Einstein Explores High Energy Astrophysics

New orbiting x-ray telescope probes supernova remnants, globular clusters, and galaxies

Advances in astronomy traditionally occur when painstaking, time-consuming observations are augmented with insight or inspiration. But the 1970's are an era of technology. Now the time-consuming work is designing and building better telescopes and detectors; once the new instruments are operating, discovery is the name of the game. A brief observation may illuminate a previously puzzling process or call into question an established theory. And that is the excitement with Einstein, the second High Energy Astronomy Observatory (HEAO-2)—an orbiting x-ray telescope with 500 times the sensitivity of prior x-ray satellites and better spatial and spectral resolution. It seems that whatever the object of study, something new is learned.

This is the first of two articles on the early results from the Einstein Observatory. The second article will discuss observations of quasars, clusters of galaxies, and ordinary stars.

Launched last November, the satellite already has doubled the number of known celestial x-ray sources. Yet the observatory's métier is not just adding new objects to the x-ray catalog, but probing deeply into the nature of high temperature and high energy astrophysical phenomena. Detailed understanding of these processes is growing faster than ever before. For example, Einstein's observations of supernova remnants—the remains of exploded, massive stars—show how debris from such dead stars is recycled through the interstellar gas, to be incorporated into a new generation of stars. But these same observations challenge the theory that hot, rotating neutron stars—very small and superdense objects—are formed in supernova outbursts. Three out of four young supernova remnants do not appear to include a pointlike x-ray source—the expected signature of a hot neutron star.

How are strong x-ray sources distributed within a galaxy? Leon Van Speybroeck of the Harvard-Smithsonian Center for Astrophysics, says that in one galaxy the pattern is not random, nor does it correlate well with the structure of the galaxy as seen in visible light. However, several of the x-ray emitters are near the edge of the galaxy, in a region rich in atomic hydrogen.

Einstein sees about 70 discrete x-ray sources in the spiral Andromeda Galaxy, the first celestial object outside our own galaxy to be studied by telescope. Most of these sources are probably similar to the brightest x-ray emitters in our own galaxy: supernova remnants, binary stars in which one member of the pair is a neutron star or a black hole, and the x-ray sources in some globular clusters. About a dozen of the x-ray objects are located in the central bulge of the Andromeda Galaxy, and these sources are two to four times brighter than those elsewhere. Ten other sources, near the center but outside the bulge, are thought to be binaries because they are also bright in visible light. Van Speybroeck suspects that when the pattern of x-ray emitters in the Andromeda Galaxy is understood, astrophysicists will have gone a long way toward understanding conditions favoring the birth or generation of x-ray sources.

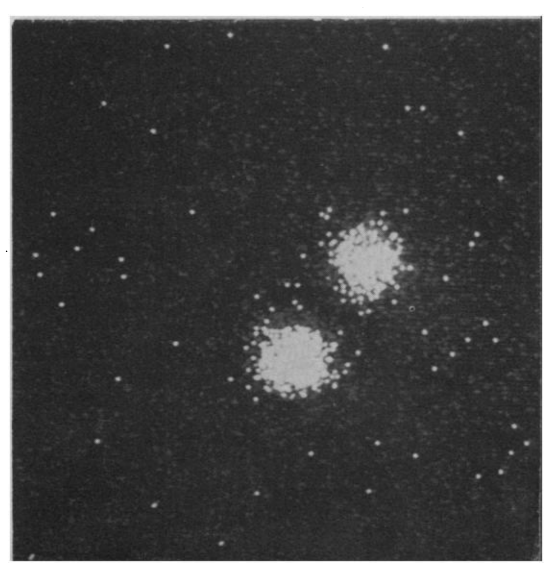
Supernova explosions are considered to play a dominant role in the energy budget of galaxies, in the synthesis of chemical elements, and in recycling the chemical elements into the interstellar medium, where they may be incorporated into new stars and planetary systems. The solar system, for example, is supposed to have condensed from interstellar material enriched with supernova debris, and this possibility gives astronomers an almost personal interest in probing supernovas. Yet, nearby star explosions occur too rarely to be observed conveniently. To learn about supernovas, their remnants must be studied, as none have been observed in our galaxy since 1604. (Galileo first turned a telescope skyward 6 years too late.)

Einstein's images of young supernova remnants—including Tycho, observed by the Danish astronomer Tycho Brahe in 1572, and Cassiopeia A, which exploded about 1657 but was not observed—confirm the scenario of violent star death that had been developed on the basis of visible light and radio wave data. A massive star explodes and a spherical shell—a shock front defined vividly by strong radio emissions—expands outward. The visible light output is greatest within the sphere, and numerous lumps of debris from the exploded star are thought to produce the so-called knots seen in optical photographs of some remnants.

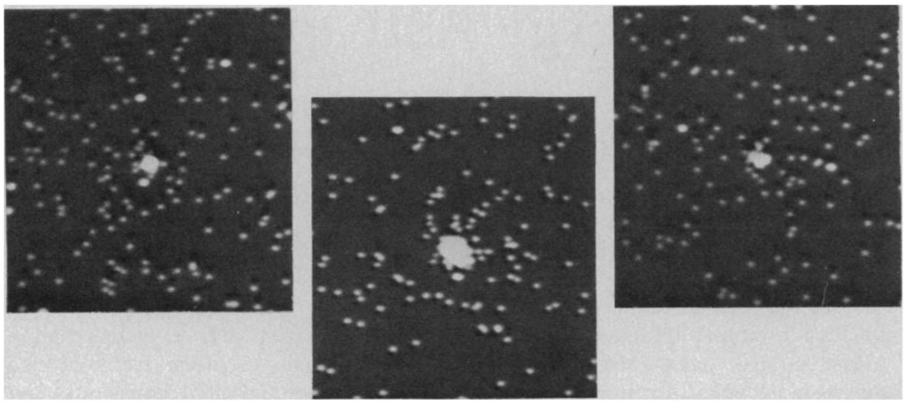
"It's incredible: Einstein's picture of Cassiopeia A tells so much!" says Stephen S. Murray of the Center for Astrophysics. Intense x-ray emissions are associated with both the shock front and the optical knots. But the x-rays from the knot region are lower in energy than those from the shock front, suggesting that there are two different mechanisms of emission.

To Murray and colleagues, the low energy of x-rays emitted near the knots is a clue that material from the lumps of debris may be mixing into the interstellar medium. If this conclusion is correct, it explains how heavy elements (to astronomers, that means all elements heavier than helium) synthesized in mature stars are made available to young stars, condensing from interstellar gas.

One of Einstein's two spectrometers recorded a detailed x-ray spectrum of Cassiopeia A, including identifiable emission lines from ions of several heavy elements. On the basis of the observed spectrum, Stephen Holt of Goddard Space Flight Center says that Cassiopeia A must contain material at two radically different temperatures—7 million and 50 million kelvins. The hotter gas presum-



Two supernova remnants in the Large Magellanic Cloud, a nearby galaxy, are brighter in x-rays than remnants in our own galaxy. [Source: Columbia University]



A series of consecutive 2½-minute exposures documents a burst of the x-ray source in the globular cluster Terzan 2. Before (left) and after (right) the burst the source is barely visible. But during the burst (center) the object is a strong x-ray emitter. [*Source: National Aeronautics and Space Administration*]

ably is found near the shock front, and its temperature was determined by HEAO-1. But it took Einstein to probe the temperature of the cooler gas. "In fact the line emission from the cooler gas dominates the x-ray spectrum from Cassiopeia A observed by Einstein," says Holt. This emission is probably the signature of the gas evaporating from the lumps of debris. Holt concludes that the heavy elements might be twice as abundant in the supernova remnant as they are in the sun. This lends credence to the idea that the solar system might have condensed from supernova debris.

Einstein's second spectrometer has the potential to reveal intimate details about the physical conditions in x-ray-emitting regions. According to Claude Canizares, Frank Winkler, and George Clark at Massachusetts Institute of Technology (MIT), hot x-ray-emitting gas in two supernova remnants, Cassiopeia A and Puppis A, may be moving at the same speed as cooler gas monitored by optical astronomers. Preliminary interpretation of the MIT data suggests that the gas in Puppis A is at a temperature of 3 million kelvins.

David Helfand of Columbia University says that Einstein's observations of supernova remnants are mystifying the origins of pulsars—rapidly spinning neutron stars. A pulsar is thought to be produced in a supernova explosion, as the collapsed remnant of the massive star. Even before the Einstein era, some astronomers felt that the rate of supernova outbursts was too low to account for the number of pulsars. Now that some of Einstein's data are in, the discrepancy has grown.

According to theory, neutron stars formed in supernovas should be hot enough to emit x-rays. Yet, when Einstein looked at four young supernova remnants, it found that only one—the Crab Nebula—includes a brilliant, point-like x-ray source (the Crab pulsar). In three other remnants, Helfand says, "either there are no neutron stars, or they are too cool to emit x-rays"—less than half as hot as expected. The implications are important. If only a small fraction of supernovas leave pulsars, then astronomers need to find another source of pulsars. Alternatively, if the neutron stars cool unexpectedly rapidly, the physics of neutron stars will need to be reworked.

In another project, Einstein has been studying the x-ray sources within some globular clusters. Only eight of the 130 or so globular clusters known in our galaxy had been shown previously to contain x-ray emitters. Even with its great sensitivity, Einstein has not yet located x-ray sources in any more globular clusters. According to Jonathan Grindlay at the Center for Astrophysics, that finding in itself is intriguing. If the clusters studied do include x-ray emitters, then they are more than an order of magnitude fainter than the observed globular cluster x-ray source.

Many of the x-ray emitters in globular clusters are bizarre objects, described as "bursters" because they seem to burst—suddenly increase their brightness roughly by a factor of 10 for several seconds. Identifying a burster is a matter of luck, because bursts are occasional and unpredictable. Nonetheless, six of the globular cluster sources are known as bursters, and by chance Einstein was watching in March when one of them burst.

According to current conjecture, the bursters might be medium-sized black holes—superdense, compact objects with a gravitational field so strong that nothing, not even light, can escape—or they might be binary stars in which one member of the pair is a neutron star or a small black hole. One difference between these two alternatives is the mass of the x-ray emitter: if it is a binary, it is expected to be about twice as massive as the typical star in the cluster; if it is a black hole, it could be much more massive.

Grindlay says that with Einstein there is a way to measure the mass of the x-ray source. All the stars in the globular cluster are revolving about the center of the cluster. In such a dynamical system, bodies heavier than average tend to gravitate toward the center. Thus the distance between the cluster center and a given object gives a clue to the object's mass.

Einstein has been locating the x-ray emitters in globular clusters, and the more measurements it makes, the more complicated the story gets. Three months ago Grindlay had measured the position of the x-ray source in one globular cluster. It was right on center, suggesting that it might be much more massive than the typical star in the cluster—possibly a black hole with 1000 times the mass of the sun. Although excited, Grindlay was cautious: "One globular cluster measurement is not proof, because the mass position is just one sample from a statistical distribution." Subsequently Grindlay has located the sources in six other clusters: none of them is as close to the center as the first one, and one of them is not very near the cluster center at all.

If the x-ray sources in the globular clusters are similar, they are most likely to be objects heavier than two solar masses. Thus they could be binaries or black holes. To get a better mass estimate and perhaps distinguish between the two possibilities, Grindlay needs to reduce the uncertainty in the position measurements. He has journeyed to the Cerro Tololo Inter-American Observatory in Chile to obtain more precise positions for the optical centers of the clusters.

Another possibility is that the x-ray sources in globular clusters are not all similar to each other. In this case, those close to the cluster center might be black holes, while those farther from the center of the cluster could be binaries.

Einstein is designed to operate for 1 year, but it will continue making observations as long as its consumable gas supplies hold out. With no mission in the works to continue probing x-ray sources in depth (the third and last satellite in the HEAO series is to be launched late this year, but it is designed to make studies of higher energy, gamma-ray processes), astronomers wish the observatory a long life.—BEVERLY KARPLUS HARTLINE