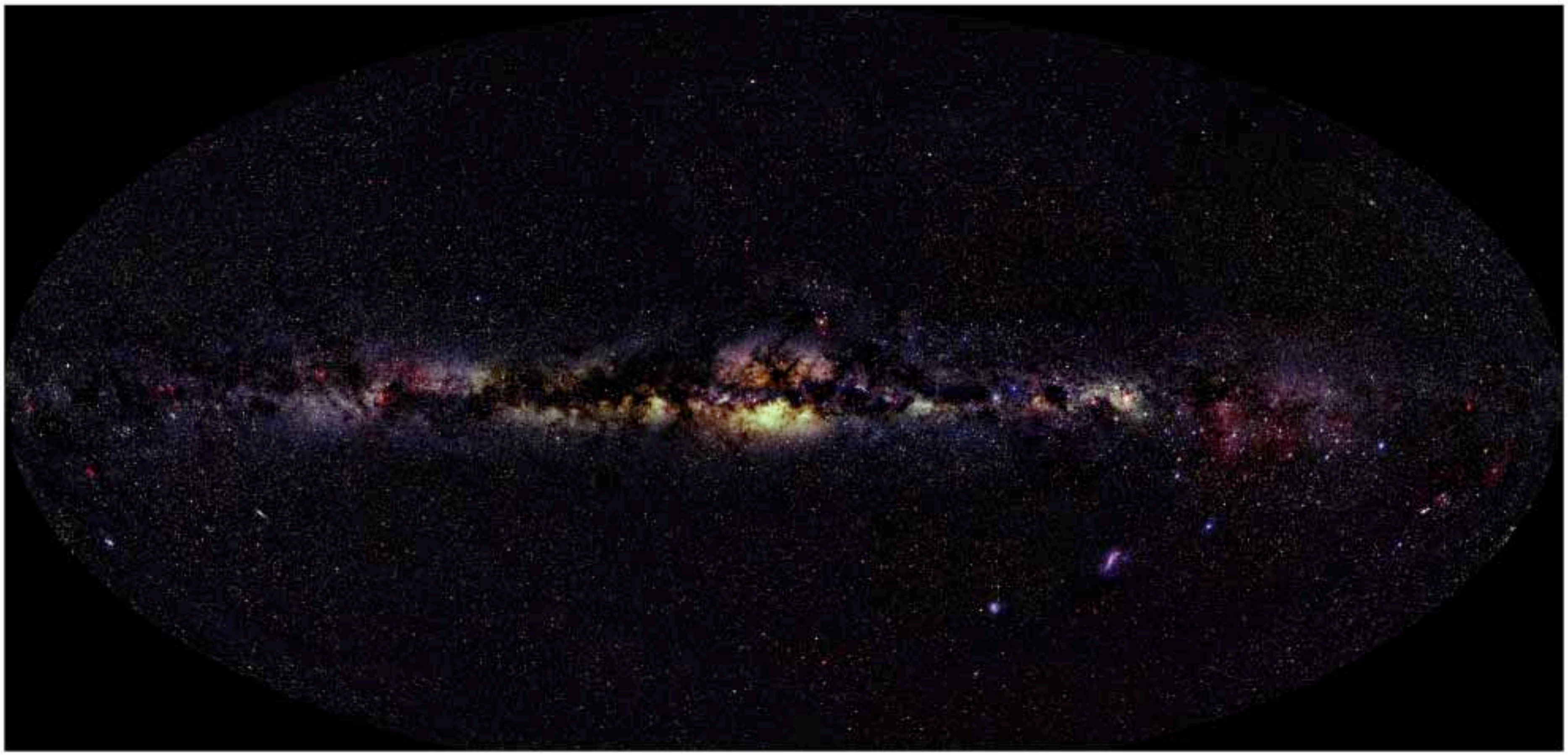
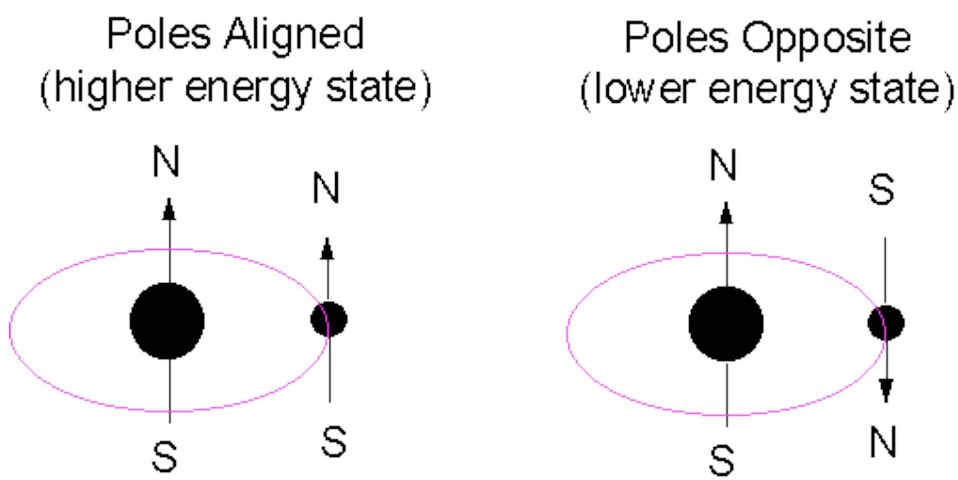
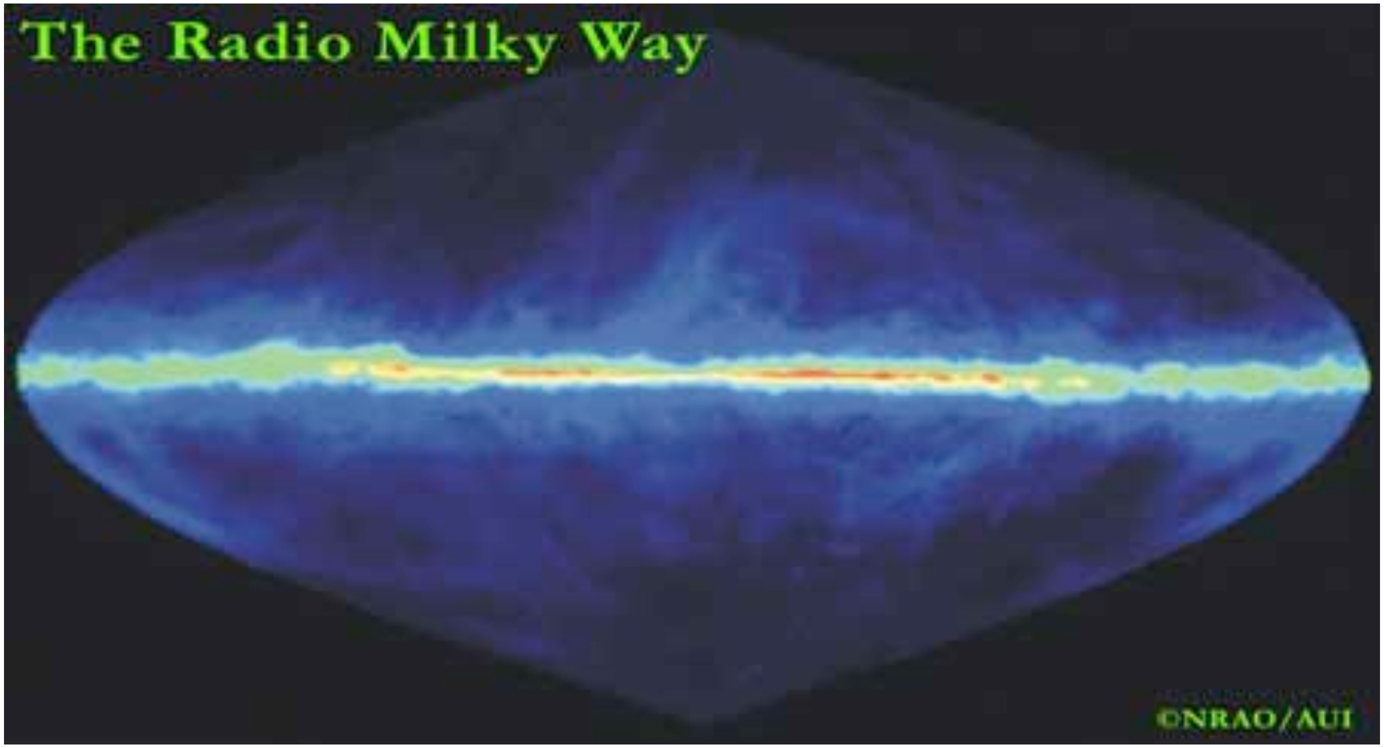
The Stuff between the Stars: The Interstellar Medium



The 21cm Neutral Hydrogen "Spin-flip" Transition



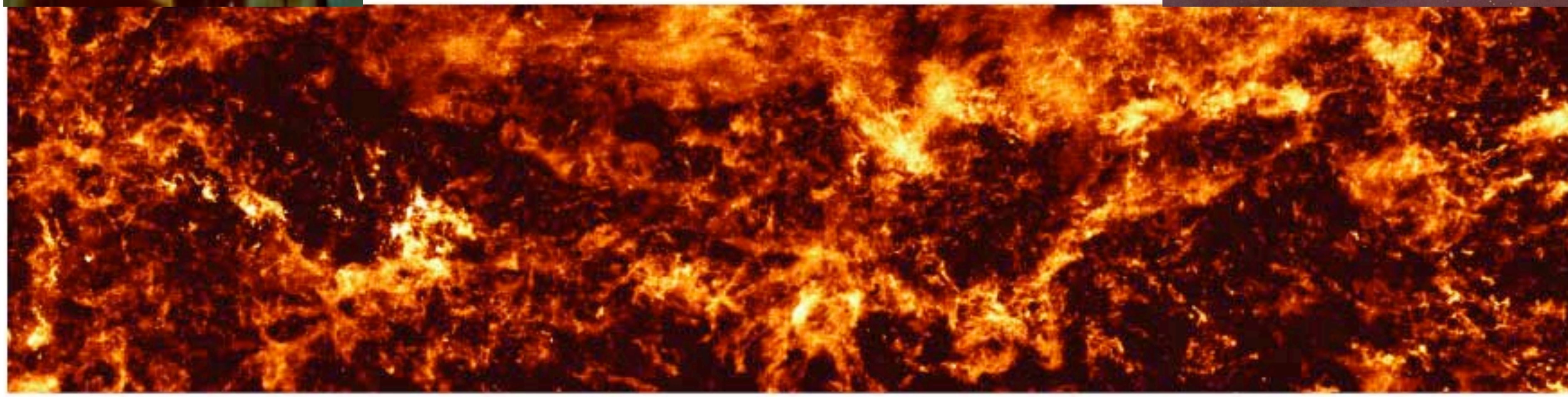
A 21-cm photon is emitted when poles go from being aligned to opposite (a spin flip).



HI in the Milky Way

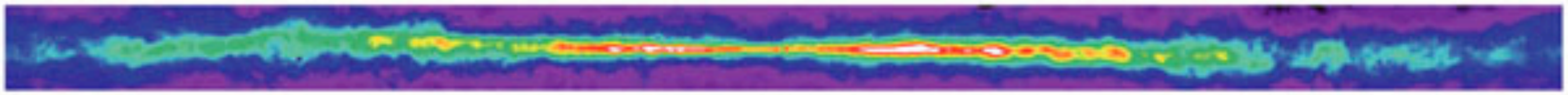
- Distribution of HI gas is different from the stars:
  - more extended: HI extends well beyond the stallar disk
  - Thinner: HI disk has a thickness of about 1000 ly (compared to 3000 ly for the stars)
- Average density ~ 1 atom/cm^3 (but “clouds” have densities up to 10^2-10^3/cm^3
- Average T ~ 100K (-273°C; -400°F)

Molecular Clouds

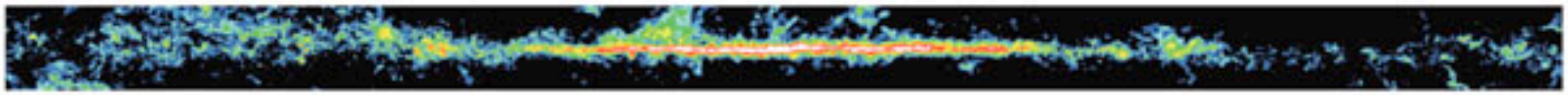


- Most of the matter in star-forming clouds is in the form of molecules (H_2, CO,…C_2H_5OH)
- These *molecular clouds* have a temperature of 10-30 K and a density of about 1000 - 100,000 molecules/cm^3
- Most of what we know about molecular clouds comes from observing the emission lines of carbon monoxide (CO)

Distribution of Gas & Stars



a 21-cm radio emission from atomic hydrogen gas.

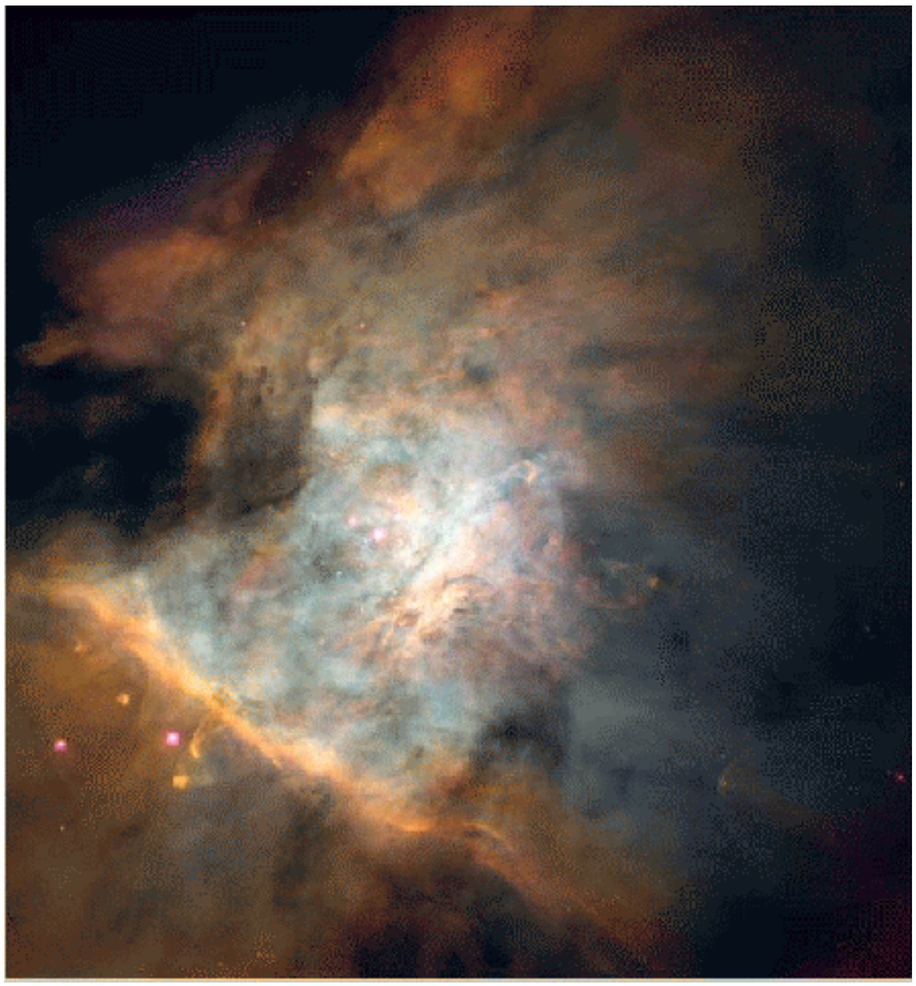


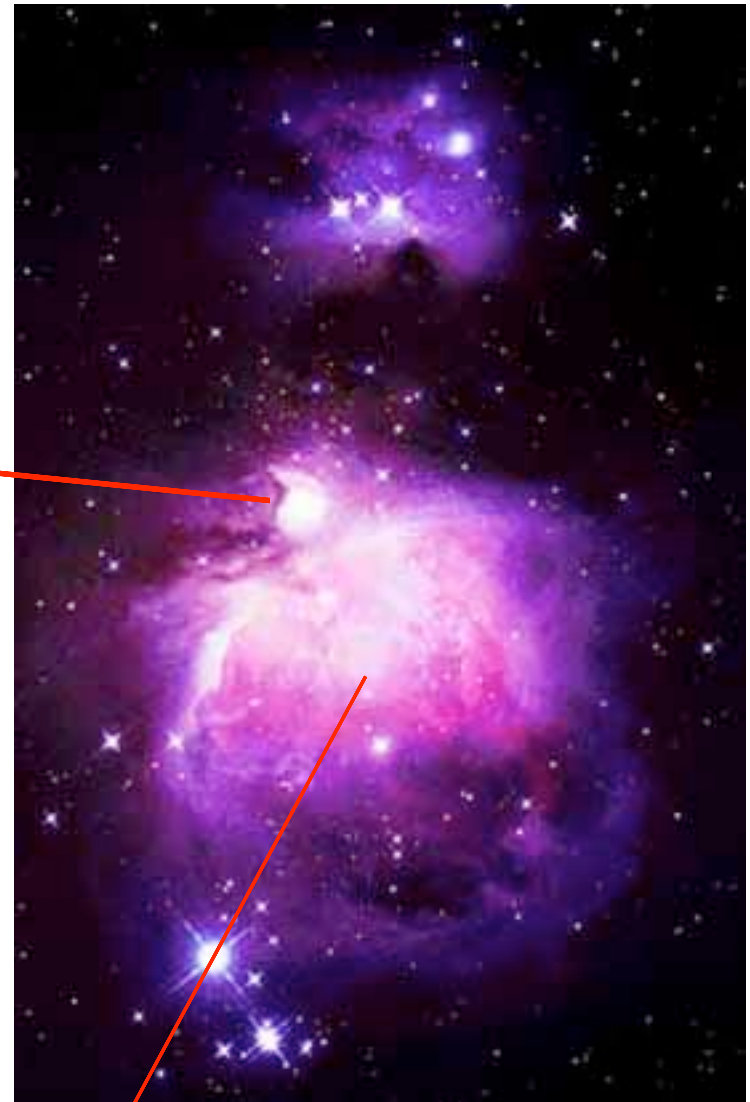
b Radio emission from carbon monoxide reveals molecular clouds.

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

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

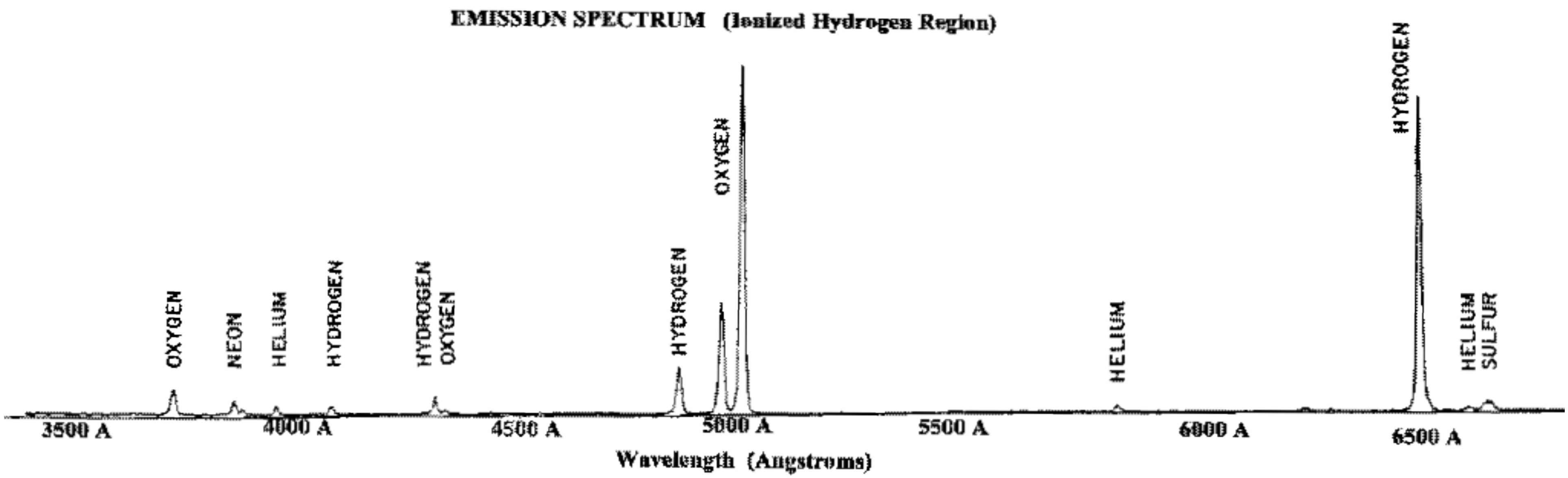
Ionized Hydrogen (HII) Regions





Ultraviolet light from newly formed massive stars ionizes and heats hydrogen gas causing it to fluoresce

HII Emission-line Spectrum

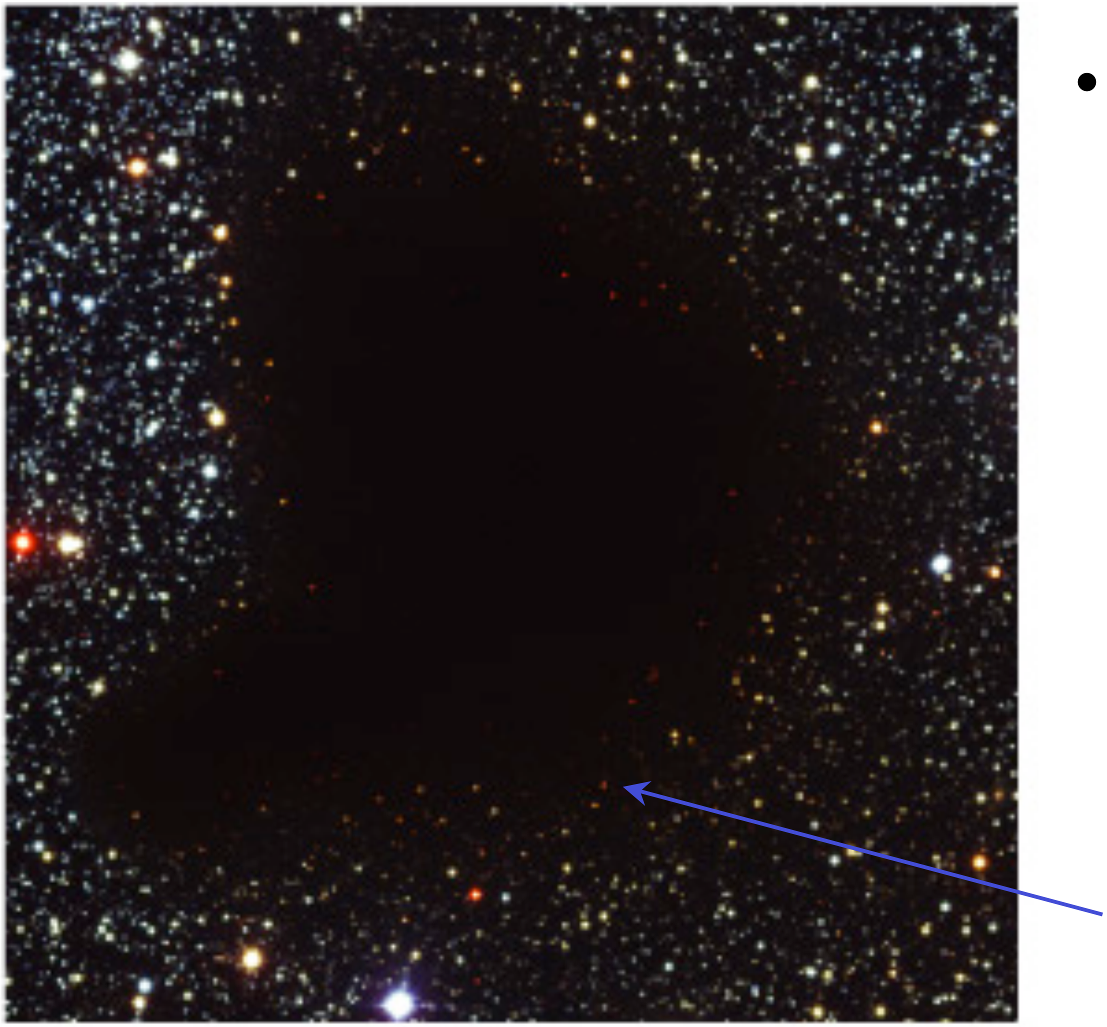


- Photoionization - hydrogen (and helium …) atoms are ionized by UV light from hot (O-type) stars
- Electrons "thermalize" - redistribute energy as thermal energy at T~10,000K
- Electrons collide with O, N, Ne, S exciting atoms which return to ground state producing emission lines
- H & He ions "recombine" - electrons are captured to outer orbits, "cascade" to ground state producing emission lines of H, He

Interstellar Dust

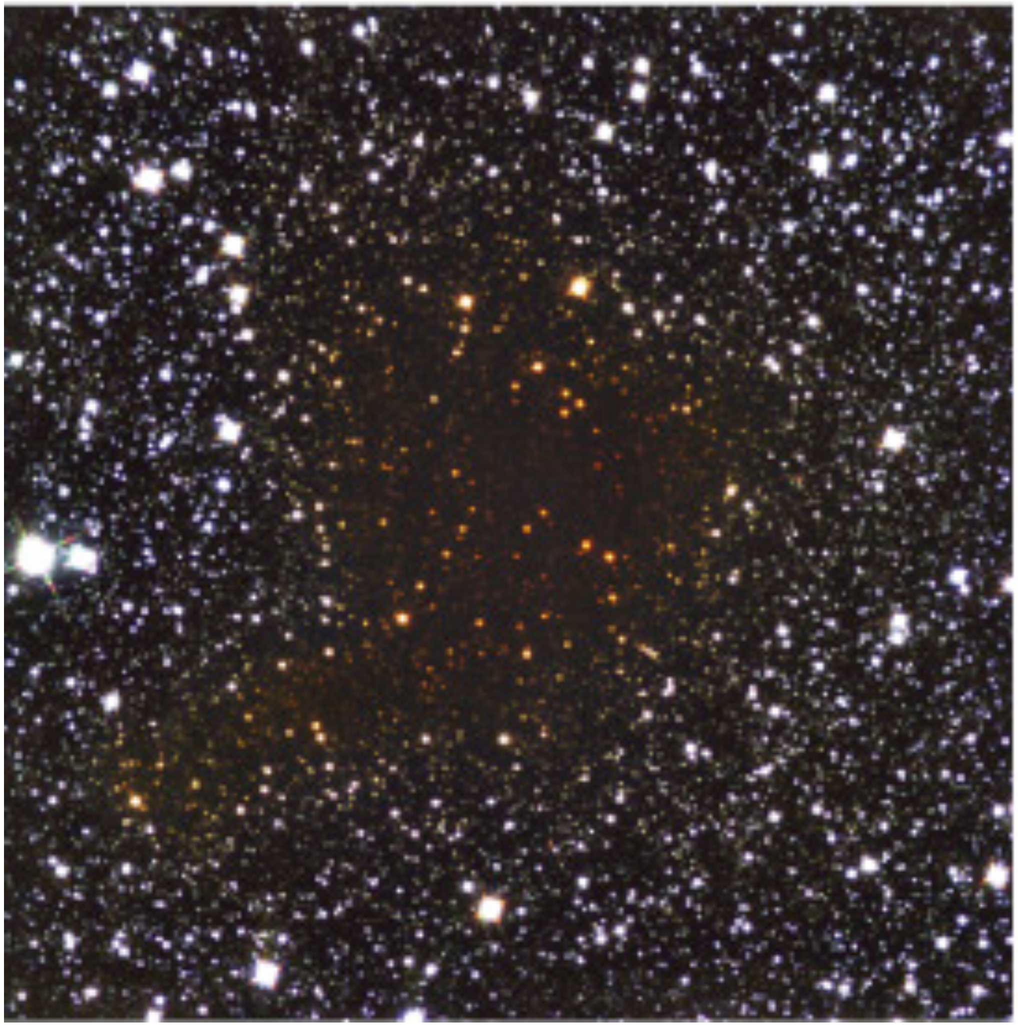
- Tiny solid particles of *interstellar dust* block our view of stars on the other side of a cloud
- Particles are < 1 micrometer in size and made of elements like C, O, Si, and Fe

Interstellar Reddening



- Stars viewed through the edges of the cloud look redder because dust blocks (shorter-wavelength) blue light more effectively than (longer-wavelength) red light

Interstellar Reddening



- Long-wavelength infrared light passes through a cloud more easily than visible light
- Observations of infrared light reveal stars on the other side of the cloud

The Pleiades - Reflection Nebula

- Dust scatters blue light preferentially

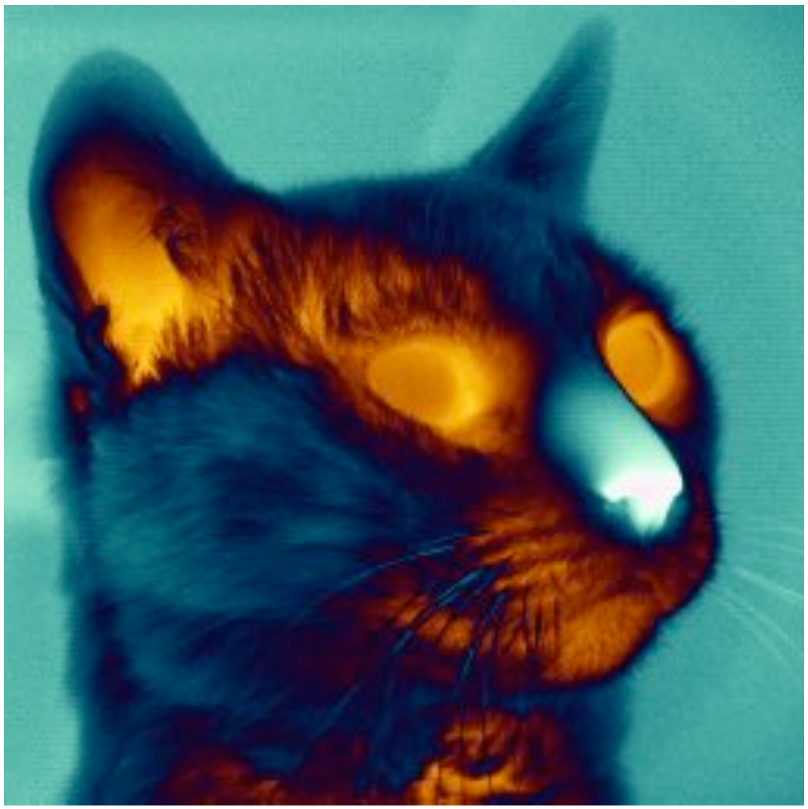
Why is the sky blue? And sunsets red?

Why is the sky blue? And sunsets red?

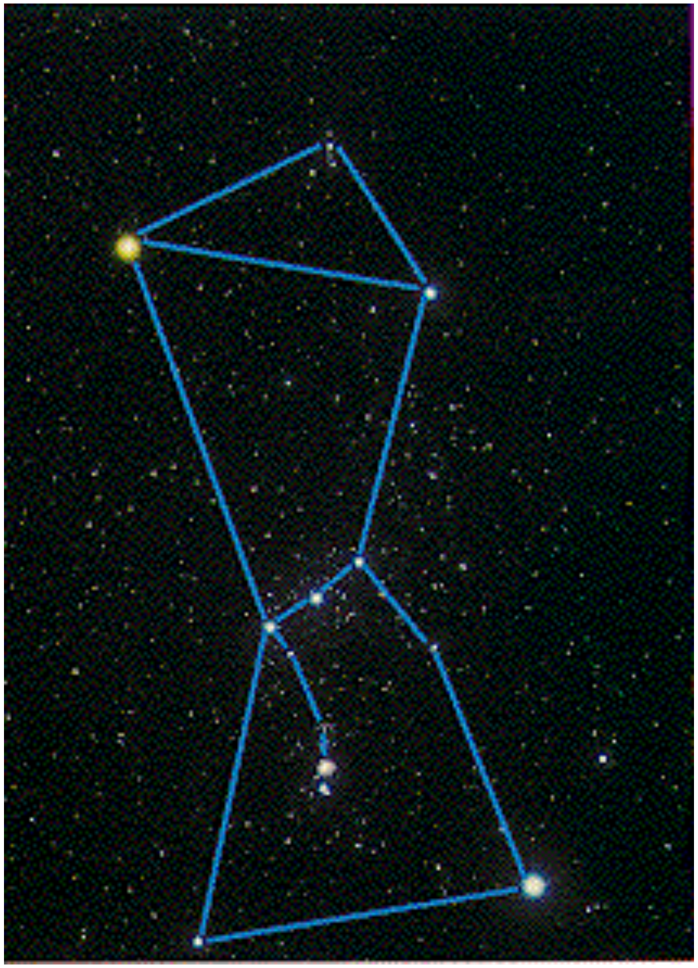
Molecules in the earth's atmosphere scatter the blue light from the sun.

The longer path through the earth's atmosphere at sunset when the sun is near the horizon has scattered out all the blue light (and most of the green & yellow) leaving only the red.

Infrared light comes from "cool" objects (T ~ 10-300K)



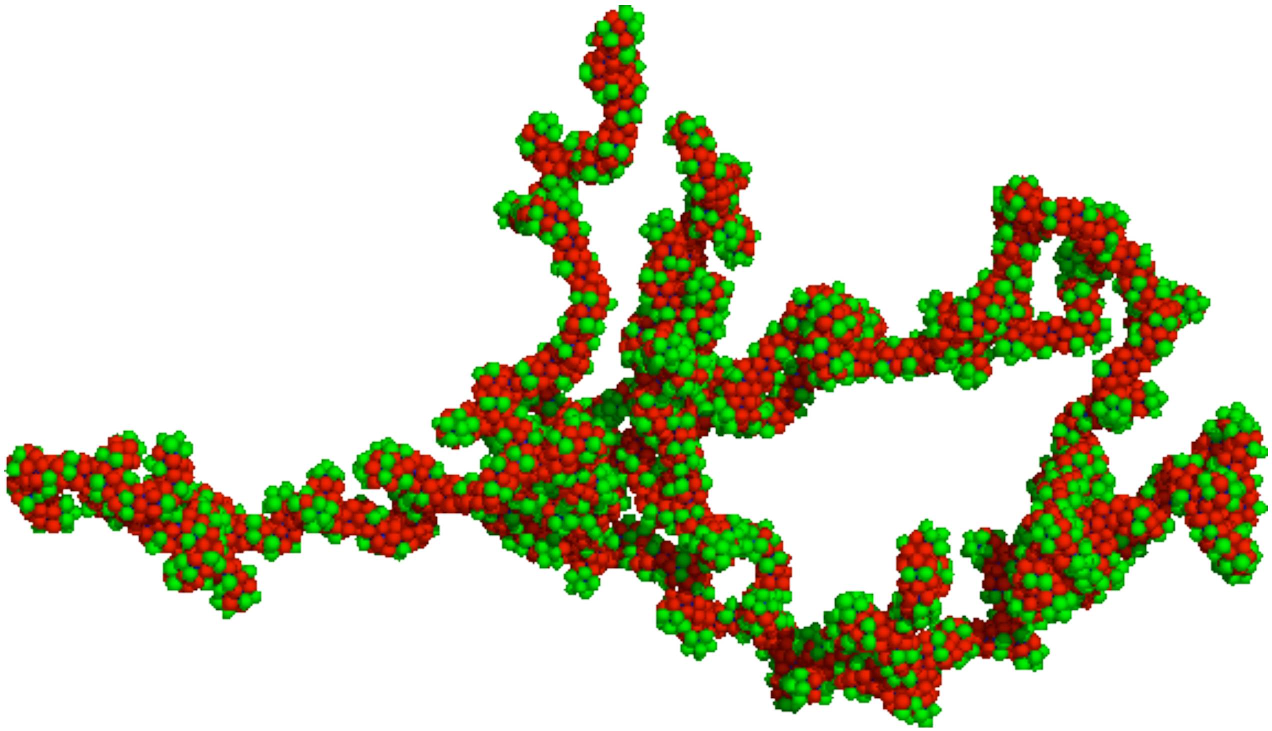
Constellation of Orion



Visible

Infrared

Astronomer's concept of a Dust Grain

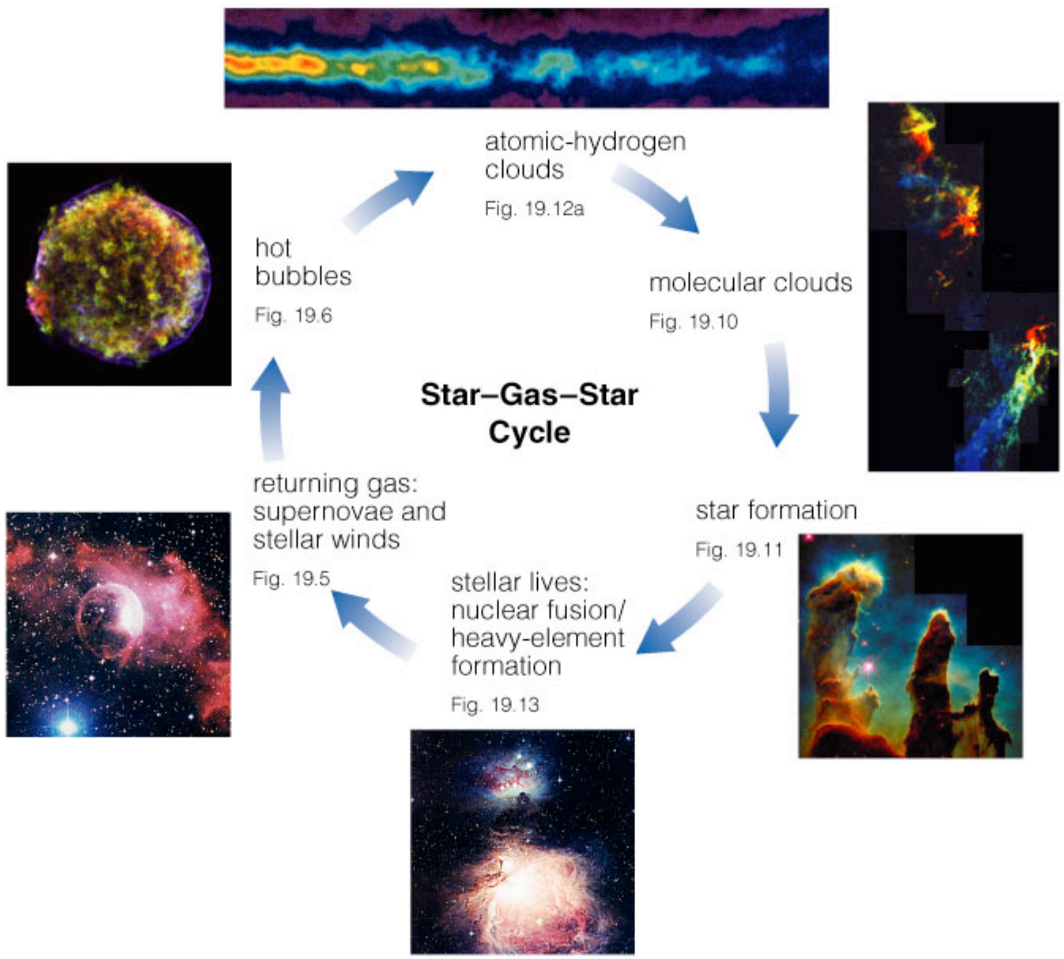


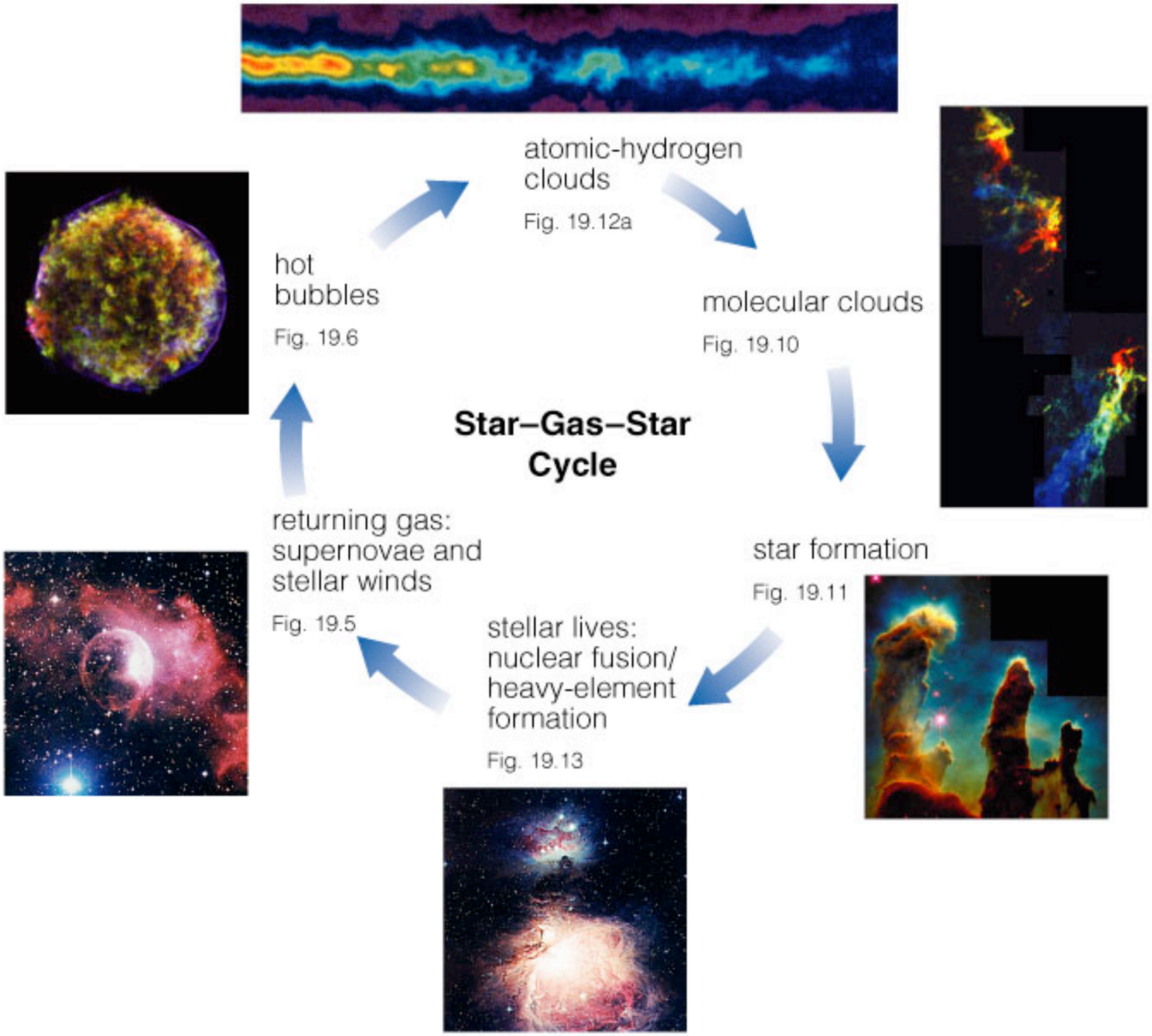
- Dust grains are about 0.1μm in size
- Are made of Carbon; Silicates (eg $MgSiO_3$)
- May have H_2O coatings

ISM Constituents

Principal Constituents of the ISM				
	Total Mass ($M_\odot$)	**"Cloud" Mass ($M_\odot$)**	**Density (cm^{-3})**	**Temperature (K)**
HI gas	~5 x 10^9		0.1-10	100-1000
H_2 gas	1-5 x 10^9	10^5-10^6	10^3-10^5	~10
Dust	~5 x 10^7			~40
HII gas		100-1000	10^3-10^4	10,000

Gas recycling in our Galaxy

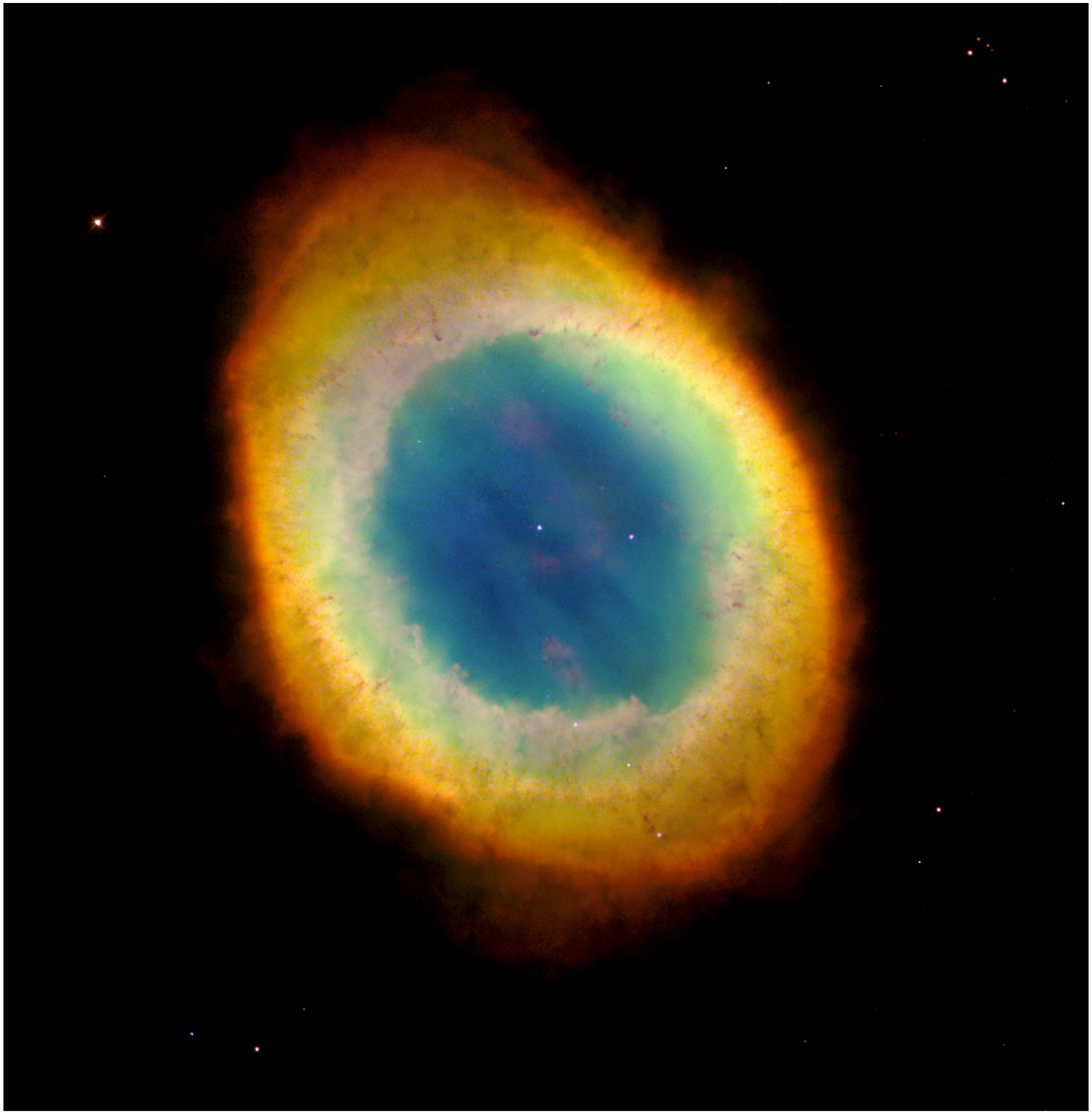




Star-gas-star cycle

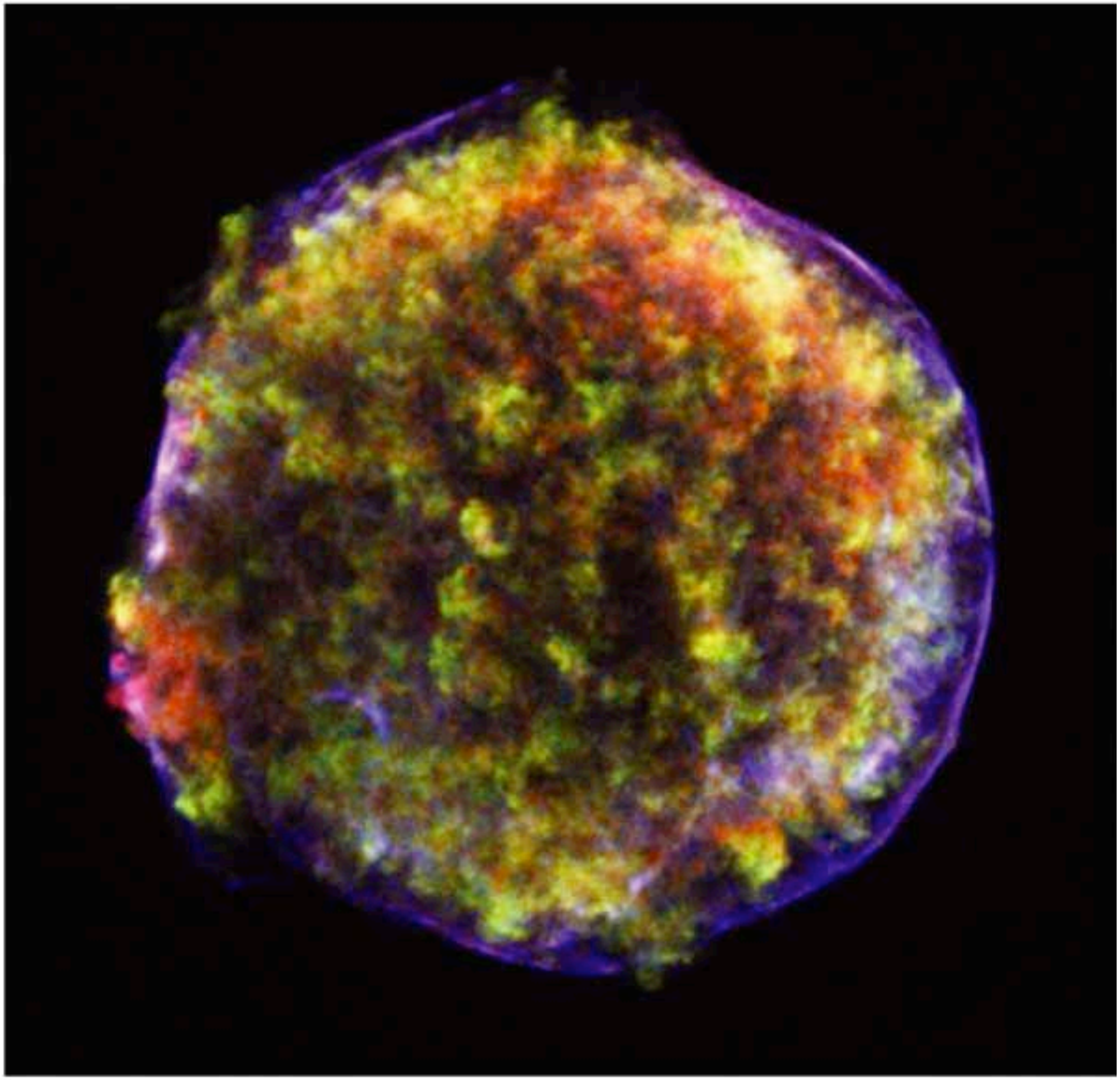
Recycles gas from old stars into new star systems

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

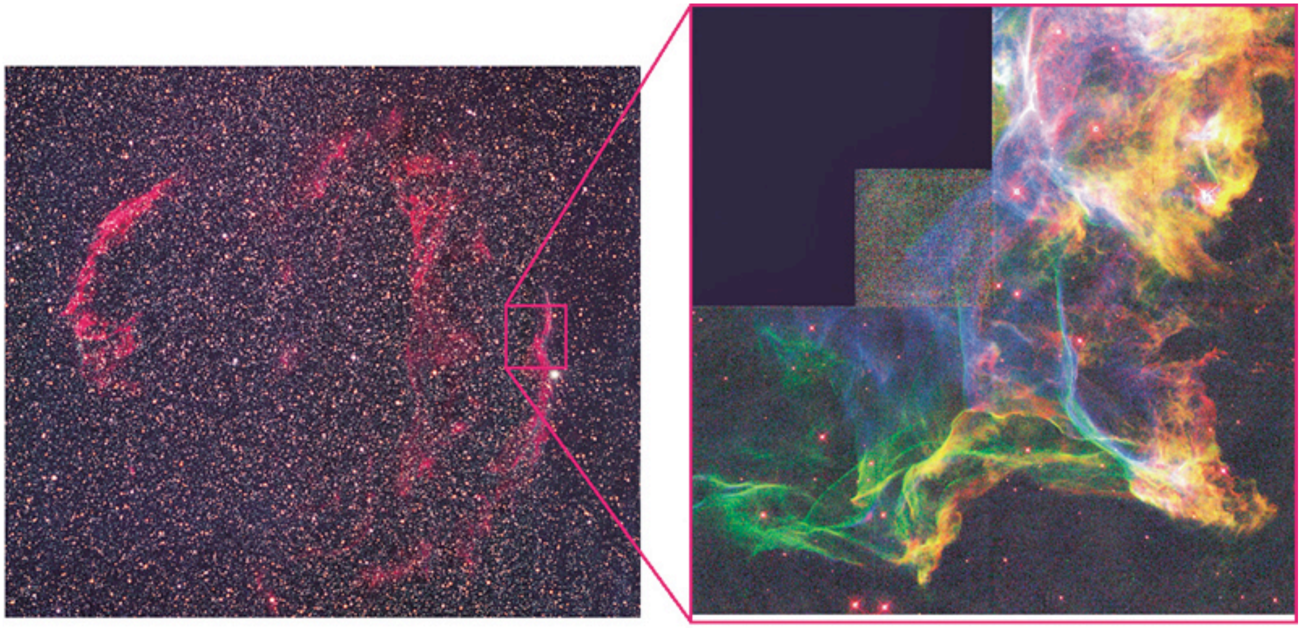


- Lower mass stars return gas to interstellar space through stellar winds and planetary nebulae

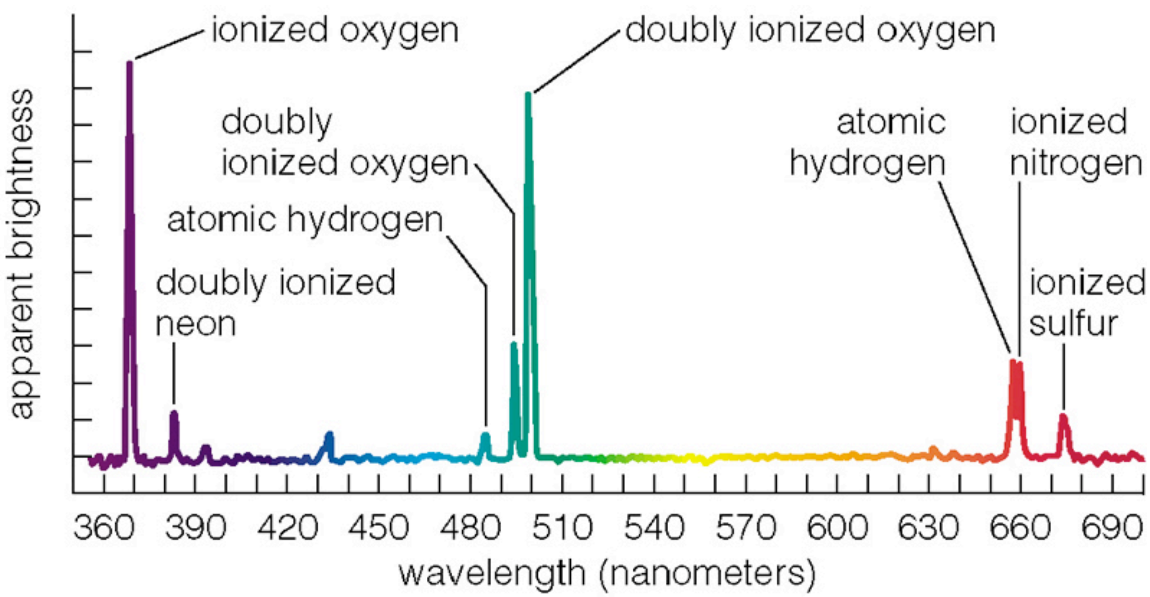
- Dust is produced in the cool atmospheres of red giants and pushed out into the ISM by radiation



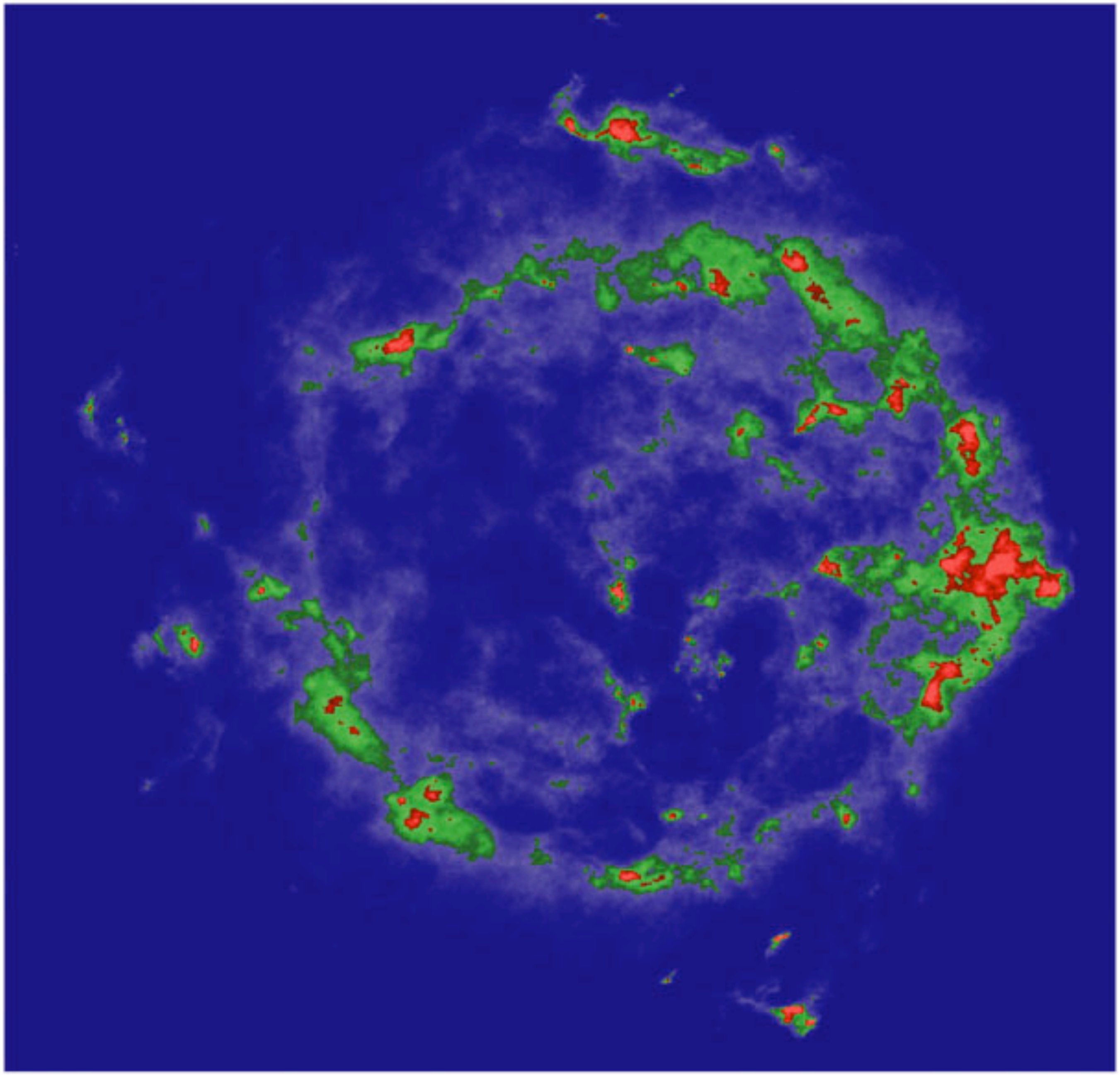
X-rays from hot gas in supernova remnants reveal newly-made heavy elements



Supernova remnant cools and begins to emit visible light as it expands

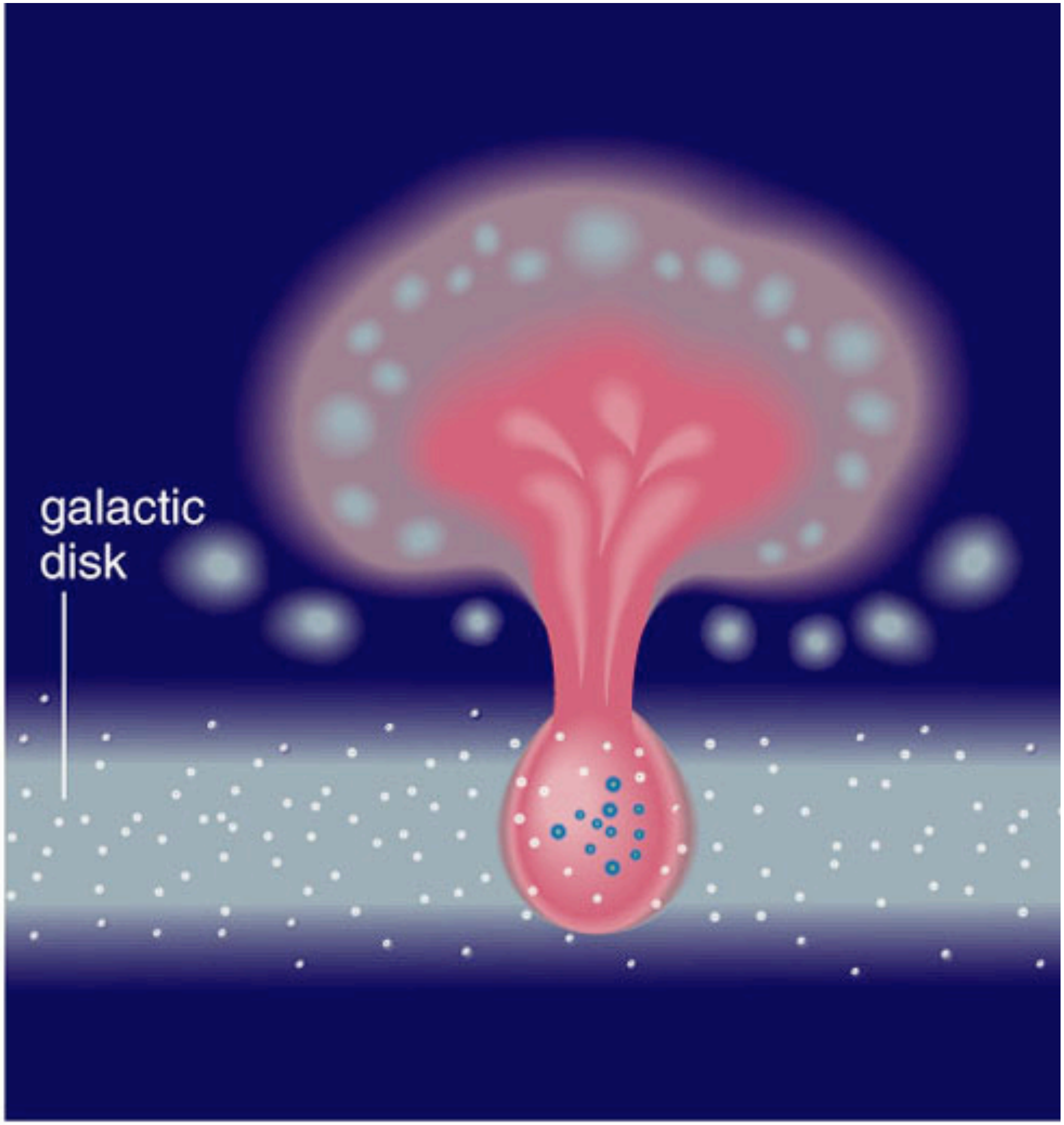


New elements made by supernova mix into interstellar medium



Radio emission in supernova remnants is from particles accelerated to near light speed

Cosmic rays probably come from supernovae

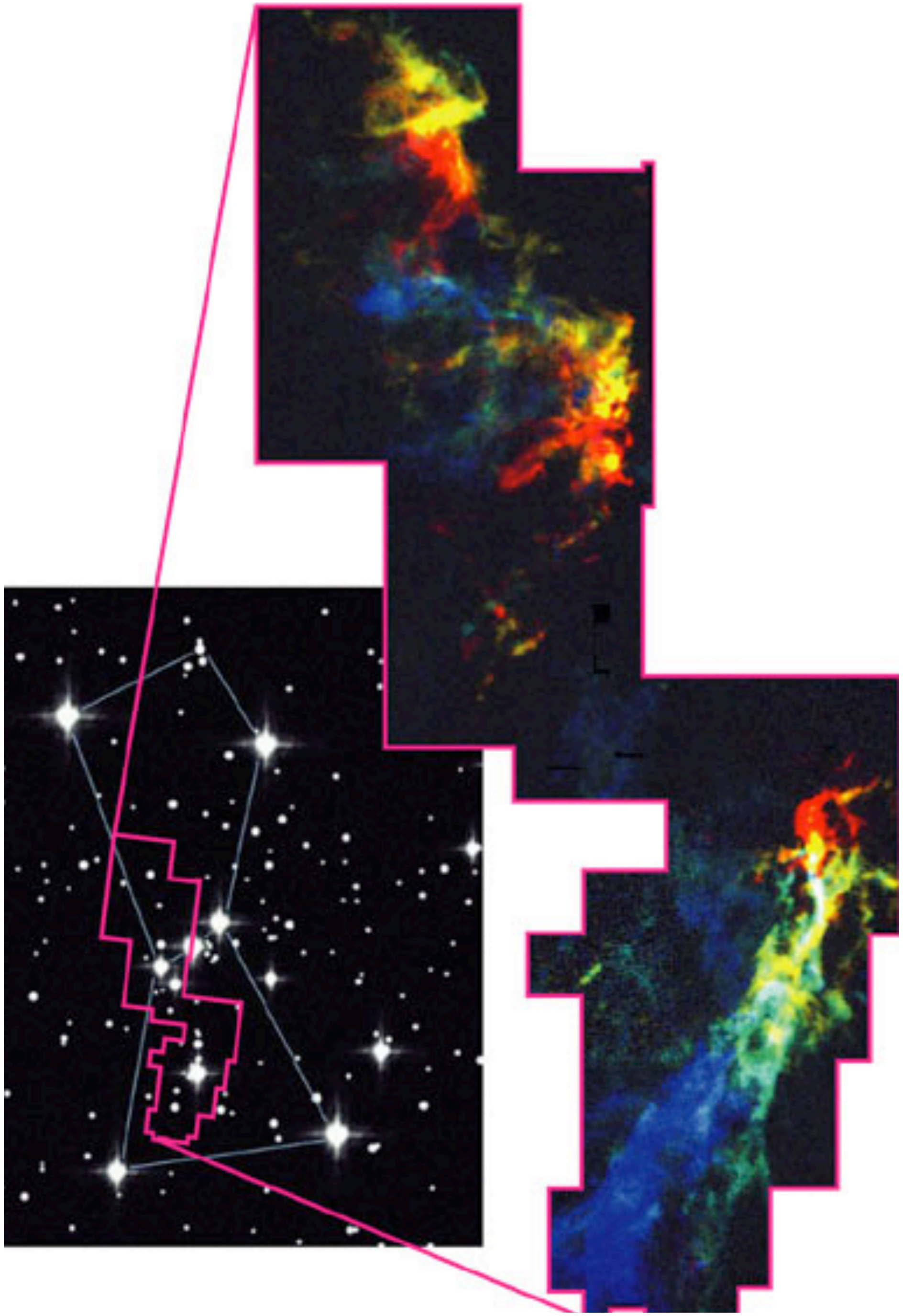


Multiple supernovae create huge hot bubbles that can blow out of disk

Gas clouds cooling in the halo can rain back down on disk

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

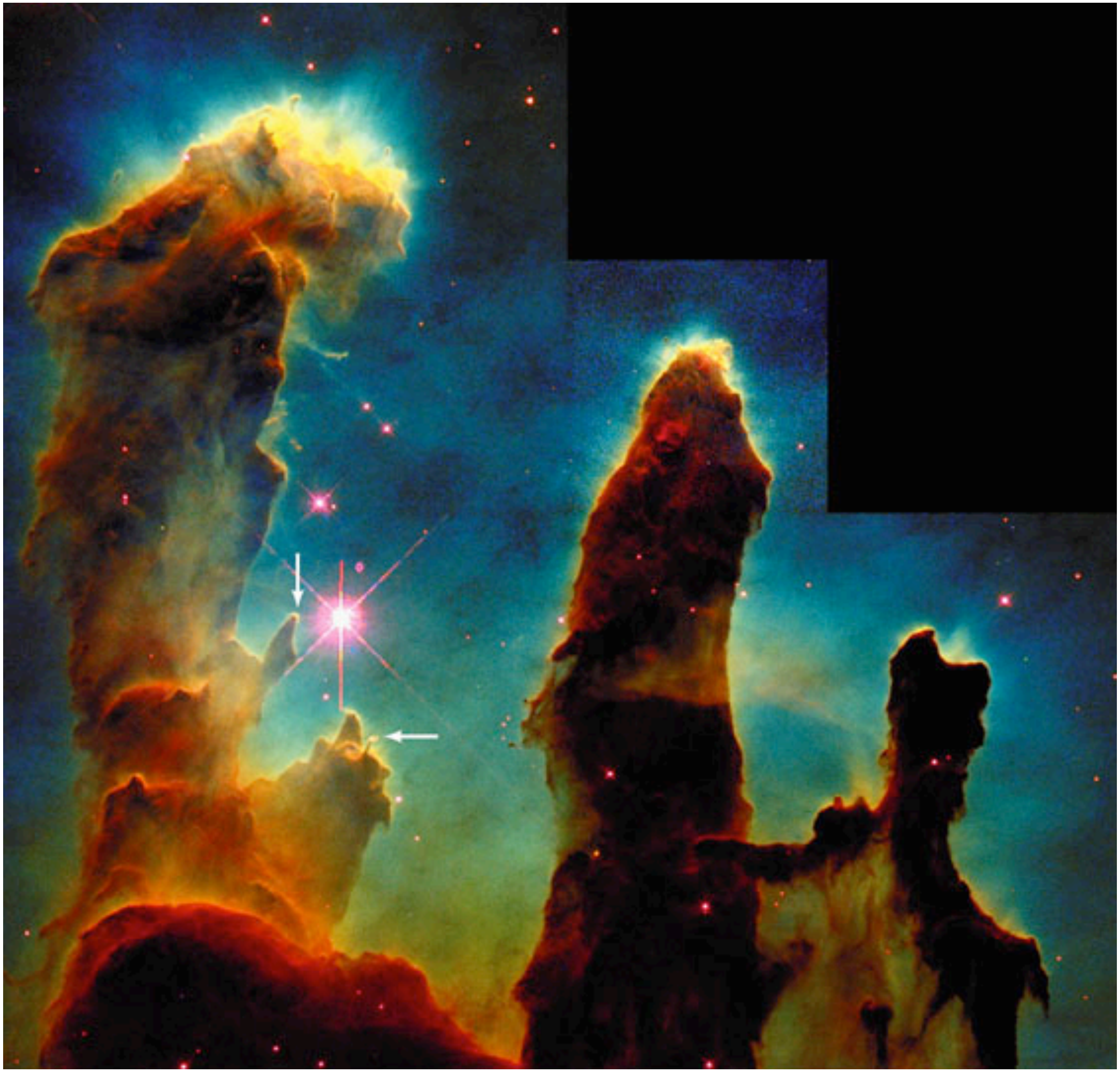
Molecular clouds form next, after gas cools enough to allow to atoms to combine into molecules



Molecular clouds in Orion

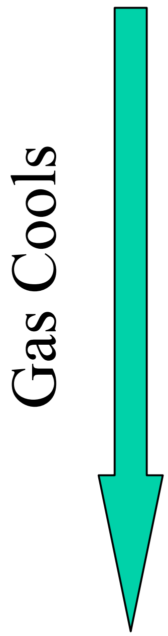
Composition:

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

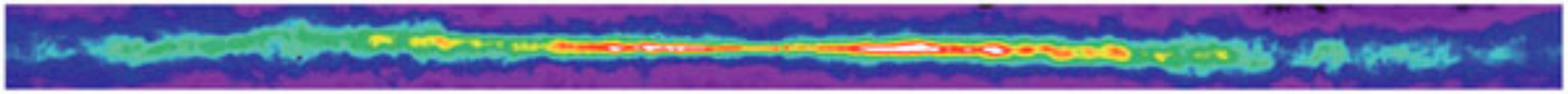


- Gravity forms stars out of the gas in molecular clouds, completing the star-gas-star cycle
- Radiation from newly formed stars is eroding these star-forming clouds

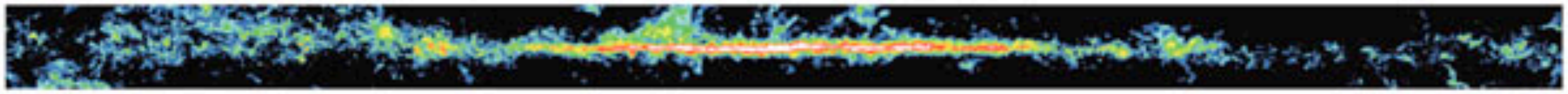
Summary of Galactic Recycling



- Stars make new elements by fusion
- Hot stars expel gas and new elements, producing hot bubbles (~10^6 K)
- Dust forms in the "cool" atmospheres of Red Giants and is pushed out into the ISM by radiation pressure
- Hot gas cools, allowing atomic hydrogen clouds to form (~100K)
- Further cooling permits molecules to form on dust grains, making molecular clouds (~30 K)
- Gravity forms new stars (and planets) in molecular clouds



a 21-cm radio emission from atomic hydrogen gas.



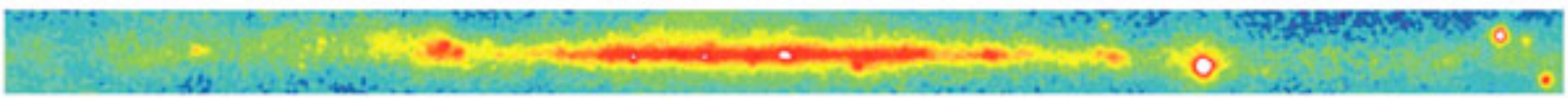
b Radio emission from carbon monoxide reveals molecular clouds.

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

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

e Visible light emitted by stars 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.

Interactive Figure

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

Infrared

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

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

Visible

Infrared light reveals stars whose visible light is blocked by gas clouds

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

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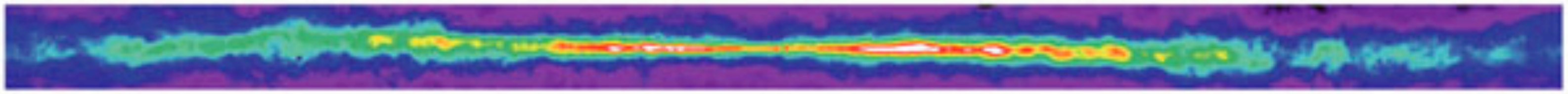
X-rays

X-rays are observed from hot gas above and below the Milky Way's disk



a 21-cm radio emission from atomic hydrogen gas.

Radio (21cm)

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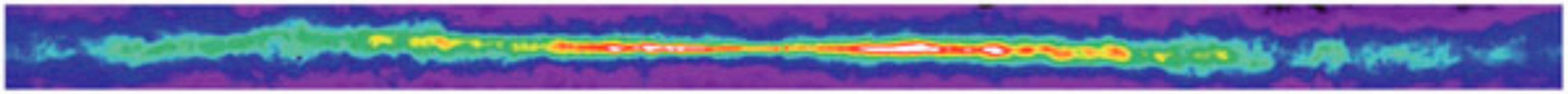
21-cm radio waves emitted by atomic hydrogen show where gas has cooled and settled into disk



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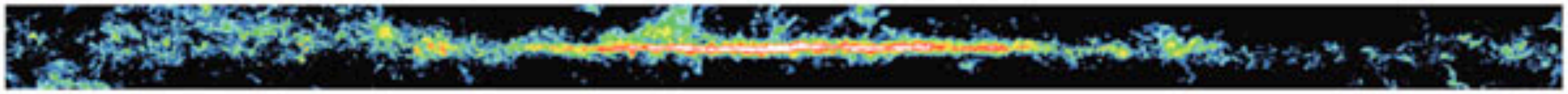

b Radio emission from carbon monoxide reveals molecular clouds.

Radio (CO)

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

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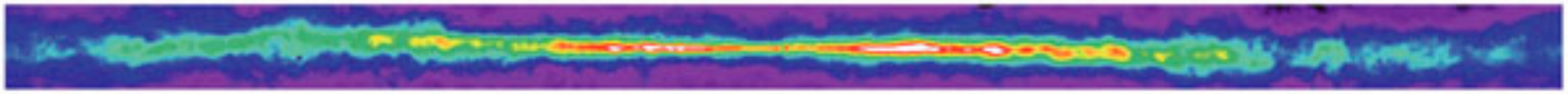
Radio waves from carbon monoxide (CO) show locations of molecular clouds



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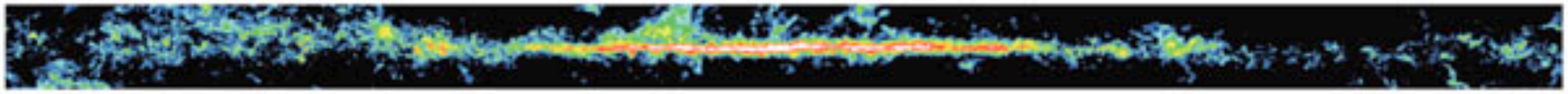

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IR (dust)

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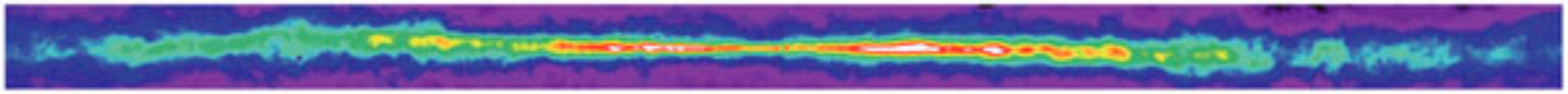
Long-wavelength infrared emission shows where young stars are heating dust grains



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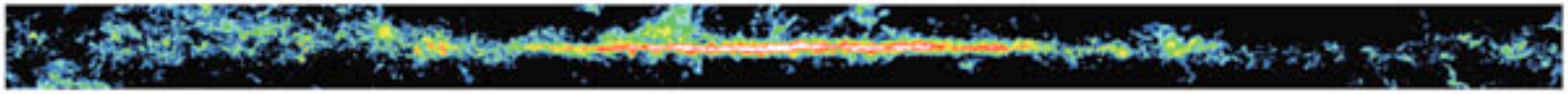

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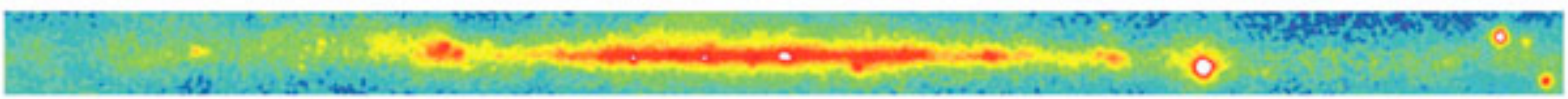
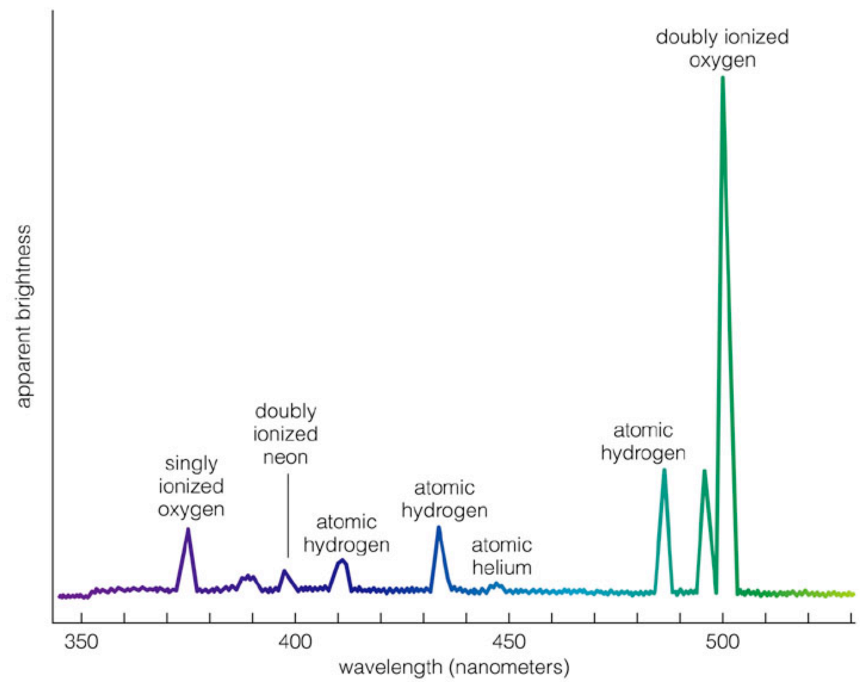


g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

Gamma rays show where cosmic rays from supernovae collide with atomic nuclei in gas clouds

Where do stars tend to form in our galaxy?

Ionization nebulae are found around short-lived high-mass stars, signifying active star formation



Reflection nebulae scatter the light from stars

Why do reflection nebulae look bluer than the nearby stars?

Reflection nebulae scatter the light from stars

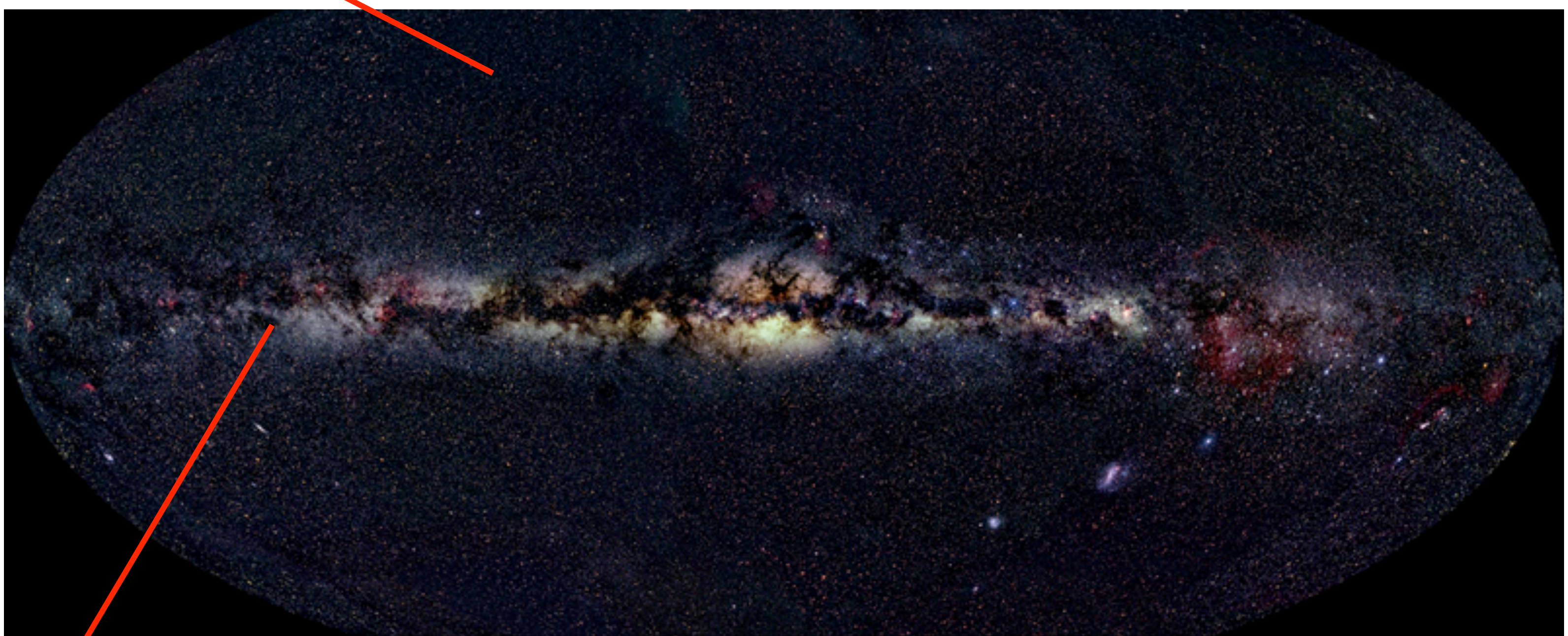
Why do reflection nebulae look bluer than the nearby stars?

For the same reason that our sky is blue!

What kinds of nebulae do you see?

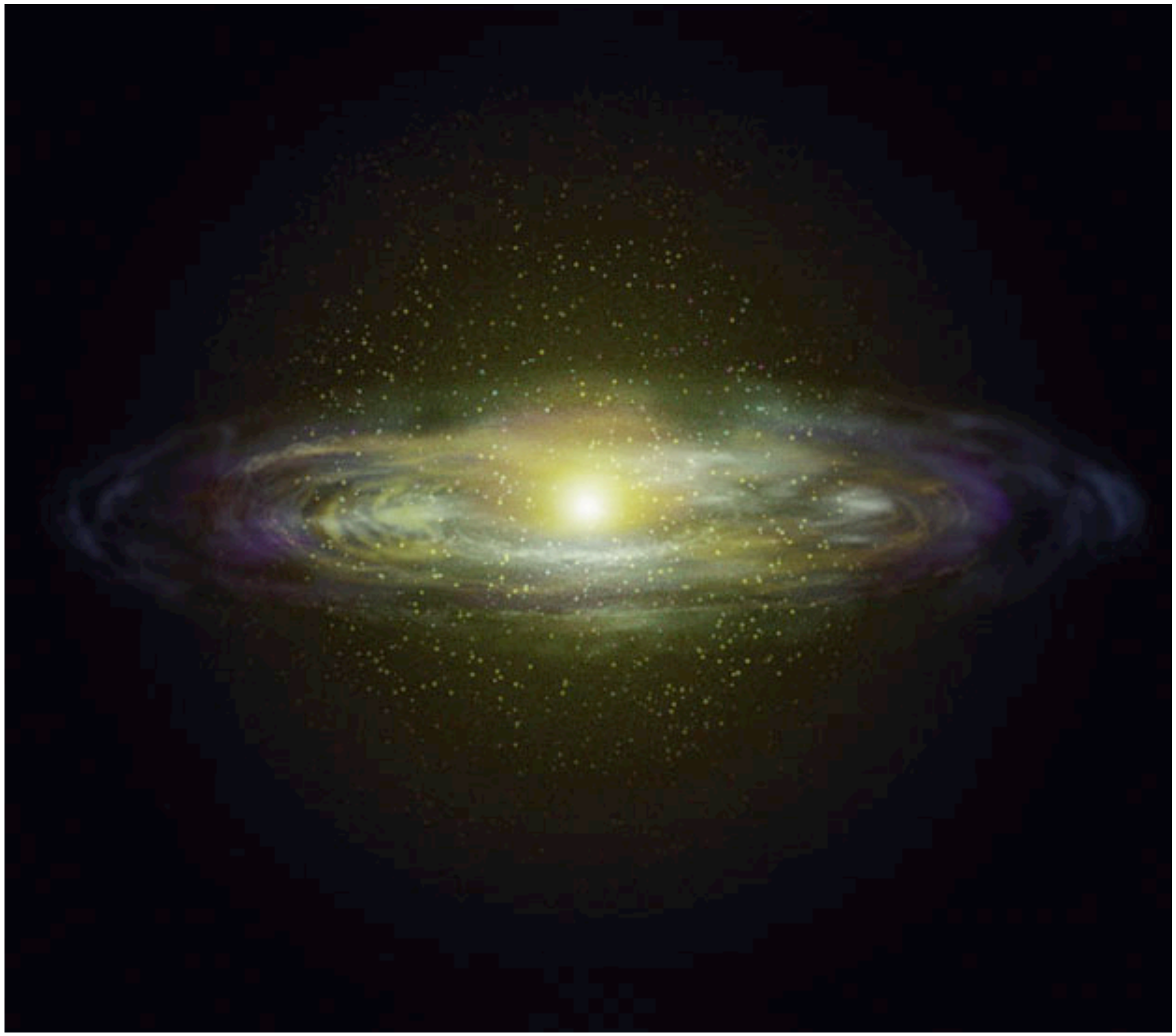
Halo: No ionization nebulae, no blue stars

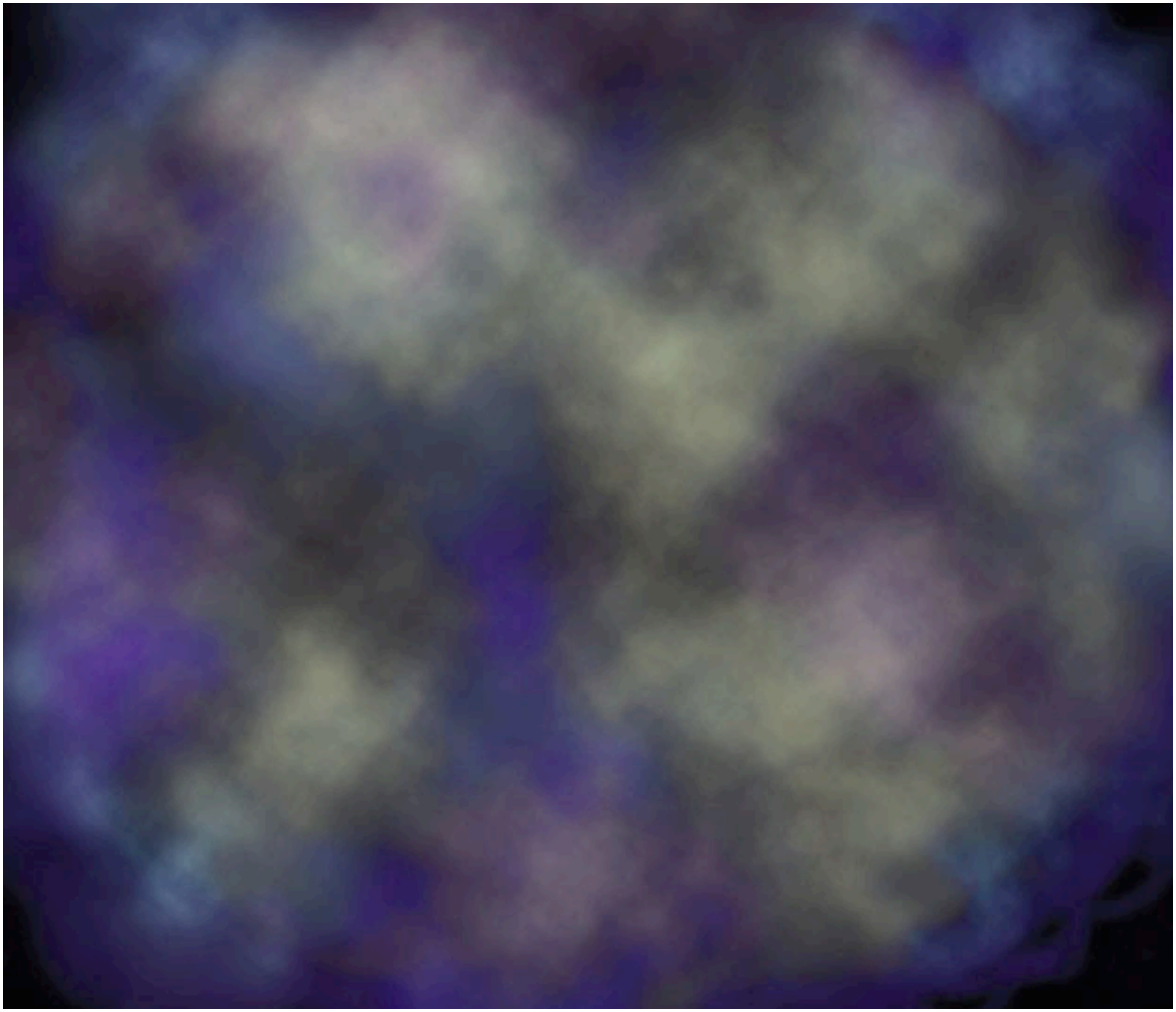
$\Rightarrow$ no star formation



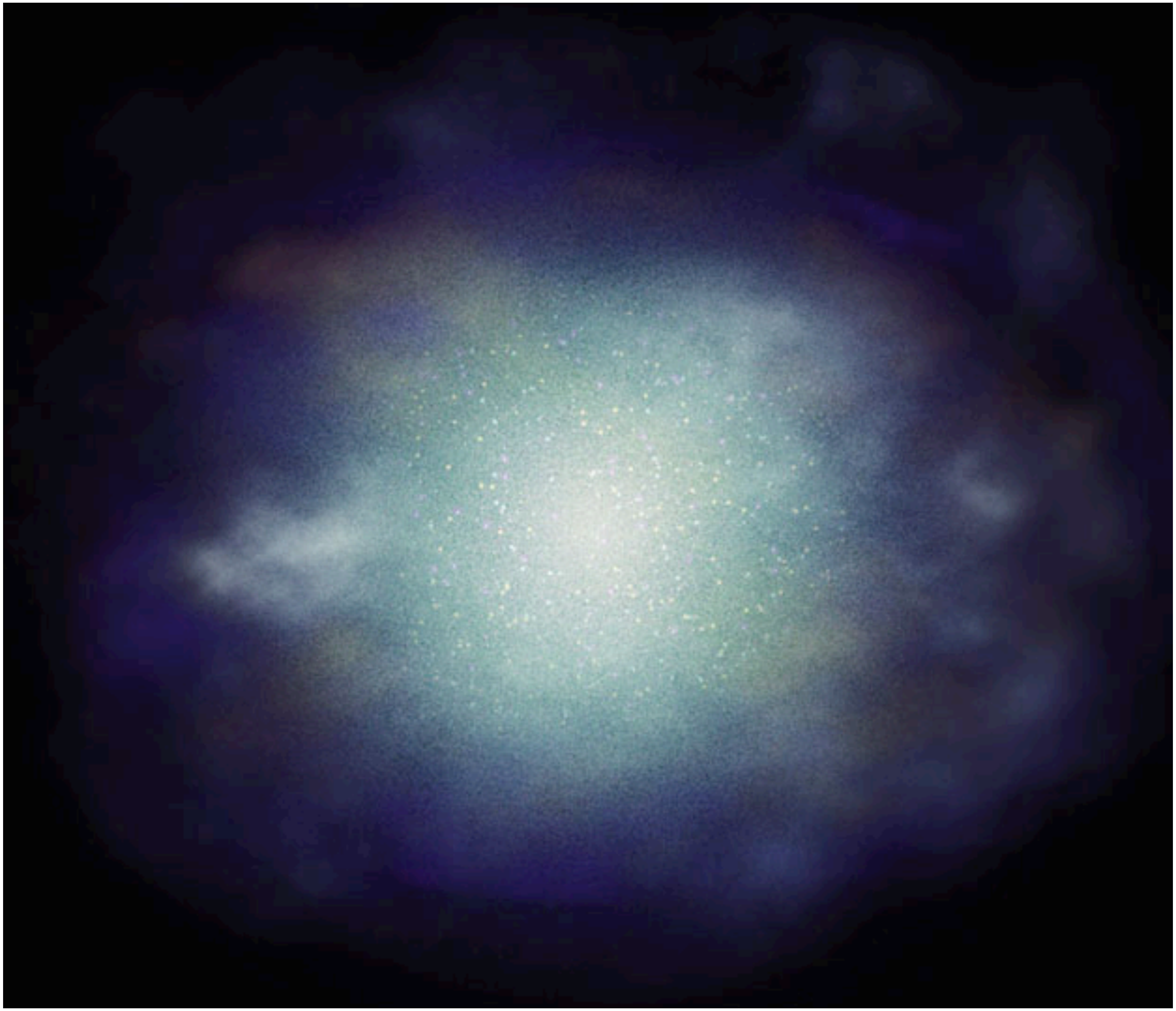
Disk: Ionization nebulae, blue stars $\Rightarrow$ star formation

How did our galaxy form?

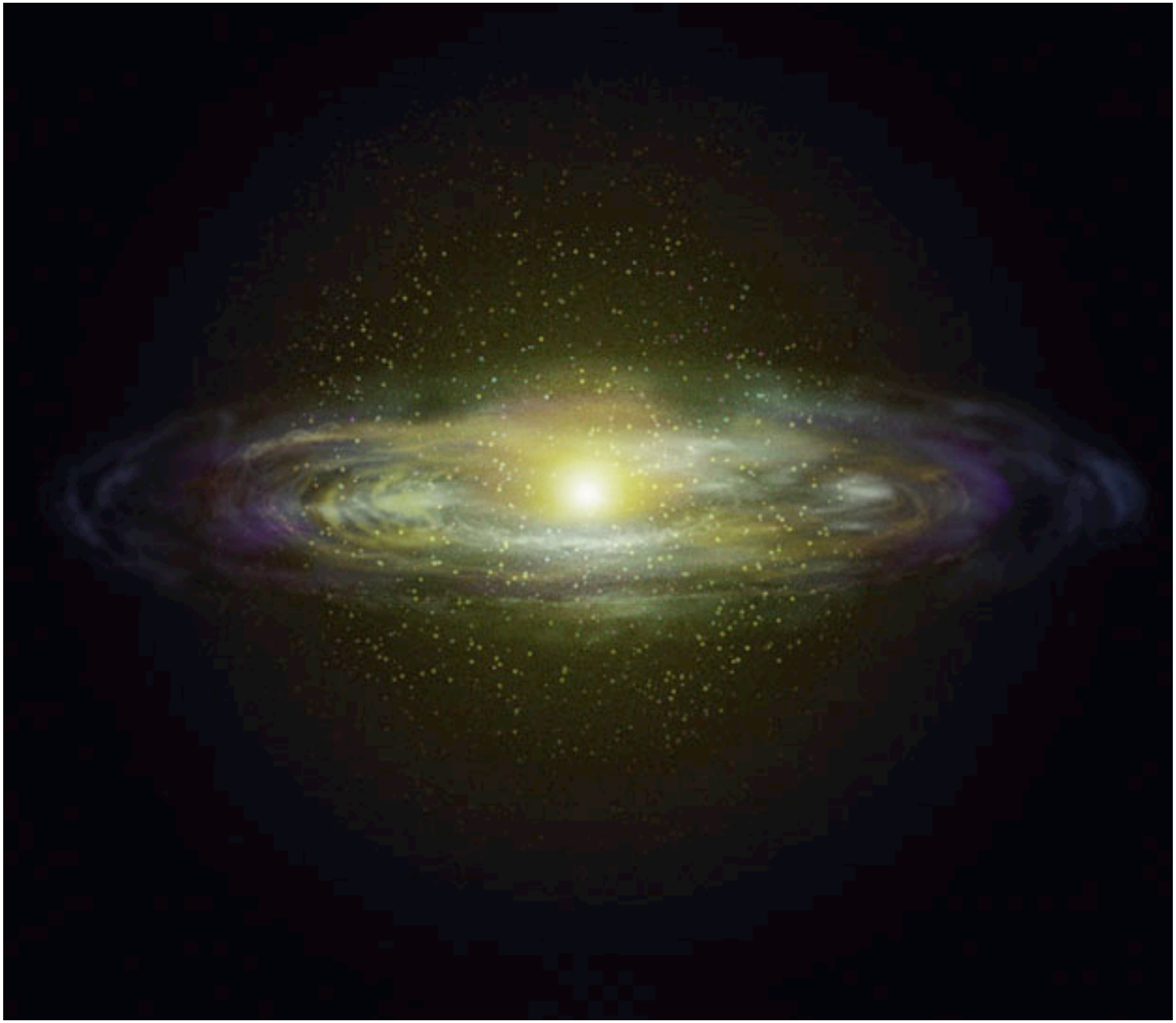




Our galaxy probably formed from a giant gas cloud



Halo stars formed first as gravity caused cloud to contract

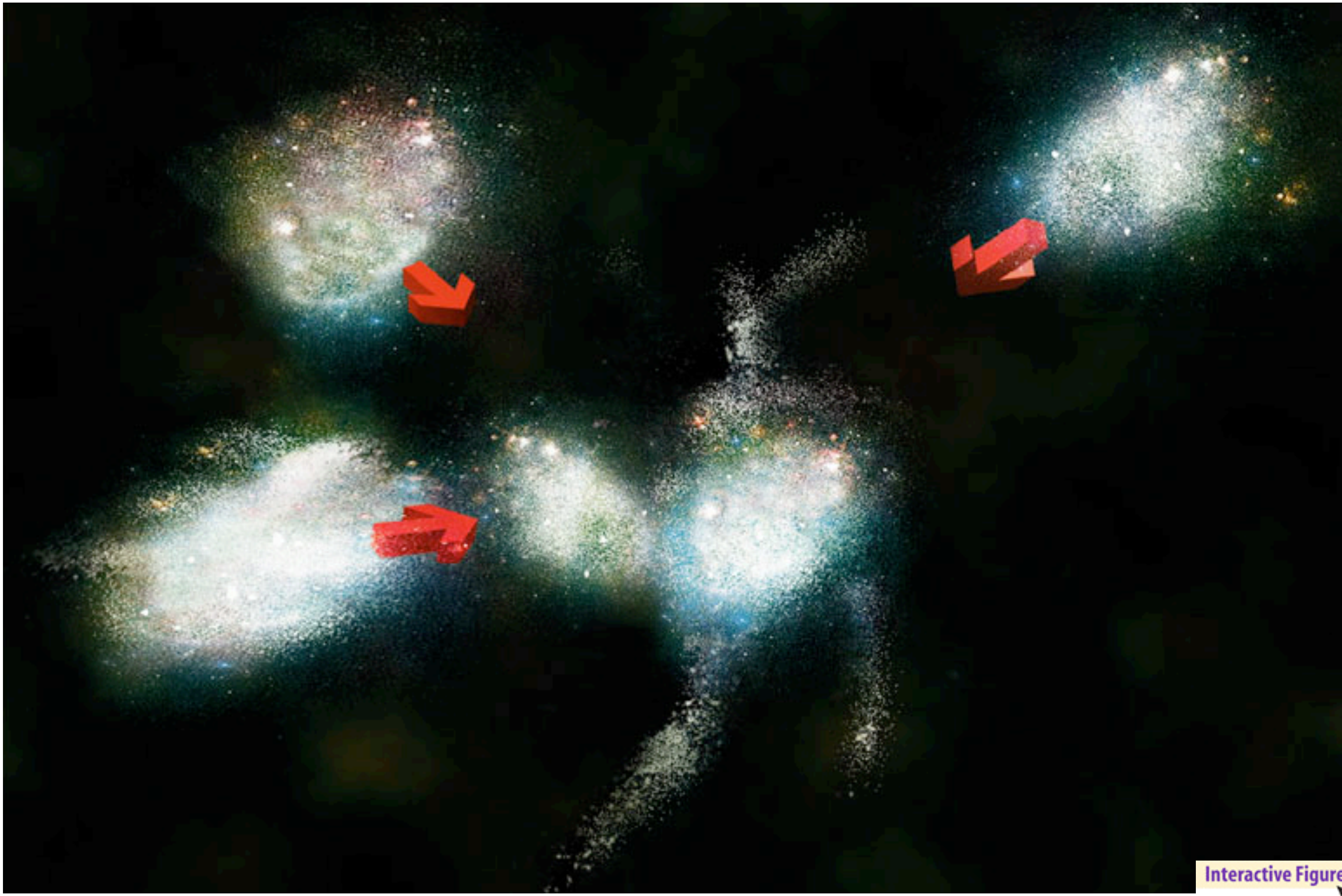


Remaining gas settled into spinning disk

Stars continuously form in disk as galaxy grows older

Warning: This model is oversimplified

Stars continuously form in disk as galaxy grows older



Detailed studies: Halo stars formed in clumps that later merged