White dwarfs & supernovae — Oct 19

- What causes pressure in white dwarfs?
- Where were the elements in the baby made?
  - Carbon was made and expelled by giants
  - Iron was made in massive stars and expelled by supernovae
  - Heavier elements were made in supernovae & in giants, where there are free neutrons. Nuclei capture neutrons.

Cygnus Loop
Supernova 20,000 yr ago

- Observing
  - Wed & Thurs, Oct 21 & 22, 8:00-10:00pm.
    - Elevator cannot go up after 10:00pm.
    - Attend only if stars are visible. See angel at 6:00pm, if weather is ambiguous.
  - Quiz. You will be asked to locate a star using the Abrams Planetarium star chart. Quiz counts as one clicker assignment.
  - Go to the south end of the building (toward Wilson Rd.) & take the elevator up to the penthouse.

- Test 2 on Wed.
  - Through Adams’ discover of a white dwarf (12 Oct)
  - Energy production in sun not included (12 Oct).
  - One 8 ½ x 11” cheat sheet.

- Open house nights at the observatory
  - Friday and Saturday, Oct. 23 and 24, 9-11pm, weather permitting.
  - Observatory:
    - Go south on Farm Lane to the end
    - Turn right. Observatory is 100 yards to the west.
Normal/degeneracy pressure
White dwarfs

- Pressure on the walls of the box is caused by the gas hitting the walls. Gas transfers momentum to the walls.
- Mental picture: Marbles hit the walls; wall pushes back.
- **Normal gas**
  \[ P V = n k T \]
  \[ m v^2 = k T \]

1. Pressure is greater at higher temperature because ____.
   I. more marbles are hitting the wall every second.
   II. the marbles are moving faster and each marble has more momentum.
   A. I only
   B. II only
   C. I & II

Pressure in a “degenerate gas”

- **Normal gas**
  \[ P V = n k T \]
  - Pressure is greater at higher temperature because the marbles are moving faster. \( m v^2 = k T \)

- **Degenerate gas. If the gas is confined to a very small space, Newton’s 2nd law becomes invalid.**
  - New laws of motion, called quantum mechanics, apply.

- Heisenberg’s uncertainty principle. Suppose a particle is allowed to move within a region of length \( x \).
  \[ m v x > h \]
  - momentum \( x > h \)
  - \( v \) is speed. \( h \) is Planck’s constant.
  - A particle must move if it is confined to a small space.
  - If you confine an electron to \( 10^{-8} \)m, it moves at 70km/s.
1. Plot shows the speed of a normal gas made of electrons with a temperature of 1000K and a degenerate gas of electrons with a temperature of 0K.
   A. I is a NG. II is a DG.
   B. I is a DG. II is a NG.

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- **Pressure of a degenerate gas**
  \[ P V^{3/3} = \text{constant } n^{3/3} \]
  - constant = \( h^2/m \)
  - Pressure does not depend on temperature!!!
Other fusion reactions?

- Sun has one more trick after He is exhausted in core.
  - Burn He in a shell
- Sun is not massive enough to shrink further and get hotter
  - Core is supported by pressure of degenerate electrons.
  - Temperature does not rise to burn anything else.
- End of the road: planetary nebula & white dwarf core

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>$^4$He $\rightarrow ^4$He</td>
<td>10 MK</td>
</tr>
<tr>
<td>$^3$He $\rightarrow ^{12}$C</td>
<td>200 MK</td>
</tr>
<tr>
<td>$^{12}$C + $^4$He $\rightarrow ^{16}$O, Ne, Na, Mg</td>
<td>800 MK</td>
</tr>
<tr>
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<td>Si $\rightarrow$ Fe peak</td>
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Supernova 1987A

- Exploded in Large Magellanic Cloud
  - LMC is small galaxy that orbits our own Milky Way Galaxy.

Pre-existing circumstellar ring lit up first by photons from SN, now by blast wave from SN.
Guest star of 1054

- Records of Sung Dynasty
  - In the first year of the period Chih-ho, ..., a guest star appeared several degrees SE of Thien-kuan. After more than a year it gradually became invisible.—p578.
- Gas expelled in 1054AD, still glowing
- Other SN
  - 1572 Tycho
  - 1604 Kepler

Supernova remnants

Crab
1,000 yrs old

Cygnus Loop
20,000 yrs old.
2500 LY away.

IC 443
8000 yrs old

We expect one supernova in Milky Way every 25-100 yrs.
Supernovae

• Explosion releases enormous energy
• Luminosity in photons temporarily exceeds that of whole galaxy full (100 billion) of stars.

What is a supernova? Why sun becomes a white dwarf, not a supernova

• In future double-shell burning sun, hot enough to burn
  \[3^4\text{He} \rightarrow \text{C}^12\]
• When He exhausted, gravity wins, and core contracts.
• Temperature rises.
• Electrons are so tight that they become degenerate.
• New source of pressure to resist gravity.
• Temperature not hot enough to burn carbon.

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What is a supernova? Why massive star becomes a supernova

- In future double-shell burning massive star, hot enough to burn $^{3}\text{He} \rightarrow ^{12}\text{C}$
- When He exhausted, gravity wins, and core contracts.
- Temperature rises by larger amount b/c gravity is stronger.
- Temperature hot enough to burn carbon. $^{4}\text{He} + ^{12}\text{C} \rightarrow ^{16}\text{O}$, etc

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What is a supernova? Why massive star becomes a supernova

- Hot enough to burn $^{4}\text{He} + ^{12}\text{C} \rightarrow ^{16}\text{O}$, etc
- When C exhausted, gravity wins, and core contracts.
- Temperature rises.
- Temperature hot enough to burn neon. $^{20}\text{Ne} + ^{4}\text{He} \rightarrow ^{20}\text{Mg}$
- Disaster with iron
  - Burning releases energy
  - Fusing iron takes up energy
- Gravity finally wins.

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What is a supernova? Why massive star becomes a supernova

- Disaster with iron
  - Burning releases energy
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- Gravity finally wins.
- Star collapses in few seconds
- Rebounds as supernova
  - Reason for rebounding is topic of current research
- Expel outer layers

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