Voids in a continuous DM density field: redshift evolution

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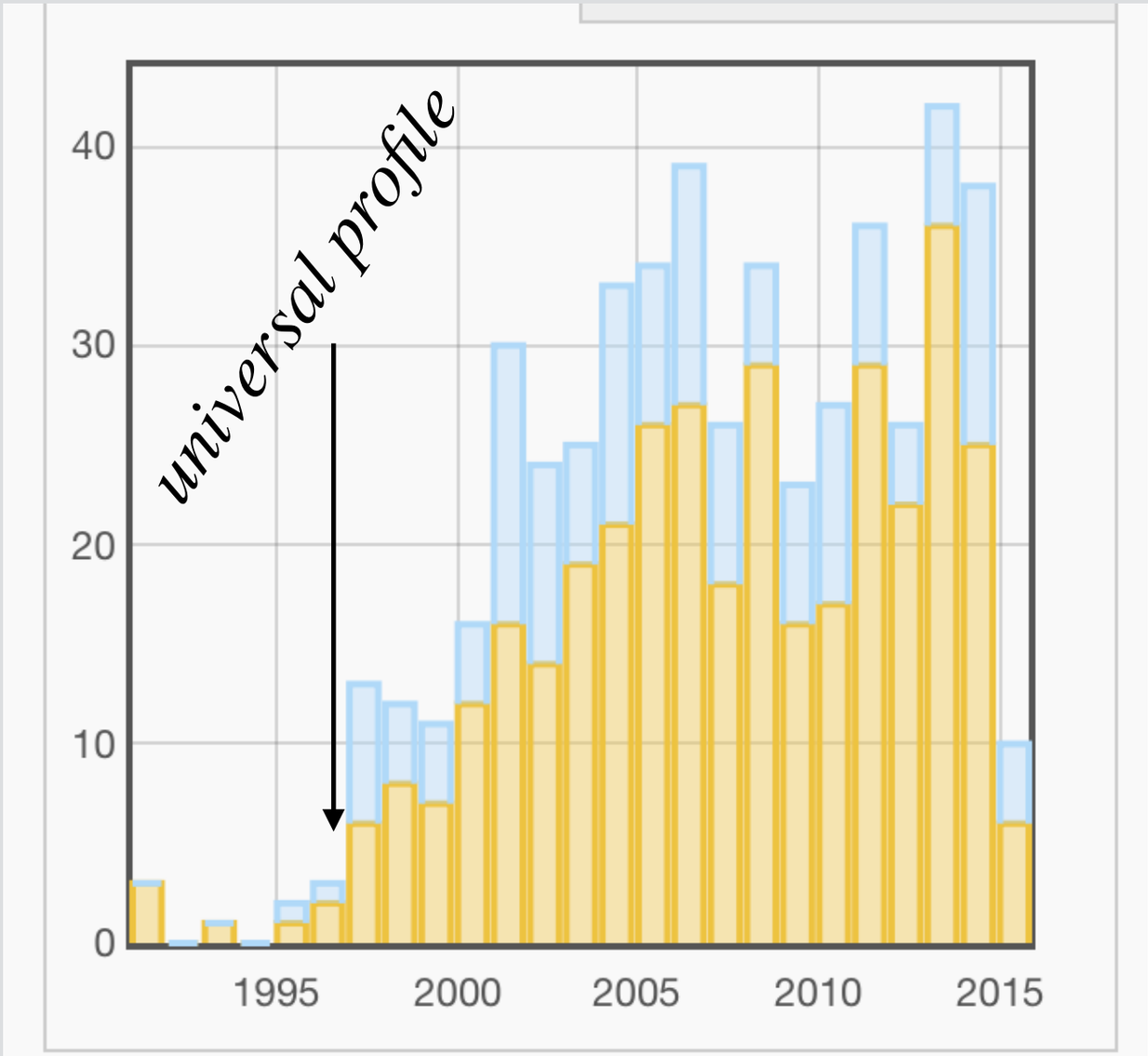
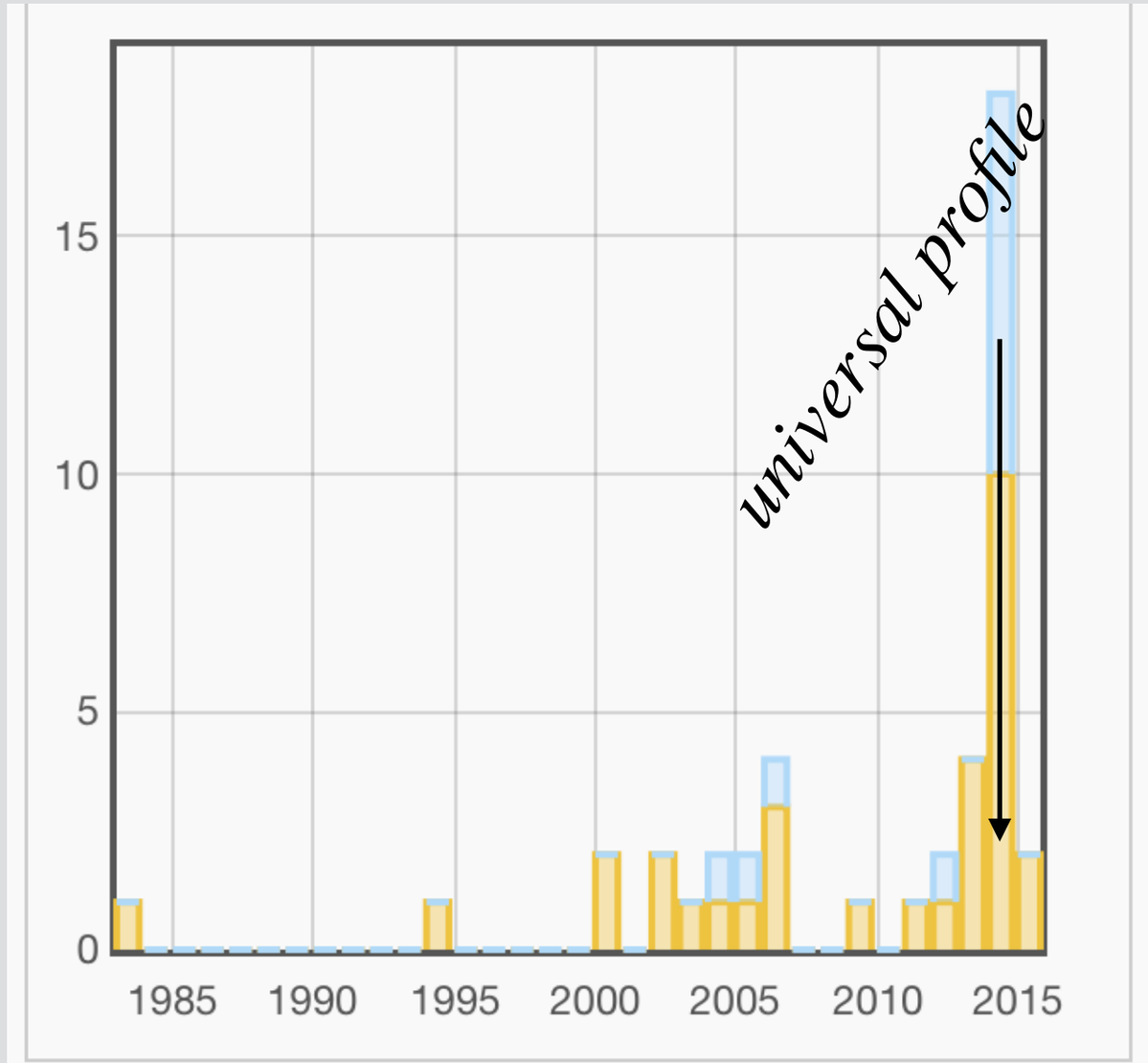
Outline

1. DM manifolds in phase space and new density estimator
2. Watershed algorithm
3. Grouping watershed basins into voids
4. Tracing evolution by matching catalogs of watershed voids: problems
5. Conditional watershed
6. From protovoids to voids: sizes, density profiles

Voids in cosmological simulations



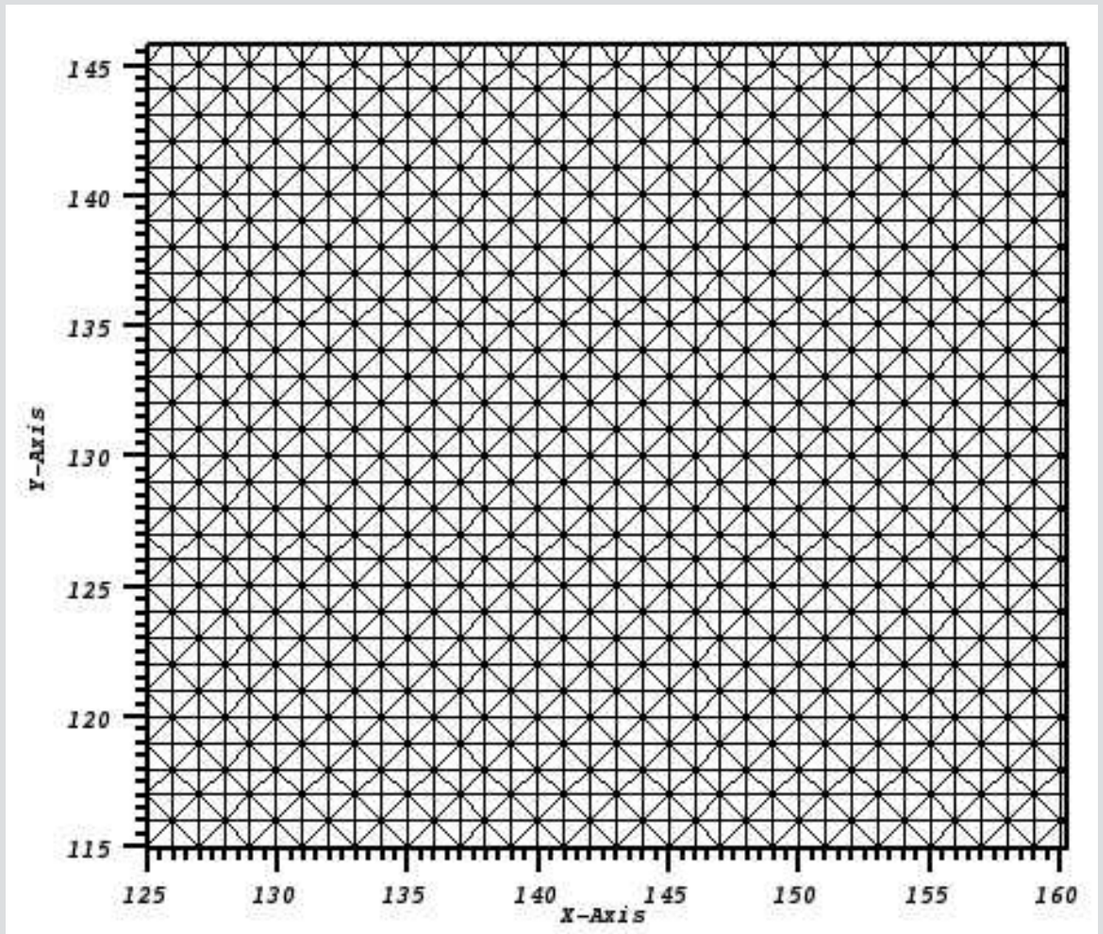


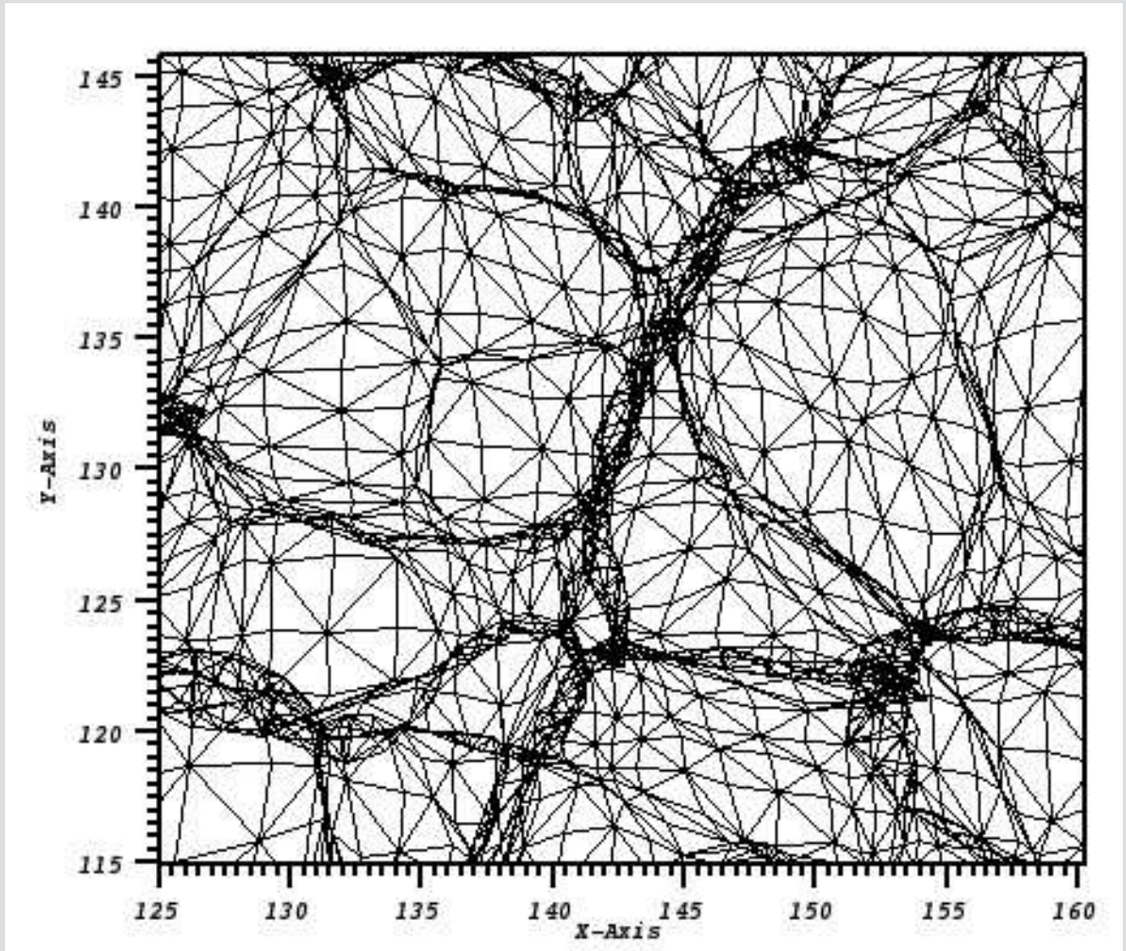
keywords: dark matter halo
density profile
simulation

keywords: void
density profile
simulation

Density from projecting DM sheets

- mass is smoothly distributed between DM particles (tetrahedra)
- density is defined at every point

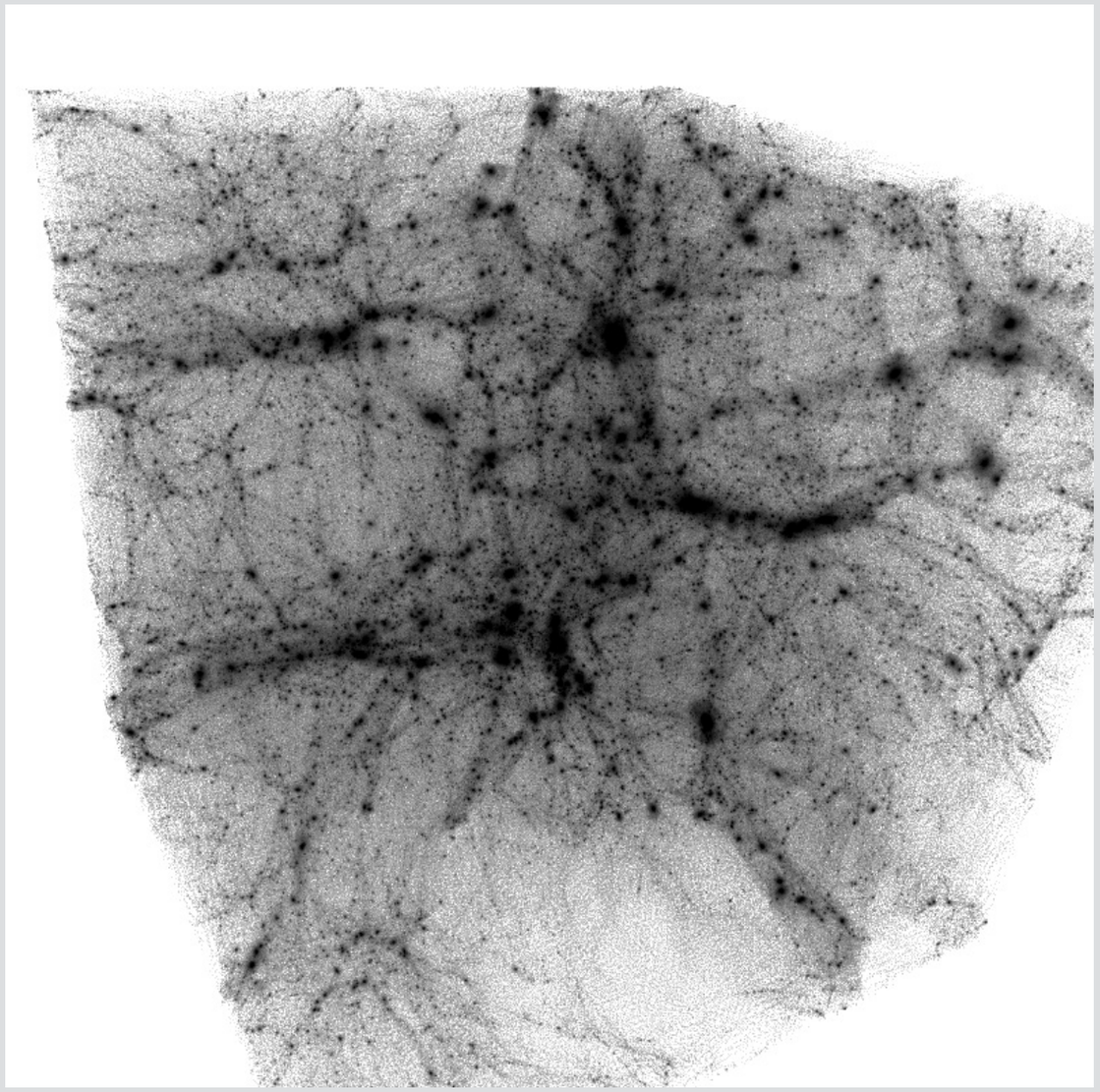




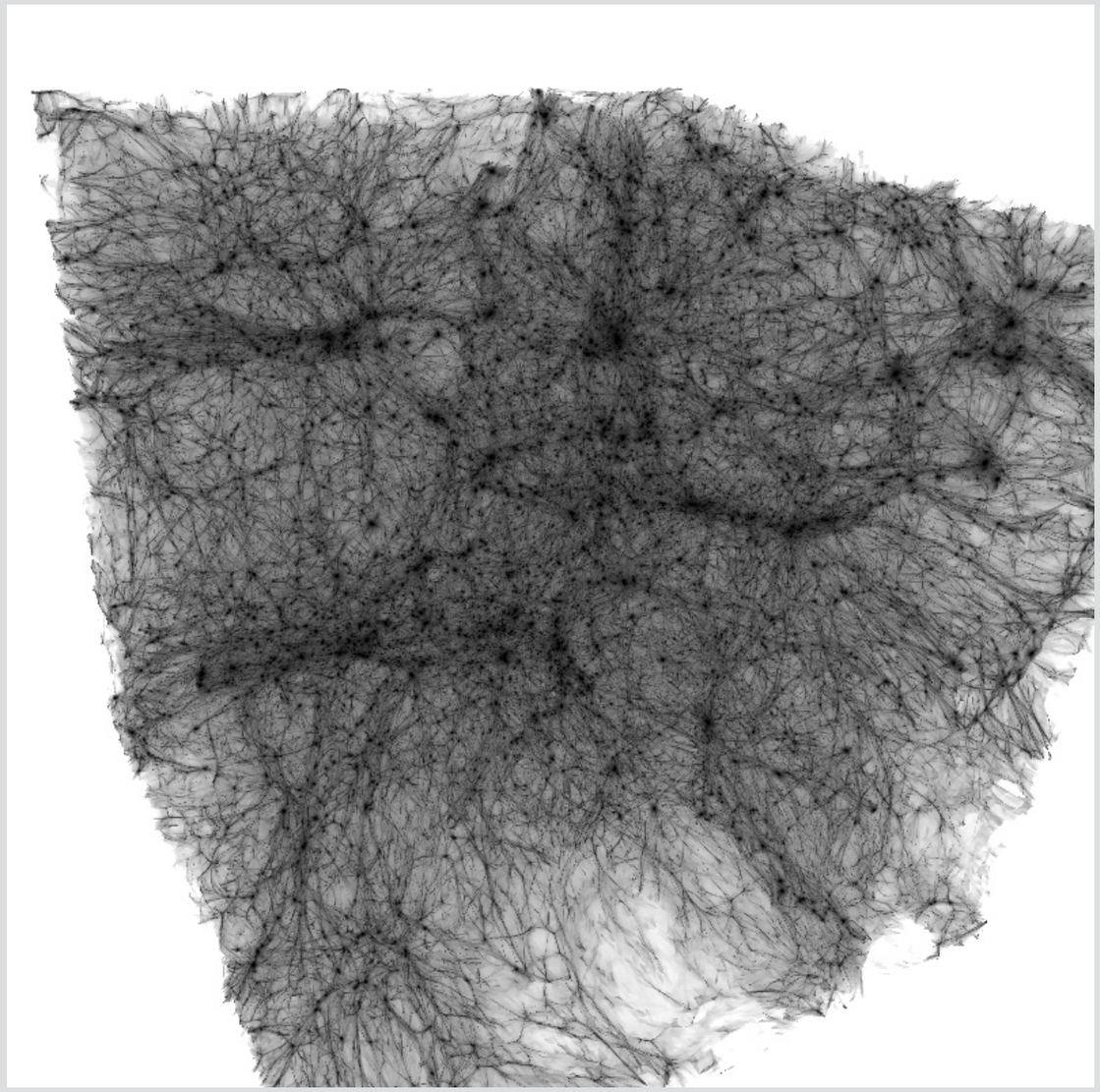
Shandarin et al (2012)

New density estimator

CIC



Tets

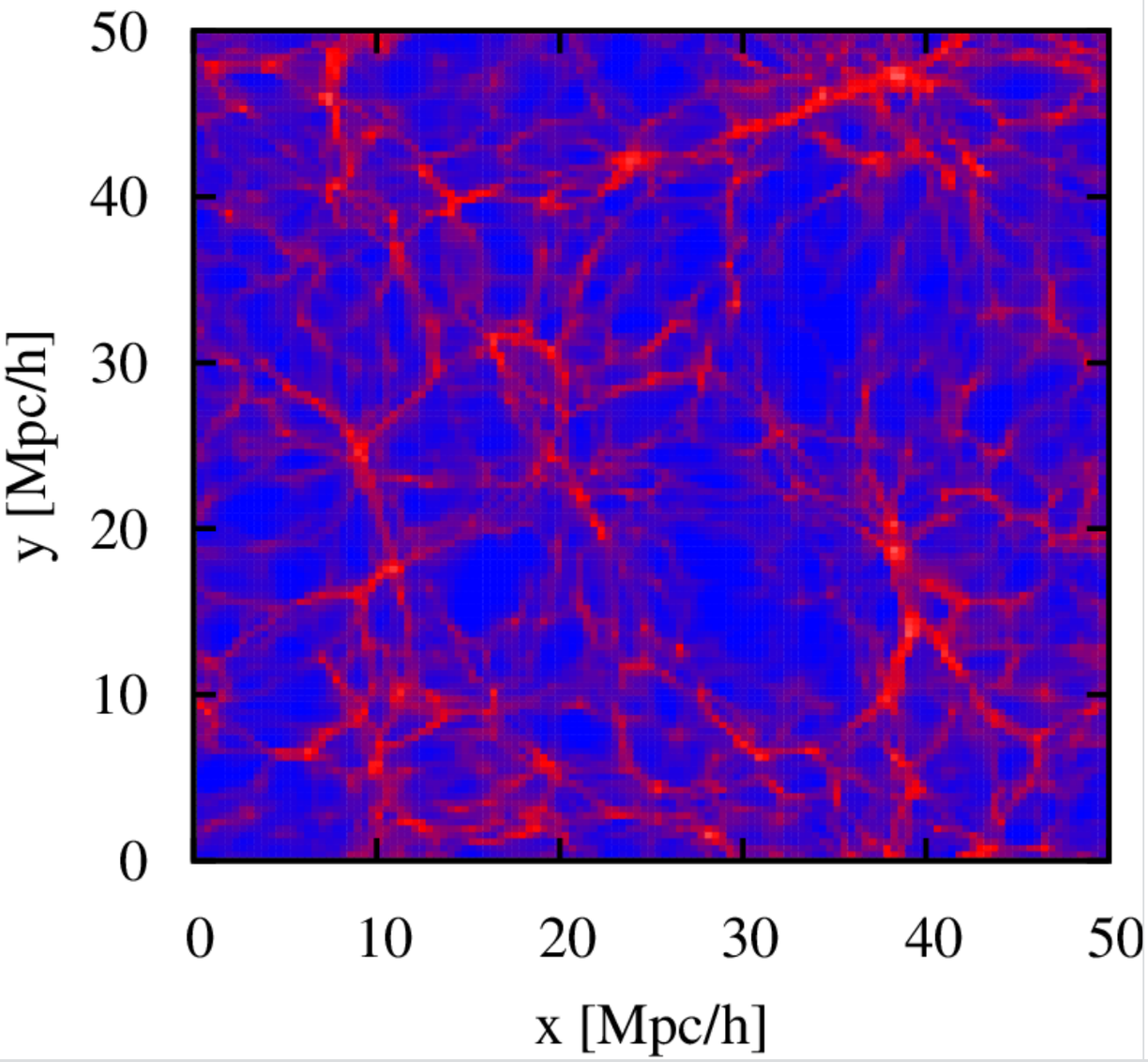


Abel, Hahn & Kaehler (2012)

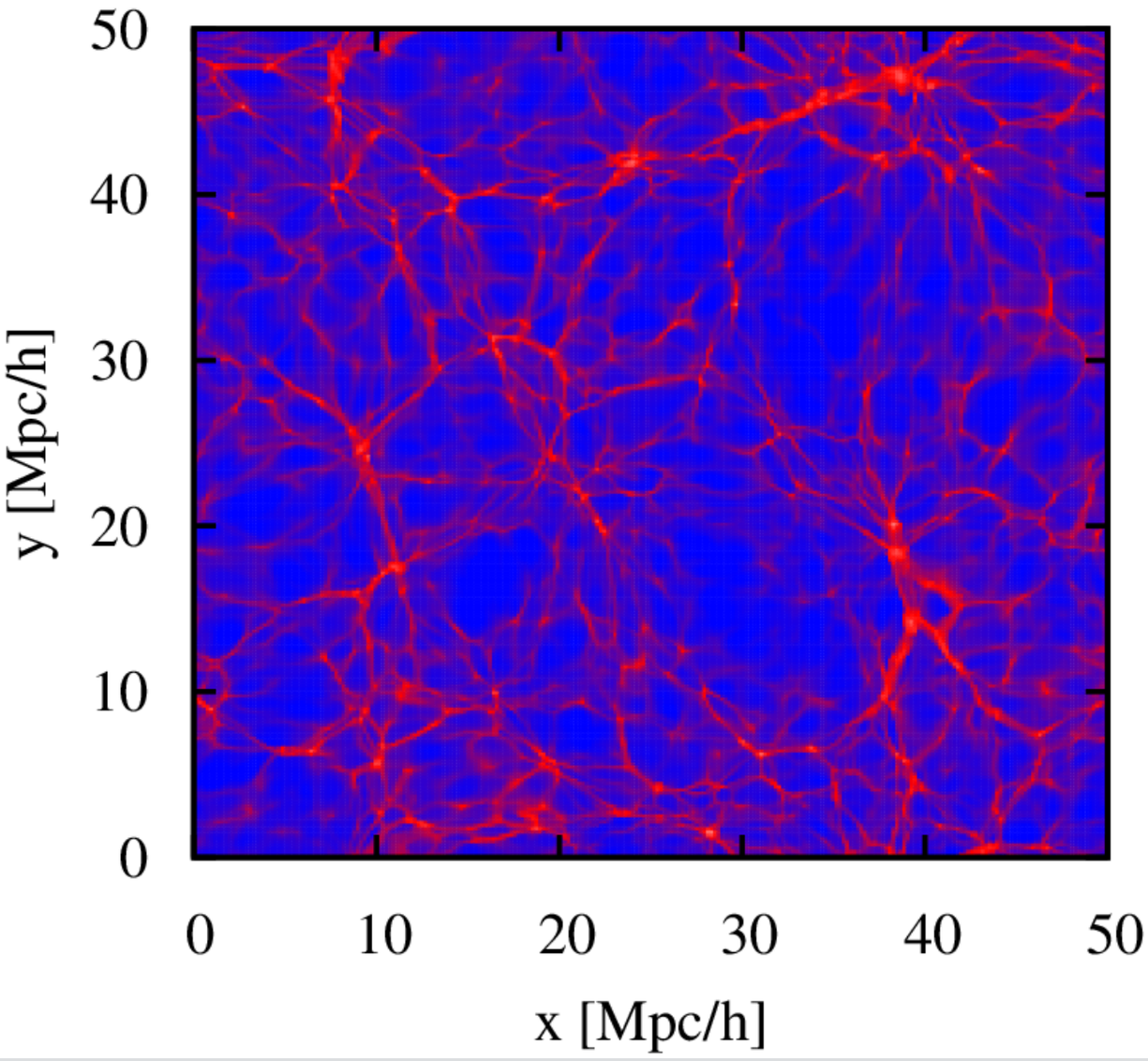
Density on regular grid

Phase Sheet Intersector (PSI)
Powell & Abel 2014

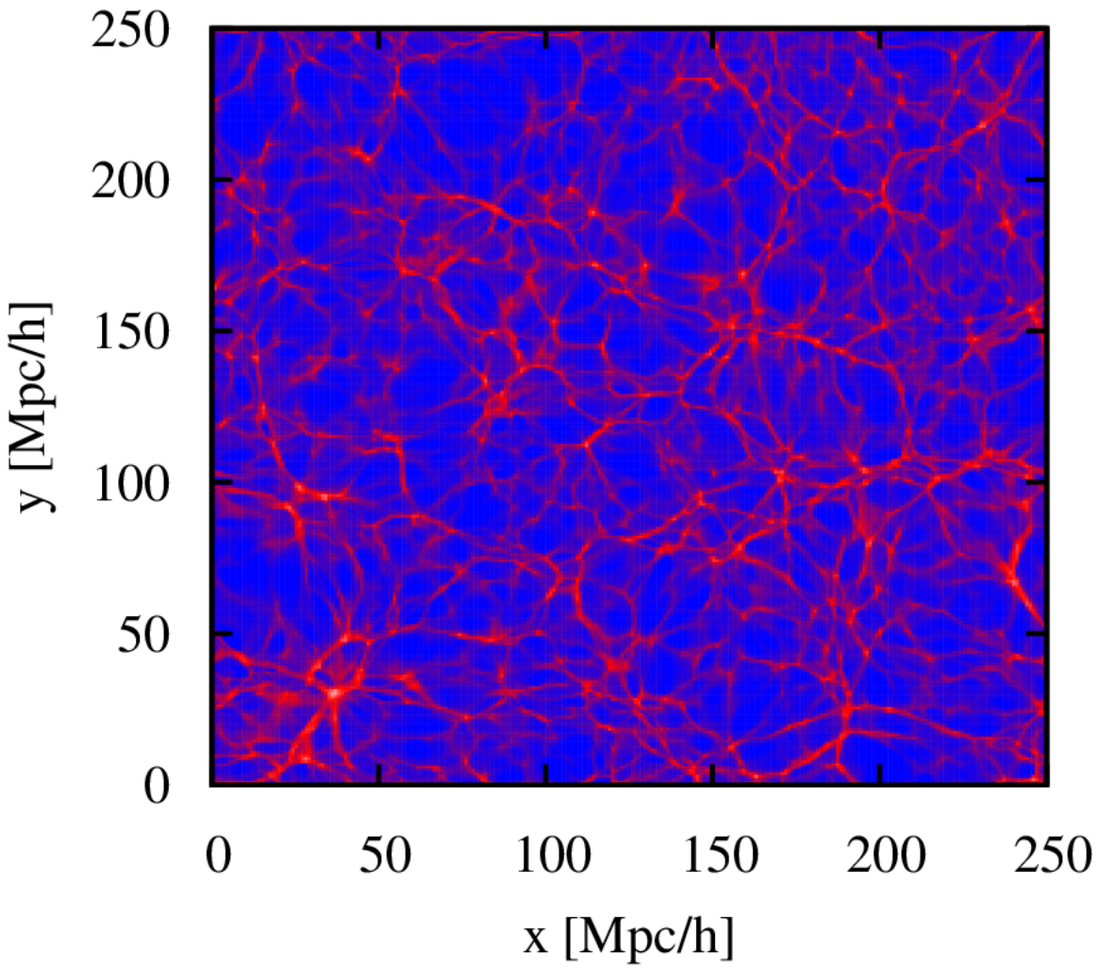
256^3 particles, 128^3 grid

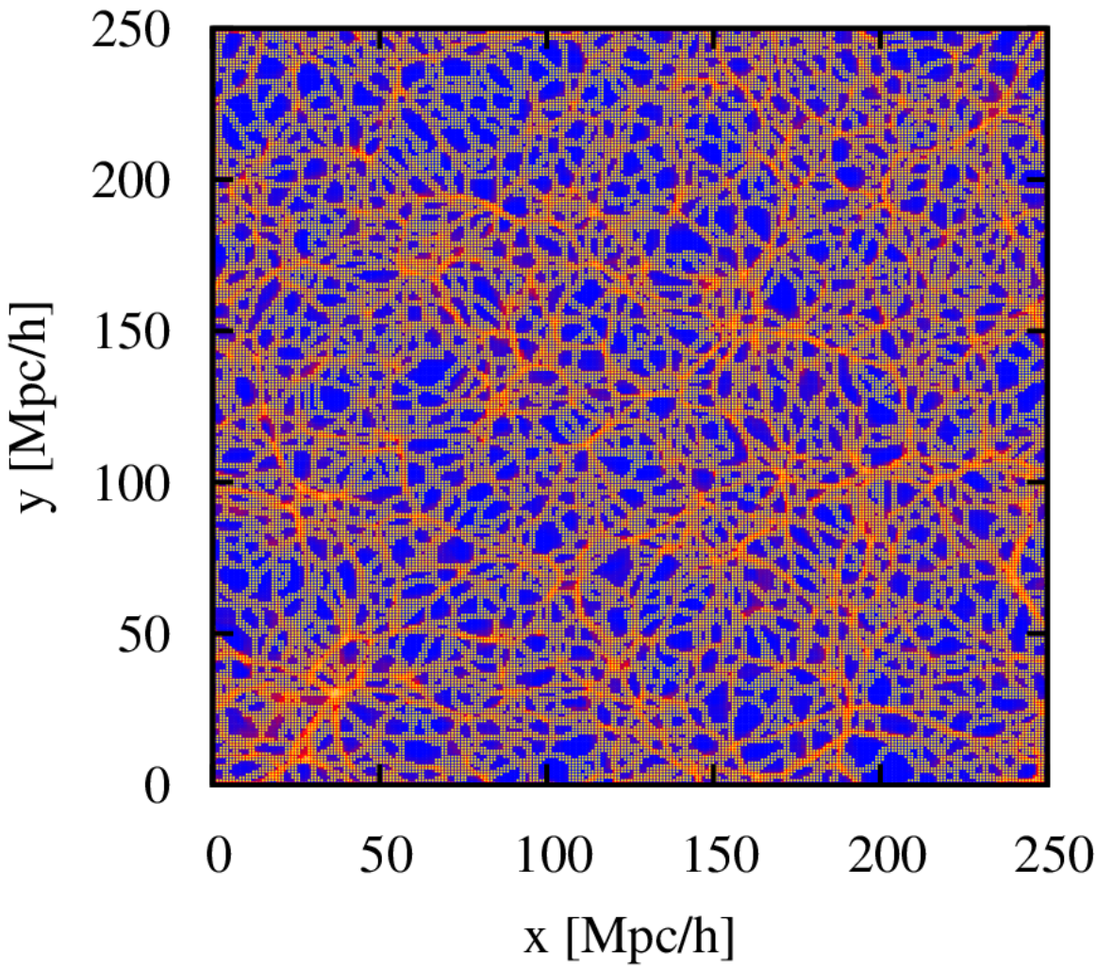


256^3 particles, 256^3 grid



Watershed algorithm

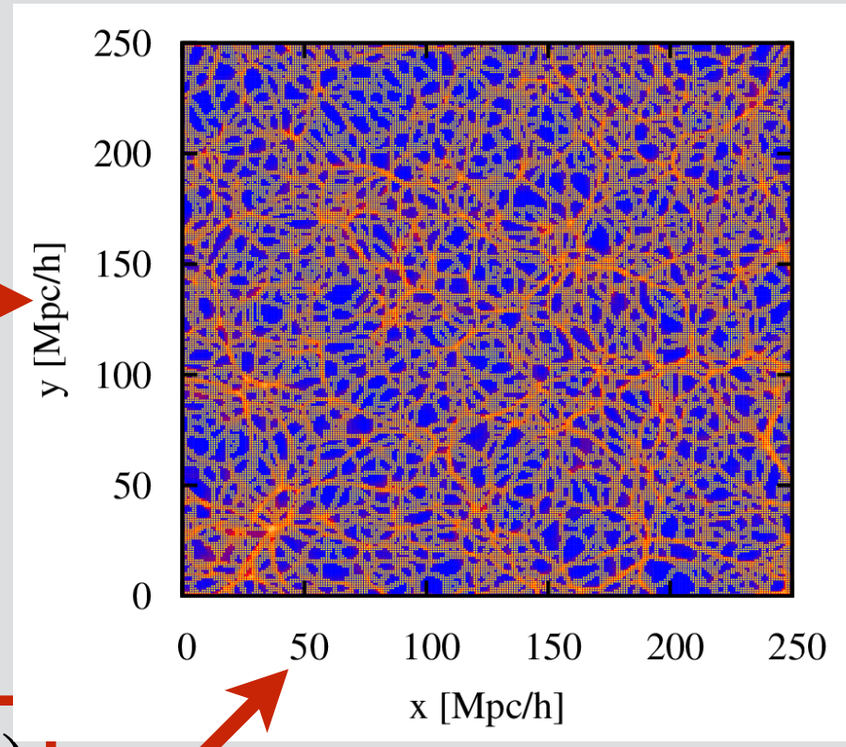




watershed basins

Voids from watershed basins

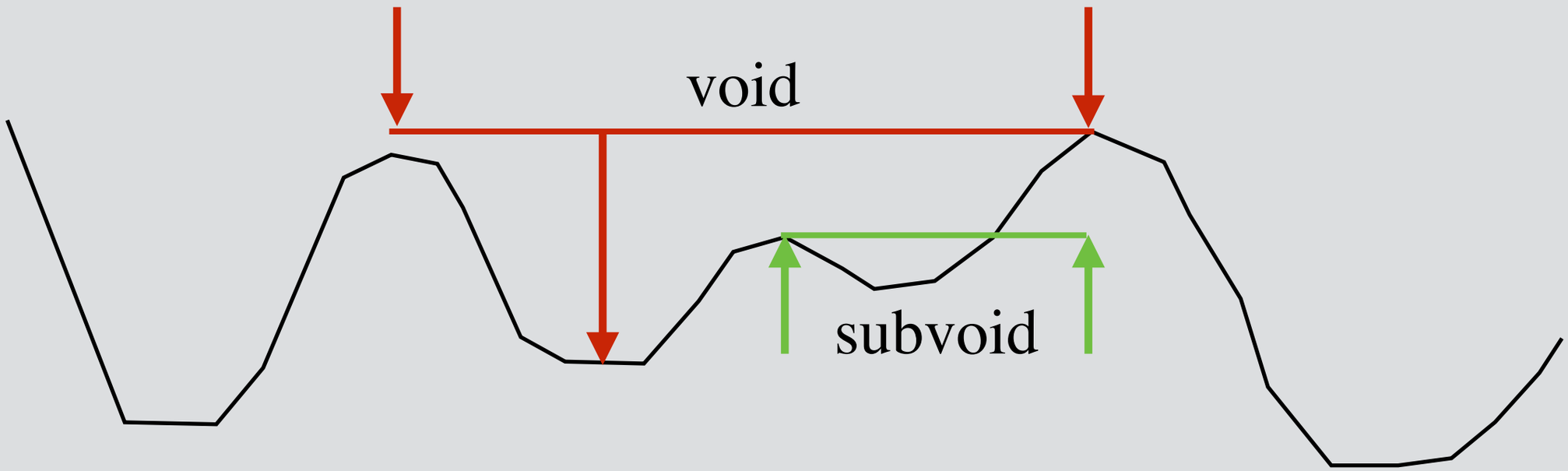
- removing boundaries (Platen et al 2007)
- no hierarchy
- parametric



- grouping basins into voids (Neyrinck 2008)
- hierarchical network
- non-parametric

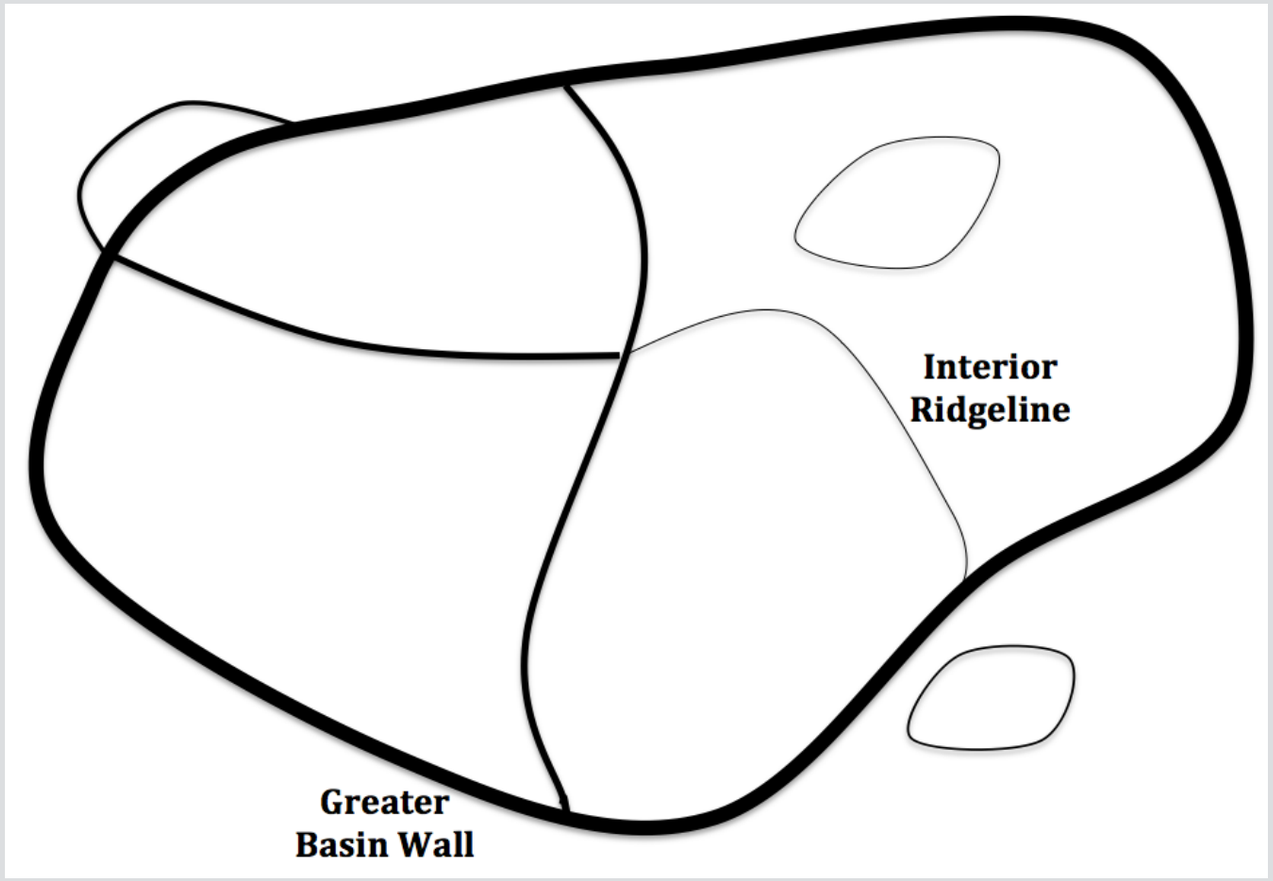
- multiscale morphology filter (Aragon-Calvo et al 2007)
- hierarchical network
- parametric

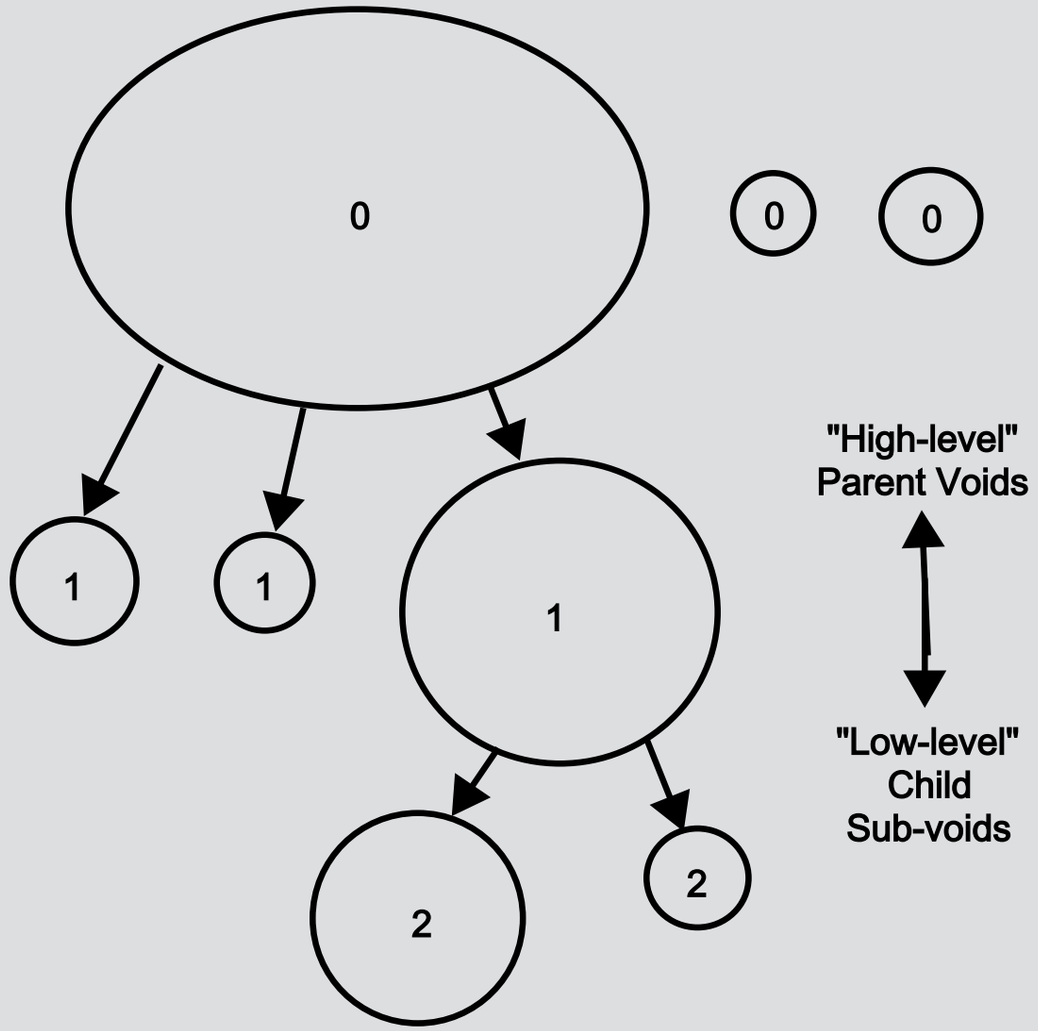
Grouping watershed basins (ZOBOV)



- minima of all basins are higher than the central basin
- saddle points inside in voids lower than saddle points at the boundaries
- non-parametric, but it a common practice to use a density threshold defining a minimum density barrer

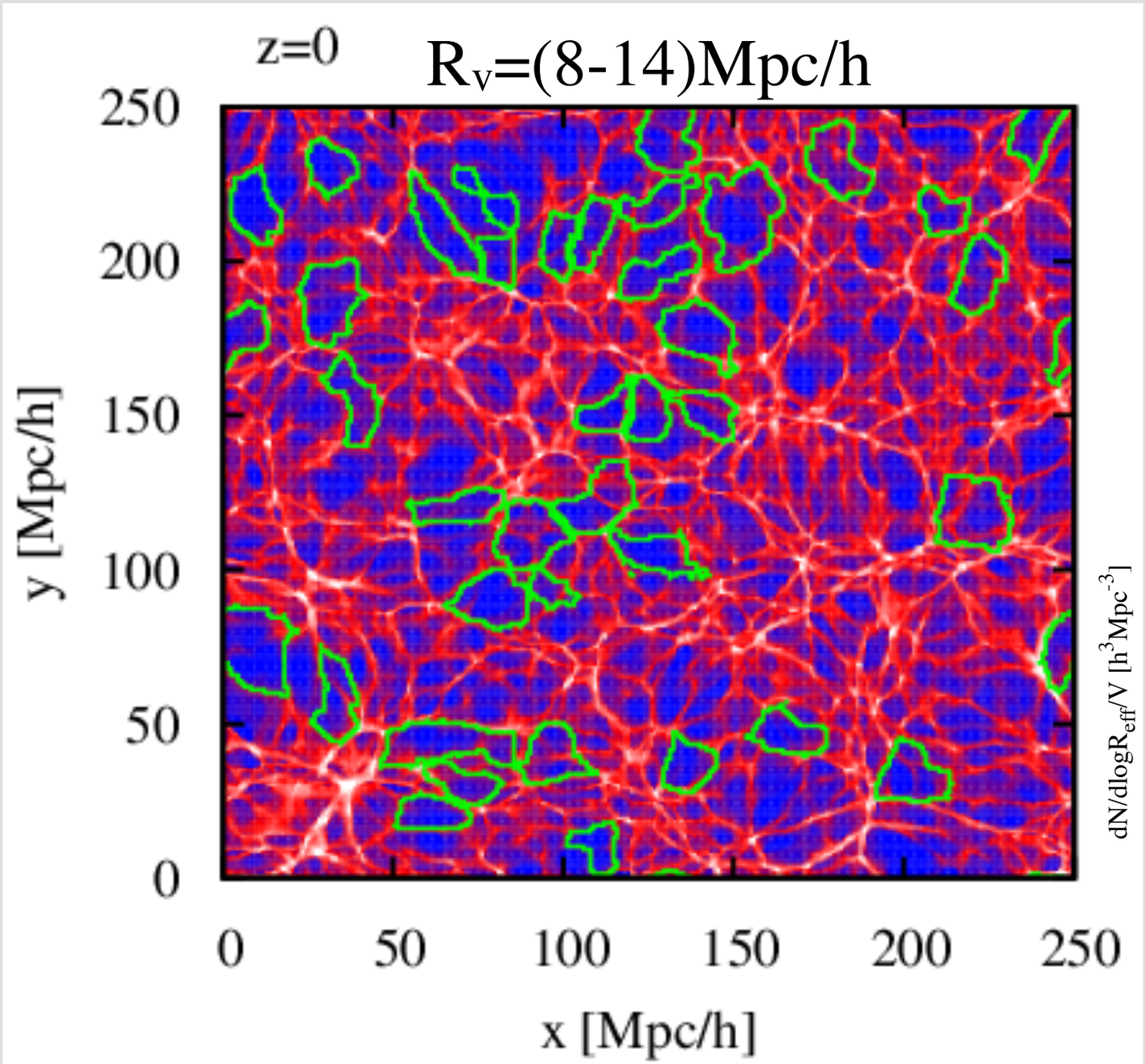
Void hierarchy





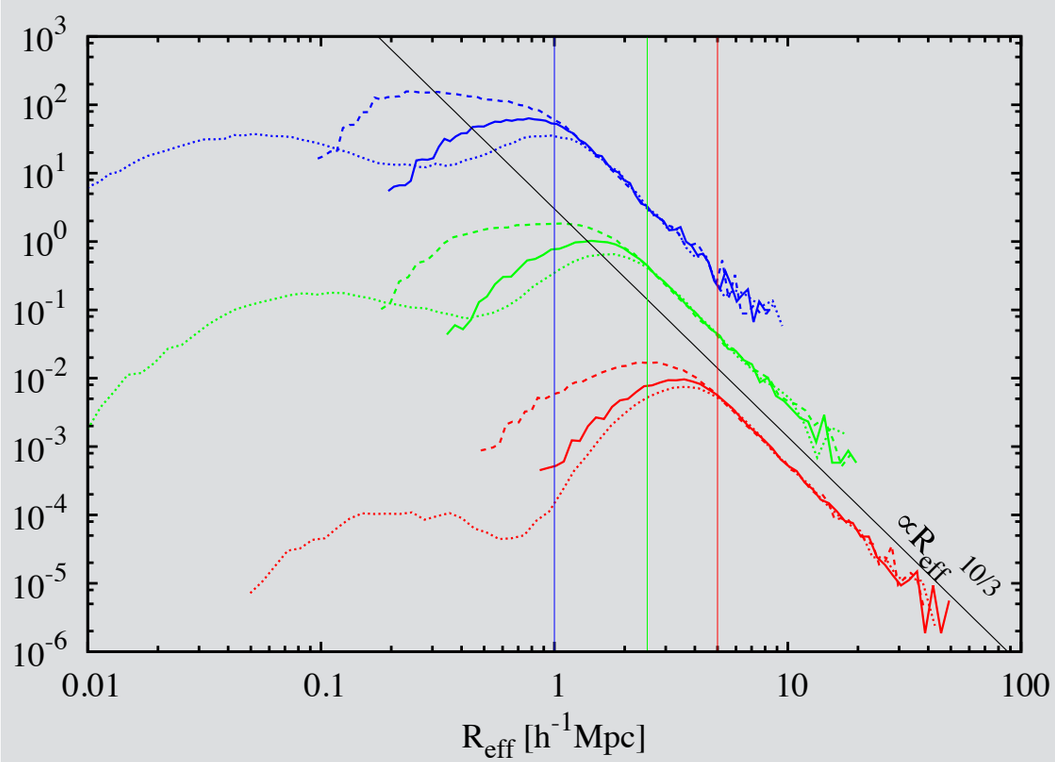
Sutter et al (2014)

Example



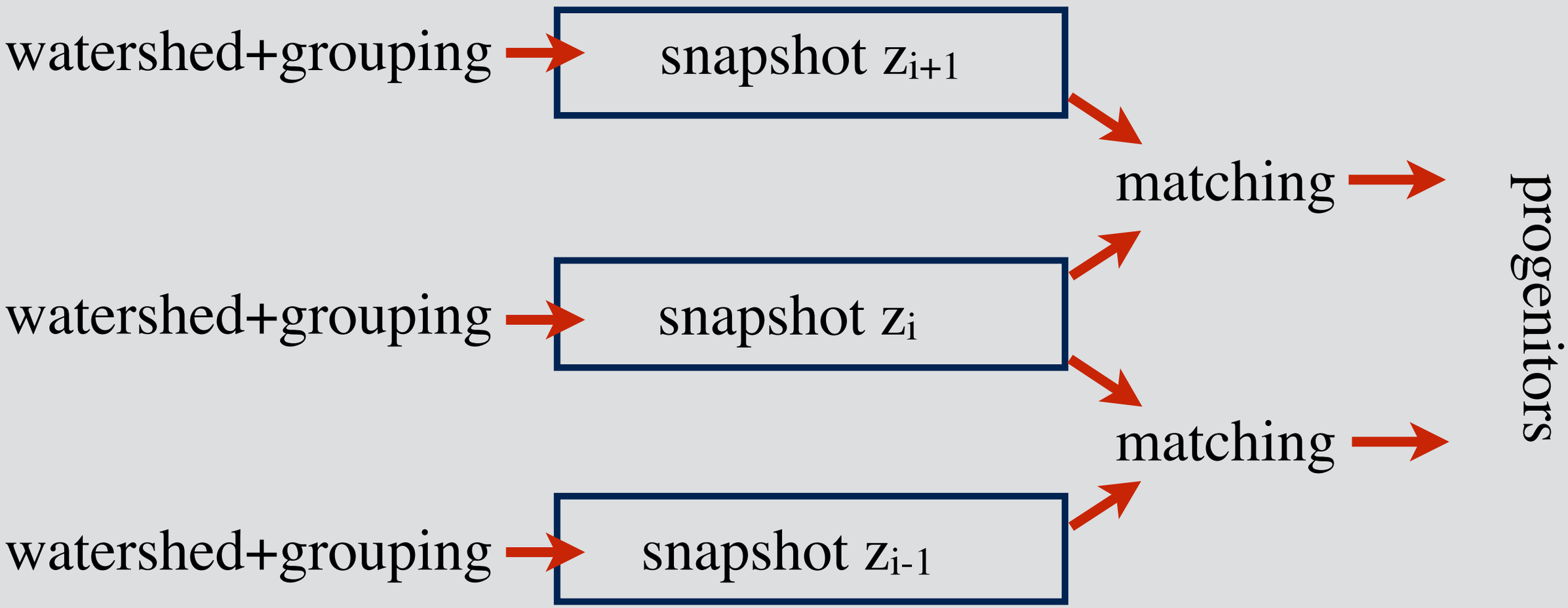
comparison:

- density estimator
- grid resolution
- mass resolution

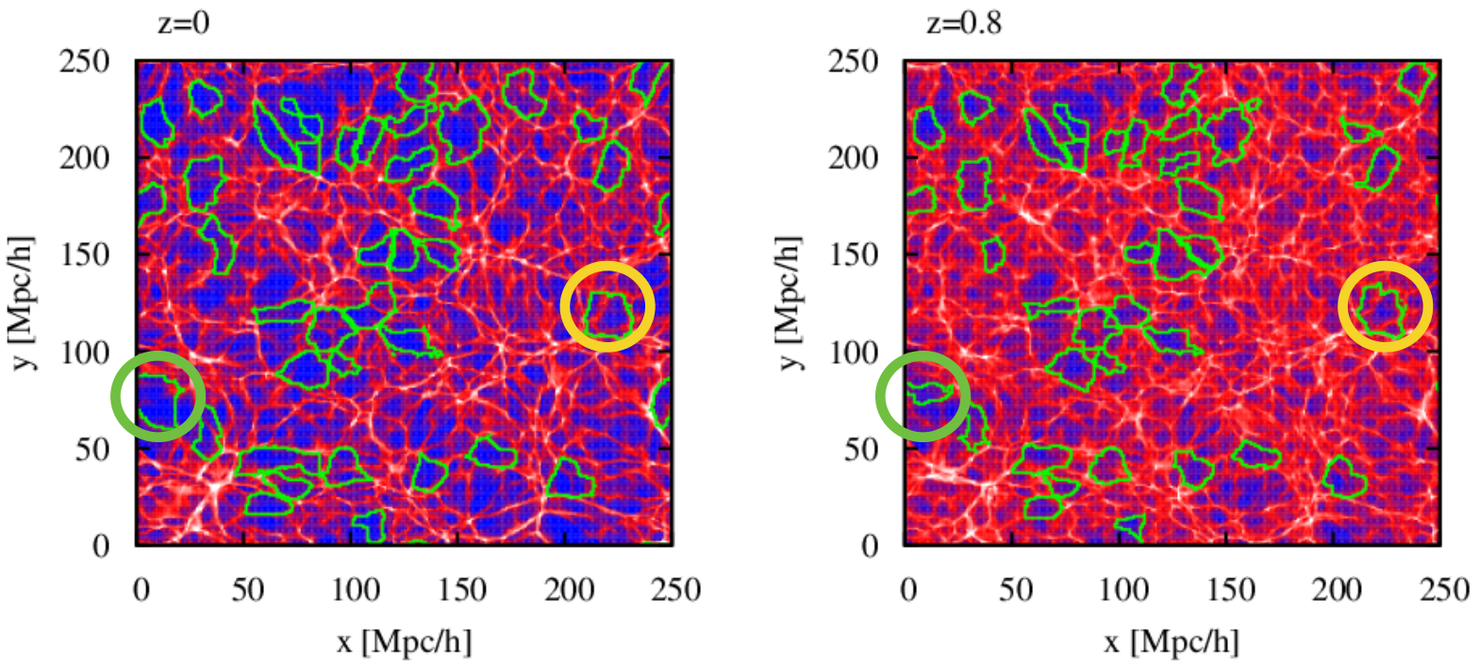


non-parametric (no density threshold)

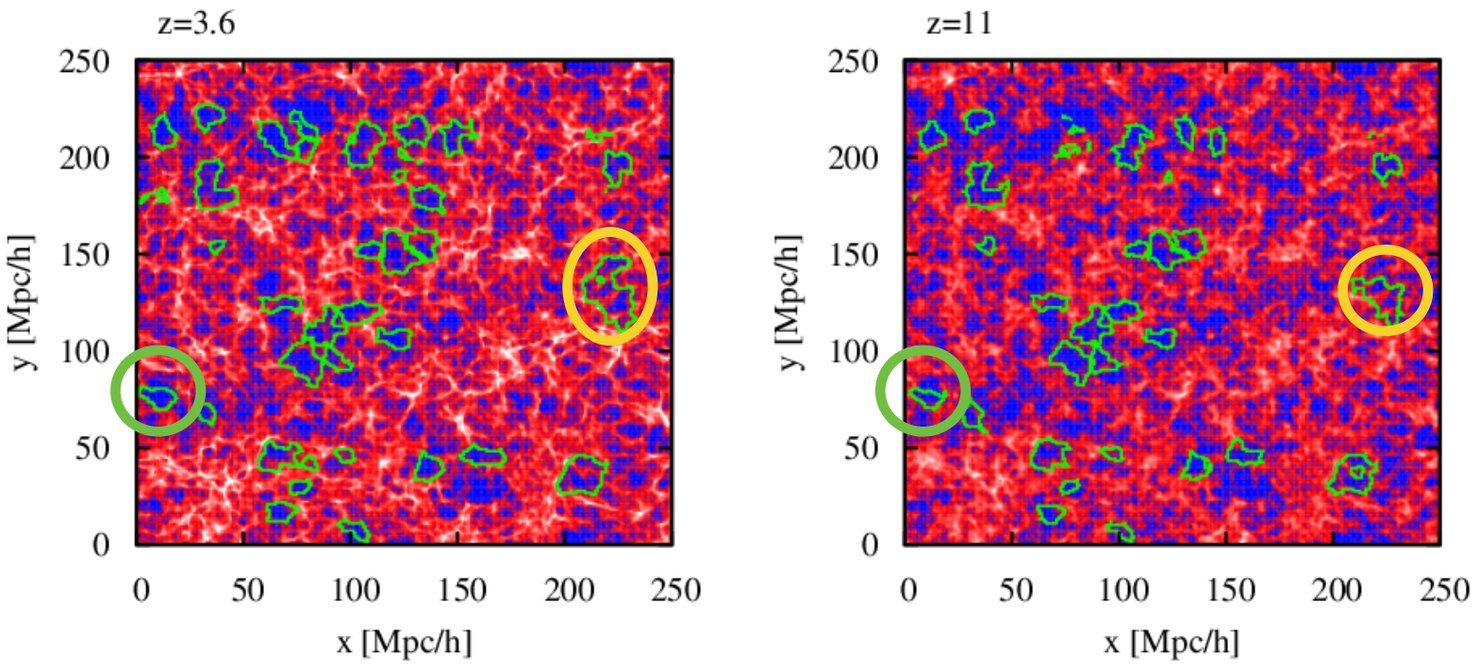
Watershed, grouping, matching



Example

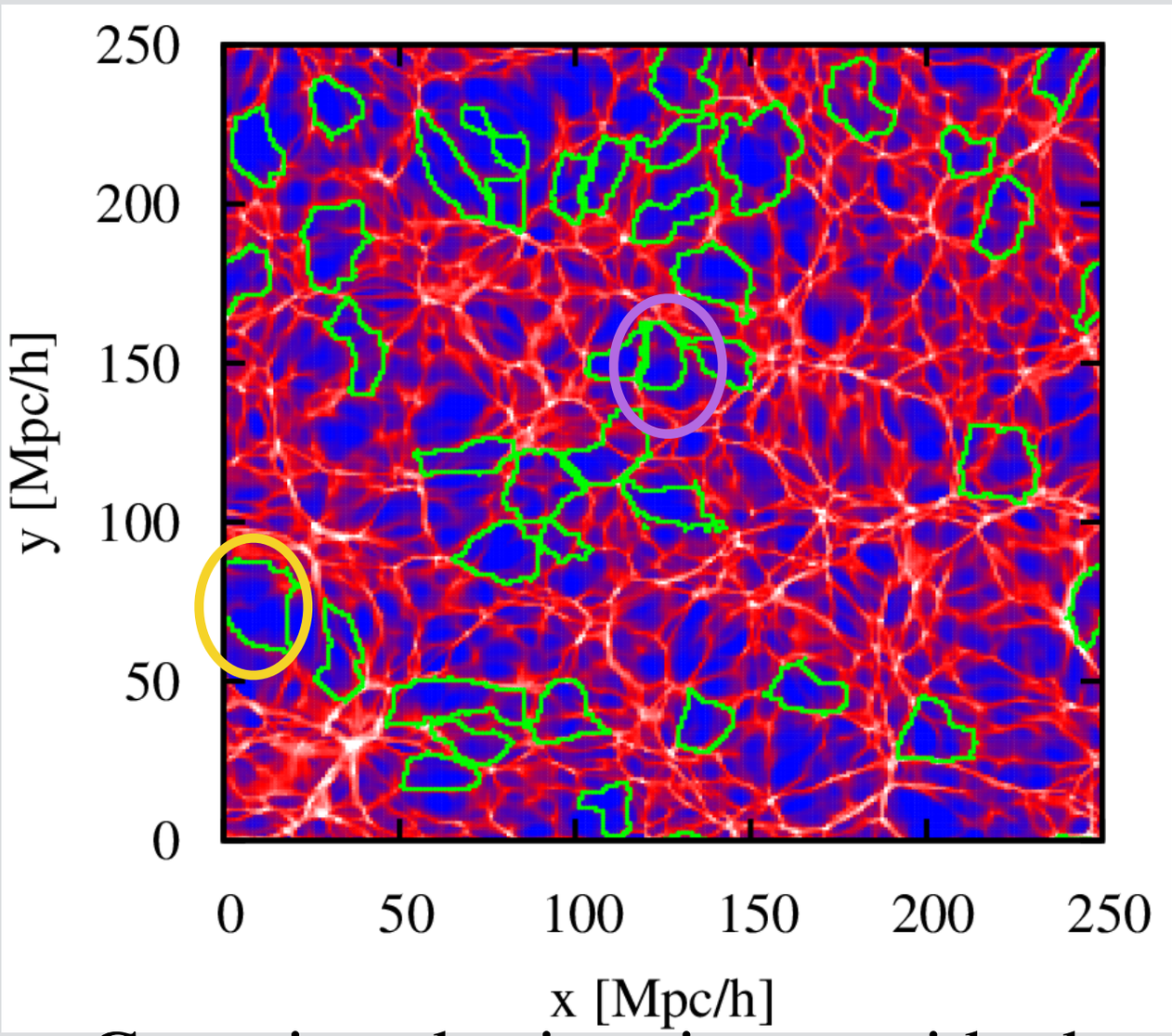


R_v=(8-14)Mpc/h at z=0

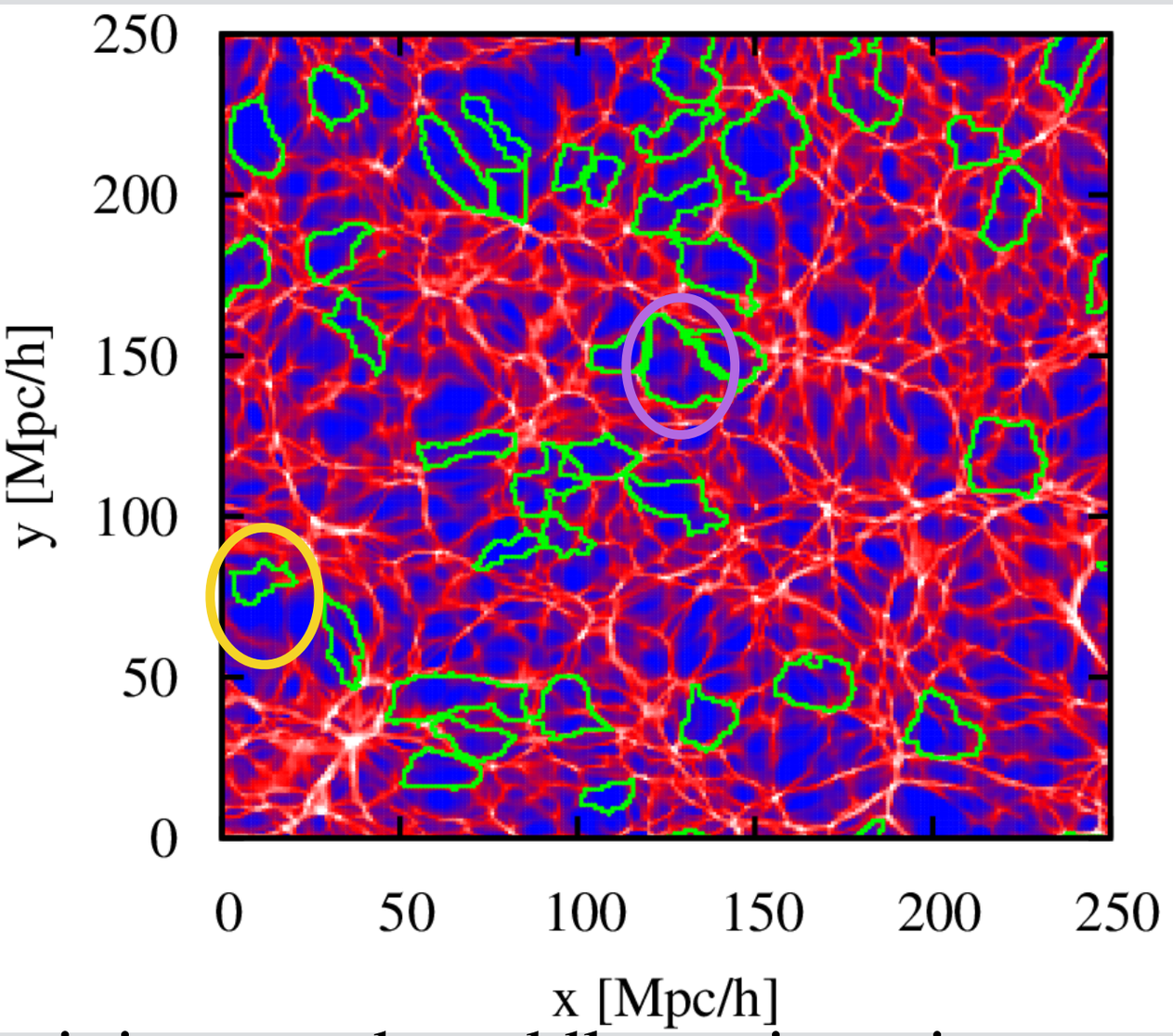


Resolution test

256^3 particles, 256^3 grid

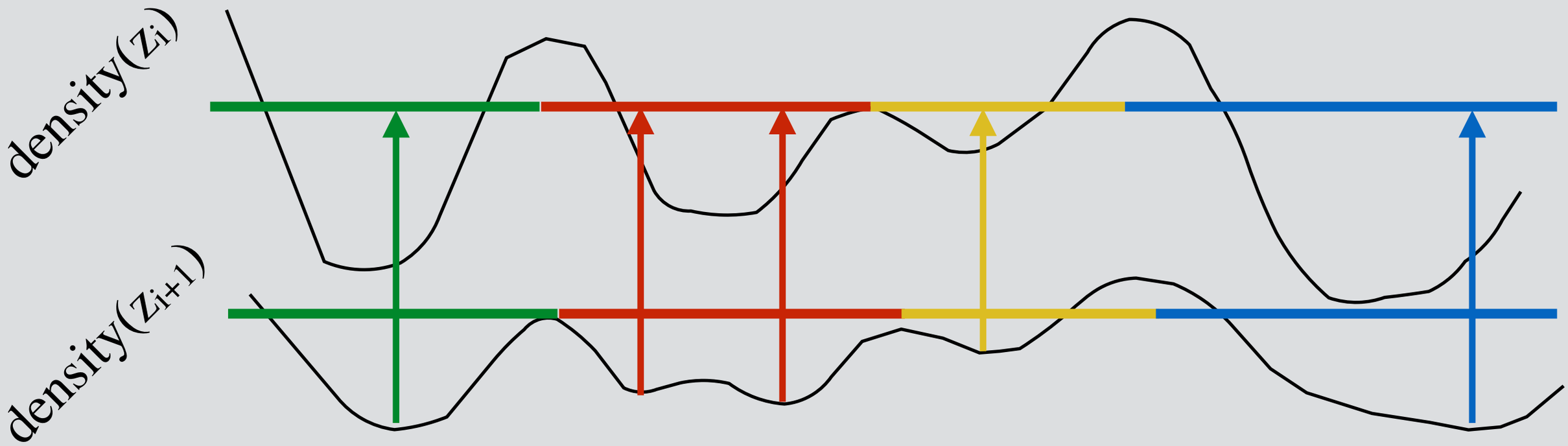


resimulation with 512^3 particles downsampled to 256^3, 256^3 grid



Grouping basins into voids by minima and saddle points is sensitive to how the critical points are ordered (changed by small-scale modes).

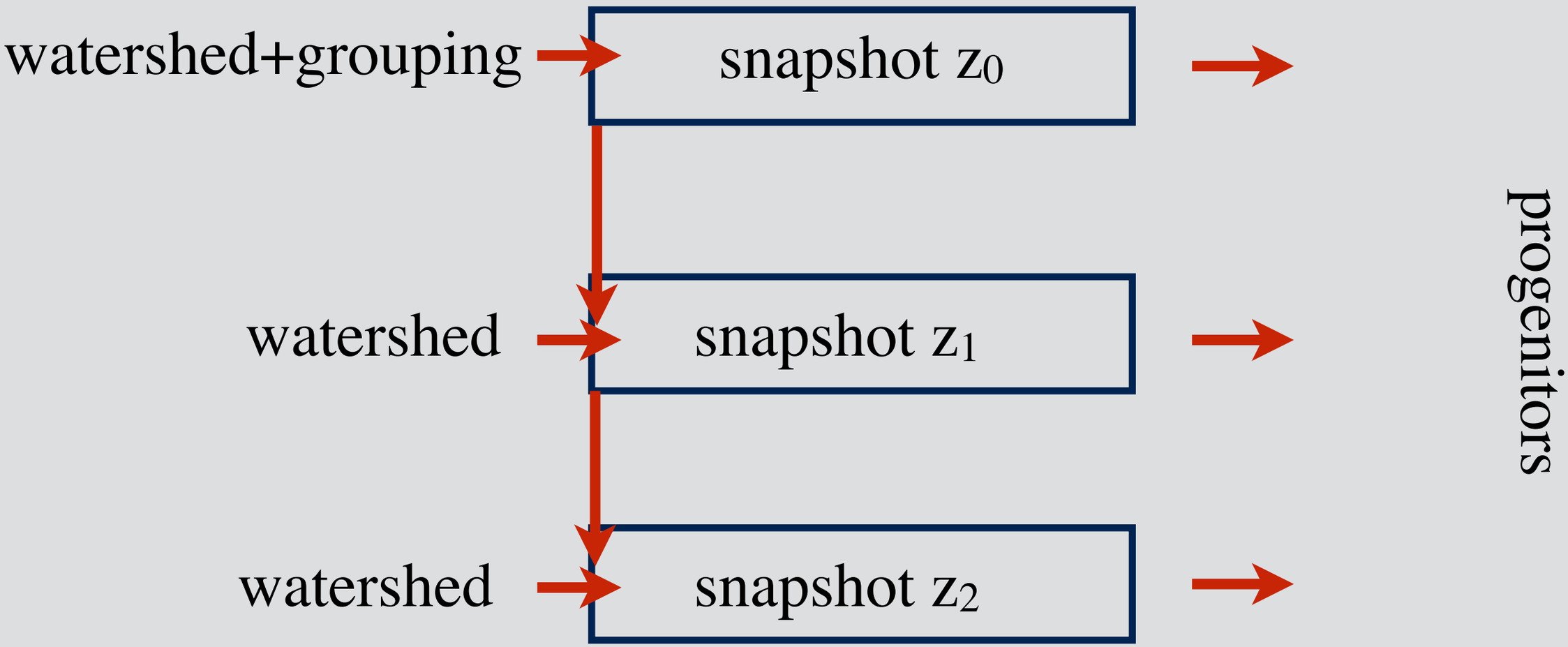
Conditional watershed instead of matching



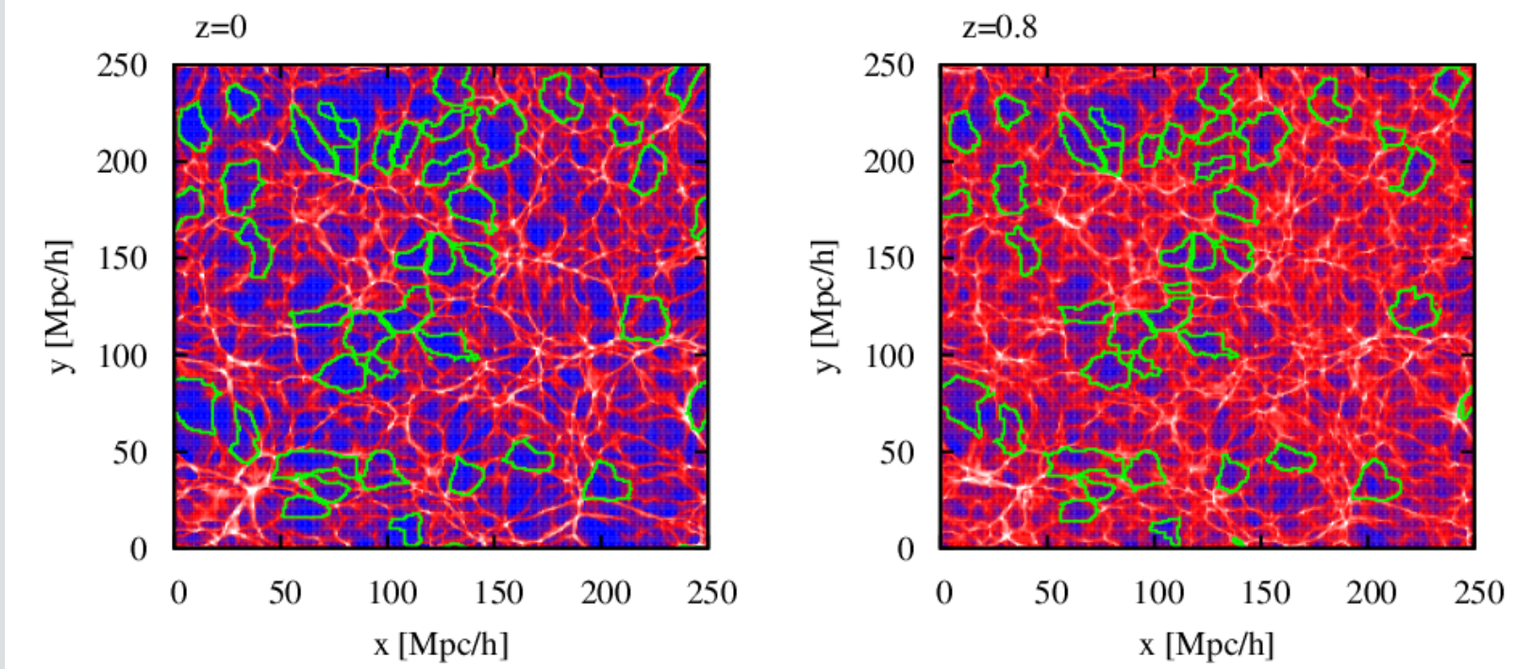
every minimum at z_i inherits a label of the corresponding basin from $z_i > z_{i+1}$

- keeps the same number of basins
- enables to keep the same grouping of basins into voids
- keeps the same hierarchical relations

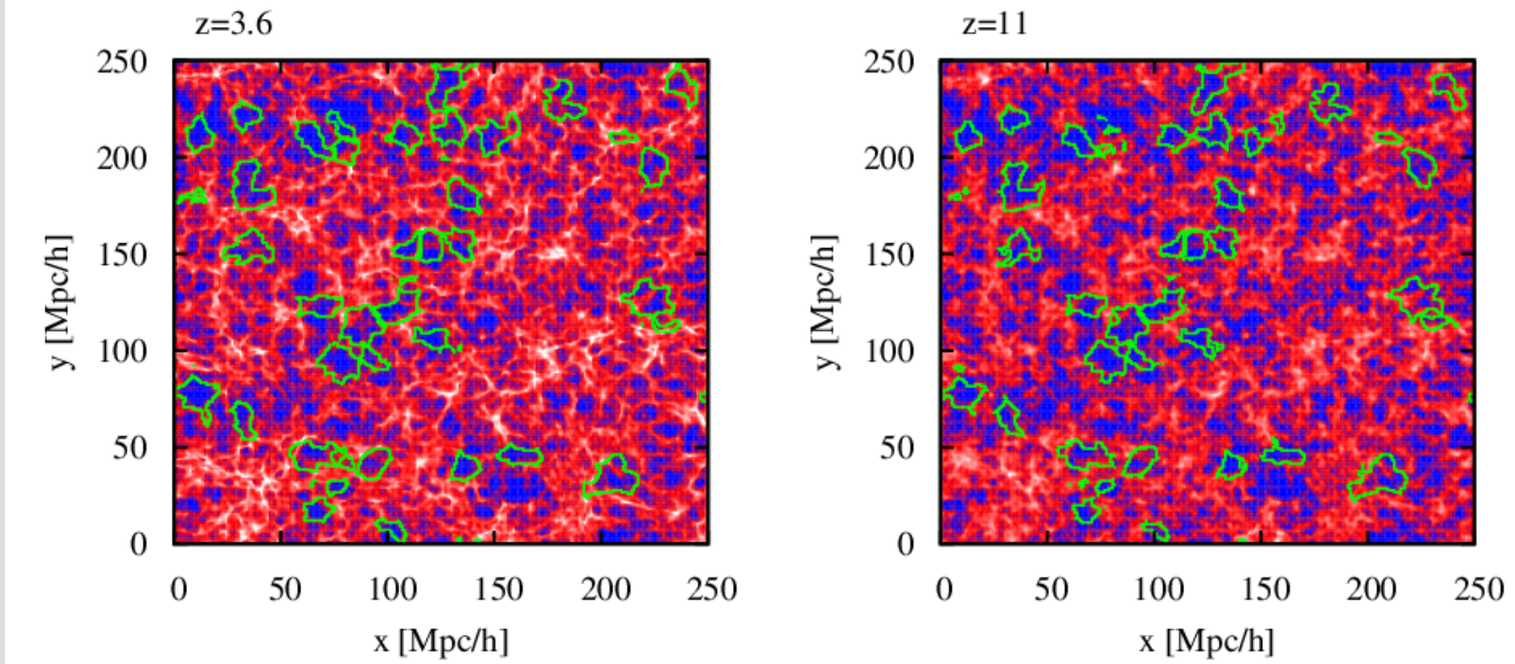
Conditional watershed with fixed grouping



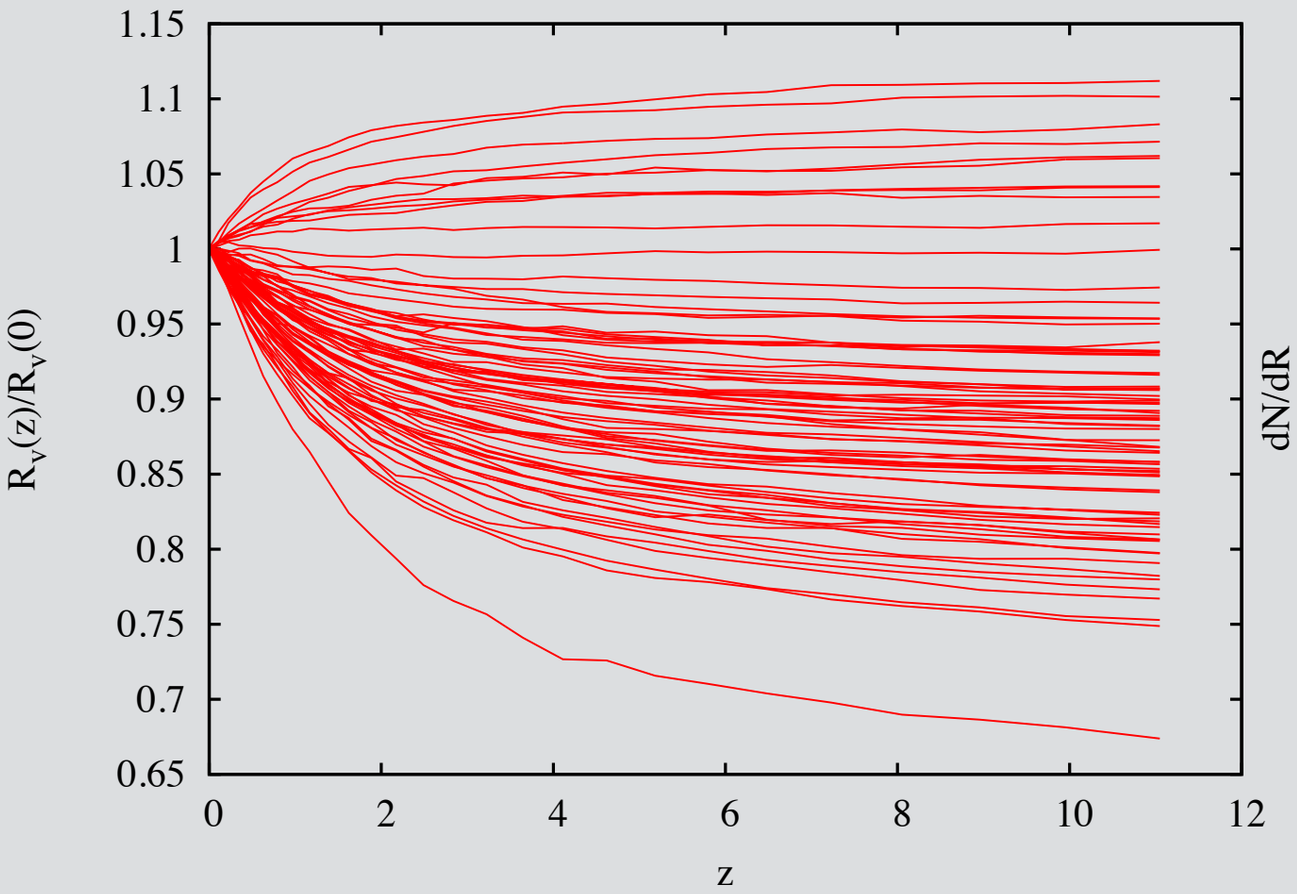
Conditional watershed: example

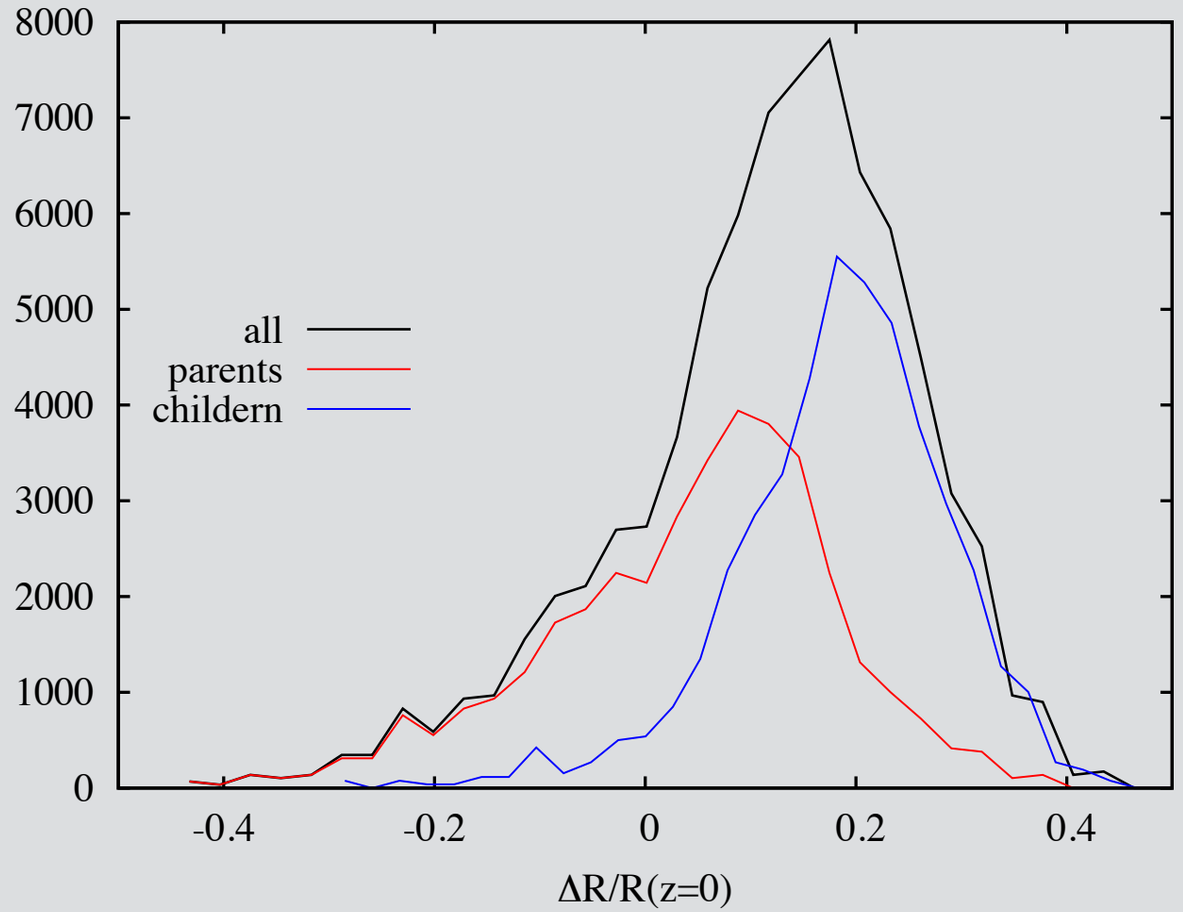


R_v=(8-14)Mpc/h at z=0



Evolution of R_v



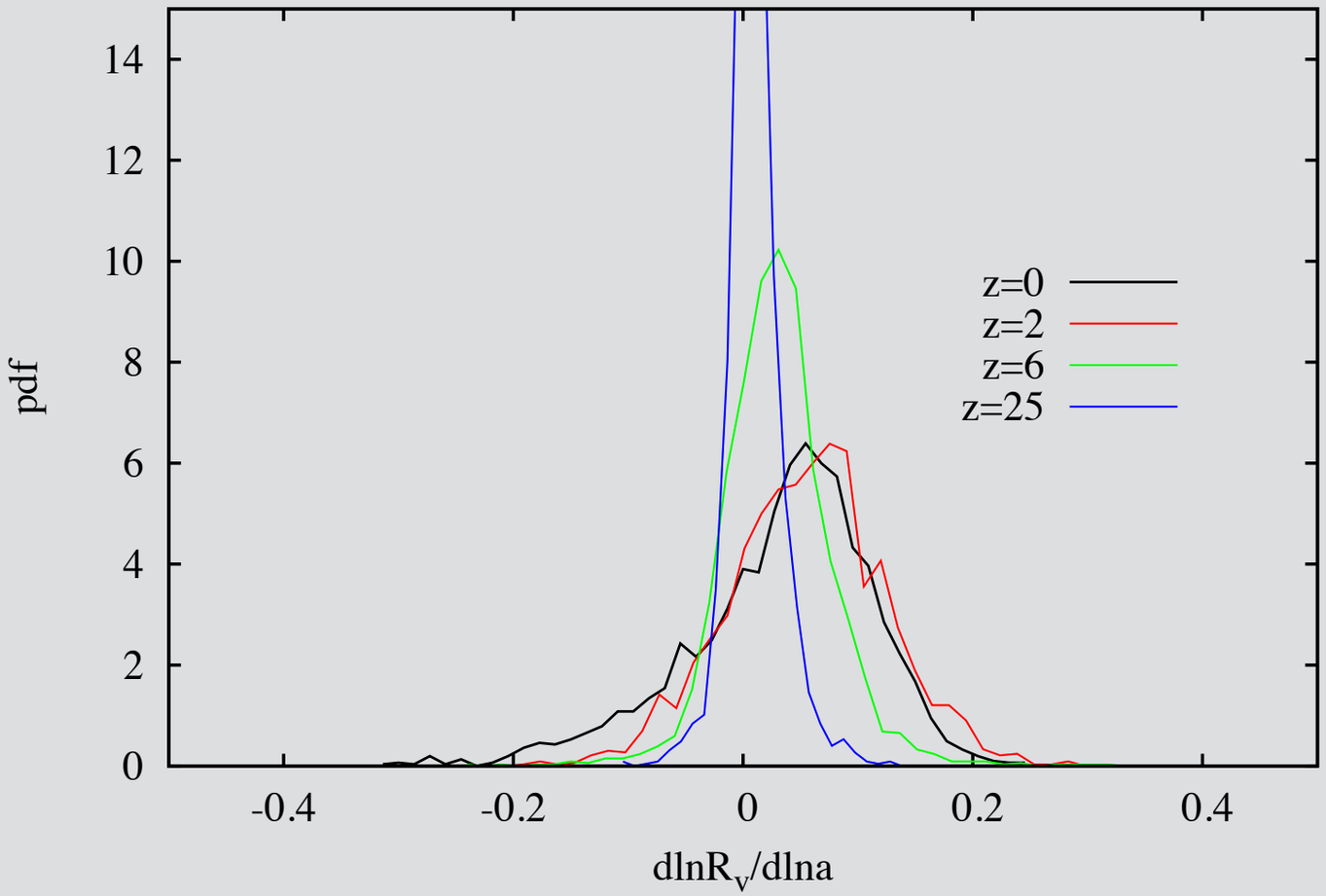


simple fitting formula:

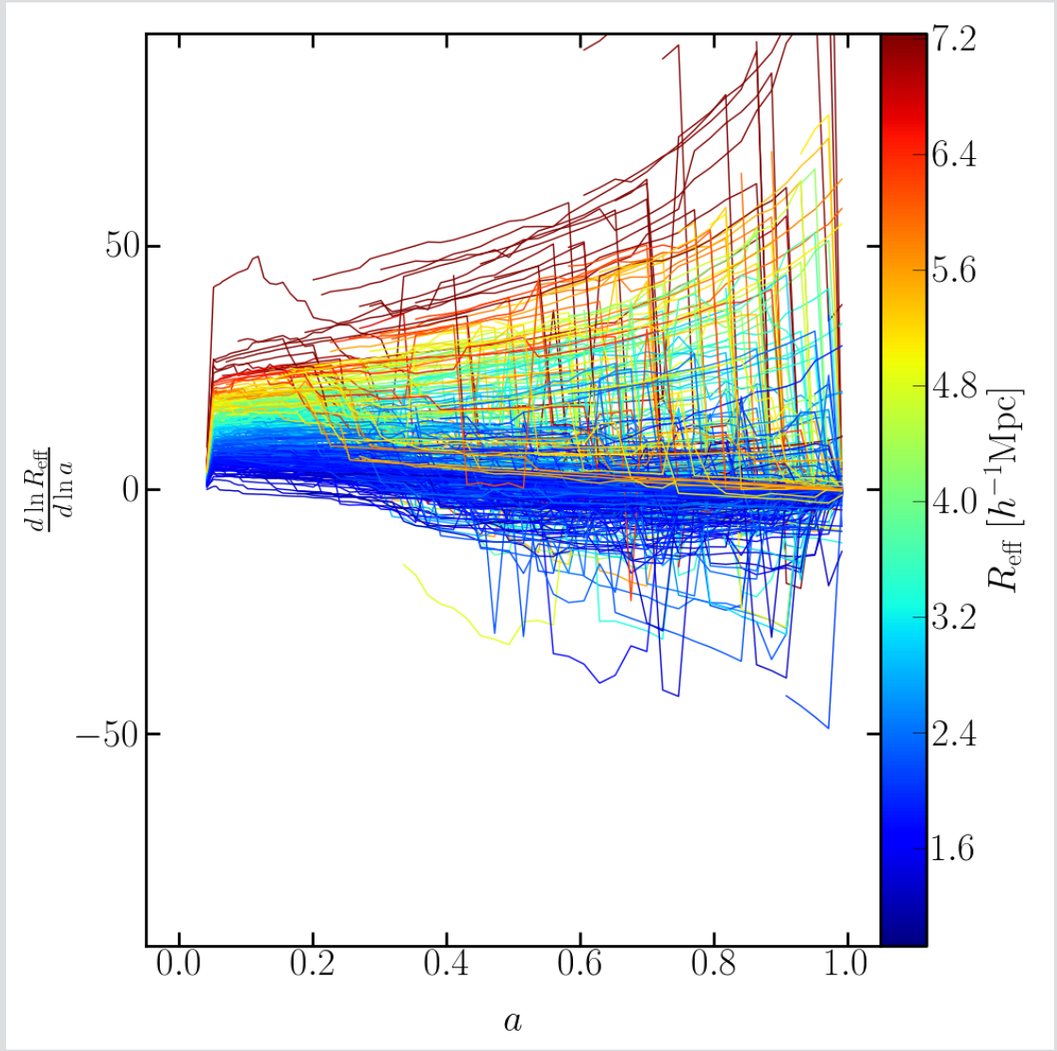
$R(z)/R(0)-1=a(z/(z+z_c))^b$

Growth $dlnR_v/dlna$

- grouping only at z=0
- non-parametric

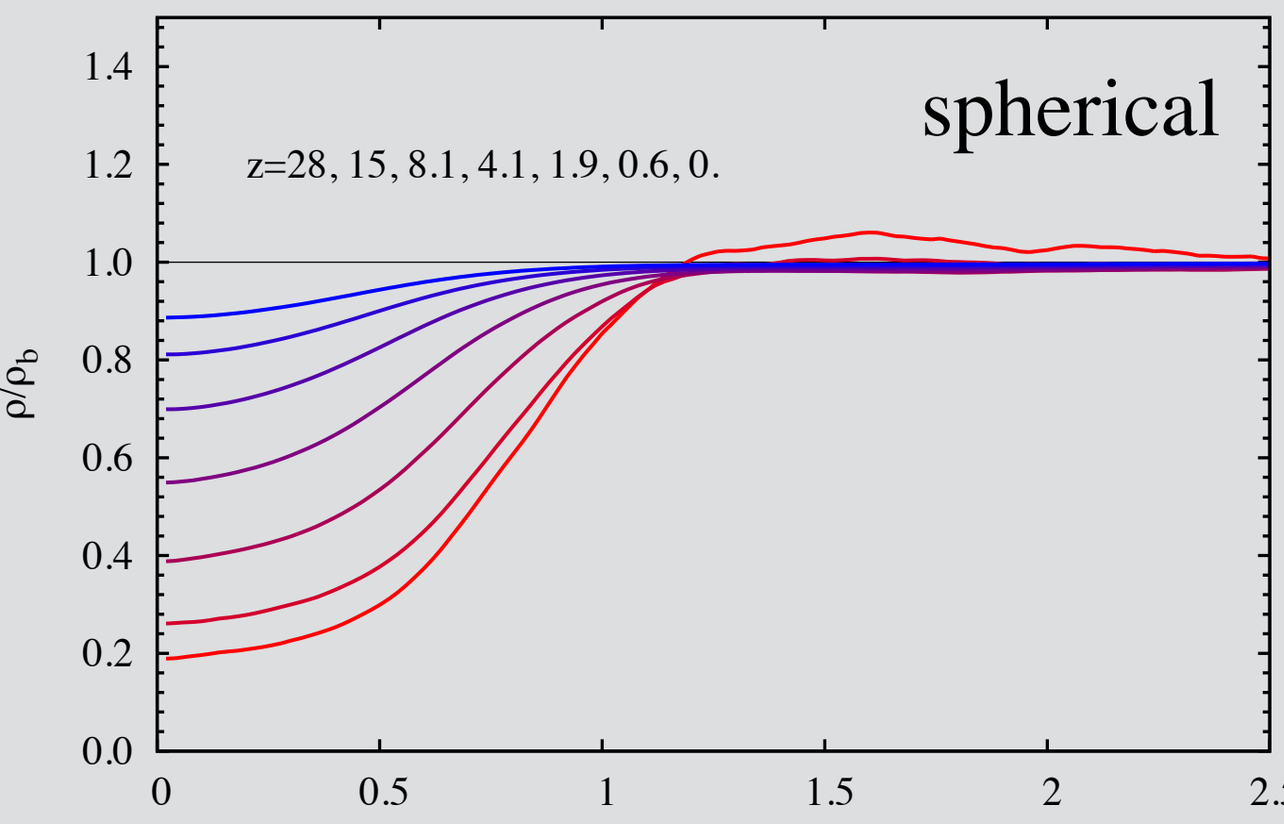


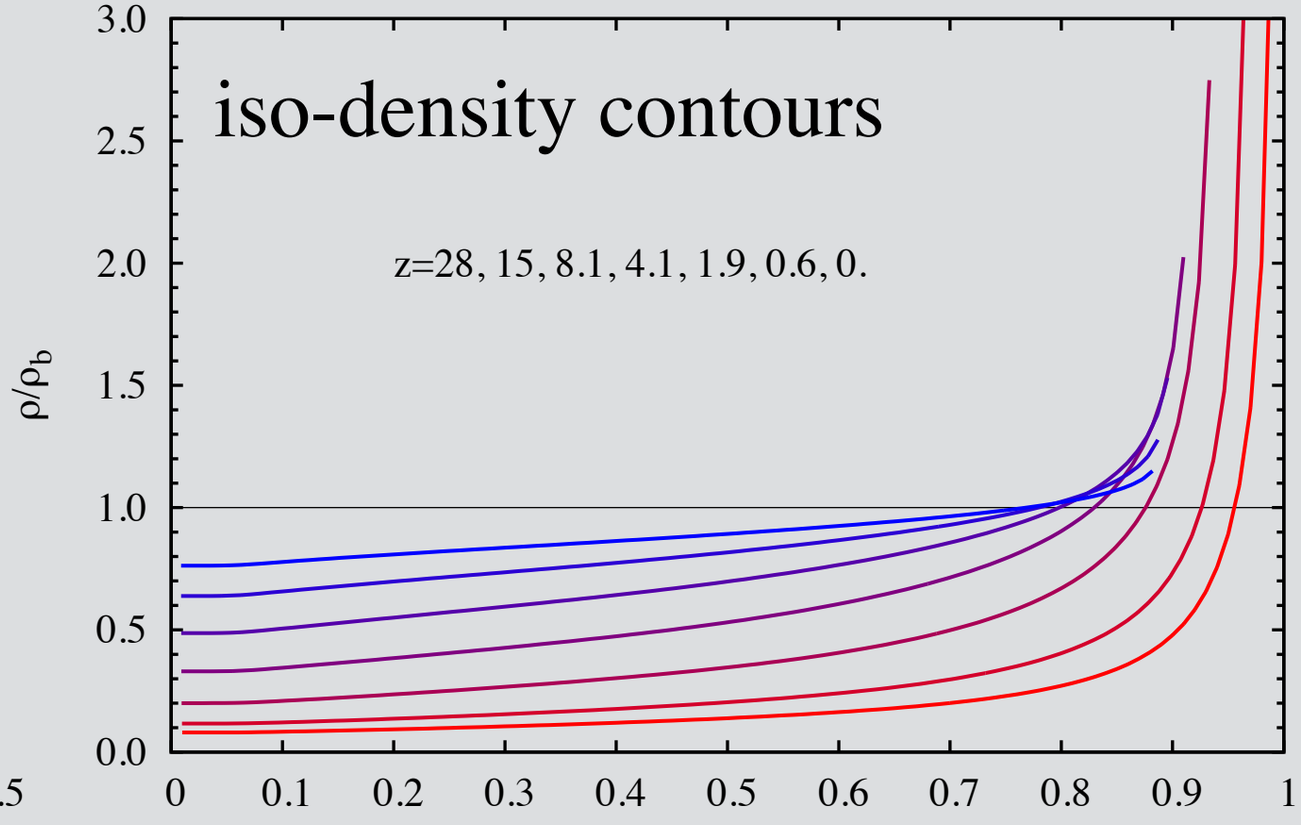
- independent grouping at every z
- density threshold

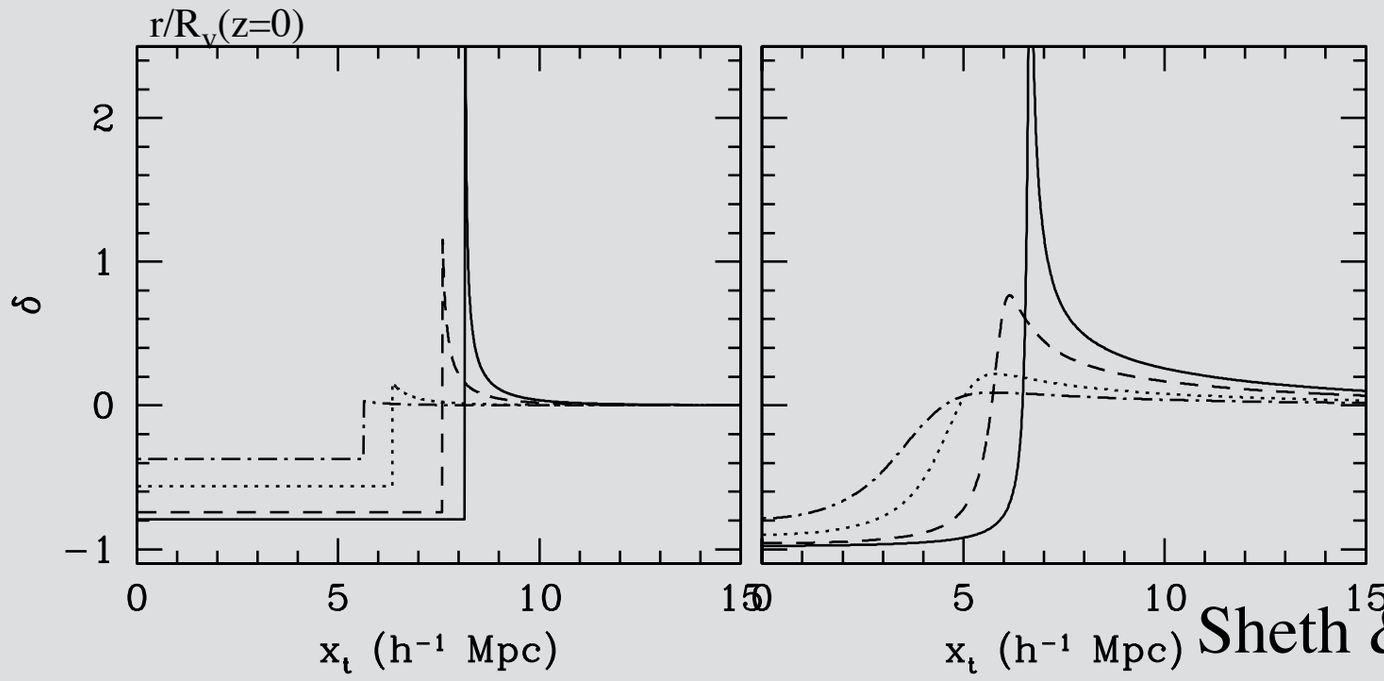


Sutter et al 2014

Evolution of density profiles







Sheth & van de Weygaert (2004)

Conclusions

1. Grouping watershed basins into voids by minima and saddle points is subject to numerical noise. It leads to artificial instantaneous reconfigurations of individual voids in the course of their evolution.
2. Tracing evolution of voids defined as sets of watershed basins requires a.) keeping the same grouping of watershed basins into voids at all redshifts b.) employing conditional watershed.
3. Voids undergo a mild evolution in terms of size.
4. Evolution of the density profiles defined by iso-density contours resembles remarkably well an analytical model of a spherical void (development of a bucket-like shape).