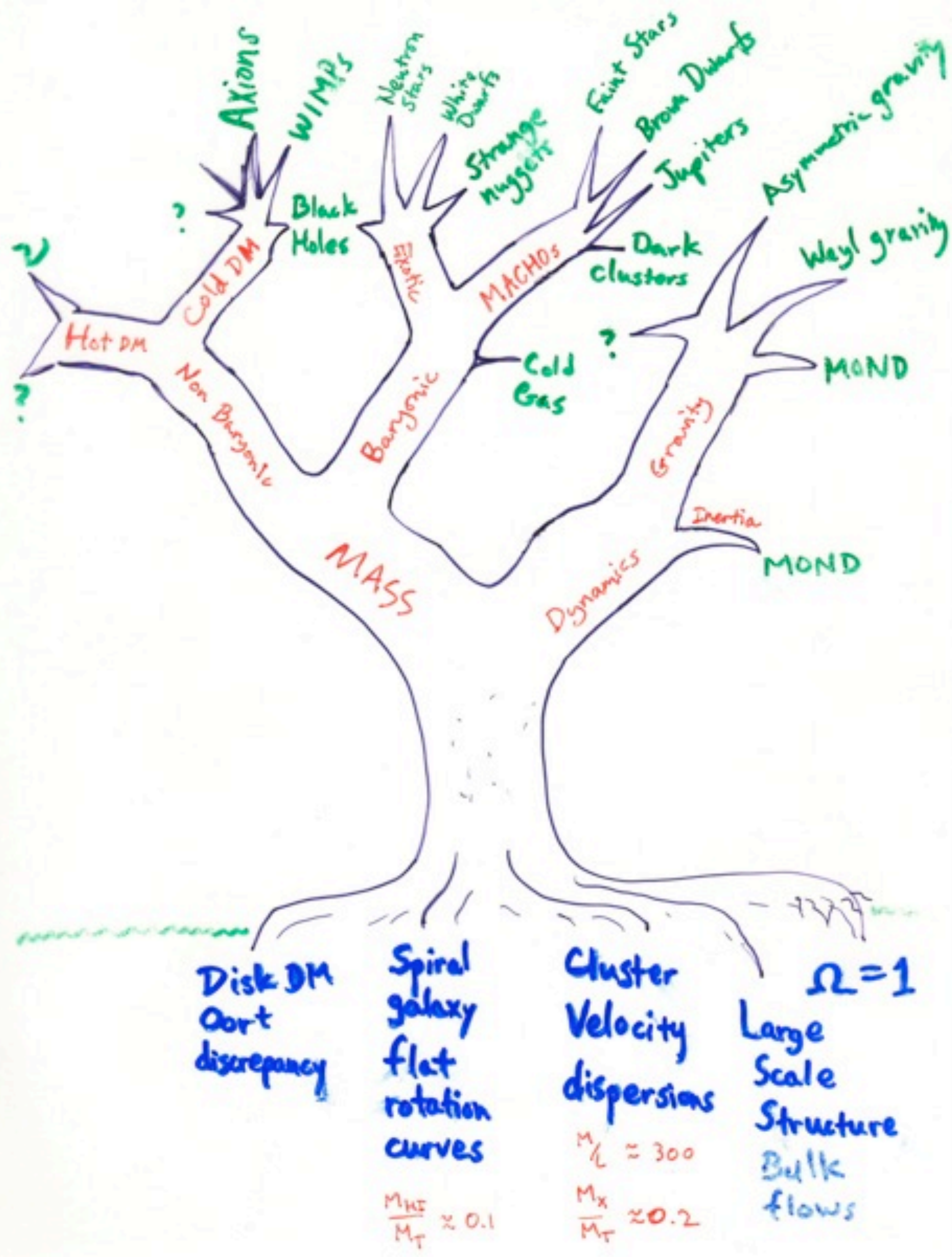
What is the Dark Matter?



Axions
WIMPs
Neutron Stars
White Dwarfs
Strange nuggets
Faint Stars
Brown Dwarfs
Jupiters
Asymmetric gravity
?
Black Holes
Dark Clusters
Weyl gravity
ν
Cold DM
Exotic
MACHOs
Hot DM
?
Cold Gas
MOND
?
Non Baryonic
Baryonic
Gravity
Inertia
MOND
MASS
Dynamics
Disk DM Oort discrepancy
Spiral galaxy flat rotation curves
$M_{HI}/M_T \simeq 0.1$
Cluster Velocity dispersions
$M/L \simeq 300$
$M_X/M_T \simeq 0.2$
$\Omega = 1$
Large Scale Structure
Bulk flows

What is the Dark Matter?

Baryonic Dark Matter

Normal things:

very faint stars, brown dwarfs

other hard-to-see objects (planets, gas)

Hot Dark Matter

neutrinos - got mass, but not enough

Cold Dark Matter

Some new fundamental particle

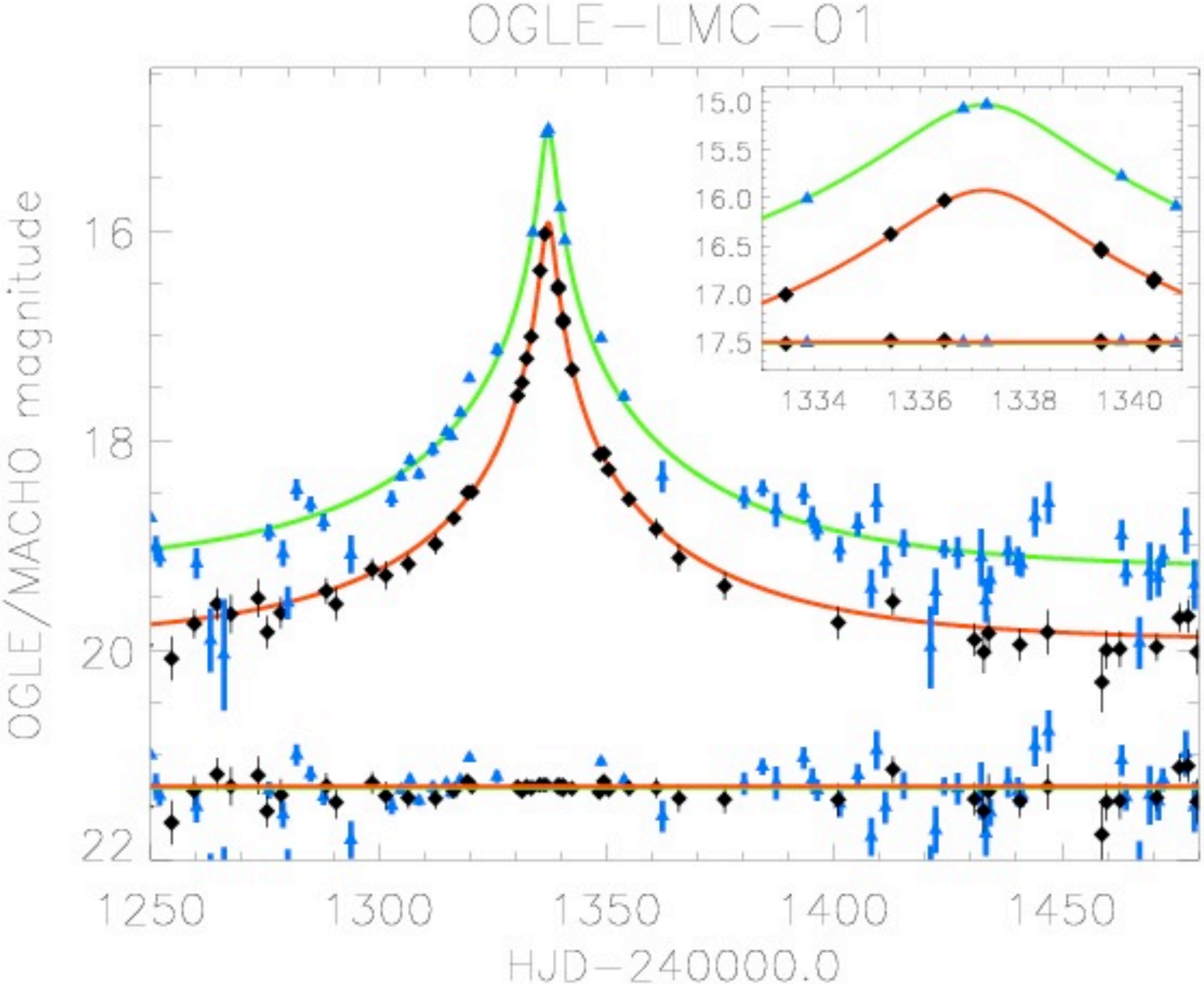
doesn't interact with light, so quite invisible.

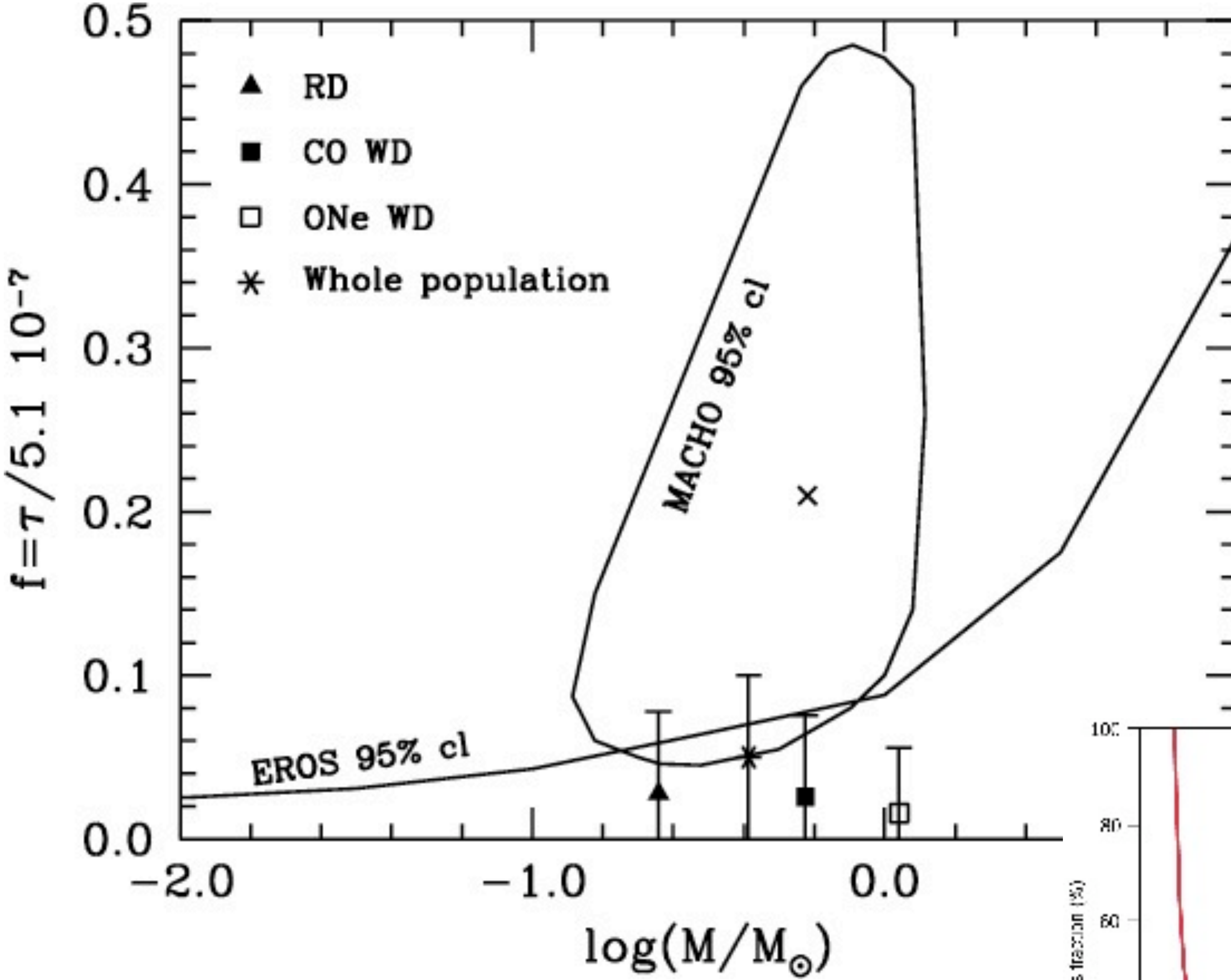
Two big motivations:

1) total mass outweighs normal mass from BBN

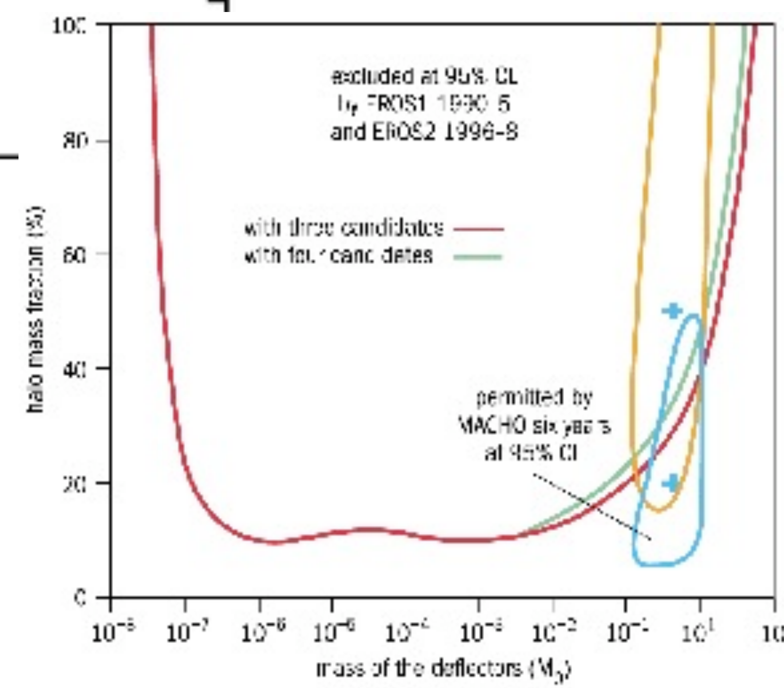
2) needed to grow cosmic structure

gravitational microlensing





RD
CO WD
ONe WD
Whole population
MACHO 95% cl
EROS 95% cl
f=τ/5.1 10⁻⁷
log(M/M☉)
0.0
0.1
0.2
0.3
0.4
0.5
−2.0
−1.0
0.0



with three candidates
halo mass fraction (%)
mass of the deflectors (M☉)
permitted by
MACHO six years
at 95% CL

Two reasons why CDM is preferred:

(1)

Normal baryonic mass = 4% of total

from Primordial Nucleosynthesis

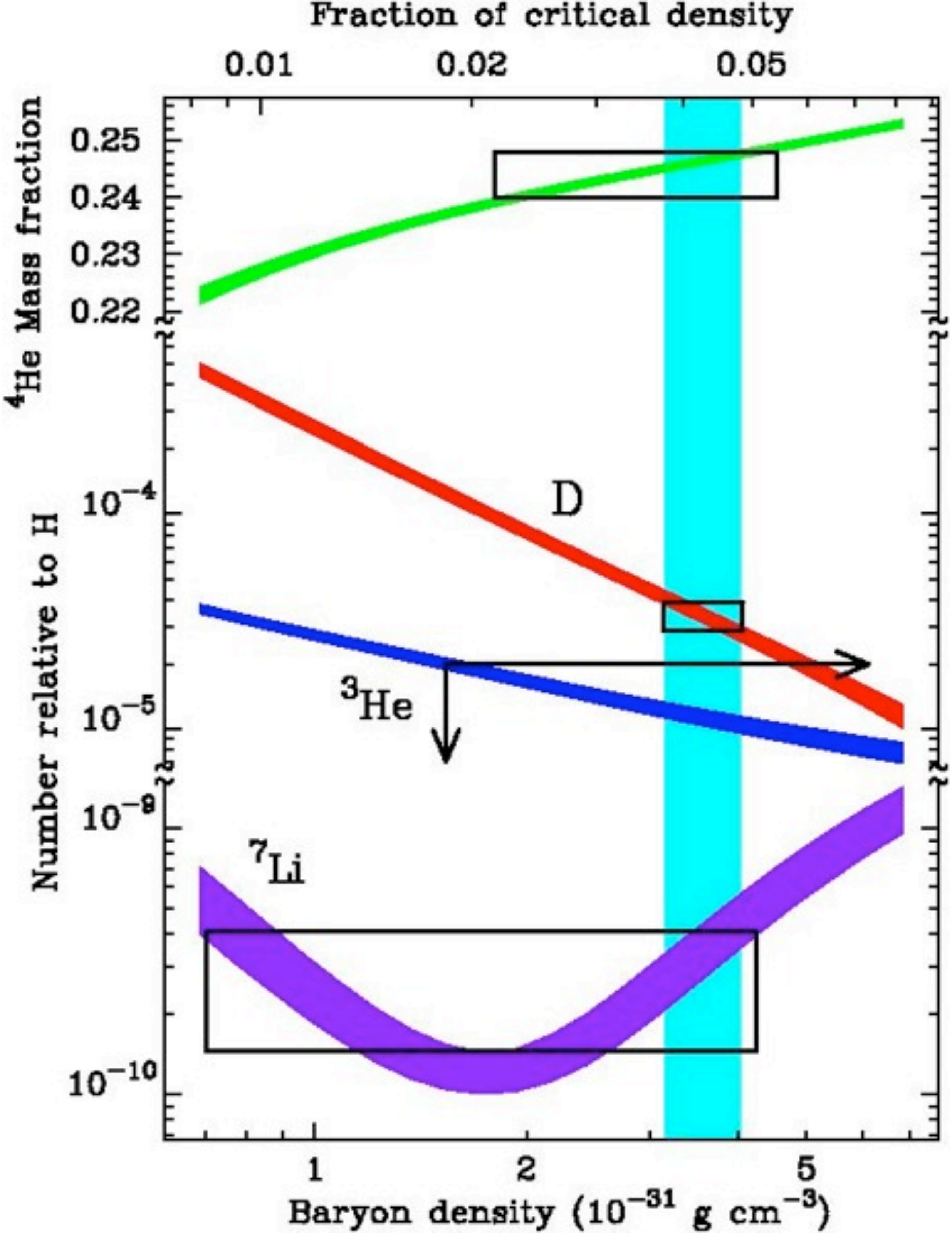
Total mass density = 27% of total

from gravity

gravitating mass >> normal mass

Most of the mass needs to be
in some brand new form!

Big Bang Nucleosynthesis



$\Omega_b \approx 0.04$

distortion of Hubble flow by local mass (Virgo cluster)

position is $v_v = 400$ km s^{-1}, and $\delta M/M = 2$. The effect on the redshift field appears at $r \ll R_1$ as a change in the expansion $\nabla \cdot \mathbf{v}$ from the global value $3H_0$ and in the quadrupole anisotropy of Equation 2. Near the center of the system the flow is complicated, with some redshifts appearing at three distances. At $r \gg R_1$ the redshift anomaly has the dipole form $v_v(R_1) \cos\theta$.

The behavior of the flow at $R < R_1$ is likely to be a good deal more

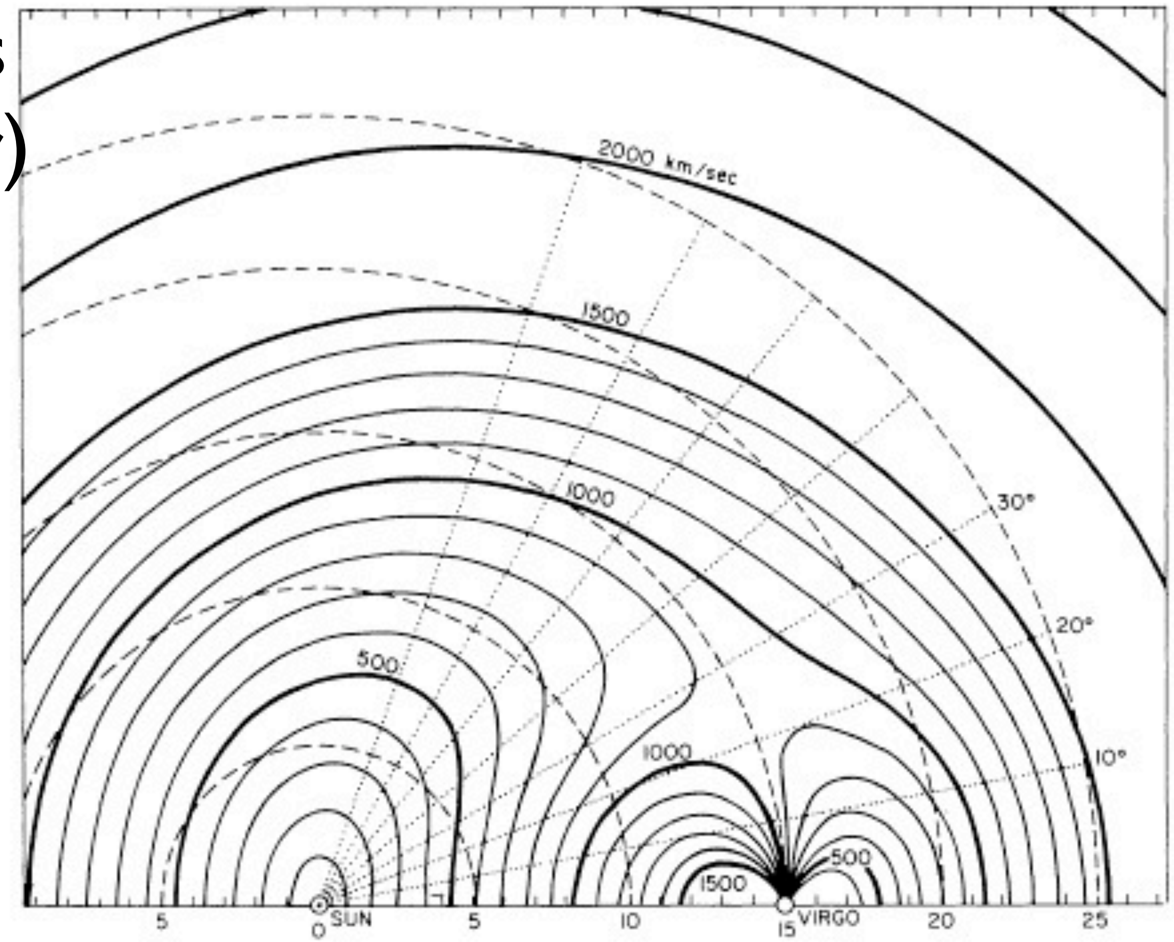
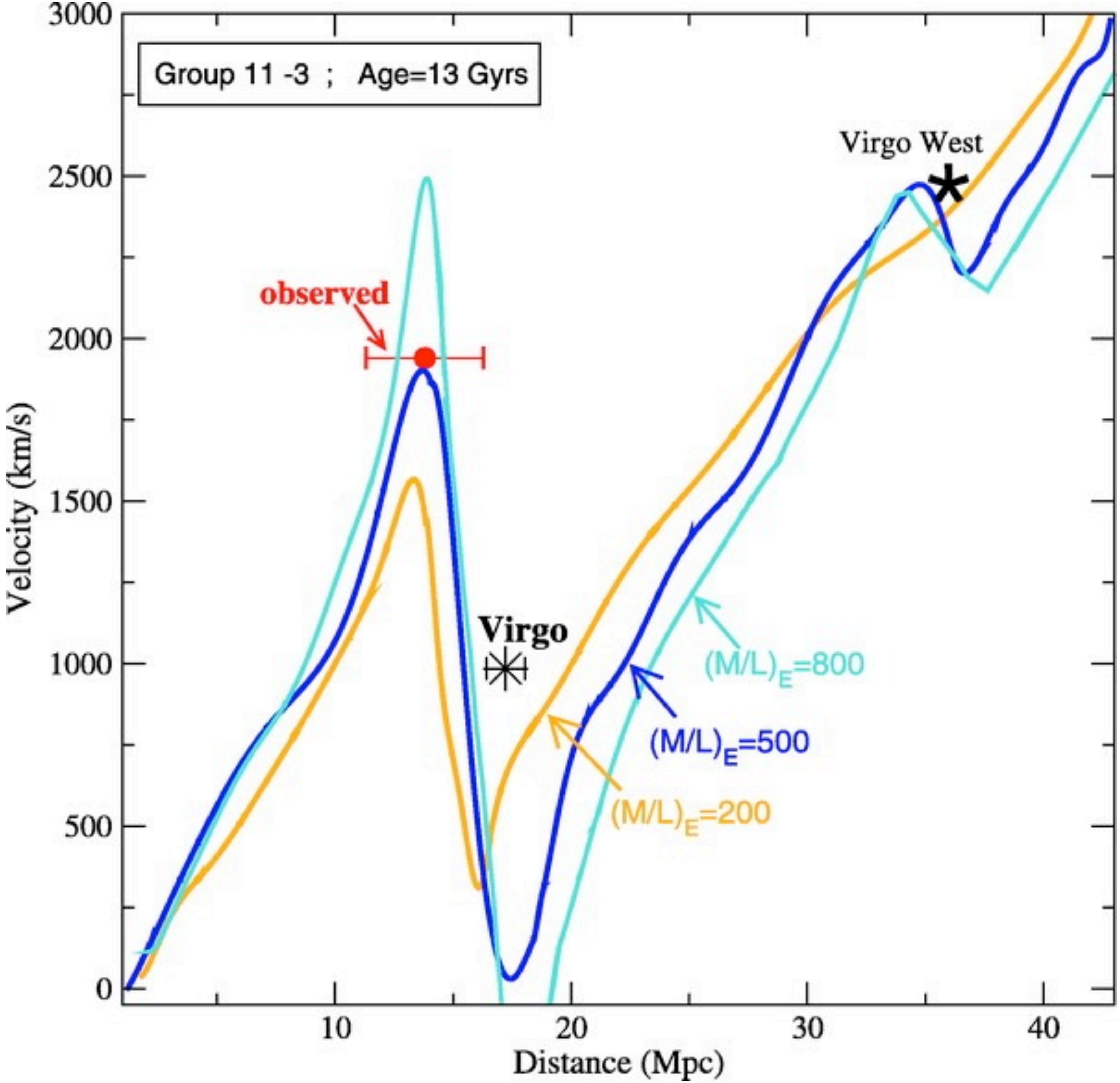


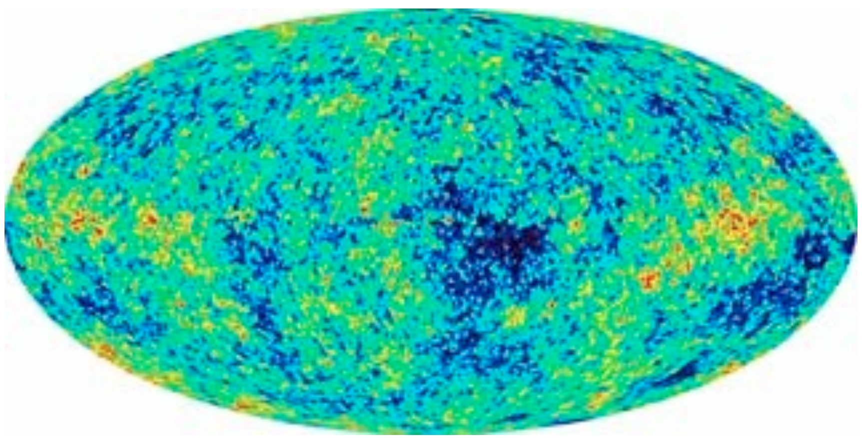
Figure 2 The redshift field around the LS in a spherical nonlinear gravitational model (93).

$$\Omega_m \approx 0.25$$


Group 11 -3 ; Age=13 Gyrs
Virgo West
observed
Virgo
(M/L)E=800
(M/L)E=500
(M/L)E=200
Velocity (km/s)
Distance (Mpc)
0
500
1000
1500
2000
2500
3000
10
20
30
40

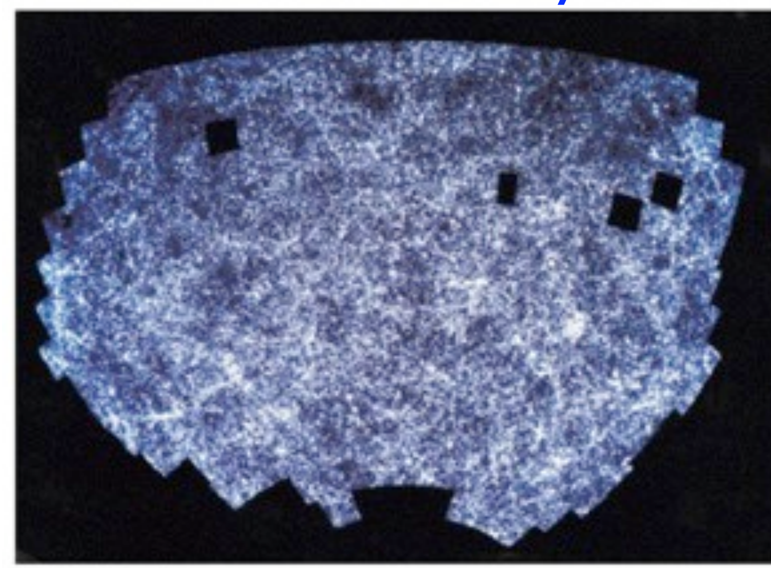
(2) There isn't enough time to form the observed cosmic structures from the smooth initial conditions unless there is a component of mass independent of photons.

$t = 3.8 \times 10^5$ yr



very smooth: $\delta\rho/\rho \sim 10^{-5}$

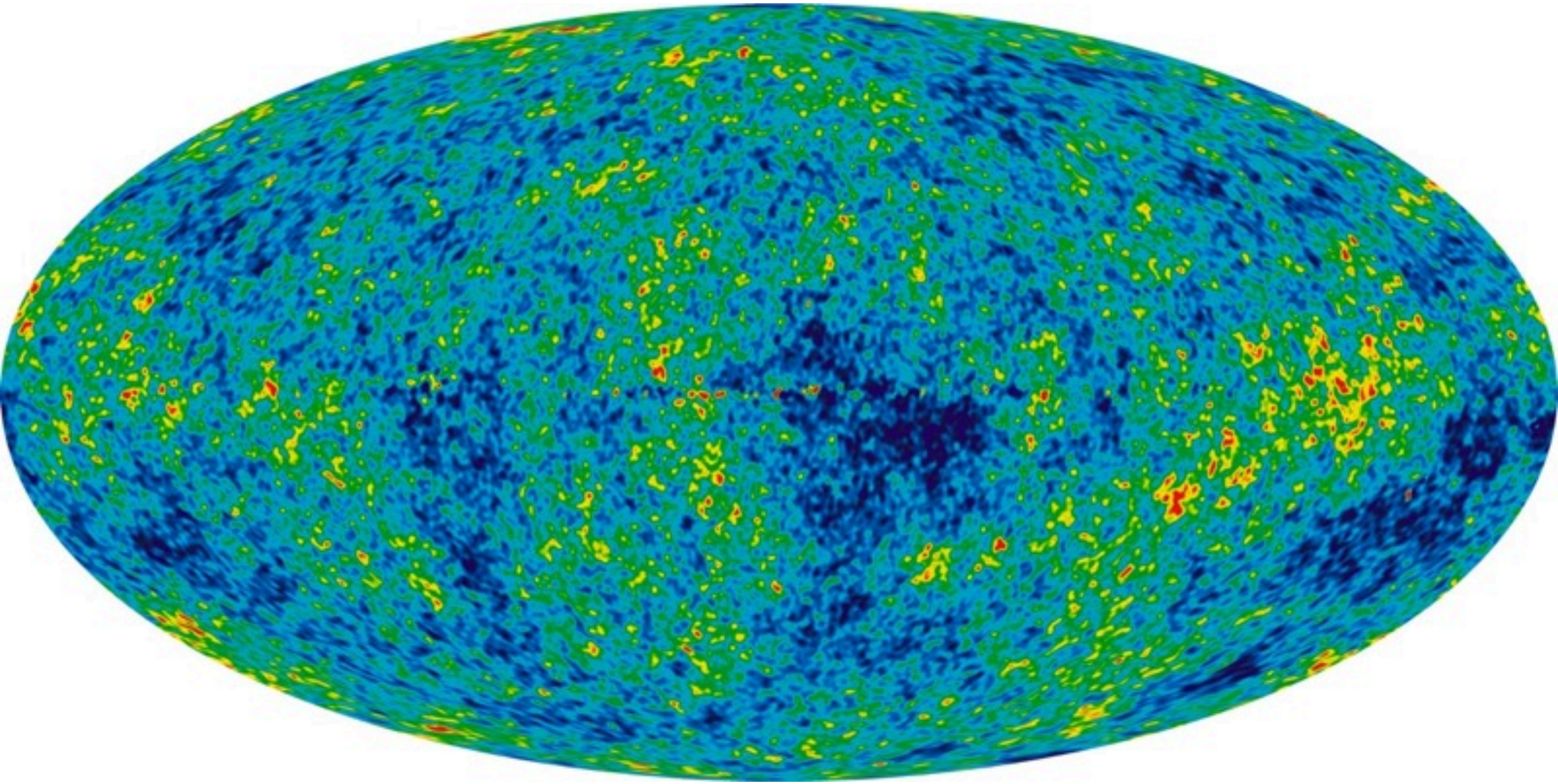
$t = 1.4 \times 10^{10}$ yr



very lumpy: $\delta\rho/\rho \sim 1$

$$\delta\rho/\rho \propto t^{2/3}$$

Initial condition measured by Cosmic Microwave Background



t = 3.8 x 10^5 yr

very smooth: $\delta\rho/\rho \sim 10^{-5}$

Large Scale Structure

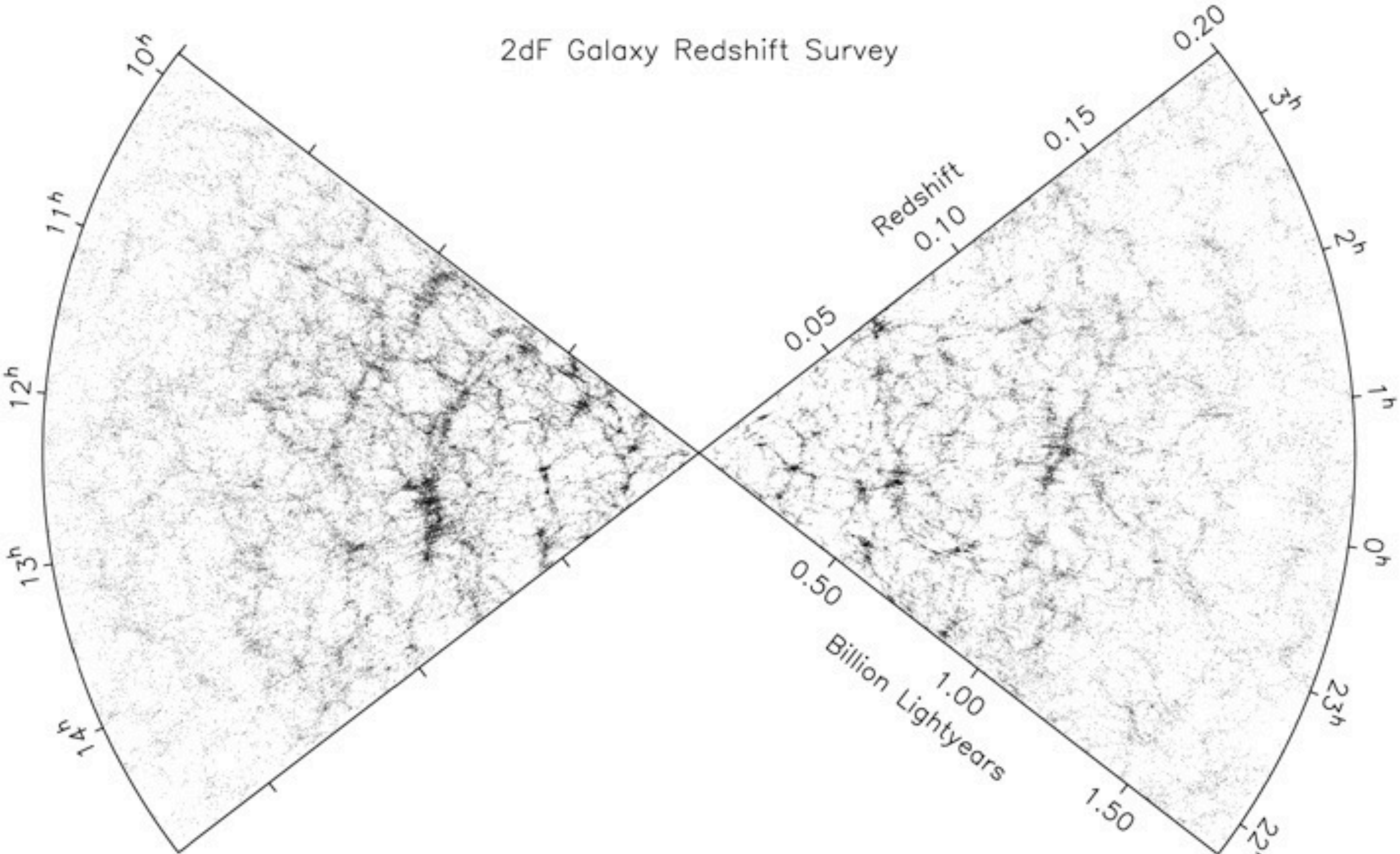


Fig 8.3 (2dF) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Present day universe very lumpy - not smooth like the CMB

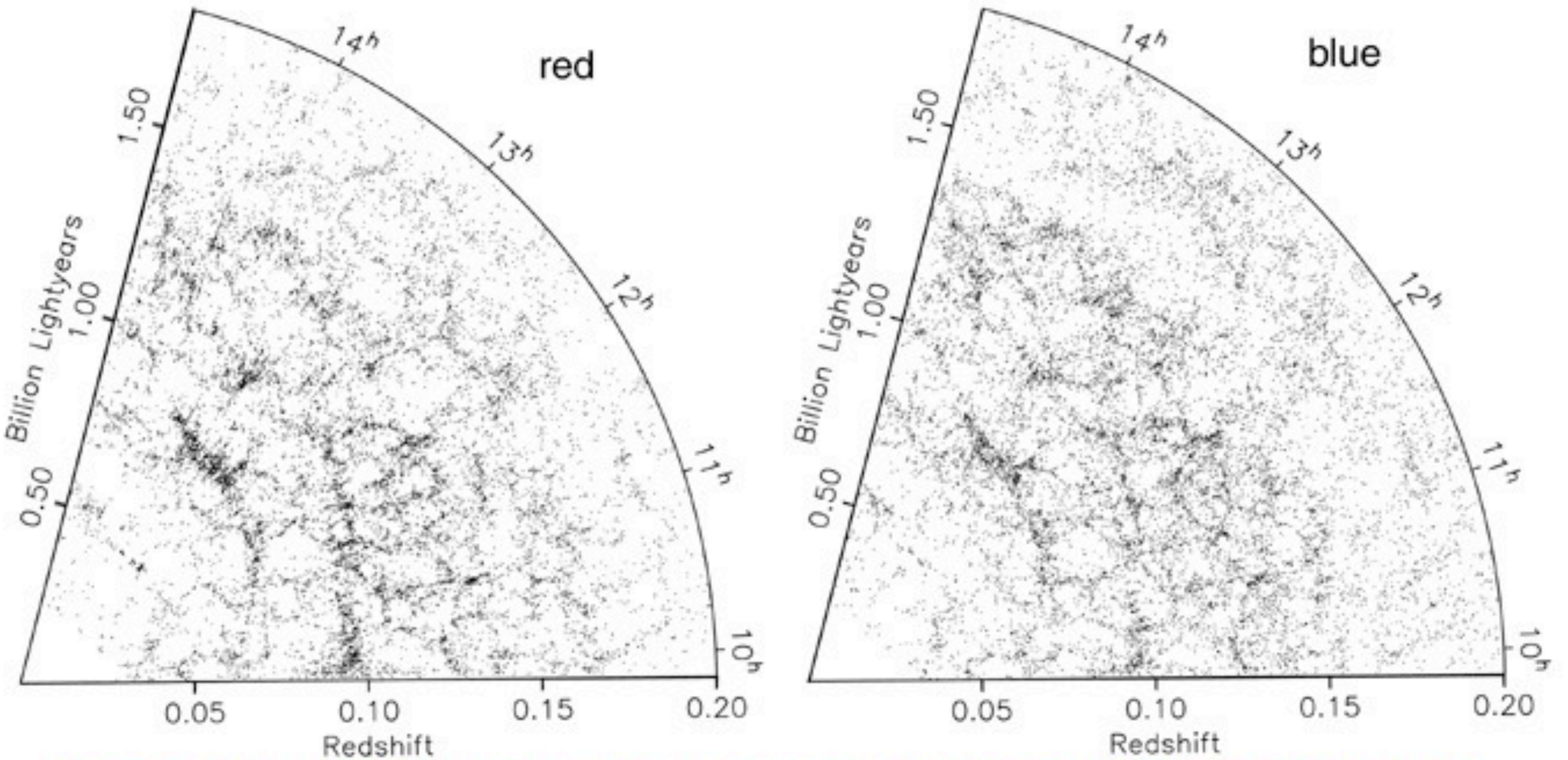


Fig 8.5 (2dF) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Large Scale Structure simulation

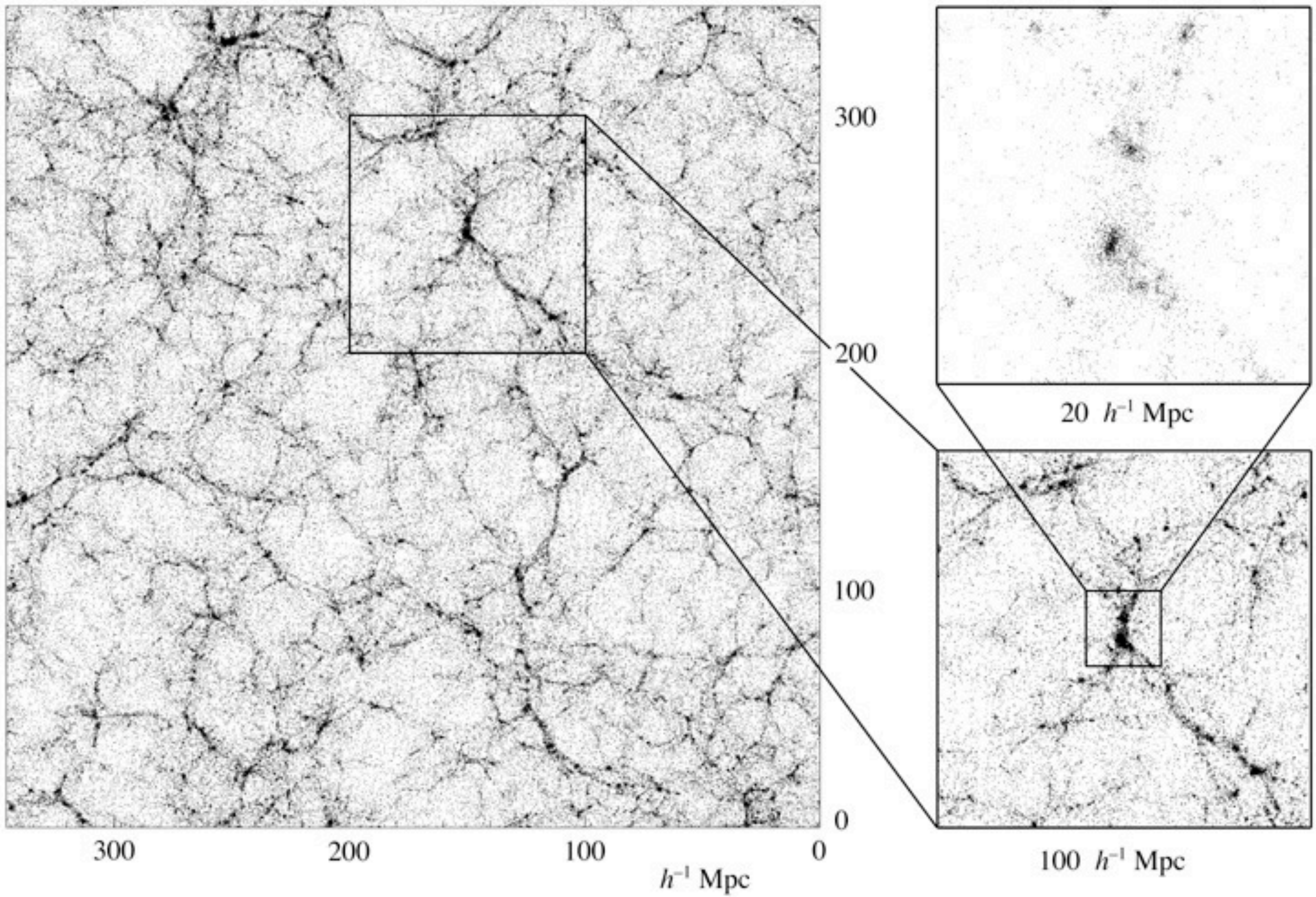


Fig 8.16 (D. Weinberg) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007