The life-cycle of stars

Star Formation
&
Stellar Evolution

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MANUU

What are stars?

Stars are huge balls of Gas radiating high amounts of energy due to nuclear fusion going on at its center.

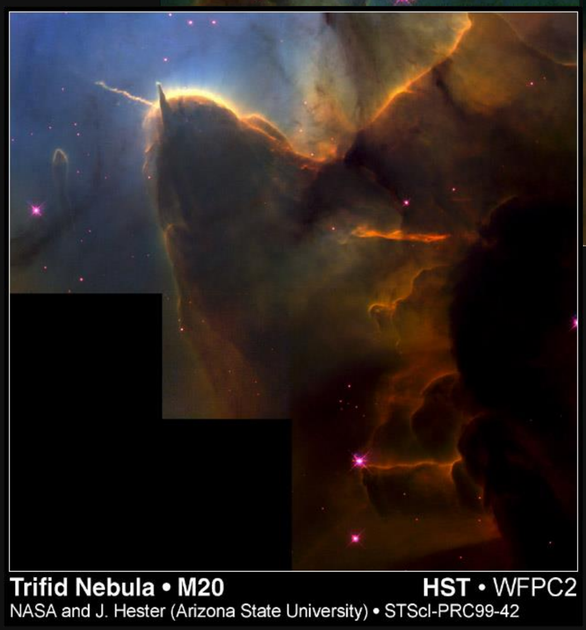
Some important questions?

- Are stars born?
- Do stars evolve?
- Do stars die?

Short answer:

Yes stars are born, since they are radiating, hence they should evolve and they end-up (die) in different forms depending their initial mass and chemical composition.

Stars are born in clouds as these:



Giant Molecular clouds

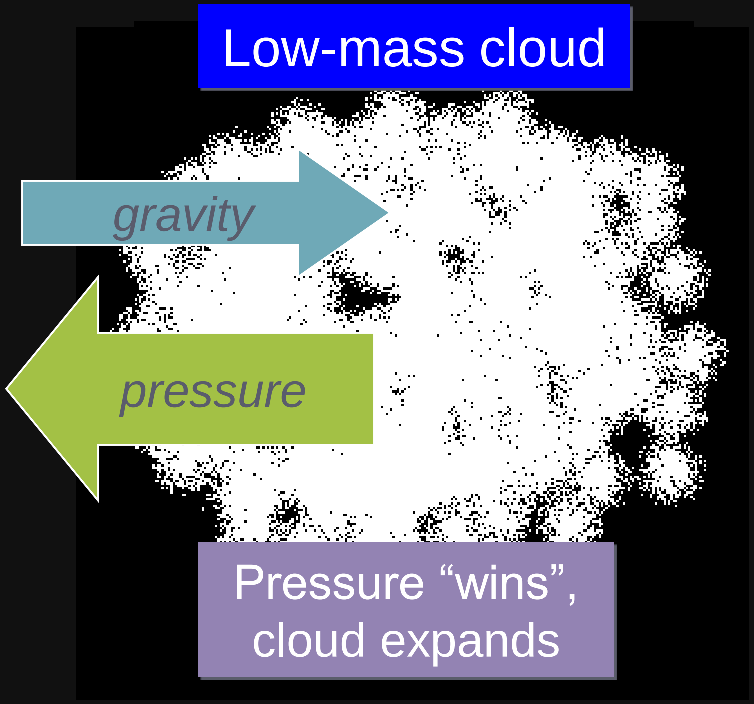
- **Low-density cloud (10,000 atoms per cm^3)**
- **Very cold: T~10-20 K**
- **Made mostly of: H (75%) and He (23-25%) and a bit of heavier elements (<2%).**

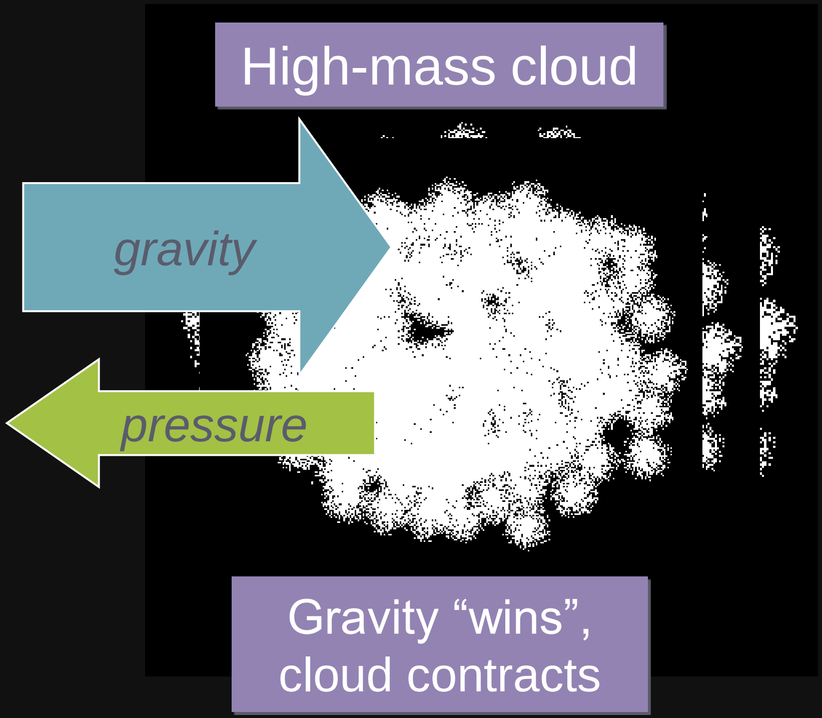
If the molecular cloud has sufficient mass and low temperature it collapses under its own gravity.

Two forces act on the system:

(1) Gravity which tries to collapse the cloud

(2) Pressure (thermal) which tries to expand the cloud





Jeans Mass

In gas clouds, the kinetic energy is due to the motions of the atoms which make up the cloud,

if there are N total atoms in the cloud

the kinetic energy is $K = (N)(\frac{3}{2}kT)$ & the gravitational Potential Energy is $U = -\frac{3}{5}\frac{GM^2}{R}$

The virial theorem states: $2K + U = 0$ Hence we get $3NkT = \frac{3}{5}\frac{GM^2}{R}$

if we want to have the cloud collapse, we have to have $3NkT < \frac{3}{5}\frac{GM^2}{R}$

The number of particles is simply the mass of the cloud divided by the mass per particle:

Assuming the cloud has a constant density, the size of the cloud can be related to the mass and density by:

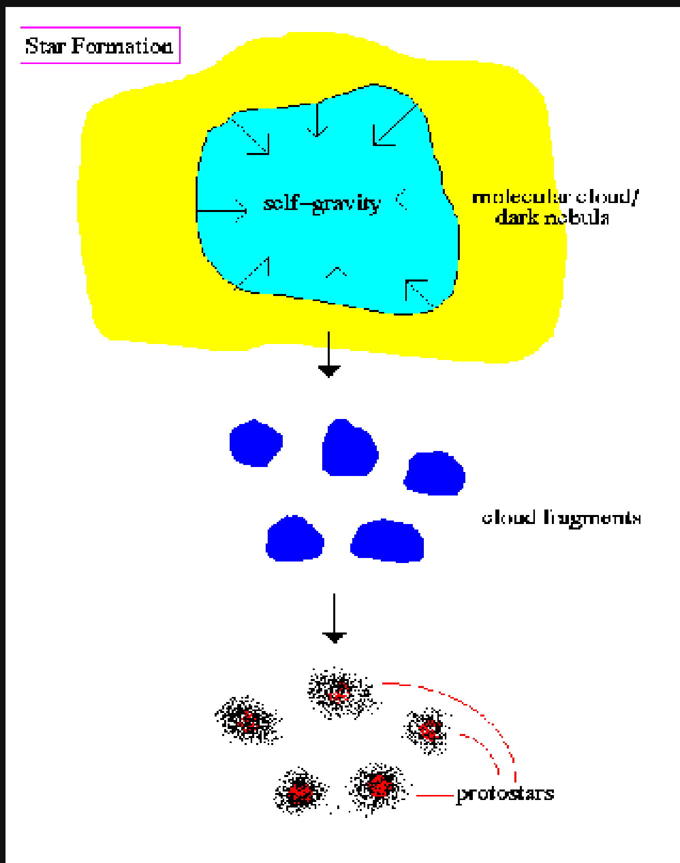
$$N = M/m \qquad R = \left(\frac{3M}{4\pi\rho}\right)^{1/3}$$

$$M_J = \left(\frac{5kT}{Gm}\right)^{3/2}\left(\frac{3}{4\pi\rho}\right)^{1/2}$$

$$\text{if } \mathrm{M}_{\text{cloud}} > M_J \quad \rightarrow \text{collapse!}$$

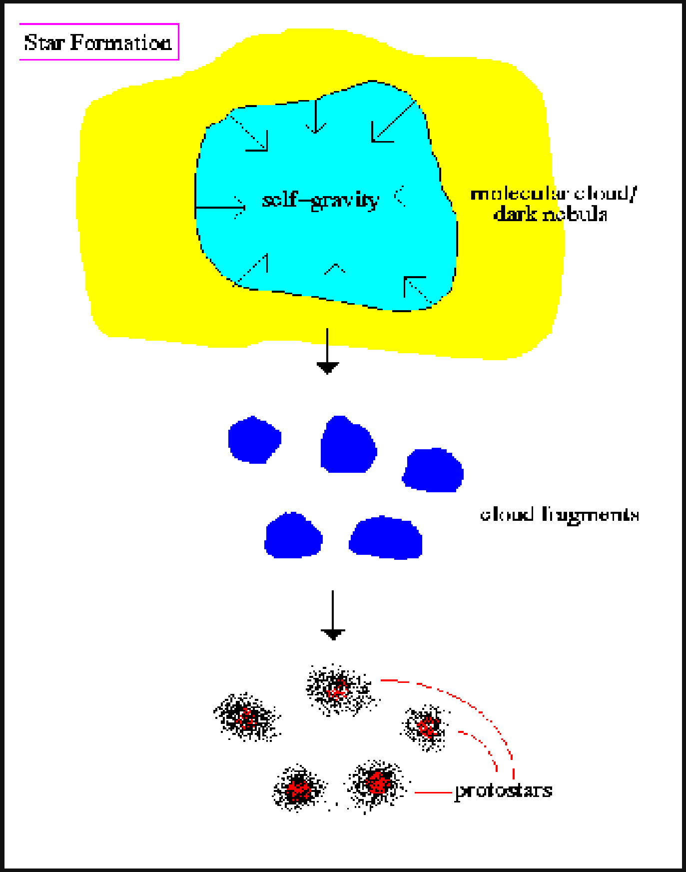
The cloud will collapse if its mass is bigger than the Jean's mass. This is called the Jean's criterion.

Cluster Formation



- Gravitational Vs Thermal energy
- M_{cloud}~10^3 M_{sun}
- $R_{cloud~}$ Lt yrs
- Fragmentation
- fragments lead to the formation of a star cluster

.....Cluster Formation



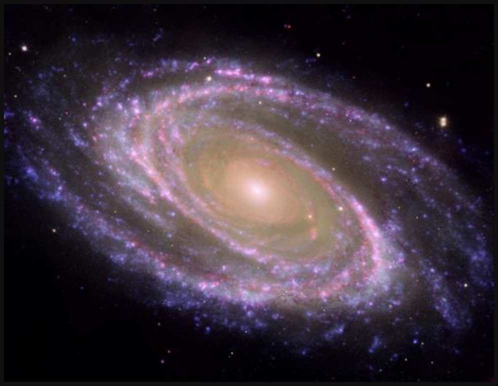
Stars are not born in isolation!

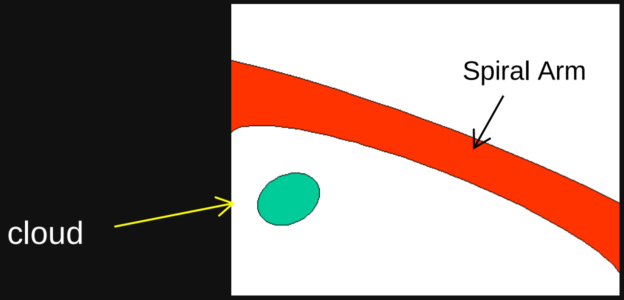
They are always born in groups

All field stars are from clusters

Star formation:
The Trigger Mechanism

- Spiral Density Waves
- Supernova
- Galaxy interactions

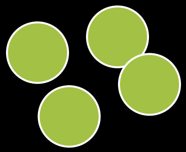




Energy production

The proton-proton chain:

BEFORE:
four protons



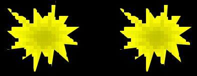
Initial total mass = 6.693 x 10^{-27} kg

AFTER:
helium nucleus
plus two positrons
plus two neutrinos

Final total mass = 6.645 x 10^{-27} kg

Difference = 0.048 x 10^{-27} kg

… and two gamma rays



… and according to $E = mc^2$
this is equivalent to ...

Energy = 0.43 x 10^{-11} joules

… which is just the energy observed
in the two gamma rays

Other important fusion reactions

In our Sun proton-proton chain dominates (91%), in other stars other reactions are very important. Here are the main ones:

CNO cycle

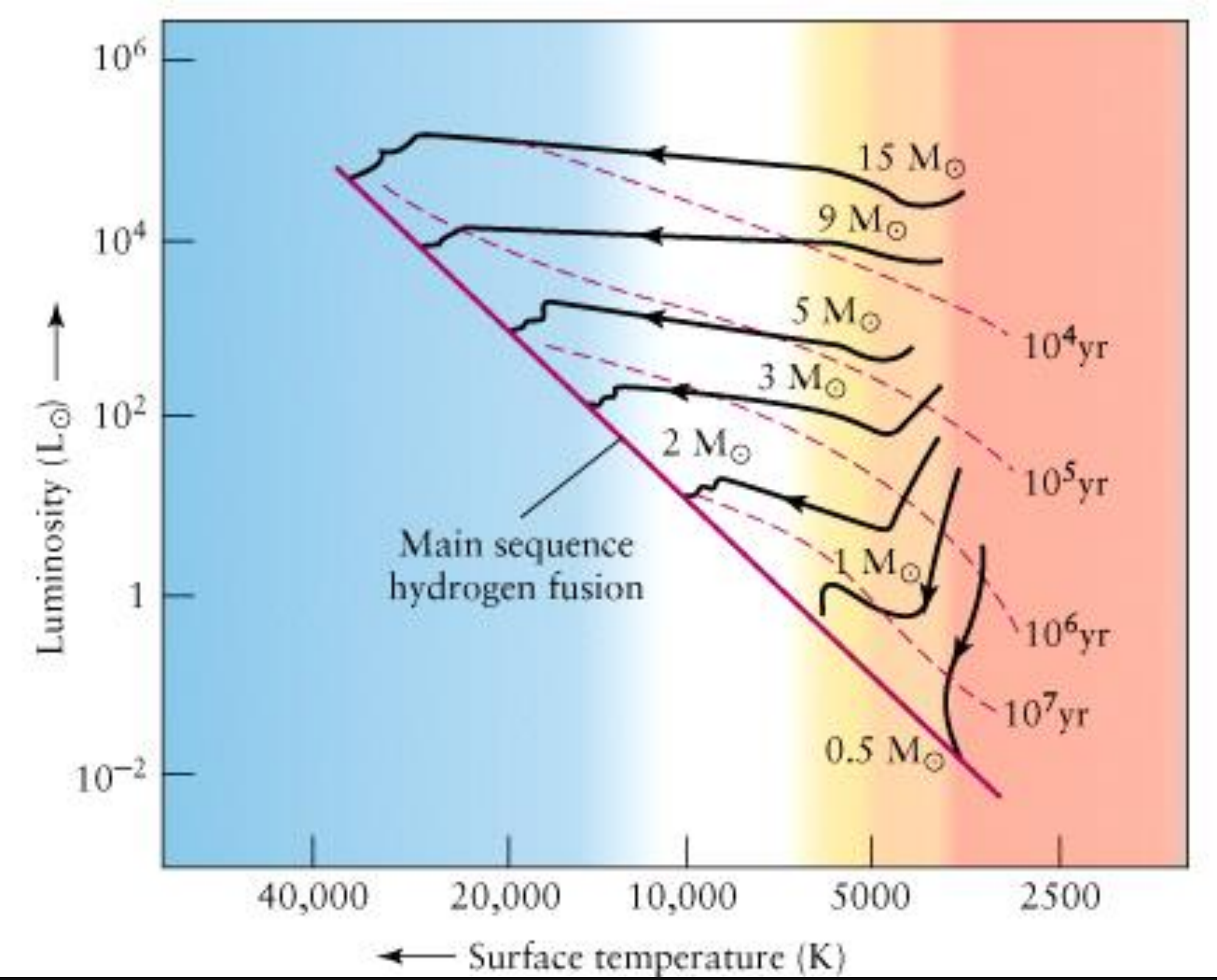
A complex series of reactions in which the transformation carbon - nitrogen - carbon - nitrogen - oxygen - nitrogen - carbon facilitates the conversion of four protons to one helium nucleus (plus energy)

Helium “burning”

Three helium nuclei fuse to create one carbon nucleus (plus energy).
This is also called the “triple-alpha reaction”.

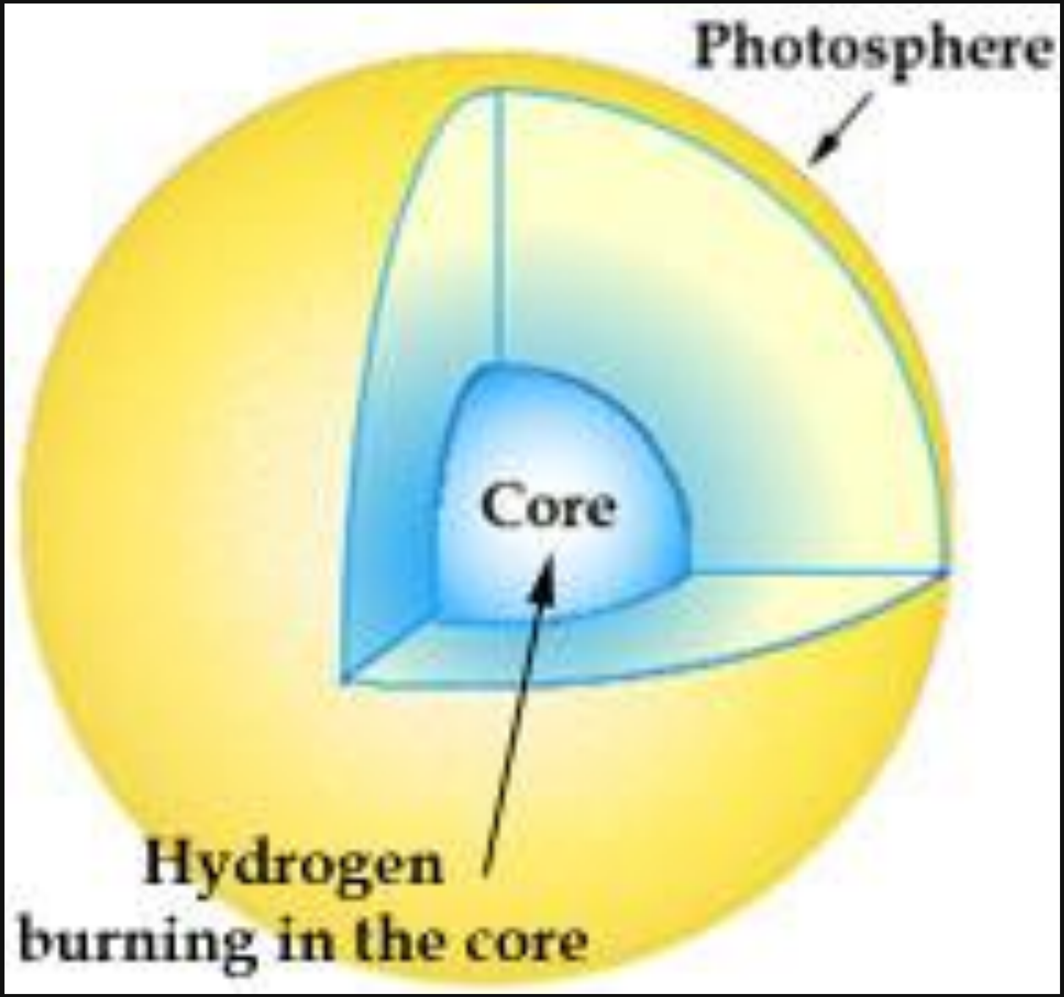
Carbon “burning”

Carbon is fused to form heavy elements (plus energy): in particular, iron is the final product of much carbon burning.

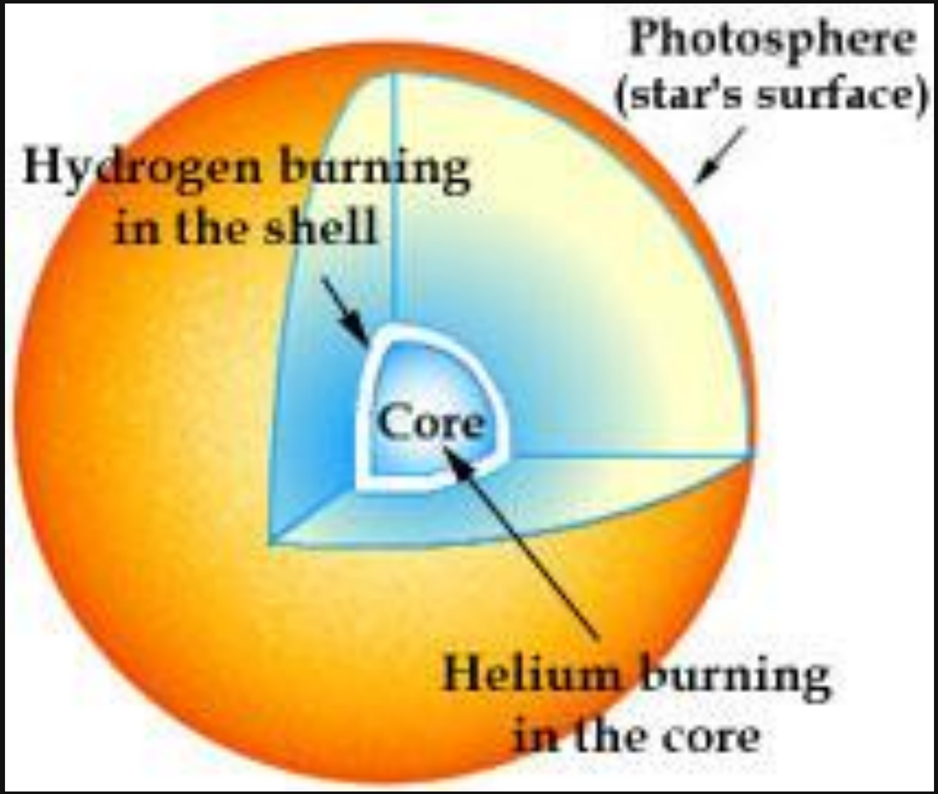


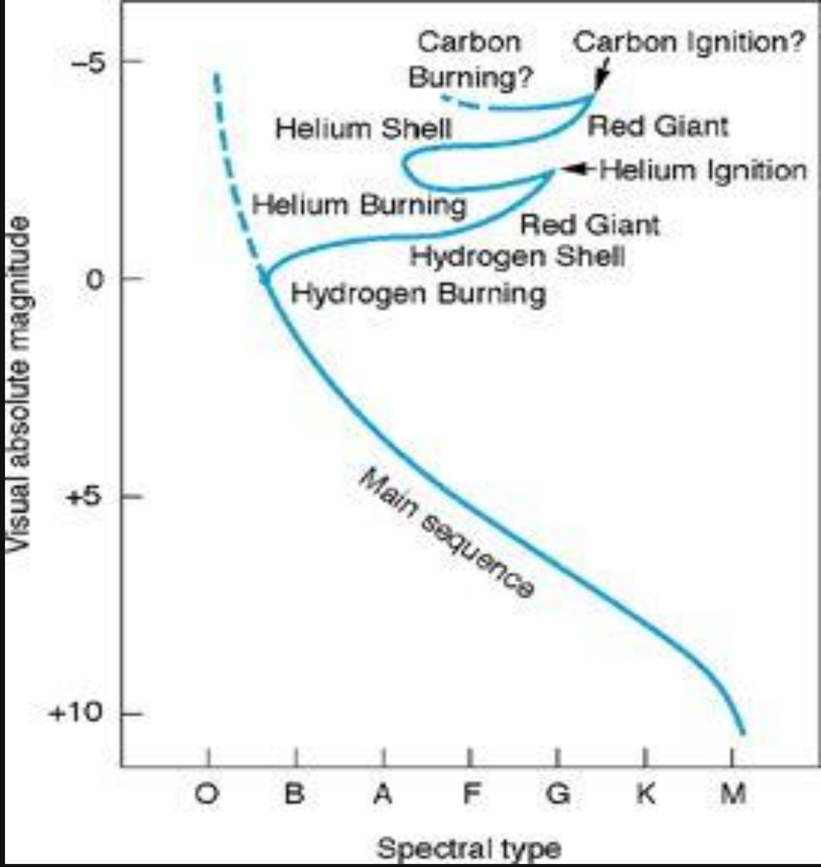
10^6
10^4
10^2
1
10^{-2}
Luminosity ($L_\odot$)
15 $M_\odot$
9 $M_\odot$
5 $M_\odot$
3 $M_\odot$
2 $M_\odot$
1 $M_\odot$
0.5 $M_\odot$
10^4yr
10^5yr
10^6yr
10^7yr
Main sequence
hydrogen fusion
40,000
20,000
10,000
5000
2500
Surface temperature (K)

Throughout most of their life, stars convert hydrogen to helium...

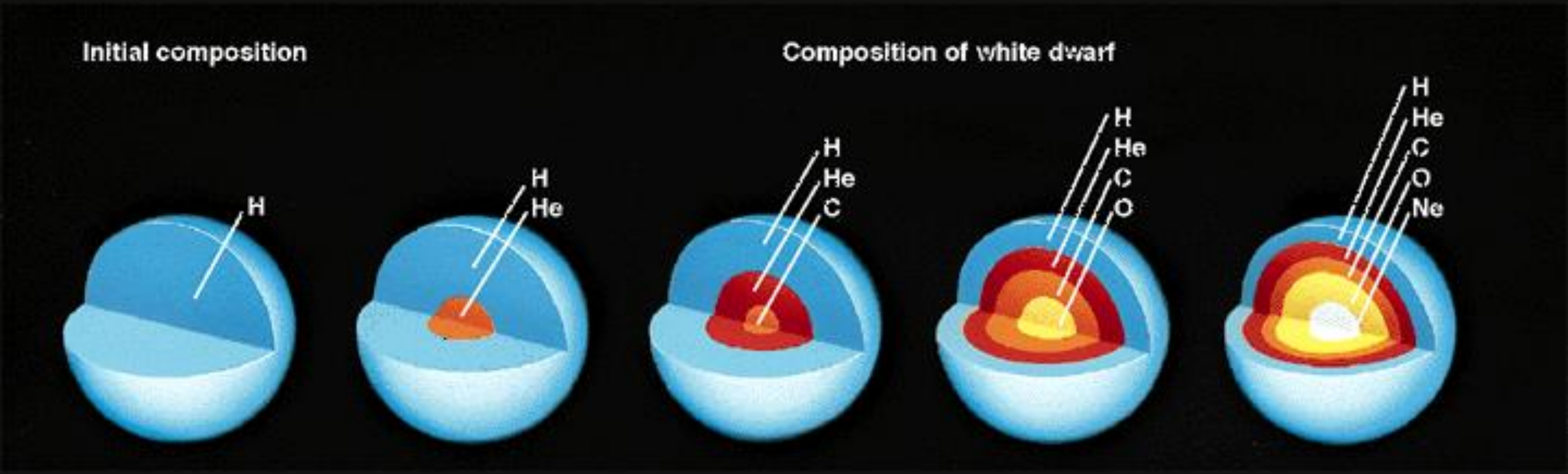


As stars run out of hydrogen, they start “burning” helium:

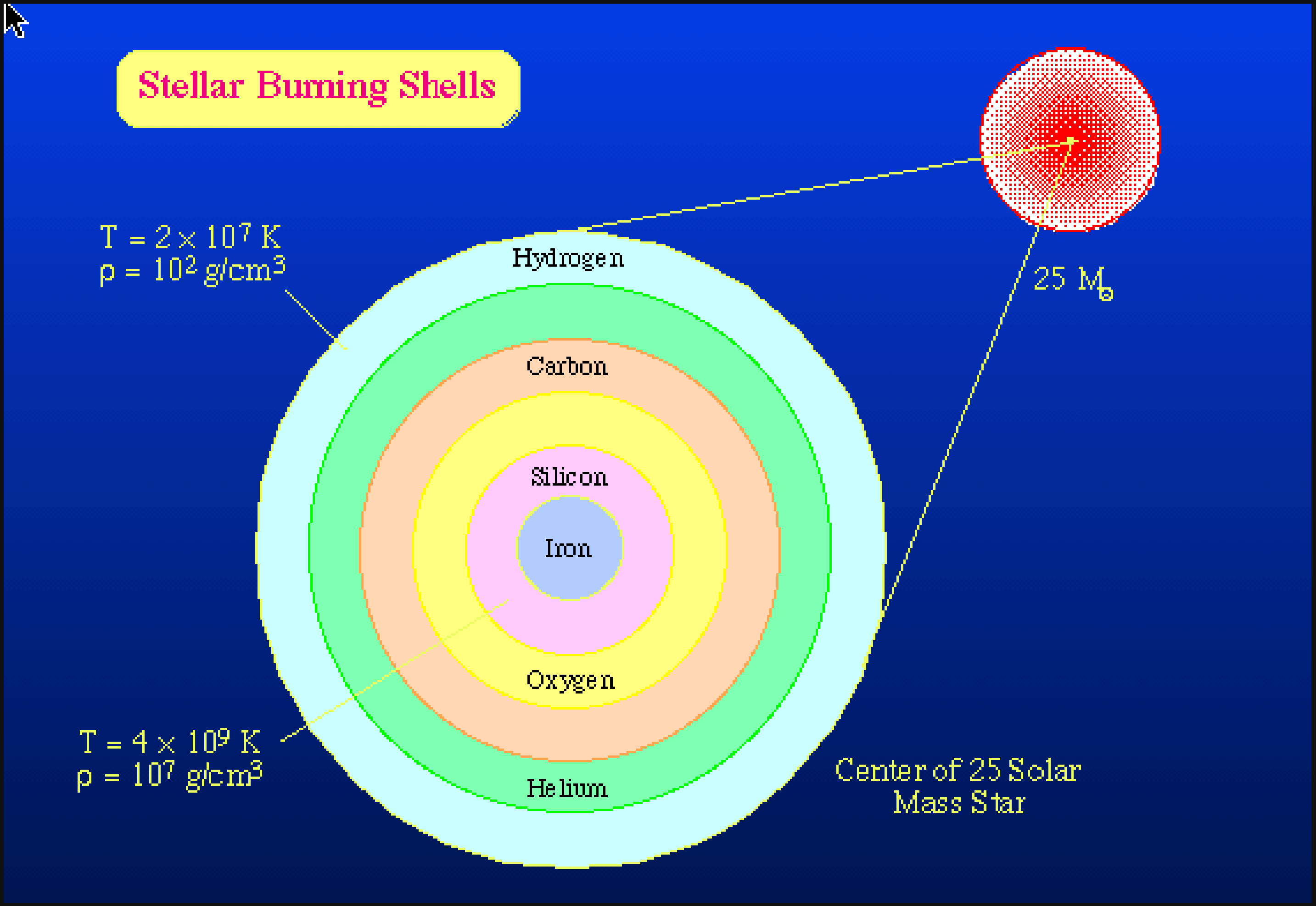


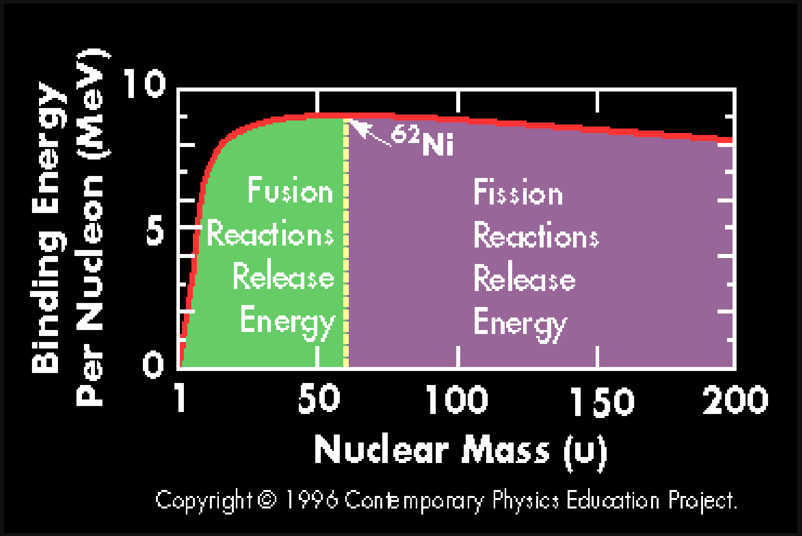


Later, the star may burn helium and other products



The stars as they evolve get a shell structure which depends of its mass





Binding Energy Per Nucleon (MeV)
10
5
0
1
50
100
150
200
Nuclear Mass (u)
^{62}Ni
Fusion Reactions Release Energy
Fission Reactions Release Energy
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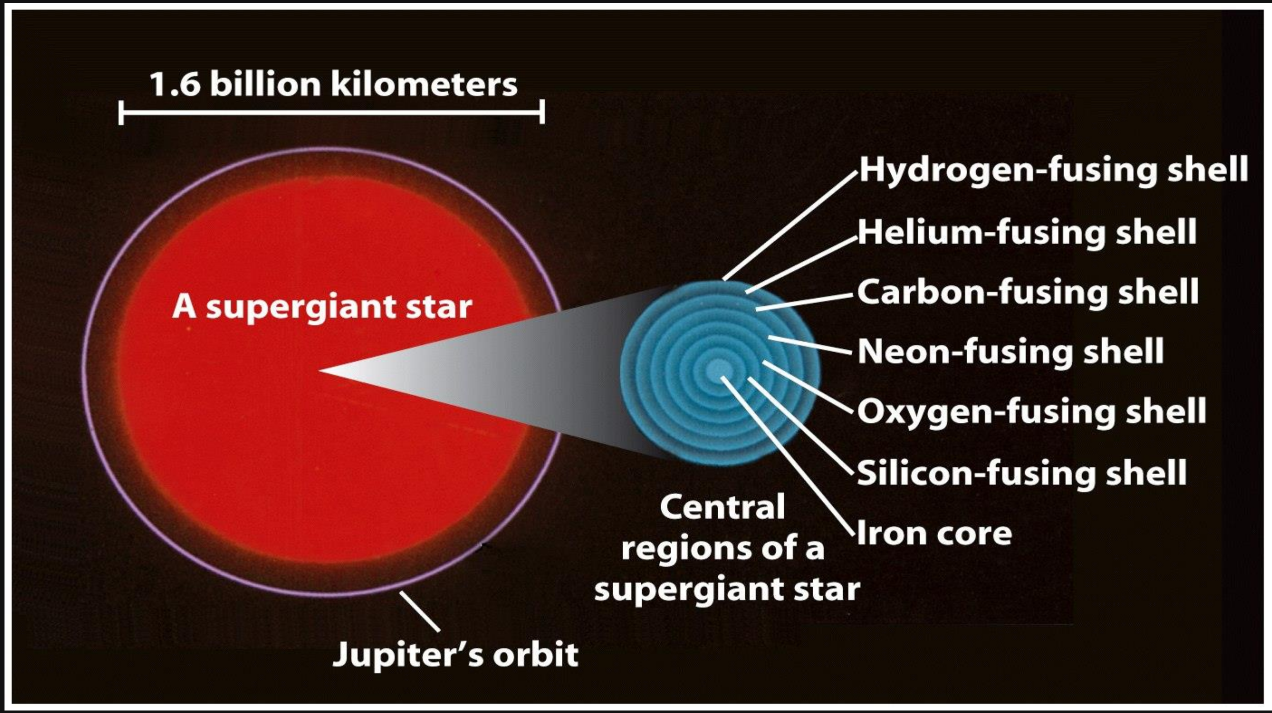
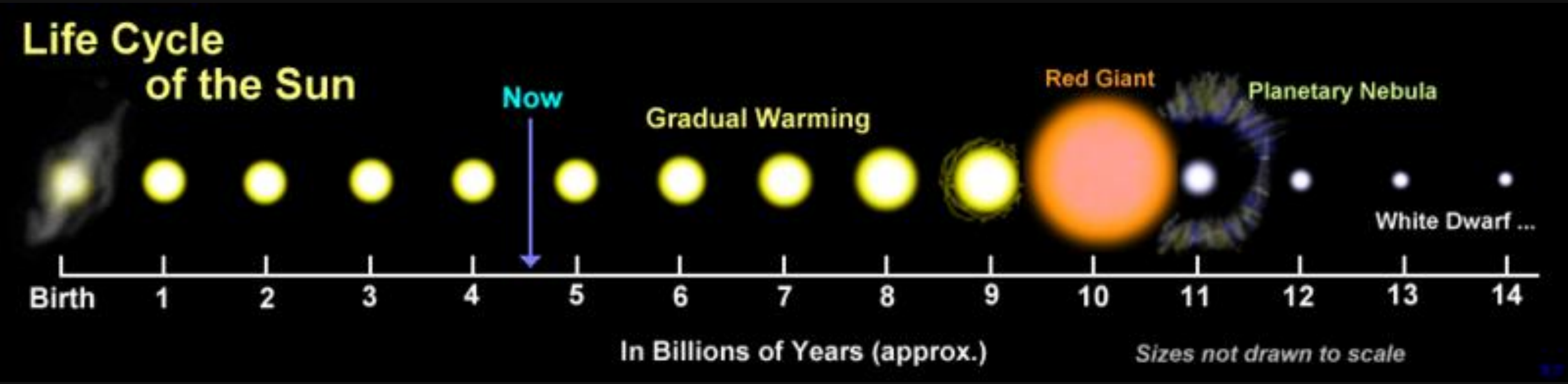
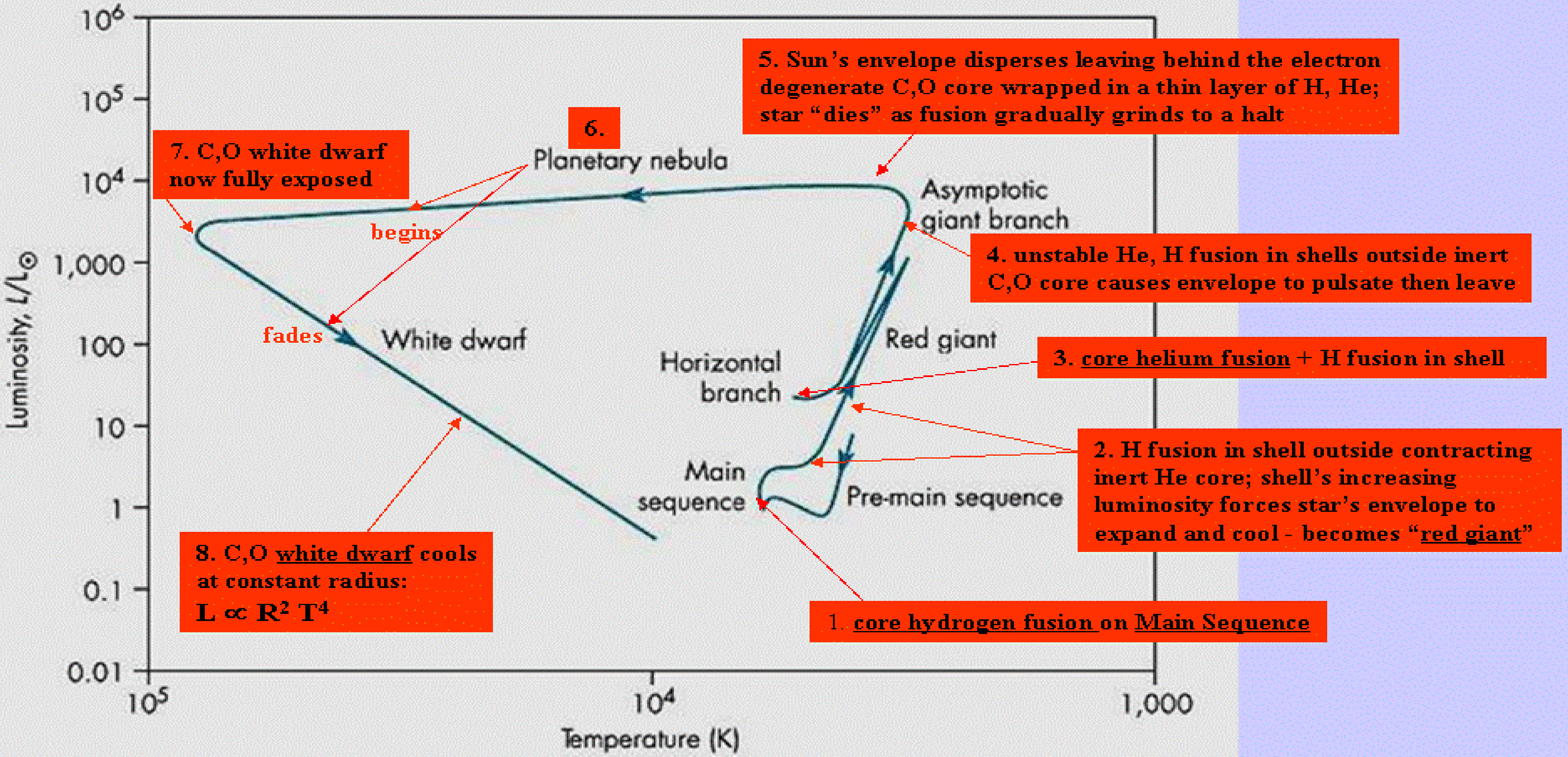


1.6 billion kilometers
A supergiant star
Jupiter's orbit
Hydrogen-fusing shell
Helium-fusing shell
Carbon-fusing shell
Neon-fusing shell
Oxygen-fusing shell
Silicon-fusing shell
Iron core
Central regions of a supergiant star

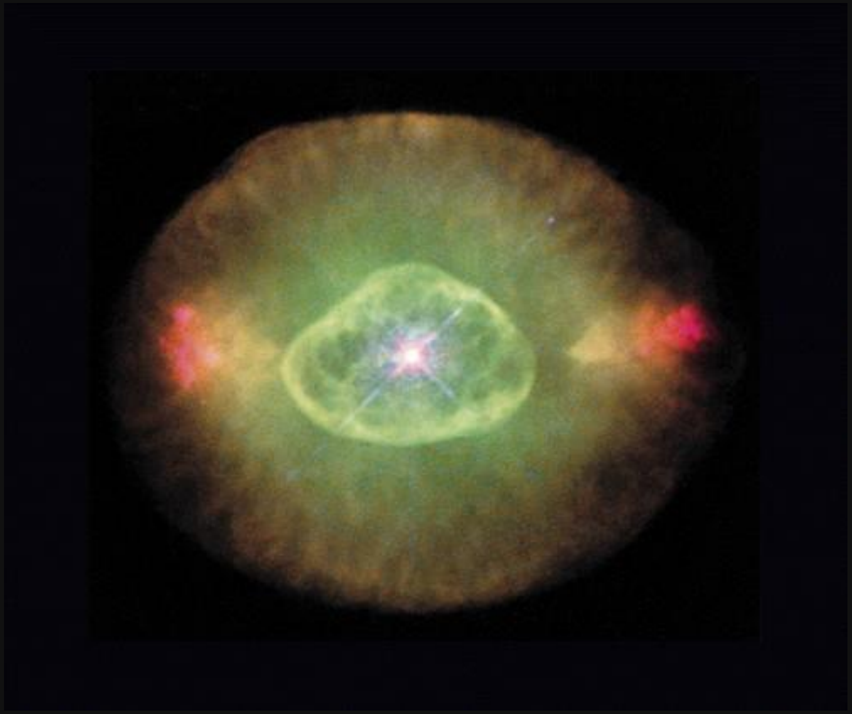
The fate of our Sun



the evolution of our Sun

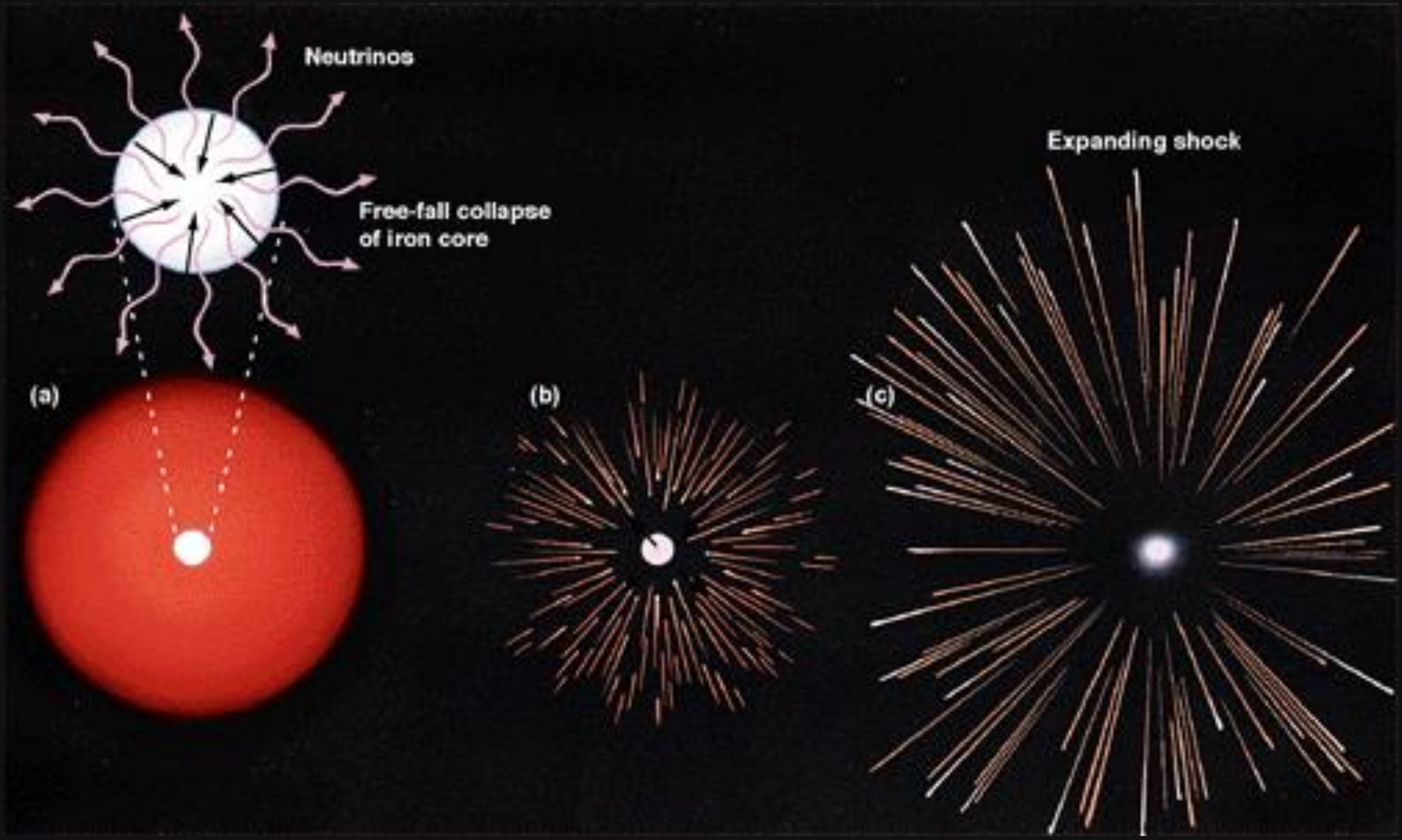


Planetary Nebula

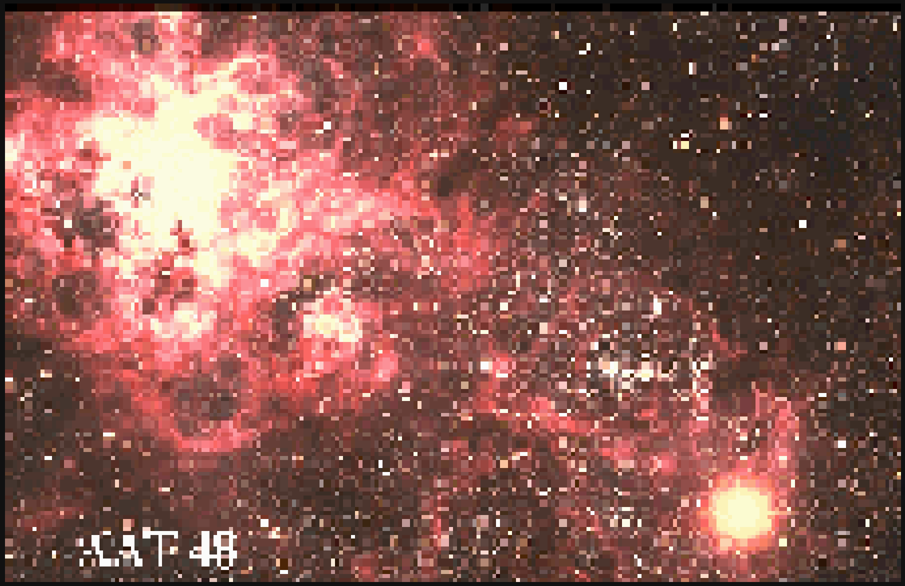


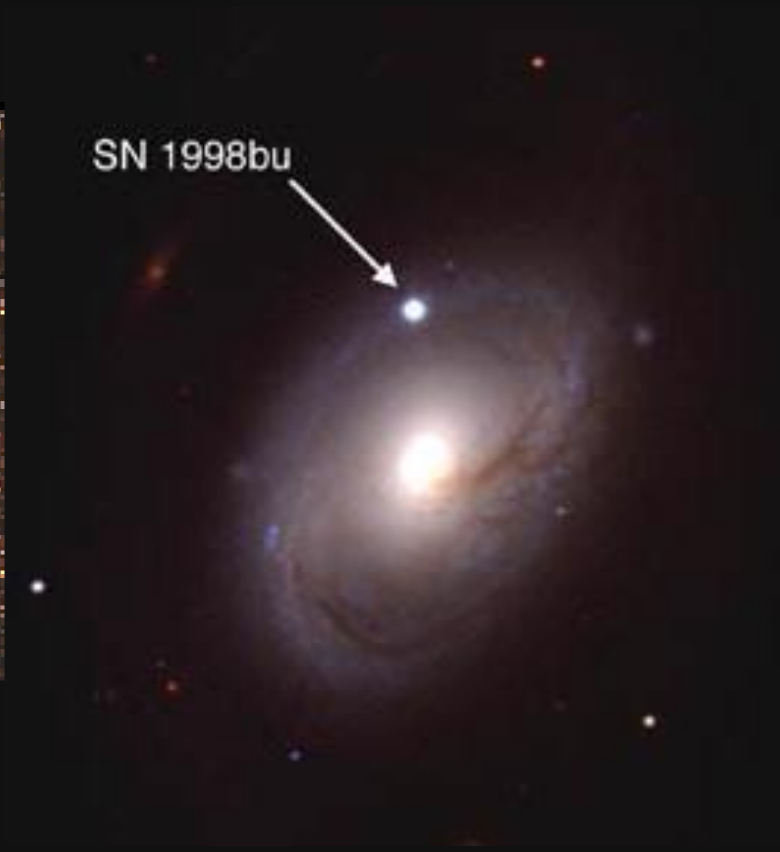
Outer atmosphere of stars is ejected and the surrounding could of gas is called a planetary nebula has nothing to do with planet formation

For heaviest stars, those with iron cores, death can come as a supernova

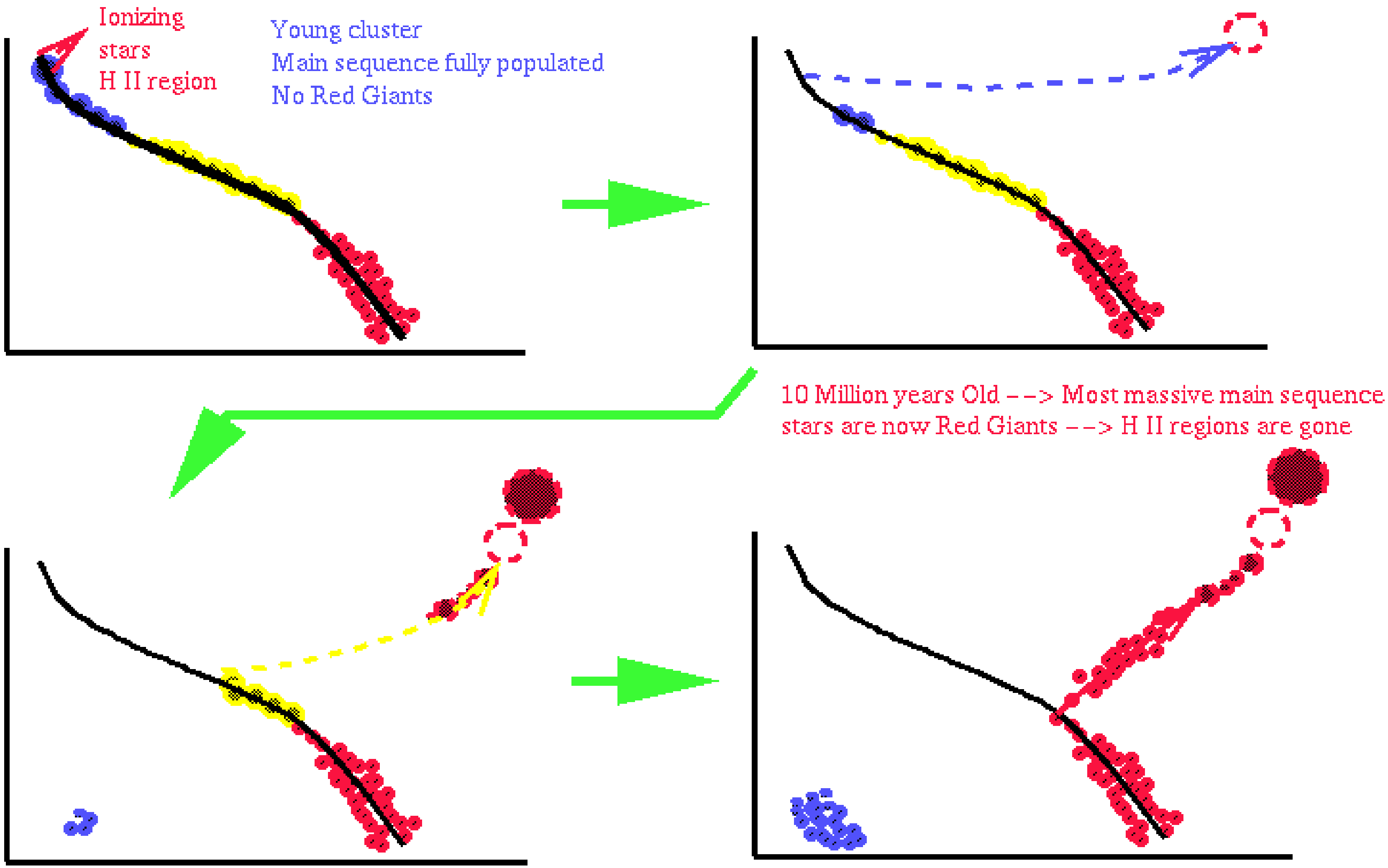


Supernovae are rare,
but they can be as bright as a whole galaxy





Evolution off the Main Sequence



1 Billion years old --> more stars on the giant branch; some white dwarfs now. Upper main sequence gone above 2 solar masses

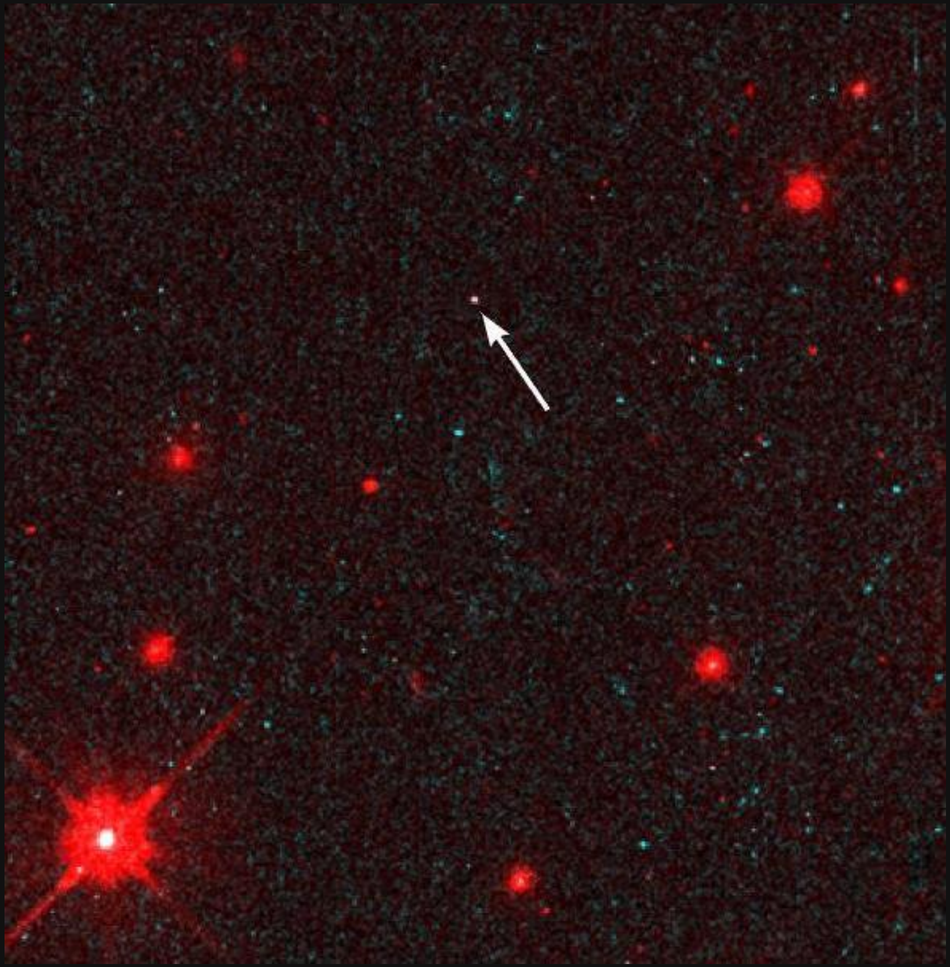
T = 10 billion years old --> just red stars left; lots of white dwarfs; no stars more massive than one solar mass left on the main sequence

Mass is the key driving of stellar evolution

More massive stars evolve faster

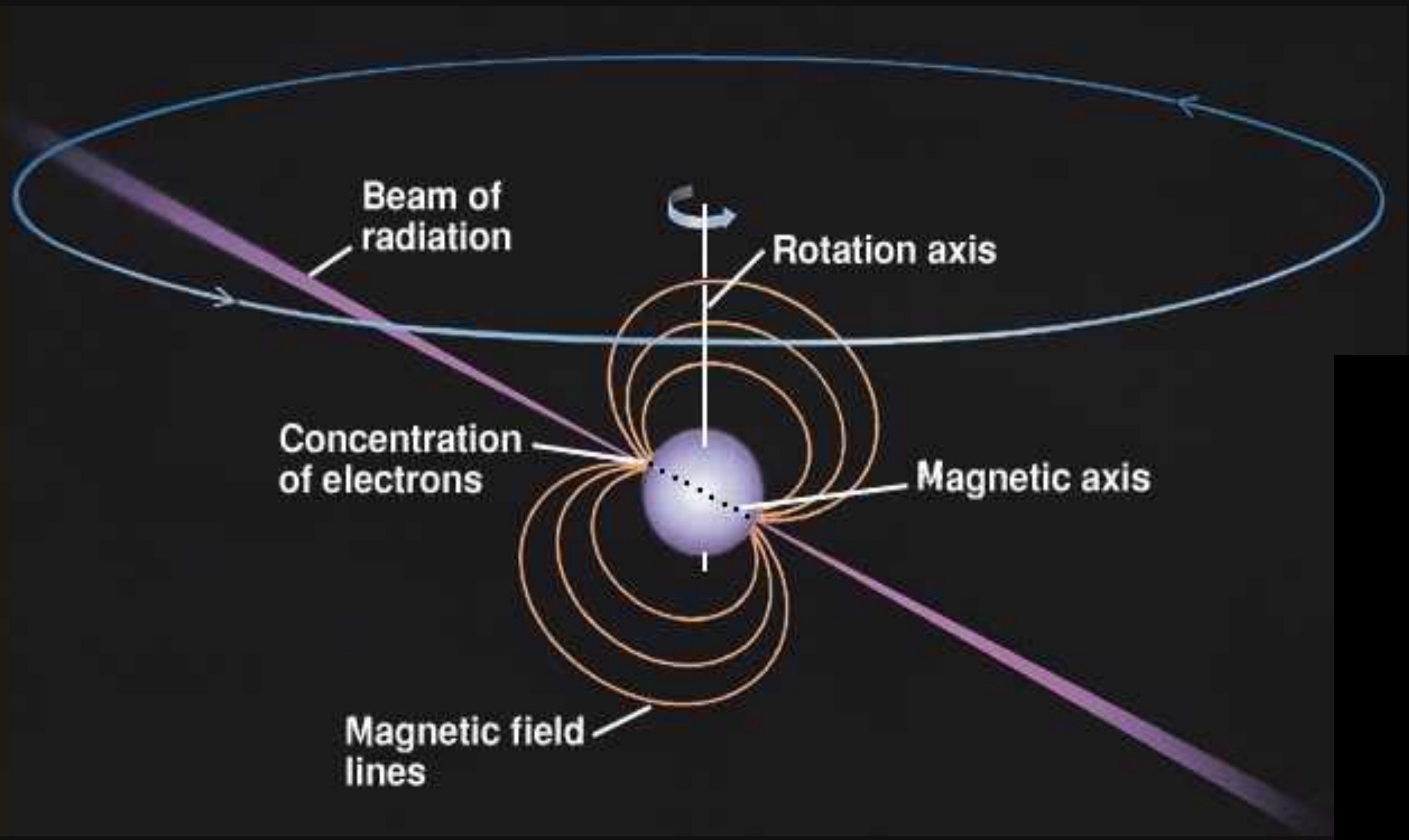
Stellar Mass	M-S Lifetime
$40M_\odot$	1×10^6 years
$15M_\odot$	12×10^6 years
$3M_\odot$	400×10^6 years
$1.5M_\odot$	3×10^9 years
$0.5M_\odot$	2×10^{12} years

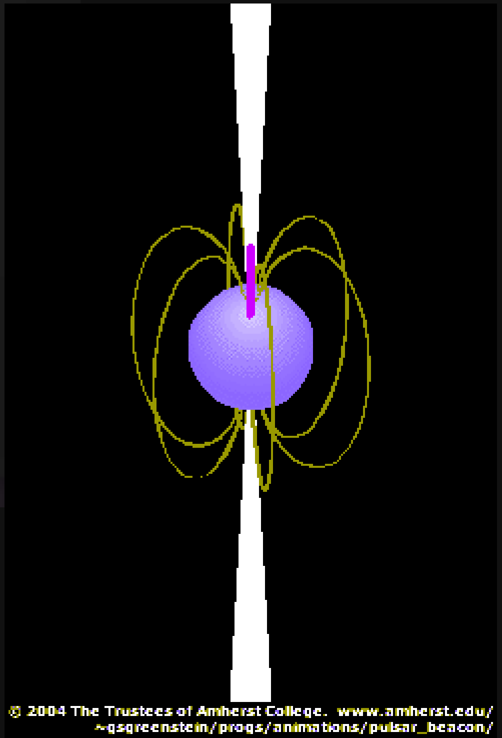
The core that remains might become a neutron star (or pulsar)



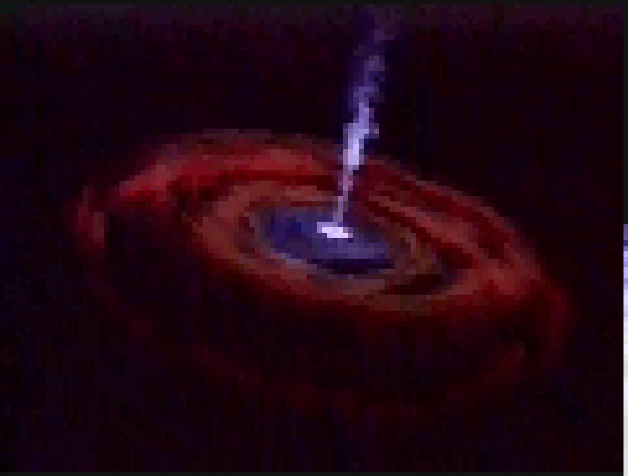
- The magnetic field collapses also, creating a very high energy density electric dynamo
- field energizes and beam out charged particle
  - “lighthouse” model

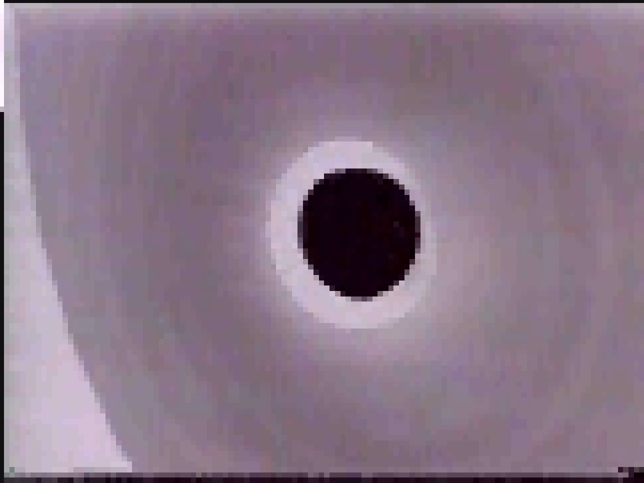
Rotating neutron stars are called pulsars



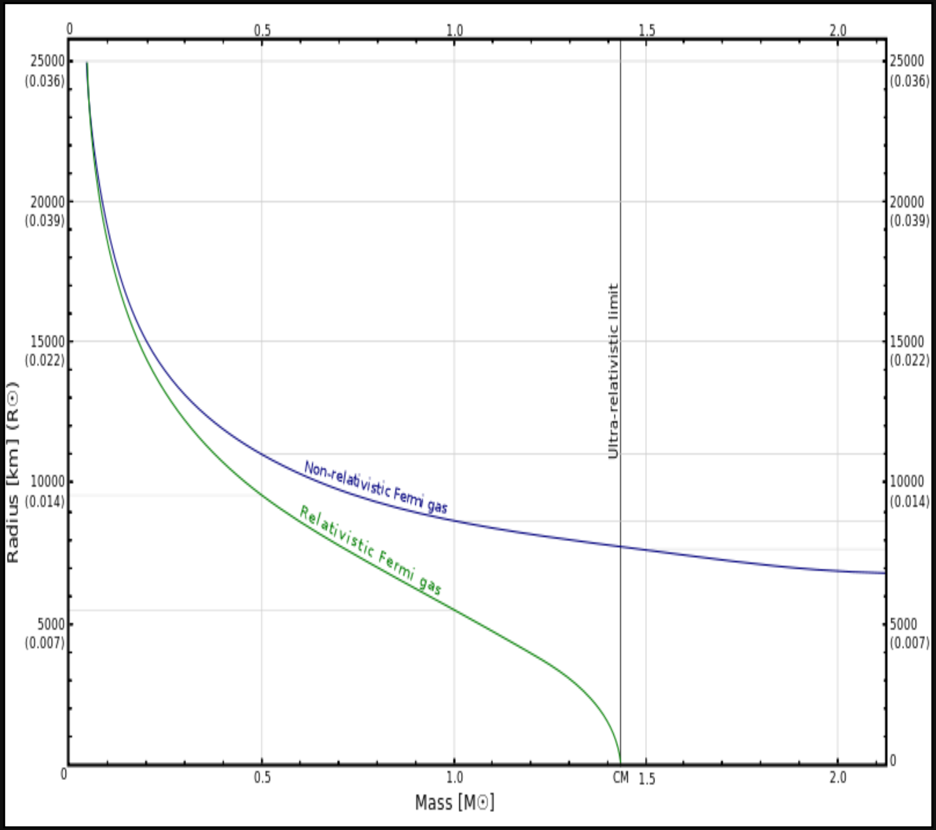


Very large stars can have their cores wind up as black holes



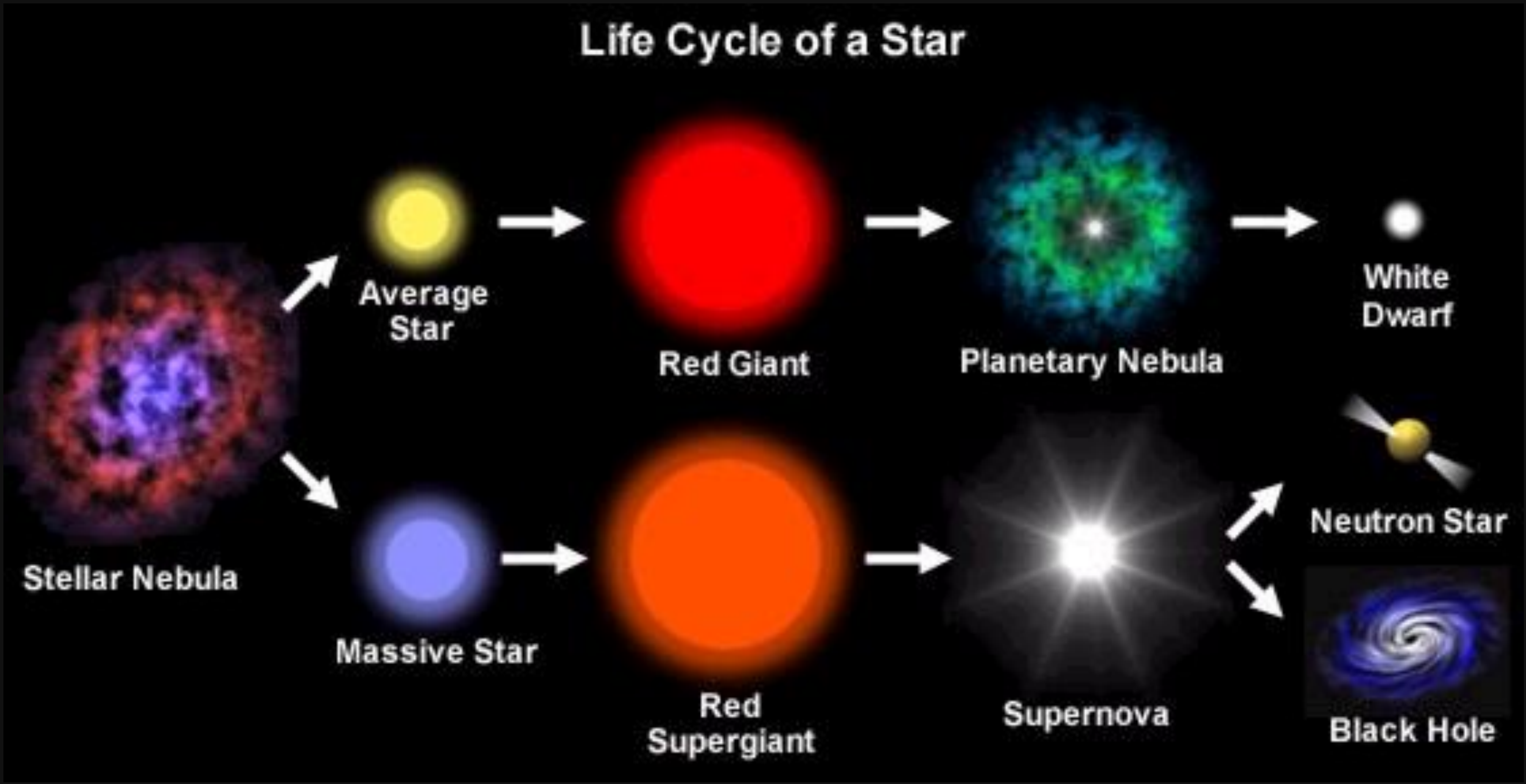


Chandrasekhar limit

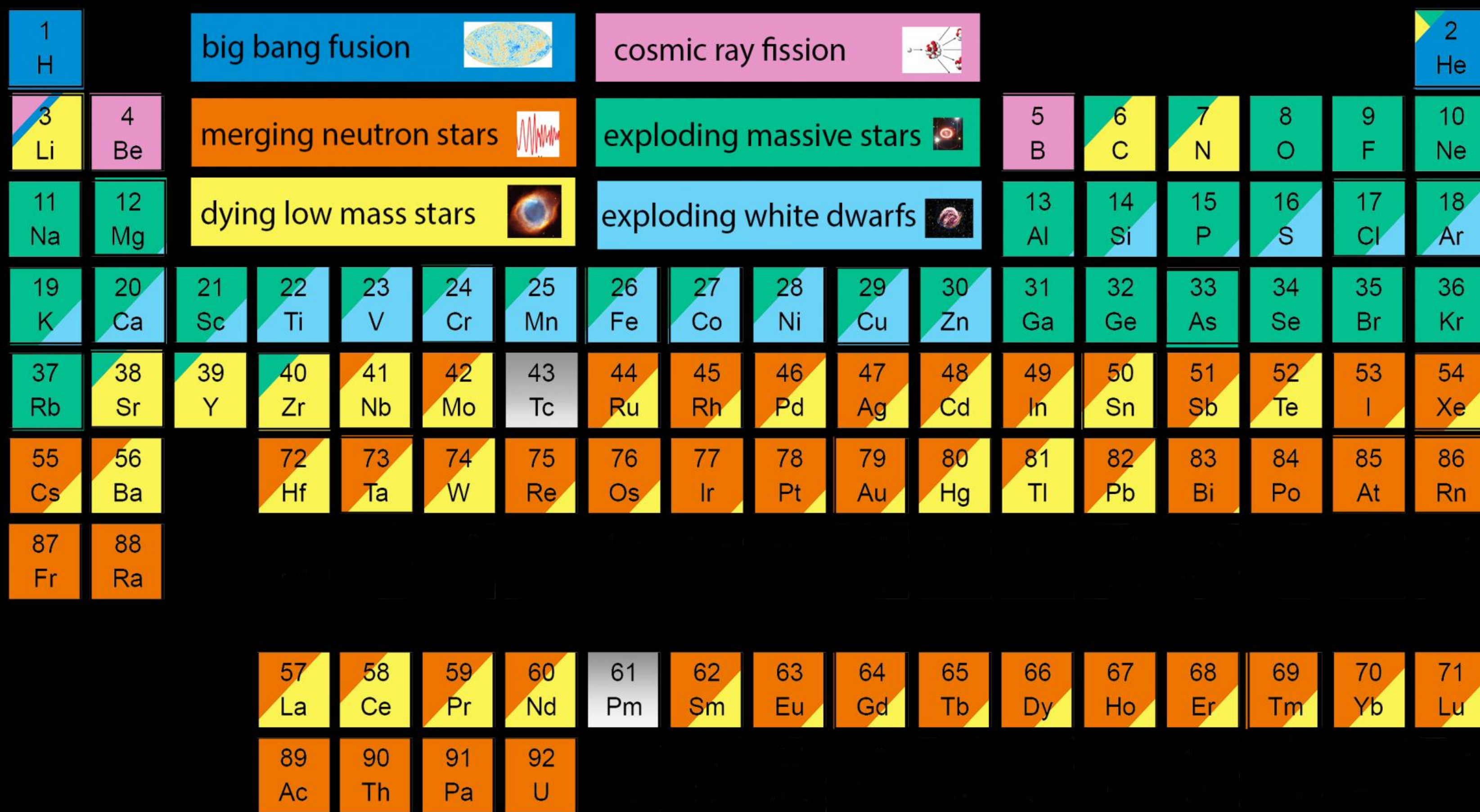


The maximum mass of a stable white dwarf star

1.44 Msun


Life Cycle of a Star
Average Star
Red Giant
Planetary Nebula
White Dwarf
Stellar Nebula
Neutron Star
Massive Star
Red Supergiant
Supernova
Black Hole

The Origin of the Solar System Elements



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