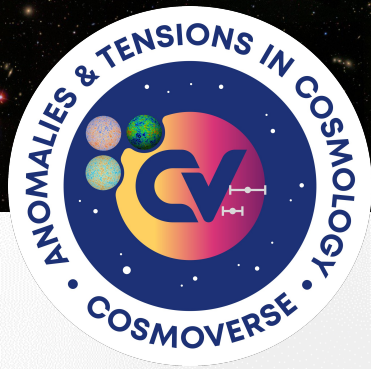






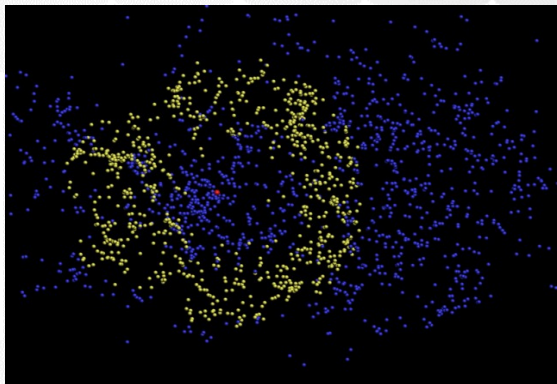


Patchwork Universe

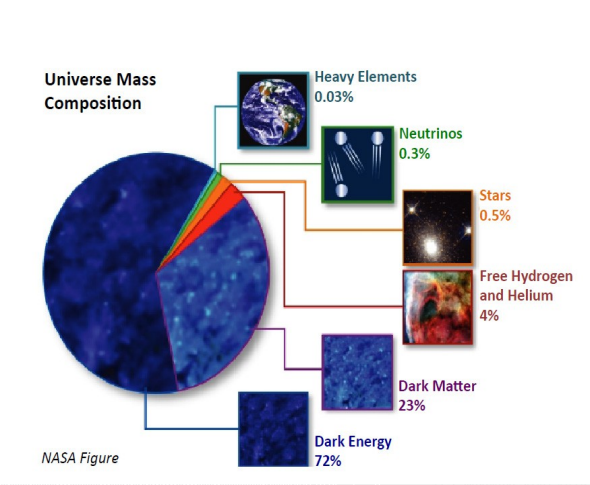
The challenge of the largest structures in the Universe

Maret Einasto

UNIVERSITY OF TARTU
Tartu Observatory
1632



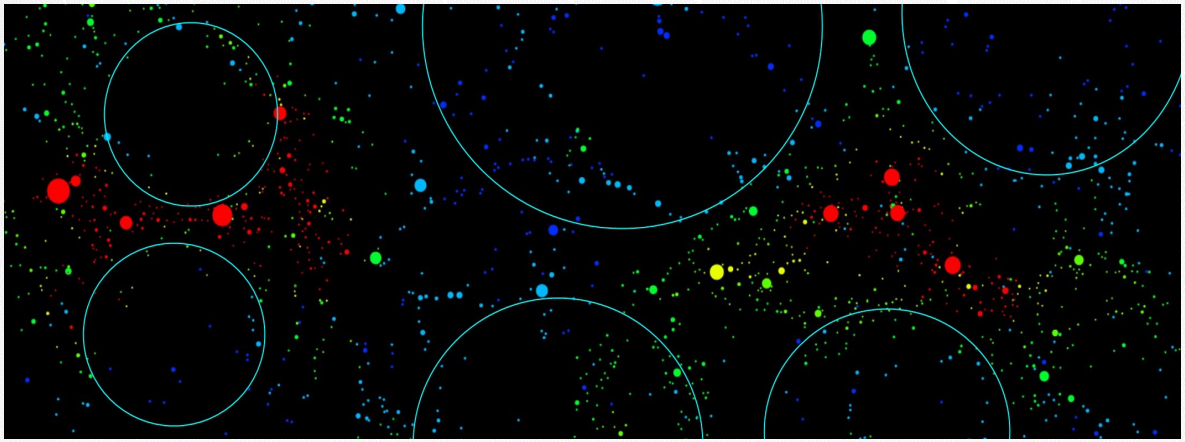




Universe:

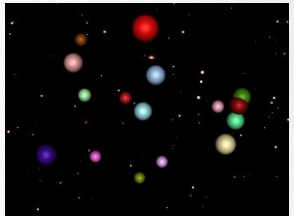
visible and dark matter, dark energy

Dark matter coronas around galaxies
Einasto, Kaasik, Saar 1974

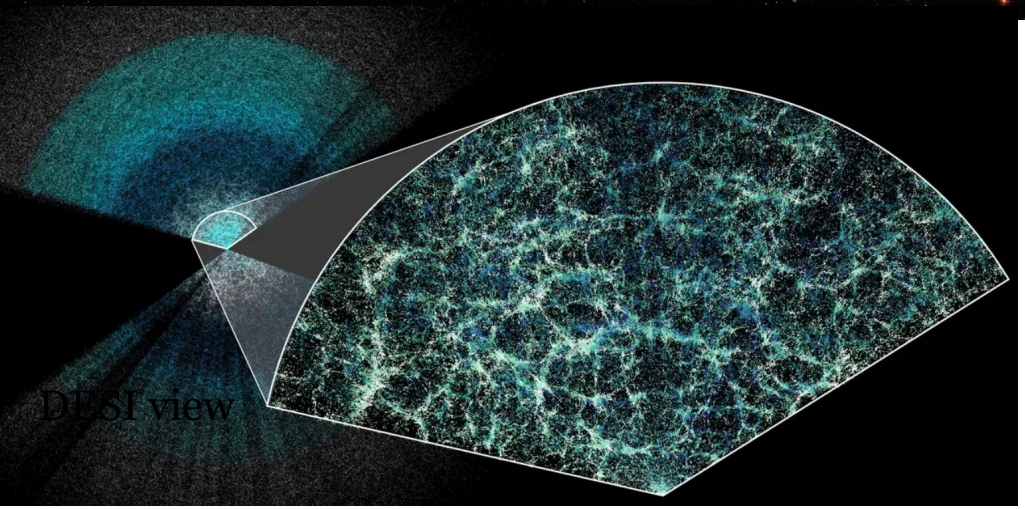


The cosmic web (supercluster – void network)
Superclusters: 1% of the volume and ~ 15 % of mass of the Universe
Voids 70 – 90% of the volume and 15 % of mass,
~ 10 – 30%: supercluster outskirts

Einasto, J. et al. 2022



Patchwork Universe – the cosmic web



Cosmic web – a network of galaxy clusters (nodes) connected by filaments of galaxies and poor groups, and separated by voids

Morphology – density relation of galaxies

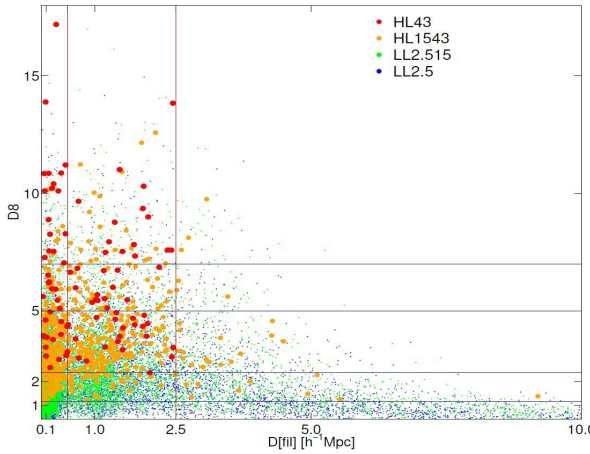
Red, early type galaxies with no active star formation in rich clusters and in groups and filaments near filament axis

(Dressler 1980, E&E1987, E92, E2022, A&A, 668, 69)

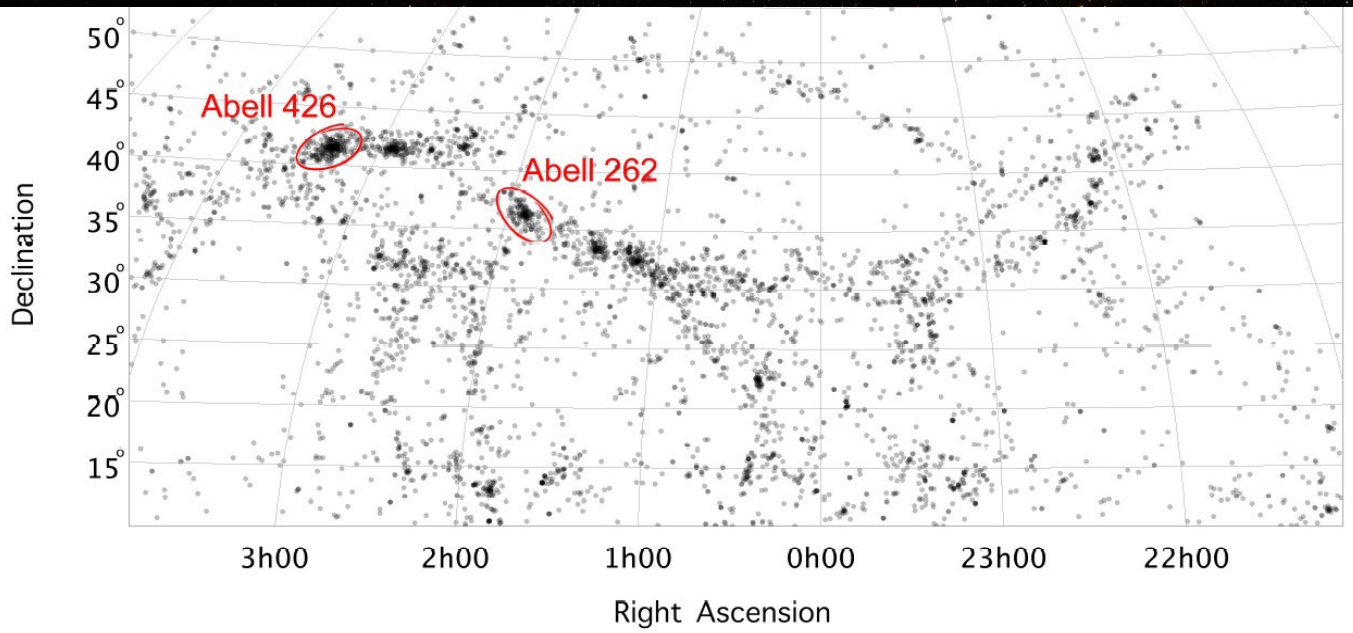
Luminosity (mass) – density relation of groups

Rich groups and clusters in superclusters or supercluster outskirts in filaments, poor groups and single galaxies everywhere in the cosmic web

(E2022, A&A, 681, 91)



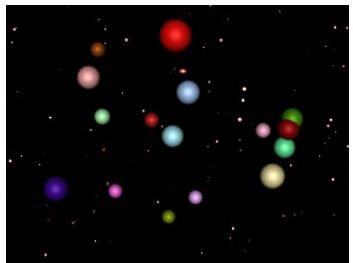
Galaxy superclusters



Perseus-Pisces supercluster
Jõeveer, Einasto, Tago 1977, 1978
Discovery of the cosmic web

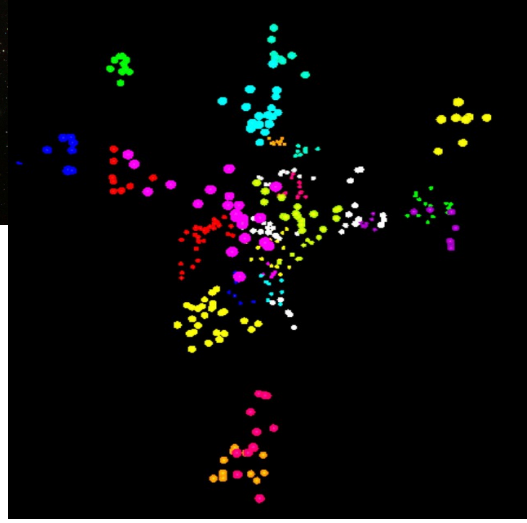
Superclusters: the largest structures in the cosmic web, embed galaxies, groups and clusters, connected by filaments
"mini-Universes"

Sankhyayan+ 2023, ApJ 958, 62; Aghanim+2024, astro-ph 2402.18455



Jaan Einasto, "Dark matter and cosmic web story", World Scientific 2024

The challenge of the largest structures in the Universe

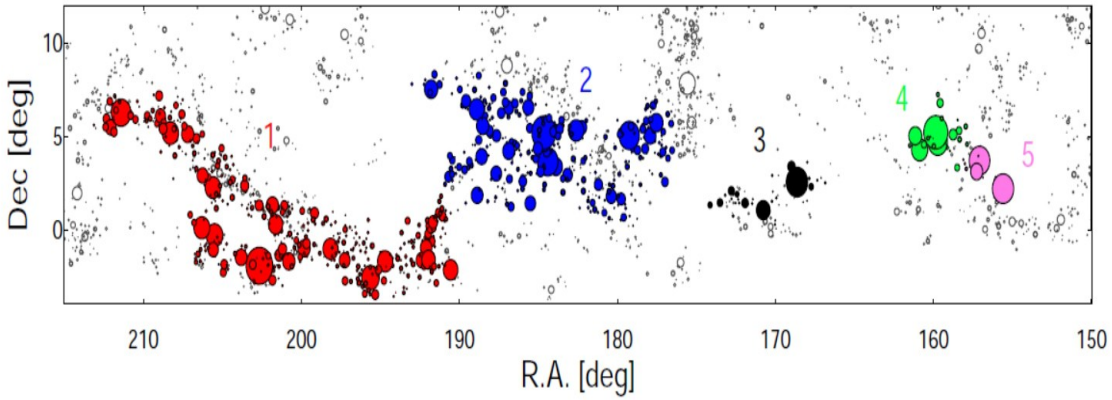


Park+ 2012

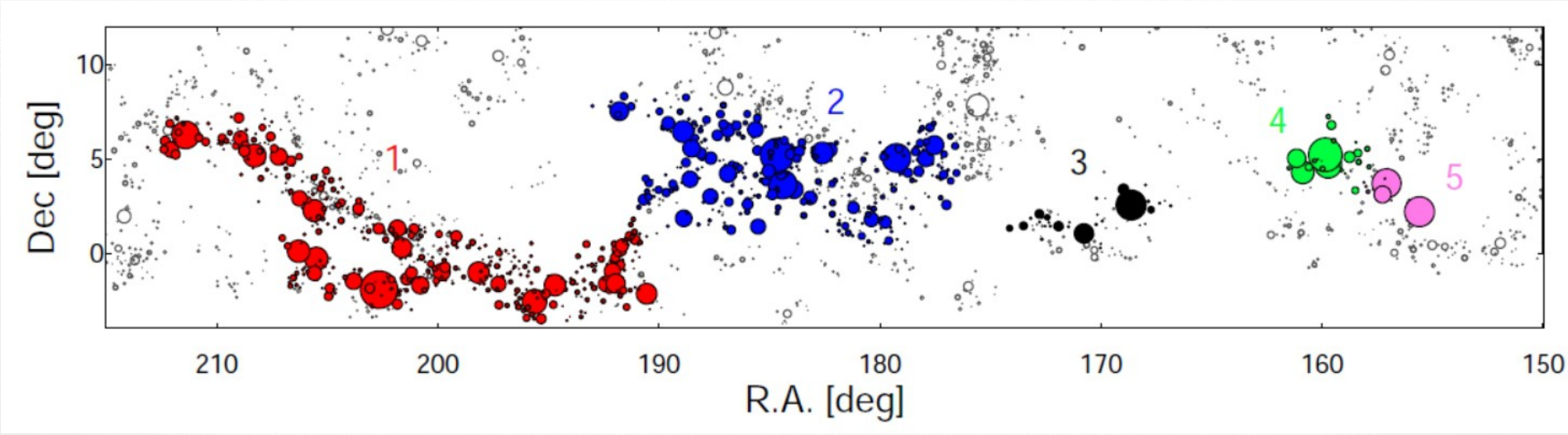
Superclusters and voids – the largest patches?
Are there even larger structures
(larger patches/inhomogeneities)?
If yes, are these structures compatible with the ΛCDM model?

Supercluster complexes, planes and shells

Regularity in the distribution of galaxy superclusters and quasar systems



Supercluster complexes: the Sloan Great Wall



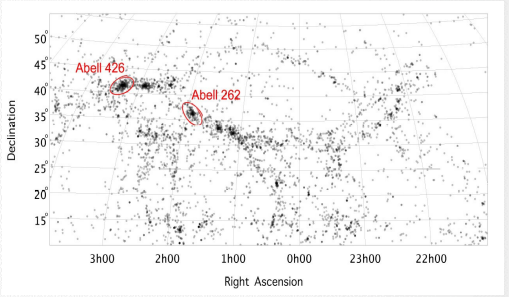
The Sloan Great Wall – complex of five superclusters

Length ~220 h^{-1} Mpc

$M_{scl} \sim 10^{17} h^{-1} M_{\odot}$

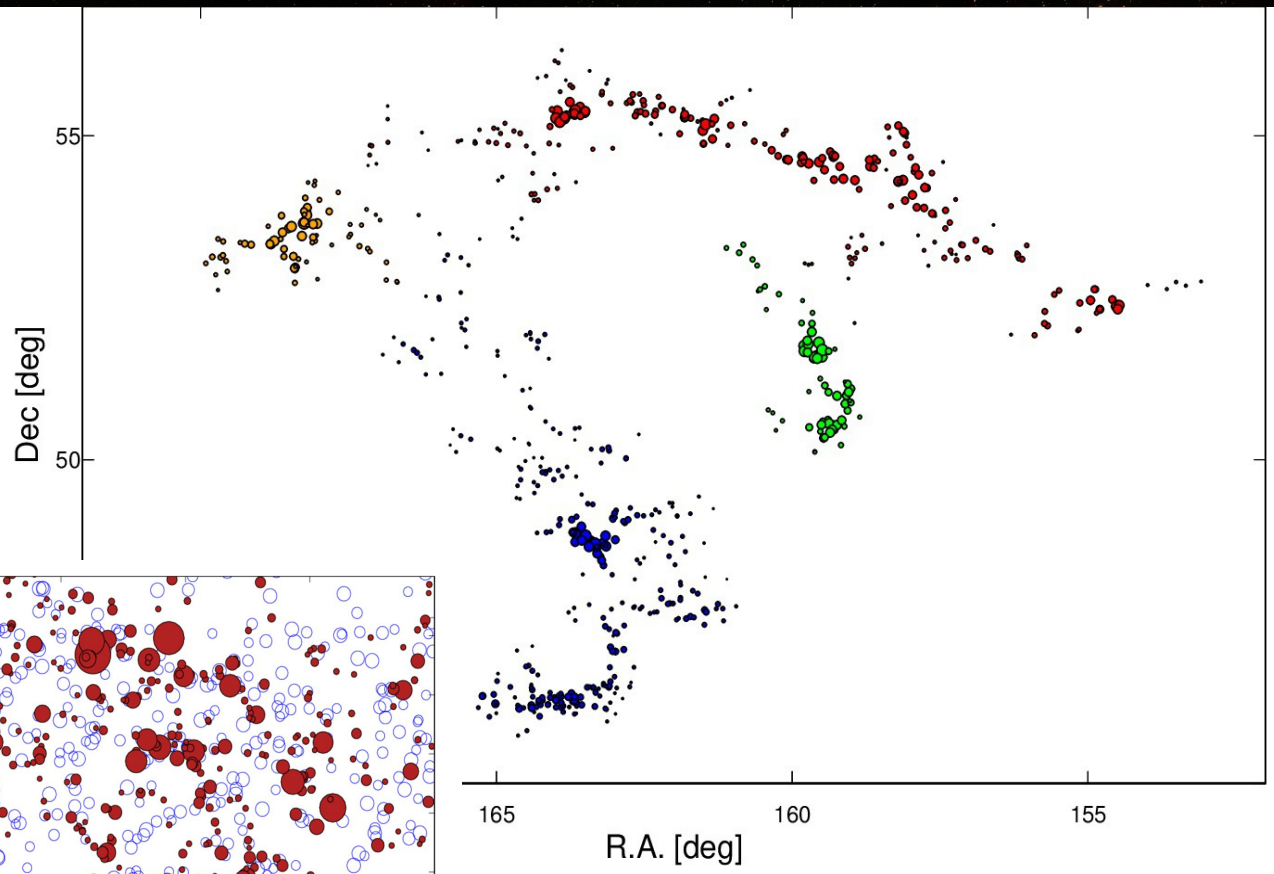
The richest superclusters from observations and simulations have similar sizes, and there may be bigger superclusters in the local Universe

Park+ 2012



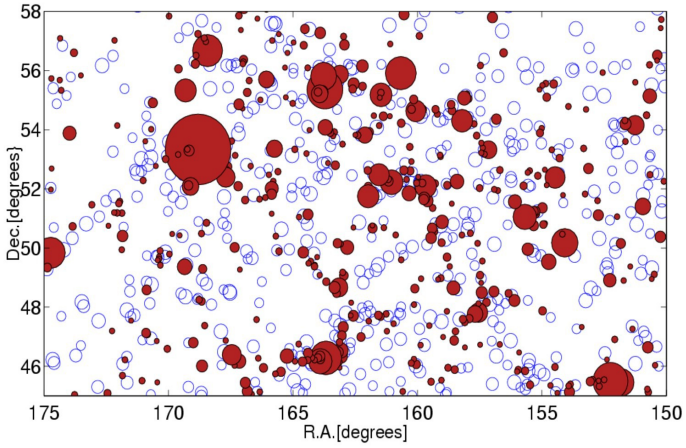
PP length ~ 60 h^{-1} Mpc

Supercluster complexes: the BOSS Great Wall

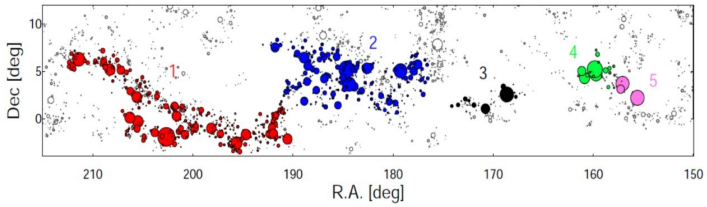


BOSS
Great Wall

Lietzen+2016

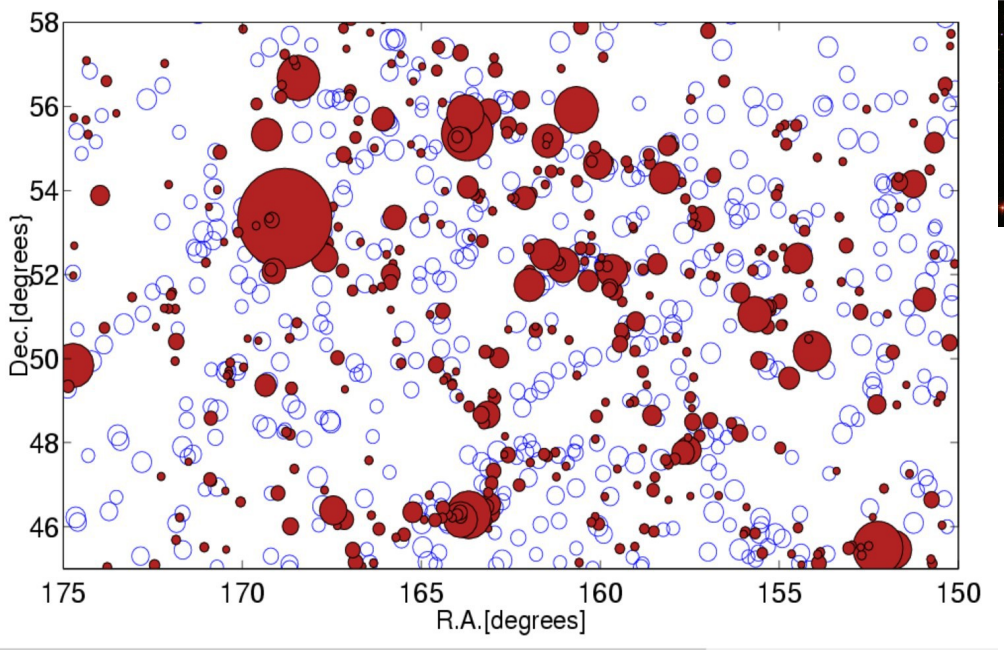


Sloan Great Wall

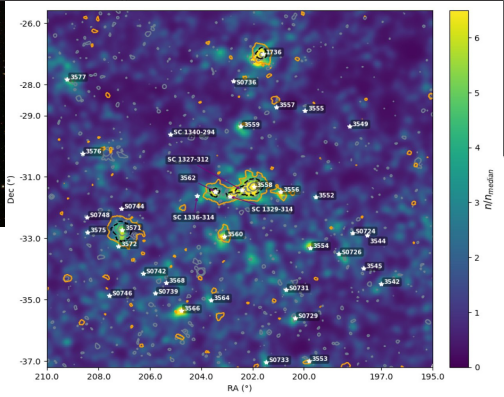


Lenght 250 h^{-1} Mpc, redshift ~ 0.46

CMASS and DESI view



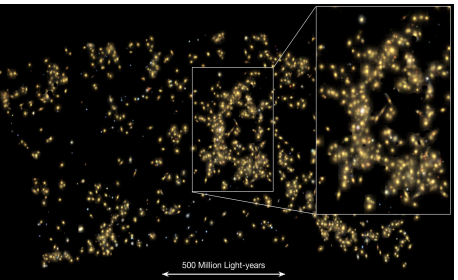


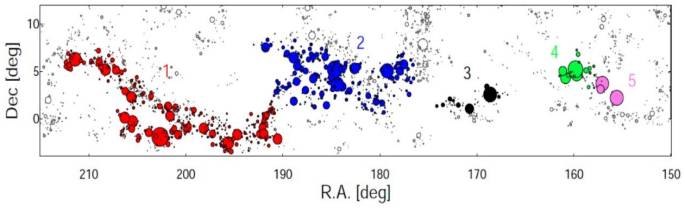


The Shapley, other very rich superclusters, the SGW, and the BGW - too many, too rich for the ΛCDM?

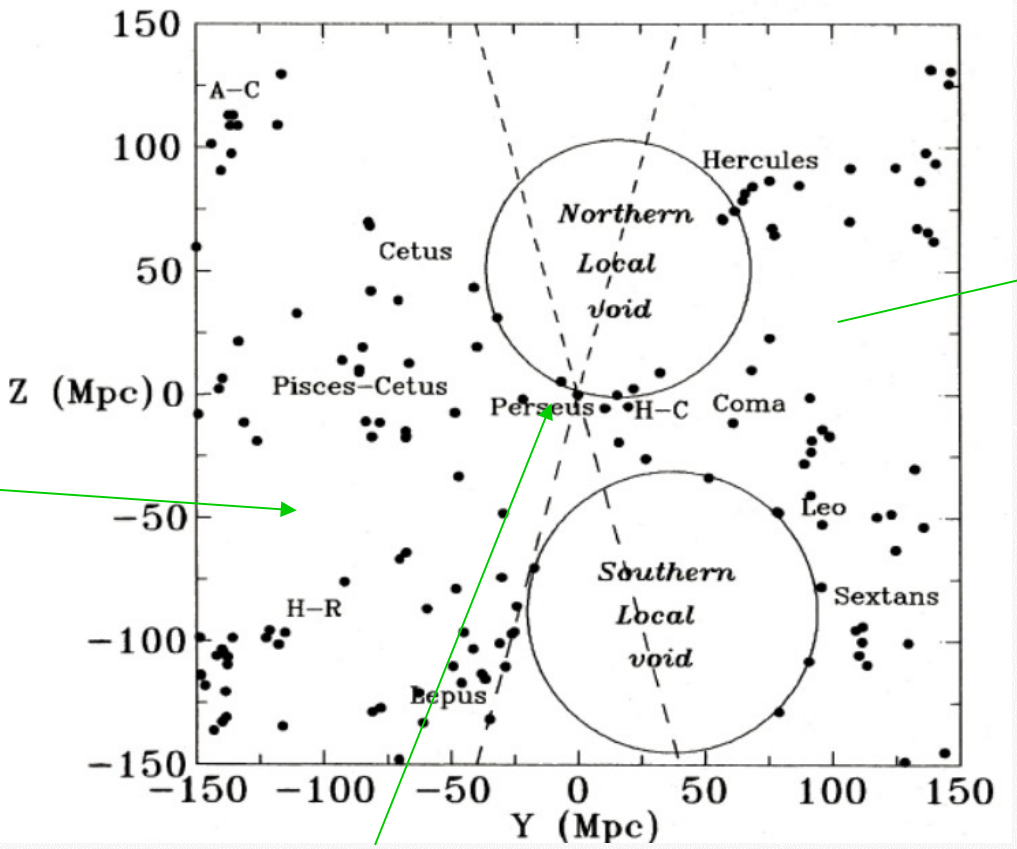
Open question!

Einasto+ 2006, A&A 459, 1; Sheth & Diaferio 2011,MNRAS 417, 2938, Park+ 2012, ApJL, 759, 7; Einasto+ 2021, A&A 649, 51, Sankhyayan+ 2023





Supercluster planes: Local plane



Towards
Sloan Great Wall

Eridanus
supervoid

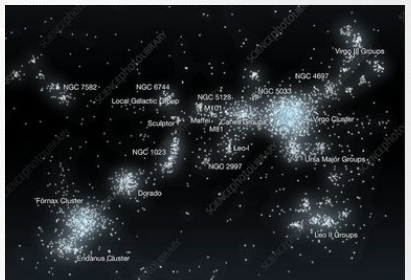
Local Supercluster Plane, thin plane with length ~ 600 Mpc

optical and X-ray clusters, superclusters, and radio galaxies

(Einasto+ 1983, 1994, Chon+ 2021, J. Peebles 2021, 2023)

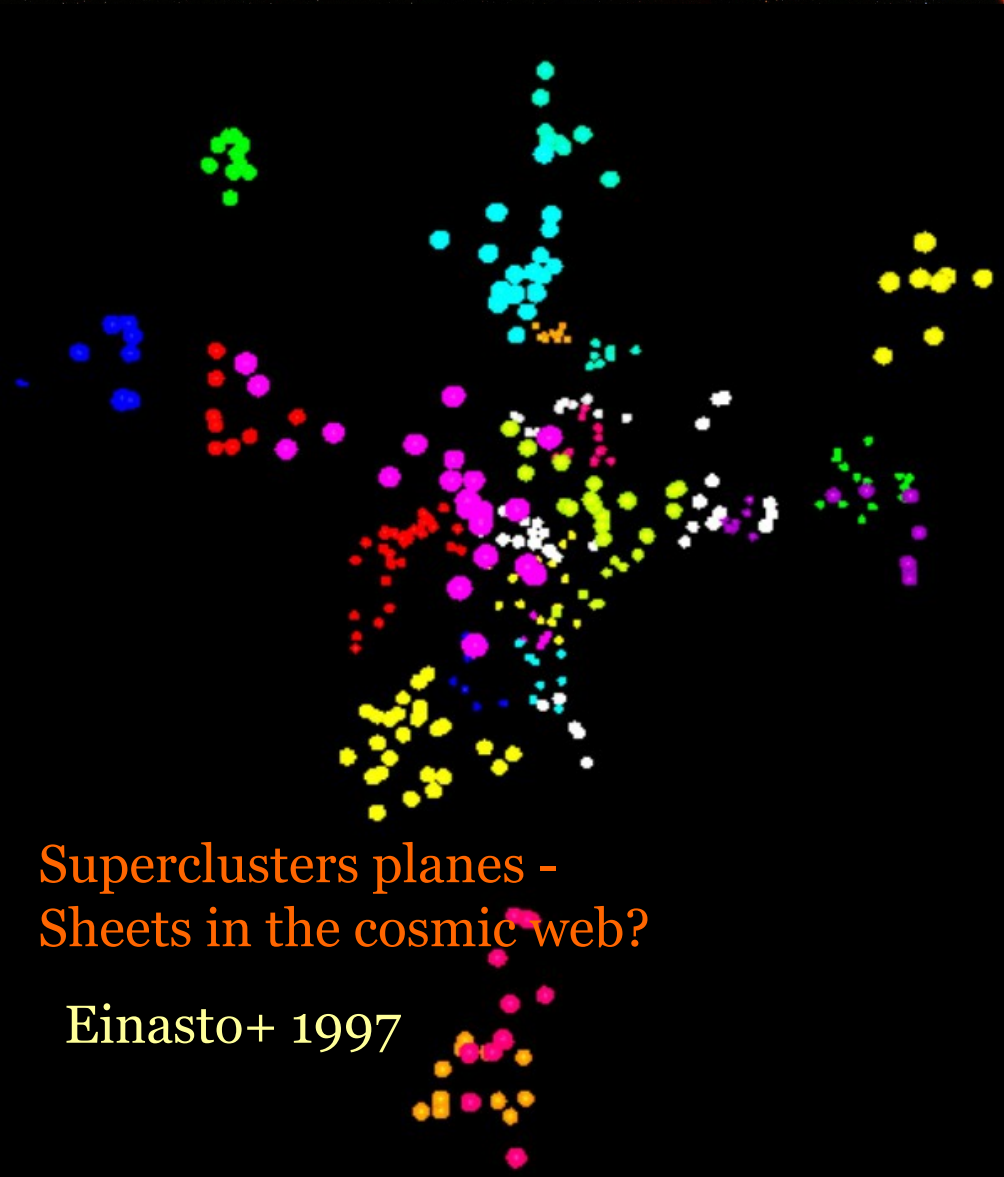
Dolag+2023, A&A 677, 169: constrained simulations: ~ 100 Mpc plane

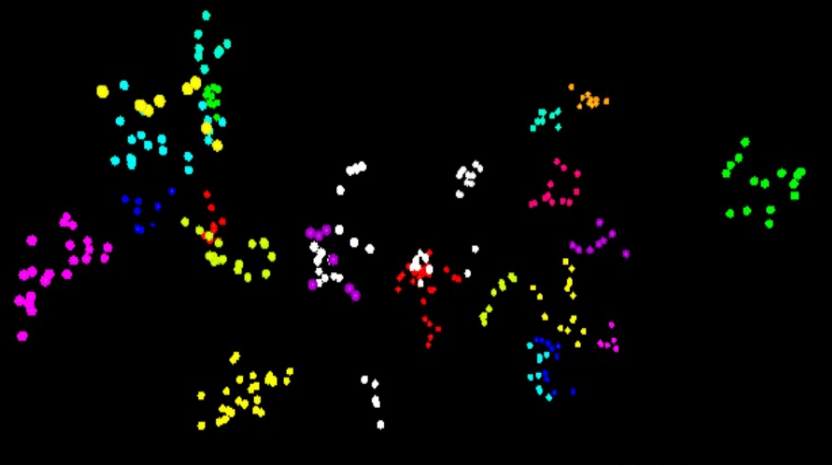
Saar+ (2002), Peebles (2024) – evidence of long strings?

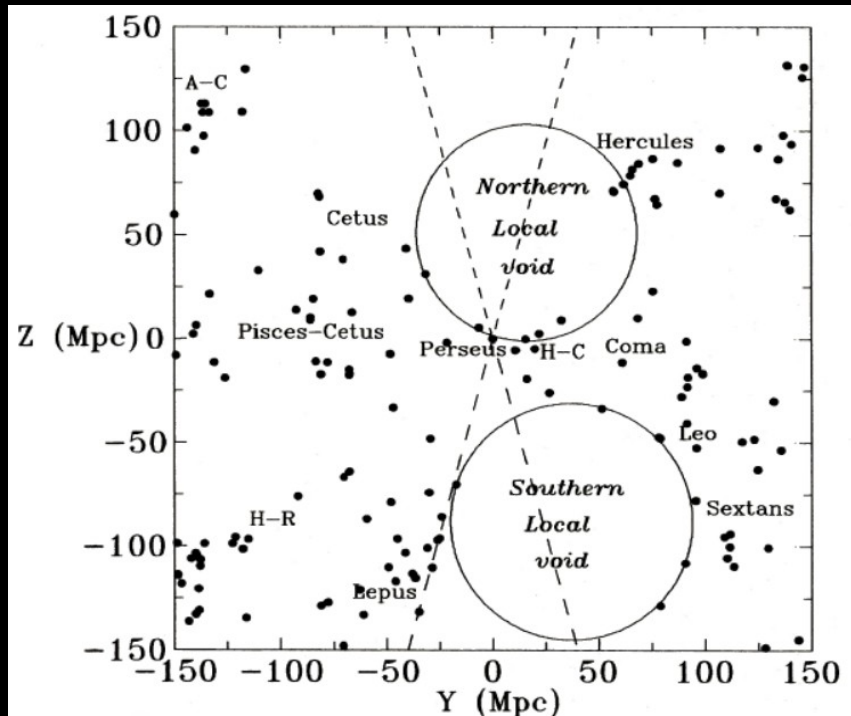


Supercluster planes: Dominant supercluster plane

perpendicular to the Local supercluster plane



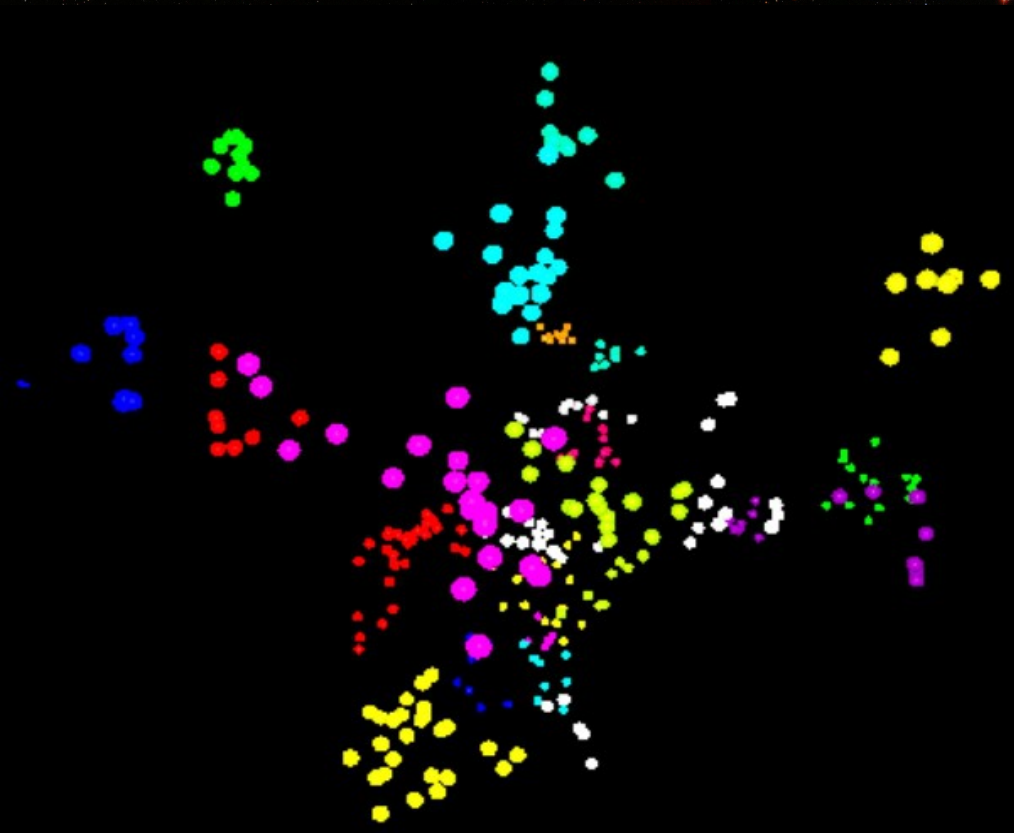




Superclusters planes -
Sheets in the cosmic web?

Einasto+ 1997

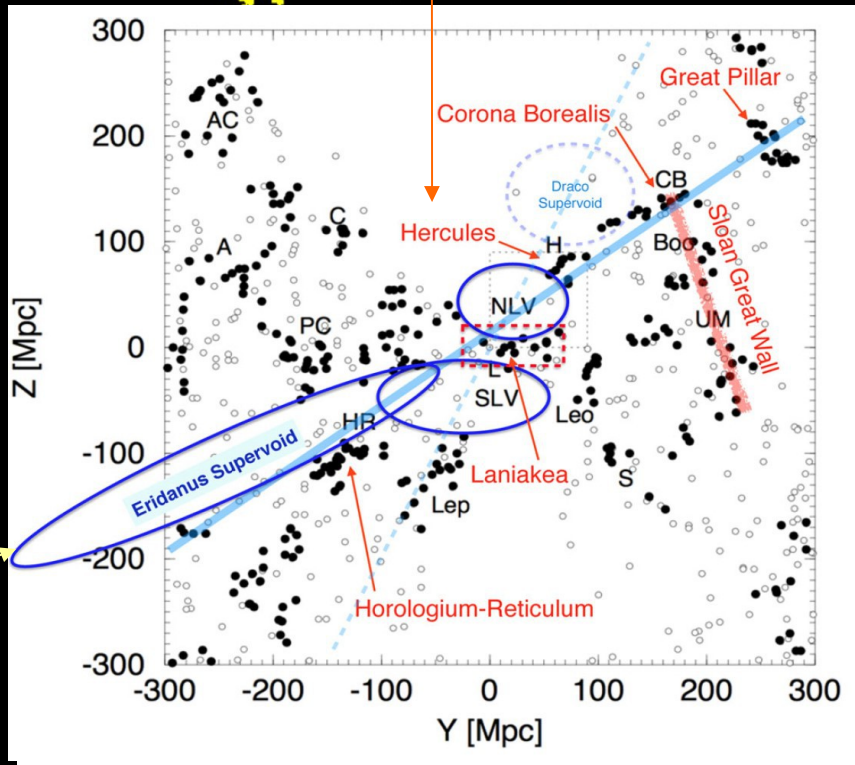
Superclusters and supervoids: regular pattern with 130 h^{-1} Mpc scale



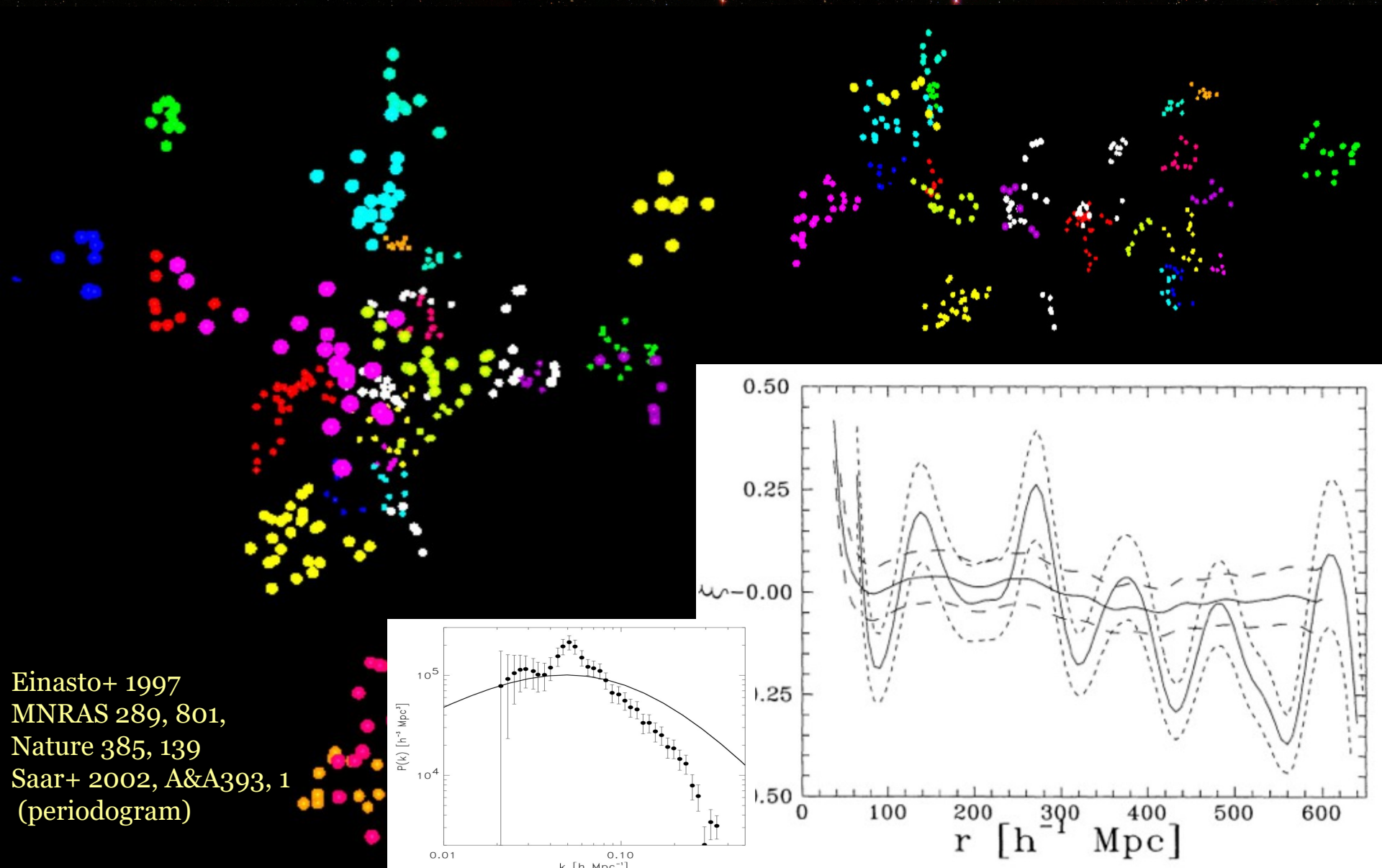
Einasto+ 1994, 1997



Lindner+ 1995
Kovacs+ 2016
Szapudi+ 2022

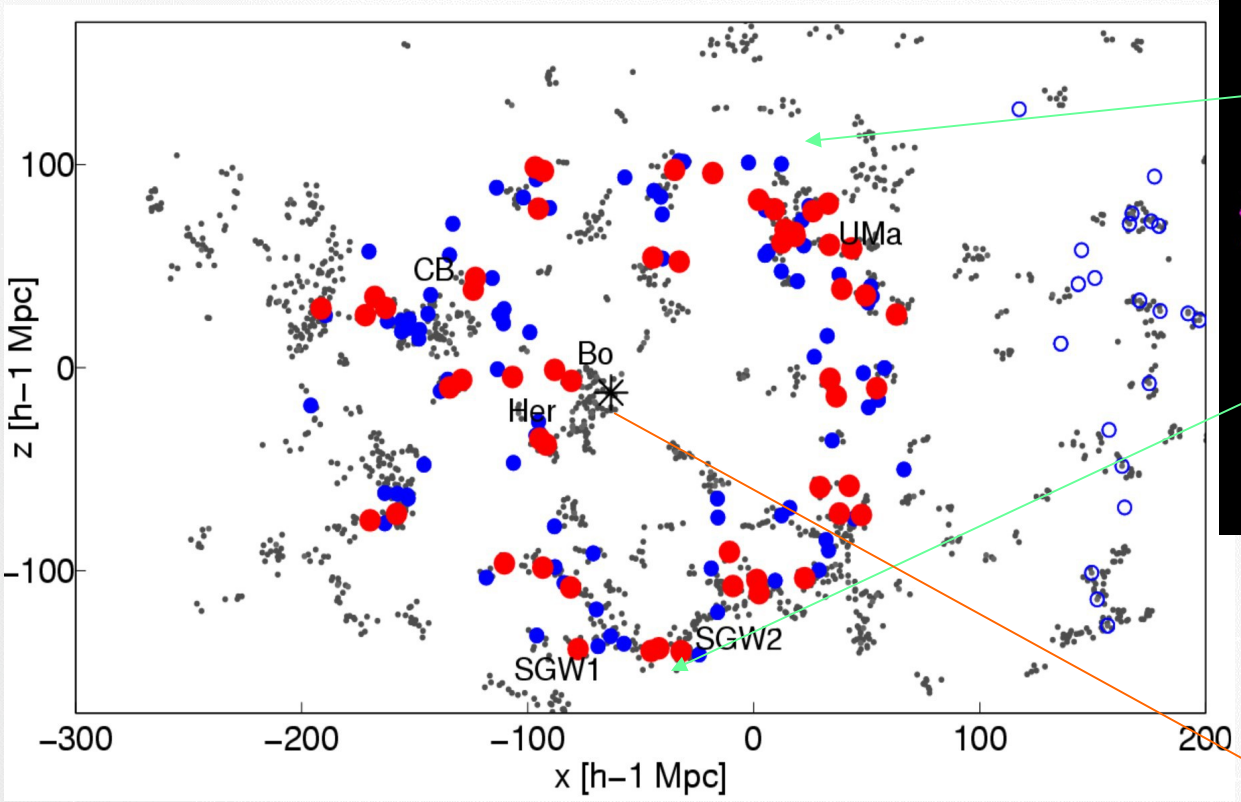


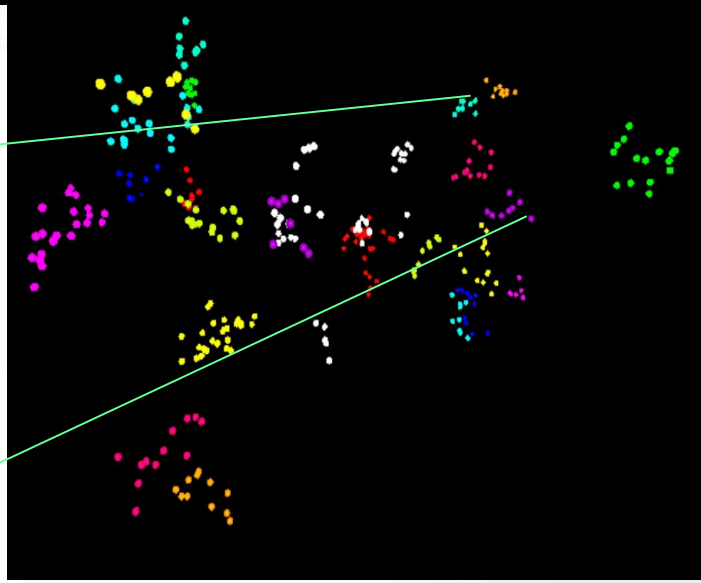
Regularity in the cluster distribution: Correlation function and power spectrum

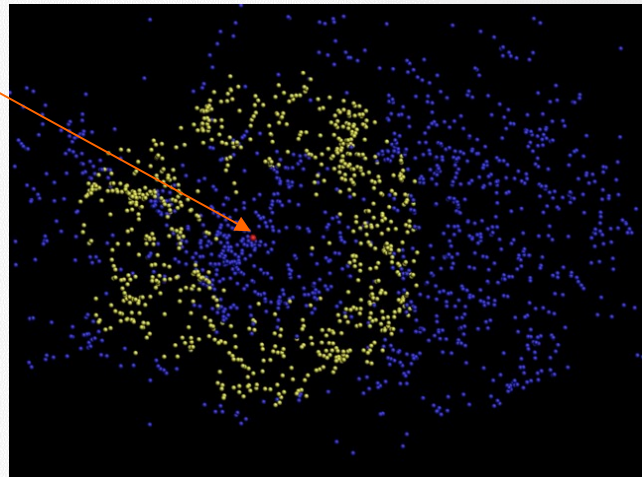


Einasto+ 1997
MNRAS 289, 801,
Nature 385, 139
Saar+ 2002, A&A393, 1
(periodogram)

Superclusters in the cosmic web: shells







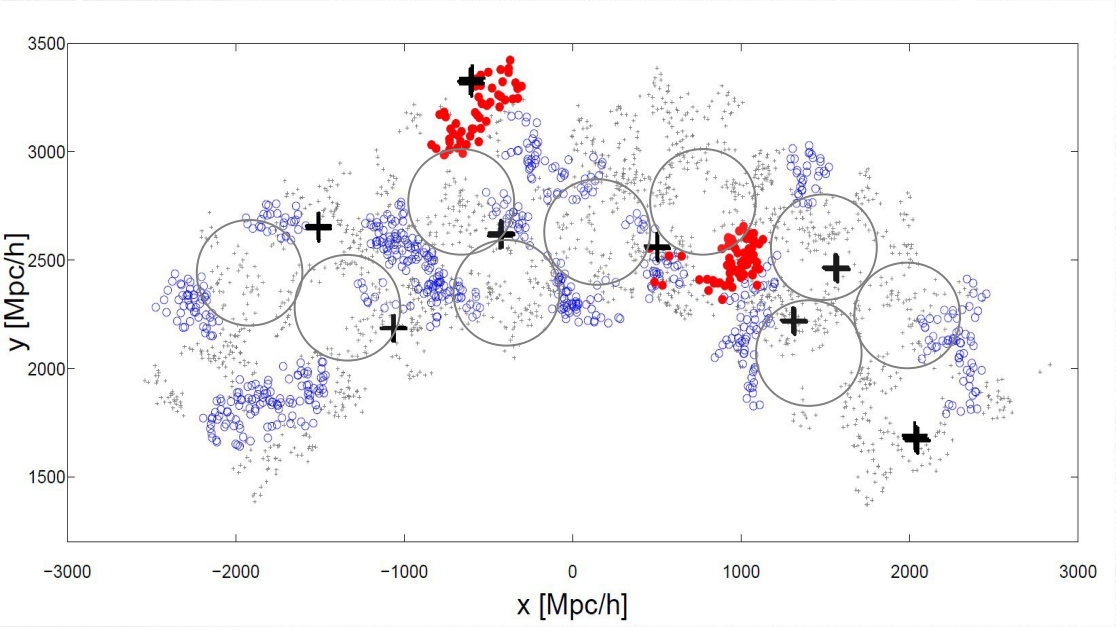
Shells of rich superclusters with 130 h^{-1}Mpc scale as a part of the regular pattern of superclusters

Not BAO shells!

Einasto+ 2011, 2016, Tully+ 2023 (BAO, H0 = 77km/s/Mpc)

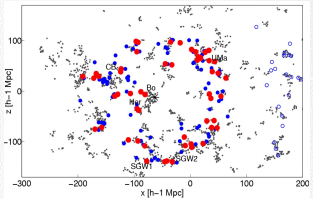
if BAO, then BAO was detected in E+1994 ☺

QSO systems at high redshifts (z > 1)



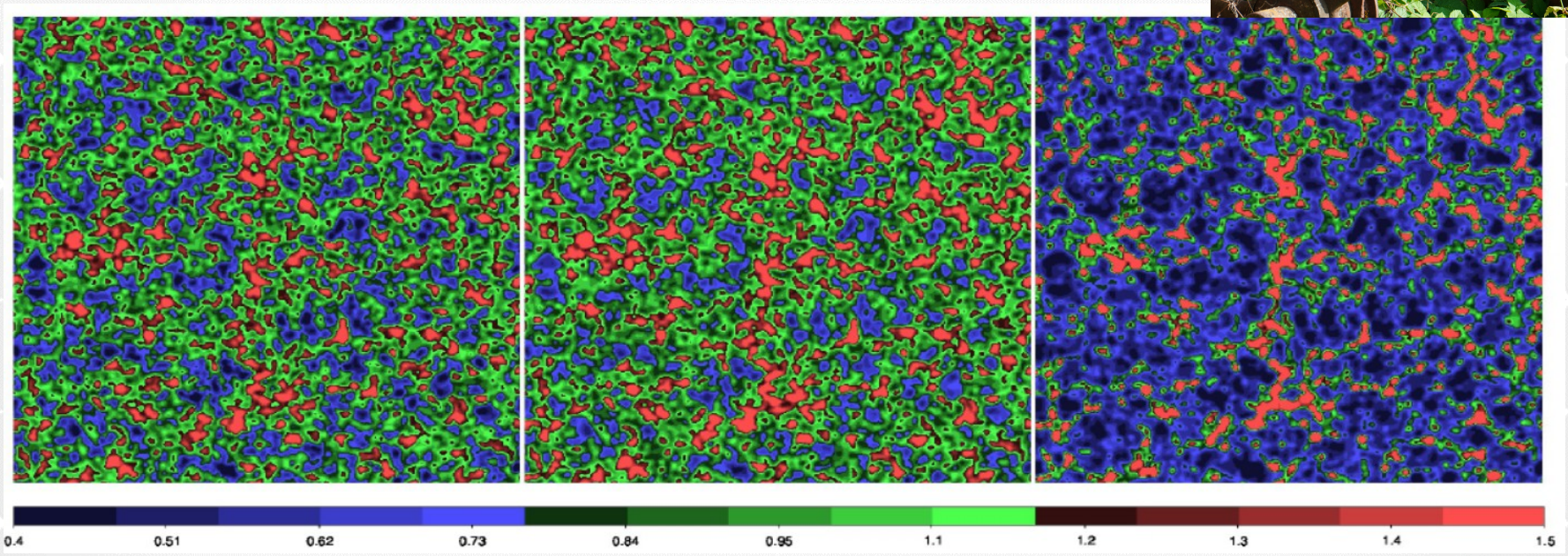
400 h^{-1} Mpc scale in the distribution of QSO systems?

E+2014



Growth of the cosmic web in simulations





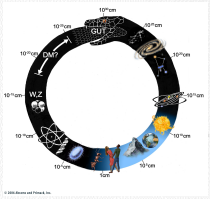
Supercluster locations do not change much

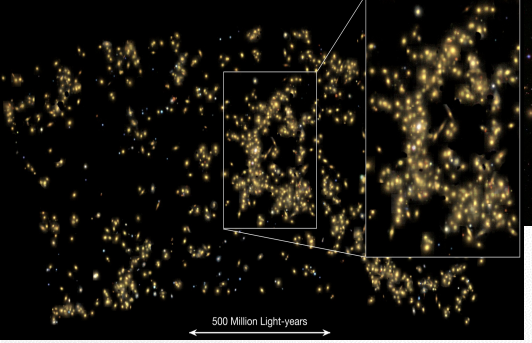
(Einasto, J. et al. 2022)

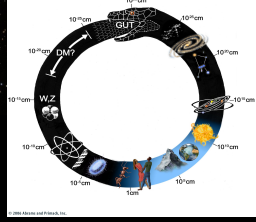
Origin of the supercluster planes and shells?

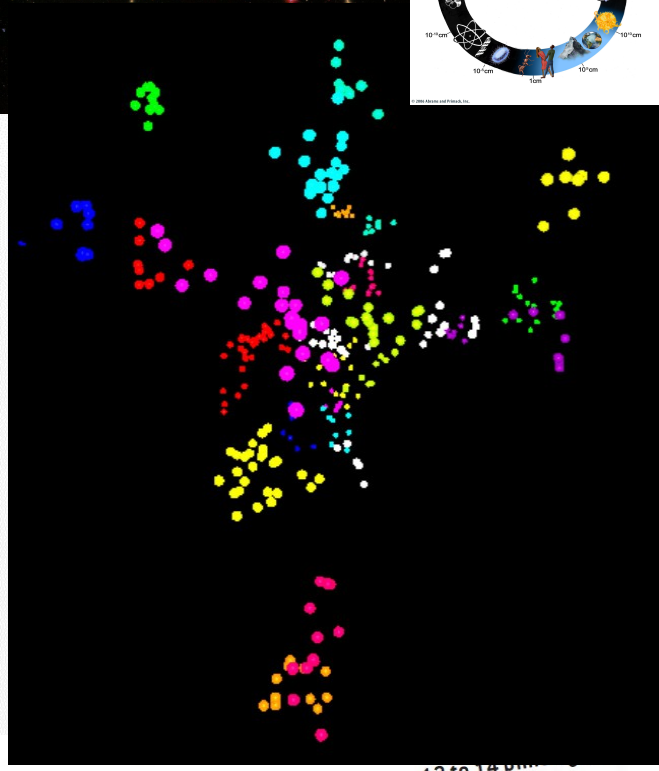
Why, when, and how they formed?

130 and 400 h^{-1} Mpc scale?







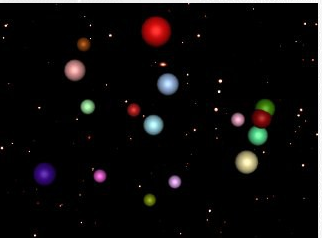


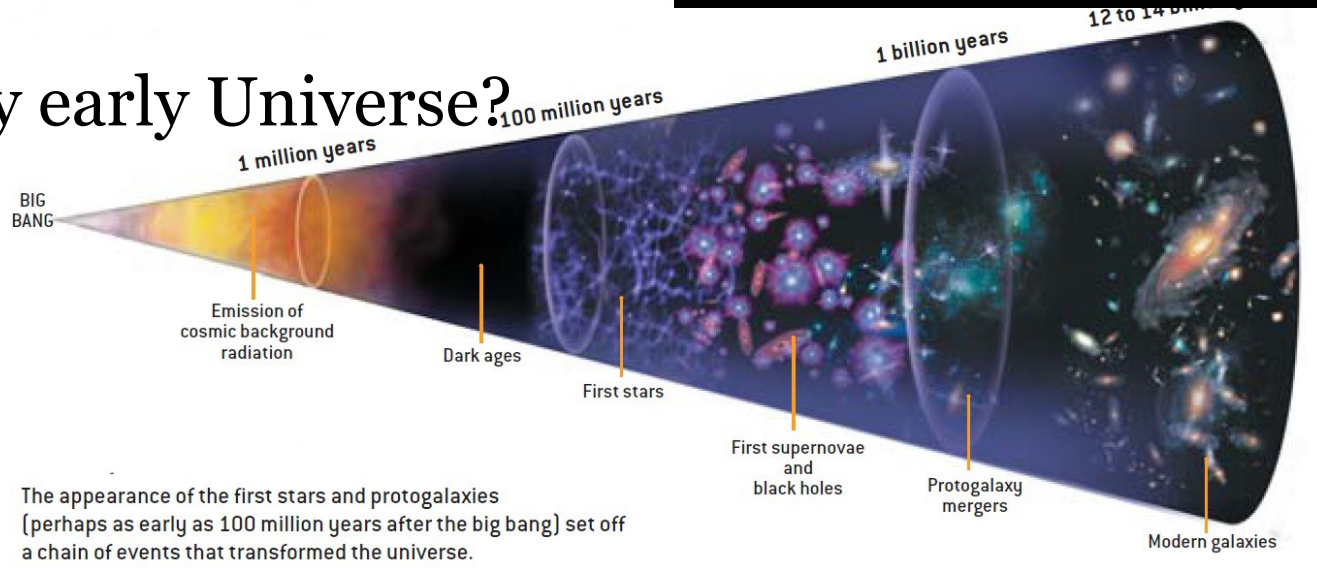
Summary

Rich superclusters form complexes, huge planes and shell-like structures -

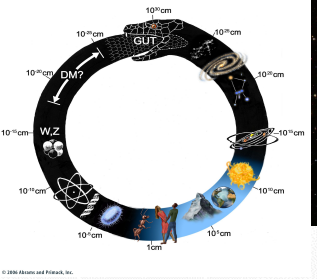
A challenge for the ΛCDM model?

Echo from the very early Universe?





The appearance of the first stars and protogalaxies (perhaps as early as 100 million years after the big bang) set off a chain of events that transformed the universe.



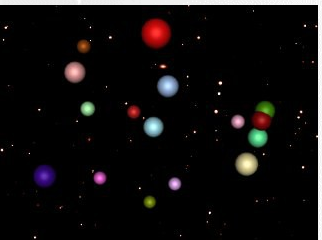


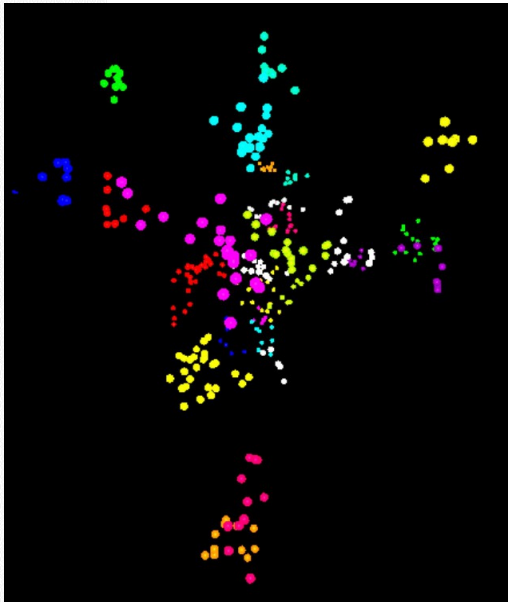
감사합니다

Thank you!

EXCOSM

ANOMALIES & TENSIONS IN COSMOLOGY
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Tartu Observatory
1632
Foundations of the Universe