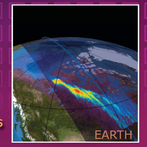
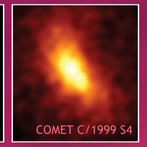
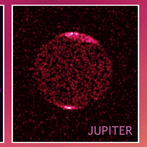
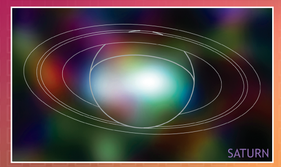
THE SOLAR SYSTEM

THROUGH CHANDRA'S EYES



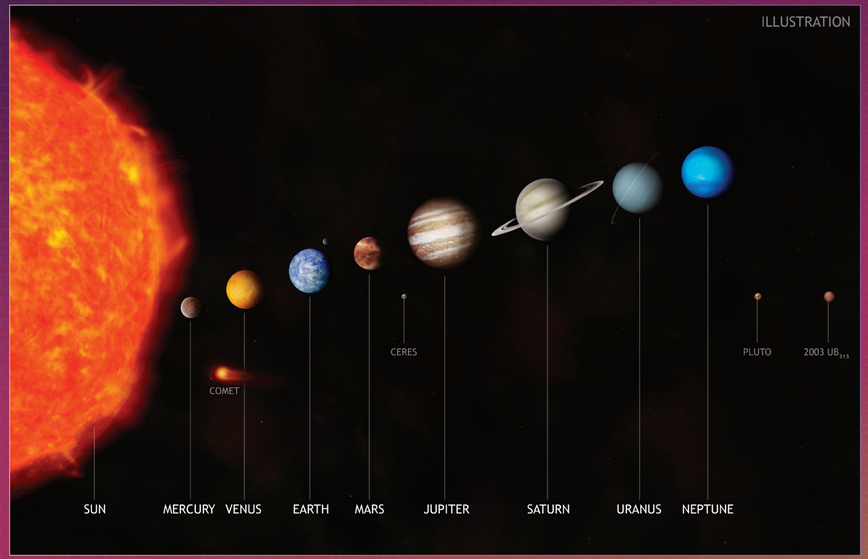






CHANDRA
X-RAY OBSERVATORY

One star, eight planets, and a myriad of moons, comets, and asteroids. This is the Earth's local neighborhood known as the Solar System. Despite studying this system for centuries, astronomers still yearn to know much more. NASA's Chandra X-ray Observatory is providing new insight and uncovering new mysteries about objects of all sizes and across all distances throughout our Solar System.



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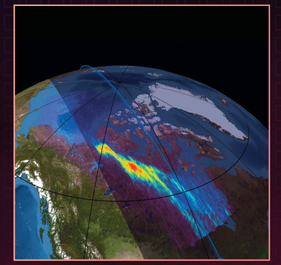
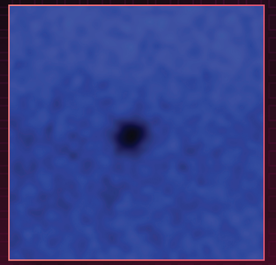
NASA's Marshall Space Flight Center, Huntsville, Ala., manages the Chandra program for the agency's Science Mission Directorate. The Smithsonian Astrophysical Observatory controls science and flight operations from the Chandra X-ray Center in Cambridge, Mass.

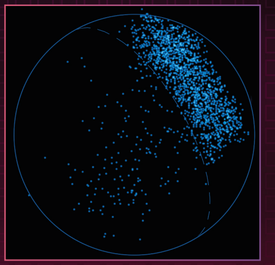
CHANDRA X-RAY IMAGES Earth: NASA/MSFC/CXC/A.Bhardwaj et al.; Earth model: NASA/GSFC/L.Perkins & G.Shirah; **Titan:** NASA/CXC/Penn State/K.Mori et al.; **The Moon:** NASA/CXC/SAO/J.Drake et al.; **Venus:** NASA/MPE/K.Dennerl et al.; **Comet C/1999 S4 (LINEAR):** NASA/CXC/C.Lisse, S.Wolk, et al.; **Jupiter:** NASA/CXC/SWRI/G.R.Gladstone et al.; **Mars:** NASA/CXC/MPE/K.Dennerl et al.; **Saturn:** NASA/U.Hamburg/J.Ness et al.. **OPTICAL IMAGES** Titan: NASA/JPL/Space Science Institute; The Moon: Robert Gendler; Venus: Konrad Dennerl; Comet C/1999 S4: NASA, H.Weaver and P.Feldman (Johns Hopkins Univ.), M.A'Hearn (Univ. of Maryland), C.Arpigny (Liege Univ.), M.Combi (Univ. of Michigan), M.Festou (Obs. Midi Pyrenees), and G. P. Tozzi (Arcetri Obs.); Mars: NASA, J.Bell (Cornell), M.Wolff (SSI) and The Hubble Heritage Team (STScI/AURA); Jupiter: NASA/HST/R.Beebe et al.; Saturn: NASA/STScI; The Sun: NASA/SOHO **ILLUSTRATIONS** Inside: NASA/SOHO; Back: CXC/M. Weiss

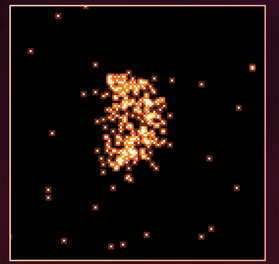
THE SOLAR SYSTEM

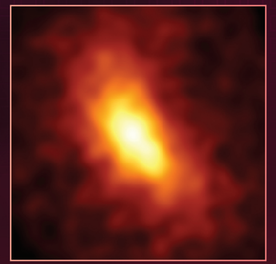
THROUGH CHANDRA'S EYES

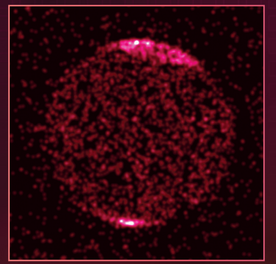


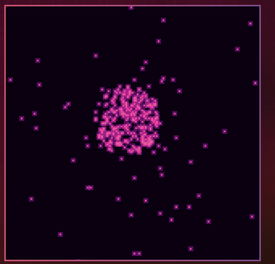


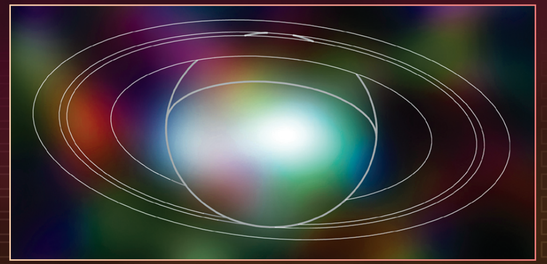












Chandra's specialty is probing the super-hot regions around exploding stars, galaxies, or black holes. But Chandra has also shown that the relatively peaceful realms of space, such as our Solar System, sometimes shine in X-ray light.

Planets, satellites and comets typically have temperatures well below 1,000 degrees, but they still can produce X-rays in a number of ways, most of which involve the Sun directly or indirectly. Although the X-ray power is relatively weak, it provides information difficult to come by with other telescopes.

NASA'S CHANDRA X-RAY OBSERVATORY

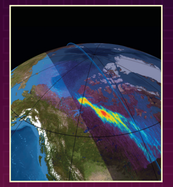
THE SOLAR SYSTEM THROUGH CHANDRA'S EYES

Illustration of Solar Wind: The white lines represent the solar wind; the purple line is the bow shock produced by the interaction of the solar wind with the Earth's protective magnetosphere (blue lines). *[Not to Scale.]*

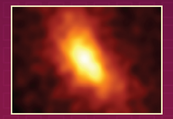
EARTH Very close to home, Chandra has detected X-rays from auroras in the Earth's north polar regions. The auroras are generated by solar storms that disturb the Earth's magnetic field, and energize electrons high in the Earth's atmosphere. As some of these electrons spiral along Earth's magnetic field lines, they collide with atoms above the north polar regions and produce X-rays.

Chandra has also detected evidence of X-rays from Earth's geocorona (extended outer atmosphere) through which Chandra moves. The geocoronal X-rays are caused by collisions between hydrogen atoms in the geocorona with carbon, oxygen and neon ions that are streaming away from the Sun in the solar wind.

This process is called "charge exchange" because an electron is exchanged between a neutral atom in the atmosphere and an ion—typically carbon, nitrogen, or oxygen—in the solar wind. After such collisions, X-rays are emitted as the captured electrons move into tighter orbits. These X-rays have an energy that is equal to the difference in energy states for the electron orbits. The spectrum, or overall distribution of X-rays with energy, from charge exchange collisions can be distinguished from other processes with a sensitive X-ray spectrometer, and provide evidence that the charge exchange collision is occurring.

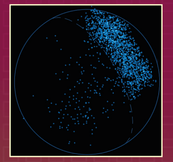


COMETS The charge exchange process operates throughout the Solar System. It is especially important for comets, which have extended atmospheres. Comets resemble "dirty snow balls" a few miles in diameter with a surrounding cloud of dust and gas. By observing X-rays due to charge exchange in the cometary atmosphere, it is possible to study the elements present in the solar wind, the structure of the comet's atmosphere, and cometary rotation. In the future it may be possible to detect X-radiation from collections of hundreds of comets around stars other than the Sun. Young stars would be the most promising candidates because they have vigorous stellar winds.

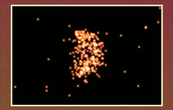


THE MOON Chandra has been used to prospect for elements on the Moon. X-rays from the Moon are caused by "fluorescence" due to the impact of solar X-rays on the surface of the Moon. When a solar X-ray is absorbed by an atom on the lunar surface, the X-ray knocks an electron out of the inner part of the atom and excites the atom to a higher energy level. The atom almost immediately returns to its lower energy state with the emission of a fluorescent X-ray. In a similar way, ultraviolet light produces the visible light of fluorescent lamps. The energy of a fluorescent X-ray is unique to the particular type of atom, so fluorescent X-rays give a direct measurement of elements present, independent of assumptions about the type of mineral or other complications.

Oxygen, magnesium, aluminum and silicon were detected over a large area of the lunar surface. Longer observations of the Moon with Chandra should help to determine if the Moon was formed by a giant impact of a planetoid with the Earth about 4.5 billion years ago, or by some other process.

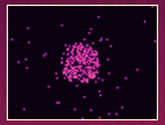


VENUS The X-rays from Venus and, to some extent, the Earth, are due to the fluorescence of solar X-rays striking the atmosphere. Chandra's image of Venus shows a half crescent due to the relative orientation of the Sun, Earth and Venus. Solar X-rays are absorbed about 120 kilometers above the surface of the planet, knocking electrons out of the inner parts of atoms, and exciting the atoms to a higher energy level. When the atoms almost immediately return to their lower energy state, they emit a fluorescent X-ray. In contrast to the X-radiation, the optical light from Venus is caused by the reflection of sunlight from clouds 50 to 70 kilometers above the surface.

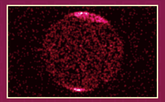


MARS Fluorescent X-rays from oxygen atoms in the Martian atmosphere probe heights similar to those on Venus. A huge Martian dust storm was in progress when the Chandra observations were made. Since the intensity of the X-rays did not change when the dust storm rotated out of view, astronomers were able to conclude that the dust storm did not affect Mars's upper atmosphere. They also found evidence that Mars is still losing its atmosphere into deep space.

A faint halo of X-rays was also detected some 7,000 kilometers above the surface of Mars. These X-rays are presumably due to the solar wind charge exchange process operating in the tenuous extreme upper atmosphere of Mars.



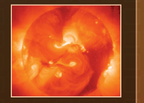
JUPITER Jupiter has an environment capable of producing X-rays in a different manner because of its substantial magnetic field. X-rays are produced when high-energy particles from the Sun get trapped in its magnetic field and accelerated toward the polar regions where they collide with atoms in Jupiter's atmosphere. Chandra's image of Jupiter shows strong concentrations of X-rays near the north and south magnetic poles. The weak equatorial X-ray emission is likely due to reflection of solar X-rays.



SATURN Like Jupiter, Saturn has a strong magnetic field so it was expected that Saturn would also show a concentration of X-rays toward the poles. However, Chandra's observation revealed instead an increased X-ray brightness in the equatorial region. Furthermore, Saturn's X-ray spectrum, or the distribution of its X-rays according to energy, was found to be similar to that of X-rays from the Sun. This indicates that Saturn's X-radiation is due to the reflection of solar X-rays by Saturn's atmosphere, the same process that may be responsible for the weak equatorial X-radiation observed from Jupiter. Further observations should help clarify whether Saturn's magnetic polar regions ever flare up in X-rays, as do Jupiter's.

TITAN Astronomers have used the lack of X-rays from Saturn's largest moon, Titan, to draw some interesting conclusions. On January 5, 2003, Titan—the only moon in the Solar System with a thick atmosphere—crossed in front of the Crab Nebula, a bright, extended X-ray source. Titan's transit enabled Chandra to image the one-arcsecond-diameter X-ray shadow cast on Chandra by the moon. This tiny shadow corresponds to the size of a dime as viewed from two and a half miles. The diameter of Titan's shadow was found to be larger than the known diameter of its solid surface. This difference in diameters yields a measurement of about 880 kilometers for the height of the X-ray absorbing region of Titan's atmosphere. The extent of Titan's upper atmosphere is consistent with, or slightly (10-15%) larger than, that implied by Voyager I observations made at radio, infrared, and ultraviolet wavelengths in 1980. Saturn was about 5% closer to the Sun in 2003, so increased solar heating of Titan may have caused its atmosphere to expand.

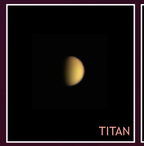
THE SUN The Sun's corona, or hot outer atmosphere, produces X-rays but it is too close and bright for Chandra to observe with its extremely sensitive detectors. An X-ray image of the Sun, courtesy of The Soft X-ray Telescope on board the Yohkoh satellite, is shown on the right. This telescope was specially designed to study the solar corona, which has a temperature of about 2-million-degrees Celsius.

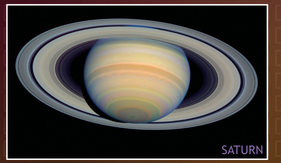


THE SOLAR SYSTEM

From small rocky comets to large gaseous planets, the Solar System is alive in X-ray light. When combined with optical images (below), Chandra's X-ray data expand the understanding—and pose new questions—about the Solar System.

[Images not to scale.]





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