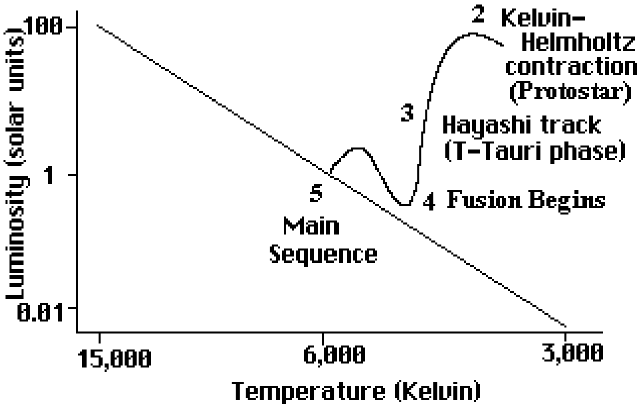
Chapter 13: The Deaths of Stars

Low Mass Stars

A. Summary of the formation and evolution of low mass stars:

1. Formation from molecular cloud.
2. Protostar formation.
3. T-Tauri stage.
4. Nuclear fusion begins.
5. Star settles down to main sequence.
6. Red Giant Phase - hydrogen exhausted in the core.
7. Helium Flash – onset of helium fusion.

Pre-Main-Sequence Evolution Summary

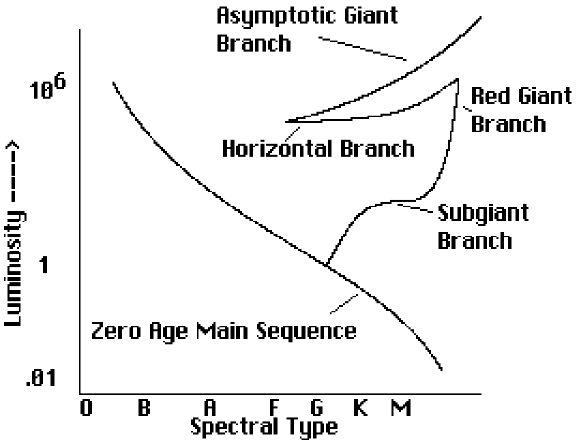


8. Horizontal Giant Phase - helium fusion.

B. Asymptotic Giant Branch: (re-ascends the Giant Branch)

1. Core is depleted of helium after a few tens of millions of years.
    - a. Electron degenerate core.
    - b. Core consists of carbon "ash". Carbon requires 600 million K to fuse but the core is at only 200 million K.
    - c. Helium and hydrogen shell fusion occur.

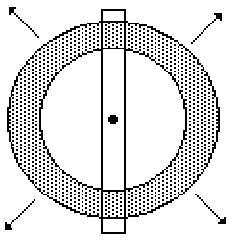
d. More massive AGB stars (> 2 $M_\odot$) can dredge up large amounts of carbon (carbon stars).

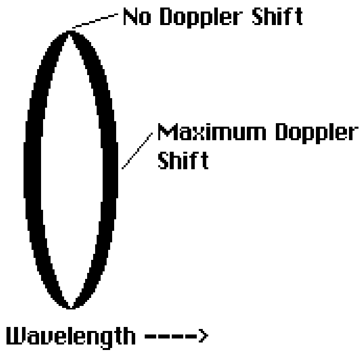


C. Planetary Nebula:

1. Ejection of atmosphere:
    a. Helium shell flashes produce fluctuations in intensity of radiation. Triple alpha process is very sensitive to small temperature changes.
    b. Outward expansion is slowed as the temperature decreases.

2. Outer atmosphere is ejected as a series of shells that expand out at about 25 km/sec.
    a. Expansion is detected by the splitting of the emission lines due to the Doppler effect.





3. Nebula glows from the UV light emitted by the exposed core.

4. Nuclear reactions in the core cease.

5. Nebula merges with the interstellar medium after about 50,000 years.

6. Evolutionary track moves to the left across the HR diagram.

D. White Dwarf

1. Carbon ash core gradually cools to a cold cinder.

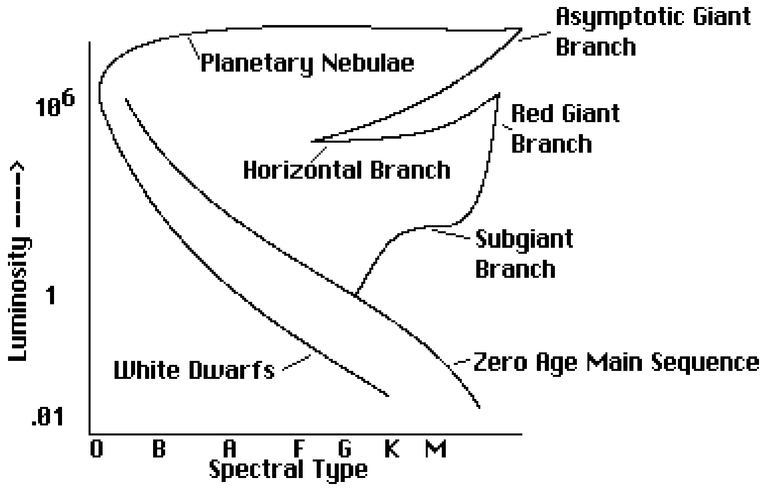
2. Electron degeneracy halts the gravitational collapse.

3. Density is about 3 billion kg/m^3.

4. Radius is about the same size or smaller than the Earth.

5. Shines by remnant heat.

6. Cools down over several billion years.



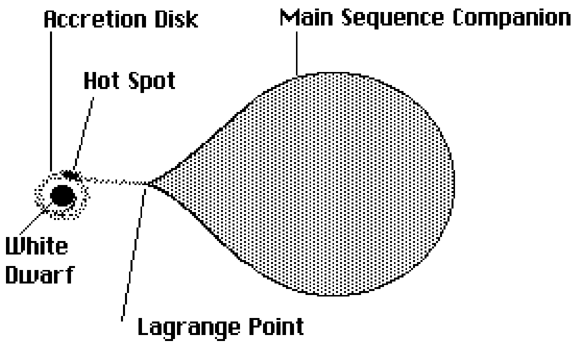
7. Chandrasekhar limit - a white dwarf has an upper limit of 1.4 $M_\odot$

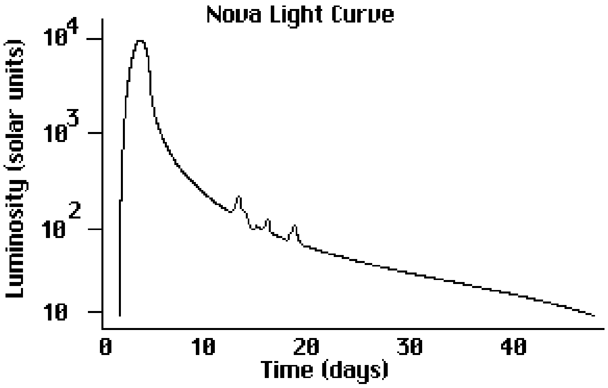
E. Novae

1. Occur when white dwarfs accumulate matter from a binary companion. Brighten by a factor of about 10,000 (10 magnitudes).

    a. Hydrogen on surface undergoes rapid fusion (explosion).
    b. Recurrent novae: white dwarfs that go nova several times.
    c. Hot spot forms where infalling stream hits the accretion disk, giving off x-rays that are observed.

d. Light curve decays over several weeks, with fluctuations.





Concept Test

The Sun will likely never become a nova because this only happens to stars
a) much more massive than the Sun.
b) much less massive than the Sun.
c) in close binary pairs.
d) that have no planetary systems.

High Mass Stars

A. High Mass Stars: two major differences (*) from low mass stars.

*1. Core is not degenerate when helium fusion begins: no helium flash for stars greater than 4 $M_\odot$.

*2. Core reaches the 600 million degrees needed to fuse carbon.

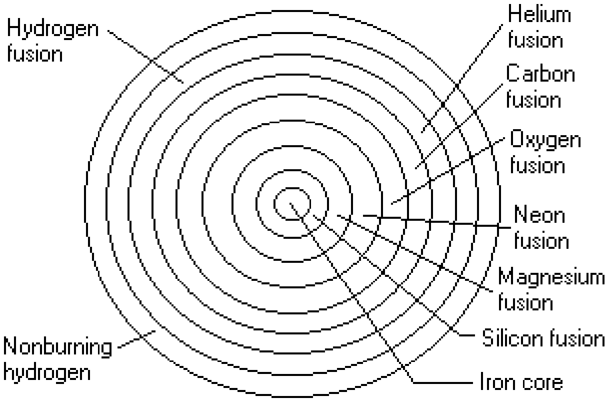
a. Core will continue fusing heavier elements up to iron.
b. Fusion stops at iron.

3. Evolutionary tracks move horizontally across the HR diagram unaffected by the onset of new burning stages.

4. Death occurs in a supernova explosion.

B. Type II Supernovae: deaths of high-mass stars (greater than 8 $M_{\odot}$).

1. Fusion of heavier elements: massive stars fuse carbon, oxygen, ..., to iron in shells.



2.Collapse of the iron core.

a. Iron causes fusion to cease, enabling gravity to overwhelm the radiation pressure of the core.

b. Implosion occurs and is accelerated by:

i. Photodisintigration: (temperature rises to 5 billion Kelvins giving photons enough energy to split iron and other nuclei apart into protons, neutrons, and electrons). Absorbs energy thus reducing the pressure.

ii. Neutronization: protons and electrons combine to form neutrons and neutrinos.

c. Neutron degeneracy pressure suddenly stops the collapse.

i. Core overshoots the density at which neutron degeneracy occurs, resulting in a rebound shock wave when the core bounces back.

d. Shock wave blasts all of the overlying matter into space.

e. From collapse to the shock wave takes about one second.

f. Star shines as brightly as 200 billion suns.

3. Type II supernovae: Hydrogen rich spectrum.

4. Supernovae remnants

a. Glowing remains. Examples: Crab Nebula, Vela Nebula and Gum Nebula.

5. Last supernova seen in our Galaxy was 400 years ago (1604).

a. We should expect to see a supernova in our galaxy about every 50 years.

b. Models of supernovae are based on observations of supernovae in other galaxies.

6. Supernova 1987a

a. Closest supernova seen in 400 years.

b. Type II. Not as bright as expected (1/10 as bright).

c. Progenitor was a blue supergiant rather than a red supergiant, which explains why it was not as bright.

d. Neutrinos were observed. Confirmed our theory on the formation of neutrinos within the core of a collapsing star.

C. Type Ia supernovae (carbon detonation): hydrogen poor spectrum.

1. Result from white dwarfs accumulating enough matter to take them beyond the Chandrasekhar limit.

a. White dwarfs that accumulate a mass greater than 1.4 $M_\odot$ will explode as a type Ia supernovae. The star destroys itself, leaving no remnant.

2. Two ways this can occur:

a. white dwarf accumulates mass by accretion from a binary companion (not all of the matter is consumed during a nova explosion).

b. two white dwarfs colliding.

D. Supernovae of a given type (Type Ia or II) all have the same absolute magnitude. Useful for calculating distances to galaxies.

1. Type Ia: absolute magnitude = -19

2. Type II: absolute magnitude = -17 (some variation)

Concept Test

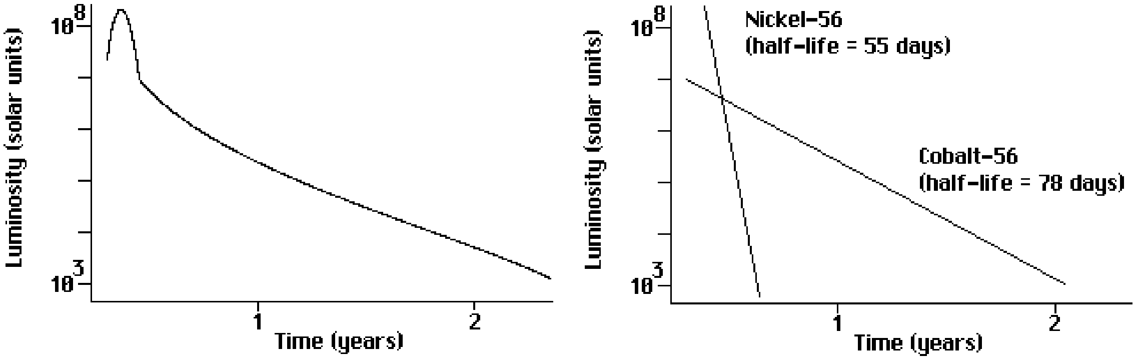
Which of the following events will not leave any remnant?
a) type I supernova.
b) type II supernova.
c) nova.

E Light Curves:

1. Type Ia - smooth decline resulting from radioactive decay of nickel into cobalt.

2. Type II - have a "plateau" in the light curve a few months after the maximum.

Diagrams illustrating the composition of a supernova light curve of the decay of radioactive elements.



Neutron Stars

A. Neutron Stars: Type II supernova remnant of stars having an initial mass between 8 $M_{\odot}$ and 25 $M_{\odot}$.(Type Ia supernovae destroy the progenitor).

1. Collapsing core forces electrons to combine with protons to form neutrons. Mass must be between 1.4 $M_{\odot}$ and 3 $M_{\odot}$.

2. Upper limit on the mass of a neutron star is called the Oppenheimer-Volkov limit.

3. Radii are about 10 km.

4. Solid: density = 10^{17} kg/m^3 (density of the atomic nucleus).

5. Composition: neutrons.

6. Rotation rate: most have rates of 3 to 30 rotations per second.

7. Magnetic field: trillion times stronger than the Earth's field.

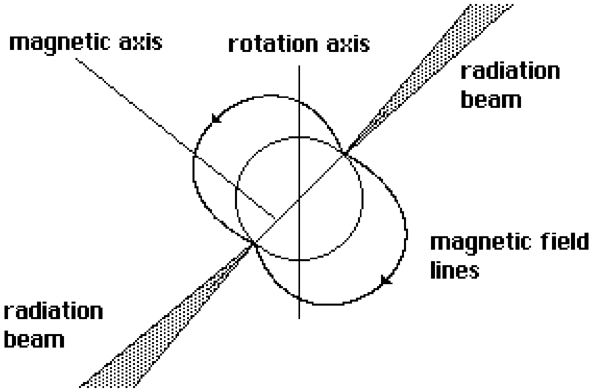
B. Pulsars: observational evidence for neutron stars (ex. Crab pulsar).

1. First discovered by Jocelyn Bell at Cambridge Univ. in 1967.

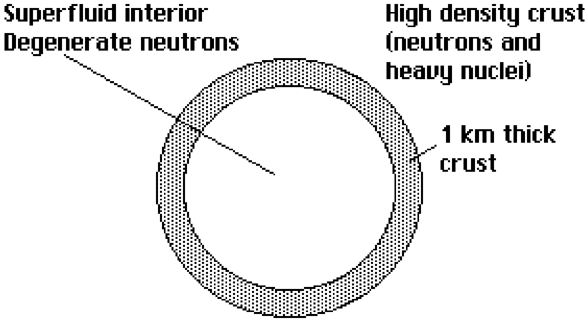
2. Most are seen in the radio region of the spectrum.

3. Pulsation periods are typically 0.03 to 0.3 seconds, and slow down with age.

4. Lighthouse model explains the pulsations. The beam must sweep past the Earth to be seen.



5. Starquakes (glitches): small drops in pulsar periods are observed.Result of the crust shrinking. Like Earthquakes, these glitches allow astronomers to create a model for the internal structure of neutron stars.



6. Neutron Star Binaries

    a. X-ray pulses: gas spiraling onto the poles of a neutron star from a companion star create hot spots that emit x-rays.

    b. X-ray bursters: like novae, but more energetic. Hydrogen from companion builds up on the surface and burns giving off a flash of x-rays. Process repeats every few hours.

7. Millisecond pulsars: rapidly rotating neutron stars (~1000 rotations per second) that are found in globular clusters, implying old age.

a. Have been spun up by drawing in matter from a companion star (conservation of angular momentum).

b. X-ray pulsars and bursters may be on their way to becoming millisecond pulsars.

8. Neutron star collisions: close binary neutron stars, where both stars are neutron stars, over time will spiral into each other. Resulting explosion will be comparable to a supernova and can produce some of the heavy elements (gold, silver, platinum, ...) that we see today.

Concept Test

Not all neutron stars are pulsars because
a) some neutron stars don't have magnetic fields.
b) some neutron stars don't have enough mass.
c) the rotational axis of some neutron stars point in the wrong direction.
d) some neutron stars are just invisible.