Starbirth Memories

A galaxy colors astronomers' impressions of star formation

By RON COWEN

The giant galaxy lay dormant, a nearly starless disk of gas and dust measuring some 100,000 light-years across. Then a mere pipsqueak of an intruder – a galaxy with just one-tenth the mass – plowed through the center of the larger galaxy, and the sleeping giant burst into life.

Astronomers liken the intrusion to the ripples created when a rock falls into a placid pond. But this celestial perpetrator exerted a far more powerful influence. It caused gas clouds to collide and form a ring of starbirth expanding outward from the center of the giant disk, lighting up the galaxy in a rainbow of colors that tells a unique tale of stellar evolution.

Just as the different layers of a tree, from new growth just beneath the bark to older layers surrounding the core, mark the passage of the years, the layout of the giant galaxy reflects increasingly ancient epochs. From the outskirts of the disk – the current location of the expanding ring – to its center, the color spectrum shifts from the bright blue of young, massive stars to the reddish hue of older, less massive objects. Within the ring lies the freshest batch, dominated by heavy, short-lived stars that radiate blue light. At the center, near the site of the fateful collision that triggered the ring's formation, starbirth has already come and gone. Here, the hot blue stars have burned out, leaving behind the telltale red of less massive, more mature stars, which last hundreds of millions of years longer.

Astronomers are now documenting these color changes for the first time. With the help of a state-of-the-art infrared detector, they have begun to reconstruct the violent past of this intriguing structure – dubbed the Cartwheel – and other so-called ring galaxies. The gradual shift in color seen in these galaxies, from their nucleus on out, offers an unusual peek into the history of star formation, enabling astronomers to test models of stellar evolution in an entirely new way, says Philip N. Appleton of Iowa State University in Ames.

Simply put, the moving ring of starbirth separates old stars from their more youthful counterparts, dramatically simplifying the study of stellar processes.

"It's very rare in astronomy that you have such a classic cosmological experiment," notes Appleton. "In a more typical galaxy, you have this [central] disk where all stars form and die – they're all jumbled together. The history of star formation gets smeared out because the old stars get mixed in with the new generation of stars, instead of being born in new [separate] regions."

"But in the ring galaxies," he adds, "we're actually seeing the sequence of events separated. In a sense, as we examine stars closer to the nucleus, we're looking back to earlier epochs in these galaxies. It's almost a unique phenomenon in astronomy that you can map out the history of star formation in a galaxy at much earlier times. In the trail of old stars [nearest the galactic center], we're seeing evidence of what the ring – and the galaxy – was like nearly 100 million years before its present state."

Appleton and a graduate student, Pamela M. Marcum, now at the University of Wisconsin-Madison, began their survey by examining the Cartwheel in unprecedented detail. One of the most geometrically perfect of the 30 or so known ring galaxies, the Cartwheel, located some 270 million light-years from Earth, contains both an inner and an outer ring, with spiral "spokes" of stars connecting the two. Appleton and Marcum set out to verify an intriguing notion based on a model of the Cartwheel described in 1987 by Appleton and Curtis Struck-Marcell, also of Iowa State. Their model suggested that if astronomers could accurately record the color distribution of stars located at different radial distances between the Cartwheel's inner and outer rings, it could provide a living memory of the galaxy's star-formation history.

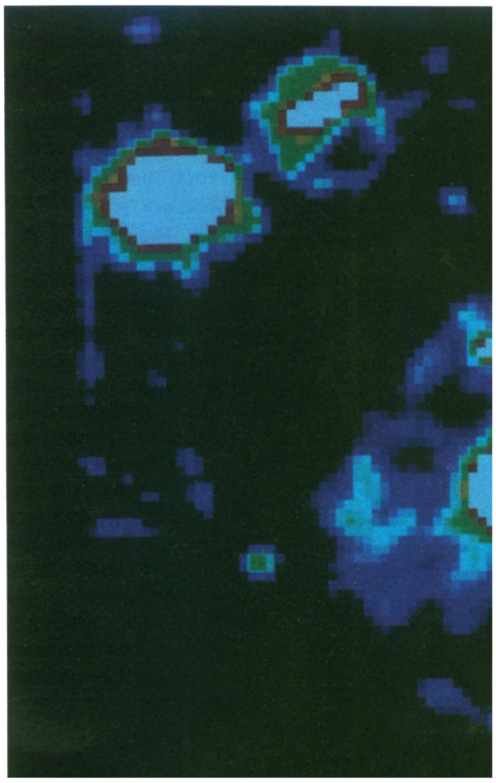
"What we're trying to do with the ring galaxies," says Appleton, "is to use them as a laboratory for exploring all sorts of ideas about the structure of galaxies and the processes that lead to bursts of star formation."

Marcum and Appleton made their recent measurements using a new, highly sensitive infrared detector called an infrared array (SN: 11/16/91, p.312), along with the U.K. Infrared Telescope atop Mauna Kea in Hawaii. The sensitivity of their detector enabled them to record Cartwheel star clusters so dim that, when viewed from a telescope on Earth, they appear no brighter than a 100-watt light bulb would appear on the moon. Combining the infrared observations with a visible-light study of the Cartwheel conducted by James L. Higdon of the University of Texas at Austin, the Iowa pair found that the color shift from blue to red far exceeded the shift seen in normal spiral galaxies. They presented their findings in January at a meeting of the American Astronomical Society in Atlanta.

The team's color map suggests that the oldest stars in the Cartwheel formed about 100 million years ago and lie just outside the inner ring – two indications that the galaxy was virtually starless before a tiny intruder apparently collided with it more than 100 million years ago. The observations, says Appleton, also indicate that the proposed collision took place slightly off center within the nucleus of the Cartwheel: A lopsided punch would generate a somewhat asymmetrical wave of starbirth, explaining why newborn stars concentrate along one section of the outer ring instead of being distributed uniformly around it.

"It's as though star formation was turned on in just one part of the ring: One quadrant is bursting with stars and the rest is virtually dead," Appleton says.

Lest anyone take the structure of a ring galaxy for granted, Appleton notes that the colorful pattern of star formation depends on more than the chance collision of a dormant galaxy with a smaller interloper. Even after a ring forms, the gradual color change from blue to red will not develop unless the time it



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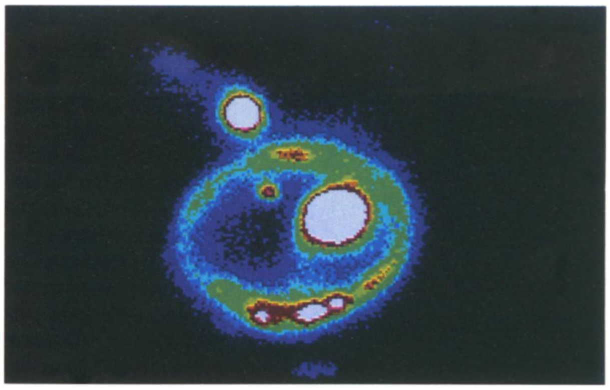
takes for the ring to move through the galaxy matches the 200-million-year lifetime of an average intermediate-mass star. "It's just a wonderful coincidence that the time scales match in the Cartwheel," says Appleton.

If the starbirth ring moved much faster, he notes, then virtually the entire galaxy would contain massive young stars and appear blue. If the ring moved much more slowly, only the oldest, least massive stars would have remained, leaving the galaxy with a reddish hue except for a tiny blue region of new stars just around the ring, Appleton says.



Marston, Appleton

False-color visible-light image of a ring galaxy called IIHz4, showing a single ring of new starbirth surrounding a nucleus of older stars. Astronomers suspect that the small galaxy at top left may have collided with IIHz4 in the distant past, creating the ring structure. White represents the highest intensity of starlight, blue the lowest.

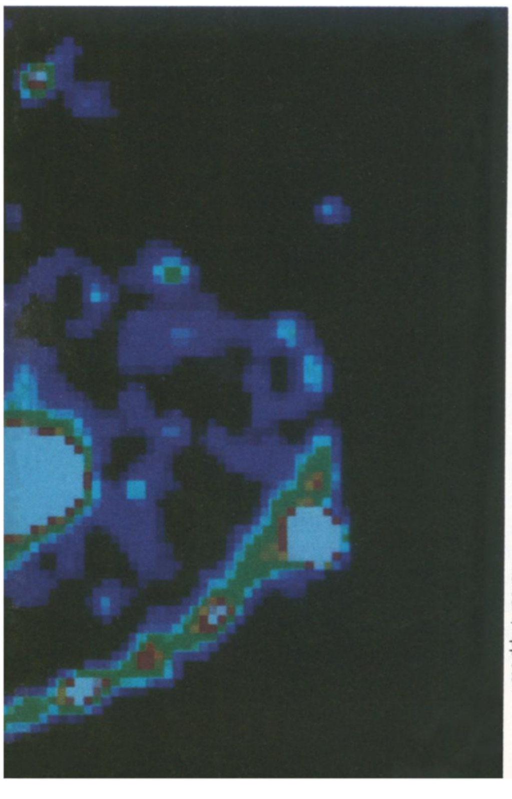
A journey from the outskirts of the Cartwheel to its center constitutes a voyage through time, he notes. "You're looking at a time-lapse sequence of star formation spread out over the galaxy," where the oldest stars lie near the center and the youngest are farther out, he notes. "That's what is so amazing about the Cartwheel."

Appleton estimates that about 1 million of the many billions of stars in the Cartwheel's outer ring range from eight to 30 times the mass of the sun and thus rank among the most massive stars in the universe. Known as O and B stars, these objects burn out in just a few million to a few hundred million years. But while they last, their intense radiation overshadows that emitted by the far larger population of less massive stars also born in the ring. Although O and B stars emit primarily blue light, infrared observations prove useful in detecting them, since these objects quickly evolve into puffed-up stars called red supergiants, which emit copious amounts of red light.

Just inside the outer ring lie older clusters of stars that have already lasted for many millions of years. In such older populations, the O and B stars have died, ending their lives explosively as supernovas. Other, less massive stars, known as the A, F and G classes, live longer and are still present in populations nearer the Cartwheel's nucleus. But when observations focus on even older populations of stars, which lie closer yet to the center of the Cartwheel, a different picture emerges. Here, even the relatively bright, intermediate-mass stars have died out, and the dimmest stars (with masses less than that of the sun) get their turn in the limelight, glowing primarily in the red.

Models of stellar evolution predict that intermediate-mass stars eventually evolve into inflated objects known as red giants (a star class separate from the shorter-lived red supergiants), shedding their outer gas envelopes and spewing dust in the process. Since dust glows brightly in the infrared, it may provide scientists with a marker for this phase of stellar evolution. In fact, observations of millions of intermediate-mass stars near the center of the Cartwheel – those old enough to have entered the red giant phase – seem to show extra emissions in the infrared, indicating that they have evolved as predicted, Appleton says.

He compares the Cartwheel's inner ring to a second "ripple" in the wake of the galactic collision that happened long ago. Over hundreds of millions of years, a third expanding ring may form near the galaxy's center, he adds.



Marcum, Appleton

False-color infrared image of the Cartwheel galaxy, showing inner and outer rings. Clusters of stars form spoke-like features between the rings; oldest clusters lie near the galaxy's core, while the youngest lie in the outer ring. Intensity of starlight rises in the outer ring, starts to drop toward the center, and then peaks in the core, which features the highest density of stars. The two small galaxies at upper left represent candidates for the tiny intruder believed to have plowed through the Cartwheel's center, prompting the onset of starbirth.

Appleton and Anthony P. Marston of Drake University in Des Moines, Iowa, have now observed 15 other ring galaxies in the infrared. A preliminary analysis of their data indicates that many of the ring galaxies exhibit telltale color gradations, some even more pronounced than those in the Cartwheel, Appleton told Science News.

Appleton now plans to reexamine the ring galaxies already observed in the infrared and in visible light, this time at radio wavelengths. "We've used this beautiful cosmic experiment to study star formation; now we're going to use it as a guide to study the magnetic field of the galaxy," he says. Since astronomers can't observe the strength of a magnetic field directly, they track its influence by detecting radiation emitted by charged particles constrained to move in circles about the field.

For instance, when massive stars in the expanding ring of the Cartwheel or one of its sister galaxies explode as supernovas, they spew out countless high-speed electrons. These charged particles then serve as radio-wave spotlights, "illuminating" the structure of the magnetic field behind the ring by interacting with it.

The distribution of high-speed electrons may also shed light on the overall structure of ring galaxies. In fact, the concentration of high-speed electrons should trace out the starbirth pattern, Appleton says. Because the supernovas – the source of fast electrons – cluster just inside the outer ring, the largest concentration of electrons should lie in the same region. Similarly, the concentration should peter out toward the center of a ring galaxy, where few, if any, supernovas reside. Higdon has already conducted radio observations that show this effect in the Cartwheel.

If new radio observations confirm Appleton's prediction, they will add weight to astronomers' growing conviction that the structure of ring galaxies offers a key to understanding many of the mysteries of stellar and galactic evolution. □