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

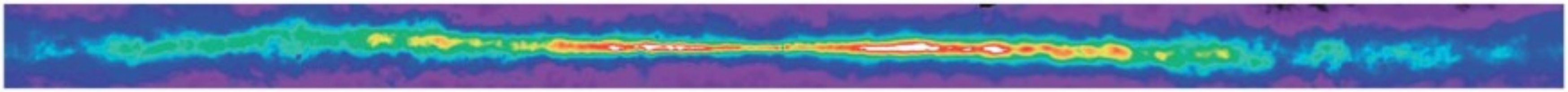
B) x-ray

C) visible

D) ultraviolet

E) radio

Multi-wavelength observations reveal different components



a 21-centimeter radio emission from atomic hydrogen gas.

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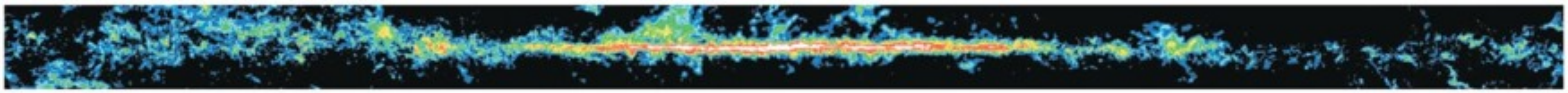

b Radio emission from carbon monoxide reveals molecular clouds.

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

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

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

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

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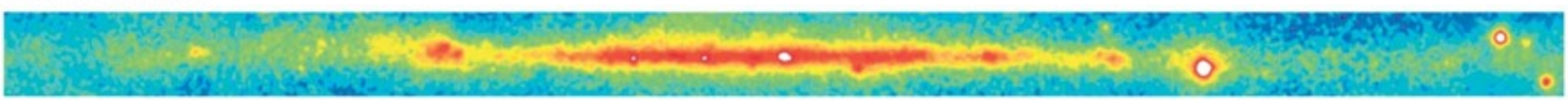

g Gamma-ray emission from collisions of cosmic rays with atomic nuclei in interstellar clouds.

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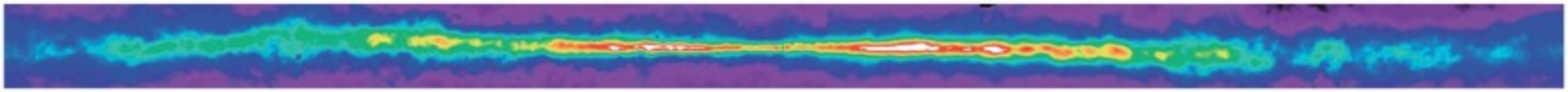
21cm radio from HI



a 21-centimeter radio emission from atomic hydrogen gas.

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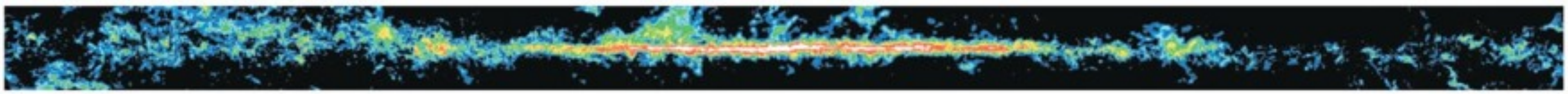
- 21-centimeter radiation comes from neutral hydrogen
- It shows the warm, neutral component of the ISM

Radio Carbon Monoxide



b Radio emission from carbon monoxide reveals molecular clouds.

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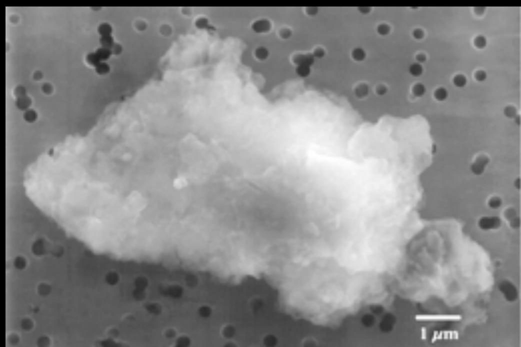
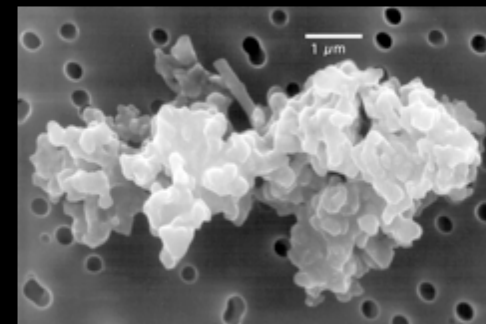
- CO molecules spin and produce radio emission lines
- They allow us to see cold, dense molecular clouds
- We can tell that molecular clouds are smaller than neutral clouds, but about the same total mass

Far-Infrared Dust





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

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- 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.

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- 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.

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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).

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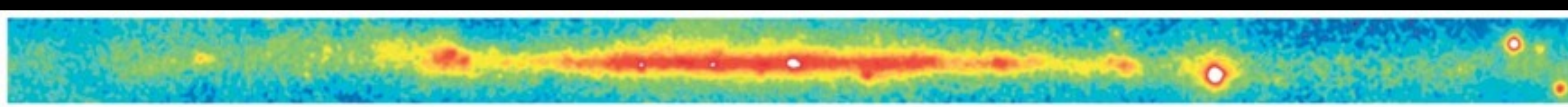
Multi-wavelength observations reveal different components

- 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.

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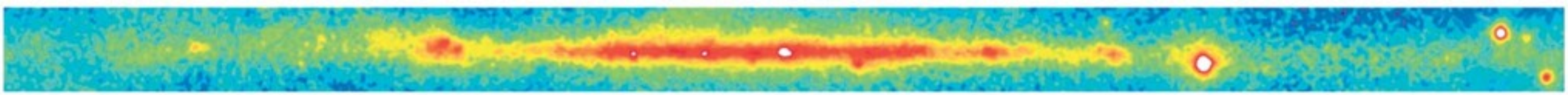
Gamma Rays and CO show a lot of the same things



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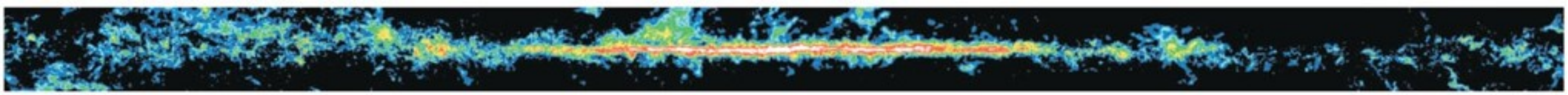
Gamma Rays and CO show a lot of the same things



b Radio emission from carbon monoxide reveals molecular clouds.

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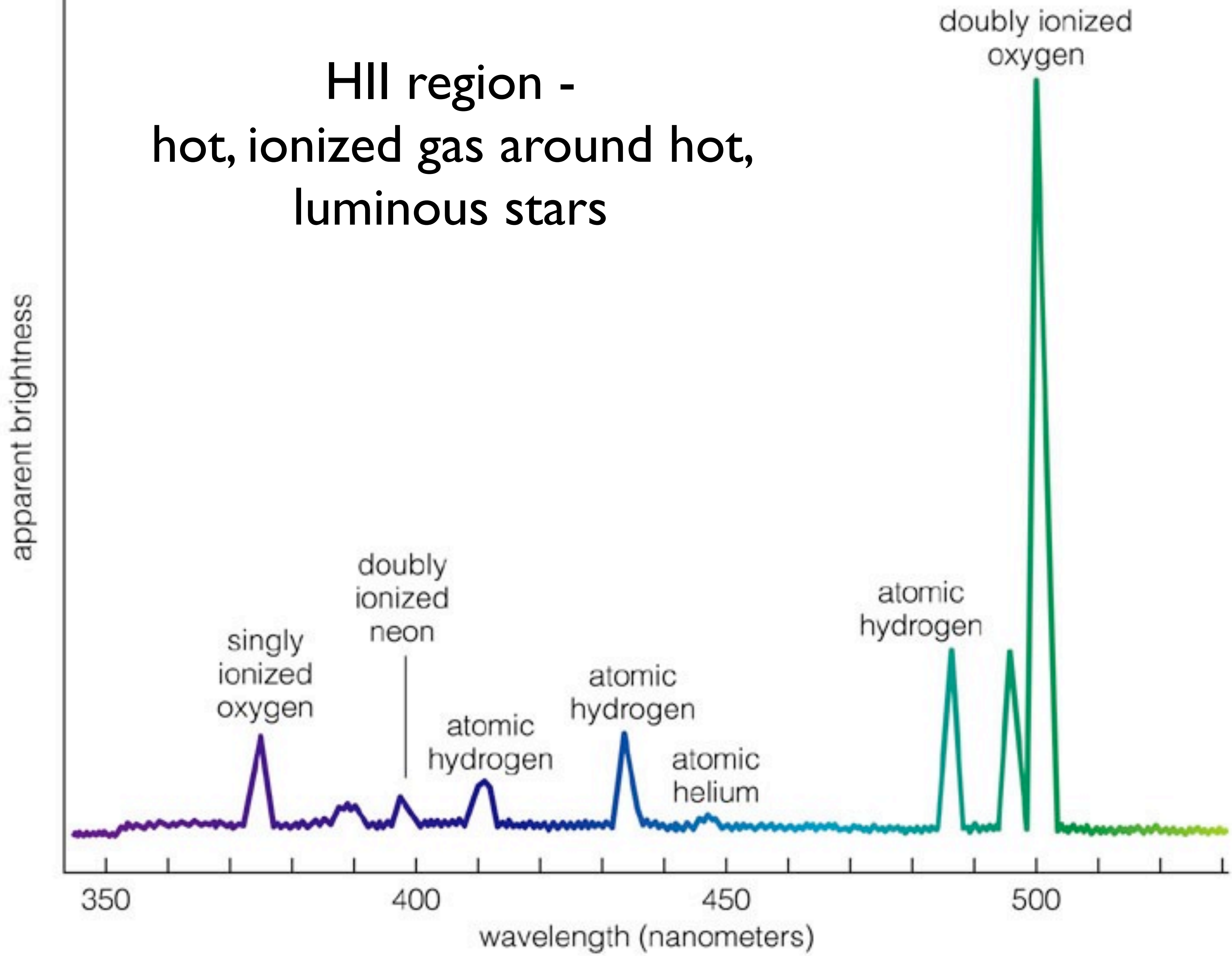
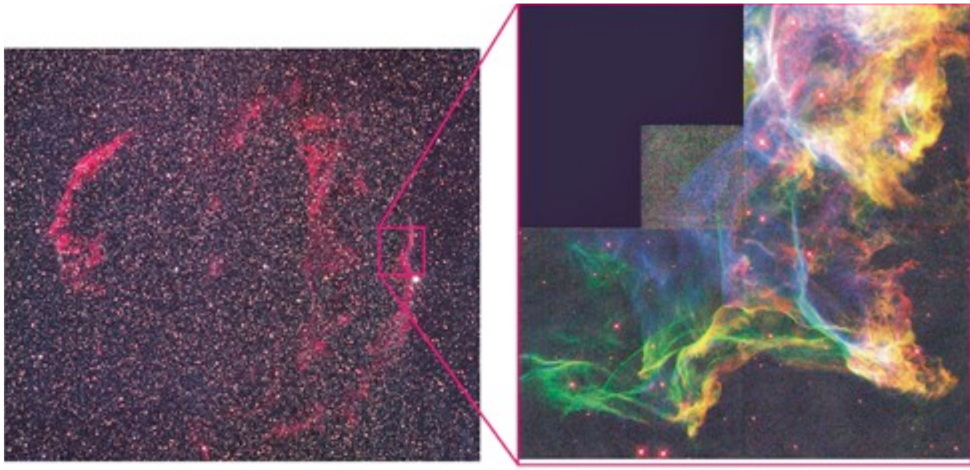
Enough wavelengths already?

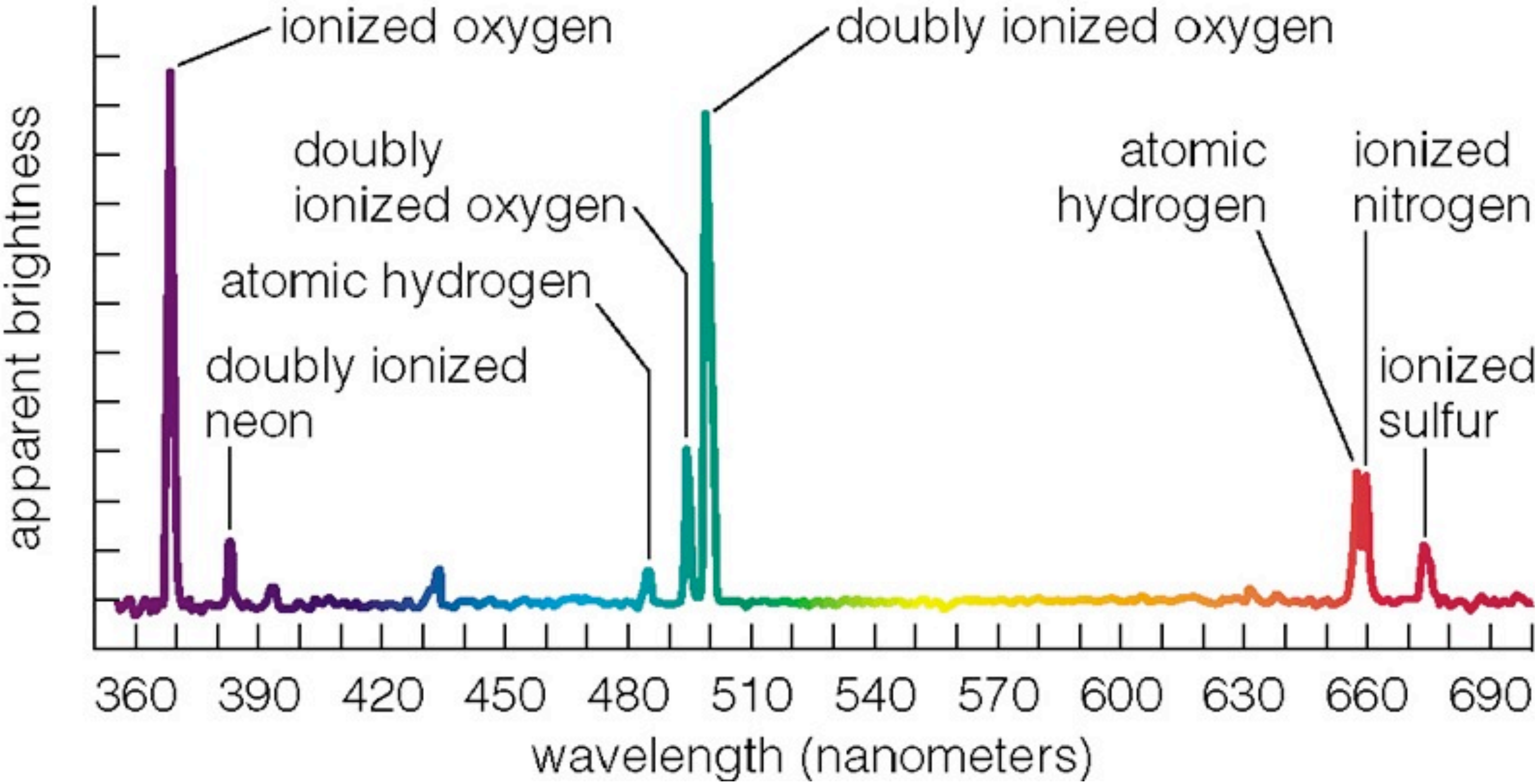
- Methods:
  - Multiwavelength imaging
  - Spectroscopy
    - Doppler Spectroscopy to determine velocities
    - Other spectroscopy to determine composition, density, and temperature

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



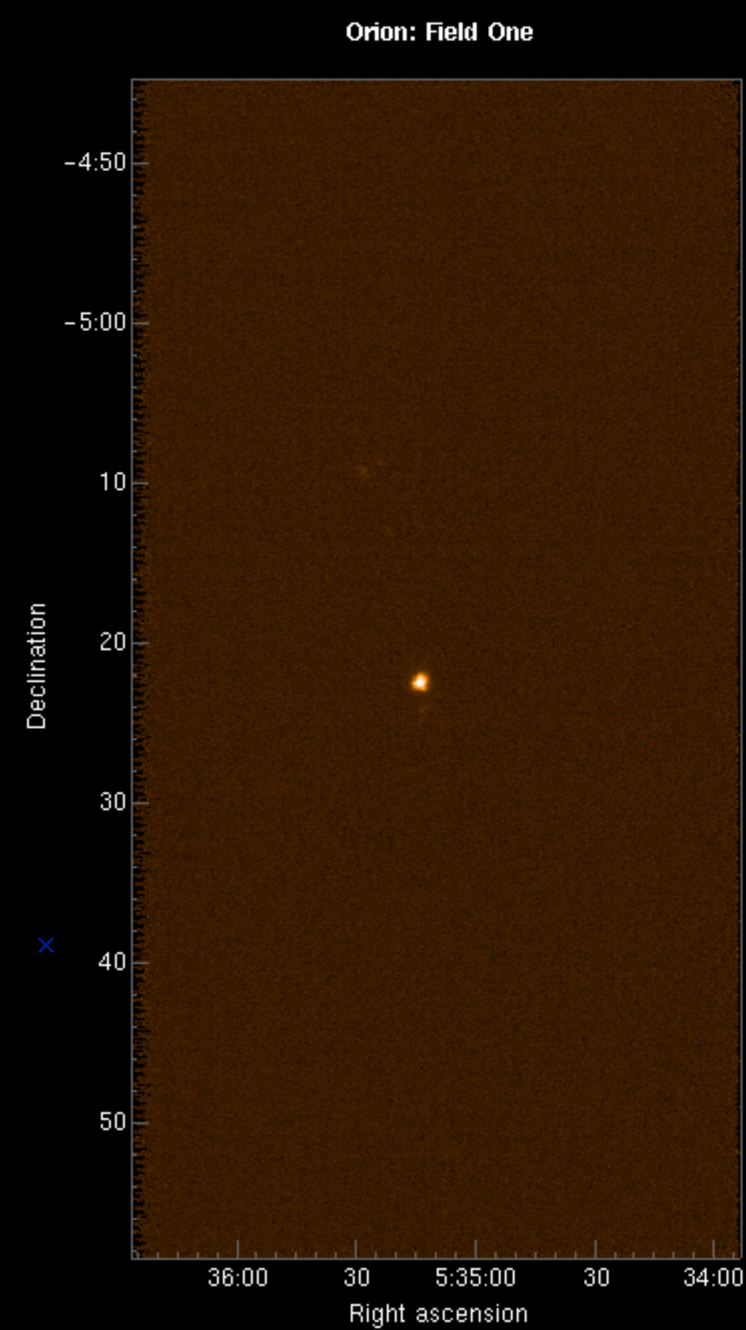


Supernova Remnants: New elements get mixed into the ISM



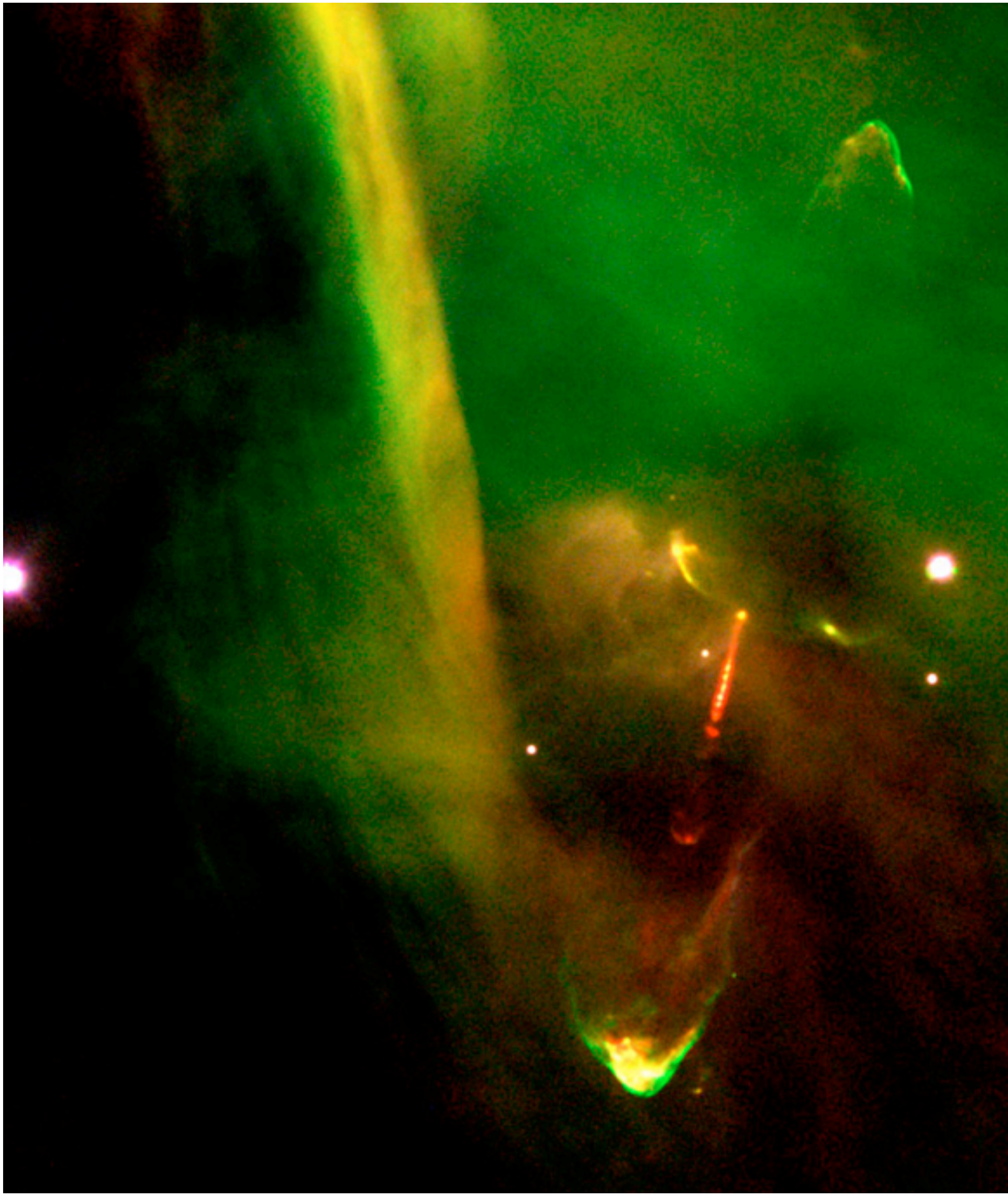
Doppler Spectroscopy: Each image is at a different velocity

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

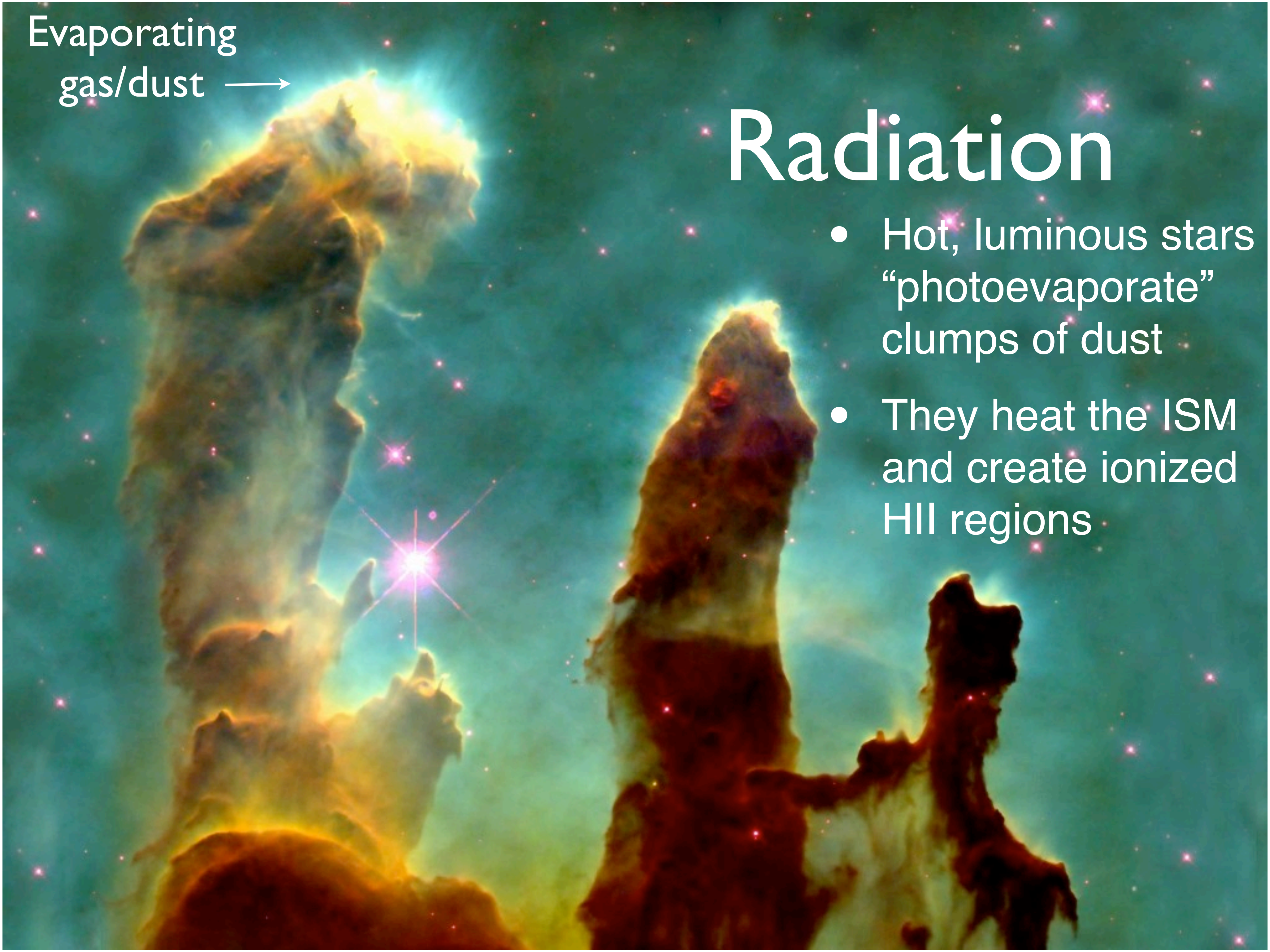


Jets

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

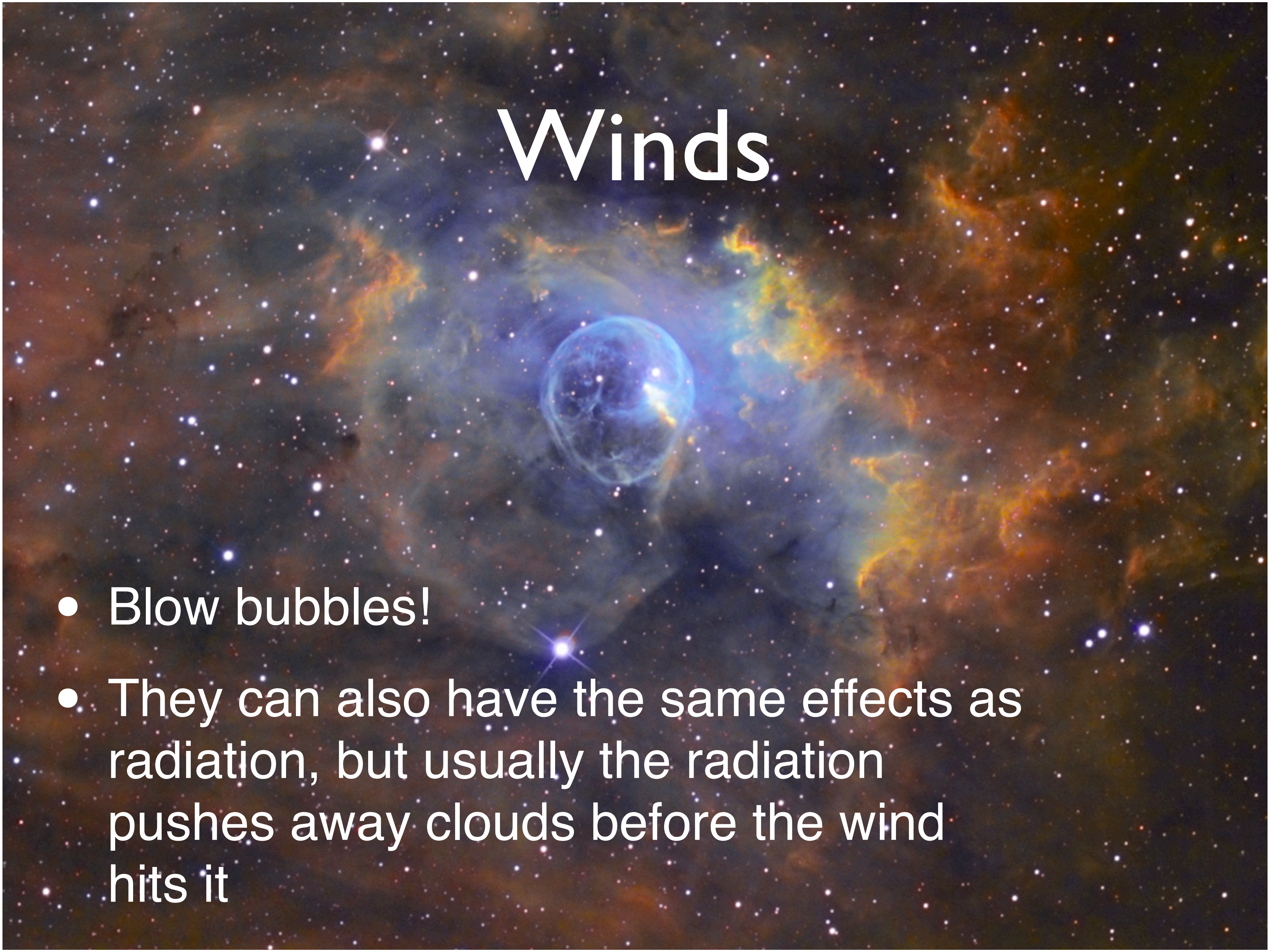
Radiation

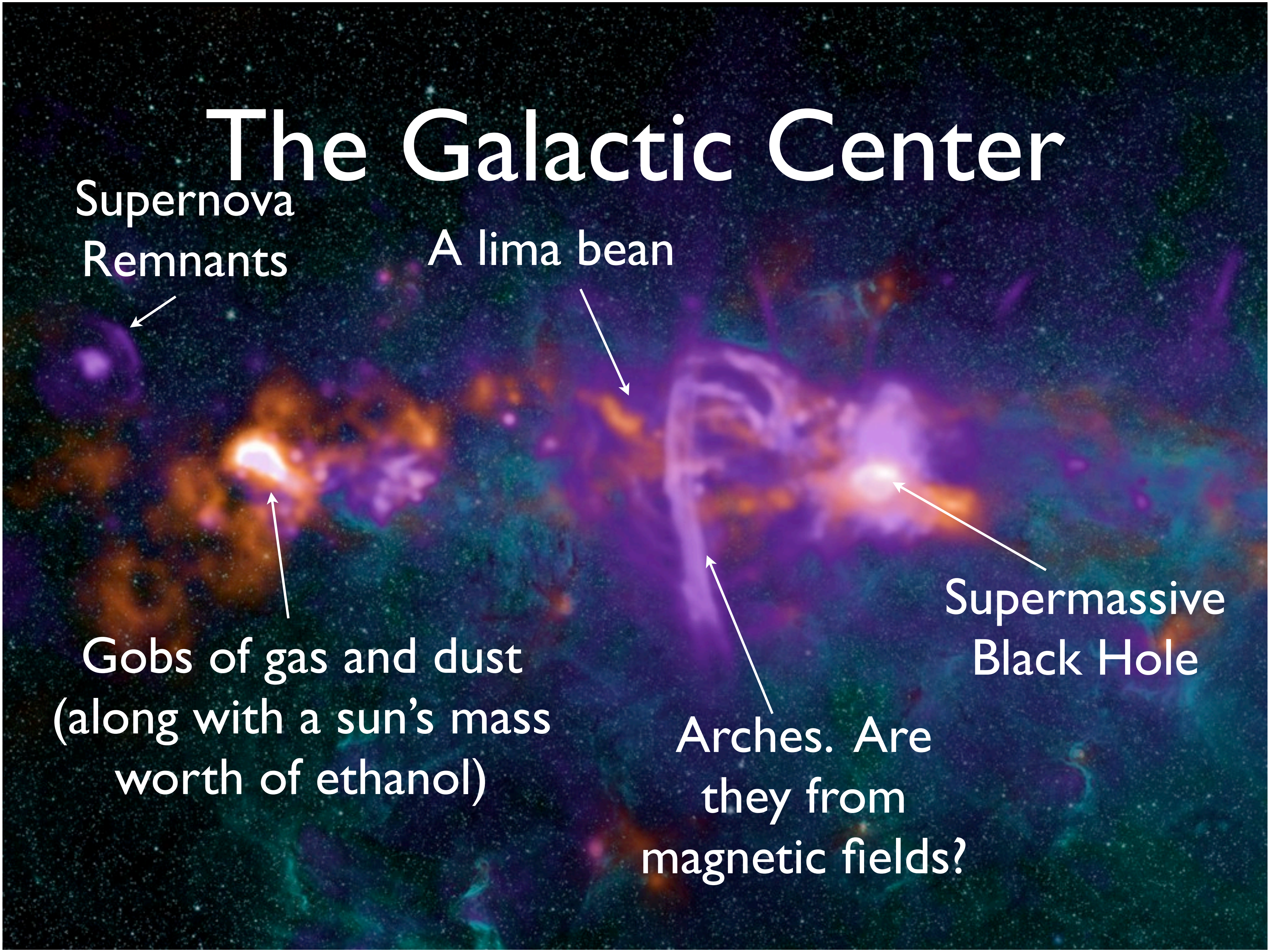
- Hot, luminous stars "photoevaporate" clumps of dust
- They heat the ISM and create ionized HII regions



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
Supernova Remnants
A lima bean
Gobs of gas and dust (along with a sun's mass worth of ethanol)
Arches. Are they from magnetic fields?
Supermassive Black Hole

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

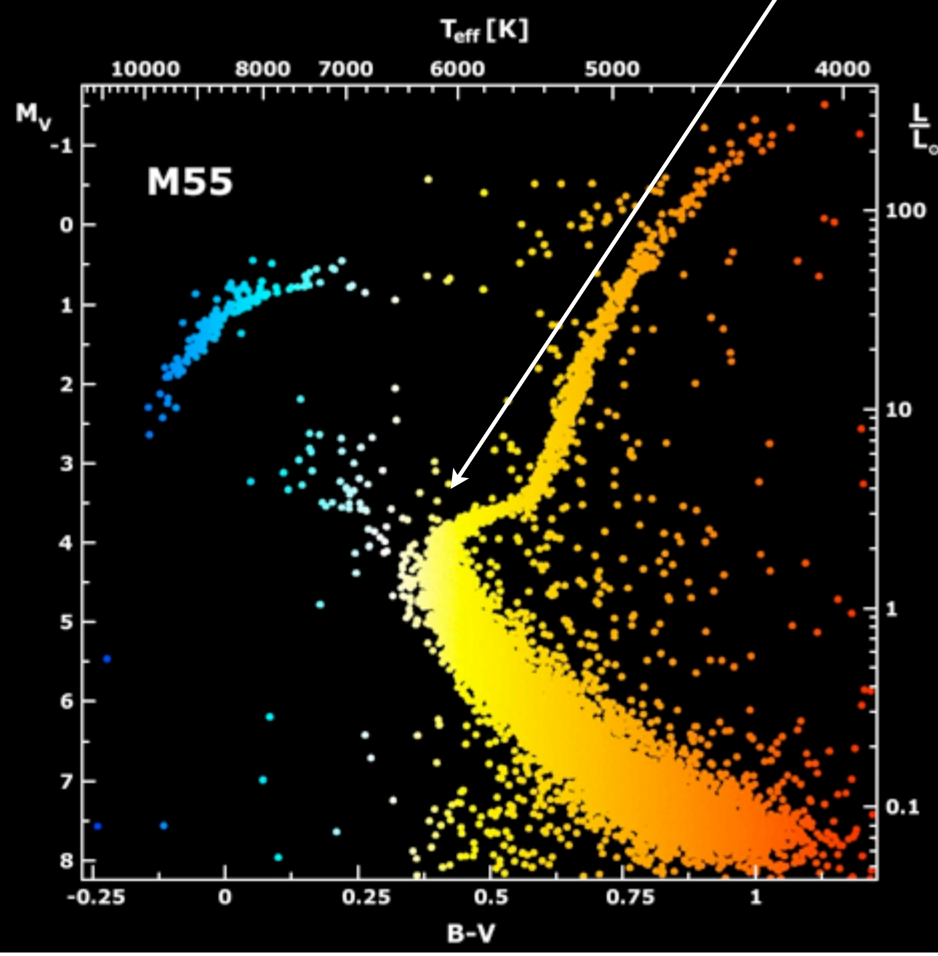
Two types

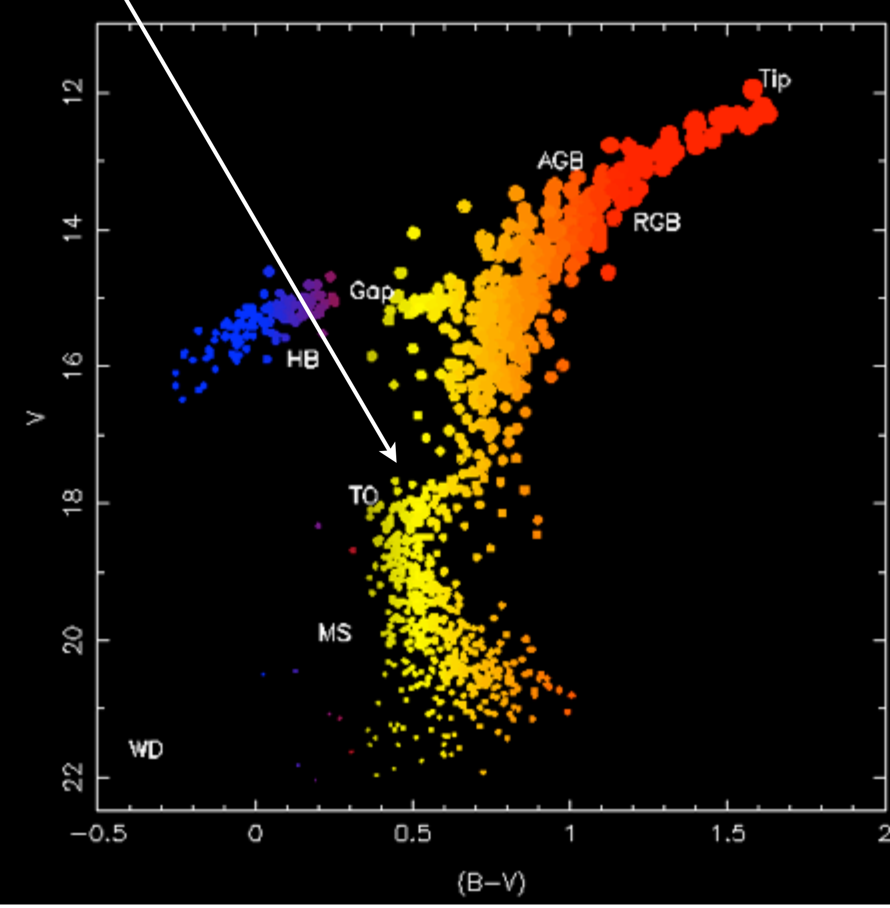
- Globular Clusters
  - Round
  - LOTS of stars (100,000s)
  - Old (12-13 GYr)
  - No gas

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

How do we know Globular Clusters are old?

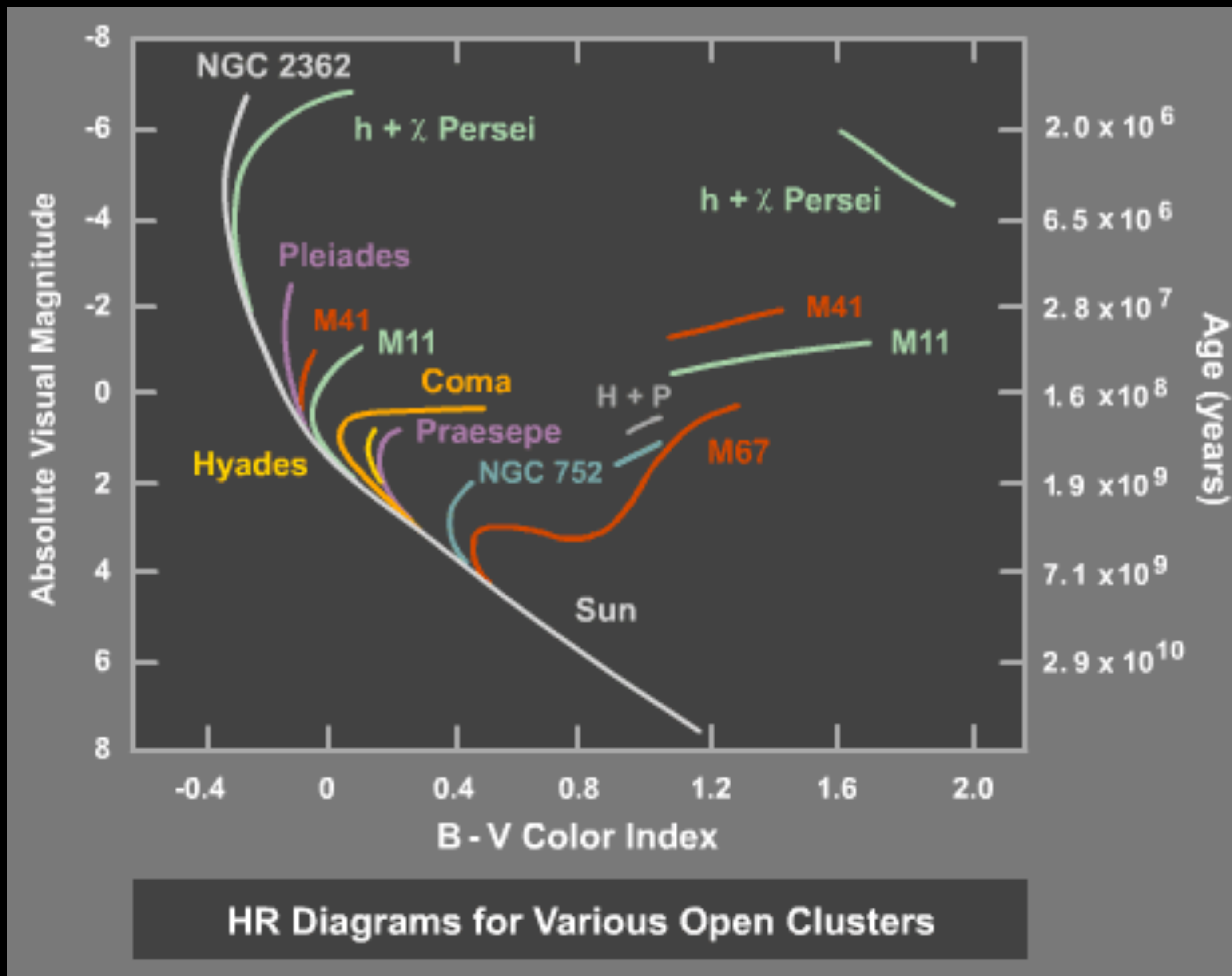
Turnoff point



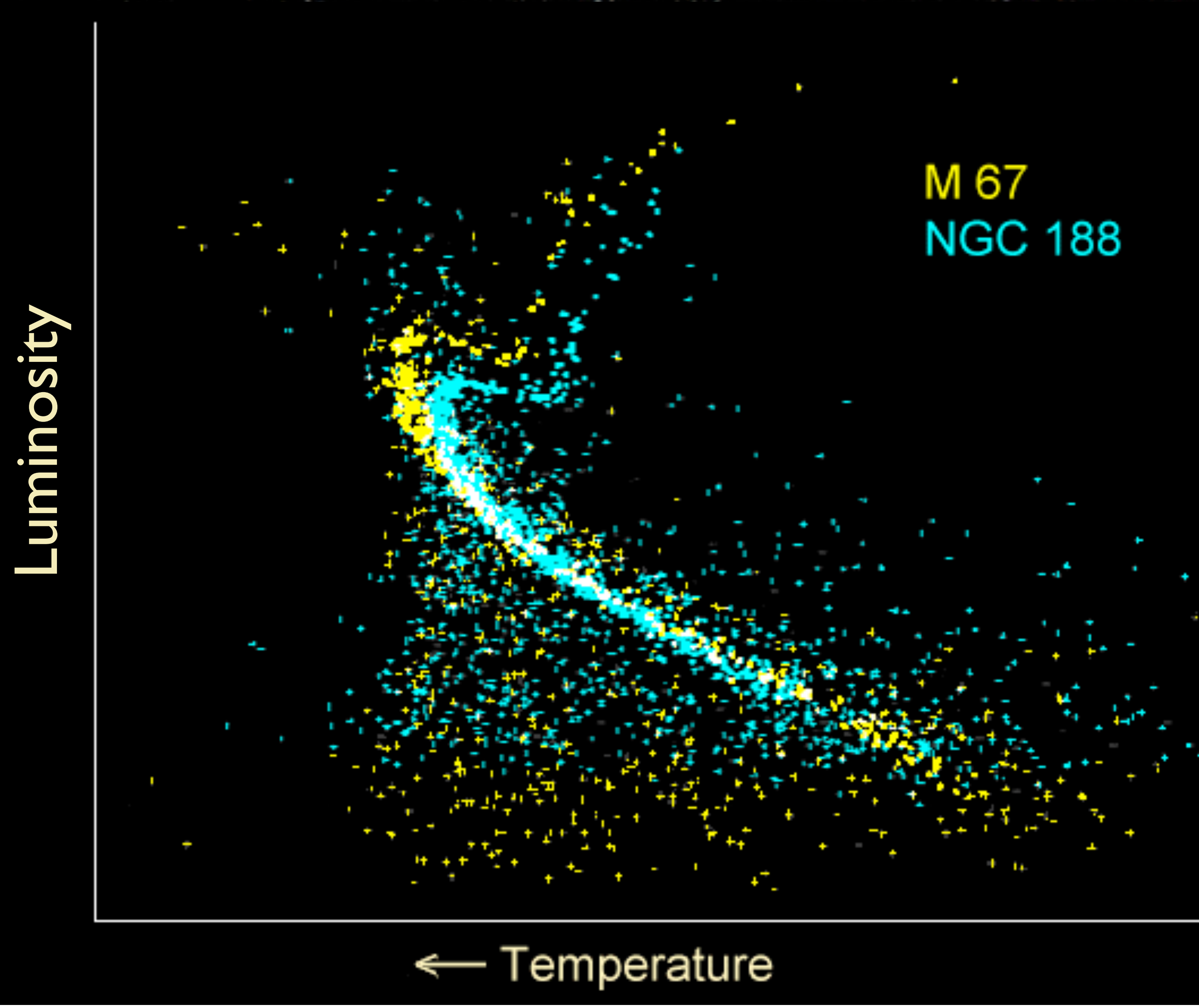


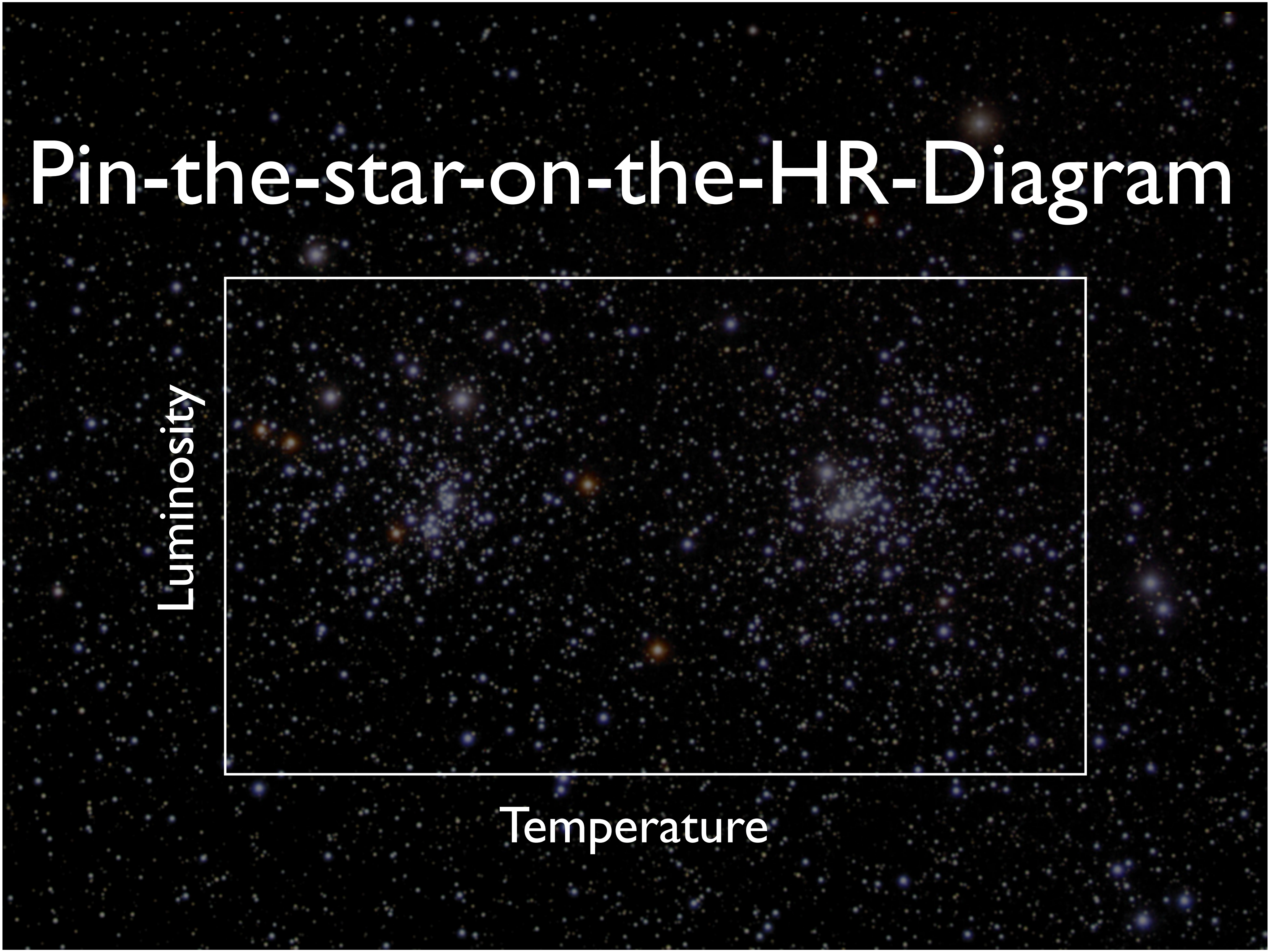
Open Cluster HR diagrams

Luminosity



Which cluster is older?




Pin-the-star-on-the-HR-Diagram
Luminosity
Temperature

I. 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*