A Cosmological Test with Large-scale Structures at Intermediate Redshifts

Hwang, Ho Seong (KIAS)

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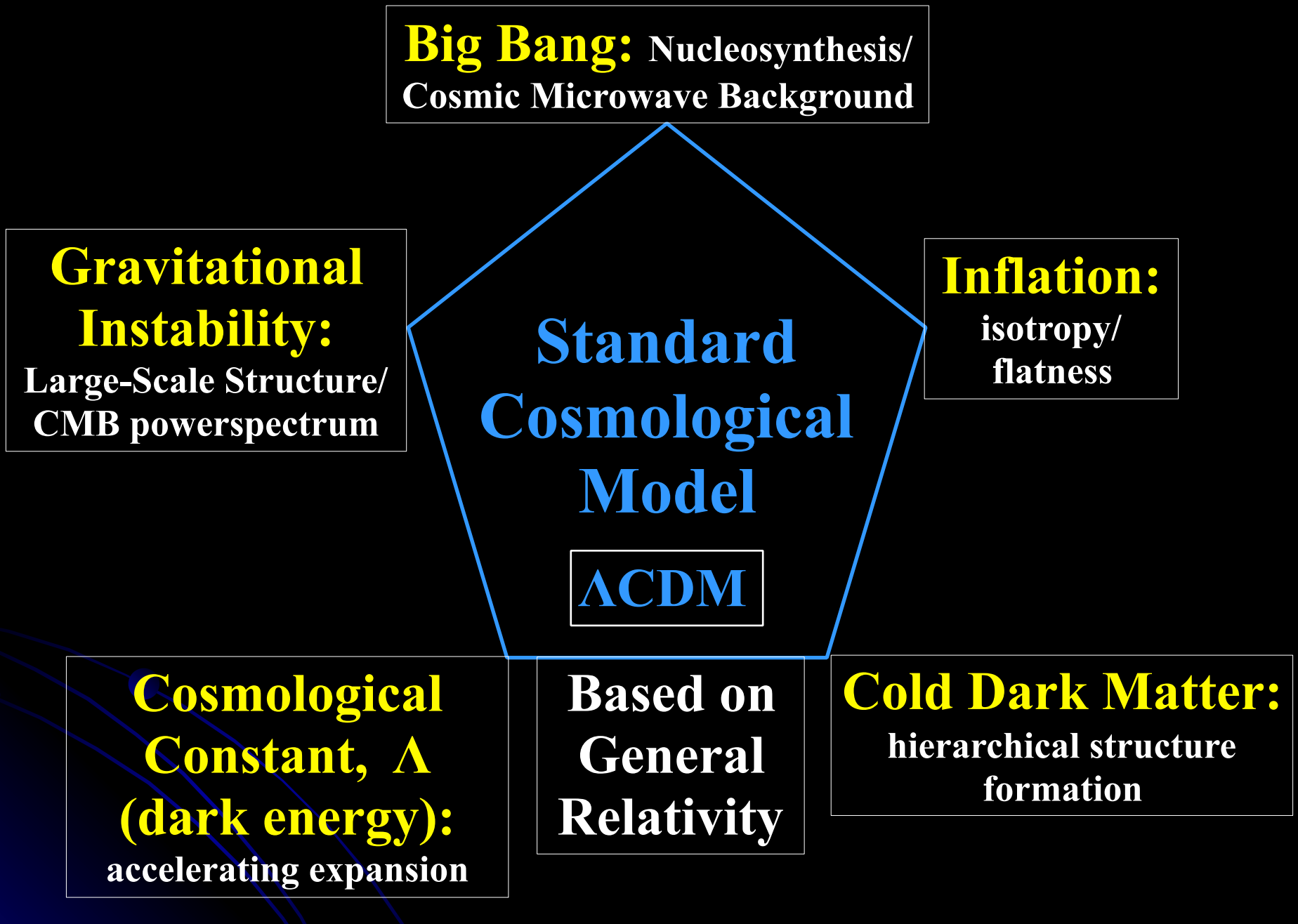
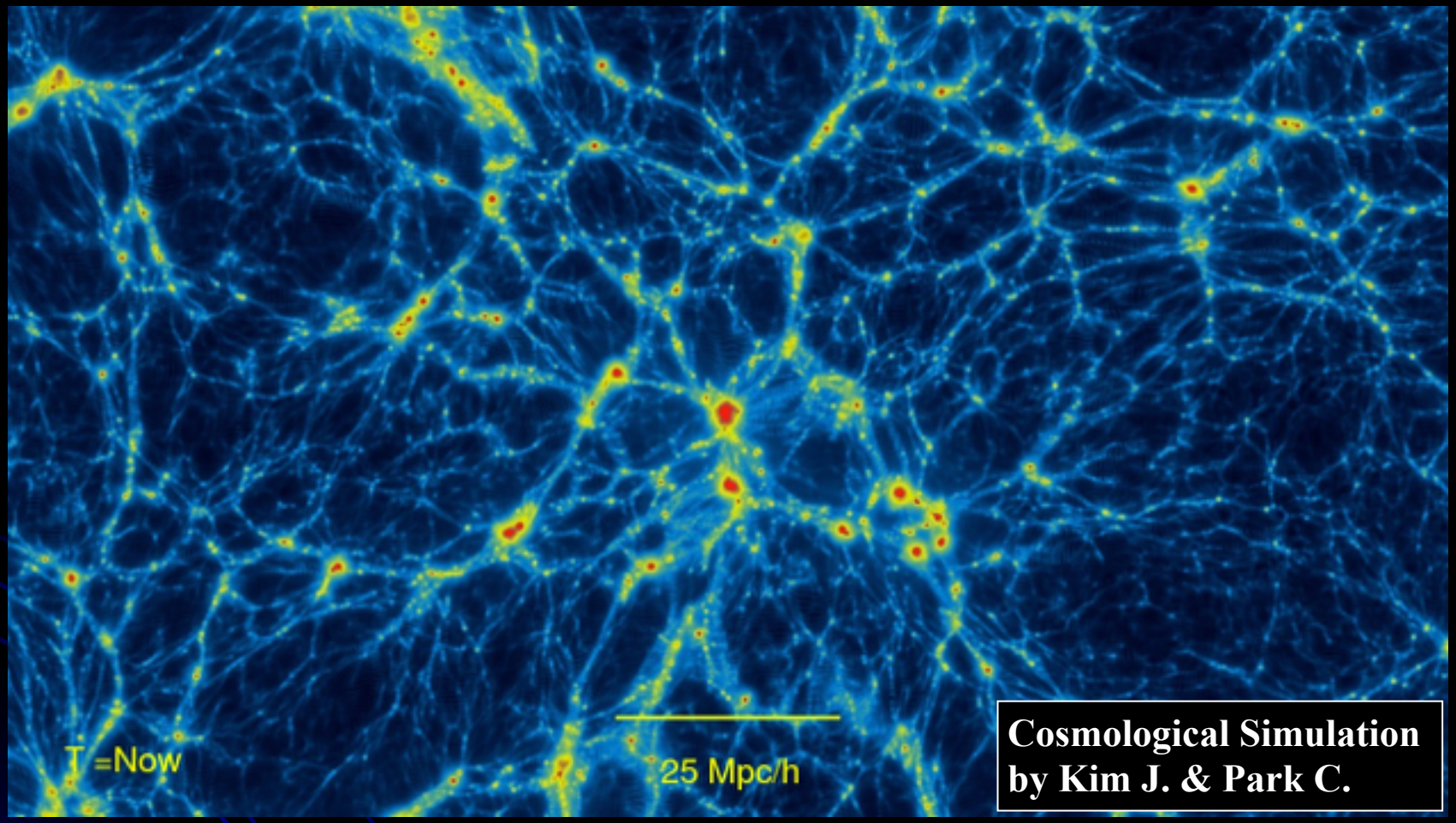
3rd Korea-Japan Workshop on Dark Energy



➢ Test the Standard Cosmological Model with Large-scale Structure of the Universe

LSS: Any structure of galaxy distribution larger than galaxy clusters (>~10 Mpc)

- Over-density Structure
  - Filament, Chain
  - Wall, Pancake, Sheet
- Under-density Structure
  - Tunnel
  - Void, Cell, Bubble



Cosmological Simulation
by Kim J. & Park C.

- Physical properties of large-scale structure depend on
  - cosmological parameters
  - physics of galaxy formation

←Strong Constraints

In this Talk,

- Cosmological Test with the large-scale structure
- There were many cosmological tests in nearby Universe
- Need to study the evolution of large-scale structure (structure is still forming)

Q: Is the large-scale structure in cosmological simulations consistent with that in observations at intermediate redshifts (9-11 Gyrs)?

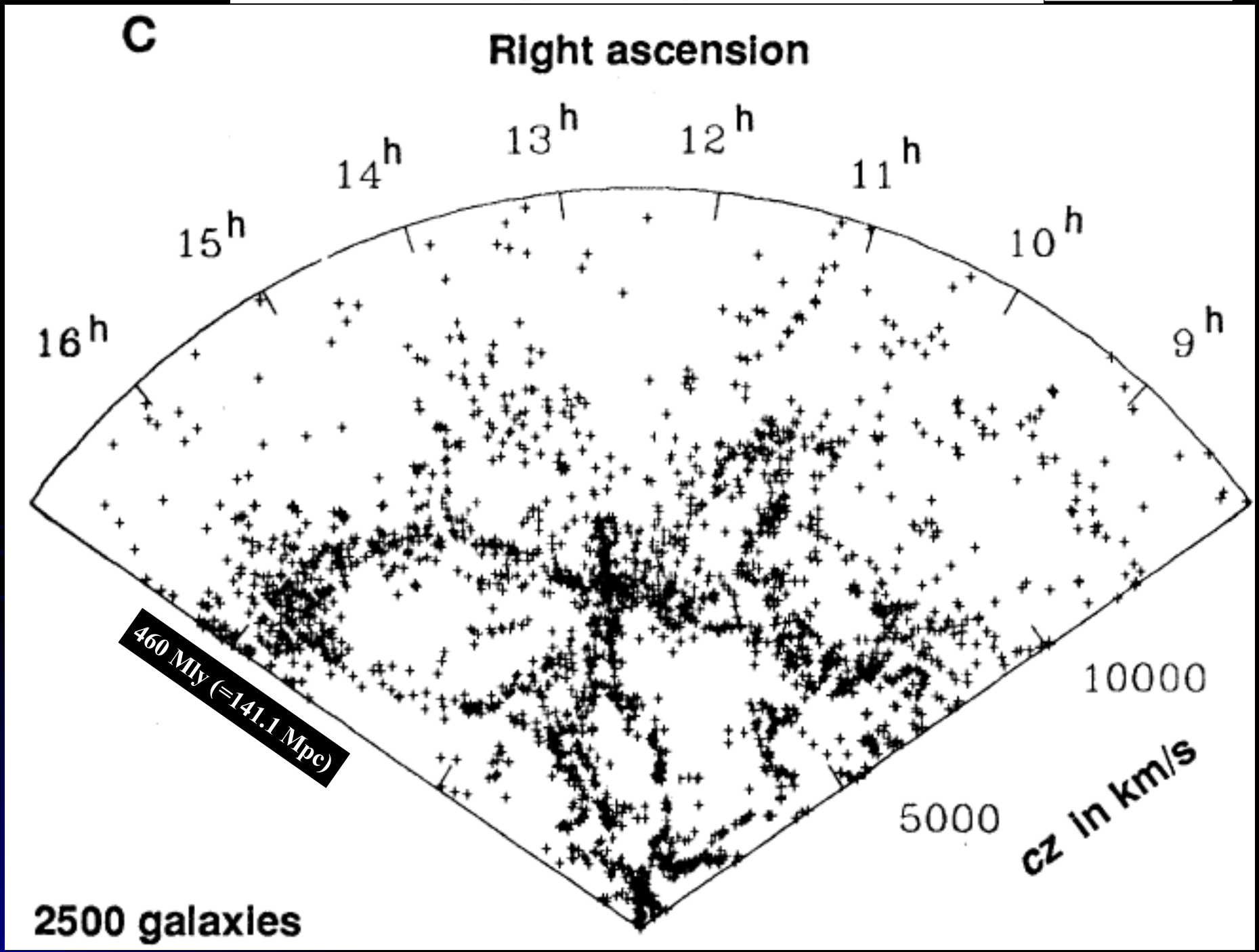

Coma Cluster (SDSS)
2D => 3D

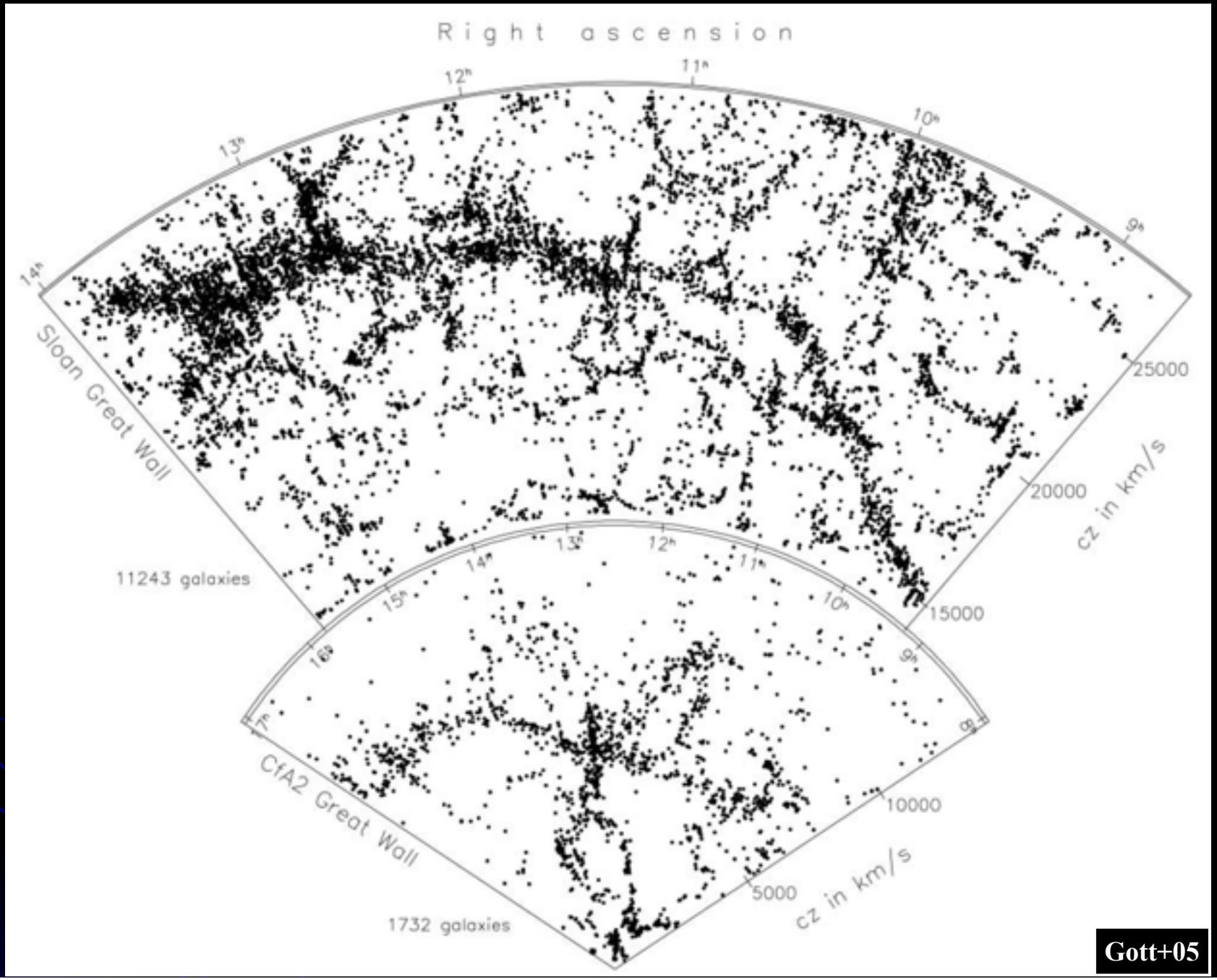
Source: *Science*, New Series, Vol. 246, No. 4932 (Nov. 17, 1989), pp. 897-903

Mapping the Universe

MARGARET J. GELLER AND JOHN P. HUCHRA

CfA Great Wall

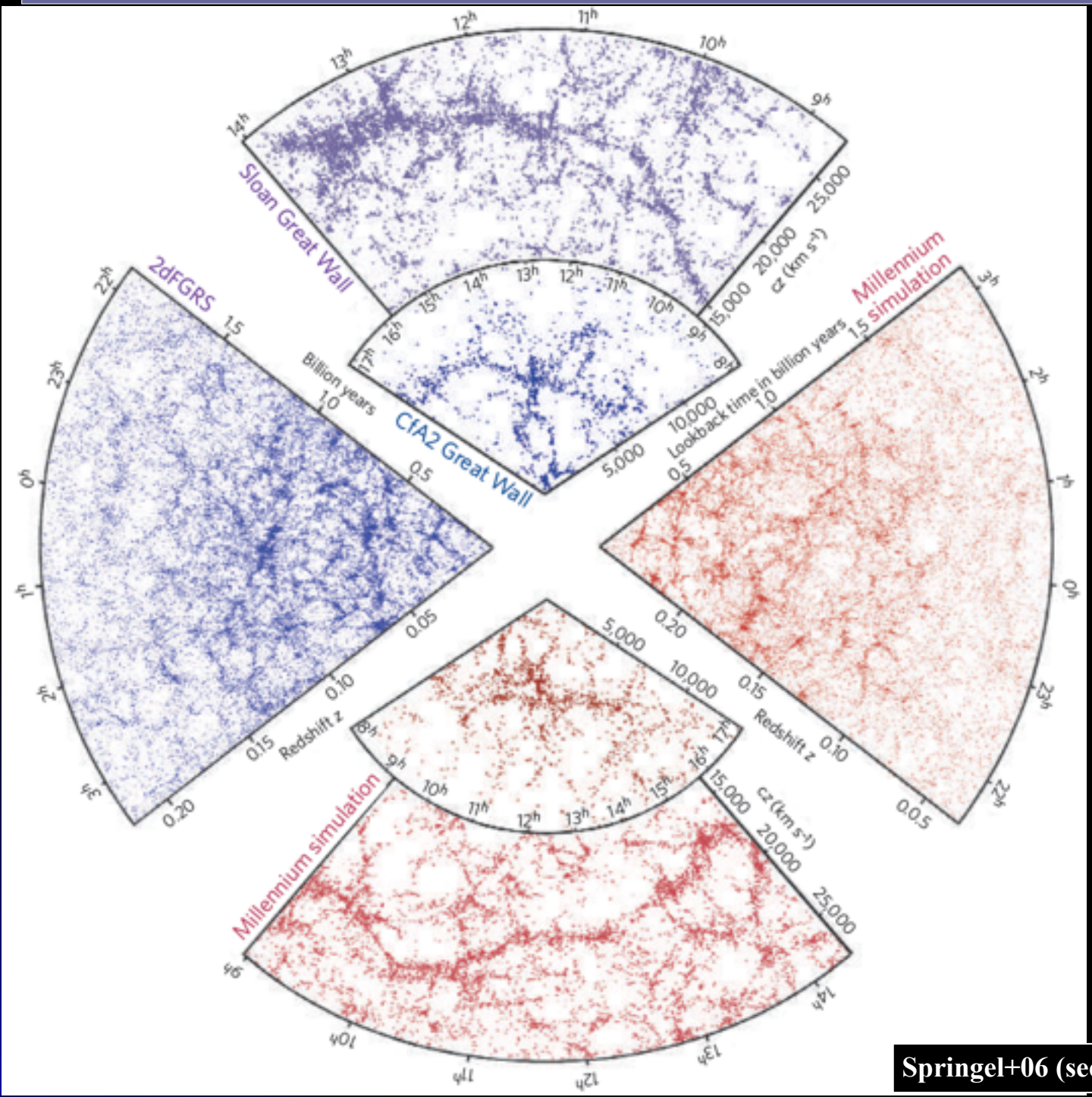




Gott+05

Q: Do we expect this kinds of largest-scale structures in our standard ΛCDM cosmology?

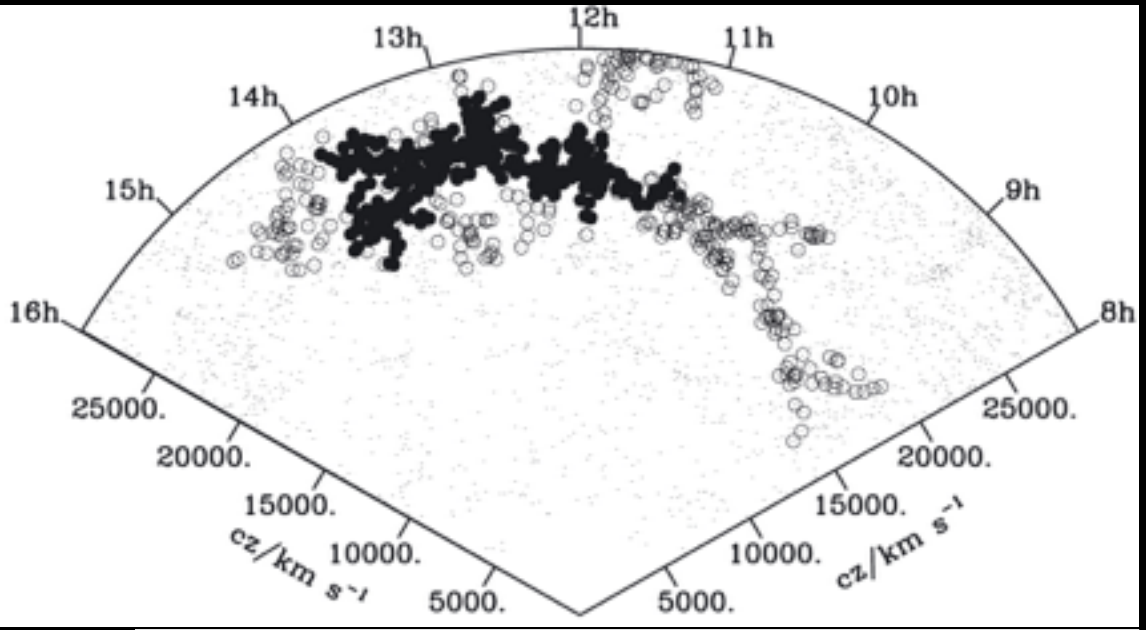
Largest Structures: Cosmological Tests



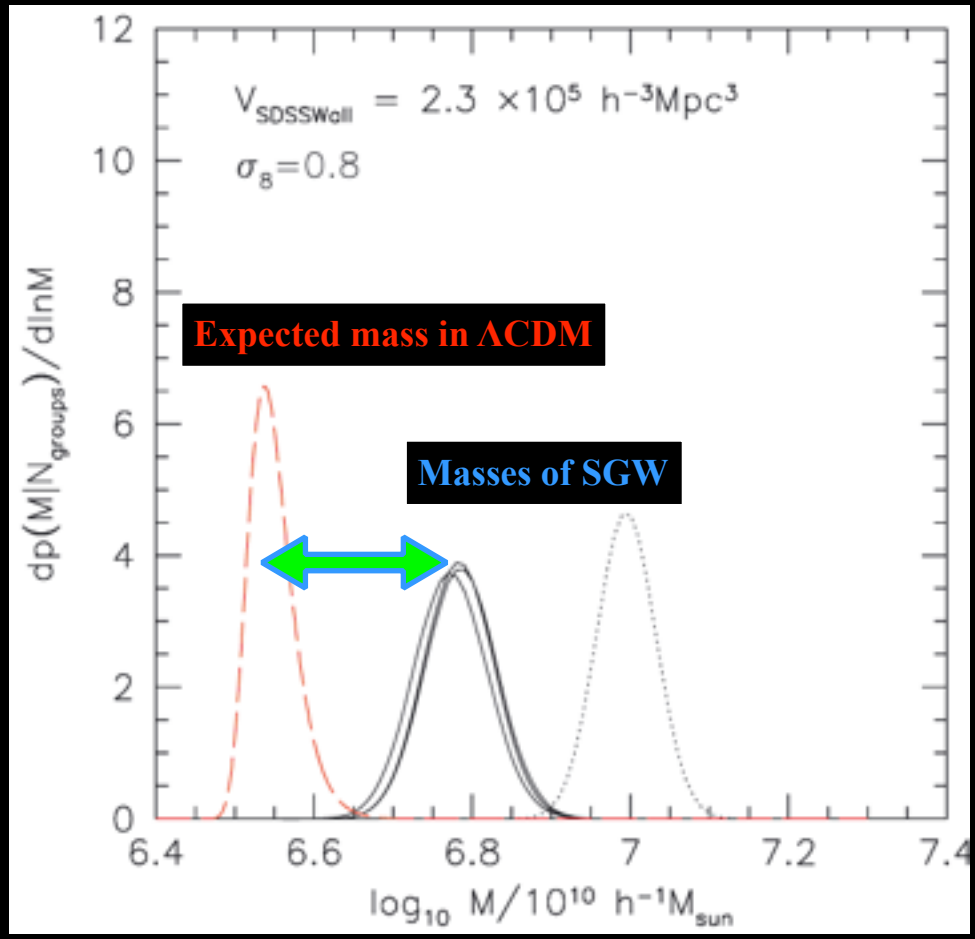
Springel+06 (see Park+90;+12;+15, Sheth & Diaferio 11)

How unusual is the Sloan Great Wall?

Sheth & Diaferio (11)



different link length: 8 h^{-1} Mpc (filled) and 12 h^{-1} Mpc (open)



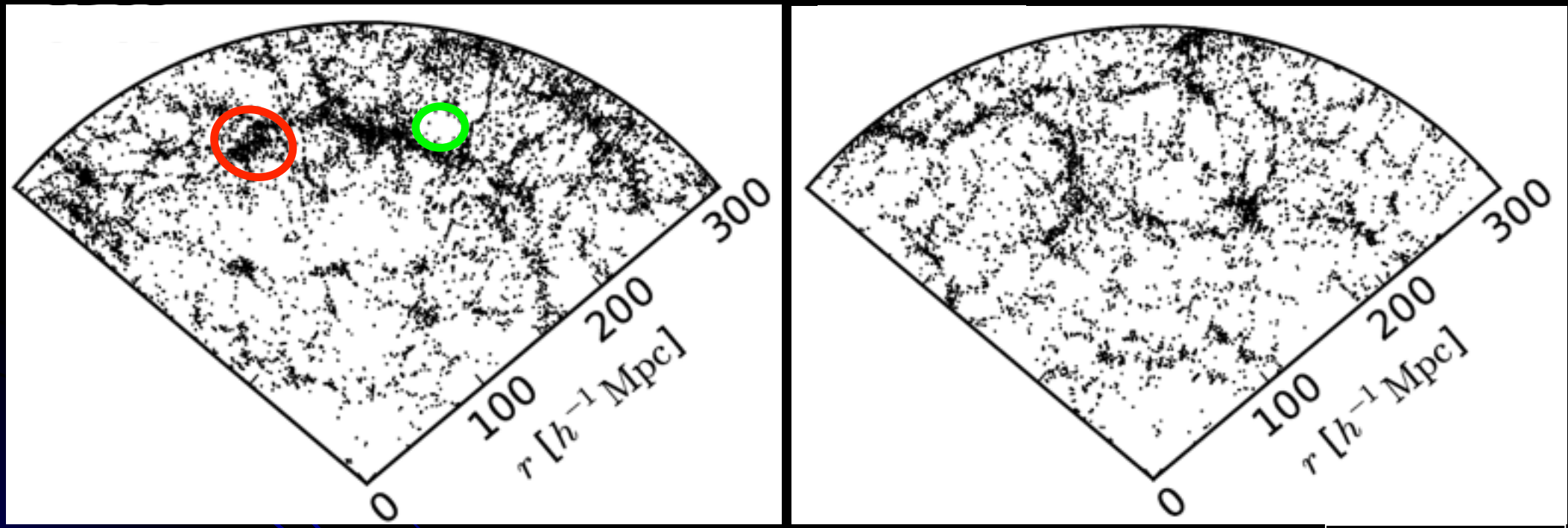
A: The Sloan Great Wall is very unusual.
Its existence is difficult (4 sigma) to reconcile with the ΛCDM model (Gaussian initial conditions & σ_8=0.8)

The Challenge of the Largest Structures in the Universe to Cosmology

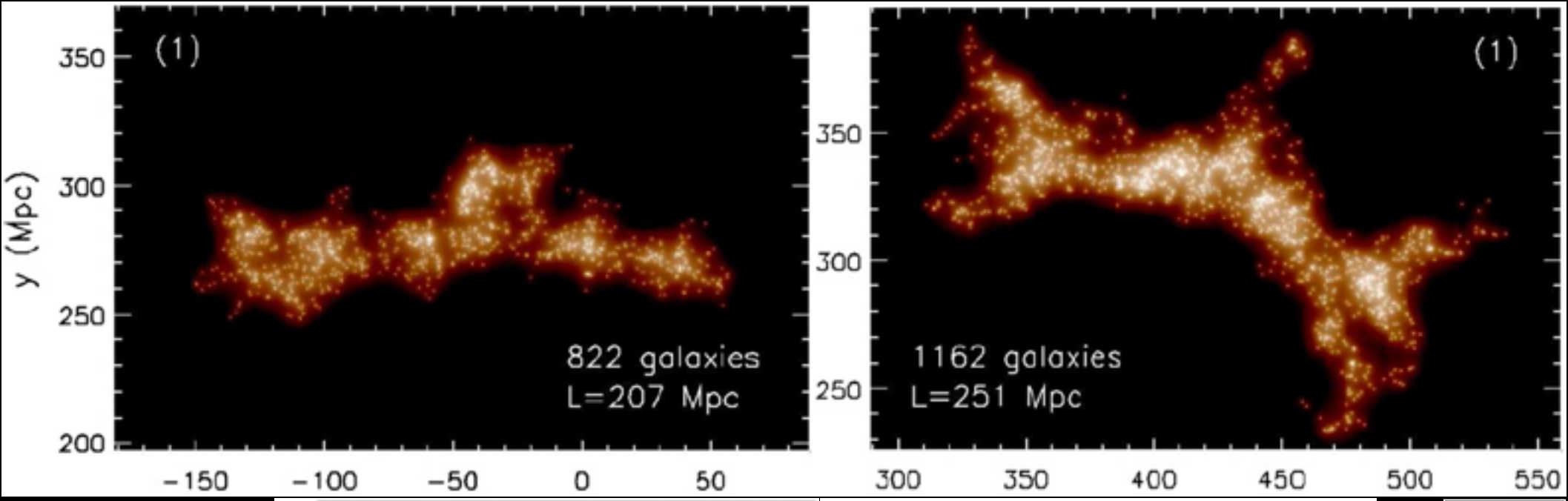
Park+12

Observation: Sloan Digital Sky Survey

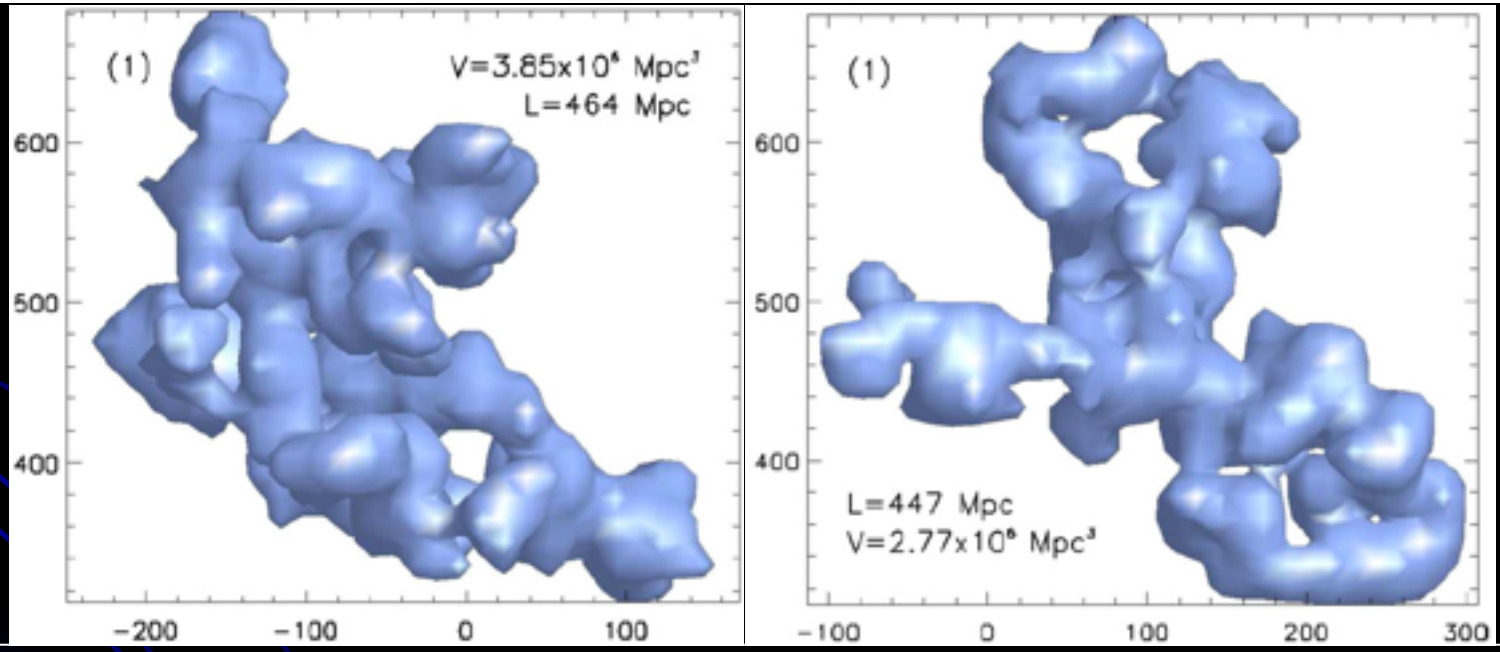
Simulation: Horizon Run 2 Kim+11



Park+12;Hong+15

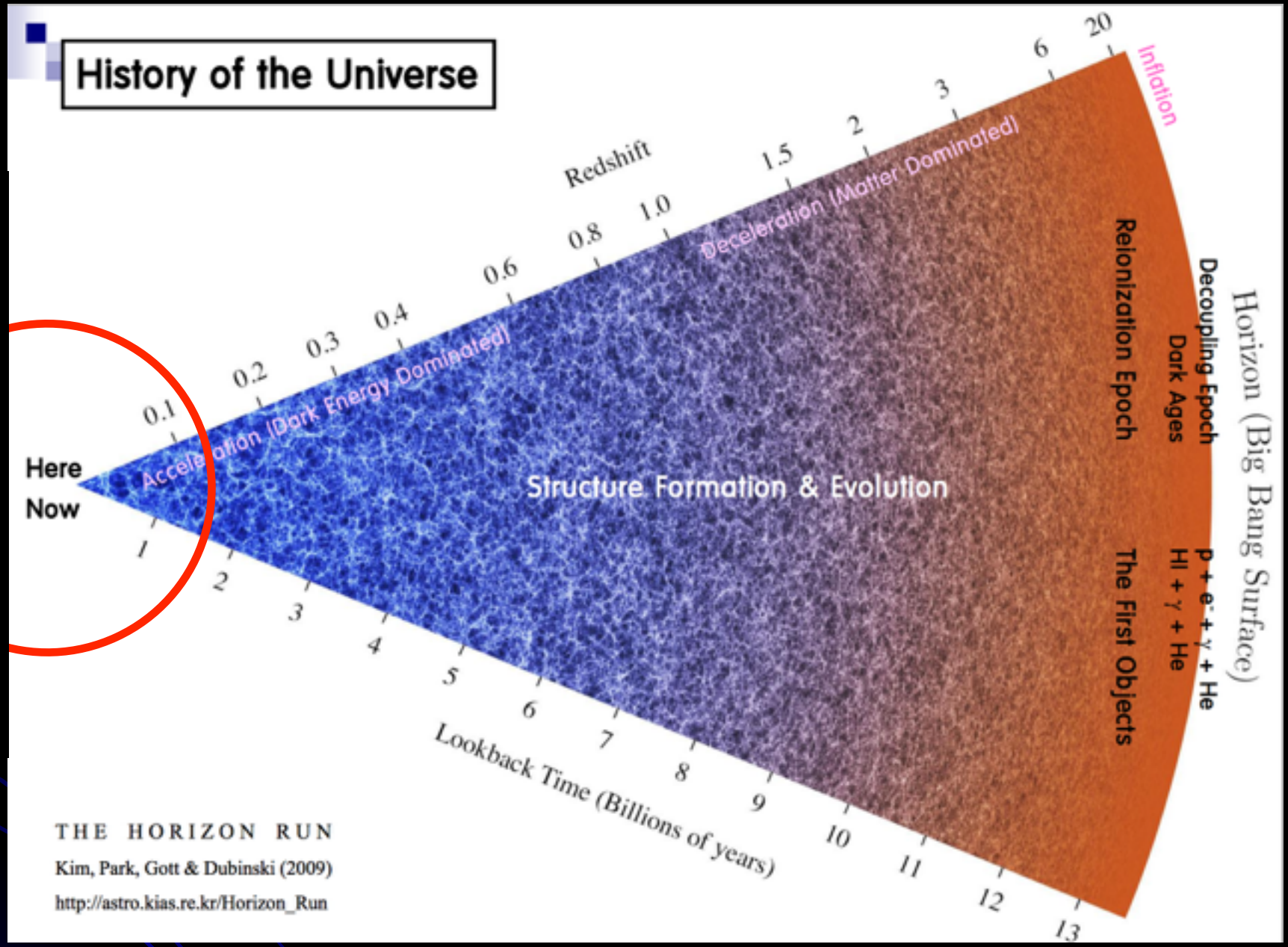


Park+12



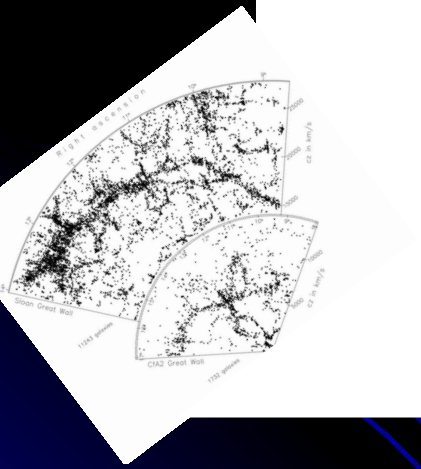
Q: Do we expect this kinds of largest-scale structures in our standard ΛCDM cosmology?

A: Yes, for nearby universe (~1.3 Gyrs ago, quantitative analysis in Park+12)

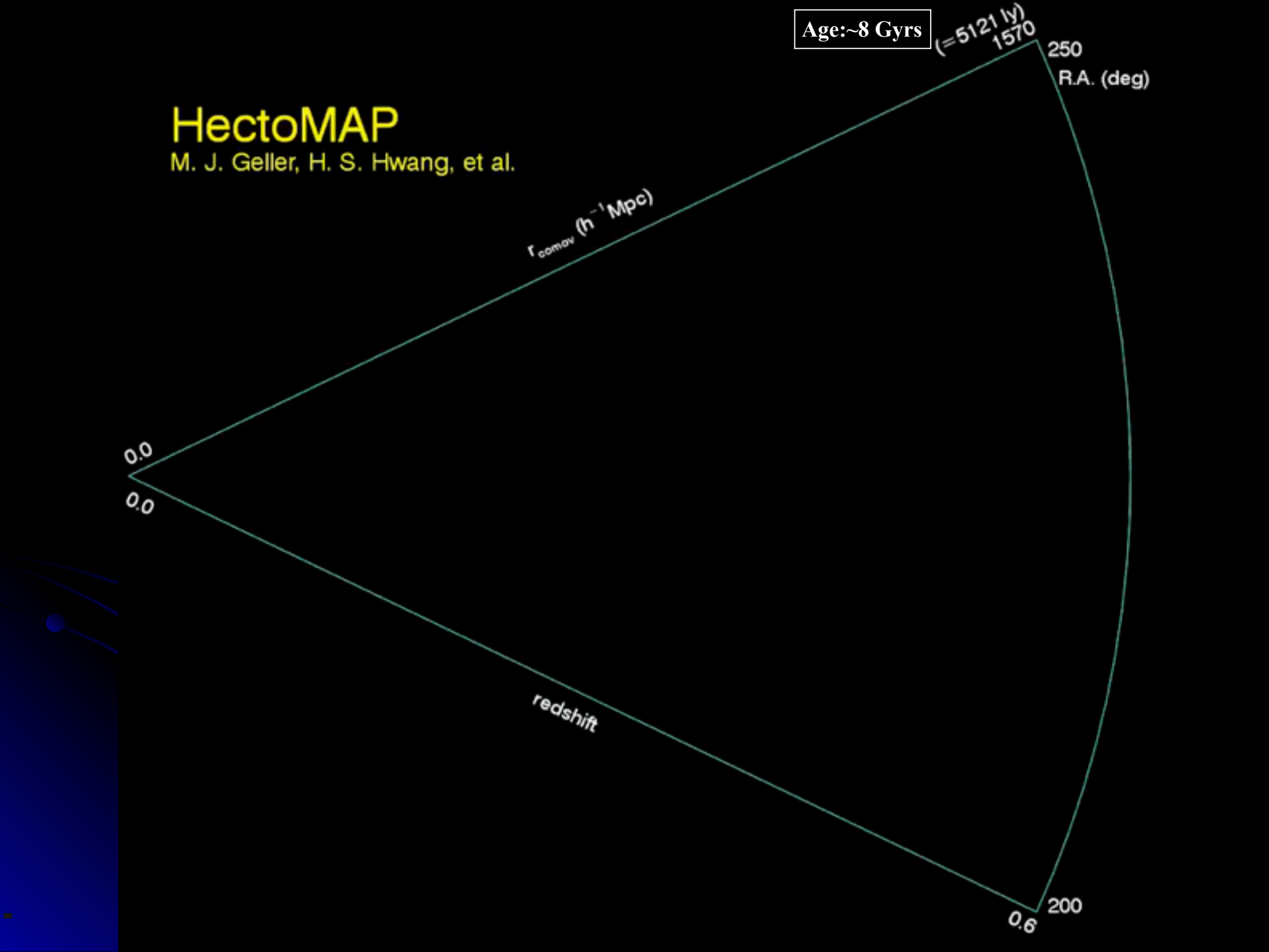


➢ **Only for nearby universe where structure formation is almost complete.**

➢ **To fully understand how structure forms in the universe,**
it is important to study the *evolution of large-scale structure,*
sensitive to dark matter and dark energy.

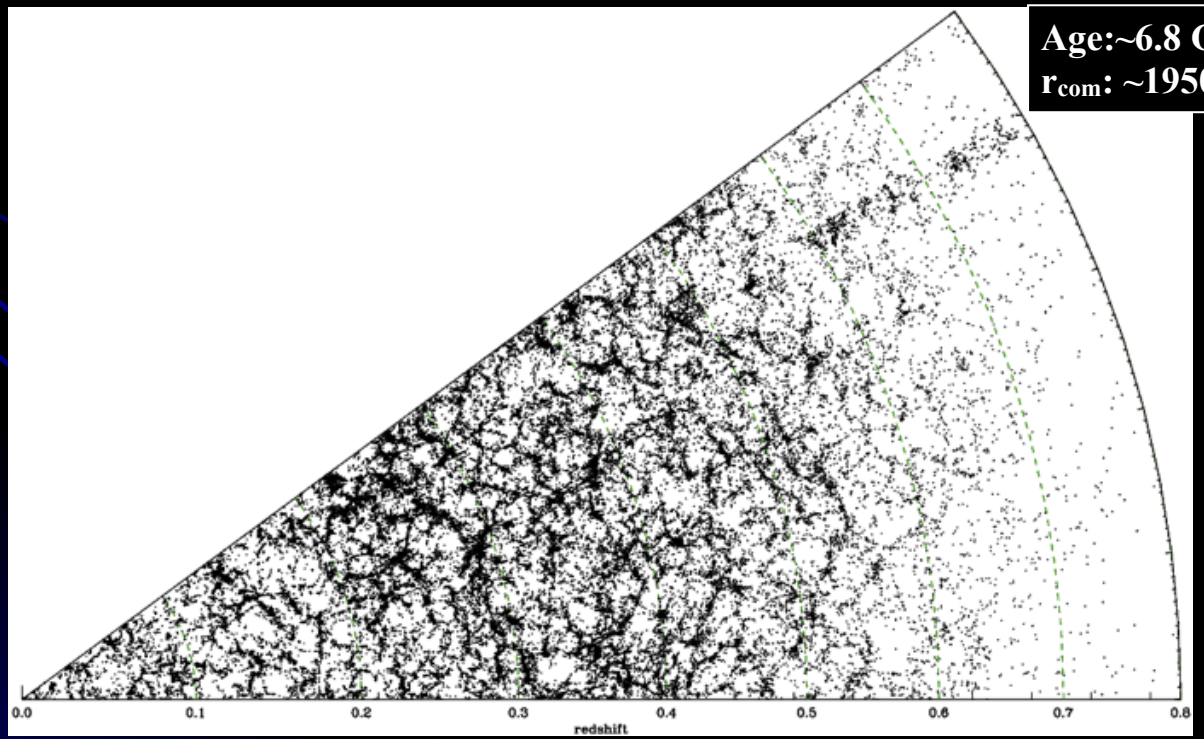


HectoMAP (Geller, Hwang+)


Age:~8 Gyrs
(=5121 ly)
1570
250
R.A. (deg)
HectoMAP
M. J. Geller, H. S. Hwang, et al.
r_{comov} (h^{-1}Mpc)
0.0
0.0
redshift
0.6
200

HectoMAP Survey

- One of densest and complete survey of red galaxies at r<21.3 (20.5)
  - HectoMAP: 600-1200 gals/deg^2, BOSS: ~150 gals/deg^2
  - Compare the mass distribution with that in weak lensing maps
  - Directly measure the mass accretion rate of galaxy clusters
  - Examine the evolution of Large-scale Structure (Hwang+16, ApJ, 818, 106)

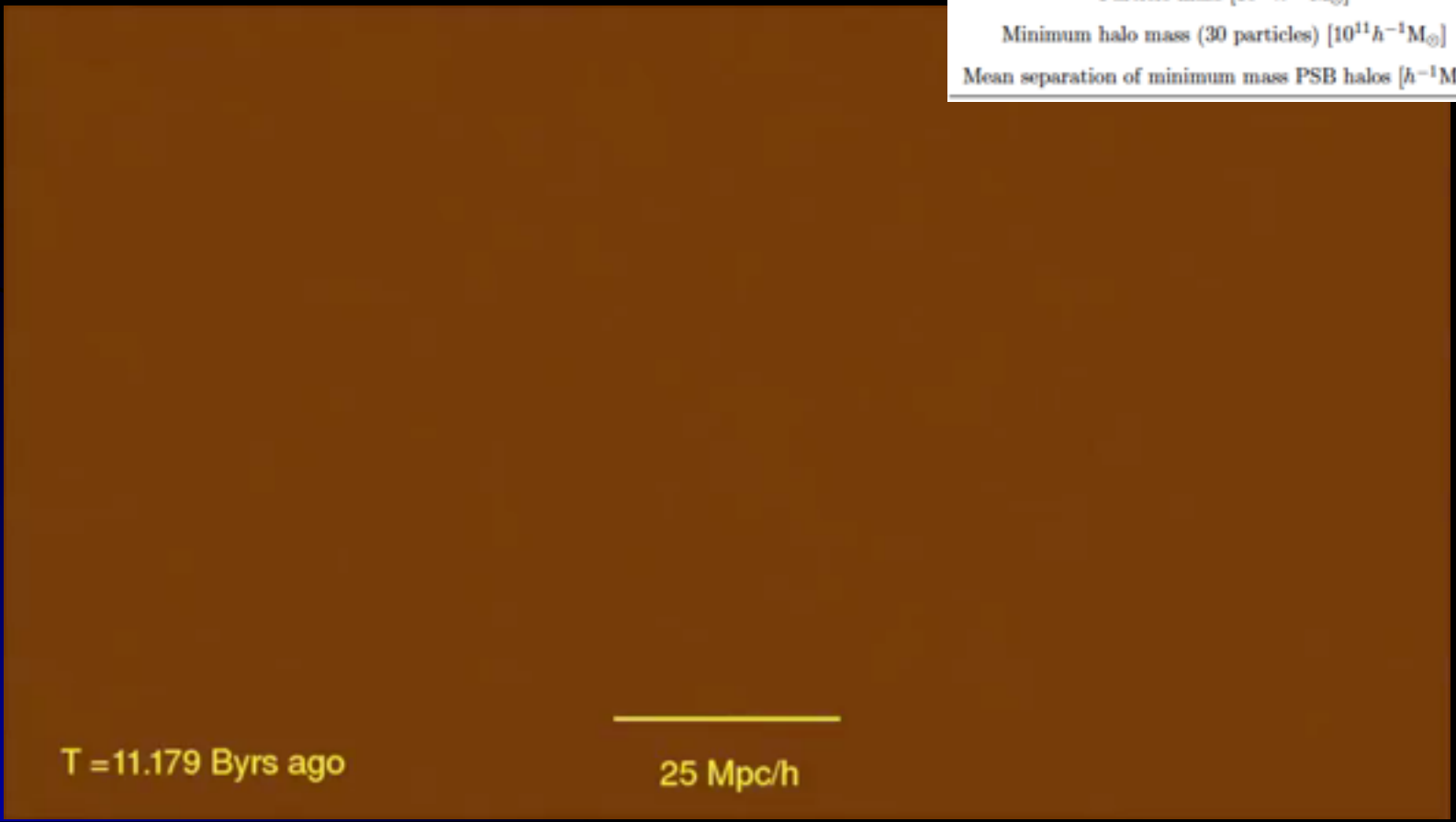


Horizon Runs @ KIAS

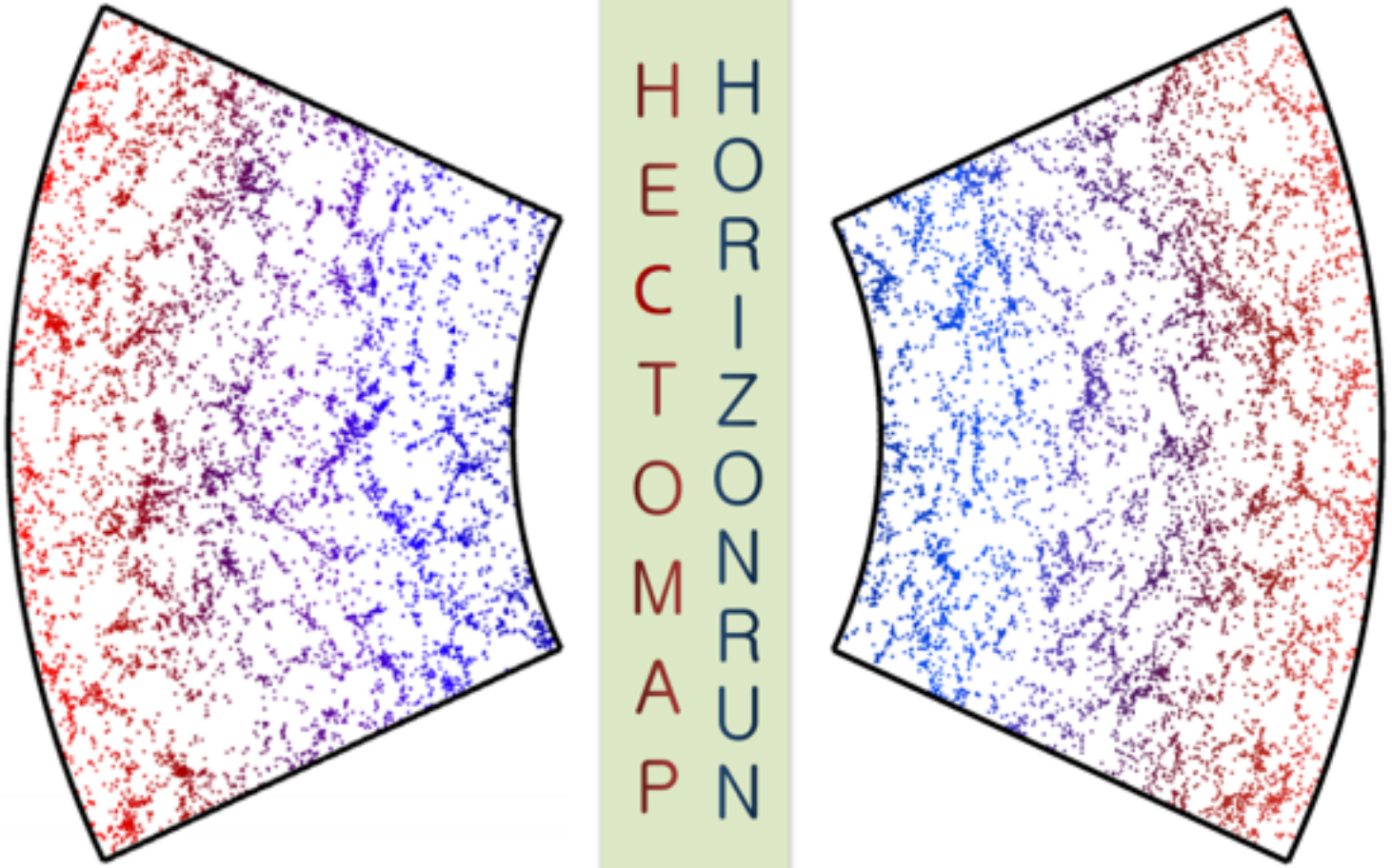
➢ **One of densest and largest cosmological simulations**

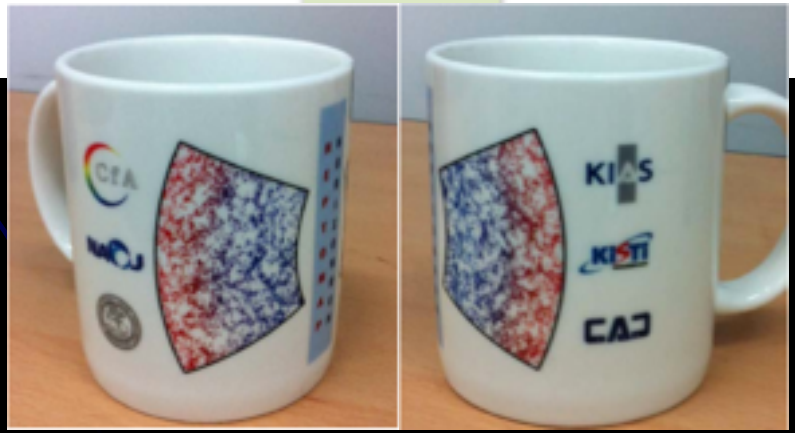
	HR1	HR2	HR3	HR4
Model	WMAP5	WMAP5	WMAP5	WMAP5
Ω_M	0.26	0.26	0.26	0.26
Ω_b	0.044	0.044	0.044	0.044
Ω_Λ	0.74	0.74	0.74	0.74
Spectral index	0.96	0.96	0.96	0.96
H_0 [100 km s^{-1}Mpc^{-1}]	72	72	72	72
σ_8	0.794	0.794	0.794	0.794
Box size [h^{-1}Mpc]	6592	7200	10815	3150
No. of grids for initial conditions	4120^3	6000^3	7210^3	6300^3
No. of CDM particles	4120^3	6000^3	7210^3	6300^3
Starting redshift	23	32	27	100
No. of global time steps	400	800	600	2000
Mean particle separation [h^{-1}Mpc]	1.6	1.2	1.5	0.5
Particle mass [$10^{11}h^{-1}M_\odot$]	2.96	1.25	2.44	0.0902
Minimum halo mass (30 particles) [$10^{11}h^{-1}M_\odot$]	88.8	37.5	73.2	2.706
Mean separation of minimum mass PSB halos [h^{-1}Mpc]	13.08	9.01	11.97	4.08

Kim J.+15



Large-scale Structures in the HectoMAP and Horizon Runs





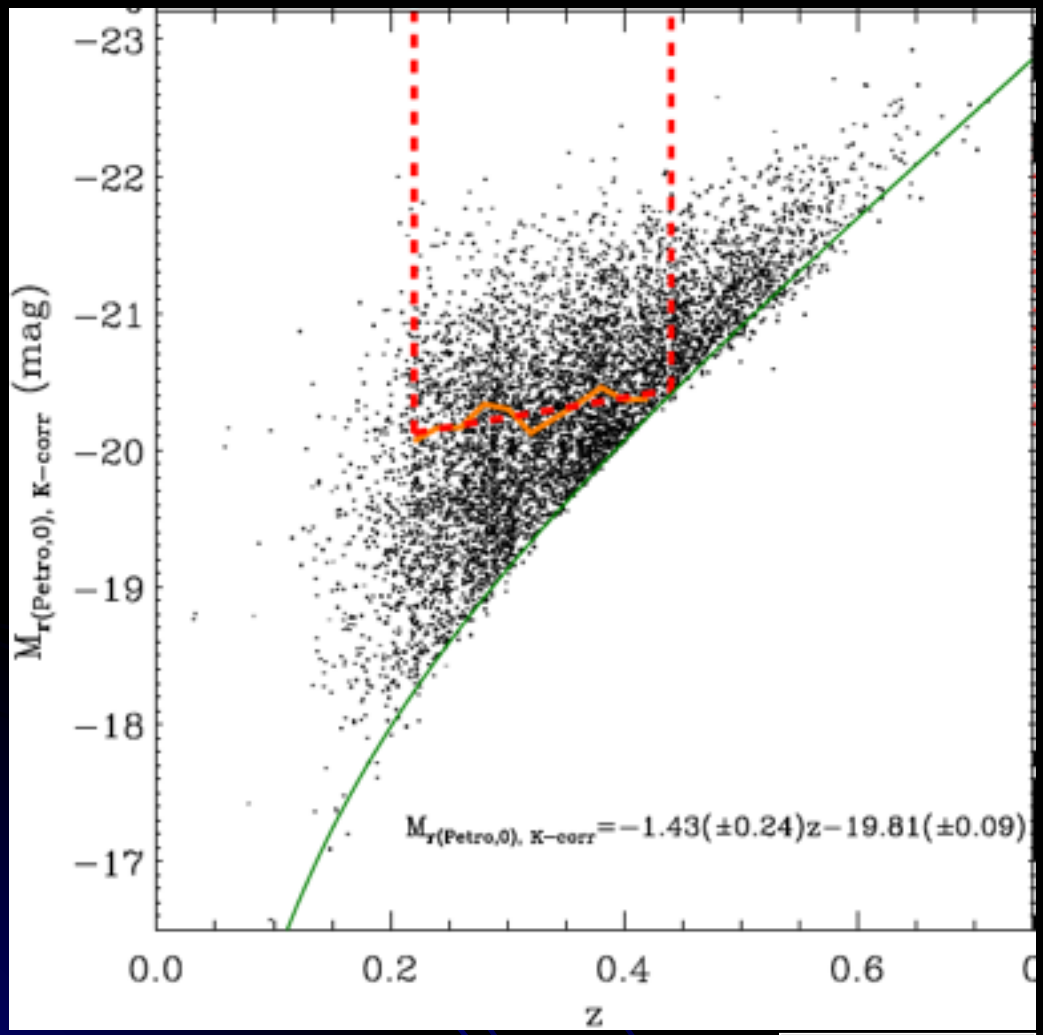
In this Talk,

By applying the same criteria to the observations and simulations to identify over- and under-dense large-scale features of the galaxy distribution,

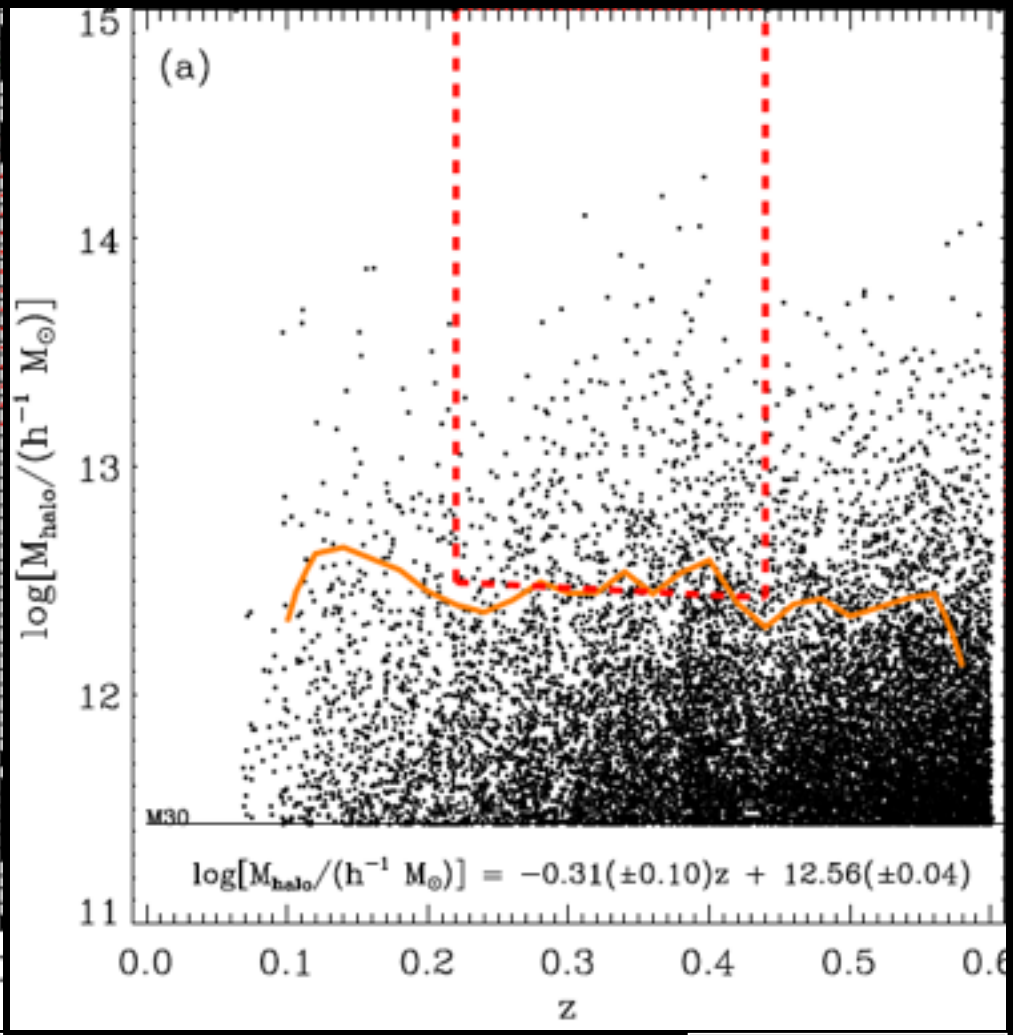
- **1) Compare the Physical Properties of over- and under-dense large scale-structures in HectoMAP and Horizon Run 4, and**
- **2) Examine the Probability to find observed largest structures in the simulation.**

LSS in HectoMAP and Horizon Run 4: Sample Construction

Volume-limited Samples with the same galaxy/halo number density

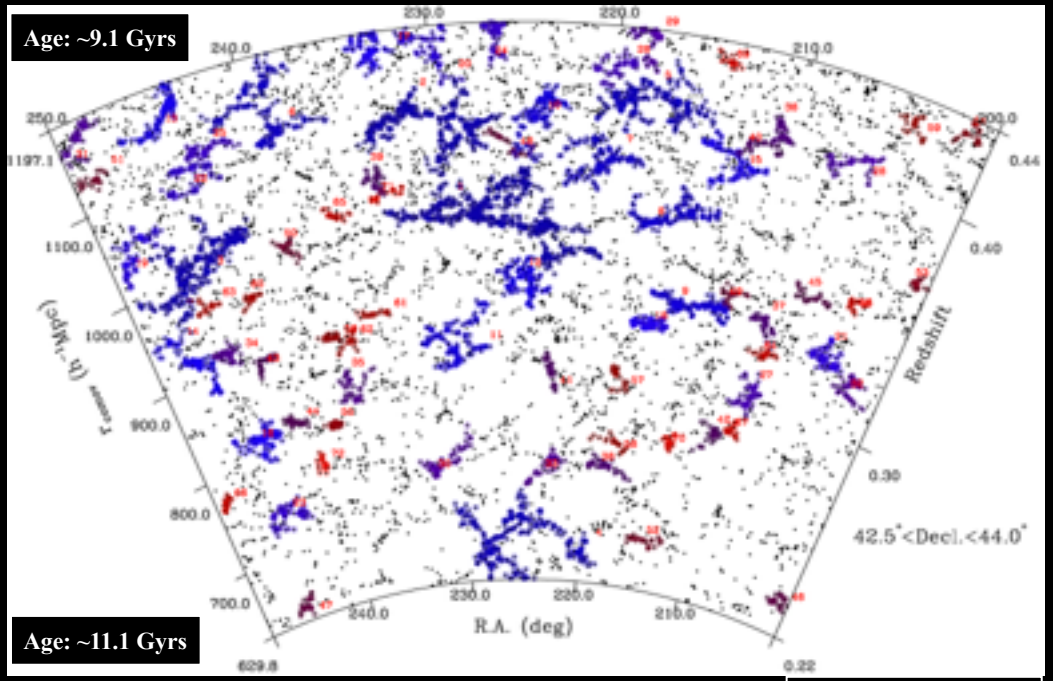


HectoMAP

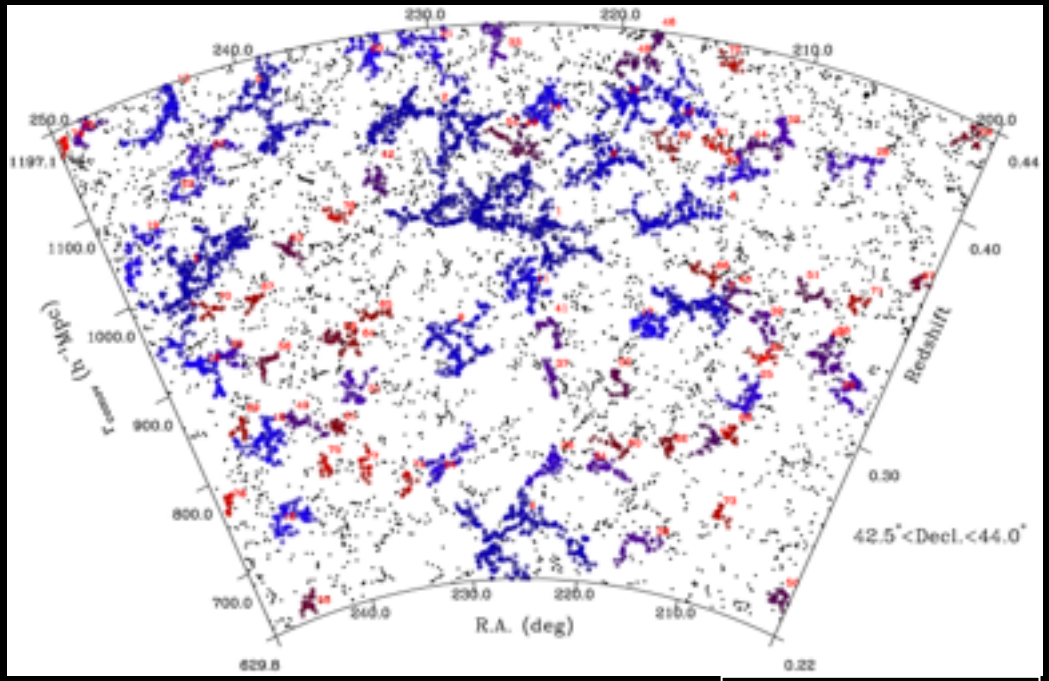


Horizon Run4

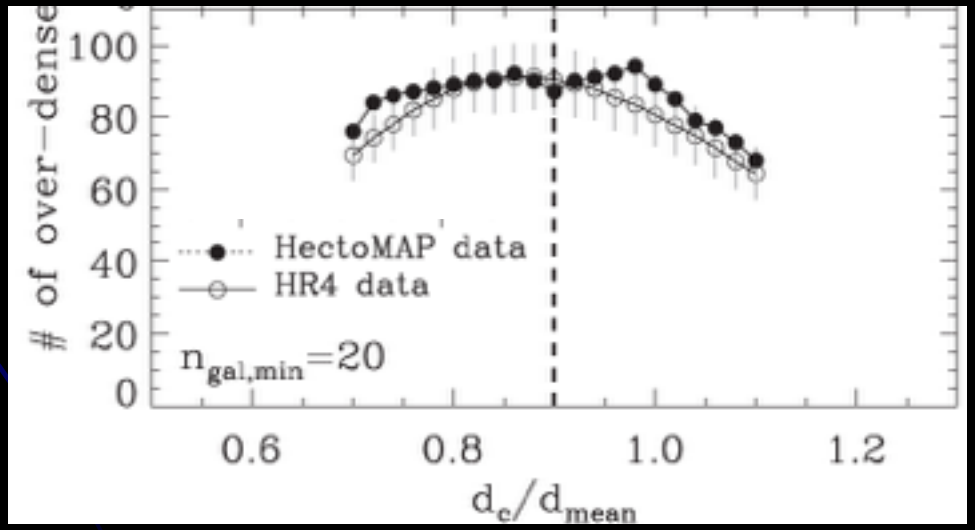
Identification of Over-dense Large-scale Structure



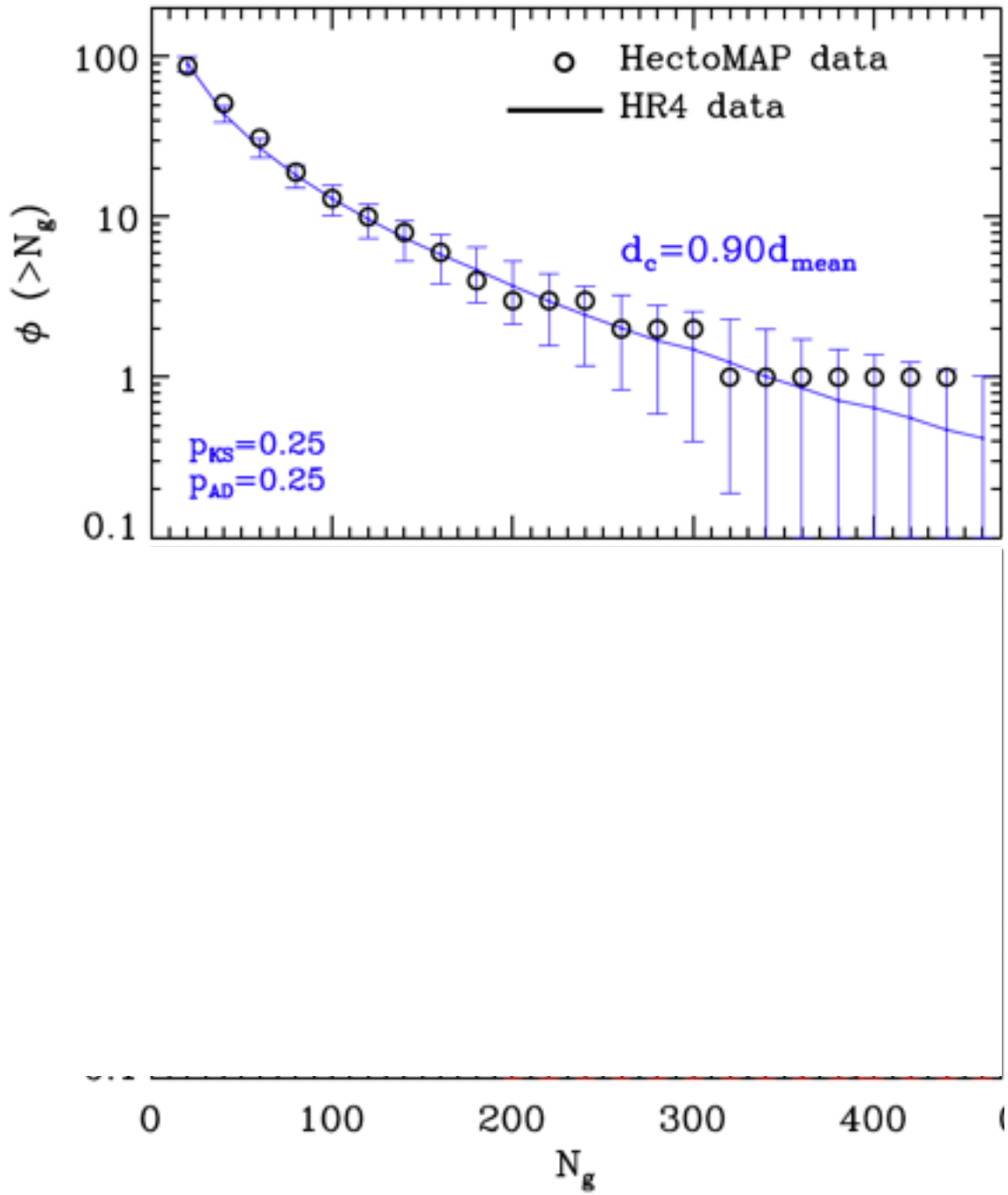
HectoMAP



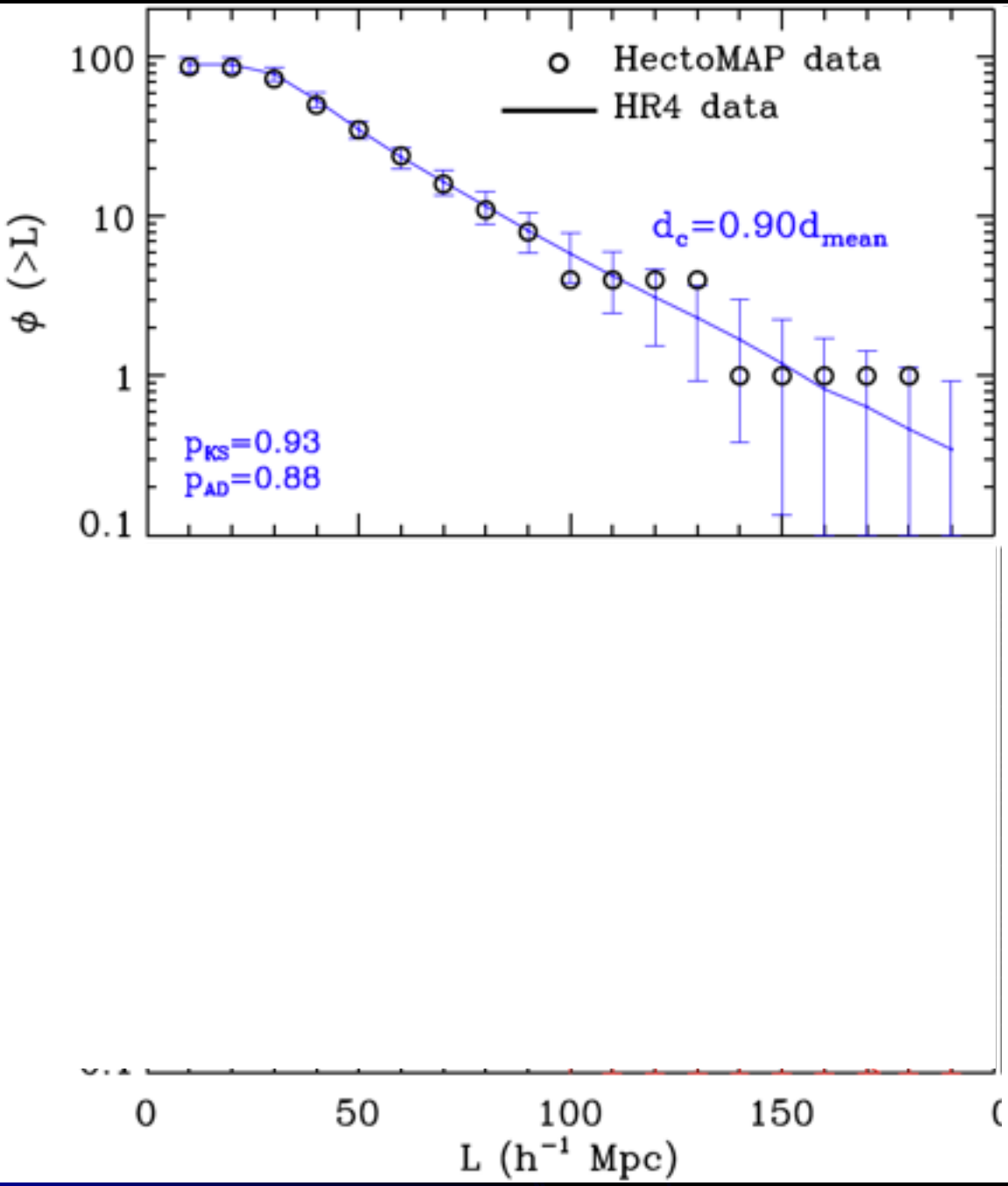
Horizon Run4



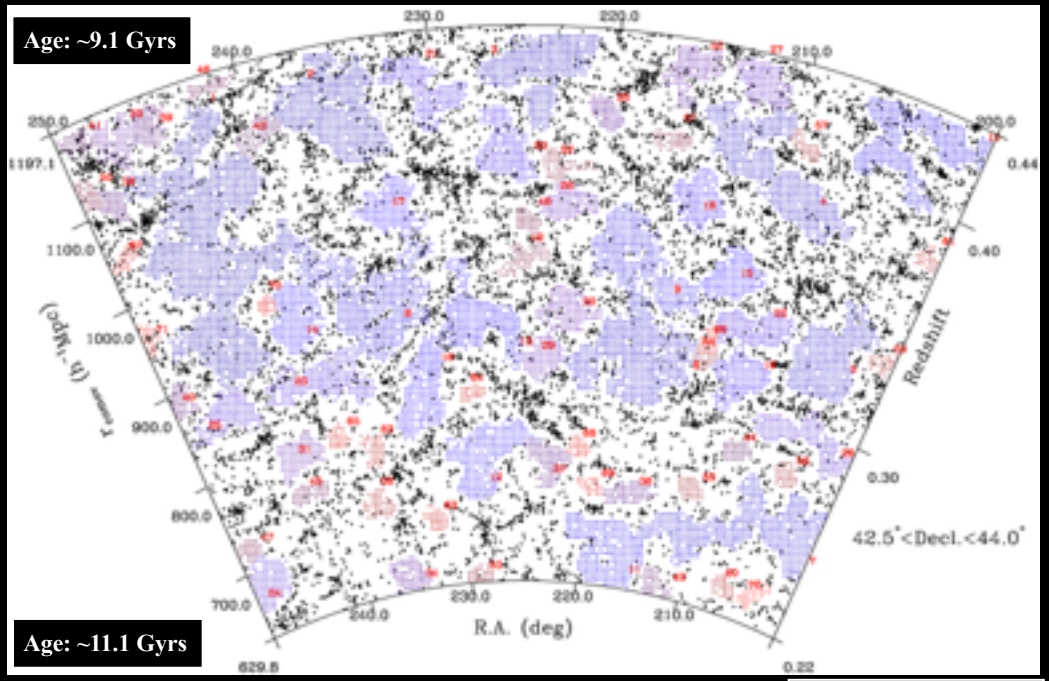
Richness Distribution of Over-dense LSS



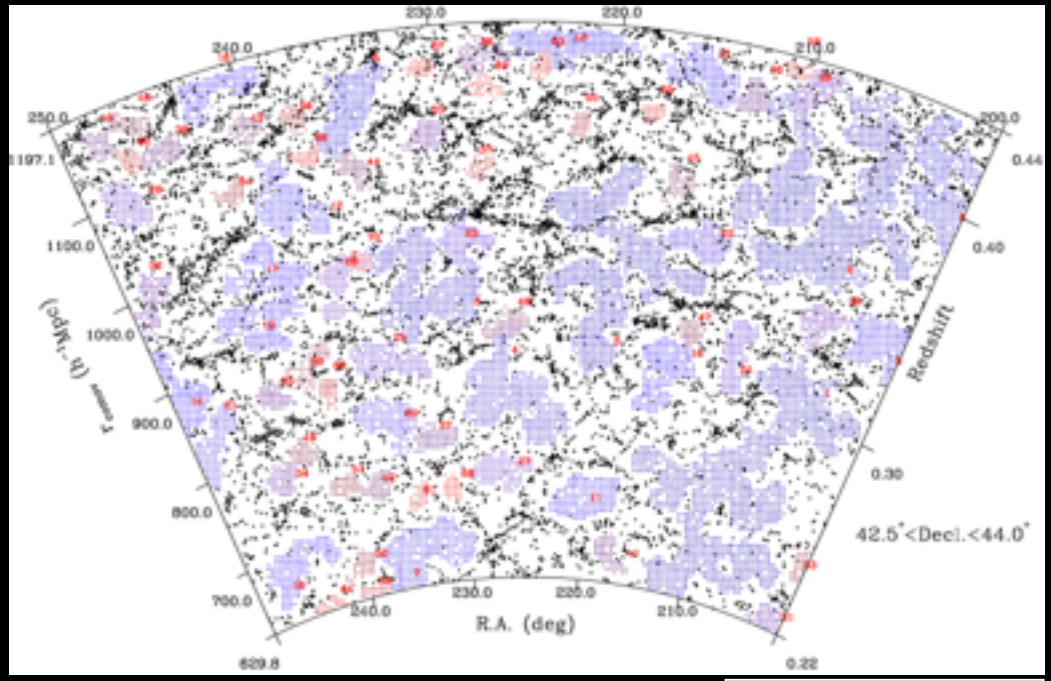
Size Distribution of Over-dense LSS



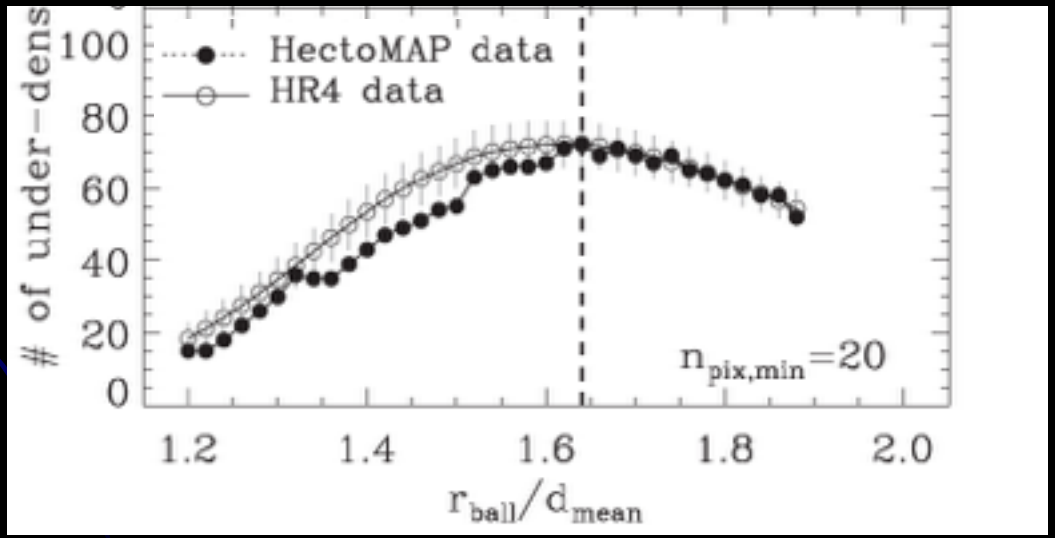
Identification of Under-dense LSS (Voids)



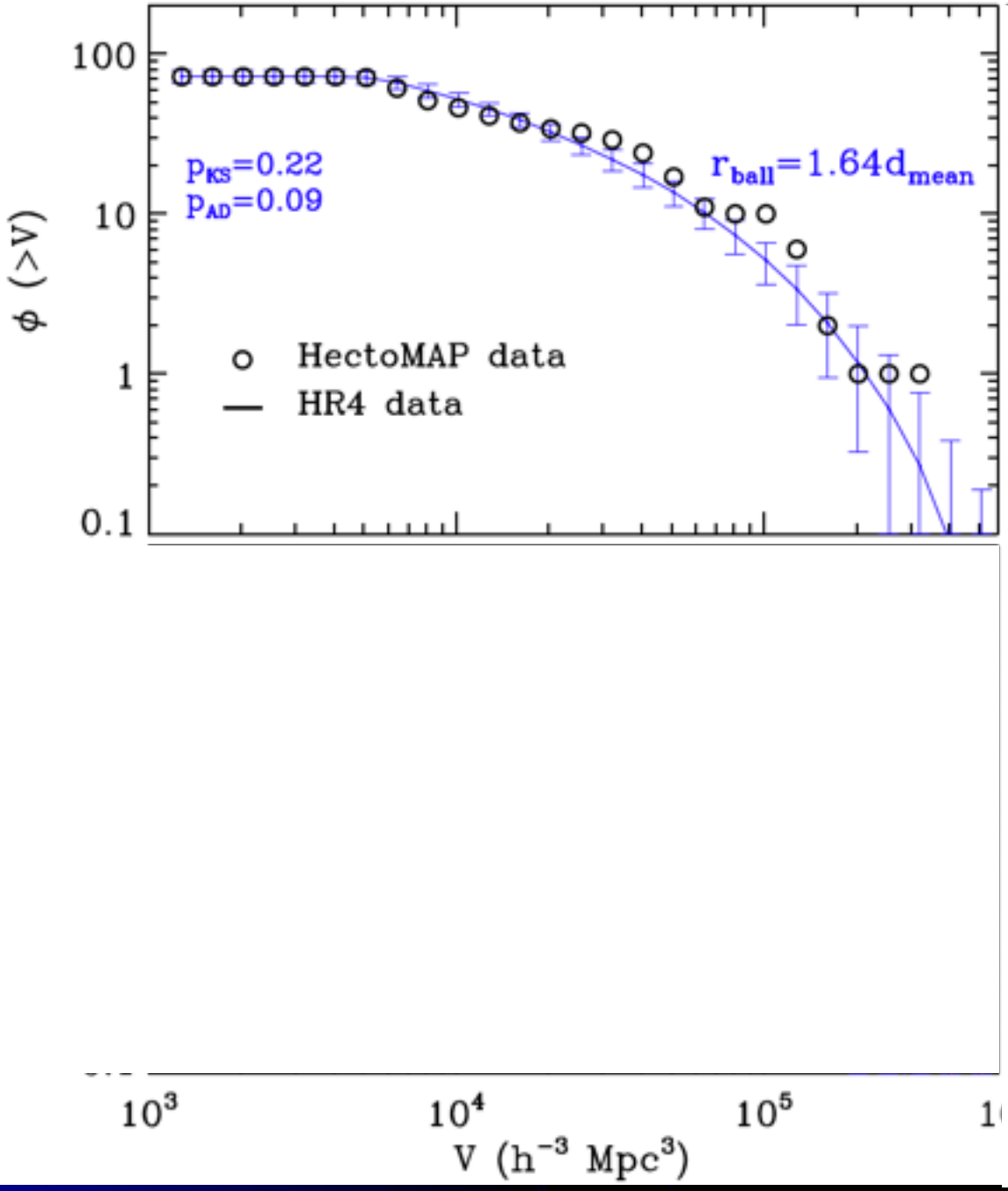
HectoMAP



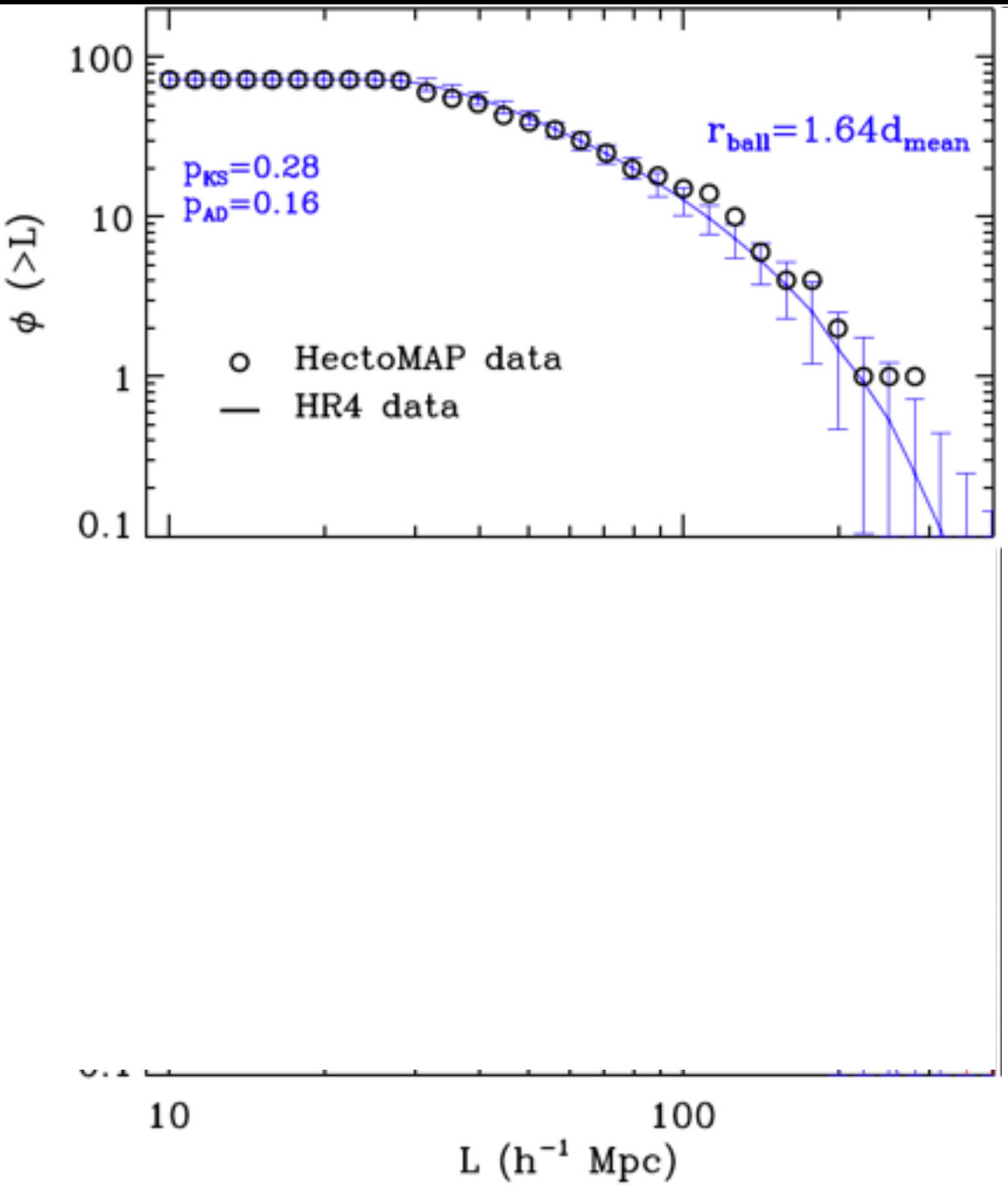
Horizon Run4



Volume Distribution of Voids



Size Distribution of Voids

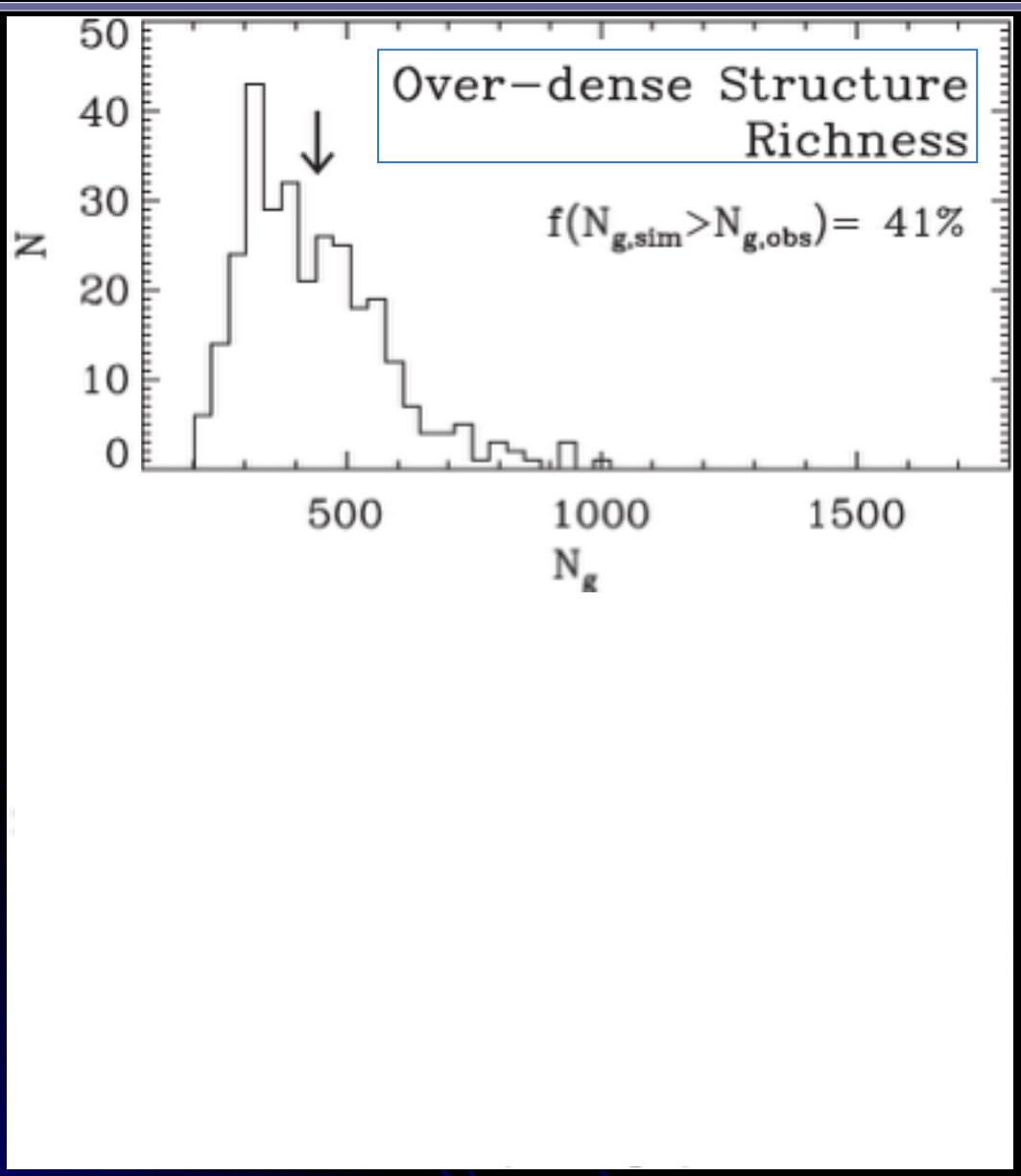


In this Talk,

➢ **1) Compare the Physical Properties of over- and under-dense large scale-structures in HectoMAP and Horizon Run 4, and**

➢ **The physical properties of observed large-scale structures at intermediate redshifts ($0.22<z<0.44$) are remarkably consistent with predictions of the standard ΛCDM model.**

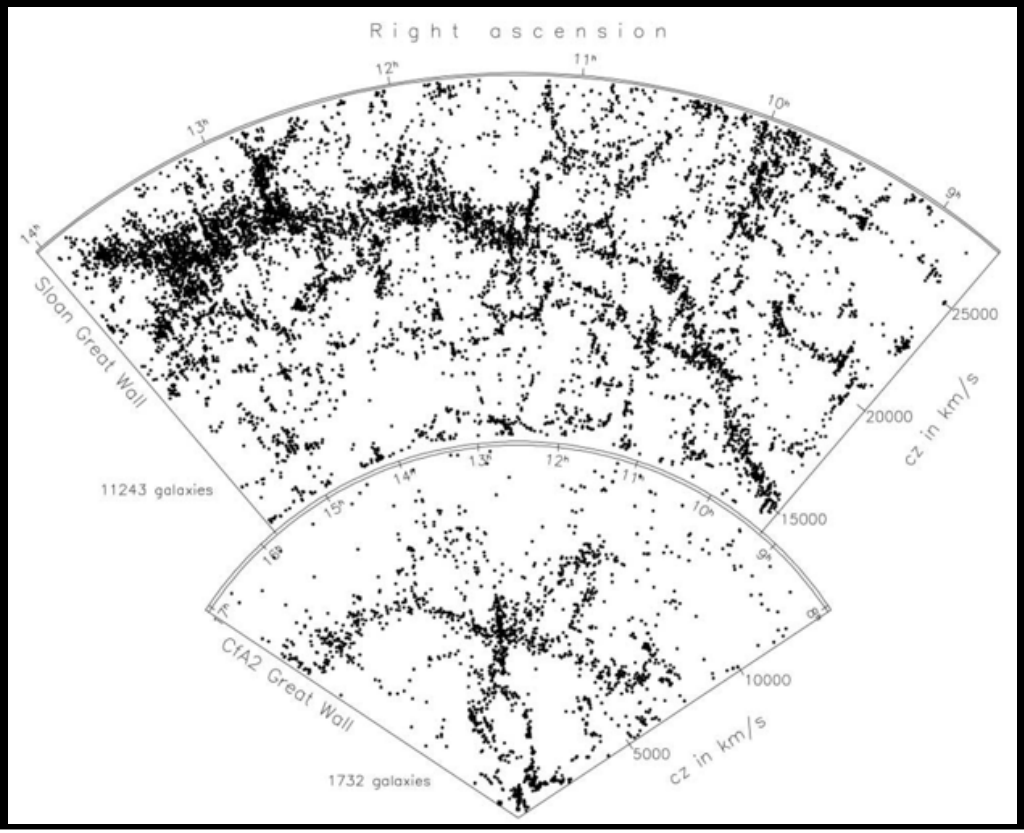
2) Largest Structures: HectoMAP vs. 300 Horizon Run 4 mock surveys



In this Talk,

➢ **2) Examine the Probability to find observed largest structures in the simulation.**

➢ **The properties of the largest over- and under-dense structures in HectoMAP are well within the distributions for the largest structures drawn from 300 Horizon Run 4 mock surveys.**

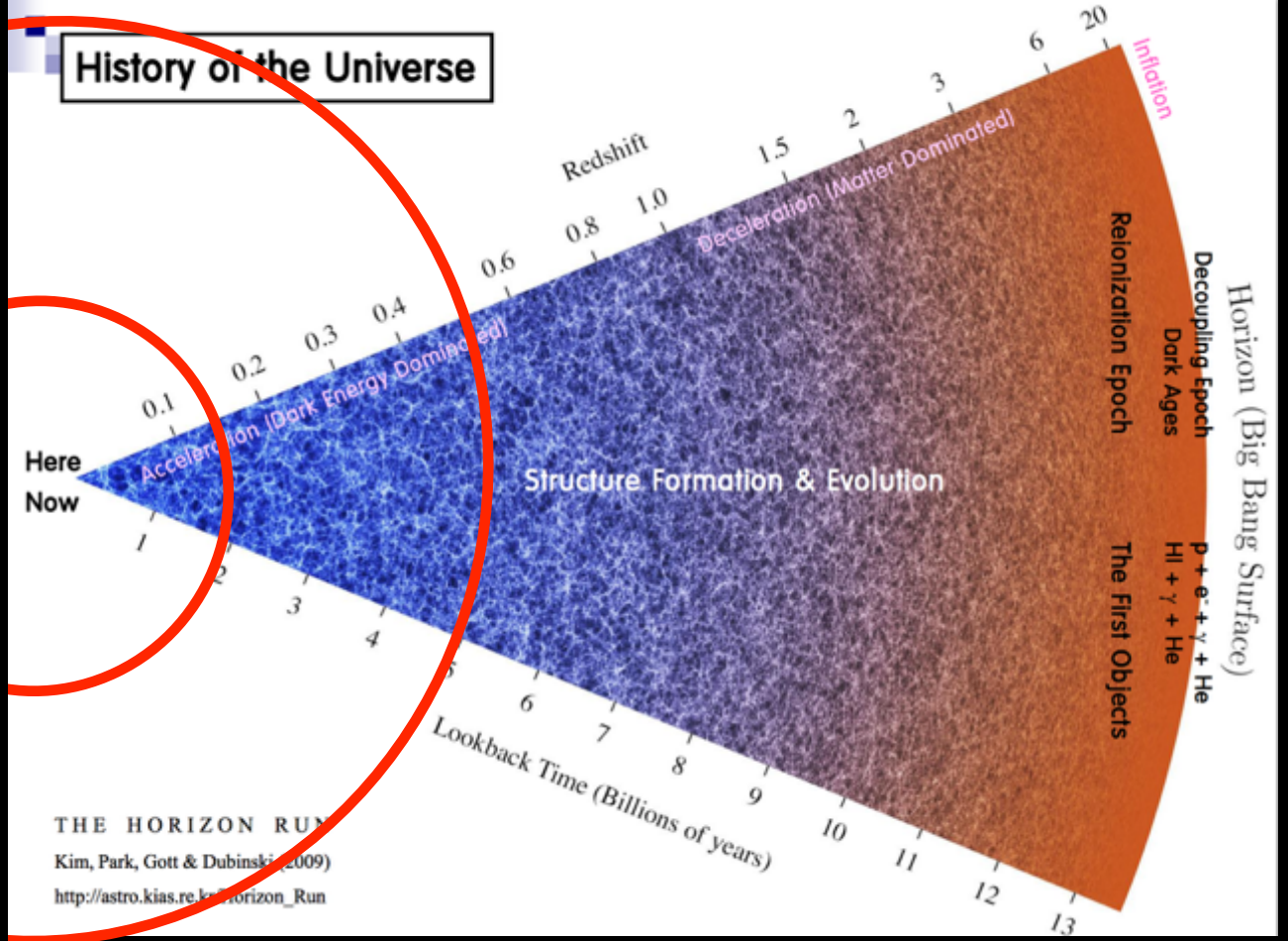


Gott+05

Q: Do we expect this kinds of largest-scale structures in our standard ΛCDM cosmology?

- **Many mock surveys for a robust test**
- **The same criteria in identifying large-scale structures in the observations and simulations**
- **Comparable samples of galaxies and halos with the matched number densities**

Summary



- ➢ The richness and size distributions of observed over-dense structures agree well with the simulated ones.
- ➢ Observations and simulations also agree for the volume and size distributions of under-dense structures, voids.
- ➢ The properties of the largest over- and under-dense structure in HectoMAP are well within the distributions for the largest structures drawn from 300 Horizon Run 4 mock surveys.

➢ The physical properties of observed large-scale structures at intermediate redshifts ($0.22<z<0.44$) are remarkably consistent with predictions of the standard ΛCDM model.