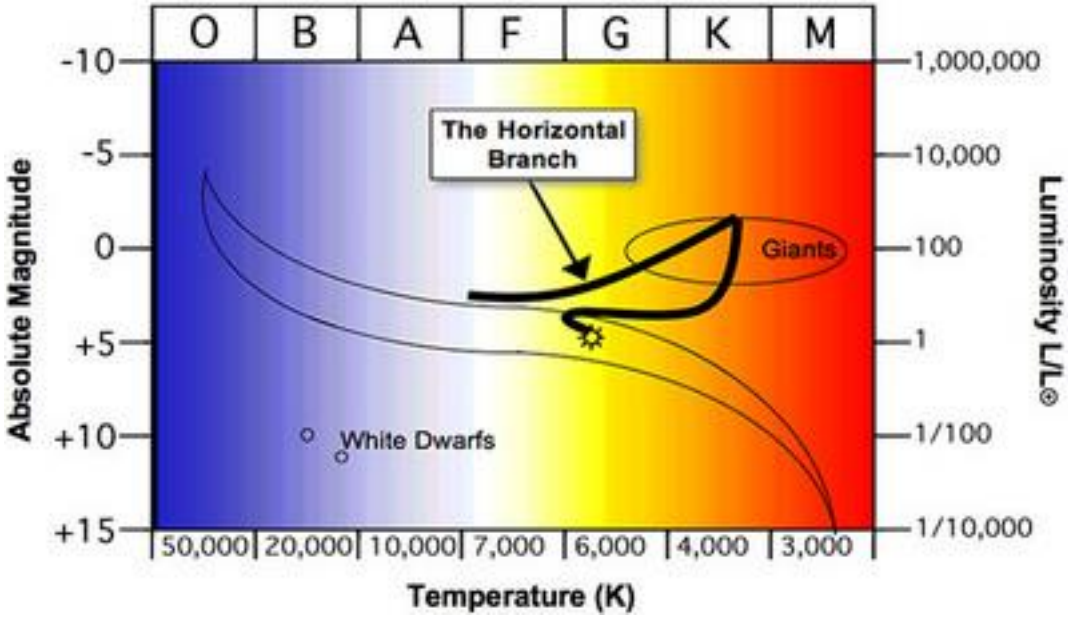
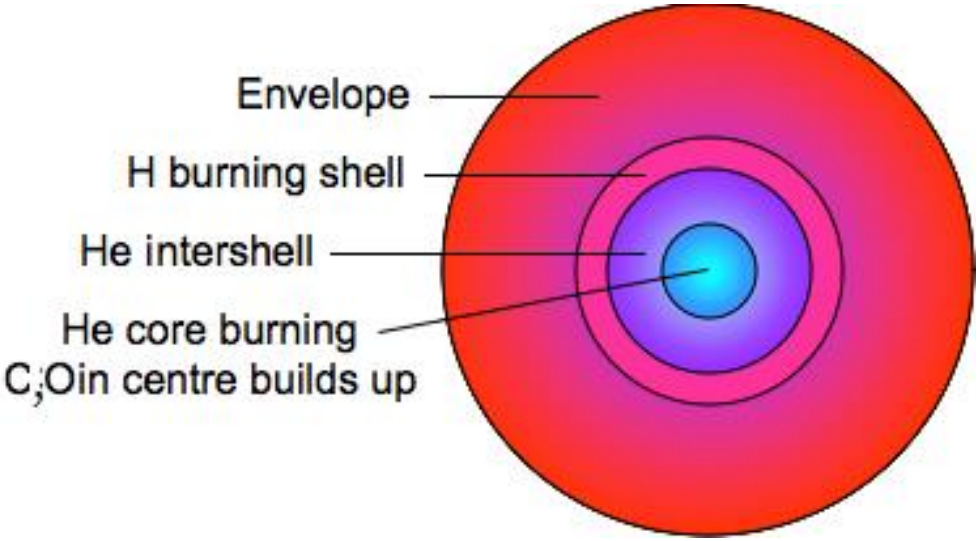
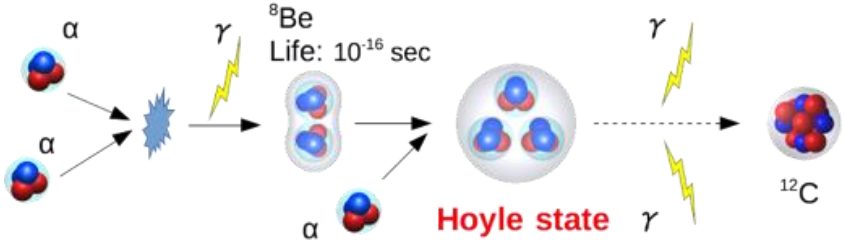
Horizontal Branch

Production of ^{12}C and ^{16}O until Helium in the core is exhausted





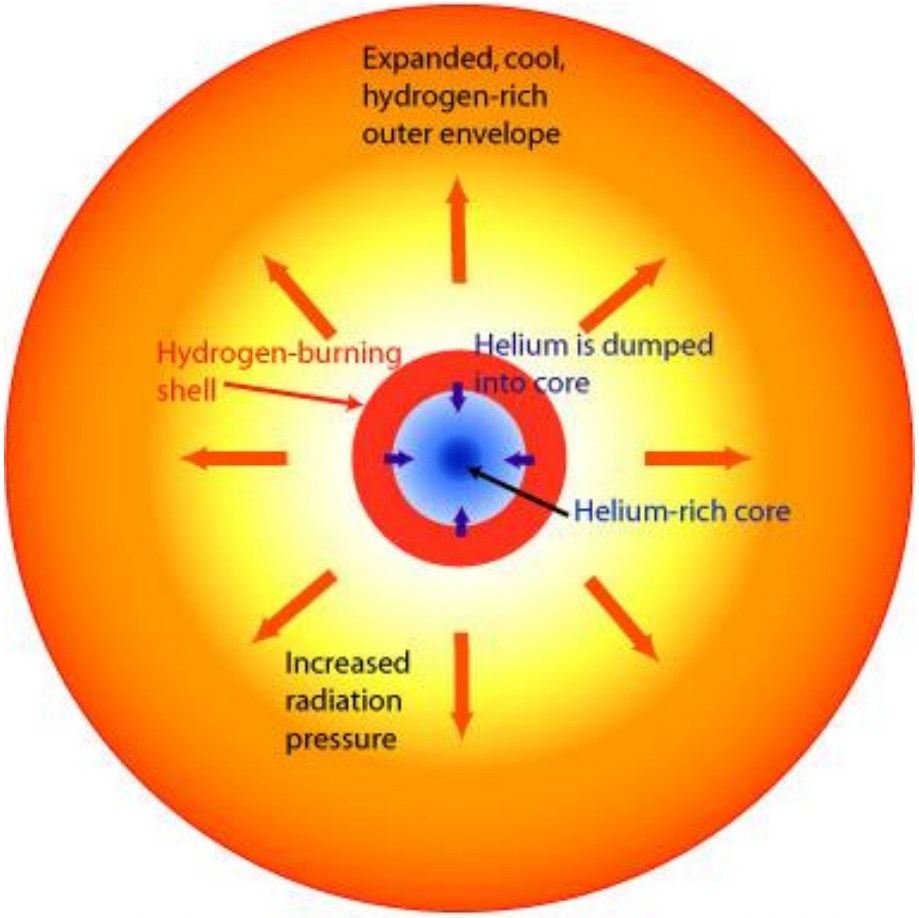


$$^{4}He + {}^{12}C \rightarrow {}^{16}O + \gamma$$

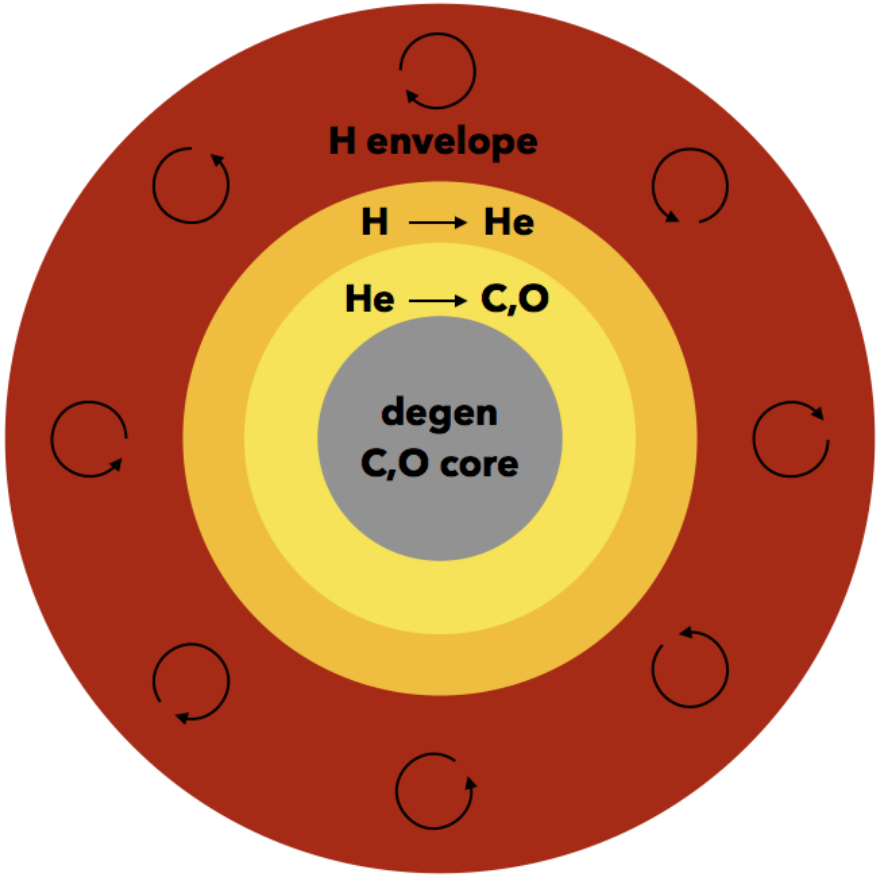
Horizontal Branch to Asymptotic Giant Branch

- Core temperature too low for C or O to ignite
- When Helium is exhausted, core begins to contract
- Releasing gravitational potential energy
- Increasing the fusion rates in the He and H fusion shells
- Atmosphere expands and temperature decreases
- Red Giant reaches the ***Asymptotic Giant Branch*** (AGB) phase

Asymptotic Giant Branch

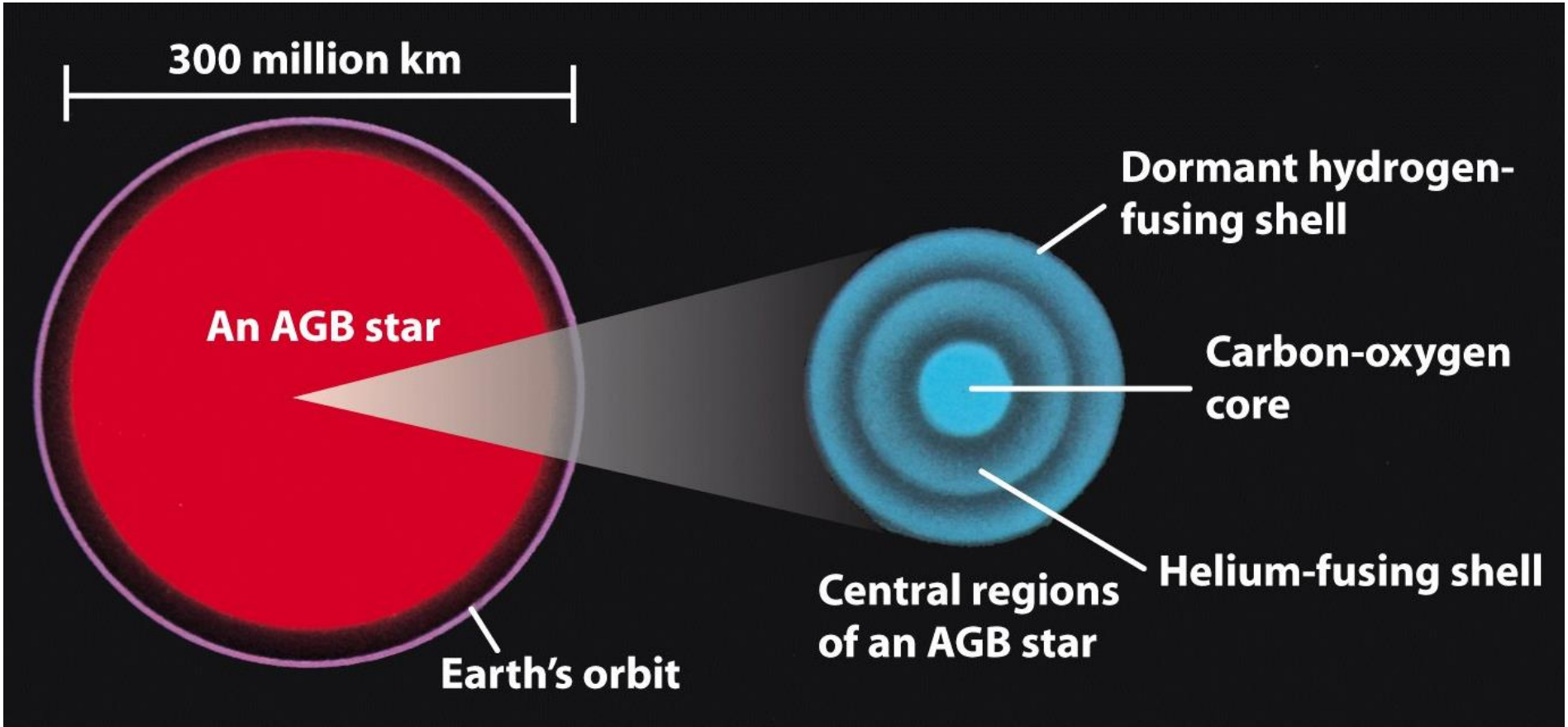


Hydrogen Shell Burning on the Red Giant Branch



Asymptotic Giant Branch

- Core is the size of the earth
- Convection in large portion of envelope

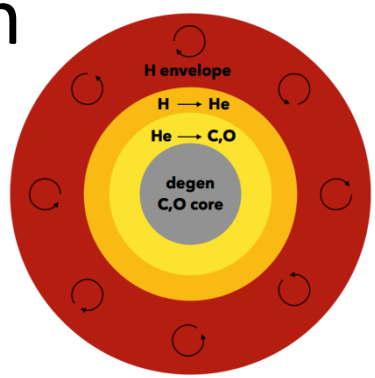


Asymptotic Giant Branch

- ***Convection*** in large portion of envelope
- Heavier elements formed in the star's interior ***mixed*** (***second dredge-up***)
- ***Strong stellar wind***
- ***Large radiation pressure*** drives stellar wind
- ***Particles absorb photons*** from radiation field and be ***accelerated out*** of the gravitational potential
- ***Interstellar medium enriched*** with mostly carbon, but also oxygen and nitrogen

Thermal Pulses

- The H-burning shell adds mass to the He-rich region between the burning shells (the intershell region) => increases the pressure and temperature at the bottom of this region
- When the mass of the intershell region reaches a critical value, helium is ignited in an unstable manner, called a ***helium shell flash***
- The large energy flux drives convection in the whole intershell region => ***intershell convection zone***
- ***Mixing***

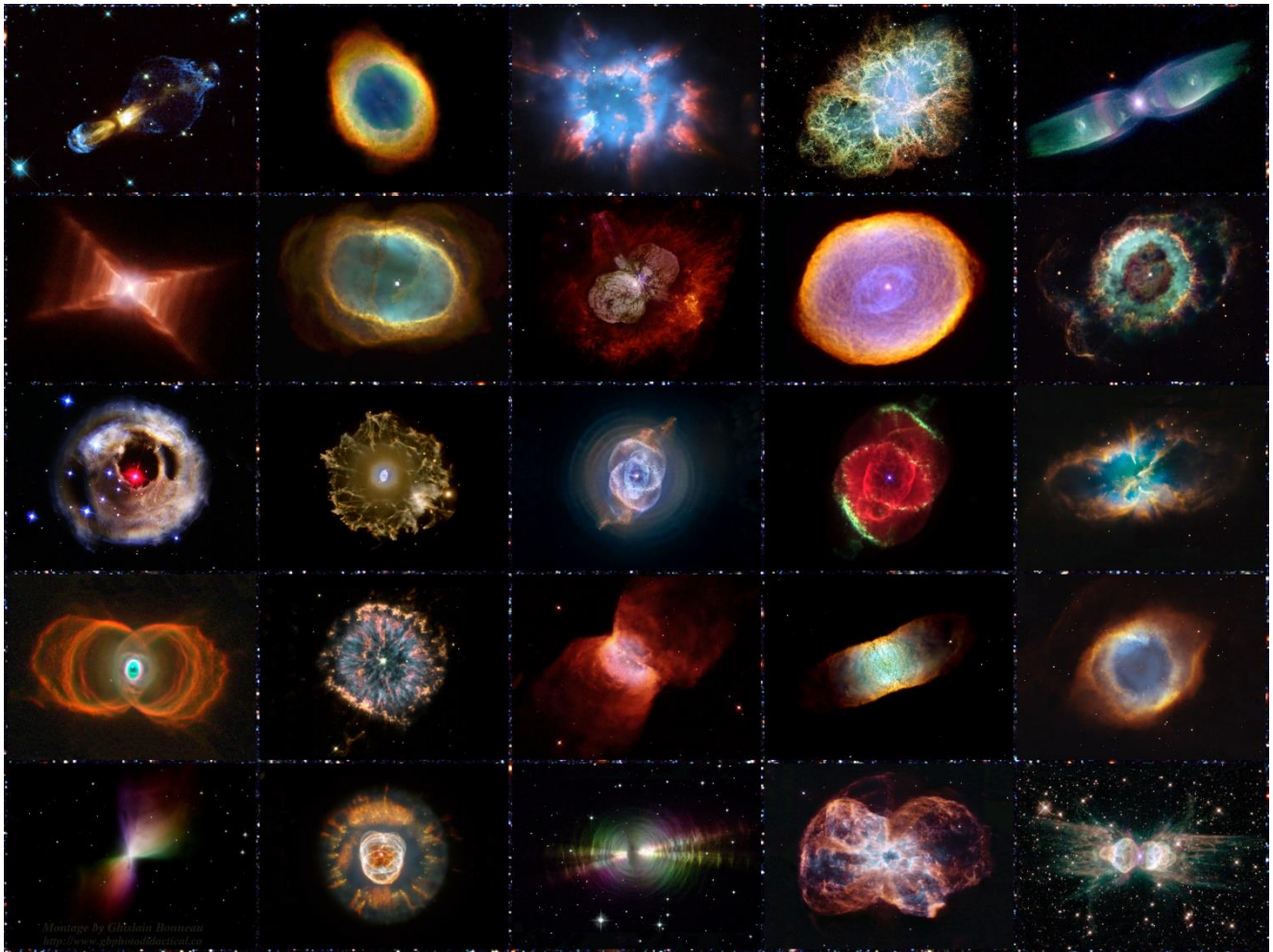


Thermal Pulses

- Large energy release => expansion of the intershell region
- He-burning shell expands and cools down, time scale of about a year => H-burning shell extinguishes => deeper penetration of the outer convective envelope
- Convection can even penetrate beyond the now extinct H-burning shell => material from the intershell region is mixed into the outer envelope
- ***Third dredge-up***
- He-burning and H-burning shell
- Long phase of stable H-shell burning follows => mass of the intershell region grows until the next thermal pulse
- The duration of this ***interpulse period*** depends on the core mass, lasting between 50 000 yrs < 1 000 yrs for the most massive AGB stars

Planetary Nebula

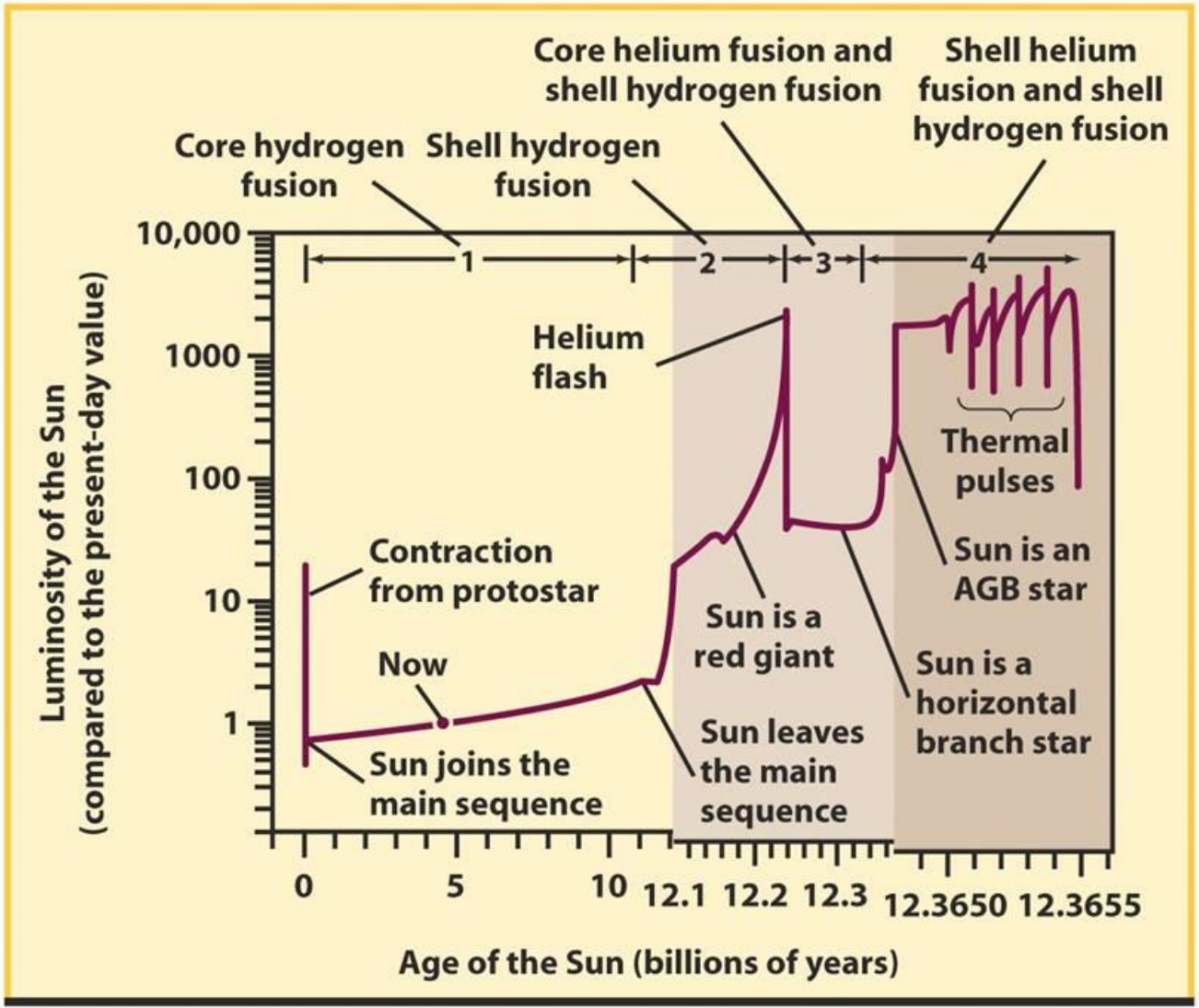
- During helium shell flashes ejection of outer atmosphere regions



Planetary Nebula

- Planetary Nebula expands at a speed ~20 km/s
- Radius of about 1 pc in 50 000 years
- The driving force is the radiation pressure caused by intense ultraviolet emission from the central core, acting upon dust grains in the nebula
- Dust grains condense out from the cooling nebula gas, because of the existence of heavy elements, such as carbon

Times Scales



Phase	yrs
Main Sequence	9×10^9
Subgiant	3×10^9
RGB	1×10^9
HB	1×10^8
AGB	5×10^6
PNe	1×10^5