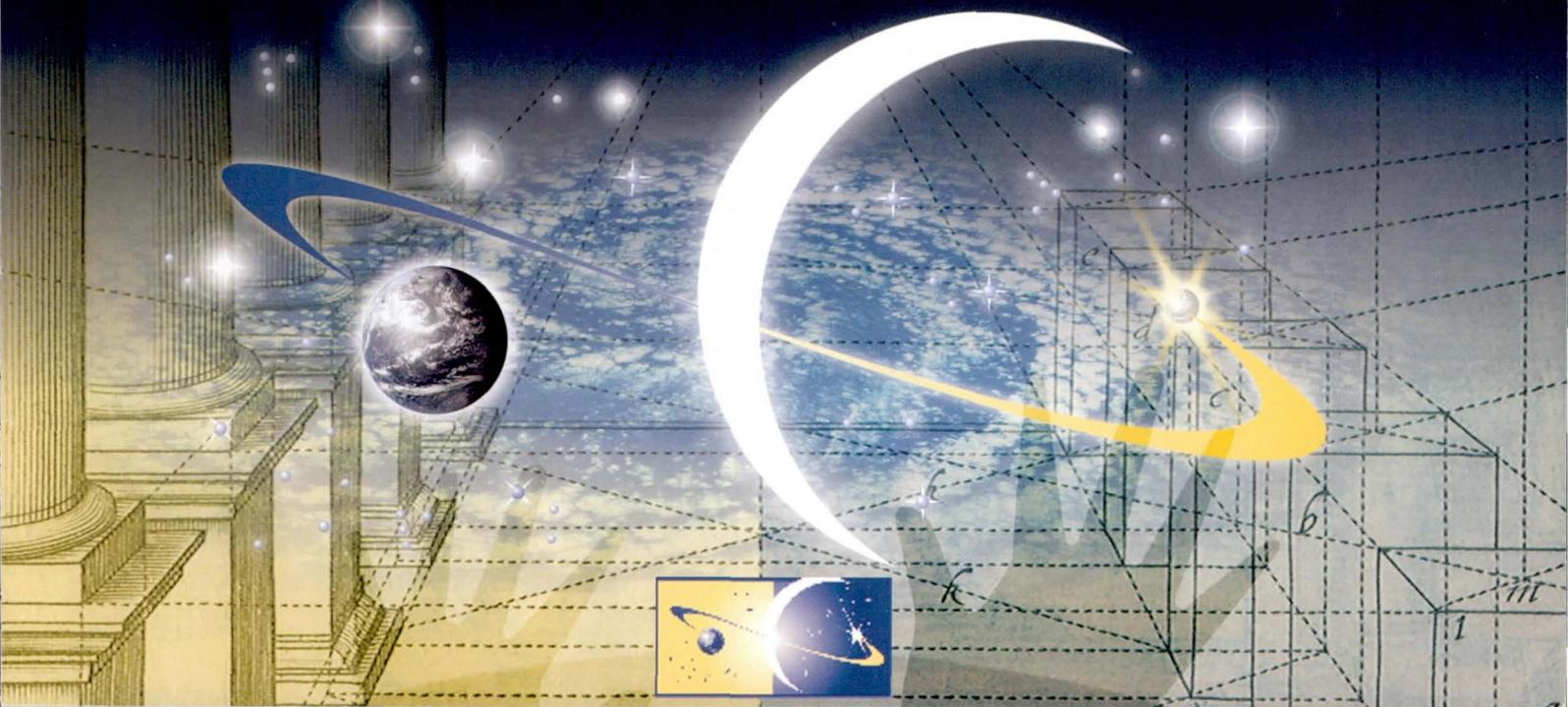




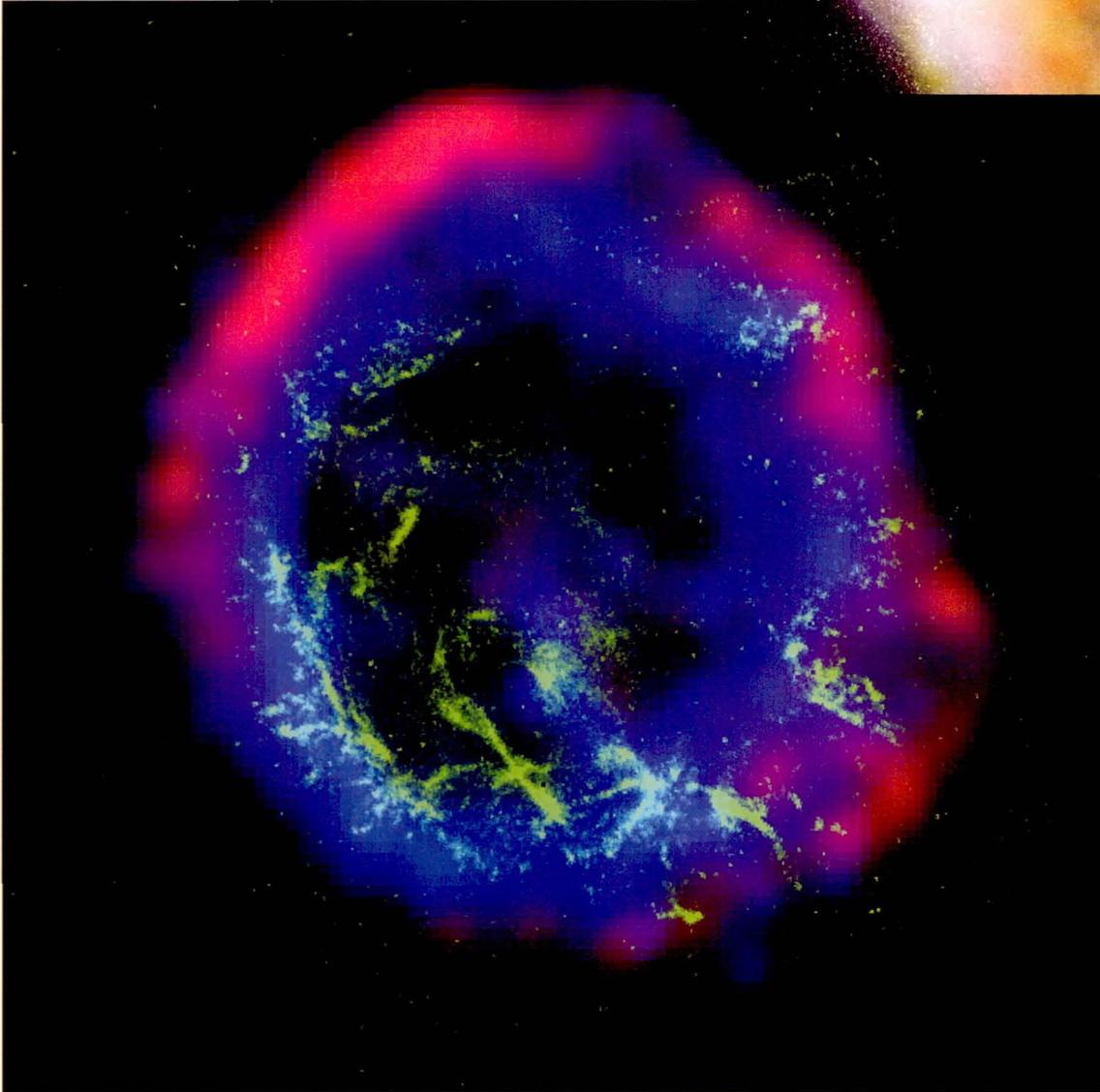
Cosmic Journeys

To the edge of gravity, space, and time...



The Chandra X-ray Observatory is the best X-ray imaging telescope ever built.

The image below is a color composite of the supernova remnant E0102-72. The Chandra X-ray image is shown in blue. Green is a Hubble Space Telescope optical image; red is a radio image from the Australia Telescope Compact Array.



A star explodes, blowing its contents into interstellar space. At its core, a black hole may form. Or maybe a neutron star or white dwarf, depending on the size of the original star. Over the next million years, a new star may form from the leftover gas. The ever-changing Universe is the ultimate recycler. NASA's Cosmic Journeys is a set of missions that will explore the Universe's many mysteries.

Our Cosmic Journeys

We are embarking upon a cosmic journey. From the safety of our home planet Earth, scientists plan to explore the very limits of the known Universe. Our travels will take us to where space and time cease to exist as we know them, and to where the secrets of the past and future lie captured in the starlight of the present across an expanse of billions of light-years.

Cosmic Journeys, a new series of NASA space science missions, will take us to the limits of gravity, space, and time. This virtual journey will use the power of resolution far greater than what current telescopes can muster to transport us to the rim of a black hole, to eagle-eye views of the galaxies and voids that pervade the Universe, and to the earliest moments of time, just fractions of a second after the Big Bang.

The goal of our Cosmic Journeys is to solve the mystery of gravity, a force that is all around us but cannot be seen. If you have ever slipped on a wet floor or had your favorite scoop of ice cream tumble over your cone, then you have come face to face with gravity. This is the force that keeps us pinned to the Earth, no matter if we live in Norway or Australia. Indeed, the Space Shuttle requires huge rocket boosters just to escape the Earth's gravity. And even in orbit, the Space Shuttle still feels the Earth's pull.

Gravity acts from here to the edge of the Universe, affecting all that is seen and much of what remains unseen. This force can never be completely removed from an environment, unlike sound or light waves. Even in the "zero gravity" of space, there is still the force of gravity that cannot be avoided or screened—a force that always attracts, never repels. We clearly understand what gravity does, but we do not fundamentally know how it does it. Yet it is this force that holds the answers to the most basic questions of our humanity, such as What is the Universe made of, how does it grow, and what is its fate?

Gravity has puzzled the greatest minds of the past century. Albert Einstein described gravity in a revolutionary way in his Theory of General Relativity, which says that mass distorts space and time to produce the force of gravity. A black hole is an extreme example of mass warping space-time. Einstein also predicted that gravity propagates in waves, just like light. These would

What is the Universe made of, and what is its fate? Gravity is at the heart of these most basic questions of our humanity.

An enormous amount of energy is required to lift the Space Shuttle off the pad and into orbit. It must travel fast enough to reach escape velocity to overcome the strong pull of the Earth's gravity.



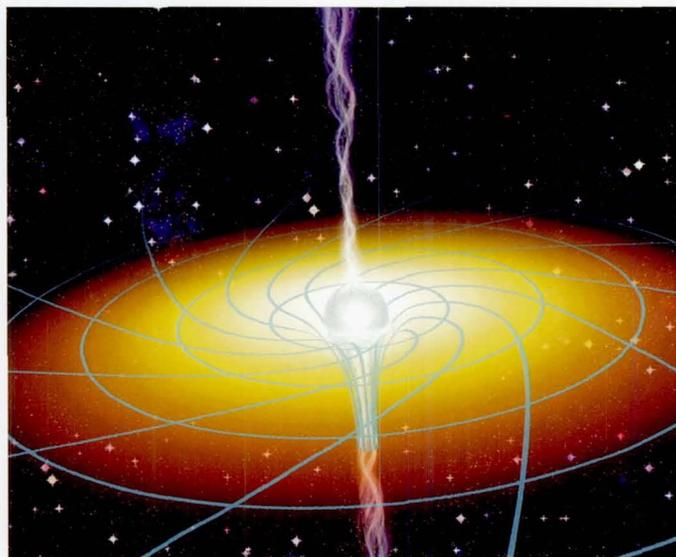
be ripples in the fabric of space that move at the speed of light. Gravity may be associated with a particle, called the graviton. If so, gravity may be similar to the other fundamental forces of nature.

The difficulty is that gravity doesn't fit into what scientists call the Standard Model, which describes the behavior of light and subatomic particles. We do not have one model that can describe everything in the Universe. Instead, we have two theories: General Relativity and Quantum Physics. General Relativity accounts for gravity, the force that acts across large scales. Quantum Physics, part of the Standard Model, describes the behavior of the other three fundamental forces: electromagnetism, weak forces (seen in radioactive decay), and strong forces (holding subatomic particles together). These forces act over small scales.

Einstein spent most of his life trying to make things simpler, to find laws of physics more general than known before and to unite gravity with electromagnetism. Today, we may be very close to merging these concepts of Quantum Physics and General Relativity into the "Theory of Everything," a unified theory that predicts the behavior of all matter and energy in all situations. Such a theory would be a windfall for science, likely leading to spectacular technological advancements that we cannot even begin to imagine. Gravity is the secret ingredient in this endeavor. So we must move beyond the Standard Model to reach our goal.

Moving beyond the Standard Model requires us to investigate the connection between General Relativity and Quantum Physics. Do these two theories meet in the earliest moments after the Big Bang, when the size of the newly formed, ultra-hot Universe was confined to quantum (very small) scales possibly described by quantum gravity? The answer may lie at 10^{-44} second after the Big Bang, when the Universe visible to us today was only 10^{-33} cm wide and when gravity—confined within what physicists call the Planck scale—played a role equal to the other forces. Also, is General Relativity the ultimate theory of gravity in the Universe? Do black holes, predicted by General Relativity, truly exist? Or are these black holes that fill the Universe some different type of phenomenon?

NASA's Cosmic Journeys seeks to answer these questions by using the Universe as a laboratory to probe the most extreme environments of gravity and temperature and the earliest moments of time. These environments exist for us to visit today in the vicinity of black holes, where gravity is king; in the early Universe, where space was hot and dense enough to perhaps unite gravity with the other three fundamental forces; and on a universal scale, where the gravity of dark matter shapes galaxies and clusters of galaxies into walls and voids. Thus, our Cosmic Journeys, in pursuit of gravity, will take us to these regions of the Universe.



*Gravity is king!
It is so powerful
that in the
region near a
spinning black
hole, it can
actually drag
around the
framework of
space itself.*

Image Credit: J. Bergeron/Sky & Telescope

Journey to a Black Hole

We are very close to a Theory of Everything, which would unite Quantum Physics with General Relativity and likely lead to spectacular technological advancements that are unimaginable today.

Nowhere is gravity greater than in the region around a black hole. These objects exert a gravitational force so great that not even a beam of light can escape their pull.

There are two main types of black holes: the stellar black hole and the supermassive black hole. A stellar black hole is a massive star that ran out of fuel. Without fuel, the core of the star collapses and the outer shell explodes into space. We can often see this explosion as a beautiful supernova remnant. The collapsed core becomes the stellar black hole, an infinitely dense object. A supermassive black hole lies in the core of perhaps all galaxies, including our own. This type of black hole is up to a billion times more massive than the stellar variety, and we do not know how it forms. Cosmic Journeys missions concentrate mostly on the more powerful, supermassive variety.

Although black holes emit no light, we can still see the action around them. Their intense gravitational fields pull in surrounding matter, perhaps from a nearby star or from interstellar gas floating freely. This transfer of gas spiraling toward the black hole, called accretion, is amazingly bright in many wavelengths of light. Once light crosses the boundary of a black hole, called the event horizon, it is lost forever. The light we see, therefore, has escaped that final plunge. Other particles are not so lucky.

The Hubble Space Telescope and the Chandra X-ray Observatory are finding that black holes are everywhere—alone in empty space, in the hearts of normal galaxies, and in the chassis of powerful quasars. Both of these telescopes are producing superb images of a variety of objects and phenomena, each one showing gravity hard at work. Hubble and Chandra, which collect optical and X-ray light respectively, are like spaceships transporting us to the world of black holes. They have taken us to the ballpark; we have a taste of the excitement. Now we want to get front-row seats. That is, we want to get close enough to actually take a picture of the black hole itself, beyond the accretion disk. This is a central Cosmic Journeys goal.

A direct image of gravity at its extreme will be of fundamental importance to Physics. Yet imaging a black hole requires a million times improvement over Chandra. That's a big step.

Over the next 20 years, the Cosmic Journeys missions will take us closer and closer to a black hole though the power of resolution. Each successive mission will further us in our journey by 10- or 100-fold increases in resolution, step by step as we

approach our goal of zooming in a million times closer. And each stop along the way will bring us new understandings of the nature of matter and energy.

GLAST is a gamma-ray observatory mission that will observe jets of particles that

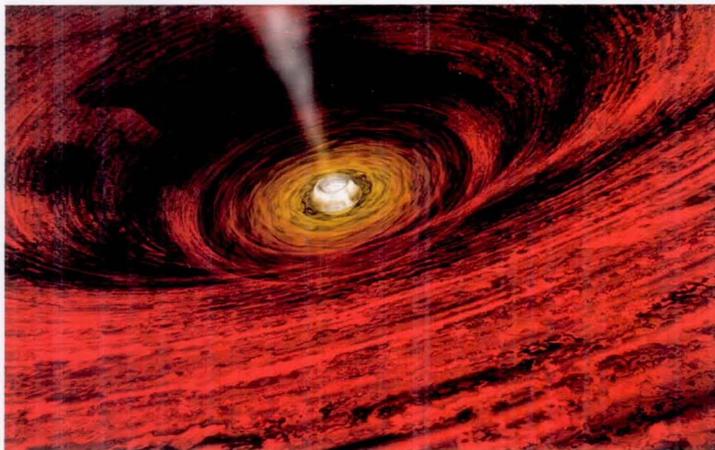


Image Credit: CXC/A.Hobart

Imaging a black hole will be of fundamental importance to physics.

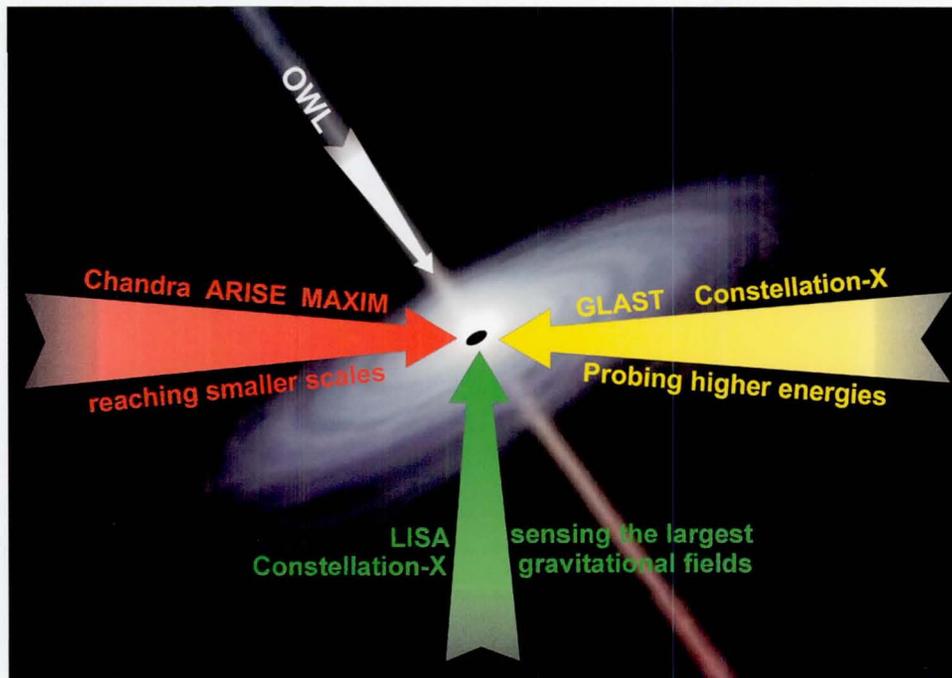
shoot away in opposite regions from a supermassive black hole at near the speed of light. We do not fully understand how a black hole, which is known for pulling matter *in*, can generate high-speed jets that stretch *out* for billions of miles. Galaxies that harbor black holes with a jet aimed in our direction are called blazars, as opposed to quasars, which have their jets aimed in other directions. GLAST, up to 50 times more sensitive than previous gamma-ray observatories, will stare down the barrel of these jets in blazars to unlock the mechanism of how the enigmatic jets form.



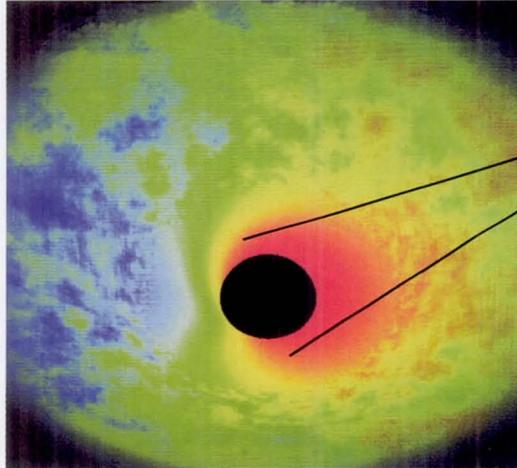
Constellation-X achieves its superior resolution by pooling the resources of four X-ray satellites orbiting in unison into one massive X-ray telescope.

The Constellation-X mission will probe the inner disk of matter swirling into a black hole, using spectroscopy to journey 1,000 times closer than any other mission before it. With such resolution, Constellation-X will be able to measure the mass and spin of black holes, two key properties. This X-ray mission will also map the distortions of space-time predicted by Einstein. Constellation-X draws its superior resolution by pooling the resources of four X-ray satellites orbiting in unison into one massive X-ray telescope.

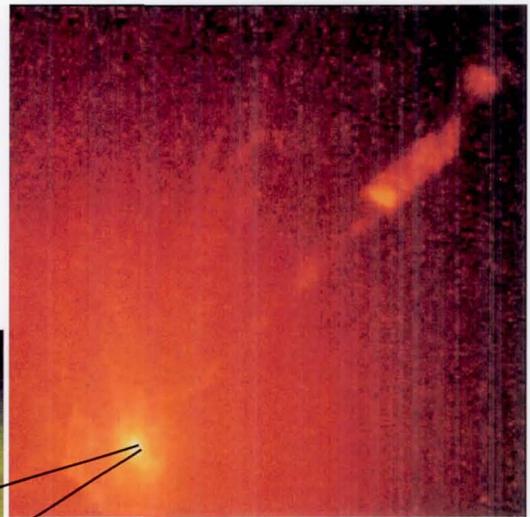
The ARISE mission will produce radio-wave images from the base of supermassive black hole jets with resolution 100,000 times sharper than Hubble's. Such unprecedented



A million times more powerful than Hubble and Chandra, MAXIM will capture a direct image of a black hole.



Simulated MAXIM Image



Hubble Image

resolution can reveal how black holes are fed and how jets are created. ARISE will attain this resolution through interferometry. This technique is used today with land-based radio telescopes. Smaller radio telescopes spread out on land—perhaps one mile apart—can work together to generate a single, huge radio

telescope with the collecting power of a one-mile radio dish. ARISE will utilize one large radio telescope in space with many other radio telescopes on Earth, bringing what is now a land-based technology to new heights.

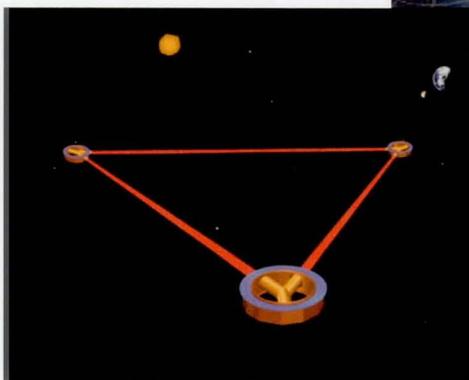
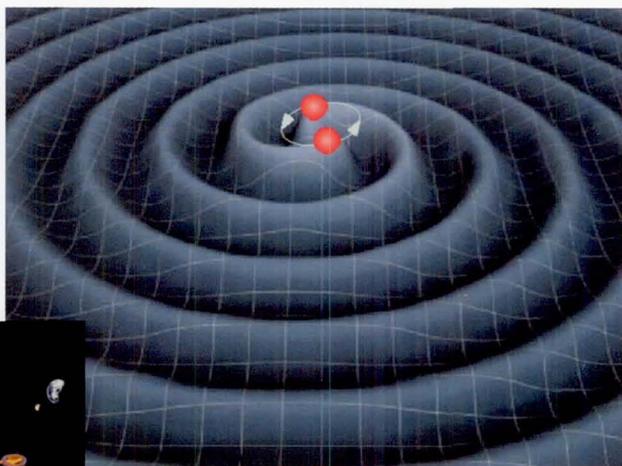
Closer and closer we will travel through resolution. The MAXIM mission, a million times more powerful than Chandra, will capture a direct image of a black hole. MAXIM will be another interferometry mission, with many smaller components positioned in a deep Earth orbit to focus X-ray photons onto a detector. X-ray interferometry, an emerging technology, has the potential to resolve the event horizon of a supermassive black hole in the nucleus of a nearby galaxy and at the center of our galaxy. This is equivalent to resolving a feature the size of a dinner plate on the surface of the Sun. With MAXIM, we will be able to see light and matter plunging across the event horizon. We will also see up close how gravity distorts light and how time comes to a virtual standstill at the event horizon.

Gravitational wave antennae, a new type of probe...

There is another window to the Universe, different from light waves, through which we can see the deepest, most dust-enshrouded sources of strong gravity. LISA is a mission that will probe the Universe through the detection of gravitational waves. These waves come from the violent motions of massive objects, such as black holes.

Gravitational waves can pierce through regions of space that light cannot shine through, for matter does not absorb these waves. As such, LISA can detect black hole activity buried within the dust and gas that other types of telescopes cannot see. With gravitational waves unimpeded by even the foggiest patches of the Universe, LISA will detect far more binary black holes than any satellite that will come before it. These are supermassive black holes in colliding galaxies or massive stellar black holes orbiting

LISA will search for gravitational waves emitted from merging black holes



each other. As the orbits slowly break down, the black holes move closer and closer to each other, creating larger and larger gravitational waves as they spiral together. Finally, the black holes coalesce in a tremendous outpouring of energy.

Like a ship floating on the ocean, LISA will detect the subtle waves that "rock" its gravitational antennae, moving them less than 100 times the width of an atom over a distance of five million kilometers. LISA comprises three satellites orbiting the Sun in the form of a triangle connected by laser beams. The beams will measure the change in distance between satellites caused by a gravitational wave. LISA will specifically detect low-frequency gravitational waves and will thus complement ground-based gravitational wave detectors now being built, which detect higher-frequency waves. The lower-frequency waves would be those waves produced by massive, coalescing black holes, as opposed to merging neutron stars, white dwarfs, and smaller black holes.

Journey Through Dark Matter

Over 90% of the matter in the Universe is in a form we cannot see with any type of telescope. This so-called "dark matter" might be composed of exotic particles that do not readily interact with our detectors on Earth, perhaps invisible matter that is all around us everyday. We simply don't know. The nature of dark matter, in fact, is one of astronomy's greatest mysteries. A Nobel Prize is likely the award for the clever souls who can figure it out!

If we can't see dark matter, you might ask, how do we know its there... and in such abundance? Basically, we can feel it. All matter exerts gravity; dark matter is no exception. In the same way that the Earth's gravity keeps us safely on the ground and the Sun's gravity controls the orbits of the planets, gravitational influence of ubiquitous dark matter is responsible for the very shape of the Universe. This is particularly evident over large scales. We know, for example, that there is not enough visible mass in clusters of galaxies to hold all the contents together. There must be the additional mass of abundant dark matter forming the glue.

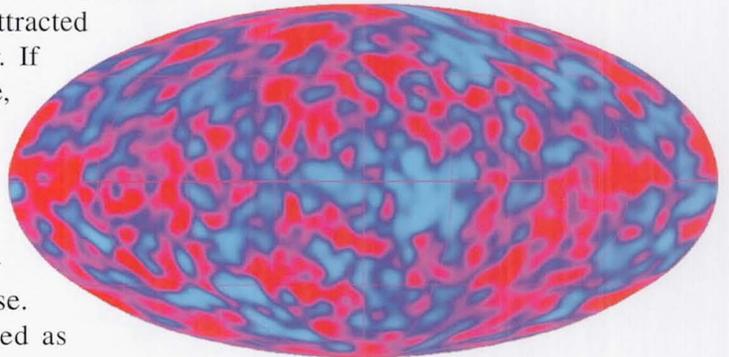
One of the great accomplishments of the last decade was creating models of the structure of the Universe with supercomputers. These models essentially place the Universe in a box, starting from the early Universe and expanding to the modern era.

Dark matter is not evenly dispersed through the Universe. Instead, it forms a cosmic web, with galaxy clusters at the intersection of long chains of galaxies, all separated by voids of apparent empty space. The gravity of the dark matter is the force behind this structure.

The Universe started as a dense, ultra-hot bundle of subatomic particles. Slight density fluctuations gave way to the large-scale structure we see today. As the Universe expanded—cooling and heating once again—dark matter collapsed under the force of gravity. Ordinary matter followed this dark matter.

Denser regions of dark matter attracted greater amounts of ordinary matter. If dark matter is the web of structure, then ordinary matter—in the form of stars and galaxies—are the flies caught on the web.

NASA's COBE mission searched for and found density fluctuations in the early Universe. These fluctuations were reflected as temperature differences in the cosmic microwave background. This low-energy radiation formed around 300,000 years after the Big Bang. Supercomputer models of the Universe build upon the COBE data, extrapolating through time to reveal the cosmic web of the modern era. The high- and low-density regions we see with COBE are essentially the walls and voids we see today.



The cosmic microwave background radiation is a remnant of the Big Bang and the fluctuations are the imprint of density contrast in the early Universe.

Although we cannot see the dark matter that influences the structure of the Universe, we can trace it in several ways in hopes of understanding its nature. Two Cosmic Journeys missions, MAP and Planck, will probe the microwave background with even greater resolution than COBE did. These missions will sharpen supercomputer models by placing greater constraints on density fluctuations, by determining the shape of the Universe, and by establishing the ratio of ordinary matter to dark matter.

Another key component to understanding dark matter will be solving the mystery of the missing baryons. More mysterious matter? Yes, it's true. As stated before, over 90 percent of all matter is dark matter. Of the remaining 10 percent, most of this is missing! This type of matter is called baryonic, the ordinary stuff we see everyday composed of protons, neutrons and electrons. Hydrogen is an example of baryonic matter. Large amounts of baryonic matter were formed in the Big Bang and are seen in the early, distant Universe in the spectra of light from quasars as it passes through clouds of hydrogen, known as the Lyman alpha forest. This matter seems to have disappeared, however, from our local Universe. Finding it will lead us to the location and distribution of dark matter.

Constellation-X will search for the missing baryons trapped in the channels of dark matter that connect galaxy clusters, the largest known structures in the Universe. In the early Universe, we see much more hydrogen than we do today because the hydrogen was cold. Clouds of cold hydrogen absorb light that passes through it. We can "see" the hydrogen clouds by virtue of the light that can't get through. The more hydrogen, the less light that passes through. As the Universe grew older, more stars began to "turn on," adding more heat to galaxy clusters and warming up the hydrogen. The gas also shock-heated as it collapsed with the force of gravity. Hot hydrogen is

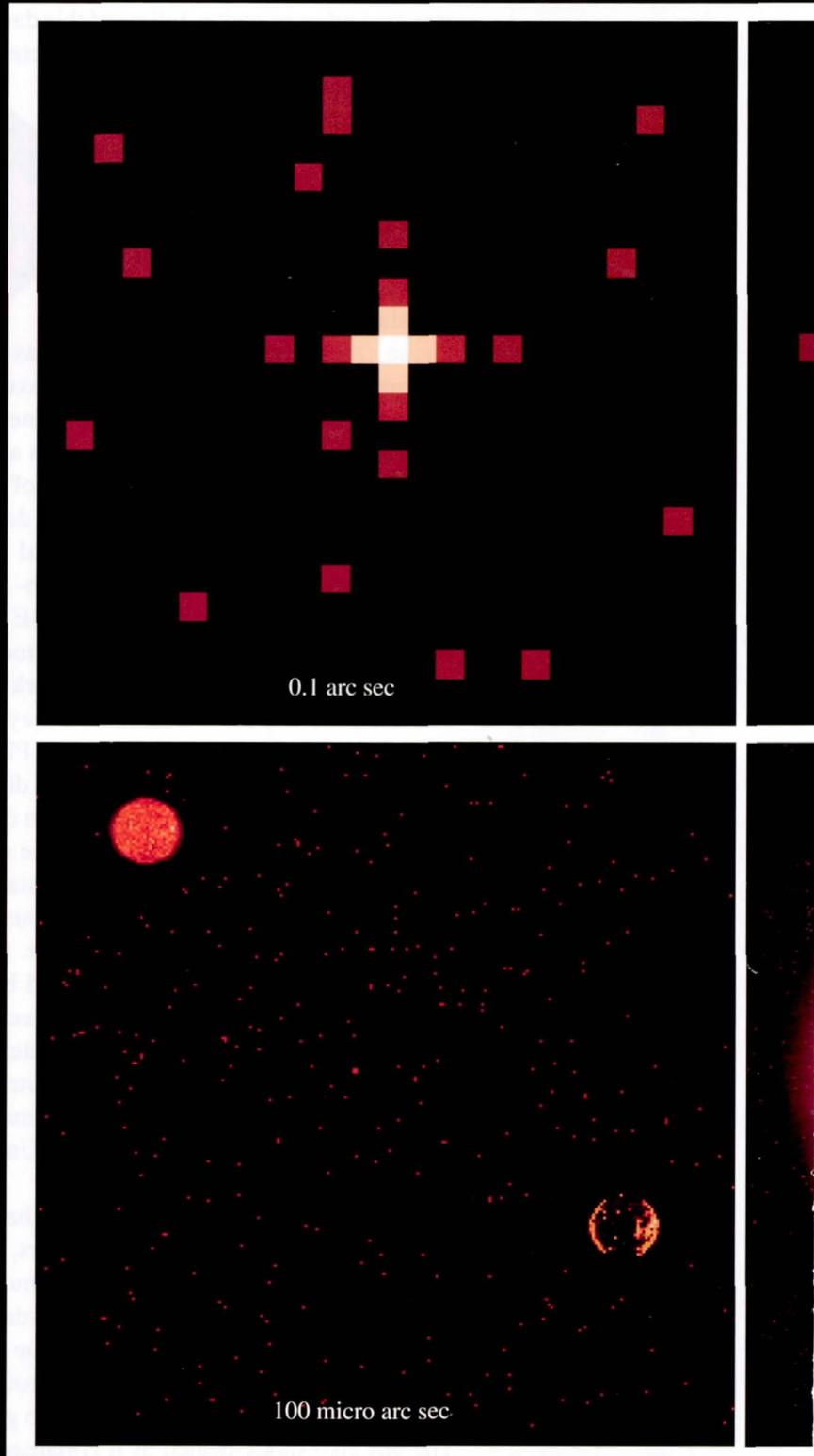
To the stars and beyond...

Where else can resolution take us other than a black hole? Imagine a trip through X-ray resolution to a binary star system called Capella, approximately 45 light-years from Earth. This is the sixth brightest star visible in the northern hemisphere, located in the constellation Auriga. Do you have your seat belt buckled? Then let's zoom in.

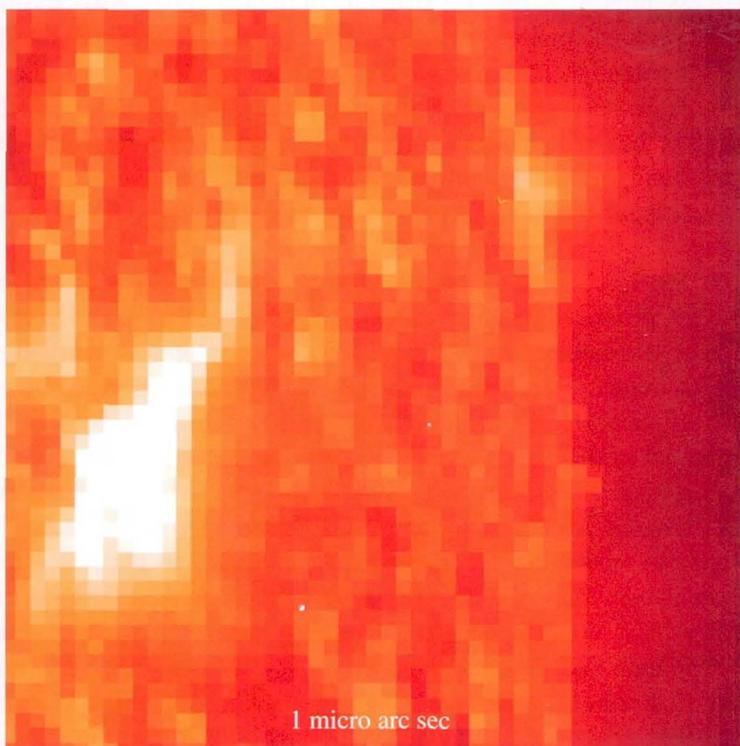
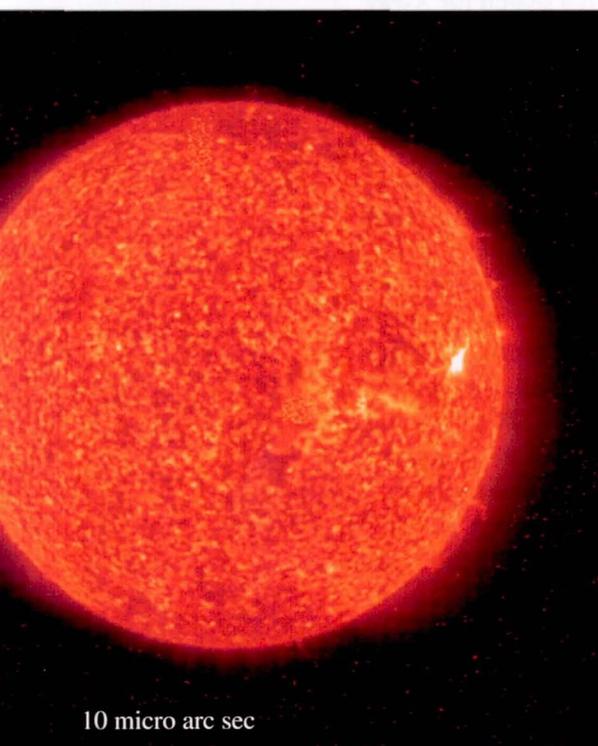
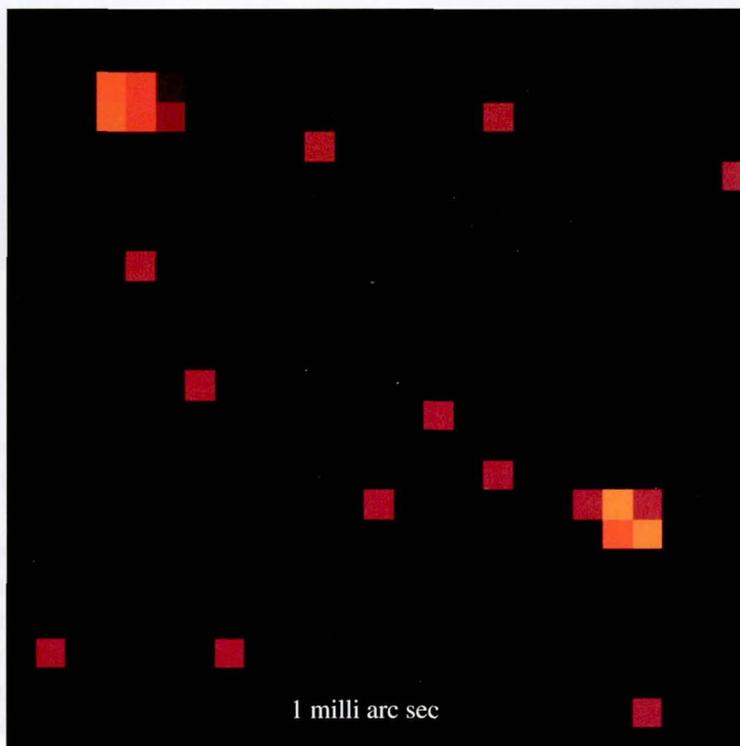
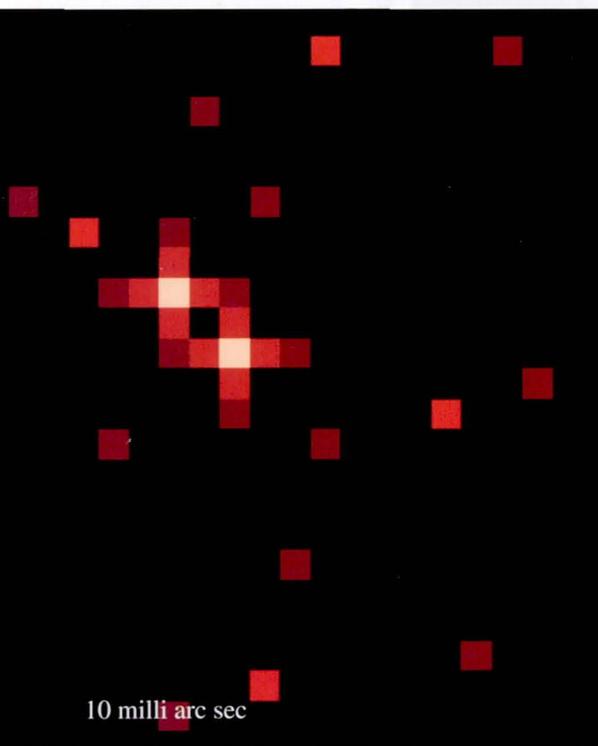
The Chandra X-ray Observatory sees this star system with up to 500 milli-arcsecond resolution. That is fantastically sharp for an X-ray telescope, yet we plan to do even better. At first glance with X-ray glasses, it is not obvious we are seeing two stars in the Capella system—just a blending into what seems like one bright source. About ten times closer, with 10 milli-arcsecond resolution, we see two distinct sources. Moving in 100 times closer from here, to 100 micro-arcsecond resolution, we see the spherical features of the two stars. The MAXIM-Pathfinder will take us to this spot. Swooping in 10 times closer yet, to 10 micro-arcsecond resolution, we see one of the stars as if it were our sun, complete with solar flares.

The journey ends 10 times closer than this, at 1 micro-arcsecond resolution, where we see detailed features on the surface of the star. The MAXIM mission, placing us a million times "closer" than Chandra, will approach this micro-arcsecond resolution. This is sharp enough to image a black hole.

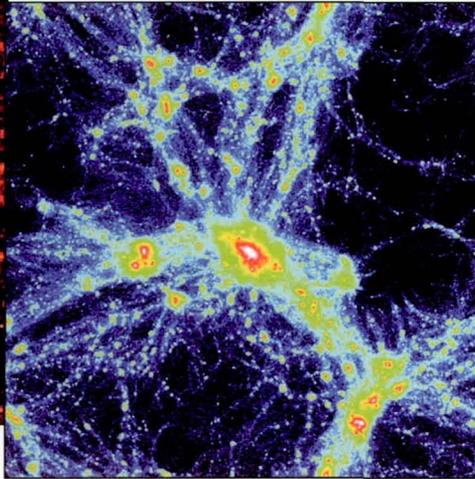
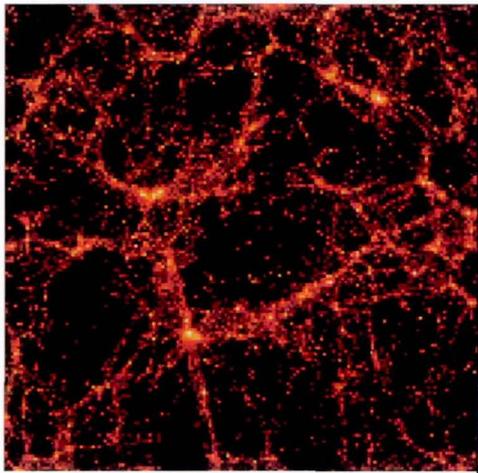
Through the power of resolution, we will travel 45 light-years in only 20 years time.



The Capella System



Images Credit: Webster Cash



Simulated X-ray Image

The Cosmic Web

harder to see. Light passes through it without being absorbed as much as when it was colder.

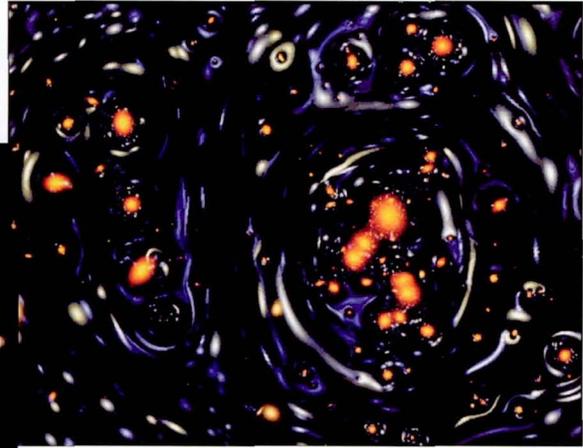
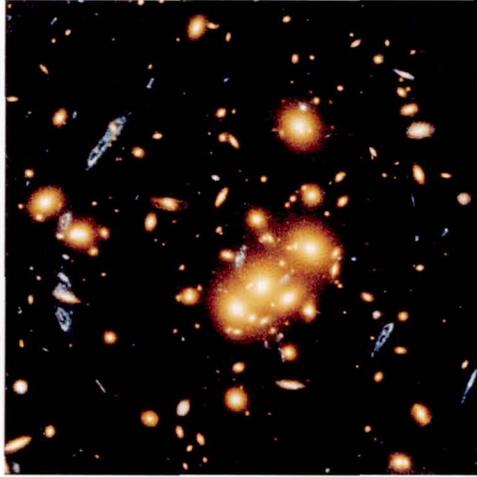
Constellation-X will instead look for absorption lines from oxygen and other elements heavier than hydrogen. These elements, which constitute perhaps only 1 percent of the missing baryons, tells us how much hydrogen is out there. These absorption lines are very faint, though. Hubble has seen traces of one type of oxygen isotope. Constellation-X will be sensitive enough to detect faint absorption lines from several isotopes of several different elements, providing tighter constraints in calculating the total amount of missing hydrogen. Also, in regions where hydrogen is hot enough to glow in X-rays, Constellation-X will observe emission lines from hydrogen gas. So, by looking for absorption lines from elements heavier than hydrogen, Constellation-X will essentially "X-ray" the structure of the Universe. Also, through a search for X-ray *emission* lines, called an X-ray survey, we will have an unbiased way of finding dark matter potentials over a wide range of redshifts and masses.

Albert Einstein's work also plays into the dark matter search. General Relativity predicts that matter (and the gravity it produces) distorts light. We have seen the way light bends as it passes by galaxy clusters and black holes, two sources of great gravitational force. The gravity of dark matter should also distort light, albeit more subtly.

Work is underway to search for the effects of gravitational lensing, or the bending of light, produced by dark matter. This involves the careful analysis of light from very distant galaxies for evidence of distortion as the light passes through intervening regions of dark matter. To observers, the light from distant spherical objects is pulled by gravity into elliptical shapes, an effect known as cosmic shear. By analyzing the cosmic shear produced in thousands of galaxies, we can determine the distribution of dark matter over large regions of the sky—a powerful tool to test the foundations of cosmology.

The GLAST mission takes a different approach. GLAST will search for dark matter by observing the gamma rays produced in the interactions of certain exotic particles—matter yet to be observed in nature but predicted by scientists. Some theorists believe that WIMPs, weakly interacting massive particles, are major contributors to dark matter. WIMPs may have formed in the early Universe and may now reside in dark matter halos that surround galaxies. GLAST will be sensitive enough to detect the gamma rays produced when WIMPs collide. In this way, GLAST uses the Universe as a laboratory to determine if these exotic particles truly exist in nature.

Simulation of weak gravitational lensing by dark matter.



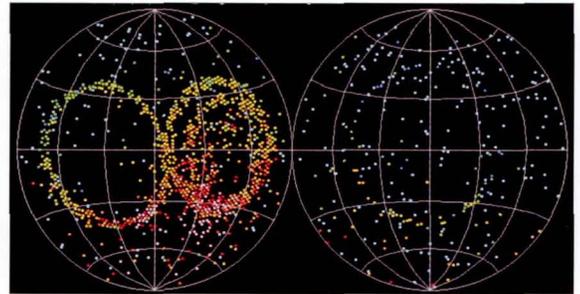
Hubble image of gravitational lens in galaxy cluster 0024+1654

The types of dark matter and their amounts are key factors in determining the structure of the Universe as well as its fate—whether it will collapse or expand forever. Scientists classify dark matter into "cold" and "hot." An example of cold dark matter would be WIMPs and axions. An example of hot dark matter is the neutrino, a particle similar to an electron but with zero charge and very little mass. Neutrinos have been detected, namely by the Super-Kamiokande neutrino detector in Japan.

Hot dark matter moves quickly and is less gravitationally bound compared to the cold variety. An abundance of hot dark matter would lead to an evenly dispersed universe. An abundance of cold dark matter, in contrast, would produce a clumpy universe. Its stronger gravitational potential leads to matter congregating about it. The evidence available to us today points to a universe with more cold dark matter than hot dark matter. Thus, we see a clumpy universe, but one that distributes its clumpiness. The collapse of dark matter created this structure, with galaxies and hot gas trapped like flies in a spider's web.

Evidence is mounting that the Universe will expand forever. The biggest discovery of recent years is that the expansion rate of the Universe appears to be accelerating. The most distant galaxies are moving farther and farther apart at an ever-increasing speed. What is driving this acceleration? Not gravity. Gravity should act to slow the expansion rate. If the Universe is truly accelerating, then there might be an unknown form of energy that counters the work of gravity. This is called "dark energy."

Solving the mystery of dark energy involves investigating the underlying conditions that point to the existence of dark energy. Namely, we must know the amount of matter in the Universe, both ordinary and dark matter, and the rate of its expansion over time. The Cosmic Journeys missions will accomplish this by teaming up to take an inventory of the Universe across many wavelengths.



Neutrino seen by Super-Kamiokande

Cosmic Journeys will search for signs of "dark energy" responsible for driving galaxies farther and farther apart at an ever-increasing rate.

Journey to the Beginning of Time

How was the Universe formed? The leading model is called the Big Bang Theory. This model says that all the matter and radiation that we see today originated at a finite time in the past—a singularity that looked like what we would expect to see in the center of a black hole! Physicists and astronomers want to journey back to as close to this time as physically possible.

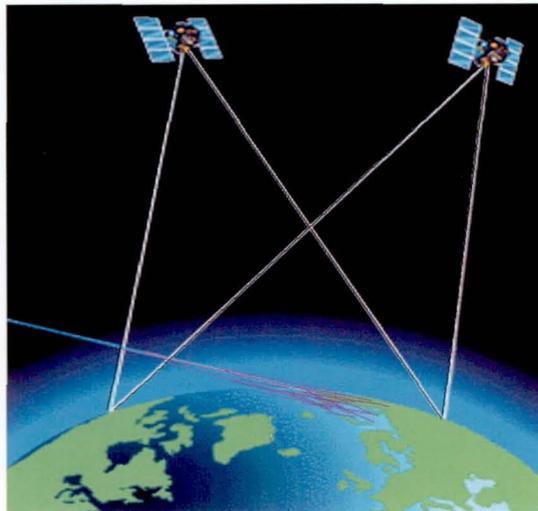
What happened in the first second after the Big Bang is as important as the billions of years that have followed. During this time, temperatures were so hot that matter and radiation as we see them today could not exist. What did exist, perhaps, were the many theorized particles that physicists hunt for today. Also, such high temperatures may have allowed gravity to merge with the other three forces.

Traditionally, physicists have used giant, earthbound particle accelerators to reproduce the heat and environment of the early Universe. So far they have reproduced an environment similar to when the Universe was a ten-billionth of a second old, a period called the electro-weak era when electromagnetism and weak forces became distinguishable. By "journeying" to this era, physicists showed that these two forces are two aspects of the same phenomenon. Our goal is to peer back even farther in time, when the Universe was far younger than even a trillionth of a trillionth of a second old.

Journeying back, we hope to see the inflation era, the Grand Unified Theory (GUT) era, and the speculative superstring era—all occurring in the first fraction of a second after the Big Bang and all crucial to our understanding of physics beyond the Standard Model. During the inflation era, a 10^{-32} second after the Big Bang, the Universe grew trillions of trillions of times larger in a mere thousandth of a second. This theorized rapid-expansion period explains the breadth of the Universe we see today. In the GUT era, when the Universe was only a 10^{-35} second old, the strong force was united with the electro-weak. GUT stands for grand unified theories, because three of the four fundamental forces were united and quantum gravity may have existed. In the superstring era at 10^{-44} second, all forces may have been indistinguishable. This is a period called Planck time, the earliest time on which physicists can speculate.

We will likely never be able to reproduce environments associated with these eras in the early Universe on Earth with particle accelerators. We can, however, use the Universe as a laboratory and journey back in time. The MAP and Planck missions are our "time machines." These satellites will detect the cosmic microwave background, radiation produced from when the Universe was only 300,000 years old, before all other forms of light. And they will do so with much greater angular and spectral resolution than any mission that has come before, from the COBE satellite in 1990 to balloon-borne experiments in 2000. Slight temperature differences in this microwave radiation reflect density difference from when the Universe was less than a 10^{-25} second old. This

It is here, in the earliest epoch of the Universe, that the four fundamental forces merge and quantum gravity may be important.



OWL will monitor huge regions of the Earth's atmosphere for cosmic ray activity.

ACCESS in position on the International Space Station.

places us at the end of the inflation era. MAP and Planck will, in fact, provide the first solid test of the inflation theory.

You wouldn't think we could travel farther back in time than that, but we plan to. The CMBPOL mission will

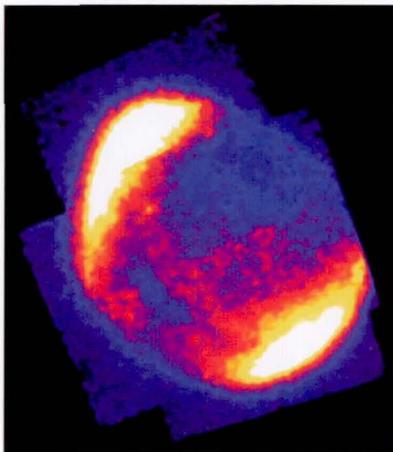
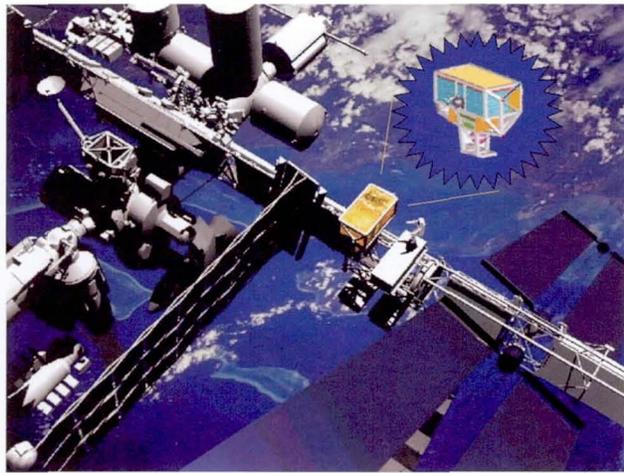
also observe the cosmic microwave background, only it will search for the polarization of the microwave radiation, not temperature. Inflation would produce gravitational waves, which could be detected via the unique polarization pattern they inscribe upon the cosmic microwave background. With CMBPOL, we journey to the beginning of the inflation era, at 10^{-32} second, closer yet to the secrets held in the GUT era.

A mission to follow LISA will directly detect gravitational radiation from this period of inflation. The mission involves two independent gravitational wave antennae tuned to a wave period one second long, where the Universe is quiet in all other forms of gravitational radiation. These gravitational waves, relics from the Big Bang, fill the Universe now, only they are too subtle to detect with our current technology.

Atomic fossils also tell tales...

The OWL mission may also probe the inflation era with its detection of rare, high-energy cosmic rays. These cosmic rays are subatomic particles moving so fast that they possess more energy than scientists thought was possible. The cosmic rays had to be produced in the local Universe, for any known particle farther than 150 million light-years would have lost energy on the long journey to Earth by colliding with the cosmic microwave background radiation. Yet we do not know of anything that close that could produce such an energetic particle. It's a Catch 22.

Some scientists believe that the highest-energy cosmic rays come from the annihilation of topological defects formed during the inflation era. But they may also come from nearby supermassive black holes or even neutron stars. We could tell which if we had a large sample of these cosmic rays. The highest-energy particles, however, are very rare—striking once per square kilometer per century. As such, no more than a few have been identified with ground-based detectors. OWL will employ a new type of technology to monitor huge regions of the Earth's atmosphere for cosmic-ray activity by looking down from space, not up. When the highest-energy particles enter the atmosphere, they produce a faint light that



ACCESS will collect medium-energy cosmic rays, which likely originate in star explosions such as SN 1006.

Big Bang

| 10^{-44} s | 10^{-35} s | 10^{-32} s | 10^{-10} s |
|---------------------|--------------|---------------|---------------|
| Superstring (?) Era | GUT Era | Inflation Era | Electro-W Era |

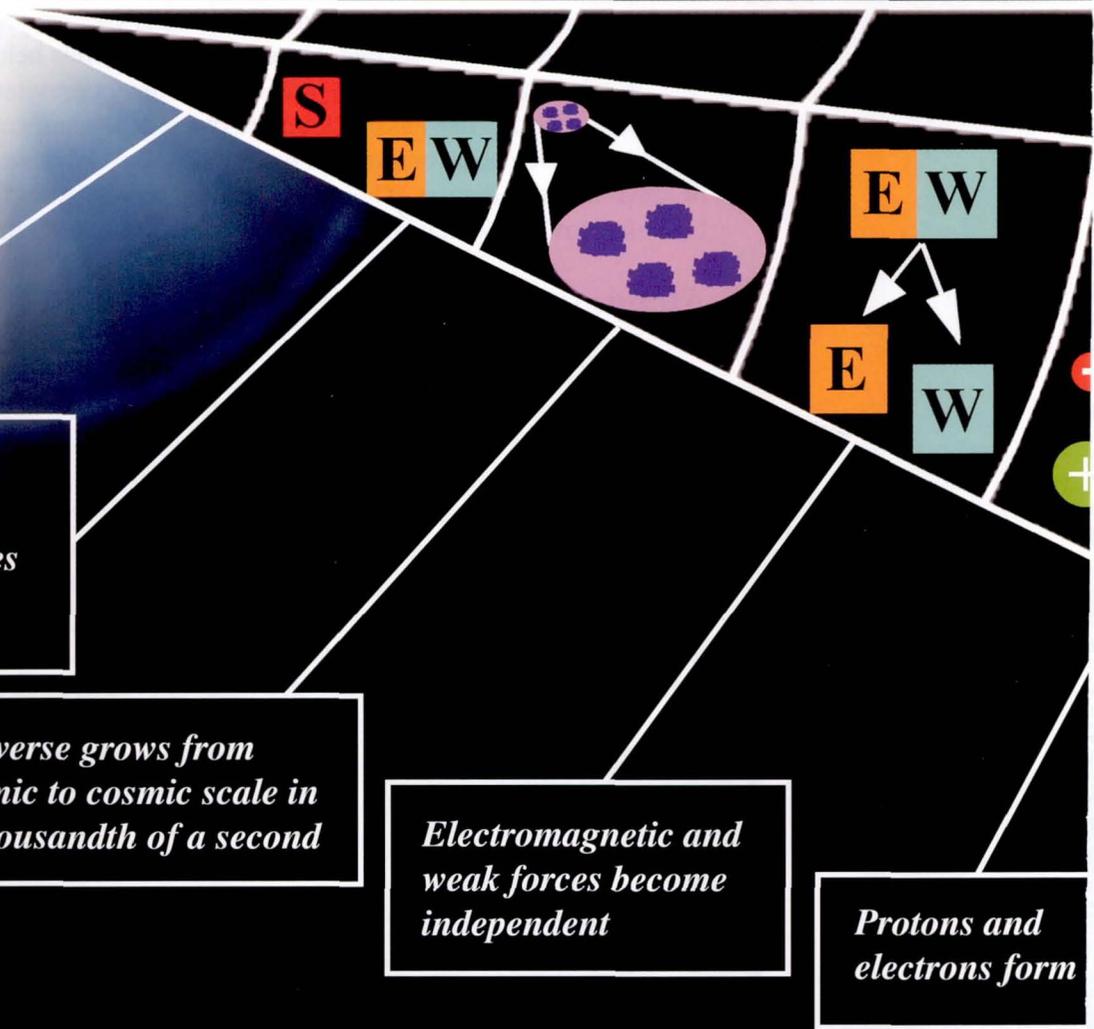
A period when all force and energy was indistinguishable, still speculative

Particles responsible for strong, weak, and electromagnetic forces emerge

Universe grows from atomic to cosmic scale in a thousandth of a second

Electromagnetic and weak forces become independent

Protons and electrons form



Time →

| 300 s | 300,000 years | 1 billion years | 15 billion years |
|--------------|-------------------|---------------------------|------------------|
| Particle Era | Recombination Era | Galaxy and Star Formation | Present Era |



Protons join with electrons; the first light from Big Bang emerges

OWL will detect. OWL hopes to identify hundreds of these mysterious particles each year with the goal of identifying their origin. They could indeed point to a yet-undiscovered phenomenon.

Cosmic rays are like fossils from the Universe, and NASA has several Cosmic Journeys missions that will collect them. The ACCESS mission will sit on the International Space Station to collect a full range of medium-energy cosmic rays, from hydrogen to bismuth. These cosmic rays are less energetic than the ones OWL will search for, and ACCESS will measure them directly in a box-shaped cosmic ray detector. ACCESS will help determine where these mysterious cosmic rays come from, what they are made of, and how they were accelerated to such high speeds. These cosmic rays likely originate in remnants of star explosions.

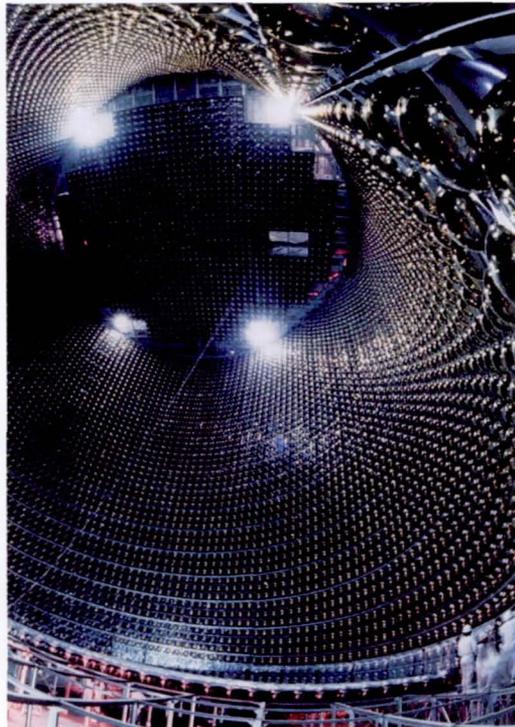
Cosmic Connections

NASA won't be alone in its Cosmic Journeys. The space agency will work hand-in-hand with the National Science Foundation (NSF) and the Department of Energy (DOE). The partnership now being forged, called "Connections: From Quarks to the Cosmos," hopes to bring together physicists, astronomers and other professionals who have traditionally worked independently.

The NSF and DOE conduct major research projects involving particle accelerators and underground particle detectors; ground-based observations of ultra-high energy cosmic rays, high-energy gamma rays, dark matter and dark energy; large-scale sky surveys in microwave, radio and optical wavelengths; spaced-based observations of cosmic rays and gamma rays; and theory and computer simulation work.

Underground detectors search for neutrinos and relics of dark matter. The NSF- and DOE-supported Super-Kamiokande neutrino detector, for example, is a 50,000-ton tank of ultra-pure water buried nearly one kilometer underground in Japan. Neutrinos are elementary particles somewhat like electrons, only they have zero charge and hardly any mass. Many believe that neutrinos contribute to some of the dark matter mentioned earlier in this booklet. Other earth-based detectors aim to directly detect the dark matter that may be all around us. These include WIMP and axion detectors. Axions, theoretical exotic particles thought to contribute to dark matter, may burst into detectable microwaves when they encounter very strong magnetic fields.

Particle accelerators are used to produce dark matter particles, discover new forces, and understand the basis of why we see more matter than antimatter in the Universe. Two DOE-supported



The Super-Kamiokande neutrino detector is a 50,000-ton tank of ultra-pure water buried nearly one kilometer underground in Japan



Aerial view of the Stanford Linear Accelerator Center (SLAC).

accelerators are at the Fermi National Accelerator Laboratory outside of Chicago and the Stanford Linear Accelerator Center, operated by Stanford University. Particle accelerators have revealed the substructure of the nucleus of an atom. Accelerators work by colliding particles, such as lead or hydrogen protons, which generate high energies and simulate the conditions of the first moments after the Big Bang when the Universe was a hot soup of subatomic particles.

The Connection among NASA, NSF and DOE will surely generate a

total that is greater than the sum of its parts.

The Cosmic Journeys Missions

Ours is a Cosmic Journey inspired by gravity and propelled by resolution. Each Cosmic Journeys mission will transport us closer to a black hole, closer to the invisible gases the percolate between stars and galaxies, closer to the very beginning of time. We will leave no star unturned. We will place the Universe under tight surveillance, examining both the massive and minute—from merging galaxies ripping apart stars to atomic particles shooting through spectacular accelerators the size of the Milky Way. These phenomena, dictated by gravity, hold the secrets about the birth of the Universe, its fate, and all the swirling and glowing that goes on in between.

We are on the verge of major breakthroughs based on connecting particle physics, gravity and cosmology. As with previous advances in fundamental physics, this new program may yield "Nobel Prize" discoveries... and perhaps even more dramatic Cosmic Journeys! Here are a few of the Cosmic Journeys missions either approved or under consideration by NASA.

Approved Missions:

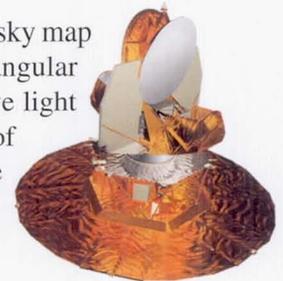
MAP

The Microwave Anisotropy Probe will produce an accurate full-sky map of the cosmic microwave background with high sensitivity and angular resolution. By measuring temperature fluctuations in this microwave light that bathes the Universe, MAP will provide insight to the nature of gravity, dark matter, and the early growth and ultimate fate of the Universe.

[\(http://map.gsfc.nasa.gov/\)](http://map.gsfc.nasa.gov/)

Swift

Swift is a mid-size satellite mission that will detect gamma ray bursts and "swiftly" (within a minute) point its UV/optical and X-ray telescopes at the burst, while at the same time relay the information to other satellites and telescopes so that they too can

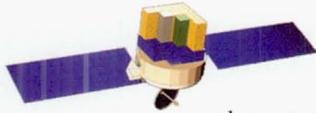


observe the bursts. Swift needs to act quickly, because these bursts—the most powerful events known in the Universe other than the Big Bang—are brightest during the first few seconds and fade away forever after a few days. Gamma-ray bursts occur randomly from all directions; their origin is not known. In between bursts, Swift will be busy studying supermassive black holes.

[\(http://swift.gsfc.nasa.gov/\)](http://swift.gsfc.nasa.gov/)

GLAST

The Gamma-ray Large Area Space Telescope will measure the most energetic form of light in the Universe, called gamma rays. One of GLAST's many targets will be black hole jets, particle accelerators in space far more powerful than anything we can build on Earth. GLAST will study the mechanism of these jets as well as search for clues to the nature of dark matter.



[\(http://glast.gsfc.nasa.gov/\)](http://glast.gsfc.nasa.gov/)

FIRST

The Far InfraRed and Submillimetre Telescope is a cornerstone mission of the European Space Agency (ESA) that will probe a poorly studied region of the electromagnetic band. FIRST will provide insight to galaxy formation, the life cycle of energy and matter, and gravity at work in the early Universe.

[\(http://astro.estec.esa.nl/\)](http://astro.estec.esa.nl/)



Planck

Planck, named after German scientist and Nobel Prize winner Max Planck, will probe the cosmic microwave background with greater accuracy than MAP. Planck is an ESA mission that will launch with FIRST.

[\(http://astro.estec.esa.nl/\)](http://astro.estec.esa.nl/)



Missions Under Formulation:

ACCESS

The Advanced Cosmic-ray Composition Experiment for the Space Station is a cosmic ray detector to be launched and attached to the International Space Station in 2006 to help us understand the origin, variety, distribution and life span of elementary particles in our galaxy.

[\(http://lheawww.gsfc.nasa.gov/ACCESS/\)](http://lheawww.gsfc.nasa.gov/ACCESS/)

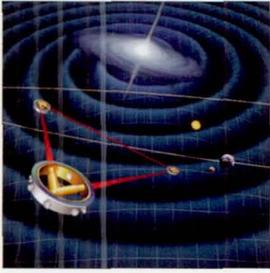


Constellation-X

Constellation-X is a next-generation X-ray telescope mission that will investigate black holes, Einstein's Theory of General Relativity, galaxy formation, the evolution of the Universe on the largest scales, the recycling of matter and energy, and the nature of dark matter. The Constellation-X spectroscopy mission entails four moderate-sized telescopes orbiting and observing in unison, combining to yield the collecting power of one giant telescope.

[\(http://constellation.gsfc.nasa.gov/\)](http://constellation.gsfc.nasa.gov/)

LISA



The Laser Interferometer Space Antenna will observe gravitational waves from very massive black holes found in the centers of many galaxies. Gravitational waves are one of the fundamental building blocks of our theoretical picture of the universe, yet they have not been observed. The LISA mission will consist of three spacecraft forming an equilateral triangle with a distance of five million kilometers between any two spacecraft. Gravitational waves passing through the solar system will generate small changes in the distance between the spacecraft.

[\(http://lisa.jpl.nasa.gov/\)](http://lisa.jpl.nasa.gov/)

Proposed Mission Concepts:

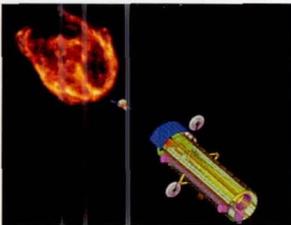
HSI

The High-resolution Spectroscopy Mission will study the highest-energy X-rays with unprecedented sensitivity, addressing fundamental questions on the origin of heavy elements and black holes. HSI will provide the closest look yet at distant quasars and nearby black holes and neutron stars.

MAXIM Pathfinder

MAXIM Pathfinder, part of the Micro Arcsecond X-ray Imaging Mission program, will test visionary technology as well as carry out important scientific objectives. This mission, as the name implies, serves as a pathfinder towards the ultimate goal of imaging a black hole, which will be accomplished by the MAXIM mission itself. MAXIM Pathfinder will be about 10,000 times more sensitive than Chandra, and will bring us ever closer to the disks and jets associated with black holes.

[\(http://maxim.gsfc.nasa.gov/\)](http://maxim.gsfc.nasa.gov/)



MAXIM

The Micro Arcsecond X-ray Imaging Mission will image a black hole, a primary goal of NASA's Cosmic Journeys and Office of Space Science. MAXIM must be a million times more sensitive than Chandra to accomplish this. A direct image of gravity at its extreme will be of fundamental importance to Physics. MAXIM's unsurpassed resolution—equivalent to resolving a feature the size of a dinner plate on the surface of the Sun—will yield untold discoveries and tremendously improve our understanding of a multitude of cosmic sources.

[\(http://maxim.gsfc.nasa.gov/\)](http://maxim.gsfc.nasa.gov/)

EXIST

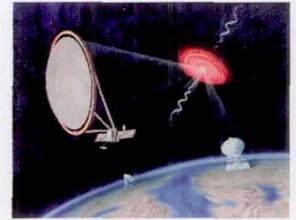
The Energetic X-ray Imaging Survey Telescope will collect the highest energy X-ray photons from sources such as neutron stars, galactic black holes, dust-enshrouded supermassive black holes and regions of nucleosynthesis. EXIST will complement HSI, a hard X-ray spectroscopy mission, and may sit on the International Space Station.

<http://exist.gsfc.nasa.gov/>

ARISE

The Advanced Radio Interferometry between Space and Earth comprises one (or possibly two) 25-meter radio telescopes in highly elliptical Earth orbit in conjunction with a large number of radio telescopes on the ground. Using the technique of interferometry, which pools together many smaller telescopes into one powerful telescope, ARISE will have the resolution needed to zoom in on the base of a black hole jet to see how matter is fed into a black hole and how these jets of particles form.

(<http://arise.jpl.nasa.gov/>)



CMPBOL

The Cosmic Microwave Background Polarization Experiment is a follow-up to the MAP and Planck missions, this time measuring the polarization of microwave radiation produced by the Big Bang, instead of temperature differences in that radiation. This mission tests the theory of inflation, which states that the early Universe grew trillions of times larger in only a thousandth of a second, perhaps at 10^{-35} second after the Big Bang. If the inflation theory is true, CMBPOL would be able to detect cosmological background gravitational waves produced by this era. CMBPOL can also discriminate between competing models for how the earliest galaxies and supermassive black holes formed.

OWL

OWL, short for Orbiting Wide-angle Light-collectors, will detect the highest energy cosmic rays. The origin of these energetic particles is a mystery: The particles must have originated somewhere close (150 million light-years), for particles from distant sources would lose energy on the way to Earth. Yet nothing that we know of close to Earth could produce such energetic particles. OWL, comprising two satellites which observe the Earth's atmosphere from above, may also tell us about the conditions of the Universe when it was only trillionths of trillionths of a second old.

(http://lheawww.gsfc.nasa.gov/docs/gamcosray/hecr/owl_new.html)

*Text: Christopher Wanjek
Scientific Review: Nicholas White*

Special Assistance: Lynn Cominsky, Jonathan Ormes, David Palmer, Steve Ritz, Gail Rohrbach, Bonnard Teegarden, Dave Thompson, Pat Tyler, Azita Valinia.

For more information about Cosmic Journeys, visit our website at <http://journeys.gsfc.nasa.gov/>

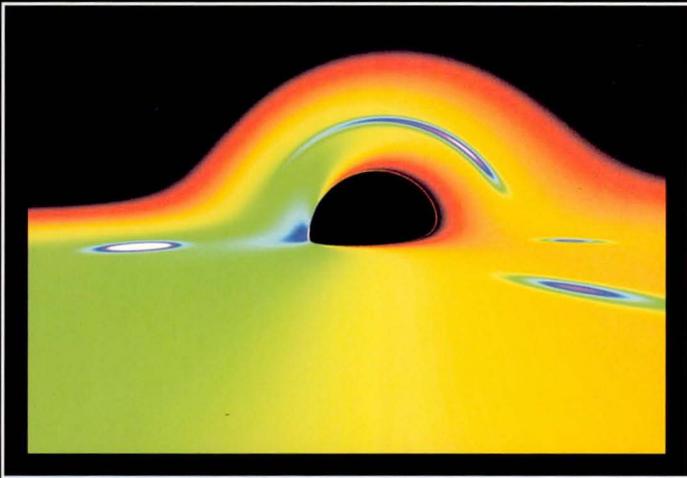
Other sites of interest:

NASA's Structure and Evolution of the Universe theme: <http://universe.gsfc.nasa.gov/>

Imagine the Universe (an educational site with lesson plans, grades 9-14): <http://imagine.gsfc.nasa.gov/>

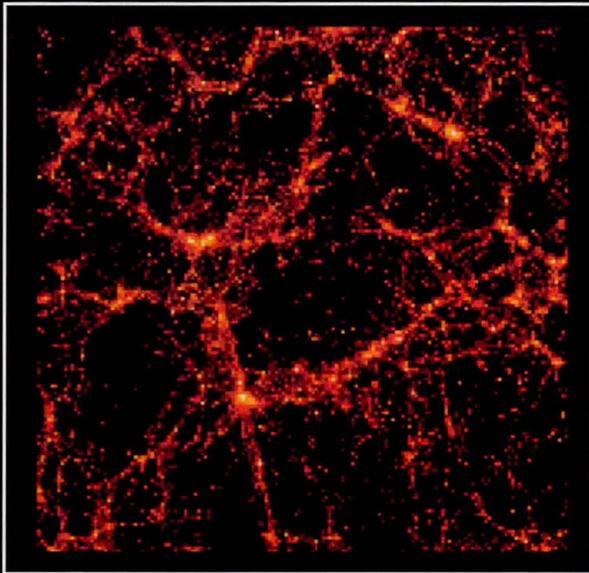
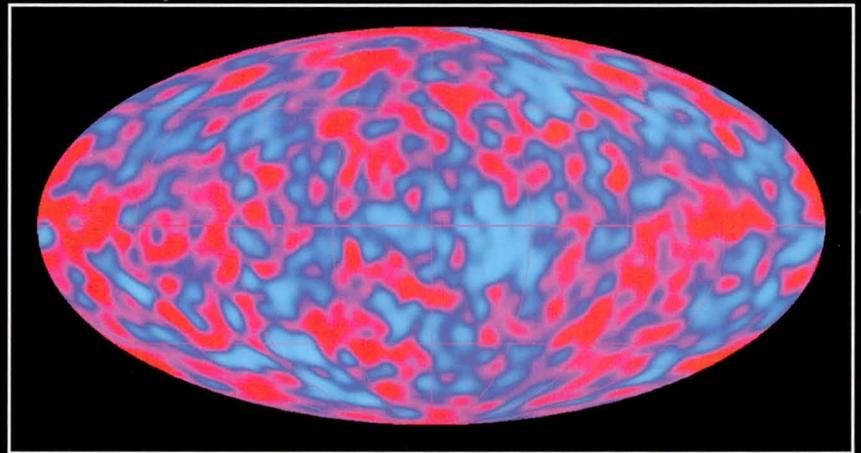
StarChild (an educational site for younger astronomers, grades K-8): <http://starchild.gsfc.nasa.gov/>

SEU Educational Forum: <http://cfa-www.harvard.edu/seuforum/>



*Gravity in the vicinity
of black holes.*

*Gravity in the
early universe.*



*Gravity on the
universal scale.*

