Galaxy clusters

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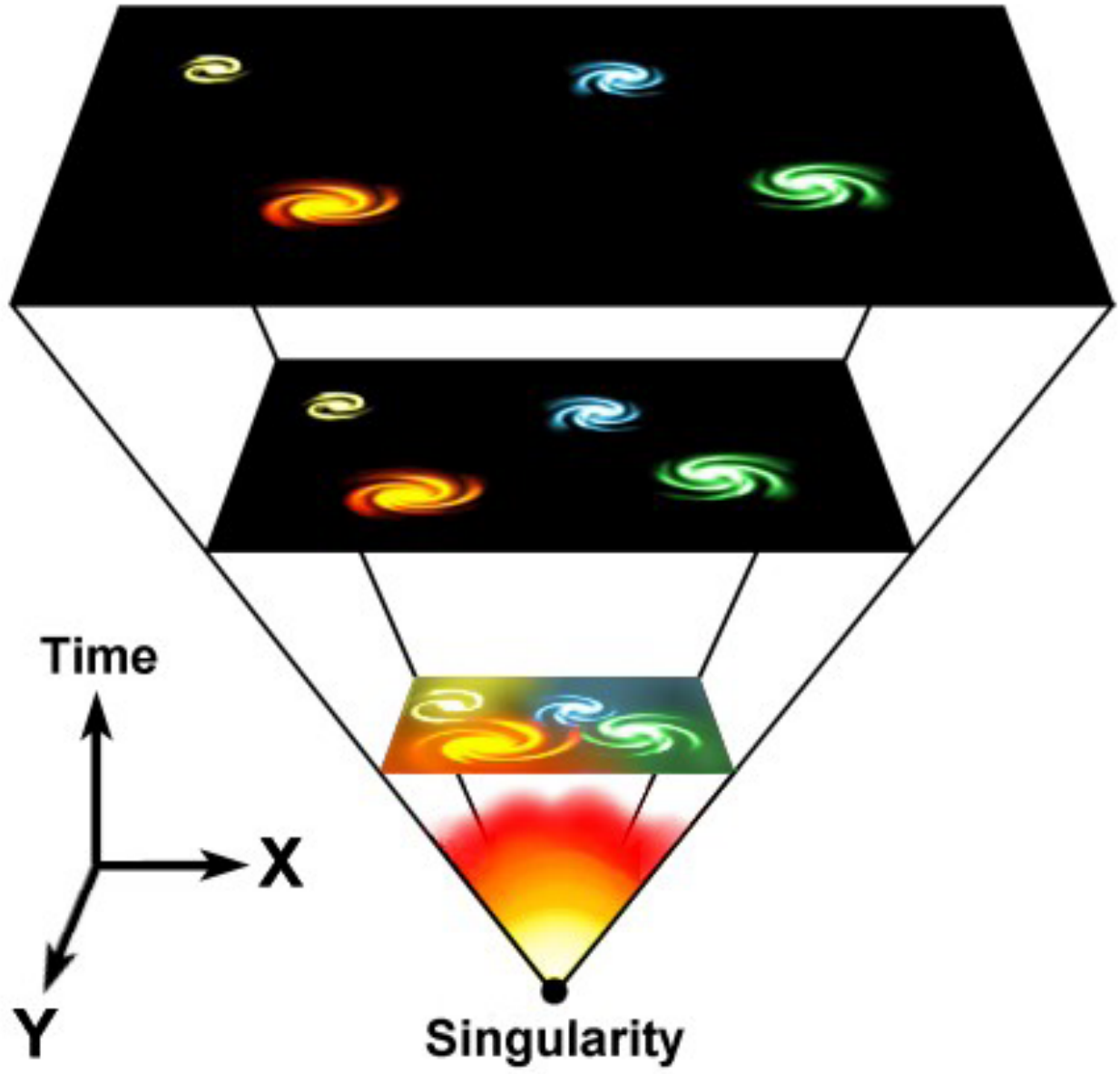
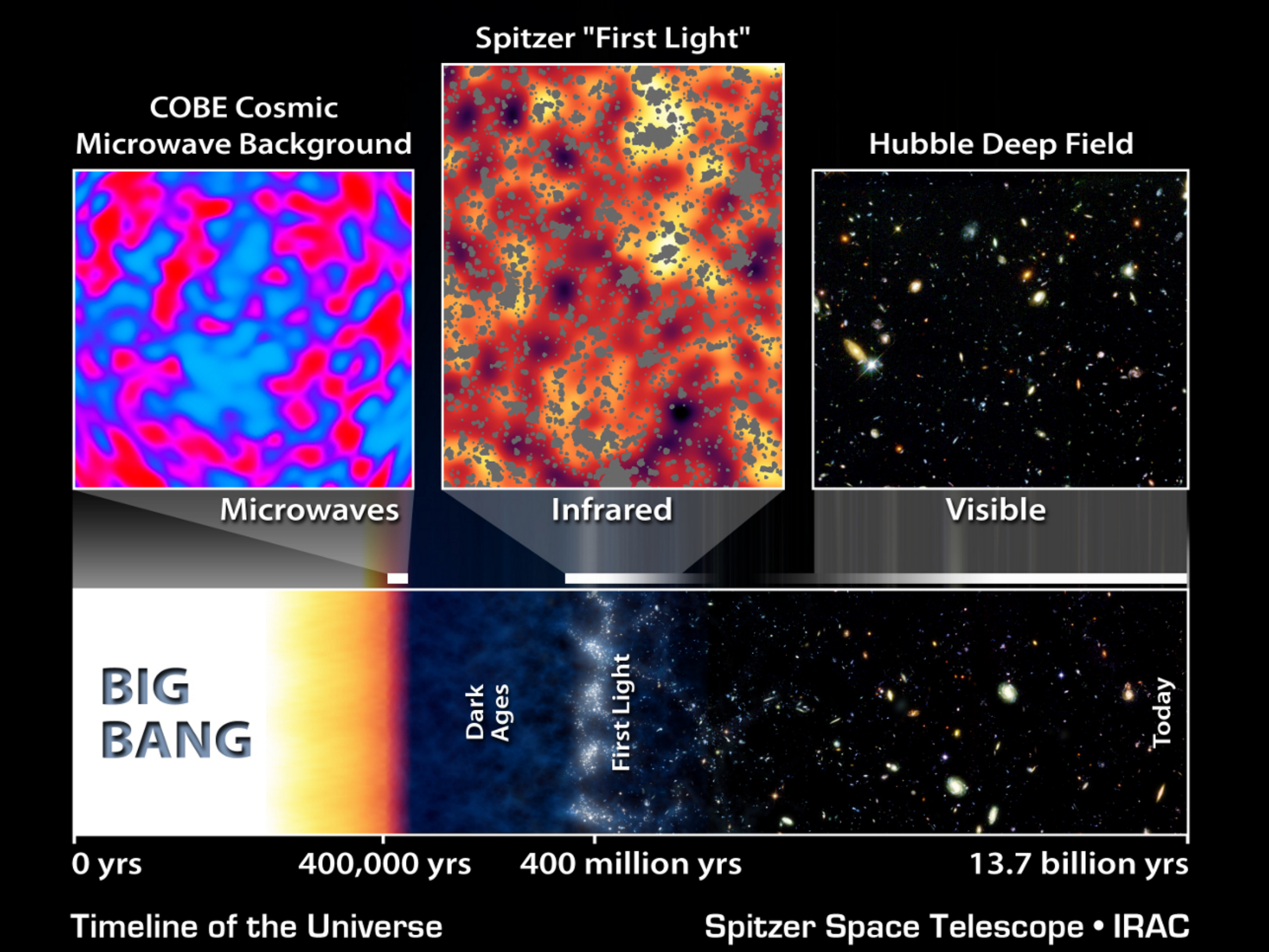
Dept. of Physics

Expanding universe & the Big Bang

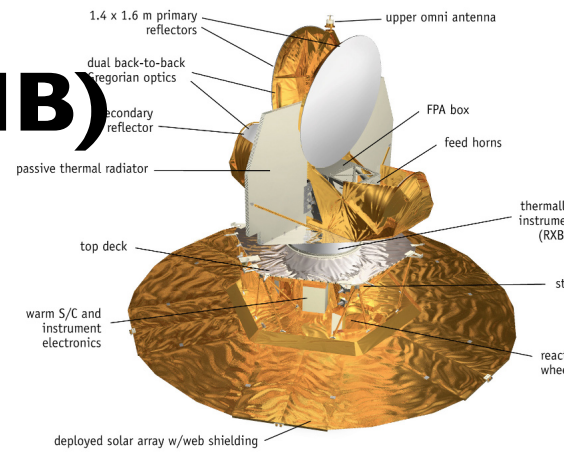


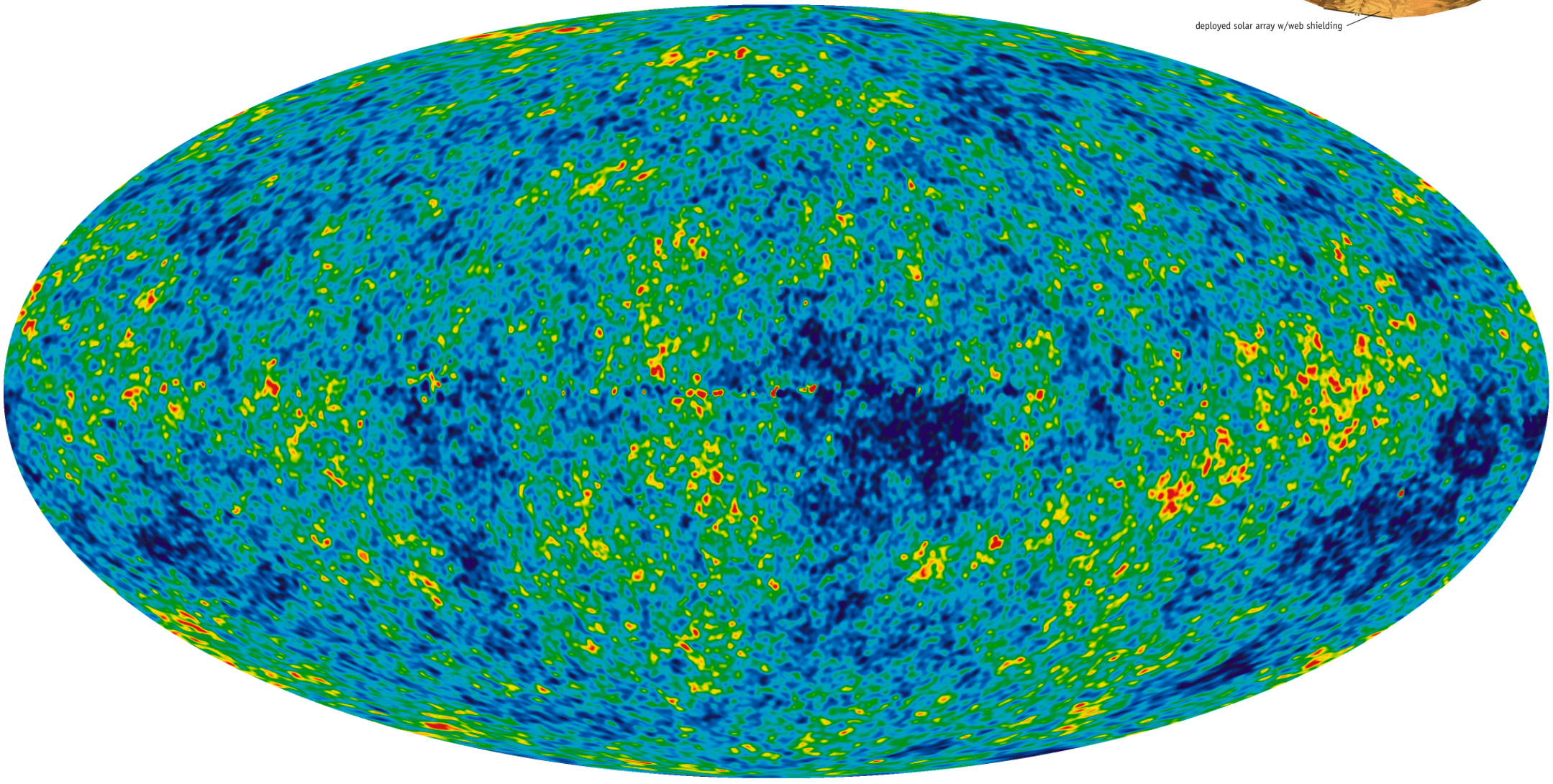

Spitzer "First Light"
COBE Cosmic Microwave Background
Hubble Deep Field
Microwaves
Infrared
Visible
BIG BANG
Dark Ages
First Light
Today
0 yrs
400,000 yrs
400 million yrs
13.7 billion yrs
Timeline of the Universe
Spitzer Space Telescope • IRAC

Cosmic Microwave Background (CMB)

Very uniform!

WMAP →





Few ten-thousands of a Kelvin fluctuation.

Cosmic Web

On the largest scales, single galaxies, groups, and clusters are most common along filamentary structures called the **cosmic web**.

Galaxies tend to avoid the **voids**.

Structure is natural consequence of gravitational collapse from Big Bang initial conditions, and can be simulated on a computer.

Cosmic web

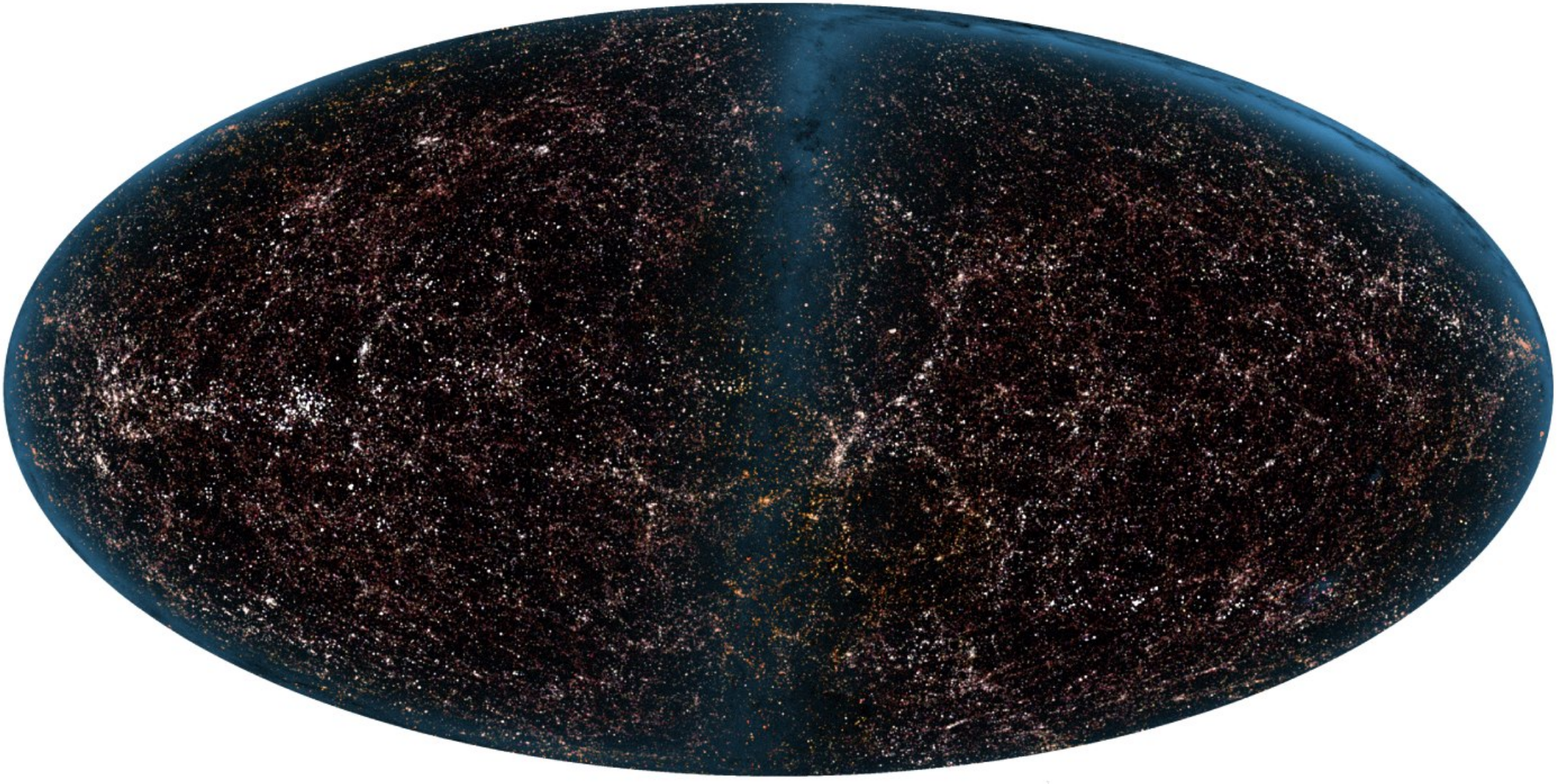
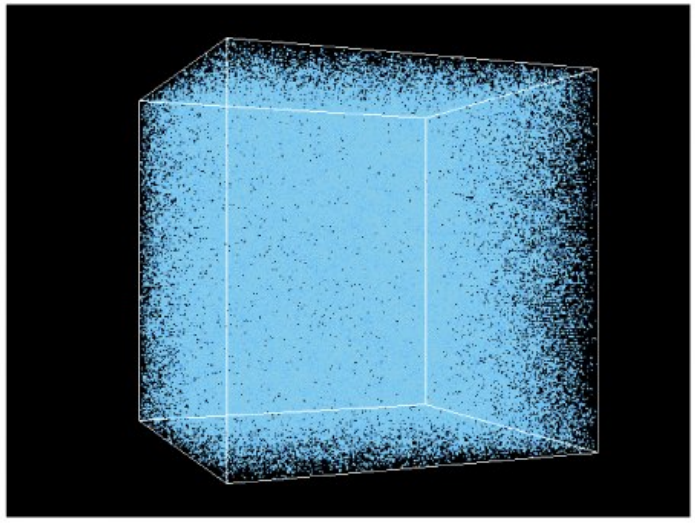
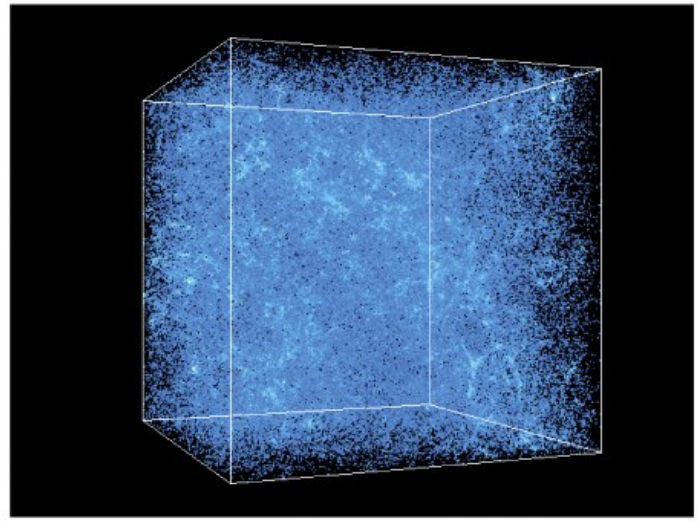


Figure 24-23
Universe, Eighth Edition

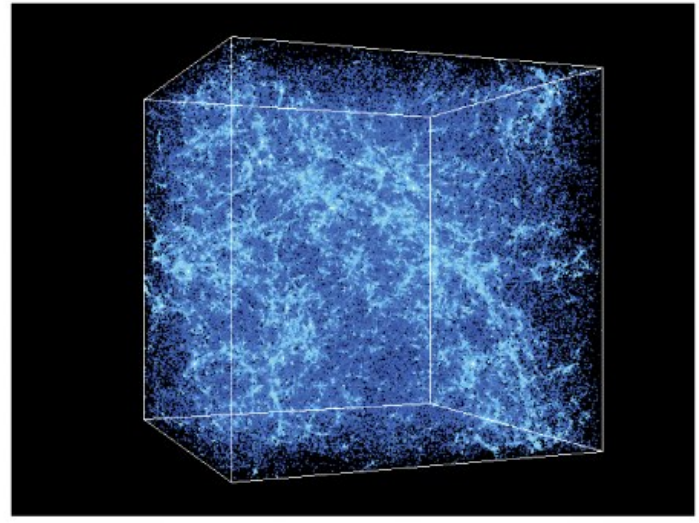
Cosmological matter simulation



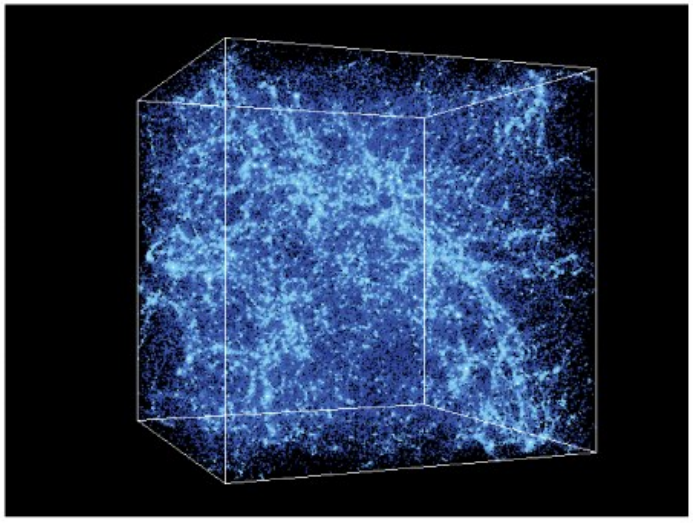
$z = 27.36$ Universe 120 million years old



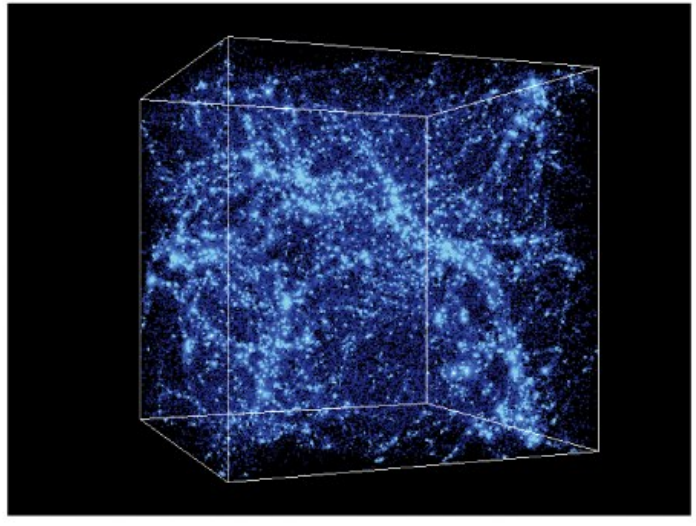
$z = 9.83$ Universe 490 million years old



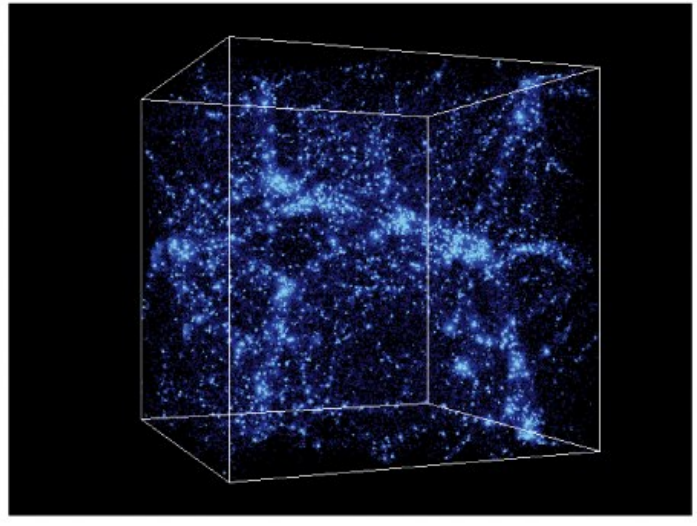
$z = 4.97$ Universe 1.2 billion years old



$z = 2.97$ Universe 2.2 billion years old

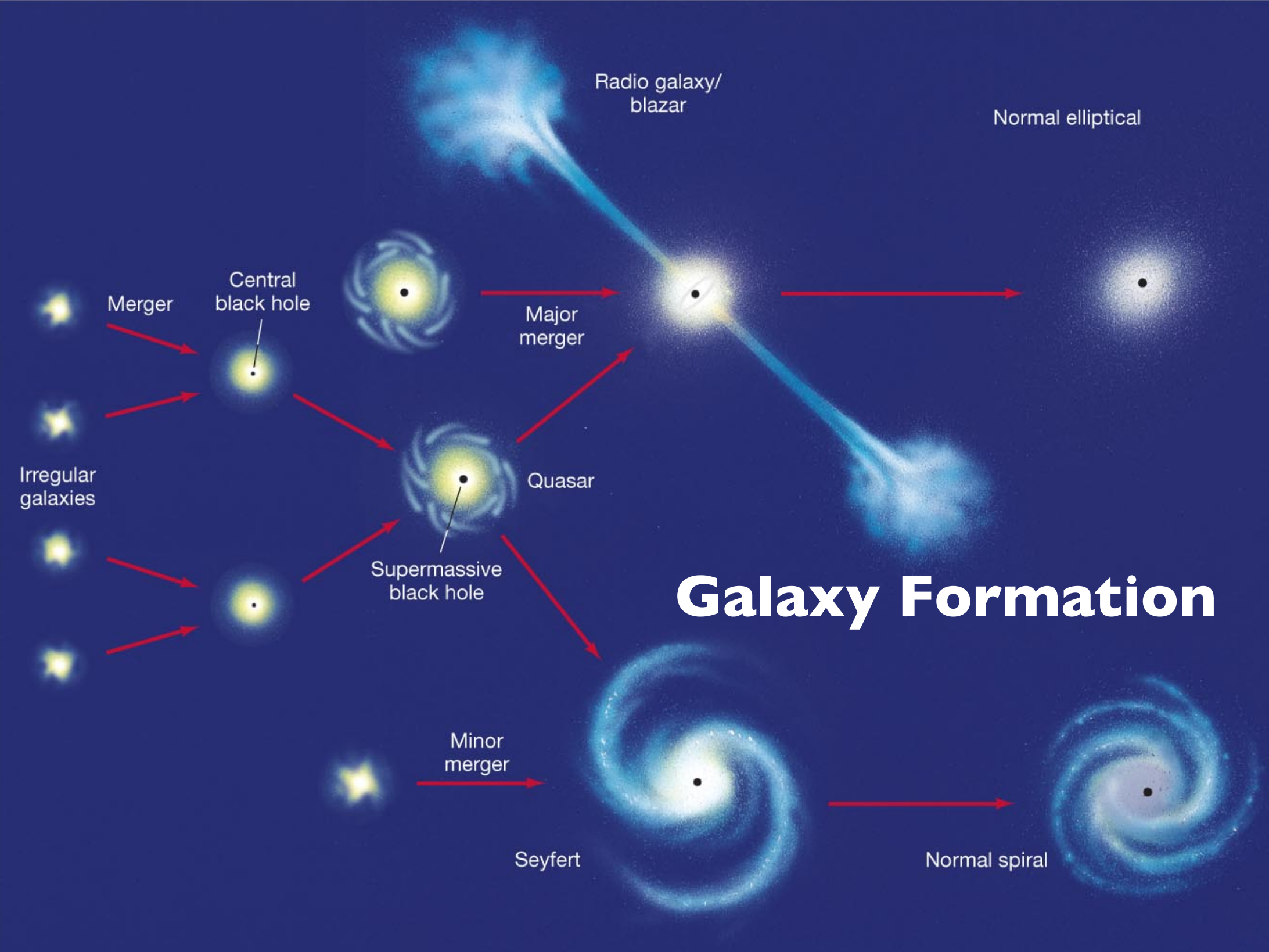


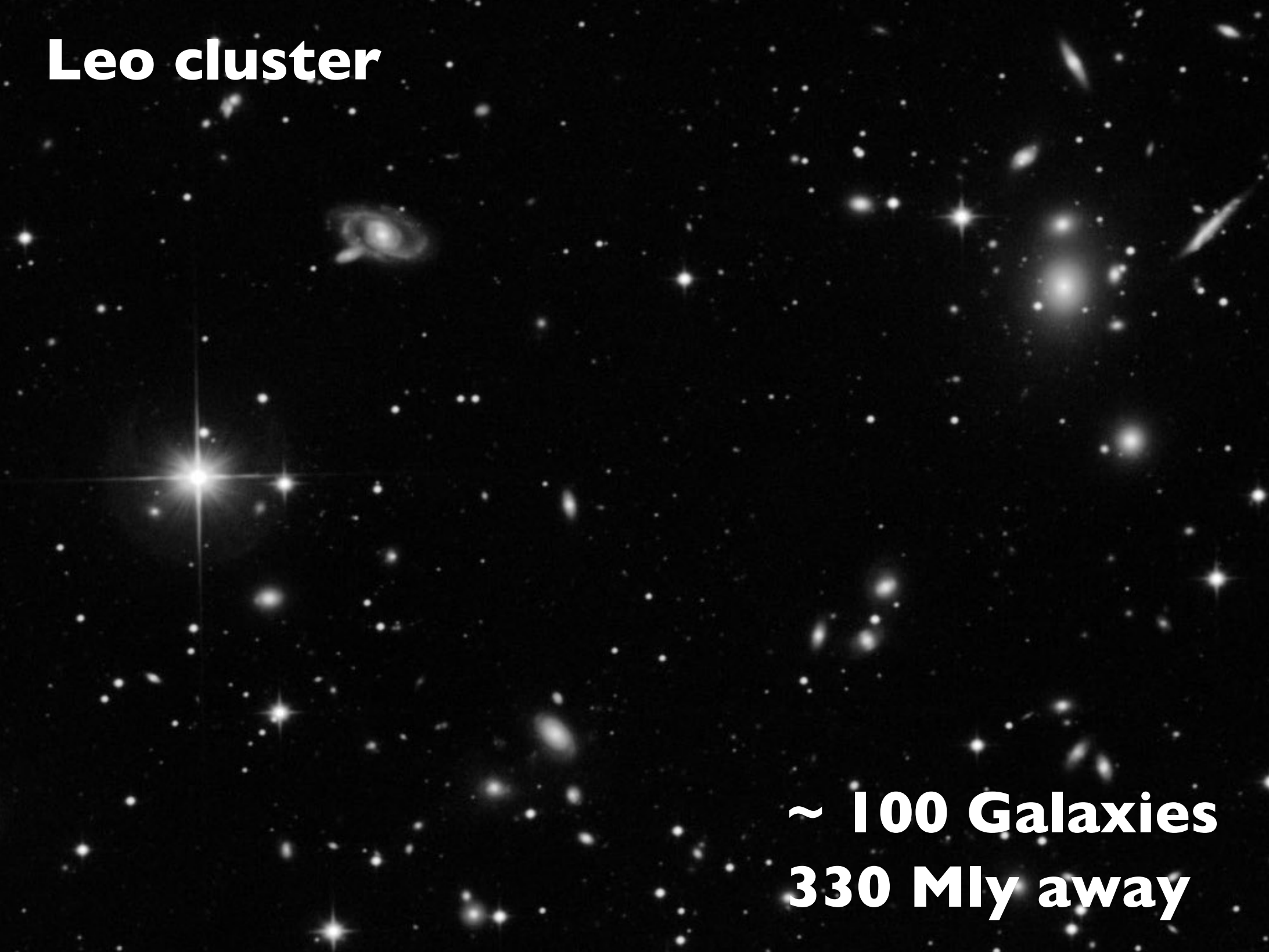
$z = 0.99$ Universe 6.0 billion years old



$z = 0.00$ Universe 13.7 billion years old

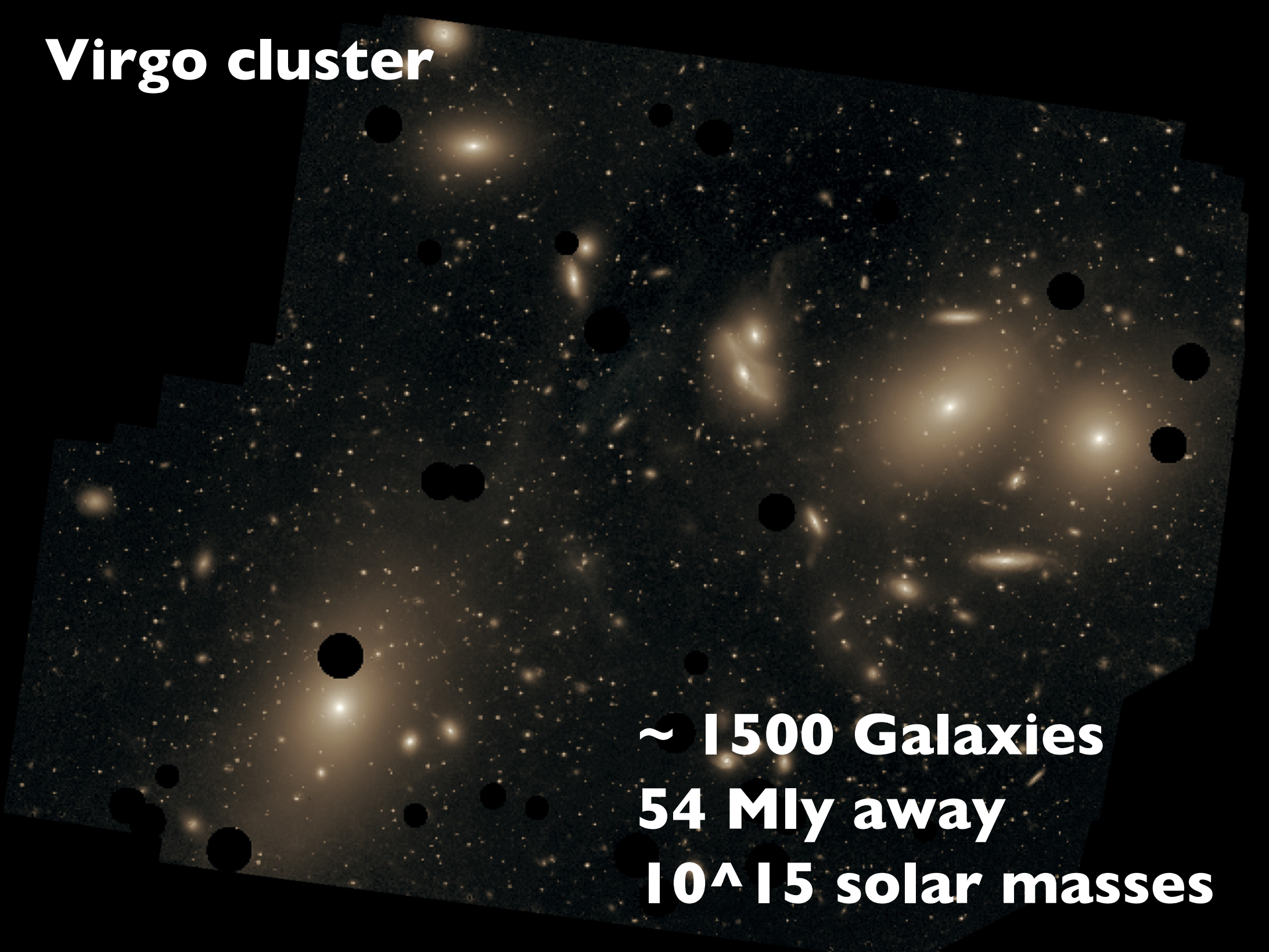
Figure 27-15
Universe, Eighth Edition


Radio galaxy/
blazar
Normal elliptical
Merger
Central
black hole
Major
merger
Irregular
galaxies
Quasar
Supermassive
black hole
Galaxy Formation
Minor
merger
Seyfert
Normal spiral


Leo cluster
~ 100 Galaxies
330 Mly away


Coma cluster
~ 1000 galaxies
320 Mly away
10^14-10^15 solar masses

Virgo cluster



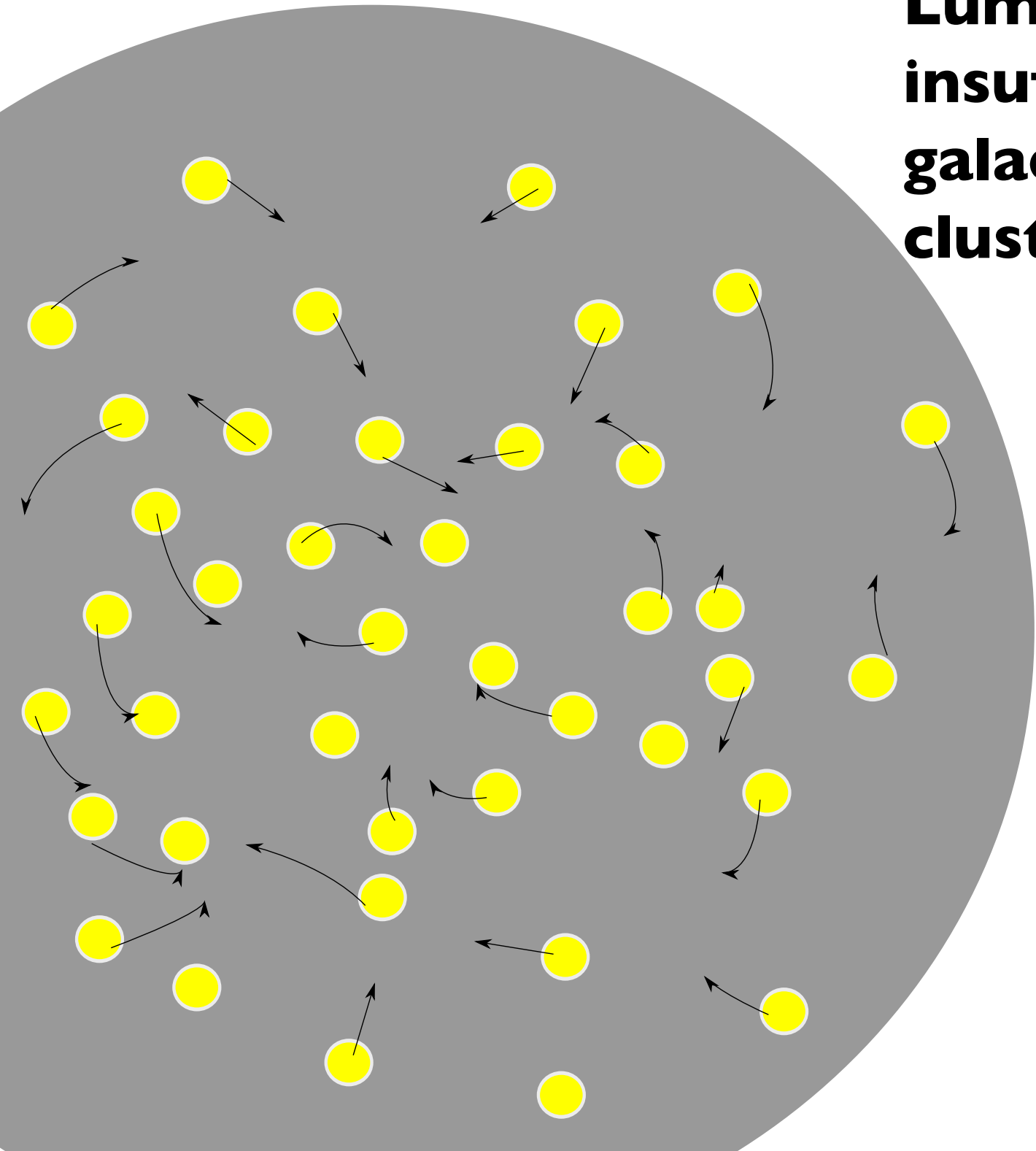
~ 1500 Galaxies
54 Mly away
10^15 solar masses

The Dark-Matter Problem

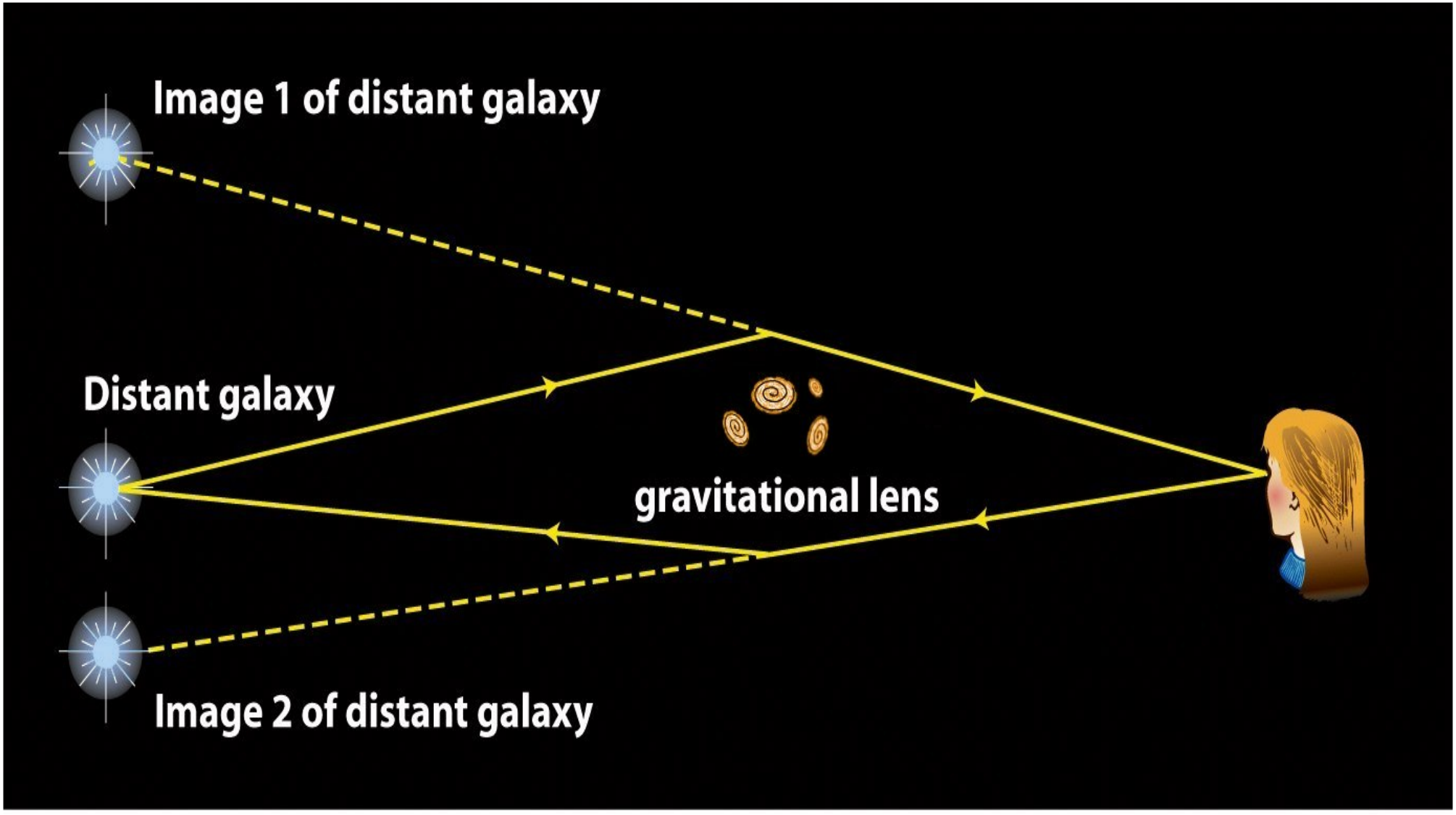
- Visible mass in *galaxy clusters* too small for galaxy motions.

Need large amounts of **dark matter.**

Gravitational lensing by a cluster gives information about the distribution of matter in the foreground cluster.



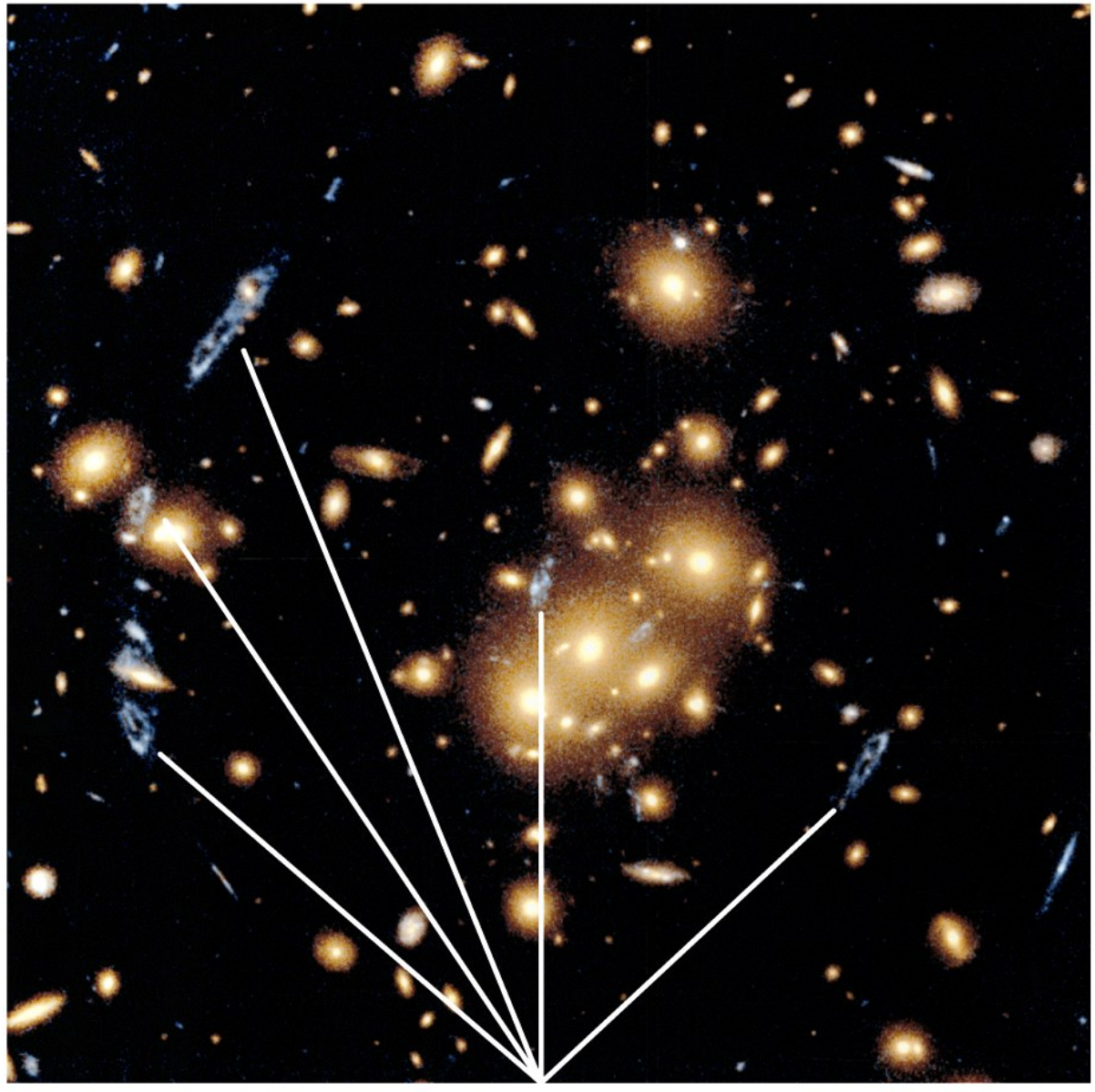
Luminous matter insufficient to explain galactic motions in clusters



How gravitational lensing happens

Figure 24-30a
Universe, Eighth Edition

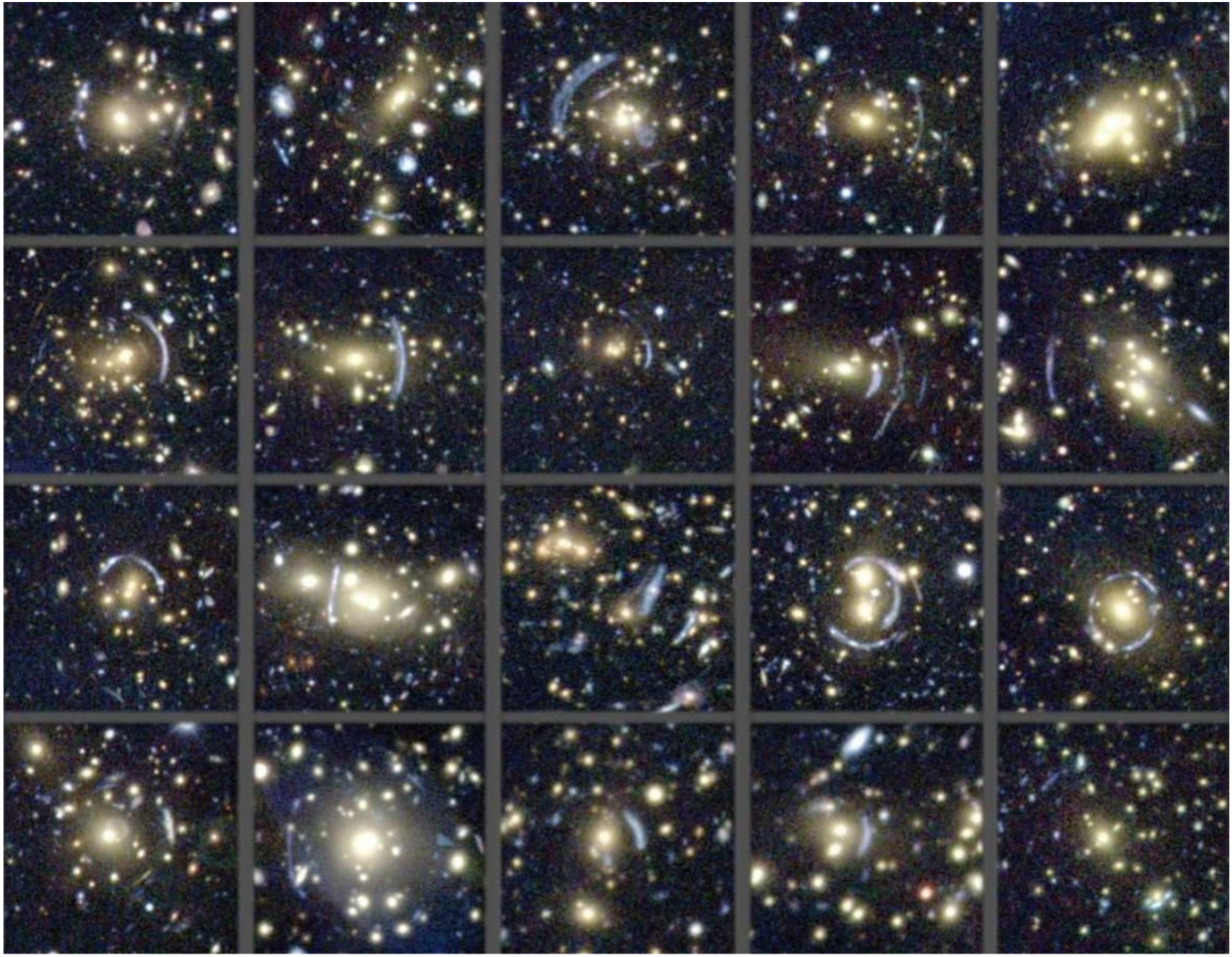
Lensing

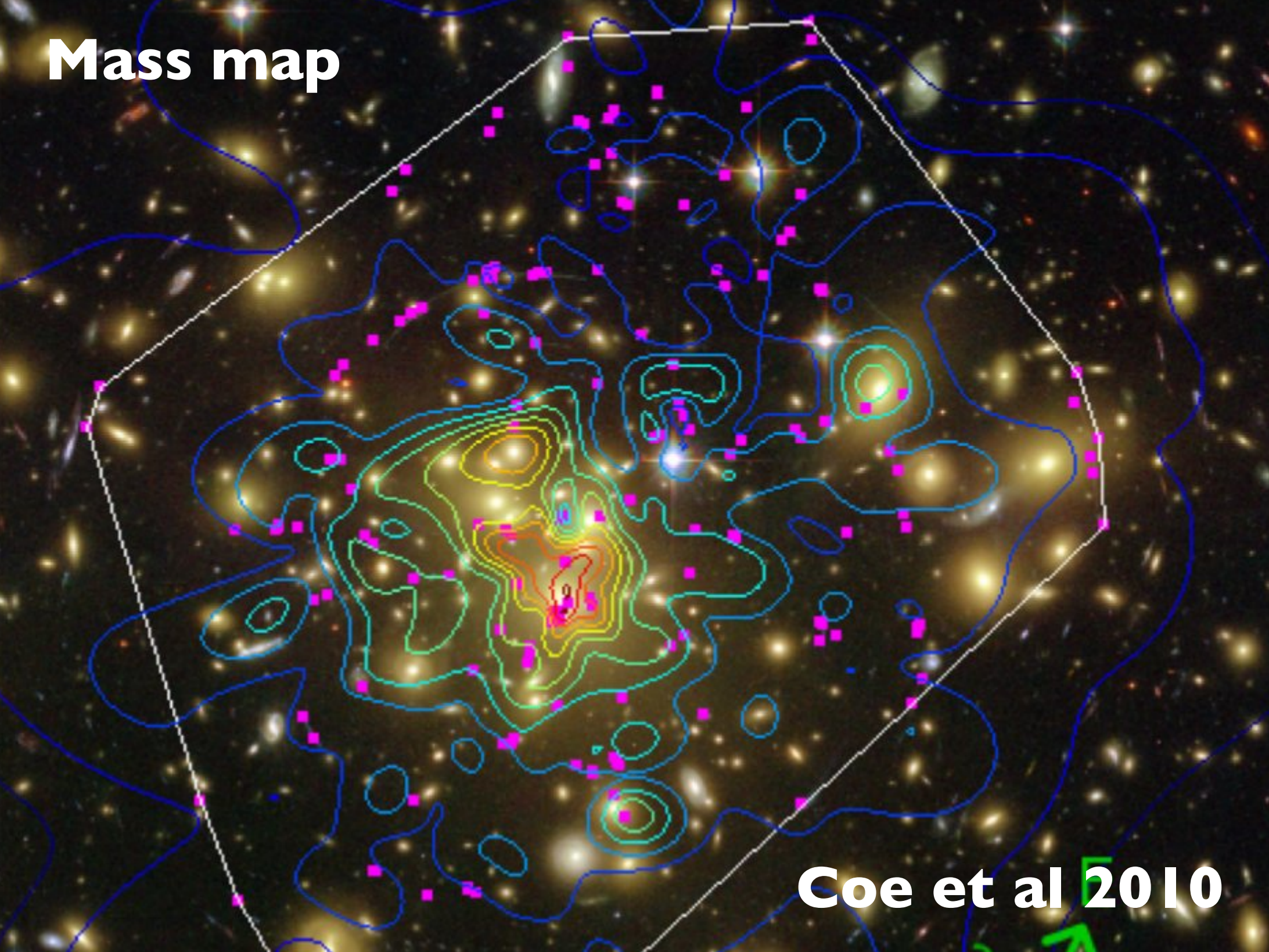


All of these blue arcs are images of the same distant galaxy.

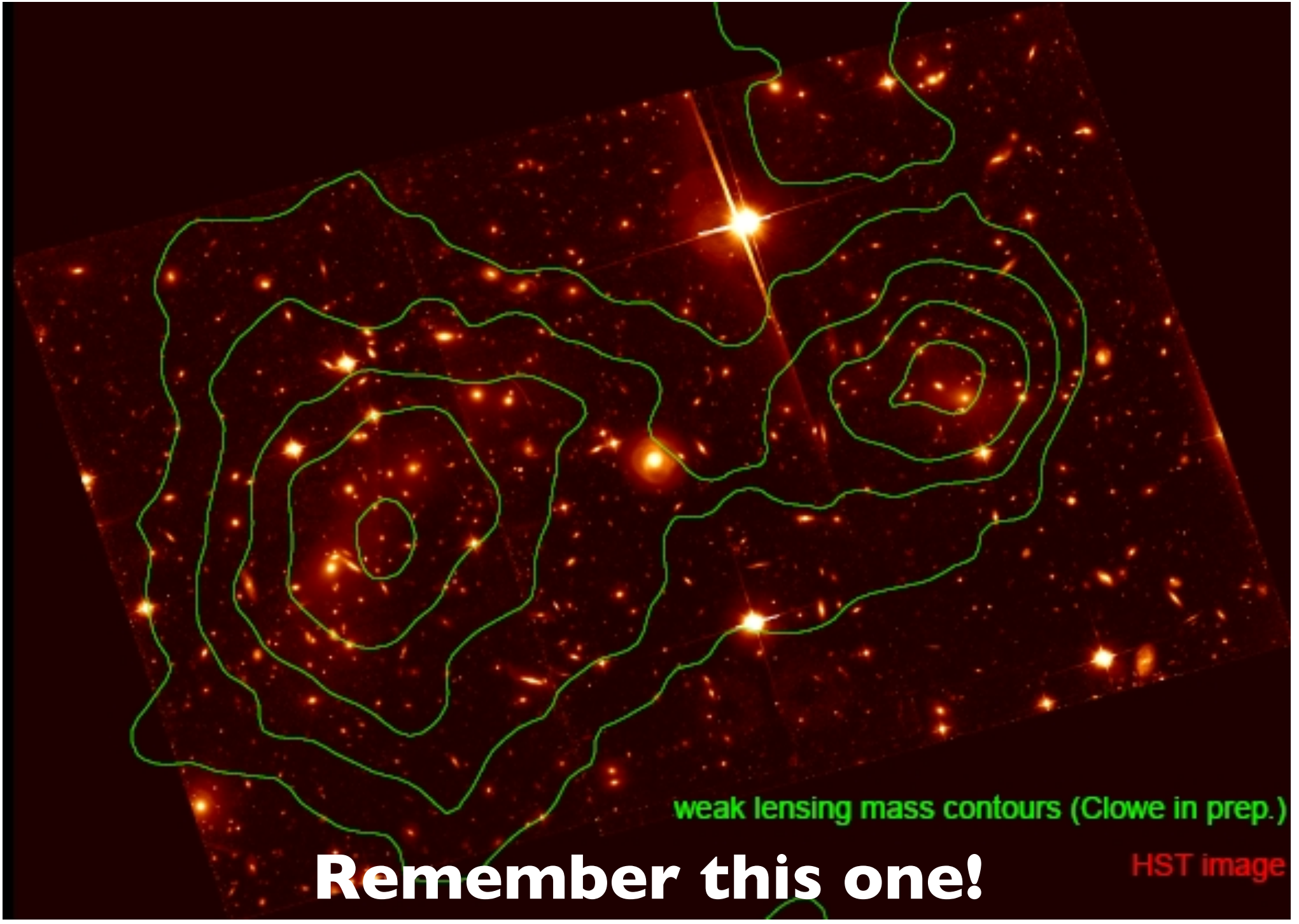
Figure 24-31
Universe, Eighth Edition

Clusters with strong lensing arcs




Mass map
Coe et al 2010

Lensing mass map



Remember this one!

Cluster X-rays

The large accumulation of matter in a galaxy cluster makes a very **deep gravitational potential well**.

Gas falls in from outside, collides with cluster gas, heats to **millions of degrees**.

Glows in **X-rays**.

X-rays observed by satellite

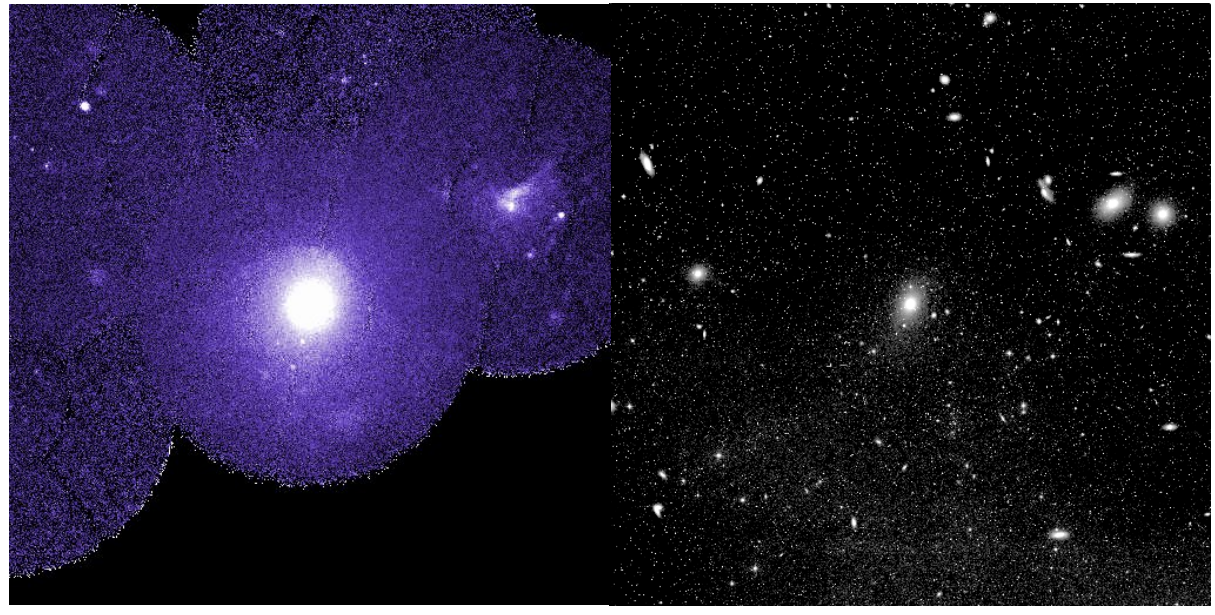
XMM-Newton

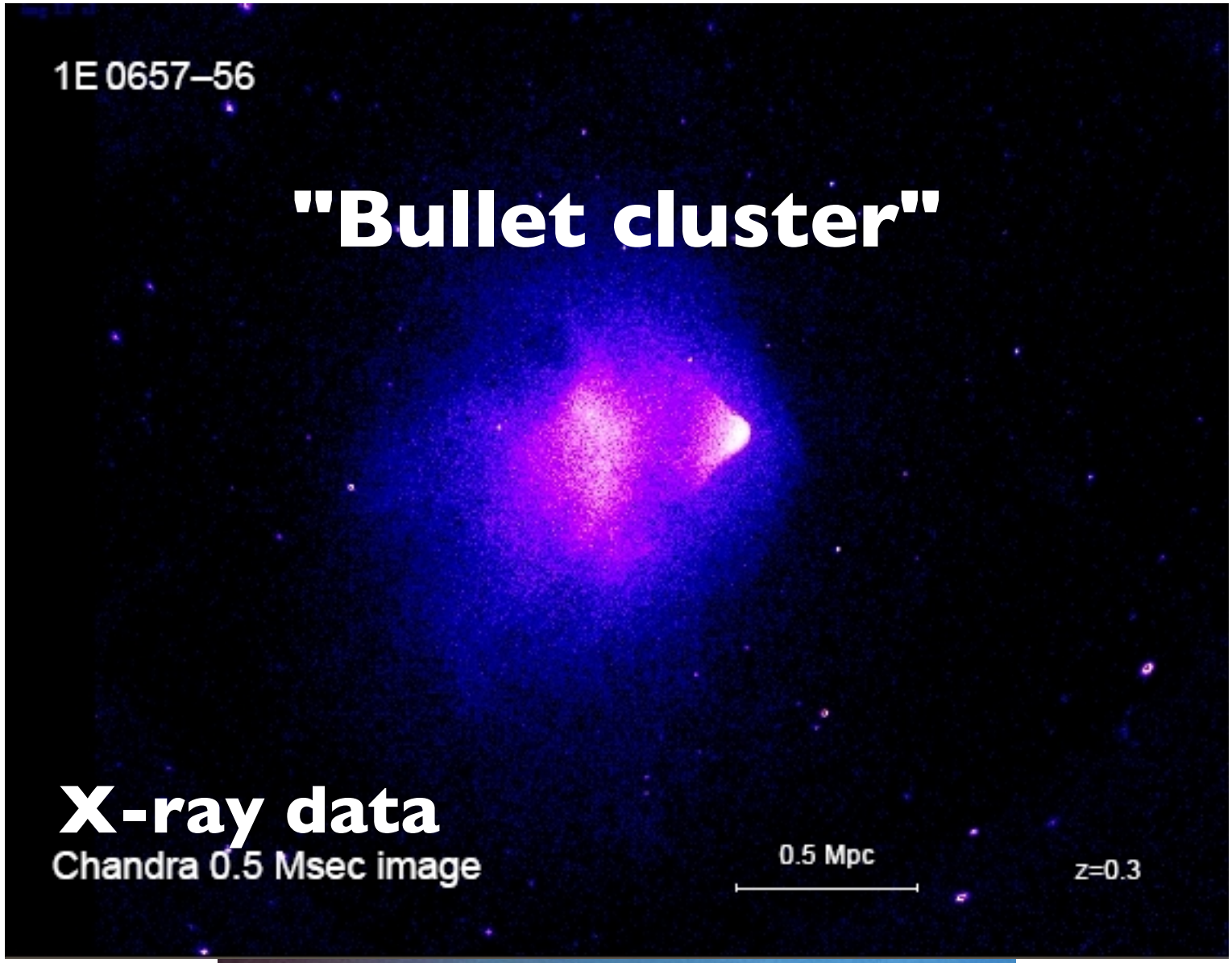
ROSAT

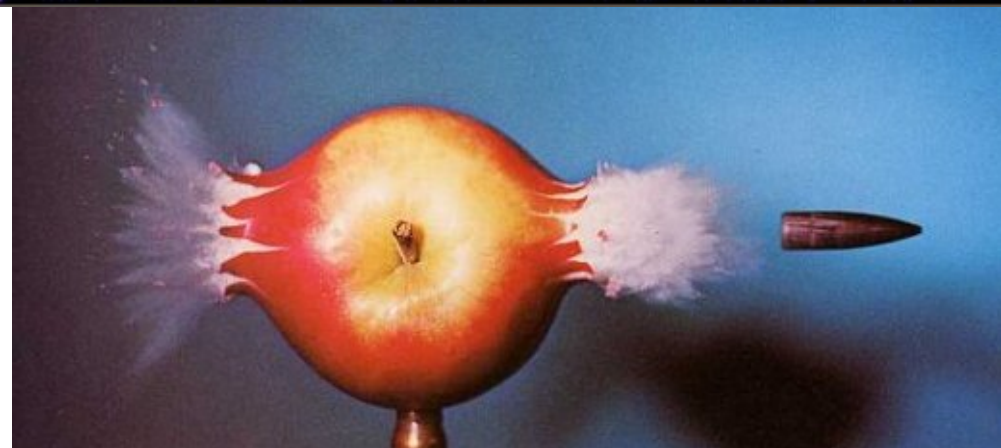
Integral...

Coma cluster

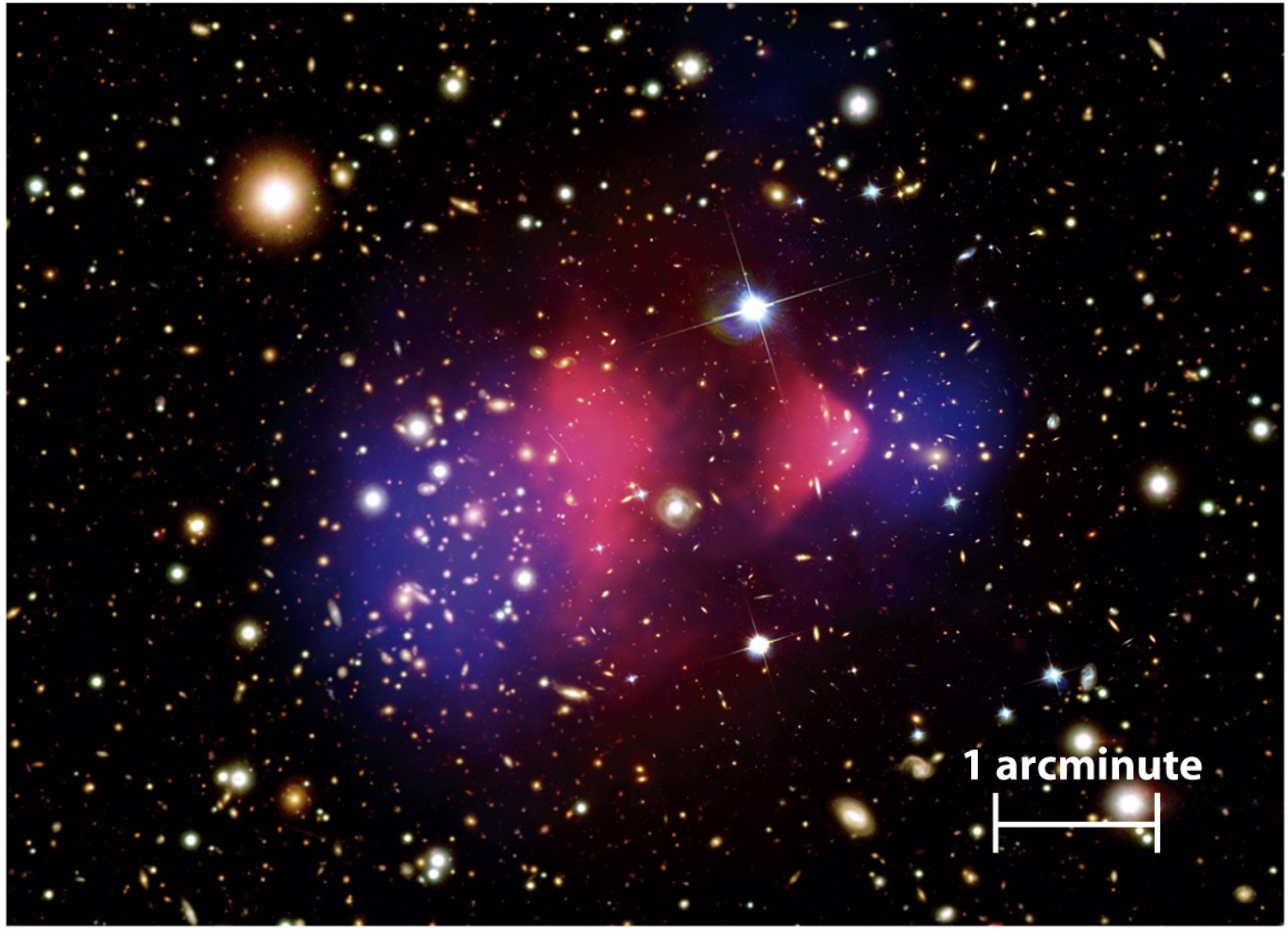
Virgo cluster




1E 0657–56
"Bullet cluster"
X-ray data
Chandra 0.5 Msec image
0.5 Mpc
z=0.3



Bullet cluster

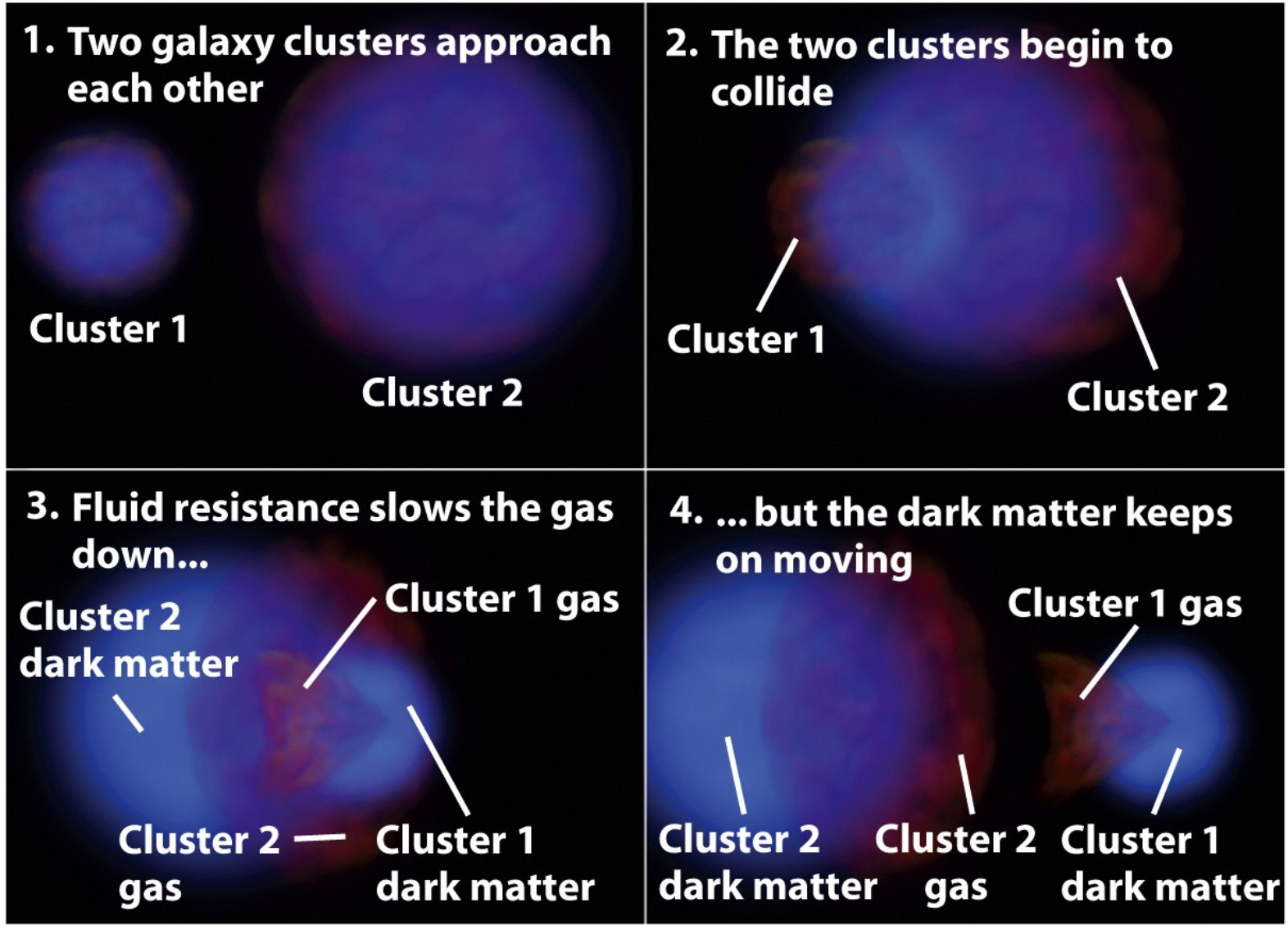


Composite image of galaxy cluster 1E0657-56 showing visible galaxies, X-ray-emitting gas (red) and dark matter (blue)

R I V U X G

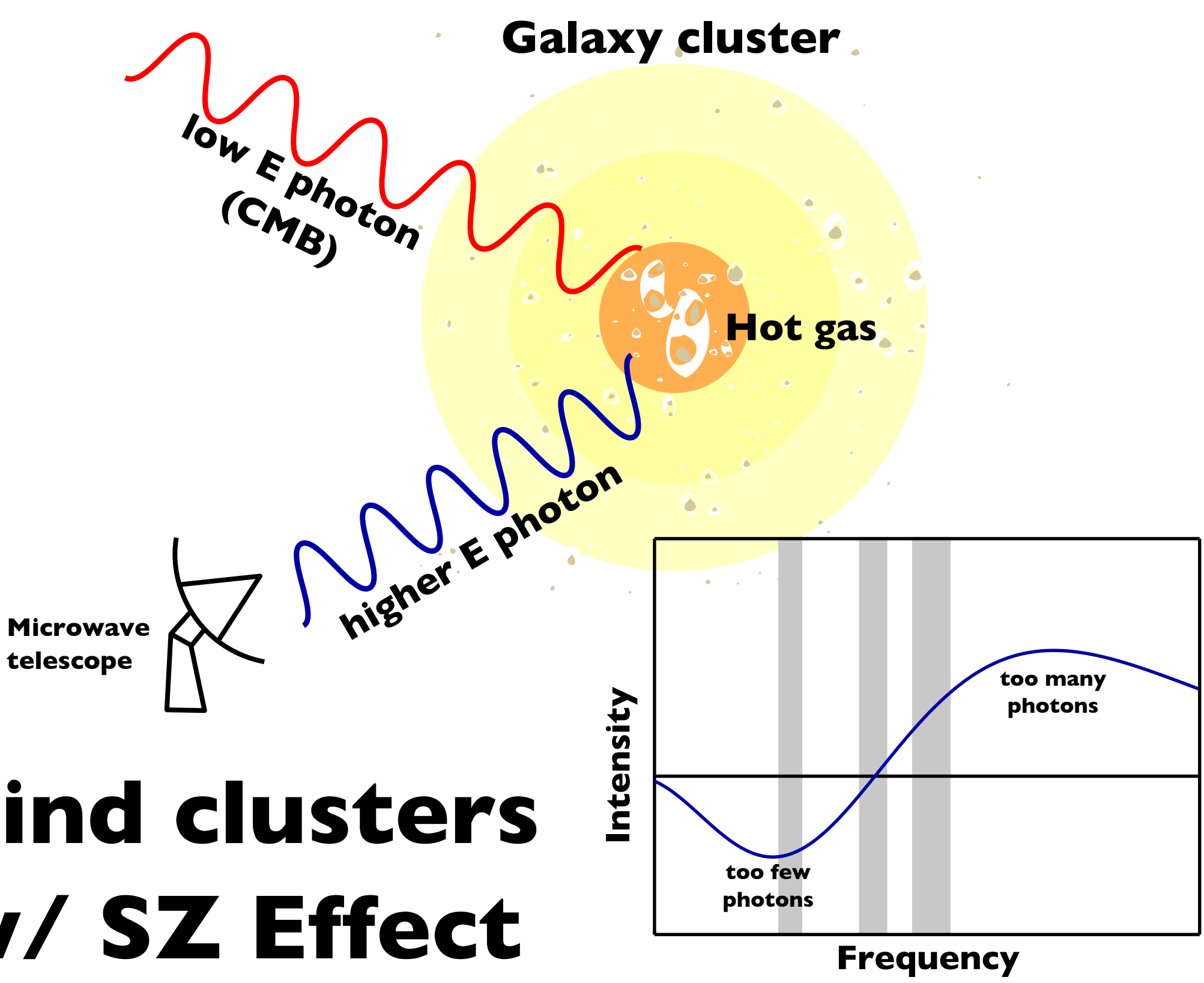
Figure 24-32a
Universe, Eighth Edition

Bullet cluster model



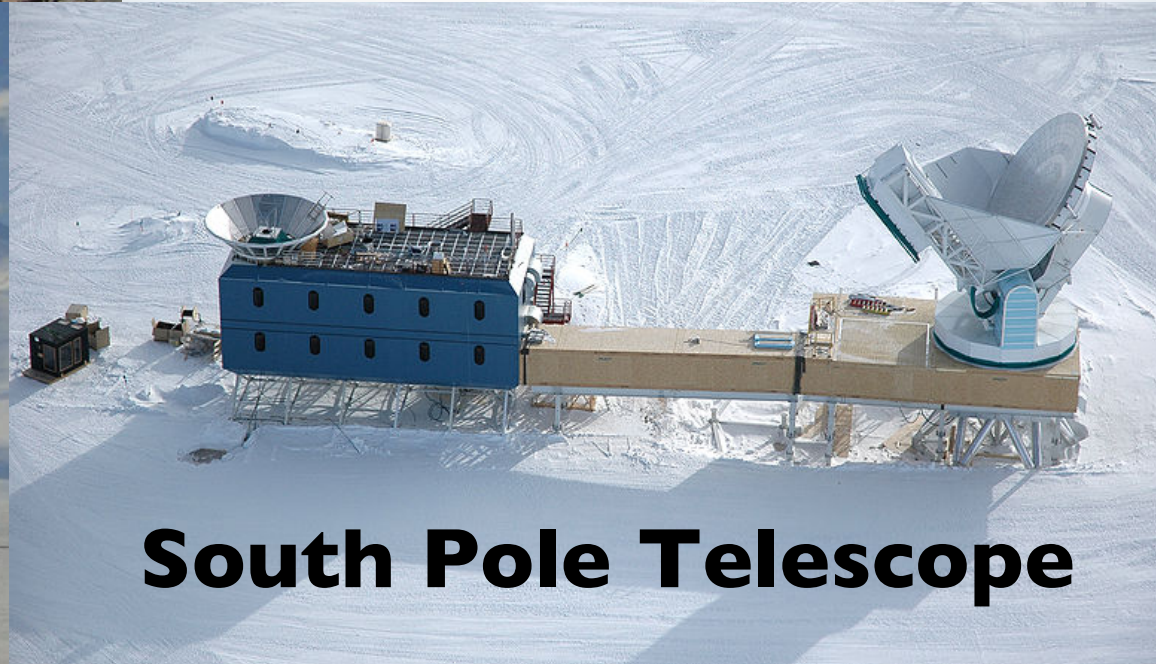
A model of how the gas and dark matter in 1E0657-56 could have become separated

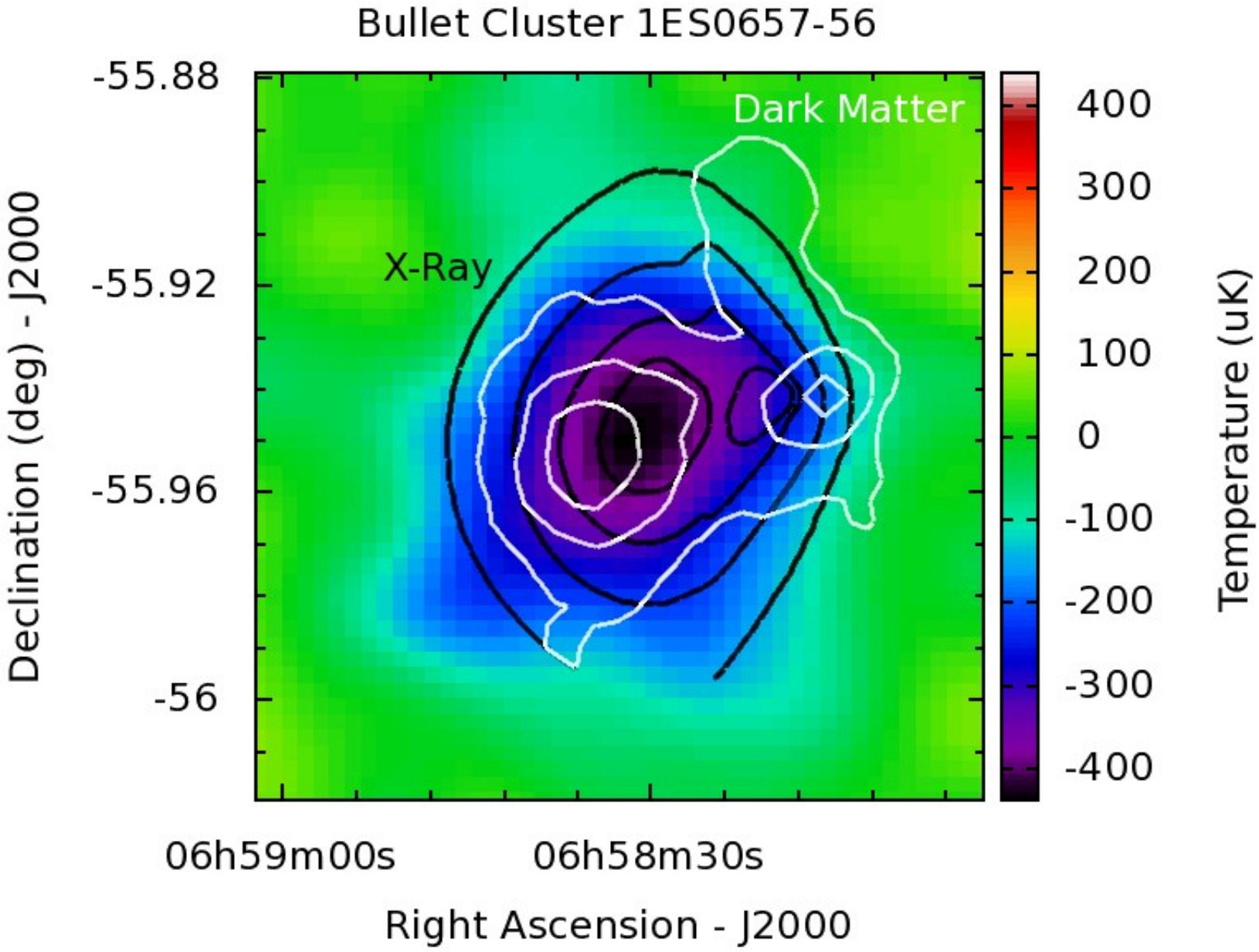
Figure 24-32b
Universe, Eighth Edition



Find clusters w/ SZ Effect

Ground / balloon based CMB telescopes




Bullet Cluster 1ES0657-56
Dark Matter
X-Ray
-55.88
-55.92
-55.96
-56
Declination (deg) - J2000
06h59m00s
06h58m30s
Right Ascension - J2000
400
300
200
100
0
-100
-200
-300
-400
Temperature (uK)

From ACT

Planck - Microwave background

Next generation satellite mission.

All-sky, compared to WMAP:

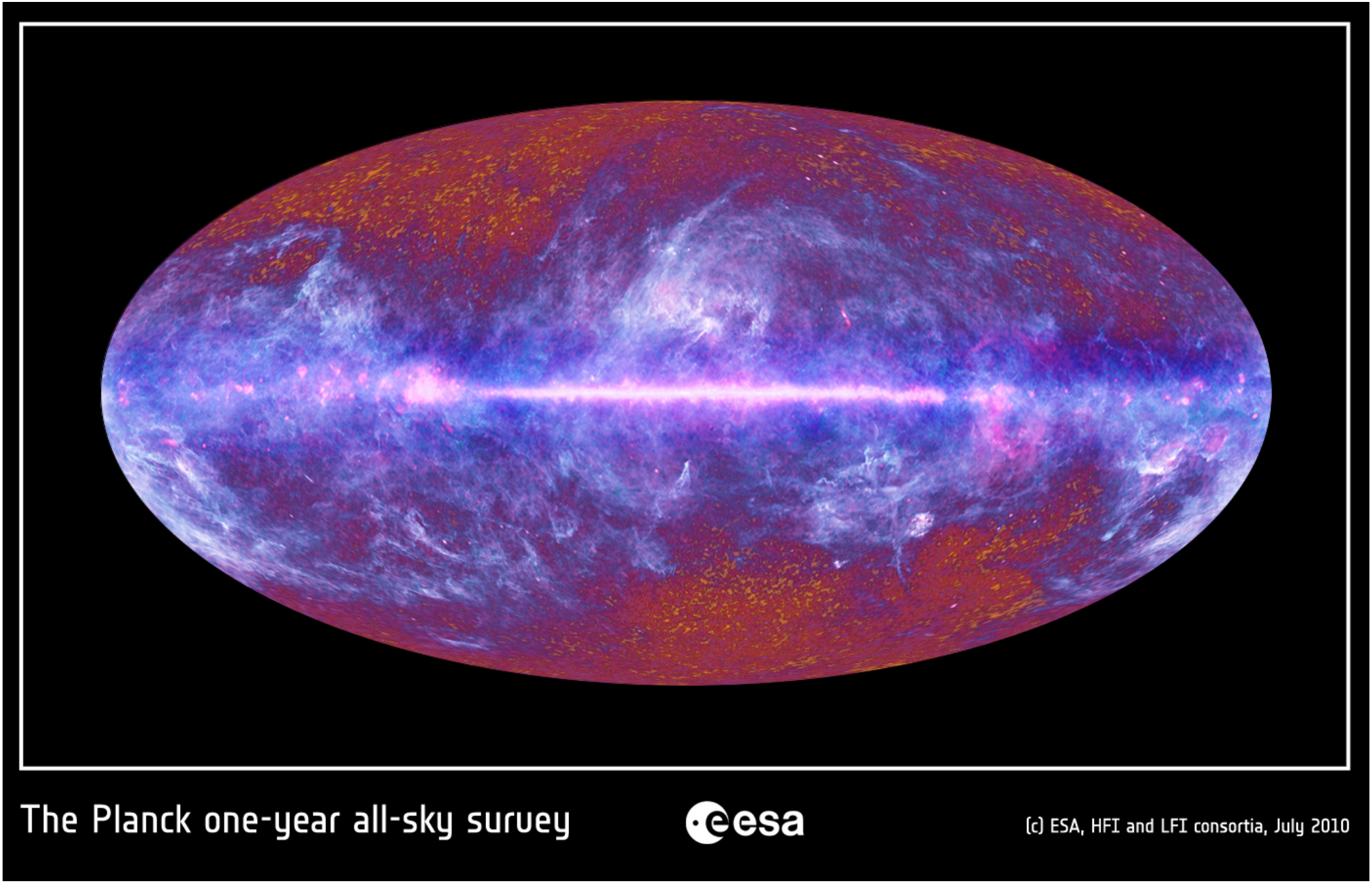
- **Wider frequency coverage.**
- **Lower noise.**
- **Higher resolution.**
- **Better polarization sensitivity.**

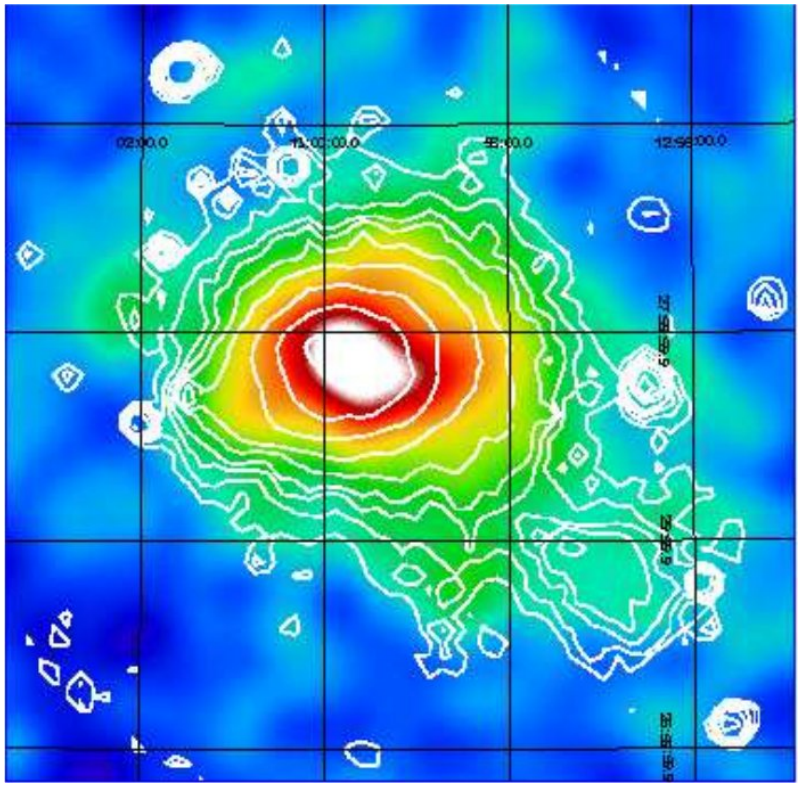
ESA/NASA mission, large collaboration.

Launched: May 14, 2009

Data releases: 2011-2013.

Preview from Planck





Coma in SZ,
by Planck

Planck early data:

~30 New cluster candidates,

~ 20 confirmed

ACT + SPT (to date): ~ 50-60 confirmed