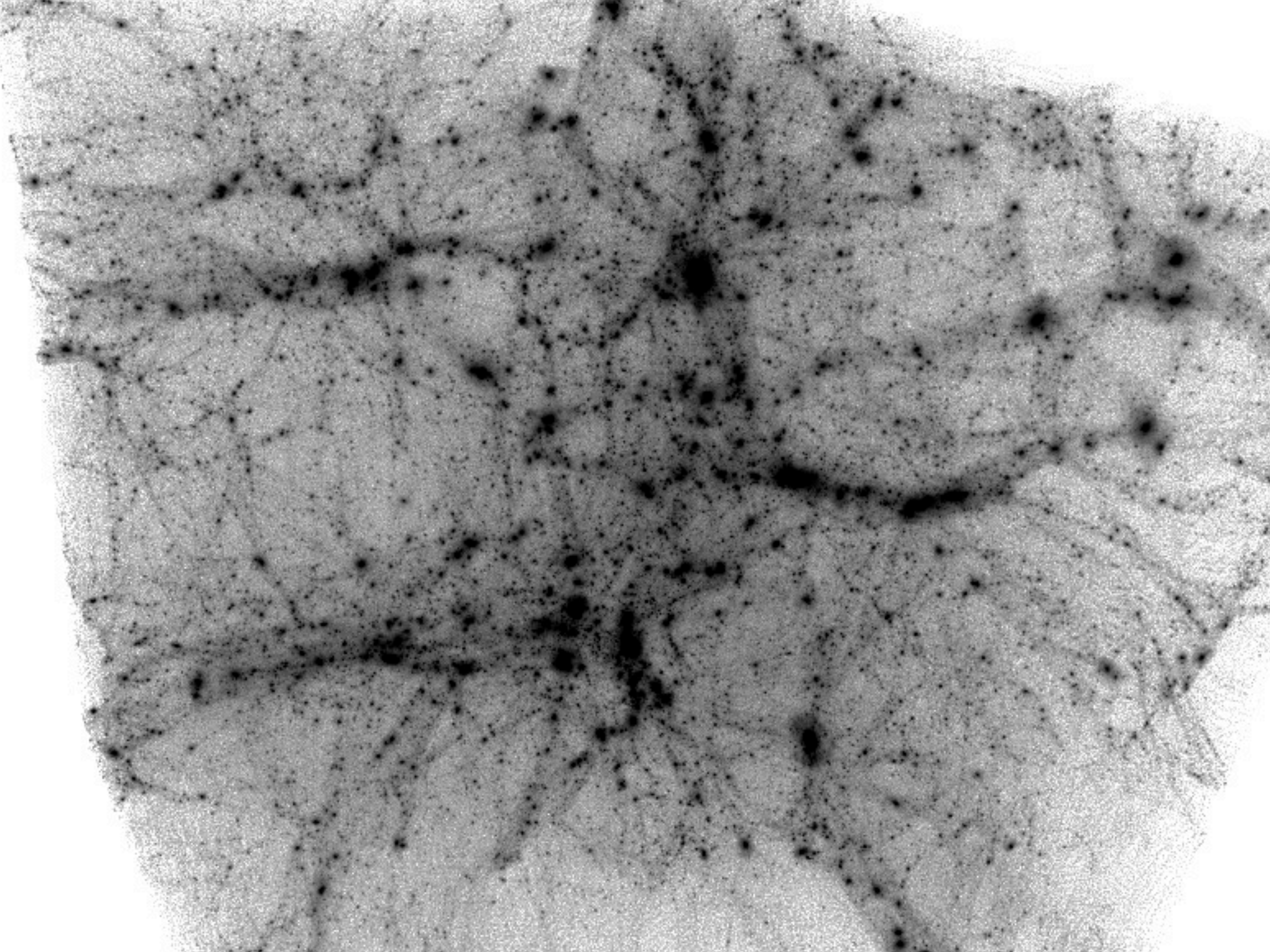
Dark Matter Dynamics

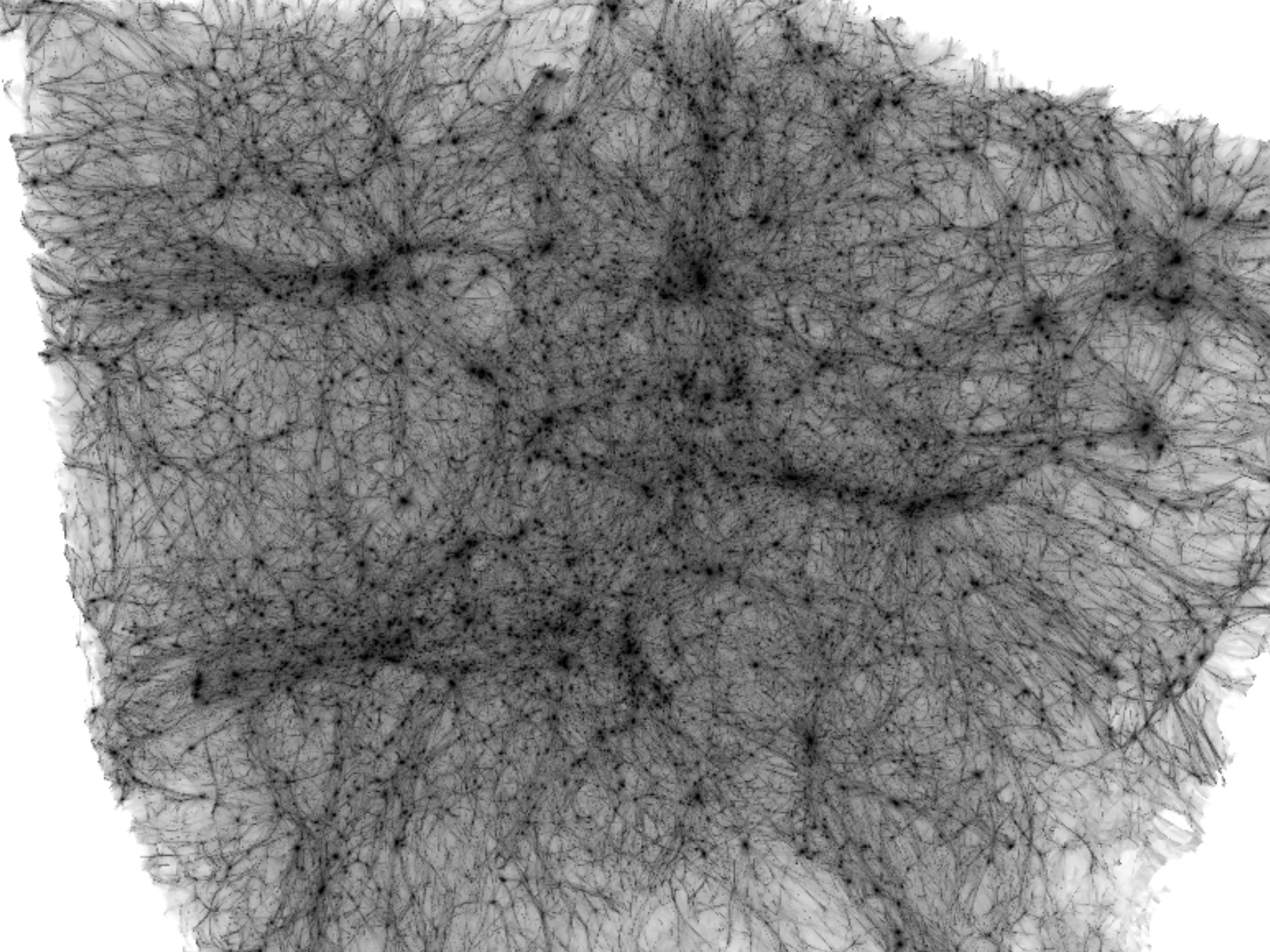
Tom Abel (KIPAC)

Abel, Hahn, Kaehler 2011 (Analysis)
Kaehler, Hahn, Abel 2012 (Visualization)
Hahn, Abel & Kaehler 2012 (Simulation)
Angulo, Hahn & Kaehler (2013) (WDM)
Angulo, Chen, Hilbert, Abel (2013) (Lensing in prep.)
Hahn, Angulo, Abel (2013) (Velocity PS in prep.)

KIPAC

SLAC NATIONAL ACCELERATOR LABORATORY





Mass “between” particles

Mass @ particles

Application to same N-body data

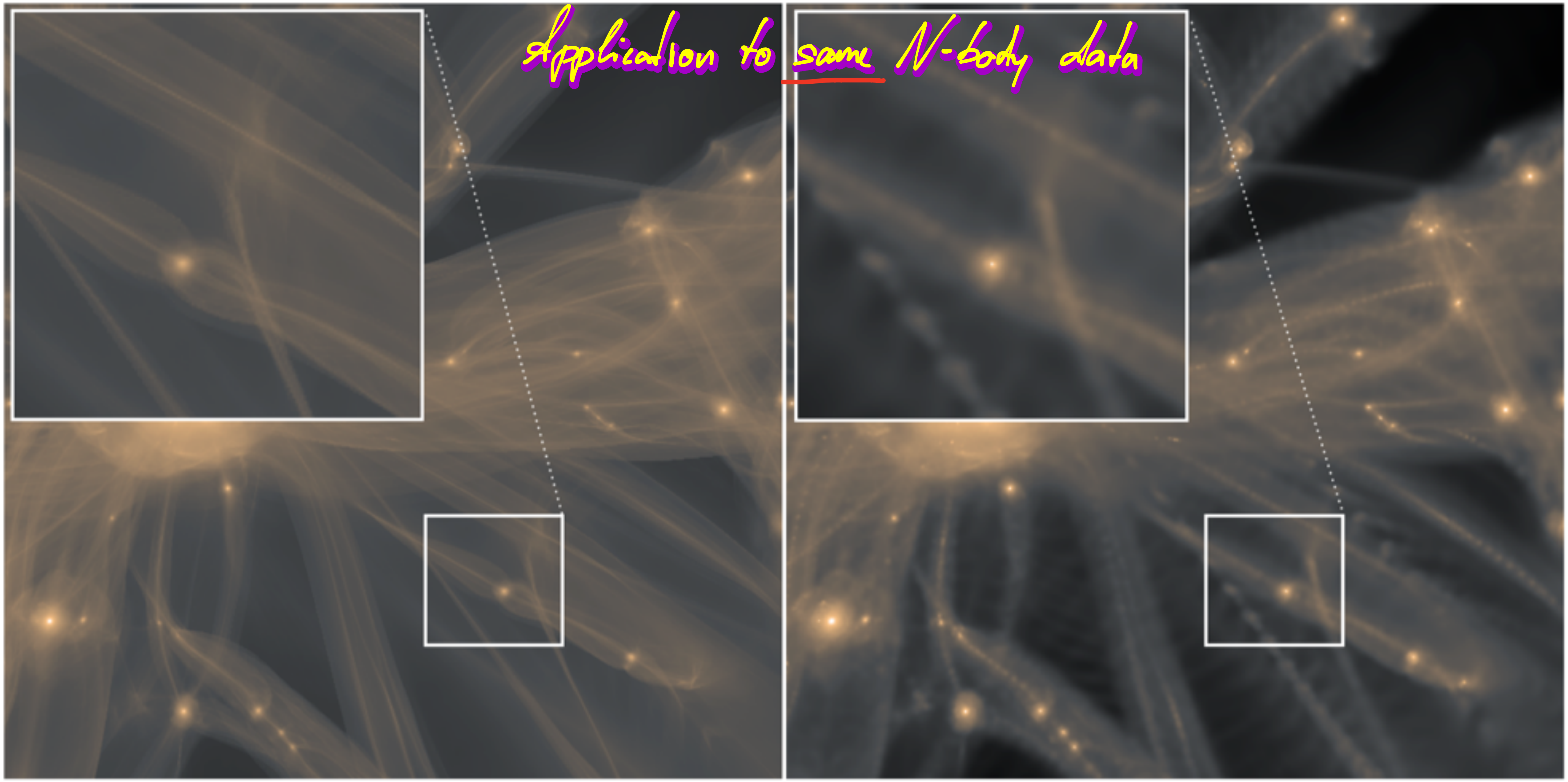


Fig. 9. A direct comparison between our tetrahedral cell-projection approach (left) and a standard SPH adaptive kernel smoothing method. Artifacts due to the poor density estimates in low-density regions are obvious for the SPH method, whereas the tetrahedral approach achieves an overall high image quality, on small and large structures.

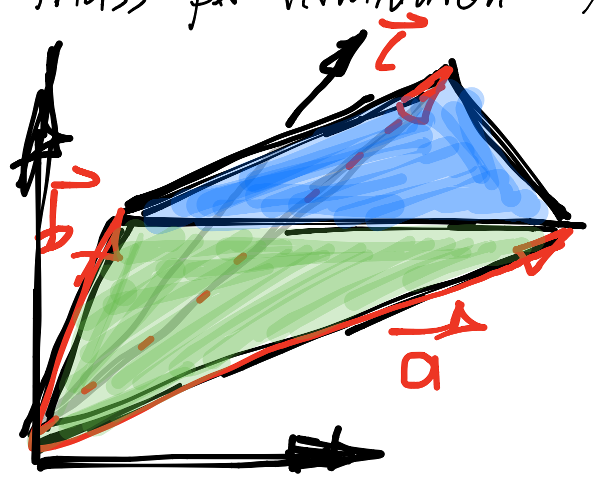
New approach gives exact densities
Recovers all caustics

Adaptive Kernel smoothing shows a number of unphysical clumps

ABEL, HAHN & KAEHLER 2011
KAEHLER, HAHN & ABEL 2012

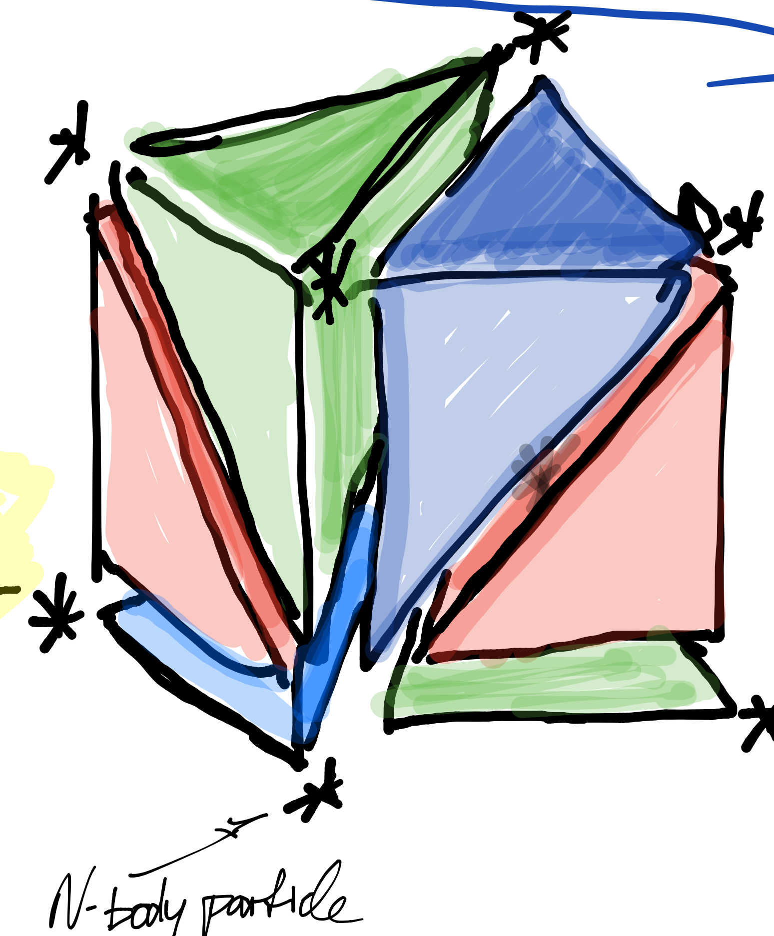
3 dimensional manifold in 6D Phase Space

- Natural tessellation takes unit cube & splits it into six equal size tetrahedra.
- mass per tetrahedron = 1/6 of DM particle mass.

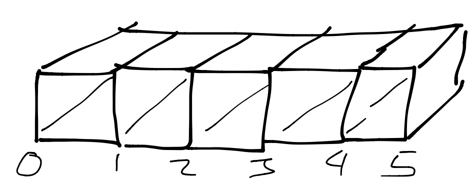


$$V = \frac{|\vec{a}\cdot(\vec{b}\times\vec{c})|}{6}$$

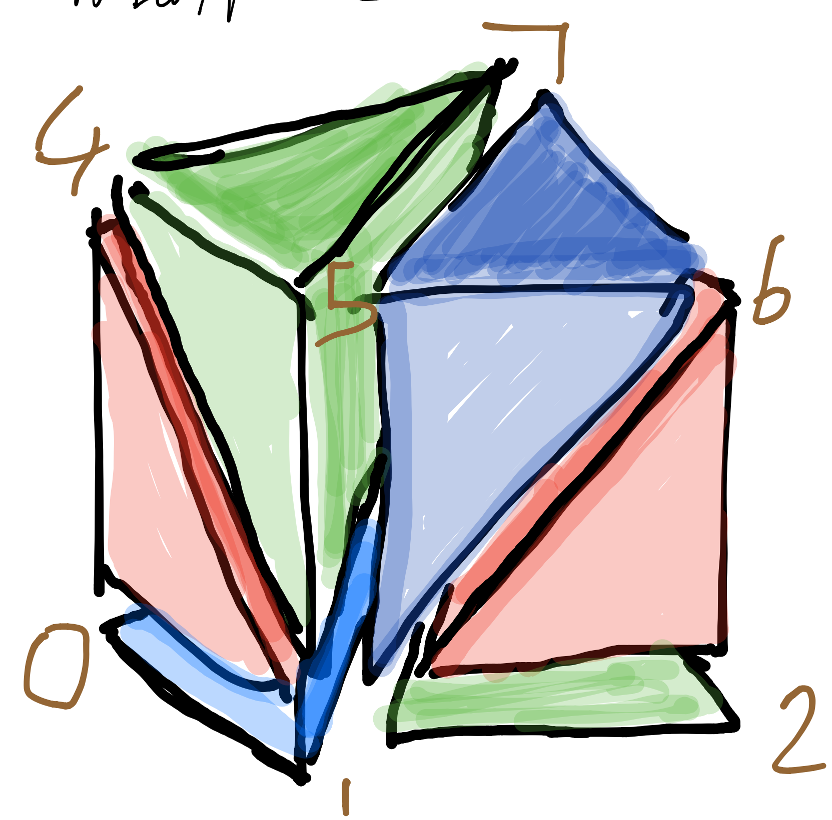
$$\Rightarrow \rho = \frac{m_p}{6V} = \frac{m_p}{|\vec{a}\cdot(\vec{b}\times\vec{c})|}$$



- Number the edges of the cube
- think of lattice

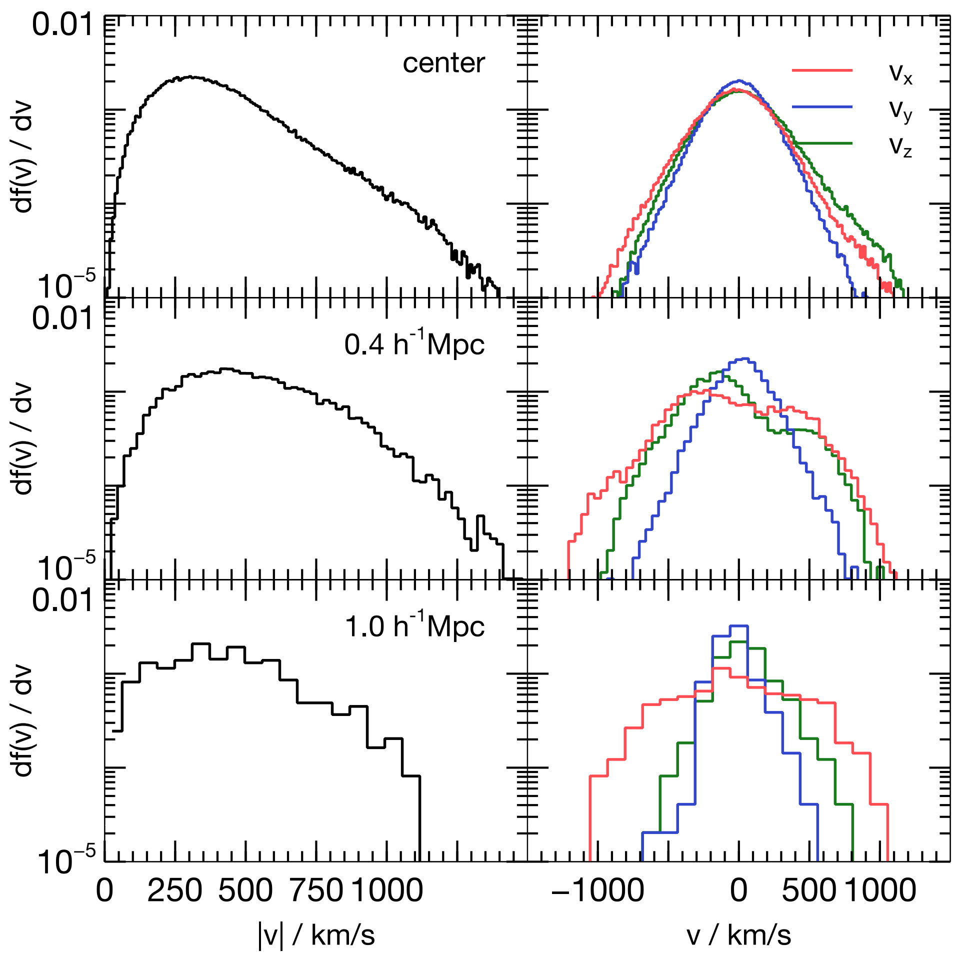


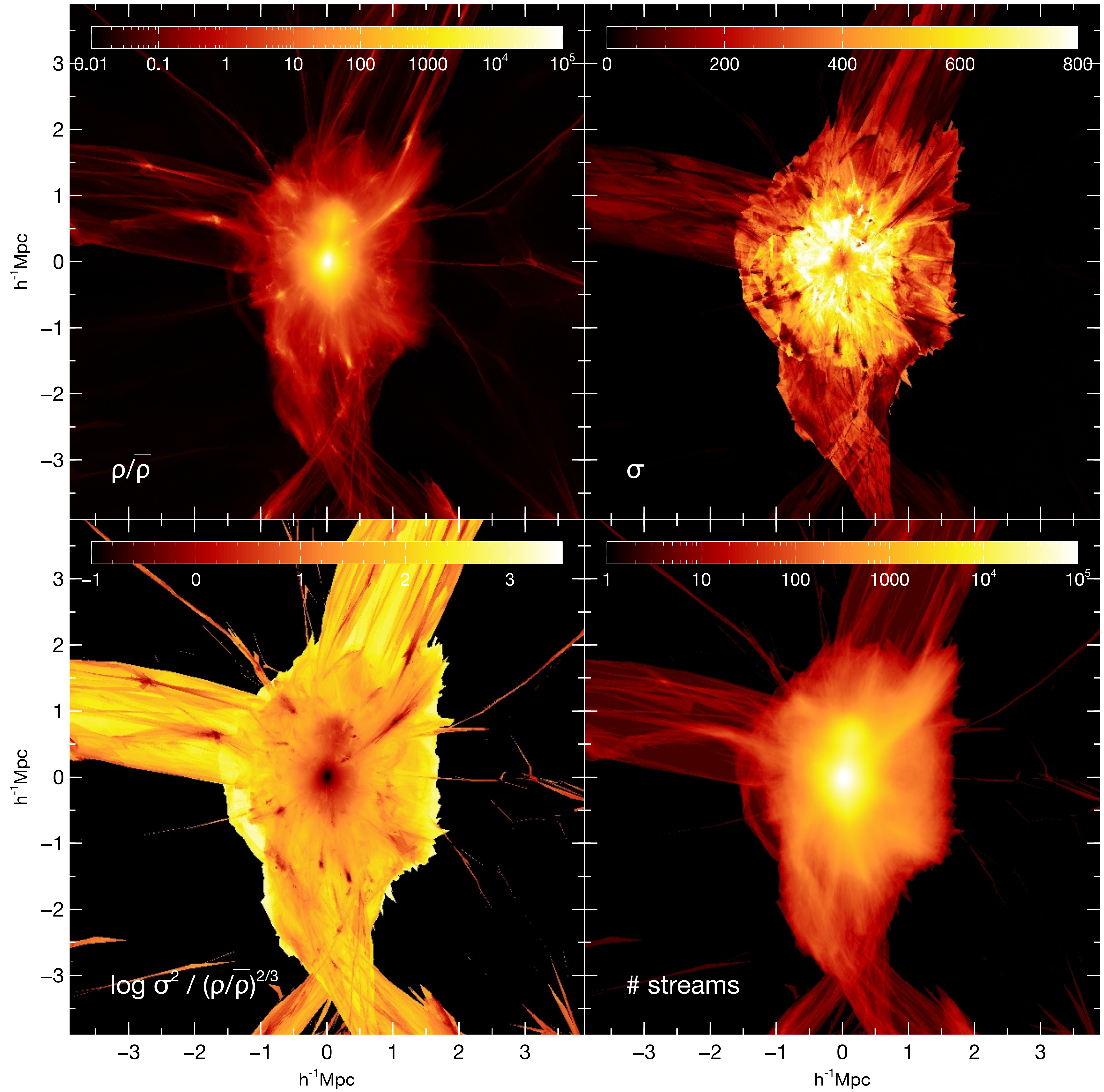
- Looping over the initial cartesian (LAGRANGIAN) lattice generates the 6N tetrahedra.

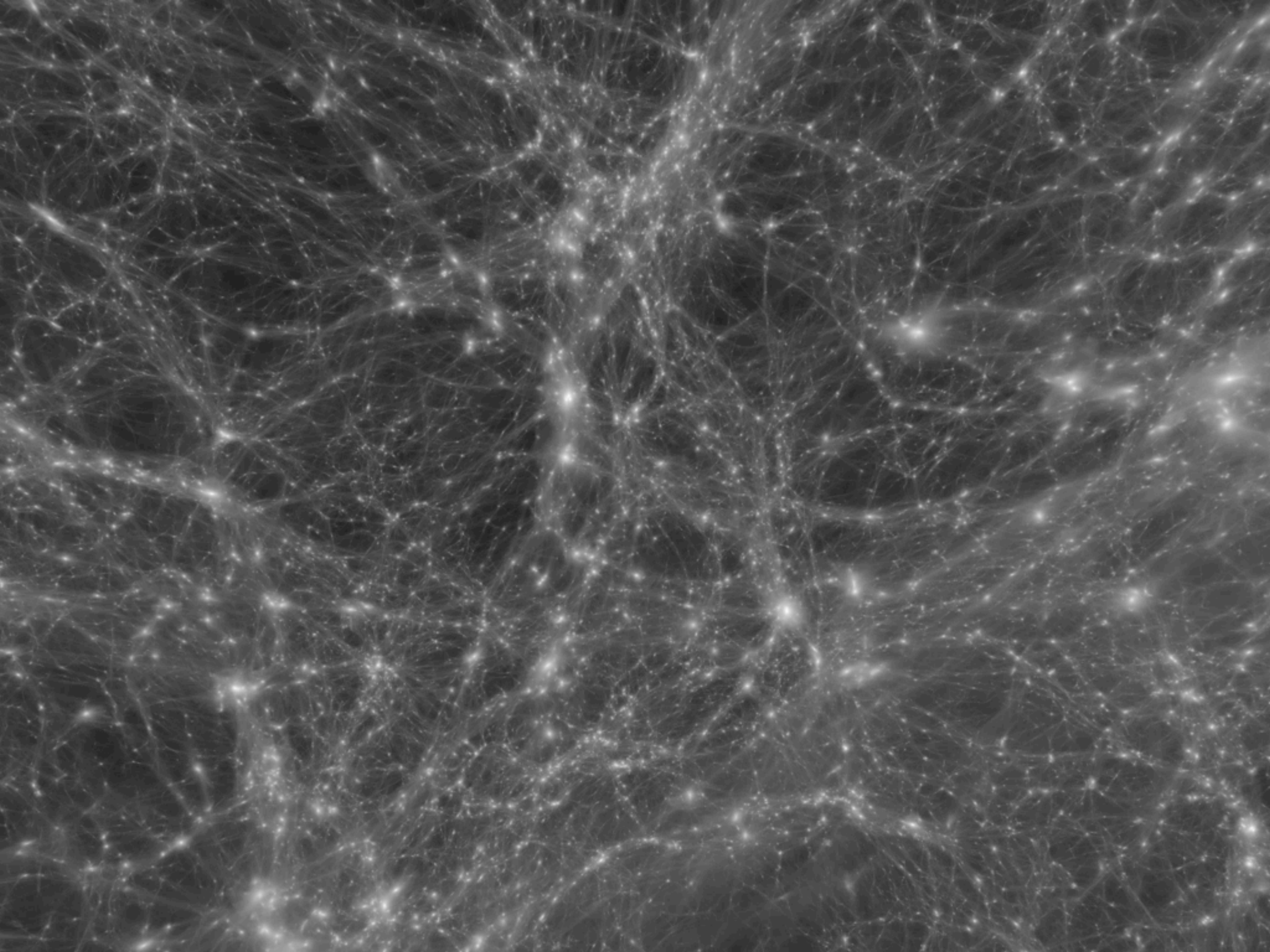


A first glimpse: analyzing phase space

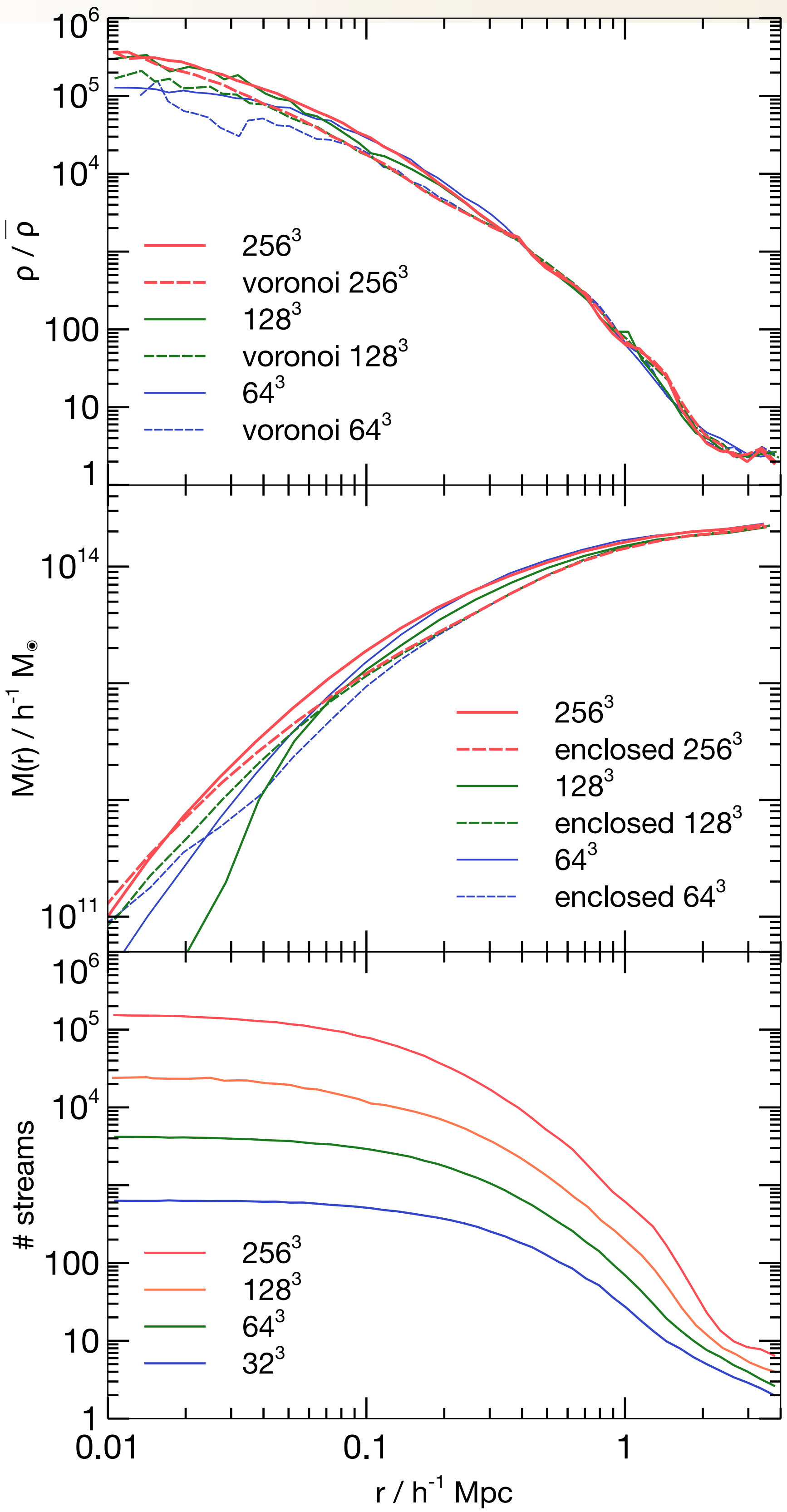
can probe fine-grained phase space structure.

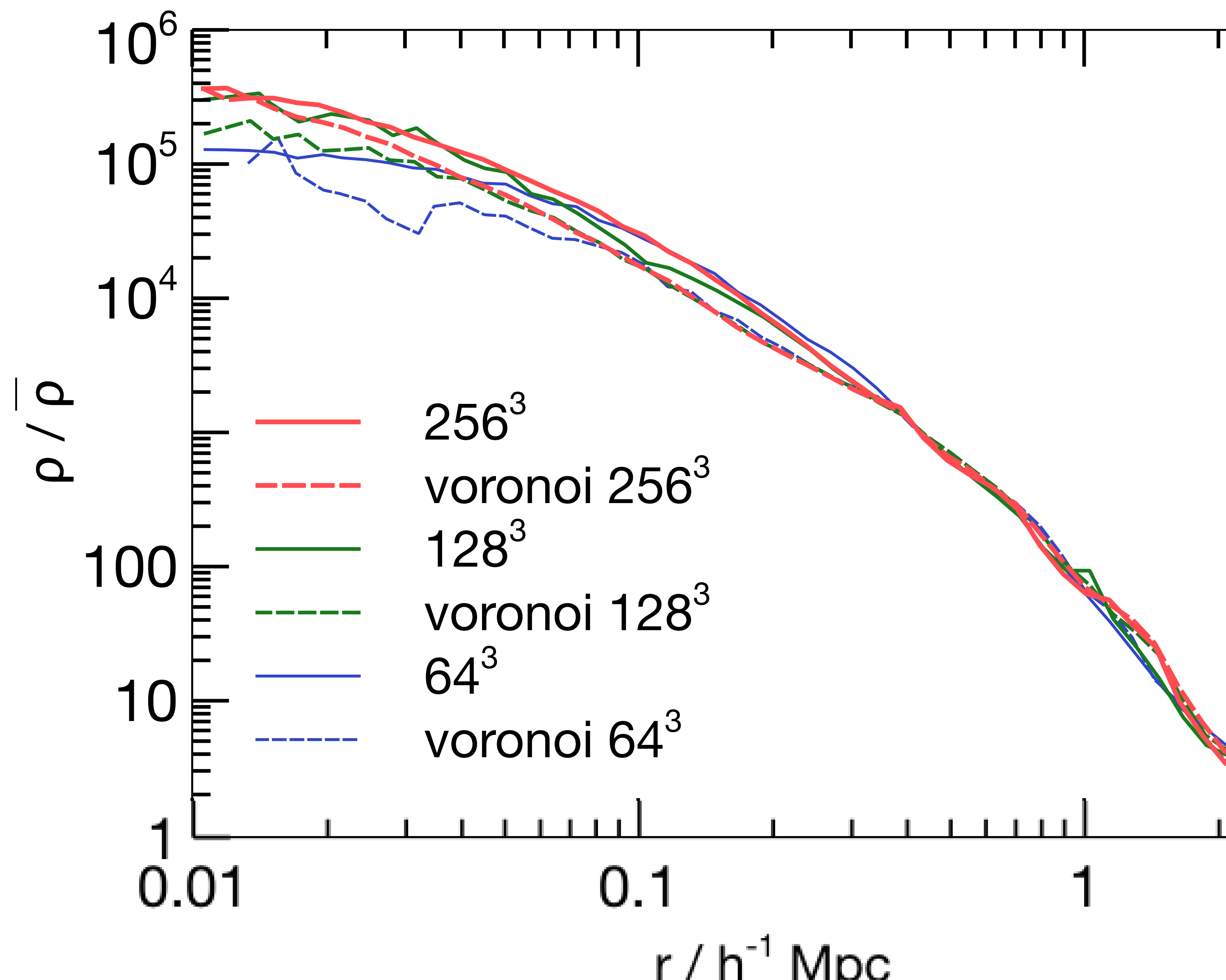






Radial profiles reveal central density bias

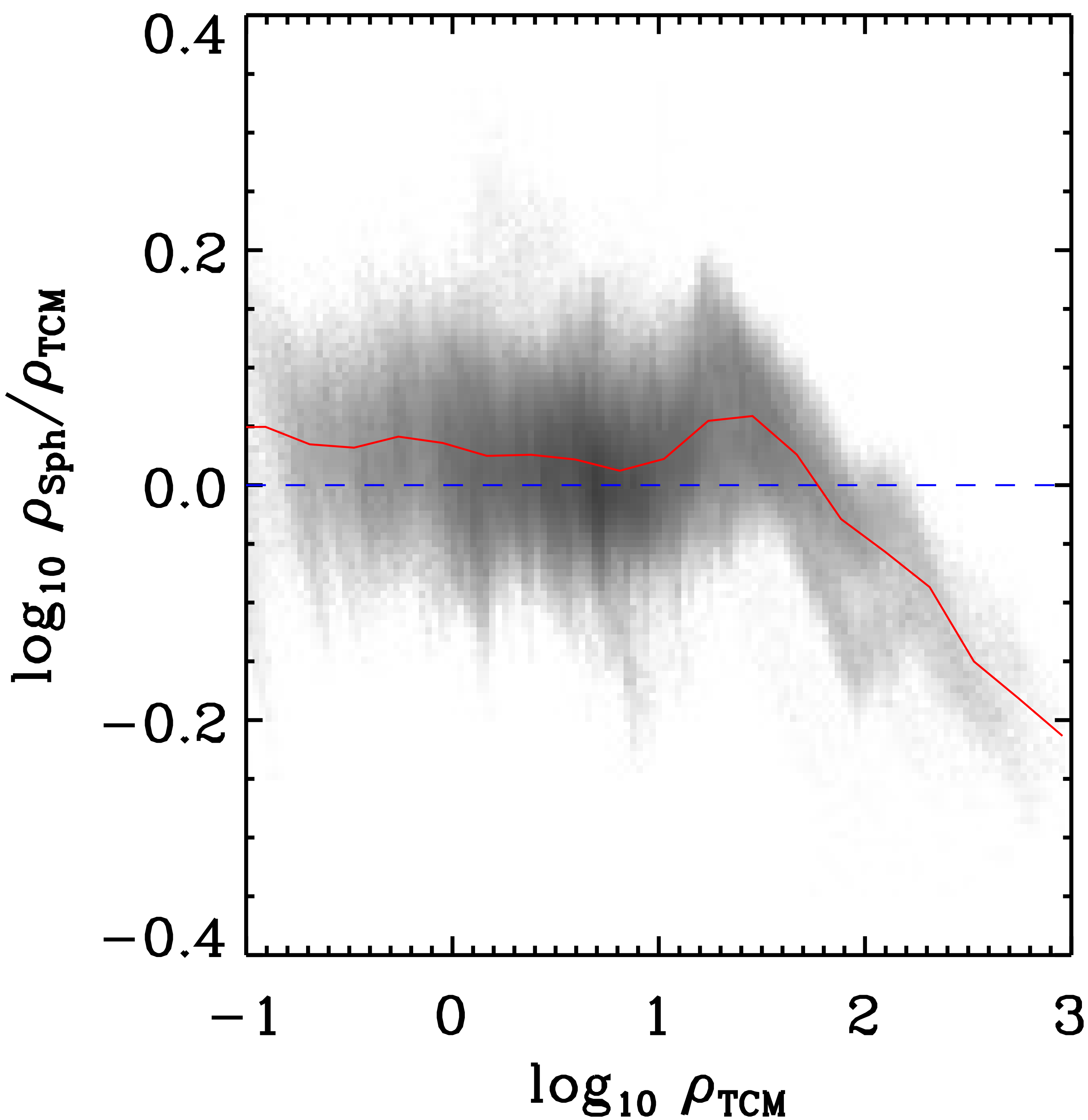




Rough way to remove high density bias

Scale out bias using the average relation between SPH surface densities and tetrahedral densities.

Rough but so far good enough.



Surface Density Maps

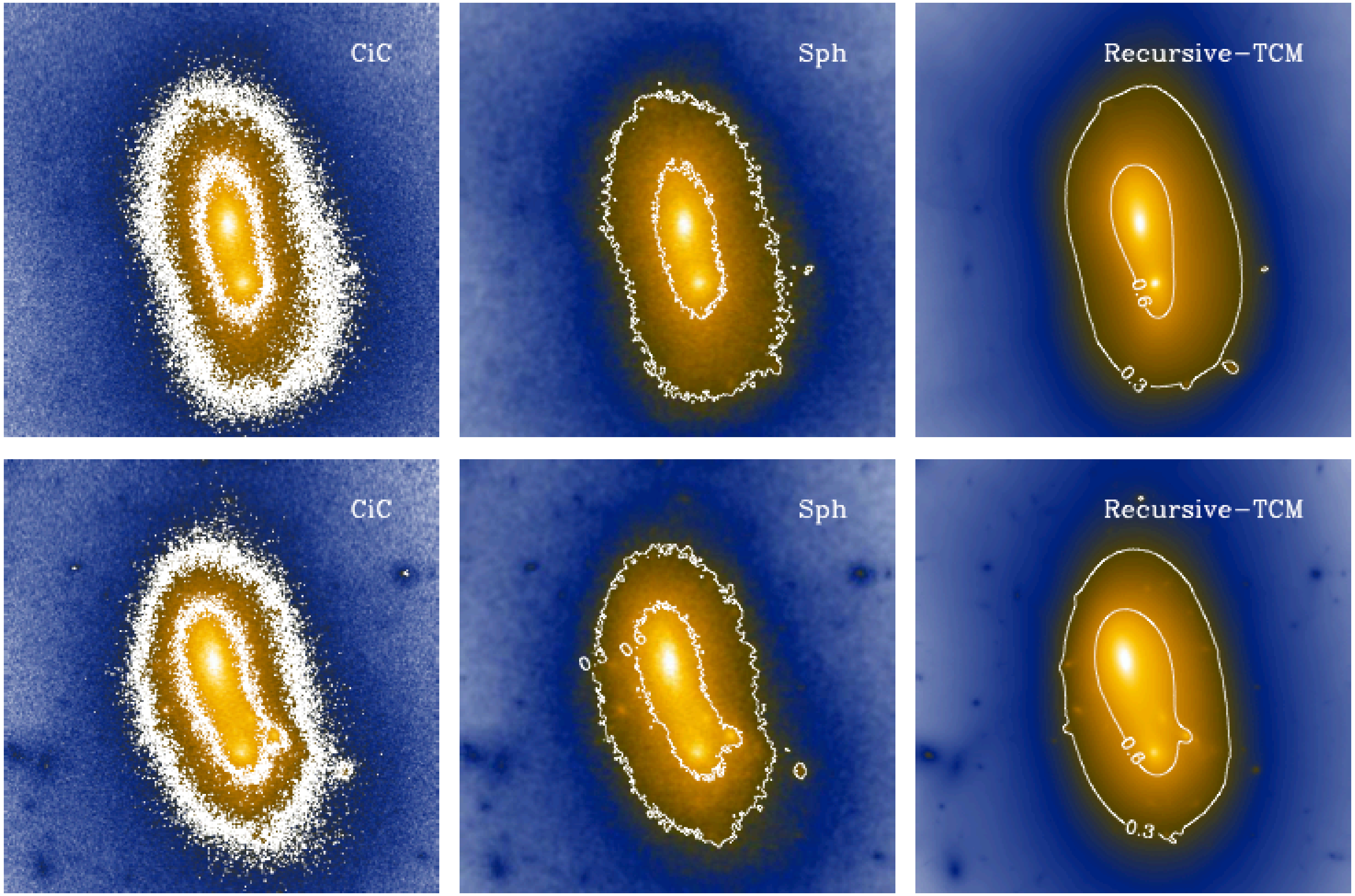


Figure 3. The surface density in units of the critical density, $\Sigma(x)/\Sigma_c$, in the central $0.6 \times 0.6h^{-1}$Mpc region about our WDM (top row) and CDM clusters (bottom row), and for three different methods to estimate the density field. We use a logarithmic colour scale that identical in all six sub-images, and ranges from 0.04 (dark blue) to 0.9 (white). This figure illustrates the different noise levels present in different projection methods. Note how the method presented here, Recursive-TCM, displays the smallest amount of small-scale noise.

Inverse Magnification

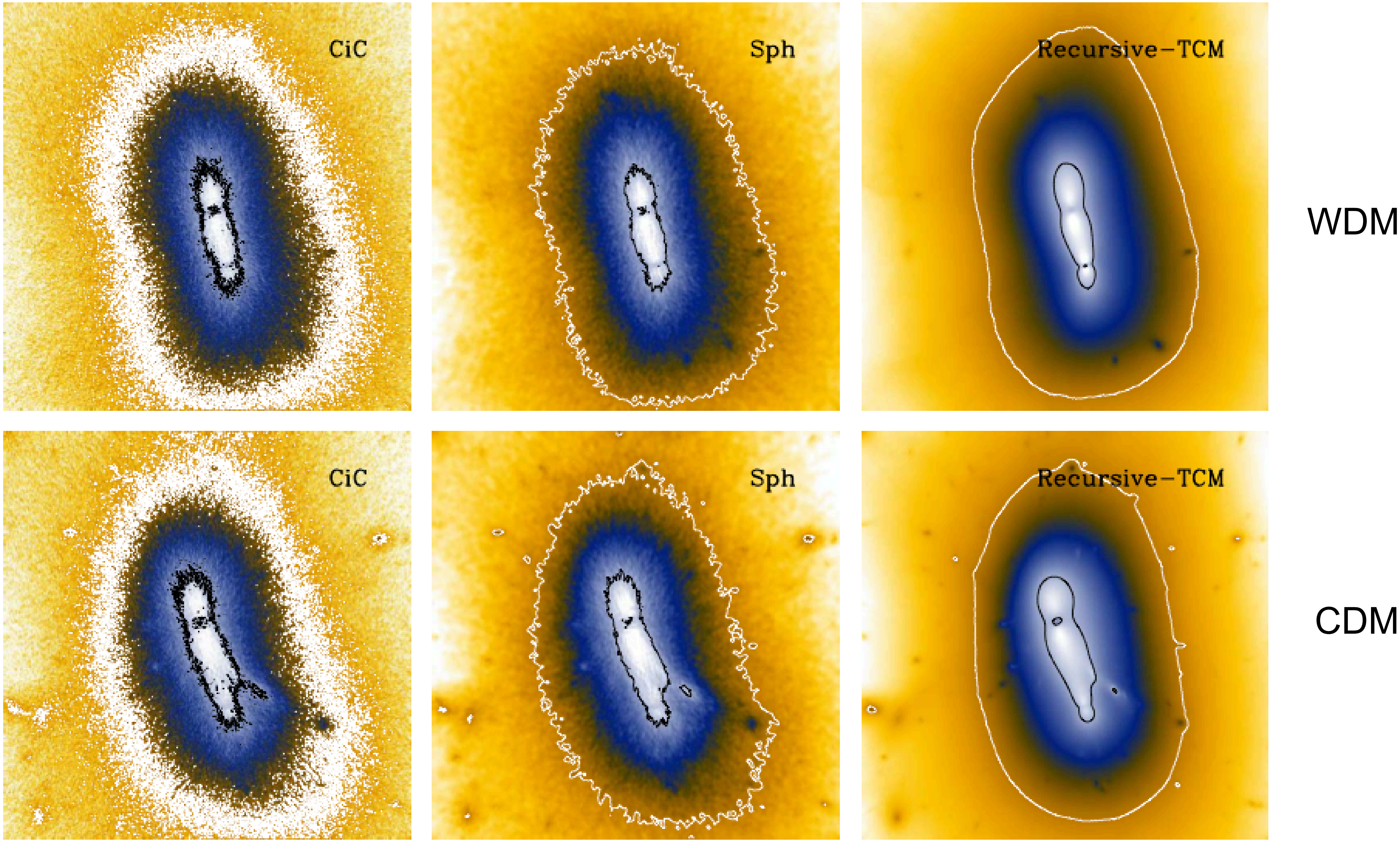


Figure 7. Map of the inverse of the magnification field, μ^{-1}, at the central region of our WDM (top) and CDM (bottom). The region displayed matches that shown in Fig. 3. White and black lines shows contours where $\mu^{-1} = 0.6$ and 0, respectively. Note we use the same linear colour scale in all panels and it ranges from -0.18 (white) to 0.85 (light yellow).

Subhalos and Inverse Magnification Contours

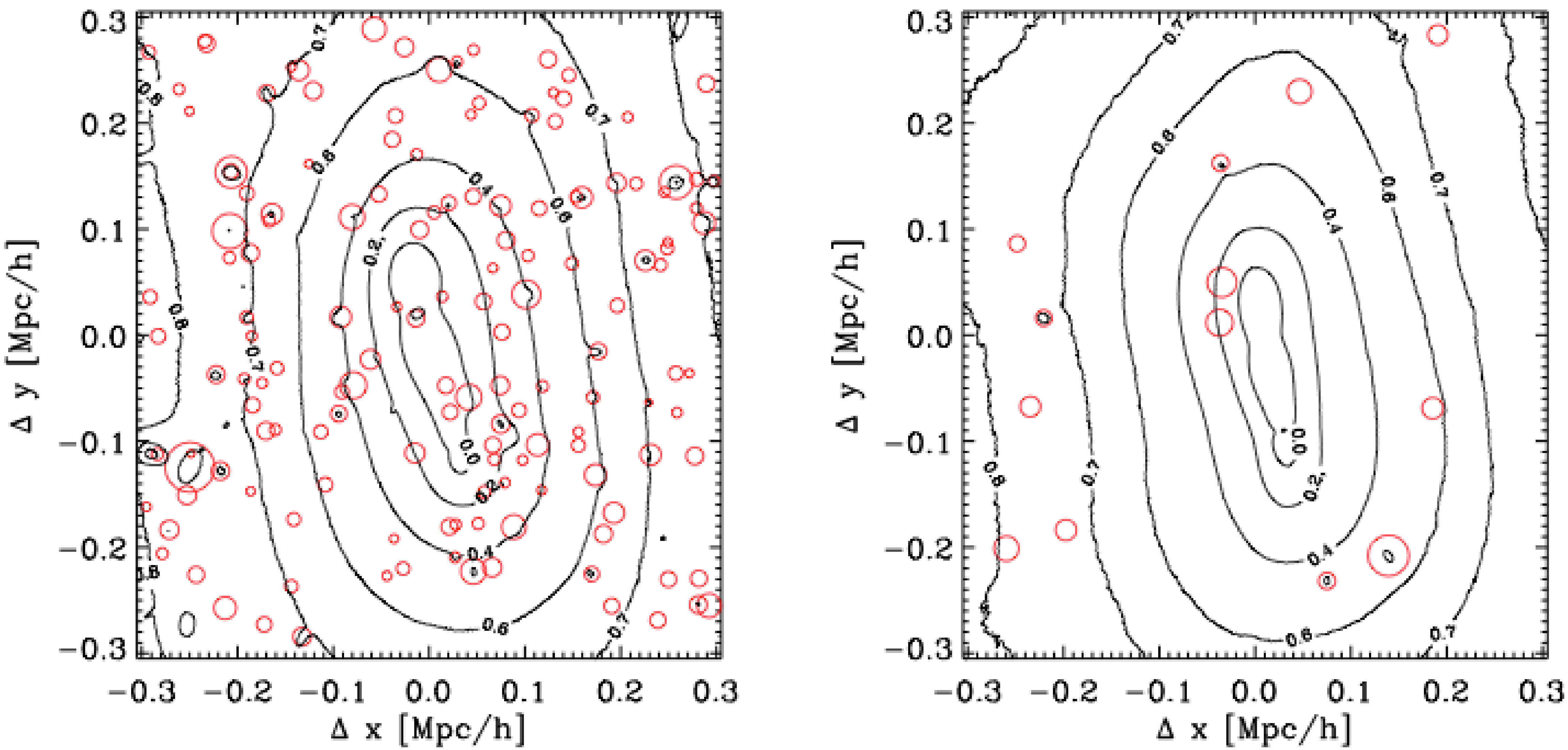


Figure 8. The relation between substructure and perturbations in lensing magnification for our simulated CDM (left) and WDM (right) halo. Black lines denote iso-magnification contours at $\mu^{-1} = 0.8, 0.7, 0.6, 0.4, 0.2$ and 0 inwards. Red circles indicate the positions where substructures were identified, and their radii is equal to the half-mass radius of the respective subhalo. Note the reduced number of substructures in the WDM case, which result from the initial suppression of small-scale fluctuations.

Lensing and the recursive deposit

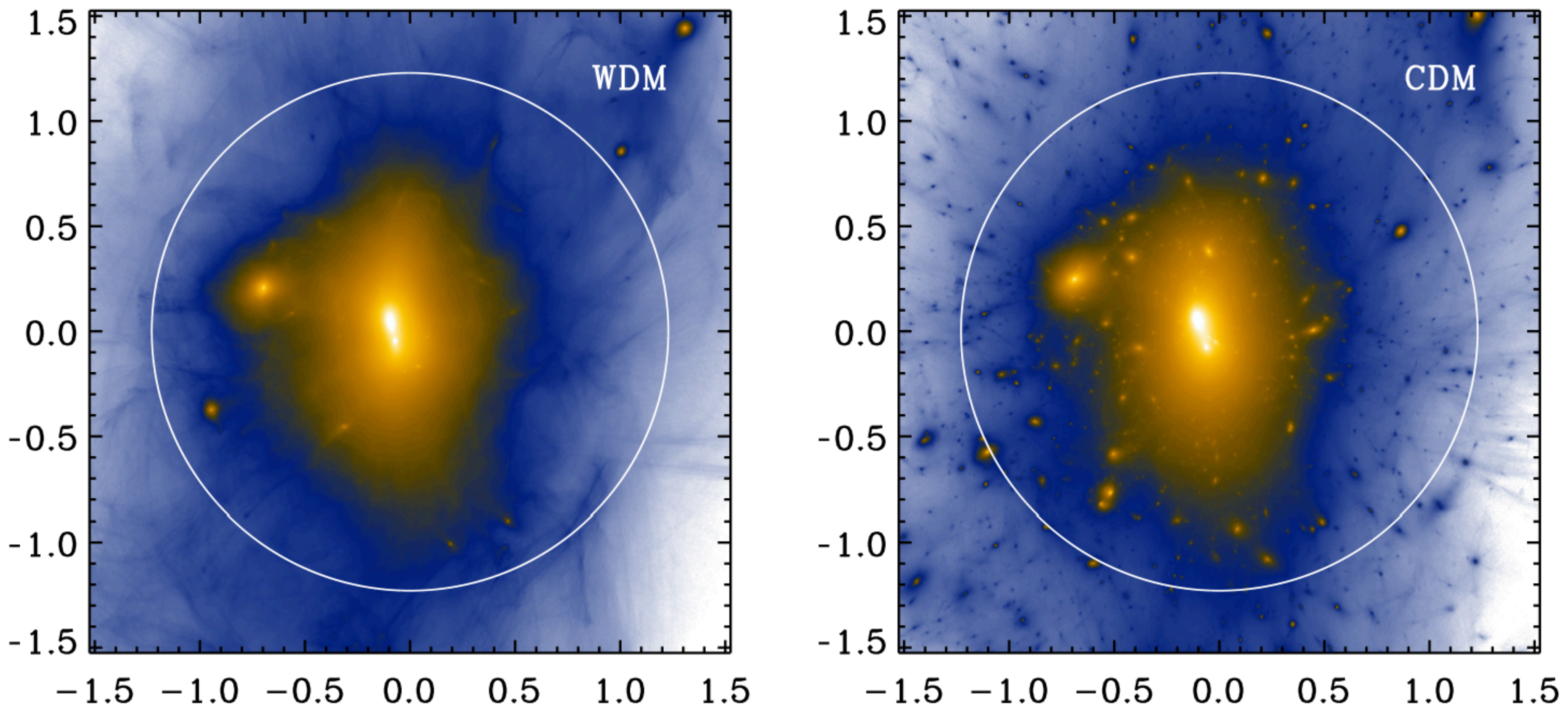
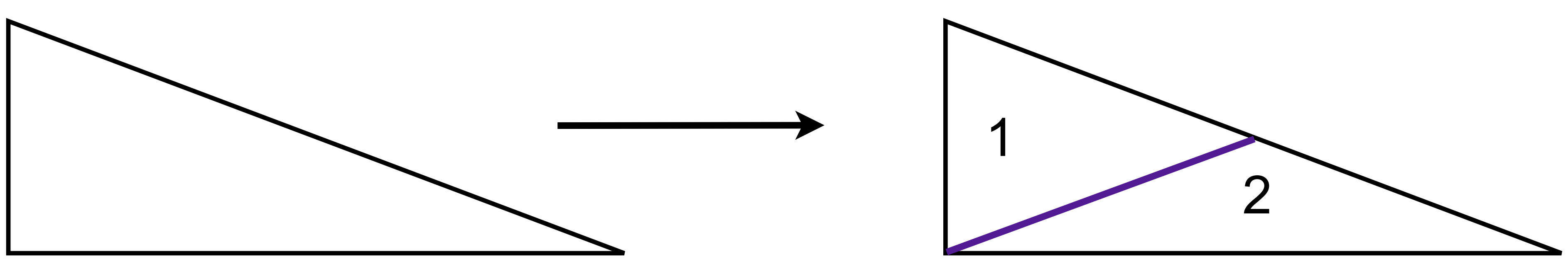
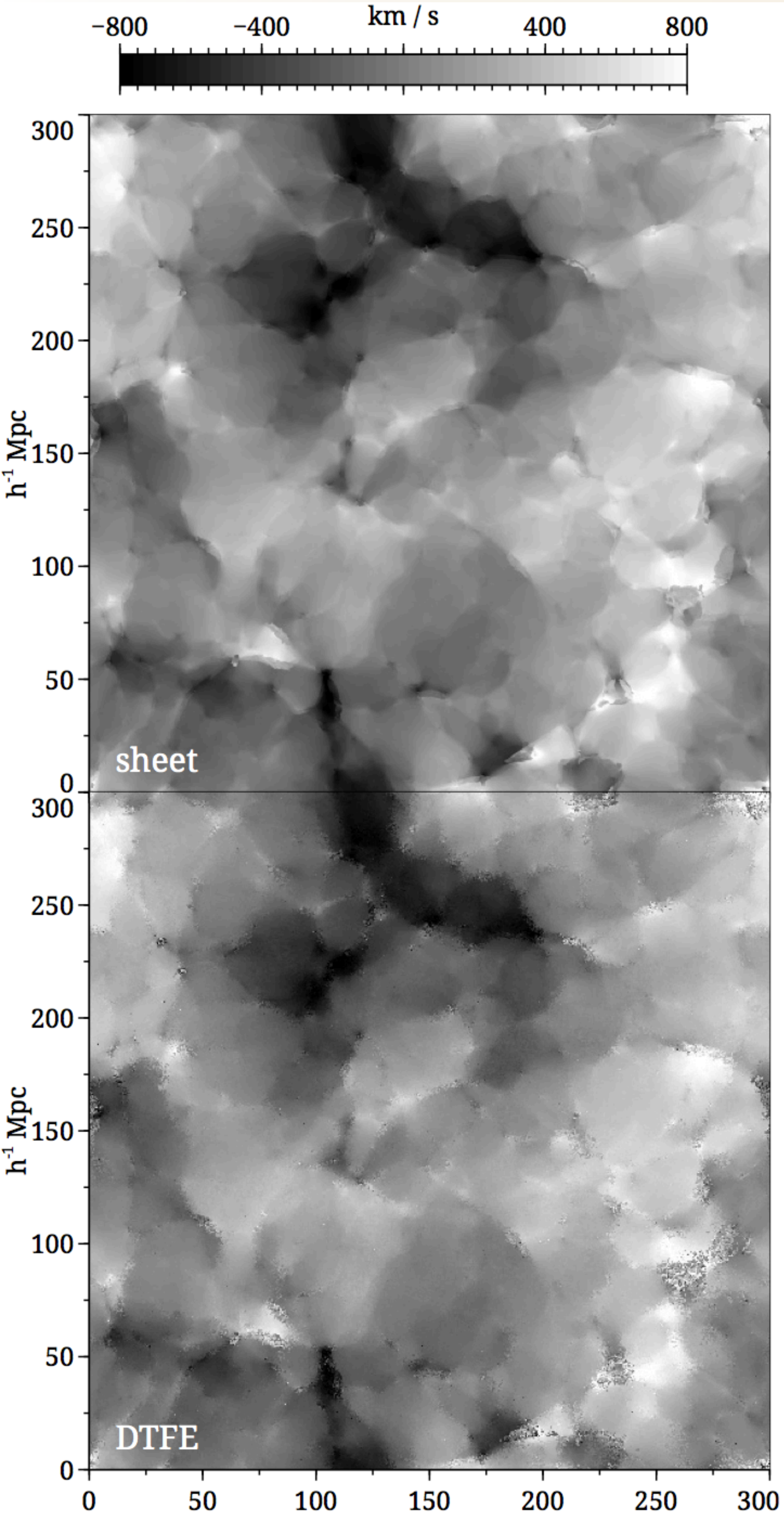


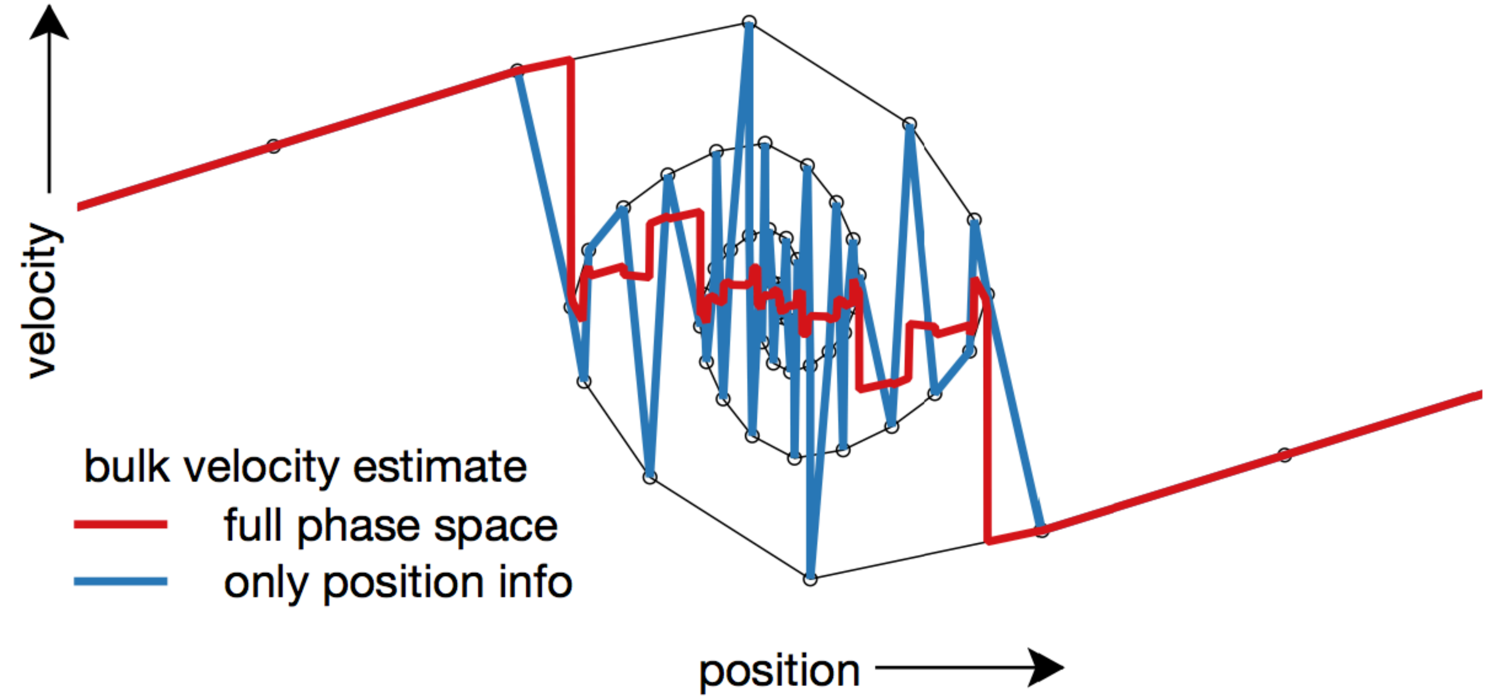
Figure 1. Projected dark matter density for the most massive DM halo in our simulations at $z = 0$ ($M_{200} = 4.38 \times 10^{14} h^{-1} M_{\odot}$). Each image corresponds to a square region of $3.05h^{-1}$Mpc a side $1.5h^{-1}$Mpc deep. The left panel is the result of simulating this object in a WDM scenario, whereas the right panel assumes a CDM cosmology. Note the similarities in the overall structure of the halo, and the differences on small scales: in CDM the halo displays a large amount of substructure, whereas in WDM these are absent and sharp caustics become more visible.

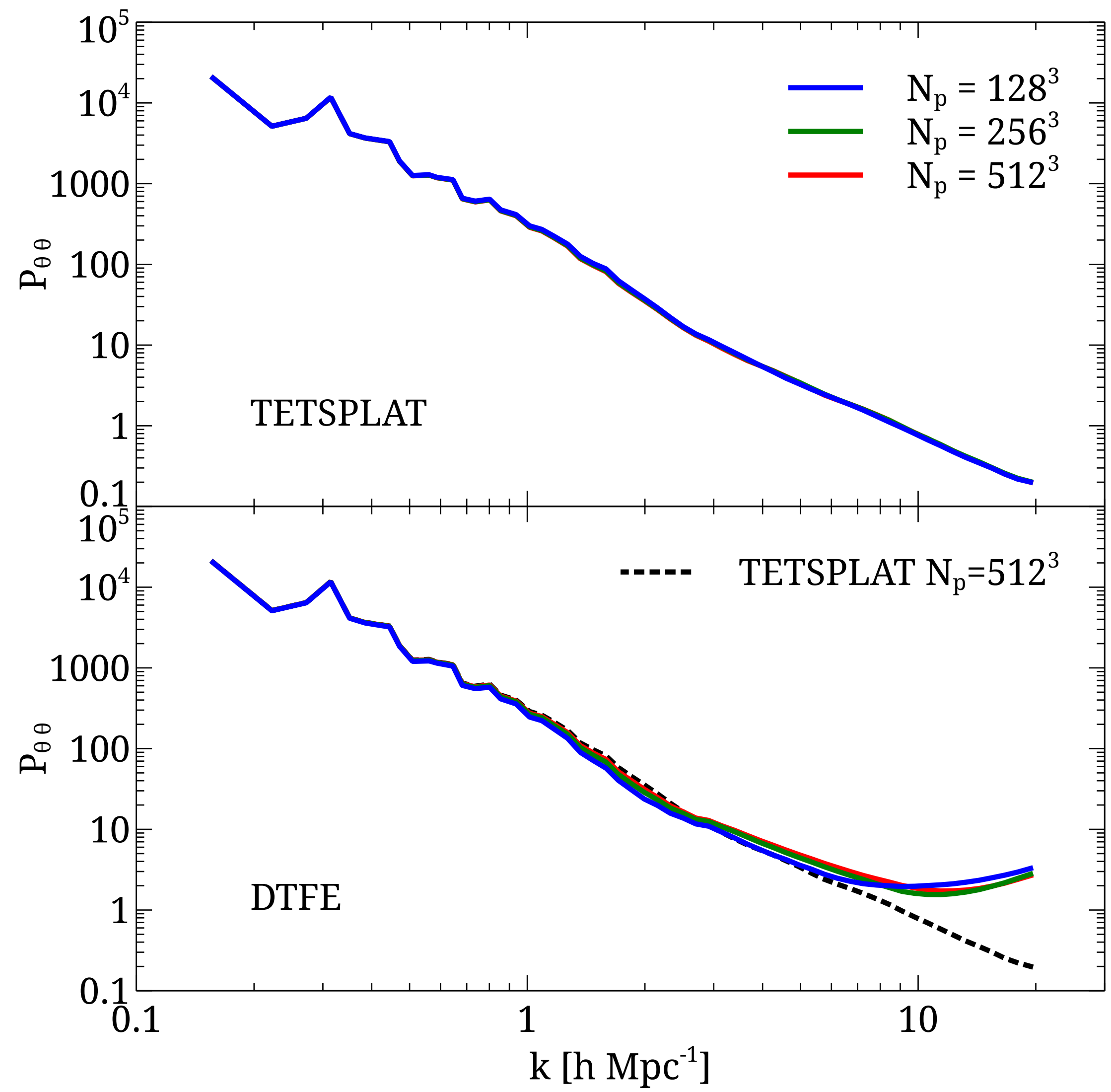
Recursive Deposit



Velocity measurements





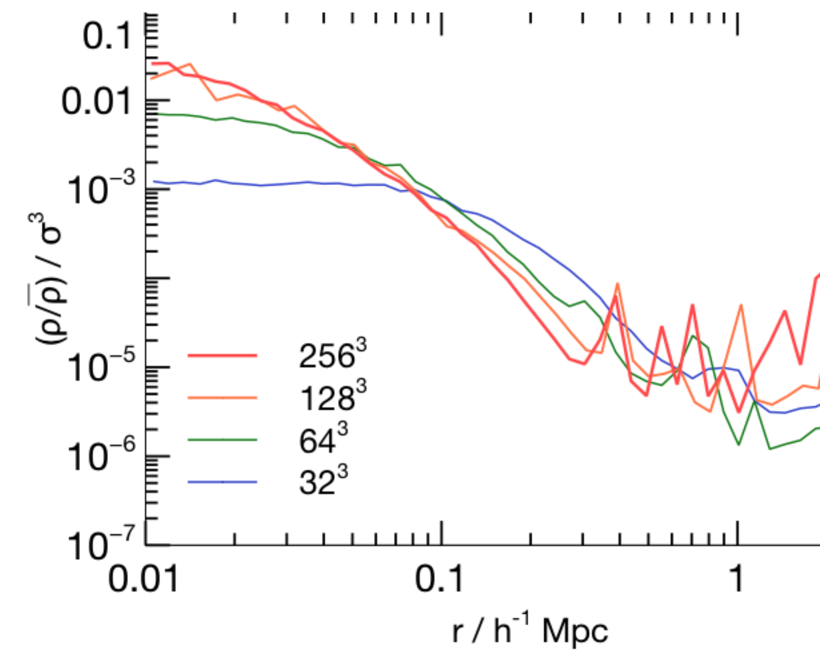


Reliable, converged velocity powerspectra.
Useful predominantly for theory.

Some open questions

Modeling:

- Is there so much phase mixing that N-body methods currently give the wrong answers? I.e. is NFW a converged but incorrect answer?
- Finally can do



Lensing

- With a noise free surface density estimator what are the most interesting applications to lensing? Strong, substructures, caustics, weak, what?
- Best way(s) to model galaxy contribution?
- Not only mass profile but also elipticity very interesting to compare to numerical predictions.
- Substructure constraints. How good can this get?
- M_{star}/M_{halo} for individual objects on smaller masses? How small?

Summary

- Lagrangian Tesselation is extraordinarily useful
  - spot errors in simulation
  - velocity statistics
  - improved density $\Longrightarrow$ improved potential $\Longrightarrow$ better accelerations
  - reliable WDM simulations
  - noiseless lensing predictions
  - and many more applications ....
- It is also very simple to program
  - Break unit cube into 6 tets once (Abel et al 2012)
  - Initital grid just replicates that N^3 times
  - Deposit 1/6 of particle mass at the centroid of the tetrahedron
    - To make a noise less image: break tets recursively along their longest side until they are smaller than a pixel (remembering that divided tets have only half the mass of parent tet)