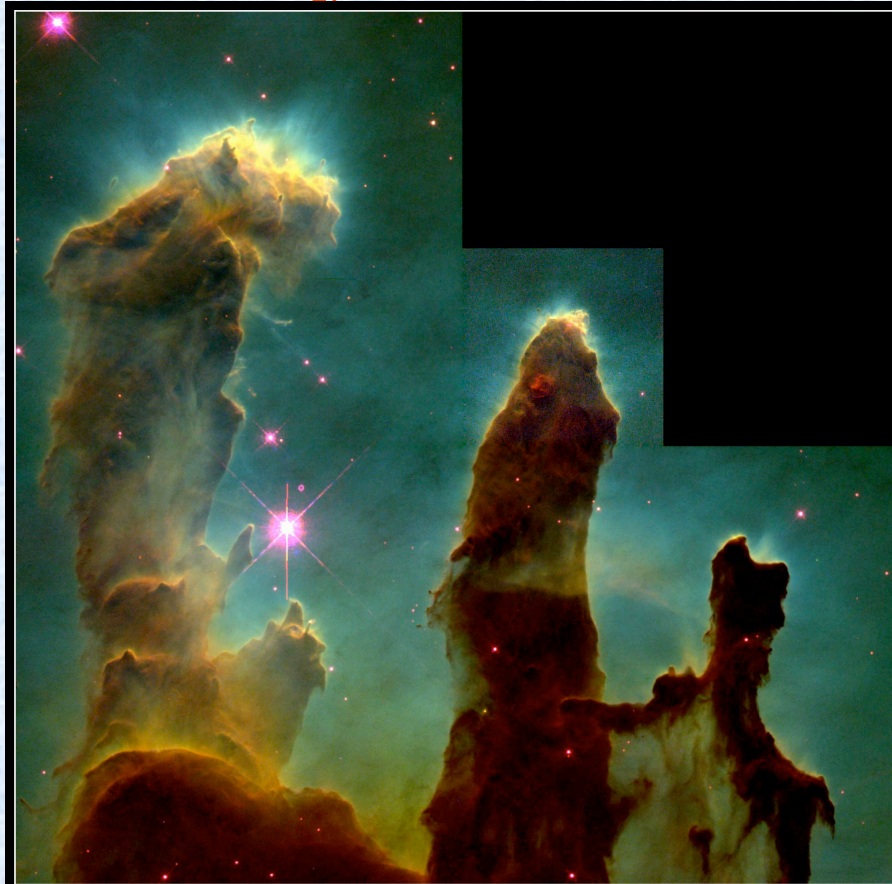


# Astronomy 1 – Winter 2011



**Gaseous Pillars in M16 • Eagle Nebula**  
Hubble Space Telescope • WFPC2

PRC95-44a • ST ScI OPO • November 2, 1995 • J. Hester and P. Scowen (AZ State Univ.), NASA

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

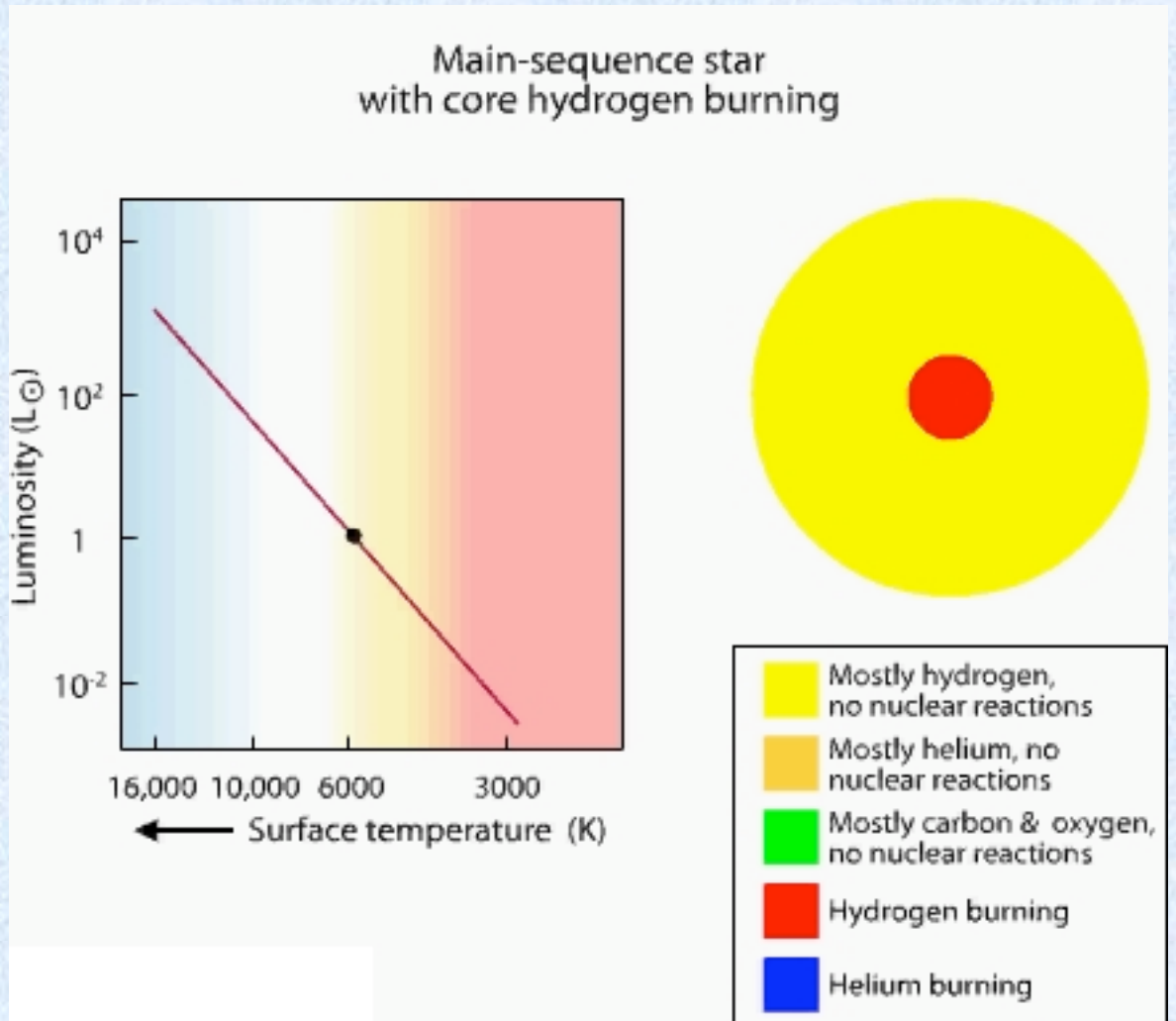


# Evolution of a star like the Sun

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

H = hydrogen  
C = carbon

He = helium  
O = oxygen

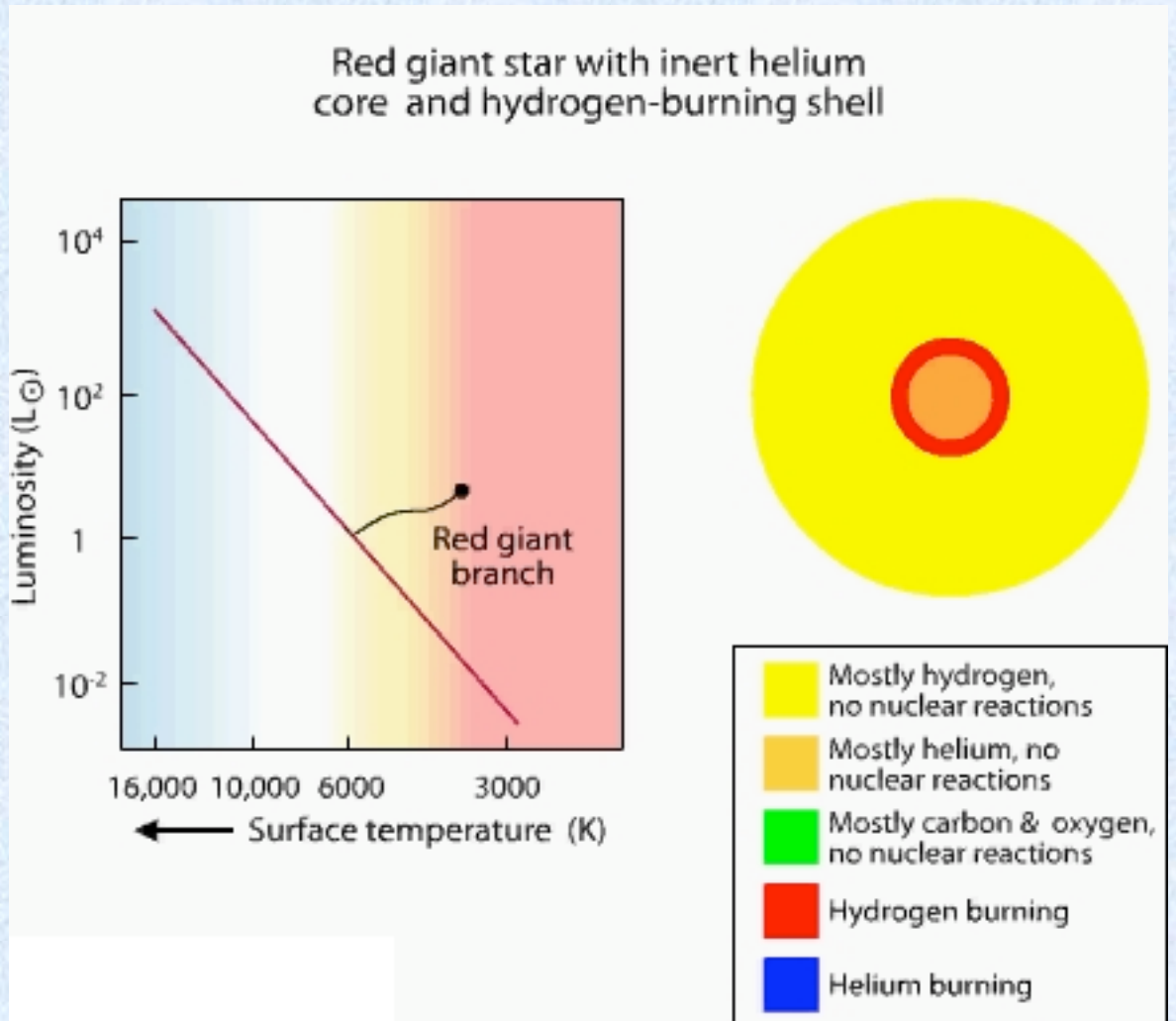


# Evolution of a star like the Sun

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

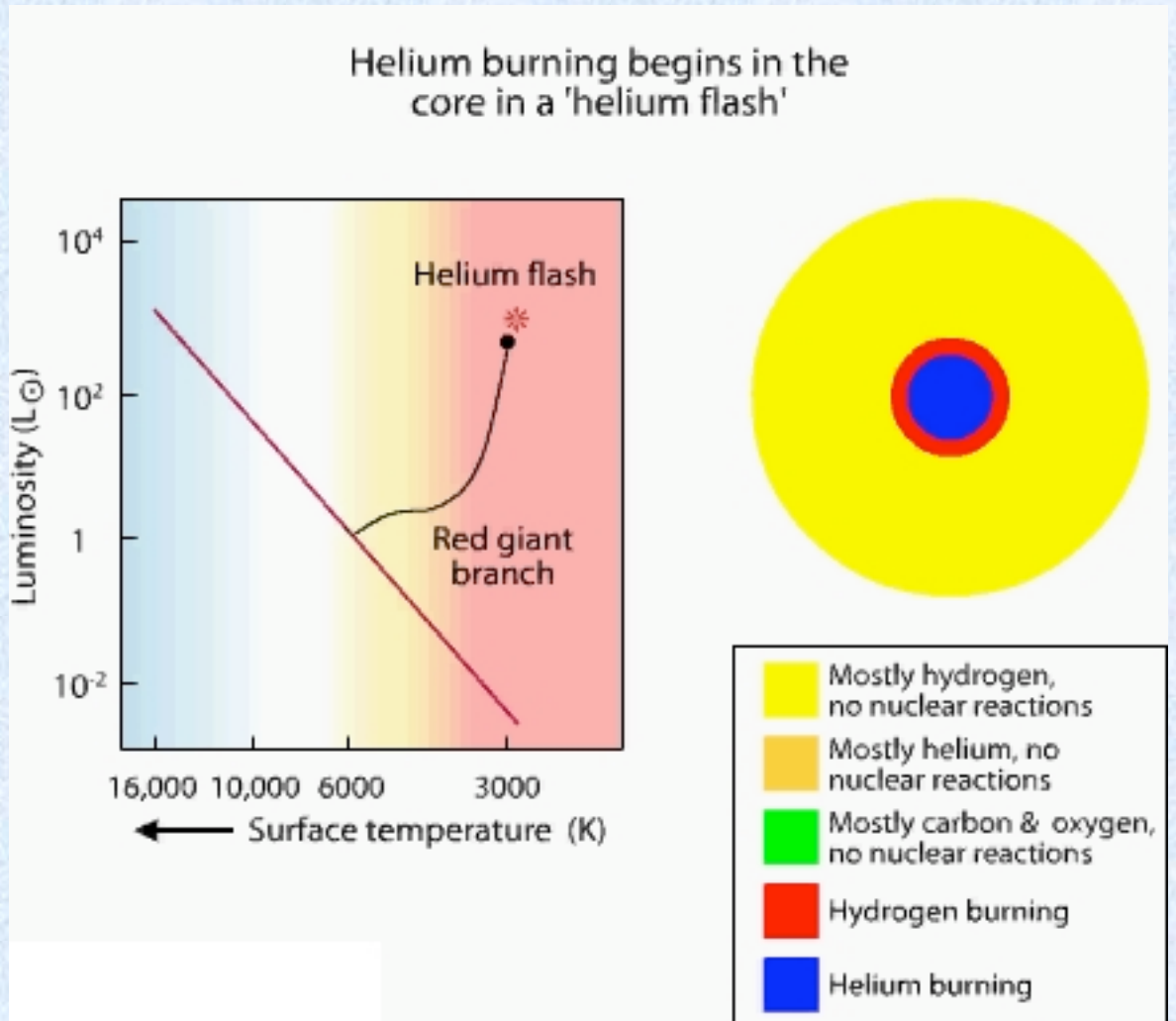
Stage 1:  
Main-sequence star (core  
H fusion)

Stage 2:  
Red giant  
(shell H fusion)

Stage 3: He core fusion  
begins

H = hydrogen  
C = carbon

He = helium  
O = oxygen



# Evolution of a star like the Sun

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

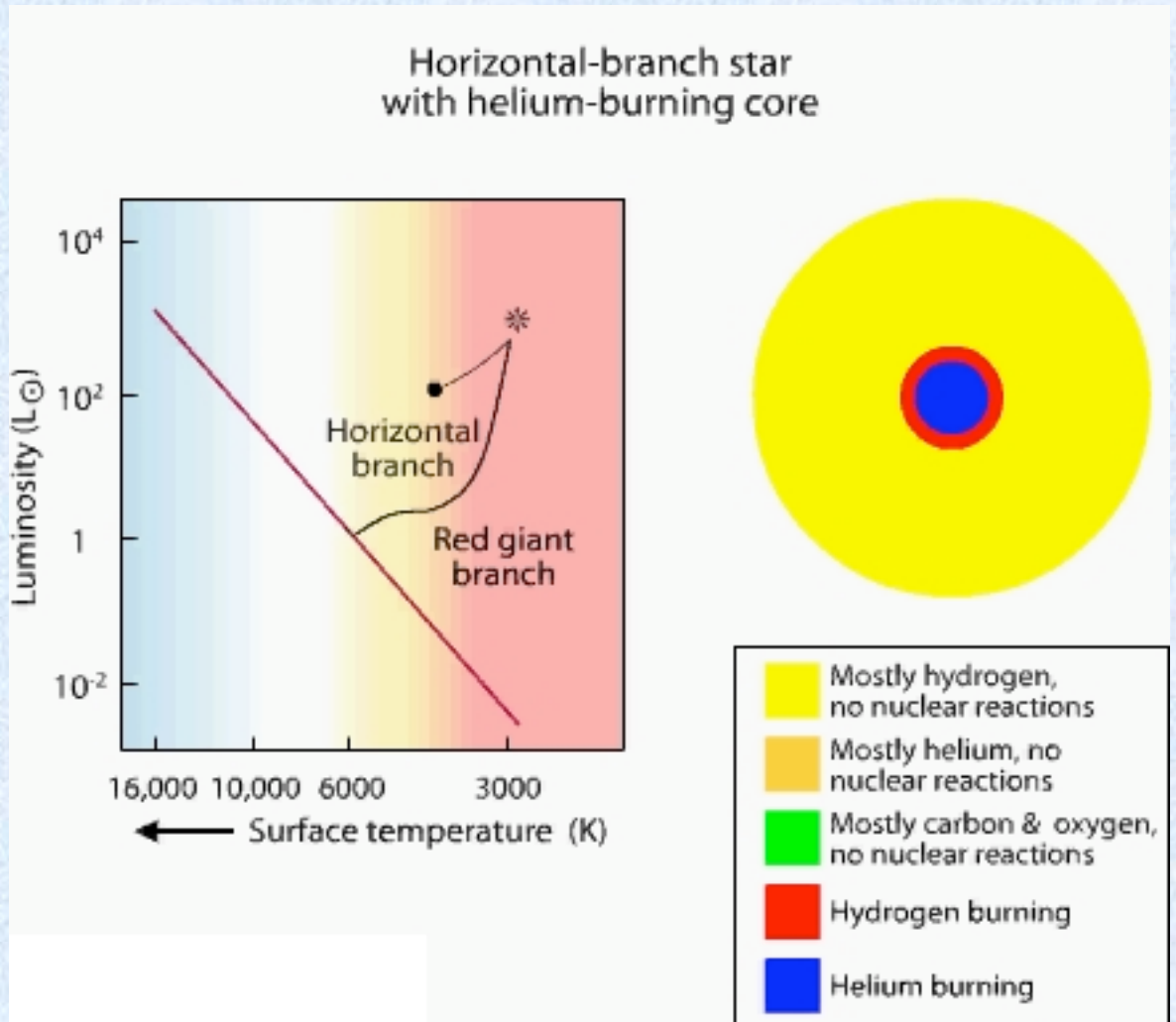
Stage 2:  
Red giant  
(shell H fusion)

Stage 3: He core fusion  
begins

Stage 4:  
Horizontal branch  
(core He fusion)

H = hydrogen  
C = carbon

He = helium  
O = oxygen





# Evolution of a star like the Sun

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

Stage 2:  
Red giant  
(shell H fusion)

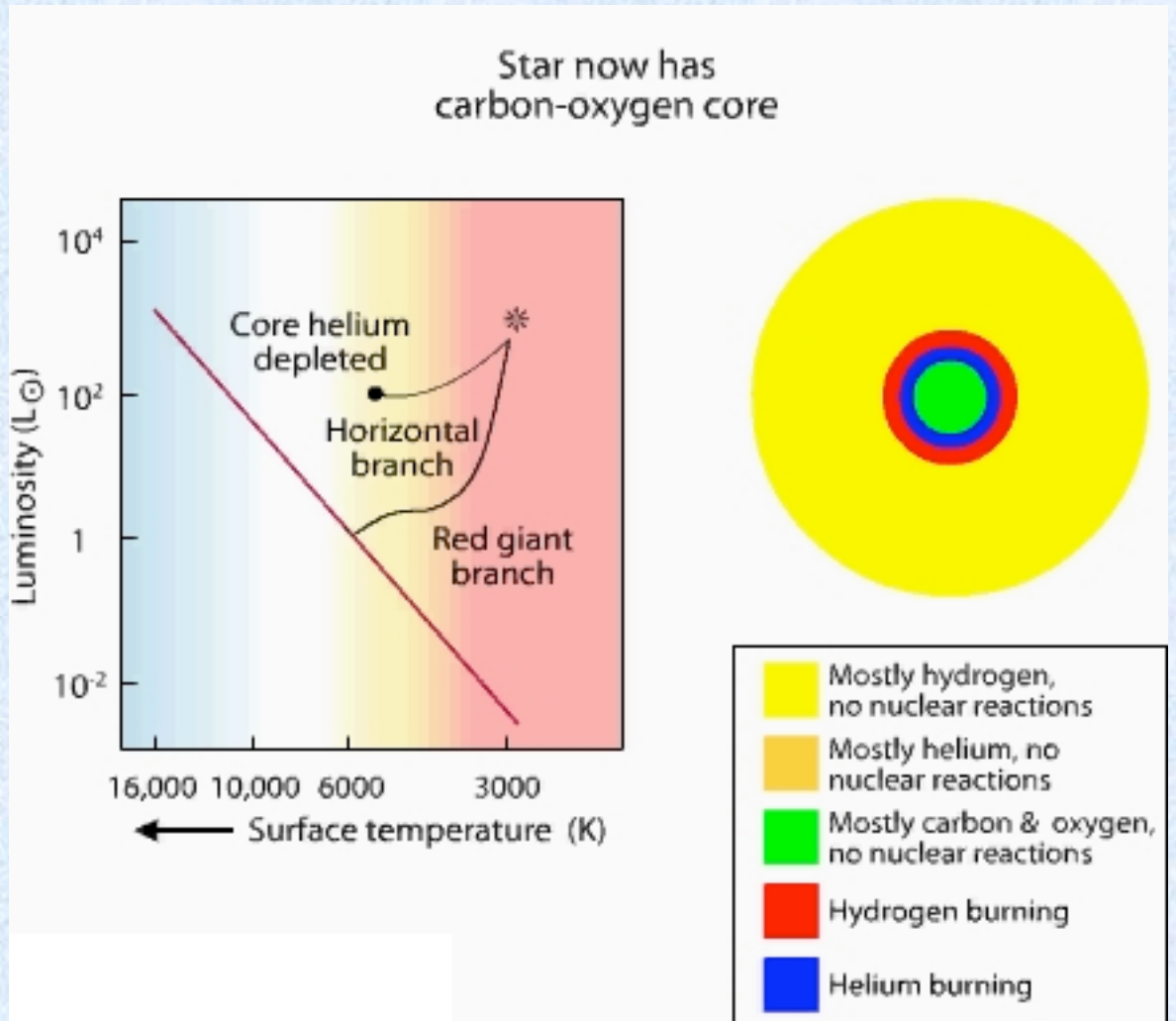
Stage 3: He core fusion  
begins

Stage 4:  
Horizontal branch  
(core He fusion)

Stage 5: C-O core

H = hydrogen  
C = carbon

He = helium  
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

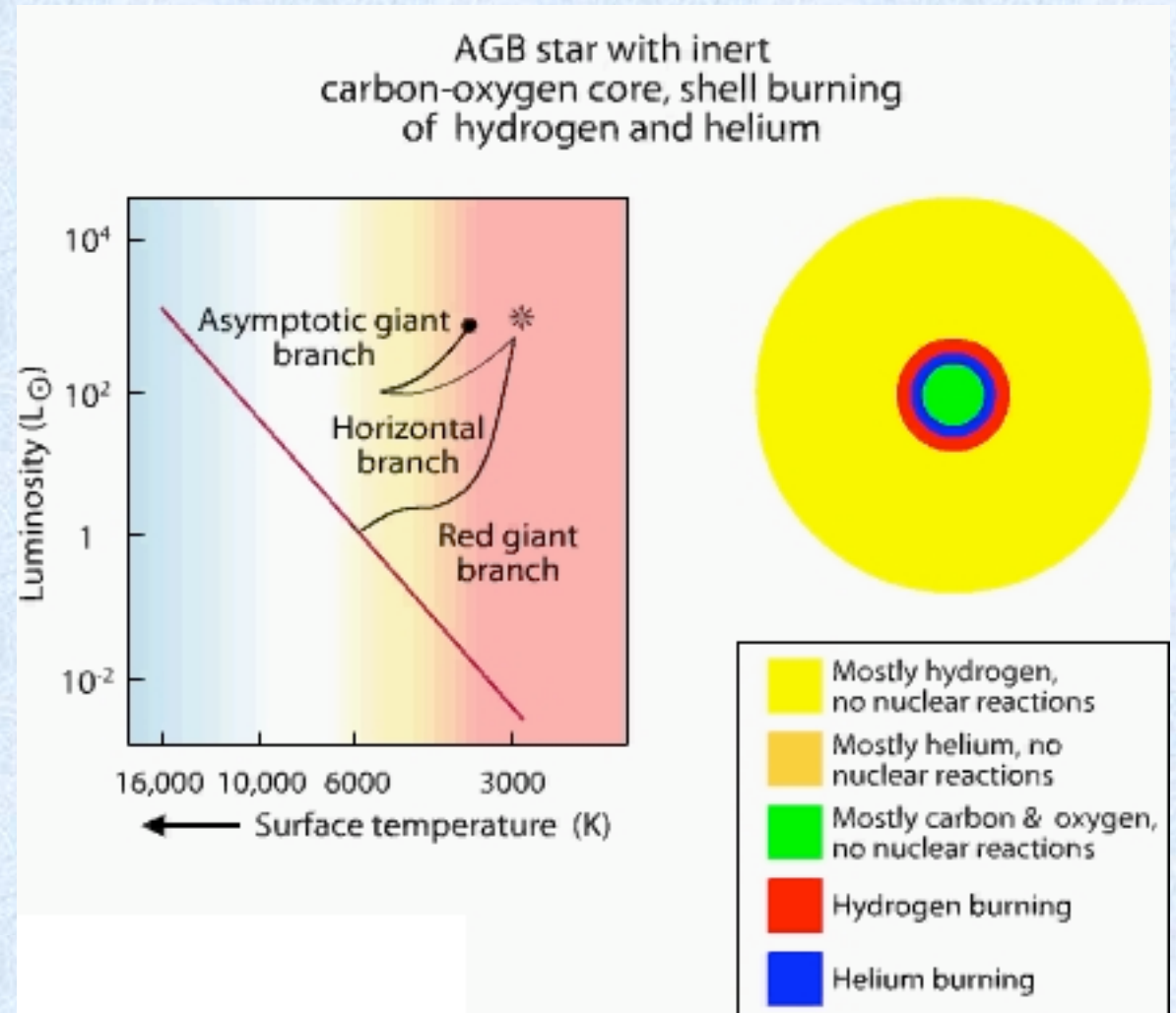
Stage 6:  
Asymptotic giant branch  
(shell H & He fusion)

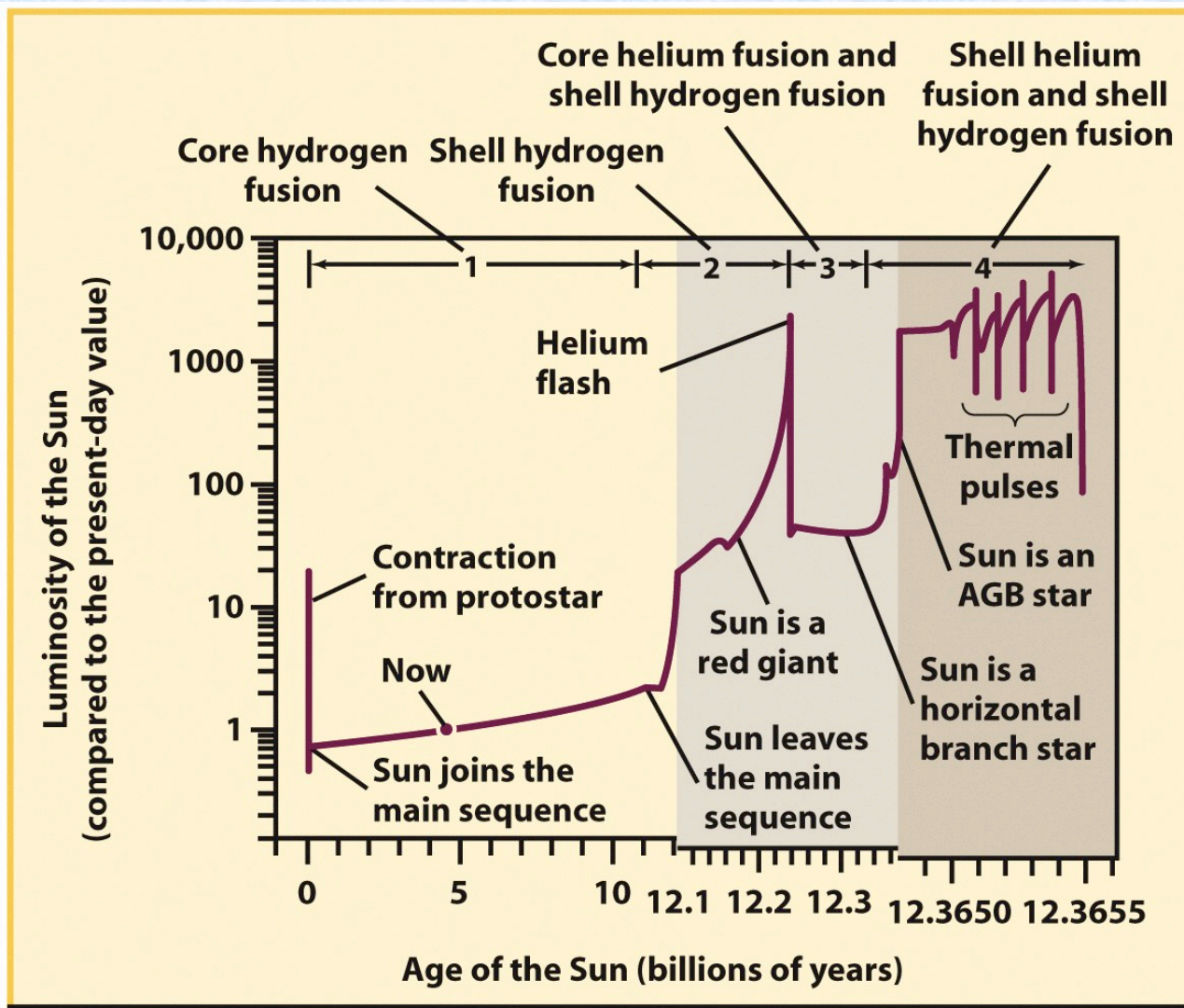
H = hydrogen

He = helium

C = carbon

O = oxygen





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

Figure 20-5  
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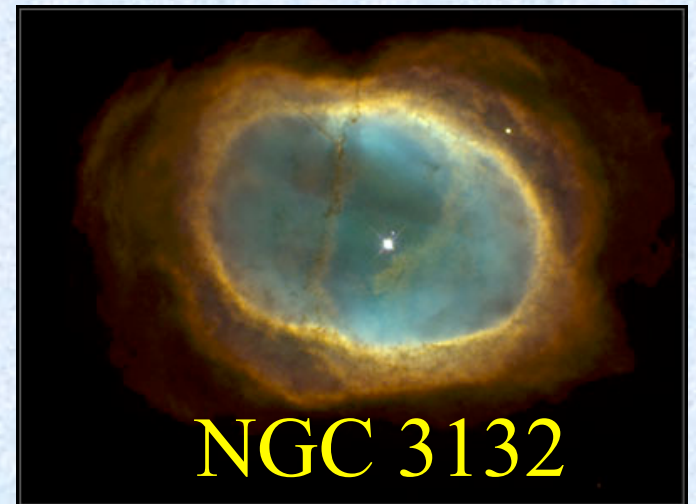
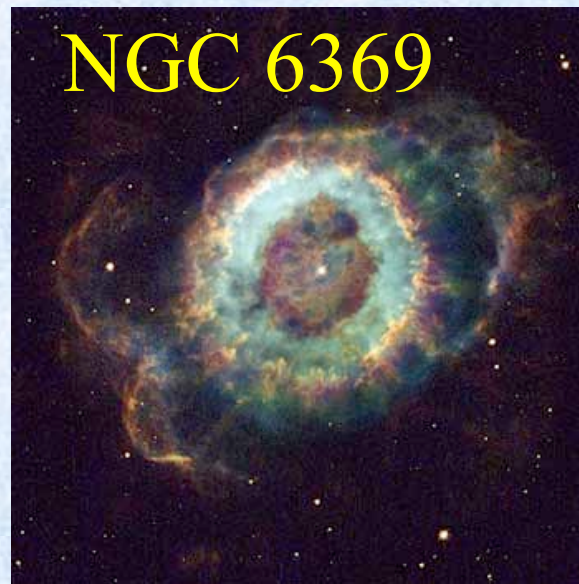
## Question 22.1 (iclickers!)

- 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)





**Central star**

**Nearly spherical shell of material  
ejected from the central star**

**The shell is so thin  
that we can see stars on  
the other side...**

**...but it appears  
substantial when we  
look near its rim.**

**Figure 20-6b**

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What's left of the star:  
A white dwarf





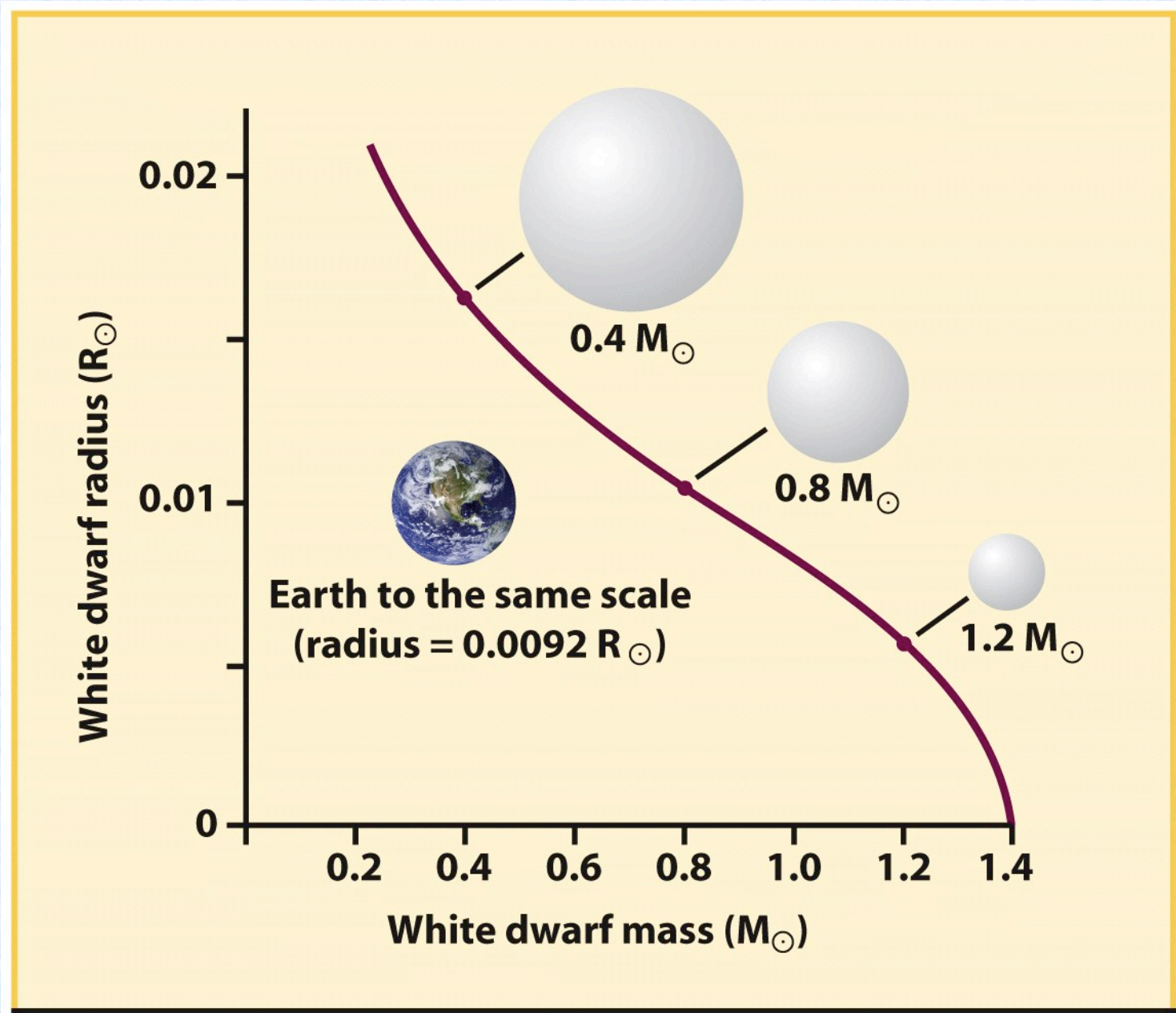
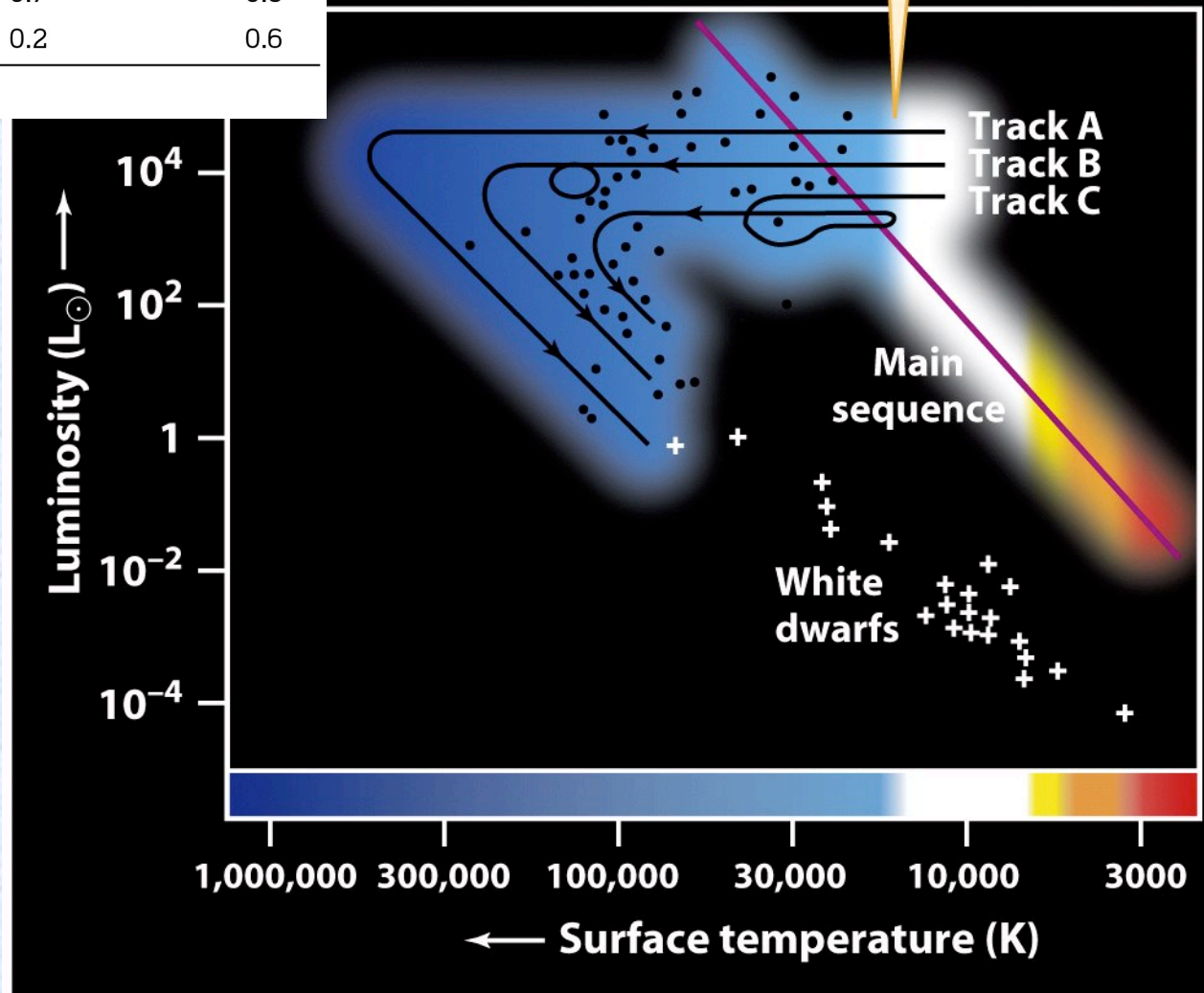


Figure 20-9  
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Evolutionary track	Mass ( $M_{\odot}$ )		
	Giant star	Ejected nebula	White dwarf
A	3.0	1.8	1.2
B	1.5	0.7	0.8
C	0.8	0.2	0.6

Figure 20-10 part 2  
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These evolutionary tracks follow three different giant stars as they eject planetary nebulae and become white dwarf stars.

Figure 20-10  
*Universe, Eighth Edition*  
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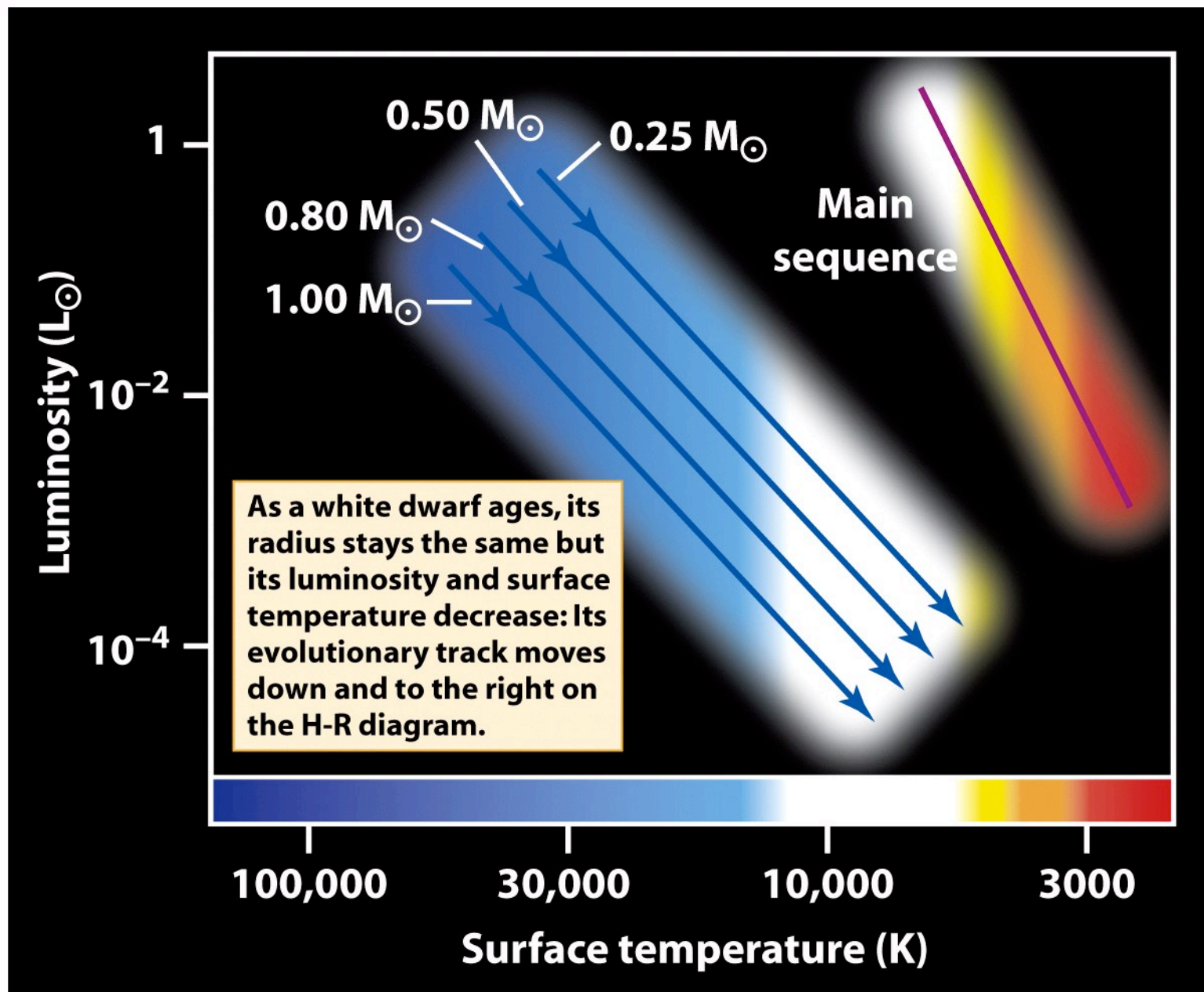


Figure 20-11  
*Universe, Eighth Edition*  
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# What supports white dwarfs?

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.

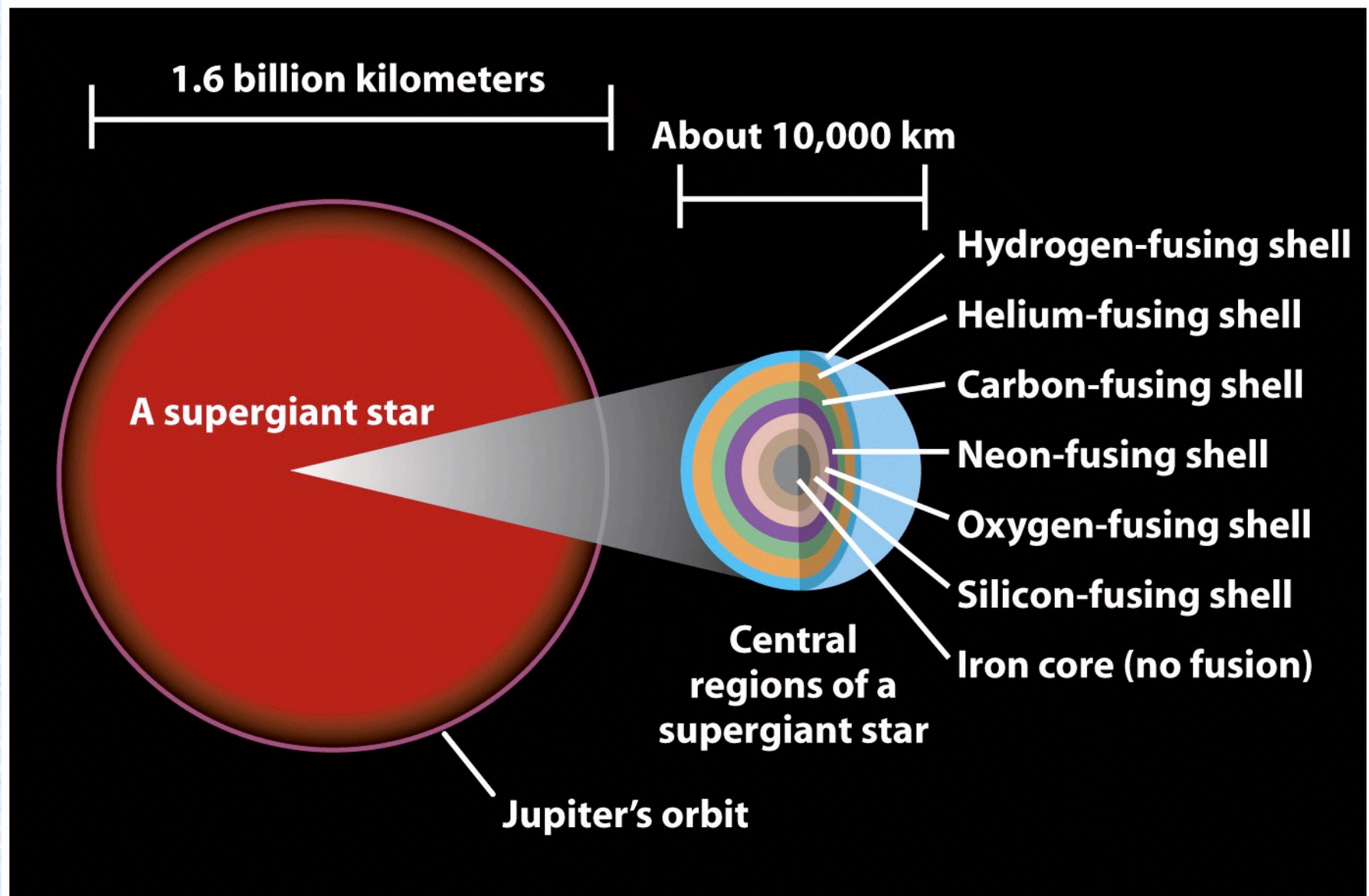


Figure 20-13  
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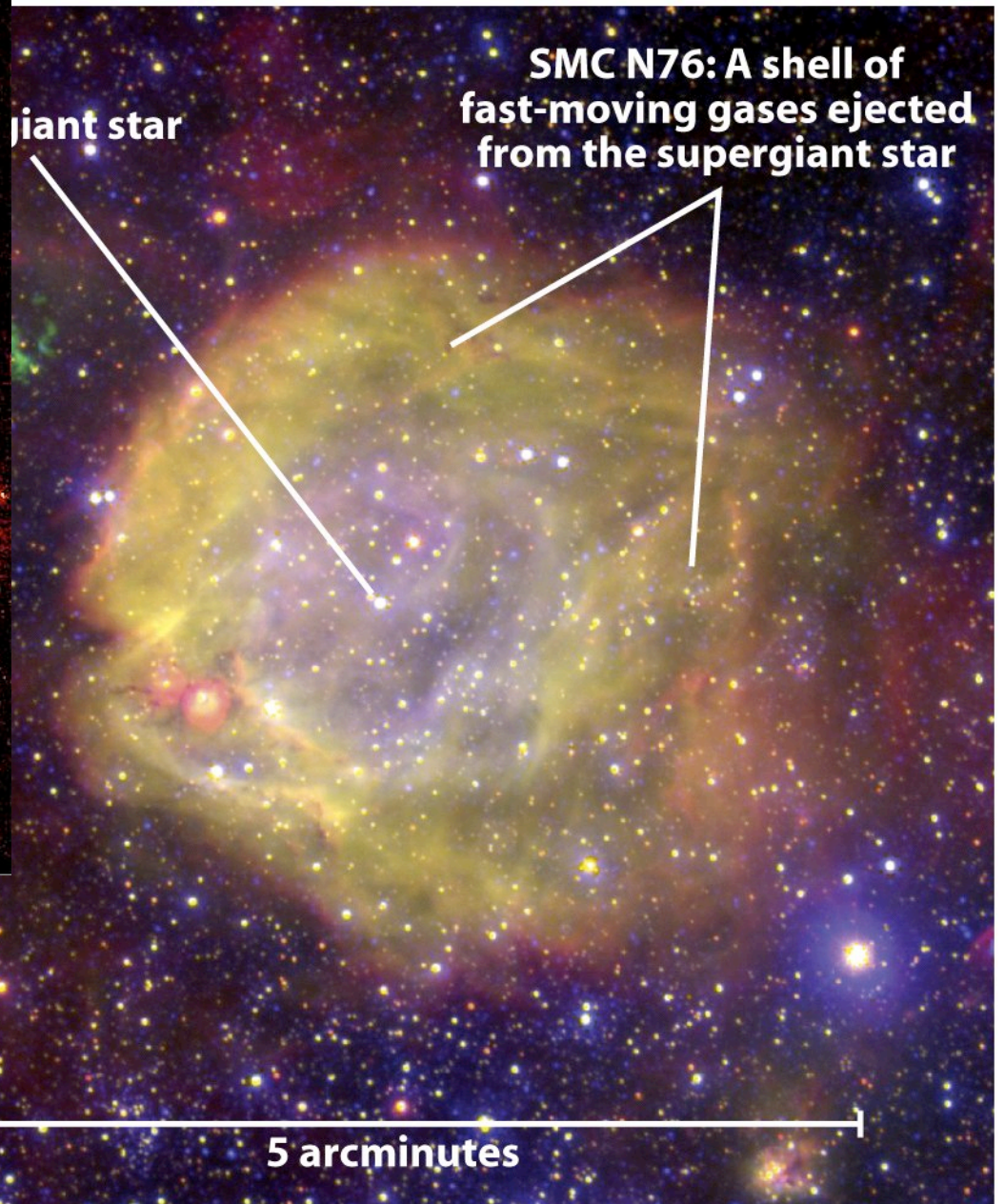
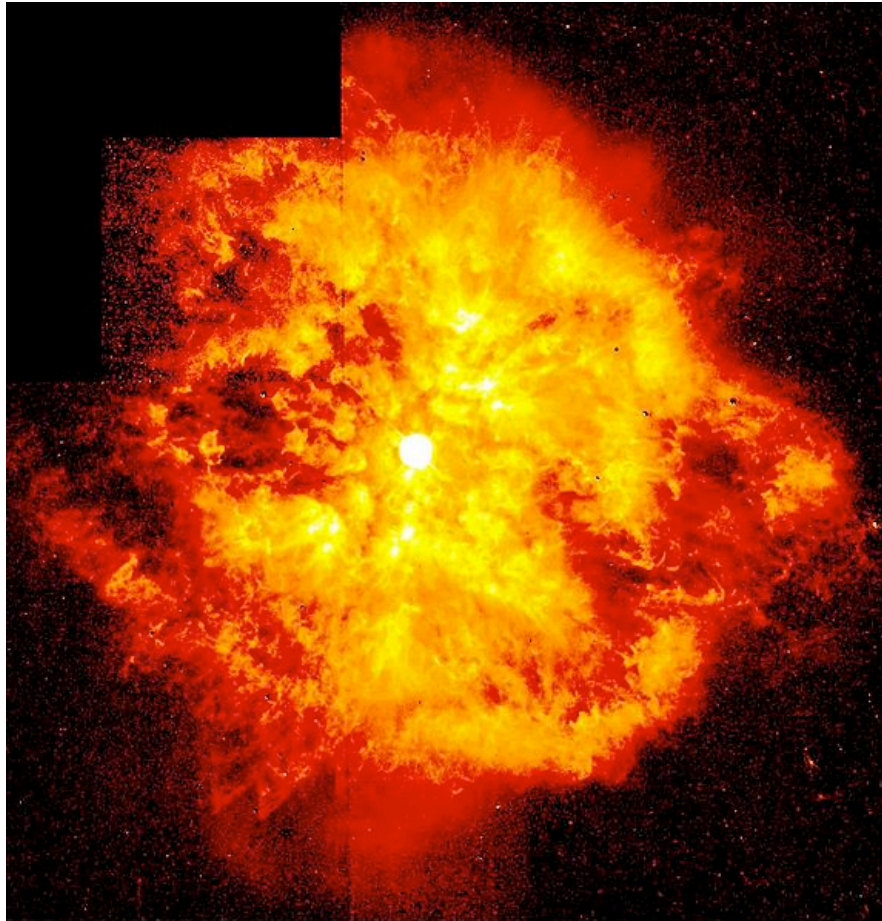


Figure 20-12  
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Stars much more massive than the Sun:  
Reactions produce elements up to iron  
(Fe, 26 protons, 30 neutrons)

Periodic Table of the Elements

1 H Hydrogen																	2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	71 Lu Lutetium	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	103 Lr Lawrencium	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110	111	112	113	114	115	116	117	118
		57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium		
		89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendelevium	102 No Nobelium		



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

Stage	Core temperature (K)	Core density (kg/m <sup>3</sup> )	Duration of stage
Hydrogen fusion	$4 \times 10^7$	$5 \times 10^3$	$7 \times 10^6$ years
Helium fusion	$2 \times 10^8$	$7 \times 10^5$	$7 \times 10^5$ years
Carbon fusion	$6 \times 10^8$	$2 \times 10^8$	600 years
Neon fusion	$1.2 \times 10^9$	$4 \times 10^9$	1 year
Oxygen fusion	$1.5 \times 10^9$	$10^{10}$	6 months
Silicon fusion	$2.7 \times 10^9$	$3 \times 10^{10}$	1 day
Core collapse	$5.4 \times 10^9$	$3 \times 10^{12}$	$\frac{1}{4}$ second
Core bounce	$2.3 \times 10^{10}$	$4 \times 10^{15}$	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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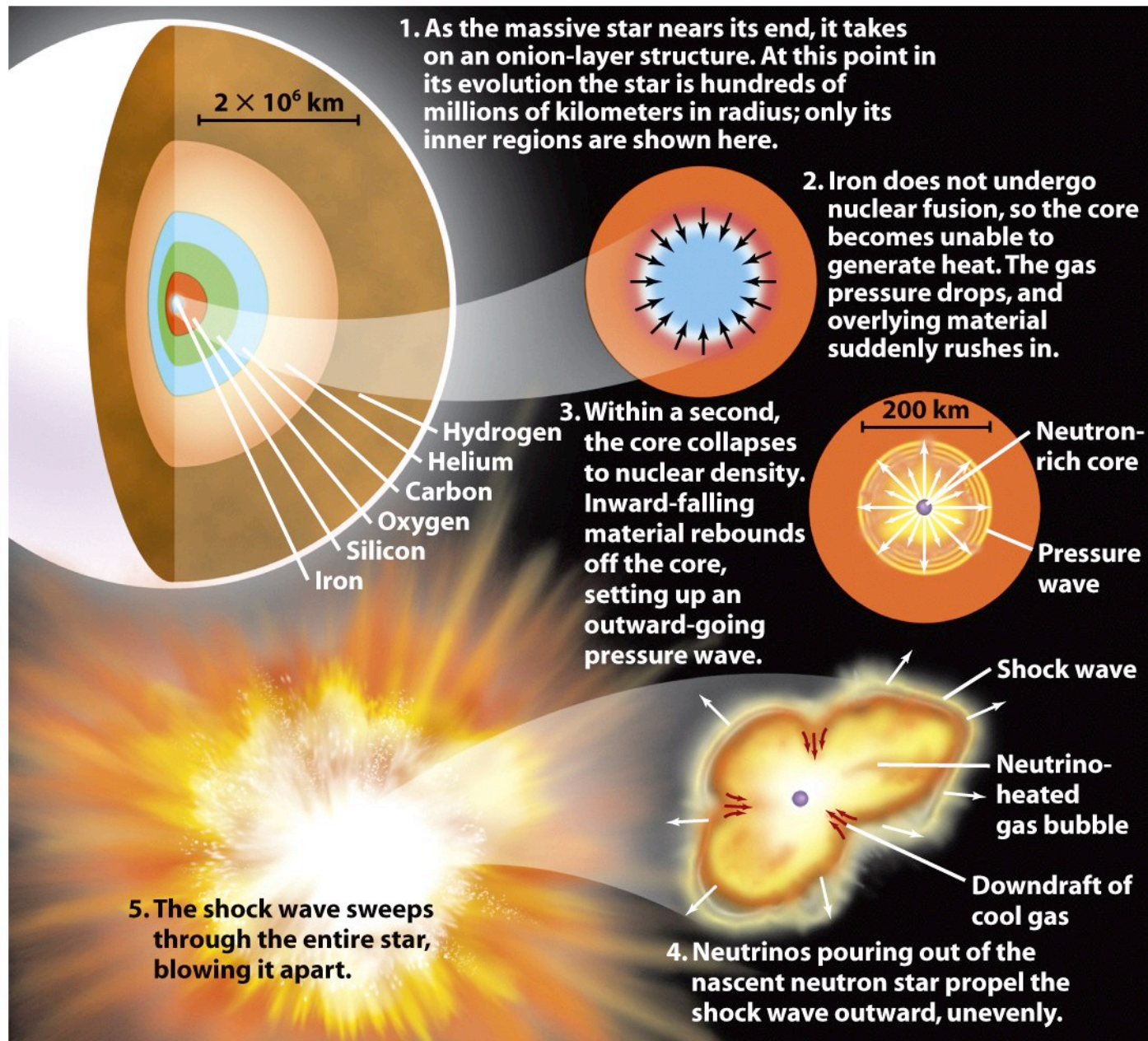


Figure 20-14

*Universe, Eighth Edition*

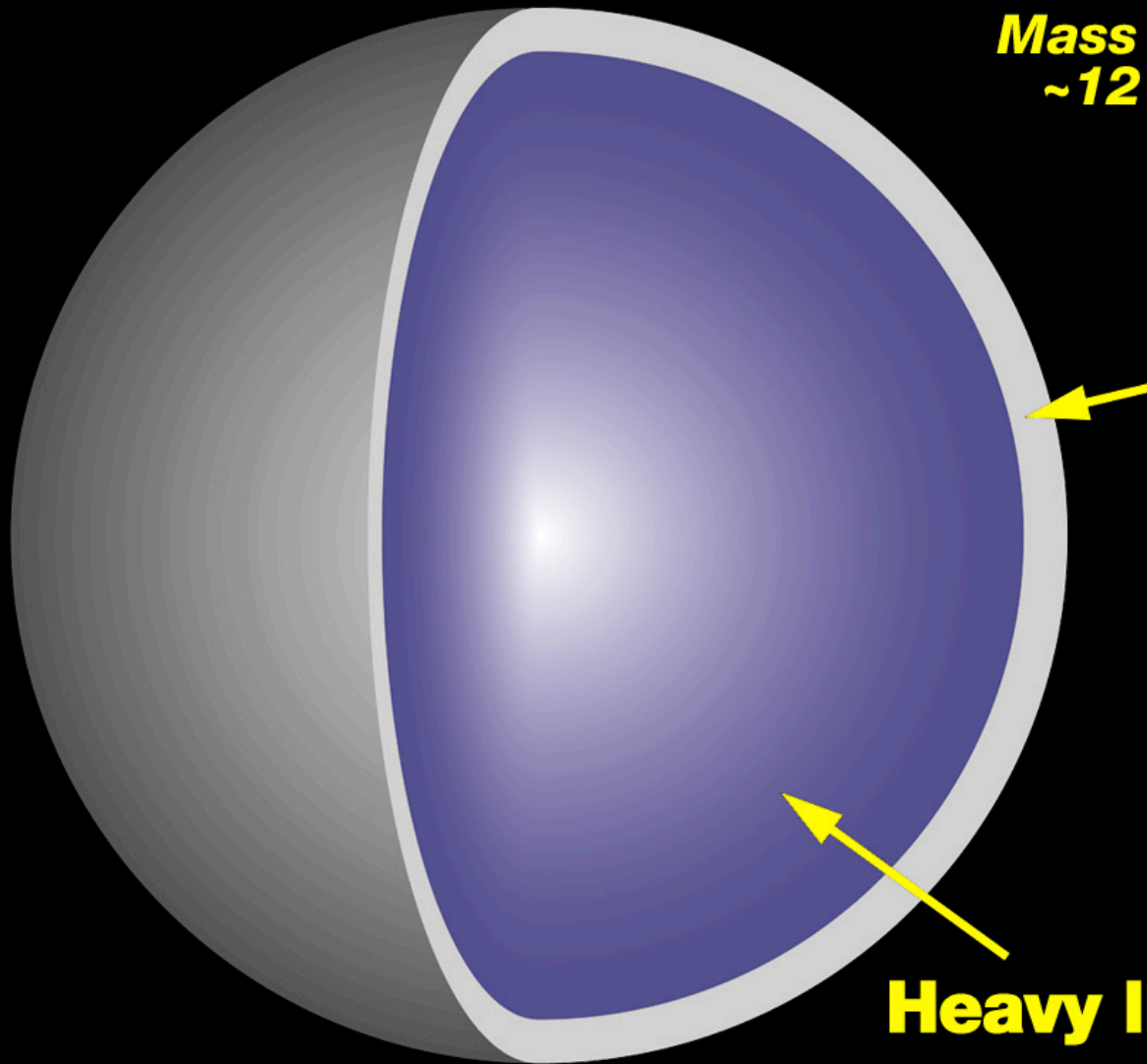
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1 teaspoon of neutron star "weighs" 100 million tons!

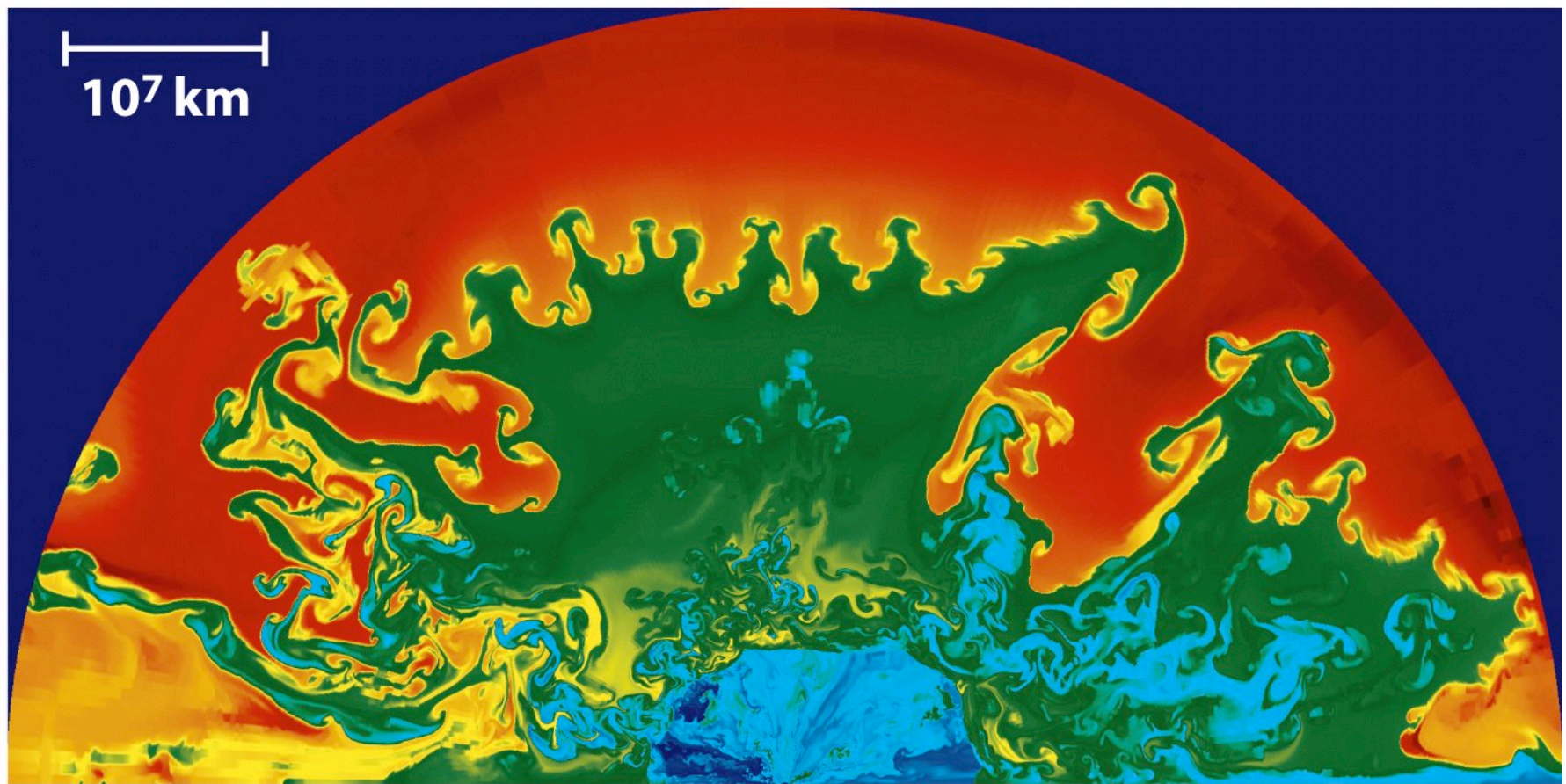
# Neutron Star

*Mass ~ 1.5 times the Sun  
~12 miles in diameter*



**Solid crust**  
*~1 mile thick*

**Heavy liquid interior**  
*Mostly neutrons,  
with other particles*

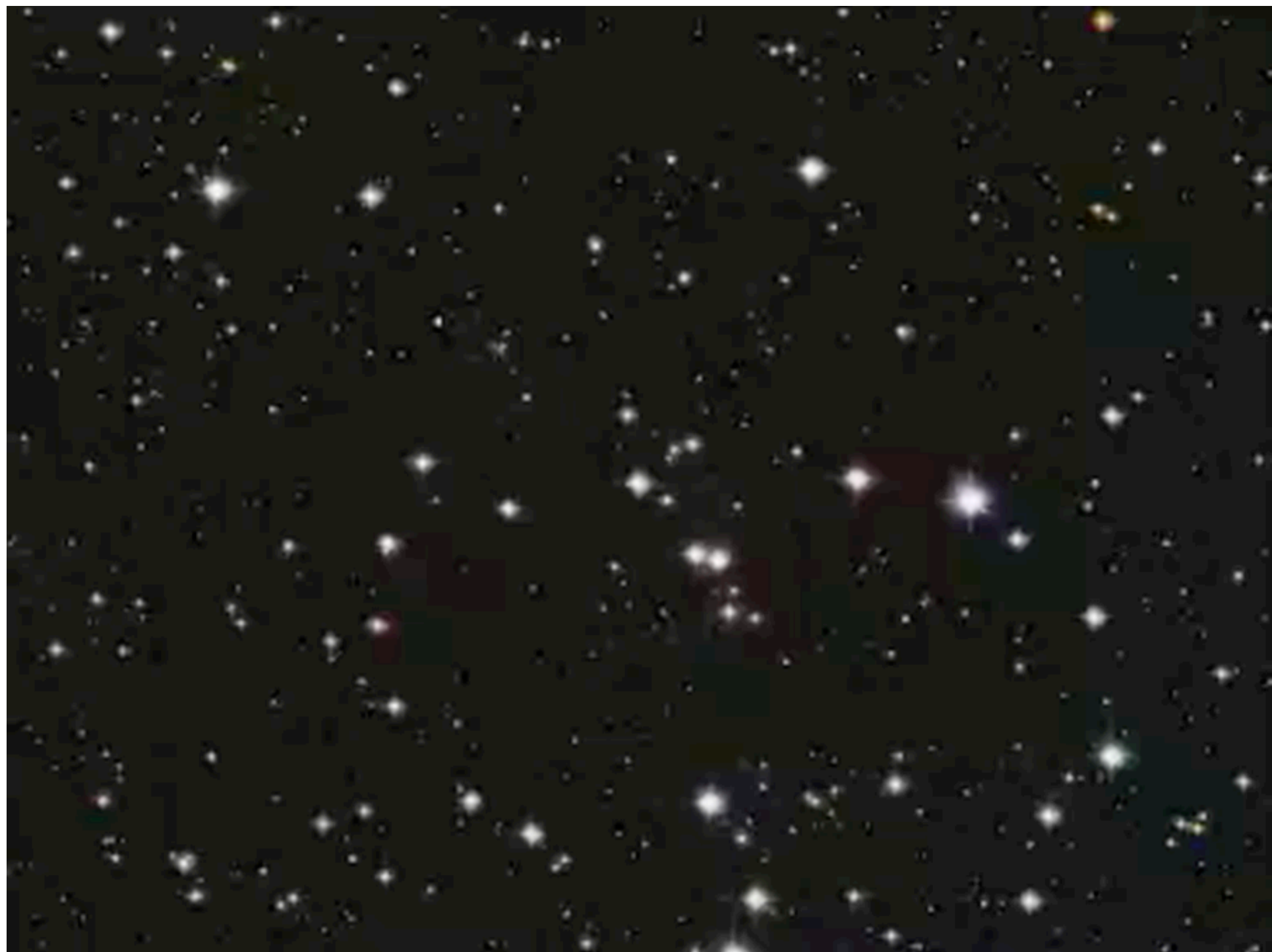


**A simulated supernova 5<sup>1</sup>/<sub>2</sub> hours after the core "bounce"  
(red = hydrogen, green = helium, turquoise and blue = carbon,  
oxygen, silicon, and iron)**

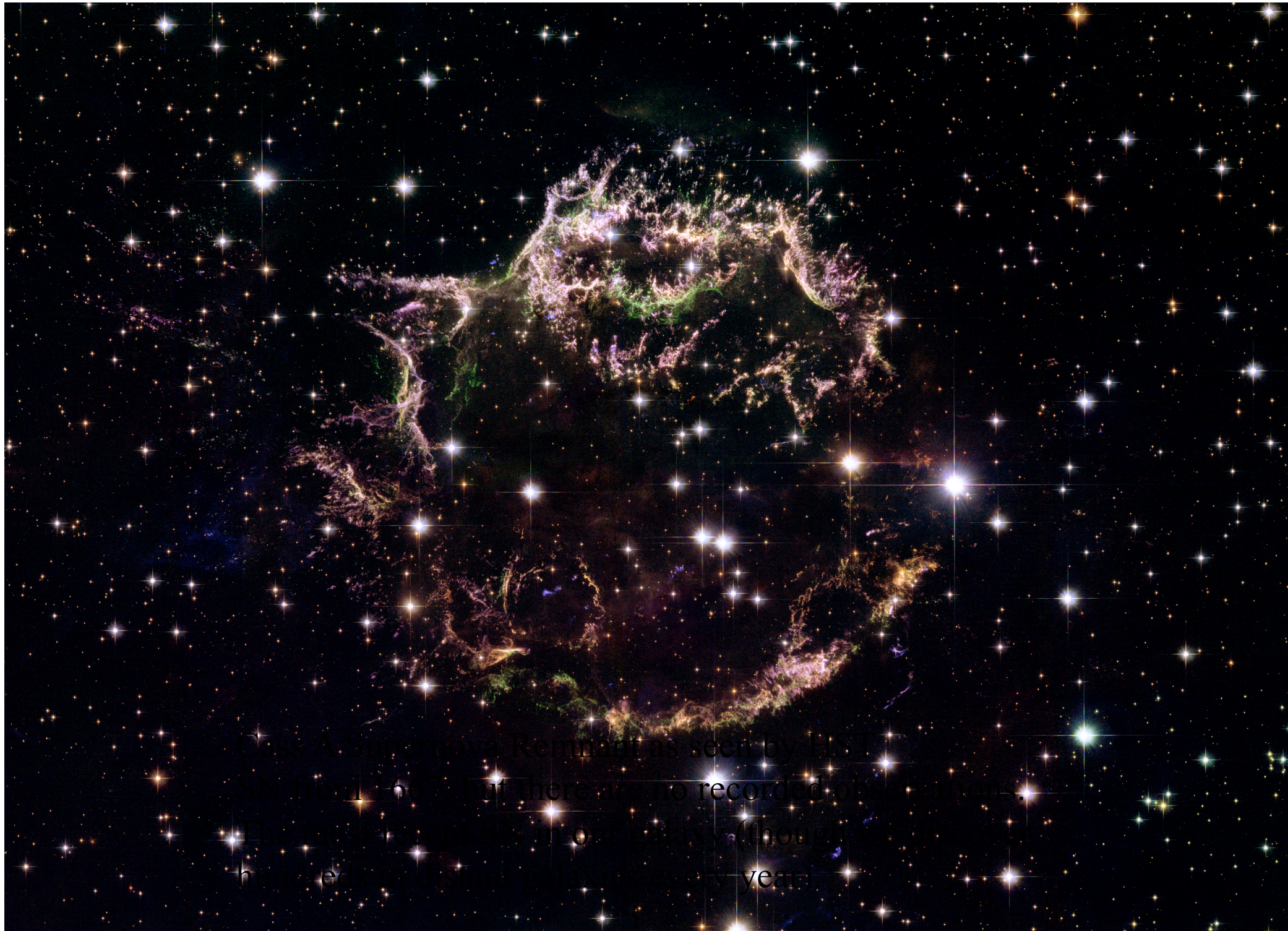
Figure 20-15a

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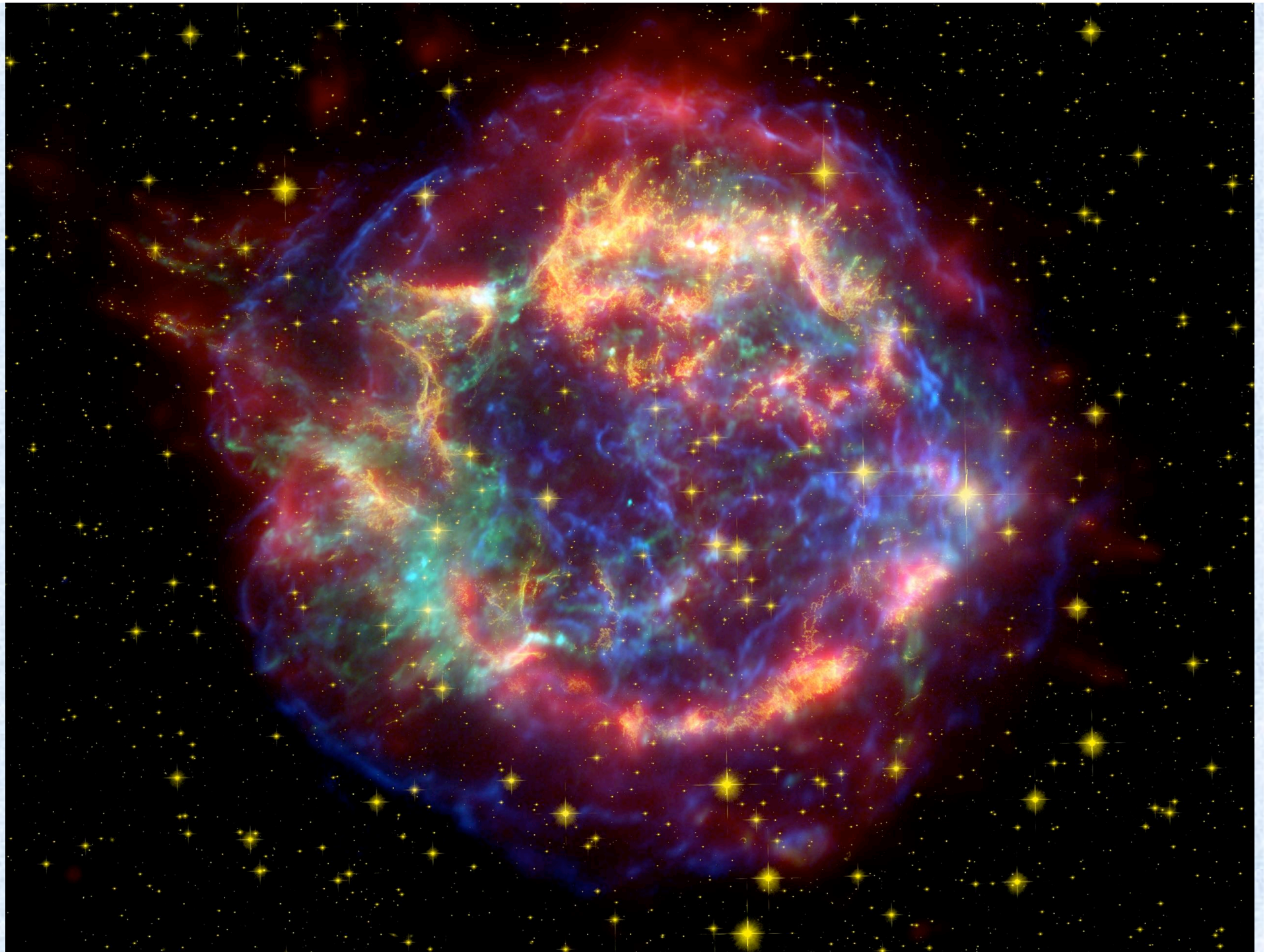




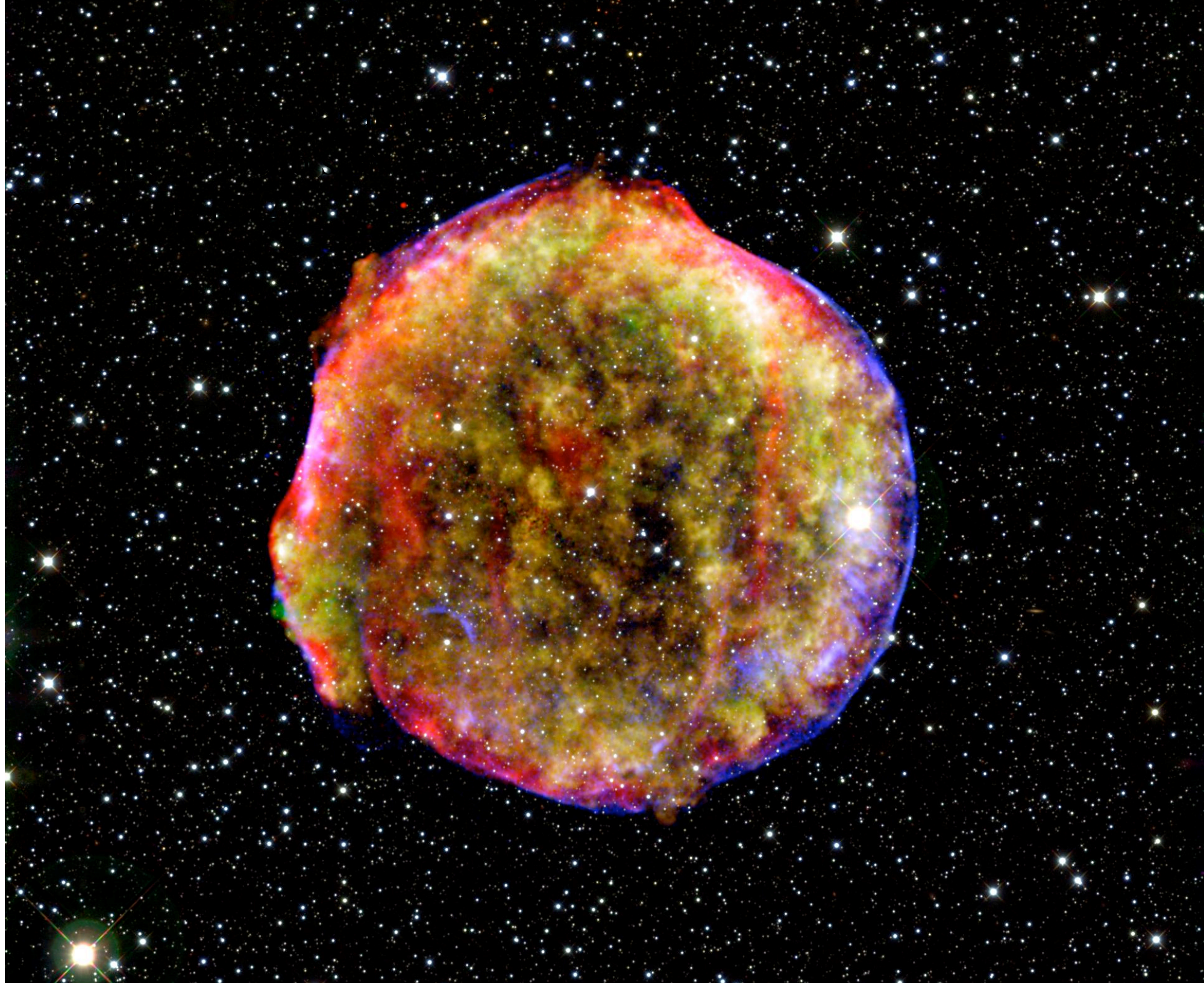


The Ringed Prawn Nebula, Kennicutt as seen by Hubble  
and the Ringed Prawn Nebula, but there are no recorded observations.  
The Ringed Prawn Nebula is a very young (though  
however, it is estimated to be only a few years







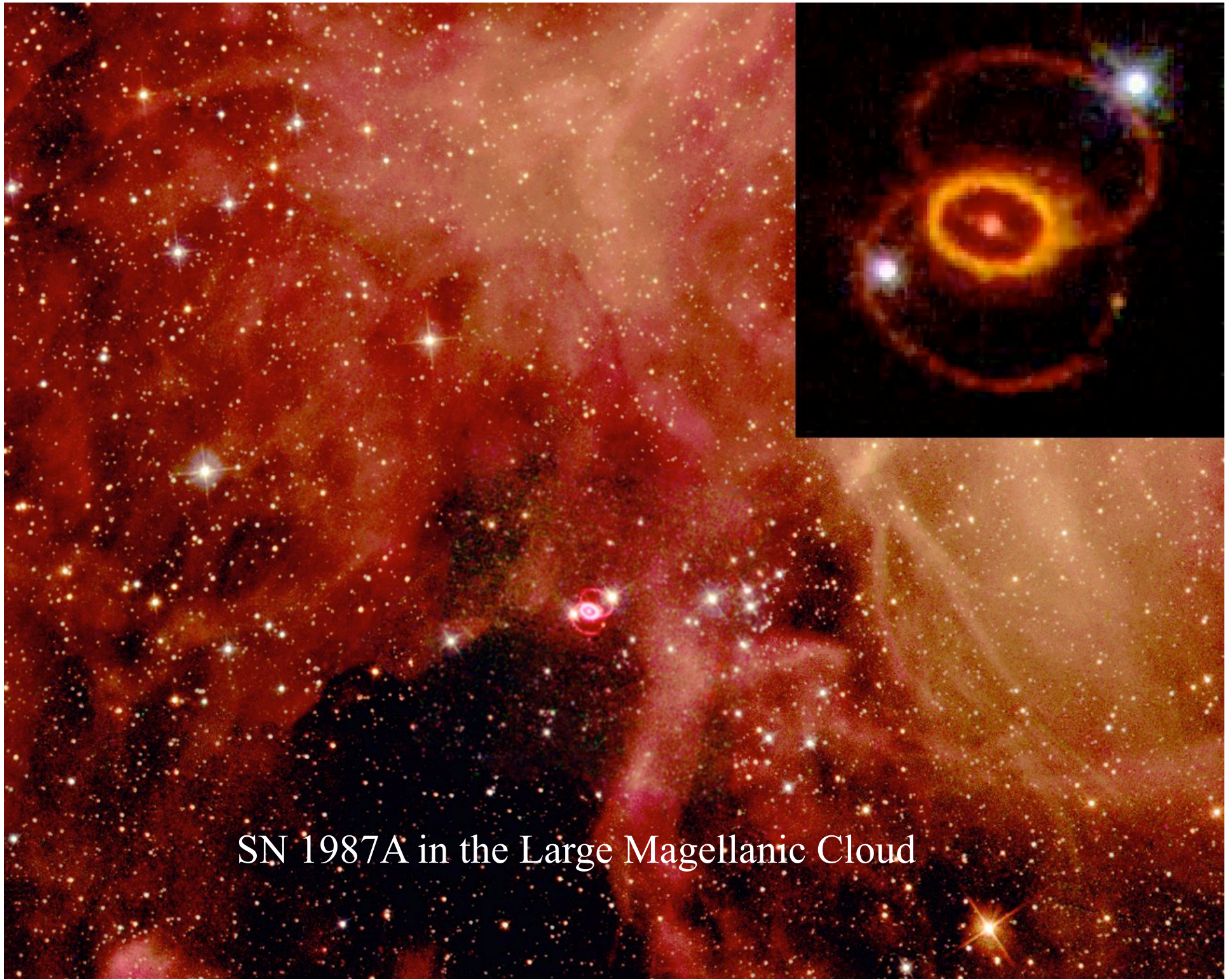






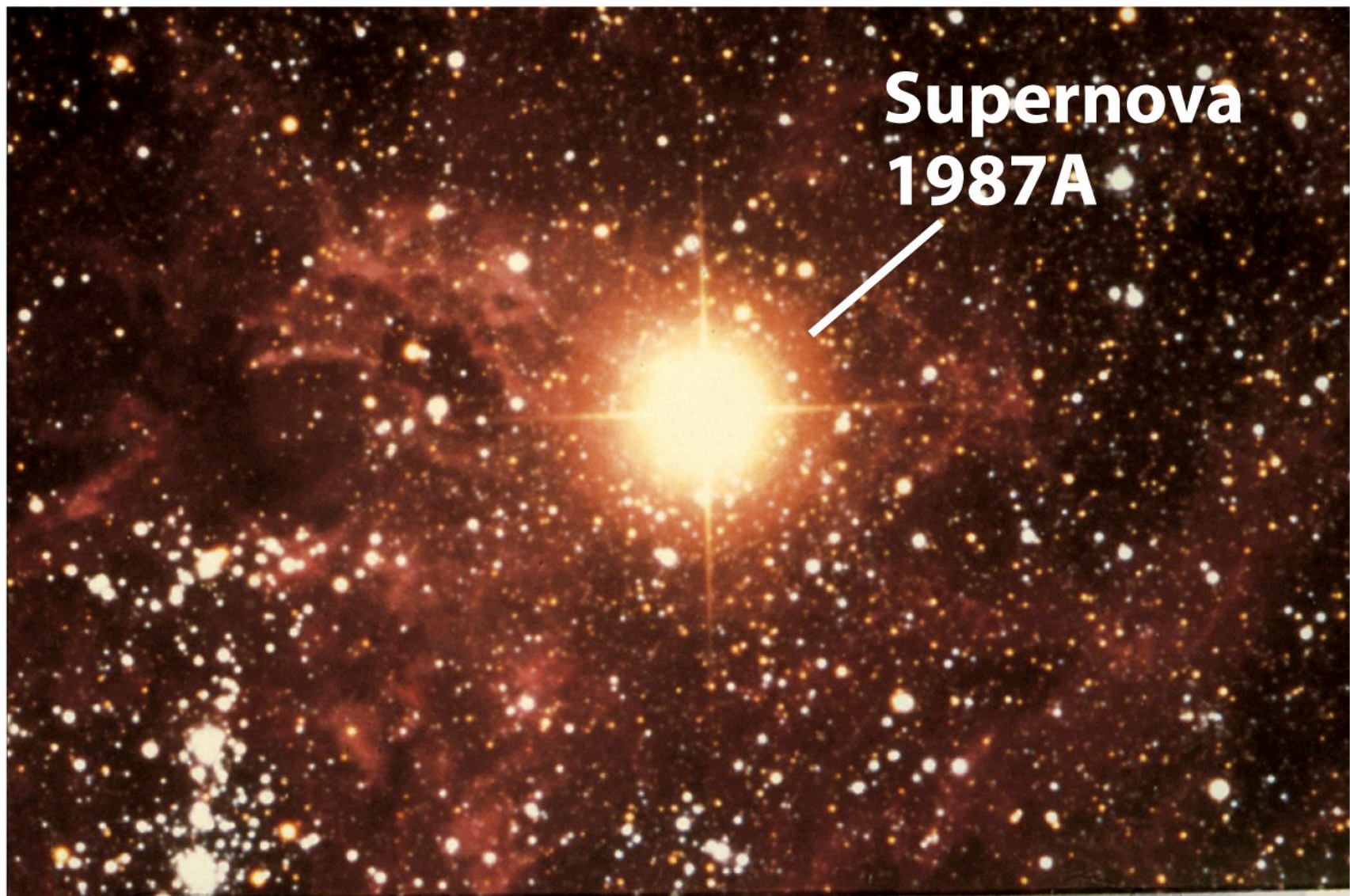
Vela Supernova Remnant (12,000 years old)  
Image scale:  $10^\circ$ , 100 lyr





SN 1987A in the Large Magellanic Cloud



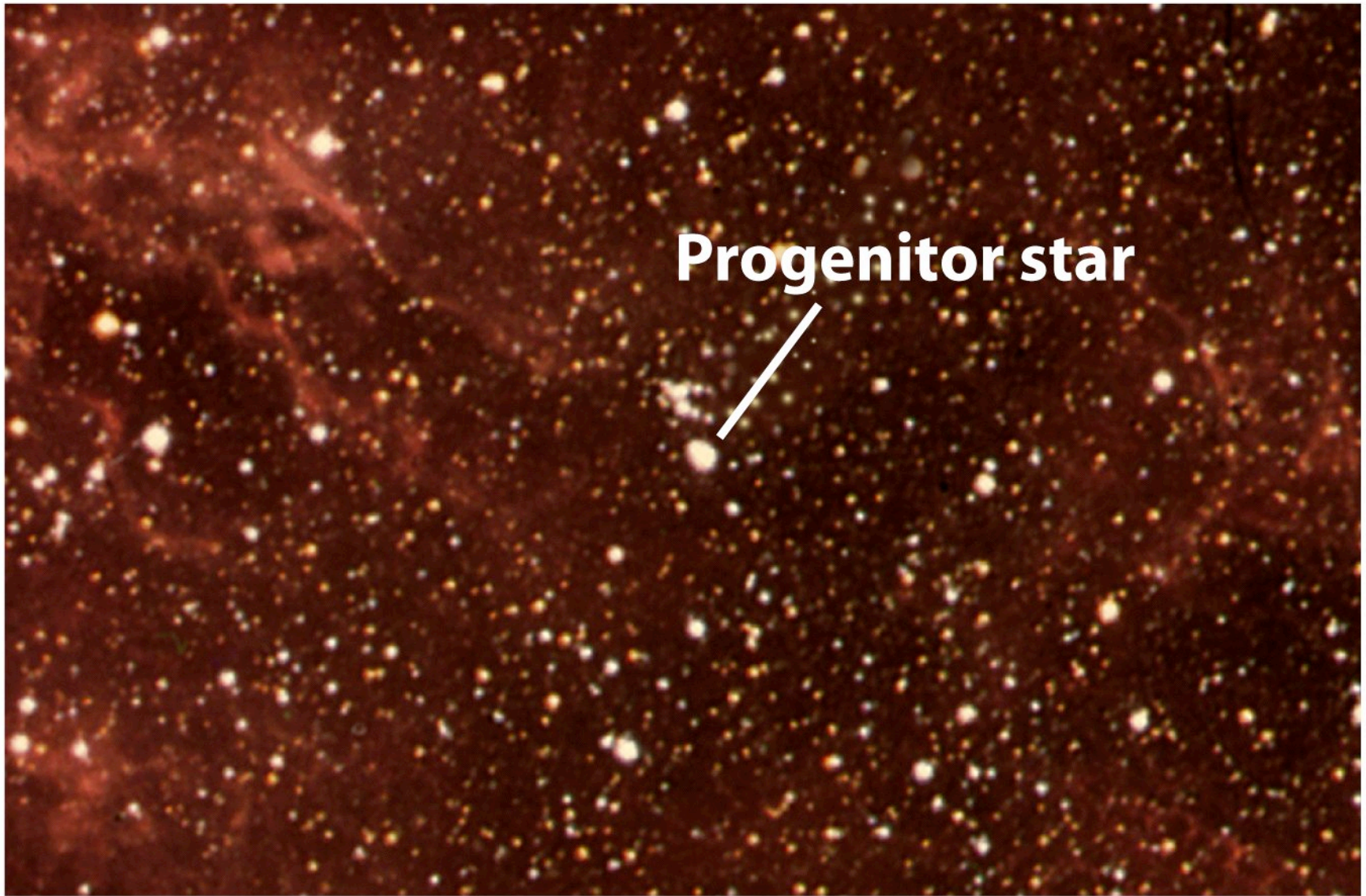


**Supernova  
1987A**

**After the star exploded**

Figure 20-18b  
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**Progenitor star**

**Before the star exploded**

Figure 20-18a

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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.

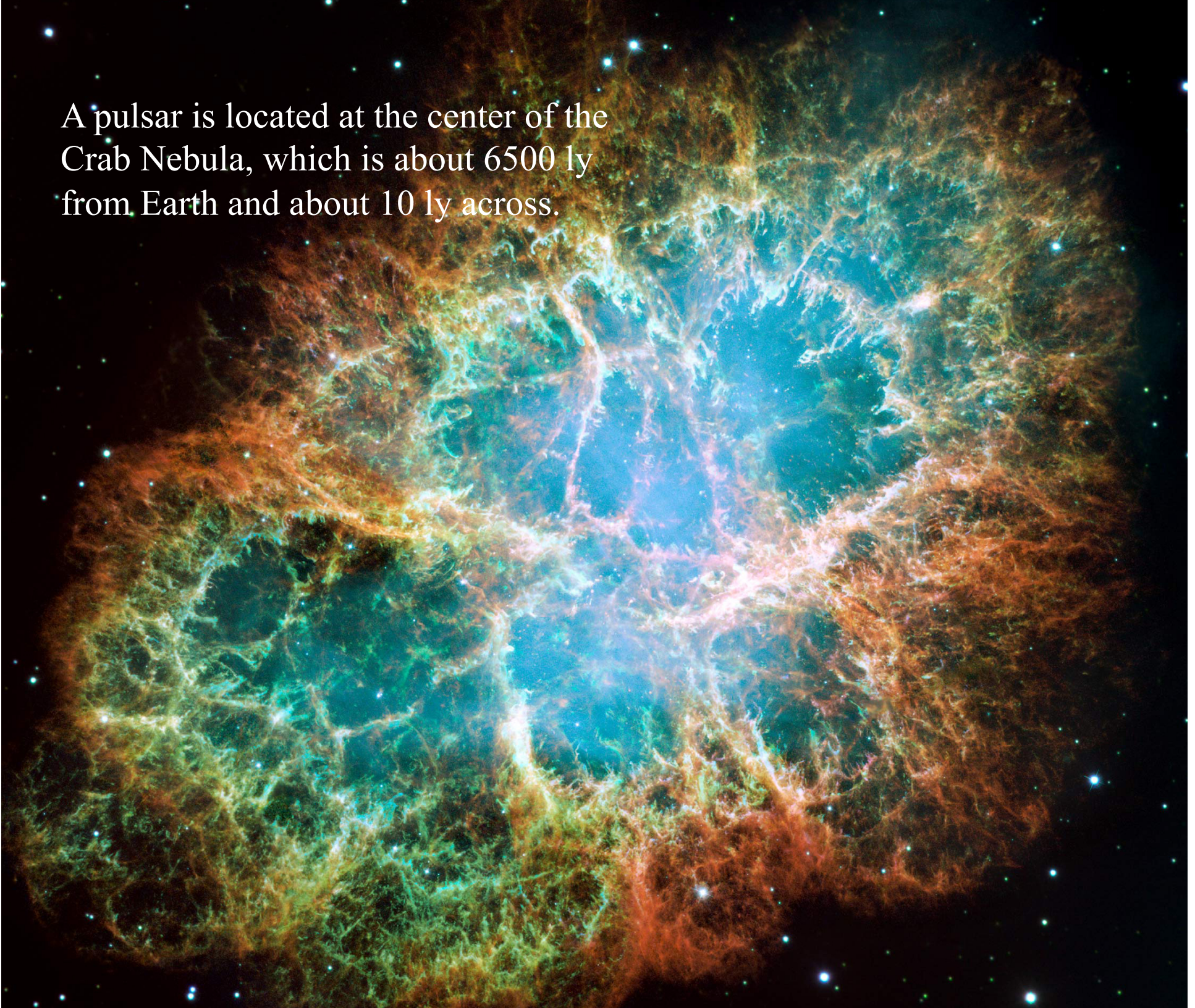
Figure 21-1

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





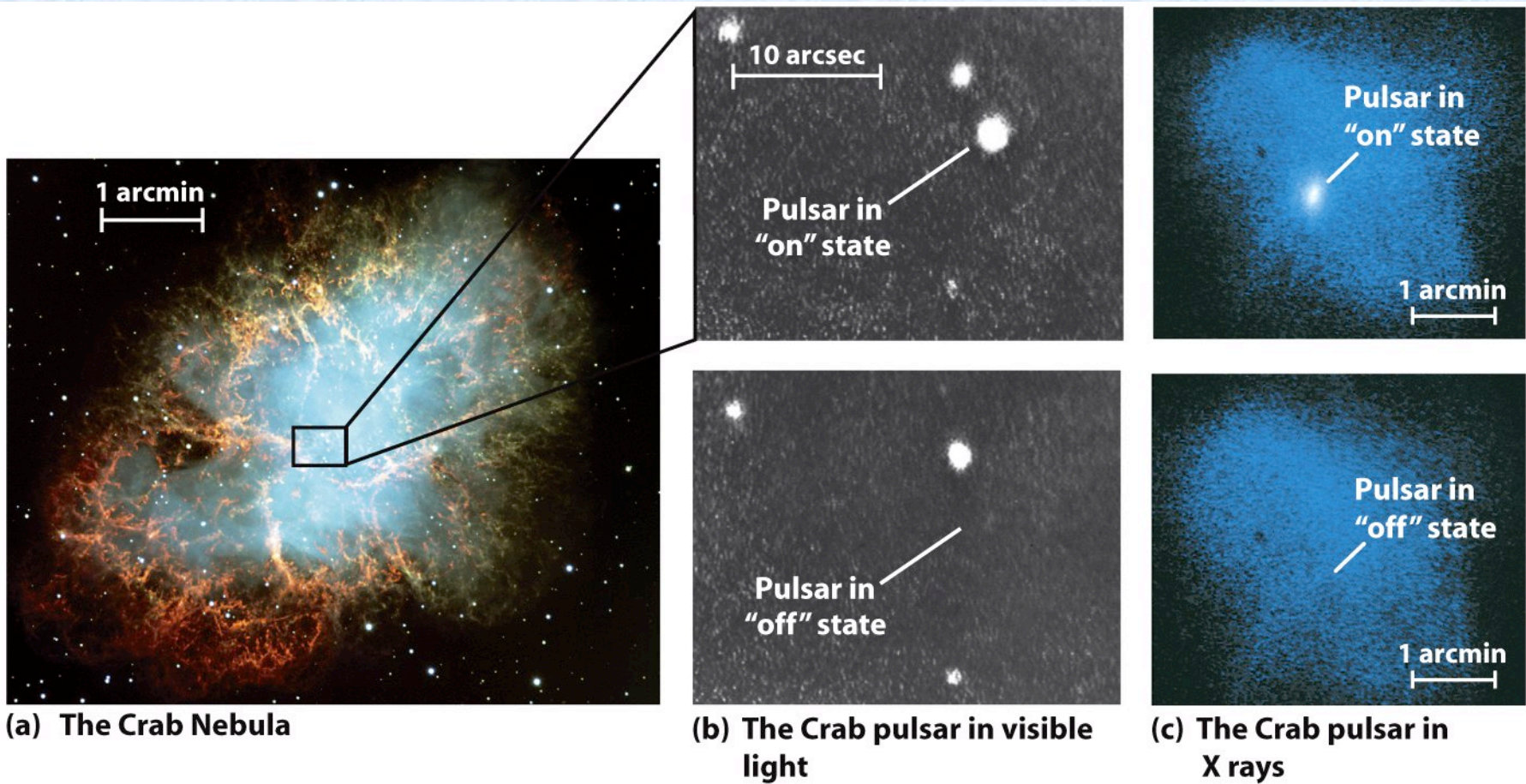


Figure 21-4  
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## Question 22.3 (iclickers!)

- 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



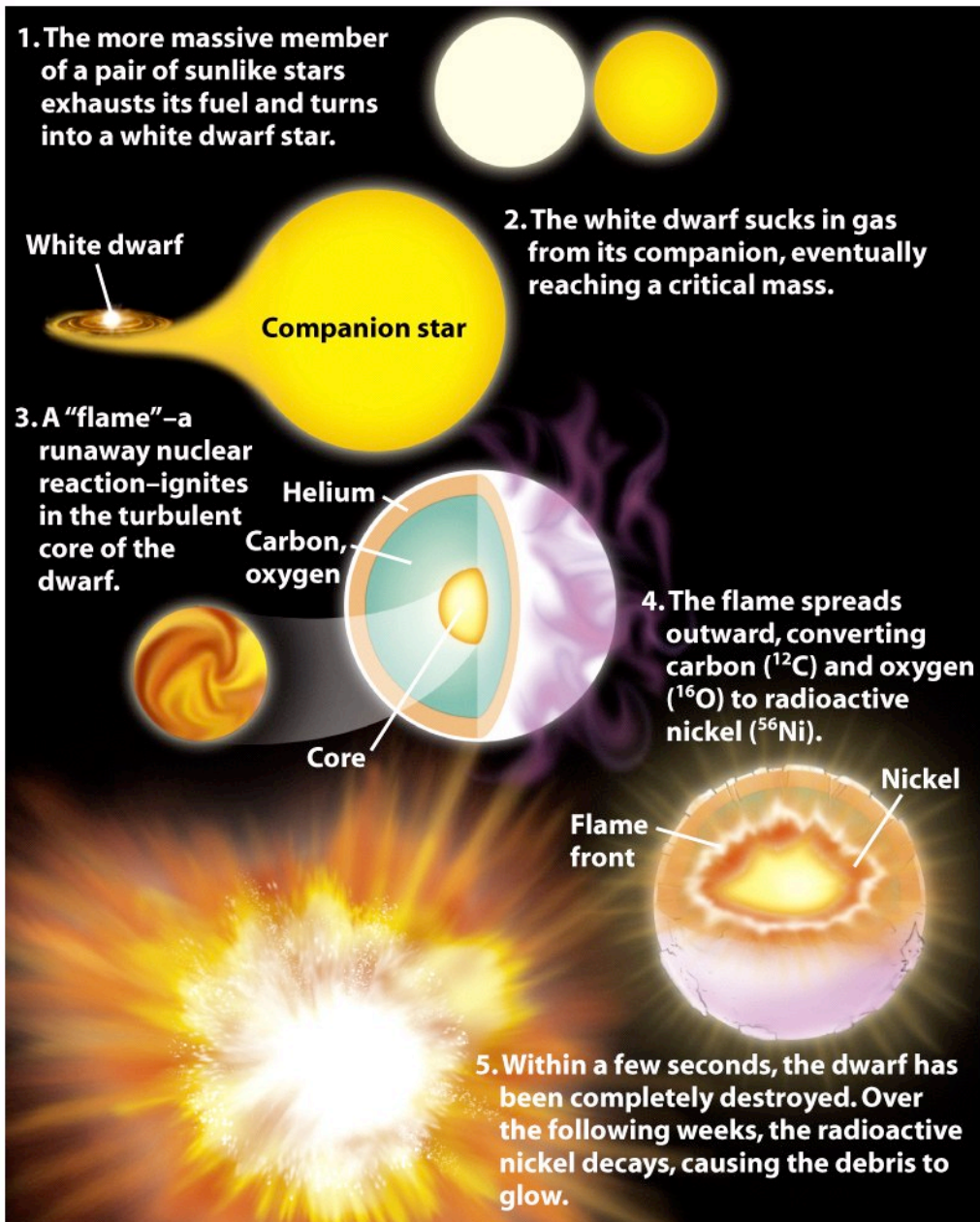
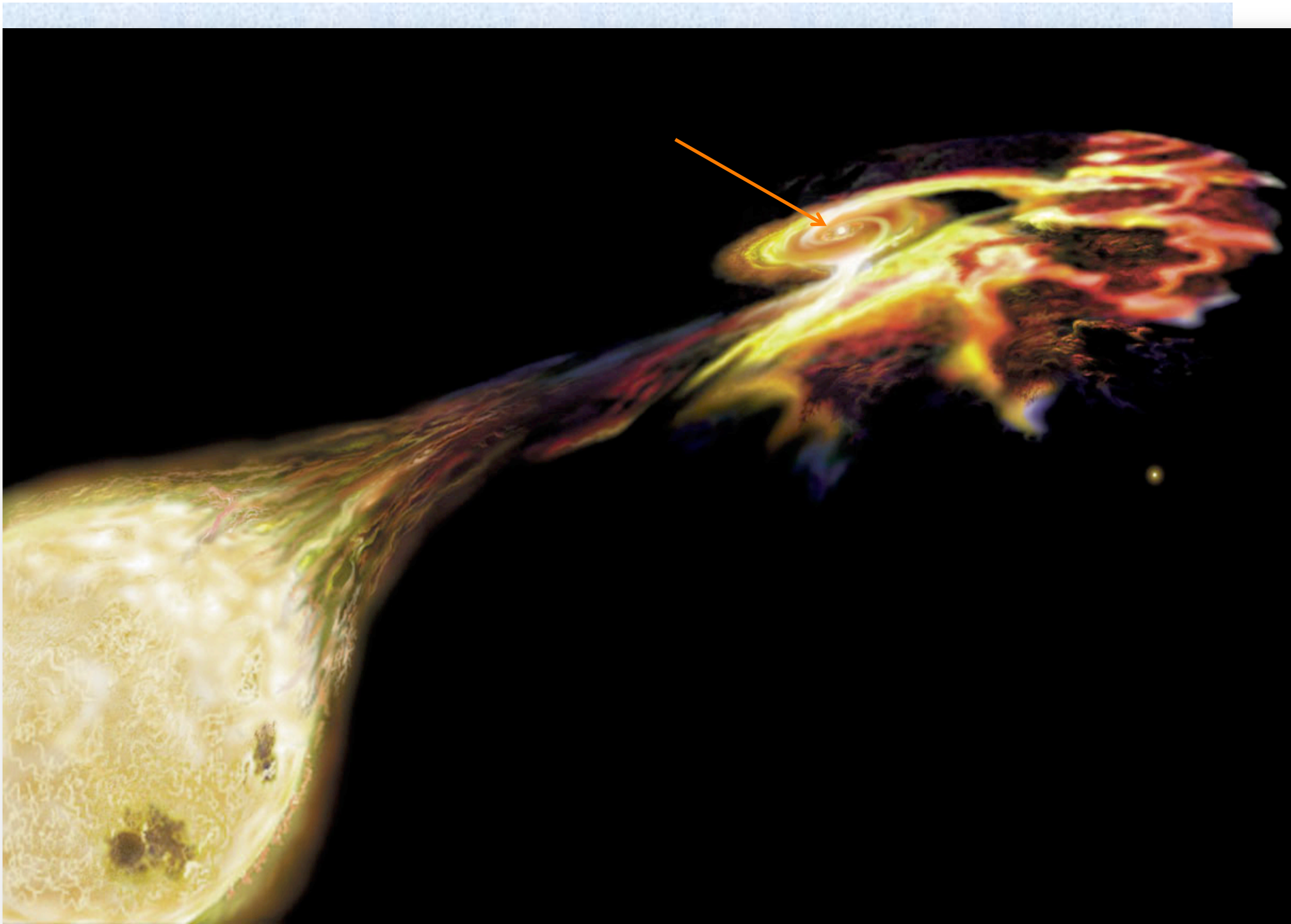


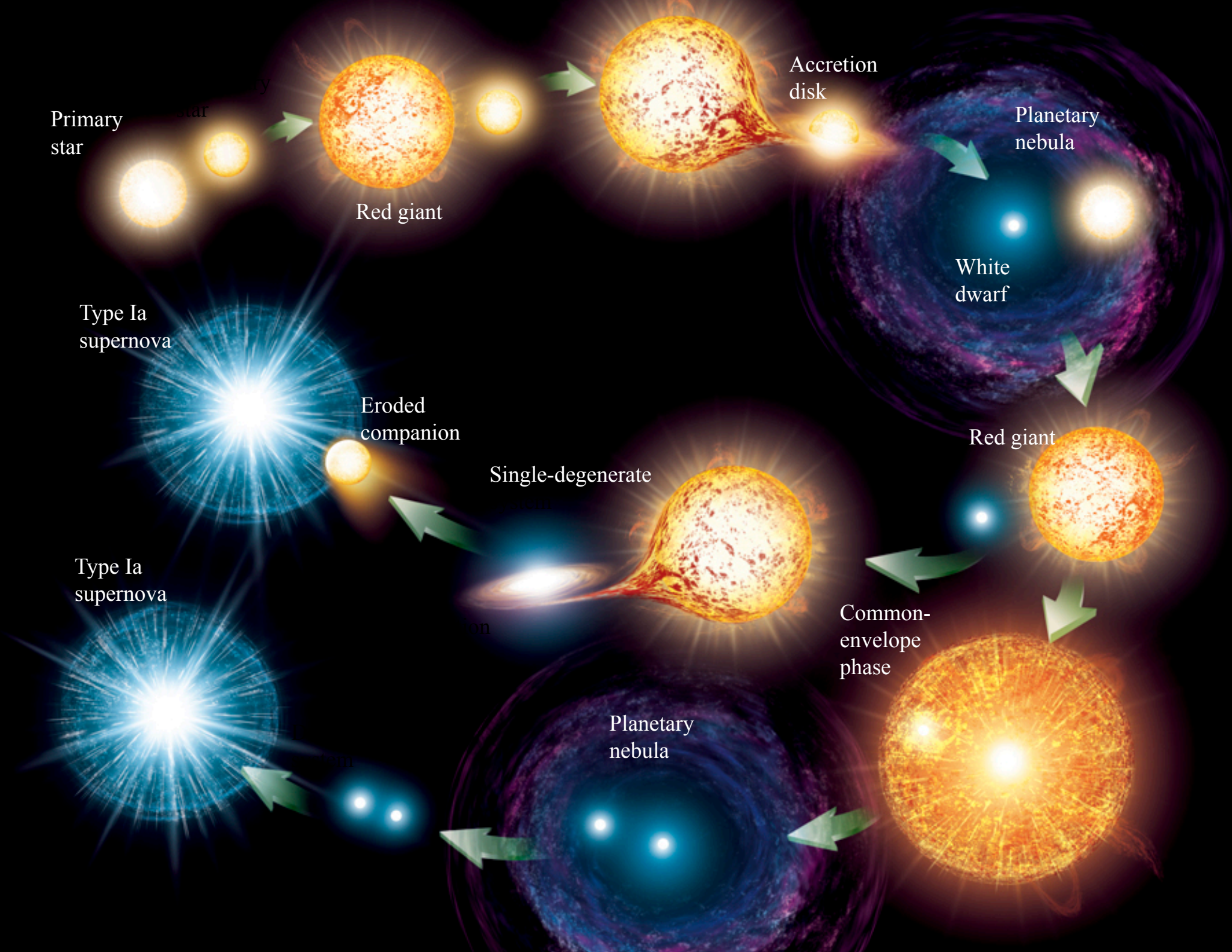
Figure 20-21

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Primary star

Secondary 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)



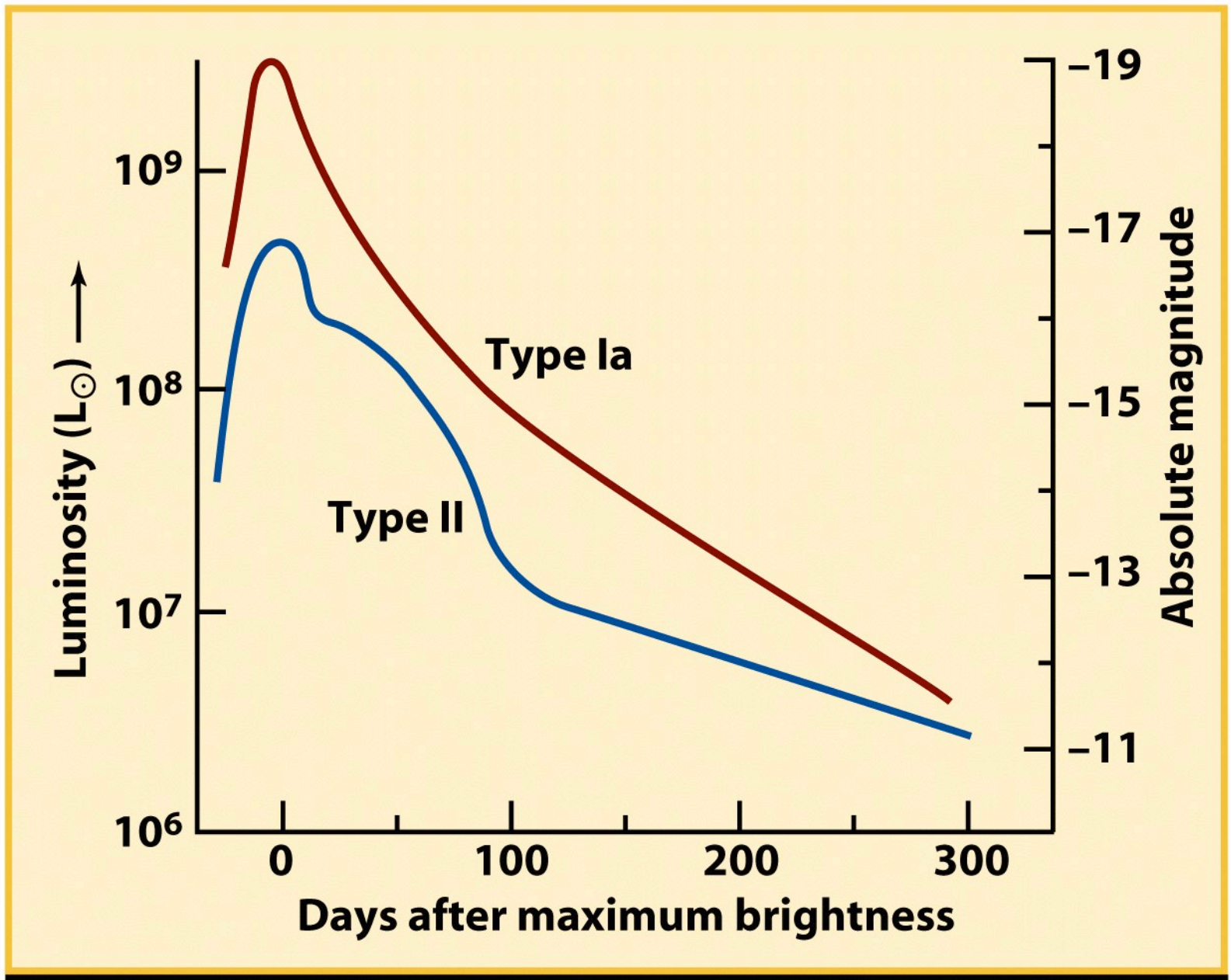
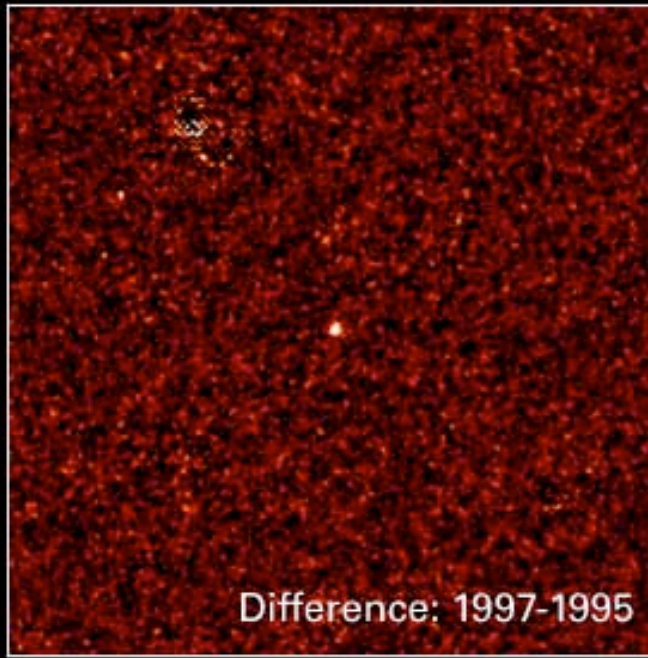
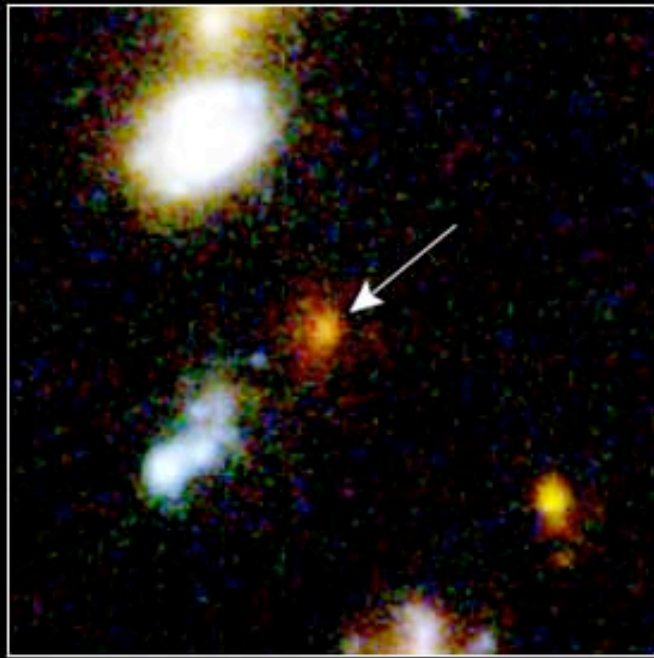
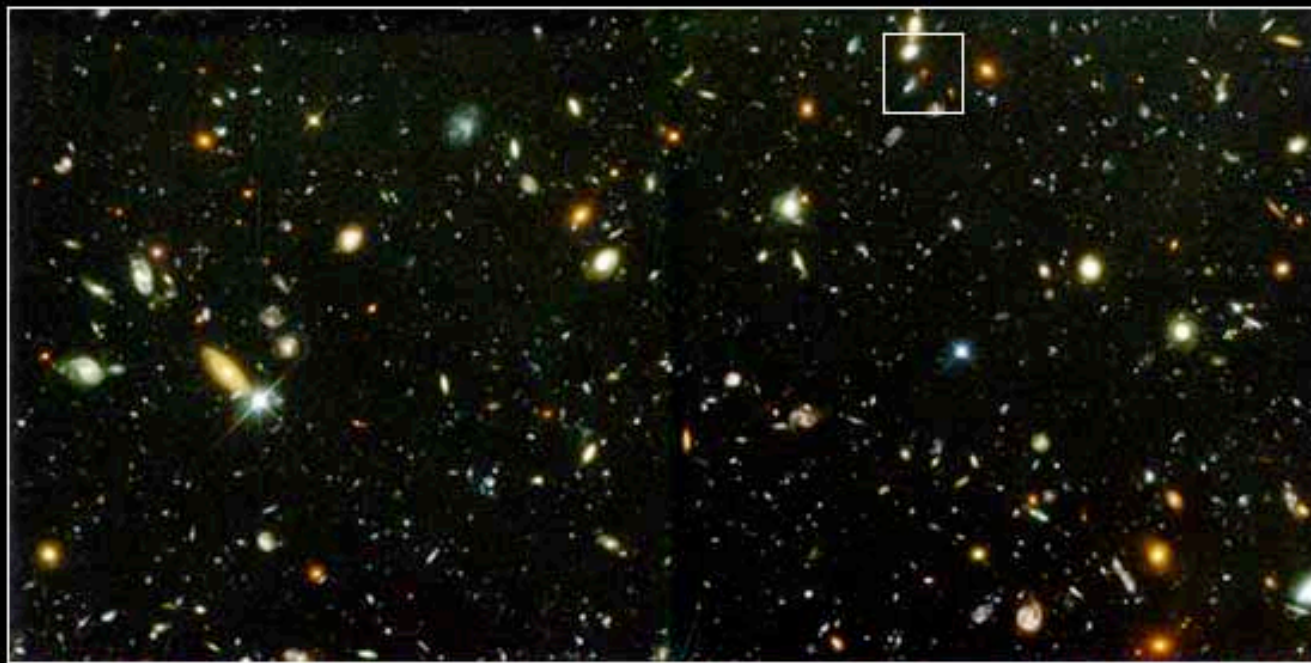


Figure 20-22  
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Difference: 1997-1995

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.

**Distant Supernova in the Hubble Deep Field** HST • WFPC2

NASA and A. Riess (STScI) • STScI-PRC01-09



# 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 half 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!