

A visualization of the cosmic web, showing a complex network of dark, filamentary structures against a light blue background. The filaments are interconnected, forming a web-like pattern that spans the entire frame. The background has a subtle, wavy texture, suggesting a fluid or gaseous medium.

*ORIGINS RU-D Day*

*Filaments on all scales*

**The cosmic web revisited**

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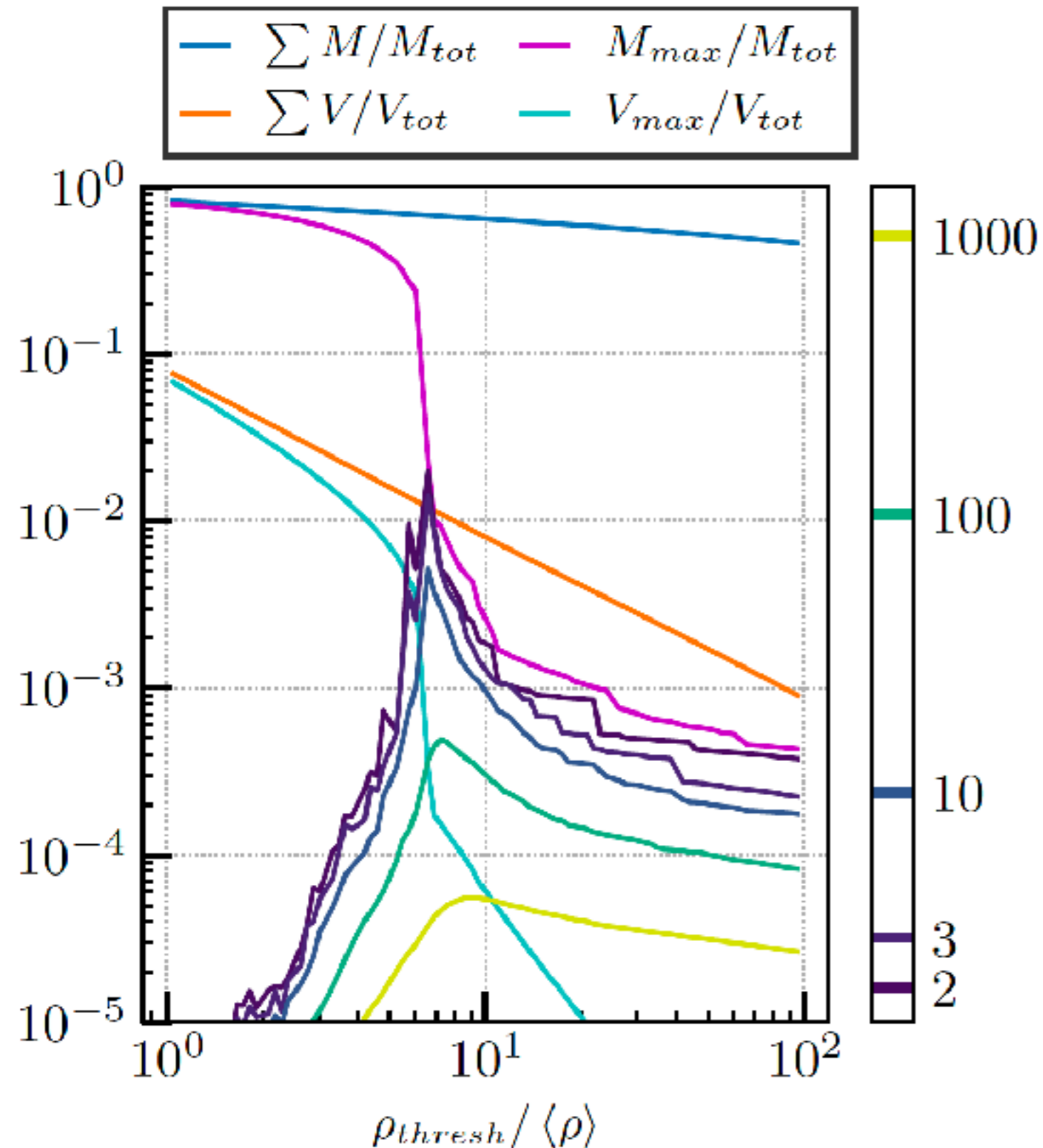
# From the Voronoi density field to halos and the Web

For a large-scale cosmological N-body simulation of the dark matter distribution

1. Make a Voronoi tessellation of the N-body particle distribution
2. Define the density associated with particle  $i$  by  $\rho_i = m_p/V_i$
3. Define particles  $i$  and  $j$  to be “friends” if their Voronoi cells share a face
4. Consider the set of all particles with density  $\rho_i$  greater than a threshold  $\rho_{\text{thresh}}$
5. Partition this set into “friends-of-friends” groups

For  $\rho_{\text{thresh}} \sim 80\langle\rho\rangle$  these groups are almost identical to standard FOF halos with  $b = 0.2$

# The cosmic web as the percolating DM structure



## The Millennium Simulation

$$L = 500 h^{-1} \text{Mpc}, \quad m_p = 8.6 \times 10^8 h^{-1} M_{\odot}$$

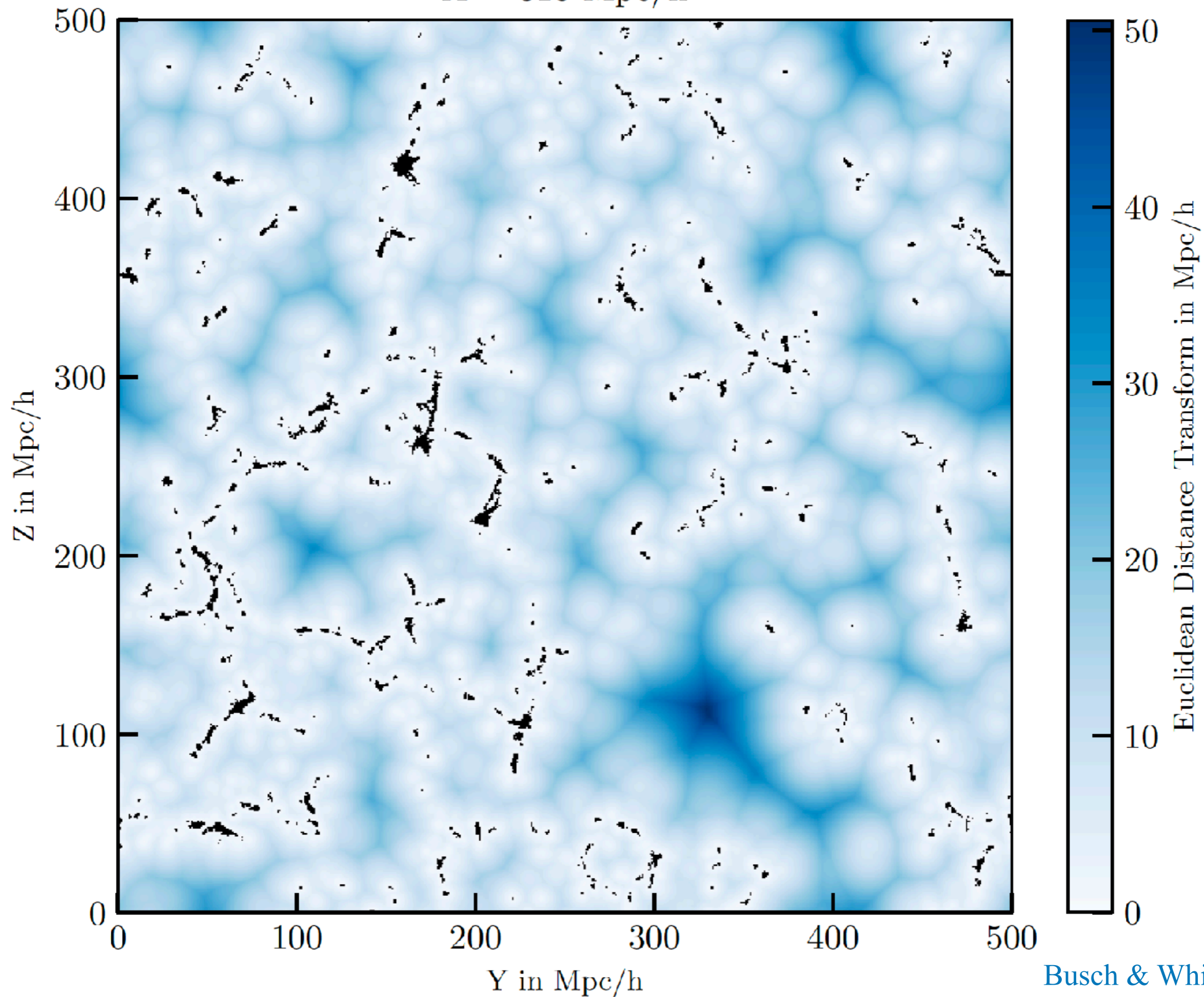
$$M_{\text{tot}} = 8.6 \times 10^{18} h^{-1} M_{\odot}$$

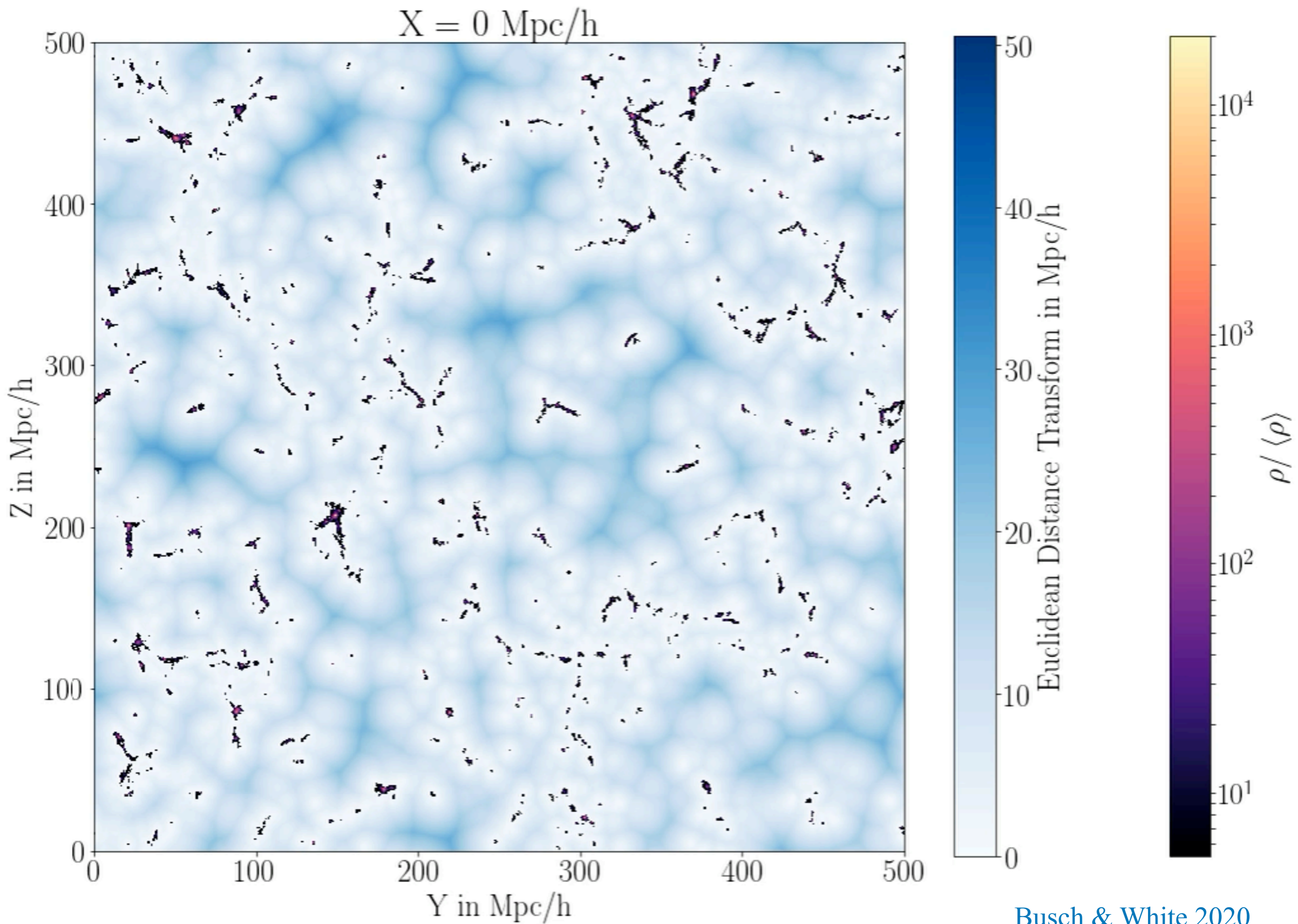
Percolation occurs for  $\rho_{\text{thresh}} \sim 7 \langle \rho \rangle$

For  $\rho_{\text{thresh}} = 5.25 \langle \rho \rangle$ , the “cosmic web” (CW) contains 35% of all mass in 0.62% of all volume.

- This defines the CW as a material object
- It is bounded by an equidensity surface
- Every particle/halo is either in the CW or not
- Little resolution dependence if halos resolved

$X = 318 \text{ Mpc}/h$





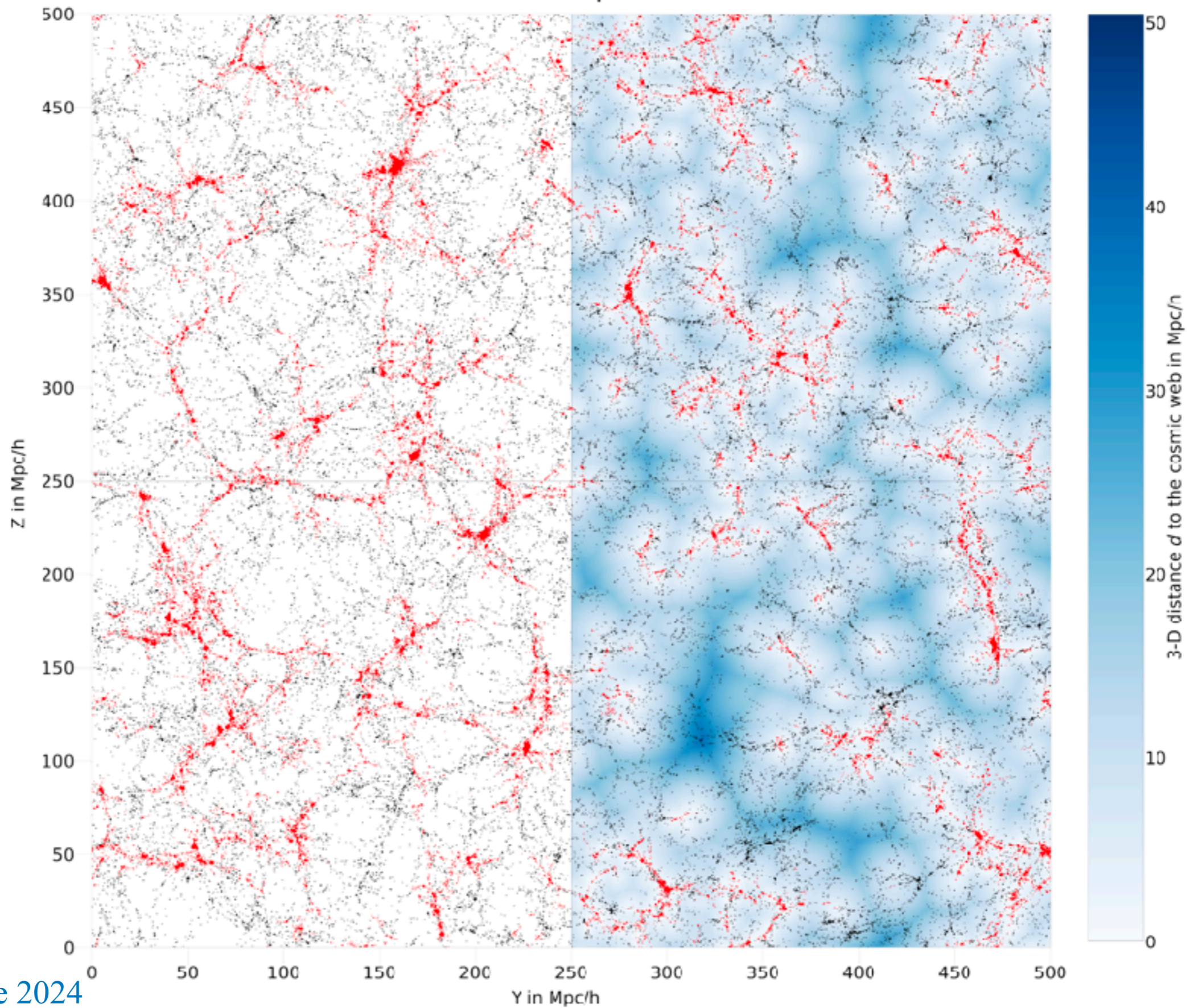
# Galaxies and the Web

$X = 318 \text{ Mpc}/h$

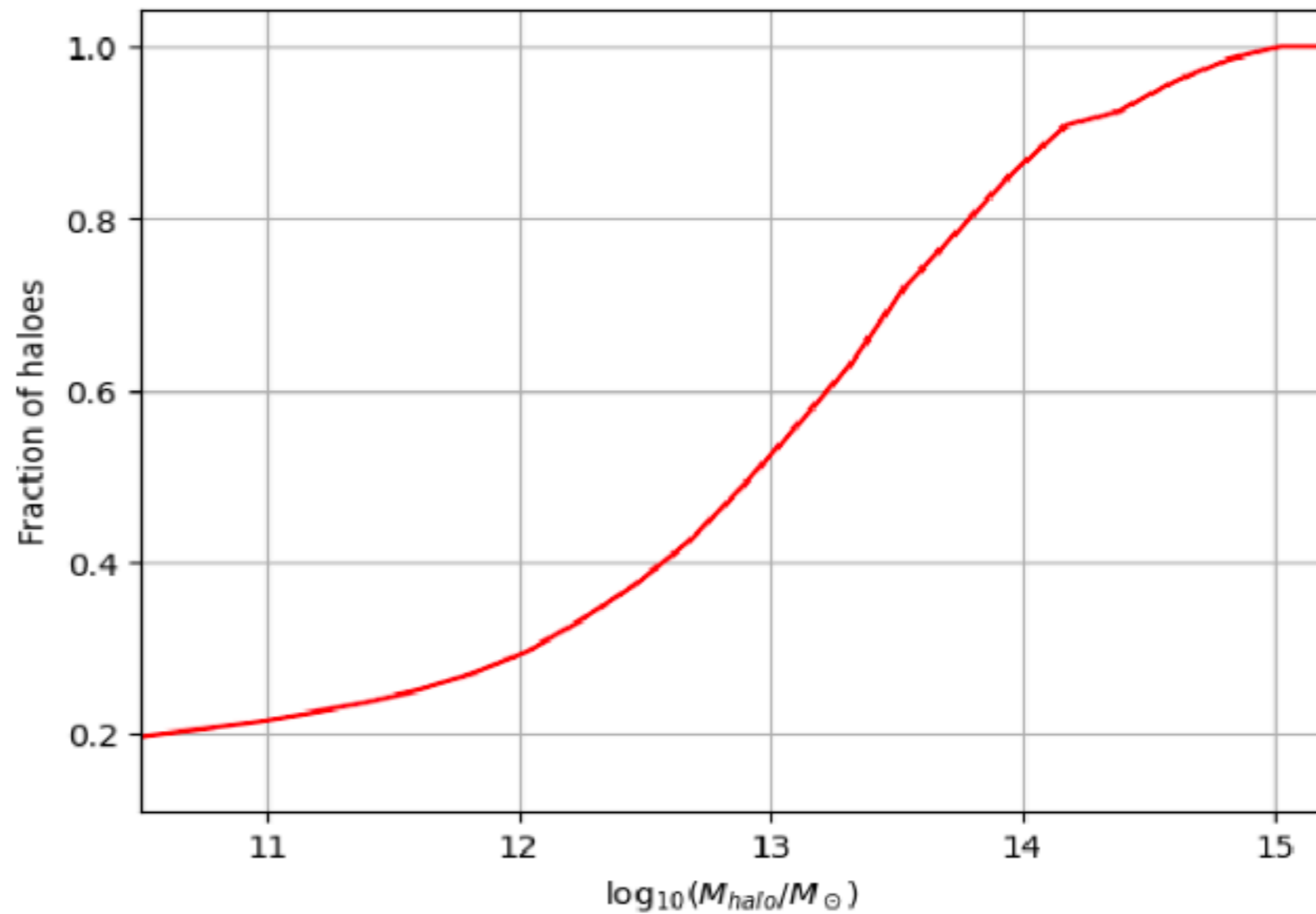
$$M_* > 10^{9.5} h^{-1} M_\odot$$

$$\Delta X = 20 h^{-1} \text{Mpc}$$

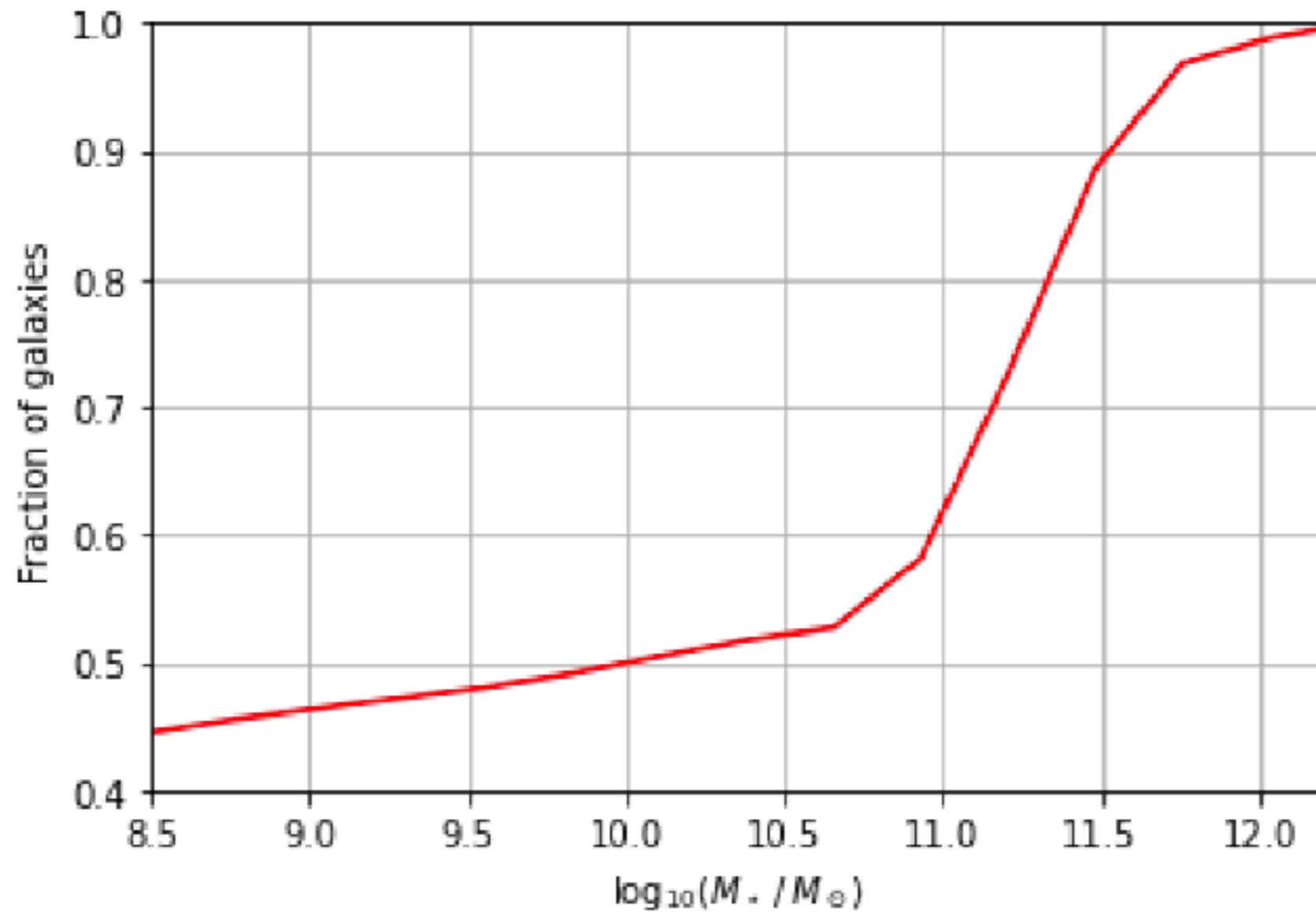
$$\rho_{\text{thresh}} = 5.25 \langle \rho \rangle$$



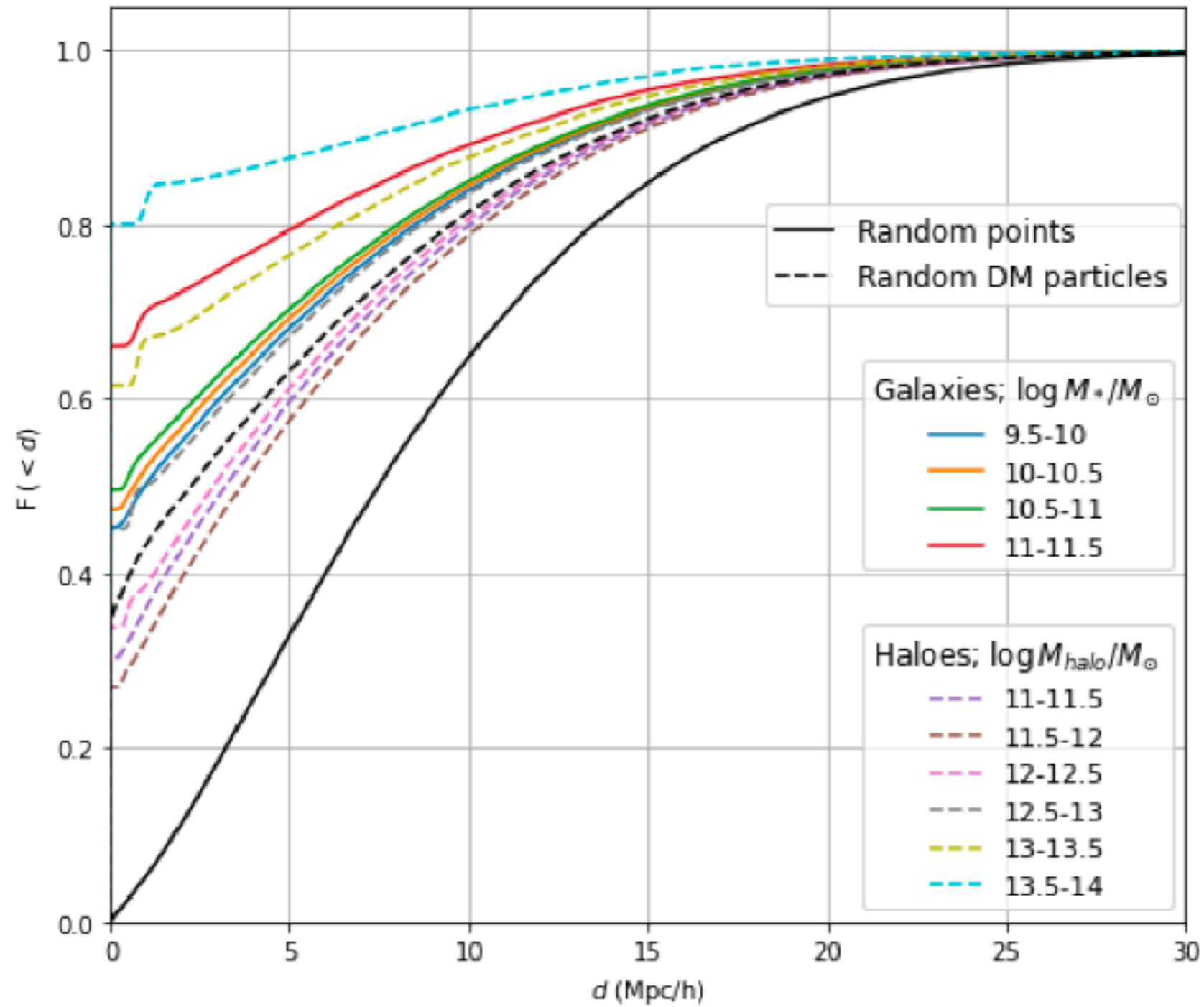
# The fraction of halos in the CW as a function of mass $M_{200}$



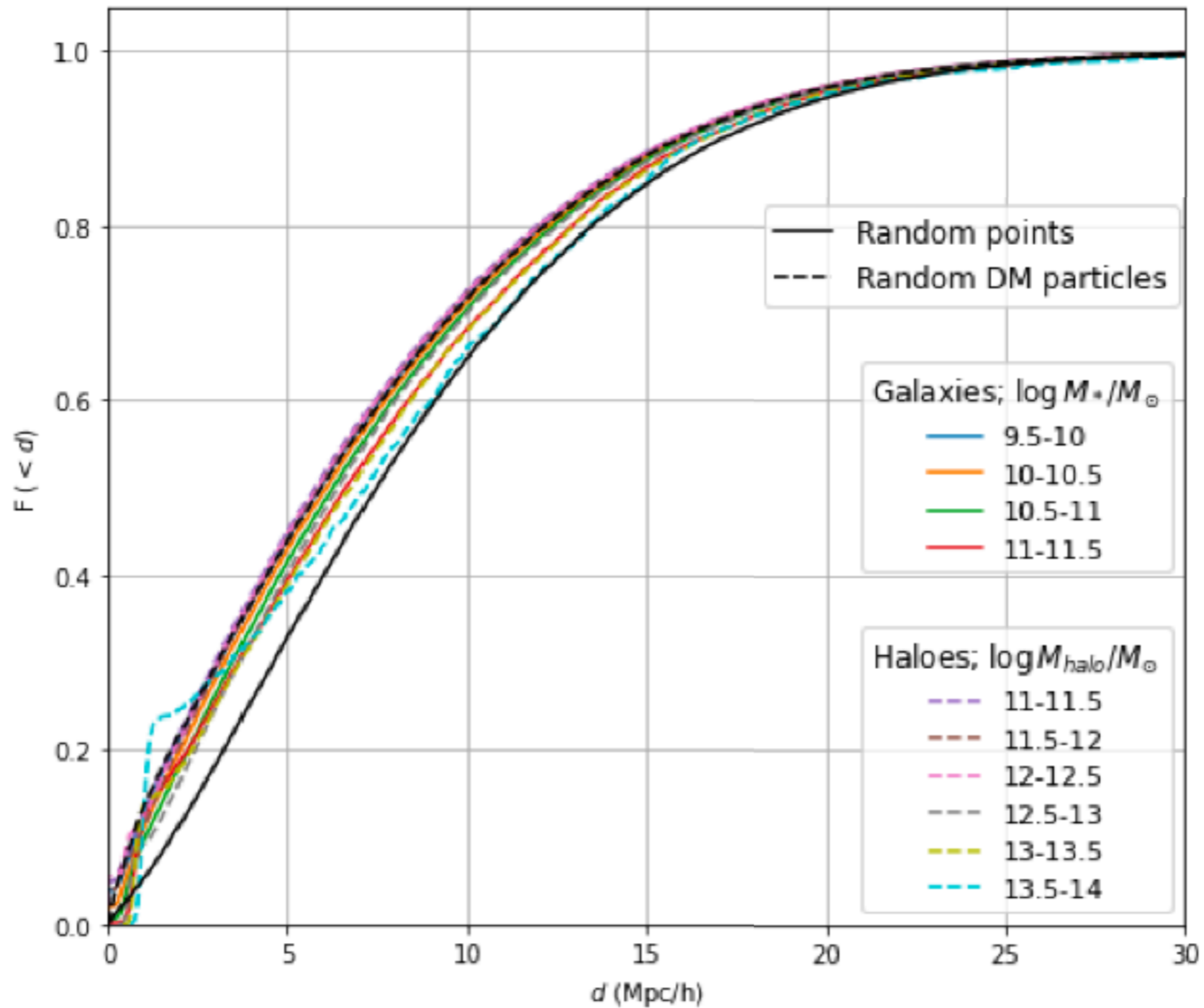
# The fraction of galaxies in the CW as a function of stellar mass



# Distance of objects to the nearest point in the CW

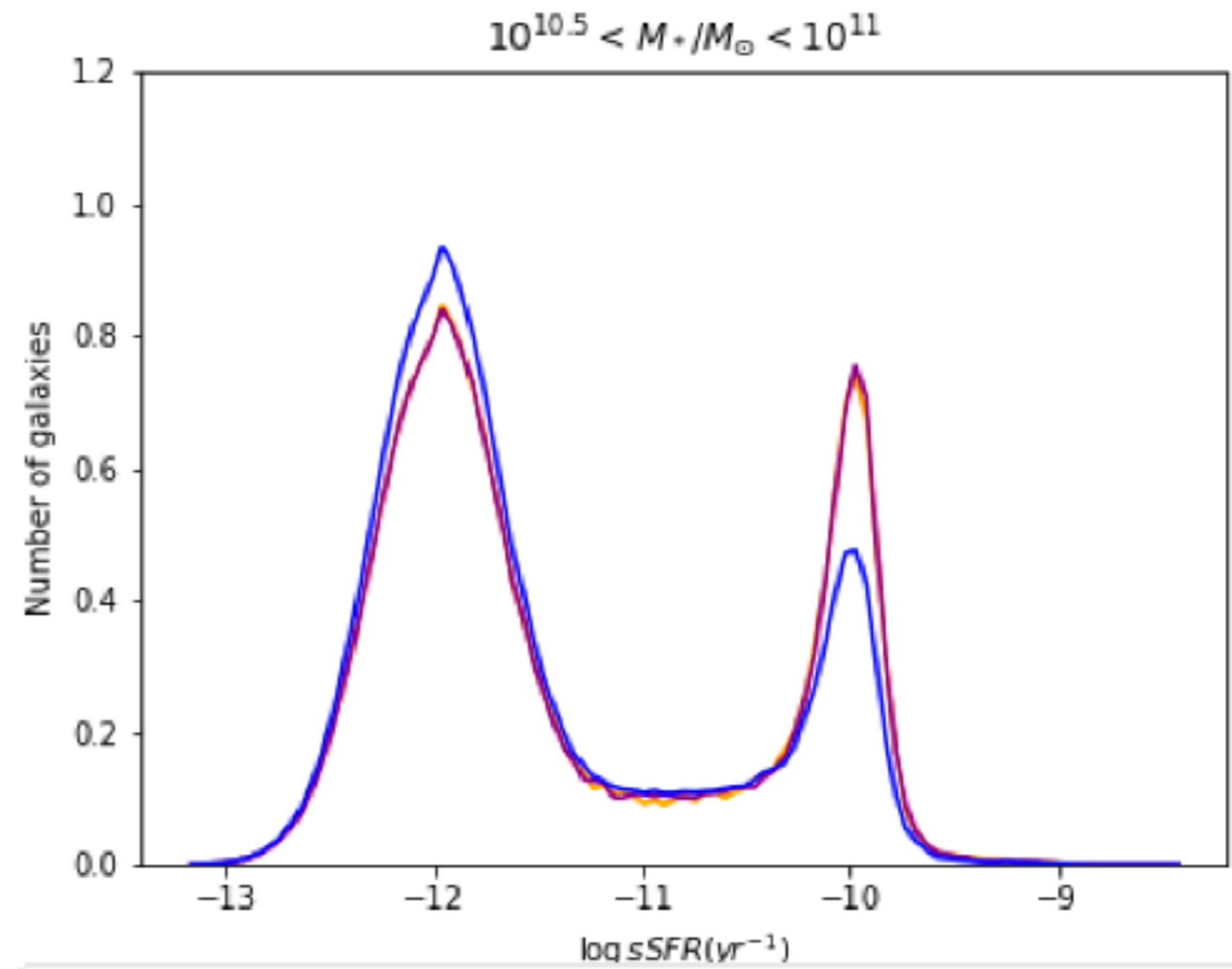
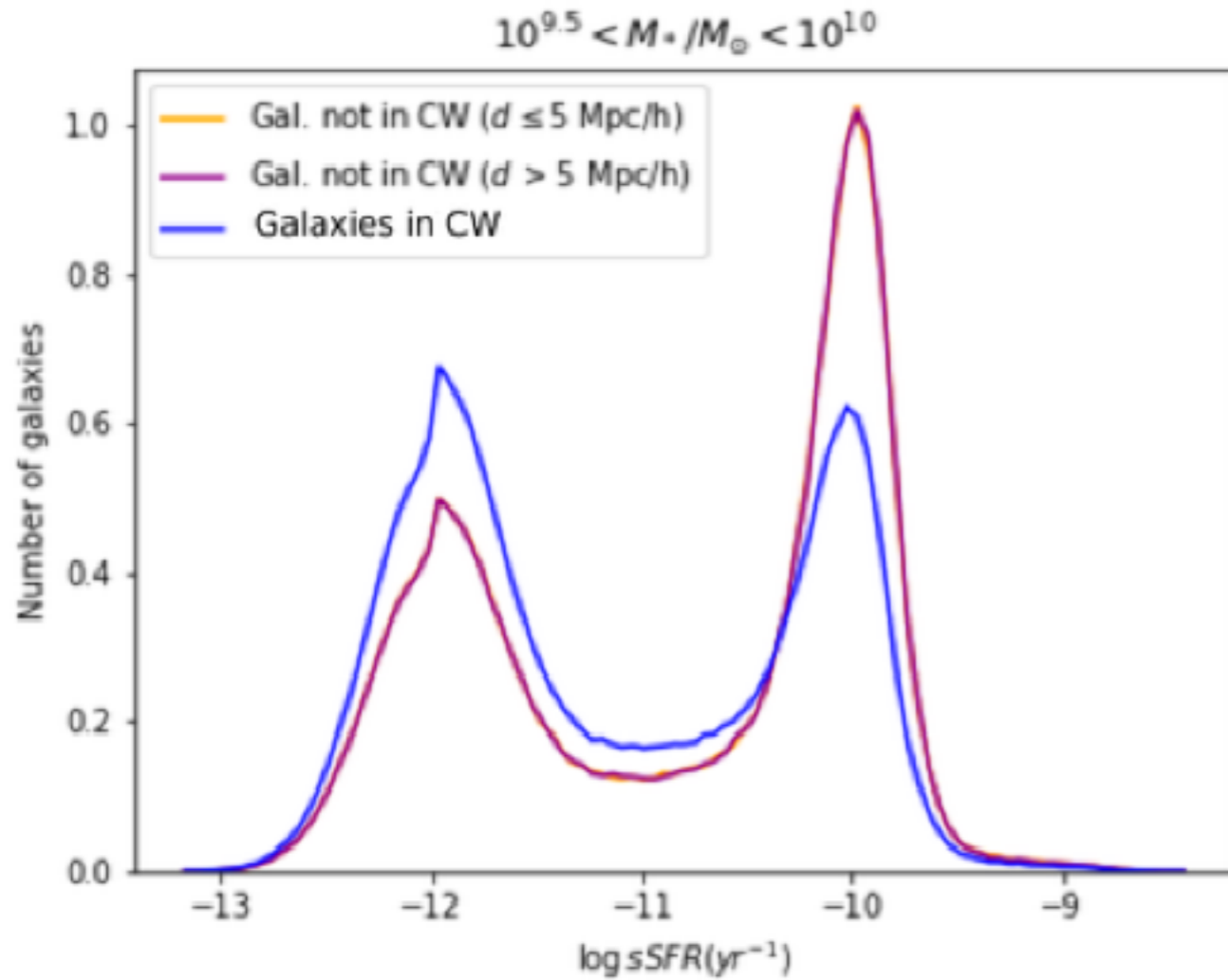


# Distance of non-web objects to the nearest point in the CW



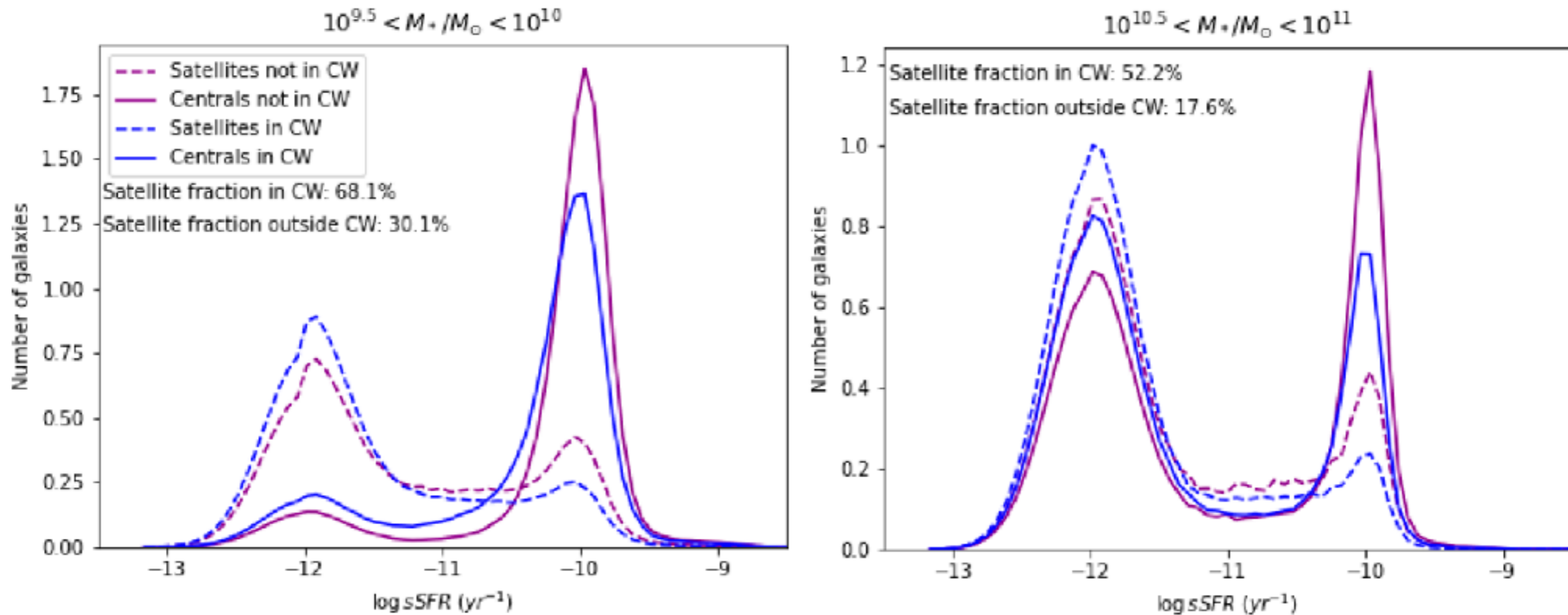
Non-web galaxies and haloes of all masses have nearly the same distribution of distance to the web as non-web dark matter

# Specific star formation rate distributions vs web distance



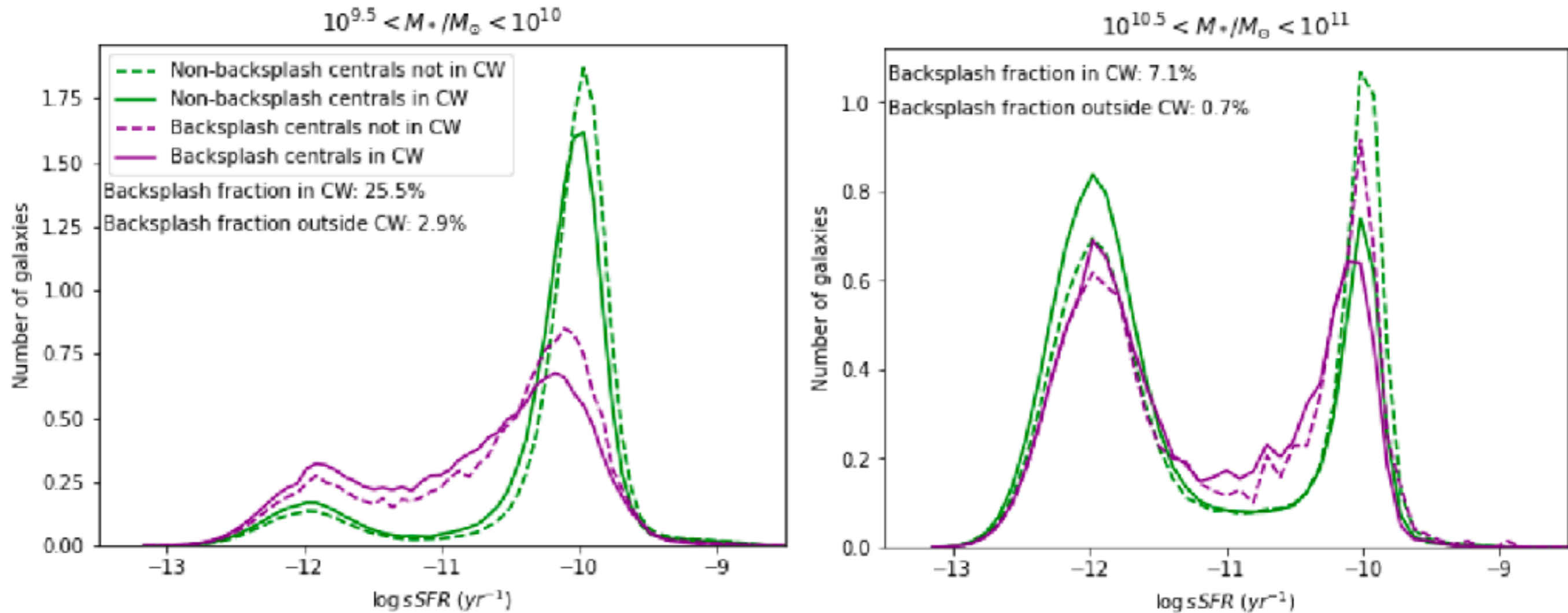
- The fraction of passive galaxies is greater in the cosmic web than outside it at all stellar masses
- For non-web galaxies the passive fraction is independent of distance from the cosmic web

# Satellite and central galaxy sSFR distributions



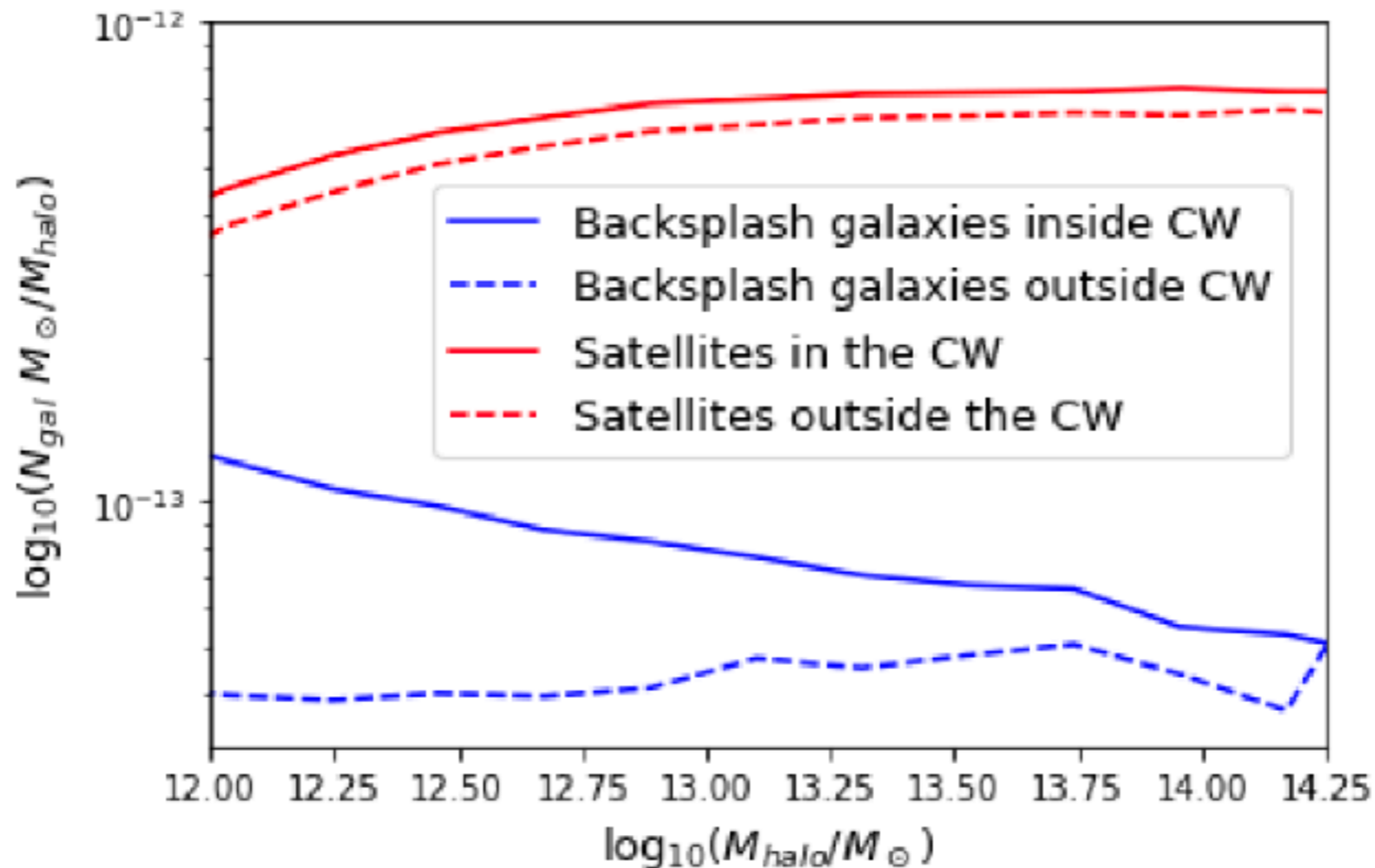
- The passive excess in the CW is mainly due to the satellite fraction being 2 to 3 times larger there
- Central galaxies in the web are more often passive than outside it

# sSFR distributions for backslash and non-backslash centrals



- Passive centrals in the web are often backslash galaxies which are much more frequent there

# Satellites and backsplash galaxies in and out of the web



- The number of satellites/unit halo mass with  $M_* > 10^{9.5} M_{\odot}$  is similar inside and outside the web
- The number of backsplash galaxies/unit halo mass is larger in the web than outside it
- Backsplash galaxies are more common in the web than outside it
- Satellites substantially outnumber backsplash galaxies everywhere.

# Conclusions

In the BW20 definition the cosmic web is the unique, fully connected, percolating object bounded by an equidensity surface with  $\rho/\bar{\rho} \sim 5$

- ★ It contains  $\sim 1/3$  of all mass and occupies  $\sim 0.5\%$  of all space
- ★ Every point in space and every object (DM particle, halo, galaxy) is either part of the web, or not
- ★ The halo fraction in the web goes from 20% at  $10^{11}M_{\odot}$  to 90% at  $10^{14}M_{\odot}$
- ★ The galaxy fraction in the web goes from 46% at  $10^9M_{\odot}$  to 90% at  $10^{11.5}M_{\odot}$
- ★ At every stellar mass, web galaxies are more likely to be passive; this is mostly because a larger fraction are satellite and backsplash galaxies
- ★ For non-web galaxies the distribution of stellar mass and sSFR is almost independent of distance to the web

These conclusions are specific to the BW20 web definition and may also be modified for a different (e.g. hydrodynamical) galaxy formation model