How Stars Make Carbon

- Carbon is all around us.
  - Pure Carbon: Graphite, Diamonds
  - Carbon Compounds: \( \text{CO}_2, \text{CH}_4 \) (methane) are gases, carbohydrates are in food, and hydrocarbons are fuel.

- Every Carbon atom in the Universe ... was made in a star.

- At temperatures of 100 Million Kelvins, three Helium Nuclei can fuse to become 1 Carbon.

- This is called the Triple Alpha Process.
Three Helium nuclei fuse into Carbon
The Sun’s Last Gasp

- In 5 billion years, the Sun will run out of Hydrogen fuel.
- The dense core of the Sun will then fuse **Helium Nuclei** producing **Carbon** and **Oxygen**.

- **Helium Fusion** is hotter than hydrogen fusion.
- The extra heat makes the outer layers expand until they are lost into space.
- These layers will form a great cloud called a: **planetary nebula**
Planetary Nebulae
Are the last gasps of dying stars
(and are not related to planets!)

Helix Nebula
(closeup view)
The Ring Nebula: A Planetary Nebula
Leaving the Main Sequence

When Main Sequence stars run out of Hydrogen fuel, their Temp. and Luminosity change. They “leave the Main Sequence” to become **Giant Stars**. They are beginning to die...
Some large, puffy giant stars actually **pulsate**, growing larger then smaller.

We’re not sure why, but it could be something like a pot of boiling water:

Pressure builds up, then a puff of steam is released.

These stars are called: **“Cepheids”**
Cepheid Variable Stars

- If a star’s brightness changes it is called a variable star.
- One type is Cepheid Variables.
  - (named for the const. Cepheus)

- In 1908, astronomer Henrietta Leavitt made a huge discovery about Cepheids.

Henrietta Leavitt
Pulsating Cepheid Stars

Cepheids **pulsate**: they get bigger and smaller every few days. They also get brighter and dimmer (their magnitude changes). The time it takes to do this is the Pulse Period, $P$.

Levitt measured $P$ for several Cepheids all at the same distance.

She noticed something very interesting:
Large, luminous Cepheids pulsate slowly (long “period”)
Small, dim Cepheids pulsate quickly (short period)
So, if we observe the period of pulsation, we can figure out exactly how bright it is...its luminosity.

The North Star is a Cepheid: it pulsates every 4 days.
A new way to measure distance

- Leavitt observed a connection between a Cepheid’s pulse period and its luminosity (or Absolute Magnitude),

This can be used **find the star’s distance**

Cepheids let us measure distance to stars!
Review

- Stars “live” by fusing Hydrogen into Helium
- When they run out of Hydrogen, they begin to “die”
- Their temperature and luminosity change, so they “move” off the HR diagram’s **Main Sequence**

- When a medium-mass star (like the Sun) begins to die, it turns into a Red Giant, a Planetary Nebula, then a White Dwarf.

- **Cepheids** are pulsating giant stars with a known Period-Luminosity relation
- This allows us to determine their distance.
Summary of the Sun’s Evolution

After leaving the Main Sequence, the Sun will first become a **Red Giant**, then a **Planetary Nebula**, and a **White Dwarf**.

It will have a “quiet retirement.”
The Deaths of Stars
(Chapter 13)
White Dwarfs

- When a Sun-like star dies, its core is left behind.
- It is very hot: around 10,000K
- They are called: **White Dwarfs**
- White dwarfs are very small!
- The Sun will end its life as a **White Dwarf**, slowly cooling down.
White Dwarfs, are small, dim and hard to detect.

The first was detected in 1910.

It is a binary companion to Sirius
Observing White Dwarfs

White dwarfs are only about as big as the Earth, but have the mass of the Sun!

So, they are extremely dense.

One teaspoon of white dwarf material would weigh 10 tons!!!
White Dwarfs

Normal stars (on the Main Sequence) resist gravity with thermal pressure from fusion.

But White Dwarfs do not have fusion.

So how do they resist the powerful force of gravity? Why don’t they collapse?

Their extreme density is the key to survival.

The matter in a white dwarf is “Degenerate”: so dense that the electrons almost “touch”
Degenerate matter is hard to compress….  

Because all energy levels are full!

This gives White Dwarfs a “Degeneracy Pressure” that resists gravity.
White Dwarfs can Explode

Astronomer S. Chandrasekhar used quantum physics to show that White Dwarfs with a mass over $1.4 \, M_{\text{sun}}$ cannot exist!

If a White Dwarf’s mass exceeds this “Chandrasekhar Limit” it will explode!!

This runaway thermonuclear reaction is called a Supernova (Type 1) and it destroy the star!

But how could a White Dwarf’s mass increase to become more than $1.4 \, M_{\text{SUN}}$?
Type Ia Supernova

If another star orbits the White Dwarf, then matter will accrete (fall onto) it, adding to its mass.

If the W.D. goes over 1.4 M\(_{\text{sun}}\)....

KABOOM
The Death of Stars

Massive stars start on the Main Sequence & quickly fuse their H. They eventually expand, and turn into SuperGiants.

After a supergiant runs out of fuel it will cause a huge explosion called a supernova.

It could become neutron star or a black hole.

Summary: Death of Massive Stars (M>8 M_{Sun})