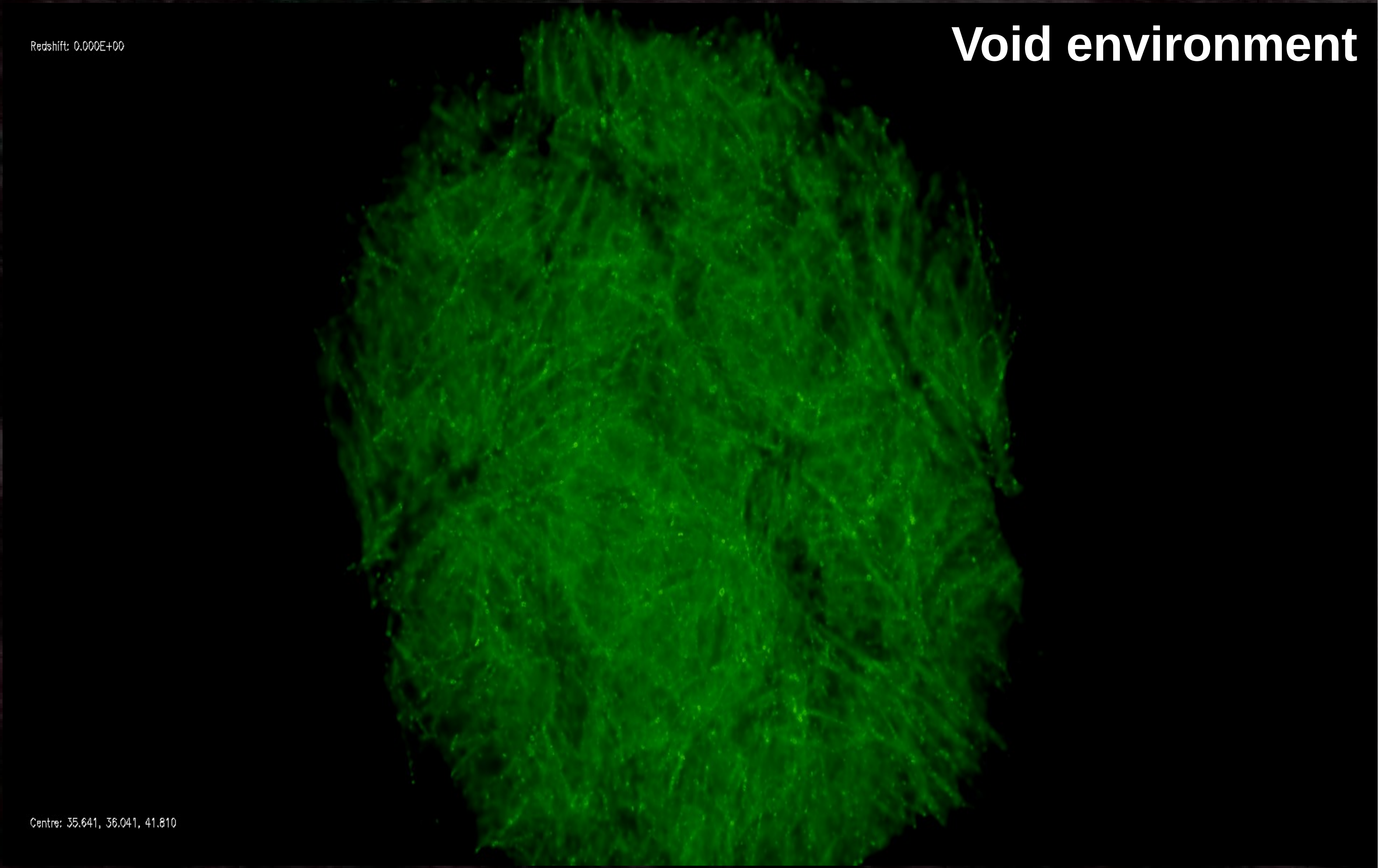
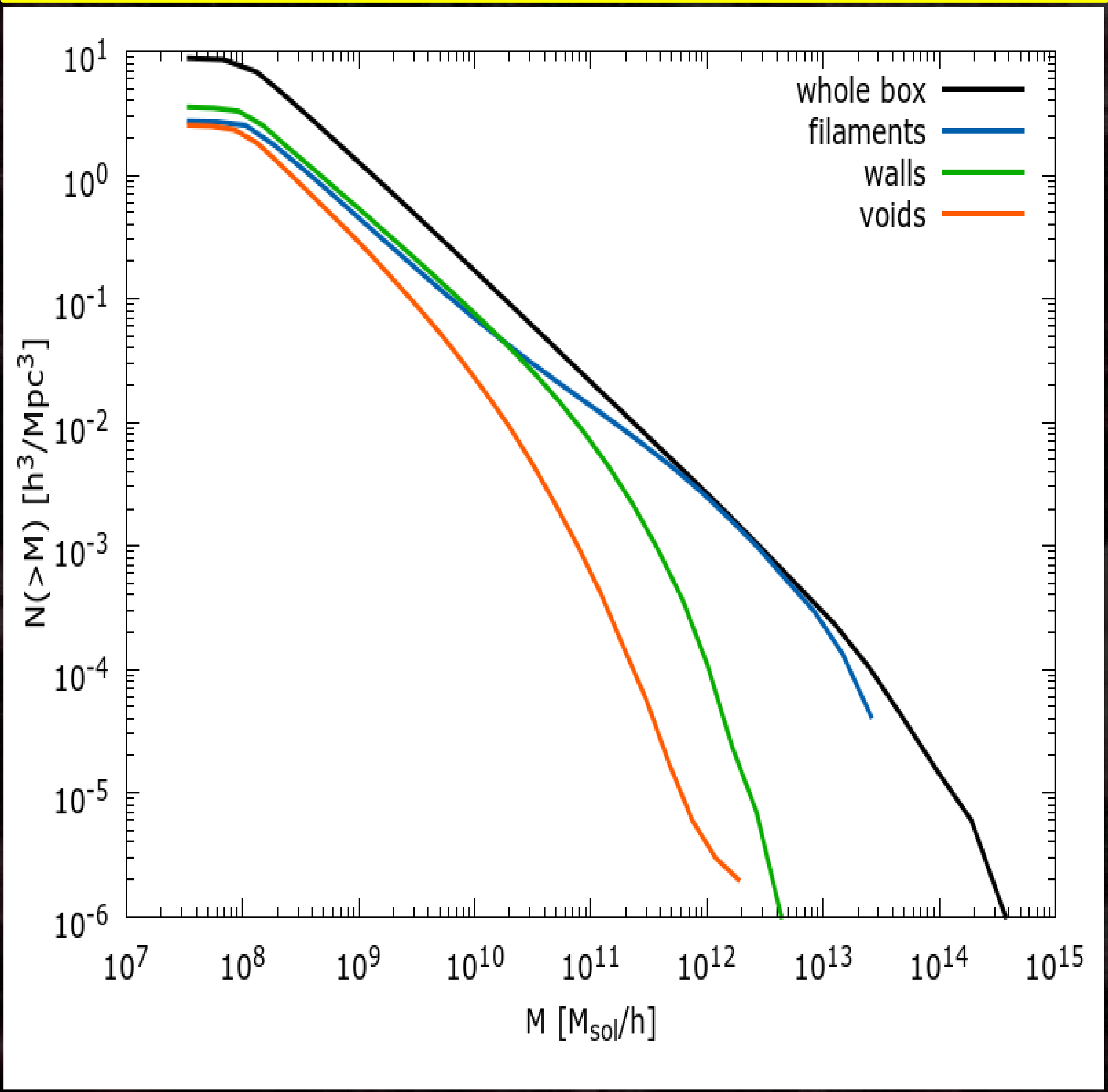


COCO Cosmic Web: the results

The mass – environment relation (from MS2)



- The clustering bias induce mass-environment bias

- If MW is a wall-nation galaxy it is already rare (<~10 %)

COCO Cosmic Web: the results

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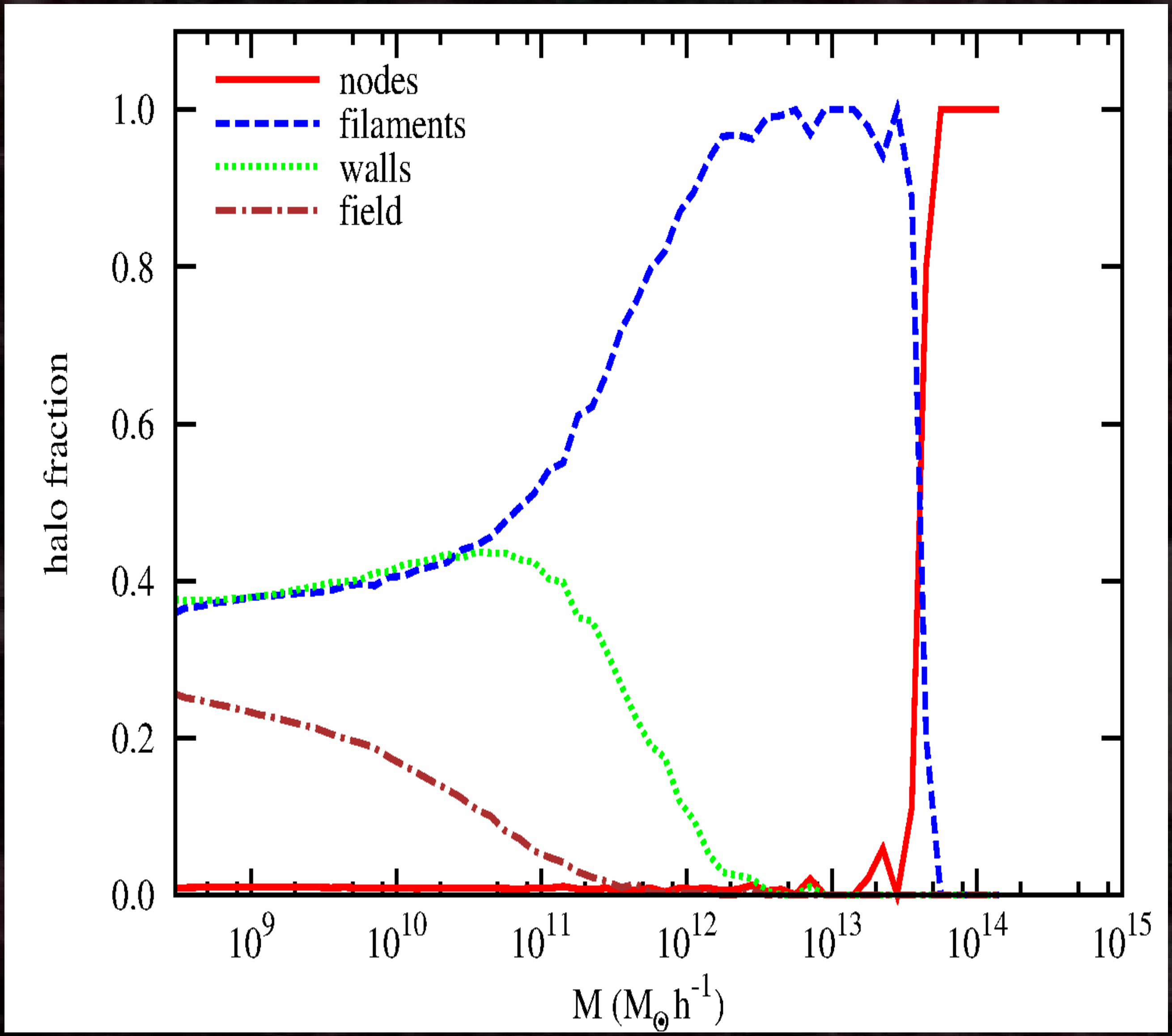

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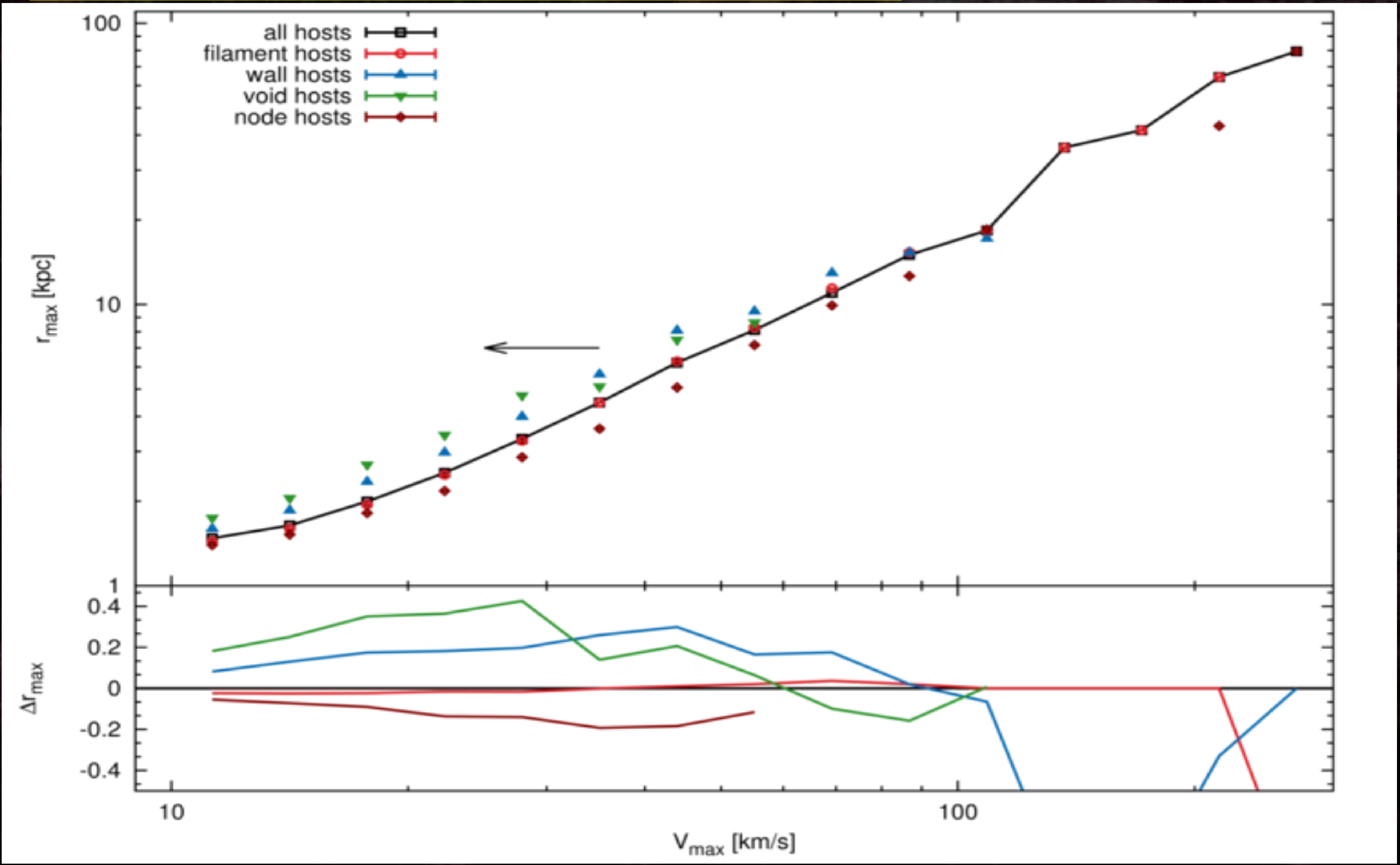
COCO Cosmic Web: the results

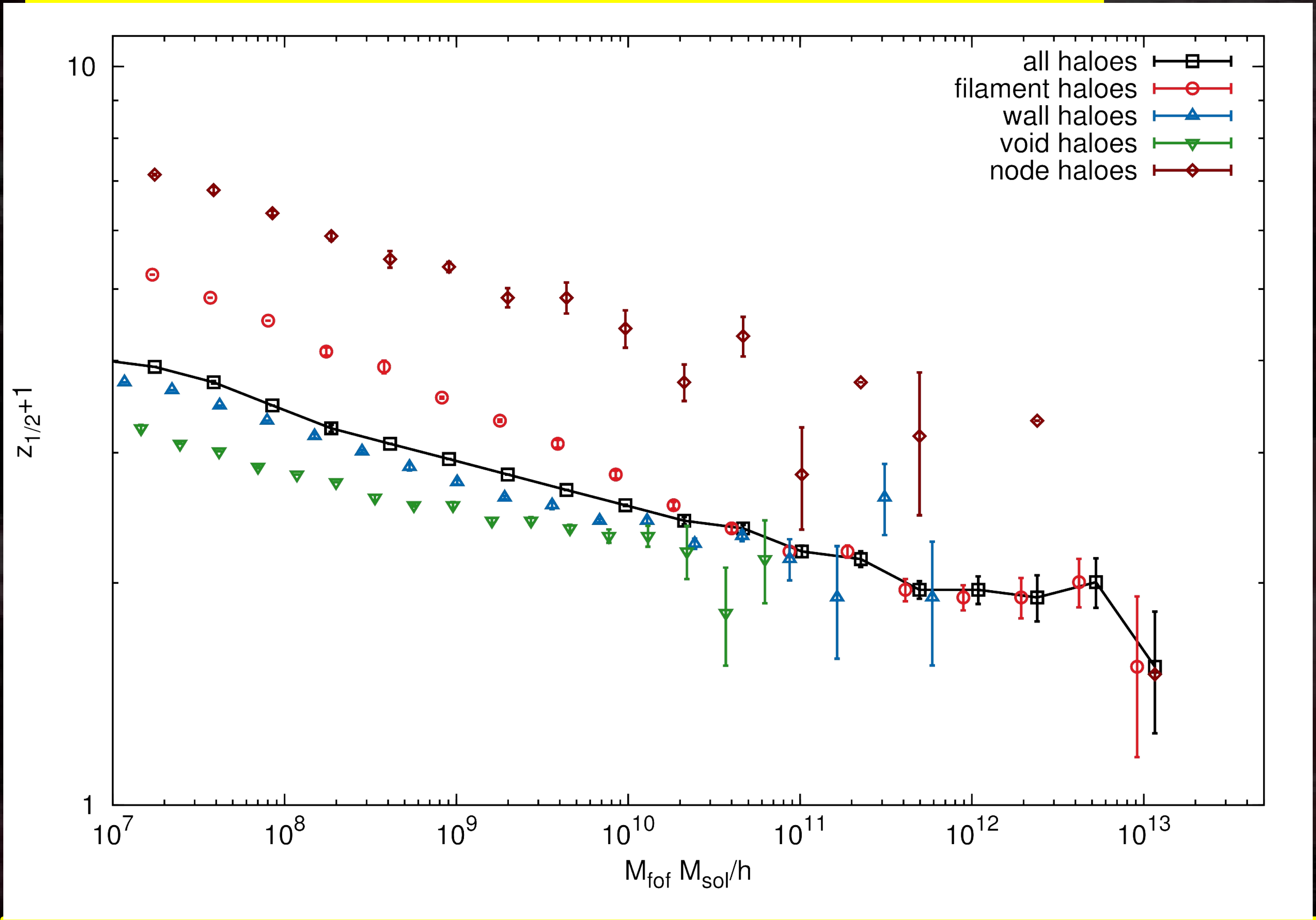
The satellite V_{max}-R_{max} : environment relation



Hellwing et al. (in prep.)

COCO Cosmic Web: the results

The $z_{1/2}$ – environment relation



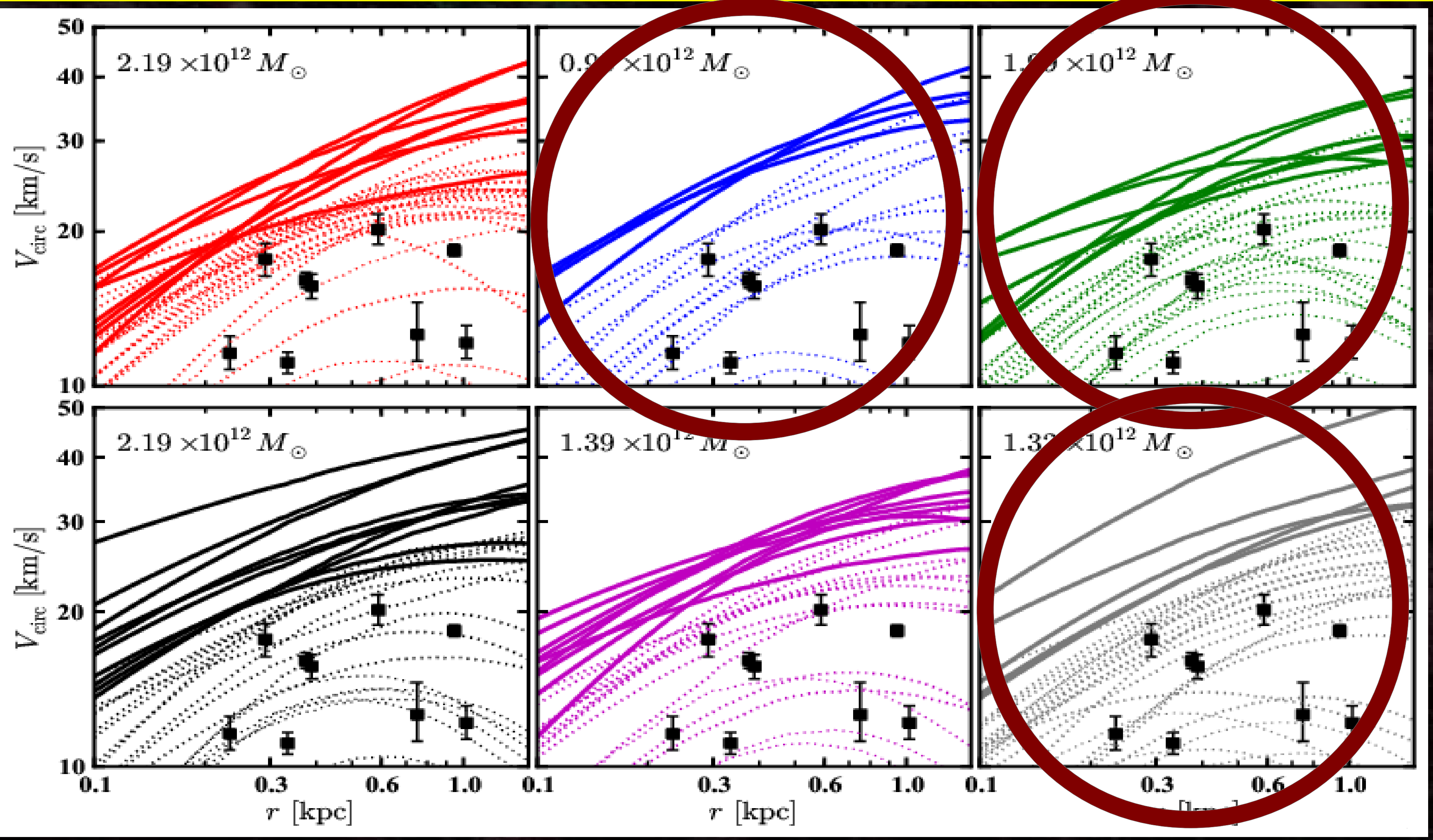
- What we see here is essentially the assembly bias

Hellwing et al. (in prep.)

“Too big too fail?”

a problem for CDM or for galaxy formation

The Aquarius six and their homes

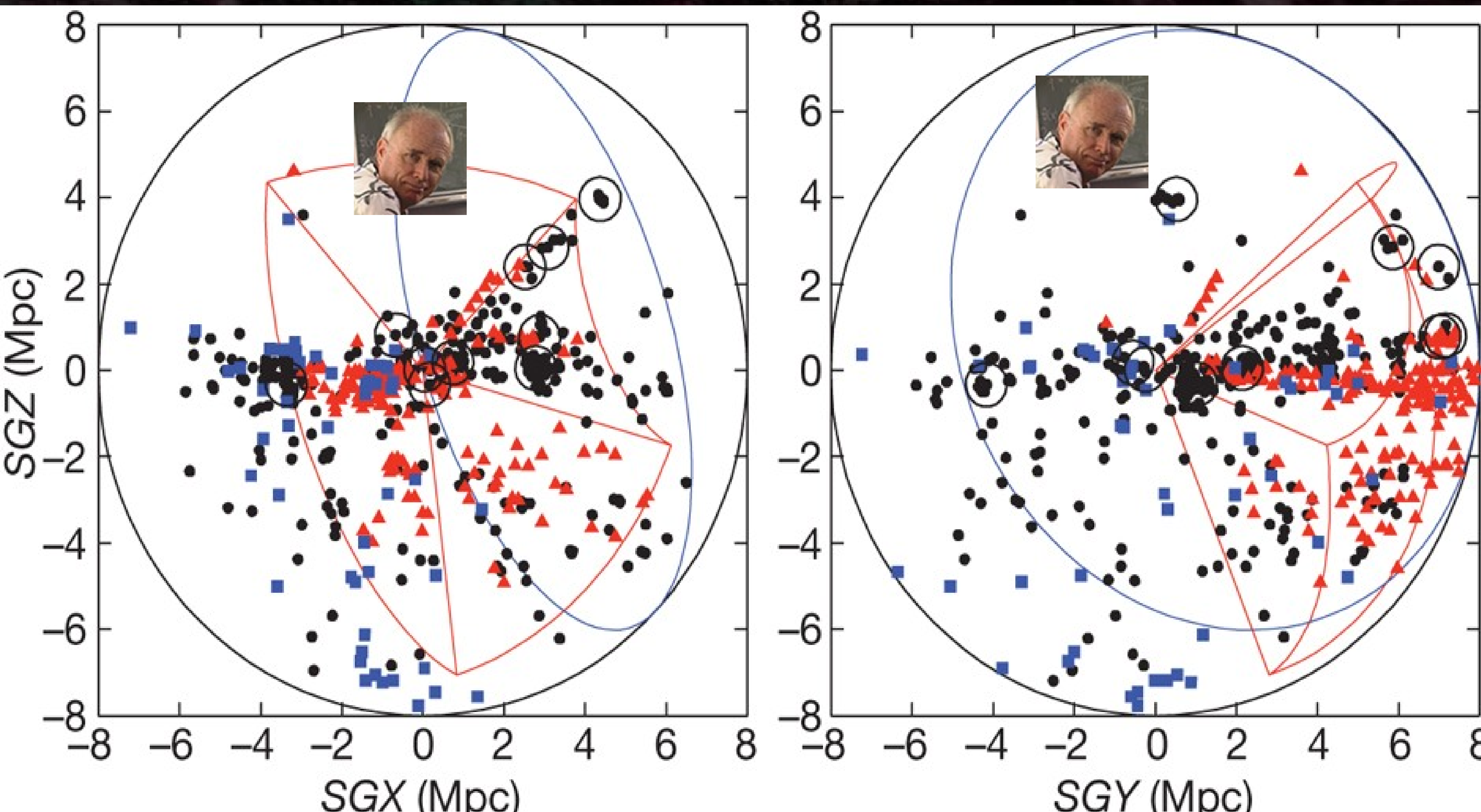


Boylan-Kolchin et al. 2011

“Too big too fail?”

a problem for CDM or for galaxy formation

Is this effect important? Who knows? But contemplate this picture...



Boylan-Kolchin et al. 2011

And now for something not completely different

using MW satellites distribution as an indicator for MW halo mass

Based on results presented in Cautun et al. (submitted)

Milky Way mass constraints from the Galactic satellite gap

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[2] *Kapteyn Astronomical Institute, University of Groningen, P.O. Box 800, 9747 AV Groningen, The Netherlands*
[3] *Interdisciplinary Centre for Mathematical and Computational Modellings, University of Warsaw, ul. Pawińskiego 5a, Warsaw, Poland*

14 August 2014

ABSTRACT

We use the distribution of maximum circular velocities, $V_{\rm max}$, of satellites in the Milky Way (MW) to constrain the virial mass, M_{200}, of the Galactic halo under an assumed prior of a ΛCDM universe. This is done by analysing the subhalo populations of a large sample of halos found in the Millennium II cosmological simulation. The observation that the MW has at most three subhalos with $V_{\rm max} \geqslant 30$ km/s requires a halo mass $M_{200} \leqslant 1.4 \times 10^{12} {\rm M}_\odot$, while the existence of the Magellanic Clouds (assumed to have $V_{\rm max} \geqslant 60$ km/s) requires $M_{200} \geqslant 1.0 \times 10^{12} {\rm M}_\odot$. The first of these conditions is necessary to avoid the "too-big-to-fail" problem highlighted by Boylan-Kolchin et al., while the second stems from the observation that massive satellites like the Magellanic Clouds are rare. When combining both requirements, we find that the MW halo mass must lie in the range $0.25 \leqslant M_{200}/(10^{12} {\rm M}_\odot) \leqslant 1.4$ at 90% confidence. The gap in the abundance of Galactic satellites between 30 km/s $\leqslant V_{\rm max} \leqslant$ 60 km/s places our galaxy in the tail of the expected satellite distribution.

Key words: Galaxy: abundances - Galaxy: halo - dark matter - Cosmology: N-body simulations

And now for something not completely different

using MW satellites distribution as an indicator for MW halo mass

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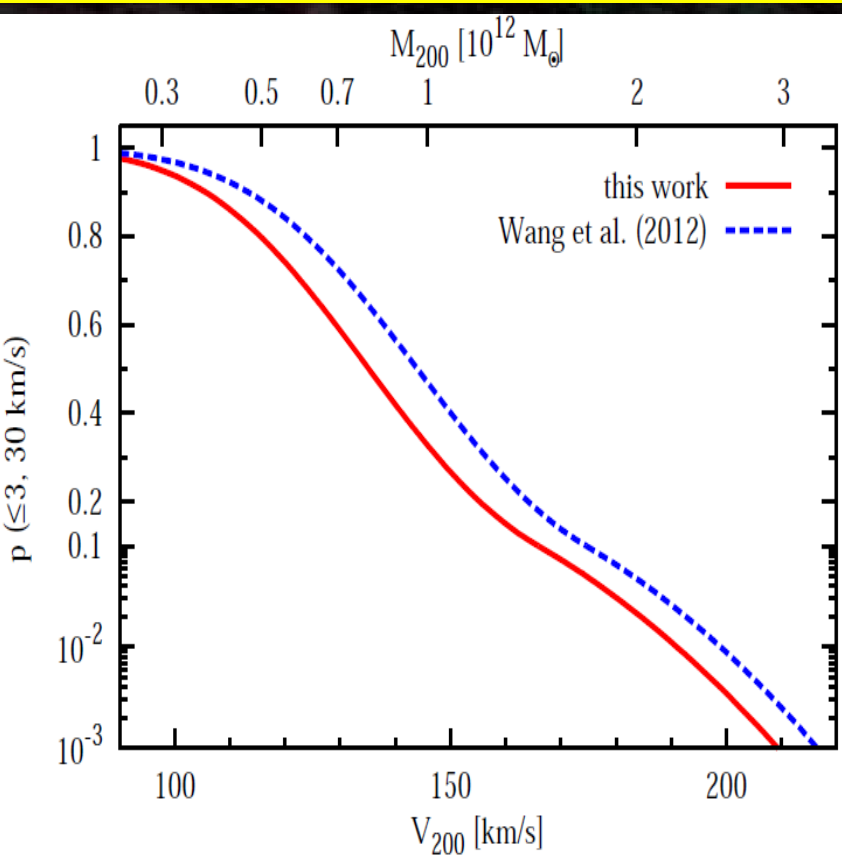

Figure 2. The probability, $p(\leqslant 3, 30\ \text{km/s})$, that a halo contains at most three subhalos with $V_{\max} \geqslant 30$ km/s as a function of the host virial velocity, V_{200}, (lower tick marks) and virial mass, M_{200}, (upper tick marks). The solid curve gives our results, while the dashed line shows the previous results of Wang12. Note that the y-axis is linear above 0.1 and logarithmic for lower values.

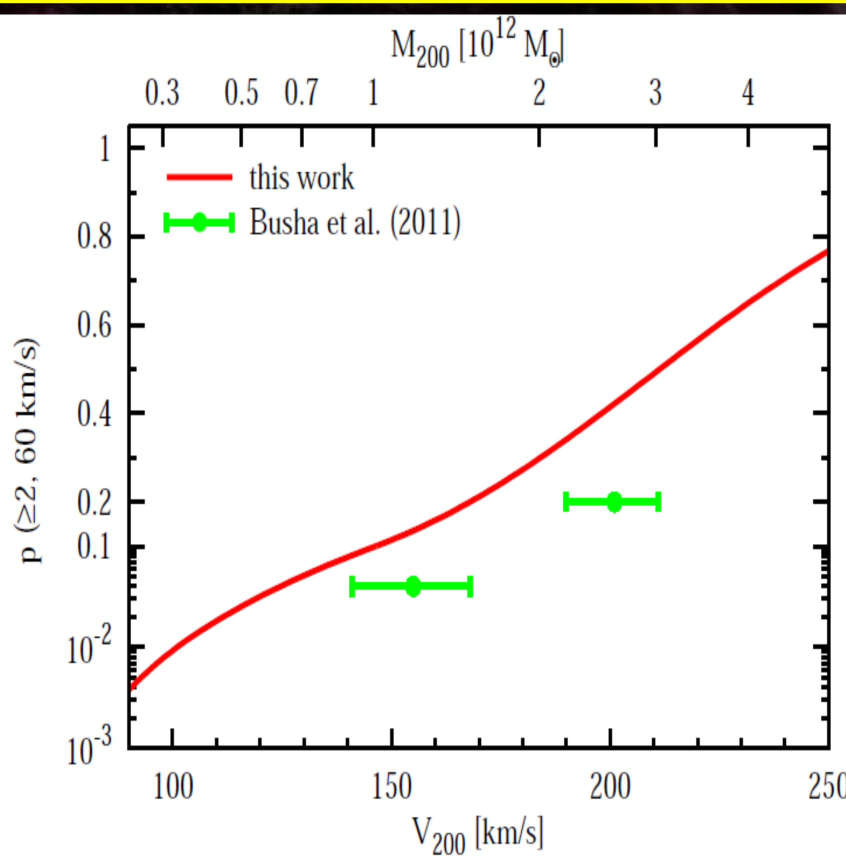

Figure 3. The probability, $p(\geqslant 2, 60\ \text{km/s})$, that a halo contains at least two subhalos with $V_{\max} \geqslant 60$ km/s as a function of the host virial velocity, V_{200}, (lower axis), and virial mass, M_{200}, (upper axis). The solid curve shows our predictions, while the filled circles show the results of Busha et al. (2011b). Note that the y-axis is linear above 0.1 and logarithmic for lower values.

And now for something not completely different

using MW satellites distribution as an indicator for MW halo mass

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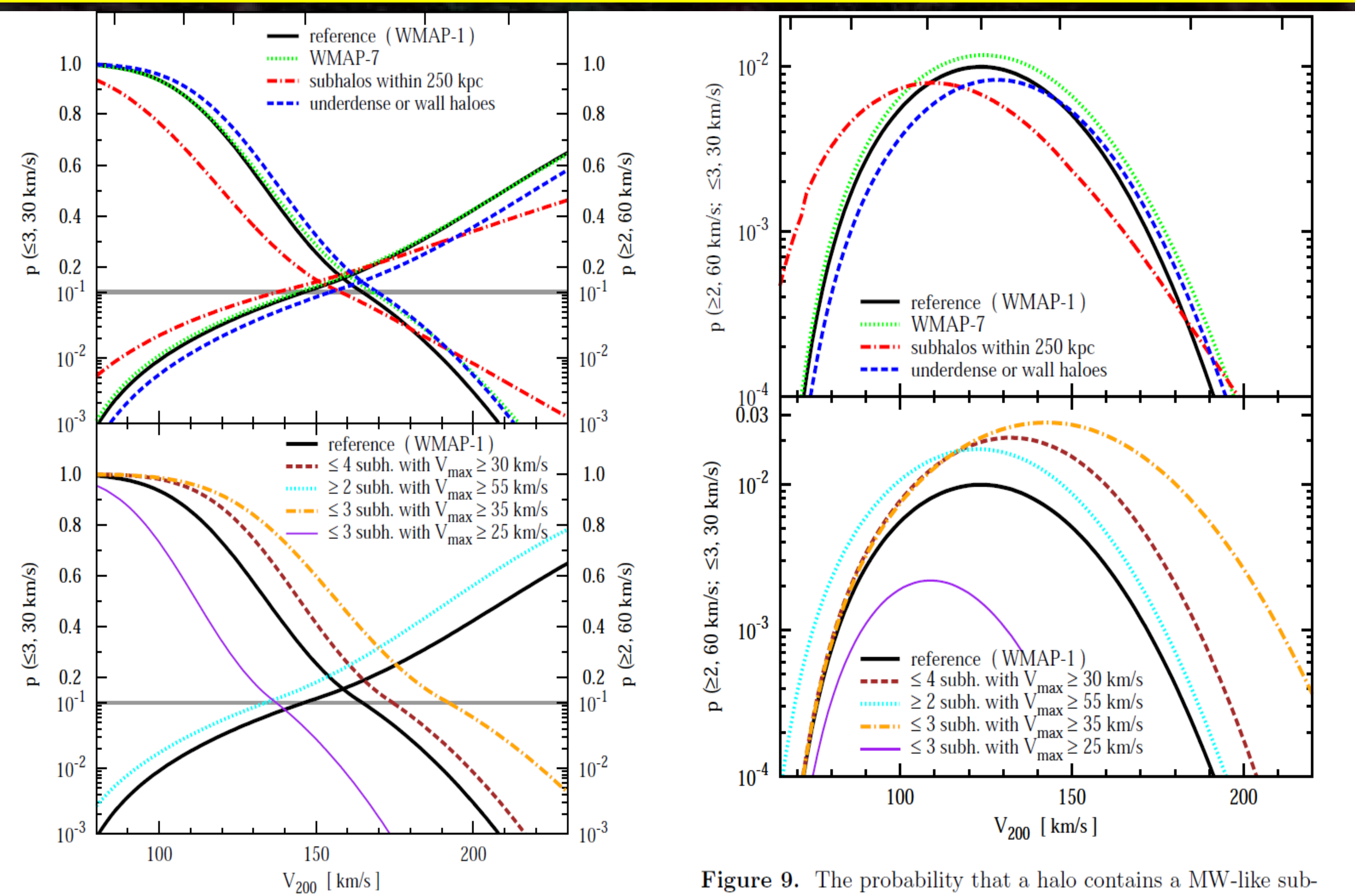
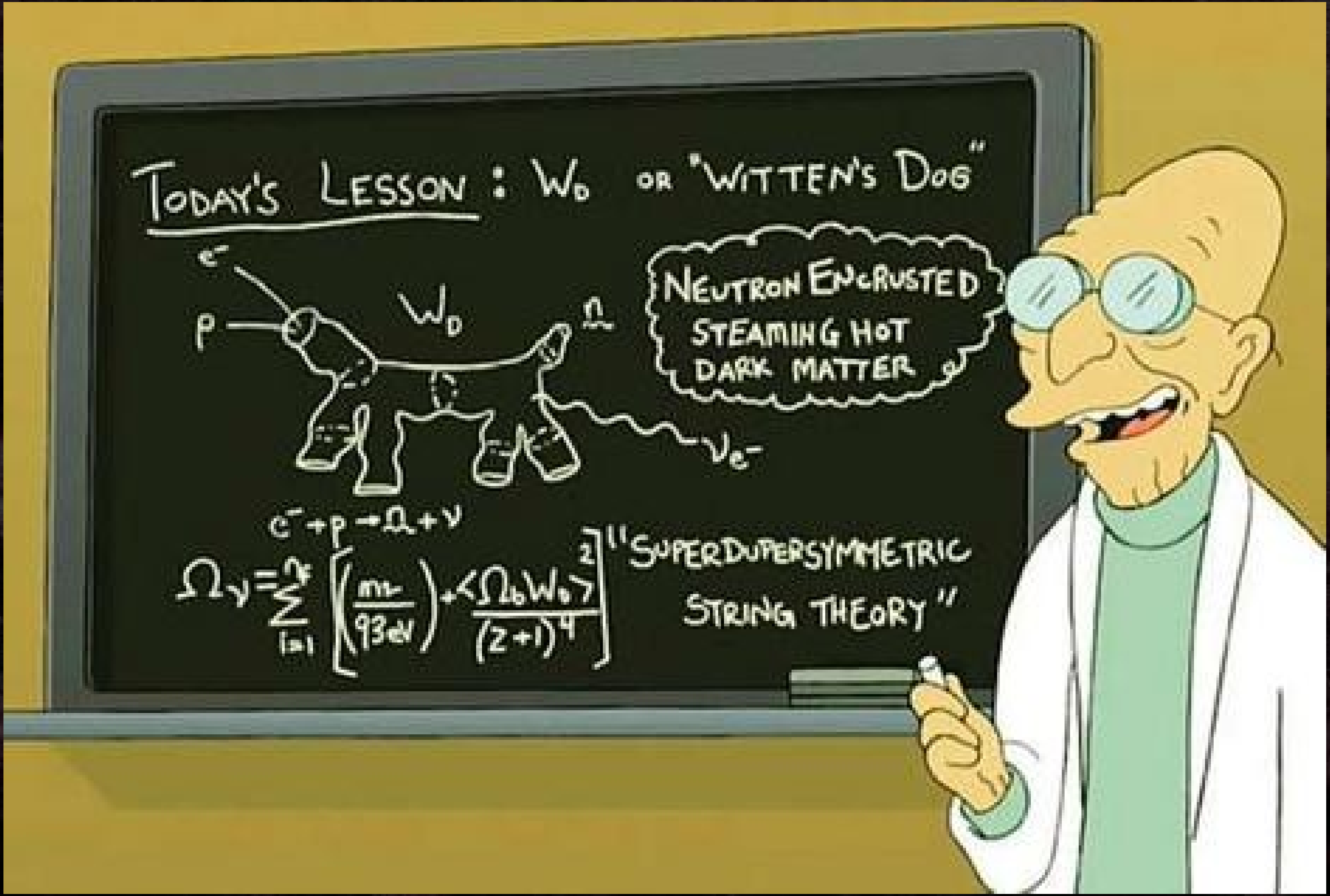


Figure 9. The probability that a halo contains a MW-like sub-

Conclusions

- Dwarf satellites despite the fact that they are *not* the building blocks of the galaxies, they are living in the building blocks of their host haloes
- Understanding the properties and distirbution of the LG dwarf galaxies is crucial for drawing cosmological conclusions
- The connection between the physical model of the Universe (LCDM) and the galaxy formation theory is not enough to understand and explain the observations
- Many secondary effects are present, one of which might be a non-trivial MW-observer bias
- All in all we might be “just another brick in the wall”

Thank You for your patience!



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