Analysing Cosmological N-body simulations

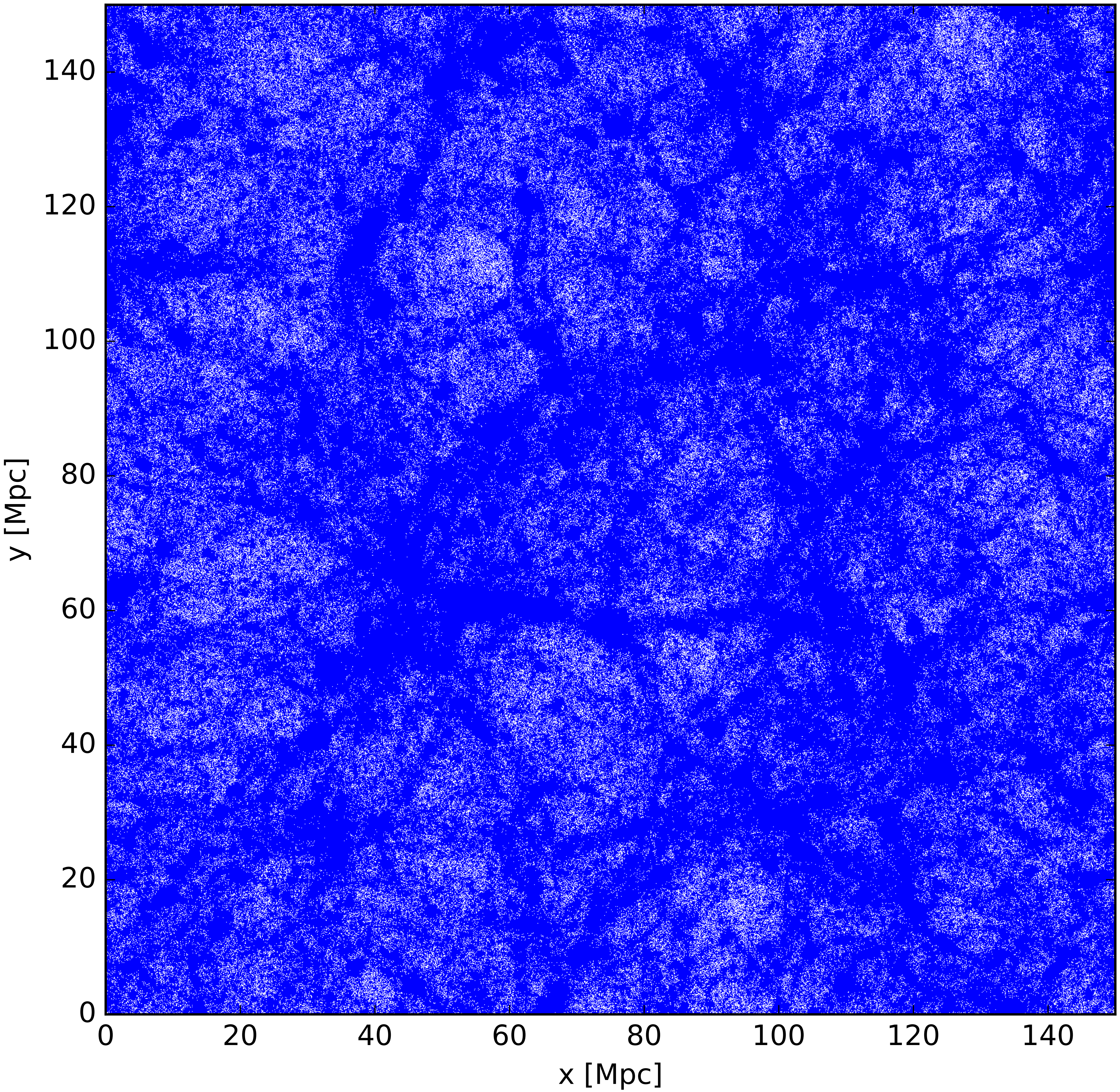
Rüdiger Pakmor

27.04.2018, CosmoTools18, Aachen

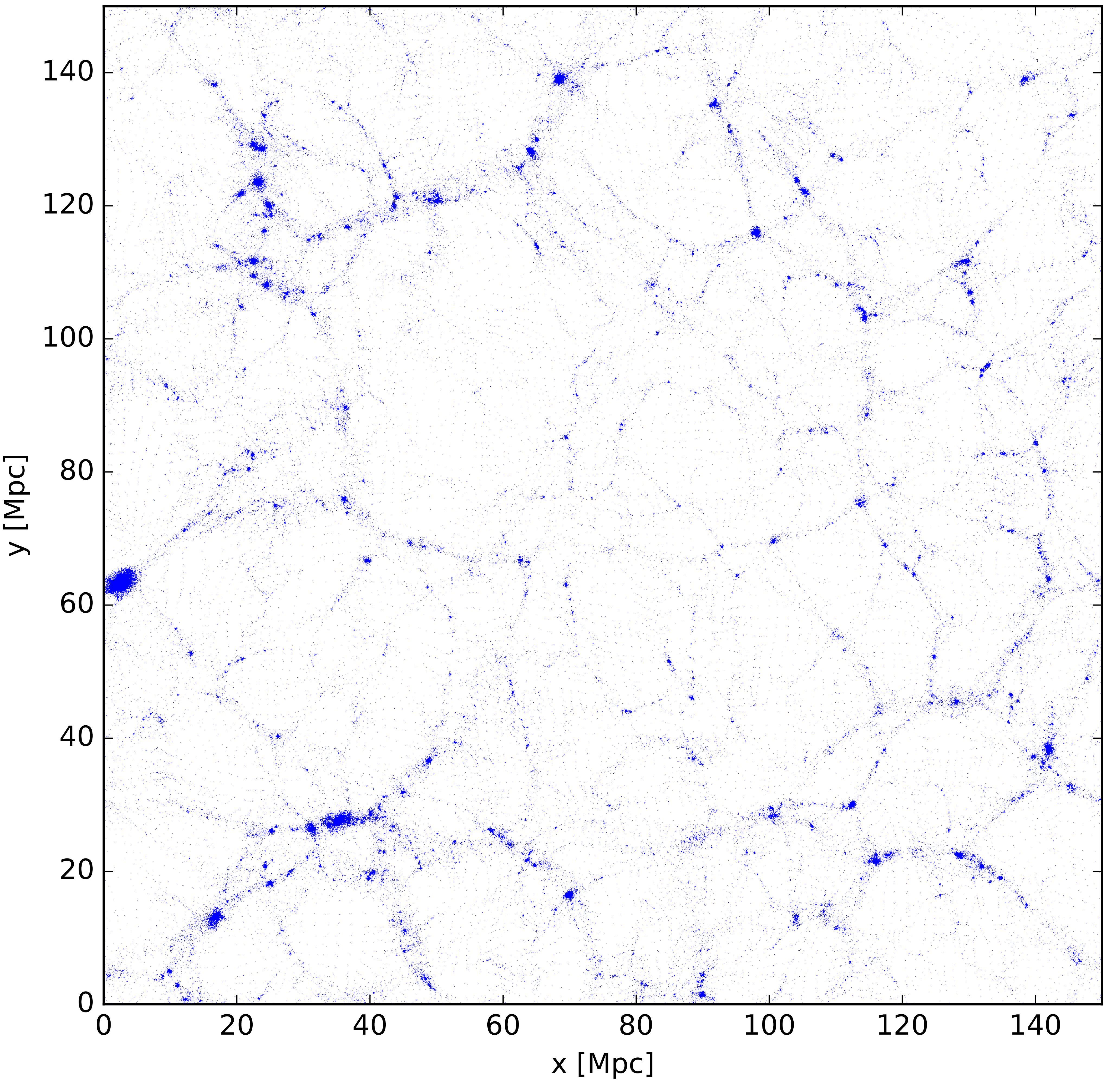
Overview

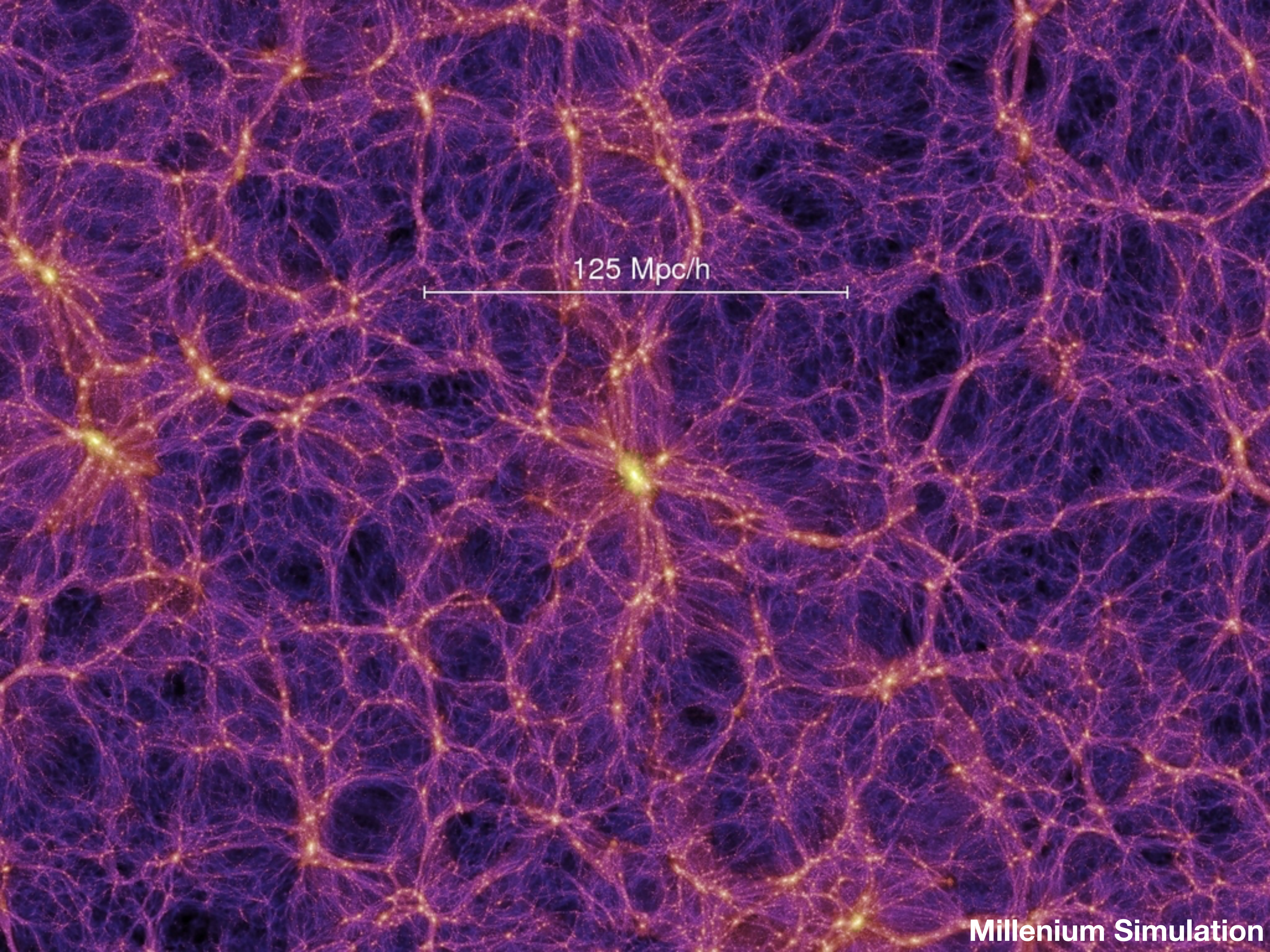
- Visualising the large-scale structure
- Powerspectra
- Halo finders
- Subhalo finders

Every DM particle in a 256^3 box is one pixel



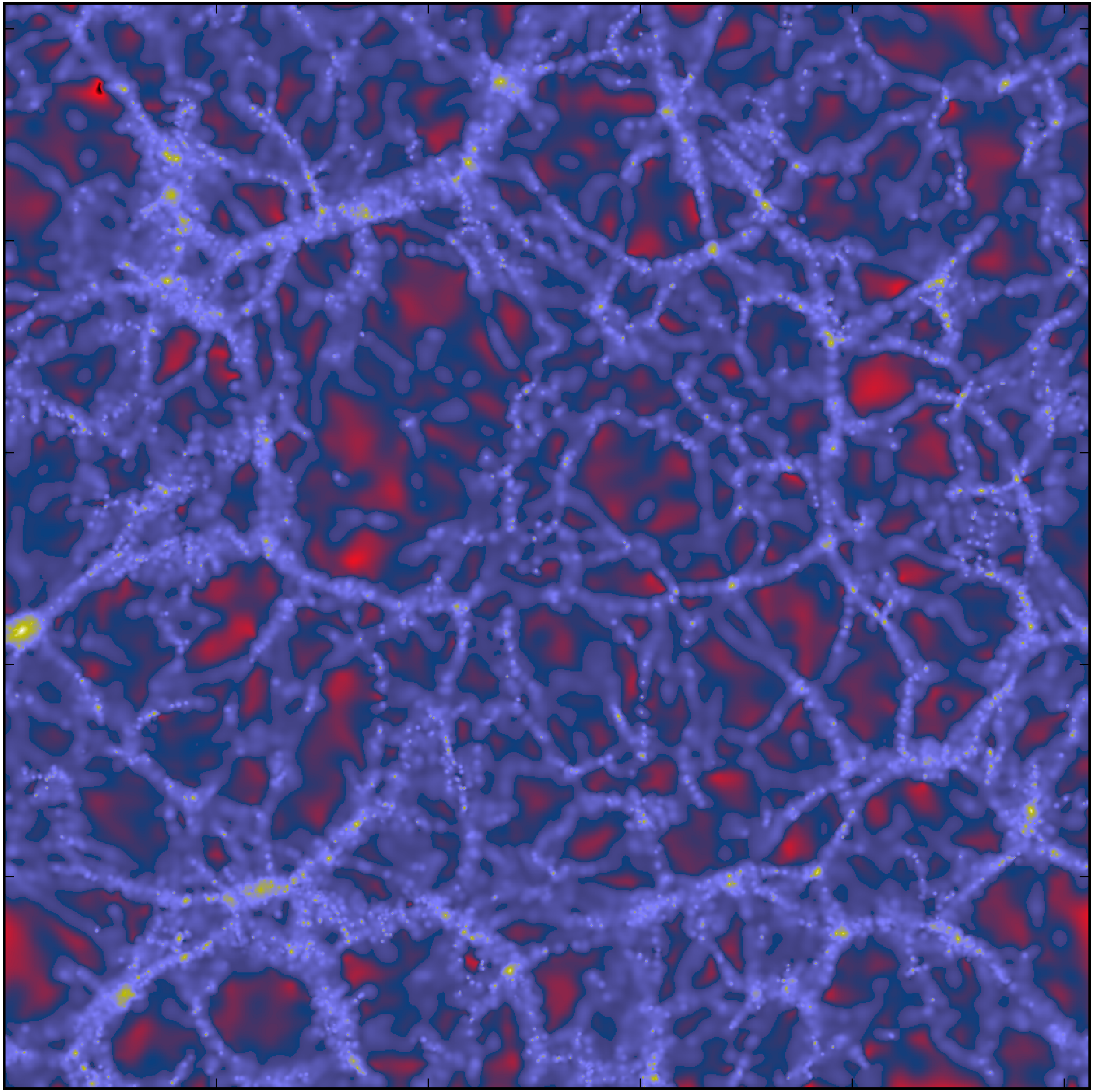
Only particles with
z in [0,1Mpc] are
shown as one pixel




125 Mpc/h
Millenium Simulation

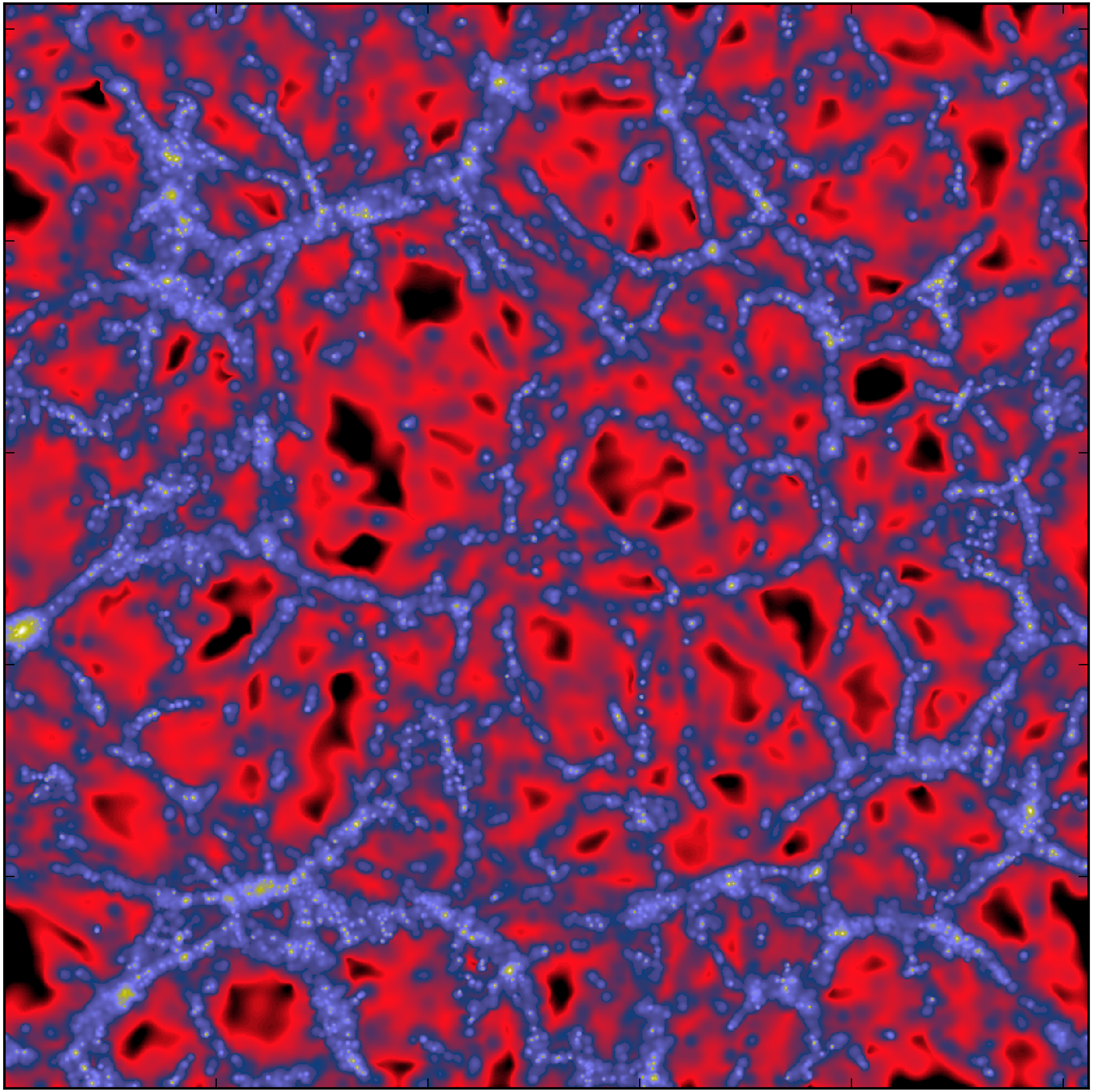
Idea: Visualise projection of smoothed density field

- Adaptive smoothing: compute radius hsml of sphere with N_{ngb} (e.g. 32) neighbours. Efficiently possible with bisection algorithm and neighbour search via tree.
- Project on Cartesian mesh as sphere with radius html
- Visualise 2D smoothed density field



Idea: Visualise projection of smoothed density field

- Adaptive smoothing: compute radius hsml of sphere with N_{ngb} (e.g. 32) neighbours. Efficiently possible with bisection algorithm and neighbour search via tree.
- Project on Cartesian mesh as sphere with radius html
- Visualise 2D smoothed density field
- Additional trick: Weight the particle mass with its local density computed from hsml
- Use 2D colormap with local velocity dispersion (see Millennium image)



Powerspectra

Fourier modes of density contrast (FFT of binned density field):

$$\delta_{\mathbf{k}} = \frac{1}{M} \sum_i m_i \exp(i\,\mathbf{k} \cdot \mathbf{x}_i).$$

Power spectrum is the mean expected power per mode (1D average):

$$\hat{P}(k) = \left\langle |\delta_k|^2 \right\rangle$$

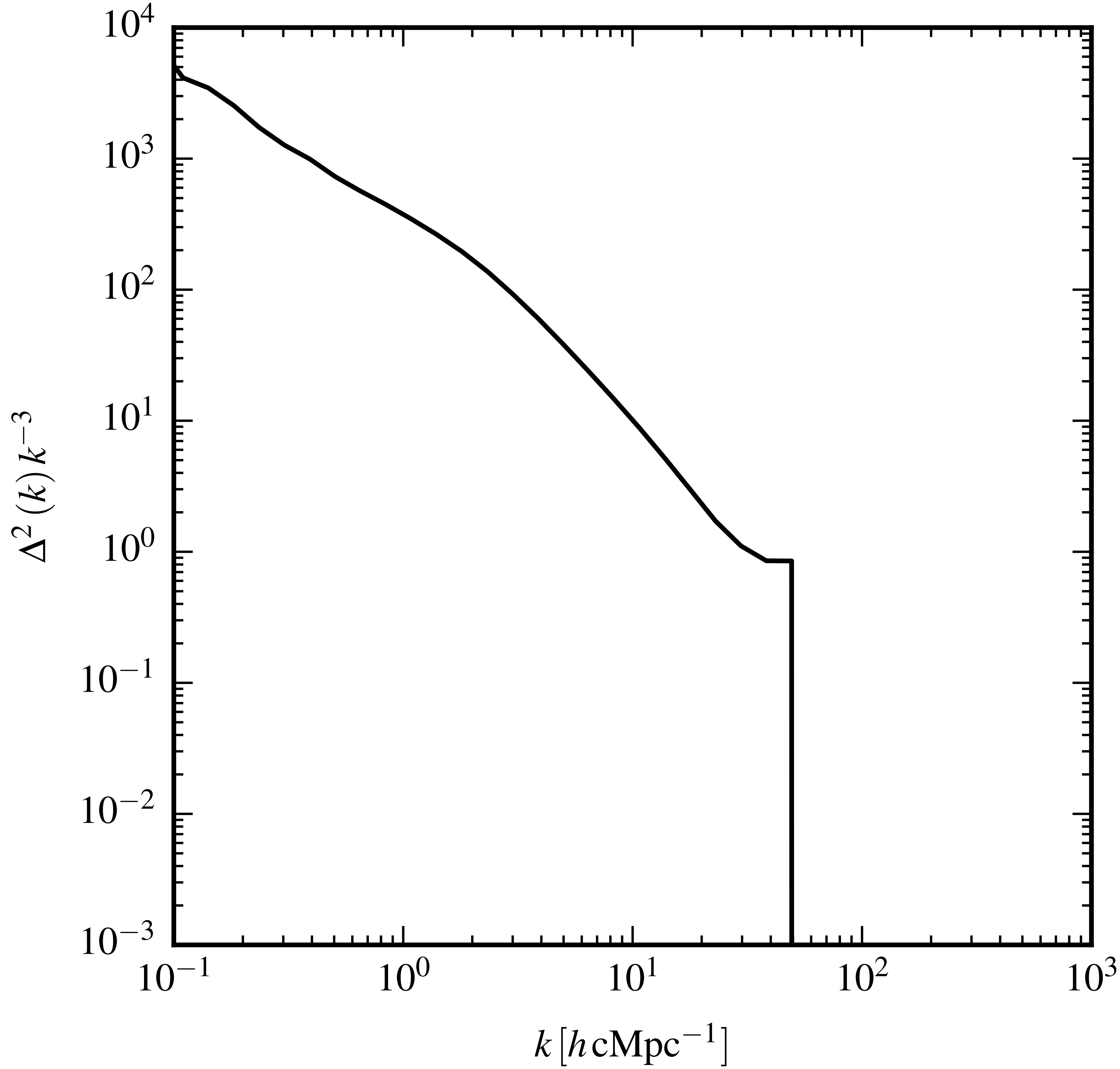
Dimensionless form:

$$\Delta^2(k) = 4\pi k^3 P(k)/(2\pi)^3$$

Computation in large parts similar to PM gravity, smallest $k=2\pi/L$, largest $k=2\pi N_{grid}/L$
-> limited dynamic range

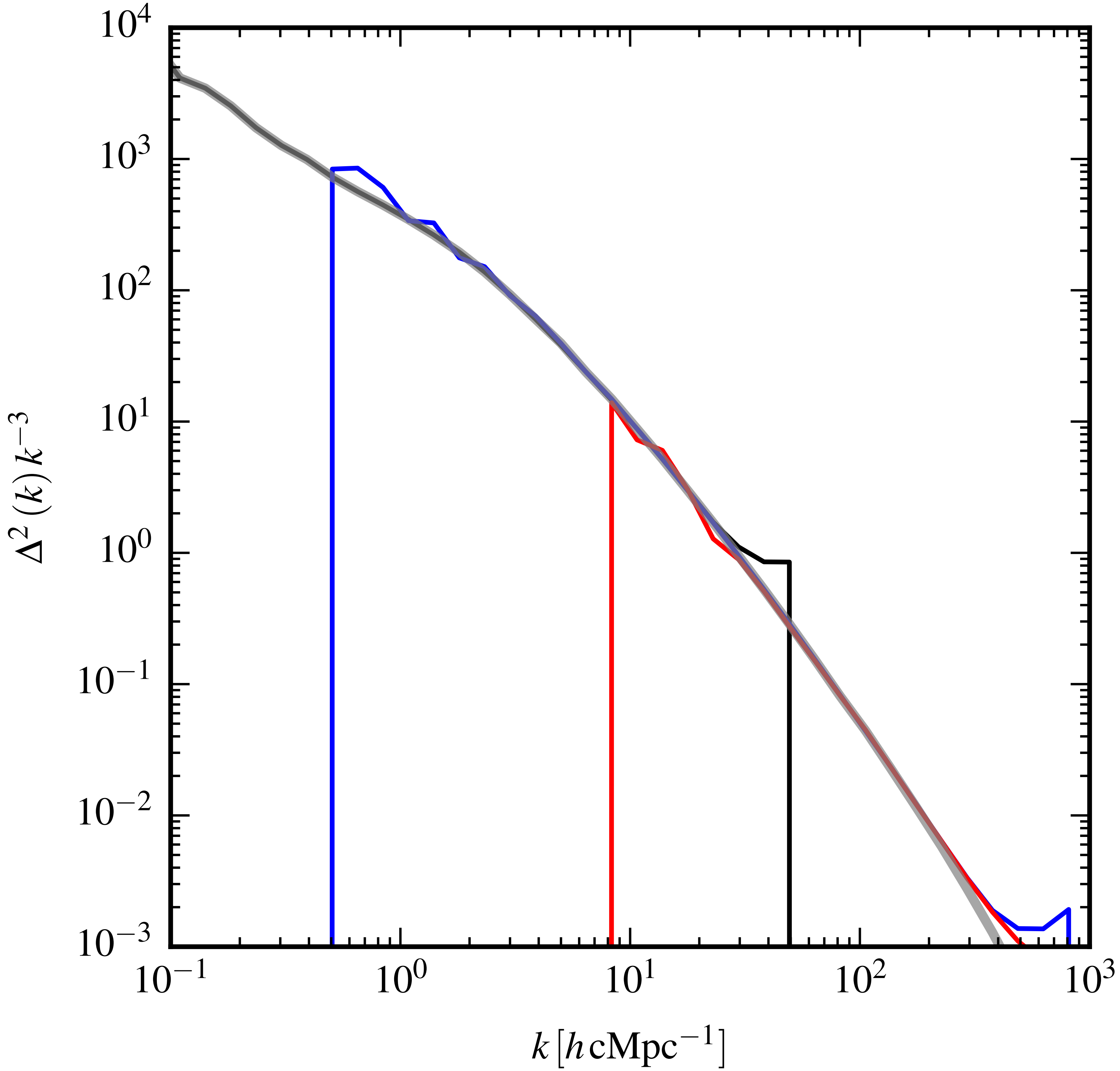
Single powerspectrum (N_{grid}=4096)

Limited dynamic range, larger N in practice not possible

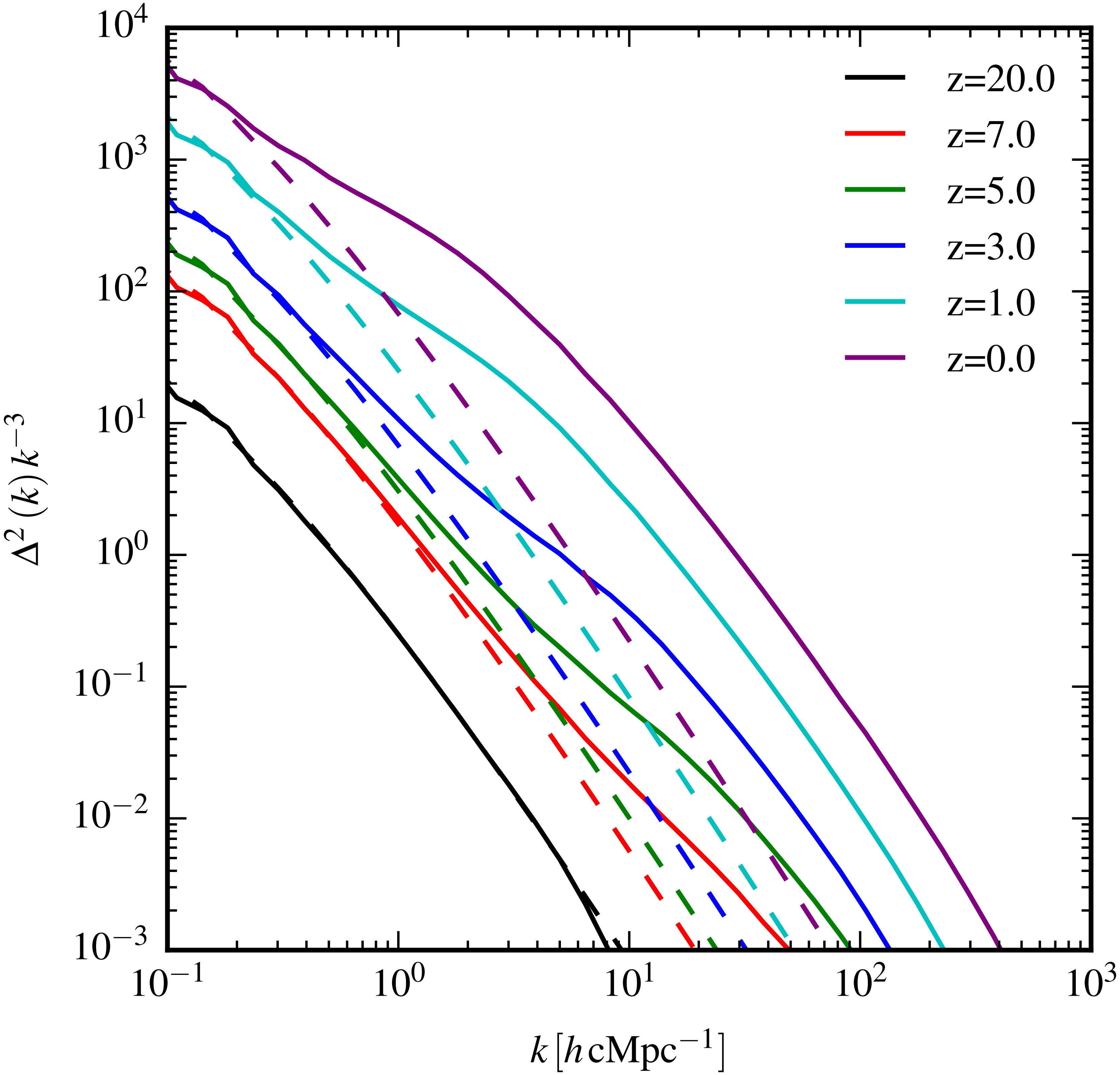


Folded powerspectra (N_{grid}=4096)

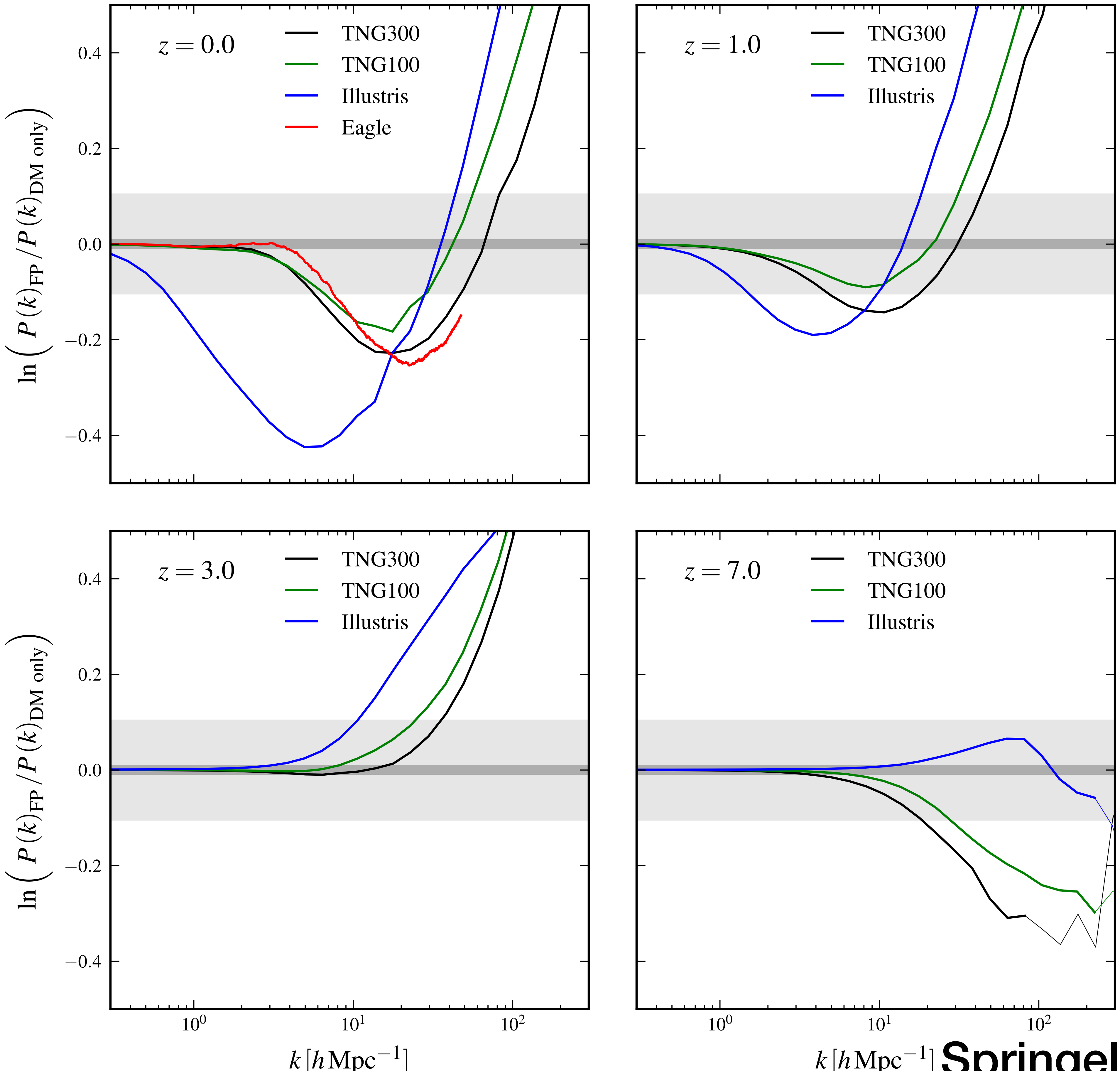
Fold coordinates in box on smaller box, moves power spectrum to smaller scales



Powerspectra of cosmological simulation with L=300Mpc and N=2500³



The effect of baryonic physics on the matter powerspectrum



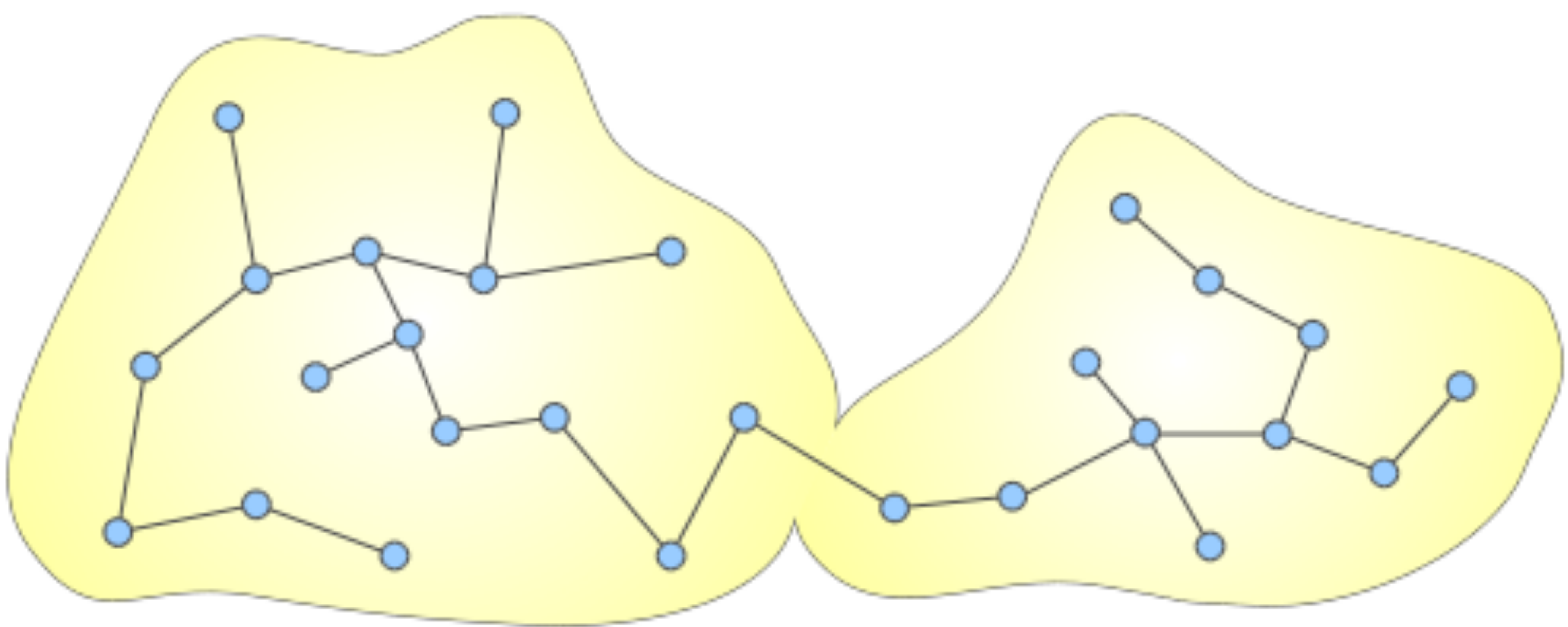
Springel et al. 2018

Friends of Fields Halo finder

Idea: group all particles together that can be connected by line fixed length

$$|\mathbf{x}_i - \mathbf{x}_j| \leq b\Delta x = bL/\sqrt[3]{N}$$

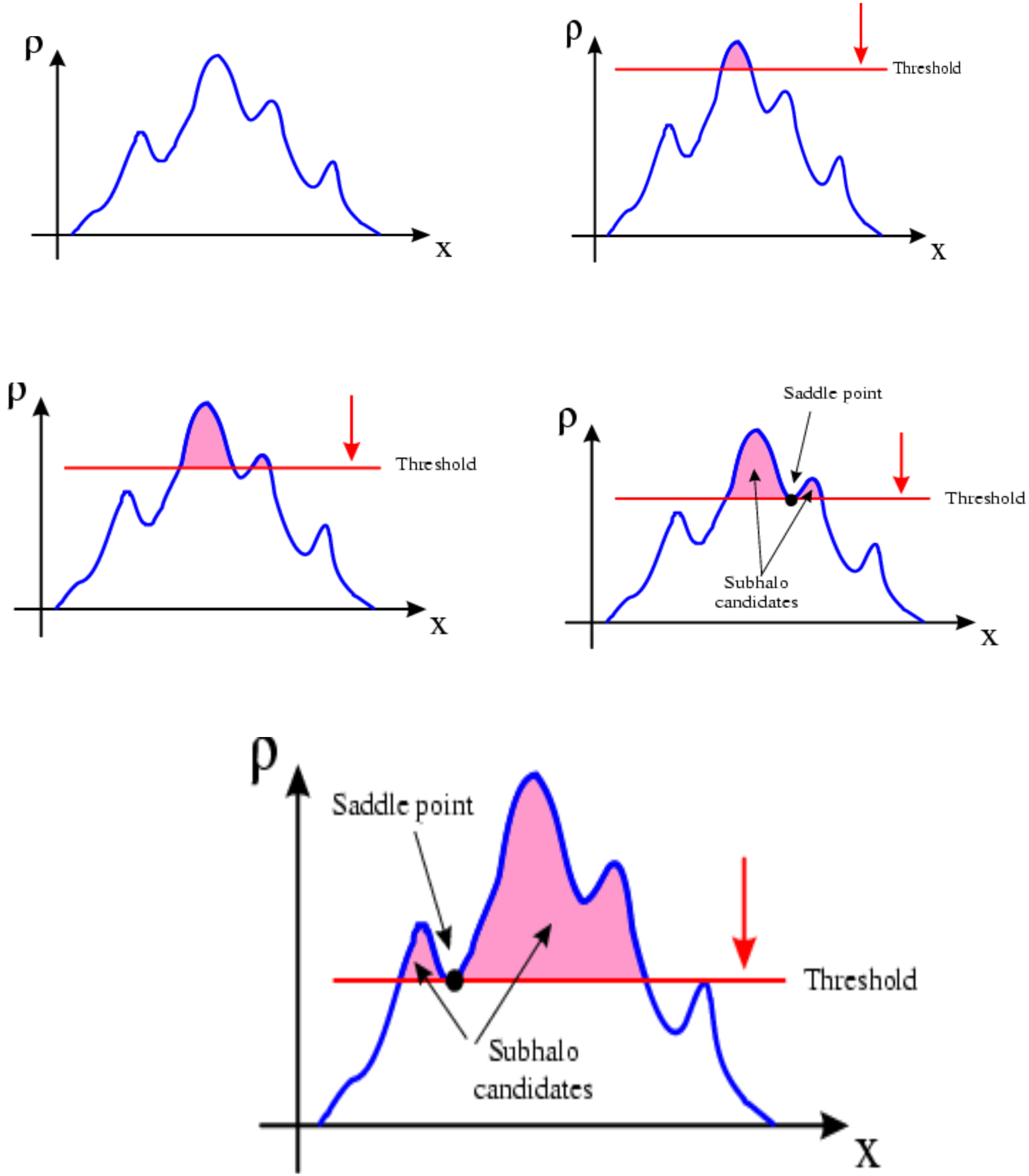
$$b \approx 0.2$$



Fast, arbitrary halo shapes, but no subhalos, can have linking bridges

Subhalo finder (SUBFIND)

- Estimate local DM density field
- Find local overdense regions with topological method
- Subject each sub-structure to a gravitational unbinding procedure



Gravitational unbinding

Idea: Use velocity information to remove unbound particles from halos

Force in spherical symmetry: $$\frac{d\phi}{dr} = \frac{GM\left(< r\right)}{r^2}$$

Integrate for potential:

$$\phi(r) = G\int_0^r \frac{M\left(< r'\right)}{r'^2} dr' + \phi(0) \qquad \phi(\infty) = 0$$

Order particles with respect to distance from center:

$$\int_0^r \frac{M\left(< r'\right)}{r'^2} dr' = \int_0^{r_1} \frac{M\left(< r\right)}{r^2} dr + \int_{r_1}^{r_2} \frac{M\left(< r\right)}{r^2} dr + \ldots + \int_{N-1}^{N} \frac{M\left(< r\right)}{r^2} dr$$

Remove unbound particles, i.e. with

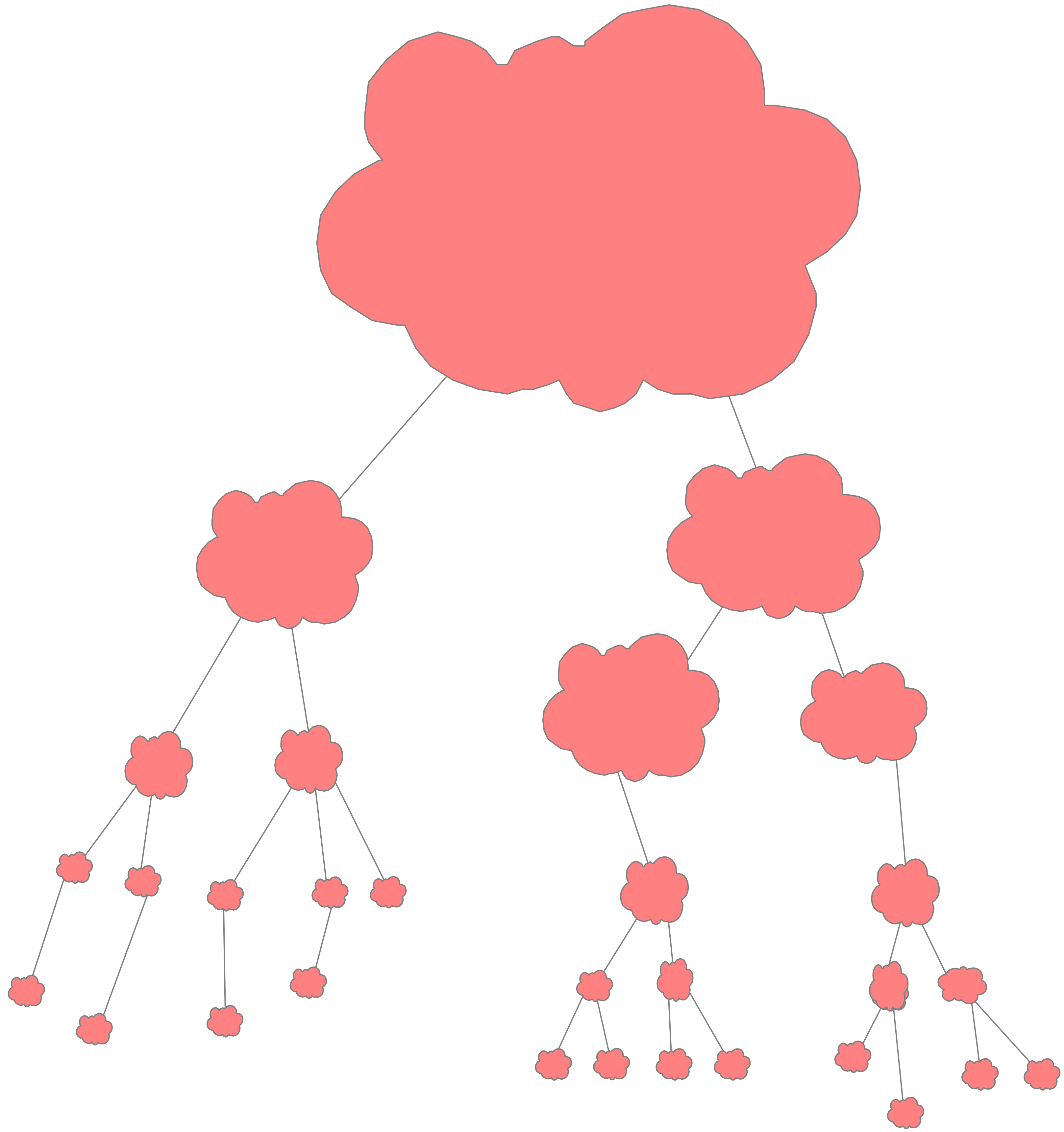
$$v_i > v_{\mathrm{esc}}(r_i) = \sqrt{2\left|\phi(r_i)\right|}$$

Repeat until no particles are removed anymore (center of mass velocity changes)

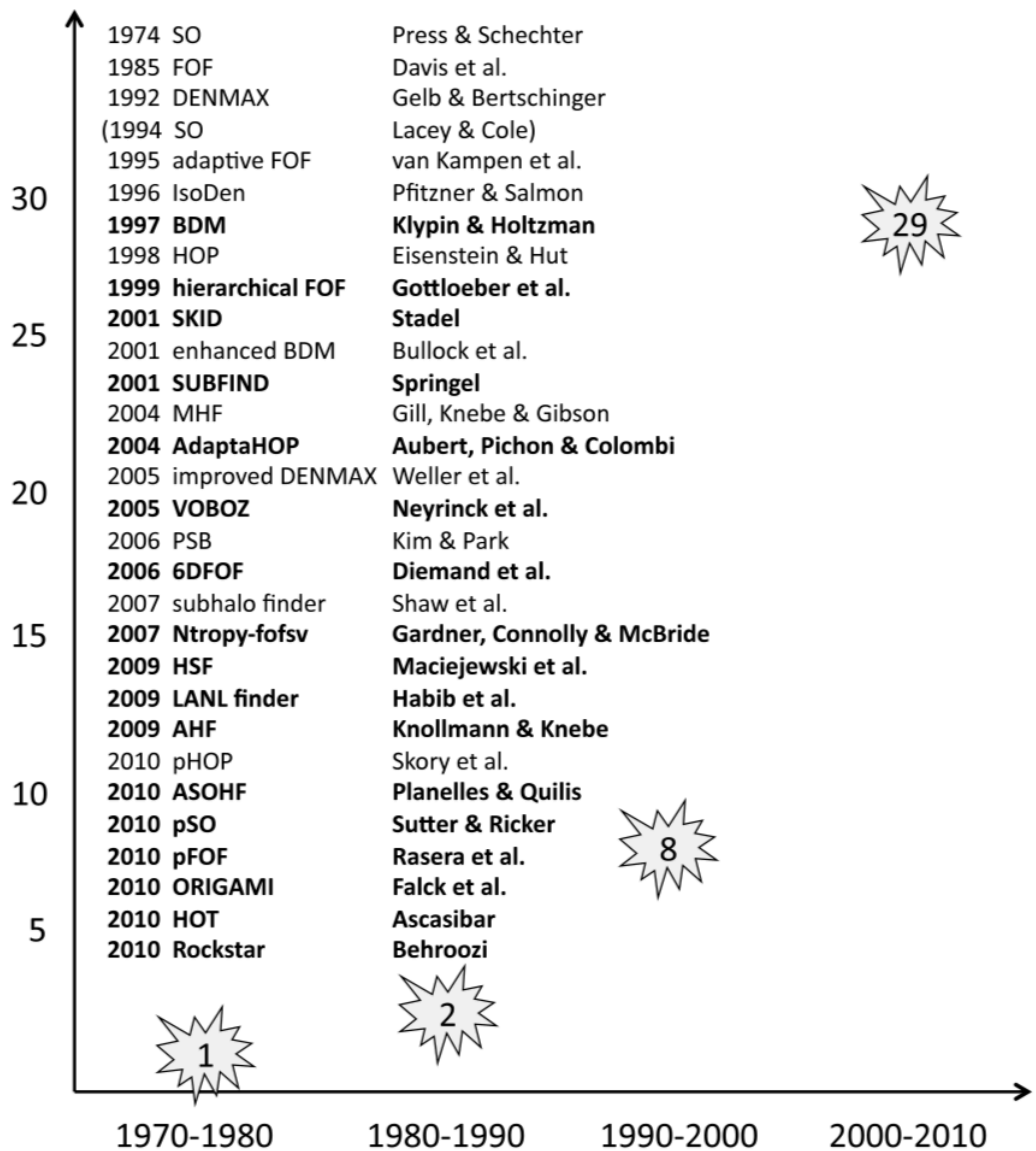
Start with halos in leaves of the tree, then walk up the hierarchy

Hierarchy of substructure candidates

- Need to unbind the leaves of the tree first
- Once they are done, erase them from the tree and do the next generation of leaves
- Repeat until you're done



Other halo finders



Knebe et al. 2011: The Halo-Finder Comparison Project

Merger trees