AST 101
Introduction to Astronomy:
Stars & Galaxies
**Summary:** When a Low-Mass Star runs out of Hydrogen in its Core

1. With fusion no longer occurring in the core, gravity causes core collapse.
3. Under degenerate conditions, core becomes hot enough to fuse Helium: Helium Flash.
Helium Fusion

- Temperatures ~ 100 million K
- He + He + He $\rightarrow$ C + energy
  - Triple-alpha process
Clicker Question

What Will Happen When There Is No More Helium in the Core?

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B. The core will start to collapse.
C. Carbon fusion will start immediately.
D. The star will explode.
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When helium runs out….

- Carbon core collapses and heats up
- Triggers burning in helium AND hydrogen shells
  - Shell burning now unstable = Thermal Pulses
• Energy generation becomes much higher again
• Outer layers lift and cool again
• Star becomes very luminous red giant – Class II
• Degeneracy pressure halts gravitational collapse before $T=600$ million K is reached
  – No carbon fusion

• Stellar winds blow material from the outside
  – Including some carbon that gets to the outer layers via convection

• Outer layers thrown off in a **big puff** around the **inert** carbon core
  – Big puff = **Planetary Nebula** (Not related to planets)
  – Inert carbon core = **White Dwarf**
    • Slowly cools and fades until it becomes a nearly invisible “black dwarf”
IC 418: The Spirograph nebula
NGC 6826: The Blinking Eye Nebula
NGC 2392: The Eskimo Nebula
NGC 7293: The Helix Nebula
Life of a Low-Mass Star

End State:

Planetary Nebula + White Dwarf
WHAT IS A WHITE DWARF?

- Exposed core of a low-mass star that has died
- Mostly made of Carbon and Oxygen
- No fusion to maintain heat and pressure to balance gravity pull. *Electron degeneracy pressure* balances inward crush of its own gravity
- Very high density and hence gravity
- Maximum mass=1.4 M$_{\text{sun}}$ (Chandrasekar limit)
Size Of A White Dwarf
Funky properties of white dwarf material

1 Kg chocolate cake

2 Kg chocolate cake

0.4 $M_{\text{sun}}$ white dwarf

0.8 $M_{\text{sun}}$ white dwarf
Hubble Space Telescope spies 12-13 billion year old white dwarfs – Formed less than 1 billion years after the creation of the universe

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Clicker Question

Which is correct order for some stages of life in a low-mass star?

A. protostar, main-sequence star, red giant, planetary nebula, white dwarf
B. main-sequence star, white dwarf, red giant, planetary nebula, protostar
C. protostar, main-sequence star, planetary nebula, red giant
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<table>
<thead>
<tr>
<th>Process</th>
<th>Stage</th>
<th>Time Scale</th>
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<tbody>
<tr>
<td>H core burning</td>
<td>Main Sequence</td>
<td>$10^{10}$ yr</td>
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<tr>
<td></td>
<td>10 billion years</td>
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<tr>
<td>Inactive He core, H shell burning</td>
<td>Red Giant</td>
<td>$10^8$ yr</td>
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<td>100 million years</td>
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<tr>
<td>He core burning (unstable)</td>
<td>Helium Flash</td>
<td>Hours</td>
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<tr>
<td>He core burning (stable)</td>
<td>Horizontal Branch</td>
<td>$10^7$ yr</td>
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<td></td>
<td>10 million years</td>
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<td>C core, He + H shells burning</td>
<td>Bright Red Giant</td>
<td>$10^4$ yr</td>
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<td>10 thousand years</td>
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<td>Envelope ejected</td>
<td>Planetary Nebula</td>
<td>$10^5$ yr</td>
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<td>100 thousand years</td>
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<td>Cooling C/O core</td>
<td>White Dwarf</td>
<td>-</td>
</tr>
<tr>
<td>Cold C/O core</td>
<td>Black Dwarf</td>
<td>$\infty$</td>
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Sirius A & B
Main Sequence Star & White Dwarf

Hubble image, visible light

Chandra image, X-ray light

Sirius A, the brightest star in the night sky, appears relatively dim in this X-ray photo . . .

. . . because its hot white dwarf companion Sirius B is brighter in ultraviolet and X-ray light.
The Big Bang produced only hydrogen and helium. Suppose the universe contained only low mass stars. Would elements heavier than Carbon and Oxygen exist?

A. Yes
B. No
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B. No

(Yes, because can have Type Ia Supernova – but gave credit for both)
Life of Intermediate/High-Mass Stars

- Low mass: < 2 times the Sun
- Intermediate mass: 2-8 times the Sun
- High mass: > 8 times the Sun
General Principles Are the Same: Battle Between Pressure and Gravity

- Main sequence lifetimes are much shorter
- Early stages after main sequence
  - Similar to a low mass star, but happen much faster
    - No helium flash
Intermediate-Mass Stars
\((2M_{\text{sun}} < M < 8M_{\text{sun}})\)

- May burn up to carbon but do not have enough mass to get temperatures high enough to go any higher up the periodic table.

- Degeneracy pressure stops the core from collapsing and heating enough: particles are squashed together as much as possible.

- End their lives with planetary nebulae, white dwarfs, similarly to low-mass stars.
High-Mass Stars ($M > 8 \, M_{\text{SUN}}$)

- Sequence of expansion/contraction repeats as higher and higher elements begin to fuse
- Each heavier element requires higher core temperatures to fuse
- Core structure keeps on building successive shells
  - Like an onion
- Lighter elements on the outside, heavier ones on the inside
QUIZ #3

Probes knowledge and understanding of the H-R diagram.

1) What are the axes of the H-R Diagram?
   a.) magnitude and size    b.) luminosity and color
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