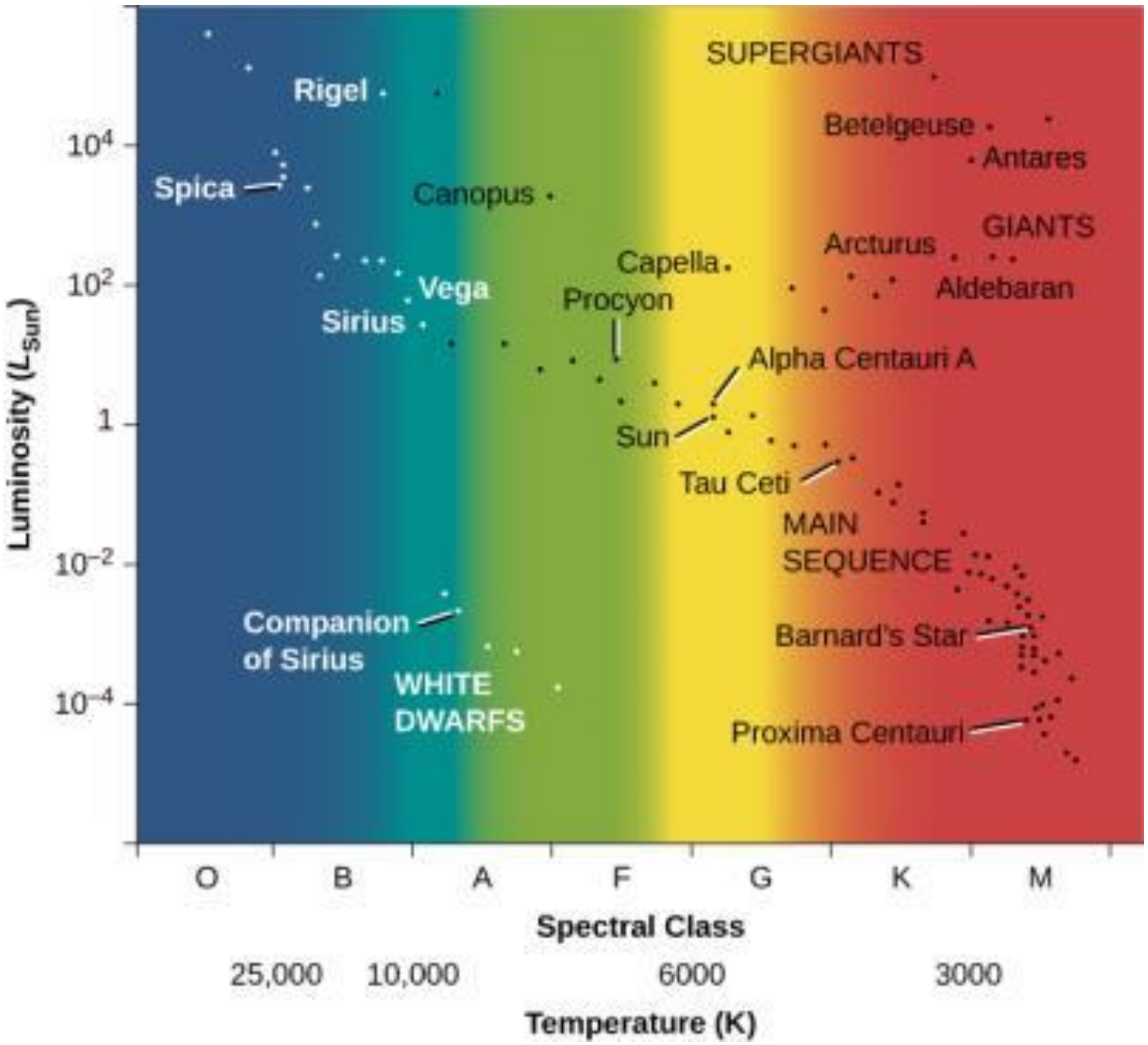
Today's Topics

Wednesday, November 20, 2019 (Week 12, lecture 29) – Chapters 18, 19, 22, 23.

1. H-R diagram.
2. Stellar evolution: Main sequence.
3. Stellar evolution: Sun to red giant.

Temperature-Luminosity Relation
H-R diagram

(Hertsprung-Russell diagram)



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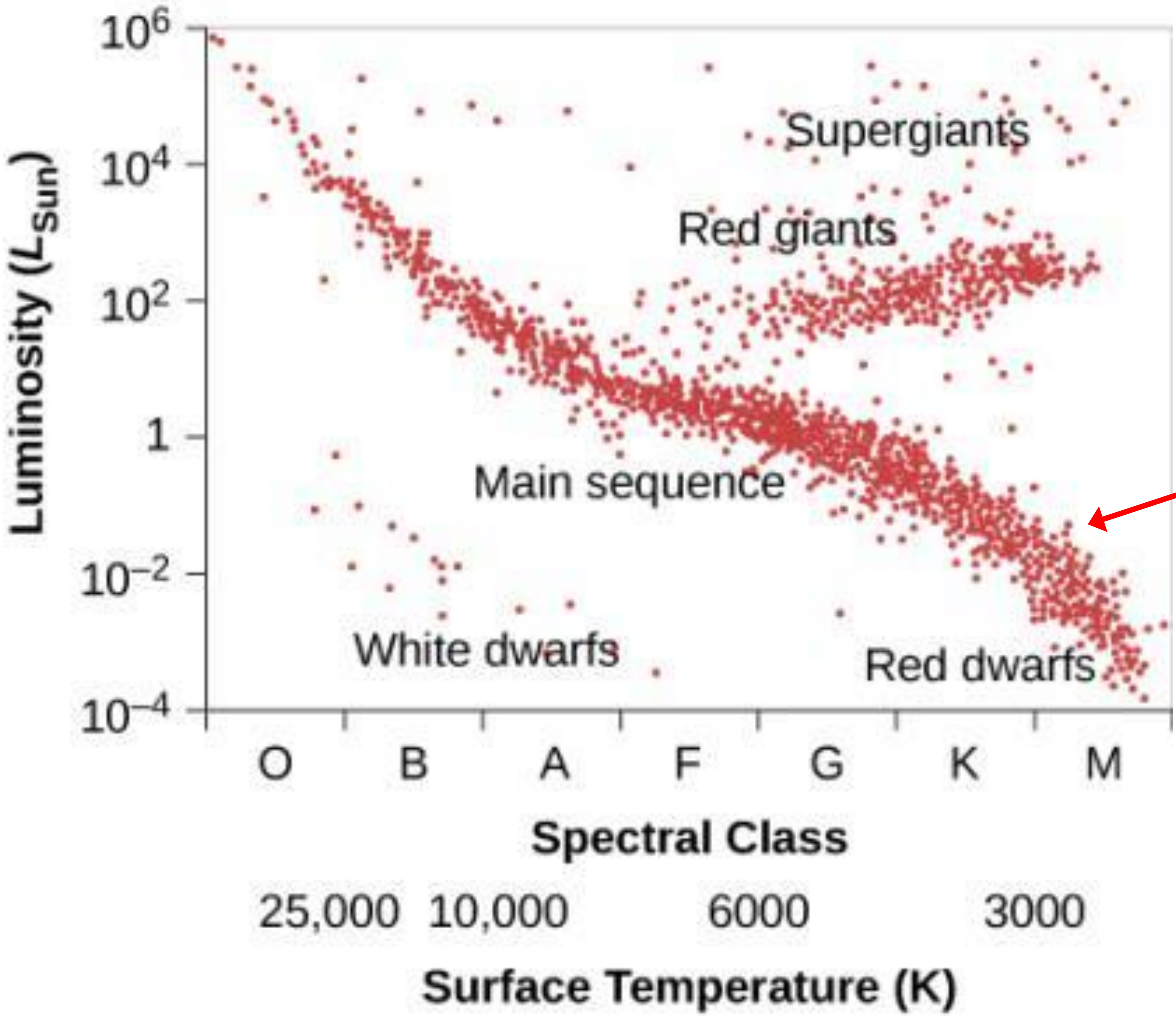

90% of stars are on “main sequence”

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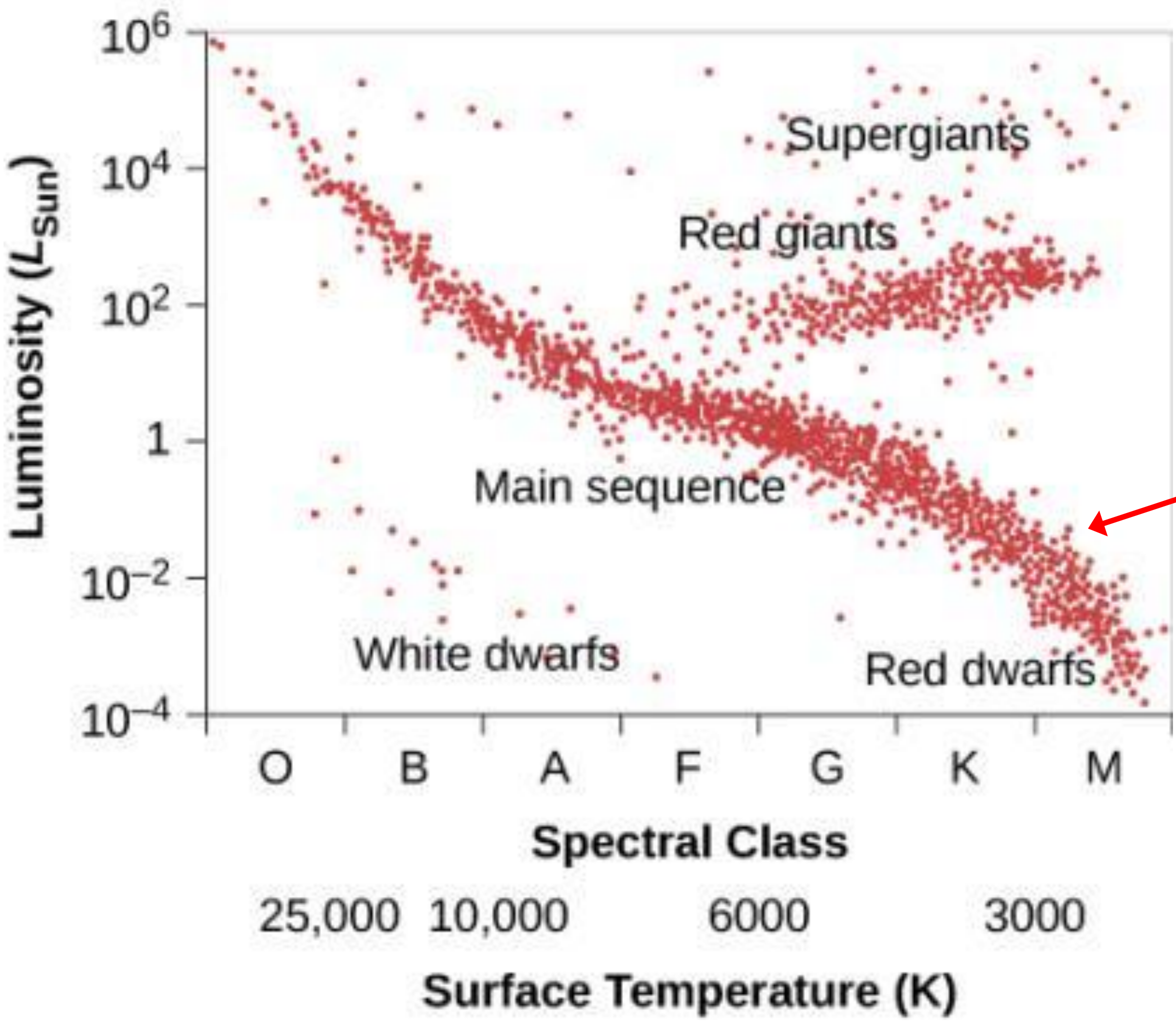

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Stars spend about 90% of their "life" on the main sequence.

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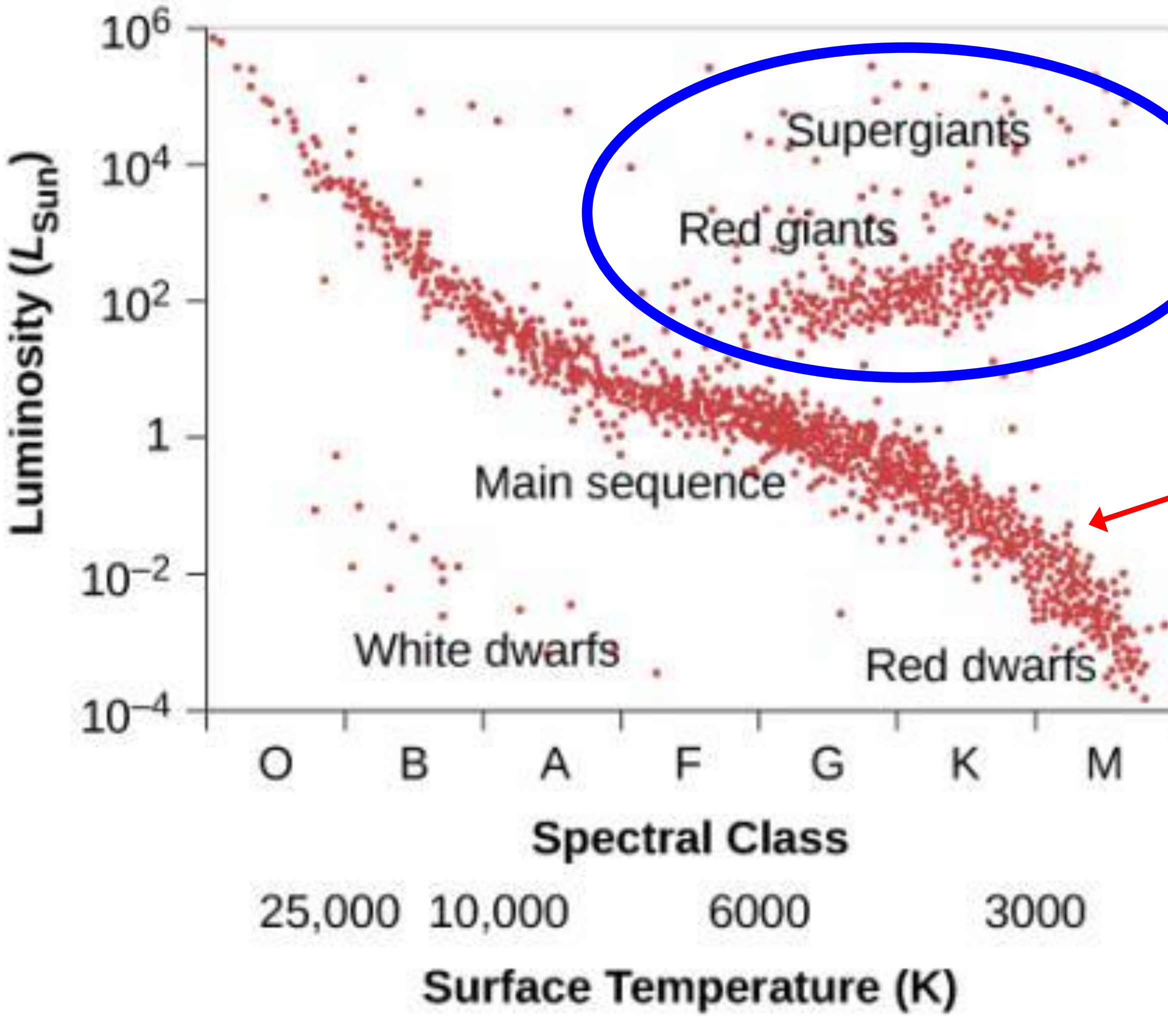

These stars are in their end stage of "star life."

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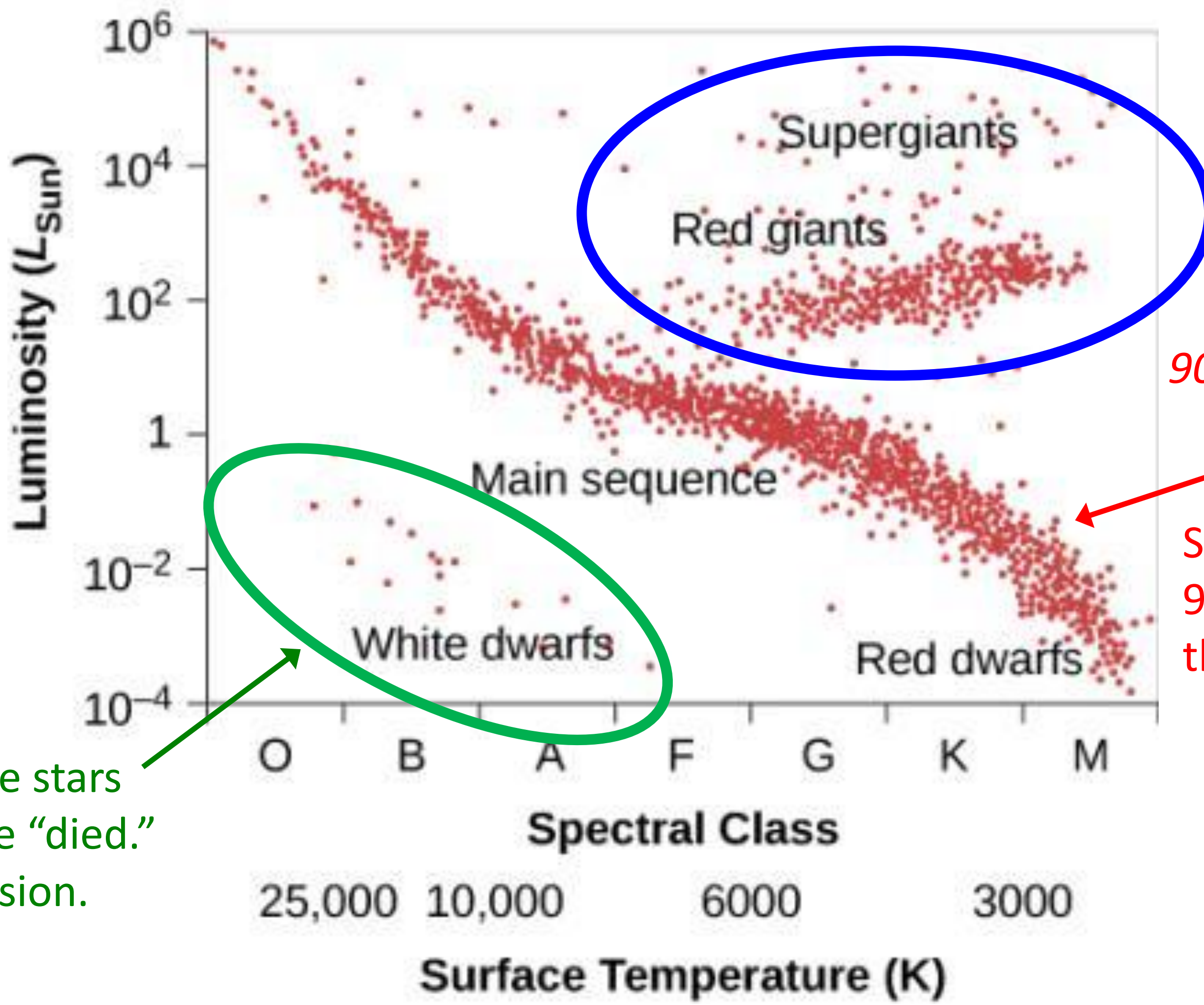


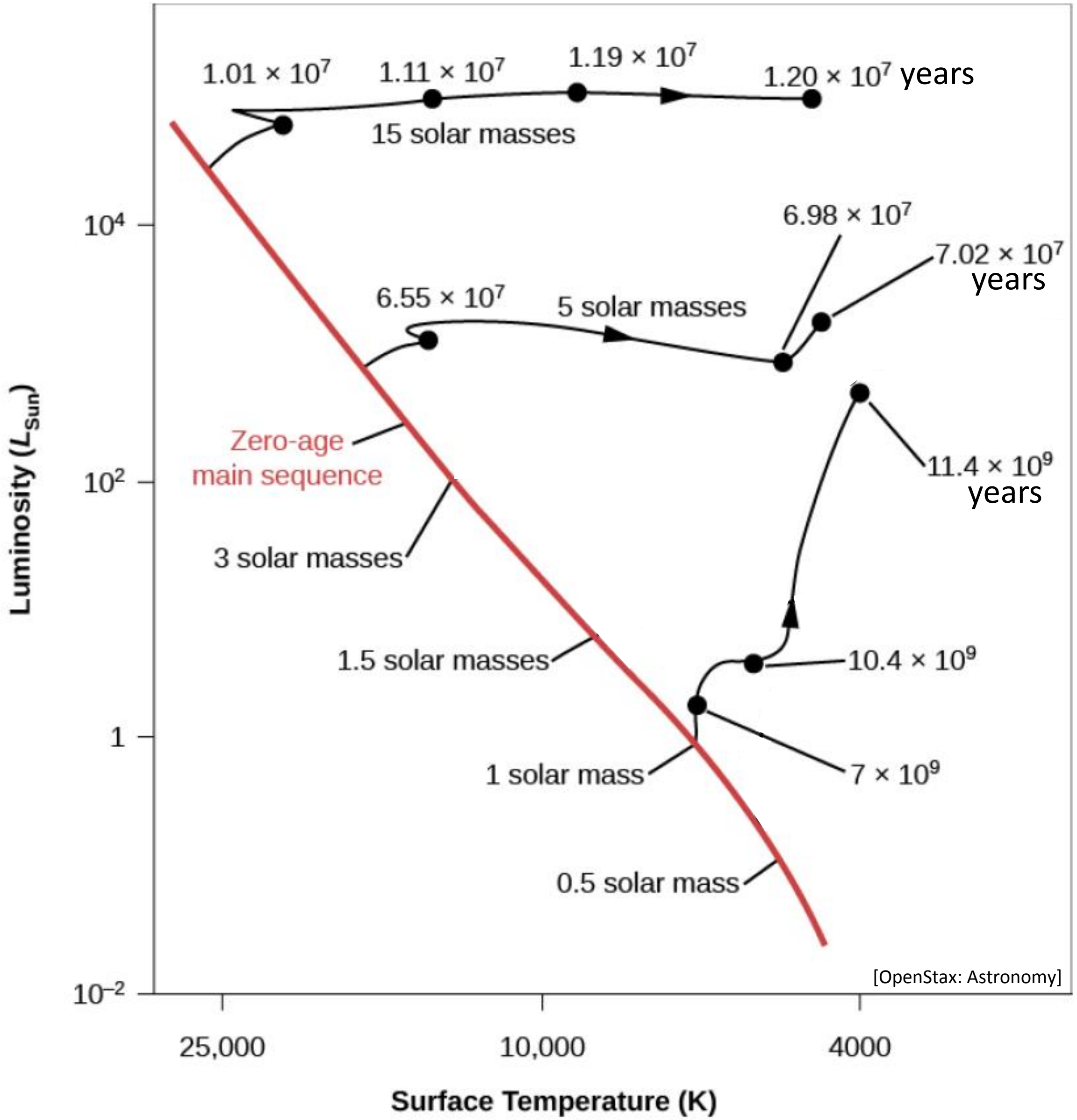
These stars are in their end stage of "star life."

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



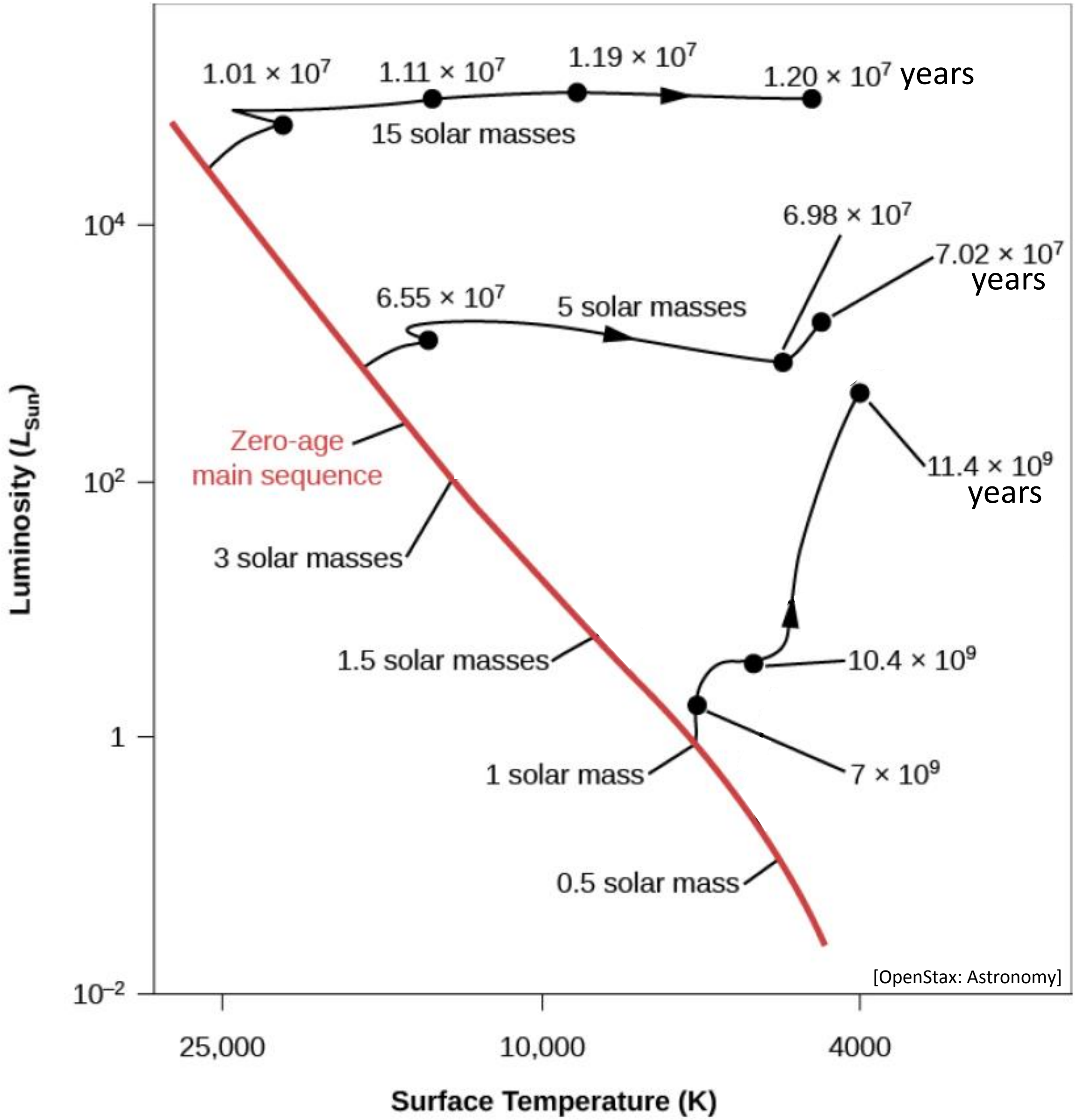
Stellar Evolution: on the H-R Diagram

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)

Stellar Evolution
Summary Table

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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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

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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
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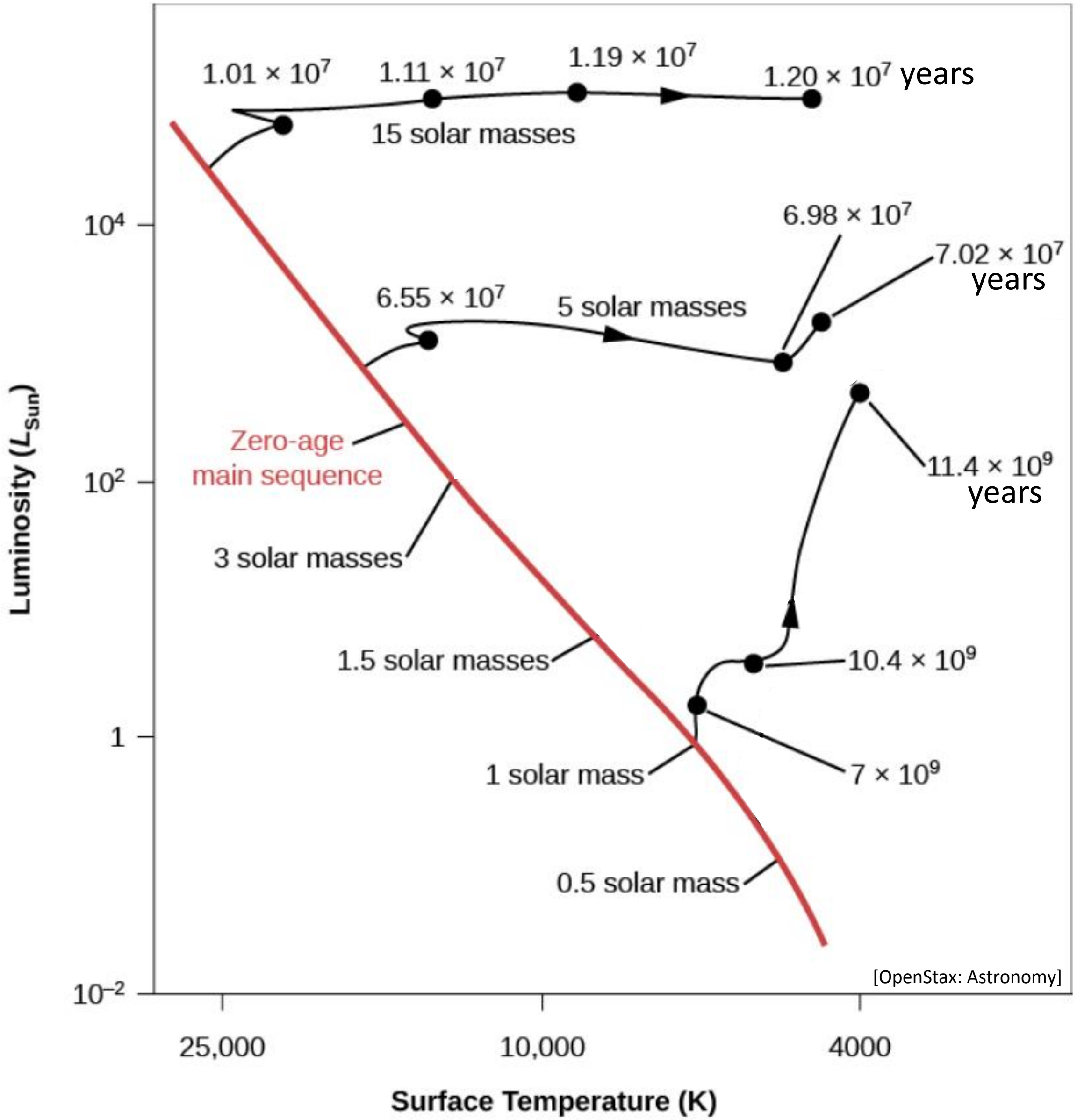

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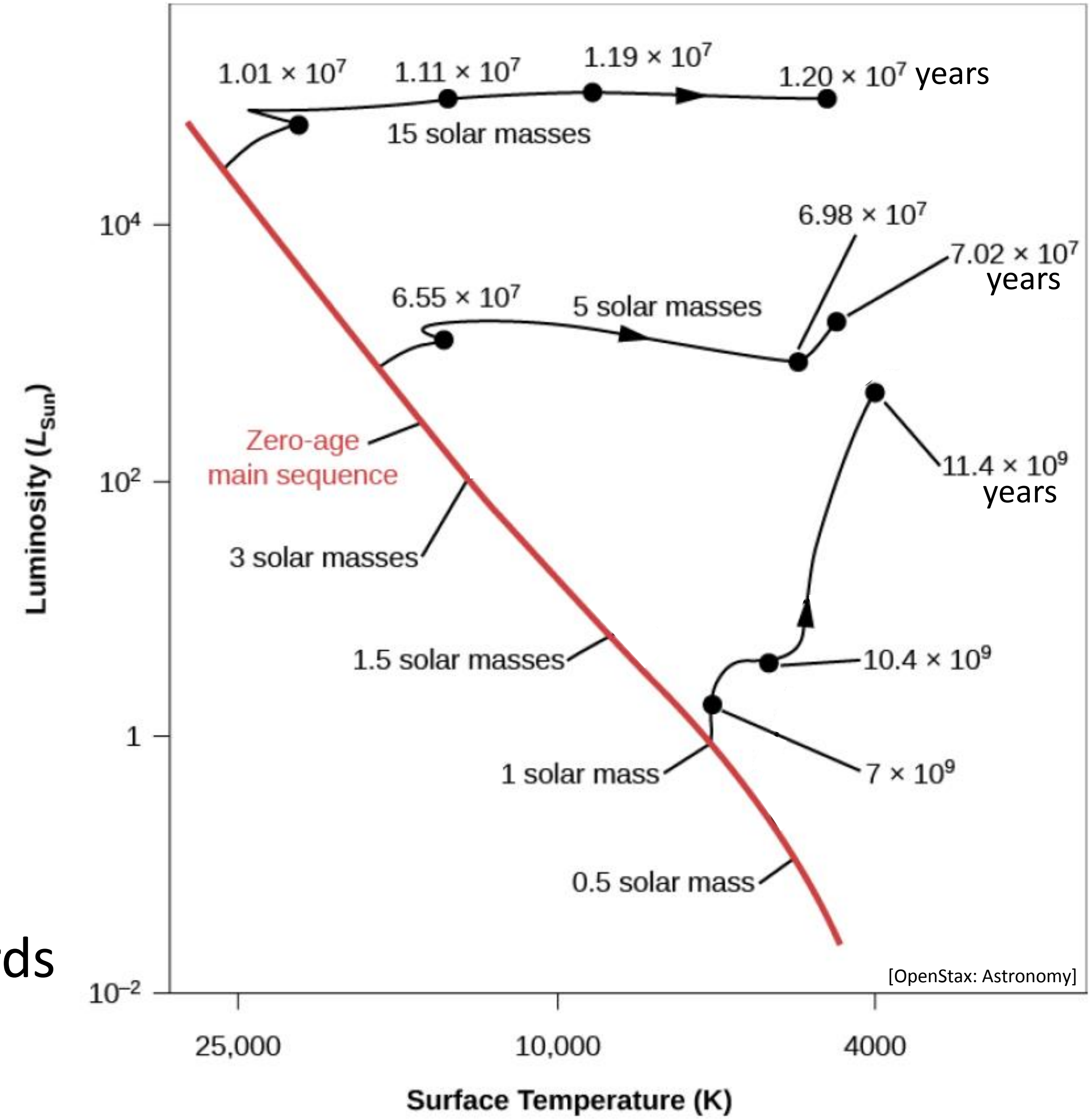
Old age

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

→ More luminous, but cooler.



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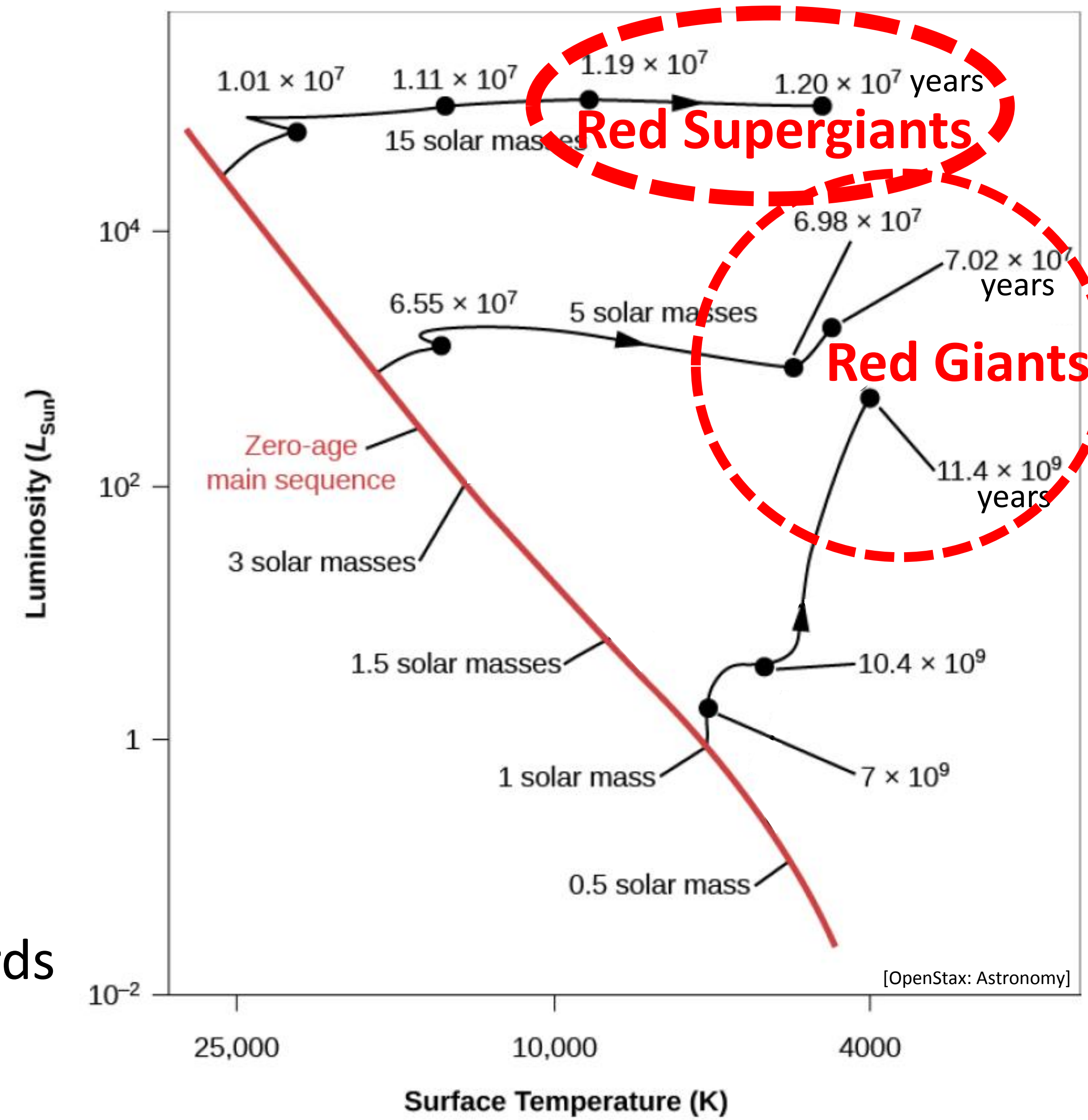
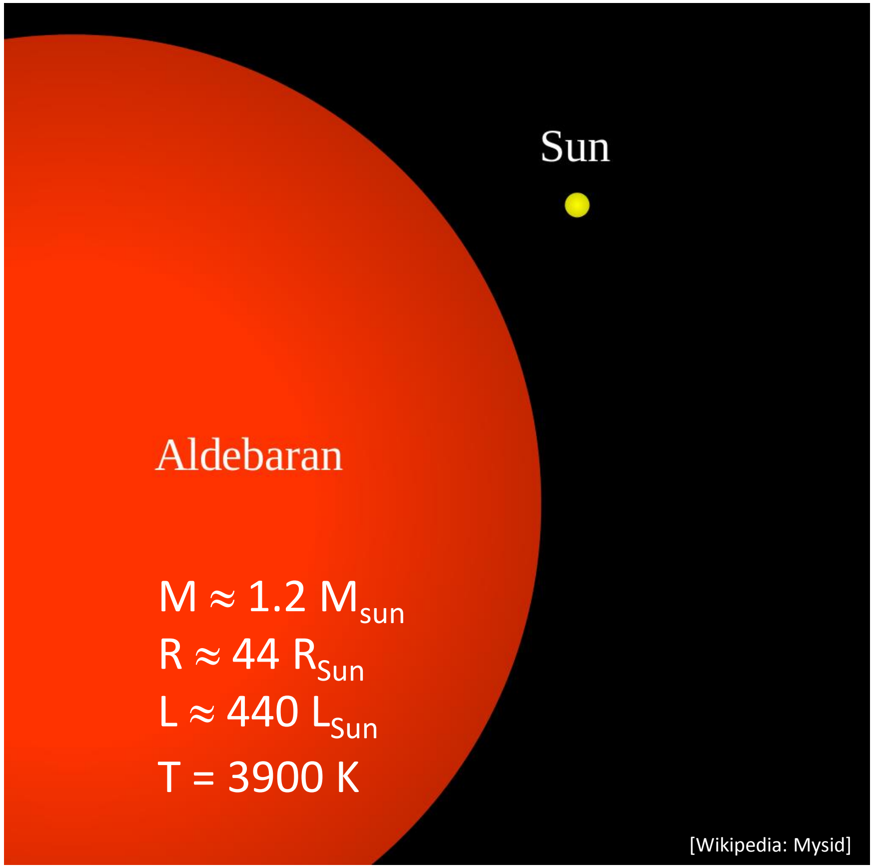


Red Giants & Supergiants

Red Giants

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



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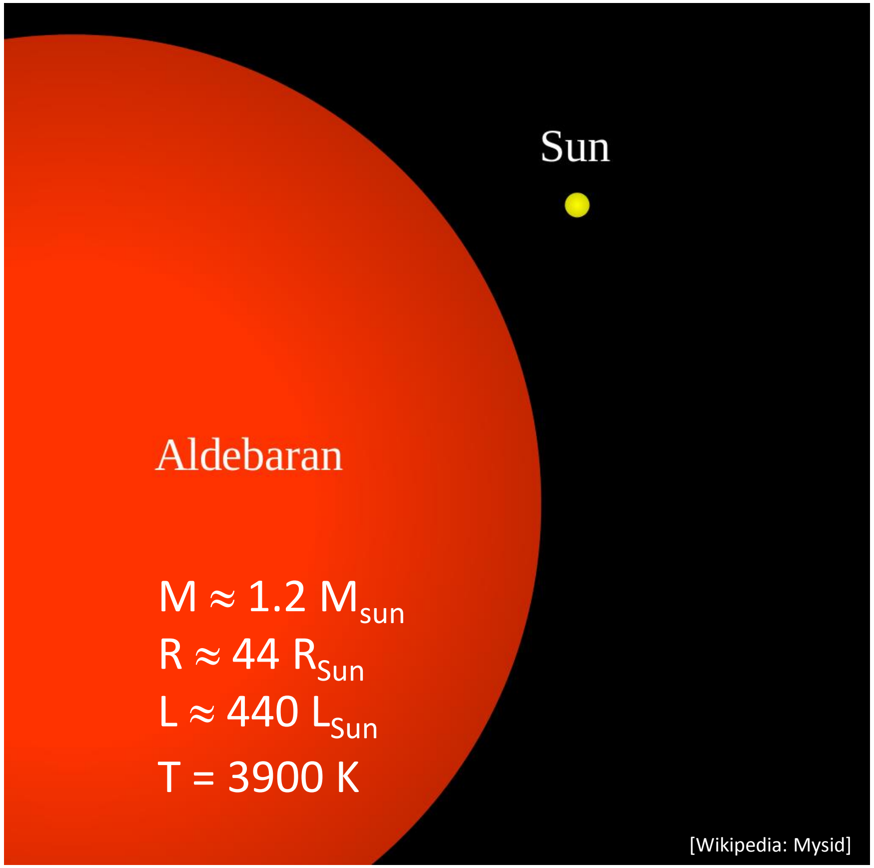
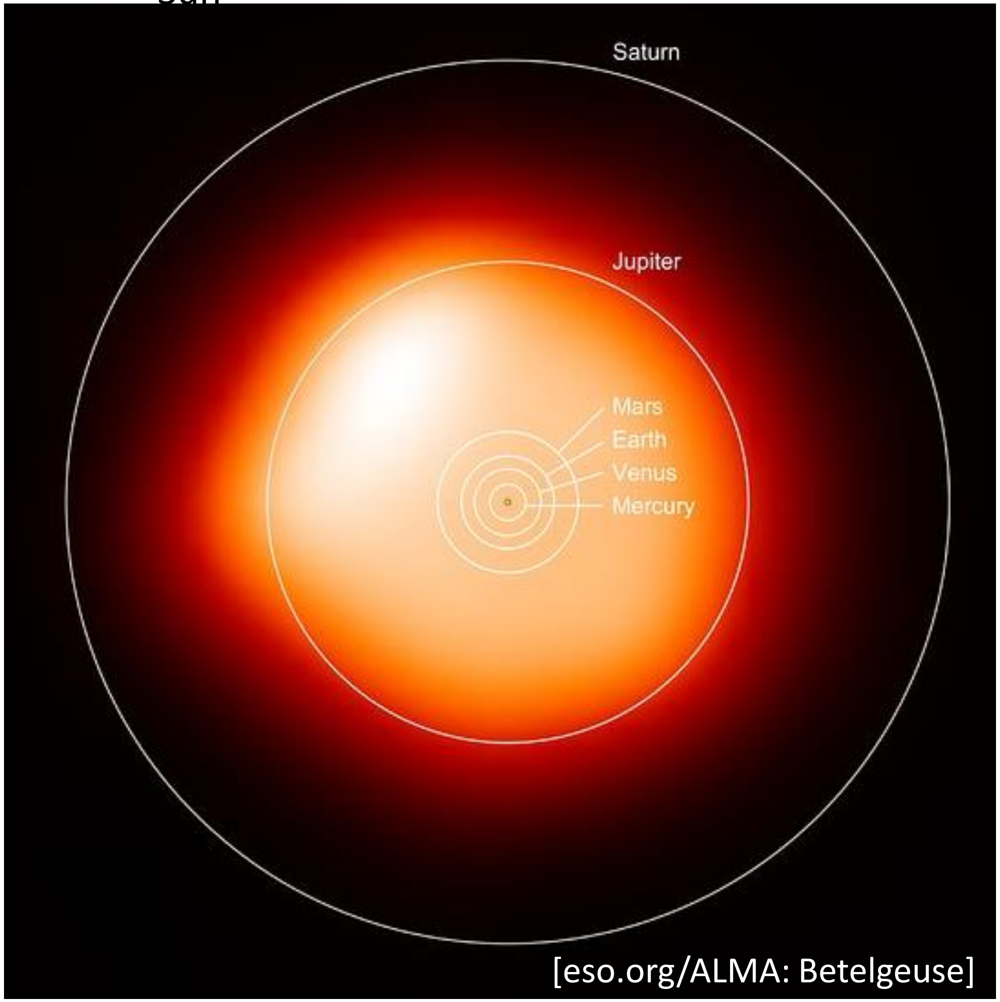
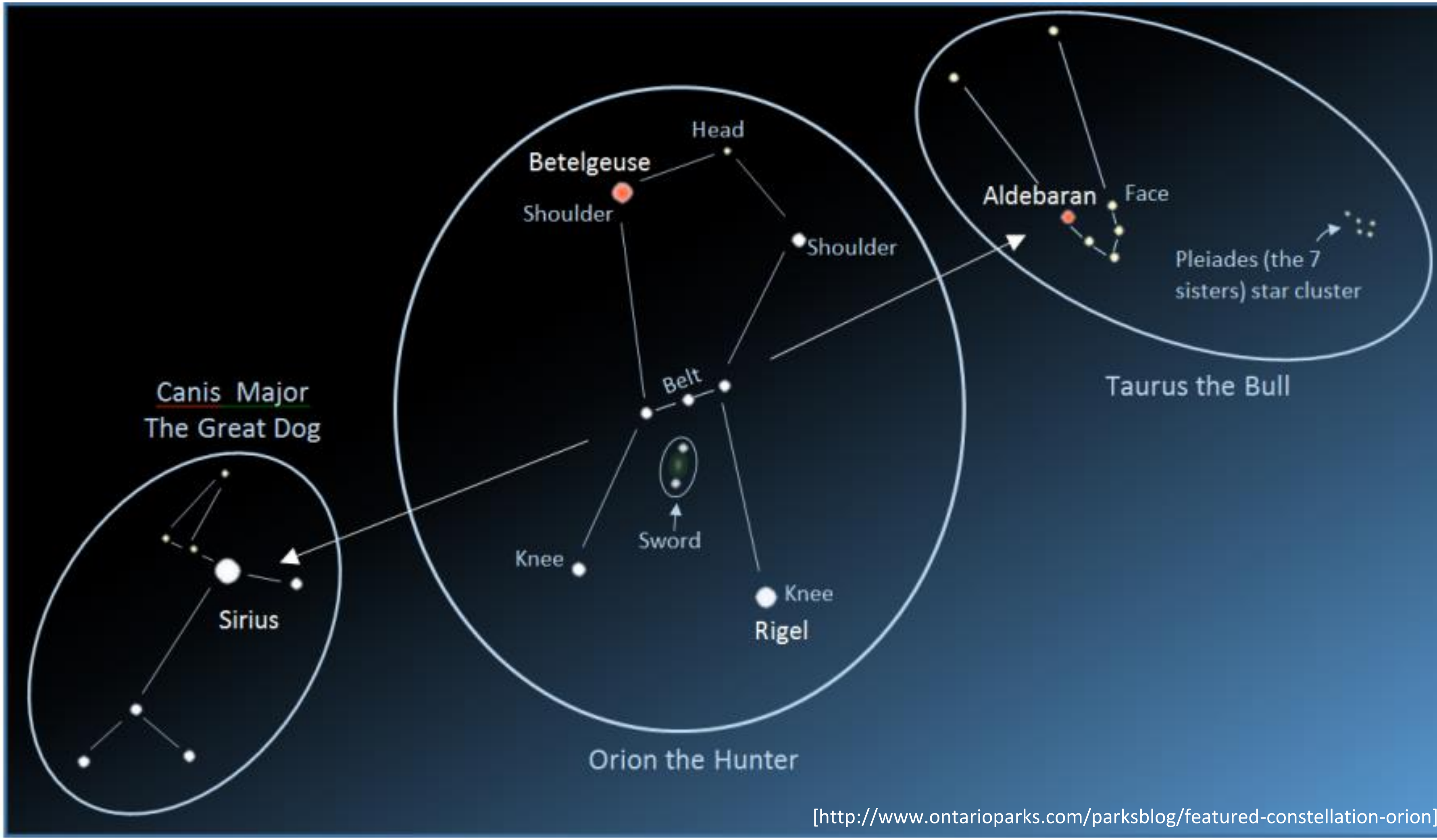


Red Supergiants

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



Aldebaran & Betelgeuse in the Sky



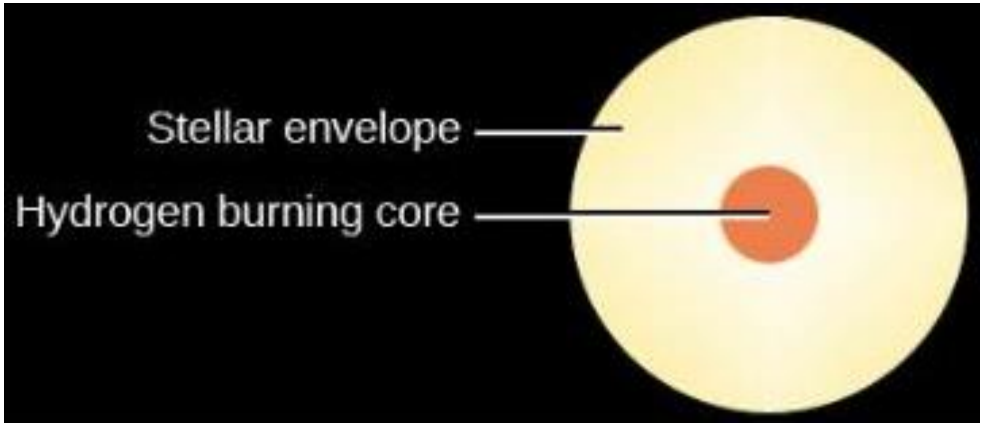
[http://www.ontarioparks.com/parksblog/featured-constellation-orion]

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	~ 1 → 0.01	~ 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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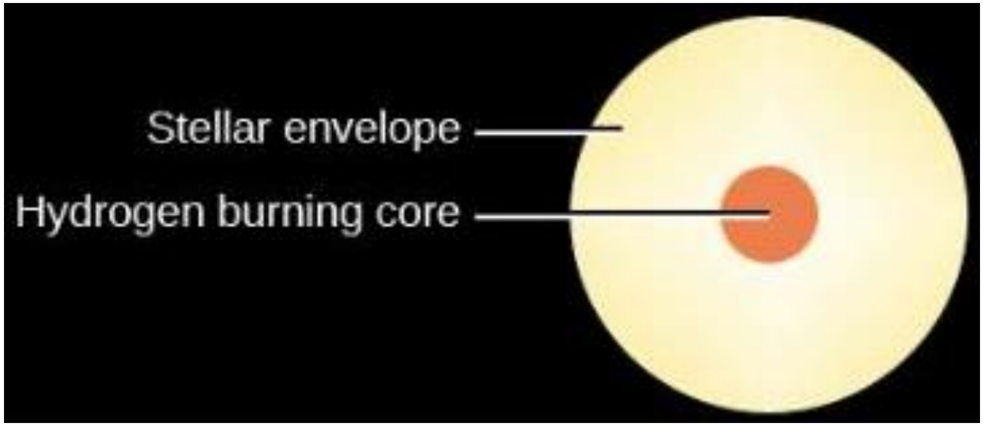

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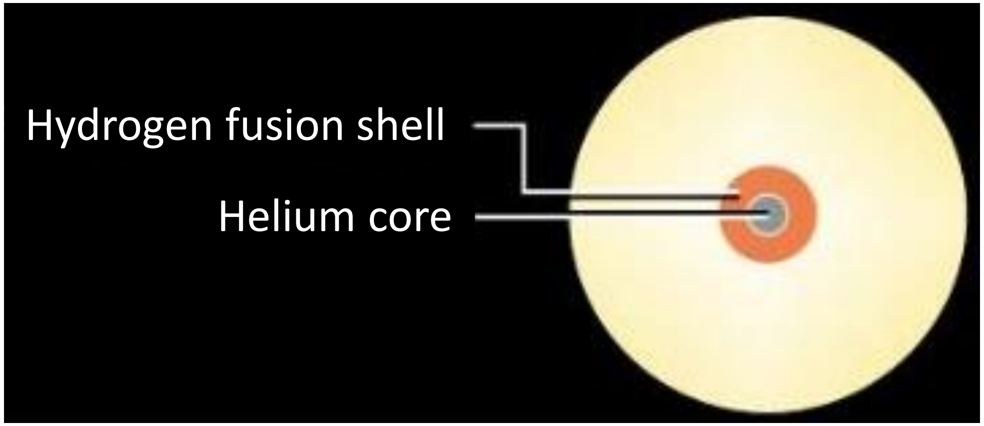

2. Core hydrogen exhausted

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

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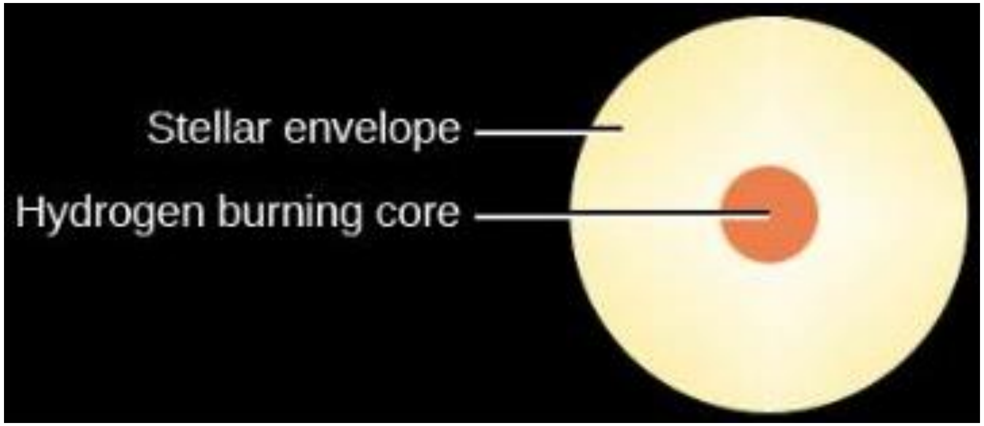

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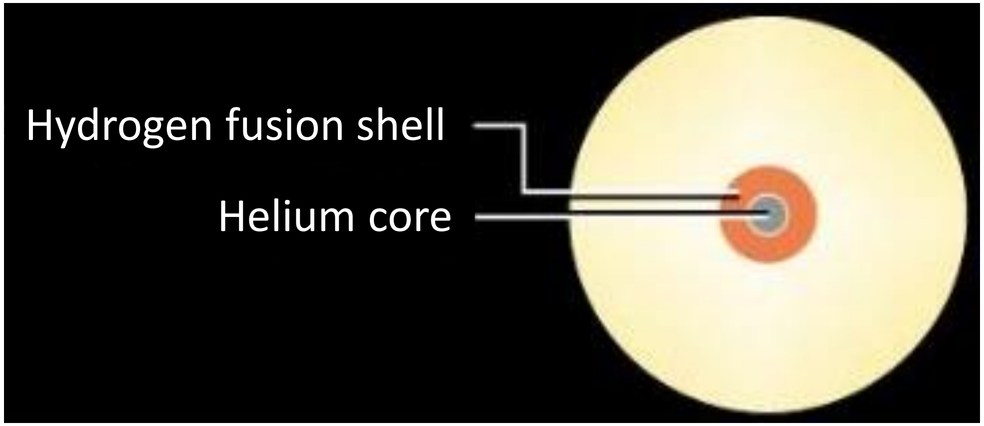
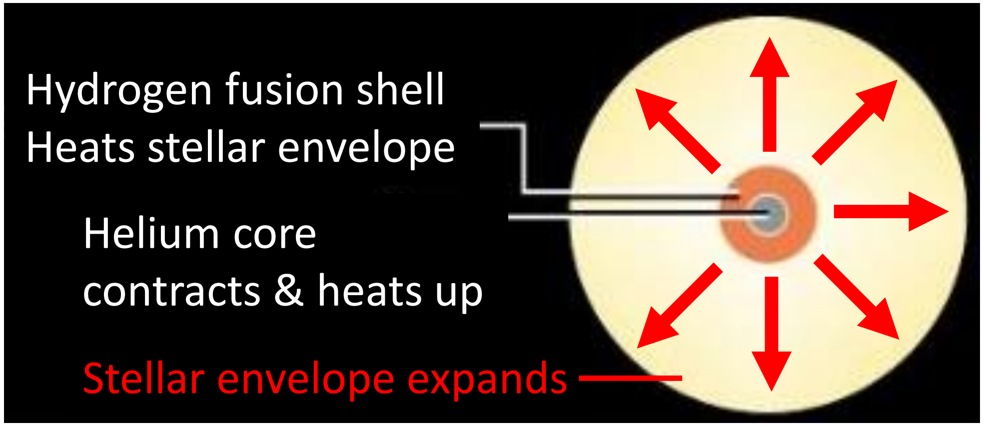


3. Expansion to red giant

- **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 ≈ 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):

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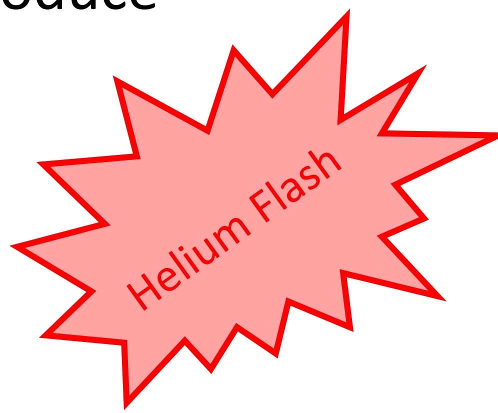
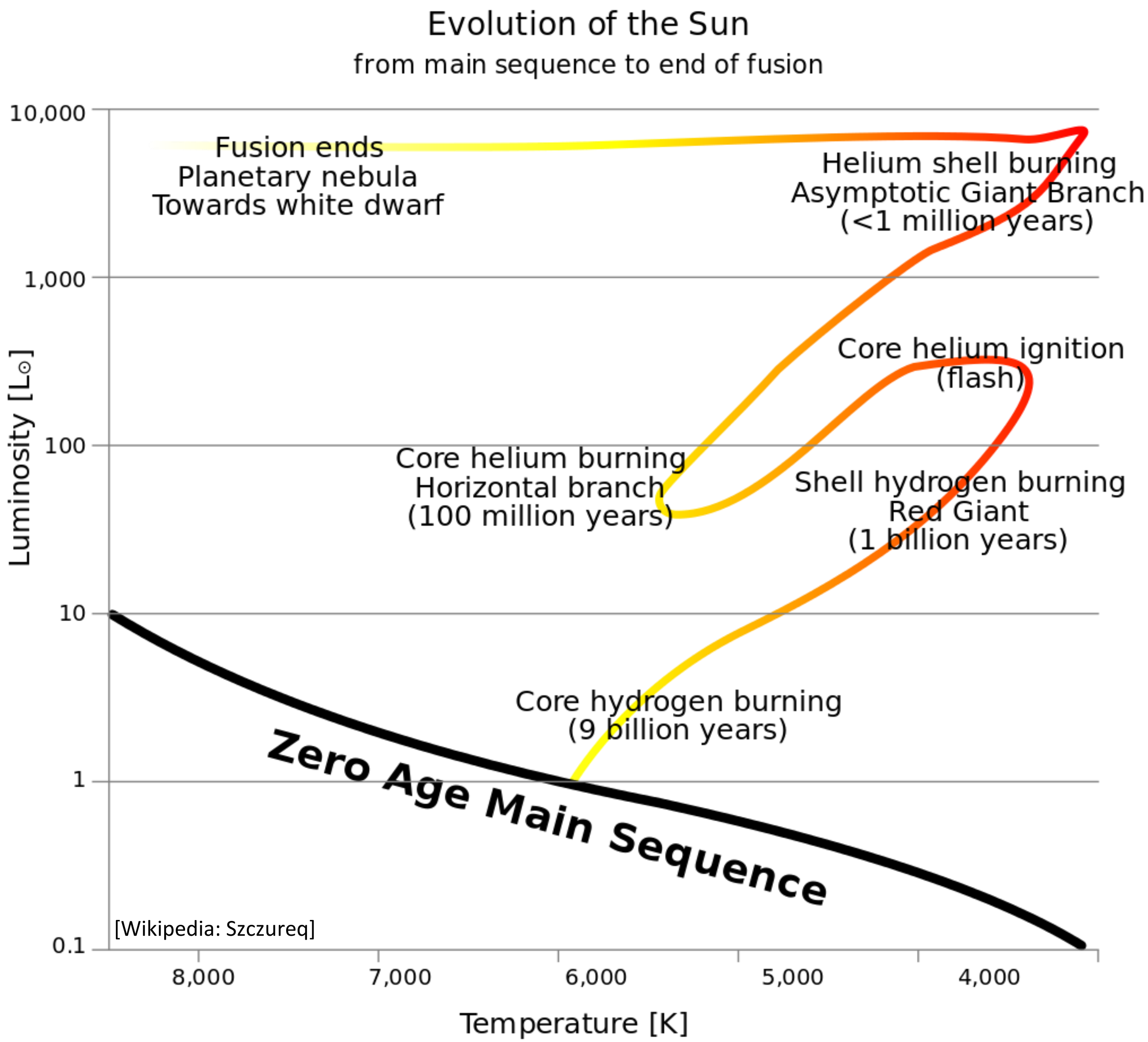
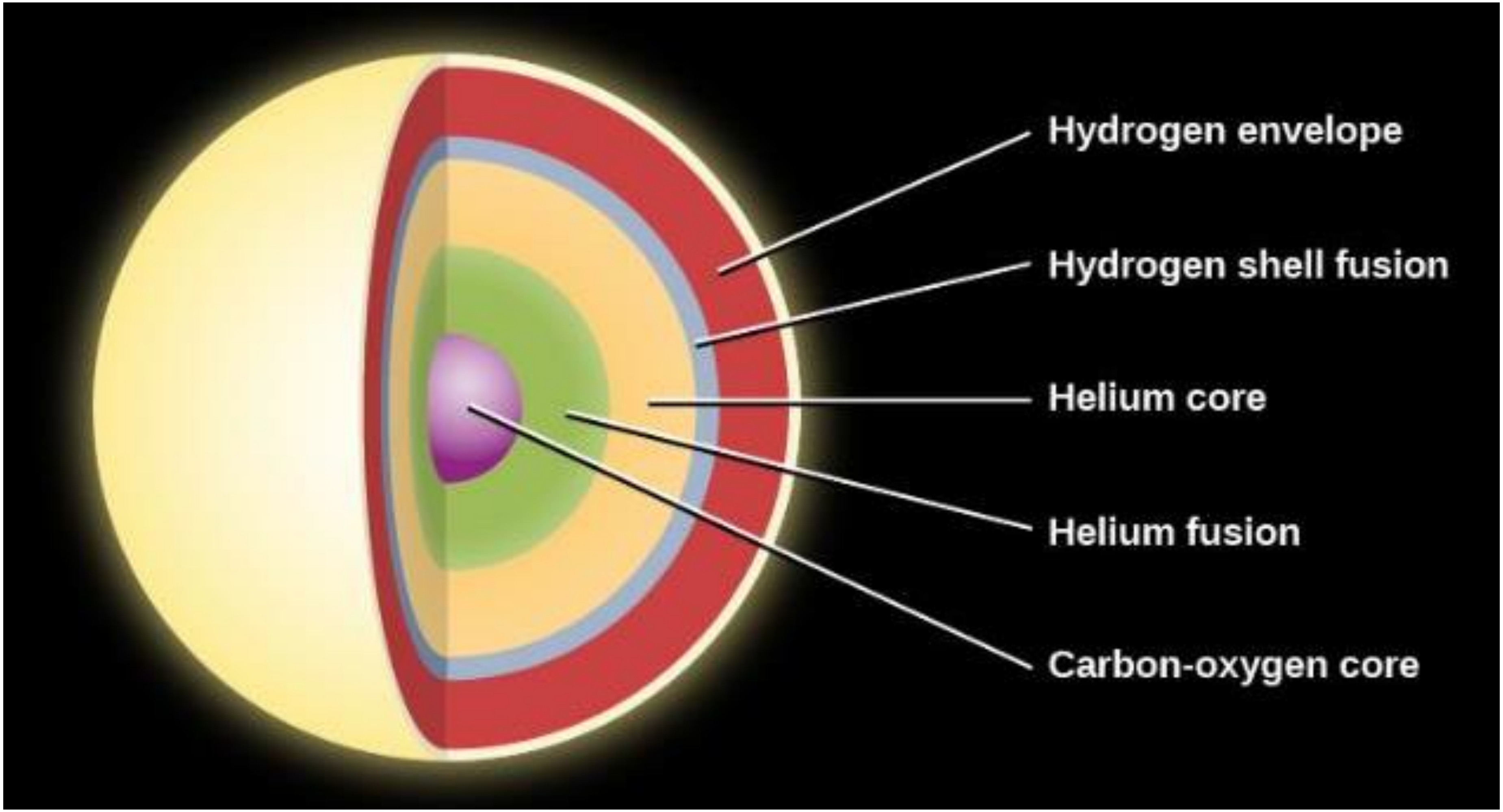


Helium Flash (for Sun-like stars)
The fusion of helium into carbon happens very quickly (possibly in a few minutes).

Red Giant Evolution from Sun-like Star



Structure of Red Giant Star before "Death"



Mass Loss: Planetary Nebula

- Over the course of its red giant phase, a Sun-like star is expected to **shed roughly 50% of its mass**.
- This ejected mass becomes a **planetary nebula** with a **white dwarf** at its center.

(note: planetary nebula has nothing to do with planets)

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[Ant nebula: NASA/ESA/Hubble]

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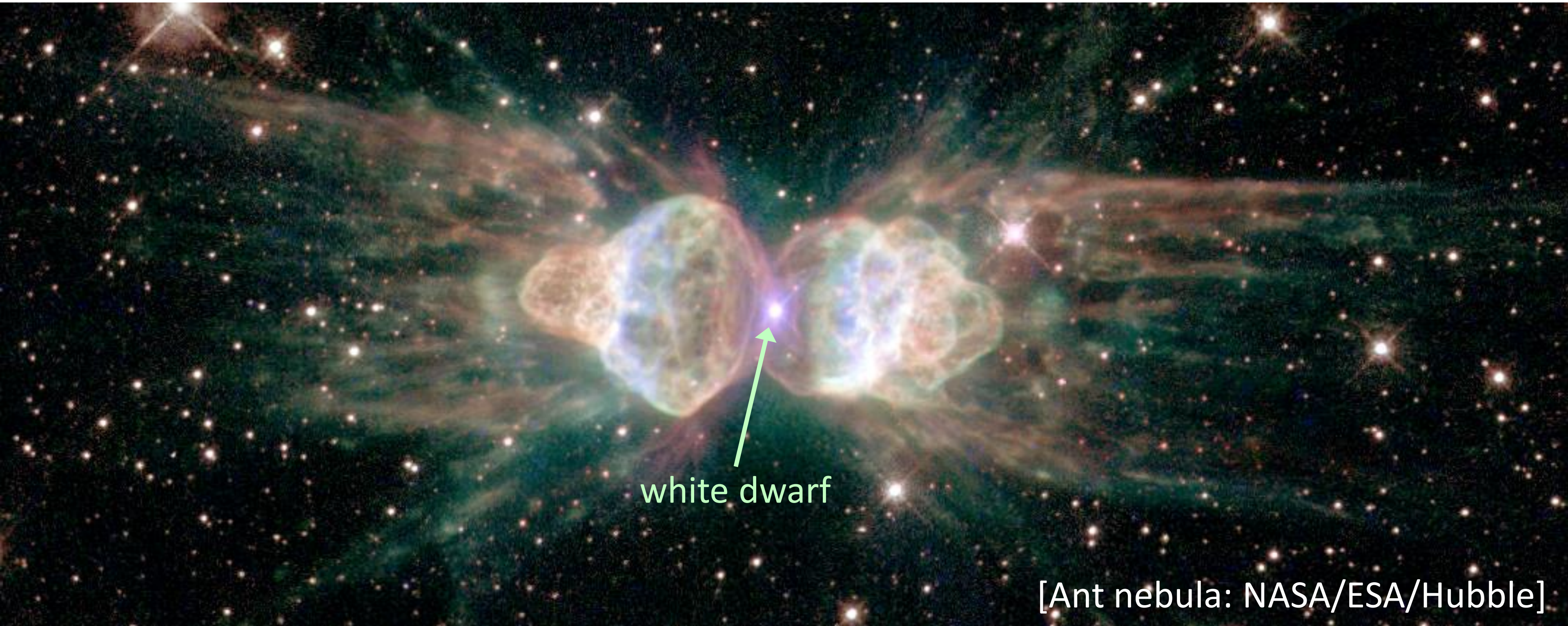

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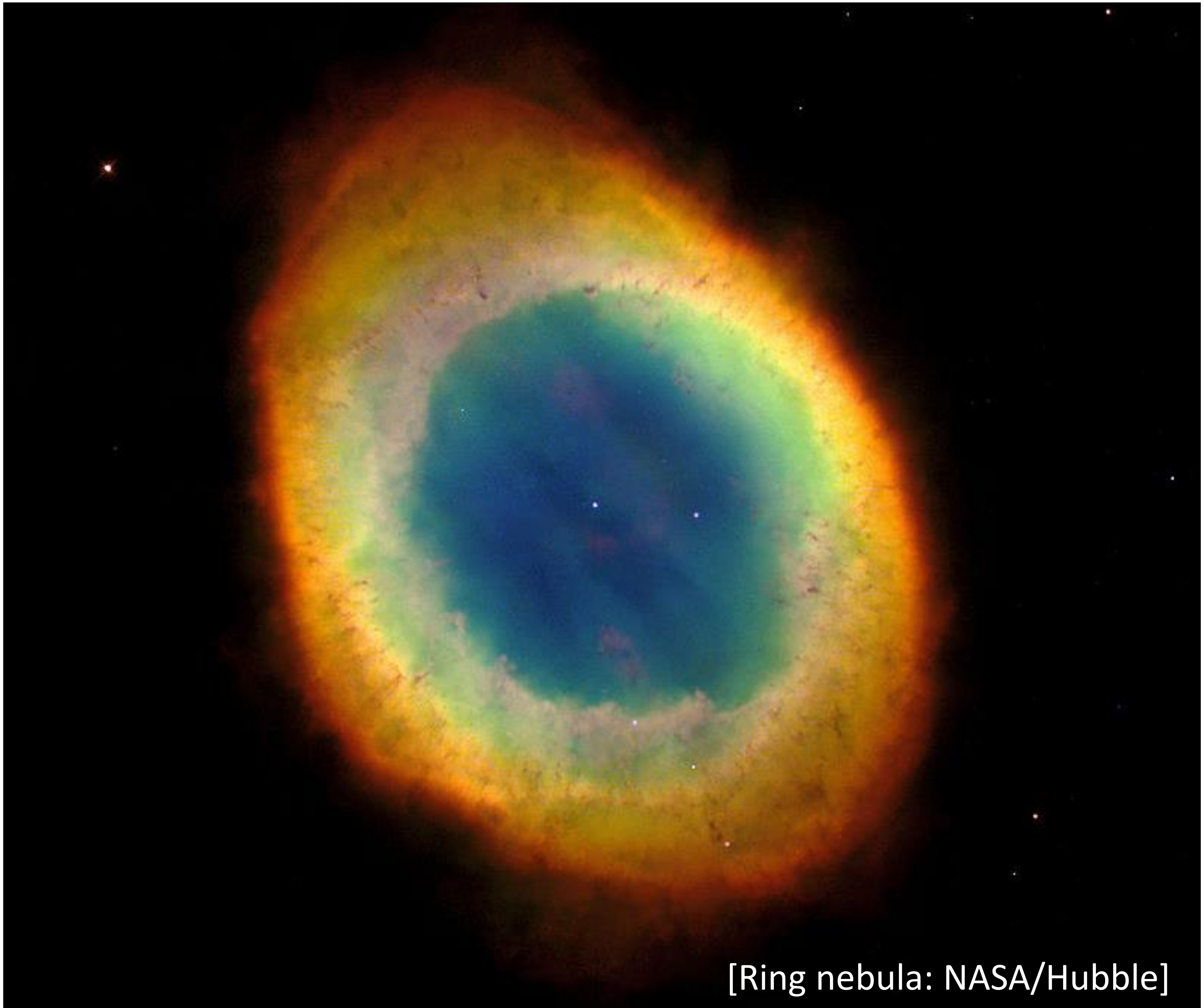

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