Stellar Evolution
Before.....During.....and After....
The Main Sequence

It’s all about gravity......
The Main-Sequence Lifetime of a Star

• The length of time a star spends fusing hydrogen into helium is called its main sequence lifetime
  – Stars spend most of their lives on the main sequence
  – Lifetime depends on the star’s mass and luminosity
  – More luminous stars burn their energy more rapidly than less luminous stars.
  – High-mass stars are more luminous than low-mass stars
  – High mass stars are therefore shorter-lived!
• Cooler, smaller red stars have been around for a long time
• Hot, blue stars are relatively young.

The Main-Sequence Lifetime of a Star

High-mass stars 10 mpg

Low-mass stars 60 mpg

What determines when a star becomes a main-sequence star?

a) When nuclear fusion generates the energy required to balance gravity
b) When convection begins in the core.
c) When optical radiation leaves the star
d) When the temperature in the core reaches a higher temperature than the corona.
Main Sequence Turn-off

What are we looking at?

a) Stars of the same mass?
b) Stars of the same color?
c) Stars of the same magnitude?
d) Stars of the same age?

Stellar Evolution on the Main Sequence

High mass stars
The CNO cycle

- Low-mass stars rely on the proton-proton cycle for their internal energy
- Higher mass stars have much higher internal temperatures (20 million K!), so another fusion process dominates
  - An interaction involving Carbon, Nitrogen and Oxygen absorbs protons and releases helium nuclei
  - Roughly the same energy released per interaction as in the proton-proton cycle. But it runs much faster!
  - The C-N-O cycle!

The solar corona has temperatures roughly the same level as temperatures in the Sun's core, where nuclear fusion takes place.

Why doesn't fusion occur in the corona?
- a) The density in the corona is too low.
- b) The corona has too many free electrons.
- c) Atoms in the corona are mostly ionized.
- d) The corona has more heavy atoms than the core.
- e) Two of the above.
Internal Structure of Stars - Convection

- **Convection** occurs in the interiors of stars whenever energy transport away from the core becomes too slow
  - Radiation carries away energy in regions where the photons are not readily absorbed by stellar gas
  - Close to the cores of massive stars, there is enough material to impede the flow of energy through radiation
  - In less massive stars like the Sun, cooler upper layers of the Sun’s interior absorb radiation, so convection kicks in there
  - The lowest-mass stars are fully convective, and are well mixed in the interior.

Solar thermostat

- Greater pressure is required to balance higher gravitational force due to higher mass.
- Greater pressure produces higher temperature (and reaches this faster).
- Higher temperature produces greater luminosity.
- Higher luminosity leads to faster fuel consumption.
- Faster fuel usage means high-mass stars burn out sooner than low-mass stars.
In a Main Sequence star, Hydrostatic Equilibrium balances 2 forces, pressure and gravity, to keep the star from imploding or exploding. If the mass of the outer portion of the star was suddenly decreased slightly, what would happen?

a) Pressure in the center would decrease, the core would contract and the star would shrink slightly.

b) Pressure in the center would increase, core expand and the star would contract slightly.

c) Pressure in the center would decrease, core would contract the star would expand slightly.

d) Pressure in the center would decrease, core would expand and the star would expand slightly.

Evolution to red giant phase

- The star is expanding and cooling, so its luminosity increases while its temperature decreases
- Position on the HR diagram shifts up and to the right…
Evolutionary tracks of giant stars

- Normally, the core of a star is not hot enough to fuse helium
  - Electrostatic repulsion of the two charged nuclei keeps them apart
- The core of a red giant star is very dense, and can get to very high temperatures
  - If the temperature is high enough, helium fuses into Beryllium, and then fuses with another helium nucleus to form carbon.
A (temporary) new lease on life

- The triple-alpha process provides a new energy source for giant stars
- Their temperatures increase temporarily, until the helium runs out
- The stars cool, and expand once again
- The end is near…

Light Curves

- To characterize the variability of a star, scientists measure the brightness, and plot it as a function of time.
  - Light Curves
- Different kinds of variability
  - Irregular Variable
    - Novae (death)
    - T Tauri stars (birth)
  - Pulsating Variable
    - Periodic changes in brightness
Yellow Giants and Pulsating Stars

- If you plot the positions of variable stars on the HR diagram, many of them fall in the “instability strip”
  - Most have surface temperatures of ~5000K, so appear yellow
  - Most are giants (Yellow Giants)
  - Instability comes from partial absorption of radiation in the interior of the star
    - Helium absorbs radiation, and the outer layers of the star get pushed away from core
    - As the star expands, the density decreases, letting photons escape
    - Outer layers head back inward toward core
    - Repeat
  - RR Lyrae and Cepheid variables are useful for finding distances to the stars, as the star’s period is proportional to its luminosity.
Periods of Variable Stars

- Cepheids:
  - Period approx. 2 weeks

- Mira variables:
  - Period approx. 1 year

- RR Lyrae variables:
  - Period approx. 1/2 day

- Pulsating white dwarfs:
  - Period approx. few minutes