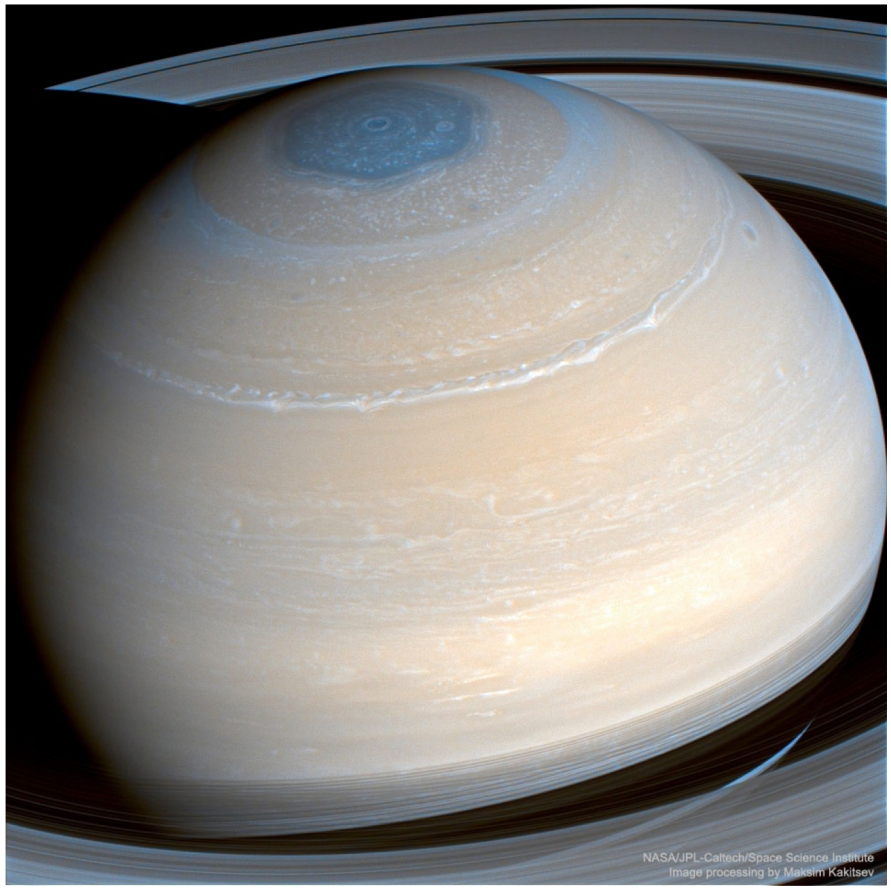
[19] Galactic Evolution and the First Galaxies (4/12/18)

Upcoming Items

1. Homework #5 due on Tues, April 24
2. Read Ch. 21.3 for next class and do the self-study quizzes
3. *I will be away next Tuesday, at the American Physical Society conference; Dr. Erin Kara will introduce you to AGN*

APOD: 4/3/17

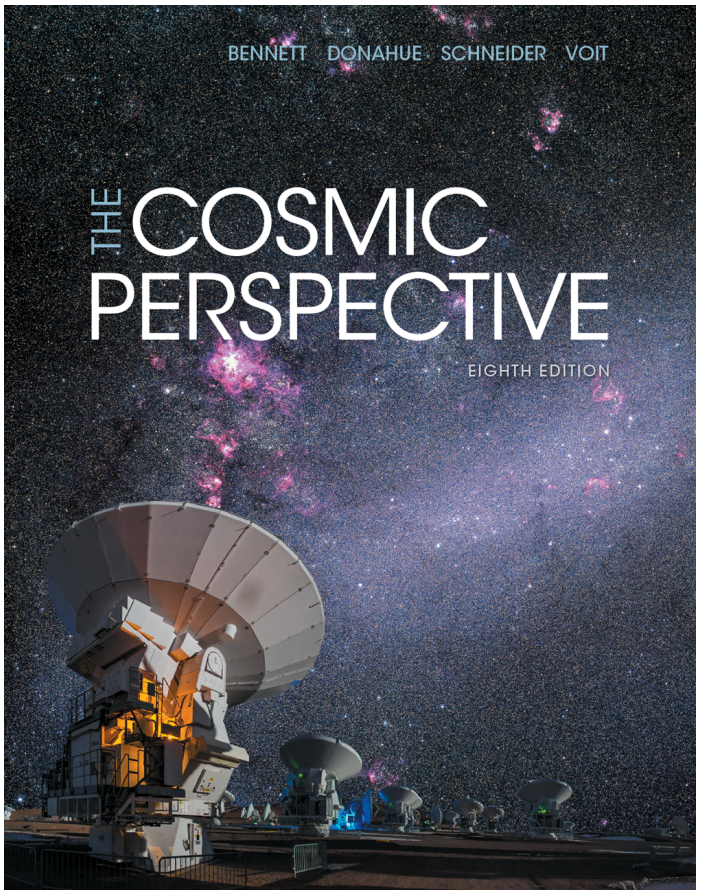


LEARNING GOALS

Ch. 21.1–21.2

For this class, you should be able to…

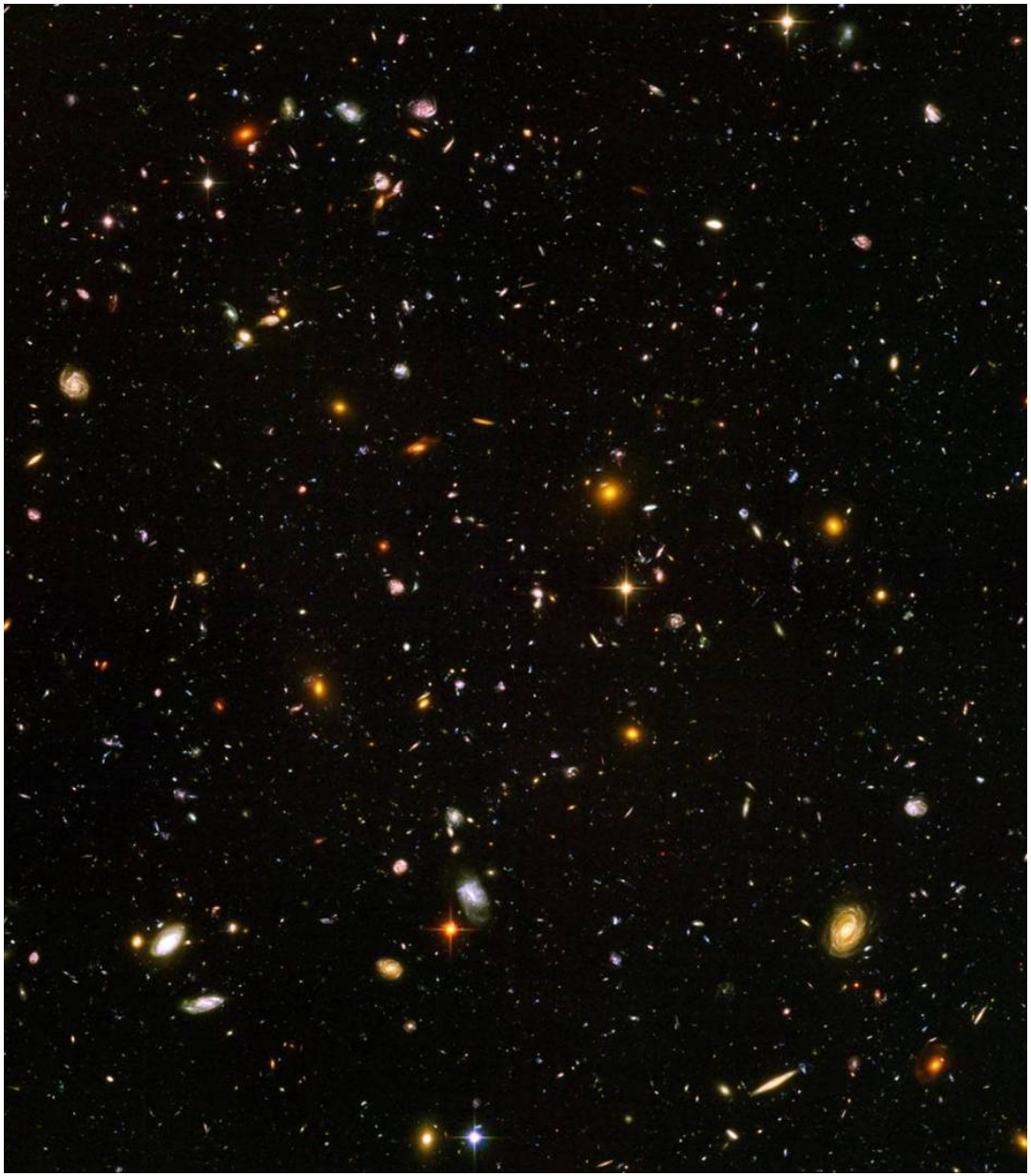
- … *explain how protogalactic rotation and density may determine whether a particular galaxy becomes a spiral or an elliptical;*
- … *describe how interactions between galaxies might affect their evolution and lead to starbursts and galactic winds.*



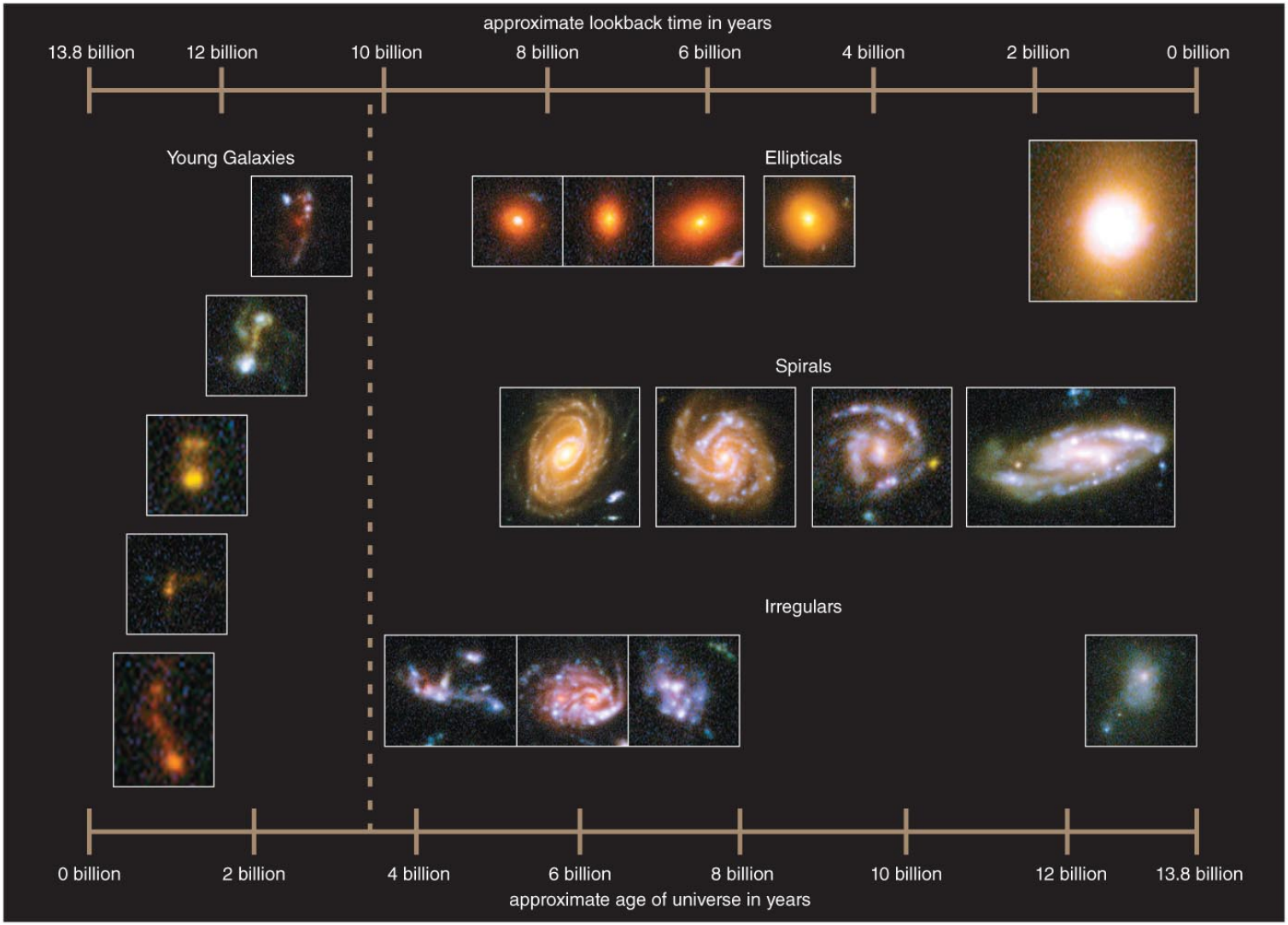
Any astro questions?

Galactic Evolution and the First Galaxies

- Note: here we have plausible stories, but the stories could change as better data and simulations become available
- Conditions in the protogalactic cloud, and subsequent collisions, may determine galaxy type.
- For the initial formation,
  - Spiral galaxies form gradually for less-dense clouds; gas has time to settle into a disk.
  - Some elliptical galaxies form immediately from dense clouds: make stars quickly, no gas left to form a disk.
- Later on, collisions can reshape galaxies.
  - Two spiral galaxies can merge to become an elliptical galaxy.
- Other factors (galactic winds, ram pressure stripping, AGN feedback) may remove gas from galaxies to prevent future star formation.

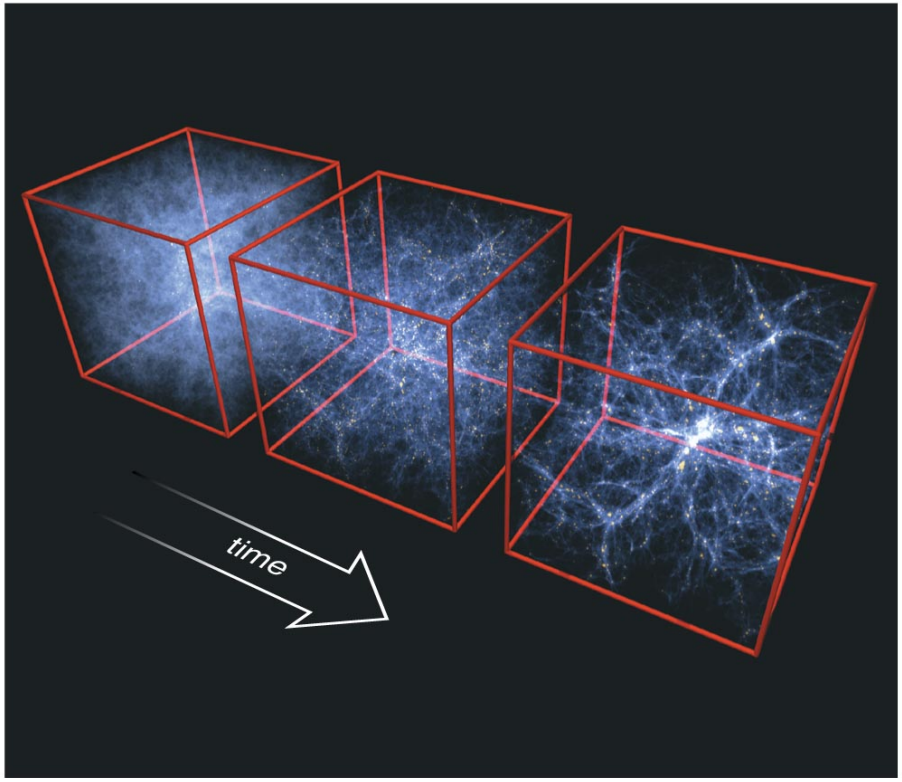


- Deep observations show us very distant galaxies as they were much earlier in time.
- (Old light from young galaxies.)



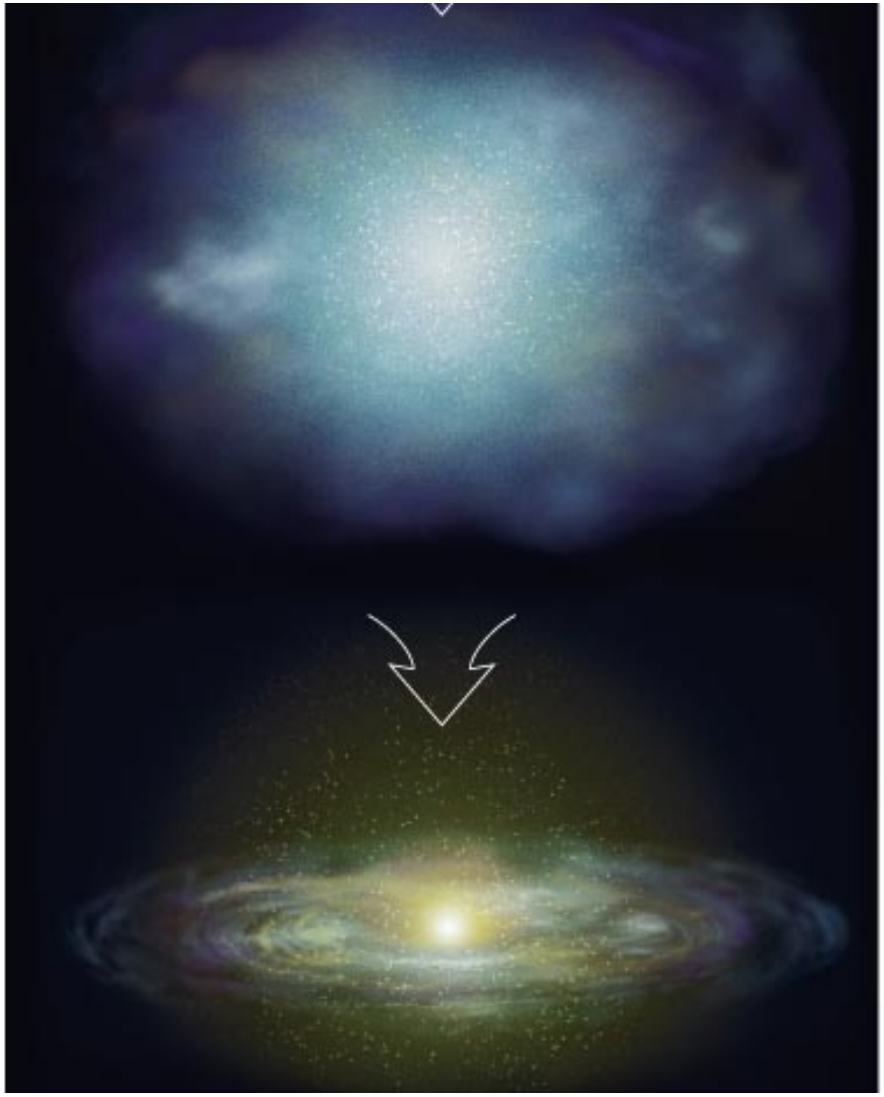
- Observing galaxies at different distances shows us how they age.

Simulating Galaxy Formation



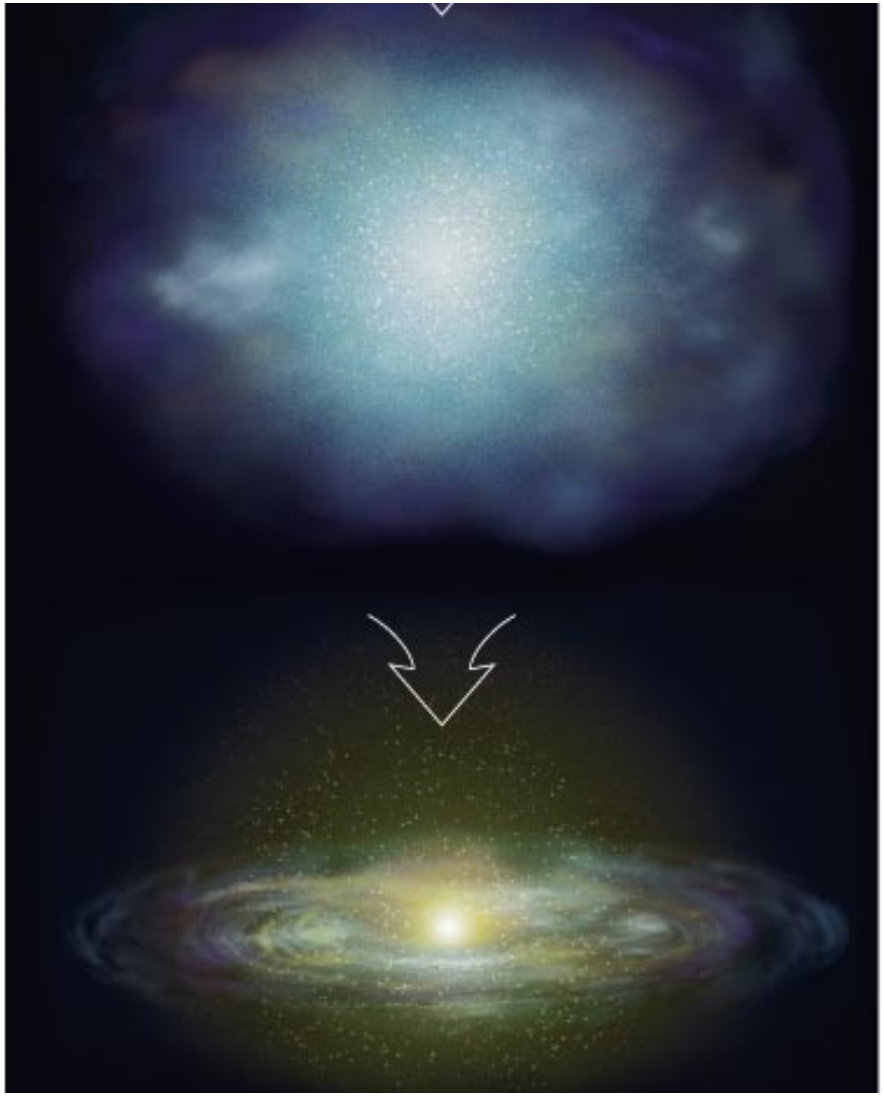
- We still can't observe the earliest galaxies directly.
- Instead, we rely on simulations of galaxy formation, comparing the results with observations.
- Our best models for galaxy formation assume:
  - Matter originally filled all of space almost uniformly.
  - Gravity of denser regions pulled in surrounding matter.

(Over)Simplified Picture: An Isolated Protogalactic Cloud



- Denser regions contracted, forming *protogalactic clouds*.
- Hydrogen and helium gas in these clouds formed the first stars.

(Over)Simplified Picture: An Isolated Protogalactic Cloud



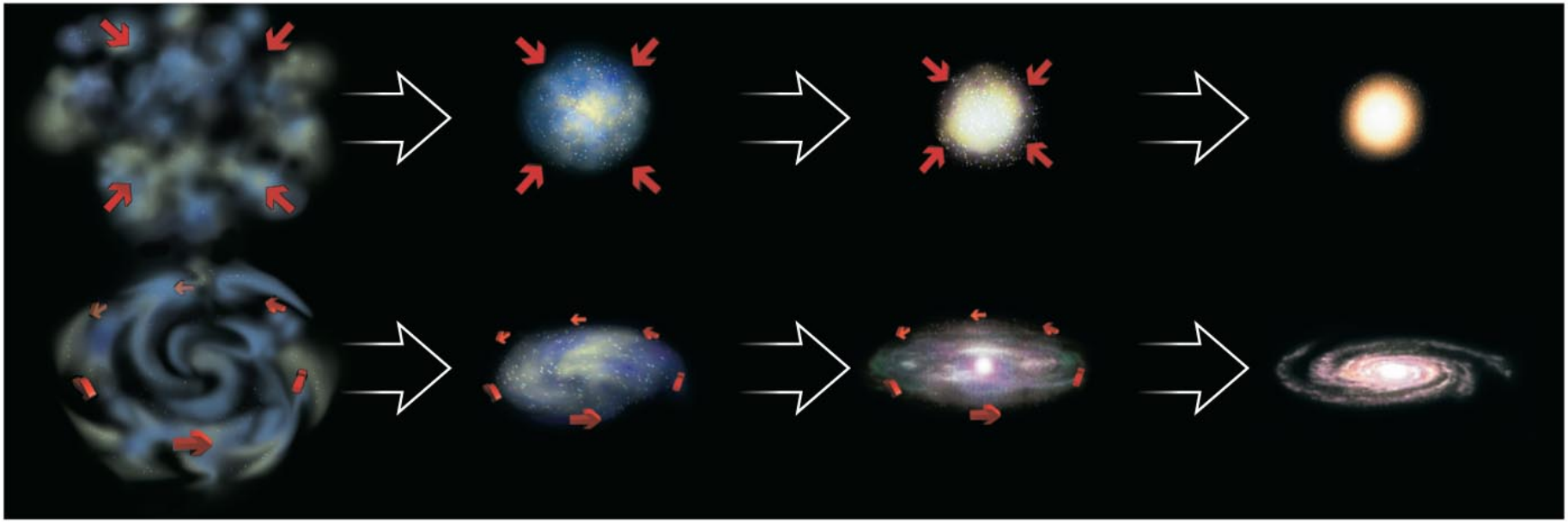
- Supernova explosions from the first stars kept much of the gas from forming stars.
- Leftover gas settled into a spinning disk due to *conservation of angular momentum*.

b NGC 4414, a spiral galaxy whose disk is somewhat tilted to our line of sight.

a M87, a giant elliptical galaxy in the Virgo Cluster, is one of the most massive galaxies in the universe. The region shown is more than 300,000 light-years across.

- But why do some galaxies end up looking so different?
- Why don't all galaxies have similar disks?

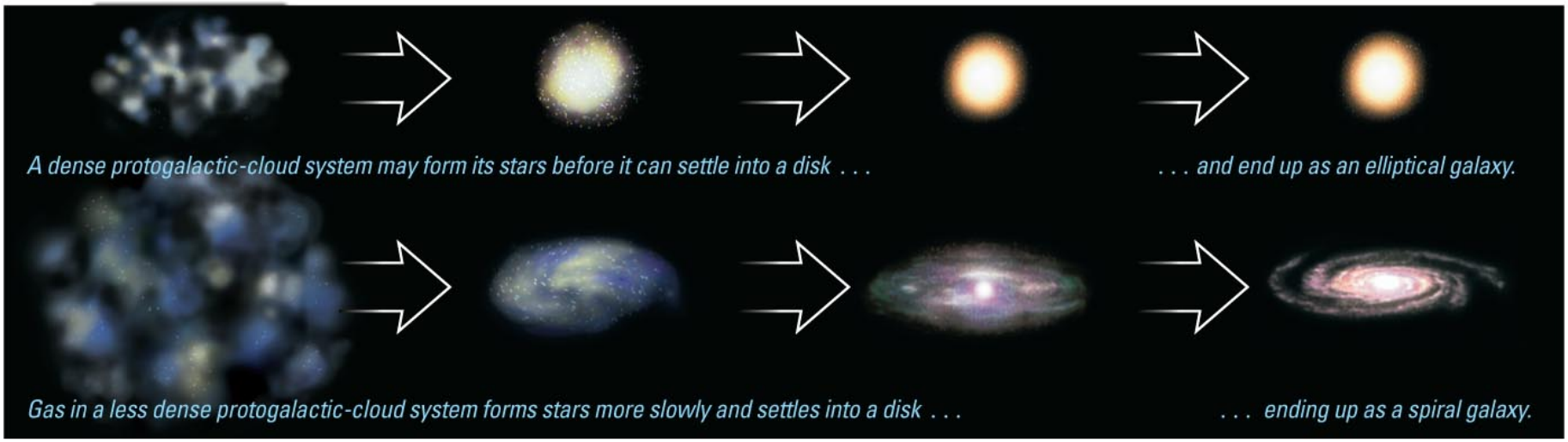
Conditions in Protogalactic Cloud?



a The angular momentum of a galaxy's protogalactic-cloud system may determine whether it ends up spiral or elliptical.

- ***Spin:*** The initial angular momentum of the protogalactic cloud could determine the size of the resulting disk.

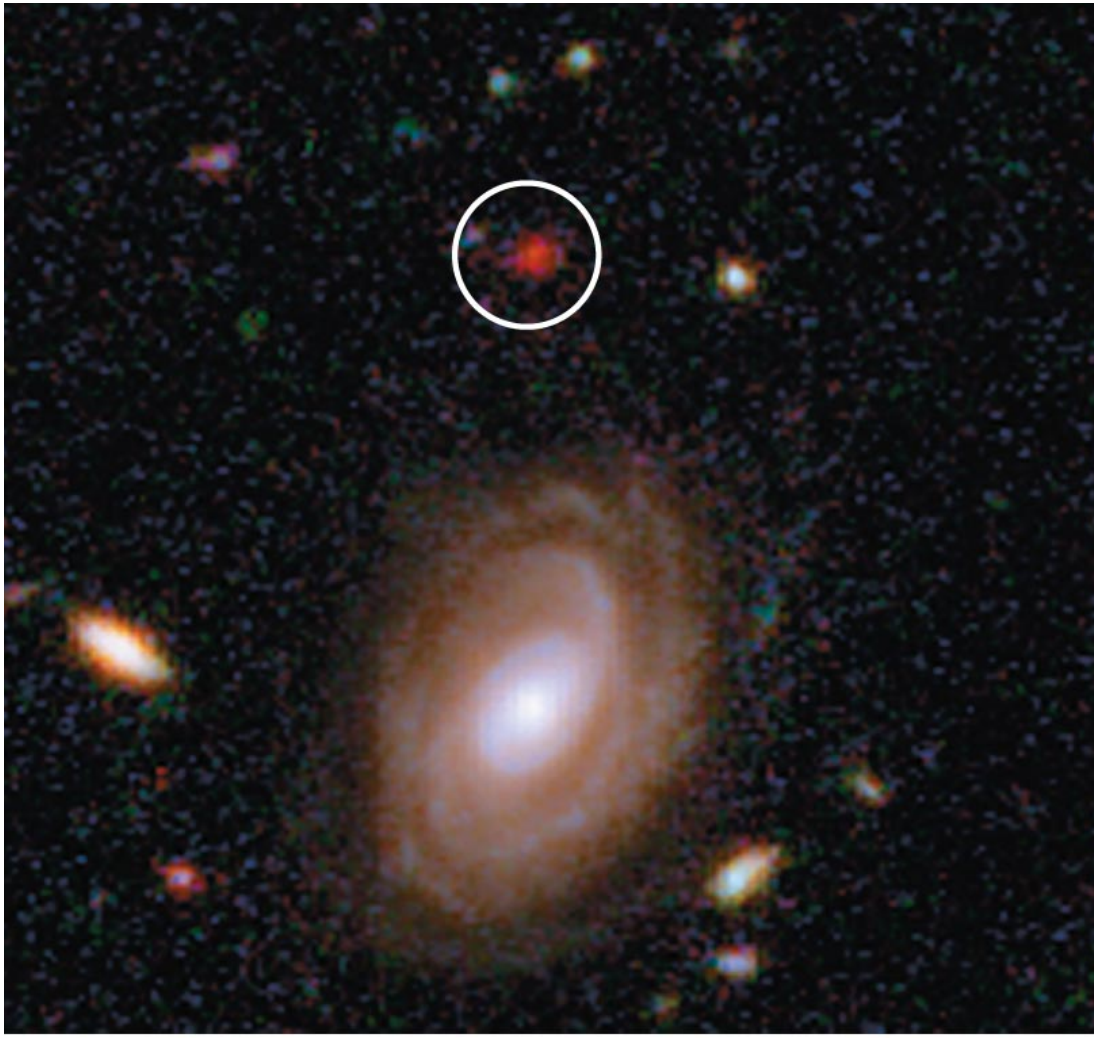
Conditions in Protogalactic Cloud?



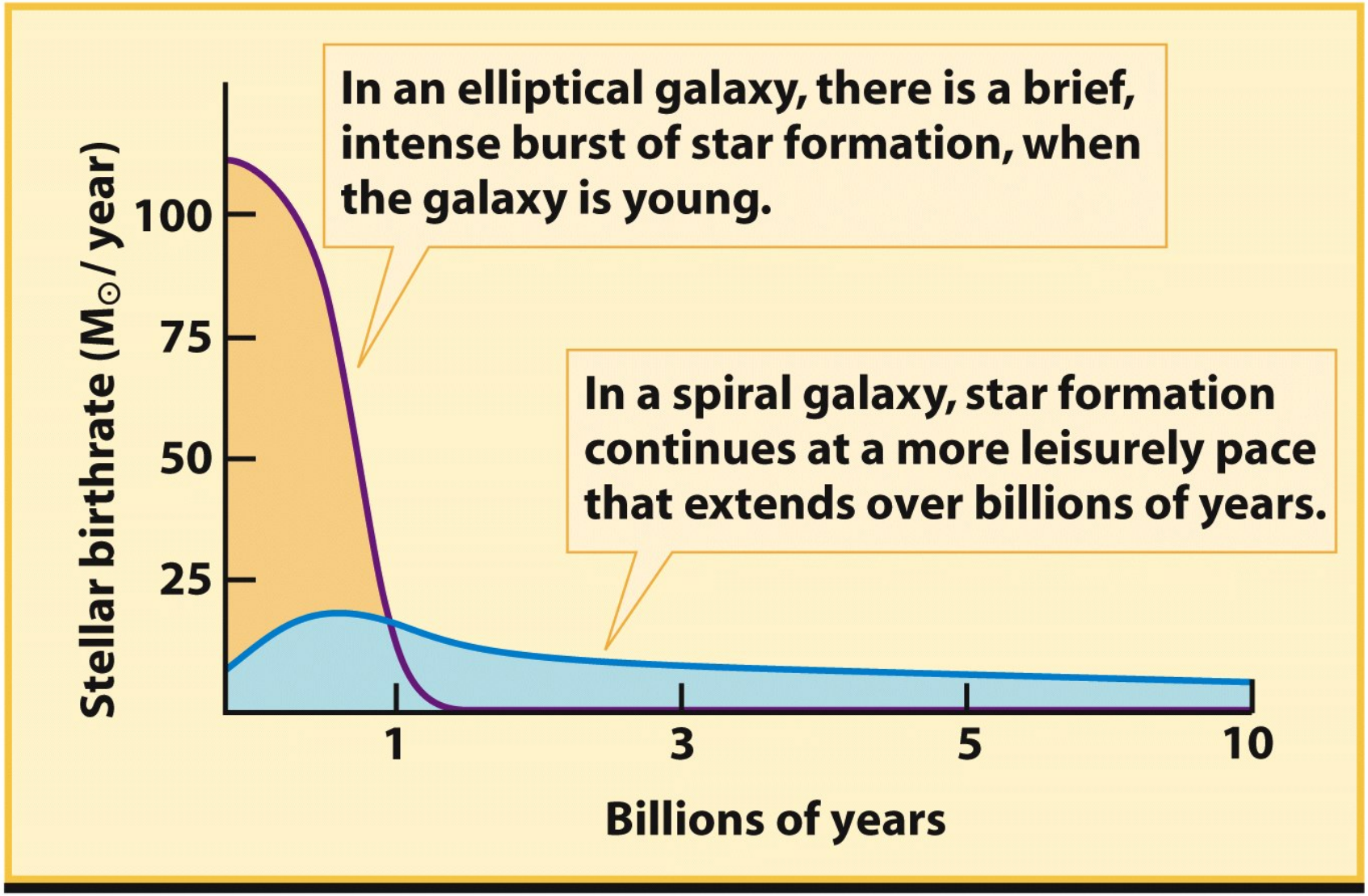
b The gas density of a galaxy's protogalactic clouds may determine whether it ends up spiral or elliptical.

- ***Density:*** Elliptical galaxies could come from dense protogalactic clouds that were able to cool and form stars before gas settled into a disk.

Distant Red Ellipticals

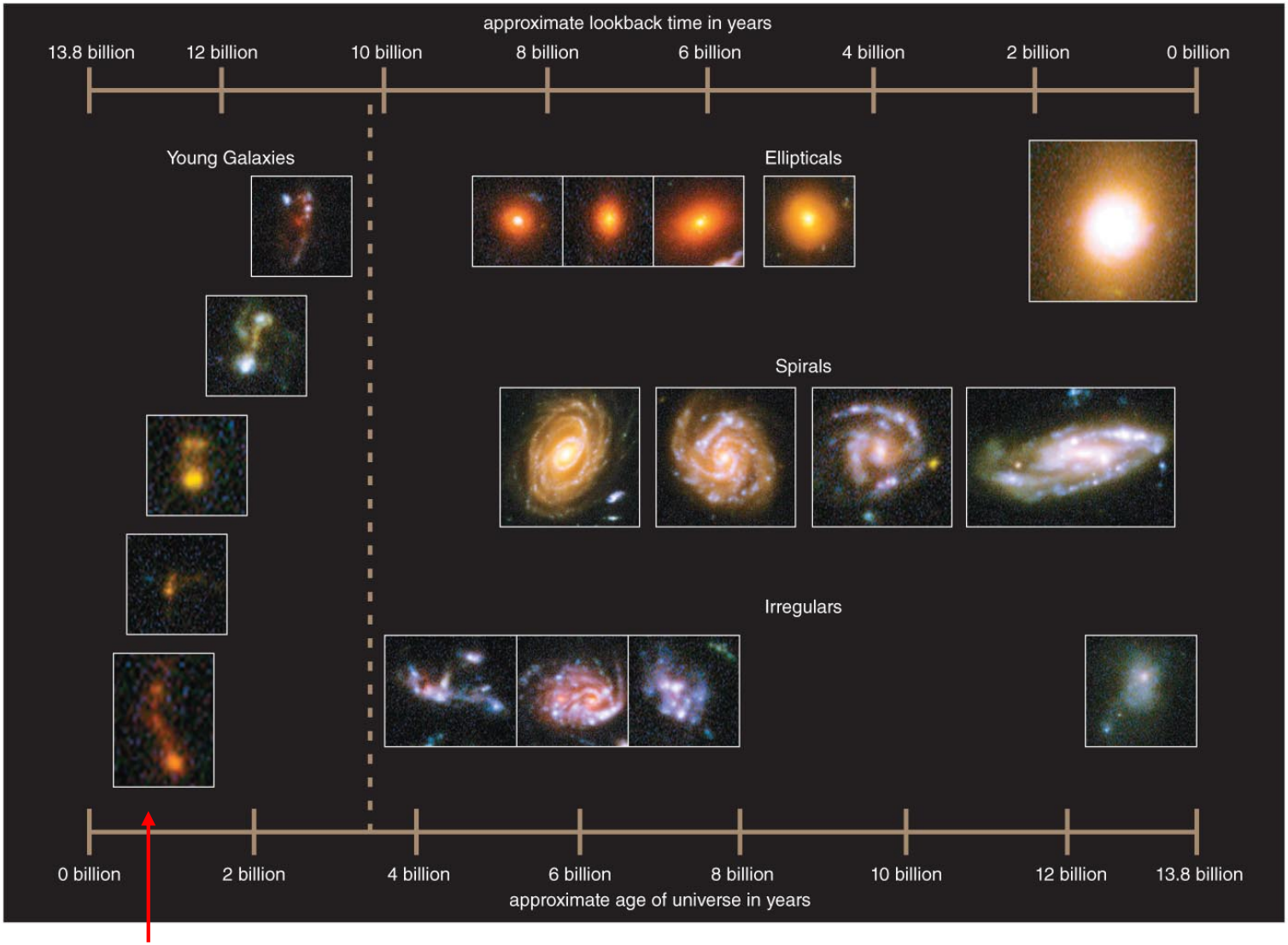


- Observations of some distant red elliptical galaxies support the idea that most of their stars formed very early in the history of the universe.

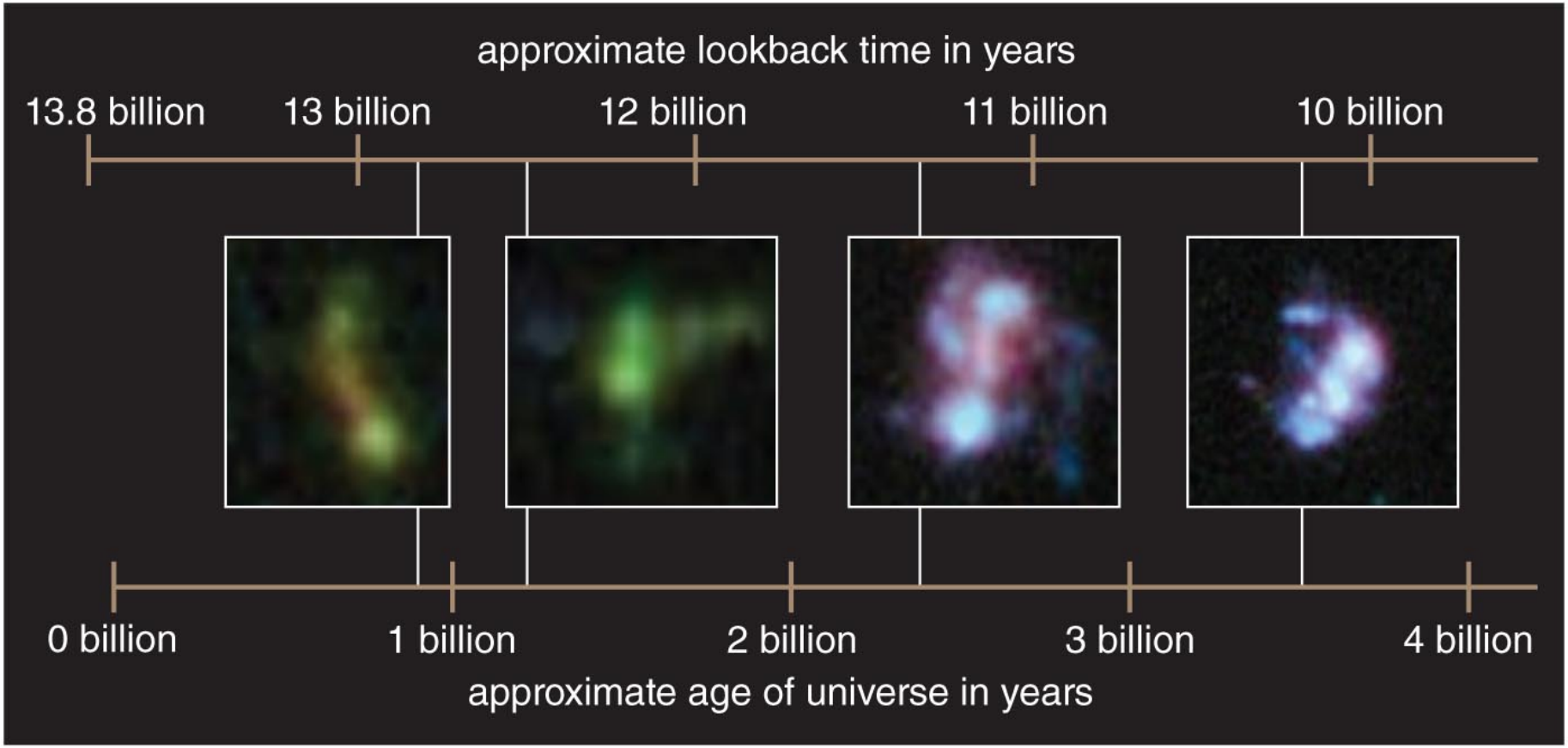


The stellar birthrate in galaxies

- We must also consider the effects of collisions.

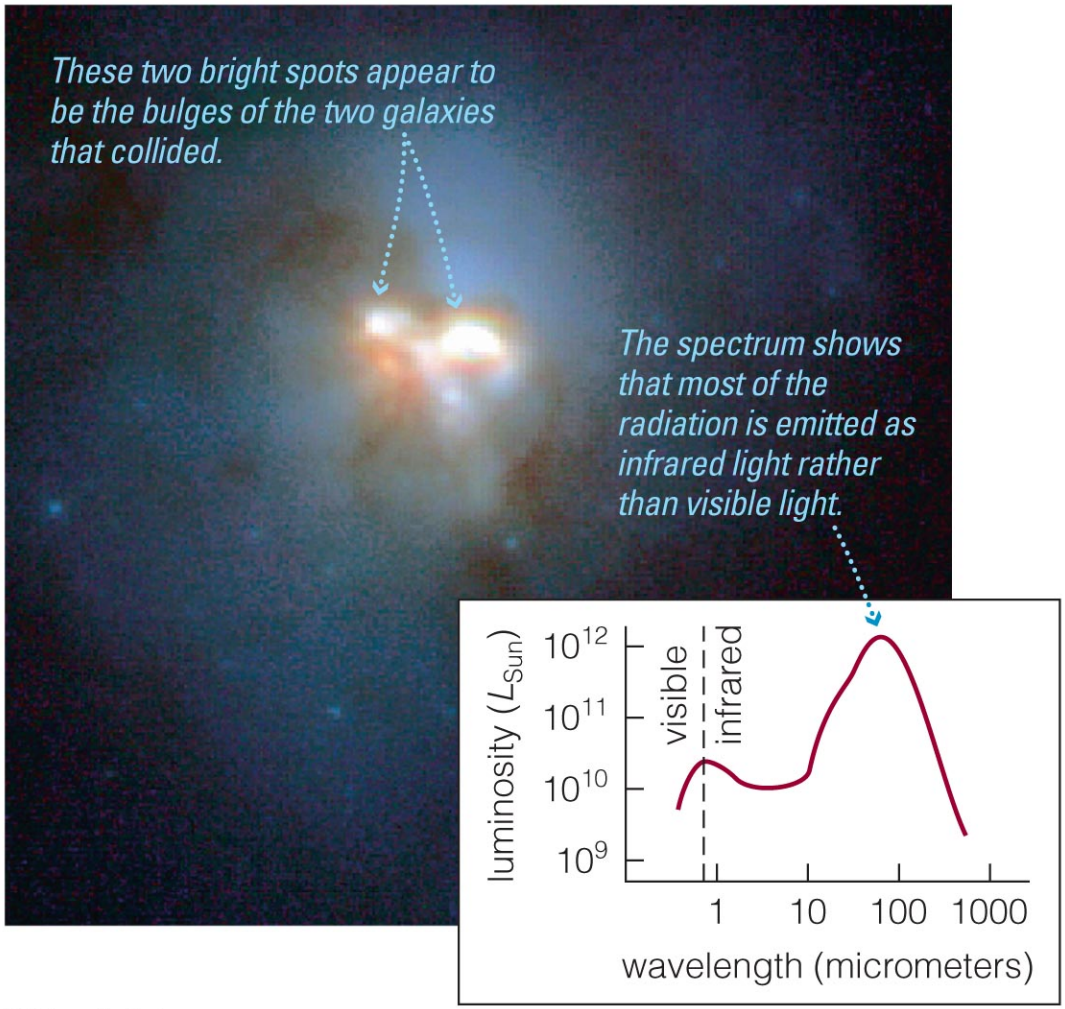


- Collisions were much more likely early in time because galaxies were closer together.

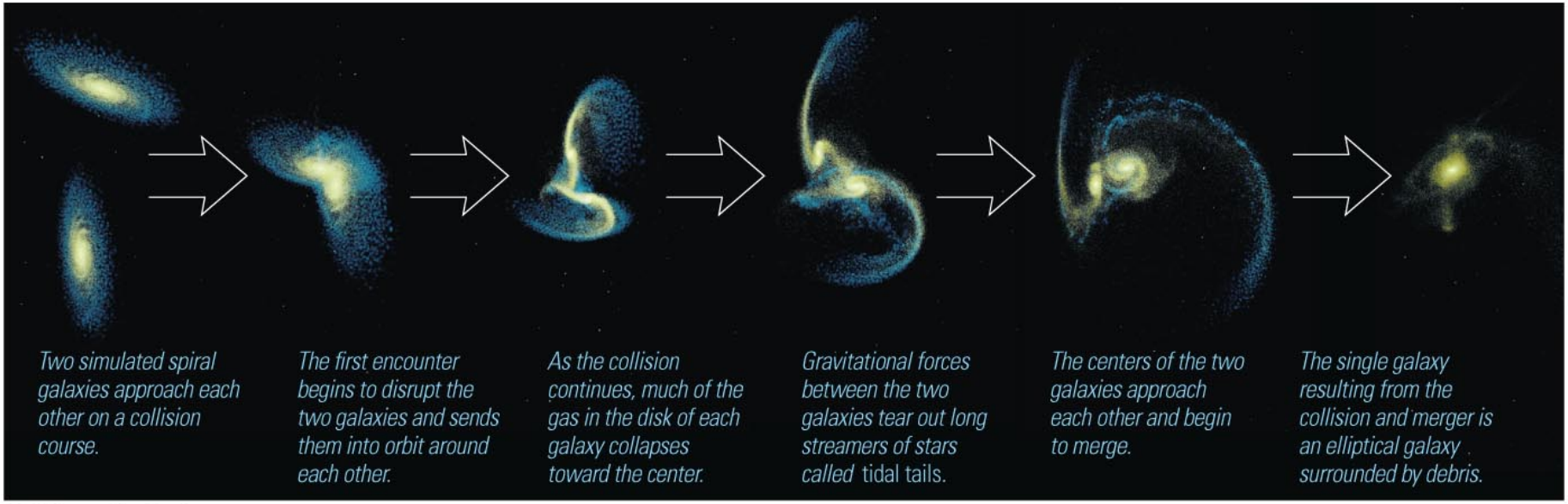


- Many of the galaxies we see at great distances (and early times) do look violently disturbed.

- The collisions we observe nearby trigger bursts of star formation.



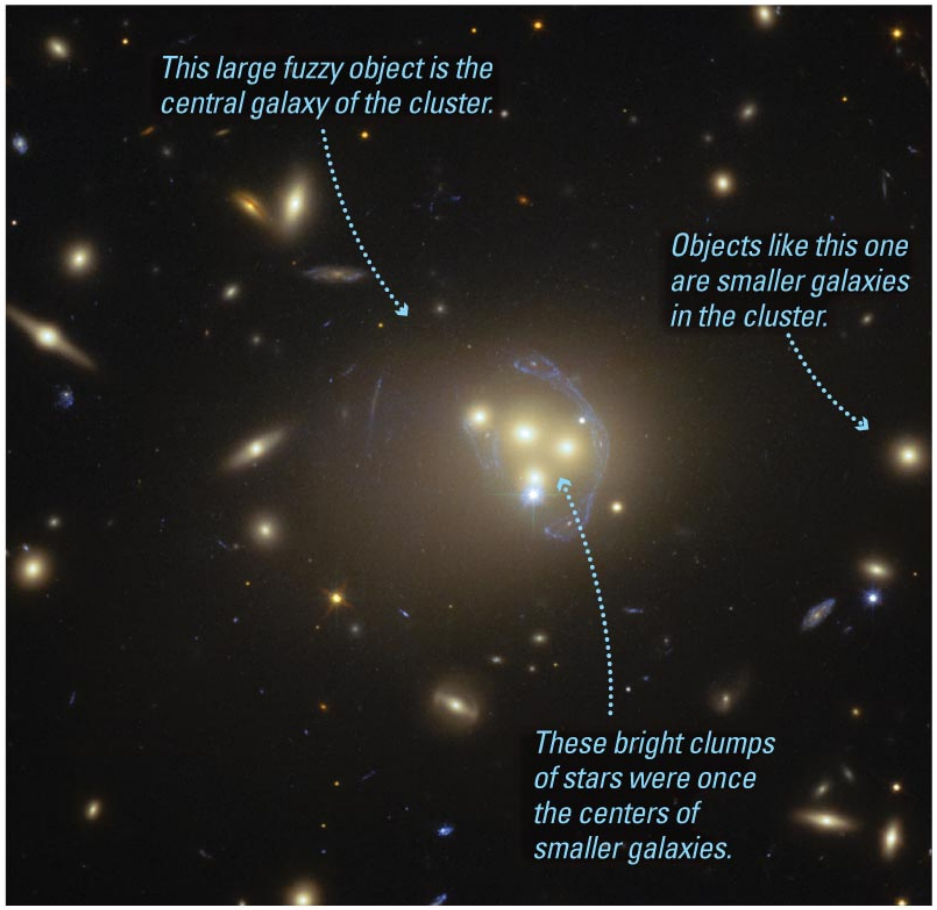
- Some galaxies, called starburst galaxies, are producing new stars at very high rates, as much as 100 times that of our galaxy!



- Modeling such collisions on a computer shows that two spiral galaxies can merge to make an elliptical.

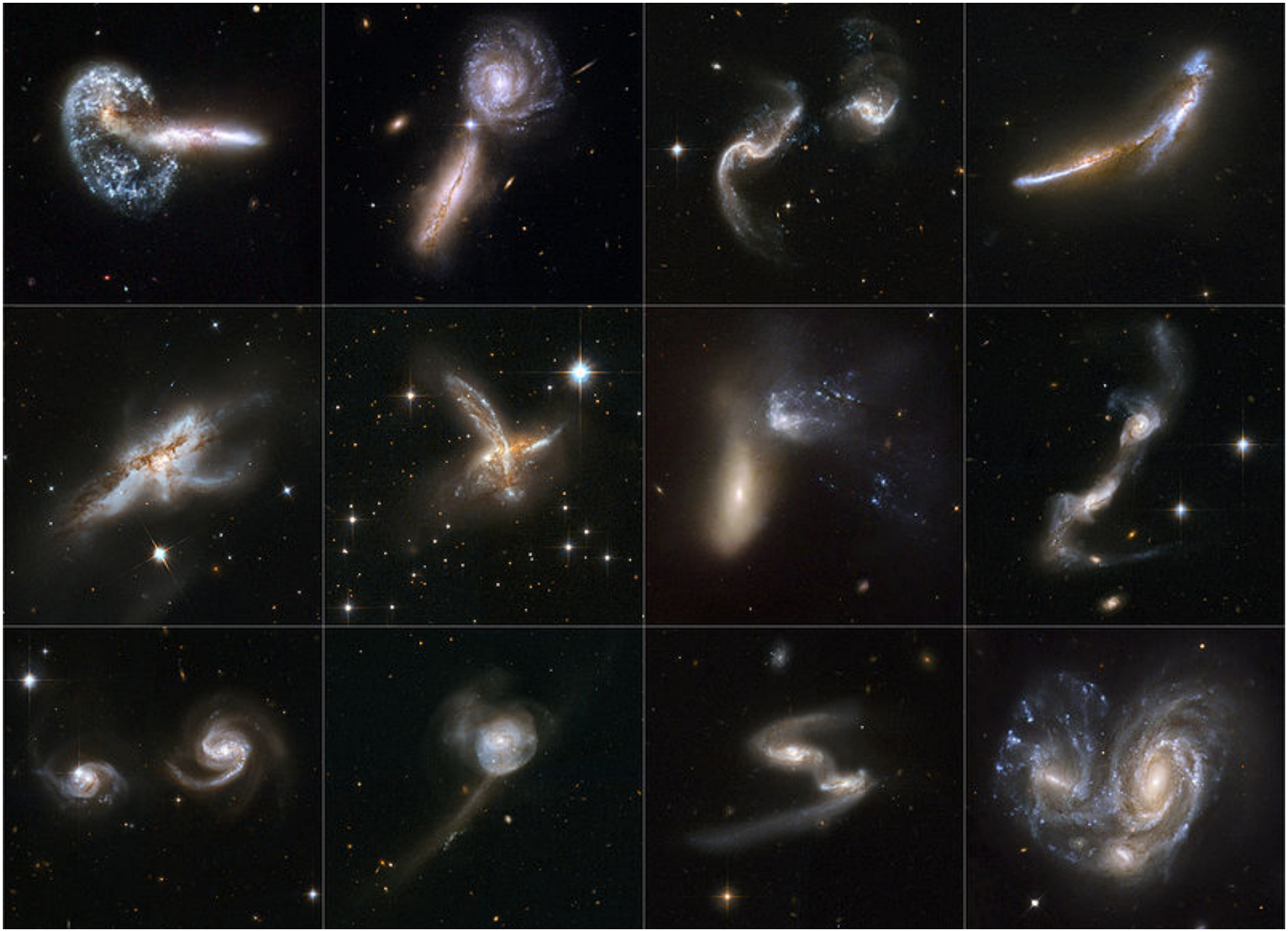
a Elliptical galaxy NGC 474 is surrounded by several distinct shells of stars that were likely produced by collisions with other galaxies.

- Shells of stars observed around some elliptical galaxies are probably the remains of past collisions.



b This image shows the central dominant galaxy of the cluster Abell 3827, which has apparently grown by consuming smaller galaxies that have collided with it. Notice that the center of this galaxy contains multiple clumps of stars that probably once were the centers of individual galaxies. (The blue streaks encircling the central galaxy represent light from a much more distant galaxy that has been distorted by the phenomenon of gravitational lensing [Section 23.2].)

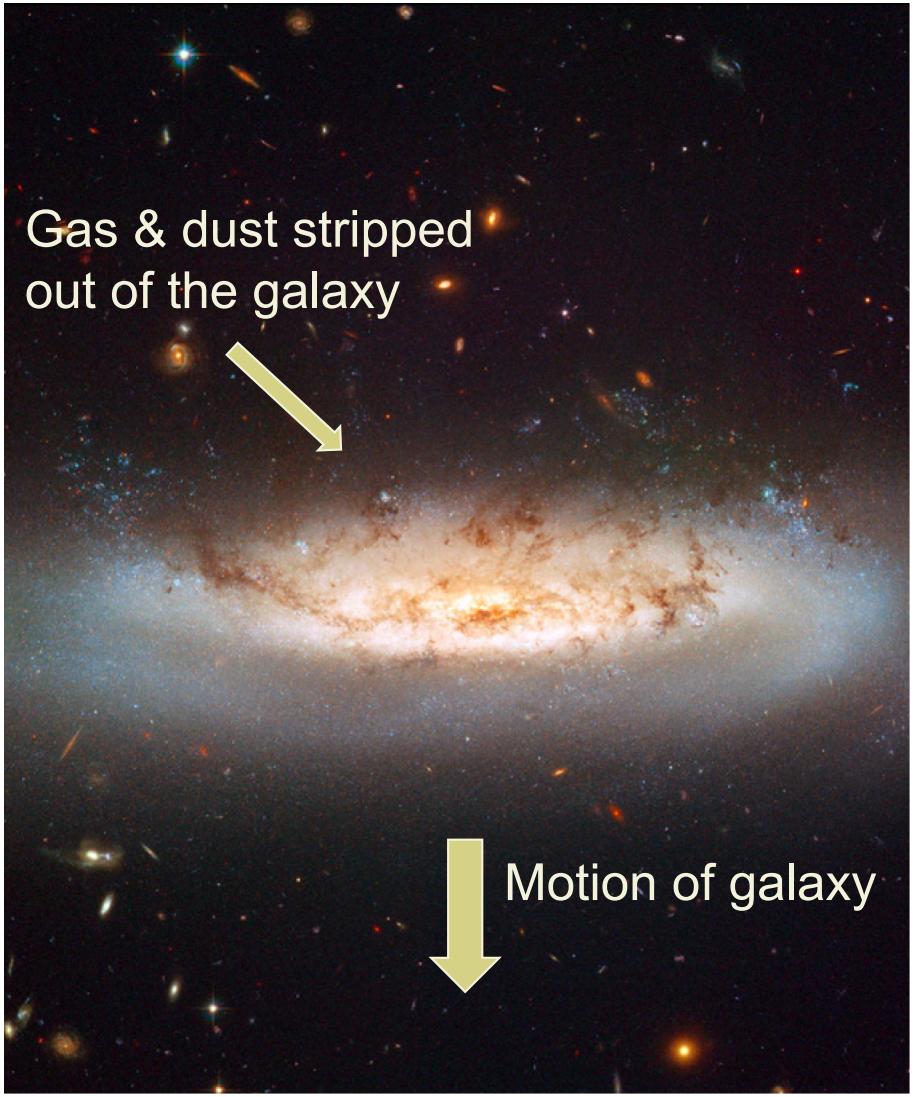
- Collisions may explain why elliptical galaxies tend to be found where galaxies are closer together.
- Giant ellipticals at the centers of clusters seem to have consumed a number of smaller galaxies: *galactic cannibalism*!



Simulated Galaxy Collisions

http://hubblesite.org/newscenter/archive/releases/2008/16/video/d/

Cluster Environments



- Galaxy clusters are filled with hot gas.
- Gas can be stripped out of a galaxy as it moves through a cluster, called *ram pressure stripping*.

Cluster Environments

- Ram pressure stripping is particularly effective for small galaxies (why?).
- Spiral galaxies that end up in galaxy clusters may become lenticular galaxies.

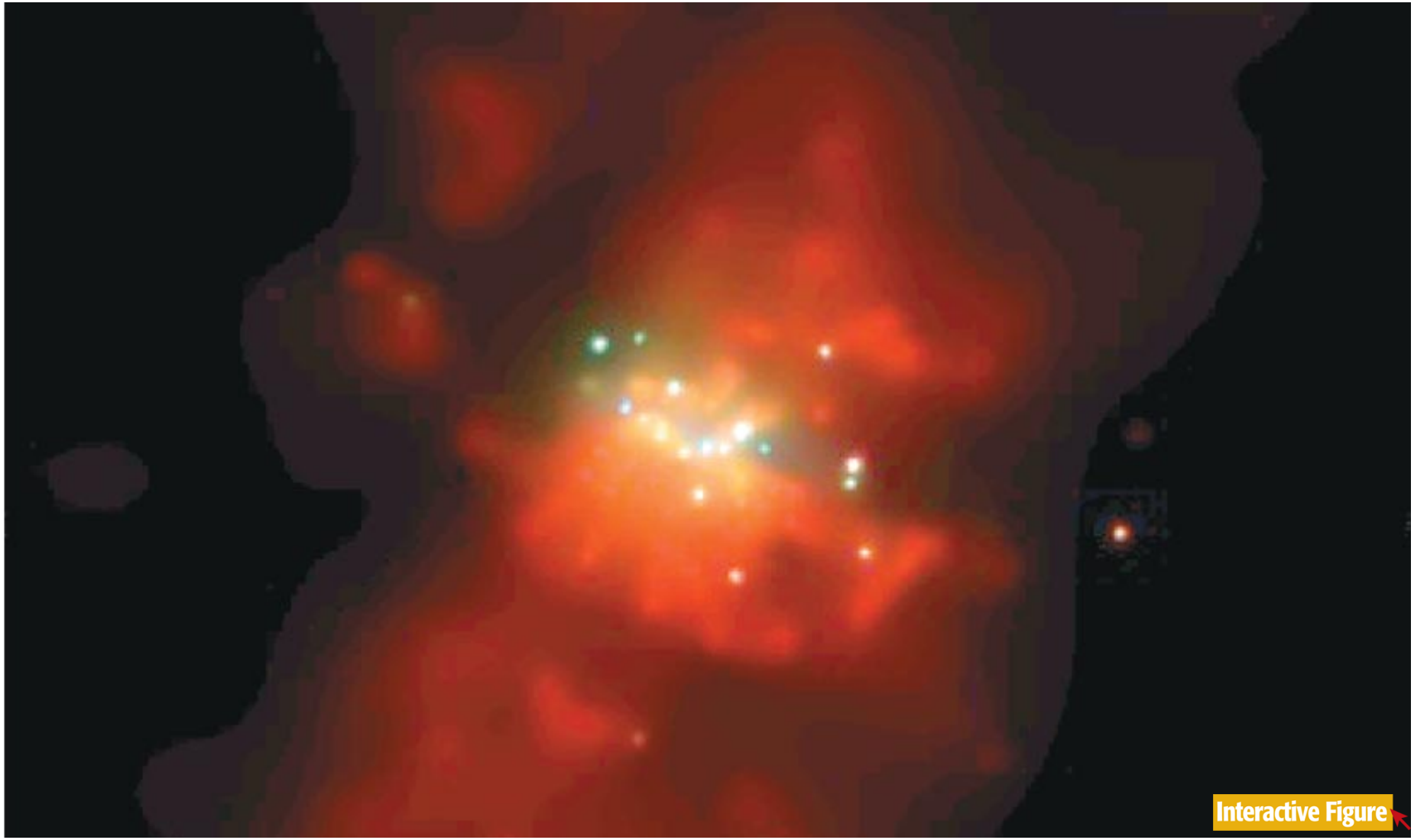
Where does the gas in ellipticals go?

- Still an open question.
- Stars form very quickly, but those stars will supernova and put material back into the galaxy.
- Need a way to remove gas entirely (or make it so hot that it never cools down enough to make stars).
- Some ways to remove gas:
  - Extreme galactic winds from stars and supernovae.
  - Gas stripped away in galaxy clusters.
  - Active galactic nuclei.

Visible-light image

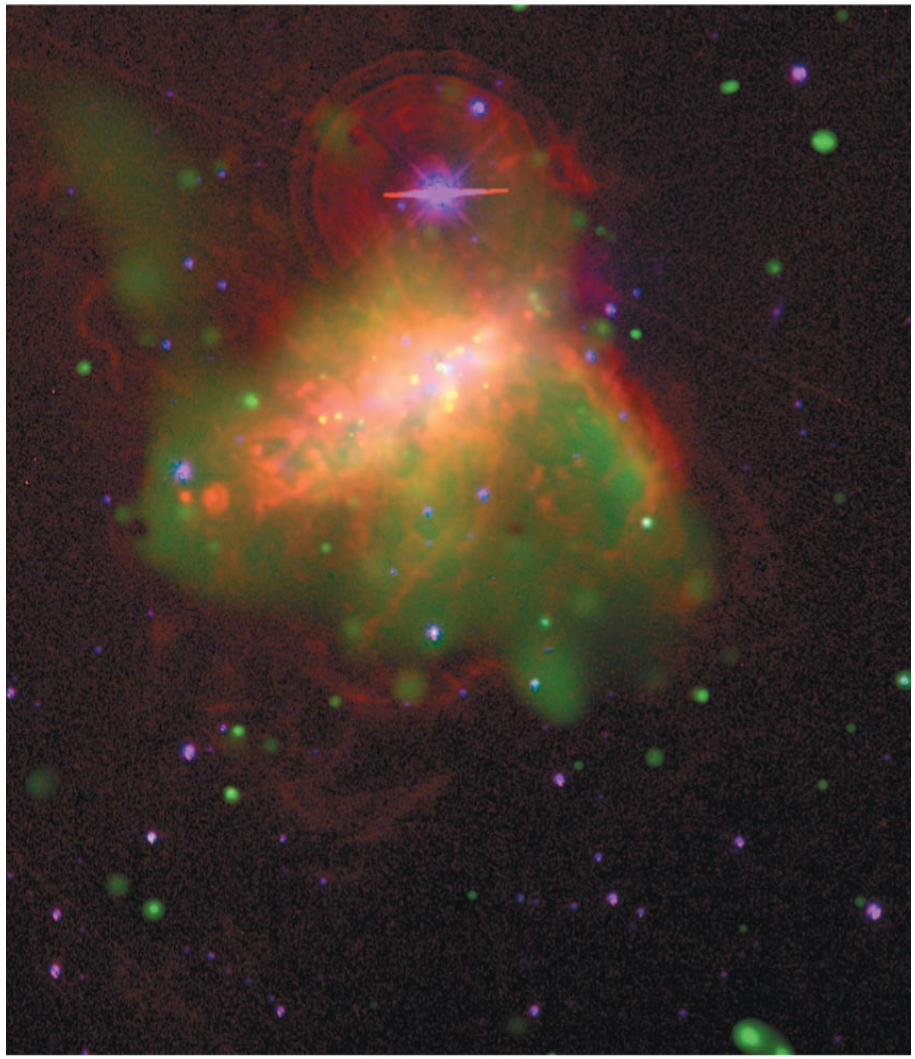
- The intensity of supernova explosions in vigorously star-forming galaxies can drive *galactic winds*. Pictured: M82.

X-ray image



- The intensity of supernova explosions in vigorously star-forming galaxies can drive *galactic winds*. Pictured: M82.

Galactic (Stellar) Winds



NGC 1569

- A galactic wind in a small galaxy can drive away most of its gas (pictured).
- But for larger galaxies, galactic winds are not strong enough to drive the gas out of the galaxy.

Active Galactic Nuclei "Feedback"

- Energy output by accreting supermassive black holes at the centers of galaxies, *active galactic nuclei* or *AGN*, can push gas out of the entire galaxy!
- astrobites.org/2012/09/16/massive-and-passive-galaxies-due-to-early-quasar-driven-outflows/
- Much more about AGN in the next two lectures…