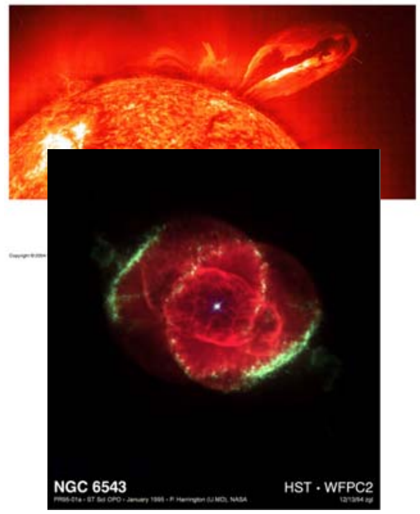
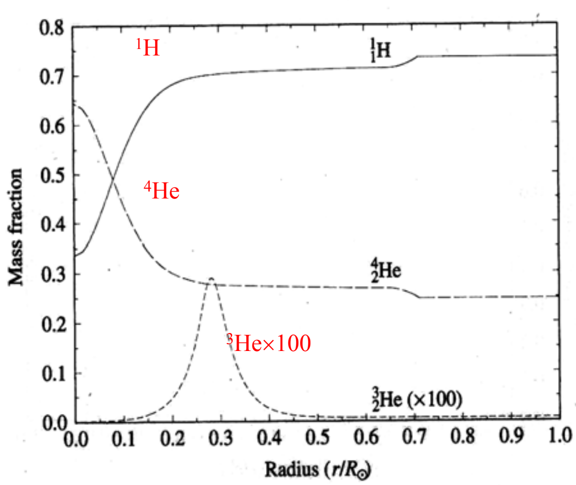
Life of the Sun—16 Oct

- 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.

1. What prevents the Earth's atmosphere from being dense at my feet but sparse at my head?
   A. Gas pressure
   B. The strength of the materials
   C. Atoms change their directions of motion.

A Balancing Act: Gravity *vs*. Gas Pressure

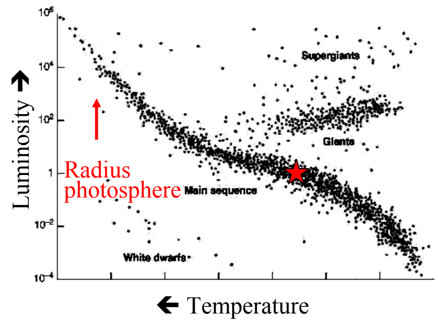
- Force of gravity balances gas pressure in the sun.
  - Force of gravity GM^2/R^2
  - Force of gas $PV=nkT$
    - k is Boltzmann's constant. k= [R, not radius]/(number in a mole)
    - Details (m is mass of gas particle)
      $P = (nm)kT/m/V=M\ kT/(mR^{3)}$
      $F = \text{area } P = R^2\ MkT/(mR^3)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

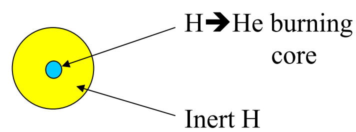
    $GMm/R=kT$

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

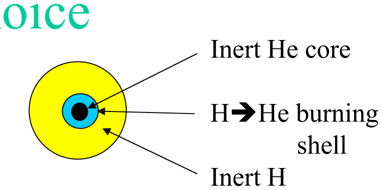
Sun as a main-sequence star

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





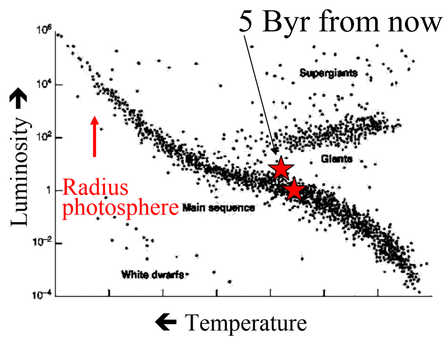
The sun's choice

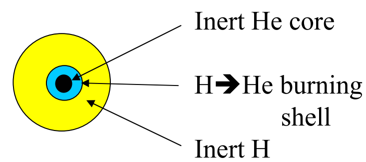


- Sun does a balancing act.
  - RT=k/(GMm)
- Sun must produce energy to replenish the energy radiated away.
- If H→He shuts off, source of energy to maintain pressure shuts off, and gravity wins.
- What does the sun do to adjust for gravity's victory?
- Core of the sun shrinks.
  - Core of sun gets hotter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

Sun as a subgiant

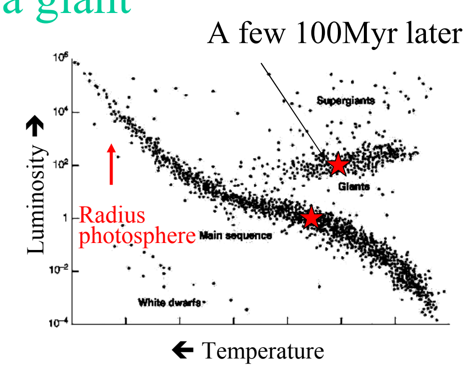
- H is gone in the core
- The never-ending battle between gravity and pressure. How does the sun adjust?
  - Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter
  - H→He in the a shell surrounding inert core
  - Balance restored.

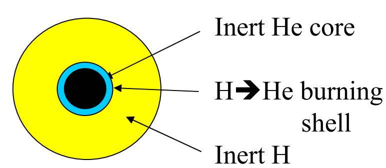




Sun as a giant

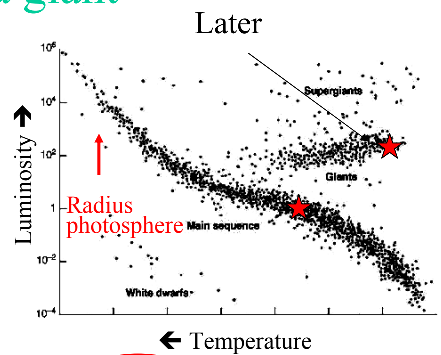
- H is gone in the core
- The never-ending battle between gravity and pressure. How does the sun adjust?
  - Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter
  - H→He in the a shell surrounding inert core
  - Balance restored.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

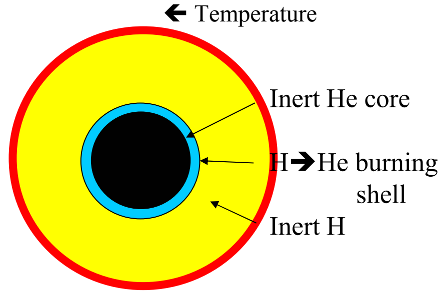




Sun as a giant

- 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

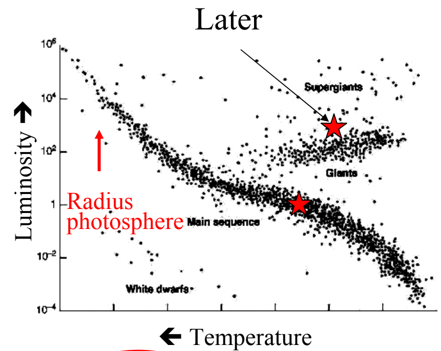
- Sun does a balancing act.
  - RT=k/(GMm)
- Sun must produce energy to replenish the energy radiated away.
- Without burning fuel to keep temperature up, pressure (PV=nRT) would fall and gravity would win.
  - Core shrinks, gets hotter T=200MK

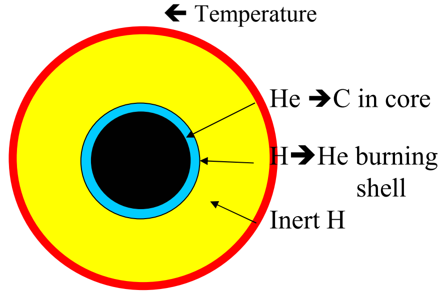
Triple-alpha process

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 (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.

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

riple-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