Galaxies, Cosmology and the Accelerating Universe

Class 3: Starlight and Stars

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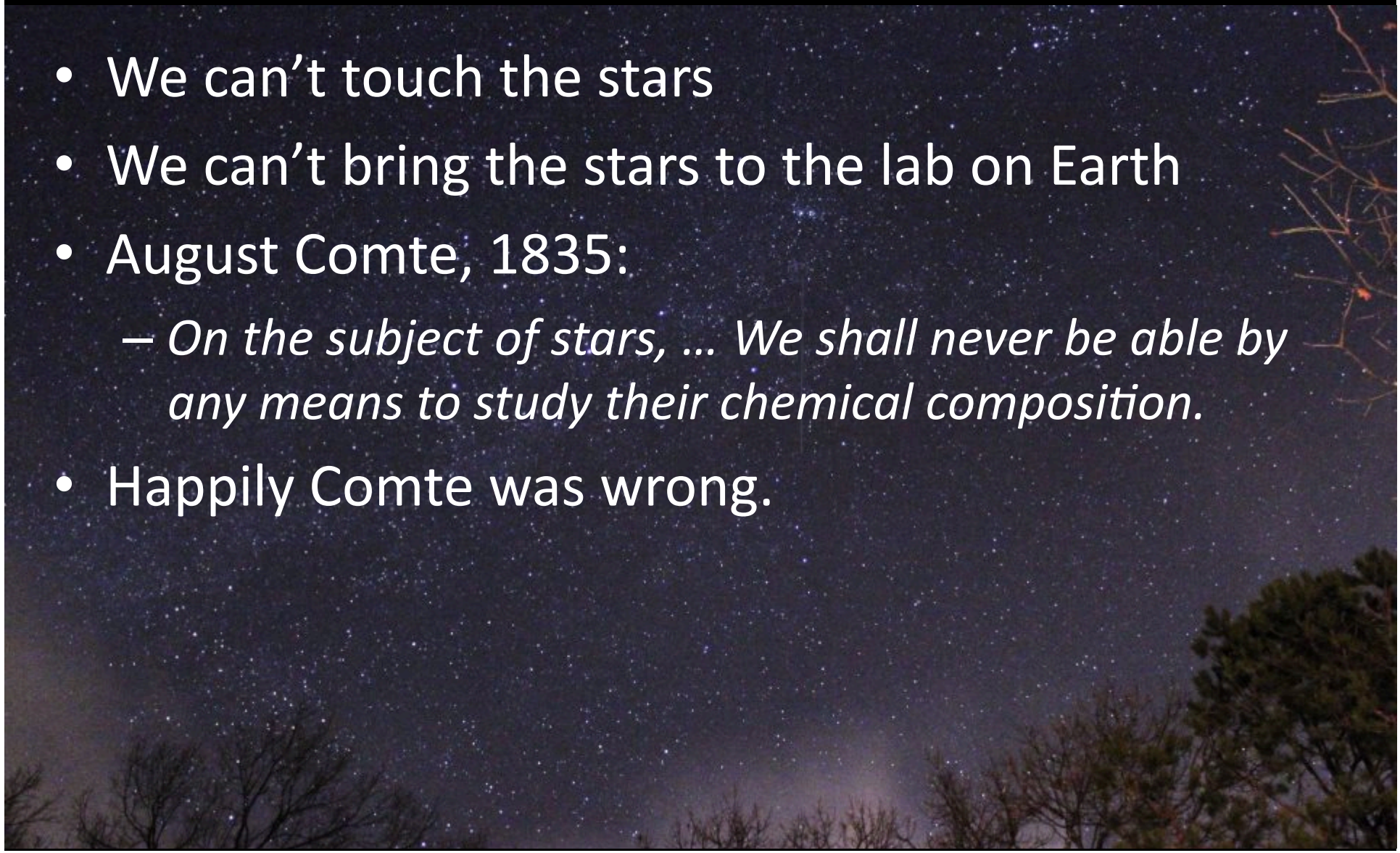
Questions?

Galaxies are Made of Stars

To understand galaxies we have to understand stars

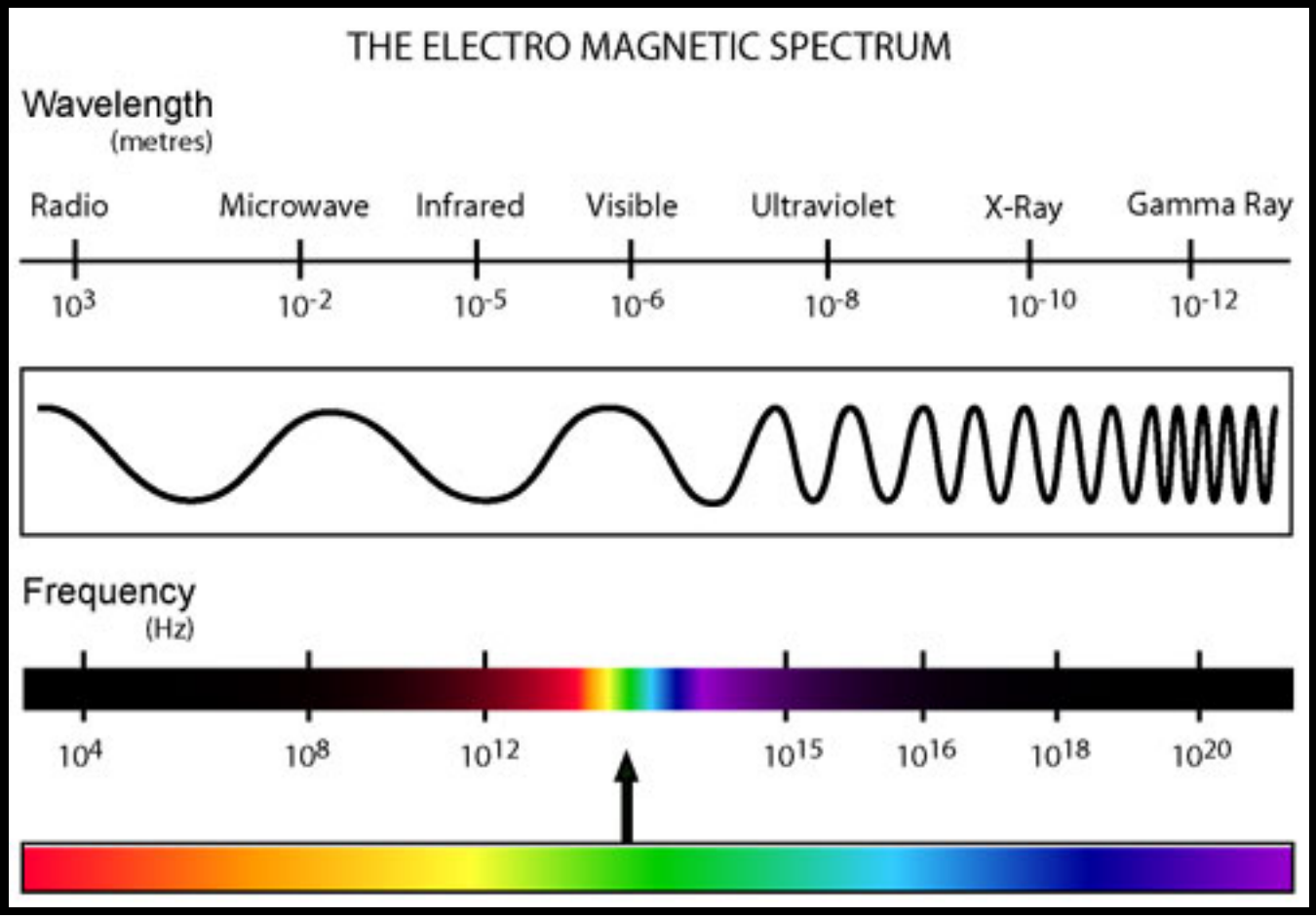
All We Have is Starlight



- We can't touch the stars
- We can't bring the stars to the lab on Earth
- August Comte, 1835:
  - *On the subject of stars, … We shall never be able by any means to study their chemical composition.*
- Happily Comte was wrong.

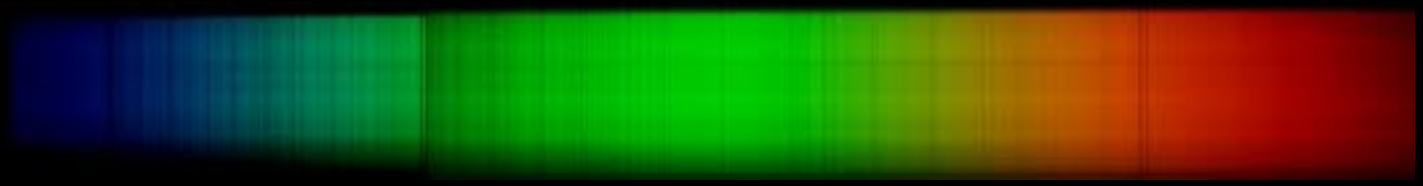
Understanding Light

- Light is waves in electric and magnetic fields
- Visible light is one small part of the *electromagnetic spectrum*



Picking Apart Starlight

- We can break starlight into its colors by using a prism (or diffraction grating)
- The resulting rainbow is called a spectrum
- Many rainbows are called spectra
- We can learn many things from spectra



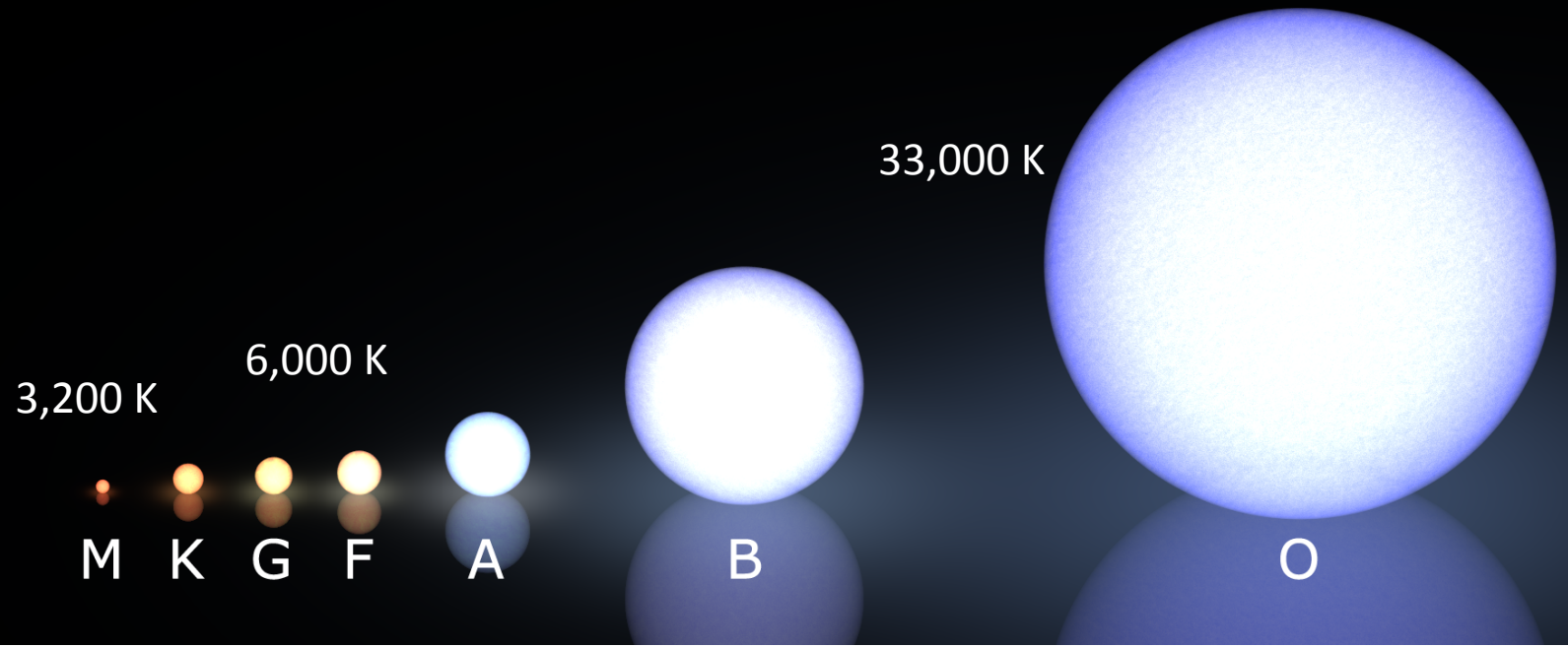
Why Things Glow

- All hot matter glows
  - Same temperature, same color
    - no matter what material

- Gas will glow in specific colors characteristic of the specific gas

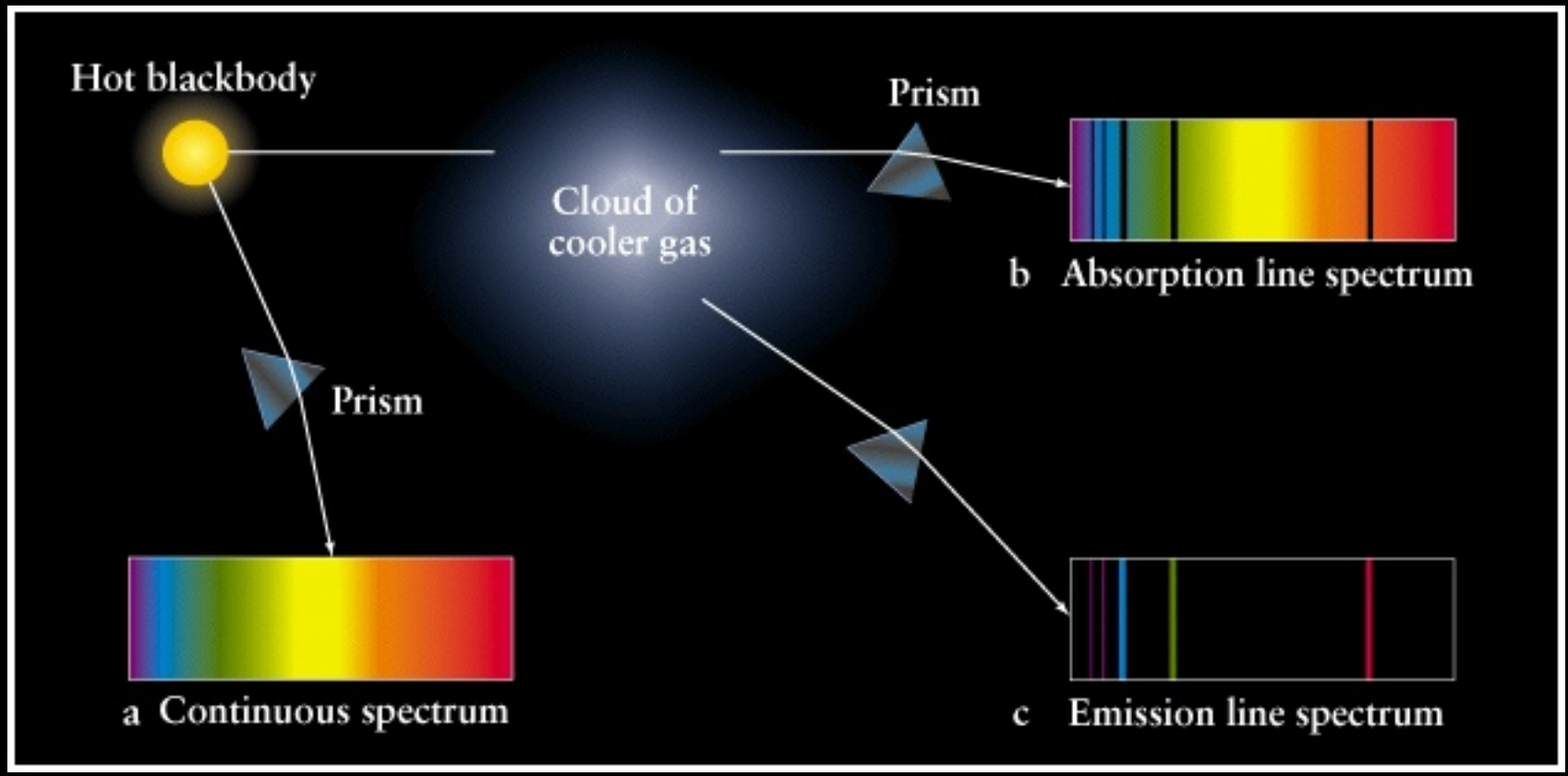
Temperature Determines Color

- All materials glow with the same color at the same temperature
  - Orange coals are about 1,000 K = 1,340° Fahrenheit
- The temperature of the surface of the star determines the color
  - The Sun is about 5,800 K = 9,941° Fahrenheit

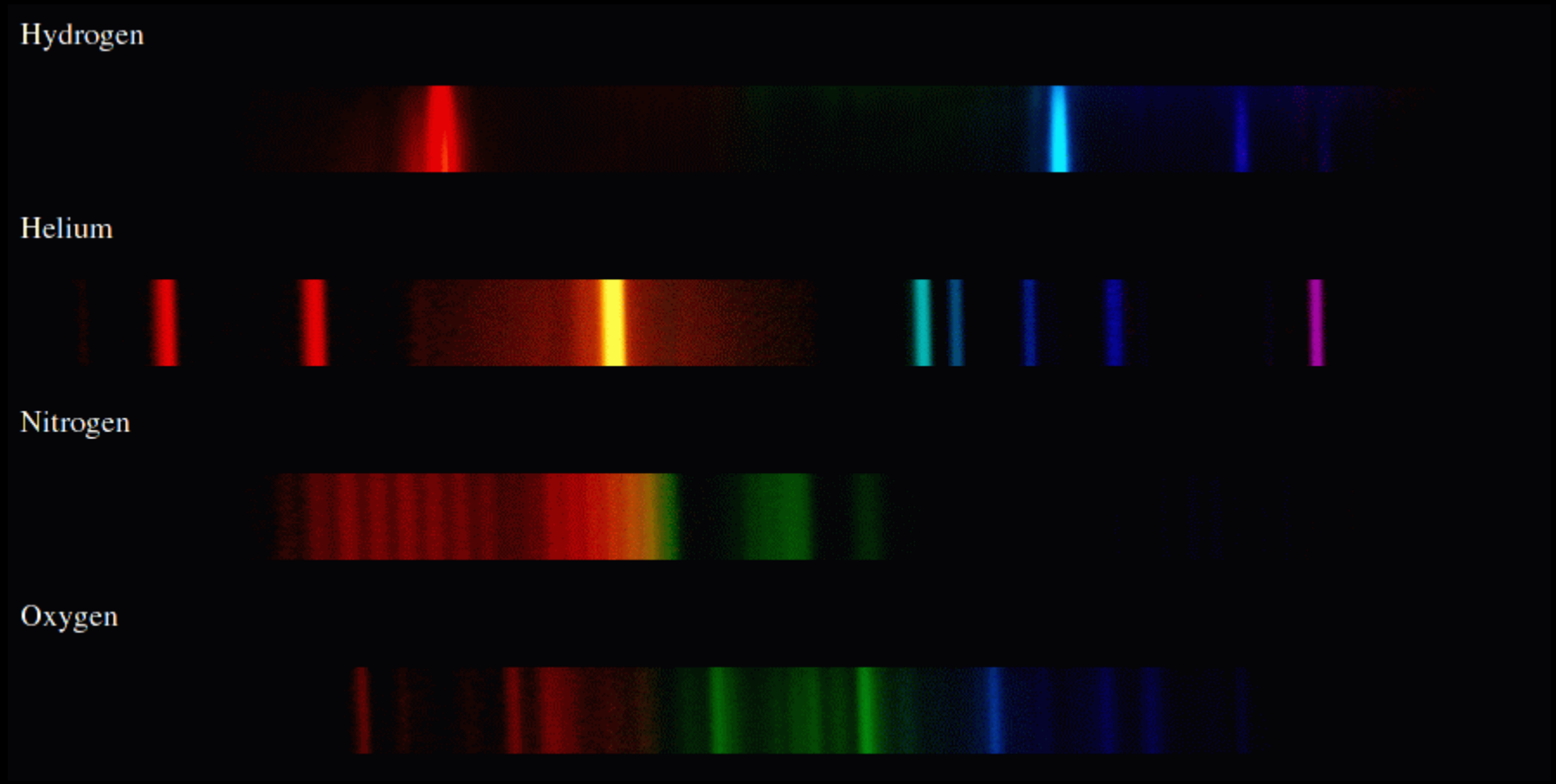


Light Interacts with Gas

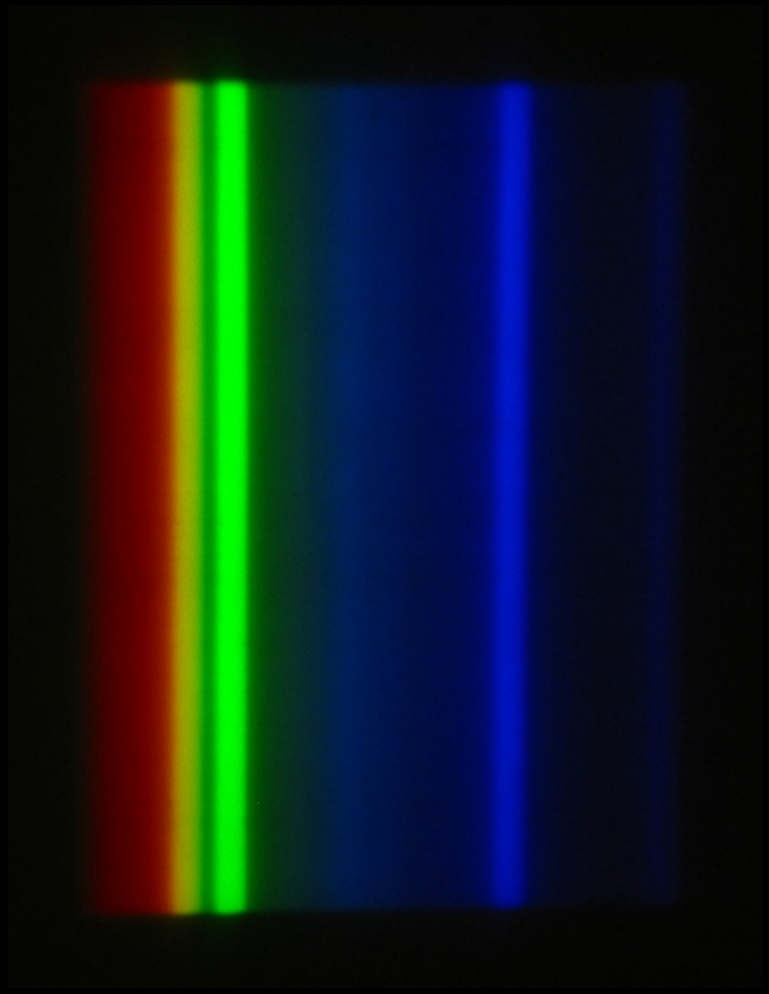
- Gas absorbs light of very specific colors
- Then re-emits the same colors



Example Gases and their colors

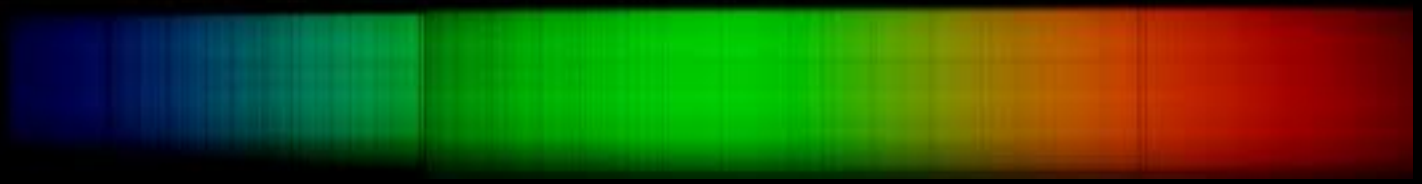


Try Your Spectrum

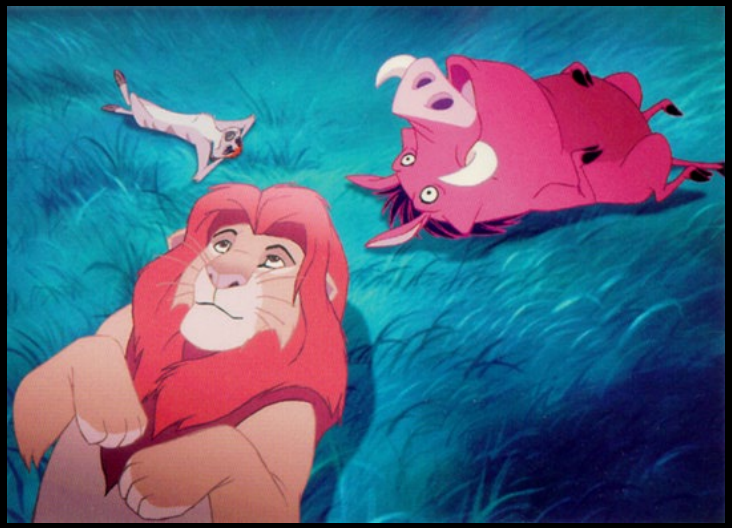


What a Spectrum Tells Us

- We use the spectrum to tell us two things about stars
  - Chemical composition
  - Motion
- We start with what stars are made of and how they live



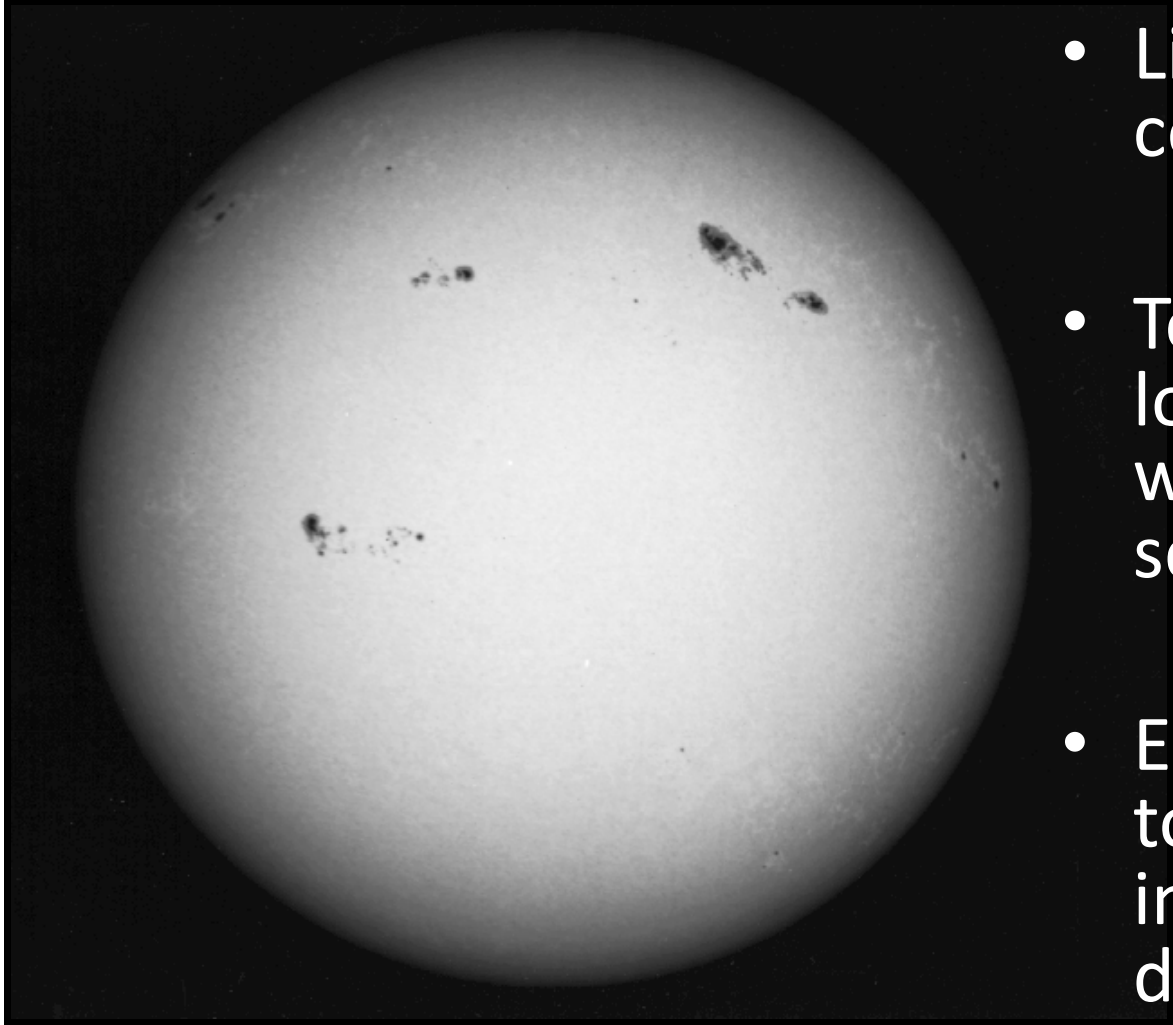
What Are Stars?



"...balls of gas burning billions of miles away"

- Pumbaa, *the Lion King*

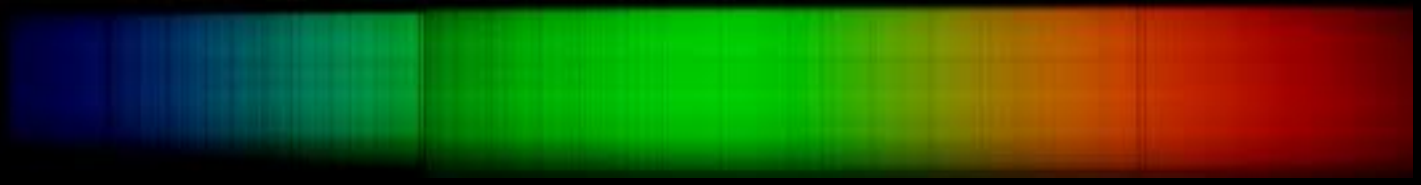
Big Ball of Gas Glowing from the Inside



- Light is created in the center
- Towards the edge it looks darker because we're seeing light scattered by the gas
- Exactly how it darkens toward the edge is important for planet detection

Measuring the Composition of Stars

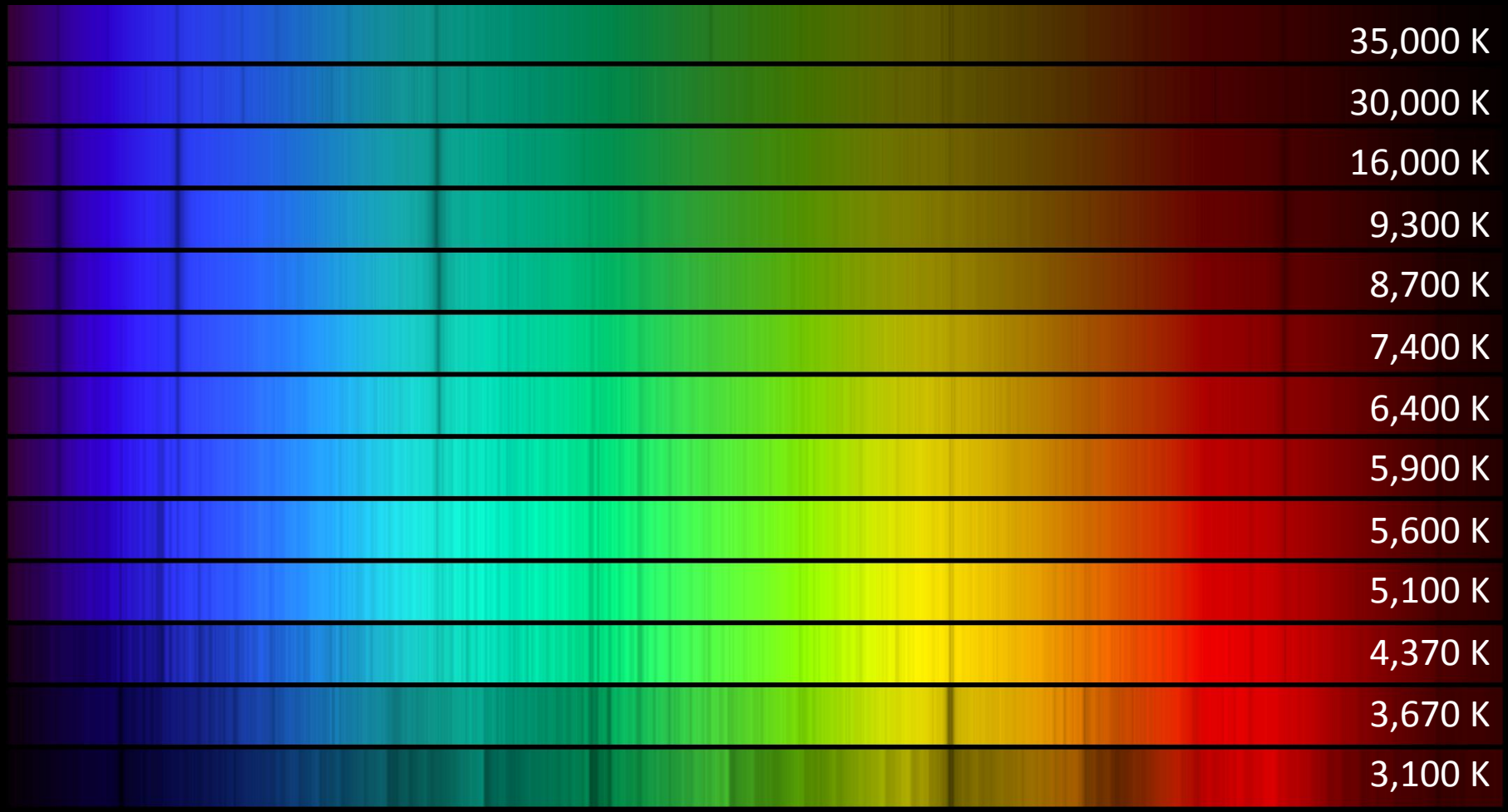
- The light from the center of the star goes through the star's atmosphere
  - Gases in the star's atmosphere absorb the light, creating lines in the spectrum
- The star's absorption lines are at the same colors as those we see in spectra on Earth
  - So they must be due to the same gases!
  - So we can say what Stars are made of!!



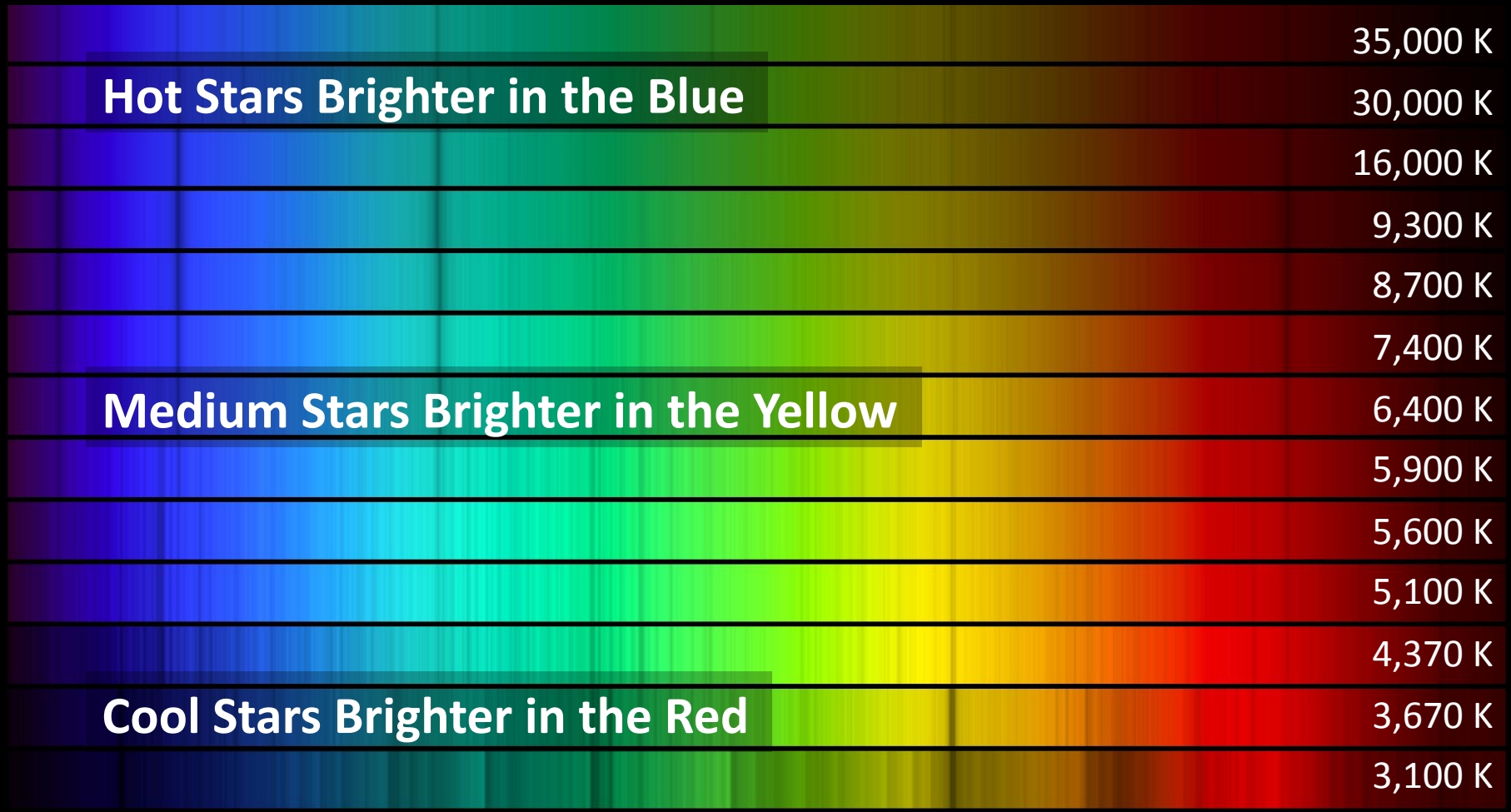
What Stars are Made Of

- Depends a little on the star
- Most stars:
  - 74.9% Hydrogen
  - 23.8% Helium
  - < 2% heavier elements
    - But the heavier elements have important effects
      - Like planets

Star Spectra of Different Temperatures



Color Depends on Temperature



Stars are Born in Large Amorphous Clouds of Gas and Dust

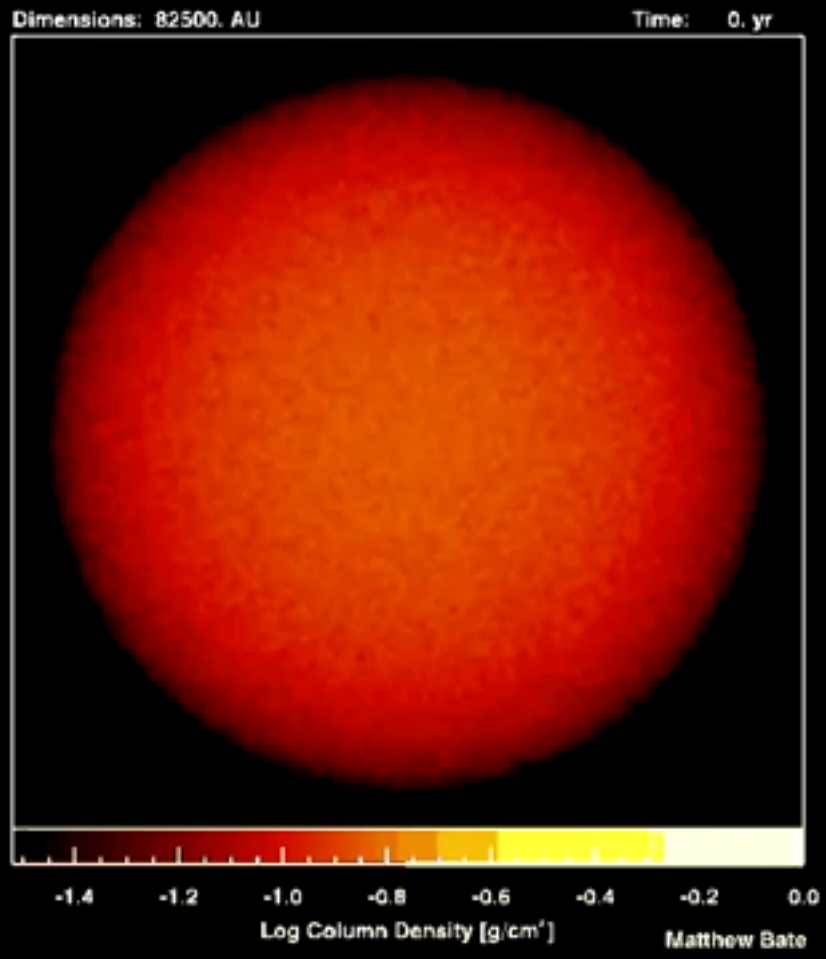
Star Birth in the Orion Nebula

Star Birth in the Orion Nebula

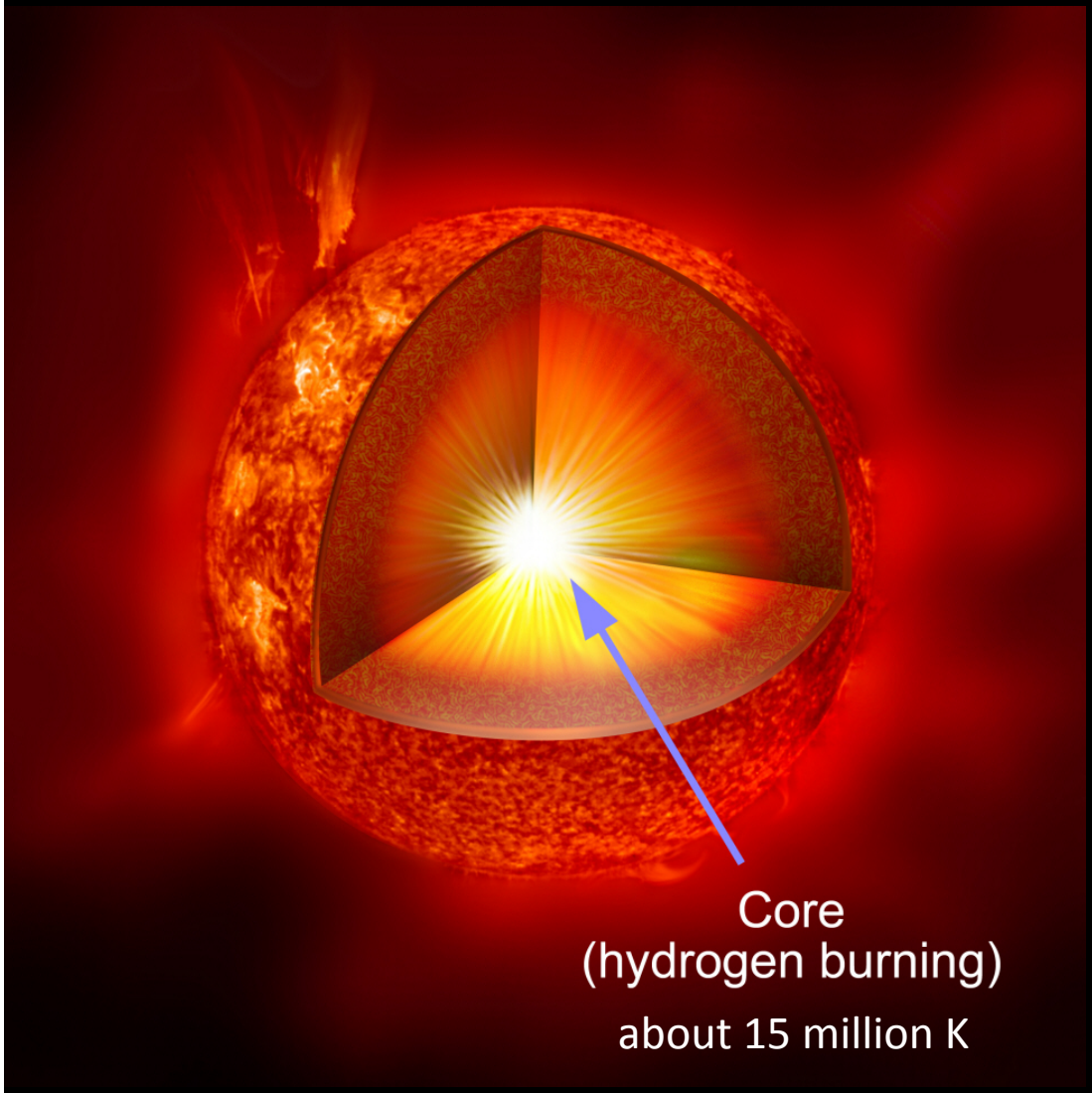
These stars are about 300,000 years old

Star Birth in the Orion Nebula

Simulated Star Birth

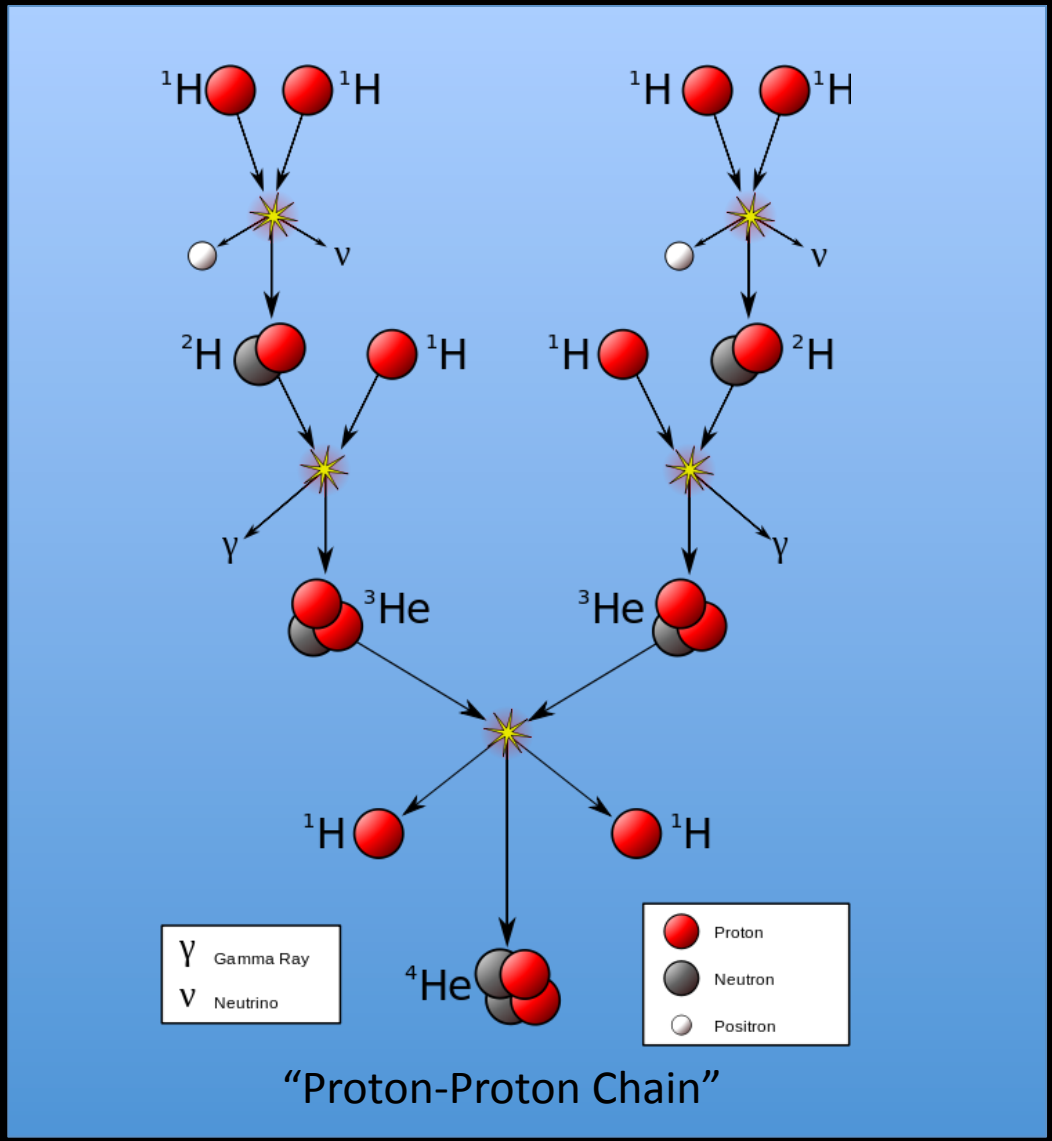


Most Stars Shine by Burning Hydrogen



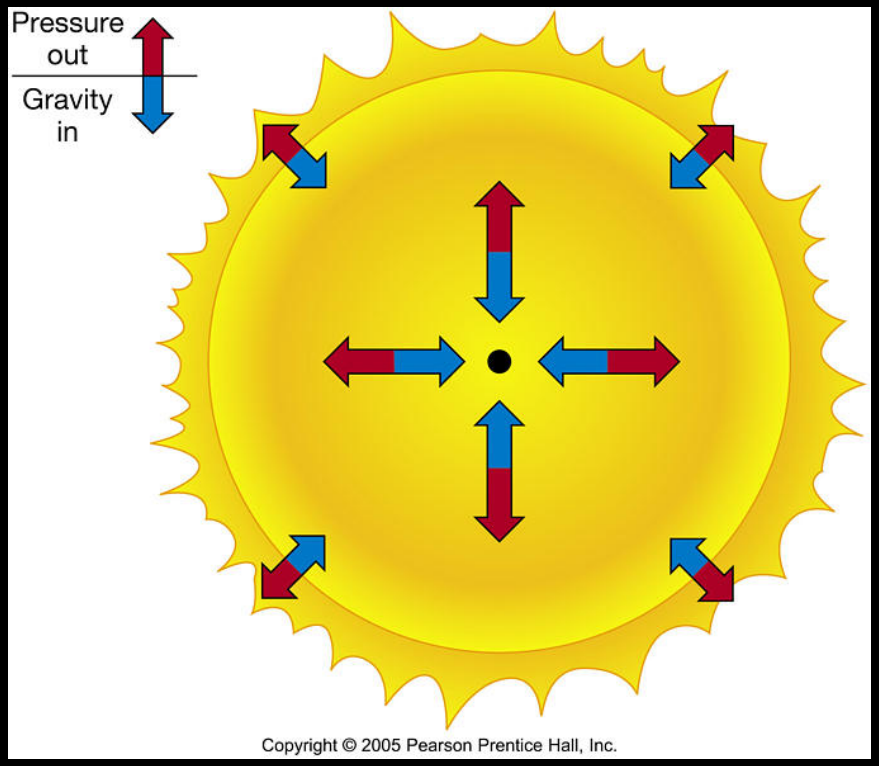
- Hydrogen fusion in the center
- Caused by the very high pressure and temperature from gravity
- Older stars burn heavier elements

Hydrogen Burning in the Sun



"Proton-Proton Chain"

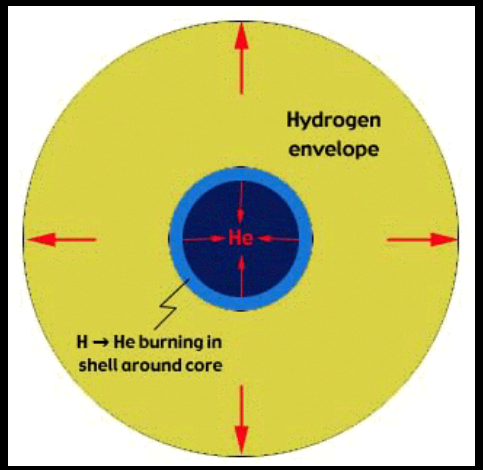
The Stellar Thermostat



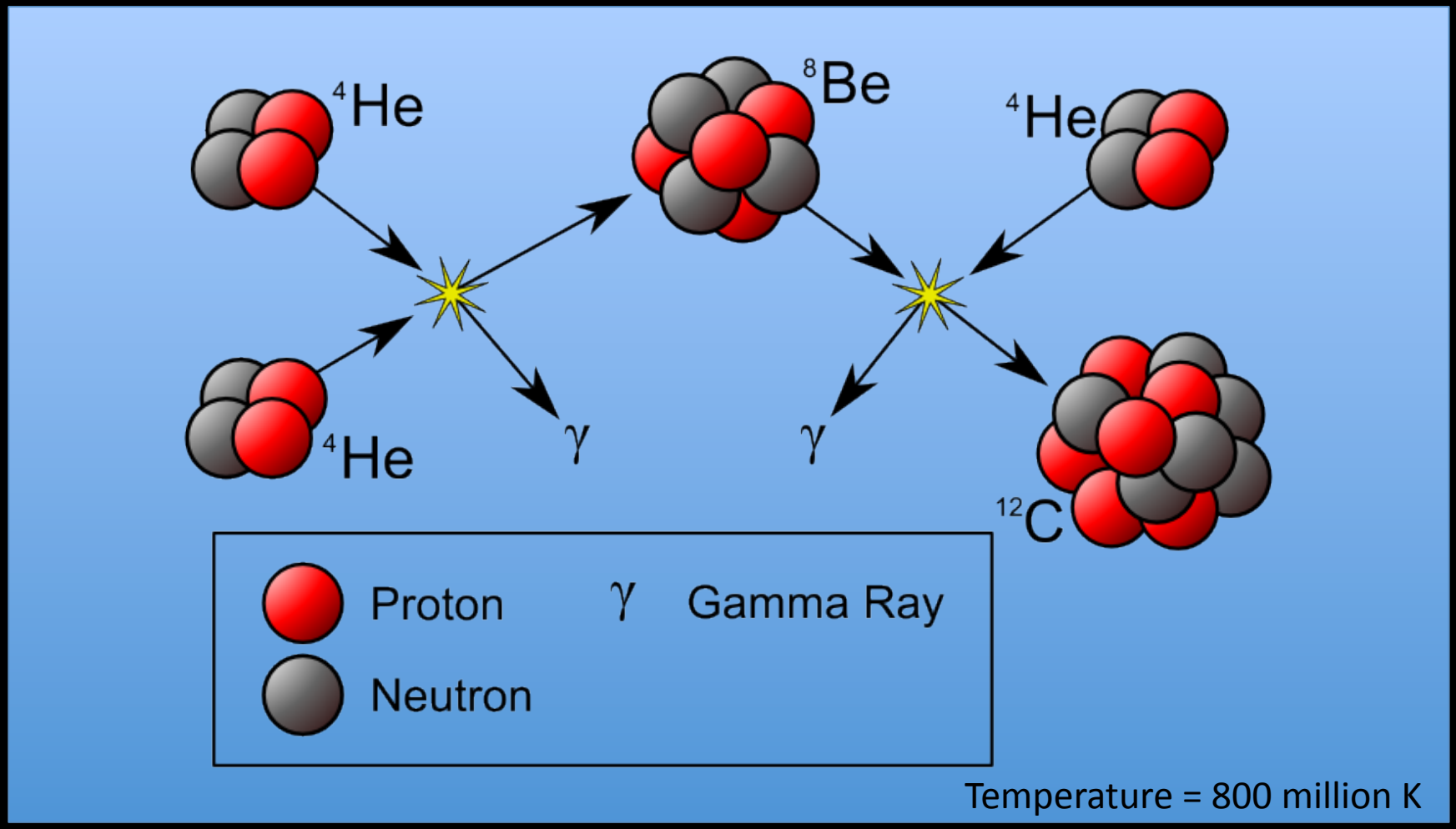
- If the star expands,
  - The center cools
  - So less force from the center
  - So gravity makes it contract
  - Which heats the center
  - Which makes the star expand…
- A stable star is in perfect balance

But Eventually the Hydrogen Runs Out

- After about 9 billion years (4 billion year from now) most of the Hydrogen in the core will be converted to Helium
- Then the burning slows down, the core cools down, gravity takes over heating the core…

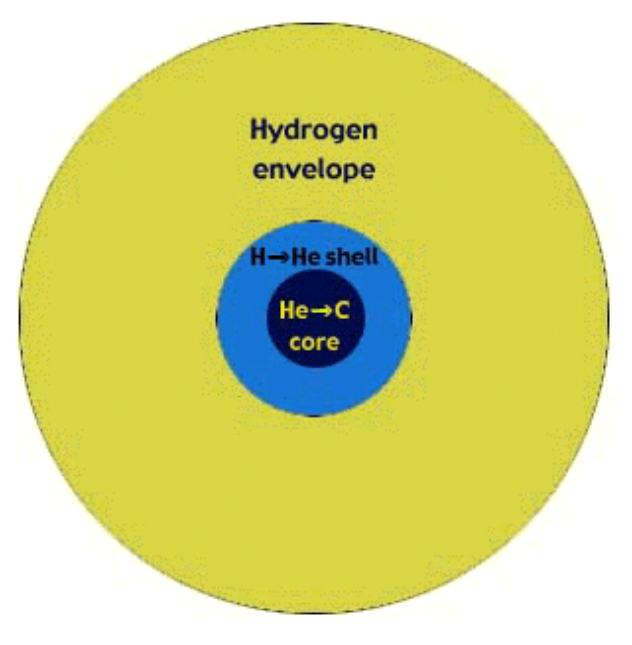


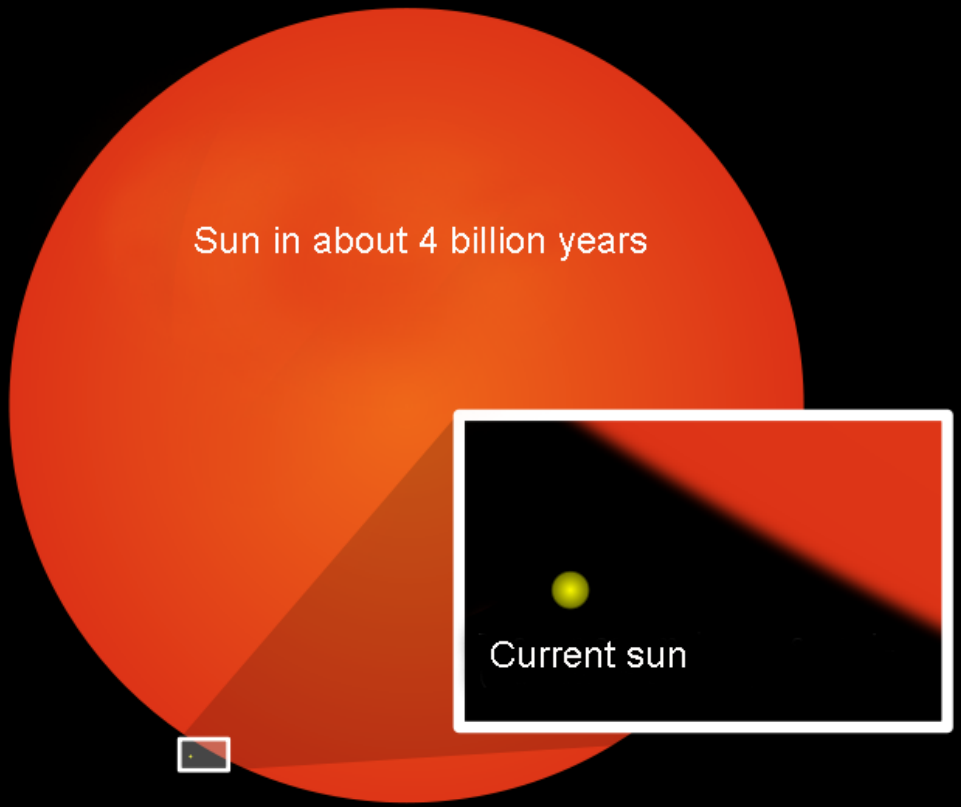
When the Core Gets Hot Enough the Helium Burns to Carbon



Because the Core is So Hot the Star Expands

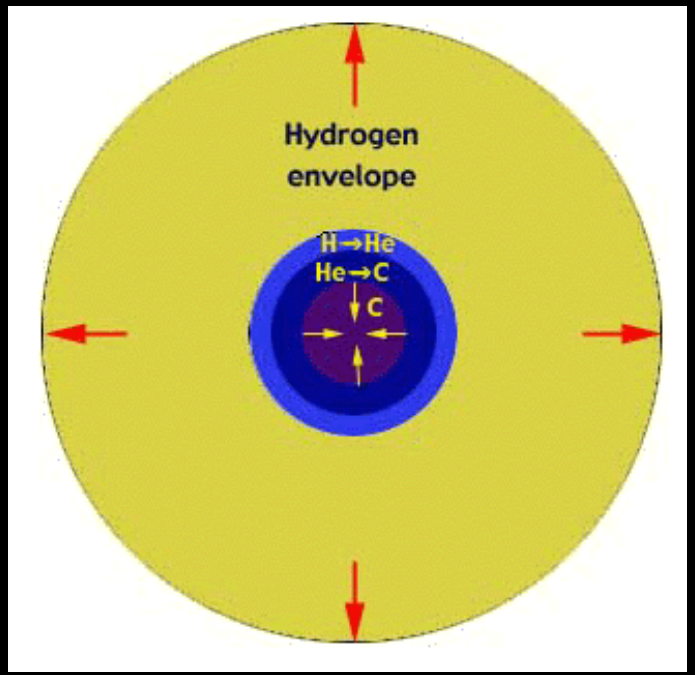
- The star's surface cools off, so it becomes redder
  - Red giant star

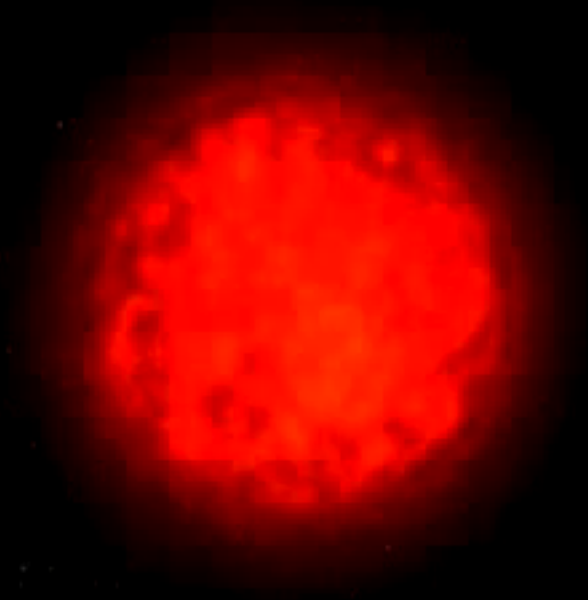




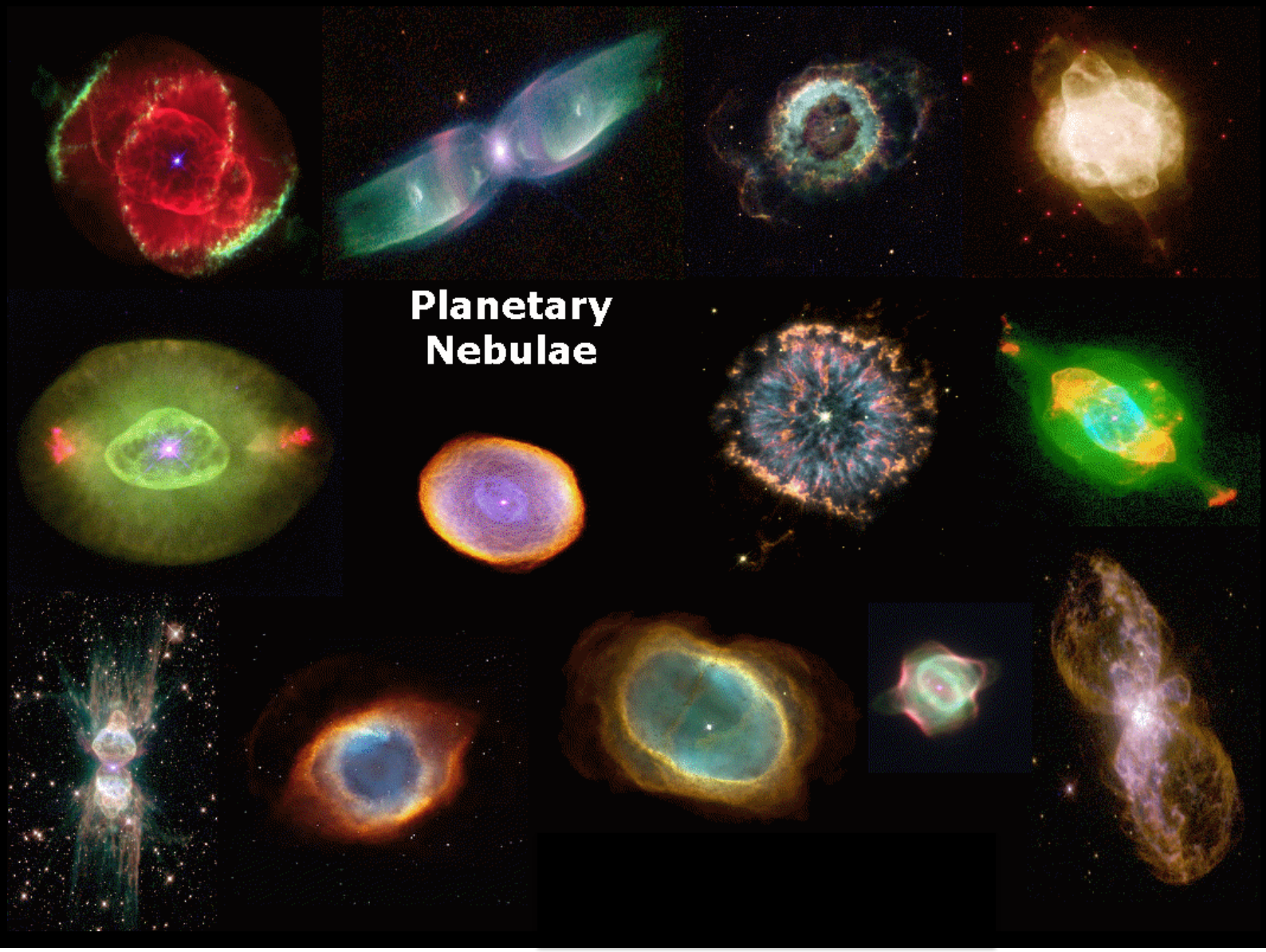
Then the Helium in the Core Runs Out

- And that's it: the Sun is not heavy enough to burn the carbon
  - Gravity takes over, heating the core and blowing off about half the sun's material as a planetary nebula



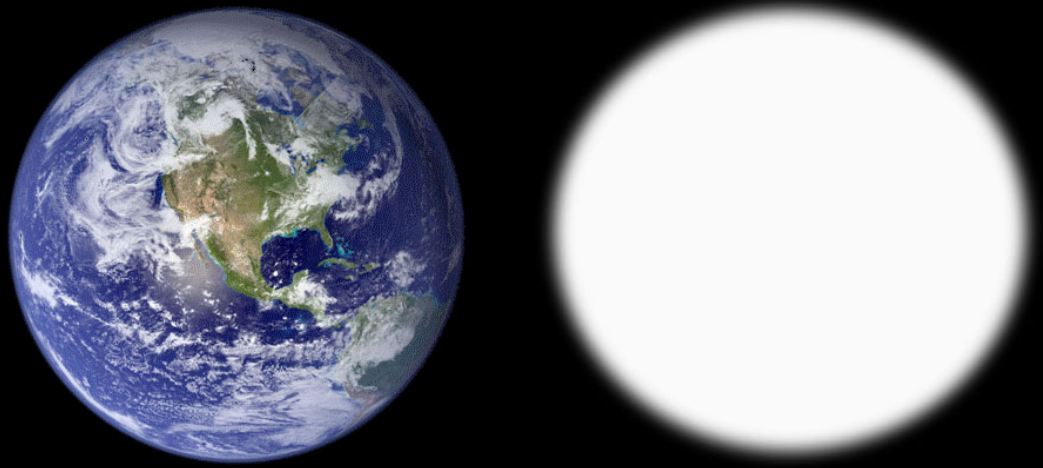


We See Lots of Planetary Nebulae

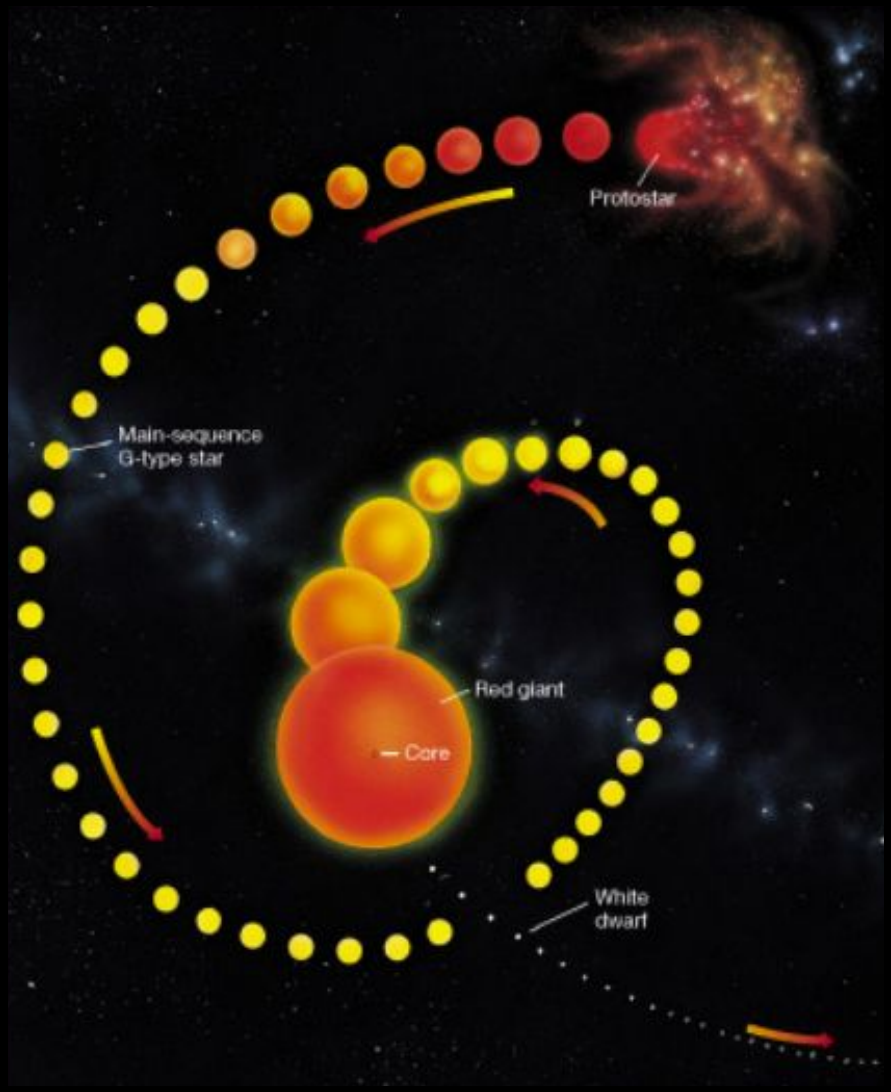


The Core of the Sun Becomes a White Dwarf

- About the size of the Earth
- Very hot on the surface
  - 30,000 to 100,000 K
  - Exposed burning Hydrogen and Helium
- Slowly burns out over trillions of years



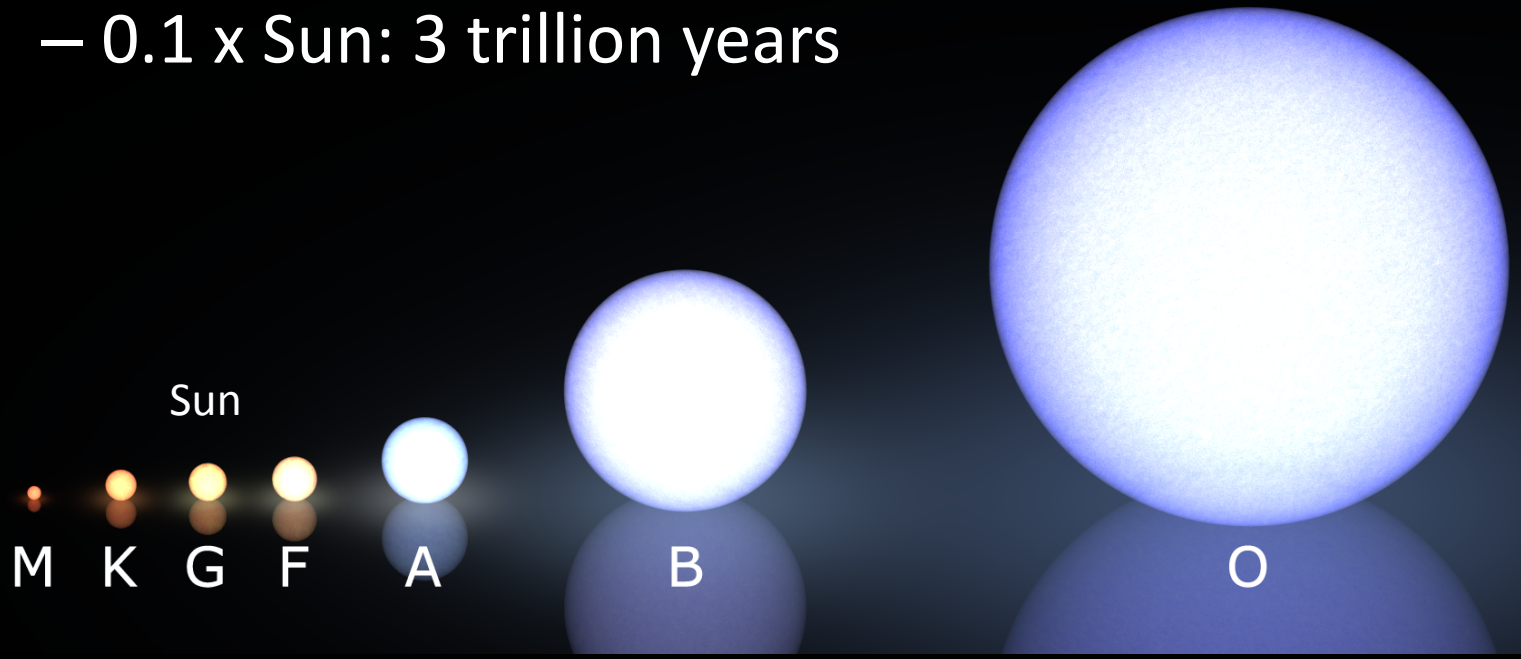
Life Cycle of Stars



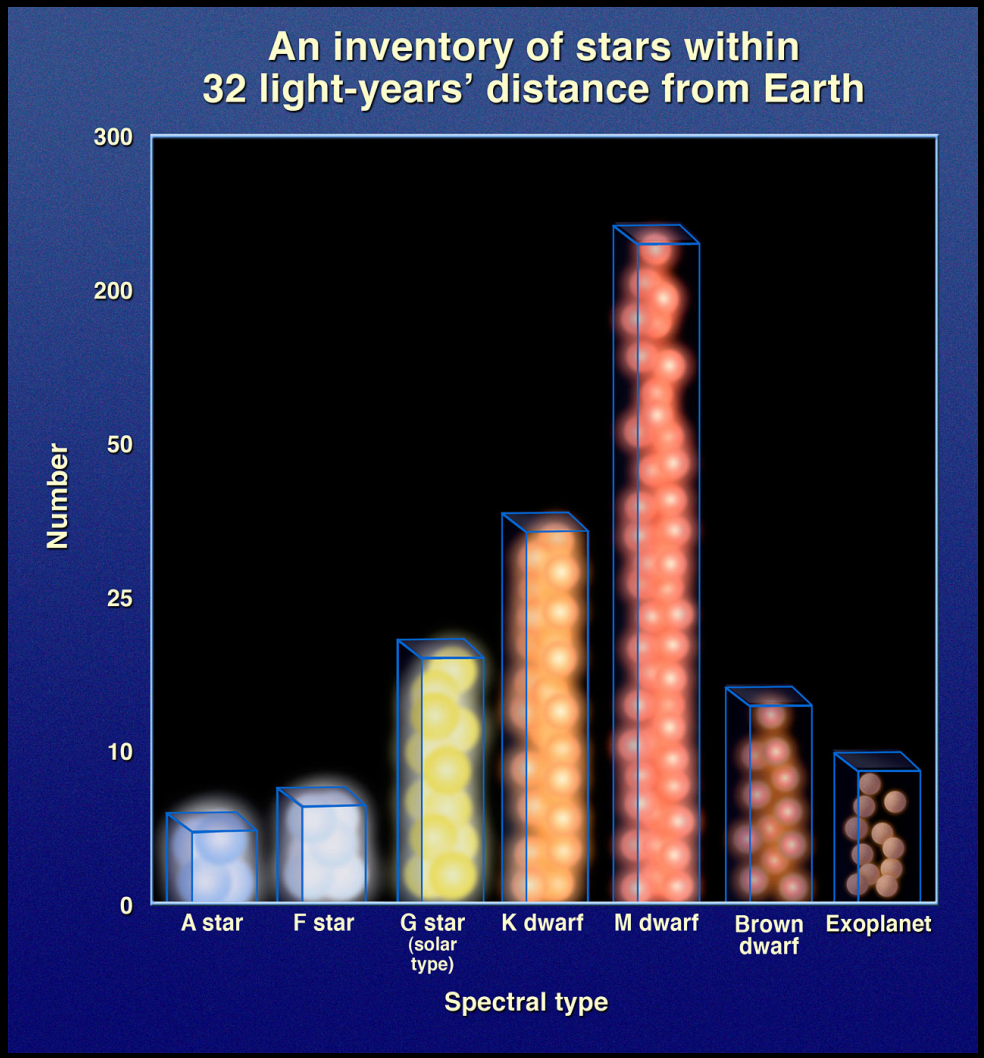
- Most of the time in the "Main Sequence"
  - The time of Hydrogen burning
- Total lifetime depends on mass
  - The heavier the star the shorter the life

Size, Color and Lifetime Depend on Mass

- Heavier stars burn faster and hotter
  - 10 x Sun: 32 million years
  - Sun: 10 billion years
  - 0.1 x Sun: 3 trillion years



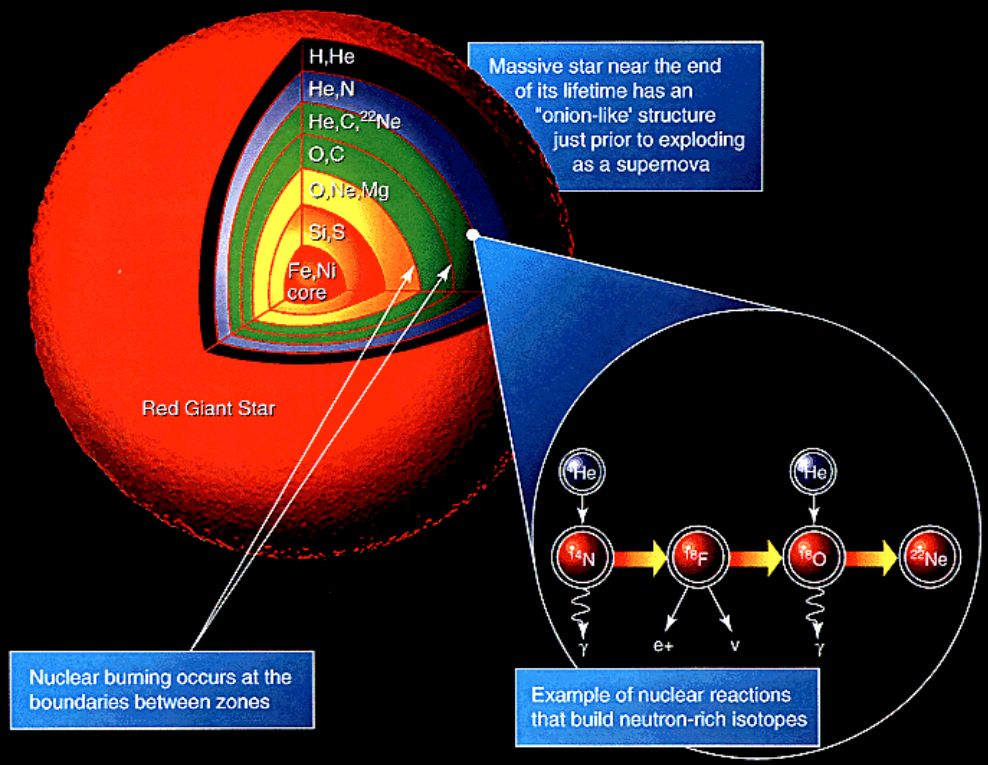
Distribution of Star Sizes



- There are many more small, cool stars

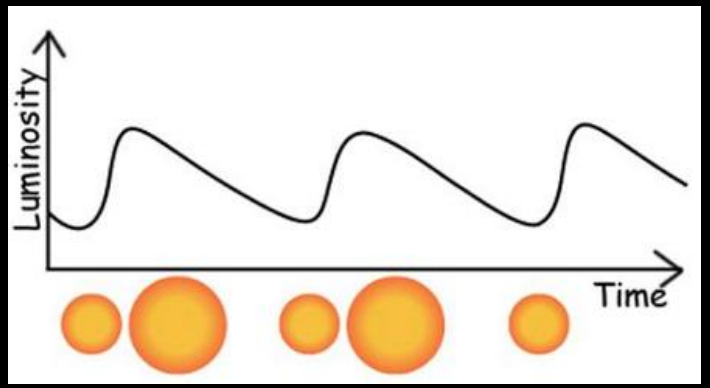
Heavier Stars Burn Beyond Carbon

- Heavier stars are hot enough to keep burning
  - Carbon -> Neon, Calcium, Magnesium, Oxygen
  - Neon -> Oxygen and Magnesium
  - Oxygen -> Silicon and Phosphorous
  - Silicon -> Sulfur, Argon, Titanium, Chromium, Iron



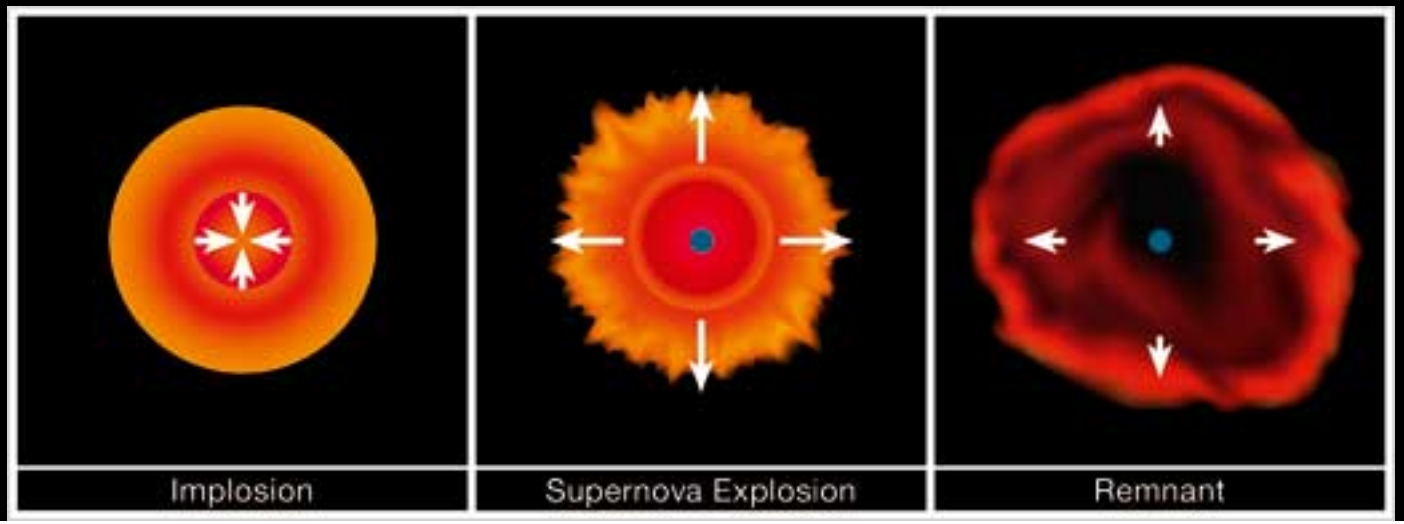
Variable Stars

- Are older, giant stars in late stages of their lives
  - The star's gas is a complex mix of heavier elements
  - The stellar thermostat gets complicated because the gas of the star becomes more or less transparent depending on the temperature
    - 1) When the interior heats up, the gas expands and becomes more transparent, so light escapes, cooling the star
    - 2) As the star cools, the gas contracts and gets less transparent, heating the interior
    - So back to step 1



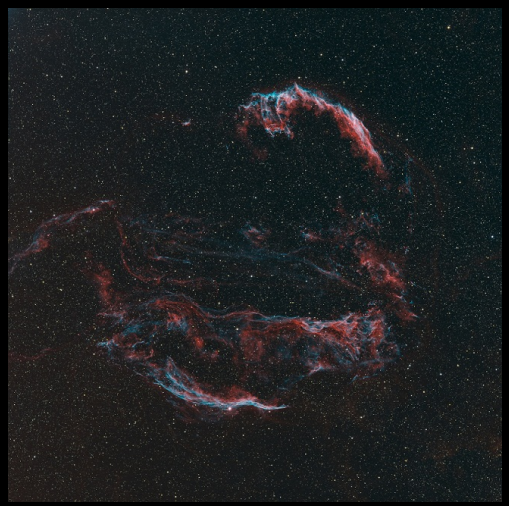
Once the Core is Iron, the Star is in Trouble

- Iron cannot burn to make heavier elements
- When the core burning to iron is complete, the burning stops and gravity takes over
- The core collapses quickly and violently
- Most of the star is blown off in a gigantic explosion
  - Type 2 Supernova: brighter than type 1a



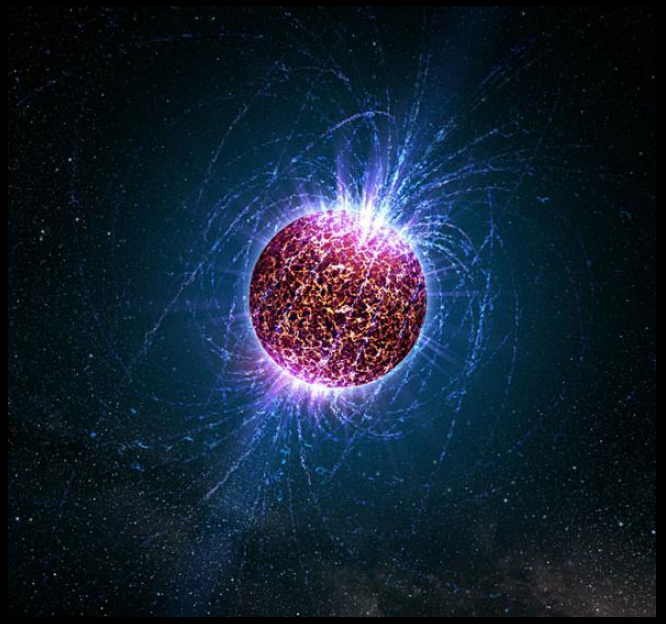
Elements Heavier than Iron from Supernovae

- During the explosion, the elements in the star are bombarded with neutrons
  - Creating heavier elements
- After the explosion the new elements are scattered into space
  - To create new stars and planets (like us)



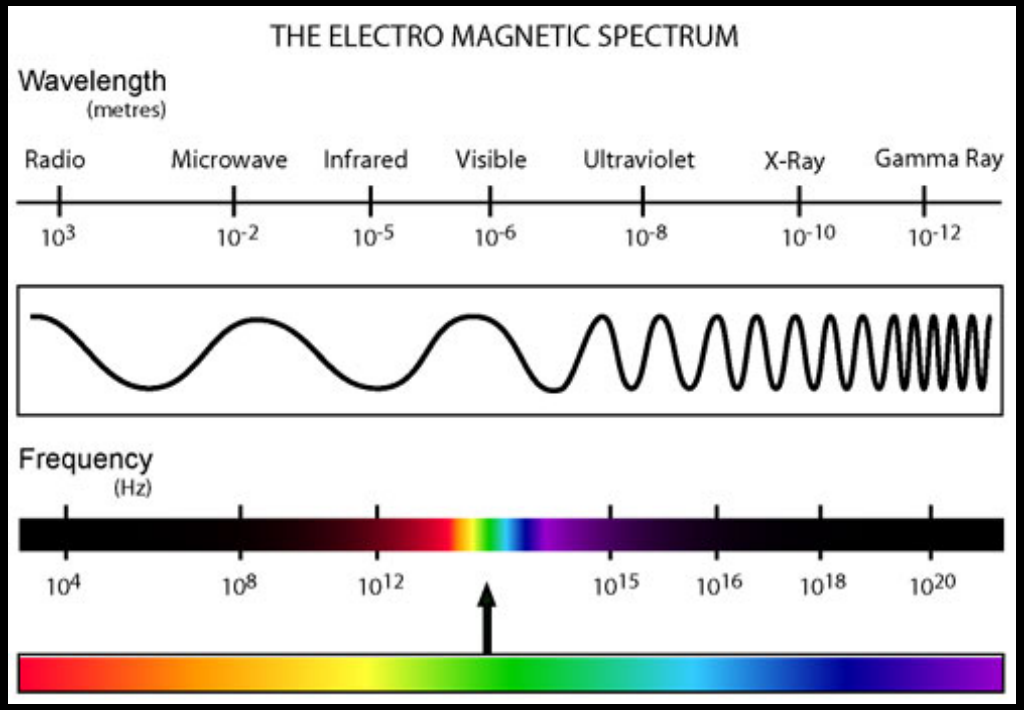
What Remains of a Supernova

- Depends on how heavy the star was
  - If the core mass is between 1.3 and 3 times the Sun's mass
    - Neutron star: 10-mile diameter sphere of pure neutrons
      - Like a really big nucleus
    - Observed as spinning pulsars
  - If the core mass > 3 times the Sun's mass
    - Black hole



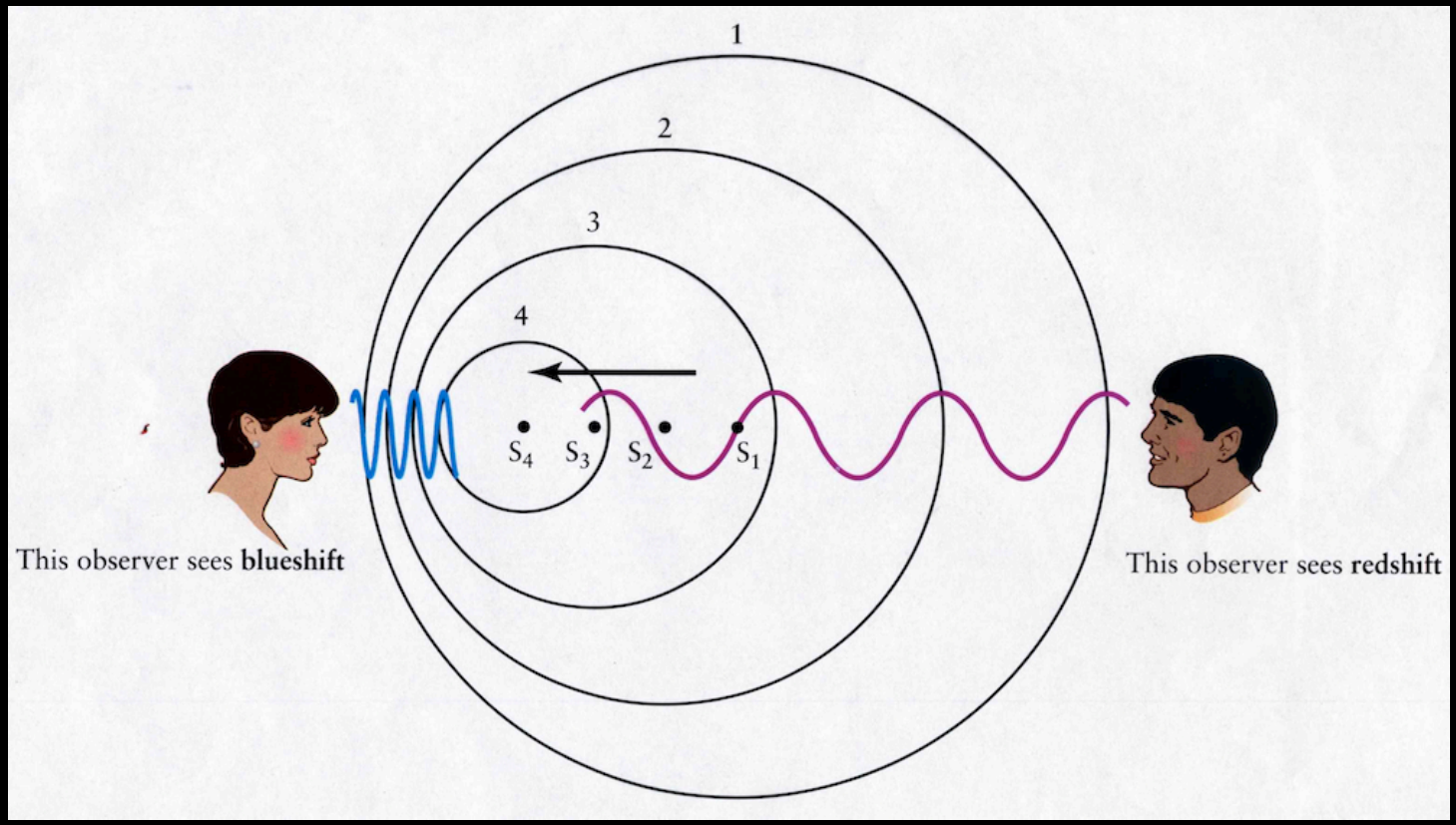
Motion from the Spectrum: the Doppler Effect

- Just like for sound waves, if the source is moving towards you it sounds like a higher frequency
  - Sound: higher pitch
  - Light: more blue
- Moving away: lower frequency
  - Sound: lower pitch
  - Light: more red



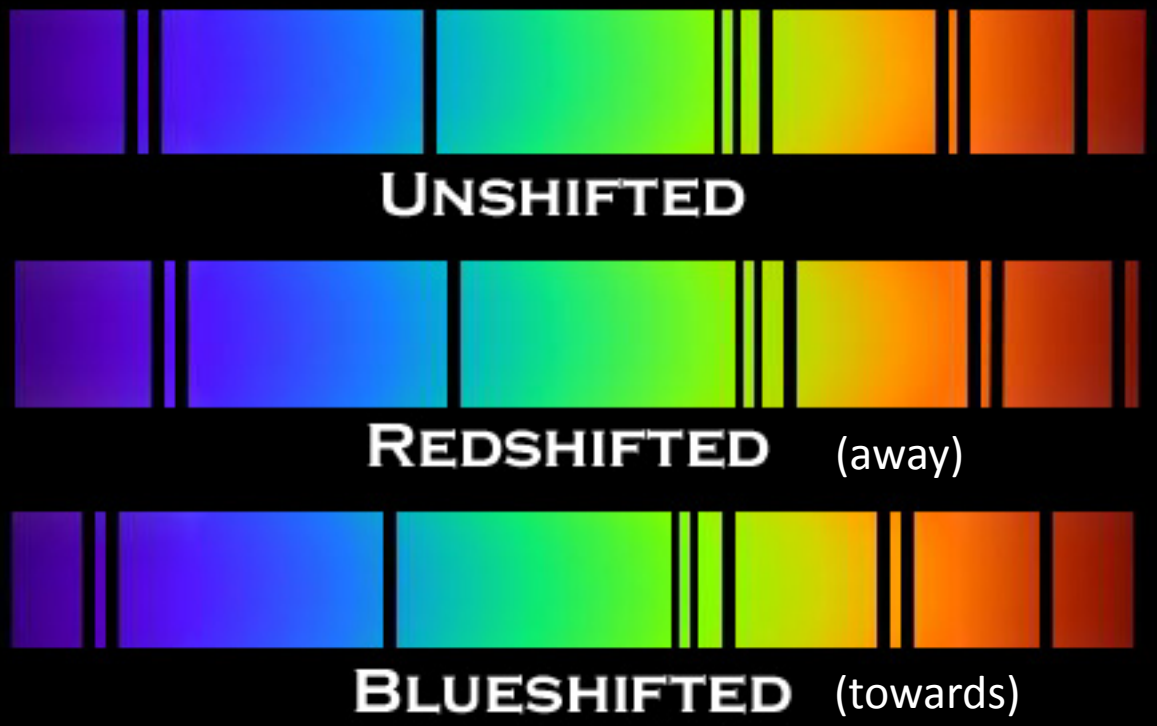
Doppler Effect

- Something moving away looks redder
- Something moving closer looks bluer



We See a Shift in the Spectral Lines

- The size of the shift tells you the speed of the source towards or away from you



Using the Doppler Effect Tells Us How Stars Move

- Allows us to plot their orbits in our Galaxy
  - We'll see a map of the Galaxy next week
- We can measure how stars orbit in nearby galaxies
  - Measure the mass of the galaxies
- We can measure the motion of entire galaxies
  - How galaxies orbit each other
  - Discover the expansion of the Universe