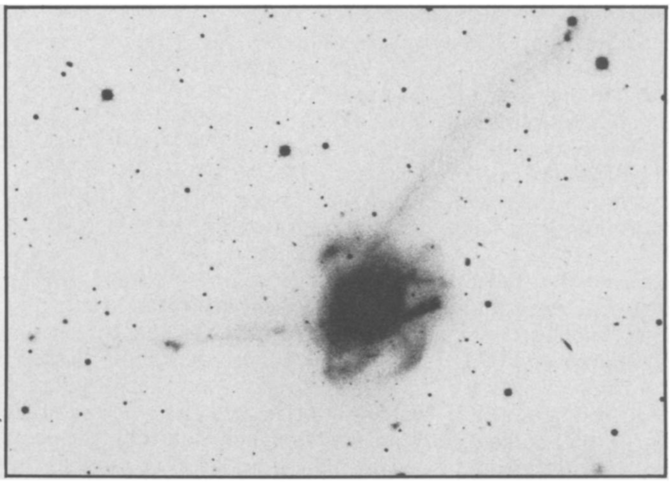
Mixing It Up in Space

Astronomers debate the role mergers play in galaxy formation

By KAREN HARTLEY

The structural forms of nebulae can be investigated with confidence because the necessary data are already available in the collections of direct photographs made with large reflectors.

— Astronomer Edwin Hubble



Courtesy Schweizer

Some astronomers think protruding tails in NGC 7252, shown in this negative image, signal merger activity. Computer simulations that merge two galaxies (see cover) have recreated such tails.

When Hubble uttered these words in the mid-1930s, he regarded the formation of galaxies, which he called nebulae, as an issue whose resolution needed only a good theory. But more than a half-century after Hubble opened the frontiers of galactic research, astronomers using sophisticated imaging devices and powerful computers remain at odds about why galaxies are the way they are.

For years, astronomers have pondered the role galaxy interactions play in this process of formation. Now, new studies have some convinced that collisions and mergers play a large part in forming most, if not all, galaxies in the universe. But many other astronomers, while agreeing that those events play some role, insist they could never form all the universe's galaxies.

"It's a very controversial subject," says James E. Gunn of Princeton (N.J.) University. "The ammunition in both camps is growing."

If researchers determine that galaxies are indeed the products of mergers, it might help solve a question that has long plagued astronomers: Why do galaxies occur in essentially two types, spirals and ellipticals?

Spiral galaxies, like our own Milky Way, are usually characterized by a disk of dust, gas and stars with a large central bulge of old stars in the middle. Spirals make up about 70 percent of the galaxies in the universe. Because of the gas and dust peppered through their spiral arms surrounding the bulge, spiral galaxies are vigorous birth grounds for new stars.

Ellipticals, on the other hand, have used up almost all of their star-making gas and dust. Devoid of most of the material needed for star birth, they consist mostly of very old stars. Yet despite their advanced stage, elliptical galaxies intrigue astronomers. These oval blobs make up some of the largest, smallest and brightest galaxies in the universe.

Most astronomers today believe the ellipticals formed in the universe's first billion years and have vigorously gone through the births and deaths of generations of stars. Spirals took several times longer to form, the result of gas and dust settling into a gravitationally collapsed disk around dense star groups that became the spirals' star-studded bulges.

A new countertheory, now winning greater acceptance, argues that ellipticals are actually the end result, not the progenitors, of dynamic intergalactic events. This theory contends that the universe would most naturally form individual spiral galaxies. Then, to form ellipticals, the spiral galaxies would go through a variety of interactions—partial collisions, full mergers, the transfer of small amounts of mass from one galaxy to another, and even outright cannibalism, in which a big galaxy consumes a small one.

Supporting this theory are several recent observations and computer simulations of interacting galaxies, says François Schweizer of the Carnegie Institution of Washington (D.C.), who has spent more than a decade studying galaxy formation.

Perhaps the most striking evidence for the galaxy-merger theory would be the coexistence of two distinct motion systems within an elliptical, Schweizer says. In the past year, four independent groups have found evidence of counter-rotations in various elliptical galaxies. "In an extreme case, the whole core of an elliptical galaxy may rotate relatively fast and in the opposite direction from the outer body, or at some arbitrary angle to it," Schweizer noted at the January meeting of the American Astronomical Society in Boston.

In a study reported in the August 1988 ASTRONOMY AND ASTROPHYSICS, researchers at the Landessternwarte Königstuhl in Heidelberg, West Germany, found that four of seven randomly chosen ellipticals showed such opposing rotations. This suggests, Schweizer says, "that many ellipticals, not just a few, may have formed through mergers of disk galaxies."

In addition to observational studies, recent simulation work by Joshua E. Barnes of the Institute for Advanced Study in Princeton, N.J., has yielded the first numerical models of interacting galaxies in which bulges, disks and massive halos are depicted in three-dimensional systems, each with thousands of particles.

Barnes' work builds on the first computer simulations modeling galaxy interactions, done in 1972 by Alar Toomre of the Massachusetts Institute of Technology in Cambridge and his brother, Juri Toomre of the University of Colorado in Boulder. The two ran computer simulations of the interaction of two gravitationally bound spiral galaxies.

Barnes' work, however, simulates successful mergers of two disk galaxies of the same mass that are not originally gravitationally bound, an important difference. Getting two unbound galaxies to merge is much more difficult.

"As the galaxies pass each other, they exert a strong gravitational pull," Barnes says, describing the simulation. "The gravity yanks the middle of [each] galaxy out from underneath, so to speak, the edge of the disk, so the stuff on the edges goes flying off in more or less a straight line." The straight lines closely resemble the long, protruding tails seen in the real-life ellipticals NGC 2623 and NGC 7252.

Barnes also factored into his equations the effects of dark matter, a type of unseen matter postulated to make up almost 90 percent of the mass of the universe. Although no one has discovered just what this matter is, astronomers have observed its effects on the motions of visible matter. In Barnes' simulation, dark matter surrounding the nucleus of each of the two colliding galaxies exerts a tremendous gravitational pull that slows the galaxy's visible parts and retards its motion in space.

Barnes concludes that such galaxies can merge on a time scale of a billion years, about the same amount of time astronomers estimate it took the tails to form in NGC 7252.

Many astronomers have suspected for decades that at least some ellipticals might represent the products of merged systems. A number of the larger ellipticals, in fact, are candidates for cannibalism, the act of swallowing smaller galaxies. But showing that mergers form the bulges in spiral galaxies — an idea first advanced by Alar Toomre — has proved a much tougher problem.

Schweizer and Patrick Seitzer of Space Telescope Science Institute in Baltimore provided a bit of supporting evidence in the May 1, 1988, ASTROPHYSICAL JOURNAL, where they reported finding telltale signs of mergers in SO galaxies, a type of spiral galaxy with a large central bulge.

The two announced in their paper early results from a subset of elliptical and SO galaxies they are studying. Preliminary analysis showed ripples — concentric shell formations of old stars — surrounding these SO galaxies. Ripples, seen in many elliptical galaxies, are thought to occur when a galaxy transfers some of its mass to a neighboring galaxy or enters an outright merger with it. Astronomers hadn't noticed ripples in these SO galaxies before, because the galaxies had been incorrectly identified, Schweizer says. "Those who found them at some time before lumped them under ellipticals," he says.

In the larger study in progress, Schweizer and Seitzer have found that of 72 ellipticals and SO galaxies in their study samples, almost half the ellipticals and about one-third the SOs exhibited these ripples. "These fractions, together with expected lifetimes for ripples of at most 1 to 2 billion years, suggest that an average elliptical or SO galaxy has experienced several major accretion events or mergers" over the life of the universe, Schweizer says. "So the suspicion is that not only ellipticals may have formed through mergers, but [also] the bulges of galaxies like the bulge in Andromeda and the bulge in our own galaxy."

But while recent observational and theoretical evidence may tantalize some astronomers, others say it doesn't add up to proof that all galaxies formed from mergers.

Princeton University's Gunn strongly argues that most or all ellipticals did not form from mergers. For starters, he says, merging two spiral galaxies to make an elliptical is statistically improbable.

As for mergers playing a role in forming the bulges found in spirals, that, too, would be difficult because of the nature of spiral galaxies, he contends.

"We now know that spirals are very fragile," Gunn says, noting that if two spirals merged, it would destroy their spiral structure. As for the shells recently observed in SO galaxies, he argues that while shells indicate merger activity, they aren't proof of a merger between galaxies of substantial mass. Instead, they may just show that a galaxy has interacted with a smaller galaxy. Schweizer himself admits that astronomers have only preliminary evidence that bulges in spiral galaxies result from mergers, but calls the observations intriguing nonetheless.

While the debate continues, astronomers pursue more observational evidence. Two or three years of research may provide the data needed to sway the opinion of the astronomy community, Schweizer says. "But," he adds, "we never know in this game." □

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