Midterm #1 Results

Average score = 86.7 /100

High score = 97 /100

Problem #1: Parallax scores were a little higher than the Tide scores.

Problem #4 had the lowest scores.

Today's Topics

Friday, March 6, 2026 (Week 6, lecture 18) – Chapters 18, 19, 22.

A. Review: Luminosity vs mass.

B. H-R diagram.

C. Stellar evolution: *Main sequence to red giants.*

D. Evolution of Sun-like stars.

E. Becoming a Red Giant.

Problem Set #6 is available on ExpertTA and is due on Wednesday, March 18 by 9:00 am

Interlude 1 Essay is due on Monday, March 23 by 9:00 am on Gradescope

Luminosity = Output Power

Stellar luminosity is given by

$$Luminosity = Output\ Power = Intensity\ \times Surface\ Area$$

- Light intensity for a blackbody is given by the **Stefan-Boltzmann law**:

$$Intensity = \sigma T^4$$

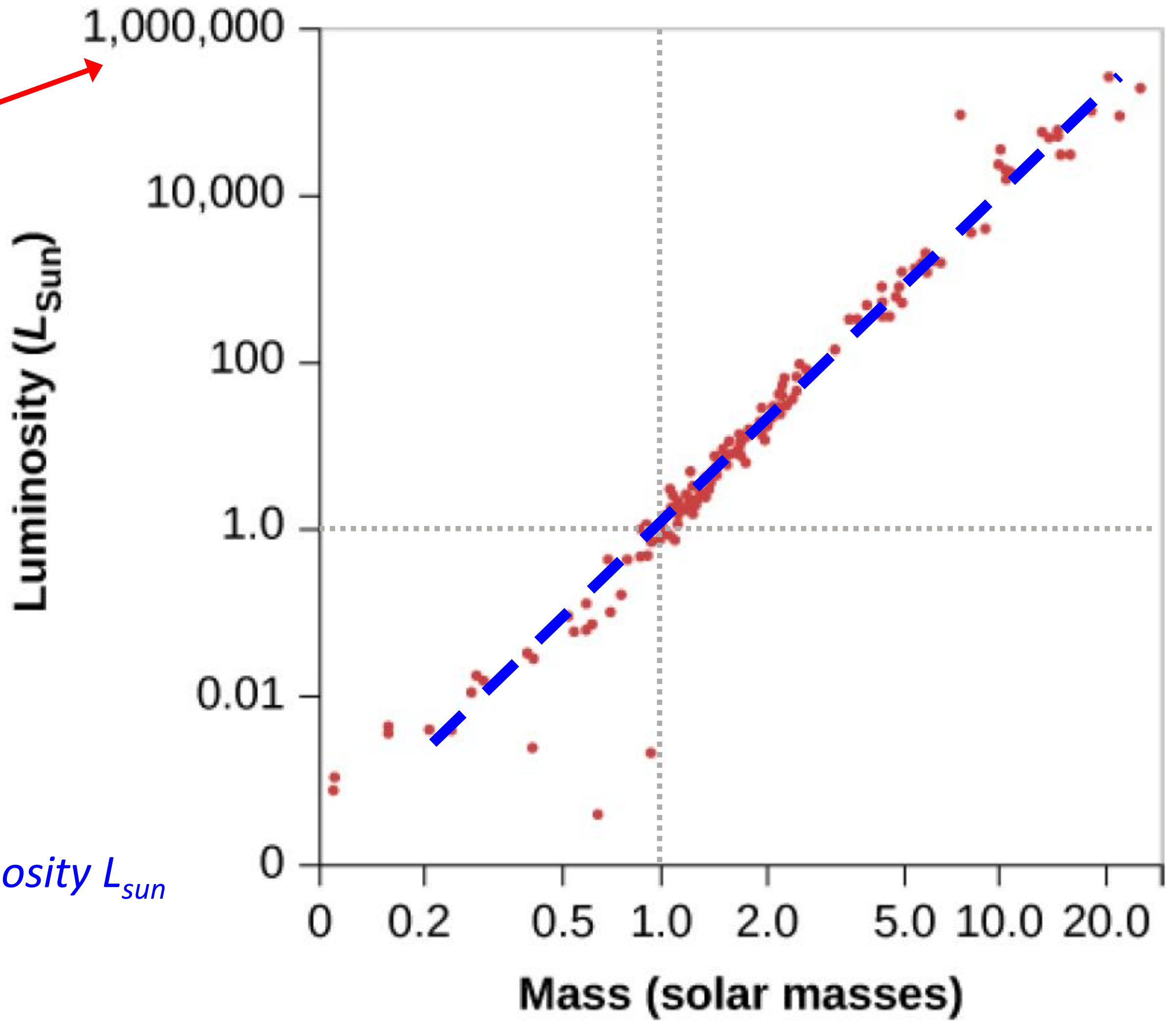
→ A hot star is more luminous

- The surface area of a star is related to its radius, i.e. size:

$$Surface\ Area = 4\pi R^2$$

→ A large star is more luminous

Mass-Luminosity Relation



logarithmic scale

Main sequence stars (not white dwarfs or red giants)

logarithmic scale

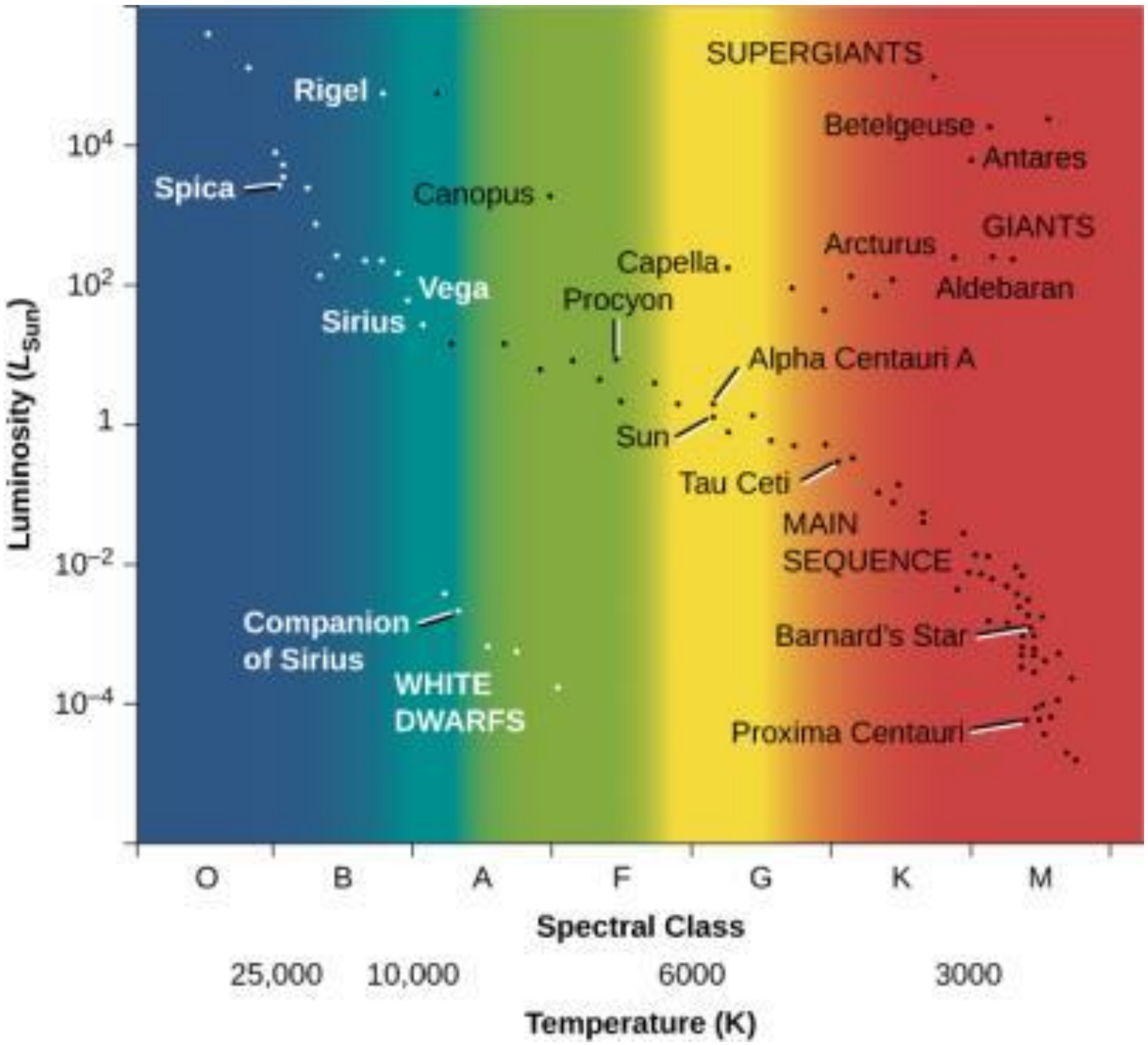
Units: Solar Luminosity L_{sun}

$$Luminosity \sim Mass^{3.9}$$

Units: Solar Mass M_{sun}

Temperature-Luminosity Relation
H-R diagram

(Hertsprung-Russell diagram)



Temperature-Luminosity Relation
H-R diagram

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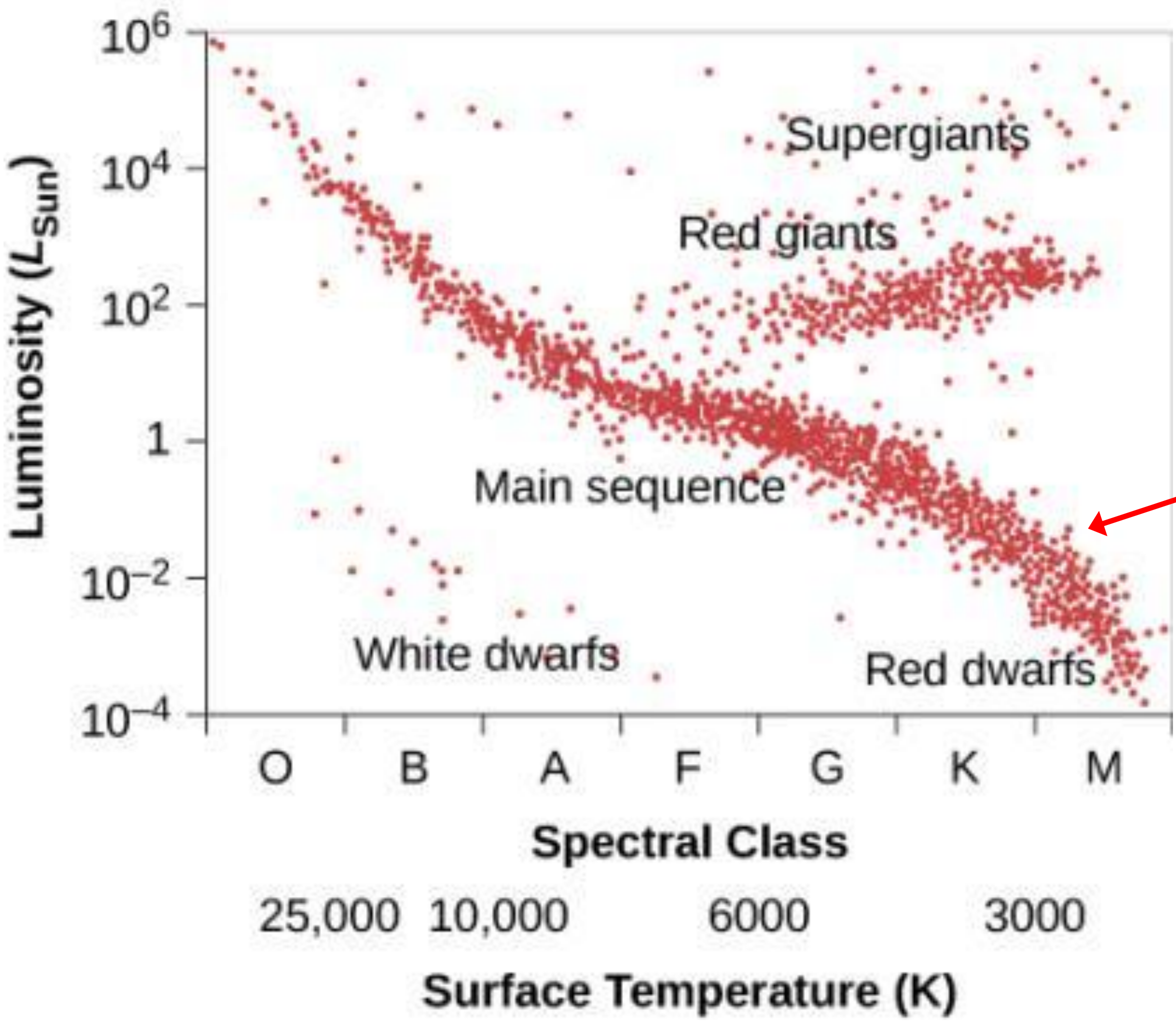

90% of stars are on "main sequence"

Temperature-Luminosity Relation
H-R diagram

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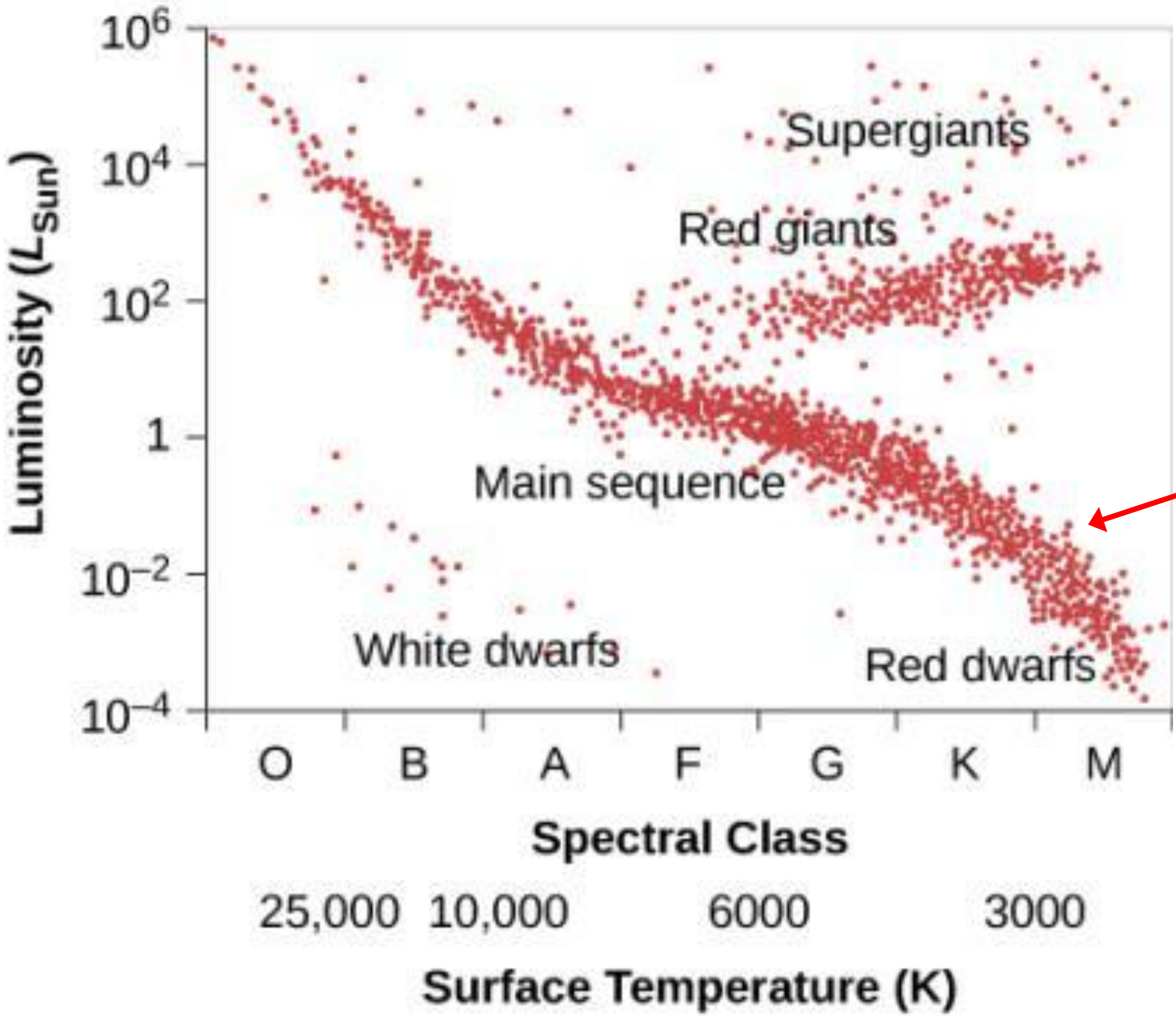

90% of stars are on "main sequence"

Stars spend about 90% of their "life" on the main sequence.

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H-R diagram

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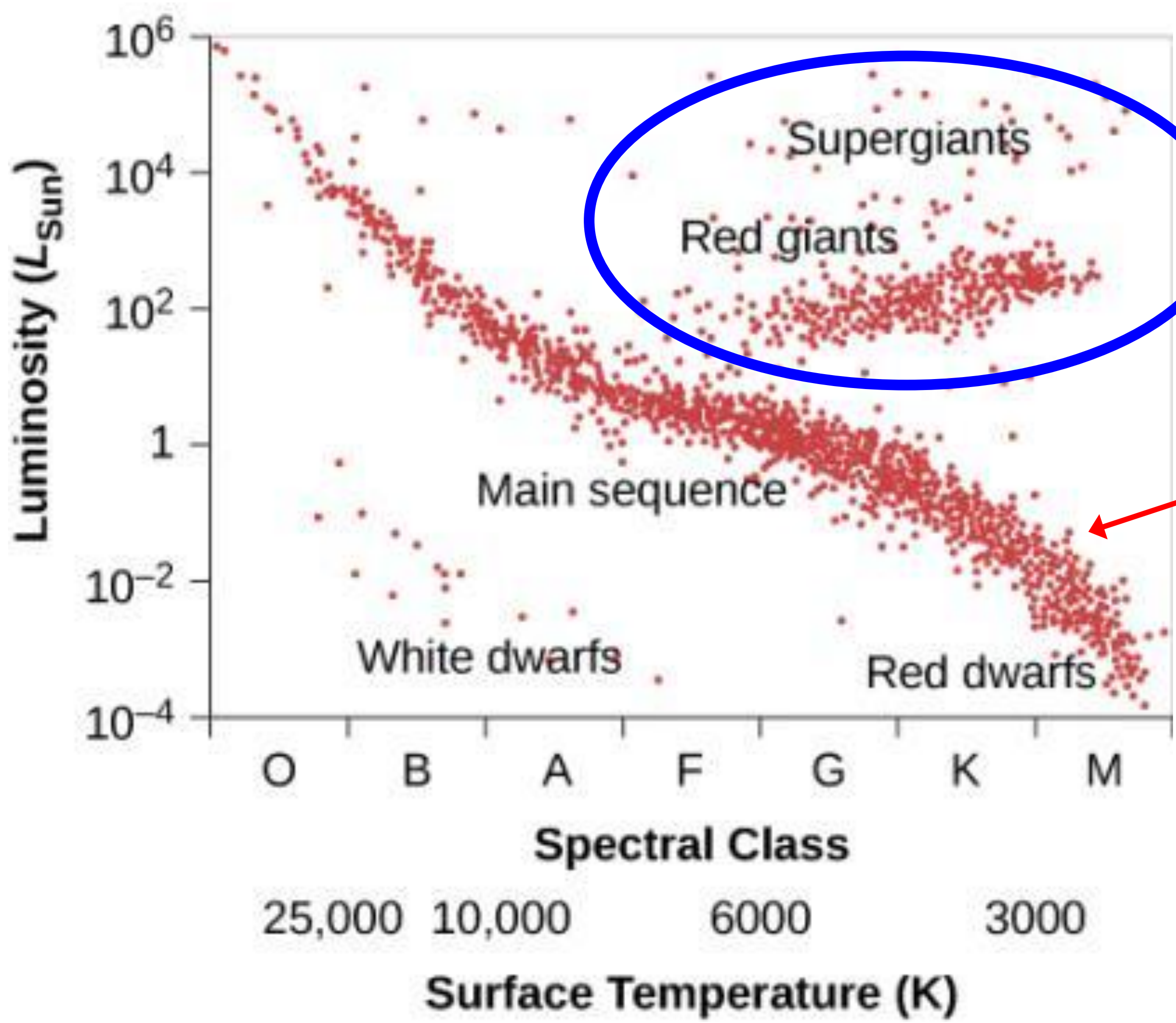

These stars are in their end stage of "star life."

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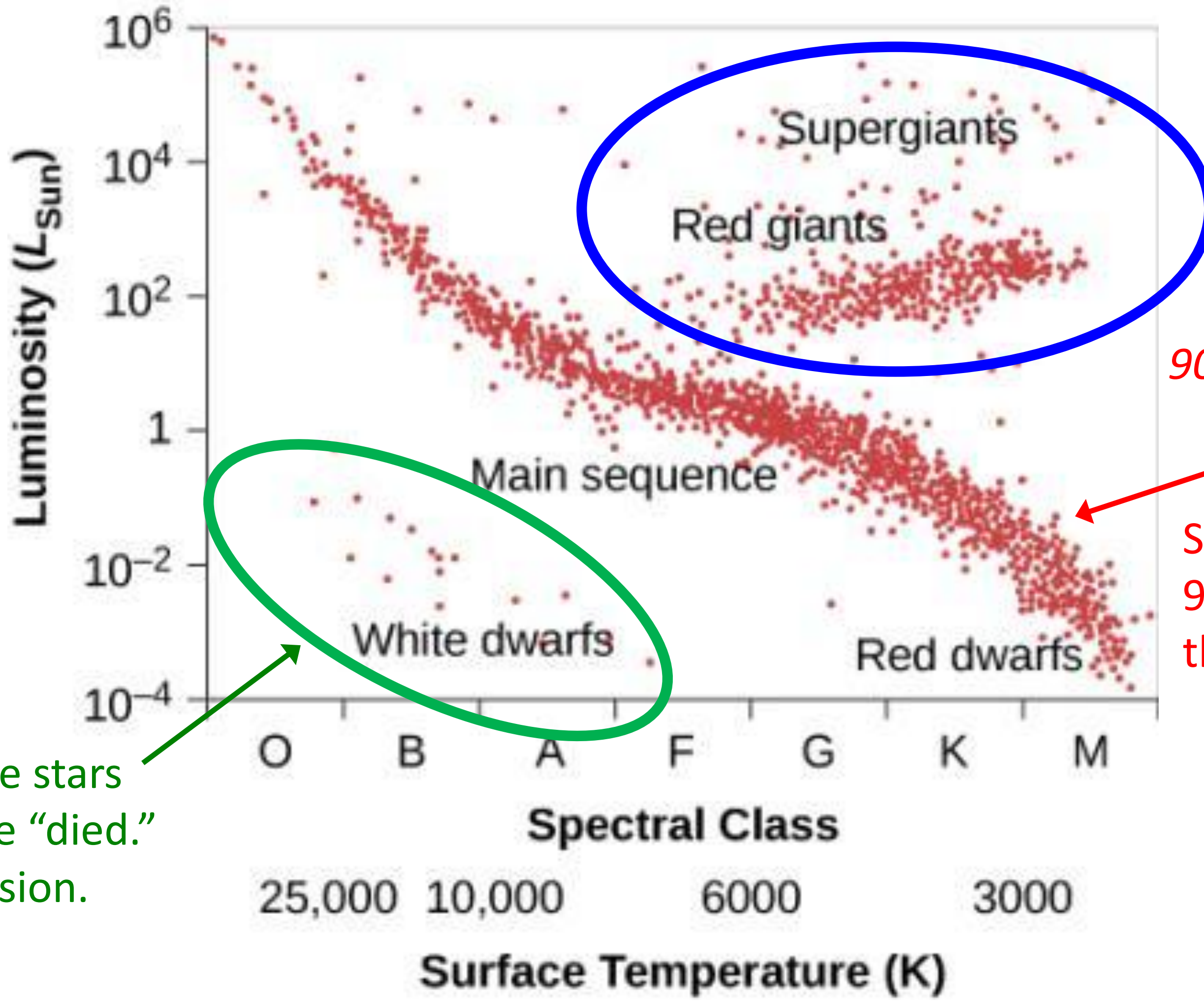


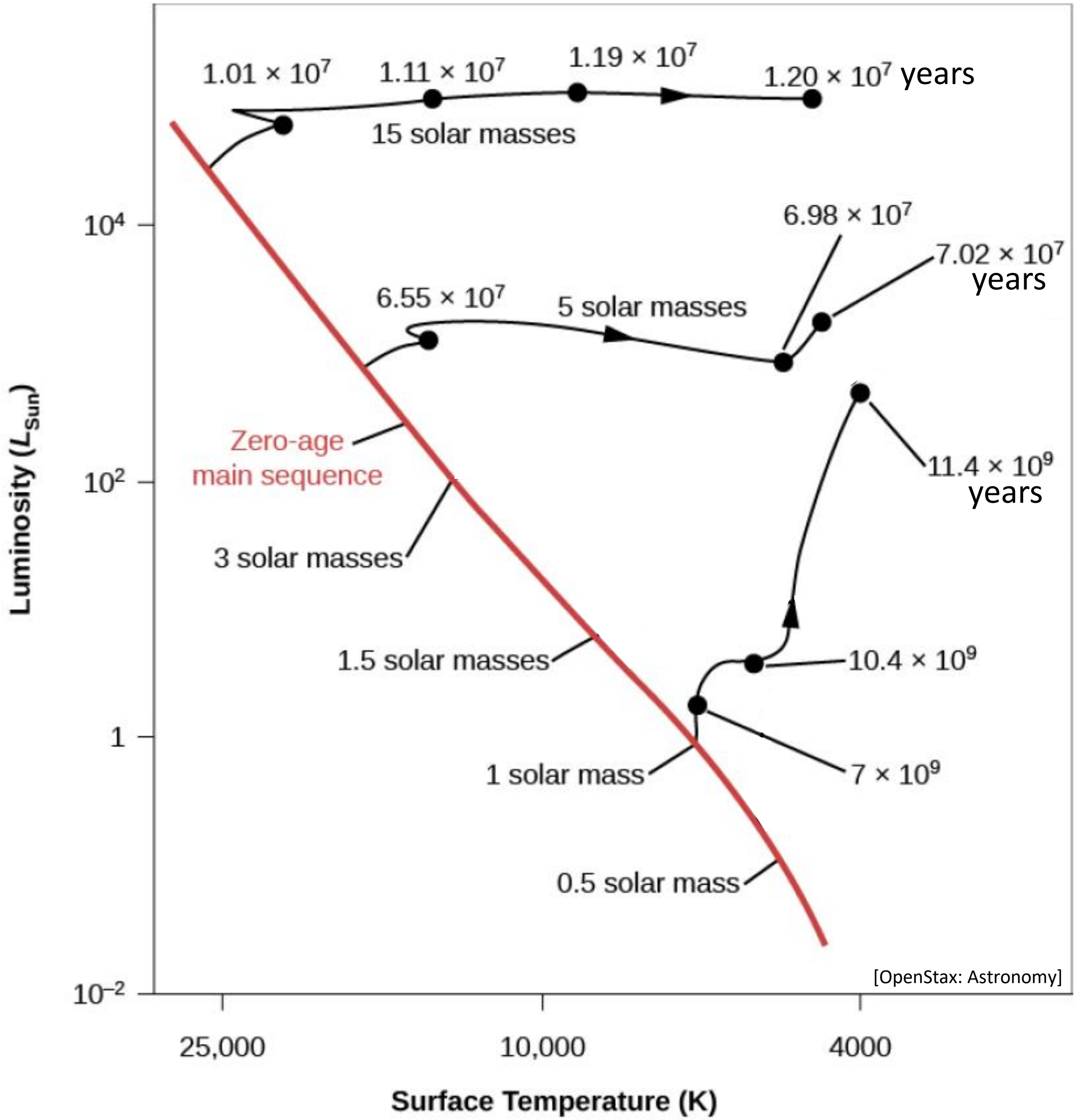
These stars are in their end stage of "star life."

90% of stars are on "main sequence"

Stars spend about 90% of their "life" on the main sequence.

These are stars that have "died."
→ No fusion.

Stellar Evolution: on the H-R Diagram



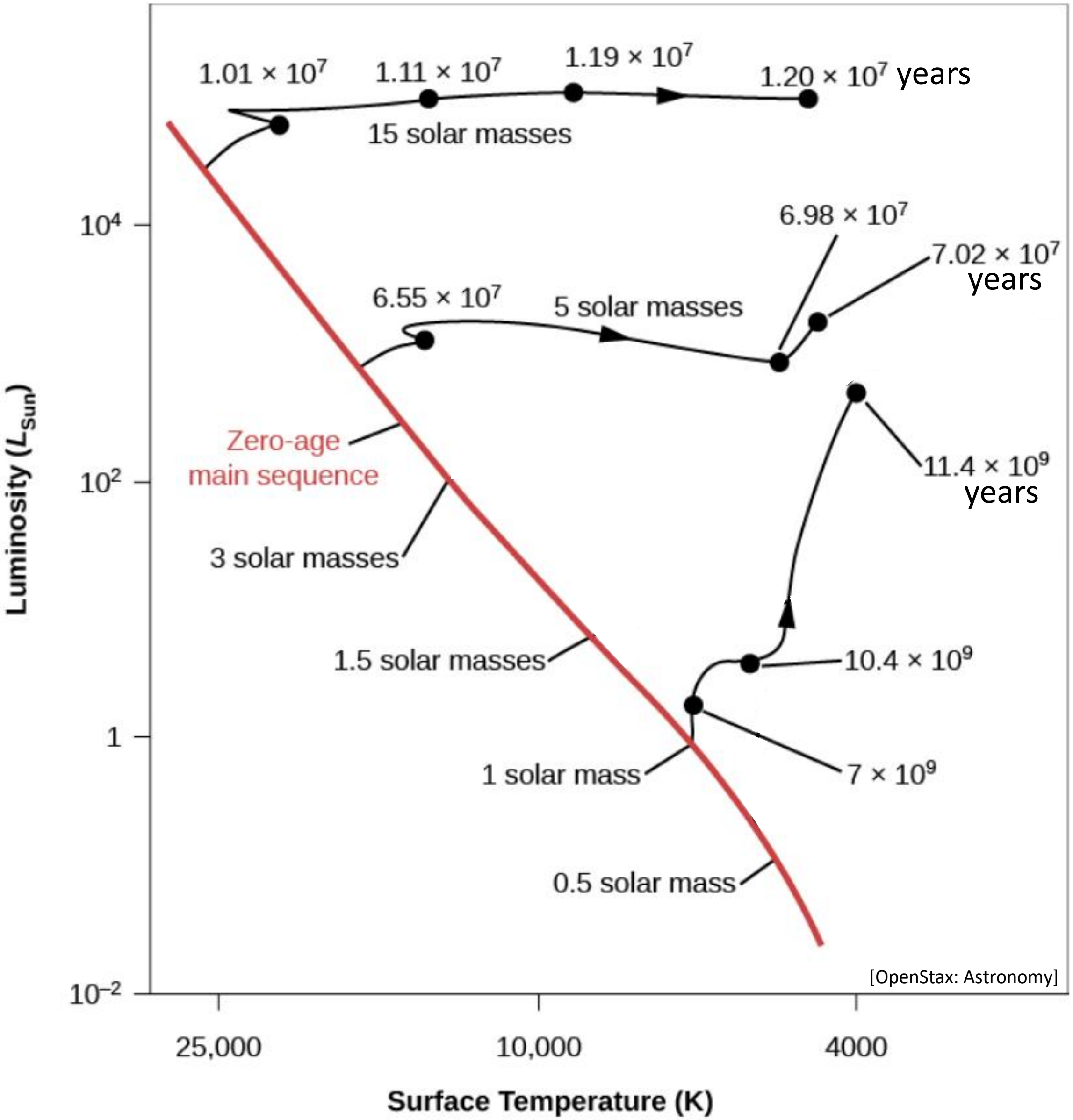
Stellar Evolution: on the H-R Diagram

Heavy stars

- Blue-ish color.
- Hot and very luminous.
- Very short lived.
  → < 1-10 million years.

Light stars (sun-like & smaller)

- Yellow and red color.
- cooler and dimmer.
- Long lived.
  → > 10 billion years.



Stellar Evolution Summary Table

Spectral Type	Mass (Sun=1)	Radius (Sun=1)	Luminosity (Sun=1)	Temperature	Lifetime (yrs) on main seq.
G0	1.1	1.1	1.4	6,000 K	9 billion

Table based on data in Tables 18.3 & 22.1 (OpenStax: Astronomy)

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Spectral Type	Mass (Sun=1)	Radius (Sun=1)	Luminosity (Sun=1)	Temperature	Lifetime (yrs) on main seq.
F0	1.7	1.4	5	7,500 K	2.7 billion
G0	1.1	1.1	1.4	6,000 K	9 billion
K0	0.8	0.8	0.35	5,000 K	14 billion

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Stellar Evolution
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A0	3.3	2.5	55	10,000 K	0.5 billion
F0	1.7	1.4	5	7,500 K	2.7 billion
G0	1.1	1.1	1.4	6,000 K	9 billion
K0	0.8	0.8	0.35	5,000 K	14 billion
M0	0.4	0.6	0.05	3,500 K	200 billion

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Stellar Evolution Summary Table

Spectral Type	Mass (Sun=1)	Radius (Sun=1)	Luminosity (Sun=1)	Temperature	Lifetime (yrs) on main seq.
O5	40	18	700,000	40,000 K	0.001 billion (1 million)
B0	16	7	270,000	28,000 K	0.01 billion (10 million)
A0	3.3	2.5	55	10,000 K	0.5 billion
F0	1.7	1.4	5	7,500 K	2.7 billion
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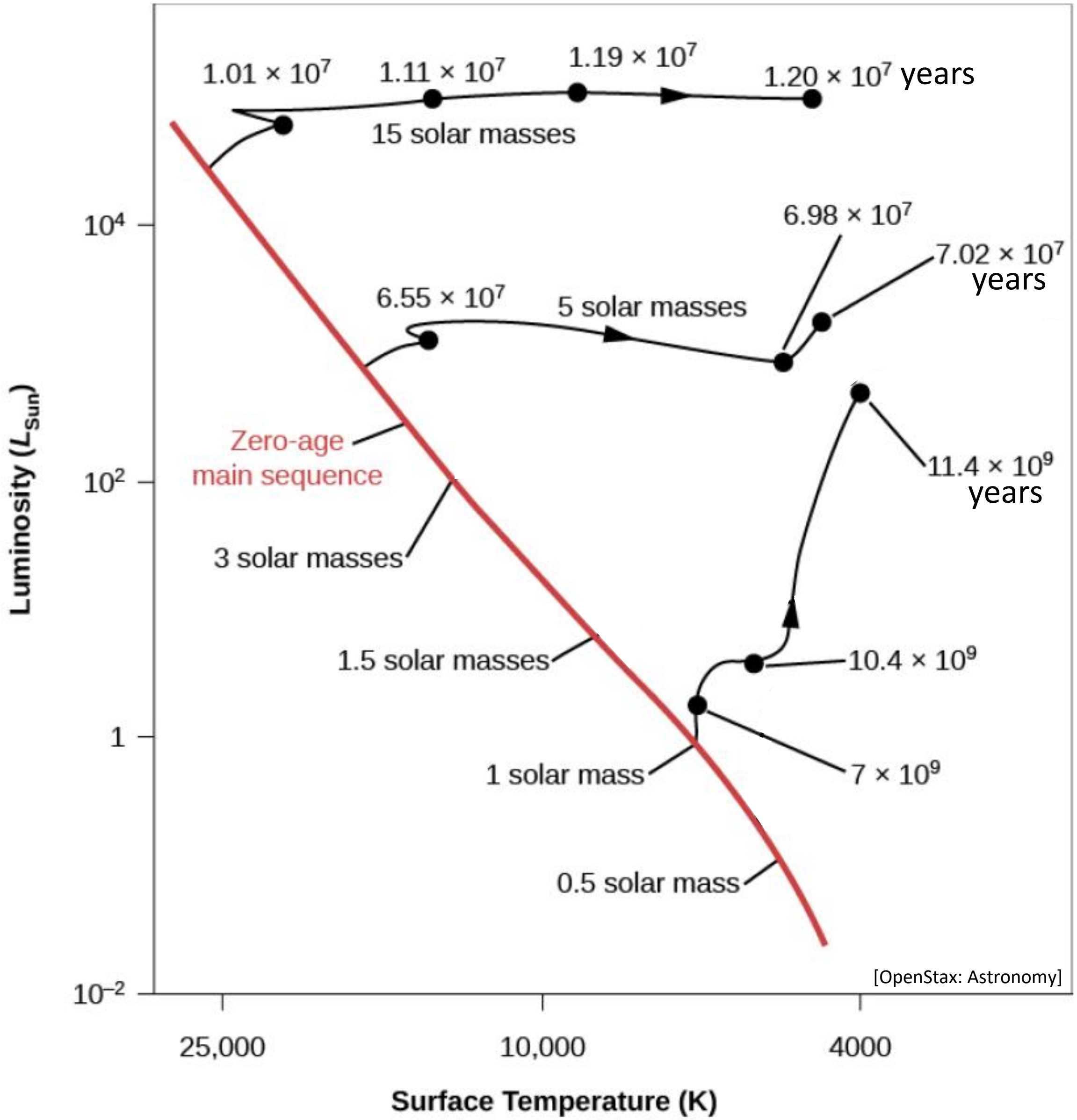

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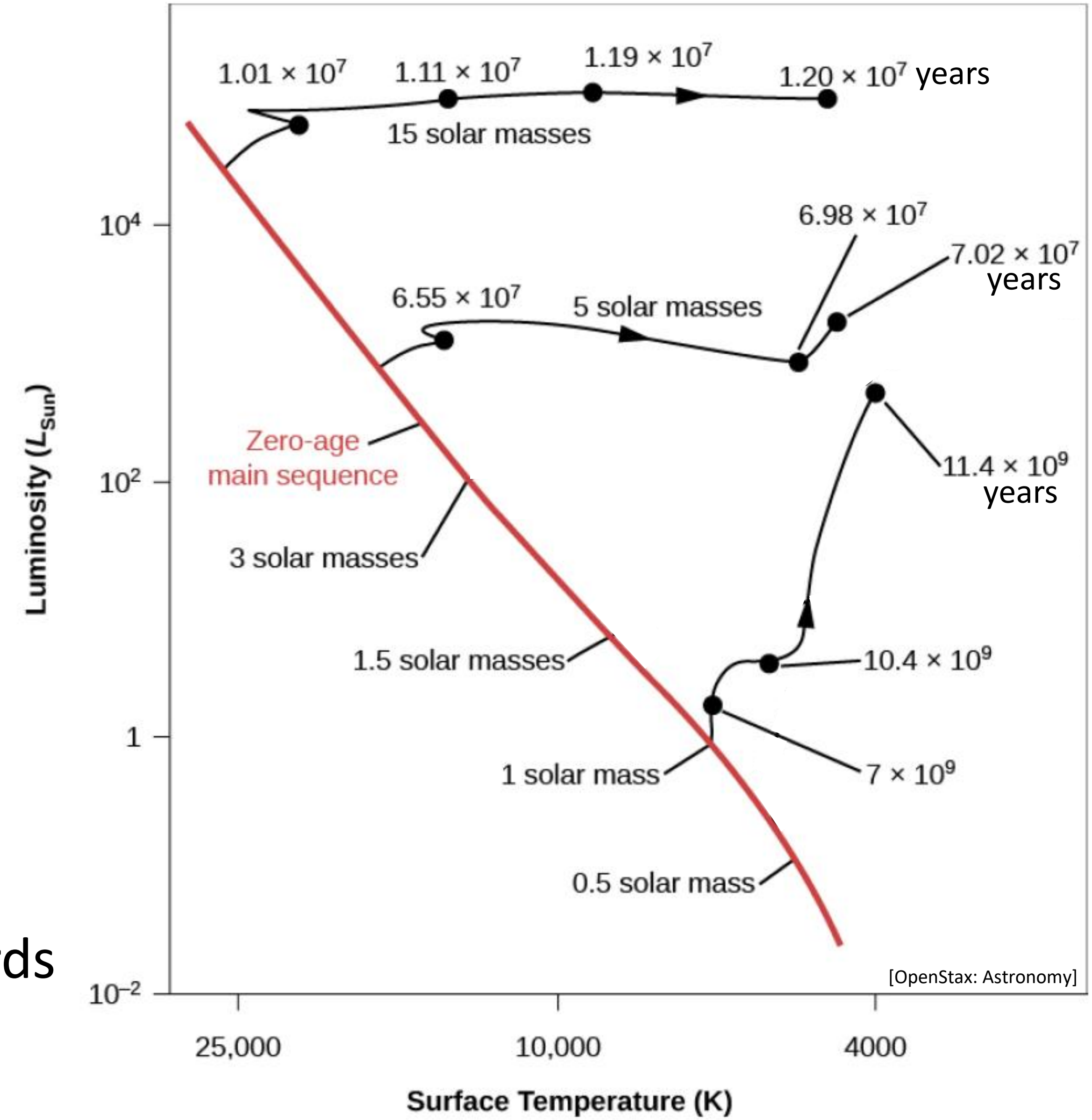
Old age

Stars evolve <u>quickly</u> towards the upper right corner.

→ More luminous, but cooler.



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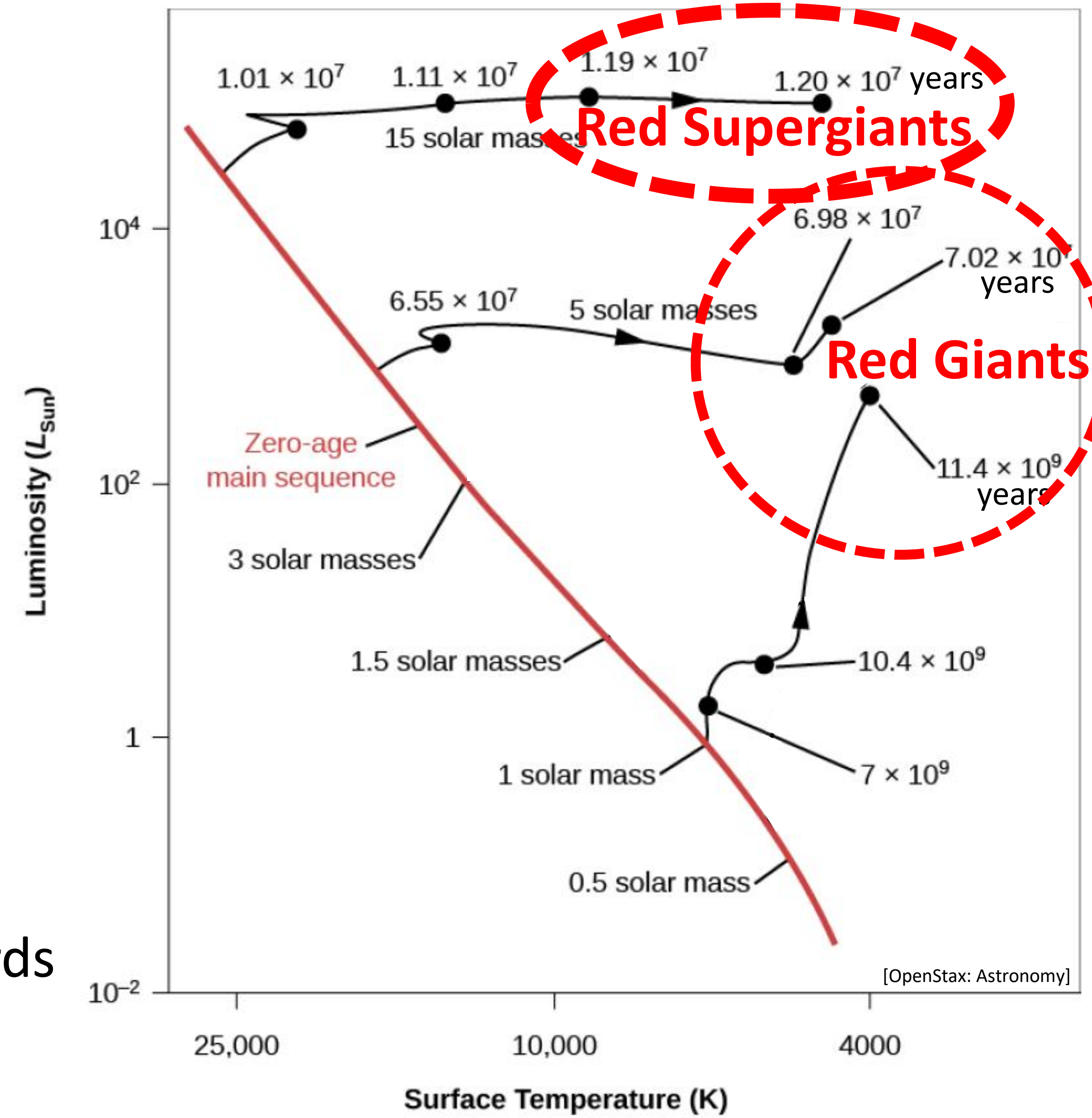
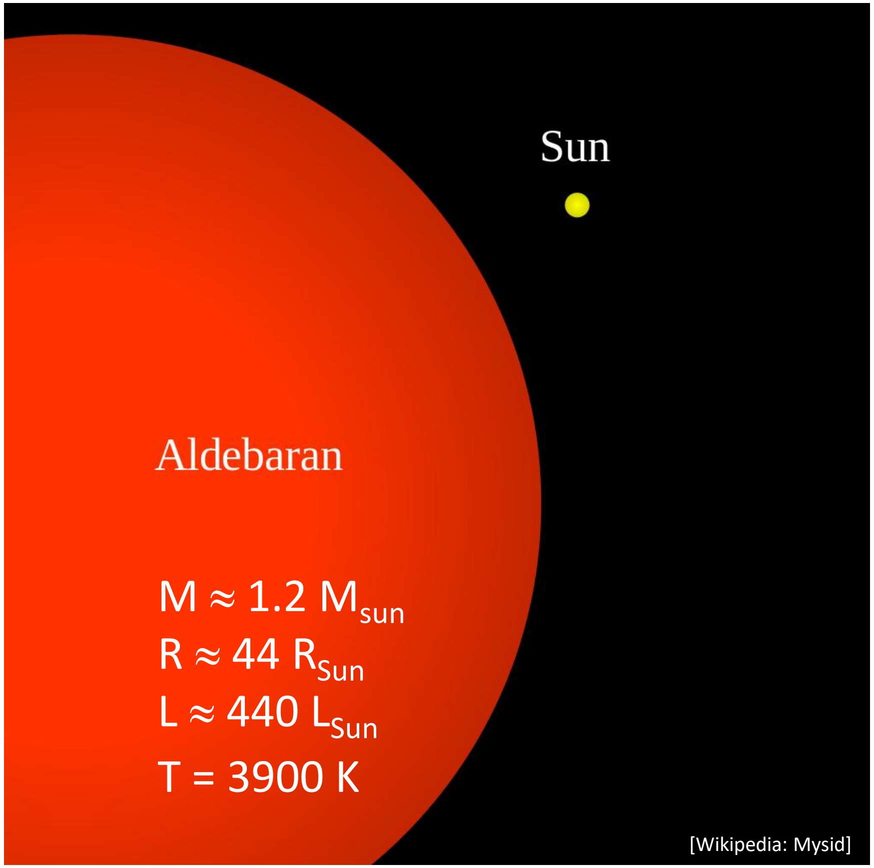


Red Giants & Supergiants

Red Giants

End-of-life stars with masses of 0.6-10 M_{Sun}.



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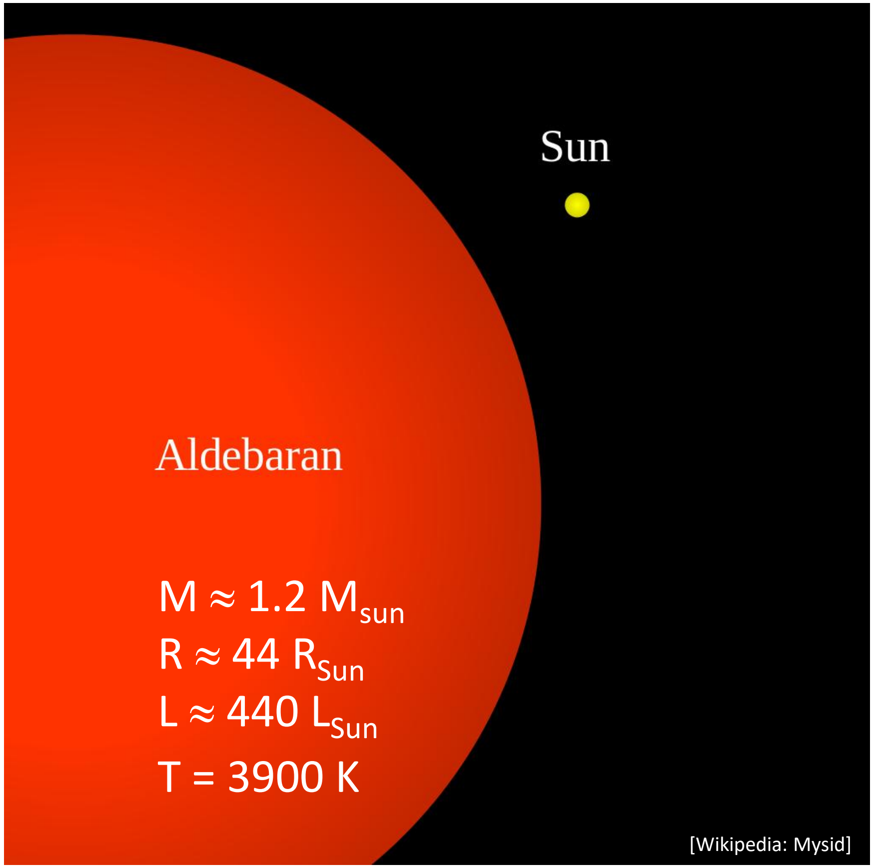
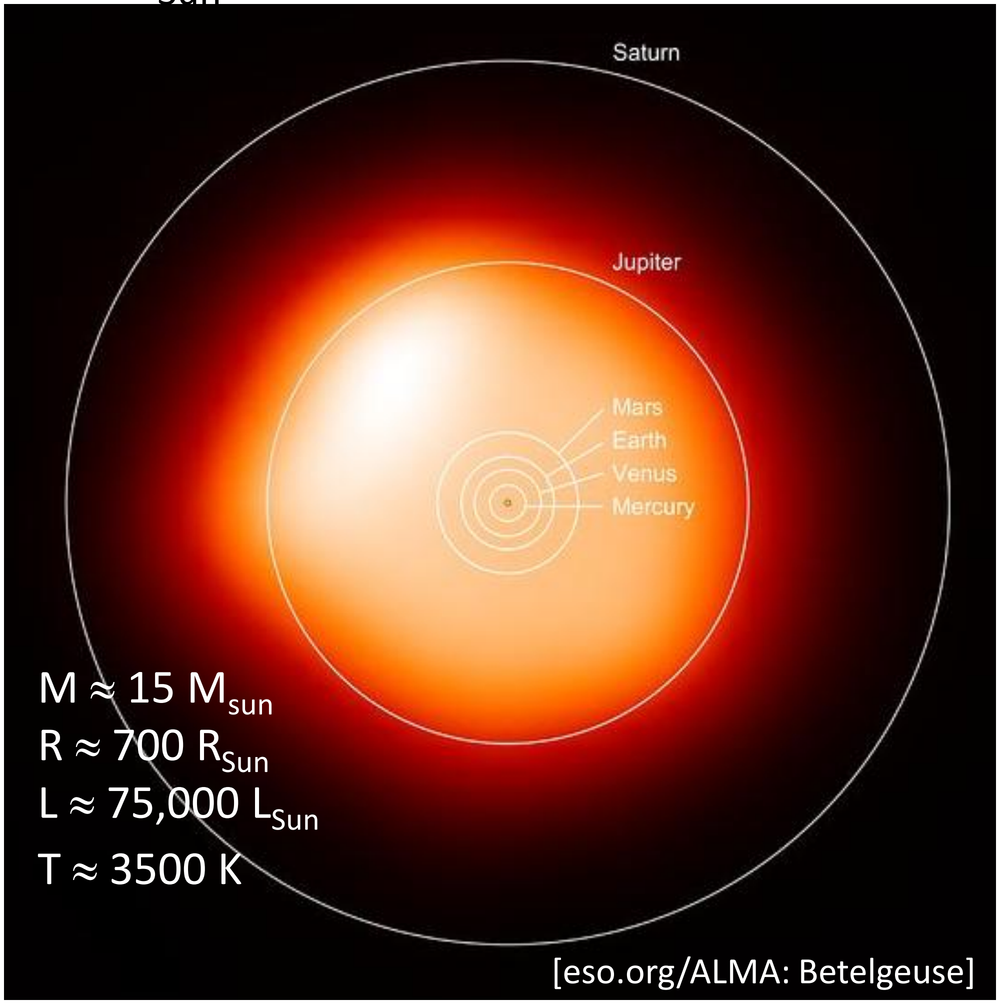
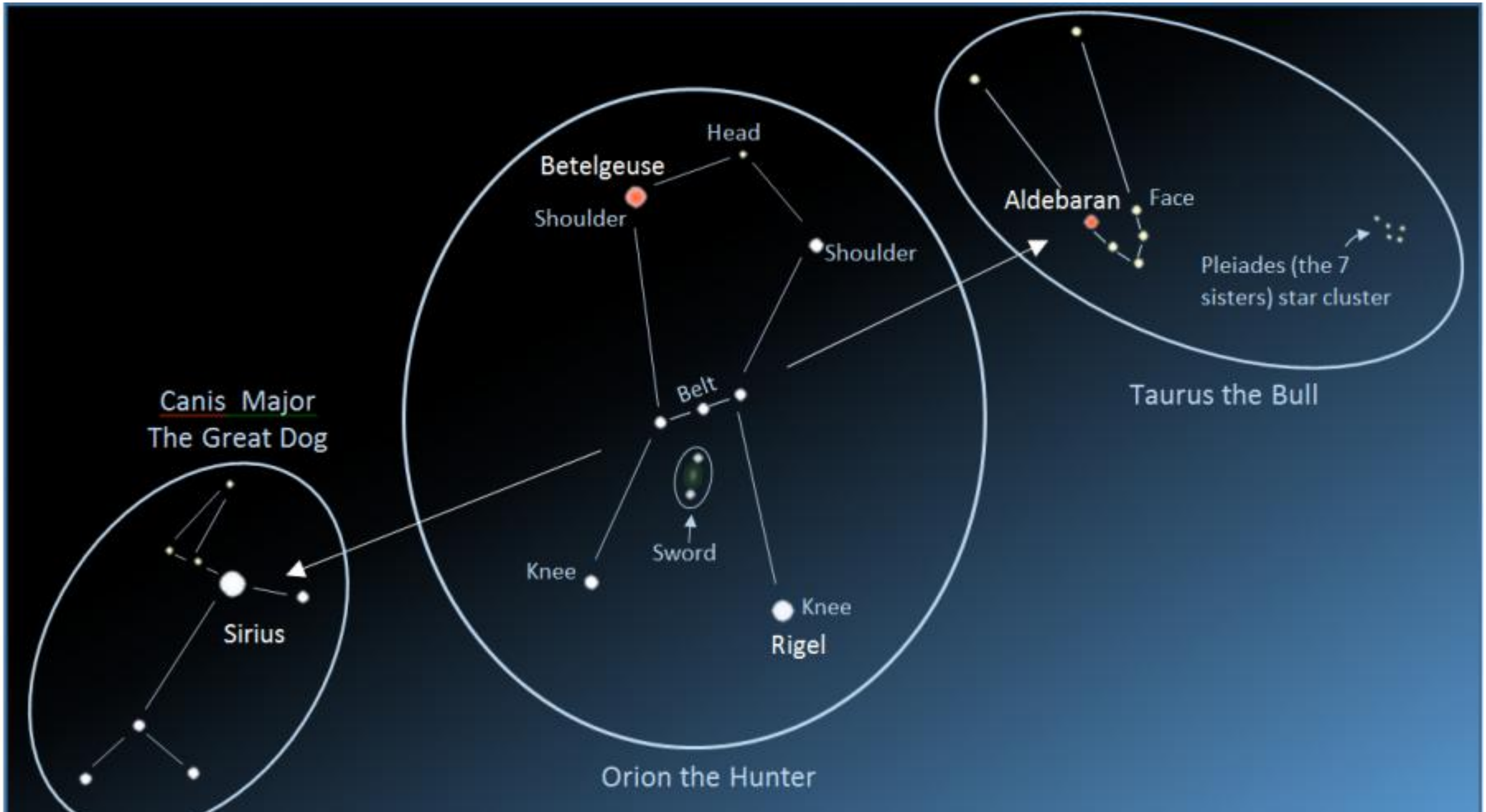


Red Supergiants
End-of-life stars with masses of 10-40 M_{Sun}.



Aldebaran & Betelgeuse in the Sky



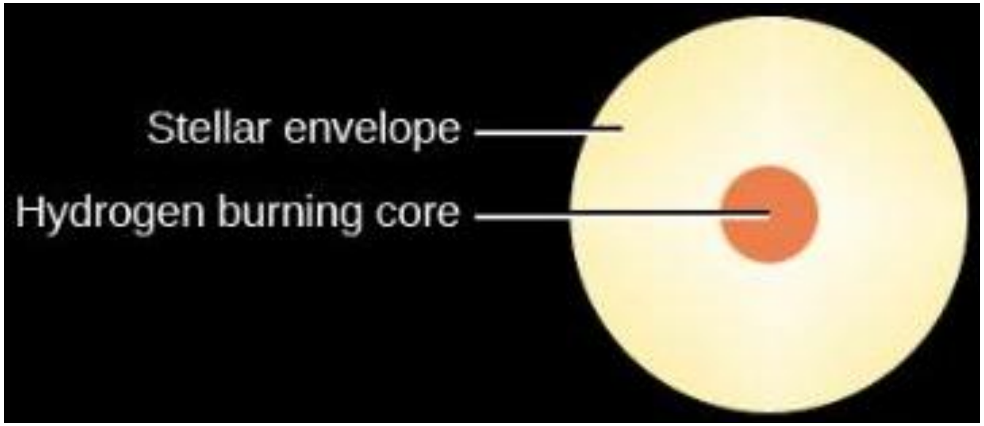
[http://www.ontarioparks.com/parksblog/featured-constellation-orion]

Evolution of Sun-like Stars

Stage	Time in This Stage (years)	Surface Temperature (K)	Luminosity (L_{Sun})	Diameter (Sun = 1)
Main sequence	11 billion	6000	1	1
Becomes red giant	1.3 billion	3100 at minimum	2300 at maximum	165
Helium fusion	100 million	4800	50	10
Giant again	20 million	3100	5200	180
white dwarf (+ planetary nebula)	“forever”	40,000 K → 4,000 K	$\sim$ 1 → 0.01	$\sim$ 0.01

[OpenStax: Astronomy]

Becoming a Red Giant



1. Main sequence operation

Proton-proton fusion chain in core

4x Hydrogen → 1 helium

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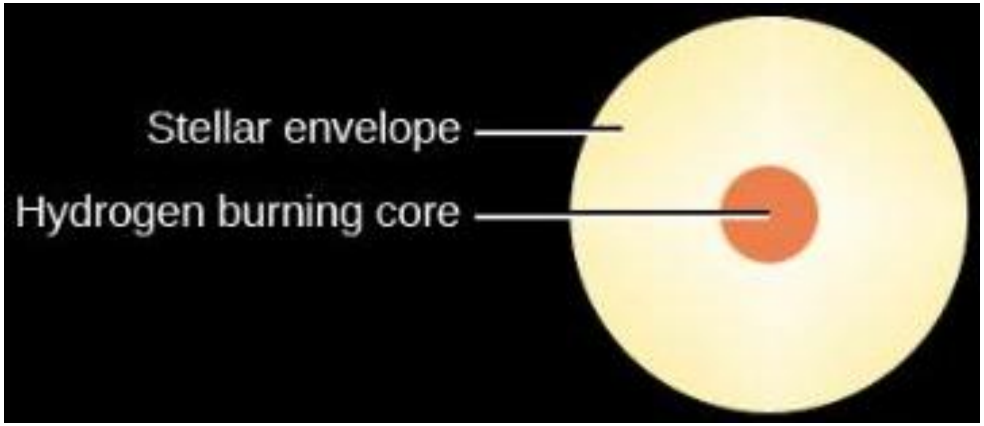
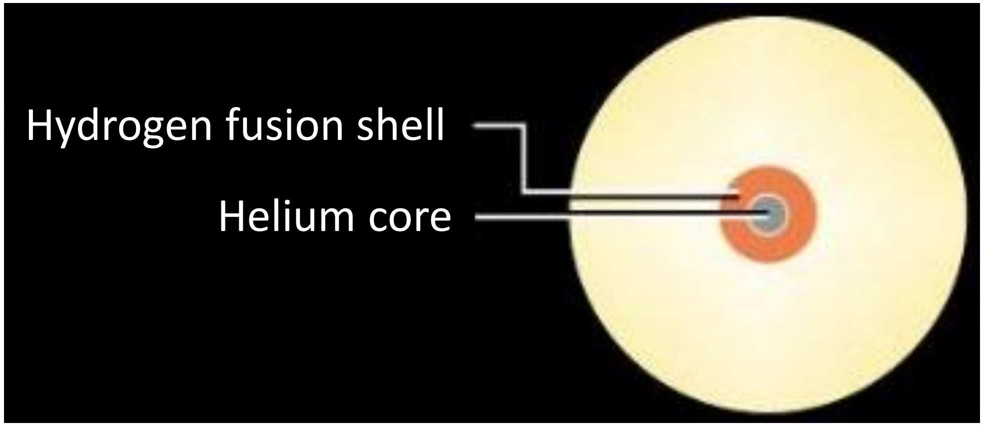


2. Core hydrogen exhausted

- Helium core begins to **contract**.
- Helium core **heats up**.
- Hydrogen just outside of helium core **begins fusion**.



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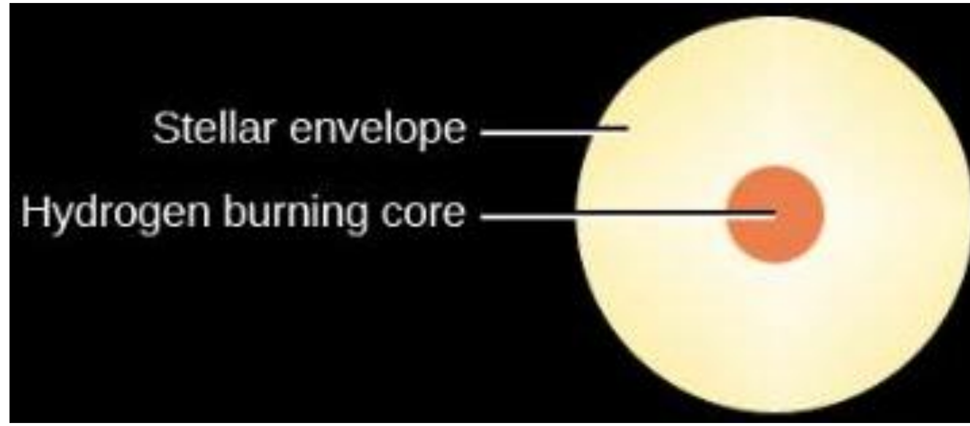

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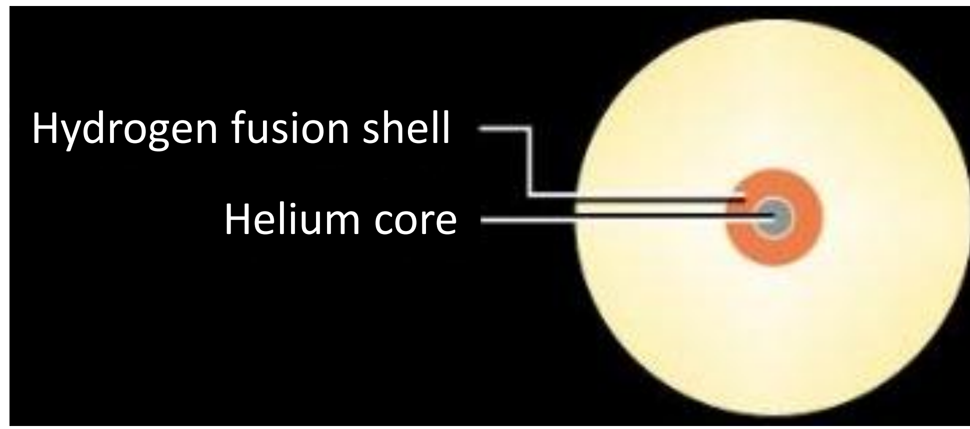
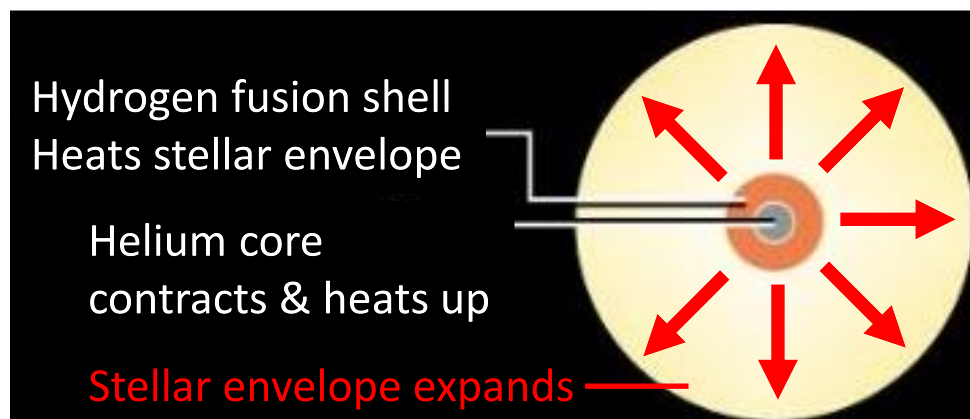


3. Expansion to red giant

- **Heat** from new hydrogen shell fusion is **significant** and heats up outer hydrogen in stellar envelope.
- Stellar envelope heats up and **expands** (outer layer then cools).
- **Helium core continues to contract and heat up**.



Helium Fusion

- At T $\approx$ 100,000,000 K, helium nuclei begin to fuse.
- Fusion of two helium nuclei **does not produce a stable isotope**: $^{4}He + ^{4}He \rightarrow ^{8}Be$ (lifetime ~ 10^{-16} - 10^{-17} s)

Triple alpha process (at 10^{8} K)
Three helium nuclei can fuse simultaneously to produce carbon-12 (stable):

$$^{4}He + ^{4}He + ^{4}He \rightarrow ^{12}C + 7.65\ MeV$$

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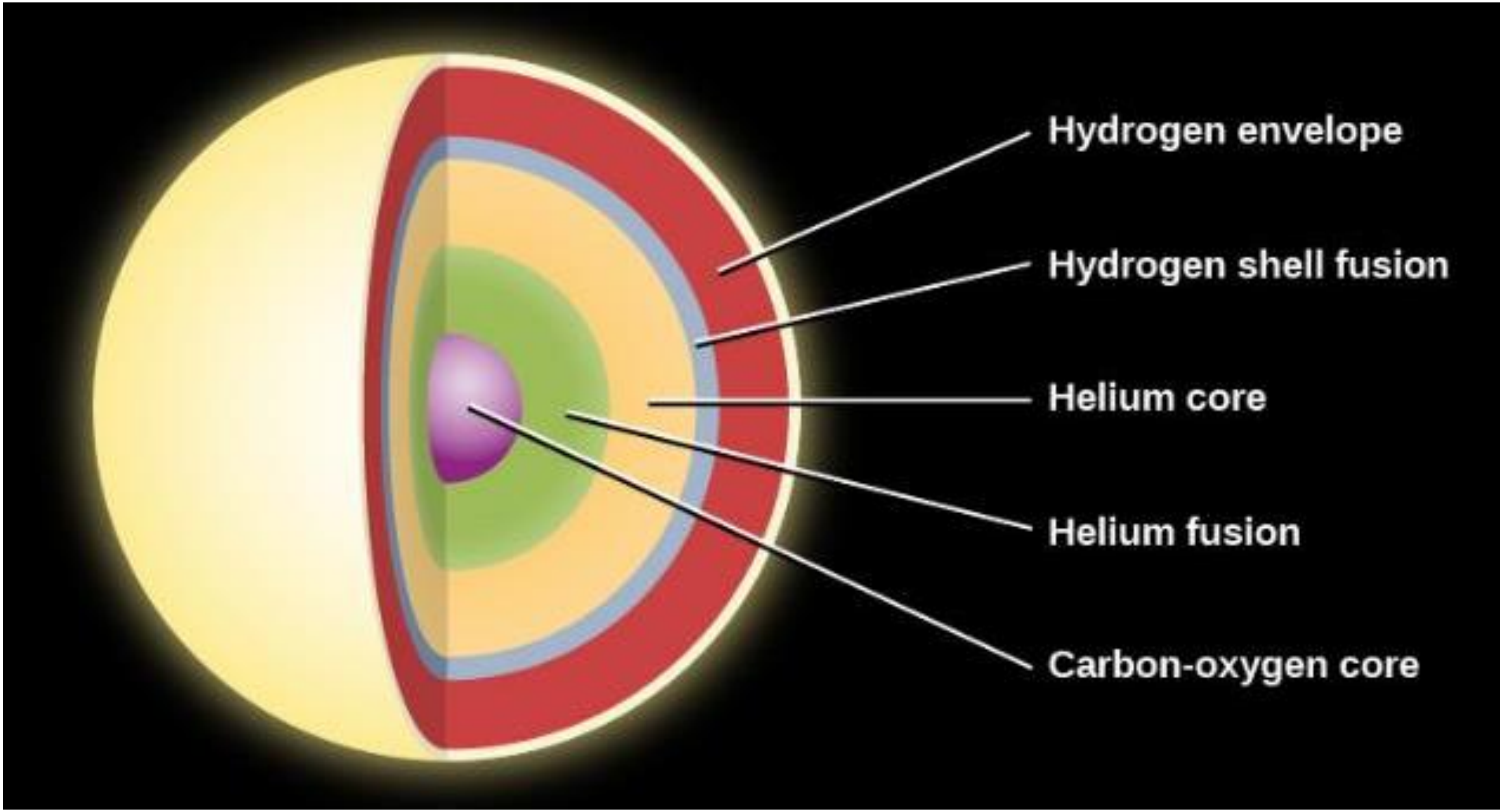
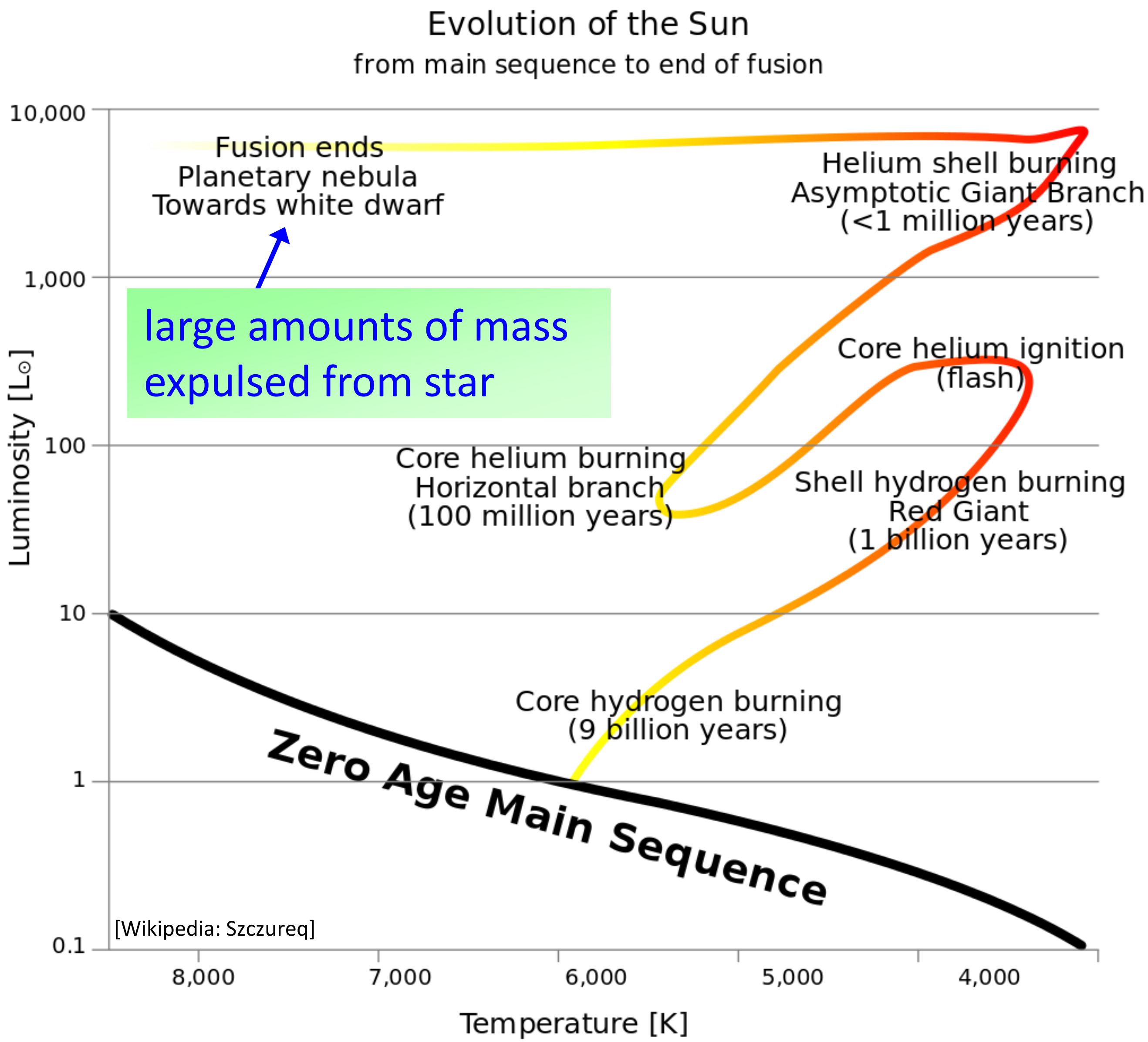
Helium Flash (for Sun-like stars)
The fusion of helium into carbon happens very quickly (possibly in a few minutes).

PollEv Quiz: PollEv.com/sethaubin

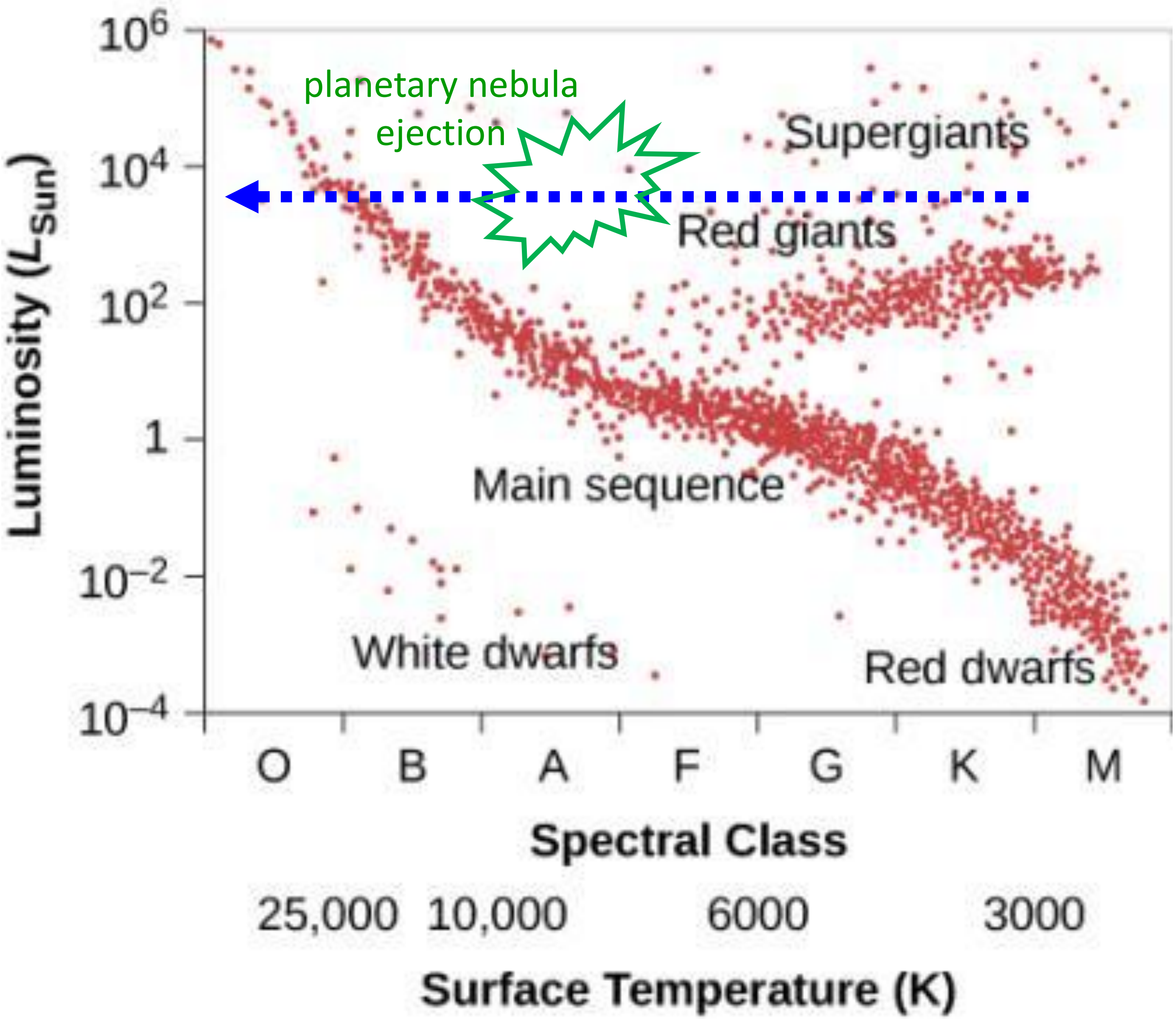
Structure of Red Giant Star before “Death”



Red Giant Evolution from Sun-like Star



Planetary Nebula



White Dwarfs