The Cosmic Web Paradigm -
Status & Problems

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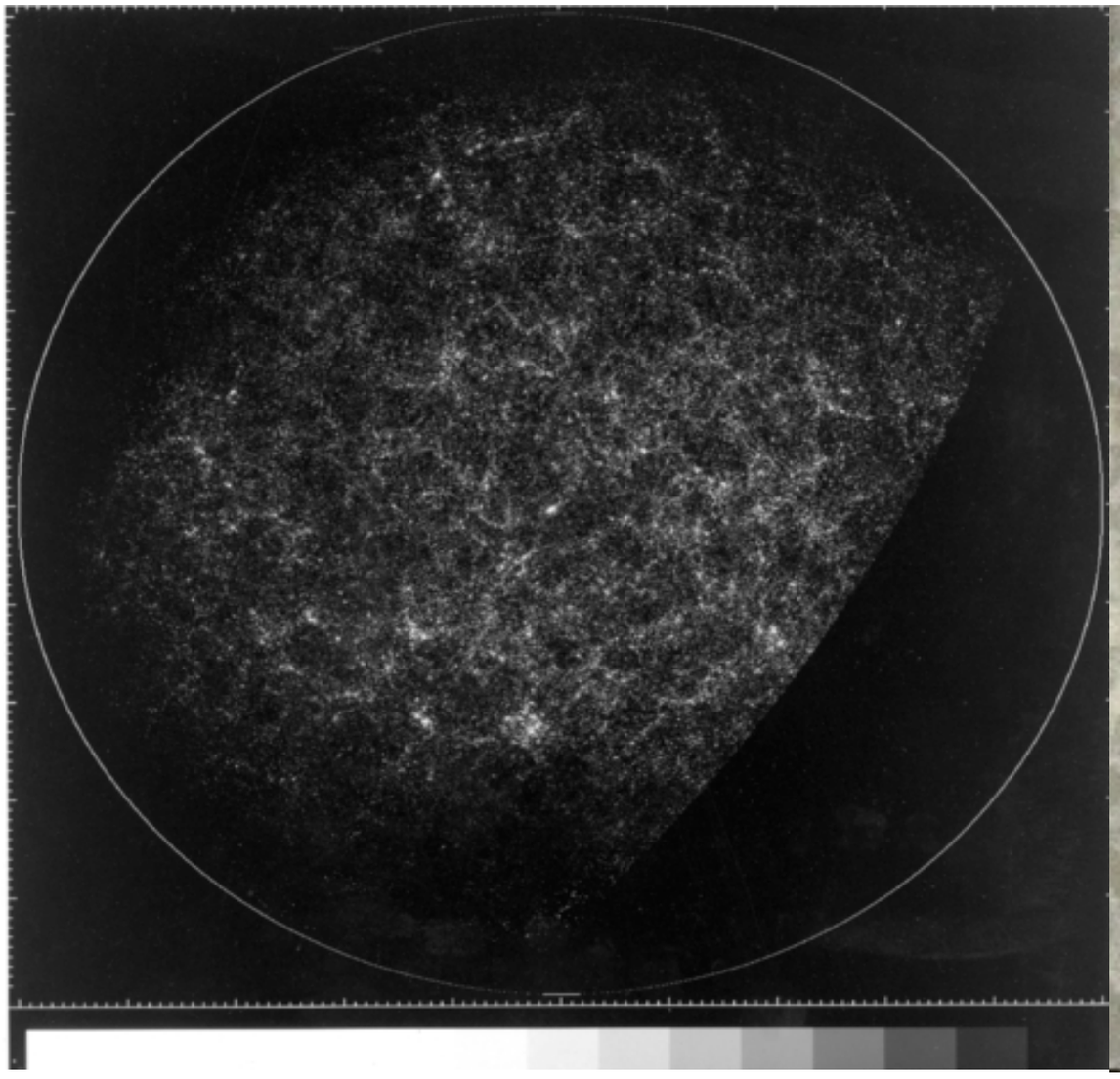
KIAS Workshop, November 4, 2014

IAU Tallinn Symposium 1977
'Large-scale Structure of the Universe'

Peebles, Zeldovich & Longair in Tallinn 1977 conference

Classical cosmological paradigm
2-D distribution of galaxies



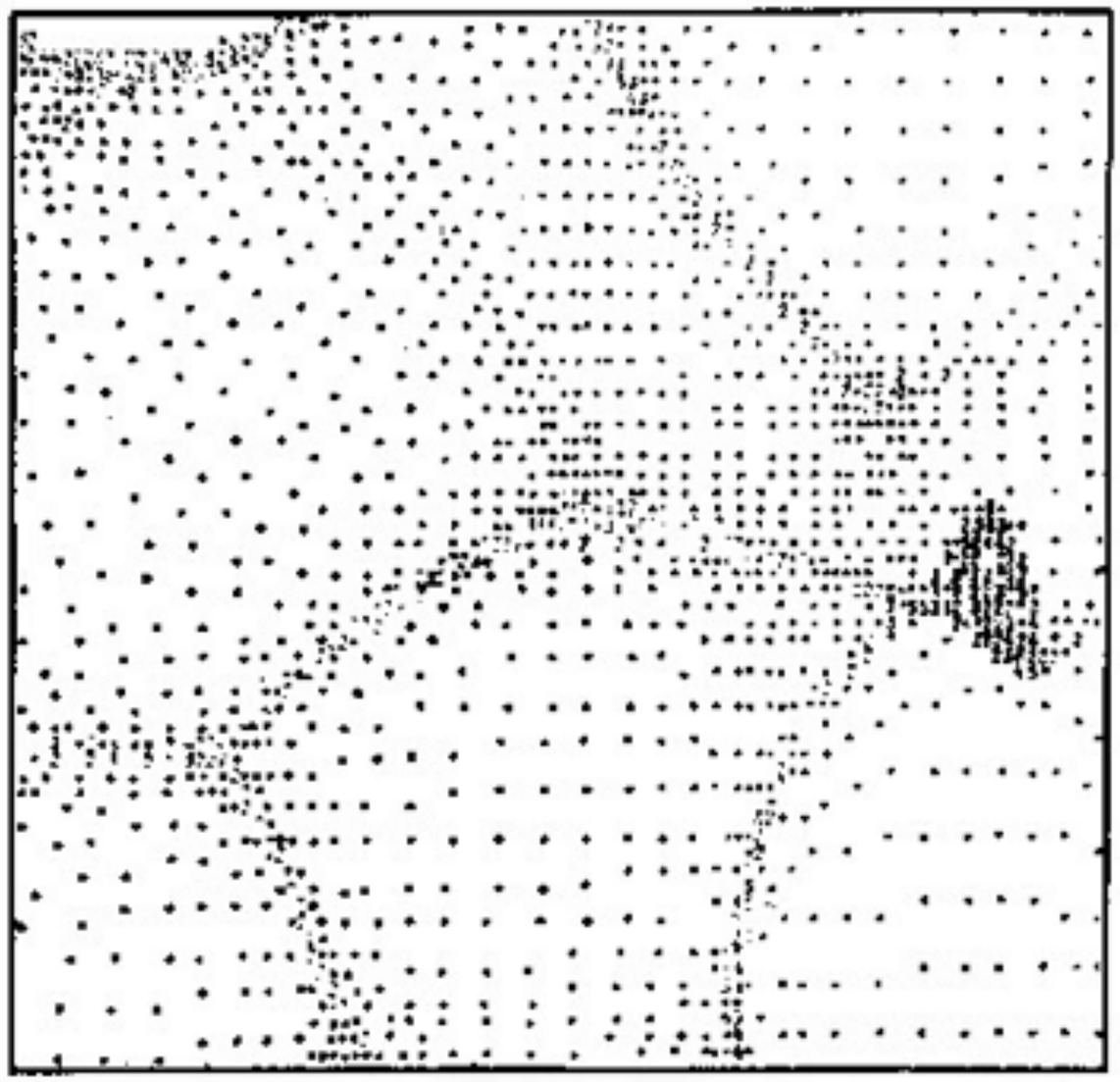
Lick Survey
Some clusters & superclusters
Field galaxies almost randomly distributed

Jim Peebles

Hierarchical clustering scenario

3-D distribution

Zeldovich prediction



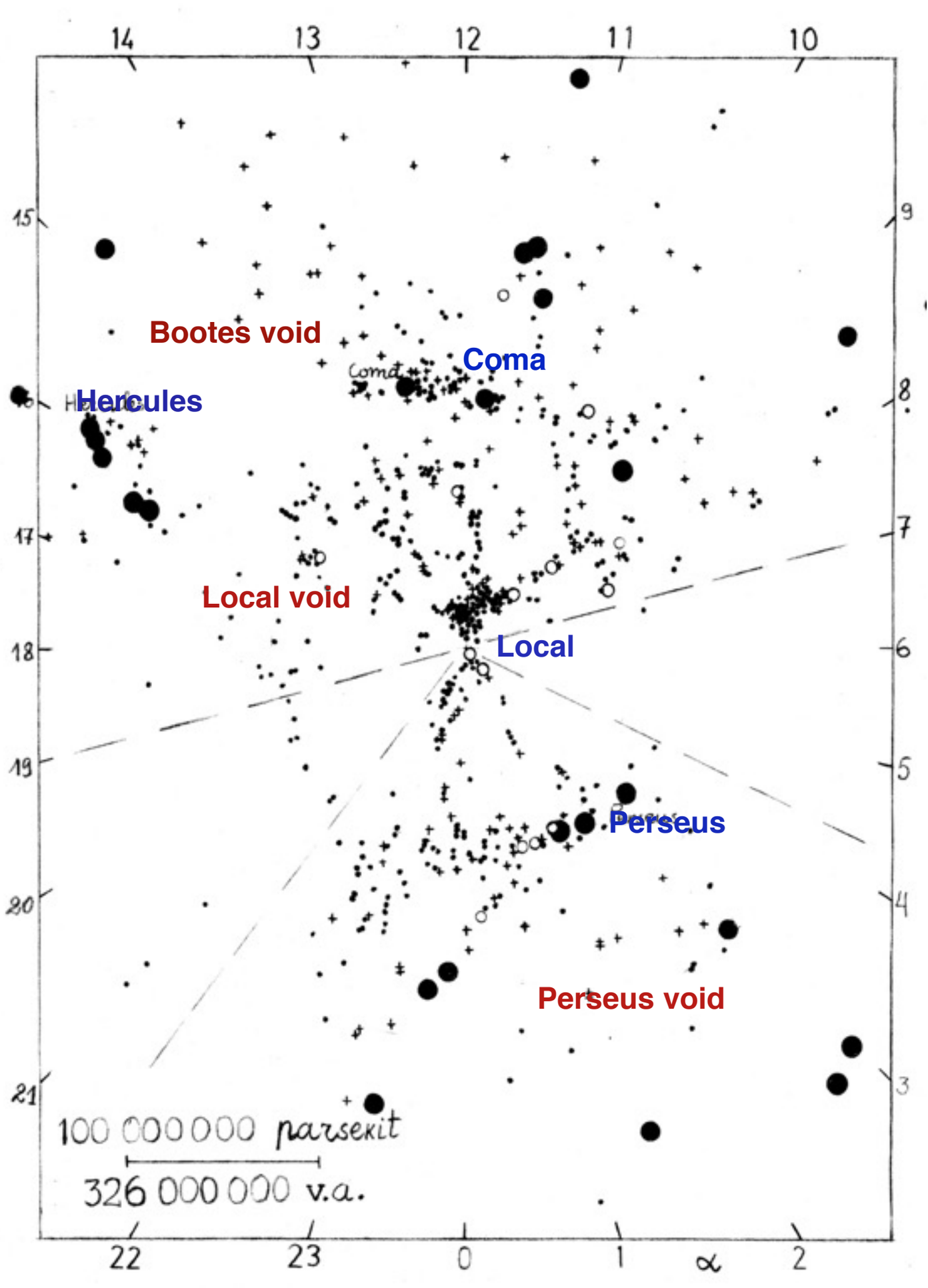
Distribution of particles in simulation (Zeldovich group 1975)

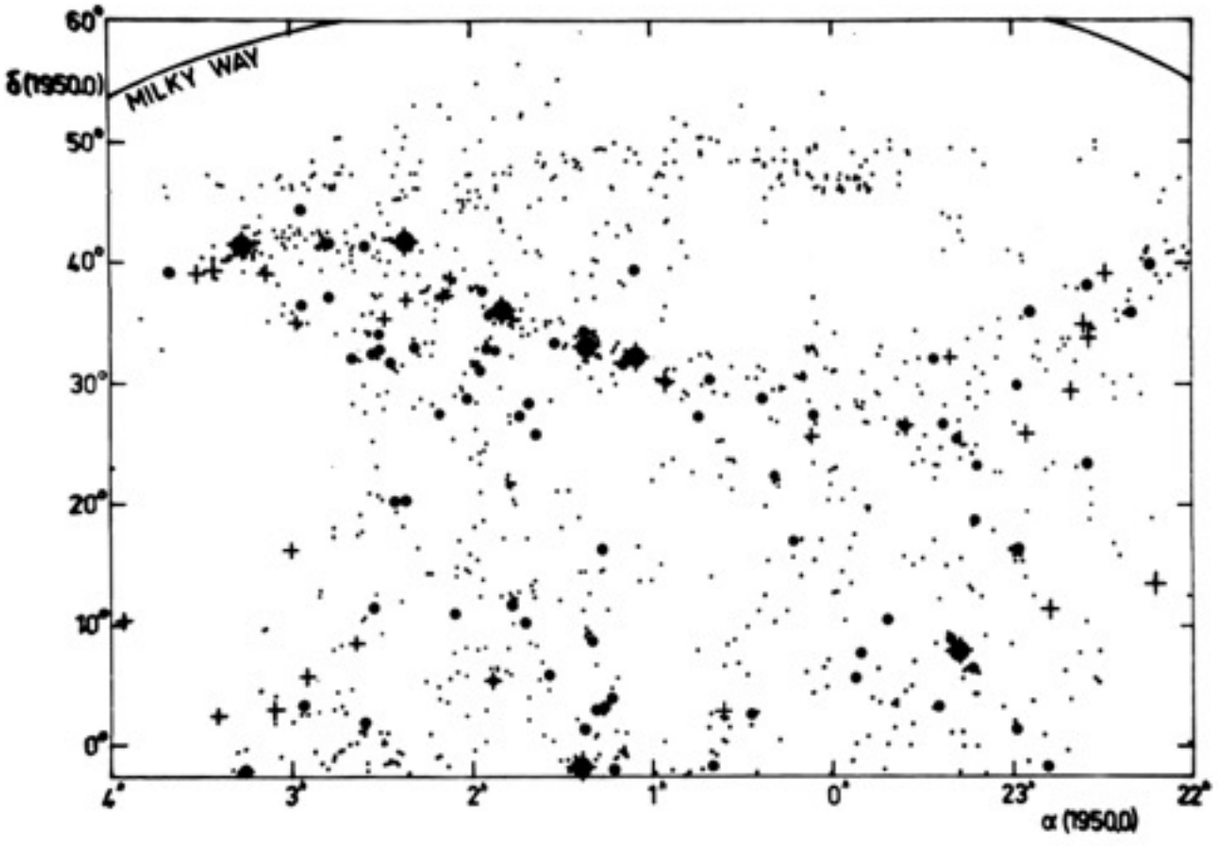
According to Zeldovich scenario first flat pancakes form, superclusters, filaments and clusters form thereafter.

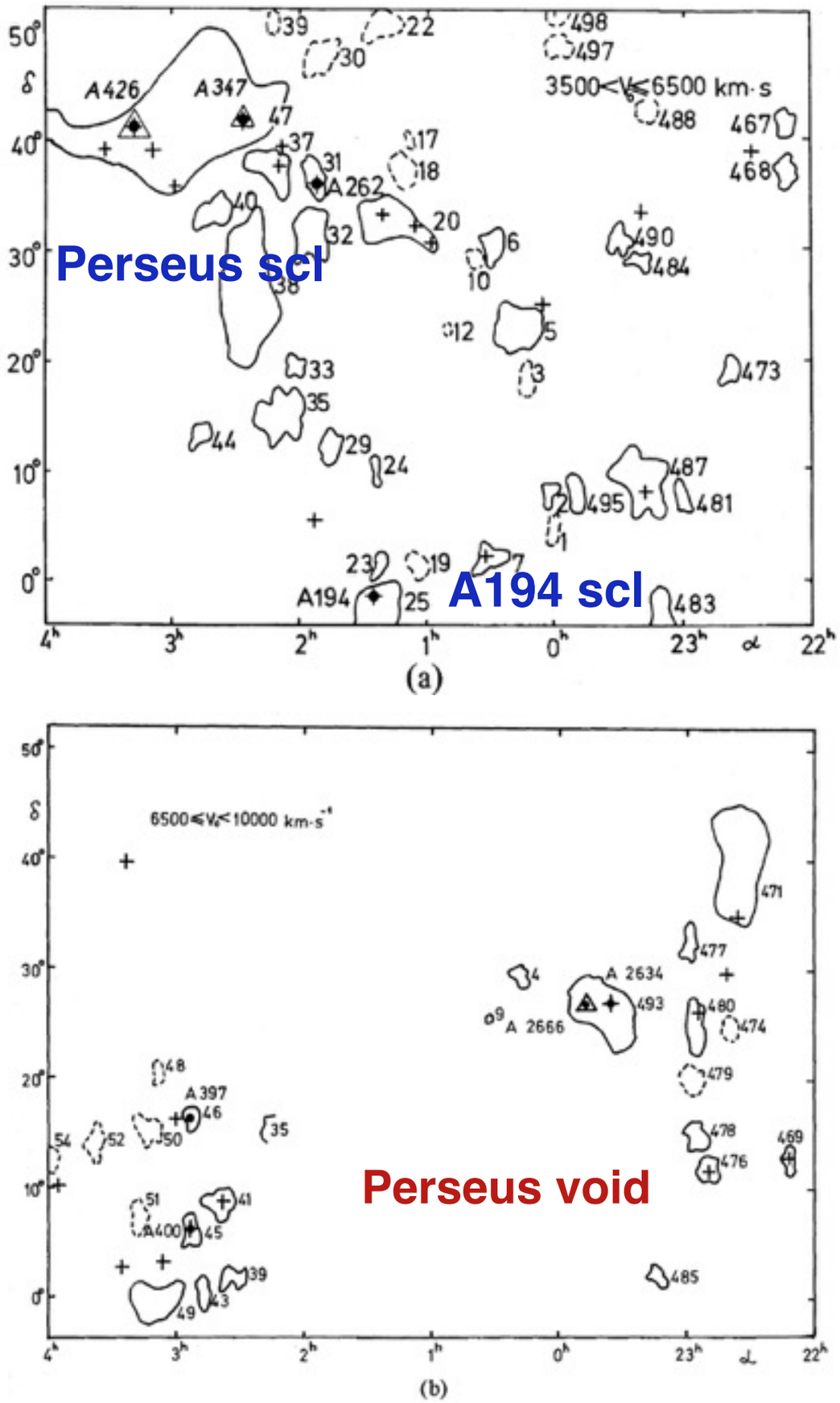
3D data Cosmic web Tallinn 1977

Web with filamentary superclusters, galaxy filaments between superclusters.

Voids between filaments are empty







Distribution of galaxies, Abell & Zwicky clusters in Perseus supercluster region at various redshift intervals.

Filaments & voids well visible

Voids defined by clusters have **diameter ~100-120** Mpc/h

Quantitative tests

Giant voids in the Universe

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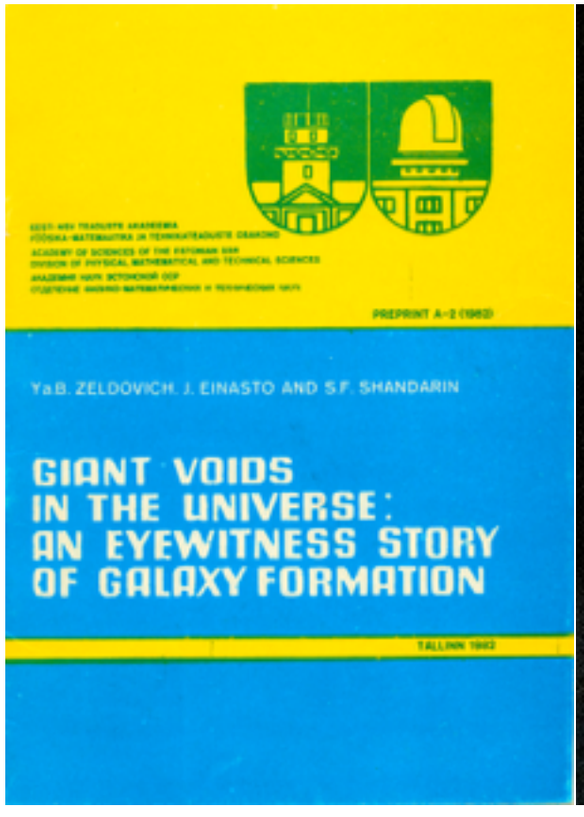
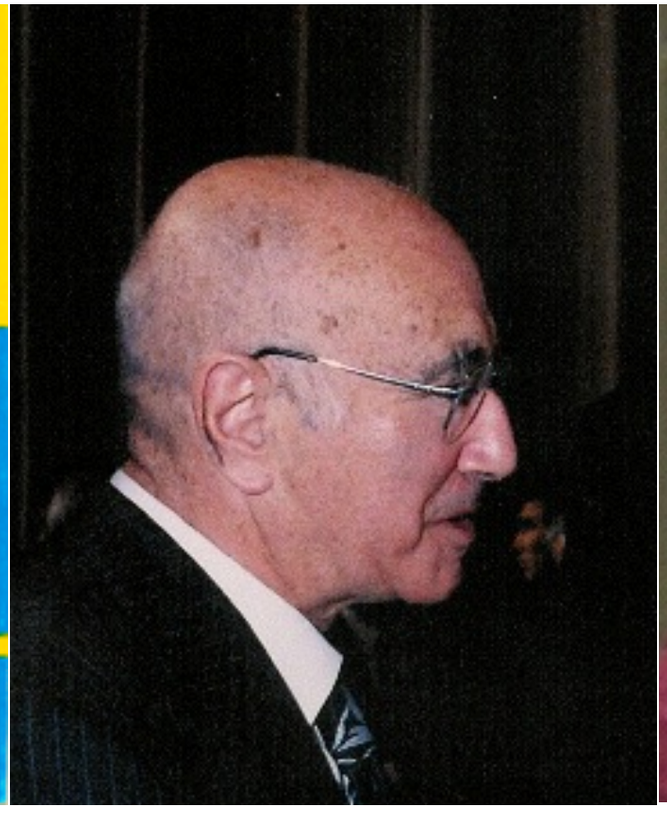
Recent observations indicate that most galaxies are concentrated in superclusters consisting of galaxies, and clusters of galaxies, aligned along strings. Giant volumes exist between superclusters which are almost empty of visible objects. Theories of galaxy formation predict the formation of non-spherical superclusters and giant voids. Large-scale structure changes very slowly, so the currently observed structure reflects the whole history of galaxy formation and structural evolution.



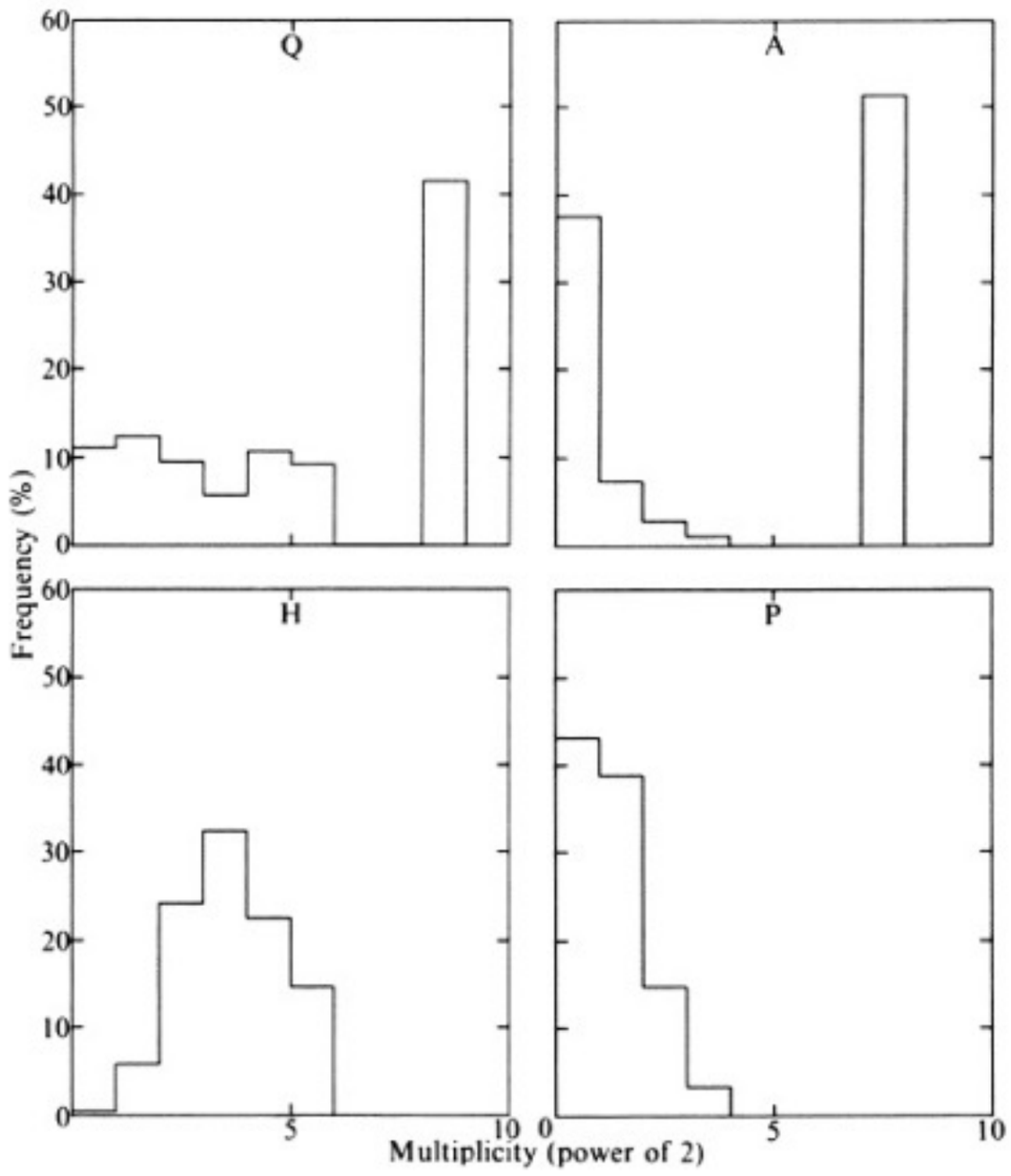


Multiplicity function test

H-model fails in all tests

A-model has no fine structure

A-model has particles in voids - galaxy formation is threshold phenomenon (no galaxies form in voids)



Non-baryonic particles slower than neutrinos needed.

Cold Dark Matter suggested (1982-1984)

Both Zeldovich & Peebles have right: their scenarios describe

different stages of structure evolution

Unsolved problem:

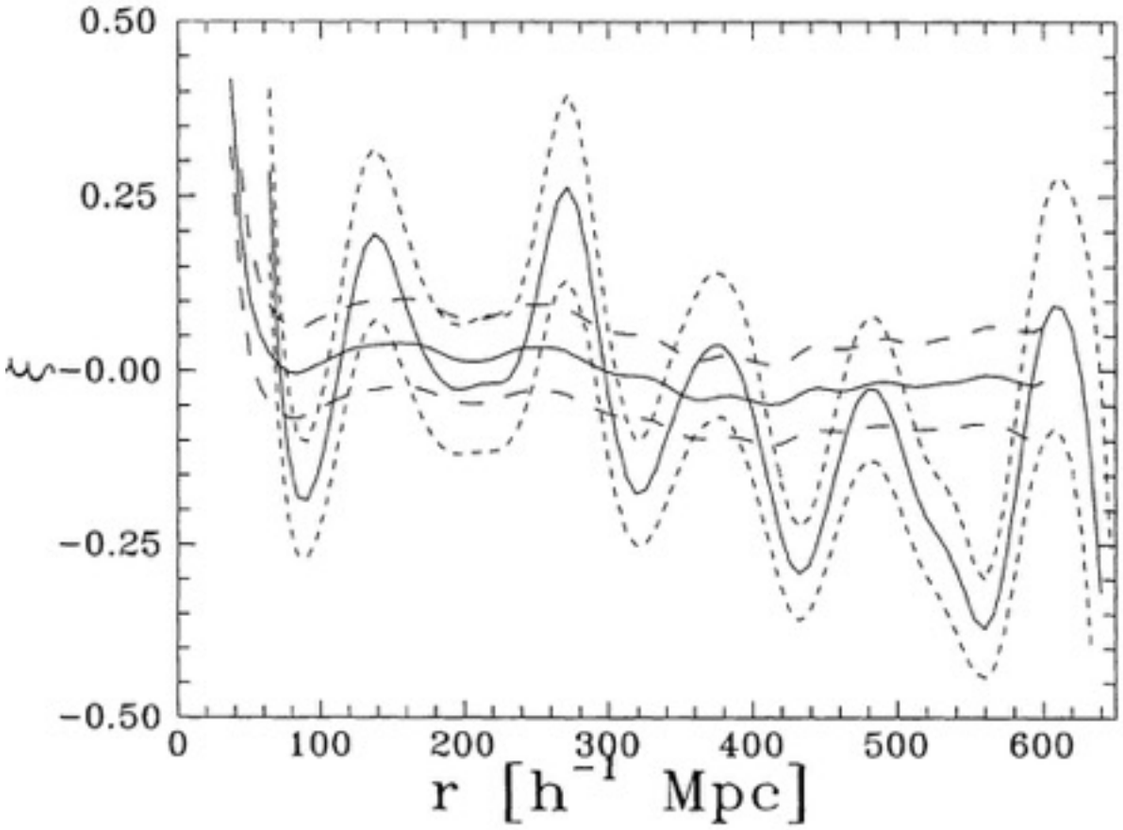
Density perturbations have all scales.

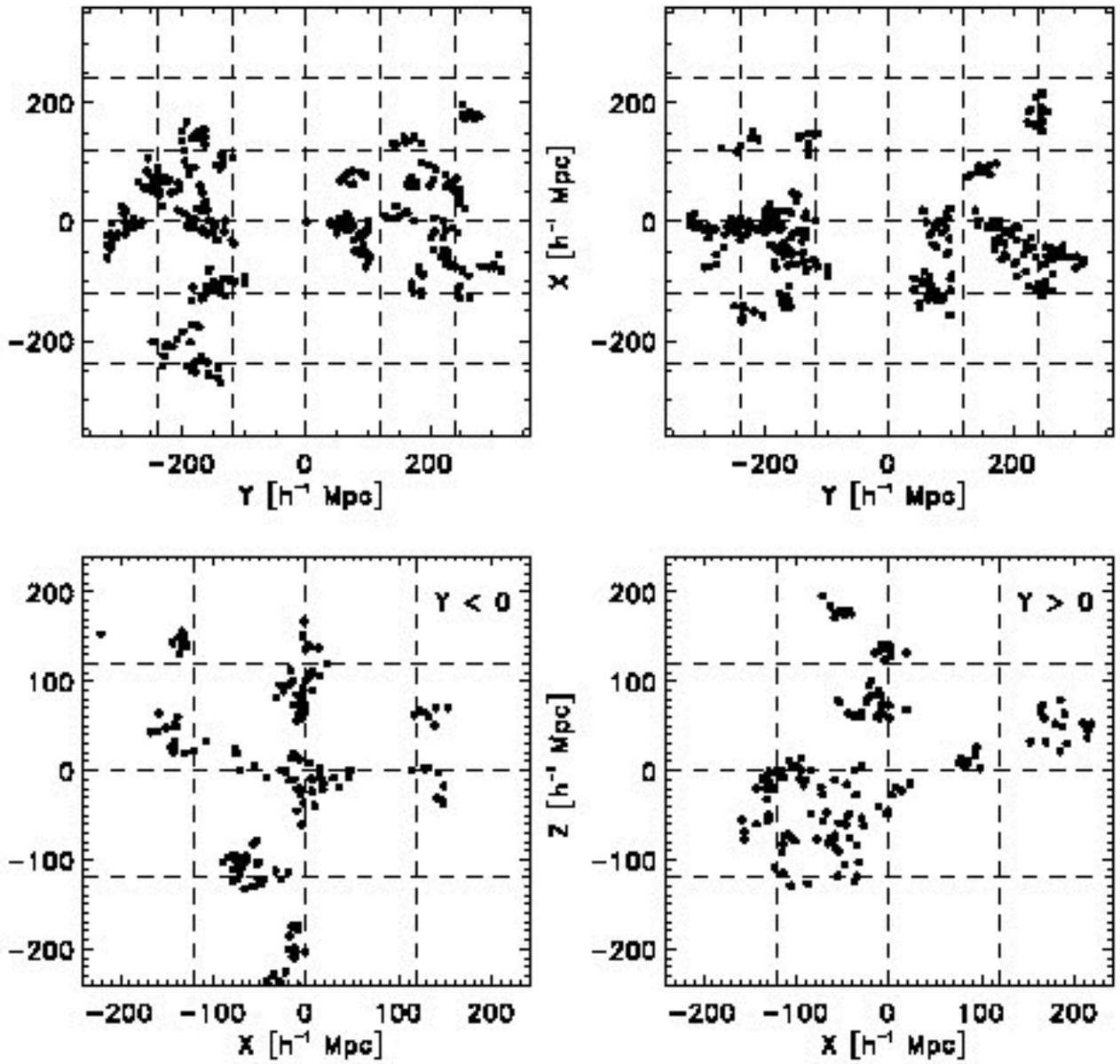
Why the Web has the ~120 Mpc/h scale?

Observational evidence: rich Abell clusters

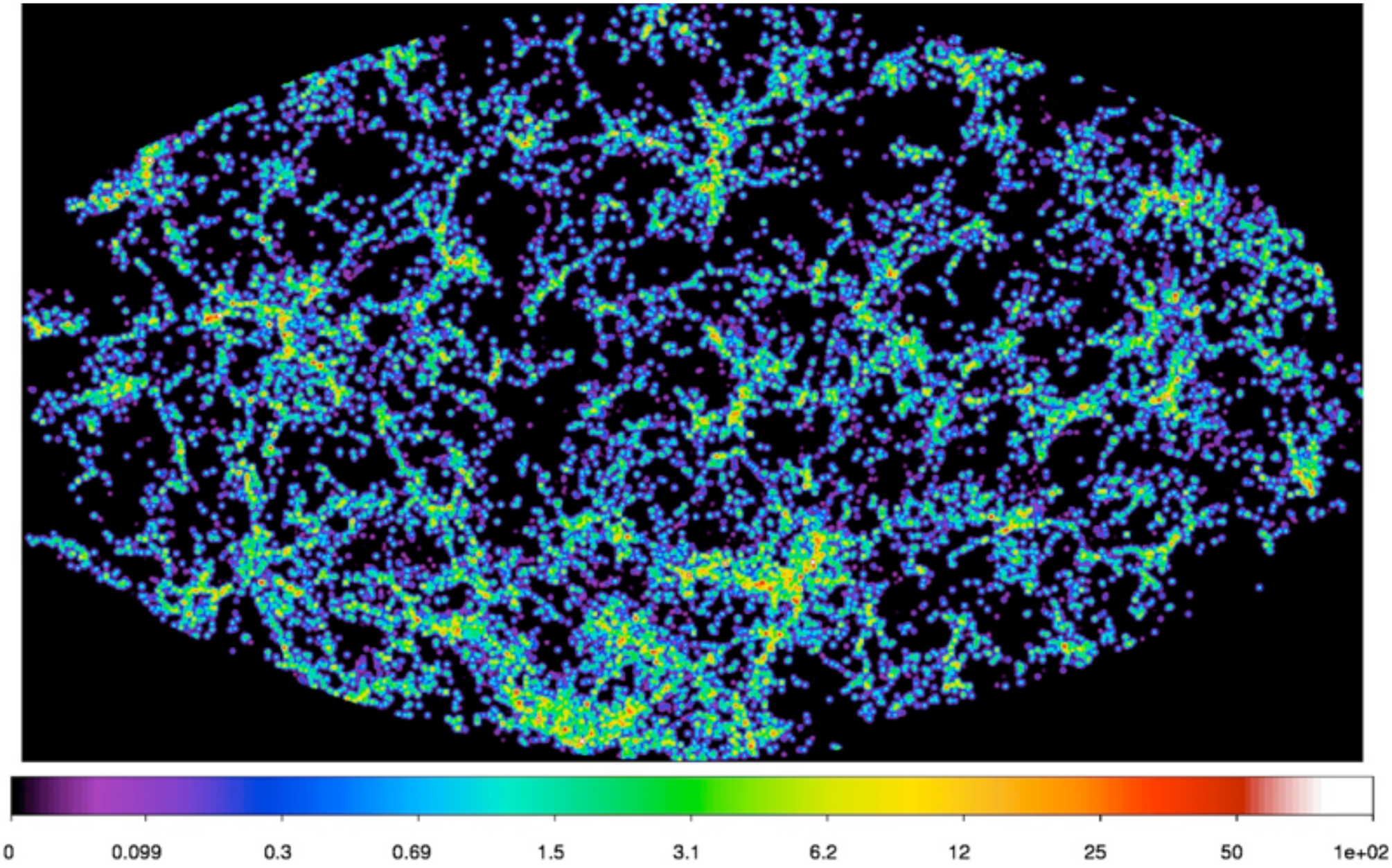
Concentration of rich clusters is seen in rich cluster distribution & correlation function (JE et al 1997)

~120 Mpc/h scale apparent



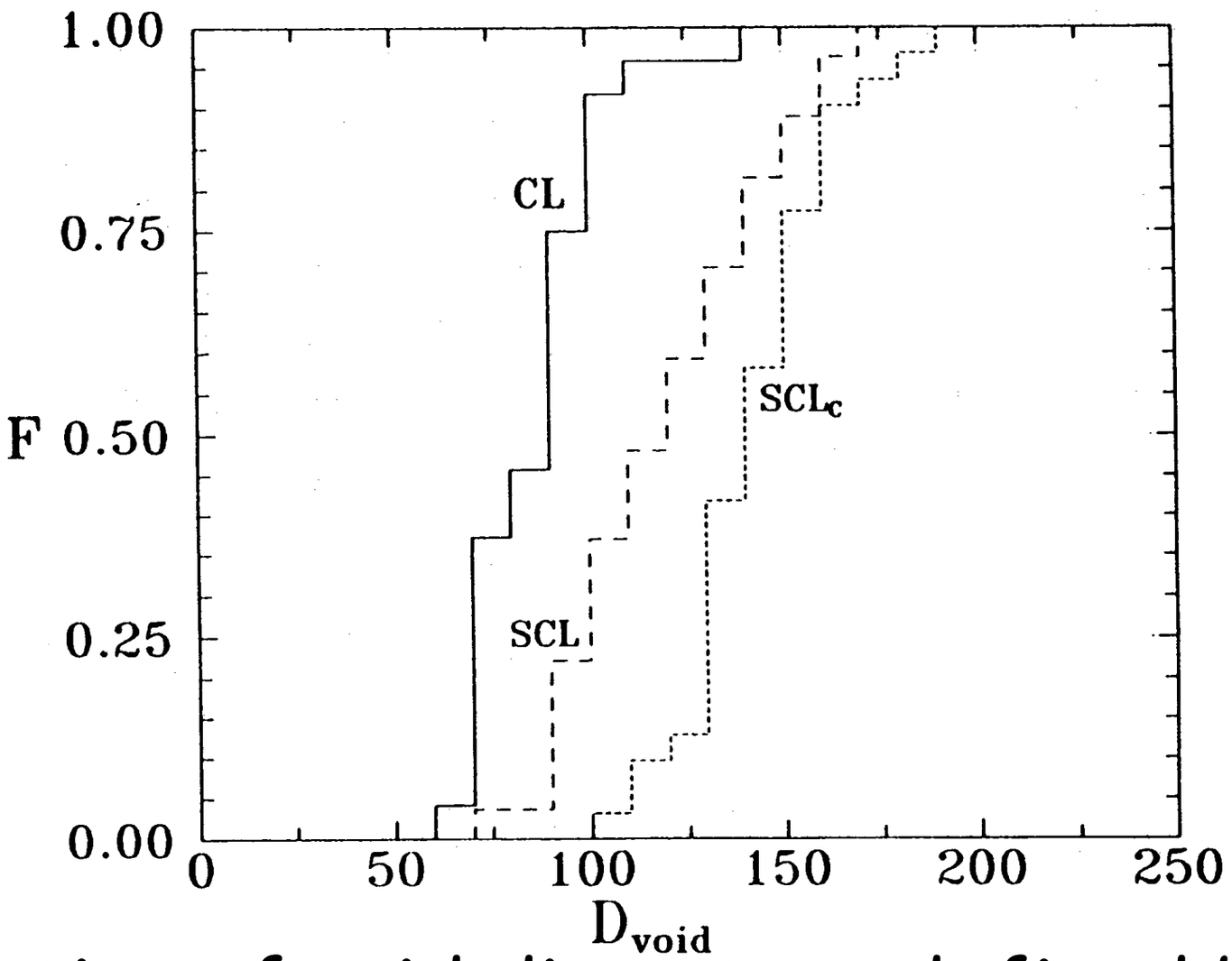


Observational evidence: cellular structure



Supercluster-void network at distance 240 Mpc/h in the luminosity density field of SDSS. Filamentary superclusters, weak filaments & voids are seen. Characteristic scale ~120 Mpc/h between rich superclusters (Suhhonenko et al. 2011).

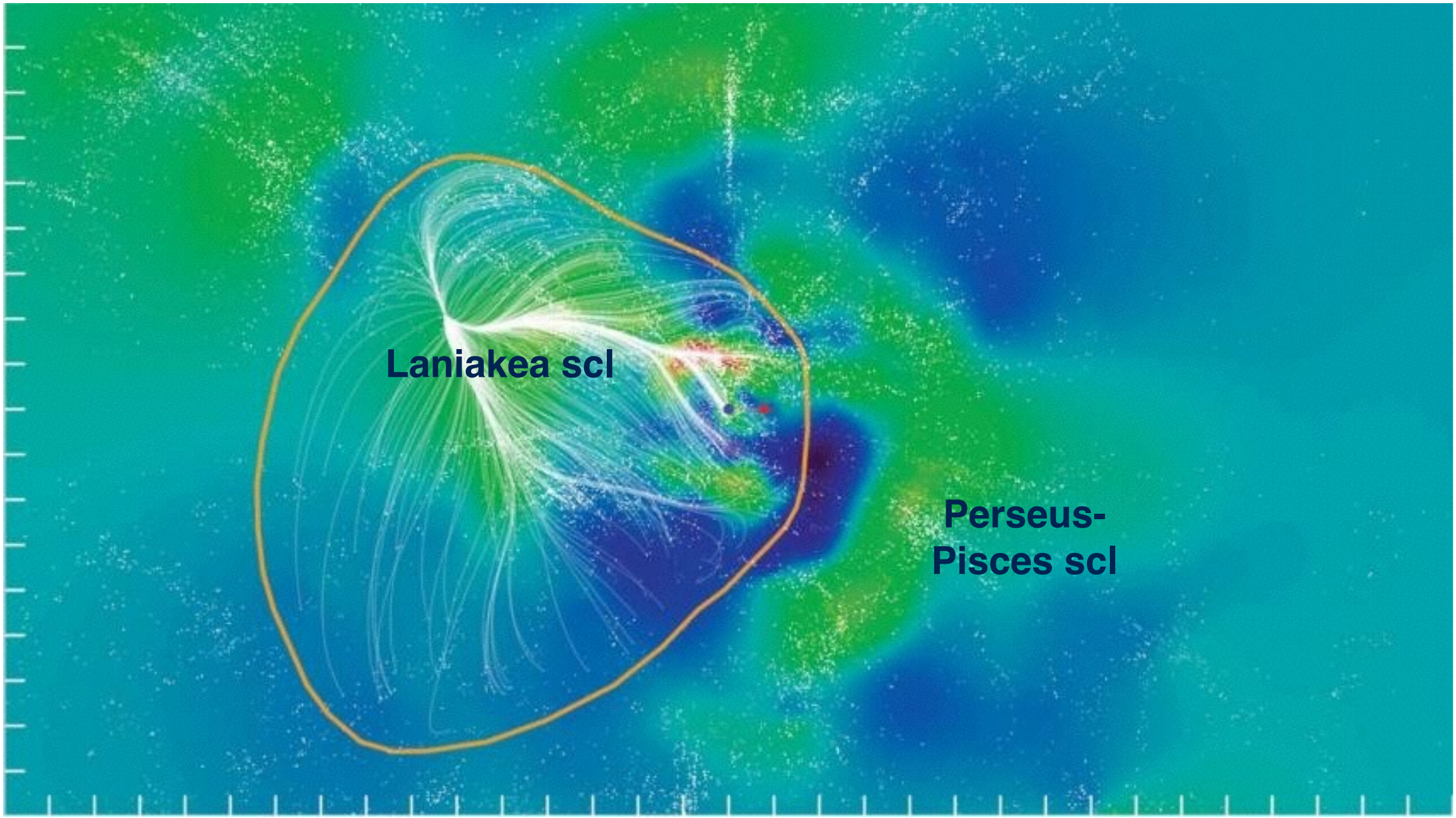
Void diameters



Distribution of void diameters defined by all clusters (CL), clusters in superclusters (SCL) & supercluster centres (SCLc) (ME et al 1994)

SCL defined void diameters have large scatter, peak at ~120 Mpc/h

Fine structure of superclusters (Tully et al 2014)



In superclusters galaxies move along filaments towards the central cluster & away from voids. Distance between centres of Laniakea & Perseus-Pisces superclusters ~ 120 Mpc/h.

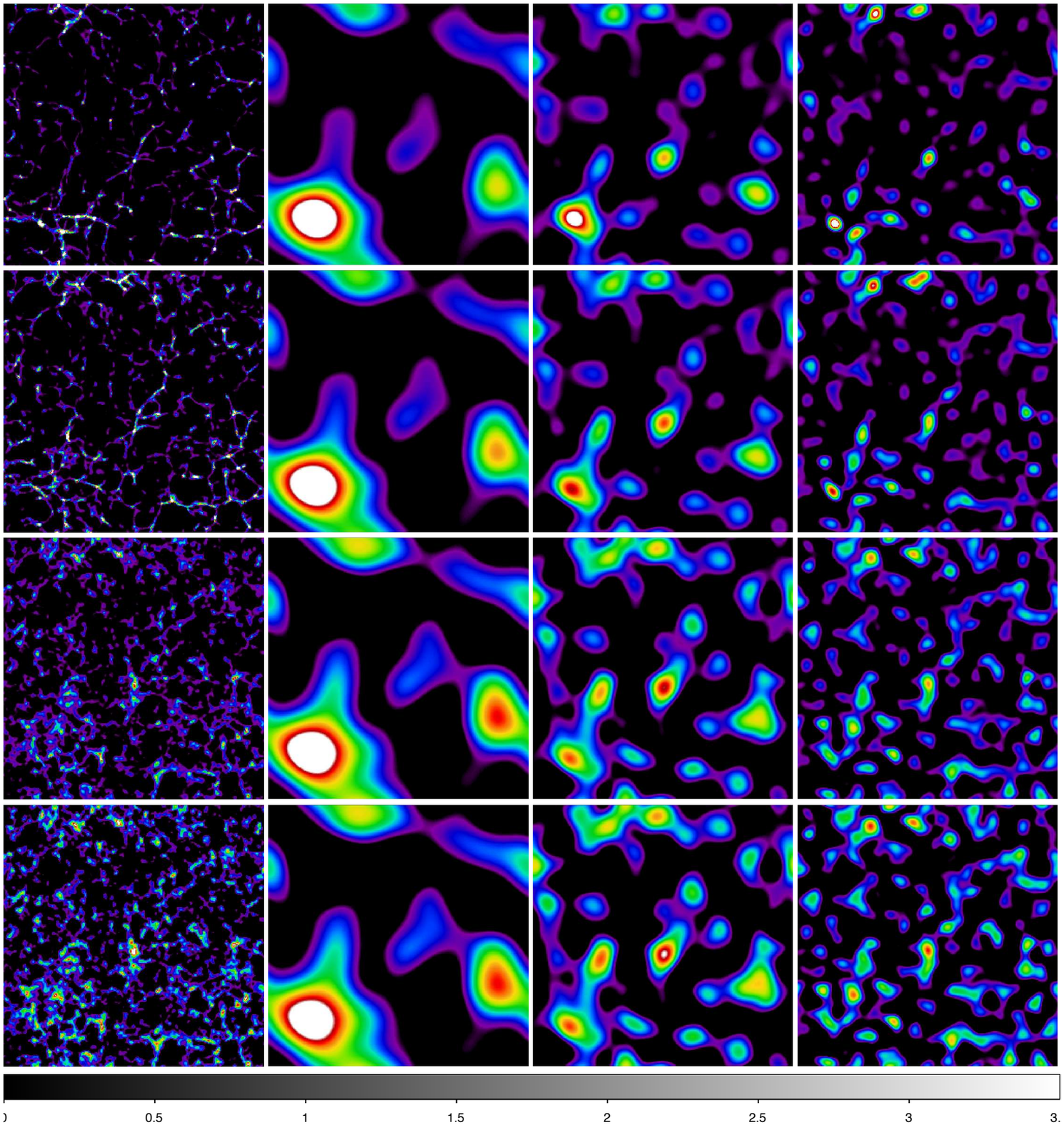
Web 120 Mpc/h scale: Evolution of density peaks

L=256 Mpc/h model DF & its wavelet decomposition at redshifts 0, 1, 5, 10

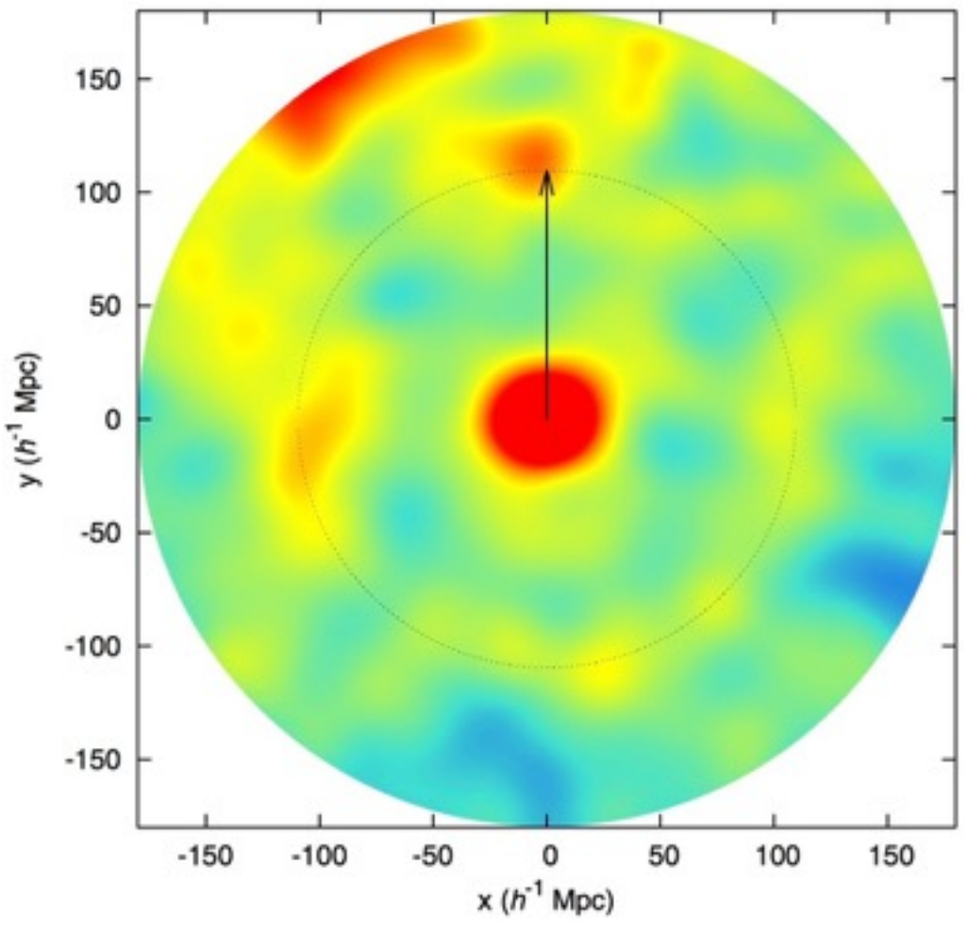
Waves of medium & large scale are synchronised by the amplification due to larger waves.

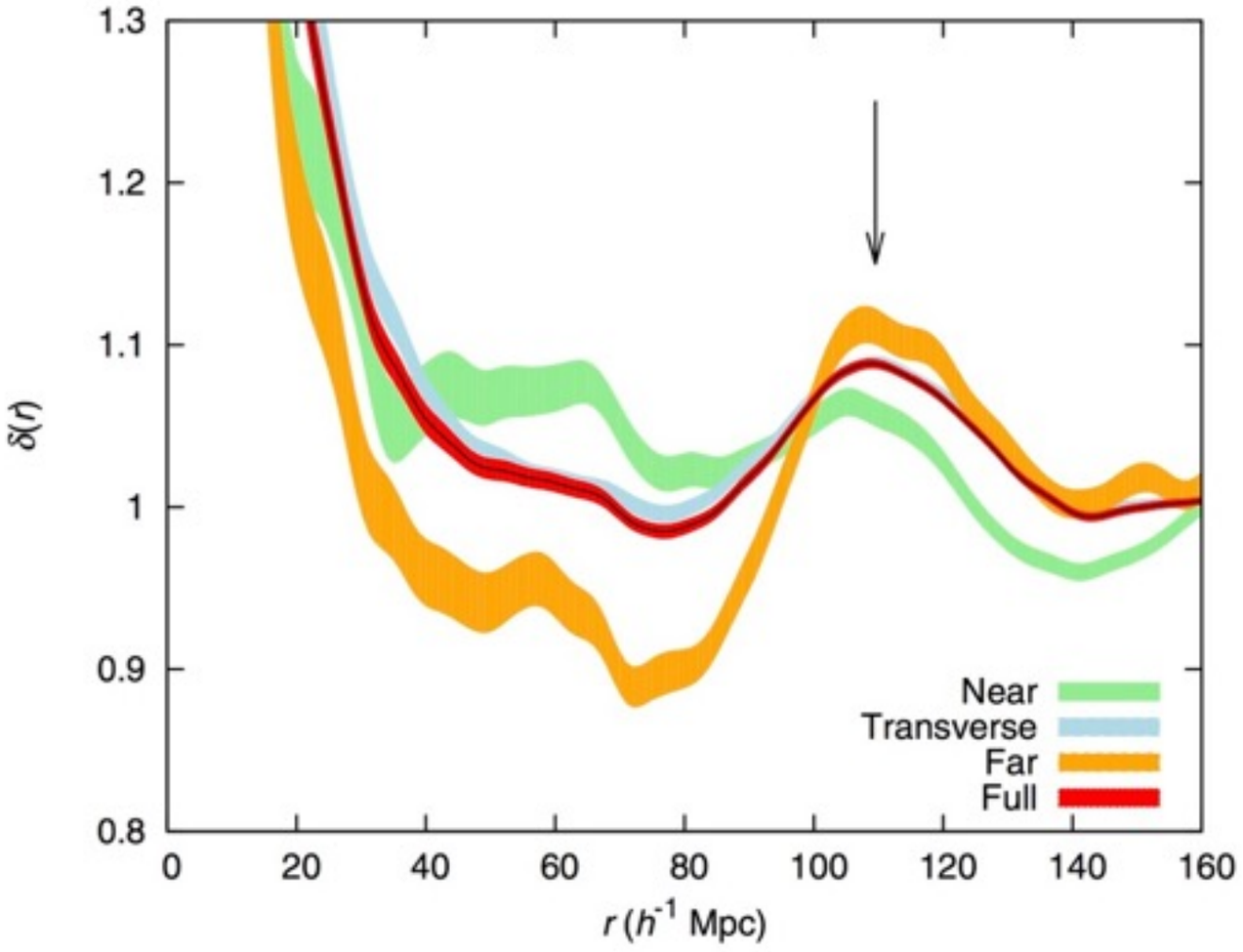
Peaks do not change positions:

Peaks were created before inflation



Relation with BAO effect?





Left: 2D slice of the stacked 3D SDSS density field

Right: Radial density profiles averaged for 1599 peaks.

Arrows: the location of r_{max} = 109.5 Mpc/h

BAO shell density contrast weak, spherical shells of fixed radius

BAO vs. Web scales

BAO - acoustic oscillations of hot plasma frozen at recombination; weak spherical shells of fixed radius r = 109 Mpc/h

Web scale ~120 Mpc/h was outside horizon from inflation to recombination; depends on processes during inflation & post-recombination (influence of Lambda term which froze the growth of fluctuations at z = 0.7?)

Are there larger systems? LRG and quasar data

The beauty of the modern cosmological paradigm

- The presence of dark matter shows that the **Nature of the Universe** is richer: it contains a new population, not detected by physicists even today.
- The **Structure of the Universe** is richer, instead of a random background of field galaxies we see now the Cosmic Web with its small and large details.

The formation of the modern cosmological paradigm was a long story, where many astronomers participated

Conclusions

1. The presence of cosmic web with filamentary superclusters & voids is well established.

2. The scale >120 Mpc/h was outside the horizon before recombination, thus it must be caused by processes in the very early Universe or after recombination;

3. The possible influence of dark energy preventing the gravitational condensation of extremely large superclusters needs clarification.

4. The 120 Mpc/h and possible larger scales not explained: Why waves of scale >120 Mpc/h do not influence the scale of the web?


Thank you!