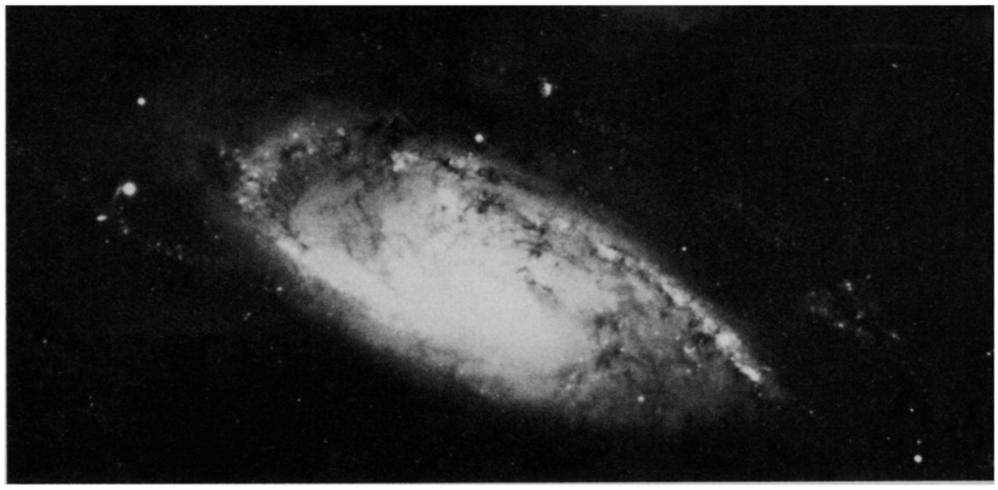
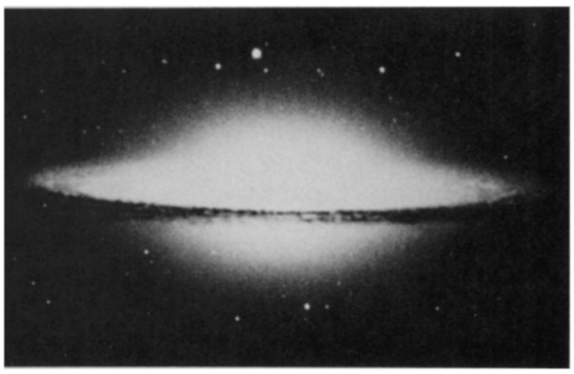
Kitt Peak Nat. Observatory/158-inch
Spiral galaxy NGC 5457 in U. Major.





Kitt Peak Nat. Observatory/158-inch
Galaxy NGC 5494 in Virgo (edge on).

Hale Observatories/200-inch
Spiral galaxy NGC 5364 in Virgo.

View of Milky Way galaxy on opposite page was painted for the book **Beyond Jupiter**—Paintings by Chesley Bonestell, Text by Arthur C. Clarke—Little-Brown, 1973. Reproduced by permission.

Galaxies strange and not so strange: What shapes them?

by Dietrick E. Thomsen

Galaxies are the primary constituents of the universe. Yet their existence was unrealized until about 50 years ago when really big telescopes began to look at the sky. Early observers established a kind of taxonomy of galaxies, dividing them into such classes as elliptical or spiral depending on their appearance and establishing (rather arbitrary) criteria for dividing "normal" from "peculiar" galaxies.

More recently, as the capabilities of study have been developed, interest has grown in the internal dynamics of galaxies. It is becoming clear that much that happens in galaxies has its origins in the mysterious regions in the centers of galaxies, the galactic nuclei. As P. C. van de Kruit, a Dutch astronomer now visiting the Hale Observatories in California, phrases it: "What is the role of the nucleus in the evolution of galaxies?"

What causes the observed structure of galaxies and the activity that goes on inside and around them? Current work in this field is exemplified by the studies of van de Kruit, whose interest lies in spiral galaxies, and another visitor at the Hale Observatories, E. E. Khachikyan of the Byurakan Observatory in the U.S.S.R., who has been studying a class of peculiar galaxies called Markarian galaxies.

Why are spiral galaxies spiral? "What maintains the spiral structure?" van de Kruit asks. The inner parts of the spiral arms are rotating faster than the outer parts so the spiral should wind itself up. For at least some part of a galaxy's history, however, the spiral arms do not wind up; they maintain themselves against dynamical expectation. What preserves them?

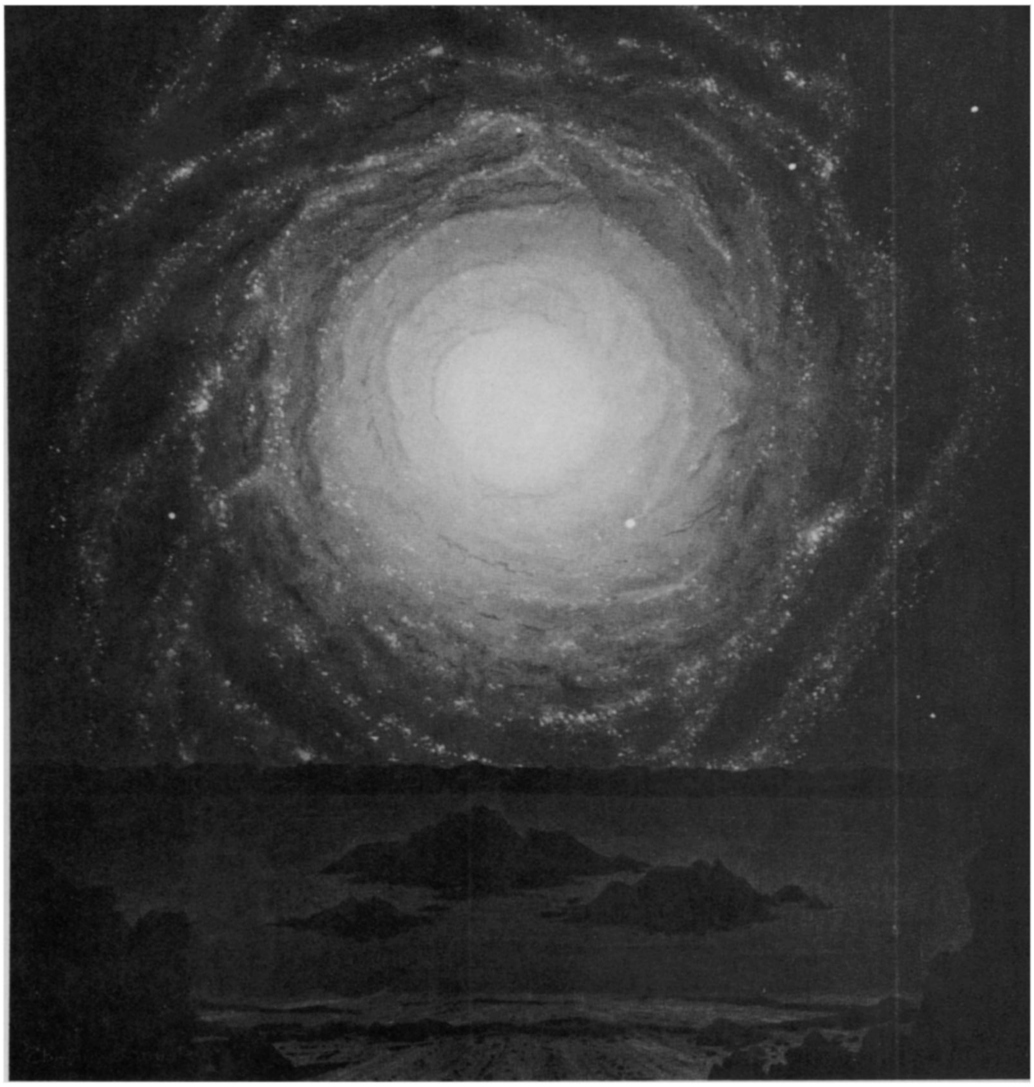
The newest theory is that the spiral arms are maintained by density waves, waves with alternating regions of compressed and rarified matter. The theory, says van de Kruit, "looks at spiral arms as temporary concentrations of matter not as permanent features." If the waves exist then there should be enhanced radio emission from the areas of strong compression. This has been seen with the array of radio telescopes at Westerbork in the Netherlands, which has the resolving power to make radio maps of distant galaxies. Theory also predicts a slight displacement between the regions of enhanced radio brightness and the optically bright spiral arms. This too has been found. In NGC 4258 the radio map shows two spiral arms in between the optical ones.

By comparing radio emission in the compression regions with that in the rest of the galaxy and getting such information for a dozen or so galaxies, astronomers can see how the compression strength relates to other characteristics. When compression is strong, there seems to be a well-developed spiral structure. Also, strong compression means a low ratio of angular momentum to total mass, and this means that most of the mass is concentrated in the nucleus.

Where there is a heavier and better developed nucleus there is more activity. Evidence of recent activity is found in a number of nearby bright galaxies. Gas expelled by the nucleus is seen moving away at high velocities. Inner parts are moving away from the

NGC 4258: Radio maps of this galaxy have found "radio arms" between the visible spiral arms.

Hale Observatories



"Why are spiral galaxies spiral?" Our own local galaxy, the Milky Way, as visualized from a distance of 300,000 light-years. The galaxy contains at least 100 billion stars and is 100,000 light-years across.

Painting by Chesley Bonestell

nucleus. In NGC 4258 there are highly ionized regions that contain no bright star to provide light for photoionization. Therefore there must be some other ionizing process at work, perhaps turbulent motion.

At Westerbork they are trying to get more information on these things. The model that seems to be emerging links spiral structure to activity in the nucleus. Gas expelled from the nucleus would gather gas as it passed outward till it arrived at the mass of a spiral arm.

Nuclei that throw things out are also found in the Markarian galaxies that Khachikyan is studying. These were first discovered at Byurakan in 1968. The name comes from their discover B. E. Markarian, an Armenian astronomer; Khachikyan was the first to apply the name. There are now about 600 Markarian galaxies known. Their distinctive characteristic is a strongly excessive emission in the ultraviolet, a characteristic they share with quasars.

Khachikyan says that it is now clear that the Markarian galaxies, under their broad umbrella of excess ultraviolet, contain many different types: Seyferts, Zwicky objects, Haro blue galaxies, many giant galaxies, many dwarf galaxies, distant galaxies and close galaxies; even quasars might be numbered among them. One of them, Markarian 132, is the brightest object in the universe with an absolute magnitude of about minus 27. Khachikyan is trying to find out the nature of these galaxies, something for which he needs high-resolution spectra, which he is trying to get in his current work.

The main question is connected with the nuclei. Among the Markarians are nuclei so active they explode, divide and eject matter. Some of the activity is on a very quick time scale. Take Markarian 6, for example. During 1968 there was no evidence of anything going on. In 1970 an explosion began, signaled by the appearance of second components in the emission lines of hydrogen. The new components were shifted toward the blue by an amount equivalent to a motion of 3,000 kilometers a second. This possibly means an ejection of gas toward the earth.

Gas is not the only thing galactic nuclei may be ejecting. Superassociations of stars are large groups of stars, around 10,000 parsecs across and with absolute magnitudes less than minus 15. Superassociations are close to the size of dwarf galaxies, and some Markarian galaxies seem to be composed of them. A superassociation appears to be moving away from a galactic nucleus at the same speed as gas. Khachikyan says it may have been ejected from the nucleus.

And then there is the possibility that galactic nuclei eject whole galaxies. Halton Arp of the Hale Observatories argues for this. There are some small groups of galaxies that to him appear to give evidence of such ejection but other astronomers caution that the idea is highly controversial.

Other small groups of galaxies, those called Shakhbazian objects, are also of interest.

In one Shakhbazian object there are nine galaxies in a diameter of 80,000 parsecs. For comparison, our own one single galaxy is 30,000 parsecs across. These tight clusters must be understood dynamically.

So far there are disparate results. Joseph Wampler of the Lick Observatory, investigating Shakhbazian 1, found very small differences of redshift among its members. The overall difference was about 60 kilometers per second, indicating, says Khachikyan, that "they just stay with each other and don't move [apart]." Khachikyan and Roger Lynds of Kitt Peak National Observatory investigated Shakhbazian 4 and found a much greater redshift spread: about 1,000 kilometers per sec.

Many outstanding questions remain. There is plenty of evidence for violence in the behavior of galactic nuclei and in the relations of galaxies to other galaxies. But how it all fits together remains to be elucidated. □