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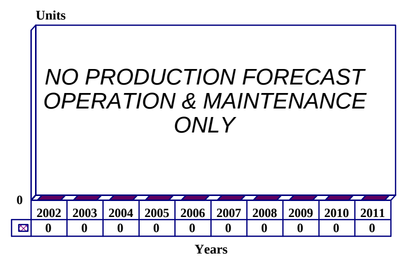
Chandra X-ray Observatory (CXO) - Archived 11/2003

Outlook

- Chandra performing beyond expectations
- Mission extended to 10 years over original five-year mission
- Constellation-X follow-on to start in 2006
- Constellation-X proposed launch in 2010

10 Year Unit Production Forecast
2002 - 2011



Orientation

Description. The Chandra X-ray Observatory (CXO), formerly the Advanced X-ray Astrophysics Facility or AXAF, is a spaced-based long-duration scientific telescope platform managed by the U.S. National Aeronautics and Space Administration (NASA). It is one of NASA's three "Great Observatories," the other two being the Hubble Space Telescope and the Compton Gamma Ray Observatory.

Sponsor

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(Telescope's Optical Bench Structure)

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(High-Resolution Camera)

Status. Operational. The Chandra X-ray Observatory was launched into orbit in July 1999 via the Space Shuttle Columbia. First images were recorded and transmitted in August 1999. The follow-on Constellation-X is expected to be launched in year 2010.

Total Produced. One

Application. Space-orbiting observatory/telescope designed to observe X-rays from high-energy regions (such as supernova) of the universe.

Price Range. Total project cost estimated at U.S.$2.7 billion, including spacecraft (U.S.$1.5 billion), mission operations and data analysis (U.S.$741 million), and Space Shuttle launch (U.S.$382 million).

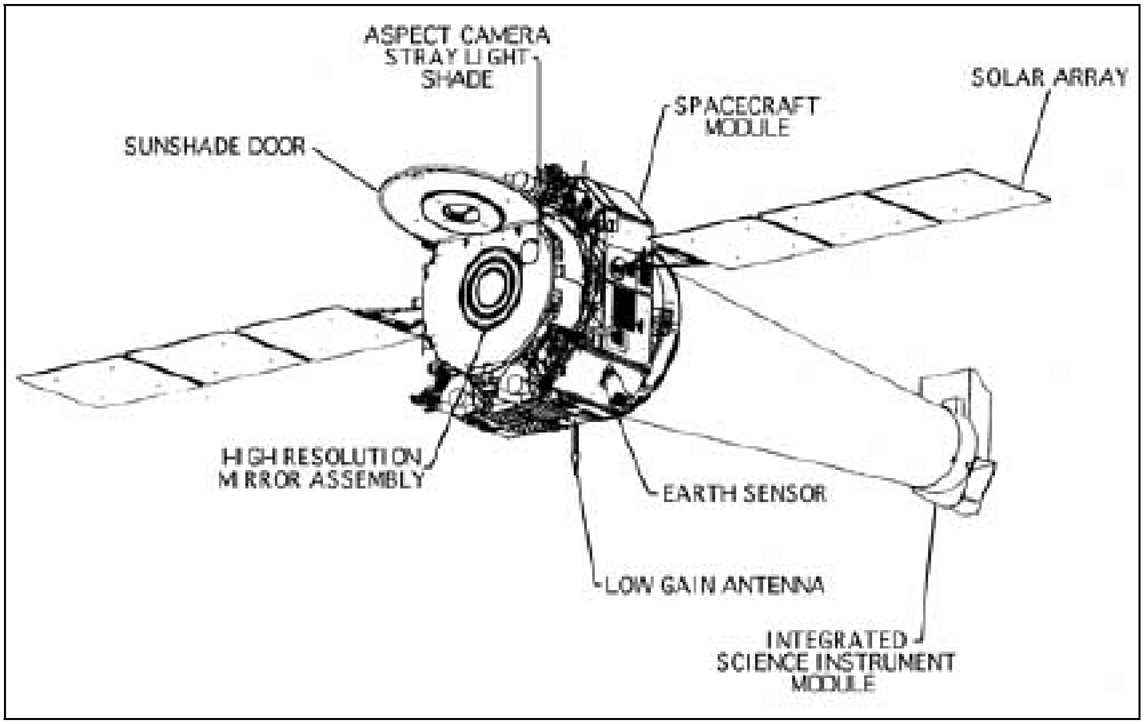
Technical Data

	Metric	U.S.
Dimensions		
Telescope length	10 m	32.8 ft
Mirror (in pairs) length	1.75 m	5.7 ft
Mirror diameter (large pair)	1.2 m	3.9 ft
Mirror diameter (small pair)	0.6 m	1.9 ft
Weights		
Satellite	22,543 kg	49,700 lb
Power		
Solar arrays	2 arrays at 3 panels each	
Power generated	2,350 watts	
Electrical power storage	3 batteries, 40-ampere-hour nickel hydrogen	
Communications		
Antennas	2 low-gain antennas	
Communications links	Shuttle Payload Interrogator Deep Space Network	
Command link	2 kbs per second	
Data downlink	32 kbs to 1,024 kbs	
Frequencies	Transmit	2250 MHz
	Receive	2071.8 MHz
On-board Data Capture		
Solid-state recorder	capacity	1.8 gbs at 16.8 hours
Science Instruments		
Charged Coupled Imaging Spectrometer (ACIS)		
High Resolution Camera (HRC)		
High Energy Transmission Grating (HETG)		
Low Energy Transmission Grating (LETG)		
Performance		
Mission duration	Chandra Science Mission	Approx. 5 years
	Orbital activation & checkout periods	Approx. 2 years
Orbital data		28.5 degrees
Inclination		86,992 sm
Altitude at apogee		6,214 sm
Altitude at perigee		64 hours
Orbital period		Up to 55 hours
Observing time per orbit		
Propulsion		
Integral Propulsion System (IPS)	Hydrazine and nitrogen tetroxide fuel	

Design Features. The Chandra X-ray Observatory is composed of three major assemblies: the spacecraft, the telescope, and the science instrument module. The spacecraft module houses computers, communication antennas, and data recorders. Its also provides rocket propulsion to move and aim the entire observatory. The telescope system is the heart of the observatory and houses the high-resolution mirror assembly, composed of special cylindrical mirrors to funnel X-rays to the instrument section for detection and study. The science instrument section of the observatory collects the X-rays for study using a high-resolution camera to record X-ray images and an AXAF CCD Imaging Spectrometer (ACIS) that is capable of recording the position, color, and energy of X-rays.

Artist's concept of the Chandra X-ray Observatory. The Chandra X-ray Observatory provides unique and crucial new information about the structure and evolution of the universe

Chandra X-ray Observatory Mission Patch



Chandra X-ray Observatory drawing showing various components and equipment

Source: NASA

Variants/Upgrades

Constellation-X. Currently in pre-Phase A studies, this system has been designated as a follow-on to the Chandra X-ray Observatory. The effort is derived from merging two previous missions concepts, the Next-Generation X-ray Observatory and the Large Area X-ray Spectroscopy Mission. Constellation-X reportedly will make observations at high spectral resolution, some 100 times more sensitive than Chandra. Its mission will address many fundamental astrophysics questions, such as those involving the origin and distribution of the elements from carbon to zinc, the formation and evolution of clusters of galaxies, the validity of general relativity in the strong gravity limit, the evolution of super massive black holes in active galactic nuclei, the details of supernova explosions and their aftermath, and the mechanisms that heat stellar corona and drive stellar winds. The mission baseline would consist of four identical satellites orbiting in formation at the L2 Lagrange point in space. Viewing the same X-ray source simultaneously, the satellites would have a combined collecting area equivalent to that of a 1.5 meter optical telescope. Mission implementation is expected to begin in October 2006. Operational capability is scheduled for year 2010.

Program Review

Background. The Chandra X-ray Observatory (formerly the Advanced X-ray Astrophysics Facility, AXAF) is one of NASA's three current "Great Observatories." (The other two are the Hubble Space Telescope and the Compton Gamma Ray Observatory.) Chandra observes matter at the extremes of temperature, density, and energy content. With unprecedented capabilities in energy coverage, spatial resolution, spectral resolution and sensitivity, Chandra is providing unique and crucial information on the nature of objects ranging from nearby stars to quasars at the edge of the observable universe.

The spacecraft can measure the expansion speed of the universe at several different times in cosmic history because it is sensitive enough to look far out in the universe, which is far back in time. These measurements, in turn, will show if the universe will continue to expand forever or will eventually stop and then contract. Thus, it is theorized, Chandra can predict the fate of the universe. The satellite will look back in time to see quasars in earlier epochs and will study the high-energy component of quasar emission.

Additionally, the satellite can contribute to the discovery and identification of black holes. Both the X-ray spectrum and the temporal behavior of X-ray intensity of a variety of black hole environments are distinctive. The Chandra X-ray Observatory will search the universe for objects that match the theoretical predictions and then study their behavior in detail. So far, the only black hole candidates have been discovered with X-ray observations. The spacecraft will help demonstrate whether these theoretical constructs really exist.

Dark matter in the universe may be in the form of asteroids, planets, dark stars, black holes, or other, unknown kinds of matter. The Chandra X-ray Observatory can lead the search for the dark matter and provide much needed data on its mass and location. It will bring the X-ray background into sharp focus, enabling the determination and examination of its composition. The satellite will also be a diagnostic tool for examining the results of stellar explosions and for understanding the cosmic processes that produced the chemical elements on Earth today.

The satellite does not look directly at the sun, though it will be able to view thousands of other stars and obtain a large statistical sample of their characteristics. Detailed measurements of many stars will enable the determination of which parameters – temperature, magnetic fields, rotation rates – are the most important in producing X-rays from stars. This information will help in determining the processes that heat stellar coronas, including that of the sun. Chandra may detect evidence of cosmic strings and exotic particles such as axions and monopoles in neutron stars.

The Early Years. The Marshall Space Flight Center was assigned responsibility for managing AXAF in 1978 as a successor to the original High Energy Astrophysics Observatory (HEAO) program. The scientific payload was selected through an Announcement of Opportunity in 1985 and confirmed for flight readiness in 1989.

In March 1991, the Marshall Space Flight Center selected the Smithsonian Astrophysical Observatory to develop and operate a science support center for the AXAF. Under the 10-year, U.S.$86.7 million contract, the center will provide a service to the international scientific community by overseeing an observation program for the X-ray telescope and by managing the reception and distribution of the data it collects.

The AXAF program was restructured in 1992 in response to decreasing funding projections for NASA programs. The original baseline was an observatory with six mirror pairs, a 15-year mission in low-Earth orbit, and Space Shuttle servicing. The restructuring produced AXAF-1, an observatory with four mirror pairs to be launched into a high-Earth orbit for a five-year lifetime, and AXAF-S, a smaller observatory flying an X-ray spectrometer (SRS). A panel from the National Academy of Sciences endorsed the restructured AXAF program.

The FY94 AXAF budget was reduced by Congress, resulting in termination of the AXAF-S mission. Committees further directed that residual FY94 AXAF-S funds be applied toward development of a similar instrument for flight on the Japanese Astro-E mission then scheduled for February 2000.

Observatory Renamed. In December 1998, NASA announced that AXAF was to be renamed the Chandra X-ray Observatory in honor of the late Indian-American Nobel laureate Subrahmanyan Chandrasekhar. “Chandra,” a shortened version of Chandrasekhar’s name, which he was said to have preferred, was chosen in a contest to rename the X-ray telescope. “Chandra” also means “Moon” or “luminous” in Sanskrit. Chandrasekhar, widely regarded as one of the foremost astrophysicists of the 20th century, won the Nobel Prize in 1983 for his theoretical studies of physical processes important to the structure and evolution of stars. He and his wife emigrated from India to the US in 1935. He served on the faculty of the University of Chicago until his death in 1995.

Mission Time Extended. The Chandra X-ray Observatory was successfully launched by the Space Shuttle and an Inertial Upper Stage on July 23, 1999. Following launch, the space observatory entered a period of checkout, followed by science operations. According to NASA, the Chandra X-ray Observatory is functioning well, and results have been very gratifying.

In September 2001, NASA announced that, based on Chandra’s outstanding results to date, it had decided to extend the observatory’s original five-year mission to ten years. The extended mission will support five additional years of day-to-day operations such as controlling the spacecraft, observing celestial targets, processing the data, and passing it on to scientists around the world. It also includes continuing the administration of hundreds of science grants for astronomers to analyze their data and publish their results.

With the Chandra X-ray Observatory performing well above expectations, NASA announced in July 2002 that it had extended its contract with the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts, through August 2003 to provide science and operational support for the Chandra X-ray Observatory. The contract is for an 11-month period of performance extension estimated at U.S.$50.75 million.

Developer of Chandra Mirrors Honored. In January 2002, a leading Chandra scientist, Leon Van Speybroeck of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts, was awarded the 2002 Bruno Rossi Prize of the High Energy Astrophysics Division of the American Astronomical Society. The Rossi Prize recognizes significant contributions in high-energy astrophysics. It is awarded annually in honor of the late Massachusetts Institute of Technology professor Bruno Rossi, an authority on cosmic ray physics and a pioneer in the field of X-ray astronomy.

Van Speybroeck, who led the effort to design and make the X-ray mirrors for NASA’s Chandra X-ray Observatory, was recognized for a career of stellar achievements in designing precision X-ray optics. As telescope scientist for Chandra, he has worked for more than 20 years with a team that includes scientists and engineers from the Harvard-Smithsonian, NASA’s Marshall Space Flight Center, TRW Inc, then-Hughes-Danbury (now Goodrich), Optical Coating Laboratories Inc, and Eastman-Kodak on all aspects of the X-ray mirror assembly that is the heart of the observatory.

The Chandra mirrors are the most precise mirrors ever made, smooth with tolerances of a few atoms. If the state of Colorado had the same relative smoothness as the surface of the Chandra X-ray Observatory mirrors, Pike’s Peak would be less than an inch tall. The smoothness and alignment of the Chandra’s mirrors are enabling scientists to make new discoveries about black holes, neutron stars, and galactic explosions.

Van Speybroeck, a graduate of the Massachusetts Institute of Technology, once took a course in optics under Rossi, but his thesis work was in high-energy physics. Upon graduation, he joined the X-ray astronomy group at American Science & Engineering and became involved in the design of the X-ray mirrors for NASA’s Skylab project. After moving to the Harvard-Smithsonian Center for Astrophysics, he had primary responsibility for designing and developing the mirrors for the Einstein X-ray Observatory, the predecessor of the Chandra X-ray Observatory.

Note: For additional details, see the “Constellation-X” report in this tab. For details on the Chandra spacecraft itself and the follow-on Constellation-X satellites, please refer to the report “Chandra X-ray Observatory/ Constellation-X” in Forecast International’s *Space Systems* Forecast.

Funding

The Chandra X-ray Observatory is funded under its own line item within NASA's Science, Aeronautics and Technology effort. Mission applications are funded under the Data Analysis section of the Technology Program which is part of NASA's Science, Aeronautics and Technology budget.

U.S. FUNDING

	FY00		FY01		FY02		FY03	
	QTY	AMT	QTY	AMT	QTY	AMT	QTY	AMT
Chandra X-ray Observatory								
Mission Ops	-	4.0	-	-	-	-	-	N/A
Data Analysis	-	291.1	-	310.5	-	319.2	-	N/A

All $ are in millions.

Source: NASA FY01 Funding

Recent Contracts

Contractor	Award ($ millions)	Date/Description
Smithsonian Astrophysical Observatory	50.75	Jul 2002 – NASA 11-month period of performance contract extension for science and operational support for the Chandra X-ray Observatory. Total contract value is now U.S.$298.2 million. The contract extension resulted from the delay of the launch of the Chandra X-ray Observatory from August 1998 to July 1999. The contract covers mission operations and data analysis, which includes both the observatory operations and the science data processing and general observer (astronomer) support. The observatory operations tasks include monitoring the health and status of the observatory and developing and distributing by satellite the observation sequences during Chandra's communication coverage periods. The revised period of performance will continue the contract through August 31, 2003, which is 48 months beyond operational checkout of the observatory. The contract type is cost reimbursement with no fee.

Timetable

Month	Year	Major Development
	1978	Original High Energy Astrophysics Observatory (HEAO) program
Aug	1984	Kodak-TRW and Lockheed Martin each win U.S.$5.2 million contracts for studies
Jan	1987	32-month observatory definition complete
	1989	AXAF program start
	1992	AXAF program restructure
Dec	1996	Mirrors complete
May	1997	Scientific instruments testing complete
Dec	1998	AXAF renamed Chandra X-ray Observatory
Jan	1999	TRW unveils complete Chandra X-ray Observatory
Jul	1999	Chandra X-ray Observatory launch on Space Shuttle Columbia
Aug	1999	Chandra first light image recorded by Advanced CCD Imaging Spectrometer
Sep	2002	Chandra X-ray Observatory mission time extended to 10 years from original five years
	2006	Planned start of Constellation-X program
	2010	Planned launches of Constellation-X satellites as a follow-on effort

Month	Year	Major Development

Worldwide Distribution

The Chandra X-ray Observatory is a **U.S. NASA**-managed mission.

Forecast Rationale

There was a point in the development of NASA's Chandra X-ray Observatory program when the only thing Chandra appeared to be observing was its own slow death due to program difficulties. Several valiant technological efforts and years later, the Chandra X-ray Observatory has redeemed itself by performing well beyond original expectations in terms of operation and data collection. In fact, Chandra has been so successful that in July 2002 NASA announced the extension of the Chandra X-ray Observatory's original five-year-mission to a full 10 years. Thanks in part to Chandra's unique X-ray vision, the system has been able to record for the first time the full impact of a blast wave from an exploding star, a flare from a brown dwarf, and a small galaxy in the process of being consumed by a much larger galaxy.

Operational, maintenance, and support funding for Chandra is expected to continue with no problems through the program's run. The system will run well beyond its designated lifetime and serve the scientific community for more years than originally intended, making it one of NASA's better investments in recent years. Even with some well-publicized failures with its Mars missions, NASA has had great luck with its three Great Observatories. These successes should help assure funding for the follow-on Constellation-X effort and future space telescopes.

Ten-Year Outlook

One Chandra X-ray Observatory has been produced. Operation and support funding is being provided by various NASA programs. The next follow-on system to Chandra X-ray Observatory will be Constellation-X. (See related report "Constellation-X.")

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