# X-ray Astronomy: HEAO Looks Further and Sees More

Improved observational capabilities and good luck have boosted x-ray astronomy into a broadly productive phase. The good luck has been that exotic phenomena such as neutron stars and black holes prefer to emit x-rays rather than other forms of radiation. The observational improvement has been the introduction of x-ray-detecting satellites, capable of surveying the entire sky for x-ray sources. A half-dozen small satellites launched by the United States, Britain, and the Netherlands between 1970 and 1975 discovered 200 x-ray-emitting objects, finding among them x-ray pulsars, flarers, and bursters. But the size and payload of these satellites were small, and the instruments they carried were therefore limited. There are undoubtedly many fainter x-ray sources, but new instruments were needed to see them.

The limitations of the small x-ray satellites were dramatically overcome last summer when the National Aeronautics and Space Administration (NASA) deployed a large satellite dedicated solely to x-ray astronomy. Named the High Energy Astronomical Observatory (HEAO), it is the heaviest unmanned space observatory ever launched, a cylinder 2.5 by 8 meters in size, weighing more than 3 tons. The first HEAO, launched on 12 August and now operating for 6 months, has four large x-ray detectors on board. The largest is a survey instrument, with an area of more than 10,000 square centimeters, that has about 10 times the sensitivity of detectors flown in the past. In addition, the satellite carries three smaller instruments with the capability to do more precise diagnostics for the x-ray sources that are found. A "cosmic" x-ray detector measures the characteristics of the background of x-ray emissions not attributable to specific stars and galaxies. A scanning instrument determines positions with an accuracy (10 seconds of arc) that approaches that of the best ground-based telescopes, and a fourth detector collects data on more energetic x-ray emissions and low-energy gamma-ray emissions.

The four instruments together can obtain spectral information over a much wider range of energies than was possible with previous x-ray satellites. The large detector area of HEAO (see Fig. 1) should make it possible for the satellite to obtain a wealth of improved data on the variability of sources on time scales as long as months and as short as tens of microseconds. HEAO is intended to play the same role in x-ray astronomy that the first large telescopes played in optical astronomy 50 years ago, observes Noel Hinners, NASA's space science director, noting that the data from those optical telescopes still provides a firm foundation for observations being made today.

Very few of the 200 x-ray sources found so far have been in other galaxies. Astronomers are particularly interested in the galaxies that appear to be exploding, such as quasars and Seyfert and radio galaxies. Before HEAO, only one quasar was observed to emit x-rays, and that was the nearest one, 3C273. In the data that have been analyzed so far (less than one-twentieth of the sky has been analyzed), two more quasars emitting x-rays have been found, and those two are halfway to the most distant objects observed (about 8 billion light-years away). HEAO is producing specific information on quasars and Seyferts that may be a clue to what is happening at their centers. The spacecraft has also detected x-ray emissions for the first time from quasarlike galaxies known as BL Lac objects.

According to Herbert Friedman, pioneer x-ray astronomer at the Naval Research Laboratory and chief scientist for the full-sky survey experiment aboard HEAO, the bulk of the new sources being found are indeed in other galaxies. Altogether, HEAO should be able to detect over 1000 sources, Friedman says.

For the last 6 months, the satellite has been operating in a survey mode—almost continually rotating so that it slowly sweeps across all parts of the sky. After 25 February, the spacecraft will spend more of its time in a pointing mode, in which it aims various detectors at specific regions of the sky for hours or days to gather more data, get better positions, and examine the emissions for variability. The sky scan has been completed, but much of the data has not yet been analyzed. Nevertheless, a number of noteworthy finds have been made.

• On 8 September the spacecraft saw an x-ray flare that had also been seen 5 days earlier by the British satellite Ariel 5. HEAO was able to determine a precise position and forward the informa-

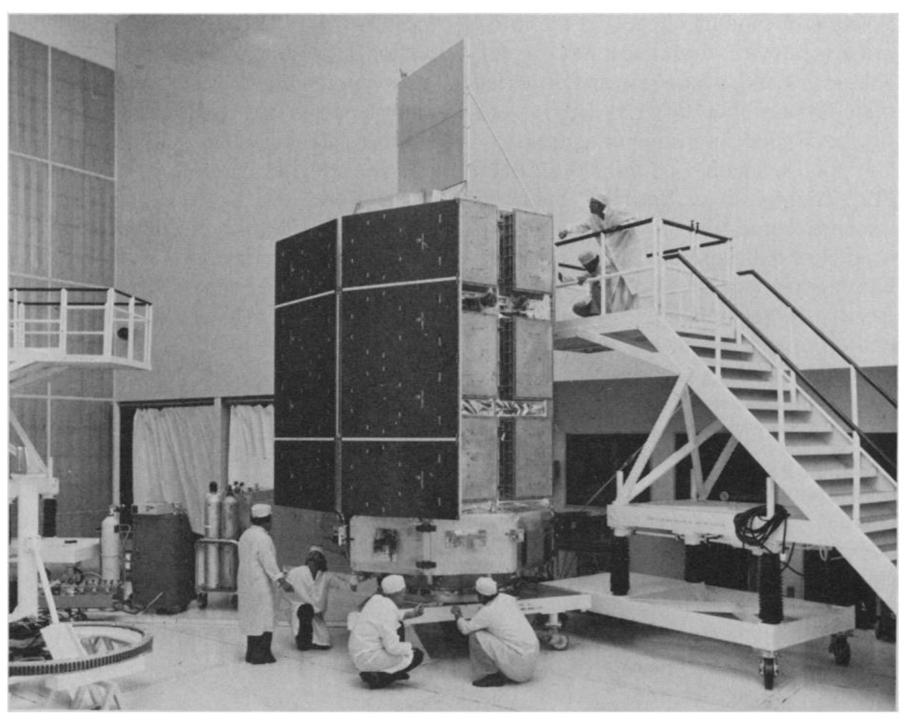

Fig. 1. The High Energy Astronomical Observatory satellite, shown during testing at TRW before launch. The dark panels are solar power cells. The six panels to the right are part of the all-sky x-ray survey experiment.



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tion to optical astronomers quickly, before the flare died out. On 10 September the x-ray source was identified with the optical flare, Nova Ophiuci, from observations made at the Anglo-American Observatory in Siding Spring, Australia.

• On 29 October HEAO discovered one of the mysterious gamma-ray bursts that were first seen in 1973. These rapid bursts, a series of emissions lasting less than 1 minute, have characteristics of nuclear explosions and remain unexplained since their discovery [*Science* **182**, 1236 (1973)].

• In early January the spacecraft observed a new x-ray pulsar, which had been discovered in late December by two of the small satellites that are still functioning, SAS-3 (the third of NASA's Small Astronomy Satellites) and Ariel 5. The new pulsar emits x-rays regularly every 3.6 seconds. Fourteen other x-ray pulsars have been found, pulsing in periods from 0.7 to 835 seconds. Some are quite stable. Others turn off for weeks, months, or years and then resume pulsing. The latest one, named 4U015+63, may be of the transient type.

• Special attention has been given to the two x-ray sources that are best candidates for black holes, Cygnus X-1 and Circinus X-1. The Cygnus source was first thought likely to be a black hole when it was found to have very rapidly changing x-ray emissions, like random shots coming from a very heavy invisible object orbiting a visible star. Circinus X-1 has also been found to produce x-ray emissions that look like the superposition of random shots, but the bursts are even more dramatic, with a very sharp rise and a very steep fall. Friedman reports that there is good statistical evidence for trains of pulses from Circinus X-1 with a periodicity of about 2.5 seconds. The periodic burst sequences come and go. Theorists have predicted that periodic bursts could occur in a hot spot developed in the disk of gas that is presumed to be orbiting x-ray–emitting black holes, but the time scale expected is milliseconds rather than seconds. The transient periodicity is an unusual phenomenon. Cygnus X-1 was identified as a probable black hole from measurements of the star it is orbiting, and Circinus X-1 is also orbiting a visible star, albeit a very faint one. It makes one orbit every 16 days, according to observations made by HEAO and SAS-3.

So far, the big x-ray–detecting satellite has not found new classes of powerful sources, but it has found weak x-ray emissions coming from surprisingly normal stars. These stars, of the U Geminorum type, apparently emit x-rays from the corona much as the sun emits x-rays from its outer atmosphere. The U Geminorum class consists of dwarf stars in binary systems, but they apparently do not revolve around superdense objects. About 280 are known from optical discoveries. The finding that these run-of-the-mill stars emit x-rays is an indication that the observing power of HEAO may have finally spanned the gap between "pathological" and common stellar objects.

One of the more controversial questions arising from x-ray astronomy has been the source of the background radiation: Does it come from many galaxies too faint to see, or from hot gases distributed throughout the universe? The cosmic x-ray experiment aboard HEAO has gathered evidence that the source could be intergalactic gas hotter than indicated by other measurements. Work done at Goddard Space Flight Center is Greenbelt, Maryland, indicates that the background radiation comes from intergalactic gas at a temperature of 500 million degrees Celsius. The energy spectrum of the x-rays indicates thermal emissions that have a characteristic energy of 45 kilo electron volts, according to Frank Marshall at Goddard. Marshall, like others before him, estimates that if the x-ray background comes from gas, the amount of gas is five times the mass of all the galaxies in the universe. This would be about half the amount of matter needed to make the universe eventually stop its expansion—the feature that characterizes a "closed universe."

HEAO has found unusual x-ray behavior from radio galaxies, but so far the most interesting extragalactic measurement appears to be the behavior of a Seyfert galaxy named NGC4151 (a notation referring to the number it was given in the New General Catalogue compiled by J. L. E. Dreyer in the 1890's). Seyfert galaxies are intermediate in total power between normal galaxies and quasars. This particular one emits x-rays at the very high rate of $10^{43}$ ergs per second. A crucial question is the size of the region that produces all this power—about $10^7$ times as much as that produced by the Milky Way. Experiments done with a smaller x-ray survey instrument on HEAO, as well as an ancillary x-ray detector on OSO-8, an older satellite of the Orbiting Solar Observatory class, have found that NGC4151 flares up to new peaks of x-ray brightness in about 1½ days and then fades back to its normal level in 1 week.

The rapidity of the flaring indicates that a very small region is producing the x-ray emissions—in fact, the upper limit on the size of the region must be 1½ light-days. That is only about ten times the size of the solar system. The scientists looking at the data at Goddard did not immediately jump to the conclusion that a very massive black hole is producing the x-rays, although many astronomers might reach such a conclusion. The Goddard team prefers to be more cautious and talk about the physical mechanism that is converting energy (from whatever source) into x-rays. They think that the physical mechanism is one in which electrons produce x-rays in a self-Compton process. They are particularly optimistic about the information that can be obtained by using radio and x-ray observations together. It is the "first time anyone has seen this sort of variability in a Seyfert," says Richard Mushotzky at Goddard, and it may tell quite a bit about the "physics of 1 to 3 light-day regions."

Not all has gone perfectly smoothly with the HEAO mission. The original mission was reduced in size by one-half and in payload by two-thirds when it was postponed in 1972 because of budget cutbacks. Launch of the reconstituted HEAO was delayed 4 months in 1977 because of difficulty with the onboard gyroscopes, and not everything has worked perfectly since the satellite reached orbit. The survey instrument has been particularly troublesome. Two of the seven modules in the detector were ruined when the spacecraft flew through a high-radiation zone over the South Atlantic with some detectors inadvertently turned on. Another module works only intermittently, and a fourth consumes so much gas that it is used only occasionally. Problems with NASA management have also occurred during the first 6 months. But now that the programmed survey is completed, investigators are hopeful that NASA will be more responsive to their scientific requests. The mission is now scheduled to run for 12 to 18 months. Meanwhile, the second HEAO satellite—entirely dedicated to "pointing" observations—is due to be launched in late 1978. Two years from now a third HEAO spacecraft dedicated to observations of cosmic rays and gamma rays will be sent up.

After almost a decade of waiting, a spacegoing capability has finally become available for the sort of massive instruments needed to observe high-energy particles and radiation. X-ray astronomy is no longer a fledgling field. Its practitioners finally have a large versatile observatory, and the field is beginning to expand in the pattern of a mature science.—WILLIAM D. METZ