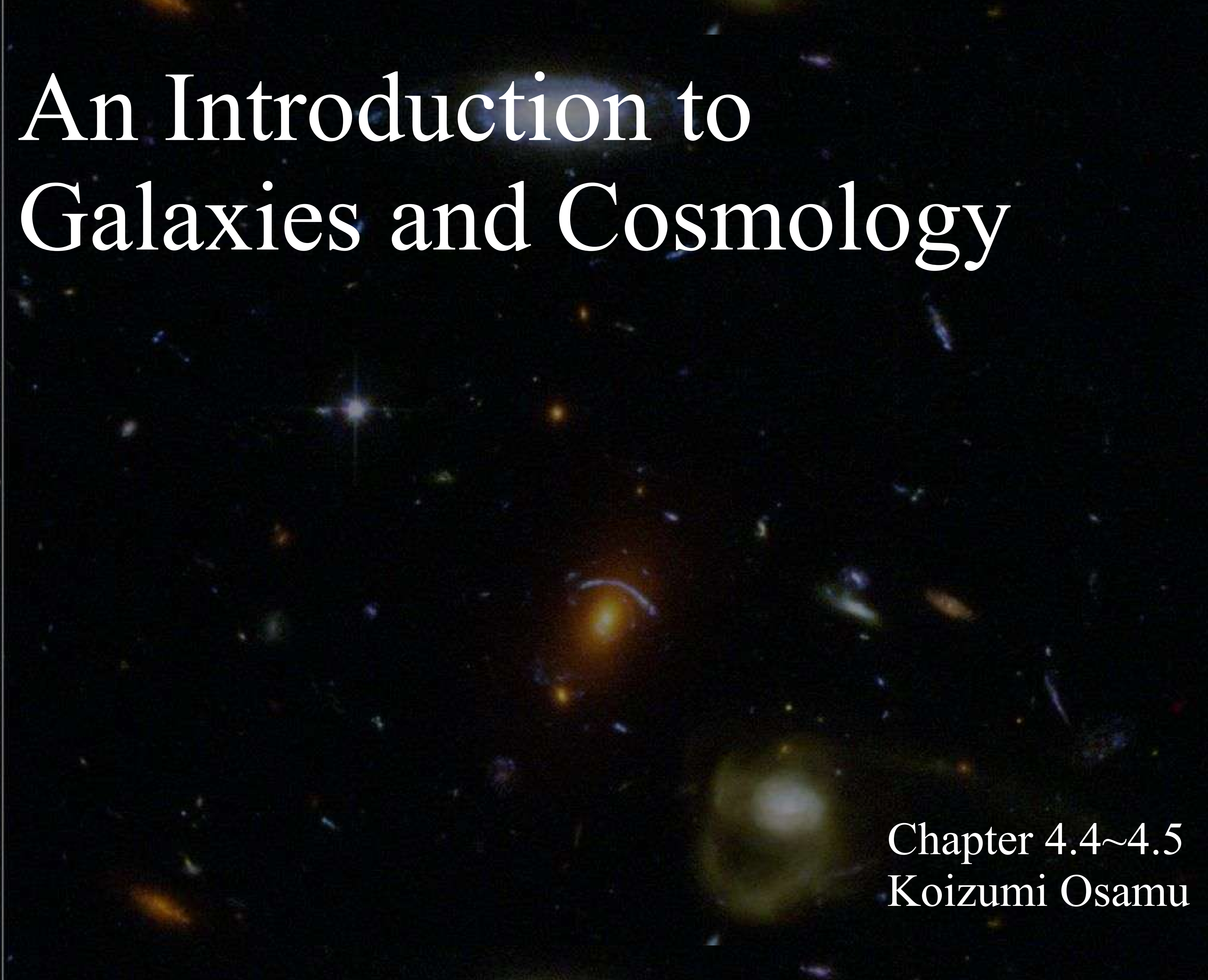
An Introduction to Galaxies and Cosmology



Chapter 4.4~4.5

Koizumi Osamu

4.4 The large-scale distribution of galaxies

star
star
star
star
star

→ galaxy
→ galaxy
→ galaxy

→ cluster
→ cluster

→ super cluster

~ 40kpc　　~ 2 Mpc　　~ 30 Mpc

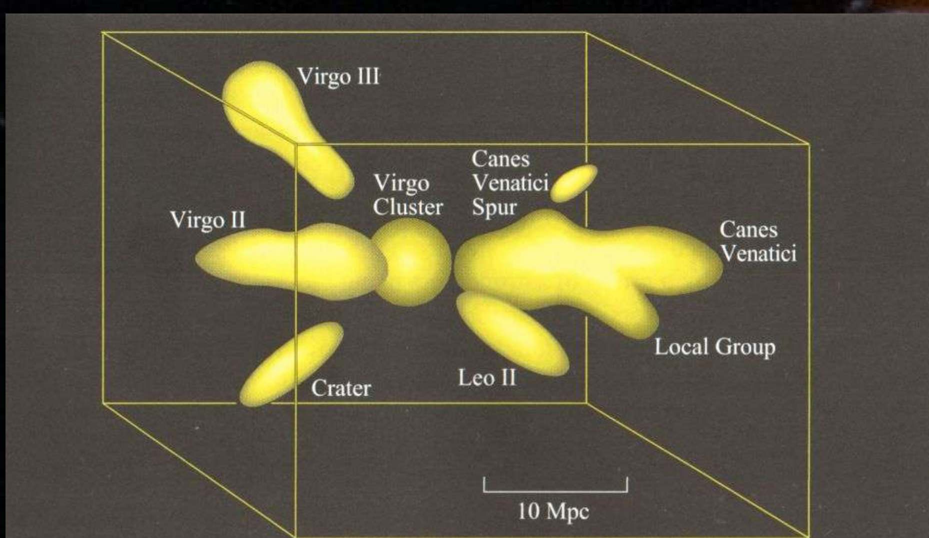


Fig. 4.17 The Local Super cluster

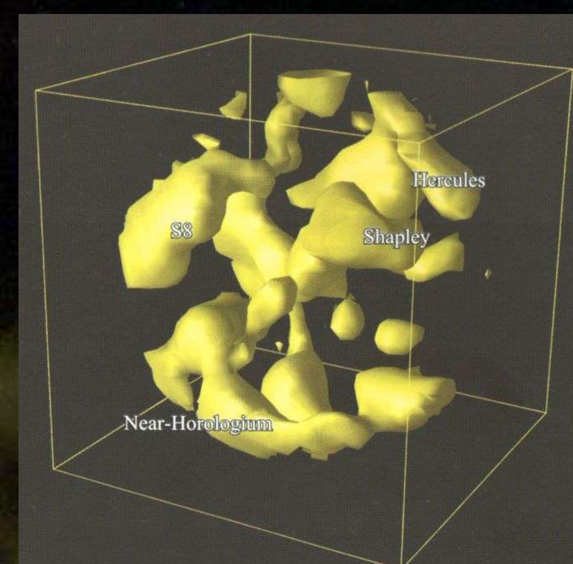


Fig. 4.18 superclusters

4.4 The large-scale distribution of galaxies

Super clusters are not themselves organized into ever larger clusters of superclusters.

But their distribution consist of filaments and sheets wrapped around empty voids.

↓

Large scale structure

filament?

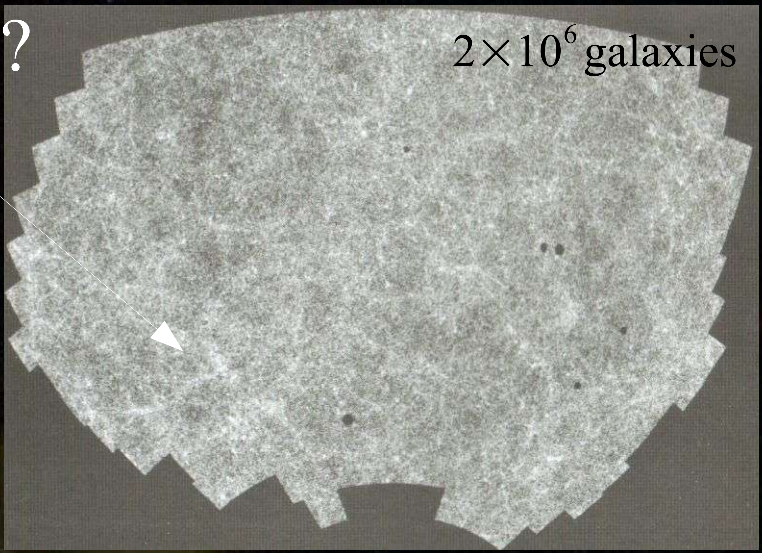
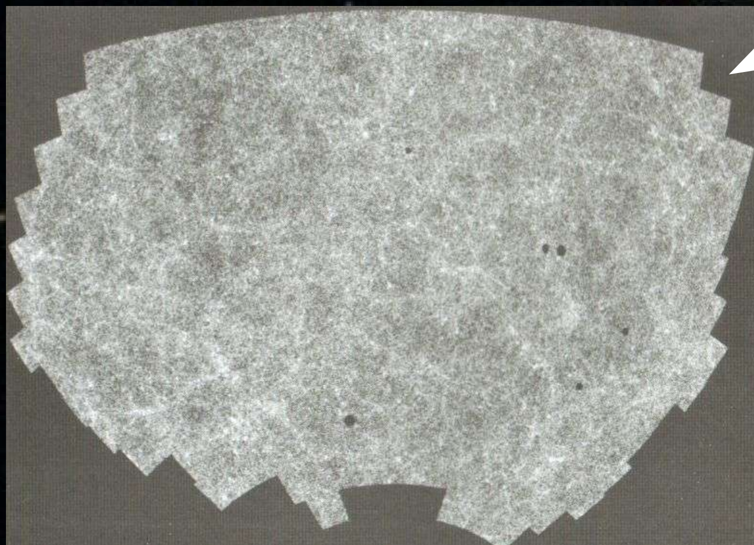


Fig. 4.19 The APM map of galaxy positions

4.4.1 Redshifts of galaxies



2D distribution map

We need a 3D information.

measuring the redshift of individual galaxy

<u>redshift survey</u>

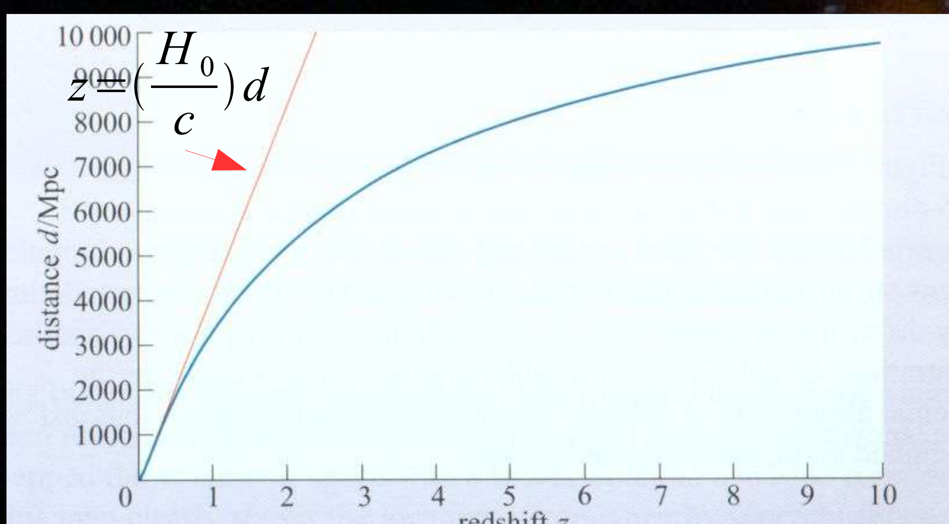


Fig. 4.20 Redshift-distance relationship

At large distances the redshift increases more rapidly with distance.

4.4.2 Mapping the Universe in three dimensions

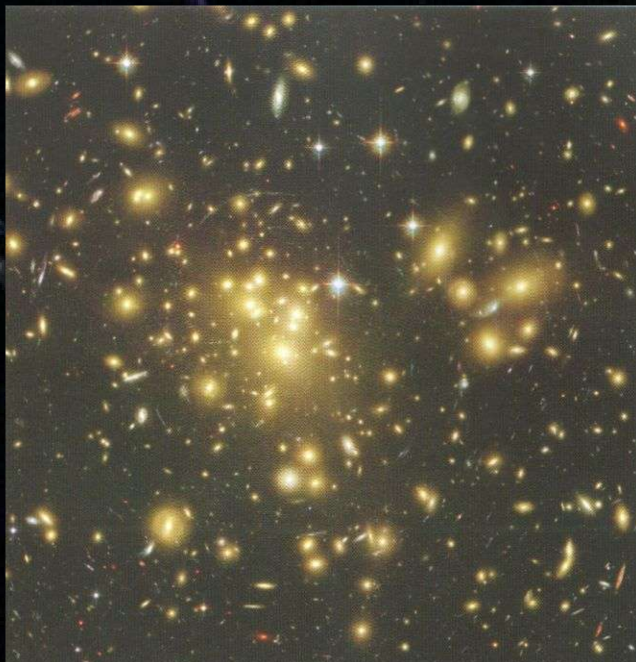


Fig. 4.21 Abell 1689

This image contains thousands of galaxies.

Redshift Surveys

sky coverage ⟷ distance probed

v.s.

1980s ~ 1990s

- Harvard-Smithonian Center for Astrophysics (CfA) survey
- IRAS (Infrared Astronomical Telescope) Point Source Catalogue z-survey (~ 200Mpc)

borehole survey (~2000Mpc) by Durham Univ. and Uviv. of California in Santa Cruz

4.4.2 Mapping the Universe in three dimensions

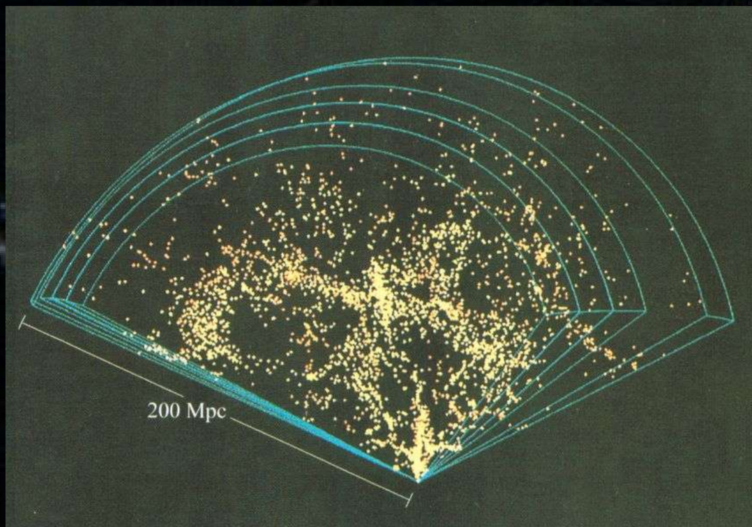


Fig. 4.22a CfA survey

Both survey confirmed the existence of features on scales larger than the Local Supercluster.

↓

We need much larger volumes, greater depth to see the large scale structures.

Fig. 4.22b Durham-Santa Cruz borehole survey

4.4.2 Mapping the Universe in three dimensions

SDSS (Sloan Digital Sky Survey)

Fig. 4.23 Sloan telescope

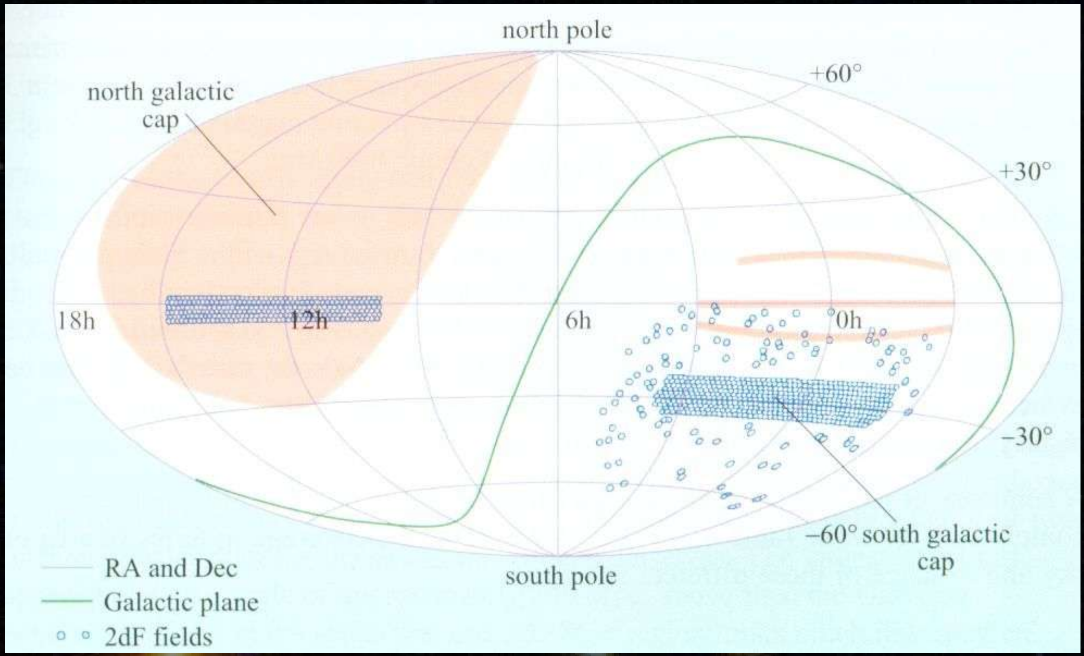


Fig. 4.24 SDSS and 2dF survey fields

- imageing one-half of the northern celestial hemisphere
- determine the positions and brightness of over 100 million objects
- providing a 3D picture of our neighbourhood of the Universe

4.4.2 Mapping the Universe in three dimensions

SDSS (Sloan Digital Sky Survey)

Deep Sky Imaging

- apparent magnitude ~ 24
- 100 million objects

Spectroscopic survey to determine redshifts

- apparent magnitude 19 or brighter
- including over a million galaxies and quasars
- typical galaxy redshift ~ 0.25

→ 3D map of our local neighbourhood out to ~ 800 Mpc
2D image out to much larger distances

4.4.2 Mapping the Universe in three dimensions

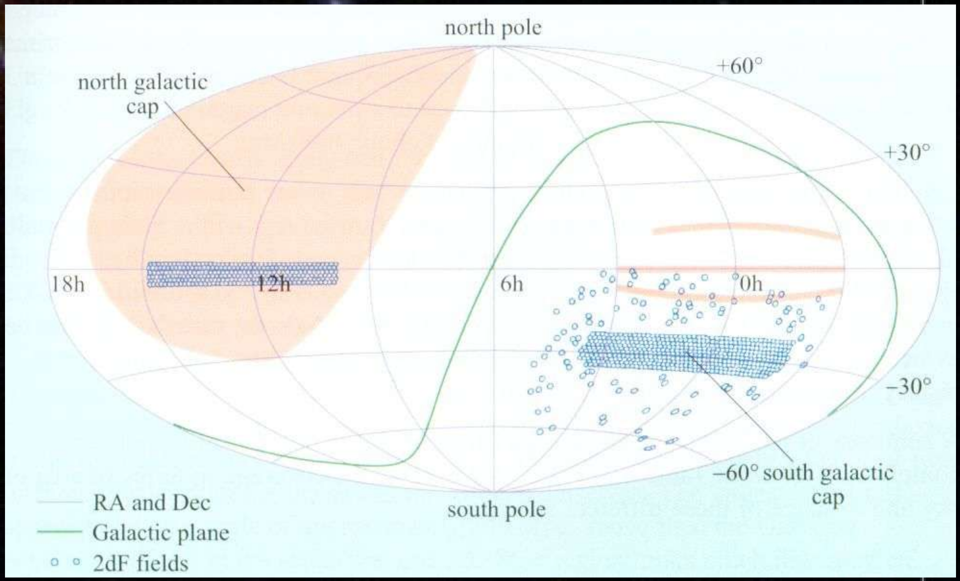
2-degree Field survey

3.9m Anglo-Australian Telescope

completed in 2002.

2dF Galaxy Redshift Survey (2dFGRS)

- Survey galaxies redshifts and positions to map the structure of the Universe ~ 600Mpc



The survey also mapped Quasar positions and redshifts to much greater distances.

4.4.2 Mapping the Universe in three dimensions

A summary of five important galaxy redshift surveys

Name	Number of galaxies in survey (approximate)	Mean redshift	Telescope diameter/m	Simultaneous spectral measurements[a]
CfA	1500	0.02	1.5	1
PSCz	15000	0.03	2.1	1
2dFGRS	250 000	0.10	3.9	400
SDSS	1000 000	0.10	2.5	640
DEEP	50 000	0.7–1.55	10	1

using fibre optic system (2dFGRS, SDSS)

Table 4.2 important surveys

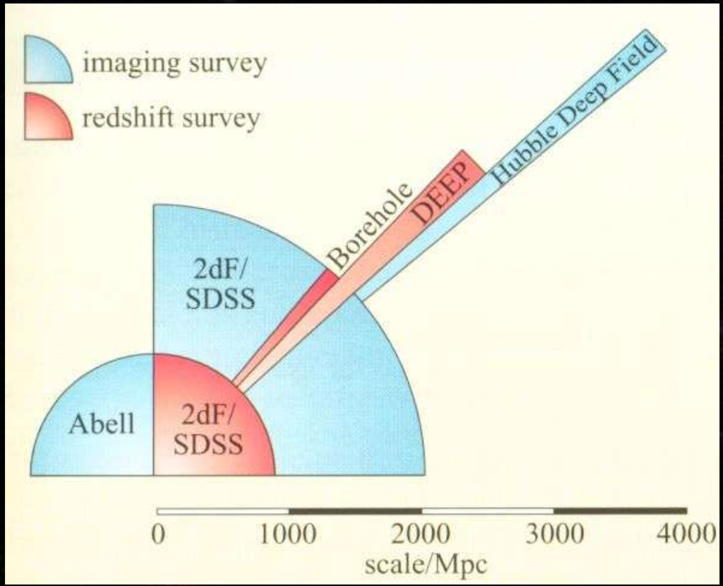


Fig. 4.25
A schematic illustration of the relative scales of the different surveys

The deeper surveys has narrower survey areas.

4.4.3 Large-scale structure revealed

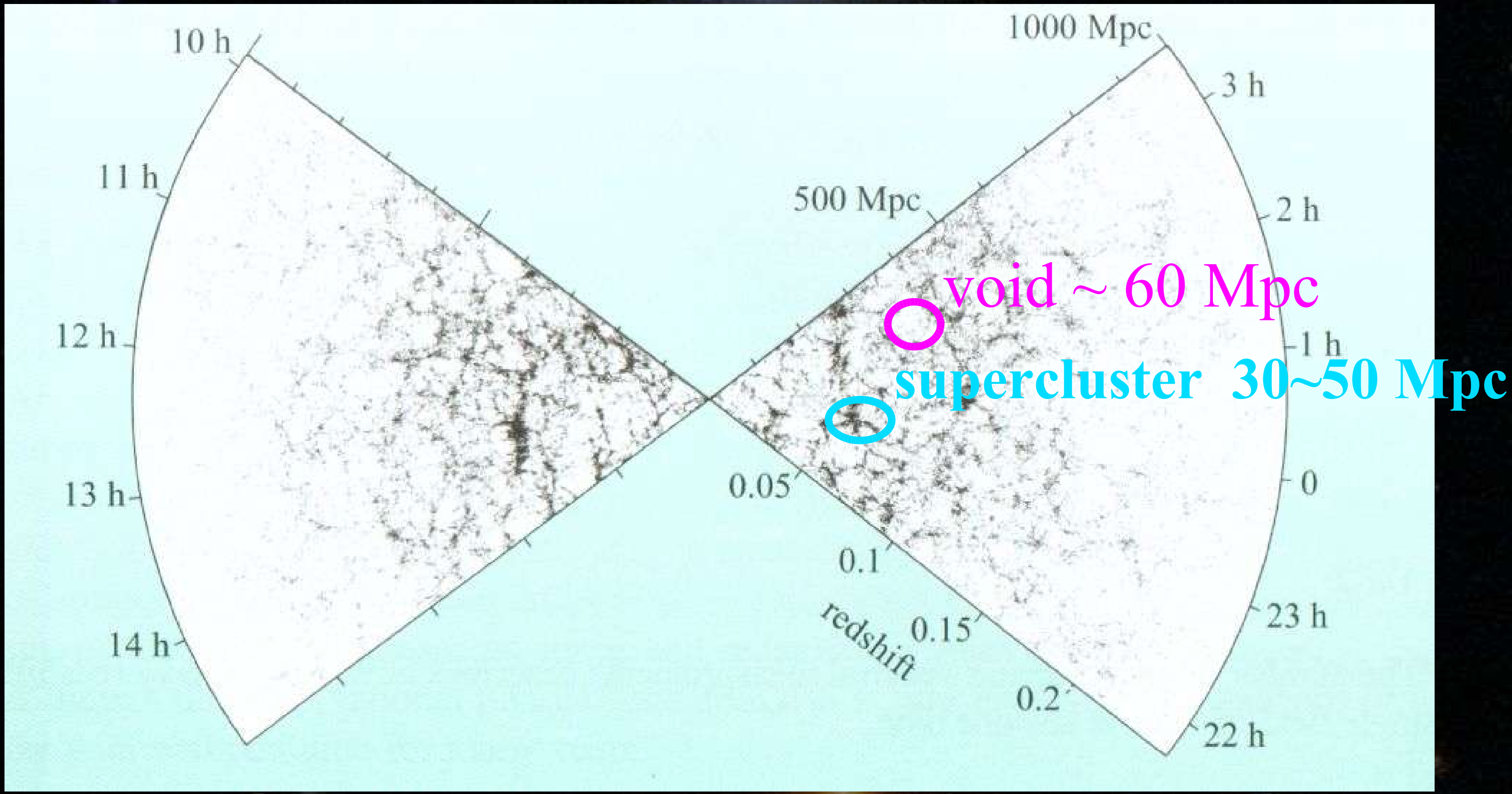


Fig. 4.26 Early results from the 2dFGRS.

The largest structures ~ 200 Mpc
above this, Universe becomes uniform

4.5 The spatial distribution of intergalactic gas and dark matter

How inter galactic gas and dark matter are distributed on large scale?

Do they follow the large-scale structure that is mapped out by the luminous matter in galaxies, or is their distribution significantly different?

4.5.1 Quasars and the Lyman α forest

intergalactic gas in clusters of galaxies → X-ray observable

gas which away from gravitational influence of a rich cluster → cannot detect by emission at any wavelength

We can use absorption lines to examine intergalactic gas clouds.

Lyman series

$$\mathrm{Ly}\,\alpha = 1216\,\text{Å}$$

transition from n = 2 to n = 1.

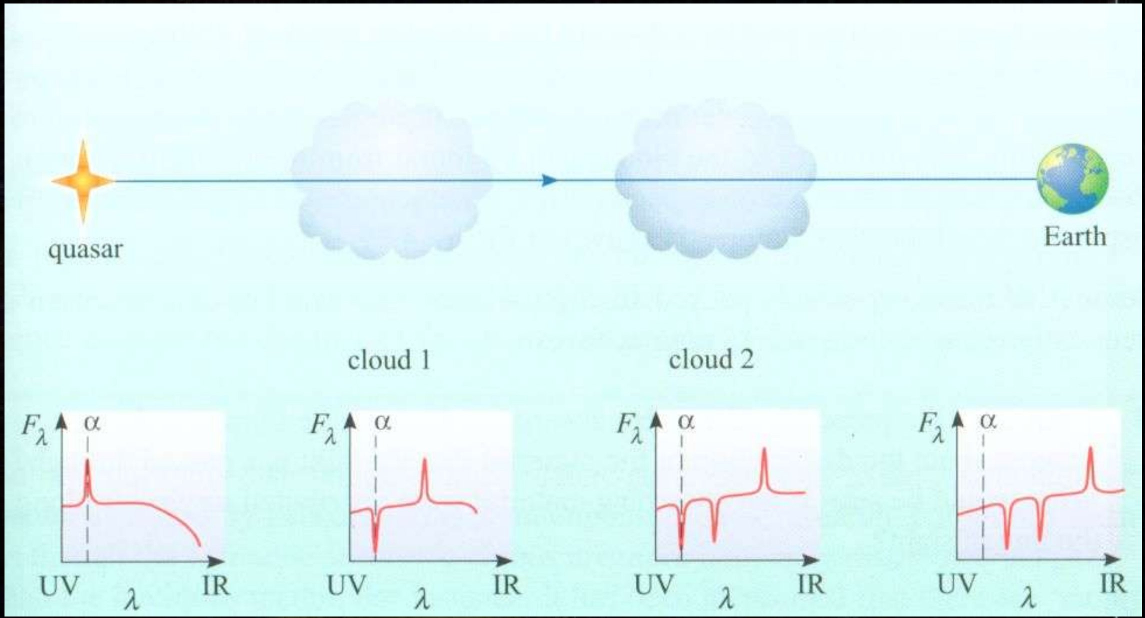


Fig. 4.27 Intervening clouds in the line of sight from a quasar.

4.5.1 Quasars and the Lyman α forest

Redshift of Ly α

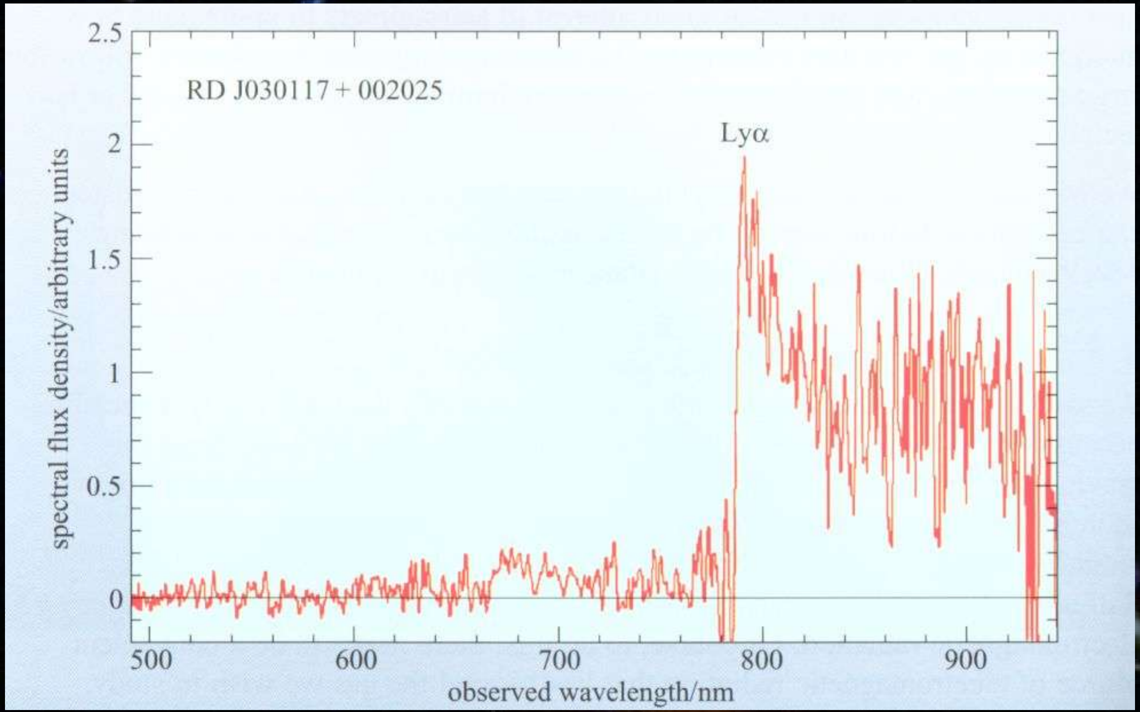


Fig. 4.28 The spectrum of quasar z = 5.5

$$1216\,\text{Å}\times(1+5.5)=7904\,\text{Å}$$

4.5.1 Quasars and the Lyman α forest

Ly α forest

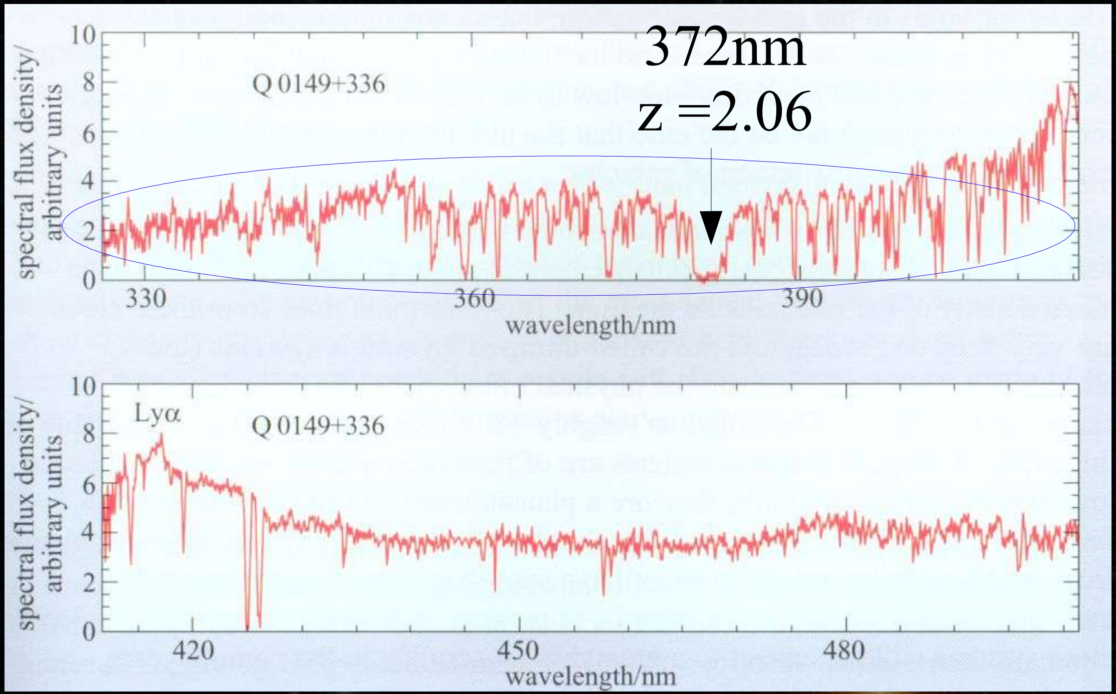


Fig. 4.29 The spectrum of quasar z = 2.431

discrete absorption lines

↓

intergalactic medium is not smoothly distributed.

Seven clouds along the line of sight whose presence is confirmed by absorption lines due to elements hevier than hydrogen or helium.

4.5.1 Quasars and the Lyman α forest

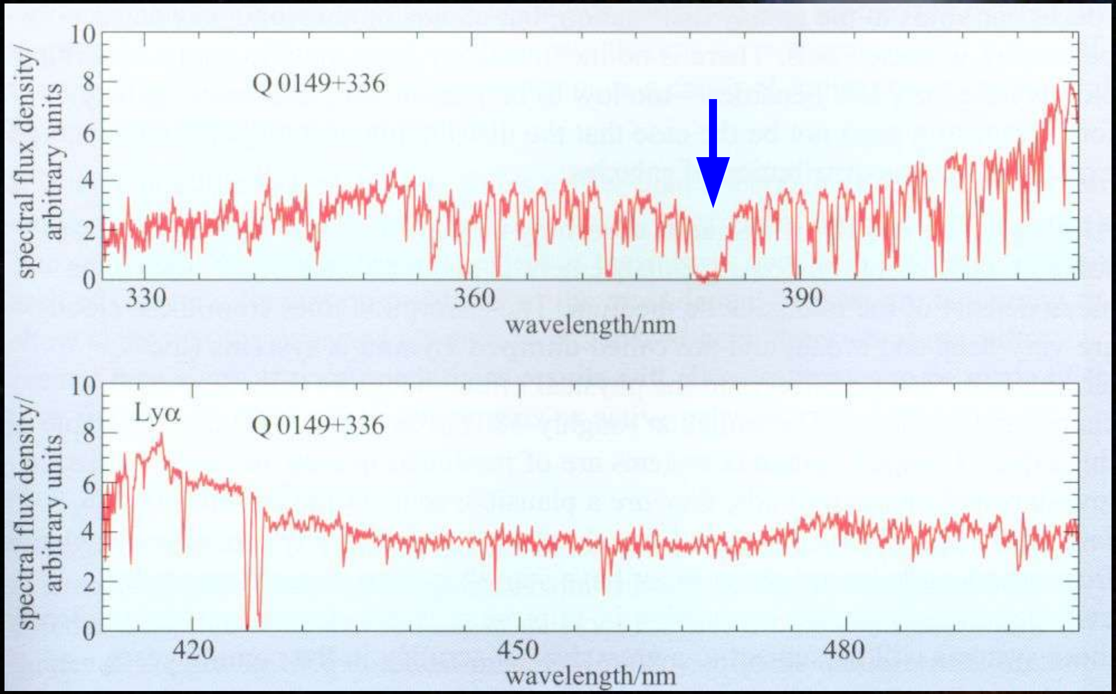


Fig. 4.29 The spectrum of quasar z = 2.431

Lyman α absorbing clouds density enhancement ~ 10^6 mean density

↓

absorption lines are very deep and broad (left)

They are plausible source of material for star formation.

The origin of galaxies?

4.5.1 Quasars and the Lyman α forest

reionization

big bang model

neutral hydrogen cause very strong absorption of the light from distant quasars. <u>Gunn-Peterson effect</u>

↓

the absorption is much lower than expected

- expected hydrogen is not present?
- any hydrogen is present but not as neutral hydrogen (it is in ionized state)

<u>reionization</u>

What is the ultraviolet radiation source ?

star formation, Active Galactic Nuclei

4.5.2 Cosmic shear

How dark matters are distributed?

The large-scale distribution of dark matter could be studied by looking for deflections of light from distant galaxies.

→ <u>cosmic shear</u>

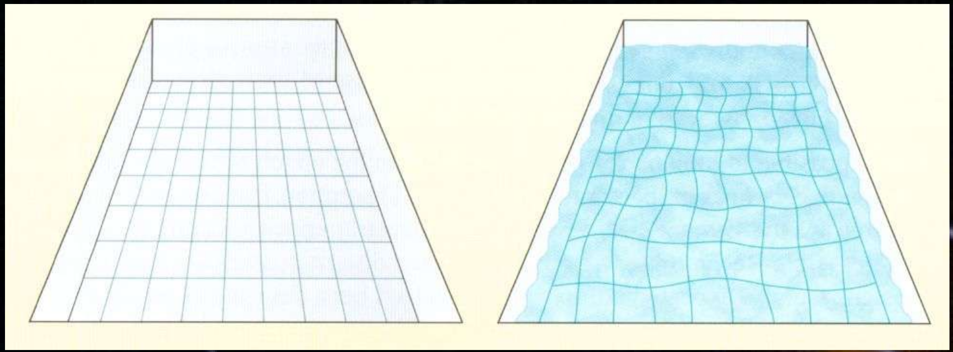
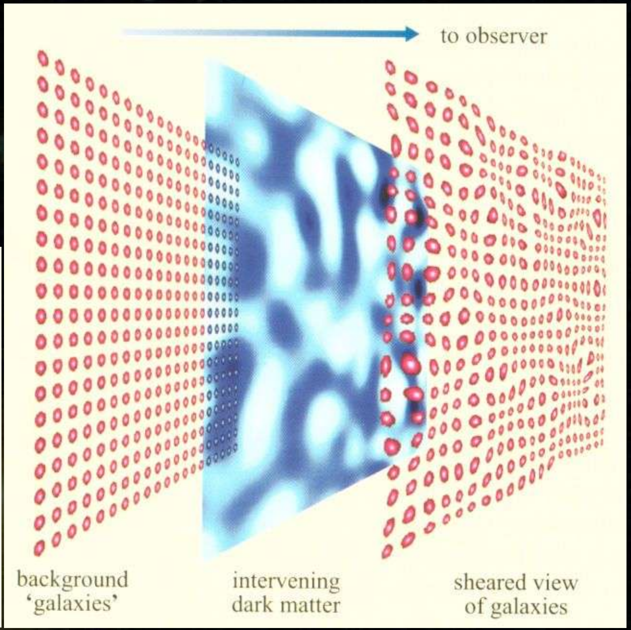


Fig. 4.30 example of swimming pool



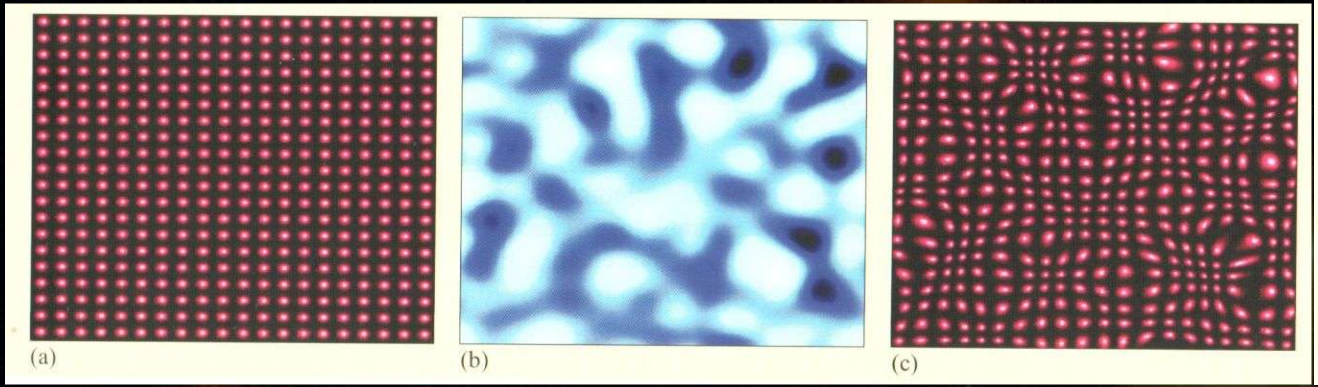


Fig. 4.31 Cosmic shear

4.6 Describing cosmic structure

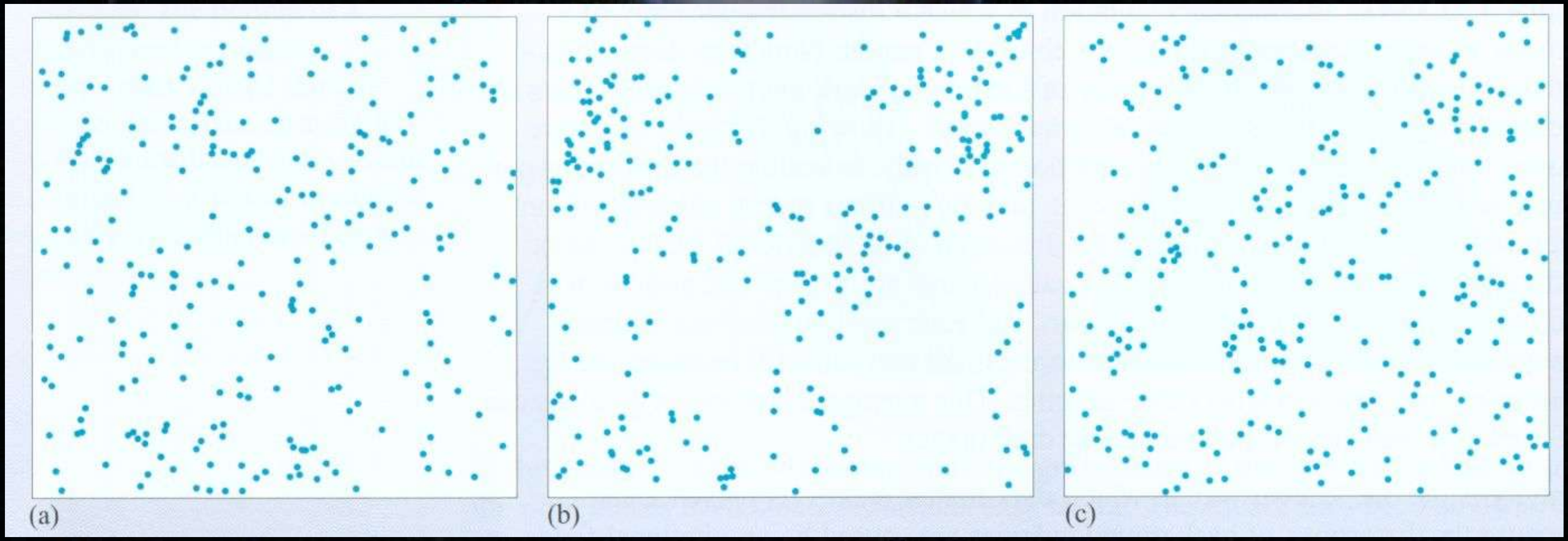


Fig. 4.32 Three different two-dimensional distributions of points

comparison of patterns

astronomers use statistical methods that describe the average properties of a given distribution or pattern.

→ We will consider a simplified example

4.6 Describing cosmic structure

Counts-in-cells method

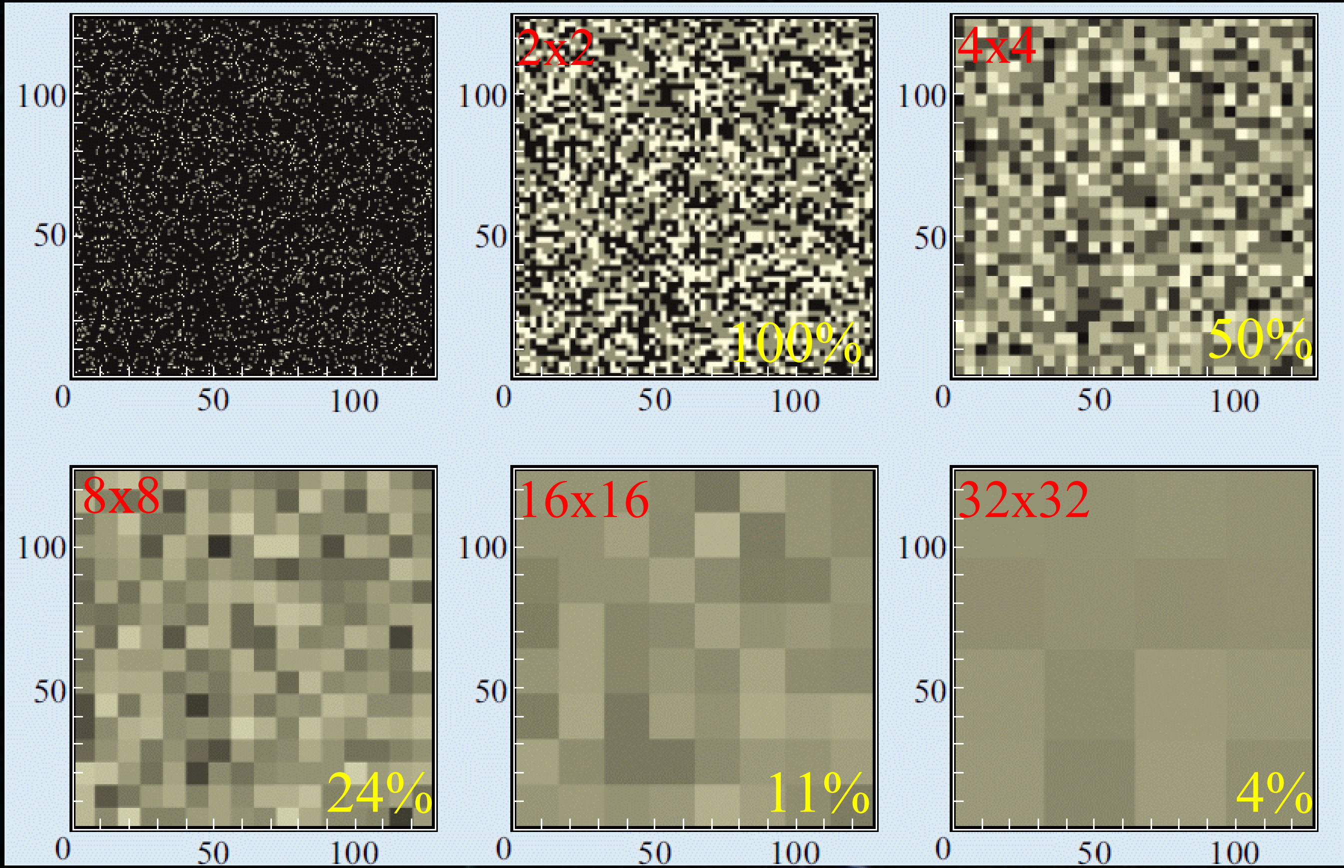


Fig. 4.33a random distribution map

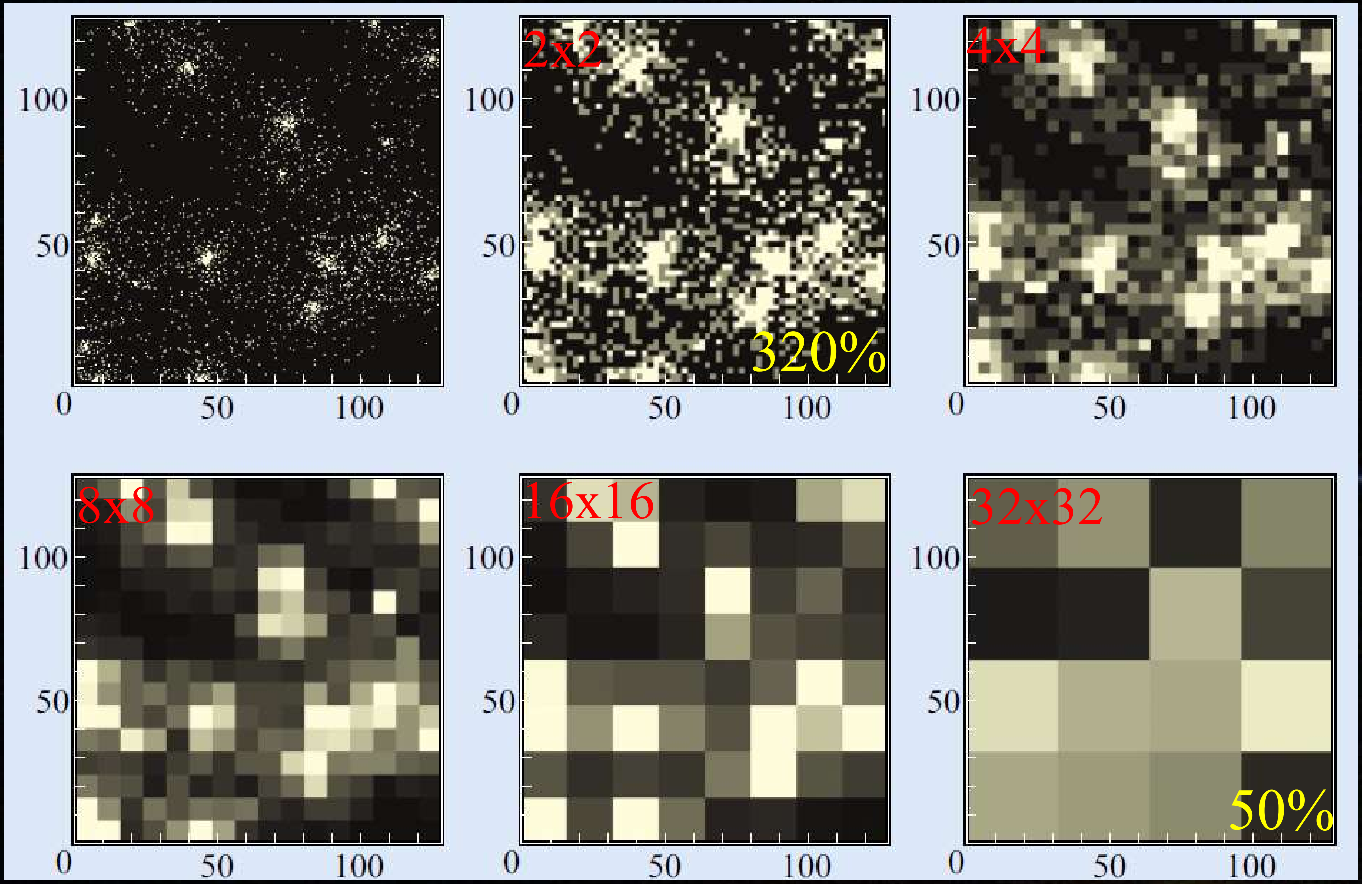
raw data
128 x 128 cells
random distribution

relative variation $\left(\frac{\Delta\rho}{\rho}\right)$

We are interested in investigating how fluctuations in density depend on length scale

4.6 Describing cosmic structure

Counts-in-cells method



raw data
128 x 128 cells
clustering distribution

relative variation $\left(\frac{\Delta \rho}{\rho}\right)$

clustering also causes 'voids'.

4.6 Describing cosmic structure

Counts-in-cells method

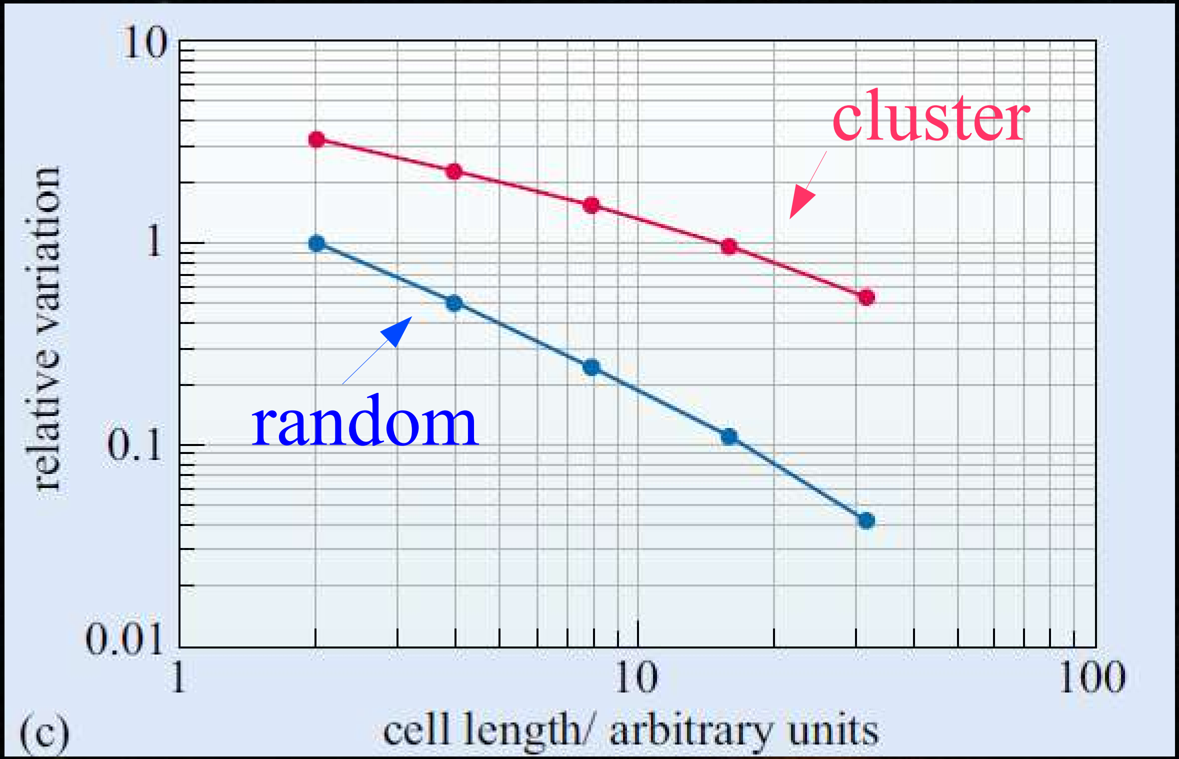


Fig. 4.33c relative variation v.s. cell length

By compairing the counts-in-cells analysis of real maps with simulations we may be able to discern which theoretical models for structure formation are consistent with observation.

4.6 Describing cosmic structure

Counts-in-cells method (Observation)

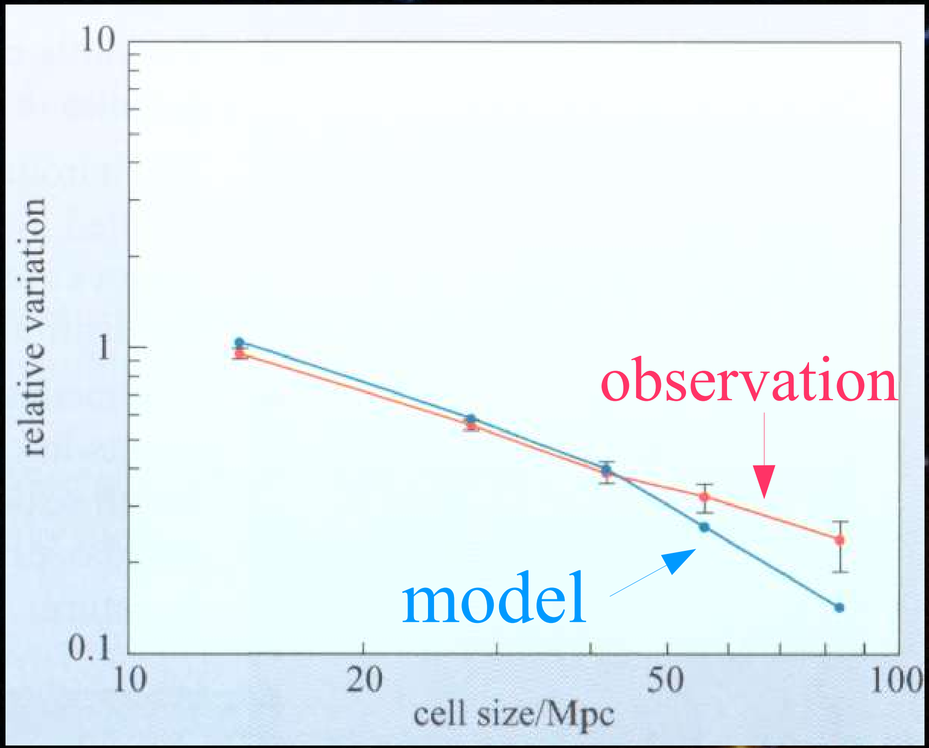


Fig. 4.34 The results of a counts-in-cells analysis of three dimensional survey data.

scale length 50Mpc
relative variation ~ 30%