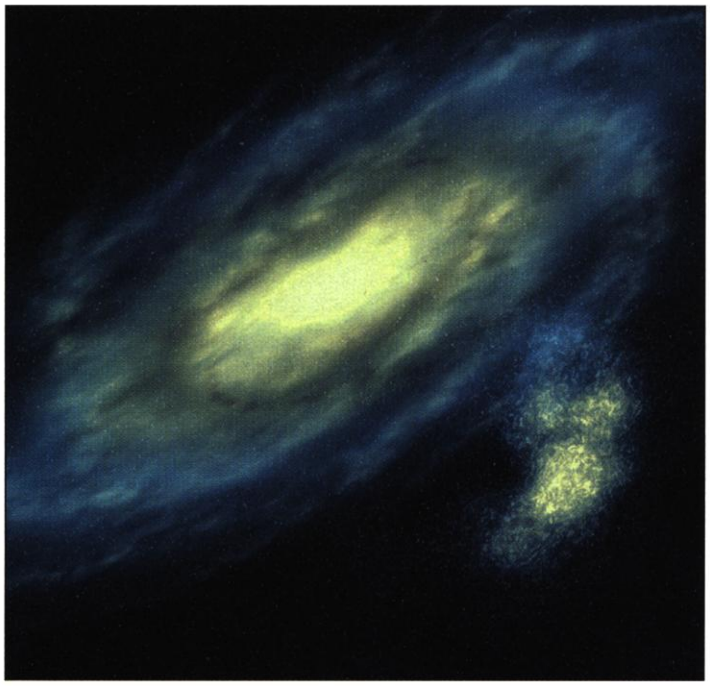
NEWS

A Crushing End for Our Galaxy

The galactic mergers that help mold the Milky Way are mere fender benders compared to the mighty collision that promises to destroy it

On Wall Street, mergers are a way of life. Big businesses gobble little ones with abandon, while giant corporations merge in multi-billion-dollar megadeals. Little do the corporate sharks know that these banal feeding frenzies mimic far grander events in the universe, where large galaxies gently gulp smaller ones or smash into each other in cataclysms that spawn the titans of the cosmos.

Despite its apparent calm, our Milky Way is not immune to this turmoil. Astronomers have long suspected that small clumps of stars and gas—the flotsam and jetsam of intergalactic space—rained down upon our infant galaxy to help build its structure. Now they are beginning to spy evidence of past mergers: stars that stream in lockstep, tracing the paths of long-vanished minigalaxies devoured by the Milky Way. Other mergers are taking place even now, as clouds of gas fall into our galaxy and a nearby dwarf galaxy is shredded by the Milky Way's intense tidal forces. And a few billion years from now—perhaps even before Earth is incinerated by our dying sun—looms our galaxy's brutal fate: a merger with M31, the Andromeda galaxy. That gigantic collision will leave behind a haphazard wrack of stars and dust.



Galactic snack. An observer on the far side of the Milky Way would see this elongated clump of stars, the Sagittarius dwarf galaxy, merging with our own. Less than a billion years from now, the process may be complete.

When telescopes began taking snapshots of collisions unfolding elsewhere in the universe, many astronomers viewed these events as the exception rather than the rule. But recent findings have erased most such doubts, says astronomer François Schweizer of the Carnegie Observatories in Pasadena, California. Indeed, violent encounters between spiral galaxies may have produced most of the bloblike elliptical galaxies in the universe today, he says. "Mergers are the major drivers of galactic evolution."

Let there be clumping

Without mergers, the universe would be populated by dwarfs. Theorists believe that the first major objects that clumped together in the early universe held about 1/100,000th the mass of today's Milky Way. These galactic building blocks contained heavy dollops of dark matter—mysterious stuff that emits no light of its own—and perhaps the earliest generations of stars. In many regions of space, clumps formed close enough to each other for gravity to draw them into head-on collisions. This process continued within clusters of galaxies, creating a universe in which galaxies grow heftier with time.

This notion of progressive clustering was appealing, but it took a stunning picture to drive it home: the Hubble Deep Field. That 1996 image from the Hubble Space Telescope revealed thousands of distant galaxies within a tiny patch of sky in the Northern Hemisphere, a glimpse of a time when the universe was as young as 10% of its current age. Most of the galaxies were not at all like the ones seen today. "The distant galaxies were smaller and more irregular, and they gave the visual impression that they were still forming," says astronomer Leo Blitz of the University of California, Berkeley.

The Milky Way is still under construction, it seems. In a talk next week at a meeting of the American Astronomical Society in Atlanta, Blitz will argue that curious patches of hydrogen gas seen all over the sky represent minigalaxies that continue to fall into the Milky Way and generate waves of star birth. Astronomers have known of these patches, called "high-velocity clouds," since 1963, but no one has explained their origins or measured their distances from Earth. Blitz's team has used indirect lines of evidence to reason that they lie outside the galaxy, scattered throughout the Local Group, a loose knot of galaxies that encompasses the Milky Way, Andromeda, and numerous dwarfs. If so, they may be remnants of the first blobs that coalesced in the universe. Blitz believes that long telescope exposures may reveal stars within the clouds.

However, astronomer Bart Wakker of the University of Wisconsin, Madison, feels Blitz is stretching his interpretations too far. Wakker and his colleagues reported in the 25 November issue of *Nature* that the largest known high-velocity cloud contains few heavy elements. That's just as one would expect if the cloud dated from the early universe. But Wakker observes that astronomers have not yet seen such hydrogen clouds in other galaxy groups, as should be the case in Blitz's scenario. Instead, he believes the clouds are remnants of gas torn from nearby dwarf galaxies that wandered near the Milky Way. Regardless of their origins, the clouds should merge with the Milky Way and replenish its hydrogen fuel supply at a pace sufficient to produce about one new star per year—roughly the observed rate, Wakker says.

If it turns out that some of the clouds are minigalaxies, they may help solve a puzzle. According to models of how the early universe formed, the Local Group should include many more small satellite galaxies than are seen, says astrophysicist Anatoly Klypin of New Mexico State University in Las Cruces. The satellites should have arisen from the smallish lumps of dark matter that dominated the young cosmos. Although large galaxies probably absorbed most of those lumps within a few billion years, many

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New Probe to Chart The Milky Way

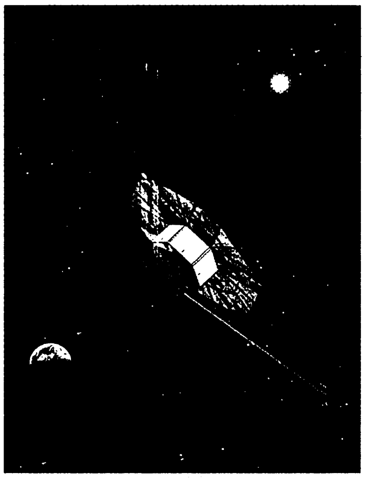
The oldest branch of astronomy is about to get a new boost. Called astrometry, it began in the 2nd century, when Greek astronomer Hipparchus of Nicea measured the brightness and positions of more than 1000 stars in the celestial sphere. Now an upcoming NASA mission promises to pinpoint millions of stars and uncover perhaps thousands of planetary systems in the Milky Way.

Astrometry took a back seat to astrophysics and cosmology for decades, until the European Space Agency (ESA) launched a satellite in 1989 named Hipparcos. By the time it had completed its mission in 1993, Hipparcos had determined the positions of over 1 million stars, 120,000 of them with an accuracy 10 times better than can be achieved from the ground, providing a fine-scaled map of our galactic neighborhood out to 500 light-years. Hipparcos scientists were also able to determine precise distances to many stars from their parallax—the ellipse a star appears to describe on the background of more distant stars as Earth circles the sun. "Hipparcos opened the eyes of many astronomers," says Lennart Lindegren of Lund University in Sweden.

Now NASA is hoping to grab some of this limelight with its Full-Sky Astrometric Mapping Explorer (FAME), a $162 million satellite set for launch in 2004. The brainchild of astronomers at the U.S. Naval Observatory in Washington, D.C., and the Harvard-Smithsonian Center for Astrophysics, FAME will feature a telescope with mirrors that allow it to observe stars in two different parts of the sky at one time, increasing the data flow. Thanks to FAME's bigger telescope and better charge-coupled devices, it will peer 10 times deeper into space than Hipparcos—covering about 1000 times more volume—and chart a whopping 40 million stars.

Over its 5-year lifetime, FAME will observe every star 1000 times, enough repetition to plot stellar positions to within 50 millionths of an arc second—the apparent size of a house on the moon, as seen from Earth—and determine precise parallaxes. Among the 40 million twinkles FAME plans to keep an eye on are a number of Cepheids, variable stars that wax and wane in brightness. Because the interval between pulses is directly related to a Cepheid's absolute brightness, these beacons are used as yardsticks for measuring distances from Earth to other galaxies. By precisely determining the parallaxes (thus distances) of about 40 nearby Cepheids, FAME will allow scientists to reduce the uncertainty in this cosmic scale bar from as much as 20% down to about 1%.

Sifting the data for unpredicted wobbles in star movements should turn up a bounty of other prizes, from unknown binary systems to an estimated 25,000 extrasolar planets that FAME scientists say might be hiding among these millions of stars. Observing the speeds at which stars whip around the galactic center should also help scientists better calculate the total mass of the galaxy and refine its proportion of dark matter, which is believed to make up about 90% of the total mass. "I think [FAME] will be a same leap forward as the one we had with Hipparcos," says George Gatewood of the University of Pittsburgh, who will use the satellite to hunt for extrasolar planets.



Starry-eyed. FAME will pinpoint precise positions for 40 million stars.

Nor will FAME have the last word: NASA aims to track stars with even greater precision with its Space Interferometry Mission, a satellite it hopes to launch in 2006. And ESA is considering plans for the most ambitious mission of all, the Global Astrometric Interferometer for Astrophysics. A possible go after 2008, this satellite would chart nearly the whole Milky Way. The renaissance of astrometry will continue.

—ALEXANDER HELLEMANS

Alexander Hellemans writes from Naples, Italy.

hundreds of dim galaxies should survive in our cosmic neighborhood today, Klypin and several co-workers claim in the 1 September *Astrophysical Journal*. Instead, astronomers have found only about 40. The high-velocity clouds could make up part of the difference.

The throng of nearby dwarfs should be dwindling slowly as they merge with the Milky Way, and astronomers may now be identifying traces of these collisions. Amina Helmi of Leiden University in the Netherlands and her colleagues studied data from the European Hipparcos satellite, which measured the motions of thousands of nearby stars. They found evidence for about a dozen stars moving at nearly identical clips and along similar paths through the tenuous but enormous spherical "halo" of stars girdling the galaxy's central bulge. "It's very unlikely to have that many stars comoving in the halo unless they had a common origin in a small galaxy that fell onto the Milky Way many billions of years ago," says Helmi, whose findings appeared in the 4 November issue of *Nature*. According to astronomer Sidney van den Bergh of the Dominion Astrophysical Observatory in Victoria, British Columbia, the research jibes with a growing suspicion that the halo is a melting pot of "little bits and pieces that have accreted over time."

Although it may seem extraordinary that stars would preserve signatures of their original orbits so long after their parent galaxies disintegrated, simulations show that those tracers are feasible, says astrophysicist Joshua Barnes of the University of Hawaii, Honolulu. "My bet is that as we look farther, we'll be able to tease apart the entire halo as a collection of these star streams from past mergers," he says. Help on this front may come from two planned NASA satellites—the Full-Sky Astrometric Mapping Explorer in 2004 (see sidebar) and the Space Interferometry Mission in 2006—which will greatly expand the number of stars with known orbits.

However, analysis of the Milky Way's dynamics suggests that most major mergers must have happened before the galaxy formed its thin disk of stars and gas, which orbits the starry central bulge like a spinning Frisbee. Astronomers think the disk is too fragile for mergers to have contributed more than a few percent of its mass in the last 5 billion years. Otherwise, the disk would be severely distorted or puffed up from the gravitational eggbeater effects of incoming stars. Thus, it seems, "not much has happened" of late on the merger front, says astronomer Rosemary Wyse of The Johns Hopkins University in Baltimore, Maryland. "We may have continued to accrete little dwarf galaxies, but that's about it."

What giveth shape, taketh away

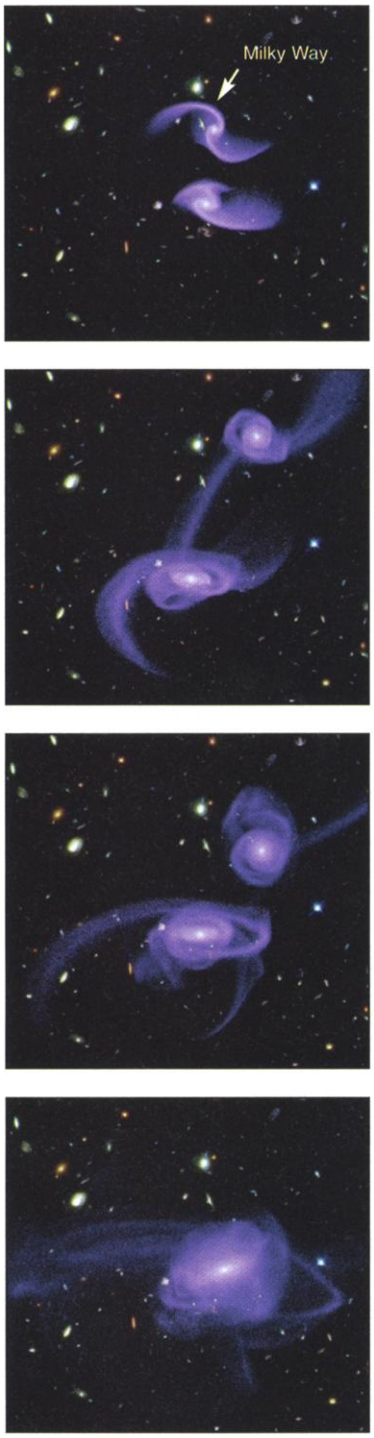
That is not to say that the era of mergers is past. For evidence to the contrary, one need look no farther than the Sagittarius dwarf galaxy, a motley bunch of stars discovered in 1994. Nearly hidden behind the dense central regions of the Milky Way, the Sagittarius dwarf contains about 1000th the mass of our galaxy. Its orbit is not yet clearly defined, but it appears to loop around the Milky Way on a

CREDIT: USNO/NASA

long, egg-shaped path. The Milky Way's tides are strong enough to rend the dwarf into a stretched-out shadow of its former self. New observations reveal a ribbon of about 10 stars along the dwarf's route that extends nearly around our galaxy, like a sinuous tail curving behind a diving kite. Presumably, those stars are "tidal debris" stripped from the dwarf during previous orbits, says astronomer Geraint Lewis of the University of Victoria in British Columbia.

The dwarf's path may already have forced it to traverse the outer parts of the Milky Way's disk several times. Its tattered condition suggests it may not survive much longer than one more orbit, or about 750 million years, says astronomer Kathryn Johnston of Wesleyan University in Middletown, Connecticut. "We've developed a really compelling picture of a galaxy being torn apart," she says.

Another merger is playing out more slowly, but it will pack more punch. The Milky Way is also mixing it up with the nearest nondwarf galaxies: the Large and Small Magellanic Clouds (LMC and SMC), visible as gauzy blurs in the Southern Hemisphere. These companions interact with each other as well as with the Milky Way's extended cocoon of dark matter and hot gas. The combined gravitational tugs produce a tortured-looking system: Gas and some stars form a bridge that connects the two distorted clouds, while the long Magellanic Stream of gas trails behind.



Future shock. Frames from a supercomputer simulation show the Milky Way and Andromeda galaxies approaching, zipping past each other, then merging in a chaotic blaze of new star birth.

Some astronomers maintain that the Magellanic Stream consists of gas stripped from the clouds as they slog through the Milky Way's extended shroud of gas. But in 1998, a team of astronomers led by Mary Putman of Australian National University in Canberra also found evidence for a more ethereal stream ahead of the LMC in its orbit. Gas stripping cannot explain that observation, Putman says, because all such material would trail behind the clouds, like hair blown back from a hair dryer. Rather, tidal forces from the Milky Way must draw gas from both the leading and trailing edges of the clouds, just as the moon raises watery tides on both the near and the far sides of Earth. Models of the clouds' orbits suggest that they will spiral into the Milky Way, a swan song that may not play out for another 10 billion years.

The LMC and its 3.5 billion or so stars are a much bigger mouthful than the Sagittarius dwarf or the other runts sucked up by the Milky Way during the last several billion years. Even at its current distance, the LMC appears to have warped the Milky Way's disk slightly, according to Martin Weinberg of the University of Massachusetts, Amherst. And when the two galaxies merge at last, the union should produce quite a fireworks show when gas-rich clouds collide and collapse from the shocks: enough new star birth in the Milky Way for it to shine at least 25% more brightly for several hundred million years thereafter.

From galactic death, life?

But by that time our own galaxy may be road kill, flattened by the onrushing Andromeda galaxy. Doppler-shifted starlight from Andromeda reveals that the two galaxies are closing the 2.5-million–light-year gap between them at nearly 500,000 kilometers per hour. That pace will quicken as the galaxies approach. If the two galaxies are headed straight on, they will smash within 3 billion years, says astrophysicist John Dubinski of the University of Toronto and the Canadian Institute for Theoretical Astrophysics (CITA). The momentum of the galaxies will carry them past each other initially, but the gravitational attraction of their dark matter halos will doom them to coalesce. At twice the size of the Milky Way, Andromeda and its tides will distort our galaxy beyond recognition, says astrophysicist Chris Mihos of Case Western Reserve University in Cleveland, Ohio. "It will be a major car wreck," he says, "and we're the Yugo in this one."

Great "tidal tails" of stars flung into space by the merger will either fall back onto the galaxies or disperse and fade with time. After 1 billion or 2 billion years, Mihos says, the new object will resemble a stirred-up elliptical galaxy, with stars following myriad orbits like moths around a lamp. Direct hits between the widely spaced stars will be extremely unlikely, but colliding gas clouds will make the supergalaxy bright with newborn suns.

Some researchers have pondered how the encounter will affect our solar system—assuming the sun has not yet swelled into a red giant and fried Earth to a crisp. If the sun is cast into intergalactic space on a tidal tail, it may escape the nascent elliptical galaxy entirely, Dubinski says. In that case, he notes, "we're safe, but our night sky will be devoid of naked-eye stars—sort of like living in downtown Toronto." Another possible fate might fling the sun inward toward blazing cradles of new stars at the merger's gas-rich core. Massive young stars exploding as supernovae and bombardment by comets nudged from their orbits might make that hotbed too harsh for life to continue. Still, the sky would look spectacular: Even many thousands of light-years from the clusters of newborn stars, says the Carnegie Observatories' Schweizer, "you would be able to read the newspaper at night by the light of the starbursts."

Whatever the outlook for our own planet, Schweizer foresees a vibrant future in the supergalaxy born of the merger. The gas in both the Milky Way and Andromeda today is chock-full of the heavy elements needed to build rocky planets, he says, thanks to generations of stars that have processed their nuclear fuel. When the ferment subsides and the most massive stars die off, a vast number of sunlike stars and planetary systems will age in unison for billions of years. "Huge waves of civilizations may reach maturity nearly simultaneously," Schweizer speculates. If so, today's elliptical galaxies—the remnants of long-ago mergers—may teem with life born in the shards of the mighty collisions that continually reshape our universe. **–ROBERT IRION**

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