Unblemished beauty. Isolated galaxies like NGC 7217 may have evolved undisturbed for billions of years.

ASTRONOMY

The Tales Told by Lonely Galaxies

To what extent is a galaxy shaped by its surroundings? To find out, astronomers are seeking the rare ones that appear to be isolated

GRANADA, SPAIN—Laden with 400 billion stars, countless planets, and vast clouds of gas, our Milky Way galaxy pinwheels through the void. Its spiral arms stretch 50,000 light-years and revolve once every 220 million years, as we plunge at 400,000 kilometers per hour toward the neighboring Andromeda galaxy. That's well known, but it's less clear how the Milky Way—or any other galaxy—came to appear as it does.

In the century since the first distant ones were recognized, astronomers have learned much about how galaxies form and evolve. But they still don't know to what extent a galaxy's properties are determined by its inner workings or through interactions with its surroundings—such as the Milky Way's potential collision with Andromeda in 3 billion years. In short, astronomers want to know how much of a galaxy's character is set by nature and how much by nurture.

To solve that puzzle, some astronomers are searching for rare galaxies well isolated from their neighbors. By comparing these loners to their more-gregarious brethren, researchers hope to tease apart the inherent inner workings of galaxies and the effects of interactions. Last month, 120 researchers gathered here to discuss such efforts.*

*Galaxies in Isolation: Exploring Nature vs. Nurture, 12–15 May.

"If there really are significant numbers of isolated galaxies, and if we can collect large enough samples of them, then they're certain to provide some sort of fundamental insight into galaxy evolution," says Jack Sulentic, an astronomer here at the Institute for Astrophysics of Andalusia (IAA). Astronomers have searched for isolated galaxies before, but recent massive galaxy surveys may unearth many more of the gems.

The notion of an isolated galaxy may be something of an oxymoron, however. Galaxies form through a "hierarchical process" in which smaller ones merge to make bigger ones, researchers think. So each galaxy is in fact the product of galaxy interactions. "I think there are no isolated galaxies," says Bärbel Koribalski, an astronomer at the Australia Telescope National Facility in Epping. Still, the few galaxies that appear to be lingering alone are worth studying, says Christian Theis, a theoretical astrophysicist at the University of Vienna in Austria. "Even if they're not formed in isolation, they may have evolved in isolation for some time," he says. "So they can give some insight into the inherent processes of evolution."

Gathering the outcasts

The first major catalog of isolated galaxies was created in 1973 by Valentina Karachentseva of Taras Shevchenko National University of Kyiv in Ukraine, working with her husband, Igor Karachentsev of the Special Astrophysical Observatory in Nizhnij Arkhyz, Russia. "We divided our work," she says. "Igor worked with the pairs, and I work on the isolated galaxies."

Karachentseva analyzed photos taken in the 1950s with a 1.2-meter telescope in the famed Palomar Observatory Sky Survey. She declared a galaxy isolated if no neighboring galaxy lay closer than 20 times the neighbor's radius or was more than four times as big in diameter as the galaxy in question. Those rules selected galaxies that had not suffered an interaction in roughly 3 billion years. The Karachentseva catalog of 1051 galaxies is "still the best game in town," say Sulentic, who works on the Analysis of the Interstellar Medium of Isolated Galaxies (AMIGA) project at IAA.

Now, however, astronomers are trawling the enormous data sets produced in the past decade in ever-bigger sky surveys. In optical wavelengths, the Six-Degree Field Galaxy Redshift Survey has used a 1.2-meter telescope on Siding Spring Mountain, Australia, to pinpoint a total of 125,071 galaxies; the Two-Degree Field Galaxy Redshift Survey has used a neighboring 4-meter telescope to spot 221,414 more; and the Sloan Digital Sky Survey has used a 2.5-meter telescope on Apache Point, New Mexico, to bag 930,000 of them.

The new data allow astronomers to fix a galaxy's position in three-dimensional space, not just on the two-dimensional celestial sphere. As the universe expands, the galaxies speed apart. The more distant a galaxy, the faster it recedes. The motion stretches a galaxy's light to longer, redder wavelengths, so by measuring that "redshift," astronomers can deduce the galaxy's speed and distance.

Using Sloan data, Hong Bae Ann of Pusan National University in South Korea has sifted through 100,000 galaxies lying between 275 million and 700 million light-years away to find about 500 isolated ones. Meanwhile, Karachentsev has used data from all three big surveys to pick out 513 isolated galaxies lying within 135 million light-years. Karachentseva has spied 3227 of them using data from the near-infrared Two Micron All-Sky Survey conducted with twin 1.3-meter telescopes on Mount Hopkins, Arizona, and Cerro Tololo, Chile.

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But as catalogs proliferate, so do the criteria used to define isolation and the tensions between them. Ann focuses on the galaxies' masses and separations, and he can set his criteria so that his list recaptures 80% of the 1973 Karachentseva catalog. However, Ann seeks extremely isolated galaxies, and when he tightens his criteria the lists do not overlap at all, he says.

Whether a galaxy appears isolated may also depend on the method used to observe it, says Oded Spector of Tel Aviv University in Israel. He used the 1-meter telescope at the Wise Observatory near Mitzpe Ramon, Israel, to spot 27 extremely isolated galaxies. He then compared the optical data with data from ALFALFA, a radio survey using the 305-meter dish at the Arecibo Observatory in Puerto Rico that can detect hydrogen gas and reveal galaxies too faint to be seen with optical and infrared instruments. The ALFALFA data showed that nine of Spector's galaxies had companions after all. "One of these had seven neighbors," he says.

Compare and contrast

Still, the few isolated galaxies there are may shed light on galaxy content, behavior, and structure, researchers say. Theorists generally agree that the cosmos took shape after the big bang as dark matter—the mysterious stuff whose gravity binds the galaxies—coalesced into clumps. Smaller clumps merged to make bigger clumps and form a vast "cosmic web" of filaments and sheets separated by voids. Meanwhile, the dark matter clumps or "halos" drew in hydrogen gas from which stars and galaxies formed like raindrops condensing in clouds.

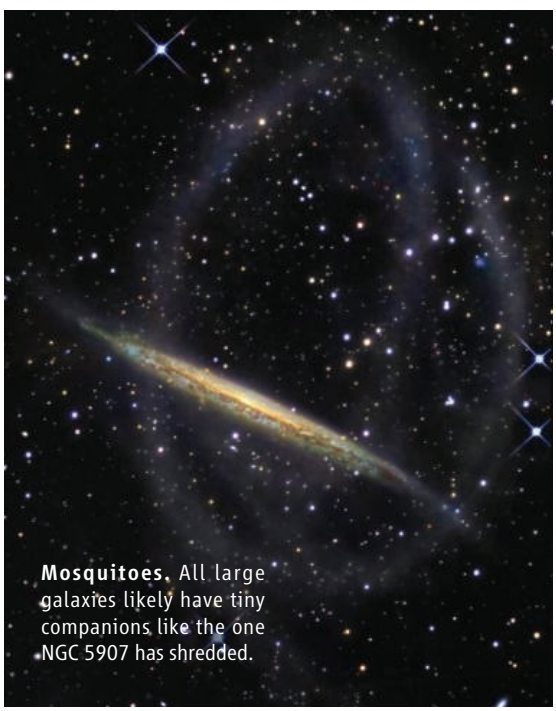
Researchers hope to fill in some of the details within this big picture. One question is whether star formation depends on a galaxy's environment. Galaxies in crowds are often "red and dead": Their stars are reddish in color, and the galaxies have stopped making new ones. That could be a natural effect of aging, as the radiation from the galaxies themselves blows out the gas needed to make new stars. Or interactions with other galaxies may have stripped out the gas.

Striking a blow for interactions and nurture, Angela Iovino of the Astronomical Observatory of Brera in Milan, Italy, and colleagues tallied galaxies as far away as 11 billion light-years (a redshift of 100%) using the Very Large Telescope on Cerro Paranal, Chile. They find signs that isolated galaxies fade from blue to red more slowly than those in groups do. "Isolated galaxies stay younger longer," Iovino says.

But Jeremy Tinker, a theorist at Lawrence Berkeley National Laboratory in California, argues for nature. Simulations of the large-scale structure of the cosmos reproduce the observed distribution of galaxy clusters and voids only if a galaxy's color and fertility depend on the mass of its dark matter halo alone, he says. "The probability of being red has to be independent of the environment," he says.

Other studies are probing the tricks of a galaxy's heart. A galaxy can possess a radiation-spewing "active galactic nucleus" (AGN) that presumably arises when gas falls into the supermassive black hole in the galaxy's center and heats up to a temperature of millions of degrees. Researchers think that can happen when one galaxy jostles another. But can it happen in an isolated galaxy?

To find out, IAA's José Sabater looked for AGNs as part of the AMIGA project, which reanalyzes the galaxies in Karachentseva's 1973 catalog using new data. With data from the Sloan survey and elsewhere, he found that 21% of 353 isolated galaxies had AGNs. That's well below the 33% rate that M. Angeles Martinez of the University of Zaragoza in Spain found in her study of galaxies in groups. The results don't necessarily prove that a galaxy can toss gas on its own heart to make an AGN, Sabater says: An isolated galaxy with an AGN may have been perturbed while consuming a now-vanished companion.



Mosquitoes. All large galaxies likely have tiny companions like the one NGC 5907 has shredded.

Still, the results put a limit on what a galaxy can do alone. AGNs come in two types: those that emit radio waves and those that are "radio quiet." Sabater finds only radio-quiet AGNs in isolated galaxies. "We can conclude that the environment is fundamental for triggering a radio AGN," he says.

Astronomers would also like to know what sorts of structures a galaxy can generate by itself. Theorists generally agree that bloblike elliptical galaxies can form only through galaxy mergers, whereas a well-isolated galaxy has a strong tendency to form a spiral. Data seem to back that up: The various studies suggest that fewer than 20% of isolated galaxies are elliptical.

Isolated galaxies have already given theorists modeling structure something to puzzle over, however. AMIGA researchers find that at least two-thirds of the isolated spirals lack the prominent bulges often seen in spiral galaxies such as the Milky Way. "Bulgeless spirals are a challenge to the simulations, because they don't produce them in great numbers," says Evangelia Athanassoula of the Astronomy Observatory of Marseilles Provence in France. So theorists may have to rethink certain details of galaxy structure formation.

A loner and its companions

The question of what counts as isolation among galaxies can be subtle, as becomes clear when researchers turn to the Milky Way. The Milky Way has remained relatively unmolested for billions of years, and theorists need invoke no external influence to explain its properties, says François Hammer, an astronomer at the Observatory of Paris. By that measure, "I would say that the Milky Way is isolated," Hammer says.

But the Milky Way is surrounded by tiny dwarf galaxies—"mosquitoes," conference attendees call them—some of which it is shredding. "The companions of the Milky Way definitely feel its effect," says Eric Wilcots of the University of Wisconsin, Madison. Given that it's ripping its neighbors apart, the Milky Way might also exemplify an interacting galaxy.

Such ambiguity aside, the search for isolated galaxies seems likely to continue as ever more data become available. The Sloan survey measured the positions of 930,000 galaxies; the proposed 8-meter Large Synoptic Survey Telescope would pinpoint billions. The data might reveal inherent and environmental effects too small to be seen now. "I think we have a good chance to solve this problem" of the relative importance of nature and nurture in galaxy evolution, Hammer says. However, the answer may depend on how precisely you define the question. **–ADRIAN CHO**

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