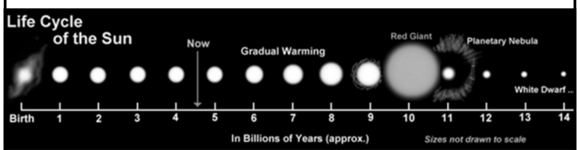
Lecture 33

The Lives of Stars



Astronomy 141 – Winter 2012

This lecture concerns the life cycle of normal stars.

Stars shine because they are hot, and need a source of energy to keep shining.

Main Sequence stars are powered by the fusion of Hydrogen into Helium in their cores

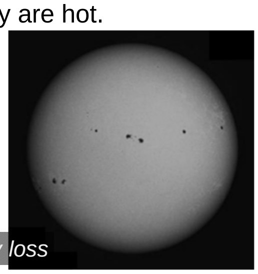
The more massive a star is, the shorter its lifetime.

Low-Mass stars are long-lived, spend some time as Red Giants, then leave behind a White Dwarf.

Very high-mass stars have very short lives, spend a short time as red supergiants, then explode as a supernova.

Stars shine because they are hot.

Starlight is internal heat "leaking" through a star's surface.



Luminosity = rate of energy loss

To stay hot, stars must replace the lost energy, otherwise they would cool and fade out.

The primary source of energy for stars over most of their lives is nuclear fusion.

Example:
Fuse 4 Hydrogen nuclei into 1 Helium nucleus

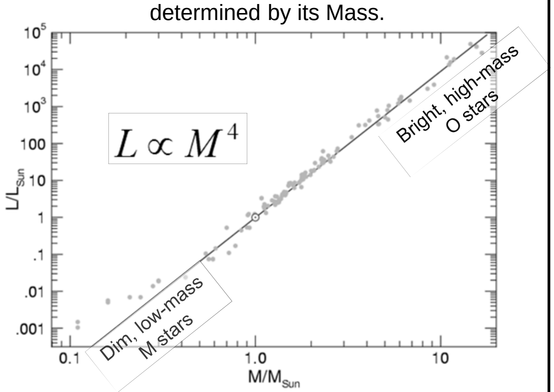
4 protons weigh slightly more than 1 Helium (2p+2n):
1 kg of Hydrogen would fuse into 0.993 kg of Helium.

Leftover 0.007 kg (7 grams) is converted into energy:

$$E = mc^2 = 6.3\times10^{14} \text{ Joules}$$

Enough energy to lift 64 megatons of mass to a height of 1 km above the ground!

The Luminosity of a Main Sequence star is determined by its Mass.



A main sequence star shines steadily only until the hydrogen in its core is used up.

The Sun will run out of fuel after a 10 Gyr "lifetime" on the Main Sequence.

Dim M stars are "subcompacts"; they stay on the main sequence for a long time.

Bright O stars are "gas guzzlers"; they run out of fuel in a relatively short time.

Lower-mass stars live long and burn slowly.
Massive stars live fast & die young.

Sun: $M = 1\ M_{sun}$
$t_{MS} \approx 10$ Gyr

B Star: $M = 10\ M_{sun}$
$t_{MS} \approx 10$ Myr

M Star: $M = 0.1\ M_{sun}$
$t_{MS} \approx 10{,}000$ Gyr

Life began on Earth about 500 Myr after the formation of the Sun.

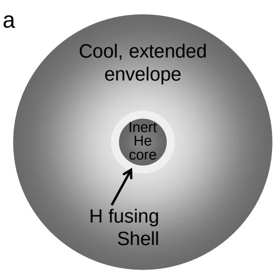
To give life a chance a star must shine stably for at least 500 Myr.

Only stars of < 3 M_{sun} live for about 500 Myr.

O & B stars are ruled out as hosts of life by this criterion: their "lifetimes" are < 500 Myr.

What happens when a star runs out of hydrogen in its core, and it leaves the main sequence?

Fusion reactions switch to a thin shell outside a core of inert Helium "ash".

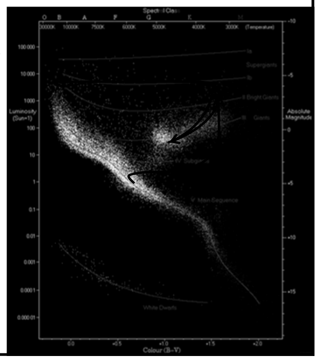


What the star does next depends on its mass...

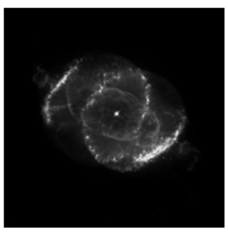
Low-mass stars ($M < 4\ M_{sun}$) become **red giants** after leaving the main sequence.

The red giant eventually becomes unstable, and blows away its outer layers into space.

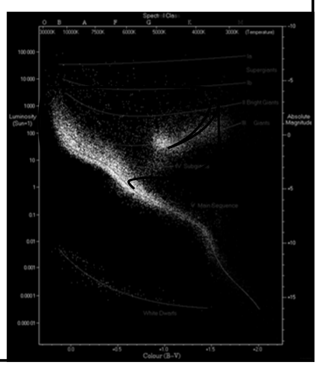
The naked core of the red giant is revealed.



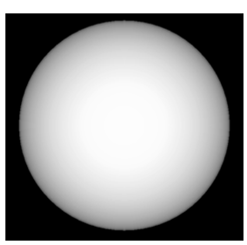
The expelled gas is briefly lit up as a planetary nebula.



The naked core becomes a White Dwarf.



White dwarfs are the remnants of relatively low-mass stars.



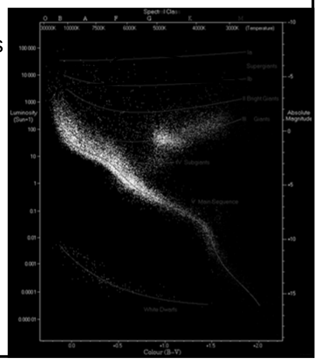
White dwarfs have **no nuclear fusion** (and thus aren't true stars by the strictest definition).

They cool slowly over many billions of years.

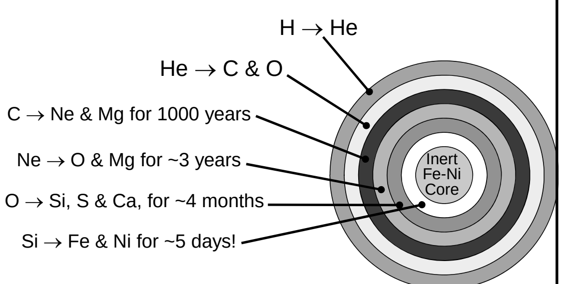
Higher-mass stars ($M > 4\ M_{sun}$) become Red Supergiants after leaving the main sequence.

Intermediate mass stars ($4\ M_{sun} < M < 8\ M_{sun}$) shed enough mass to settle down as White Dwarfs.

Very high mass stars ($M > 8\ M_{sun}$) have a more spectacular fate!



Very high mass stars run through a succession of nuclear fusion reactions in their cores.

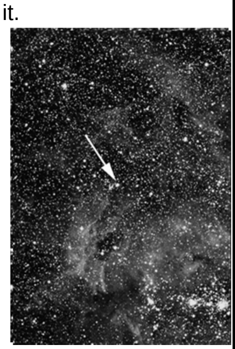


An increasing large iron-nickel core grows at the star's center.

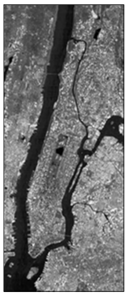
Fusion to form elements heavier than iron and nickel takes energy; it doesn't release it.

When the iron-nickel core grows to $1.4\ M_{sun}$, it collapses catastrophically.

The core bounces back and triggers a supernova explosion.

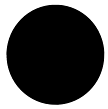


The remnant core of the massive star becomes either a Neutron Star or a Black Hole.



Manhattan

Neutron Star
$M=1.5\ M_{sun}$
R=10 km



Black Hole
$M=1.5\ M_{sun}$
$R_S=4.5$ km

The material ejected by a supernova is rich in Carbon, Oxygen, and other heavy elements.

The Earth and everything on it are made of recycled star stuff.