GALAXY OF NEW IDEAS

Our understanding of what galaxies really look like and how they formed is in a state of transition

BY MICHAEL A. GUILLEN

Galaxies, among the most wondrous of cosmic manifestations, are also among the most enigmatic. These mammoth islands of stars, gas and dust, which come mostly in two varieties — elliptical and spiral — have confounded the imaginations of astrophysicists who seek to explain their origin and evolution from a presumably chaotic beginning to their present, well-ordered majesty.

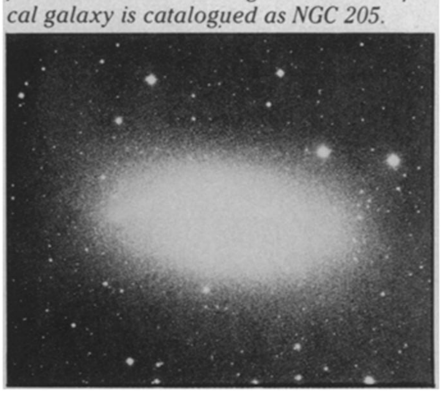
During the past decade, astrophysicists have enlisted the assistance of sophisticated computers that simulate the primeval conditions in which galaxies likely formed more than ten billion years ago. Most of these computer re-enactments feature gravity as the choreographer mainly responsible for tugging stars into gigantic assemblages, typically hundreds of quadrillions of miles in diameter and often containing many hundred billions of stars.

The results of two recent simulations, one concerning elliptical galaxies and the other spirals, have contributed significantly, even if provocatively, to a better understanding of these perplexing phenomena. The two kinds of galaxies together still represent a single puzzle, but each also offers difficulties peculiar to itself.

Humberto Gerola and Philip E. Seiden of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., have addressed the especially formidable task of explaining the formation and persistence of spiral arms. Although examples of spiral structure abound and are easily scrutable on human scales — children's whirlygigs, pinwheel fireworks and fluid whirlpools around drainage holes — they are, on the cosmic scale, a riddle that has vexed many great astronomers beginning with Lord Rosse, who in 1848 first identified the spiral appearance of M51 (the fifty-first entry in Charles Messier's catalog of nebulous objects), a galaxy in Canes Venatici.

Whereas previous hypotheses, including the currently popular spiral density wave model, have generally relied on the far-ranging influence of gravity as the prime mover behind the formation of spiral arms in galaxies, Gerola and Seiden's notion does not. Their antithetical point-of-view, described in the July 1 ASTROPHYSICAL JOURNAL, is based on an idea originally suggested by W. David Arnett of the University of Chicago and Mark W.

Spectacular examples of the two major kinds of galaxies. The spiral galaxy labeled M51 (above) was first to have its pinwheel structure recognized. The elliptical galaxy is catalogued as NGC 205.



Mueller of the University of Illinois at Urbana. Rather than far-ranging, their *prima mobile* derives from the nongravitational influence of a massive star on its immediate neighborhood of gas and dust. During its lifetime, such a star is a tempestuous source of electromagnetic radiation and winds of charged particles, which, like any violent weather, profoundly alter its environment. At its death, the effects crescendo to a climax in the form of a supernova explosion that radiates shock waves which can compress the surrounding tenuous material into a dense condensation that eventually becomes another massive star. This recursive effect can presumably continue indefinitely as a chain reaction — one massive star begets another and so forth.

Arguable as the validity of this hypothetical picture is, it's embraced by Gerola and Seiden in their computer simulation and it quite efficiently causes the occurrence of ragged, stellar chains, which with the additional effect of differential rotation bear a remarkable resemblance to the long, arching arms of actual spiral galaxies. (Differential rotation refers to the observation that material tends to spin faster toward the center than the periphery of spiral galaxies. As in most simulations, Gerola and Seiden's includes this important feature.)

The success of the work is visually represented by simulating the shapes of two galaxies, M81 and M101, favorite objects of study because of their relatively face-on orientation. The computer simulations reveal quite clearly the spiral structures actually visible (see accompanying photos). Besides these two favorable comparisons between reality and theory, Gerola told SCIENCE NEWS, he and Seiden have more recently obtained similar agreement with a wide range of variously shaped spiral galaxies.

But the apparent triumph of the researchers' simulation includes more than this achievement, which by itself would not be entirely without precedent nor as noteworthy. The Gerola and Seiden simulations have succeeded — where others have in only a limited and not entirely satisfactory manner — in creating spiral arms that last for a time comparable to the typical lifetime of a galaxy, which is about ten billion years. This seems to be a more realistic outcome than the ones commonly portrayed in previous simulations wherein the spiral arms of a hypothetical galaxy appear, then disappear like some transient feature. That is, many hypotheses can account for the development within a galaxy of spiral structure, but not as successfully for its long-term persistence. Although astronomers haven't been observing galaxies for a time anywhere long enough to discern directly the actual longevity of spiral arms, indirect evidence disputably suggests that they are indeed a feature considerably more permanent than those that most simulations have managed to describe. Gerola and Seiden's

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Miller (right) and B. Smith with ILLIAC IV.

simulation has apparently hurdled this major theoretical obstacle.

Beatrice Tinsley of Yale University told SCIENCE NEWS that their work "looks very convincing" for a variety of spiral galaxies. But although Richard B. Larson, also of Yale, felt similarly, calling it a "very interesting idea that has stirred up a lot of interest," he further cautioned that it "can't claim to be a complete theory." Furthermore, he worried that "another bandwagon might be getting underway," upon which "many people are climbing" without thinking, as they did several years ago with the density wave idea.

A preliminary hint of another coup by their simulation was related by Gerola to SCIENCE NEWS. It pertains to the age of a galaxy as represented by its "color," a numerical index that derives from the observed relative proportions in a galaxy of old stars (which appear red) and young stars (which appear blue). The various galaxies whose visible appearances were successfully mimicked by the computer also had their colors accurately predicted, Gerola said.

Currently, the two researchers are collaborating with Kevin H. Prendergast of Columbia University to improve the details of their analysis. Among other things, they will use the appropriate theoretical physics to treat more realistically the interactions between stars, supernovae, gas and the complex process of stellar creation. In addition to expecting that their initial success will not be overturned by this more accurate rendition of what is actually going on in the universe, Gerola speculated that a possible reconciliation might even be discovered between their model and the popular spiral density wave picture.

This rival hypothesis, elaborately developed in 1964 by Chia C. Lin of the Massachusetts Institute of Technology and Frank H. Shu of the University of California at Berkeley from earlier ideas expressed by the renowned Swedish astronomer Bertil Lindblad, suggests that a gigantic, rotating gravitational disturbance (like some spiral-shaped weather front) pushes its way around the galactic material, which, traveling faster, is considerably hindered and compressed in its journey through these high pressure regions. In their passage through these arms, then, galactic constituents are caused to tarry and become more crowded together, making manifest the familiar whirlpool pattern. This density wave disturbance may also be analogized to a spiral-shaped bottleneck that causes oncoming traffic to slow down and jam up, resulting in a discernible concentration of materials.

Astronomical observations will in time, of course, provide the data that finally arbitrate among the various contending hypotheses. Reasoning on the basis of Gerola and Seiden's work, one might expect, for example, to see chains of stars in

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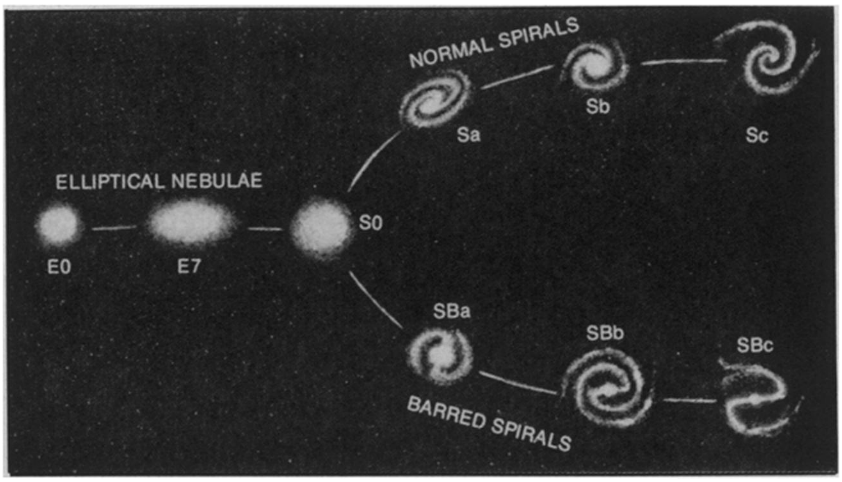
Everything you always wanted to know about galaxies



Systematic arrangement of commonly seen spiral and elliptical galaxies.

Many people associate the Milky Way with a band of diffuse white light laid across a star-speckled night sky. More precisely, of course, the Milky Way is a rather typical spiral galaxy composed of almost 100 billion stars. Outcasts of sorts, the sun and its family of planets are carried around at a half million miles per hour on the galaxy's periphery, some 200 quadrillion miles from the center.

When one stares directly into the white swath of light commonly called the Milky Way, one is actually peering into and along the galaxy's disk at the accumulated light of stars inhabiting the intervening 600 quadrillion miles of space between earth and the opposite edge of the galaxy.

Being within the Milky Way and therefore unable to step back and see its shape, earth astronomers deduced its spiral structure by more clever means. First it was observed that arms of other spiral galaxies were preferentially populated by young, bright stars and hot gas, including hydrogen — indications of their being stellar birthplaces. Fortunately, since hydrogen broadcasts its presence by emanating invisible radiation of a distinctive frequency, astronomers had only to use their radio telescopes to determine its location within the Milky Way. As expected, the tell-tale radiation seemed to originate from only certain regions in the sky, which on a completed map form arm-like appendages — the spiral structure of our galaxy.

Before 1925, it was commonly believed, but heatedly debated, that the Milky Way was the entire universe, encompassing all of the astronomical objects in existence (see p. 136). In that year, however, Edwin Hubble discovered, using Mount Wilson's 100-inch telescope, that in fact many nebulous objects exist at distances far, far beyond the relatively local boundary of our galaxy.

In the course of his extensive observations of these nebulae, now called galaxies, Hubble devised a scheme by which the various kinds could be ordered in some logical fashion. His so-called "tuning-fork" diagram has survived largely unaltered to this day. The chart is based on an arrangement of galactic shapes, each of which is assigned an alphanumeric label. Astronomers use these labels as convenient measures of comparison among several galaxies.

The handle of the fork includes elliptical galaxies. These are bulbous groups of stars whose shapes range from spherical (E0) to very flat (E7). They may contain as few as 100,000 stars or as many as hundreds of billions, and their major dimensions extend anywhere from slightly less than 100 to more than 1,000 quadrillion miles. Except for the smaller ones, called dwarves, ellipticals tend not to be spinning very much, in contrast to the spiral galaxies.

The spiral galaxies seem to come in two varieties in that some have a conspicuous bar through their centers and others do not. Recognizing this, Hubble assigned the index SB to the former (commonly called barred spirals) and S to the latter. In either case, a galaxy may have arms that are tightly wound (Sa or SBa) or more loosely arranged (Sc or SBc). In terms of Hubble's classification, the Milky Way is an Sb galaxy. Generally speaking, the number of stars and typical sizes of spiral galaxies are not too unlike those of ellipticals. The ellipticals range more widely in mass than spirals, and, on the whole, ellipticals have major dimensions only slightly smaller than those of spirals.

—*M.A.G.*

... Galaxies

galactic arms that are chronologically ordered, with the oldest at one end and the youngest at the other. Examples of this phenomenon have, in fact, been seen, but because their existence is also consistent with the density wave idea, it is currently unclear whether this particular observation will be capable of discriminating between the two.

A similar trial awaits the results of another simulation study directed by Richard H. Miller of NASA's Ames Research Center (on leave from the University of Chicago). Using the world's largest computer, ILLIAC IV, Miller found that a rotating sphere of 115,000 randomly distributed stars tends to collapse into a tumbling prolate shape — that is, something like a solid rectangle with smeared edges. These simulated objects are most naturally identified with elliptical galaxies.

This is a rather unexpected finding, however, because most theoretical calculations have hitherto assumed that ellipticals were rotating, *oblate* objects — that is, objects more like squat, deformed spheres not too unlike the earth's shape. The reason such confusion can still exist about the shapes of objects observed constantly with sophisticated telescopes is that from many angles either of these geometrical shapes — prolate or oblate — can appear to be very similar. And, unfortunately for astronomers, an elliptical galaxy during the course of many human lifetimes presents itself at only one aspect, its actual motion being imperceptible. Deprived of the opportunity to inspect these objects from various perspectives, then, astronomers must infer the actual three-dimensional shapes from surrogate evidence that is often ambiguous.

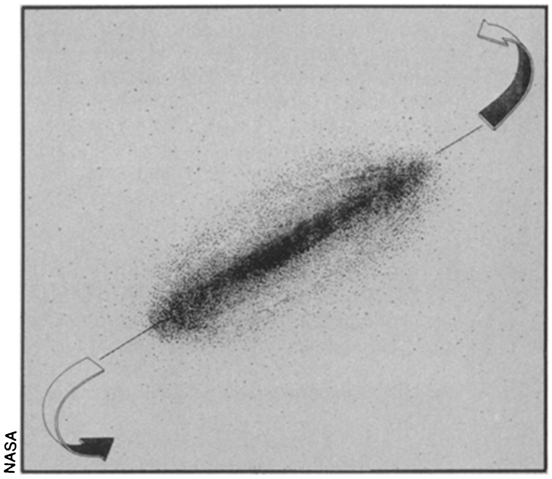
The studies of ellipticals and spirals are not entirely disparate since there has long been a suspicion by some astronomers that the two kinds are distinct offspring of a common parent that was a primordial, amorphous collection of stars, gas and dust. If this cosmic blob had had by chance sufficient spin to fling its constituents out into a flattened disk, then a spiral galaxy might have been the final outcome; otherwise it would have ended up as an elliptical.

Although this naive simplification is by no means a part of today's conventional wisdom, it illustrates the possibility that ellipticals and spirals may simply be two expressions of a common origin or indeed two major stages in a galaxy's full lifetime — the spiral (for technical reasons) representing its adolescence and the elliptical its adulthood.

Whatever the reality is one day discovered to be, it seems clear today from many previous computer simulations, and especially Miller's, that initially formless conglomerations of stars seem to naturally collapse under the influence of their mutual gravity first into short-lived disks than ultimately into prolate or bar-shaped objects. It remains to be shown whether spiral galaxies are cosmic mutations of this natural evolution toward ellipticals or objects largely unrelated to ellipticals and the result, rather, of some special mechanism like the one suggested by Gerola and Seiden's research.

In detail, the galactic evolution depicted by Miller's computer simulation provides other surprises besides the one already mentioned. After having collapsed into a disk, for instance, the stellar group reinflates into a sphere, but with only half the original diameter. Following this, the stars eventually assemble into "the second unexpected feature: the appearance of two parallel sheetlike density condensations normal to the rotation axis." Shortly afterward, the saucer-shaped plates fall together and pass through one another. After going through other temporary configurations, the stars finally settle into the preferred prolate shape.

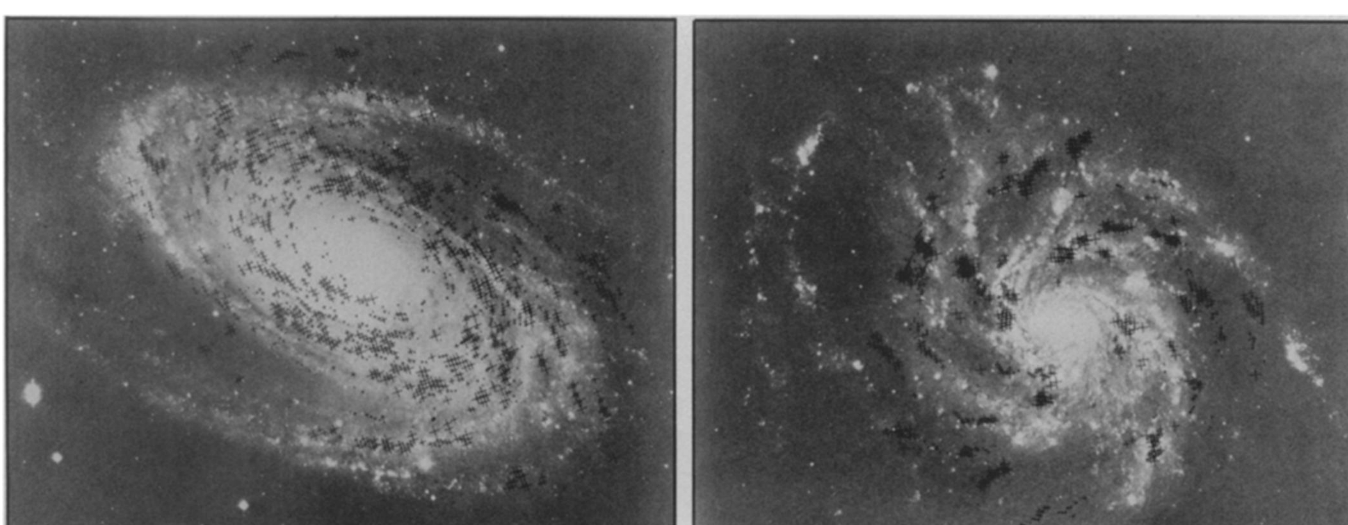
Miller's work is exceptionally revealing because of the enormous computer he used and because his is one of very few simulations carried out fully in three dimensions. Most computer simulations to date have wrangled with only the two-dimensional analogues of these problems because they are more tractible and, although not entirely realistic, are accurate enough to provide valuable information and insight. This strategy is not unlike what cartographers use in depicting the earth's three-dimensional topography in terms of contour lines on a two-dimensional map. But, as Miller's results indicate, there are important details that are ultimately discovered only when one looks at the fully dimensional situation.



NASA

ILLIAC depicts a tumbling elliptical.

Any person who is content with simply appreciating the stark visual beauty of the celestial theatre would probably find it difficult to identify with the predicament of modern astrophysicists who pursue satisfaction through a scientific investigation of the universe and its peculiar inhabitants. The ambitious computer simulations in this discussion are gratifying not only because they are theoretical victories, but, since they relate their information visually, provide one with the incomparable experience of witnessing, even if symbolically, extraordinary astronomical phenomena, which otherwise would remain entirely and almost unbearably aloof from our direct scrutiny. □



H. Gerola and P. Seiden

Superimposed upon the actual photos of M81 and M101 are the spiral arms generated by Gerola and Seiden's computer program.