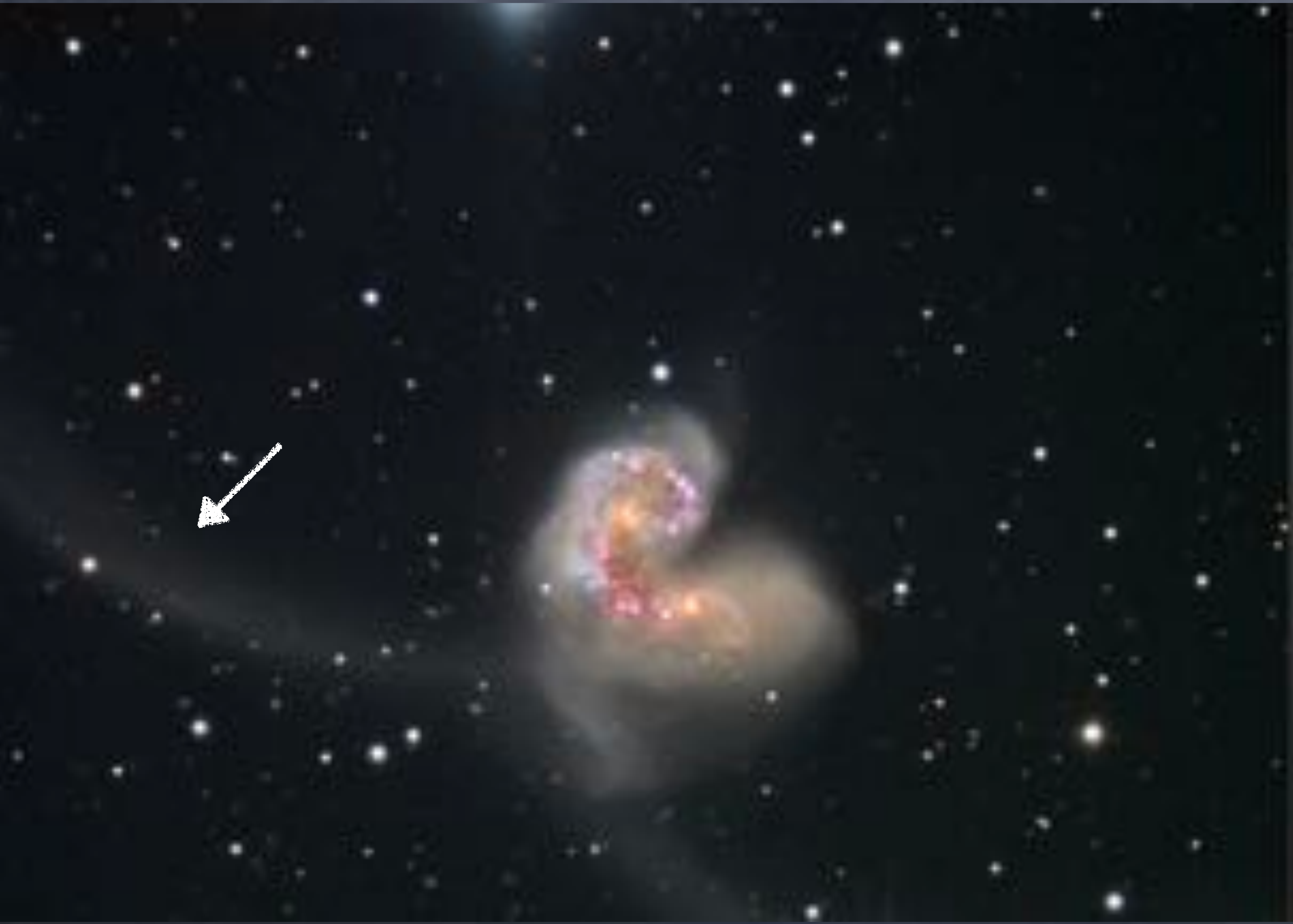
The Evolution of Galaxies

Chapter 28

A image of colliding galaxies. This galaxy is named the antenna galaxy for the long tails.



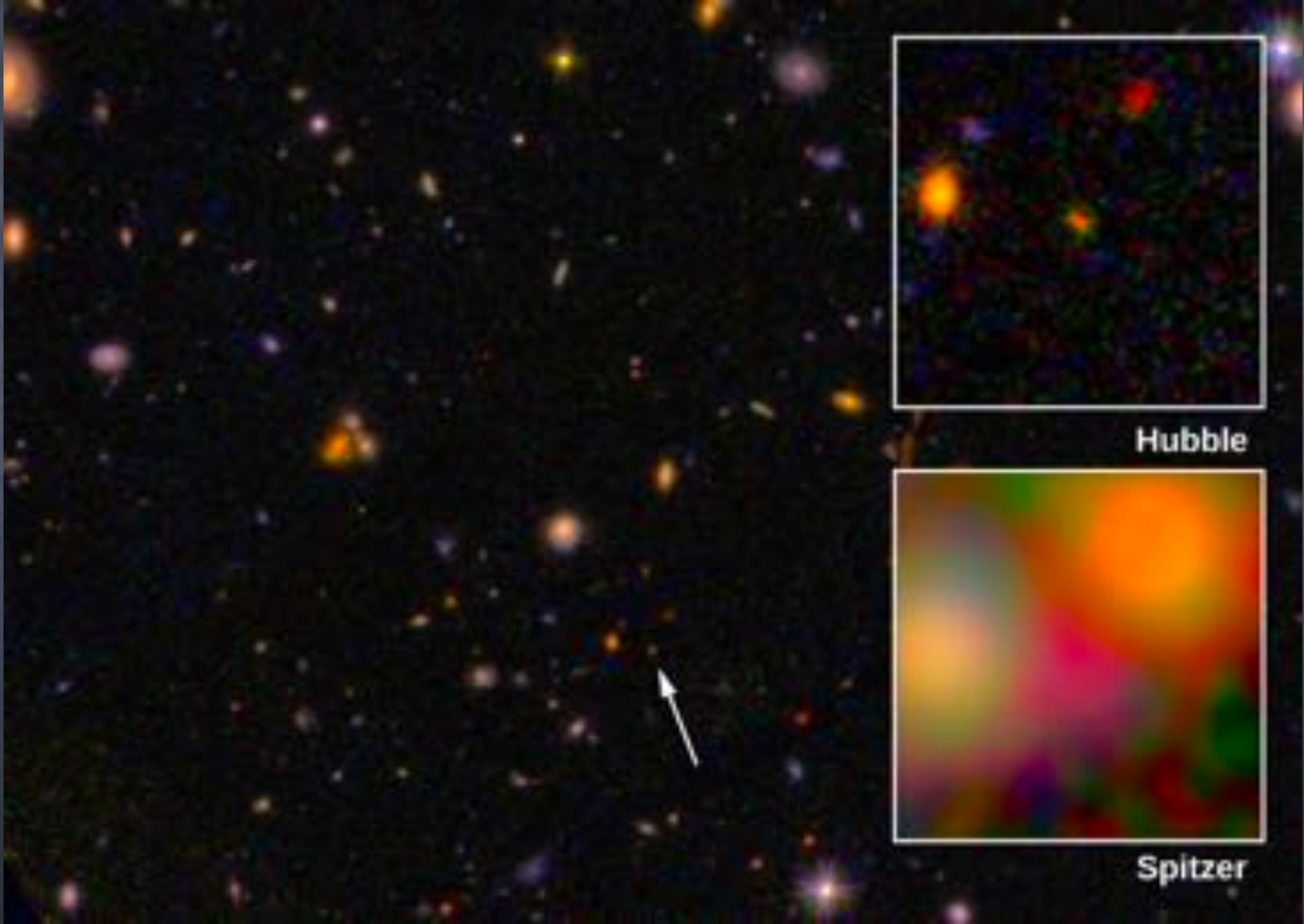
Evolution of Galaxies

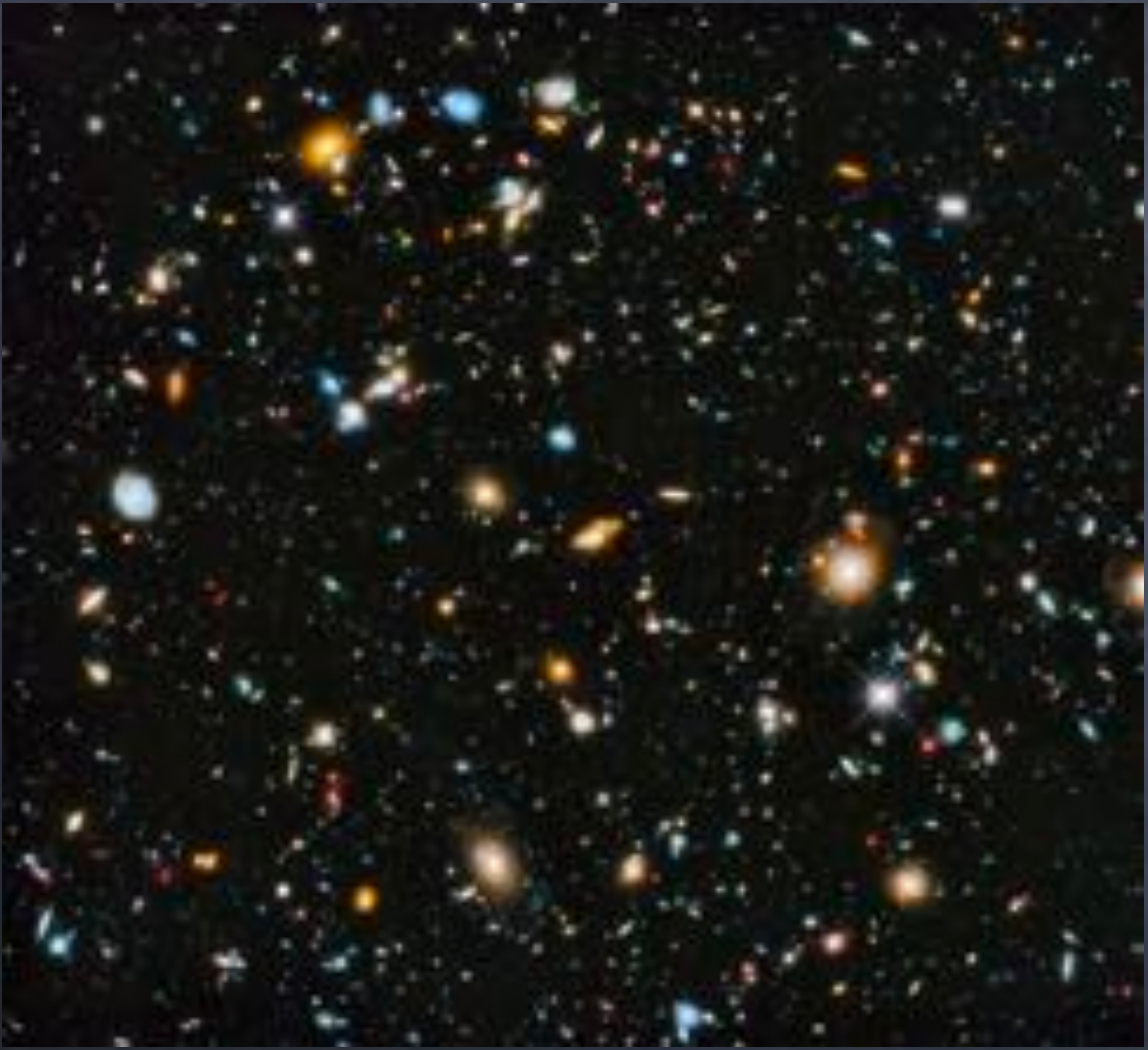
- We can not actually observe galaxies changing because they change only over billions of years.
- Luckily we can observer different galaxies at different times thanks to the finite speed of light. When we see galaxies that are billions of light years away, we see galaxies that were billions of years younger.
- Thus why we can not see the evolution of an individual galaxy we can study how the galaxy population has changed with time.

Time Travel

- Looking at a single image of galaxies allows us to look back in time.
- The bright cluster galaxies are 3.5 billion years old.
- Some of the faint blue galaxies are 12 billion years old.

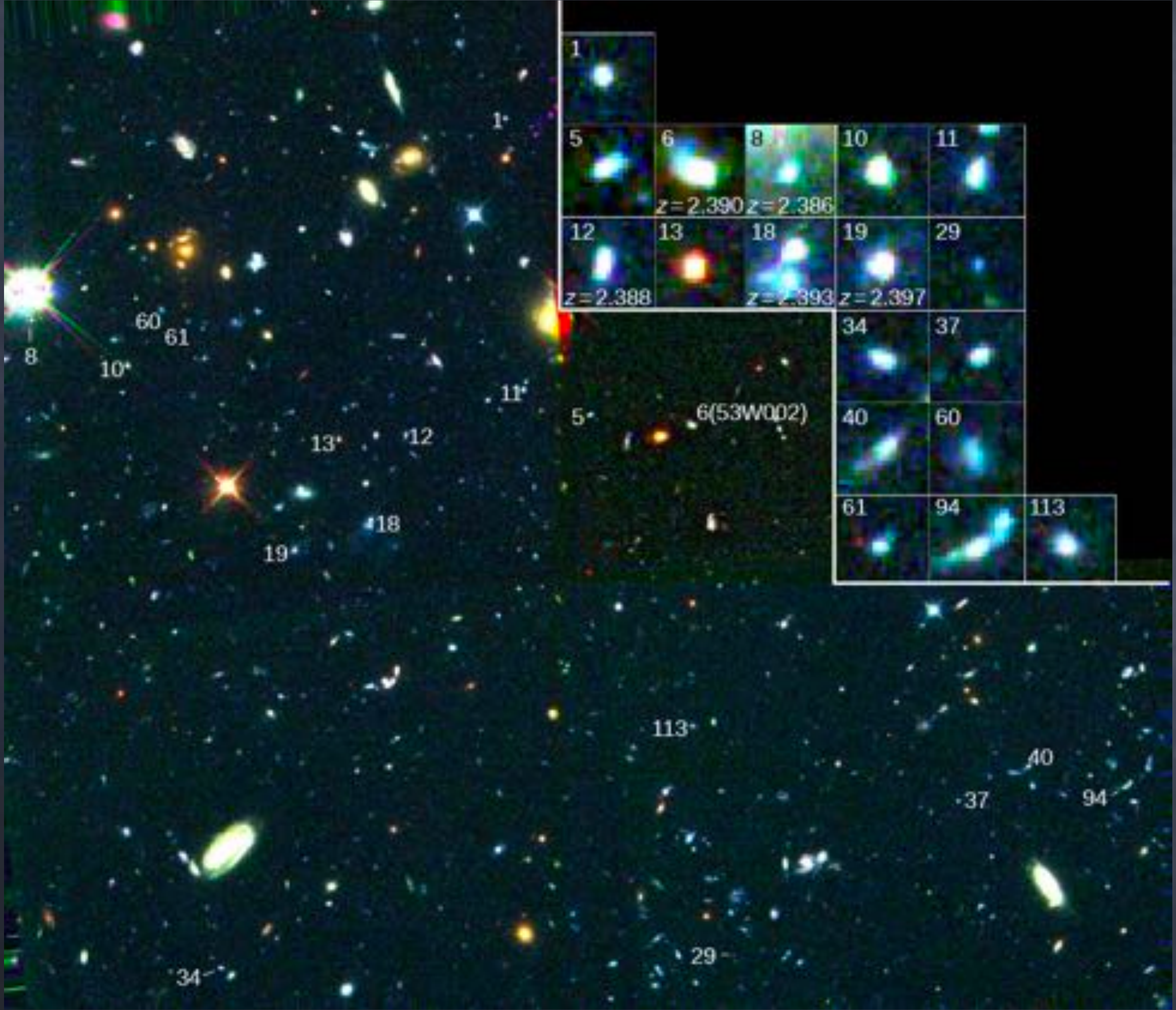
A redshift of 8.7 or 13.2 billion year ago galaxy. Distant galaxies are very hard to find and study in detail.





The Hubble ultra deep field, you can see all kinds of galaxies, different colors, shapes, sizes and brightnesses. These of course include many different ages since the galaxies are at different distances.

- What can we learn when we view different galaxies?
- For far away galaxies we can not see individual stars, so we have to look at properties of the galaxy.
- We can see colors which tell us about the star formation and dust in a galaxy.
- We can measure velocity from spectra and get some idea of the mass of the galaxy.
- We can measure the shapes and sizes of galaxies.
- And we can measure the amount of heavier elements in the galaxy from the spectra.

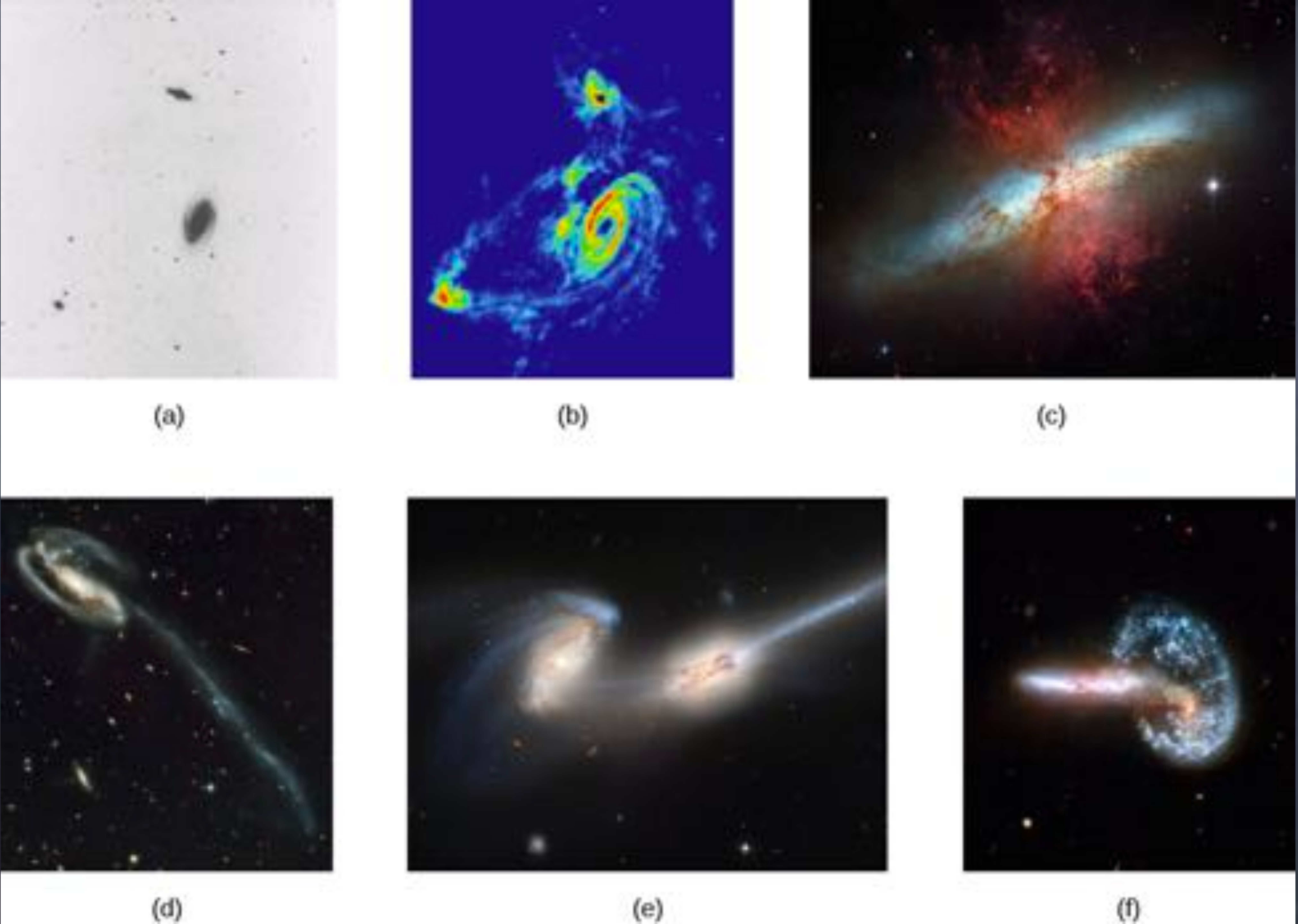


Close ups of some of the most distant galaxies in the ultra deep field. We see they are mostly blue and small. They don't have spiral structure and many have distorted shapes.

One tool that can help us see distant galaxies is gravitational lensing. This is the bending of light by gravity that we have discussed previously.
The bending can be so great for galaxies that the light is highly magnified and creates multiple images. The boxes to the right show 3 images of the same galaxy that has been lensed by this cluster of galaxies.

Galaxy Mergers and Collisions

- One thing we see looking back in time is that galaxy collisions are rare today but where more common in the past.
- These collisions can be the main way a galaxy grows in mass and also can transform the shape of a galaxy.
- Collisions can trigger star formation

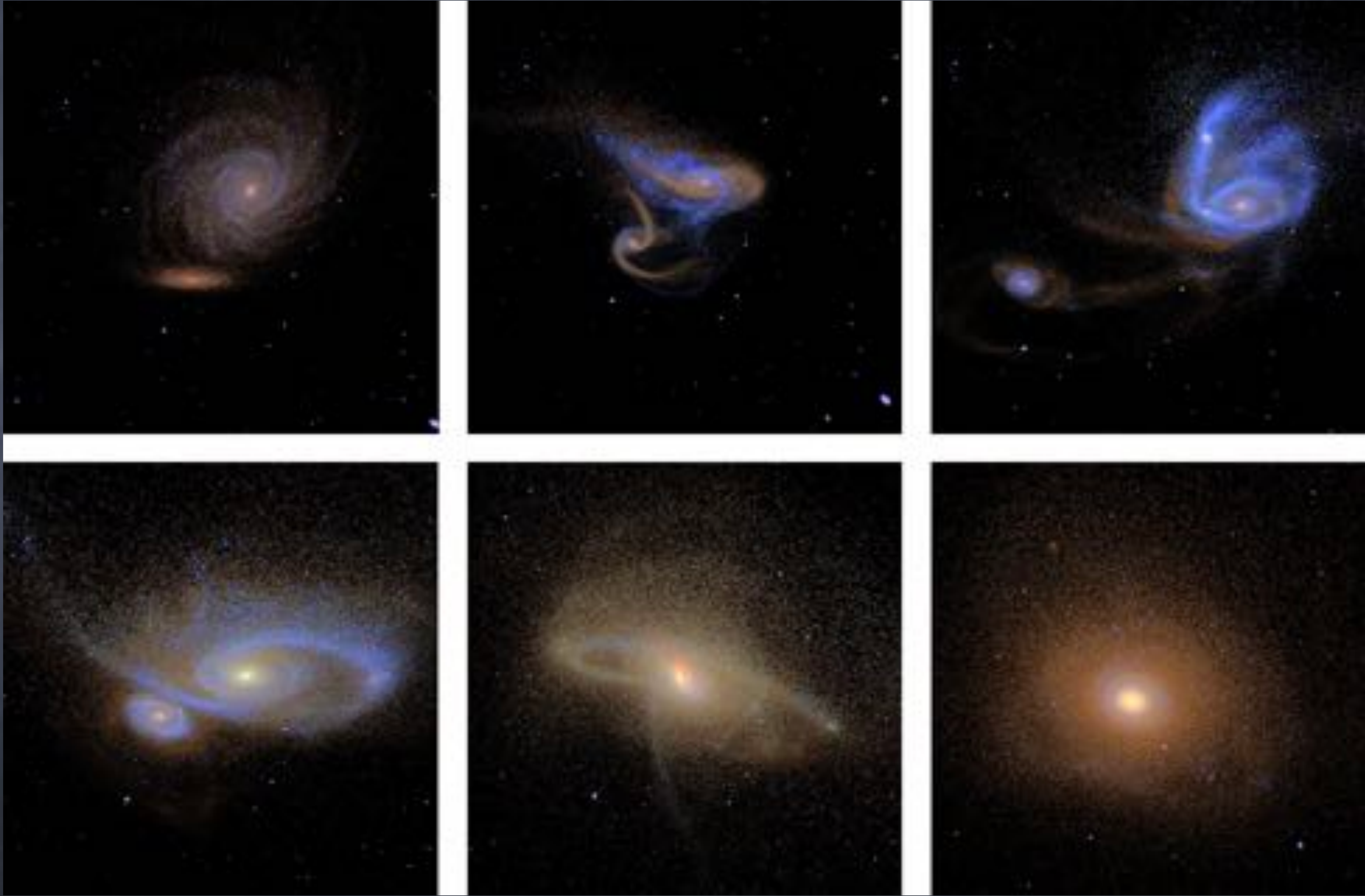


Many different examples of galaxy mergers. The more dramatic the easier to identify a merger. But even galaxies that are fairly far apart can be seen to be interacting by looking closely for abnormal features. Wavelength also matters, a and b are the same pair, in visible they look unperturbed but in radio the interaction is clear.

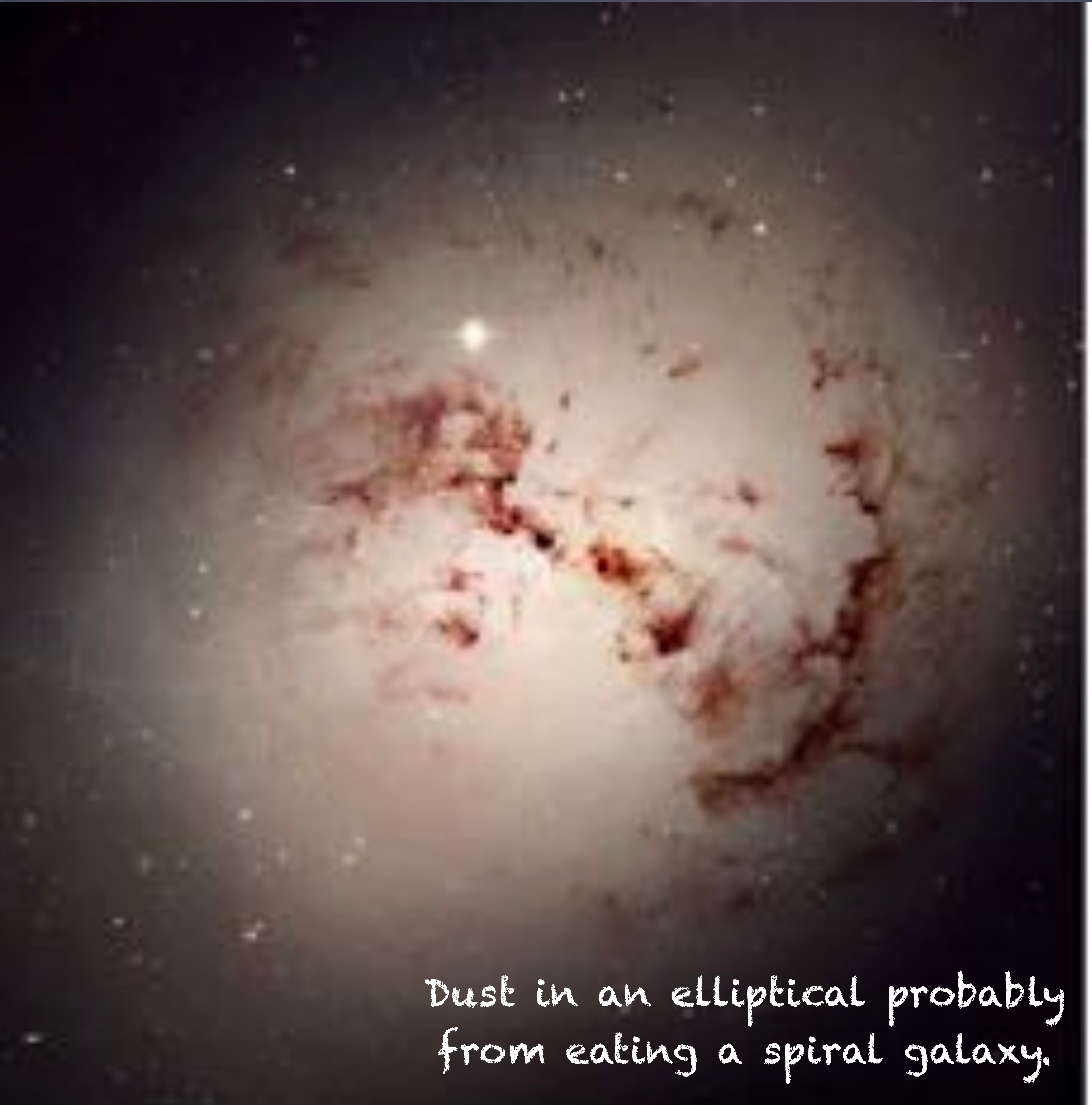
Why Galaxies Often Collide But Stars Rarely Do

- When galaxies collide the stars in them almost never do. This is because the distance between stars is much greater relative to their sizes than the distance between galaxies.
- If our Sun was the size of grapefruit in New York City then the nearest star would be another grapefruit in San Francisco. The distance is 27 million times the diameter.
- If our Galaxy was a pancake on one side of a kitchen table, the nearest large galaxy would be a pancake at the other end of the table. The distance is 24 times the diameter.

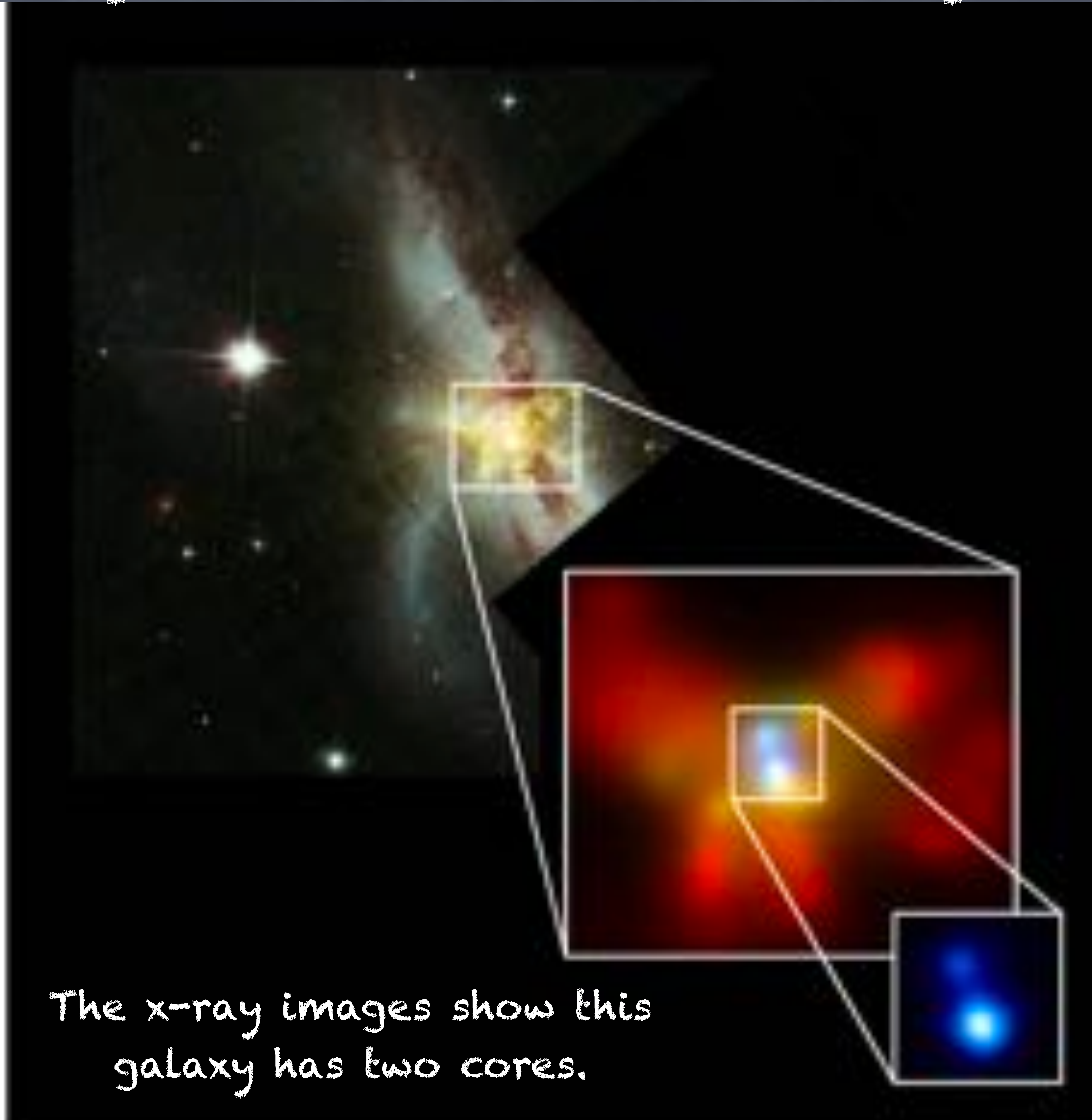
Computer simulations show that the merger between two spiral galaxies can result in one elliptical galaxy. In fact this is how we think all ellipticals are made.



Very large ellipticals continue to grow by swallowing smaller galaxies. Our Milky Way grows the same way.

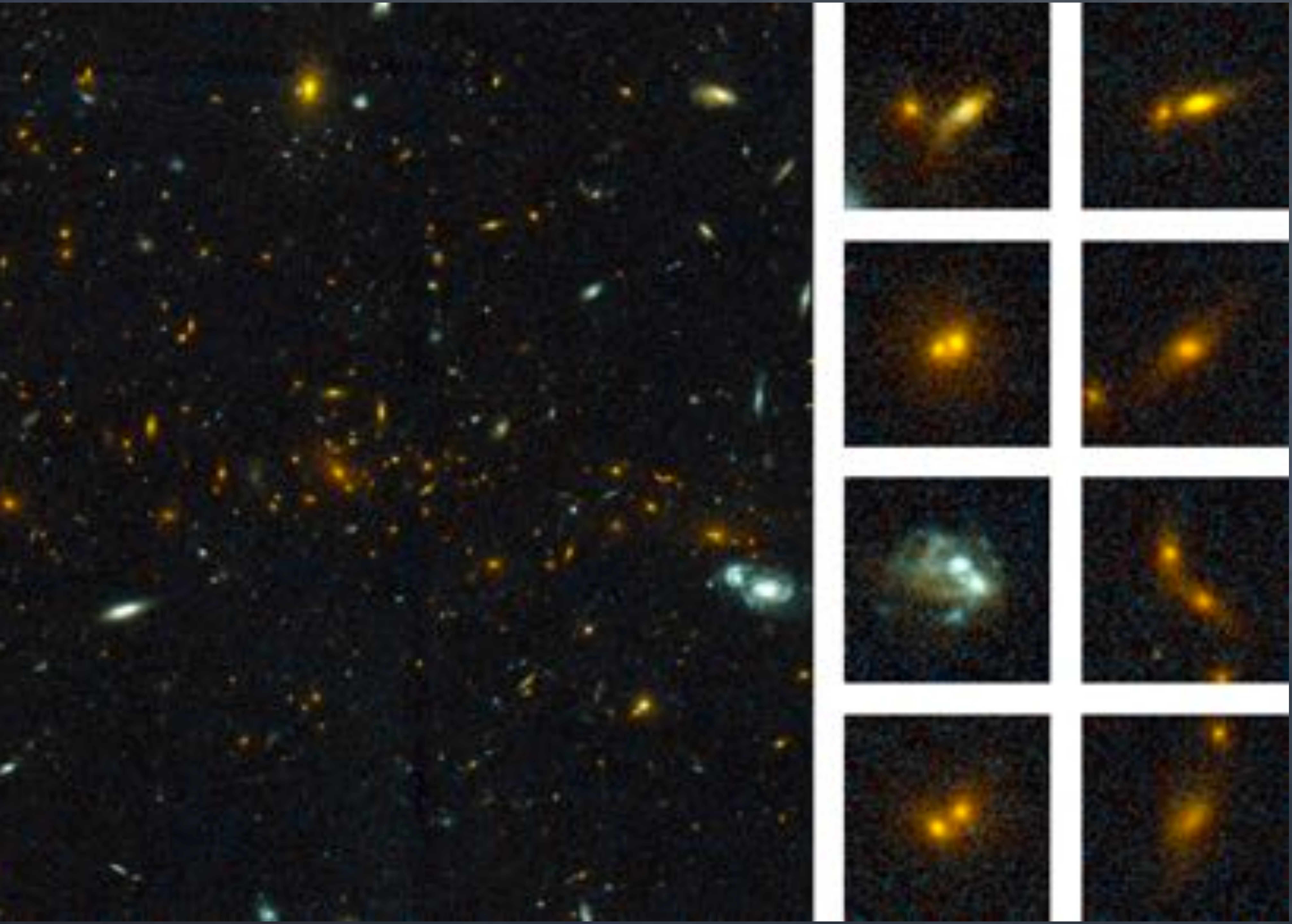


Dust in an elliptical probably from eating a spiral galaxy.



The x-ray images show this galaxy has two cores.

Galaxy collisions can also cause increased star formation. Some merging galaxies are forming stars at a rate 100 times normal and are called starburst galaxies.



Distant galaxies resemble nearby mergers. We can not see them as clearly, but we often see distorted shapes and enhanced star formation

Mergers are also likely to trigger AGN activity as gas is funneled to the galaxy center. This can explain why quasars were more common in the past.

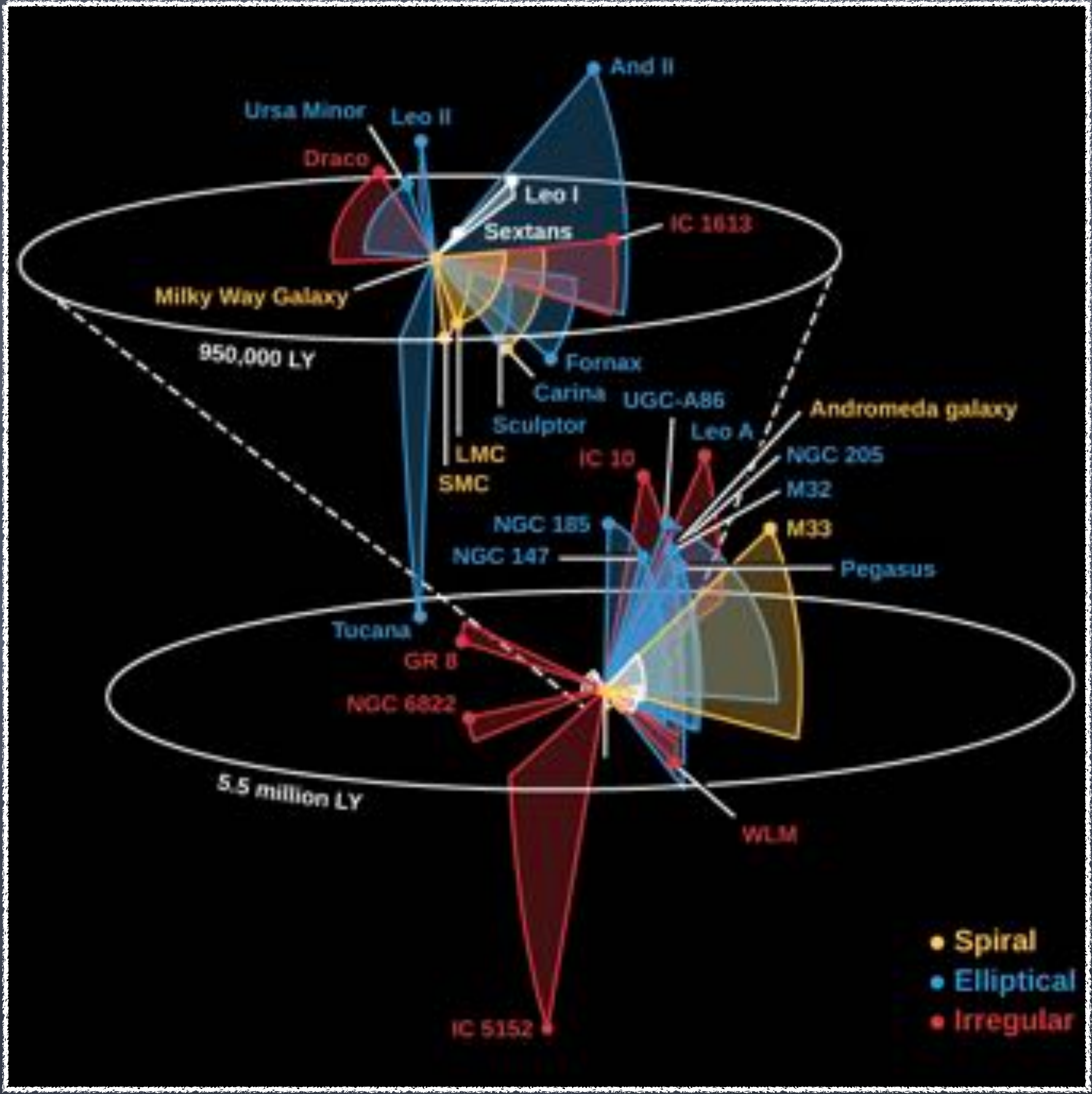
The Cosmological Principle

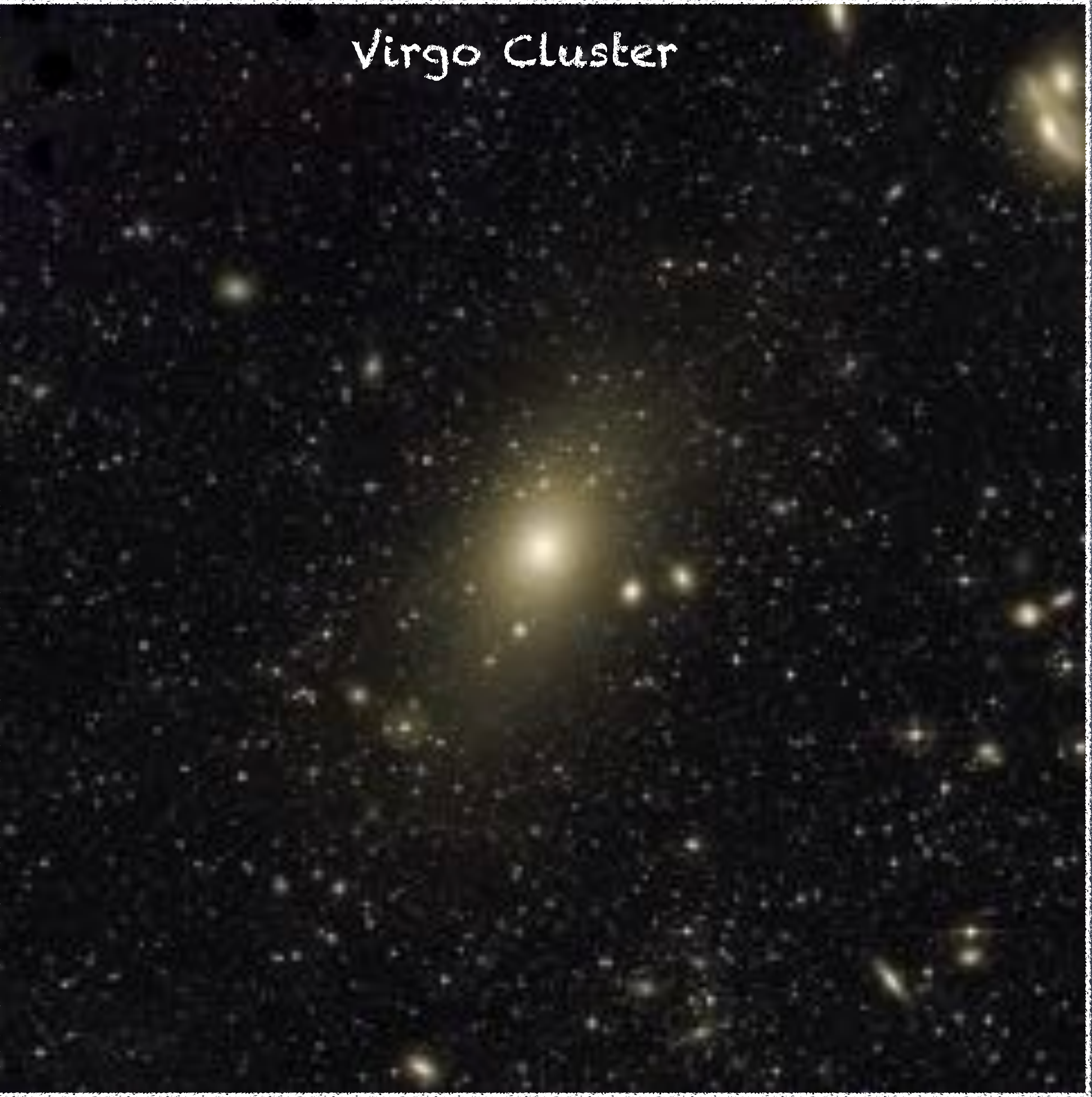
- The cosmological principle is that the universe is homogenous and isotropic. This means that you find the same amount of stuff everywhere and every direction looks the same.
- In truth the universe is only homogenous on large scales (about half a billion lyrs). At smaller scales galaxies are clumped into structures.

The Local Group

- Our Milky Way and Andromeda are part of what is called the Local Group.
- The top circle shows the volume just around our Galaxy which contains many dwarf galaxies.
- The lower circle is 5 times the radius and includes other spirals, Andromeda and M31 as well as many smaller galaxies.

https://www.youtube.com/watch?v=4No4fPGgm14





Galaxy Clusters

- Larger groupings of galaxies are called galaxy clusters and can contain thousands or tens of thousands of galaxies.
- These are the largest bound structures in the universe.
- Giant elliptical galaxies are often found in the center of galaxy clusters.

The coma cluster is the closest really big cluster with tens of thousands of galaxies. It is 10 million lyrs in diameter. It's total mass is about 2×10^{15} solar masses.

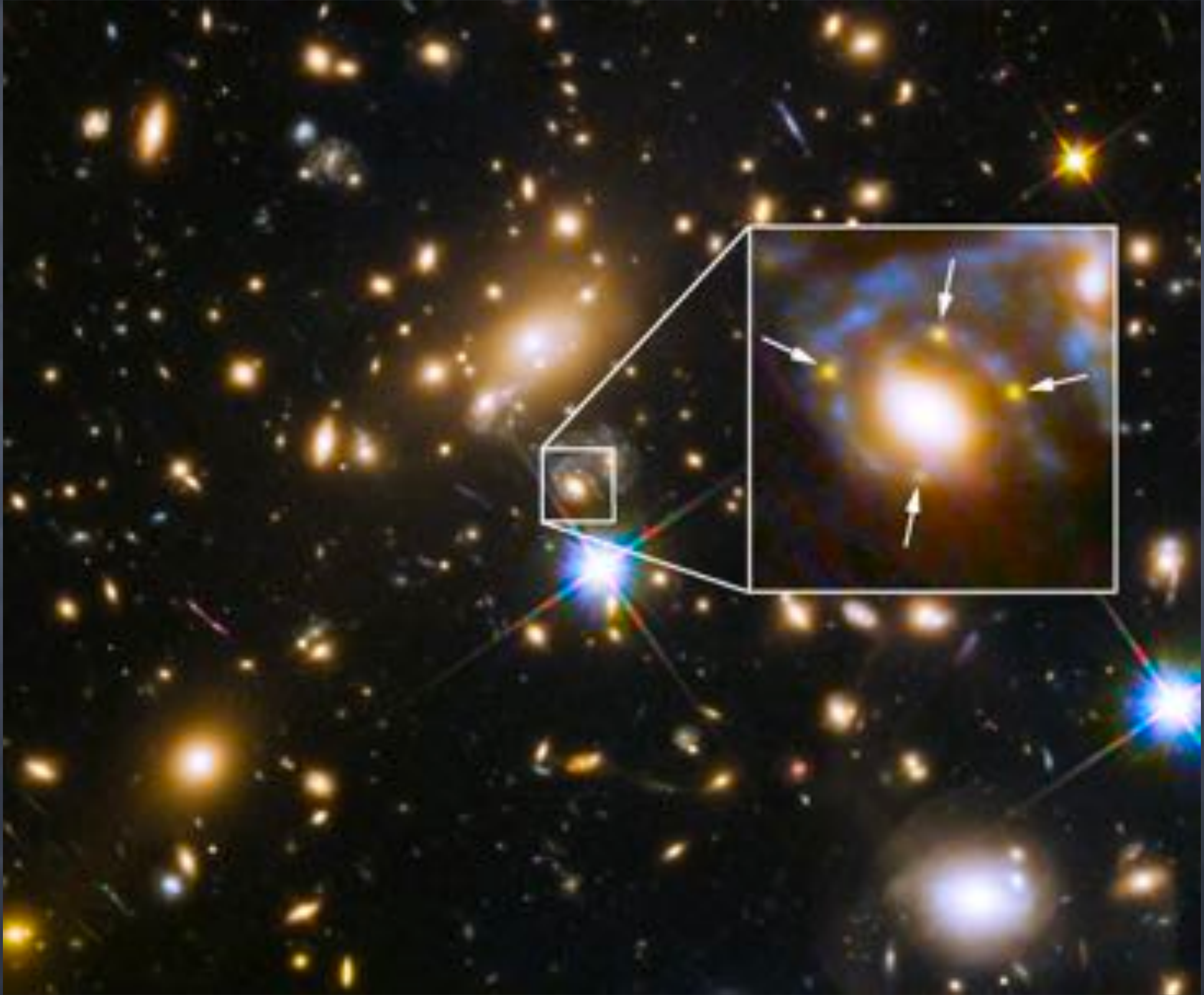
Coma Cluster

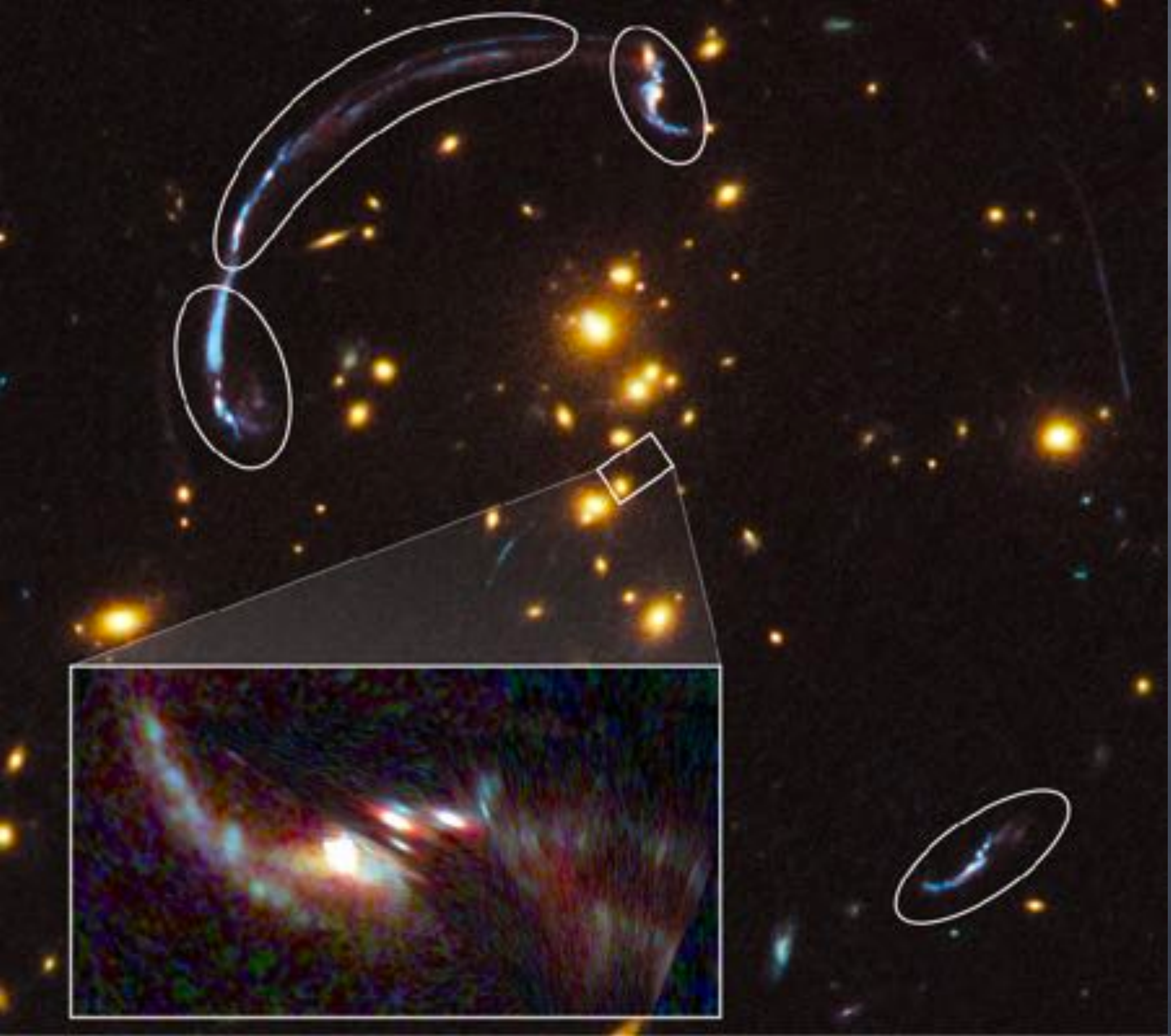
- Clusters also have a great deal of hot gas the can be seen in the x-ray, so it is a million to 10 million K.
- This hot gas is ten times the mass of the stars in the galaxy.
- But the dark matter mass is still 10 times more than that.
- So clusters are 90% dark matter, 9% hot gas and 1% stars.

Gravitational Lensing

Clusters often act as gravitational lenses. They are so massive they bend light so much that there are two or more images of a single object. This images can be used to reconstruct the mass of the lens and provides one of the best ways to measure mass.

Light from a supernova at a distance of 9 billion light-years passed near a galaxy in a cluster at a distance of about 5 billion light-years. In the enlarged inset view of the galaxy, the arrows point to the multiple images of the exploding star. The images are arranged around the galaxy in a cross-shaped pattern called an Einstein Cross. The blue streaks wrapping around the galaxy are the stretched images of the supernova's host spiral galaxy, which has been distorted by the warping of space.

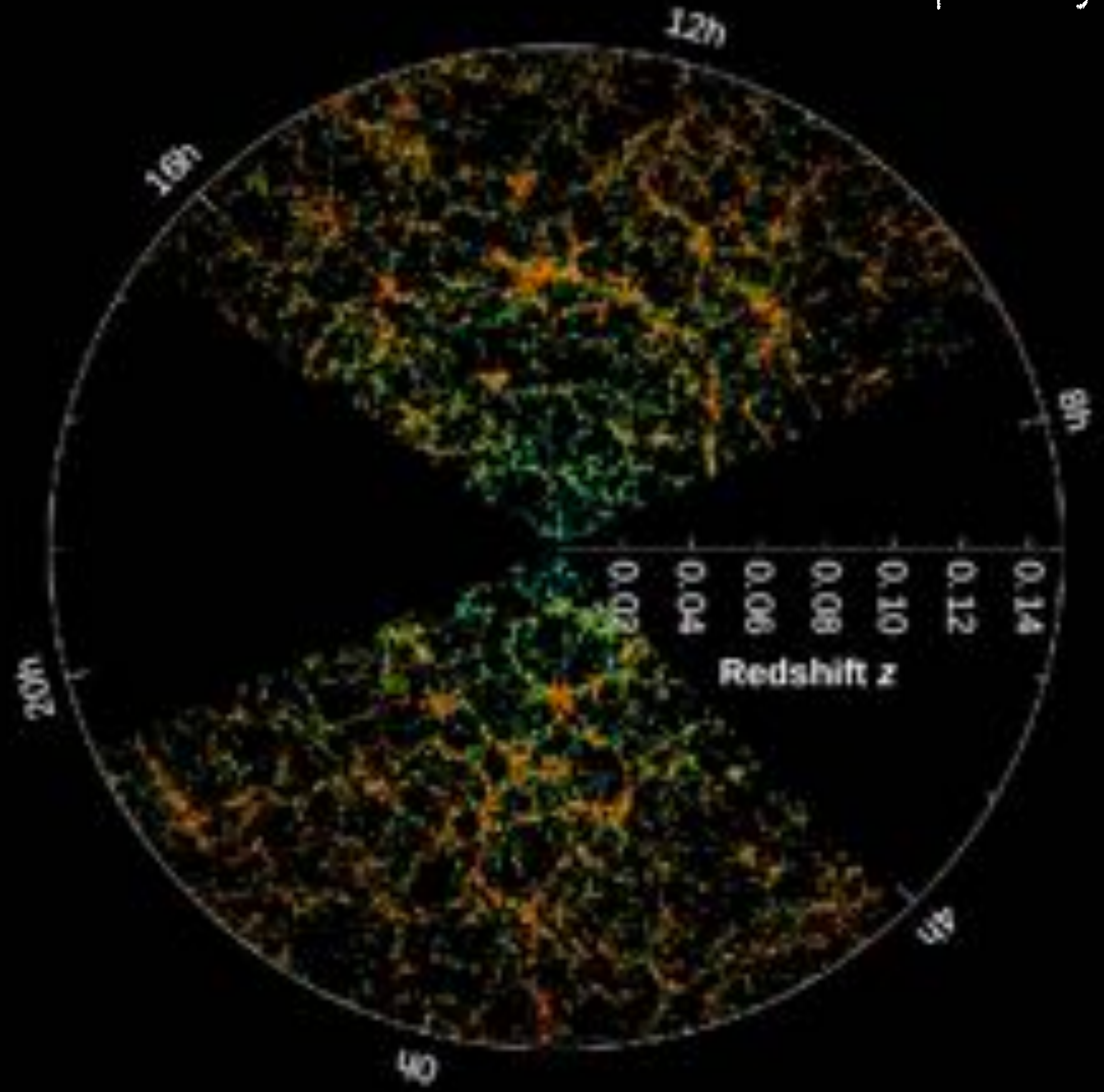




The rounded outlines show the location of distinct, distorted images of the background galaxy resulting from lensing by the mass in the cluster. The image in the box at lower left is a reconstruction of what the lensed galaxy would look like in the absence of the cluster, based on a model of the cluster's mass distribution, which can be derived from studying the distorted galaxy images. The reconstruction shows far more detail about the galaxy than could have been seen in the absence of lensing. As the image shows, this galaxy contains regions of star formation glowing like bright Christmas tree bulbs. These are much brighter than any star-formation regions in our Milky Way Galaxy.

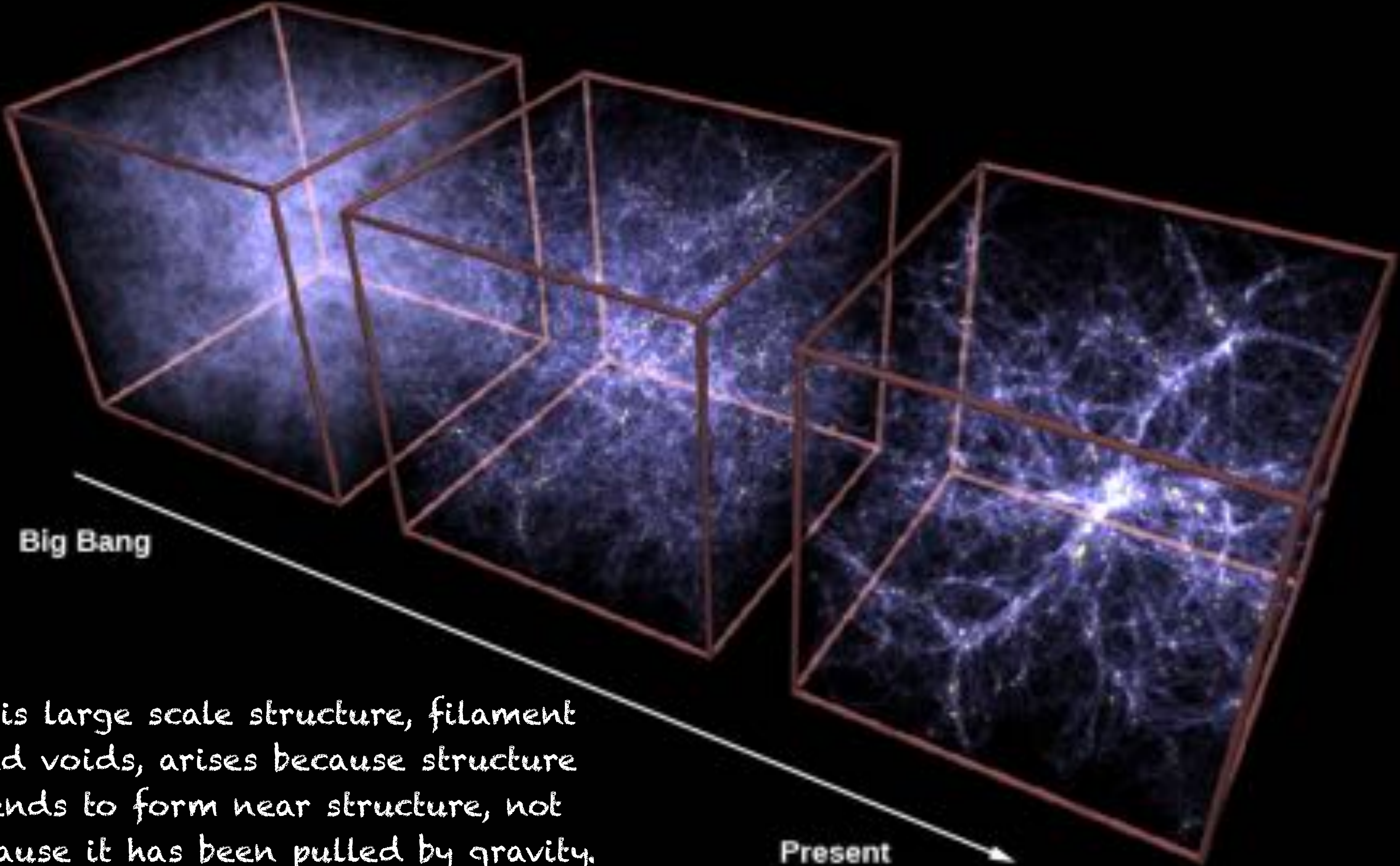
The distribution of galaxies from the Sloan Digital Sky Survey. And these very large scales we see super clusters, multiple clusters near one another and voids, regions with almost no galaxies.

https://www.youtube.com/watch?v=08LBltePDZw



We also see that while there is lots of structure it starts to become homogenous at these large scales.

http://burro.case.edu/Academics/Astr222/Cosmo/Clusters/spall_anim.2003.08.09.gif



This large scale structure, filament and voids, arises because structure tends to form near structure, not because it has been pulled by gravity.

Galaxy Formation

- The basic outline of galaxy formation is based on 3 simple ideas:
    - The total mass of a system sets the temperature of gas, and hot gas doesn't have enough time to cool and form stars.
    - Gas that can cool will have some angular momentum and thus end up in a disk like what happens when solar systems form.
    - Mergers between galaxies will destroy disks and form spheroids.


Small clouds
Galaxies
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Cluster Of Galaxies