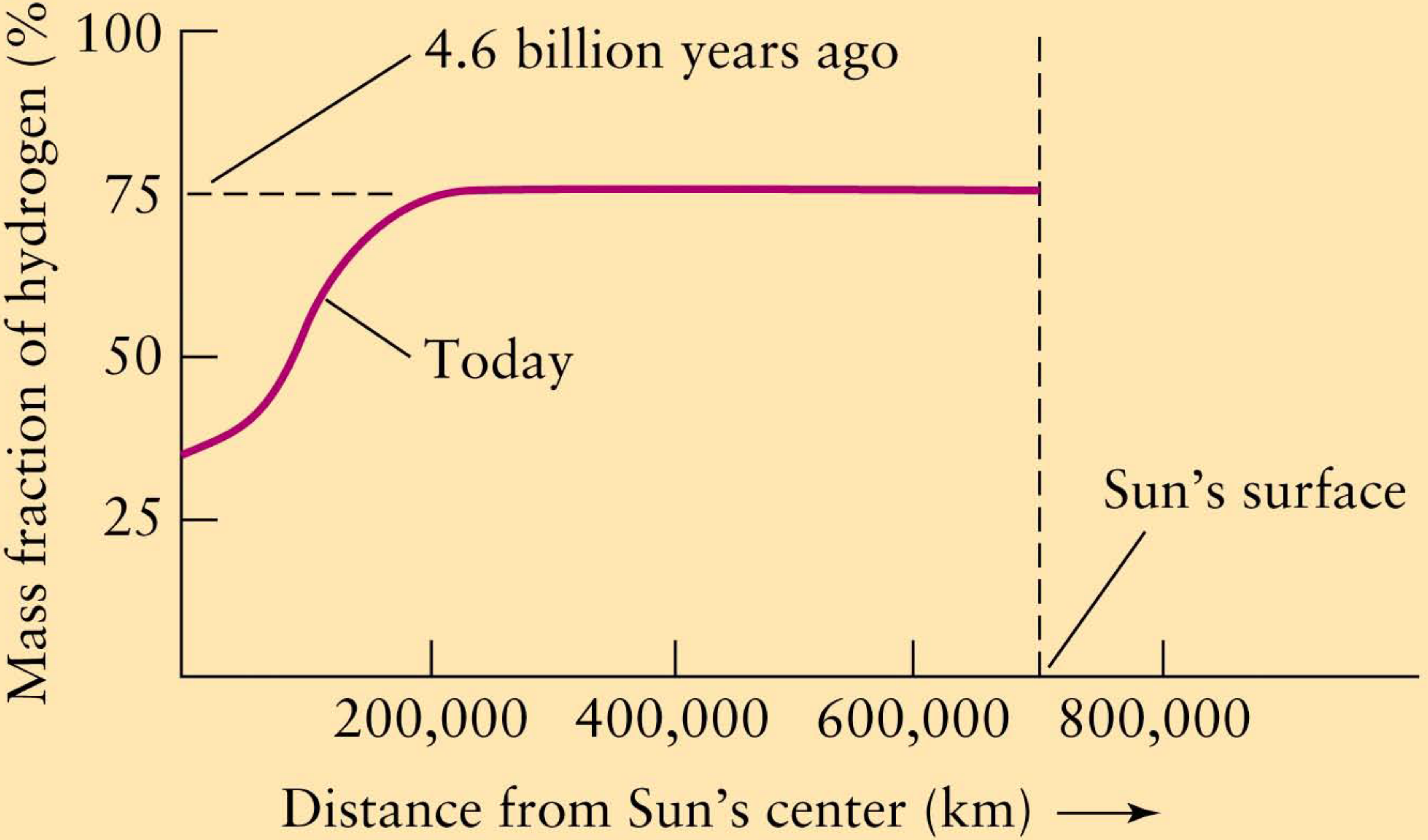
The Future of the Sun

(Note: not in textbook)

The Sun fuses hydrogen into helium in a stable reaction. But what happens when the Sun runs out of hydrogen in its core?

The timescale for this is about 10 billion years; we are about halfway there.

When the Sun runs out of energy, its structure ***has*** to change: **stellar evolution**.



Mass fraction of hydrogen (%)
100
75
50
25
4.6 billion years ago
Today
Sun's surface
200,000
400,000
600,000
800,000
Distance from Sun's center (km)

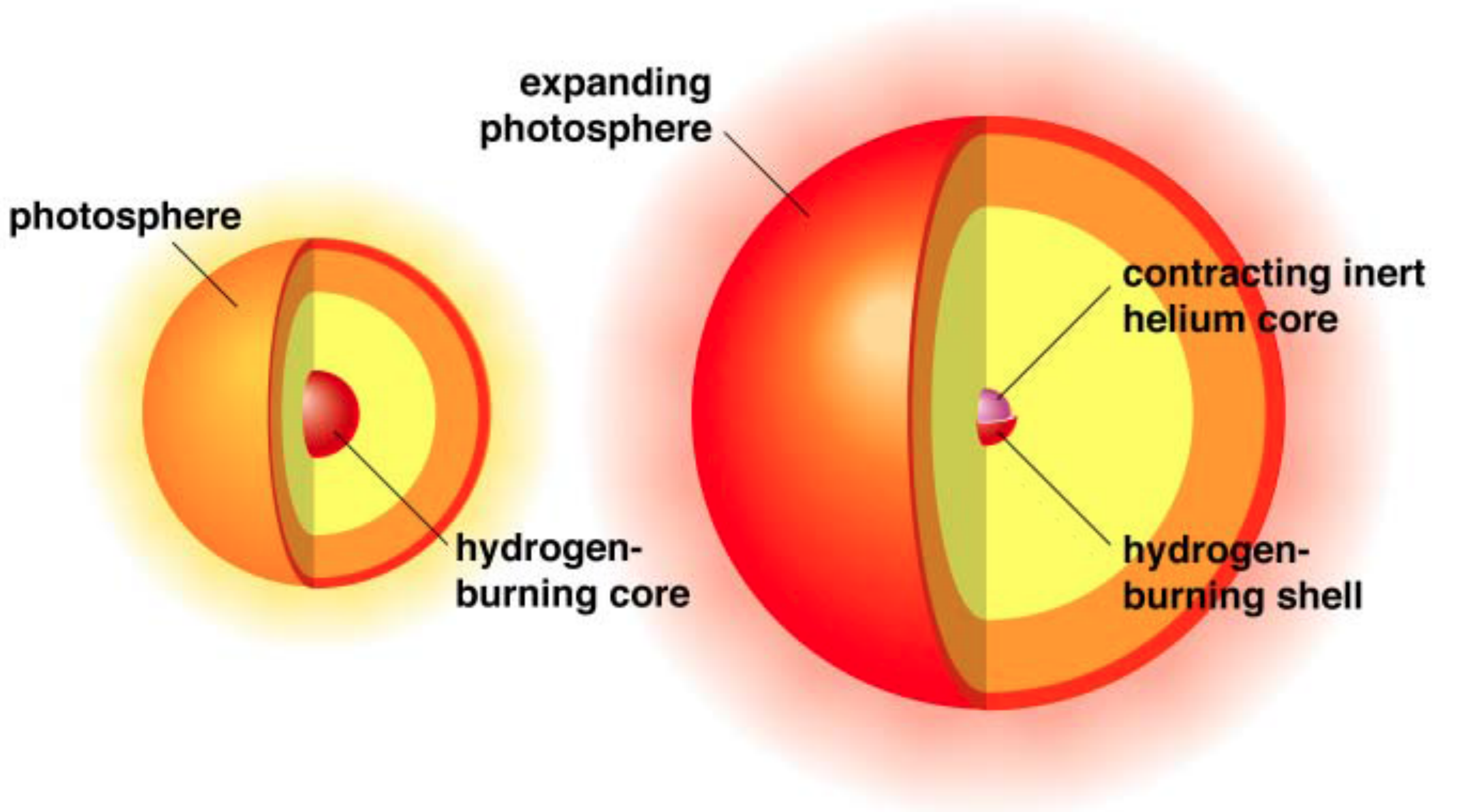
The Future of the Sun

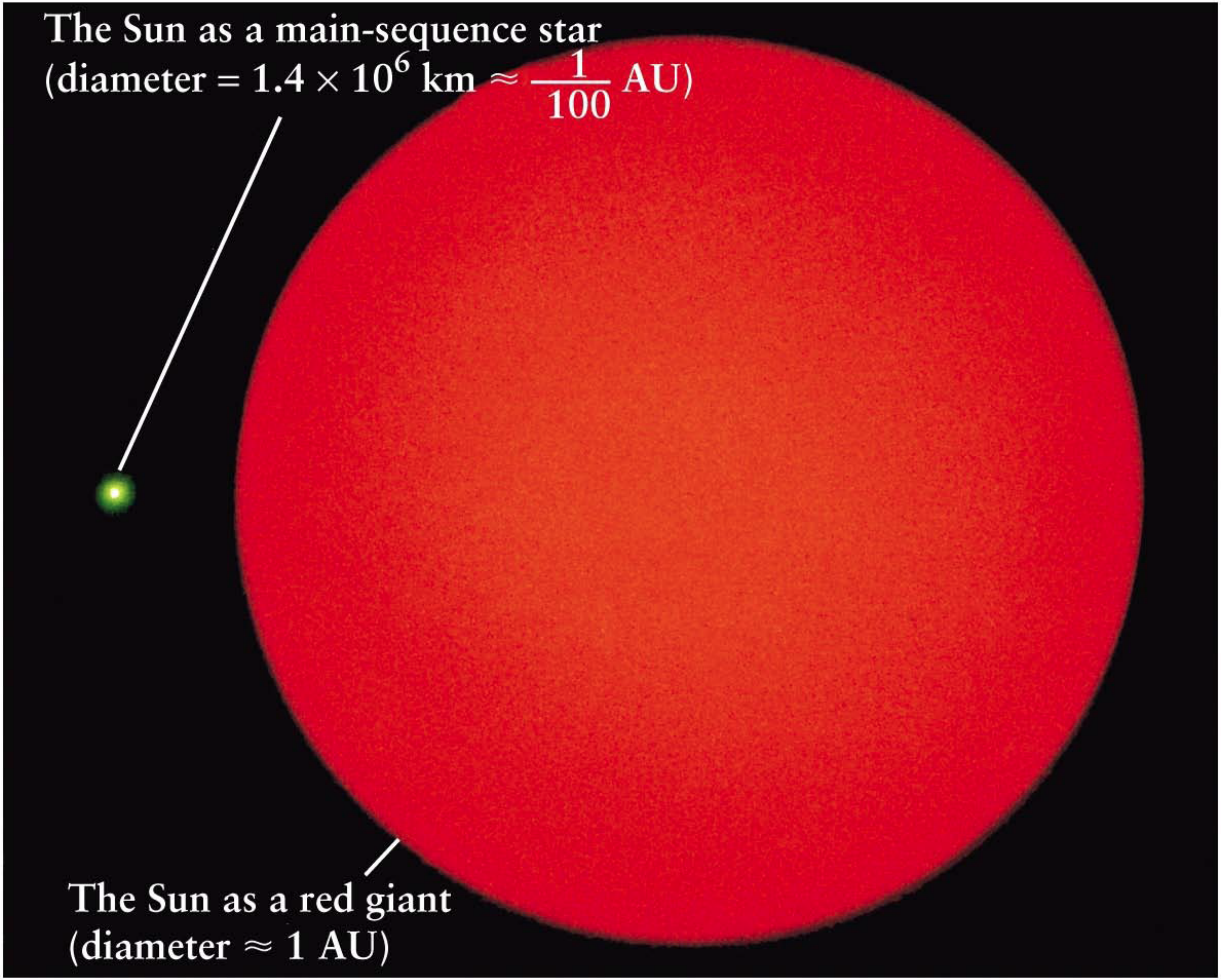
(Note: not in textbook)

- Nuclear fusion of Hydrogen ➔ Helium provides the energy that helps support the Sun against gravitational contraction. Without that, the inner regions will contract and heat up.

- When that happens, the hydrogen just outside the core will get hot enough to start fusing into helium even more quickly than the core did: **excess energy**.

- The Sun brightens and the outer regions expand and cool. The Sun becomes a **red giant**.

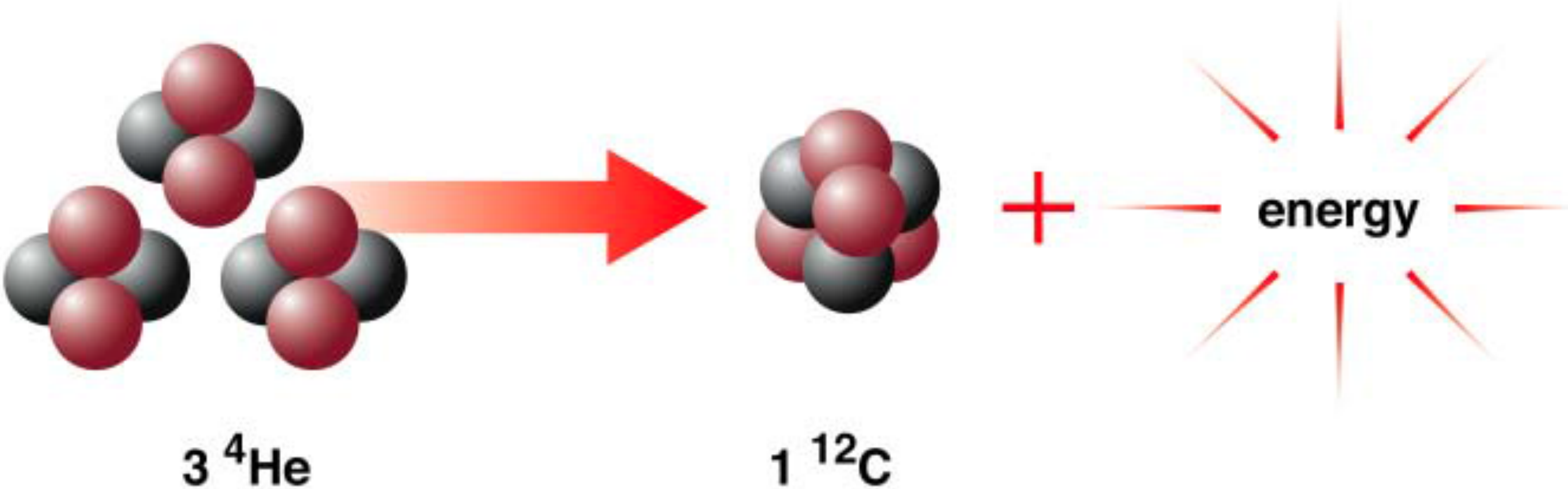

photosphere
hydrogen-
burning core
expanding
photosphere
contracting inert
helium core
hydrogen-
burning shell


The Sun as a main-sequence star
(diameter = 1.4×10^6 km $\approx \frac{1}{100}$ AU)
The Sun as a red giant
(diameter $\approx$ 1 AU)

The Future of the Sun

(Note: not in textbook)

Eventually the temperature of the contracting Helium core gets so high that Helium can start fusing into Carbon and Oxygen and release energy. The Sun settles down for a short time, much brighter than before but relatively stable.



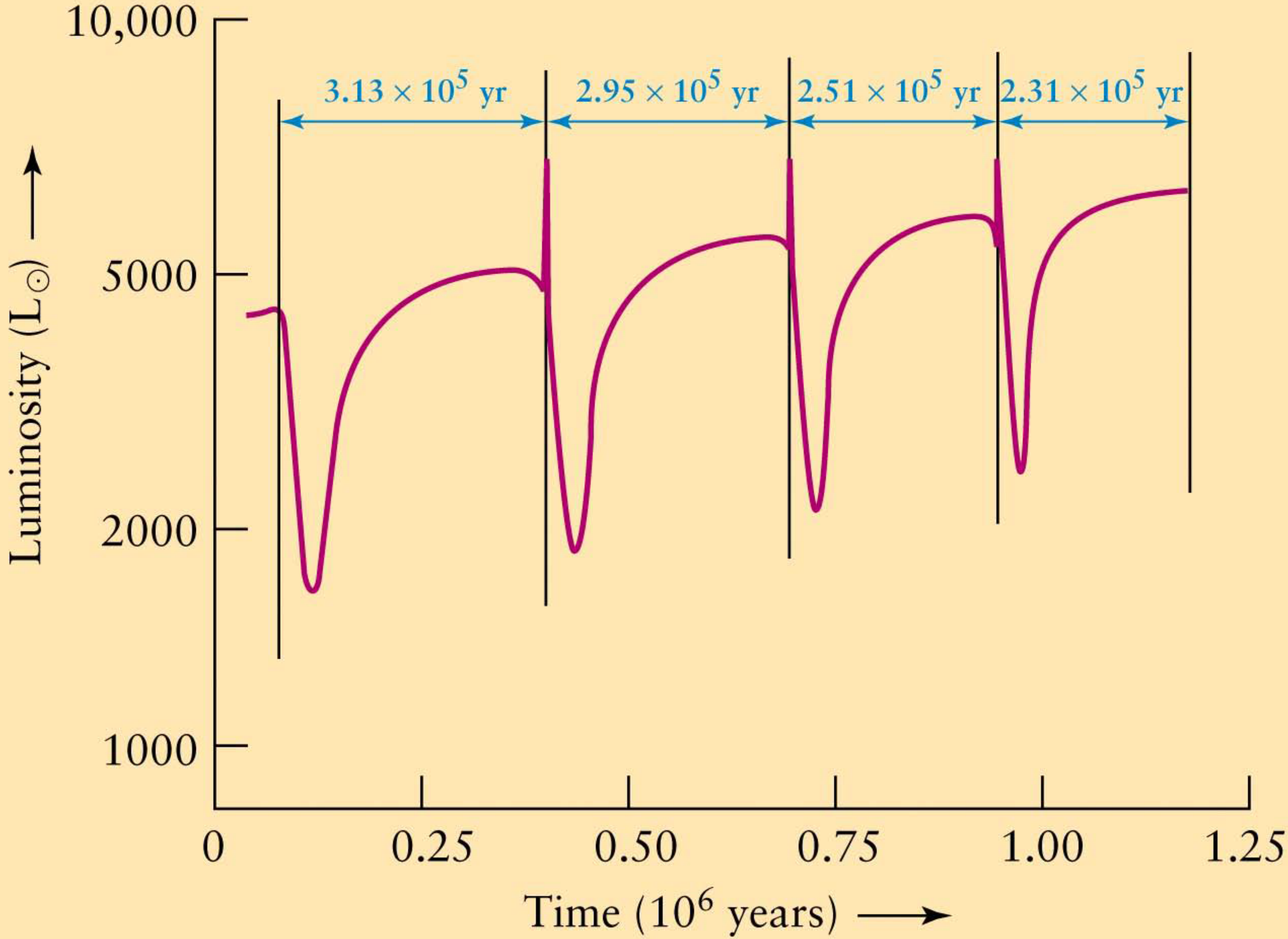
The Future of the Sun

(Note: not in textbook)

- Only ~ 100 million years after starting to burn Helium, the Sun will use up all the Helium in its core and have turned it into Carbon and Oxygen. What then?

- Same thing that happened to make the Sun a red giant, except with Helium burning in a shell around the Carbon/Oxygen core. The Sun swells even more and becomes a **red supergiant**.

- At this point, the Sun is unstable, and the energy released comes in bursts which can actually push away the Sun's. outer layers.



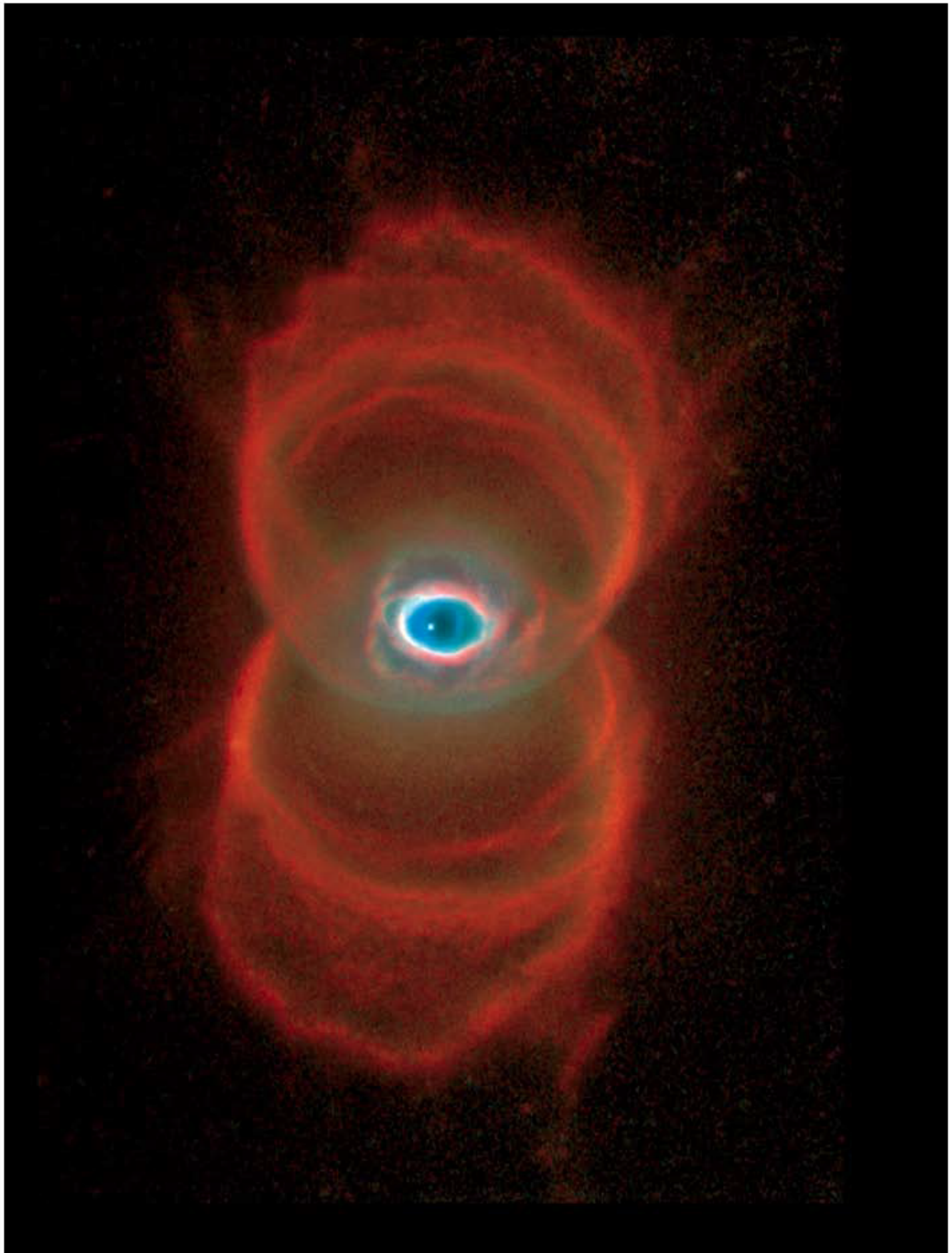
10,000
5000
2000
1000
Luminosity ($L_\odot$)
3.13×10^5 yr
2.95×10^5 yr
2.51×10^5 yr
2.31×10^5 yr
0
0.25
0.50
0.75
1.00
1.25
Time (10^6 years)

The Future of the Sun

(Note: not in textbook)

- The outer layers of the Sun will be pushed out into space, leaving behind the small Carbon/Oxygen core.
- The heat from this core causes the expanding outer layers to shine, making a **planetary nebula**.
- *Planetary nebula have nothing to do with planets!*

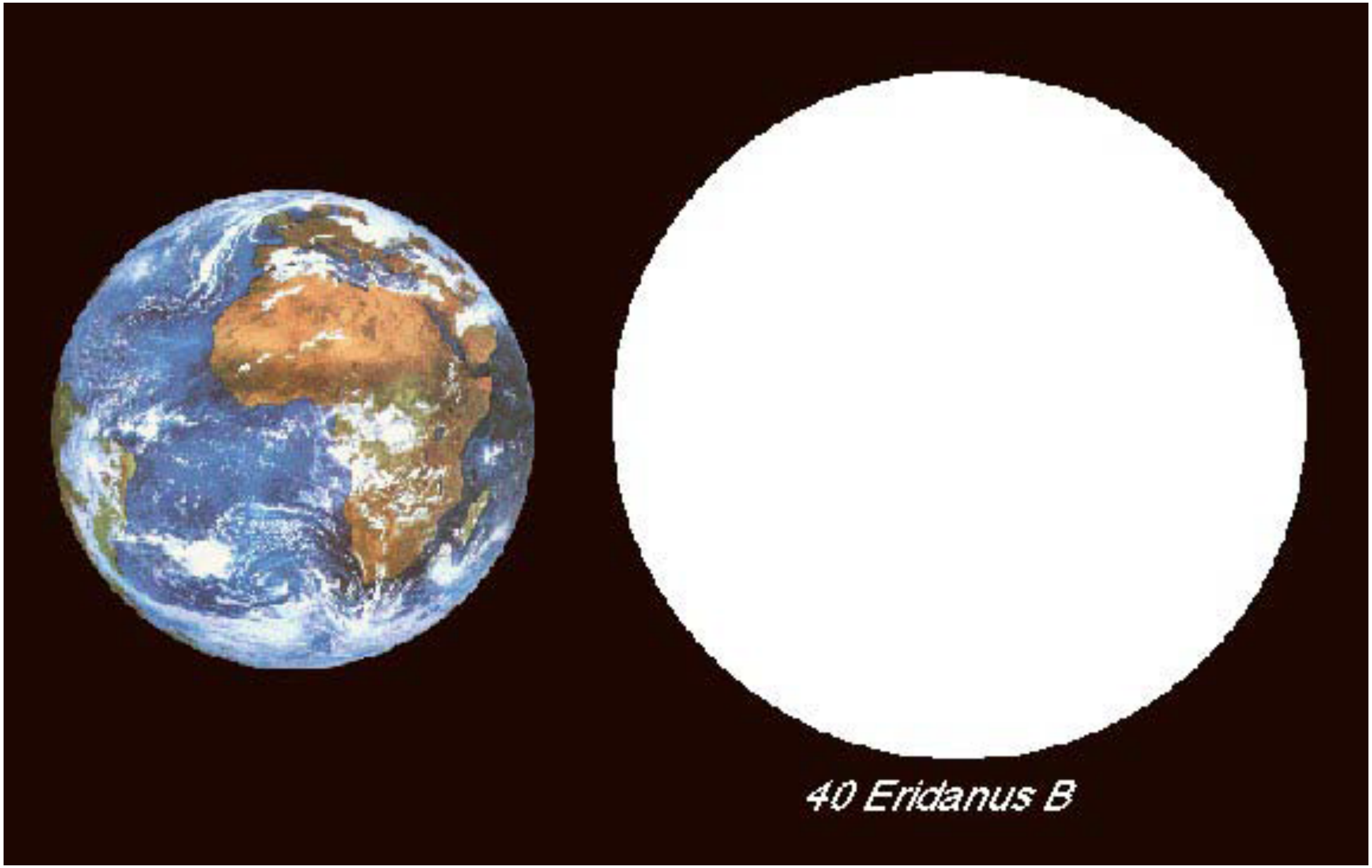
b

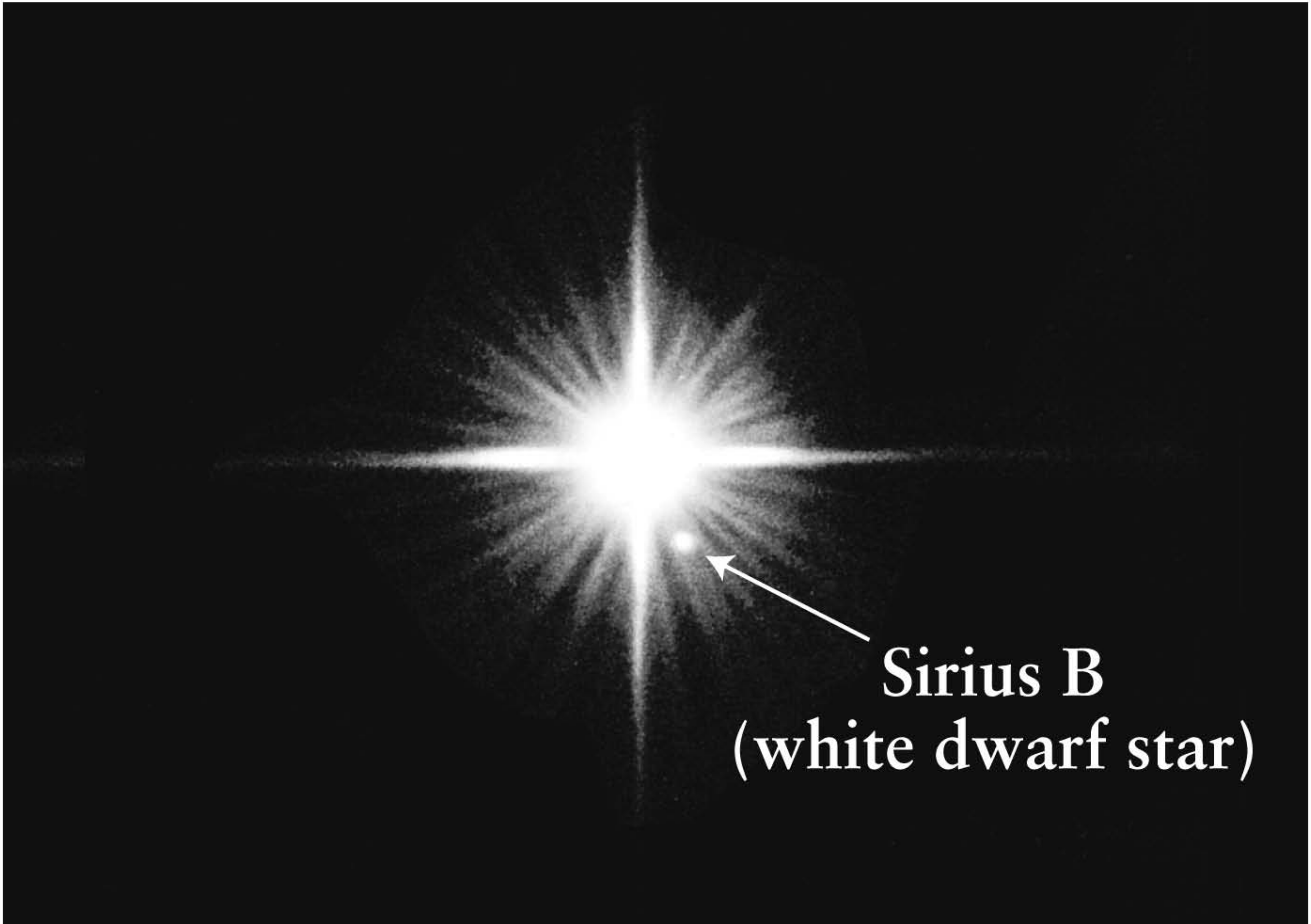


The Future of the Sun

(Note: not in textbook)

- After the outer layers drift away and stop shining, all that is left behind is the cooling core of carbon and oxygen, called a **white dwarf**.
- It shines faintly because it is hot, but its not hot enough to drive nuclear reactions involving carbon or oxygen.
- It is extremely dense, with a mass about half that of the Sun and a size not much larger than the Earth.
- Over billions of years, the white dwarf simply cools off and fades out.


40 Eridanus B


Sirius B
(white dwarf star)