Recap: lecture 14

Solar Thermostat

pressure is dependent on the temperature

- **gas pressure**
- **radiation pressure**

Recap: lecture 14

Solar Thermostat — pressure is dependent on the temperature

- gas pressure
- radiation pressure

Degeneracy pressure — pressure is independent on the temperature

- electron degeneracy pressure
- neutron degeneracy pressure

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nuclear burning in degeneracy condition is unstable

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Solar Thermostat — pressure is dependent on the temperature

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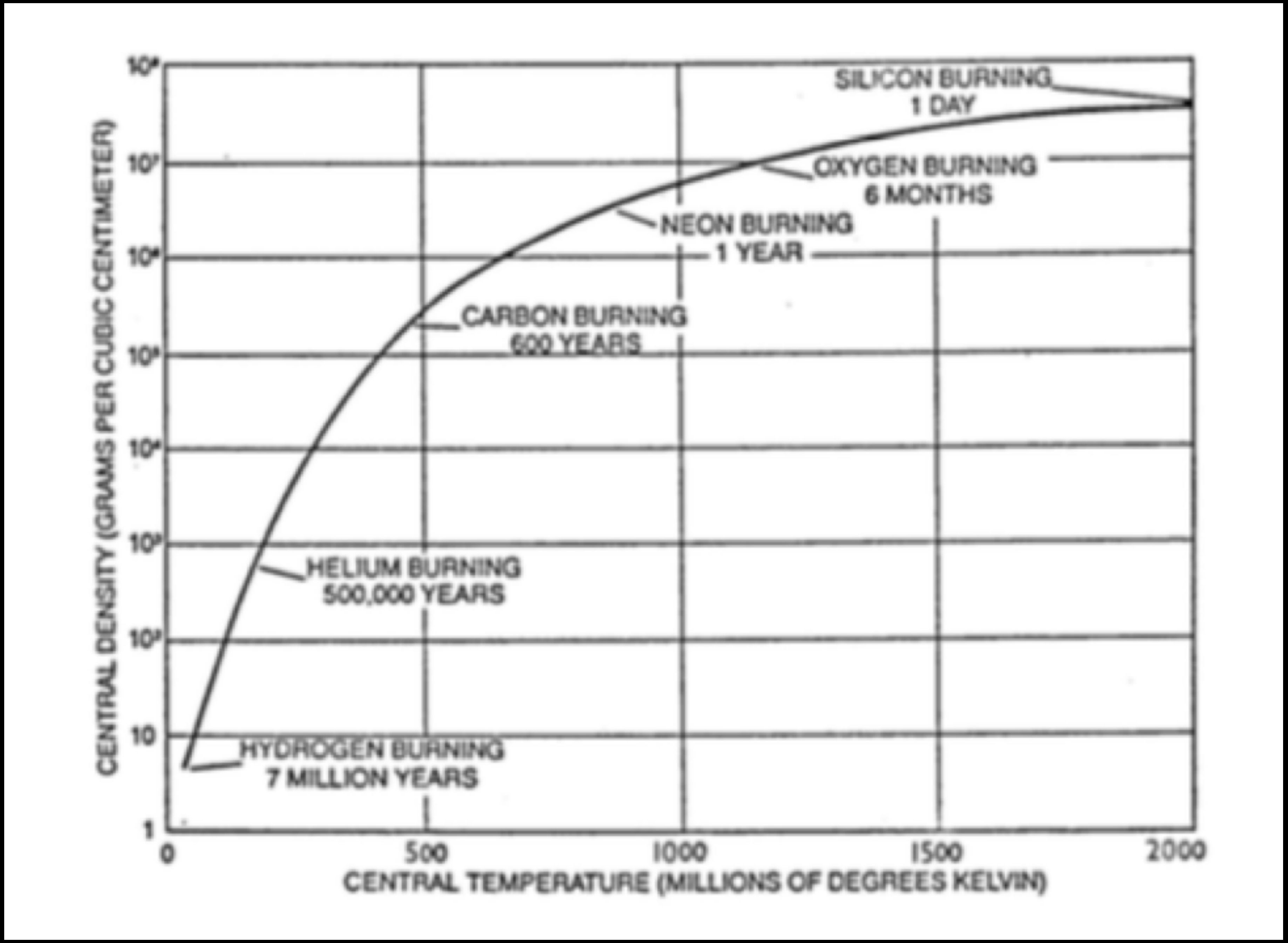
nuclear burning in degeneracy condition is unstable

- Helium flash in low mass stars at the end of the red giant phase
- Helium burning in the shell (during the two shell phase, AGB) create the pulses that strip the low mass stars

Recap: lecture 14

The star contract while not producing enough energy with nuclear burning. Temperature increase and start to burn a different element.



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as the temperature increase in the star more reactions will happen: Hydrogen, Helium, Carbon ……

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Stellar evolution depends on the mass of the star

Recap: lecture 14

Brown Dwarf below 0.08 M⊙

No Hydrogen burning technically not a stars

very low-mass stars between 0.08 M⊙ and 0.8 M⊙

low-mass stars between 0.8 M⊙ and 2 M⊙

intermediate-mass stars between 2 M⊙ and 8-10 M⊙

massive stars more massive than 8-10 M⊙

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Hydrogen burning $\longrightarrow$ Helium White Dwarf

(No star with $M<0.7\ M_\odot$ has actually evolved off the main sequence)

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develop a degenerate helium core after the main sequence, leading to a relatively long-lived red giant branch phase. The ignition of He is unstable and occurs in a so-called helium flash

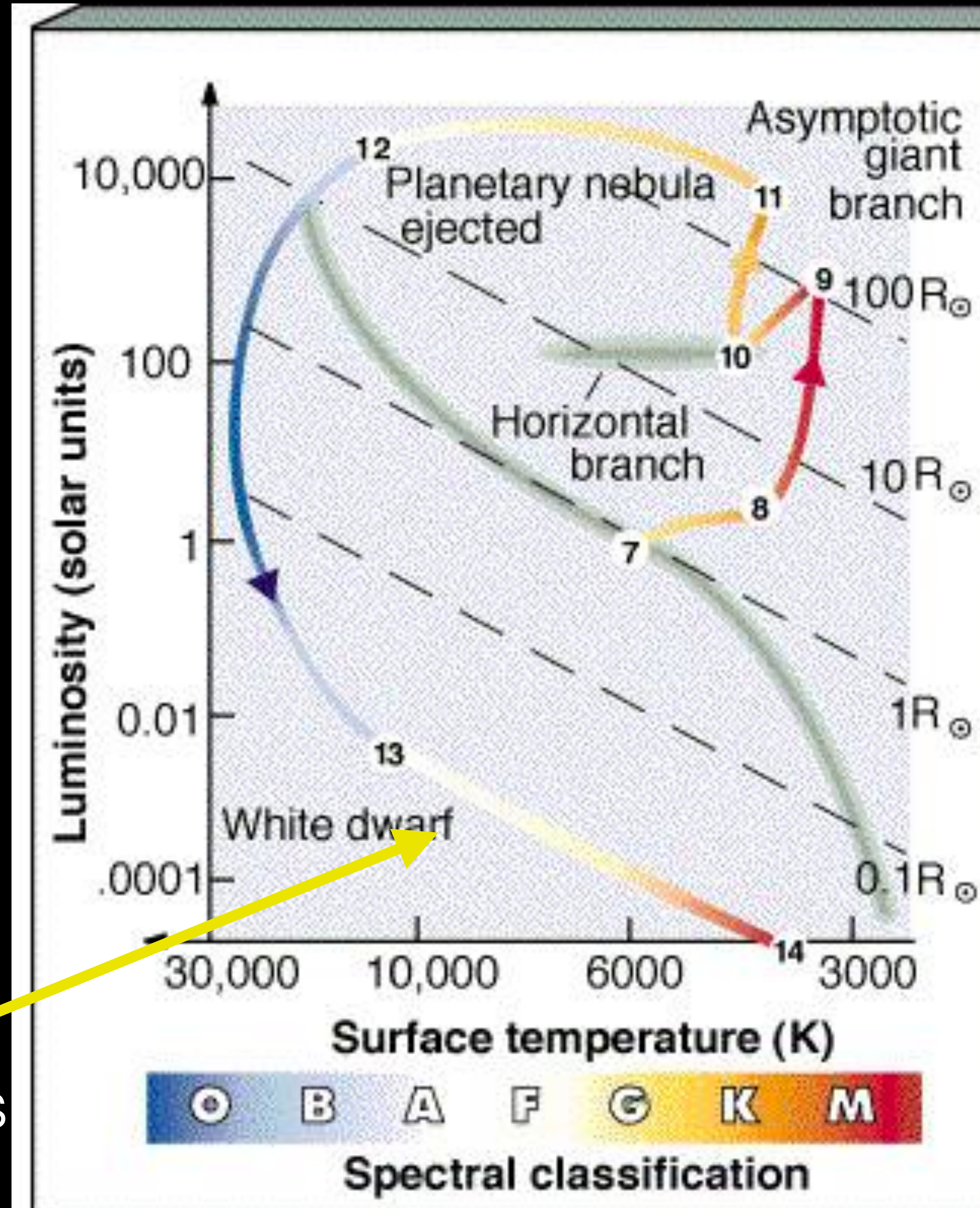
Low-mass stars shed their envelopes by a strong stellar wind at the end of their evolution and their remnants are CO white dwarfs

intermediate-mass stars between 2 $M_\odot$ and 8-10 $M_\odot$

massive stars more massive than 8-10 $M_\odot$

low mass stars

Main sequence:
H fuses to He in core.
Red giant:
H fuses to He in shell around He core.
Helium core burning:
He fuses to C in core while H fuses to He in shell.
Double shell burning:
H and He both fuse in shells.
Planetary nebula leaves white dwarf behind.



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Very low-mass stars after burning H in the shell, do not reach the temperature to burn Helium and that will end as **He white dwarfs** soon after the RSG branch

low-mass stars

between 0.8 $M_\odot$ and 2 $M_\odot$

develop a **degenerate helium core** after the main sequence, leading to a relatively long-lived red giant branch phase. The ignition of He is unstable and occurs in a so-called **helium flash**

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intermediate-mass stars

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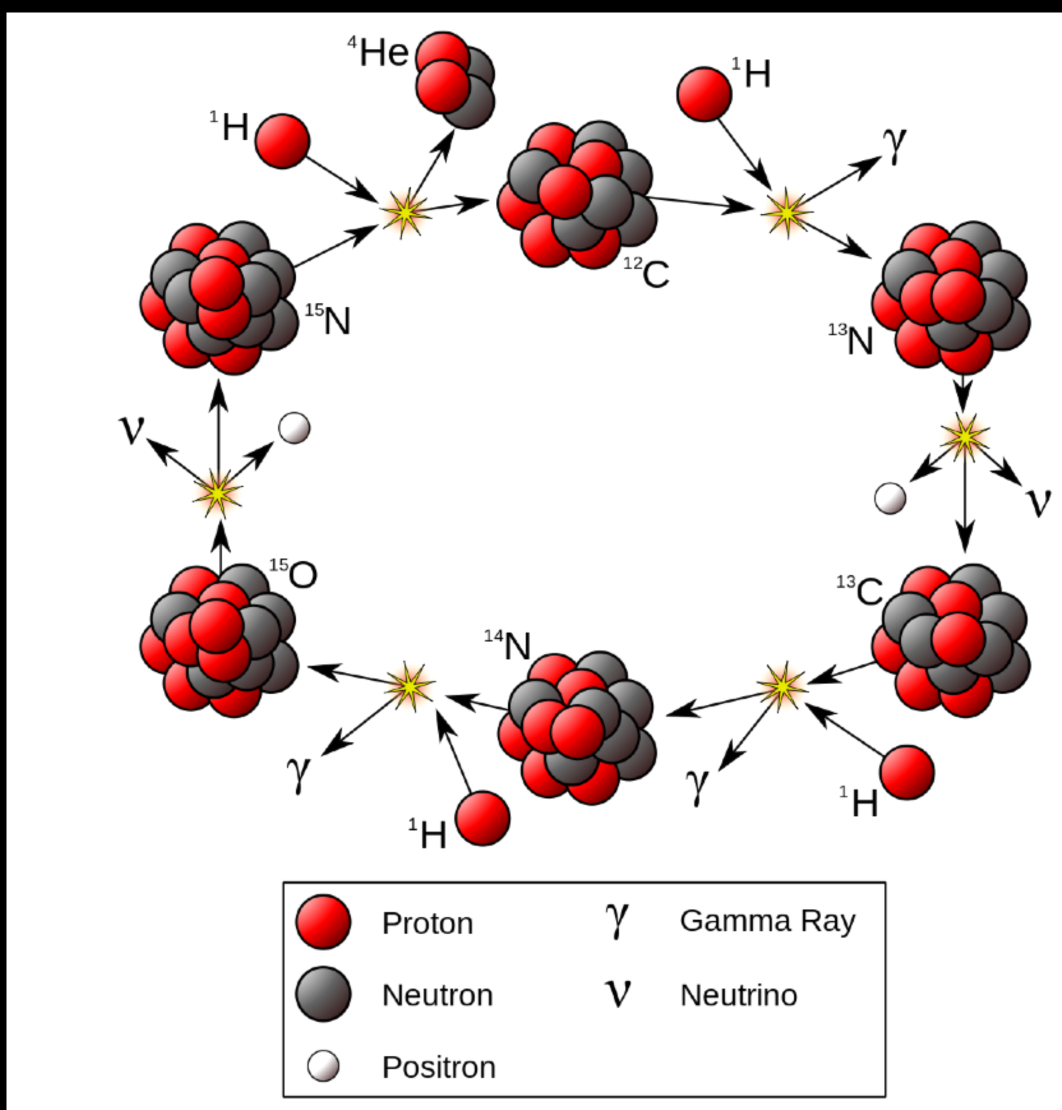
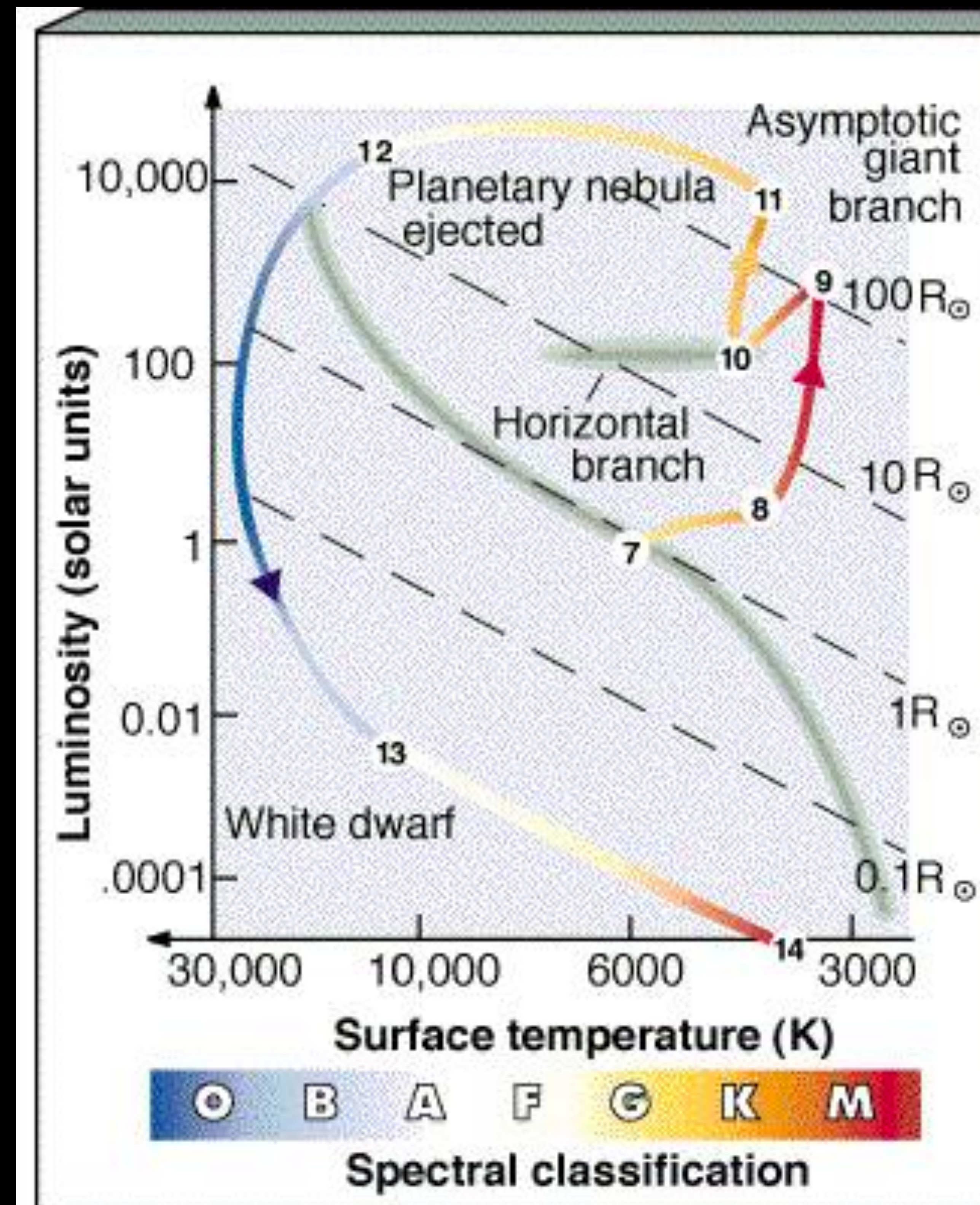
develop a **helium core** that remains **non-degenerate**, and they ignite helium in a **stable manner**. After the central He burning phase they form a **carbon- oxygen core that becomes degenerate**. Intermediate-mass stars shed their envelopes by a strong stellar wind at the end of their evolution and their **remnants are CO white dwarfs**

intermediate mass stars

main sequence

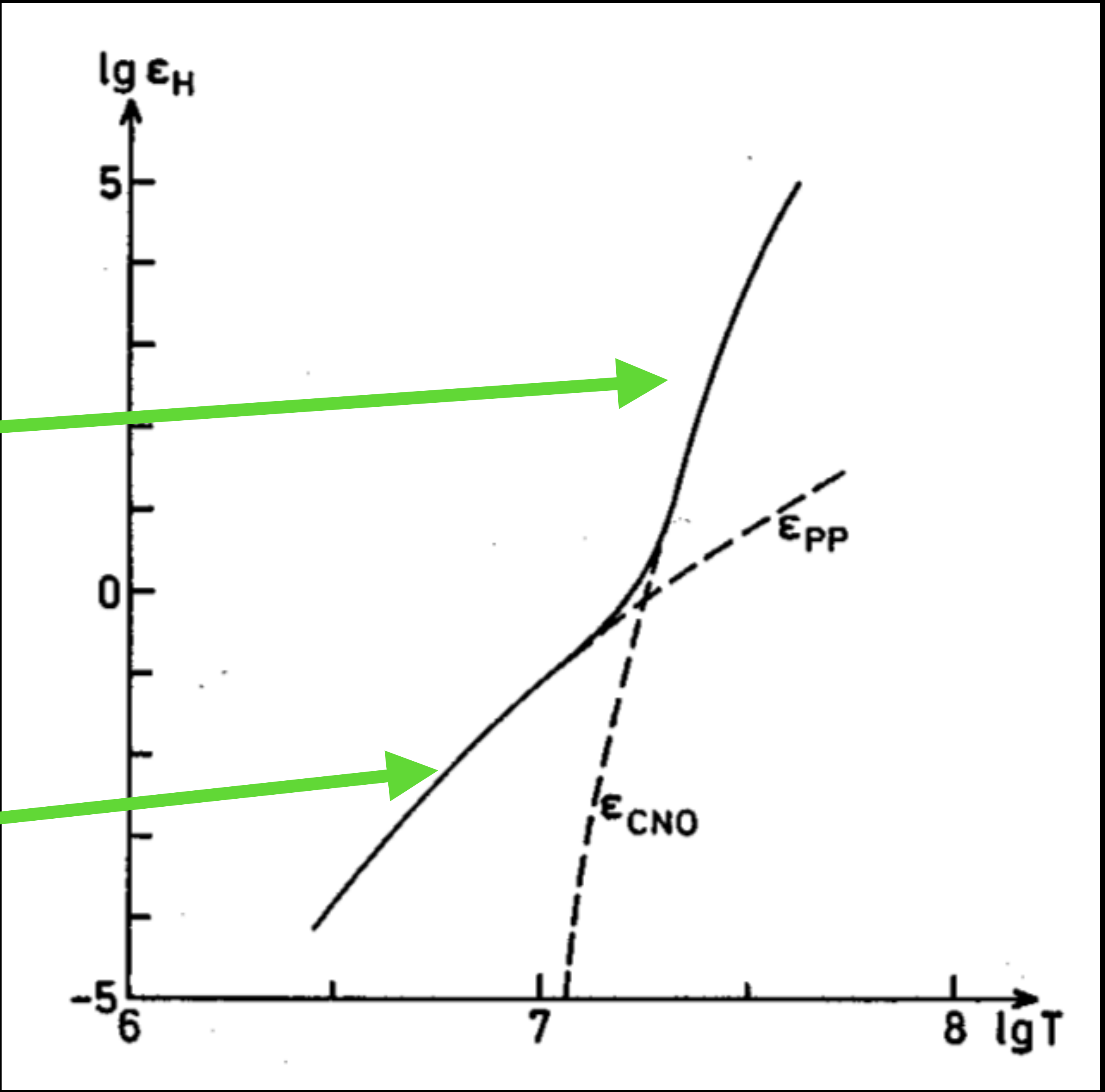
At higher temperatures, a different mechanism exists to fuse: CNO cycle





PP vs CNO

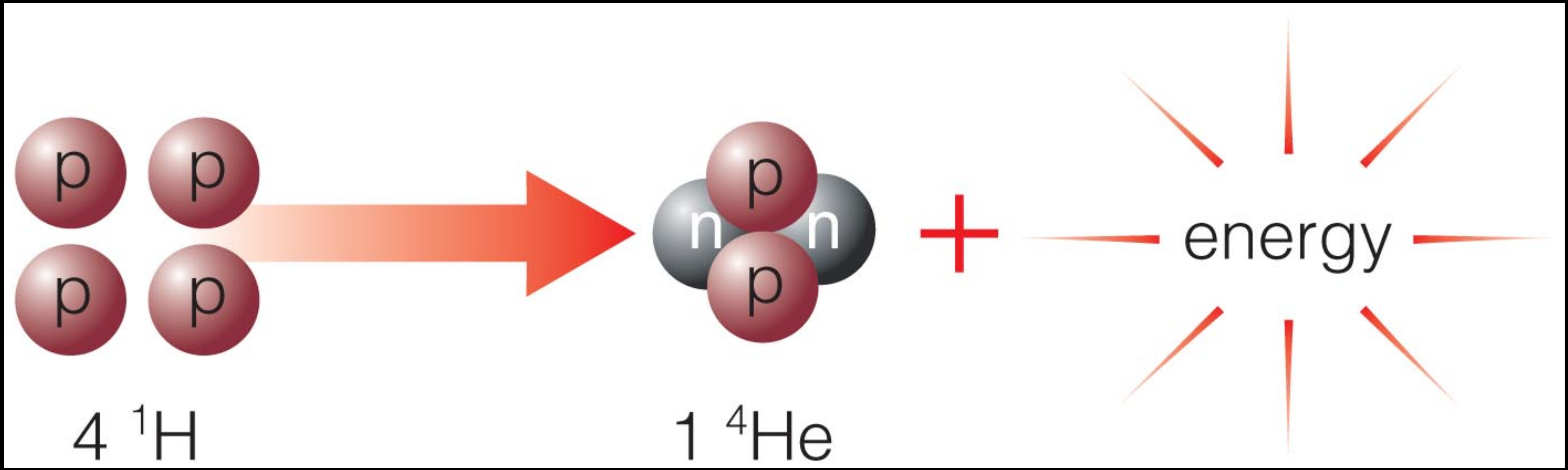
Temperature~10^7 K



High mass stars

Low mass stars

Energy Production in Stars: The short form.



4 Hydrogen Atoms fuse to make 1 Helium Atom and a bunch of energy.

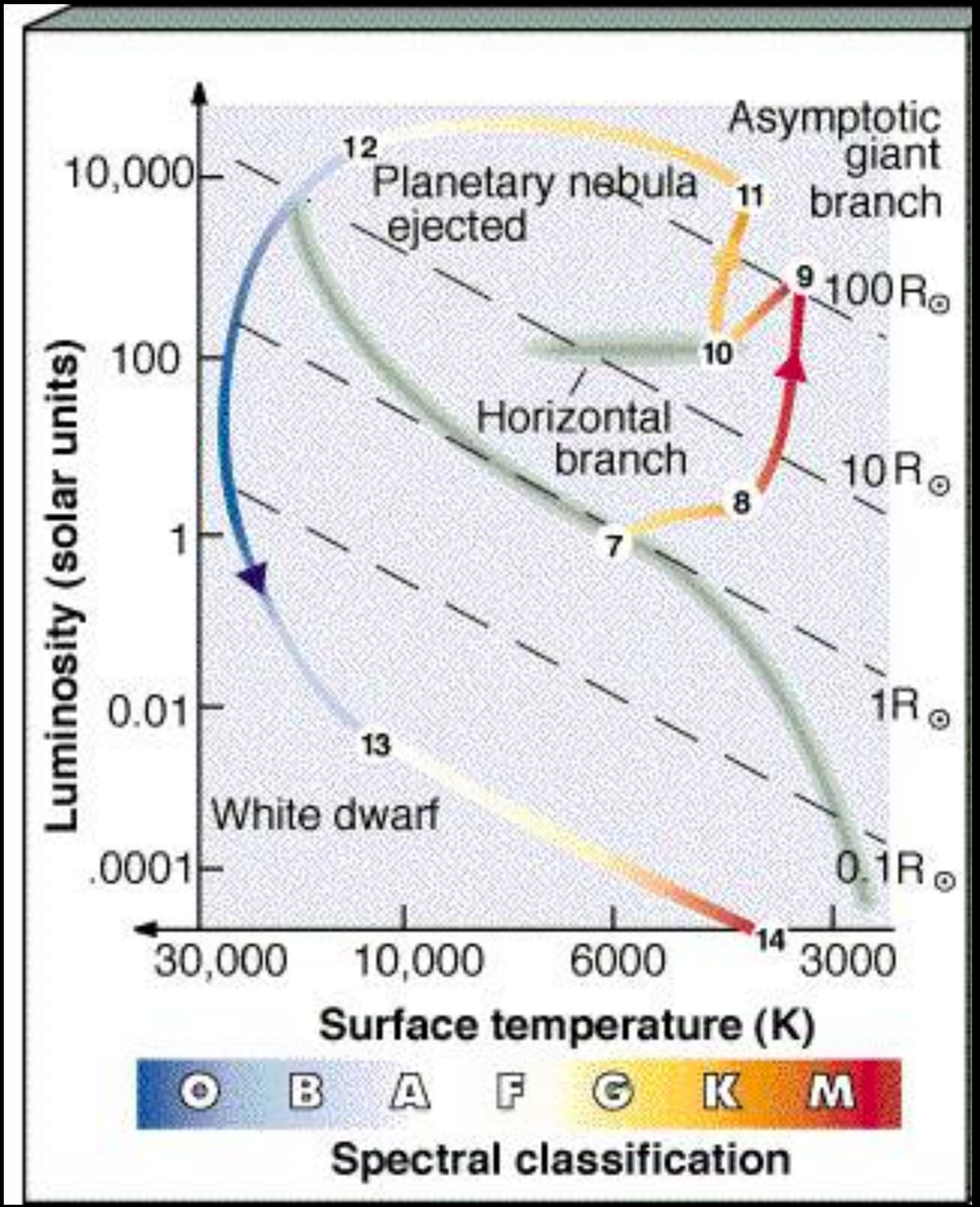
intermediate mass stars

main sequence

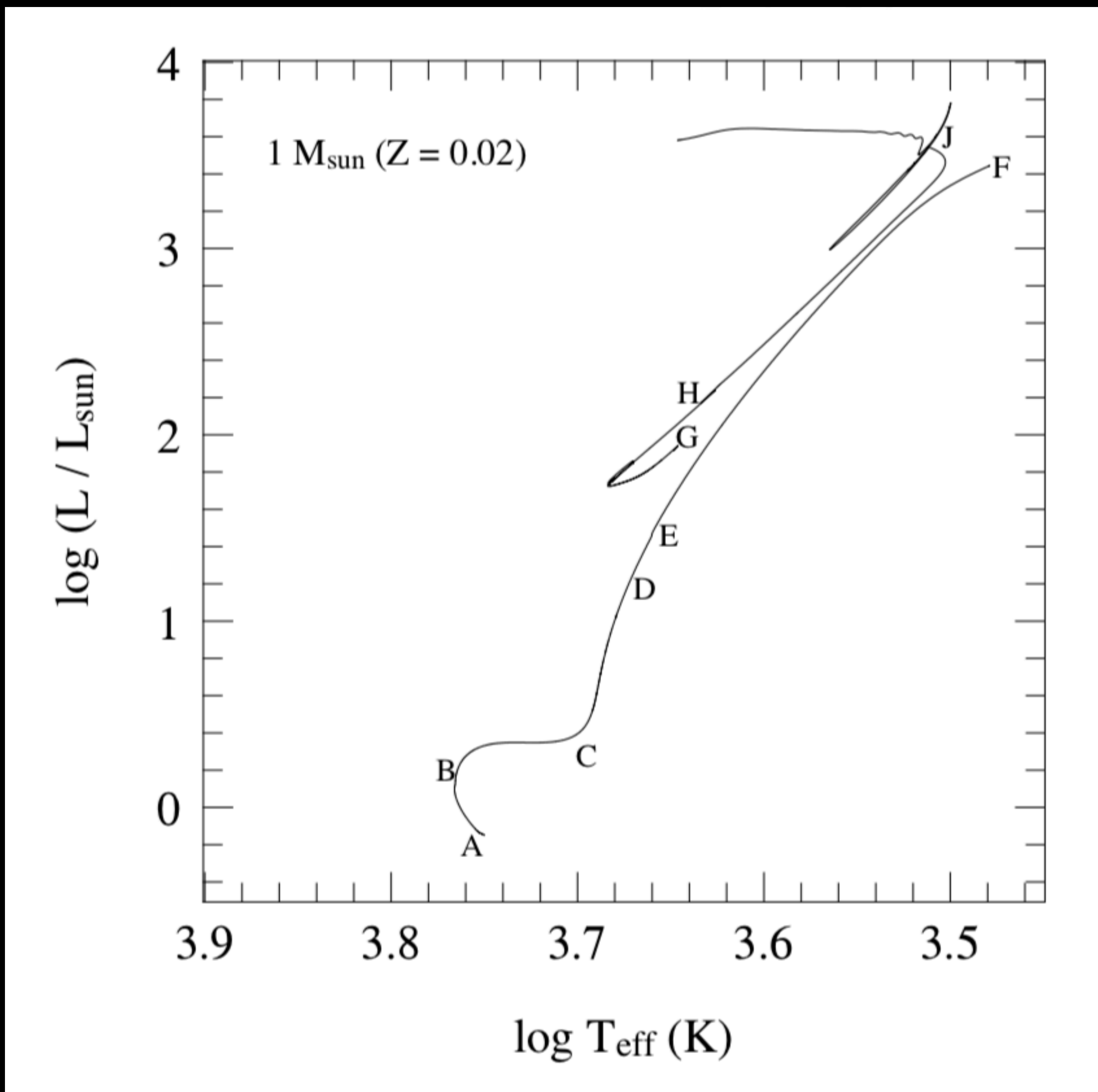
At higher temperatures, a different mechanism exists to fuse: CNO cycle

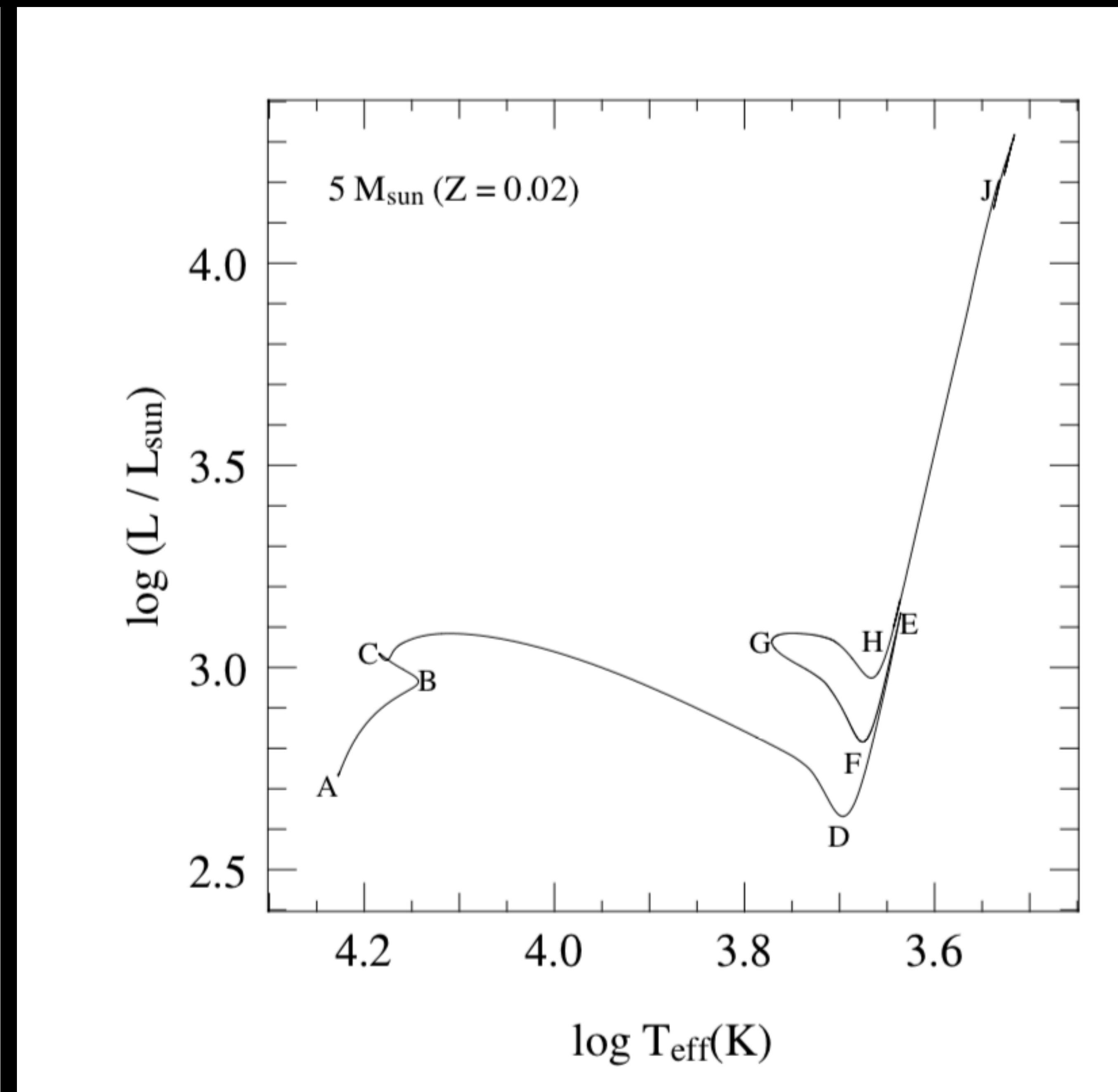
H burning in the shell

Helium core does not become degenerate so when the center run out of Hydrogen and we start to burn Hydrogen in a shell, the Helium core can contract much more than in low mass stars and the envelope expand and cool down much more that low mass stars.



low vs intermediate mass stars





intermediate mass stars

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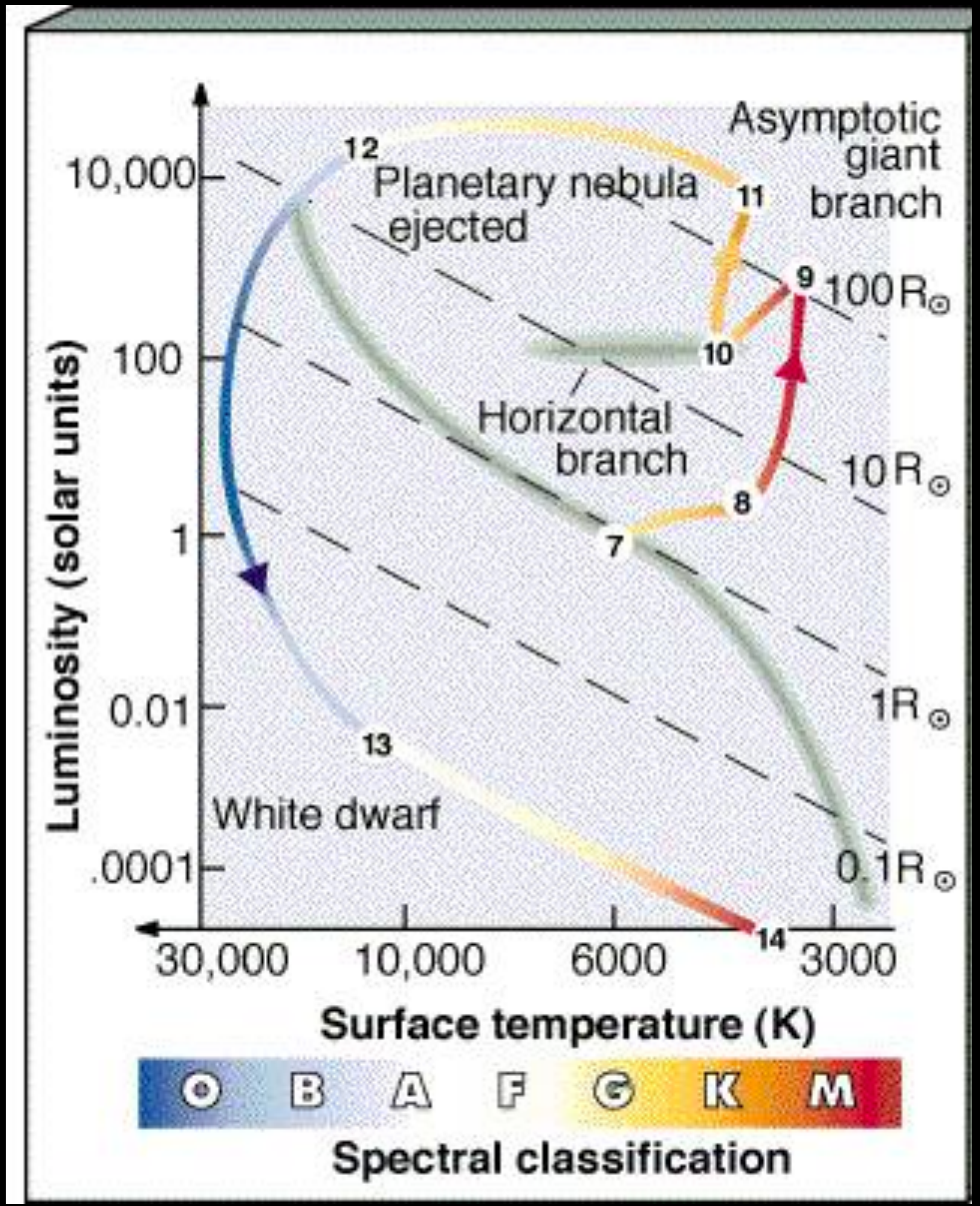

no Helium flash

intermediate mass stars

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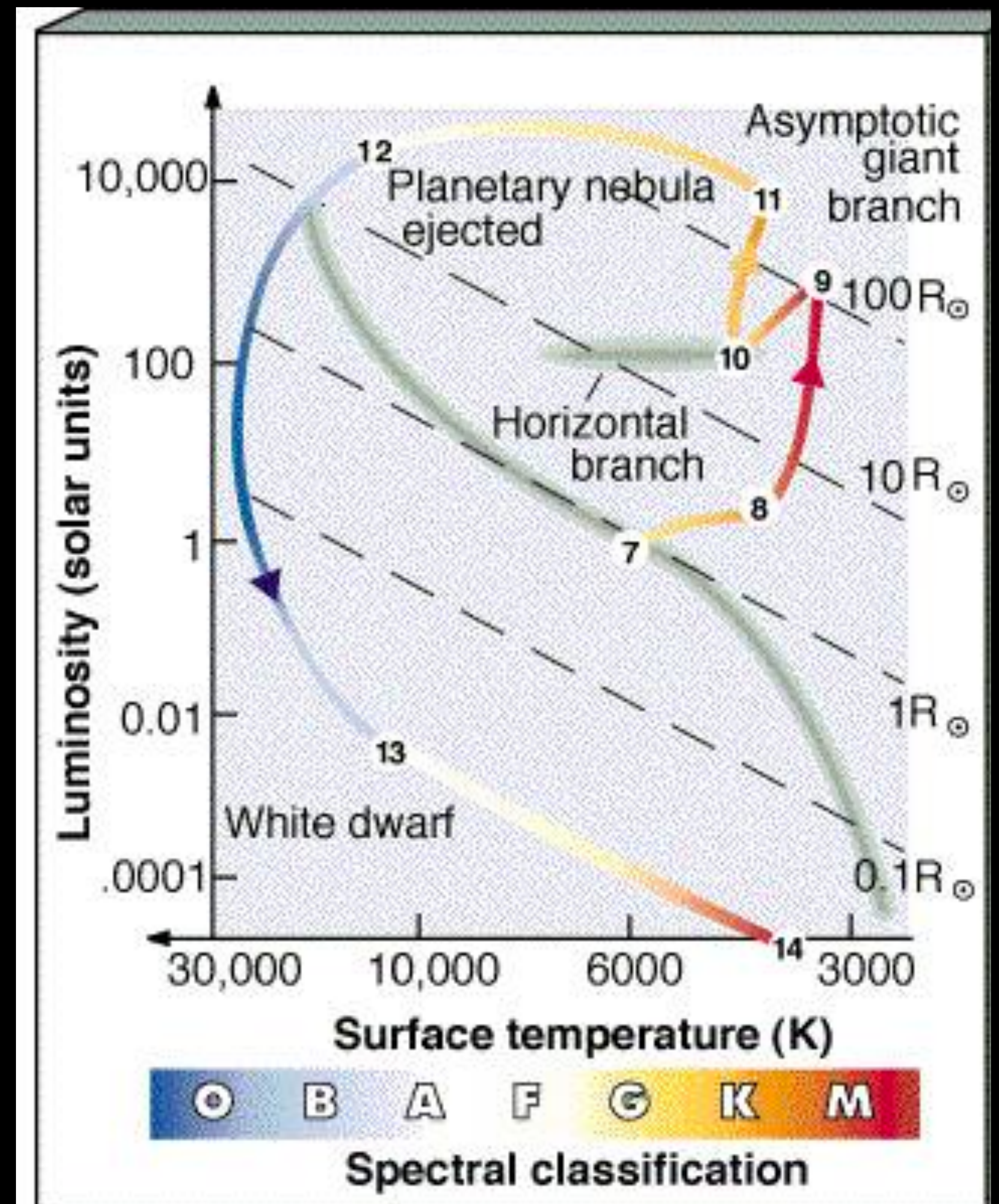

very low-mass stars   between 0.08 $M_\odot$ and 0.8 $M_\odot$

Very low-mass stars after burning H in the shell, do not reach the temperature to burn Helium and that will end as **He white dwarfs** soon after the RSG branch

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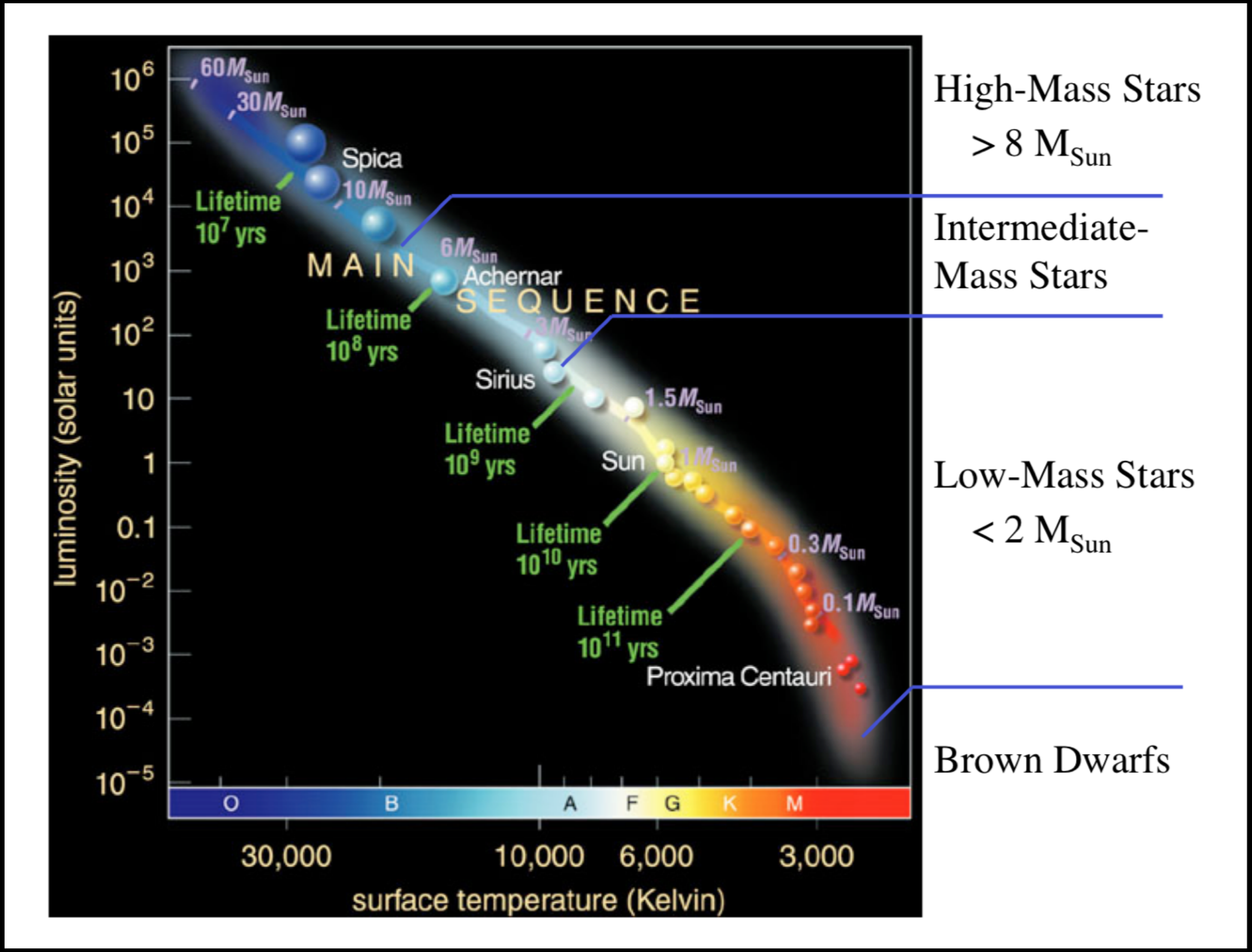
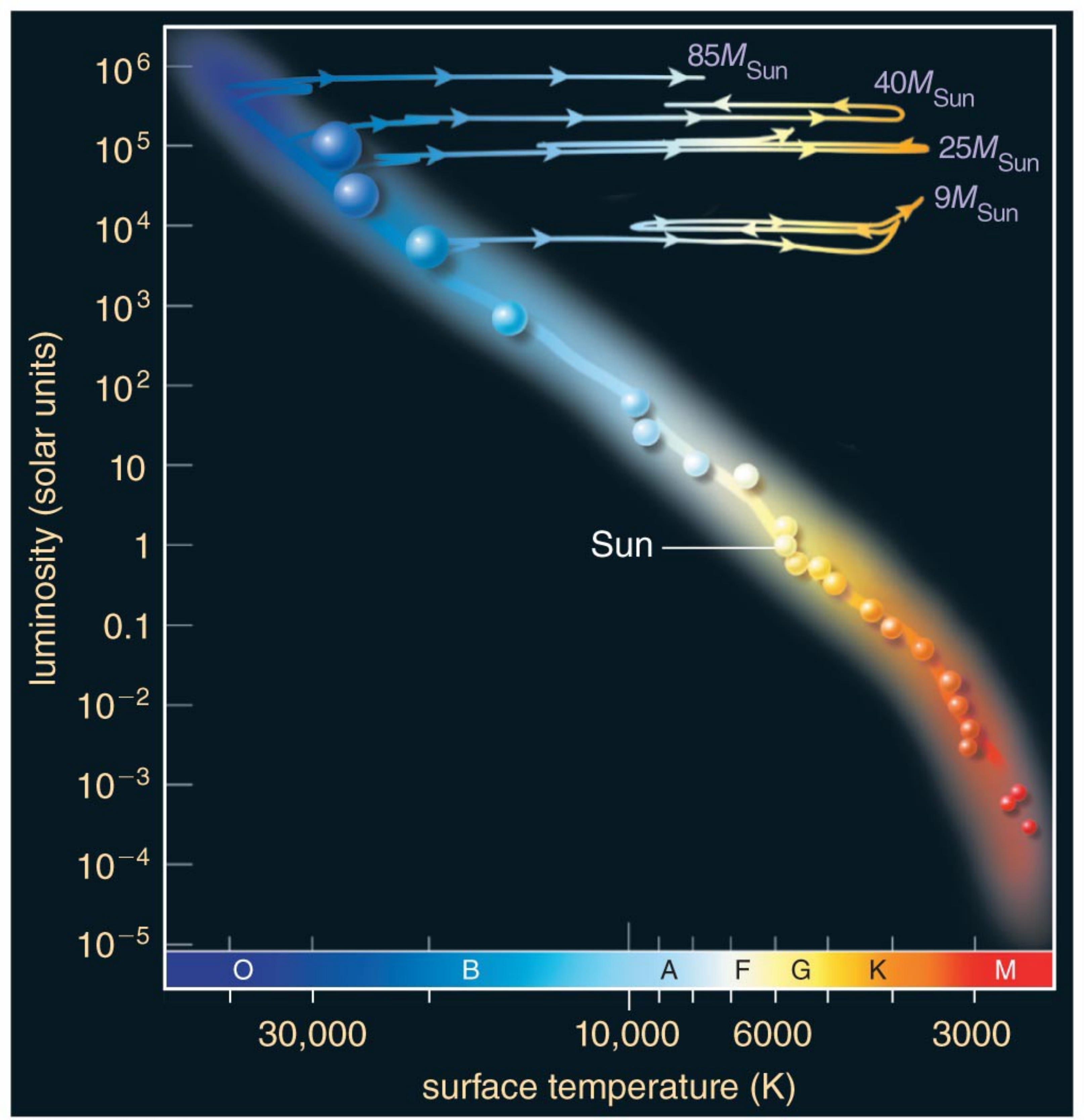
massive stars   more massive than 8-10 $M_\odot$

Massive Stars

Blue and luminous on the main sequence



Life tracks of high-mass stars



- High Luminosity for entire lifetime (which is short)
- Notice that they do not end up as white dwarfs…

The life cycle of high-mass stars

- Live fast, die young: they quickly run out of Hydrogen in the core
- Shell burning continues, but core keeps collapsing
- Core keeps heating up…

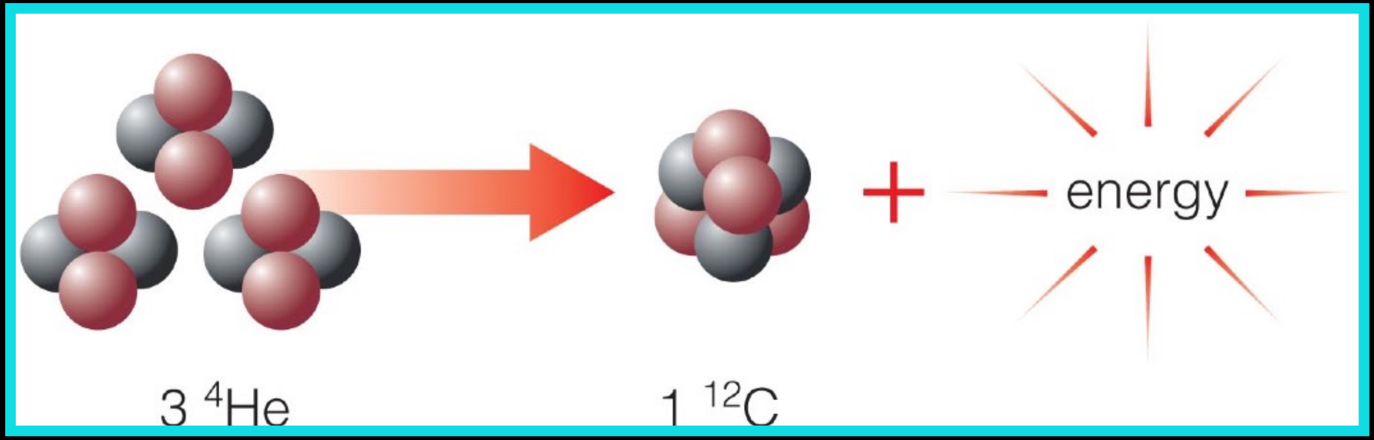
High-mass stars say:

- Dang! My core is hot, hot, hot
- Hey, I can burn up this next heavier element in my core
- Woohoo! Still shining!

But only while the next fuel lasts! Cycle repeats!

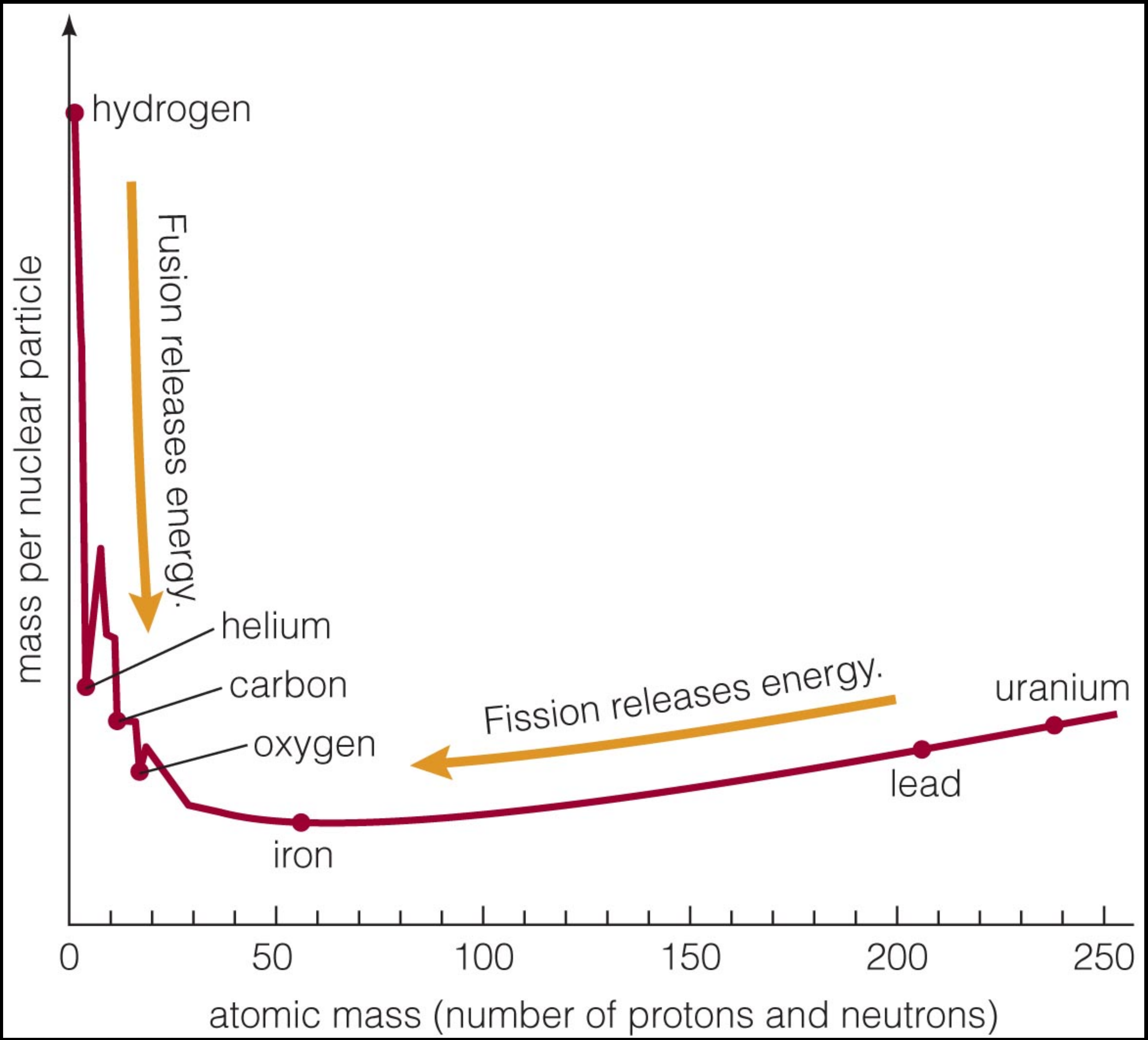
Life stages of high-mass stars

- Post-Main Sequence stages of high-mass stars are similar to those of low mass stars:
  - Hydrogen core fusion ends (end of main sequence lifetime)
  - Hydrogen shell burning (supergiant)
  - Helium core fusion (supergiant)



Core fusion and shell-burning fusion then continues with progressively heavier elements

Why Helium → Carbon?



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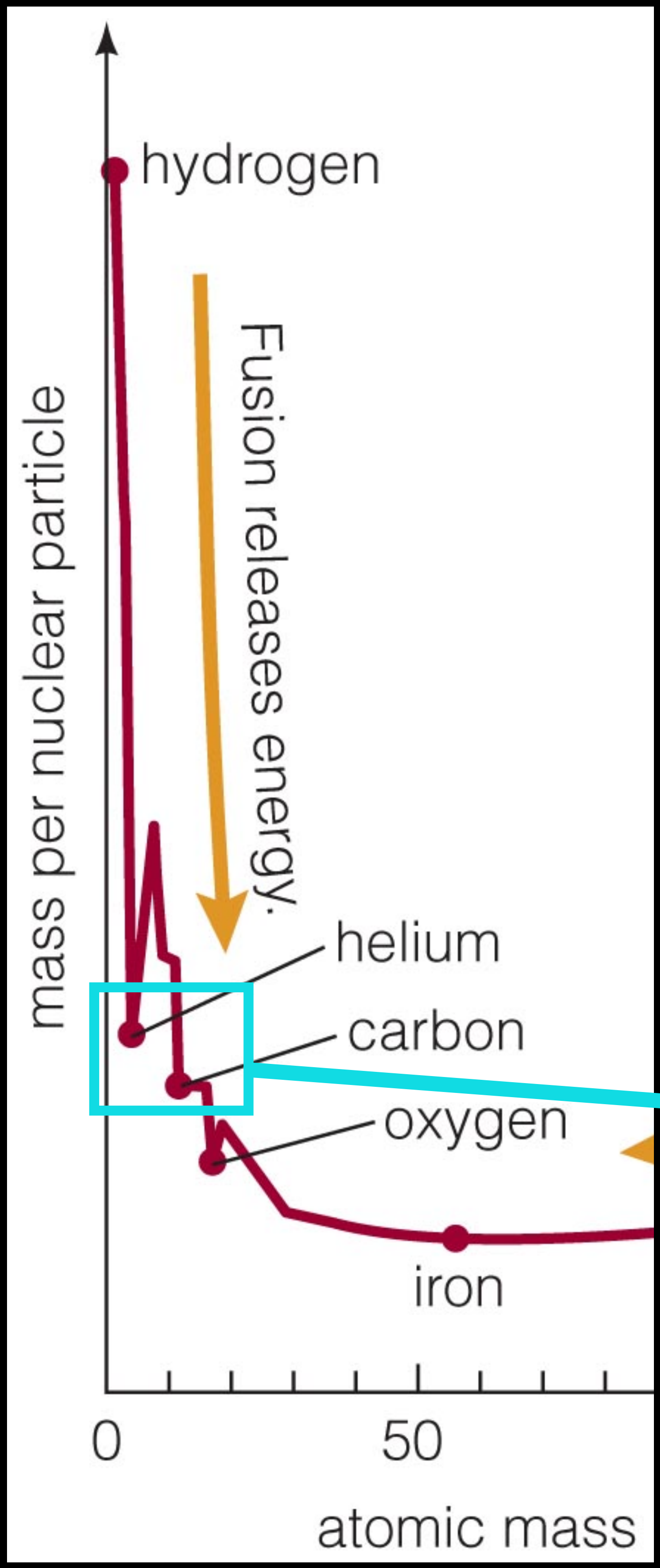
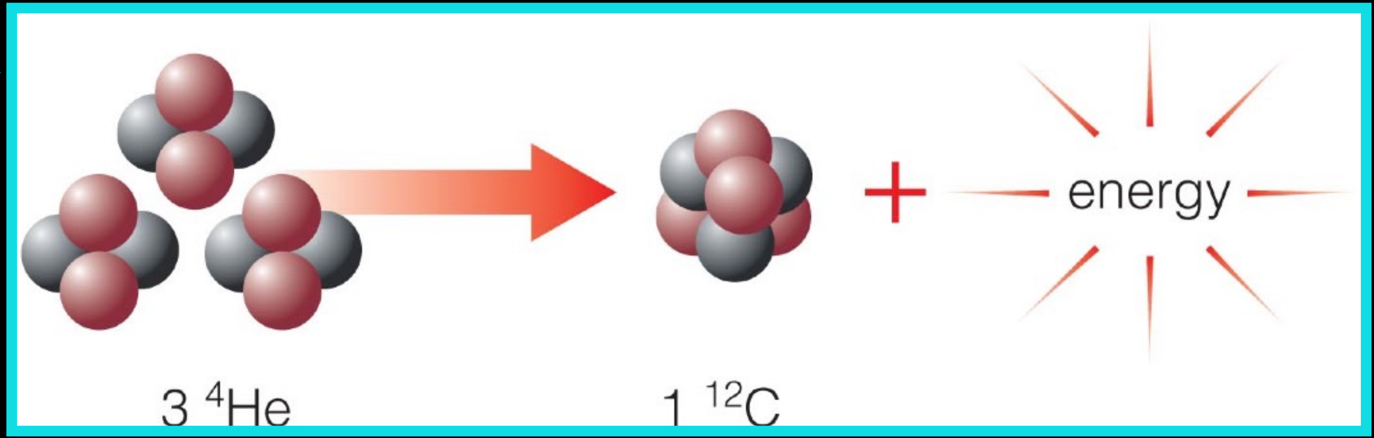
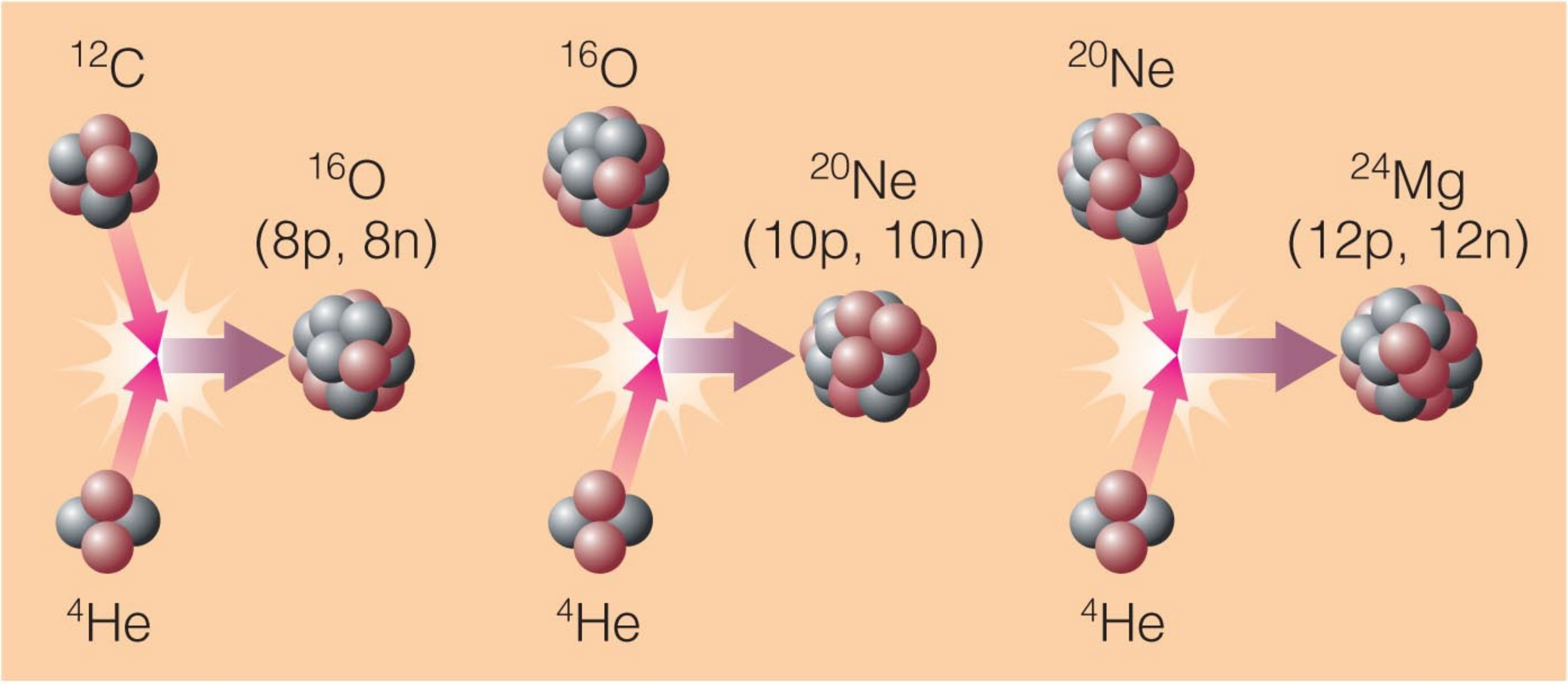


- Stars must release energy from fusion, in order to prevent gravitational collapse
  - Hydrogen → Helium fusion releases energy
  - (He + H) → Lithium would not release any energy!
  - Need (He + He + He) → Carbon (and even this releases far less energy than H fusion!)



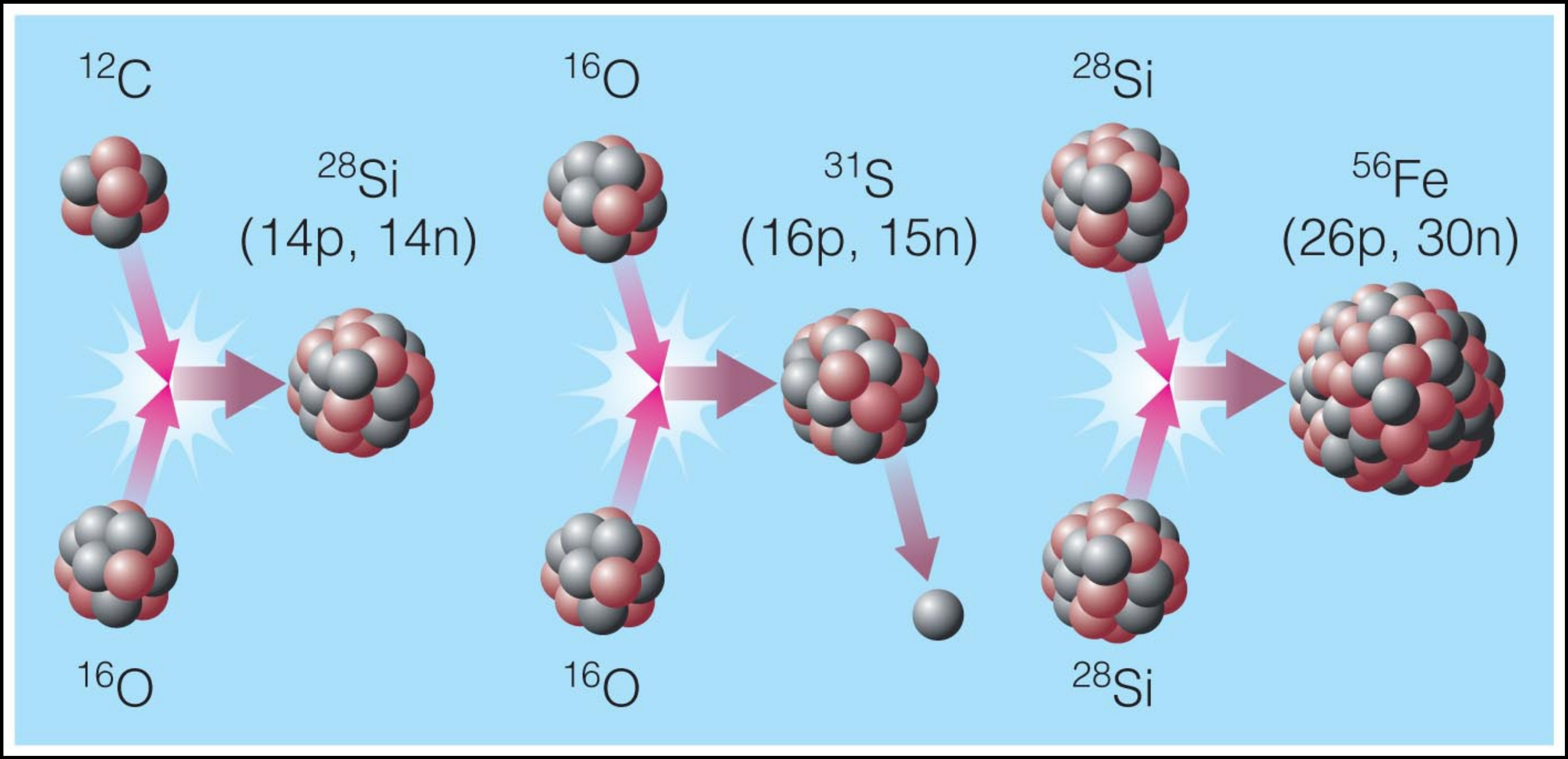
Helium capture: fusion beyond Carbon



a Helium-capture reactions.

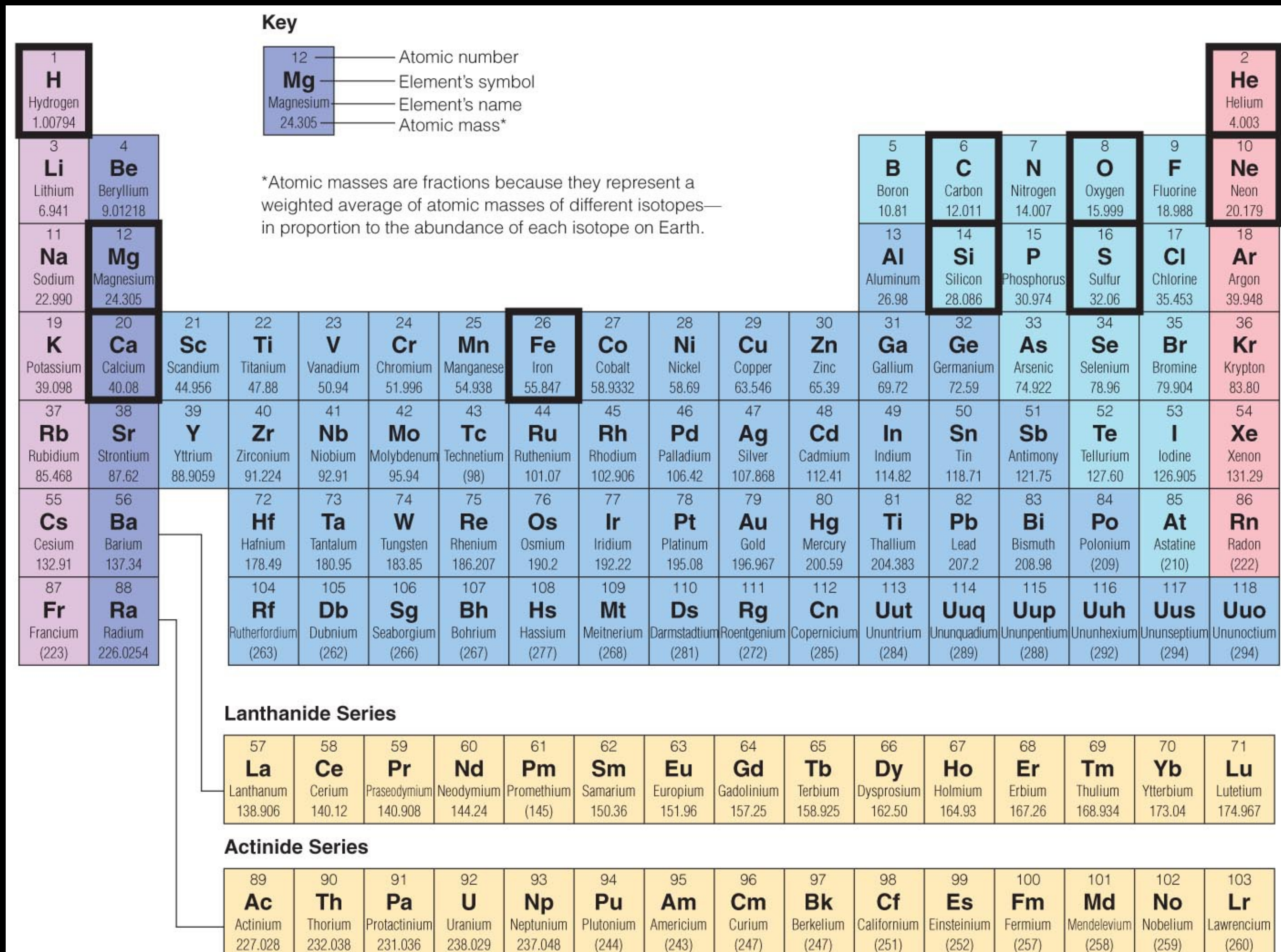
- In massive stars, high core temperatures allow helium to fuse with heavier elements

Advanced nuclear burning



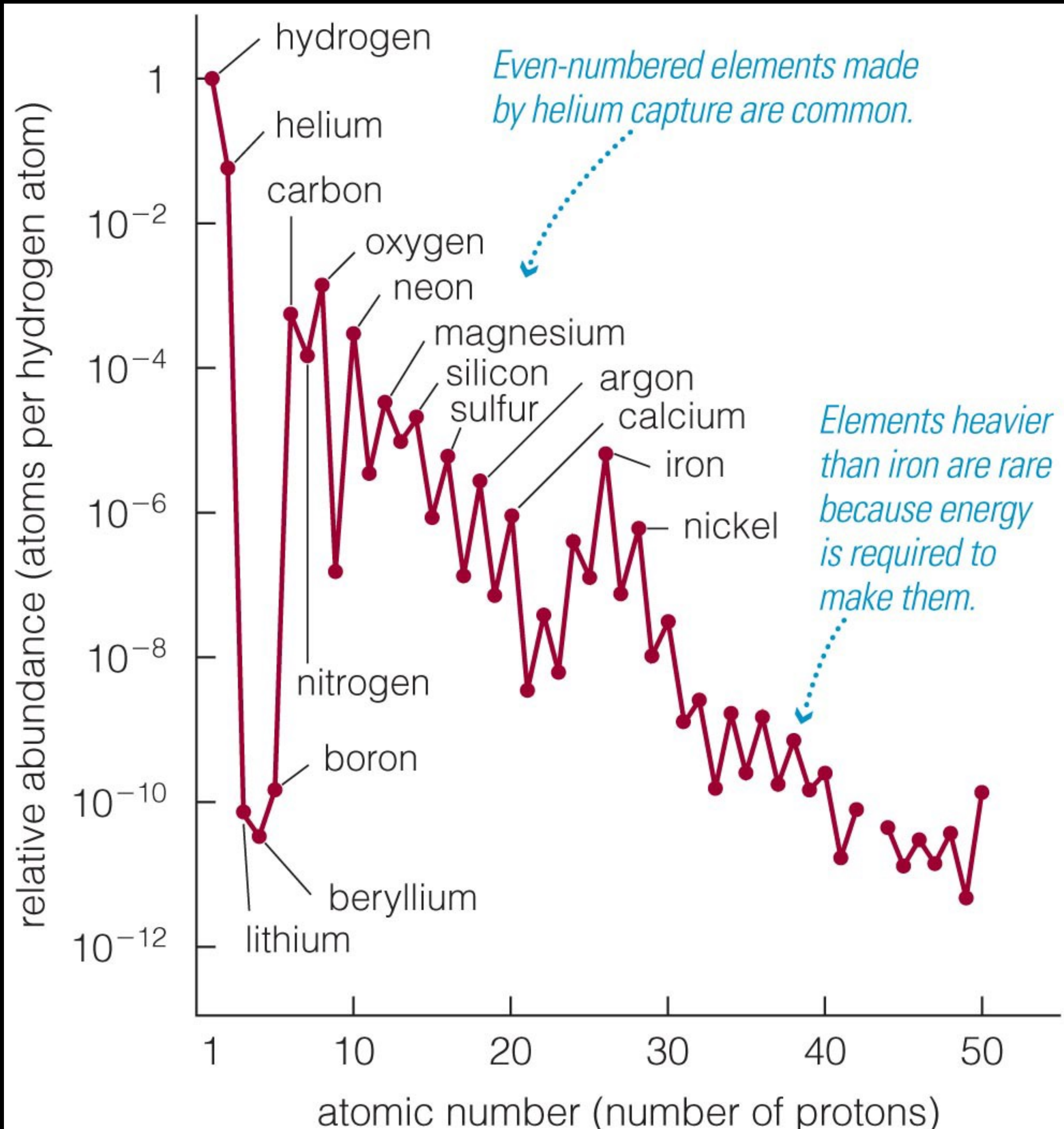
- Core temperatures in stars with $M > 8\ M_{Sun}$ allow fusion of elements as heavy as **iron**

Origin of the elements!



Main elements created by fusion in massive stars

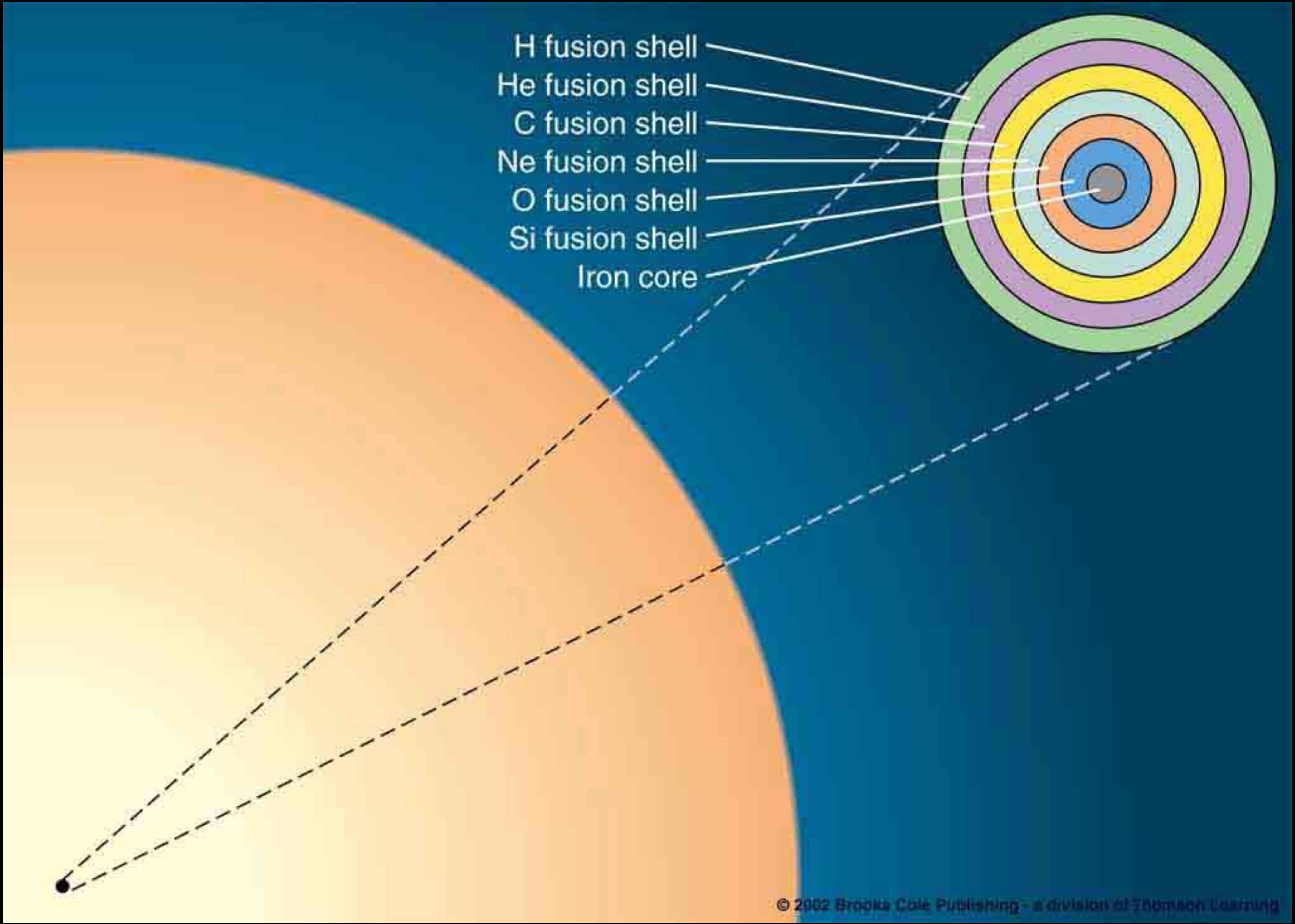
Abundances of elements in the Solar System



Evidence that this process really happens!

Main elements created by fusion in massive stars

High-mass stars keep on going past He fusion, with many repetitions of the cycle



Like all desperate measures, each fix is less successful than the first…

- Core is hotter and hotter each time
- Burn rate is faster and faster…
- …but less and less energy is released per fusion reaction
  - (energy difference between H and He is particularly large; He to C is smaller; further reactions are smaller still)

Each Cycle is shorter than the one before!

For a massive star…

- H-burning: lasts 7 million years
- He-burning: lasts 500,000 years
- C-burning: lasts 600 years
- Ne-burning: lasts 1 year
- O-burning: lasts 6 months
- Si-burning: lasts 1 day!
- And then what?