Caught In The Web:

MS2 haloes and their environment

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The outline

- Cosmic Web
- NEXUS+ algorithm
- MS2 haloes and their environment
- Conclusions

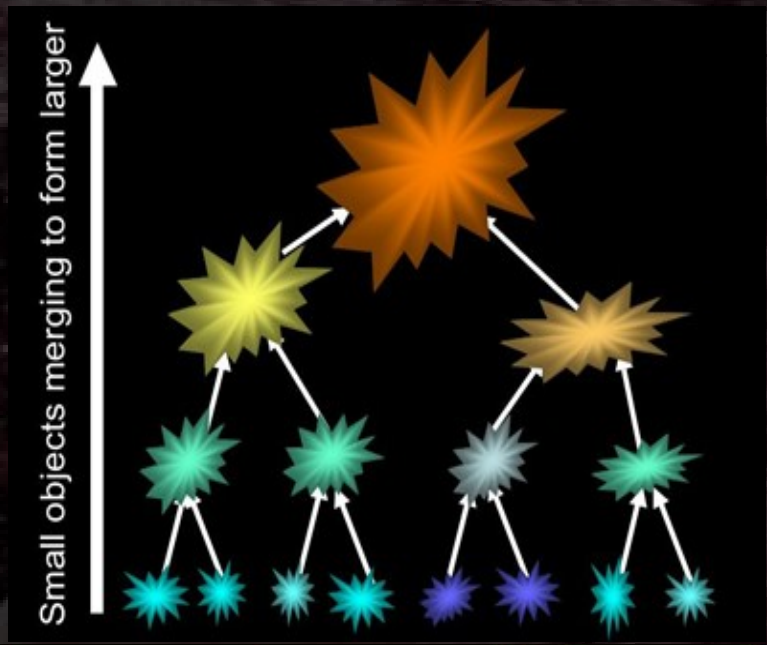
THE COSMIC WEB

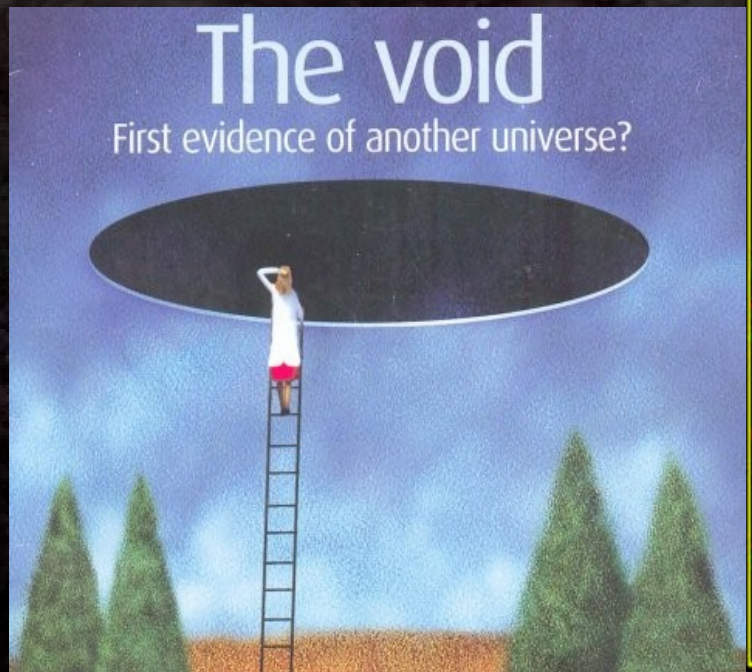
The key aspects of the Cosmic Web related to the processes that shape the LSS:

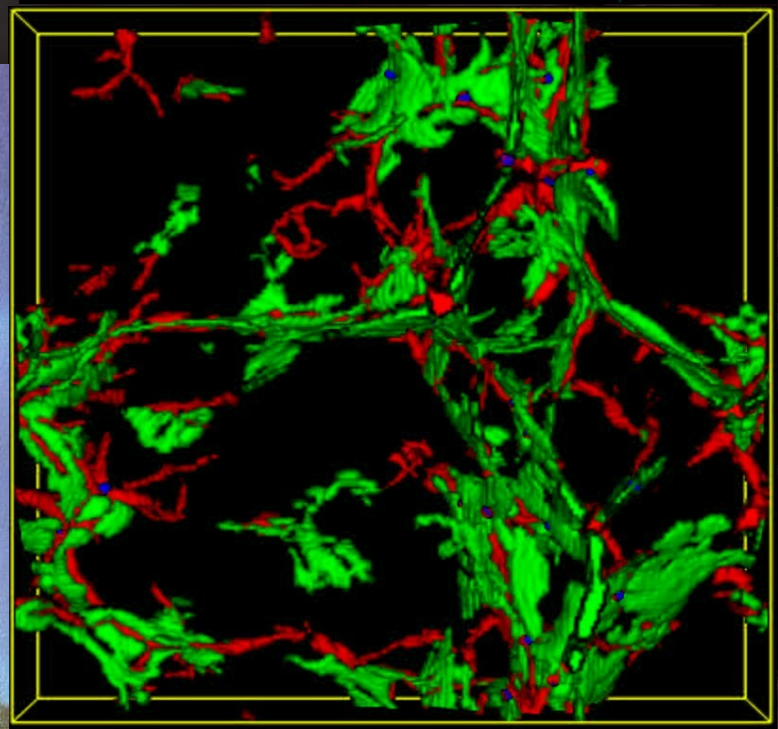
Hierarchical structure formation
- ➡ Multi-scale character

Anisotropic collapse
- ➡ Web-like network of walls, filaments & voids

skewness of the density distribution
- ➡ Volume dominance of voids







THE COSMIC WEB

Forming processes:

Hierarchical structure formation

Anisotropic collapse

skewness of the density distribution

Underling Physics:

Nature of Gravity

Physics Of DM

Background Expansion History (DE)

Resulting properties:

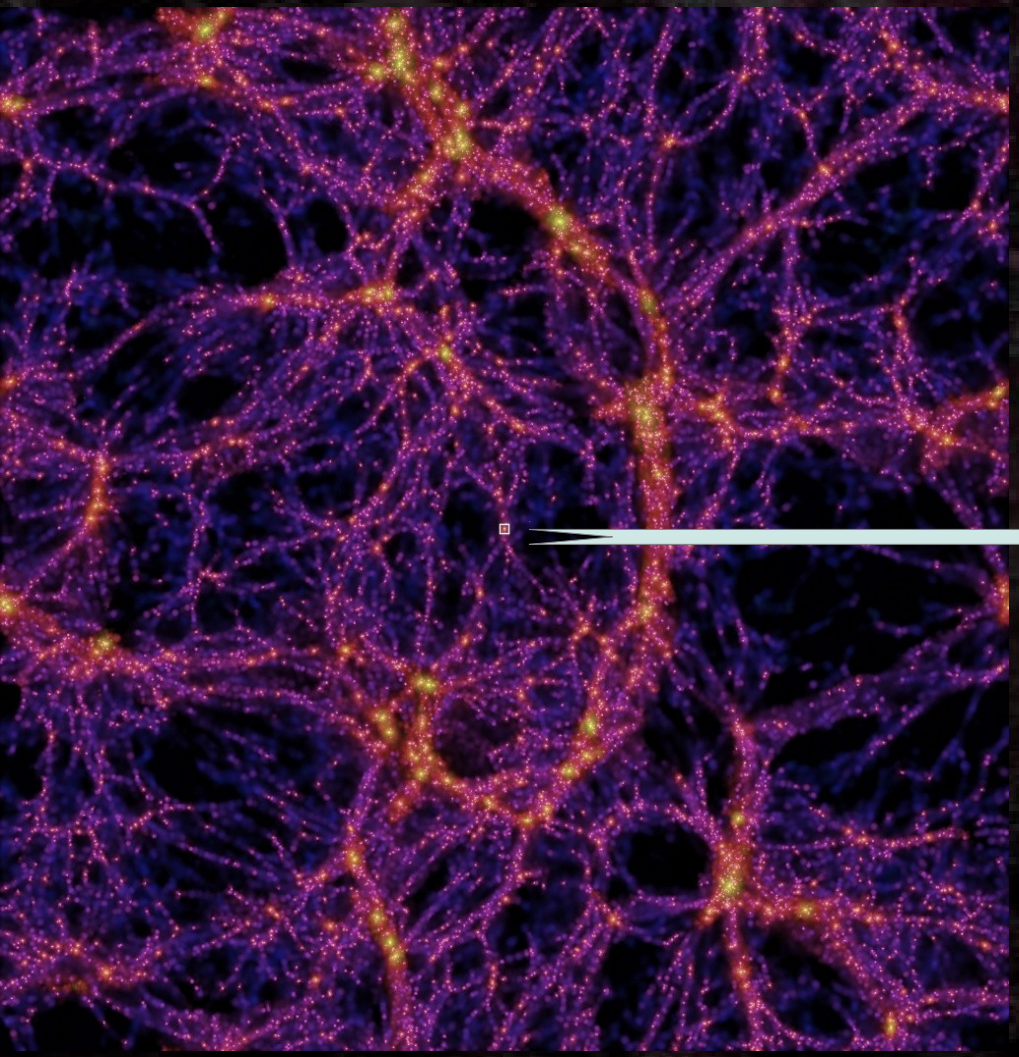
Multi-scale character

Web-like patterns

Volume dominance of The Voids

THE COSMIC WEB

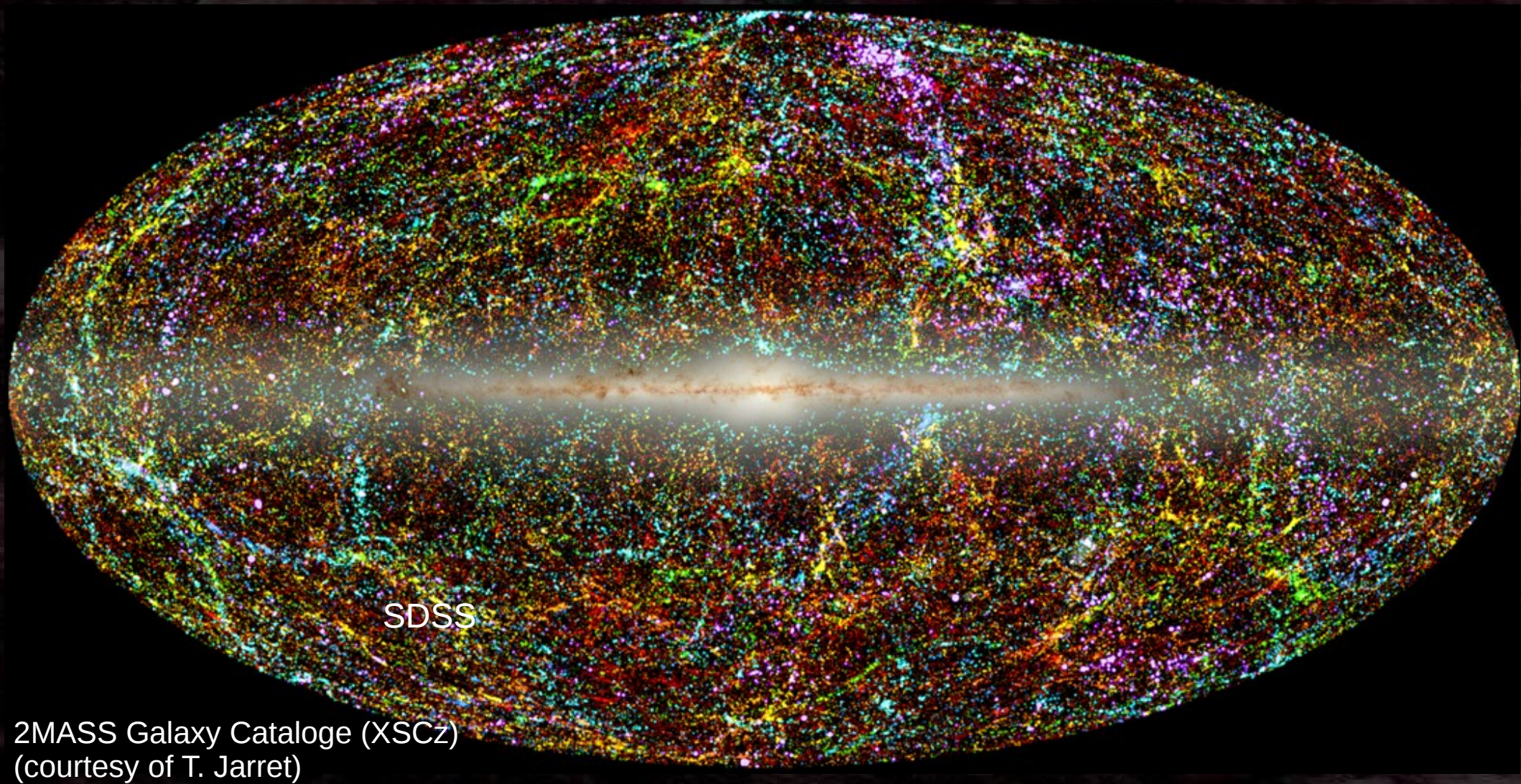
a home for haloes and galaxies woven within



Aquarius simulation

THE COSMIC WEB

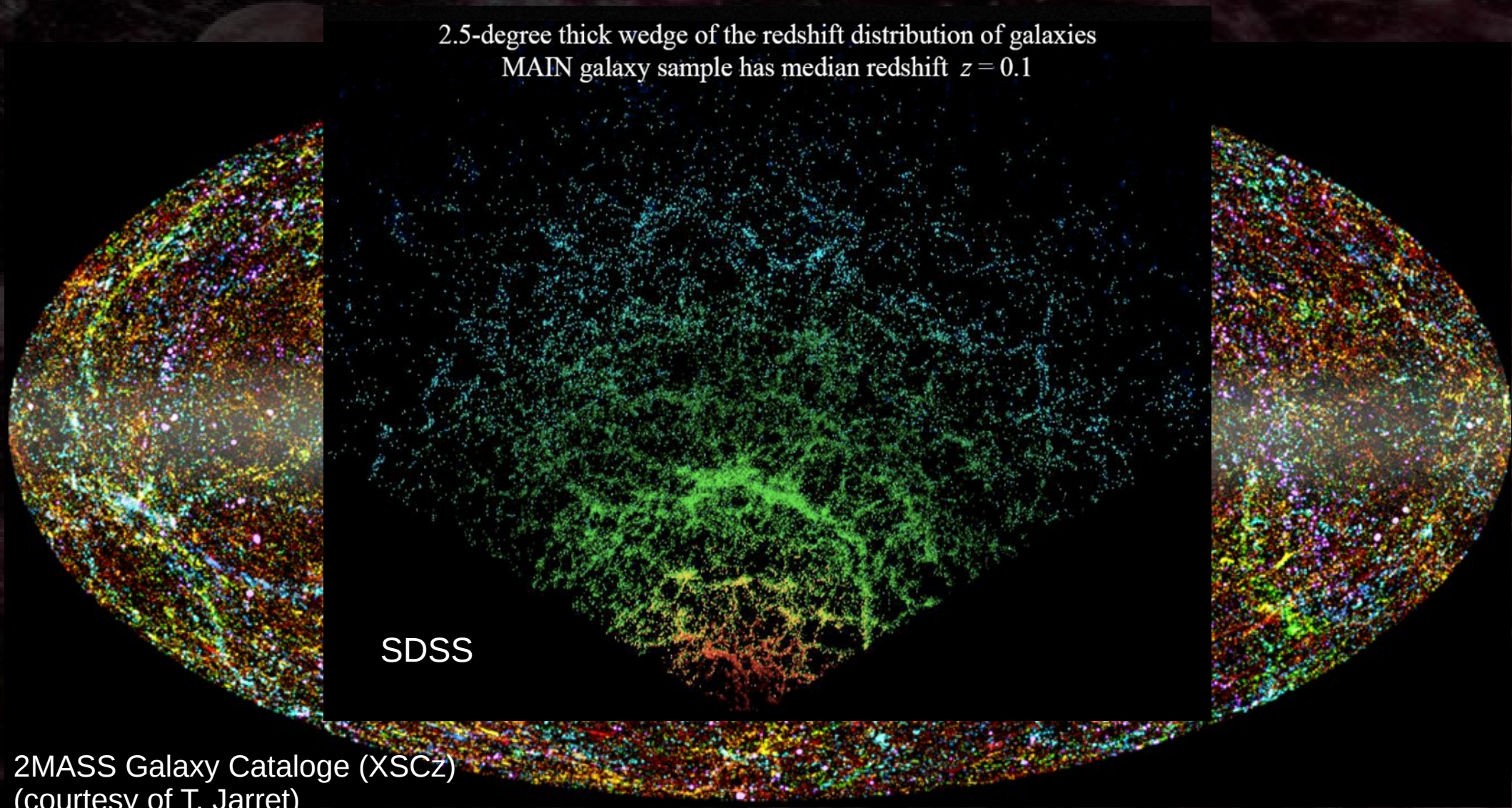
a home for haloes and galaxies woven within



2MASS Galaxy Cataloge (XSCz)
(courtesy of T. Jarret)

THE COSMIC WEB

a home for haloes and galaxies woven within



2MASS Galaxy Cataloge (XSCz)
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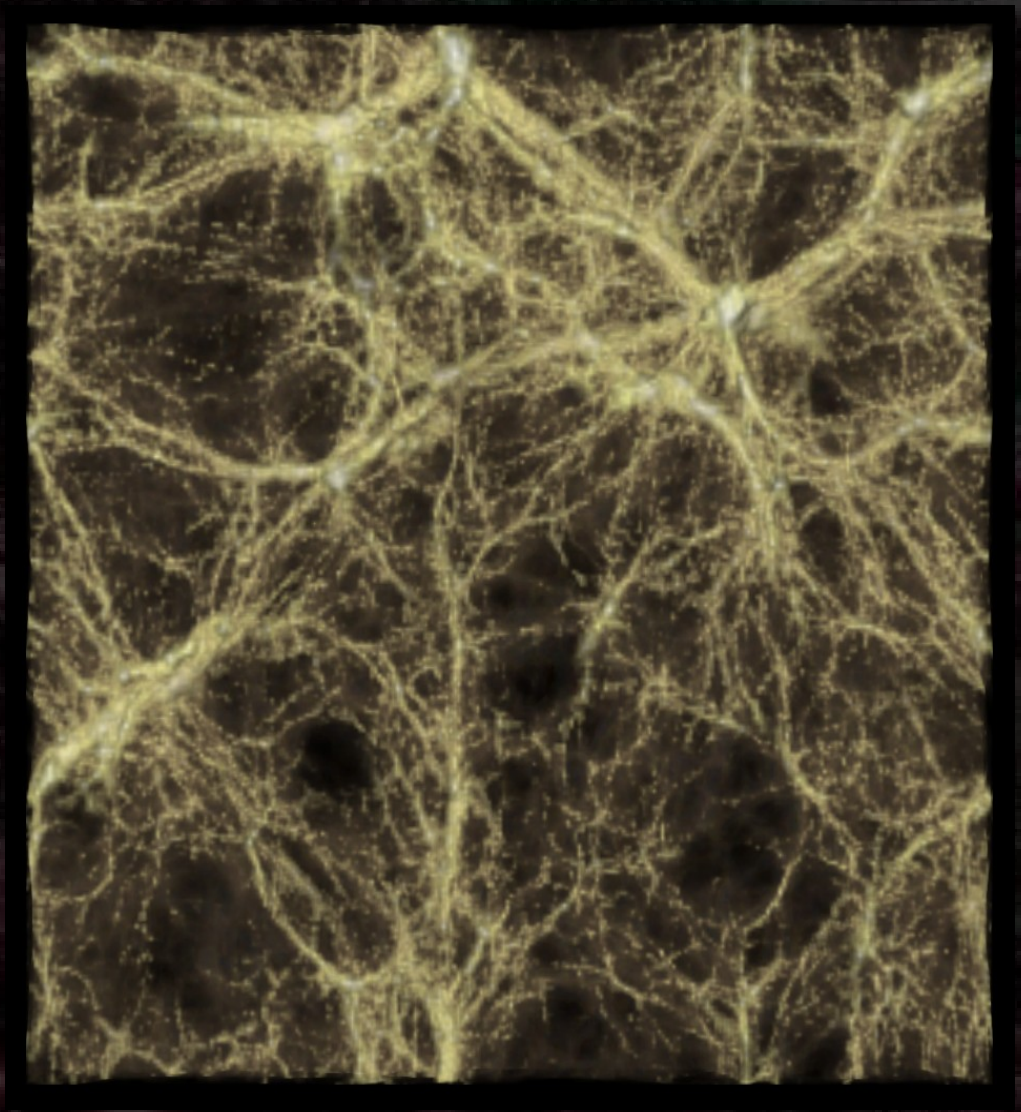
THE COSMIC WEB

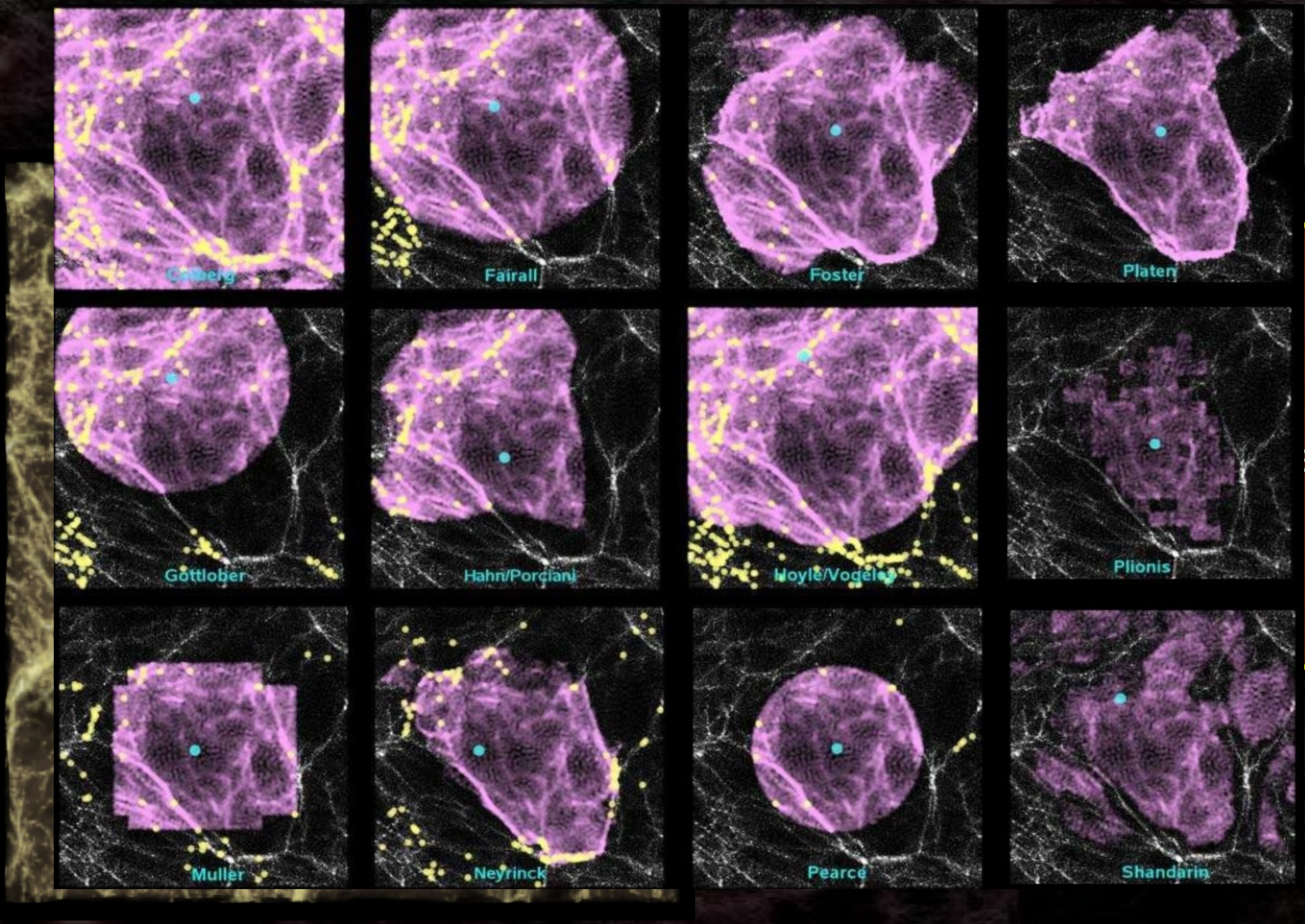
a home for haloes and galaxies woven within



Challenges:

- Multiscale distribution
- No clear defined boundaries
- Orders of magnitude variation in the density field

THE COSMIC WEB

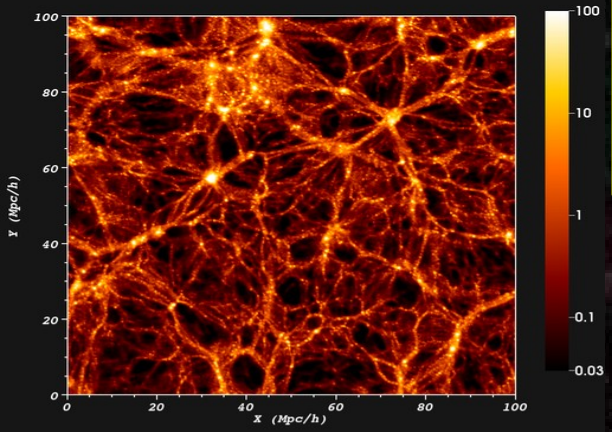


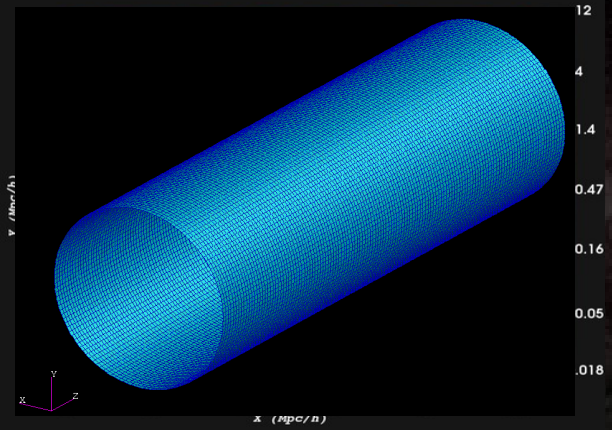
Aspen-Amsterdam Void Comparison project
(Colberg et al. 2008)

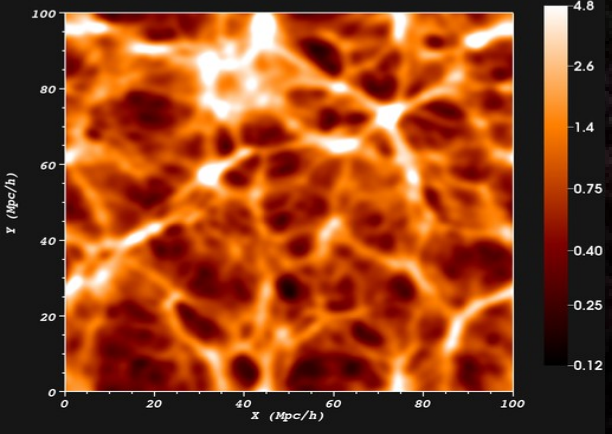
THE NEXUS+ algorithm (bowdlerized)

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	$\lvert\lambda_1\rvert \gg \lvert\lambda_2\rvert;\ \lvert\lambda_1\rvert \gg \lvert\lambda_3\rvert$	$\lambda_1 < 0$

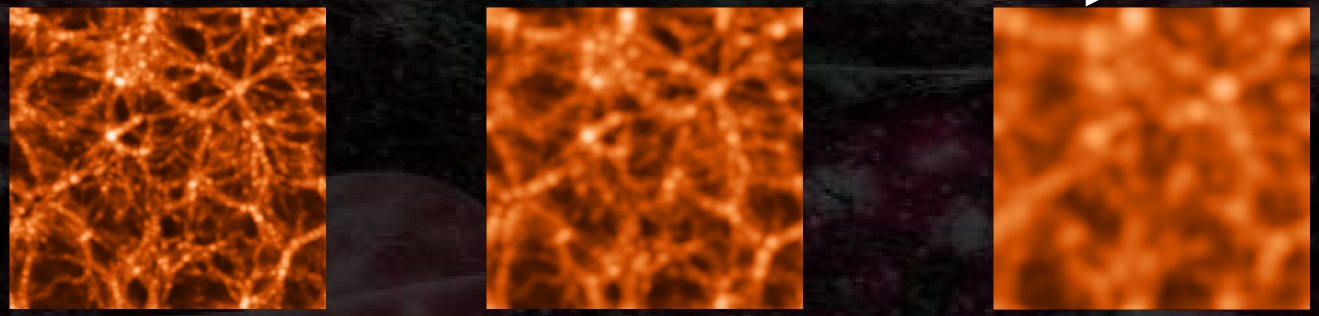
$$H_{ij,R_n}(\mathbf{x}) = R_n^2 \frac{\partial^2 f_{R_n}(\mathbf{x})}{\partial x_i \partial x_j},$$

Compute the Hessian for the input field

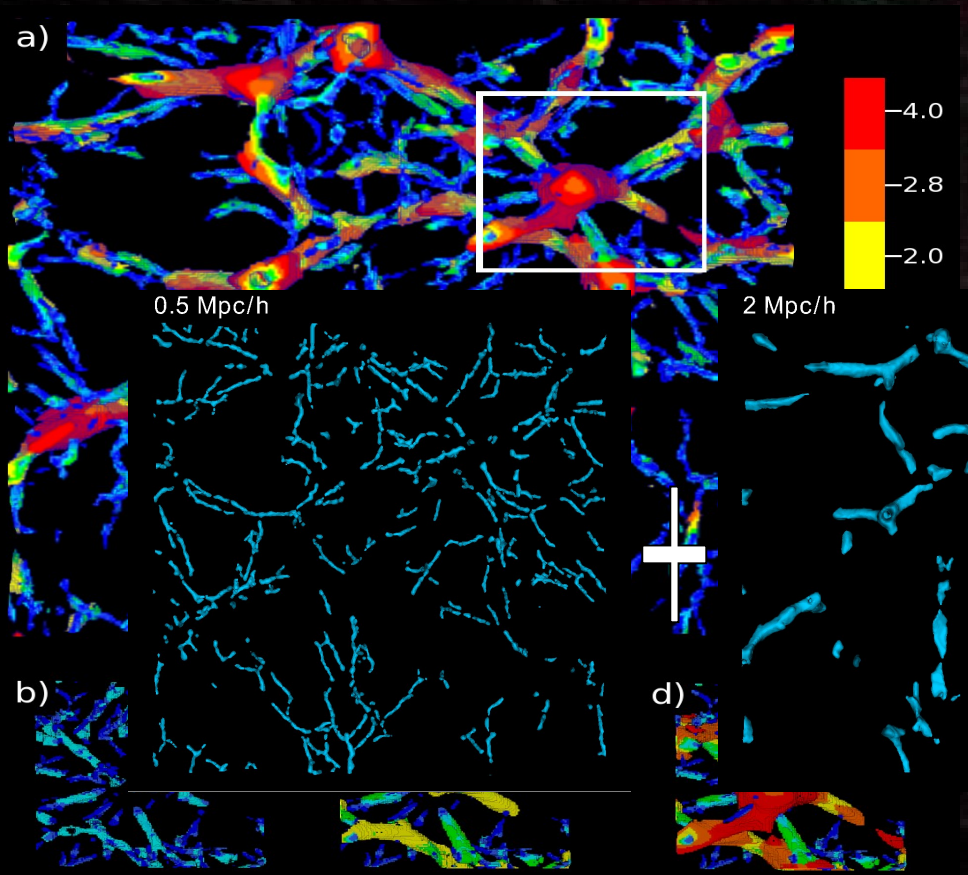
THE NEXUS+ algorithm (bowdlerized)

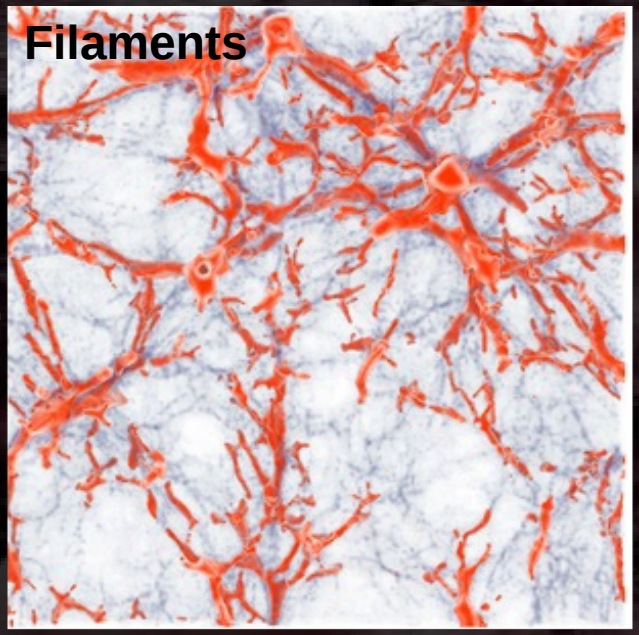
Cautun et al. (2012)

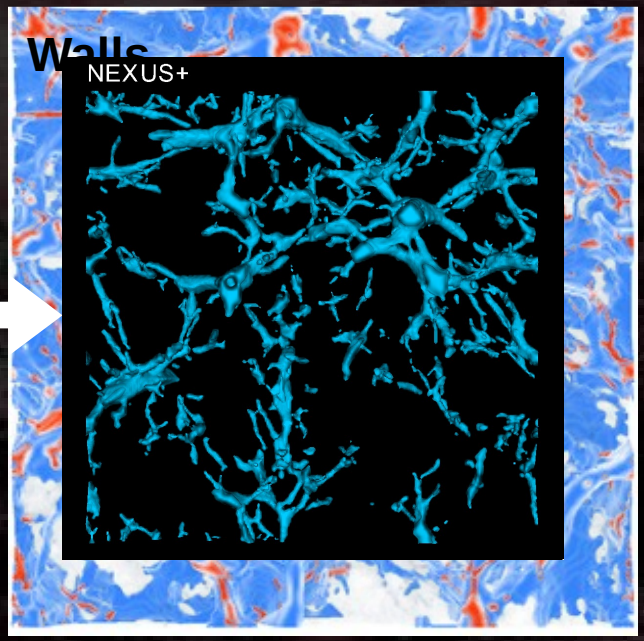
increasing filter size



Iterate for a range of smoothing scales







THE NEXUS+ algorithm (bowdlerized)

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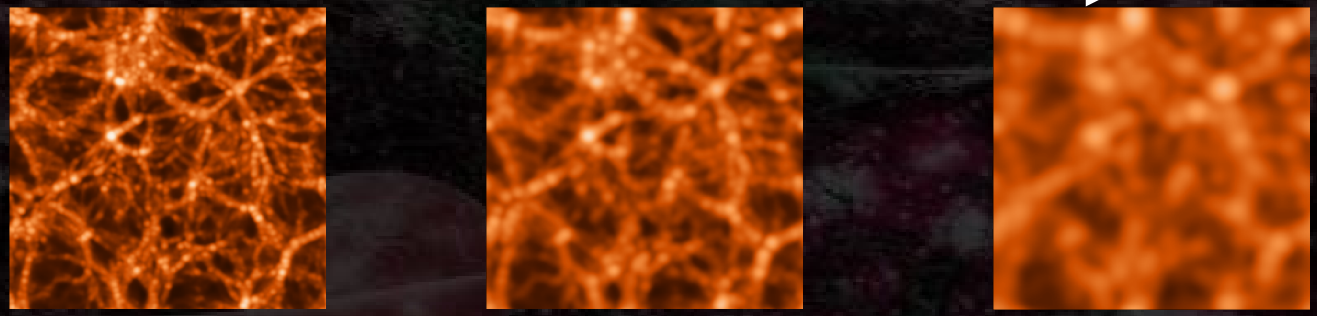

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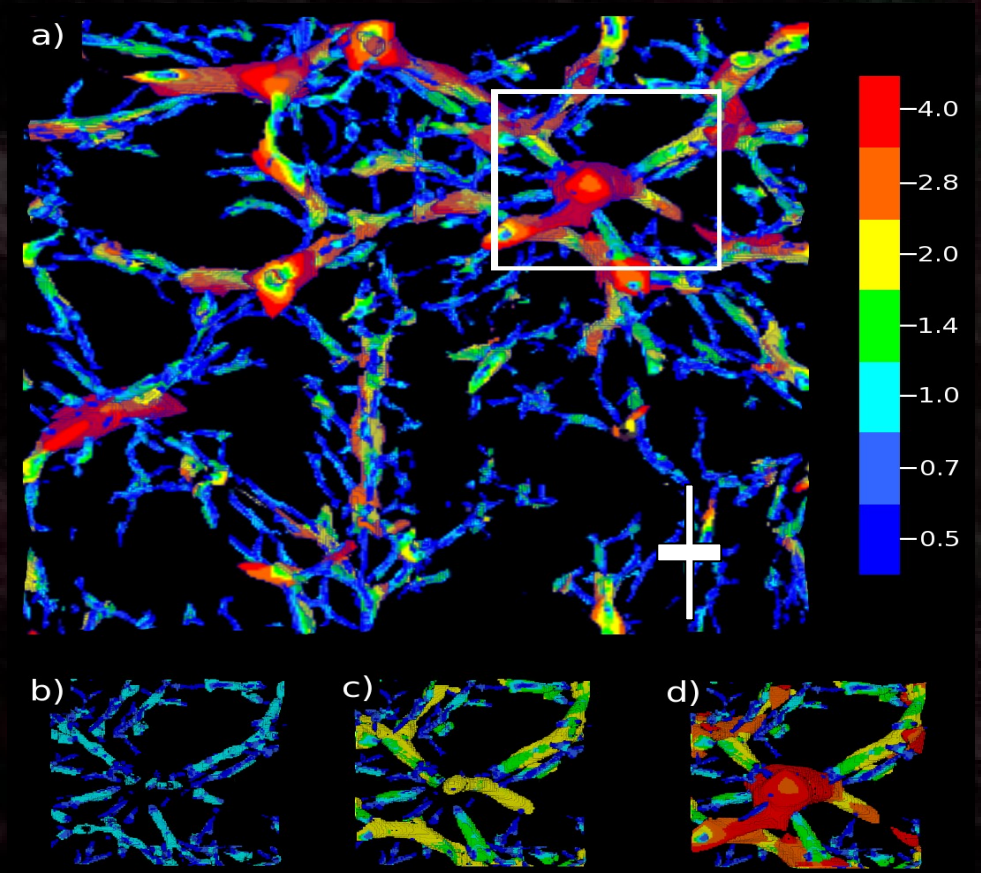
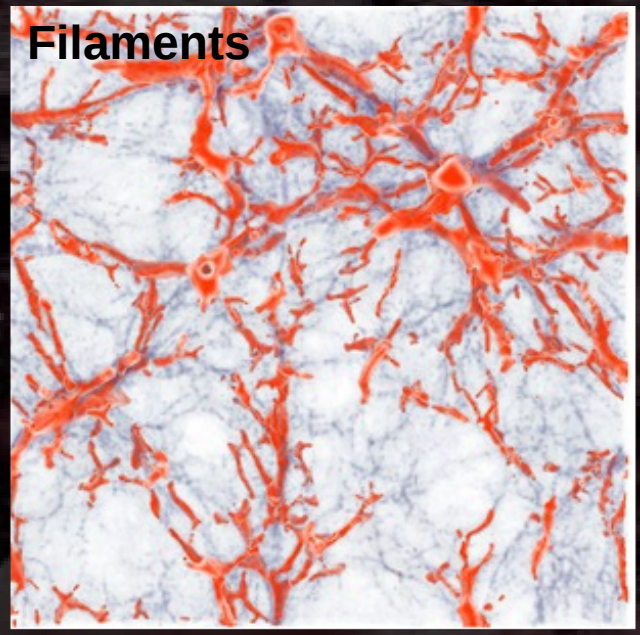
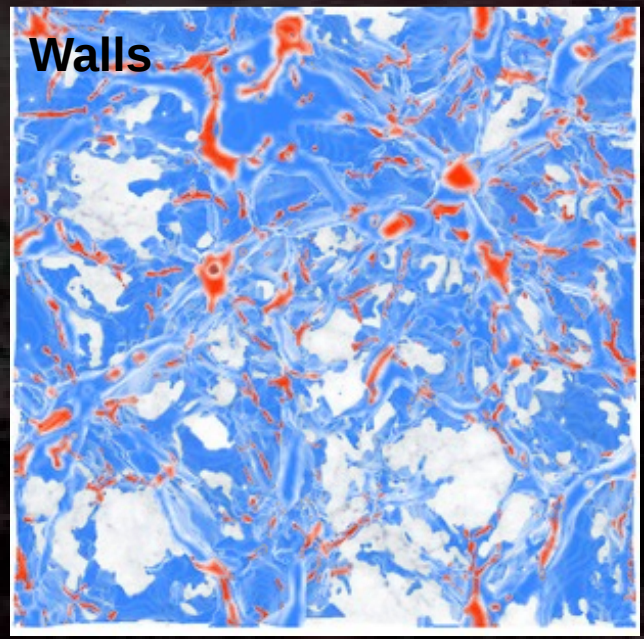
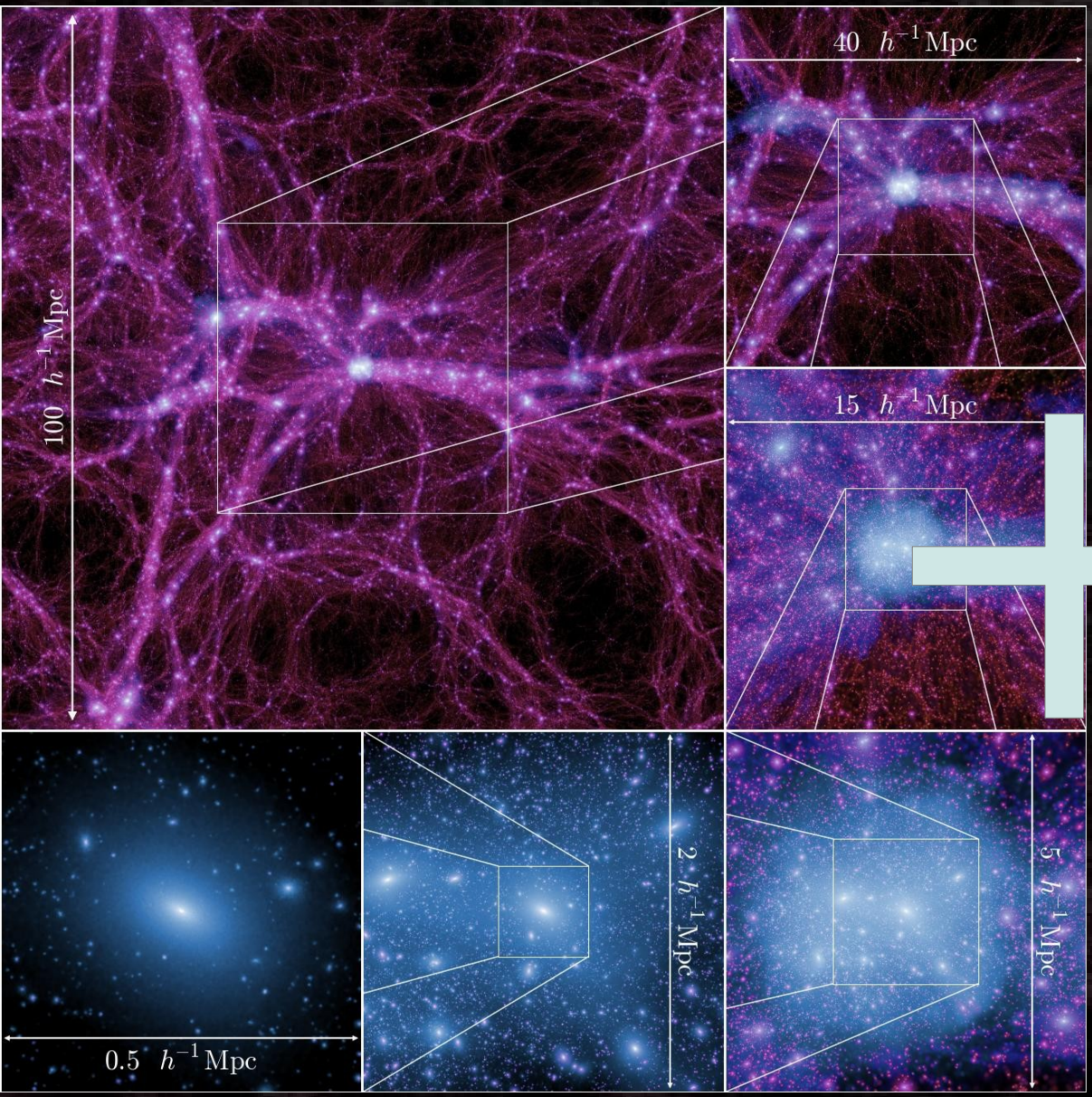




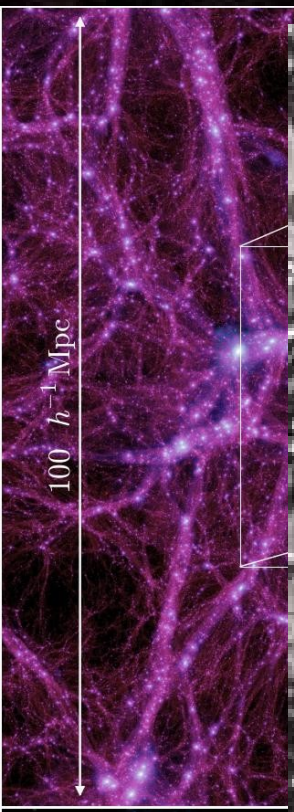


Untangling the Cosmic WEB in Millennium 2

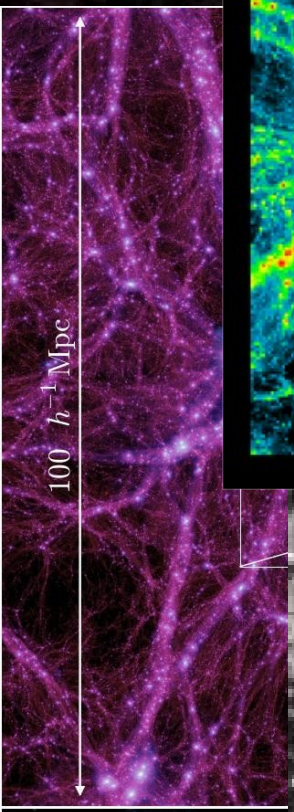


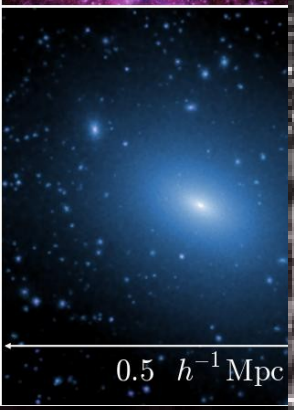
Boylan-Kolchin et al.

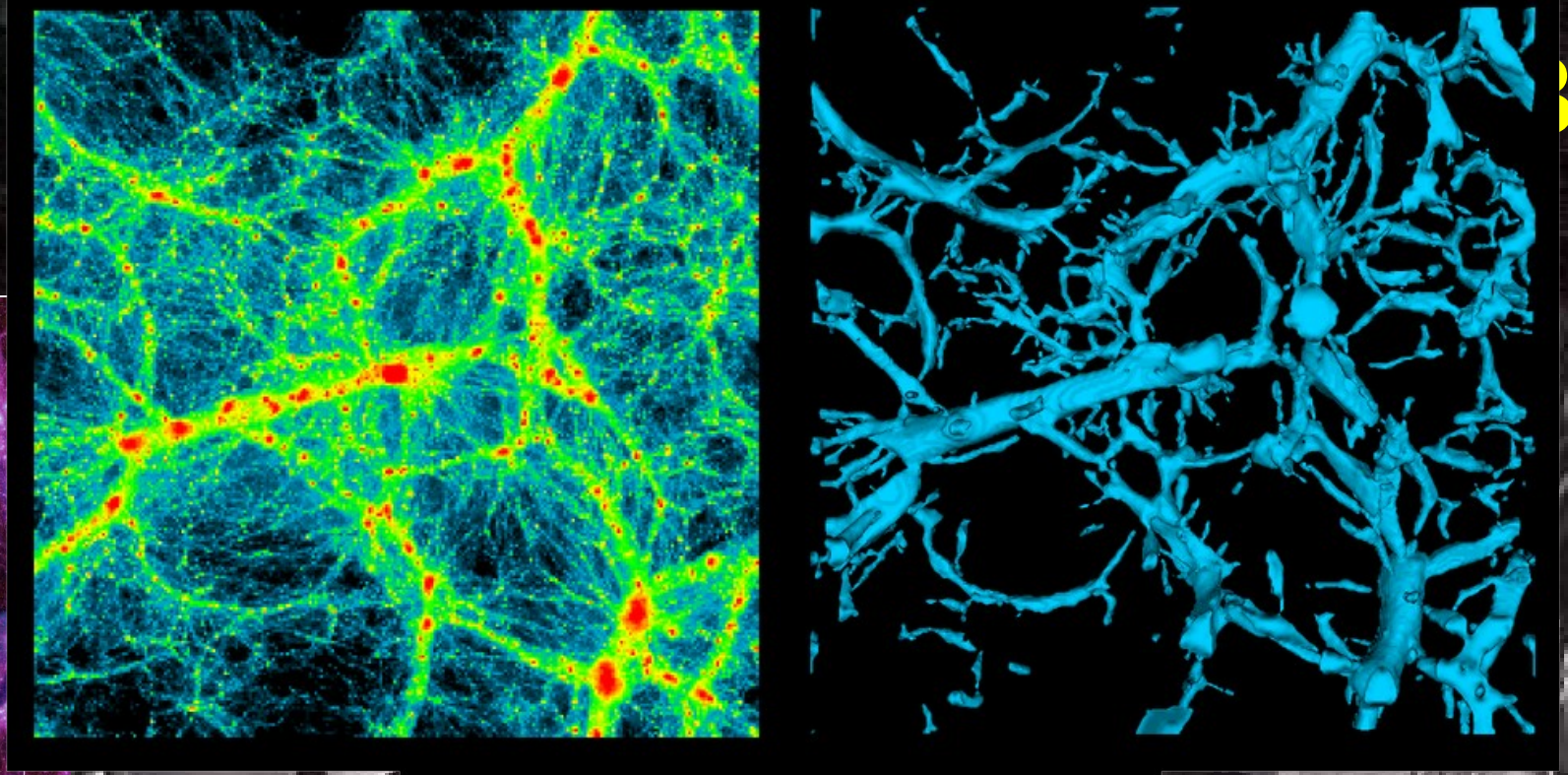
Untangling the Cosmic WEB in Millennium 2

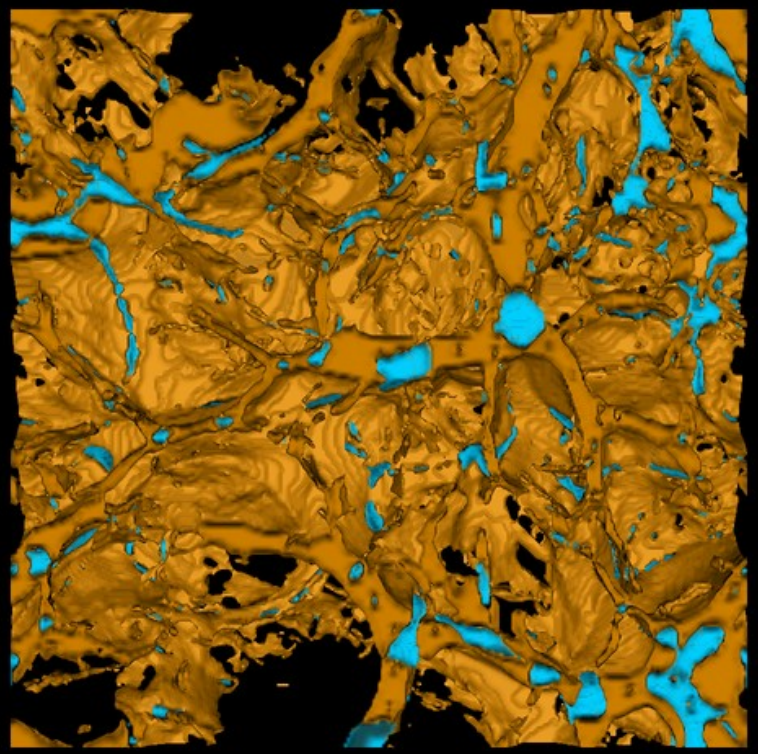


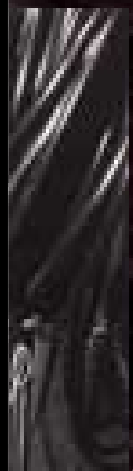
Boylan-Kolchin et al.











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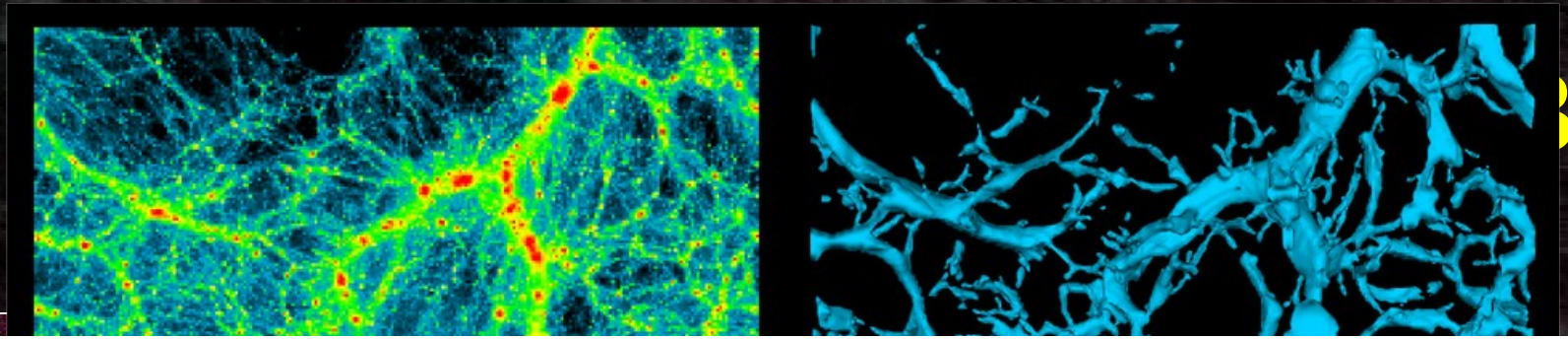
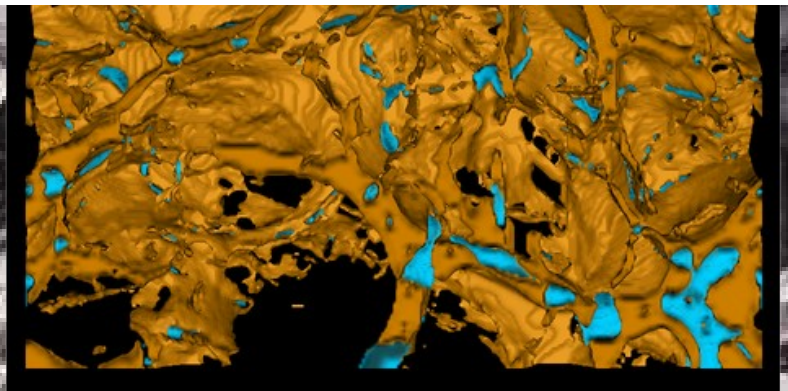
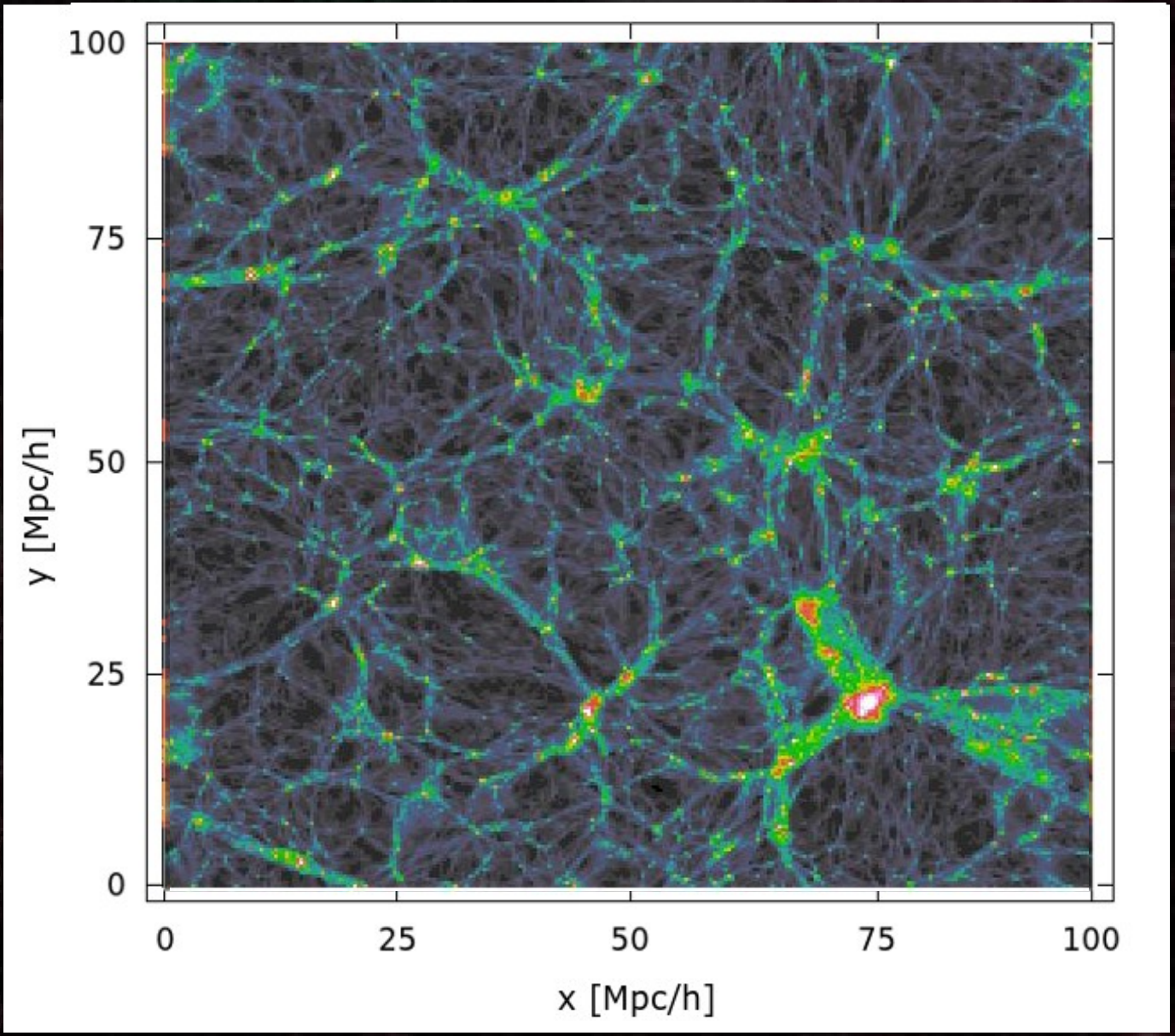


	Volume filling(%)	Mass filling(%)
clusters	0.03	8
filaments	4.4	51
walls	17	24
voids	79	17

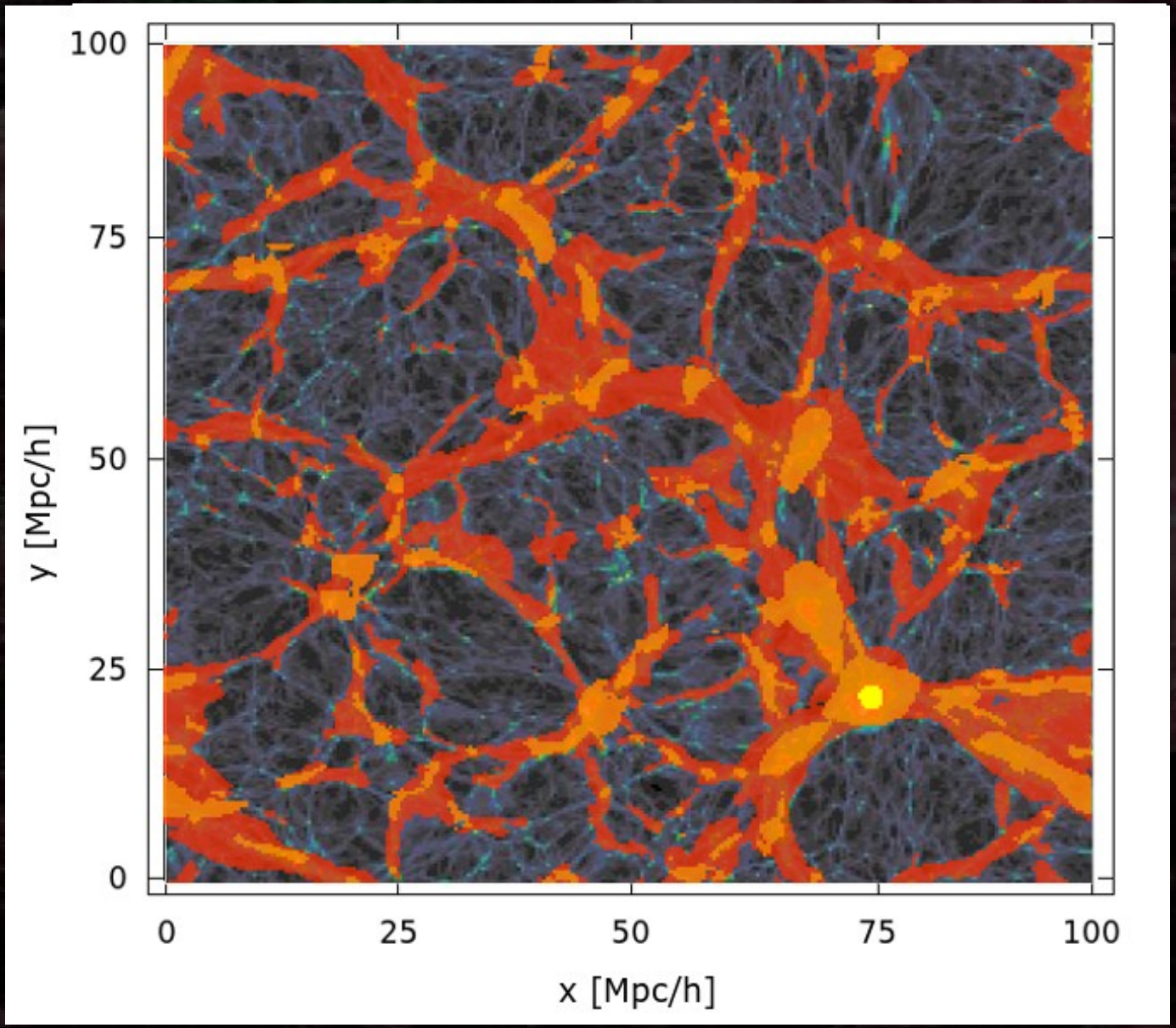


Boylan-Kolchin et al.

Untangling the Cosmic WEB in Millennium2

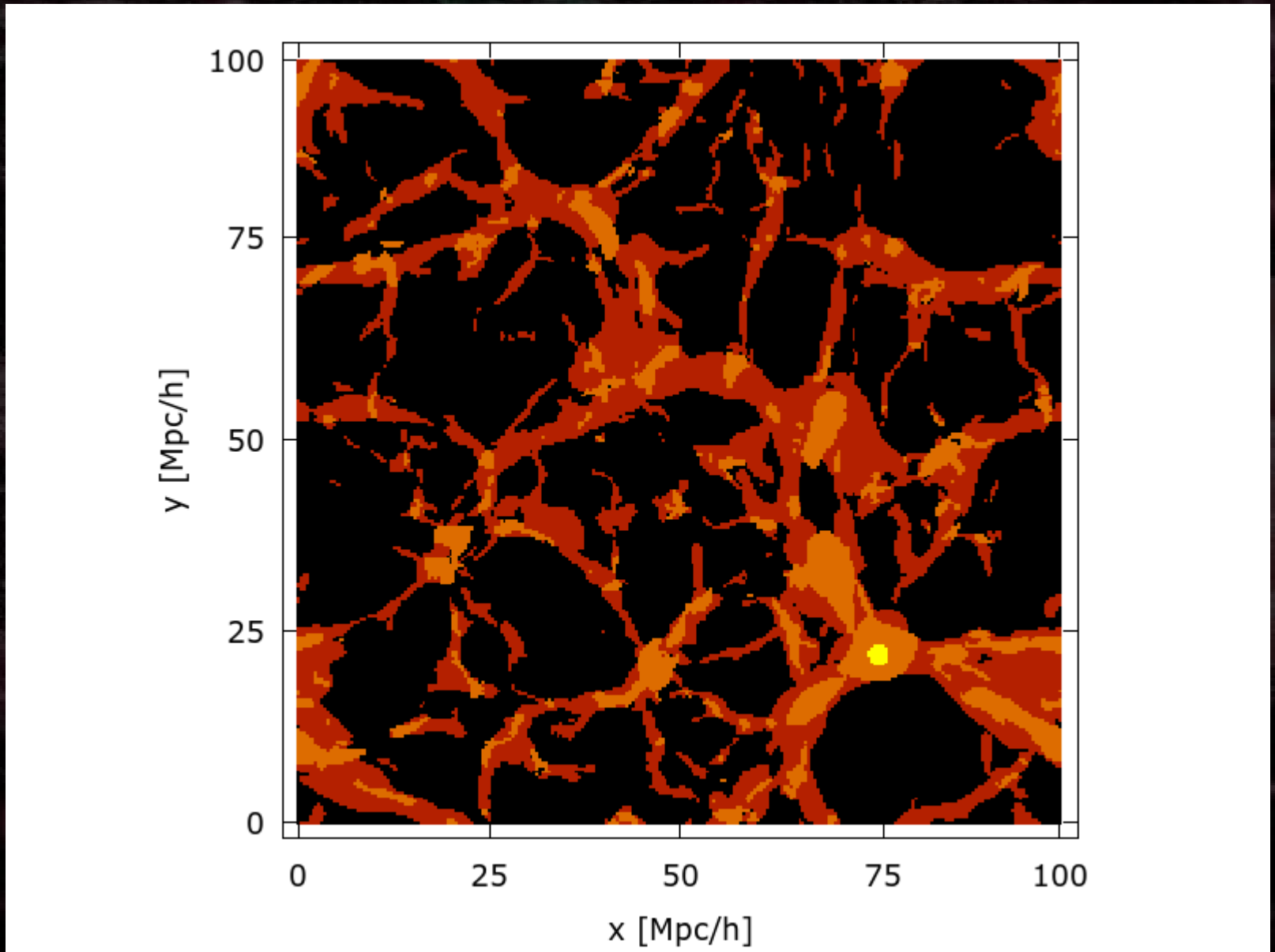


Untangling the Cosmic WEB in Millennium2



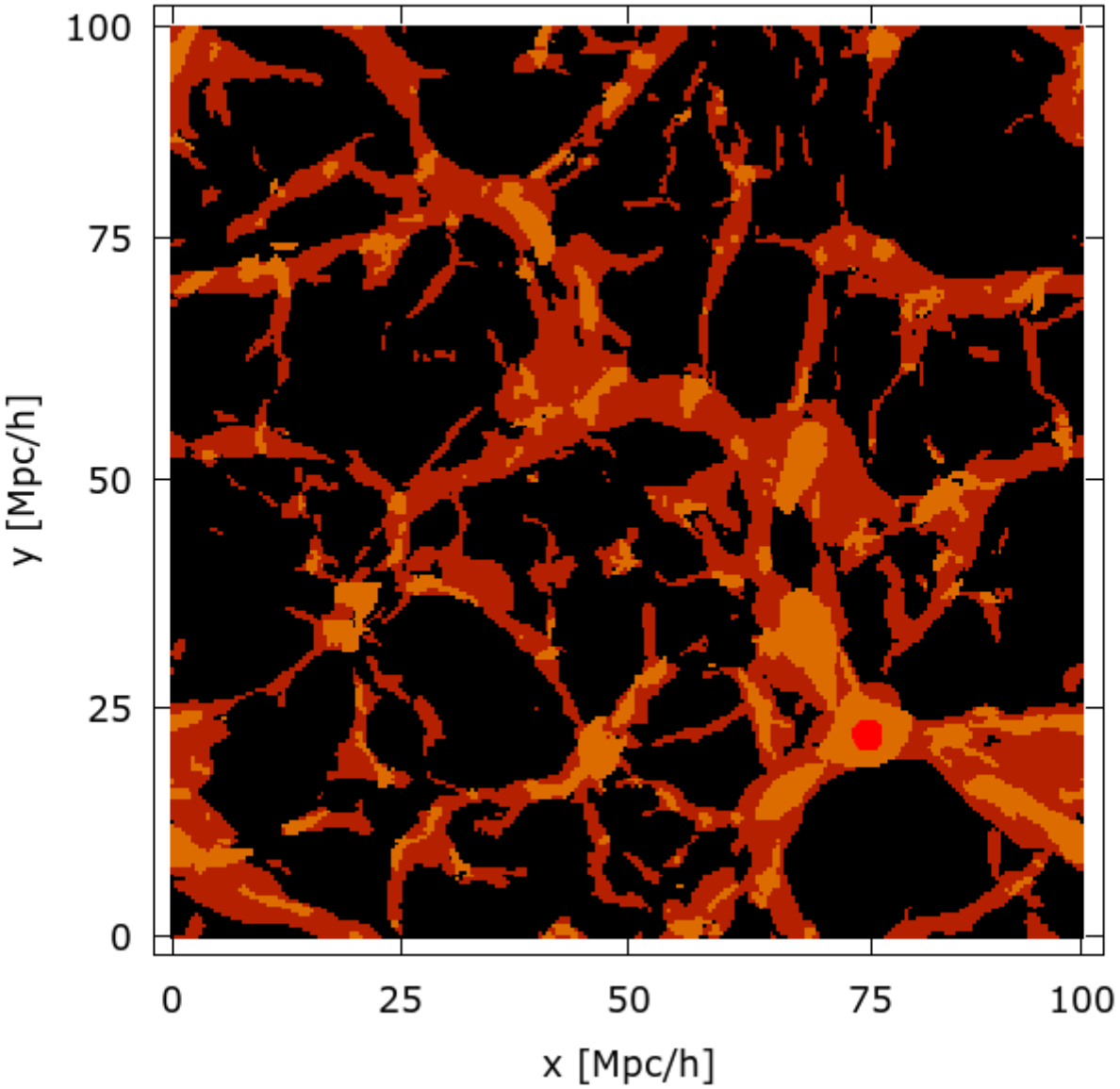
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: The NEXUS env map



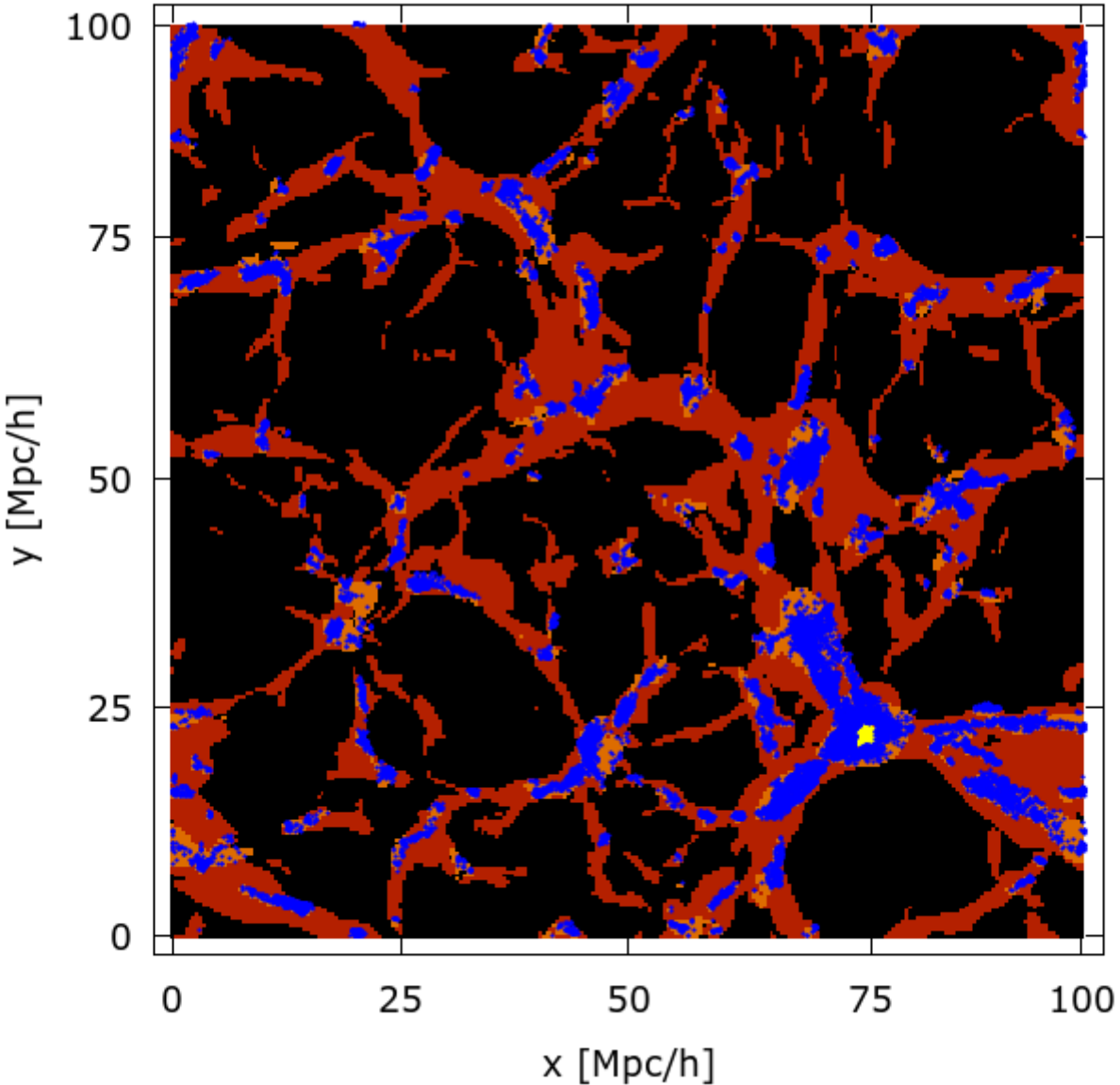
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: cluster haloes & subhaloes



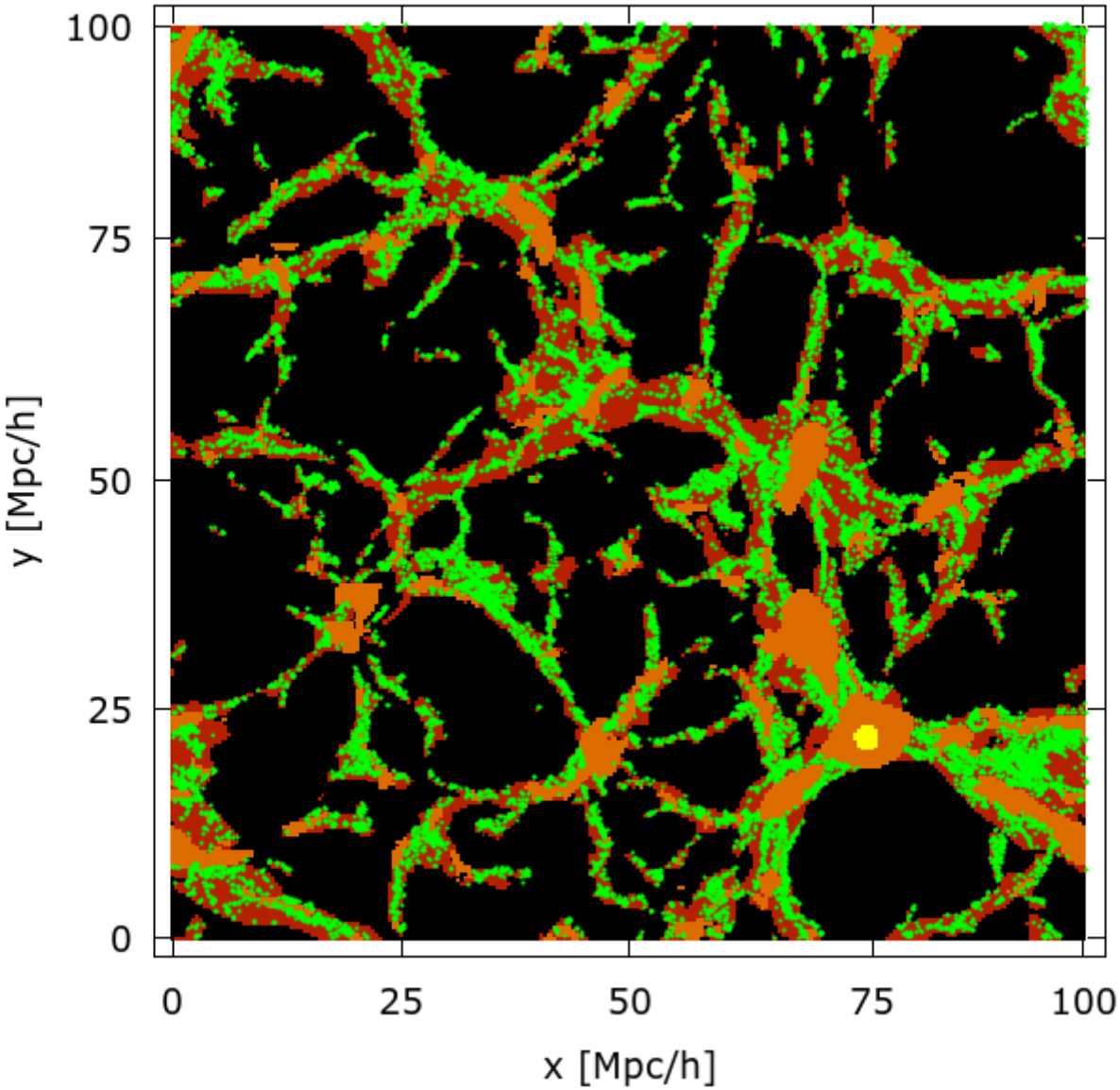
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: filaments haloes



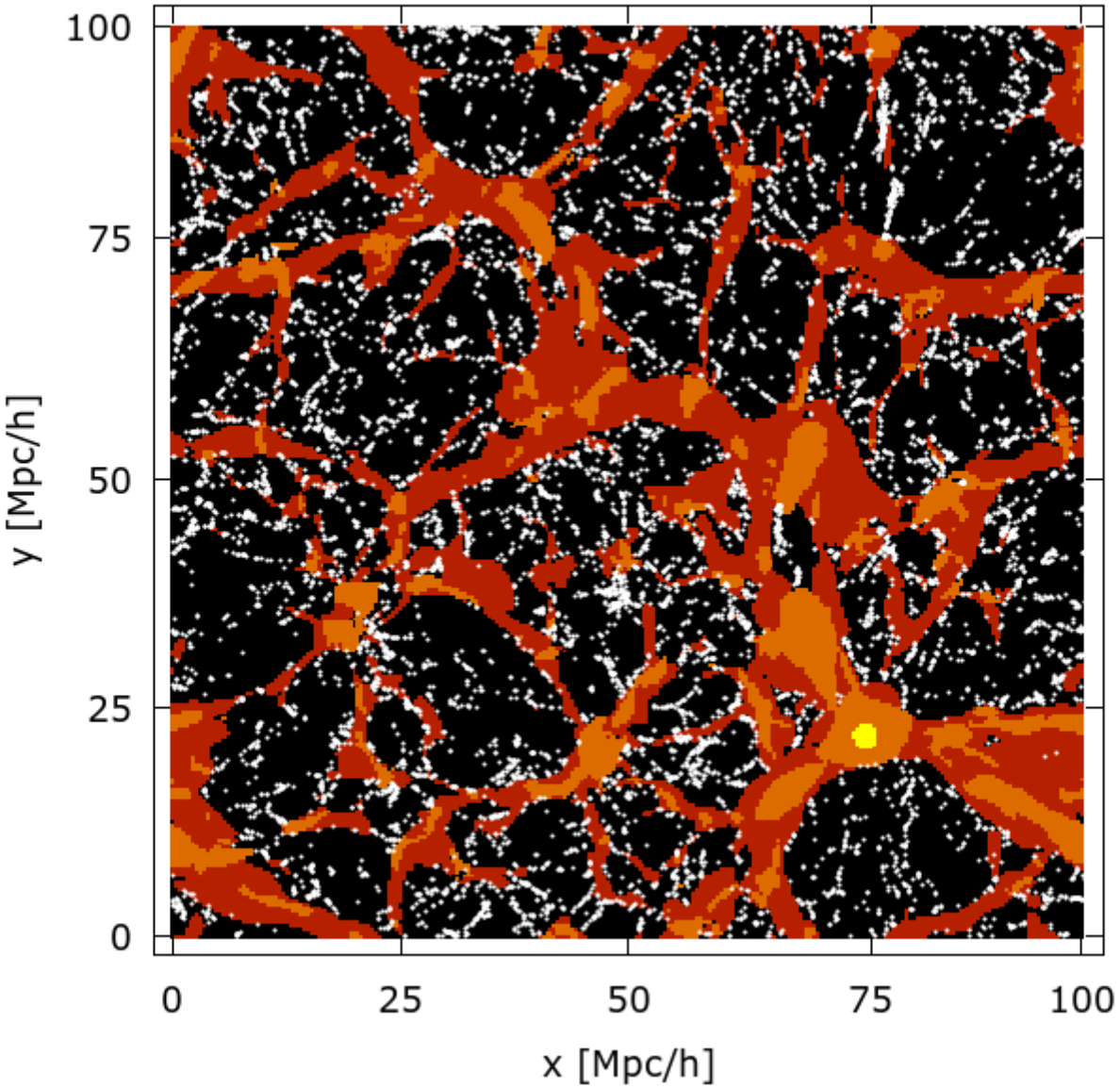
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: wall haloes



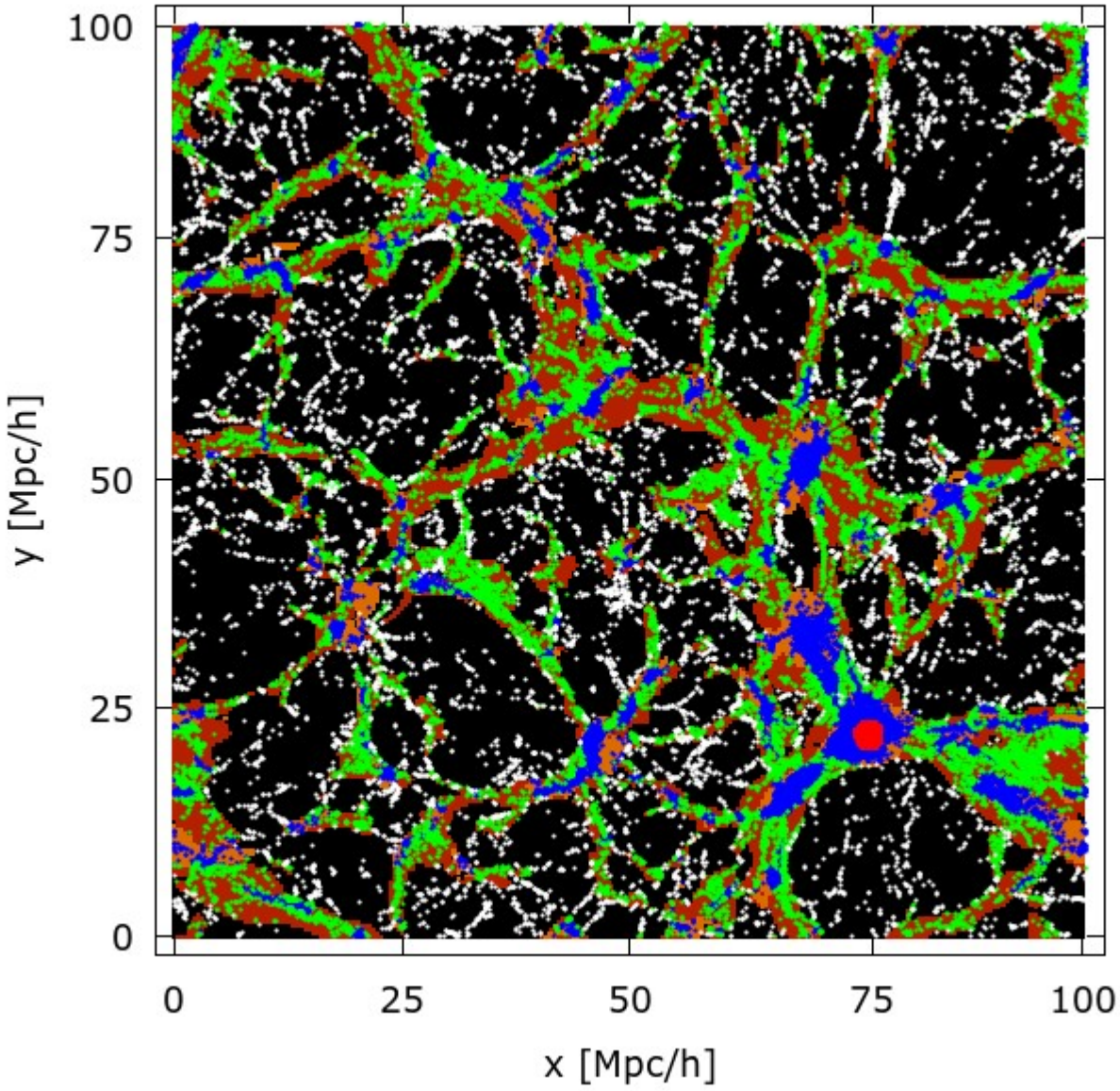
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: void haloes



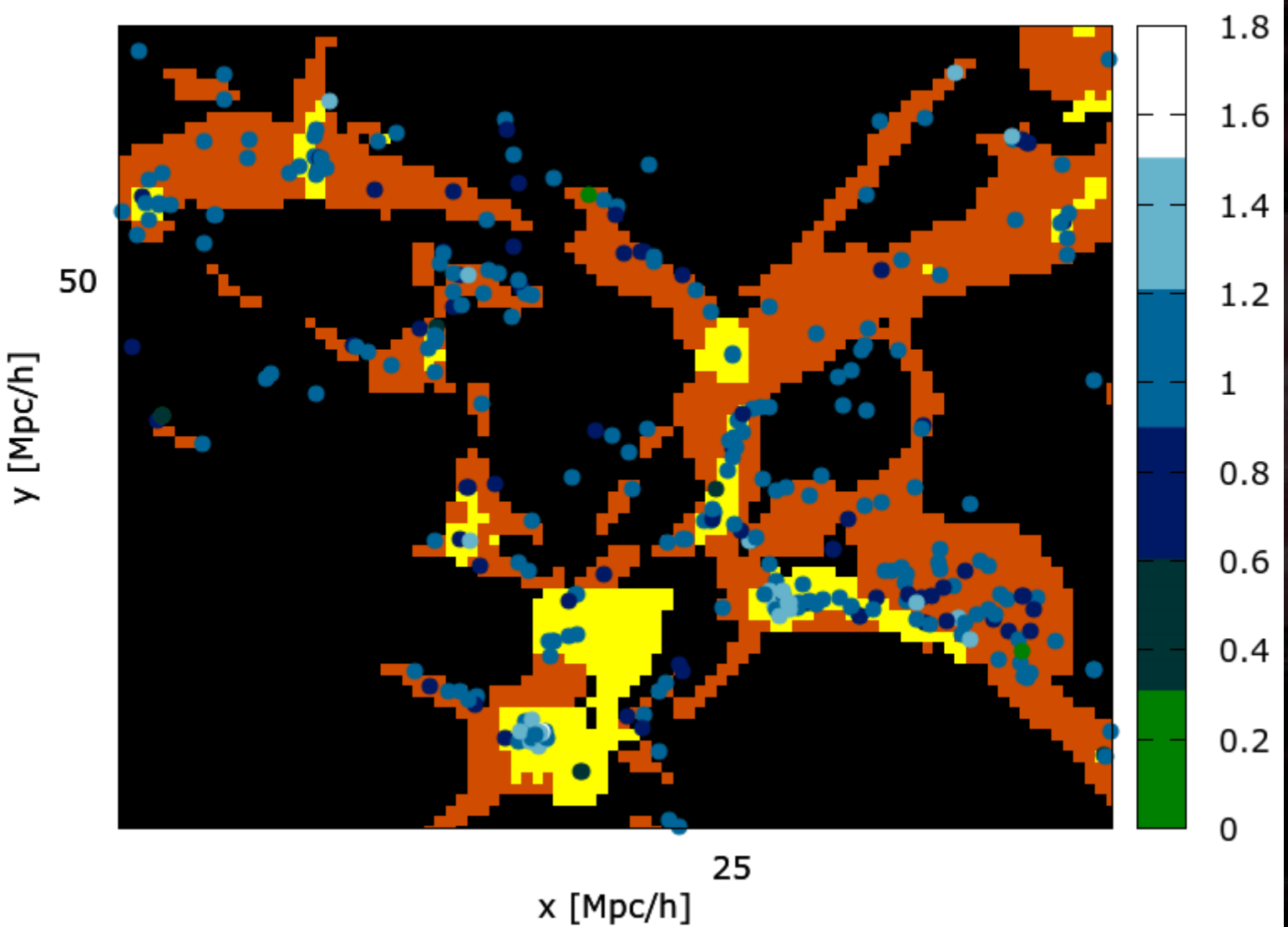
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: all haloes



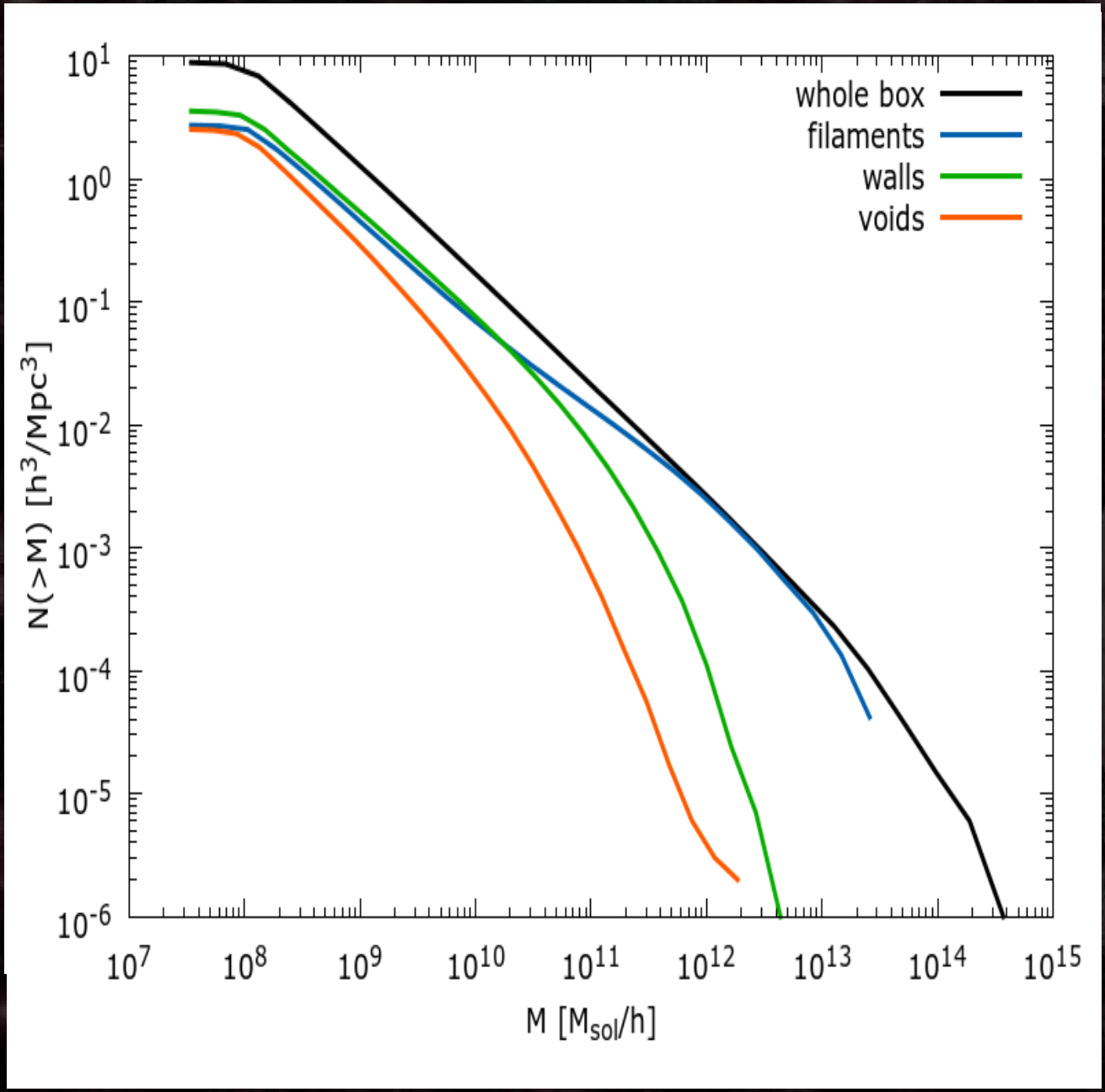
MS2 Cosmic Web halo environments

~0.5 Mpc/h slice through M2: example for cNFW



MS2 Cosmic Web: the results

The mass – environment relation



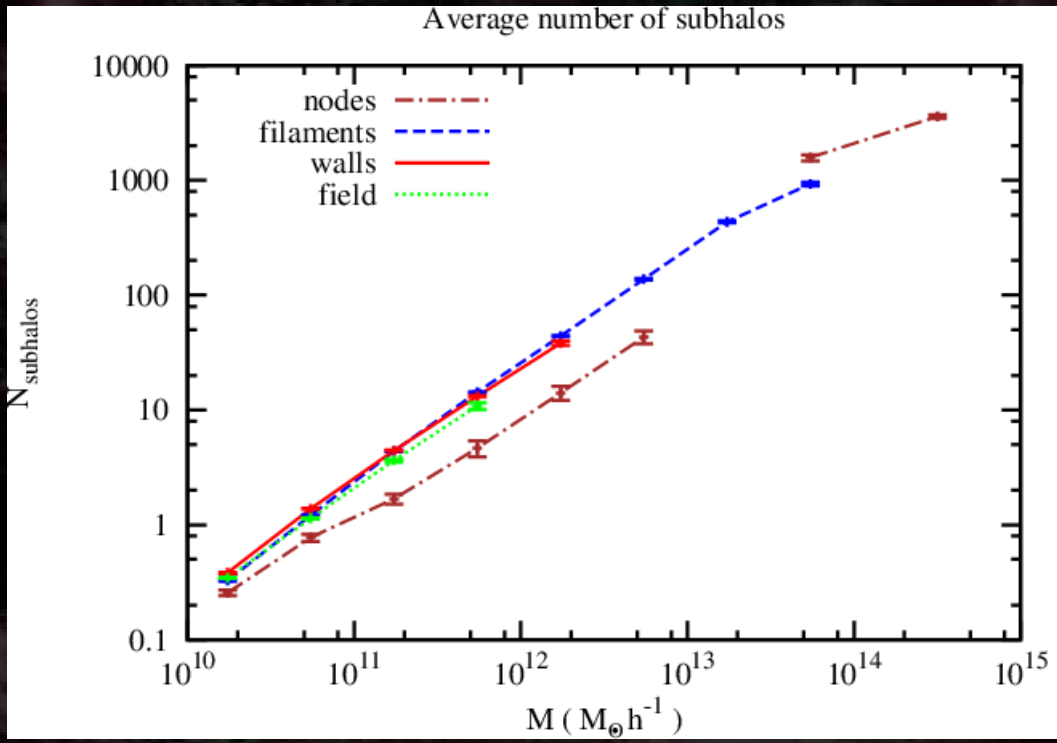
- The clustering bias induce mass-environment bias

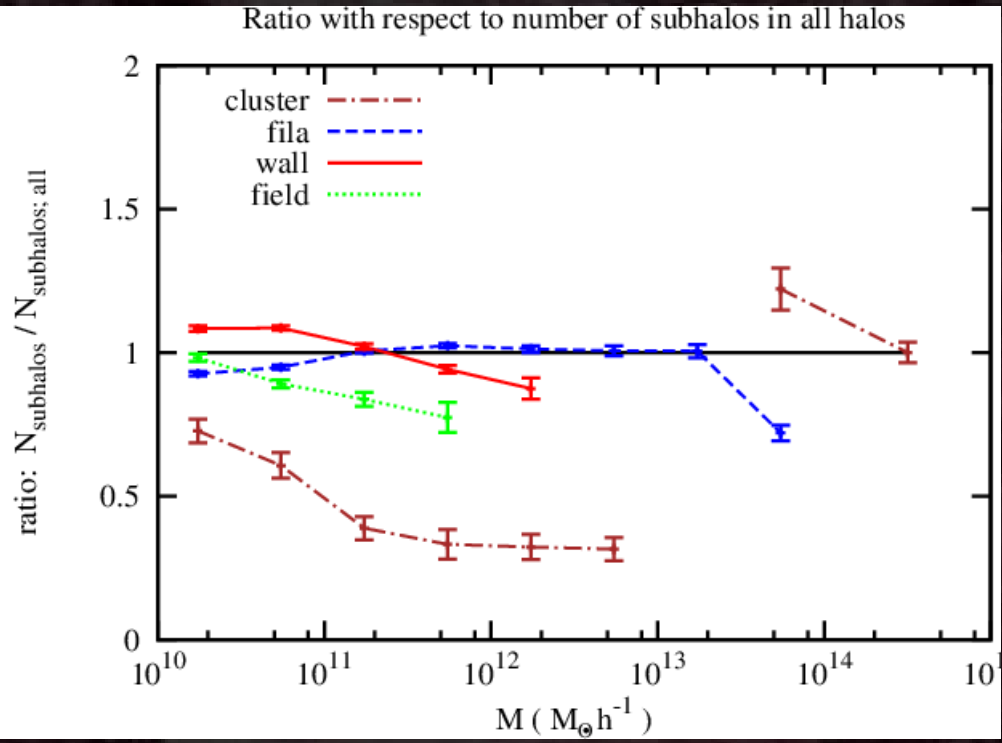
- If MW is a wall-nation galaxy it is already rare (<~10 %)

Hellwing, Cautun et al. (in prep.)

MS2 Cosmic Web: the results

The satellite richness – environment relation



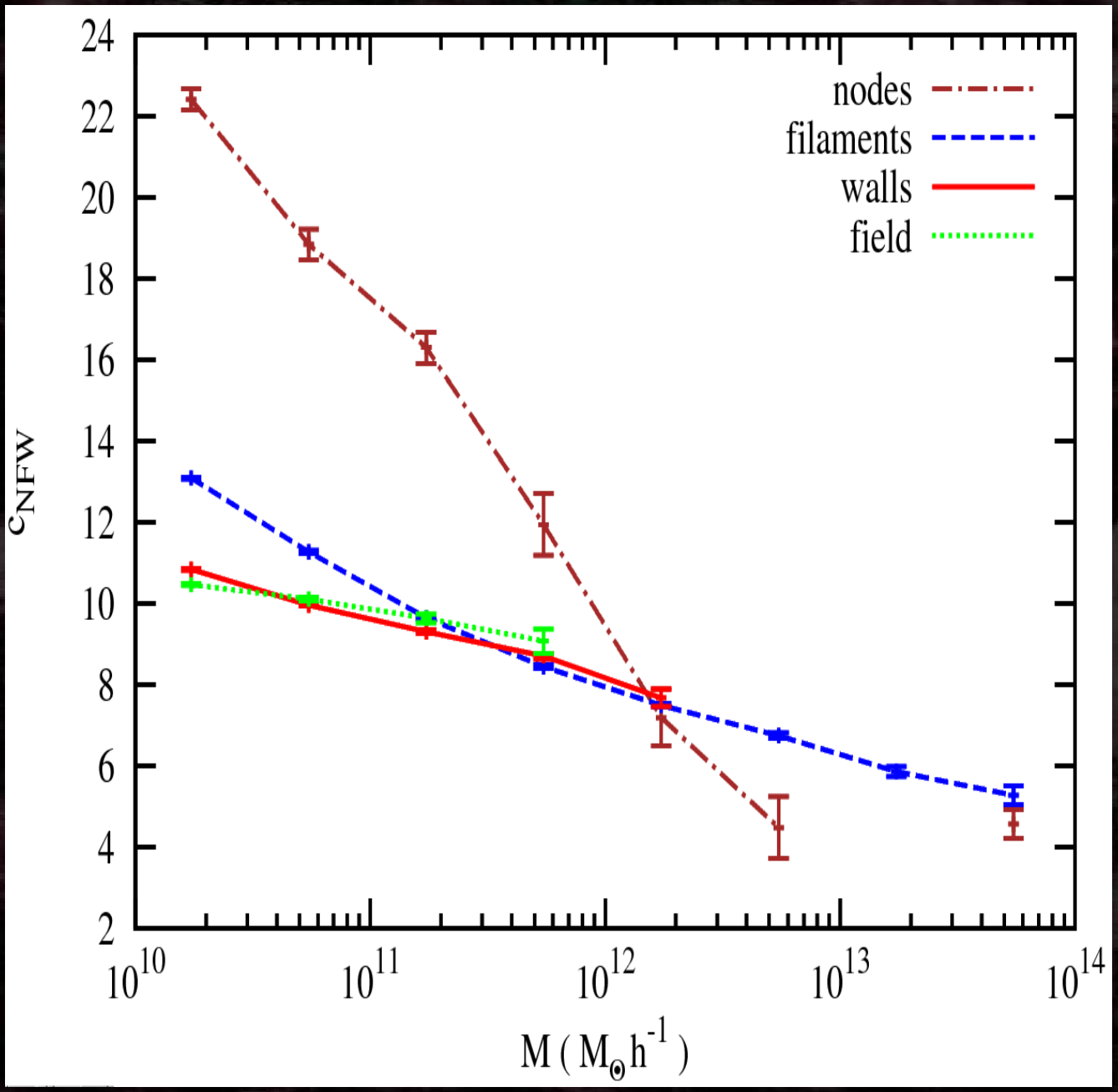


- The environment determines the structure of the merger trees and accretion histories
- MW-like haloes living in walls will have on average less subhaloes and usually quieter MAH's

Hellwing, Cautun et al. (in prep.)

MS2 Cosmic Web: the results

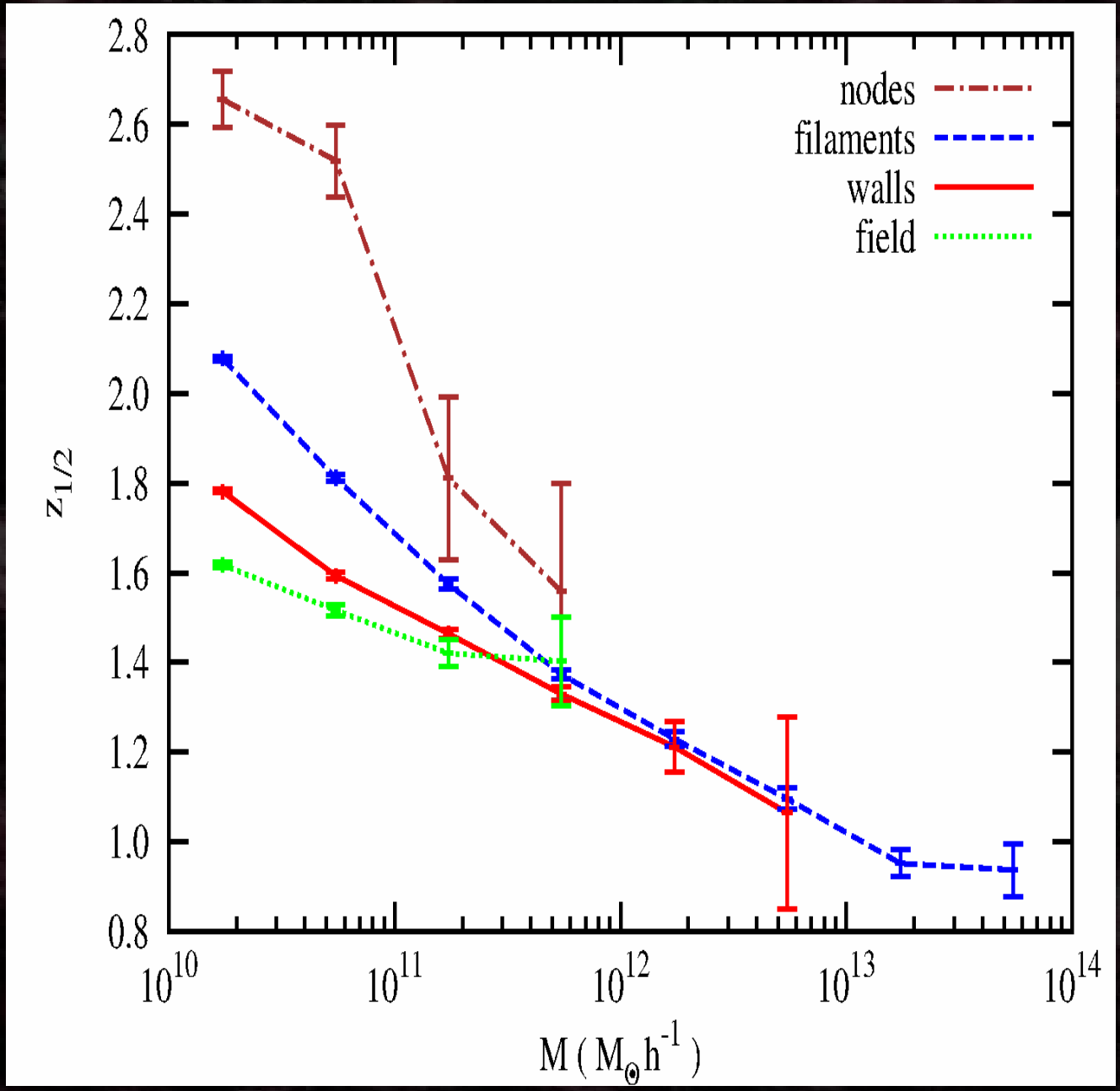
The cNFW – environment relation



Hellwing, Cautun et al. (in prep.)

MS2 Cosmic Web: the results

The z1/2 – environment relation



- This is complementary to the previous plot
- What we see here is essentially assembly bias

Hellwing, Cautun et al. (in prep.)

Conclusions

- The LSS/Cosmic Web environment is much more complicated than just background density
- The Cosmic Web neighborhood has impact on DM halo properties
- Hence Cosmic Web environment will be important factor for galaxy formation and evolution
- Detailed study of the Cosmic Web effects in M1&2 are in progress.
- We hope that braking the environment degeneracy will help to understand better galaxy formation and allow to improve galaxy formaion models
- If there will be interested we plan/hope to include halo/galaxy environments flags into the databases
- the Future is bright: the DOVE, COCO & EAGLE