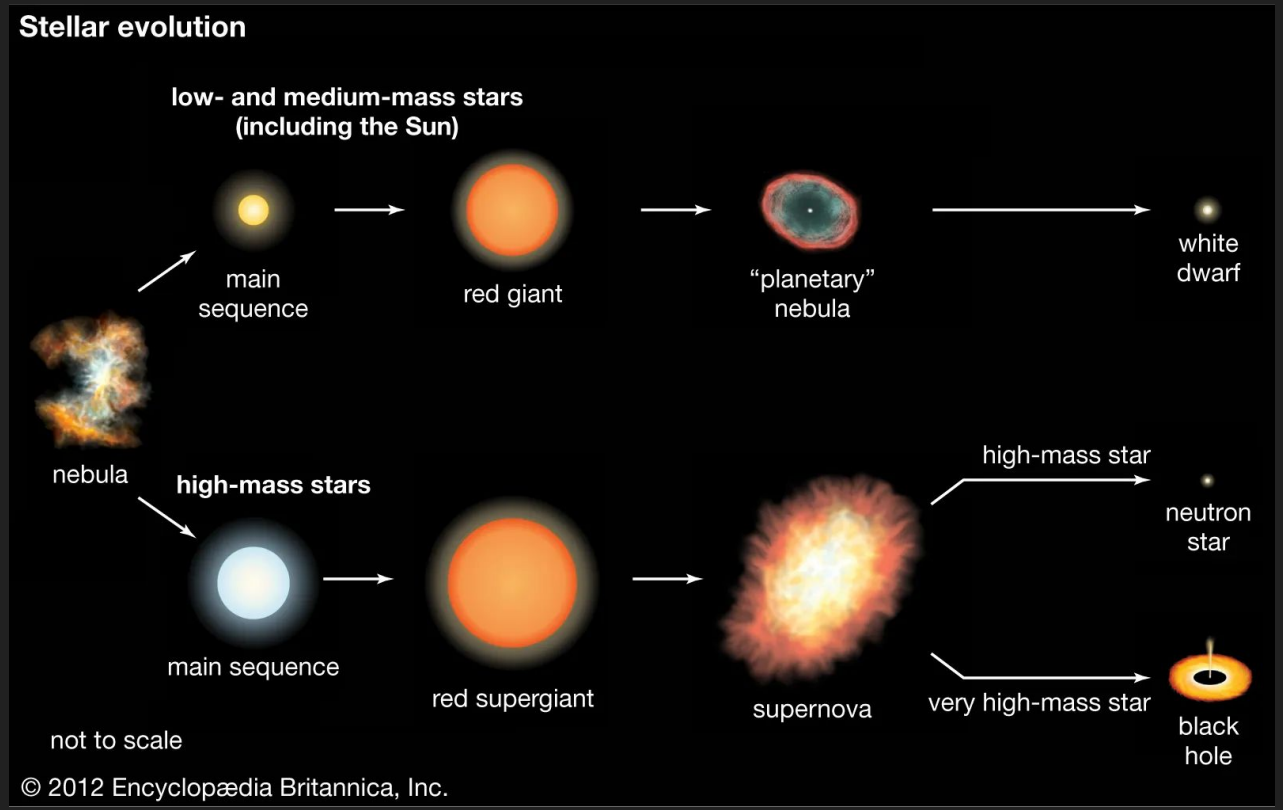
The Death of Stars I

Outline

- Evolution of stars
- Evolution of solar-type star
- Red giant phase
- Helium burning, triple alpha
- Horizontal branch
- Asymptotic Giant Branch
- Planetary Nebulae
- Cepheid variable
- White dwarf
- Binary stars, novae
- Globular cluster

Evolution of stars



Path of a Solar-mass star

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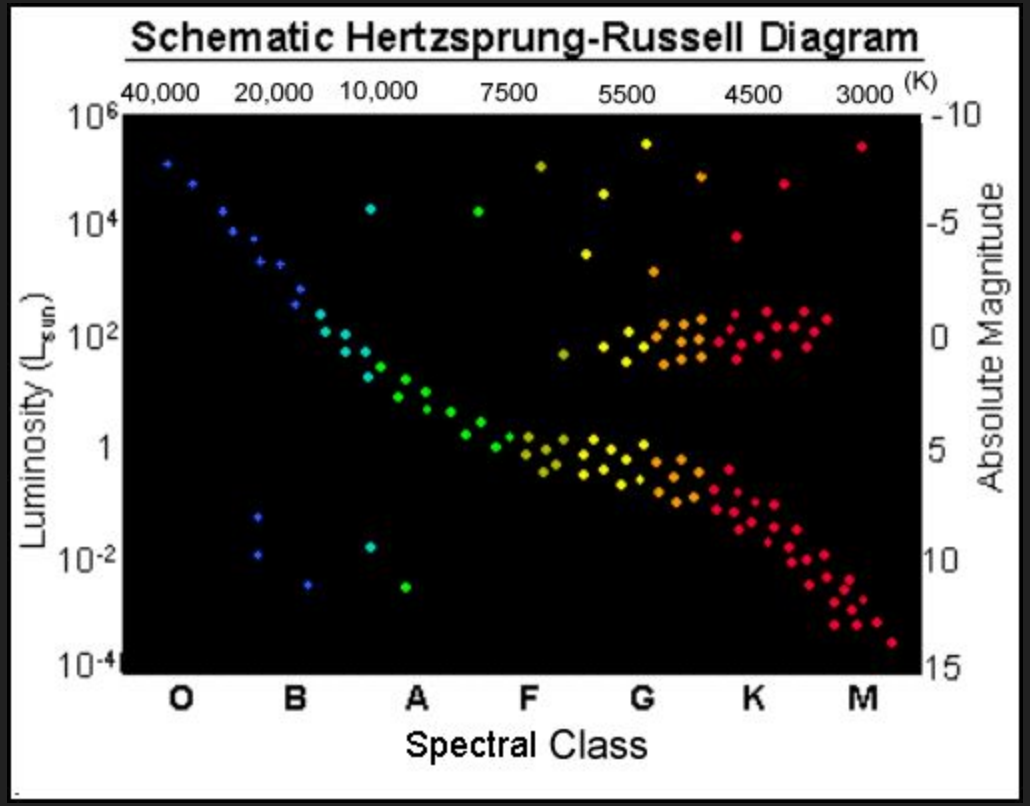

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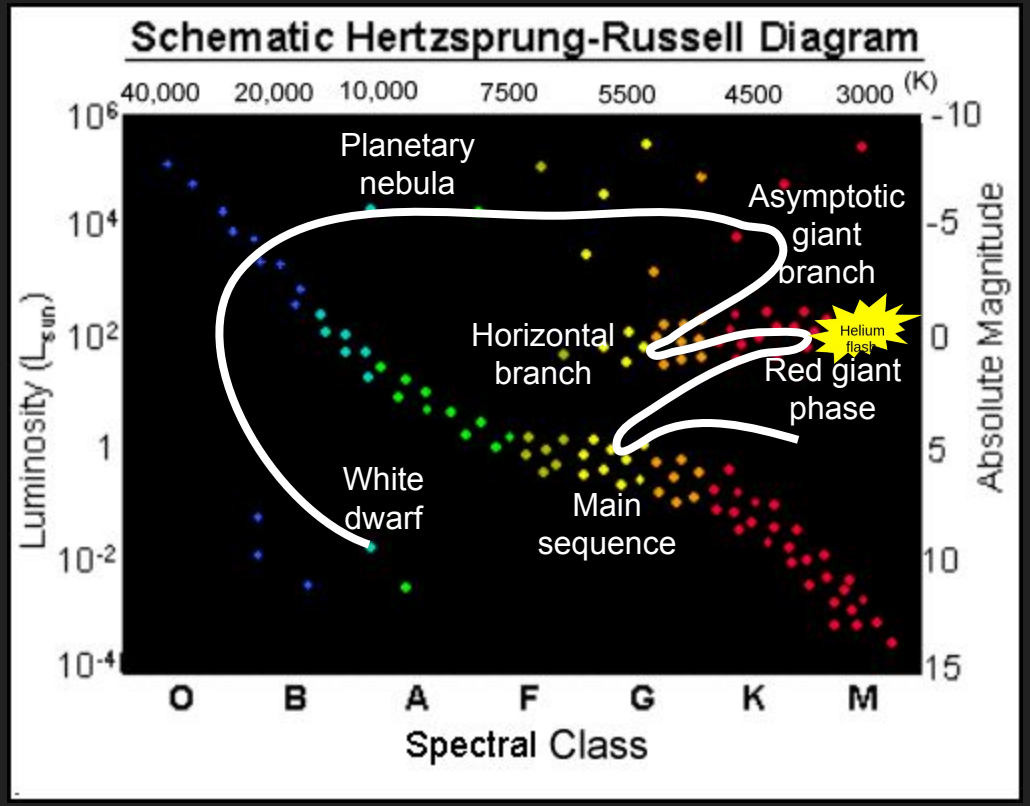

Life of a low-mass star

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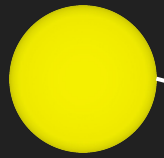
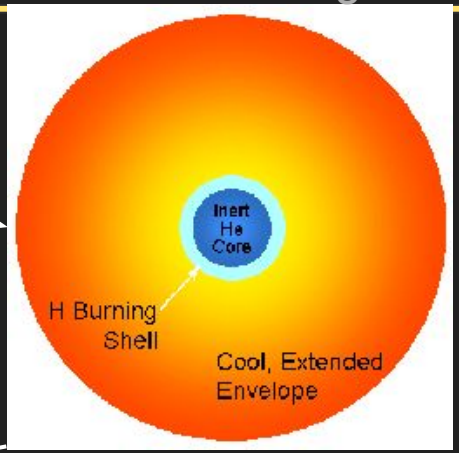
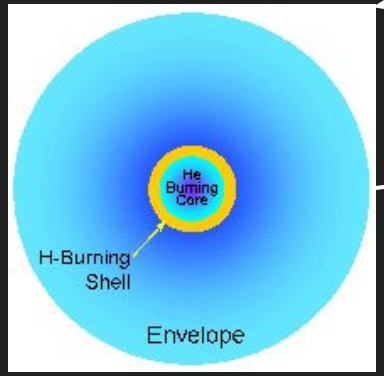


Main sequence
Core hydrogen burning
T_{core} ~ 15 million K

Red giant
Hydrogen shell burning

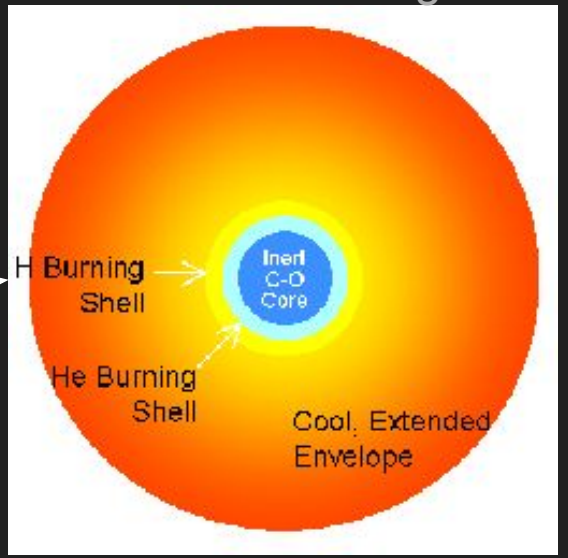


Helium flash

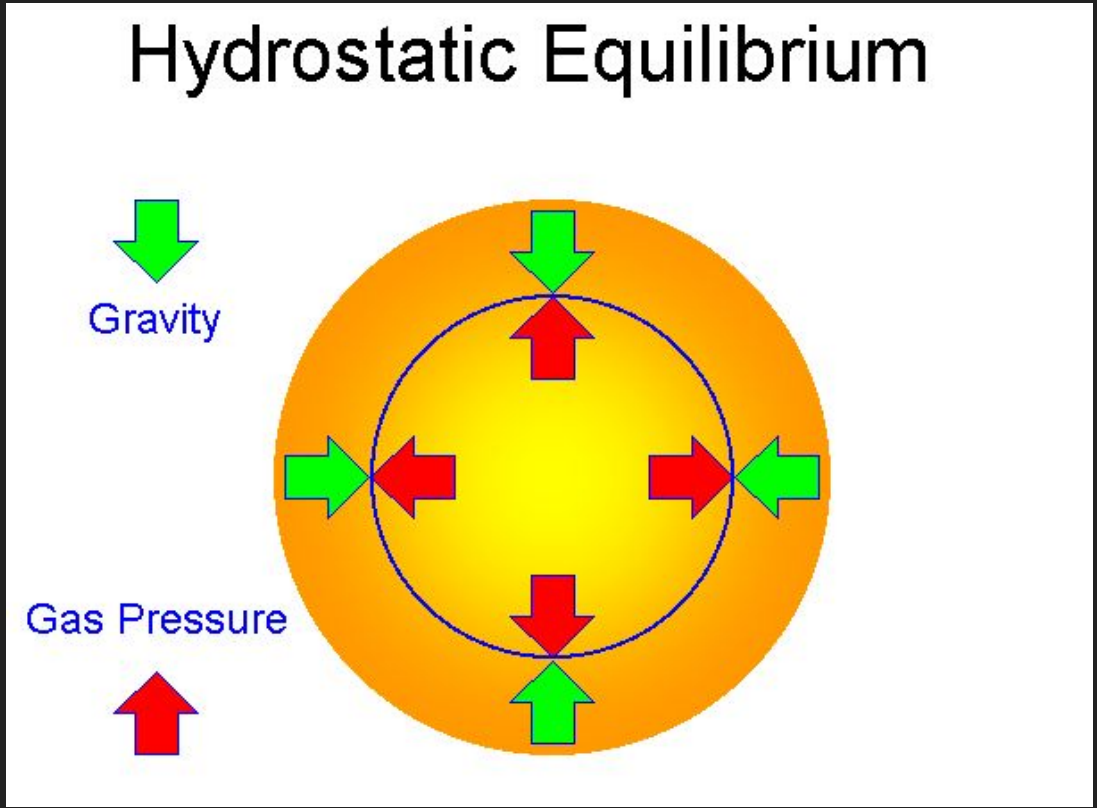


Horizontal branch
Core helium burning
T_{core} ~ 100 million K

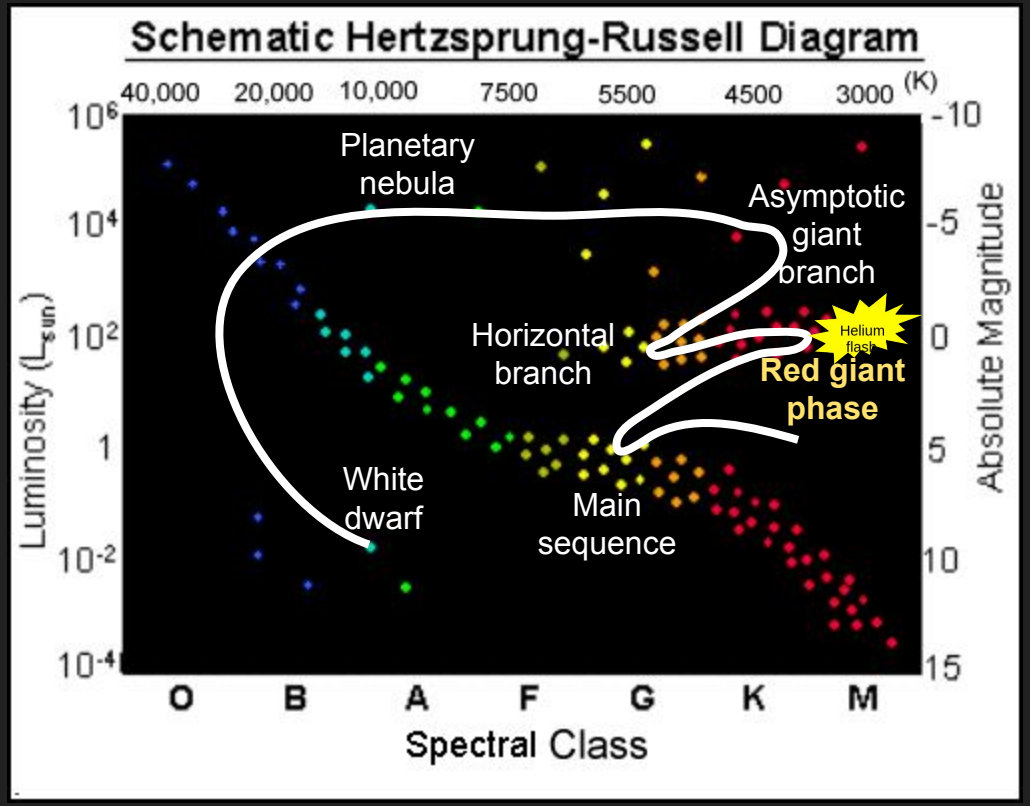
Asymptotic giant branch
Shell helium burning



Hydrostatic equilibrium

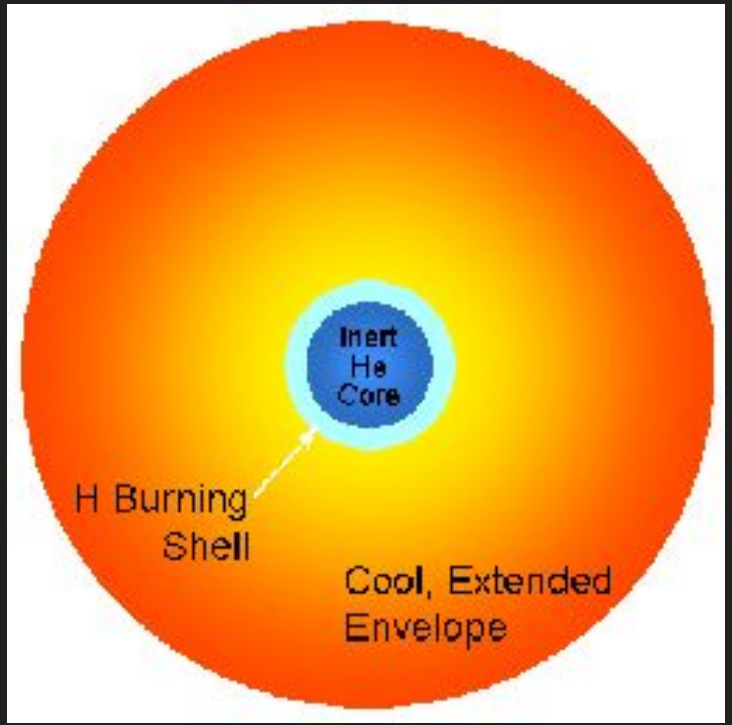


Red giant phase



Red giant phase

- When the hydrogen in the core is gone, fusion stops
- The core starts to contract under its own gravity
- Contraction heats up areas of the star near the core, hydrogen fusion starts in a shell around the core
- Push from fusion in the shell expands the star
- The outer layers move further from the core and cools, becomes red giant



Question

1. Imagine a star is expanding and its surface becomes cooler. This would cause its position on the HR diagram to shift

    a. Right and down
    b. Left and down
    c. Left and up
    d. Right and up

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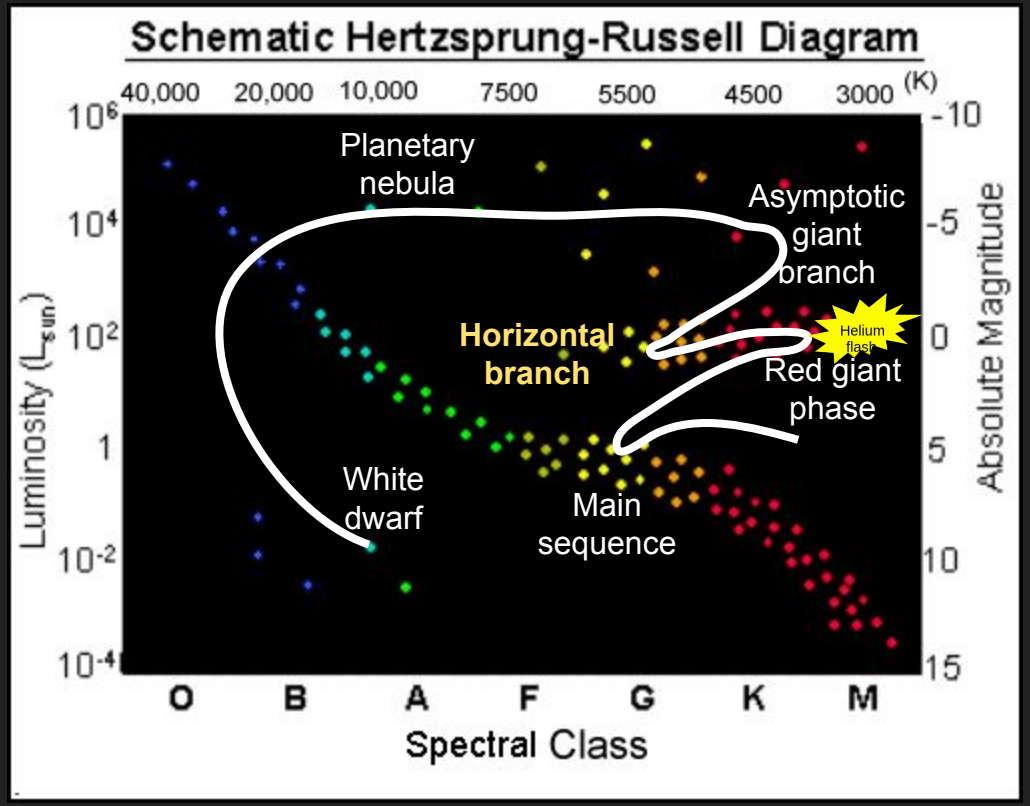
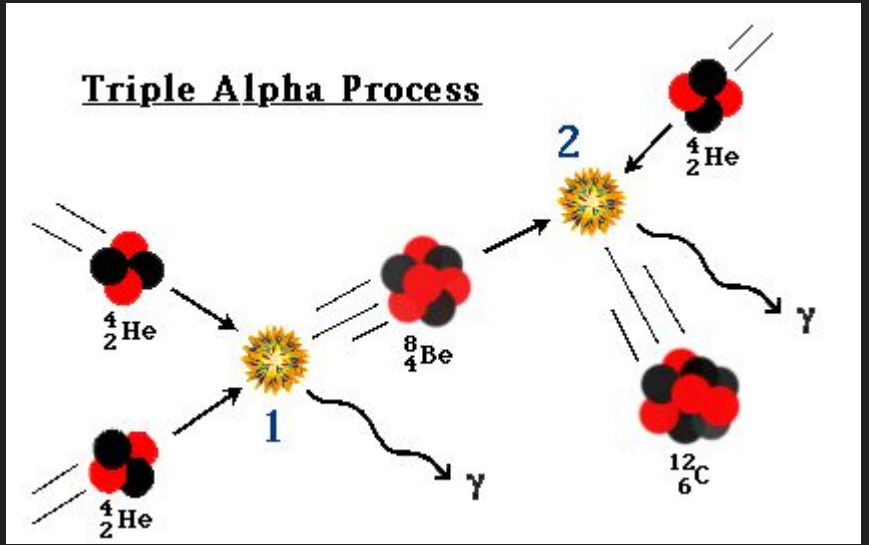
Horizontal Branch



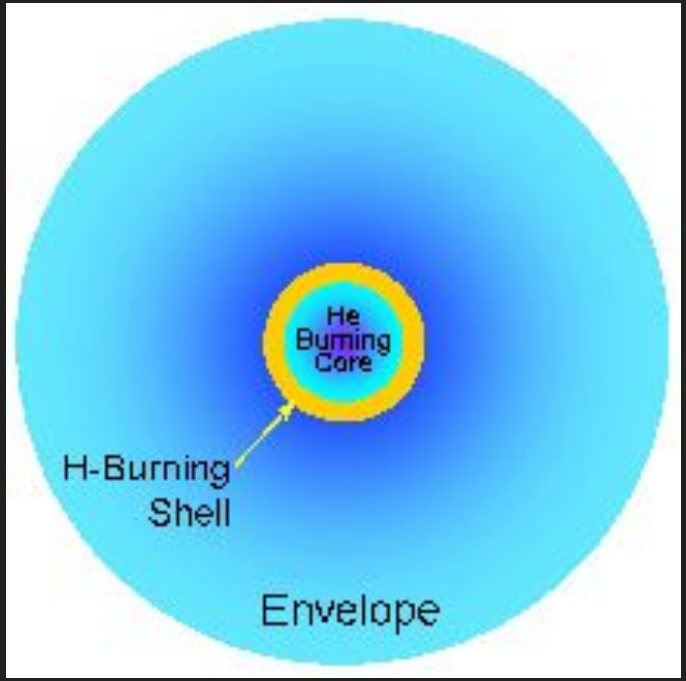
Triple-alpha process

- When the core of the star reaches 100 million K, it can fuse helium into carbon
- Called the triple-alpha process
- Converts 3 helium nuclei (alpha particles) into one carbon + energy



The Horizontal Branch

- When the core reaches 100 million K, it can start to fuse helium into carbon
- Stabilizes the core, the core stops contracting
- The star shrinks slightly and the surface heats up
- Helium fuel doesn't last very long
- Horizontal branch lifetime is about 10 % the main sequence lifetime
- Our Sun will burn helium for about 1 billion years



Poll everywhere

When poll is active respond at **PollEv.com/nikhilpatten355**

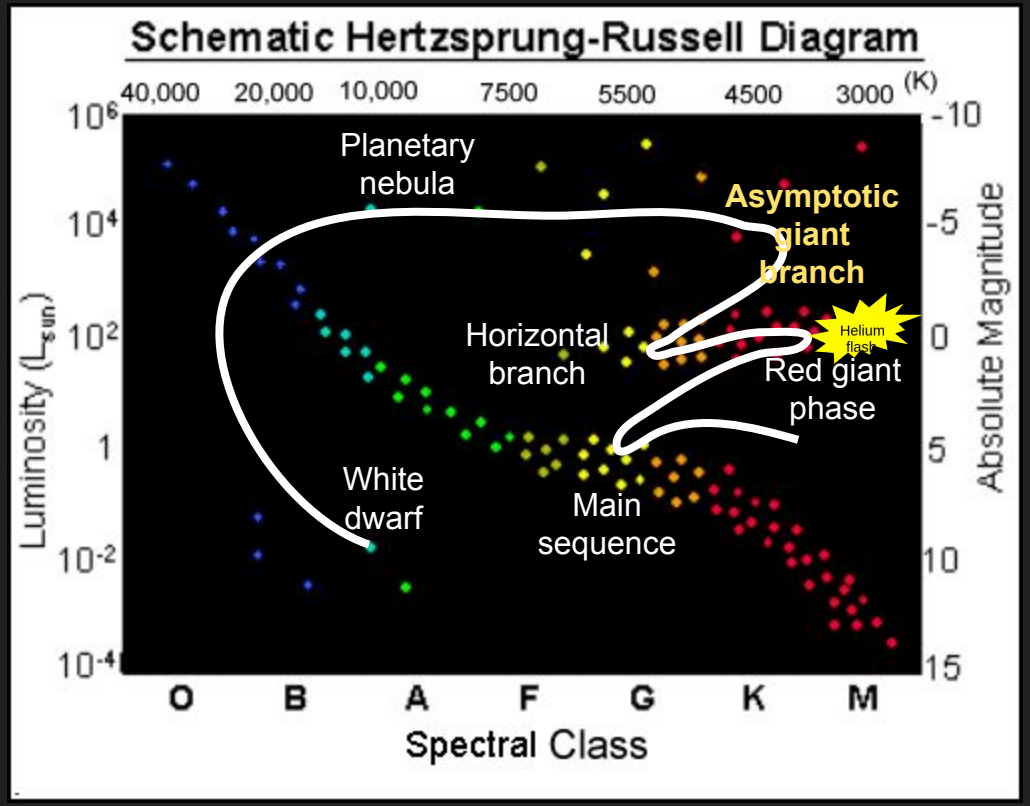
Send **nikhilpatten355** to **22333**

$$\tau_{\rm MS} = 10^{10} \left[\frac{M}{M_\odot}\right]^{-2.5} \quad (\text{for } 0.1 \lesssim M_* \lesssim 50)$$

Poll everywhere

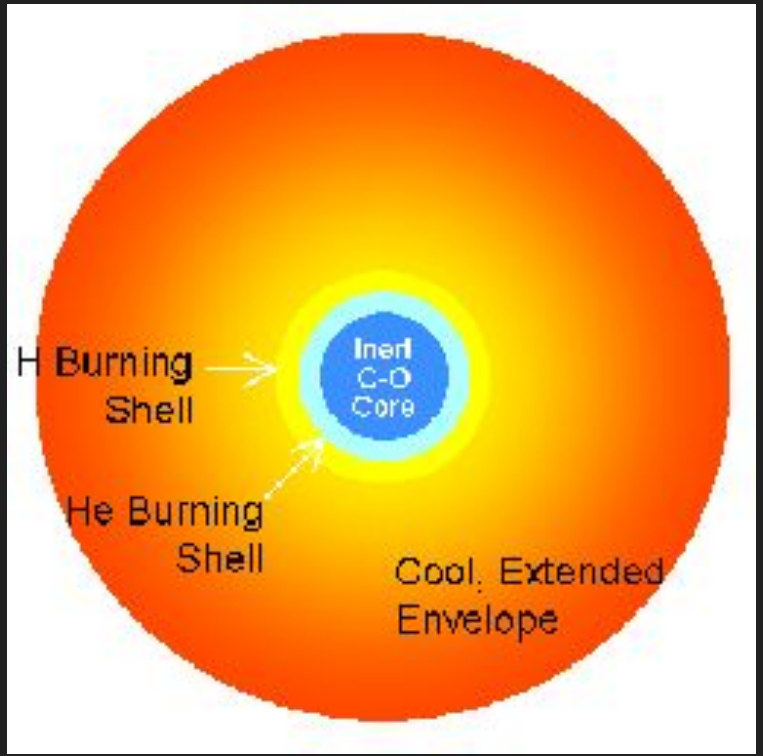
results

Asymptotic Giant Branch (AGB)



What happens when helium runs out?

- Fusion in the core stops, helium has been converted to carbon and oxygen
- This is where carbon and oxygen in our universe come from!
- Every carbon atom in your body is the remnant of a dying star
- The star's core collapses under its own gravity
- A shell near the core starts to fuse helium (periodic) and the star expands and cools (again)
- That star is now an AGB star



Asymptotic Giant Branch (AGB)

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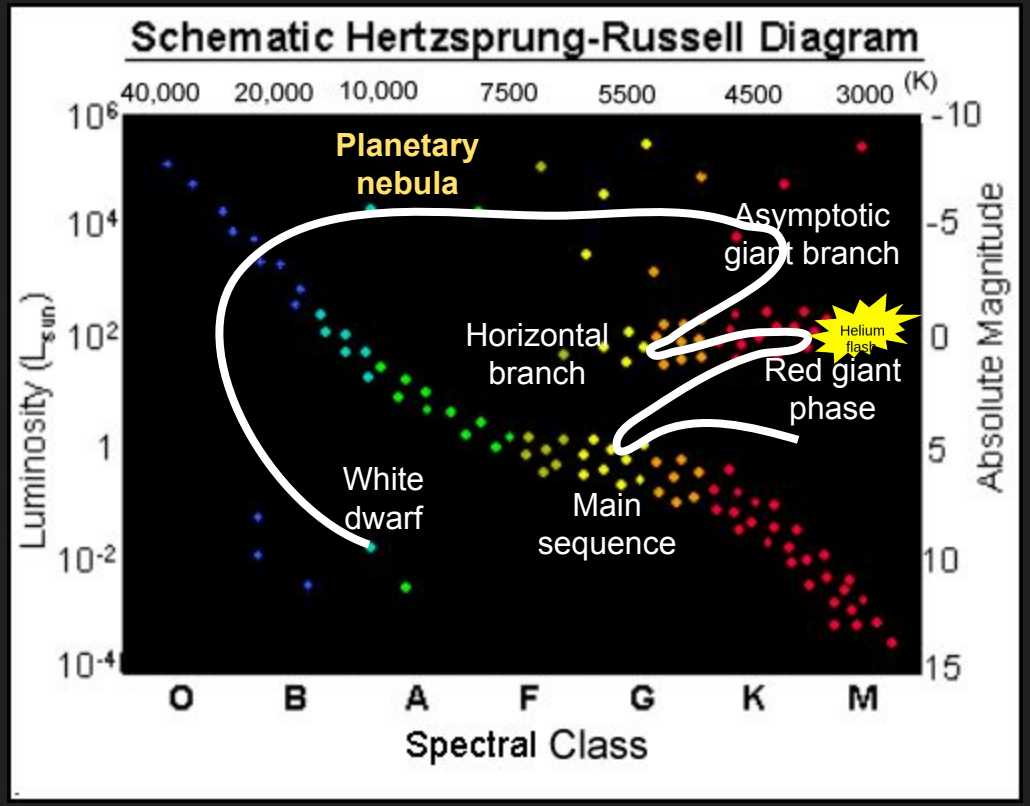
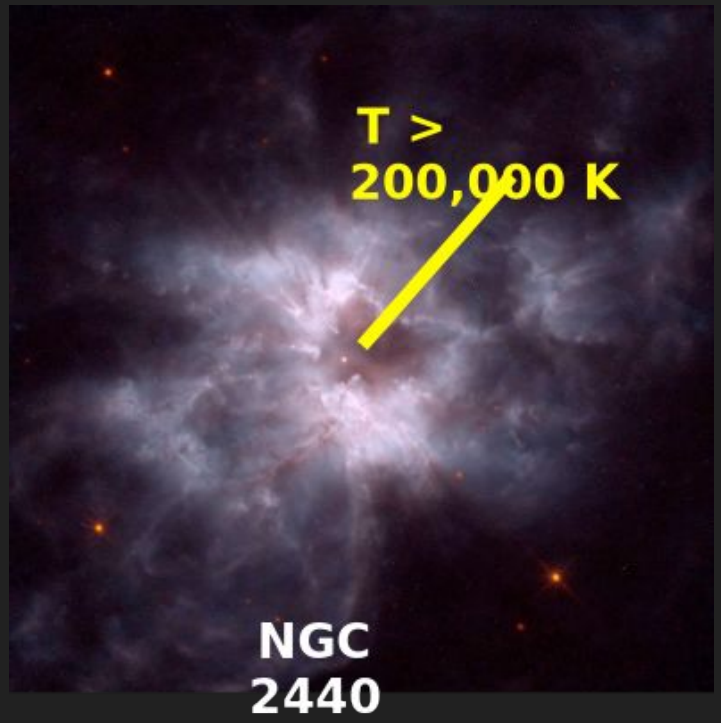


End game

- The outer layers of the AGB star are cast off
- 80 % of the star's original mass
- The core remains, made of carbon and oxygen from helium fusion
- The core is still very hot, above 200,000 K
- Ultraviolet radiation from the core ionizes the cast off outer layers at constant velocity
- Star becomes a planetary nebula



Planetary nebulae

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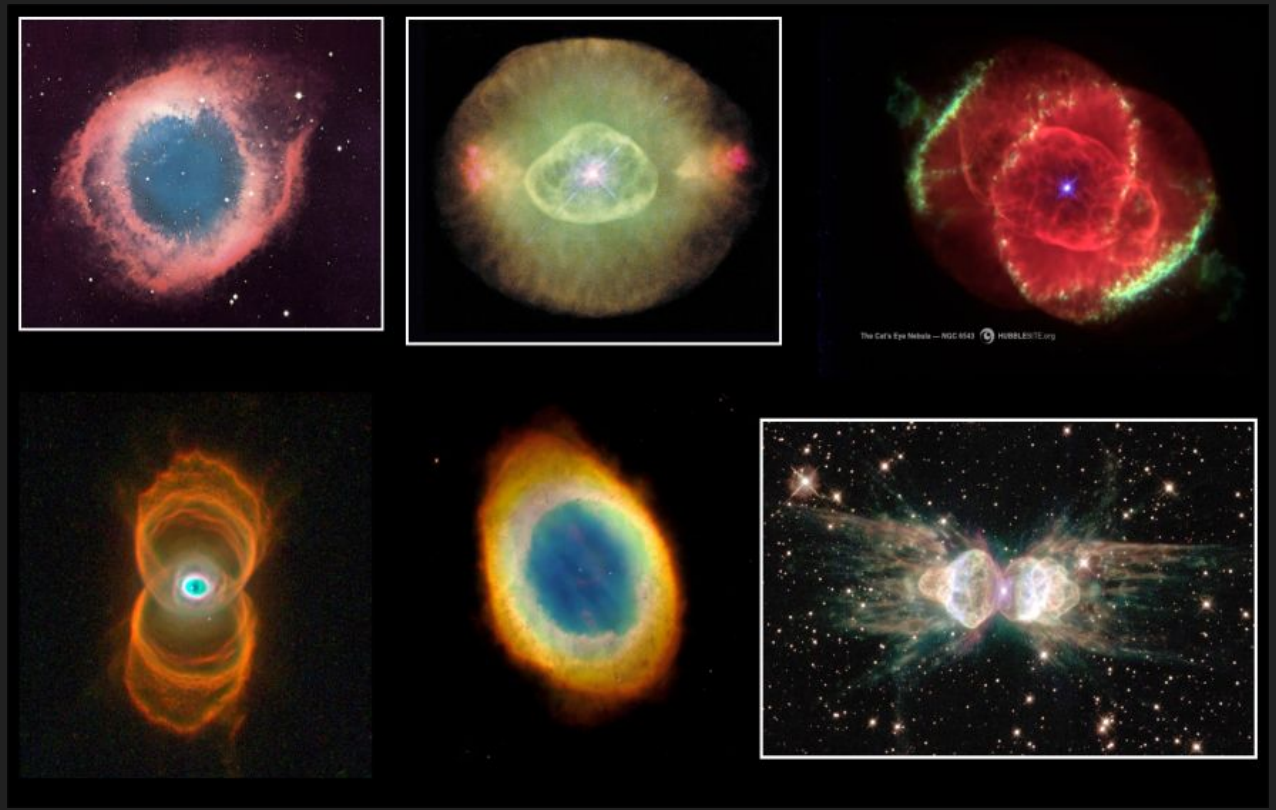
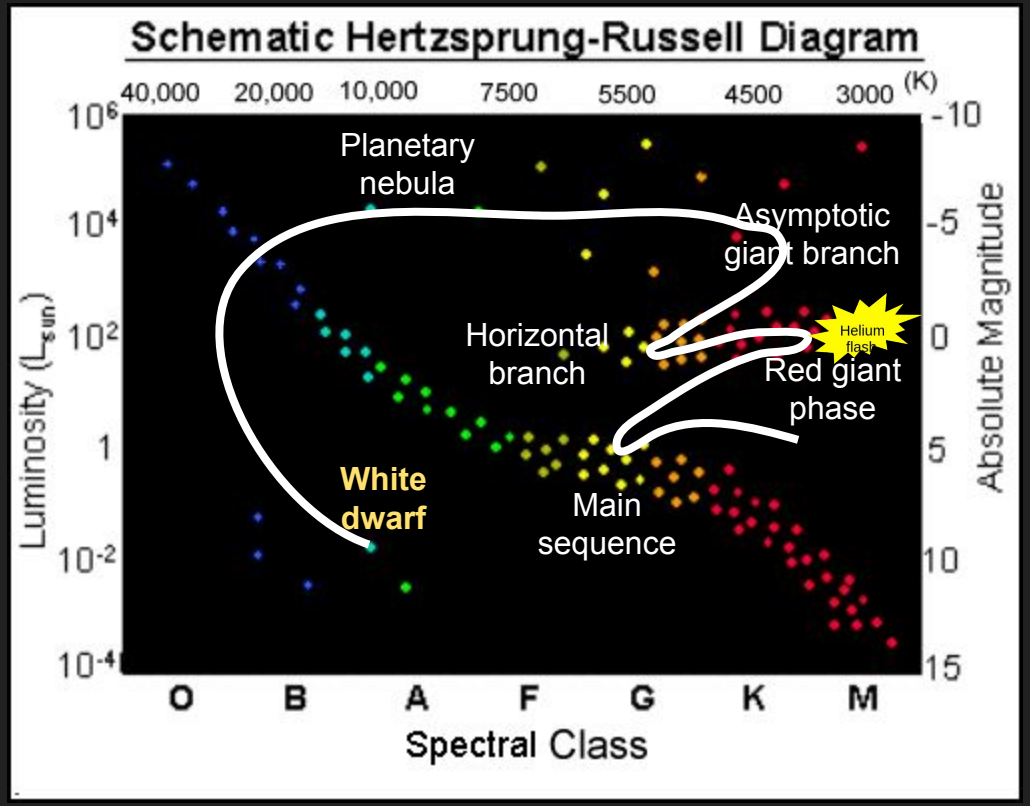
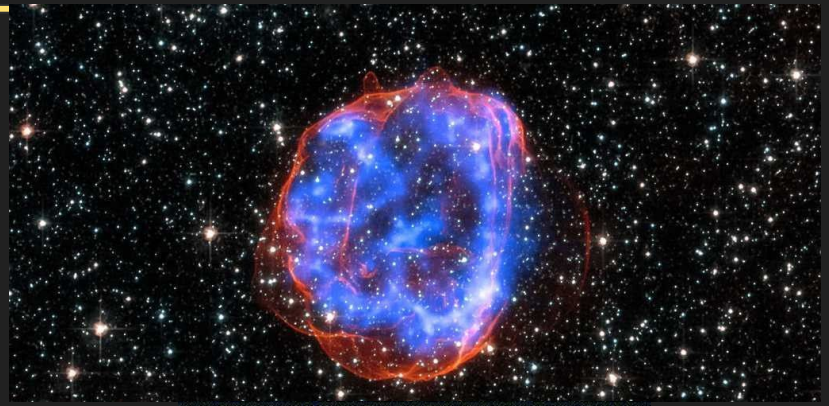


White dwarf


Schematic Hertzsprung-Russell Diagram
40,000
20,000
10,000
7500
5500
4500
3000
(K)
Planetary nebula
Asymptotic giant branch
Horizontal branch
Helium flash
Red giant phase
White dwarf
Main sequence
Luminosity (L_{sun})
Absolute Magnitude
O
B
A
F
G
K
M
Spectral Class

What happens to the core?

- Nuclear fusion has stopped and gravity begins to win the battle
- The core contracts to the size of the Earth
- Mass is about 60 % of the Sun's mass
- The star ends its life as a white dwarf
- The white dwarf slowly cools over billions of years



Why doesn't the white dwarf continue to contract?

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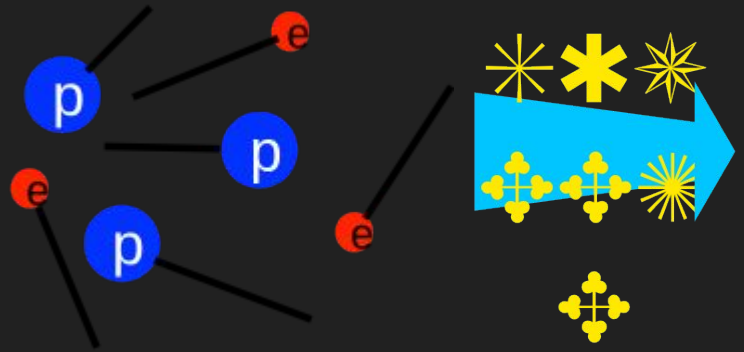
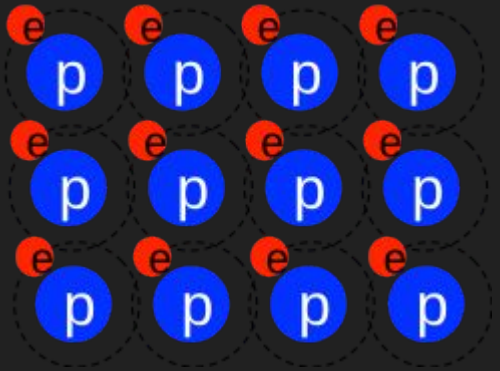
- Quantum effect known as electron degeneracy pressure
- The electrons squashed together towards a quantum limit
- Classically unphysical
- This creates a pressure counter to gravity
- Stops contraction

Matter in a normal star



Electron-degenerate matter



Size of the white dwarf

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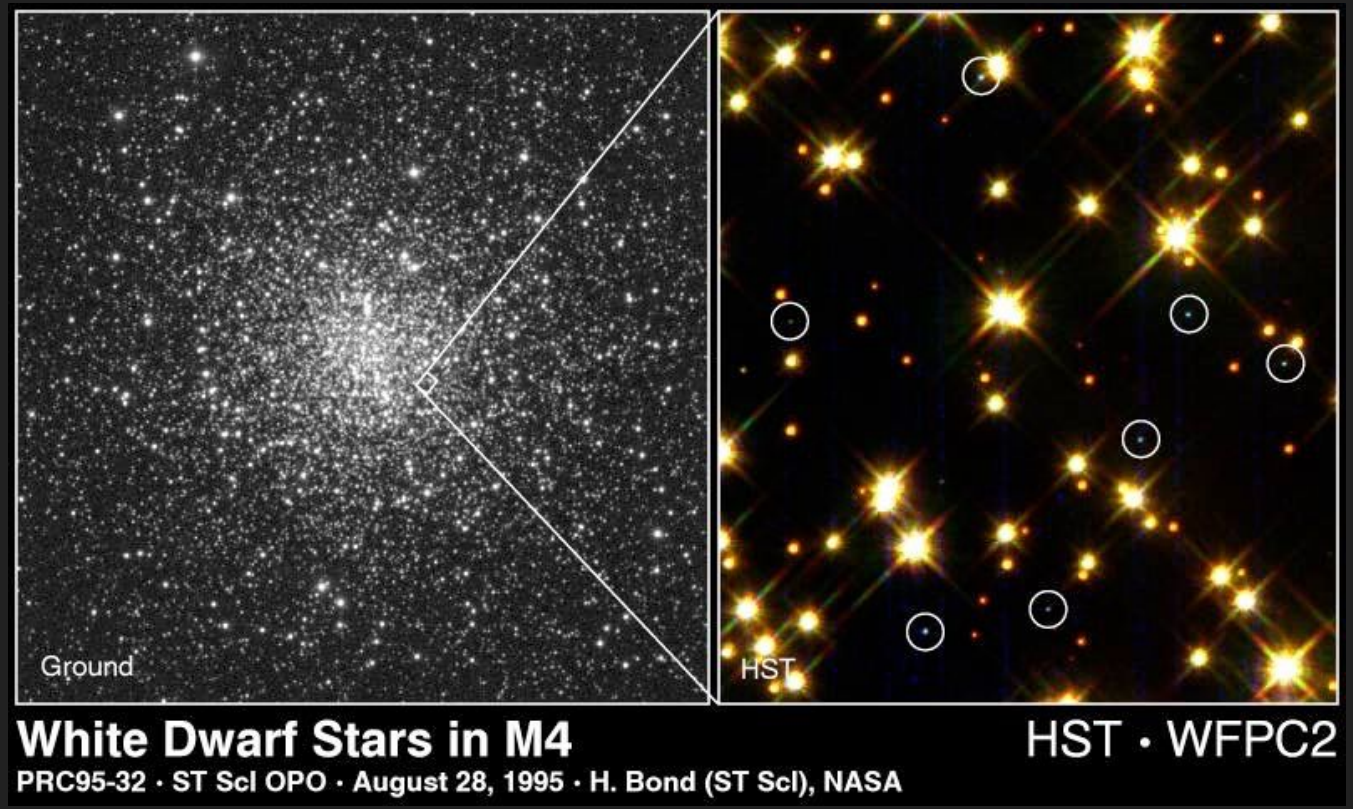
An insignificant little planet

A white dwarf ~0.6 M_Sun

Planetary nebulae



Announcements

- Homework 6 due today
- No lab next week

Next time

- The Death of Stars II