

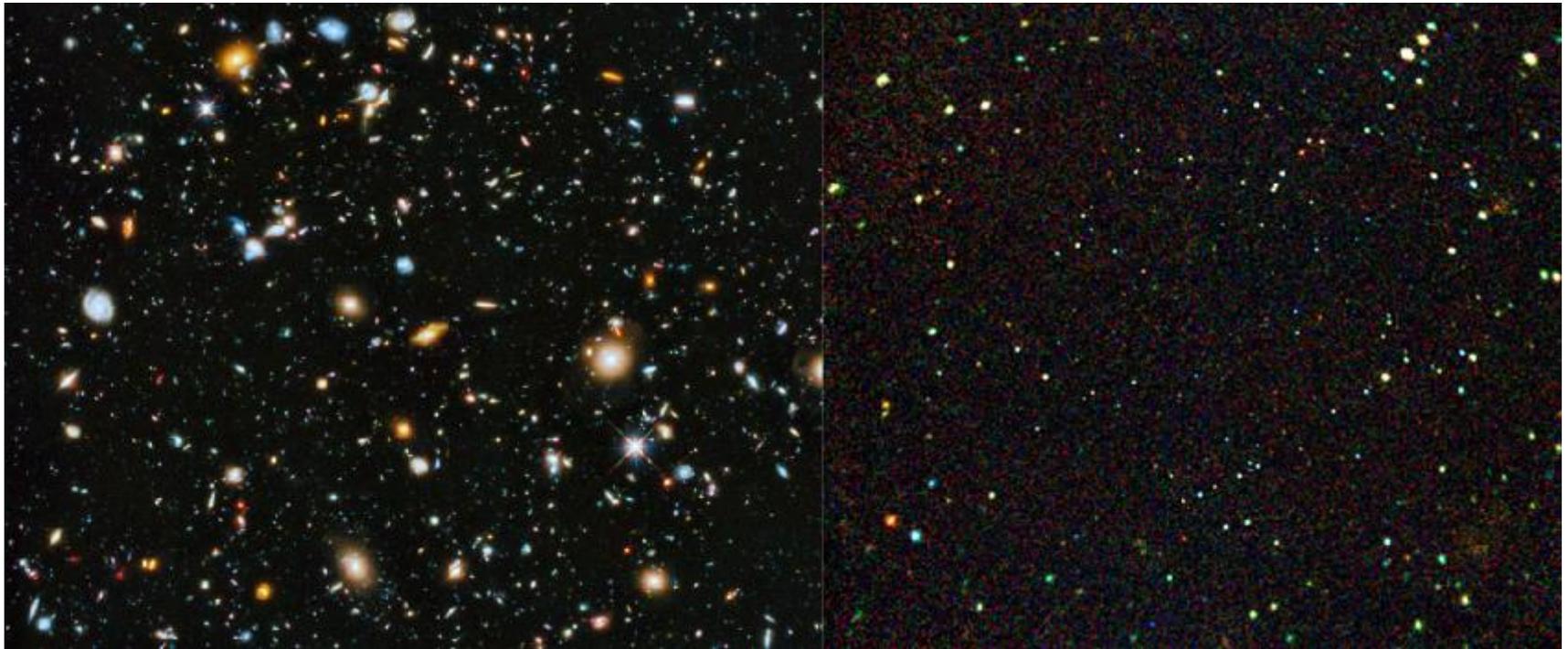
ASTRONOMY

Chapter 27 ACTIVE GALAXIES, QUASARS, AND SUPERMASSIVE BLACK HOLES

PowerPoint Image Slideshow



FIGURE 27.1



Hubble Ultra-Deep Field. The deepest picture of the sky in visible light (left) shows huge numbers of galaxies in a tiny patch of sky, only 1/100 the area of the full Moon. In contrast, the deepest picture of the sky taken in X-rays (right) shows large numbers of point-like quasars, which astronomers have shown are supermassive black holes at the very centers of galaxies. (credit left: modification of work by NASA, ESA, H. Teplitz and M. Rafelski (IPAC/Caltech), A. Koekemoer (STScI), R. Windhorst (Arizona State University), and Z. Levay (STScI); credit right: modification of work by ESO/Mario Nonino, Piero Rosati, ESO GOODS Team)

FIGURE 27.2

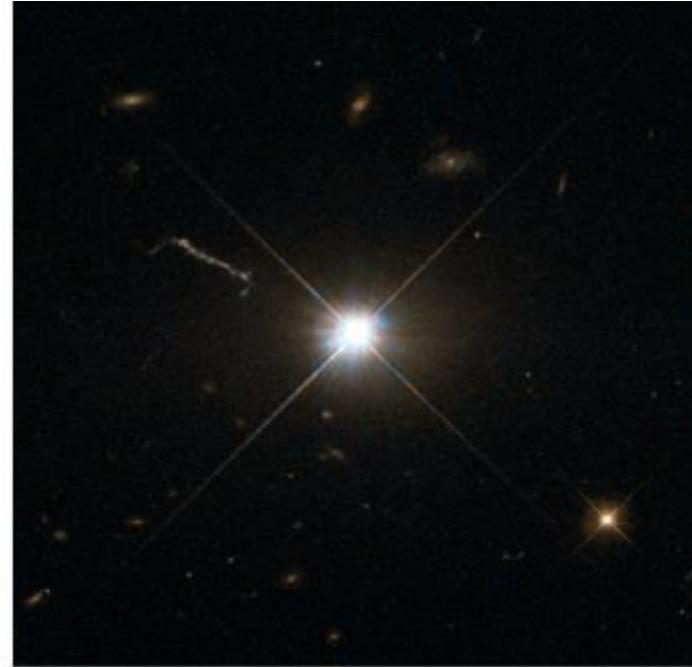


Typical Quasar. The arrow in this image marks the quasar known by its catalog number, PKS 1117-248. Note that nothing in this image distinguishes the quasar from an ordinary star. Its spectrum, however, shows that it is moving away from us at a speed of 36% the speed of light, or 67,000 miles per second. In contrast, the maximum speed observed for any star is only a few hundred miles per second. (credit: modification of work by WIYN Telescope, Kitt Peak National Observatory, NOAO)

FIGURE 27.3



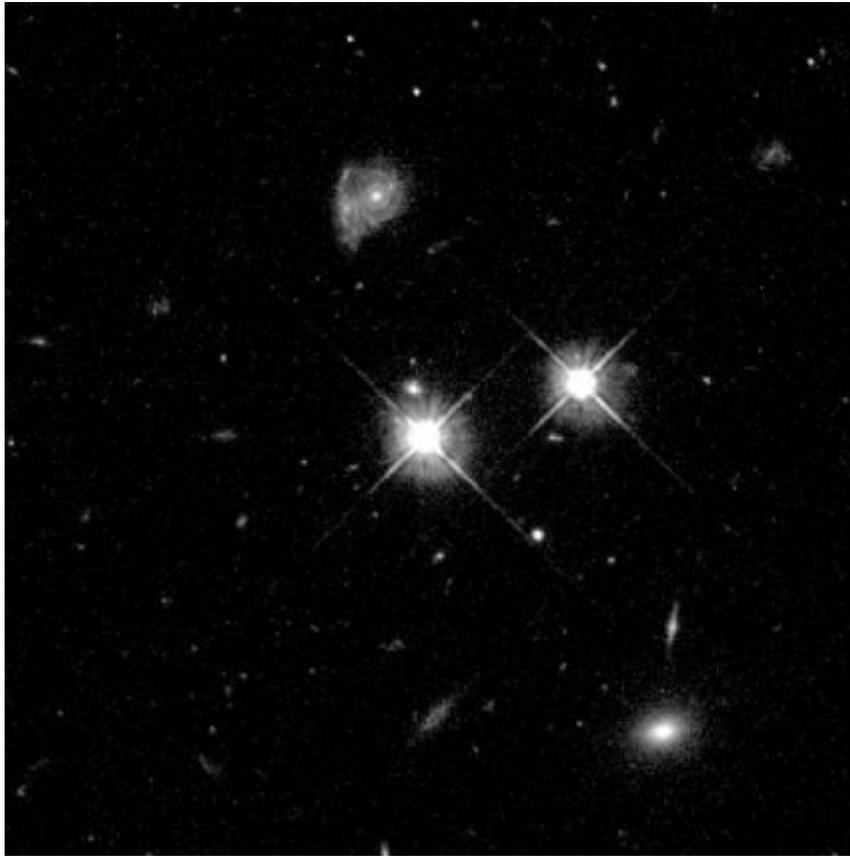
(a)



(b)

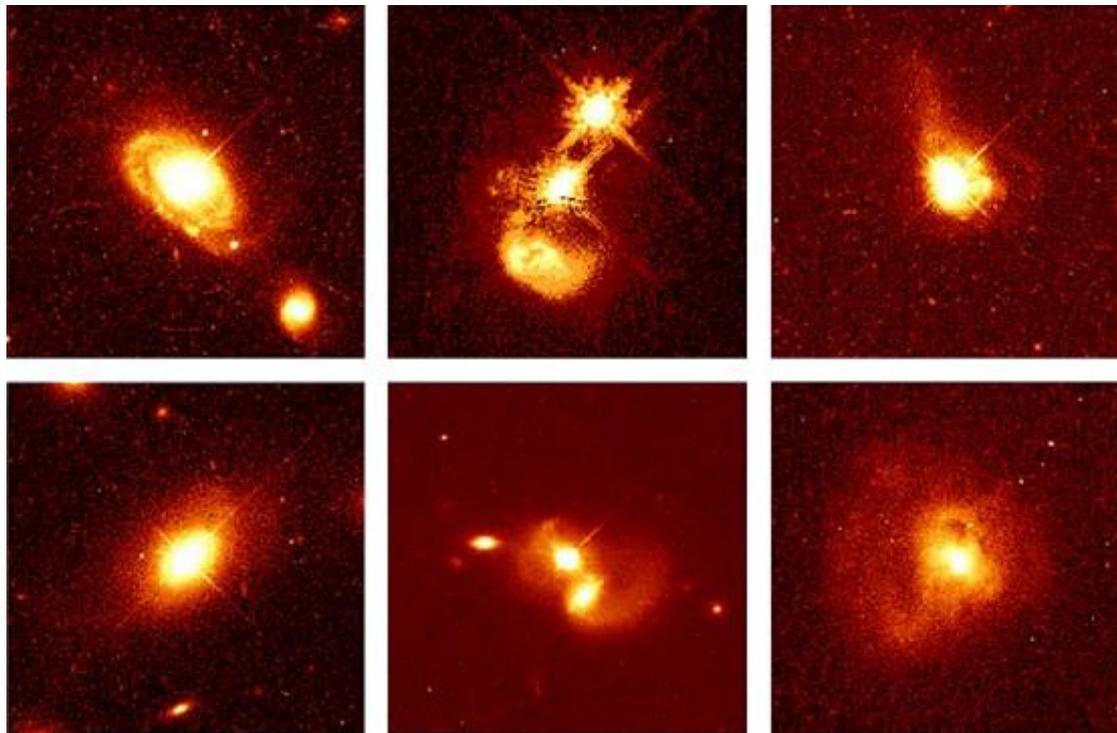
Quasar Pioneers and Quasar 3C 273. (a) Maarten Schmidt (left), who solved the puzzle of the quasar spectra in 1963, shares a joke in this 1987 photo with Allan Sandage, who took the first spectrum of a quasar. Sandage was also instrumental in measuring the value of Hubble's constant. (b) This is the first quasar for which a redshift was measured. The redshift showed that the light from it took about 2.5 billion years to reach us. Despite this great distance, it is still one of the quasars closest to the Milky Way Galaxy. Note also the faint streak going toward the upper left from the quasar. Some quasars, like 3C 273, eject super-fast jets of material. The jet from 3C 273 is about 200,000 lightyears long. (credit a: modification of work by Andrew Fraknoi; credit b: modification of work by ESA/Hubble/NASA)

FIGURE 27.4



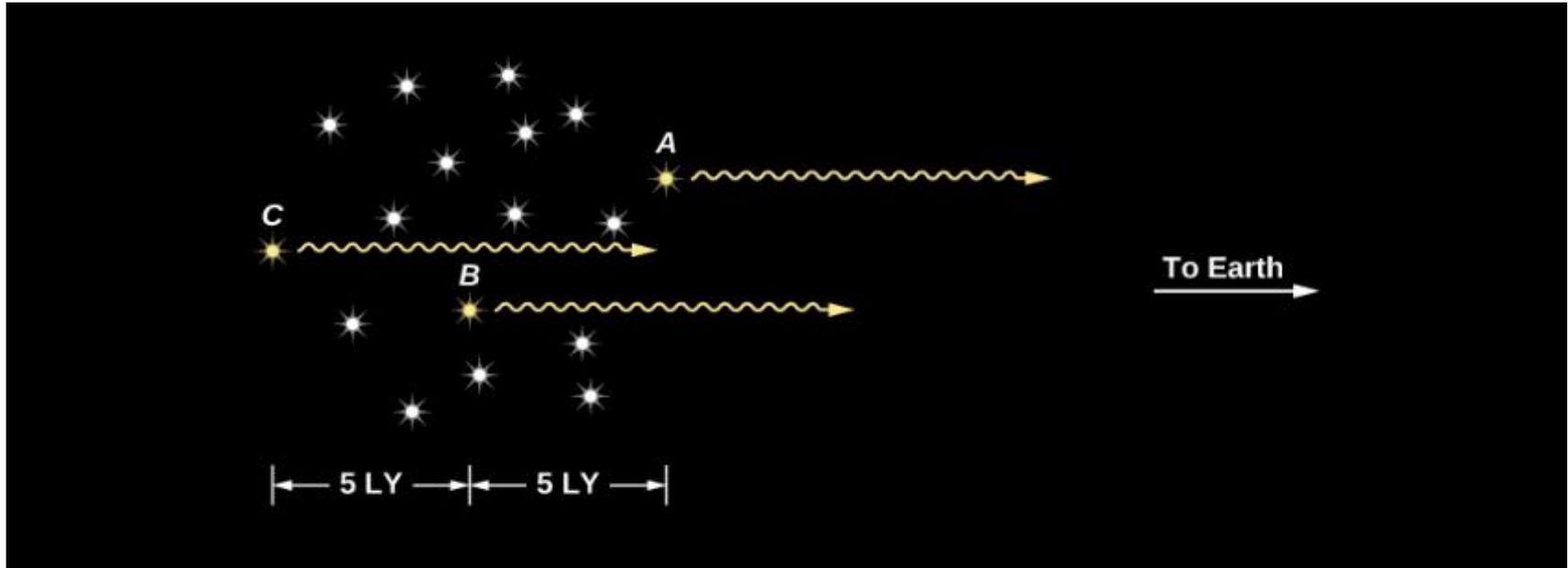
Typical Quasar Imaged by the Hubble Space Telescope. One of these two bright “stars” in the middle is in our Galaxy, while the other is a quasar 9 billion light-years away. From this picture alone, there’s no way to say which is which. (The quasar is the one in the center of the picture.) (credit: Charles Steidel (CIT)/NASA/ESA)

FIGURE 27.5



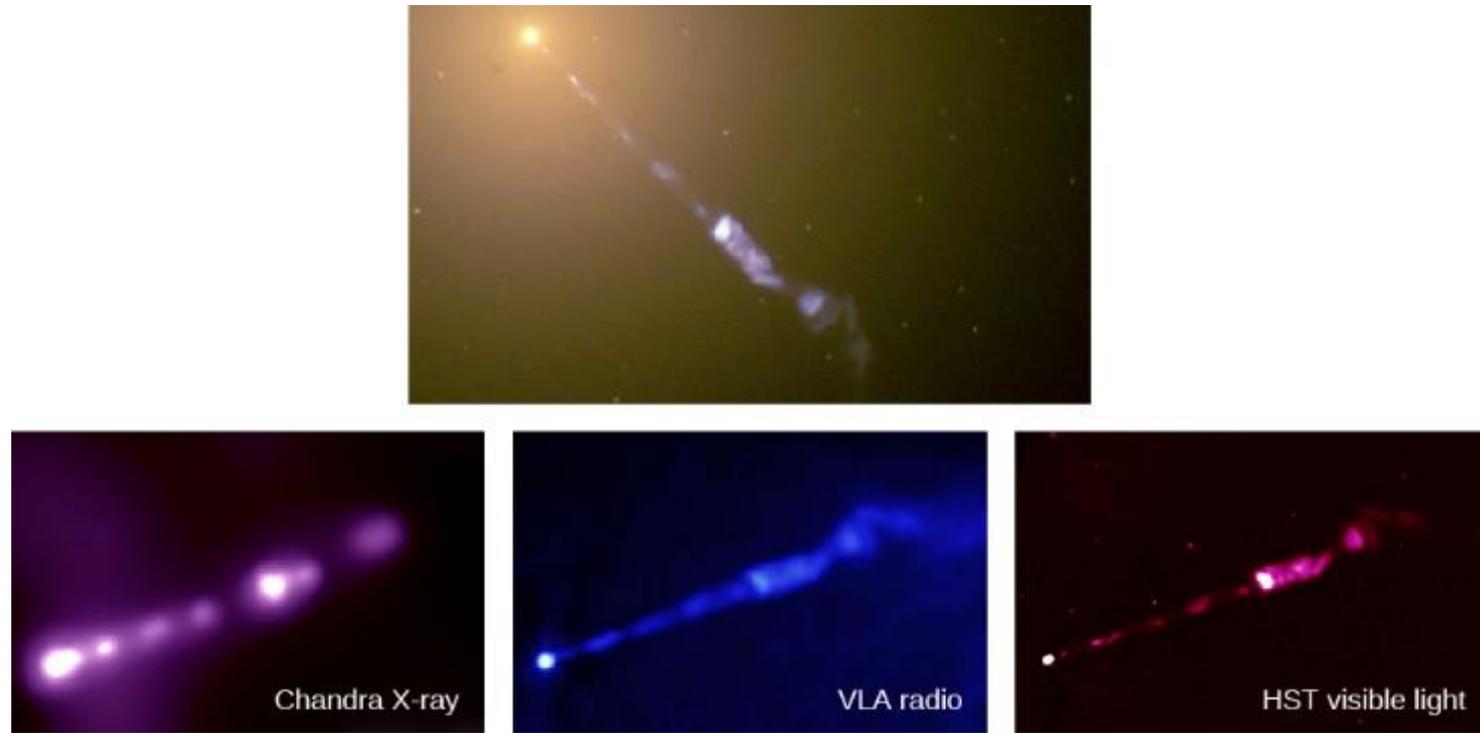
Quasar Host Galaxies. The Hubble Space Telescope reveals the much fainter “host” galaxies around quasars. The top left image shows a quasar that lies at the heart of a spiral galaxy 1.4 billion light-years from Earth. The bottom left image shows a quasar that lies at the center of an elliptical galaxy some 1.5 billion light-years from us. The middle images show remote pairs of interacting galaxies, one of which harbors a quasar. Each of the right images shows long tails of gas and dust streaming away from a galaxy that contains a quasar. Such tails are produced when one galaxy collides with another. (credit: modification of work by John Bahcall, Mike Disney, NASA)

FIGURE 27.6



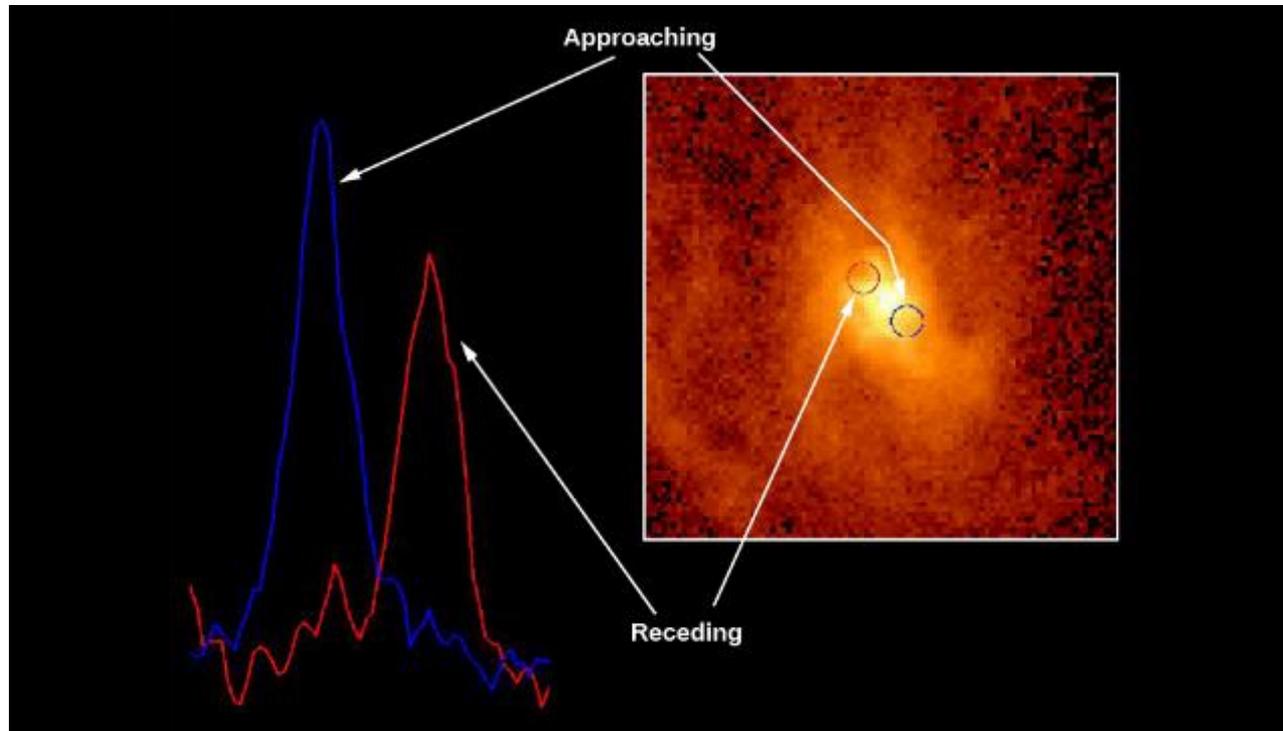
How the Size of a Source Affects the Timescale of Its Variability. This diagram shows why light variations from a large region in space appear to last for an extended period of time as viewed from Earth. Suppose all the stars in this cluster, which is 10 light-years across, brighten simultaneously and instantaneously. From Earth, star *A* will appear to brighten 5 years before star *B*, which in turn will appear to brighten 5 years earlier than star *C*. It will take 10 years for an Earth observer to get the full effect of the brightening.

FIGURE 27.7



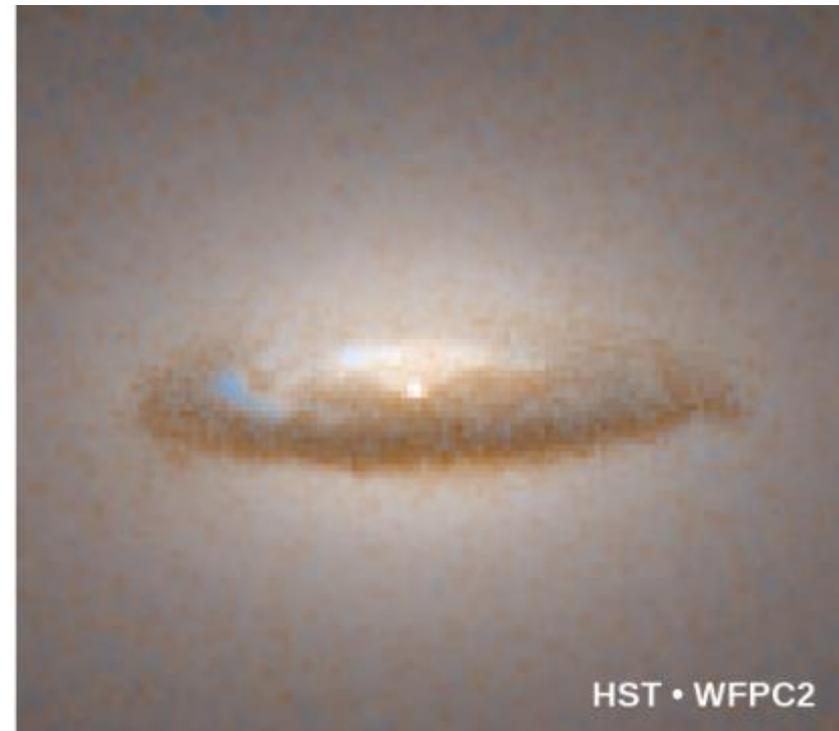
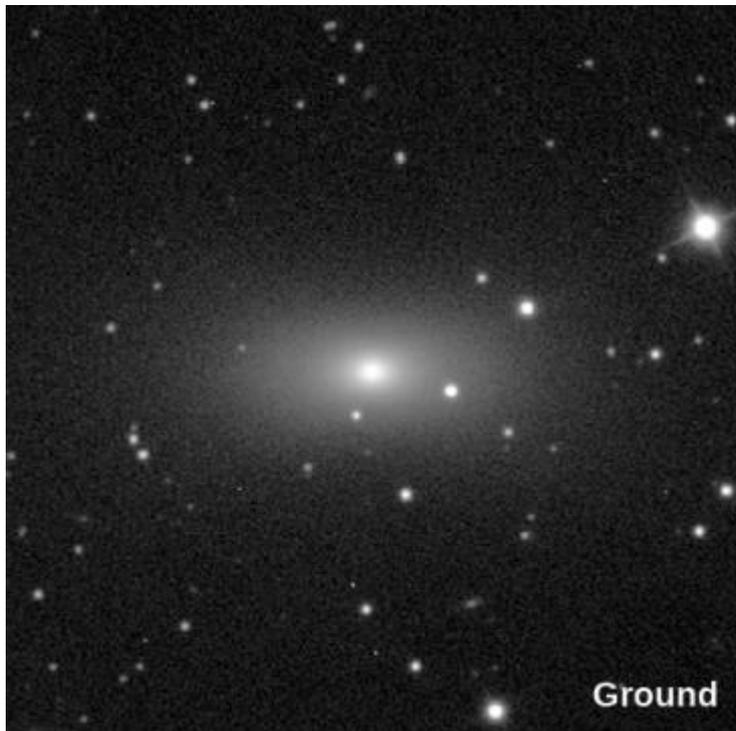
M87 Jet. Streaming out like a cosmic searchlight from the center of the galaxy, M87 is one of nature's most amazing phenomena, a huge jet of electrons and other particles traveling at nearly the speed of light. In this Hubble Space Telescope image, the blue of the jet contrasts with the yellow glow from the combined light of billions of unseen stars and yellow, point-like globular clusters that make up the galaxy (at the upper left). As we shall see later in this chapter, the jet, which is several thousand light-years long, originates in a disk of superheated gas swirling around a giant black hole at the center of M87. The light that we see is produced by electrons twisting along magnetic field lines in the jet, a process known as synchrotron radiation, which gives the jet its bluish tint. The jet in M87 can be observed in X-ray, radio, and visible light, as shown in the bottom three images. At the extreme left of each bottom image, we see the bright galactic nucleus harboring a supermassive black hole. (credit top: modification of work by NASA, The Hubble Heritage Team(STScI/AURA); credit bottom: modification of work by X-ray: H. Marshall (MIT), et al., CXC, NASA; Radio: F. Zhou, F. Owen (NRAO), J. Biretta (STScI); Optical: E. Perlman (UMBC), et al.)

FIGURE 27.8



Evidence for a Black Hole at the Center of M87. The disk of whirling gas at right was discovered at the center of the giant elliptical galaxy M87 with the Hubble Space Telescope. Observations made on opposite sides of the disk show that one side is approaching us (the spectral lines are blueshifted by the Doppler effect) while the other is receding (lines redshifted), a clear indication that the disk is rotating. The rotation speed is about 550 kilometers per second or 1.2 million miles per hour. Such a high rotation speed is evidence that there is a very massive black hole at the center of M87. (credit: modification of work by Holland Ford, STScI/JHU; Richard Harms, Linda Dressel, Ajay K. Kochhar, Applied Research Corp.; Zlatan Tsvetanov, Arthur Davidsen, Gerard Kriss, Johns Hopkins; Ralph Bohlin, George Hartig, STScI; Bruce Margon, University of Washington in Seattle; NASA)

FIGURE 27.9



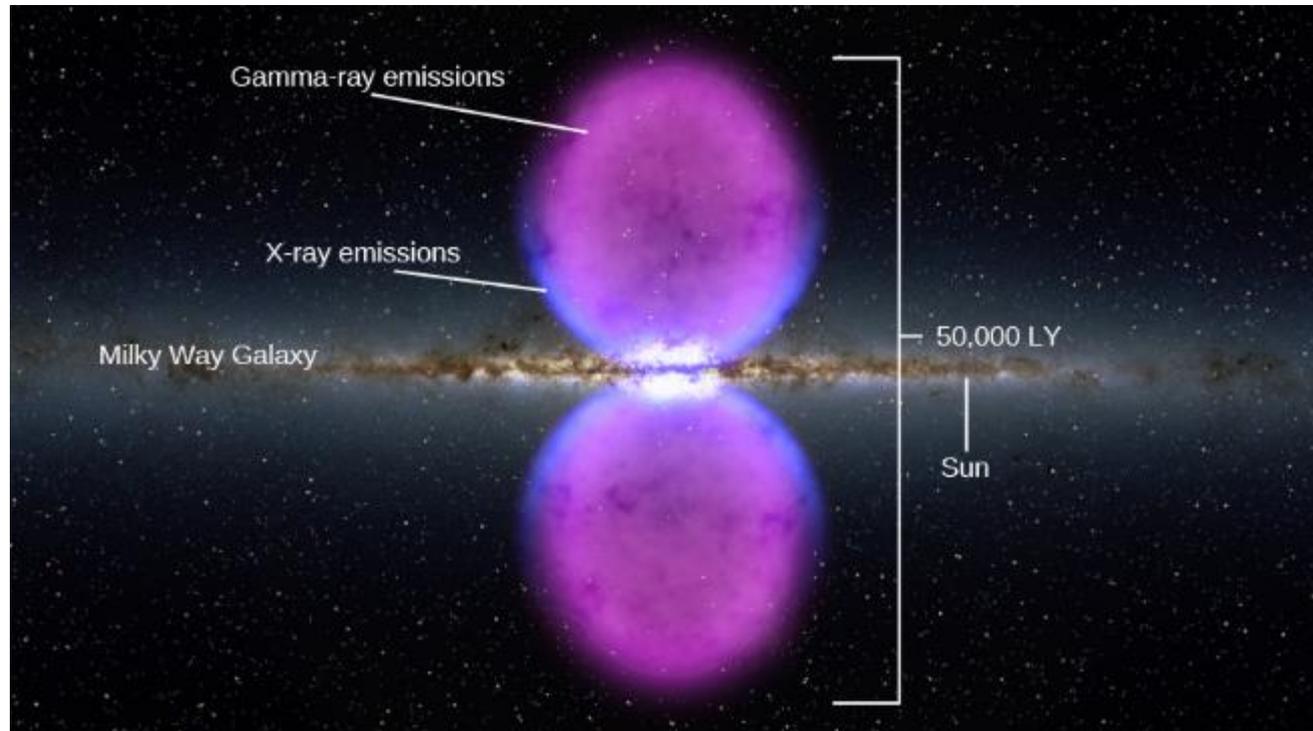
Another Galaxy with a Black-Hole Disk. The ground-based image shows an elliptical galaxy called NGC 7052 located in the constellation of Vulpecula, almost 200 million light-years from Earth. At the galaxy's center (right) is a dust disk roughly 3700 light-years in diameter. The disk rotates like a giant merry-go-round: gas in the inner part (186 light-years from the center) whirls around at a speed of 155 kilometers per second (341,000 miles per hour). From these measurements and Kepler's third law, it is possible to estimate that the disk is orbiting around a central black hole with a mass of 300 million Suns. (credit: modification of work by Roeland P. van der Marel (STScI), Frank C. van den Bosch (University of Washington), NASA)

FIGURE 27.10



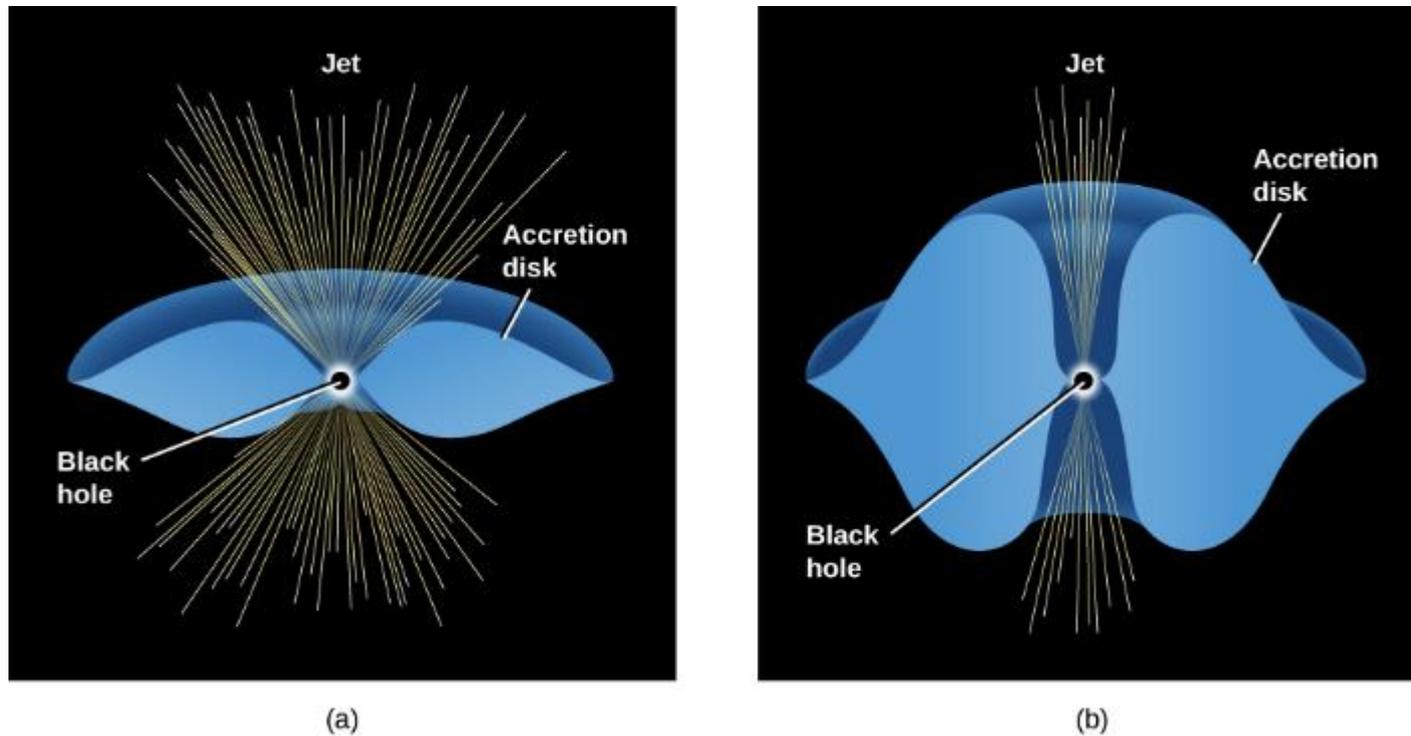
Friction in Earth's Atmosphere. In this artist's impression, the rapid motion of a spacecraft (the Apollo mission reentry capsule) through the atmosphere compresses and heats the air ahead of it, which heats the spacecraft in turn until it glows red hot. Pushing on the air slows down the spacecraft, turning the kinetic energy of the spacecraft into heat. Fast-moving gas falling into a quasar heats up in a similar way. (credit: modification of work by NASA)

FIGURE 27.11



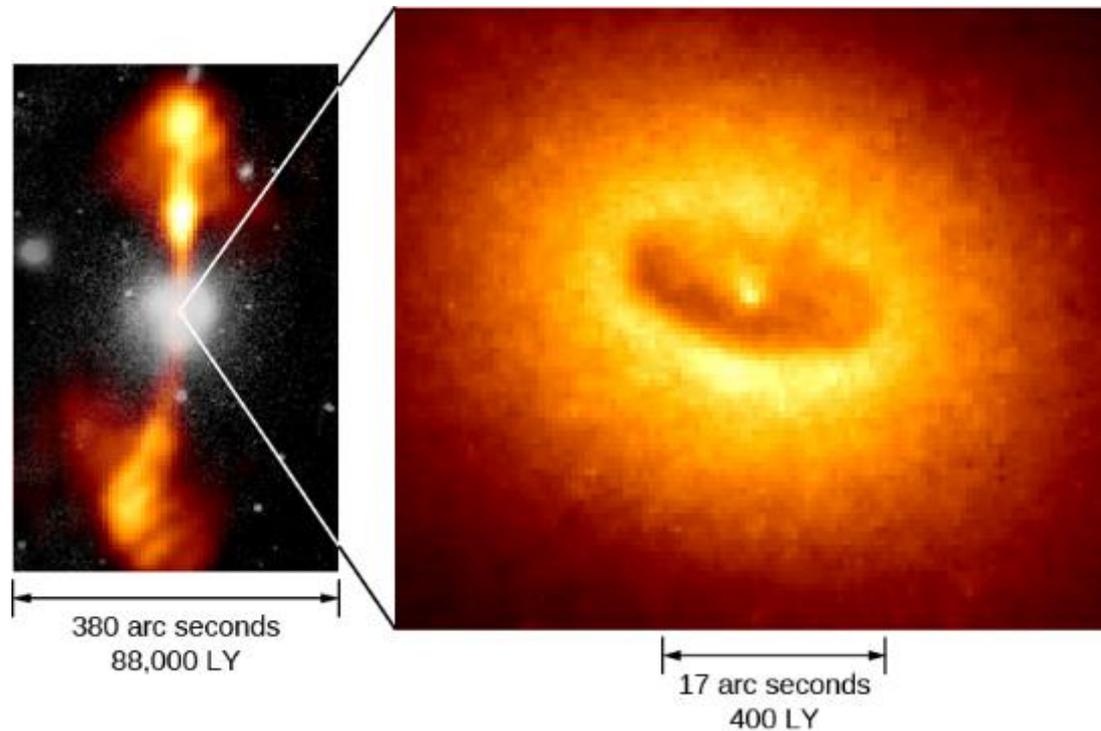
Fermi Bubbles in the Galaxy. Giant bubbles shining in gamma-ray light lie above and below the center of the Milky Way Galaxy, as seen by the Fermi satellite. (The gamma-ray and X-ray image is superimposed on a visible-light image of the inner parts of our Galaxy.) The bubbles may be evidence that the supermassive black hole at the center of our Galaxy was a quasar a few million years ago. (credit: modification of work by NASA's Goddard Space Flight Center)

FIGURE 27.12



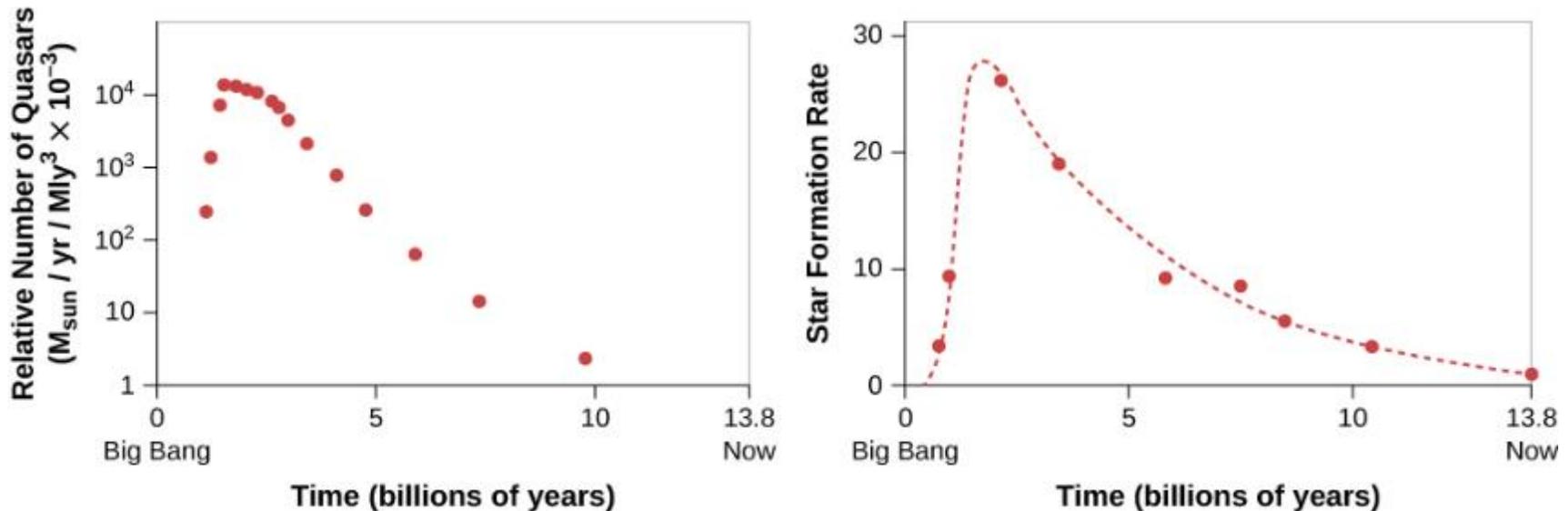
Models of Accretion Disks. These schematic drawings show what accretion disks might look like around large black holes for (a) a thin accretion disk and (b) a “fat” disk—the type needed to account for channeling the outflow of hot material into narrow jets oriented perpendicular to the disk.

FIGURE 27.13



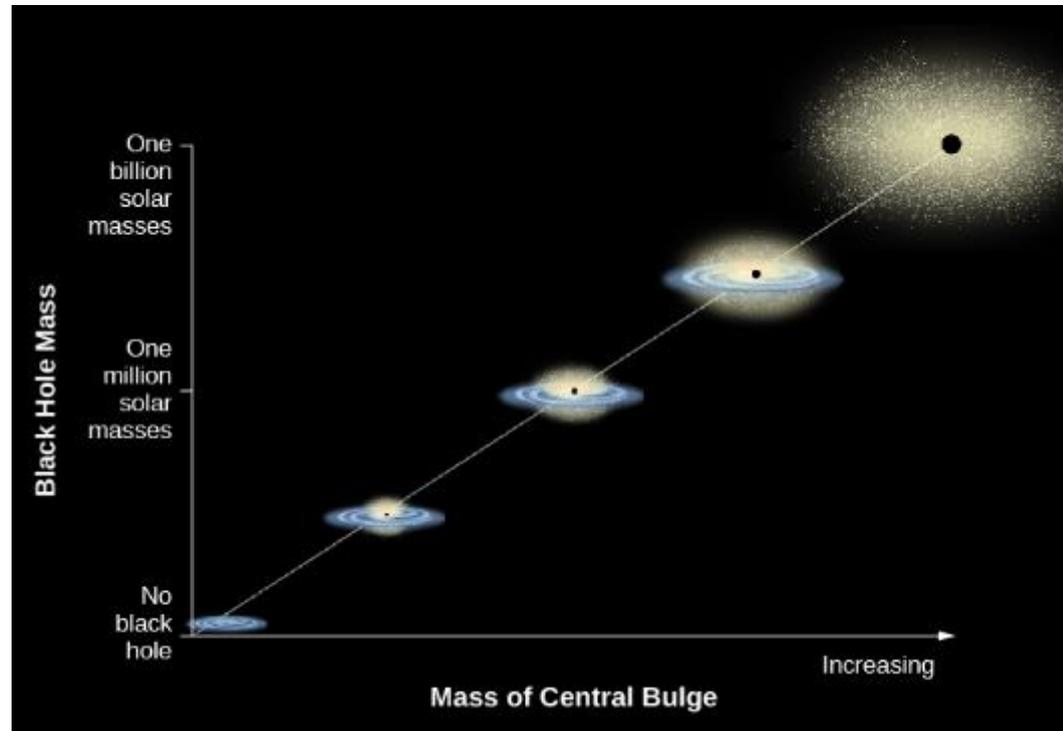
Jets and Disk in an Active Galaxy. The picture on the left shows the active elliptical galaxy NGC 4261, which is located in the Virgo Cluster at a distance of about 100 million light-years. The galaxy itself—the white circular region in the center—is shown the way it looks in visible light, while the jets are seen at radio wavelengths. A Hubble Space Telescope image of the central portion of the galaxy is shown on the right. It contains a ring of dust and gas about 800 light-years in diameter, surrounding a supermassive black hole. Note that the jets emerge from the galaxy in a direction perpendicular to the plane of the ring. (credit: modification of work by ESA/HST)

FIGURE 27.14



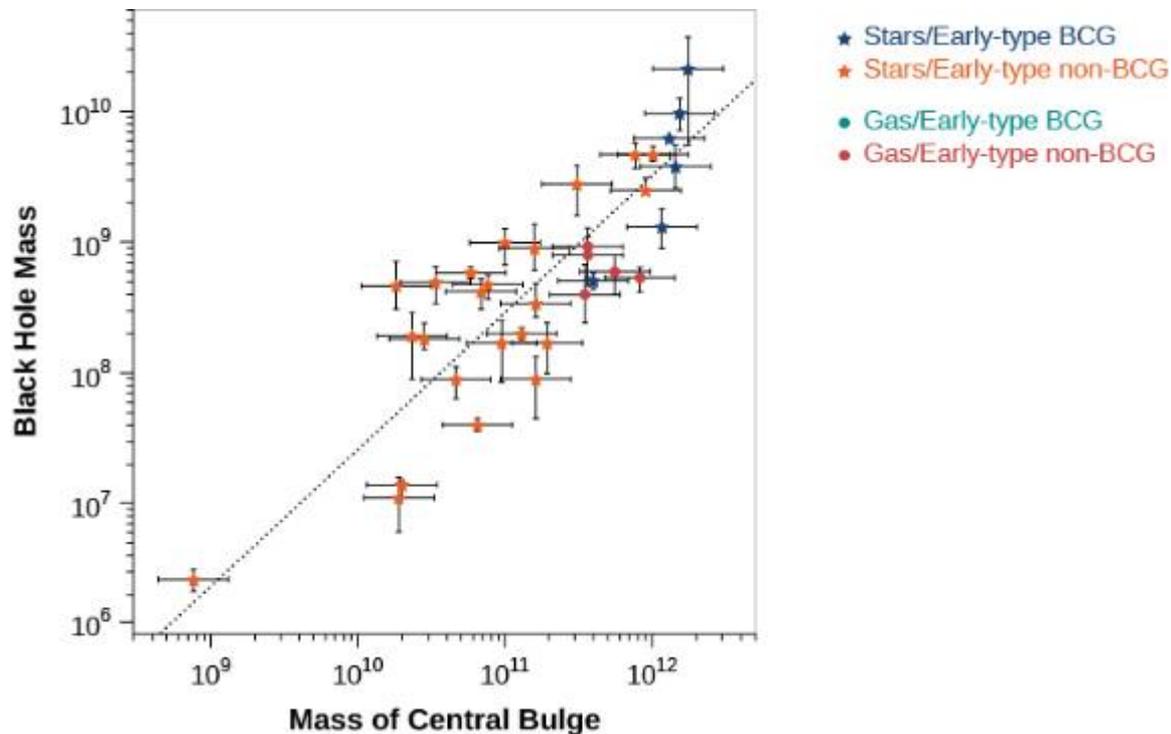
Relative Number of Quasars and Rate at Which Stars Formed as a Function of the Age of the Universe. An age of 0 on the plots corresponds to the beginning of the universe; an age of 13.8 corresponds to the present time. Both the number of quasars and the rate of star formation were at a peak when the universe was about 20% as old as it is now.

FIGURE 27.15



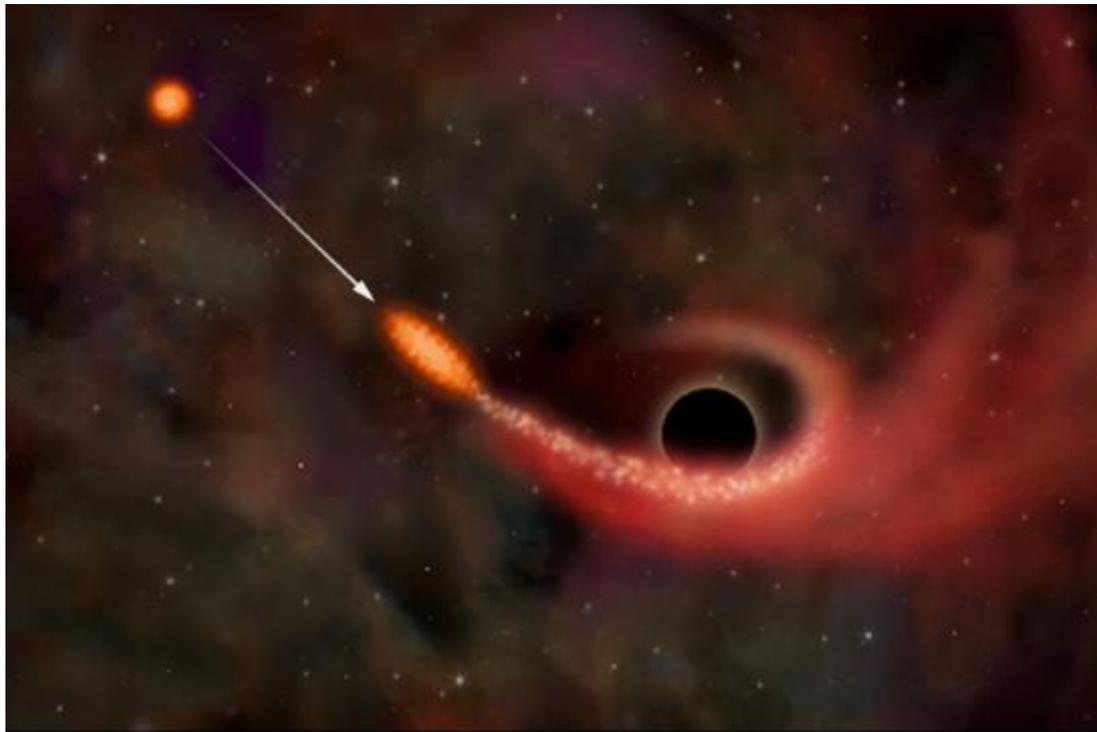
Relationship between Black Hole Mass and the Mass of the Host Galaxy. Observations show that there is a close correlation between the mass of the black hole at the center of a galaxy and the mass of the spherical distribution of stars that surrounds the black hole. That spherical distribution may be in the form of either an elliptical galaxy or the central bulge of a spiral galaxy. (credit: modification of work by K. Cordes, S. Brown (STScI))

FIGURE 27.16



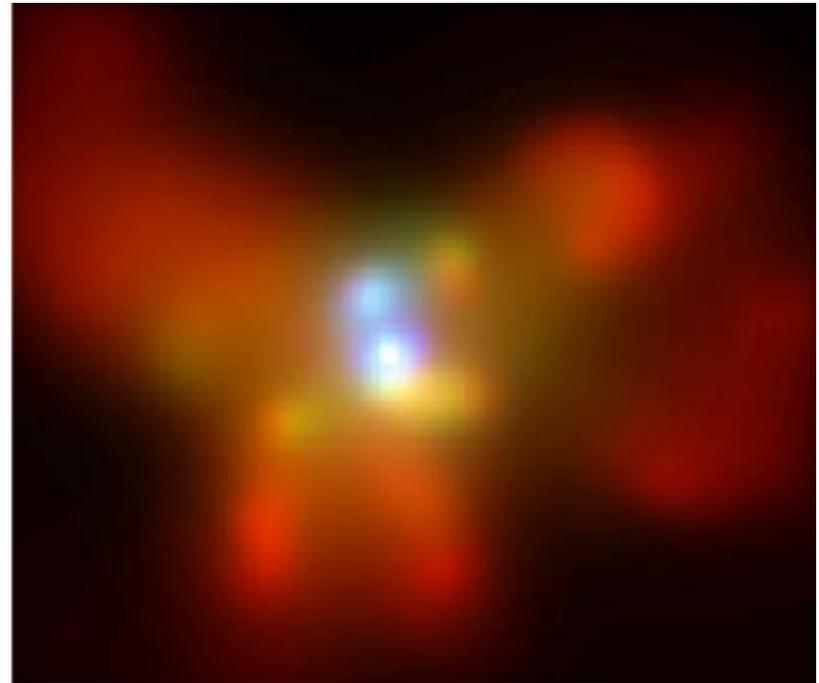
Correlation between the Mass of the Central Black Hole and the Mass Contained within the Bulge of Stars Surrounding the Black Hole, Using Data from Real Galaxies. The black hole always turns out to be about 1/200 the mass of the stars surrounding it. The horizontal and vertical bars surrounding each point show the uncertainty of the measurement. (credit: modification of work by Nicholas J. McConnell, Chung-Pei Ma, "Revisiting the Scaling Relations of Black Hole Masses and Host Galaxy Properties," *The Astrophysical Journal*, 764:184 (14 pp.), February 20, 2013.)

FIGURE 27.17



A Black Hole Snacks on a Star. This artist's impression shows three stages of a star (red) swinging too close to a giant black hole (black circle). The star starts off (top left) in its normal spherical shape, then begins to be pulled into a long football shape by tides raised by the black hole (center). When the star gets closer still, the tides become stronger than the gravity holding the star together, and it breaks up into a streamer (right). Much of the star's matter forms a temporary accretion disk that lights up as a quasar for a few weeks or months. (credit: modification of work by NASA/CXC/M. Weiss)

FIGURE 27.18



Colliding Galaxies with Two Black Holes. We compare Hubble Space Telescope visible-light (left) and Chandra X-ray (right) images of the central regions of NGC 6240, a galaxy about 400 million light-years away. It is a prime example of a galaxy in which stars are forming, evolving, and exploding at an exceptionally rapid rate due to a relatively recent merger (30 million years ago). The Chandra image shows two bright X-ray sources, each produced by hot gas surrounding a black hole. Over the course of the next few hundred million years, the two supermassive black holes, which are about 3000 light-years apart, will drift toward each other and merge to form an even larger black hole. This detection of a binary black hole supports the idea that black holes can grow to enormous masses in the centers of galaxies by merging with nearby galaxies. (credit left: modification of work by NASA/CXC/MPE/S.Komossa et al; credit right: NASA/STScI/R. P. van der Marel, J. Gerssen)



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