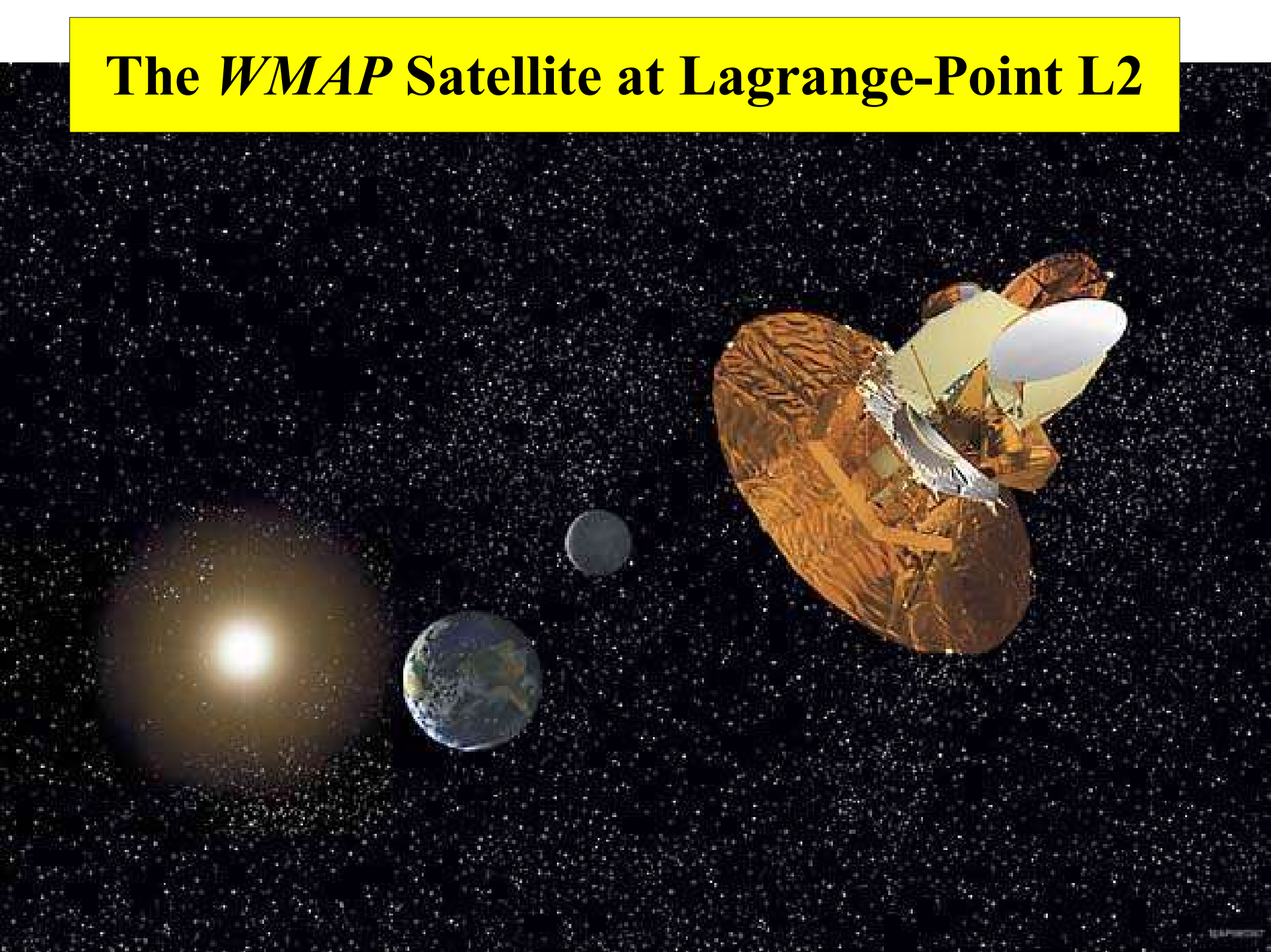


A visualization of the cosmic web, showing a dense network of red and orange filaments and clusters of matter against a dark background.

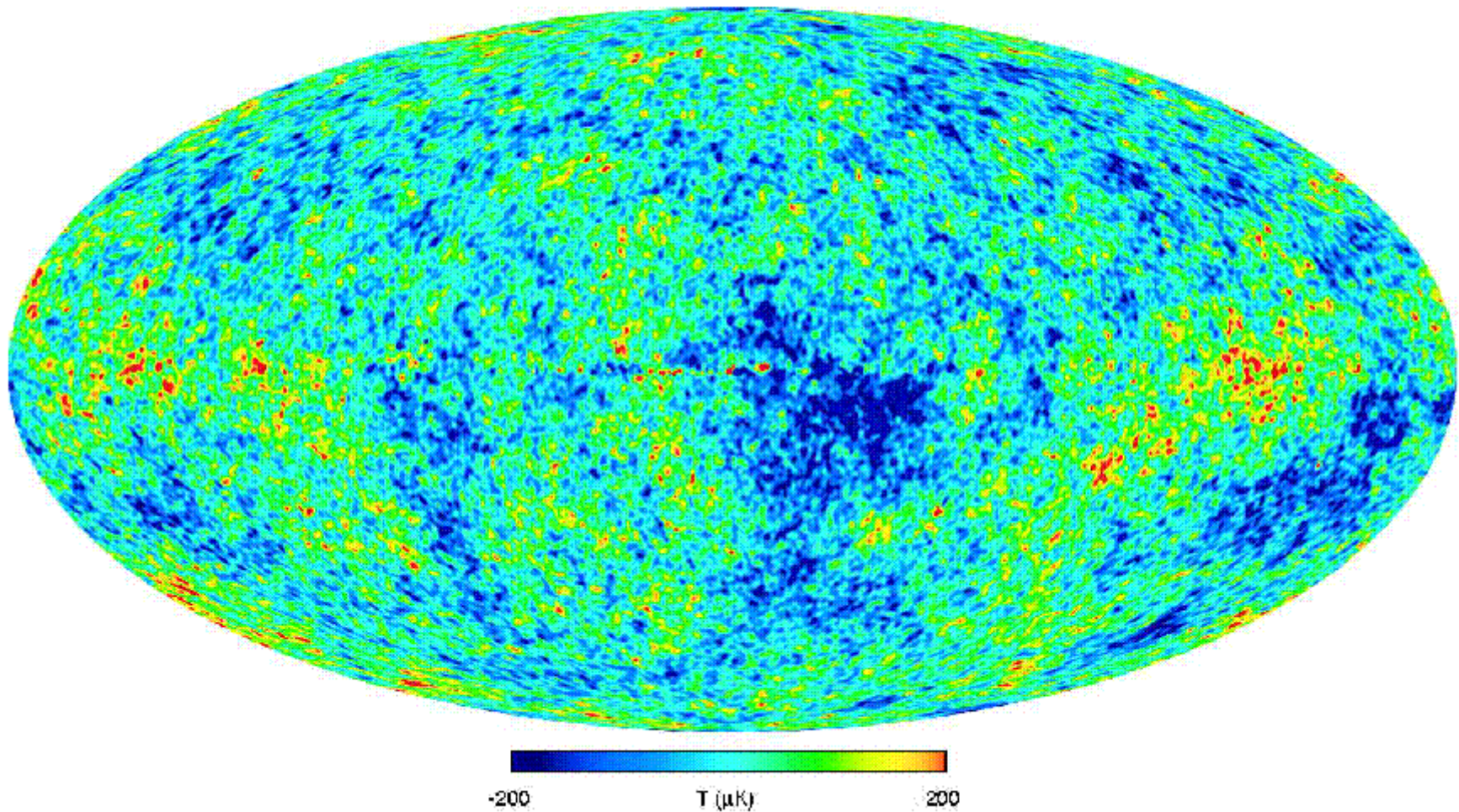
The (virtual) Creation of the World: dark matter and structure formation

Simon D.M. White
Max Planck Institut für Astrophysik

The *WMAP* Satellite at Lagrange-Point L2

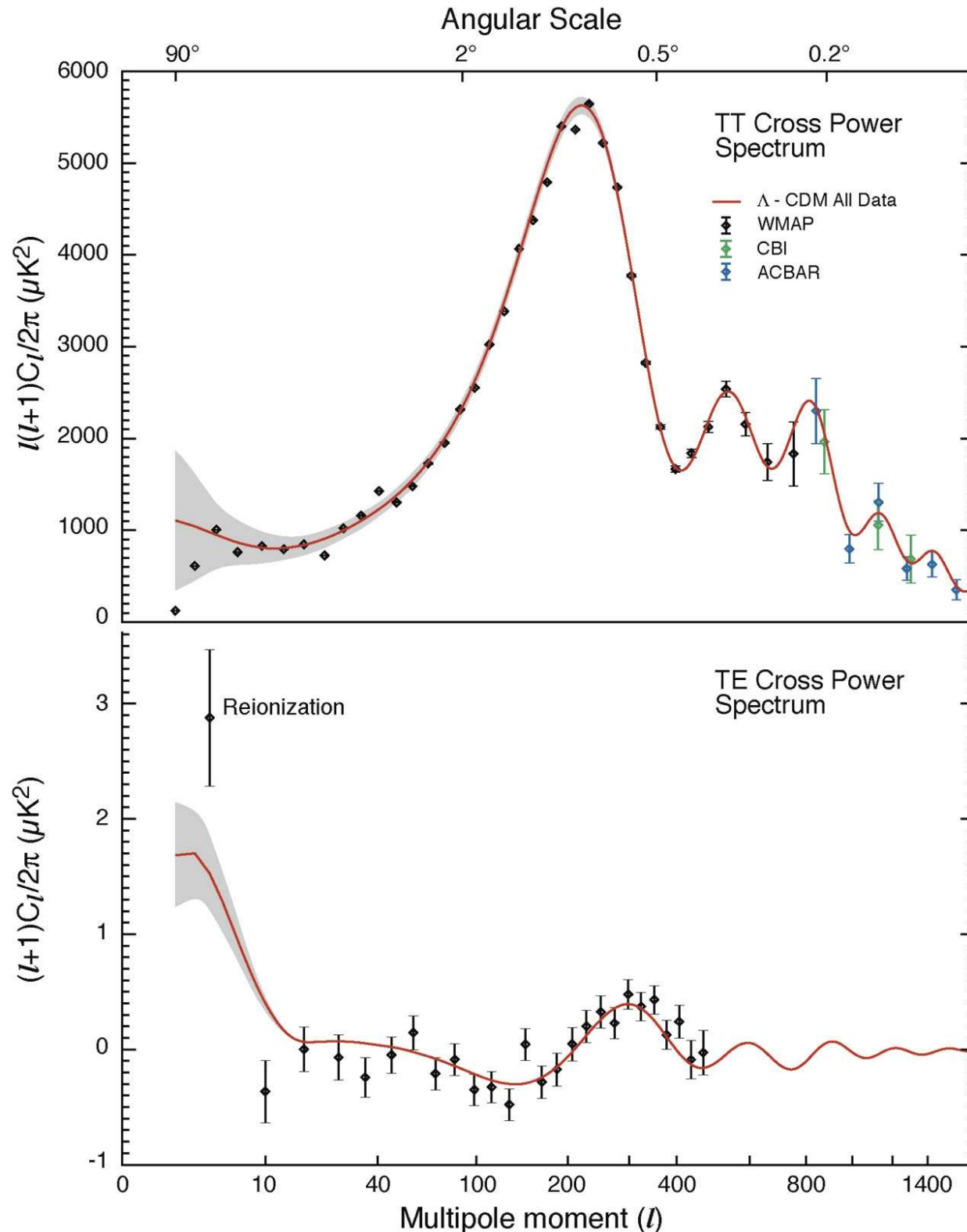


WMAP Map of the whole Sky



Bennett et al 2003

Initial conditions for the formation of all structure



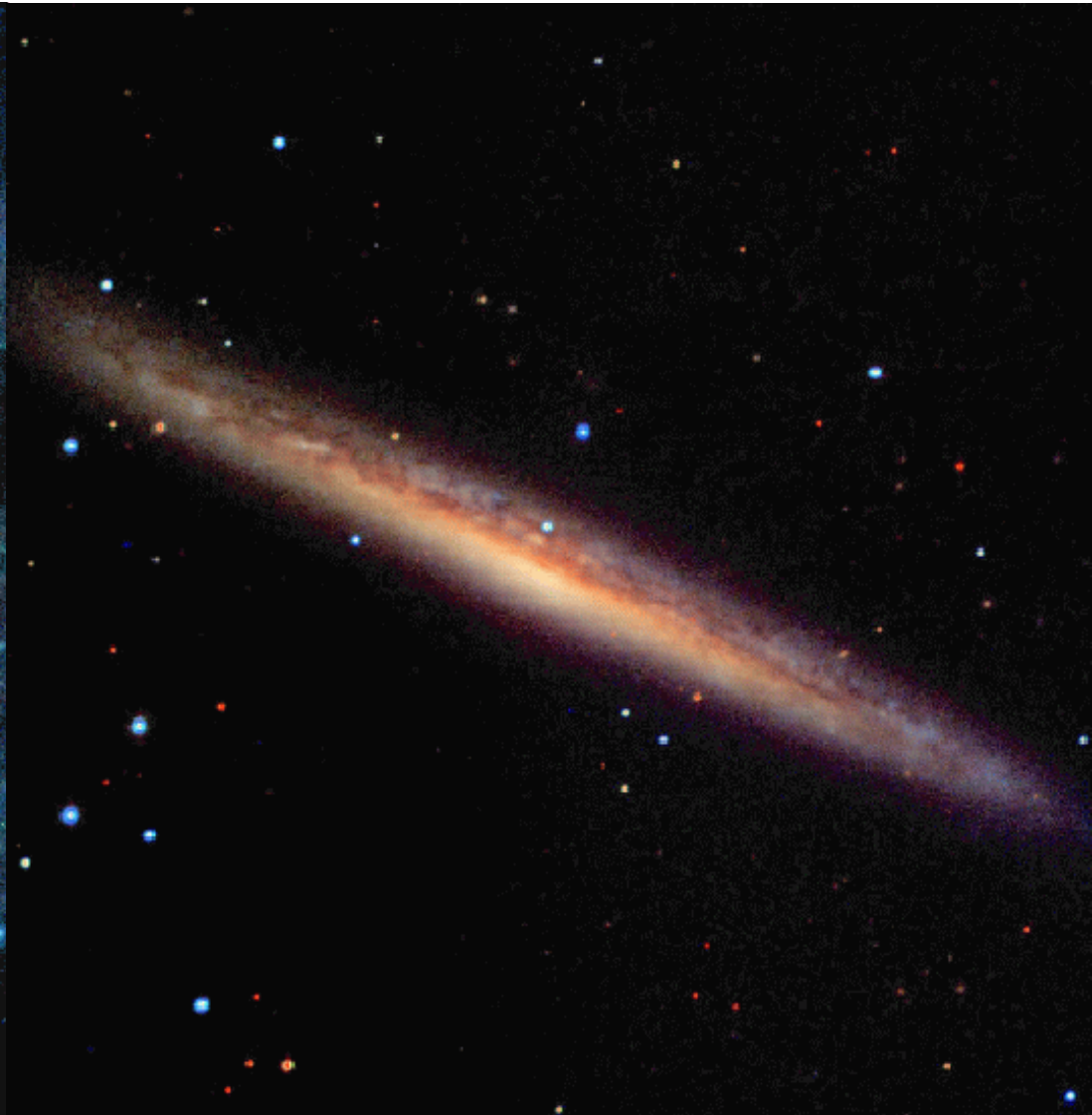
- Our Universe is flat
- It is 13.7 ± 0.2 billion years old.
- It is made of 70% dark energy, 26% cold dark matter and only 4% normal baryonic matter
- 30,000 years after the Big Bang it was nearly uniform
- All structure was imprinted in the first 10^{-30}s
- The first stars formed early

Spiral galaxies

M101



NGC 5907



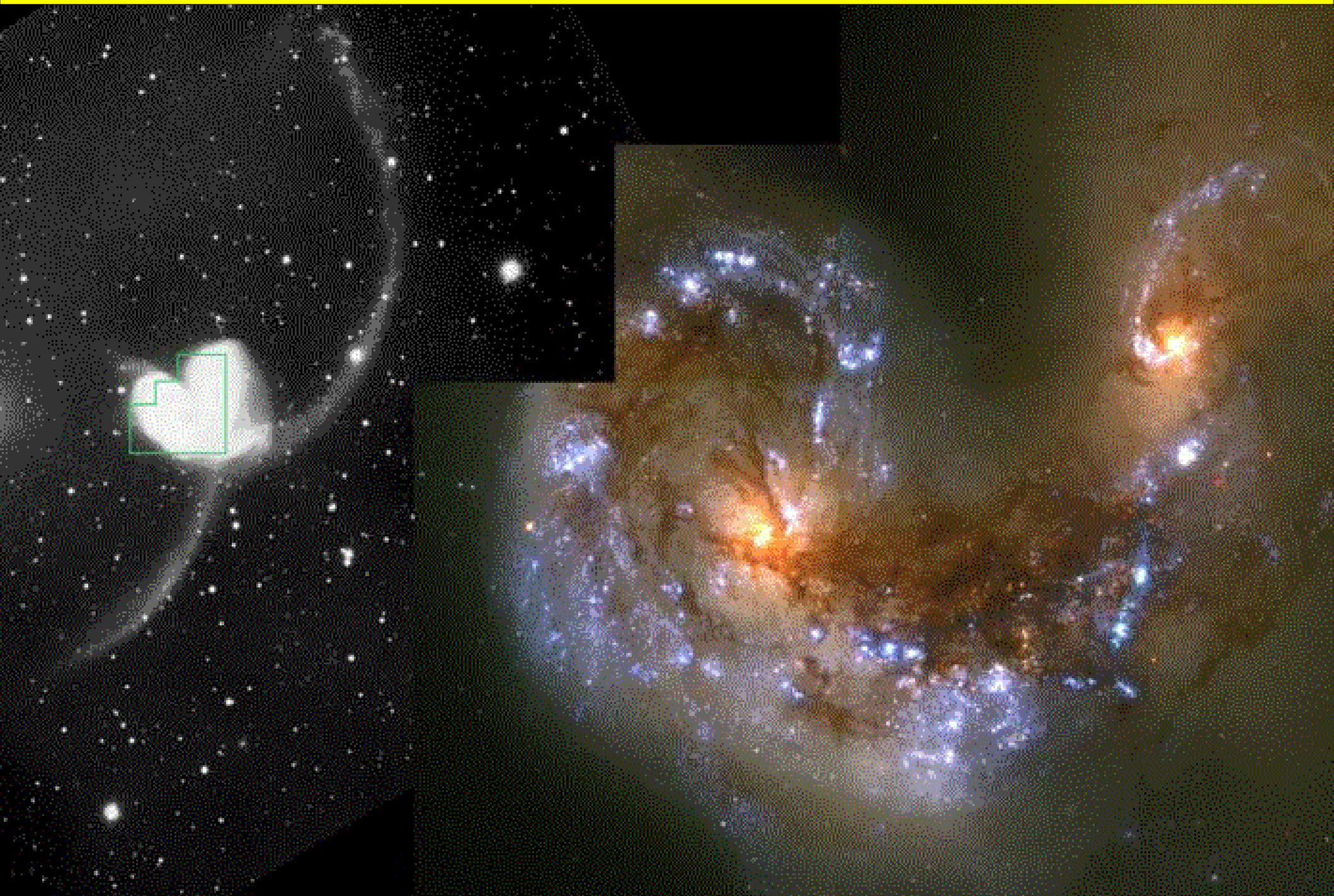
**NGC 4414 -- a
galaxy like our own**



NGC 3314
Two more
spiral galaxies!



NGC 4038/4039 -- a galactic traffic accident

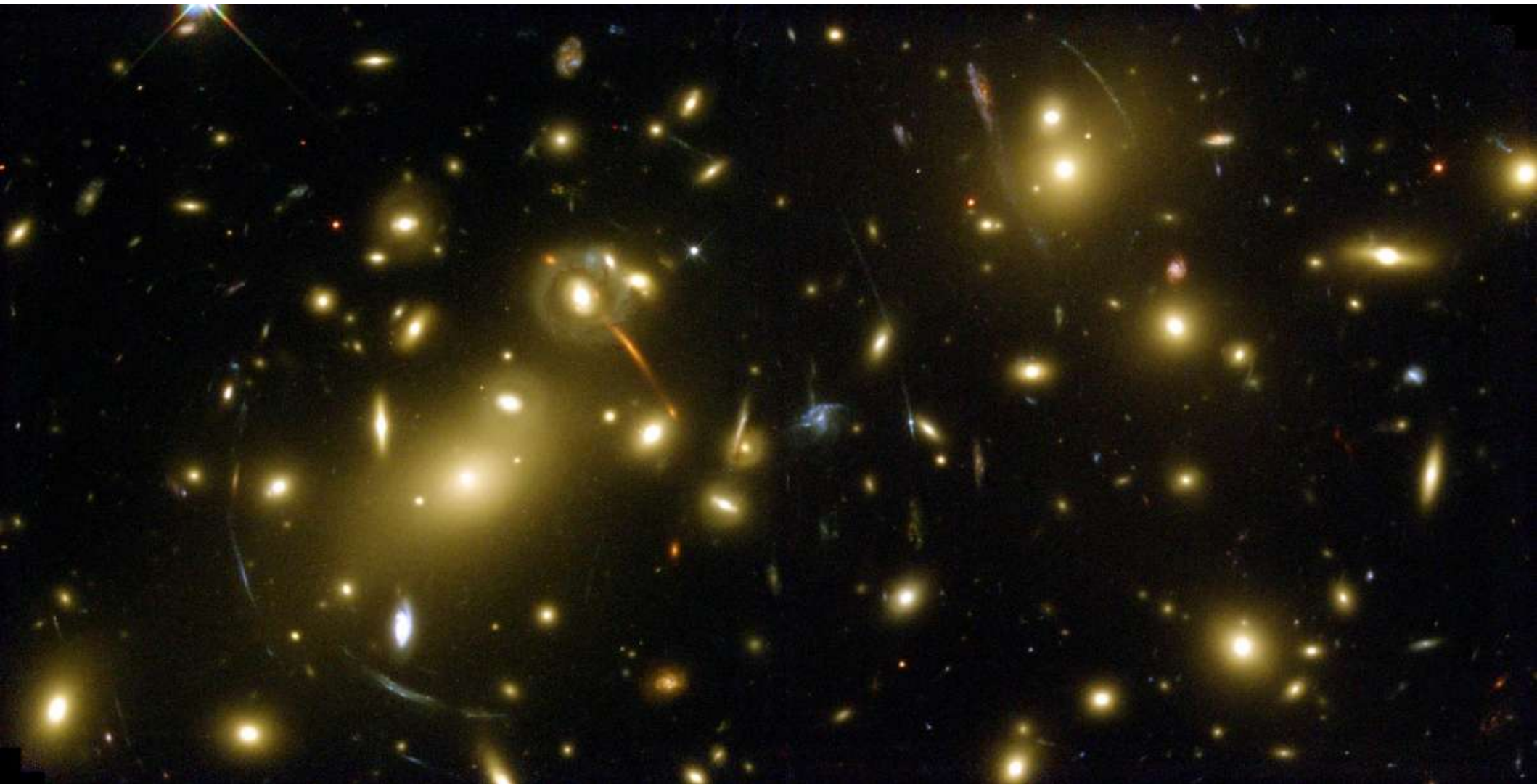




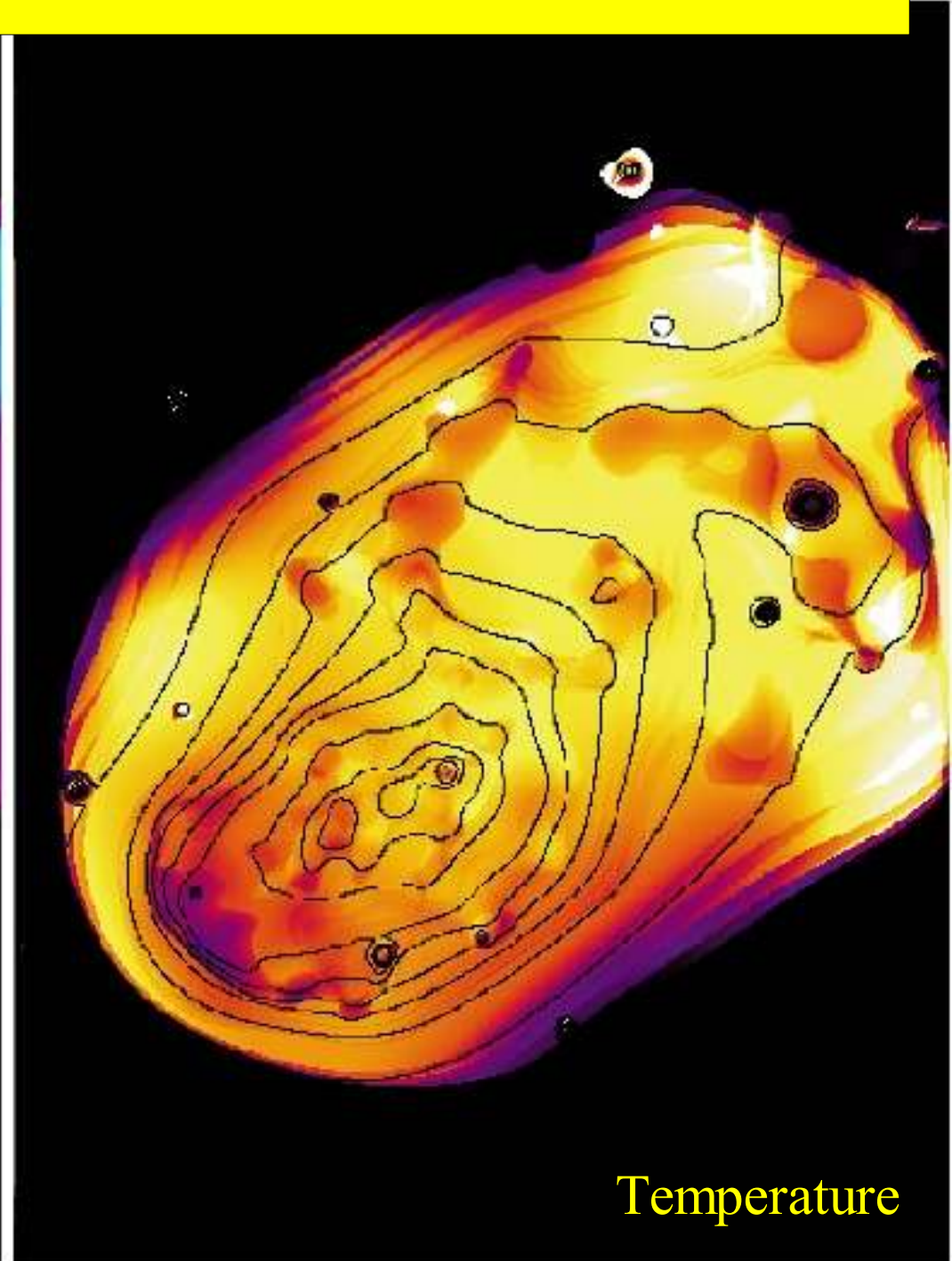
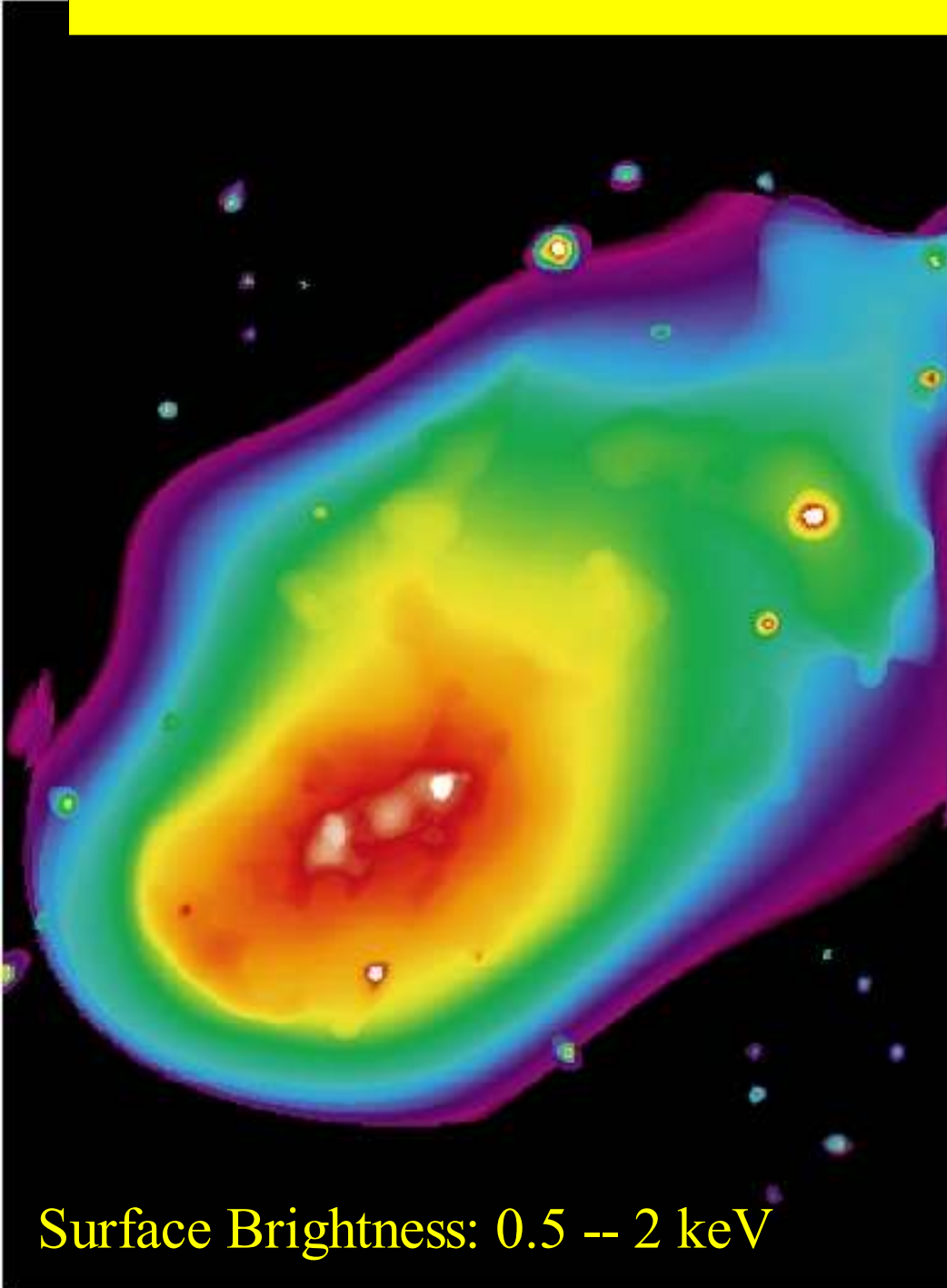
**Elliptical
galaxies in
a cluster**

Gravitation lens effects: the dark matter in a cluster becomes visible

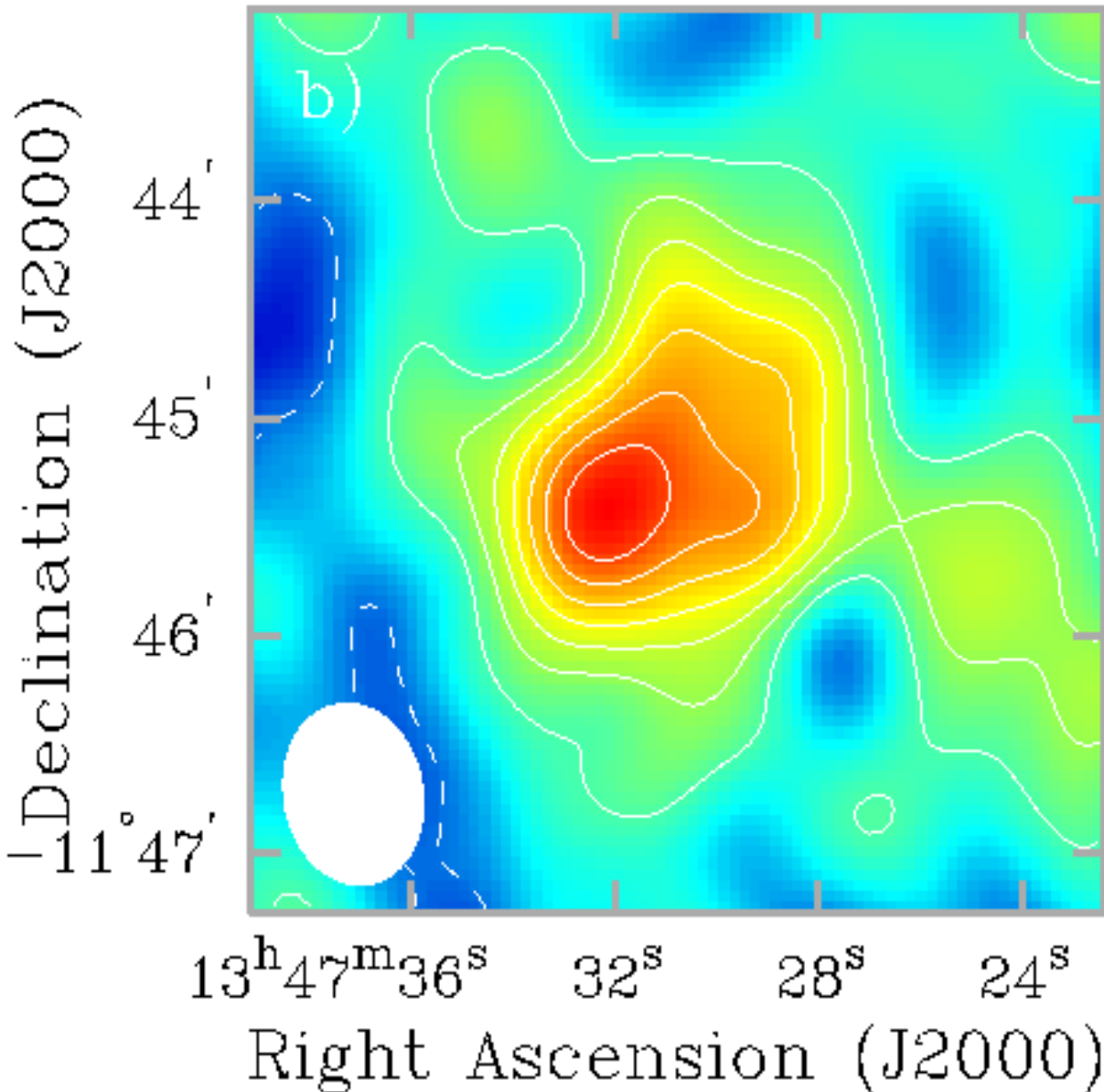
Abell 2218 $z=0.17$



Rosat X-ray image of the cluster Abell 3667



Cluster shadows on the microwave background



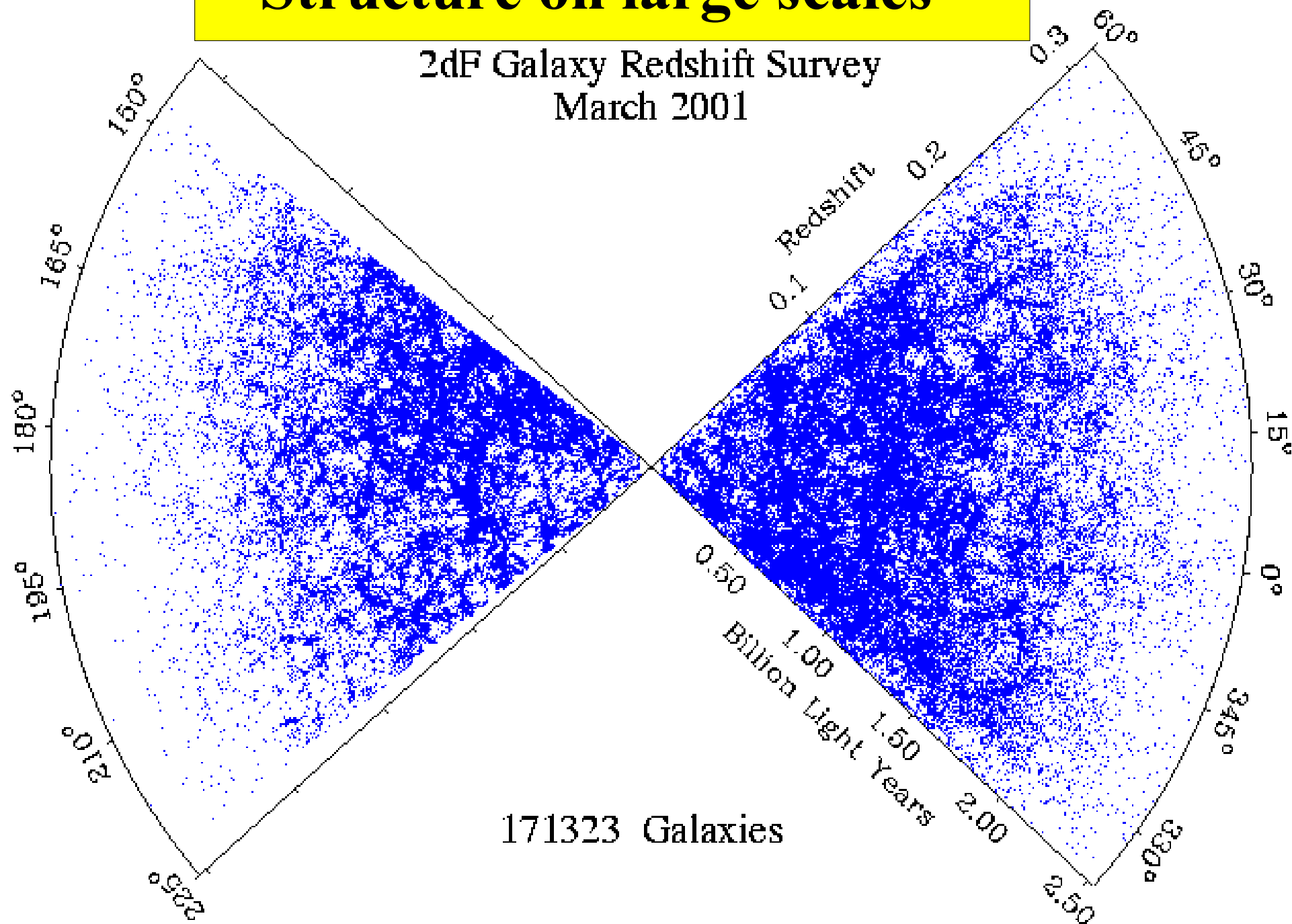
- Compton upscattering of CMB photons by e^- in the hot intracluster gas leaves a deficit in the background

Sunyaev-Zeldovich effect

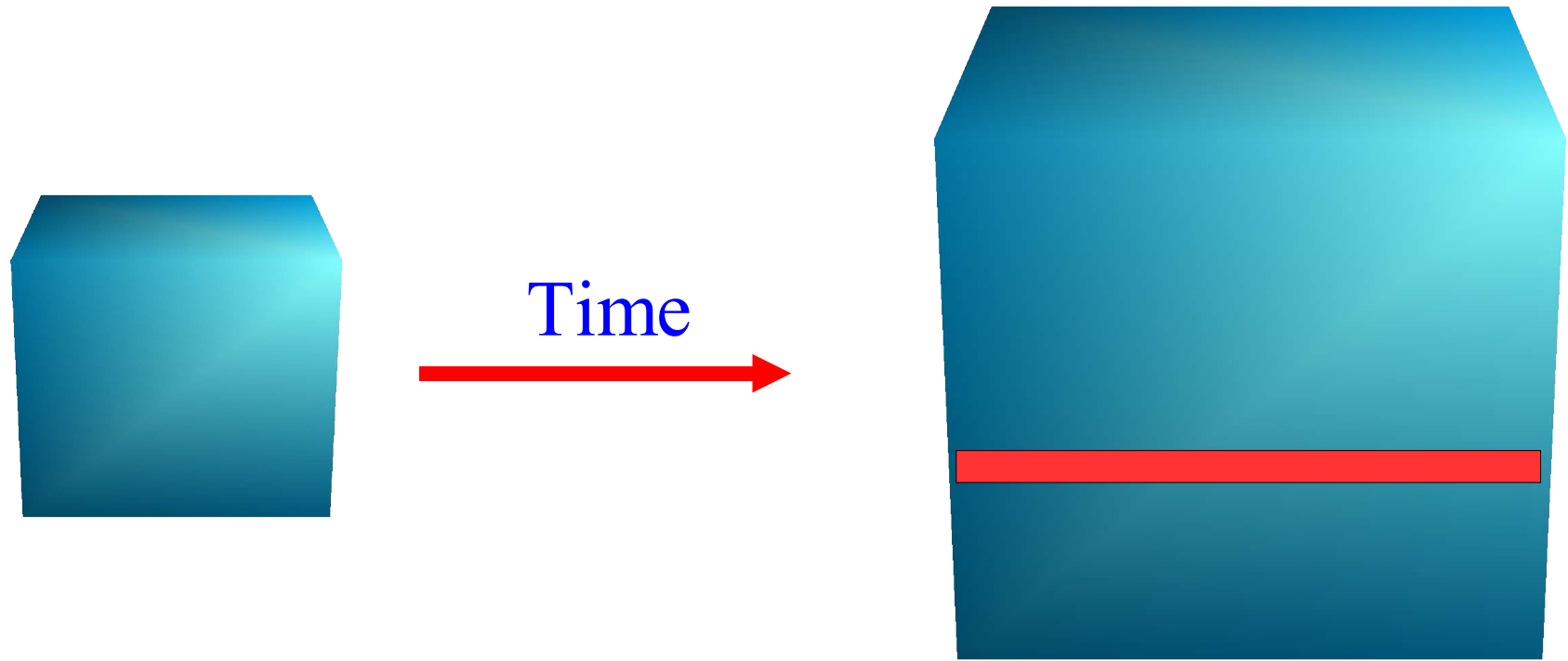
- Map made using the BIMA interferometer
Carlstrom et al 2001

Structure on large scales

2dF Galaxy Redshift Survey
March 2001



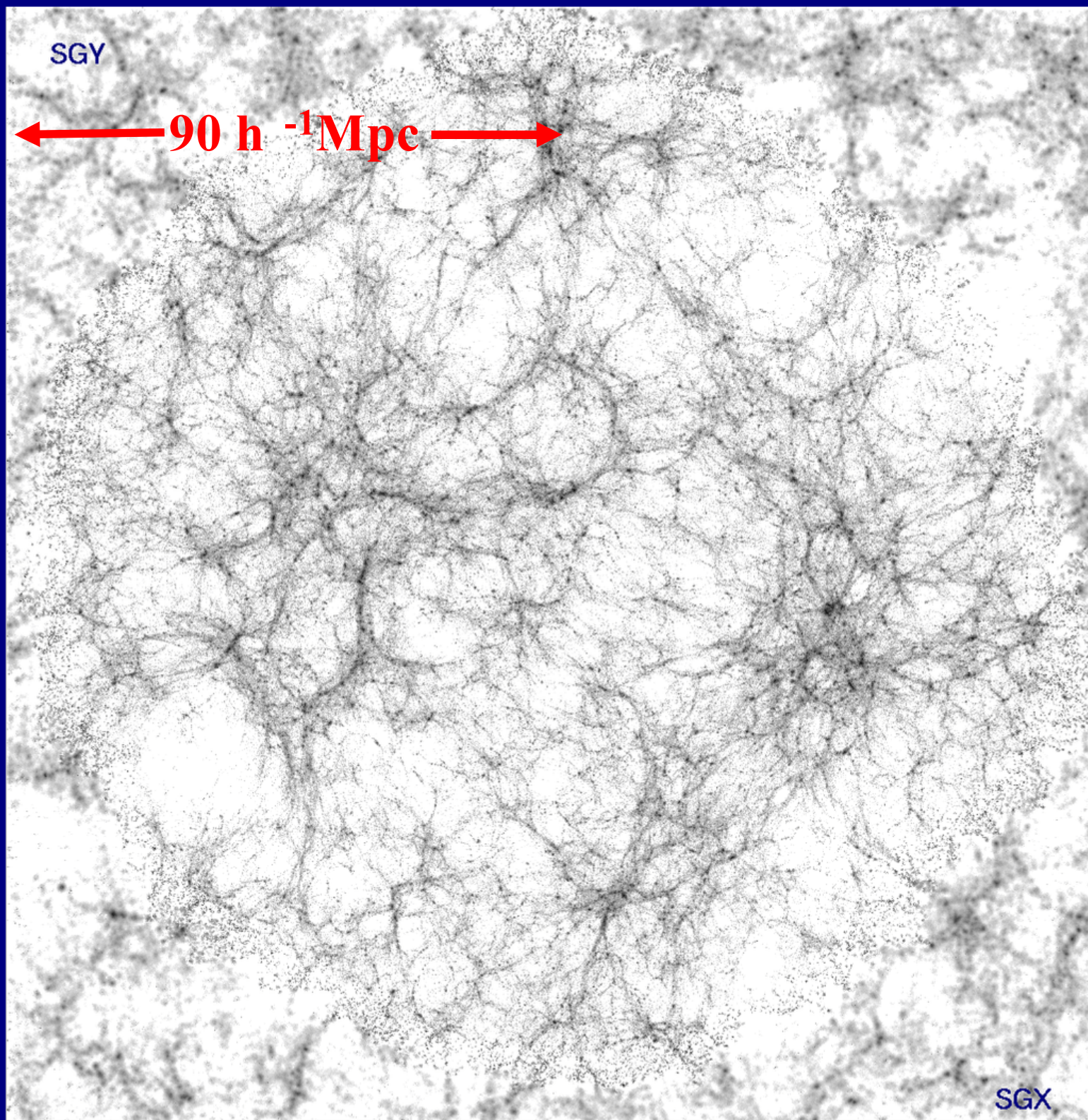
How to follow the evolution of the Universe on a supercomputer



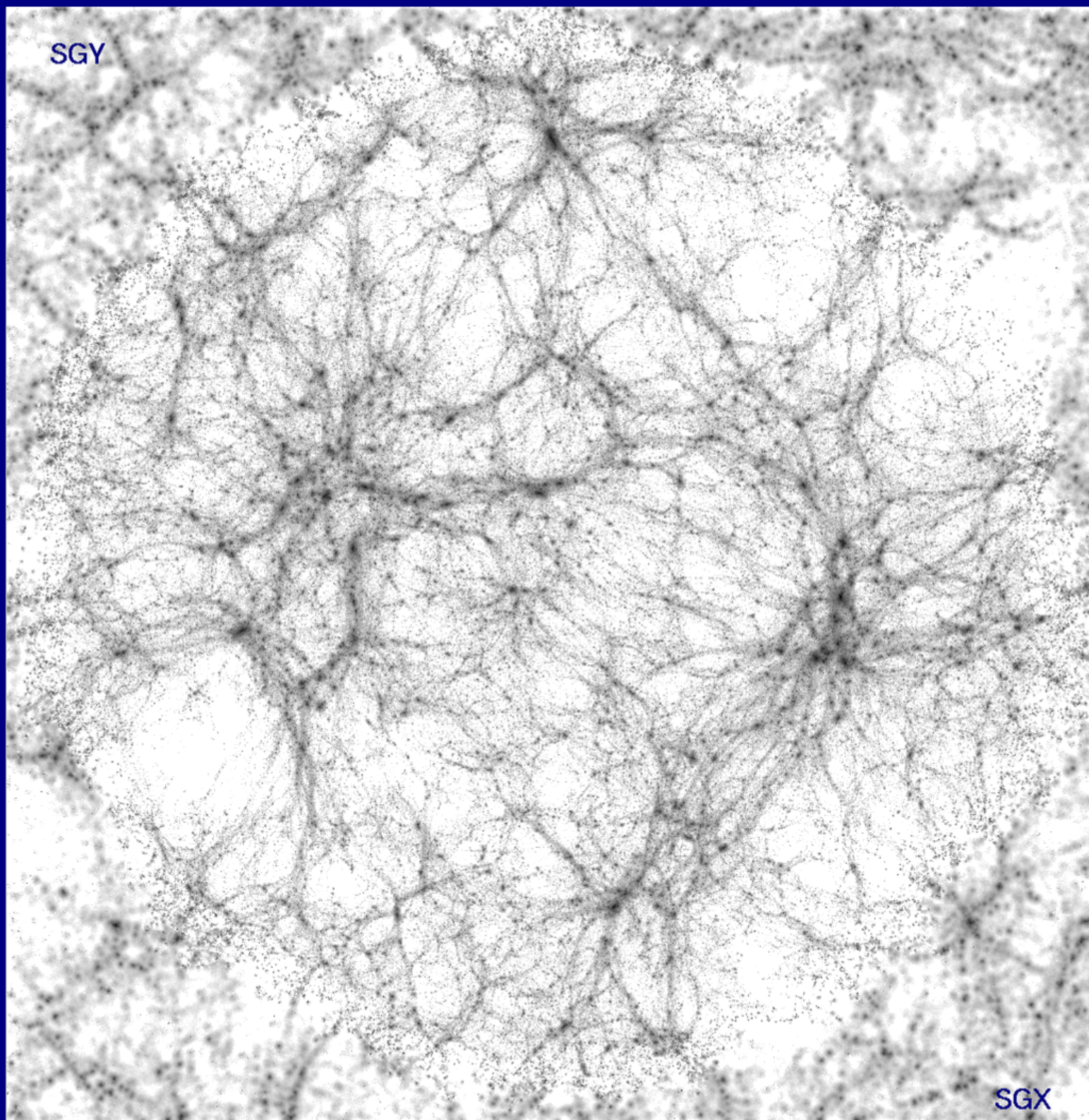
- Follow the material in an expanding cube
- Start 300,000 years after the Big Bang
- Choose initial conditions to match the microwave background
- Calculate forwards to the present day

**Our cosmic
neighborhood
at redshift
 $z=2.4$**

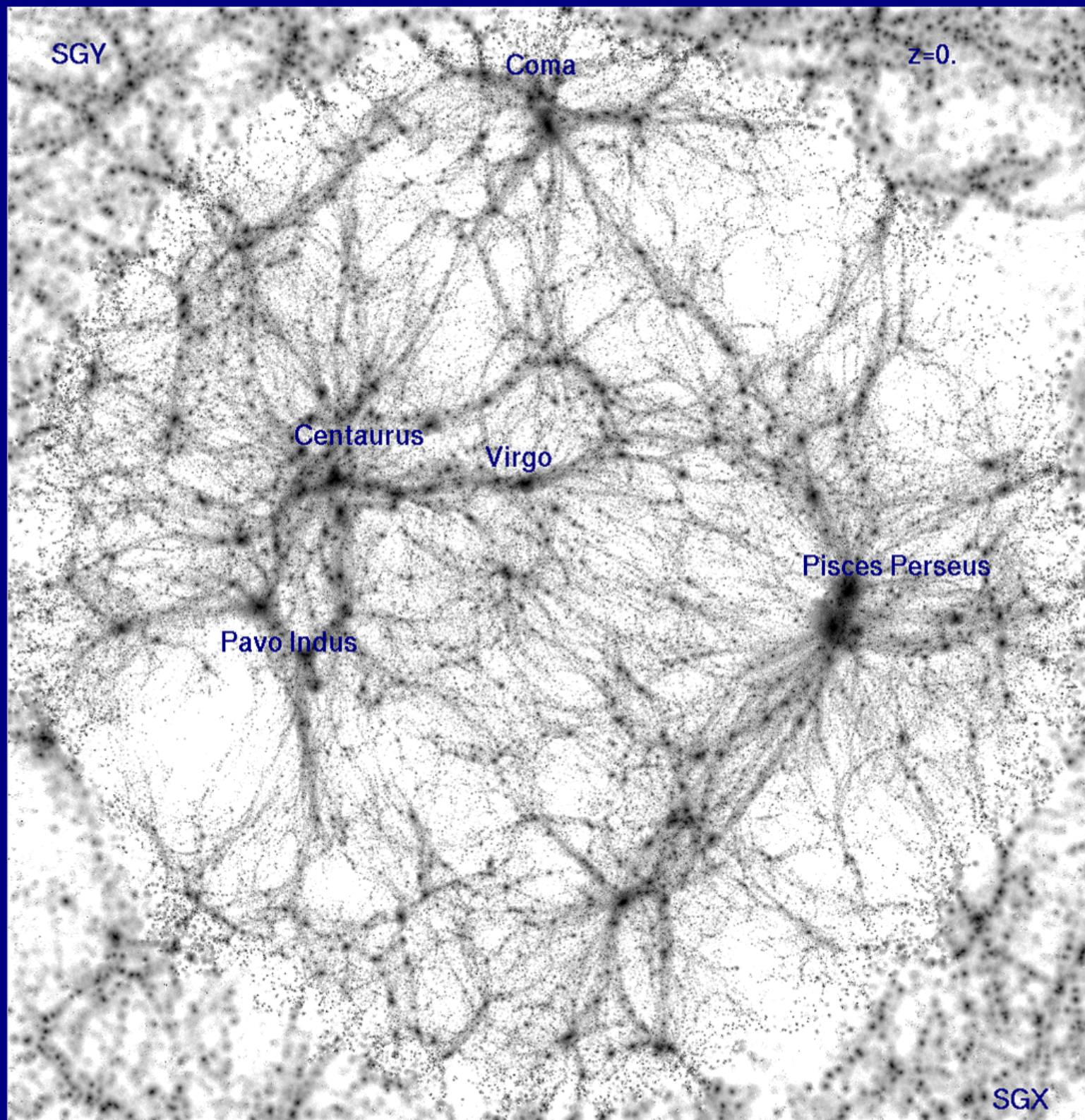
Mathis et al 2001



**Our cosmic
neighborhood
at redshift
 $z = 0.8$**



Our cosmic neighborhood today



A simulation of the entire visible Universe

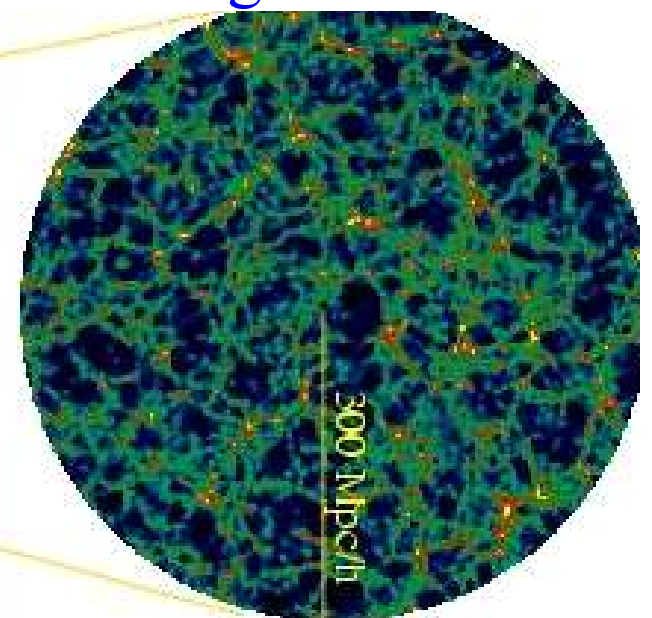
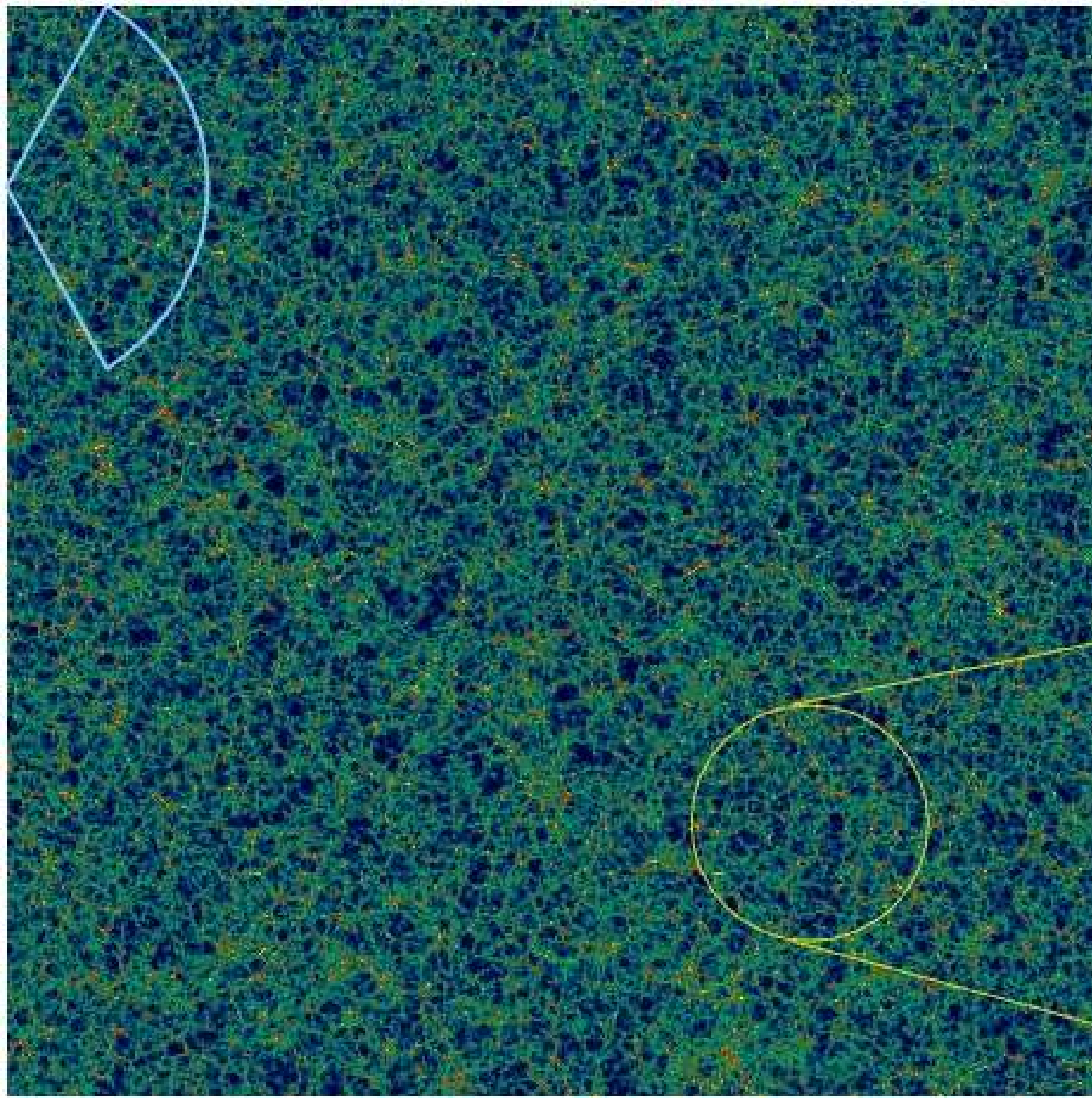
Λ CDM Universe

$$\Omega_{\Lambda}=0.7 \quad \Omega_{\text{m}}=0.3$$

Simulated with 10^9
gravitating particles

Evrard et al 2001

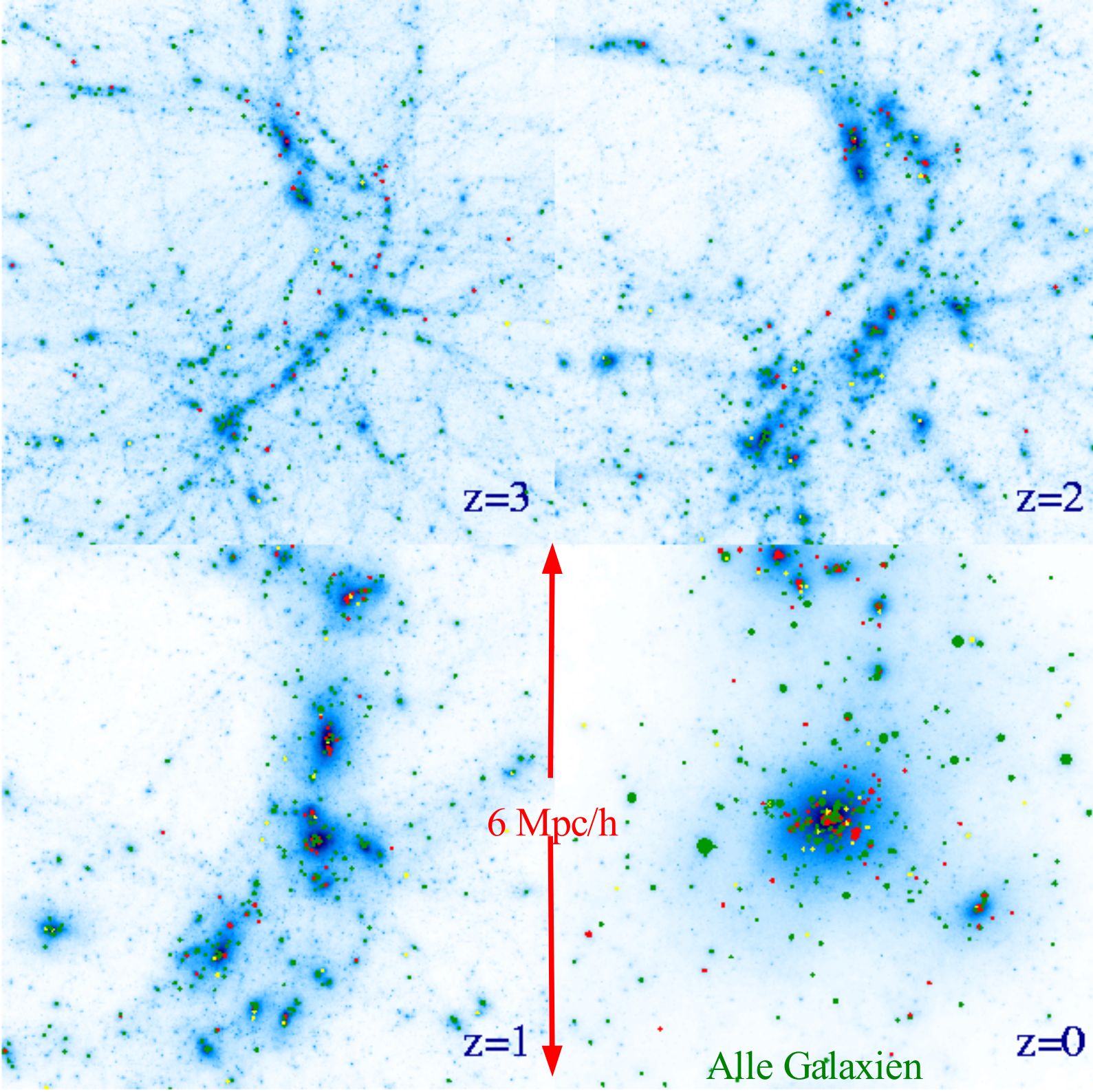
The Virgo Consortium



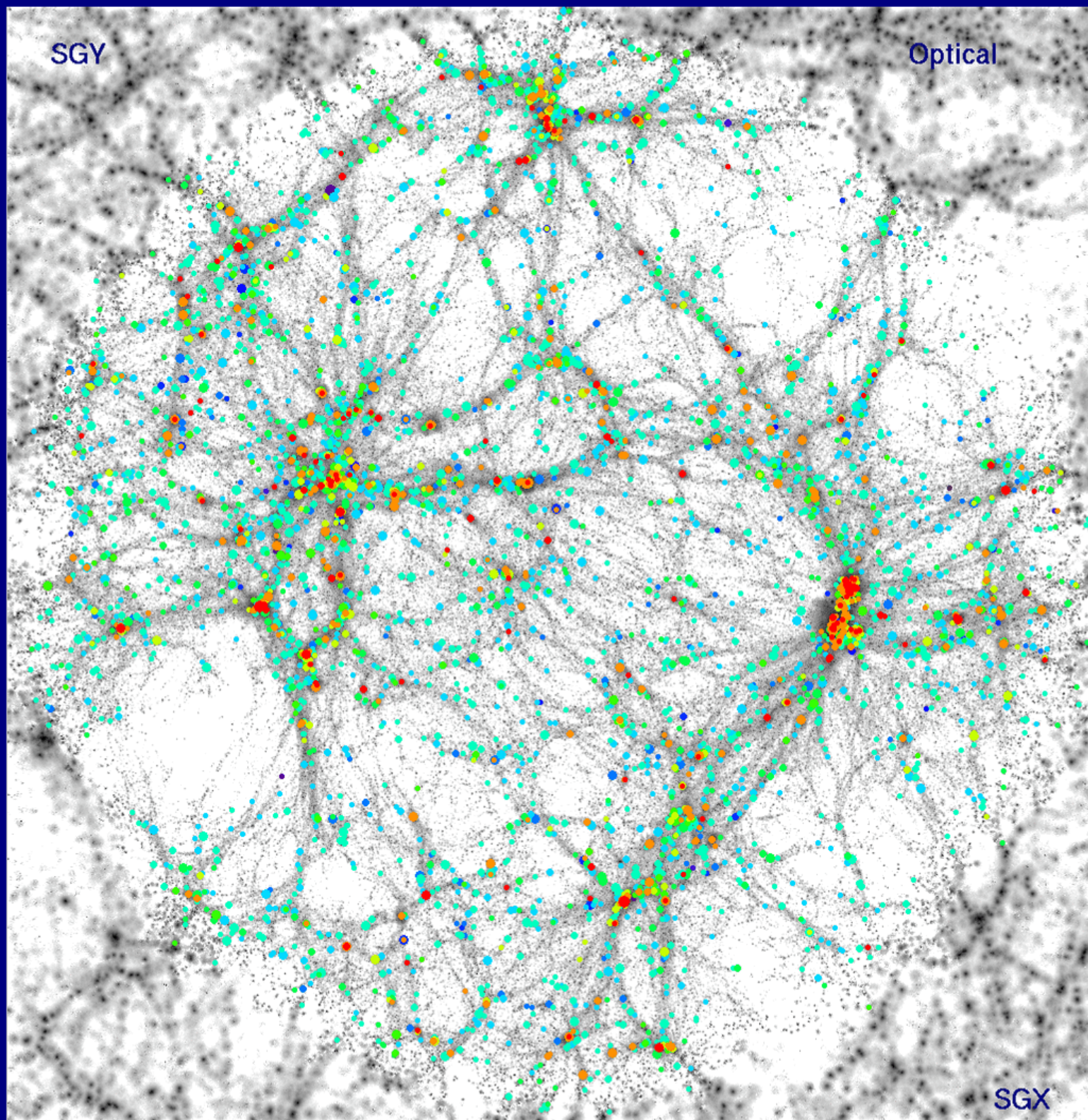
Evolution of the galaxies in a cluster

Springel et al 2001

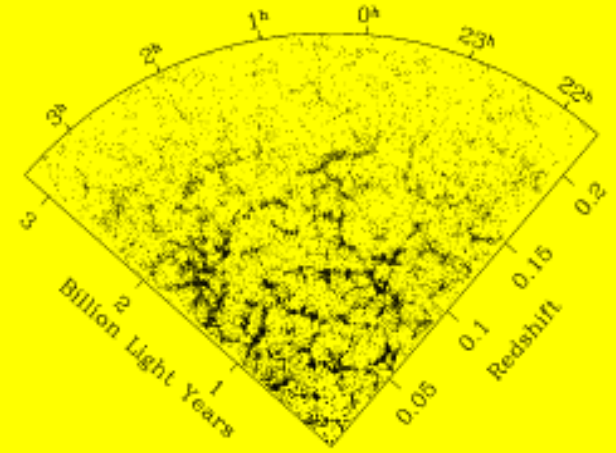
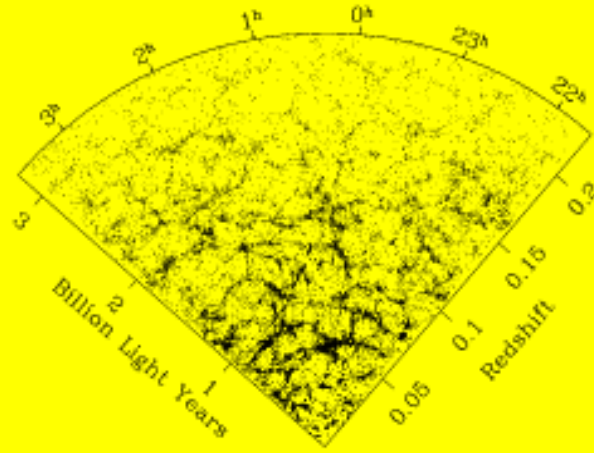
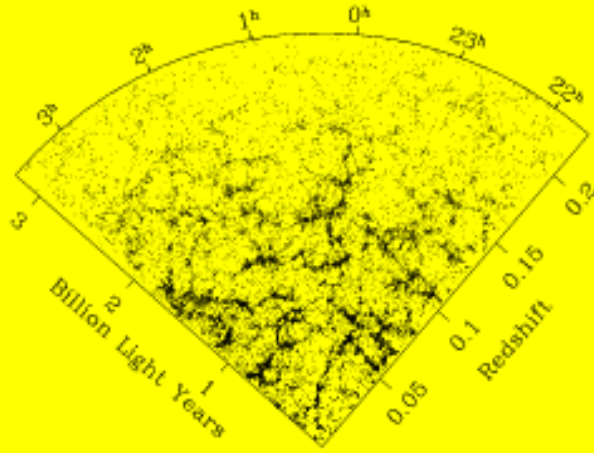
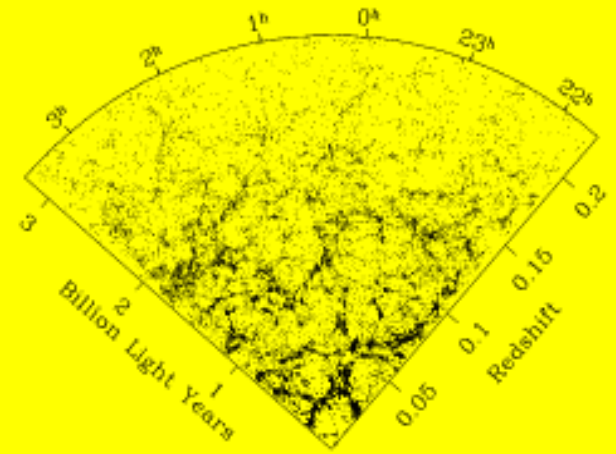
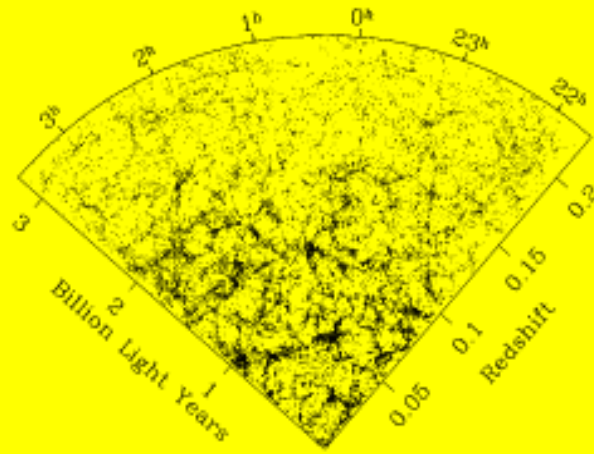
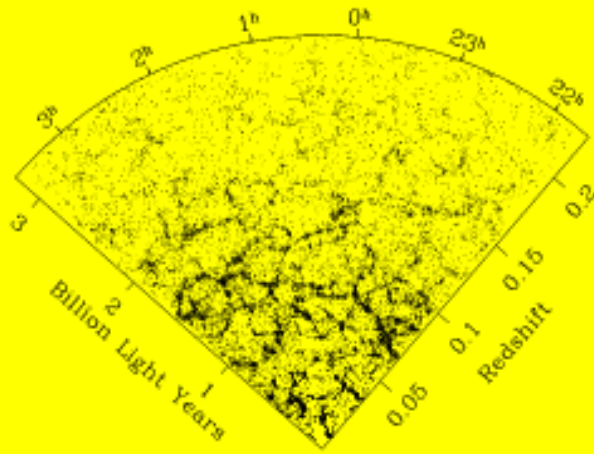
- The dark matter is shown in blue
- Colored points represent the galaxies



**Our cosmic
neighborhood
with
galaxies**

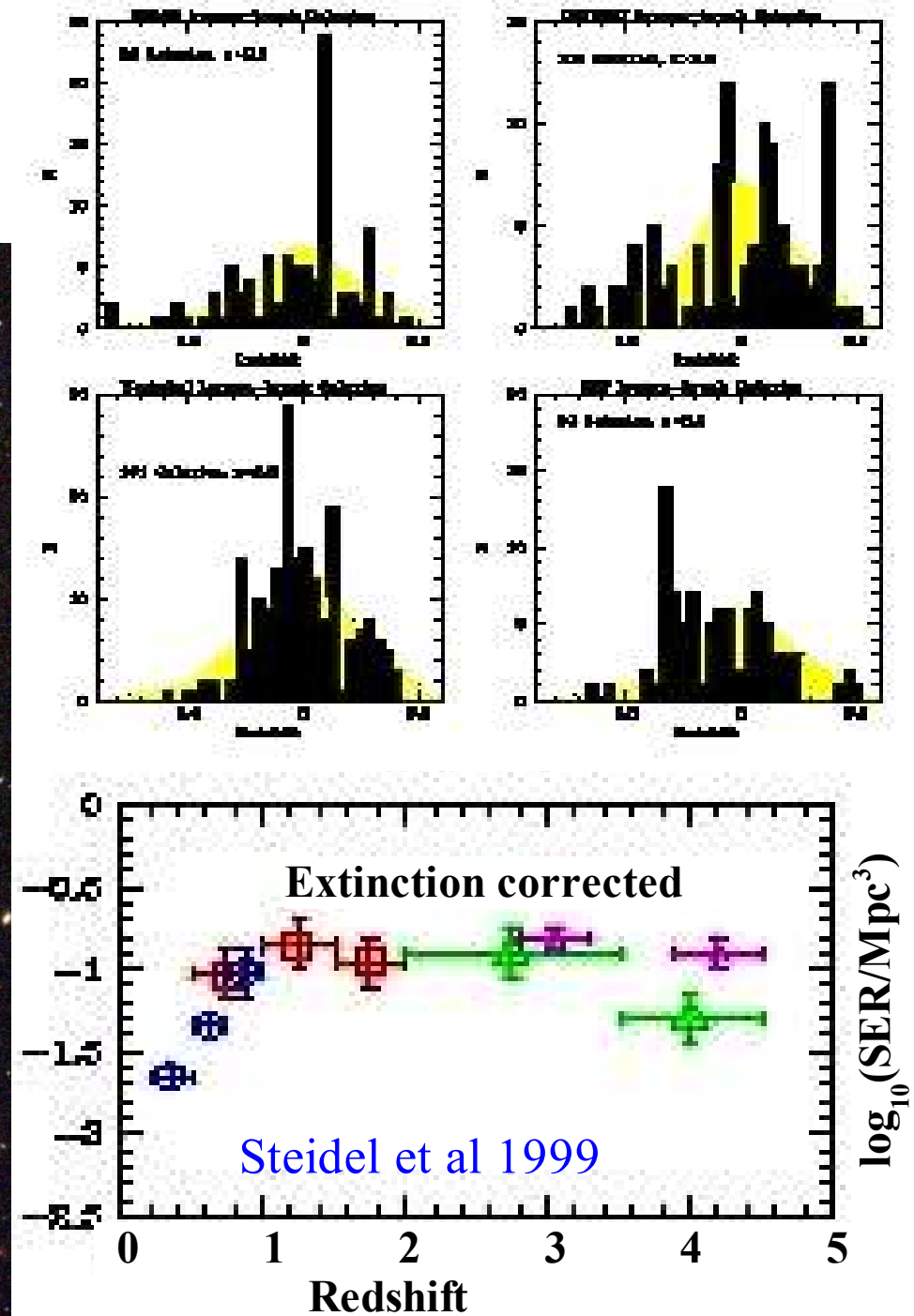
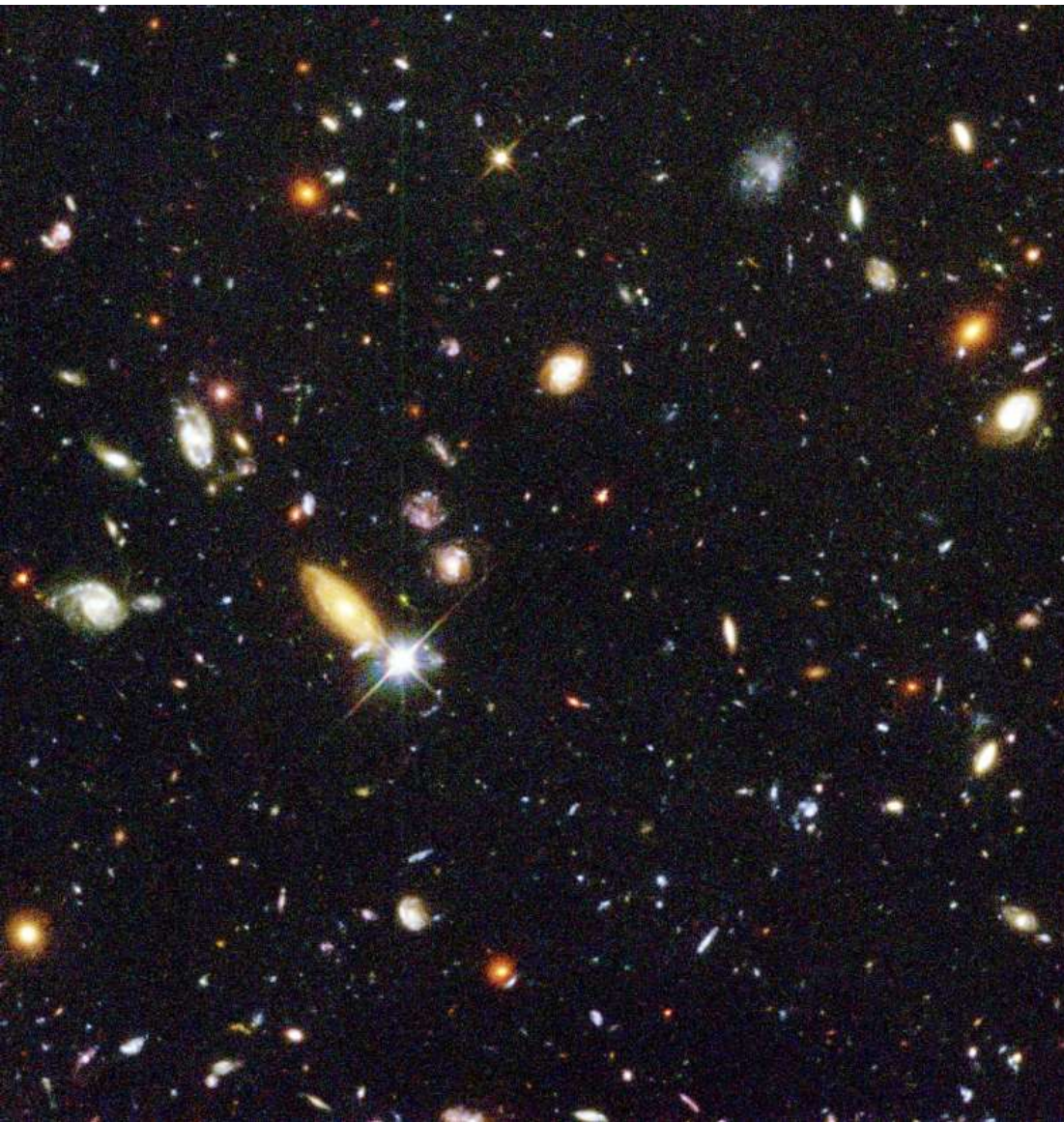


VIRTUAL vs REAL UNIVERSES II

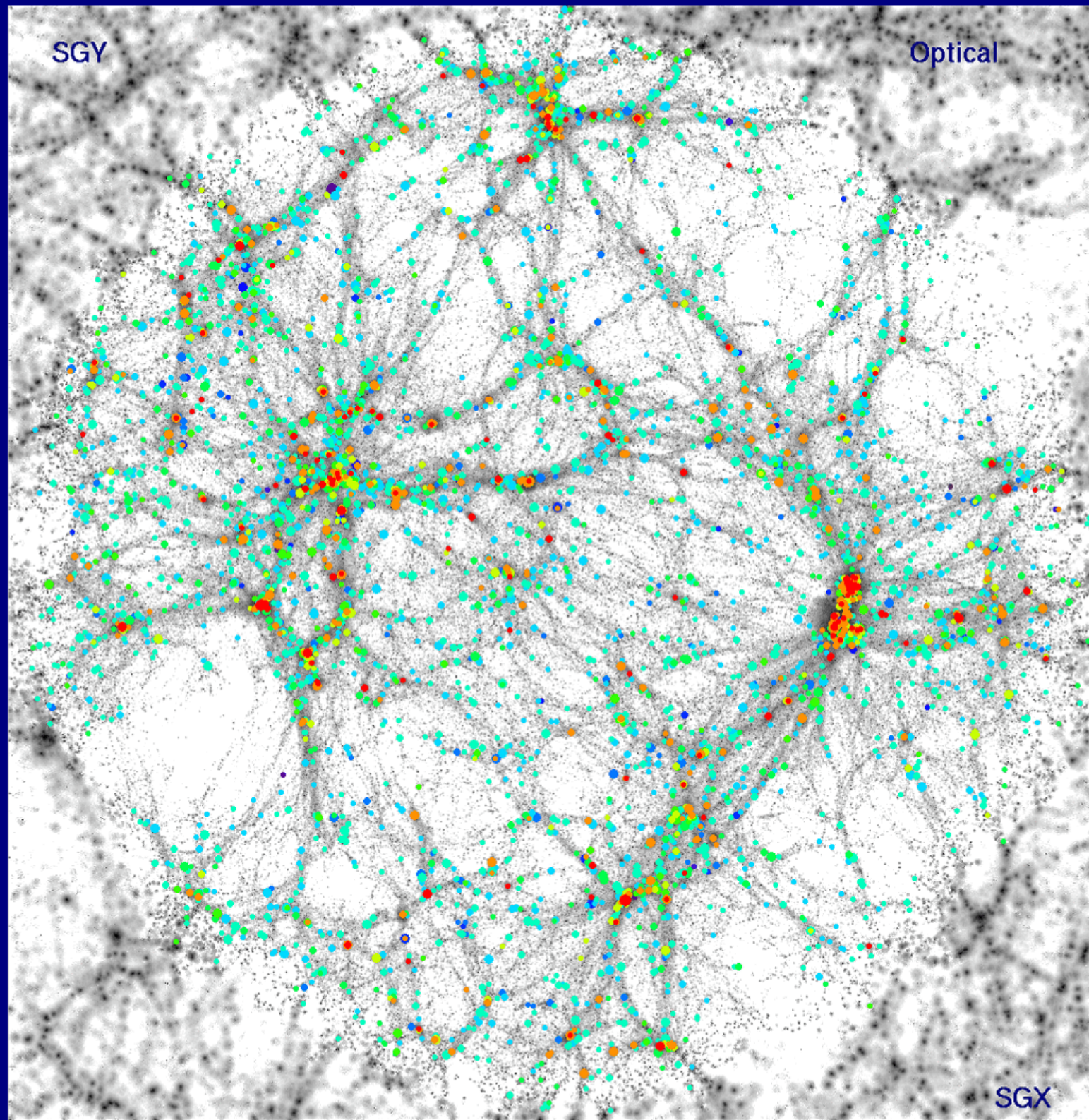


Telescopes as time machines: glimpses of the past

The Hubble Deep Field

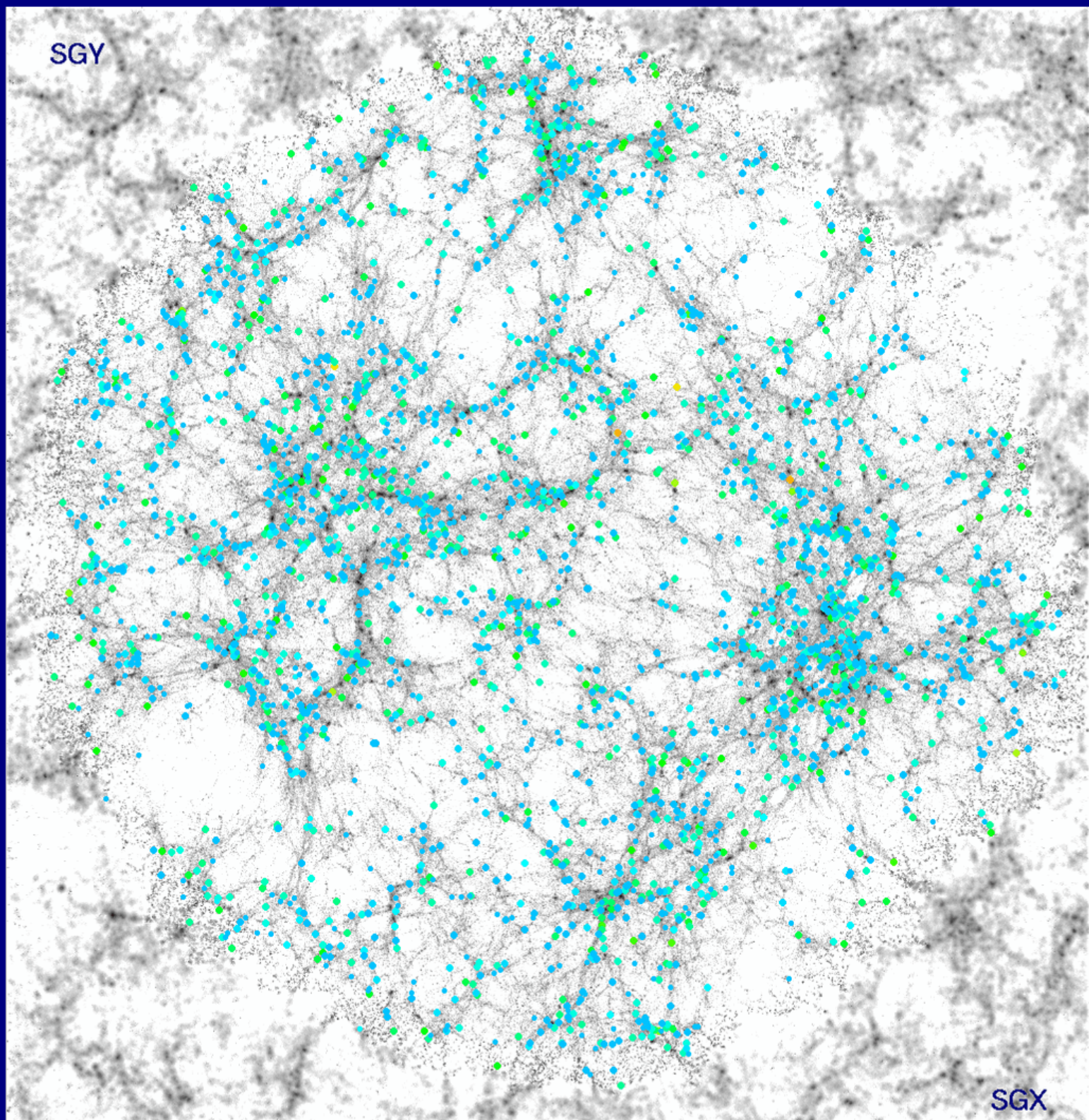


**Our cosmic
neighborhood
with
galaxies**

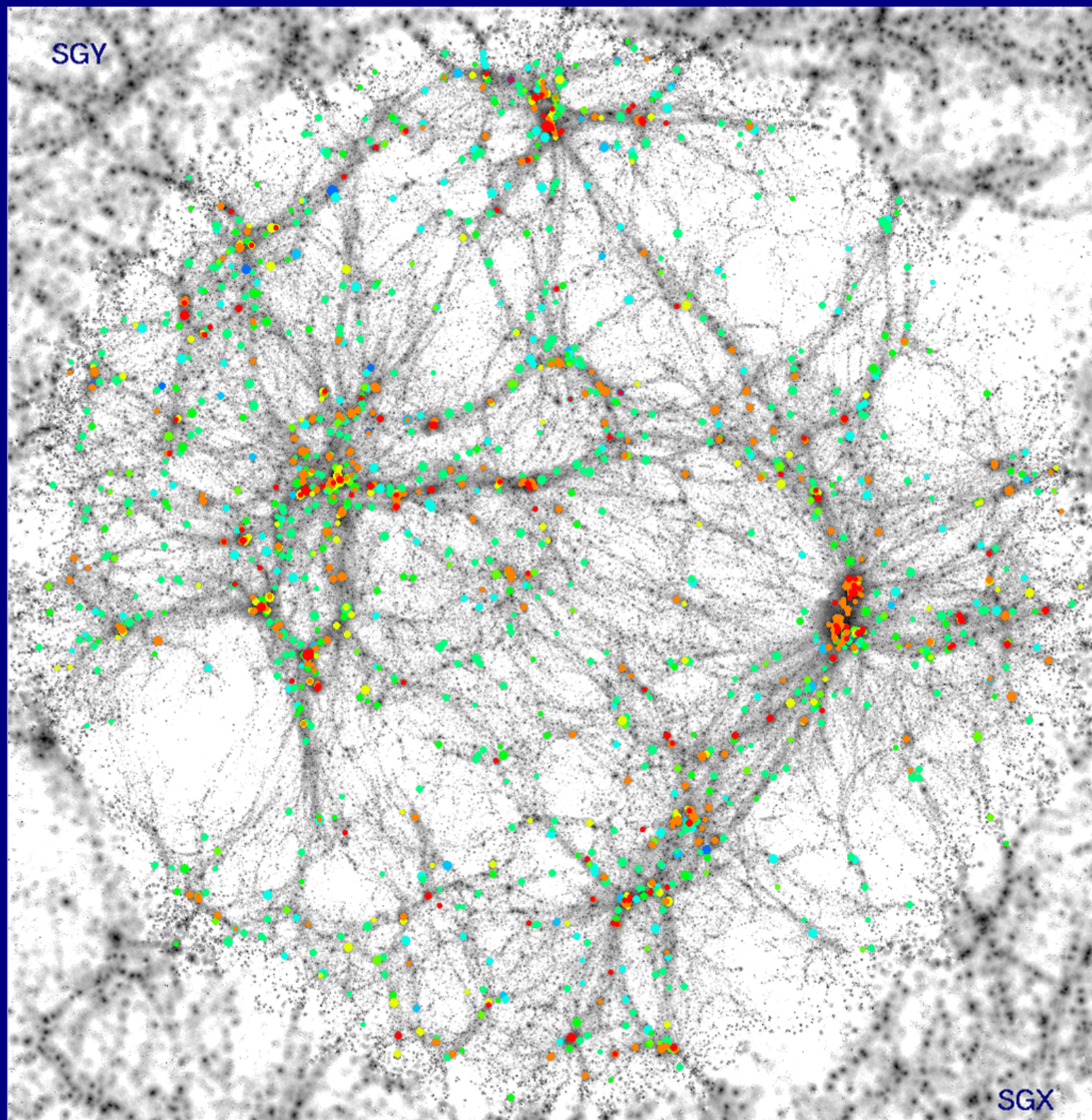


**Bright galaxies
at redshift
 $z=2.4$**

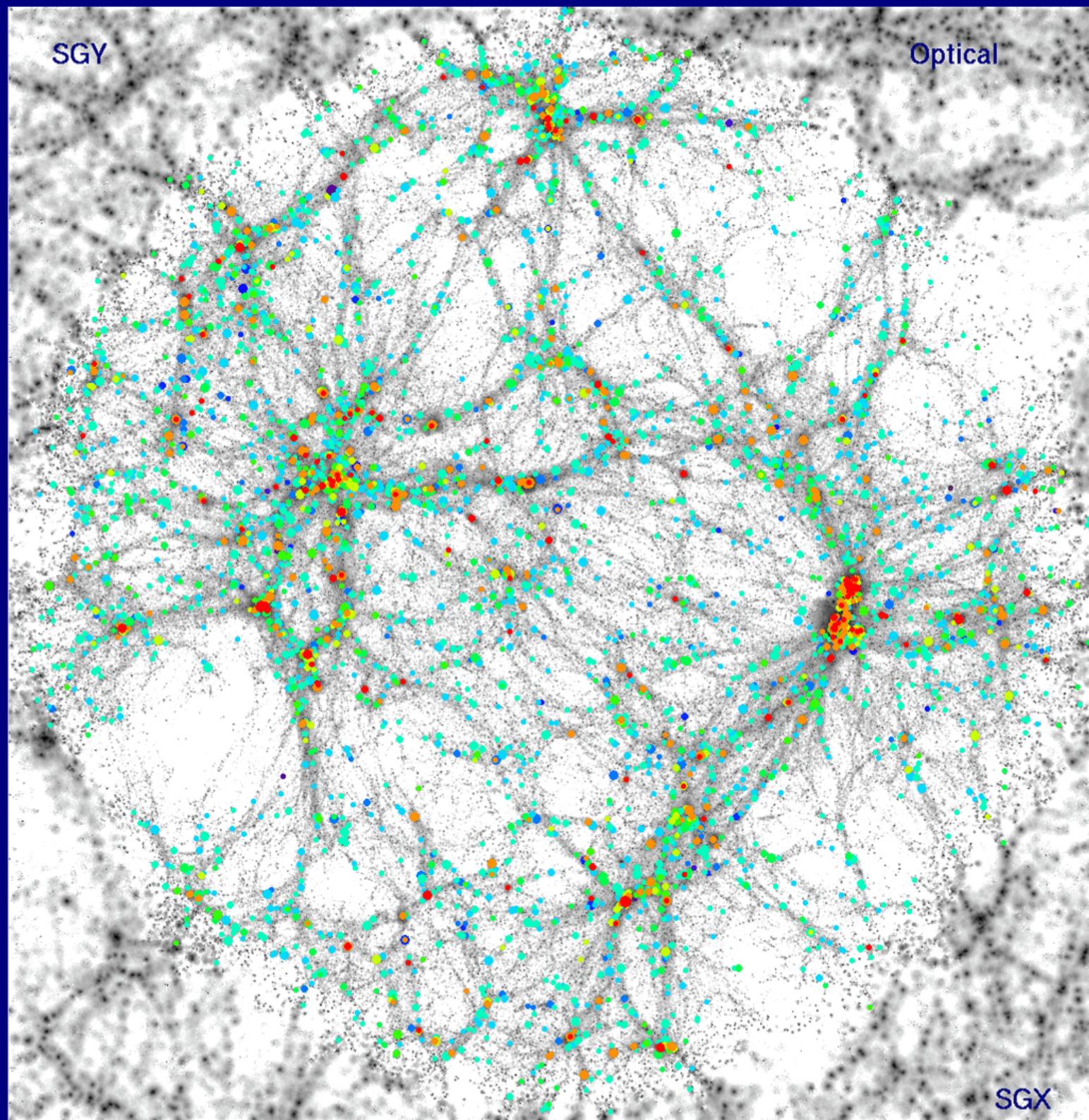
$\text{SFR} > 5.0$



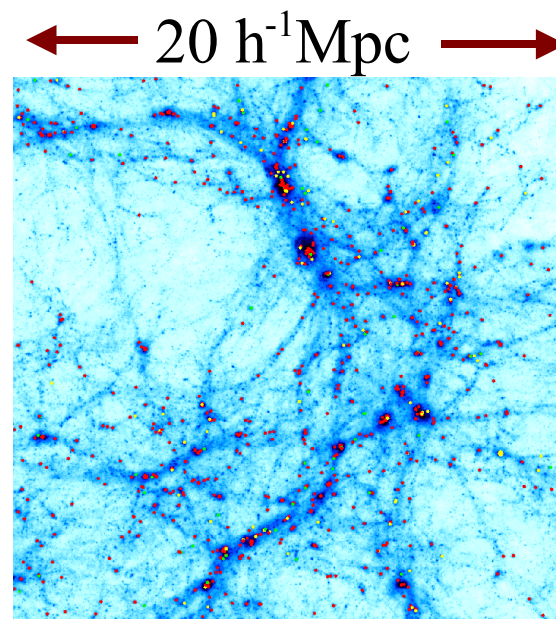
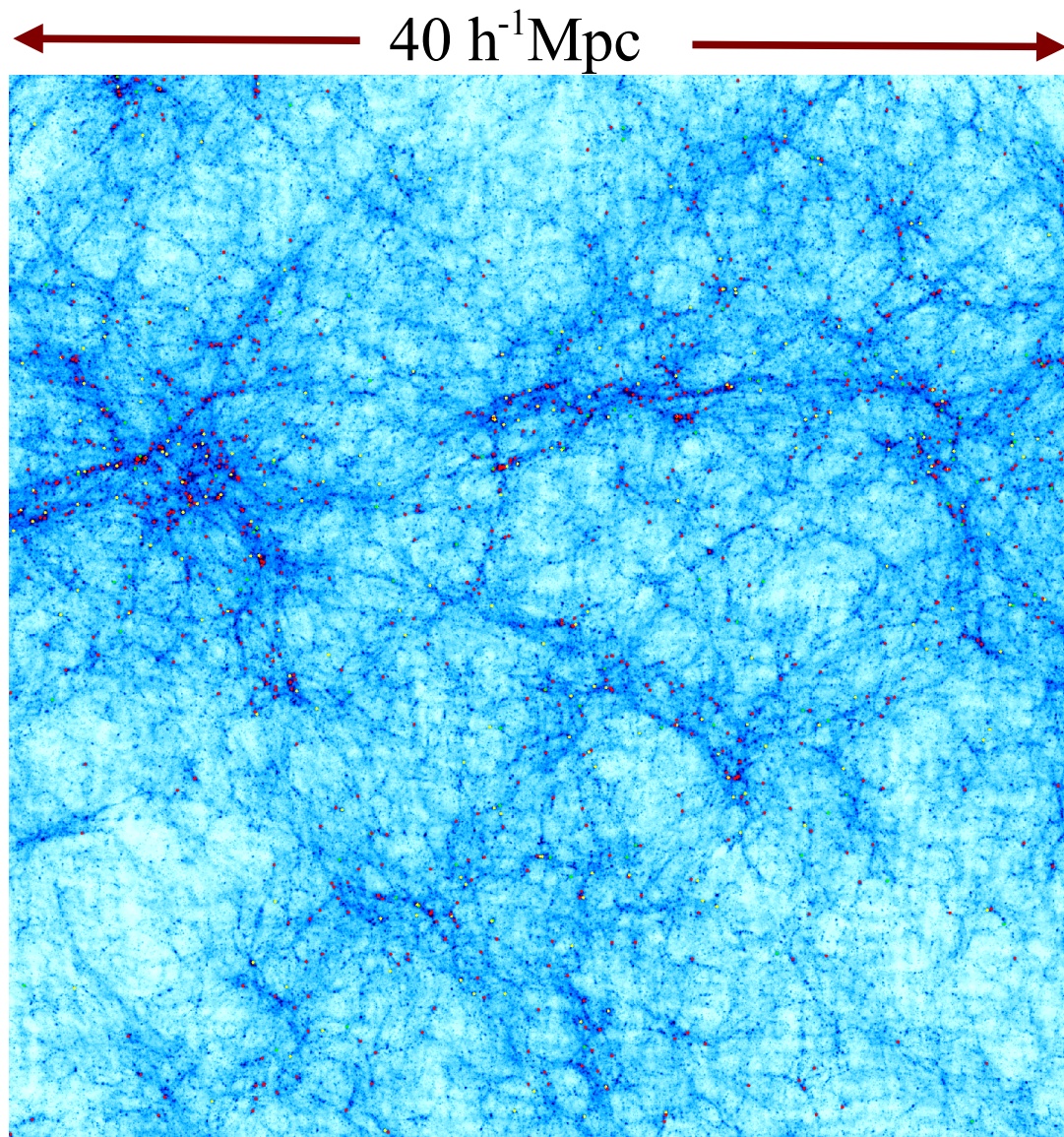
**Present-day
descendents
of bright
galaxies from
redshift $z=2.4$**



**Our cosmic
neighborhood
with
galaxies**



Early galaxy formation

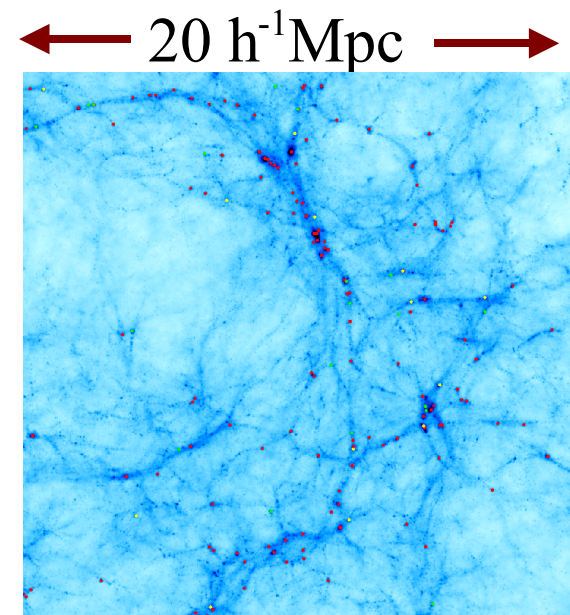
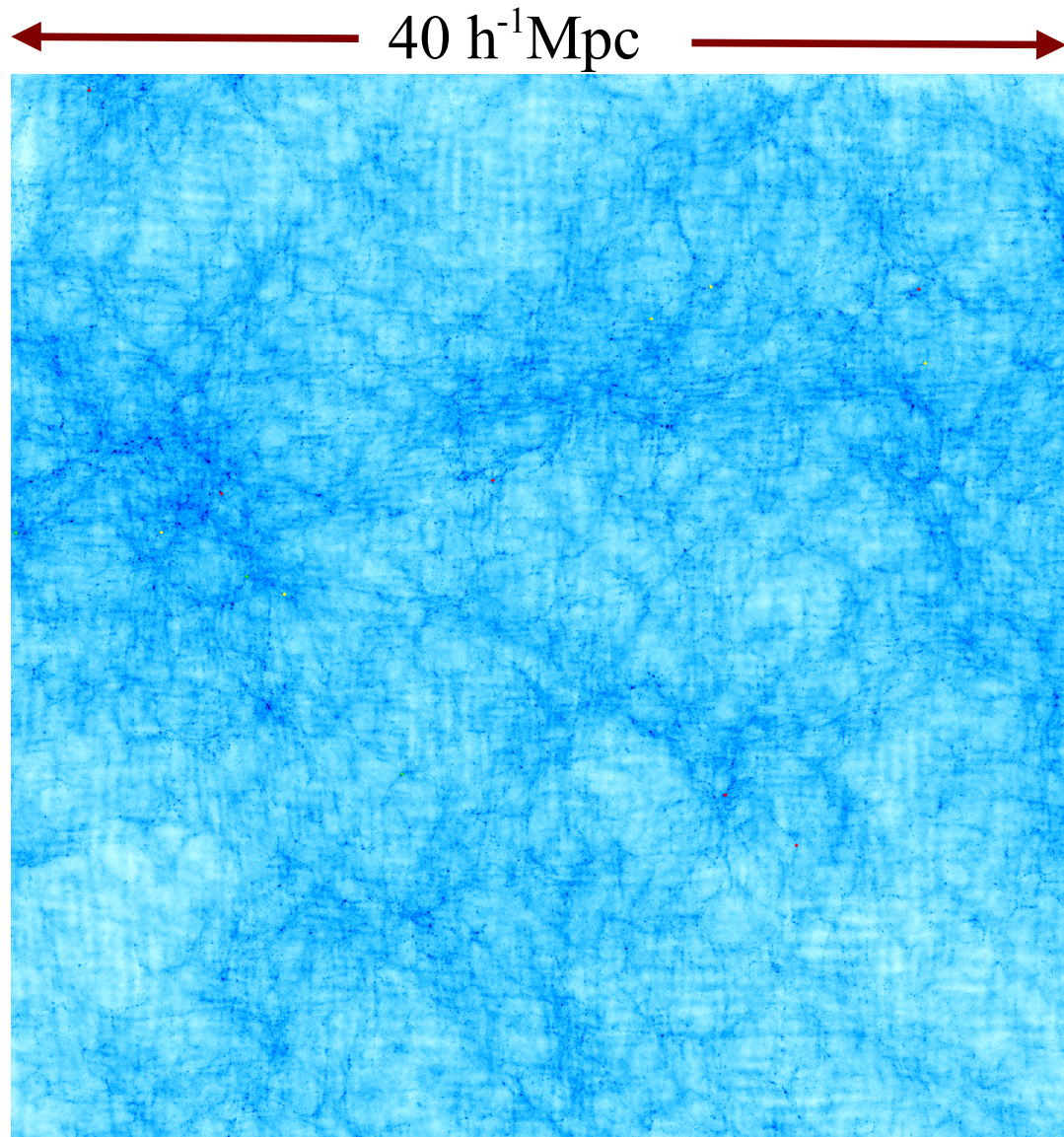


Proto-cluster

$$z = 5$$

Typical region

Early galaxy formation



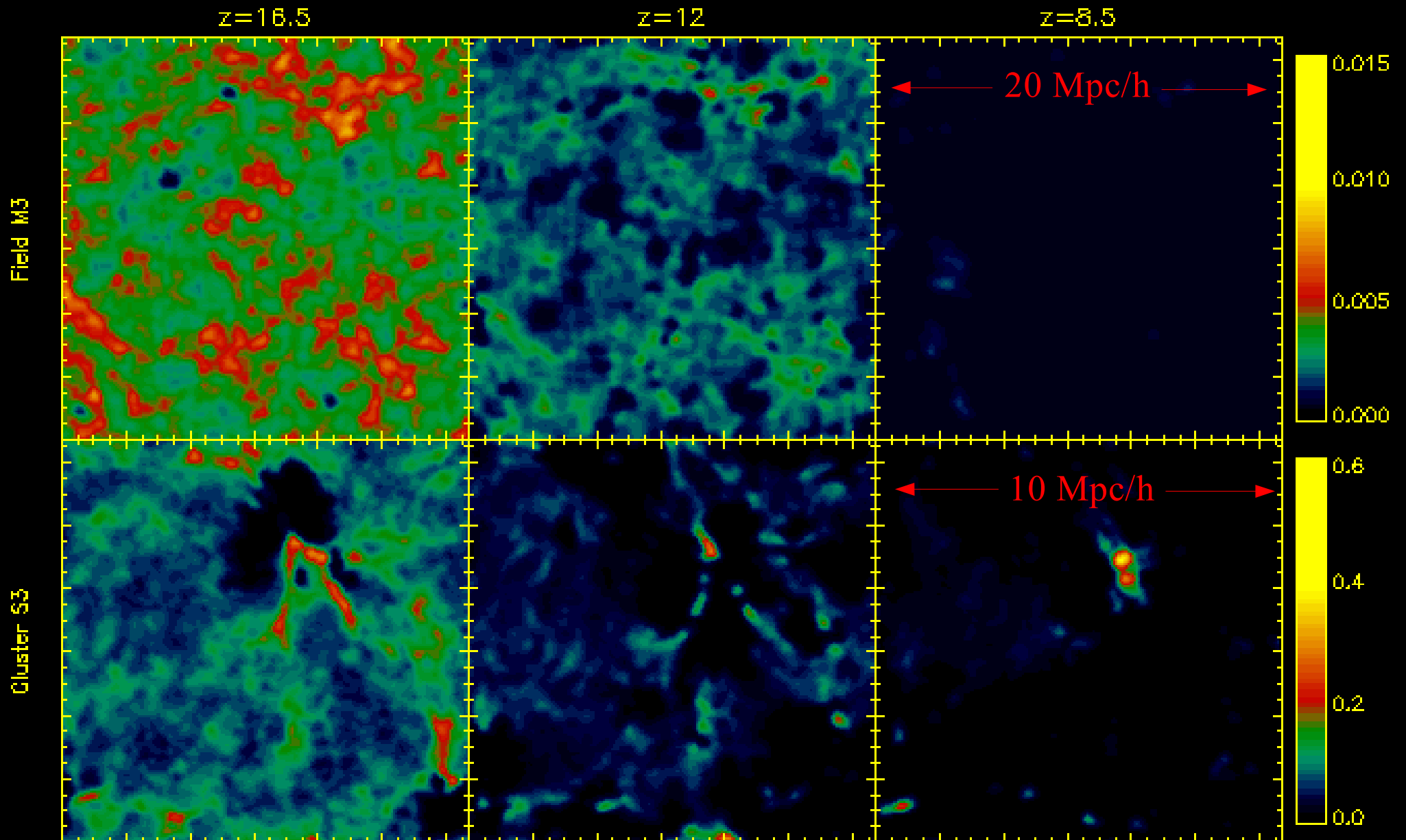
Proto-cluster

$z = 10$

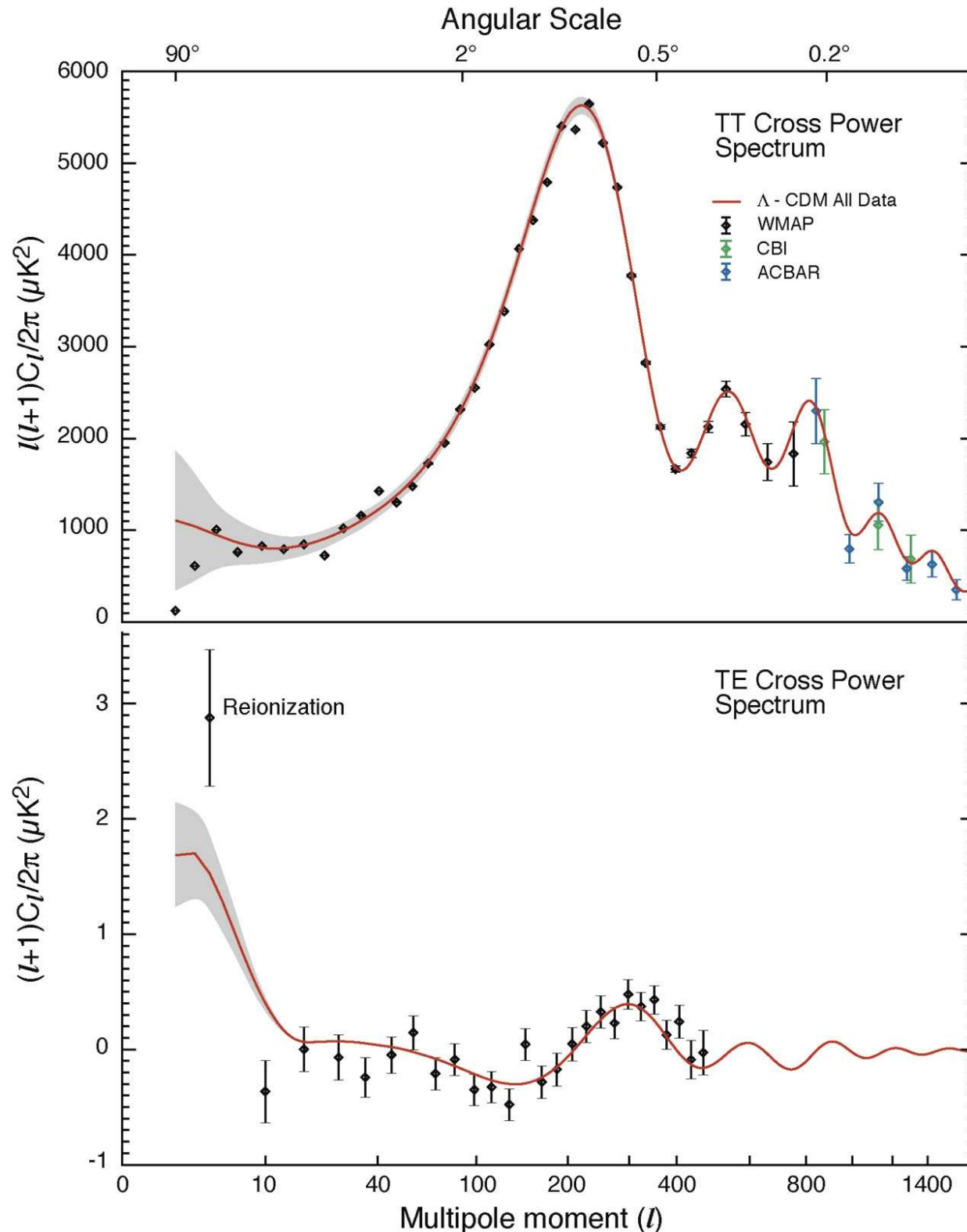
Typical region

Reionisation of the intergalactic gas

Ciardi, Stoehr & White 2003



Initial conditions for the formation of all structure



- Our Universe is flat
- It is 13.7 ± 0.2 billion years old.
- It is made of 70% dark energy, 26% cold dark matter and only 4% normal baryonic matter
- 30,000 years after the Big Bang it was nearly uniform
- All structure was imprinted in the first 10^{-30}s
- The first stars formed early

To conclude.....

- In the beginning the Universe was hot, dense and almost uniform
- All structure has grown from quantum fluctuations of the vacuum
- Normal material is only 4% of the content of the Universe
- About 25% is made of as yet unidentified elementary particles
- About 70% consists of a new and as yet unidentified form of dark energy which is accelerating the expansion of the Universe.
- Galaxies, galaxy clusters and larger structures, as well as stars and planets have formed from the primordial gas through the effects of gravity