Tracing the evolution of voids

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Voids in cosmological simulation





keywords: dark matter halo density profile simulation keywords: void density profile simulation

Outline

- 1. Finding voids with watershed algorithm
- 2. How to find progenitors at high redshifts ?
- 3. Evolution of:
 effective radii
 density profiles
 shapes (axial ratios)
 sphericity
 alignment of voids
- 4. Summary and conclusions

Motivation

protovoids in IC



What is the evolution of basic properties such sizes, shapes, orientations ? To what degree some properties are determined in IC and to what degree they are modified by late-time dynamics ?

Voids from watershed

step 2

step 1





step 3

density field:

- regular grid (spacing 1Mpc/h)
- density by projecting DM
 sheet (3d-manifold in phase
 space)

Shandarin et al. (2012)

Abel et al. (2012)

Powell & Abel (2015)

watershed segmentations: r
regions around local minima delineated by ridge lines of the density field (watershed basins) N

Platen, van de Weygaert & Jones (2007)

merging basins into voids:

- same as in ZOBOV
- hierarchical network

Neyrinck (2008)

Two possible ways of finding progenitors

same as for halo trees new (no analogy to haloes) Sutter et al 2014

- find voids in all snapshots
- match voids between adjacent snapshots
- void finder applied many times
- voids can exchange basins

- find voids (groups of basins)
- match basins between adjacent snapshots
- void finder applied once
 every void is defined by a unique group of basins

Voids @ z=0

matching basins (new)

matching voids



Comparison @ z=1

matching basins (new)

matching voids



Two methods: effective radii



Effect of small scales modes

256³ particles, 256³ grid

resimulation with 512³ particles downsampled to 256³, 256³ grid



Effect of small scales modes

256³ particles, 256³ grid

resimulation with 512³ particles downsampled to 256³, 256³ grid



From voids at z=0 to protovoids in IC



Evolution from protovoids (IC) to voids (z=0)



Motion of geometric centre



Coherence of motion



Evolution of effective radii



Average density profile

density profiles calculated on iso-density surfaces



Expansion and contraction

density profiles calculated on iso-density surfaces



Volume decreases by factor of 1.6

Volume increases by factor of 3

Shapes of voids (z=0)

c:b:a~0.45:0.65:1.0



Shandarin et al. (2006)

Evolution of shapes



- distribution of axial ratios remain nearly the same at all redshifts
- axial ratios of individual voids can change over time (+/- 20%)

(Co)evolution of shapes



Sphericity

z=0 z=100 (IC)





 $|\cos(\theta)|$

Platen, van de Weygaert & Jones (2008)

Alignment of voids from IC to z=0



void-subvoid pairs excluded

Summary

1. Progenitors of voids: regular density grid, tracking watershed basins defining voids z=0.

2. Initial underdensities in protovoids evolve into profiles with a characteristic bucket-like shape.

2. Nonlinear phase of evolution: expansion/contraction of voids boundaries, motion of geometric centres, evolution of shapes and sphericities, mild evolution of alignment.

3. Despite every individual void can change its shape, the distribution of shapes at z=0 is nearly the same as in IC.

4. Alignment of voids is *in large part* determined by the primordial density field.