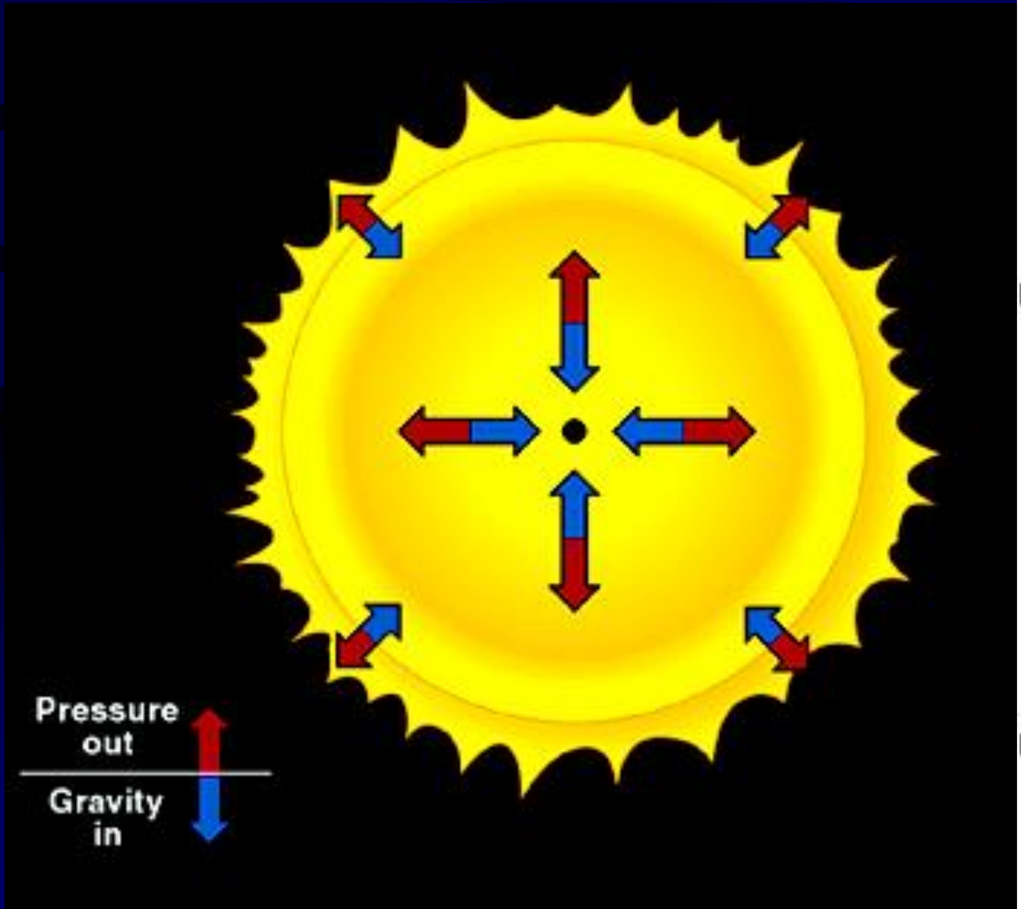
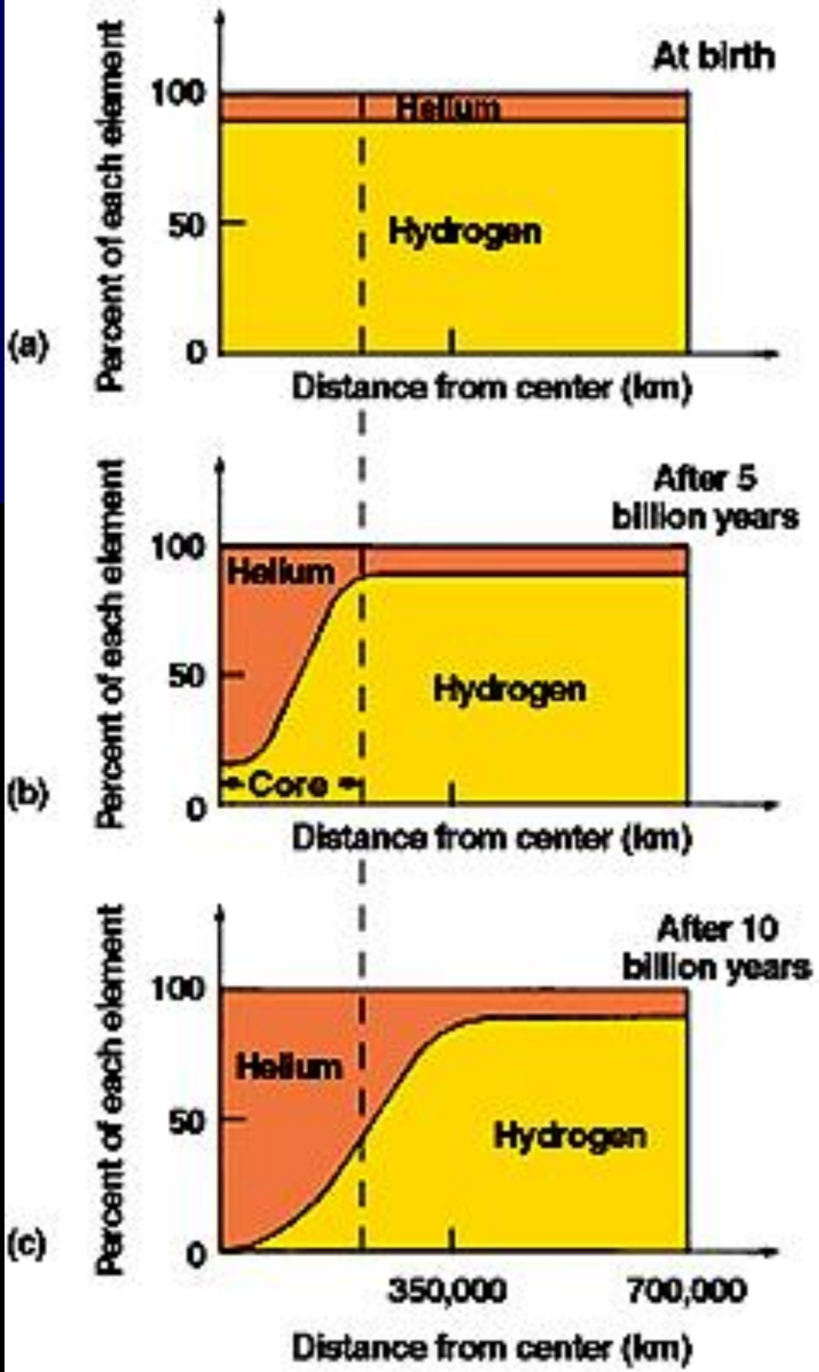
Star Deaths

Why Do Stars Leave the Main Sequence?

- Running out of fuel





Observing Stellar Evolution by studying Globular Cluster HR diagrams

- Plot stars in globular clusters in Hertzsprung-Russell diagram
- Different clusters have different age
- Observe stellar evolution by looking at stars of same age but different mass
- Deduce age of cluster by noticing which stars have left main sequence already

Lessons from Star Clusters
(M3: Sandage/Arp 1953)

- Idea: All stars in a cluster are same age, composition, distance!
- As stars age, they leave the Main Sequence and climb into the giant branch

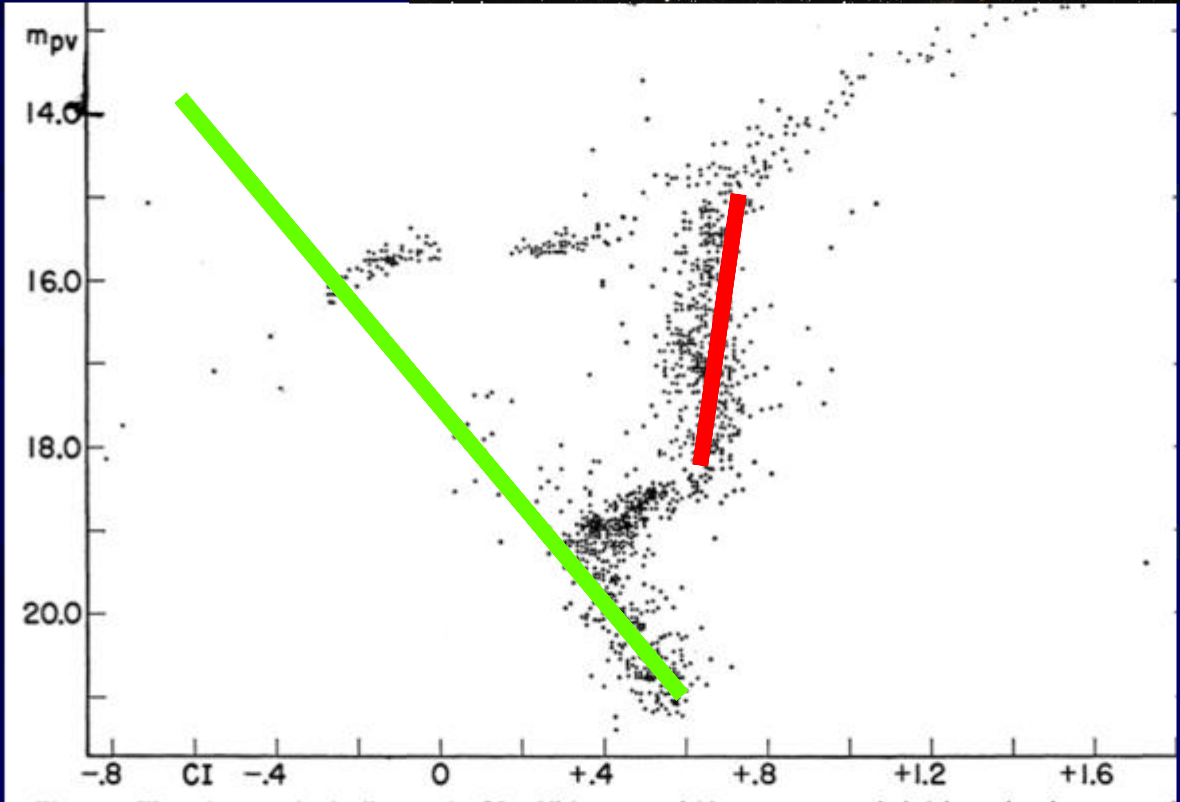
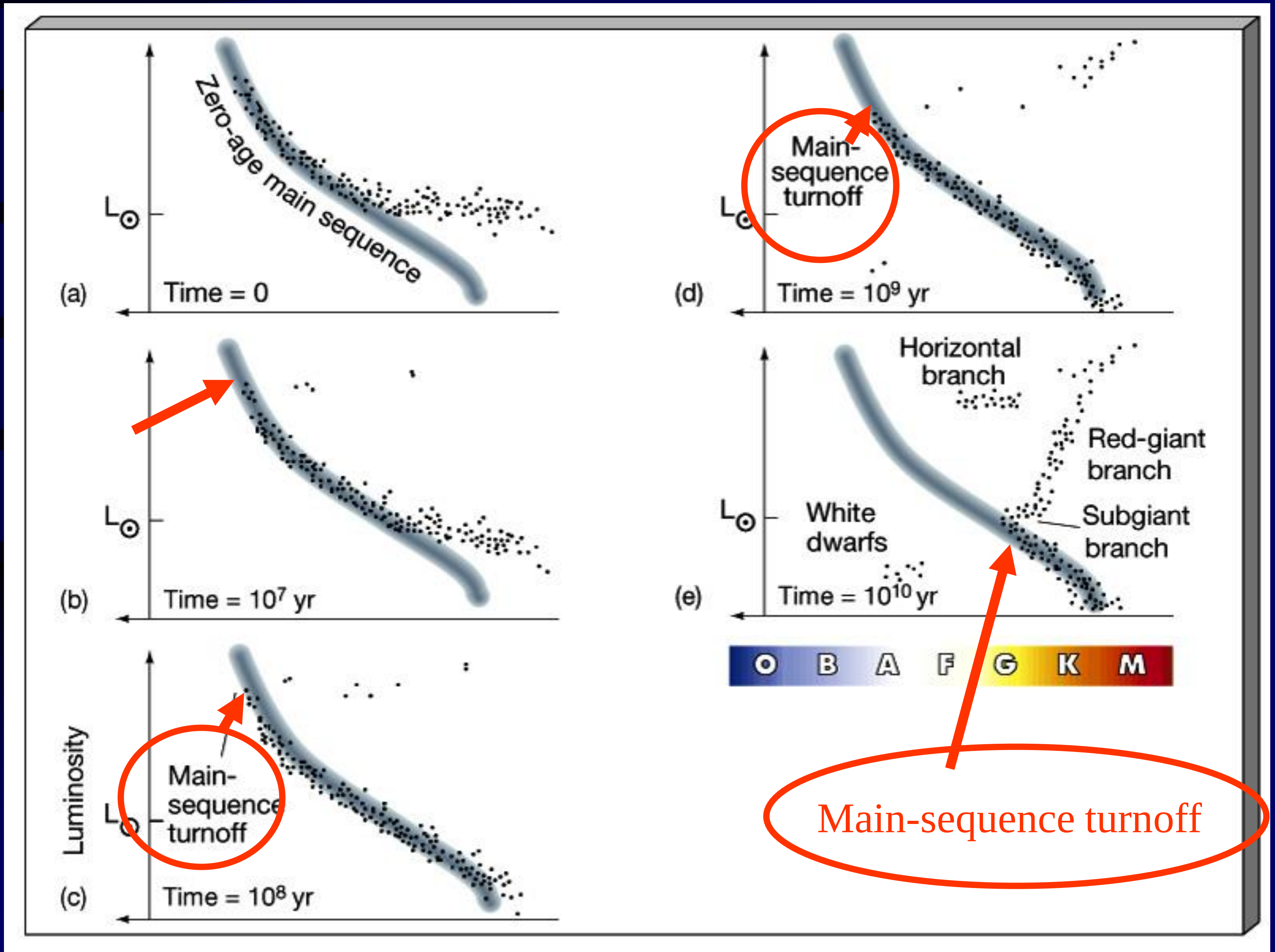


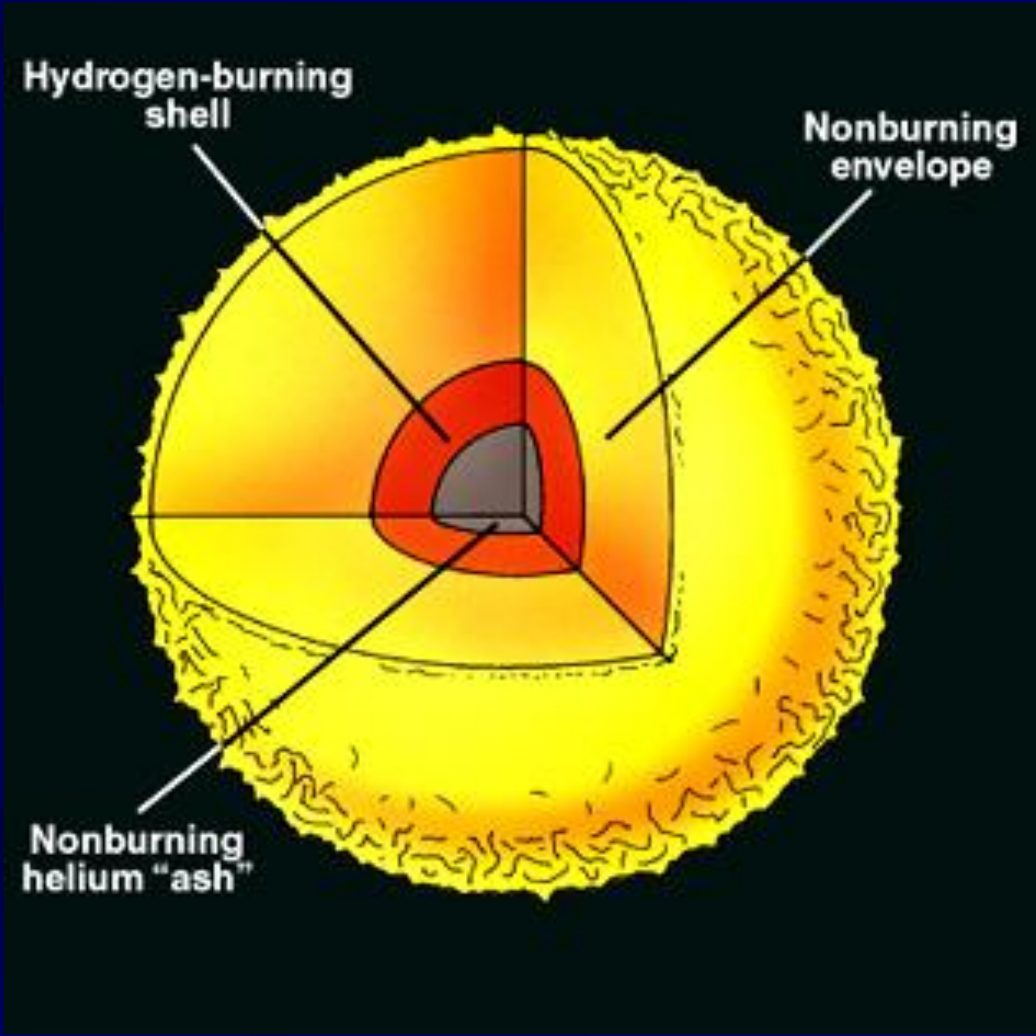
Figure 1. The color-magnitude diagram for M3. All known variable stars were excluded from the photometry. ordinate and abscissa are on the magnitude and color system of the photographic materials. The transformation to *P* and *V* system of Stebbins, Whitford, and Johnson may be made by use of the color equations 1, 2, and 3 given in text. The diagram does not represent a homogeneous sample. The density of points does not, therefore, give a rela luminosity function.

Catching Stellar Evolution "red-handed"



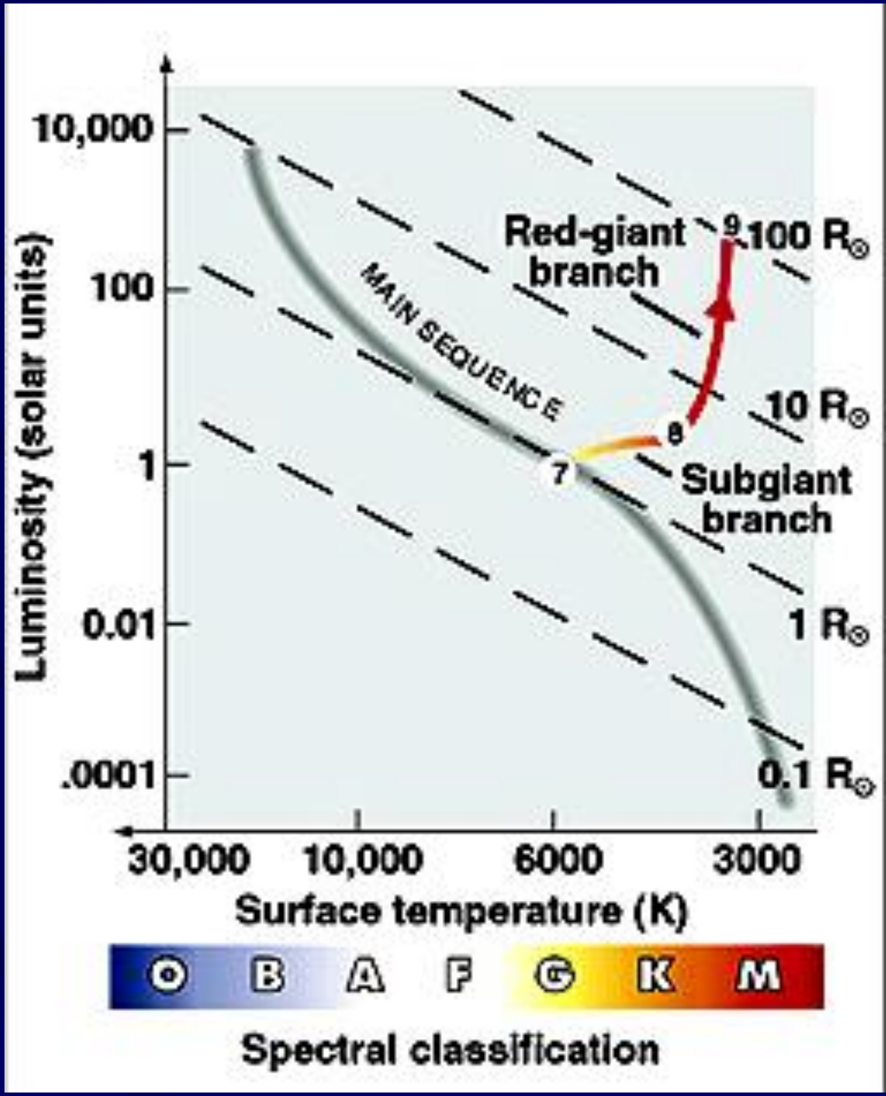
Stage 8: Hydrogen Shell Burning

- Cooler core → imbalance between pressure and gravity → core shrinks
- hydrogen shell generates energy too fast → outer layers heat up → star expands
- Luminosity increases
- Duration ~ 100 million years
- Size ~ several Suns



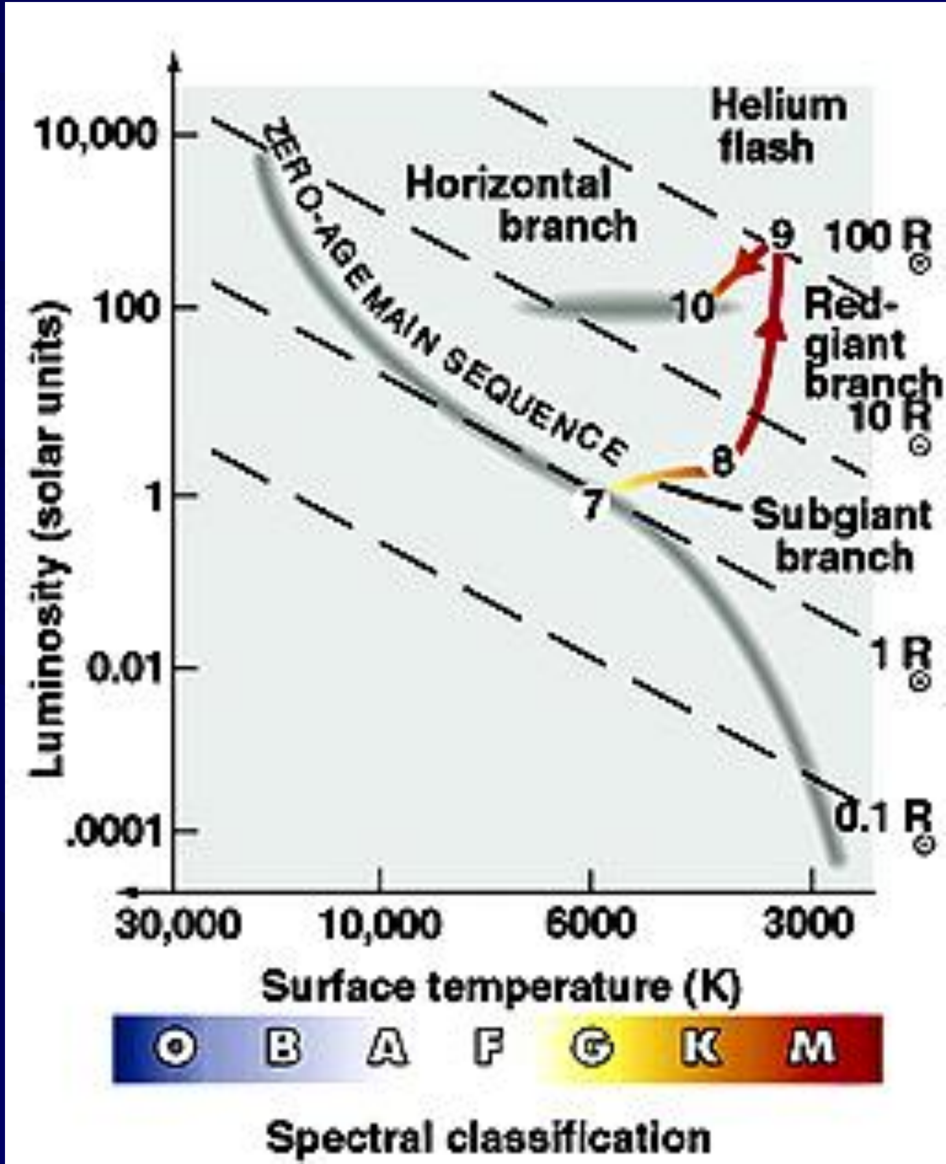
Stage 9: The Red Giant Stage

- Luminosity huge (~ 100 Suns)
- Surface Temperature lower
- Core Temperature higher
- Size ~ 70 Suns (orbit of Mercury)



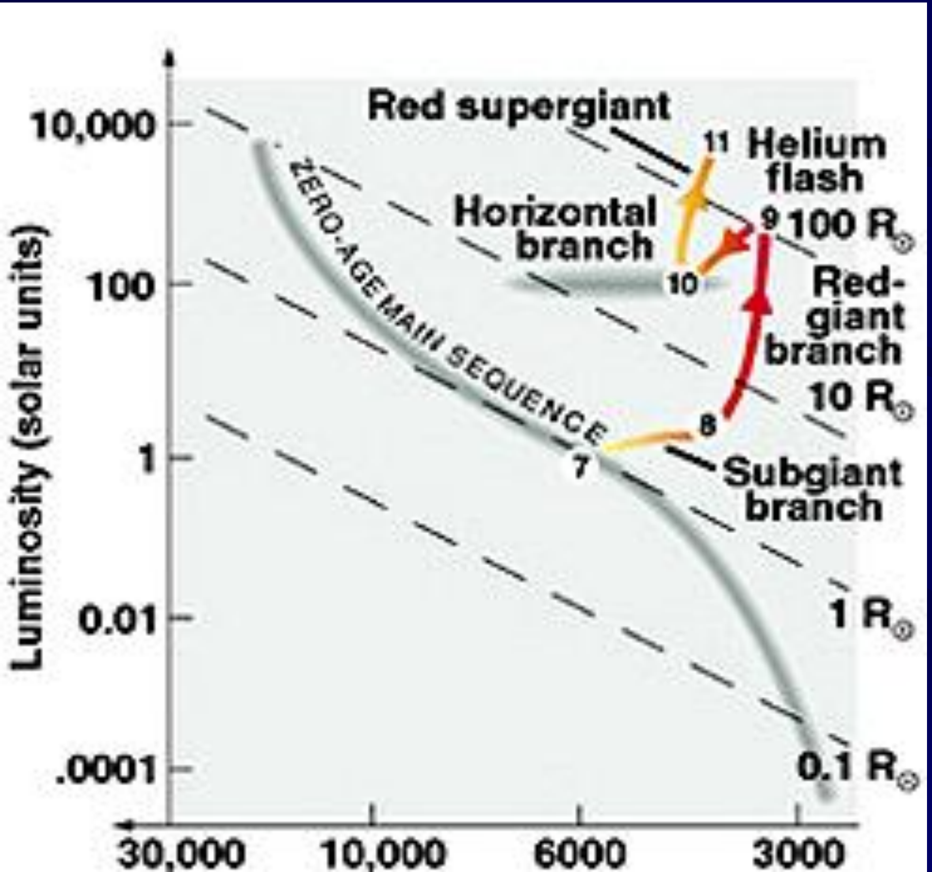
The Helium Flash and Stage 10

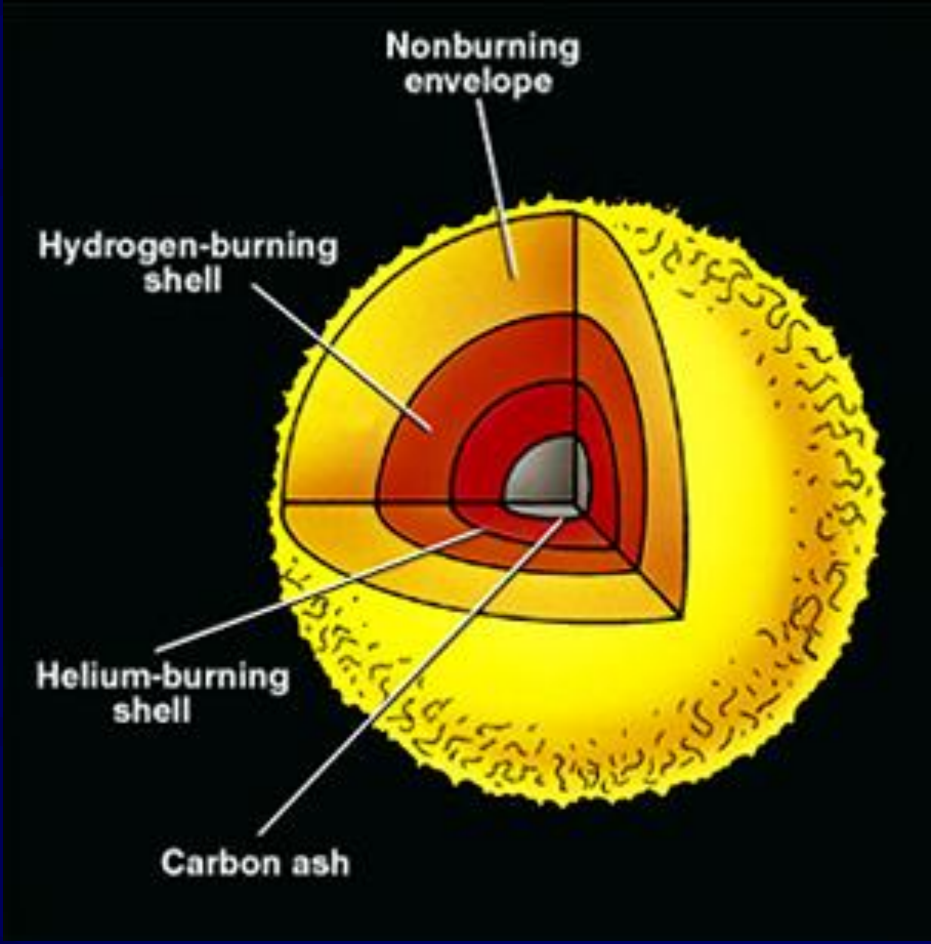
- The core becomes hot and dense enough to overcome the barrier to fusing helium into carbon
- Initial explosion followed by steady (but rapid) fusion of helium into carbon
- Lasts: 50 million years
- Temperature: 200 million K (core) to 5000 K (surface)
- Size ~ 10 × the Sun



Stage 11

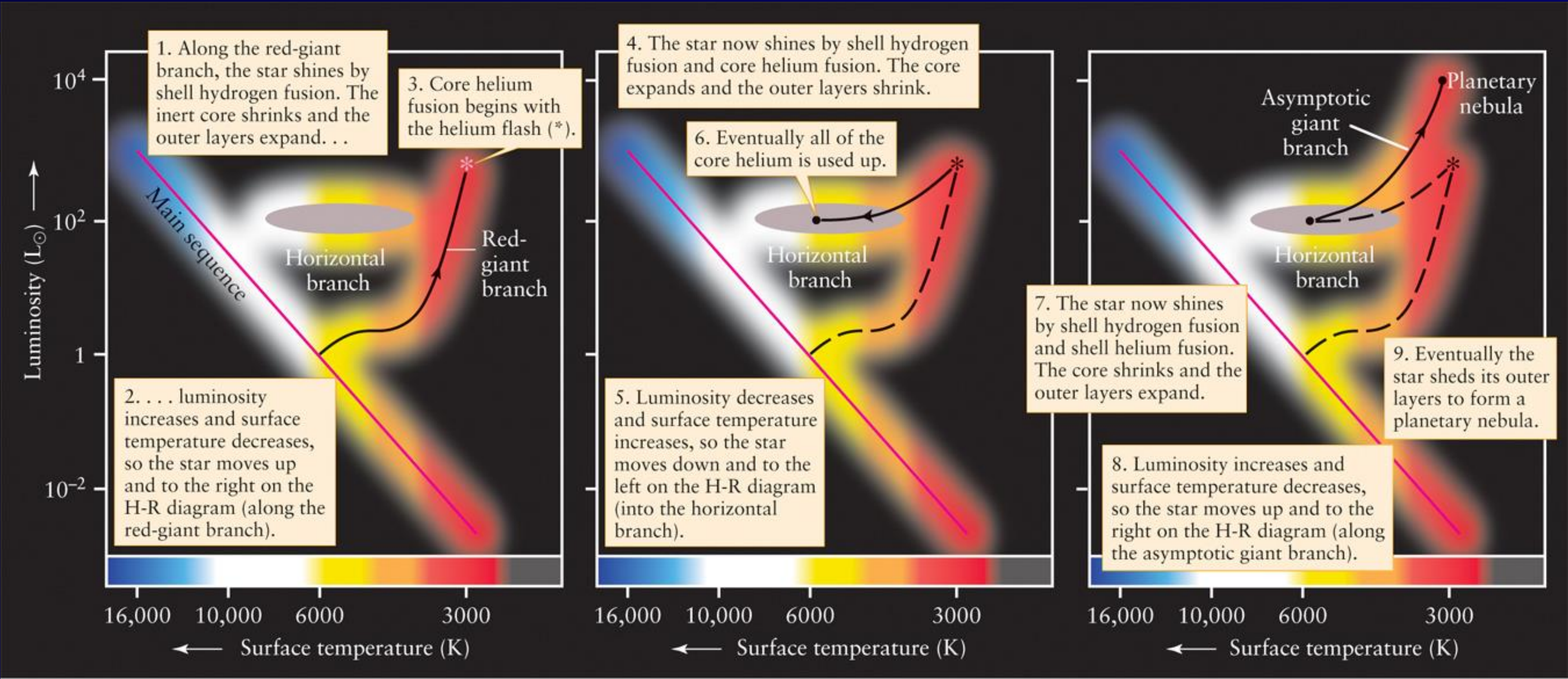
- Helium burning continues
- Carbon “ash” at the core forms, and the star becomes a Red Supergiant





- Duration: 10 thousand years
- Central Temperature: 250 million K
- Size > orbit of Mars

Two Red Giant Stages



(a) Before the helium flash: A red-giant star

(b) After the helium flash: A horizontal-branch star

(c) After core helium fusion ends: An AGB star

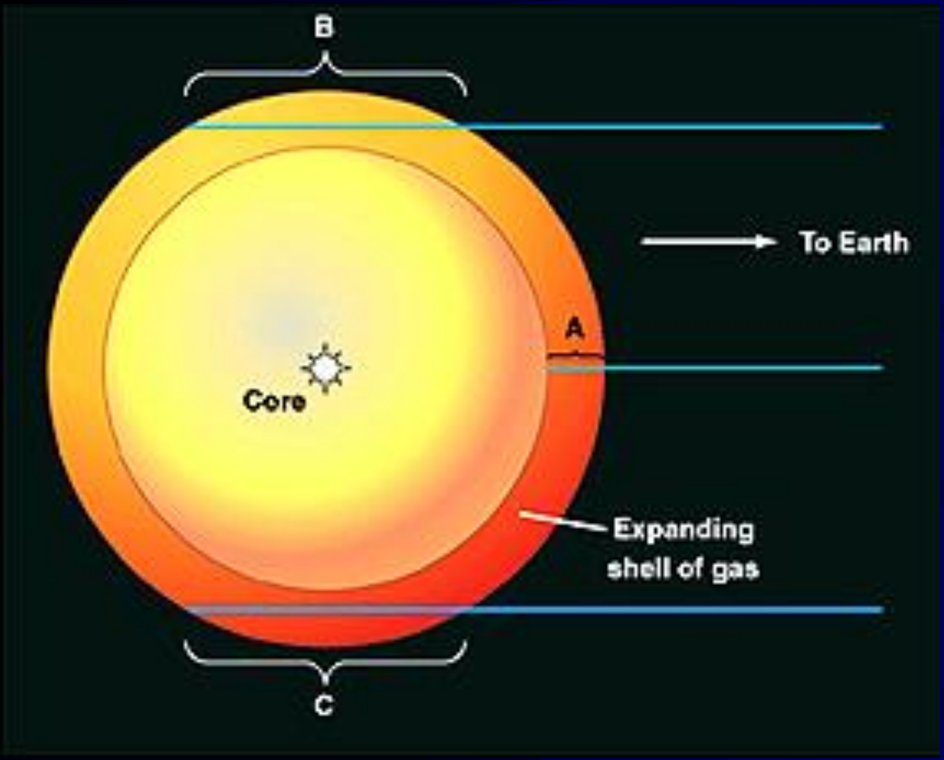
Type of Death depends on Mass

- Light stars like the Sun end up as White Dwarfs
- Massive stars (more than 8 solar masses) end up as Neutron Stars
- Very massive stars (more than 25 solar masses) end up as **Black Holes**

Reason for Death depends on Mass

- Light stars blow out their outer layers to form a Planetary Nebula
- The core of a massive star (more than 8 solar masses) collapses, triggering the explosion of a Supernova
- Also the core of a very massive stars (more than 25 solar masses) collapses, triggering the explosion **Supernova**

Light Stars: Stage 12 - A Planetary Nebula forms



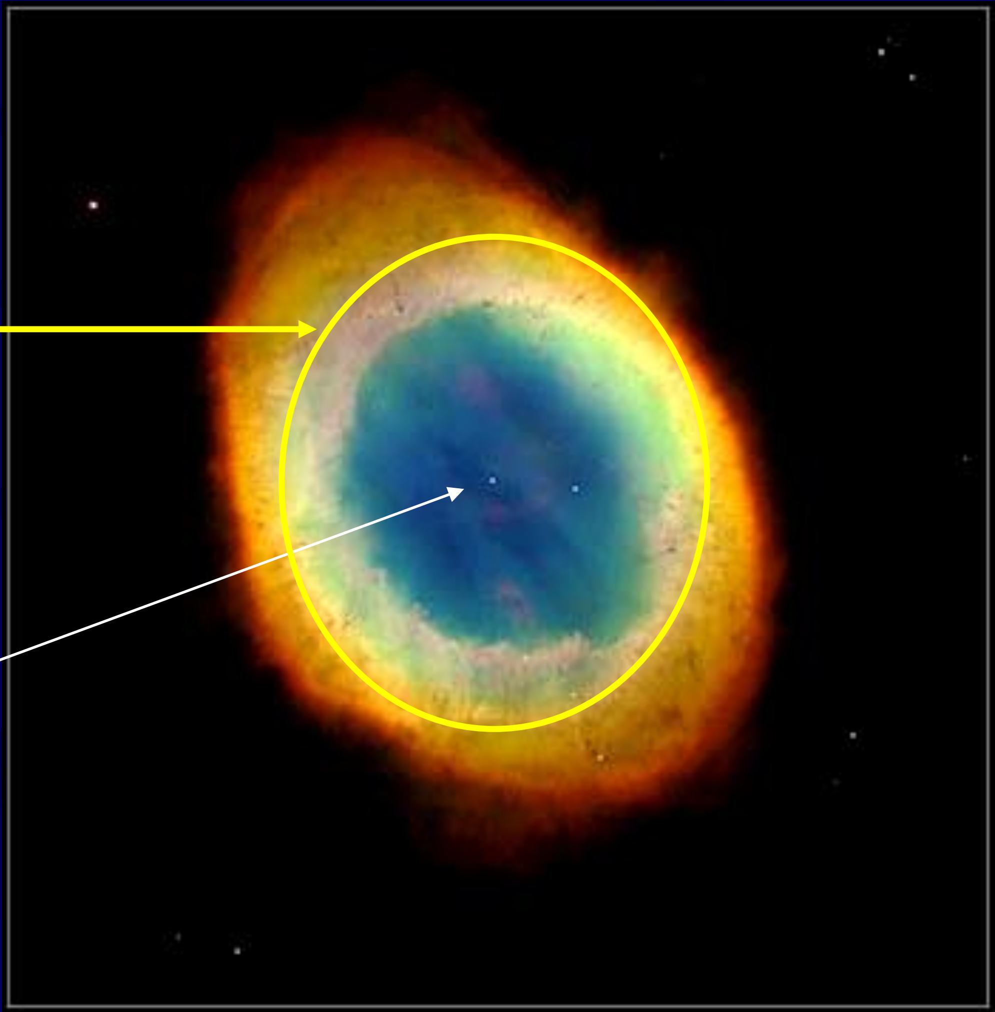
Duration: 100,000 years
Central Temperature: 300 × 10^6 K
Surface Temperature: 100,000 K
Size: 0.1 × Sun

- Inner carbon core becomes "dead" – it is out of fuel
- Some helium and carbon burning continues in outer shells
- The outer envelope of the star becomes cool and opaque
- solar radiation pushes it outward from the star
- A planetary nebula is formed

Deep Sky Objects: Planetary Nebulae

- Classic Example: Ring nebula in Lyra (M57)

- Remains of a dead,
- exploded star
- We see gas expanding in a sphere
- In the middle is the dead star, a **“White Dwarf”**



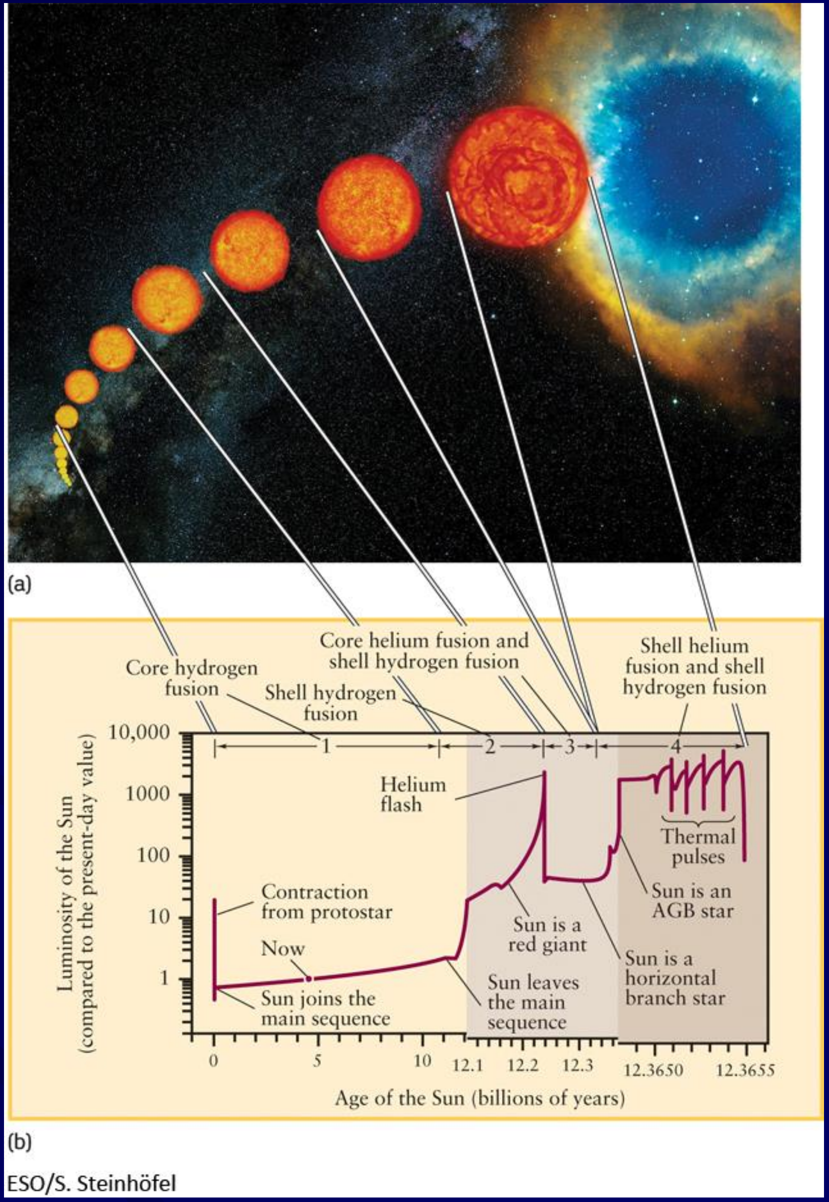
“Eskimo” Nebula

Rooftop: Eskimo Nebula

The Life of the Sun

- Or any other 1 solar mass star

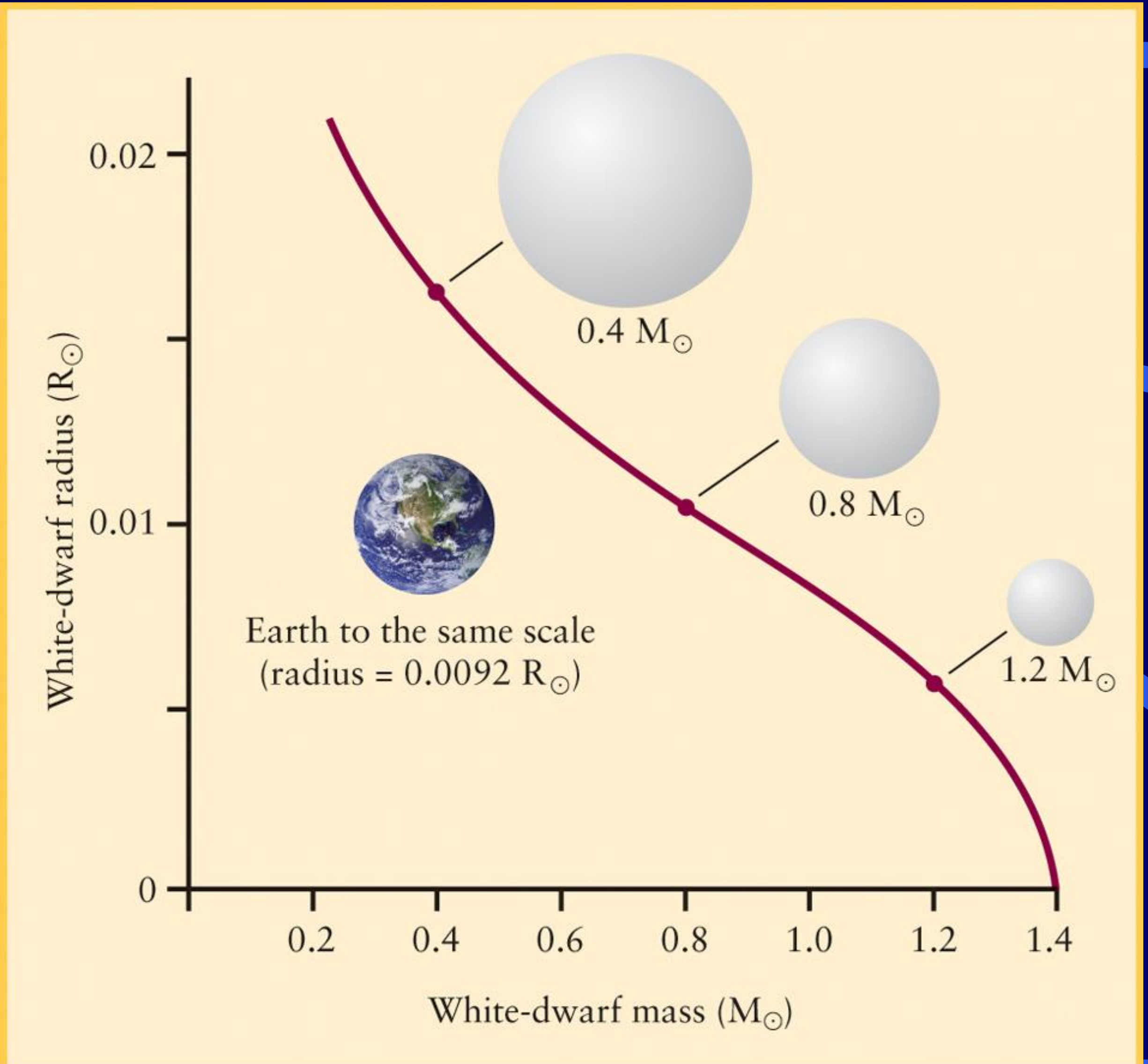
- That's how well we understand stars: 6 sig figs!



White Dwarf Size goes down with mass

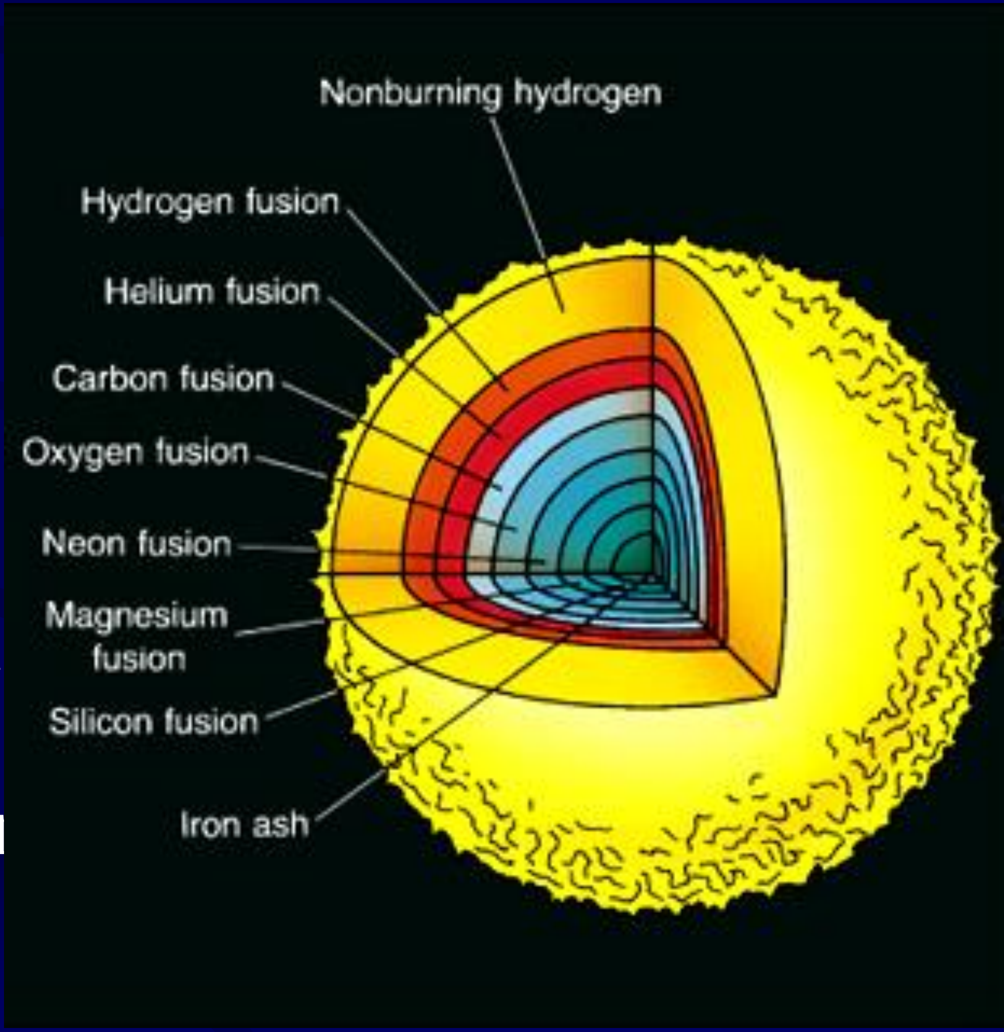
- Note that size is zero for M=1.4 solar masses

➔Chandrasekhar limit



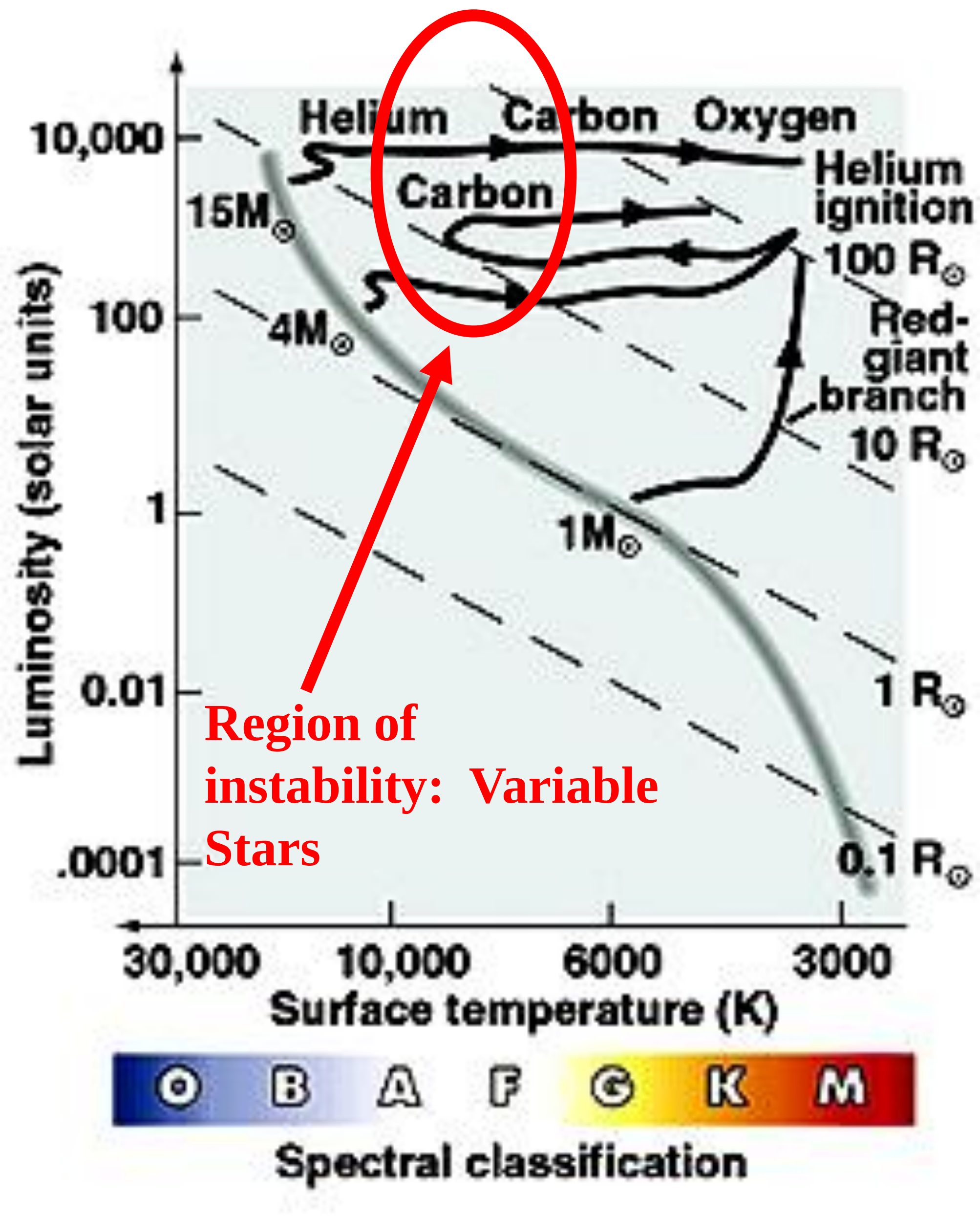
More Massive Stars ($M > 8M_{Sun}$)

- The core contracts until its temperature is high enough to fuse carbon into oxygen
- Elements consumed in core
- new elements form while previous elements continue to burn in outer layers



Evolution of More Massive Stars

- At each stage the temperature increases
  → reaction gets faster
- Last stage: fusion of iron does not release energy, it absorbs energy
  → cools the core
  → "fire extinguisher"
  → core collapses

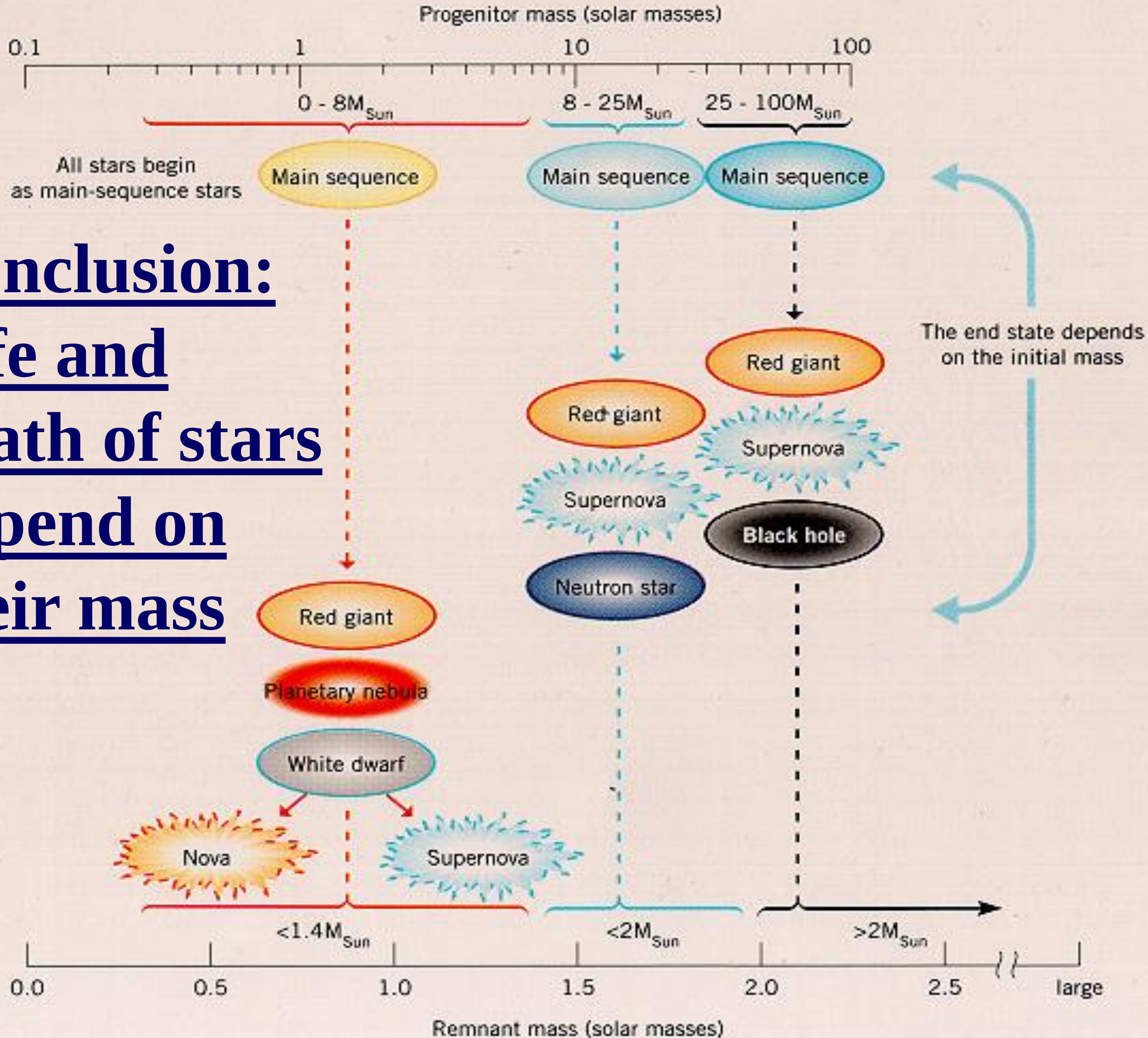


Supernovae – Death of massive Stars

- As the core collapses, it overshoots and “bounces”
- A shock wave travels through the star and blows off the outer layers, including the heavy elements – a supernova
- A million times brighter than a nova!!
- The actual explosion takes less than a second

Supernova Observation

Conclusion: Life and death of stars depend on their mass



Implications for Cosmology

- Elements get "produced": nucleosynthesis
- Original content of the universe has changed over the last 13.8 billion years!
- We are star dust!
  - All "heavy" elements were made in a former generation of (massive) stars
  - "Recycled" in the interstellar medium to form new stars like the sun, with more heavy stuff