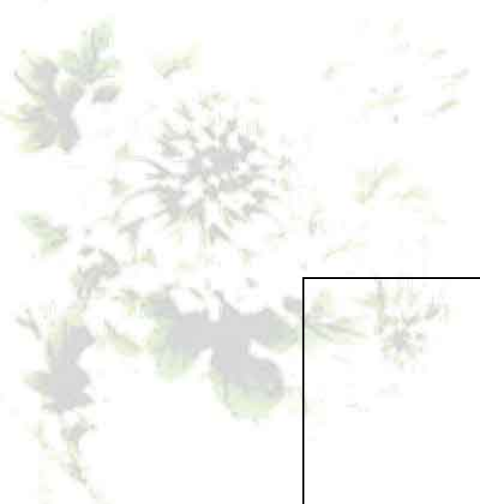




Introduction to Large Scale Structure of the Universe

Pyeong Chang Summer Institute, KIAS, July 27-30, 2015

Changbom Park

(Korea Institute for Advanced Study)



History of KIAS Pyeong Chang Summer Institute

Cosmology and Structure Formation

Open KIAS Summer Institute 2009

Issues on Galaxy Formation

2009. 8. 19-23 평창 봄여름가을겨울 팬션

자유롭고 여유 있는 분위기에서 특정 분야·주제를 놓고 심도 있는 과학적 토론을 함으로써 후진들에게 토론 문화를 경험케 하고, 여러 연구자와의 접촉을 통해 다양한 학문적 경험 기회를 부여함.

최신 이슈에 대한 토론을 통해 연구주제 창출과 공동연구 진작.

알려진 지식보다 알려지고 있는 지식/모르고 있는 사실
과학적 사고의 표현력
프로시딩 - 질문과 대답 / 생각의 공유

History of KIAS Pyeong Chang Summer Institute



OPEN KIAS
SUMMER INSTITUTE

Issues on Galaxy Formation

2009. 8. 19 ~ 23

강원도평창
봄여름가을겨울 펜션



조직위원

박창범(고등과학원) 안홍배(부산대) 이명균(서울대)
이영욱(연세대) 임명신(서울대) 천무형(천문연)
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<http://astrokias.kias.re.kr/summer09/>

OPEN KIAS SUMMER INSTITUTE

Structure Formation

2011. 08. 16 ~ 19, 호수파크밸리

OPEN KIAS Summer Institute

STRUCTURE FORMATION

2011. 08. 16 - 19, 호수파크밸리

<http://workshop.kias.re.kr/psec/structure>

조직위원
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마무리하며

지난 사흘 간 이곳 항성의 깊은 계곡 속에서
참으로 행복했습니다. 학문의 동반자 선생님들
과 이를 이어받아 가는 후진들이 힘을 모아 하
나의 행위 예술을 이룬 것입니다. 수 천년 유구
한 천문학의 역사를 지닌 우리 속의 디엔에이
가 오랜 갈증의 끝에 봄비를 맞은 나무처럼 꽃
피어나는 것 같았습니다. 또 누구와도 자신의
지식을 나누며 함께 나아가는 선량한 마음들
을 볼 수 있어 참 좋았습니다.

이번에도 여러 분들의 적극적인 참여가 빛나
는 모임이었습니다.감사를 드립니다. 2년
뒤에 다시 모여서 또 한 편의 예술을 만들어
보기로 합시다.

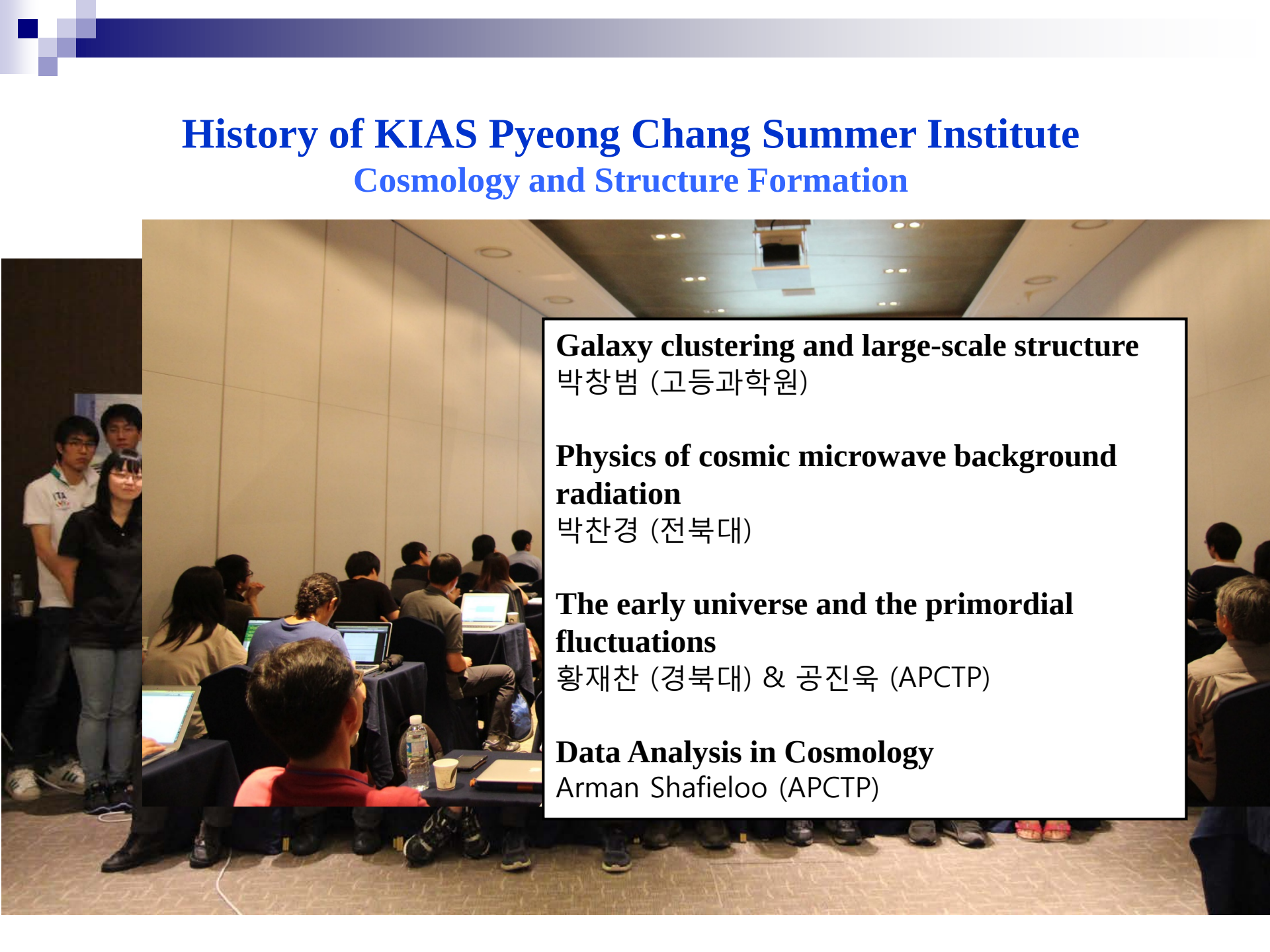
크밸리

주최 : 고등과학원

<http://workshop.kias.re.kr/psec/structure/>

History of KIAS Pyeong Chang Summer Institute

Cosmology and Structure Formation



Galaxy clustering and large-scale structure

박창범 (고등과학원)

Physics of cosmic microwave background radiation

박찬경 (전북대)

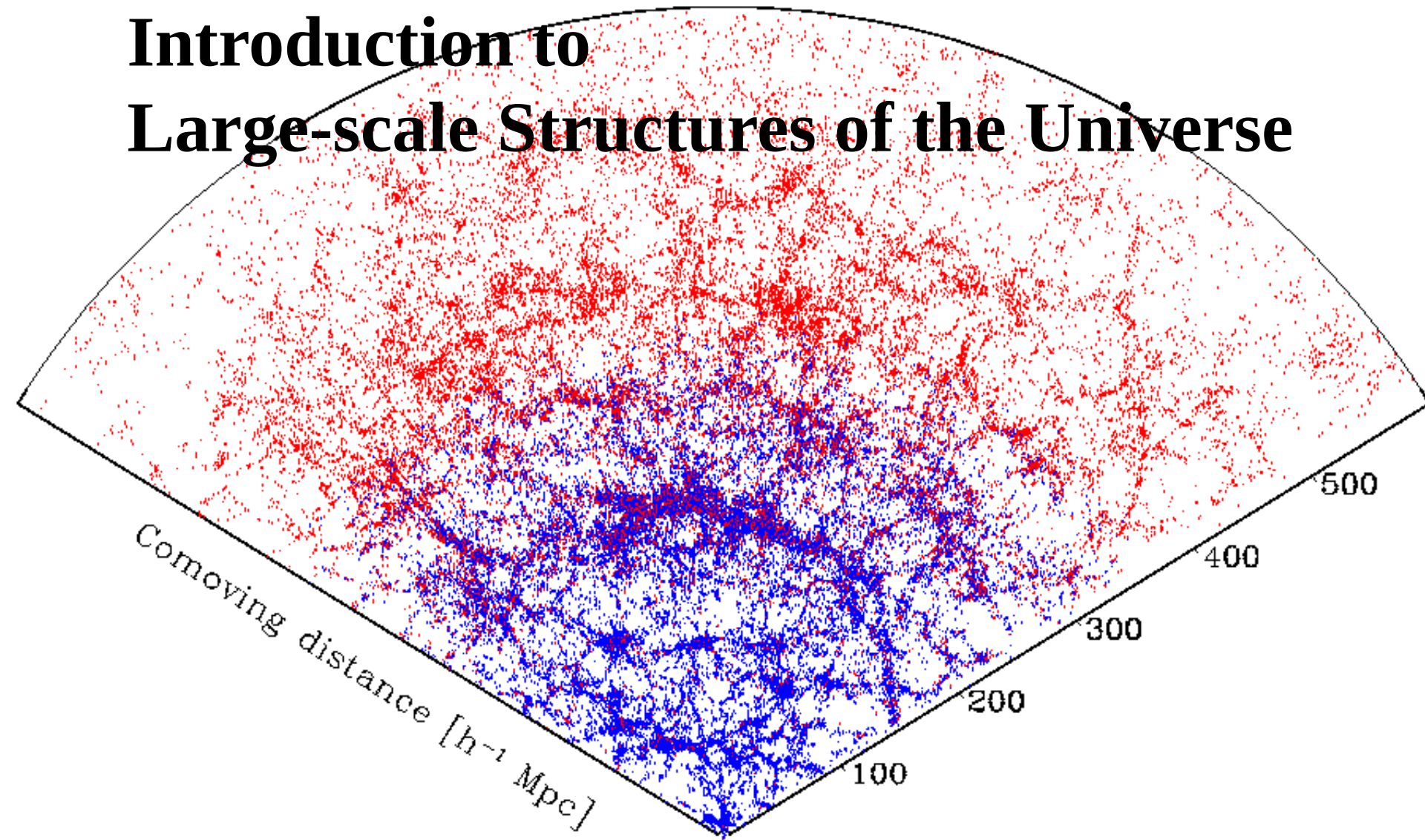
The early universe and the primordial fluctuations

황재찬 (경북대) & 공진욱 (APCTP)

Data Analysis in Cosmology

Arman Shafieloo (APCTP)

Introduction to Large-scale Structures of the Universe



There are BIG structures in the universe !

Definition of LSS

Clustering of astronomical objects is a rule!

star+planets+etc. → planetary system ($\sim 10^{-9}$ Mpc; bound)

stars(+gas) → star clusters ($\sim 10^{-5}$ Mpc; bound or unbound)

stars+gas+dark matter → The Milky Way Galaxy ($\sim 10^{-2}$ Mpc)

Galaxies → galaxy groups (a few bright galaxies; $\sim 10^0$ Mpc; not relaxed),
galaxy clusters (100-10s bright galaxies; $\sim 10^0$ Mpc; ~relaxed)

Clusters+groups → superclusters (a few clusters; $\sim 10^{+1}$ Mpc)

Large-scale structure of the universe (no exact definition)

= Any structure in the distribution of galaxies larger than clusters.

Properties of large-scale structures of the universe

Size: > about 10Mpc.

Shape: amorphous (superclusters, filaments, walls, voids..)

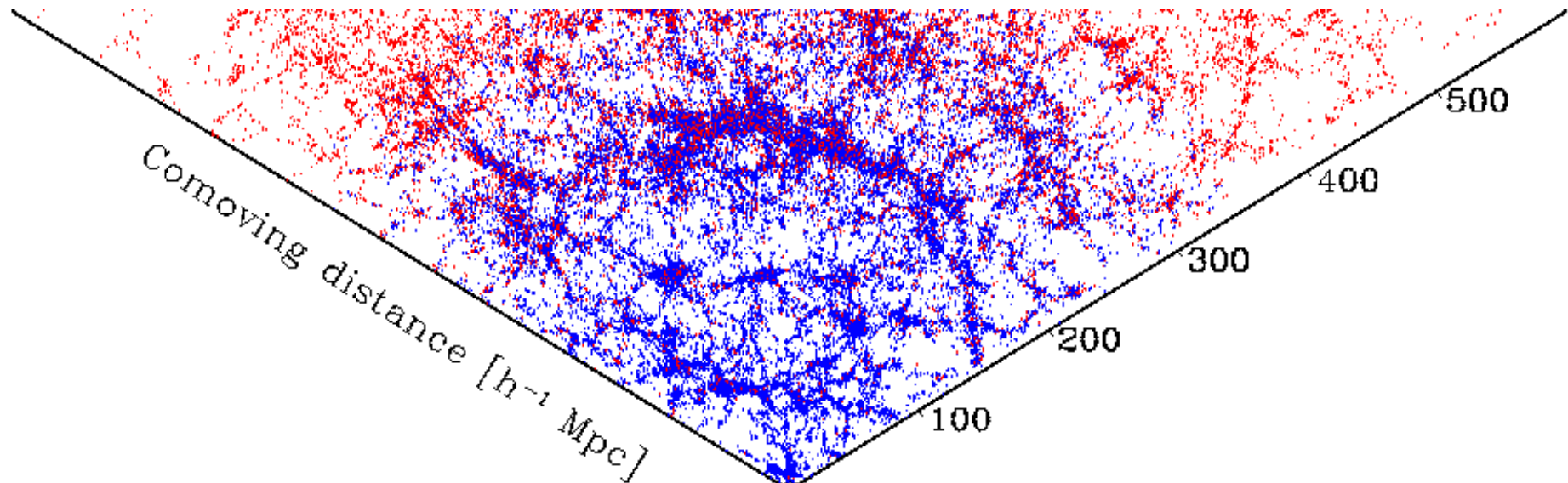
Dynamics: Participating in cosmic expansion, but gravitationally evolving.

Examples: CfA Great Wall

($\sim 100h^{-1}\text{Mpc}$; CfA-2 survey; de Lapparent et al. 1986)

Sloan Great Wall ($\sim 300h^{-1}\text{Mpc}$; SDSS survey; Gott et al. 2005)

Bootes void ($\sim 60h^{-1}\text{Mpc}$; Kirshner et al.)



Large-scale Structures of the Universe

Overall shape - Sponge, Network, Web

Over-density Large-scale Structures

- Wall, Pancake, Sheet
- Filament, Chain
- Supercluster

Under-density Large-scale Structures

- Tunnel
- Void, Cell, Bubble

2. History of LSS observation

First large galaxy catalogs (till the 1970s)

Shapley & Ames (1932)

Zwicky et al. (1961-1968)

Lick catalog of galaxies (Shane & Wirtanen 1967)

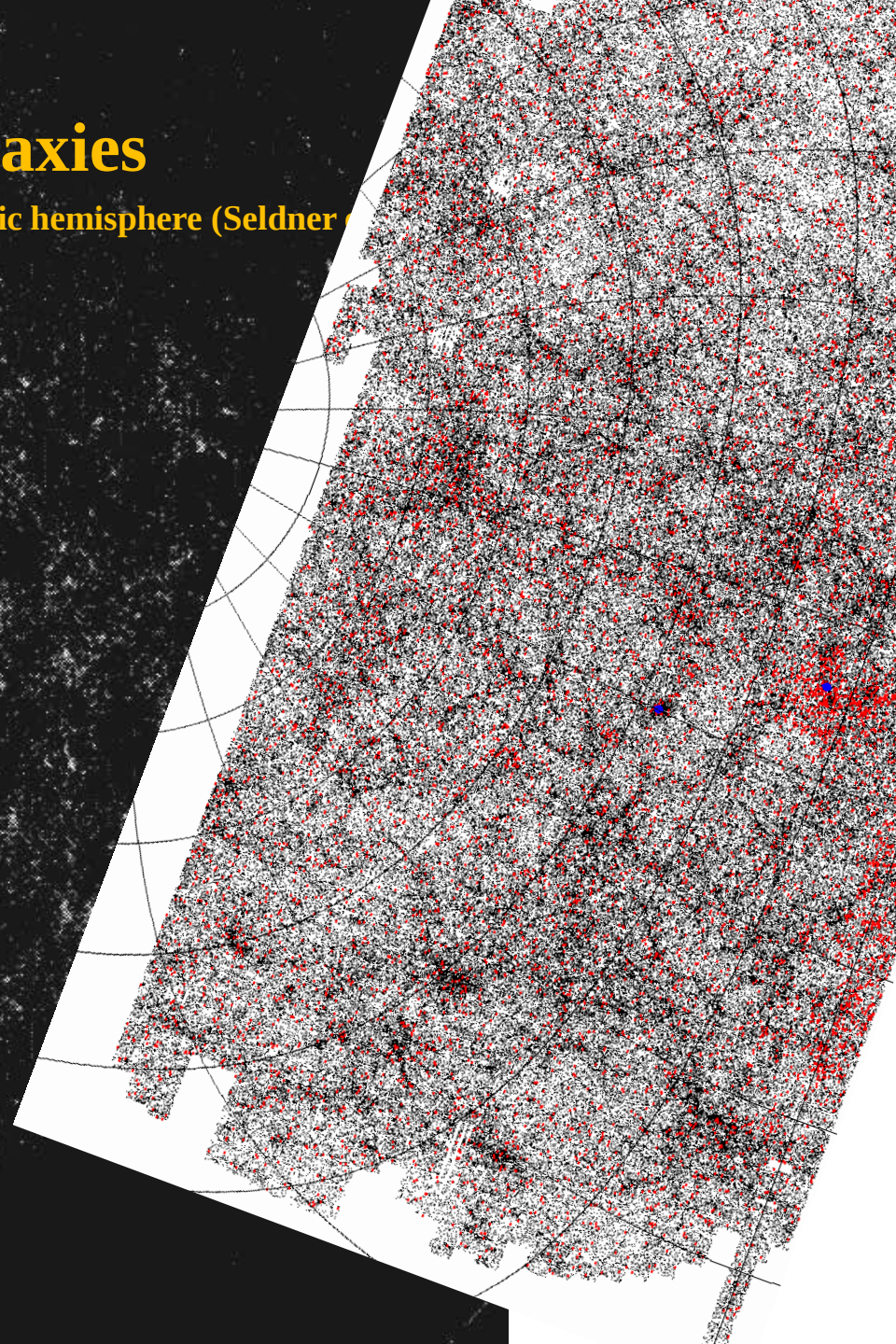
→

Large-scale structure in the distribution of galaxies noticed

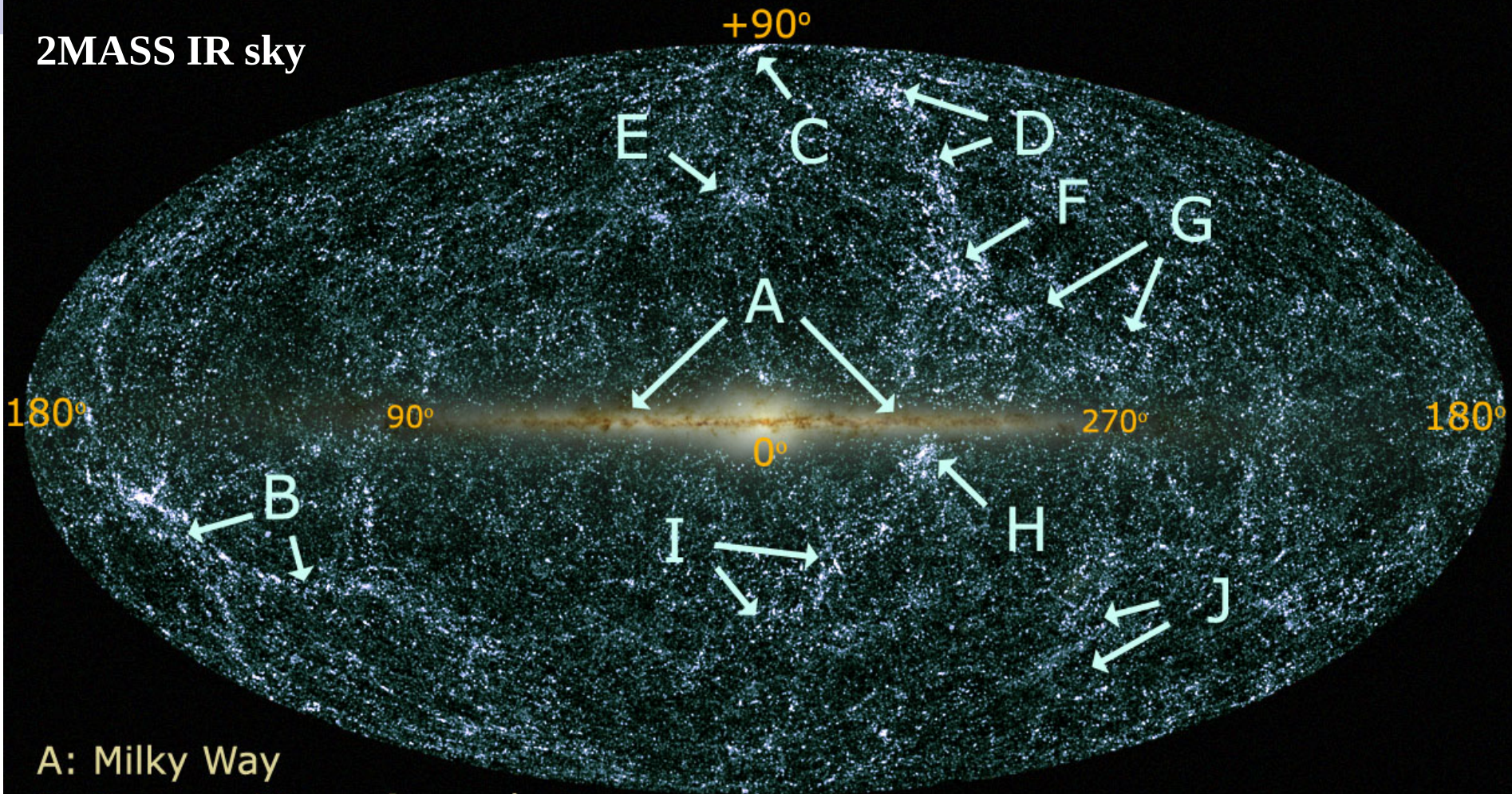
Angular CF as a measure of galaxy clustering developed

Lick catalog of galaxies

Galaxy counts in the northern galactic hemisphere (Seldner &



2MASS IR sky



A: Milky Way

B: Perseus-Pisces Supercluster

C: Coma Cluster

D: Virgo Cluster/Local Supercluster

E: Hercules Supercluster

F: Shapley Concentration/Abell 3558

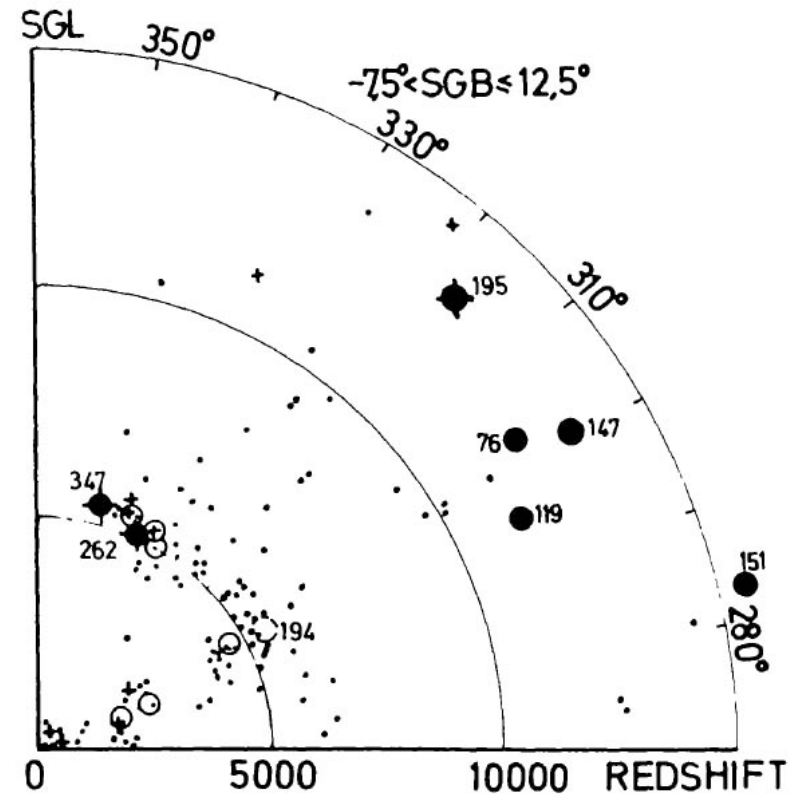
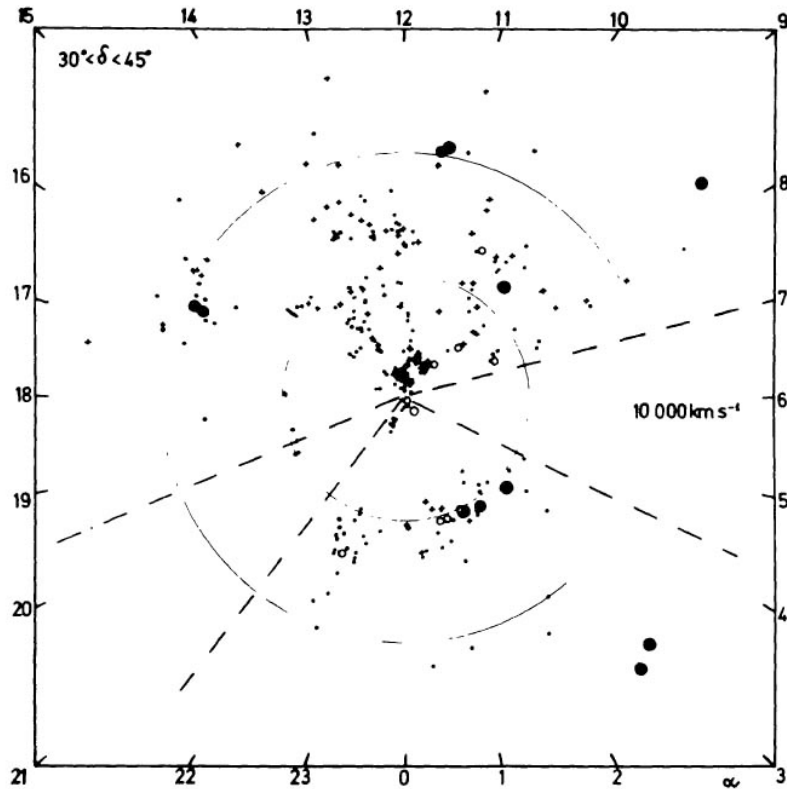
G: Hydra-Centaurus Supercluster

H: "Great Attractor"/Abell 3627

I: Pavo-Indus Supercluster

J: Horologium-Reticulum
Supercluster

Joeveer & Einasto (1978) — Has the universe the cell structure?

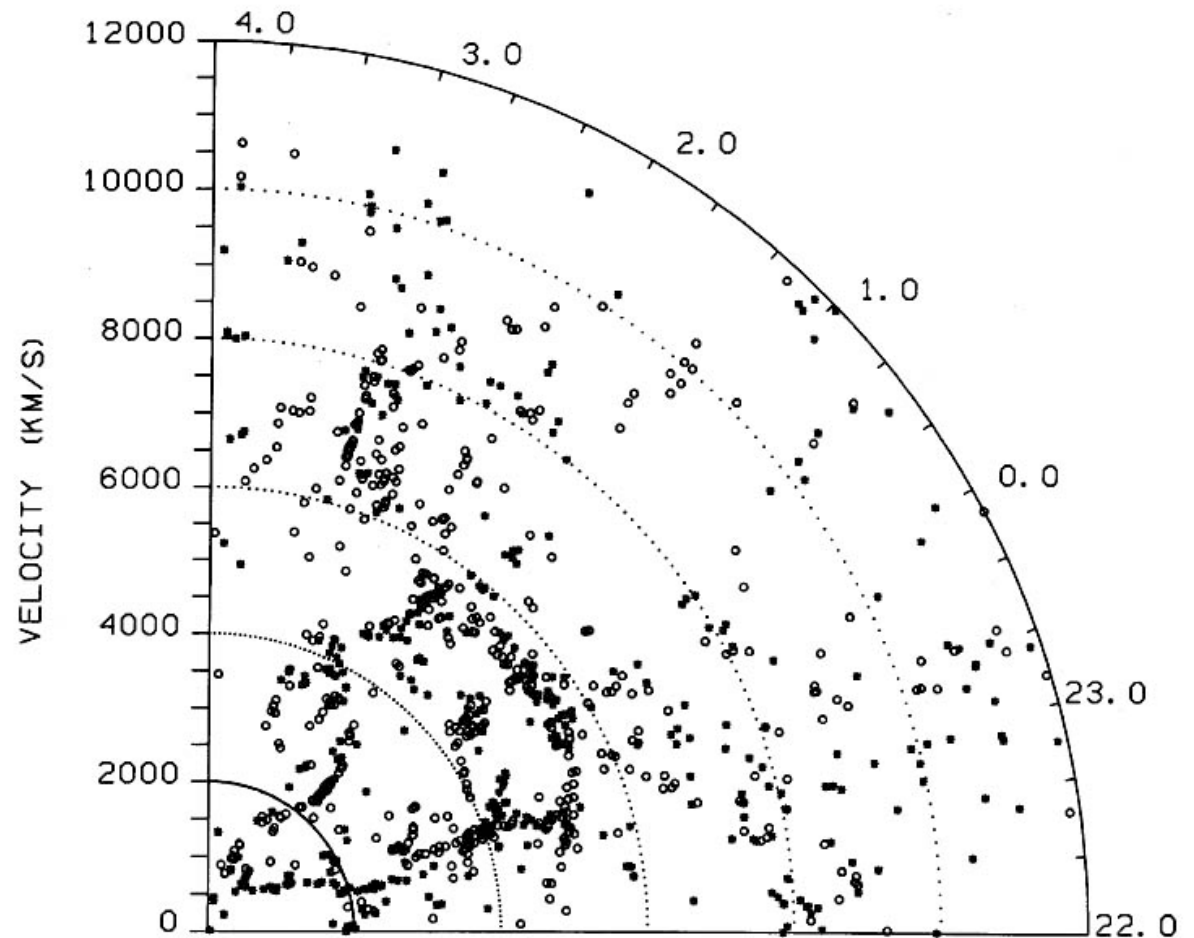


Galaxies and Abell clusters (heavy dots)

Haynes & Giovanelli (1986)

2700 galaxies in the region of
the Pisces-Perseus supercluster

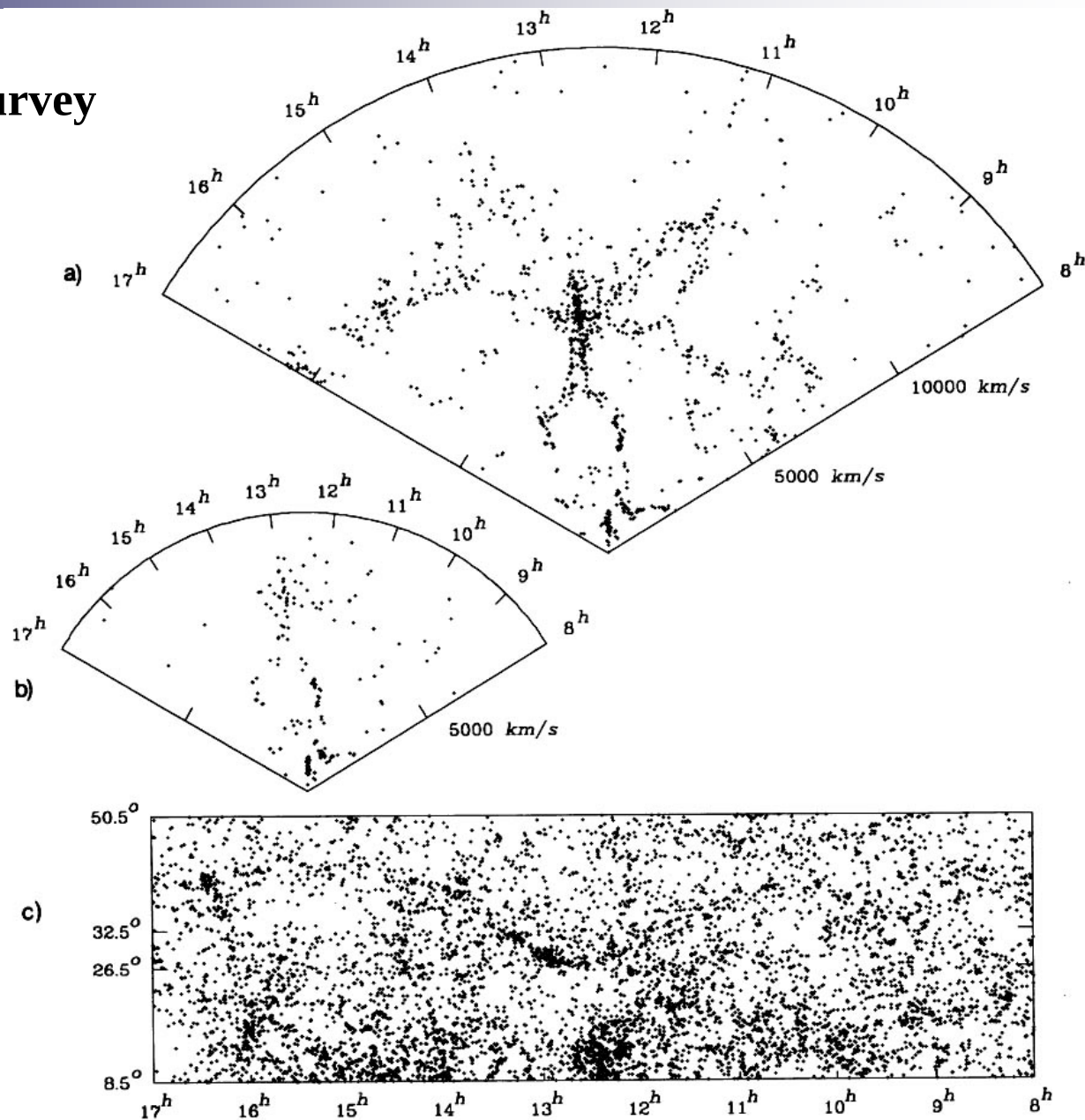
945 galaxies:
asterisks in $10 < \delta < 20$
open circles in $10 < \delta < 10$



The CfA2 Redshift Survey

(de Lapparent et al. 1986)

1100 galaxies with $m_B < 15.5$
in a slice going through
the Coma cluster

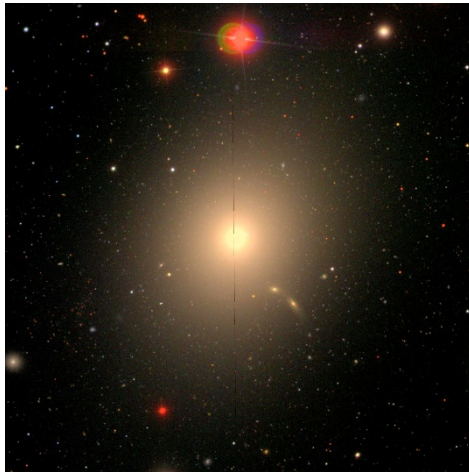




대답되지 않은 의문들

Morphology : a key physical property of galaxies

왜 다양한 은하 형태? : Initial morphology + evolution (성장, 변화, 변환)



Early

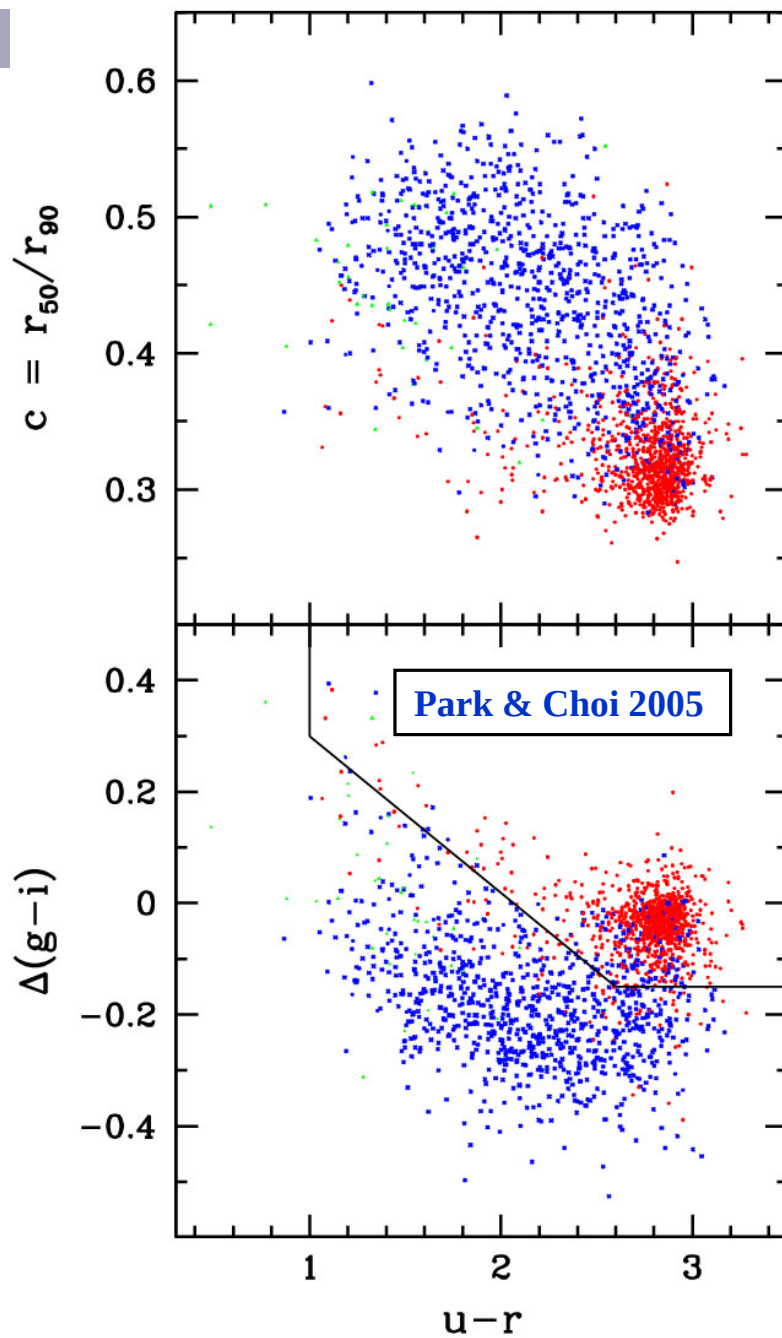


Red &
compact

Late

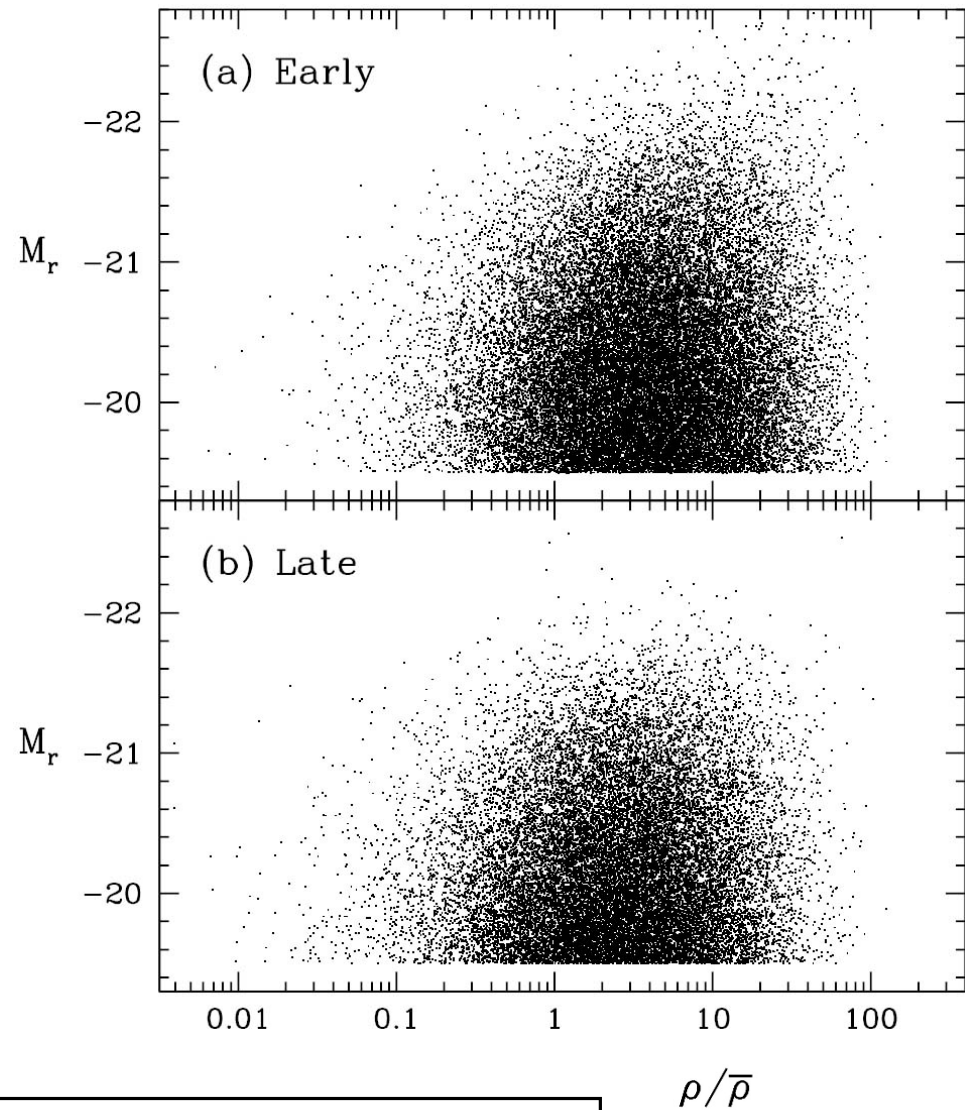
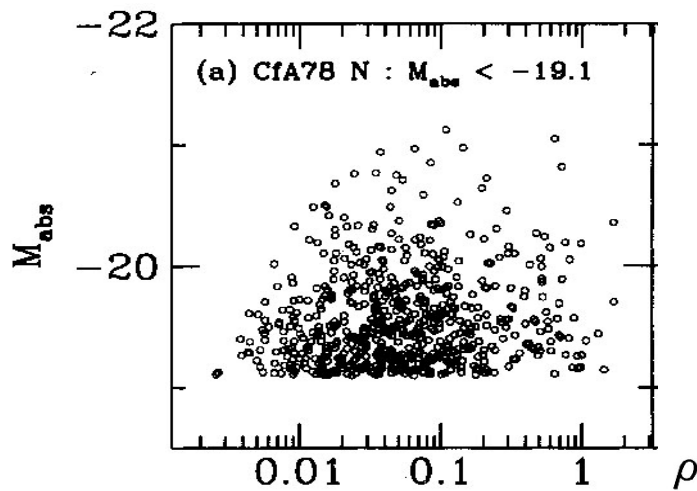


blue &
extended



광도함수

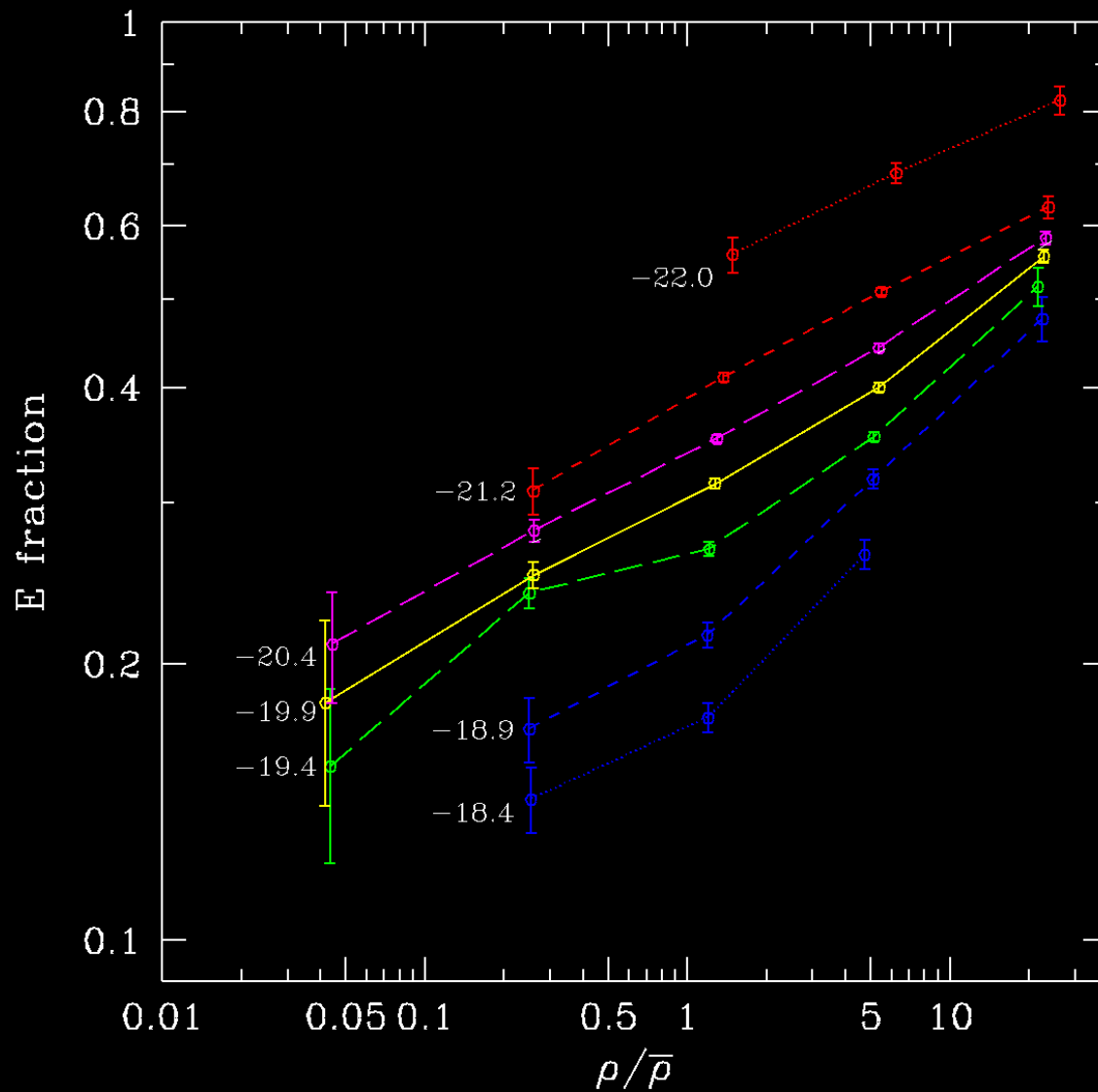
Park et al. 1994



CfA2 Survey [Park et al. 1994] 저밀도지역에 밝은 은하가 없음 !!!

➔ 광도함수가 밀도환경에 의존 !

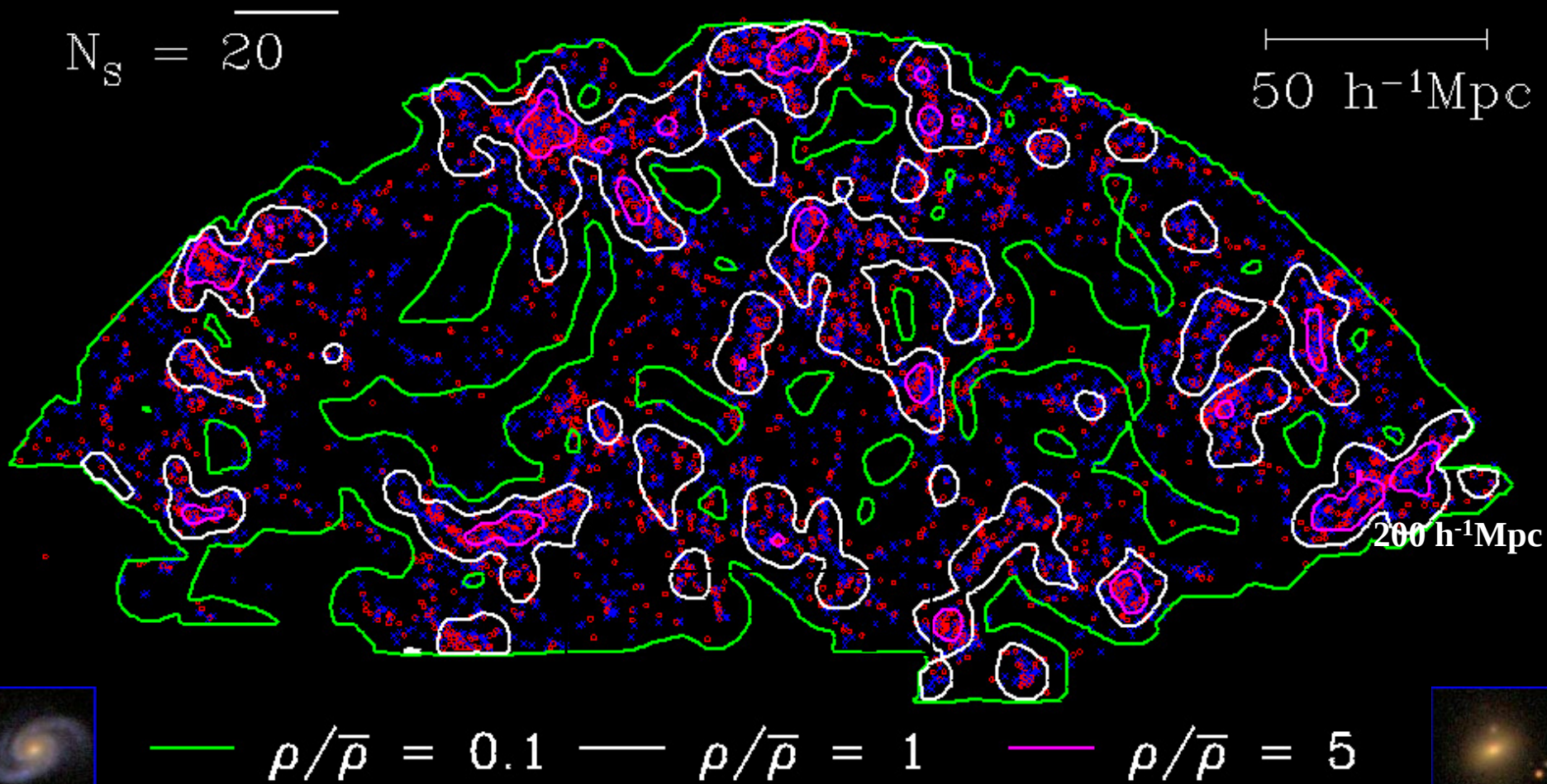
은하형태가 밀도환경에 의존 ! - SDSS Survey [Park et al. 2007]



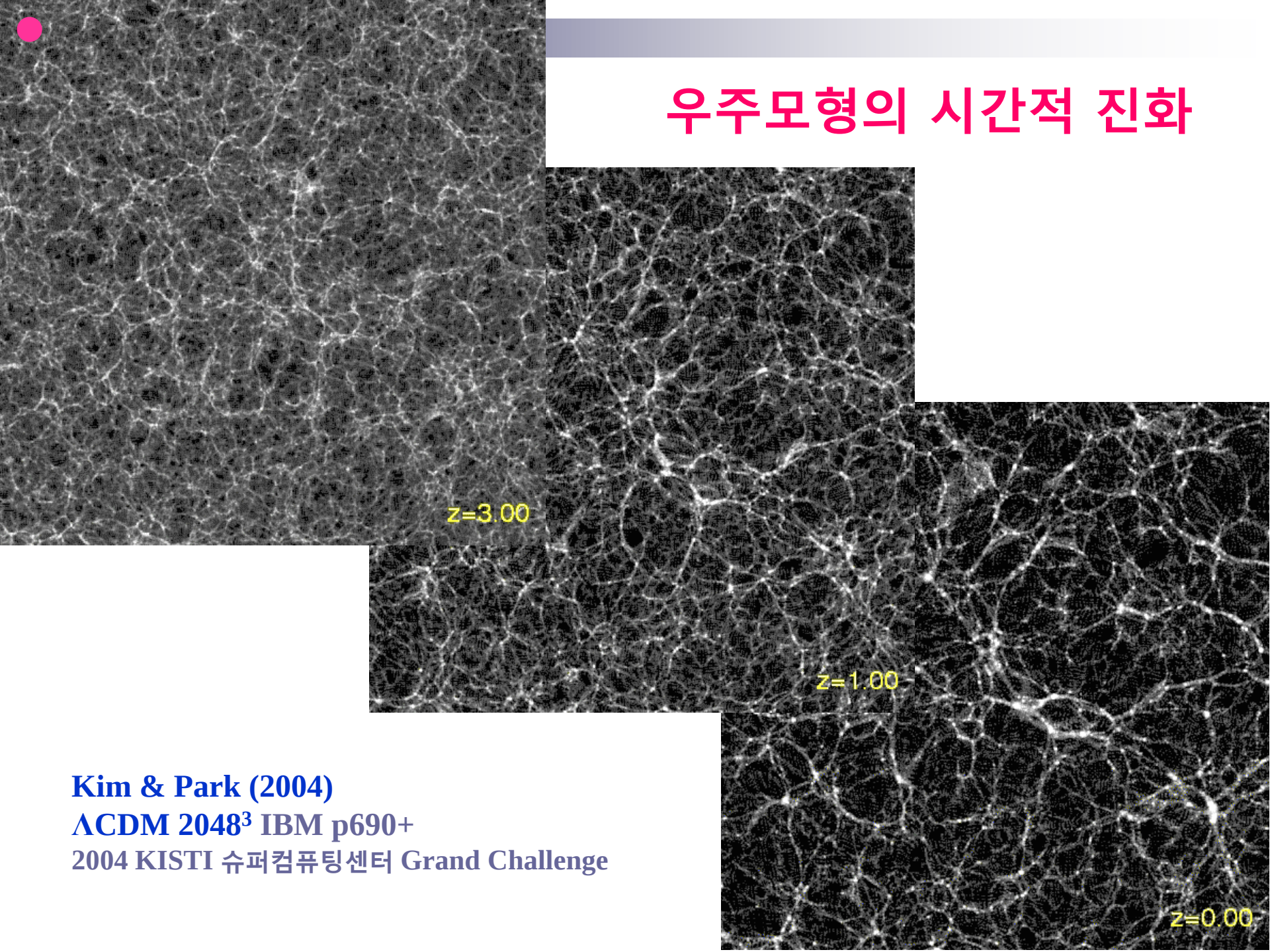
은하성질의 LSS환경 의존성

고밀도 : 밝고, 붉고, 早期형 은하; 저밀도 : 어둡고, 푸르고, 晩期형 은하

LSS 유형에 따라 은하 성질 차이? – cluster/filament/wall/void



우주모형의 시간적 진화

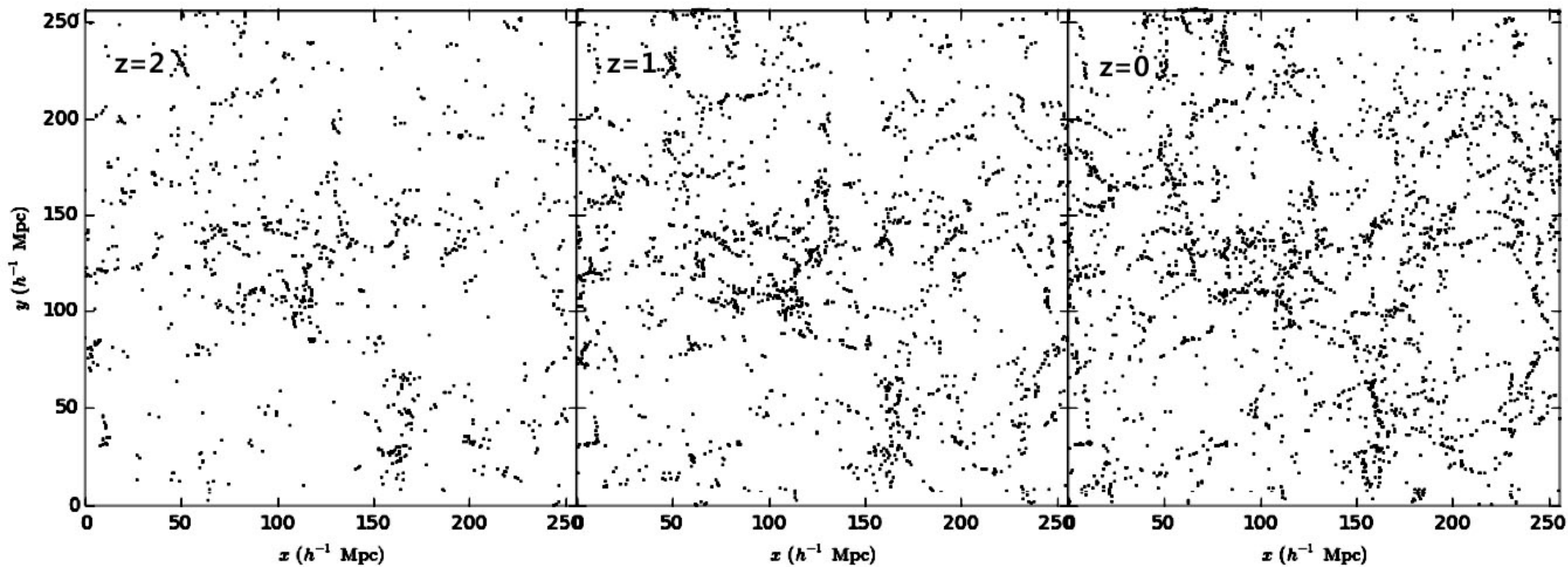


Kim & Park (2004)

Λ CDM 2048³ IBM p690+

2004 KISTI 슈퍼컴퓨팅센터 Grand Challenge

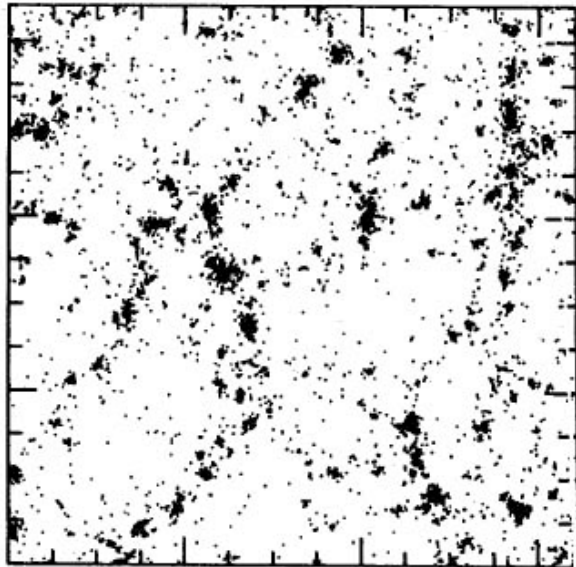
Formation and clustering of dark matter halos



우주모형(power spectrum 모양)의 차이

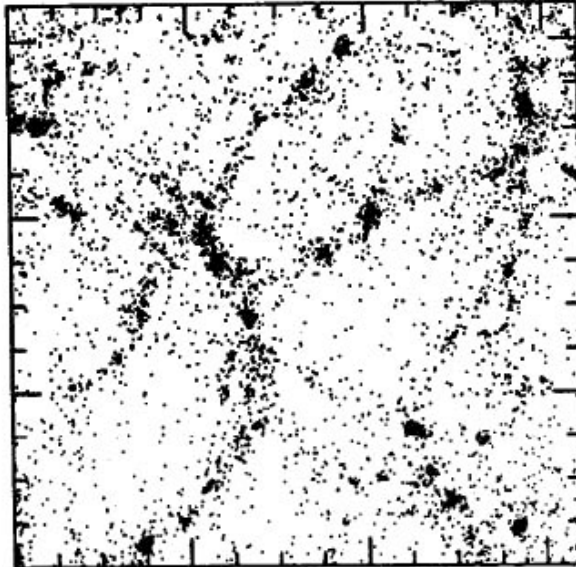
White noise

$z = 0.$



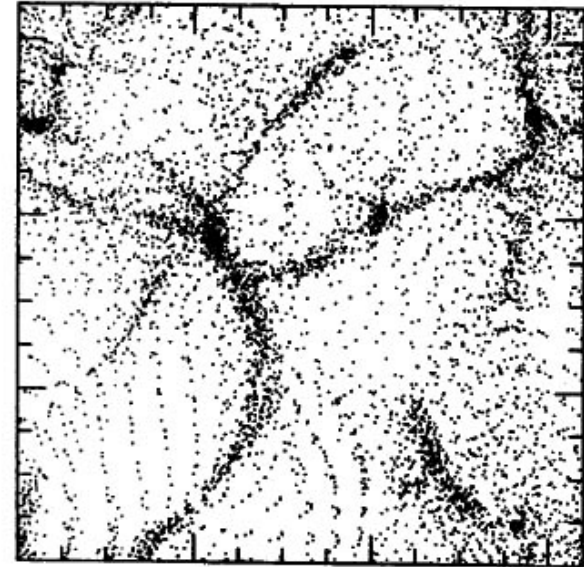
CDM

$z = 0.$



HDM

$z = 0.$



Weinberg & Gunn (1990)

LSS의 모양, 크기, 은하성질...

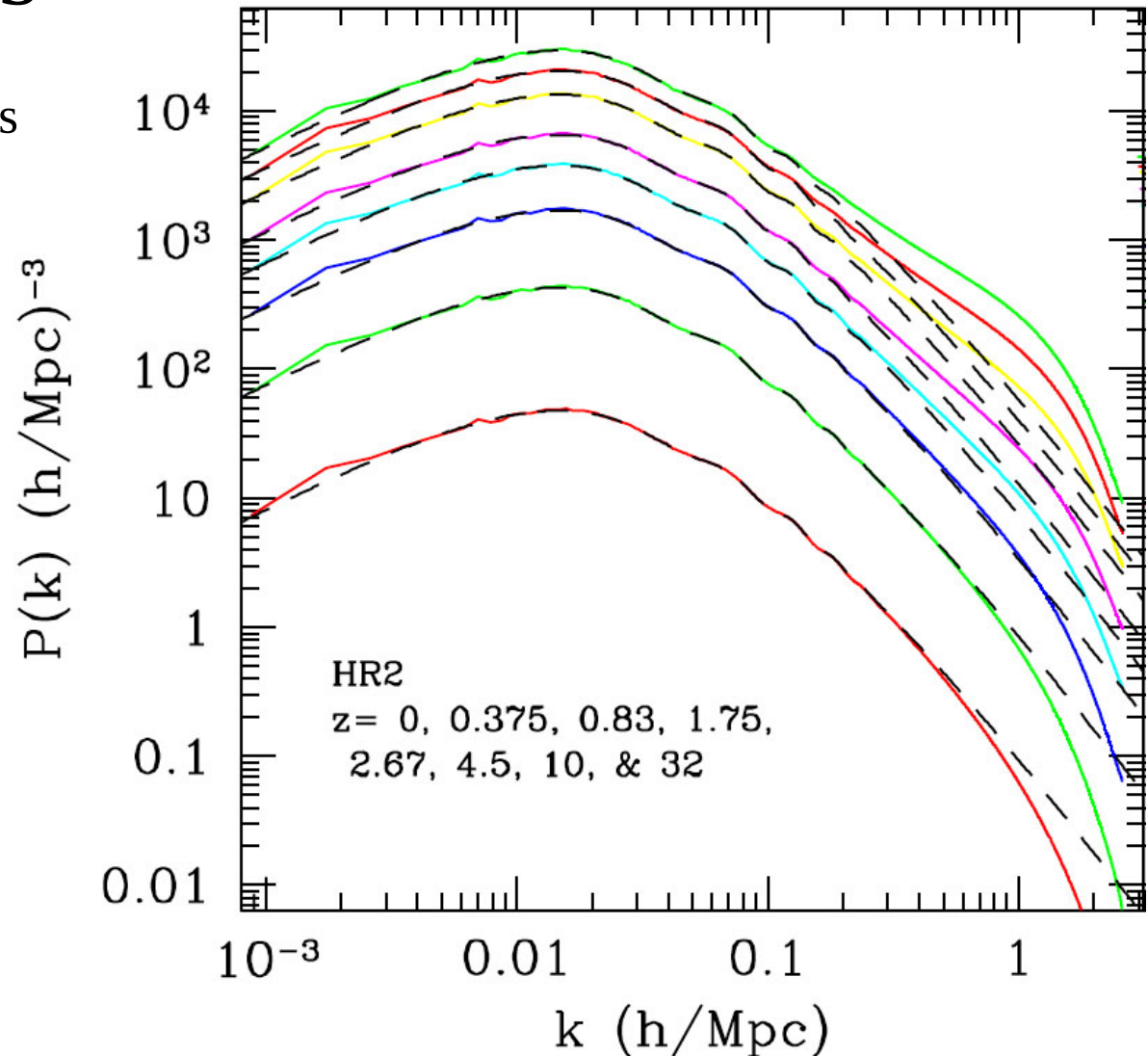
은 우주모형에 따라 크게 다르고
우주의 시기에 따라 크게 다르다!

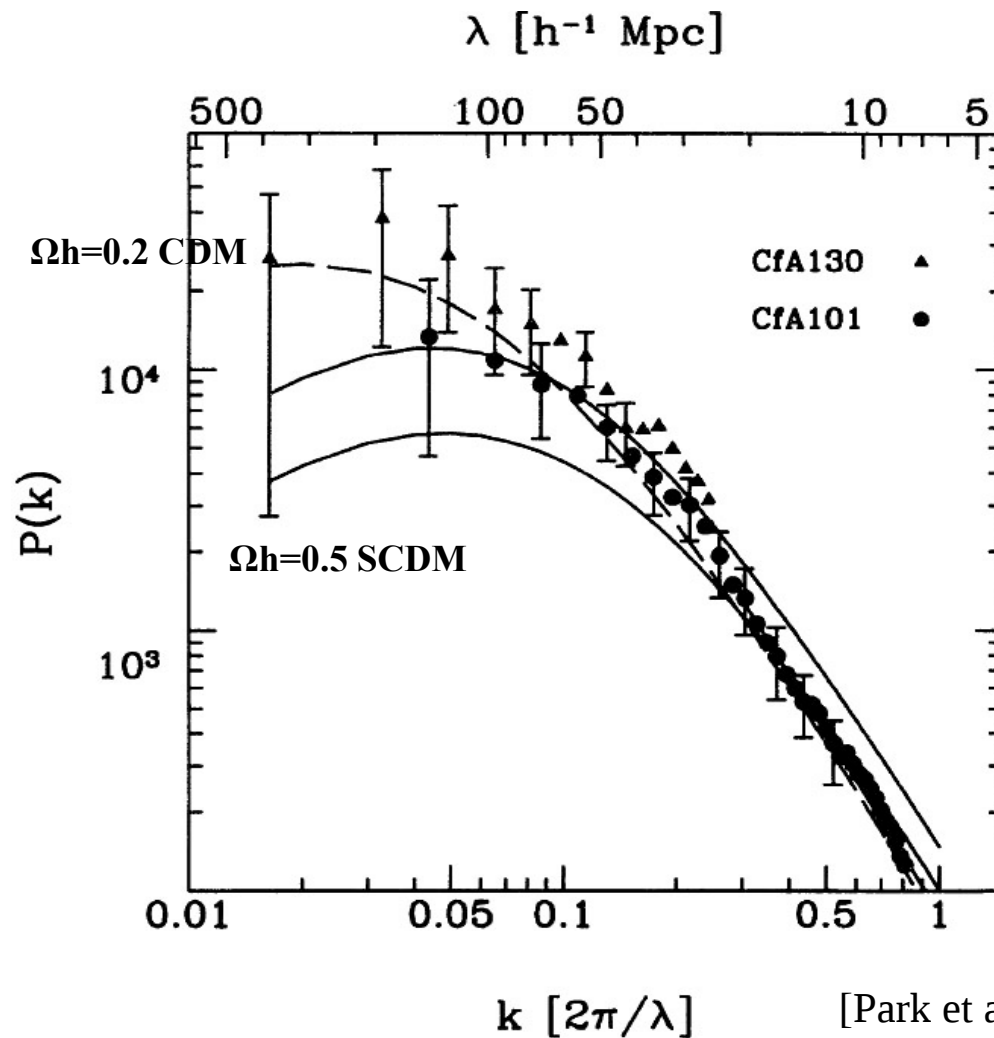
- 관측된 우주는?

Evolution of PS

: Growth
of density fluctuations

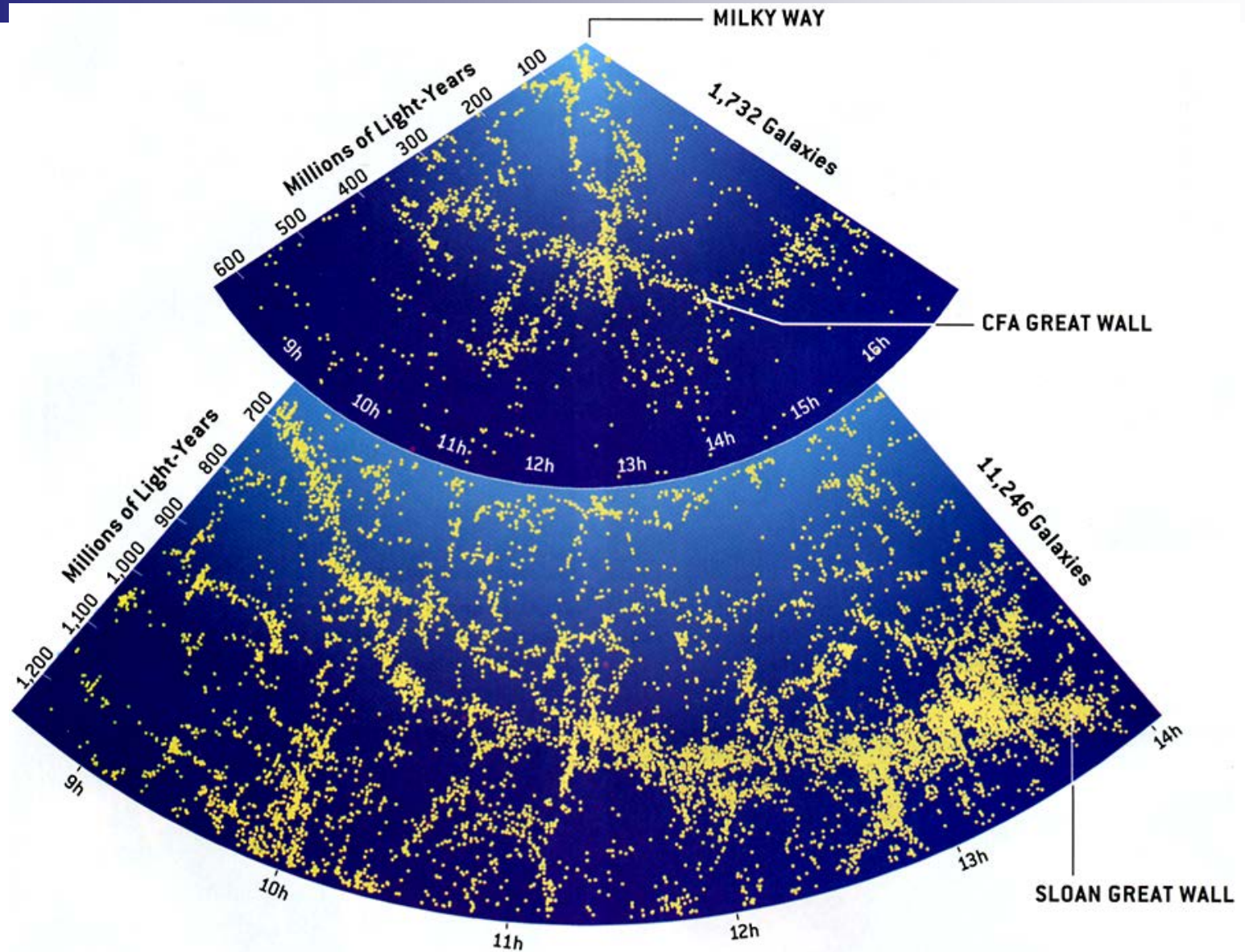
Horizon Run 2 (Kim et al. 2011)



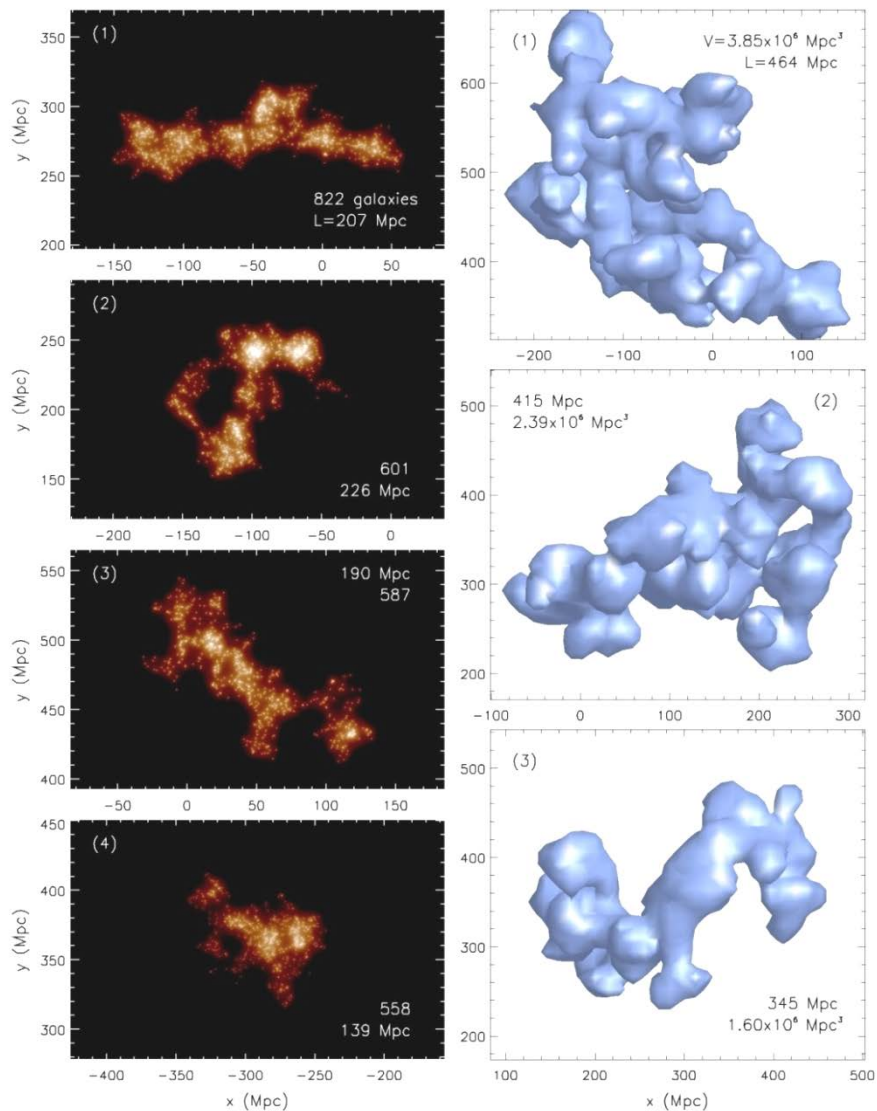


[Park et al. 1992, 1994]
First galaxy PS measured

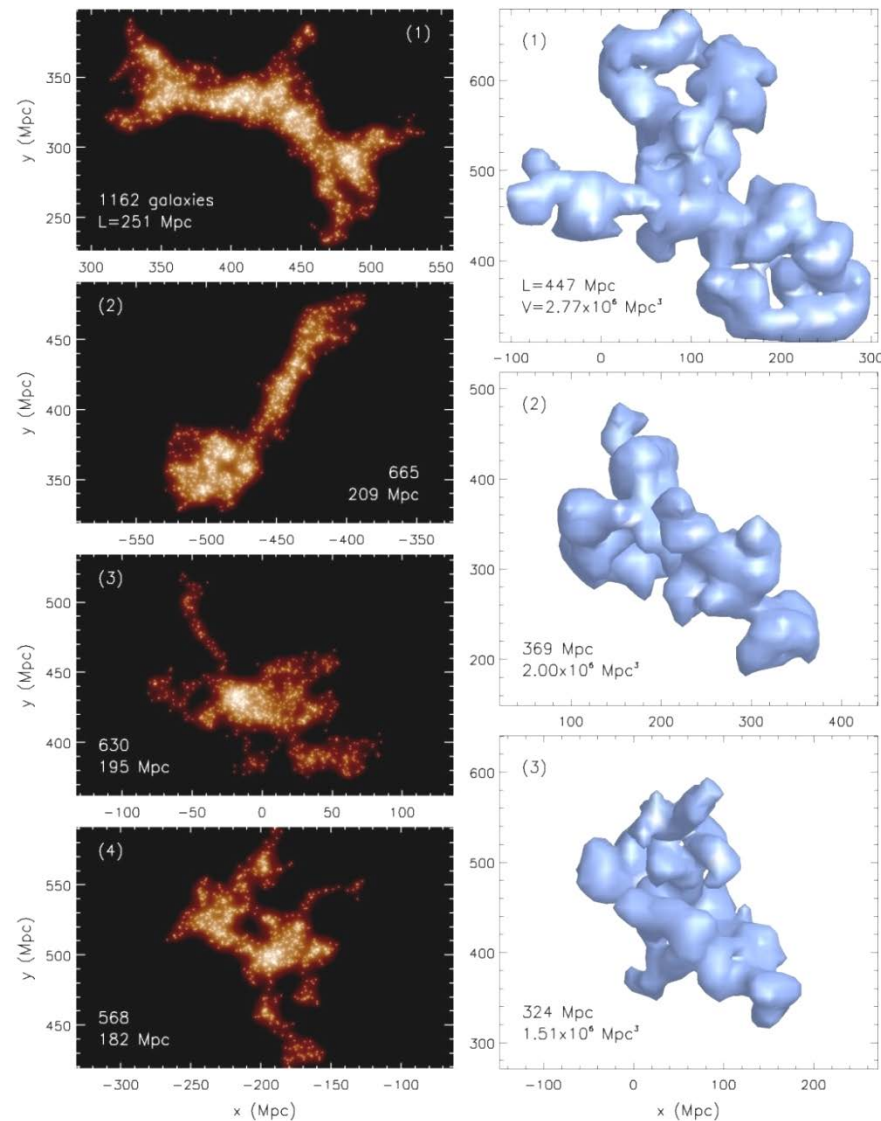
: Shape of galaxy PS on very large scales and very small scales



How large is the largest structure of the universe?



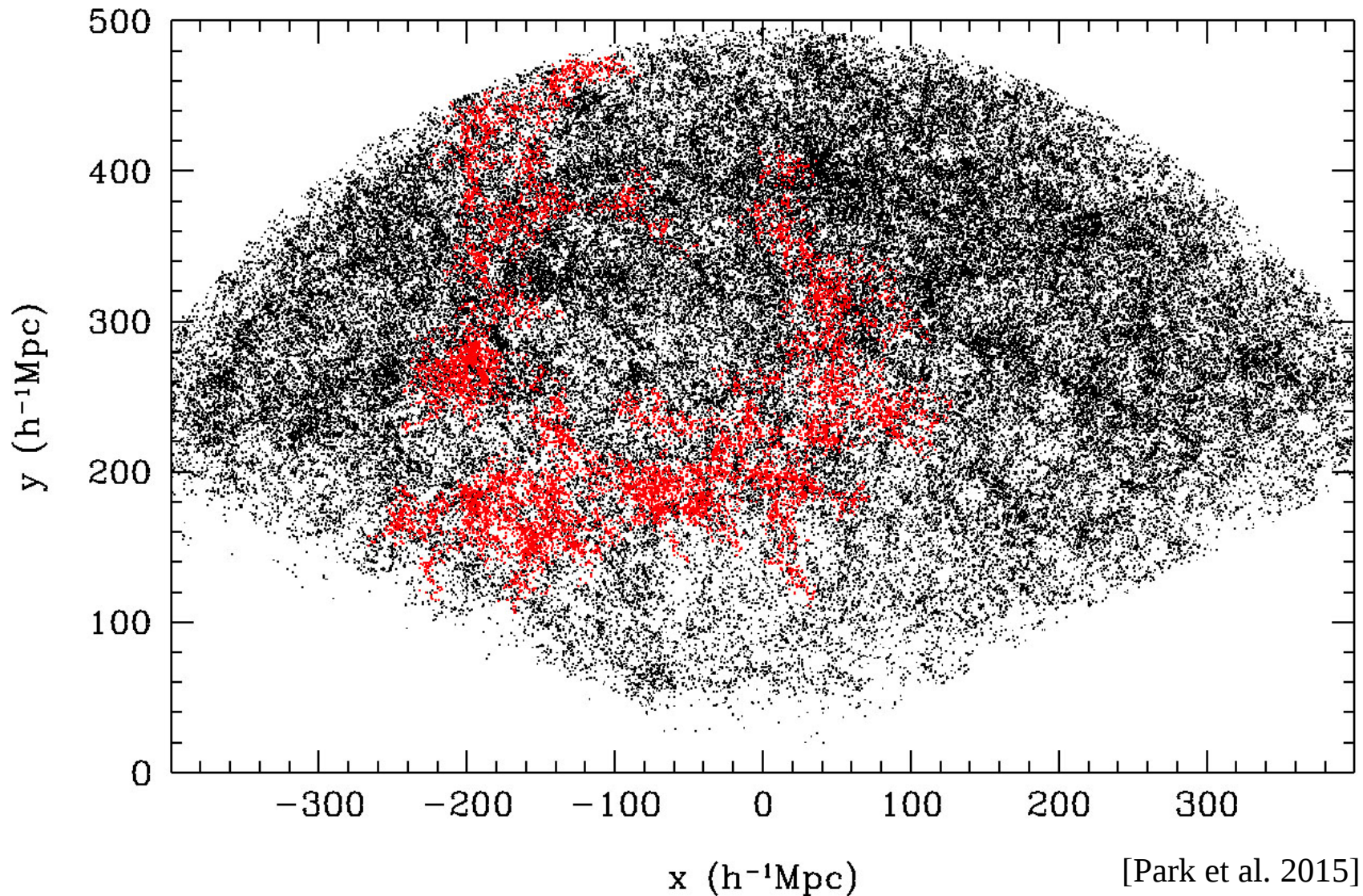
Top 4 high-density and top 3 low-density LSSs from DR7



Median top 4 high-density and median top 3 low-density LSSs from mock DR7 in HR2

Super-scale structures of LSSs / LSS across redshifts

- How to define ‘cosmic structures’ at different epochs?

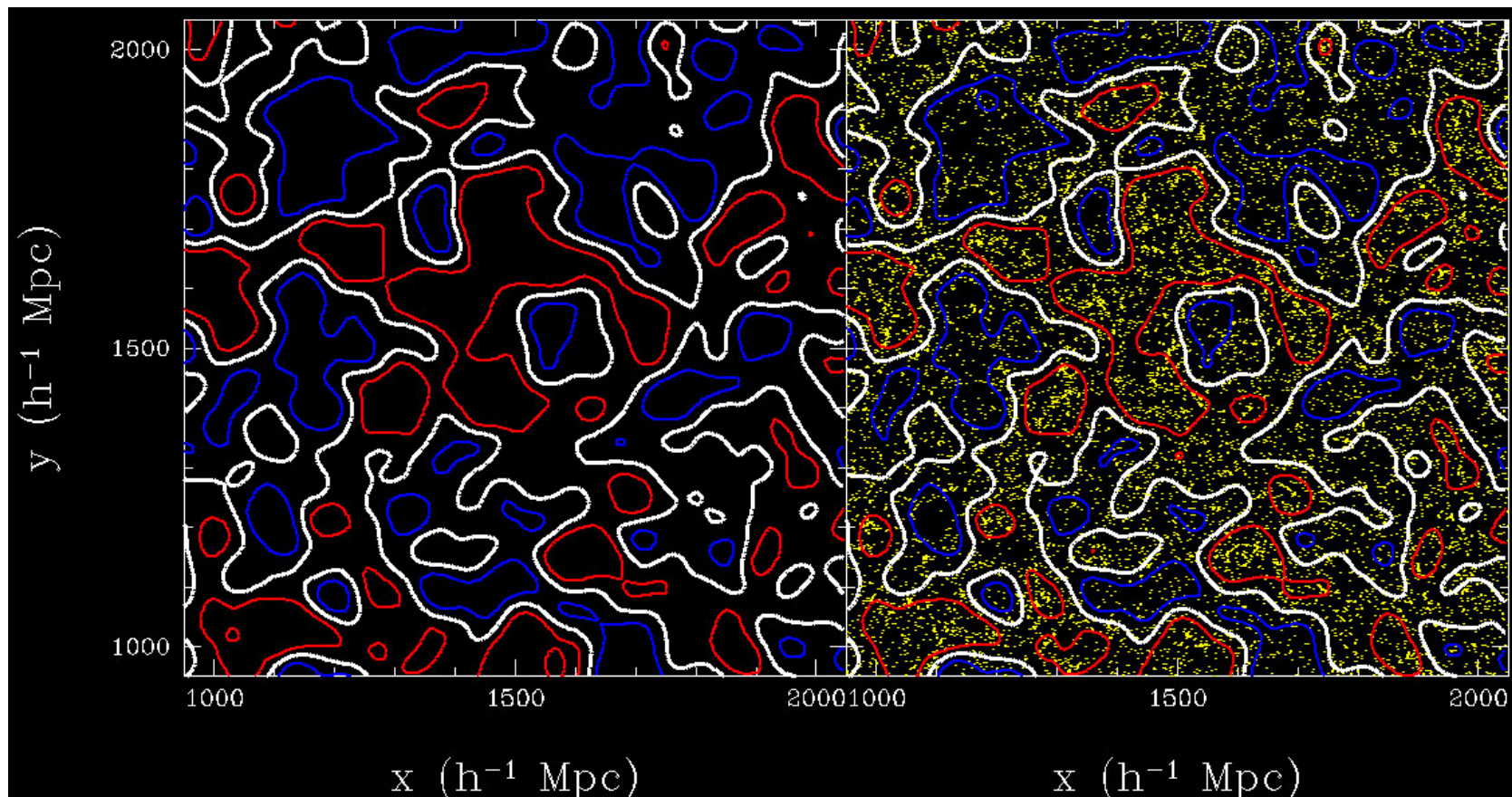


Cosmic sponge conserved [Park & YR Kim 2010]

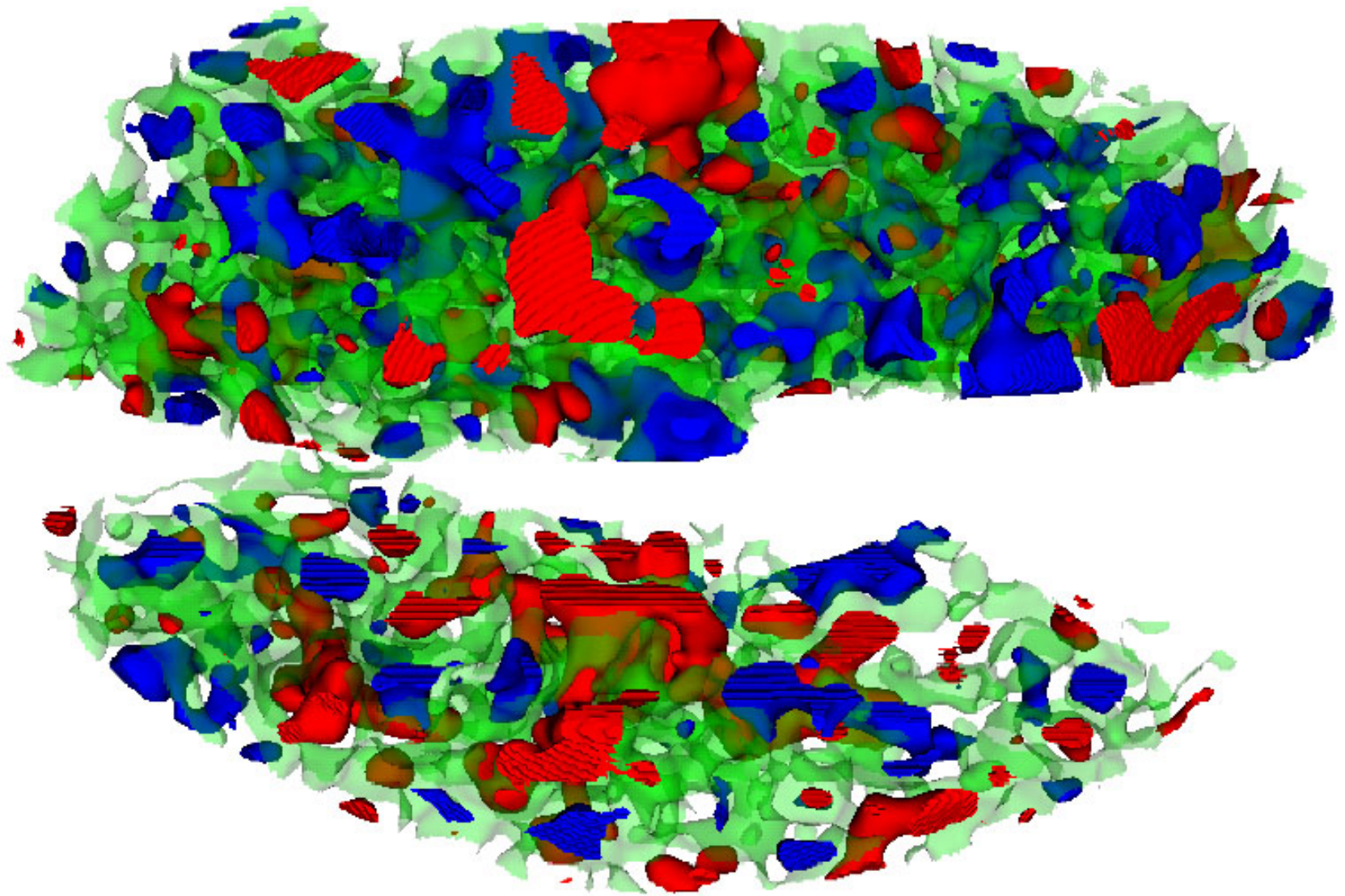
LSS in linear regime maintains the primordial sponge topology at all redshifts!

[Initial density field]

[Final density field at $z=0$]



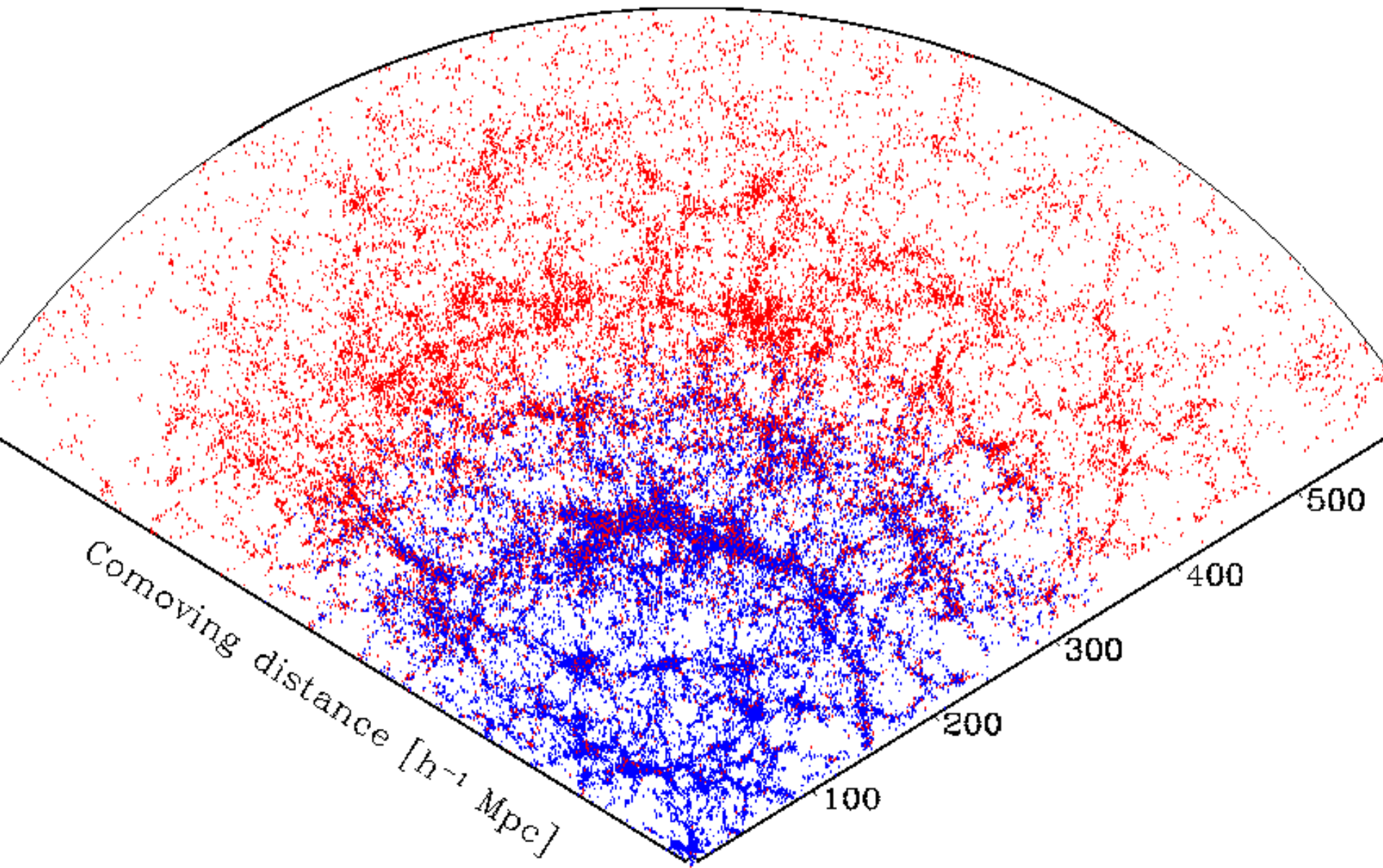
Flat LCDM, $R_G=25h^{-1}\text{Mpc}$



Connectivity of over-density and low-density regions

Voids (blue - 7% low), filaments/clusters (red - 7% high) SDSS DR4+ (Gott et al. 2008)

Cosmic Ripples – A phase-correlation feature associated with the Sloan Great Wall?



新五行圖

인간 -- 자연



관측
Observation

은하분광관측
(황호성)

기기
Instrumentation

실험
Simulation

은하생성실험(김주한)

분석
Data analysis

천문자료분석
(아미르 아가모우사)

이론
Theory

평창여름학교

호기심
발상

평창 Summer Institute 2015

제 4회 고등과학원 『우주론 및 천체생성 평창여름학교』

2015. 7. 27 – 30

학교준비위원: 박창범, 박명구(경북대), 김주한(KIAS), 황호성(CfA)

<강의>

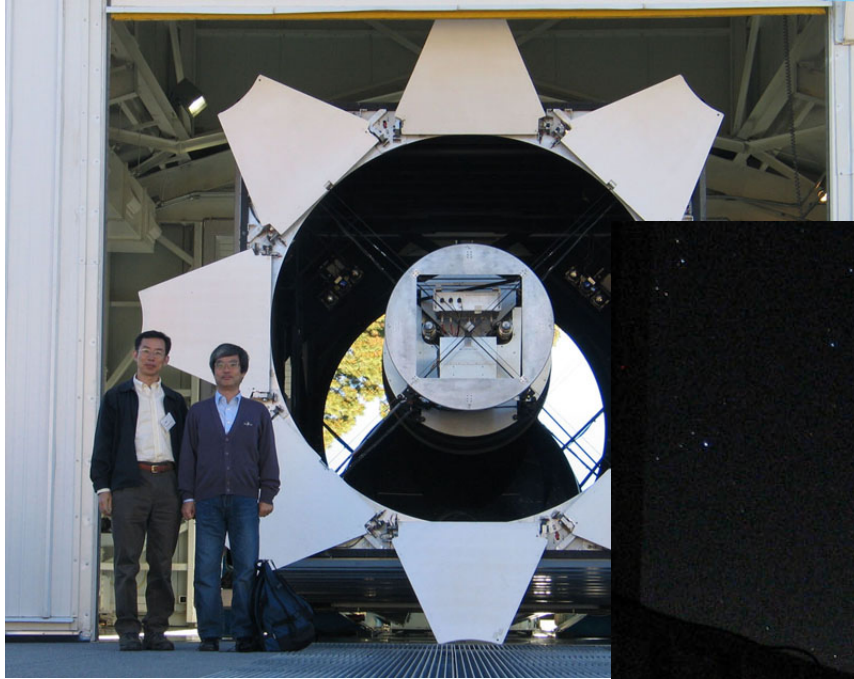
박창범 Introduction

김주한 Simulating Cosmic Structure Evolution

황호성 Observations for Cosmology and Structure Formation

아미르 아가모우사 Data Analysis in Cosmology





Studies from Redshift survey & LSS data

Internal Physical Properties of Galaxies

Color, Luminosity
Morphology, Size
Surface brightness
Concentration
Velocity dispersion
Spectral type, SFR..

Collective Physical Properties of Galaxies

Clustering Amplitude :
Correlation Function
Power Spectrum, ...
Topology of LSS :
Genus, MFs, ...

Peculiar Velocity Field

Distribution Functions:
Luminosity, Color, Size, Con. indx,
Velocity Dispersion ...

Environment:

Local Density (scales) &
Cosmic Epoch

CMB Anisotropy

Initial density fluctuation
Galaxy biasing,
 Ω_m , σ_8 , etc.

Galaxy Formation & Evolution

(Origin of morphology,
L-C-M biases ...)

+

**Cosmological
Parameters**

Different Tracers : galaxy subclasses, cluster, Ly- α cl, quasar..

Expansion of LSS surveys (large 3d)

