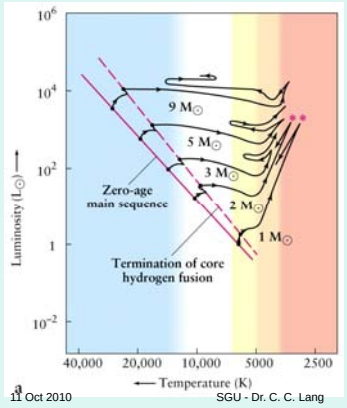
Stars, Galaxies & the Universe Announcements

- **HW#7 – due Friday by 5 pm! (available Tuesday)**
- **"Midterm Grades (points)" posted today in ICON**
- **Exam #2 next week (Wednesday)**
  - Review sheet and study guide posted by Thursday
  - Office hours and Astronomy Tutorial hours
  - Covers material since Exam #1 (plus background material)

Stars, Galaxies & the Universe Lecture Outline

1. **Red Giants: What happens after the Main-Sequence for stars like the Sun**
2. **Planetary nebulae**

   (White dwarves – corpses – will be covered on Wednseday)
3. **Evolution for High Mass Stars**

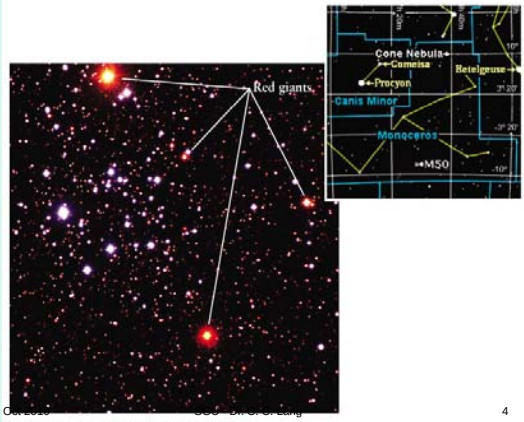


Changes in a star's physical state

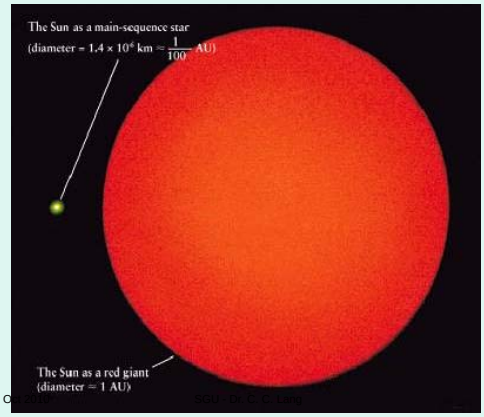
result in changes on the H-R diagram

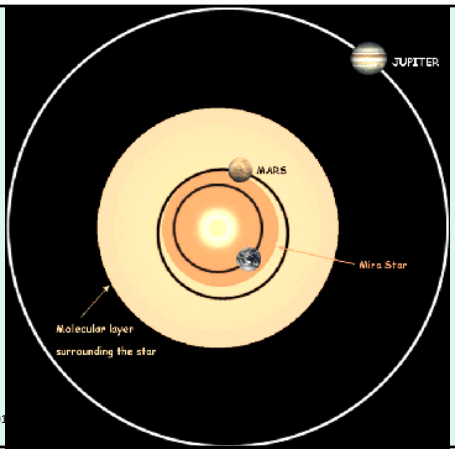
Red Giants are
LARGER
COOLER
than the Sun

UPPER RIGHT

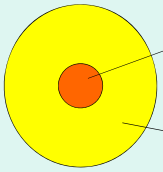


b Red-giant stars in the star cluster M50



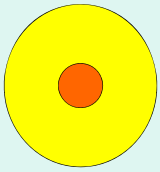


Sun's Structure



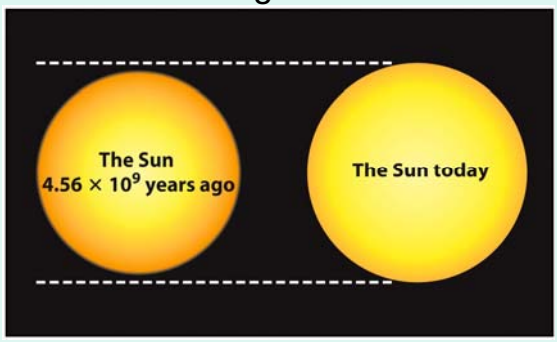
- Core
  - Where nuclear fusion occurs
- Envelope
  - Supplies gravity to keep core hot and dense

Main Sequence Evolution



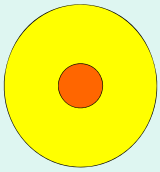
- Core starts with same fraction of hydrogen as whole star
- Fusion changes H $\rightarrow$ He
- Core gradually shrinks and Sun gets hotter and more luminous

Gradual change in size of Sun



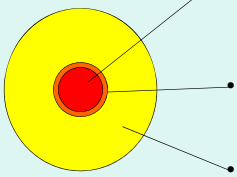
Now 40% brighter, 6% larger, 5% hotter

Main Sequence Evolution



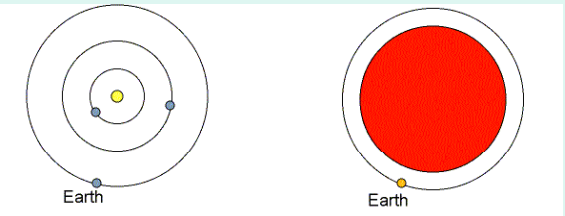
- Fusion changes H → He
- Core depletes of H
- Eventually there is not enough H to maintain energy generation in the core
- Core starts to collapse

Red Giant Phase



- He core
  - No nuclear fusion
  - Gravitational contraction produces energy
- H layer
  - Nuclear fusion
- Envelope
  - Expands because of increased energy production
  - Cools because of increased surface area

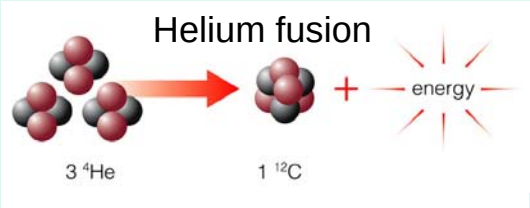
Sun's Red Giant Phase



Now: hot core + warm surface; small size.

Future: very hot core + cool surface. Large size but less mass; very bright.

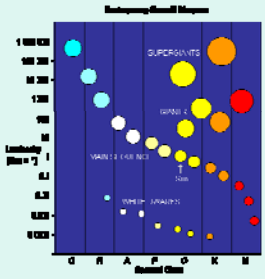
Helium fusion



Helium fusion does not begin right away because it requires higher temperatures (i.e. collision speeds) than hydrogen fusion—larger charge leads to greater repulsion

Fusion of two helium nuclei doesn't work, so helium fusion must combine three He nuclei to make carbon

What happens next depends on initial mass



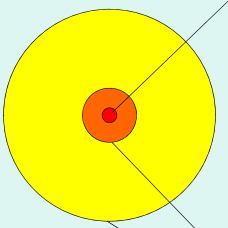
1. Stars ~ 1 solar mass

"Helium Flash" – explosive consumption of He fuel
T ~ 300 million K
L ~10^{14} solar luminosity

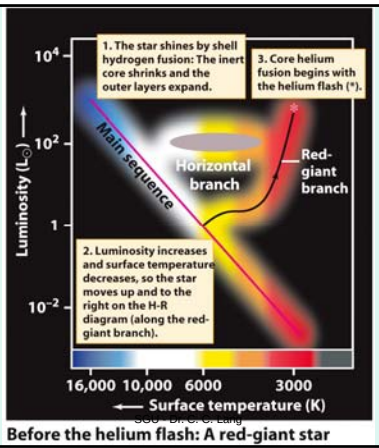
2. Stars > 2 solar masses

Continue to fuse He and carbon to make core rich in oxygen and carbon

Helium Flash

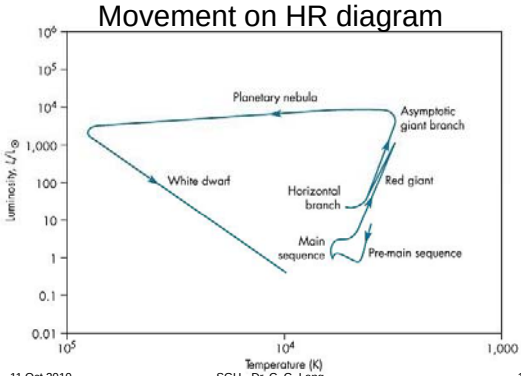


- He core
  - Eventually the core gets hot enough to fuse Helium into Carbon.
  - This causes the temperature to increase rapidly to 300 million K and there's a sudden flash when a large part of the Helium gets burned all at once.
  - We don't see this flash because it's buried inside the Sun.
- H layer
- Envelope

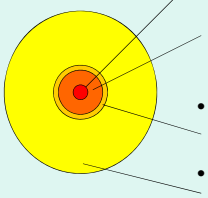


Before the helium flash: A red-giant star

Movement on HR diagram

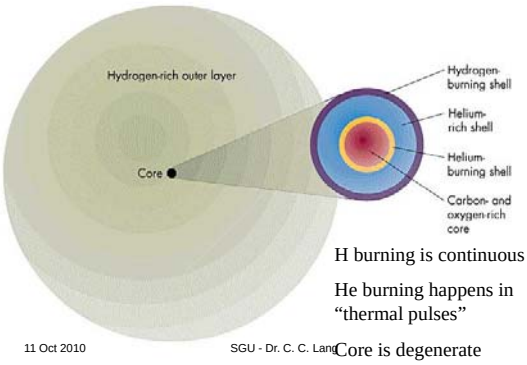


Red Giant after Helium Ignition



- He burning core
  - Fusion burns He into C, O
  - Depending on how much matter is there and what the physical conditions are like
- He rich core
  - No fusion
- H burning shell
  - Fusion burns H into He
- Envelope
  - Expands because of increased energy production

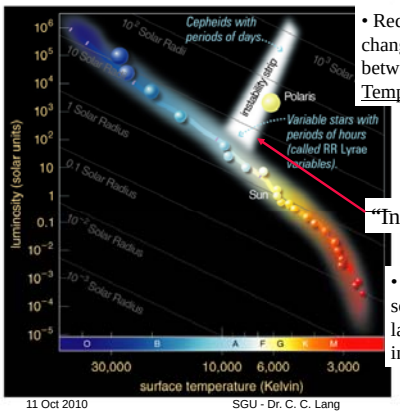
Helium burning in the core stops



H burning is continuous

He burning happens in "thermal pulses"

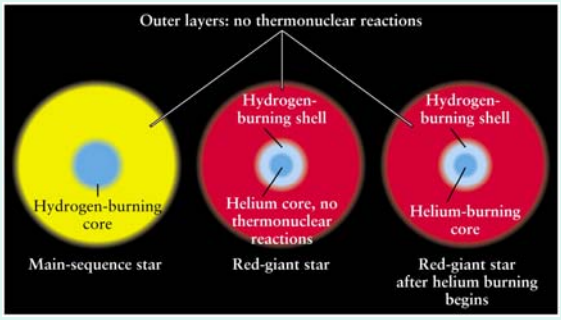
Core is degenerate



• Red Giants are constantly changing their relationship between Luminosity and Temperature

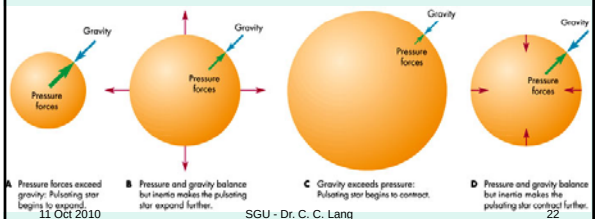
"Instability Strip"

• with every expansion, some of the star's outer layers are lost into the interstellar medium

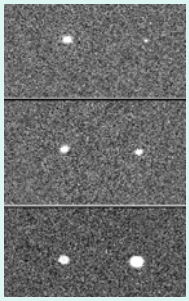


Red Giants: instabilities & brightness variations

- very delicate balance between pressure, gravity
- easily offset – causing star to expand, contract
- these changes can be observed as a variation in star's brightness as it "pulses"



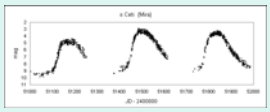
Instability of Red Giants – Variable Stars



Optical images of Mira spaced over a few days

Prototype: Mira (omicron Ceti)

- brightness changes by a factor of two because of pulsations in the star
- can see the "signature" of changes over a few days



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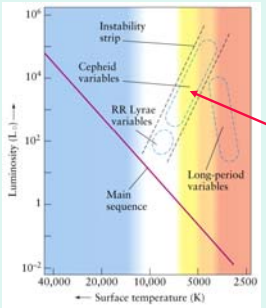


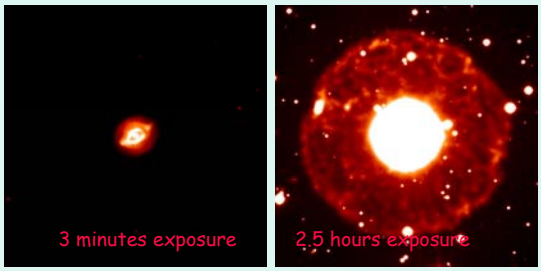
- Red Giants are constantly changing their relationship between Luminosity and Temperature

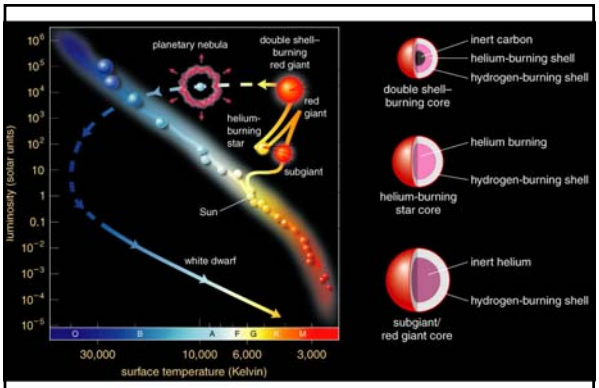
"Instability Strip"

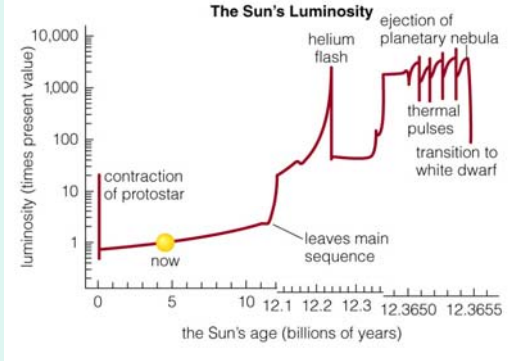
- with every expansion, some of the star's outer layers are lost into the interstellar medium

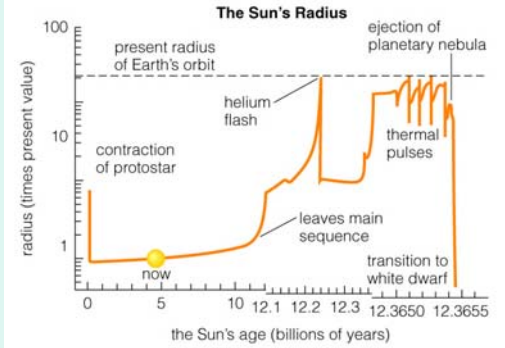
Red Giant expanding into the interstellar medium

NGC 6826



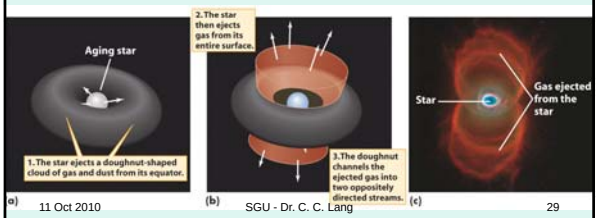


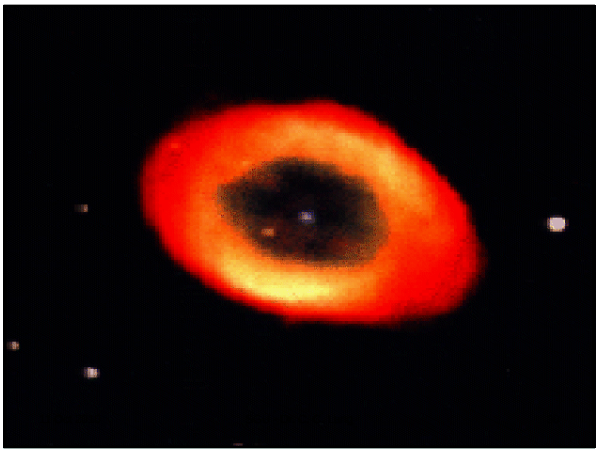


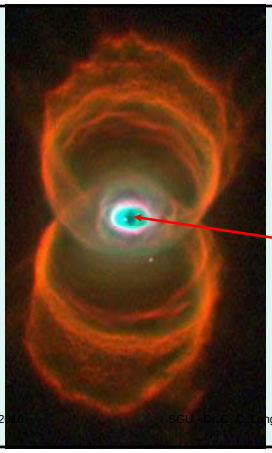


Lost mass from the star is heated by the carbon or carbon-oxygen core (which is still hot)

→ Photons from hot core can ionize the expelled gas and cause it to glow
→ Different colors represent different transitions of different Elements which compose the star's material (nitrogen, oxygen, carbon)
→ The shells of gas from the star are known as *PLANETARY NEBULAE*

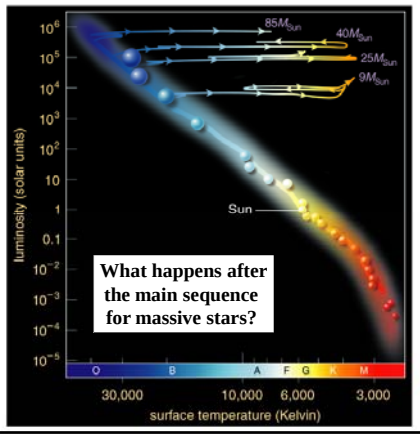




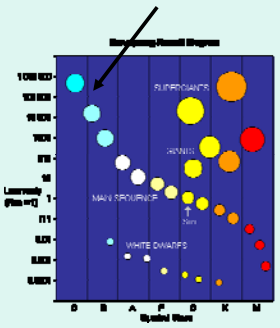


Hourglass nebula

White dwarf: the stellar corpse!



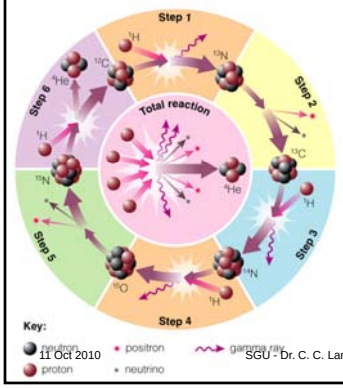
Lives of Massive Stars: Main Sequence



- Fusing H → He in core
- Star "leaves" the MS when H → He stops
- Very short MS lifetimes compared to the Sun:

25 M_o ~ 3 million years
15 M_o ~ 15 million years
3 M_o ~ 500 million years
1 M_o ~ 10 billion years

Fusion proceeds using a different reaction



The C-N-O Cycle

→ C, N, O although in small amounts, can act like catalysts

Step 1:
^{12}Carbon + **proton** = ^{13} Nitrogen + *gamma ray* (γ)

Step 2:
^{13}Nitrogen → ^{13}Carbon + ν + γ

Step 3:
^{13}Carbon + **proton** = ^{14} N + γ

Step 4:
^{14} N + **proton** = ^{15}Oxygen + γ

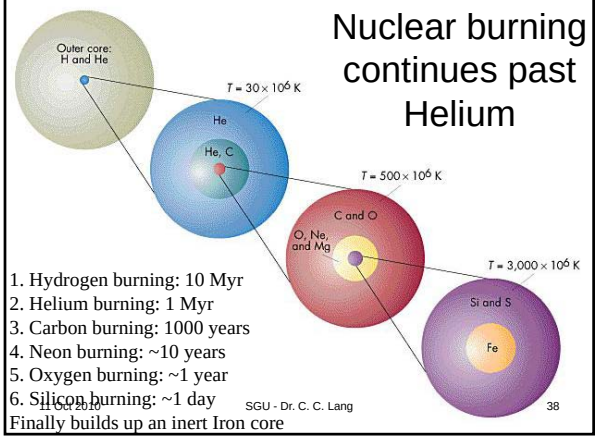
Step 5: ^{15}Oxygen → ν + positron + ^{15} Nitrogen

Step 6:
^{15}Nitrogen + **proton** = ^{4} He + ^{12}C

C-N-O cycle proceeds rapidly

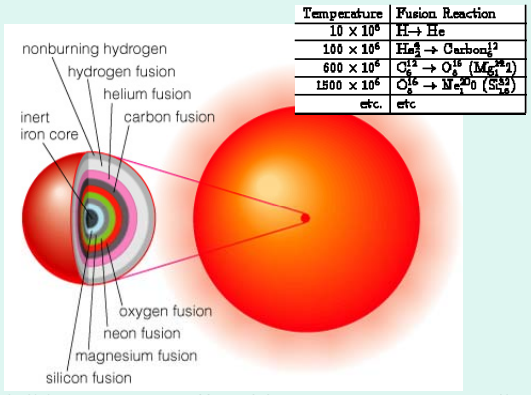
- C-N-O cycle proceeds at much higher temperatures than are possible in low-mass stars
- Luminosities: 1 million times higher!
- M-S Lifetimes: millions of times shorter
  - → *solar mass star: 10 billion years*
  - →*25 solar mass star: 10 million years*

Nuclear burning continues past Helium



1. Hydrogen burning: 10 Myr
2. Helium burning: 1 Myr
3. Carbon burning: 1000 years
4. Neon burning: ~10 years
5. Oxygen burning: ~1 year
6. Silicon burning: ~1 day

Finally builds up an inert Iron core



Temperature	Fusion Reaction
10×10^6	$H \rightarrow He$
100×10^6	$He_2^4 \rightarrow Carbon_6^{12}$
600×10^6	$C_6^{12} \rightarrow O_8^{16}\ (Mg_{12}^{24})$
1500×10^6	$O_8^{16} \rightarrow Ne_{10}^{20}\ (Si_{14}^{32})$
etc.	etc

Temperature in core of massive star is very hot

-in order to break bonds of more complicated elements
(opposing charges from a lot of electrons/protons)

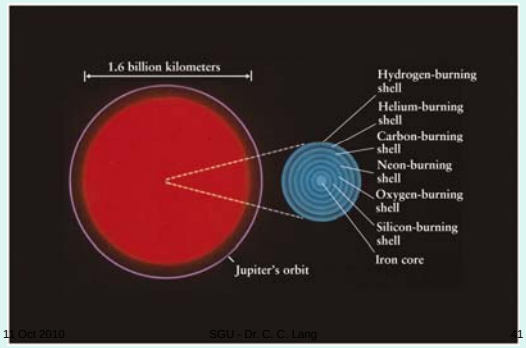
Table 22-1 Evolutionary Stages of a 25-$M_\odot$ Star

Stage	Core temperature (K)	Core density (kg/m³)	Duration of stage
Hydrogen burning	4×10^7	5×10^3	7×10^6 years
Helium burning	2×10^8	7×10^5	7×10^5 years
Carbon burning	6×10^8	2×10^8	600 years
Neon burning	1.2×10^9	4×10^9	1 year
Oxygen burning	1.5×10^9	10^{10}	6 months
Silicon burning	2.7×10^9	3×10^{10}	1 day
Core collapse	5.4×10^9	3×10^{12}	¼ second
Core bounce	2.3×10^{10}	4×10^{15}	milliseconds
Explosive (supernova)	about 10^9	varies	10 seconds

Very extreme physical conditions!

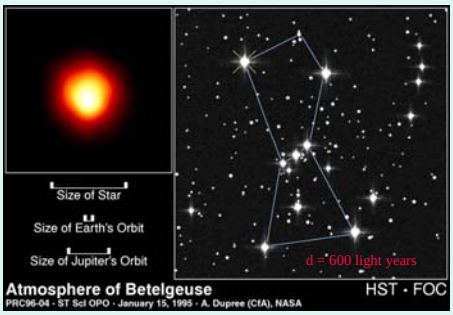
Red Supergiant

- Every layer undergoing nuclear fusion
- Star expands to Jupiter's orbit – 5 AU!

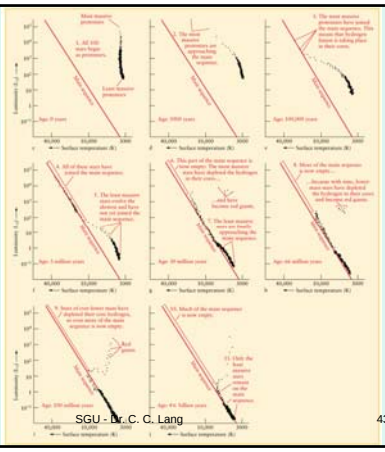


Supergiants

Familiar red star in Orion constellation
Betelgeuse is a red supergiant!



Evolution of a group of stars on the H-R diagram



Stellar Clusters : Many stars do not live alone

Globular Clusters:

- stars gravitationally bound to the cluster
- as many as 1 million stars – usually 50,000 – 500,000
- may be 15 billion years old (less massive than the Sun)
- much lower in "heavy elements" formed early in the universe
- Our Galaxy has ~200 globular clusters

M15 globular cluster in Pegasus ~40,000 ly more than a million stars

Stellar Clusters : Many stars do not live alone

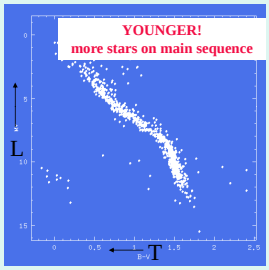
"Open" Clusters:

"Pleiades or 7 sisters"

- related stars very loosely bound together
- usually drift apart over time
- only a few million years old (stars much more massive than Sun: 10-50 solar masses)
- after 100 million years, the cluster has disbanded – many stars will have gone "supernova"

Stellar Clusters : Open vs. Globular -- AGES

you can learn about the "age" of a cluster by looking at the H-R diagrams



OLDER – more "evolved" stars