Lecture 22
Stellar Evolution & Death (Low Mass)
November 19, 2018
Deaths of Stars

• As stars burn H to He, He builds up in the core.

• Stars begin to “die” when they run out of hydrogen in their core.

• No hydrogen fusion in core

• Core collapses because there is no longer balance between gravity and outward pressure (no more hydrostatic equilibrium)
Red Giant Phase

• Temperature increases (gravitational energy)

• Hydrogen **shell burning** begins outside core.

• Release of energy from shell burning causes star to swell.

• Core continues to collapse, so core is shrinking while atmosphere is expanding!
Red Giant Phase

- Star expands, and cools.
- Moves from main sequence, to Red-giant branch on HR diagram.
- Solar winds are strong
Betelgeuse
Why does the core of an old main sequence star collapse?

A. The iron core becomes so massive that its gravitational pull causes the collapse.
B. The pressure due to fusion energy production is less.
C. The outer layers of the star become too massive.
D. Hydrostatic equilibrium forces the core into a smaller volume.

Response Counter

90
What makes a red giant star so large?

A. The helium-rich core has expanded, pushing the outer layers of the star outward.
B. The star has many times more mass than the Sun.
C. Centrifugal force from rapid rotation.
D. The hydrogen-burning shell is heating the envelope and making it expand.

Response Counter

A. 0%
B. 0%
C. 0%
D. 90%
• Core continues to collapse
• Pressure and temp increases suddenly in helium flash
• Helium in core fuses to form carbon. Star is still expanding due to hydrogen shell fusion.
• Core energy output decreases because there is less energy per fusion.
• Star now contracts and becomes temporarily stable (horizontal branch)
Helium Core Fusion Ends

- During He fusion carbon ash builds up in the core
- Runs out of He, core begins to collapse again.

What happens next in a dying star depends on the *mass* of the star....
Low Mass Stars \((M < 5M_{\odot})\)
(high mass stars discussed in next lecture)

- Core collapse ends because carbon atoms become electron degenerate
  - force of electrons around atoms keeps from collapse (no energy is produced). This force originates from the Pauli Exclusion Principle
  - core temperature never reaches the 600 million K required to burn carbon or oxygen, so core fusion ends.
Double Shell-Fusion Red Giant Phase

Helium shell around core starts to fuse into carbon
• Moves along asymptotic giant branch
  – expands and cools
  – luminosity increases
  – Cooling, condensed material gets pushed outward
Formation of Planetary Nebula

- Double-shell burning causes strong stellar winds, star expels all of its outer layers
- Expelled material, rich in heavy elements such as carbon and silicon, forms planetary nebula.
- ~60% of mass is lost in planetary nebula
- The process of expelling material and forming the planetary nebula occurs over a period of thousands of years
• Planetary Nebula
  – Expanding shell of hot gas around a dying or dead star.
  – Emission nebula that is ionized by UV light from the hot, dense core.
  – Some of the most beautiful objects in the sky
Planetary Nebula M2-9
PRC97-38a • ST ScI OPO • December 17, 1997
B. Balick (University of Washington) and NASA
The physical process that provides the energy to eject a planetary nebula from a star is

A. the transfer of hydrogen-rich material to the surface by a companion star.

B. a series of thermal pulses in a helium-burning shell.

C. a collision with another star.

D. the violent explosion of the shell upon core collapse.
White Dwarf

• Small, dense, electron degenerate carbon core
  – 1 tsp. of a white dwarf would weigh 5 tons!
  – ~ size of the Earth.

• Slowly cools
  – Very small, less area to lose heat

• Cools to become a black dwarf.

• White dwarf cannot be larger than 1.4 $M_\odot$, the Chandrasekhar Limit
White Dwarf Stars

White Dwarf Stars in M4

Ground

HST

HST \cdot WFPC2

PRC95-32 \cdot ST Sci OPO \cdot August 28, 1995 \cdot H. Bond (ST Sci), NASA
Interactive Figure
The process that produces energy inside a white dwarf is

A. the combining of protons and electrons to form neutrons within its core.
B. the helium flash – very efficient and rapid helium fusion.
C. nonexistent; a white dwarf is slowly cooling off.
D. the fusion of carbon atoms into oxygen.