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The Milky Way's Middle

Getting a clear view

Ron Cowen

Astronomers can peer at galaxies clear across the universe, but they have a hard time looking at the center of our own Milky Way. Only 26,000 light-years from Earth, the galaxy's core is like a smoggy metropolis. Shrouds of dust mask a hotbed of activity. In this teeming galactic city, hundreds of thousands of young stars emerge from their birthing clouds, and massive, elderly stars meet explosive deaths that leave behind X ray-emitting corpses. And at the very center lies a quiescent monster, a black hole some 2.5 million times as heavy as the sun.

Only in the 1970s did astronomers begin to piece together a fuzzy portrait of the galactic center. The first glimmers came from observations of radio waves and X rays, which easily pass through dust, and studies of near-infrared radiation, which can penetrate dust 10 times better than visible-light can. But most telescopes, even if they were tuned to the proper wavelength, weren't sensitive or sharp enough to capture a true image. Now, the eyes of two recently launched X-ray observatories, as well as radio and infrared surveys using sensitive ground-based instruments, have depicted the center of our home galaxy as never before.

TWO VIEWS. In these depictions of the Milky Way's core, dark dust clouds hide much of the structure in the visible-light image (left) but infrared radiation (right) penetrates most of the dust.
H. McCallon, G. Kopan/2MASS

The new images, which reveal hundreds of previously unknown sources of X-ray and radio emissions, confirm that "the center of the galaxy is where the action is," notes Q. Daniel Wang of the University of Massachusetts in Amherst. What's more, getting good views of that action is currently one of the few ways to learn about the formation and evolution of galaxies billions of light years from our own.

"A detailed picture of the physical processes that influence this extraordinary region [in the Milky Way] is key to understanding all other galactic nuclei in the universe," comments Andreas Eckart of the University of Cologne in Germany.

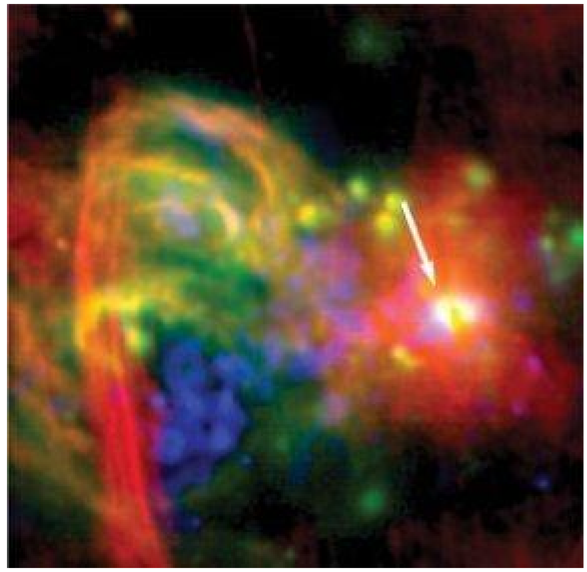
Wang and other scientists unveiled the Milky Way images last month at a meeting of the American Astronomical Society in Washington, D.C.

Panoramic outlook

Using NASA's Chandra X-ray Observatory, which began collecting data over 2 years ago, Wang and his collaborators homed in on high-energy emissions from the Milky Way's central region. The resulting panorama, a composite of 30 pictures showing compact stars bathed in a fog of hot gas, solves a long-standing puzzle. Earlier studies with lower-resolution telescopes had led researchers to assume that most of the X rays came from diffuse gas distributed throughout the core.

To account for all the X-ray emissions, the gas would not only have to be extremely massive but searingly hot?about 100,000 kelvins. A large amount of hot gas is difficult for a galaxy to create and even harder to confine. Astronomers needed to either come up with some new mechanism that could explain the situation or find out what was wrong with their picture.

That's where Chandra has come in. With it, astronomers for the first time can distinguish between X-ray emissions from point sources, typically individual stars, and from the diffuse gas at our galaxy's center. The images show that along with the gas, at least 1,000 point sources?only 20 of which had been previously identified?contribute to the emission.



MULTIWAVELENGTH PORTRAIT. Composite image reveals a star-forming region at the Milky Way's center as recorded at several wavelengths invisible to the eye. Red indicates radio-wave emission, green indicates radiation in the mid-infrared, and blue is X-ray emission at 6,400 electron-volts. Arrow indicates the supermassive black hole at the galaxy's exact center.

Q. Daniel Wang, U. Mass.

With X-ray radiation about equally divided between gas and stars, the gas at the galactic center needn't be as massive or hot as astronomers had estimated. In fact, its temperature need only be about 10,000 kelvins?one-tenth the value that had been originally inferred. Gas at this temperature is much less likely to escape from the central region, Wang notes. In addition to describing these findings at the astronomy meeting, he and his colleagues report their study in the Jan. 10 *Nature*.

Wang's research team focused on X rays associated with iron at the Milky Way's center. Iron atoms radiate most of their X rays at two particular wavelengths, one of which corresponds to an energy of 6,700 electron-volts. This emission is produced by iron atoms stripped of all but 2 of their 26 electrons, and Chandra revealed that most of this radiation comes from point sources.

X rays of exactly this energy are produced when the gravity of a compact star, such as a white dwarf, neutron star, or stellar-mass black hole, rips matter from a lower-density companion star. This suggests that many of the point sources observed with Chandra are extremely dense stars locked in a gravitational embrace with ordinary stars, Wang says.

Iron also emits X rays at the slightly lower energy of 6,400 electron-volts. This radiation occurs when an energetic X-ray source bombards and weakly ionizes the atoms, causing them to fluoresce. The Chandra data reveal that much of the diffuse emission at the galaxy's center is associated with this fluorescence, yet researchers haven't been able to identify any group of X-ray sources bright enough or numerous enough to bombard the iron atoms so effectively.

Wang and his collaborators speculate the source might, in fact, be the supermassive black hole known to lurk at the galaxy's exact center. The region surrounding the black hole today emits little radiation, suggesting that the hole isn't gobbling up much of its surroundings. But several hundred years ago, Wang's team theorizes, the hole may have been more of a glutton. The greater amount of material feeding the hole at that time would have emitted more X rays.

Those X rays would have been scattered by colder gas and by now would have reached a few hundred light-years from the black hole. That's the very region where Chandra's sensors detect fluorescence from iron atoms. The fluorescence could therefore be a sign that the galactic center was a more violent place in the recent past, Wang speculates.

Further observations of the Milky Way's center with Chandra may have an even grander payoff, notes Rosemary F.G. Wyse of Johns Hopkins University in Baltimore. They may shed light on a poorly understood aspect of galaxy formation.

By studying the properties of gas at the galaxy's center, astronomers plan to examine the interaction between the gas and massive stars, which form at a furious rate in a confined region and end their brief lives as supernova explosions, Wyse says.

The interaction, or feedback, played a key role during the earliest days of galaxy formation, notes Wyse. As gas in galaxies cooled, it condensed into stars. When the very first generation of massive stars exploded, it heated the gas that hadn't yet cooled enough to form stars. That heating process, in turn, considerably slowed the process of star formation.

Without such heating, the first, small galaxies to form would rapidly have converted all of their gas into stars. By the time the earliest galaxies merged to form larger ones, most of their gas would have been consumed by star formation and the vast halos of gas that give large galaxies like the Milky Way their enormous breadth would simply not exist.

Although the first supernovas had a profound influence on early star formation, the exact nature of that impact, which astronomers call feedback, remains poorly understood. Since feedback involves gravity and many other factors?such as gas pressure, shock waves from the supernovas, and the effect of radiation emitted during these stellar explosions?it is horrendously difficult to incorporate into computer models of galaxy formation.

"We do not understand how feedback works, and the galactic center is a great test bed" for finding out, Wyse says.

A bird's-eye view

Near-infrared light?which is just beyond the red edge of the visible spectrum?can't penetrate dust as well as X rays can. But observing the Milky Way at these longer wavelengths reveals the more common, cooler stars that make up the bulk of the galaxy's stellar population. Using a select group of 30,000 stars among the 300 million or so cataloged in a huge near-infrared survey called 2MASS (Two Micron All Sky Survey), researchers have produced the first bird's-eye view of our galaxy's spiral disk and the cigar-shape structure, called a bar, at its center.

NEW PERSPECTIVE. The Milky Way as it would be seen by an observer looking down on it. Created by plotting the positions of 30,000 carbon stars, the map depicts the tilted bar at the galaxy's core as well as the outer limits of the starlit disk. Green marks the sun's location; red indicates the galaxy's center.
Skrutskie, Weinberg *et al*./2MASS

Securing such a perspective is no mean feat, considering that earthlings reside within the flattened, rapidly rotating disk of the Milky Way, about one-third of the way in from its outer edge. Our view of the galaxy is normally limited, as though the Milky Way were a dusty, rapidly spinning phonograph record and we were trapped on its surface. The new map, still a work in progress, takes the observer out of the disk of the galaxy, providing the first accurate portrait of what the Milky Way would look like if we could observe it from above.

To attain this lofty perspective, a team led by Michael F. Skrutskie of the University of Virginia in Charlottesville and Martin Weinberg of the University of Massachusetts zeroed in on carbon stars, the brilliant, final stage of stars that weigh one to four times as much as the sun. These middle-aged stars have nearly run out of nuclear fuel. The carbon they produce at their core, as one of their final products of nucleosynthesis, migrates to the surface, where it can be easily detected.

Of all the stars recorded by 2MASS, the astronomers chose to analyze carbon stars first because of three remarkable properties. First, the stars are so bright that telescopes on Earth can detect them throughout the galaxy. Second, although the Milky Way's dust dims the light from carbon stars, the stars remain easy to recognize and they can't be confused with other stars in the survey. Best of all, carbon stars act as standard candles?all these stars have about the same luminosity, as if they were light bulbs of the same wattage. That property turns them into veritable mileage posts marking off distances throughout the galaxy.

By comparing the luminosity of a carbon star to how bright it appears in the sky, Skrutskie, Weinberg, and their colleagues determined the distance to each of the 30,000 carbon stars in 2MASS. Their preliminary map reveals the outer limits of the Milky Way's stellar disk. At the center of the galaxy, the map shows that the galactic bar measures about 15,000 light-years across.

"What is different and new here is that [the team] has been able to map out what is essentially the entire galaxy using these stars," notes Leo Blitz of the University of California, Berkeley. "The very large number of [carbon] stars produces a high-quality bird's-eye image."

The Milky Way's bar and more

Researchers aren't sure how galactic bars form, but computer models suggest that when stars circle the center of a galaxy extremely rapidly, many of their orbits elongate and the stars congregate in a rotating rectangular arrangement. Bars may play a vital role in the evolution of a galaxy because they funnel gas and dust toward the galaxy's center. The infalling material may trigger waves of star formation within the central region. Alternatively, it may provide a steady supply of fuel for supermassive black holes, like the one at the center of our galaxy, notes Blitz.

From an analysis of infrared radiation recorded by a balloon-borne detector, Blitz and David N. Spergel of Princeton University deduced a decade ago that the Milky Way's center should contain a bar. Blitz calls the new map "the most outstanding visual confirmation" of this structure because it plots the positions of individual stars rather than simply accounts for the total amount of light they emit.

Skrutskie and Weinberg are now working to incorporate the other nearly 300 million stars recorded by 2MASS into their galactic map. That's a monumental task, says Skrutskie, because unlike the carbon stars, only a few of the other stars in the survey act as standard candles. For most of the stars, brightness doesn't directly indicate its distance.

Instead, the team is applying statistical methods to place these stars on the map. Relying on known information about the structure of the Milky Way, the researchers seek the model of our galaxy that best matches the colors and positions of all the stars detected by 2MASS. If there's a mismatch, the team slightly varies such properties of the model as the length of the bar or the tightness of the galaxy's spiral arms and then reevaluates the fit between the model and the data.

This iterative, computer-intensive approach could yield within a year a much more detailed map of the entire Milky Way, including its starlit spiral arms, says Skrutskie. The current map provides only a hint of the arms, in part because uncertainties in the distances of the carbon stars effectively blur out such structures, he notes.

A more detailed map could allay concerns of astronomers like Wyse. She worries that carbon stars, which are not the oldest stars in the galaxy, may not be good tracers of the most ancient parts of the Milky Way.

Meanwhile, other astronomers are also constructing new maps of the galactic center, combining radio observations from the Very Large Array radio telescope in Socorro, N.M., with infrared studies and data recorded by the European Space Agency's X-ray Multi Mirror-Newton Observatory, launched in 1999. The goal, says David Helfand of Columbia University, is nothing less than a complete census of stellar birth and death in the crowded core of the Milky Way.

"The bright central regions are all we can see of [distant] galaxies," notes Gerry Gilmore of the University of Cambridge in England. "So if we are to understand them, we need an appreciation from detailed local information in the Milky Way of what processes and time scales are involved" in shaping galaxy cores.

The information, Gilmore cautions, is just beginning to pour in. He notes, "All these new studies are providing a list of the things we have yet to understand."

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Additional information and images from the Chandra X-ray survey of the Galactic Center is available at http://www-astro.phast.umass.edu/~wqd/gcs/.

Further Readings:

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For additional information on the 2MASS survey, go to http://www.ipac.caltech.edu/2mass/index.html.

For a primer on the structure of the Milky Way, see http://casswww.ucsd.edu/public/tutorial/MW.html.

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