Today’s “Bizarre” Events

- Evolution of massive stars through giant and supergiant phases: fusion occurs in “successive layers of onion”
- End life as supernova explosion, leaving behind either neutron star or black hole
- Supernova can create neutron stars
- Consider “pulsars” – fast spinning neutron stars with fierce magnetic fields
- Read 18.4 Black Holes with some care
- Come see us if need help with HW # 6
- Homework # 5 returned graded + answer sheet

Binary Systems: The Algol Paradox

- Algol is a binary system consisting of a 3.7 solar mass main sequence star and a 0.8 solar mass red giant. Why is this strange?
  - A. A 3.7 star should have become a red giant before a 0.8 solar mass star
  - B. Binary stars usually have the same mass
  - C. 0.8 solar mass stars usually never become red giants

Clicker Puzzle: Algol Binary System

- A. Binary stars can have different masses but usually ARE formed at the same time.
- More massive star should have had a shorter main sequence lifetime

What happened?

Binary Mass Exchange

- The 0.8 solar mass star once was more massive (3.0), with a 1.5 mass companion
- As it became a red giant, it swelled and poured material onto its companion (lost 2.2)
- The red giant (0.8) is now less massive than its companion (3.7)
- Future: when the other star becomes red giant, it may pour gas back…?

Overview reminder: Life track of low-mass star
Now consider evolution of massive stars after MS.

Clock runs faster, can burn heavier elements. First 4 steps pretty familiar, but no helium flash.

Successive core & shell fusion burning of C, O, Ne, Si...

Elements are created going up periodic table in steps of 2.

High-mass zigs and zags in H-R diagram:
- Elements of higher mass fusion burn successively, releasing energy to support the star against gravity.
- Reactions may change too fast for outer layers to respond, so last zig/zags are small.

Many “layers of onion” in massive star:
Core structure from successive burning stages:
lesser elements on outside, heavier on inside.

Fusion by “alpha-capture” (He nucleus) burns C, O, Ne, Mg, Si...

- Helium nucleus (2 protons) is absorbed, energy is released
- Elements are created going up periodic table in steps of 2.
BIG Evolutionary SWINGS

Cross the pulsational instability strip: Cepheids

Massive red giant or supergiant:
Fierce hot winds and pulsed ejecta

Hubble

Wildest of all!

ETA CARINAE

Supermassive star (100 $M_\text{Sun}$) late in life, giant outburst 150 yr ago

Violent bipolar ejecta + disk at equator

Evolution of V838 Light Echo (HST)

Red Giant or SG with intense brightening

‘Light Echo’ from pulse

Star V838 Monocerotis HST-ACS

Evolution of V838 Light Echo (HST)

Creation of elements from He-capture?

- Mixture of elements in our near universe follows the pattern of He-capture fusion reactions, up to iron
- Even heavier elements are made by nucleosynthesis during supernova explosion

Even numbers favored!
Iron does NOT release energy when it fuses!

"Core collapse" SUPERNOVA

"Rapid disassembly" of elements in core
→ neutrons
+ neutrinos

Neutron degeneracy pressure stiffens
+ push of neutrinos
→ envelope 'bounces'!
→ SHELL BLOWS OFF

"Core Collapse SUPERNOVA"

• Exploding remnant of massive star disperses heavy elements through the galaxy
• Inside may be a neutron star – a remnant core of pure neutrons!

"Onion-shell fusion burning" stops with
IRON (Fe, 26 protons)

Several fates for massive star

1. Strong winds shrink star, may end as WHITE DWARF
2. Or core burns to Fe, eventually sudden CORE COLLAPSE!
   ➞ SUPERNOVA

FINAL FATE OF MASSIVE STAR

1. CORE EXPLOSION RARE IN WIND/PRECAMBRIAN SUPERNOVA
   < 1.4 M☉ LEFT ➞ WHITE DWARF
   (WD can convert to neutron star for masses > 1.4 M☉)

2. ENDS CORE EXPLOSION
   NO MORE NUCLEAR ENERGY CAN BE SECURED!
   AND > 1.4 M☉ LEFT
   COLLAPSE CAN BE STOPPED BY EXPANSION
   ➞ NEUTRON STAR
   OR BLACK HOLE

Only supernova explosion creates elements heavier than iron:
magic of nucleosynthesis

SN shells, and what is left at center?

Was Crab SN recorded in Chaco?
....and nothing recorded in Europe!

• Petroglyph from Chaco Canyon:
• Correct position relative to new moon for Crab Supernova
• Check this on your SkyGazer software
Neutron stars

More massive, smaller in size!

Star with a crystal crust!

Idea of neutron stars first suggested in 1930s (Landau, Zwicki, Baade, Oppenheimer) but seemed like dreaming.

Favorite Postcard: Size of Neutron Stars

- Structure determined by gravity vs. neutron degeneracy pressure
- Size ~ 10 km, more massive, smaller!!
- Crushing gravity at its surface, so not a nice neighbor...or place to visit...as tourist try Big Apple instead.

Neutron star over NYC!