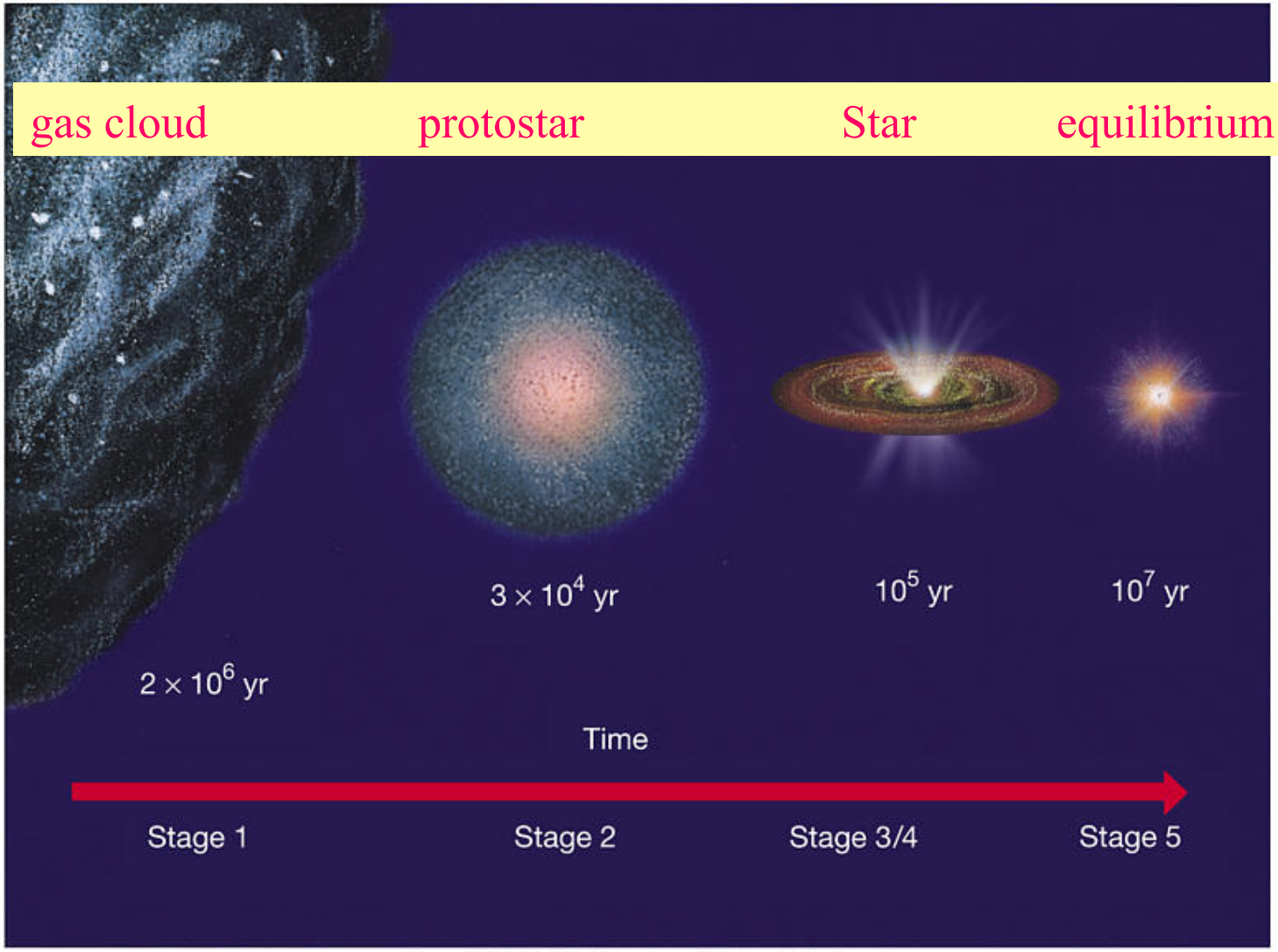
Review…

- "Spectral" Parallax
  - From stars whose distances were measured directly, absolute magnitude could be determined from apparent magnitude
  - These absolute magnitudes correlated with spectral classes (O B A F G K M)…
  - Spectral classes are correlated with temperature, that is determined from the peak wavelength of "blackbody" spectrum
  - Luminosity and spectral classes of stars > 500 LY are related on HR diagram… therefore DISTANCE of these stars can be calculated

Star Formation



Star Formation

STEPS

1. Collapsing Gas Cloud
2. Protostar: hot ball but no fusion
3. Star: nuclear fusion but not final equilibrium
4. Main Sequence Star: final equilibrium with excess gas blown away

Gravity and Star Formation

Gravity causes the material (gas and dust) in a cloud to be attracted to each other

- compresses into smaller volume
- increases temperature and density
- If the temperature at the center becomes large enough (5 million degrees) then H to He fusion can occur:
- Star is born
- Many stars formed from same cloud

Gravity II

Fusion provides a new source of energy

- Core stops compressing. Have equilibrium with thermal (electromagnetic) pressure=gravitational pressure
- "Surface" defined as excess gas blown away
- Main sequence star Luminosity depends on MASS

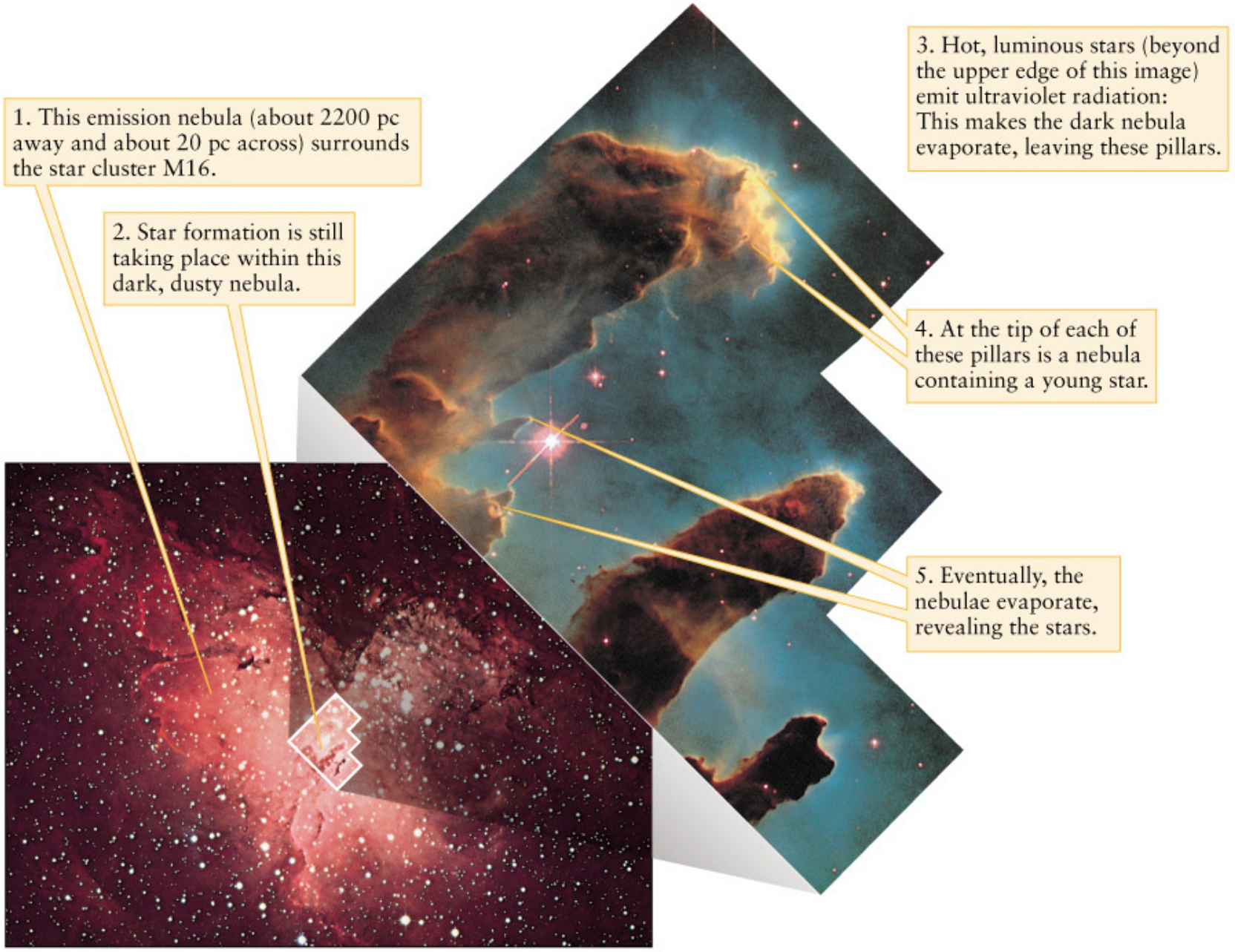
Star Formation

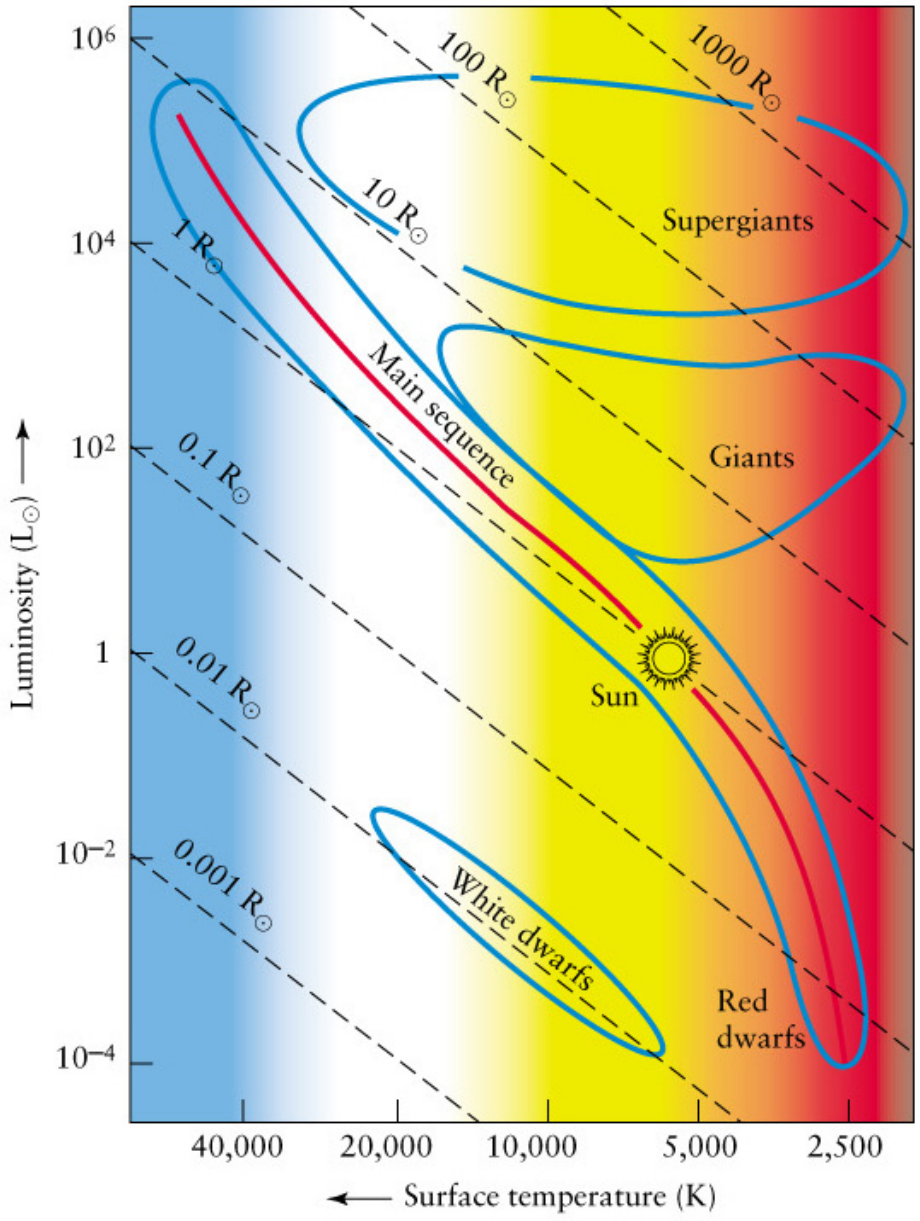
1. Collapsing Gas Cloud → Main Sequence Star
2. Brightness depends on Mass
3. Higher Mass also evolve faster
   - highest mass only "live" a few million years
   - Sun will "live" about 10 billion years
   - lower mass stars "live" 100 billion years

Catalysts for Star Formation

Stars: formed inside giant clouds. New stars help initiate formation of stars in nearby regions

- Material ejected from forming stars
- Pressure from light radiation from new stars (especially large ones)
- Supernova explosions (which occur a few million years after a large star is formed)
  → ejects material plus shock wave

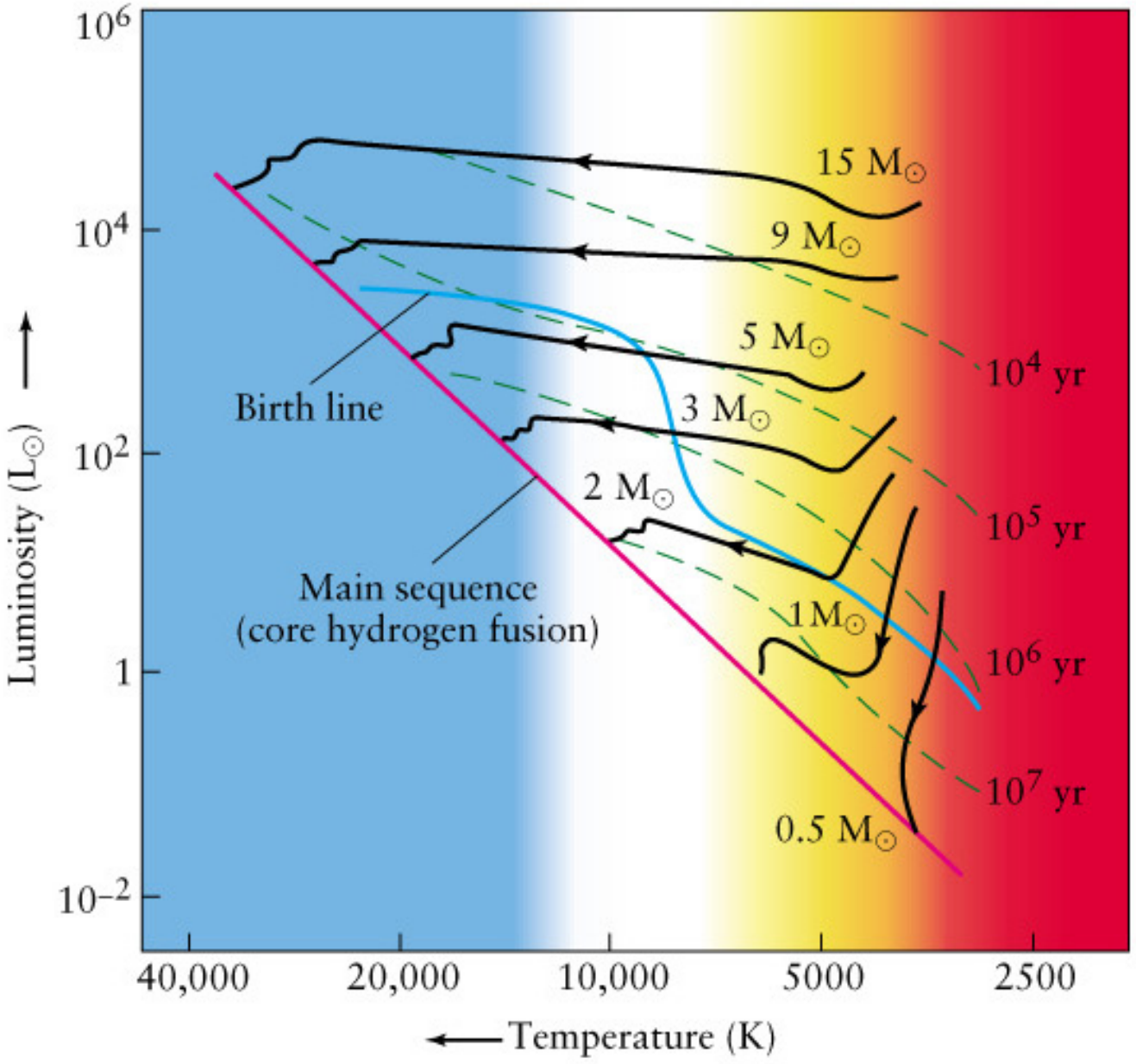

1. This emission nebula (about 2200 pc away and about 20 pc across) surrounds the star cluster M16.
2. Star formation is still taking place within this dark, dusty nebula.
3. Hot, luminous stars (beyond the upper edge of this image) emit ultraviolet radiation: This makes the dark nebula evaporate, leaving these pillars.
4. At the tip of each of these pillars is a nebula containing a young star.
5. Eventually, the nebulae evaporate, revealing the stars.



Reminder Hertzprung-Russell Diagram

Plot Luminosity vs surface temperature

Stars with larger sizes are brighter then a smaller star with the same surface temperature



Star Formation

protostar → main sequence star. Happens faster if larger mass

Key Properties of Main Sequence Stars

Mass/M_{Sun}	Luminosity/L_{Sun}	Effective Temperature (K)	Radius/R_{Sun}	Main sequence lifespan (yrs)
0.10	3×10^{-3}	2,900	0.16	2×10^{12}
0.50	0.03	3,800	0.6	2×10^{11}
0.75	0.3	5,000	0.8	3×10^{10}
1.0	1	6,000	1.0	1×10^{10}
1.5	5	7,000	1.4	2×10^{9}
3	60	11,000	2.5	2×10^{8}
5	600	17,000	3.8	7×10^{7}
10	10,000	22,000	5.6	2×10^{7}
15	17,000	28,000	6.8	1×10^{7}
25	80,000	35,000	8.7	7×10^{6}
60	790,000	44,500	15	3.4×10^{6}

Core Temperature

5,000,000

15,000,000

40,000,000

Higher mass → faster rate of fusion

Stellar Evolution

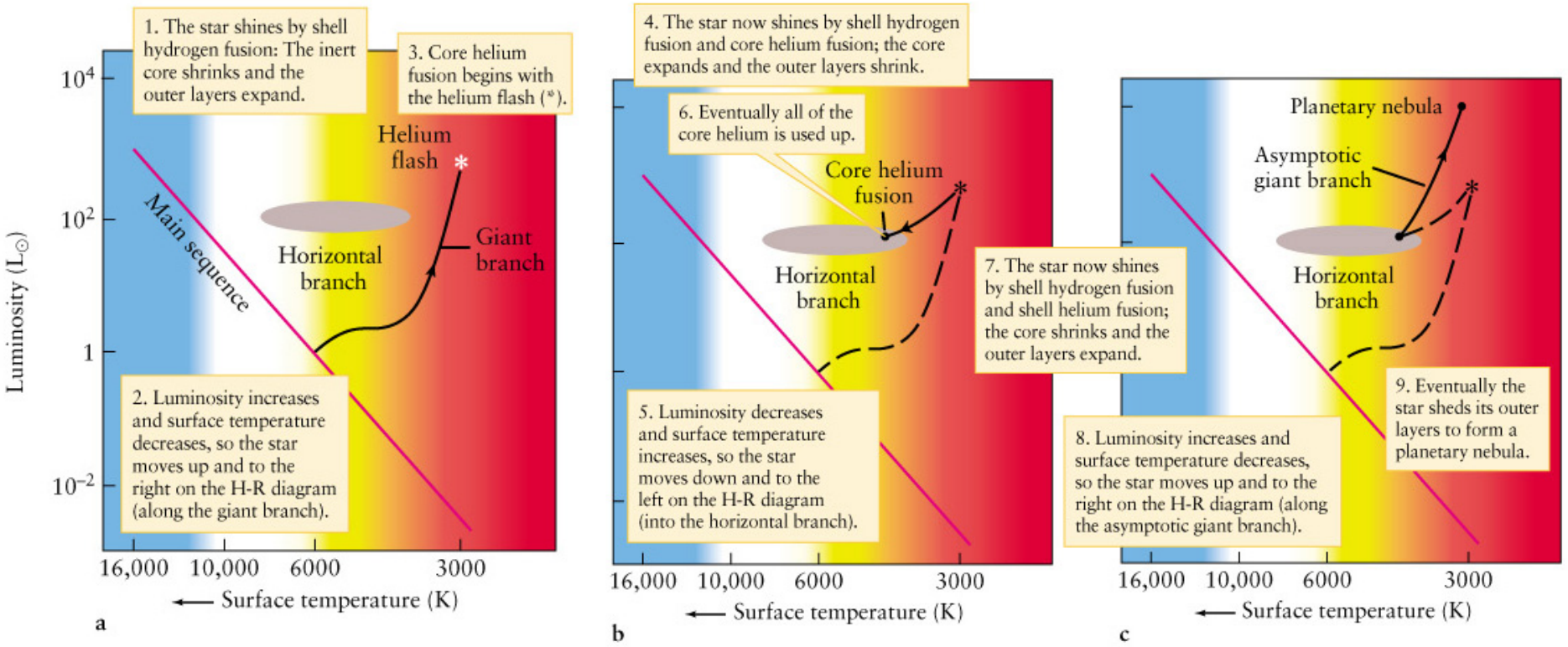
90% of its lifetime: star converts Hydrogen to Helium

- p-p cycle Main Sequence

  Helium builds up in the core, but not yet burning
- Gravity compresses which increases temperature
- Helium starts burning, more energy produced

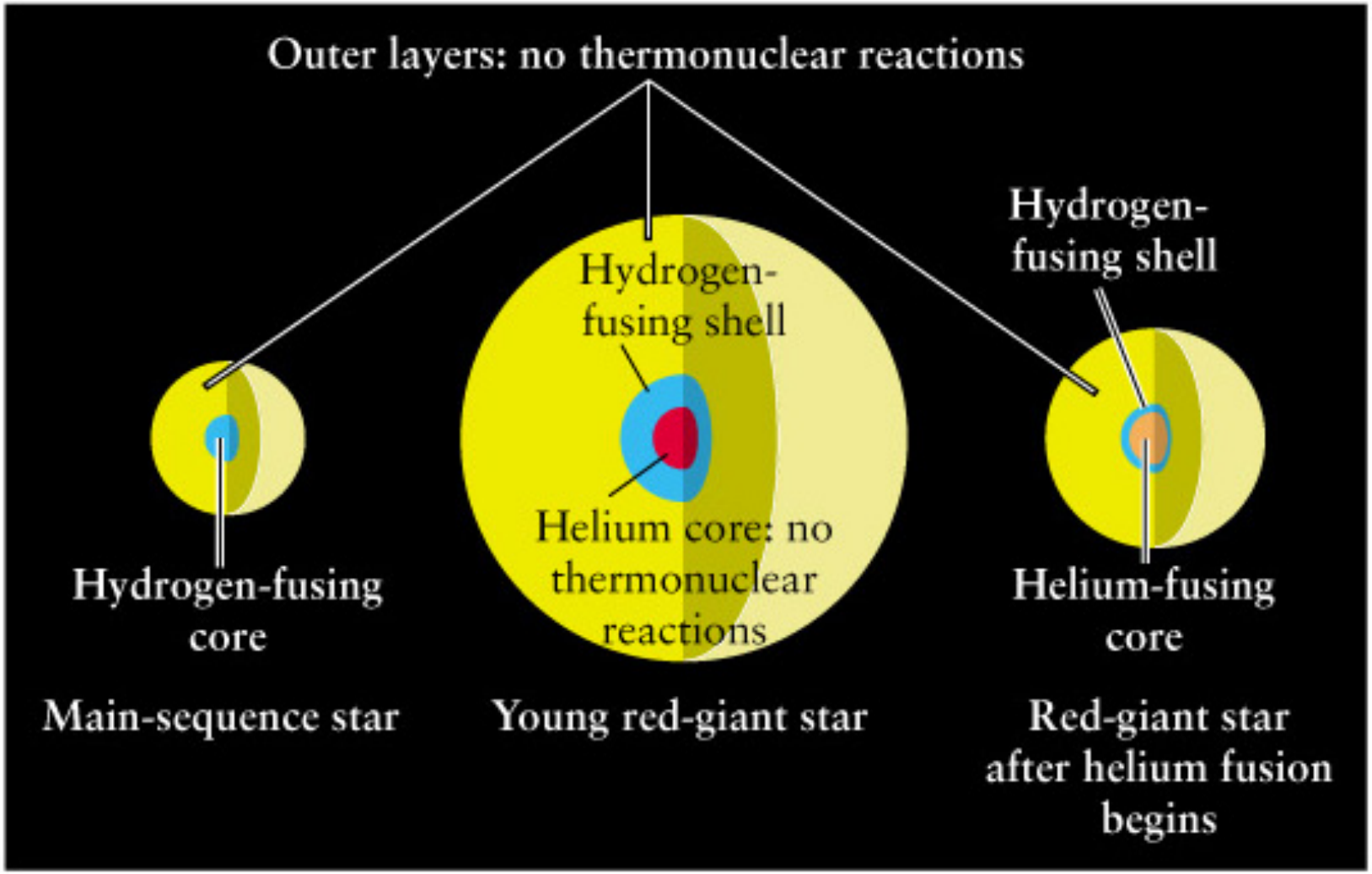
  Different equilibrium, less stable
- NOT on main sequence
- Where on HR diagram is complicated **(you don't need to know)**
- Simplistically Red Giants=He burning

Main Sequence → Red Giant



don't need to know

Helium Fusion → Red Giant



Helium Fusion I

As mass Carbon12 (6p,6n) is less than the mass of 3 He4 (2p,2n) then combining 3 He into C releases energy

$$m(^4He) = 4.0026u$$
$$m(^8Be) = 8.0053u$$
$$m(^{12}C) = 12.000u$$

3-Body Reaction

He+He+He → C

two 2-Body Reactions

He+He → Be(4p,4n)

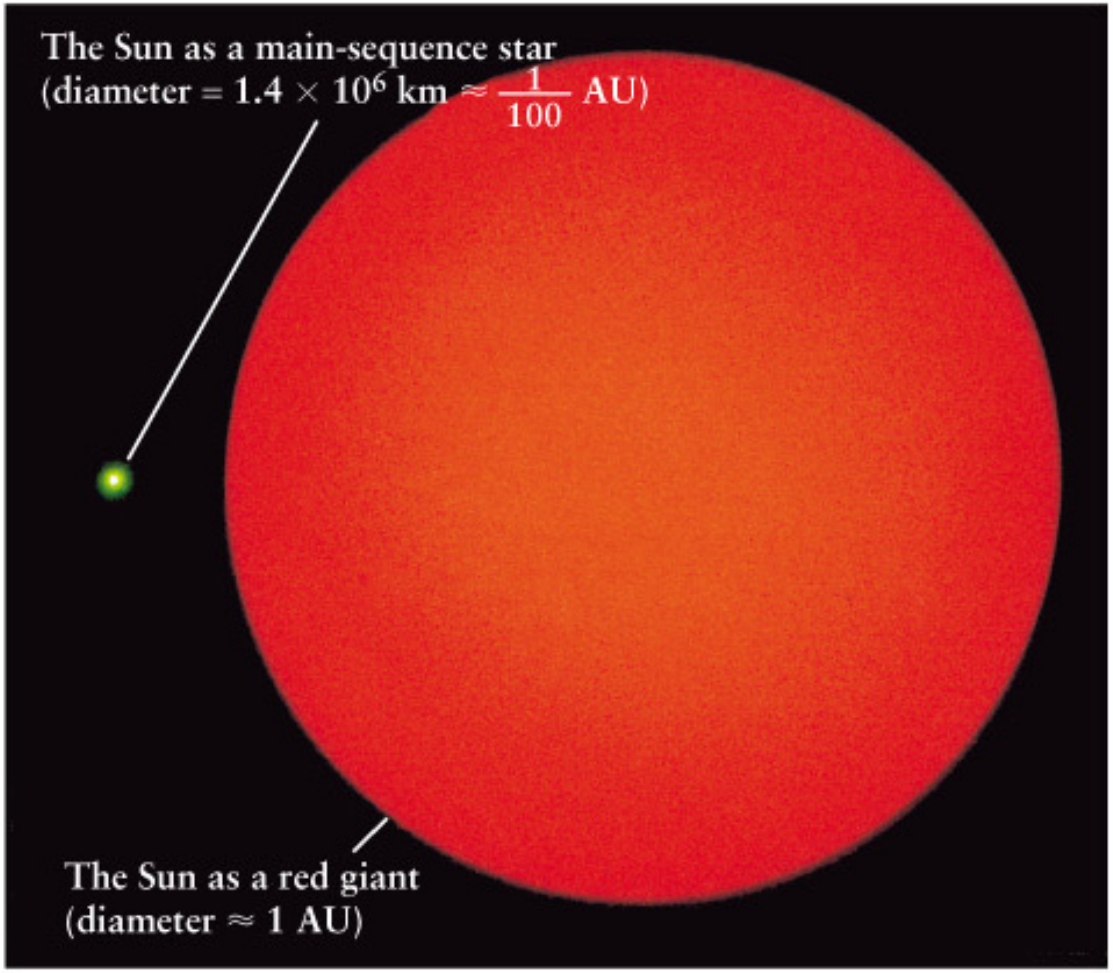
He+Be → C

Helium Fusion II

Helium to Carbon burning is suppressed

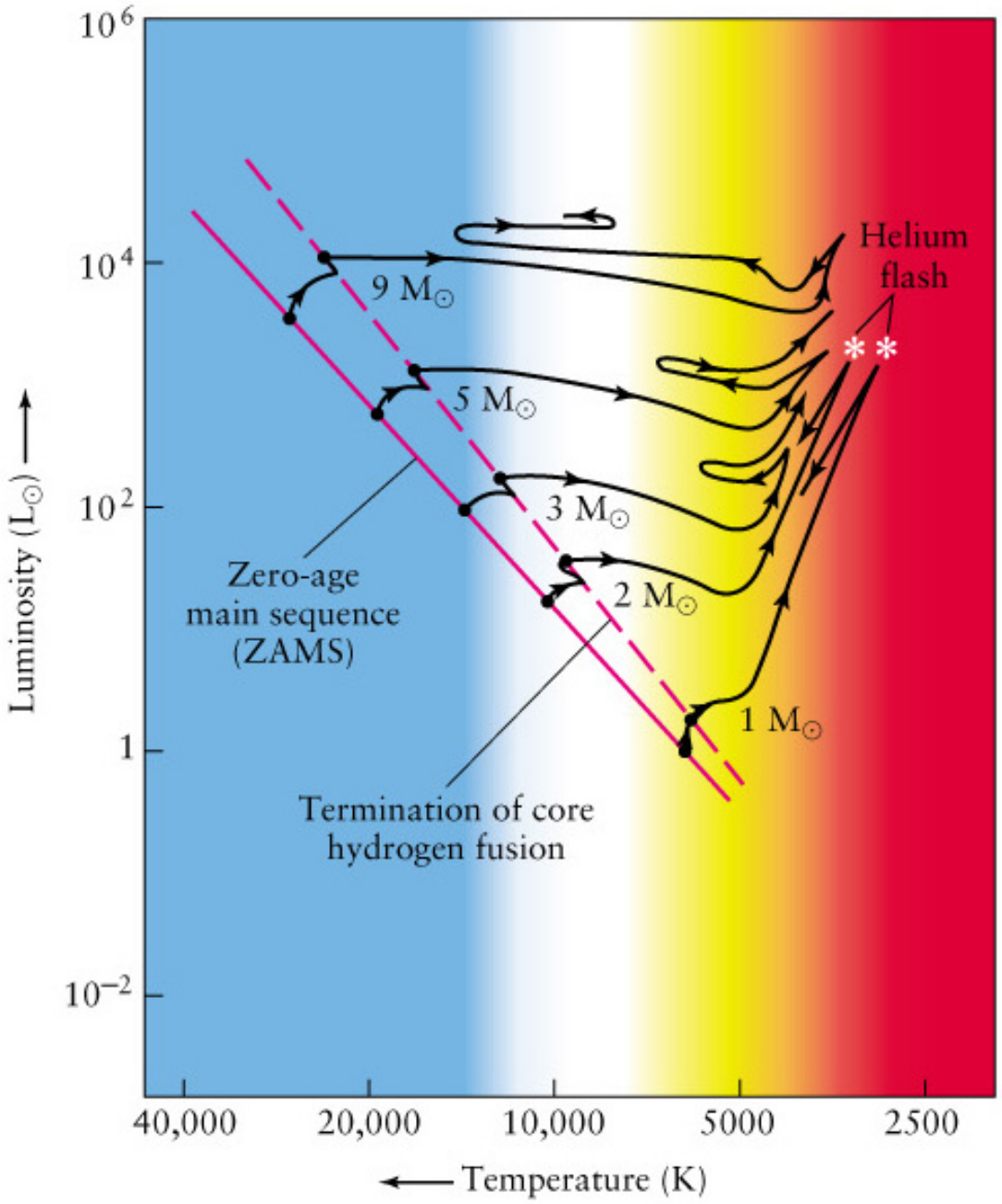
- 3-body reactions are always suppressed
- 2-body Beryllium(8) is unstable. (It decays into 2 He nuclei in 10^{-16} seconds). An "accident" of Nature. Need to have Be+He reaction occur before the Be decays → slows up reaction
- Larger electric repulsion than p-p as larger electric charge (2 for He and 4 for Be). Therefore need about 100,000,000 degrees K for He burning
- → Stars like our Sun remain main sequence longer due to this

Our Sun → Red Giant



a The Sun today and as a red giant

in ~5 billion years, our Sun will expand to about the size of 1 AU = Earth's orbit



Helium Fusion → Red Giant

Stellar Evolution

- Test out model of stellar evolution using Star Clusters
- HR diagram of a cluster gives "snapshot" of stars with the same age but different masses
- Birth → Main Sequence → Red Giant → "live+die" faster if higher mass
- Tell age of cluster by most massive star still on Main Sequence

Star Clusters

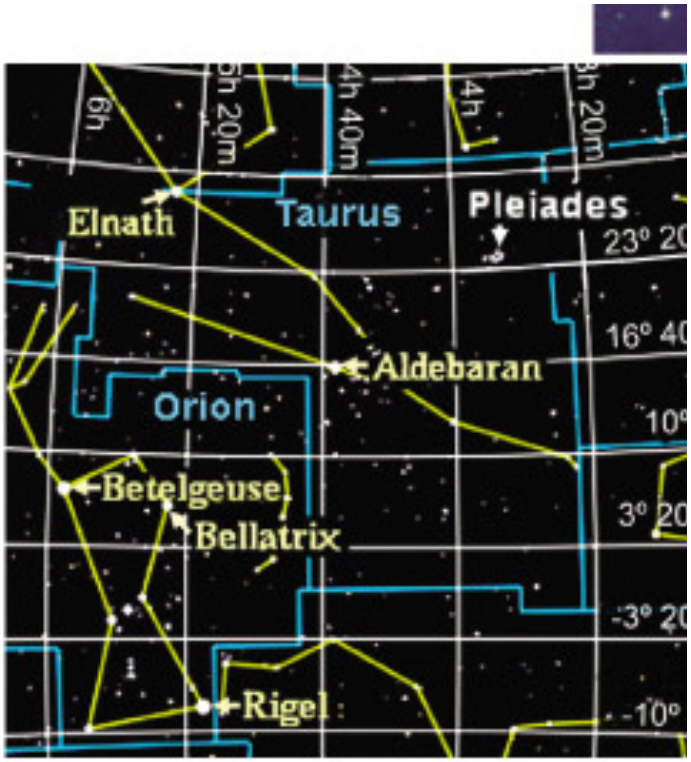
Stars are usually near other stars - CLUSTER

- Formed at the same time
- Similar chemical composition
- About the same distance from us

Can classify by appearance and use to:

- Study stellar lifetimes
- Measure distances (earlier: spectroscopic parallax)

Open Star Clusters - Pleiades



"Seven Sisters" being chased by Orion the hunter (Greek)

Subaru cluster (Japan)

Subaru Telescope, Hawaii

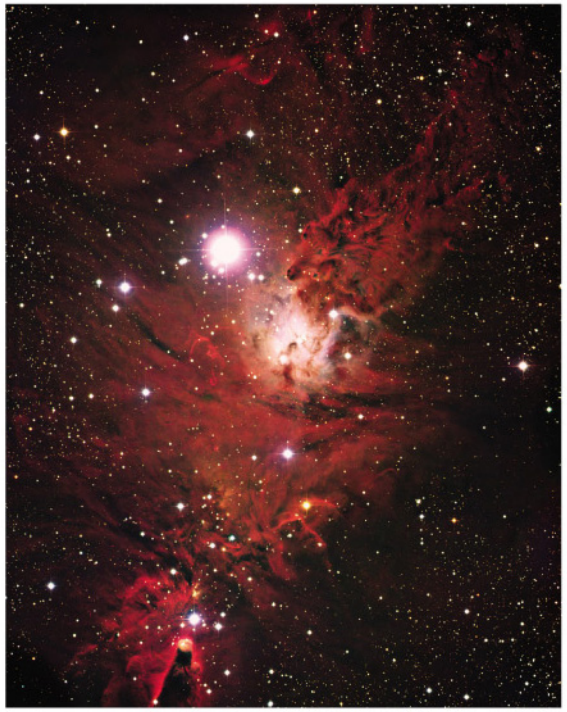
Globular Star Clusters

"fuzzy cotton ball" by eye or with modest telescope

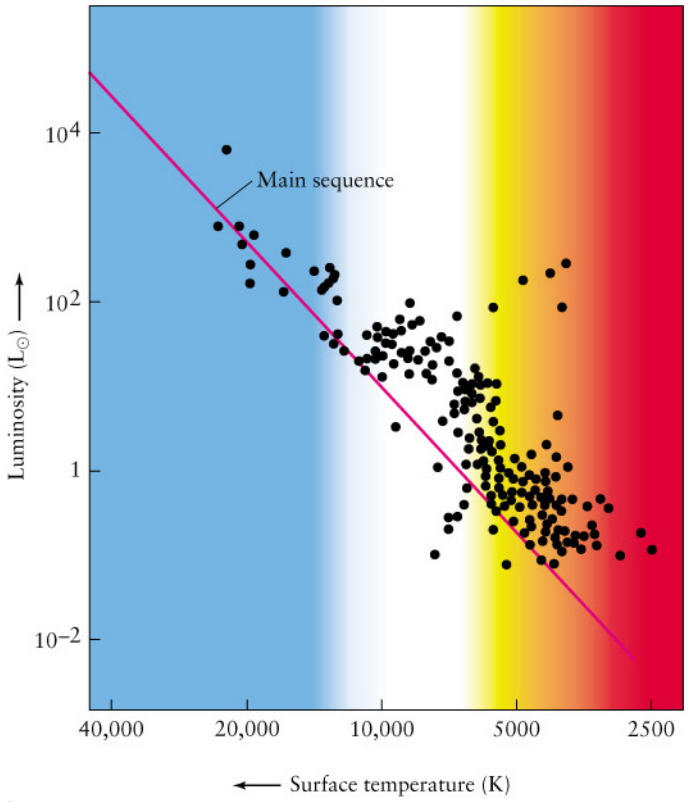
- usually dim red stars
- dense with 100,000 stars in 50-300 LY region with less than LY separating stars
- no heavy elements. Just Hydrogen and Helium
- often outside plane of galaxy

Understood as group of old stars formed in early history of the galaxy 3-12 billion years old

Very Young Star Cluster



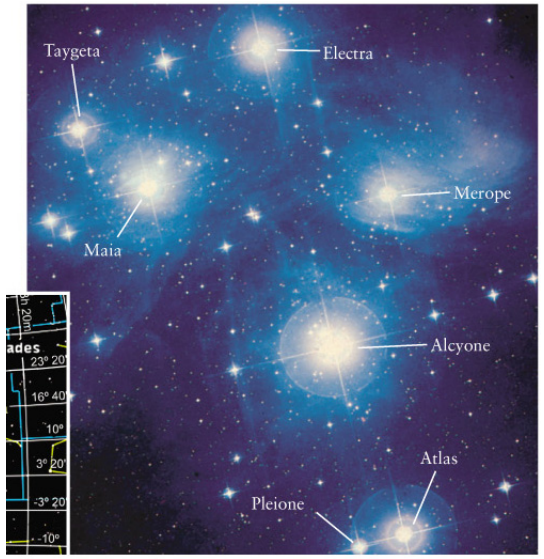
NGC 2264

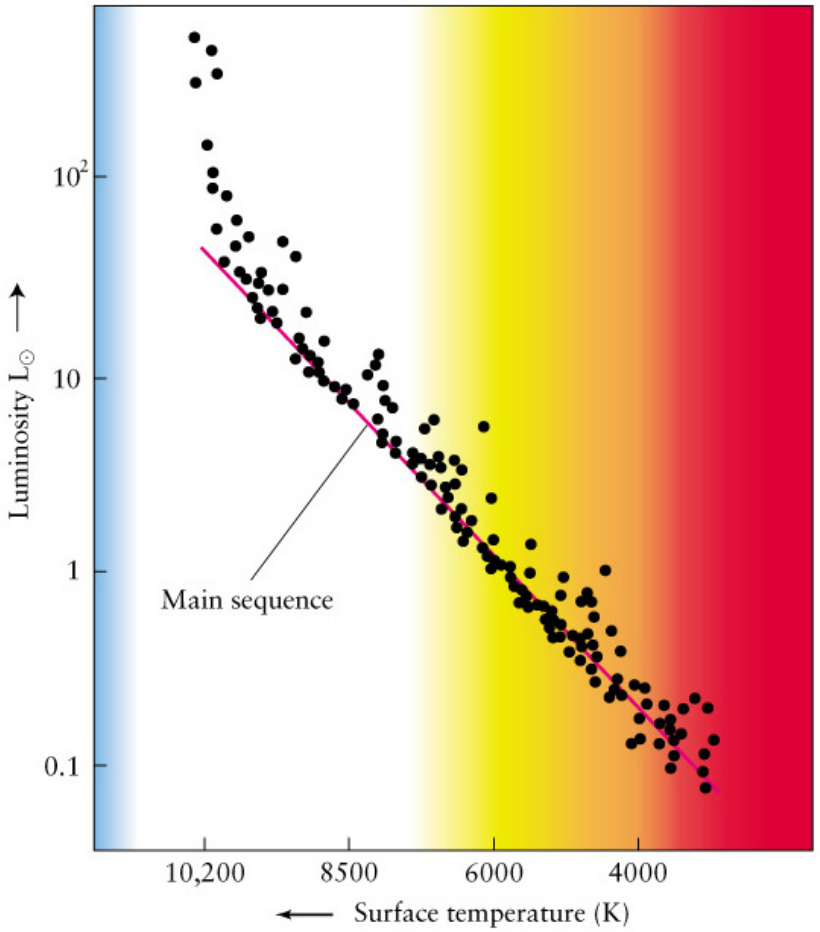


"moving" to main sequence

Note many more low mass stars

100 million year old Star Cluster



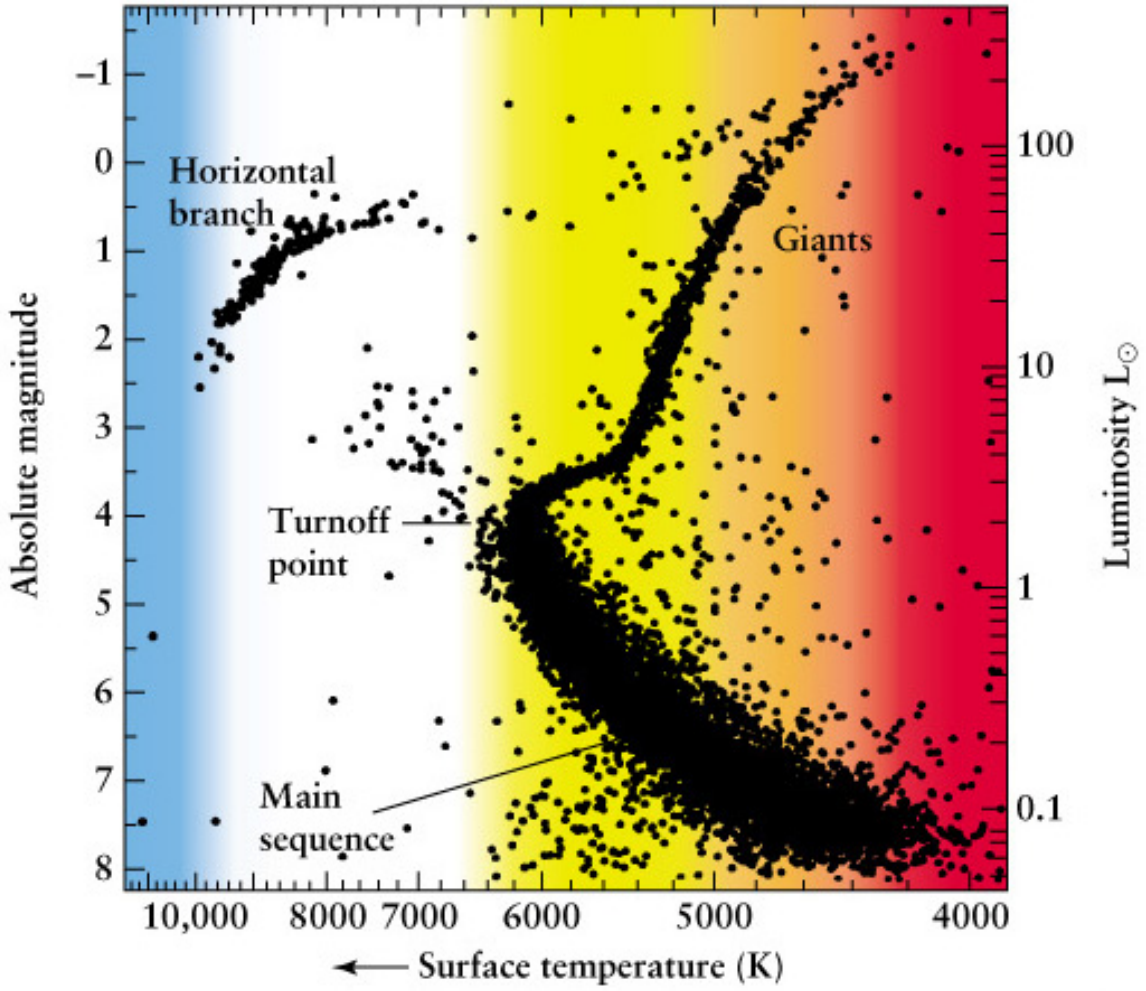


PLEIADES

largest stars

"moving" off main sequence to become giants

5 billion year old Star Cluster



largest stars are gone

stars little more massive the Sun have become giants

Fate of Stars

INITIAL MASS	Final State
relative to Sun's mass	
$M < 0.01$	planet
$.01 < M < .08$	Brown dwarf (not true star)
$0.08 < M < 0.25$	not Red Giant→ White Dwarf
$0.25 < M < 12$	Red Giant→White Dwarf
$12 < M < 40$	Supernova: neutron star
$M > 40$	Supernova: black hole