ELUCID: Exploring the Local Universe with re-Constructed Initial Density field

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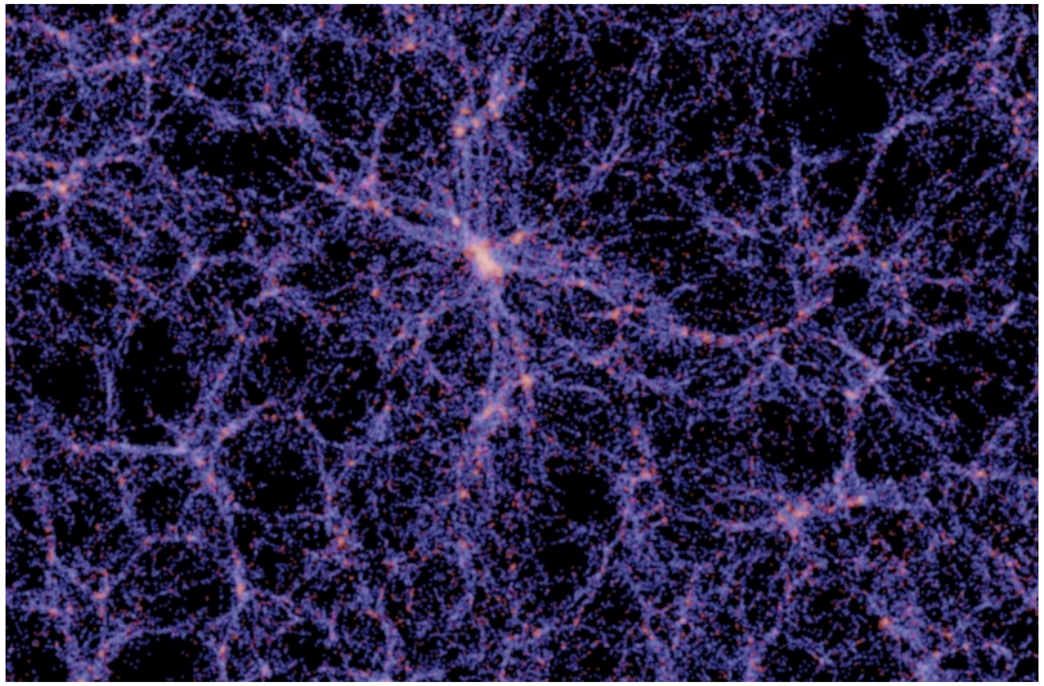
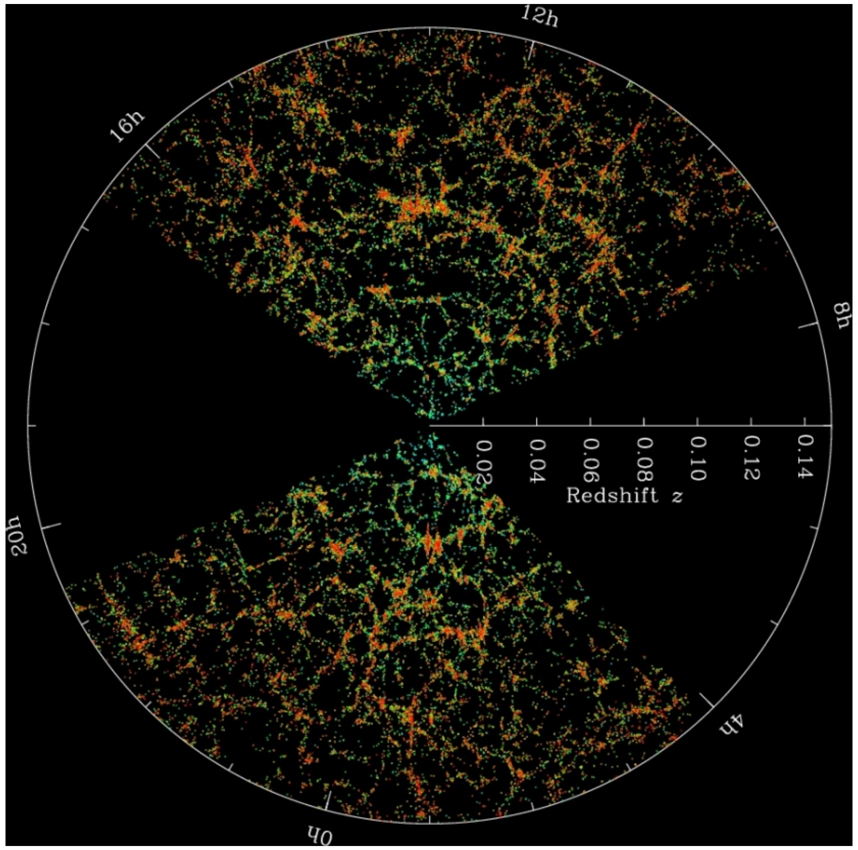
Motivation





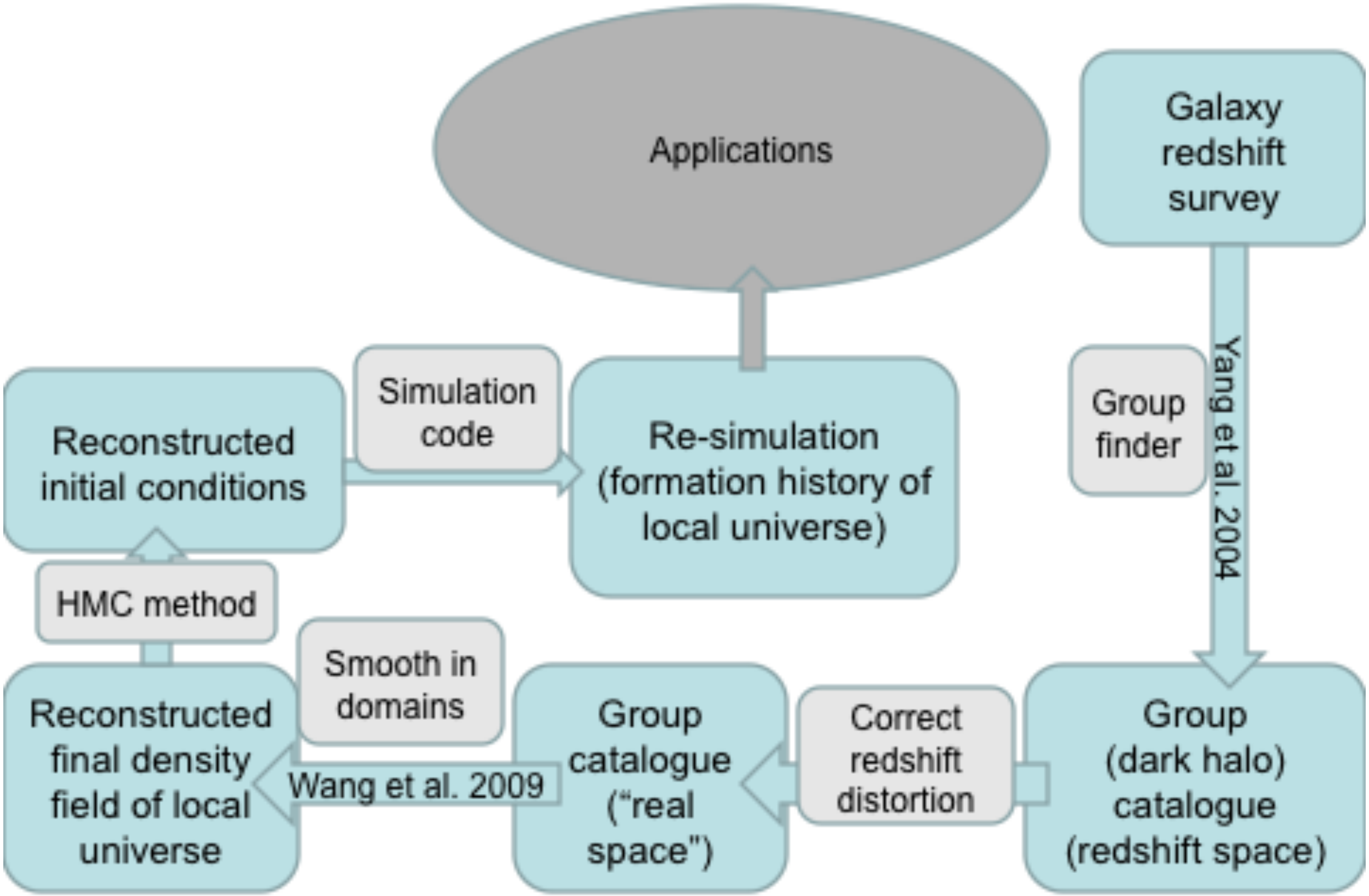
Shortcomings in comparing theory (simulations) with data in a statistical way:

(1) cosmic variance (environmental effects);

(2) only part of information is used.

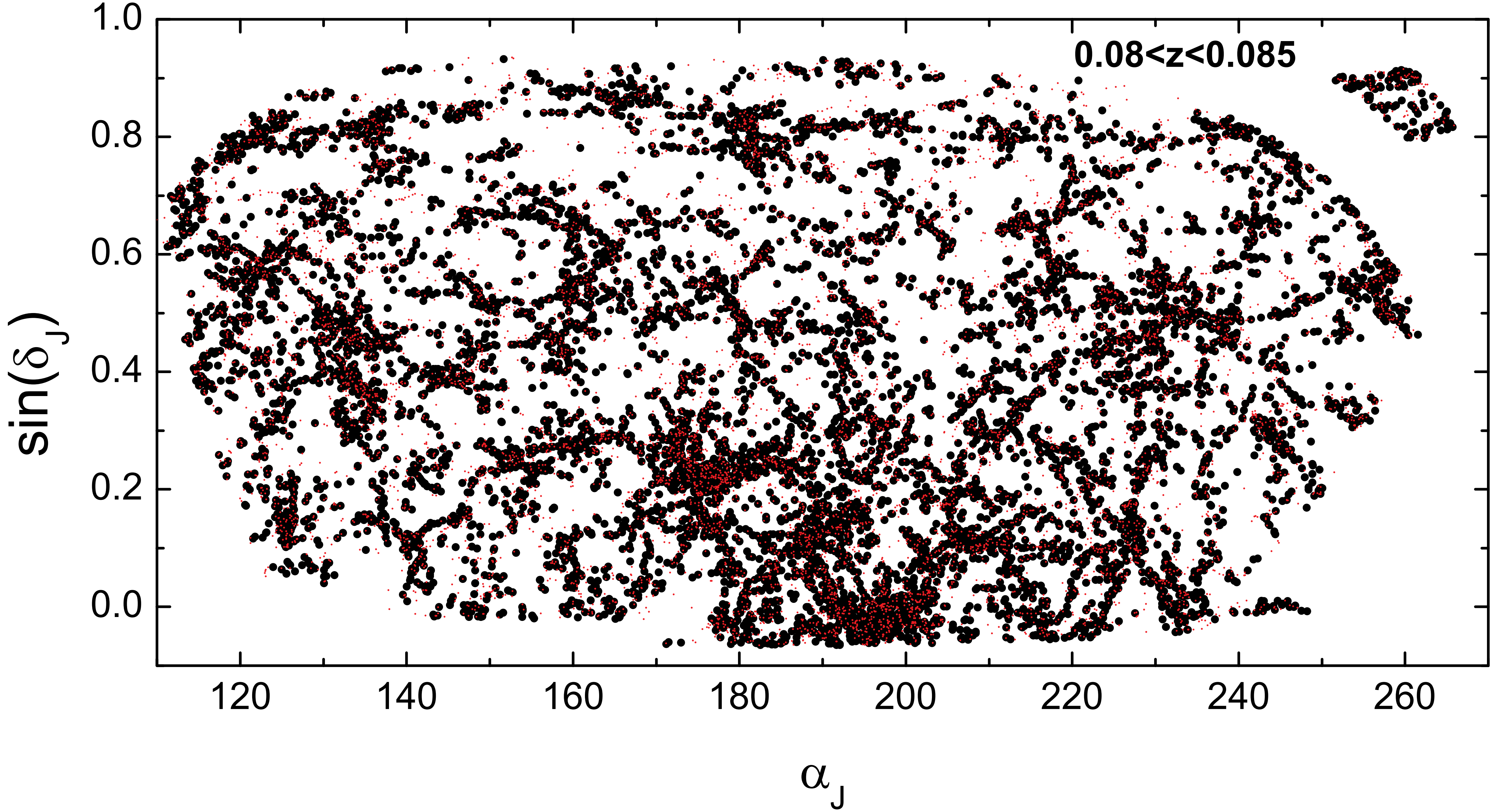
If we can accurately reconstruct the initial condition of the local Universe, we can compare data and theory 'directly'.

The ELUCID Project



Reconstruct the current density field using halos above a certain mass

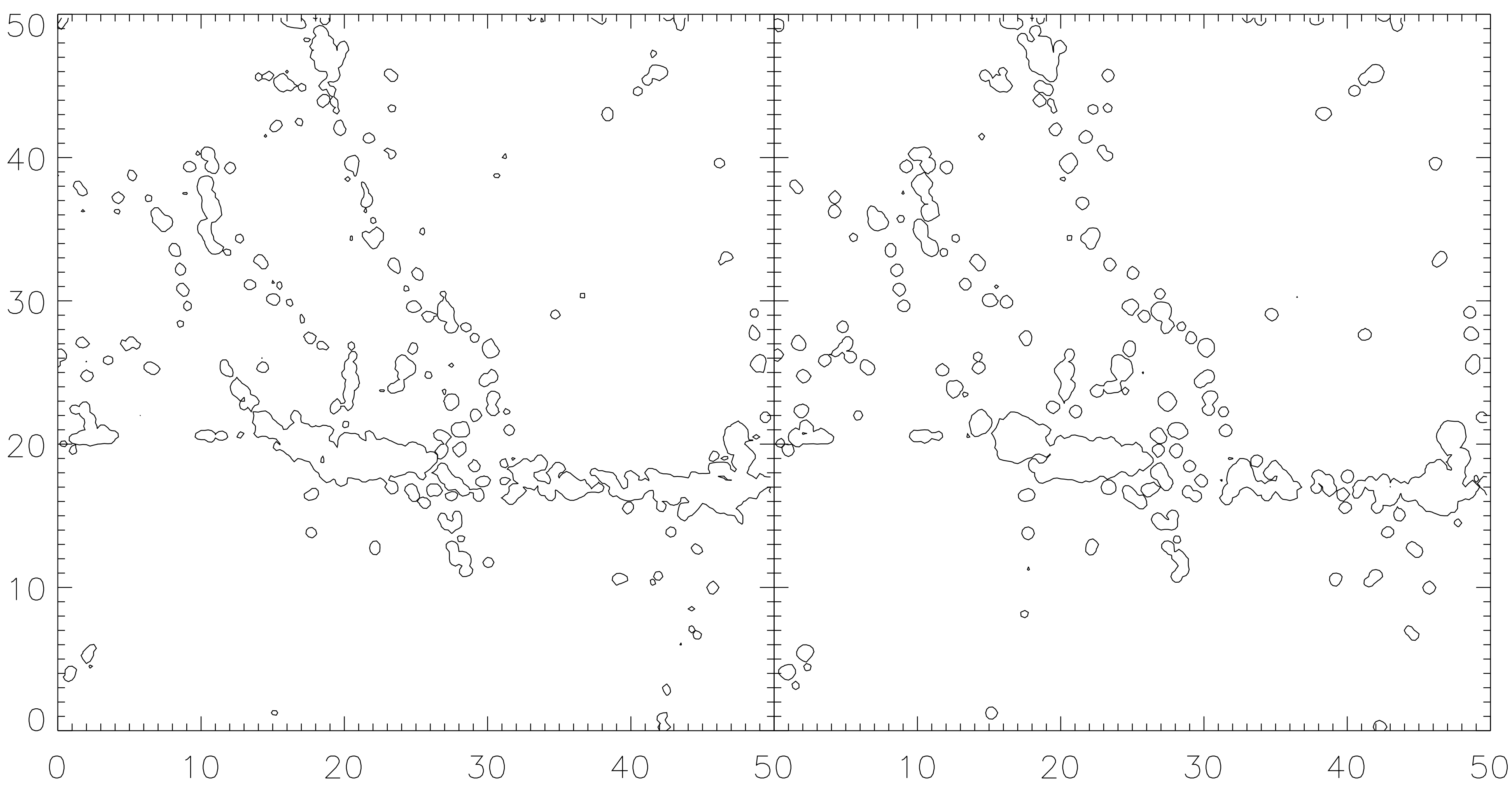
$M_{\rm th} = 10^{12} h^{-1} \mathrm{M}_{\odot}$ limited by SDSS redshift survey



Method:

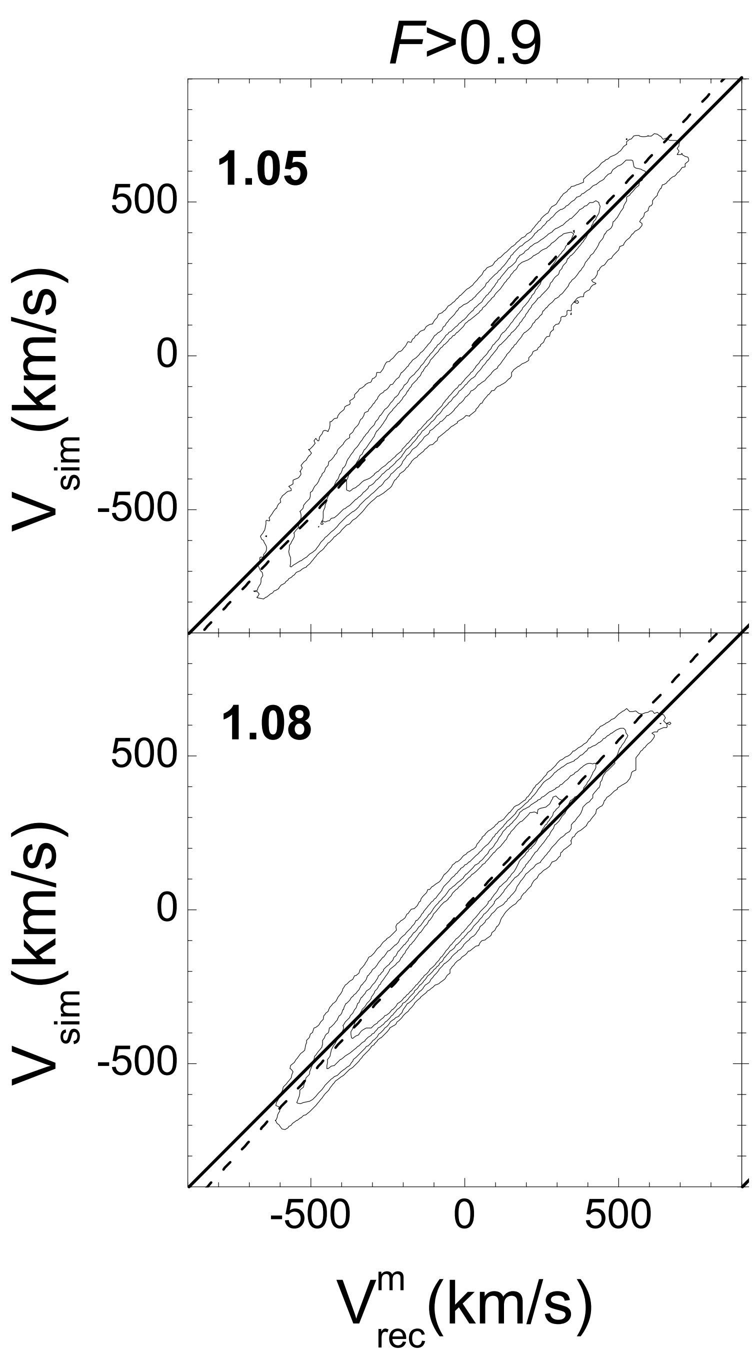
(1) Each point in space is assigned to its nearest halo according to distance scaled by halo virial radius;

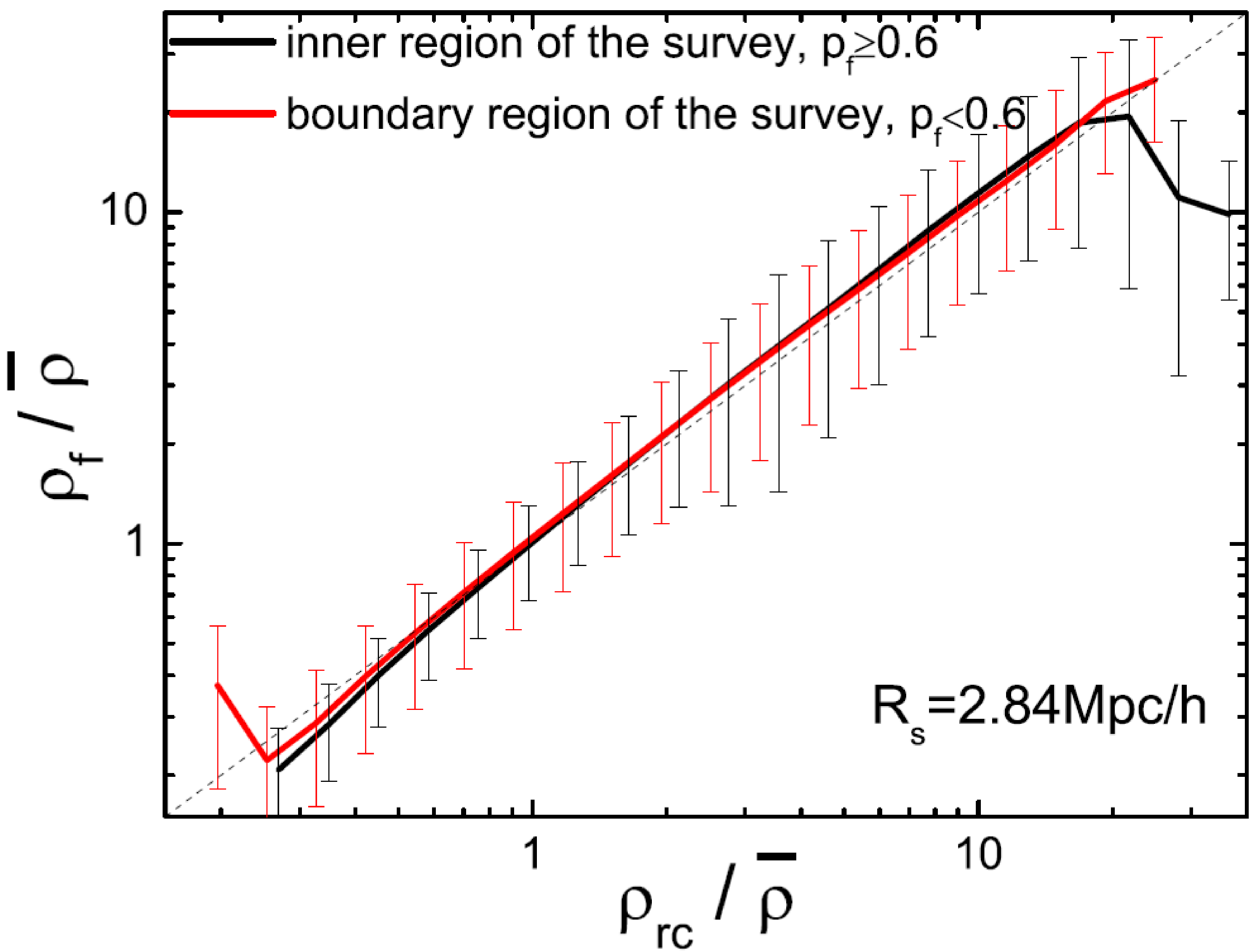
(2) The density at the point is given by the cross-correlation between halos and mass given by the chosen cosmological model.



Test with mock catalogs

simulation + halo occupation + SDSS selection function + redshift space + group finder





Reconstructing the initial density field

From $\rho_{\mathrm{f}}(\mathbf{x})$ to $\delta_j(\mathrm{k})$

$$Q(\delta_j(\mathbf{k})|\rho_{\mathrm{f}}(\mathbf{x})) = \mathrm{e}^{-\sum_{\mathbf{x}}[\rho_{\mathrm{mod}}(\mathbf{x})-\rho_{\mathrm{f}}(\mathbf{x})]^2\omega(\mathbf{x})/2\sigma_{\mathrm{f}}^2(\mathbf{x})} \prod_{\mathbf{k}}^{\mathrm{half}} \prod_{j=0}^{1} \frac{1}{[\pi P_{\mathrm{lin}}(k)]^{1/2}} \mathrm{e}^{-[\delta_j(\mathbf{k})]^2/P_{\mathrm{lin}}(k)}$$

(likelihood)

(prior)

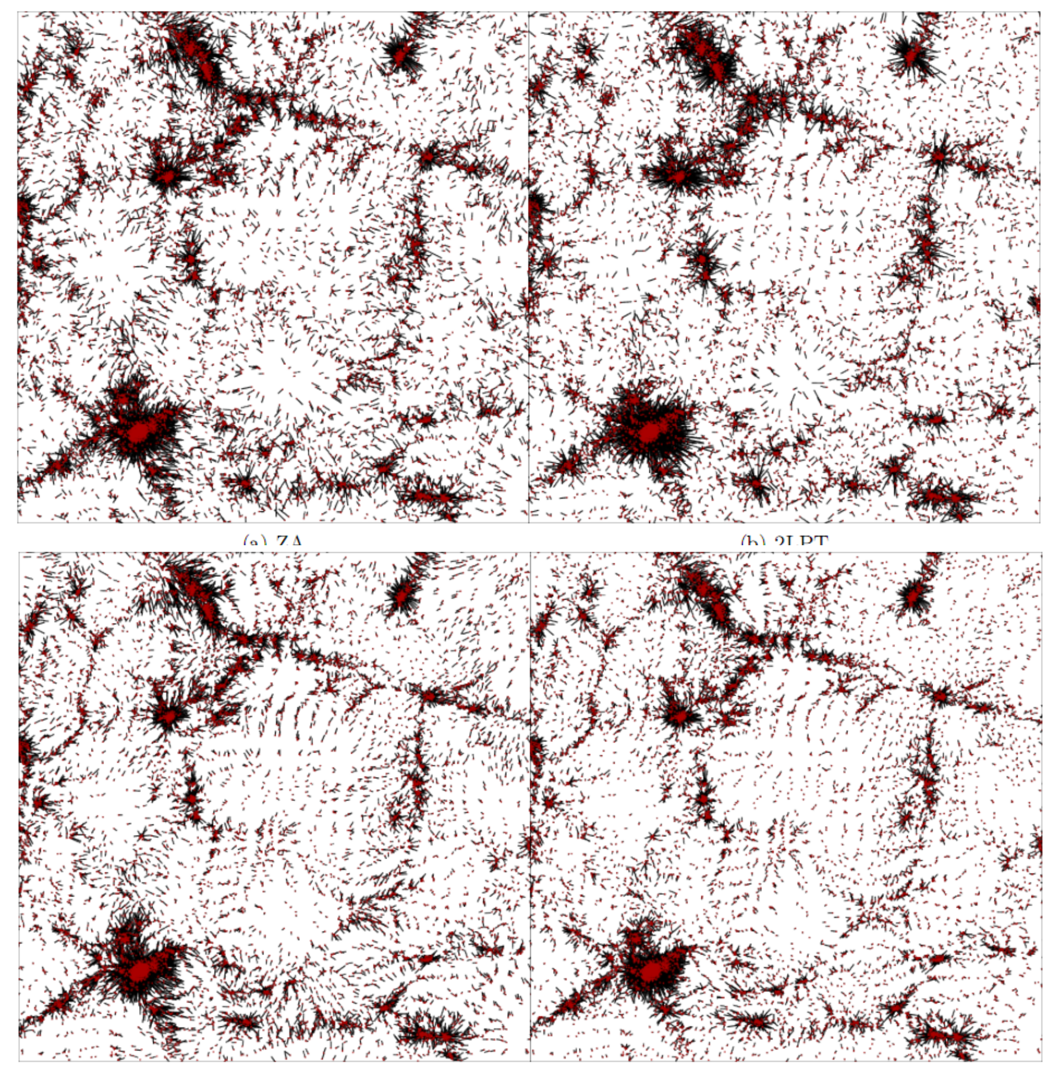
From $\delta_j(\mathrm{k})$ to $\rho_{\mathrm{mod}}(\mathbf{x})$

Modified Zel'dovich approximation

$$Q(\boldsymbol{k},\eta) = R_Q(k,\eta)Q_\star(\boldsymbol{k},\eta) + Q_{MC}(\boldsymbol{k},\eta)$$

$$R_Q(k,\eta) = \frac{\langle Q(\boldsymbol{k},\eta)Q_\star^*(\boldsymbol{k},\eta)\rangle}{\langle Q_\star(\boldsymbol{k},\eta)Q_\star^*(\boldsymbol{k},\eta)\rangle}$$

Tassev & Zaldarriaga 2012



(c) ZA with transfer function

(d) 2LPT with transfer functions

Hamiltonian Markov Chain Monte Carlo method

In this subsection, we briefly outline the HMC method (see Hanson 2001; Taylor et al. 2008; JW12 for some more detailed descriptions). The method is itself based on an analogy to solving a physical system in Hamiltonian dynamics. As a first step, we define the potential of the system to be the negative of the logarithm of the target probability distribution,

$$\begin{aligned}\psi[\delta_j(\mathbf{k})] &\equiv -\ln[Q(\delta_j(\mathbf{k})|\rho_{\mathrm{f}}(\mathbf{x}))] \\ &= \sum_{\mathbf{k}}^{\mathrm{half}} \ln[\pi P_{\mathrm{lin}}(k)] + \sum_{\mathbf{k}}^{\mathrm{half}} \sum_{j=0}^{1} \frac{[\delta_j(\mathbf{k})]^2}{P_{\mathrm{lin}}(k)} + \sum_{\mathbf{x}} \frac{[\rho_{\mathrm{mod}}(\mathbf{x}) - \rho_{\mathrm{f}}(\mathbf{x})]^2 \omega(\mathbf{x})}{2\sigma_{\mathrm{f}}^2(\mathbf{x})} .\end{aligned} \tag{4}$$

For each $\delta_j(\mathbf{k})$, a momentum variable, $p_j(\mathbf{k})$, and a mass variable, $m_j(\mathbf{k})$, are introduced. The Hamiltonian of the fictitious system can then be written as

$$H = \sum_{\mathbf{k}}^{\mathrm{half}} \sum_{j=0}^{1} \frac{p_j^2(\mathbf{k})}{2m_j(\mathbf{k})} + \psi[\delta_j(\mathbf{k})] . \tag{5}$$

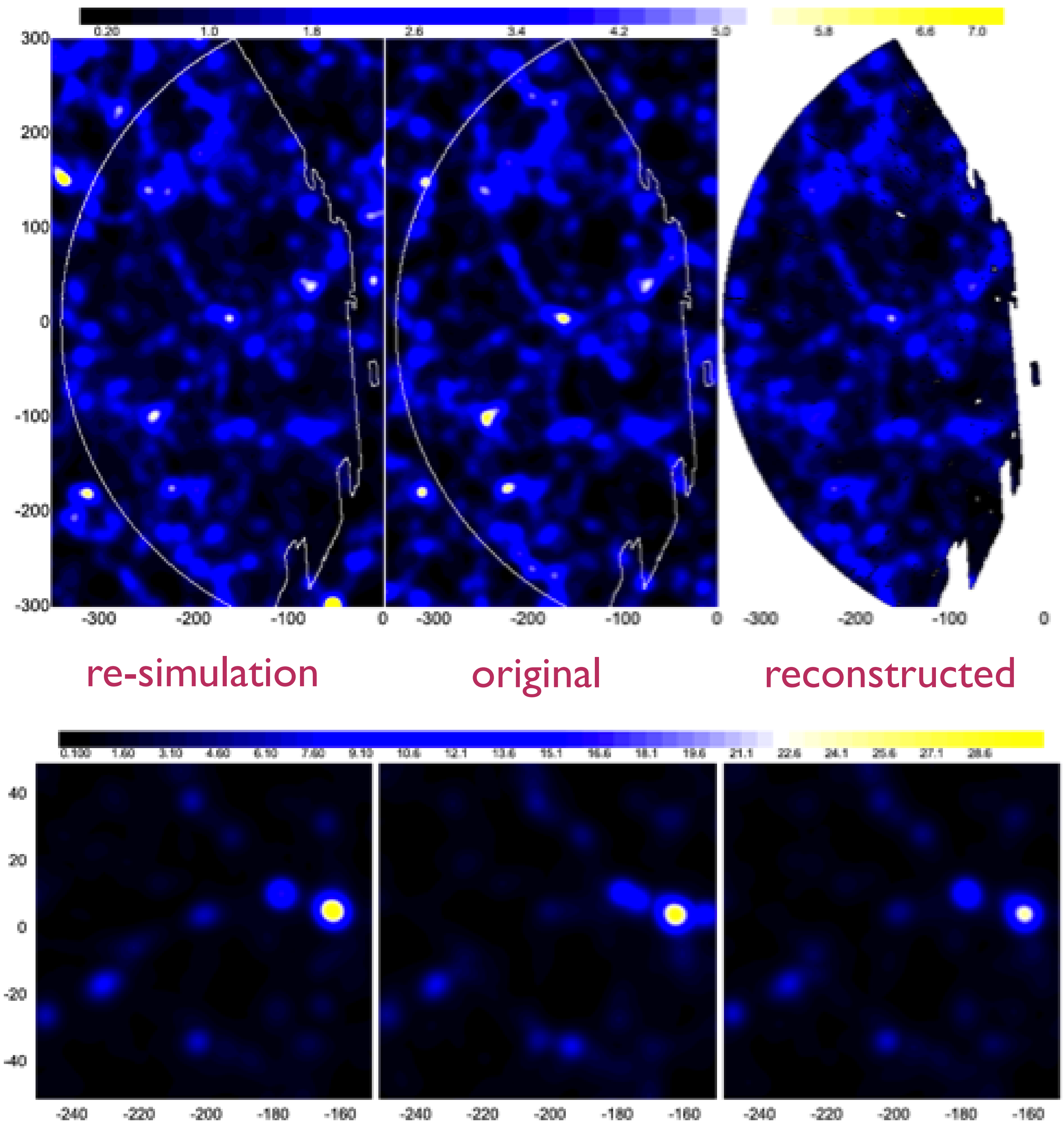
The statistical properties of the system is given by the partition function, $\exp(-H)$, which can be separated into a Gaussian distribution in momenta $p_j(\mathbf{k})$ multiplied by the target distribution,

$$\exp(-H) = Q[\delta_j(\mathbf{k})|\rho_{\mathrm{f}}(\mathbf{x})] \prod_{\mathbf{k}}^{\mathrm{half}} \prod_{j=0}^{1} \mathrm{e}^{-\frac{p_j^2(\mathbf{k})}{2m_j(\mathbf{k})}} . \tag{6}$$

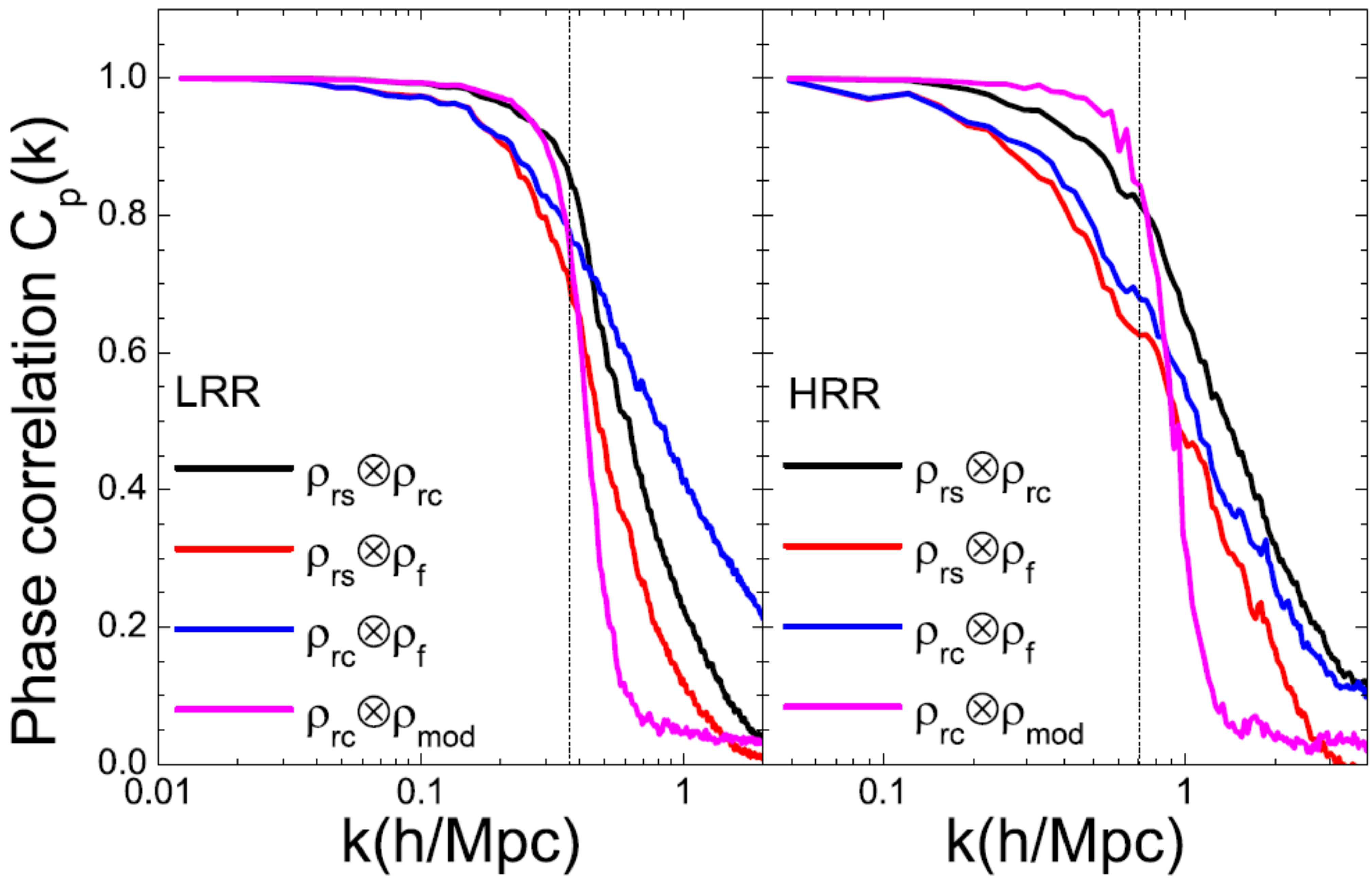
Thus, the target probability distribution can be obtained by first sampling this partition function and then marginalizing over momenta (i.e setting all the momenta to be zero).

Test with SDSS Mock Catalogs

Final density field reconstructed from mock group catalog as input

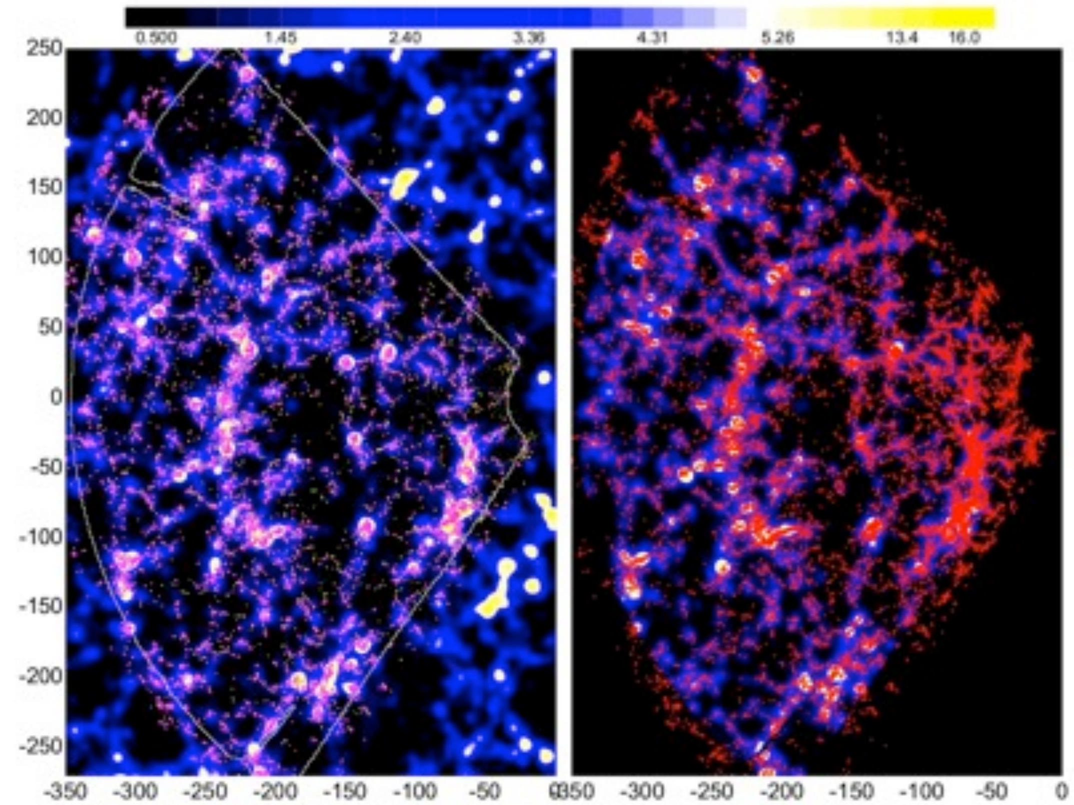


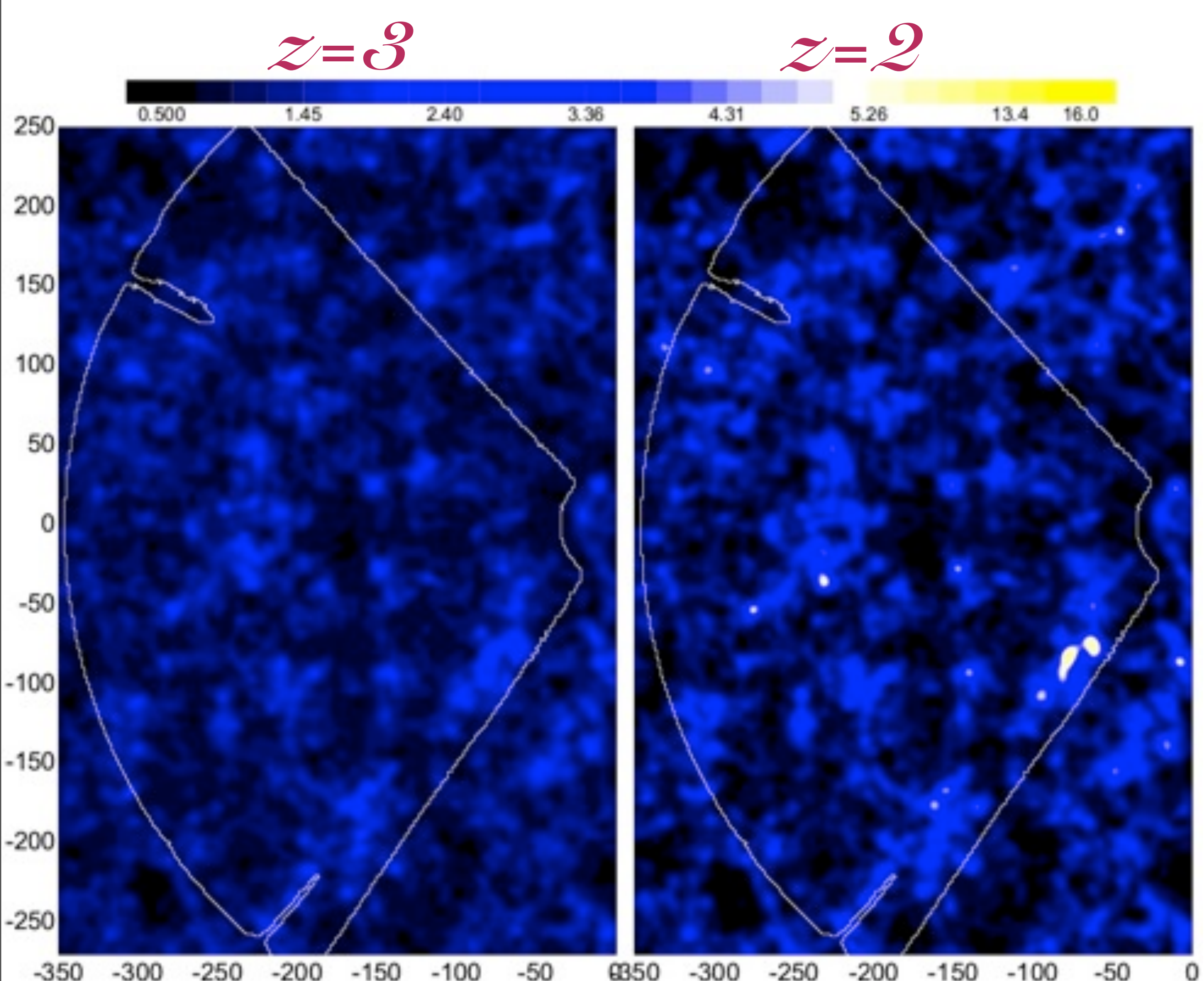
Phase correlation

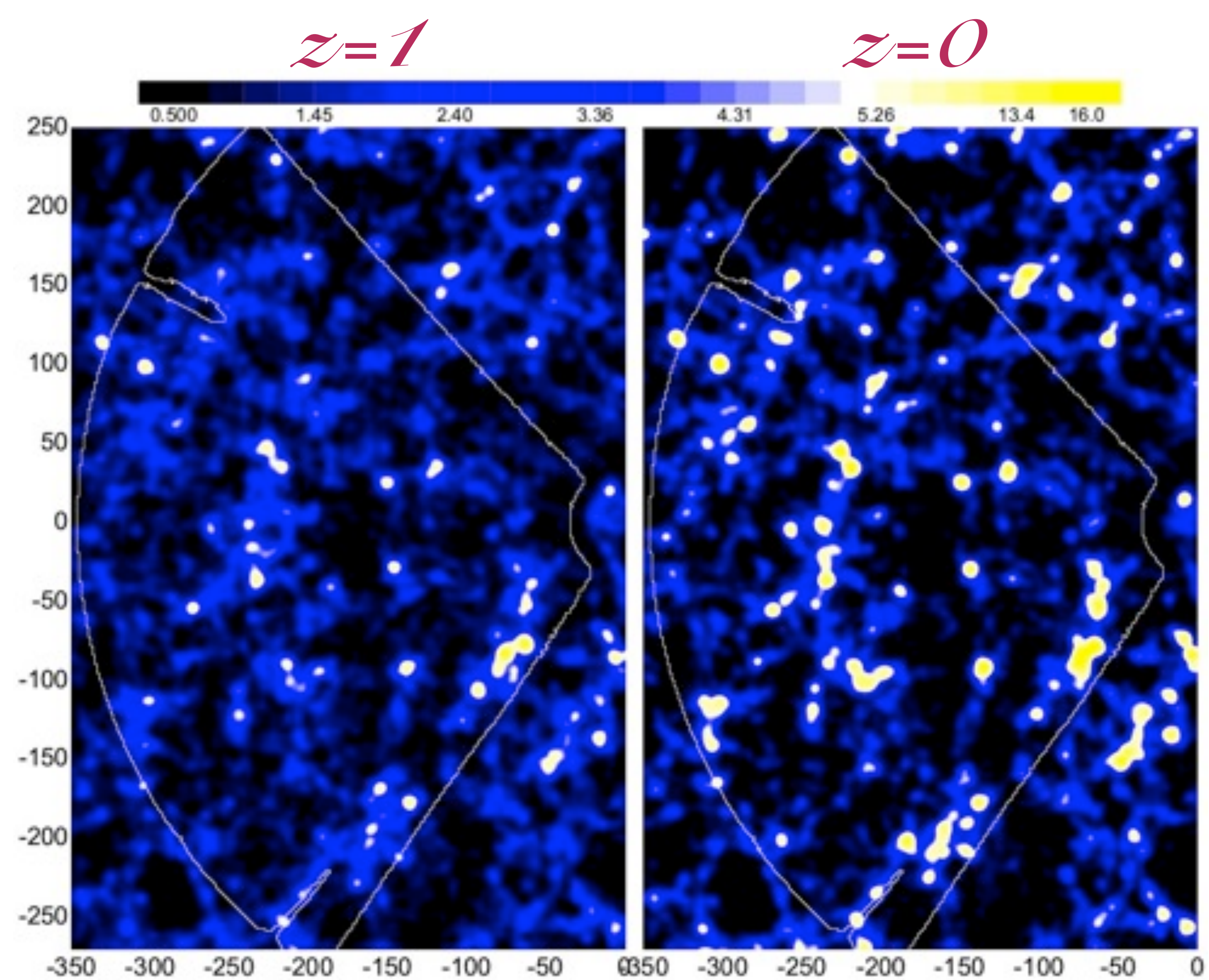


Application to SDSS

The Great Wall Region

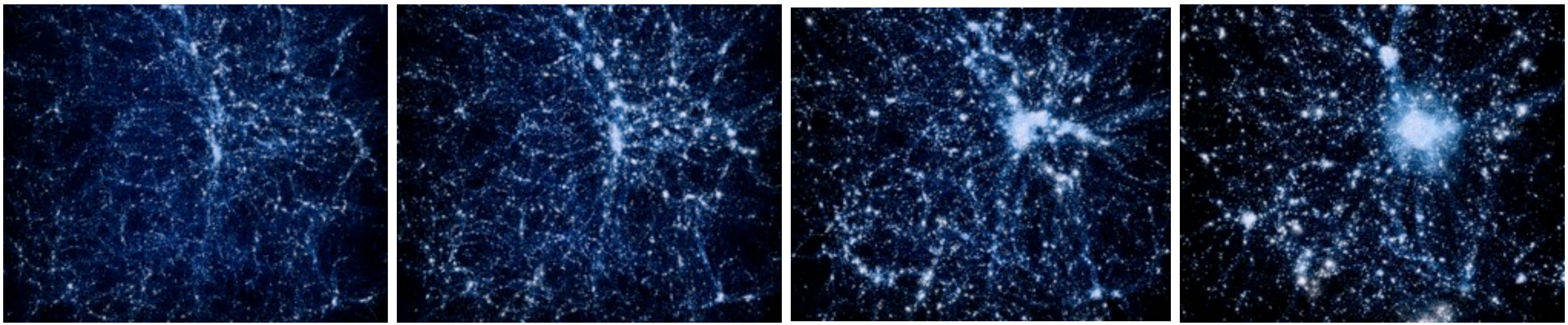


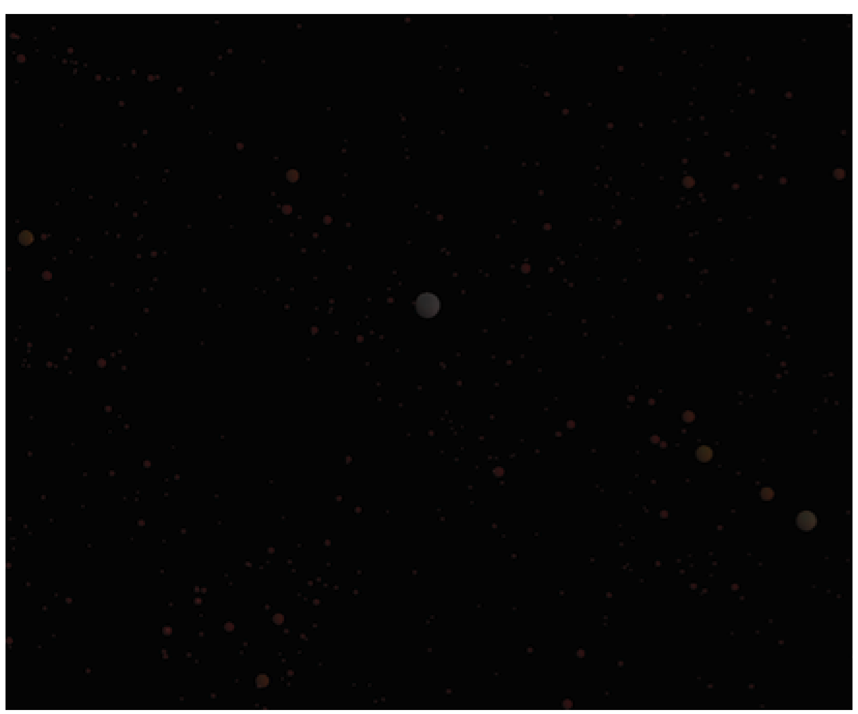


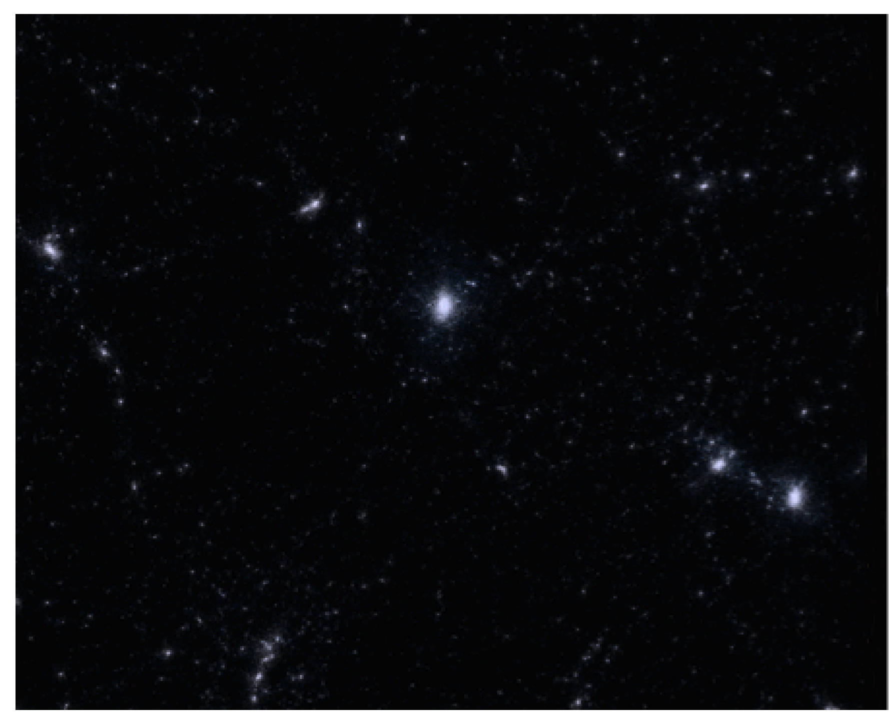


Formation of Coma Cluster

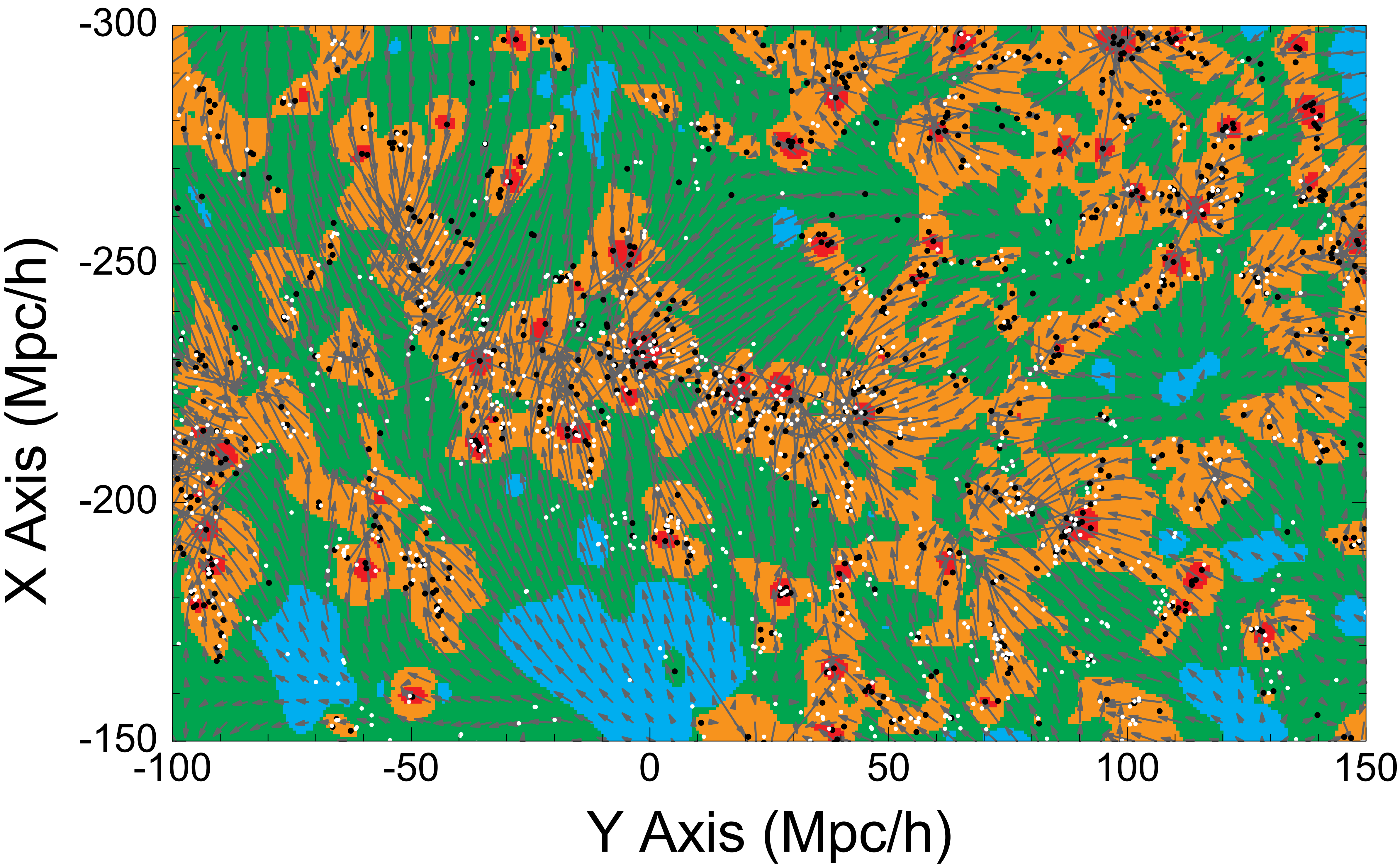
z=3 *z=2* *z=1* *z=0*



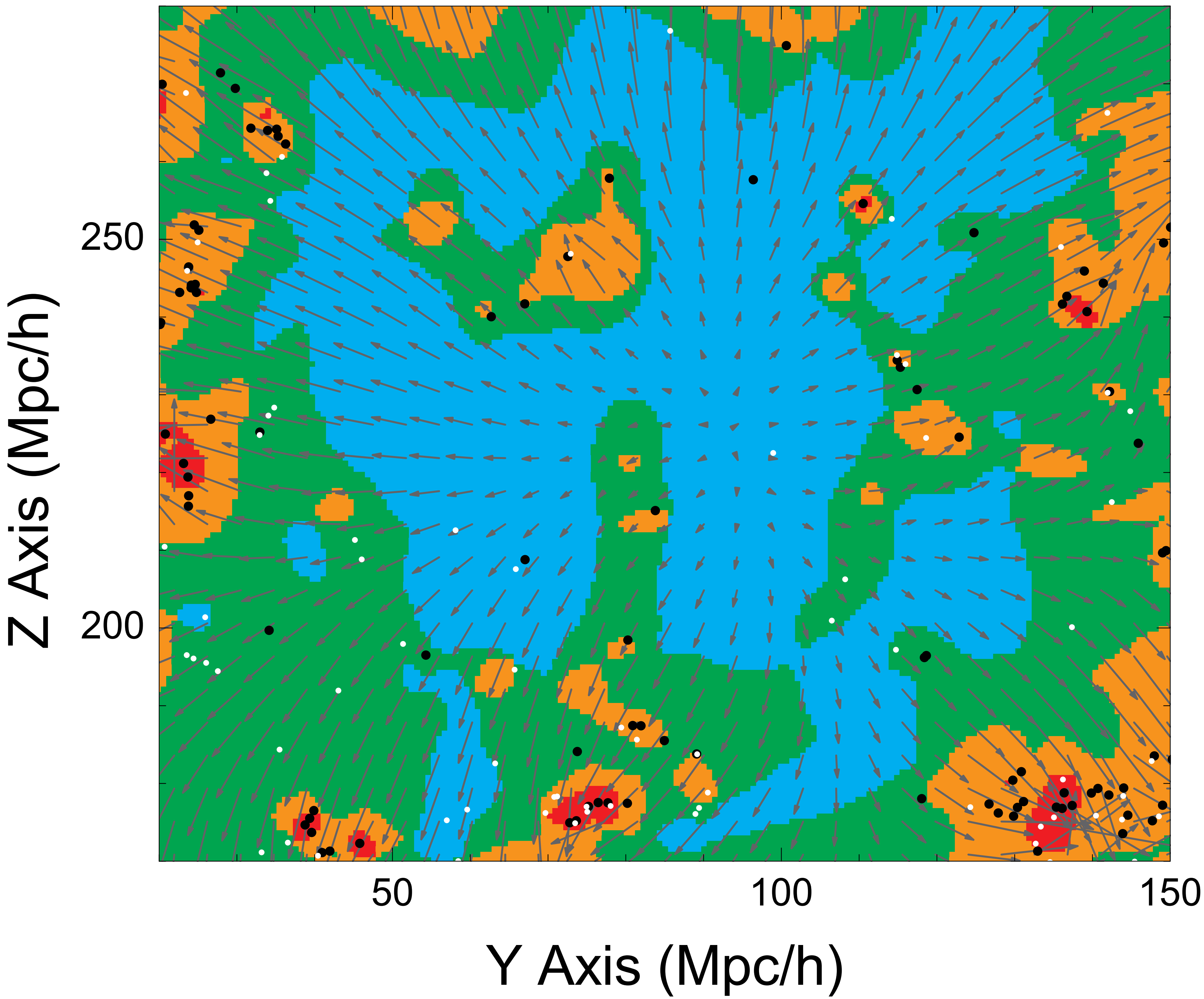




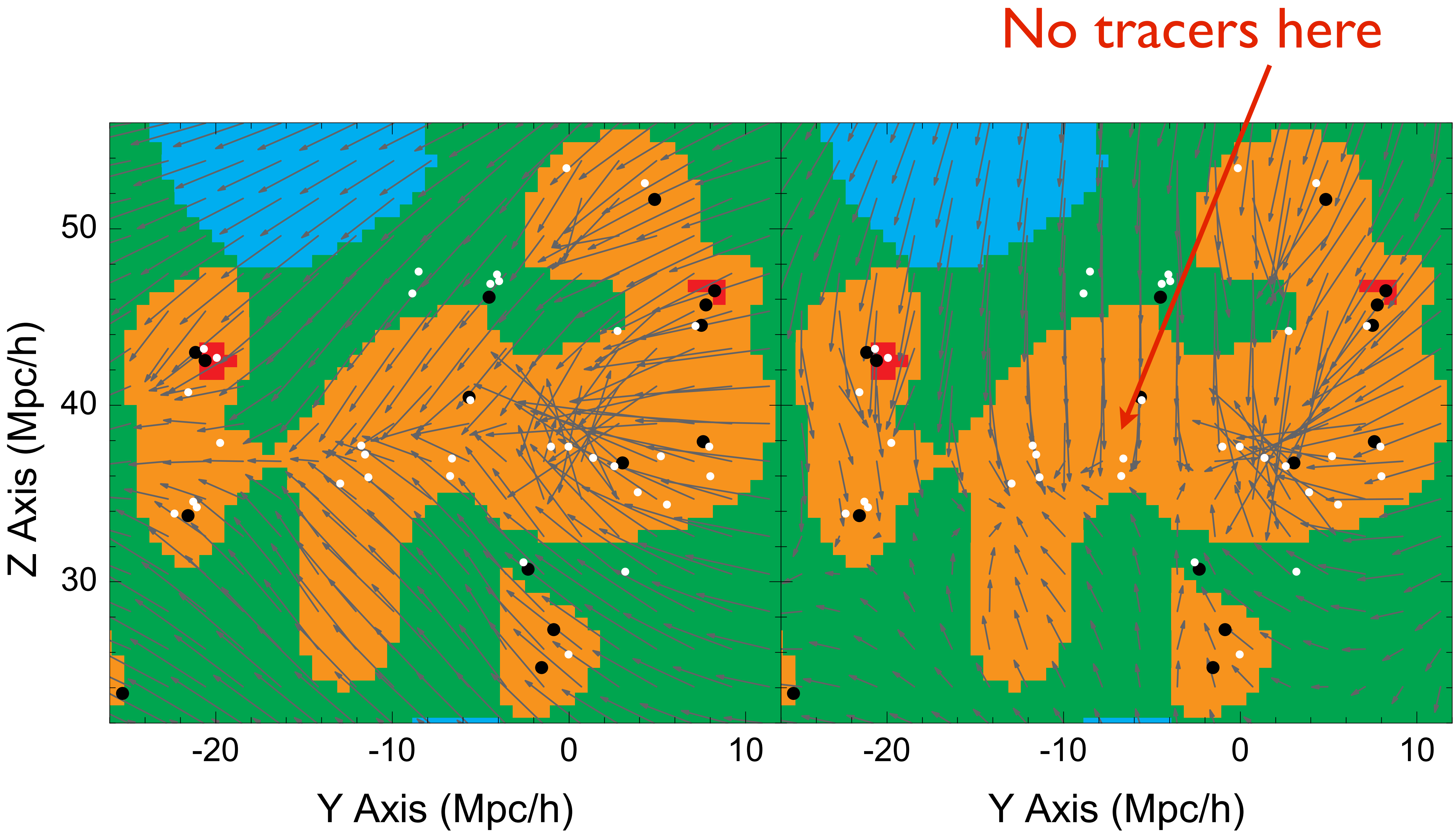
Velocity field



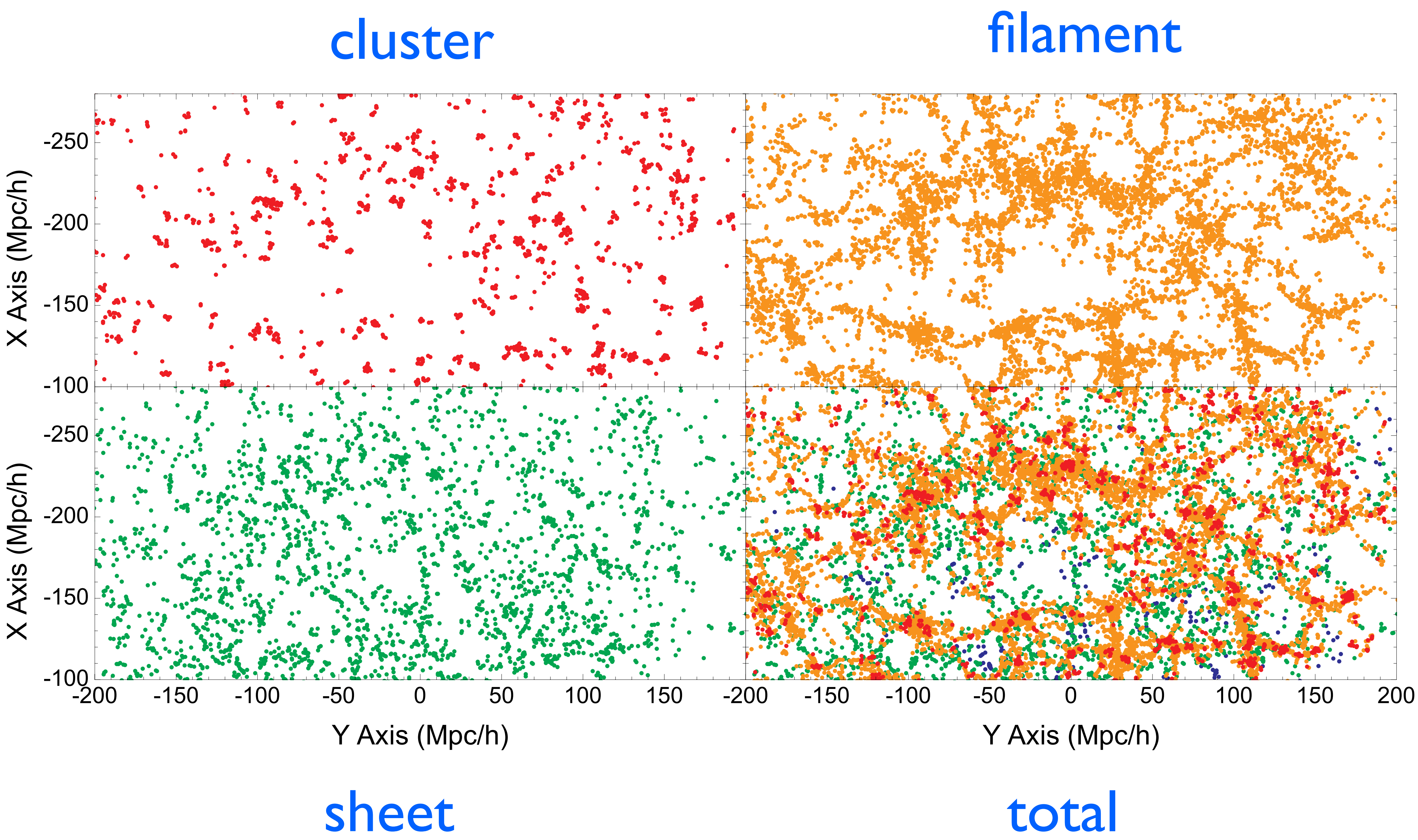
In a void region



Coherent motion



Classification based on eigenvalues of tidal tensor



Summary

- For a given cosmology, galaxy groups identified from local large redshift surveys can be used to reconstruct the initial density field.
- Simulations with such initial conditions allow us to trace the evolution of the local universe.
- Possible applications: large-scale environments of SDSS galaxies; cosmic variance in the constrained simulations; halo merger trees for galaxy formation model; gas simulations of large-scale structure, etc