Cosmology and Large Scale Structure

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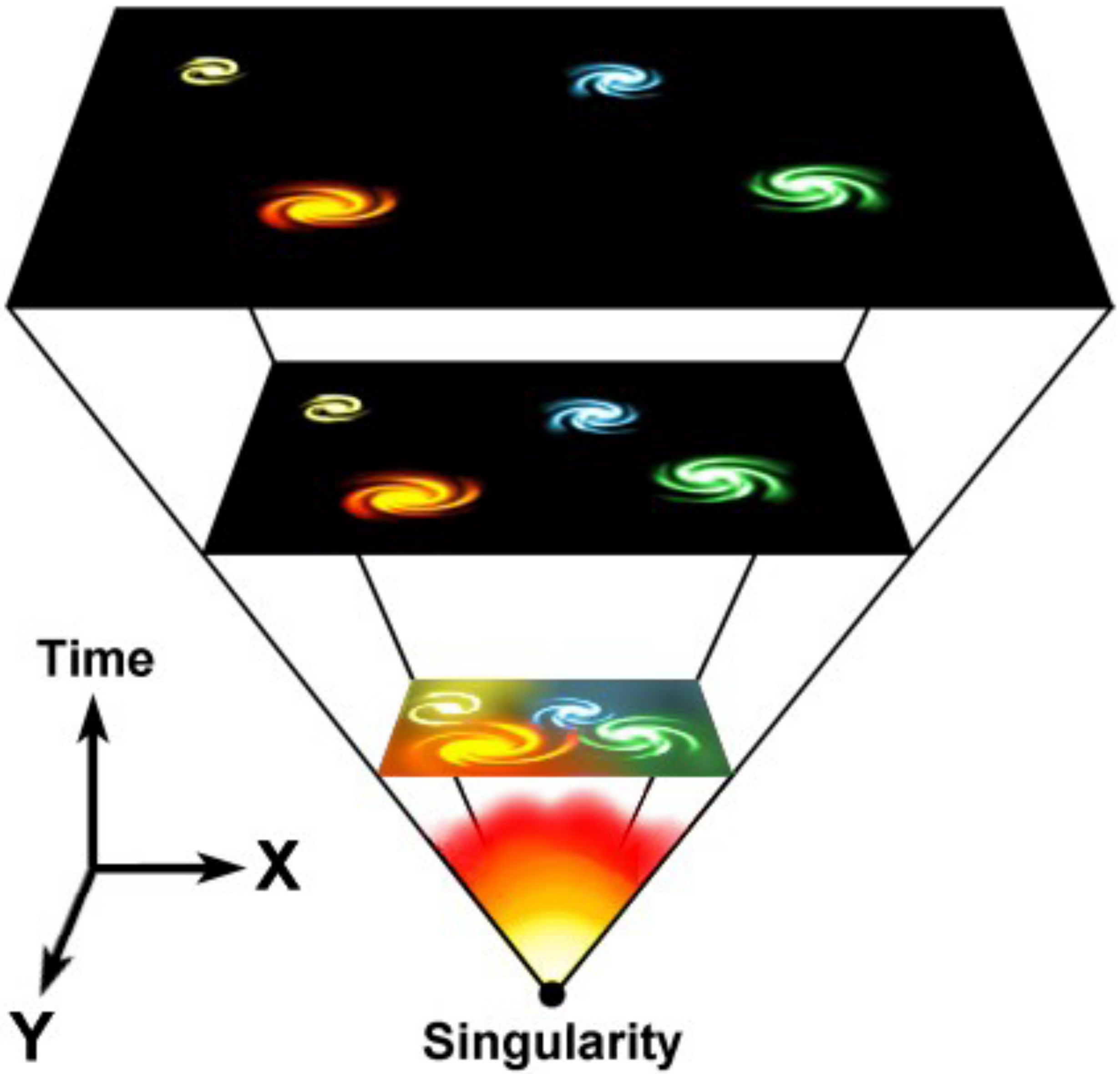
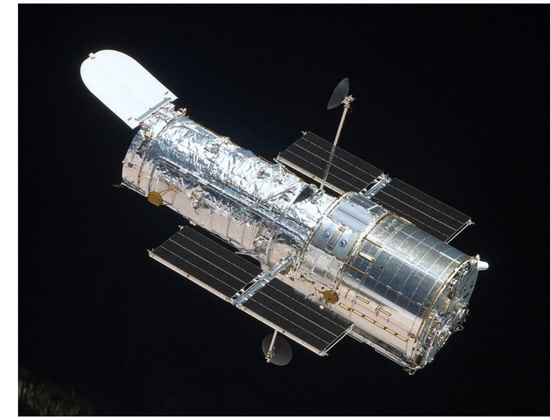
Dept. of Physics

Expanding universe & the Big Bang



Big Bang
Cosmic inflation
Origin of fluctuations
Particles form
Ordinary matter particles are coupled to light and dark matter particles start building structures
Recombination
Ordinary matter particles decouple from light and the Cosmic Microwave Background is released
Dark ages
Ordinary matter particles fall into the structures created by dark matter
First stars & galaxies
Galaxy evolution
Clusters of galaxies and superclusters form
Today
0
10^{-32} seconds
10^{-30} seconds
1 second
100 seconds
1 year
100 years
380 000 years
200 million years
1 billion years
10 billion years
13.82 billion years

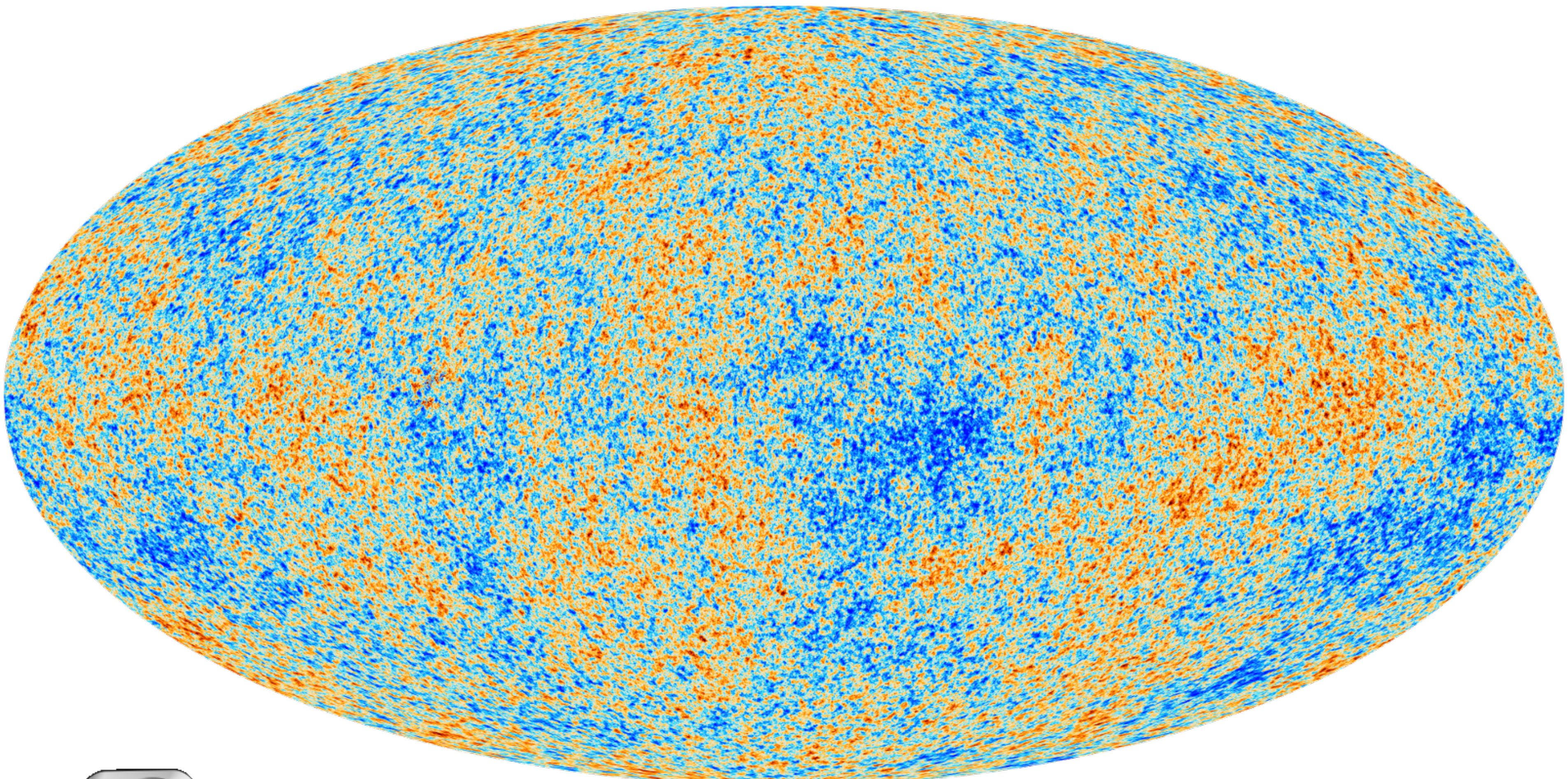


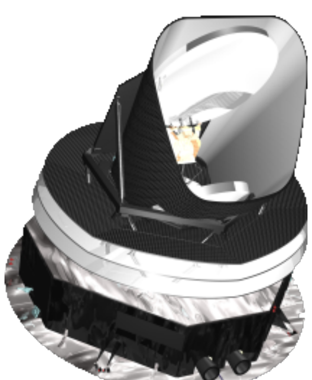
In Fornax, 11.0 $arcmin^2$

1 mm^2 @ 1 m

13 million such patches to cover sky.

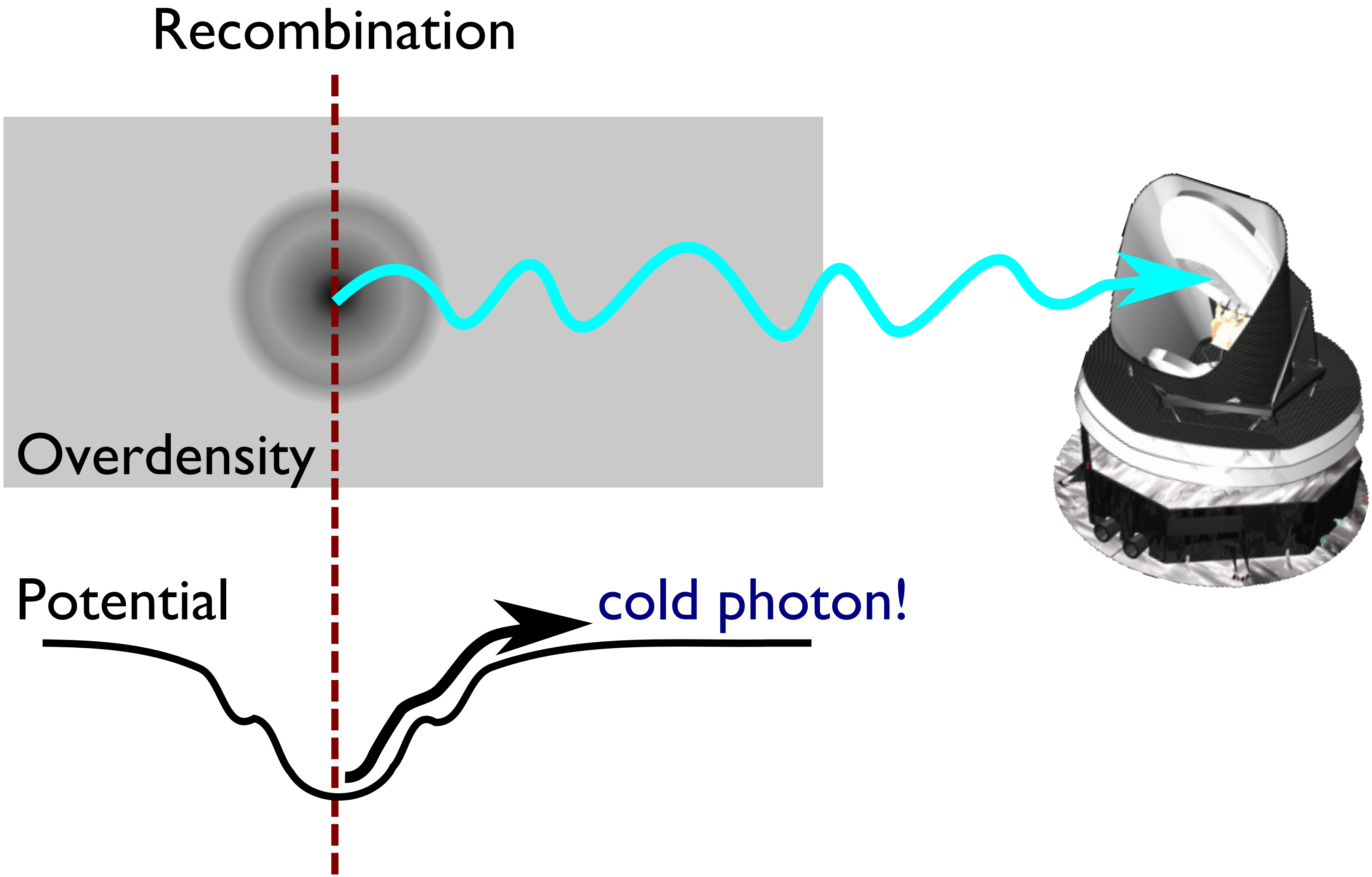
CMB fluctuations





~ few hundred μK around mean *T*

Probing gravitational potential



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

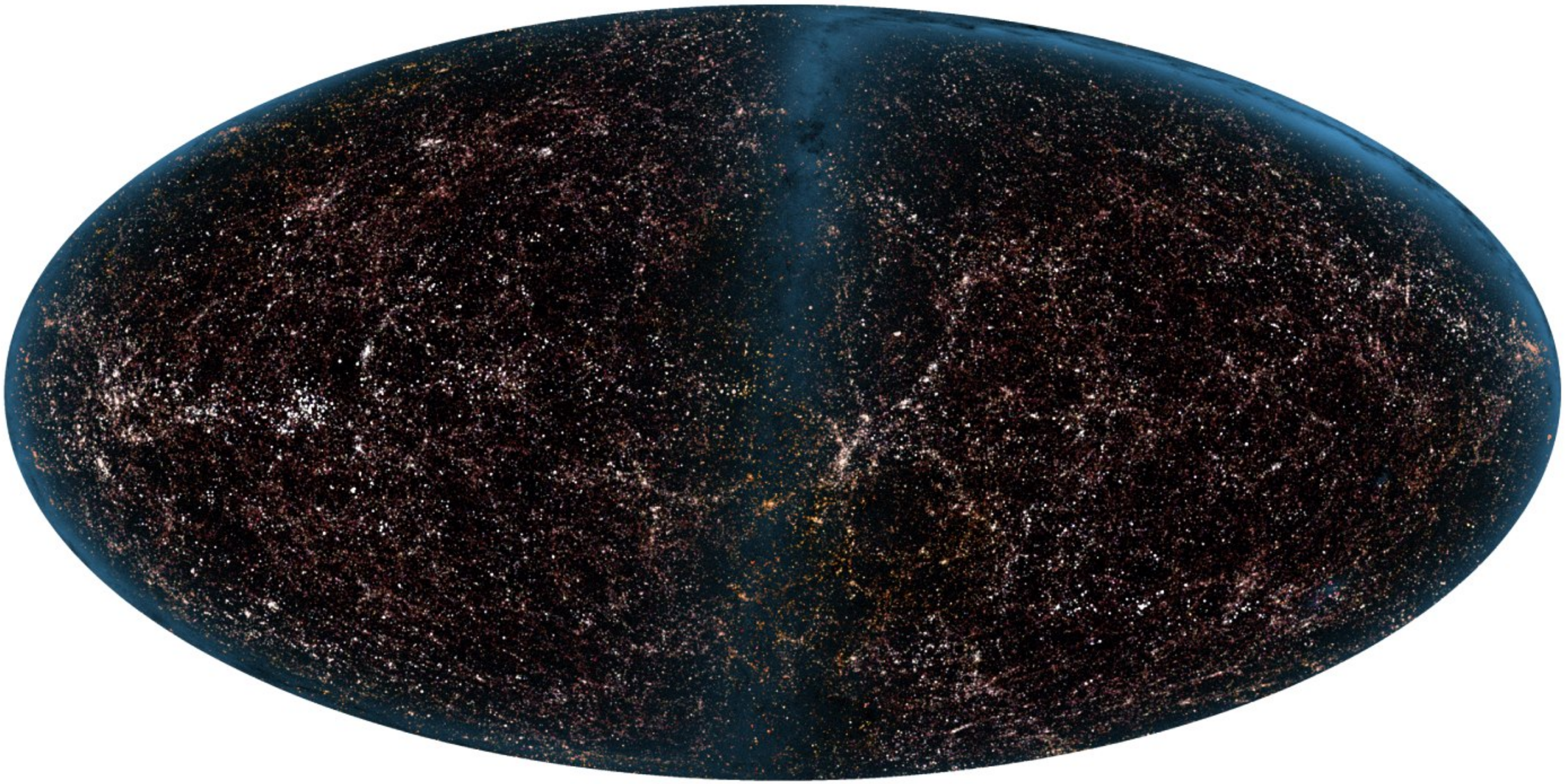


Figure 24-23
Universe, Eighth Edition

Cosmological matter simulation

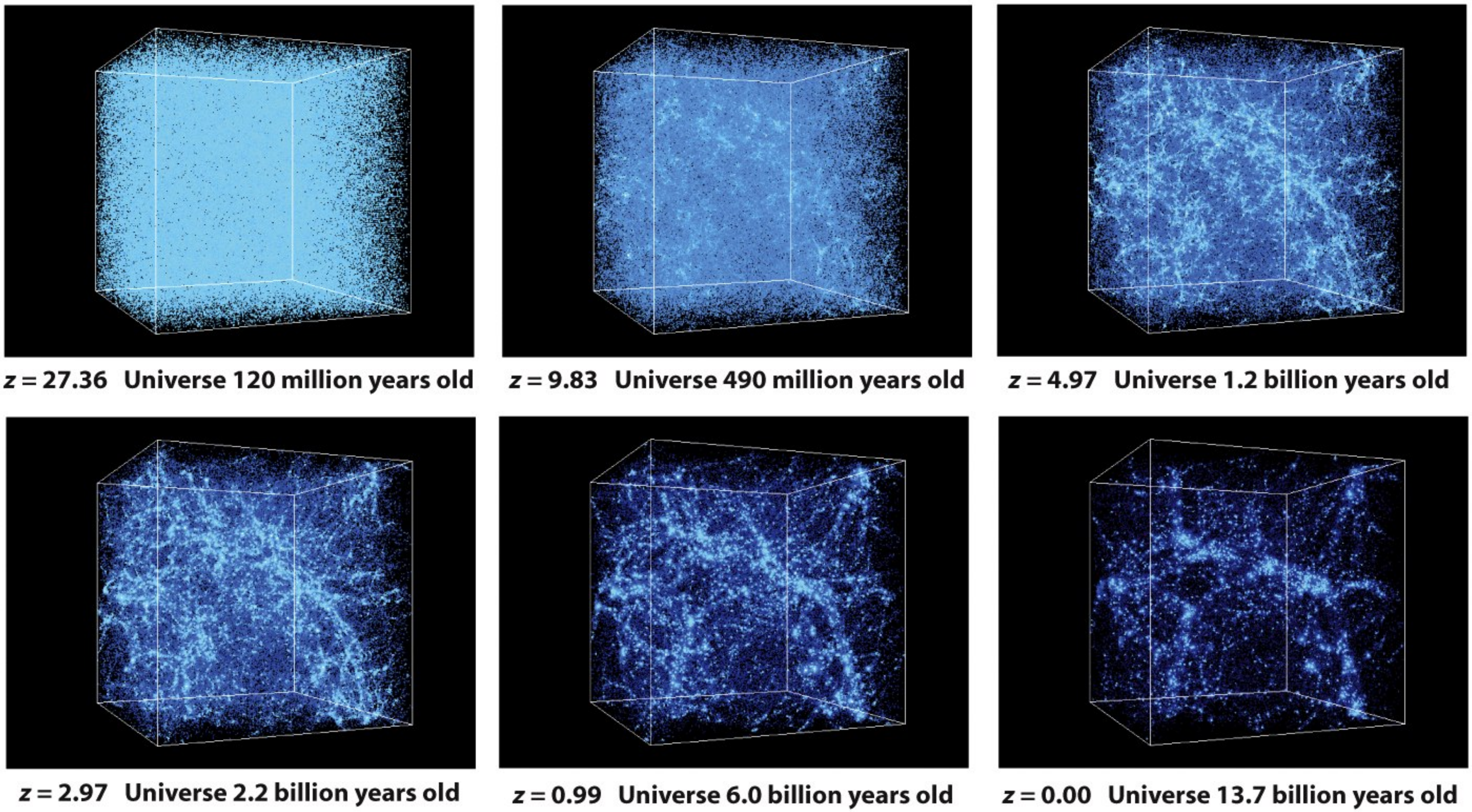
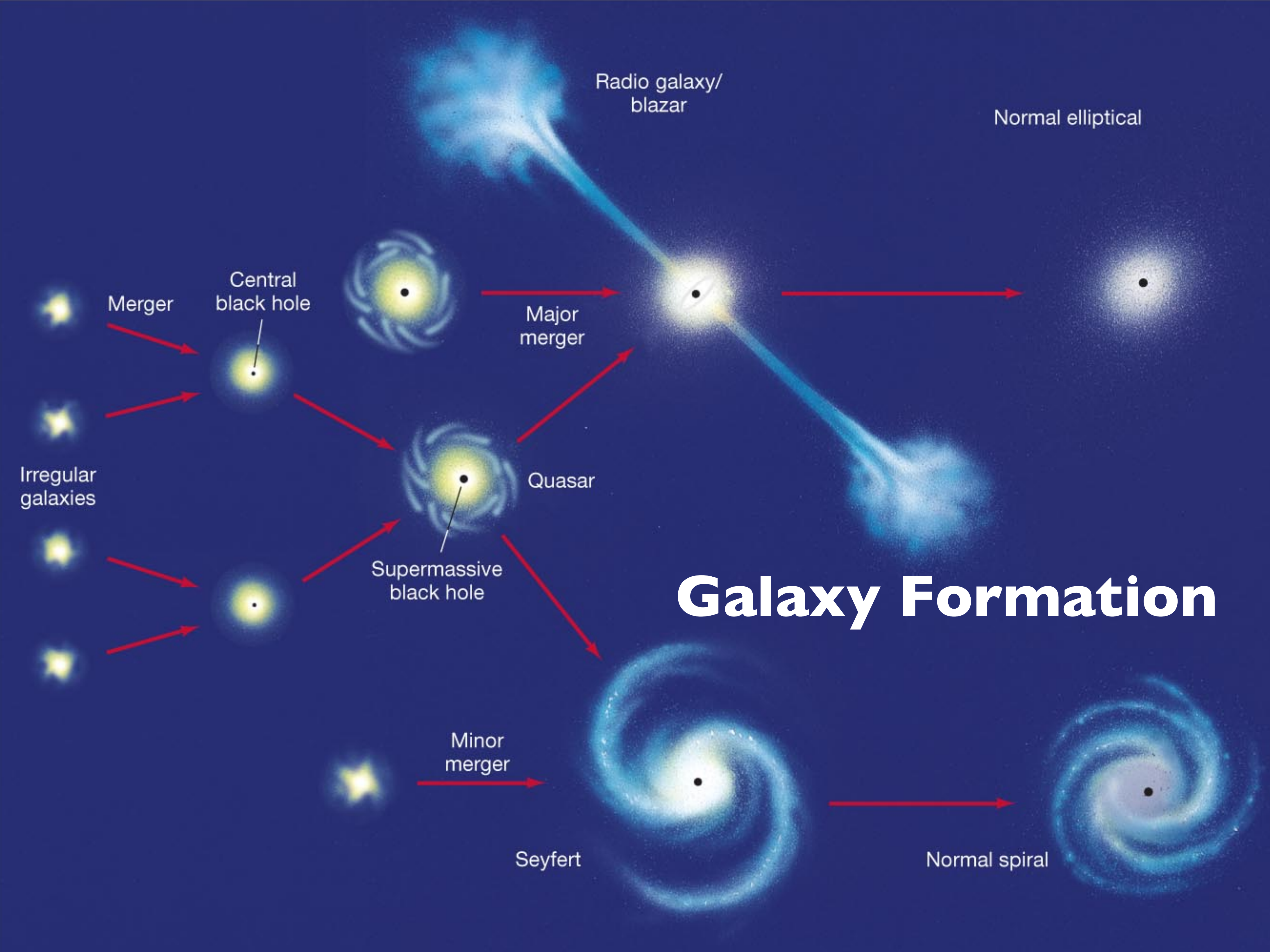
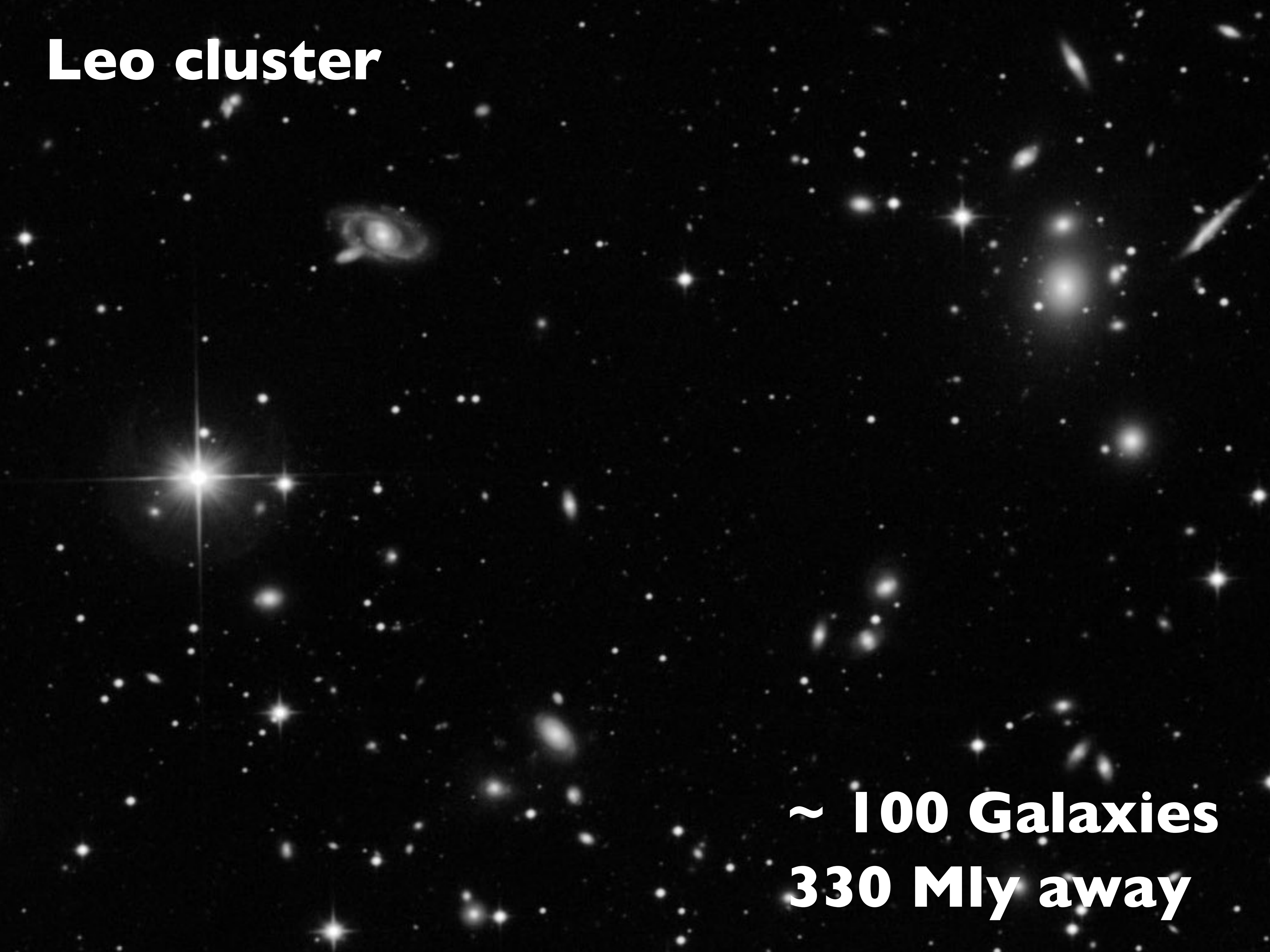


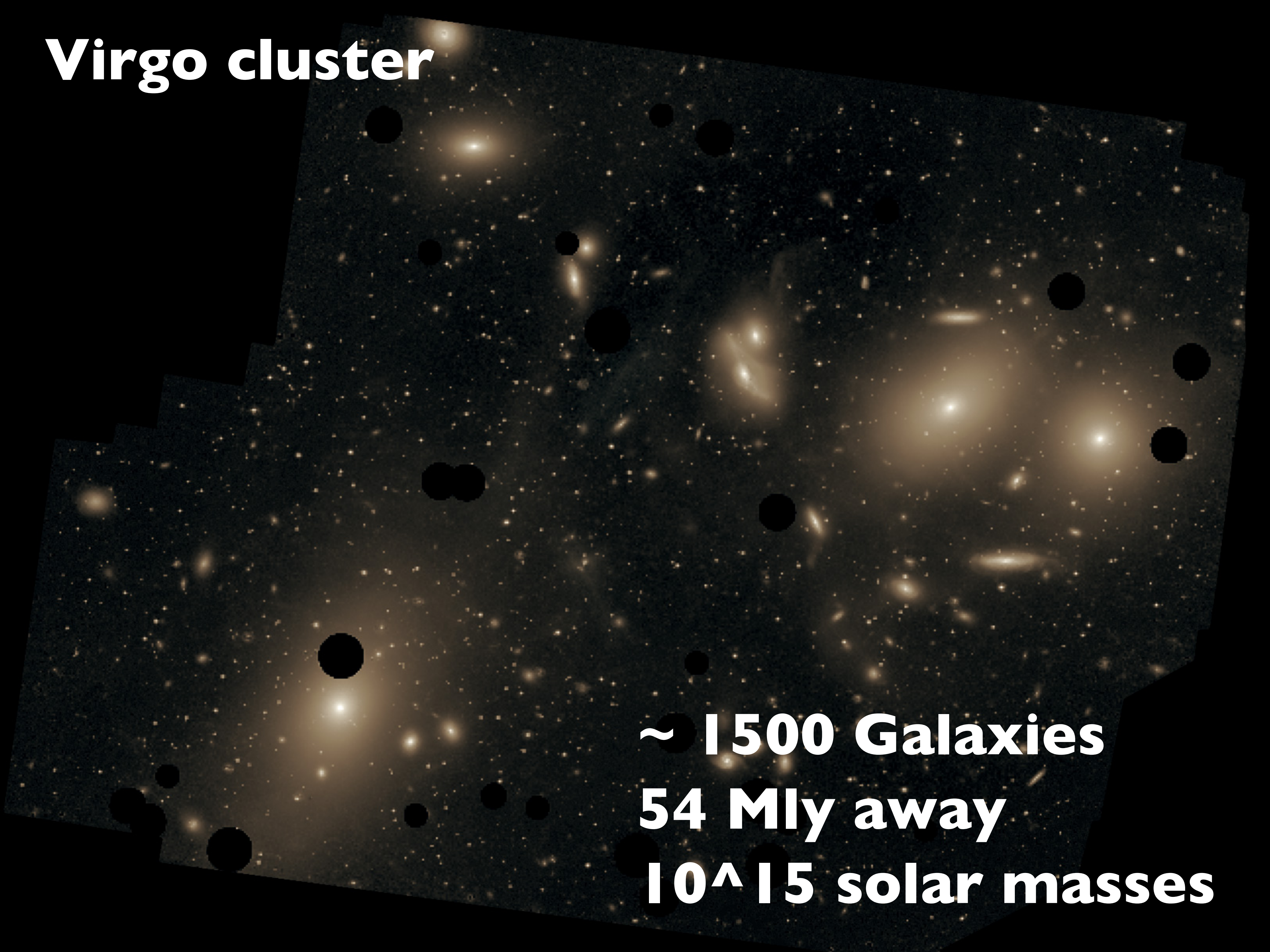
Figure 27-15
Universe, Eighth Edition

Galaxy Formation




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

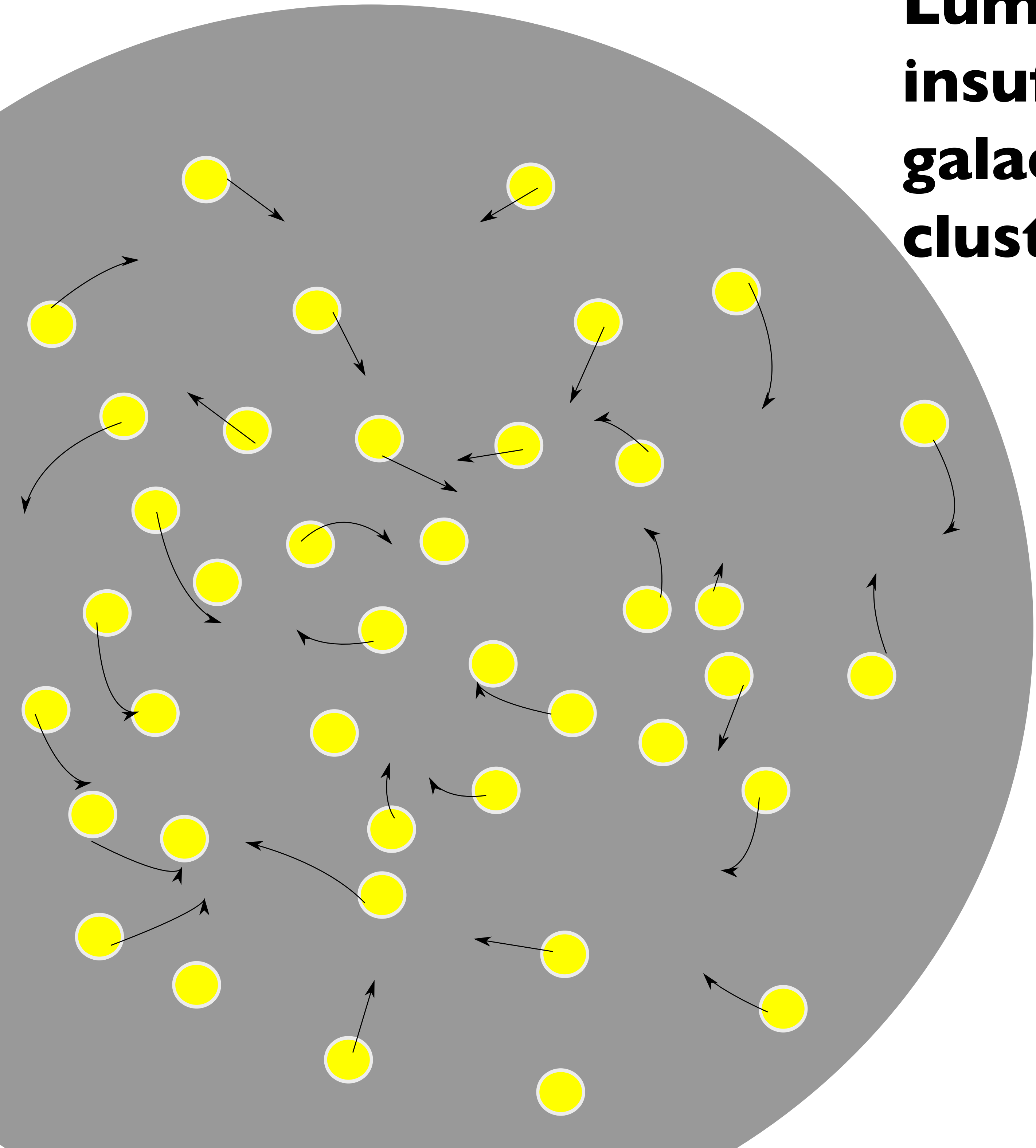
The Dark-Matter Problem

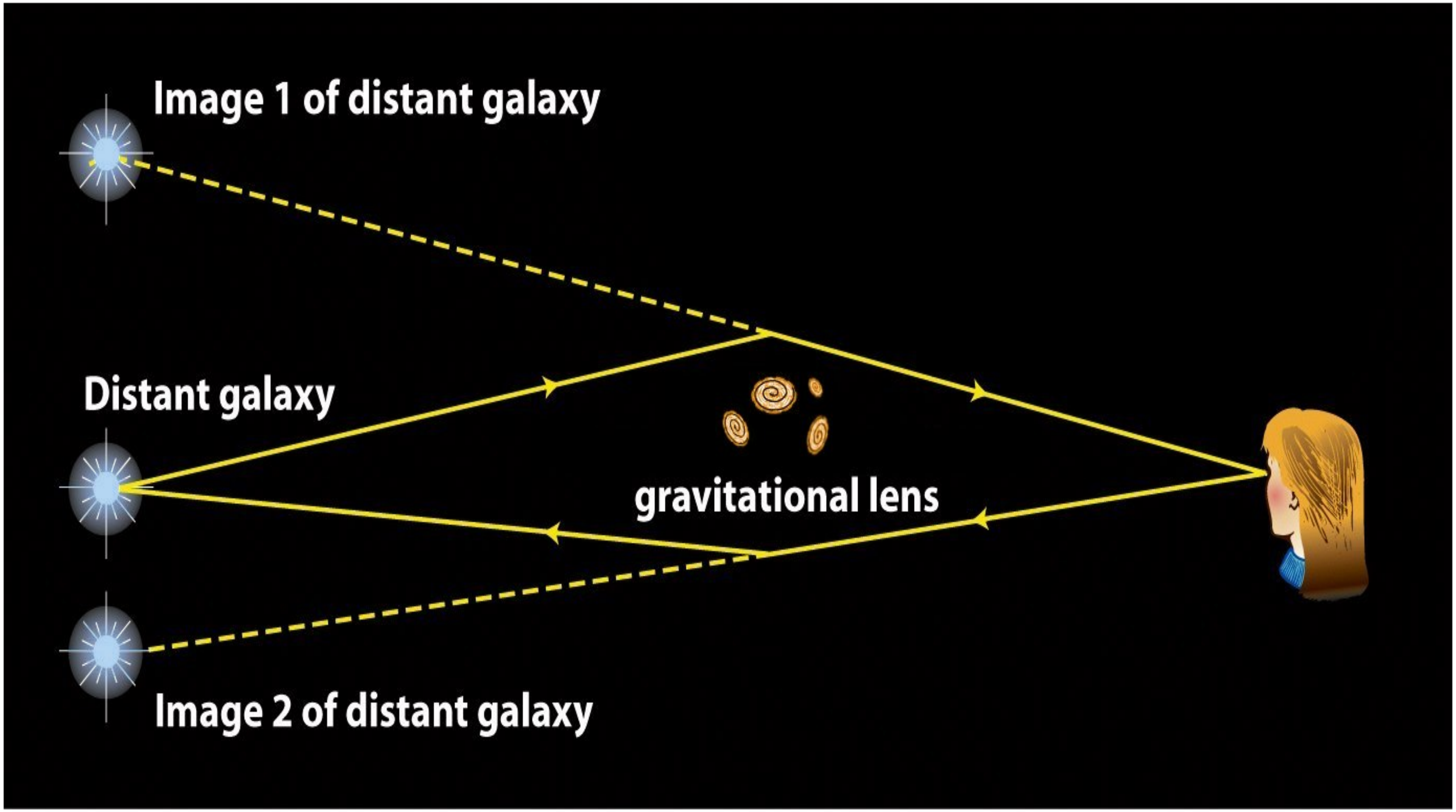
- Visible mass in *galaxy clusters* too small for galaxy motions.

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

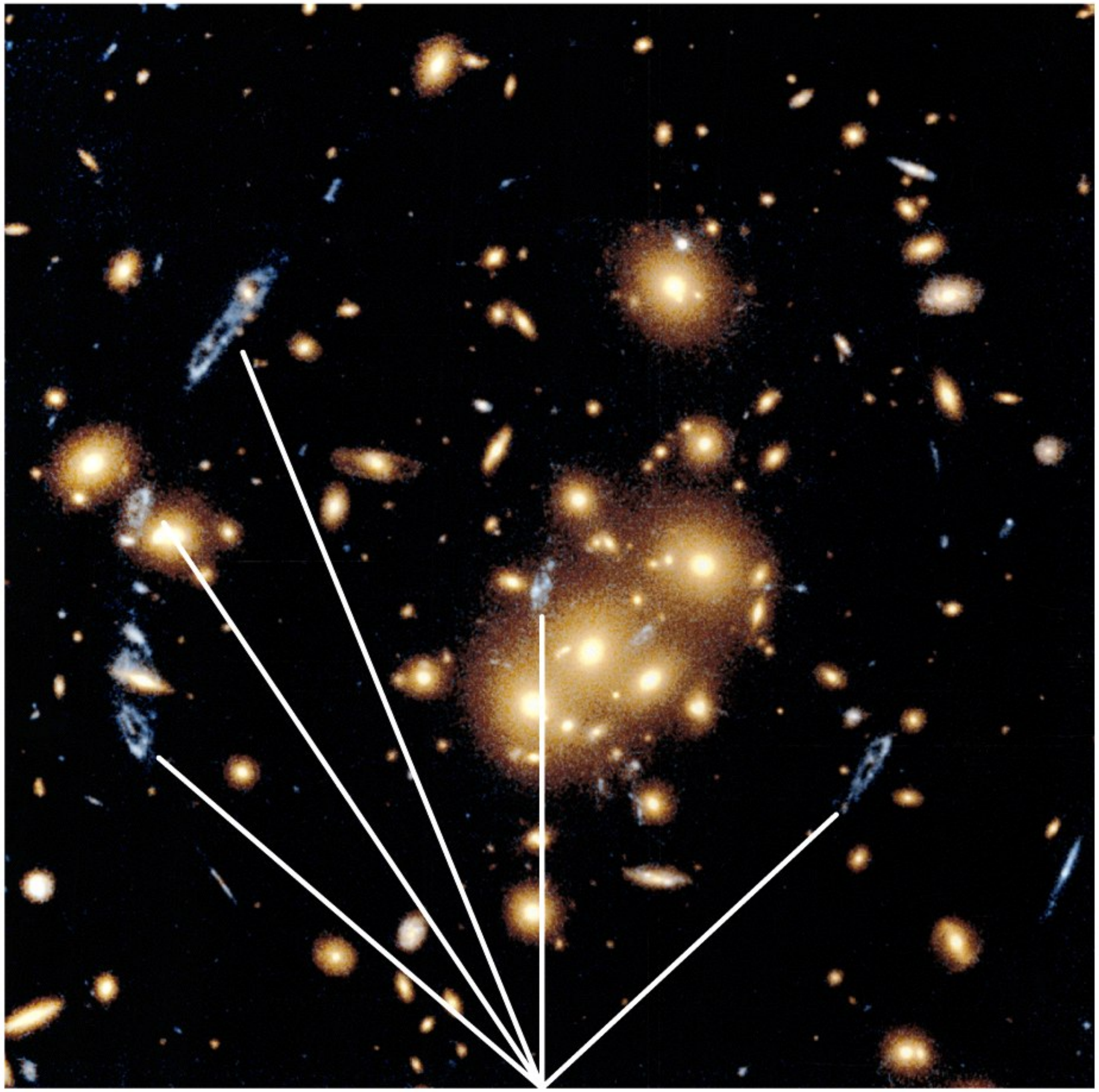




How gravitational lensing happens

Figure 24-30a
Universe, Eighth Edition

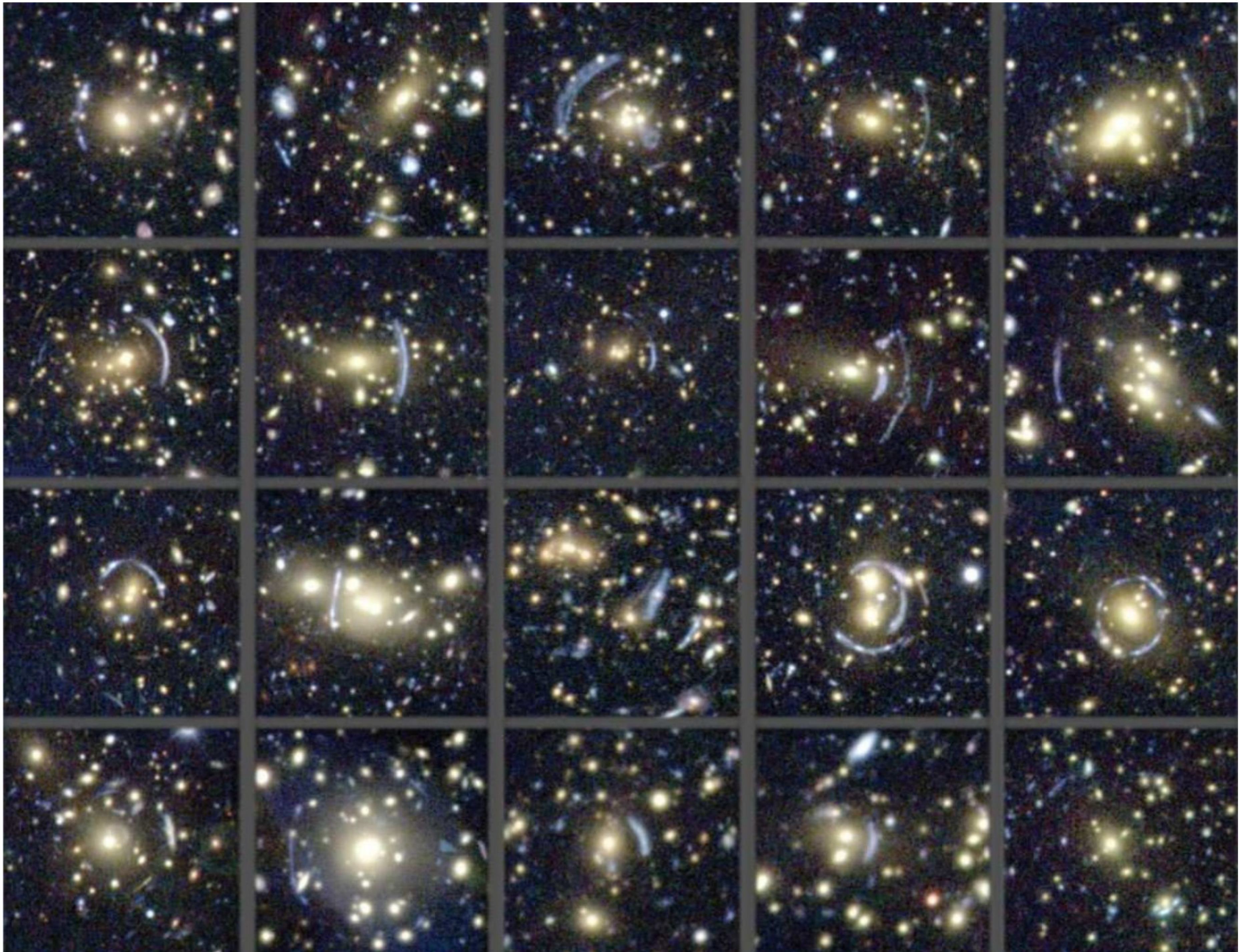
Lensing

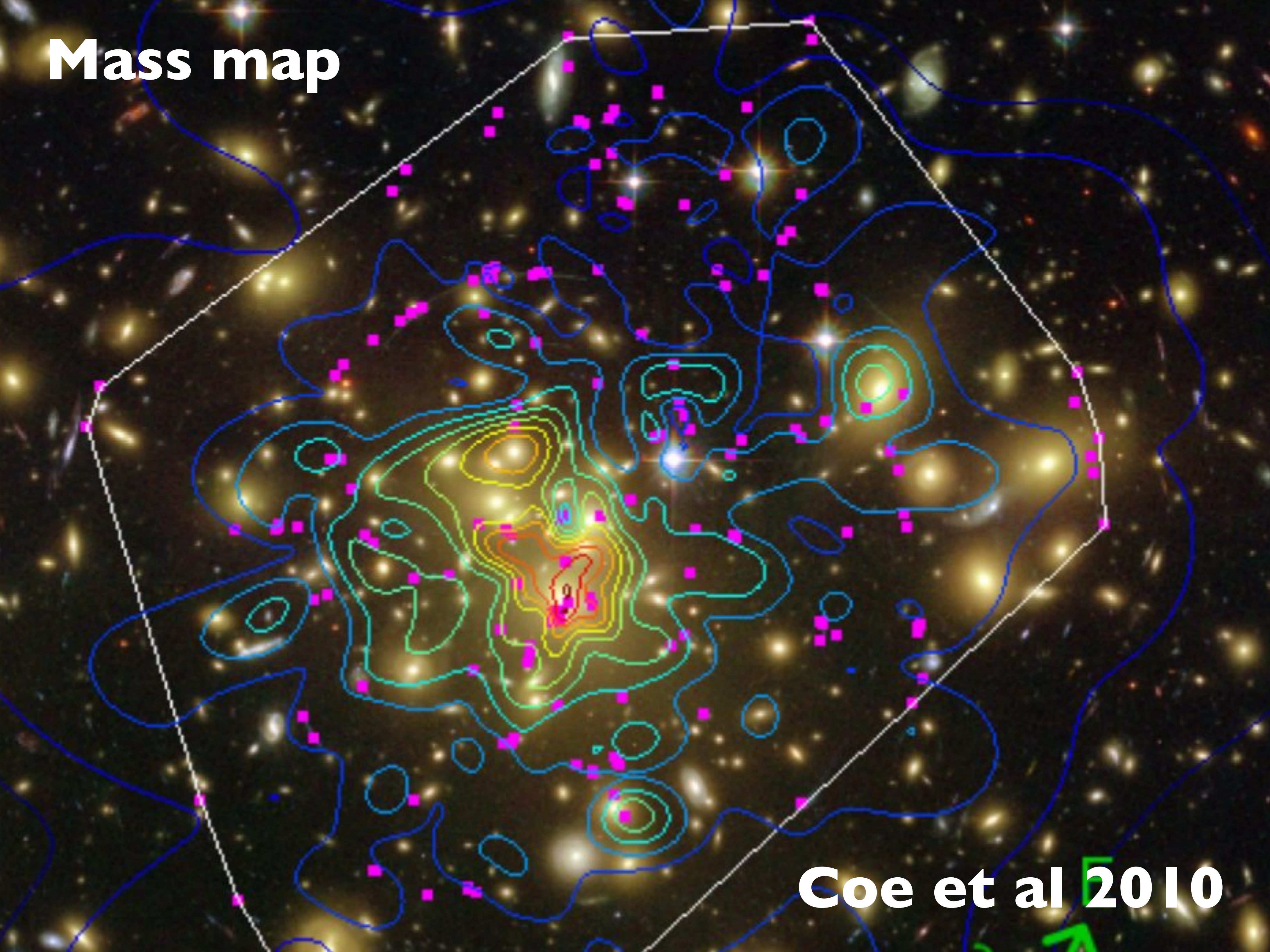


All of these blue arcs are images of the same distant galaxy.

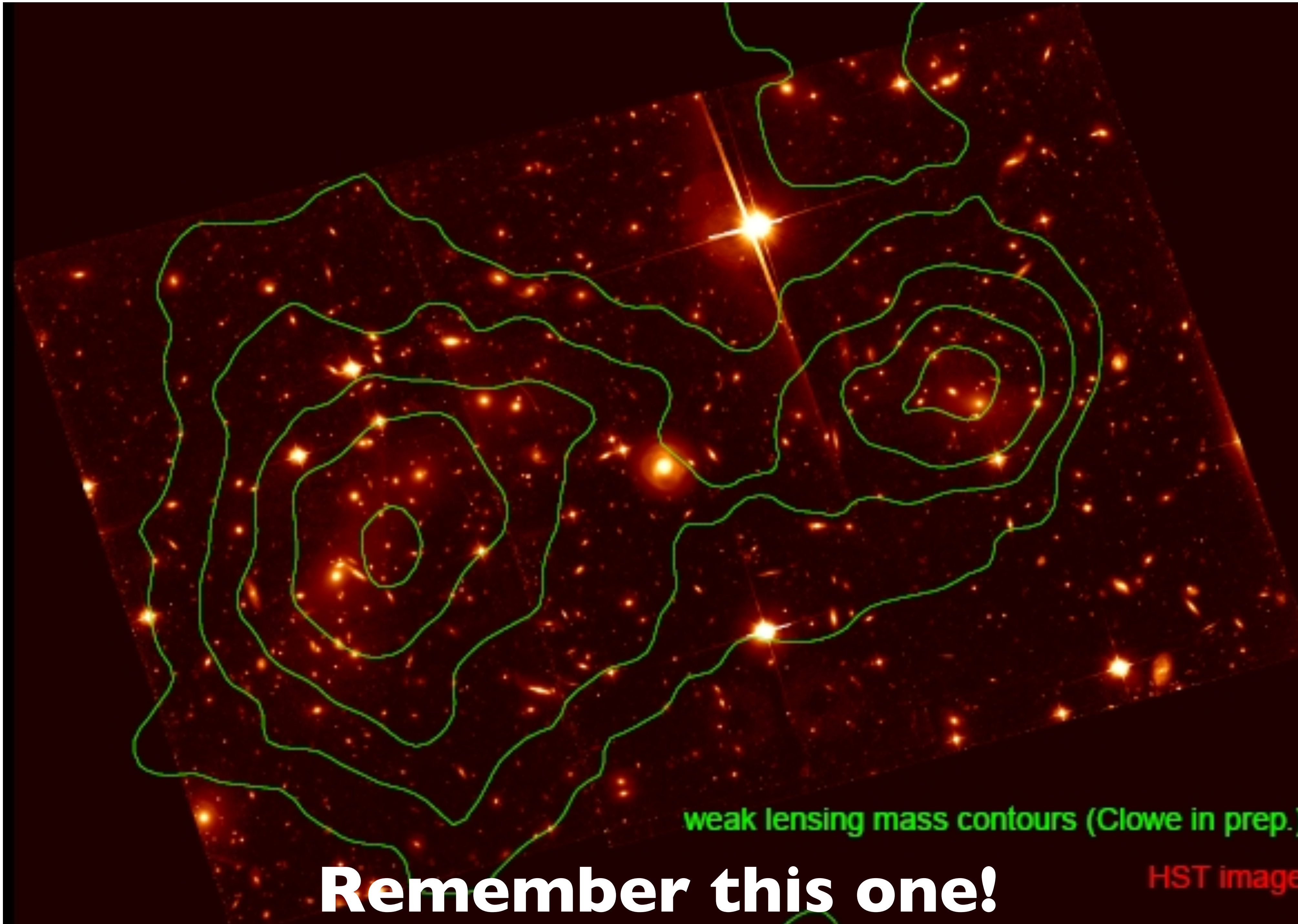
Figure 24-31
Universe, Eighth Edition

Clusters with strong lensing arcs



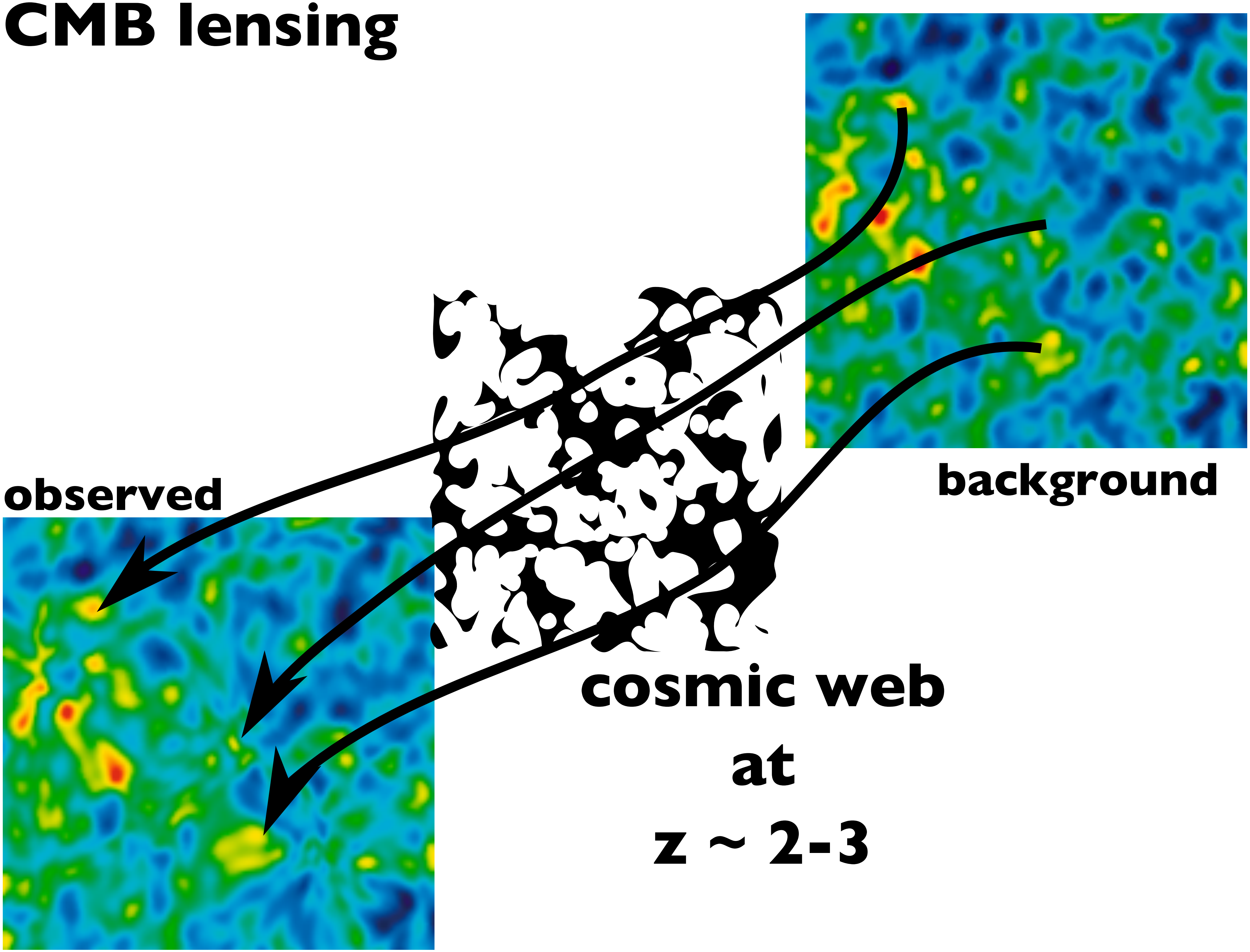

Mass map
Coe et al 2010

Lensing mass map



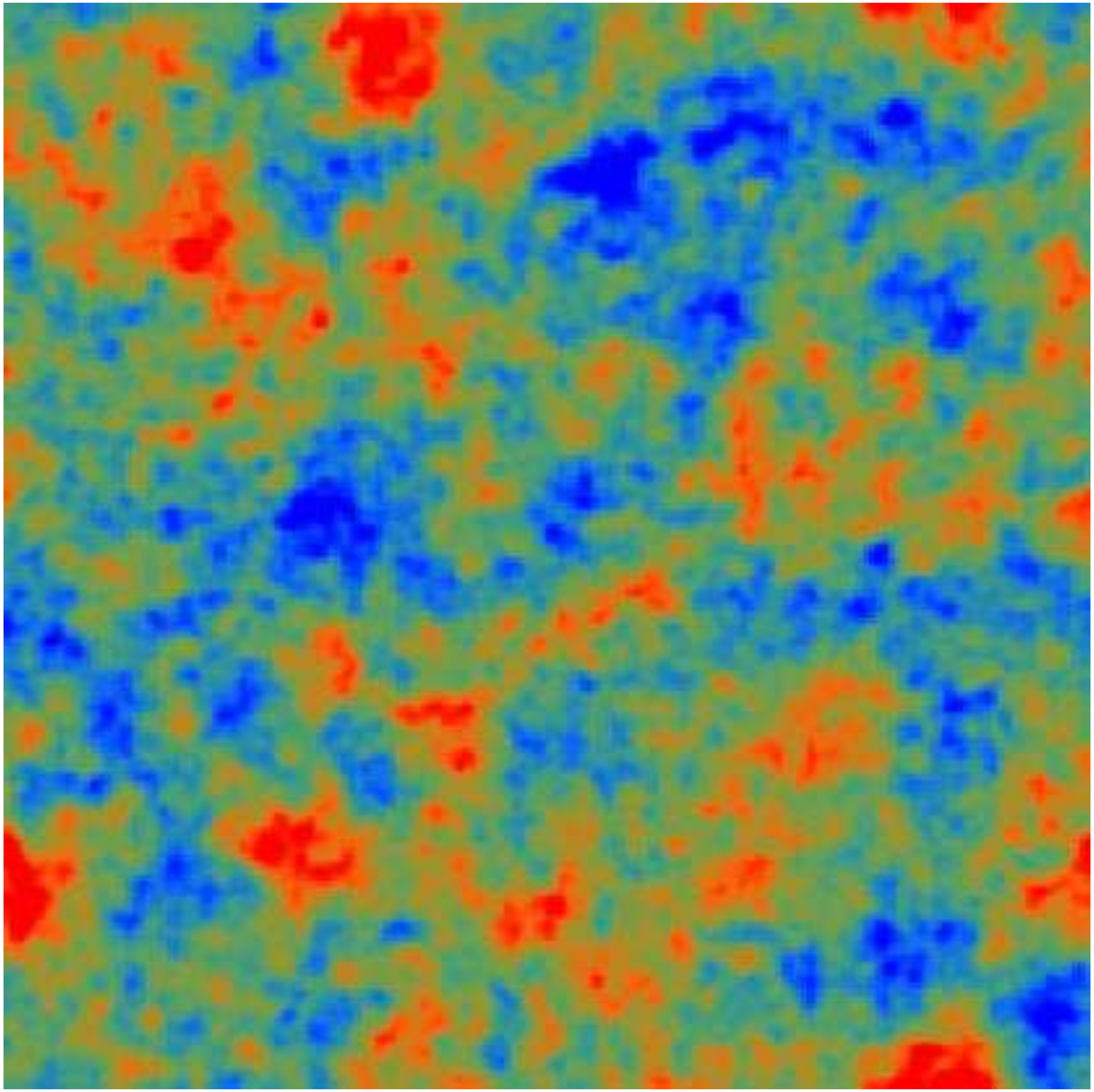
Remember this one!

CMB lensing



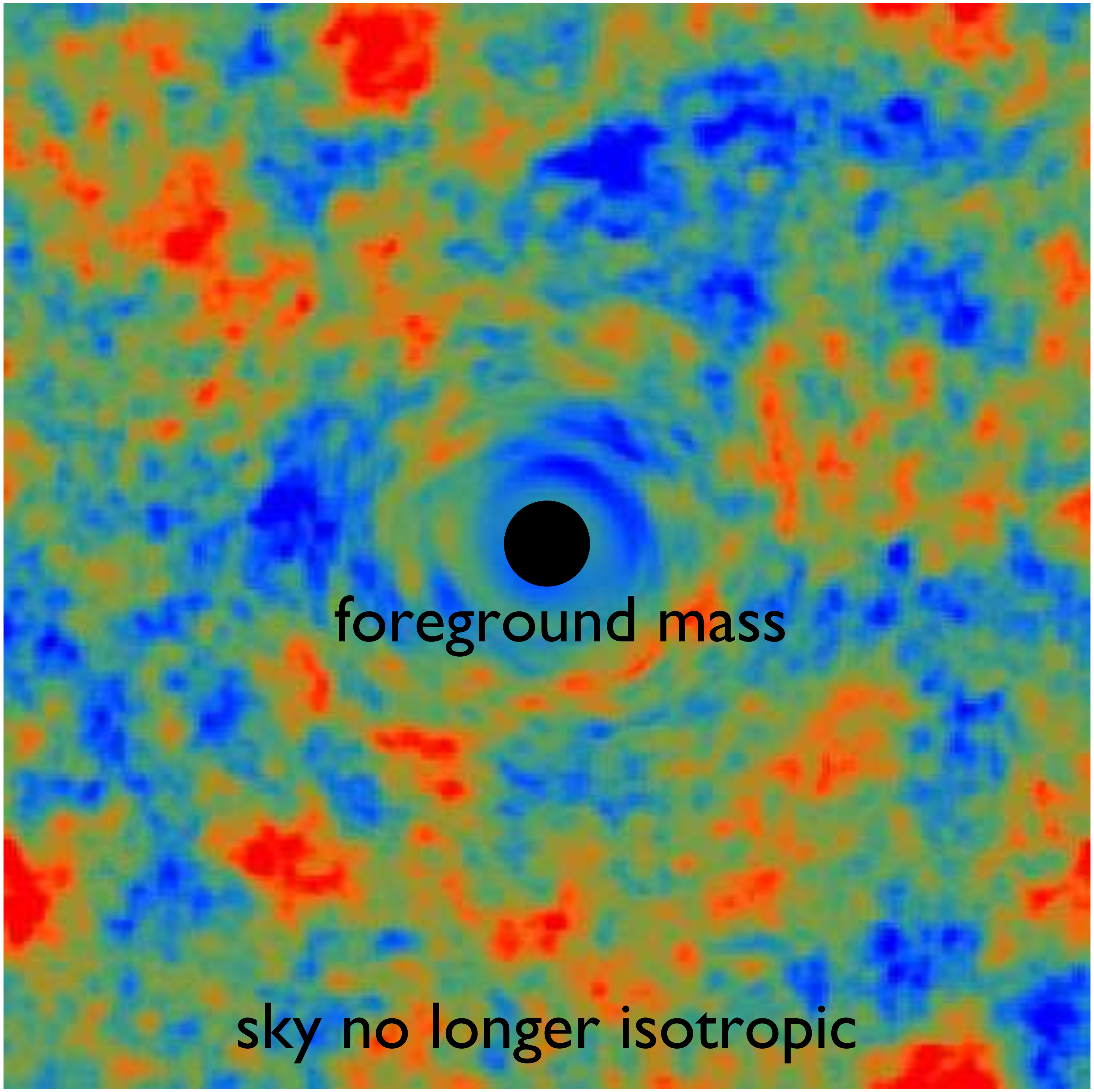
CMB

(Hu & Okamoto 2001)



CMB lensed

(Hu & Okamoto 2001)



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**.

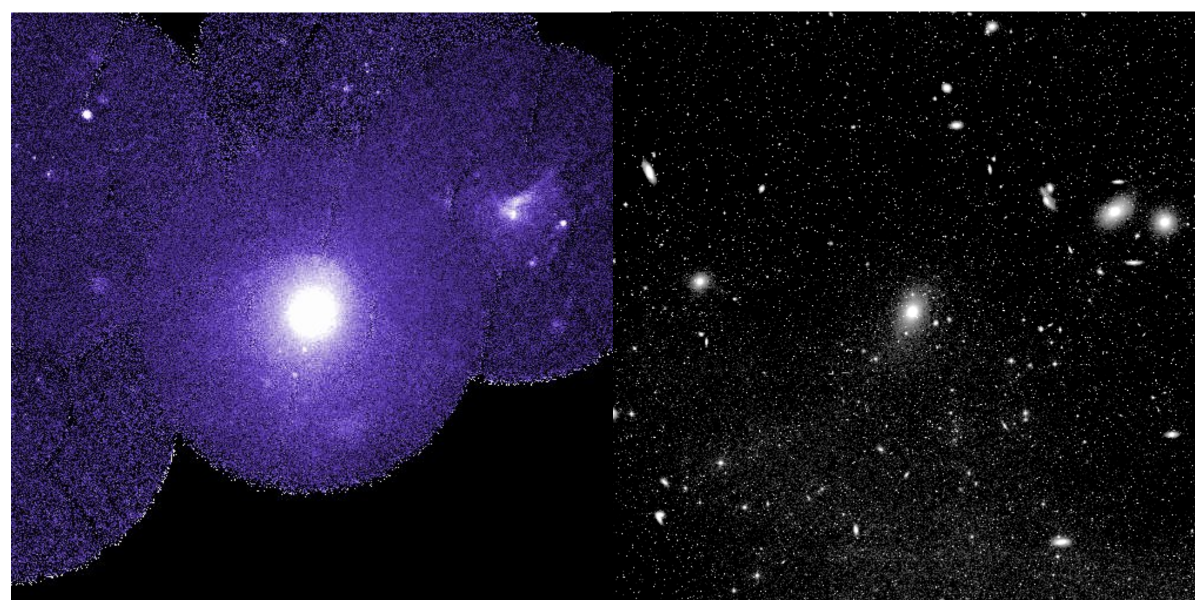
Glows in **X-rays**.

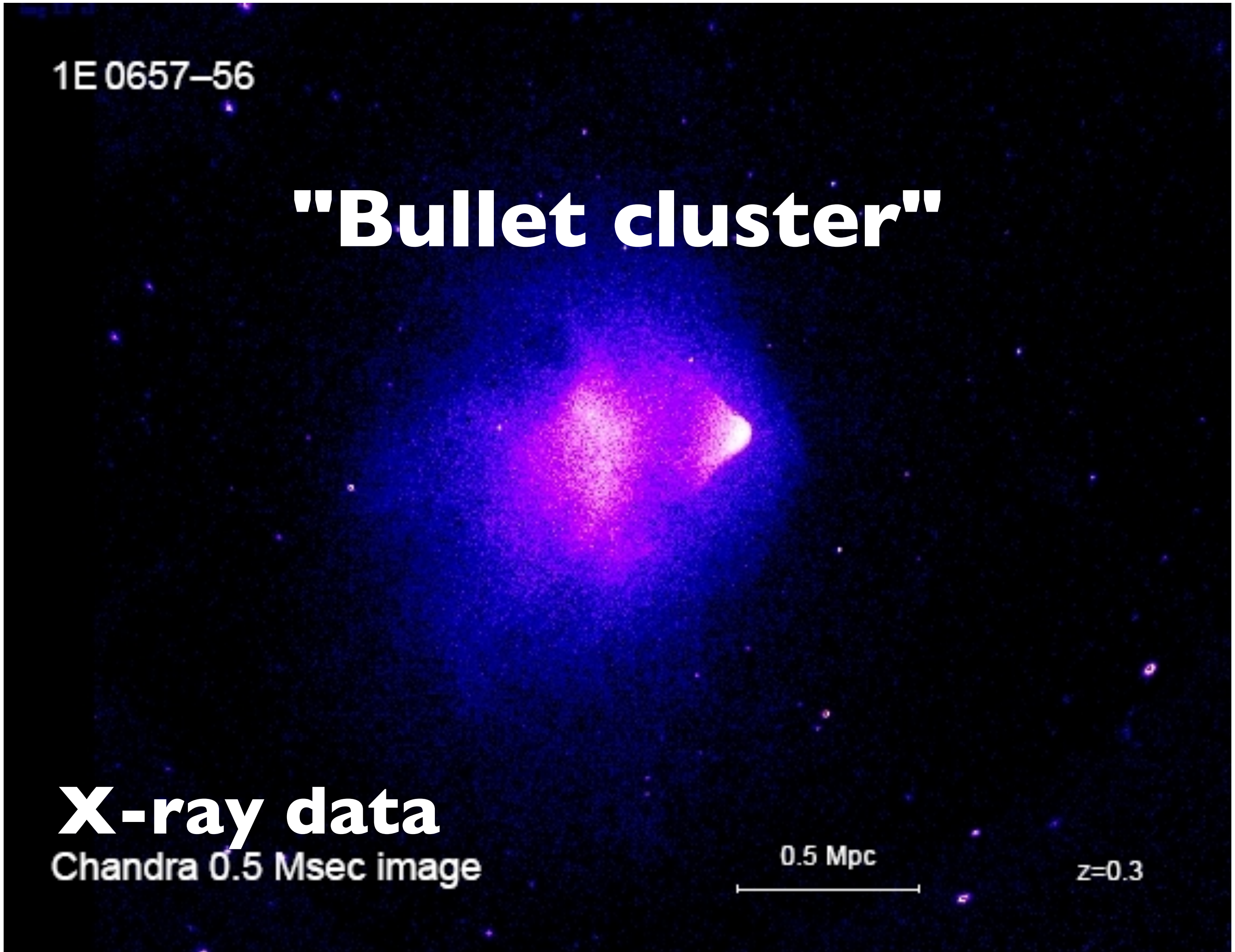
X-rays observed by satellite

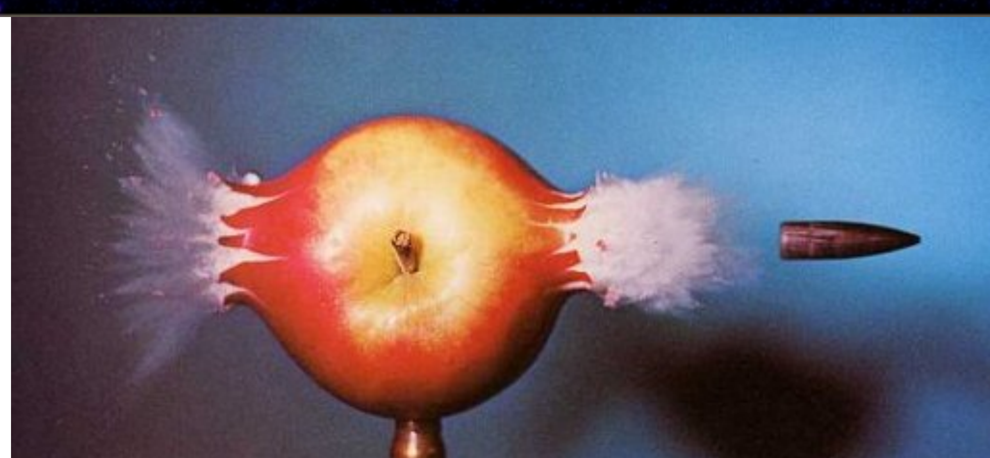
XMM-Newton
ROSAT
Integral...

Coma cluster

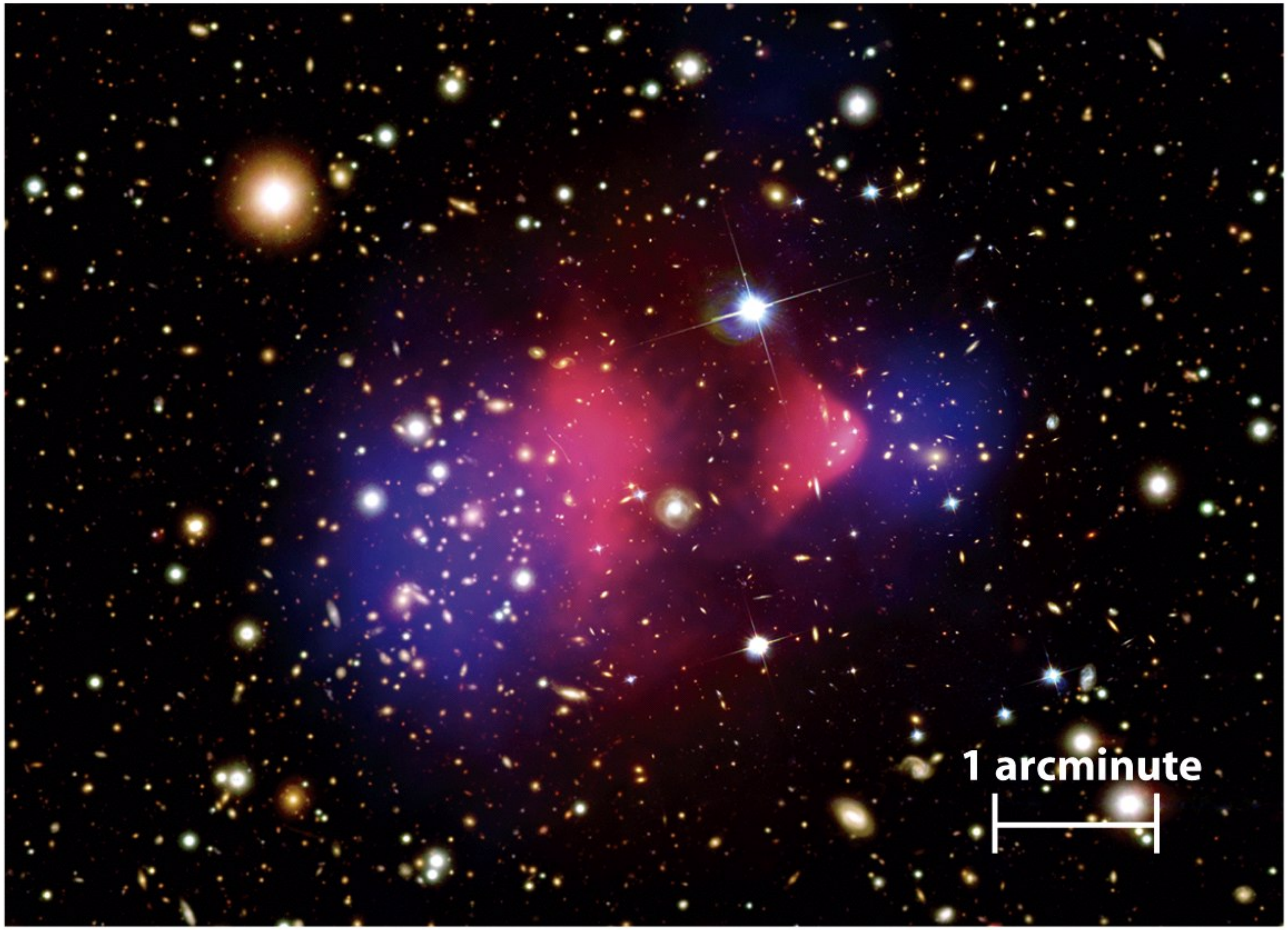
Virgo cluster




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



Bullet cluster

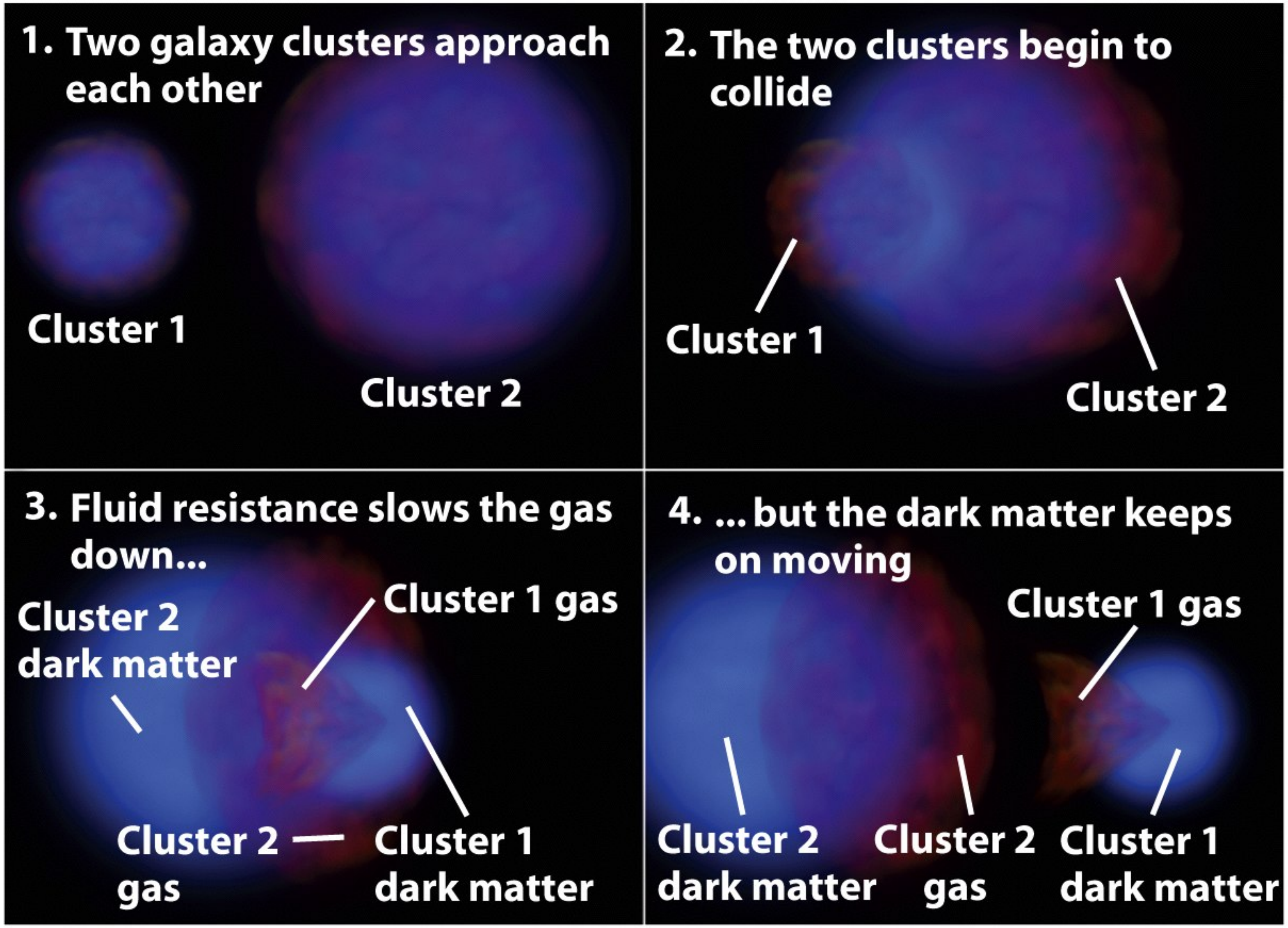


Composite image of galaxy cluster 1E0657-56 showing visible galaxies, X-ray-emitting gas (red) and dark matter (blue)

R I V U X G

Figure 24-32a
Universe, Eighth Edition

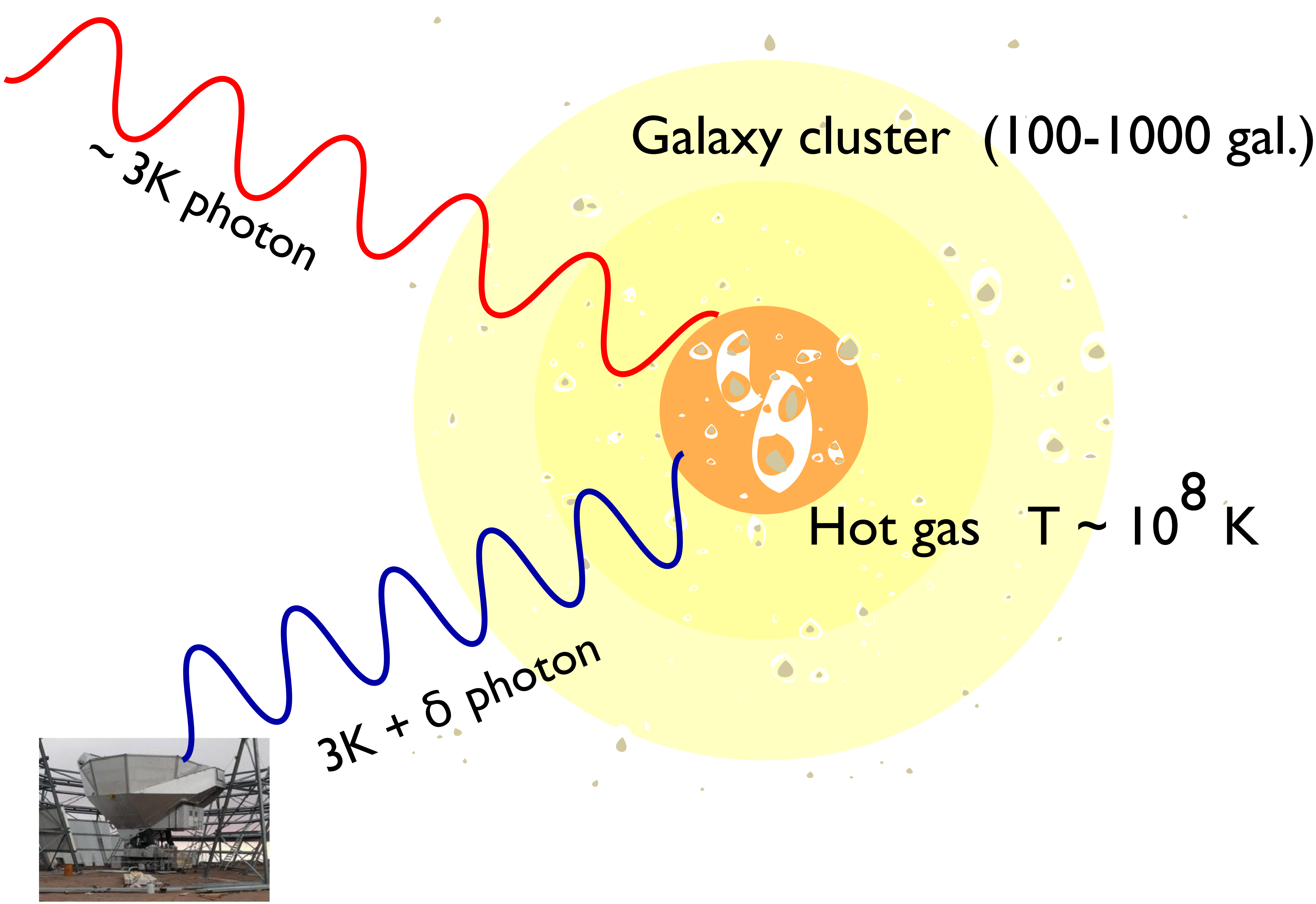
Bullet cluster model



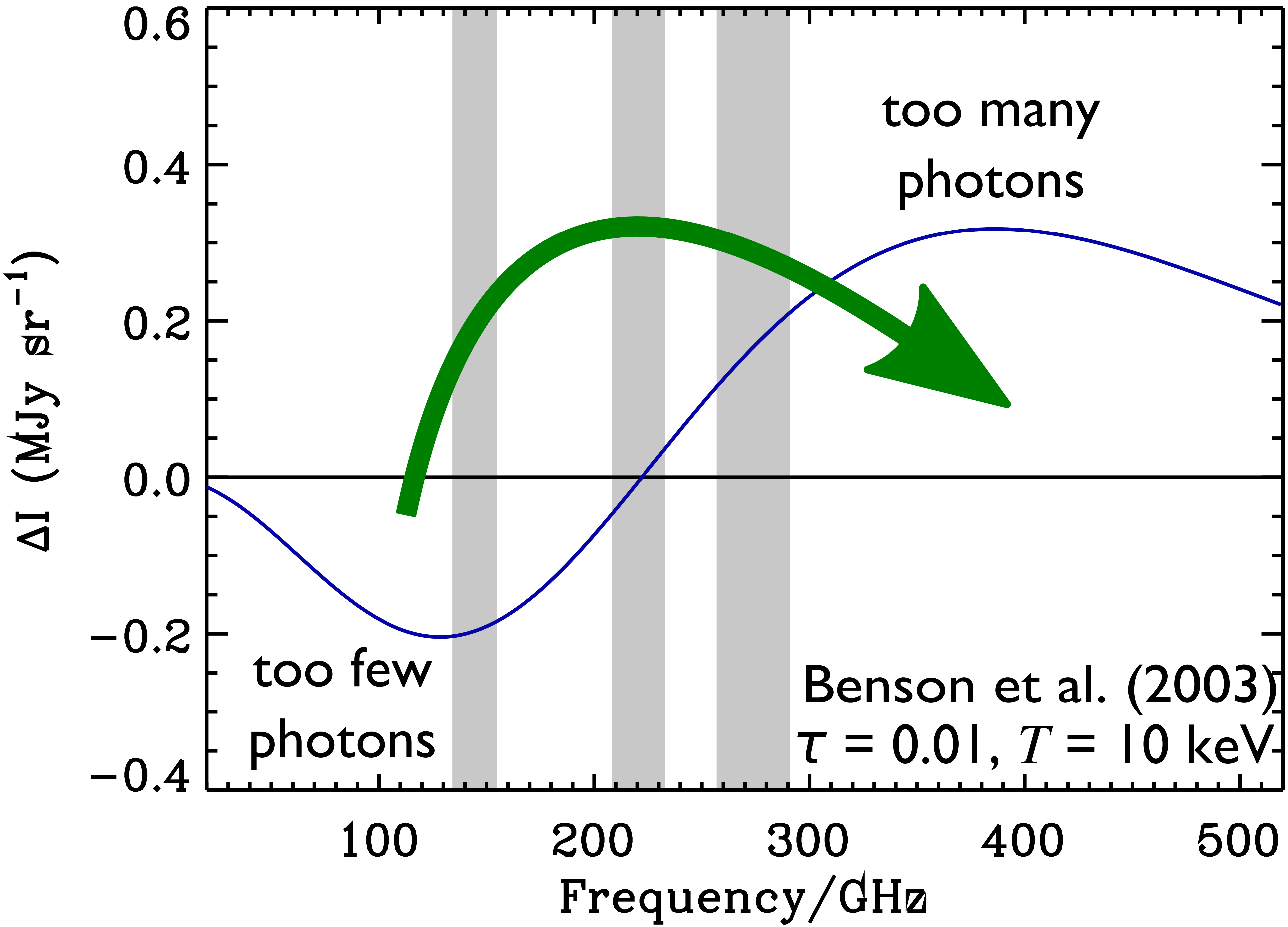
A model of how the gas and dark matter in 1E0657-56 could have become separated

Figure 24-32b
Universe, Eighth Edition

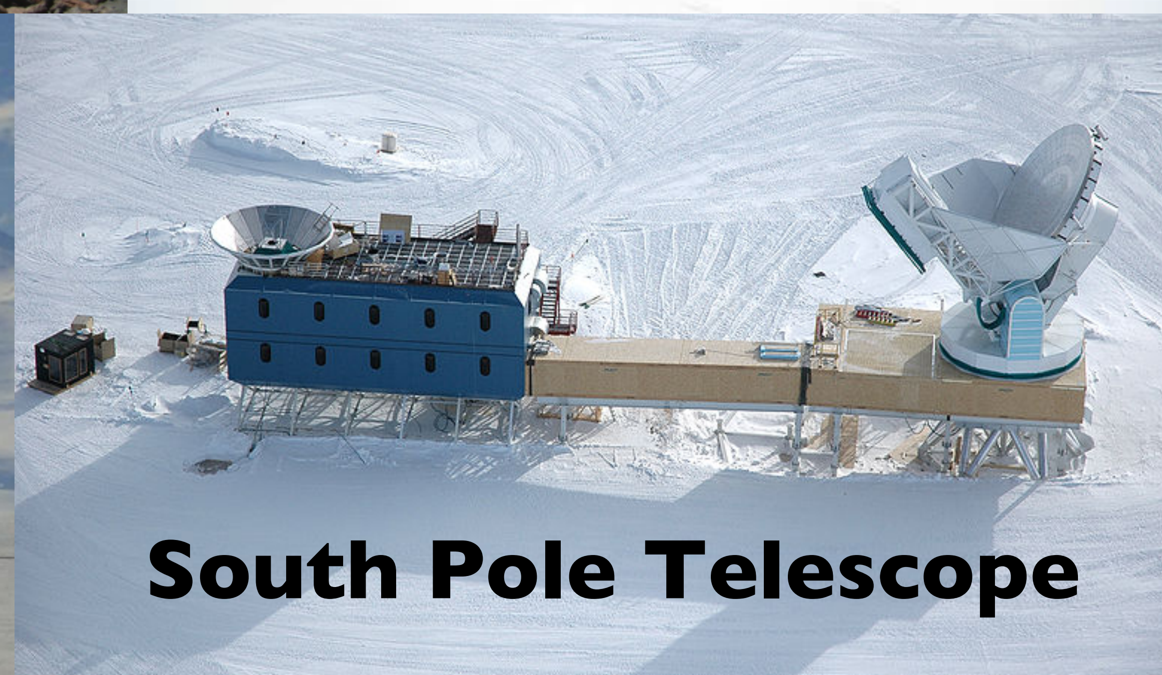
Sunyaev-Zeldovich effect

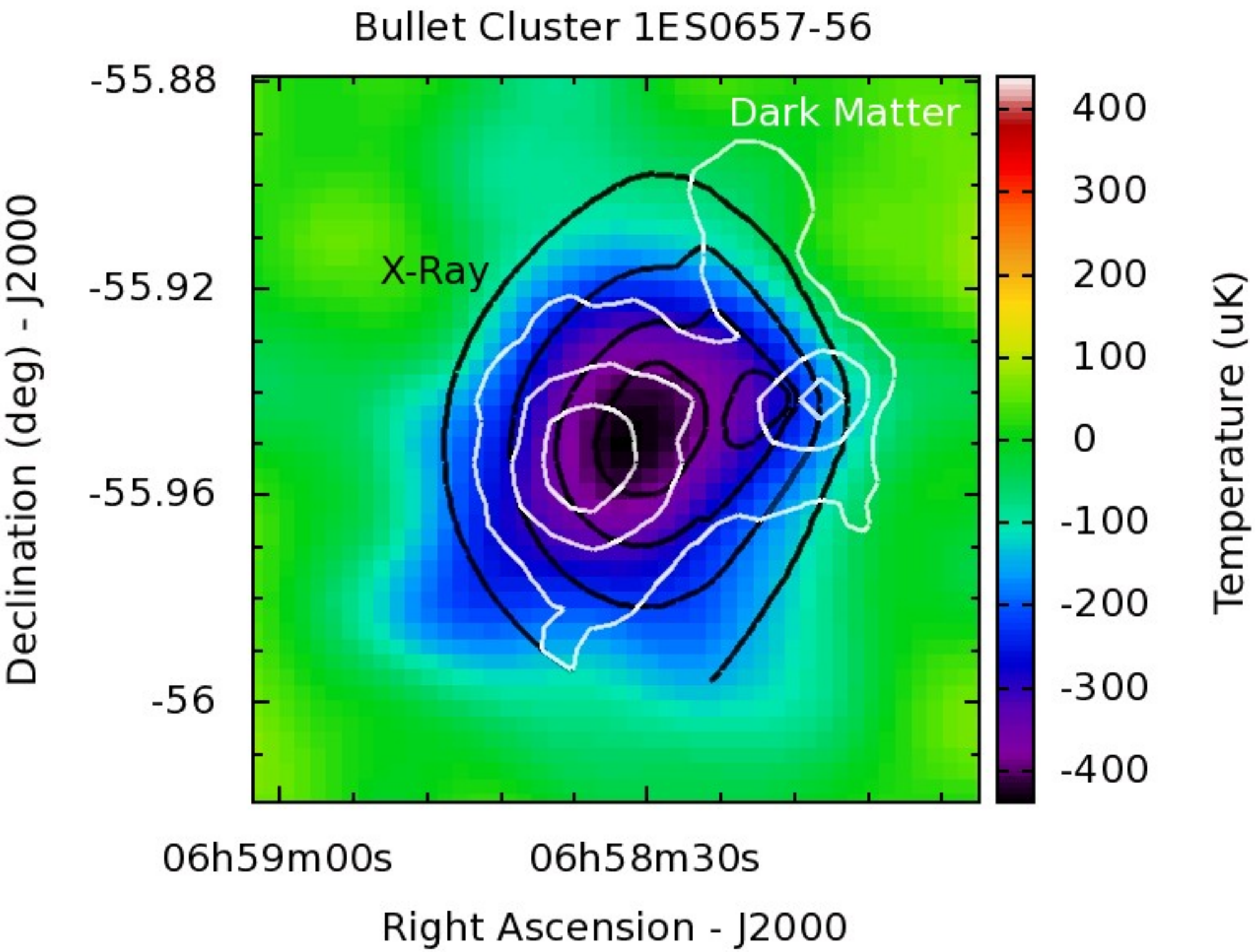


SZ distorts CMB blackbody

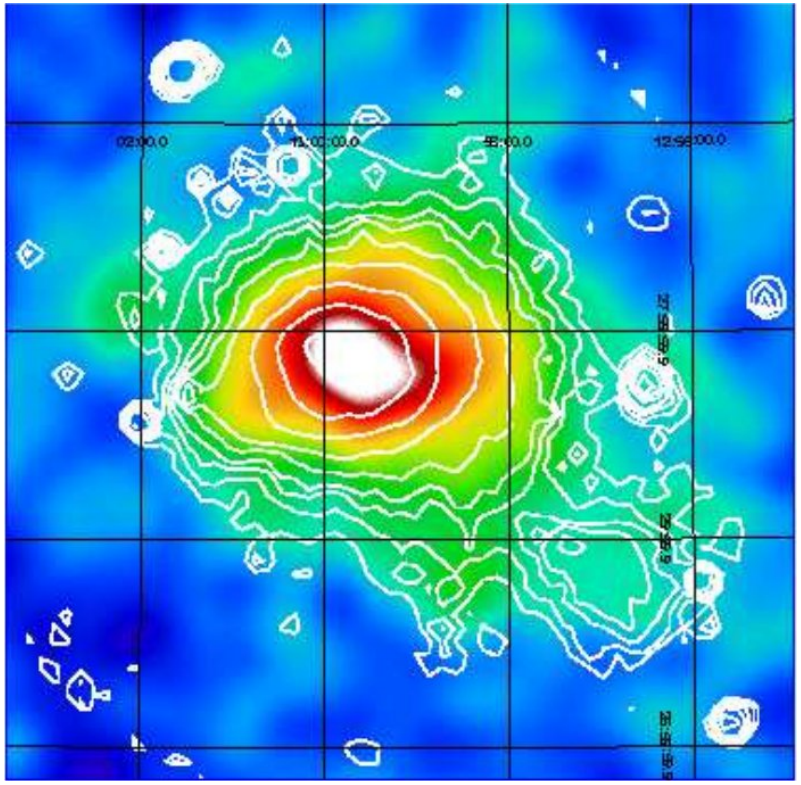


Ground / balloon based telescopes




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



Coma in SZ,
by Planck

Planck early data:

~30 New cluster candidates,

~ 20 confirmed

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