White Dwarfs & Other Ends—March 21

- When the sun dies, it becomes a white dwarf. Why is a white dwarf different from a main-sequence star?
- What causes pressure?
  - In a main-sequence star, gas particles move because they are hot. (Normal gas)
  - In a WD, electrons move because they are close to each other. (Degenerate gas)
- Other ends
  - Neutron star
  - Black hole
  - Supernova

Cygnus Loop
Supernova 20,000 yr ago

What happens to the earth?

- Planetary nebula shell expelled, far beyond earth.
- Sun much larger, may engulf earth. (1 Myr)
- Star continues to shrink. Surface becomes very hot.
- Sun 1000X brighter. Earth 1000K (100 Myr)

Stars with < 2 M\(_\odot\)

- End is He \(\rightarrow\) C, O burning.
- Core never gets hot enough for further reactions.

Planetary Nebulae

Planetary nebulae, former red giants, blow away outer 25% of their mass.

The remnant in the center becomes a white dwarf.

Pictures from Hubble Space Telescope
Gravity vs Pressure

- Gravity pulls in, and pressure pushes out. A never ending contest.

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Min. Temp.</th>
<th>Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>$4^3\text{H} \rightarrow ^7\text{He}$</td>
<td>$2 \times 10^9$</td>
<td>O$^8 \rightarrow$ Mg, S</td>
</tr>
<tr>
<td>$3^4\text{He} \rightarrow ^7\text{C}$</td>
<td>$3 \times 10^9$</td>
<td>Ne$^5 \rightarrow$ O, Mg</td>
</tr>
<tr>
<td>$^6\text{C} + ^4\text{He} \rightarrow ^{10}\text{O$, Ne}$</td>
<td>$8 \times 10^8$</td>
<td>$\text{C} + 4^4\text{He} \rightarrow ^{16}\text{O$, Ne, Na, Mg}$</td>
</tr>
<tr>
<td>O$^8 \rightarrow$ Mg, S</td>
<td>$2 \times 10^8$</td>
<td>$3^4\text{He} \rightarrow ^{12}\text{C}$</td>
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<td>No fuel in center ⇒ pressure drops ⇒ gravity wins ⇒ shrink &amp; temperature rises ⇒ not hot enough to burn Ne ⇒ new kind of pressure ⇒ pressure balances gravity</td>
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Pressure in a normal gas

- What is pressure?
  - Think of gas particles in a balloon as baseballs in the balloon.
  - Baseballs move and hit walls of balloon
  - Baseballs push on the balloon

- Normal gas
  - Pressure is greater at hotter temperature
    - Baseballs move faster at hotter temperature
    - Baseballs hit walls faster & more often
    - Pressure is higher

Pressure in a degenerate gas

- What is pressure?
  - Think of gas particles in a balloon as baseballs in the balloon.
  - Baseballs move and hit walls of balloon
  - Baseballs push on the balloon

- Degenerate gas
  - Pressure is not greater at hotter temperature
  - Baseballs move because they are close together
  - Quantum mechanics: uncertainty relation
    - Speed \(\times\) confinement = Planck’s constant
  - Pressure is greater if gas is confined to smaller region
    - In a smaller star, baseballs move faster
    - Baseballs hit walls faster & more often
    - Pressure is higher

White dwarf

- Degenerate gas
  - Pressure is not greater at hotter temperature
  - Baseballs move because they are close together
  - Quantum mechanics: uncertainty relation
    - Speed \(\times\) confinement = Planck’s constant
  - Pressure is greater if gas is confined to smaller region
    - In a smaller star, baseballs move faster
    - Baseballs hit walls faster & more often
    - Pressure is higher

- A teaspoon of white dwarf weighs several tons
  - To get the largest amount of WD matter, choose the smallest one.
• Q Why does the sun end up as a carbon white dwarf?
  a. There is not enough mass to burn neon.
  b. The sun becomes degenerate
  c. The sun loses too much mass as a planetary nebula
  d. It takes too long to burn neon.