NASA Facts

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Space Administration

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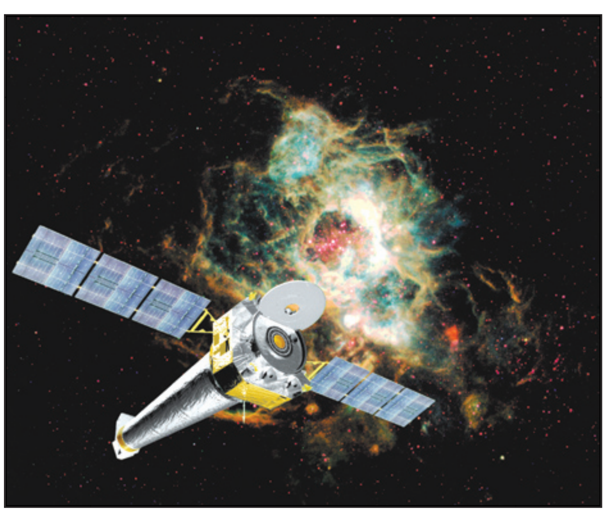
Huntsville, Alabama 35812

Exploring The Invisible Universe: The Chandra X-ray Observatory

To the human eye, space appears serene and void. It is neither. To the “eye” of an X-ray telescope, the universe is totally different — a violent, vibrant, and ever-changing place. Temperatures can reach millions of degrees. Objects are accelerated by gravity to nearly the speed of light and magnetic fields more than a trillion times stronger than the Earth’s, causing some stars to crack and tremble.

The Chandra X-ray Observatory is part of NASA’s fleet of “Great Observatories” along with the Hubble Space Telescope, the Spitzer Space Telescope and the now deorbited Compton Gamma Ray Observatory. Chandra allows scientists from around the world to obtain unprecedented X-ray images of exotic environments to help understand the structure and evolution of the universe. The observatory not only helps to probe these mysteries, but also serves as a unique tool to study detailed physics in a laboratory that cannot be replicated on Earth. Already surpassing its five-year life, NASA's Chandra X-ray Observatory is rewriting textbooks and helping advance technology. NASA fuels discoveries that make the world smarter, healthier and safer.



Artist concept of the Chandra X-ray Observatory.

Named in honor of the late Indian-American Nobel laureate, Subrahmanyan Chandrasekhar, the Chandra X-Ray Observatory provides information on the nature of objects ranging from comets in our Solar System to quasars at the edge of the observable universe. Some of the major questions addressed by Chandra are:

- What and where is the "dark matter" in our universe? The largest and most massive objects in the universe are galaxy clusters — enormous collections of galaxies that include some like our own. These galaxies are bound together into a cluster by gravity. Much of the mass in the cluster is in the form of an incredibly hot, X-ray emitting gas that fills the entire space between the galaxies. Yet, neither the mass of the galaxies, nor the mass of the hot X-ray gas is enough to provide the gravity that we know holds the cluster together. Additional mass, due to a mysterious substance called dark matter, is required. X-ray observations with Chandra are mapping the location of the dark matter and helping us to identify it.

- What is the powerhouse driving the explosive activity in many distant galaxies? The centers of many distant galaxies are incredible sources of energy and radiation — especially X-rays. Scientists theorize that massive black holes are at the center of these active galaxies, gobbling up any material — even whole stars — that pass too closely. Detailed studies with Chandra are probing the faintest of these active galaxies. The research shows not only how their energy output changes with time, but also how these objects produce their intense energy emissions in the first place.

- Does the Universe contain “dark energy” and if so, how important is it? Because galaxy clusters are the largest bound structures in the Universe, they likely represent a fair sample of the matter content in the Universe. If so, the ratio of dark matter to hot gas would be the same for every cluster. Scientists used this assumption and Chandra data from galaxy clusters to show that the rate of expansion of the Universe began to accelerate about six billion years ago. This is an important confirmation of results from optical observations of supernovae in distant galaxies. Many scientists attribute the driving force behind cosmic acceleration to “dark energy,” which would make it the dominant form of energy in the Universe. Although there is no accepted explanation for dark energy, most astrophysicists think that dark energy may be intimately connected with the nature of space-time itself.

Since X-rays are absorbed by the Earth’s atmosphere, space-based observatories are necessary to study these phenomena. To meet this scientific challenge, the Chandra X-ray Observatory was carried into low-Earth orbit by the Space Shuttle Columbia on July 23, 1999. Chandra was then deployed from the Shuttle’s cargo bay 155 miles above the Earth. Two firings of an attached Inertial Upper Stage rocket and several firings of its own on-board Integral Propulsion System after separating from the Inertial Upper Stage placed Chandra into its working orbit.

Unlike the Hubble Space Telescope’s circular orbit that is relatively close to the Earth, Chandra was placed in a highly elliptical — or oval-shaped — orbit. At its closest approach to Earth, the observatory reaches an altitude of about 6,000 miles. At its farthest point of approximately 86,400 miles, Chandra travels almost one-third of the way to the Moon.

It takes Chandra 64 hours to complete one full orbit, during which the observatory takes uninterrupted observations for about 55 hours. Chandra cannot take science observations while it travels through Earth’s radiation belts that surround the planet, since the radiation can disturb Chandra’s sensitive instruments.

Observatory Elements

The Chandra X-ray Observatory has three major elements: the spacecraft system, the telescope system and the science instruments.

The Spacecraft System

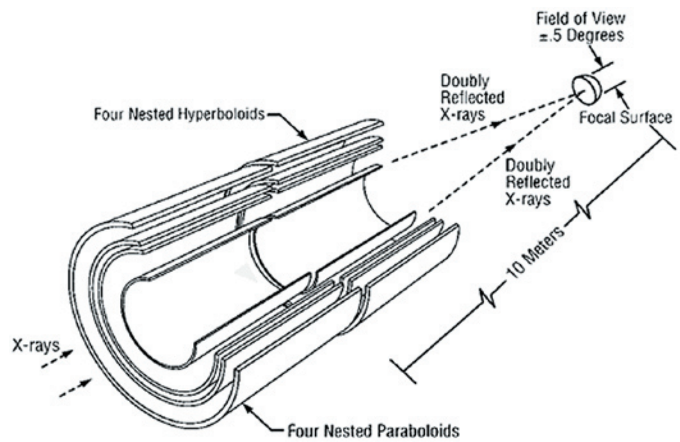
The spacecraft module contains computers, communication antennas and data recorders to transmit and receive information between the observatory and ground stations. The onboard computers and sensors, with ground-based control center assistance, command and control the vehicle and monitor its health.

The spacecraft module also provides reaction wheels to aim the entire observatory, a set of small momentum unloading system thrusters to control momentum buildup, an aspect camera that tells the observatory its position relative to the stars, and a Sun sensor that protects it from excessive light. Electrical power is provided by solar arrays that also charge three nickel-hydrogen batteries that provide backup power.

The Telescope System

At the heart of the telescope system is the High Resolution Mirror Assembly. Since high-energy X-rays would penetrate a normal mirror, special cylindrical mirrors were created. The two sets of four nested mirrors resemble tubes within tubes. Incoming X-rays graze off the highly polished mirror surfaces and are funneled to the instrument section for detection and study.

The mirrors of the Chandra X-ray Observatory are the largest of their kind and the smoothest ever created. If the surface of the state of Colorado were as relatively smooth, Pike’s Peak would be less than 1 inch tall. The largest of the eight mirrors is almost 4 feet in diameter and 3 feet long. Assembled, the mirror group weighs more than 1 ton.



The High Resolution Mirror Assembly is contained in the cylindrical “telescope” portion of the observatory. The entire length of the telescope is covered with reflective multi-layer insulation that assists heating elements inside the unit in keeping a constant internal temperature. By maintaining a precise temperature, the mirrors within the telescope are not subjected to expansion and contraction, thus ensuring greater accuracy in observations.

The assembled mirrors were tested at NASA’s Marshall Space Flight Center in Huntsville, Ala. Marshall’s X-ray Calibration Facility verified the mirrors’ exceptional accuracy, which allows Chandra to detect objects separated by one-half arc second. This is comparable to reading the letters of a stop sign 12 miles away.

The Chandra X-ray Observatory represents a scientific leap in ability over previous X-ray observatories like NASA’s Einstein, which orbited the Earth from 1978 to 1981. With its combination of large mirror area, accurate alignment and efficient X-ray detectors, Chandra has eight-times greater resolution and is 20 to 50 times more sensitive than any previous X-ray telescope.

Science Instruments

Two instruments, each of which can serve as an imager or spectrometer, are located at the narrow end of the telescope cylinder to collect X-rays and study them in various ways. By studying the X-ray rainbows, or spectra, and recognizing signatures of known elements, scientists can determine the composition of the X-ray producing objects, and learn how the X-rays are produced.

The High Resolution Camera records X-ray images, giving scientists an unequaled look at violent, high-temperature occurrences like the death of stars or colliding galaxies. The camera is composed of two clusters of 69 million, tiny lead-oxide glass tubes. The tubes are only one-twentieth of an inch long and just one-eighth the thickness of a human hair. When X-rays strike the tubes, particles called electrons are released. As the electrons are accelerated down the tubes by high voltage, they cause an avalanche of about 30 million more electrons. A grid of electrically charged wires at the end of the tube detects this flood of particles and allows the position of the original X-ray to be precisely determined.

Complementing the High Resolution Camera is the Advanced Charge-Coupled Device Imaging Spectrometer, which is also located at the narrow end of Chandra. This detector is capable of recording not only the position, but also the color (energy) of the X-rays. The imaging spectrometer is made up of 10 charge-coupled device arrays. These detectors are similar to those used in home video recorders and digital cameras, but are designed to detect X-rays. Commands from the ground control center allow astronomers to select which of the various detectors to use. The imaging spectrometer can distinguish up to 50 different energies within the range Chandra operates.

In order to gain even more energy information, two screen-like instruments, called diffraction gratings, can be inserted into the path of the X-rays between the telescope and the detectors. The gratings change the path of the X-ray depending on its color (energy) and the X-ray cameras record the color and position. The High Energy Transmission Grating concentrates on the higher and medium energies and the Low Energy Transmission Grating disperses low energy X-rays. Both gratings can be used in conjunction with either the imaging spectrometer or the High Resolution Camera.

Observatory Operations

The Smithsonian Astrophysical Observatory controls science and flight operations of the Chandra X-ray Observatory for NASA from Cambridge, Mass. The Smithsonian manages two electronically linked facilities — the Operations Control Center and the Science Center.

The Operations Control Center is responsible for directing Chandra's mission as it orbits Earth. A control center team interacts with Chandra about three times a day — receiving science telemetry and spacecraft housekeeping information from its data recorders. The control center team also transmits new instructions to Chandra as needed and transfers the downlinked science data to the Science Center.

The Science Center is an important resource for scientists who wish to study X-ray-emitting celestial objects like quasars and colliding galaxies. The Science Center provides user support to researchers, including science data processing and a science data archive. The Science Center works with NASA and the scientific community to allow public access to the scientific results.

Accomplishments to Date

A Chandra timeline reveals some of its most noteworthy discoveries:

- Chandra finds a ring around the Crab Nebula. After only two months in space, the observatory reveals a brilliant ring around the heart of the Crab Pulsar in the Crab Nebula — the remains of a stellar explosion — providing clues about how the nebula is energized by a pulsing neutron, or collapsed star. (Sept. 28, 1999)
- Chandra reveals a possible black hole in the Milky Way. Culminating 25 years of searching by astronomers, researchers say that a faint X-ray source, newly detected by Chandra, is the long-sought X-ray emission from a known supermassive black hole at the center of our galaxy. (Jan. 14, 2000)
- Chandra finds the most distant X-ray cluster. Using the Chandra X-ray Observatory, astronomers find the most distant X-ray cluster of galaxies yet. Approximately 10 billion light-years from Earth, the cluster 3C294 is 40 percent farther than the next most distant X-ray galaxy cluster. (Feb. 20, 2001)
- Chandra discovers X-rays from Jupiter. Using Chandra, astronomers discover a pulsating hot spot of X-rays in the polar regions of the planet's upper atmosphere and uncover evidence the X-ray source is not arising from the region of Jupiter where previously believed. (Aug. 29, 2002)
- Chandra makes first I.D. of a binary black hole. By revealing two active black holes in the nucleus of the extraordinarily bright galaxy NGC 6240, a Chandra image proves for the first time that two supermassive black holes can co-exist in the same galaxy. (Nov. 11, 2002)
- Chandra makes deepest X-ray exposure. A Chandra image, Deep Field North, captures for 23 days an area of the sky one-fifth the size of the full moon. Even though the faintest sources detected produced only one X-ray photon every four days, Chandra finds more than 600 X-ray sources, most of them supermassive black holes in galaxy centers. (June 19, 2003)
- Chandra sheds new light on the Vela Pulsar. Chandra offers new insight into pulsars, small and extremely dense stars. Created from a series of Chandra observations, an X-ray movie of the Vela pulsar reveals a spectacularly erratic jet that varies in a way never before seen, whipping about like an untended fire hose at about half the speed of light. (June 30, 2003)
- Chandra 'hears' a black hole. Using the Chandra X-ray Observatory, astronomers for the first time detect sound waves

from a supermassive black hole. Coming from a black hole 250 million light years from Earth, the "note" is the deepest ever detected from an object in the Universe. (Sept. 9, 2003)
- Chandra finds evidence of new class of black holes. Chandra finds that mysterious, powerful X-ray sources found in nearby galaxies may represent a new class of objects. These sources, cooler than typical neutron-star or black-hole X-ray sources, may be a large new population of black holes with masses several hundred times that of the sun. (March 1, 2004)
- Chandra opens new line of investigation on dark energy. Using galaxy-cluster images from Chandra, astronomers apply a powerful, new method for detecting and probing dark energy. The results offer intriguing clues about the nature of dark energy and the fate of the Universe. (May 18, 2004)

NASA and Partners

The Chandra X-ray Observatory program is managed by the Marshall Center for the Science Mission Directorate, NASA Headquarters, Washington, D.C. Northrop Grumman of Redondo Beach, Calif., formerly TRW, Inc., was the prime development contractor that assembled and tested the observatory for NASA. Using glass purchased from Schott Glaswerke, Mainz, Germany, the telescope's mirrors were built by BF Goodrich Optical, formerly Perkin-Elmer, Danbury, Conn. The mirrors were coated by Optical Coating Laboratory, Inc., Santa Rosa, Calif., and assembled by ITT Industries, formerly Eastman Kodak Co., Rochester, N.Y.

The Chandra X-ray Observatory Advanced Charge-Coupled Device Imaging Spectrometer was developed by Pennsylvania State University, University Park, Pa., and the Massachusetts Institute of Technology (MIT), Cambridge. One diffraction grating was developed by MIT, the other by the Space Research Organization Netherlands, Utrecht, Netherlands, in collaboration with the Max Planck Institute, Garching, Germany. The High Resolution Camera was built by the Smithsonian Astrophysical Observatory. Ball Aerospace & Technologies Corporation of Boulder, Colo., developed the aspect camera and the Science Instrument Module.

The Smithsonian Astrophysical Observatory (SAO) in Cambridge, Mass., is responsible for the conduct of the day-to-day flight operations and science activities from the Operations Control Center and Chandra X-ray Center facilities. SAO also coordinates science planning for the observing program and provides user support as science products are made available to the scientific community.

Chandra X-ray Observatory Technical Details

Size: 45.3 feet long by 64.0 feet wide (solar arrays deployed)
Weight: 10,560 pounds
Life: Originally planned for five years, but now planning for at least 10 years
Orbit: 6,000 by 86,400 miles, 64-hour period per orbit
Power: Two three-panel, silicon solar arrays (2,350 watts). Three 40-amp-hour nickel-hydrogen batteries for power in eclipse
Data recording: Solid-state recorder; 1.8 gigabits (16.8 hours) of recording capability
High Resolution Mirror: Assembly of four sets of nested, grazing incidence paraboloid/hyperboloid mirror pairs, constructed of Zerodur material

- Weight of assembly: 2,104 pounds
- Focal length: 10 meters (about 33 feet)
- Outer diameter: 1.2 meters (about 4 feet)

Advanced Charge-coupled Imaging Spectrometer: Ten charge-coupled device arrays provide simultaneous imaging and spectroscopy
High Resolution Camera: Micro-channel plates detect X-ray photons
Transmission Gratings: One high/medium and one low-energy, gold grating

More Information
Links to the Chandra X-ray Observatory can be found on the following Web sites at:

http://chandra.nasa.gov/
http://chandra.harvard.edu
and
http://www.nasa.gov

Explore. Discover. Understand.

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