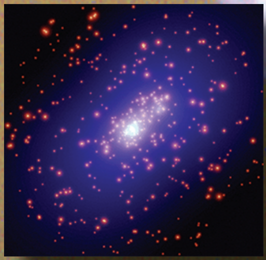
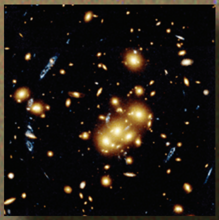
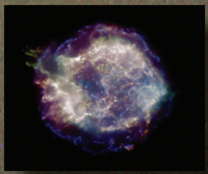
A BEYOND EINSTEIN MISSION

CONSTELLATION X-RAY OBSERVATORY







UNLOCKING THE MYSTERIES OF

BLACK HOLES

DARK MATTER

DARK ENERGY

AND *LIFE CYCLES OF MATTER*

IN THE UNIVERSE

National Aeronautics and
Space Administration

Goddard Space Flight Center

Chandra X-ray Observatory

Artist's impression of the Constellation X-ray Observatory

Constellation-X is modeled after the Keck Observatory, twin optical telescopes each 10 meters (37 feet) wide. Both observatories can collect an enormous amount of light. Keck and Constellation - X are the complements to the great high-angular-resolution space telescopes: the Hubble Space Telescope and the Chandra X-ray Observatory, respectively.

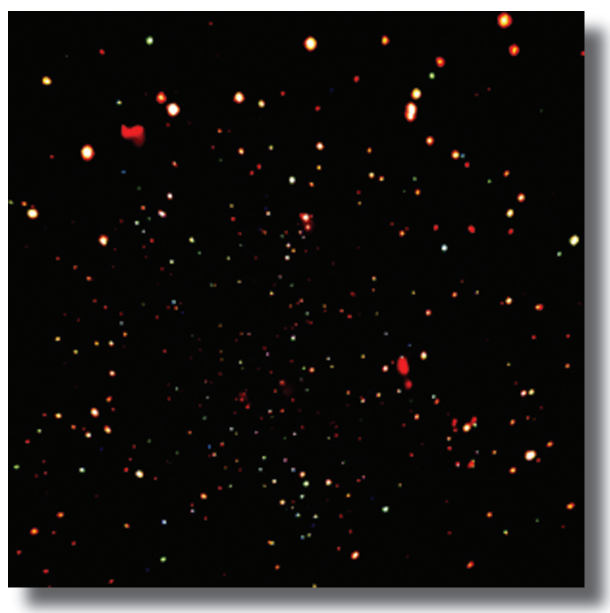
Hubble Space Telescope

Keck Observatory

THE CONSTELLATION X-RAY MISSION

Space. Time. Energy. The Universe presents itself to us as a series of profound mysteries. From a primordial, chaotic fireball known as the Big Bang, the Universe grew into the elegant structure we see today of stars, galaxies and clusters of galaxies separated by deep voids of seemingly empty space. Yet how did we get from there to here? What forces chiseled out the Milky Way, our neighboring galaxies, and the billions of galaxies beyond the horizon? Where did the atoms in our body come from? What happens to space and time near a black hole? What is the fate of the Universe?

The Constellation-X Observatory is a team of next-generation X-ray telescopes that will help us understand the great mysteries of space, time and energy. Planned as four individual X-ray telescopes flying separately in space yet operating together, Constellation-X will study black holes, the nature of gravity (by testing Einstein's Theory of General Relativity), the nature of "dark matter" and "dark energy", how galaxies and the largest structures formed, and how matter and energy are "recycled" in stars. These phenomena reveal themselves in X-ray light, far more energetic than the visible light our eyes can detect.



NASA/CXC/PSU/D.M. Alexander et al.

The Chandra Deep Field. Most of the pinpoints of light pictured here are from very distant galaxies with powerful black holes at their core. Constellation-X will gather detailed information about even the faintest of these galaxies.

Like all X-ray telescopes, Constellation-X must be positioned in space because X-ray light does not penetrate the Earth's atmosphere. In designing Constellation-X, however, scientists wanted an X-ray telescope similar to traditional, large Earth-bound telescopes to collect as much light as possible – which would be too large to launch on a rocket. These requirements led to Constellation-X's unique multi-satellite design. The four satellites are light enough to be launched individually or in pairs, yet once in orbit they combine to provide a sensitivity 100-times greater than any past or current satellite mission.

With Constellation-X, scientists will be able to collect more data in an hour than they would have collected in days or weeks with current X-ray telescopes. We will learn about thousands of faint X-ray emitting sources, not just the bright sources that are visible to us with today's X-ray telescopes.

The multi-satellite design also saves money and reduces risks. It is less expensive to build and launch smaller, identical telescopes. And with separate launches for individual telescopes – or perhaps for pairs of telescopes, if the design permits – we avoid putting all our eggs in one rocket, so to speak.

Constellation-X is modeled after the Keck Observatory, twin optical telescopes each 10 meters (33 feet) wide, positioned high atop Mauna Kea in Hawaii. Both observatories have superior collecting areas, or apertures, for analyzing the components of light. Both Keck and Constellation-X are the complements to the great high-angular-resolution space telescopes: the Hubble Space Telescope and the Chandra X-ray Observatory, respectively. No single telescope can do it all, however. Hubble provides fantastic images of distant galaxies with unprecedented clarity, while the Earth-based Keck supports Hubble by collecting enough light to study the motion of gas in those distant galaxies. Likewise, the Chandra Observatory, launched in 1999, has the best imaging resolution of any X-ray telescope so far. Scientists will use the unparalleled data from Constellation-X together with Chandra in analyzing X-ray light to form a more complete picture of the X-ray Universe.

Exploring the Universe Using X-ray Spectroscopy

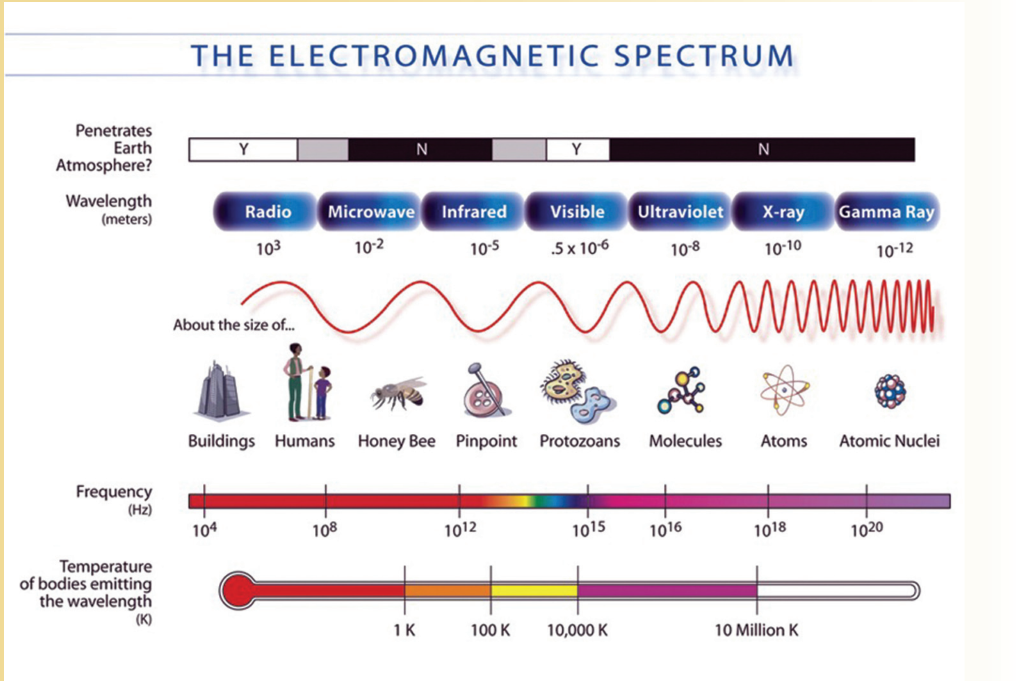
Different types of telescopes detect different types, or wavelengths, of light – from microwaves and radio waves, to infrared, visible light and ultraviolet, to high-energy X-ray photons and gamma rays. Studying each wavelength band is important for composing a full view of the Universe.

WMAP, a microwave telescope, studies the afterglow of the Big Bang, the most ancient light in the Universe. From this, scientists have determined the age and shape of the Universe, along with the time the stars first ignited. Radio telescopes, on the other hand, were the first to detect quasars, extremely distant galaxies that emit incredible amounts of radio energy. Radio telescopes also provided the first evidence of planets outside our Solar System.

Infrared telescopes have identified dust clouds between stars and galaxies, as well as "nurseries" for possible star formation. Optical telescopes, such as Hubble Space Telescope, have created spectacular images of stars and galaxies, both near and far. These images are what our minds are most familiar with because our eyes, like Hubble, collect and process visible light. Hubble also measures the sizes, distances and compositions of celestial objects.

High-energy gamma-ray telescopes have discovered the most energetic explosions since the Big Bang, called gamma-ray bursts, likely signaling the birth of a black hole. Thus, the entire electromagnetic spectrum is important for a complete picture, because different objects emit the bulk of their radiation at different wavelengths. Black holes, a prime target for Constellation-X, are best detectable at high energies – that is, in X rays and gamma rays.

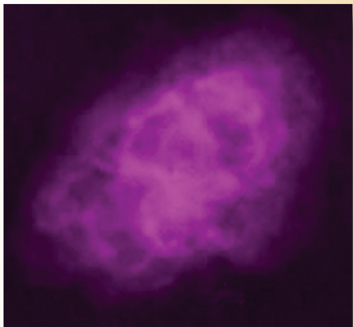
The electromagnetic spectrum consists of all wavelengths of light including low-energy radio waves, infrared, visible, ultraviolet light and high-energy X rays and gamma rays. Only by observing the full electromagnetic spectrum can we gain a complete understanding of the Universe.



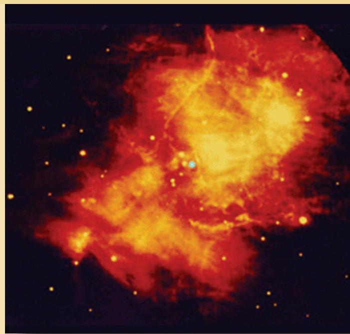
An X-ray telescope collects photons, or light "particles," created naturally in some of the most violent and energetic events in the Universe. This mechanism for collecting photons is quite different from taking an "X-ray" of a broken bone. Unlike a medical X-ray machine that produces X rays, the X-ray telescope doesn't generate X-ray photons. Rather, it collects these tiny packets of high energy that travel through space from vast distances. X-ray detectors on satellites are like the film in the doctor's X-ray machine.

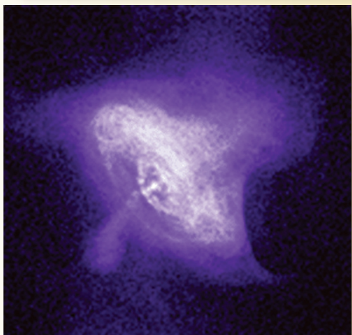
The Sun produces some X rays, particularly during a solar flare. However, Constellation-X's focus will be far beyond our Solar System. The observatory will turn its attention to black holes, star explosions, galaxies that release great amounts of X rays from their centers, and the pervasive gas that dominates space between stars and galaxies that is bright in X rays but invisible to optical telescopes like Hubble. Constellation-X will document these objects and regions with images and, more important, with spectra. Spectra, the soul of Constellation-X, are like the fingerprints of elements in far away stars and dusty clouds of hot gas. These are diagrams of spectral energy patterns that reveal almost every characteristic of a distant gas, solely from the light it emits. With high-resolution X-ray spectroscopy, we can zoom in to within a few kilometers of the border of a black hole, as close to the black hole itself as any observation can theoretically get. Spectra can be used to see how extreme gravity around a black hole distorts space and affects the composition, pressure, density, temperature and velocity of the gas swirling into it. Spectra of black holes, supernova remnants and galaxy clusters provided by Constellation-X will be the next best thing to reaching out and sampling these objects.

VLA/NRAO (radio)



WM Keck OBS. (infrared)

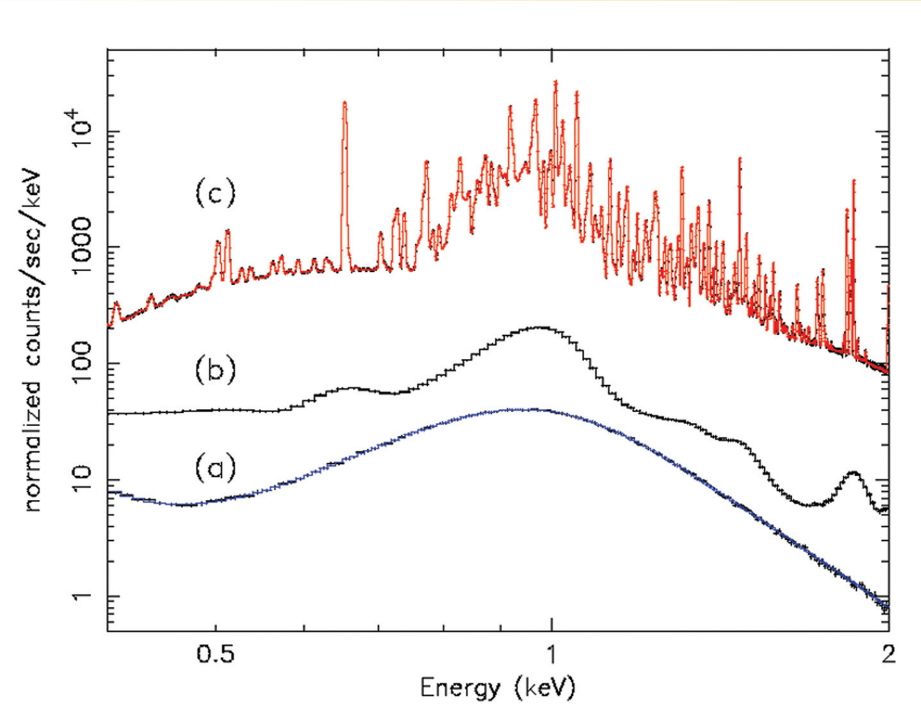




NASA/CXC/SAO (x-ray)

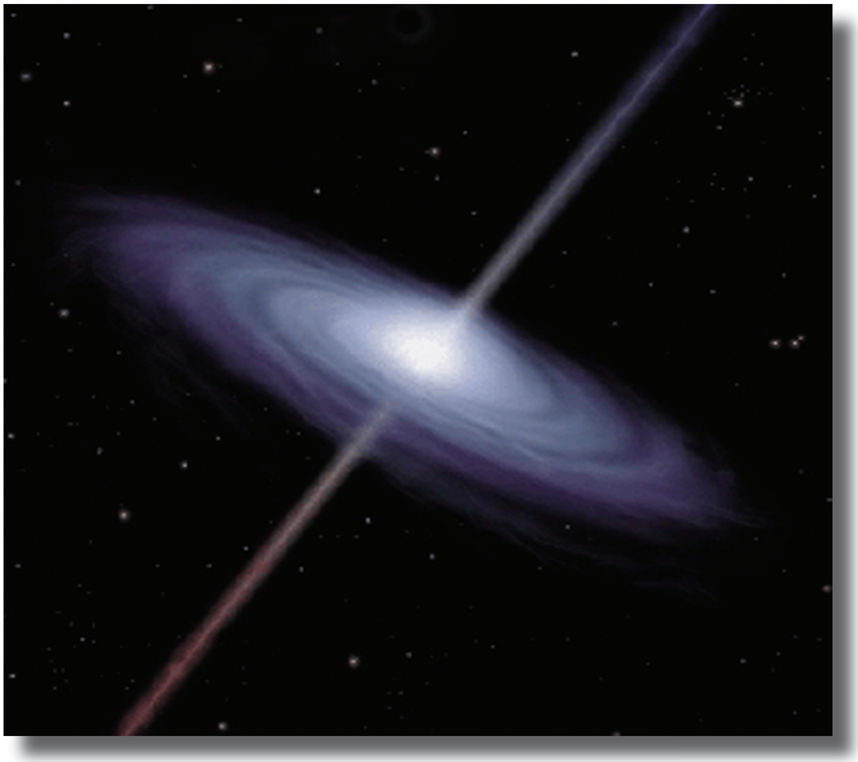
Palomar Obs. (visible)

These images show the Crab supernova remnant and pulsar as they appear (clockwise from upper left) in radio, infrared, visible and X- ray light.



The evolution of spectroscopy: (a) Early X-ray detectors provided little detail about a patch of 10 million degree gas. (b) Newer X-ray detectors called CCDs provide greater detail of the features of the gas. CCDs of this caliber are flying now on the Chandra and XMM-Newton satellites. (c) Constellation-X's spectrometer will provide even more detail and 100 times greater sensitivity than those used today.

Understanding the Limits of Extreme Gravity: Black Holes and Active Galactic Nuclei



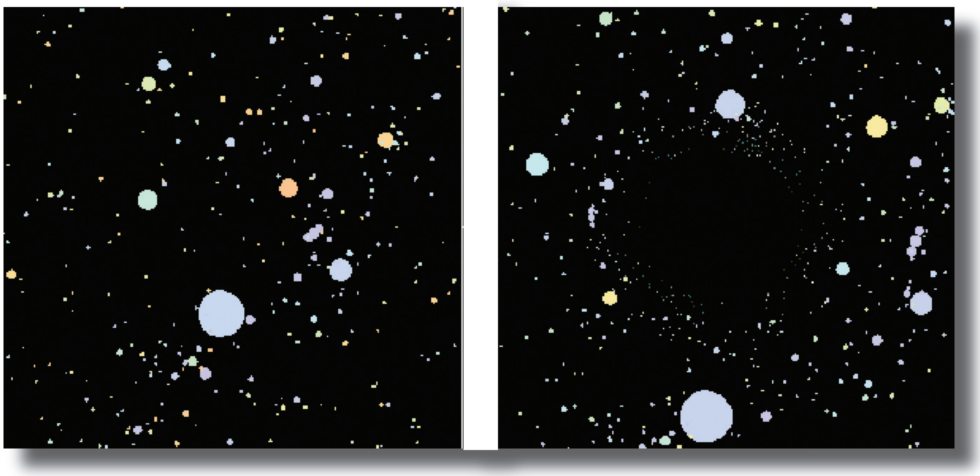
A. Kamajian

This artist's impression of a supermassive black hole highlights the accretion disk of gas and stars swirling around the black hole, and the jets of material ejected along the poles.

Constellation-X will measure how the extreme forces of gravity operate near a black hole by mapping the distortions of space-time predicated by Einstein's Theory of General Relativity. The Observatory will study three known classes of black holes. There are stellar black holes, also called galactic black holes, the remains of massive stars 10-100 times the size of our Sun that have exploded. There's an emerging and mysterious class of "intermediate-mass" black holes, discovered in recent years, that contain the mass of hundreds to thousands of Suns. Then there are the powerhouses, supermassive black holes in the center of most galaxies, containing the mass of millions to billions of Suns. Our Milky Way galaxy is home to thousands of stellar black holes and likely a supermassive black hole in the center.

Within all classes of black holes, space and time as we know them collapse. At the black hole border, called the event horizon, space is greatly distorted and time comes to a crawl. Einstein described the three physical dimensions (length, width, height) and time as one four-dimensional concept called space-time. A black hole's gravity is so strong that it can actually bend space-time, sort of like stretching the fabric of space. A black hole (or a neutron star, another dense object) is often envisioned as a heavy weight, like a bowling ball, on a mattress. The force of gravity, Einstein said, is the curvature in space-time cased by any object. When a black hole spins, it is so massive and produces a curvature so great that it can spin space-time along with it. Thus, black holes are cosmic laboratories, allowing us to explore the ultimate limits of the law of gravity and other forces.

One unavoidable challenge when studying black holes, however, is that they're almost invisible. A black hole is defined by its event horizon, the point at which gravity is so strong that nothing, not even light, can escape. Inches outside the border, gravity is intense but light can escape. Inches inside the border... forget it!



R.J. Nemiroff (MTU)

The extreme gravity around a black hole curves spacetime so that light no longer travels in a straight line. These computer generated pictures highlight how strange things would look if you got too close to a black hole having about twice the mass of our sun. On the left is the constellation Orion. Notice the three blue stars of nearly equal brightness near the center of the image that make up Orion's belt. On the right is the same constellation, but this time you, the observer, are sitting 26 miles away from the event horizon of a black hole. The black hole has such a strong gravity that light noticeably bends around it – causing unusual visual distortion. Each star seems to appear twice, once on each side of the black hole (Orion's belt is visible at the left and right of the image). Near a black hole, you can actually see the whole sky because light from every direction is bent around and comes back to you.

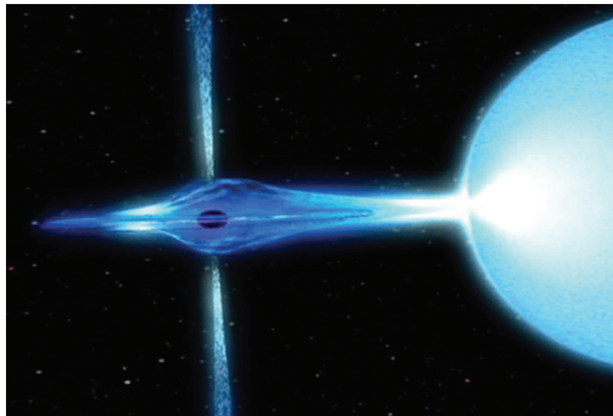
All matter that crosses the event horizon is crushed into a singularity at the center, a point of infinite density, hidden behind the event horizon. The event horizon of a stellar black hole is only a few miles across. In supermassive black holes, it is only about the size of our Solar System.

Supermassive black holes are likely the power source for Active Galactic Nuclei (AGN), the bulging glow seen in many galactic cores. AGN might be the result of a huge black hole gobbling up whole stars and pulling in dust and gas from the nearby interstellar medium with such fury that the energy produced in this relatively small region outshines the entire galaxy.

How do we go about observing black holes if they are so compact and emit no visible light? There are a couple of tricks. Stellar black holes are often part of a binary star system, two stars revolving around each other. What we see from Earth is a visible star orbiting around what appears to be nothing. In reality, it is orbiting around the black hole. We can infer the mass of the black hole by the way the visible star is orbiting around it. The larger the black hole, the greater the gravitational pull, and the greater the effect on the visible star.

Galactic (stellar-sized) black holes are often found in a binary system. This artist's impression shows how the accretion disk forms as material is pulled from the companion star and swirls into the black hole.

Another way we can "see" a black hole is by observing X rays generated around it. Because a black hole has such a powerful gravitational force, a galactic black hole in a binary system can literally tear apart its companion star. Gas from the companion swirls into the black hole like water down a drain.

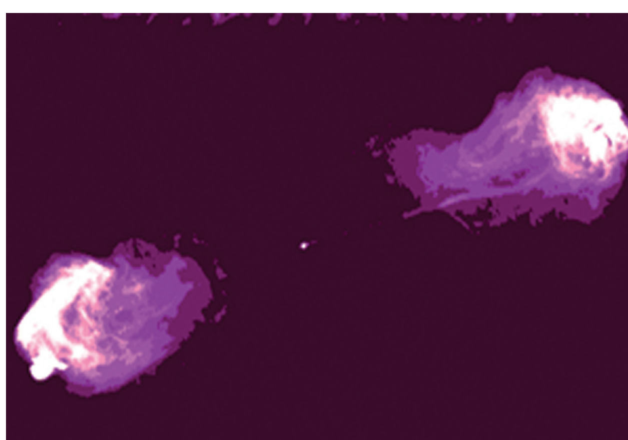


NASA/ D. Berry

The swirling gas is what scientists call an accretion disk. As the gas gets closer to the black hole, it heats up from the friction of ever-faster-moving gas molecules. Just outside the black hole's event horizon, the gas heats to temperatures in the range of millions of degrees. Gas heated to these temperatures releases tremendous amounts of energy in the form of X rays.

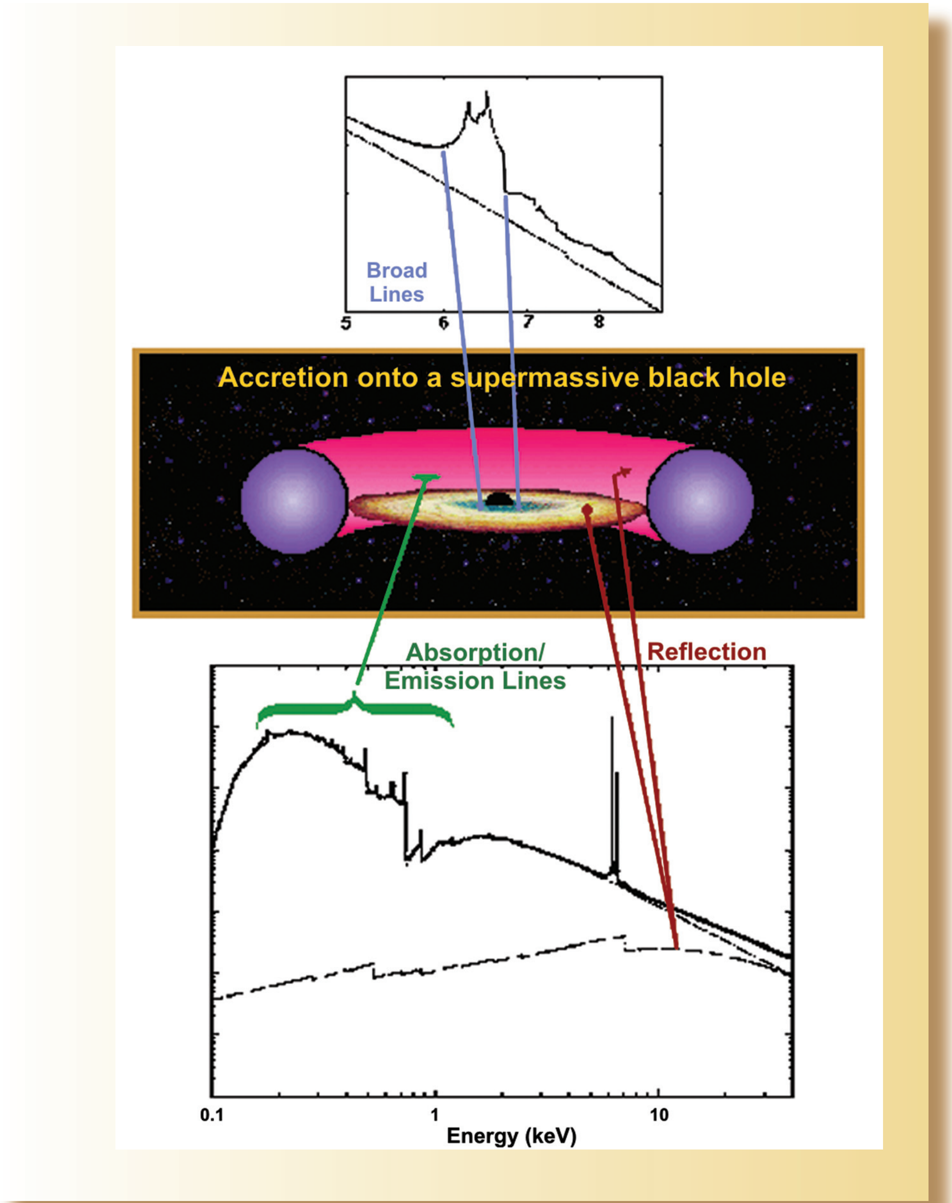
Supermassive black holes also have an accretion disk that emits X rays. This is formed not by a single star, as in a binary star system, but by the great amounts of gas present in the regions between stars. In about 10% of supermassive black holes, jets of energized matter thousands of light years in length shoot out in opposite directions. These jets can be detected in radio, visible, X-ray and gamma-ray wavelengths. The jets accelerate matter to nearly the speed of light through a mechanism not well understood, but something Constellation-X may tell us. This is because Constellation-X can view so close to the event horizon that we can see this "do-or-die" region where matter pouring into the black hole suddenly – perhaps due to magnetic fields – has the opportunity to be diverted from the void and escape the region via these particle jets. It's a bit of cosmic irony how black holes, notorious for pulling matter in, can manage to shoot matter away too at such high speeds.

The radio image of the nearby active galaxy Cygnus A shows its prominent jets that extend for almost 18,000 light years in either direction.



NRAO/AUI

From small to large-scale black holes, many questions abound: What are the masses and rates of rotation of black holes? How is material fed directly into the black hole? How do jets form? Why do some black holes have jets, while many more do not? What keeps the jets powered for millions of years? Why are AGNs more common in the past than today? How do supermassive black holes participate in the formation and evolution of galaxies?

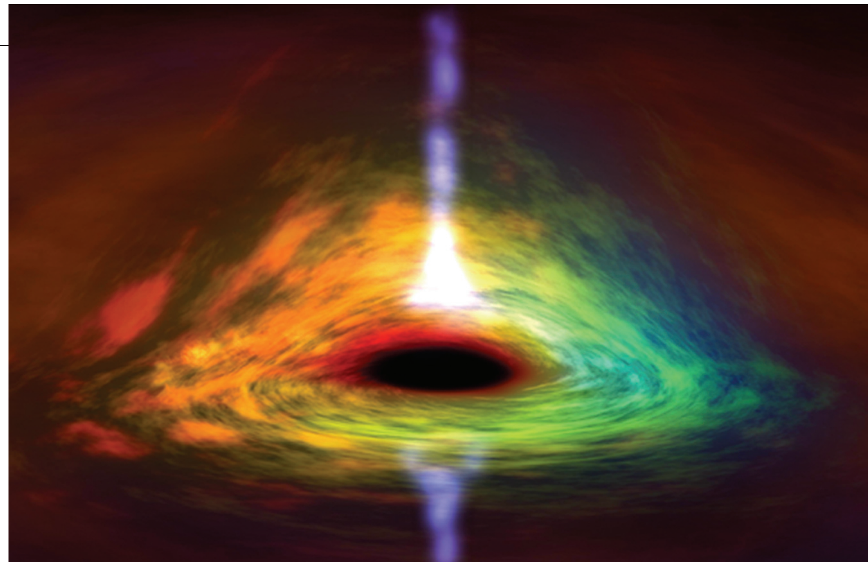


I. George (GSFC)

The upper panel shows a spectrum of the X rays produced in the accretion disk, near the event horizon. Iron gas is present in the disk and radiates X-ray light at a characteristic energy. The spike in the spectrum reveals this. This spike is broadened, however, by the force of extreme gravity from the black hole, tugging back at the light as it leaves the black hole region towards Earth. Scientists call this spectrum characteristic the "broad iron K line". Broad lines are present close to the black hole, where gravity is most intense; and the extent of broadening and other characteristics in spectra relate to the mass and spin rate of the black hole.

The middle panel is a diagram of the innermost regions of an AGN, with an accretion disk bordered by a thick tube of dust.

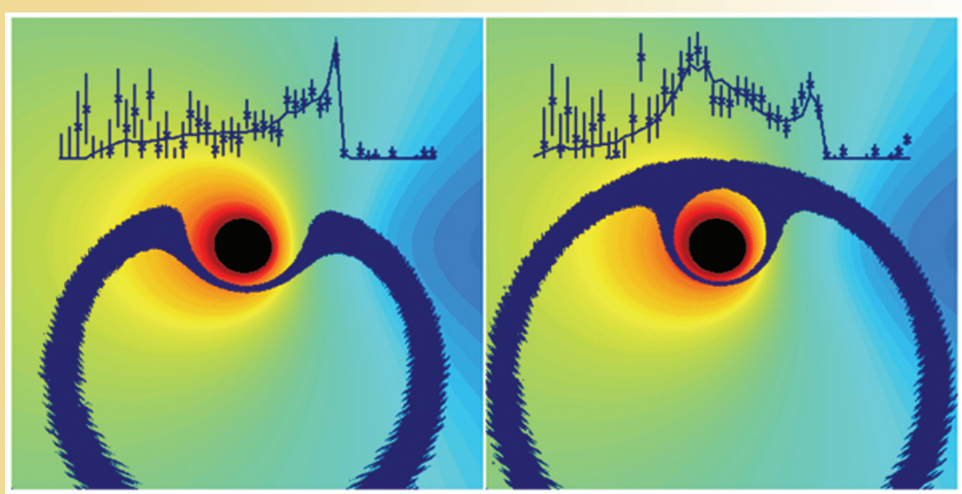
The lower panel is a spectrum of dust and gas outside the accretion disk. Constellation-X's superior sensitivity will measure the motion and composition of this material and determine how it enters the accretion disk. Note that the spikes representing light emitted farther away from the black hole aren't as broad as the spikes closer to the black hole.



This simulated image shows what an accretion disk around a black hole might look like. The distortions of time and space by the intense gravity of the black hole cause the unusual shape, and the motion of the material at close to the speed of light causes emission to be shifted to longer (red) and shorter (blue) wavelengths as matter flies away from us and then back towards us, around and around the black hole.

NASA/D. Berry

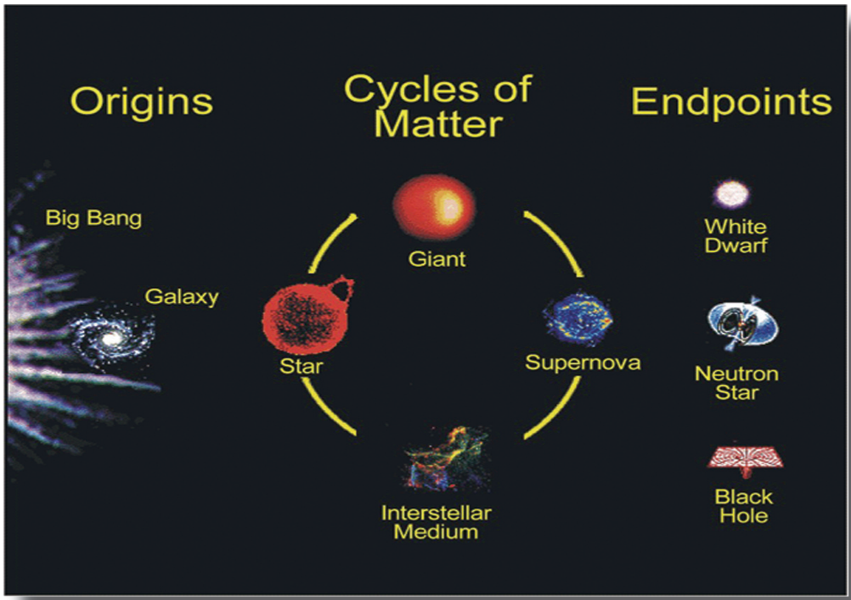
Constellation-X's large X-ray collecting area and superior spectral resolution, or clarity, will provide the most detailed, quantitative observations of the region surrounding a black hole. Views using current telescopes can take us near a black hole, but Constellation-X will take us to within a few miles of its edge. Experiments will be able to measure the mass and spin of a black hole, two of its defining characteristics. Such measurements will enable scientists to begin to answer the many questions that remain about the formation and evolution of black holes, and about how the laws of physics – particularly those based on Einstein's equations – behave in extreme environments.



Simulated cartoon images of an accretion disk around a maximally-rotating 100-million mass black hole, color coded to show regions of redshift and blueshift. The circular, dark blue region represents the expanding wavefront, or "light echo", of an X-ray flare from above the accretion disk. The upper inset images show the spectrum of the corresponding iron K line, 2000 seconds apart. Detecting change in the shape of the line will allow scientists to map out the gravitational forces near the black

C. Reynolds (UMD)

The Life Cycles of Matter and Energy in the Universe

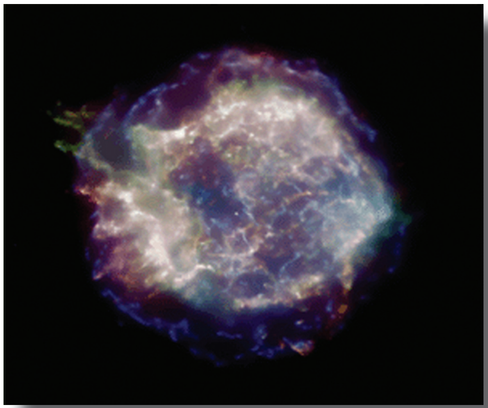


L. Whitlock (GSFC)

The Universe as an ecosystem: Much like biologists, astronomers trace the flow of matter and energy from one form to another in order to understand the dynamics of the entire system and how it evolves.

Another goal of the Constellation-X mission is to understand how the elements made in stars are dispersed and recycled throughout the Universe, particularly through a supernova, an explosion that marks the end of a massive star's life.

Supernova explosions are one of the most powerful forces in the Universe. A supernova explosion releases more energy than our Sun does over 100 million years. The ultrahigh temperatures generated by supernova explosions can fuse the mid-size elements made in stars (carbon, iron) into heavier ones (gold, uranium). All elements heavier than iron are created in this explosion process. Shock waves from these explosions send the elements made in stars racing into space, often to be recycled billions of miles from their origin. The elements that make up our bodies, in fact, came from an exploded star dispersed by a distant supernova explosion.



NASA/CXC/SAO

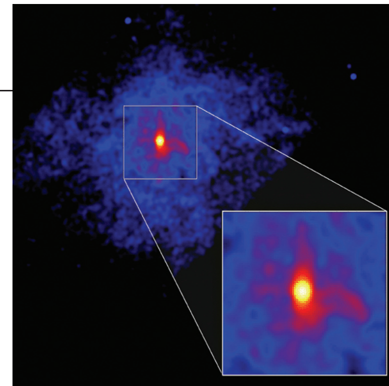
The supernova Cassiopeia A is located in the constellation Cassiopeia 10,000 light years away. This Chandra X-ray image shows the debris of a gigantic stellar explosion.

The material from the outer layers of a star blown into space by the explosion forms the supernova remnant. This afterglow can be seen for tens of thousands of years. With X-ray spectra from Constellation-X, we will be able to precisely determine the amounts of elements created and dispersed by the supernova.

Chandra and another current X-ray mission, XMM-Newton, have confirmed theories of how stars produce the most abundant elements and have mapped supernova remnants with great accuracy. Constellation-X will revolutionize this research area with an ability to make extremely sensitive maps of known supernova and observe X rays from sources 100 times fainter than any other X-ray mission could detect. We will be able to construct a full map of the explosion scene by measuring even the least abundant ele-

Chandra observations of the neutron star RX J1856.5-3754 (left) and the pulsar in 3C58 (right) hint that the matter in these collapsed stars is even denser than nuclear matter, the most dense matter found on Earth. The observations suggest that these stars may be composed of exotic quarks rather than neutrons.

NASA/SAO/CXC/J.Drake



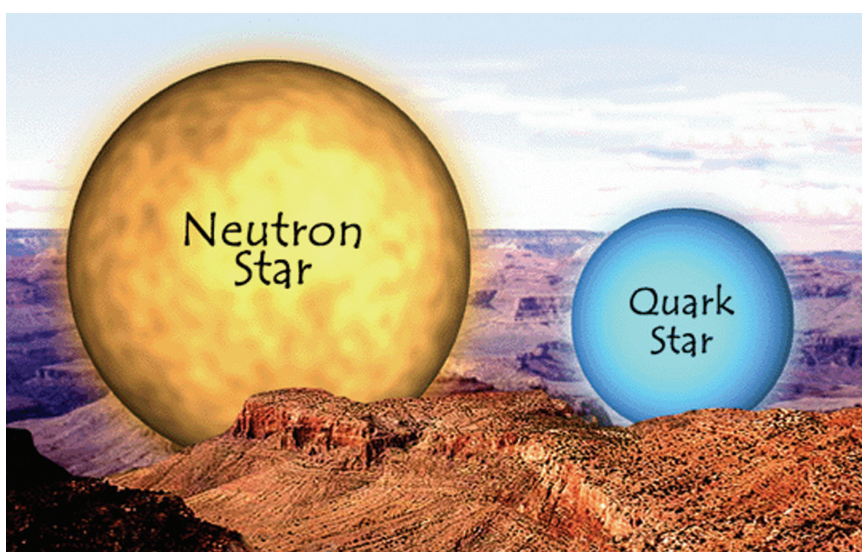
NASA/SAO/CXC/P.Slane

ments. The Universe is the ultimate recycling machine, and understanding this process will be yet one more tool in understanding the Universe's structure and evolution.

Constellation-X might also lead scientists to new types of matter and forces, such as exotic quarks and gluons that could exist in the center of neutron stars. Neutron stars represent another endpoint in the life cycle of a star. While the cores of stars at least 10 times more massive than the Sun ultimately collapse into black holes, slightly less massive stars form neutron stars. These objects contain the mass of about 1.4 suns compacted into a sphere only about 10 miles in diameter. At such density, all the space is squeezed out of the atoms inside the neutron star, and protons and electrons squeeze into neutrons, leaving a neutron superfluid. The tiny white dot in the center of the image of Cassiopeia A (preceding page) might be the light from a neutron star.

To understand what is inside a neutron star, which scientists call "the equation of state," they need to measure its density. This is a ratio between its mass and radius, a tricky measure to come by. Constellation-X could make this measurement by observing explosions that occur on the surface of neutron stars, bright in X rays. If the neutron star is dense enough, then the neutron core itself might be squeezed to liberate the quarks and gluons that make up all ordinary matter. Such "free" quarks and gluons are only known to have existed at the moment of the Big Bang. The current generation of X-ray telescopes provides tantalizing evidence of the existence of these stars, a possible stepping-stone between neutron stars and black holes.

This illustration shows the relative sizes of the Grand Canyon, a neutron star and a quark star. The Grand Canyon is 18 miles rim to rim. A neutron star is about 12 miles across, and a quark star is about 7 miles across.



CXC/D. Berry

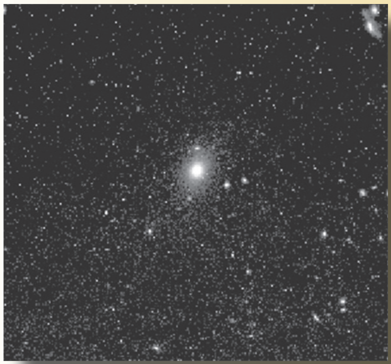
Structure of the Universe: Dark Matter and Dark Energy

Galaxy clusters, the largest objects in the Universe, serve as an ideal laboratory for studying the structure and evolution of the Universe. Galaxy clusters are complex, multi-component systems containing hundreds of galaxies, a hot intracluster medium and "dark matter" all evolving in a tightly coupled manner. Understanding clusters of galaxies is analogous to understanding how an entire forest works, not just a few trees.

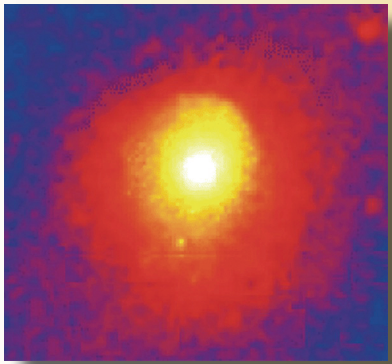
For the first time, Constellation-X will measure the mass motion of gas in the core of clusters and in the "interaction region" of possibly merging galaxies. These measurements will test theories of cluster mergers and cluster evolution, a basis for us to understand all structure in the Universe. Most of the detectable mass in a galaxy cluster is contained in the gas between the galaxies. Constellation-X will map the X rays produced by this gas. Such observations will help us understand how clusters form and change over billions of years. Also, Constellation-X's detailed measurements of all elements between carbon and zinc will yield information about the metals produced by supernova in member galaxies over cosmic time.

One mystery that Constellation-X hopes to unravel is the nature of dark matter. One of the most striking discoveries of contemporary astronomy has been that most of the mass of galaxy clusters – and the entire Universe – is in a form that we cannot see. We simply do not know the nature of this unseen mass, collectively known as dark matter.

We know of the existence of dark matter, however, through the effects of its gravitational field. In the same way that Earth holds the Moon in place, something is holding together clusters of galaxies, keeping them from spreading even farther apart. The mass that we can detect in regions within and between galaxies (the vast majority of which is gas, not stars) isn't enough to be doing the job by itself. Although Constellation-X will not directly observe dark matter, it will be able to map the hot gas which tells us where the hot dark matter is in the Universe – a crucial step in understanding its physical nature.



R. White (UA)



S. Snowden, R. Mushotzky (NASA/GSFC)

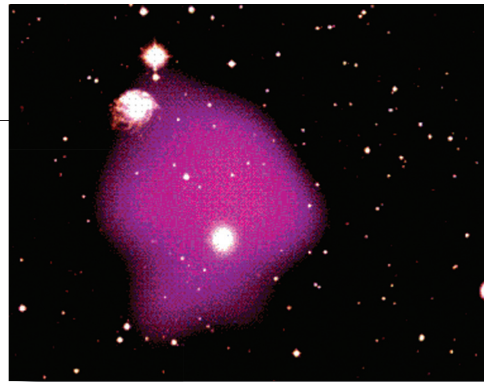
The search for dark matter: In this optical image of the Virgo galaxy cluster, a bright central elliptical galaxy is seen surrounded by a cluster of similar smaller galaxies. The X-ray image of the same region shows a very large ball of hot gas, whose mass is at least three times greater than all of the Virgo Galaxies. This gas is trapped by the gravitational pull of dark matter, which comprises the bulk of the mass of the entire system.

Ordinary matter makes up only about 4% of the Universe. Dark matter makes up another 25%. The rest, over 70% of the Universe, seems to be a mysterious repulsive force acting counter to gravity, dubbed "dark energy," discovered in 1998. Gravity is not slowing the expansion of the Universe, pulling all matter together, as scientists have long thought. Rather, a dark energy is ripping the Universe apart. What could this force be? Constellation-X addresses this dark energy question by once again studying the dynamics of galaxy clusters. Here we see the tug-of-war among all the players: Ordinary matter flows down channels of dark matter, dictated by the force of gravity. A web of larger structures emerges, pulling matter inward to form chains of galaxies. Meanwhile, dark energy is expanding space, separating the distances between objects.

Constellation-X's cluster observations combined with WMAP measurements of the microwave background in the same directions (the so-called Sunyaev-Zeldovich effect) can yield precise distances to these objects. And the relationship between the distance to an object and its redshift (the degree to which light is stretched) is a measure of the geometry of the Universe. This data can be used to derive precision measurements of the factors that control the geometry, such as the scale factor or expansion rate of the Universe, called the Hubble constant, how much matter is in the Universe, and the amount of and nature of the dark energy. These types of results are complementary to those provided by measurements of the type Ia supernova, a technique largely performed with optical and infrared telescopes that led to the 1998 discovery of dark energy.

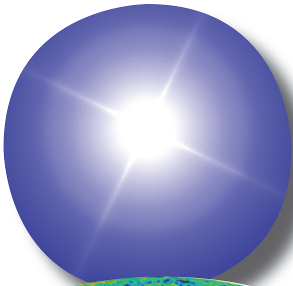
The evolution of galaxy clusters – that is, how their numbers and masses change with cosmic time – is also controlled by the geometry of the Universe. Theoretical calculations can accurately predict how many clusters of a given mass should exist at any one time and how this changes. However these calculations are very sensitive to the amount of and nature of the dark energy and how much dark matter there is. Thus, in principle, measurements of the evolution of galaxy clusters out to great distances can provide fundamental information about the dark energy. There is one catch: The theoretical calculations are for the mass of the cluster, which is dominated by dark matter. Constellation-X measurements are needed to determine the masses of the clusters. Only Constellation-X has the required sensitivity to derive the masses of large samples of clusters at great distances to make this technique practical.

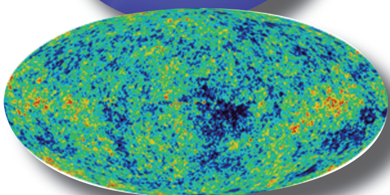
There's one more interconnection. First, the relationship between the amount of ordinary matter in a cluster (baryonic fraction) and the amount of dark matter is yet another function of the geometry of the Universe. Second, the relationship among the X-ray brightness of a cluster, its size and the temperature of the hot X-ray emitting gas, and the baryonic fraction of the cluster is directly related to its "true" distance – which, stated above, depends on the amount of dark energy. Constellation-X can supply the data from distant, faint objects required for this type of dark energy measurement. The nature of dark energy is indeed a complex issue, and Constellation-X could provide the first, solid steps towards understanding it.



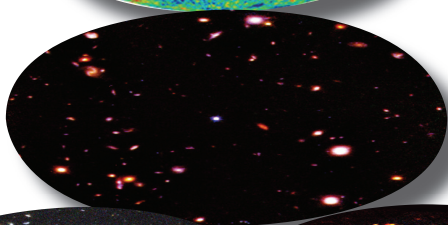
R. Mushotsky (NASA/GSFC)

The NGC 2300 group of galaxies contains a large reservoir of million-degree gas glowing in X rays. A false-color X- ray image of the hot gas is superimposed here on an optical picture of the galaxy group. Gravity from the galaxies alone is not enough to keep the gas in its place. There must be large quantities of dark matter whose gravity is preventing the gas from escaping.

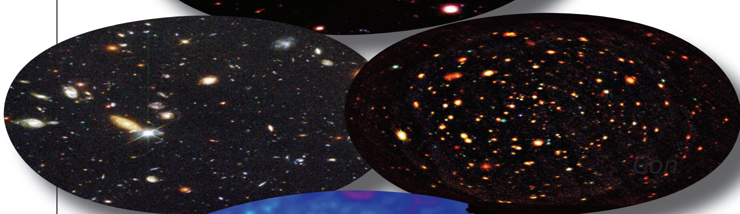




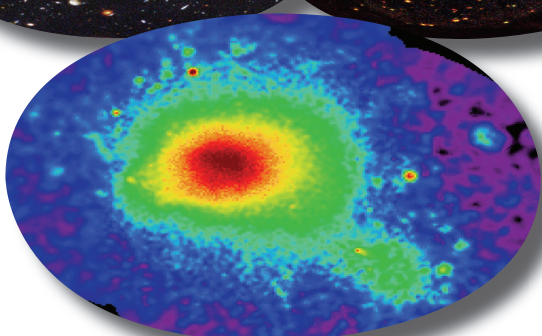
Cosmic Seeds (WMAP)



First Galaxies (Spitzer)



Galaxies and AGN (Hubble and Chandra/ XMM-Newton and Constellation-X)

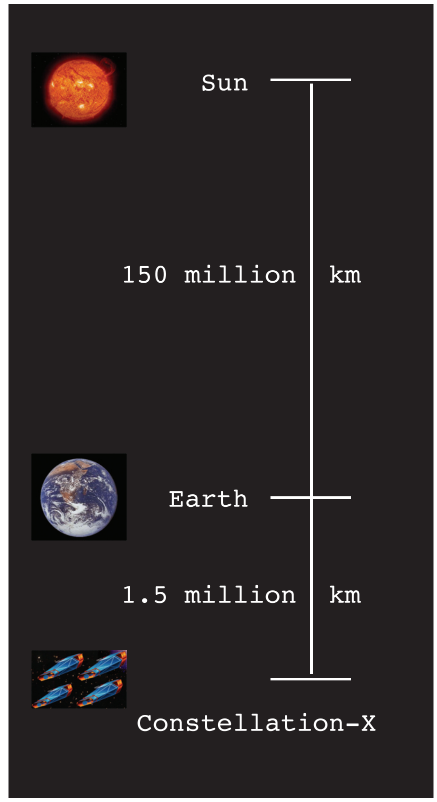


Clusters of Galaxies (Constellation-X)

Hierarchical cosmological models predict that the largest structures in the Universe formed the most recently, from the bottom up. However, the time of the formation of galaxies and clusters is not well understood. To resolve this question, NASA has planned a series of missions, some of which are now in orbit. The WMAP mission has determined that the first stars ignited about two hundred million years after the Big Bang, much earlier than expected. The Spitzer Space Telescope is zooming in on the first galaxies to form. The Chandra mission has found that black holes are common in the early Universe and has mapped the structure of the "adolescent" Universe, roughly half its current age. With Constellation-X looking at clusters of galaxies, the formations that likely followed galaxies, we will have a fuller picture of how the Universe came to be the way it is now.

About the Telescopes and Their Orbit:

Constellation-X's orbit (figure at right) lies at the outer Lagrangian or L2 point where the Sun and the Earth exert equal gravitational forces on the satellite.

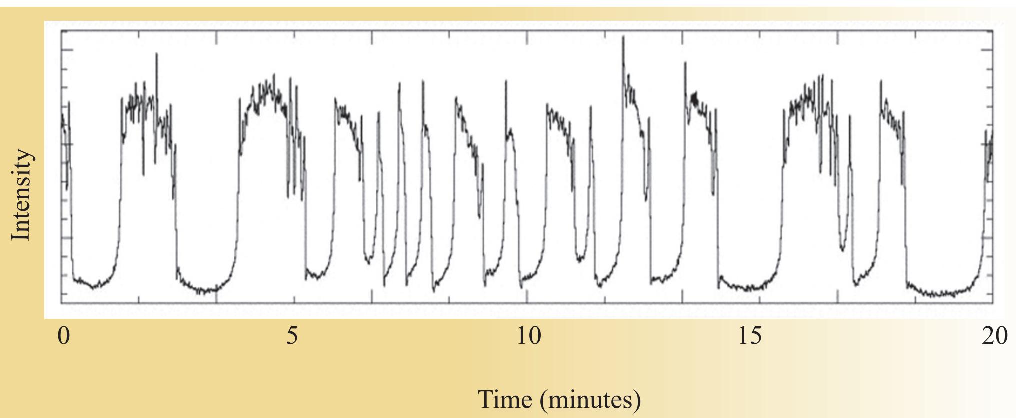


The total collecting area of Constellation-X's four telescopes will be three square meters. The satellites will detect a broad band of wavelengths, with a range a thousand times wider than that of visible light. The improvement in scope and resolution for this X-ray observatory over other X-ray telescopes is like jumping from common optical telescopes found at smaller universities to the largest optical telescopes in the world. Such improvement in X-ray technology translates to huge leaps in what can be observed and discovered.

Constellation-X will collect more data in shorter times than previous X-ray telescopes – hours instead of days or weeks. Imagine collecting rainwater in a bucket. If you only check your bucket once in the morning, you won't know whether the rain fell in a long, steady drizzle throughout the night or during one, short downpour. Constellation-X will collect enough high-energy photons to produce useful information in short observations. This feature makes the Observatory a powerful X-ray astronomy tool for understanding objects such as black holes, where changes in the local environment are occurring rapidly.

As currently conceived, the individual Constellation-X satellites will have special design features to ensure a lightweight and compact launch on a medium-sized rocket. These include, among many, lightweight instruments and folding solar arrays. Finally, Constellation-X will orbit Earth along the outer Lagrangian point (or L2). This is nearly a million miles away from the Earth. (The Hubble Space Telescope, in comparison, is about 400 miles from Earth, and the Moon is about 250,000 miles away.) The L2 point is where the Earth's and Sun's gravity allows the satellites to trail the Earth in orbit around the Sun; where the satellites' view will not be blocked by the Earth; where the temperature is ideal (cooler environments are better for the instruments aboard the satellite); and where the satellites will take the least beating from the rough space environment.

These X-ray light curves from the Rossi X-ray Timing Explorer satellite show the black hole GRS 1915+105. Changes in X-ray emission from GRS 1915+105 occur quickly. Constellation-X will be able to record more changes in this black hole's spectrum over small time intervals.



RXTE/ T. Belloni et al

The Path to Discovery:

The discovery of X rays by Wilhelm Conrad Rontgen over 100 years ago marked a new era in physics that shaped many of the technological advances of the 20th century. When observations commence during the next decade, Constellation-X also will mark a new era in X-ray astronomy. We will begin to answer fundamental astrophysics questions and test hotly debated theories involving the formation and evolution of clusters of galaxies, the validity of general relativity for extreme gravity, the evolution of supermassive black holes in active galactic nuclei, the details of supernova explosions and their aftermath, and the nature of "dark matter" in the Universe.

The Observatory will bring the young field of X-ray astronomy to maturity and will be an indispensable tool poised at the cutting edge of astrophysical research.*

The four satellites that make up Constellation-X will orbit together in space within a few hundred miles of each other.

**The mission described here is the current GSFC-SAO reference mission. The actual mission may look very different once industry partners become involved.*

For more information on the Constellation X-ray Observatory, visit our website at
http://constellation.gsfc.nasa.gov

Other sources of Structure and Evolution of the Universe (SEU) information:

Constellation-X is part of NASA Office of Space Science's Structure and Evolution of the Universe theme. Below are a number of web sites available with more information on the SEU theme and its missions.

SEU homepage
http://universe.nasa.gov/
This site is the central location for NASA's SEU theme, including the missions, science and technology roadmaps, press releases, etc.

NASA Office of Space Science homepage
http://www.hp.nasa.gov/office/oss/
This site provides the larger context for the SEU theme with an emphasis on the entire Space Science Enterprise. The strategic plan is available at this location as well as current news and connections to the other space science themes.

Educational and Outreach Web Sites:

SEU Educational Forum
http://cfa-www.harvard.edu/seuforum/
This site introduces the SEU Education Forum managed by the Harvard-Smithsonian Center for Astrophysics.

Imagine the Universe!
http://imagine.gsfc.nasa.gov/
This educational site is aimed at grades 9-14. It explores and explains all of the ways scientists probe the structure and evolution of the Universe, what they have found, and what mysteries remain. An extensive Teacher's Corner features lesson plans, activities and other resources.

StarChild
http://starchild.gsfc.nasa.gov
This is an education site for younger astronomers (grades K-8). Science topics from galaxies to the Solar System are explained so that it makes sense to kids; every topic has interactive activities or puzzles!

AstroCappella
http://www.astrocapella.com/
AstroCapella is a site of songs, pictures and activities about astronomy; created and sung by scientists in a professional *a capella* group.

Astronomy Picture of the Day
http://antwrp.gsfc.nasa.gov/
Each day a different image or photograph of our fascinating Universe is featured on this site, along with a brief explanation written by a professional astronomer.

Text	**Review**	**Brochure Preparation**
Christopher Wanjek	**Nicholas White**	**Irene Stone**
Kimberly Weaver	**Robert Petre**	**Pat Tyler**
Richard Mushotzky	**Jim Lochner**	
	Ilana Harris	

Smithsonian Astrophysical Observatory