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Great Observatories: Chandra X-Ray Observatory

The High-Energy Universe

Aira Astralis

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Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

The hottest places in the universe are invisible. Gas at temperatures of millions of degrees, matter shredded by black holes, stellar corpses crushed to crystal density, the shock waves of exploded stars: all of it shines, but almost none of the light reaches the ground. It is X-ray light, born in the most violent physics there is, and the atmosphere of the Earth swallows it entirely, which is one of the reasons the air is breathable. For most of human history the high-energy sky was not merely unseen, it was unsuspected, and the discovery of what lives up there is one of the youngest chapters in astronomy.

The instrument that brought that chapter into focus is the subject of this book.

The Chandra X-ray Observatory, launched from the Space Shuttle Columbia on July 23, 1999, is a telescope built to do one thing supremely well: make sharp pictures of the X-ray sky. That sounds modest, and it was anything but. X-rays refuse to reflect at ordinary angles, so they must be caught at glancing angles off surfaces polished more perfectly than any mirrors made before them; the resulting telescope, with nested cylinders gathering light down a ten-meter focal path, produced images several times sharper than any X-ray instrument had ever managed, and a hundred times more sensitive than its predecessors. Where earlier missions could say "there is X-ray light from that region," Chandra could say where, precisely, down to detail finer than a second of arc on the sky.

The chapters that follow trace that observatory's story whole: how X-ray astronomy fought its way from sounding-rocket experiments to a flagship mission; how the telescope was conceived, descoped, nearly lost, launched, damaged in its first months, repaired by procedure, and operated for more than a quarter of a century, far past any reasonable expectation for a machine in space. It covers the science the observatory made possible, from the neutron star at the heart of a glowing remnant to the dim, flickering monster four million suns heavy at our own galaxy's core, from the gas colliding in galaxy clusters to the quiet hum of hot plasma around ordinary galaxies. And it covers the human machinery as well: the research center in Cambridge that runs the telescope for NASA, the thousands of astronomers whose proposals drive it, the archive that outlives any single observing season, and the budget fights that now decide whether the mission's third decade will have an ending.

No prior background is assumed. X-ray optics, charge-coupled detectors, radiation belts, and the rest of the machinery are explained in ordinary language as they appear, and the one piece of specialist vocabulary that cannot be avoided, the arcsecond, is simply a way of dividing the sky: the full

Moon spans about 1800 of them, so a telescope that resolves half an arcsecond separates detail a few thousand times finer than the eye can. Every number in the book is traceable to published mission records, and where the story involves disputes, over budgets or over physics, the disputes are reported rather than settled, which is the honest posture for a history still in progress.

A reader coming to this book from the earlier volumes of the series will find the familiar shape of the observatory biography: the discovery chapter first, then the instrument explained for the non-specialist, the mission in the context of its siblings and rivals, the discoveries, the open questions, the future. Each chapter stands on its own, but the whole is one argument, and the argument is this: precision is the rarest and most expensive thing in astronomy, and when a mission buys it, the field changes in ways no one predicted in the proposal that justified the cost.

One thing should be said plainly at the start, because it is the frame for everything that follows. Chandra is the only X-ray observatory of its kind ever built, and it is old. It was designed for five years. It has flown for more than twenty-five, with no servicing possible, its far point reaching more than a third of the distance toward the Moon, kept alive by careful engineering and rearguard funding actions. The story of the mission is therefore two stories braided together: a story of discovery, in which the instrument has rewritten the book on neutron stars, black holes, and hot gas at every scale, and a story of endurance, in which the people who operate it have made an aging machine perform beyond any specification its designers dared to write down. Both stories are worth knowing. The second is being decided right now, in budget documents, and it will determine whether the first continues.

Chapter 1: The Discovery of Chandra X-Ray Observatory

The discovery that there was an X-ray sky at all was made by accident, in the desert of New Mexico in June 1962, by a team of researchers led by Riccardo Giacconi who had lofted a detector on a sounding rocket to look for X-rays from the Moon. The Moon, as it turned out, was dark in X-rays. But the detector, flying above the atmosphere for a few minutes, found a strong source somewhere in the constellation Scorpius, and a diffuse glow across the whole sky. The source, later catalogued as Scorpius X-1, turned out to be a binary star system in our galaxy: a dense stellar remnant stripping gas from a companion, the infalling matter heated to tens of millions of degrees on the way down. The glow, fainter and all around, was the accumulated X-ray light of the whole universe, and it demanded explanation.

The result puzzled the field from the start, because the source was absurdly bright for anything stellar, brighter in X-rays than the Sun's entire visible output, and no conventional star could do it. The resolution, worked out over the following decade, was the first of the field's great lessons: that gravity, not fusion, can be an engine. A neutron star or black hole pulling gas from a neighbor accelerates the infalling matter to fantastic energies and releases a hundred times more energy per kilogram than hydrogen fusion, and the shining of Scorpius X-1 was the friction of matter falling in. X-ray astronomy, a discipline begun as a curiosity, turned out to be the study of gravity's most extreme financial statements.

That one rocket flight opened a field. Within a decade the pace quickened: the first dedicated X-ray satellite, Uhuru, was launched from Kenya in 1970 and catalogued hundreds of sources, finding black-hole candidate binaries and the X-rays of galaxy clusters. Then, in 1978, NASA launched the Einstein Observatory, the first X-ray telescope capable of making real images, using grazing-incidence mirrors of the kind first worked out on paper by the German physicist Hans Wolter in 1952. For the first time X-ray sources could be resolved, located, separated. Giacconi, who had opened the field and designed its instruments, would eventually share the 2002 Nobel Prize in Physics for the work; by then the field he had started had a flagship.

The flagship was proposed early. In 1976 Giacconi and his collaborator Harvey Tananbaum wrote the initial plan for a large X-ray observatory, eventually named the Advanced X-ray Astrophysics Facility, a telescope meant to carry the Einstein Observatory's imaging idea to its full power: four times the area, far sharper optics, and instruments that could both image and take spectra.

The concept, accepted into NASA planning, became one of the four Great Observatories, the agency's program of flagship instruments covering the electromagnetic spectrum: Hubble for visible light, the Compton Gamma Ray Observatory for the highest energies, AXAF for X-rays, and, later, Spitzer for the infrared. AXAF was to be the X-ray leg, big and general-purpose, a telescope every astronomer could use.

Reality, in the form of budgets, intervened. In 1992 and 1993 the project was restructured and descoped to save money, and the cuts fell on the heart of the design: the mirror set, which had grown in planning to as many as twelve nested cylinders, was cut to eight and then to six, settling finally at four pairs after further work; the instrument suite was cut from six planned to the four that flew; the orbit, which had been intended to allow servicing by shuttle crews like Hubble, was changed to a high elliptical path no shuttle could reach, making the mission forever unserviceable. The descoping was painful and productive of hard feeling at the time, but the survivors of the cuts became a coherent machine: a smaller telescope, but one built with extraordinary care, because there would be no second visit to fix anything.

The descoping era left a mark on the field's culture that outlasted the hardware decisions, and it is worth recording why. The astronomers who lost their instruments, and the engineers who watched a decade of design shrink, carried the lesson into every later mission they touched: that a large telescope's survival depends on guarding its schedule and its cost with the same rigor as its optics. The survivors' compensation, the one the community accepted, was a promise that whatever flew would be excellent rather than merely adequate, and the finished machine kept that promise so thoroughly that the argument over what was cut has largely faded from memory, while the standard it set has not.

The construction was distributed across the American aerospace and academic landscape: the Marshall Space Flight Center in Huntsville managed the project, with Martin Weisskopf leading the development as project scientist; the precision mirrors, the most difficult part, were polished and figured to atomic smoothness by the optics shops of the era and coated for X-ray reflection; the two cameras were built in university laboratories: the Advanced CCD Imaging Spectrometer under Gordon Garmire of Penn State, with detectors made at MIT's Center for Space Research in collaboration with Lincoln Laboratory, and the High Resolution Camera under Stephen Murray of the Smithsonian Astrophysical Observatory. TRW built the spacecraft. In 1998, a year before launch, NASA announced the result of a naming contest for schoolchildren and students across the country: the facility would honor the astrophysicist Subrahmanyan Chandrasekhar, universally known as Chandra, the Nobel

laureate who had worked out the physics of white dwarfs and stellar structure, and who had died in 1995, four years before the observatory that bore his name flew.

One more piece of the pre-launch story deserves telling, because it is easy to forget how crowded the sky had become: the observatory was ready for flight in the late 1990s, but the shuttle fleet's manifest was filling with the first assembly missions of the International Space Station, and science flights waited in line. The launch slipped repeatedly across 1998 and 1999, and the delays, frustrating as they were, bought the project extra months of testing and rehearsal, so the mission arrived on orbit with a commissioning plan refined beyond anything a hurried schedule would have allowed: first light came within five weeks of deployment.

The launch, on the shuttle mission STS-93 in July 1999, was commanded by

Eileen Collins, the first woman to command a shuttle flight, and it very nearly went wrong in the way that haunts mission planners. During ascent an electrical short knocked out a pair of primary engine controllers, and a small hydrogen leak caused the main engines to run early out of propellant, shutting down with the vehicle slightly short of its planned velocity margin; a five-second shortfall was clawed back by the orbital engines. The payload, meanwhile, was fine. The observatory was pushed out of Columbia's bay, boosted by an Inertial Upper Stage and then by its own integral propulsion system through a series of burns lasting days, and finally released into the most unusual orbit of the Great Observatories: an ellipse ranging from about ten thousand kilometers at its low point to about a hundred and forty thousand kilometers at its high point, more than a third of the distance to the Moon, a circuit of the Earth taking roughly two and a half days.

The unusual orbit was the design's answer to the problem of the radiation belts. A low orbit like Hubble's passes through the belts twice every ninety minutes; the belts' trapped protons would blind and damage X-ray detectors and flood the data with noise. Chandra's tall ellipse spends its time far above them, dipping down and through quickly at each perigee, and the price of that safety is the ability of nothing and no one to ever reach it again. It was launched to live alone.

The first months also taught the mission's hardest lesson, recounted in a later chapter: the observatory's camera took radiation damage in the belts, scattering and intensifying the standard precautionary procedures that have defined its operations ever since. The damage was the price of a risk taken in ignorance, and its management became one of the mission's quiet triumphs.

First light came on August 26, 1999, roughly a month after launch, and the target chosen to show what the new telescope could do was the supernova remnant Cassiopeia A, the glowing debris of a star that had detonated some three hundred years earlier, about eleven thousand light-years away, previously known to X-ray astronomers only as a rough patch. Chandra's first image resolved it into fine structure, knots and filaments of million-degree gas, and at the center, for the first time ever, showed a compact point source: the neutron star left by the explosion, which no instrument in history had ever seen. It was precisely the kind of discovery the mission had been promised to make, and it arrived in the first weeks.

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ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.