# X-Ray Astronomy: The Unkindest Cut

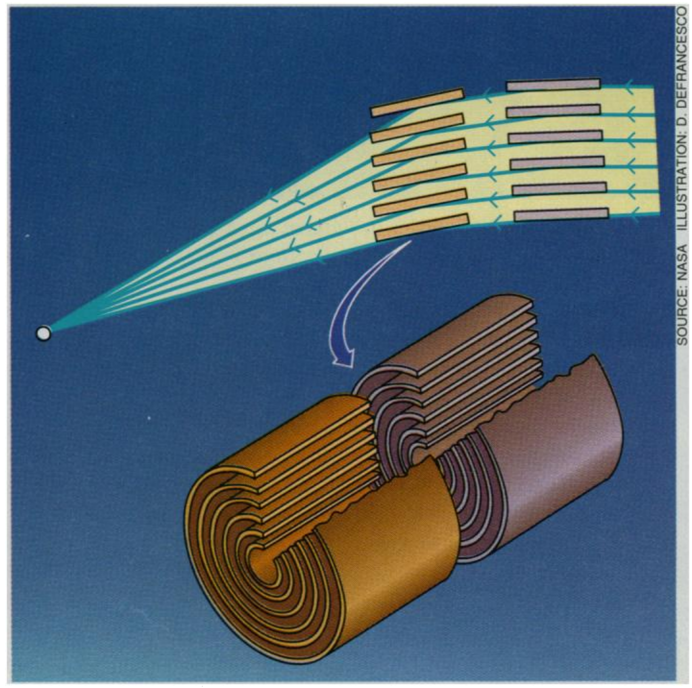
*A 30-year compaign for a Hubble-sized x-ray telescope has broad support from astronomers and survived a bet with Congress, but the launch date just slipped again*

SOME OF THE NATION'S LEADING ASTROPHYSicists took an extraordinary gamble a few years ago—a bet that came due last month with a bittersweet payoff. U.S. scientists had watched in frustration as their colleagues in Japan and Europe forged ahead over the last decade in x-ray astronomy (see box), and they were hoping to get started on this century's best hope for a blockbuster U.S. entry in the field—the Advanced X-Ray Astrophysics Facility (AXAF). It was an ambitious space telescope that would take a decade to build, and it promised to send back high-resolution images of some of the most puzzling and violent scenes in the universe—remote quasars, details in the structure of supernovae, and emissions from clusters of interacting galaxies.

But back in the spring of 1988, Congress simply wasn't ready to buy. When astronomers asked for funds to make an official new start on this $1.6-billion project, the House appropriations subcommittee that controls the space budget frowned. Then its chief staffer, Richard Malow, hit upon a solution, which the subcommittee proposed as a challenge: Congress would give the astronomers enough money to build two of the required 12 mirrors for AXAF. If the mirrors were finished by September 1991, and if the optics worked as well as the scientists predicted, then Congress would pay for the entire telescope. But if the mirrors were not ready on time, or if they failed this severe test, the whole project would die.

"I don't know that we had a choice" about this offer, recalls Harvey Tananbaum, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics. "Technically, we weren't asked if this was acceptable or not; it was decided in a closed meeting...and the word came back that this is what we were to do." What had Tananbaum and his engineering colleagues worried was that it might prove impossible in just 36 months to polish mirrors of this complexity to a degree of smoothness never before achieved.

Indeed, even as recently as last July, with just 2 months to deadline, no one knew for sure that the challenge would be met. That was when two 500-pound cylinders of Zerodur ceramic glass were loaded onto an air-cushioned van by the manufacturer, Hughes Danbury Optical Systems of Connecticut. Had the company—the former Perkin Elmer (the one that muffed the Hubble telescope mirror)—met its specs this time? No one knew because the schedule was so tight in the final days that Hughes had to polish the glass right up to the last moment. The mirrors left the plant before workers took the final measurements.




**X-ray vision.** *If they arrive head-on, x-rays penetrate glass, so AXAF will focus them with 12 "grazing incidence" surfaces.*

But 2 months later, after a "very long week" at NASA's Marshall Space Flight Center in Huntsville, Alabama—a week plagued by disappointing results, a software bug, and a last-minute adjustment to compensate for gravity—the final data came in. The mirrors passed the test by a wide margin. The celebrations began, and on 11 September NASA put out a press release declaring success. Jubilant, the astrophysicists returned to Congress for their reward.

What they received instead was a tough lesson in the sorry state of national budget-making. Far from signaling a green light, Congress cut AXAF's planned 1992 funds by $60 million. The telescope, like many other projects, got squeezed by the space station and the Earth Observing System as Congress let these mammoth projects grow but held the agency's overall budget to a growth rate of 3%. The result is that AXAF's launch will be put off another year (until 1999), its total cost will grow $150 to $200 million—with no tangible benefit—and its future is still not entirely guaranteed. As one House staffer said, "Now that the mirrors have performed well, we're forced to screw [the AXAF people], because we can't give them the money."

The AXAF case reveals in microcosm some of the frustrations that likely face all big space science projects in the next few years as NASA tries to build its $30-billion space station, its $11-billion-plus Earth Observing System, and its $2.3-billion new shuttle solid rockets. It also illustrates how decisions are made in Washington, with powerful committee aides in Congress calling the shots on major projects. And the painful history of AXAF reveals how difficult it has become to keep these big projects on schedule—even in the best of circumstances, when the management is good, the contractors efficient, and the scientific pedigree excellent.

### A 30-year dream

When it comes to pedigree, few projects have had one as long. Thirty years of planning, dreaming, experimentation, and infighting hung on the results of last month's make-or-break tests of AXAF's mirrors. The campaign to build a high-resolution x-ray telescope began in 1960, recalls Tananbaum, and the prime mover was his friend and former boss, Riccardo Giacconi, now director of the Hubble Space Telescope Science Institute. Giacconi led a small group of researchers who argued that if astronomers could collect x-rays in space and focus them into sharp images, they would gain access to a wealth of new information about the universe. Undetectable on Earth (because the atmosphere blocks them) x-rays emanate from powerful energy bursts in the cosmos and, Giacconi argued, detailed "photos" of the universe lit by x-rays might reveal unexpected galactic structures and new details about the life of stars.

But Giacconi's vision faced a practical barrier: because x-rays are more energetic than visible light, they penetrate a mirror's surface. Giacconi, however, had a different kind of focusing mechanism in mind. He argued that a technology that had been tested unsuccessfully for an x-ray microscope would probably work on a larger scale in a telescope. In this system, the x-rays would ricochet into focus by bouncing at slight angles off the inner walls of carefully shaped, hollow cylinders. The concept was tested in the early 1960s, and it worked.

Buoyed by this success, Giacconi led an effort, funded by NASA and centered at the Harvard-Smithsonian center, to put this technology in a large x-ray telescope. The first instrument he proposed would have been as big as AXAF. NASA embraced this dream in the late 1960s, but soon it halved the diameter of the big mirror and trimmed the mission "due to overall NASA funding and launch vehicle constraints," according to an official report. The final version, named the High-Energy Astronomical Observatory-2 or the Einstein Observatory, was actually built and sent into space in 1978. It performed brilliantly for more than 2 years, identifying many new x-ray sources, and proving that x-rays could be focused. But it couldn't capture faint images or high-resolution spectral data.

Even before Einstein was lofted into space, the campaign to build a high-resolution telescope resumed with feasibility studies in the late 1970s. The first objective, says Tananbaum, was to win peer support. That came in 1982 with a solid endorsement from the National Academy of Sciences' Astronomy Survey Committee, chaired by renowned astrophysicist George Field of Harvard. It named AXAF the top priority for space and ground astronomy in the 1980s. A Physics Survey Committee also favored AXAF in 1986.

### An astronomical culture clash

An endorsement from the National Academy of Sciences was nice to have, but it certainly didn't guarantee political success for the project. First came a hostile reception at NASA, where other big science projects were competing for funds. "We had a very difficult review," Tananbaum recalls when he thinks back to the reaction when scientists proposed AXAF as a "new start" at NASA in 1987. A comet rendezvous mission (CRAF/Cassini) and the Earth Observing System were demanding attention, and the long-delayed Hubble Space Telescope was eating up more and more of the budget. The Hubble was also giving AXAF problems of a less direct nature: Its cost overruns and schedule slippages gave NASA officials cold feet about getting into another big-ticket science project. Indeed, the easy


**Polished performance.** *An AXAF mirror.*

analogy with Hubble has been the bane of AXAF's existence, according to scientists in the program. Asked to compare the two telescopes, Martin Weisskopf, AXAF's project scientist at the Marshall Space Center, leans back, puts his hands to his head, and groans: "Our cross to bear..."

In conversation, Weisskopf, Tananbaum, Richard Mushotsky of the Goddard Space Flight Center, and other x-ray astronomers suggest that they belong to a different culture from the visible-light people who created Hubble. One said bluntly, "It's the difference between professionals and amateurs," in that the x-ray people have been

## Chipping at the Edges of AXAF's Territory

When U.S. scientists talk about other nations' plans for x-ray telescopes, they reveal a trace of envy. For example, ask Martin Weisskopf, NASA's chief scientist for the big, billion-dollar U.S. Advanced X-Ray Astrophysics Facility (AXAF), when the Japanese will fly their little $50- to $100-million Astro-D satellite, and he replies: "Noon on something or another in February 1993"—then he adds with a smile: "I think they're anticipating a 45-minute slip."

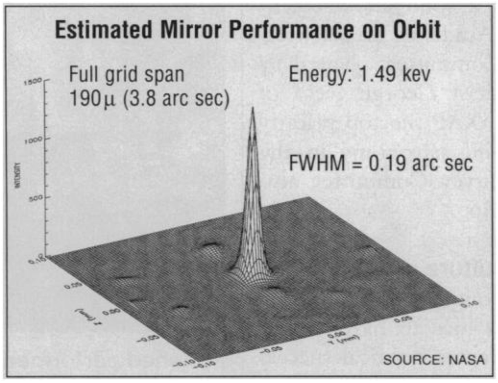
Japan's adherence to its long-term plans contrasts starkly with the U.S. performance. The original plan was to fly AXAF in 1991. Then the date moved back to the mid-'90s; then to 1998; and this fall, it is receding further, to 1999. The Japanese, Weisskopf observes, "do things a little differently than we do."

Both Japan and Germany will have flown small, relatively inexpensive satellites during the two decades it is taking the United States to plan, (perhaps) build, and (presumably) launch its "ultimate" high-resolution x-ray telescope.

In a sense, the other projects are preparing the way for AXAF: The German satellite, ROSAT, a collaboration involving the United States and Britain that went into space in June 1990 on a U.S. rocket, has already completed a full survey of the sky, identifying new x-ray objects that may be examined in detail by AXAF. ROSAT is also chipping at the edges of the work AXAF was designed to do—for example, locating faint quasars and identifying x-ray sources that contribute to a mysterious background of x-rays flooding the universe. Astro-D, for its part, is scheduled to begin doing sophisticated x-ray spectroscopy in 2 years with a set of mirrors from a shuttle mission and advanced sensors developed for the AXAF program. (And the United States also contributed a telescope to a U.S.-Japanese-British satellite, named Solar-A, that was flown into space on a Japanese rocket last September, and that is sending back unparalleled images of the sun's x-ray corona.)

All of which brings Weisskopf to claim that the United States now leads the world in the development of x-ray telescopes, and that "everybody else is imitating our technology." But that becomes a bittersweet claim if AXAF continues to be delayed (see main text). No instrument on any nation's drawing board has as much potential to make scientific breakthroughs as AXAF does. It will have 100 times the sensitivity and 5 to 10 times the angular resolution of its most powerful predecessor, the Einstein Observatory, whose brief but productive life ended in 1981. And AXAF is expected to live 6 times longer—for about 15 years. ■ E.M.

building and using spacecraft all their lives, while the optical observers have grown up in the more traditional world of ground observatories. In addition, the AXAF crowd is a tightly knit group. Its members have now had 20 years' experience working together on mirrors, detectors, and spacecraft. For example, Leon von Speybroeck, one of the world's top experts on x-ray optics and a member of the Harvard-Smithsonian team, worked on the first "grazing incidence mirrors" on Giacconi's staff. He oversaw the fabrication of Einstein's mirror, and is now AXAF's mirror specialist. He often spots problems before the contractors do, says Tananbaum.




**Perfect shot.** *Test spike shows the mirror has far better than 0.5 arc second resolution.*

In addition, many technical aspects distinguish Hubble from AXAF. Tananbaum says he has argued this point many times in talks with skeptics in the scientific community, NASA, Congress, and the press. For example, AXAF has been deliberately simplified to avoid complications that might cause delays. Mushotsky even feels that it has been stripped down to avoid raising hard-to-answer technical questions in congressional hearings. Tananbaum points out that AXAF has fewer than 10 modes of operation, whereas Hubble was designed with about 100. AXAF has only four instruments. Its pointing requirements are a factor of 100 less demanding than Hubble's. Its data transmission rate is much slower. The optics will be complex, but they will be more thoroughly tested than Hubble's.

### Showdown in Congress

These arguments, together with the strong backing from the scientific community, persuaded NASA to include the project as a new start in its 1989 budget. The Office of Management and Budget rejected it, but when NASA planned to appeal to the president, the budget staff retreated. AXAF made it into the president's request and sailed through the authorizing committees in Congress, but in the spring of 1988, it ran into a formidable skeptic in the House appropriations subcommittee for NASA.

Malow, the subcommittee's staff chief for the past 19 years, names three factors that troubled him that spring. The "primary" issue was the "experience with Hubble," which started out with a price tag of $495 million and had just been capped by the committee at a little over $1 billion. "We were concerned that we not get into something of the same geometric proportions again," he says. Hubble was then in a garage costing $8 million a month while it awaited a ride into space. "It was sitting there ticking, raising our consciousness," says Malow. Second, Congress had a concern about management. NASA had used two centers and two "associate contractors" to build Hubble. This created a lot of confusion. Malow saw some of the "same players"—including Hughes Danbury (Perkin Elmer)—coming back again. Recognizing the problems with the earlier structure, NASA named only one center to direct AXAF (Marshall) and one prime contractor (TRW).

Malow's third concern was based on gossip, but it's the kind that often carries weight in Congress. He says a person "in the business" of building spacecraft came to visit him at the subcommittee and warned that the telescope would probably never meet its promised angular resolution of 0.5 arc second. This visitor claimed that the Einstein telescope "had not achieved on orbit what they anticipated it would achieve" on paper. And that worried Malow. Weisskopf replies in exasperation: "I've told [Malow] over and over again that it's wrong....It's just bizarre....There's nothing in the literature" to that effect.

Malow says the plan to have AXAF's mirrors pass a test before funding the entire telescope arose over a period of 3 months in discussions between himself and Lennard Fisk, NASA's associate administrator for space science and applications. "Fisk gives me some credit and I give him some credit" for dreaming it up, Malow says.

The challenge worked, bringing all the collaborators on AXAF together into an efficient team, united in their determination to "show Dick Malow" they could beat the test, says Tananbaum. All went reasonably well until January of this year, when Tananbaum says he realized that "we weren't making any progress" in the polishing. Vibrations in the workshop were making it impossible to take accurate measurements. "We took a long, hard swallow," Tananbaum recalls, called Fisk, and got permission to halt all work for 2 months while the equipment was redesigned and completely overhauled. By March, "we were back on the air," and the team made up for lost time by compressing the schedule. For example, Eastman Kodak, which had the crucial task of mounting the mirrors on a test stand after they had been polished, gave up 80 of the 130 calendar days that had been allotted. The Hughes Danbury crews continued working, as they had for more than a year, on round-the-clock, 7-day weeks. In August, the mirrors were shipped to Marshall. Testing began in early September.

The pass-fail index set by Congress was that the mirrors should be able to focus a wide, diffuse x-ray signal to a very fine point, defined as less than 0.5 arc second in a test of resolving power. The first raw data were not encouraging; the value was higher than 0.5 arc second. Then Kodak looked closely at its software and found that it had failed to include a key effect of gravity in its computer code. Likewise, the Harvard-Smithsonian group found that it had omitted a critical factor from its mechanical analysis, and—most remarkable—the value of the two errors was identical. For this reason, Kodak and the Smithsonian group had been getting the same results and failed to detect the error until the mirror was on the test bed.

To counteract the effects of gravity, Kodak made a set of small springs that, when attached to the frame, removed the unwanted "ovalization" of the mirrors. Then the cylinders performed beautifully, producing a resolution of about 0.23 arc second, far better than required.

The spokespersons for AXAF and NASA say they are pleased with the results of Congress' close oversight in this case. Yet frustration runs deep. Mushotsky, for example, says, "Science doesn't work to rigid requirements." He thinks the whole notion of legislating milestones for research is wrongheaded. Tananbaum also wonders how much real progress is being made through this approach: "Since we formally started on this program [the mirror test], 3 years have gone by and launch has receded between 2.5 and 3 years; that's very disturbing," he says.

Whether it increases efficiency or not, legislative overseers are likely to impose more tests like this in the future, especially since Congress liked the way this one worked out. As Malow says, the AXAF test "worked out pretty darn well....If my career had to come to an end suddenly, I would like to go out with that one."

The test itself may have worked well, but it's not yet clear that Congress is ready to live up to its end of the deal struck with the astrophysicists 3 years ago. AXAF will continue to struggle for funds as NASA tries to fit the space station into its budget, and the astronomers will probably continue to watch in frustration as a 30-year project struggles for yet another decade. ■ ELIOT MARSHALL