Today in Bizarre-Land

• Return to 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
• Pulsars – fast spinning neutron stars with fierce magnetic fields; gradually slow down
• Synchrotron radiation makes the light seen as pulses – and thus Crab nebula + pulsar shines (and pulses) brightly in many wavelengths
• Read 18.2 Neutron Stars and 18.3 Black Holes
• PlanetFinder help session in G116 today 4-5pm

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. 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
Clicker -- Paths in H-R Diagram

- Star moves upwards and to the right on the H-R diagram. What is probably happening in the core?
  
A. Core has just started to burn a new element
B. Inner core is contracting and heating up; shell burning is increasing
C. All nuclear burning is slowing down
D. The inner core temperature is cooling

HR diagram shifts

- B. Core is contracting and heating; shell burning is increasing
  
- Moving upwards on HR diagram means more luminosity → more nuclear fusion
- This is usually due to the inner core heating due to gravitational collapse potential → thermal → faster burning

Upward and to the right in H-R:
Giant phases in life track of low-mass star

Luminosity (solar units)

Now consider evolution of massive stars after MS

Evolution of massive stars

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...

all with "alpha capture" (or He)

stars make many shallow H-R loops
Many "layers of onion" in massive star

Core structure from successive burning stages:
- lesser elements on outside, heavier on inside

Fusion by "helium-capture" (alpha-particles)
- Helium nucleus (2 protons) is absorbed, energy is released
- Elements are created going up periodic table in steps of 2

Creation of elements from He-capture: evidence
- 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

A few of many other fusion reactions also feasible in high-mass stars
- Even numbers favored!

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

BIG Evolutionary SWINGS
- Cross the pulsational instability strip: Cepheids
Massive red giant or supergiant:

Fierce hot winds and pulsed ejecta

Hubble ST

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

Red Giant or SG with intense brightening

‘Light Echo’ from pulse

Star V838 Monocerotis

HST-ACS

Evolution of V838 Light Echo (HST)

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

Iron does NOT release energy when it fuses!

Actual “mass / nuclear particle”

Iron does NOT release energy when it fuses!
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

“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!

“Core collapse” (massive star) SUPERNOVA

“Rapid disassembly” of elements in core
→ neutrons + neutrinos

Neutron degeneracy pressure stiffens collapsing core →
push of neutrinos

→ envelope ‘bounces’! → SHELL BLOWS OFF

Observing Supernovae

- About 1 per century per galaxy (none in Milky Way since 1604 – Kepler)
[1572 – Brahe; 1054 – Crab; 1004 – brightest]
- Bright explosion visible for weeks/months – some visible in daytime!
- Remnant visible for 10,000+ years as huge bubbles and “veils” – longer in radio
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!

Pulsars and Neutron Stars

Pulsars are lighthouses in our Galaxy!

Spinning Bowling Ball Demo

Neutron Star in the Lab