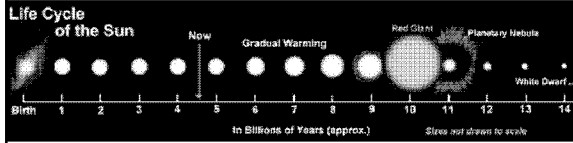


Wednesday, November 10 "Life" and "Death" of Stars



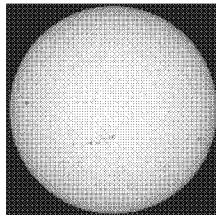
Problem set #3 will be due on Monday.

"Life" and "Death" of Stars Key Concepts

- 1) Main sequence stars are powered by the fusion of hydrogen into helium in their cores.
- 2) Low-mass stars spend some time as red giants, then leave a white dwarf behind.
- 3) Very high-mass stars spend a short time as red supergiants, then explode as a supernova.

Stars shine because they are hot.

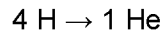
Starlight can be thought of as internal heat "leaking" through the star's surface.



To stay hot, stars must replace the leakage; otherwise, they'll cool & fade.

Stars generate energy by nuclear fusion.

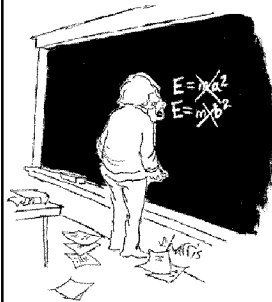
Main sequence stars fuse hydrogen into helium in their cores.



1 kilogram of hydrogen is converted into 0.993 kilograms of helium.

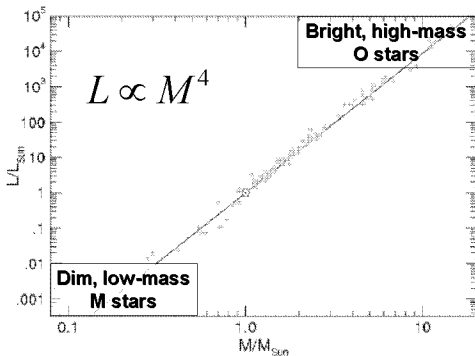
What happens to the lost 7 grams?

The lost **mass** is converted into **energy**:



$$E = mc^2$$
$$= 6.2 \times 10^{14} \text{ joules}$$

Main sequence stars have a luminosity that is **strongly** dependent on mass.

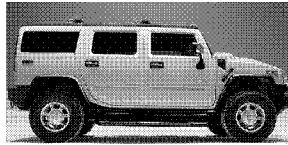


A main sequence star shines steadily only until the hydrogen in its core is used up.

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.

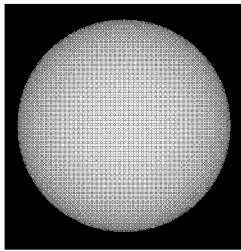


Bright O stars are "gas guzzlers"; they run out of fuel in a relatively short time.

Massive stars live fast & die young.
Lower-mass stars live long at a low flame.



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



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



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

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



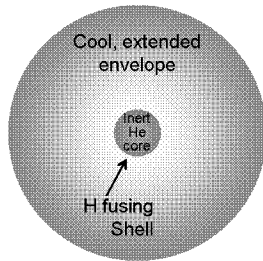
To give life a chance, a star must shine stably for at least 500 Myr; this implies a stellar mass $M < 3 M_{\text{sun}}$.

O & B stars are ruled out by this criterion: their "lifetimes" are $< 500 \text{ Myr}$.

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 helium "ash".

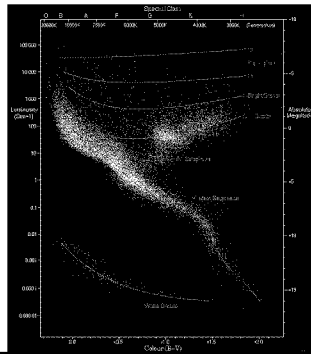
What a star does next depends on its mass.



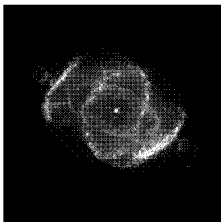
Low-mass stars ($M < 4 M_{\text{sun}}$) become **red giants** after leaving the main sequence.

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

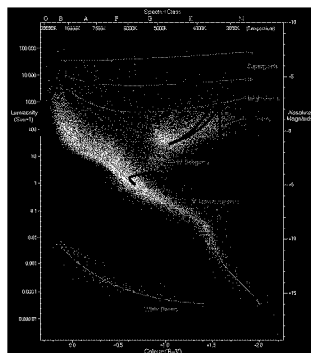
The naked core of the red giant is revealed.



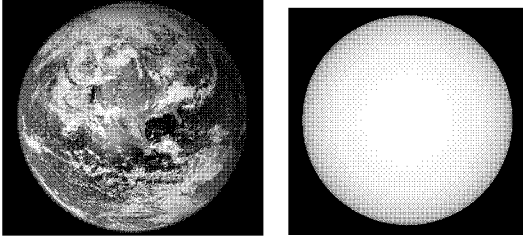
The expelled gas is briefly lit up as a **planetary nebula**.



The naked core becomes a **white dwarf**.



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

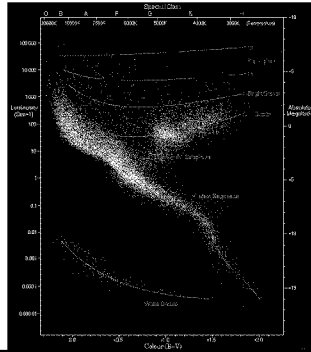


White dwarfs have **no nuclear fusion** (& thus aren't stars by the strictest definition); they cool slowly over billions of years.

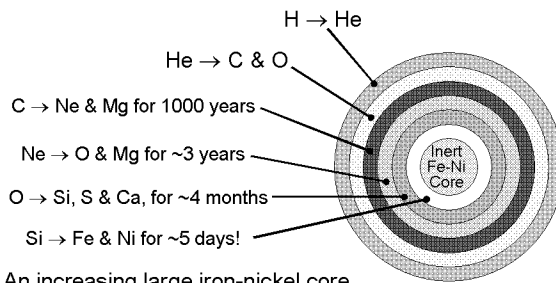
Higher-mass stars ($M > 4 M_{\text{sun}}$) become **red supergiants** after leaving the main sequence.

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

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



Very high mass stars run through a succession of fusion reactions.

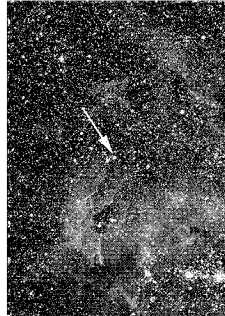


An increasing large iron-nickel core grows at the star's center.

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

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

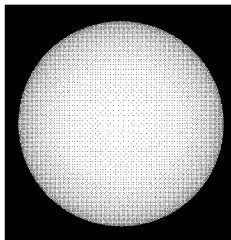
The core bounces back and triggers a **supernova** explosion.



The remnant core of the massive star becomes either a neutron star or a black hole.



Manhattan



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



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

Friday's Lecture:
Habitable Zones of Other Stars

This Week's Reading:
Chapter 11
