When Galaxies Collide

By A. J. Smuskiewicz

Backyard astronomers interested in witnessing a cosmic clash of giants should train their telescopes on Stephan's Quintet, a visual group of galaxies in the constellation Pegasus. Decades of scientific observations have revealed that the spiraling star clusters and twisted clouds of luminous gases in this beautiful grouping are actually the wreckage from violent galactic encounters powered by gravitational forces. In one such encounter, hundreds of millions of years ago, an outside galaxy tore through much of the group, leaving a streamer of trailing stars and dust 100,000 light-years long. (A light-year is the distance that light travels in one year—approximately 9.5 trillion kilometers [6 trillion miles]). Today, one member of the quintet can be observed ripping through the core of the group at a speed of 1.6 million kilometers (1 million miles) per hour. Powerful shock waves generated by the galactic collisions in Stephan's Quintet have triggered the formation of untold numbers of stars, mainly in clouds of hot gases between the galaxies.

The galaxies of Stephan's Quintet are not unique. The universe is continually changing, evolving, developing. Nothing stays the same, especially galaxies. For many years, astronomers thought galaxies were isolated islands in the cosmos. Now we know that galactic collisions, mergers, and even cannibalism are common. By studying these interactions with both space- and ground-based telescopes, scientists are gaining a better understanding of the nature of the universe, including how it developed, how it has changed over time, and how it may change in the future.

What are galaxies?

A galaxy is a system of billions or even trillions of stars—as well as planets, gas, dust, and other matter—held together by mutual gravitational attraction. For hundreds of years, astronomers thought that the Milky Way, the galaxy in which the sun and Earth are located, was the only galaxy in the universe. Since the early 1900's, astronomers have learned that the visible universe contains billions of galaxies—500 billion, according to one estimate. Galaxies range in size from a few thousand to millions of light-years in diameter.

Galaxies exist in a variety of shapes, but the three main types are spiral, elliptical, and irregular. A spiral galaxy, such as the Milky Way, has a rotating disc-like structure with long sweeping arms of stars wrapped around the galactic center. The arms also contain clouds of gas (mostly hydrogen and helium) and dust called nebulae, where new stars form. The *nucleus* (center) of the galaxy consists of a crowded concentration of stars in a bright bulge that extends above and below the disc. Typically at the center of this bulge, according to astronomers, is a supermassive black hole, an extremely dense region of space where the gravitational pull is so strong that nothing —not even light—can escape. Astronomers also believe that a huge sphere of dark matter surrounds the visible part of a typical spiral galaxy. Dark matter is the invisible substance or substances thought to make up the majority of the matter in the universe. Unlike ordinary matter, dark matter does not give off, reflect, or absorb light rays.

An elliptical galaxy is shaped like a sphere—though the sphere may be round or flattened—with most of its stars concentrated in the bright central region. Stars in elliptical galaxies are generally many billions of years old. Because these galaxies contain little gas and dust, few new stars form within them. Elliptical galaxies sometimes result from the merger of spiral galaxies.

An irregular galaxy has a patchy, disordered appearance. These galaxies generally contain large amounts of gas and dust, with enough nebulae to generate new stars for many billions of years. Like spiral galaxies, irregular galaxies appear to be surrounded by large halos of dark matter. The strange shapes of irregular galaxies often result from the gravitational tugs of nearby galaxies.

How do scientists study galaxies?

Astronomers use a variety of telescopes to study galaxies and their interactions. Space-based telescopes offer a view of space that is not obscured by Earth's atmosphere. Some of the most spectacular images of galaxies have been made by the space-based Hubble Space Telescope (HST), launched in 1990. In 2009, the HST was refurbished with the Wide Field Camera 3, which can detect the *infrared* (heat) radiation emitted by extremely distant galaxies dating from when the universe was only about 600 million years old. (The farther away a galaxy is, the longer its light must travel to reach us. Thus, galaxies that are farther away in distance are also farther away in time. Scientists believe that galaxies began developing soon after the formation of the universe roughly 14 billion years ago.)

The Spitzer Space Telescope, which was launched in 2003, can also be used to analyze some of the most distant galaxies known. The Chandra X-ray Observatory is another space-based telescope that has been used to observe many colliding galaxies since its launch in 1999.

One of the more ambitious ground-based observation projects, the Sloan Digital Sky Survey (SDSS), relies on the Apache Point Observatory near Sunspot, New Mexico, to conduct detailed surveys of the sky. Astronomers have used the SDSS to map the locations of more than 900,000 galaxies, produce high-quality images of many of these galaxies, discover previously unknown "companion" galaxies to the Milky Way, map the distribution of dark matter around galaxies, and analyze clustering and interactions among galaxies.

Other major ground-based telescopes used in galaxy observations include the Keck I, Keck II, and Subaru telescopes on Mauna Kea volcano in Hawaii; the Very Large Telescope array on Cerro Paranal, a mountain in northern Chile; and the Very Large Array, a group of 27 radio telescopes near Socorro, New Mexico. A radio telescope detects radio waves coming from objects in space.

Astronomers use different telescopes to analyze galaxies based on the different forms of electromagnetic radiation that galaxies emit. The six forms of electromagnetic radiation—gamma rays, X rays, ultraviolet rays, visible light, infrared rays, and radio waves—make up the electromagnetic spectrum. The gas, dust, stars, and other material in galaxies reflect, absorb, or emit all forms of electromagnetic radiation. Analyses of all these forms is important for a thorough understanding of the chemical composition, large-scale structure, internal behavior, and external interactions of galaxies. Images and other data obtained through telescope observations of galaxies are often analyzed with the aid of sophisticated computer programs.

How do galaxies interact?

Most galaxies are located within groups of 20 to 100 galaxies or within clusters of thousands of galaxies. The Milky Way, for example, belongs to the so-called "Local Group," which consists of some 40 galaxies, including the Andromeda Galaxy (which is similar in size and shape to our own galaxy) and the irregular Large and Small Magellanic clouds (which orbit our galaxy at distances of more than 150,000 light-years). Groups and clusters of galaxies reside in enormous superclusters, which may contain tens of thousands of galaxies. Interactions among galaxies occur most commonly in the relatively crowded regions of groups and clusters.

Galaxies interact in four main ways—through collisions, mergers, cannibalism, and distortion. Many galactic interactions fall into more than one of these categories. The term *collision* is often used as a general term for interactions in which two or more galaxies come together. In some cases, the colliding galaxies eventually merge into a single, larger galaxy. When galaxies collide, it is usually the nebulae and other gaseous and dusty components that make contact with one another. The vast amount of space between the stars in a galaxy means that the stars themselves are most likely spared direct collisions.

As two galaxies approach each other, they may exert strong tidal forces on each other. Tidal forces are physical strains caused by the uneven pull of gravity on different parts of an object. The tidal forces spread through the interacting galaxies and stretch and twist them into new shapes.

The tidal forces and other gravitational effects within the colliding galaxies also produce *supersonic* (faster-than-sound) shock waves that cause nebulae to collapse. If the gas collapses upon itself with enough pressure, nuclear fusion reactions are triggered. These reactions, in which *atomic nuclei* (cores of atoms) chemically combine and release the energy of heat and light, mark the violent "birth" of new stars. The gravitational and tidal forces may also cause long "tails" of hot gas and stars to be ejected from the galaxies and into *intergalactic* (between galaxies) space.

When galaxies ram into each other at relatively high speeds, they sometimes can pass through each other, changing their shapes to various extents in the process. These powerful head-on collisions may result in shock waves that spur the formation of a huge ring of bright star-forming material surrounding a smaller, central part. A beautiful example of such a ring appears in the Cartwheel Galaxy. A faint trail of hydrogen gas extends from this giant ring to a small galaxy off to the side. Astronomers suspect that the small galaxy may be a remnant of a star system that plowed through the original Cartwheel. So-called "Sacred Mushroom" galaxies—consisting of a ring and a companion galaxy resembling a mushroom cap and stalk—are in the early stage of ring development after a collision. An example of a partial, crescent-shaped ring—evidence of an off-center collision—can be seen in a pair of galaxies, NGC 7714 and NGC 7715, in the constellation Pisces.

Other evidence of a galaxy collision can be seen in the Sleeping Beauty Galaxy, in which the center of this spiral galaxy appears to be rotating in the opposite direction from the spiral's outer regions. This strange activity may be the result of a small galaxy colliding with a large galaxy—with the combination not yet fully merged.

Galaxies typically merge over a period of millions of years when they collide at relatively slow speeds. Astronomers believe that such mergers have been happening since the formation of the first galaxies more than 13 billion years ago. Since that time, innumerable small galaxies have merged to produce the large galaxies, groups, and clusters that astronomers observe today. Deep-space observations with the HST suggest that during the past 9 billion years, virtually every galaxy has merged with at least one other galaxy. Computer *models* (simulations) based on HST observations suggest that small "dwarf" galaxies have come together with large galaxies three times more often than large galaxies have come together with other large galaxies. Observations have also revealed cases in which numerous galaxies are merging simultaneously, such as the central group of nine elliptical galaxies within the cluster called V Zw 311.

Computer models indicate that the collision and merger of two or more equally large spiral galaxies can produce a giant elliptical galaxy. Scientists believe, for example, that in about 3 billion years, our spiral Milky Way Galaxy will merge with its nearest spiral neighbor, the Andromeda Galaxy, to produce a giant elliptical star system.

Astronomers have discovered many elliptical galaxies in the crowded centers of galaxy clusters, where gravity has apparently pulled large numbers of spiral star systems together. As galaxies merge, the pull of gravity tends to draw matter toward the center of the merging mass. This process can cause extremely massive stars—that is, stars consisting of a great amount of matter—to form at the galaxy's center. These giant stars deplete their fuel and "die" quickly—often after less than 1 million years—in violent explosions called supernovae. These explosions may leave behind black holes, several of which may merge to form a single supermassive black hole with a mass of more than 1 billion times that of the sun.

Cannibalism is a type of merger in which a large galaxy interacts with a small companion galaxy that is typically in orbit around the larger galaxy. The gravitational field of the more massive galaxy captures the smaller galaxy and gradually strips gas and other material from it. The stripped material is incorporated into the larger galaxy—heating up the larger system—and the small galaxy is ultimately destroyed. Scientists believe that the gravitational field of the Milky Way will fully cannibalize the Large and Small Magellanic clouds within the next few hundred million years. The Milky Way is already growing by incorporating material from these irregular clouds.

Examples of cannibalism in a more advanced stage include the internaction between large elliptical galaxy NGC 4472 and its dwarf companion UGC 7636. The dwarf galaxy in this system shows signs of extreme tidal disruption, including a large cloud of gas stripped from it by the gravitational field of NGC 4472.

In distortions, the gravitational and tidal forces resulting from galaxy interactions may cause long tails, bridges, ripples, or other forms of galactic material to stretch out for vast distances from the main bodies of galaxies. Such effects can be seen in the two colliding galaxies known as the Antennae Galaxies. Bright clusters of star formation triggered by this collision can also be seen around the two adjacent nuclei of the combining systems.

Distortions resulting from collisions can produce galaxies with bizarre shapes. The nicknames of some of these distorted galaxies reflect their appearance. For example, two large spiral galaxies that collided with an irregular galaxy have formed an object known as "the Bird" (ESO 593-IG 008), which appears to have a central body with wings to either side. In "the Mice" (NGC 4676A and NGC 4676B), two spiral galaxies in the process of merging have apparently passed through each other, forming what appear to be two oval bodies (the galaxies' nuclei) with long tails made of clusters of bright young stars.

Plans to learn more

Astronomers hope that several new, highly advanced telescopes will help them gain an even better understanding of the intricacies of galaxy interactions and the ways in which galaxies have evolved over time. Some of these telescopes, such as the James Webb Space Telescope, scheduled for launch in 2018, may be able to spot the first generation of galaxies that formed in the cosmos. The NuSTAR (Nuclear Spectroscopic Telescope Array) X-ray space observatory, scheduled for launch in 2012, and the Atacama Large Millimeter/submillimeter Array, an international radio telescope project scheduled to be operational in 2013, are both expected to reveal fresh information about star formation and the behavior of gases in galaxies. In addition, increasingly advanced computer models are helping scientists to create more realistic simulations of galaxy interactions. These simulations may help researchers clarify the physical processes involved in such interactions.