ASTRONOMY

Chapter 23 THE DEATH OF STARS

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Introduction to

Astronomy

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FORMATION OF A PLANETARY NEBULA ($M < 25\ M_{SUN}$)

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- The high temperature central regions drive the outer part of the star away in a brisk stellar wind, lasting a few thousand years.
- When the process is complete, the remaining core remnant is uncovered and heats the now distant gases and causes them to glow.

RUNNING OUT OF FUEL

A star will shine steadily as long as it can maintain balance between gravity and pressure and between the rates at which energy is generated in its core and released into space at its surface.

Hydrogen fusion in the core can maintain this state of balance as long as the core contains enough hydrogen.

But fusion cannot continue forever.

FIGURE 23.1

Stellar Life Cycle. This remarkable picture of NGC 3603, a nebula in the Milky Way Galaxy, was taken with the Hubble Space Telescope. This image illustrates the life cycle of stars. In the bottom half of the image, we see clouds of dust and gas, where it is likely that star formation will take place in the near future. Near the center, there is a cluster of massive, hot young stars that are only a few million years old. Above and to the right of the cluster, there is an isolated star surrounded by a ring of gas. Perpendicular to the ring and on either side of it, there are two bluish blobs of gas. The ring and the blobs were ejected by the star, which is nearing the end of its life. (credit: modification of work by NASA, Wolfgang Brandner (JPL/IPAC), Eva K. Grebel (University of Washington), You-Hua Chu (University of Illinois Urbana-Champaign))

POST MAIN SEQUENCE LIFE OF THE SUN

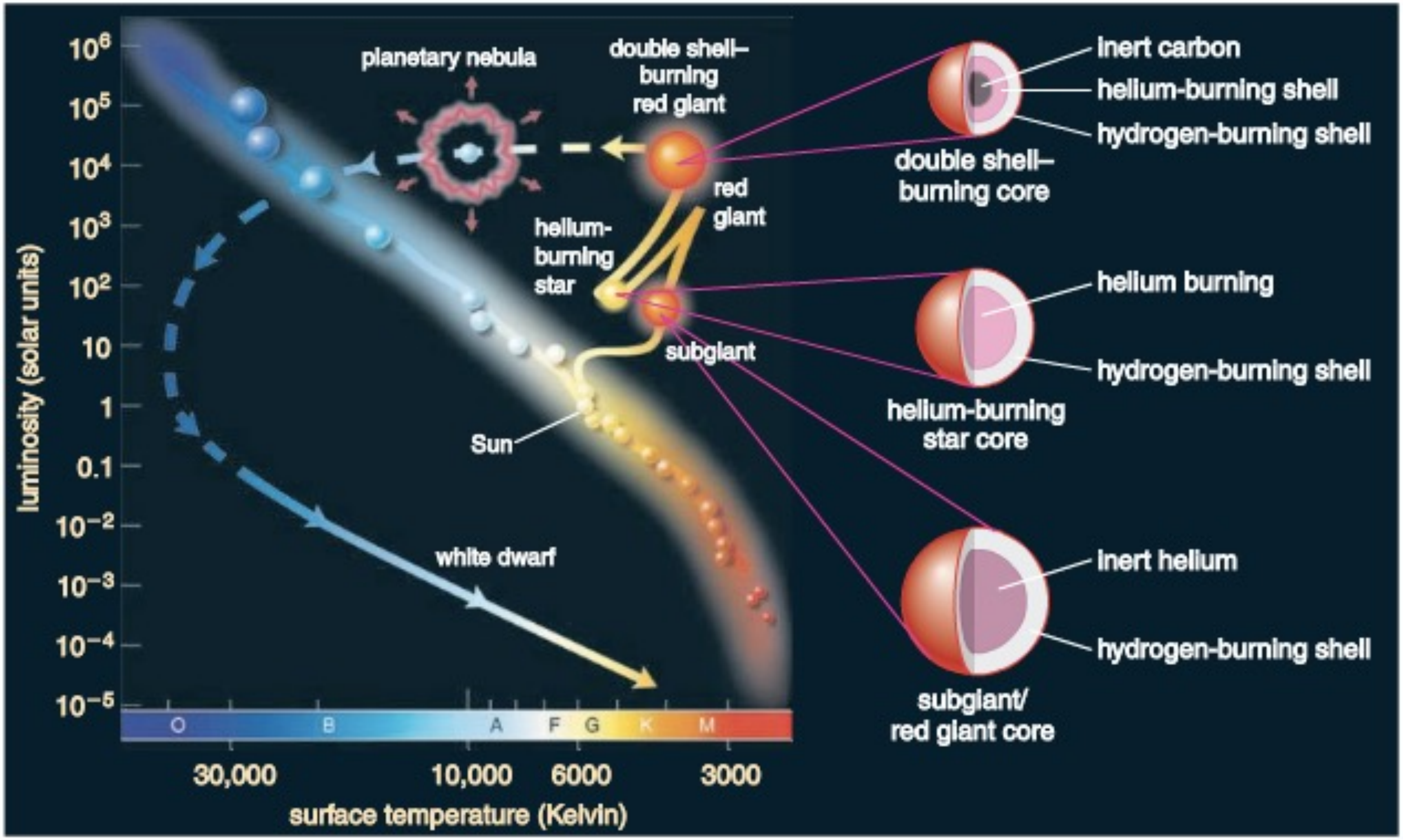

Figure 9.11. Page 151. ***The Cosmic Perspective Fundamentals.***
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HOW DO HIGH-MASS STARS END THEIR LIVES?

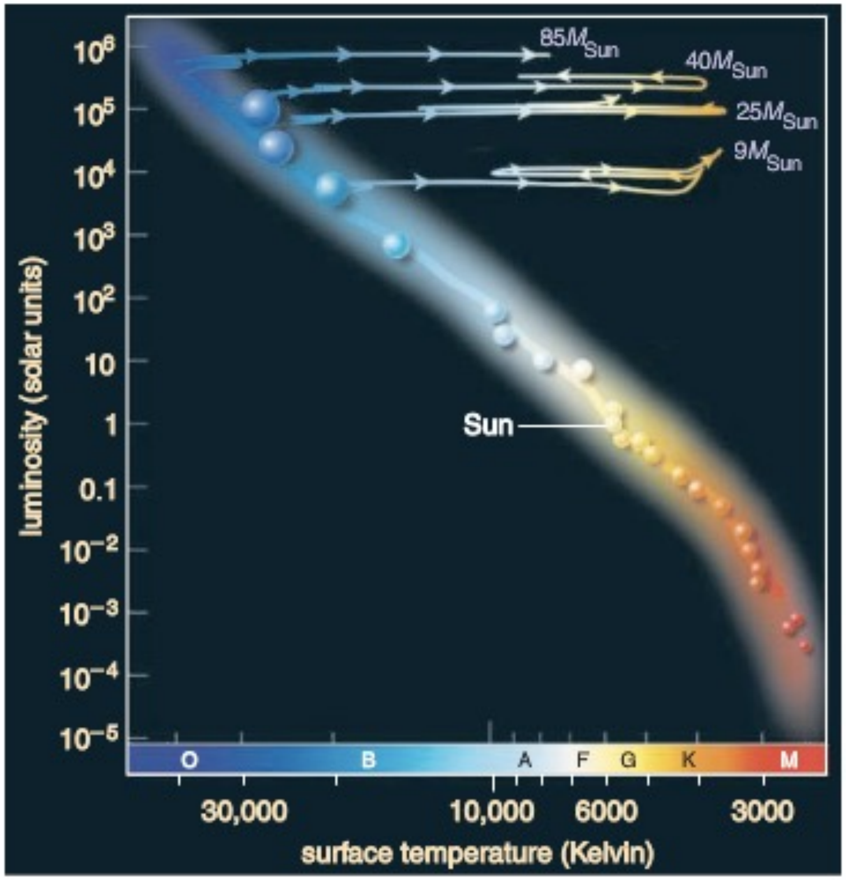

Figure 9.12 | Life tracks on the H-R diagram from main-sequence star to red supergiant for selected high-mass stars. Labels on the tracks give the star's mass at the beginning of its main-sequence life. Because of the strong wind from such a star, its mass can be considerably smaller when it leaves the main sequence. (Based on models from A. Maeder and G. Meynet.)

Figure 9.12. Page 152. ***The Cosmic Perspective Fundamentals*****.**
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FOR EXAMPLE, $M > 25\text{-}M_{SUN}$ STAR

At first, these end stages are very similar to those of a low-mass star like the Sun, except they proceed much more rapidly.

Lasts only a few million years as a hydrogen-burning main-sequence star before it goes out of balance.

As its core hydrogen runs out, a hydrogen-burning shell forms around a shrinking helium core, generating so much energy that the star’s outer layers expand outward until the star becomes a supergiant.

M > 25-M_{SUN} STAR (CONTINUED)

Gravitational contraction of the helium core continues until it becomes hot enough to fuse helium into carbon.

Triple-alpha process: He => C, N, O

The high-mass star fuses helium into carbon (N, O) so rapidly that it is left with an inert carbon core after no more than a few hundred thousand years.

CNO cycle: C, N, O => Fe

M > 25-M_{SUN} STAR (CONTINUED)

After that, the life stages of this 25-solar-mass star become quite different from those of the Sun.

Gravitational contraction simply continues after carbon fusion ends, the inert carbon core shrinks, and the core pressure, temperature, and density all rise.

The shrinking core gets hotter and hotter, and it soon becomes hot enough for carbon fusion.

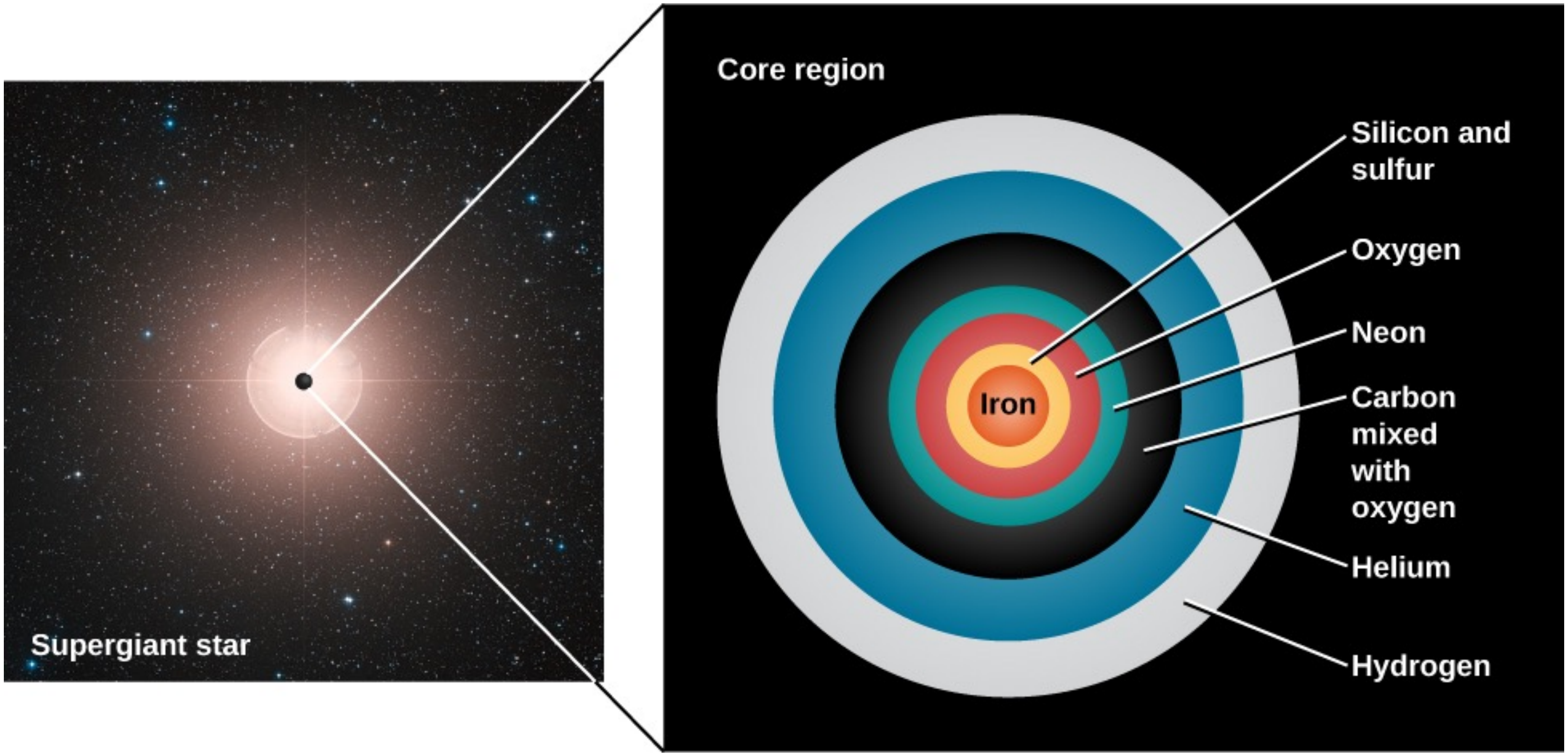
M > 25-M_{SUN} STAR (CONTINUED)

The core and shells go through several more phases of fusion of increasingly heavy elements—producing the “star stuff” that makes our lives possible—while the star’s outer layers continue to swell in size.

Despite the dramatic events taking place in its interior, the high-mass star’s outer appearance changes slowly. As each stage of core fusion ceases, the surrounding shell burning intensifies and further inflates the star’s outer layers.

Each time the core flares up, the outer layers contract somewhat, but the star’s overall luminosity remains about the same. The result is that the star’s life track zigzags across the top of the H-R diagram.

FIGURE 23.6



Structure of an Old Massive Star. Just before its final gravitational collapse, the core of a massive star resembles an onion. The iron core is surrounded by layers of silicon and sulfur, oxygen, neon, carbon mixed with some oxygen, helium, and finally hydrogen. Outside the core, the composition is mainly hydrogen and helium. (Note that this diagram is not precisely to scale but is just meant to convey the general idea of what such a star would be like.) (credit: modification of work by ESO, Digitized Sky Survey)

THE MASS PER NUCLEAR PARTICLE

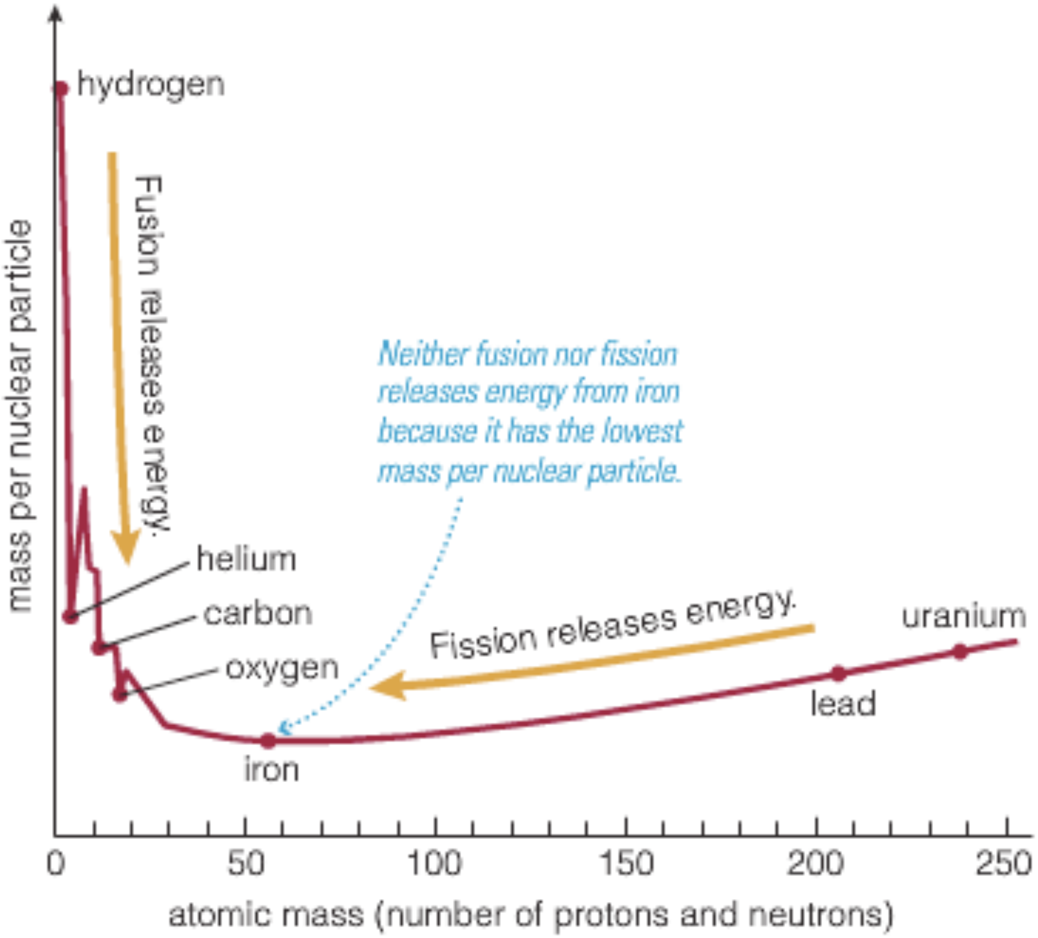


Figure 9.15. Page 153. ***The Cosmic Perspective Fundamentals*.**
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THE MASS PER NUCLEAR PARTICLE

The mass per nuclear particle tends to decrease as we go from light elements to iron, which means that fusion of light nuclei into heavier nuclei generates energy.

This trend reverses beyond iron:

The mass per nuclear particle tends to increase as we look to still heavier elements.

As a result, elements heavier than iron can generate nuclear energy only through fission into lighter elements.

Iron has the lowest mass per nuclear particle of all nuclei and therefore cannot release energy by either fusion or fission.

THE SUPERNOVA EXPLOSION

Degeneracy pressure cannot support the inert iron core because the immense gravity of a high-mass star pushes electrons past their quantum mechanical limit.

Once they get too close together, they can no longer exist freely.

<u>In an instant, the electrons disappear by combining with protons to form neutrons, releasing the tiny subatomic particles known as neutrinos in the process.</u>

THE SUPERNOVA EXPLOSION

In a fraction of a second, an iron core with a mass comparable to that of our Sun and a size larger than that of Earth collapses into a ball of neutrons just a few kilometers across, making the type of stellar corpse that we call a neutron star.

THE SUPERNOVA EXPLOSION

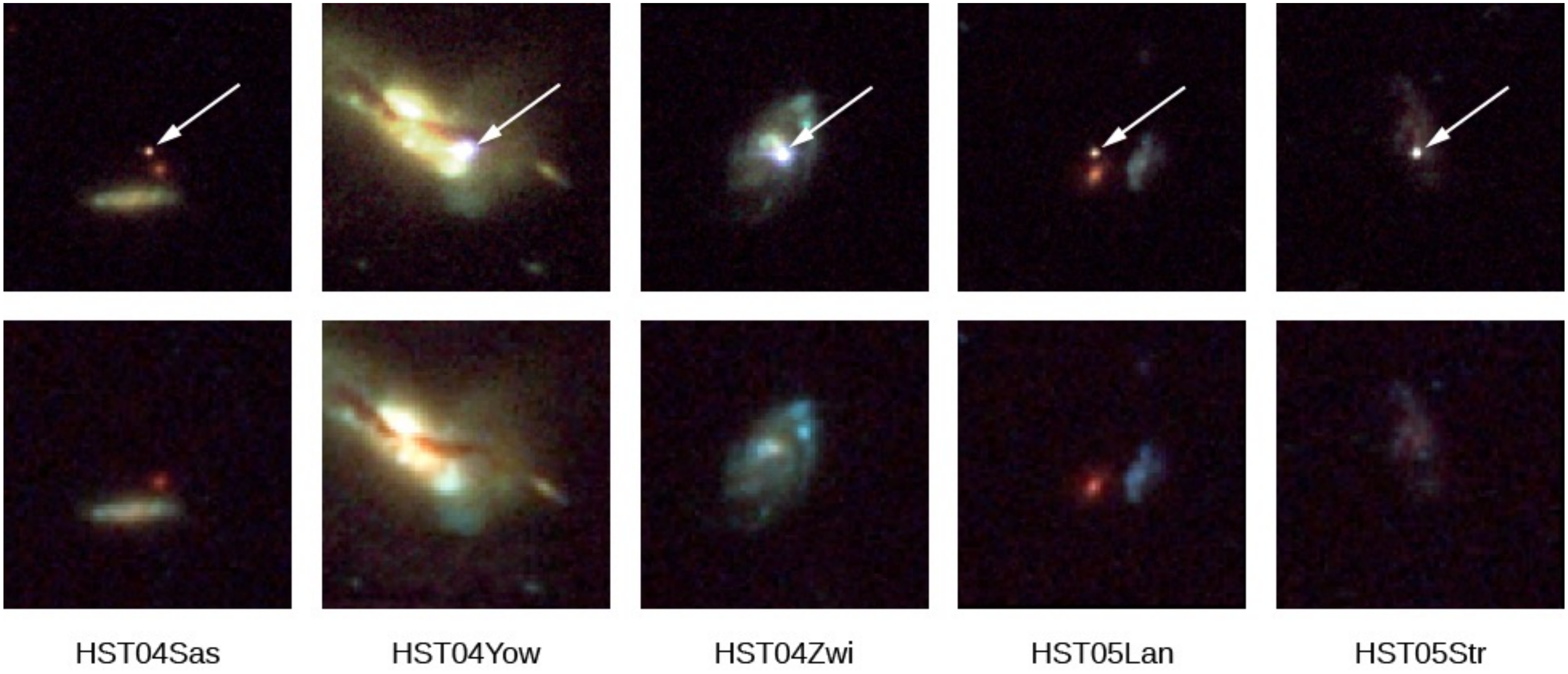
The collapse halts only because the neutrons have a degeneracy pressure of their own. In some cases, the remaining core may be massive enough that gravity also overcomes the degeneracy pressure of the neutrons, in which case the core continues to collapse until it becomes a **black hole.**

THE SUPERNOVA EXPLOSION

The gravitational collapse of the core releases an enormous amount of energy—more than a hundred times what the Sun will radiate over its entire 10-billion-year lifetime.

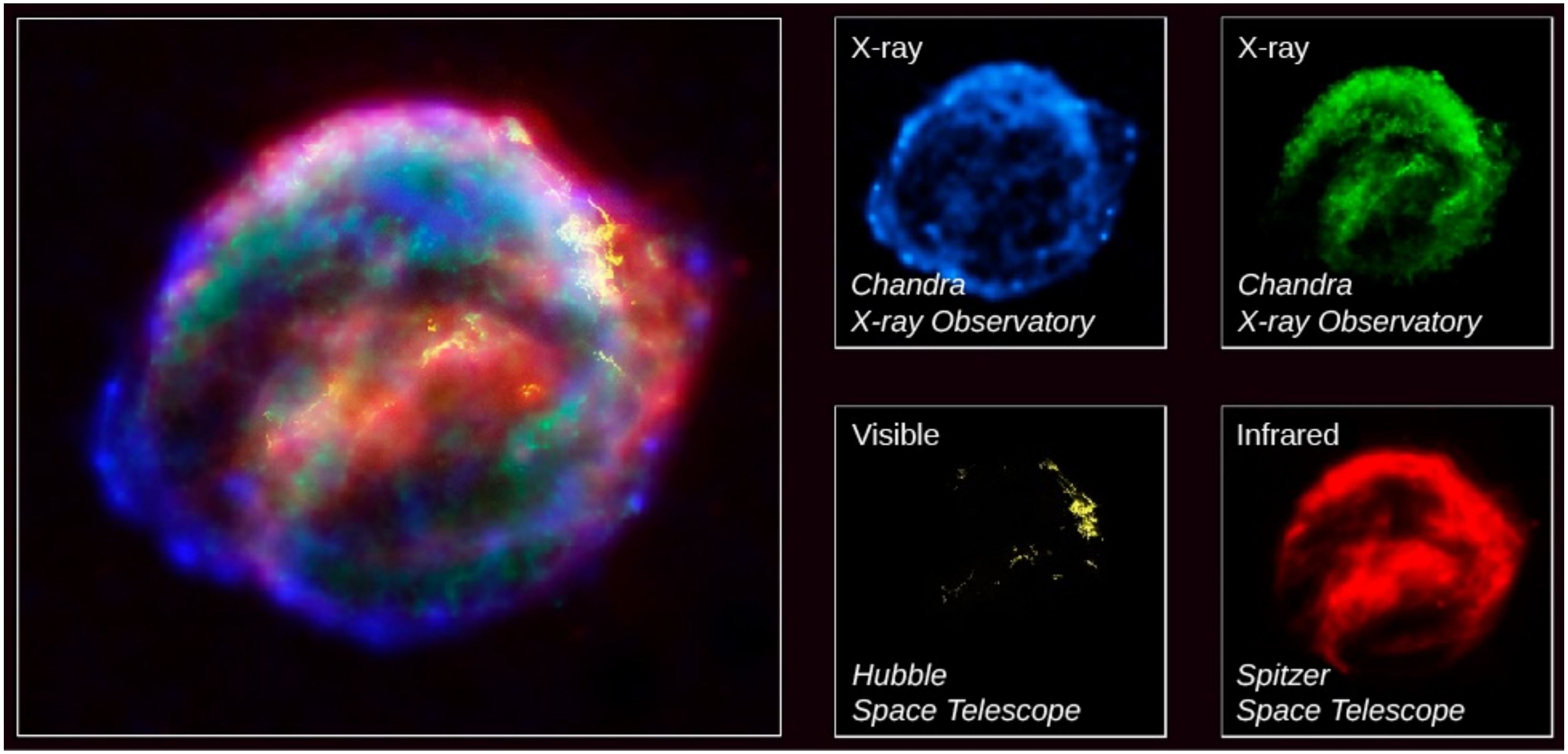
This energy drives the outer layers of the star off into space in a titanic explosion called a supernova.

FIGURE 23.7



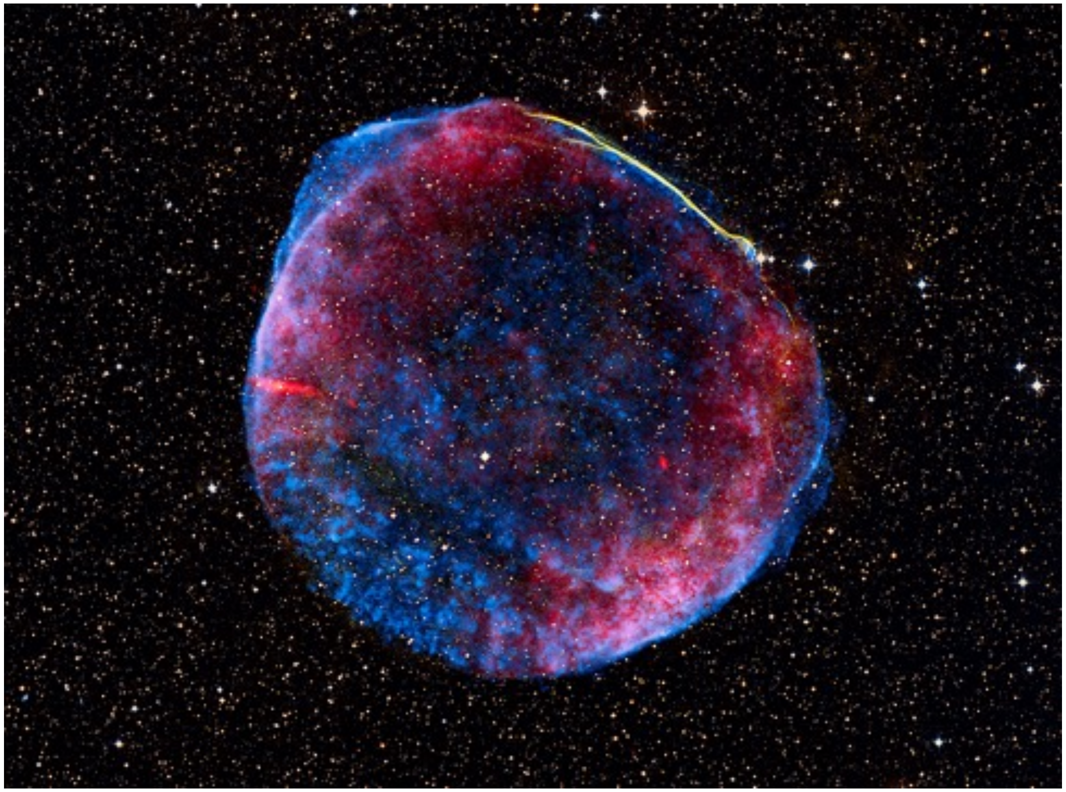
Five Supernova Explosions in Other Galaxies. The arrows in the top row of images point to the supernovae. The bottom row shows the host galaxies before or after the stars exploded. Each of these supernovae exploded between 3.5 and 10 billion years ago. Note that the supernovae when they first explode can be as bright as an entire galaxy. (credit: modification of work by NASA, ESA, and A. Riess (STScI))

FIGURE 23.8



Kepler Supernova Remant. This image shows the expanding remains of a supernova explosion, which was first seen about 400 years ago by sky watchers, including the famous astronomer Johannes Kepler. The bubble-shaped shroud of gas and dust is now 14 light-years wide and is expanding at 2,000 kilometers per second (4 million miles per hour). The remnant emits energy at wavelengths from X-rays (shown in blue and green) to visible light (yellow) and into the infrared (red). The expanding shell is rich in iron, which was produced in the star that exploded. The main image combines the individual single-color images seen at the bottom into one multi-wavelength picture. (credit: modification of work by NASA, ESA, R. Sankrit and W. Blair (Johns Hopkins University))

FIGURE 23.9

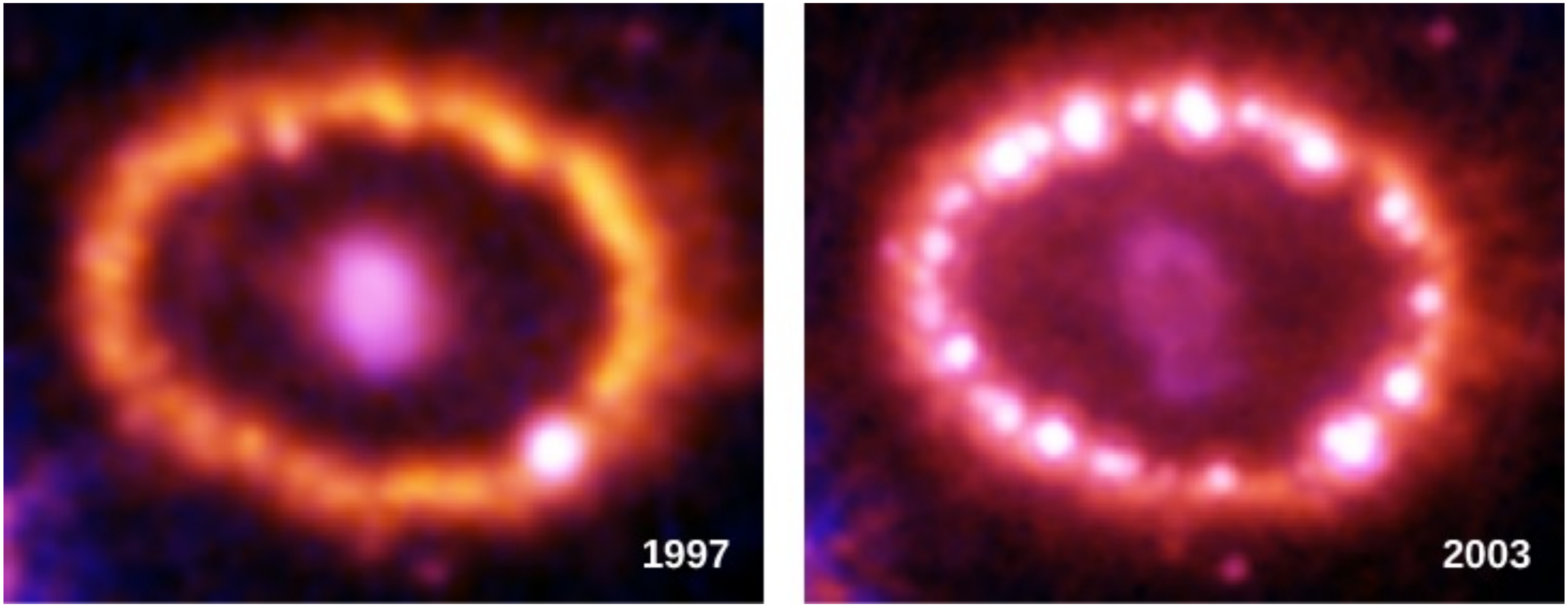


Supernova 1006 Remnant. This composite view of SN 1006 from the Chandra X-Ray Observatory shows the X-rays coming from the remnant in blue, visible light in white-yellow, and radio emission in red. (credit: modification of work by NASA, ESA, Zolt Levay(STScI))

FIGURE 23.11

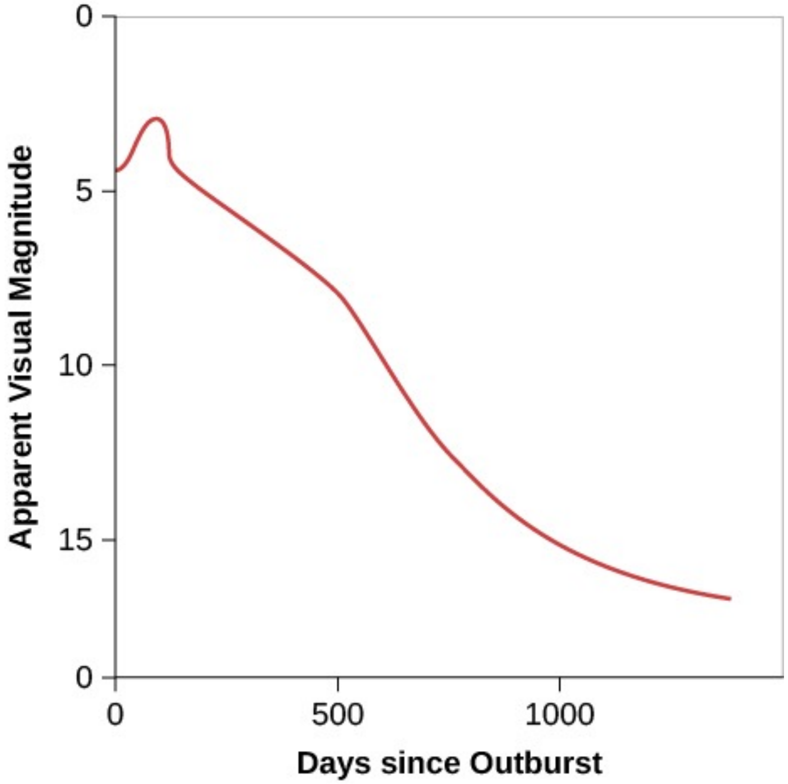
Hubble Space Telescope Image of SN 1987A. The supernova remnant with its inner and outer red rings of material is located in the Large Magellanic Cloud. This image is a composite of several images taken in 1994, 1996, and 1997—about a decade after supernova 1987A was first observed. (credit: modification of work by the Hubble Heritage Team (AURA/STScI/NASA/ESA))

FIGURE 23.12



Ring around Supernova 1987A. These two images show a ring of gas expelled about 30,000 years ago when the star that exploded in 1987 was a red giant. The supernova, which has been artificially dimmed, is located at the center of the ring. The left-hand image was taken in 1997 and the right-hand image in 2003. Note that the number of bright spots has increased from 1 to more than 15 over this time interval. These spots occur where high-speed gas ejected by the supernova and moving at millions of miles per hour has reached the ring and blasted into it. The collision has heated the gas in the ring and caused it to glow more brightly. The fact that we see individual spots suggests that material ejected by the supernova is first hitting narrow, inward-projecting columns of gas in the clumpy ring. The hot spots are the first signs of a dramatic and violent collision between the new and old material that will continue over the next few years. By studying these bright spots, astronomers can determine the composition of the ring and hence learn about the nuclear processes that build heavy elements inside massive stars. (credit: modification of work by NASA, P. Challis, R. Kirshner (Harvard-Smithsonian Center for Astrophysics) and B. Sugerman (STScI))

FIGURE 23.13

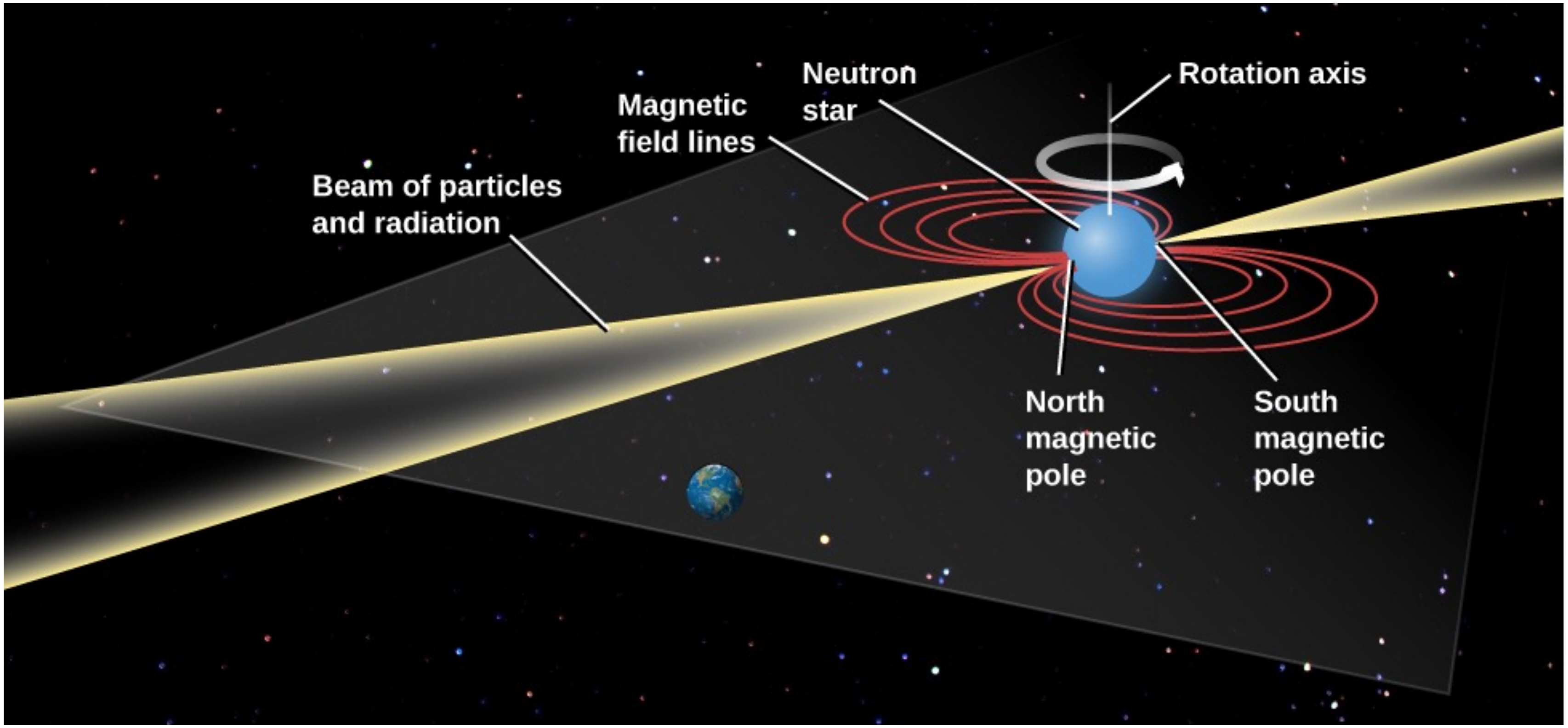


Change in the Brightness of SN 1987A over Time. Note how the rate of decline of the supernova’s light slowed between days 40 and 500. During this time, the brightness was mainly due to the energy emitted by newly formed (and quickly decaying) radioactive elements. Remember that magnitudes are a backward measure of brightness: the larger the magnitude, the dimmer the object looks.

FIGURE 23.14: NEUTRON STAR PULSAR

Crab Nebula. This image shows X-ray emmisions from the Crab Nebula, which is about 6500 light-years away. The pulsar is the bright spot at the center of the concentric rings. Data taken over about a year show that particles stream away from the inner ring at about half the speed of light. The jet that is perpendicular to this ring is a stream of matter and antimatter electrons also moving at half the speed of light. (credit: modification of work by NASA/CXC/SAO)

FIGURE 23.16

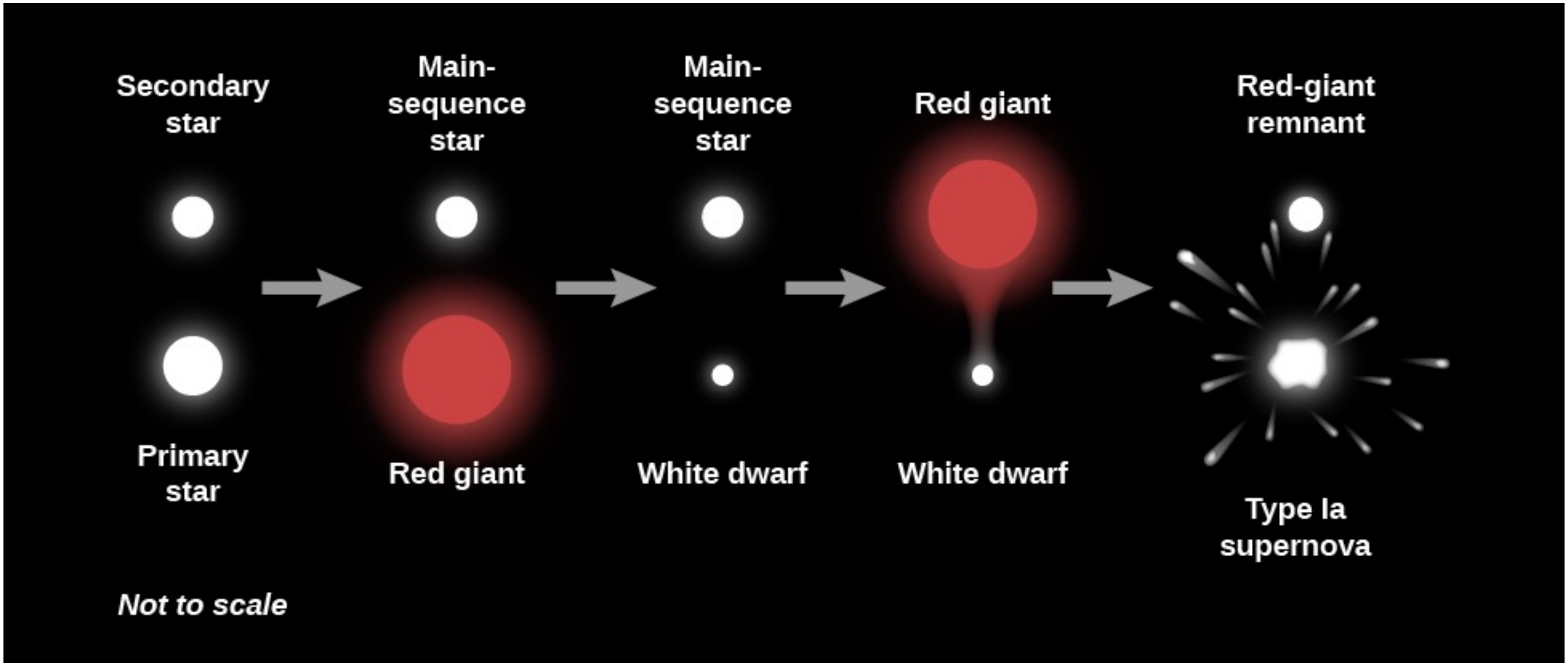


Model of a Pulsar. A diagram showing how beams of radiation at the magnetic poles of a neutron star can give rise to pulses of emission as the star rotates. As each beam sweeps over Earth, like a lighthouse beam sweeping over a distant ship, we see a short pulse of radiation. This model requires that the magnetic poles be located in different places from the rotation poles. (credit "stars": modification of work by Tony Hisgett)

FIGURE 23.17

Speeding Pulsar. This intriguing image (which combines X-ray, visible, and radio observations) shows the jet trailing behind a pulsar (at bottom right, lined up between the two bright stars). With a length of 37 light-years, the jet trail (seen in purple) is the longest ever observed from an object in the Milky Way. (There is also a mysterious shorter, comet-like tail that is almost perpendicular to the purple jet.) Moving at a speed between 2.5 and 5 million miles per hour, the pulsar is traveling away from the core of the supernova remnant where it originated. (credit: X-ray: NASA/CXC/ISDC/L.Pavan et al, Radio: CSIRO/ATNF/ATCA Optical: 2MASS/UMass/IPAC-Caltech/NASA/NSF)

FIGURE 23.18



Evolution of a Binary System. The more massive star evolves first to become a red giant and then a white dwarf. The white dwarf then begins to attract material from its companion, which in turn evolves to become a red giant. Eventually, the white dwarf acquires so much mass that it is pushed over the Chandrasekhar limit and becomes a type Ia supernova.

STAR STUFF

The high-mass star has died, but the variety of elements produced in the star’s nuclear furnace are now scattered throughout the gas clouds of interstellar space.

Millions or billions of years later, a new round of star formation may incorporate this supernova debris into a new generation of stars.

Some of the heavy elements that came from this supernova will become the building blocks of new planets—and perhaps even new life forms—around those newborn stars.

The building blocks of Earth and of our bodies came from supernovae in the distant past.

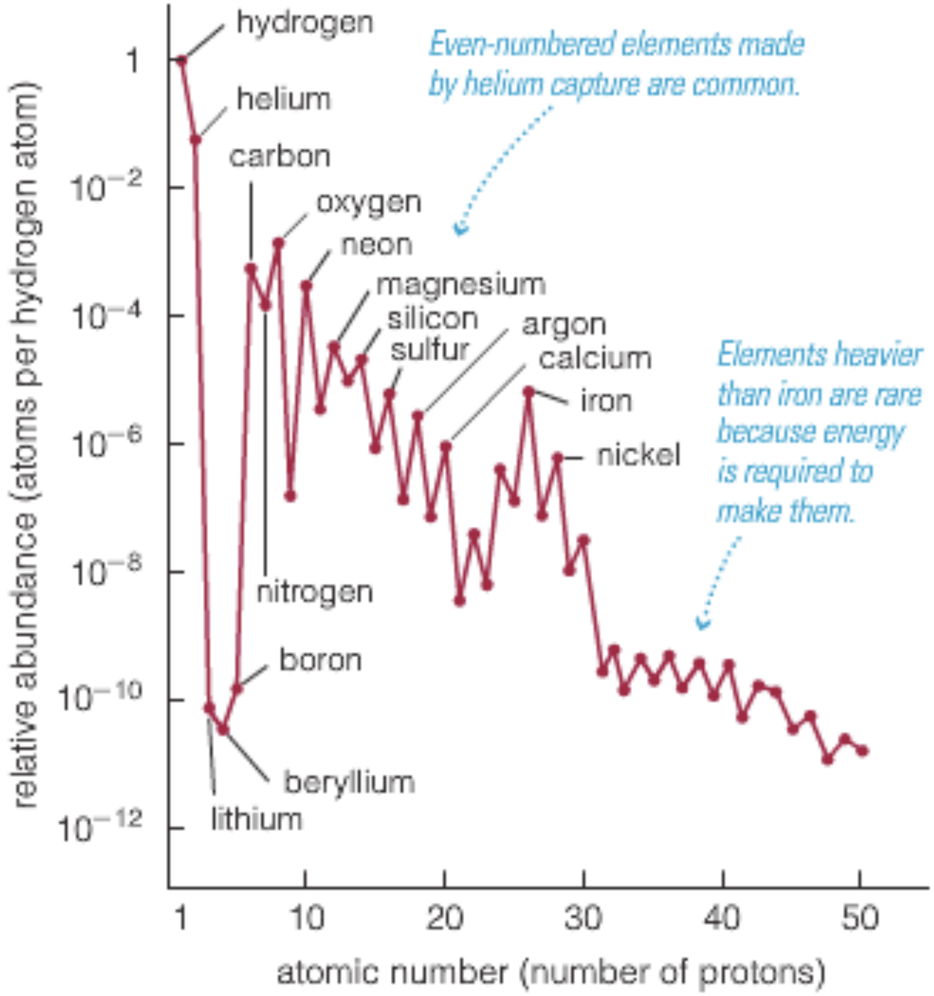


Figure 9.18. Page 155. ***The Cosmic Perspective Fundamentals*.**
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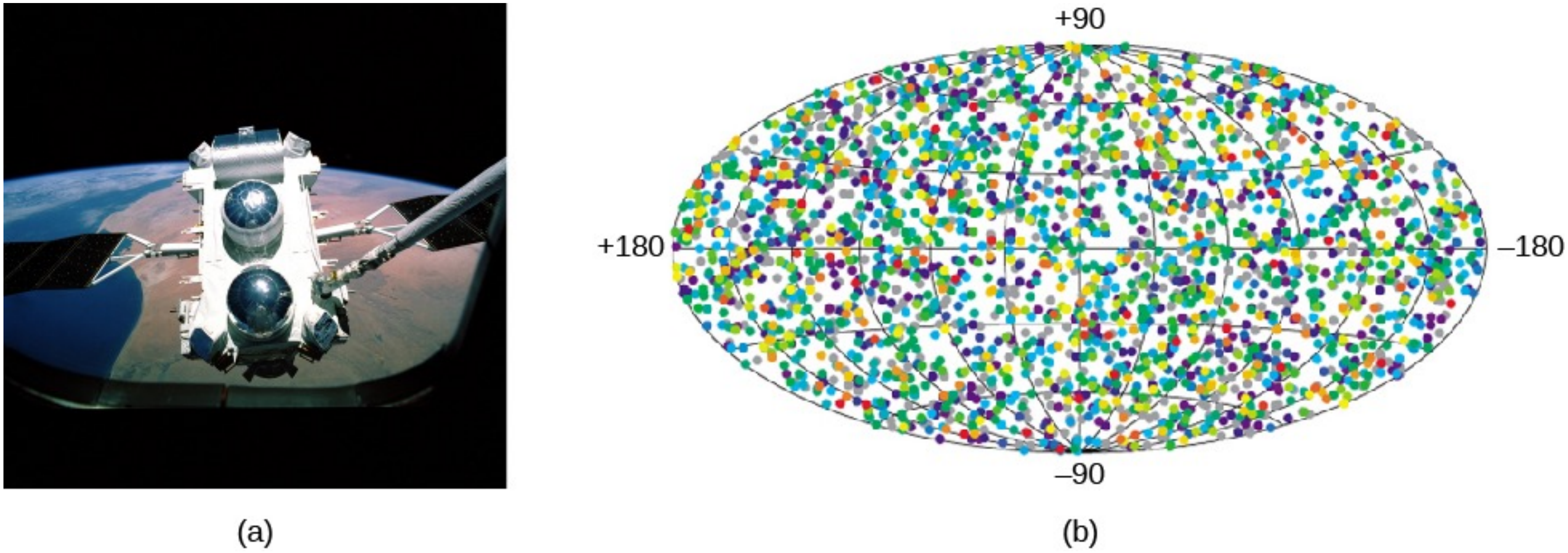
FIGURE 23.19

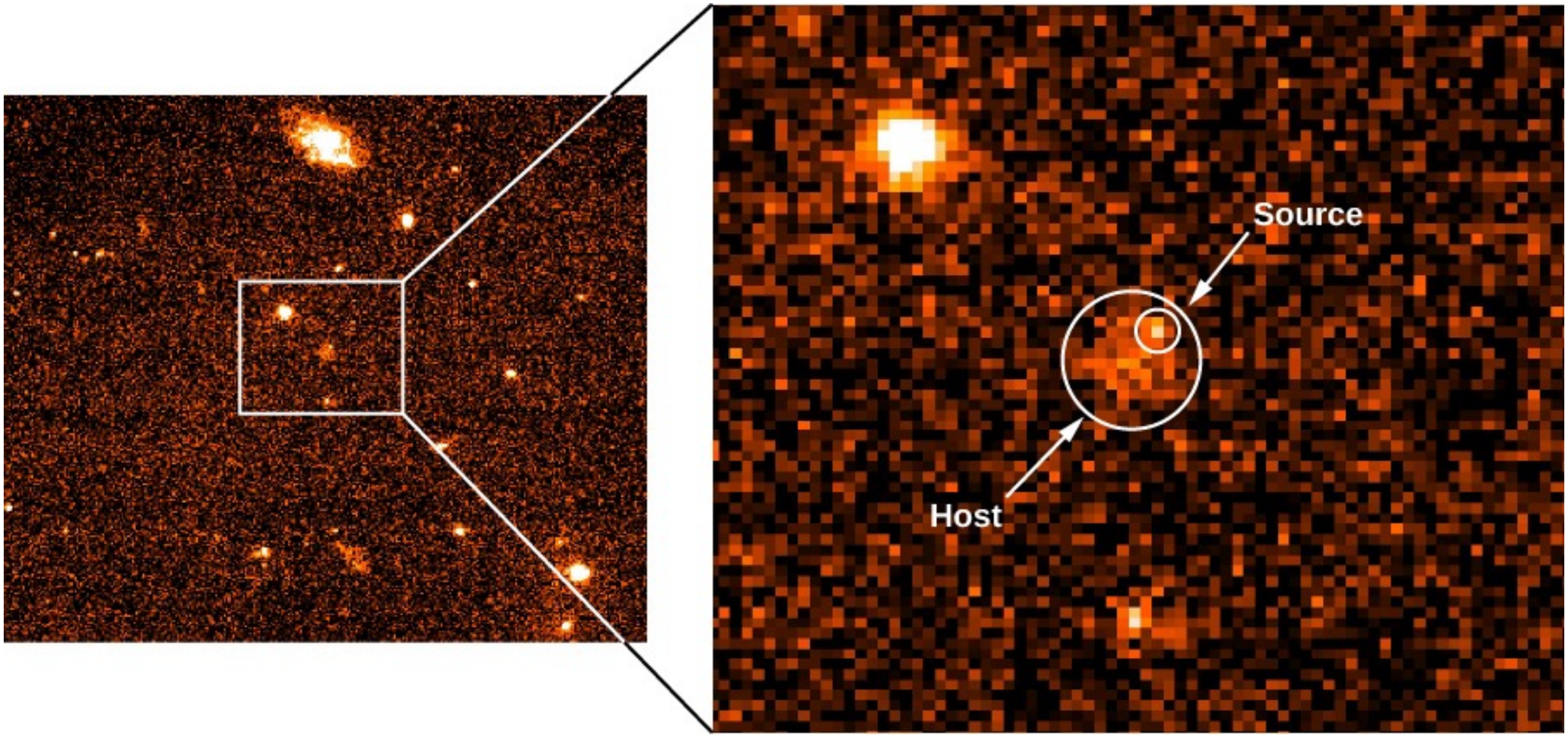


Compton Detects Gamma-Ray Bursts.

(a) In 1991, the Compton Gamma-Ray Observatory was deployed by the Space Shuttle Atlantis. Weighing more than 16 tons, it was one of the largest scientific payloads ever launched into space.

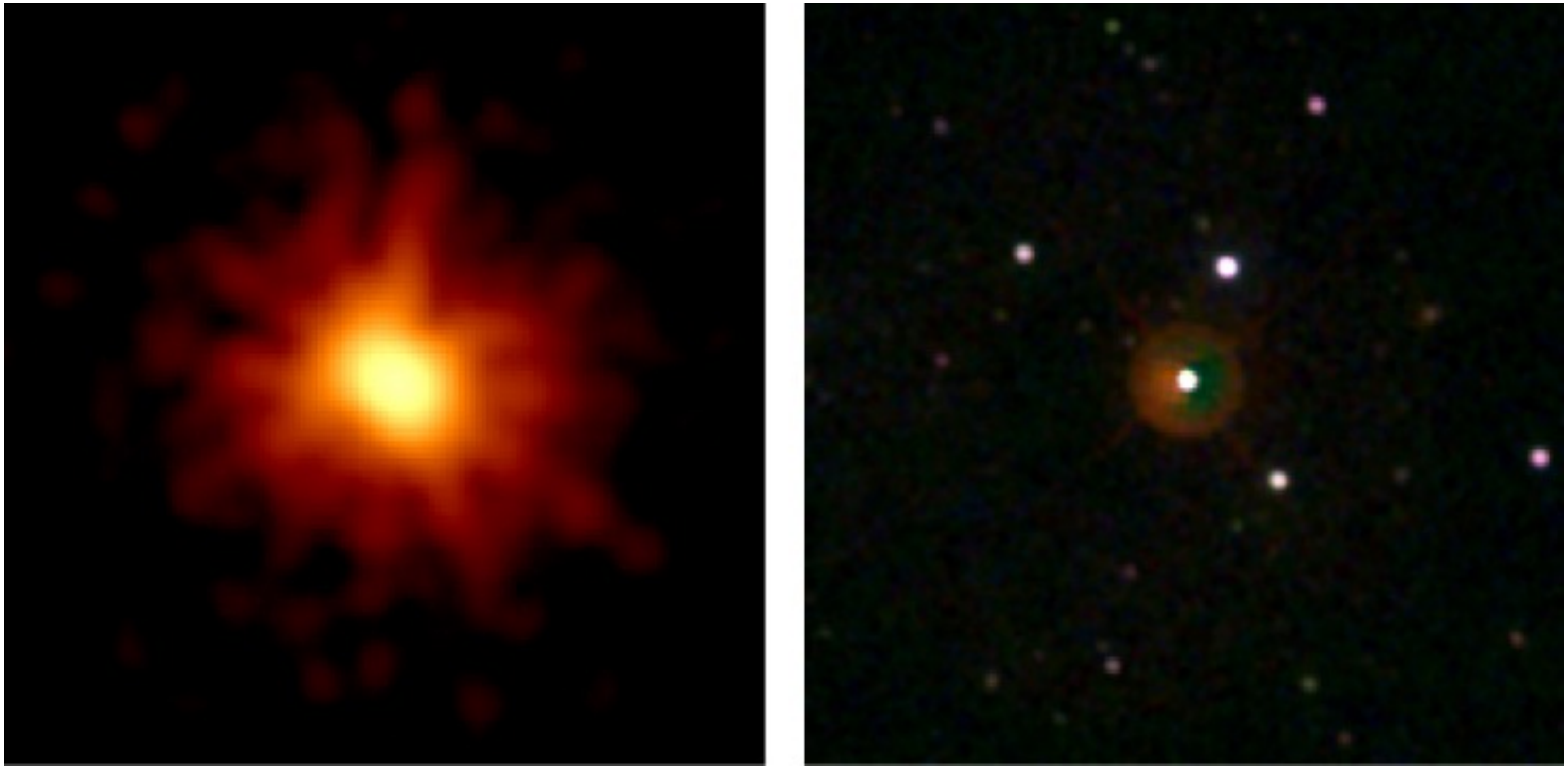
(b) This map of gamma-ray burst positions measured by the Compton Gamma-Ray Observatory shows the isotropic (same in all directions), uniform distribution of bursts on the sky. The map is oriented so that the disk of the Milky Way would stretch across the center line (or equator) of the oval. Note that the bursts show no preference at all for the plane of the Milky Way, as many other types of objects in the sky do. Colors indicate the total energy in the burst: red dots indicate long-duration, bright bursts; blue and purple dots show short, weaker bursts. (credit a: modification of work by NASA; credit b: modification of work by NASA/GSFC)

FIGURE 23.20



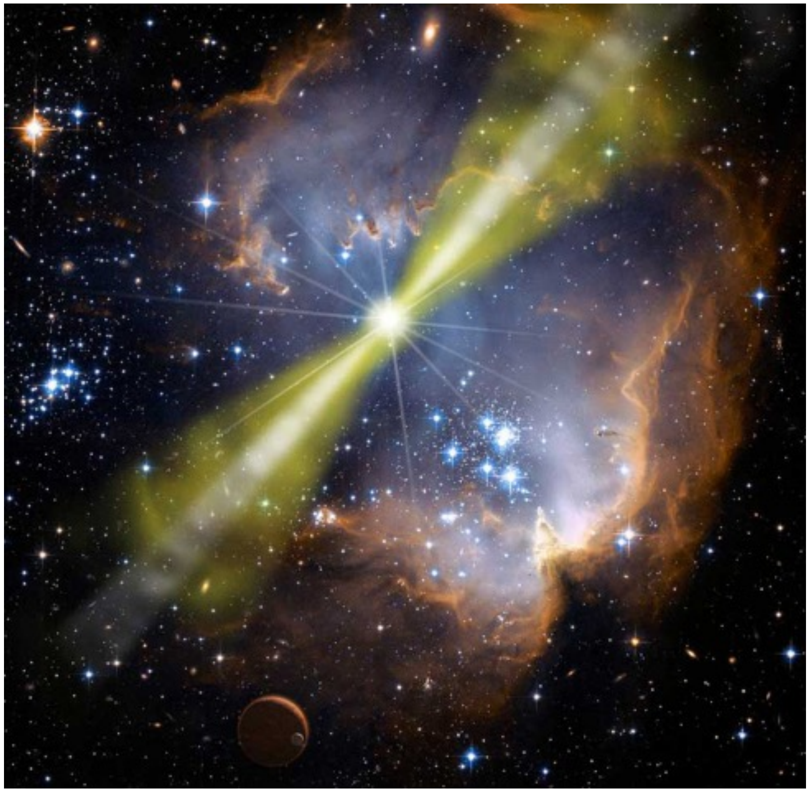
Gamma-Ray Burst. This false-color Hubble Space Telescope image, taken in September 1997, shows the fading afterglow of the gamma-ray burst of February 28, 1997 and the host galaxy in which the burst originated. The left view shows the region of the burst. The enlargement shows the burst source and what appears to be its host galaxy. Note that the gamma-ray source is not in the center of the galaxy. (credit: modification of work by Andrew Fruchter (STScI), Elena Pian (ITSRE-CNR), and NASA, ESA)

FIGURE 23.21



Gamma-Ray Burst Observed in March 2008. The extremely luminous afterglow of GRB 080319B was imaged by the Swift Observatory in X-rays (left) and visible light/ultraviolet (right). (credit: modification of work by NASA/Swift/Stefan Immler, et al.)

FIGURE 23.22



Burst That Is Beamed. This artist’s conception shows an illustration of one kind of gamma-ray burst. The collapse of the core of a massive star into a black hole has produced two bright beams of light originating from the star’s poles, which an observer pointed along one of these axes would see as a gamma-ray burst. The hot blue stars and gas clouds in the vicinity are meant to show that the event happened in an active star-forming region. (credit: NASA/Swift/Mary Pat Hrybyk-Keith and John Jones)

HOW SURE ARE WE OF OUR STELLAR MODELS?

You might be wondering how scientists can be so confident in their models of the Sun and other stars.

After all, the lives of stars are so much longer than human lifetimes that all our observations of stars amount to only very brief snapshots of their lives.

OBSERVATIONS OF STAR CLUSTERS

- Two key reasons why clusters are important:

1 . All the stars in a cluster lie at about the same distance from Earth, meaning that the apparent brightness of each star directly tells how its luminosity compares with that of other stars in the cluster.

2 . All the stars in a cluster formed at about the same time, from the same large molecular cloud, meaning that they are all now about the same age.

STAR CLUSTERS COME IN TWO BASIC TYPES

Modest-size open clusters and densely packed globular clusters.

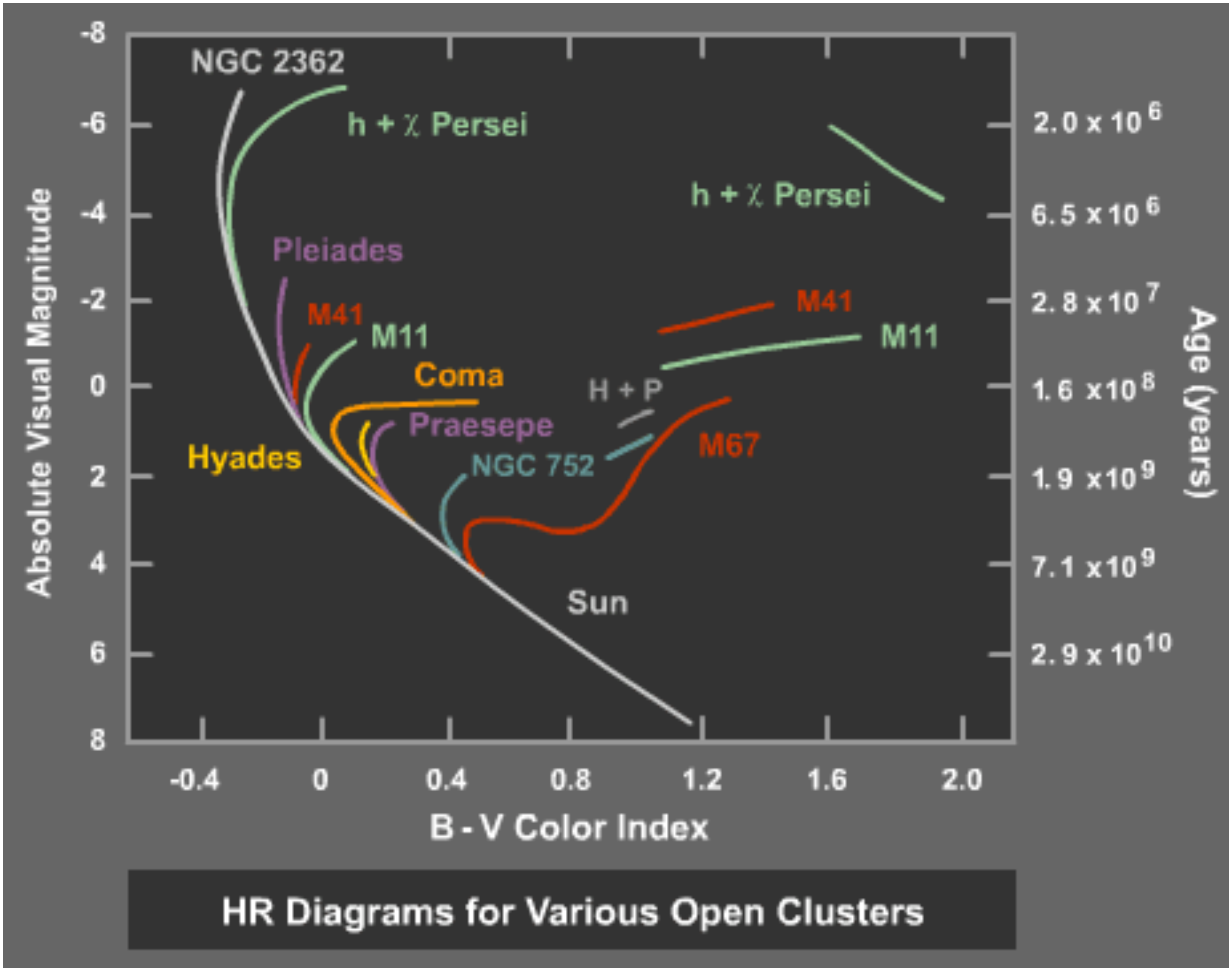
The two types differ not only in how densely they are packed with stars but also in age.

Open clusters, such as the Pleiades, typically contain a few hundred to a few thousand relatively young stars in a region about 30 light-years across.

STELLAR CLUSTERS

The Pleiades cluster. Credit: *D. Malin/AAO*

http://outreach.atnf.csiro.au/education/senior/astrophysics/stellarevolution_clusters.html



Credit: *Mike Guidry*, ***University of Tennessee***

http://outreach.atnf.csiro.au/education/senior/astrophysics/stellarevolution_clusters.html

GLOBULAR CLUSTERS

Globular clusters are much more densely packed and contain some of the oldest stars in the universe.

A globular cluster can contain more than a million stars in a ball-shaped region no more than about 150 light-years across. Its center may have 10,000 stars packed into a space just a few light-years across

A GLOBULAR CLUSTER

The globular cluster 47 Tuc.

Credit ***NASA and Ron Gilliland (STScI)and David Malin AAO***

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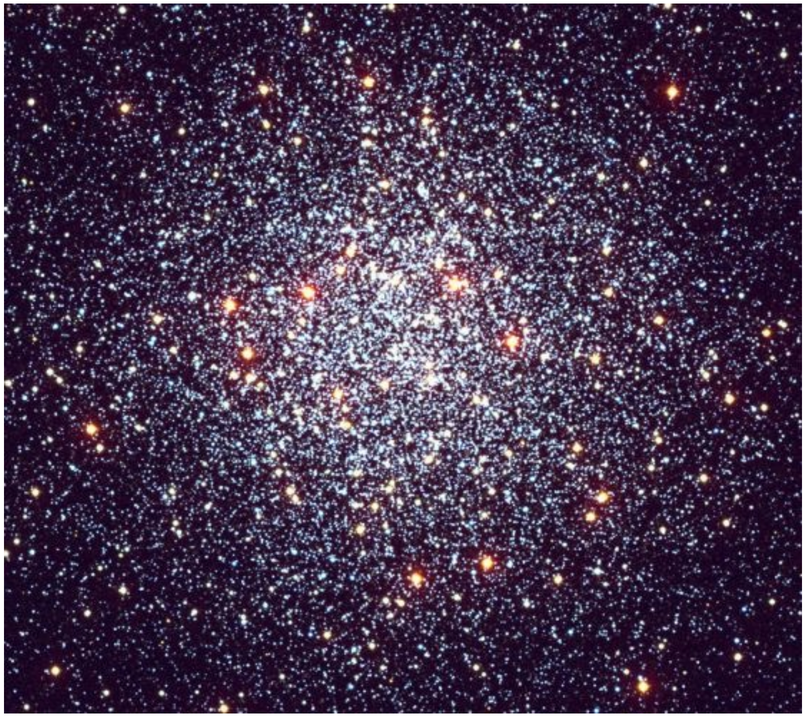
M55: A GLOBULAR STAR CLUSTER



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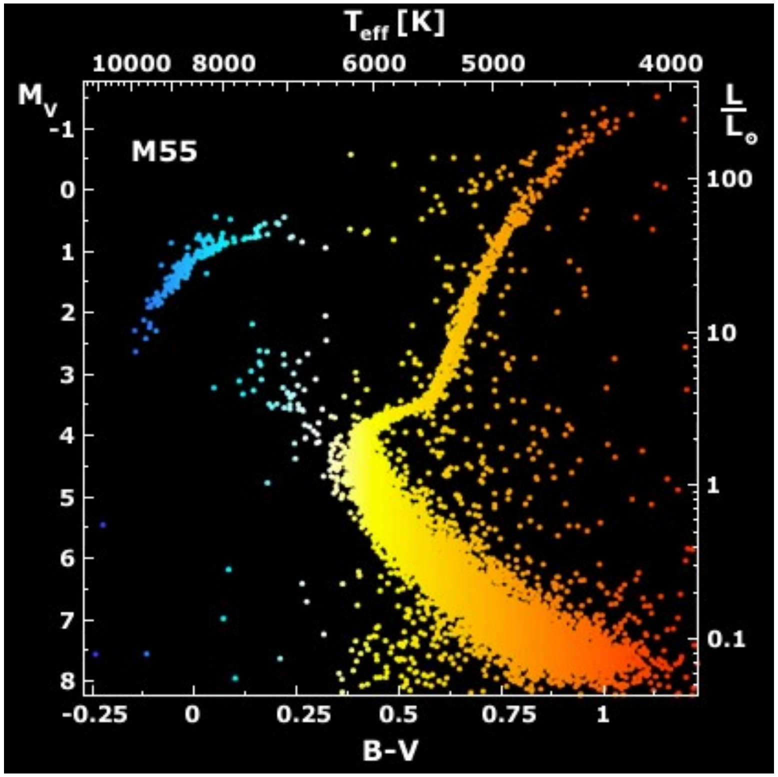

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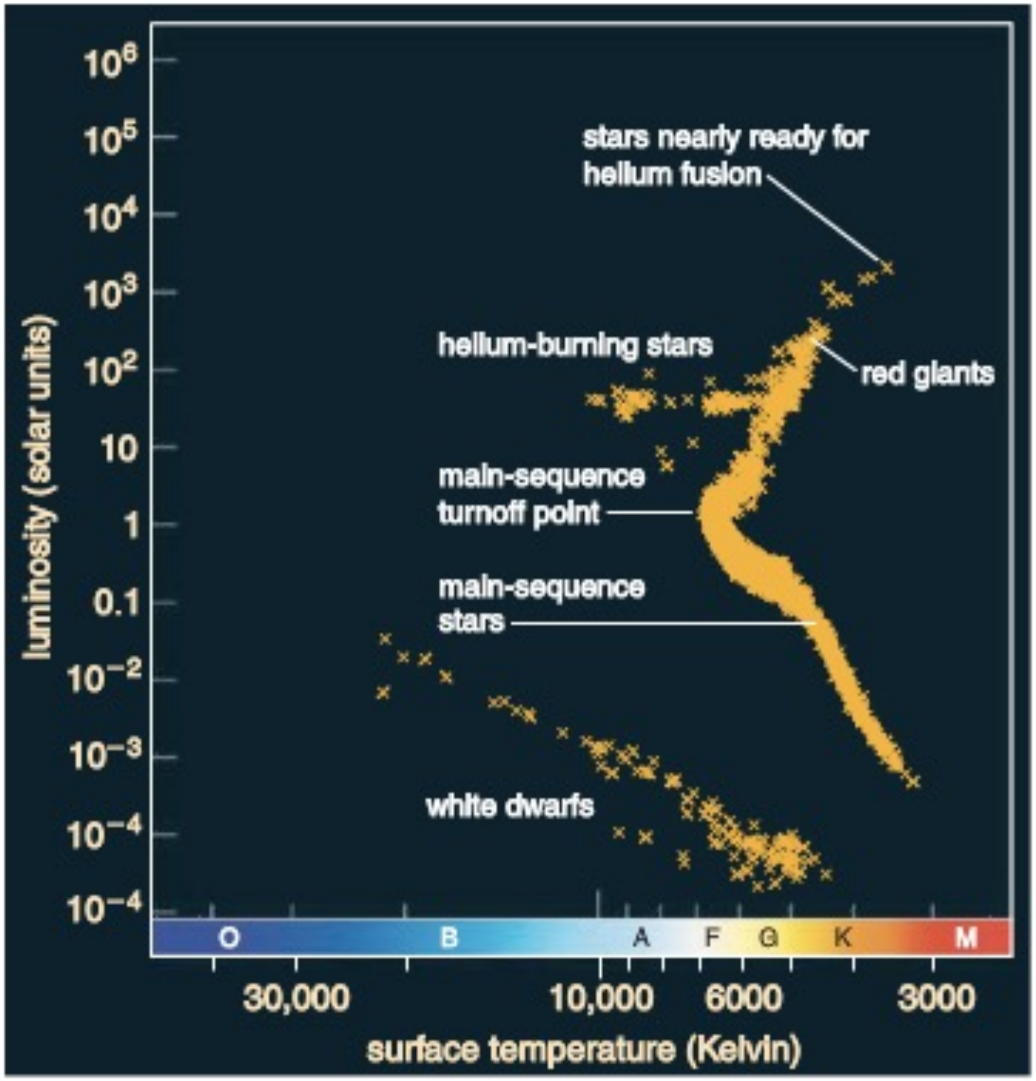

Figure 9.23 | This H-R diagram shows stars from the globular cluster M4, with an age of around 13 billion years.

Figure 9.23. Page 157. ***The Cosmic Perspective Fundamentals.***
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