

Cosmology

- Problems with the Big Bang
 - The horizon problem
 - The flatness problem
- The solutions to the problems

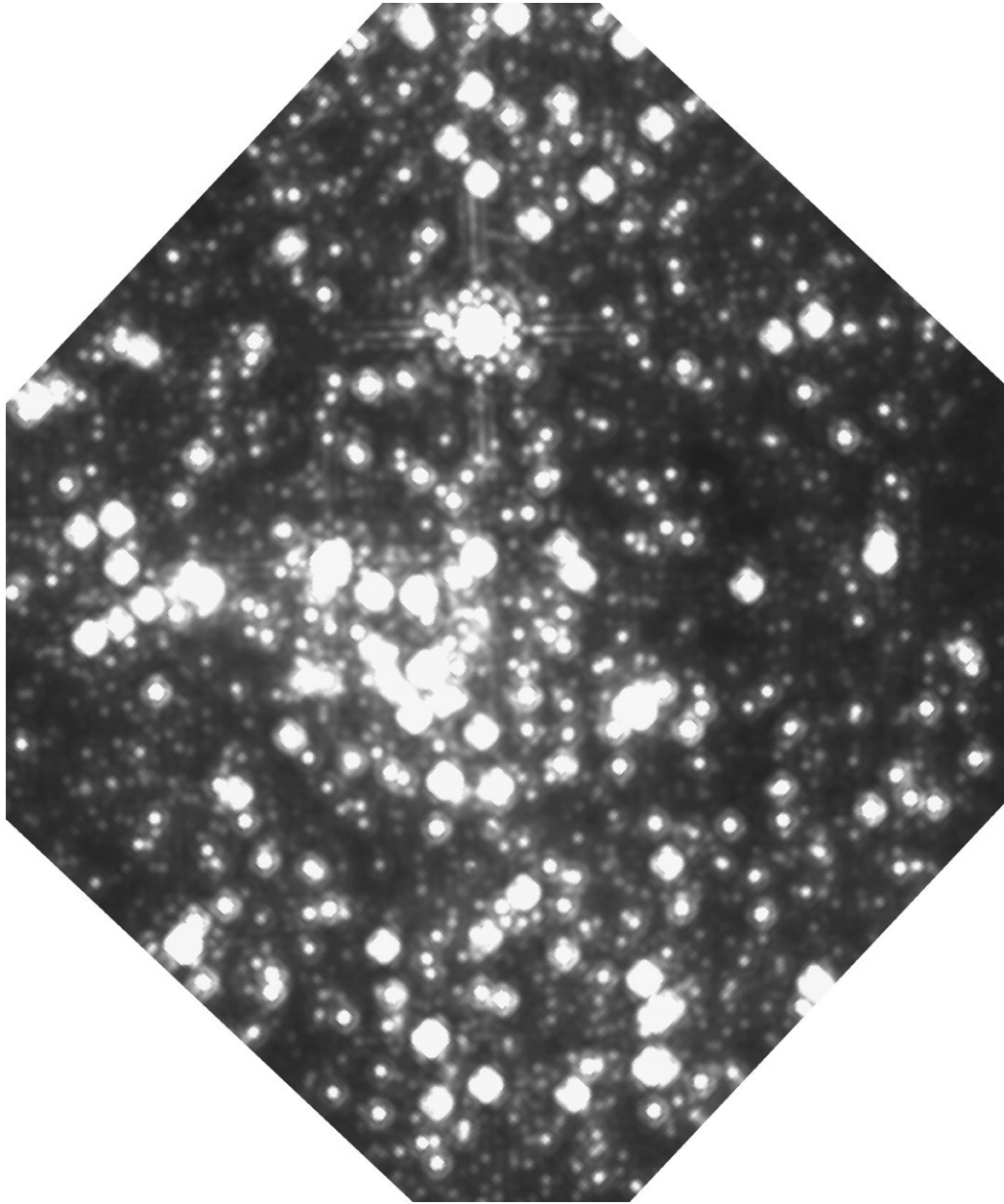
Hubble showed that certain “nebulae” are actually whole galaxies by

- A) measuring the distance to them
- B) showing that they have spiral arms like the Milky Way
- C) measuring their recession speed
- D) measuring their mass

Does the center of the Milky Way
contain many or few stars?

A) Few

B) Many



Infrared image, central 3 ly

Sgr A* does not
appear.

There are about
1,000,000 stars in
the area covered by
this image.

Stars are only 1000
AU apart.

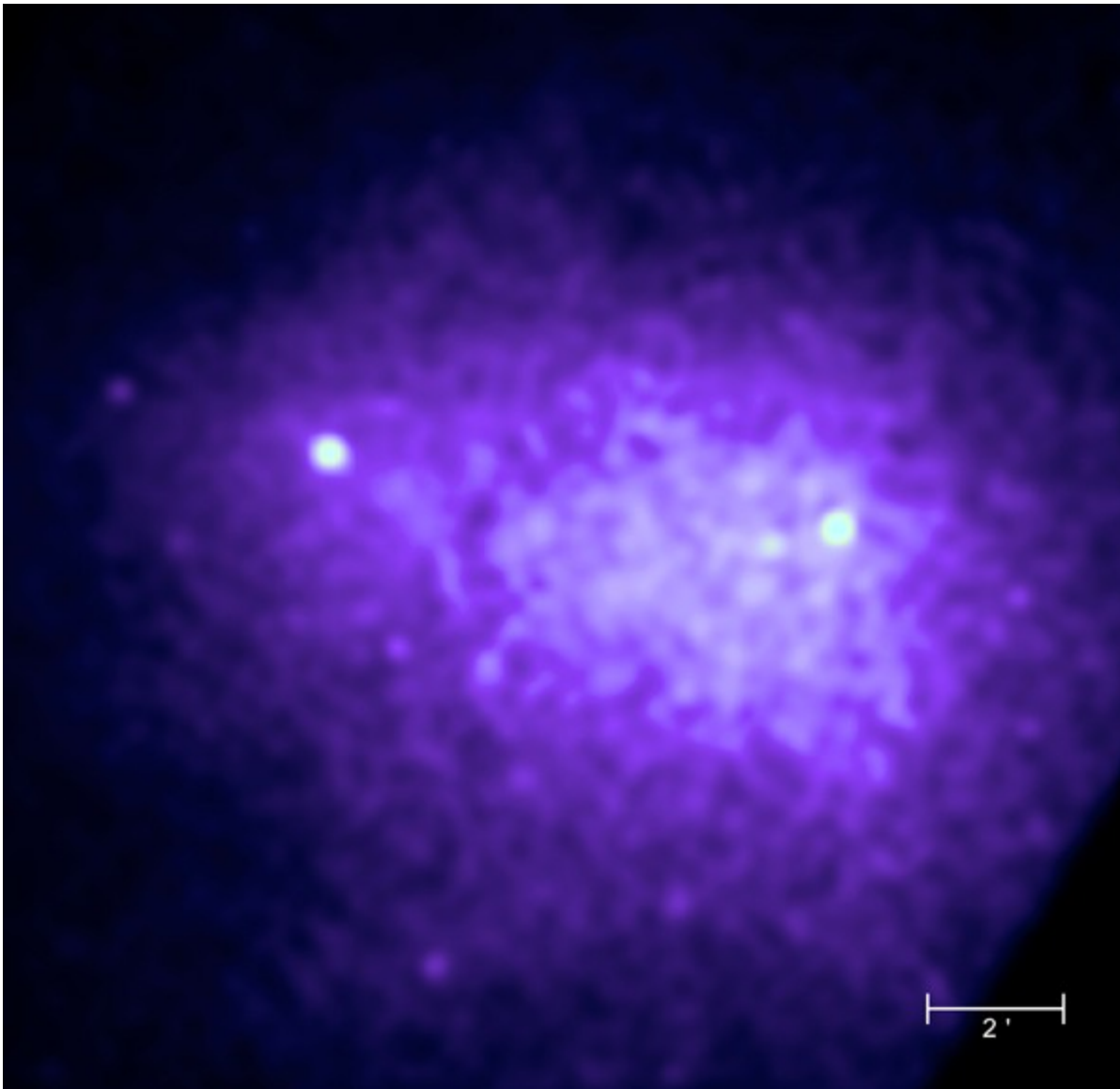
Most of the normal matter in clusters of galaxies is

- A) in stars within the galaxies
- B) in hot gas between the galaxies
- C) in cool gas within the galaxies
- D) in black holes at the centers of the galaxies



Coma
cluster

Coma cluster in X-rays



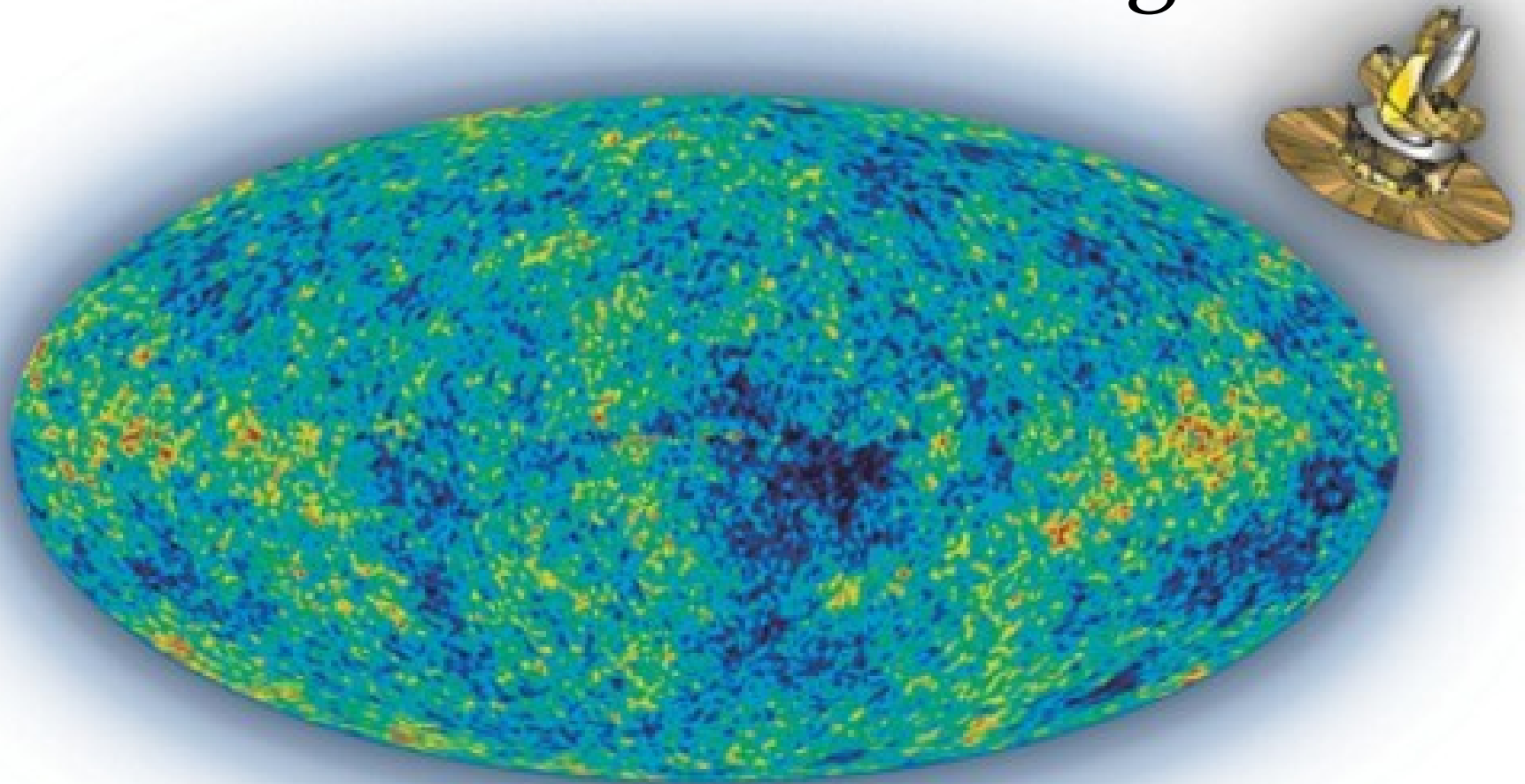
Coma cluster

- 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.

Problems with the Big Bang

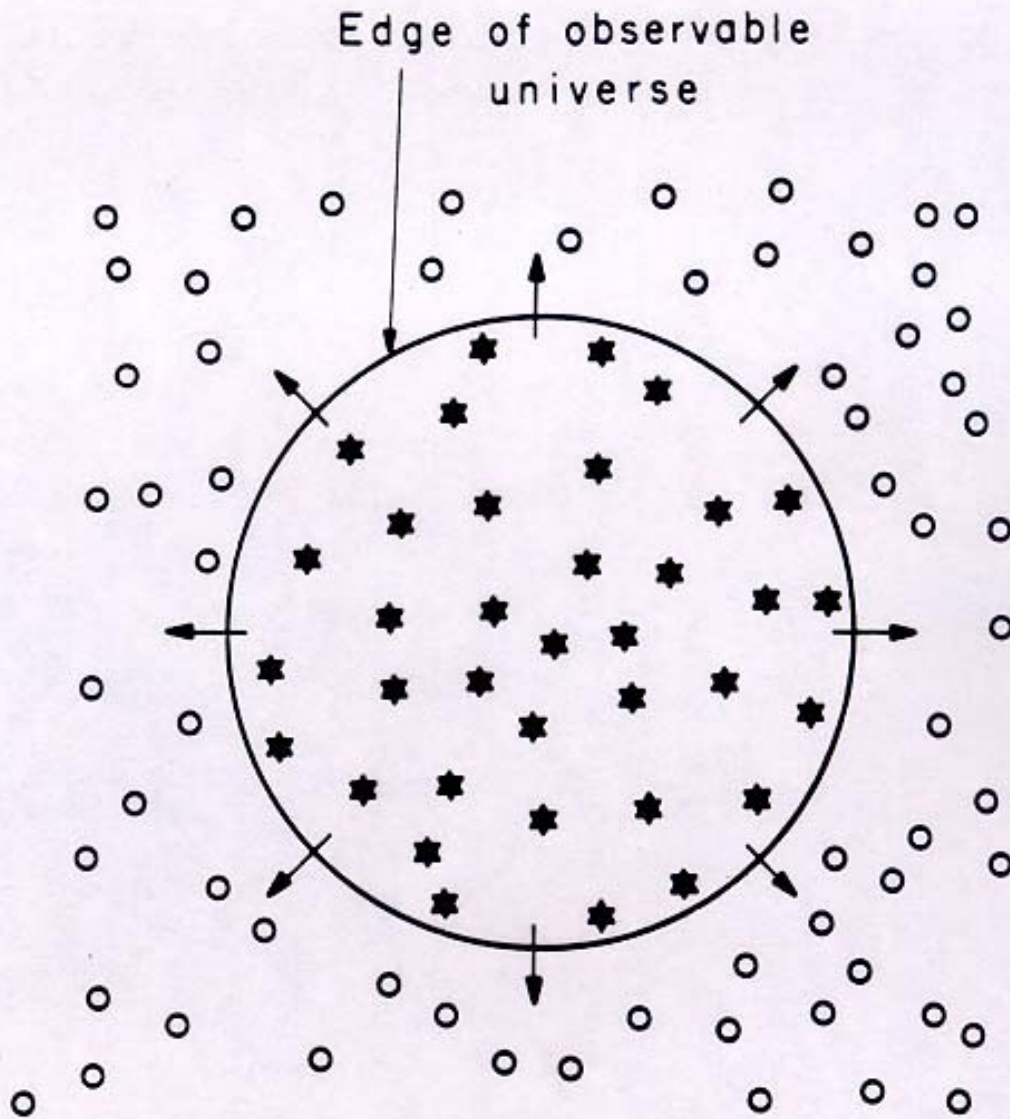
- The horizon problem
- The flatness problem

Cosmic Microwave Background



The Universe glows at 2.7 K in every direction.

The temperature is the same to $< 0.1\%$.

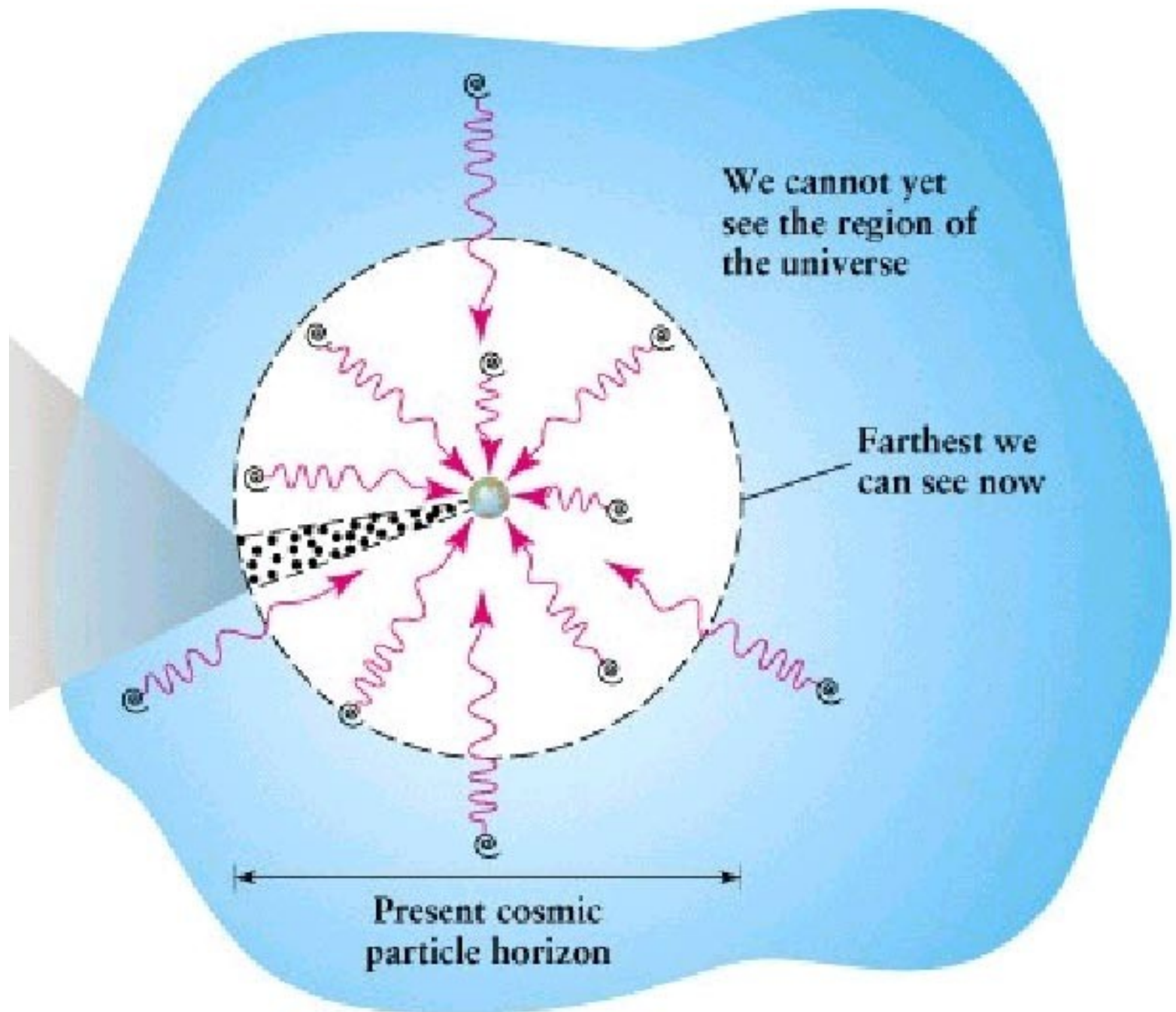


Edge of observable universe

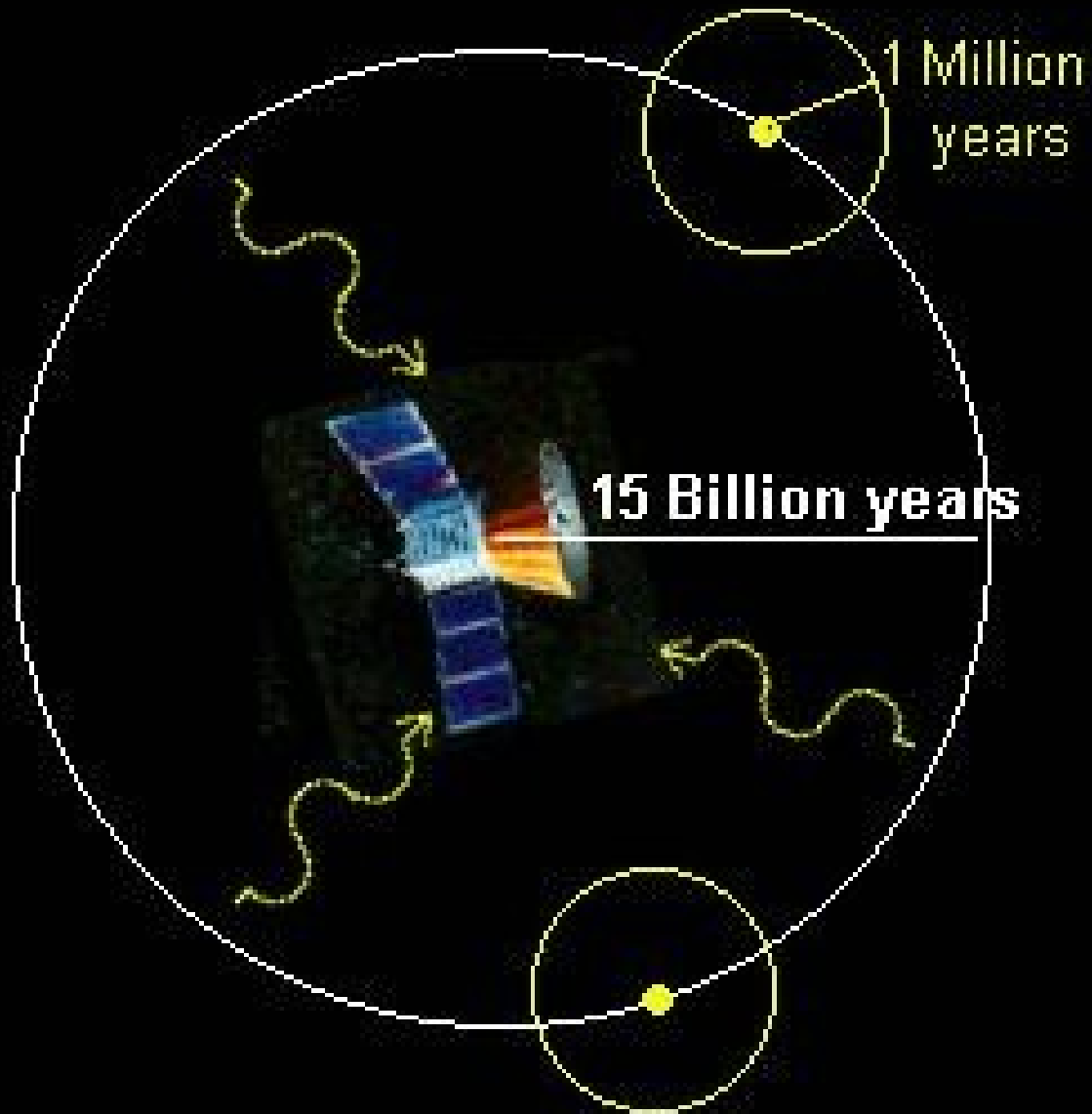
- ★ Stars visible
- Stars not yet visible

Observable Universe

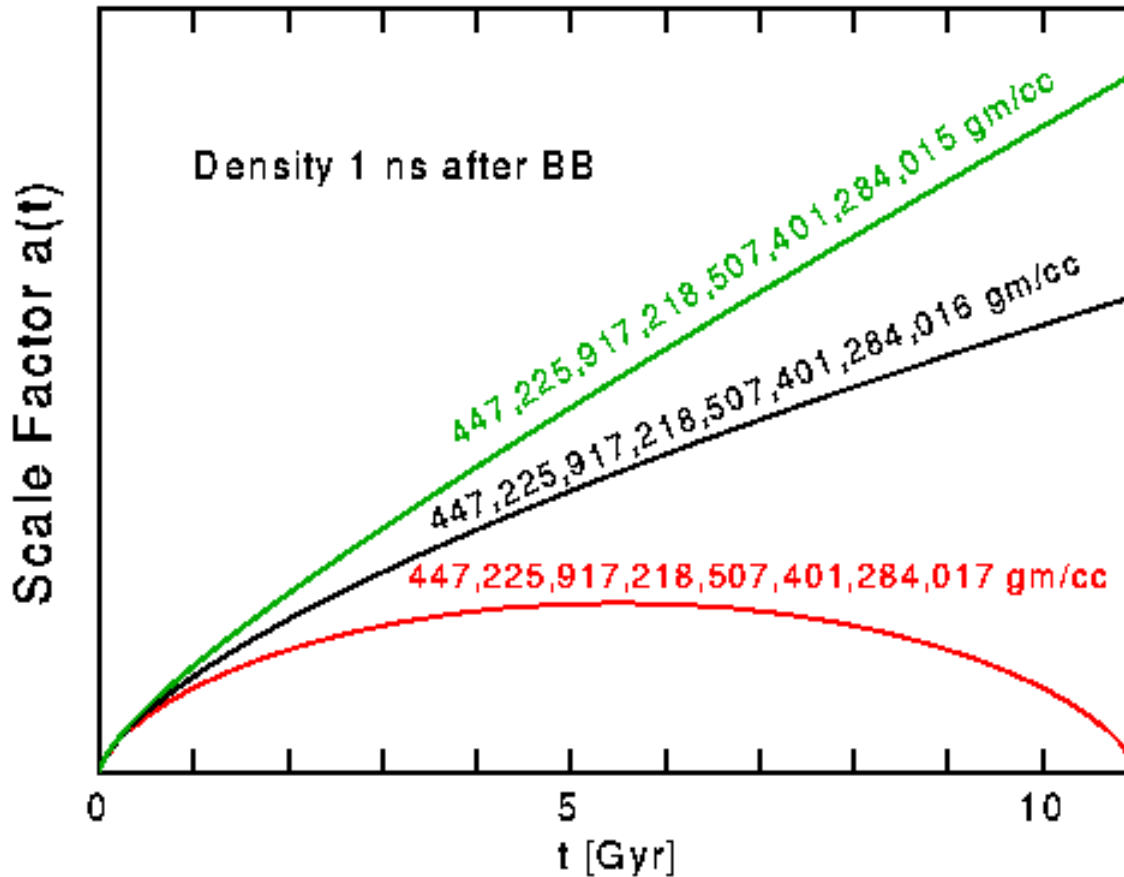
We can only see the parts of the Universe from which light has had time to travel to us.



Horizon Problem

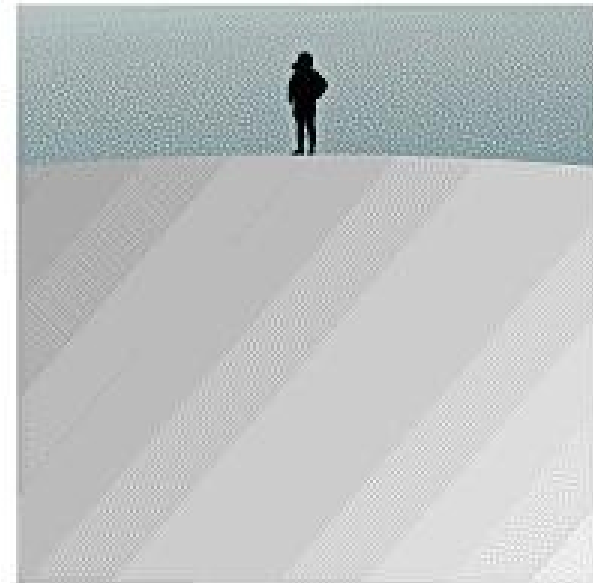
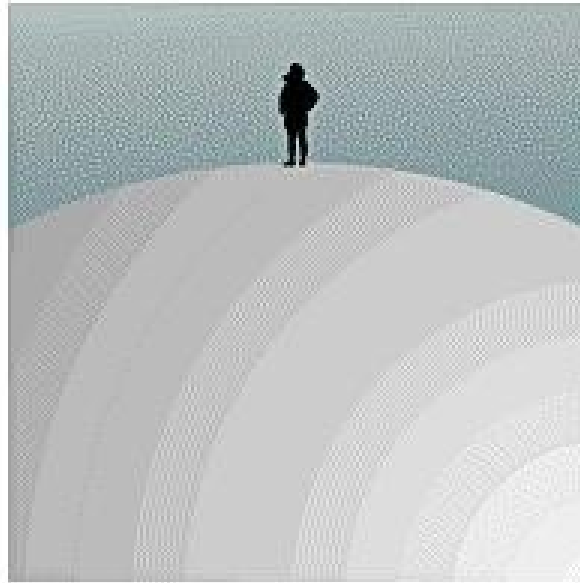
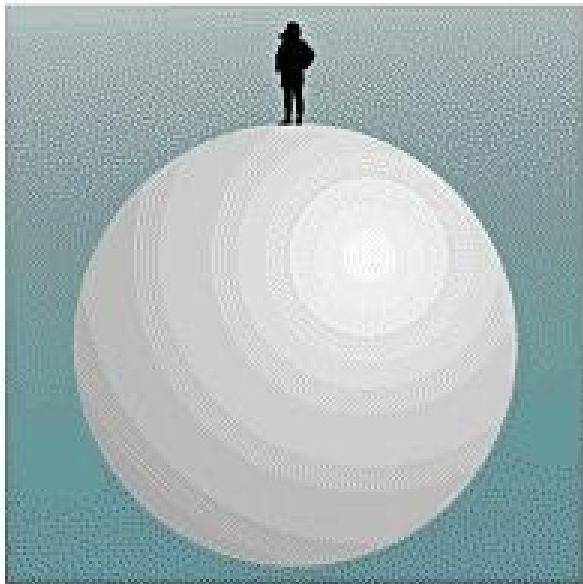


Flatness problem

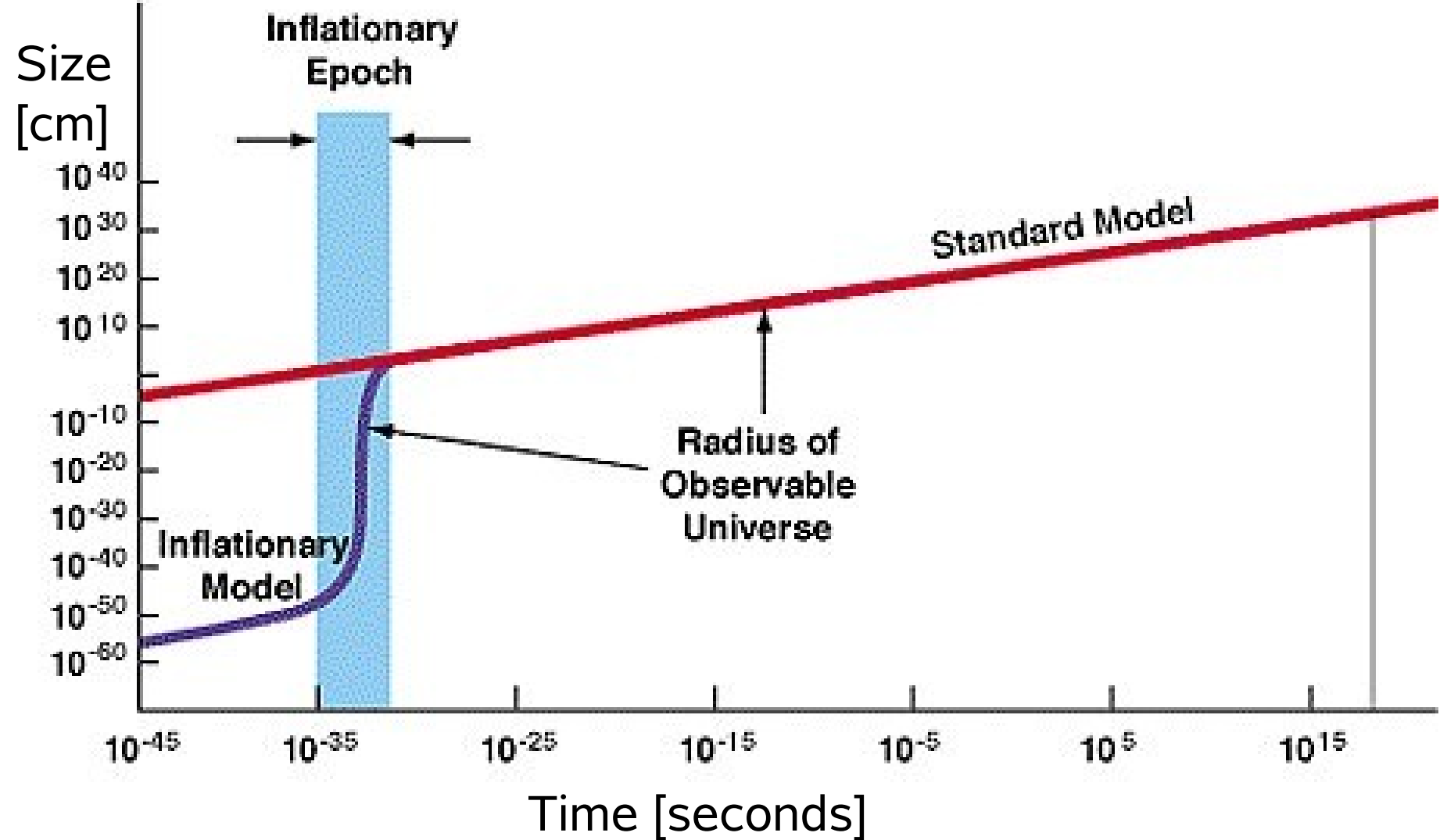


Any tiny deviation from the critical density is amplified over time.

Inflation makes the Universe flat



Inflation



Whole observable universe came from a tiny region.

Inflation and cosmology

- The Universe is very uniformity and very close to flat.
- A new theoretical idea, inflation, gives an explanation for the uniformity and flatness of the Universe.
- Inflation still needs to be tested.
- ESA will launch the Planck satellite on May 14 that hopes to test inflation.

Review questions

- Why is it surprising that the microwave background has almost exactly the same temperature in all directions on the sky?
- Why is it surprising that the geometry of the universe is so close to flat?
- What is the best explanation to date of why the Universe is uniform and flat?