

Galaxy Archaeology with Amateurs

A backyard astrophotographer helps reveal the building blocks of galaxies.

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Galaxy evolution is a hot field of research today. Astronomers are asking how galaxies formed then evolved to produce the grand design we see around us.

How did galaxies grow as big as they are? The most widely accepted cosmological model, known as Cold Dark Matter, or CDM, proposes a hierarchical scenario in which low-mass galaxies in the early universe merged to form increasingly larger assemblages surrounded by an entourage of smaller survivors (S&T: October 2007, page 20). Until recently the best evidence of this scenario was

our own Milky Way's interactions with its smaller satellite galaxies. Now other examples of galaxy cannibalism are coming to light with the help of an unexpected source: amateur astrophotographers.

Galaxies formed when the universe was young, making it virtually impossible to study firsthand the processes involved. Spiral galaxies in and near our Local Group are the best laboratory for the up-close investigation of stellar fossils associated with galaxy formation.

Using high-resolution computer simulations, astronomers compare observations of Local Group galaxies with theoretical predictions about their hierarchical formation. This research suggests that large galaxies such as the Milky Way may have devoured more than 100 low-mass star systems during the past 13 billion years. The remains of these mergers should be visible as faint arcs and loops known as tidal star streams.

These streams are vast rivers of material pulled from an orbiting dwarf galaxy as it is gravitationally disrupted by the larger spiral companion. The trail of debris, which can persist for several billion years, is littered with stars, globular clusters, and possibly dark matter. These structures trace the dwarf's final orbits and can completely

While hunting for evidence of galaxy cannibalism, Spanish astrophysicist David Martínez-Delgado invited California amateur astronomer R. Jay Gabany to join an international team searching for faint tidal streams surrounding warped spiral galaxies. *Left:* With more than 11 hours of exposures using his 20-inch telescope and SBIG STL-11000M CCD camera, GaBany caught faint tidal streams while imaging NGC 5907, a spiral galaxy in Draco. *Right:* GaBany later processed the raw image for aesthetic purposes, displaying both the faintest and brightest parts of the galaxy simultaneously.



R. JAY GABANY / COSMOTOGRAPHY.COM (2)



In this model of the tidal stream surrounding NGC 5907, colors correspond to the age of each structure. For example, dark blue represents material lost from the progenitor dwarf galaxy about 3½ billion years ago.



field of view, their distance reduces their brightness and requires long exposures to gather data. Unfortunately, competition for professional telescope time limits extended observations.

Enter today's amateur astronomers. Recent advances in the sensitivity of commercially available CCD cameras, coupled with larger-aperture amateur telescopes in dark sites, opens the possibility for new research. In 2006 the authors began a collaborative effort to find stellar streams surrounding nearby spiral galaxies.

Our first target was NGC 5907, a spiral galaxy in Draco, about 40 million light-years from Earth. This galaxy shares several characteristics with the Milky Way: shape, luminosity, and mass. In 1998 a group of Chinese researchers led by Zhaohui Shang obtained deep images that first revealed a very diffuse elliptical ring in this galaxy's outer halo, located about 160,000 light-years from the spiral's central region.

Our series of observations between June and August 2006 accumulated more than 11½ hours of exposure time with a 20-inch (0.5-meter) telescope. The resulting image (shown on page 92) clearly shows that the ring discovered

by Shang and his team is only the brightest part of a larger structure consisting of several ghostly diffuse arches sur-

rounding NGC 5907. They were probably produced by the tidal destruction of a satellite galaxy.

Half a dozen arches extending on both sides of the galaxy's disk seem to share a common structure and are very similar to the rosette shape rendered by computer models. Although these arches have similar widths and curvatures, they do not reveal the number of satellites involved in their creation. To resolve this issue, Jorge Peñarrubia, a theoretical astrophysicist at Canada's University of Victoria, prepared a computer simulation that described the destruction of a low-mass orbiting galaxy paired with a larger companion having a gravitational potential similar to NGC 5907.

Peñarrubia's model provides an explanation for the position, size, and orientation of the arches seen in our image. It suggests that we're witnessing the final destruction of a single dwarf galaxy that has already lost about 60% of its mass. Its low-eccentricity, almost polar orbit shares an extraordinary similarity to the location of the Sagittarius stream around the Milky Way.

The model also suggests that the complex tidal stream was formed during four orbits. The oldest tail was deposited about 4 billion years ago, making it the most ancient galaxy fossil detected in the halo of a spiral galaxy. For comparison, the known parts of the Milky Way's Sagittarius stream were deposited during the past 2 billion years.

But the image of NGC 5907 does not provide any hints on the position or final destination of the dwarf that produced the surrounding structure. The simulation offers clues that it may be located behind the spiral's disk, but it is also plausible that its current size and surface brightness fall well below the detection limits of the image. Therefore, the progenitor dwarf galaxy may be buried somewhere in the stream.

The image is also noteworthy because it displays the first direct observational evidence that the stars and dark matter comprising tidal streams can penetrate the spiral disk of a galaxy — a phenomenon that had already been predicted by theoretical models of the Milky Way's Sagittarius stream. The effect of this interaction on the



To listen to a podcast interview with Jay GaBany, visit SkyandTelescope.com/archeology.



According to the Cold Dark Matter model, spiral galaxy halos should still contain fossils of at least 100 cannibalized dwarf galaxies. This computer simulation depicts some of these structures, visible as streams of stars surrounding the disk of the galaxy. Images are revealing these tidal streams around nearby spiral galaxies and our own Milky Way.

SANJIB SHARMA / KATHRYN JOHNSTON / JAMES BULLOCK

galaxy's disk is still unknown, although it's reasonable to speculate that it could induce star formation and other large-scale disturbances.

Discovery in NGC 4013

NGC 4013, also known as the Diamond Ring galaxy, is about 55 million light-years away in the direction of Ursa Major. Professional astronomers made an unsuccessful search for tidal streams around NGC 4013 in 2002 using a 1-meter telescope at Arizona's Kitt Peak National Observatory. Of all the galaxies sampled during that investigation, NGC 4013 was the only example displaying a diffuse, faint, and very elongated cloud. Unfortunately, its faintness and the short exposure's poor signal-to-noise ratio prevented astronomers from discerning whether it was part of a stream or just a bright peripheral spiral arm.

Once again, GaBany's new, deep images revealed an enormous loop-shaped structure and confirmed the initial suspicions. This loop is practically hidden by the galaxy's disk and possesses two possible extensions on the other side of the spiral, seen edge on from our perspective.

An interesting corollary to this discovery is the pos-



RON WODASKI

Although R. Jay GaBany's 20-inch Ritchey-Chrétien telescope is modest by professional standards, it's capable of producing high-quality scientific data by simply making very long exposures. Time is the single greatest advantage amateurs have over professional astronomers.

sible relationship between the stream and NGC 4013's prodigious disk warp. For example, the presence of gigantic, seemingly windblown, and sometimes star-studded gas structures can modify the shape of galaxy disks such that, when viewed edge on, they have the appearance of the integral symbol (\int). Although warps have been known for decades, astronomers continue to debate their origin.

An early theory attributed warps to gravitational interaction with satellite galaxies, but this idea was discarded due to the absence of detectable companions near many warped spirals. This was the case for NGC 4013 and NGC 5907, which have long been regarded as isolated galaxies.

But our observations indicate that both galaxies are experiencing interactions with one of their satellites as evidenced by the huge star streams. For this reason, both galaxies can no longer be considered isolated. Each represents a Rosetta Stone in our understanding of the formation of warped galaxies.

Future Prospects

The study of tidal streams is a relatively young field of research that provides new opportunities for addressing open issues related to the formation and evolution of galaxies. These include questions about the effect of tides on stellar populations within dwarf galaxies and the impact of mergers on the shape of spiral galaxy disks.

Furthermore, the radial velocities of globular clusters and planetary nebulae within tidal streams, obtained with 10-meter-class telescopes, will improve our understanding of the gravitational potential of nearby spiral galaxies. This will also help us probe one of the most profound galaxy mysteries: the nature of their dark-matter halos.

While waiting to collect information from large professional telescopes, our search for tidal streams in local spiral galaxies will continue with modest amateur instruments. Our investigations into galactic archaeology demonstrate the potential of 21st-century amateurs, armed with the latest technology, to participate in highly competitive international scientific projects. ♦

David Martínez-Delgado of the Astrophysical Institute of the Canaries continues to collaborate with California-based amateur astrophotographer R. Jay GaBany to reveal other mysteries of galaxy evolution.



R. JAY GABANY / COSMOTOGRAPHY.COM

GaBany's deep exposure of NGC 4013 reveals a prime example of galaxy cannibalism in action. The resulting CCD image unveils an enormous star stream. The structure was only hinted at in earlier views obtained with a 1-meter telescope at Kitt Peak National Observatory.