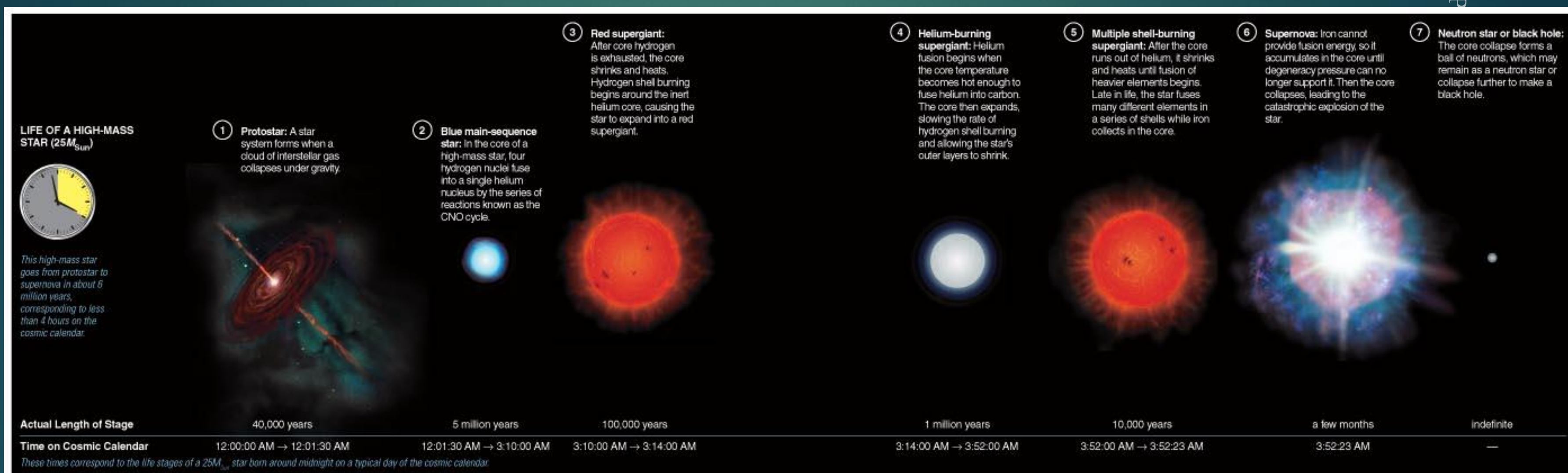
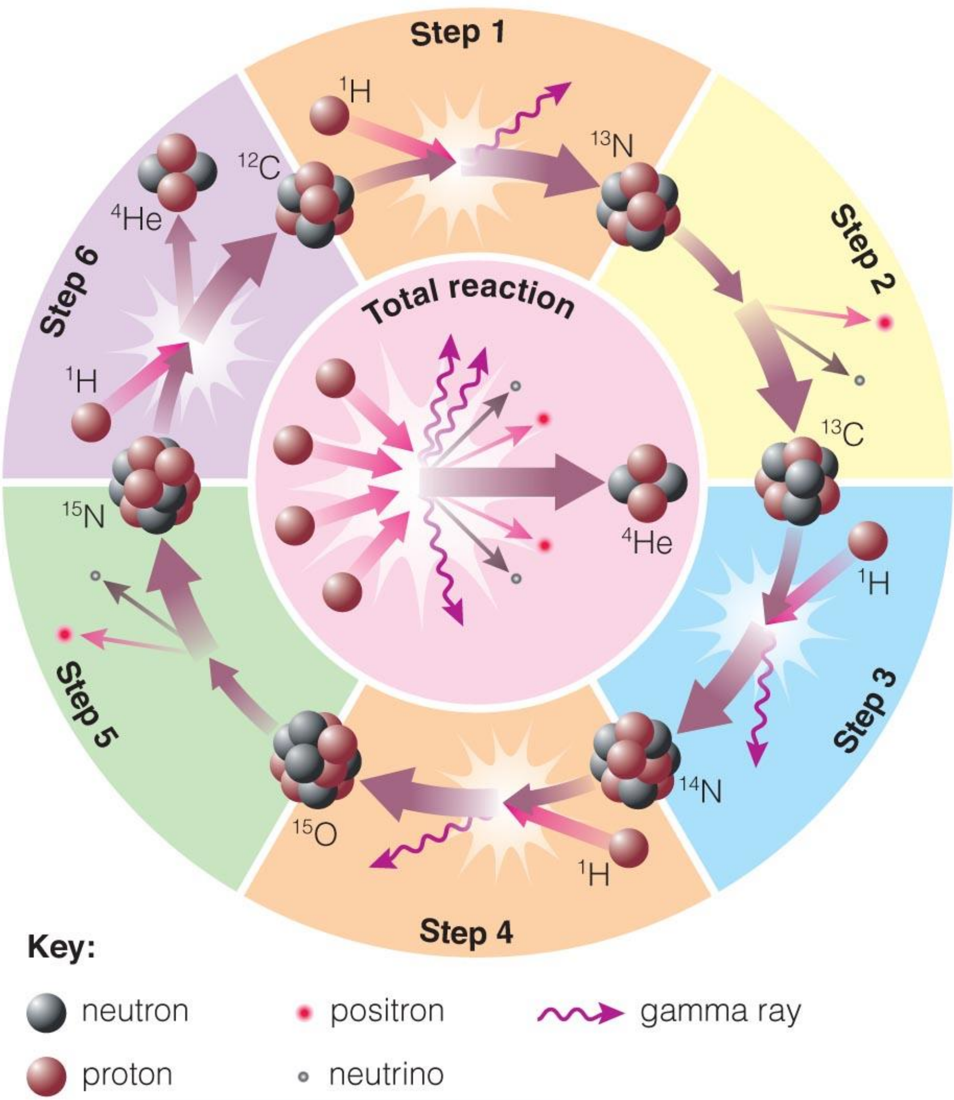
17.3 Life as a High-Mass Star

- Our goals for learning:
  - **What are the life stages of a high-mass star?**
  - **How do high-mass stars make the elements necessary for life?**
  - **How does a high-mass star die?**

What are the life stages of a high-mass star?



CNO Cycle

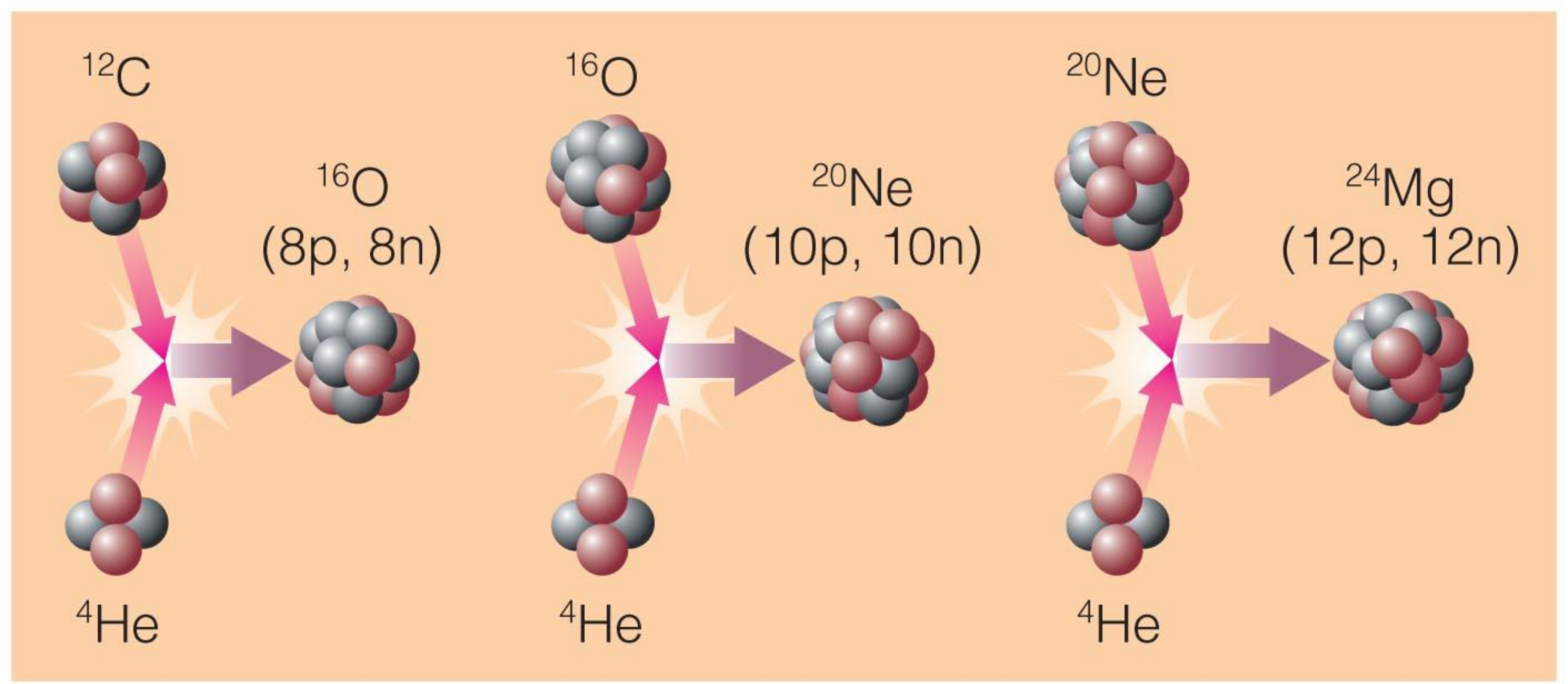


- High-mass main-sequence stars fuse H to He at a higher rate using carbon, nitrogen, and oxygen as catalysts.
- Greater core temperature enables hydrogen nuclei to overcome greater repulsion.

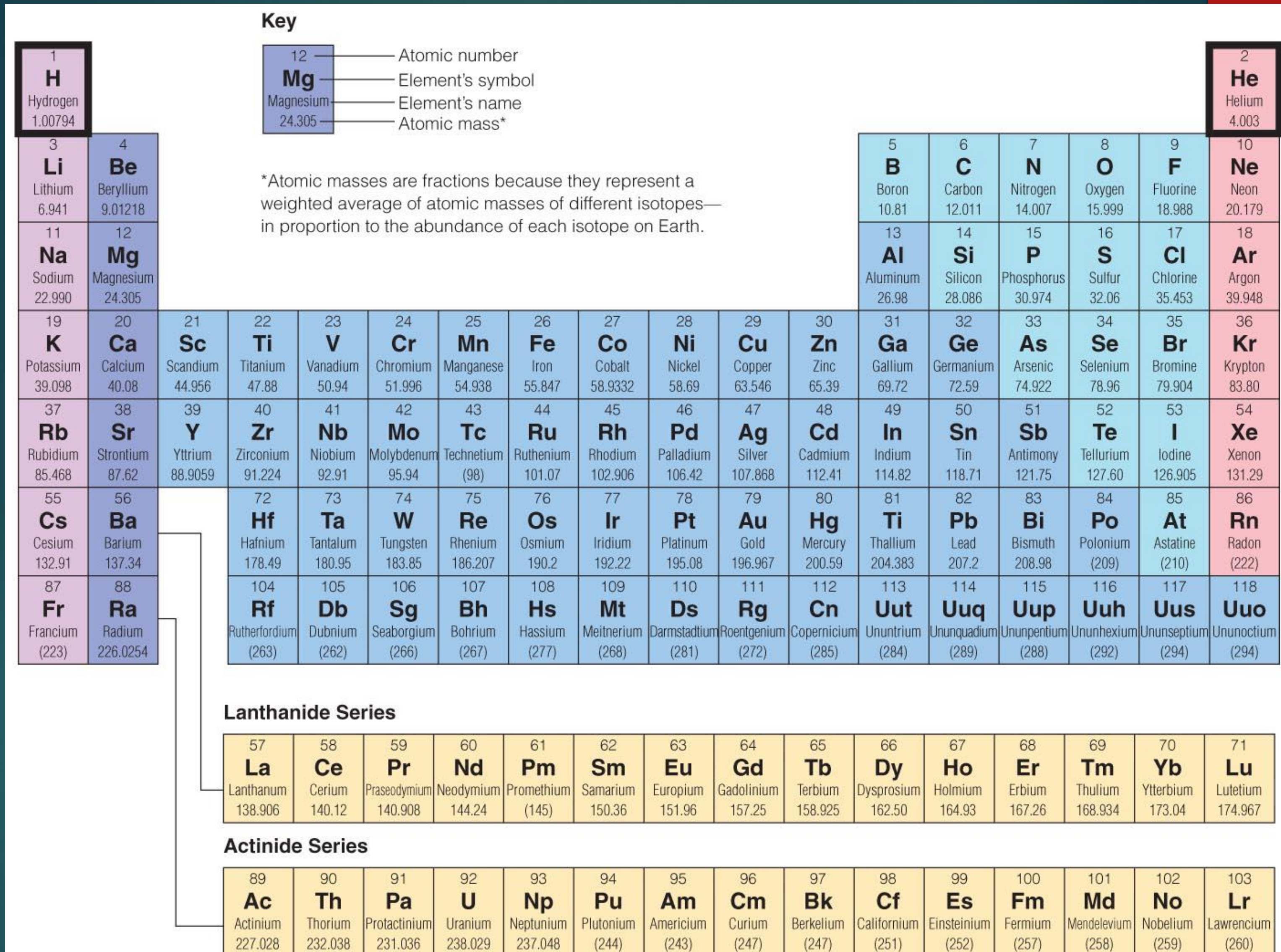
Life Stages of High-Mass Stars

- Late life stages of high-mass stars are similar to those of low-mass stars:
  - Hydrogen core fusion (main sequence)
  - Hydrogen shell burning (supergiant)
  - Helium core fusion (supergiant)

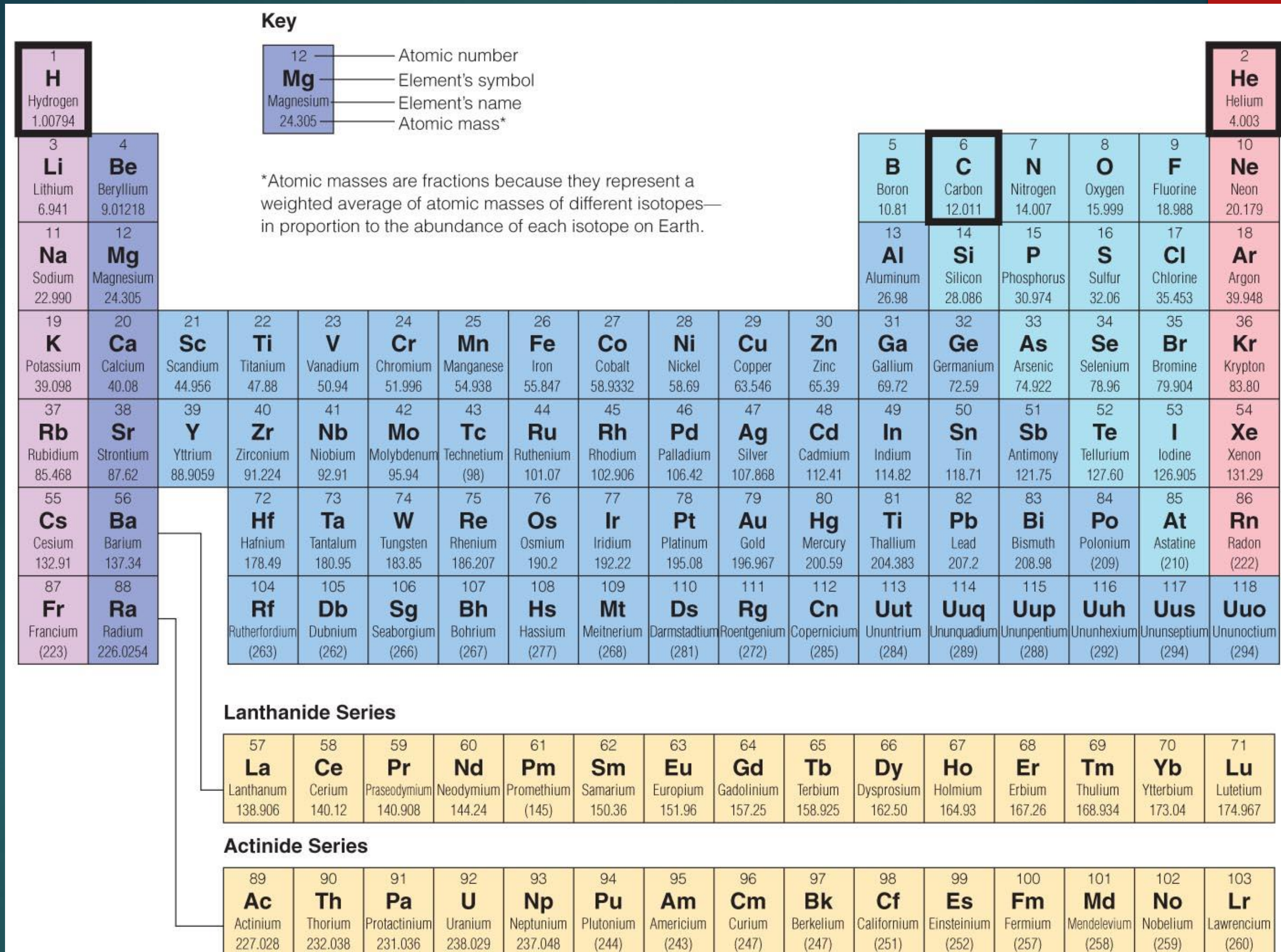
How do high-mass stars make the elements necessary for life?



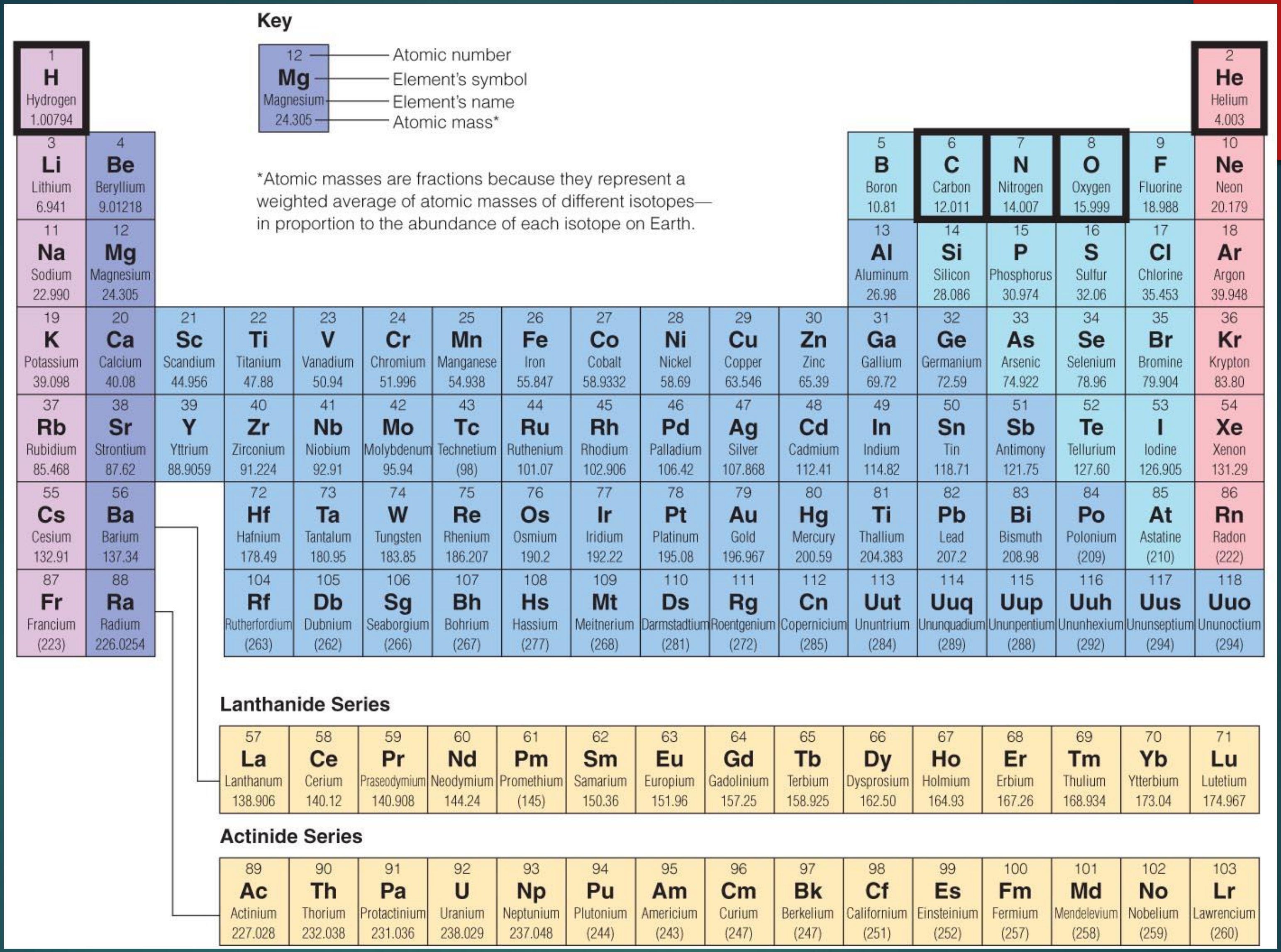
a Helium-capture reactions.



- Big Bang made 75% H, 25% He; stars make everything else.

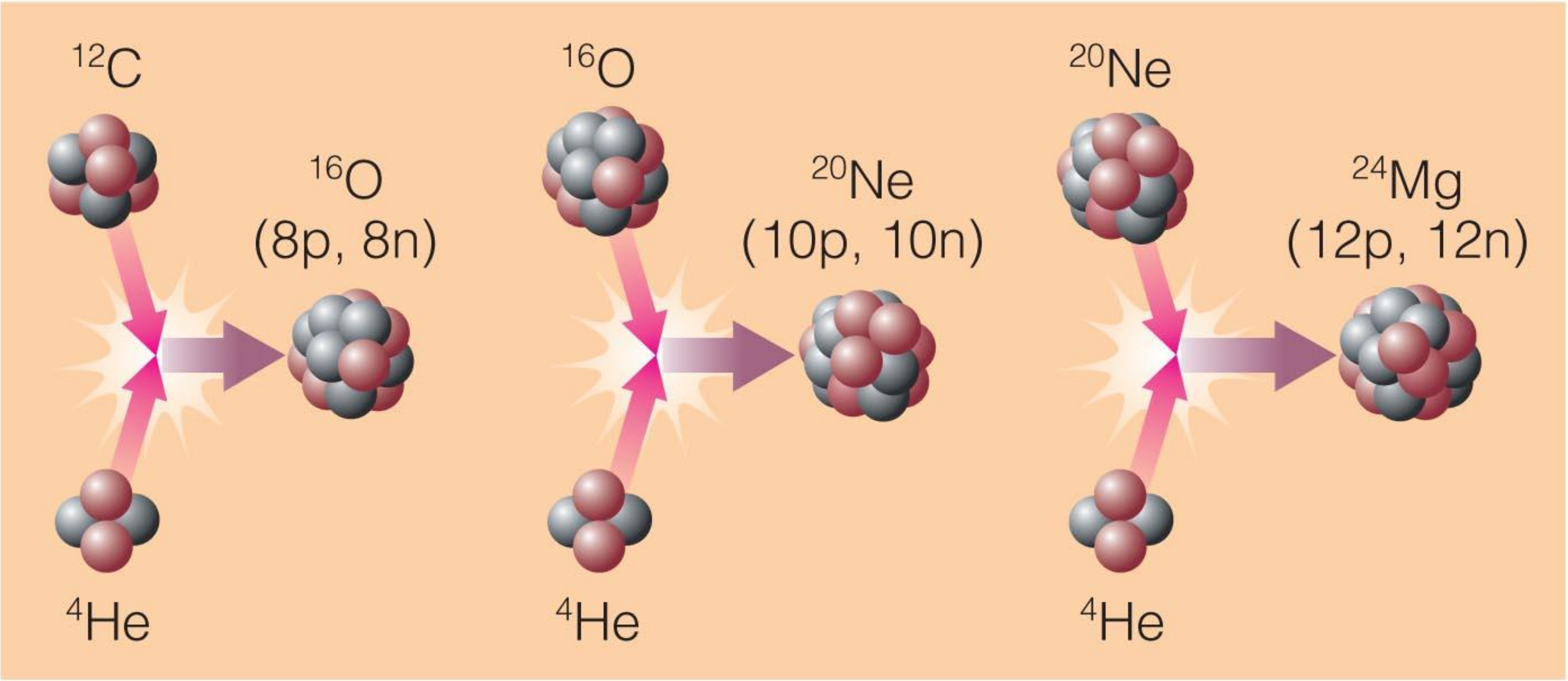


- Helium fusion can make carbon in low-mass stars.



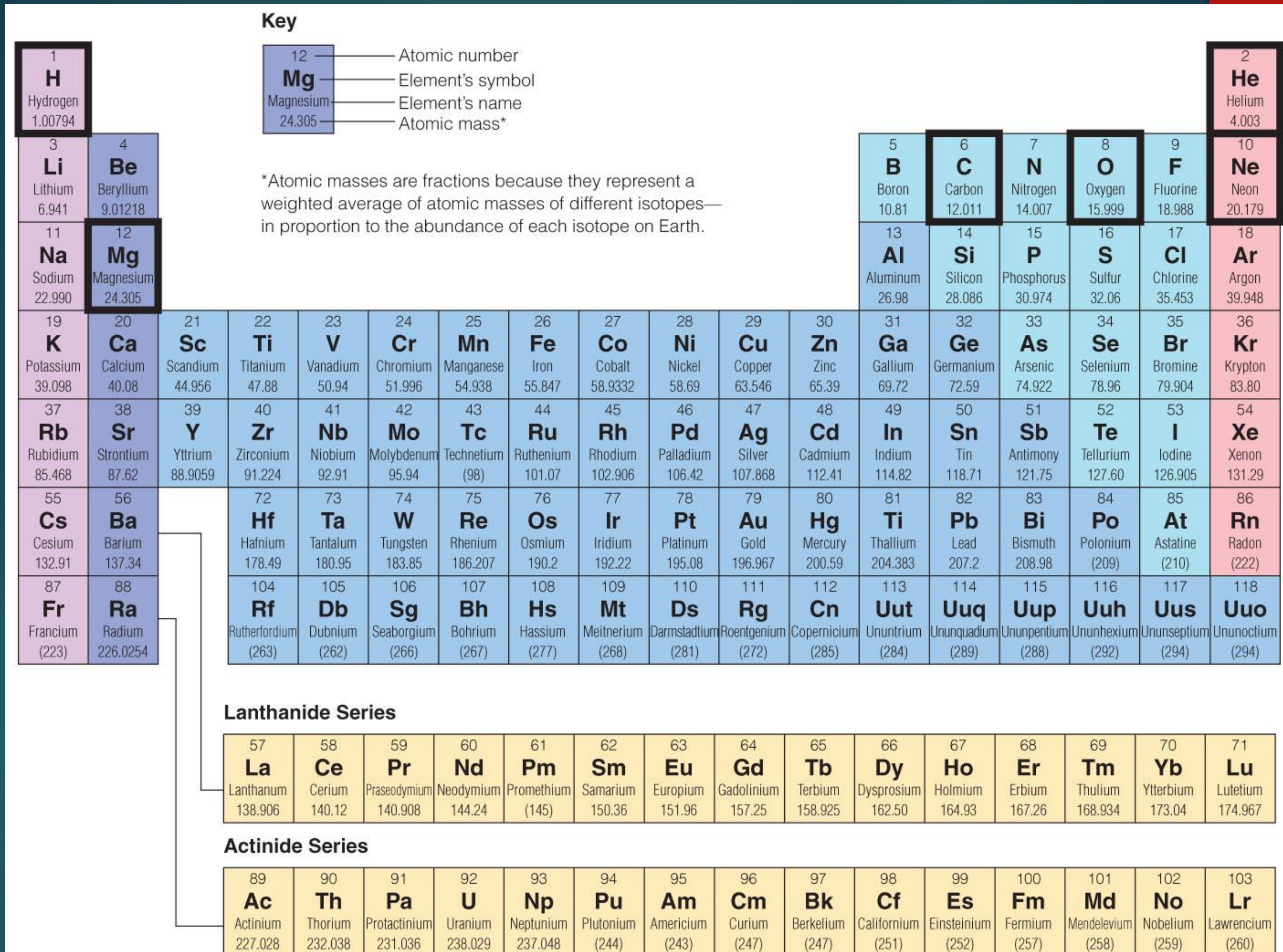
- CNO cycle can change carbon into nitrogen and oxygen.

Helium Capture



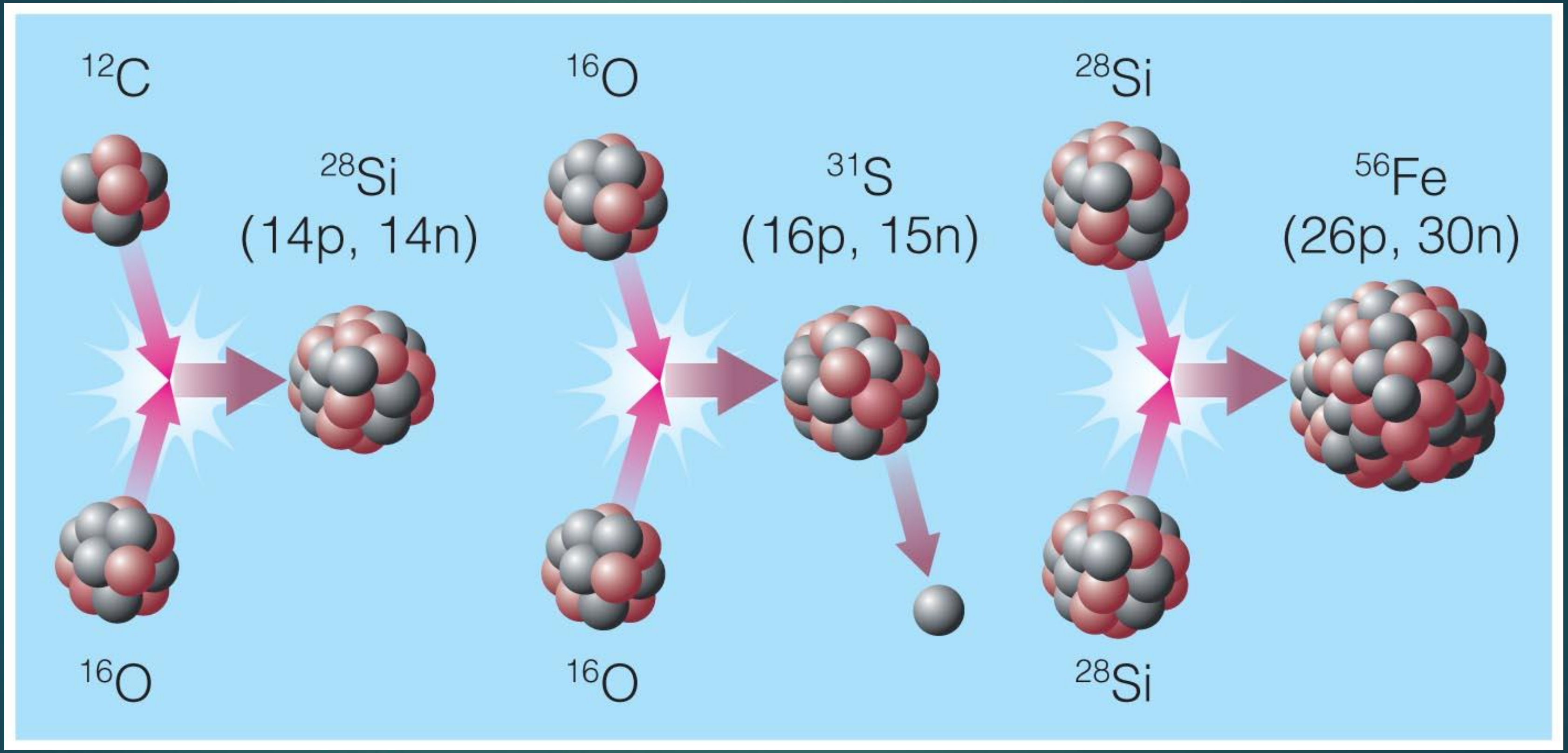
a Helium-capture reactions.

- High core temperatures allow helium to fuse with heavier elements.

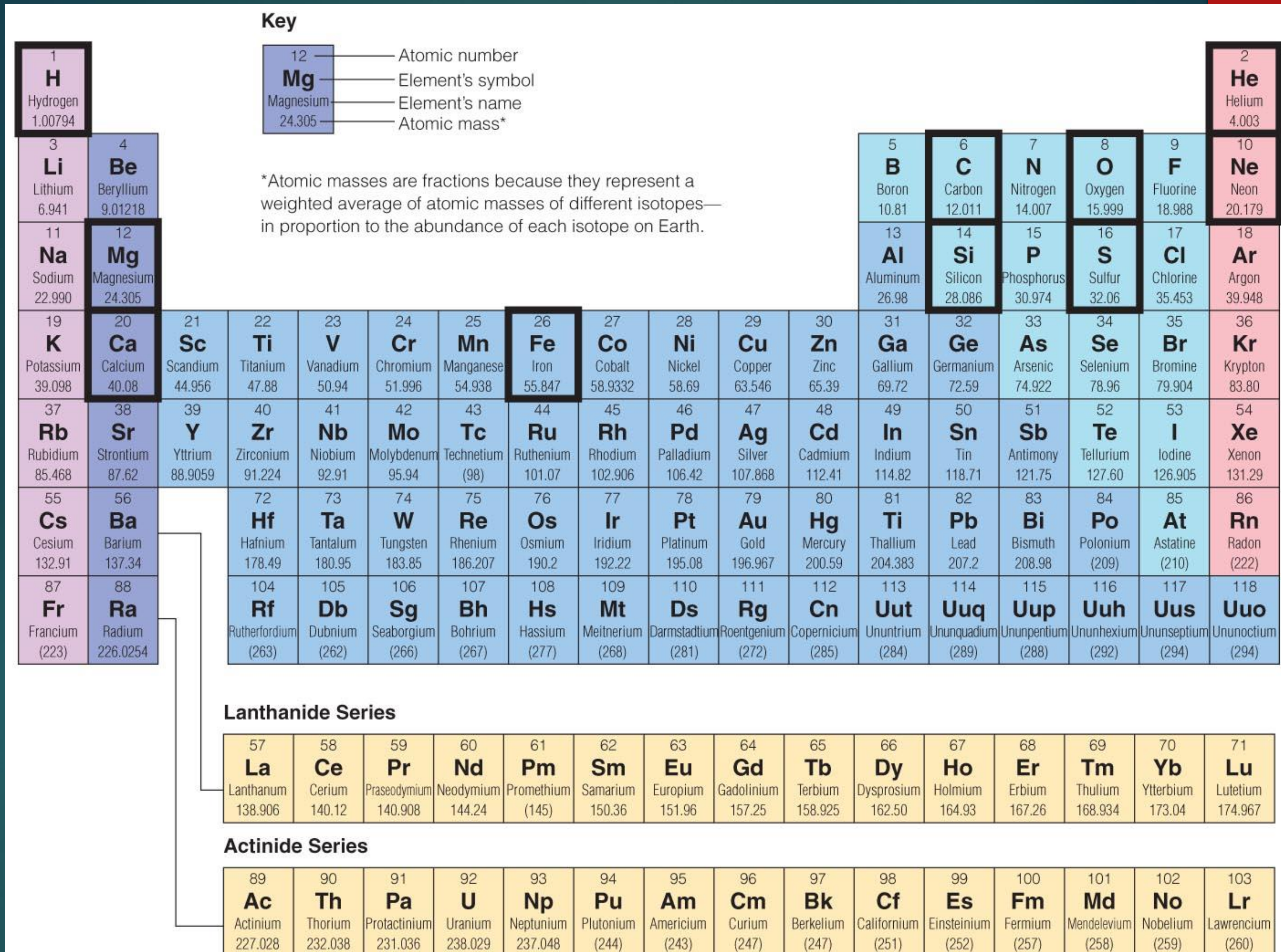


- Helium capture builds carbon into oxygen, neon, magnesium, and other elements.

Advanced Nuclear Burning

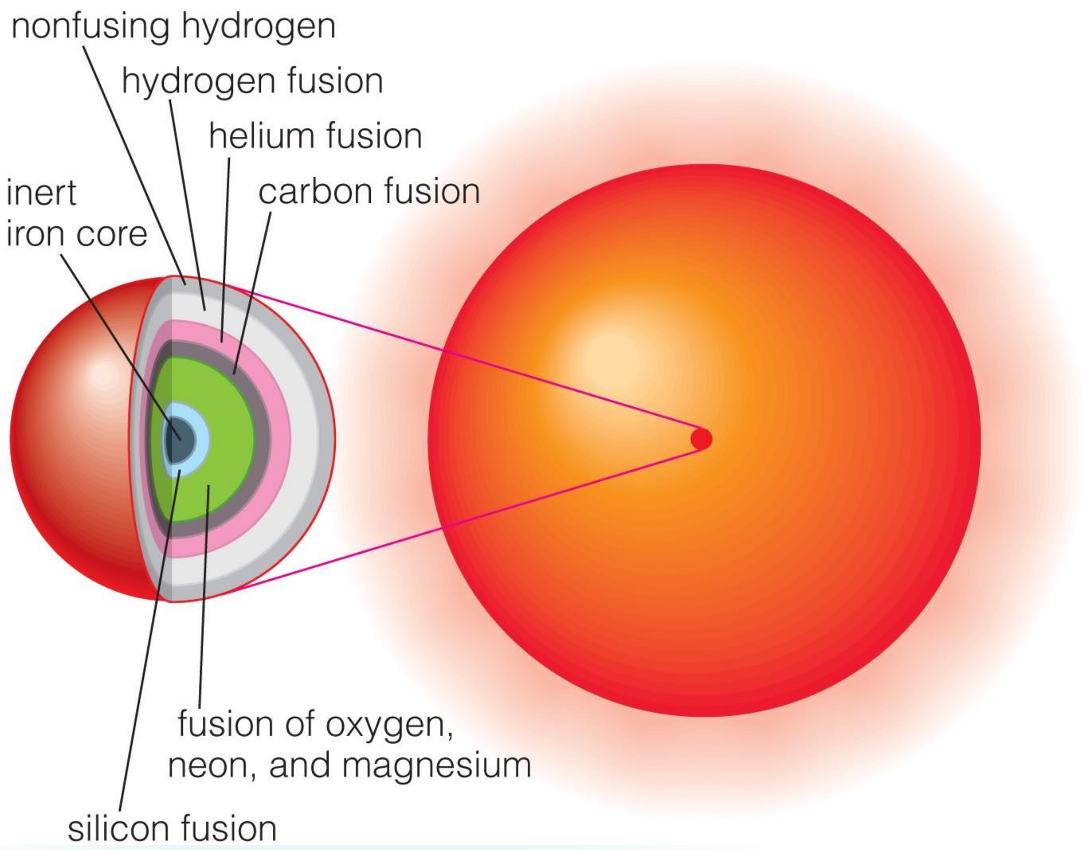


- Core temperatures in stars with $>8M_{Sun}$ allow fusion of elements as heavy as iron.

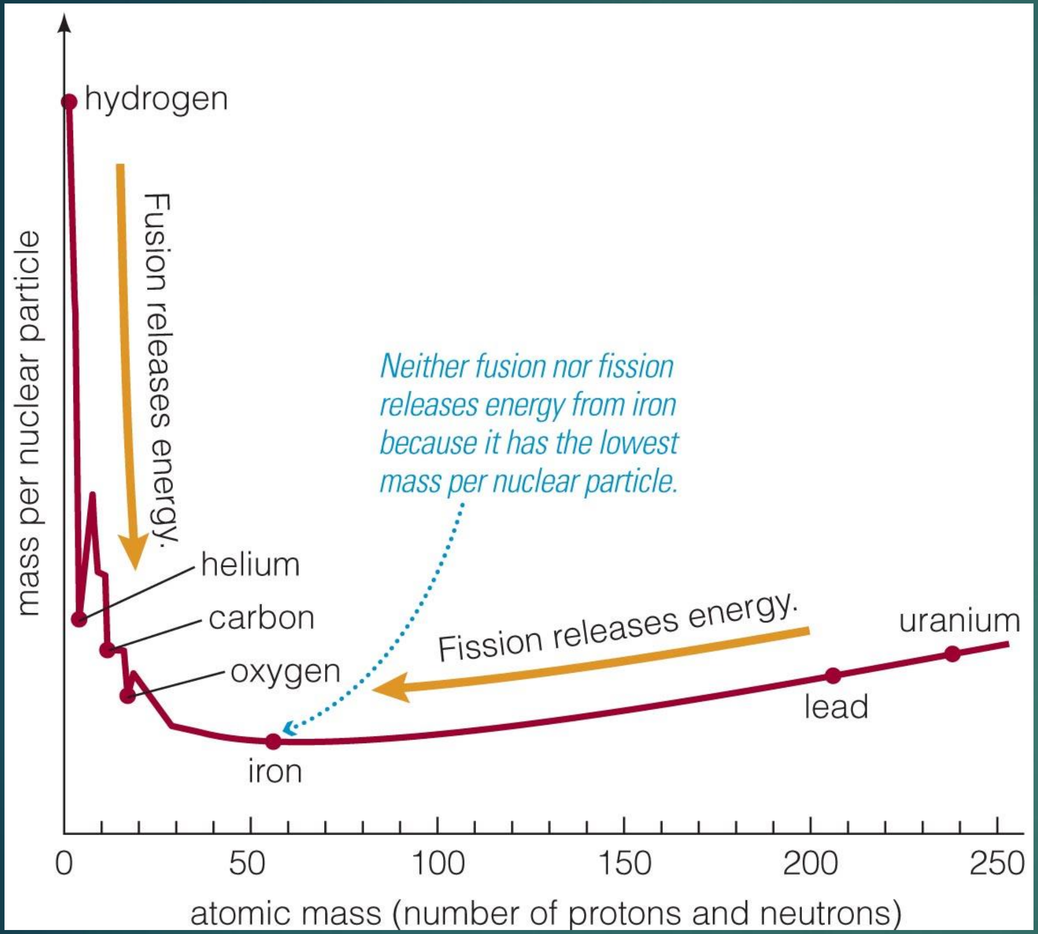


- Advanced reactions in stars make elements like Si, S, Ca, Fe.

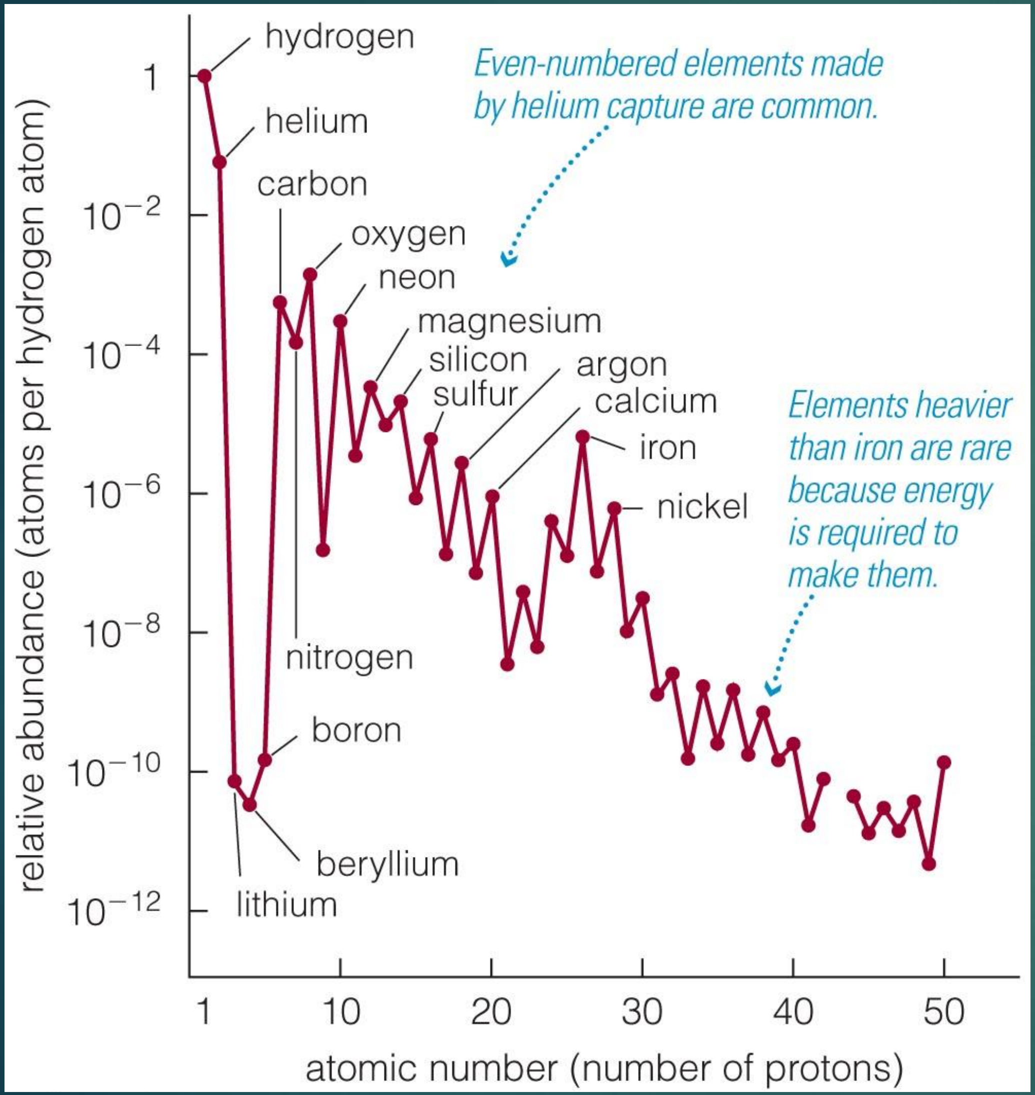
Multiple Shell Burning



- Advanced nuclear burning proceeds in a series of nested shells.

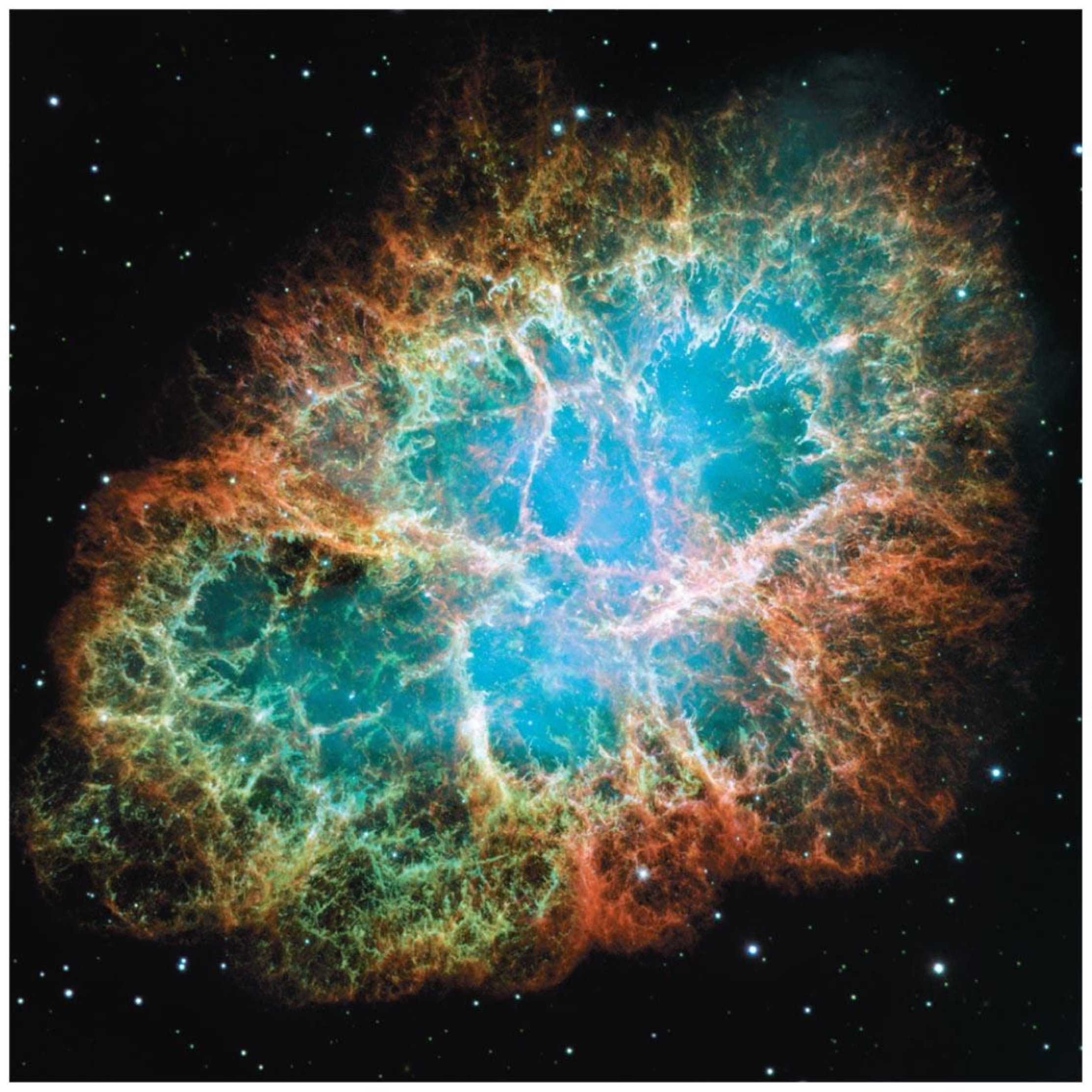


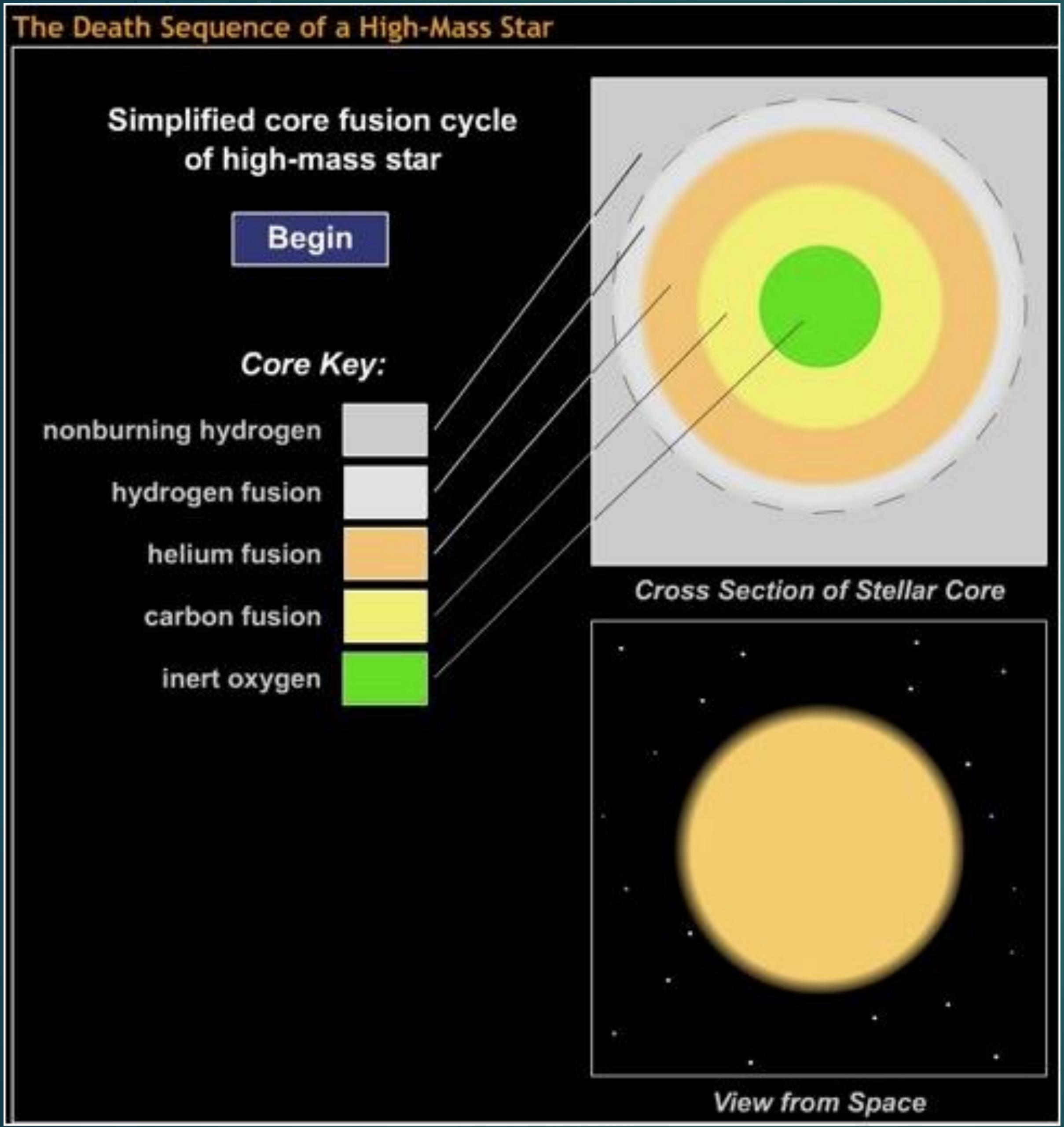
- Iron is a dead end for fusion because nuclear reactions involving iron do not release energy.
- (This is because iron has lowest mass per nuclear particle.)



- Evidence for helium capture:
- Higher abundances of elements with even numbers of protons

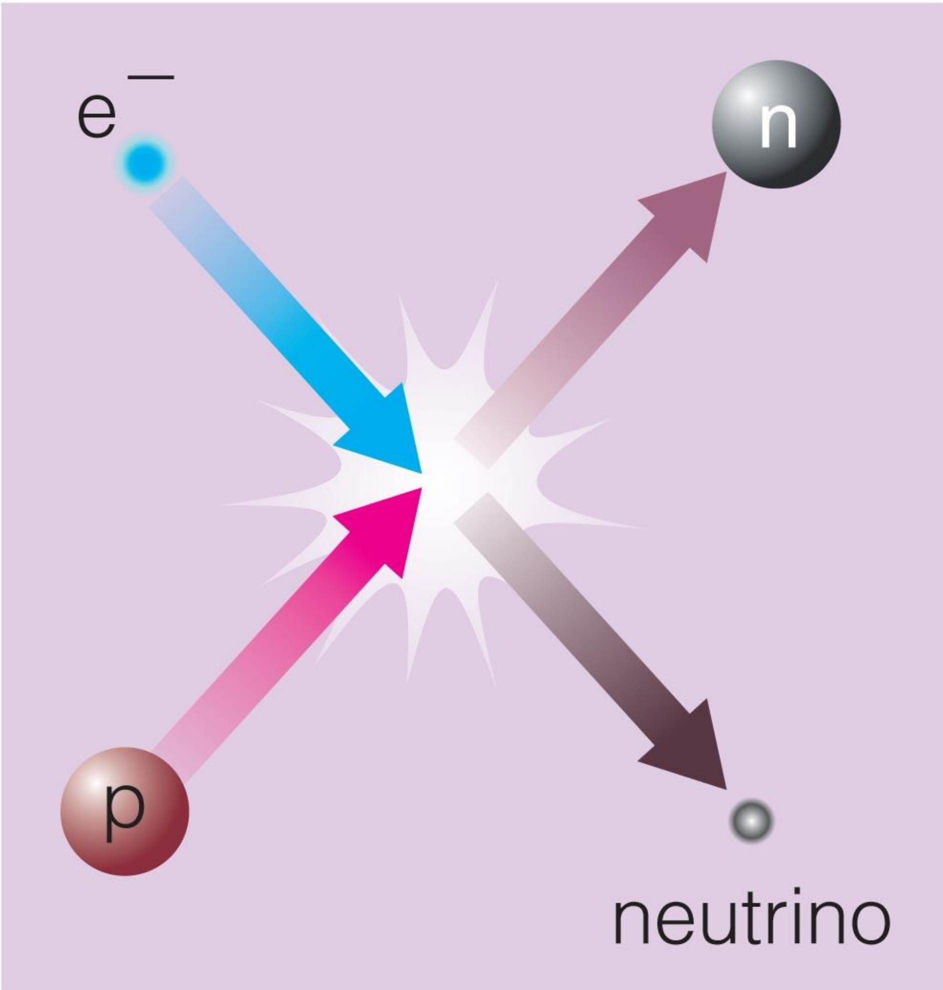
How does a high-mass star die?



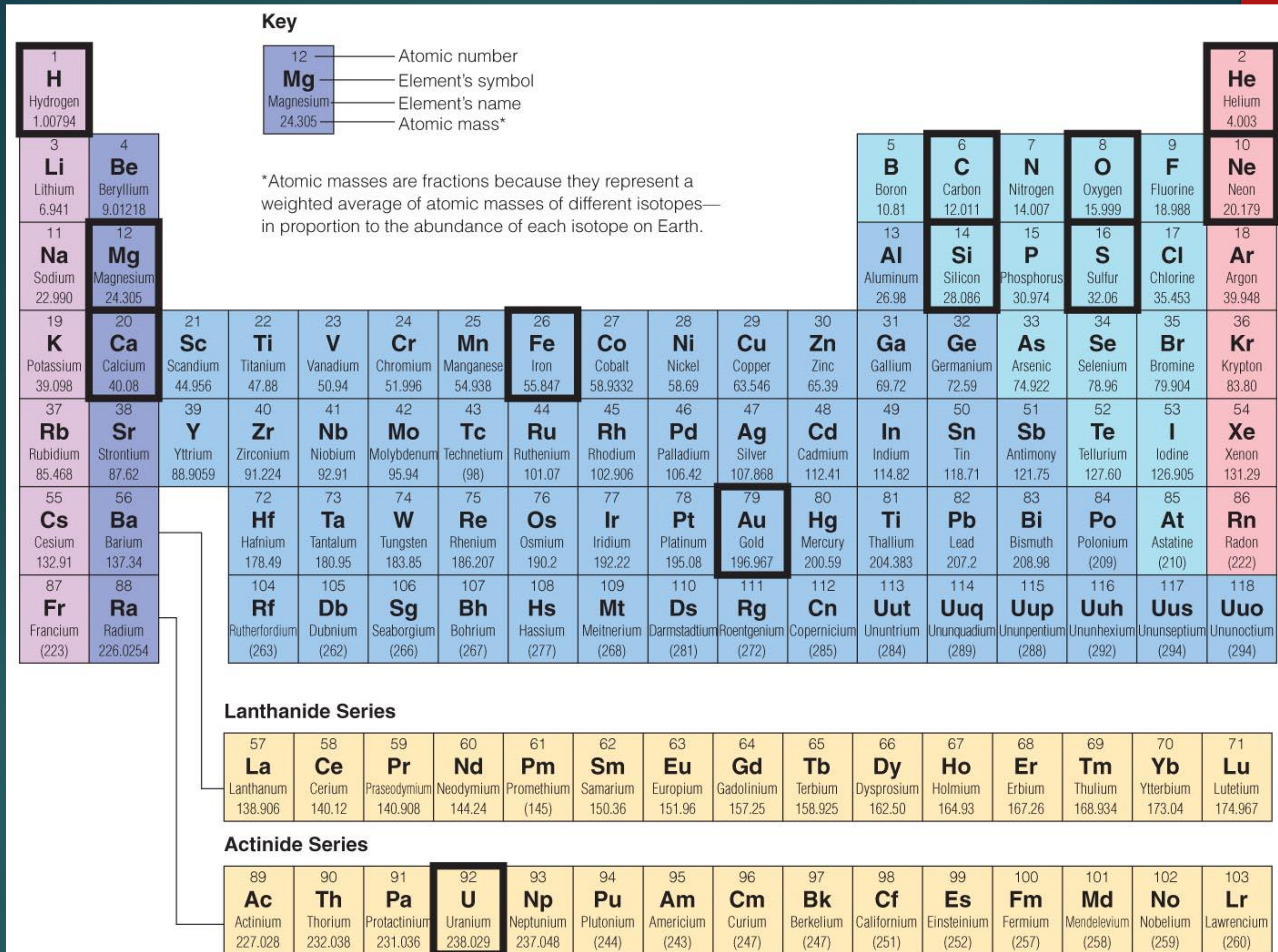


- Iron builds up in core until degeneracy pressure can no longer resist gravity.
- The core then suddenly collapses, creating a supernova explosion.

Supernova Explosion

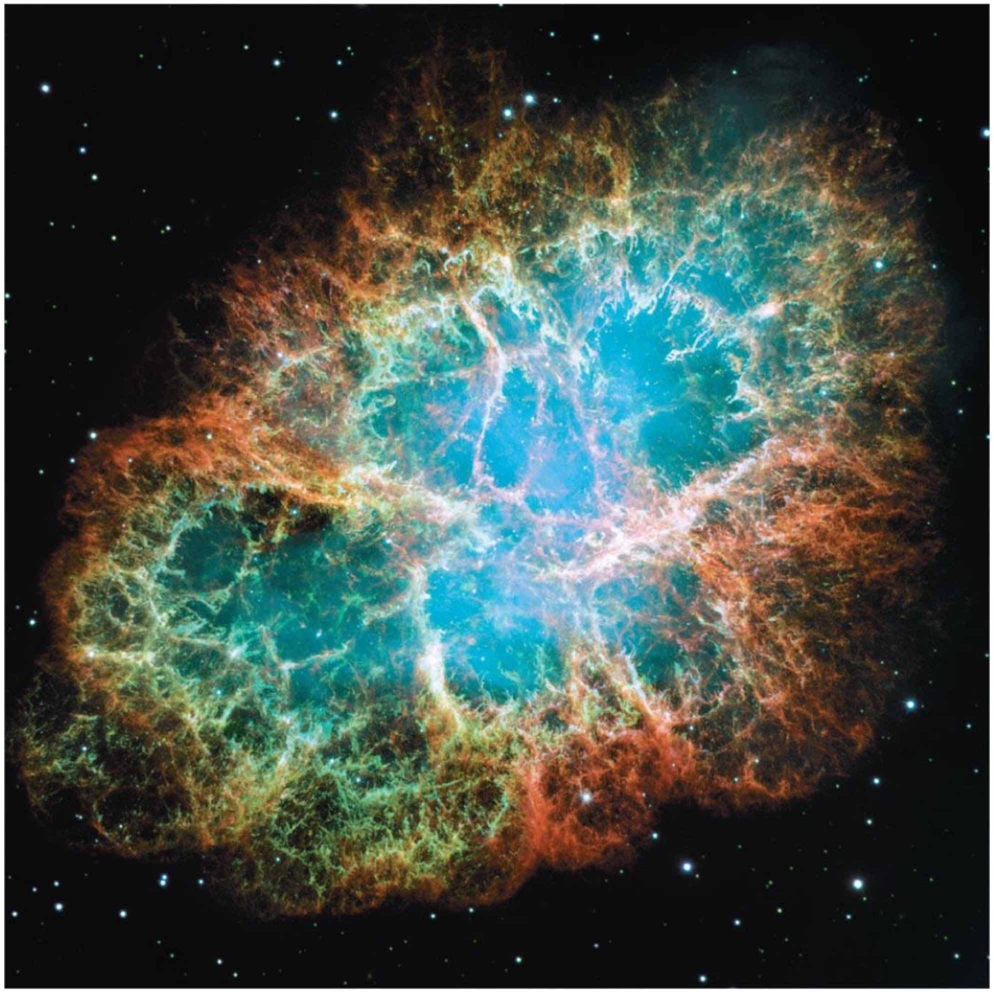


- Core degeneracy pressure goes away because electrons combine with protons, making neutrons and neutrinos.
- Neutrons collapse to the center, forming a **neutron star.**



- Energy and neutrons released in supernova explosion enable elements heavier than iron to form, including gold and uranium.

Supernova Remnant

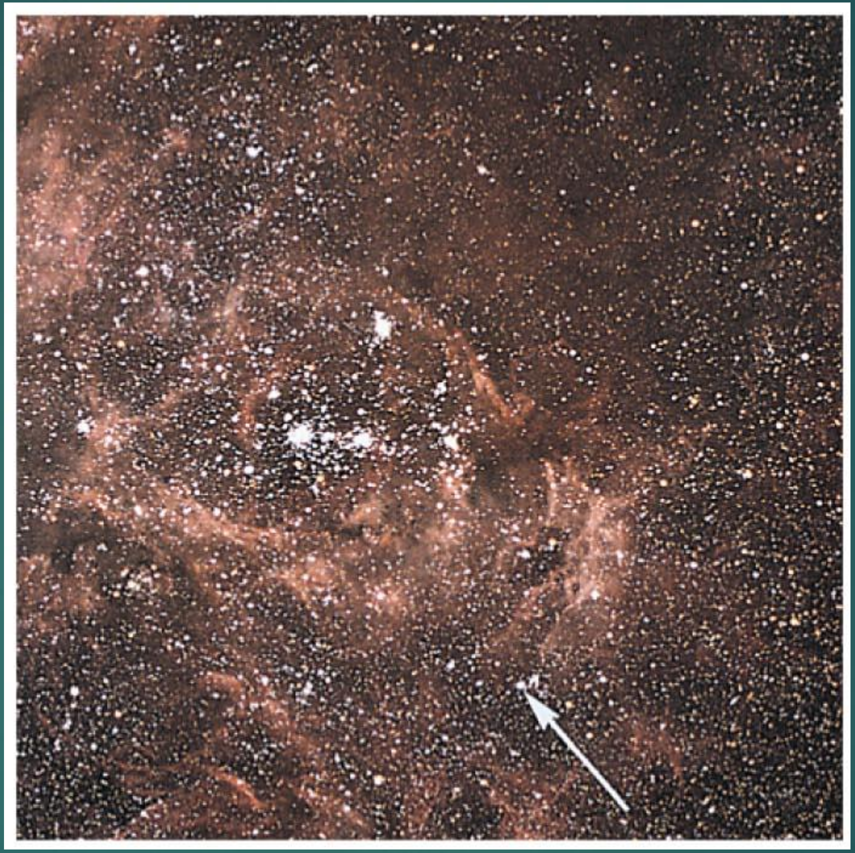


- Energy released by the collapse of the core drives the star's outer layers into space.
- The Crab Nebula is the remnant of the supernova seen in A.D. 1054.

Supernova 1987A

- The closest supernova in the last four centuries was seen in 1987.

Rings around Supernova 1987A



- The supernova's flash of light caused rings of gas around the supernova to glow.

Impact of Debris with Rings

- More recent observations show the inner ring lighting up as debris crashes into it.

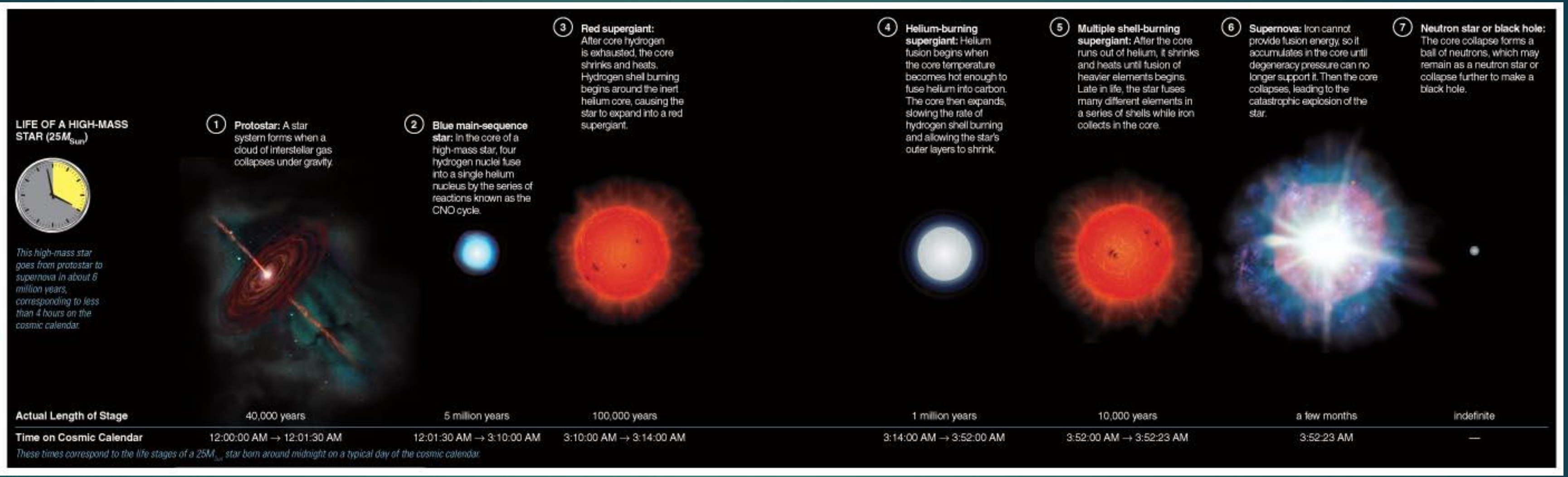
What have we learned?

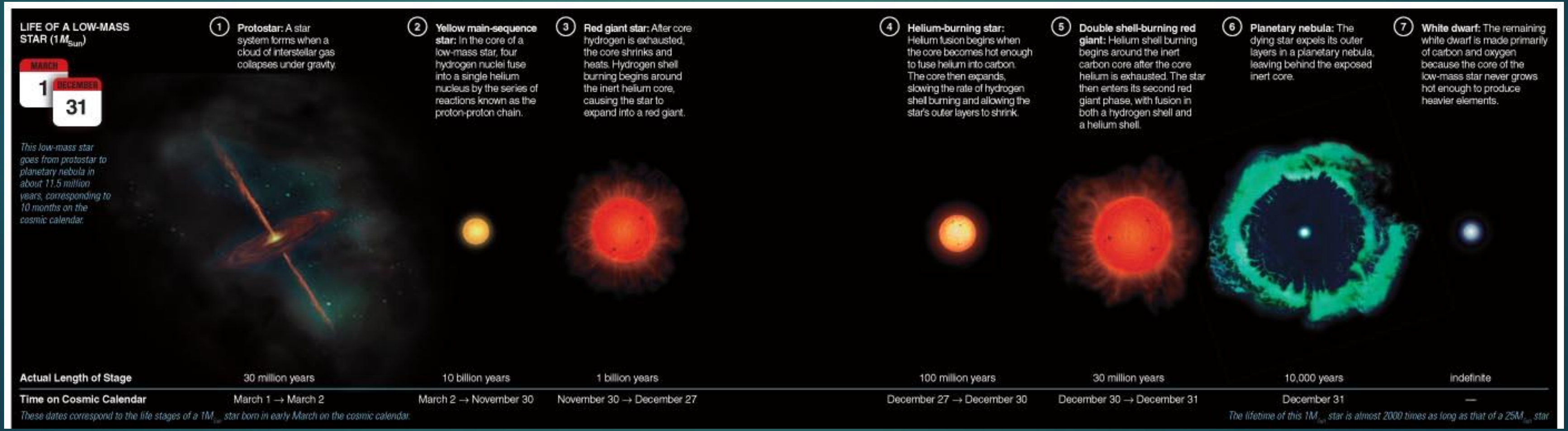
- **What are the life stages of a high-mass star?**
  - They are similar to the life stages of a low-mass star.
- **How do high-mass stars make the elements necessary for life?**
  - Higher masses produce higher core temperatures that enable fusion of heavier elements.
- **How does a high-mass star die?**
  - Its iron core collapses, leading to a supernova.

17.4 The Roles of Mass and Mass Exchange

- Our goals for learning:
  - **How does a star's mass determine its life story?**
  - **How are the lives of stars with close companions different?**

How does a star's mass determine its life story?

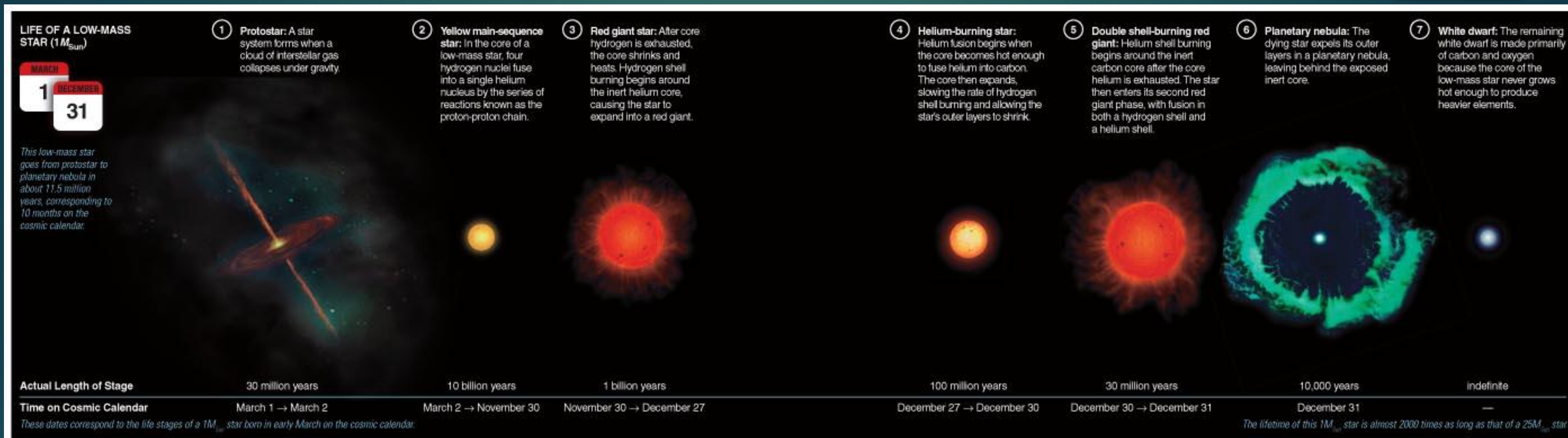




Role of Mass

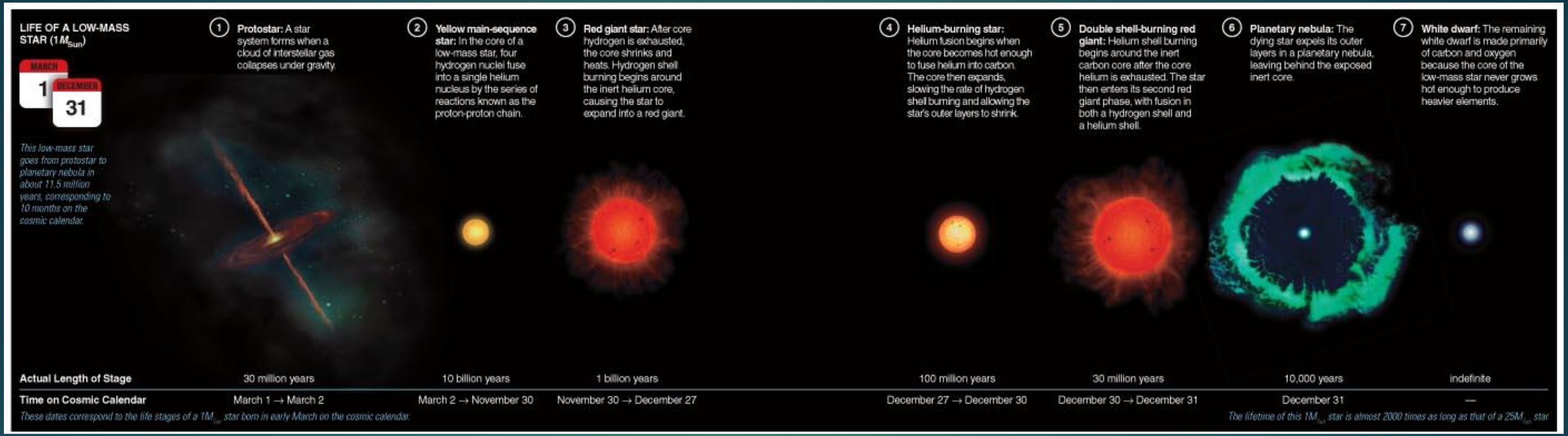
- A star's mass determines its entire life story because it determines its core temperature.
- High-mass stars with > $8M_{Sun}$ have short lives, eventually becoming hot enough to make iron, and end in supernova explosions.
- Low-mass stars with < $2M_{Sun}$ have long lives, never become hot enough to fuse carbon nuclei, and end as white dwarfs.
- Intermediate-mass stars can make elements heavier than carbon but end as white dwarfs.

Low-Mass Star Summary



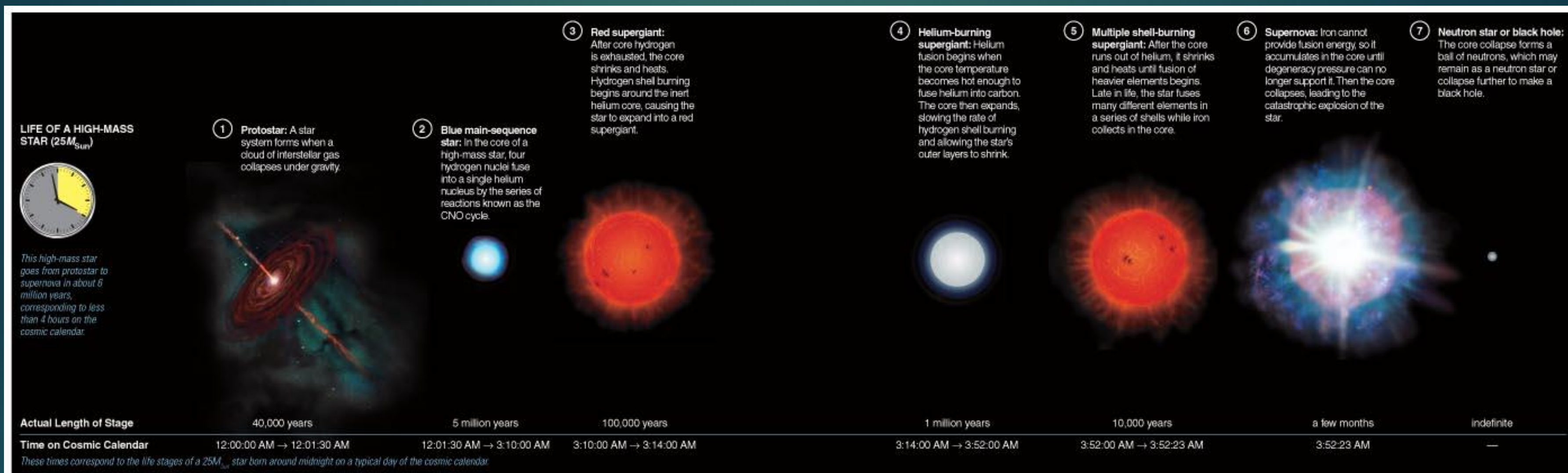
1. Main sequence: H fuses to He in core.
2. Red giant: H fuses to He in shell around He core.
3. Helium core burning: He fuses to C in core while H fuses to He in shell.
4. Double shell burning: H and He both fuse in shells.
5. Planetary nebula leaves white dwarf behind.

Reasons for Life Stages



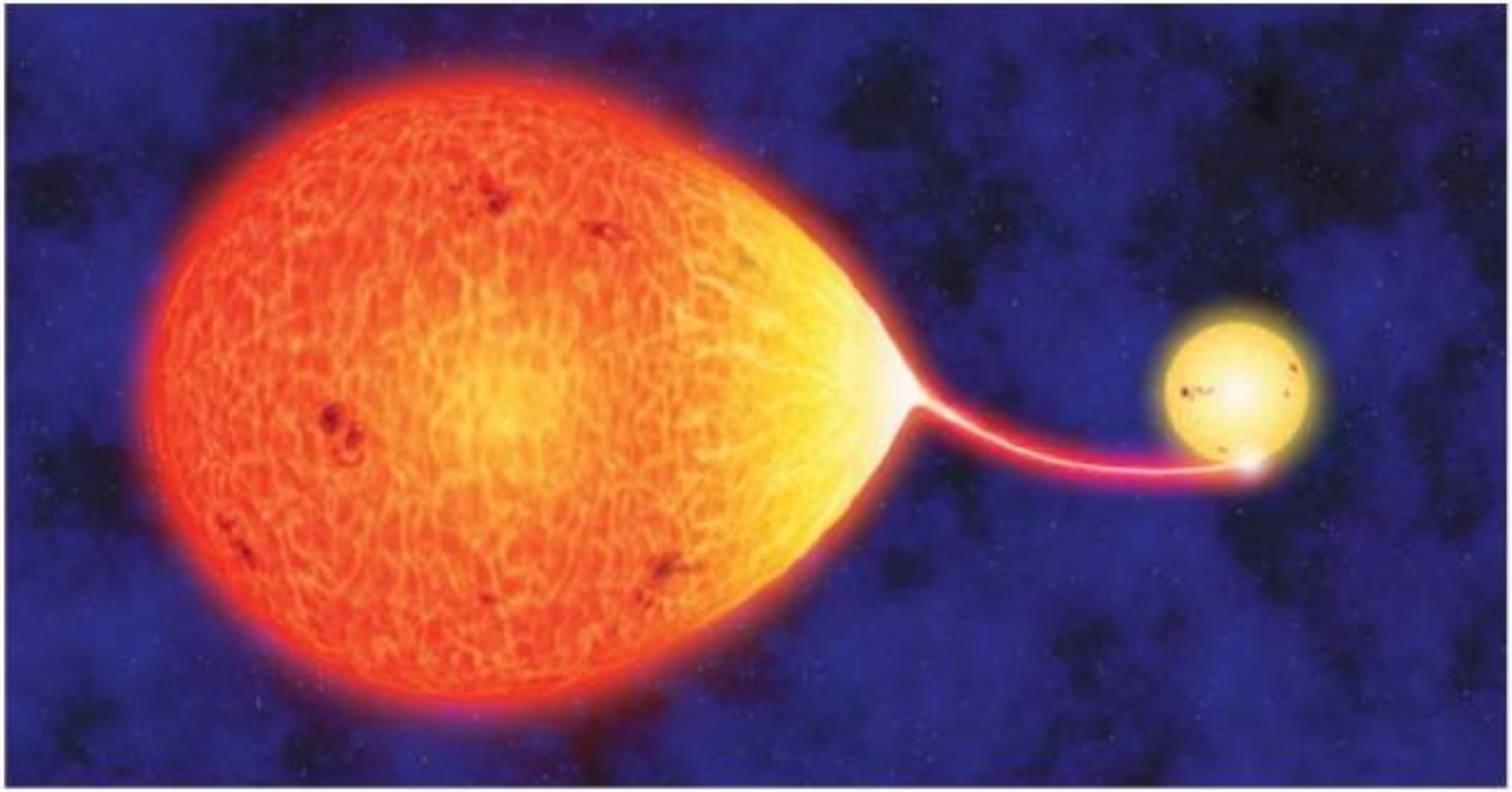
- Core shrinks and heats until it's hot enough for fusion.
- Nuclei with larger charge require higher temperature for fusion.
- Core thermostat is broken while core is not hot enough for fusion (shell burning).
- Core fusion can't happen if degeneracy pressure keeps core from shrinking.

Life Stages of High-Mass



1. Main sequence: H fuses to He in core.
2. Red supergiant: H fuses to He in shell around He core.
3. Helium core burning:
4. He fuses to C in core while H fuses to He in shell.
5. Multiple shell burning:
6. Many elements fuse in shells.
7. Supernova leaves neutron star behind.

How are the lives of stars with close companions different?



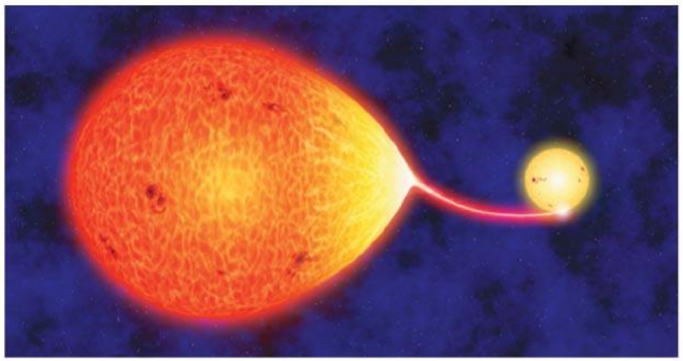
Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.

Thought Question

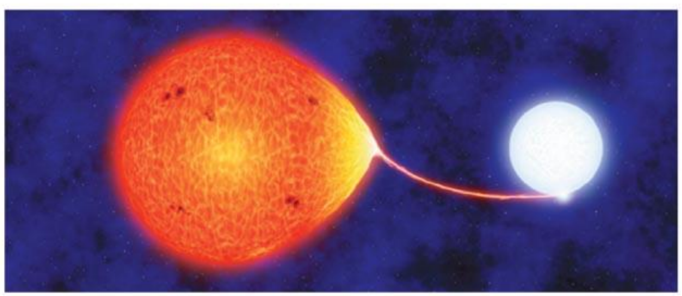
- The binary star Algol consists of a $3.7M_{Sun}$ main-sequence star and a $0.8M_{Sun}$ subgiant star.
- What's strange about this pairing?
- How did it come about?

Thought Question Answers

Algol shortly after its birth. The higher-mass star (left) evolved more quickly than its lower-mass companion (right).



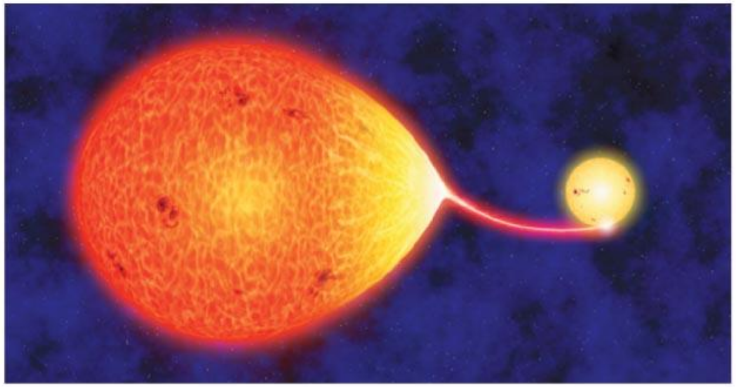
Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.



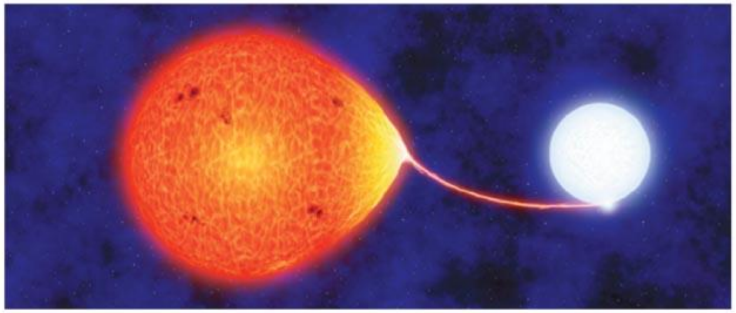
Algol today. As a result of the mass transfer, the red giant has shrunk to a subgiant, and the normal star on the right is now the more massive of the two stars.

- The stars in Algol are close enough that matter can flow from the subgiant onto the main-sequence star.

Algol shortly after its birth. The higher-mass star (left) evolved more quickly than its lower-mass companion (right).



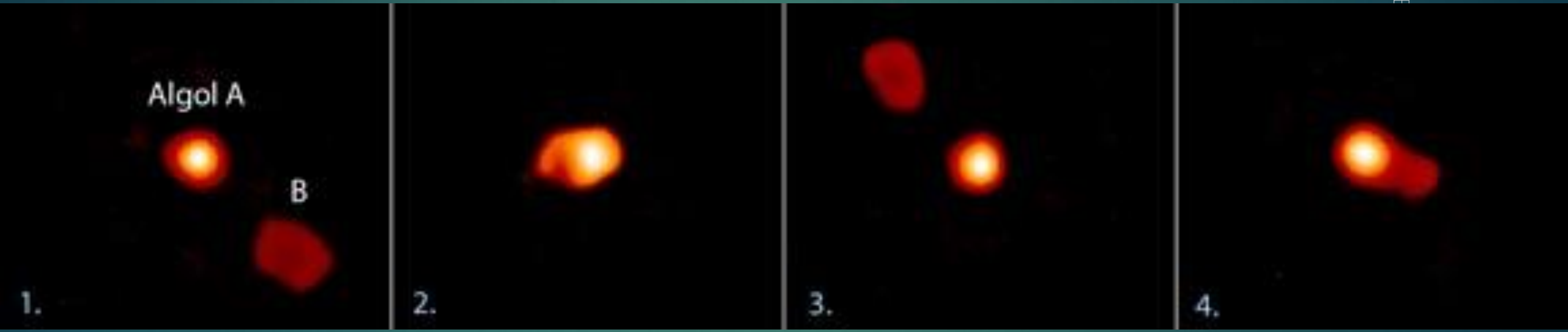
Algol at onset of mass transfer. When the more massive star expanded into a red giant, it began losing some of its mass to its normal, hydrogen core fusion companion.



Algol today. As a result of the mass transfer, the red giant has shrunk to a subgiant, and the normal star on the right is now the more massive of the two stars.

- The star that is now a subgiant was originally more massive.
- As it reached the end of its life and started to grow, it began to transfer mass to its companion (*mass exchange*).
- Now the companion star is more massive.

Images of Algol



What have we learned?

- **How does a star's mass determine its life story?**
  - Mass determines how high a star's core temperature can rise and therefore determines how quickly a star uses its fuel and what kinds of elements it can make.
- **How are the lives of stars with close companions different?**
  - Stars with close companions can exchange mass, altering the usual life stories of stars.