Life of the Sun—16 Oct

- Sun will use up the hydrogen in the center in 5Byr
- Center of sun must shrink to get hotter to balance gravity
- Sun will become a red giant. Surface expands.
- Sun will become a planetary nebula
- Sun will become a white dwarf

Composition of the sun

- In center, hydrogen is half used up.
A Balancing Act

- All astronomical objects do a balancing act.
  - Gravity pulls inward.
  - Something else pushes outward or gravity causes acceleration to change the motion.

1. The Earth does a balancing act. What prevents the Earth from collapsing?
   A. Gas pressure
   B. The strength of the materials
   C. Atoms change their directions of motion.

A Balancing Act: Gravity vs. Gas Pressure

- Force of gravity balances gas pressure in the sun.
  - Force of gravity \( \frac{GM^2}{R^2} \)
  - Force of gas \( PV=nkT \)
    - \( k \) is Boltzmann’s constant. \( k = \frac{[R, \text{ not radius}]}{(\text{number in a mole})} \)
    - Details (\( m \) is mass of gas particle)
      \[ P = \frac{(nm)kT}{m} = \frac{M}{(mR^3)} \]
      \[ F = \text{area} \ P = \frac{R^2 MkT}{(mR^3)} = \frac{M}{(mR)} \]
  - In balance
    \[ GMm/R = kT \]

1. We are watching the birth of the sun. The not-yet sun is a gas cloud slowly shrinking. It is getting
   A. warmer
   B. cooler
**Sun as a main-sequence star**

- H $\rightarrow$ He in the core
- T = 15 MK
- Fuel will last another 5 Byr.

**The sun’s choice**

- Sun does a balancing act.
  - RT = k/(GMm)
- Sun must produce energy to replenish the energy radiated away.
- If H $\rightarrow$ He shuts off, source of energy to maintain pressure shuts off, and gravity wins.
- What does the sun do to adjust for gravity’s victory?
- Core of the sun shrinks.
  - Core of sun gets hotter
  - H $\rightarrow$ He in the a shell surrounding inert core
  - Balance restored.
Sun as a subgiant

- H is gone in the core
- The never-ending battle between gravity and pressure. How does the sun adjust?
  - Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter
  - H→He in the a shell surrounding inert core
  - Balance restored.

Sun as a giant

- H is gone in the core
- The never-ending battle between gravity and pressure. How does the sun adjust?
  - Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter
  - H→He in the a shell surrounding inert core
  - Balance restored.
  - Inert He core expands
Sun as a giant

- H is gone in the core
- The never-ending battle between gravity and pressure. How does the sun adjust?
  - Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter
  - H→He in the a shell surrounding inert core
  - Balance restored.
- Inert He core expands

The sun’s choice

- Sun does a balancing act.
  - \( RT = \frac{k}{GMm} \)
- Sun must produce energy to replenish the energy radiated away.
- Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter
  \( T = 200 \text{MK} \)

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<thead>
<tr>
<th>Reaction</th>
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<tr>
<td>(^1\text{H} \rightarrow \text{He})</td>
<td>10 MK</td>
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<tr>
<td>(3 \text{He} \rightarrow \text{C})</td>
<td>200 MK</td>
</tr>
<tr>
<td>(^{12}\text{C} + 4\text{He} \rightarrow ^{16}\text{O}, \text{Ne, Na, Mg})</td>
<td>800 MK</td>
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<td>Ne \rightarrow \text{O, Mg}</td>
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<tr>
<td>O \rightarrow \text{Mg, S}</td>
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<tr>
<td>Si \rightarrow \text{Fe peak}</td>
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Sun Burns Helium

- H is gone in the core & shell is exhausted
- The never-ending battle between gravity and pressure. How does the sun adjust?
  - Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter T=200MK
  - 3He→C in the core (triple alpha process)
  - Balance restored.

The sun’s choice

1. Why does fusion of helium require a higher temperature?
   A. Helium is heavier
   B. Helium has 2 protons
   C. Helium has two neutrons
   - With more charge, it takes higher speeds to bring two He nuclei close enough to fuse.
   - Carbon has 6 protons.
Other fusion reactions?

- Sun has one more trick after He is exhausted in core.
  - Burn He in a shell
- Sun is not massive enough to shrink further and get hotter
  - Core is supported by pressure of degenerate electrons.
  - Temperature does not rise to burn anything else.
- End of the road: planetary nebula & white dwarf core

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