Read Ch. 13 Stellar Evolution (all)

Croswell: (Skim Ch. 11 & 12)
Read Ch. 13
As a 1 $M_{\text{SUN}}$ star cools, the H$^{-}$ ion can form, and absorb considerable light.

This creates a growing convection region that:

1. transports heat to the surface more quickly (increasing $L$)
2. “dredges up” elements produced in the core by nucleosynthesis.

These elements can be observed spectroscopically: fragile Lithium disappears from the spectrum.
Increasing core temp. eventually permits $^{4}\text{He}$ to fuse into $^{12}\text{C}$, in the "Helium Flash"

(For $M<1.8\ \text{M}_{\odot}$, the Flash is accelerated by conditions of electron degeneracy)

For a few seconds, the core’s luminosity is about $10^{11}\ \text{L}_{\odot}$....BUT:

1. most of this light is absorbed by the envelope.

2. the star gets dimmer! ...due to smaller Radius
\( ^{4}\text{He} \) now fuses in the core (Triple Alpha) creating a new “main sequence” phase. \( ^{1}\text{H} \) continues to fuse in the shell. Star’s Temp. changes while \textit{Luminosity is constant}: “\textbf{Horizontal Branch}” star.

Core \( ^{4}\text{He} \) is quickly exhausted, but continues to fuse in a Helium Shell.

Convection sets in again (due to high temps.) and another “dredge up” occurs.

Luminosity increases as the star climbs the “\textbf{Asymptotic Giant Branch}” (AGB star)
At the top of the AGB, fusion occurs in two shells: a thick H-fusion shell and a thin He-fusion shell below.

Newly formed Helium rains down onto the He-fusion shell causing periodic flare-ups.

Star’s structure is unstable to oscillation, and it becomes a long-period variable star (P~100-700 days).

Mira (ο Ceti), the first variable star discovered, is a pulsating AGB star. \( V = 2.0 \) to 10.1 !!!
Pulsations in giant stars cause outer layers to be lost to space. Mass-loss rates can reach:

$$\frac{dM}{dt} = 10^{-4} \, M_{\text{SUN}}/\text{year} \sim 30 \, M_{\text{Earth}}/\text{year}!$$

Matter ejected into space becomes a Planetary Nebula.

**FIGURE 13.9** The surface luminosity as a function of time for a 0.6 M$_{\odot}$ star undergoing helium shell flashes on the TP-AGB. (Figure adapted from Iben, *Ap. J.*
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
Evolution of 1 \( M_{\odot} \) Star  

Evolution of a 5 \( M_{\odot} \) Star
White Dwarfs

Stars with Mass between 1-8 \( M_{\text{SUN}} \) lose varying amounts of mass.

Only their cores (composed of Carbon & Oxygen) remain as White Dwarfs.

Curiously, they all seem to lose so much mass, that they are left with only 1.4 \( M_{\text{SUN}} \) or less.

WD’s gradually cool off.

But what keeps them from collapsing?
Neutrinos react very rarely. Their signal is swamped by other reactions, e.g., cosmic rays...unless these contaminants are shielded out. So place your detector underground...

A neutrino from this PP reaction:

Might collide with a Chlorine atom:

You'll need a lot of Cl!
Electron Degeneracy

Electrons have spin 1/2, so are **Fermions**. Two Fermions cannot occupy the same quantum state. Under conditions of extreme density, (*Degeneracy*), this prevents electrons from being compressed further. **Electron Degeneracy Pressure** keeps White Dwarfs from collapsing.

But degeneracy pressure has limits.

In 1930, S. Chandrasekhar solved the equations of state for a White Dwarf...with curious results:
Type 1a Supernova

Chandrasekhar determined the mass & radius of WD’s. WD’s get *smaller* the more mass they have. At a mass of 1.4 $M_{\text{SUN}}$ they have zero size! Degeneracy Pressure cannot support WD’s greater than this.

If a WD gains enough mass to go above this “Chandrasekhar Limit”, runaway thermonuclear fusion of Carbon occurs.

This detonation utterly destroys the star & is called a Supernova Type 1a.