Organizing the properties of stars: The H-R Diagram

Luminosity versus Temperature

Hertzsprung-Russel Diagram

Spectral type: O  B  A  F  G  K  M

Spectral Classification

- O, B, A, F, G, K, M
  - “Oh Be A Fine Girl/Guy Kiss Me”
  - “Only Boring Astronomers Feel Good Knowing Mnemonics”

- Subdivisions 0-9
  - Sun is a G2 star
  - Predict temperature to 5%

Rigel is much more luminous than Sirius B. Rigel and Sirius B have the same temperature. Which star has the bigger size?

A. Rigel  
B. Sirius B  
C. They have the same size  
D. There is not enough information to answer the question

You observe two stars with the same luminosity and determine that one is larger than the other. Which star has the greater temperature?

A. The larger star  
B. The smaller star  
C. The temperatures are the same
Which star looks brighter from Earth?

<table>
<thead>
<tr>
<th>Star</th>
<th>Apparent Magnitude</th>
<th>Absolute Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Y</td>
<td>2</td>
<td>6</td>
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</tbody>
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Which star is more luminous?

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Which star is closer to Earth?

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Chapter 13:
The Lives of Stars

Space is Not Empty

The Constellation Orion
The Orion Nebula

This material between the stars is called the **Interstellar Medium**. It is very diffuse and thin… In fact it is almost a vacuum.
How do we know it’s there?

1. Nebulae
2. Absorption lines
3. Reddening

The Interstellar Medium (ISM)

The Interstellar Medium is composed of:
- Gas (99%) and Dust (1%) by mass
  - Hydrogen (~75%)
  - Helium (~25%)
  - Carbon, etc. (< 1%)

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Star Formation: Cloud Collapse

How does a thin cold cloud of gas and dust become a dense hot shining star?

The problem is density:
- ISM: \(10^3\) atoms/cm\(^3\)
- Star: \(10^{23}\) atoms/cm\(^3\)

To become a star, the cloud must condense tremendously.

Gravity versus Pressure

Gravity can create stars only if it can overcome the force of thermal pressure in a cloud.

Star Formation

1. Start with a cloud - ISM
2. Form little dense regions
   a. From collapse
   b. From shock waves
3. Dense regions collapse under gravity
4. Dense regions get hotter

Protostars

Part of a nebula condenses into a knot of gas called a protostar.

Protostars are surrounded by material which can form planets.
Star Formation from Shocks

When a high mass O type star ends its life, it explodes as a supernova.

Material from the exploding star might collide with a nebula in its path.

Crab Nebula. A Supernova which exploded in 1054 AD.

Shocks Triggering Star Formation

Shock waves can “push” material together in a cloud, creating dense regions.

Hydrostatic Equilibrium

- **Gravity** is pulling the outer part of a star toward the center.
- **Thermal Pressure** can resist the pull of gravity.
- **Nuclear fusion** in the core of a star releases huge amounts of energy.
- This energy (heat) creates the thermal pressure.
- **Hydrostatic Equilibrium** occurs when gravity and pressure forces balance.

What would happen if a star’s fusion reactions suddenly got slower?

A. The star’s internal thermal pressure would decrease
B. The star’s internal thermal pressure would increase
C. The star’s internal thermal pressure would not change

Pressure-Temperature Thermostat

- Main sequence stars are self-regulating systems, small changes get corrected.

If thermal pressure drops:
1. Star shrinks a little
2. Density increases
3. Temperature increases
4. Nuclear reactions speed up
5. Thermal pressure rises again

Hydrostatic equilibrium keeps stars stable for billions of years.

The inward force of **gravity** is balanced by the force of **pressure** pushing out.

All stars on the **Main Sequence** (of the HR Diagram) are stable and in equilibrium.
Lifetimes of Stars

Estimate a star’s lifetime based on how much fuel it has, and how fast it uses up its fuel

\[ T = \frac{1}{M^{2.5}} \]

- **M** = Mass of star in solar masses (M\(_{\text{Sun}}\))
- **T** = Lifetime of star in solar lifetimes (T\(_{\text{Sun}}\))

Lifetimes of Stars

- Low-mass stars: Economy Cars
- High-mass stars: Gas guzzlers

Star Formation and Lifetimes

Lecture-Tutorial: Pg. 119-120

- Work with a partner or two
- Read directions and answer all questions carefully. Take time to understand it now!
- Come to a consensus answer you all agree on before moving on to the next question.
- If you get stuck, ask another group for help.
- If you get really stuck, raise your hand and I will come around.

Creating Elements with Nuclear Fusion

- Nuclear fusion is the source of energy for all stars.
- Hydrogen (H) can be fused into Helium (He) in two ways:
  - Proton-Proton Chain
  - C-N-O Cycle
- Stars can also fuse He into: Carbon, Nitrogen & Oxygen
- Anything heavier than Lithium is only made in stars!

Examples of Nuclear Fusion

The “Proton-Proton” Chain

Used by the Sun to fuse protons (H nuclei) into He

\[ {}^4\text{H} \rightarrow {}^4\text{He} + \text{energy} \]

CNO Cycle: Another way to fuse H -> He

CNO cycle is used in massive stars and involves: Carbon (C) Nitrogen (N) & Oxygen (O)
Low-Mass Stars
(0.4 $M_{\odot}$ or less)

- HUGE convection zone!
- Hydrogen & Helium get mixed throughout star’s lifetime
- T > 100 billion years
  – Longer than the age of the universe

Average-Mass Stars

- Lifetime of the Sun: About 10 billion years total
- After H fuel is used up in the core, fusion stops
- Core contracts: heats up area around the core
- H shell fusion around He core
- Energy from shell fusion forces outer layers to expand, cool off: the Sun becomes a Red Giant

Average-Mass Stars

- The Sun becomes a Giant, leaves the Main Sequence (doesn’t move in space!)
- It runs out of fuel, the Thermal Pressure in the core decreases, and gravity will cause the core to shrink
- If the core can shrink enough, it can start Helium fusion

Planetary Nebulae

- The last gasps of dying stars
  (not related to planets!)
- Helium burning ends with a pulse that ejects the H and He into space as a planetary nebula
- The core left behind becomes a white dwarf