Life of the Sun—19 Oct

- Announcements on Test 2 & Hwk 6
- Public Talk
- Outline
  - 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, made of a degenerate gas
  - Physics of a degenerate gas

Announcements

- Test 2 is on Wed, 26th
  - New material is Newton through class on 19th
  - Mostly on new material not on first test.
  - Practice test. See link on the syllabus.
  - Missouri Club, Tues, 25th, 7:40-8:40pm, BPS 1420
  - Send me formulas for cheat sheet by Wed, 26th, 1:00am
- Hwk 6
  - Absolute deadline is 3:10pm on Mon, 24th.
  - Ask about homework 6 in class on 24th.
  - Answers will be posted by end of day on 24th.
  - Due date is incorrect on Hwk 6.

Public Talk

"The history of the Universe in a nutshell: from the Big Bang to life and the end of time"

John Mather, Nobel Prize winner in physics, 2006

Tonight, 8:00 pm, BPS 1410

A Balancing Act: Gravity *vs.* Gas Pressure

- Force of gravity balances gas pressure in the sun.
  - Force of gravity $F_{grav} = GM^2/R^2$
  - Gas pressure $PV = nkT$
    - Force=pressure×area

$$F_{gas} = P\ 4\pi R^2 = \frac{nkT}{V} 4\pi R^2$$

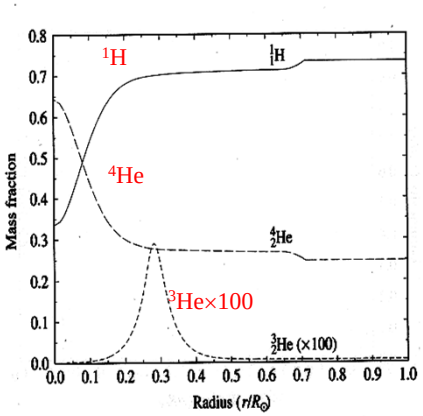
  - Result (without constants)

$$T = M/R$$

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

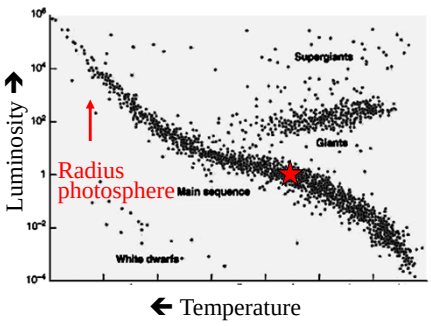
Review

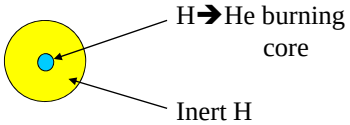
- The sun produces energy by fusing hydrogen into helium $4\mathrm{p}\rightarrow{}^{4}\mathrm{He}$.
  - For this to occur, the protons must collide vary fast to overcome the electric repulsion.
  - Repulsion force depends on the product of the charges $Z_1 Z_2$.
    - $Z = 1$ for H
    - $Z = 2$ for He
- Half of the hydrogen in the center is used up.



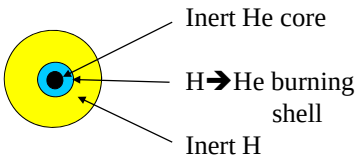
Sun as a main-sequence star

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





The sun's choice



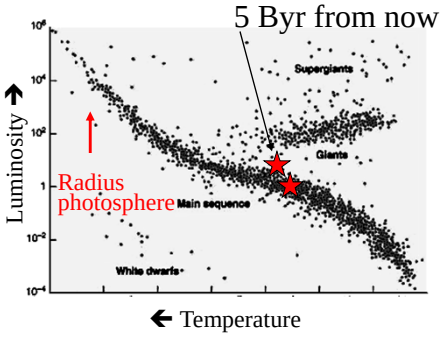
- Sun does a balancing act.

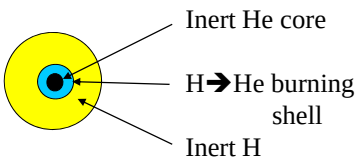
$$\frac{M}{R} = T$$

- Sun must produce energy to replenish the energy radiated away.
- If H→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→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 would fall and gravity would win.
  - Core shrinks, gets hotter
  - H→He in the a shell surrounding inert core
  - Balance restored.

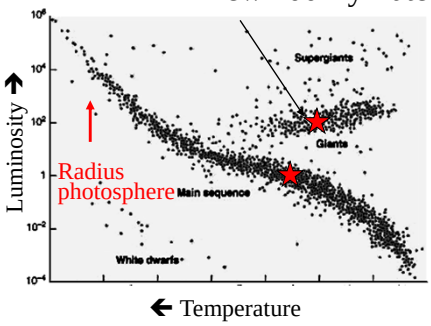


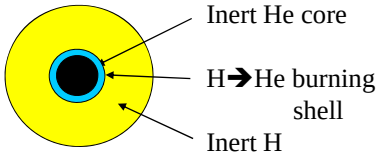


Sun as a giant

A few 100Myr later

- 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 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

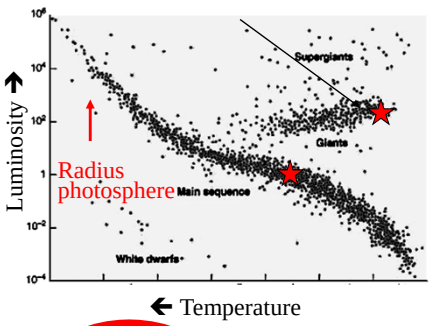


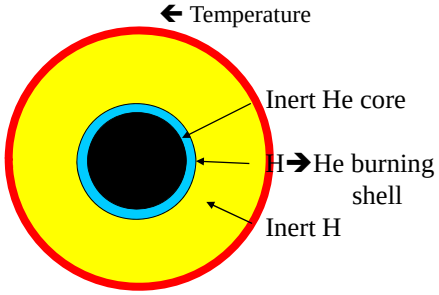


Sun as a giant

Later

- 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 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.

$$\frac{M}{R} = T$$

- Sun must produce energy to replenish the energy radiated away.
- Without burning fuel to keep temperature up, pressure would fall and gravity would win.
  - Core shrinks, gets hotter T=200MK

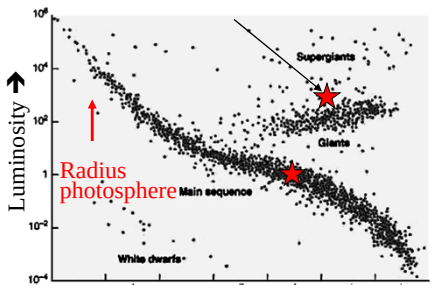
Triple-alpha process

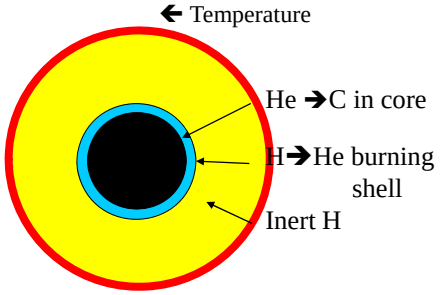
Reaction	Min. Temp.
4 ^{1}H ➔ ^{4}He	10 MK
3 ^{4}He ➔ ^{12}C	200 MK
^{12}C + ^{4}He ➔ ^{16}O, Ne, Na, Mg	800 MK
Ne ➔ O, Mg	1500MK
O ➔ Mg, S	2000MK
Si ➔Fe peak	3000MK

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 would fall and gravity would win.
  - Core shrinks, gets hotter T=200MK
  - 3He→C in the core (triple alpha process)
  - Balance restored.

Later





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.

Triple-alpha process

Reaction	Min. Temp.
4 ^{1}H → ^{4}He	10 MK
3 ^{4}He → ^{12}C	200 MK
^{12}C + ^{4}He → ^{16}O, Ne, Na, Mg	800 MK
Ne → O, Mg	1500MK
O → Mg, S	2000MK
Si →Fe peak	3000MK

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

Triple-alpha process

Reaction	Min. Temp.
4 ^{1}H → ^{4}He	10 MK
3 ^{4}He → ^{12}C	200 MK
^{12}C + ^{4}He → ^{16}O, Ne, Na, Mg	800 MK
Ne → O, Mg	1500MK
O → Mg, S	2000MK
Si →Fe peak	3000MK

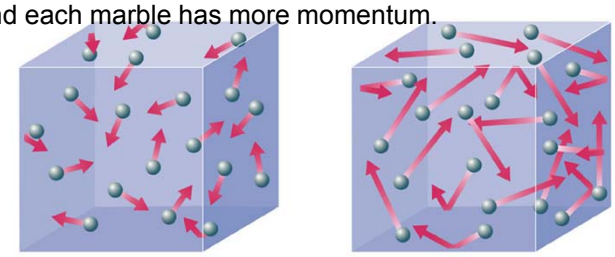
Normal/degeneracy pressure
White dwarfs

- Pressure on the walls of the box is caused by the gas hitting the walls. Gas transfers momentum to the walls.
- Mental picture: Marbles hit the walls; wall pushes back.
- **Normal gas**

  $P V = n k T$

  $mv^2 = kT$

1. Pressure is greater at higher temperature because ___. I. more marbles are hitting the wall every second. II. the marbles are moving faster and each marble has more momentum.
   A. I only
   B. II only
   C. <u>I & II</u>



Longer arrows mean higher average speed.