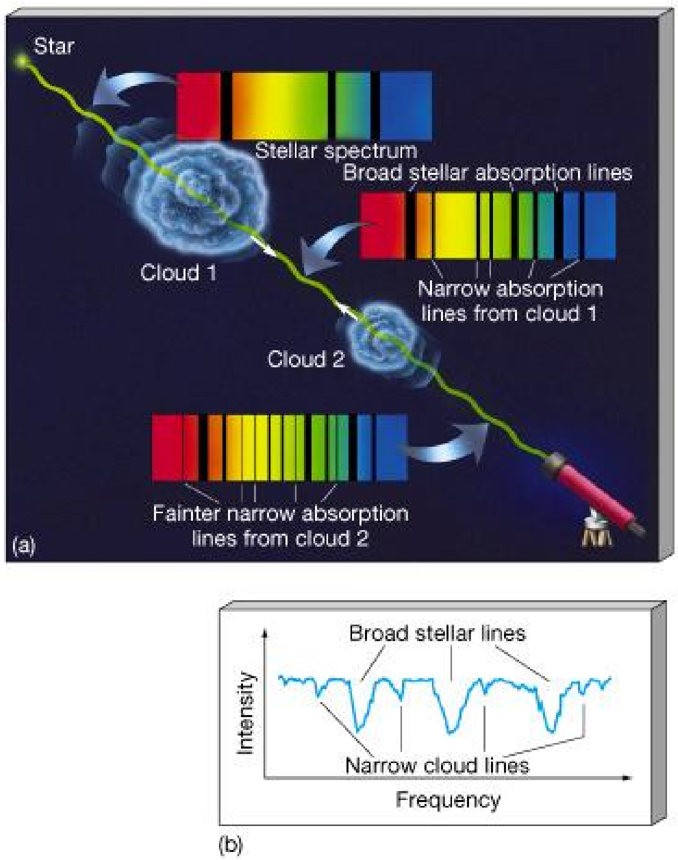
Chapter 12: The Lives of Stars from Birth Through Middle Age

Stars are formed out of interstellar gas and dust clouds (interstellar medium).
Constituents of the interstellar medium:

A. Gas:

1. 74% is hydrogen
2. 25% helium (by mass)
3. 1% everything else

How do we know this gas exists? Stellar spectra reveal the presence of narrow absorption lines arising from diffuse interstellar gas clouds.



Spectra of diffuse interstellar clouds
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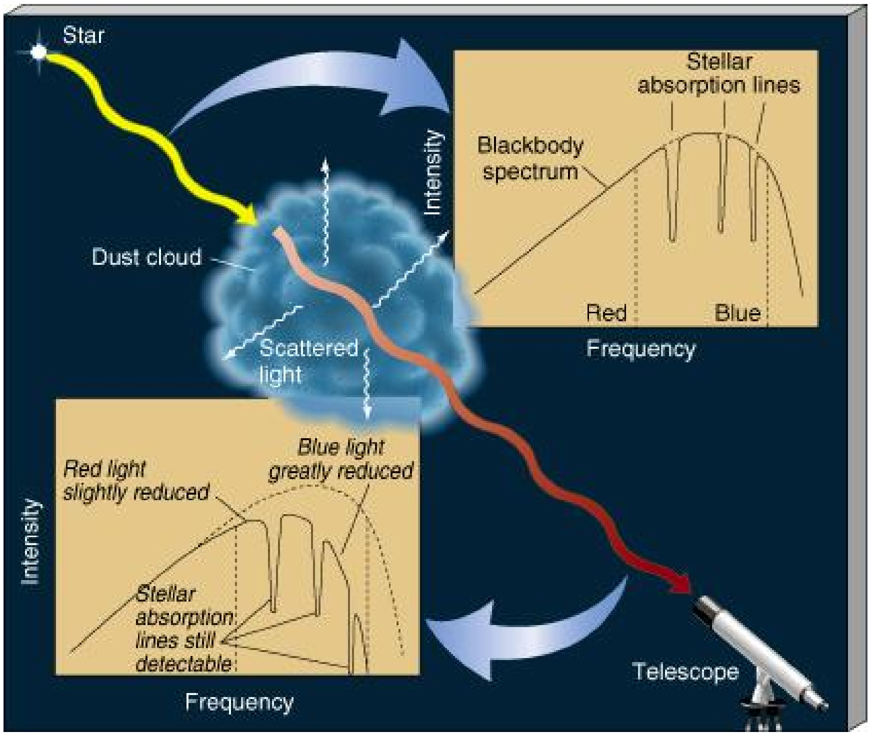
B. Molecules: Many types of molecules have been detected.

C. Dust: composed of silicon, carbon compounds and ices. Presence revealed by:

1. Interstellar extinction - dimming of starlight.
2. Interstellar reddening- starlight that has passed through dust is redder than it actually is.



Interstellar reddening by dust

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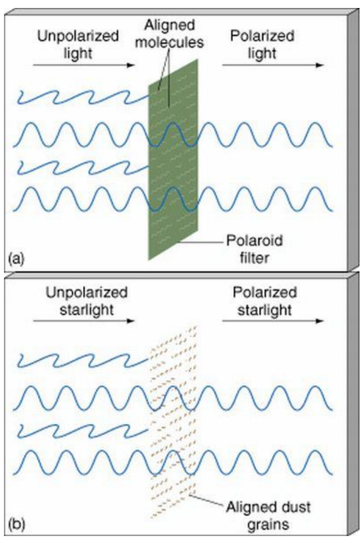
3. Polarization of starlight - lets astronomers determine the shape and size of the dust grains.



Polarization by dust

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4. Typical size is about 0.005 micrometers.

Concept Test
A star seen through clouds of interstellar dust will appear
a) farther away and bluer in color. b) farther away and redder in color. c) closer and redder in color. d) closer and bluer in color.

Examples of the Interstellar Medium:

A. **Giant Molecular clouds** - dense regions of gas, dust, and molecules.

B. **Reflection Nebulae** - regions of dust surrounding young stars.

C. **H II Regions** (Emission Nebulae) - regions of gas excited by hot young stars.

D. **Dark Nebulae** - regions of dust that obscure background stars.

Stellar Birth: Protostar through Pre-main Sequence

A. Gravitational collapse of an interstellar cloud.

1. Supernovae can compress an interstellar cloud.

2. Interstellar clouds can collide causing them to collapse.

3. UV radiation from hot luminous stars can compress interstellar clouds.

B. Fragmentation of the interstellar cloud. Gravitational instabilities cause the cloud to break into smaller fragments after the cloud begins to collapse. Fragments are called Bok Globules

Bok Globules

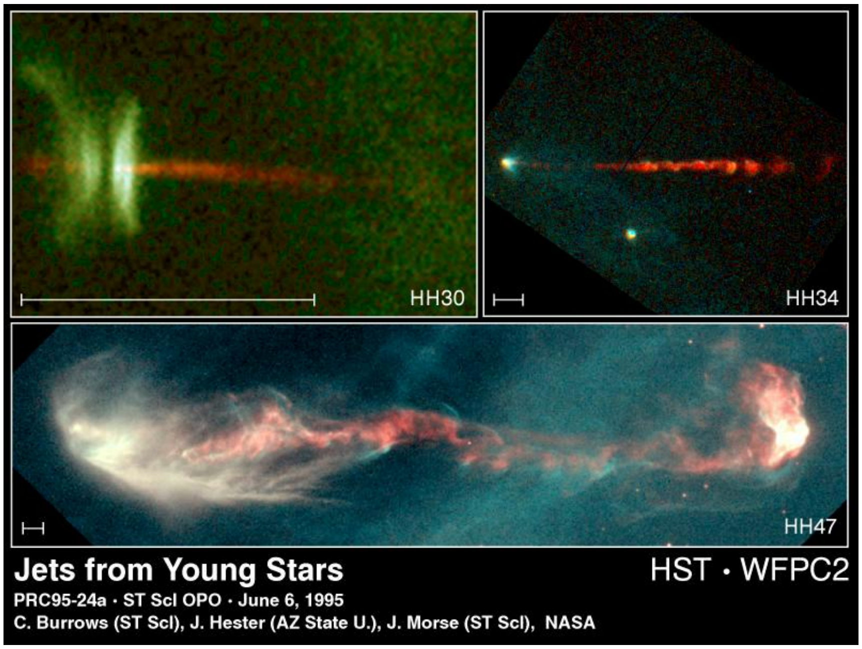
C. The fragments collapse to form protostars, which grow in mass as the protostars accrete matter.

D. Pre-main-sequence star. Outward radiation pressure prevents in falling gas from reaching the protostar.

Concept Test

As a star first begins to condense from the dust and gas clouds, it emits primarily in which wavelength region?
a) X-ray
b) ultraviolet
c) visual
d) infrared
e) radio

E. Prior to the onset of nuclear fusion a star like our Sun experiences vigorous gas ejection. During this phase it is called a T-Tauri star. Because the star is surrounded by an accretion disk, most of the gas is ejected along the poles of the star. Herbig-Haro objects are examples of this bi-polar flow.



Herbig-Haro objects exhibiting bi-polar flow

F. Nuclear fusion begins when the core reaches 10,000,000 K.

G. Star settles down to the main sequence along a path called the birth line.

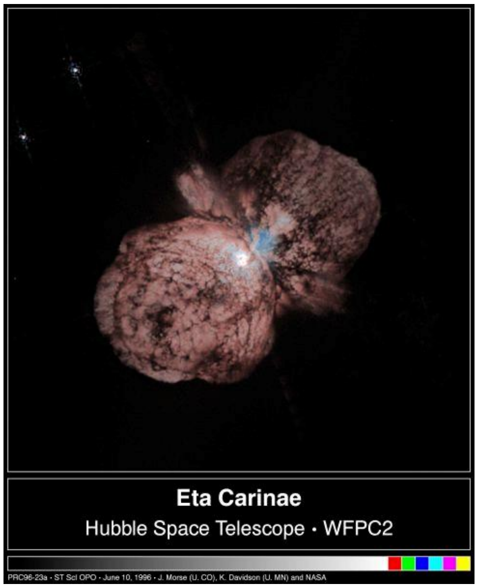
H. Effects of Mass.

1. Stars with more than 2 M move from right to left on the HR diagram without changes in luminosity.

2. Stars with more than 7 M start fusing hydrogen during the protostar phase.

3. Protostars with less than 0.08 M are too small to fuse hydrogen and instead become brown dwarfs.

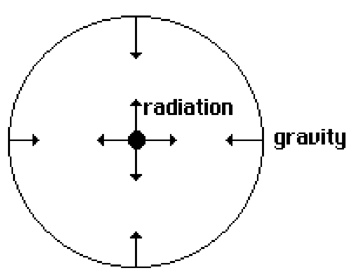
4. Upper limit is ~130 M. Examples: Eta Carina, Pistol Star



5. Time required to reach the main sequence depends on the star's mass.
Larger stars reach the main sequence faster than lower mass stars.

Main Sequence

A. Zero-Age Main Sequence: point on the HR diagram where a star first becomes stable. When a star is stable the inward force of gravity balances the outward force of radiation pressure. We call this hydrostatic equilibrium.



Hydrostatic Equilibrium

B. Stars spend most of their lives on the main sequence.

C. More massive stars spend less time on the main sequence since they consume their hydrogen fuel at a faster rate.

D. Red dwarf stars (0.08 to 0.4 M) completely convert all of their hydrogen into helium because their interior is completely convective.

E. Main Sequence Lifetimes: mass is the most important factor influencing a star's lifetime.

1. Massive stars fuse hydrogen at a much faster rate than the Sun due to the higher densities in their cores ⇨ short lifetime!

2. Low mass stars fuse hydrogen much more slowly ⇨ long lifetime.

$$\text{lifetime} \propto \frac{\text{mass}}{\text{luminosity}}$$

Example: Y Cygni

Mass = 17.4 M

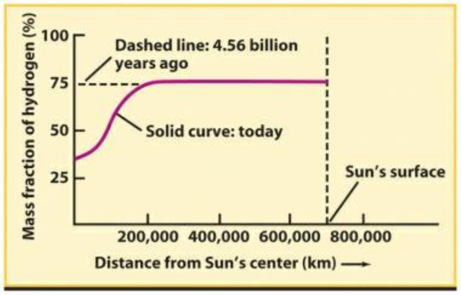
luminosity = 36,300 solar luminosities

Lifetime = 17.4/36300 = 4.8 x 10^{-4} lifetime of Sun (4.8 million years)

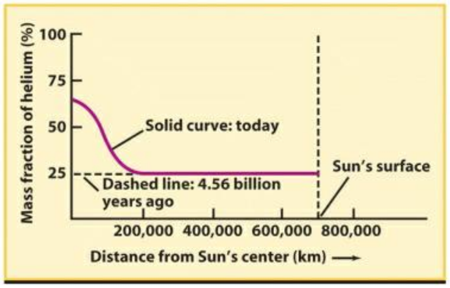
Stellar Evolution After the Main Sequence

Red Giant Phase

A. Supply of hydrogen in the core is eventually depleted.



Hydrogen in the Sun's interior



Helium in the Sun's interior

1. Core is composed of helium "ash" with a hydrogen fusing shell.

2. Core contracts since the radiation pressure is not able to balance the inward force of gravity.

3. The contracting core heats up, which causes the atmosphere of the star to expand.

4. Electron degeneracy halts the contraction.

a. Pauli exclusion principle prevents electrons from getting too close together. This provides a greater outward pressure that does not change with temperature.

5. Temperature rises until it reaches 100,000,000 Kelvins.

6. Helium flash occurs. Helium fusion begins after the temperature has reached 100,000,000 Kelvins. Electron degeneracy causes the helium reaction rates to rise rapidly (helium flash) until the helium in the core can resume acting as a normal gas.

7. Triple Alpha Process: three helium atoms combine to form a carbon atom plus energy. This is the dominant energy process in a red giant.

$$^{4}He + {}^{4}He + {}^{4}He \longrightarrow {}^{12}C + \gamma$$

Helium can also combine with carbon to form oxygen.

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

8. The star moves off the main sequence and up the red giant branch of the HR diagram.

Concept Test

As a one solar mass star evolves into a red giant, its
a) surface temperature and luminosity increase.
b) surface temperature and luminosity decrease.
c) luminosity decreases while the surface temperature increases.
d) luminosity increases while the surface temperature decreases.

Post-Helium Flash Stars

A. Post-helium flash stars move to the left along the HR diagram and are called horizontal giant branch stars. They have luminosities of about 50 times that of the Sun.

1. Often found in globular star clusters

2. Helium fusing cores.

3. Radiation pressure maintains hydrostatic equilibrium.

B. Variable Stars - the evolutionary tracks of horizontal giant branch stars take them through the instability strip where they pulsate.

1. RR Lyrae variables.

a. Periods shorter than one day. Typically range from 0.5 to 1 day.

b. They all have about the same luminosity.

c. Low mass stars.

2. Cepheid variables.

a. Periods range from about 1 to 100 days. Periods are related to the luminosities (Period-Luminosity Law).

b. High mass stars.

c. Type I Cepheids - brighter metal-rich stars (Population I).

d. Type II Cepheids - dimmer metal-poor stars (Population II).

3. Long Period Variables (Mira Type Variables)

a. Periods lasting months to years. Not very predictable.

b. Luminosities change from 10 to 10,000 times the Sun's luminosty.

c. Cool red giants.

d. Many eject large amounts of dust and gas.

Star Clusters (Stars Gravitationally Bound Bogether)

A. Stars within clusters have the following common properties:

1. Age.

2. Composition.

3. Same distance from Sun.

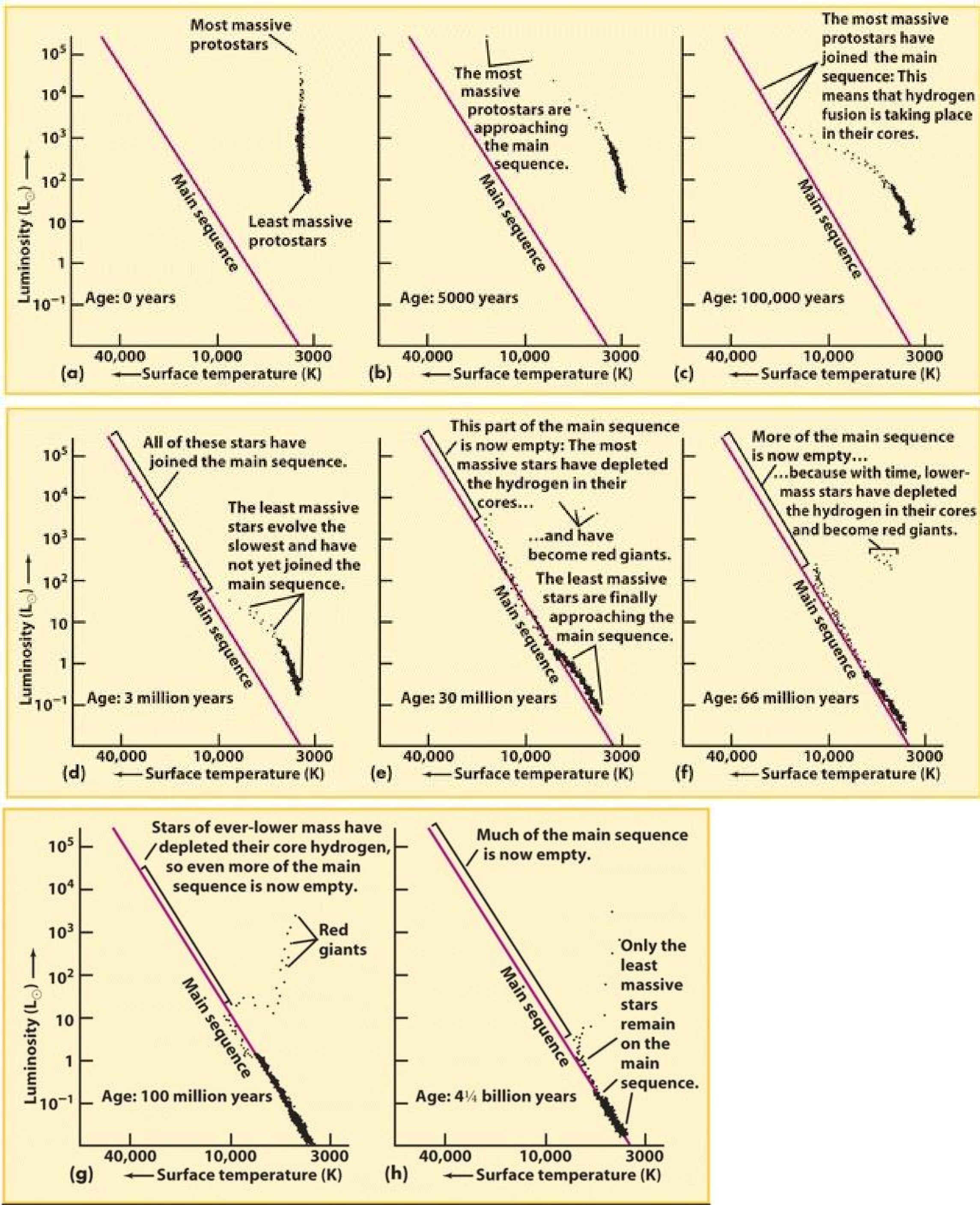
B. Clusters allow astronomers to test theories of stellar and galactic evolution using HR diagrams.

C. Plotting a star cluster on an HR diagram tells us the age of the cluster.

1. HR diagram for M55 (see figure 12-25 on p. 338 of the text). Globular cluster.

2. HR diagram for M45 (see figure 12-3b on p320 of the text). Open cluster.

3. Turnoff point tells us the age of a cluster. M55 is an older than M45 since its turnoff point is much lower down on the main sequence than M45.



Evolution of a Star Cluster
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D. Cluster types:

1. Open clusters - formed within H II regions. Located along the MilkyWay.

   a. Contain a few tens to hundreds of stars.
   b. Contain many O and B type stars. The bright O and B stars within an H II region are called OB associations
   c. Population I stars.- younger stars that have formed from material that has been previously processed by an earlier generation of stars.
   d. Metal rich.
   e. Young.

2. Globular clusters - distributed throughout the sky.

   a. Contain thousands of stars in a small volume.
   b. No O or B type stars, contain low-mass red stars and intermediate-mass yellow stars.
   c. Population II stars -older stars that are metal poor.
   d. Metal poor.
   e. Old.

Concept Test

Because stars in a cluster all have similar age and distance, the main underlying physical cause of their different appearances is their
a) color.
b) radius.
c) mass.
d) chemical composition.
e) temperature.

Mass Transfer in Close Binaries

The evolution of stars can be significantly altered in the case of close binary systems.

A. Detached Binary (see Figure 12-15a): Both stars live out their lives separately.

B. Semi-Detached Binary (see Figure 12-15b): One of the stars fills its Roche lobe and transfers mass to the other star.

C. Contact Binary (see Figure 12-15c): Both stars fill their Roche lobes.

D. Overcontact Binary (see Figure 12-15d): Both stars overfill their Roche lobes and end up sharing the same atmosphere.

Example: ϕ Persei has evolved so that the originally more massive star is now the less massive star. The star that gained mass has had its evolution accelerated, while the star that lost mass has had its evolution slowed.