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Galaxy formation

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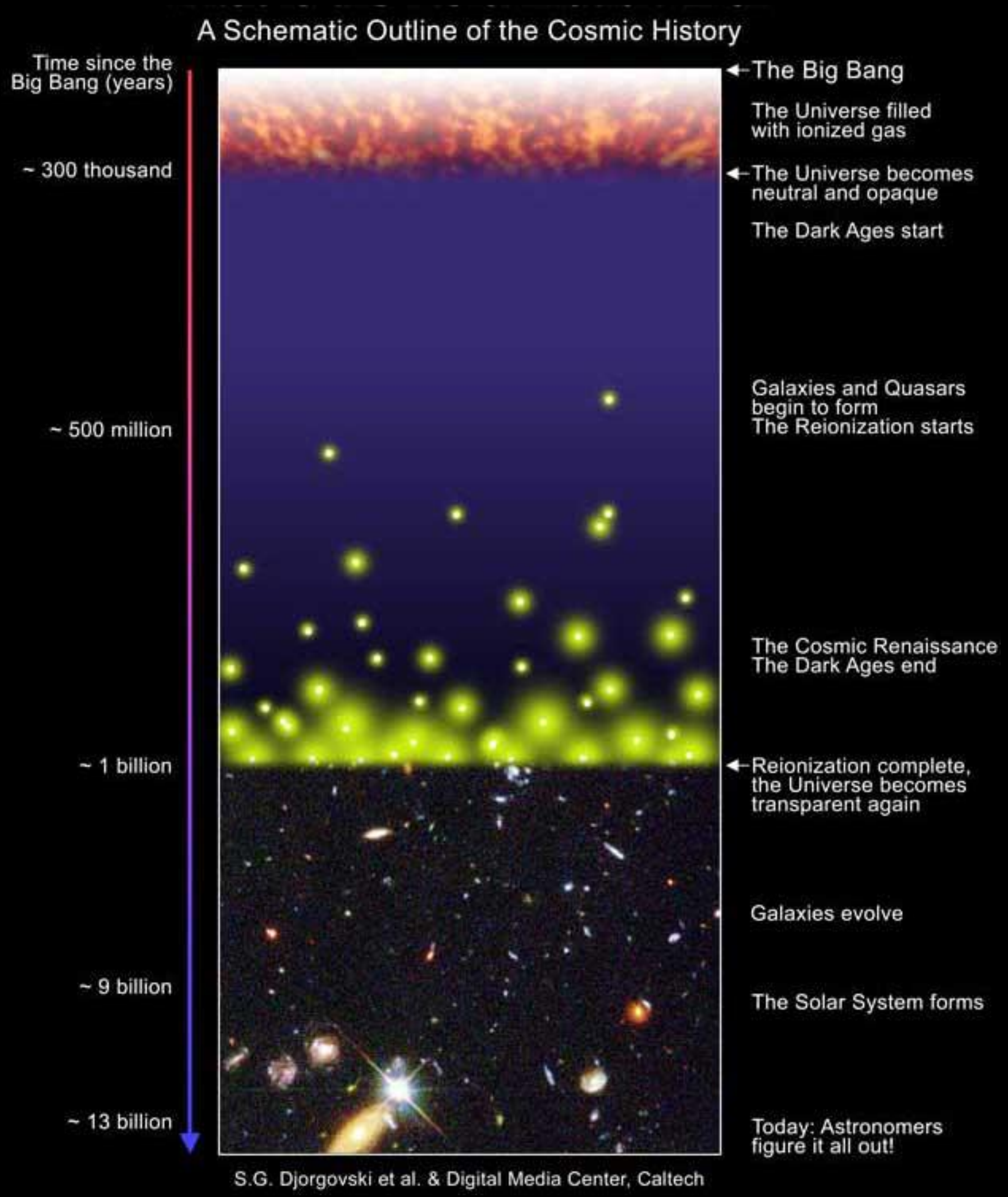
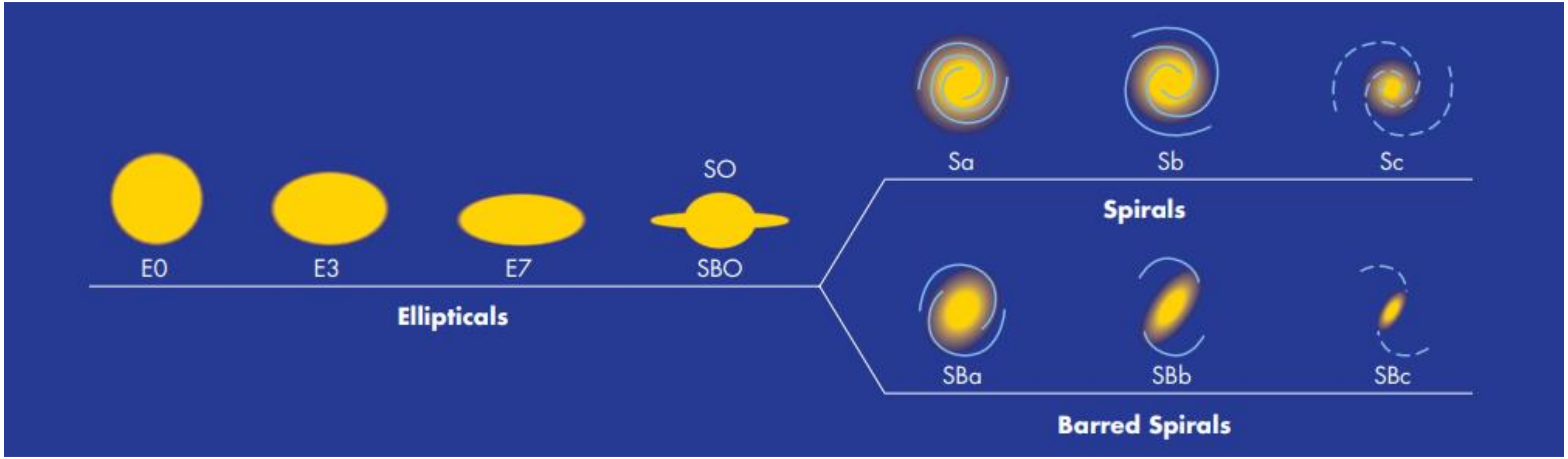
- Role of stars in galaxy formation
- New type of galaxy can result from collisions between galaxies



introduction

Observations by Hubble Space Telescope and ground-based instruments show that the first galaxies took shape as little as one billion years after the Big Bang, which probably took place about 13 billion to 14 billion years ago.

First idea of galaxy formation



In 1920s Many astronomers, regarded the Hubble classification system as an evolutionary sequence. Hubble proposed that galaxies formed as elliptical systems, which then expanded. Next, a bar developed as matter was expelled from the central elliptical region. The spiral arms formed from the ends of the bar and grew larger and more open as time passed. In some galaxies, the bar remained; in others it went away.

Modern theories of galaxy formation

There are two leading theories to explain how the first galaxies formed:

One says that galaxies were born when vast clouds of gas and dust collapsed under their own gravitational pull, allowing stars to form.

The other, which has gained strength in recent years, says the young universe contained many small "lumps" of matter, which clumped together to form galaxies.

Classical theory of galaxy formation :gravitational instability

Gravity pulls matter in.

Pressure pushes it back out.

When pressure wins -> *stable oscillations* (sound waves).

When gravity wins -> *collapse*.

Cooling lowers pressure, triggers collapse.

Applies to both *Star Formation* and *Galaxy Formation*.

- ***Jeans Length*** : $$L_J \sim \left(\frac{kT}{G \rho m} \right)^{1/2}$$
- Gravity wins when $L > L_J$.

Density fluctuations and structure formation

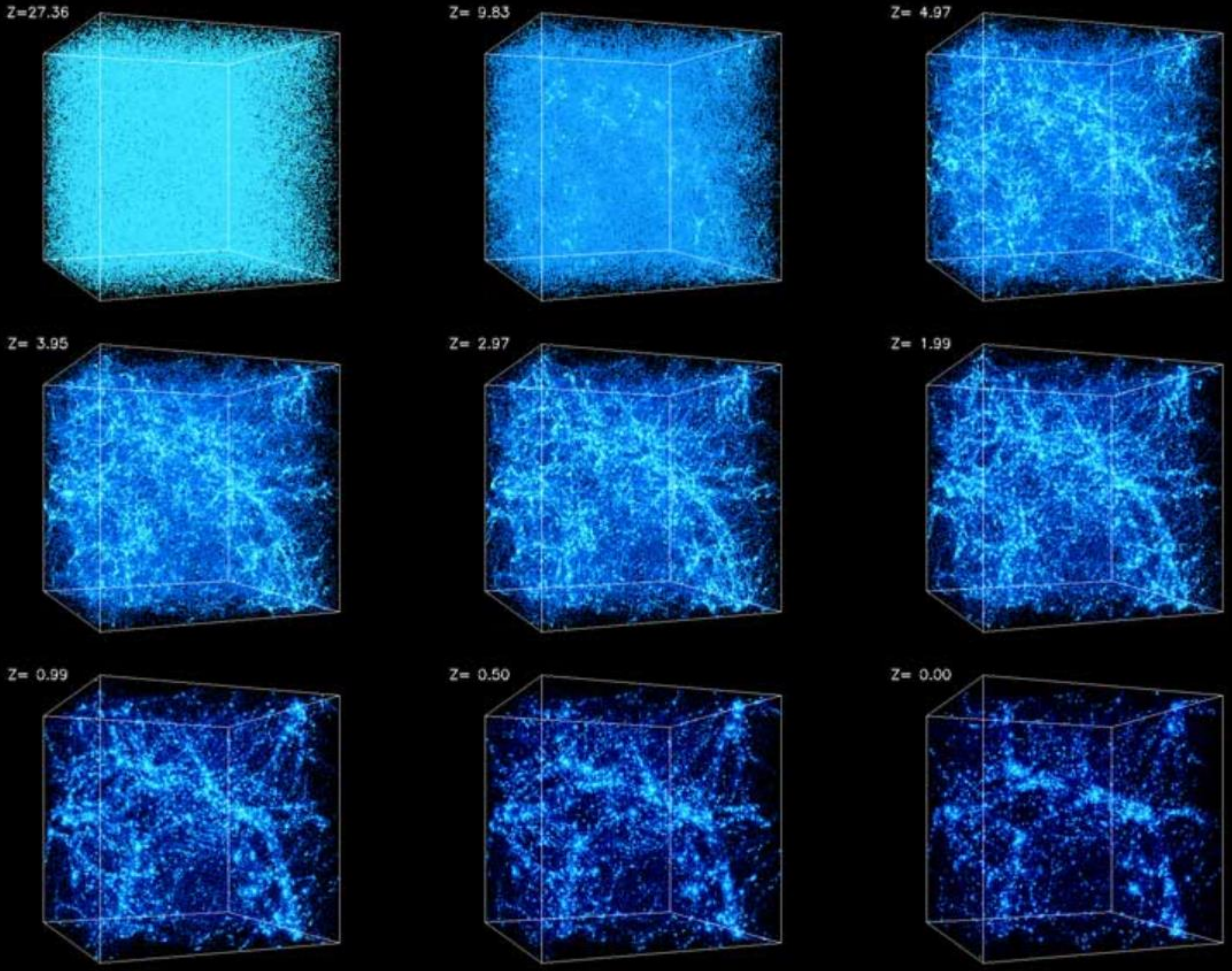
Anisotropies in the CMB temperature

→ density ripples $$\frac{\Delta\rho}{\rho} \sim \frac{\Delta T}{T} \sim 10^{-5}$$

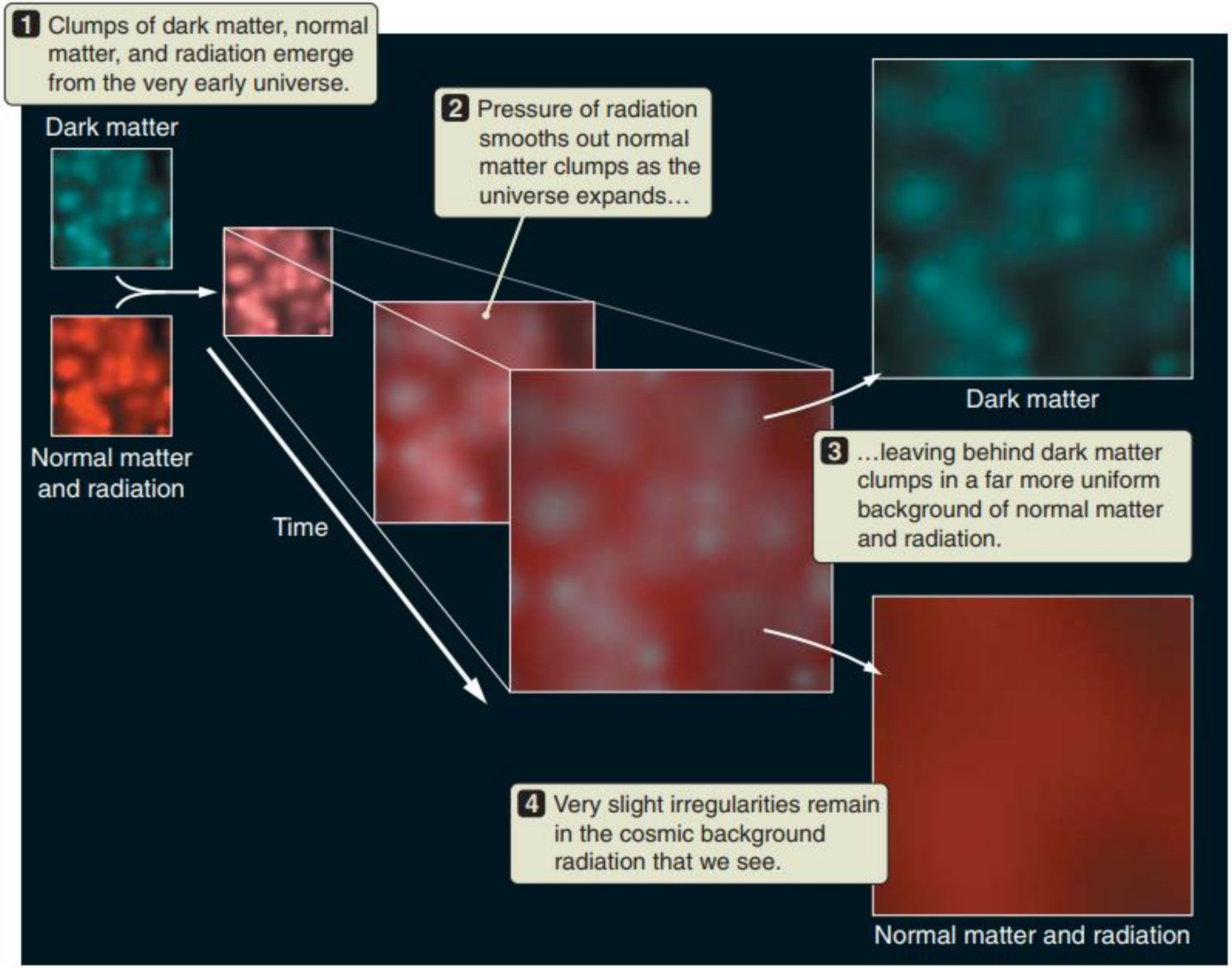
at the time of decoupling.

These are the seeds

that grow to form galaxies.

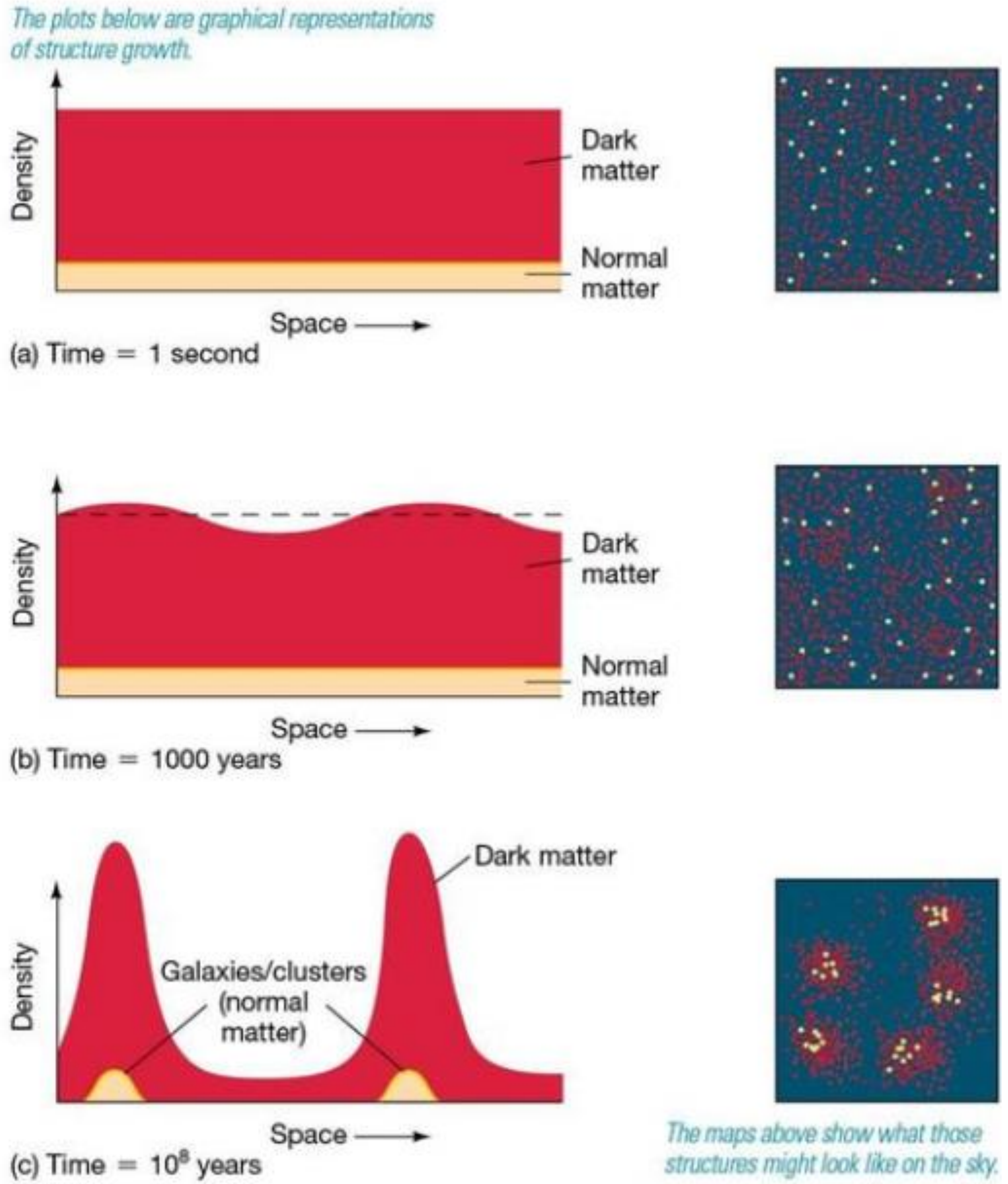


The frames illustrate the results of computer simulation of the formation of clusters and large-scale filaments in the Cold Dark Matter model with dark energy. Each frame portrays the evolution of structures in a 43 million parsecs (or 140 million light years) box, from redshift of 30 to the present epoch (upper left z=30 to lower right z=0).

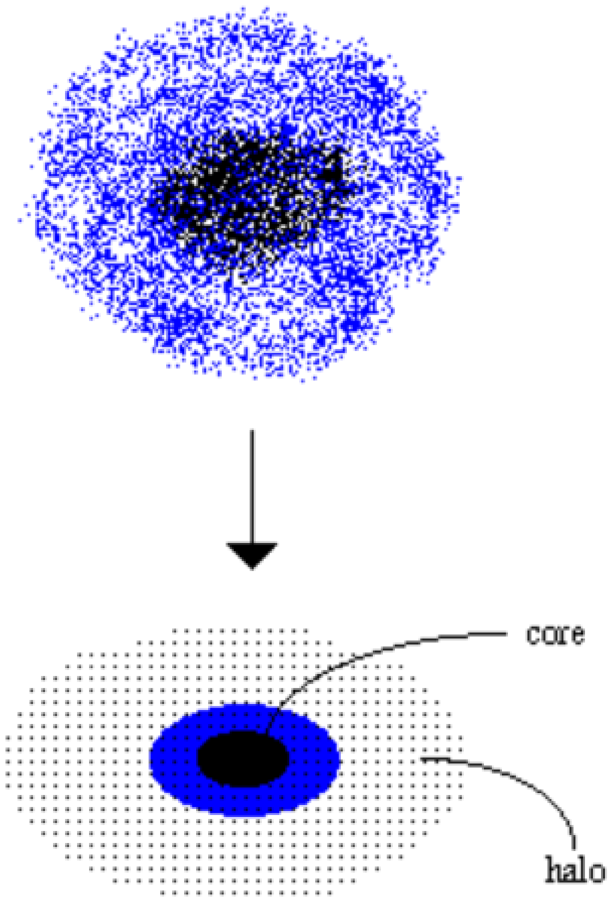


Radiation pressure and other processes in the early universe smoothed out variations in normal matter, but irregularities in the dark matter survived to become the seeds of galaxy formation.

Galaxies could then form around the dark matter clumps, resulting in the universe we see.



a lump of dark matter and gas from the time of recombination collapses under its own gravity to form a protogalaxy



gravity separates out the protogalaxy into a core and halo. The baryons that make up the gas can interact to lose energy and fall to the core of the protogalaxy. The dark matter, which only weakly interacts, remains in the halo.

Dark matter and ordinary matter (in the form of hydrogen and helium gas at this time) separate at this time. Gas can dissipate its energy through collisions. The atoms in the gas collide and heat up, the heat is radiated in the infrared (light) and the result is the gas loses energy, moves slowly = collapses to the center. Dark matter does not interact this way and continues to orbit in the halo.

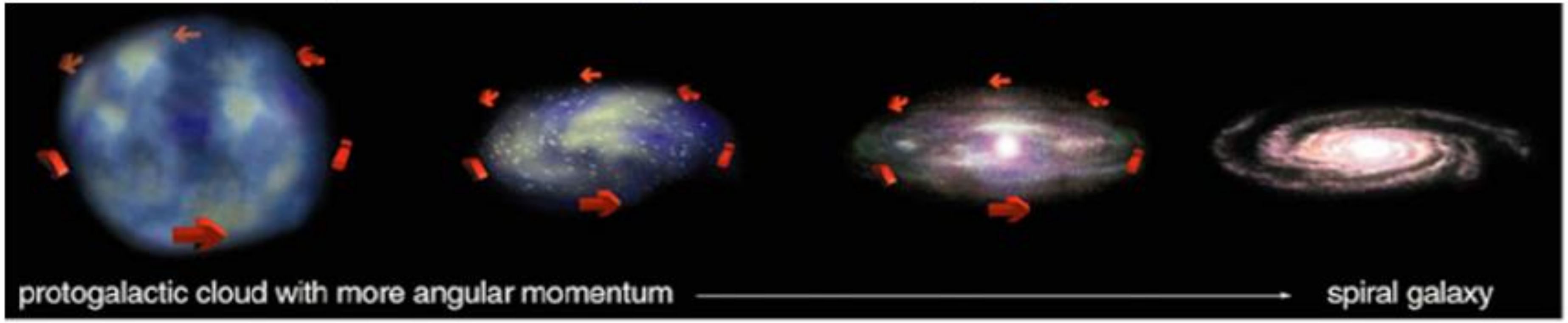
Even though there are no stars yet, protogalaxies should be detectable by their infrared emission (i.e. their heat)

Why do galaxies differ?

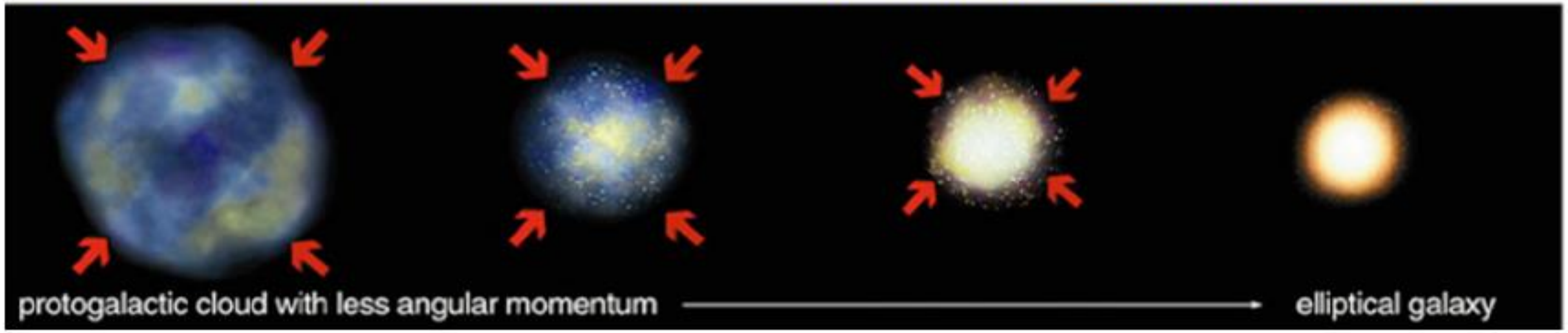
Initial conditions in the protogalactic clouds are different.

1. Protogalactic spin:

Faster rotation (more initial angular momentum): Spiral Galaxies



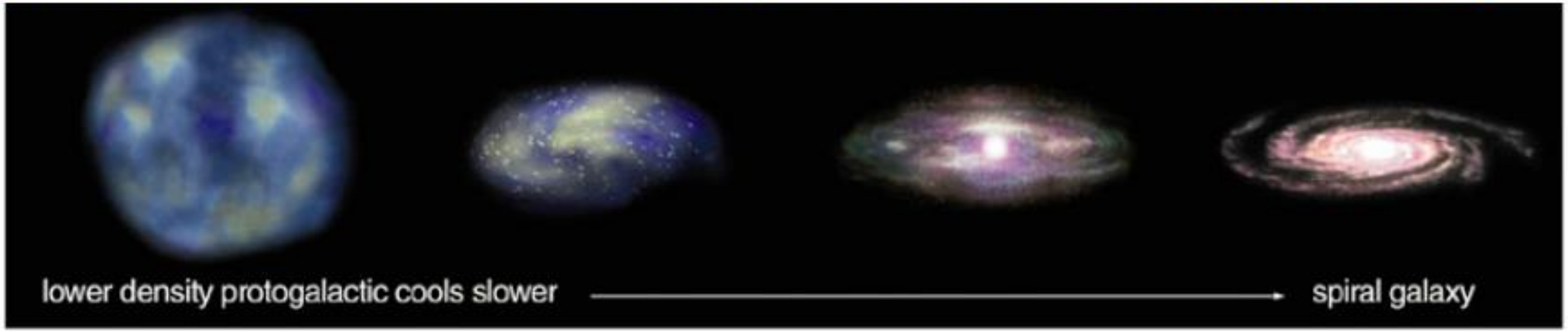
Slower rotation (little/no initial angular momentum): Elliptical Galaxies



2. Protogalactic density:

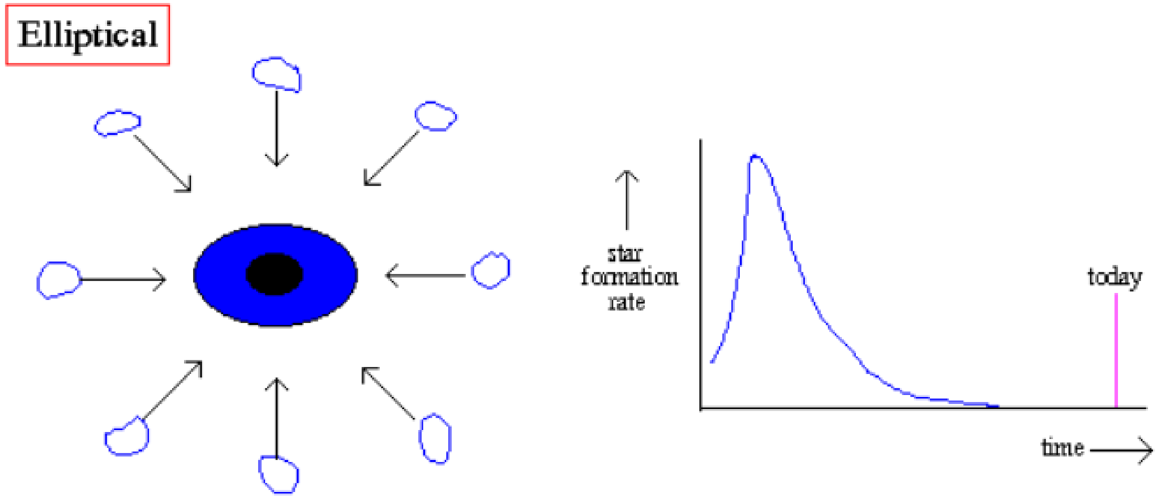
High gas density results in quicker cooling, faster star formation before gas settled into a disk: Elliptical Galaxies

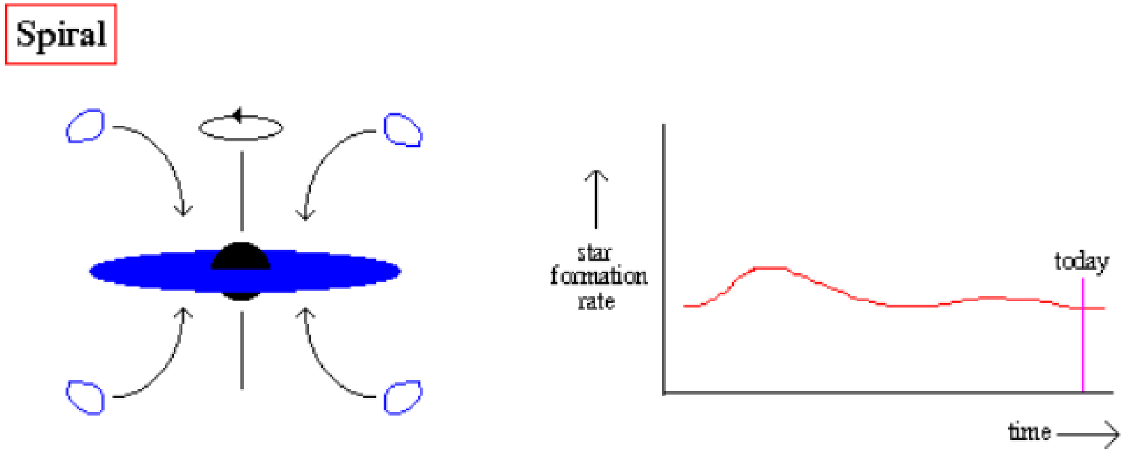
Low gas density, less star formation, gas settled into a disk: Spiral Galaxies



Initial Star Formation Rates

the appearance of a galaxy is determined by its initial star formation rate, which determined if all its gas was used to make stars all in one burst, or slowly over billions of years



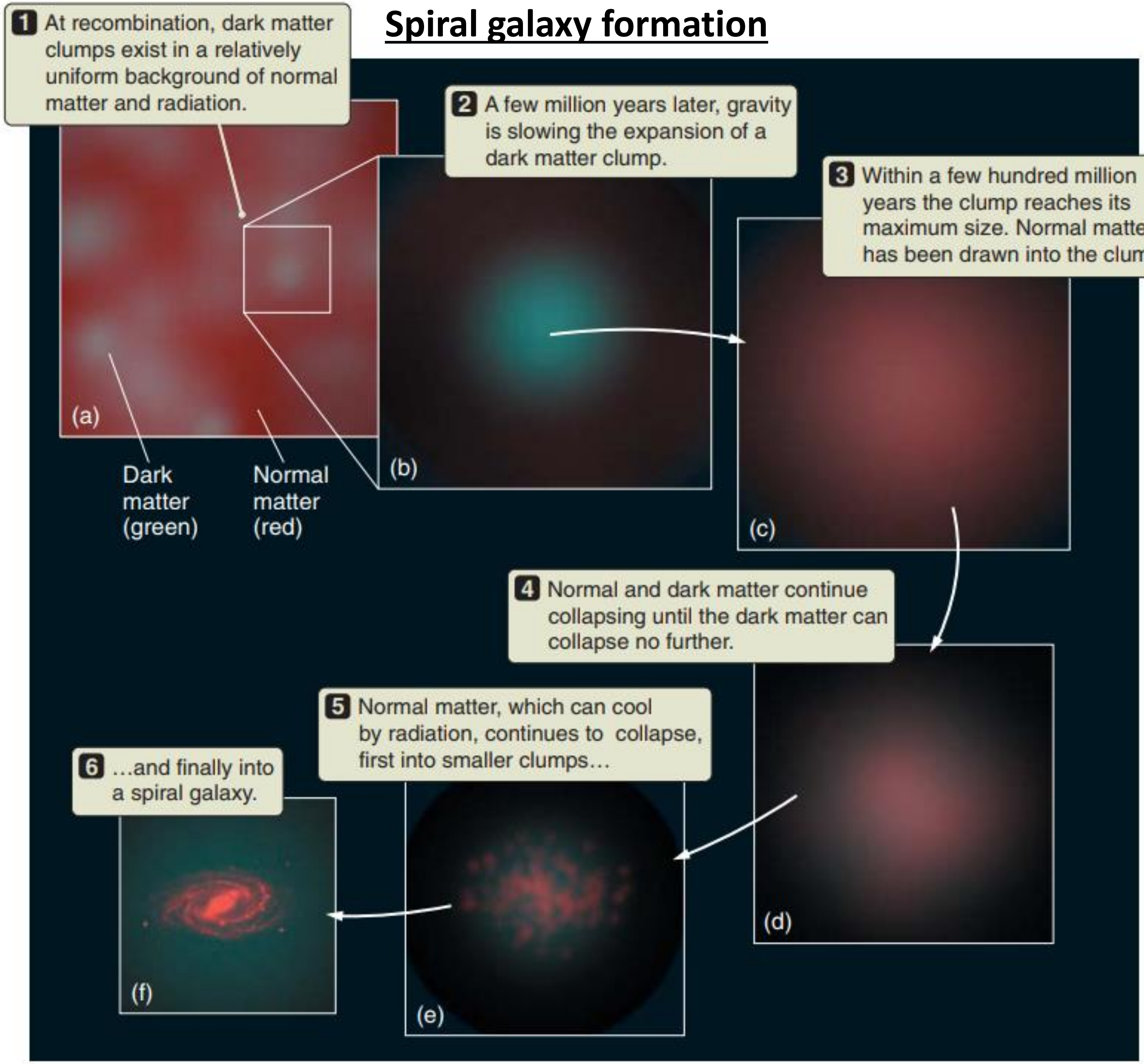


The two most distinct galaxy types are ellipticals and spirals. Ellipticals have no ongoing star formation today, spirals have a lot. Assuming that ellipticals and spirals are made from the same density enhancements at the time of recombination, why did they evolve into very difference appearances and star formation rates?

The answer is how rapid their initial star formation was when they formed. If star formation proceeds slowly, the gas undergoes collisions and conservation of angular momentum forms a disk (a spiral). If star formation is rapid and all the gas is used up in an initial burst, the galaxy forms as a smooth round shape, an elliptical.

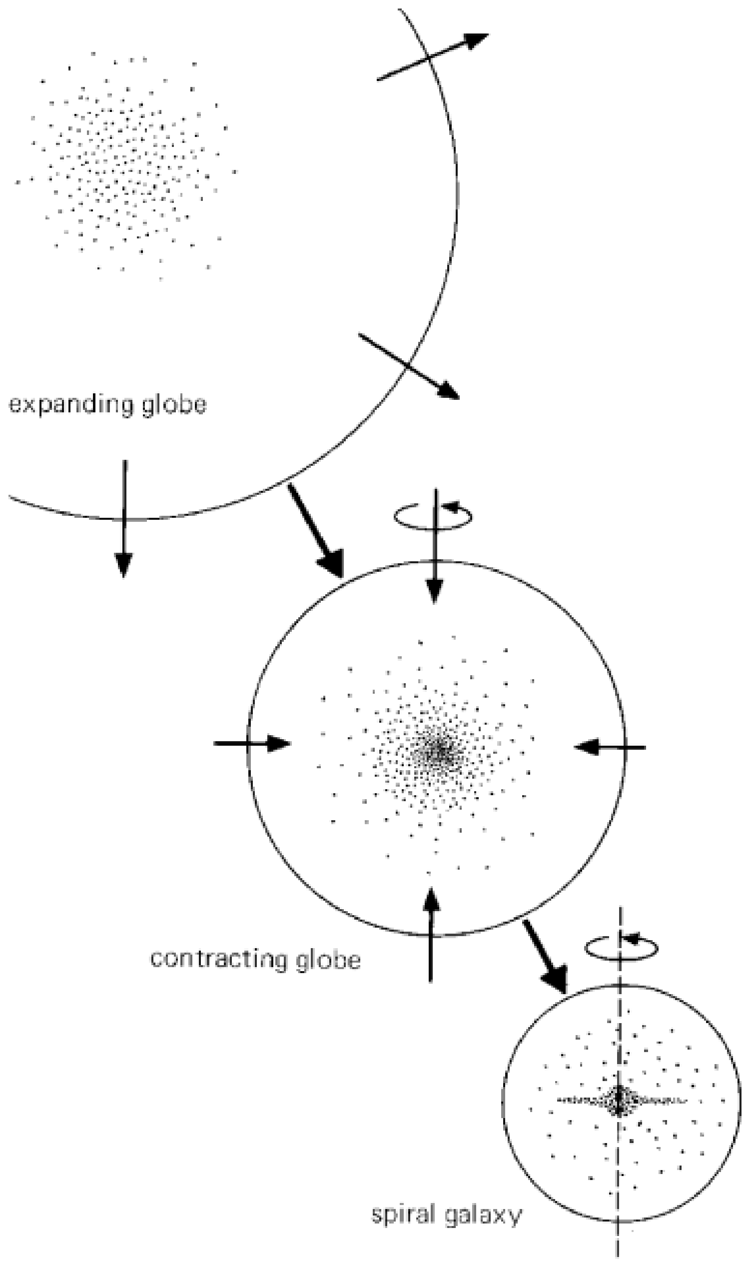
Gas falling into a spiral disk is slowed by collisions and star formation continues till today. The spiral arms and patterns are due to ongoing star formation, whereas ellipticals used all their gas supplies in an initial burst 14 billion years ago and now have no ongoing star formation.

Spiral galaxy formation



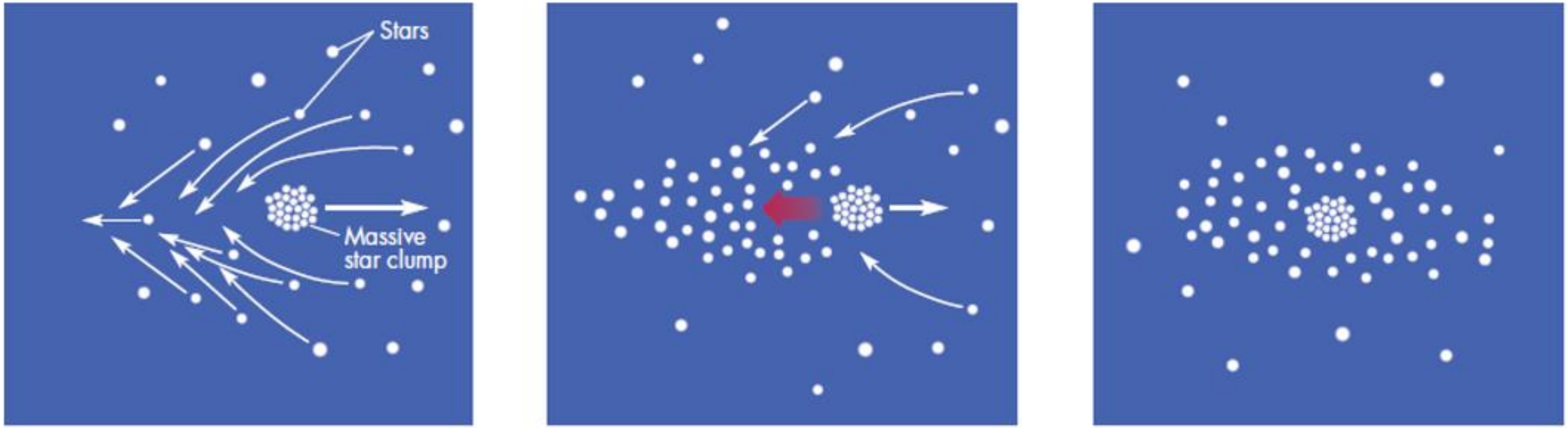
Spiral galaxy formation

This figure shows one possible way in which a spiral galaxy might form. The expanding universe, already hundreds of millions of years old, has fragmented into large globes of gas. At first, each globe continues to expand, but slower than the universe, then later it stops expanding and begins to collapse. Population II stars in large numbers form in the central region. Gas from the outer regions of the globe falls inward and forms a rotating disk in which population I stars are slowly born.



elliptical galaxy formation

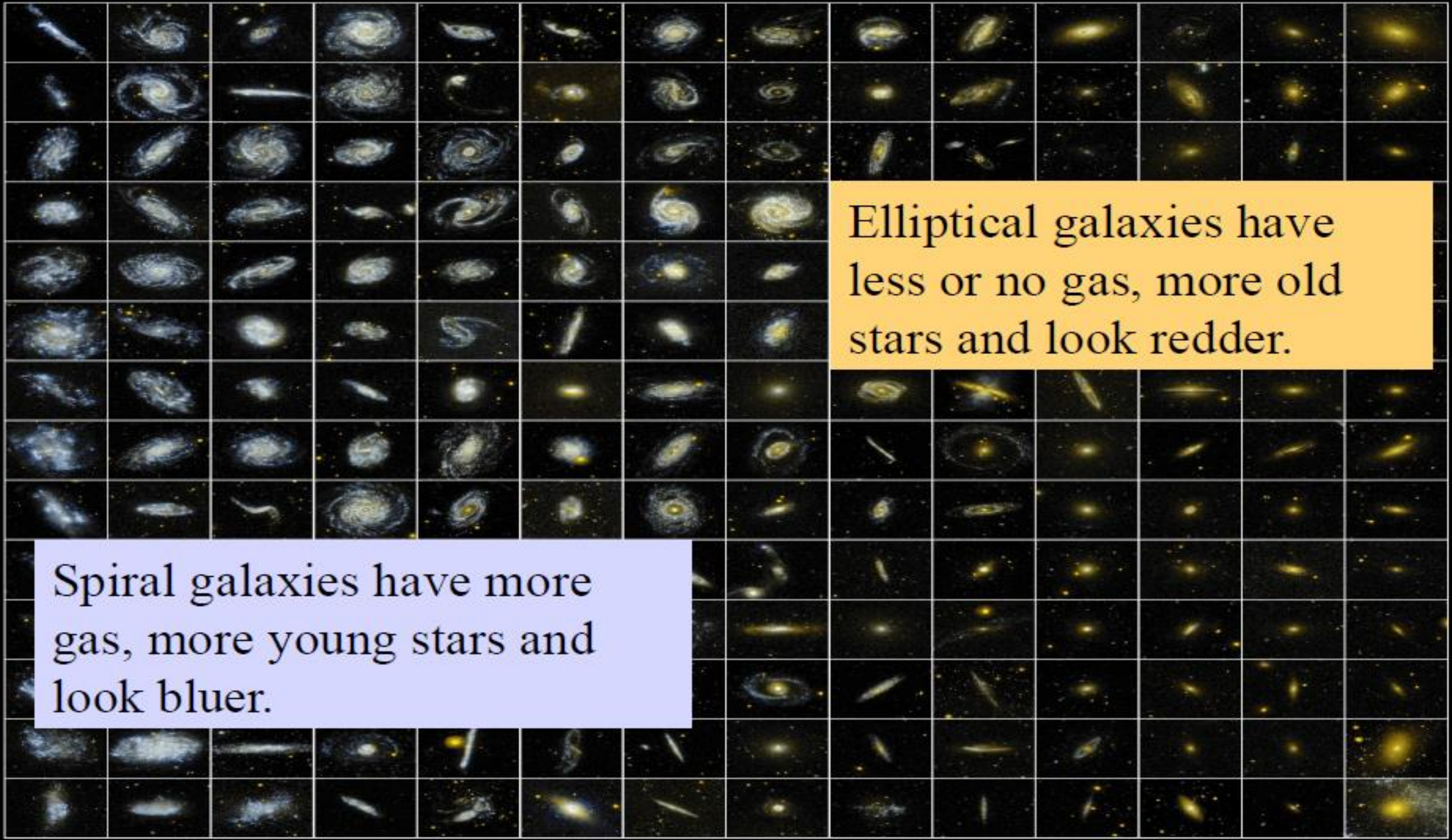
A, As a massive star clump moves through a protogalaxy, the matter it passes is deflected by the clump's gravity and converges behind it. **B,** The gravitational pull of the deflected matter then slows the clump and causes it to settle to the center of the protogalaxy. **C,** The angular momentum of the resulting elliptical galaxy has been transferred to the surrounding (mostly dark) halo of matter.



A Matter converges in a wake behind the massive star clump.

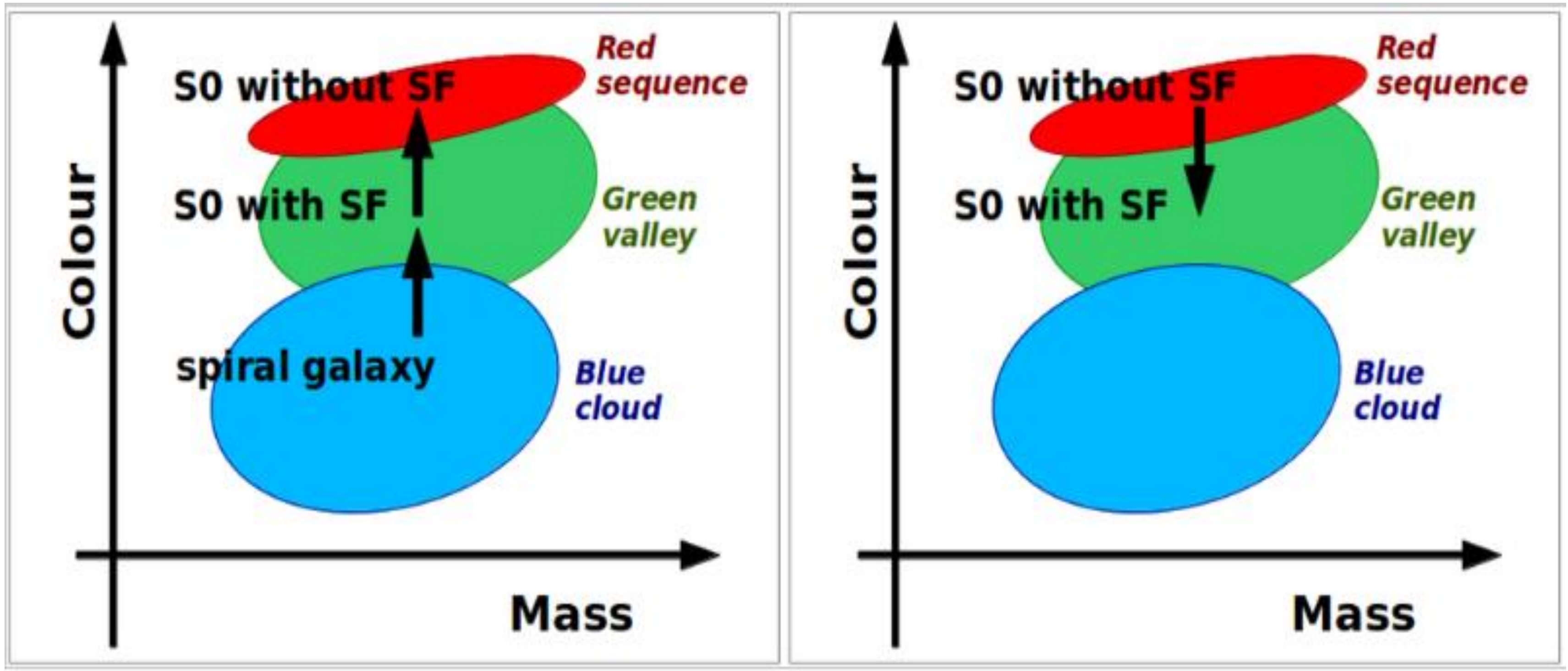
B The matter in the wake exerts a gravitational pull on the star clump.

C The star clump eventually slows down and settles toward the center of the cloud.


Elliptical galaxies have less or no gas, more old stars and look redder.
Spiral galaxies have more gas, more young stars and look bluer.

Role of stars in galaxy formation

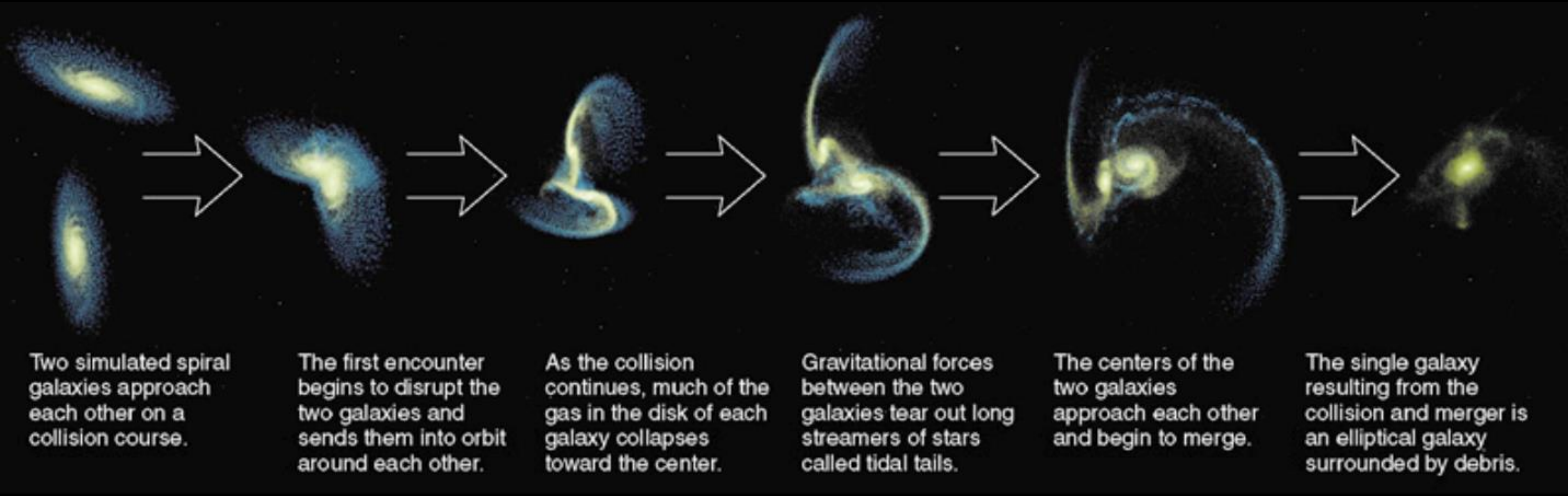
The colour-magnitude diagram (CMD):
(plot of observational data which shows how a population of stars can be plotted)



About half of S0 galaxies lie in the region of the colour-magnitude diagram (CMD) of galaxies that is called green valley. With respect to the blue cloud (where galaxies have blue colours and are actively star forming) and to the red sequence (*i.e.*, the sequence of red and nearly passive galaxies), galaxies that populate the green valley are red but "not so dead", *i.e.*, they still form stars at some level.

Where do S0 galaxies that lie in the green valley come from? A possible explanation is that S0 galaxies cross the green valley during their transformation from actively star forming to passive galaxies. According to an alternative scenario, star-forming S0 galaxies are "rejuvenated" ETGs: after having already reached the red sequence, they came back to the green valley, because star formation was re-activated thanks to the accretion of fresh gas.

New type of galaxy can result from collisions between galaxies



Thank you for your attention