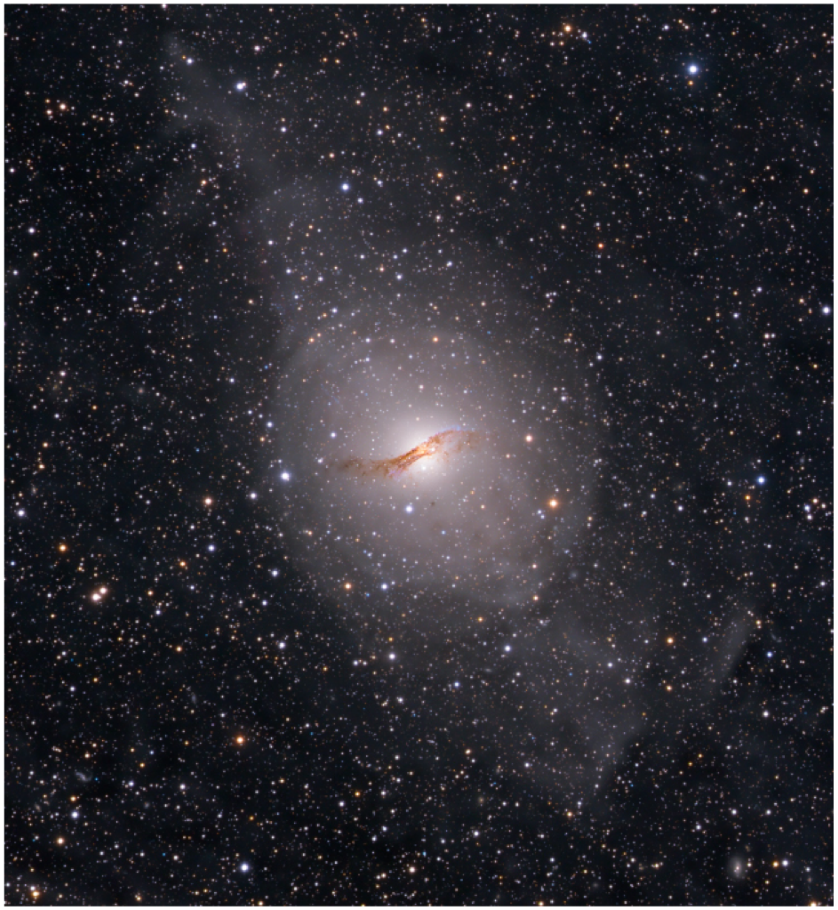
# [13] Galactic Recycling (3/13/18)

## Upcoming Items

1. Read probability.pdf, then read statistics.pdf, in Files->derivations
2. Homework #3 due today

## APOD 3/9/17: Centaurus A



# LEARNING GOALS

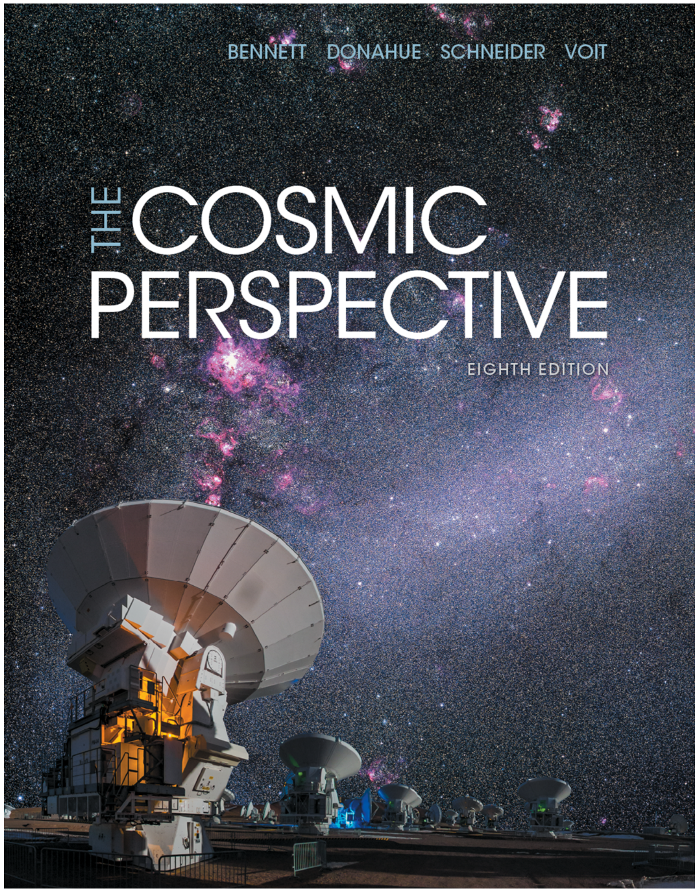
Ch. 19.2–19.3

*For this class, you should be able to…*

… *describe the stages in the star-gas-star cycle and predict what the Milky Way will look like after many cycles;*

… *explain how the orbital motion of stars and gas clouds leads to persistent spiral arms in our galaxy, and how this causes the arms to be so bright and blue;*

… *summarize the current understanding of the stages of formation of the Milky Way.*



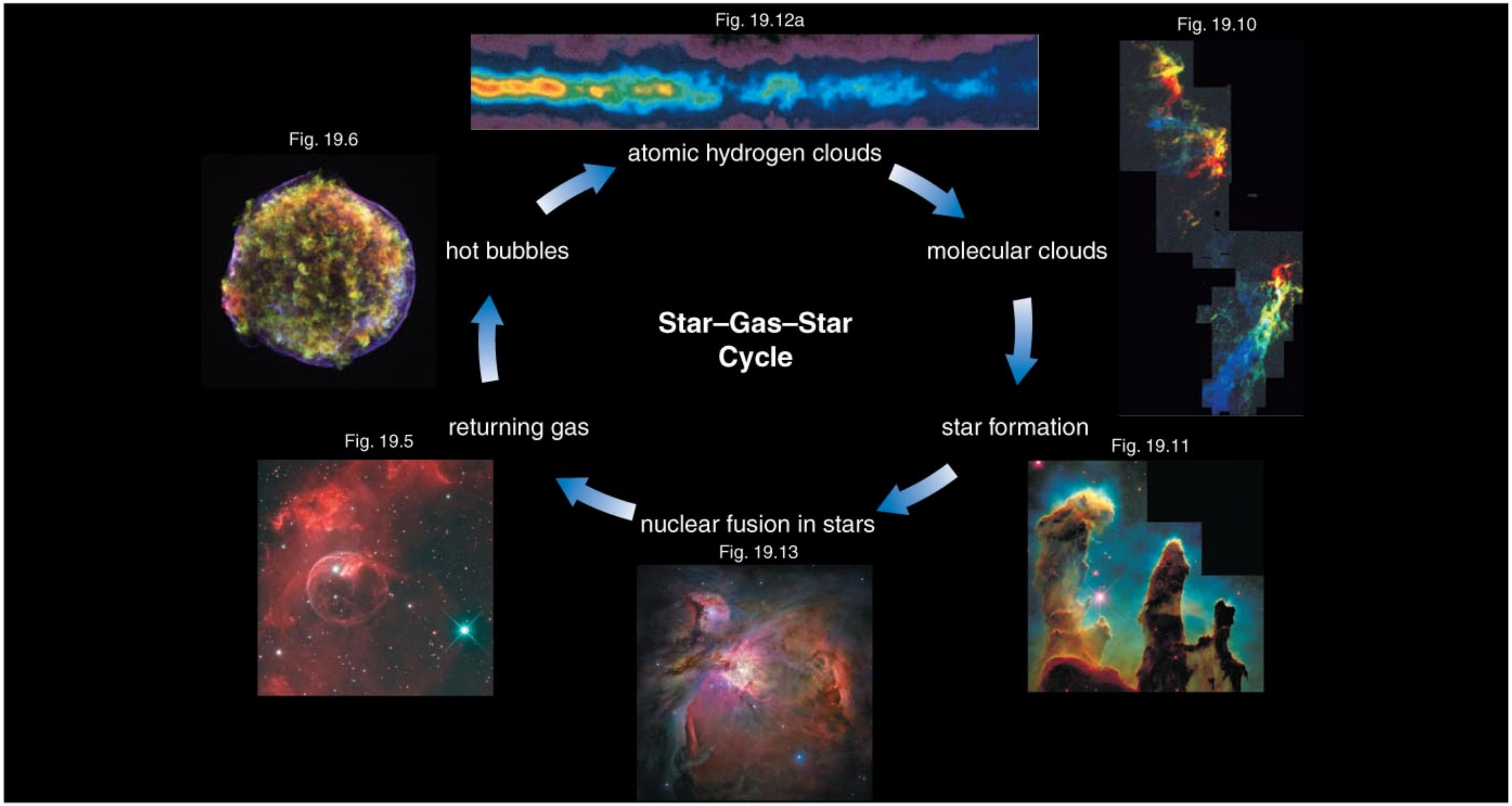
# Any astro questions?

# Mid-semester evaluation

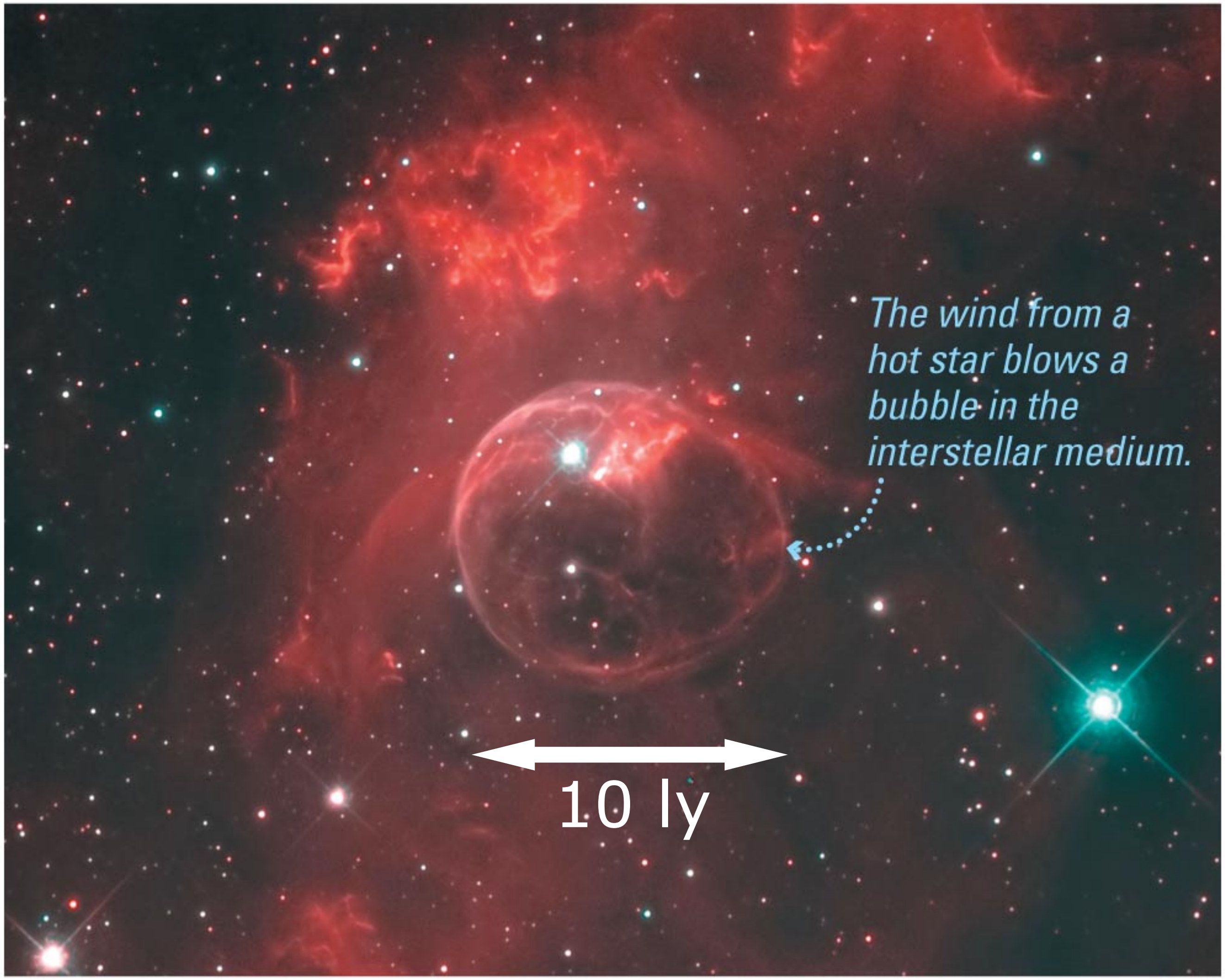
- As before, we will value your **anonymous** input
- Please fill out the form, without putting your name on it; this will be helpful as we go forward
- We will hand around a separate sheet of paper; please **print** your name, and that will give you an in-class quiz credit of 5 points!

# Galactic Recycling

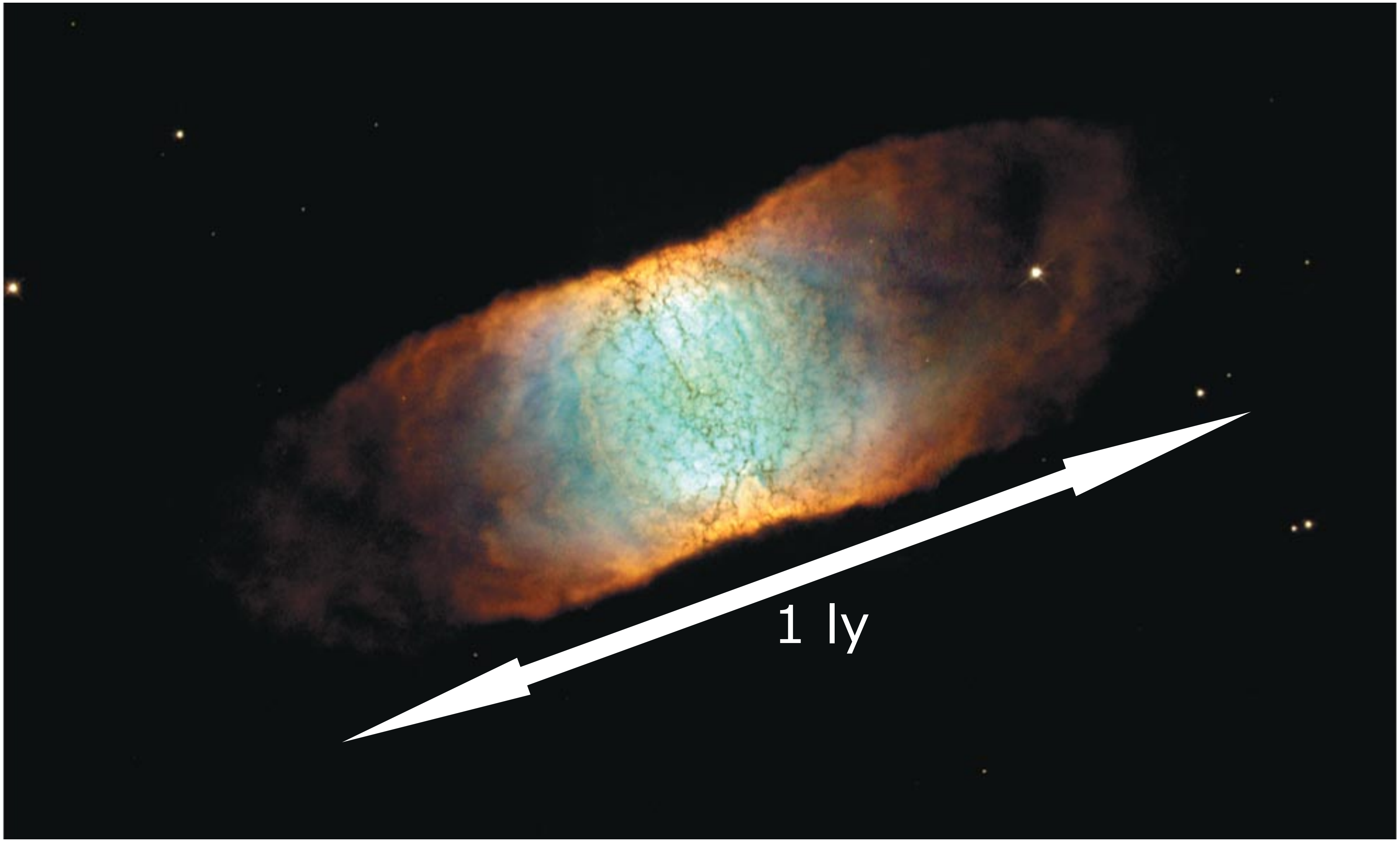
- Star-gas-star cycle: hot ionized gas ejected from stars in supernovae, planetary nebulae, and stellar winds cools into atomic gas clouds (H I regions) and slowly contracts into molecular clouds that form new stars.
  - Observed light emission depends on temperature & environment.
- Gas and dust in star-forming regions can emit (ionization nebula/H II region), reflect, or obscure star light.
- Spiral arms represent waves of star formation.
- Old, “metal”-poor stars in the halo indicate early star formation there that stopped long ago. So halo formed first from a collapsing gas cloud, then the spinning disk.
  - Movies!



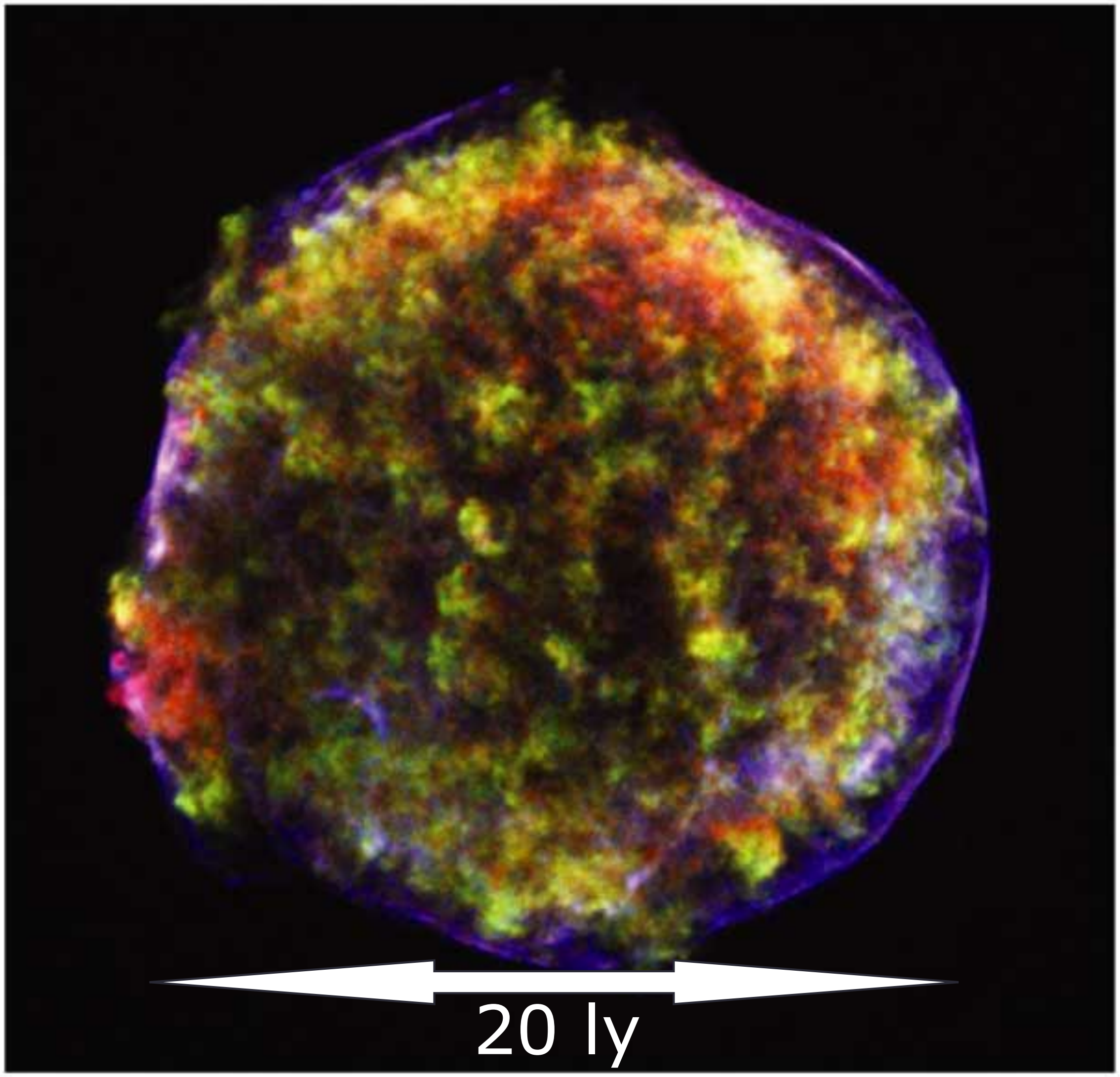

- *Star-gas-star cycle:* gas from old stars is recycled into new star systems.



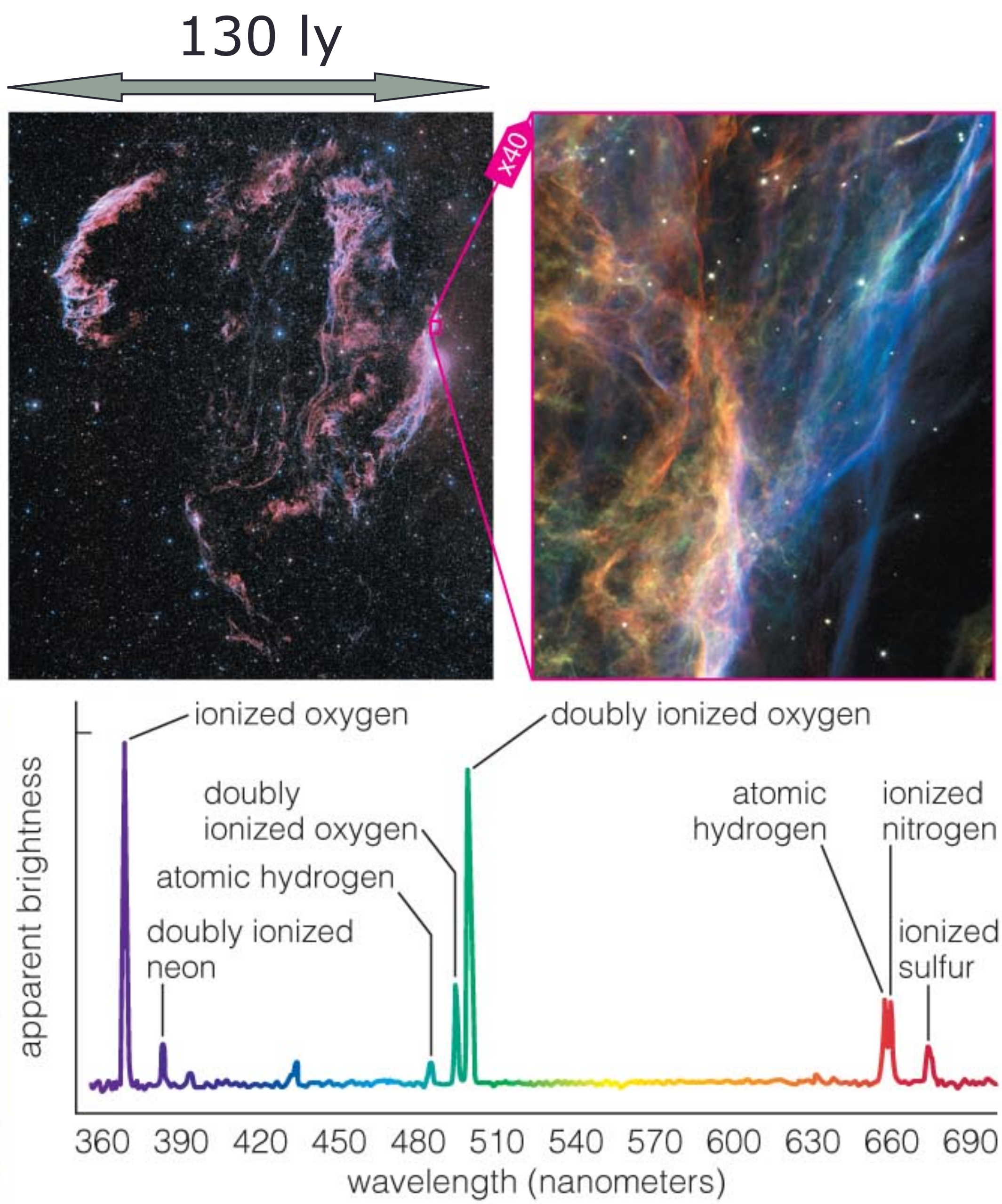

High-mass stars have strong stellar winds that blow bubbles of hot gas.




Lower-mass stars return gas to interstellar space through stellar winds and planetary nebulae.



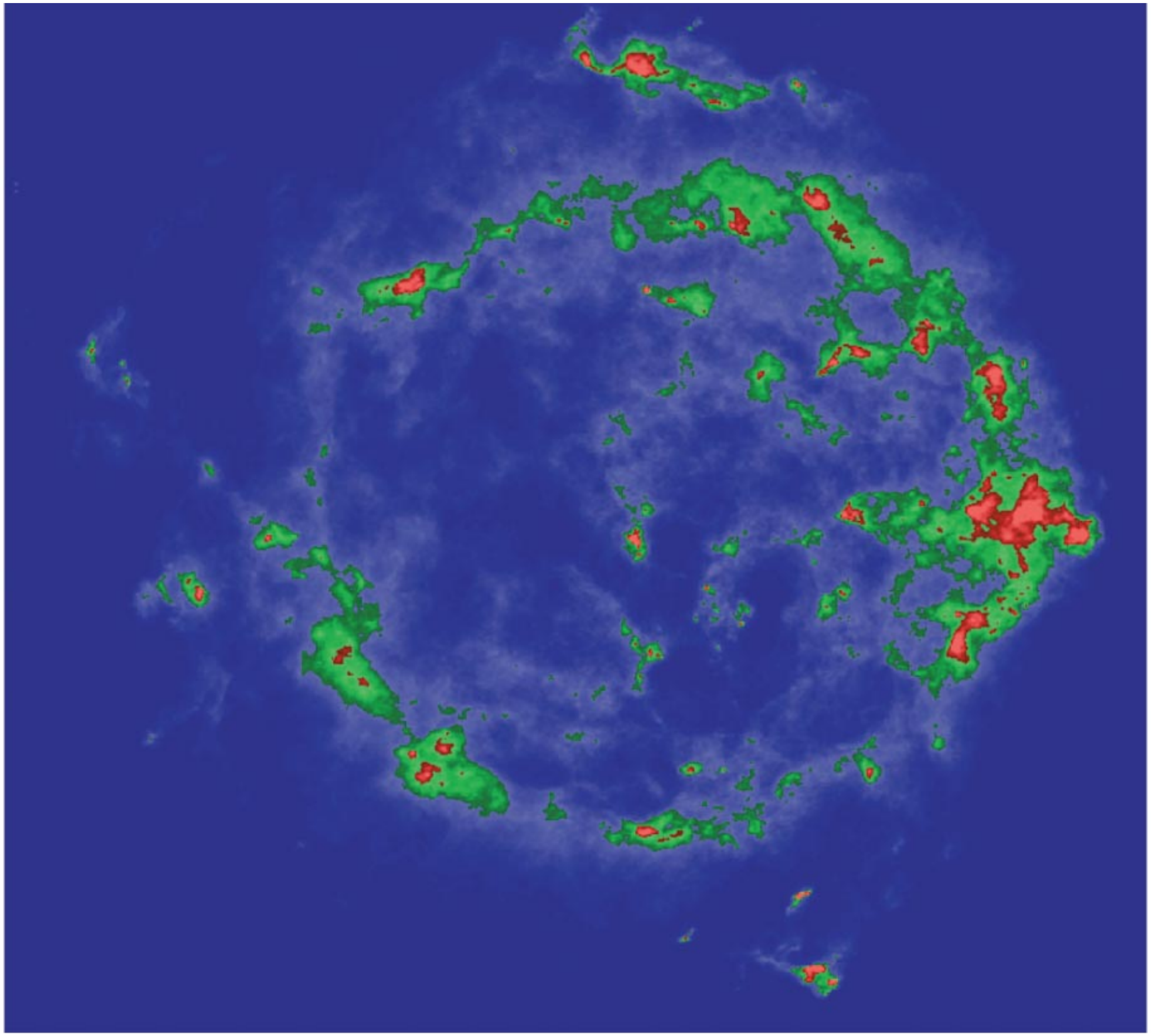

Supernovae generate shock waves (revealed by X-rays from hot gas) as they burst into the interstellar medium.



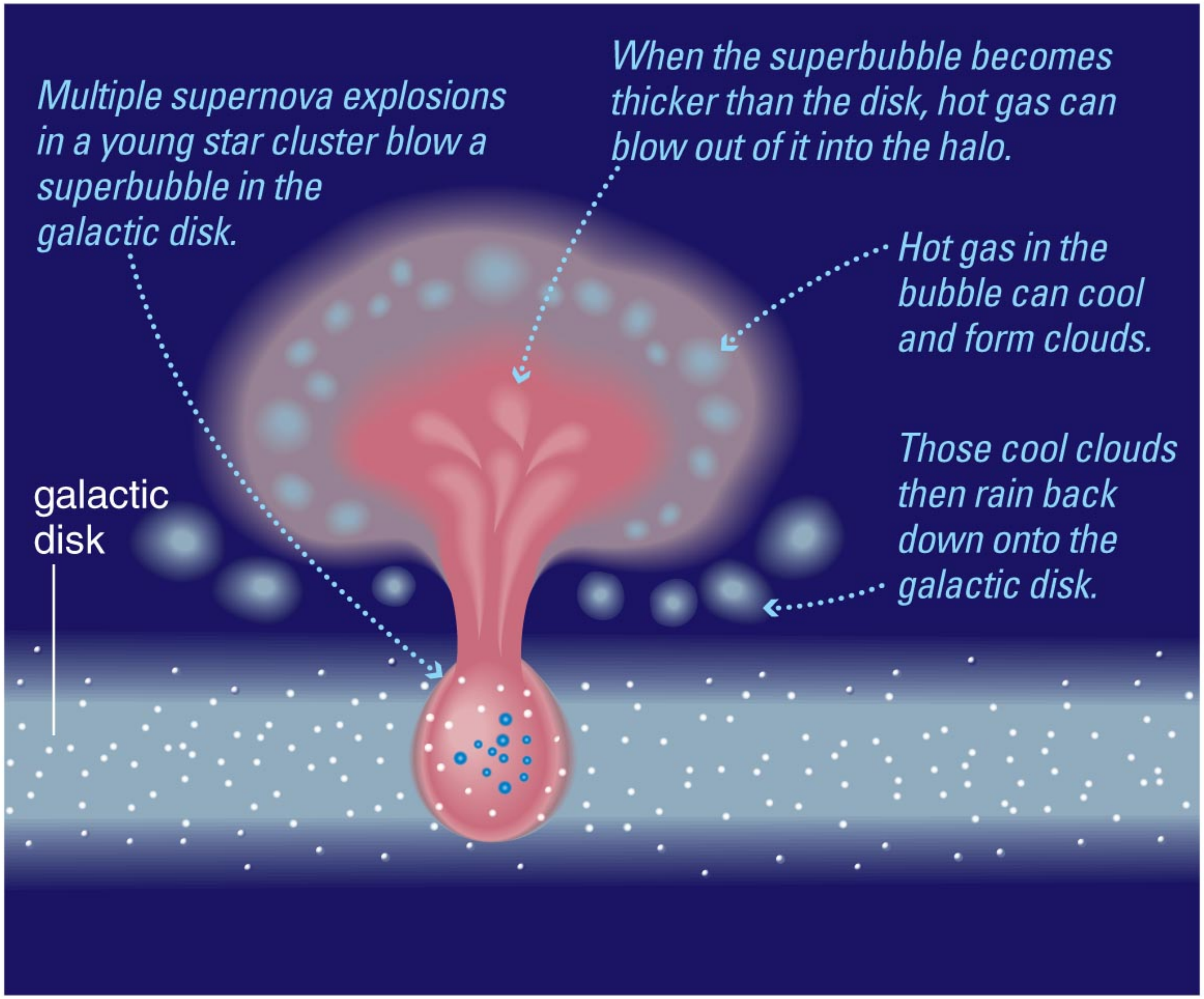

- A supernova remnant cools and begins to emit visible light as it expands.
- New elements made by a supernova mix into the interstellar medium.

# Group Q: Formation date of a star

- Suppose that you make careful observations of a main sequence star in the disk of the Milky Way
- The star has less than the mass of the Sun, so its lifetime is more than the age of the universe
- How can you make an estimate of when the star formed?



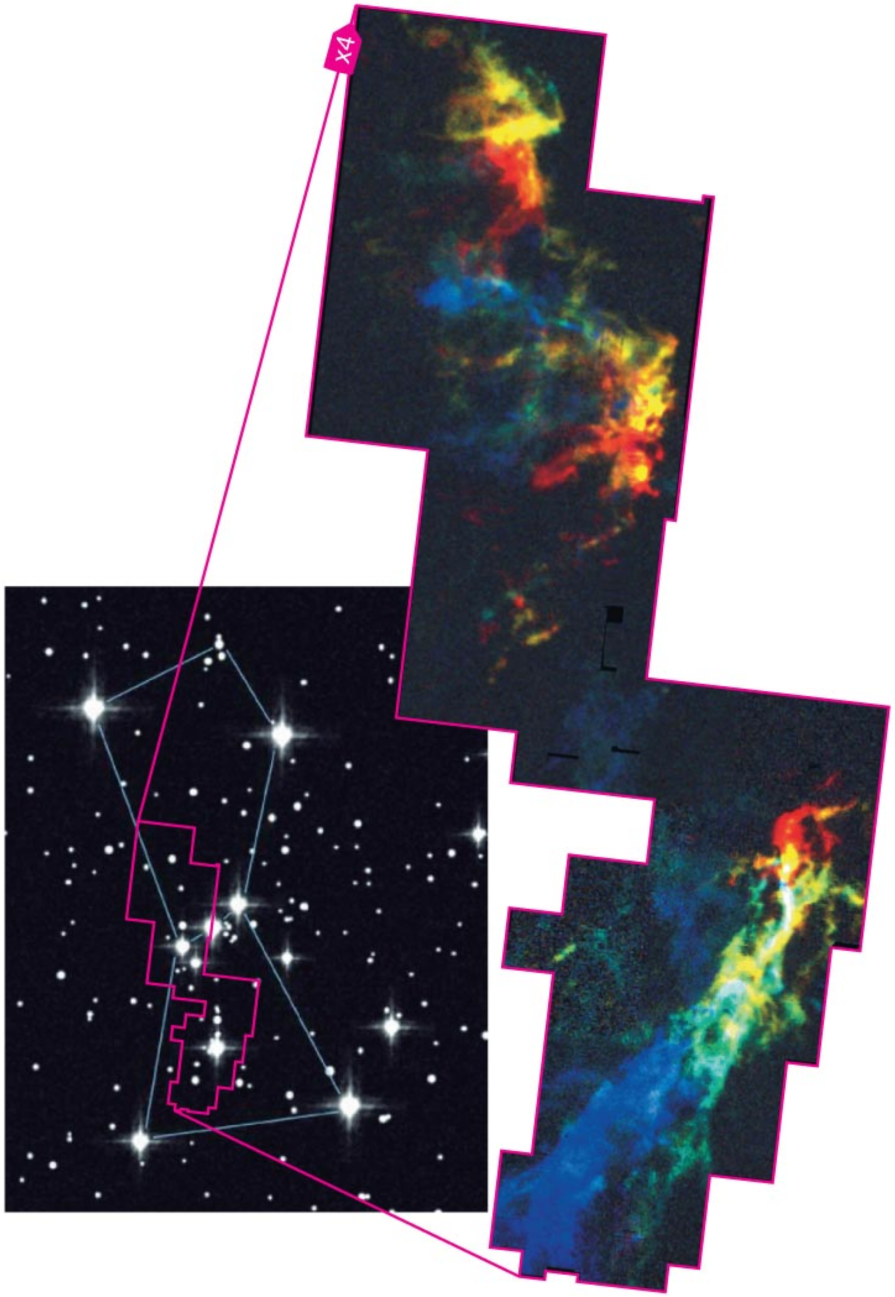
- Radio emission in supernova remnants is from particles accelerated to near light speed.
- Many cosmic rays probably come from supernovae.




- Multiple supernovae create huge hot bubbles that can blow out of the disk.
- Gas clouds cooling in the halo rain back down on the disk.

- ***Atomic hydrogen gas*** forms as hot gas cools, allowing electrons to join with protons.

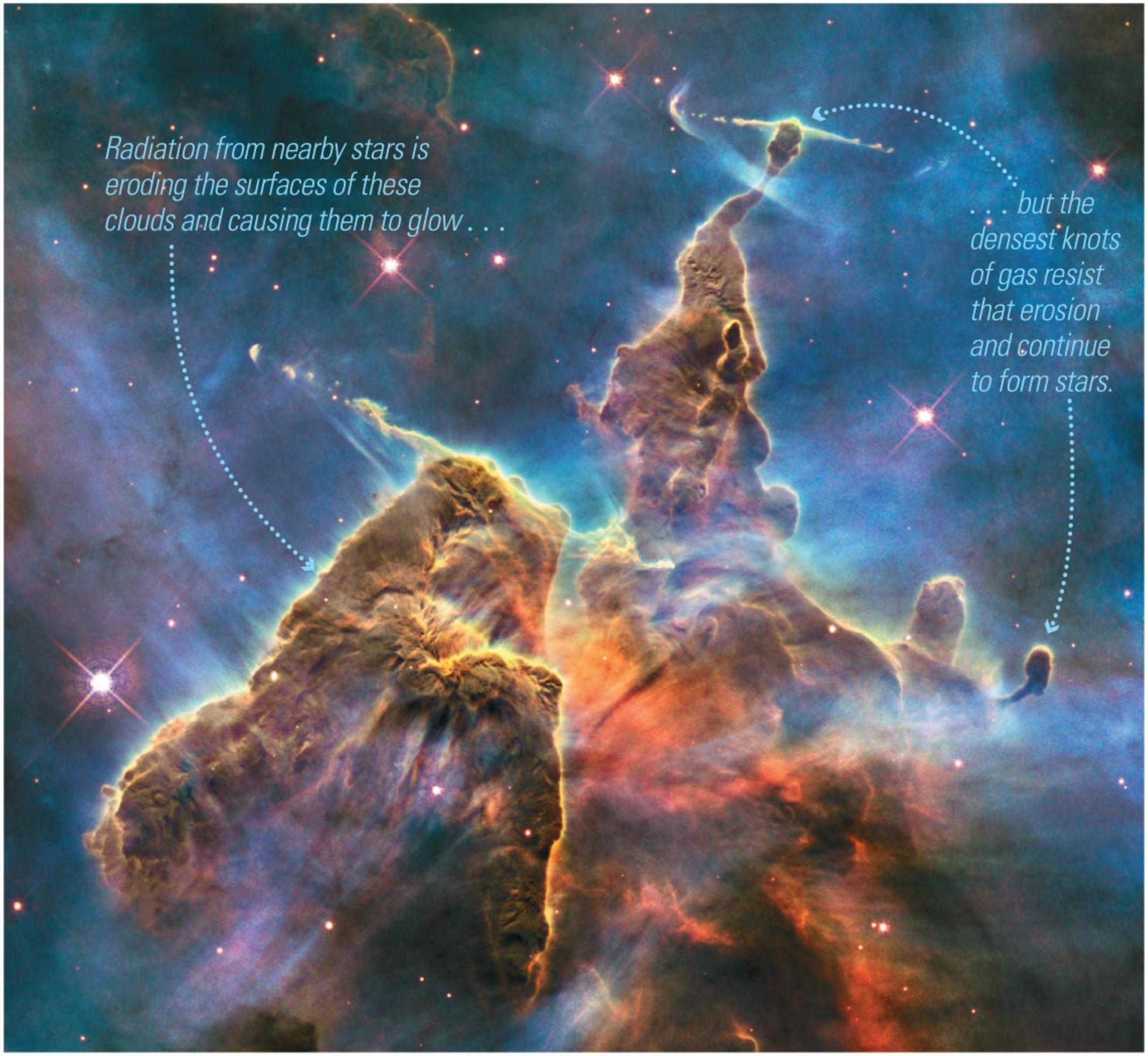
- ***Molecular clouds*** form next, after gas cools enough to allow atoms to combine into molecules.




Molecular clouds in Orion.

Composition:

- Mostly $H_2$.
- About 28% He.
- About 1% CO.
- Many other molecules.

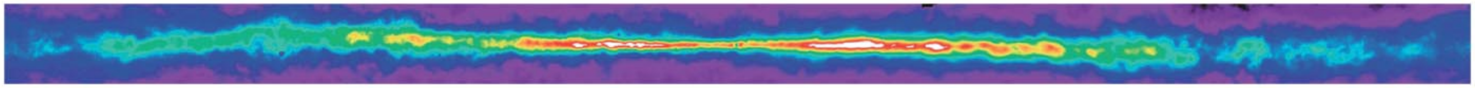



- Gravity forms stars out of the gas in molecular clouds, completing the star-gas-star cycle.
- Radiation from newly formed stars is eroding these star-forming clouds.

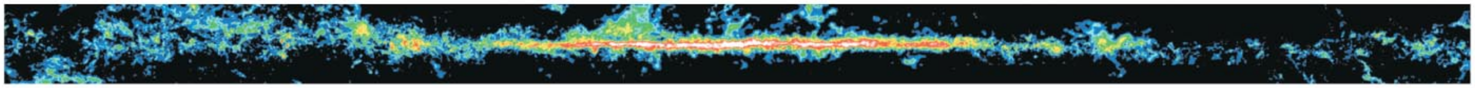
# Summary of Galactic Recycling

Gas Cools

- Stars make new elements by fusion.
- Dying stars expel gas and new elements, producing hot bubbles (~$10^6$ K).
- Hot gas cools, allowing atomic hydrogen clouds to form (~100–10,000 K).
- Further cooling permits molecules to form, making molecular clouds (~30 K).
- Gravity forms new stars (and planets) in molecular clouds.



**a** 21-centimeter radio emission from atomic hydrogen gas.



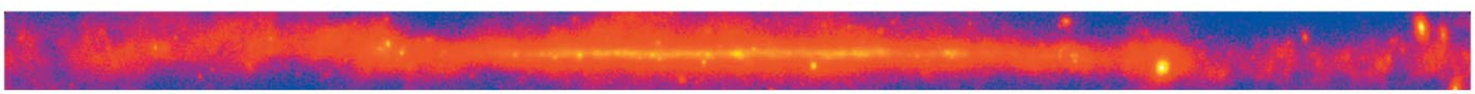
**b** Radio emission from carbon monoxide, revealing molecular clouds.

**c** Infrared (60–100 μm) emission from interstellar dust.

**d** Infrared (1–4 μm) emission from stars, which penetrates most interstellar material.

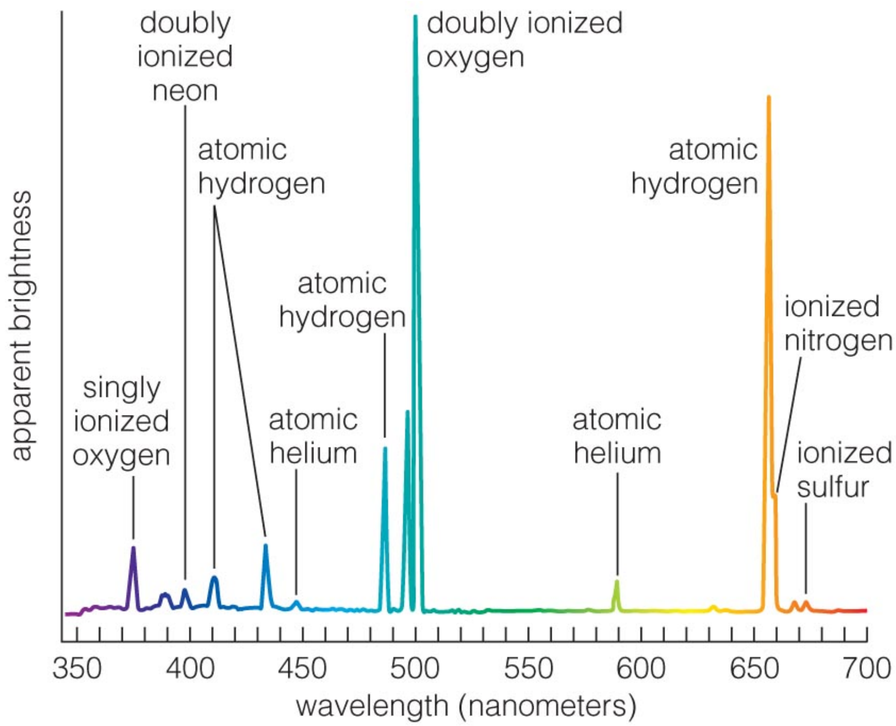
**e** Visible light emitted by stars, which is scattered and absorbed by dust.

**f** X-ray emission from hot gas bubbles (diffuse blobs) and X-ray binaries (pointlike sources).



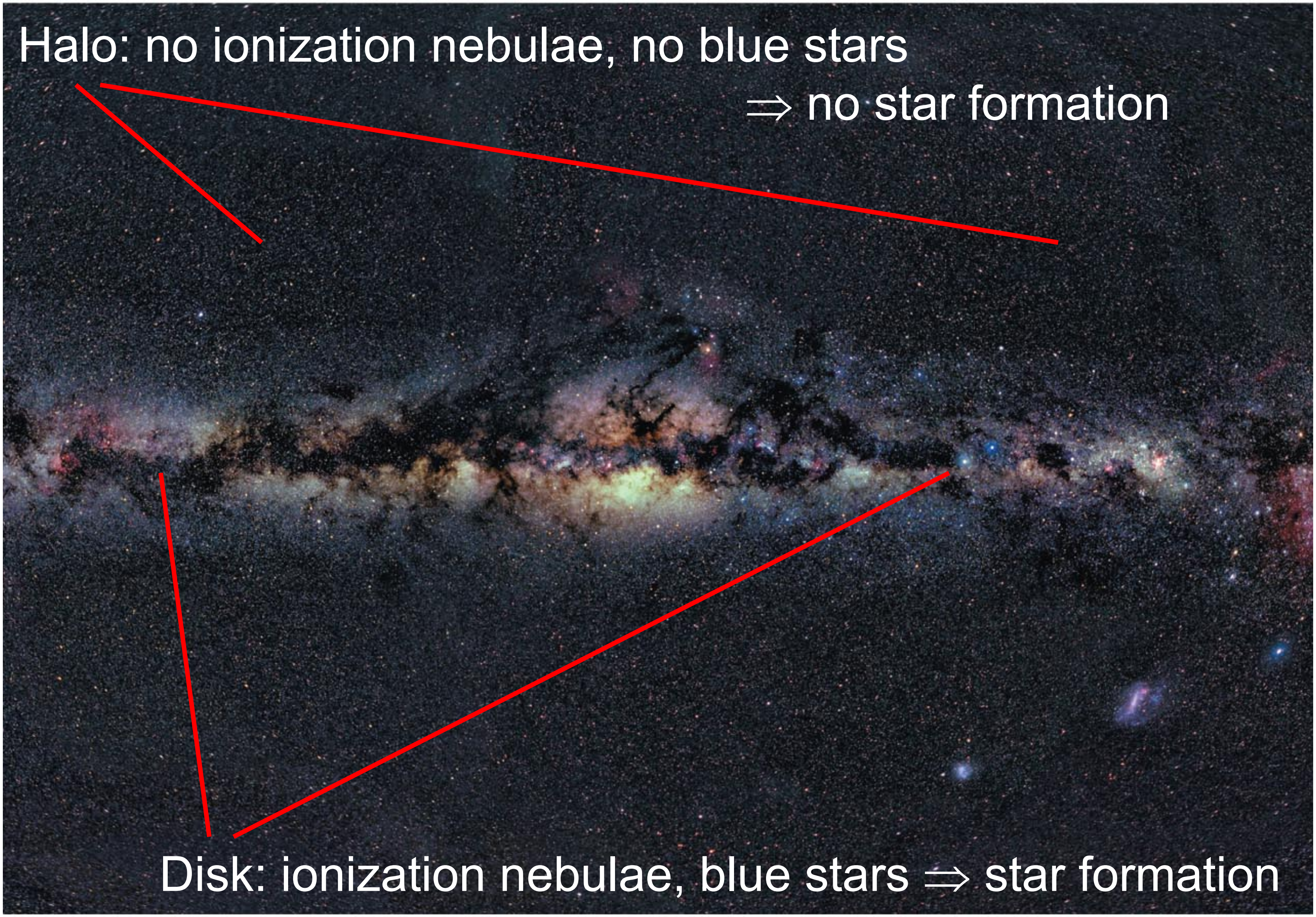
**g** Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

- We observe the star-gas-star cycle operating in Milky Way’s disk using many different wavelengths of light.




- ***Ionization nebulae*** (also known as emission nebulae and H II regions) are found around short-lived high-mass stars, signifying active star formation.

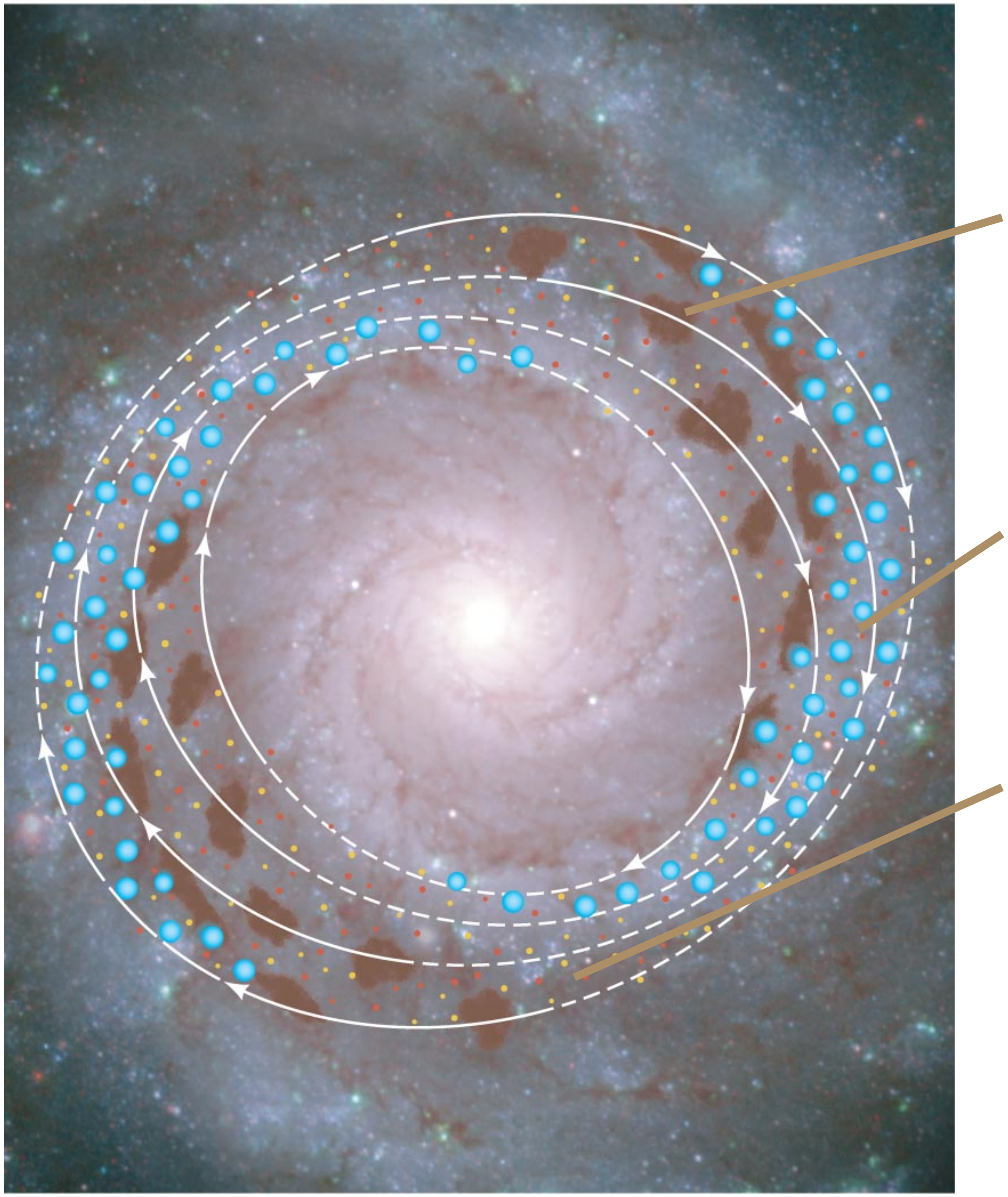
- ***Reflection nebulae*** scatter the light from stars.
- They're blue for the same reason the sky is blue: Rayleigh scattering.


Halo: no ionization nebulae, no blue stars
⇒ no star formation
Disk: ionization nebulae, blue stars ⇒ star formation

- Much of the star formation in the disk happens in the spiral arms.

Blue stars
Ionization nebulae
Gas clouds

Whirlpool Galaxy (M51)

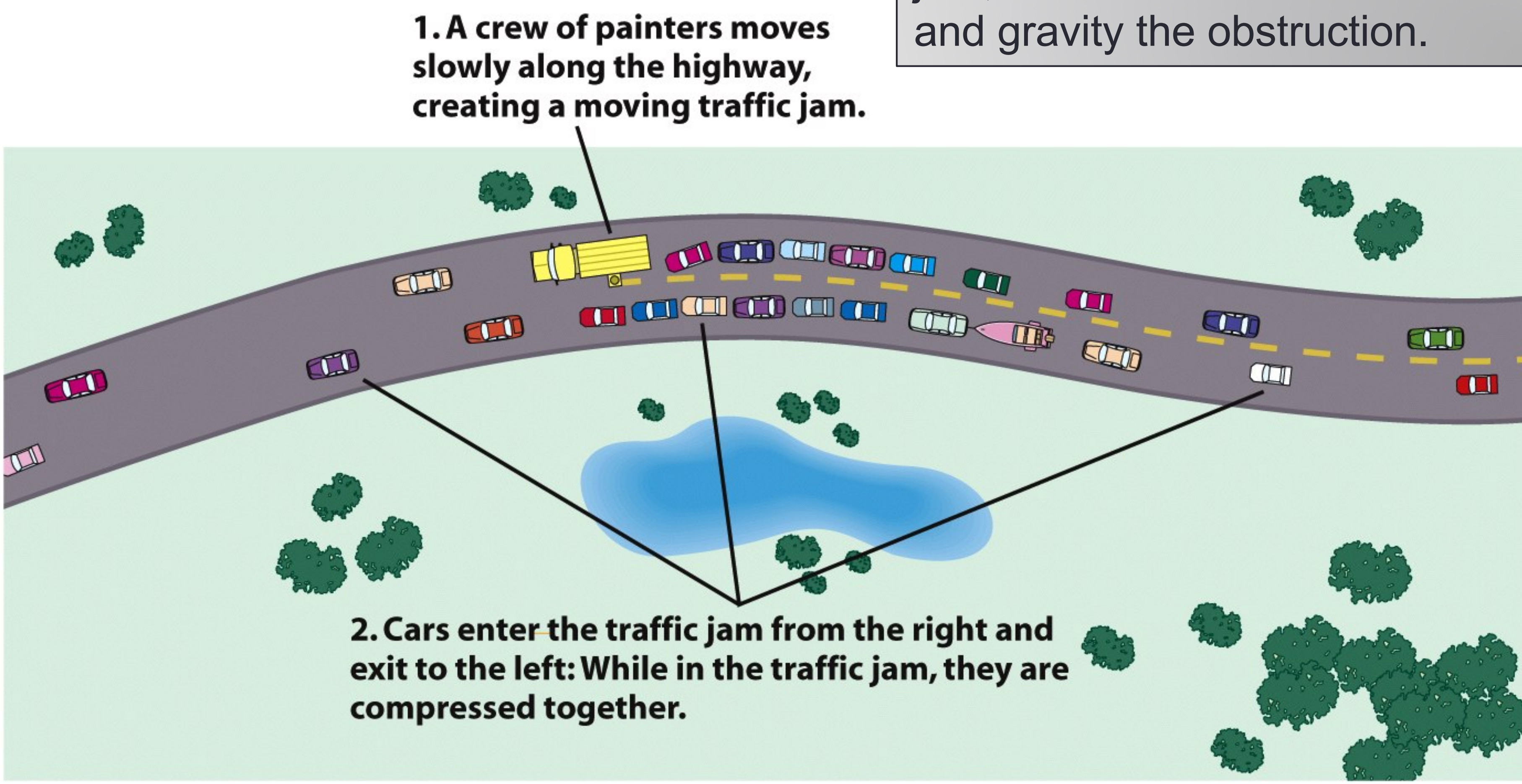


- Spiral arms are *density waves*.

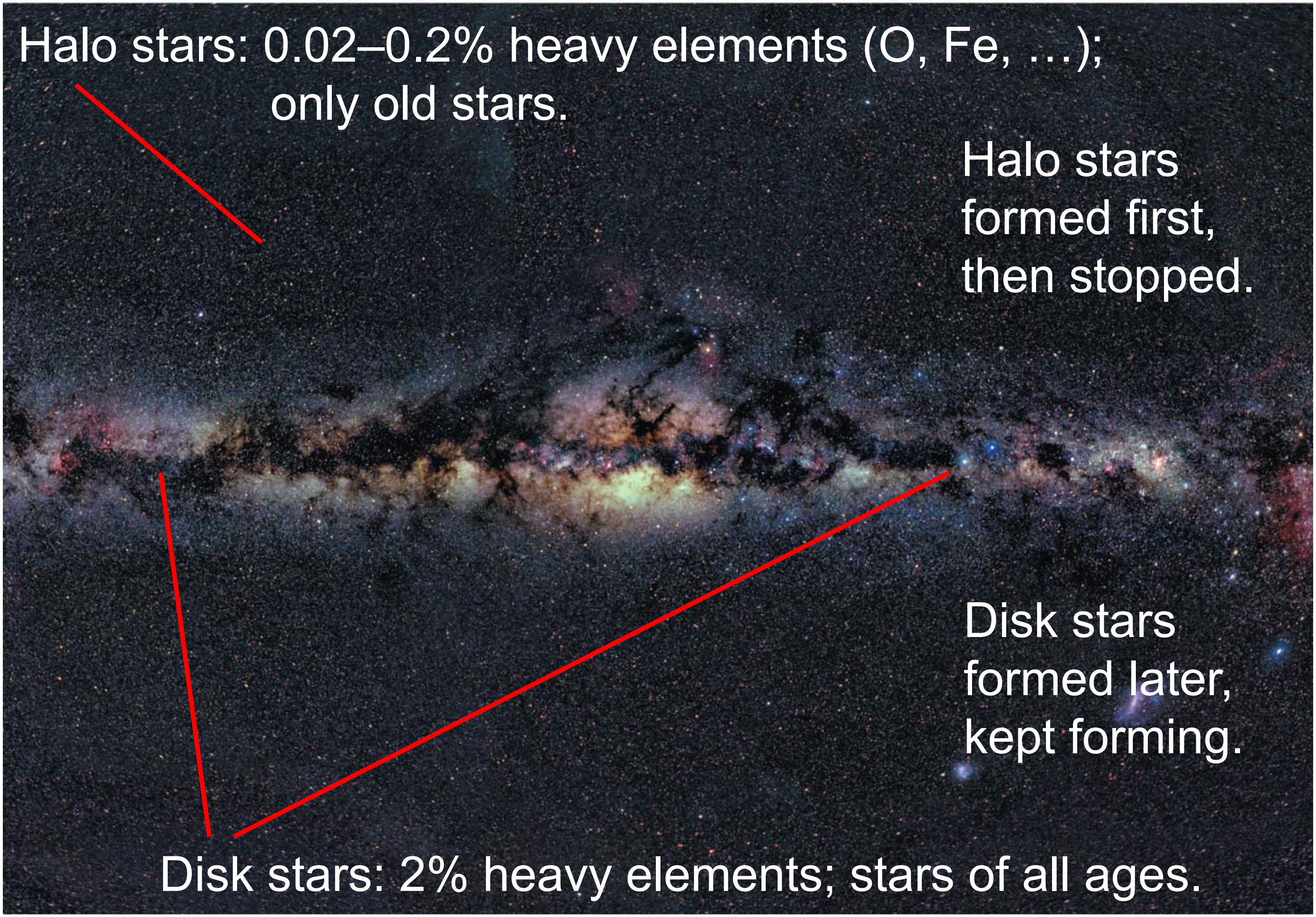
1. Gas clouds get squeezed as they move into spiral arms.
2. Squeezing of clouds triggers star formation.
3. Young stars flow out of spiral arms.

- So spiral arms are essentially waves of star formation.

A density wave is like a traffic jam, with stars & clouds for cars and gravity the obstruction.




https://youtu.be/Suugn-p5C1M
http://traffic-simulation.de/


Halo stars: 0.02–0.2% heavy elements (O, Fe, …);
only old stars.
Halo stars
formed first,
then stopped.
Disk stars
formed later,
kept forming.
Disk stars: 2% heavy elements; stars of all ages.

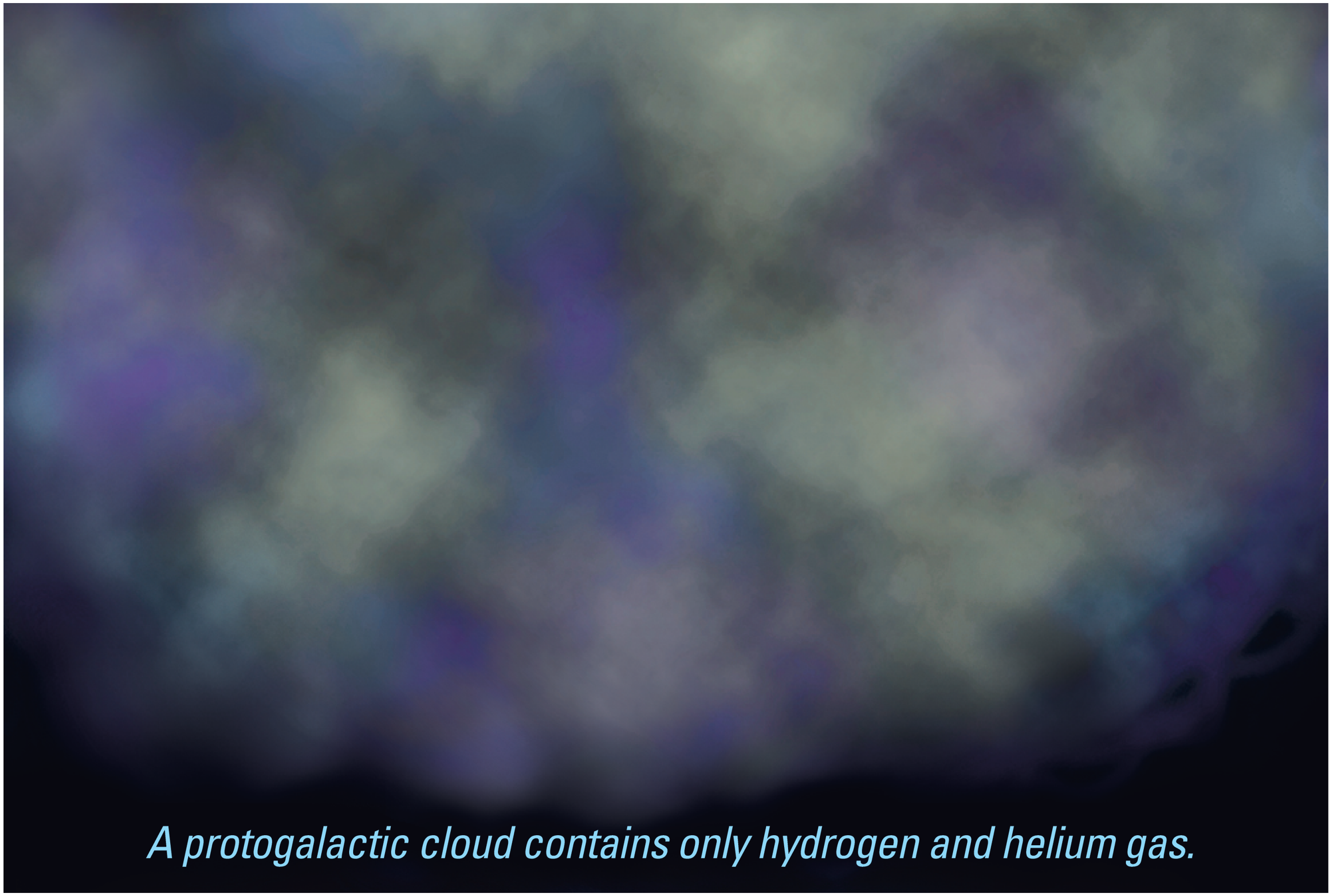
# Dwarf Galaxy Formation Simulation

**THE FORMATION OF A BULGELESS GALAXY WITH A SHALLOW DARK MATTER CORE**

**Fabio Governato** (University of Washington)
**Chris Brook** (University of Central Lancashire)
**Lucio Mayer** (ETH and University of Zurich)
and the N-Body Shop

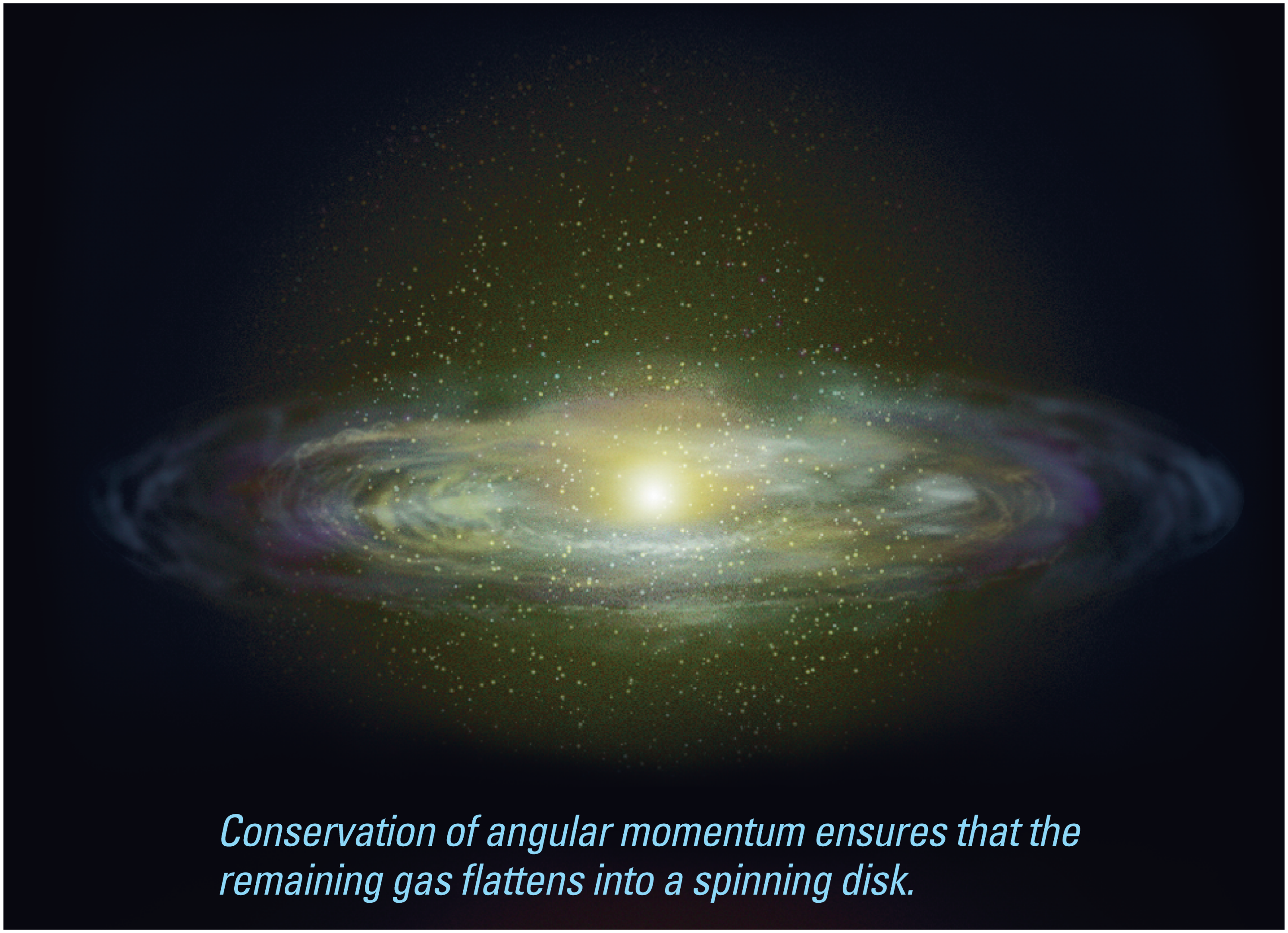
KEY: Blue: gas density map. The brighter regions represent gas that is actively forming stars. The clock shows the time from the Big Bang. The frame is 50,000 light years across.

Simulations were run on Columbia (NASA Advanced Supercomputing Center) and at ARSC

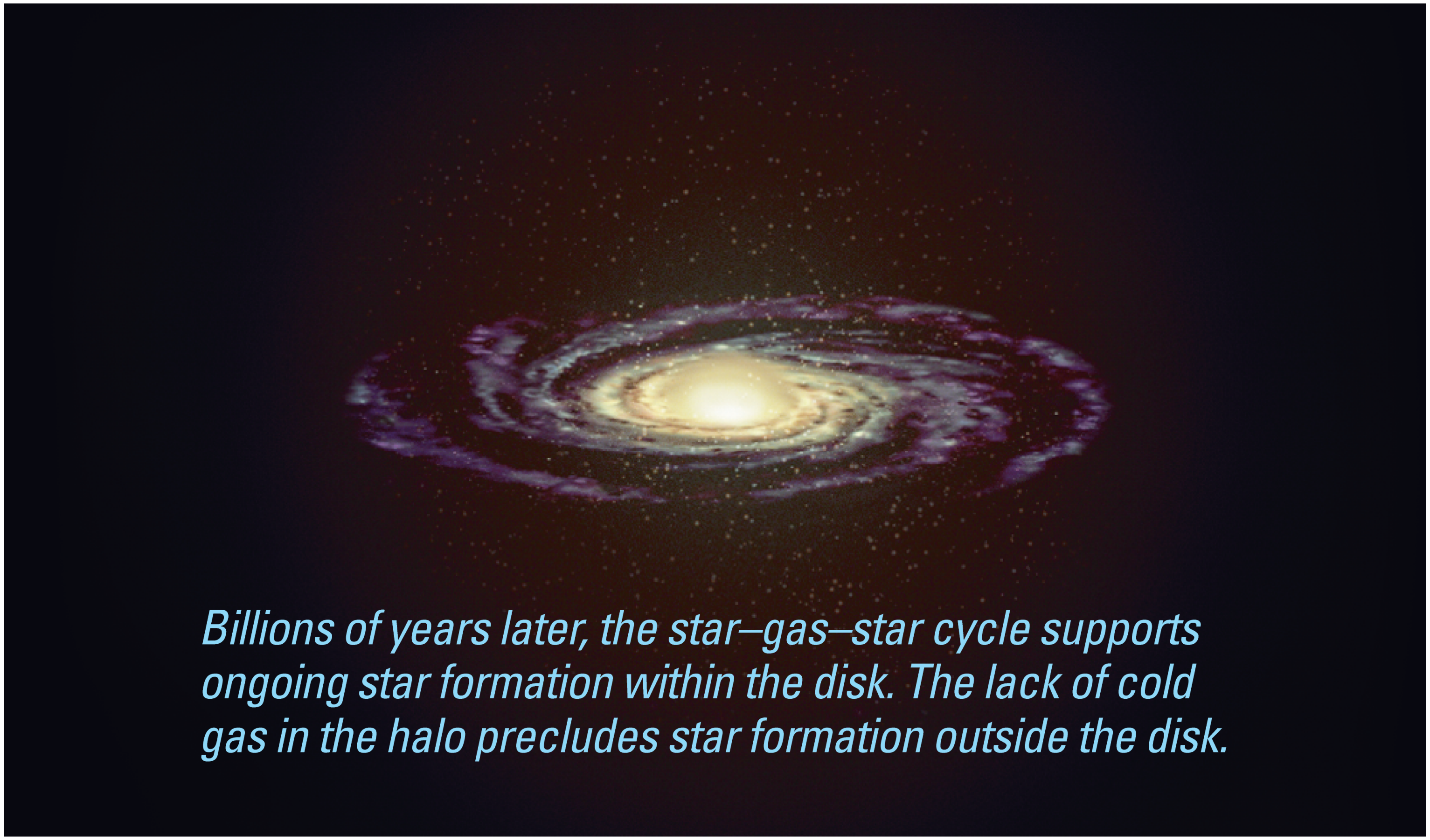



- Our galaxy formed from a cloud of intergalactic gas.

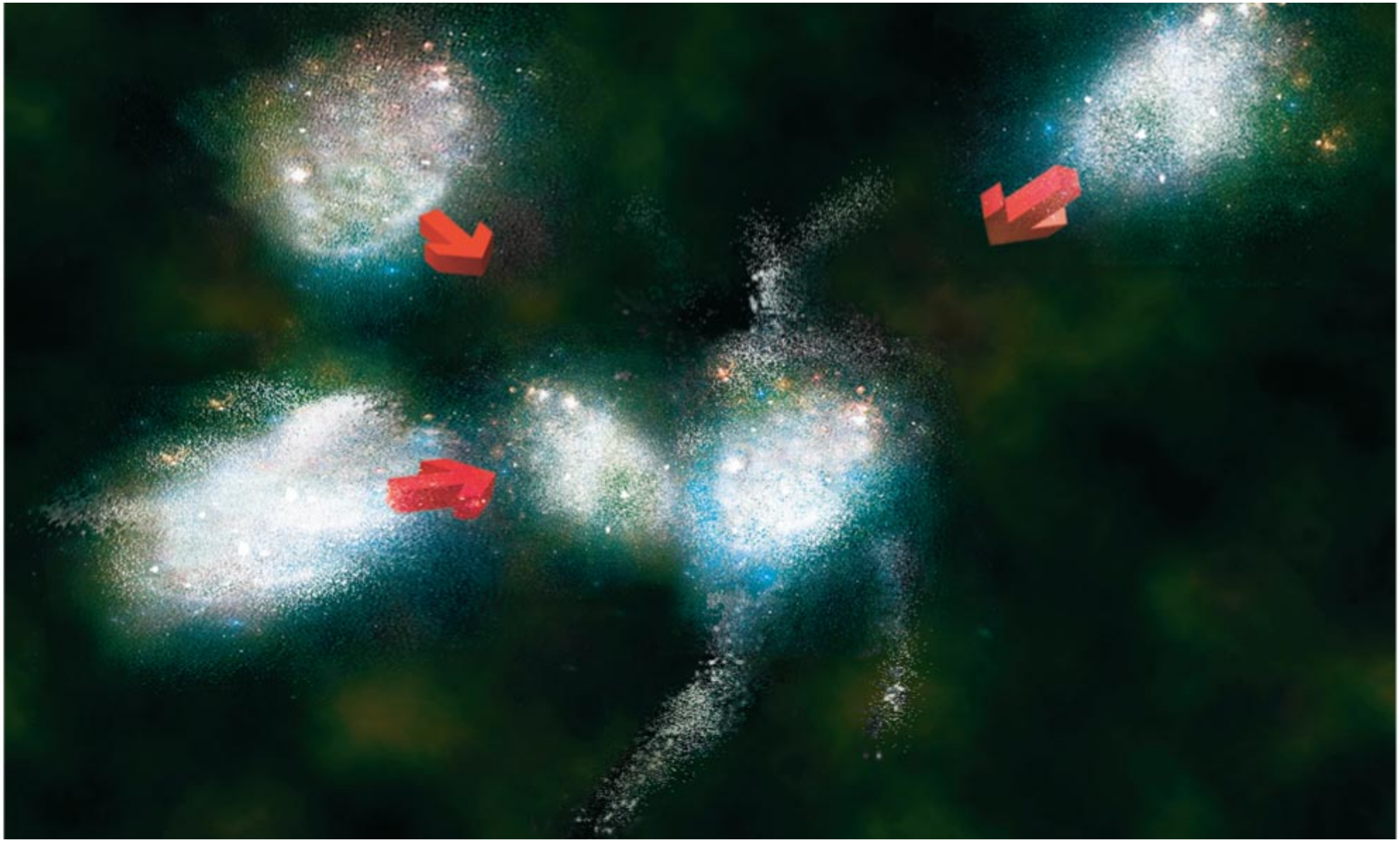

- Halo stars formed first as gravity caused gas to contract.




- Remaining gas settled into a spinning disk.




- Stars continuously form in disk as galaxy grows older.
- ***WARNING: this model is oversimplified!***



- Detailed studies show that halo stars formed in clumps that later merged.

# Galaxy Merger Simulation