Where no Telescope Has Gone Before

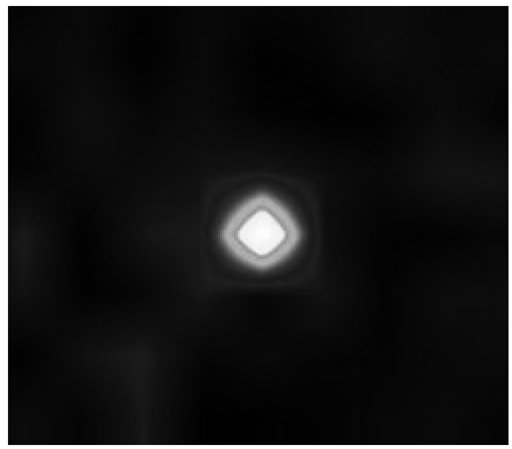
Scientists at NASA's Marshall Space Flight Center have captured the first focused hard x-ray images of the cosmos.

presented by ThursdaysClassroom.com

http://science.msfc.nasa.gov/headlines/y2001/ast07jun_1.htm

The real voyage of discovery consists not in seeking new landscapes, but in having new eyes. -- *Marcel Proust*

June 7, 2001 -- Since 1931, when Karl Jansky accidentally invented the radio telescope, astronomers have found again and again that there's more to the Universe than the human eye can see. Radio telescopes, infrared and ultraviolet detectors, x-ray and gamma-ray satellites -- they've revealed details of a cosmos teeming with exotic objects like black holes and pulsars that don't show up through the eyepiece of an optical telescope. Indeed, every part of the electromagnetic spectrum has offered one surprise or another to astronomers.



Now, say astronomers, prepare to be surprised again. Just last month scientists at NASA's Marshall Space Flight Center (MSFC) opened a new wavelength band for high-sensitivity astronomy: "hard" x-rays.

Above: The first-ever focused hard x-ray image of Cygnus X-1. Image credit: MSFC HERO team.

"What we've done is really just a first step," says Brian Ramsey, the leader of the MSFC team -- but it's a big one. Using a revolutionary telescope floating on a balloon 40 km above Earth's surface, Ramsey and his colleagues, including engineers Jeff Apple, Kurtis Dietz and others, captured *focused* hard x-ray images of Cygnus X-1 (a black hole accretion disk) and the Crab Nebula (the seething remnant of a supernova explosion) and its pulsar. They are the first such pictures of any heavenly body.

"This is an historic breakthrough," said Martin Weisskopf, project scientist for NASA's Chandra X-ray Observatory. "Collecting the very first focused hard x-ray images of these sources is an exciting milestone."

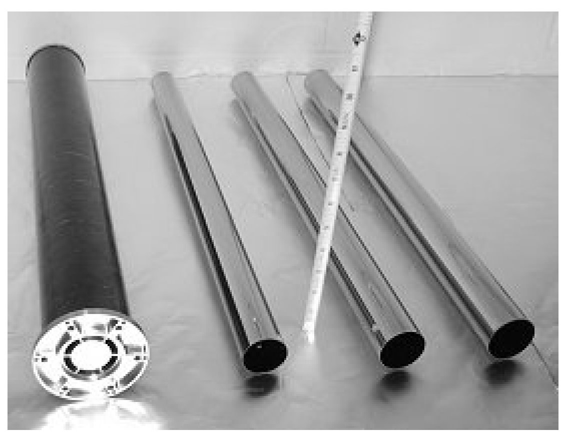
Hard x-rays are photons with about the same energy as medical x-rays (> 10 keV), or ~20,000 times more energy than visible light. Such x-rays reveal some of the most violent phenomena in the Universe, including colliding galaxies, fiery stellar explosions, and hot disks that swirl around black holes. Astronomers have flown hard x-ray detectors before, but until now none could focus the radiation to produce crisp images with high sensitivity.

"Focusing hard x-rays is difficult, because they are absorbed by conventional lenses and mirrors," explains Ramsey. "The only way to reflect a hard x-ray photon is to bounce it from a mirror at grazing incidence -- that is, at a very shallow angle." It's a little like skipping stones across a stream. The rock (or x-ray photon, as the case may be) will skip only if it glances off the surface at a small angle. "The reflection angles for x-ray mirrors are just a few arcminutes," says Ramsey. "That's why x-ray mirrors are shaped like long cylinders."

Above: A cutaway diagram of nested grazing incidence hard x-ray mirrors.

"The really important thing about focusing x-rays is not just the ability to produce detailed images -- it's also about sensitivity," he continued. "Suppose we sent aloft a 1000 square-centimeter detector on a high-altitude balloon and pointed it toward the Crab Nebula. We might collect 50 hard x-ray photons per second from the Crab. Meanwhile, the detector would also be hit each second by, perhaps, a thousand unwanted background photons -- x-rays produced when cosmic rays hit Earth's atmosphere and the infrastructure of the experiment itself. That's a poor signal to noise ratio.

"The power of x-ray mirrors is that they take all the photons from a source like the Crab and focus them on one tiny spot. Signal to noise shoots way up! In fact, the better the mirror's angular resolution, the better the signal-to-noise ratio will be. That's why good mirror performance is *so* important."



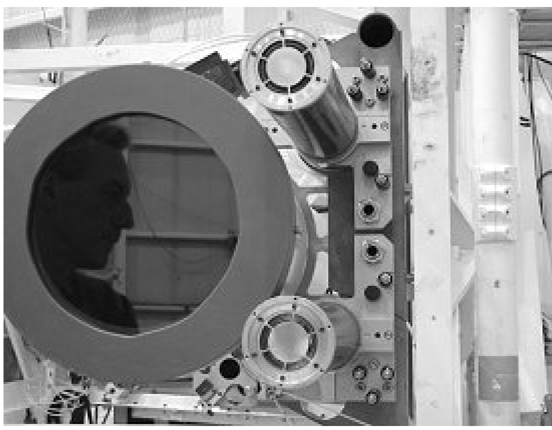
Right: Three "mass produced" HERO x-ray mirror shells (right) and a nested grouping of mirrors within one cylindrical tube (left). Photo credit: Carl Benson, MSFC.

Grazing incidence x-ray mirrors *per se* are nothing new. Ones on board NASA's Chandra observatory focus soft x-rays and produce images with sub-arcsecond resolution -- better even than groundbased optical telescopes can do. "Chandra's doing a superb job on the soft x-ray sky," notes Ramsey, "but the *hard* x-ray sky remains mostly unexplored because, until now, we've never had focusing mirrors that worked well above 10 keV."

Why not?

Ramsey explains: "At hard x-ray energies, the incidence angle for a good reflection is so small that a single mirror offers little collecting area. The only way to gather enough photons to form a good image is to use many mirrors." In years past that was expensive and difficult.

But no longer. Ramsey and his team used a replication technique to mass produce affordable high-precision x-ray mirrors, which they can nest one inside another to increase collecting area. "We call the program High Energy Replicated Optics -- or HERO for short," says Ramsey. The replication technique works like this: the mirror-builders electroplate nickel alloy onto an aluminum mold polished in the shape of an x-ray mirror. Next, they cool the nickel-coated mold. Aluminum contracts more than nickel, so the nickel shell, in the form of a HERO mirror, slides right off. Vacuum-coating the mirror with iridium, a dense metal that reflects x-rays better than other substances, is the final step in the process.



Earlier this year the team assembled a prototype double-barreled x-ray telescope consisting of two mirror assemblies with three shells each. It passed laboratory tests with flying colors, but that wasn't enough. An x-ray telescope on the ground is like an optical telescope with the lens cap on. "Cosmic x-rays don't reach Earth's surface," explains Ramsey, "because our atmosphere is opaque to this high energy radiation." It was time to go to space -- or as near to it as they could get.

Above: The star tracking camera (within a protective covering) and two x-ray mirror assemblies that flew on board HERO's May 2001 test flight. Photo credit: Carl Benson, MSFC.

On May 23rd, the National Scientific Balloon Facility launched the HERO team's innovative telescope from Fort Sumner, NM, on board a helium-filled balloon. The payload ascended to 40 km altitude (above 99.7 percent of Earth's atmosphere) where the sky is mostly transparent to hard x-rays.

It worked beautifully, says Ramsey. Each of the HERO mirror assemblies focused hard x-ray photons from the Crab Nebula and Cygnus X-1 onto a spot seven-tenths of a millimeter in diameter. "Despite a collecting area of only 4 square centimeters," he says, "the mirrors gathered plenty of photons from these sources. We achieved almost the same sensitivity as a 1000-square centimeter detector would with no focusing mirrors."

"Our mirrors weren't the only breakthrough," he added. "We also developed an optical camera that can track stars down to 9th magnitude in broad daylight." With such a camera to guide them, the x-ray mirrors, mounted on a motion controlled platform in the balloon's gondola, could remain accurately pointed for several hours at a time. "We wanted to prove that we could point from a moving platform and get the full resolution of the optics -- and we did it," says Ramsey.

"That's important," he continued, "because balloons are less costly than space missions." Indeed, NASA is working toward ultra-long-duration 'near-space' balloon flights that stay up for 200 or 300 days. With that much time aloft, balloons can compete favorably with orbiting satellites at a fraction of the cost.

Right: On the ground before launch, Ramsey's team tests the gondola's alt-azimuth pointing mechanism. Photo credit: Carl Benson, MSFC.

As exciting as these results are, says Ramsey, "what we've done so far is just a proof of concept." In two to three years Ramsey's team hopes to fly a balloon laden with 240 x-ray mirror shells. "That telescope will be sensitive to hard x-ray photons up to 75 keV, and it will produce images with 15 arcsecond resolution." (The May 2001 experiment flew 6 mirror shells, and was sensitive to 50 keV photons at 45 arcsecond resolution.)

What will they find? "We don't know," says Ramsey. There's a whole new sky up there ... full of surprises for HEROic explorers to discover.

.

Discussion Questions

1. What are examples of objects in the universe that the human eye can not see?

2. What tools have astronomers developed to 'see' some of these invisible objects?

3. Scientists at Marshall Space Flight Center has just developed a new tool for observing. What is it?

4. What is Cygnus X-1?

5. How did NASA astronomers get their x-ray telescope out beyond the Earth's atmosphere?

6. Why are these pictures so exciting?

7. What do these hard x-rays reveal?

8. Why is focusing x-rays difficult?

9. What does 'signal to noise' mean?

10. How do NASA scientists make the new x-ray mirrors?

11. Besides focusing x-ray photons, what else were the astronomers trying to prove?

12. What would you need to make a HERO?

13. What new discoveries do you think astronomers will make with HERO?

14. If you had a hard x-ray telescope in your classroom, what kind of pictures do you think that you could get?

15. If you had a space ship, what would you want in terms of standard detection equipment besides a window and radar? Why?