ROSAT Revelations

Satellite provides a new view of the X-ray and ultraviolet universe

By RON COWEN

The hidden half of a supernova remnant. Clumps of matter that may be among the largest and oldest in the universe. Stars that glow brightly, but only in the extreme ultraviolet. These are some of the dramatic discoveries emerging from an orbiting observatory called ROSAT.

Launched last June on a mission that will last several years, the German-U.S.-British satellite allows astronomers to explore the sky in two novel ways. One of its telescopes captures X-ray images with unprecedented sharpness; the other detects ultraviolet wavelengths never before imaged from space.

In February, ROSAT (short for Roentgen Satellite) completed its first assignment: a search for low-energy X-ray sources throughout nearly the entire sky. Scanning the heavens in great circles that pass through the north and south ecliptic poles, the German-built X-ray telescope imaged much fainter objects and achieved an angular resolution three times greater than the orbiting Einstein Observatory, which conducted a smaller X-ray-imaging survey in 1979. Astronomers estimate that ROSAT's X-ray telescope, which will now home in on specific targets, has so far imaged 60,000 previously unknown X-ray sources.

ROSAT's other telescope has mapped the sky with an even wider field of view, providing astronomers with their first glimpses of celestial emissions in the extreme ultraviolet. According to ROSAT investigator John Pye of the University of Leicester in England, the British-built wide-field camera has yielded at least one surprise: a potentially new class of bright stars, which seem to shine only in the extreme ultraviolet.

Pye's team is still piecing together the extreme-ultraviolet images, but German researchers have already released more than a dozen photos from the X-ray survey. These depict structures ranging from supernova remnants in the Milky Way to quasars that lie more than halfway to the edge of the observable universe. At the April meeting of the American Physical Society in Washington, D.C., Guenther Hasinger, Bernd Aschenbach and Juergen Schmitt from the Max Planck Institute for Extraterrestrial Physics in Garching, Germany, shared many of ROSAT's X-ray revelations.

A supernova's pulsing heart

The Vela supernova remnant has puzzled astronomers ever since the Einstein Observatory detected its X-ray emissions. In the Einstein images, this Milky Way object — the vestige of a massive star that exploded 20,000 years ago — appeared kidney-shaped and seemed to lie next to a young, energetic pulsar. But the pulsar's position posed a quandary.

In the standard model for many supernovas, the expanding shock wave of interstellar dust and gas swept outward by the explosion harbors a pulsar — a compact star that emits bursts of X-rays — at its center. Thus, astronomers usually assume that a pulsar represents the dense, rapidly rotating "heart" left behind after such an explosion. In Vela's case, however, that picture didn't seem to fit. Rather than lying at the center of the remnant, the pulsar appeared off to one side, leading investigators to wonder whether it had any connection to the supernova.

But ROSAT's X-ray telescope tells a different story. The new, high-resolution images reveal that the Vela supernova remnant is twice as large as astronomers had estimated. The missing piece: a dimmer half that other instruments, including Einstein's, didn't see.

Viewed in its entirety, Vela now appears nearly spherical, not kidney-shaped, reports Aschenbach. And the pulsar lies precisely at its center, squelching doubts that the rotating object belongs to Vela.

The ROSAT photos also reveal that Vela's long-hidden, fainter half produces higher-energy X-rays than its brighter side, indicating that the fainter region has a higher temperature. The new data suggest that the contrast in temperature and luminosity developed because Vela's two halves expanded in different directions, Hasinger told SCIENCE NEWS.

The researchers speculate that one half began emitting higher-intensity X-rays as it shoved its way into a denser region of interstellar gas and dust — toward the center of the Milky Way — while the other half released less X-ray energy because it collided with fewer particles during its expansion.

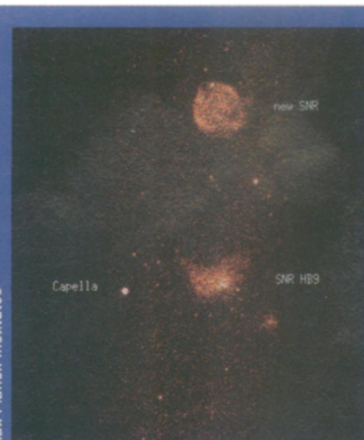
A remnant search reversed

Most supernova remnants, including Vela, radiate strongly at radio wavelengths — so strongly, in fact, that astronomers rely on radio emissions to point the way to undiscovered remnants. When observations reveal a powerful radio source several times more massive than the sun, researchers use orbiting telescopes to see if it also emits a significant amount of X-rays, clinching the object's identity as the vestige of a supernova. Every remnant discovery has begun with the detection of radio emissions — until now.

ROSAT turned the standard search procedure around, discovering a brilliant supernova remnant in the Milky Way's Auriga constellation through X-ray emissions alone.

Astronomers in Bonn, Germany, followed up by training the ground-based Effelsberg radio telescope on the same celestial location. They discovered that the newly identified remnant does emit radio waves, but with only one-quarter the intensity of any other remnant known.

The relative faintness of these emissions all but guaranteed that a radio telescope would not have spotted the remnant, says Schmitt. Surprisingly, even though the object ranks as one of the



Max Planck Institutes

Above: ROSAT image of the constellation Auriga shows newly discovered supernova remnant ("new SNR") — the first such remnant identified by an X-ray telescope. The object may represent a new class of supernova remnants that emit high-intensity X-rays but relatively few radio waves. Photo also depicts the bright star Capella and a known remnant called HB9.

Science Service, Inc. is collaborating with JSTOR to digitize, preserve, and extend access to Science News. www.jstor.org

Milky Way's 10 brightest supernova remnants at X-ray wavelengths, other X-ray instruments had failed to detect it.

The discovery marks a milestone in the search for supernova remnants, says astrophysicist Robert Petre of NASA's Goddard Space Flight Center in Greenbelt, Md. He and others suggest that this stellar leftover represents the first of a new class of X-ray-bright remnants that have gone undetected because of their weak radio emissions.

Two features of the remnant – its faint radio emissions and its nearly perfect spherical shape – suggest it lies between two spiral arms of the galaxy. Because such zones contain low-density material, a remnant's expanding shell of gas and dust could retain its spherical shape and would produce only dim radio emissions, Aschenbach says.

Calculations of this remnant's luminosity and size indicate that it lies about 10,000 light-years from Earth. ROSAT researchers estimate that the supernova exploded about 26,000 years ago and that its remnant has a diameter of about 270 million light-years – making it the largest remnant ever detected.

The finding may help solve a longstanding mystery about supernovas. Estimates of the number of supernovas in the Milky Way, based on the number of known remnants, seem too low to account for the abundance of pulsars. ROSAT might resolve that mismatch by detecting many more remnants too faint for radio telescopes to identify, says Petre.

In an upcoming ASTRONOMY AND ASTROPHYSICS, the remnant's discoverers write: "If . . . the absence of strong radio emission is a rather common phenomenon, in particular for old remnants, then previous radio surveys might have missed a substantial number of galactic remnants, and X-ray surveys offer a more sensitive technique."

A loop and a bubble

Another Milky Way mystery revolves around a 15,000-year-old supernova remnant called the Cygnus Loop. Astronomers have wondered whether the Loop might be part of a larger, gaseous region called the Cygnus Superbubble, which appears in the same general area of the sky. But in the late 1970s, data from an X-ray satellite called HEAO-1 suggested that the Superbubble is three times more distant than the Loop. Preliminary ROSAT observations now appear to verify that finding, indicating that the Loop does not lie within the Superbubble and thus may be totally unrelated to it.

At the same time, the new images reveal a peculiarity within the Loop: a bright arc that may represent an area of extreme turbulence. And in the Superbubble, yet another intriguing feature shows up: an abundance of hot, young stars. Hasinger speculates that these stars formed in repeated supernova explosions that might once have bombarded the region. In addition to creating a slew of new stars, he says, the combined force of such explosions could have blown the Superbubble out to its current diameter of 1,000 light-years.

Herculean outburst

In March, ground-based telescopes detected an outburst of a previously undiscovered nova – a star that undergoes periodic explosions. Just five days later, ROSAT captured the first X-ray image of that star. Never before had astronomers detected a nova's X-rays so soon after an explosion, Hasinger says.

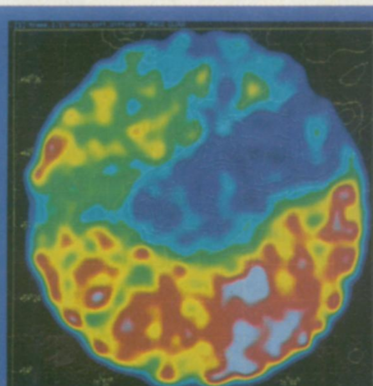
The ROSAT data showed that the nova, known as Herculis, radiated high-energy X-rays at high intensity. In contrast, several novas observed by previous satellites months after an outburst had radiated weakly in the same X-ray band.

Hasinger and his colleagues think the lower intensity may indicate that novas gradually accumulate gas and other material, which increasingly absorb the X-ray emissions from the outburst and thus diminish the amount reaching Earth's vicinity over time. By monitoring Herculis' X-ray emission pattern from an early point onward, "you can learn something about the physics of [its] initial surrounding medium," Hasinger says.

Shadowy signposts

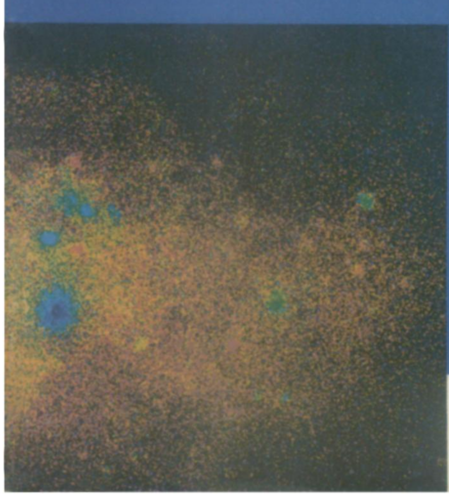
When you look at the night sky, it seems impossible to tell which stars are nearest and which are more distant. Although astronomers can gauge distances by measuring redshifts, the technique works only if the luminous objects are very distant from Earth and spaced relatively far apart – in separate galaxies, for instance. But imagine that the sky contains a few dark areas, each at a known distance

Below: Image of the Large Magellanic Cloud indicates temperatures of X-ray-emitting gas, ranging from about 0.5 million kelvins (red) to 10 million kelvins (blue). Other X-ray sources in this photo include the binary star system LMC X-1 (largest blue spot), a pulsar (single blue spot above and slightly to the left of the binary) and the star-forming Tarantula nebula (three blue spots clustered above and to the right of the binary).



Burrows, Mendenhall

Left: X-ray image shows that a Milky Way cloud called Draco (blue, lower-intensity region at upper right), about 900 light-years from Earth, blocks most X-rays from our galaxy's diffuse, low-energy background. The X-ray background shines much more brightly (light blue, green, red and white) through regions of space unaffected by the cloud.



NASA

Right: Deep-space image of the northern ecliptic plane shows high-density X-ray sources – possibly quasars – as well as clouds of photons that indicate a clustering of the distant, diffuse X-ray background.

Max Planck Institutes

from Earth, that absorb the light coming from behind them. Astronomers observing in visible light have for years gauged the distance of stars by determining whether they lie behind or in front of these light-absorbing regions.

Now, David N. Burrows and Jeffrey A. Mendenhall of Penn State in University Park have discovered such a region in ROSAT's X-ray images, and have used it as an indicator of more distant sources for the diffuse, low-energy X-ray "background" that bathes the Milky Way.

The origins of the Milky Way's background radiation – and the higher-energy X-ray background that exists outside our galaxy – have perplexed astronomers for more than two decades. Some have conjectured that most of the low-energy (250-electron-volt) background pervading the Milky Way radiates from a cavity of extremely hot gas, or plasma, within a region close to the solar system. All low-energy X-rays coming from farther away, they reason, would get absorbed by the galaxy's interstellar medium before ever reaching the solar system.

But an unprecedented observation by ROSAT's X-ray telescope raises questions about that assumption. Above the disk of the Milky Way, ROSAT detected a molecular cloud whose shadow seems to block X-rays arriving from more distant regions. The cloud – about 900 light-years from Earth in the constellation Draco – appears to absorb about two-thirds of the X-ray emissions previously thought to come from sources closer to Earth, Burrows and Mendenhall report in the June 20 NATURE.

X-ray astronomers rarely find such dark zones, and this is the first associated with our galaxy. The discovery suggests that a substantial portion of the Milky Way's low-energy X-ray background comes from sources more than 900 light-years from Earth, and likely penetrates the solar system, Burrows says.

He cautions, however, that previous space-borne X-ray detectors did not find any such shadows. Instead of blocking diffuse X-ray emissions, the Draco cloud may just happen to lie in front of a "galactic fountain" – a hot, X-ray-emitting gas spewing into a small portion of the Milky Way's halo. For now, says Burrows, the true nature of the low-energy background remains unclear. "Until we do this experiment with ROSAT in a lot of different directions, we won't know what the general answer is."

Hasinger contends that the Penn State finding, coupled with a Draco observation made by his group and reported in the June 14 SCIENCE, has already altered the standard picture of the galaxy's low-energy background. "Our finding is that only half the background is really localized; the other half is from larger distances in our galaxy – either the halo of our galaxy or even beyond, from another galaxy," he says.

Adds Schmitt: "We have for the first time directly demonstrated the existence of a hot X-ray-emitting plasma at a large distance [from the solar system]."

Hasinger's team plans to use ROSAT to search for other shadows. "We have to analyze lots of the shadows in order to get a three-dimensional picture of where in our galaxy the background is produced," he says. One goal is to determine whether an entire galaxy can cast a giant shadow. If so, says Hasinger, scientists may one day use such galaxies as celestial signposts to gauge whether an X-ray source lies in front of or behind them.

Petre credits the shadowy findings to ROSAT's Position-Sensitive Proportional Counter, particularly its ability to distinguish real X-rays from spurious electronic signals. "This is the kind of experiment that no other [X-ray] satellite has been able to do," he says.

A cluster of quasar finds

Peering deeper into space than any of its X-ray-detecting predecessors, ROSAT has revealed dozens of previously unknown quasars some 10 billion light-years from Earth. Those observations also shed light on the origins of the X-ray background beyond our galaxy.

Whereas the Milky Way's X-ray background peaks at an energy of only about 250 electron-volts, the extragalactic background ranges from about 1,000 to 15,000 electron-volts – and anything beyond 2,400 exceeds ROSAT's detection abilities. Nonetheless, research teams in England and Germany have used the satellite to examine the extragalactic background at different regions of the sky. The two investigations, conducted separately, have yielded contrasting findings.

One group, led by Ioannis Georgantopoulos of the University of Leicester, England, focused on test images made last fall while ROSAT was still in its calibration phase. The deep-space, high-resolution images depict a sky region believed to contain a high density of quasars. In a small area near the center of the images, the researchers detected 39 energetic X-ray sources. To find out whether any of these represented quasars, they turned to the Anglo-Australian Telescope in Coonabarabran, Australia, for an optical view of the same sky region. Using individual optical fibers to home in on the visible-light spectrum of each X-ray source, the team found that 24 of the 39 sources are indeed quasars. Georgantopoulos reported the finds this month at a quasar workshop in Victoria, British Columbia.

To determine how much of the X-ray background might come from the quasars, he and his co-workers went on to compare the X-ray spectra of the 24 quasars with that of the background in the ROSAT images. They found that the quasars' X-ray intensity declined more steeply with increasing energy than did the background.

This discrepancy, according to Georgantopoulos, indicates that no more than about 30 percent of the extragalactic X-ray background detected by ROSAT could have come from quasars. The rest, he reasons, would have to come from sources whose X-ray output does not drop as rapidly with increasing energy – such as young galaxies undergoing their first wave of starbirth. Indeed, Georgantopoulos says, emissions from these "starburst" galaxies themselves may account for all the X-ray background that does not originate with quasars.

Hasinger and his colleagues studied a different set of deep-space images, centered on the north ecliptic pole. The German team did not use a ground-based telescope to determine the quasar status of the numerous X-ray sources in these images. But in comparing the images with data from the Einstein Observatory, they concluded that many of those sources are quasars.

In addition, their analysis of the ROSAT images indicates that the background in this region is not entirely uniform: The shower of low-energy photons seems to originate from faint clumps of material. Moreover, the overall intensity of the clumps appears to match that of the individual quasar candidates in the same images. This circumstantial evidence leads them to propose that the clumps are quasar clusters that ROSAT could not fully resolve, lying some 8 to 12 billion light-years from Earth. At last January's meeting of the American Astronomical Society in Philadelphia, they reported that if the clumps are indeed quasar clusters, this would suggest that the universe began growing "lumpy" – forming galaxies and other structures – earlier and on a larger scale than standard theories can easily explain (SN: 1/26/91, p.52).

The Leicester group, on the other hand, saw no evidence for quasar clumping in their images. And whereas Georgantopoulos estimates that quasars contribute only 30 percent of the diffuse X-ray background, Hasinger says his group's findings suggest that quasar clusters could generate at least 50 percent.

Hasinger told SCIENCE NEWS that ROSAT examined several regions of the sky last month for 100,000 seconds – four times as long as its previous deep-sky observations. Even longer exposures are planned, he adds. Hasinger hopes the longer exposures will help resolve more of the X-ray background and enable researchers to identify new, faint X-ray sources. The May images also offer the tantalizing possibility of fully identifying the clumpy background, he says.

If the clumps truly represent quasar clusters, he adds, "then an X-ray puzzle that has existed for quite a long time would finally begin to be solved." □