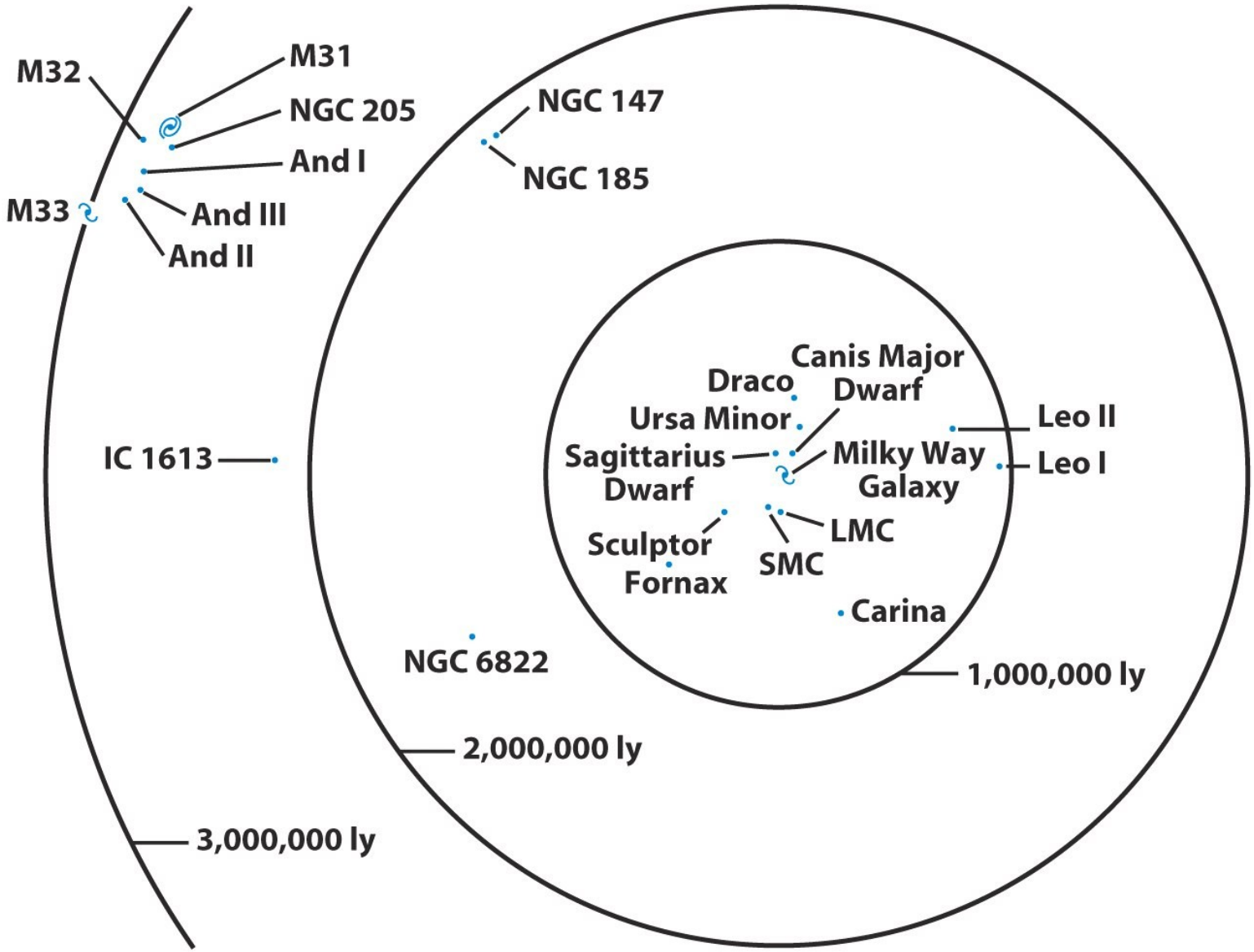
The Large Scale Structure of the Universe

Clusters of galaxies

X-rays from clusters of galaxies

Sheets and voids

Our Galaxy is a member of a small cluster called the Local Group

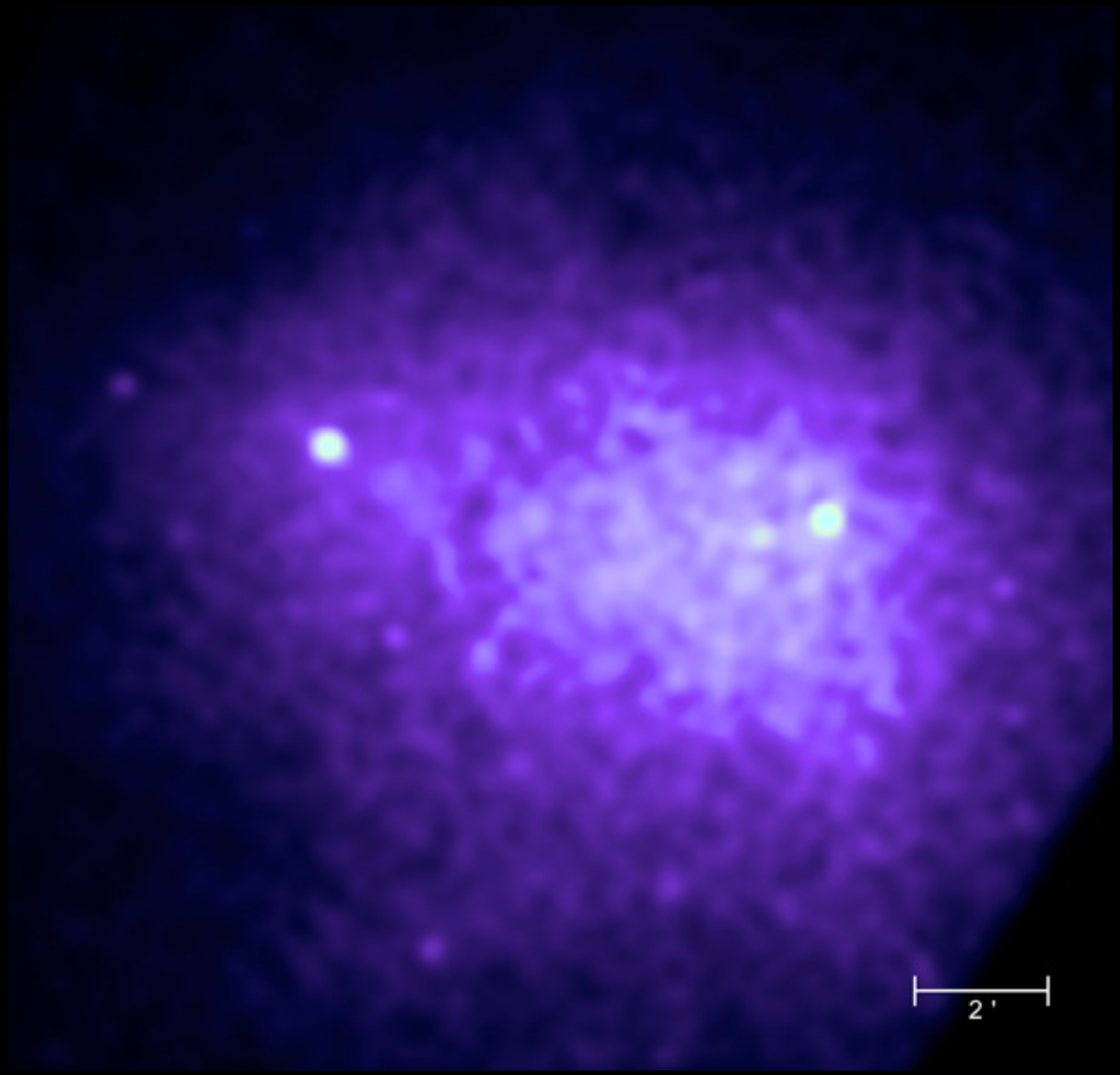


Stephane's Quintet


Virgo cluster


Abell 2218
HST WFPC2 ACS
200,000 light-years
70,000 parsecs
21″
At the distance of Abell 2218
2 billion light-years or
600 million parsecs
N
E

Coma cluster



Coma cluster in X-rays

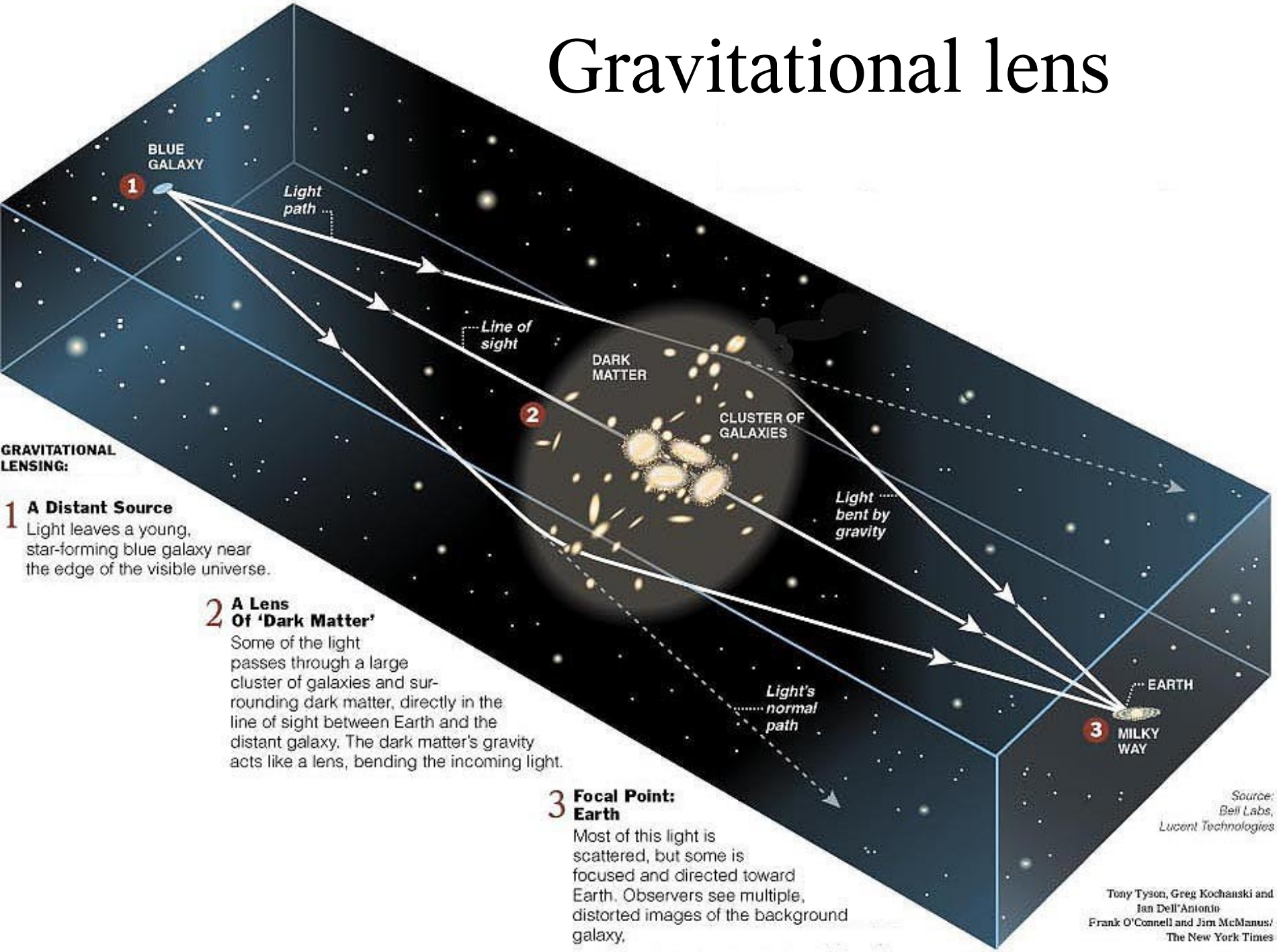
Coma cluster

X-ray emitting gas is at a temperature of 100,000,000 K.

The total X-ray luminosity is more than the luminosity of 100 billion Suns.

From this, the amount of X-ray emitting gas can be calculated. The mass of X-ray emitting gas is greater than the mass in all the stars in all the galaxies in the cluster.

Gravitational lens



GRAVITATIONAL LENSING:

1 A Distant Source
Light leaves a young, star-forming blue galaxy near the edge of the visible universe.

2 A Lens Of 'Dark Matter'
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.

3 Focal Point: Earth
Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.

Source: Bell Labs, Lucent Technologies

Tony Tyson, Greg Kochanski and Ian Dell'Antonio
Frank O'Connell and Jim McManus/ The New York Times

Gravitational lenses

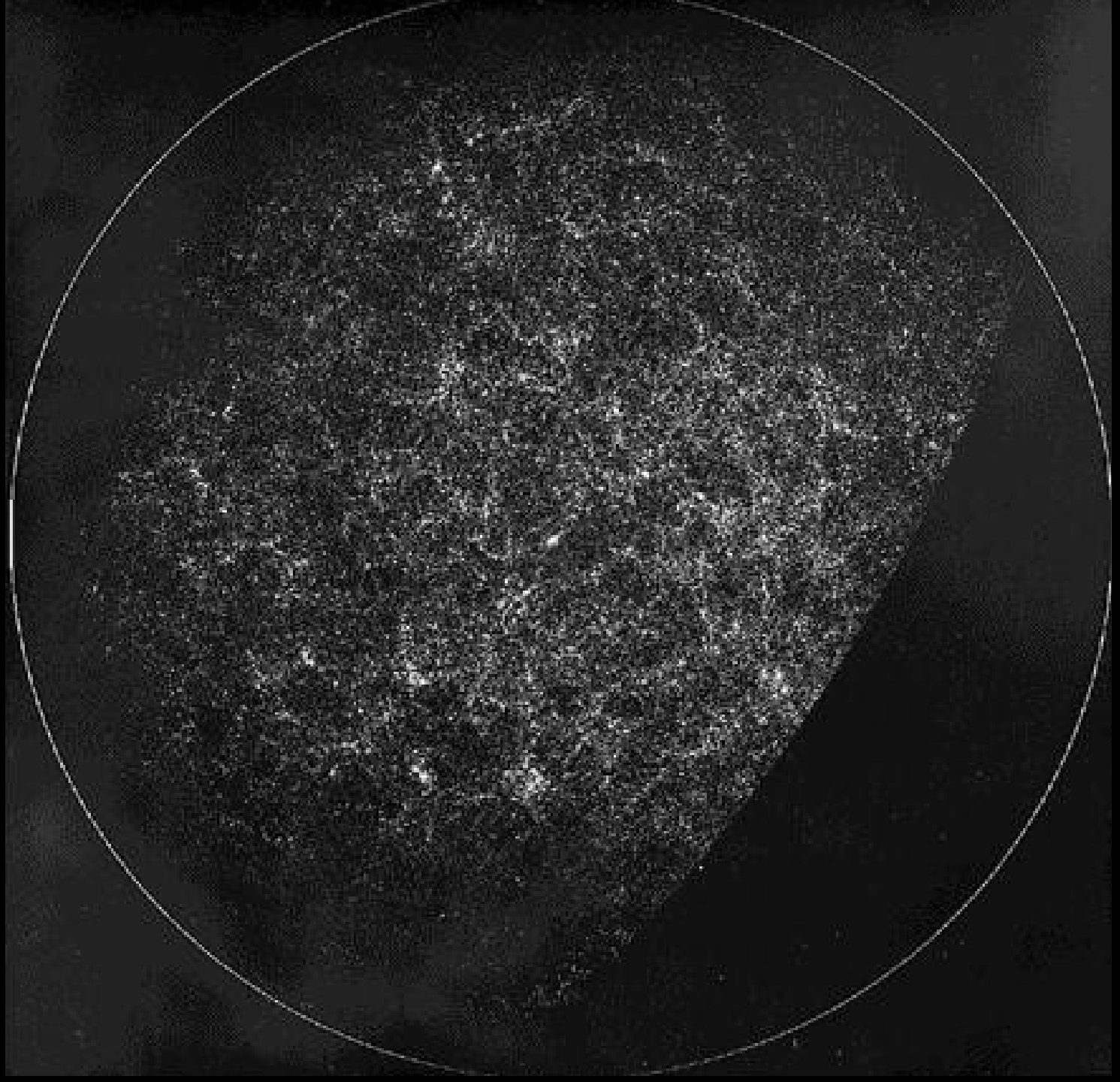
By measuring multiple images of one source, we can figure out the total mass in the lens. This provides an independent confirmation of dark matter.

A lense can act as a huge telescope. The deepest images of the most distant galaxies are obtained with clusters acting as gravitational lenses.

The red Galaxy is 13 billion light years away.
We are seeing it 750 million years after the Big Bang.

Large Scale Structure

Are clusters of galaxies the largest structures in the Universe?



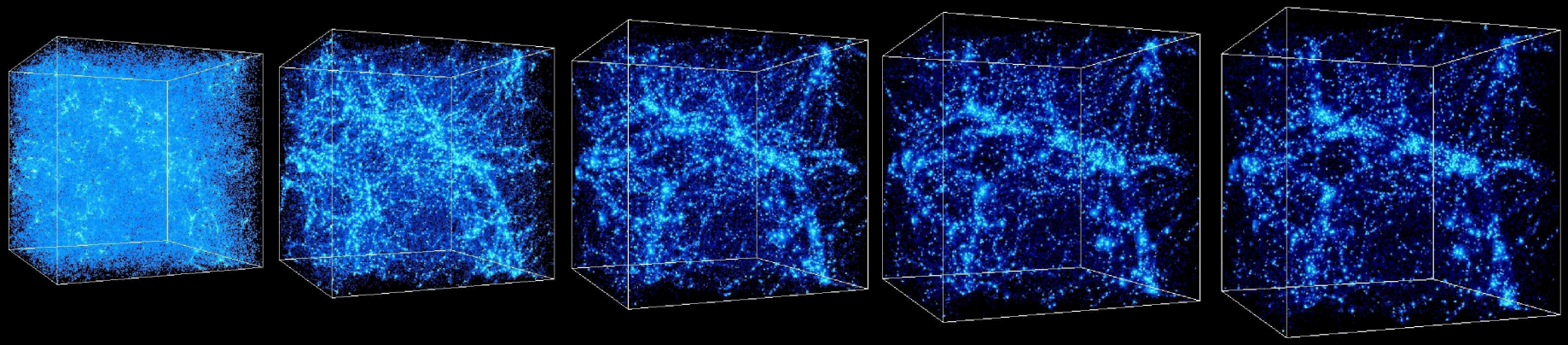
Large Scale Structure

Galaxies and clusters of galaxies are organized on irregular sheets separated by voids containing few galaxies.

The density fluctuations seen in the cosmic microwave background are likely the seeds for the formation of the sheets, clusters, and galaxies.

How that process occurs is now being worked out.

Simulation of Structure Formation



Movie

Review Questions

How can we measure the mass of a cluster of galaxies?

At what wavelength do galaxy clusters glow brightest?

On the largest scales, how are galaxies arranged?