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

It’s all about gravity……

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…
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?
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.

Evolutionary tracks of giant stars
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…

Helium Fusion

- 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 nuclei to form carbon.
The Fate of Sunlike Stars

- The Sun’s Lifetime:
  - 10 billion years on the main sequence
  - Once the hydrogen is consumed, it will enter the red giant phase
  - Helium burning begins, starting the yellow giant phase
  - Once helium is consumed, core contracts and outer envelope expands, beginning the red supergiant phase
  - Core begins to cool and the outer envelope expands again, forming a planetary nebula
  - The core remains as a white dwarf
Formation of Planetary Nebula

- As a red giant expands, it cools
  - Outer layers cool enough for carbon flakes to form
  - Flakes are pushed outward by radiation pressure
  - Flakes drag stellar gas outward with them
- This drag creates a high-speed stellar wind!
- Flakes and gas form a planetary nebula

The Hourglass Nebula
White Dwarf Stars

- At the center of the planetary nebula lies the core of the star, a white dwarf
  - Degenerate material
  - Incredibly dense
- Initially the surface temperature is around 25,000 K
- Cools slowly, until it fades from sight.

Why do stars pass quickly along the HR diagram as they reach the Planetary Nebula Phase?

- A) High velocity gas cools quickly changing the color of the star quickly.
- B) As the outer layers expand, the star they become more diffuse, exposing more hot inner layers.
- C) As the atmosphere expands, the core shrinks and heats up, becoming bluer.
- D) Planetary nebula are fast moving particles that heat the “interstellar medium”.
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Eskimo Nebula
The Hourglass Nebula

Ant Nebula
What's really going on?

Three thousand light-years away, a dying star throws off shells of glowing gas. This image from the Hubble Space Telescope reveals The Cat's Eye Nebula to be one of the most complex planetary nebulae known. In fact, the features seen in the Cat's Eye are so complex that astronomers suspect the bright central object may actually be a binary star system.
The primary source of energy for a White Dwarf

- A) Nuclear fusion
- B) Nuclear fission
- C) gravitational contraction
- D) stored heat, cooling passively
- E) chemical heat

Formation of Heavy Elements

- Hydrogen and a little helium were formed shortly after the Big Bang
- All other elements were formed inside stars!
- Low-mass stars create carbon and oxygen in their cores at the end of their lifespan, thanks to the higher temperatures and pressures present in a red giant star
- High-mass stars produce heavier elements like silicon, magnesium, etc., by nuclear fusion in their cores
  - Temperatures are much higher
  - Pressures are much greater.
- Highest-mass elements (heavier than iron) must be created in supernovae, the death of high-mass stars
The Lifespan of a Massive Star

**Layers of Fusion Reactions**

- As a massive star burns its hydrogen, helium is left behind, like ashes in a fireplace.
- Eventually the temperature climbs enough so that the helium begins to burn, fusing into Carbon. Hydrogen continues to burn in a shell around the helium core.
- Carbon is left behind until it too starts to fuse into heavier elements.
- A nested shell-like structure forms.
- Once iron forms in the core, the end is near...
Core Collapse of Massive Stars

- Iron cannot be fused into any heavier element, so it collects at the center of the star
- Gravity pulls the core of the star to a size smaller than the Earth’s diameter!
- The core compresses so much that protons and electrons merge into neutrons, taking energy away from the core
- The core collapses, and the layers above fall rapidly toward the center, where they collide with the core material and “bounce”
- The “bounced” material collides with the remaining infalling gas, raising temperatures high enough to set off a massive fusion reaction. The star then explodes.
- This is a supernova!

Before and After – a Supernova
Light Curve for a Supernova

- The luminosity spikes at the moment of the explosion, and gradually fades, leaving behind a…

Supernova Remnant

- The supernova has left behind a rapidly expanding shell of heavy elements that were created in the explosion.
- Gold, uranium and other heavies all originated in a supernova explosion!
The Crab Nebula

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Types of Supernovae

- Type Ia: The explosion that results from a white dwarf exceeding the Chandrasekhar Limit (1.4 solar masses)
- Type II: Supernovae resulting from core collapse
- Less common:
  - Type Ib and Ic: Results from core collapse, but lacks hydrogen, lost to stellar winds or other processes
Stellar Corpses

A type II supernova leaves behind the collapsed core of neutrons that started the explosion, a \textit{neutron star}.

If the neutron star is massive enough, it can collapse, forming a \textit{black hole}…