The Interstellar Medium

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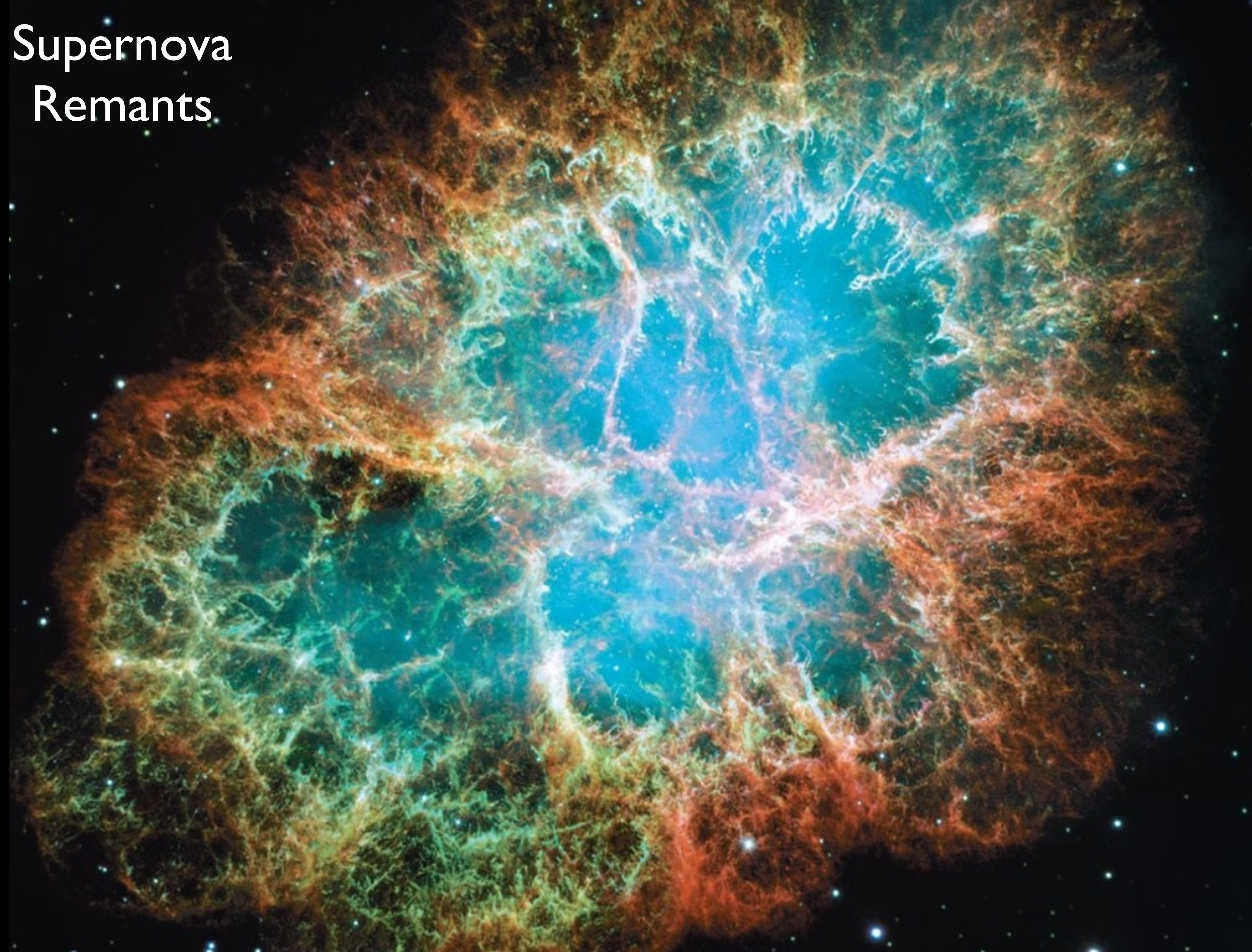
Learning Goals

- What is between the stars?
  - ISM = Interstellar Medium
- Why is a bunch of gas and dust important?
- What stuff makes the prettiest pictures in astronomy?
  - Actually, pretty much all pictures that aren't of stars...


What do we see
in the ISM?
Hot gas
Cold dust

Supernova Remants

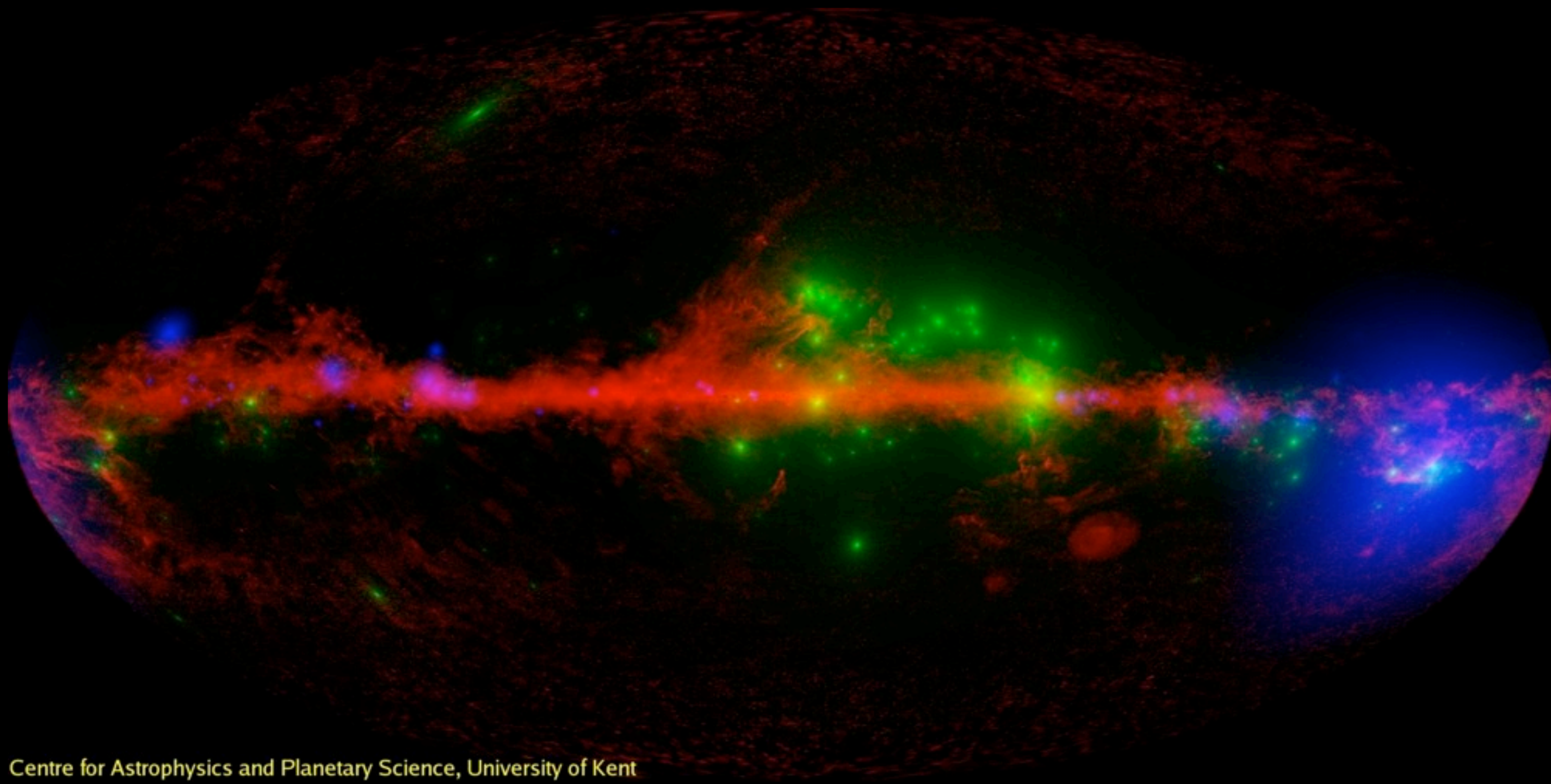


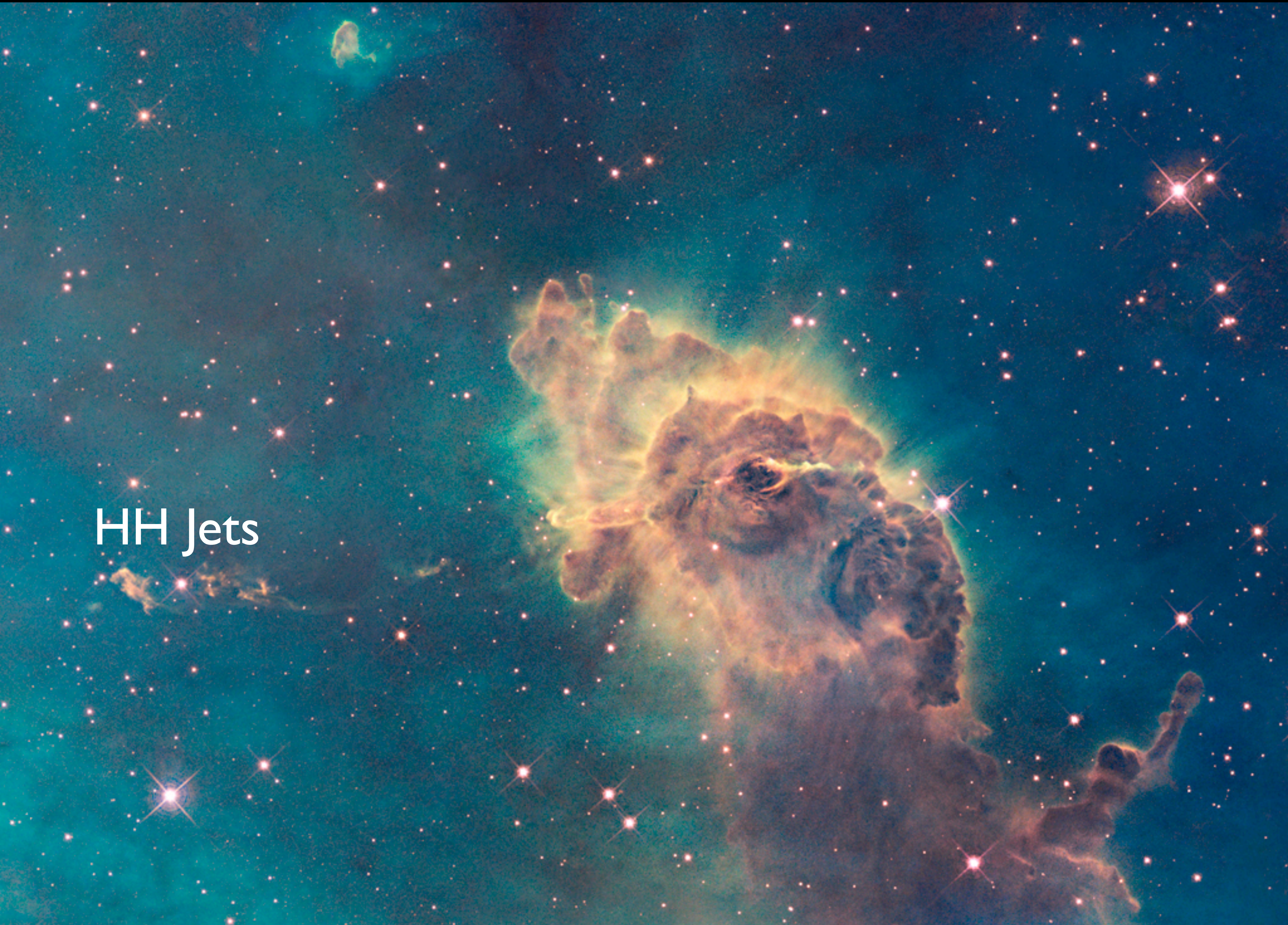
Planetary Nebulae

Novae

Spiral Arms in Galaxies

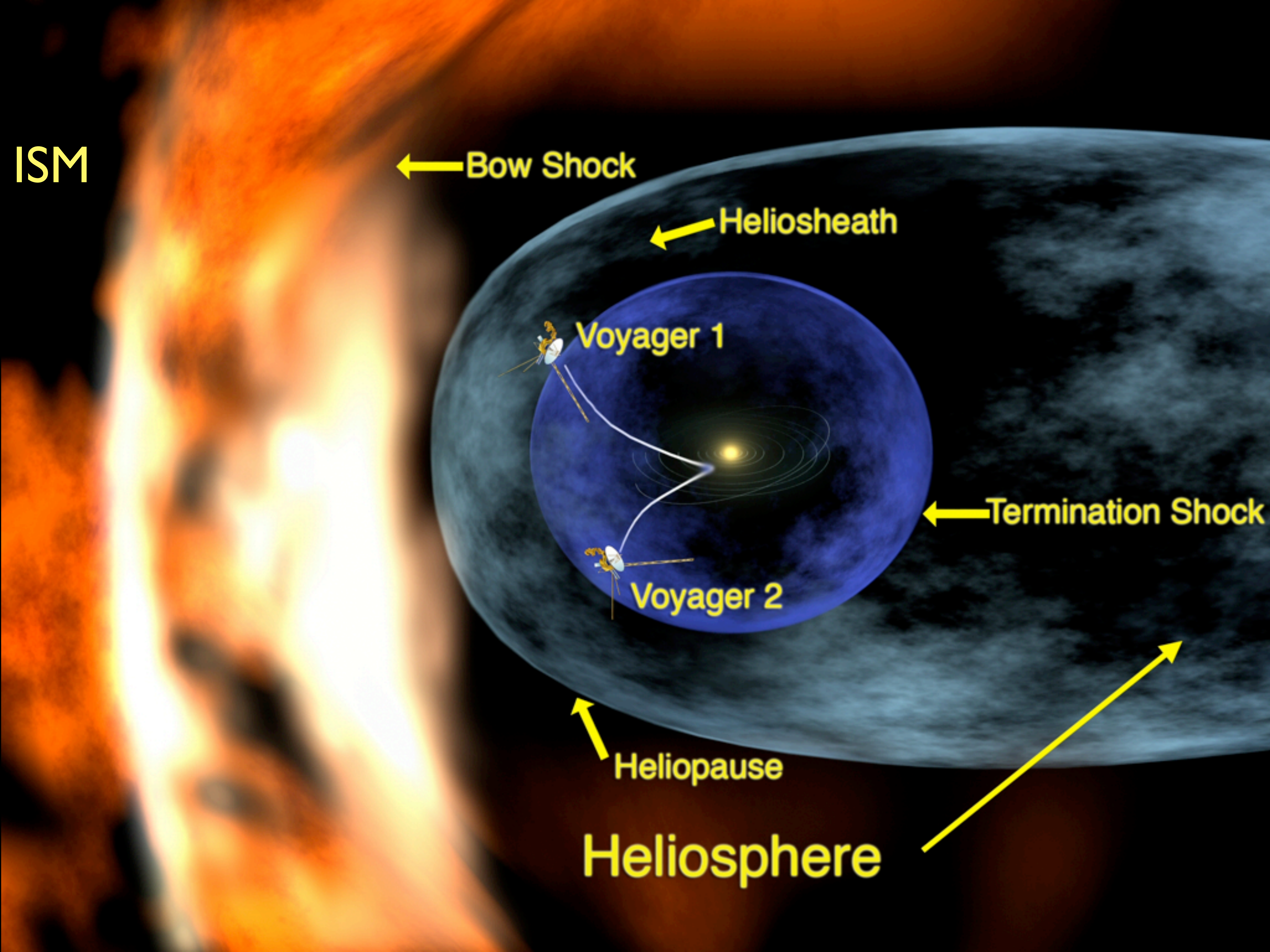
And in our own




HH Jets

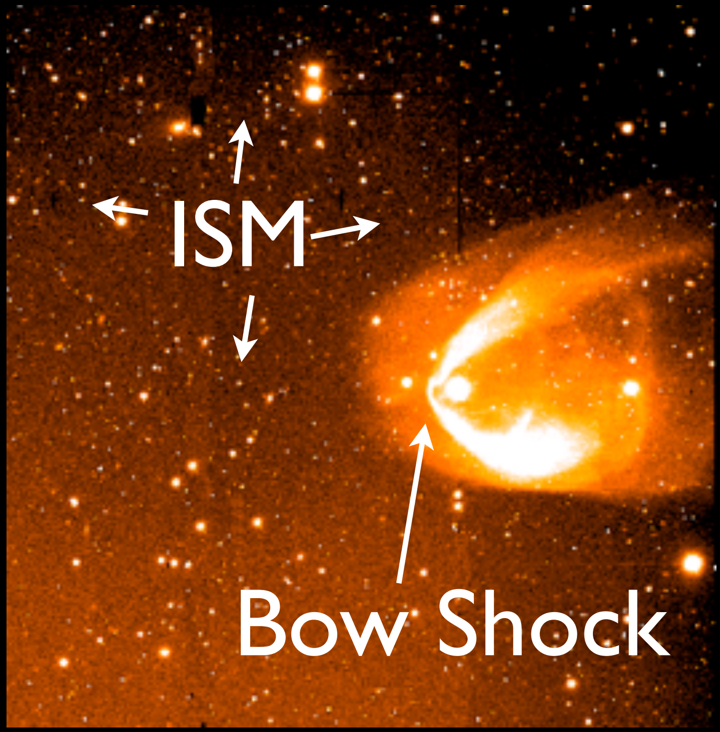
Outline

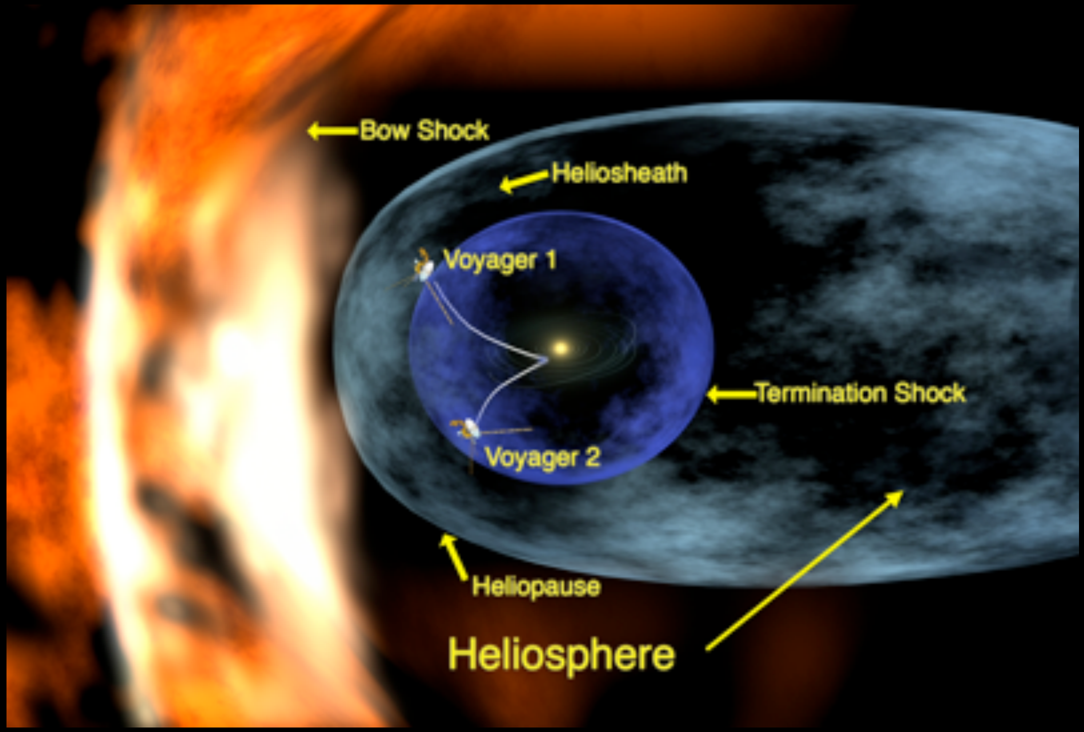
- Where is the ISM?
- What physical laws are important in the ISM?
- Where does it come from?
- How do we know it's there?
- Throughout, we'll cover: Why is it important? What does it do?


ISM
Bow Shock
Heliosheath
Voyager 1
Termination Shock
Voyager 2
Heliopause
Heliosphere

Where is the ISM?

- Interstellar = Between the Stars
- It is all the stuff that is not stars, planets, or dark matter in our galaxy
- It starts immediately outside our solar system





Physics in the ISM

- Gravity
  - As we know, all masses gravitationally attract all other masses
- Gas Pressure
  - Pressure ∝ Density x Temperature
  - $P \propto \rho T$

Pressure

- If you heat up a gas, what happens to it?

A) it gets more massive

B) it contracts

C) it expands

D) it ignites fusion

E) not a clue

Pressure

- If you increase the pressure in a bubble, it will expand to balance outside pressure
  - The pressure on the inside and outside of the balloons is equal
  - If you squeeze a balloon, the pressure inside goes up

Pressure in the ISM

- In the ISM, pressure is approximately the same everywhere
- $P \propto \rho\, T$
- That means if the density is higher, the temperature is lower

Photo credit: T. A. Rector/University of Alaska Anchorage, H. Schweiker/WIYN and NOAO/AURA/NSF

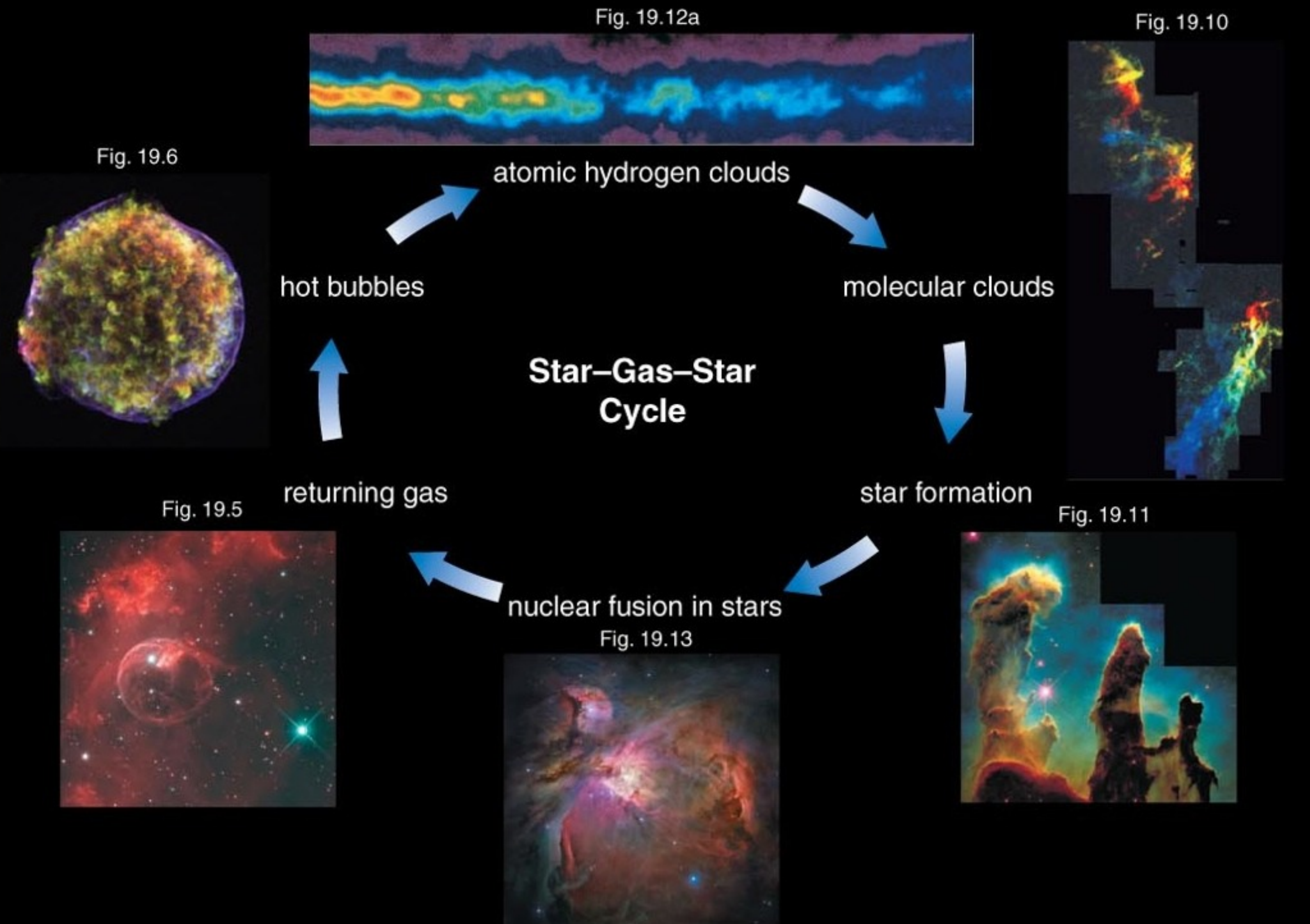
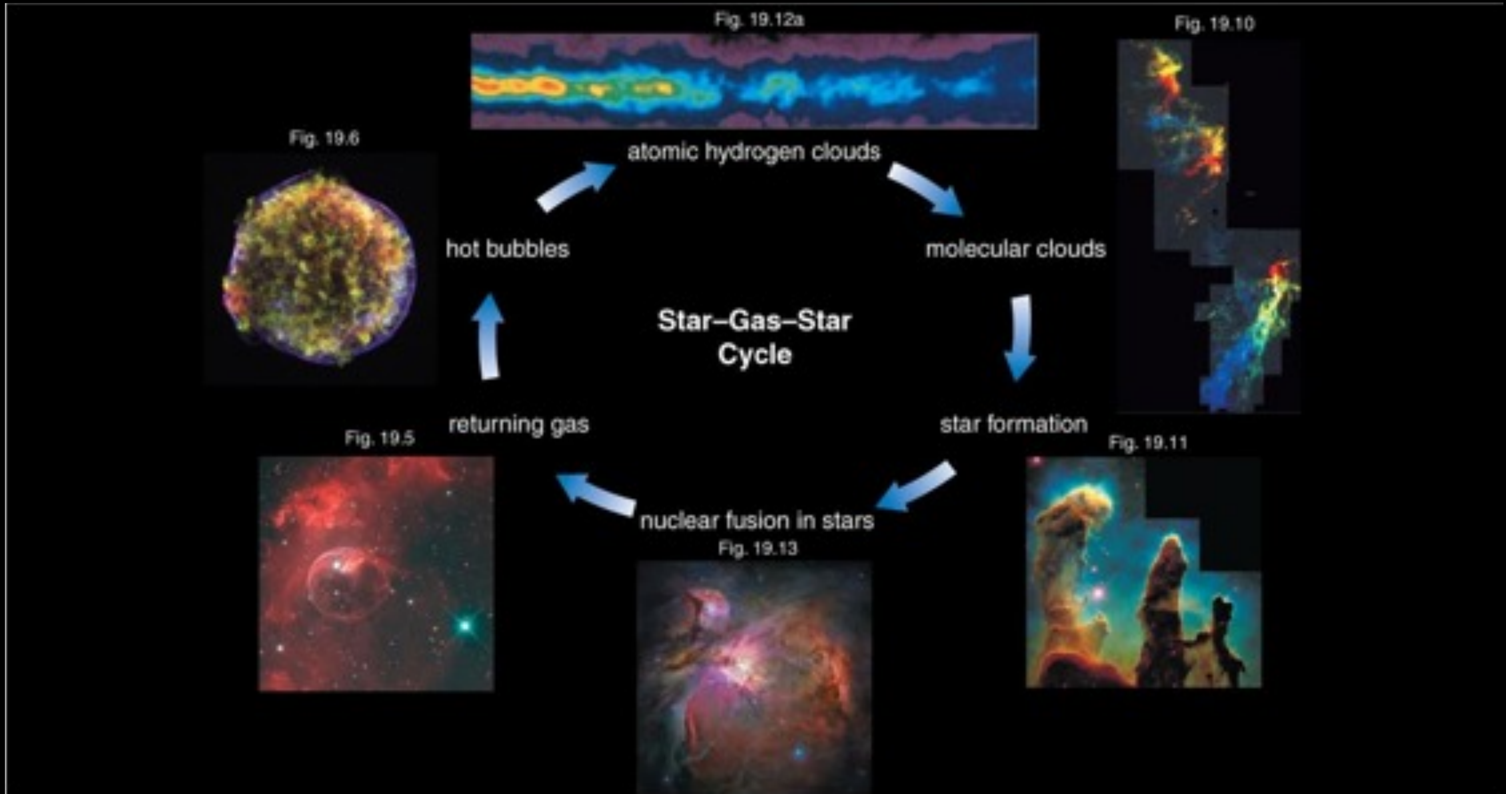


Fig. 19.12a
atomic hydrogen clouds
Fig. 19.10
molecular clouds
star formation
Fig. 19.11
nuclear fusion in stars
Fig. 19.13
returning gas
Fig. 19.5
hot bubbles
Fig. 19.6
Star–Gas–Star
Cycle

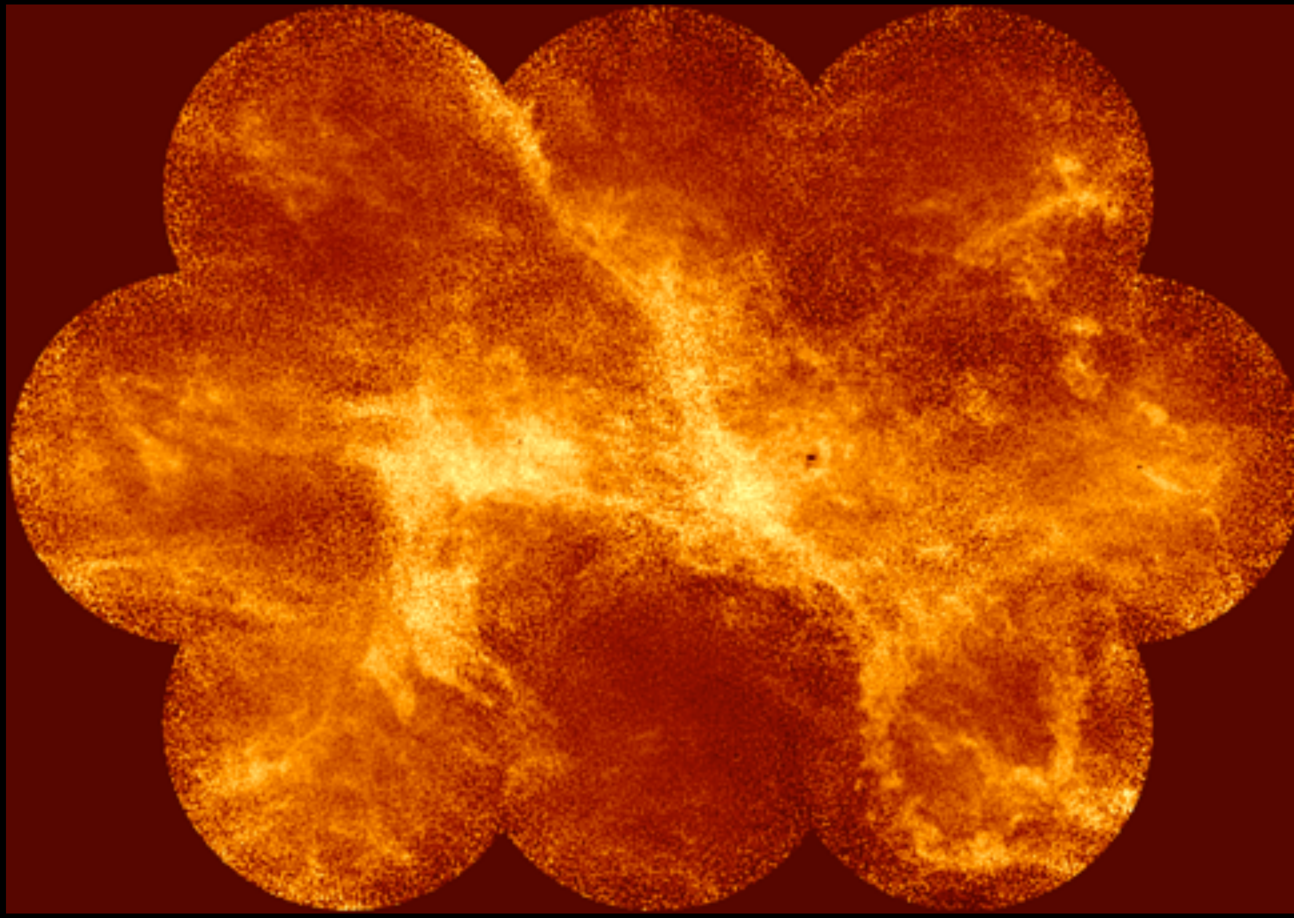
Recycling

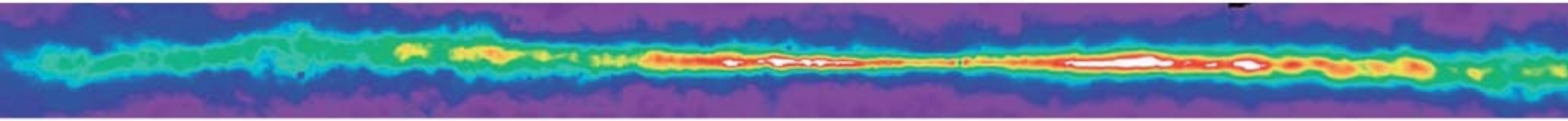
- The material in the interstellar medium goes through a cycle
  - Stars form from gas and dust
  - Stars live for a while
  - Then they die and give back some or all of that material



1. Warm, diffuse, atomic gas

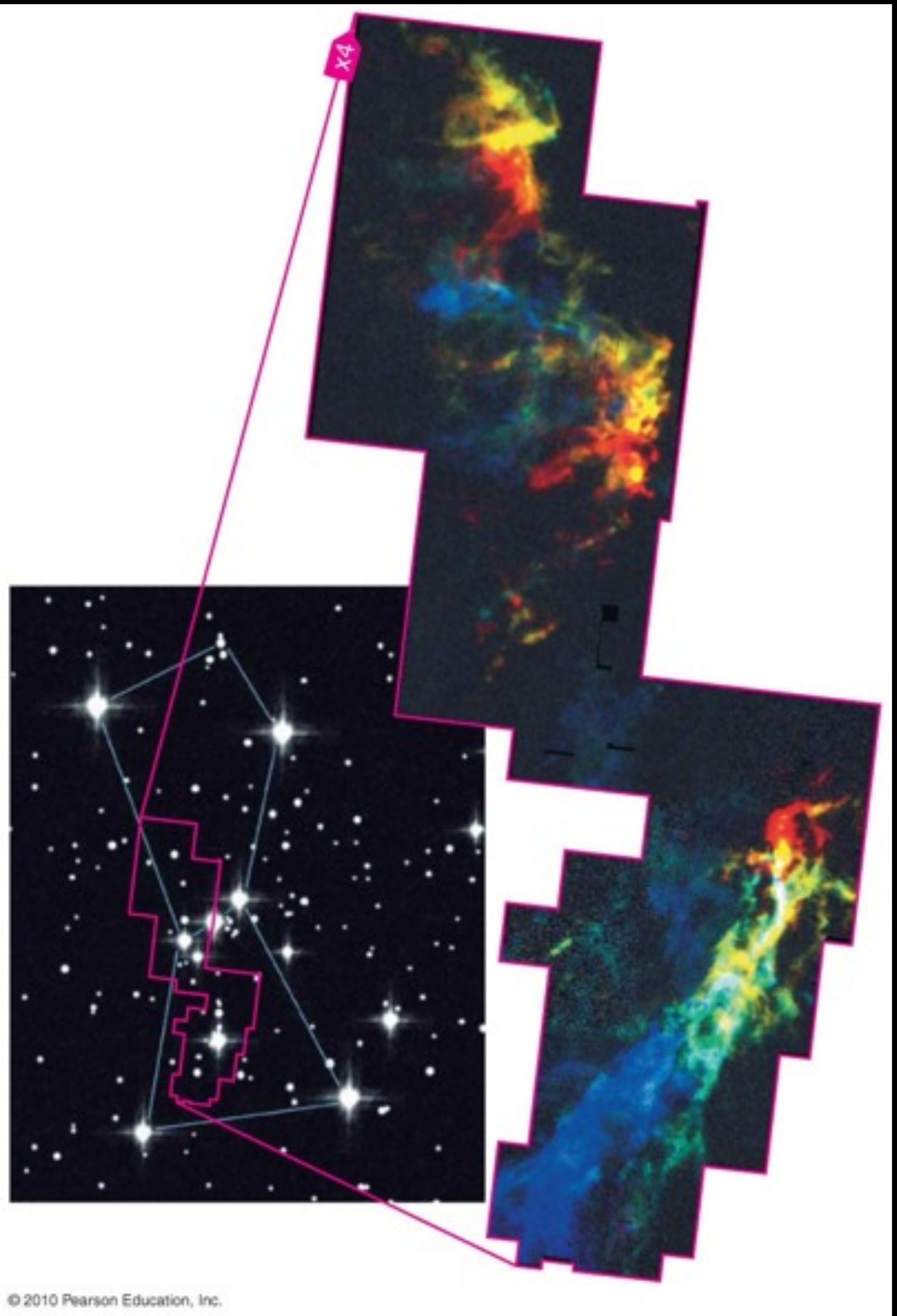
- About half of the gas by mass
- about 6,000-10,000 degrees, low densities
- Diffuse stuff that moves and changes very slowly



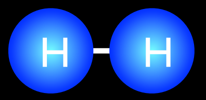


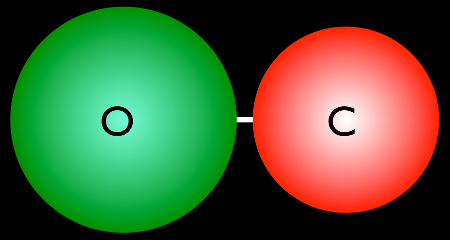
a 21-centimeter radio emission from atomic hydrogen gas.

2. Molecular Cloud

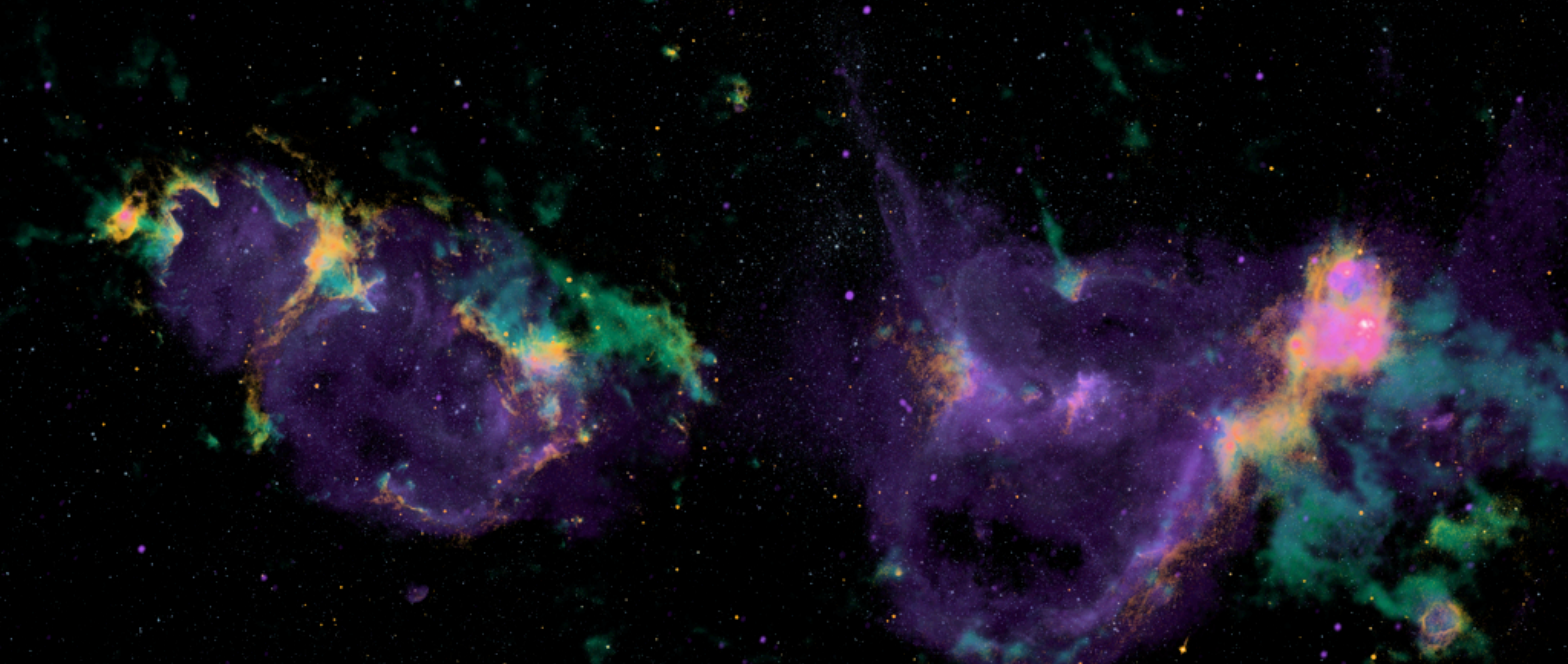


- Cold (10K), high-density
- About half of the mass of the ISM
- Why molecular?
  - Mostly made of H_2 molecules
  - Other molecules form: we see CO
  - Molecules only survive in cold (less than about 100 K) gas; radiation and collisions break them apart elsewhere





Aside



- I work on molecular clouds! And star-forming regions!

3. Star Formation

- Molecular Clouds collapse under gravity to form protostars
  - Lecture 8 (Monday) covered star formation
- Densities get very high, but temperatures stay cool: gravity dominates over gas pressure

4. Stars have formed

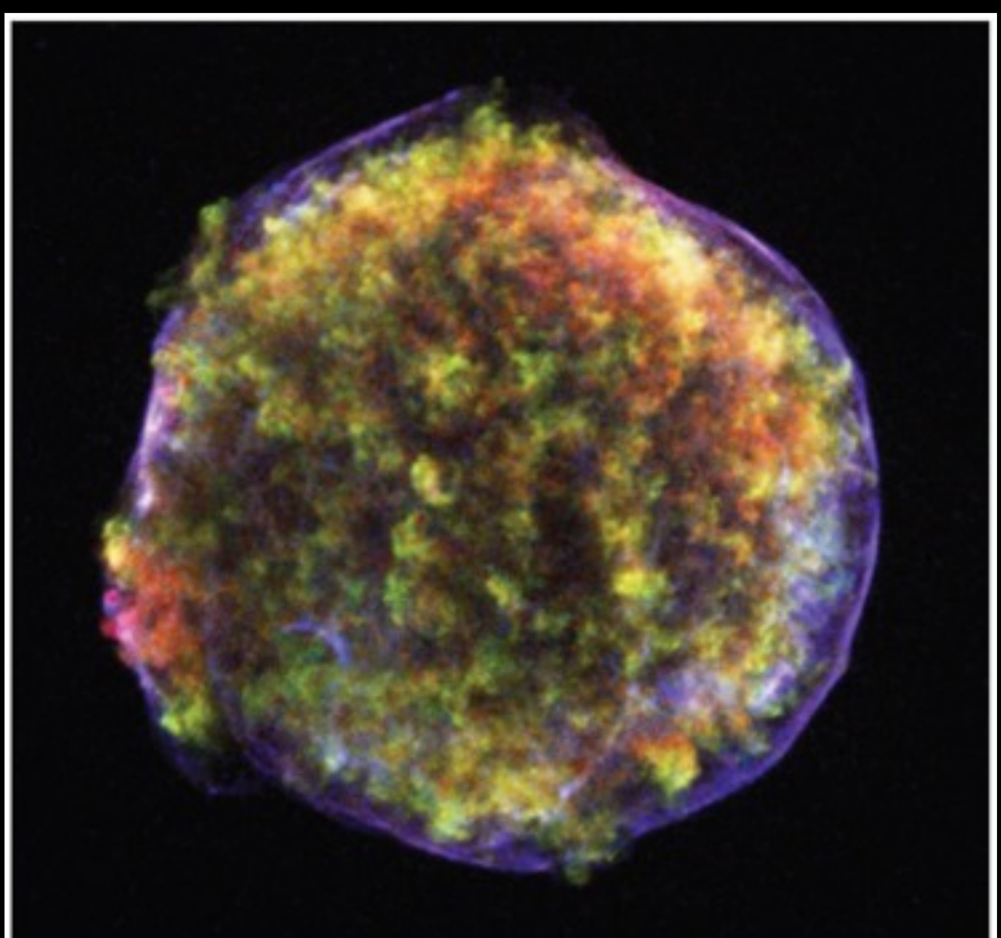
- Once the gas has formed into stars, it stays in that state for a long while
  - How long?
- Hot stars will also evaporate molecular clouds
  - they return some material to the hot atomic state

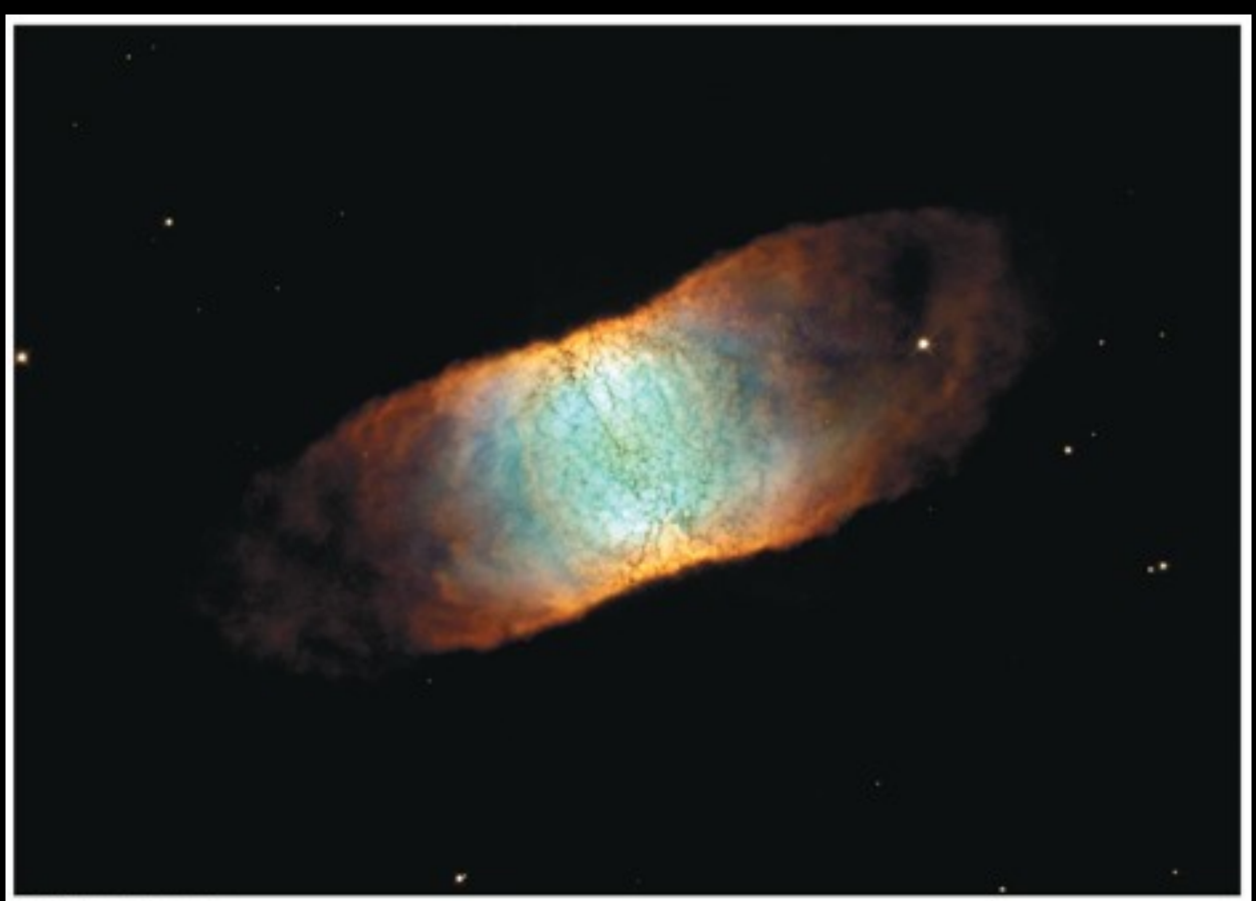
5. Stellar Winds

- Stellar winds shove the gas around
- They also return some of the mass from a star to the ISM
- Wind bubbles and supernovae are very hot - millions of degrees

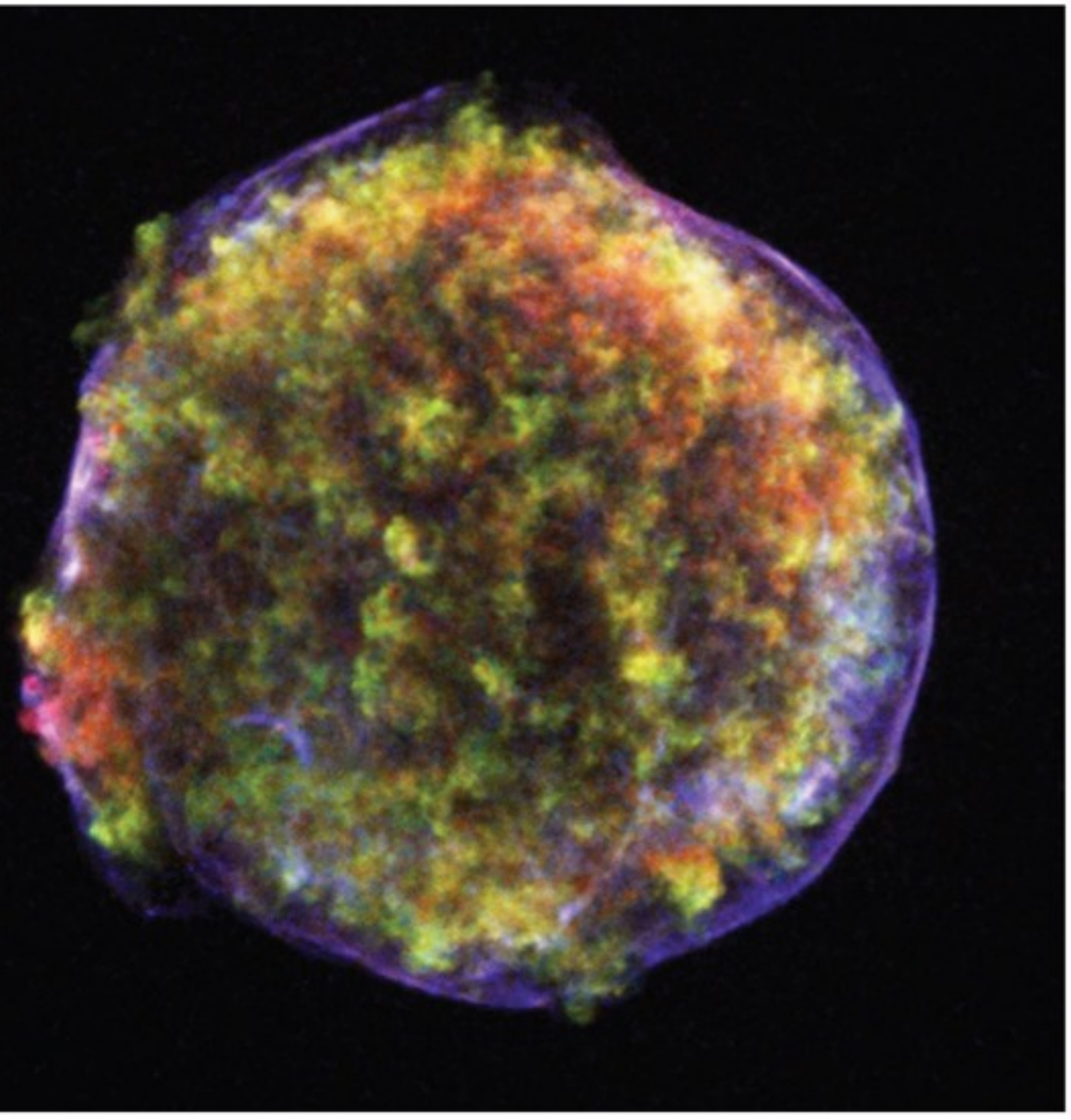
6. Explosions and Death

- Both low and high mass stars eject their outer layers
  - Low mass stars will return about half their mass to the ISM
  - High mass stars return most or all of their mass





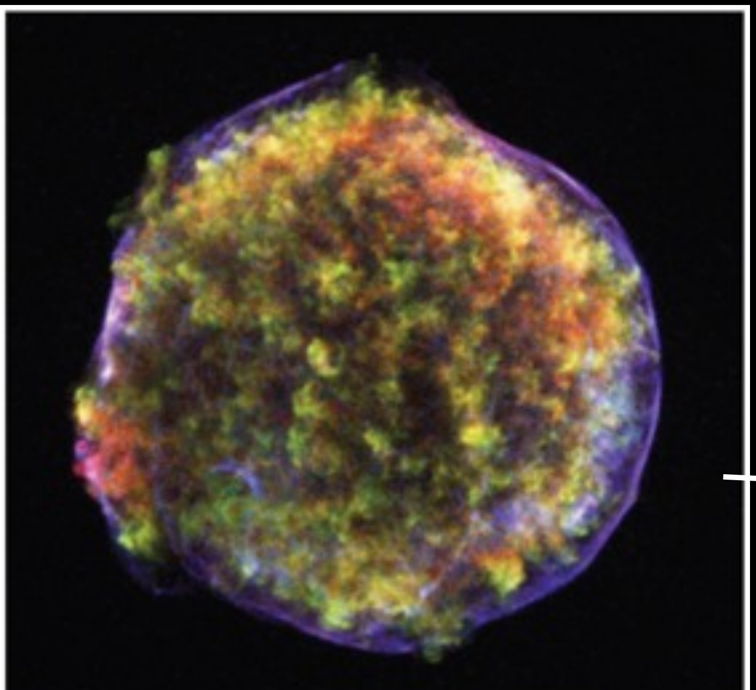
The new stuff is different!

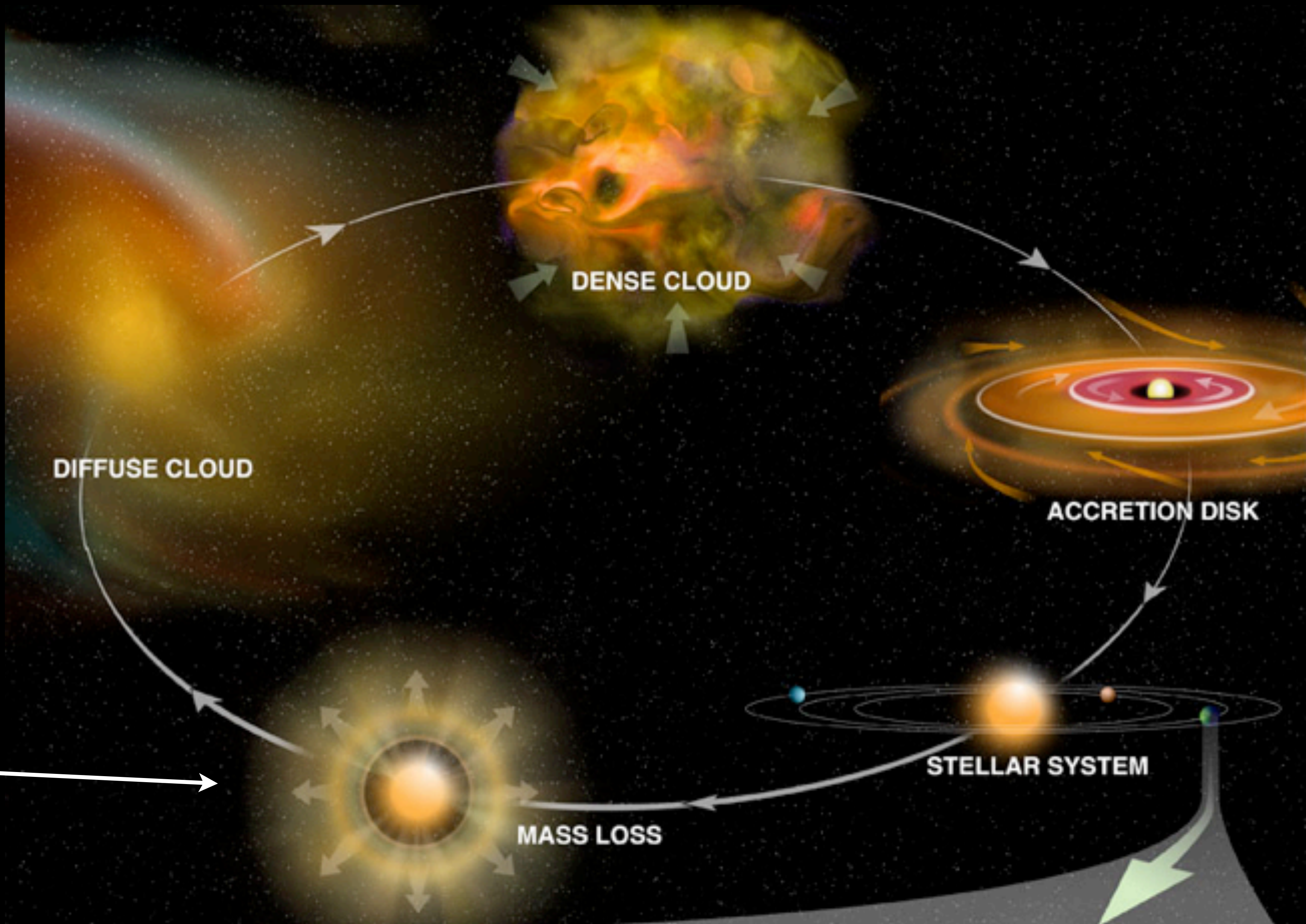


- Matter "returned" to the ISM has been processed through the interiors of stars
  - Fusion products and supernova nucleosynthesis products come out
- We're made of star stuff!

Star Stuff

- Supernova debris gets mixed in to diffuse clouds, which slowly cool into molecular clouds
- They collapse into stars that form accretion disks and planets
- The cycle is completed!





What stars make

- In the beginning of the universe, there was only hydrogen, helium, and a little lithium. Stars made heavier elements. What else did they create that wasn't there in the beginning?

A) deuterium

B) buckyballs

C) galaxies

D) dust

E) air conditioning

Dust Production

- Supernovae and red giant winds both produce large quantities of dust

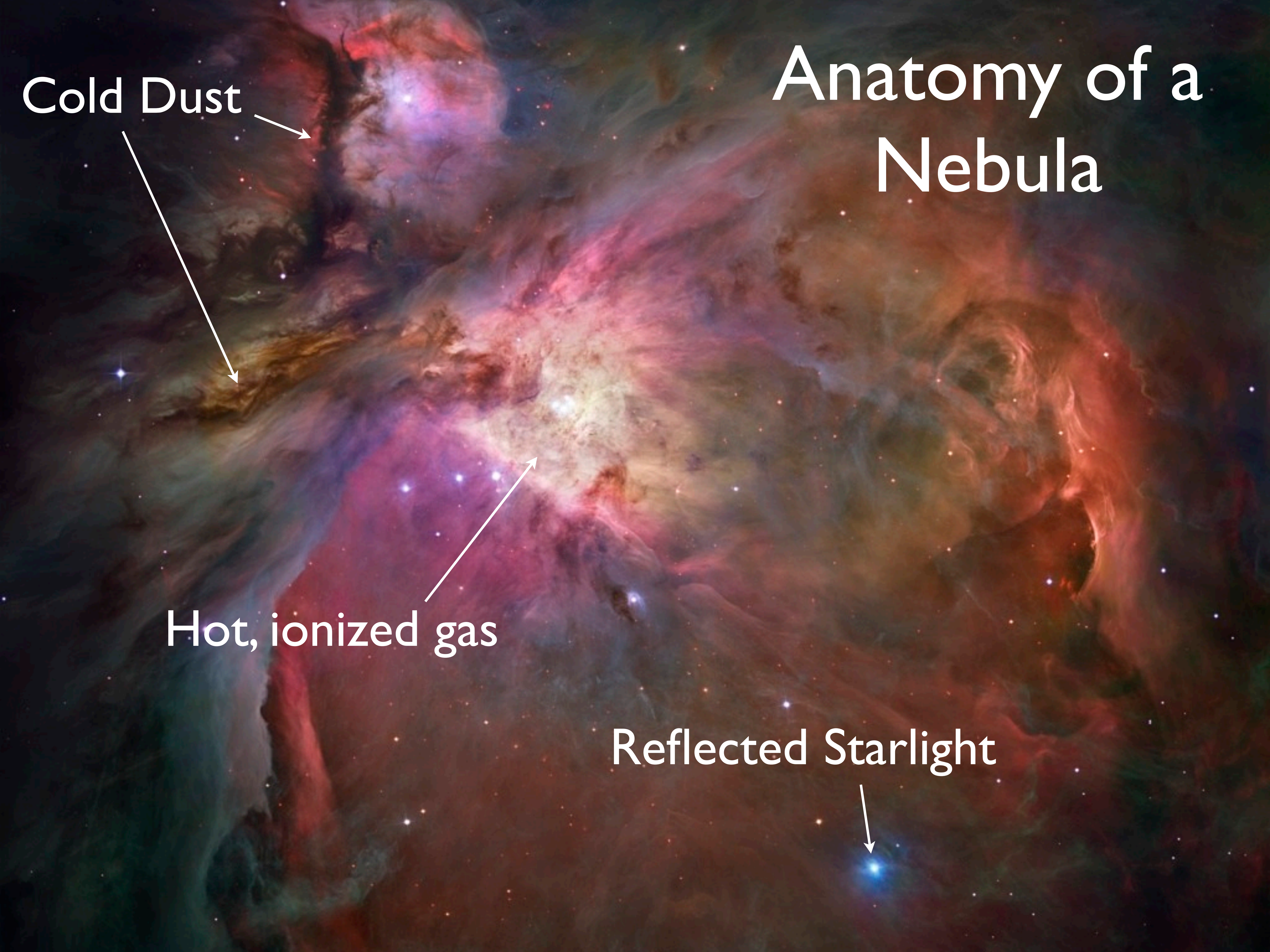

Dust makes stars more red
by scattering blue light

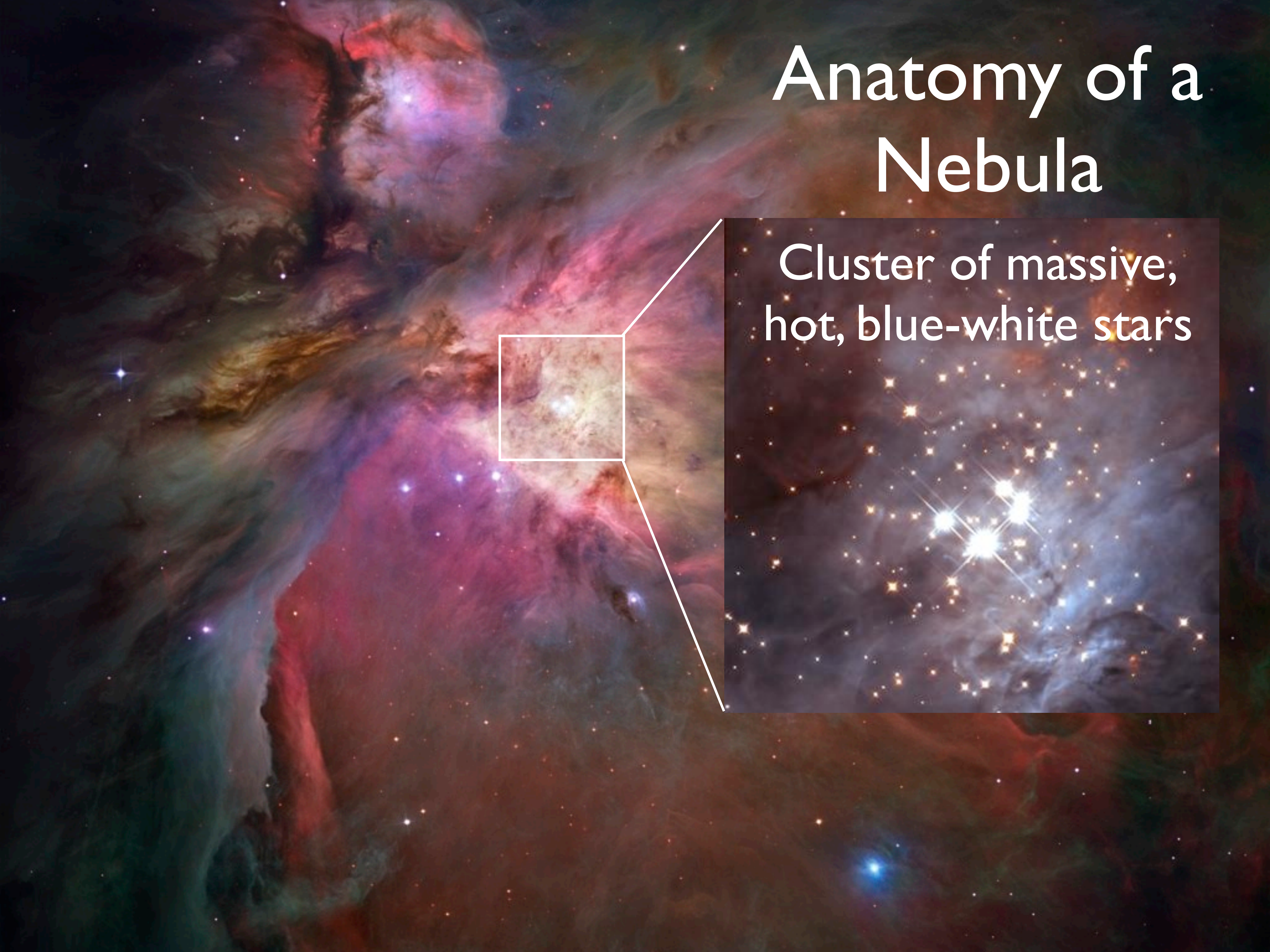
Since dust scatters blue light more than red, stars seen through a lot of interstellar dust would look

A. bluer than expected for their spectral type.
B. redder than expected for their spectral type.
C. the same as when seen without dust.

What gives reflection nebulae their blue color?

A. Blue light from nearby stars
B. Preferential scattering of blue light from dust grains
C. emission lines in the blue part of the spectrum from atomic hydrogen
D. emission lines in the blue part of the spectrum from molecular hydrogen


Anatomy of a Nebula
Cold Dust
Hot, ionized gas
Reflected Starlight


Anatomy of a
Nebula
Cluster of massive,
hot, blue-white stars

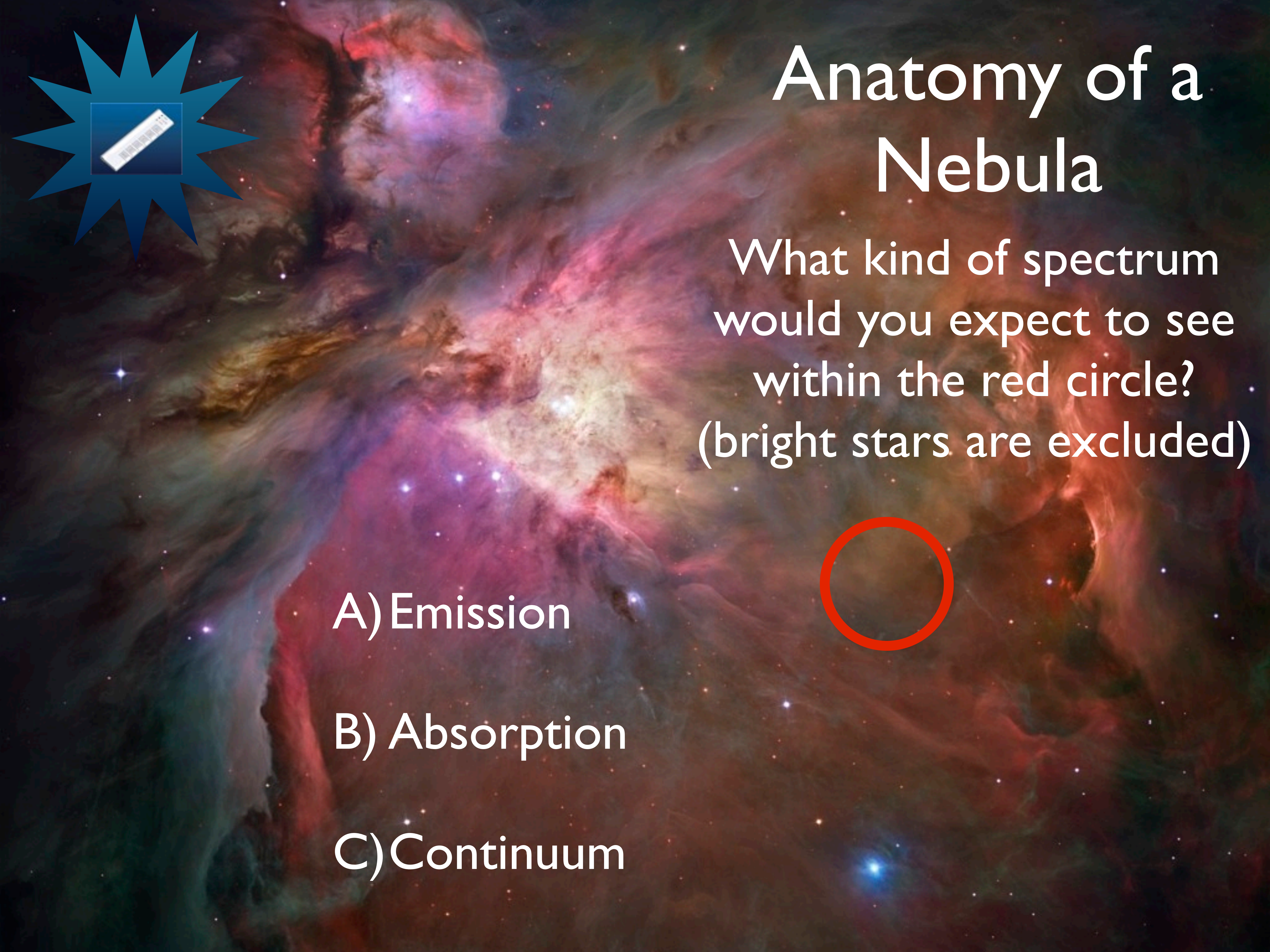
Anatomy of a Nebula

What kind of spectrum would you expect to see within the red circle?

A) Emission

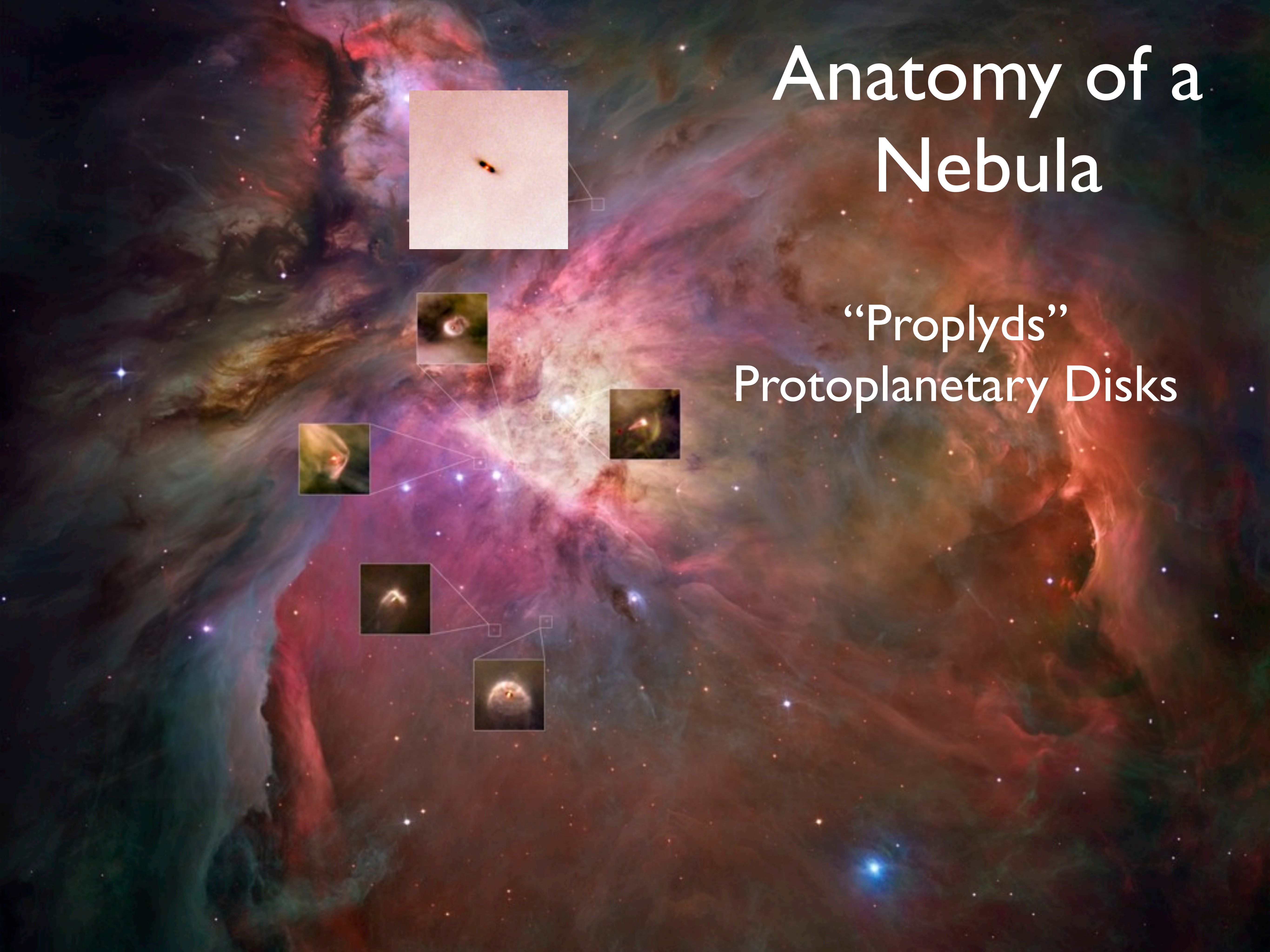
B) Absorption

C) Continuum


Anatomy of a Nebula
What kind of spectrum would you expect to see within the red circle? (bright stars are excluded)
A) Emission
B) Absorption
C) Continuum

Anatomy of a Nebula

"Proplyds"
Protoplanetary Disks



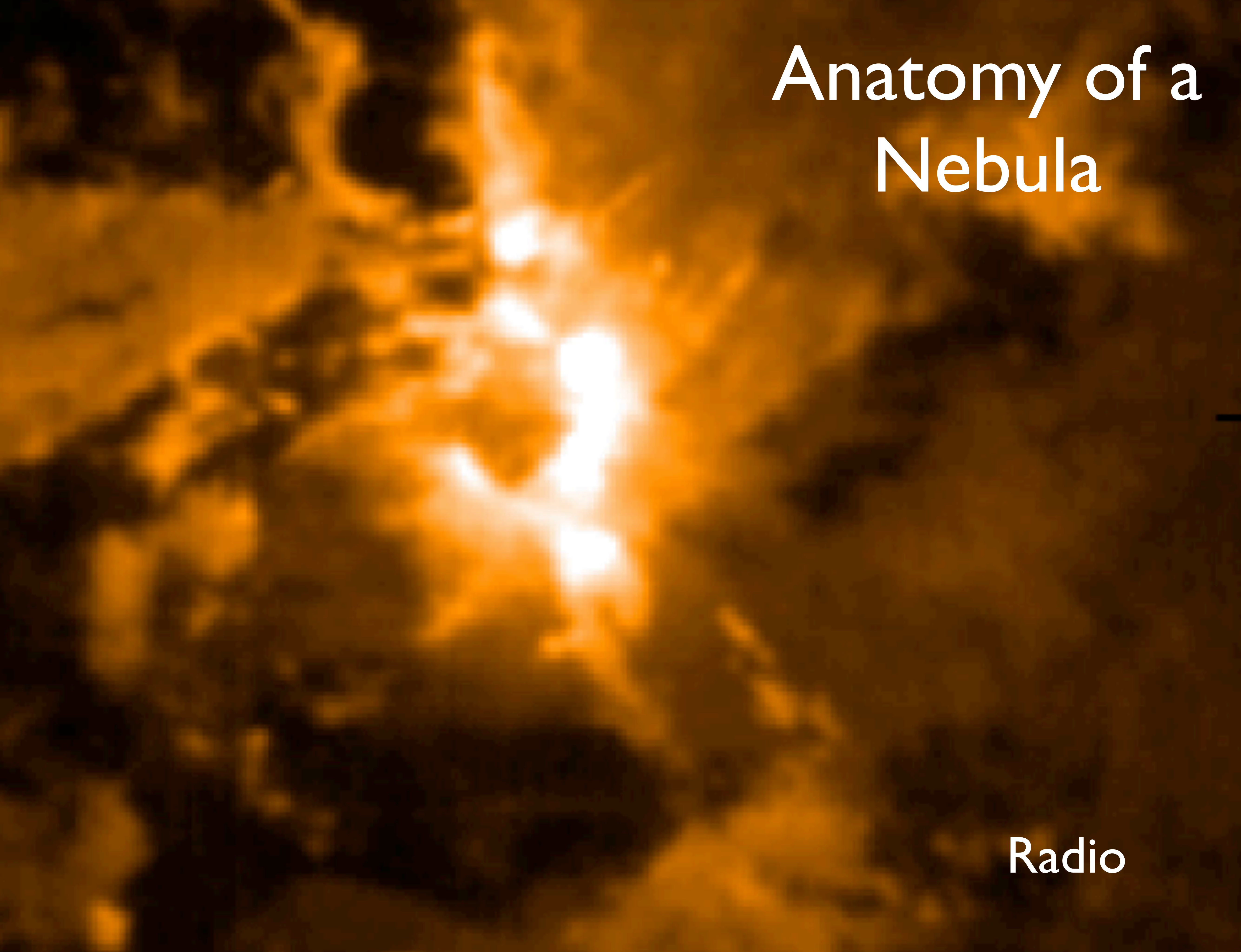
Anatomy of a Nebula

Anatomy of a Nebula

Near Infrared


Anatomy of a Nebula
Mid Infrared

Anatomy of a Nebula



How do we know it's there?

- You've seen a lot of pictures. They tell part of the story.
- What other methods do we use to examine the ISM?

Where stars form...

- If you wanted to find out where stars are most likely to form next, what wavelength would you use?

A) gamma rays

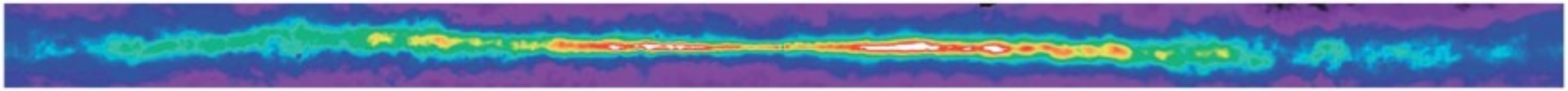
B) x-ray

C) visible

D) ultraviolet

E) radio

Multi-wavelength observations reveal different components



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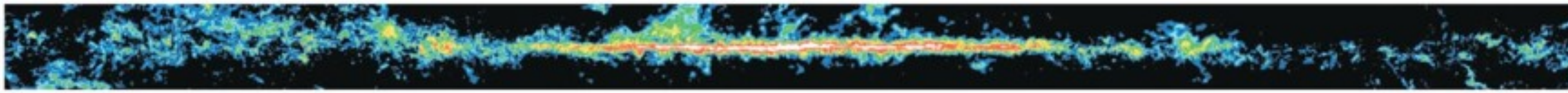


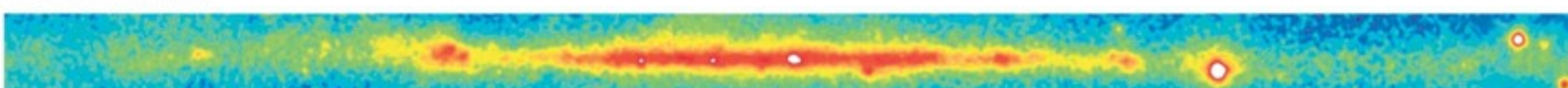
b Radio emission from carbon monoxide reveals molecular clouds.

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

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

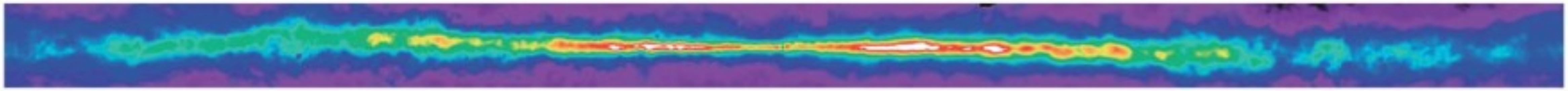
e Visible light emitted by stars is scattered and absorbed by dust.

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.

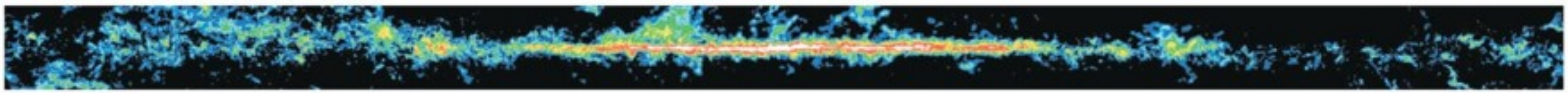
21cm radio from HI



a 21-centimeter radio emission from atomic hydrogen gas.

- 21-centimeter radiation comes from neutral hydrogen
- It shows the warm, neutral component of the ISM

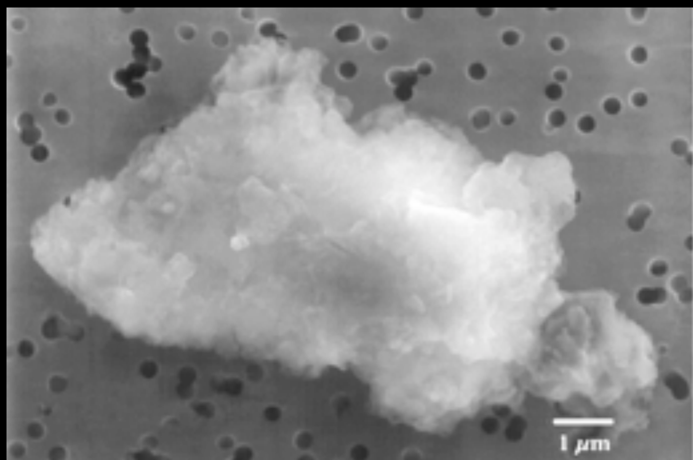
Radio Carbon Monoxide

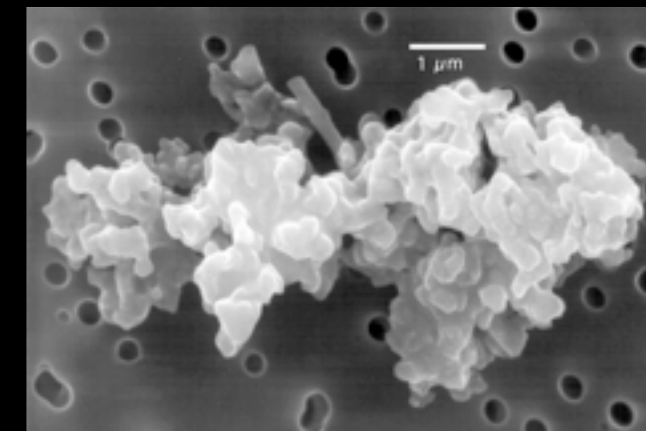


b Radio emission from carbon monoxide reveals molecular clouds.

- CO molecules spin and produce radio emission lines
- They allow us to see cold, dense molecular clouds
- We can tell that molecular clouds are smaller than neutral clouds, but about the same total mass

Far-Infrared Dust





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

- The whole galaxy is filled with dust
- The brightest dust comes from the same place as molecular clouds: molecular clouds contain more stuff, so they contain more dust
- About 99% of the ISM is gas, 1% is dust

Near-infrared starlight

- Dust is more transparent in infrared light than in the visible

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

- Stars can shine right through!

Visible light, invisible dust

- In visible light, the dust hides the background stars and nebulae
- By counting the number of stars in the infrared and comparing to the visible, we can estimate how much dust is there

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

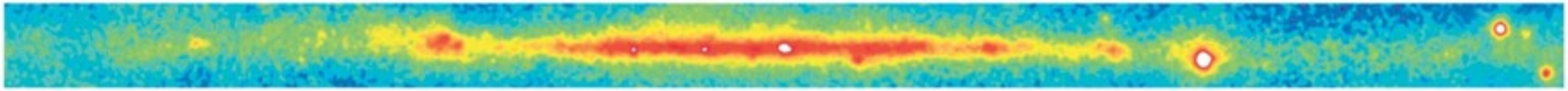
X-rays show hot gas

- X-rays let us see the hottest gas
- Supernovae heat bubbles of gas to millions of degrees
  - Sometimes stellar wind bubbles get that hot

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

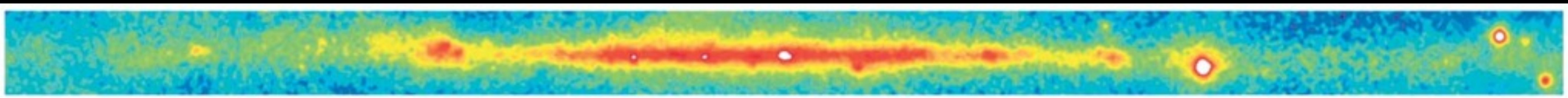
Multi-wavelength observations reveal different components

- Gamma rays come from cosmic rays (fast-moving protons) interacting with dense gas in molecular clouds
- They get through just about everything, so we can see all the way through the galaxy



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

Gamma Rays and CO show a lot of the same things



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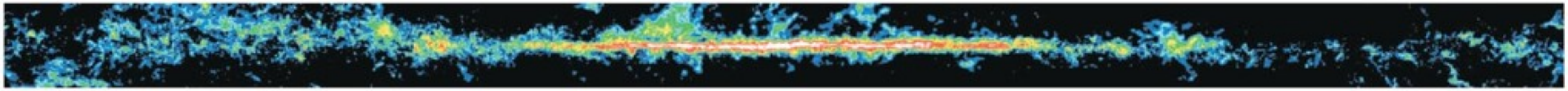
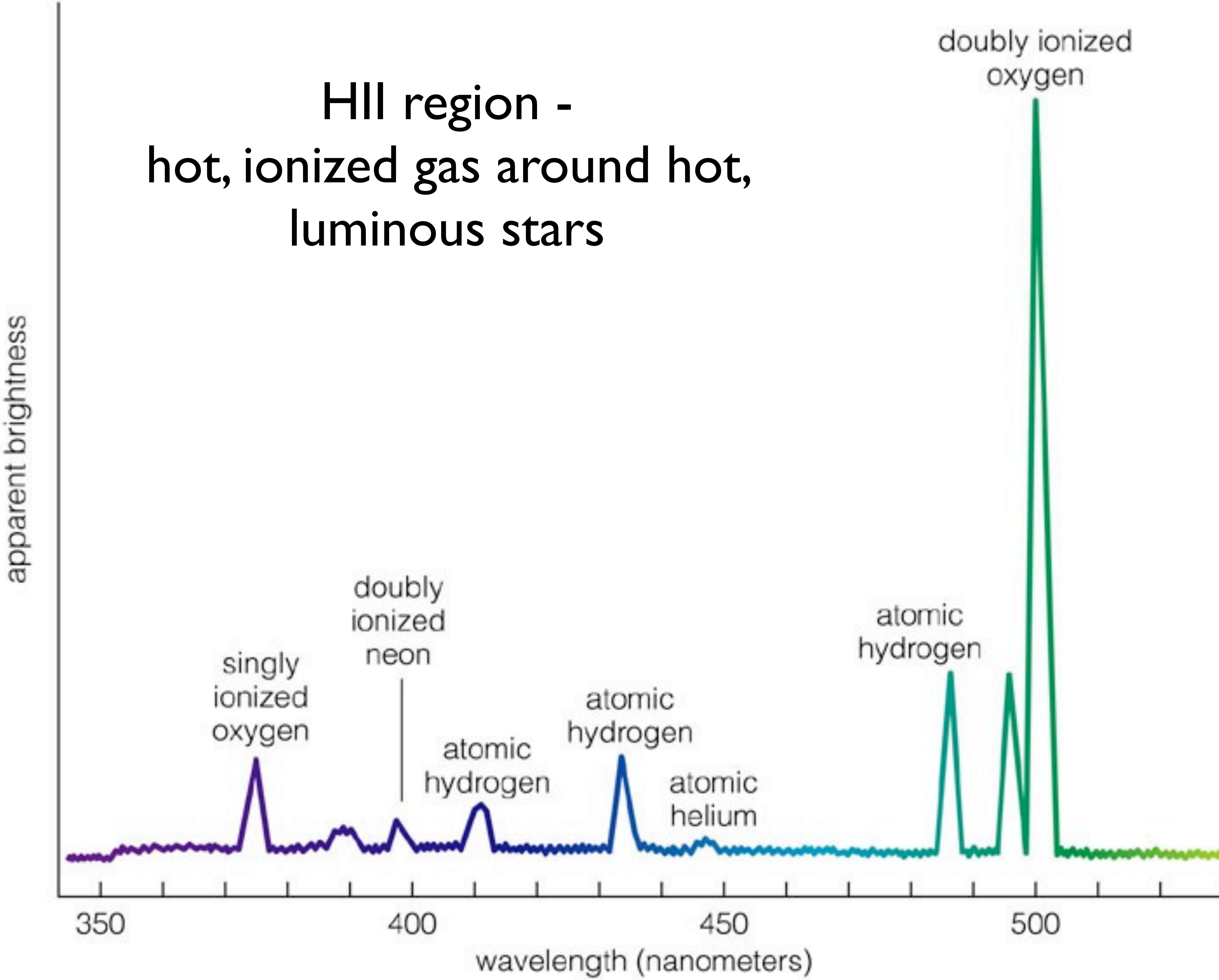


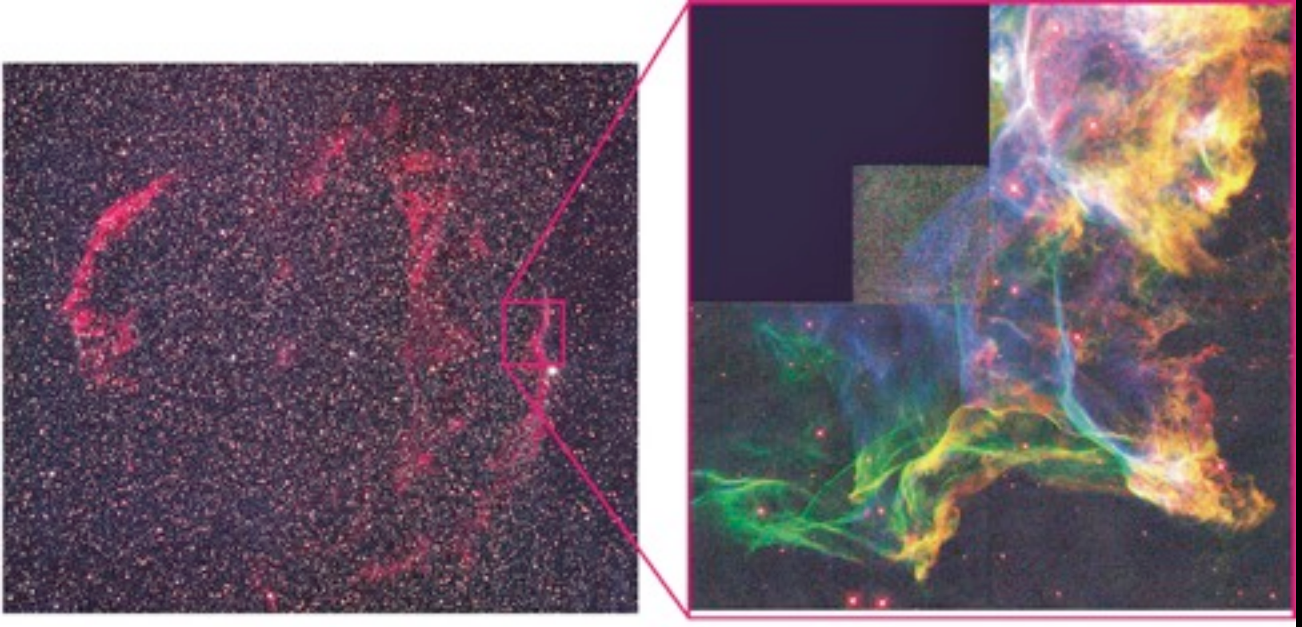
b Radio emission from carbon monoxide reveals molecular clouds.

Enough wavelengths already?

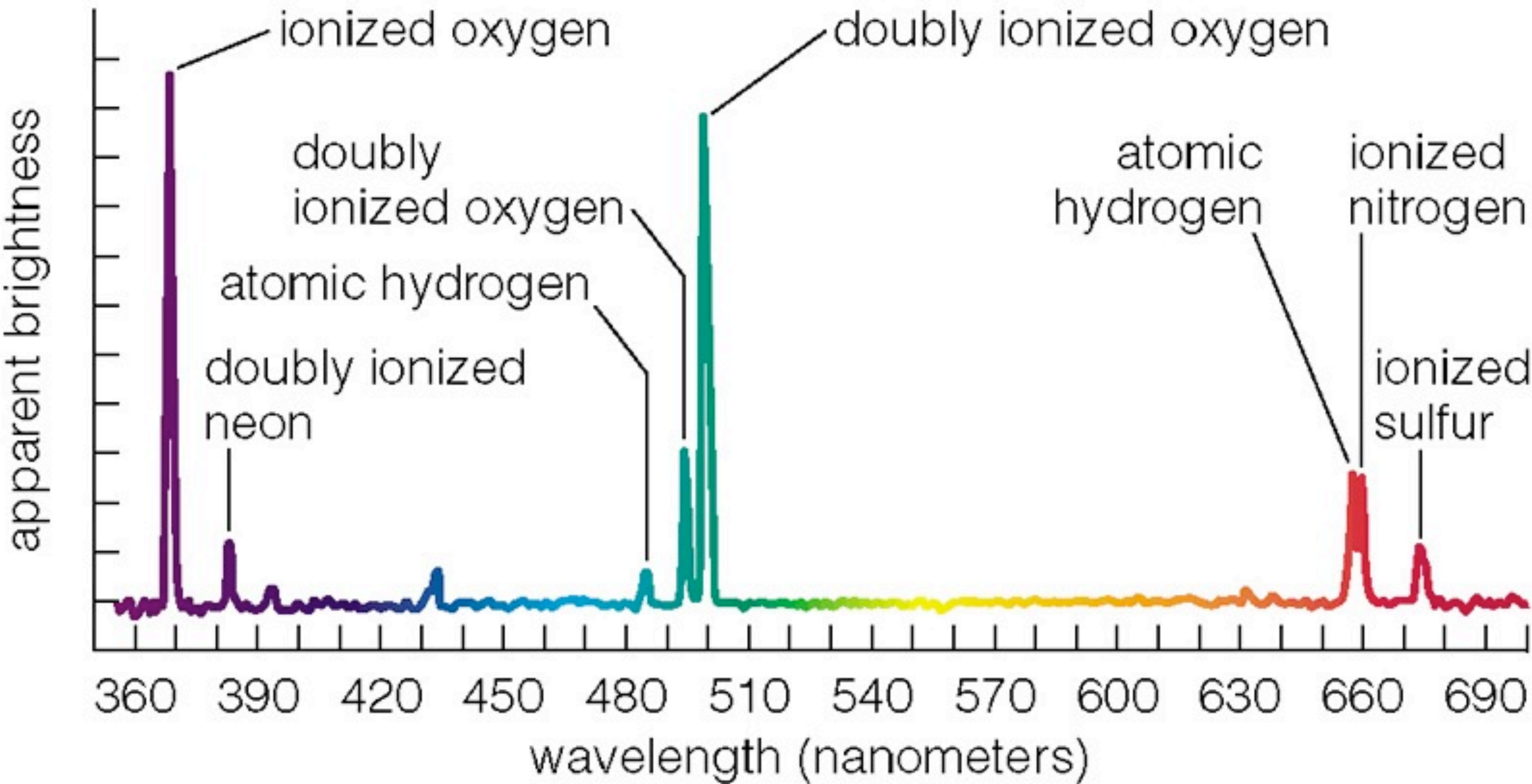
- Methods:
    - Multiwavelength imaging
    - Spectroscopy
        - Doppler Spectroscopy to determine velocities
        - Other spectroscopy to determine composition, density, and temperature

HII region -
hot, ionized gas around hot, luminous stars



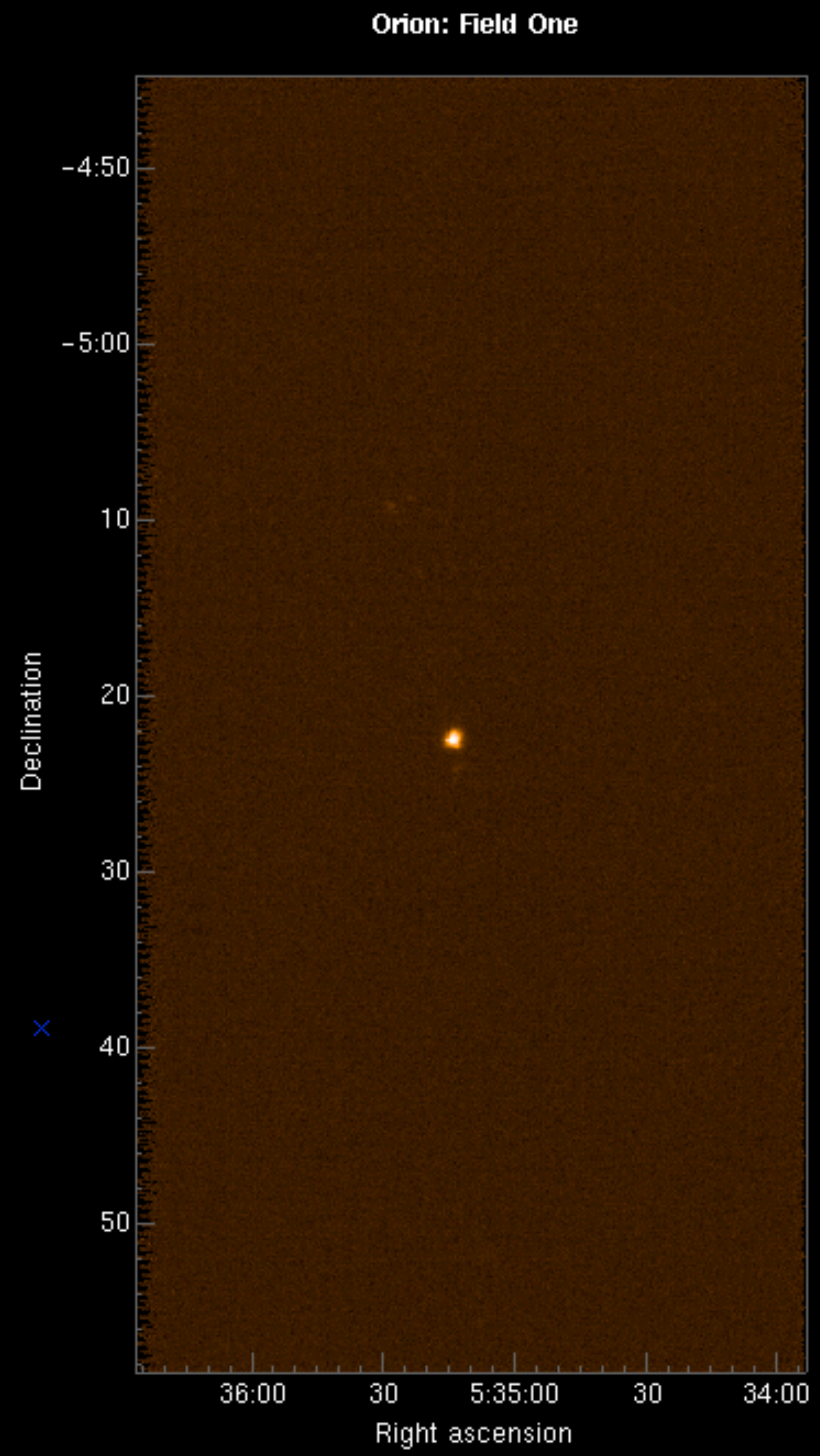


Supernova Remnants: New elements get mixed into the ISM



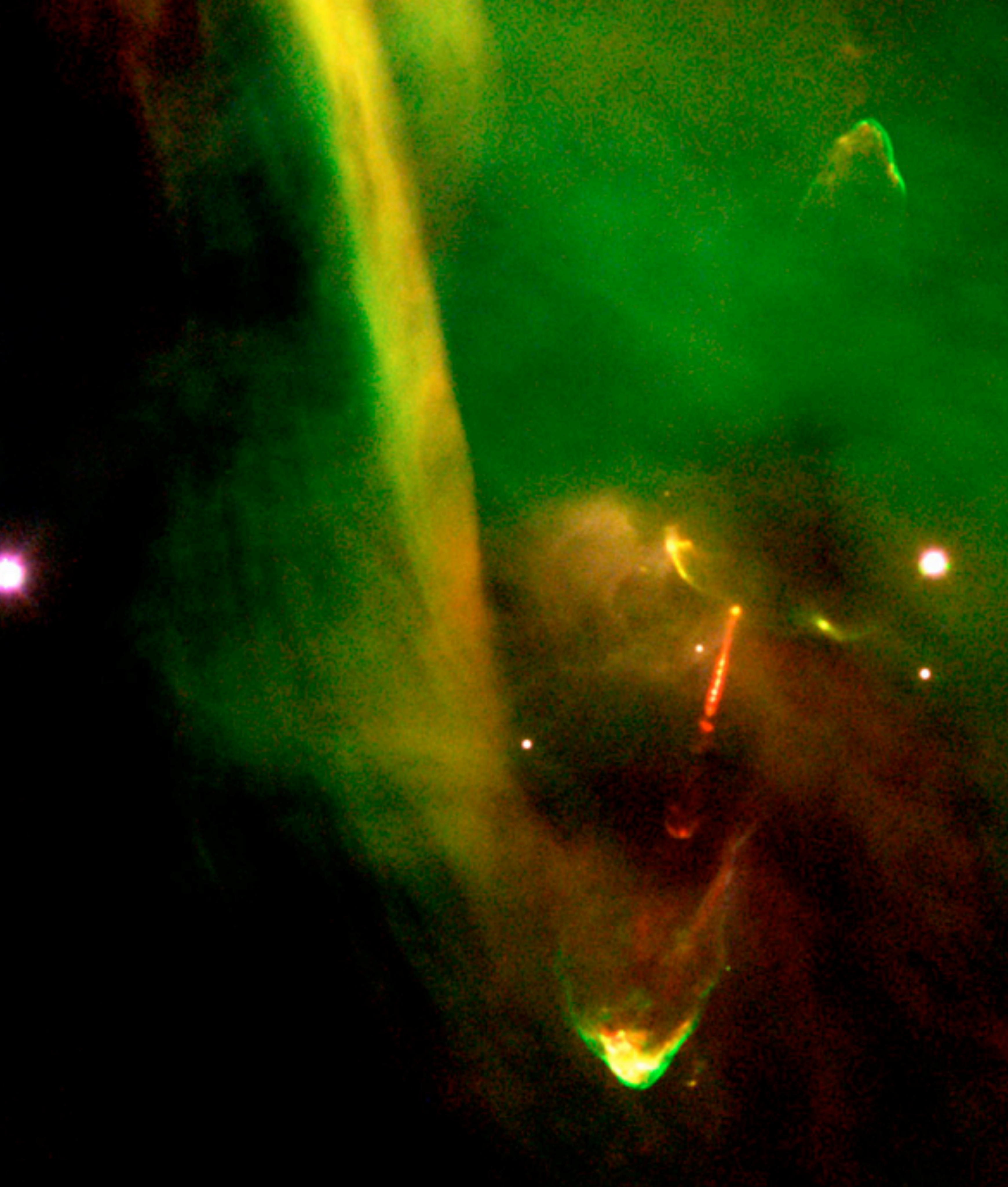
Doppler Spectroscopy: Each image is at a different velocity

The nebula is turbulent and parts are expanding and moving around



Interaction of Stars and ISM

- Jets, Winds, and Radiation
- All 3 inject energy into the ISM and stir it up



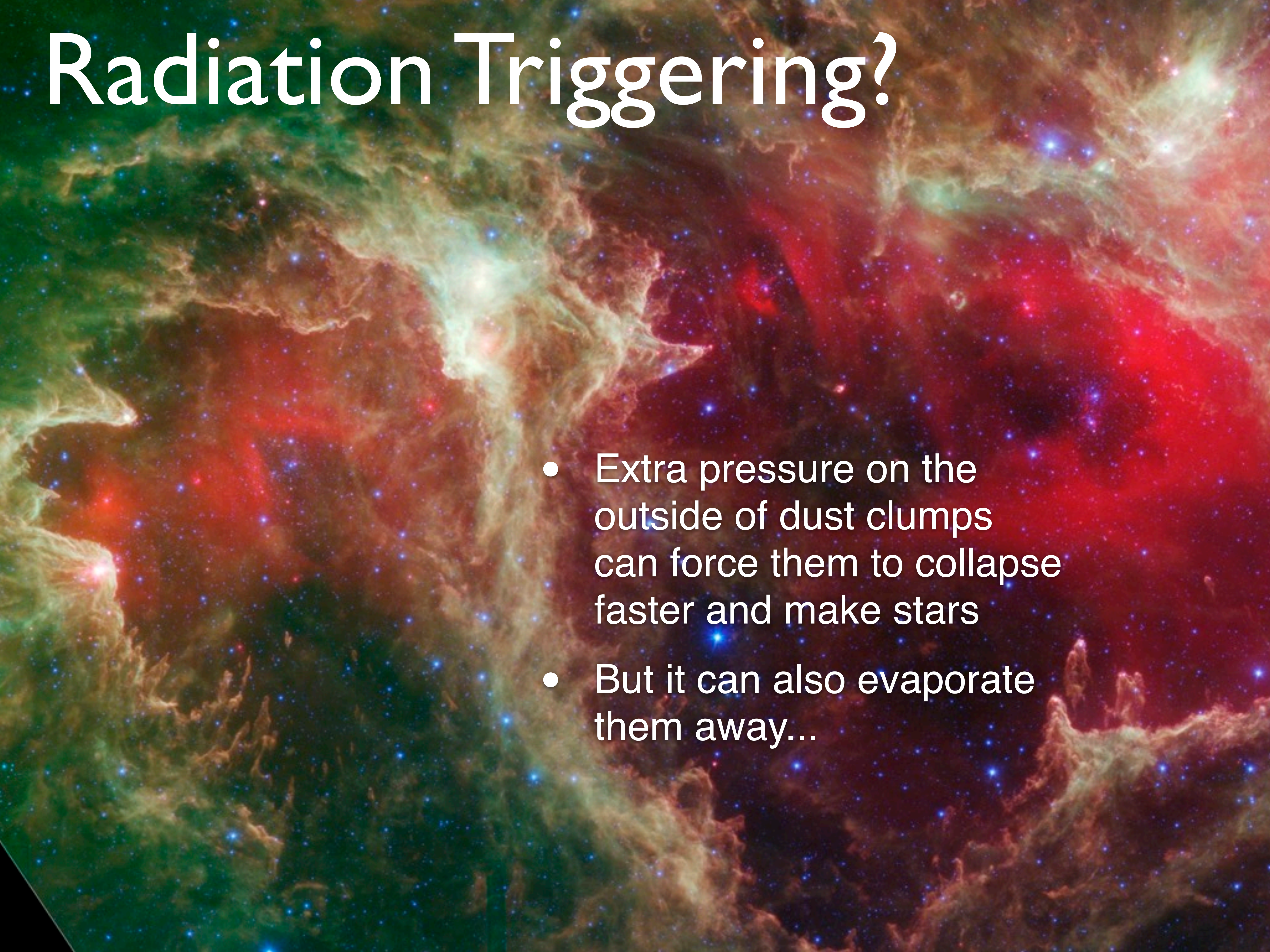
Jets

- Reminder: they come from young star accretion disks
- They mostly stir up turbulence. They're very powerful, but narrow-beamed

Radiation

- Hot, luminous stars "photoevaporate" clumps of dust
- They heat the ISM and create ionized HII regions

Radiation Triggering?

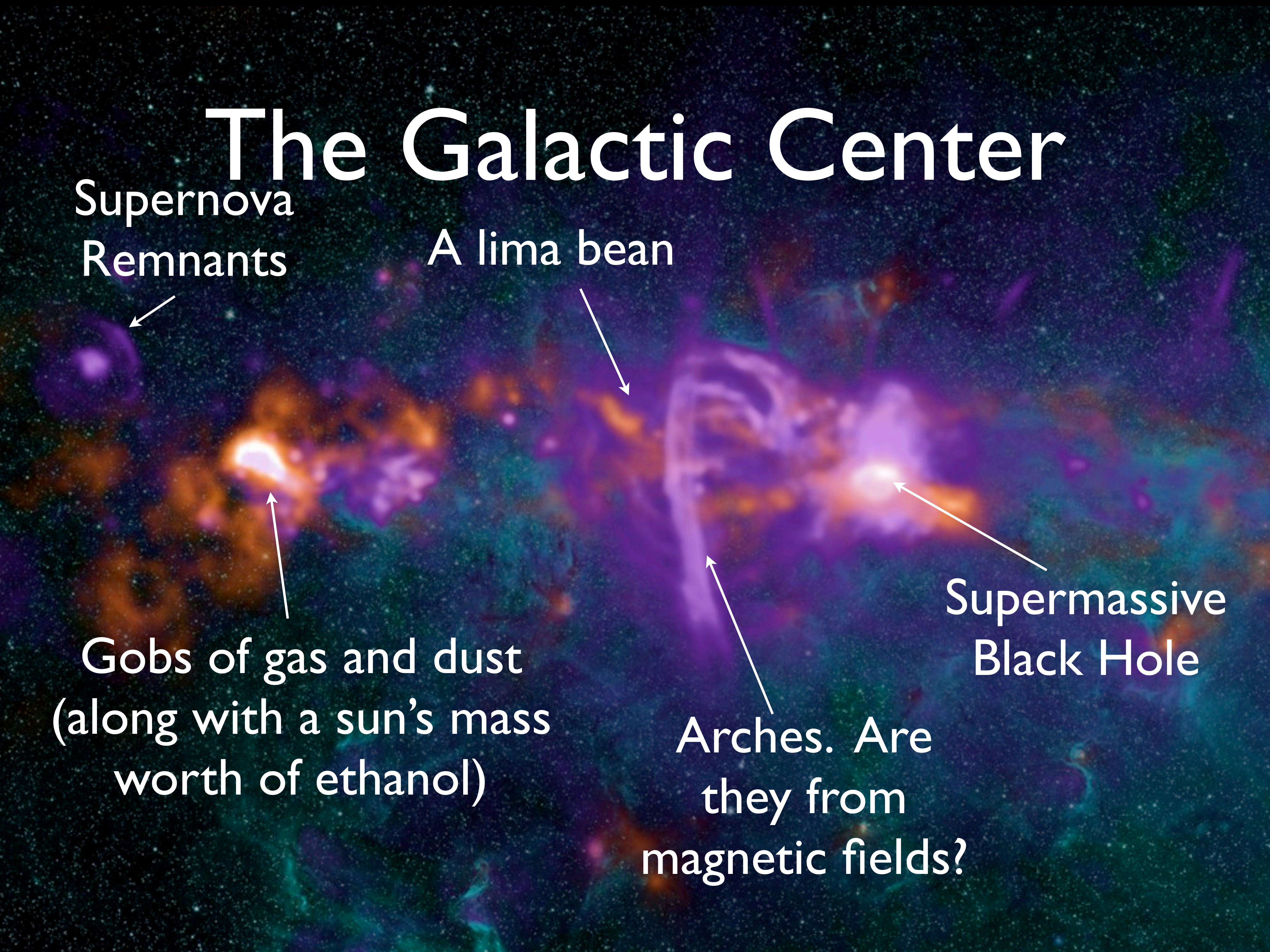


- Extra pressure on the outside of dust clumps can force them to collapse faster and make stars
- But it can also evaporate them away...

Winds

- Blow bubbles!
- They can also have the same effects as radiation, but usually the radiation pushes away clouds before the wind hits it

The Galactic Center



BREAK

- Clusters and activity next

Clusters

- Definition: Groups of stars that are gravitationally bound
  - If they just look like they're close together, they're "asterisms" but not clusters
- Usually form all at once from the same parent molecular cloud

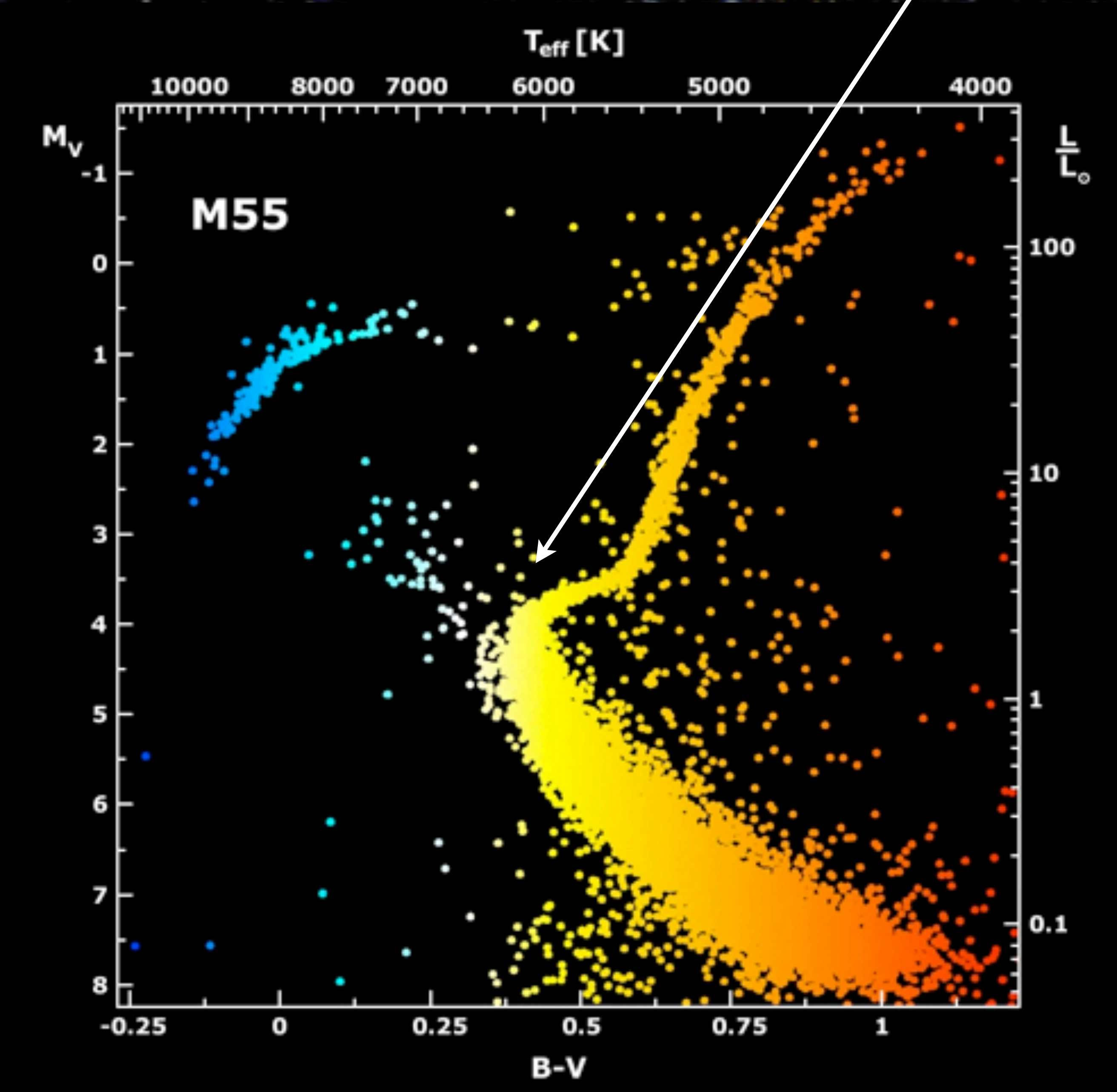
Two types

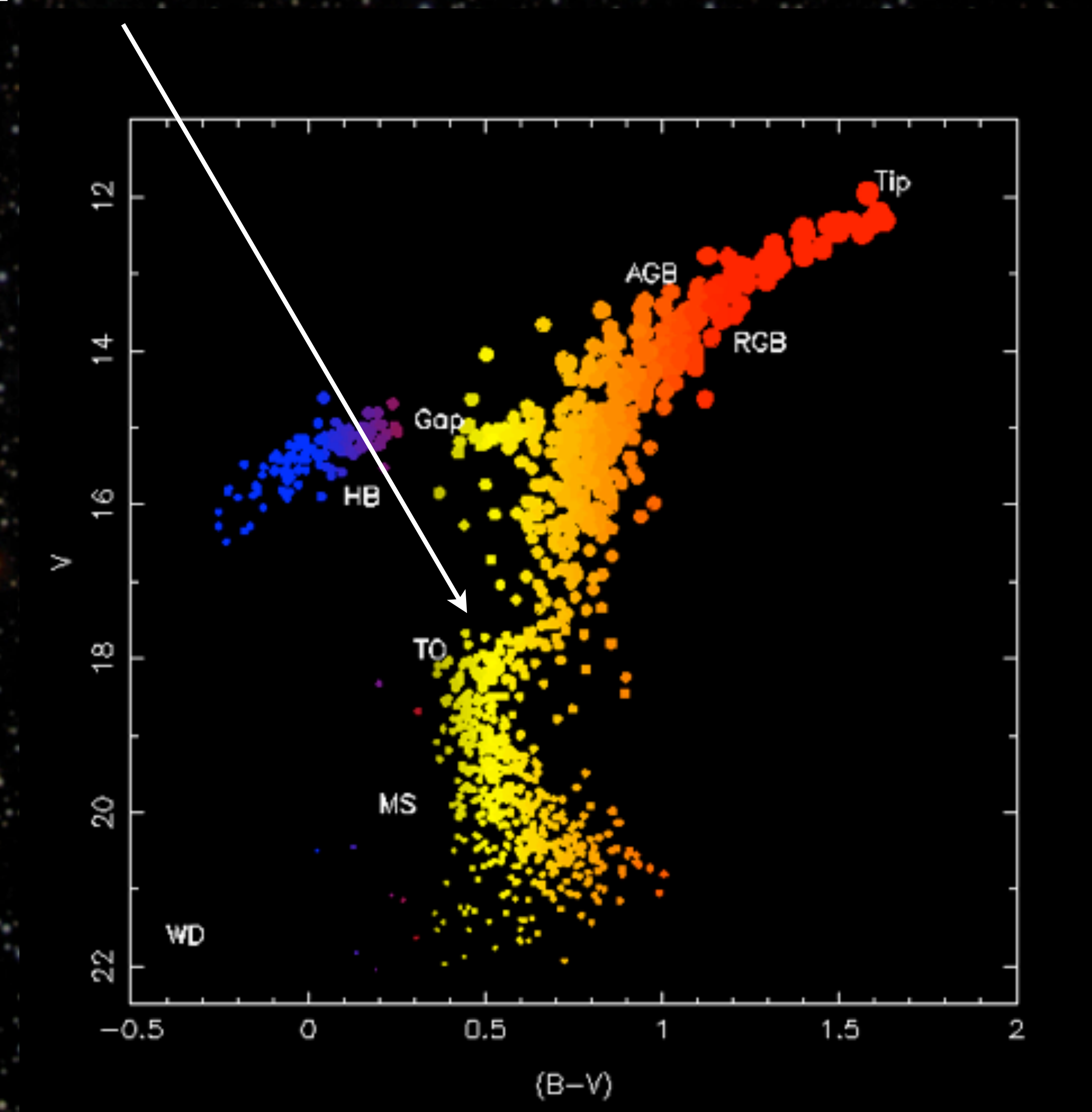
- Globular Clusters
  - Round
  - LOTS of stars (100,000s)
  - Old (12-13 GYr)
  - No gas

- Open Clusters
  - Not necessarily round
  - Smaller (10s-1,000s of stars)
  - Young
  - May be gassy

How do we know Globular Clusters are old?

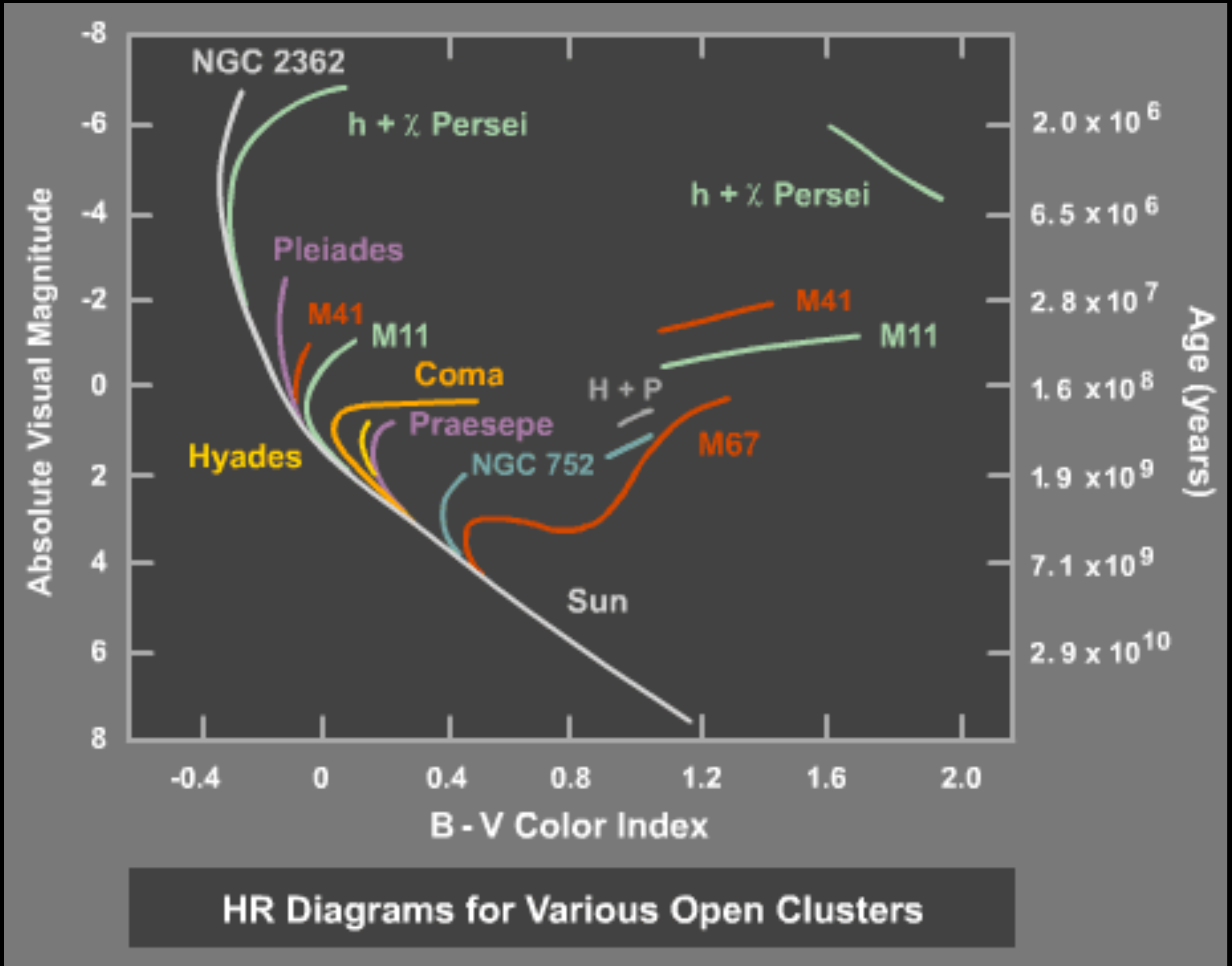
Turnoff point



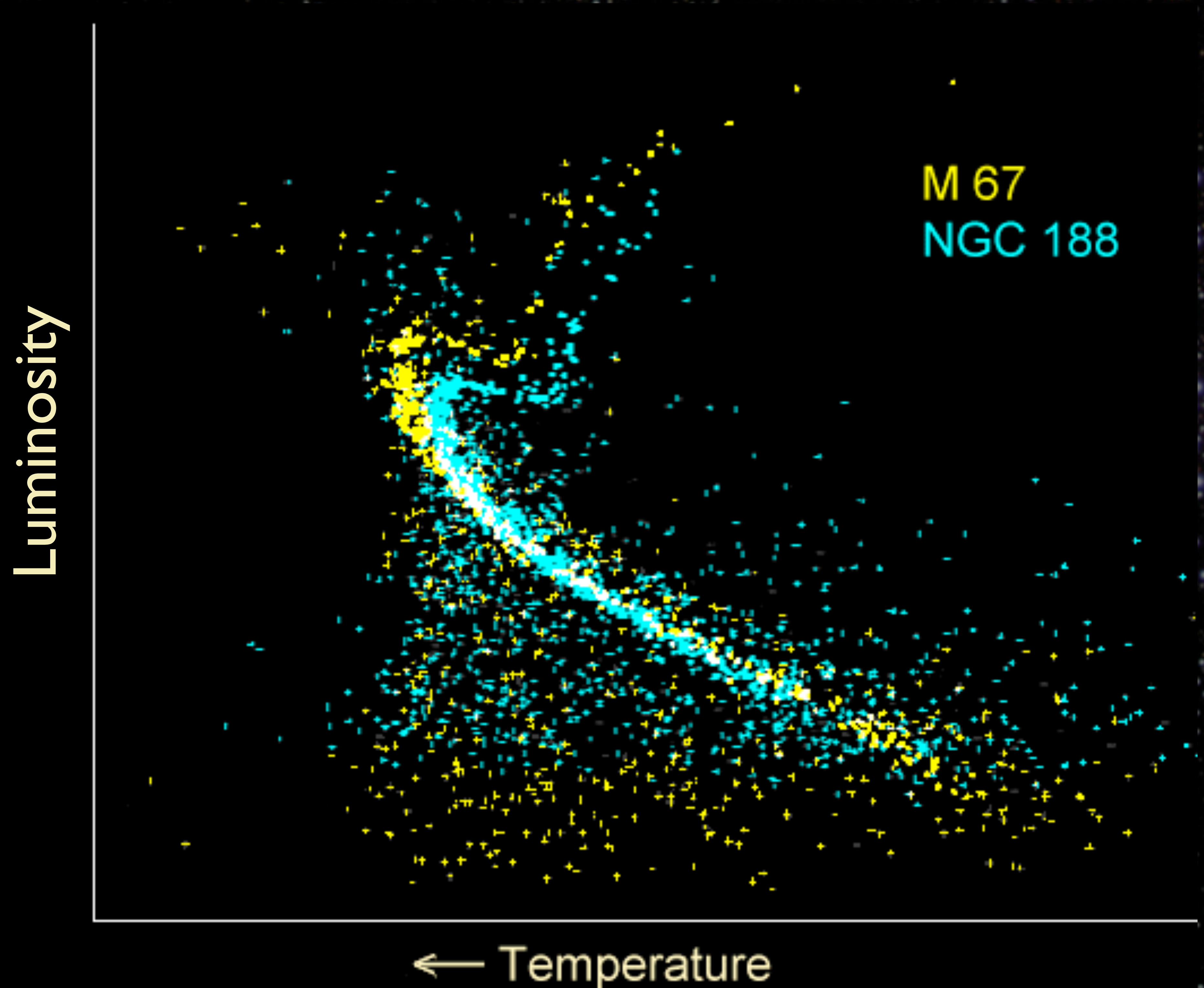


Open Cluster HR diagrams

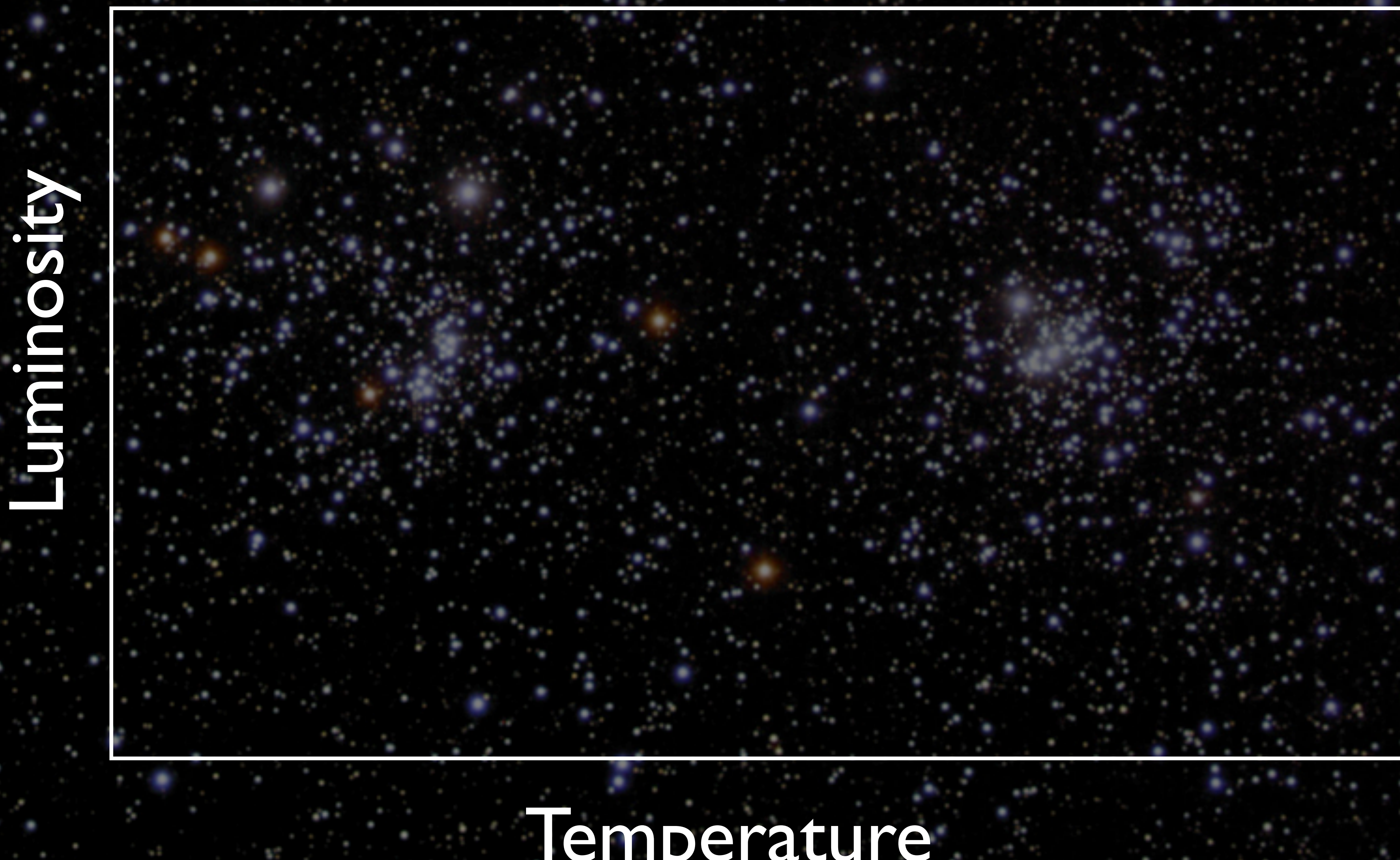
Luminosity



Which cluster is older?



Pin-the-star-on-the-HR-Diagram



1. Fill it all in

1. The Sun
2. The Main Sequence
3. Brown Dwarves
4. Red Giants
5. Horizontal Branch
6. Asymptotic Giant Branch
7. White Dwarves
8. Eta Carina ($T=20,000$, $L=10^{6.5}$)
9. Supergiants
10. Neutron Stars
11. Protostars

2. Clusters

1. A 10 billion year (Gyr) old cluster
    a. The sun
    b. The red giant branch
    c. The lower main sequence
    d. White Dwarves
2. A 10 million year (Myr) old cluster
    a. The sun
    b. A B-star, with T=20,000 and $L=10^5$
    c. The main sequence (plus upper turnoff)
    d. Pre-main-sequence stars (use an L=1, T=2500 star as the peak)

3. General Sense

1. Draw an arrow in the direction of increasing *radius*
2. Draw an arrow in the direction of increasing *lifetime*
3. Draw an arrow indicating the direction towards which binaries would be shifted (i.e., if you plotted a pair of identical stars as one point on the diagram, where would it go?)
4. Draw an arrow indicating the direction of *dust reddening*. Does dust along the line of sight make stars appear hotter or colder?

4. Brightness

- Draw two clusters that are both 10 Gyr old
  - One has the sun at relative brightness = 1
  - The other is 10x *closer*