Today’s “Bizarre” Events

- **Helium flash** goes off in shrinking degenerate core of red giant: horizontal branch star with He core burning
- Double shell burning (H and He) yields red supergiant (RG II), blows off planetary nebula
- What does “electron degeneracy” mean?
- Look at properties of white dwarfs as end of life cycle for low mass stars

HW #6 due in class, new HW #7 passed out
Read 18.2 Neutron Stars and 18.3 Black Holes

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**REMINDER:**

2: Subgiant to Red Giant (first visit)

- H burning in shell makes much more energy
- Vast expansion, RG phase lasts ~ 500 MY
- Huge convective envelope

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Oops!
Thermostat is missing in degenerate gas
Could get exciting!
Complex aside:

"Degeneracy" pressure

Degeneracy pressure

...similar structure of giants and supergiants!

1. **Pauli Exclusion Principle**
   - Matter resides too much confinement
   - Example:
     1. Incompleteness of liquid state: degenerate atoms
     2. Core of low-mass (~5.5-8.0 M☉) red giants, also white dwarfs:
        - **Degenerate Electron**
     3. Neutron star, De Paolis:
        - **Degenerate Neutrons**

3: Helium Flash

He core burning -- removes electron degeneracy

- He core burning now with thermostat!
- "horizontal branch star"

He core burning to triple-alpha fusion

Helium flash → He fusion to C in core (horizontal branch)

H-R diagram of globular cluster

Discussion:
What does it tell us? Why is it useful?

4: Horizontal branch star

He core burning, H shell burning

Short phase, lasts ~50 MY

Triple-alpha fusion

3 He → C
5. Red Supergiant

Double-shell burning of H and He

Phase could be very short if He burning is erratic (unstable) – then lasts only a few MY, and blows off outer shells

Life track in H-R diagram of solar-mass star

Many meanders, but MS phase longest, red giant phase(s) shorter, finally white dwarf left to cool slowly

Clicker Poll of Advice

• How do you take notes (or listen) during lectures?
  A. I get most of it by just listening
  B. I write down some notes, then go back to book to look things up
  C. I listen, take some notes, then get copies of lecture slides from course website
  D. I enjoy talking with my buddies, and they tell me later if I missed anything

6. Planetary Nebula

Outer shells of red supergiant "puffed off"

Great pictures!

"Naked" white dwarf emerges

Soon turn to discussion: Shapes of Planetary Nebulae
What is likely to account for the vast range of shapes (many beautiful) of these ejecta?

Planetary nebulae in many shapes: probably rotation and magnetic fields?

7. White Dwarf
Inert C core, He & H shells
Electron degeneracy
Pressure holds it up
Very dense, size of Earth
Max mass of 1.4 $M_{\text{Sun}}$

Sizes of white dwarfs

More massive white dwarfs are SMALLER!

Final stage:
冷却白矮星——打盹……
但如果WD有双星伴星，够了！

Evolution track of 1 $M_{\odot}$ star

Life after brief "planetary nebula" stage ……

Hot central core emerges as
WHITE DWARF
Overview reminder: Life track of low-mass star

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