Astronomy from Space: New Class of X-ray Sources Found

While x-ray astronomy has revealed many varied and interesting sorts of phenomena in our galaxy, the x-ray emissions have most often come from regions where relatively young stars are found—especially the nearby spiral arms of the Milky Way. But x-ray satellites have recently pinpointed a completely different class of sources associated with very old star clusters that are generally far from the spiral arms of the galaxy.

In at least five cases documented so far, x-rays have been detected emanating from globular star clusters, which are distributed above and below the pinwheel disk of the galaxy, in a halo at least as large in diameter as the galactic disk (about 100,000 light years across). These spherical clusters, containing up to 200,000 stars each, were left behind as the rest of the primordial galactic matter fell into the disk of the galaxy over 10 billion years ago. Still bound to the rest of the galaxy by gravitational forces, the globular clusters slowly orbit about the center, almost like tiny separate galaxies (Fig. 1). They are like the "bony frame" of the galaxy, said Harlow Shapley, the late Harvard astronomer who studied them extensively.

In the globular clusters, the birth of new stars ended shortly after the formation of the cluster itself, according to the evidence of classical astronomy, so the individual stars are also nearly 10 billion years old. Therefore, globular clusters are not expected to contain any of the sort of young binary star systems, less than 100 million years old, that are believed to make up the majority of galactic x-ray sources. This fact, along with the finding that sources are much more plentiful in globular clusters than in the galactic disk, seems to indicate that some different x-ray producing process is occurring. Three sorts of explanations have been offered, including the suggestion that very large black holes, 1000 times as massive as the sun and situated in the centers of the globular clusters, are causing the x-ray emissions.

Three of the new class of x-ray sources were actually discovered by UHURU, the x-ray survey satellite that made full-sky observations possible for the first time after it was launched in 1970. The satellite, which was offically named the first Small Astronomy Satellite, detected 125 x-ray sources before it stopped functioning in 1974. About 80 of those sources were thought to be associated with various objects in the galaxy, but the satellite's capability to determine source positions was quite limited in some cases. The error in position measurements was typically large enough that the region identified encompassed many different objects.

The three sources were clearly identified with globular clusters when subsequent x-ray experiments aboard the seventh Orbiting Solar Observatory (OSO-7), launched in 1971, reduced some of the position errors considerably. Although the OSO-7 experiments could not match the positional accuracy of optical telescopes (typically 1 second of arc), they did narrow the probable position to a region comparable in size to a globular cluster (a circle 10 minutes of arc in diameter). In addition, two more x-ray sources in globular clusters were found by George Clark, Claude Canizares, Thomas Markert, James Neighbours, and their associates at the Massachusetts Institute of Technology in Cambridge, Massachusetts, who were the investigators for the OSO-7 experiment. So now five globular cluster sources are known (Table 1).

The intensities of all five of the sources found in globular clusters are variable, as are the intensities of the young binary sources. But many of the binary system sources have a periodic variation of intensity, repeating in 1 to 10 days, that is, every time the two members orbit each other. No such periodicity has yet been observed for globular cluster sources, although it cannot be ruled out until more observations are made. The cluster sources are all observed to change intensity by factors of 2 to 5 over weeks or months, and the brightest one sometimes doubles in strength within a few minutes.

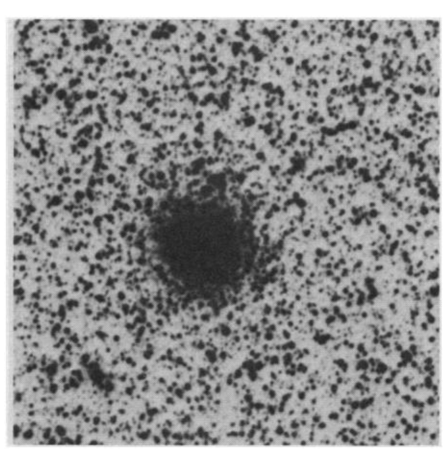

Fig. 1. One of the globular clusters that is known to emit x-rays, NGC 6624, is seen behind a dense screen of closer stars in the Milky Way. [Source: Palomar Sky Atlas]

With five x-ray sources discovered among the 119 globular clusters that are visible in the galaxy (20 more are thought to be hidden by the galactic disk), the x-ray producing process is estimated to occur once among 10^7 stars in clusters, or approximately 100 times more frequently than in the galaxy as a whole. The x-ray emissions are not drastically different from those of other galactic sources; that is, their intensities and spectra are similar.

The most intriguing explanation of the globular cluster x-ray sources is that they are caused by very massive black holes. [Black holes are collapsed states of matter, in which the gravitational forces of compression have overcome both the atomic and nuclear counterpressures that would ordinarily halt further collapse. The collapse then proceeds without limit, and nearby space is greatly distorted. Within a certain radius (about 30 km for a 10 solar mass black hole) matter loses most of its distinguishing characteristics, and nothing, not even light, can escape.]

Presumably the most massive stars in globular clusters collapsed into black holes when they reached the end of their burning phases. After billions of years of close collisions with other stars in the cluster, a black hole would lose energy and sink to the center of the cluster. There many black holes, with masses of 10 to 100 solar masses, could coalesce and form one massive black hole.

Black holes produce x-rays by accreting matter, which heats up to 10 million degrees as it falls inward. At that temperature, the matter radiates thermal x-rays. The major differences among various models of cluster x-ray emissions lie in the proposed sources of matter for accretion. During the normal course of stellar evolution, the stars in the cluster will eject gases, in the amount of one solar mass every million years. These gases could be a source of material falling into a black hole to produce x-rays, if they are not ejected too rapidly from the parent stars (so they do not escape from the cluster). Another possible source of material near a massive black hole is the debris of stars torn up as they passed too close. A star approaching within one solar radius of a massive black hole would be subjected to such different gravitational forces on its nearest and farthest sides (tidal forces) that it would be pulled apart.

Massive black holes in globular clusters were proposed by John Bahcall at the Institute for Advanced Study, Princeton, New Jersey, and Jeremiah Ostriker at Princeton University. Similarly massive black holes have also been proposed as a source of the x-rays by Joseph Silk and Jonathan Arons, at the University of California, Berkeley, who emphasize the idea that gases feed the accretion needed to produce x-rays. Silk and Arons think that in most regions of the cluster, the stellar wind will blow too uniformly to pile up gases in one location, but that the winds at the center will be uneven enough that gases will be drawn into the black hole. Both models predict that the x-ray source should be located at the center of the globular cluster, and that the x-rays should have no eclipses and no intensity fluctuations shorter than about 0.1 second (due to particles orbiting near the black hole). Better x-ray detectors will be needed to check these predictions.

A massive black hole could also change the star distribution near the center of a globular cluster, according to James Peebles at Princeton. In fact, bright, point-like concentrations of starlight have been observed near the centers of two globular clusters that emit x-rays. Neta Bahcall at Princeton has reported a bright spot in the middle of the most luminous x-ray cluster, NGC 6624. The cluster NGC 7078 also has an unusual distribution of starlight at its center, with a cusp in the radial distribution of light intensity, as reported by Ivan King at the University of California, Berkeley. Calculations also indicate that the globular clusters that emit x-rays are among those with gravitational conditions most likely to retain stellar debris in the center of the cluster.

Thus the circumstantial evidence for massive black holes in cluster centers is impressive. But the model does not provide any natural explanation, according to Clark, for the fact that the globular cluster sources are no more luminous than the young binary sources, in which the accreting object is thought to be a much less massive neutron star (1 to 2 solar masses).

Another process suggested is that a smaller black hole might produce the observed x-ray flux, if it were steadily fed with matter from a surrounding disk. Jack Hills, at the University of Michigan, Ann Arbor, has proposed that a black hole of 10 to 100 solar masses might disrupt passing stars by tidal forces. But in his model the black hole does not swallow the stellar debris all at once (which might make the x-ray emissions of very short duration). Instead, he postulates that the tidal forces also slow the fall of the debris, so that much of it goes into a disk around the black hole, from which it is slowly accreted into the black hole. With a smaller black hole, the minimum period for x-ray fluctuations should be much shorter than that

Table 1. Five globular star clusters have so far been found to emit x-rays. Generally the x-ray sources are found in the larger clusters.

Globular cluster	Distance (10^3 light years)	X-ray luminosity (10^{36} erg/sec)
NGC 1851	31	4.7
NGC 6441	(30)	(23.0)
NGC 6624	15	22.0
NGC 7078	31	3.7
NGC 6440	(30)	(75.0)

predicted by the massive black hole models, perhaps as short as 1 millisecond. A similar model has also been proposed by Arrigo Finzi at the Technion in Haifa, Israel.

A third explanation of the x-ray emissions from globular clusters is that they come from binary stars which are now behaving like the x-ray binaries in the galactic disk, but which had very different origins. George Clark suggests that a significant number of single compact stars (either neutron stars or black holes) are lurking in the centers of the globular clusters, and that they may capture slowly evolving ordinary stars, which have not yet burned out, to form a binary. Although such captures would be unlikely for compact stars outside clusters, the high stellar density in the center of a cluster makes capture more probable. Following its capture, when the ordinary star reaches the end of its main sequence burning phase and expands, it will overflow onto the compact star and "turn on" as an x-ray source. Clark further estimates that approximately one such binary should be present at the center of each of the globular clusters, waiting to be turned on.

Other astronomers who favor a late captured binary as the source of the x-ray emission, think that a relatively light black hole could do the capturing. Andrew Fabian, James Pringle, and Martin Rees, at the Institute of Astronomy in Cambridge, England, have proposed that a black hole with a few solar masses could capture another star, to form a binary, because the tidal forces would dissipate the energy of the approaching star. It would be captured into an eccentric orbit, which would soon be circularized and shrunk. This view is criticized by some astronomers, who question whether the circularization would occur.

Although all the proposed explanations predict that the x-ray sources should be right at the centers of the galactic clusters, other predictions differ enough that there is some hope of deciding which explanation is best. If binaries cause the cluster x-rays, then some of them should show eclipses, as the expanding star orbits in front of the compact star. Clark observes that the plane of the orbit is generally tilted in such a way that an eclipse can be observed from the earth only about 10 percent of the time. Thus it is understandable that no eclipses have been observed among five sources. Most astronomers expect more cluster sources to be found, so an eclipse criterion should become more definitive with more data. On the other hand if no eclipses are seen, then measurements of the short fluctuations could discriminate between the more and less massive black hole models. Also, the x-ray spectrum from a massive black hole should be different from that of an ordinary binary.

The eighth Orbiting Solar Observatory, which is operating now, has some capability for measuring short variations, and it can reach the range of millisecond variations for periodic signals. The black hole x-ray variations are not expected to be periodic, however. The third Small Astronomy Satellite (SAS-3), launched on 7 May, is also operating now, and it will be able to determine positions much more accurately than UHURU or OSO-7 could because it can point at one source as long as desired, whereas UHURU was continually scanning through a great circle as the satellite slowly rotated. However, SAS-3 does not have sufficient detecting area to observe millisecond variations in the fainter cluster sources.

Two other x-ray satellites that are now operating have made important contributions to different sorts of x-ray studies. The British Ariel 5 satellite, launched in October 1974, was the second satellite entirely devoted to x-ray astronomy, after UHURU, and has been particularly successful in the study of nova phenomena—that is, x-ray sources that quickly grow very bright (in one recent case as bright as Scorpius X-1, the most intense x-ray emitter in the sky) and then fade out over a time of many weeks. The other x-ray satellite now functioning is the ANS (Netherlands Astronomical Satellite) vehicle, which has been particularly valuable in studying the source Cygnus X-1, a young binary system about 7000 light years away that almost certainly contains a black hole as one of its members.

For better resolution of the very short time fluctuations that need to be studied to test the models of globular cluster emissions, much larger x-ray detectors will be needed. Those will become available with two large and powerful U.S. satellite observatories. The first High Energy Astronomical Observatory (HEAO) will be launched in 1977, and the second one, which will carry the first focusing x-ray telescope, is planned to be launched in 1978.—William D. Metz