What is the Sun’s structure?
From inside out, the layers are:
• Core
• Radiation Zone
• Convection Zone
• Photosphere
• Chromosphere
• Corona

How does the Sun shine?
• The Sun has its own energy source
  – Main difference between a star and a planet
  – Not well understood until 1940’s
• Need to explain lifetime & luminosity

Luminosity of the Sun
• Energy output: $3.9 \times 10^{24}$ Joules/sec
• A 100-Watt light bulb emits 100 Joules per second
If we could completely cover the Earth in 100-Watt light bulbs, how many light-bulb-covered Earths do you think we would need to equal the Sun’s output?

Lifetime of the Sun
• Need a vast, constant source of energy
• Sun is at least 4.6 billion years old (from fossils)
• Most ideas could not sustain the energy rate needed

Core: Energy generated by nuclear fusion
• Inner 25%
• ~ 15 million K
• Very dense!

Radiation Zone: Energy transported upward by photons
• $10^6-10^7$ K
• Photons spend a long time here
**Convection Zone**

Energy transported upward by rising hot gas

Outer 30%

$10^4$-$10^6$ K

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**Nuclear Power on Earth**

**Fission**

Big nucleus splits into smaller pieces
(Nuclear power plants)

**Fusion**

Small nuclei stick together to make a bigger one
(Sun, stars)

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**Nuclear Fission**

Breaking large nuclei
This is what happens in nuclear power plants.

**Nuclear Fusion**

Combining small nuclei
This has only been used for weapons.

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- **San Onofre Fission Plant, CA**
- **Hydrogen (fusion) bomb, Pacific Ocean, 1962**

---

**High temperature enables nuclear fusion to happen in the core:**

Overcome electrical repulsion

**Low Speed Interaction**

**High Speed Interaction**
Nuclear Fusion

- 4 hydrogen nuclei (protons) must collide
  - Not very likely
- Helium nucleus is built up in steps
- This sequence of steps is called the proton-proton chain

\[ 4 \, ^1H \rightarrow \, \text{energy} \]

Where Stars Get Their Energy

End product of fusion process is a helium nucleus

\[ 1 \, \text{He} \text{ is less massive than } 4 \, \text{H by a factor of } 0.007 (0.7\%) \]

Where did that mass go? \[ E = mc^2 \]

c is the speed of light
\[ c = 3 \times 10^8 \text{ m/s} \]
\[ \text{so } c^2 = 9 \times 10^{16} \text{ !!!!} \]

A small amount of mass can produce a lot of energy

Energy from the Sun:

- The Sun has hydrogen at its core, at ~15 million K
- Basic Particles:
  - Protons (in nucleus), positive charge
  - Neutrons (in nucleus), no charge
  - Electrons, negative charge
- Particles in nucleus have binding energy

Core is so hot, the hydrogen is in plasma form: the electrons are free

Fusion in the Sun

- P-P chain
- 3 steps:

\[ 2 \, ^1H \rightarrow ^2H + e^+ + \nu \quad (14 \text{ billion years}) \]
\[ ^2H + ^1H \rightarrow ^3He + \gamma \quad (6 \text{ seconds}) \]
\[ ^3He + ^3He \rightarrow ^4He + 2 \, ^1H \quad (1 \text{ million years}) \]

Most of the stuff in the Sun has not yet undergone fusion! (and that’s a good thing…)

Surveying the Stars
Measuring the Distance to Stars

The best method for measuring distances of nearby stars is called **parallax**.
This involves observing a star from **two different places**.

**Parallax on Earth**

Parallax happens because the observer changes her position.

Distance between observations = **baseline**

**Distance vs. Parallax**

- Big distance (object is far away) => small parallax
- Small distance (object is close) => big parallax

**Parallax**

- Most stars have a very small parallax angle: **p**
- **p** is usually measured in **arc seconds**
- **Distances** to stars are measured in either: light years, or **parsecs**. (1 pc = 3.26 LY)
- parsec = **PARallax of one arcSEC**

**Parallax and Distance**

\[ p = \text{parallax angle} \]

\[ d \text{ (in parsecs)} = \frac{1}{p \text{ (in arcseconds)}} \]

\[ d \text{ (in light-years)} = 3.26 \times \frac{1}{p \text{ (in arcseconds)}} \]
The Parsec Lecture-Tutorial: Pages 37-39

• 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.

How Powerful Are the Stars?

• Luminosity: Total energy output of stars
  – Usually use solar units

• Magnitude: Ranking of visible light (Backwards number scale!)
  – Apparent Magnitude (m): as measured from Earth
  – Absolute Magnitude (M): what the app. mag. would be if star were moved to a distance of 10 parsecs

Magnitudes

• Way to group stars by intensity/brightness
• Brighter star = lower magnitude
• Fainter star = higher magnitude

• Difference of 1 in magnitude < --> factor of 2.5 in brightness

• EX: Mag. 3 star vs. mag. 6 star:
  – Mag. 6 star is fainter
  – 2.5 x 2.5 x 2.5 times fainter = 15.6 times fainter

Examples of Magnitudes

• Sun: apparent -27, absolute 4.8
• Alpha Centauri: apparent -0.01, absolute 4.3

Luminosities of Different Stars

• Faint M Star: 0.0001 L_{sun}
• G Star 1.0 L_{sun}
• A Star (Vega): 50 L_{sun}
• Giant star: 100 L_{sun}
• Most luminous star known (Pistol Star): 10 Million L_{sun}!
What about size?

- How do we know how big a star is?
- What is the range of sizes for stars?

Characterize by *radius*

Nor the largest!

Miniscule compared to supergiants:

**Luminosity, Temperature, and Radius**

Imagine two hot plates of the same size (but the right one is hotter), and we want to cook identical pots of spaghetti.

![K Star and O Star](image)

Which will cook a pot of spaghetti faster?

**Luminosity, Temperature, and Radius**

Imagine two hot plates of the same temperature (but the right one is larger):

![Red Dwarf and Red Giant](image)

Which will cook a pot of spaghetti faster?
Luminosity, Temperature, and Radius

Imagine two hot plates with different sizes and different temperatures:

Which will cook a pot of spaghetti faster?

Organizing the properties of stars: The H-R Diagram

Luminosity versus Temperature

Hertzsprung-Russell Diagram

Spectral Type

• 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%