A Star’s Fate Depends on its **Mass**

We will consider stars in 3 **mass** ranges:

- **Small Stars:** Mass $< 0.4 \, M_{\odot}$
- **Medium Stars:** $0.4 \, M_{\odot} < \text{Mass} < 8 \, M_{\odot}$
- **Large Stars:** $8 \, M_{\odot} < \text{Mass}$
Plan A: Fuse H into He

In the Core
The Sun in 5 billion years:

- Leaving the Main Sequence
-- Core is:
  0 % H
  100 % He

Plan B: Fuse H into He
In a Shell around the core

Shell fusion deposits heat in the star, causing it to expand....
Becoming a Red Giant
The Sun will become so large it will swallow up Mercury and Venus!
The Sun Becomes a Red Giant

- When a star becomes a Giant star it will be more luminous.
- Its surface will also be cooler.
- It leaves the Main Sequence.

- The shell runs out of Hydrogen and gravity shrinks the core.

- The Helium core becomes so dense that a new nuclear reaction can take place:
  - Helium can fuse into Carbon.
How Stars Make Carbon

- Carbon is all around us.
  - Pure Carbon: Graphite, Diamonds
  - Carbon Compounds: CO$_2$, CH$_4$ (methane) are gasses, 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.
Plan C: Carbon

1. $^4\text{He}$
2. $^4\text{He}$
3. $^8\text{Be}$

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
The Cat Eye 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...
Cepheid Variable Stars

- If a star’s brightness changes its called a variable star.
- One type of giant star is called a Cepheid Variable.
  (named for Delta Cephei, the first example of such a star.)
- 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!
Recap

- Stars “live” by fusing Hydrogen into Helium
- When they run out of Hydrogen, the 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!!!