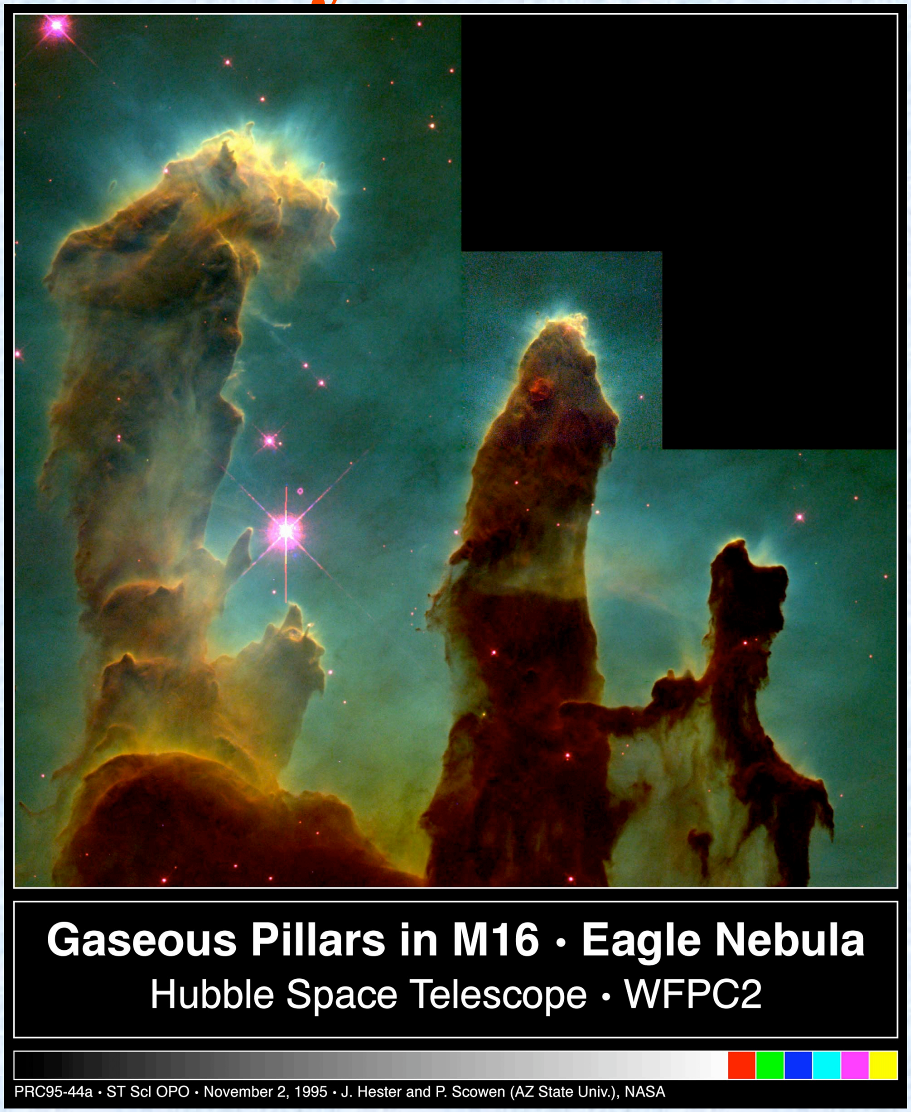
Astronomy 1 – Winter 2011



Lecture 22; March 2 2011

Previously on Astro-1

- The Main-Sequence is a mass sequence
- High mass stars live fast and die young
- Stars form in clouds of cold gas, collapsing under gravitational instability
- Protostars are heated by gravitational collapse and often form disks and jets around them
- H-R diagrams can be used to age-date star clusters.
- Stars on the main sequence burn hydrogen in the core

Last homework – Due 03/09/11

- On your own: answer all the review questions in chapters 19 20 and 22
- To TAs: answer questions 19.37 19.38 20.39 20.46 22.33 22.46

Question 21.3 (iclickers!)

- The major source of energy in the pre-main sequence life of the Sun was
  - A) gravitational
  - B) nuclear fusion
  - C) chemical burning of carbon atoms
  - D) nuclear fission

Today on Astro-1

- **The late stages of stellar evolution**
- **Stellar afterlife**
  - Intermediate mass stars
  - High mass stars

The late stages of stellar evolution

As a star ages,
it continually tries
to establish
a new equilibrium…

Luminosity and radius
both change

Moral:

when a star’s core contracts,

- the star’s luminosity increases
- the star’s outer layers expand and cool

Conversely,

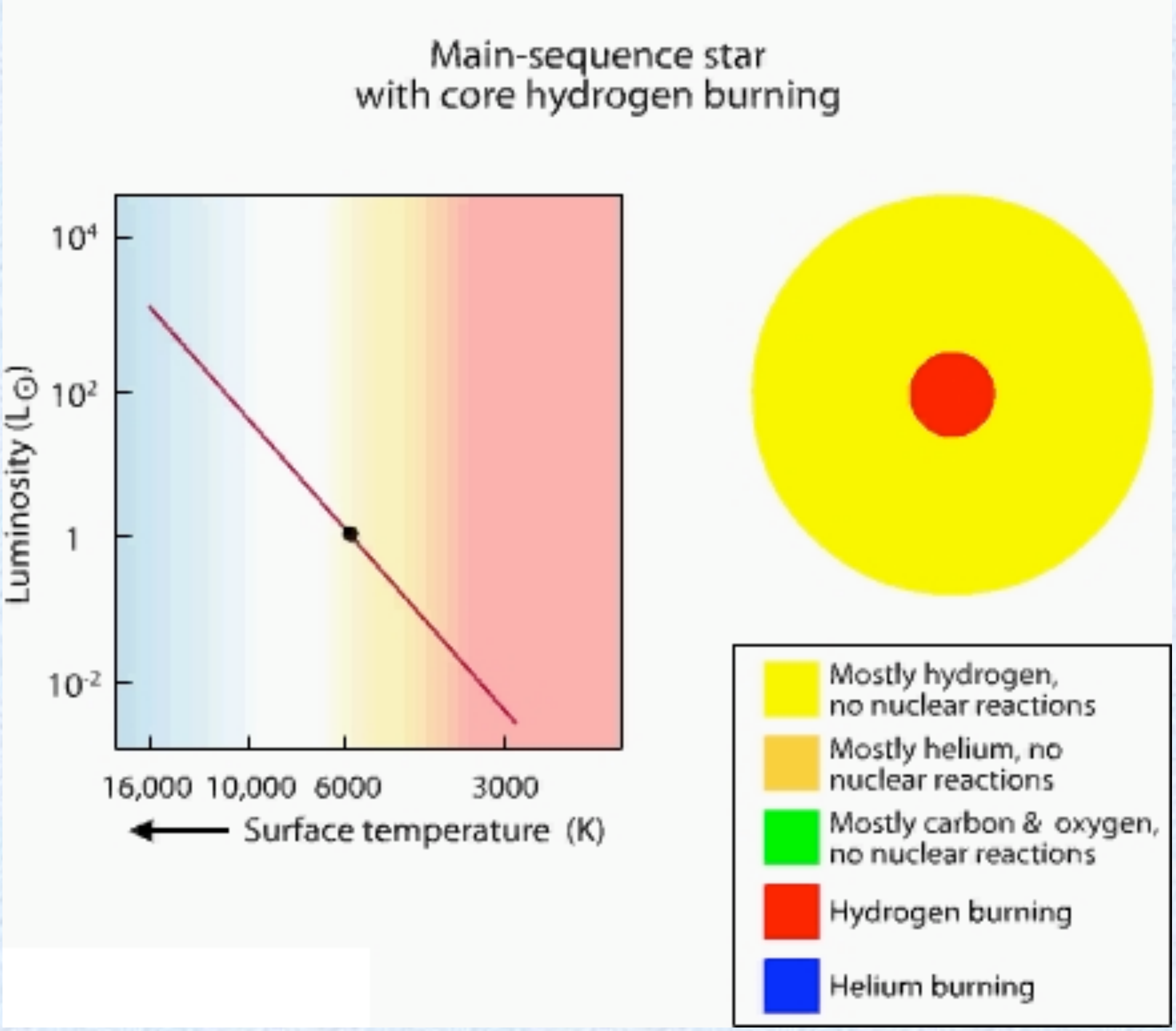
when a star’s core expands,

- the star’s luminosity decreases
- the star’s outer layers contract and heat up

Evolution of a star like the Sun

Main–sequence star (core H fusion) Stage 1:

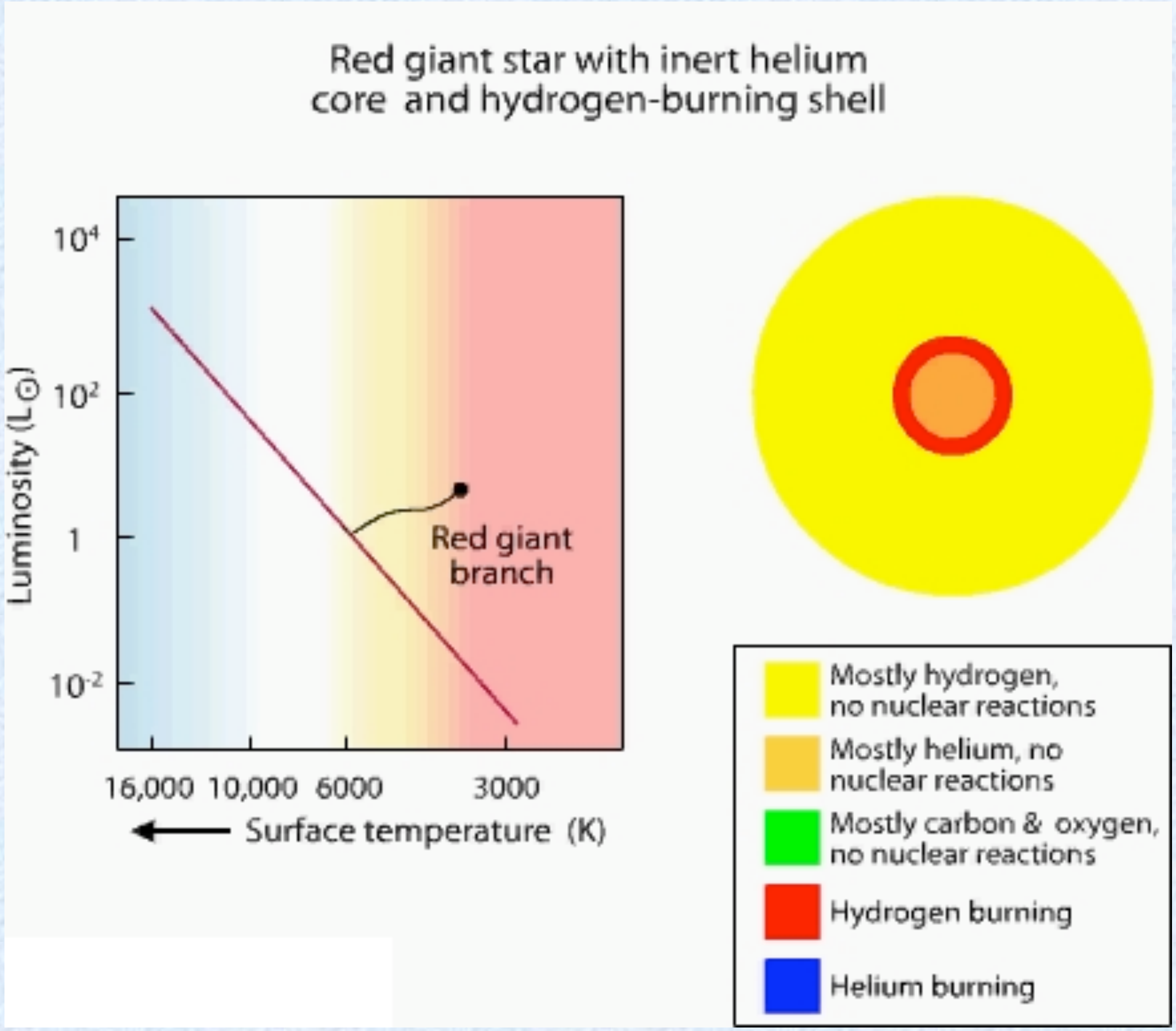
H = hydrogen He = helium
C = carbon O = oxygen



Evolution of a star like the Sun

Stage 1:
Main–sequence star (core H fusion)
Stage 2:
Red giant
(shell H fusion)

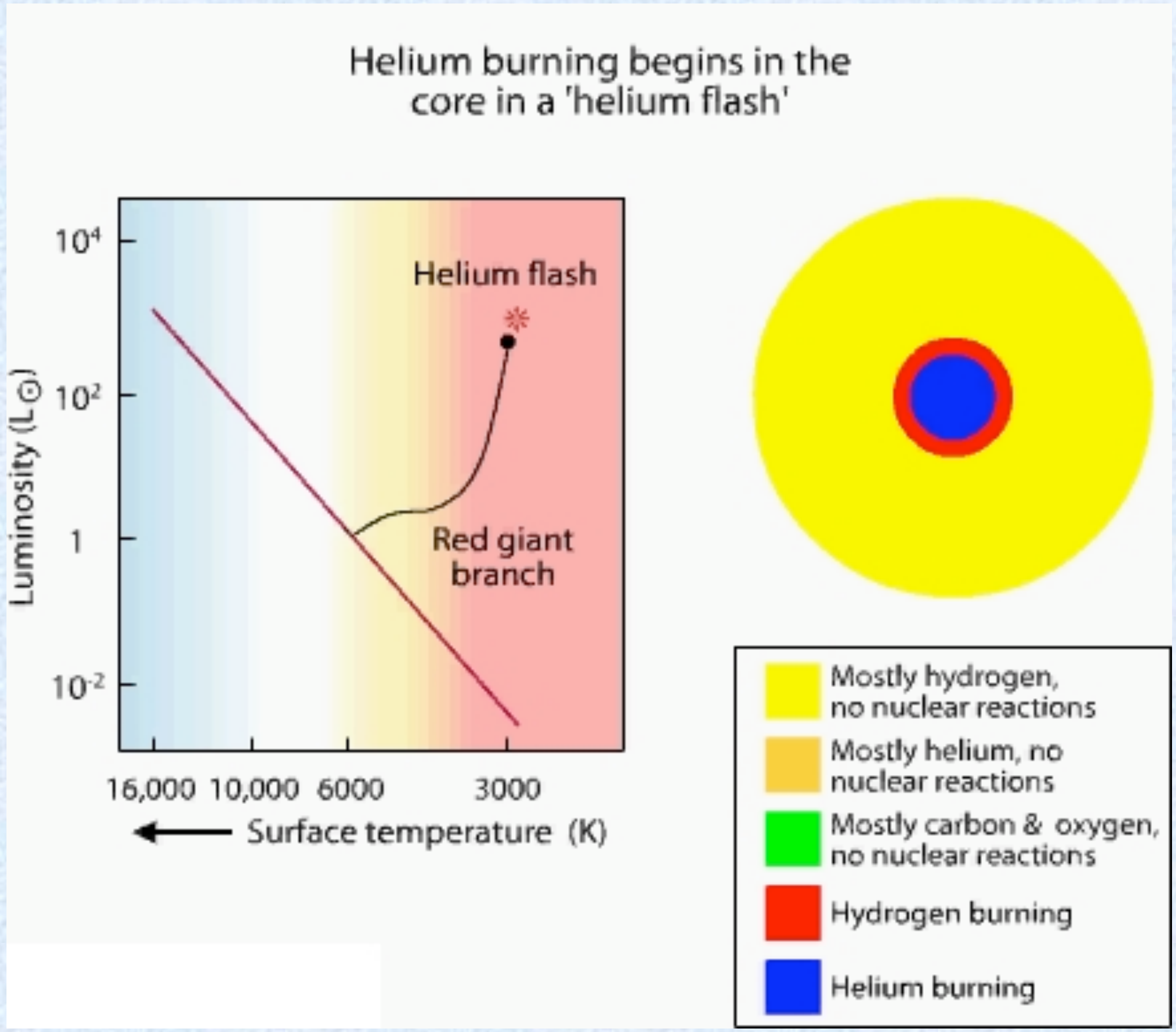
H = hydrogen   He = helium
C = carbon   O = oxygen



Evolution of a star like the Sun

Stage 1:
Main–sequence star (core H fusion)
Stage 2:
Red giant
(shell H fusion)
Stage 3: He core fusion begins

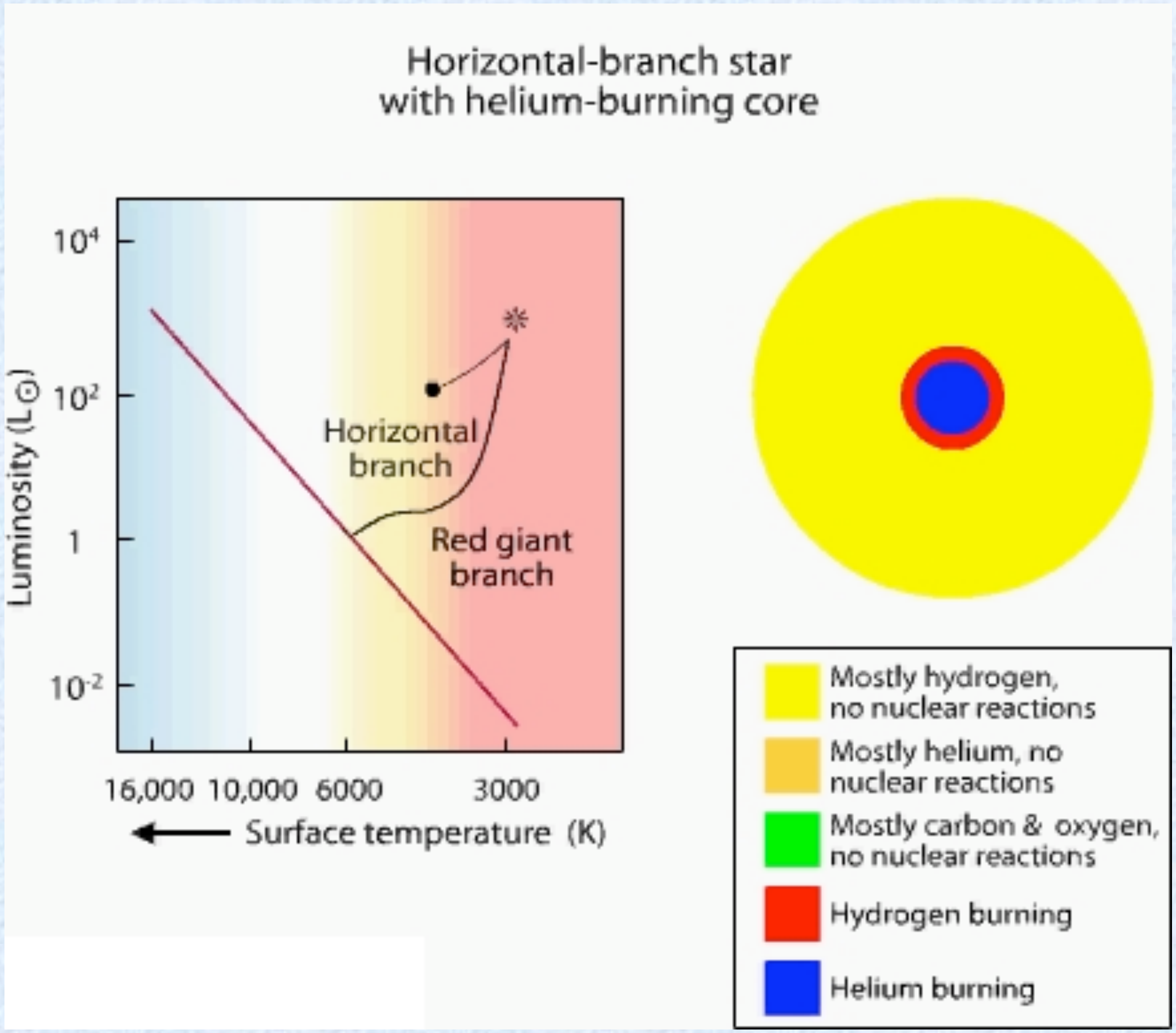
H = hydrogen   He = helium
C = carbon   O = oxygen



Evolution of a star like the Sun

Stage 1:
Main–sequence star (core H fusion)
Stage 2:
Red giant
(shell H fusion)
Stage 3: He core fusion begins
Stage 4:
Horizontal branch
(core He fusion)

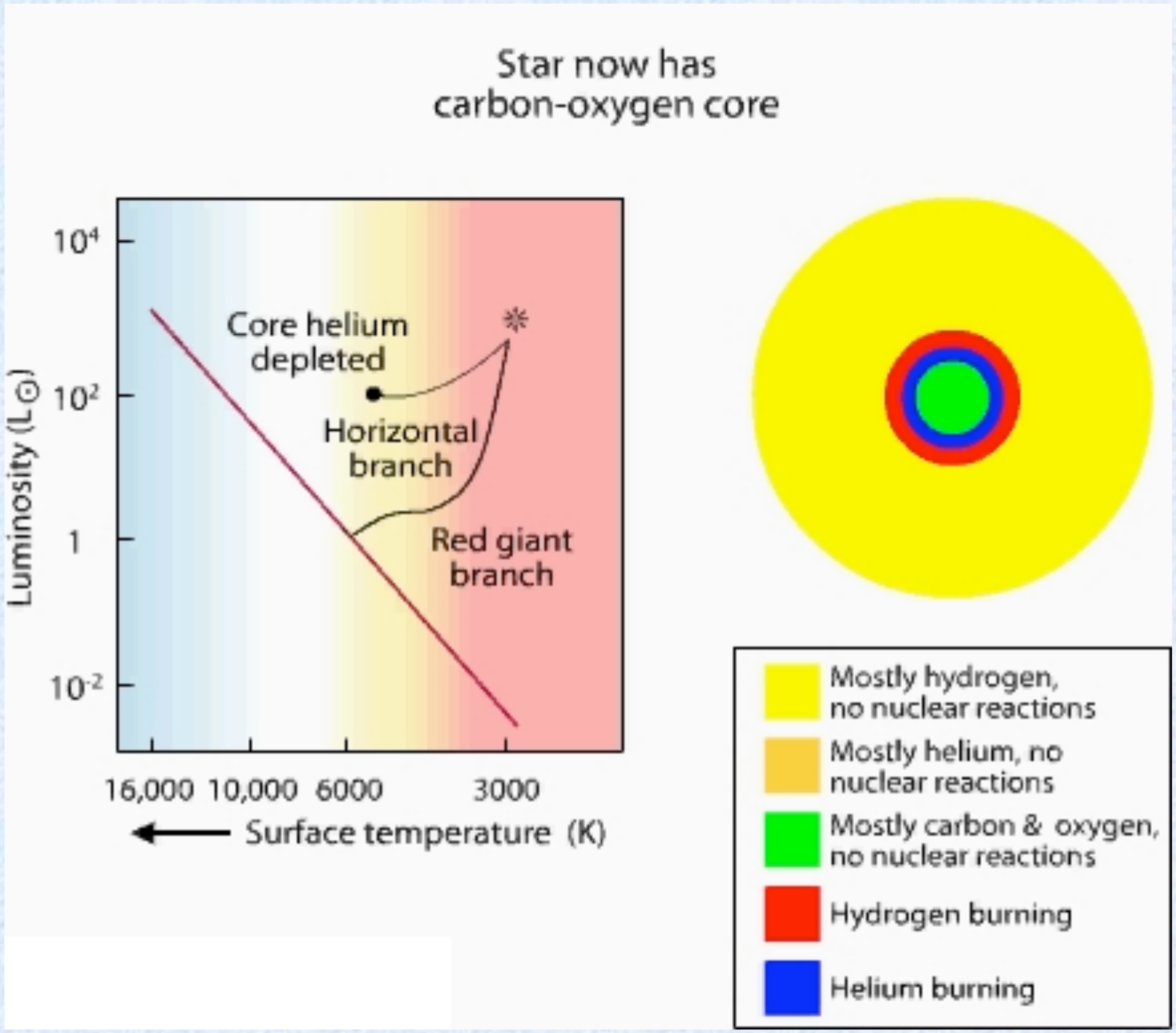
H = hydrogen He = helium
C = carbon O = oxygen



Evolution of a star like the Sun

Stage 1:
Main–sequence star (core H fusion)
Stage 2:
Red giant
(shell H fusion)
Stage 3: He core fusion begins
Stage 4:
Horizontal branch
(core He fusion)
Stage 5: C-O core

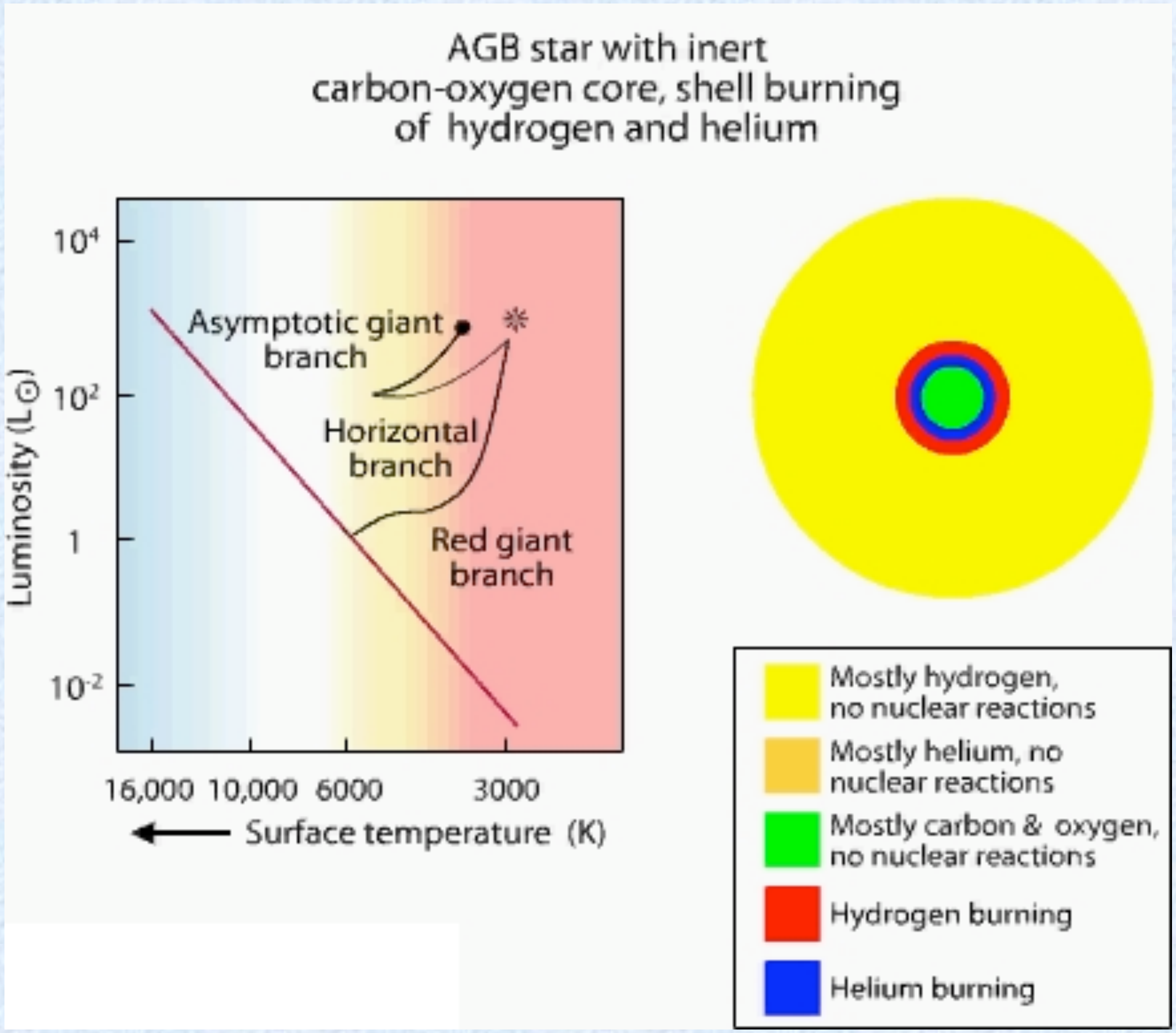
H = hydrogen He = helium
C = carbon O = oxygen



Evolution of a star like the Sun

Stage 1:
Main–sequence star (core H fusion)
Stage 2:
Red giant
(shell H fusion)
Stage 3: He core fusion begins
Stage 4:
Horizontal branch
(core He fusion)
Stage 5: C-O core
Stage 6:
Asymptotic giant branch
(shell H & He fusion)

H = hydrogen He = helium
C = carbon O = oxygen



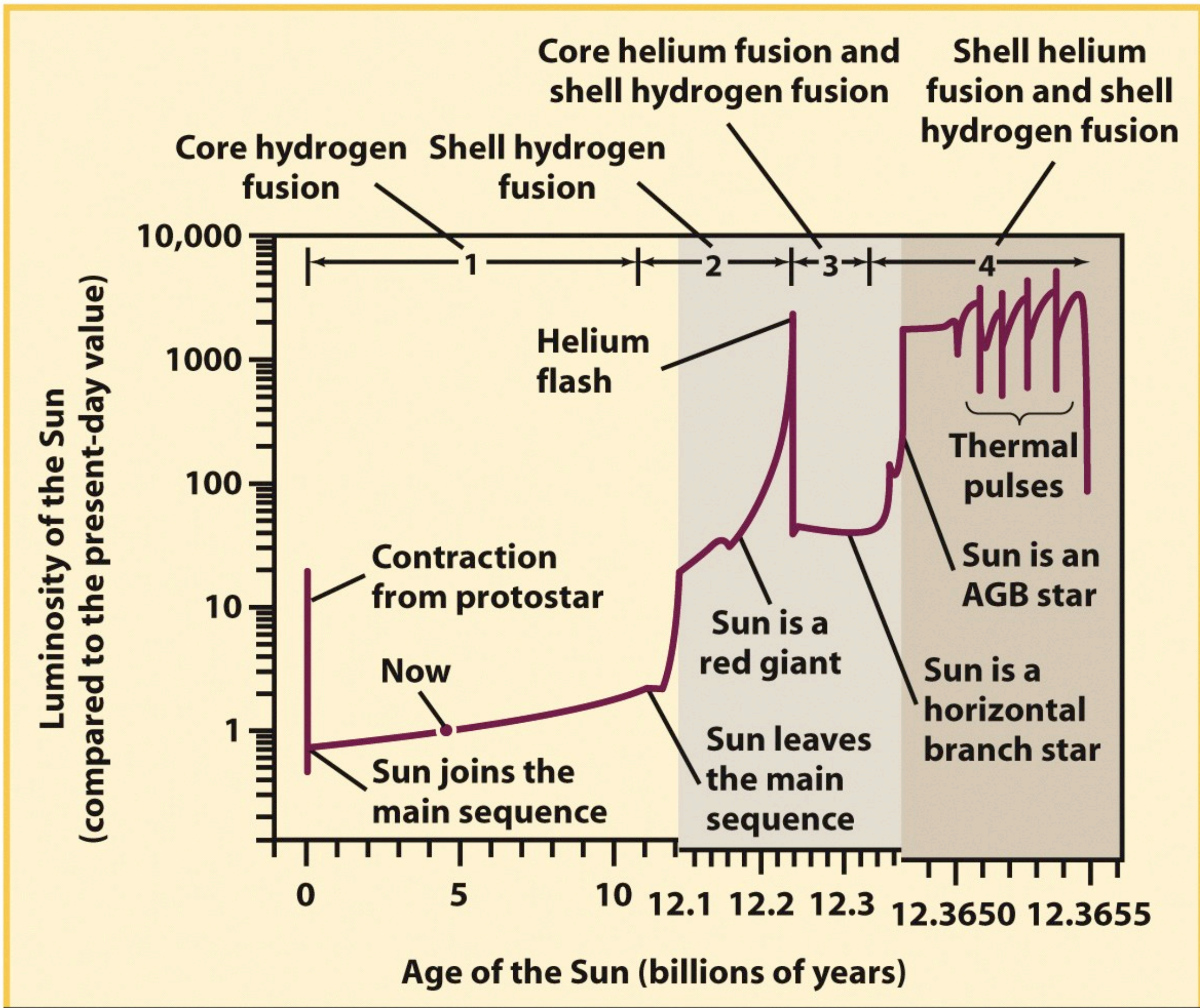


Figure 20-5
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. During the AGB stage there are brief periods of runaway helium fusion, causing spikes in luminosity called thermal pulses.

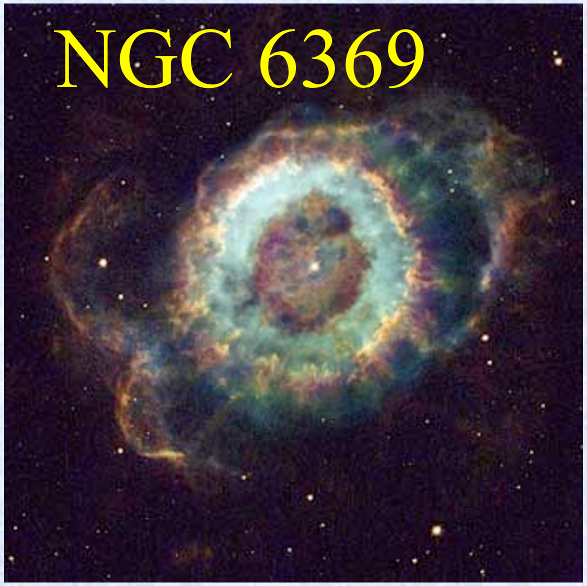
Question 22.1 (iclickers!)

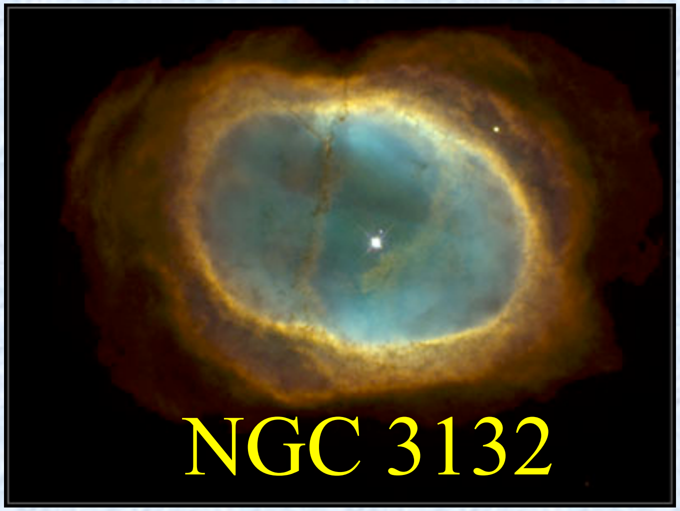
- During its life the Sun will experience all of the following energy sources, except
  - A) Gravitational Contraction
  - B) Hydrogen burning
  - C) He burning
  - D) C burning

Late stages of evolution for intermediate mass stars like the sun

Final evolution of a star like the Sun:

planetary nebula (PN)





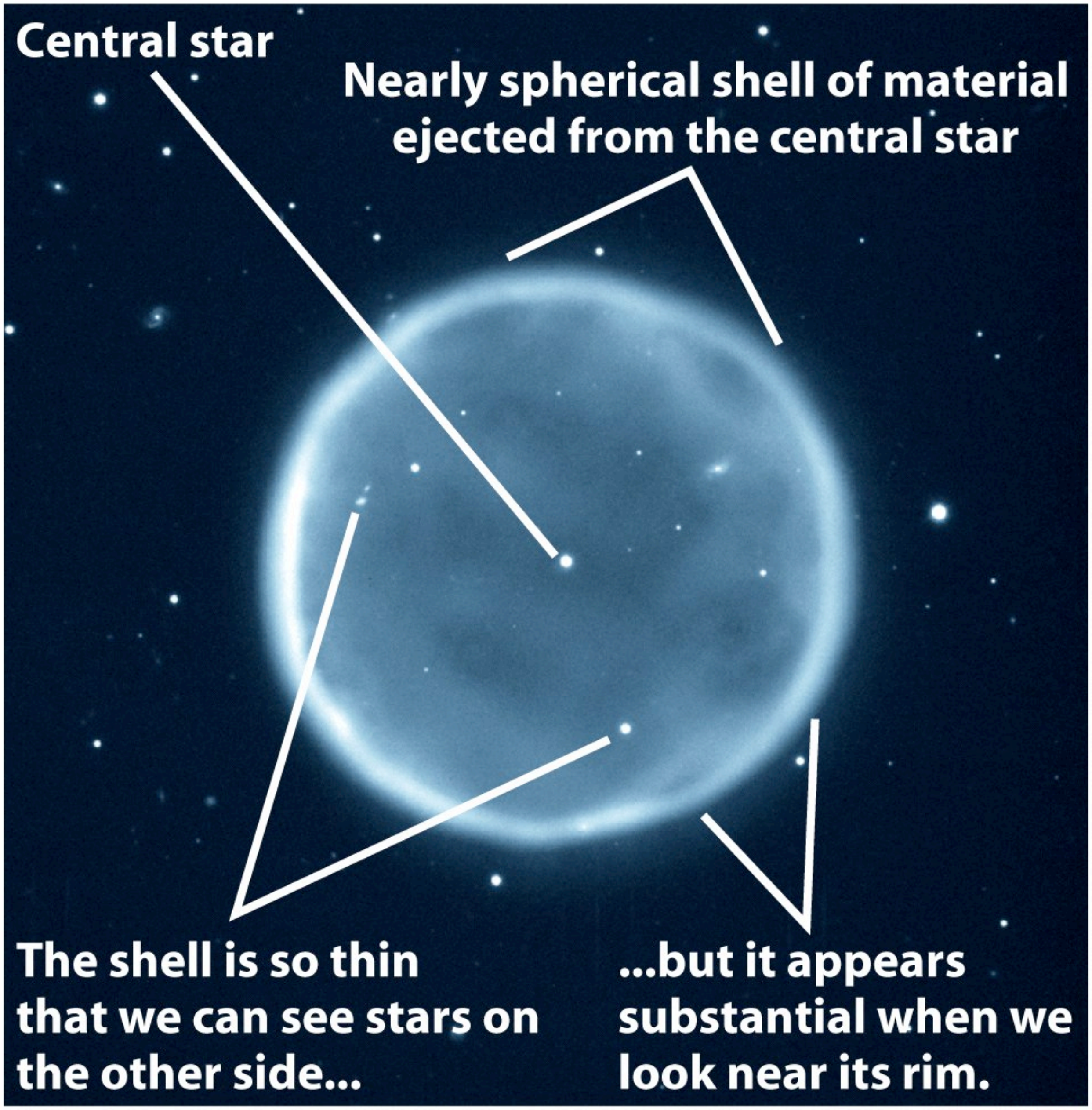


Figure 20-6b
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What's left of the star:
A white dwarf

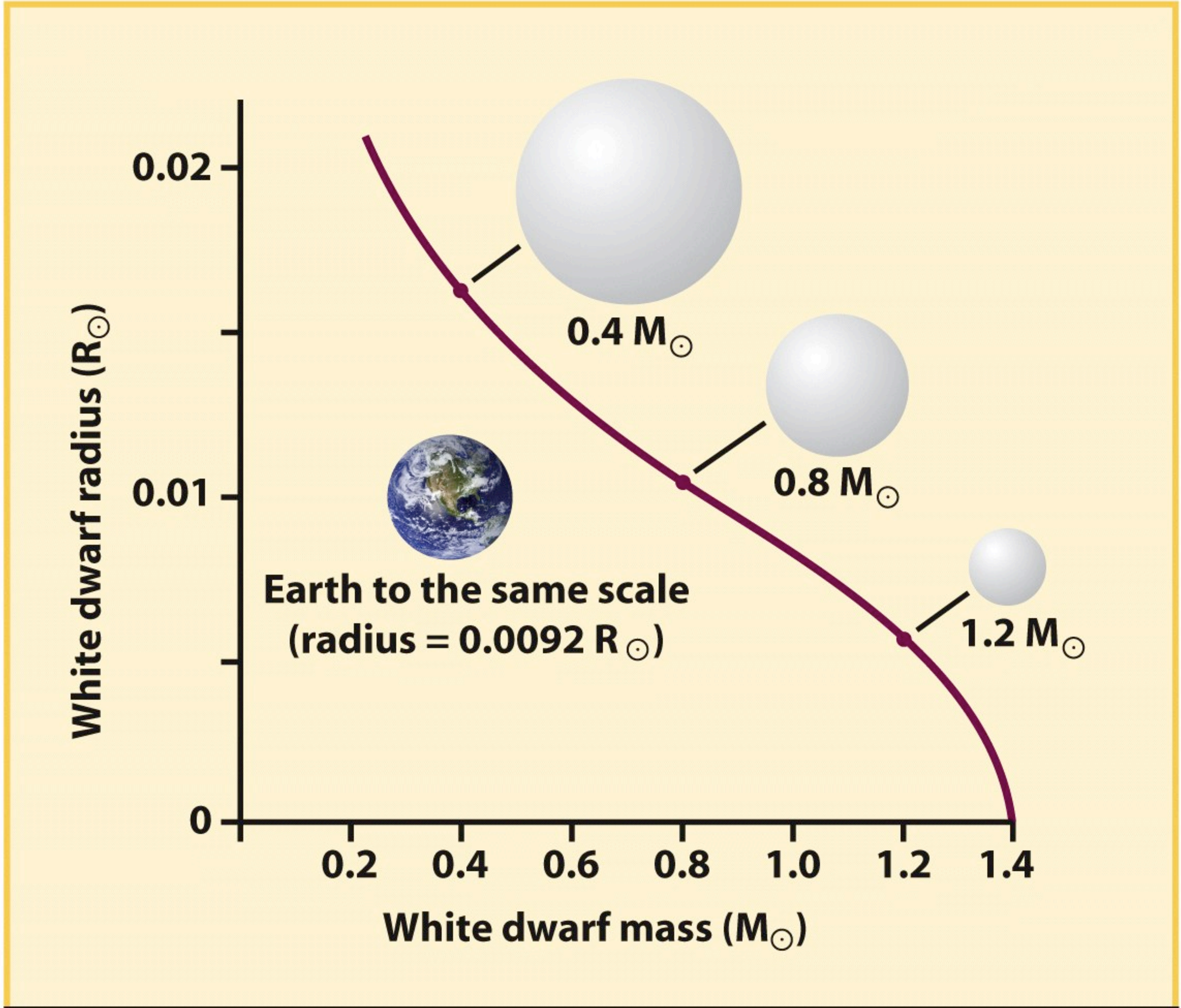

Figure 20-9
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Evolutionary track	Mass ($M_\odot$) Giant star	Ejected nebula	White dwarf
A	3.0	1.8	1.2
B	1.5	0.7	0.8
C	0.8	0.2	0.6

Figure 20-10 part 2
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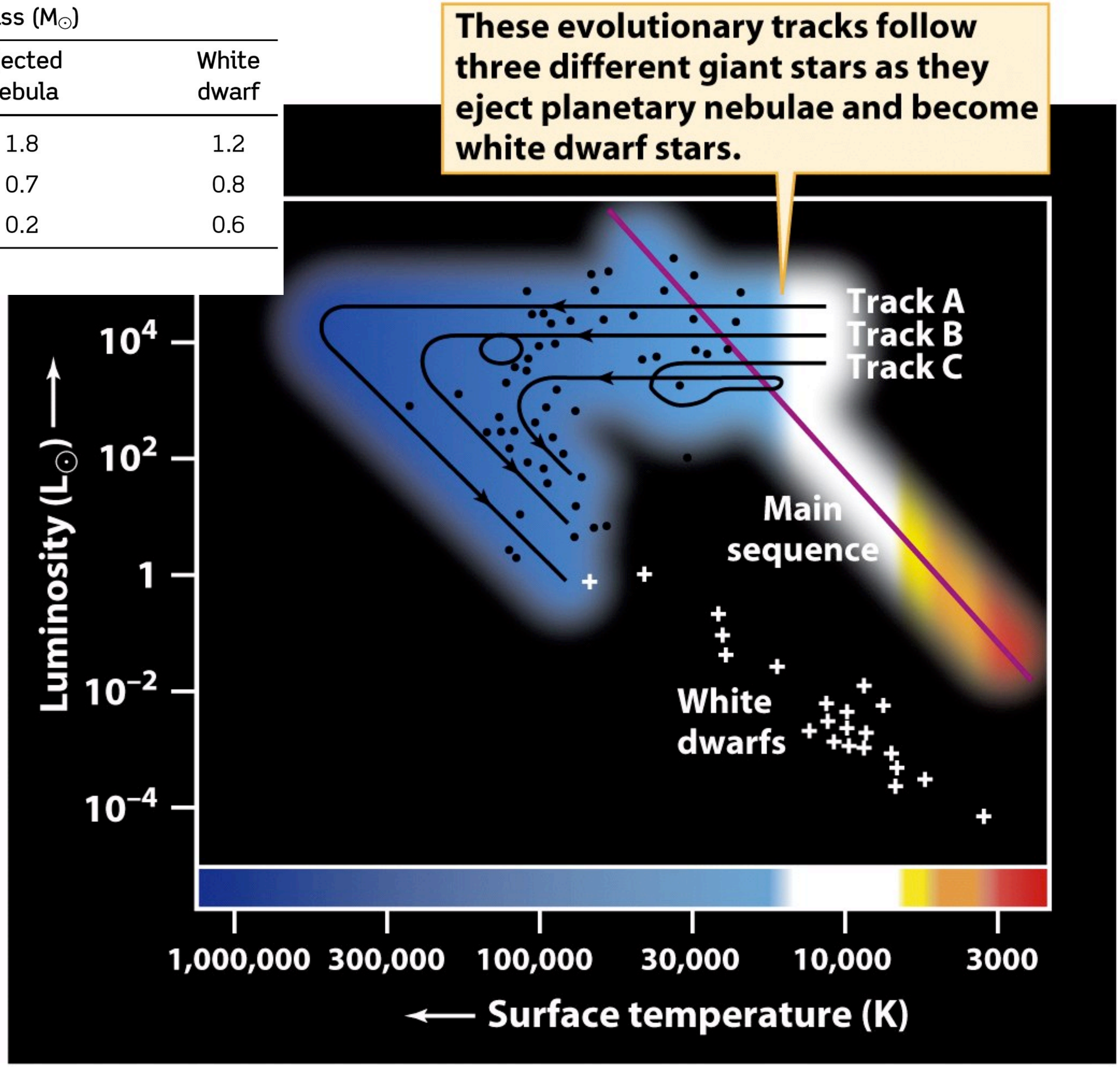

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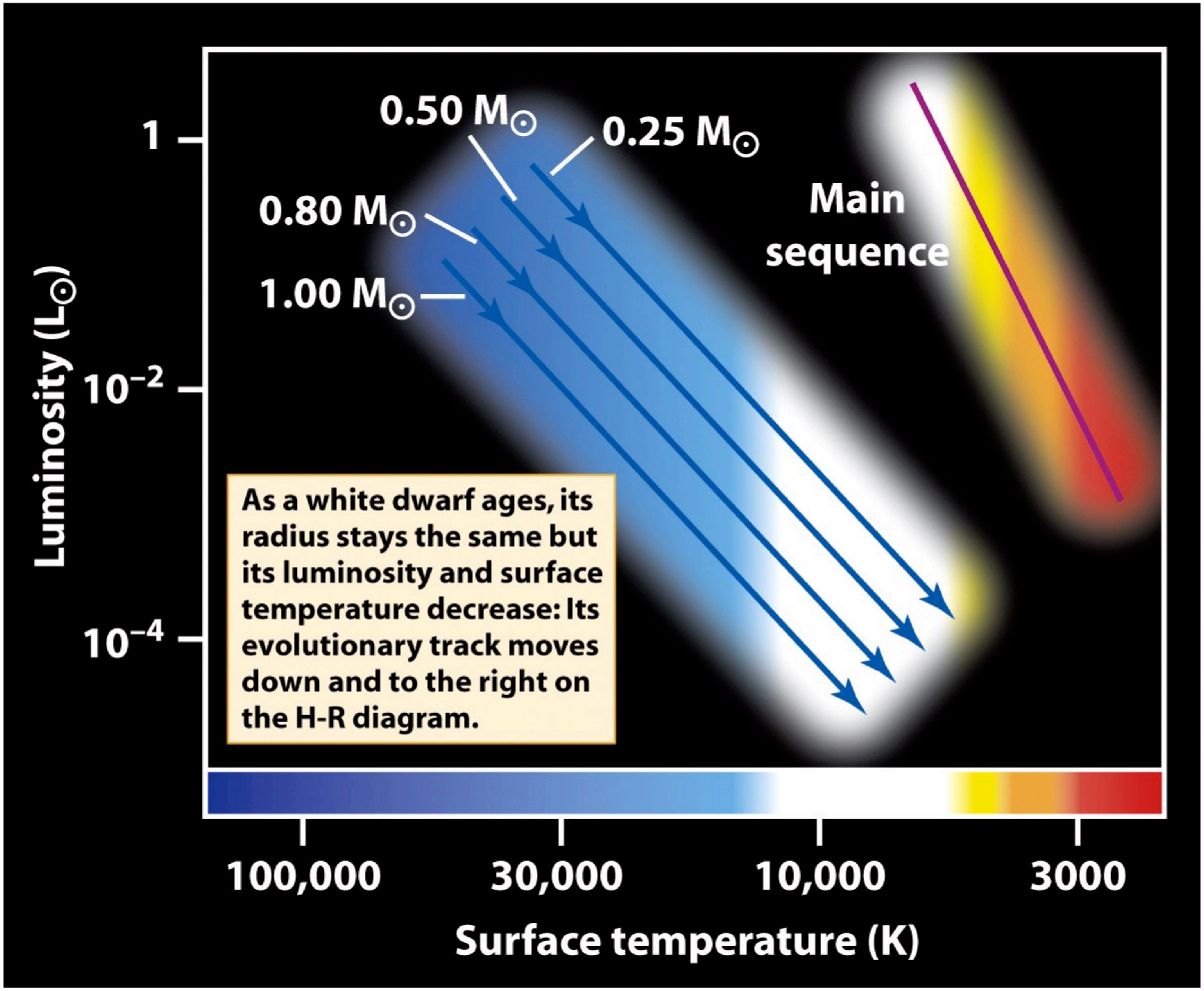

Figure 20-11
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What supports white dwarfs?

When nuclear fuel is exhausted in the core of a star, it contracts until it reaches a point where the electrons cannot be packed any tighter because of the Pauli Exclusion principle.

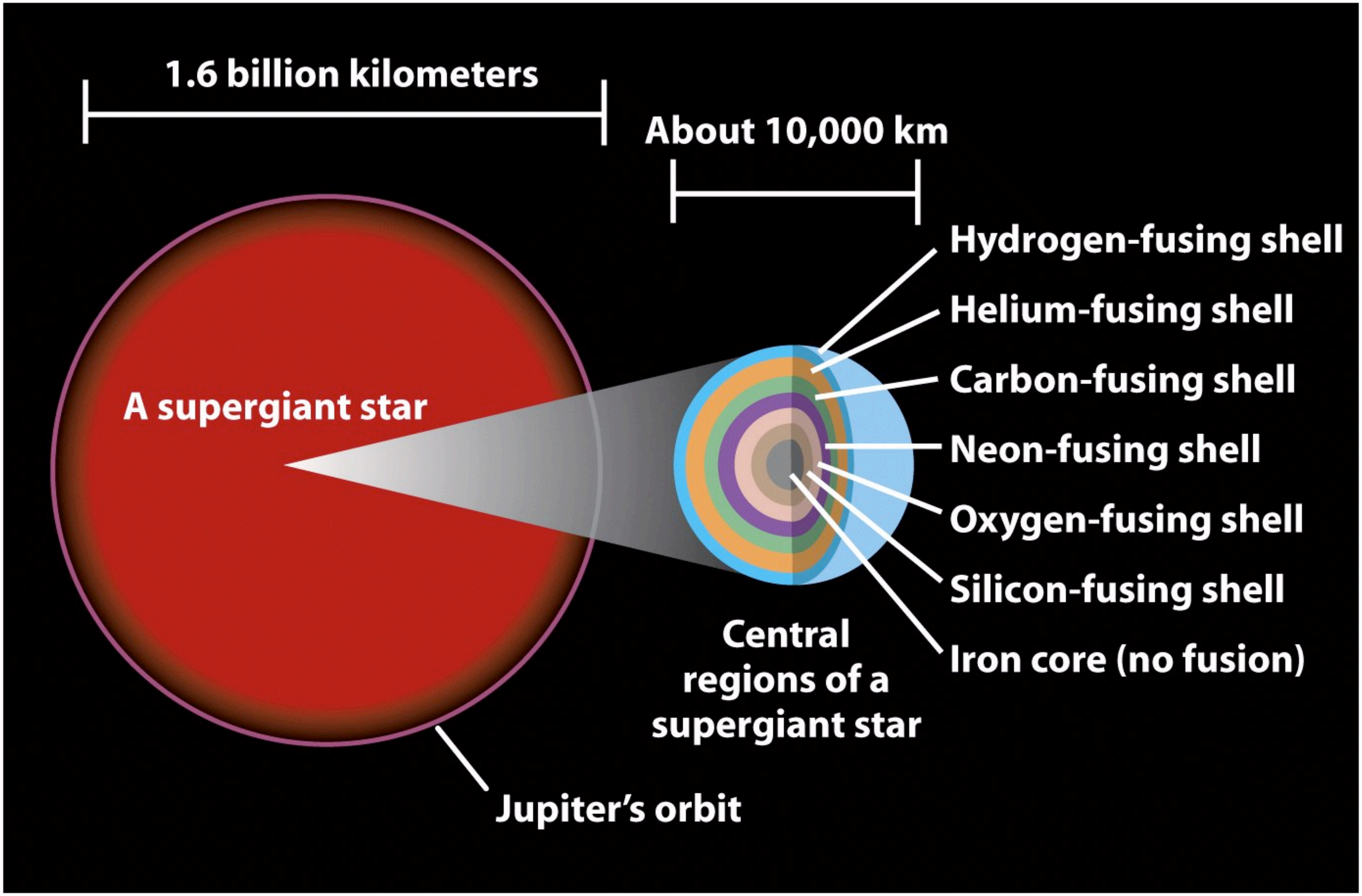
This *electron degeneracy pressure* supports the core against further collapse. Up to a certain limit, known as Chandrasekar's mass (1.4 solar masses)

Question 22.2 (iclickers!)

- A white dwarf is generating energy from what source?
  - A) it no longer generates energy but it is cooling slowly
  - B) nuclear fusion of heavy elements in the core
  - C) gravitational potential energy as the star slowly contracts
  - D) nuclear fusion of hydrogen into helium

Life in the fast lane. High mass stars

A >8 solar mass star on the last day of its life.



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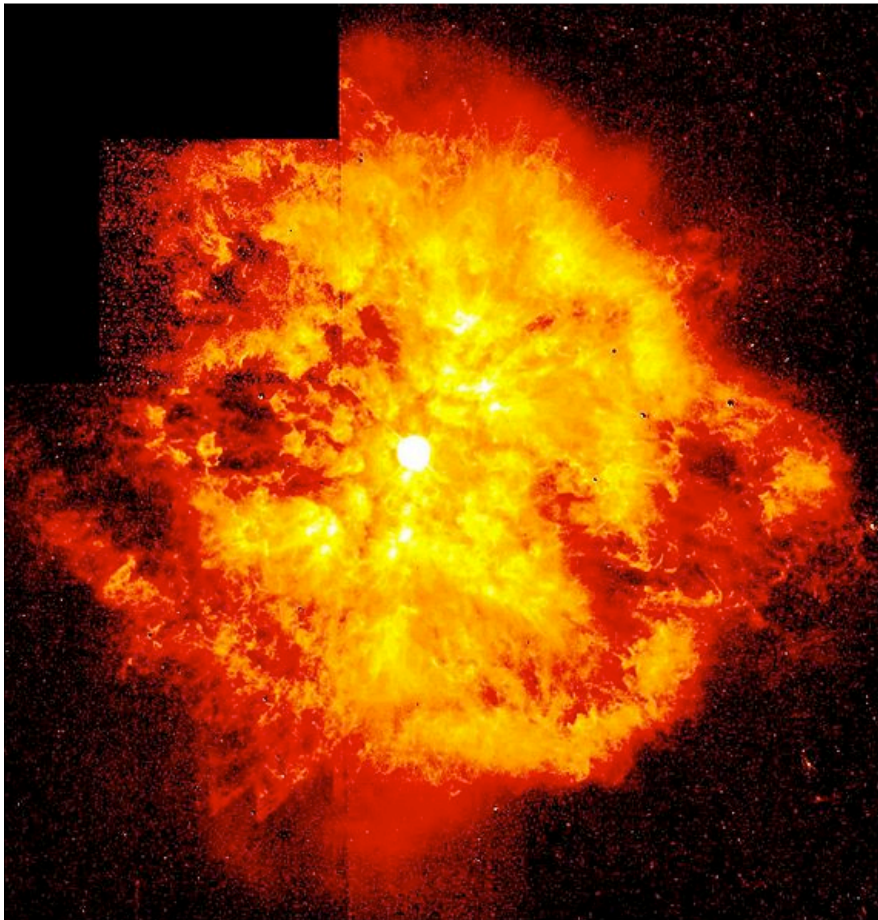

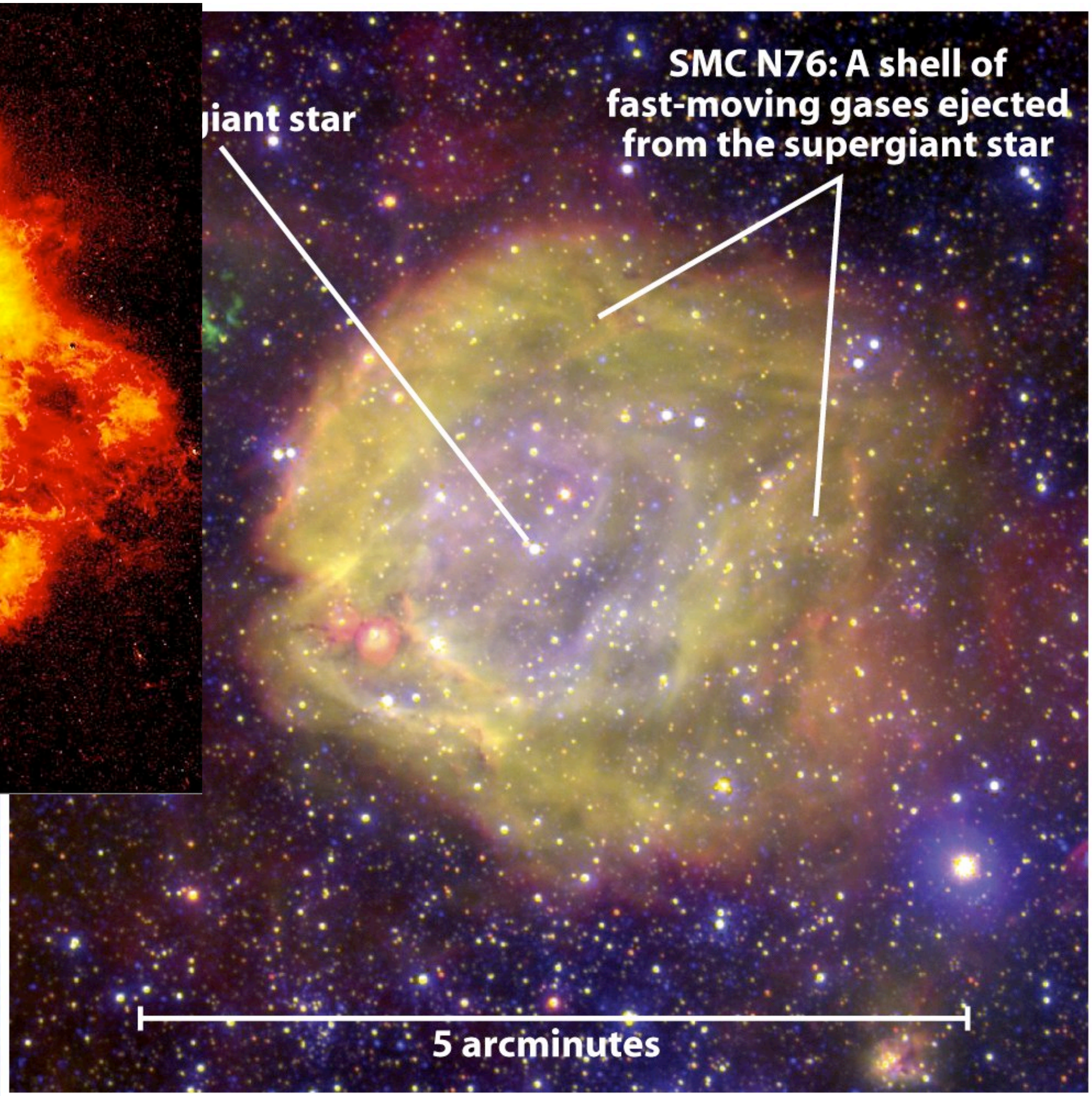

Figure 20-12
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Stars much more massive than the Sun:

Reactions produce elements up to iron (Fe, 26 protons, 30 neutrons)

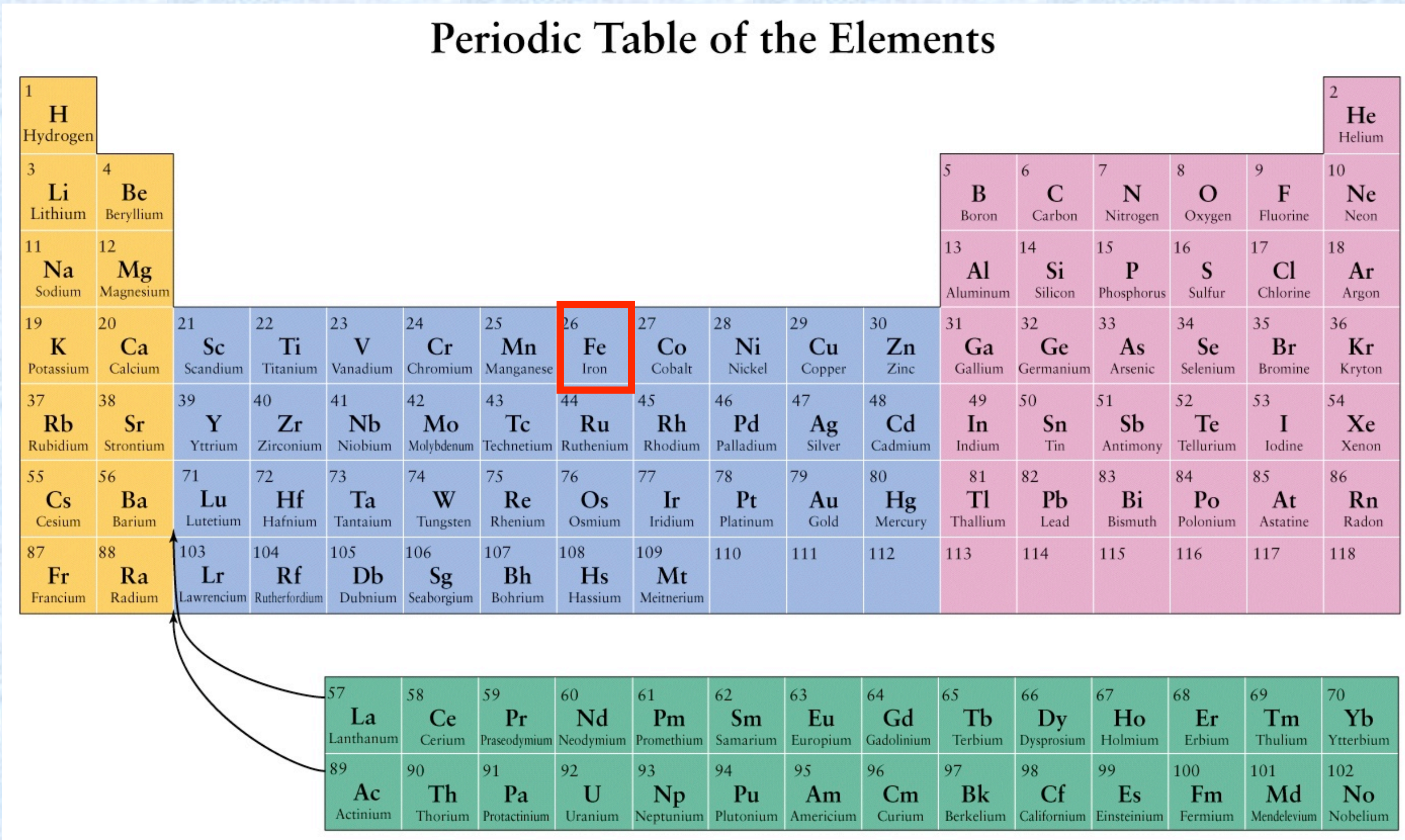

Table 20-1 Evolutionary Stages of a 25-$M_\odot$ Star

Stage	Core temperature (K)	Core density (kg/m^3)	Duration of stage
Hydrogen fusion	4×10^7	5×10^3	7×10^6 years
Helium fusion	2×10^8	7×10^5	7×10^5 years
Carbon fusion	6×10^8	2×10^8	600 years
Neon fusion	1.2×10^9	4×10^9	1 year
Oxygen fusion	1.5×10^9	10^{10}	6 months
Silicon fusion	2.7×10^9	3×10^{10}	1 day
Core collapse	5.4×10^9	3×10^{12}	$^1/_4$ second
Core bounce	2.3×10^{10}	4×10^{15}	milliseconds
Explosive (supernova)	about 10^9	varies	10 seconds

Based on calculations by Stanford Woosley (University of California, Santa Cruz) and Thomas Weaver (Lawrence Livermore National Laboratory).

Table 20-1
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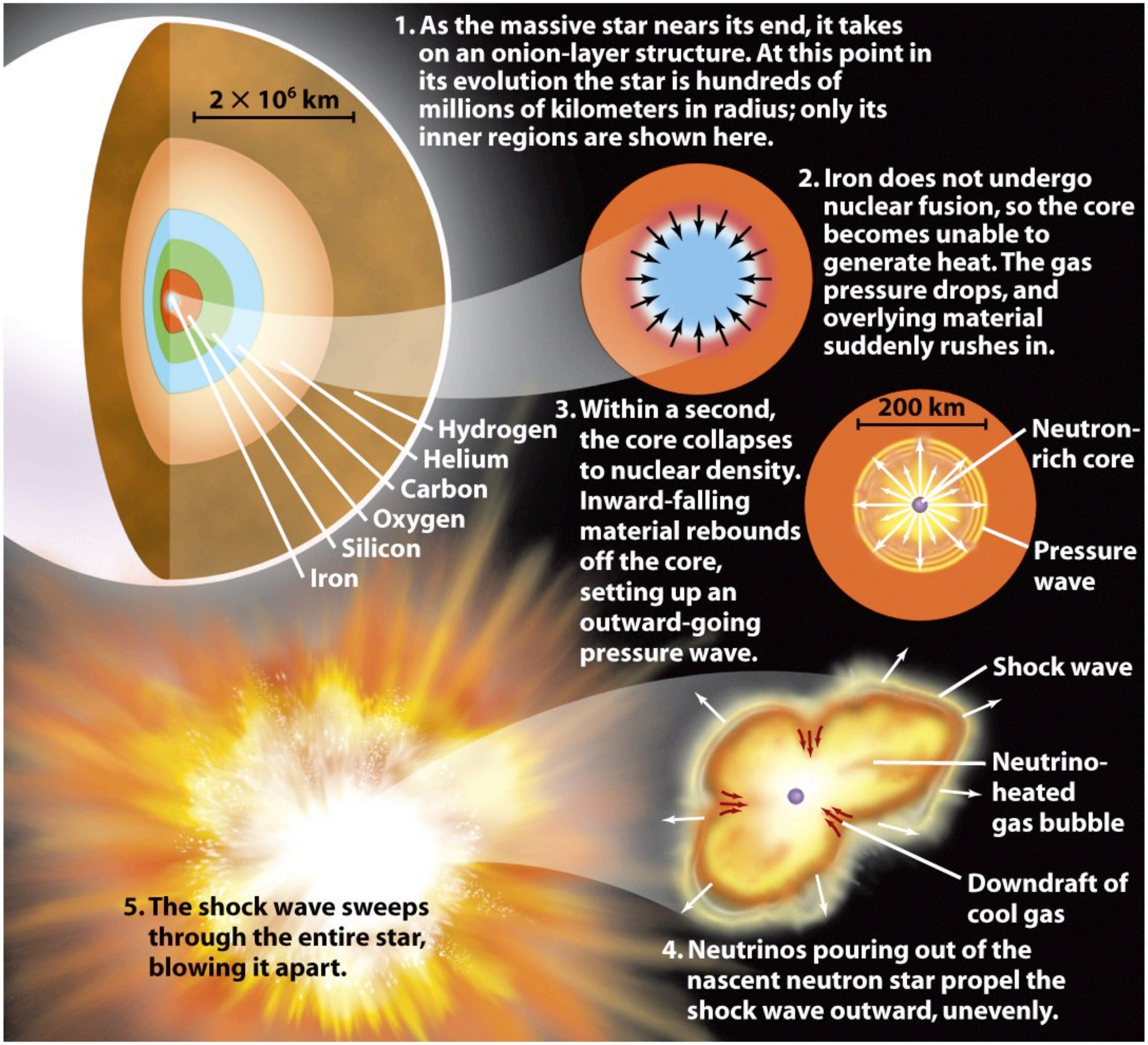

Figure 20-14
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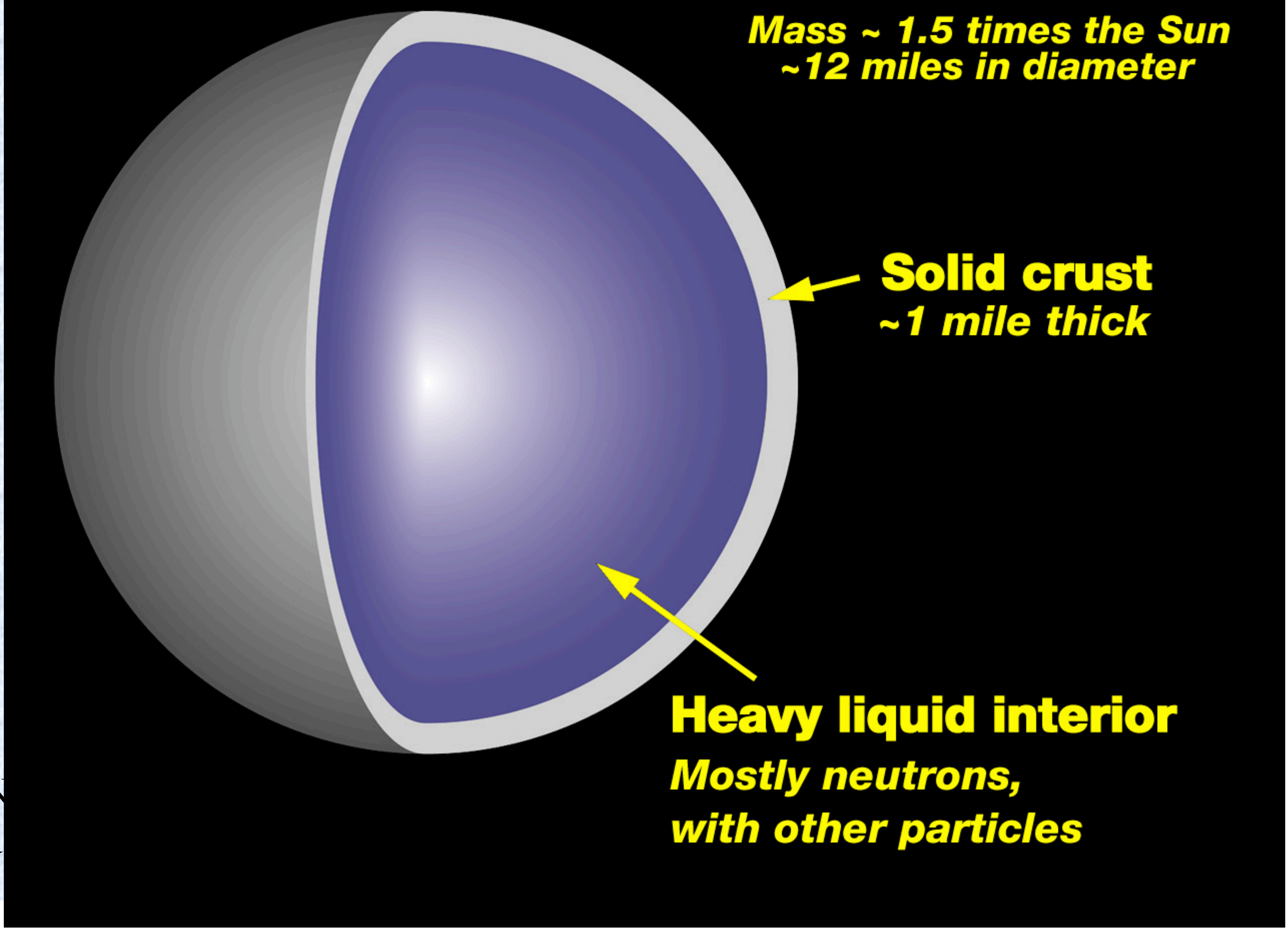
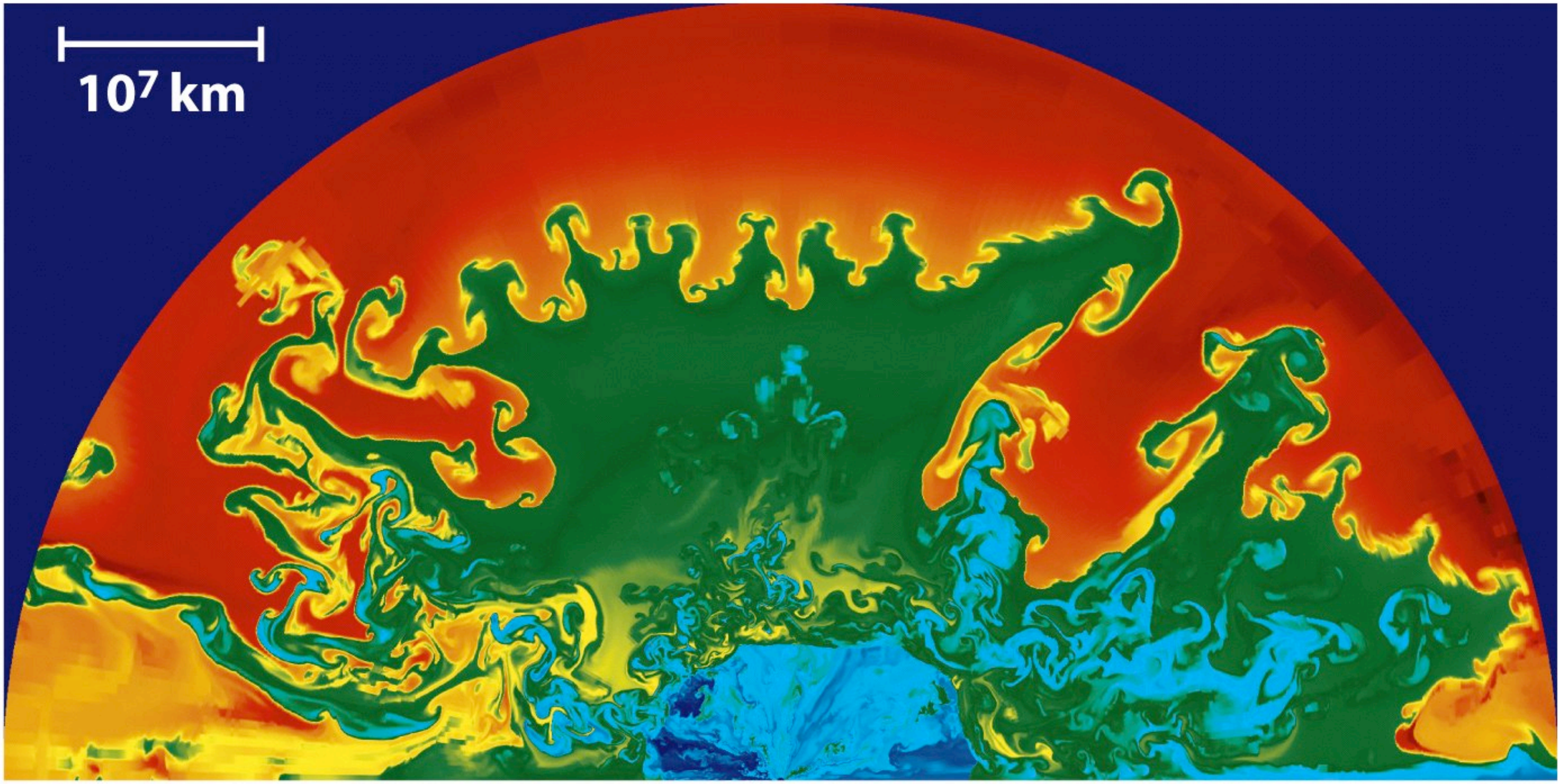
1 teaspoon of neutron star ?weighs" 100 million tons!



N
d



A simulated supernova $5\frac{1}{2}$ hours after the core "bounce" (red = hydrogen, green = helium, turquoise and blue = carbon, oxygen, silicon, and iron)

Figure 20-15a
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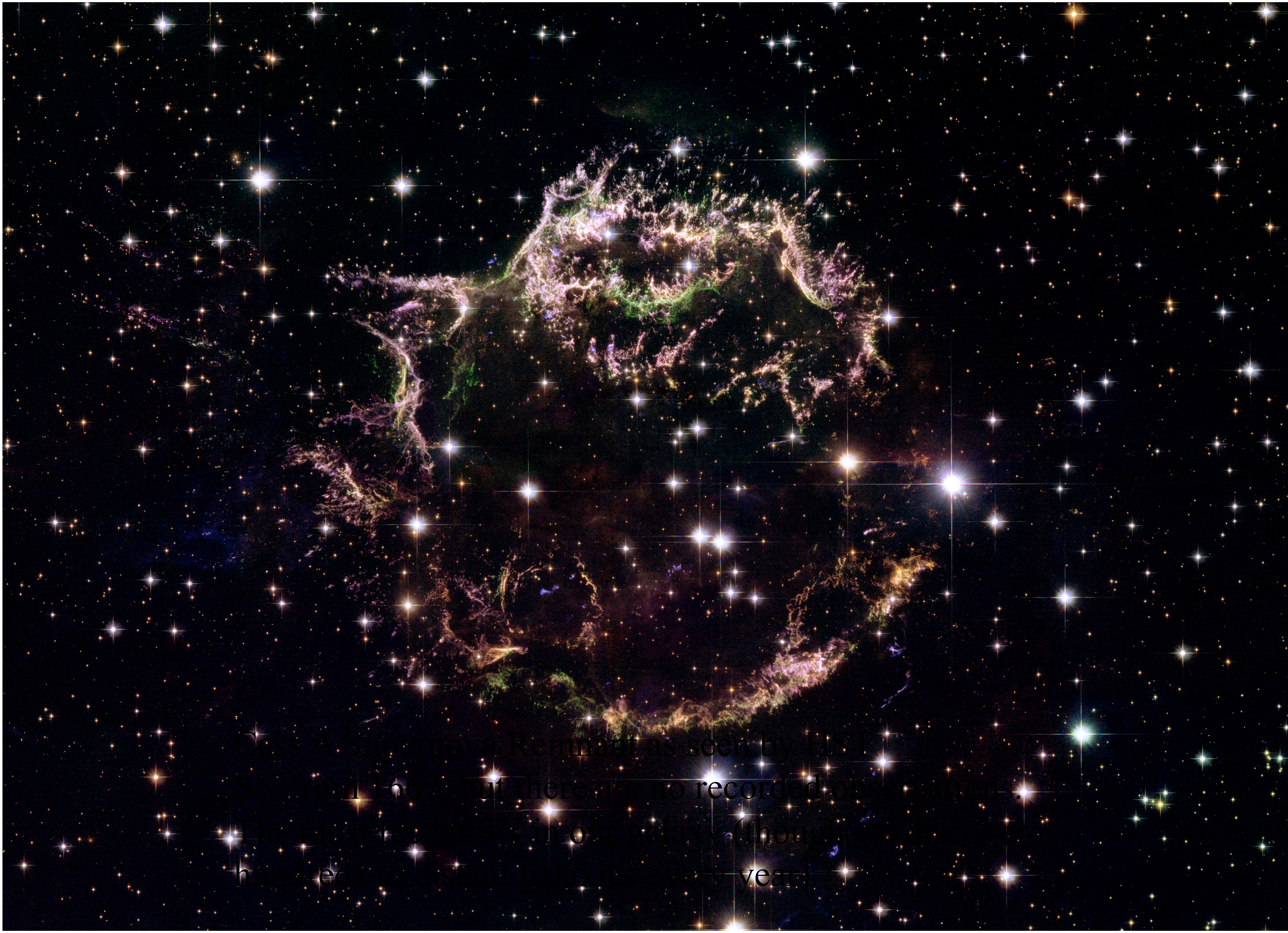
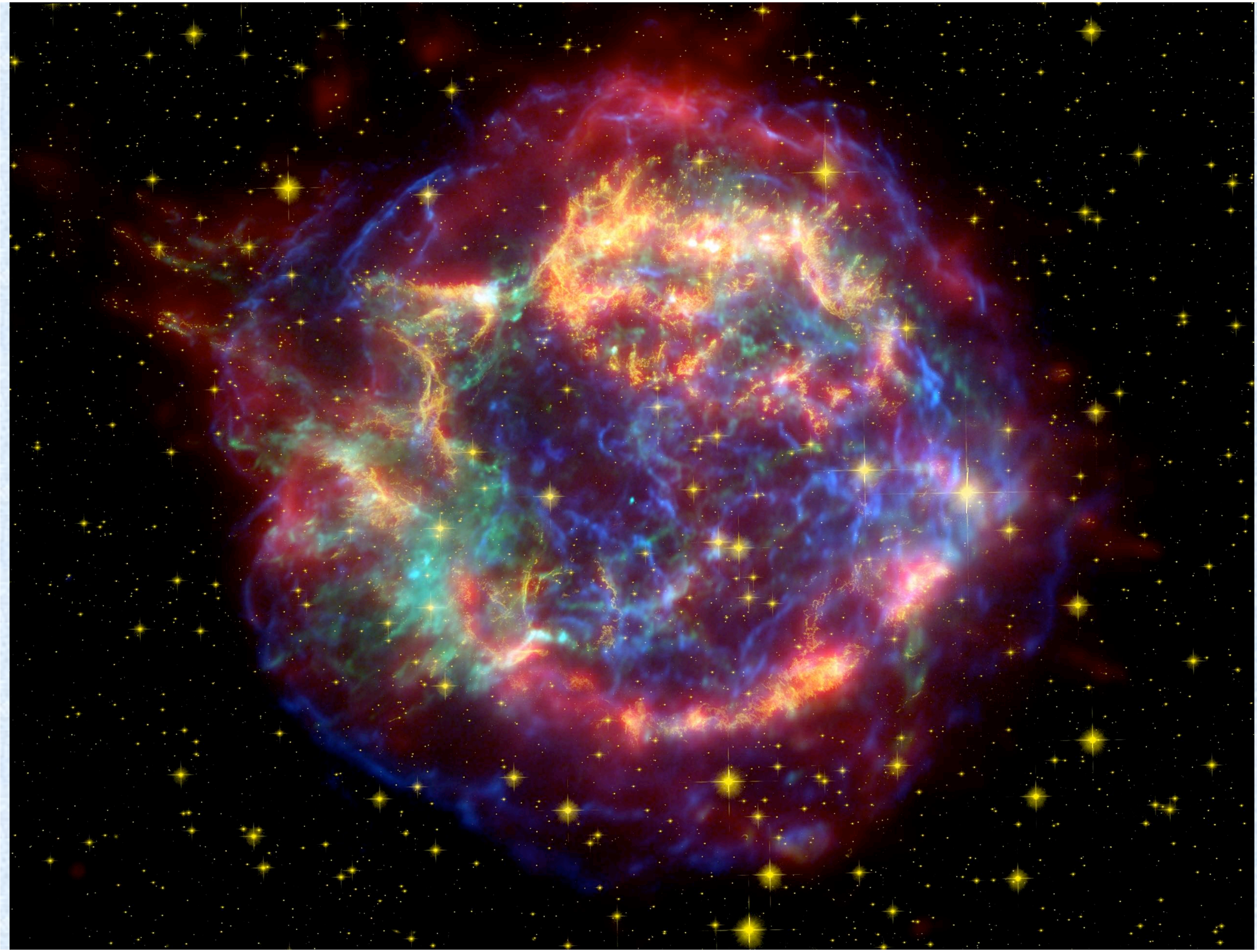


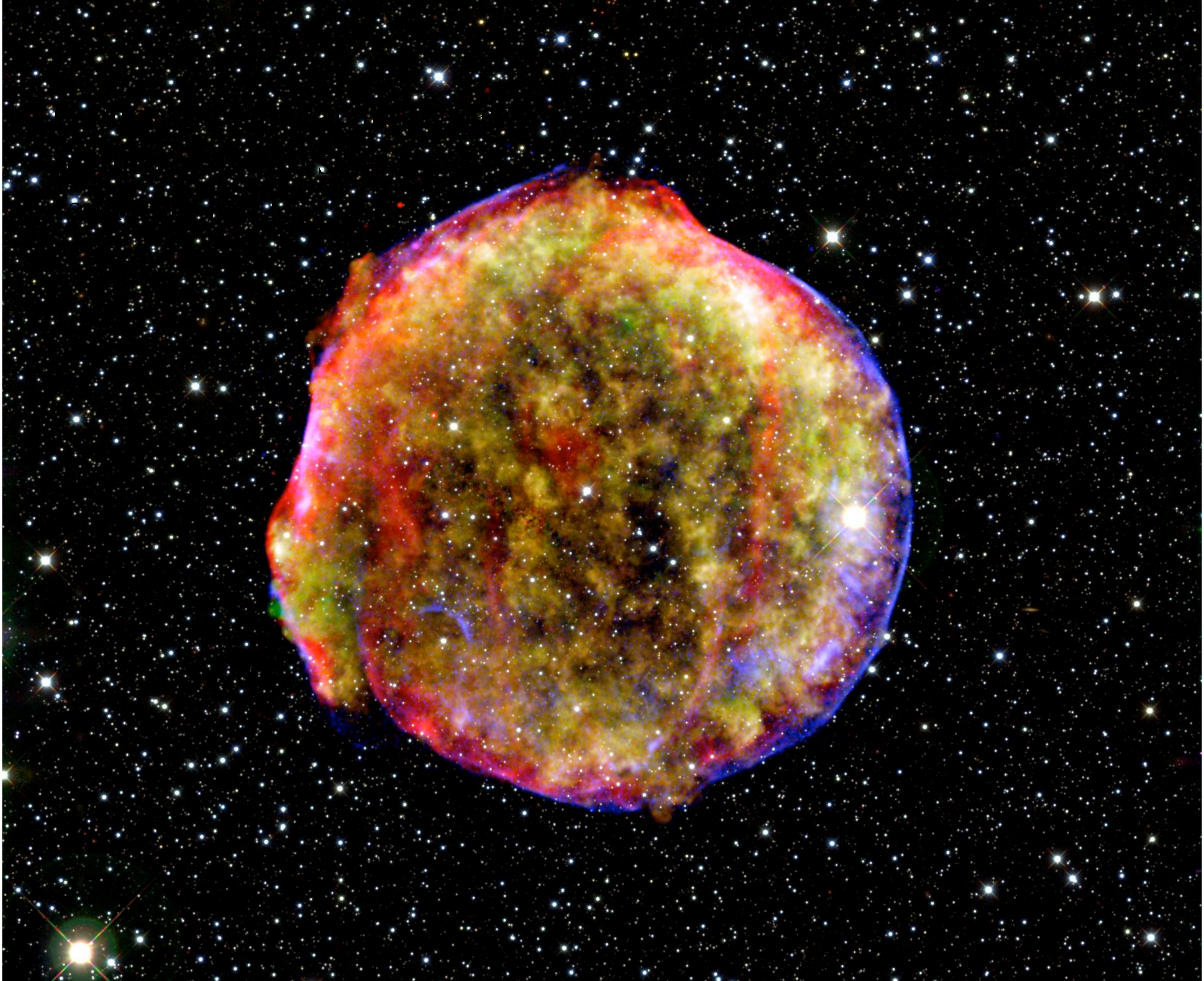
Cass A Supernova Remnant as seen by HST

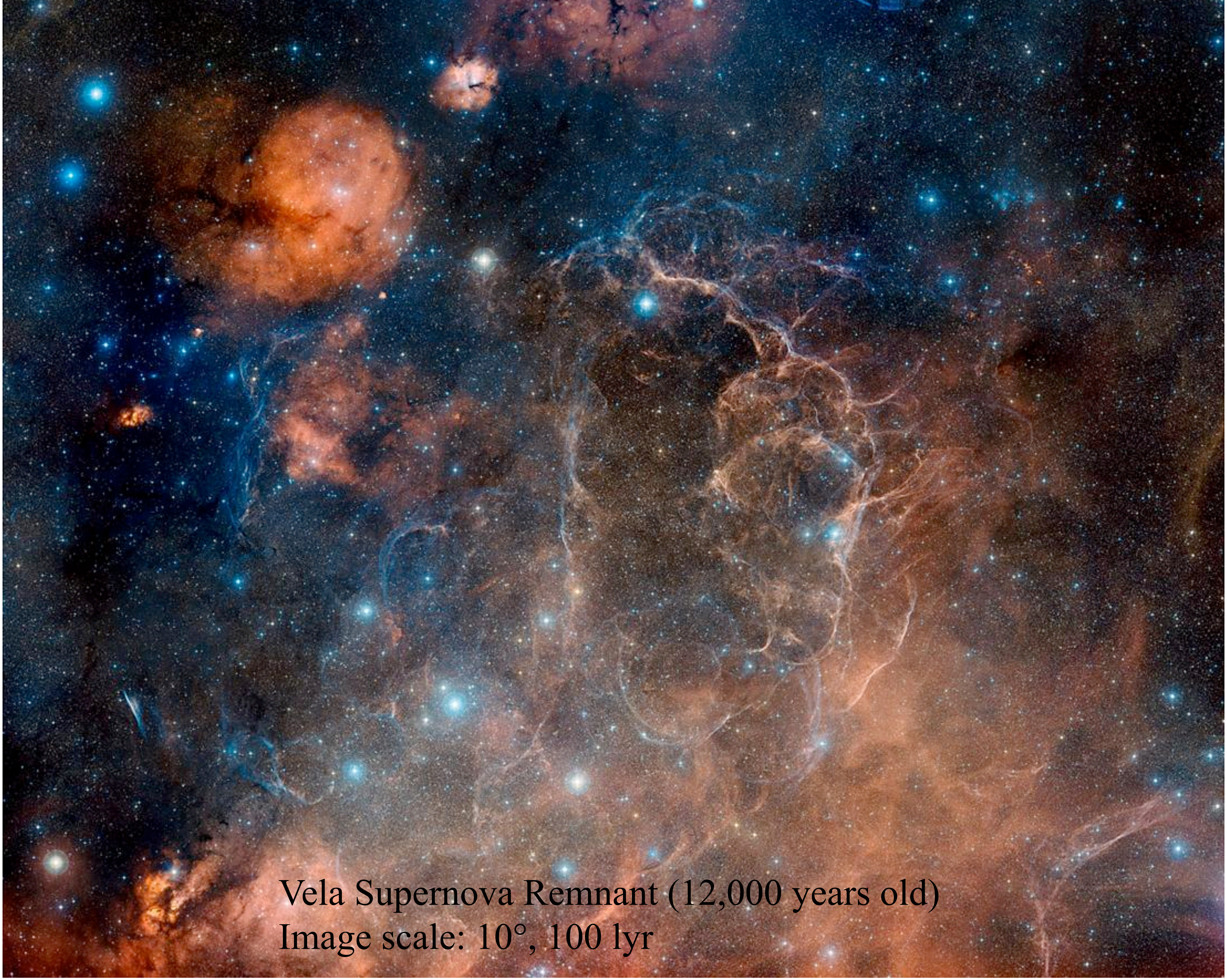
SN from 166[illegible] but there are no recorded observations.

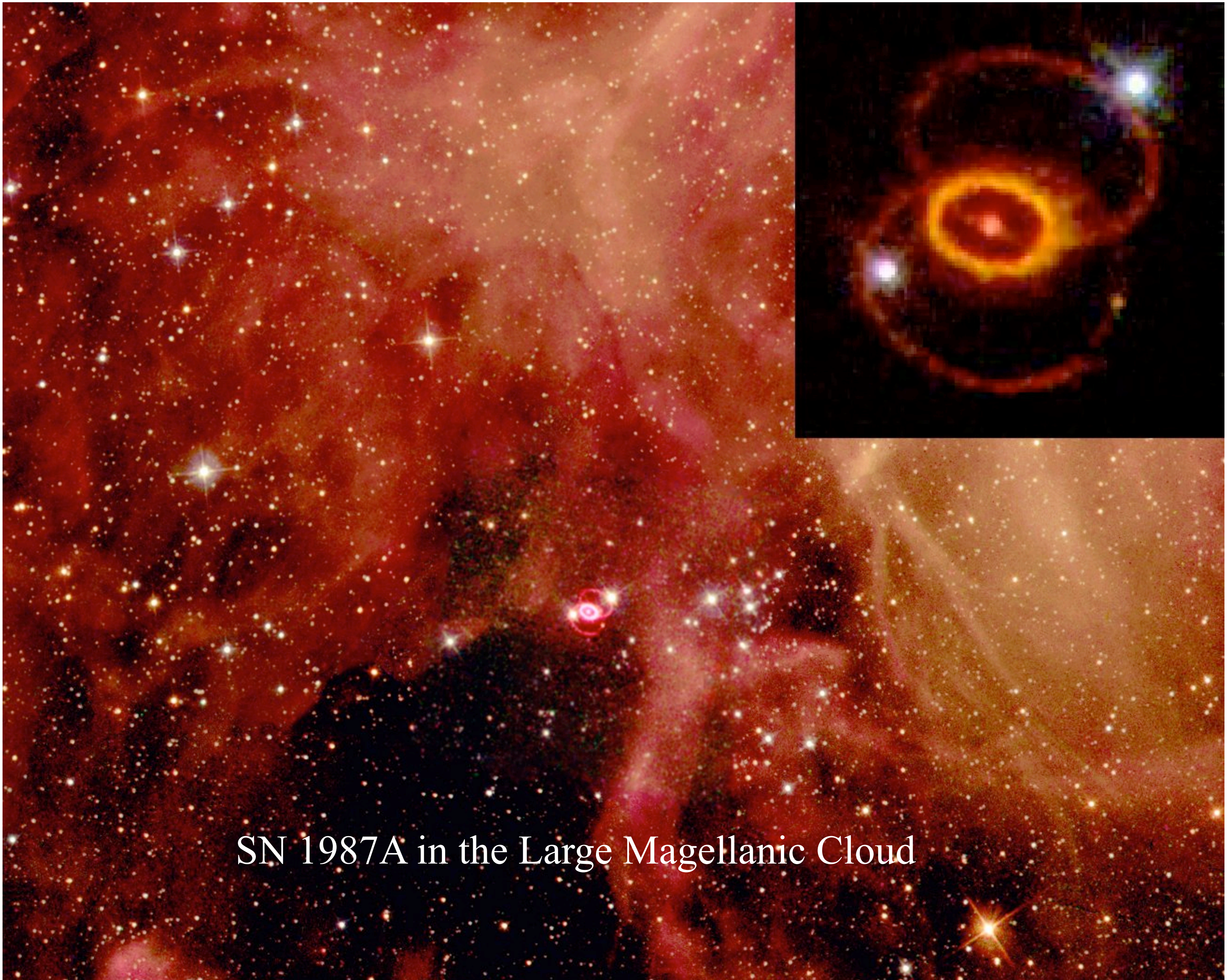
The most recent SN in our galaxy (though [illegible]

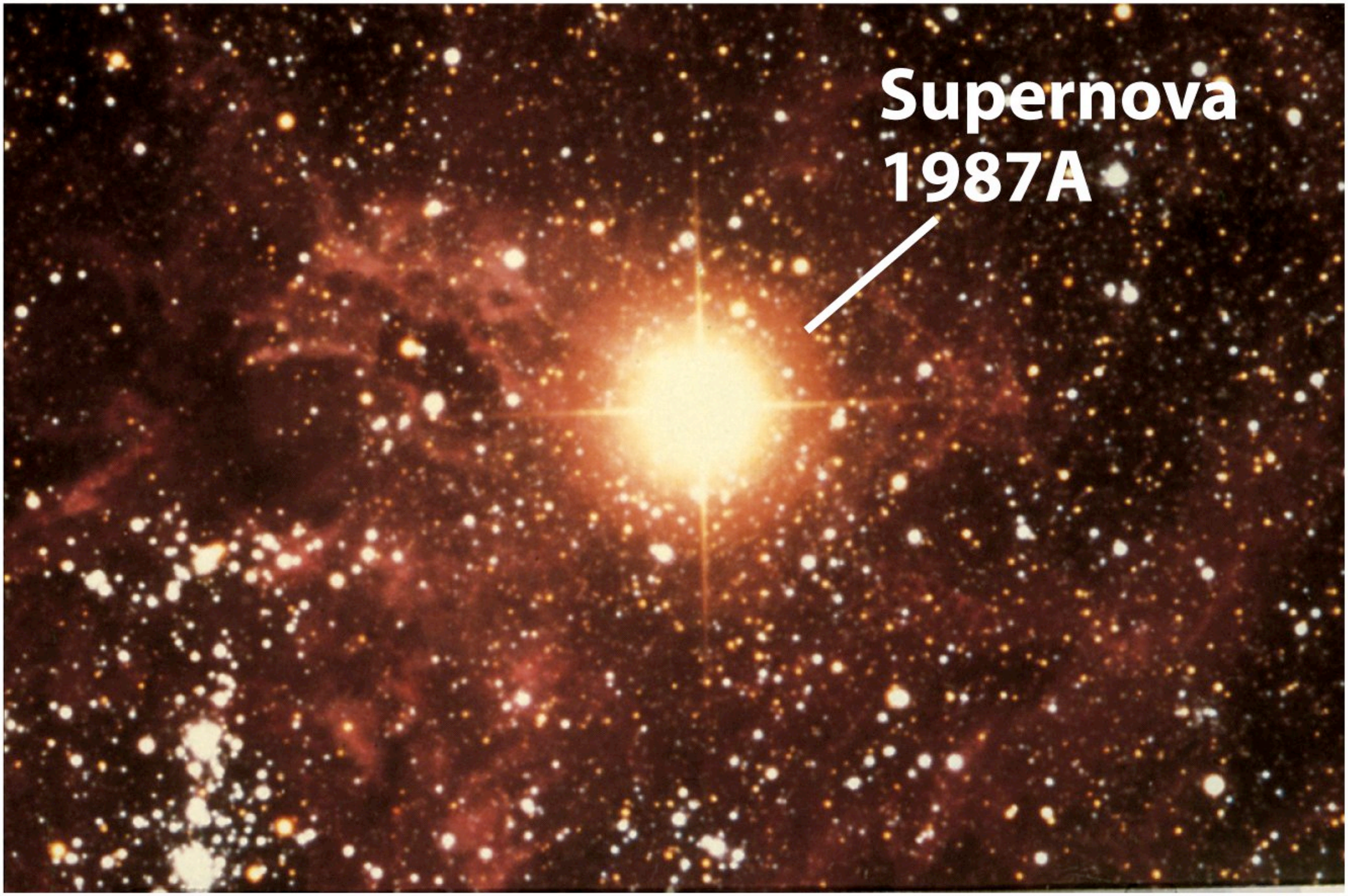
hundreds in distant galaxies every year)






Vela Supernova Remnant (12,000 years old)
Image scale: 10°, 100 lyr


SN 1987A in the Large Magellanic Cloud



After the star exploded

Figure 20-18b
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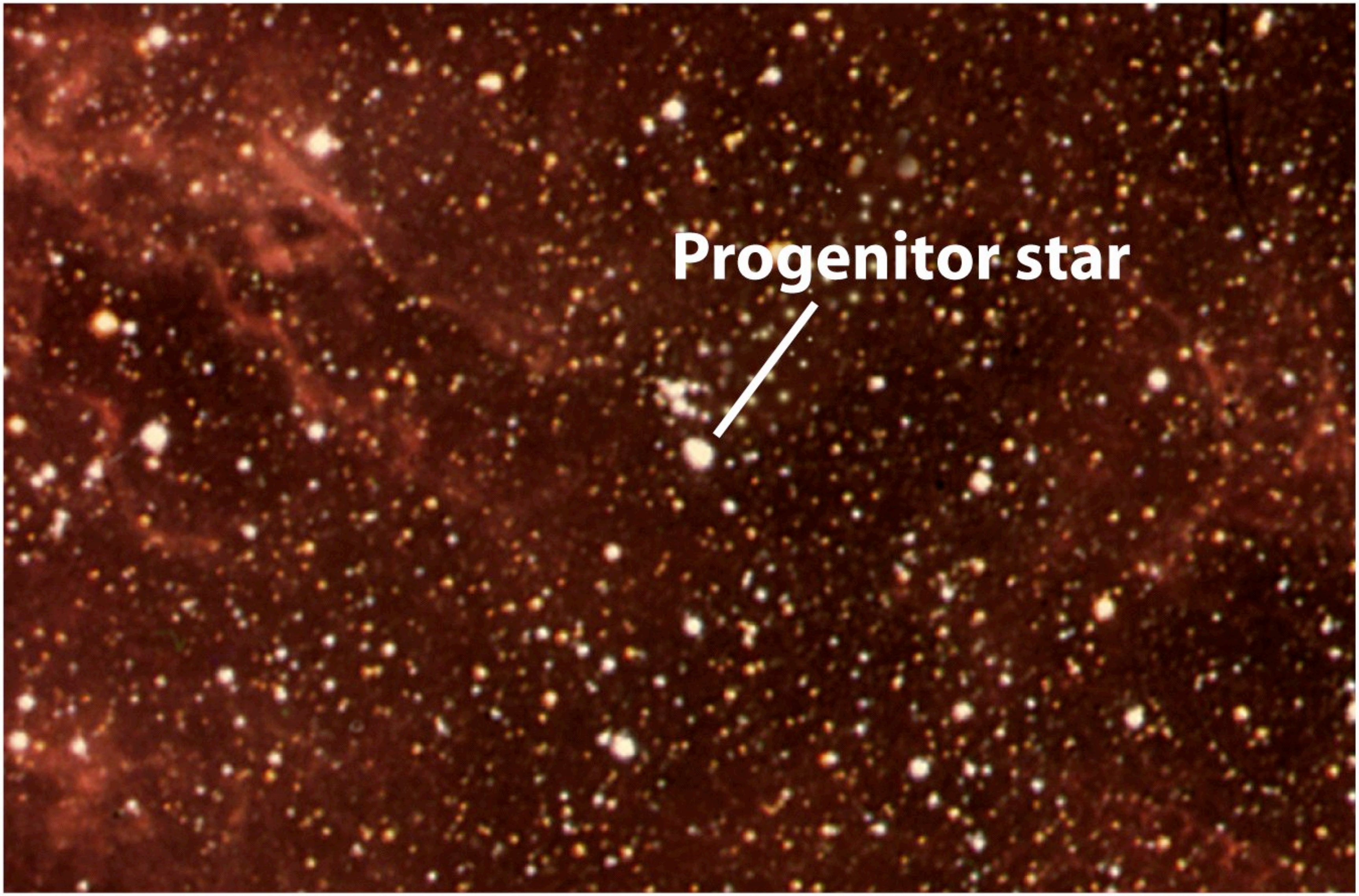

Before the star exploded

Figure 20-18a
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Figure 21-1
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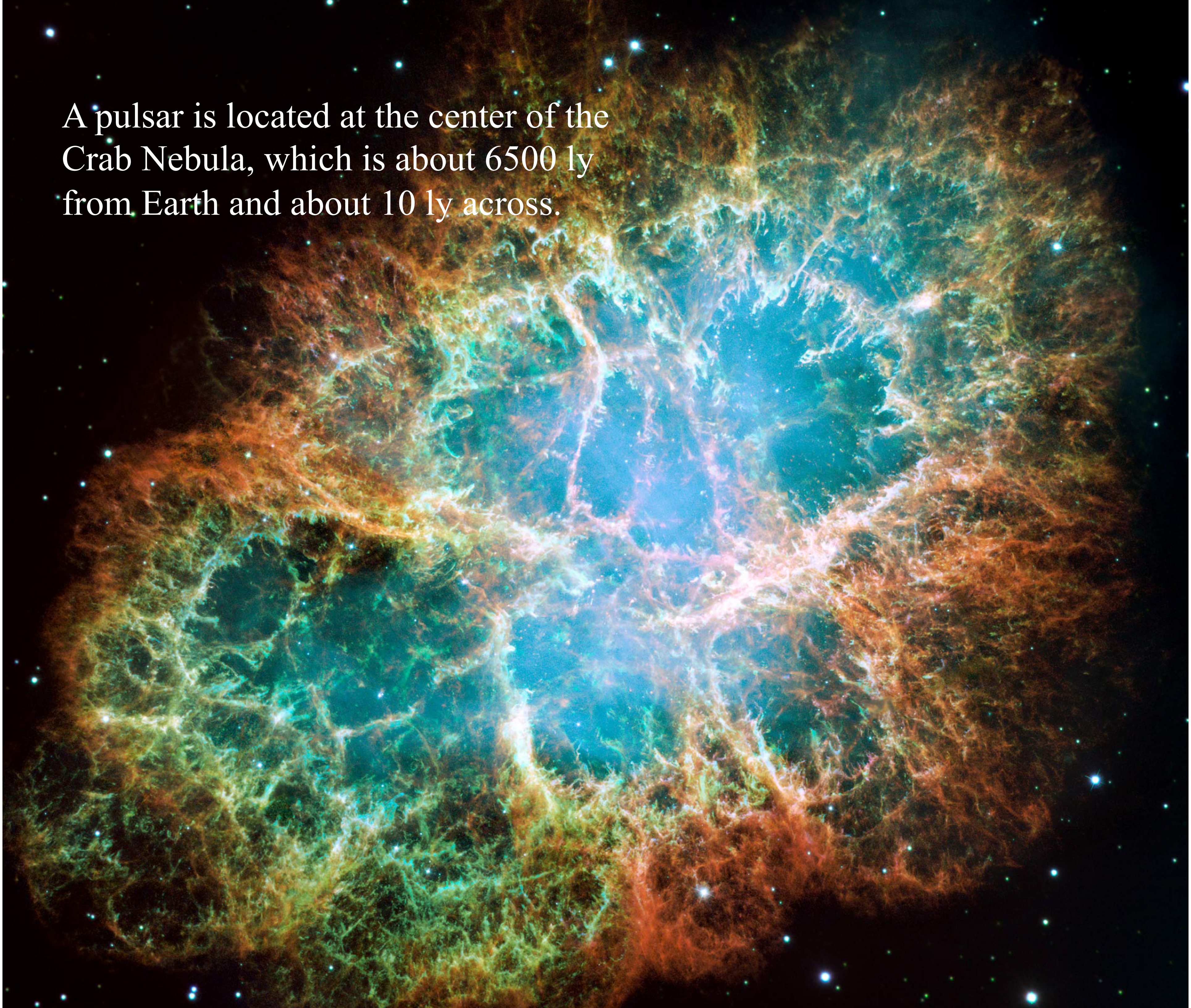
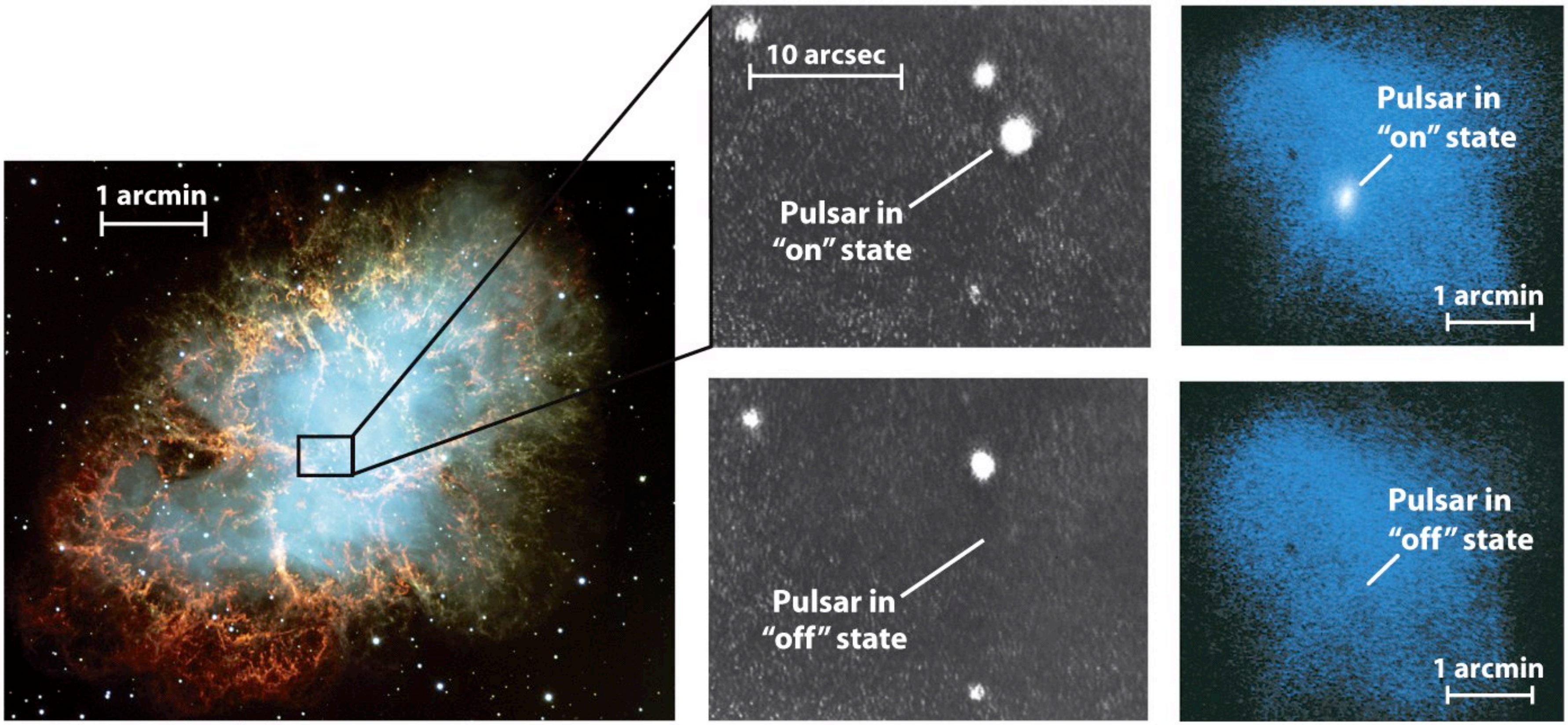
This drawing in an eleventh-century structure in New Mexico shows a ten-pointed star next to a crescent. It may depict the scene on the morning of July 5, 1054, when a “guest star” appeared next to the waning crescent moon.


A pulsar is located at the center of the Crab Nebula, which is about 6500 ly from Earth and about 10 ly across.



(a) The Crab Nebula

(b) The Crab pulsar in visible light

(c) The Crab pulsar in X rays

Figure 21-4
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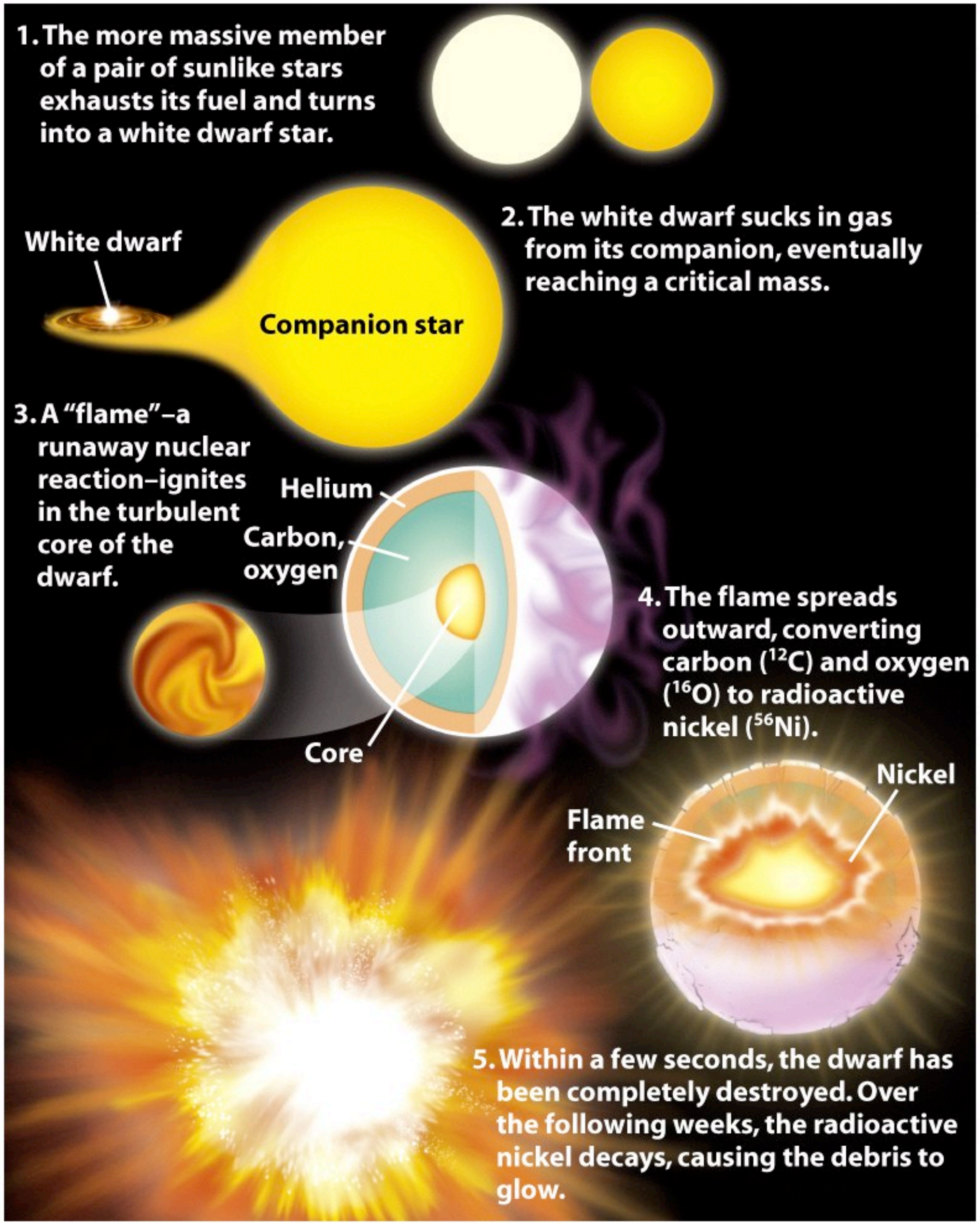
Question 22.3 (iclickers!)

- An old high mass star can have a number of shells (H, He, C, Ne, O, Si) plus an iron core. Fusion generally takes place everywhere except
    - A) The H shell
    - B) The He shell
    - C) The Si shell
    - D) The Fe core

Supernovae Ia



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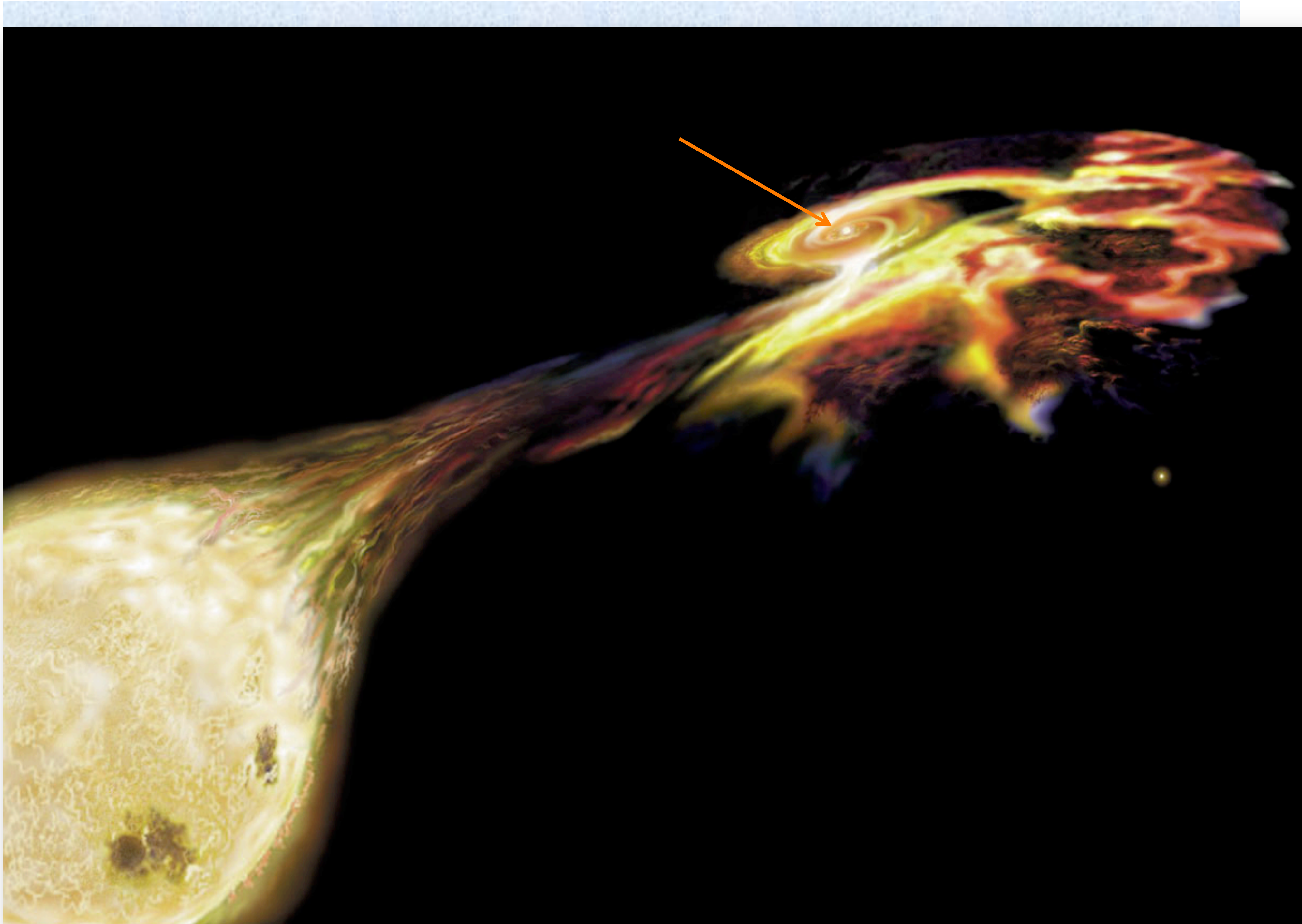
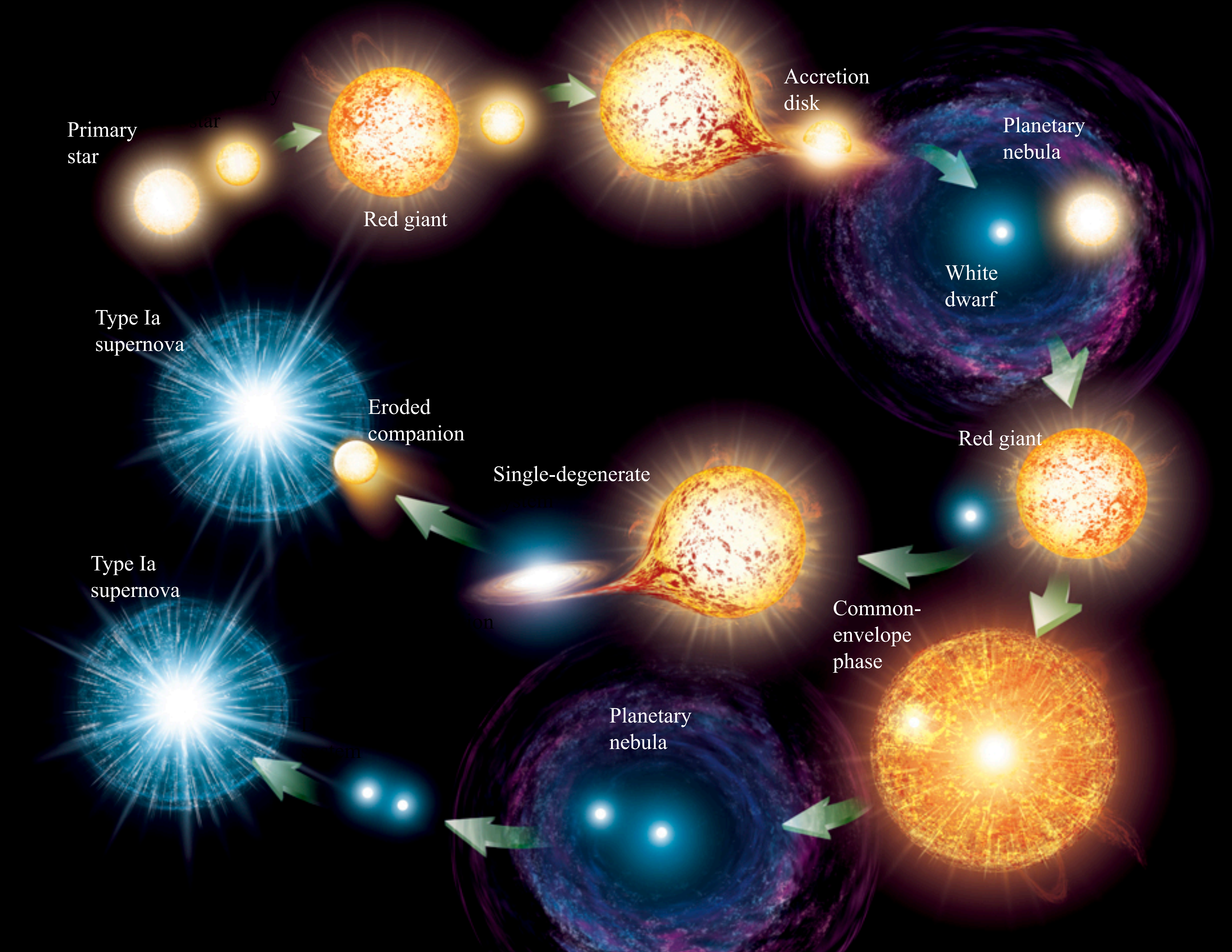
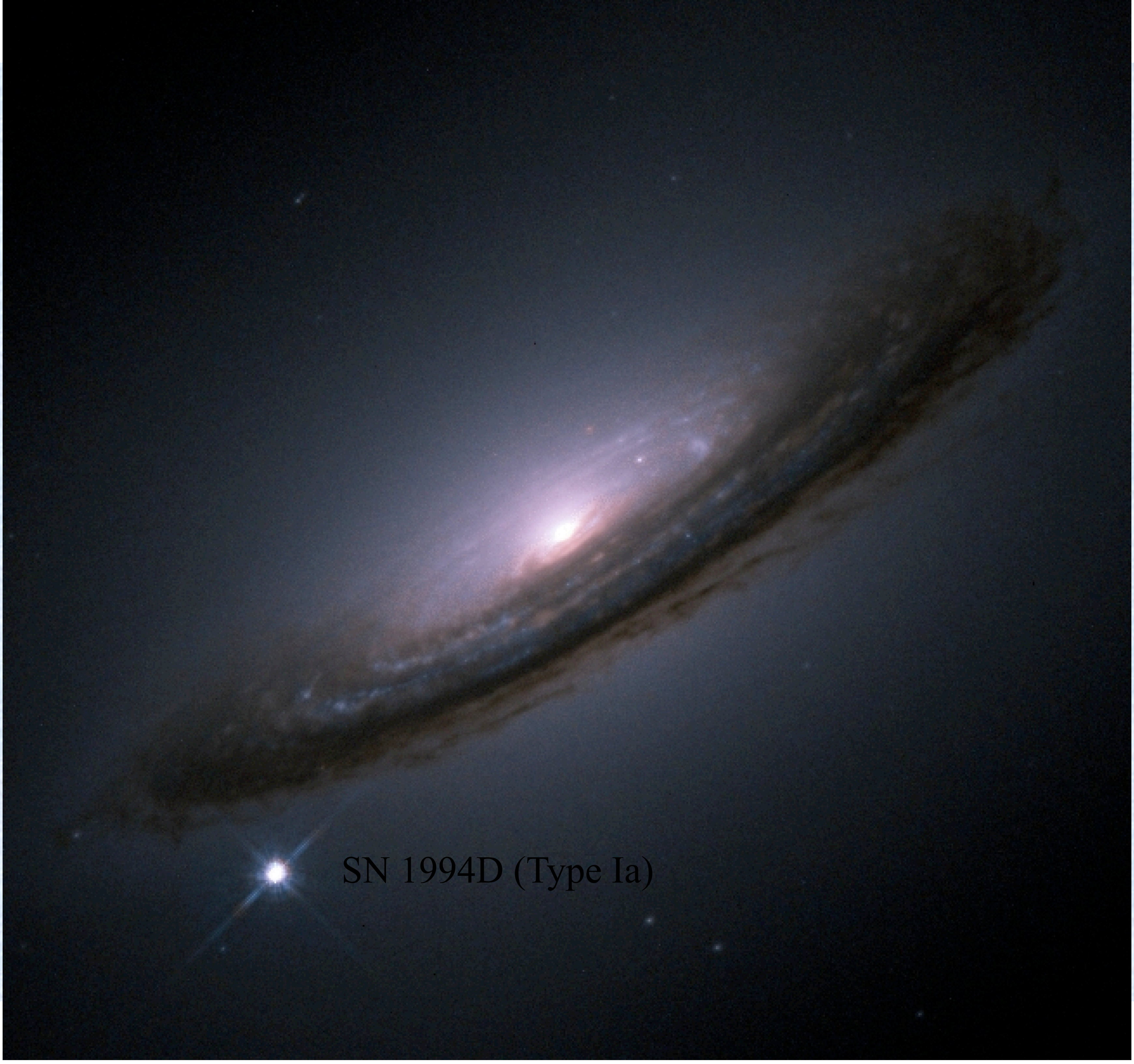
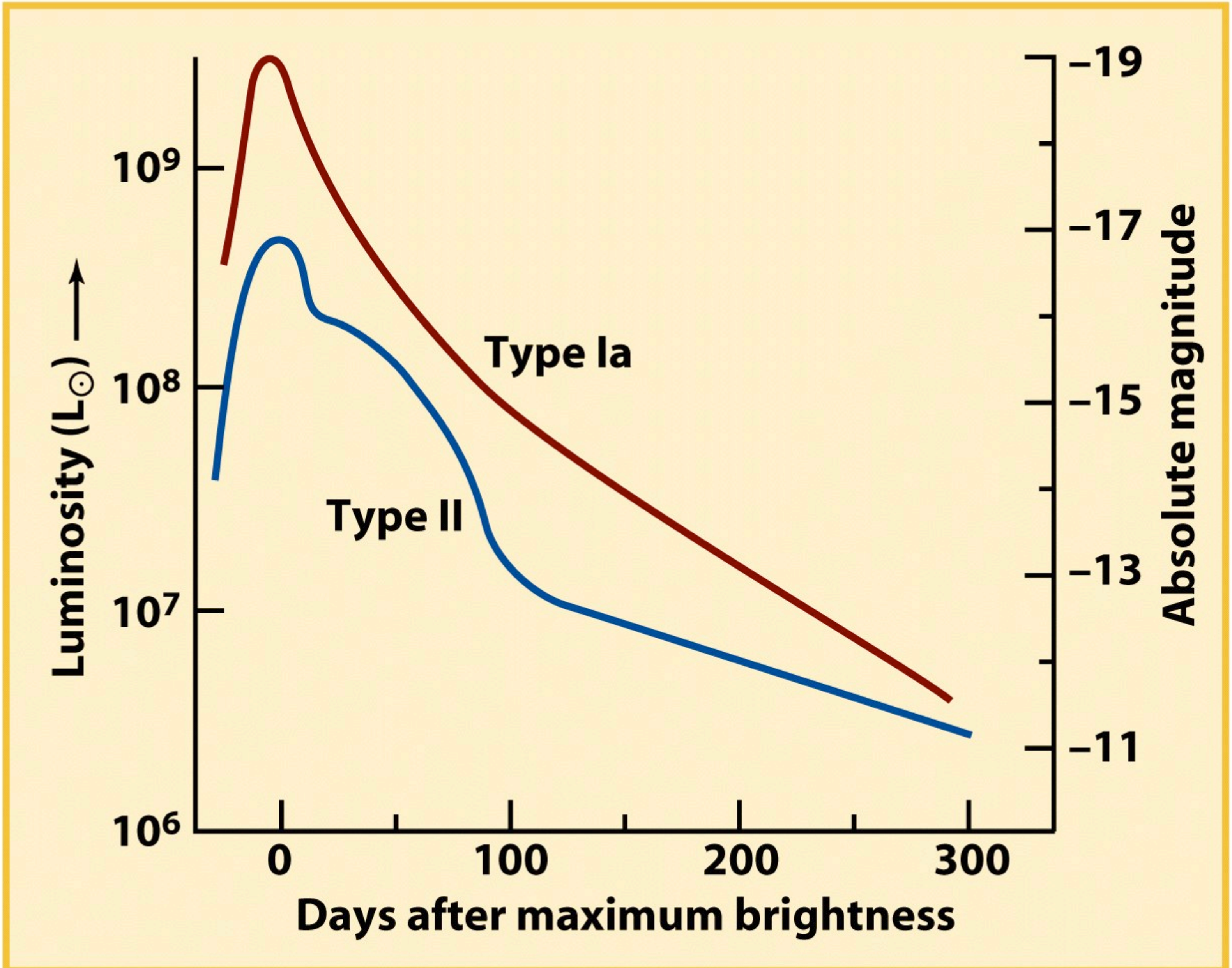



Primary
star
Red giant
Accretion
disk
Planetary
nebula
White
dwarf
Type Ia
supernova
Eroded
companion
Single-degenerate
Red giant
Type Ia
supernova
Common-
envelope
phase
Planetary
nebula


SN 1994D (Type Ia)



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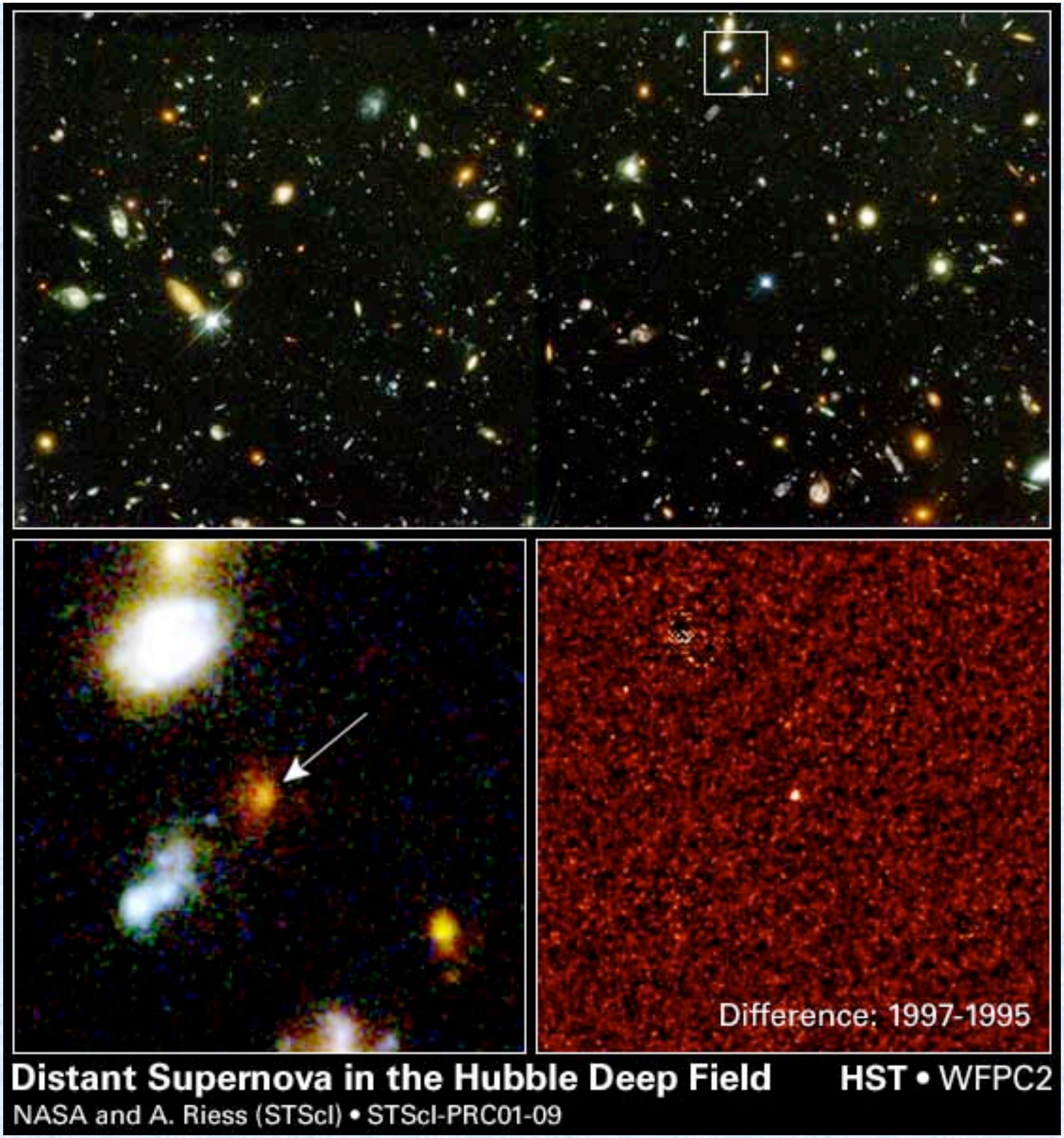

The most distant supernova. Supernovae are so bright (~7 billion solar luminosities) that you can see them very far away. This one was dates from 10 billion years ago.

Summary

- Late evolution and death of intermediate-mass stars (about 0.4 $M_\odot$ to about 4 $M_\odot$):
  - red giant when shell hydrogen fusion begins,
  - a horizontal-branch star when core helium fusion begins
  - asymptotic giant branch star when the no more helium core fusion and shell helium fusion begins.
  - Then alf of the mass of the star is ejected exposing the CO core of the star. The core is a white dwarf the envelope a planetary nebula.
- Late Evolution and death of High-Mass Star (>4 $M_\odot$)
  - Can undergo carbon fusion, neon fusion, oxygen fusion, and silicon fusion, etc
  - The highest mass stars eventually find themselves with a iron-rich core surrounded by burning shells (>8 $M_\odot$). The star dies in a violent cataclysm in which its core collapses and most of its matter is ejected into space: a supernova!! 99% of the energy can come out in neutrinos!

The End

See you on friday!