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**ASTRONOMY**

**Chapter 28 THE EVOLUTION AND DISTRIBUTION OF GALAXIES**  
PowerPoint Image Slideshow




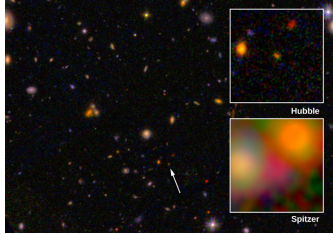


**28.1 OBSERVATIONS OF DISTANT GALAXIES** 




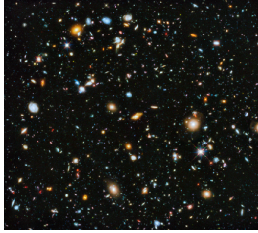
- ▶ **Astronomical Time Travel.** This true-color, long-exposure image, made during 70 orbits of Earth with the Hubble Space Telescope, shows a small area in the direction of the constellation Sculptor. The massive cluster of galaxies named Abell 2744 appears in the foreground of this image. It contains several hundred galaxies, and we are seeing them as they looked 3.5 billion years ago.
- ▶ **Gravitational Lensing.** The immense gravity in Abell 2744 acts as a gravitational lens to warp space and brighten and magnify images of nearly 3000 distant background galaxies. The more distant galaxies (many of them quite blue) appear as they did more than 12 billion years ago, not long after the Big Bang. Blue galaxies were much more common in that earlier time than they are today. These galaxies appear blue because they are undergoing active star formation and making hot, bright blue stars.

**Figure 28.3** 




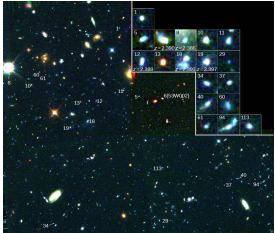
- ▶ **Very Distant Galaxy.** This image was made with the Hubble Space Telescope and shows the field around a luminous galaxy at a redshift  $z = 8.68$ , corresponding to a distance of about 13.2 billion light-years at the time when the light was emitted (indicated by the arrow and shown in the upper inset). Long exposures in the far-red and infrared wavelengths were combined to make the image, and additional infrared exposures with the Spitzer Space Telescope, which has lower spatial resolution than the Hubble (lower inset), show the redshifted light of normal stars. The very distant galaxy was detected because it has a strong emission line of hydrogen. This line is produced in regions where the formation of hot, young stars is taking place.

**Figure 28.4** 



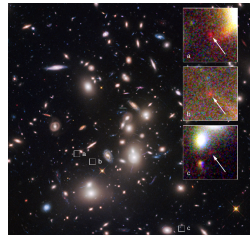
- ▶ **Hubble Ultra-Deep Field.** This image is the result of an 11-day-long observation with the Hubble Space Telescope of a tiny region of sky, located toward the constellation Fornax near the south celestial pole. This is an area that has only a handful of Milky Way stars. (Since the Hubble orbits Earth every 96 minutes, the telescope returned to view the same tiny piece of sky over and over again until enough light was collected and added together to make this very long exposure.) There are about 10,000 objects in this single image, nearly all of them galaxies, each with tens or hundreds of billions of stars. We can see some pinwheel-shaped spiral galaxies, which are like the Milky Way. But we also find a large variety of peculiar-shaped galaxies that are in collision with companion galaxies. Elliptical galaxies, which contain mostly old stars, appear as reddish blobs.

**Figure 28.5** 



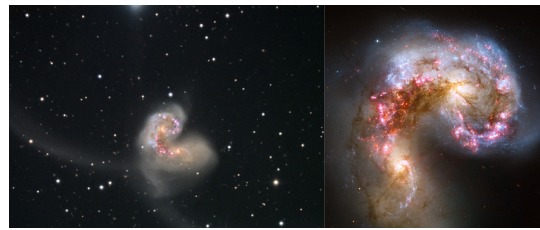
- ▶ **Early Galaxies.** This Hubble Space Telescope image shows what are probably "galaxies under construction" in the early universe. The boxes in this color image show enlargements of 18 groups of stars smaller than galaxies as we know them. All these objects emitted their light about 11 billion years ago. They are typically only about 2,000 light-years across, which is much smaller than the Milky Way, with its diameter of 100,000 light-years. These 18 objects are found in a region only 2 million light-years across and are close enough together that they will probably collide and merge to build one or more normal galaxies. (credit: modification of work by Rogier Windhorst (Arizona State University) and NASA)

Figure 28.6

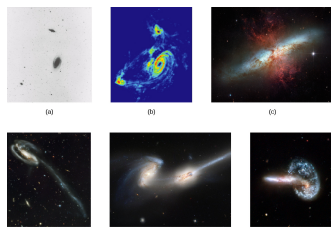


- ▶ **One of the Farthest, Faintest, and Smallest Galaxies Ever Seen.** The small white boxes, labeled a, b, and c, mark the positions of three images of the same galaxy. These multiple images were produced by the massive cluster of galaxies known as Abell 2744, which is located between us and the galaxy and acts as a gravitational lens. The arrows in the enlarged insets at right point to the galaxy. Each magnified image makes the galaxy appear as much as 10 times larger and brighter than it would look without the intervening lens. This galaxy emitted the light we observe today when the universe was only about 500 million years old. When the light was emitted the galaxy was tiny—only 850 light-years across, or 500 times smaller than the Milky, and its mass was only 40 million times the mass of the Sun. Star formation is going on in this galaxy, but it appears red in the image because of its large redshift.

28.2 GALAXY MERGERS AND ACTIVE GALACTIC NUCLEI

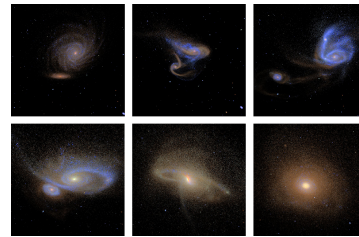


- ▶ **Colliding Galaxies.** Collisions and mergers of galaxies strongly influence their evolution. On the left is a ground-based image of two colliding galaxies (NGC 4038 and 4039), sometimes nicknamed the Antennae galaxies. The long, luminous tails are material torn out of the galaxies by tidal forces during the collision. The right image shows the inner regions of these two galaxies, as taken by the Hubble Space Telescope. The cores of the twin galaxies are the orange blobs to the lower left and upper right of the center of the image. Note the dark lanes of dust crossing in front of the bright regions. The bright pink and blue star clusters are the result of a burst of star formation stimulated by the collision.

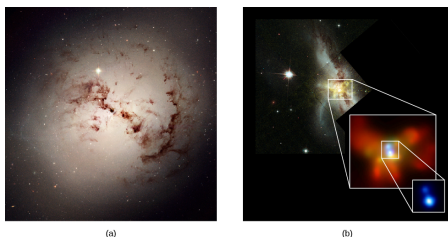


- ▶ **Gallery of Interacting Galaxies.** (a) in a black-and-white visible light image and (b). The hydrogen image shows that the two galaxies are wrapped in a common shroud of gas that is being tugged and stretched by the gravity of the two galaxies. (c) this interaction powered by supernovae explosions of massive stars formed in the burst of star formation that was a result of the collision. (d) has been disrupted by the passage of a smaller galaxy. (e) you can see the long, narrow tails of stars pulled away from the galaxies by the interactions of the two spirals. (f) The two appear to have already passed through each other once, causing a shockwave that reformed one into a bright blue ring of star formation, like the ripples from a stone tossed into a pond.

Figure 28.8



- ▶ **Computer Simulation of a Galaxy Collision.** This computer simulation starts with two spiral galaxies merging and ends with a single elliptical galaxy. The colors show the colors of stars in the system; note the bursts of blue color as copious star formation gets triggered by the interaction. The timescale from start to finish in this sequence is about a billion years.



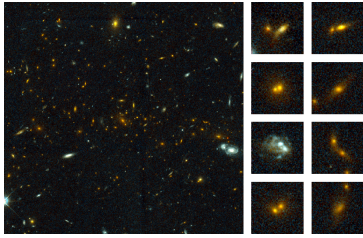
- ▶ **Galactic Cannibalism.** (a) This Hubble image shows the eerie silhouette of dark dust clouds against the glowing nucleus of the elliptical galaxy NGC 1316. Elliptical galaxies normally contain very little dust. These clouds are probably the remnant of a small companion galaxy that was cannibalized (eaten) by NGC 1316 about 100 million years ago. (b) The highly disturbed galaxy NGC 6240, imaged by Hubble Space Telescope (background image) and Chandra X-ray Telescope (both insets) is apparently the product of a merger between two gas-rich spiral galaxies. The X-ray images show that there is not one but two nuclei, both glowing brightly in X-rays and separated by only 4000 lightyears. These are likely the locations of two supermassive black holes that inhabited the cores of the two galaxies pre-merger; here they are participating in a kind of “death spiral,” in which the two black holes themselves will merge to become one.

Figure 28.10



- ▶ **Starburst Associated with Colliding Galaxies.** (a) Three of the galaxies in the small group known as Stephan's Quintet are interacting gravitationally with each other (the galaxy at upper left is actually much closer than the other three and is not part of this interaction), resulting in the distorted shapes seen here. Long strings of young, massive blue stars and hundreds of star formation regions glowing in the pink light of excited hydrogen gas are also results of the interaction. (b) Most galaxies form new stars at a fairly slow rate, but members of a rare class known as starburst galaxies blaze with extremely active star formation.

Figure 28.11



- › **Collisions of Galaxies in a Distant Cluster:** The large picture on the left shows the Hubble Space Telescope image of a cluster of galaxies at a distance of about 8 billion light-years. Among the 81 galaxies in the cluster that have been examined in some detail, 13 are the result of recent collisions of pairs of galaxies. The eight smaller images on the right are close-ups of some of the colliding galaxies. The merger process typically takes a billion years or so.

Figure 28.12



- › **Composite View of the Galaxy Centaurus A.** This artificially colored image was made using data from three different telescopes: submillimeter radiation with a wavelength of 870 microns is shown in orange; X-rays are seen in blue; and visible light from stars is shown in its natural color. Centaurus A has an active galactic nucleus that is powering two jets, seen in blue and orange, reaching in opposite directions far outside the galaxy's stellar disk, and inflating two huge lobes, or clouds, of hot X-ray-emitting gas. Centaurus is at a distance of 13 million light-years, making it one of the closest active galaxies we know.