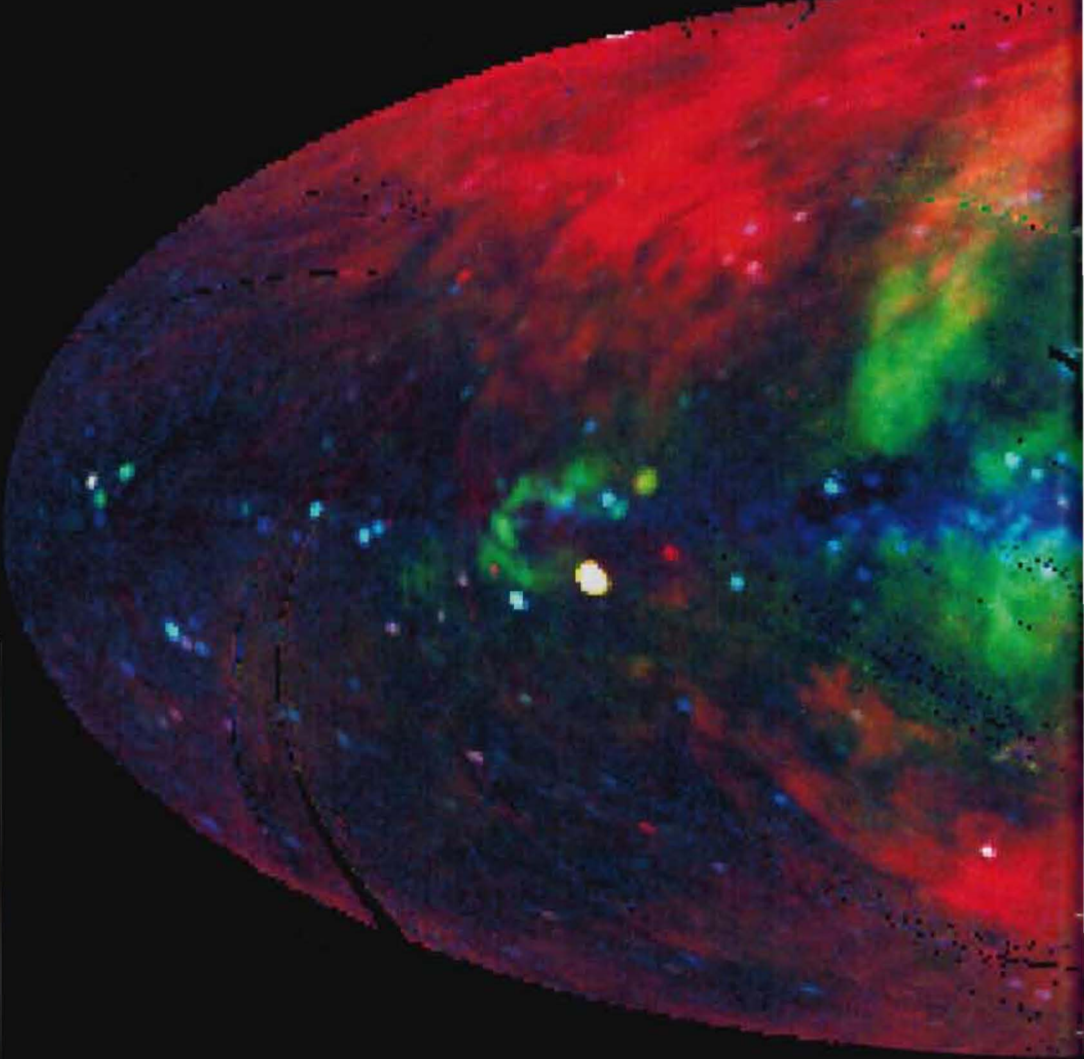
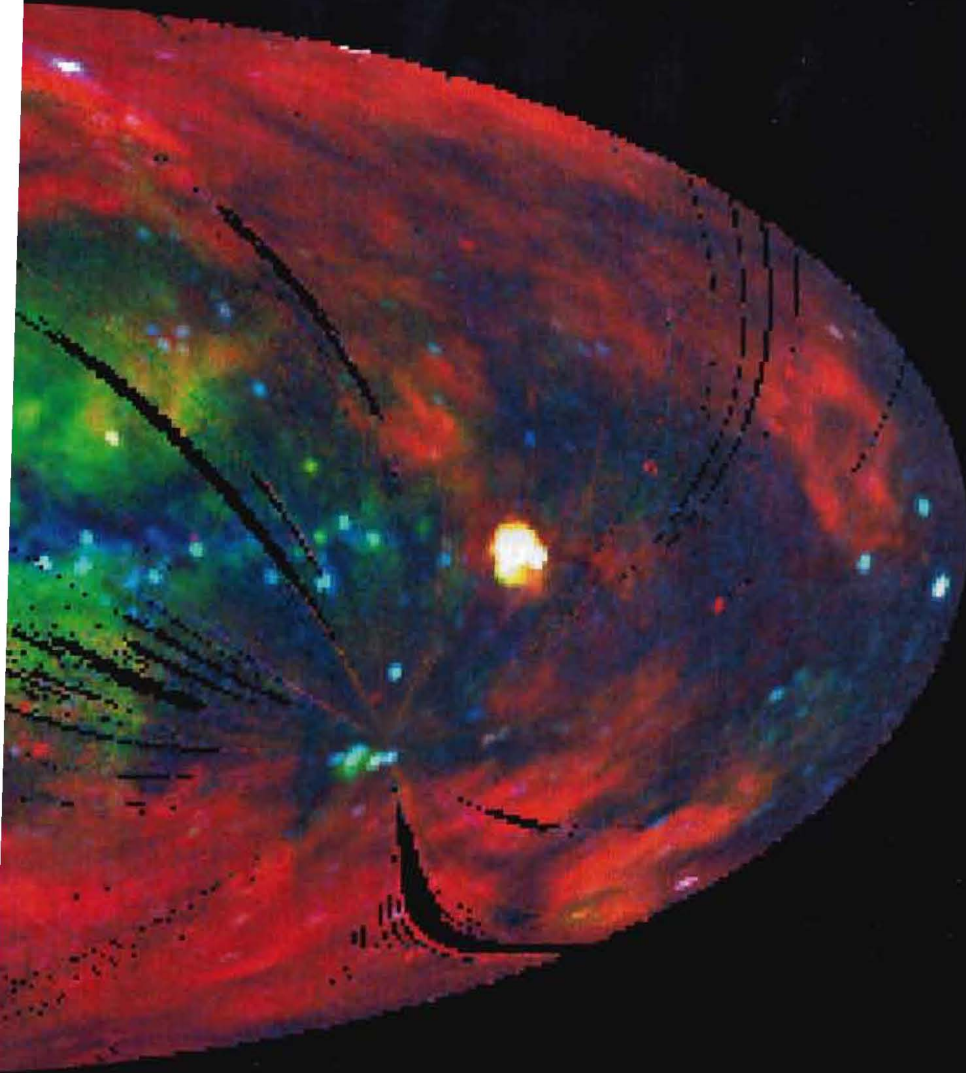


X RAYS EXPOSE A VIOLENT SKY

BY MARCIA BARTUSIAK



A composite image of the entire sky shows how it would look if we saw at X-ray rather than visual wavelengths. Inset: The X-ray telescope tube is raised so the cylindrical nested mirrors can be inserted.

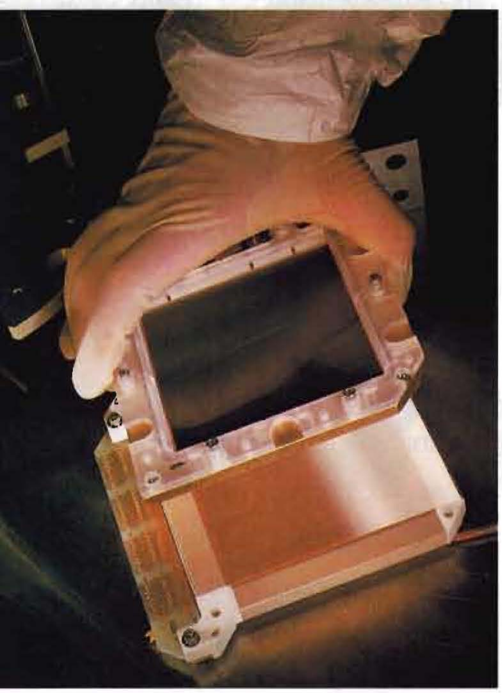
SOME OF THE MOST FURIOUS GOINGS-ON IN THE UNIVERSE SHINE BRIGHTEST IN X RAYS—NOW WE'LL SEE THEM BETTER

WITHIN THE CONSTELLATION CENTAURUS IN THE SOUTHERN SKY, A CELESTIAL dance proceeds—a pas de deux from hell. There, an unimaginably dense object known as Cen X-3, a neutron star, whips around a very close yet more normal stellar companion. Forged in a powerful supernova explosion years earlier, Cen X-3 is the remnant core of a once massive star. It contains a Sun's worth of mass, but squeezed into a sphere a mere dozen miles wide. A spoonful of its pure matter would outweigh a mountain. So strong is its gravitational field that Cen X-3 draws a river of gas from its binary partner. Spiraling inward and glowing in X rays as it's heated to millions of degrees, this gas eventually crashes onto the superhard surface of the neutron star at very high speed. What results is an additional torrent of X rays, beamed into the galaxy. The Milky Way is sprinkled with hundreds of such X-ray binaries, flashing on and off like cosmic fireflies. And some of these rays are directed toward Earth.

Also in the southern sky resides a blue variable star called Eta Carinae. About 150 years ago this gargantuan star, roughly 100 times heavier and four million times brighter than our Sun, erupted like a volcano, releasing two lobes of dust and gas that continue to speed outward in opposite directions at hundreds of miles per second. Slamming into the tenuous gas and dust of interstellar space, this ejecta emits an impressive flush of X rays. More recently, it was suggested that Eta Carinae may have a partner, the two stars completing an orbit once every five and a half years. X-ray emissions would then increase when the two stars are closest and their stellar winds smash together. And some of that radiation is headed in our direction.

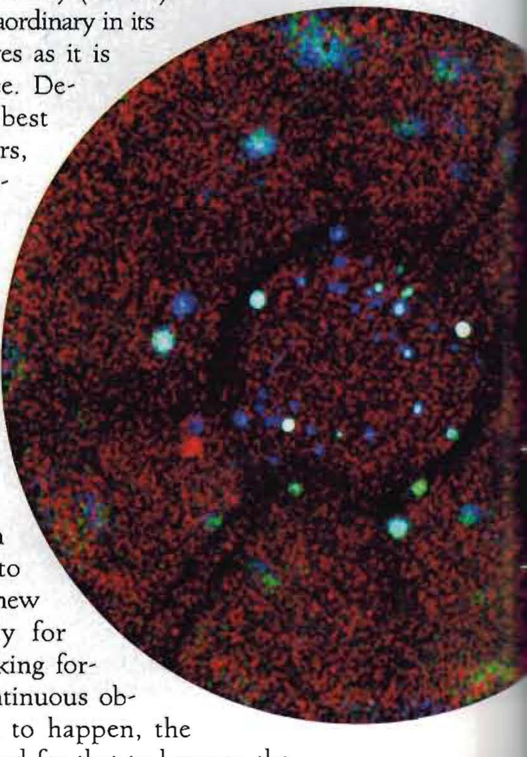
Many of the most spectacular and most significant phenomena in our universe involve velocities and temperatures beyond our imagination. So much energy is released that they shine brightest at X-ray rather than visual wavelengths. If you want to study these hot spots, X rays are the best teachers.

It is 1996. Technician Shirley Medeiros sits in a laboratory clean room in what had been a Sears store in Cambridge, Massachusetts. She attaches a grid of gold wires to a plate of glass about a millimeter thick. This microchannel plate is actually a hexagonal array of millions of glass tubes, each about the size of a human blood cell. Any one tube can convert a single incoming photon into an avalanche of electrons, amplifying the signal strength a millionfold. Pouring onto the gold mesh, the electrons record their points of impact, so that an X-ray image can be assembled, dot by dot. The microchannel plates and the gold mesh grid together constitute the detector, or High Resolution Camera (HRC).



A microchannel plate, which amplifies signals, is lowered onto a grid of gold wire, which records their position.

Eventually, X-ray photons from the violent X-ray binary, Cen X-3, and from Eta Carinae, will streak into Earth's neighborhood and into a set of concentric cylindrical mirrors that form the X-ray telescope. The mirrors will focus the X rays onto the detector. The whole apparatus will fly through space aboard a satellite known as the Advanced X-Ray Astrophysics Facility (AXAF).

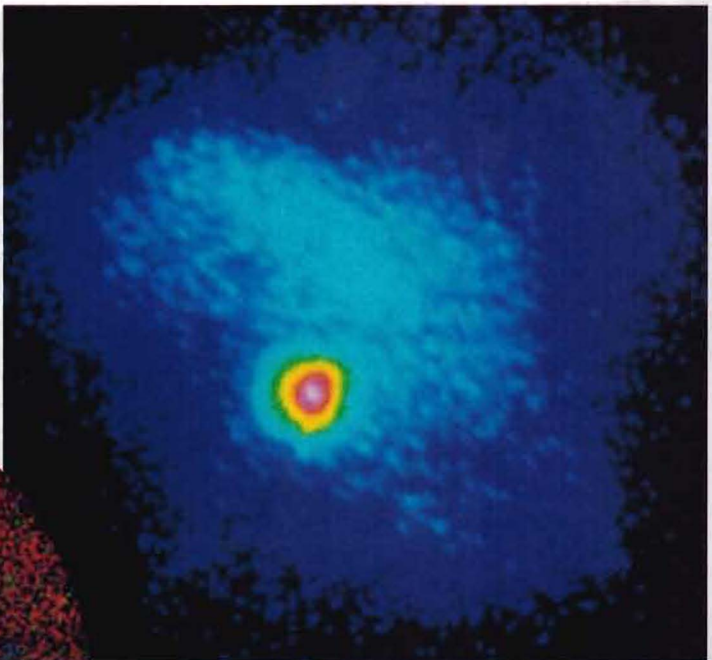


The HRC is as extraordinary in its impact on human lives as it is as a scientific device. Decades of work, the best part of entire careers, have produced a detector exactly four inches by four inches. It was created in part by astronomers who began the field, who once could only observe the X-ray sky for minutes at a time with devices borne on rockets that soon plummeted back to Earth. Now, with a new X-ray satellite ready for launch, they are looking forward to years of continuous observations. For that to happen, the HRC has to work. And for that to happen, the scientists have to test and retest, and then test again.

The testing laboratory, right outside the clean room, resembles a miniature warehouse, it is so crammed with instrumentation. Amid a forest of liquefied-gas tanks, computer monitors and steel racks of electronic modules, instruments flash their measurements in glowing reds and greens. Here, a few dozen engineers, scientists and technicians, all with the Smithsonian Astrophysical Observatory (SAO), are assembling the camera.

Talk is minimal on a September day as team members gather in the windowless room to watch "first light." A generator in a corner of the lab is about to fire a beam of X-ray photons down a long, evacuated pipe, mimicking the arrival at the camera of X rays from some distant celestial source. The target, mounted within a bulbous vacuum chamber that resembles a tiny submarine, is the camera's key component, its X-ray detector. After years of work, the researchers are finally testing whether it will be able to "see" the rays. Physicists Almus Kenter and Gary Meehan

RICHARD HOWARD; P. 82 TRW INC.; PP. 82,83 DR. STEVE SNOWDEN/GODDARD SPACE FLIGHT CENTER/MAX PLANCK INSTITUTE



Above: The Crab pulsar shines at its peak X-ray brightness. Left: An X-ray image reveals young stars in the constellation Ophiuchus; a third of these stars cannot be seen visually.

PP. 84,85 DR. THOMAS PREIBISCH/ASTRONOMISCHES INSTITUT, WÜRZBURG, GERMANY; P. 85 F. R. HARNDEN, JR./HARVARD-SMITHSONIAN CENTER FOR ASTROPHYSICS

have been preparing for days, delayed by a minor but frustrating problem with the high-voltage cables.

This is a crucial year for the team. They are about to switch from working with "breadboards," ungainly prototypes assembled on several long tables about the lab, to constructing and handling the more streamlined equipment set to travel into space. From now on, each test runs the risk of damaging a flight-ready instrument. In fact, every nut, bolt and resistor is painstakingly catalogued, so any broken or faulty piece can be replaced with one manufactured in the same batch.

"Are we all set?" asks Kenter.

"Let's do it," responds Stephen Murray, principal investigator of the camera team.

To the pulsing, background tones of vacuum pumps and generators, each participant wordlessly performs an intricate dance around the setup, tweaking knobs or adjusting voltage levels. The detector is exposed to the X rays for five minutes. On a computer monitor, digital dots start filling the screen, each blip representing an X-ray photon impinging on the detector, like raindrops splashing on a windowpane. The picture building up is blandly uniform.

"There are no hot spots," says Kenter with relief.

"We can't work with the plate if its response varies too much across its surface," explains Murray.

The test continues without a hitch . . . which can be dangerous. "When you have no problems, you lose an edge, and that's when you tend to screw up," notes Murray.

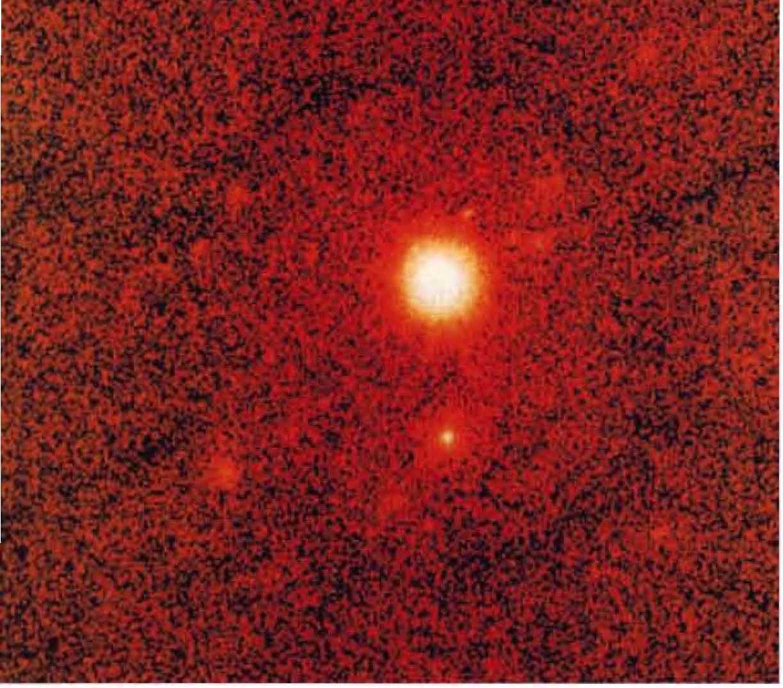
This is a side of space science the public seldom sees. "When people hear I'm working on an astrophysics project, they ask me what interesting celestial objects I'm seeing at the moment," recounts Kenter. "Then I have to tell them I'm worried about measuring the size of a hole: the celestial X rays hit the detector, which triggers a signal. But how do you interpret that signal? You need to know its strength, which means you need to know very precisely the size of the hole through which the X rays entered. The story of the X-ray telescope is a series of these many, mundane concerns."

Scheduled to be launched by space shuttle and then inserted into a higher orbit by a booster rocket this December, the $1.5 billion satellite will loop around Earth once every 64 hours and 18 minutes, going out as far as 86,000 miles (about a third of the way to the Moon) and then returning as close as 6,000 miles. From that superb vantage point, largely removed from Earth's disruptive radiation belts, the telescope will peruse the X-ray sky for at least five years. By then it will have a new name.

Whatever its future moniker, it promises to be the most powerful X-ray space instrument to date, offering a vision equivalent to the best ground-based optical telescopes. That's eyesight ten times keener than previous X-ray telescopes sent into space could manage. And its improved detectors will spy X-ray sources up to 100 times fainter.

THOSE CELESTIAL X RAYS WILL BE NO DIFFERENT FROM the rays directed into your mouth during a dental exam. In some cases, they are even generated by a similar process. In an X-ray machine, high voltages accelerate electrons to a soaring velocity. When abruptly stopped by a piece of metal, the electrons must give up that kinetic energy as electromagnetic radiation—in this case, as X rays. Charged particles plummeting onto a neutron star also emit X rays when suddenly halted, but here the intensities are literally astronomical. Comparing an X-ray binary to an X-ray machine is like comparing a hydrogen bomb to a match.

Once in space, AXAF will observe the most bizarre phenomena the Universe has to offer. Take the X-ray burster GRO J1744-28, for example. First discovered in 1995 near the galactic center, this spinning neutron star, also part of a binary system like Cen X-3, occasionally (yet unpredictably) emits an intense X-ray burp. This happened in 1996, and it was the brightest object in the X-ray sky. Sometimes it burst once an hour, sometimes not at all. Astronomers are not yet sure why an X-ray-emitting neutron star should suddenly burst more intensely. One guess is that the gas being siphoned off its binary companion is getting spread over the entire surface of the city-size orb. Eventually squeezed by the pressing force of gravity, the



The bright light at the center is a binary star in the constellation Lacerta. The small red dots are X-ray photons of lower energy than those from the binary system.

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layer suddenly ignites in a gigantic thermonuclear flash.

AXAF cameras will also be spying on whirlpools of agitated matter swirling around and eventually falling into black holes, massive stars crushed so densely at the end of their lives that they've tucked themselves away in an infinite gravitational warp, allowing no bit of light to escape. The telescope will sift through the filamentary shreds of ancient supernovas to conduct celestial autopsies. The X rays given off by the remnants' incandescent atoms reveal what chemical elements were brewed inside the former star. Quasars, the extraordinarily bright objects found at the centers of many galaxies, will be targets as well. So plentiful are quasars that they fill all of space with a diffuse X-ray glow. "It's difficult to imagine that we will ever visit a quasar or obtain any benefit from one," concedes Leon Van Speybroeck, who worked on the first design for AXAF in 1970. "But we humans find pleasure in understanding the Universe."

X-RAY ASTRONOMERS ARE NOTHING IF NOT A PATIENT lot. Optical astronomers nightly trek up mountains to gather the streams of starlight that fall upon Earth. Radio astronomers can work days as well as nights. X-ray astronomers are not so fortunate. The high-energy radiation they yearn to collect is absorbed about 100 miles up by Earth's blanket of air. It takes years to develop the spaceborne instrumentation necessary to "see" it. So X-ray astronomy is sporadic: a very fruitful period while an instrument is active is followed by long interludes preparing for the next launch by balloon, rocket or space shuttle. "We're photon starved," says Murray. Moreover, X rays are a rare commodity in space; while optical astronomers can collect millions of photons over any one second, X-ray astronomers are lucky to gather a handful or two.

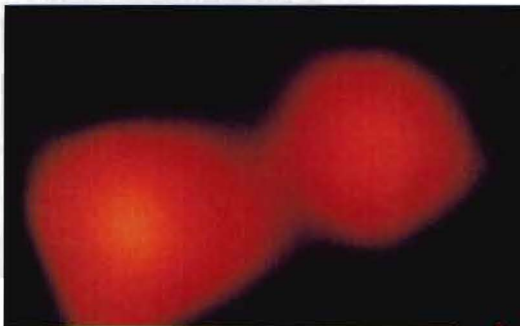
The Smithsonian Astrophysical Observatory has been a major player in X-ray astronomy. Several of the senior scientists started work in X-ray astronomy in the 1960s and early '70s. SAO engineers have the same longevity. And now these veterans are working with the next generation, who were still in kindergarten when their older colleagues began to unveil the X-ray sky.

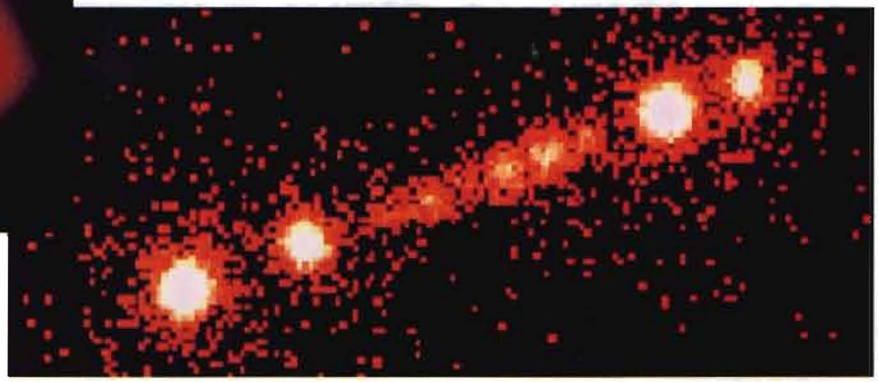
X rays require a special collector, an instrument markedly different from an ordinary telescope. An optical telescope consists of a mirrored disk that collects the visible light and reflects it to a central point, the focus. But X rays can't be gathered in that way; they would simply penetrate the mirror and be absorbed. An X-ray telescope has to operate like a billiard table. When X rays hit a mirrored surface at a small angle, they don't get absorbed, they ricochet, like well-placed bank shots. In an X-ray telescope, the incoming photons ricochet off the insides of a group of cylinders, mirrored on the inside and nested like a set of kitchen measuring cups. The photons then go through a second set of cylinders that brings the rays to a focus.

The SAO team is building one of two detectors that will operate at the focus. (Two other instruments were originally planned but were lost to budget cuts.) The other camera is a CCD imaging spectrometer constructed by Penn State and MIT scientists. It uses arrays of charged coupled devices to construct a video picture as X rays activate the individual imaging elements. This system complements the High Resolution Camera. The spectrometer, which has a smaller field of view than the HRC, can peg an X ray's energy and collect higher-energy photons. The HRC, on the other hand, is better at collecting lower-energy X rays and is big enough to see extended objects in the sky.

The HRC team had thought that because they were using a proven technology, their task would be relatively easy. The first HRC-like detector, a smaller version designed by Murray, flew aboard the Einstein observatory launched in 1978 (SMITHSONIAN, September 1980). But with the long hiatus between missions, the companies that supplied the camera's parts had lost an edge. "Making microchannel plates became a black art," says Kenter.

Along with developing the HRC, the Smithsonian snared another AXAF plum: the AXAF Science Center, which will be the center for satellite operations, the allocation of observing time and data analysis as the telescope is running. The science agenda is ambitious. "I think we'll see an explosion in the black hole industry," predicts Harvey Tananbaum, a member of the team that discovered the first X-ray binary and now director of the center. AXAF might even be the first to see the pulsing neutron star believed to lurk behind the murky cloud of debris thrown





At left is a real X-ray image of an area around a black hole. Above is a simulation of how much better the resolution will be with the new detector aboard AXAF.

AXAF SCIENCE CENTER/SMITHSONIAN ASTROPHYSICAL OBSERVATORY (2)

off by SN 1987A, a supernova that was briefly visible to the naked eye a decade ago (SMITHSONIAN, April 1988).

Axaf will also be tackling cosmological problems. In his spacious SAO office, Tananbaum takes out two pictures. He first shows an optical image of a rich cluster of galaxies known as Abell 1367. The picture displays nearly 100 extended smudges, each a galaxy containing hundreds of billions of stars. "You're seeing the sum of the light from all these stars, which have temperatures of 5,000 to 100,000 degrees Kelvin. Most of their energy is in the form of visible light," explains Tananbaum.

BUT AN X-RAY PICTURE OF THE SAME REGION, LOCATED about 300 million light-years away, looks entirely different. There are a few bright spots, which might correspond to a galaxy or two, but mostly what are seen are big, smooth patches of gas spread throughout the cluster. Some of that gas got blown out of the galaxies from high-powered supernovas, but it was likely supplemented as the galaxies mingled within the cluster and gravitationally stripped matter off one another. "We're going to map X-ray clusters like crazy with AXAF," says Tananbaum. "There are lots of phenomena that only announce their presence—reveal themselves—when you look at X-ray wavelengths."

The X-ray-emitting gas seen in such clusters as Abell 1367 is very hot, 10 million to 100 million degrees Kelvin, which means it should have diffused over space and disappeared long ago, like steam drifting from a boiling kettle. But it hasn't. "That tells us that something is there to hold it together," notes Tananbaum. "But there's not enough material in the form of stars to do that." That means something else is lurking in space, a dark matter that may simply consist of ordinary celestial objects too faint to be seen from afar, such as black holes or dim white dwarf stars. More intriguingly, it could possibly indicate the presence of a weighty sea of elementary particles yet to be discovered.

As the Cambridge gang wound up its work, Murphy's Law was much in evidence. A microchannel plate was broken because of a flawed vacuum grip. A contractor mistakenly drilled a hole right through the bottom of the camera's titanium case. Computers regularly ran out of memory space during the daily lab tests. Resistors in the camera grid initially turned out to be too strong, distorting the signals. "It's why I don't sleep at night," says Murray.

Eventually, however, the halls were lined with large wooden crates filled with equipment ready to be shipped to the Marshall Space Flight Center in Huntsville, Alabama, for calibration. The experience of the flawed Hubble telescope mirror (now fixed) hovers over the camera group like a shadow. They don't have the same room for error; once AXAF attains its high orbit, the space shuttle won't be able to reach it for fixes.

Construction of AXAF resembled an elaborate military campaign. The telescope's mirrors were ground and polished in Connecticut, shipped to California for coating, then assembled in New York. The science instruments were integrated as a module in Colorado. All the elements eventually met up in California for final assembly. The completed telescope arrives at NASA's Kennedy Space Center in Florida a few months before launch.

During the final hectic days in Cambridge, the clean room remained a haven of peace. Inside the double doors, Medeiros had carefully assembled the microchannel plates onto their holders. Then she meticulously stitch-bonded the wire grid of the camera. She snipped a slim thread of metallic gold off a spool and, with a special bonding machine, linked a wire on the grid, also made of gold, to the pad of resistors that line the circumference of the plate. She needed a microscope to see what she was doing; each thread is thinner than a human hair and only a sixteenth of an inch long. Like a space-age Betsy Ross, she was sewing the pathway for the signal.

"At times, I get overwhelmed by the idea that what I'm working on will soon be thousands of miles above my head," said Medeiros.

The wonders that AXAF ultimately sees will find their way through these golden threads.

Marcia Bartusiak, the author of Thursday's Universe *and* Through a Universe Darkly, *writes often on physics and astronomy.*