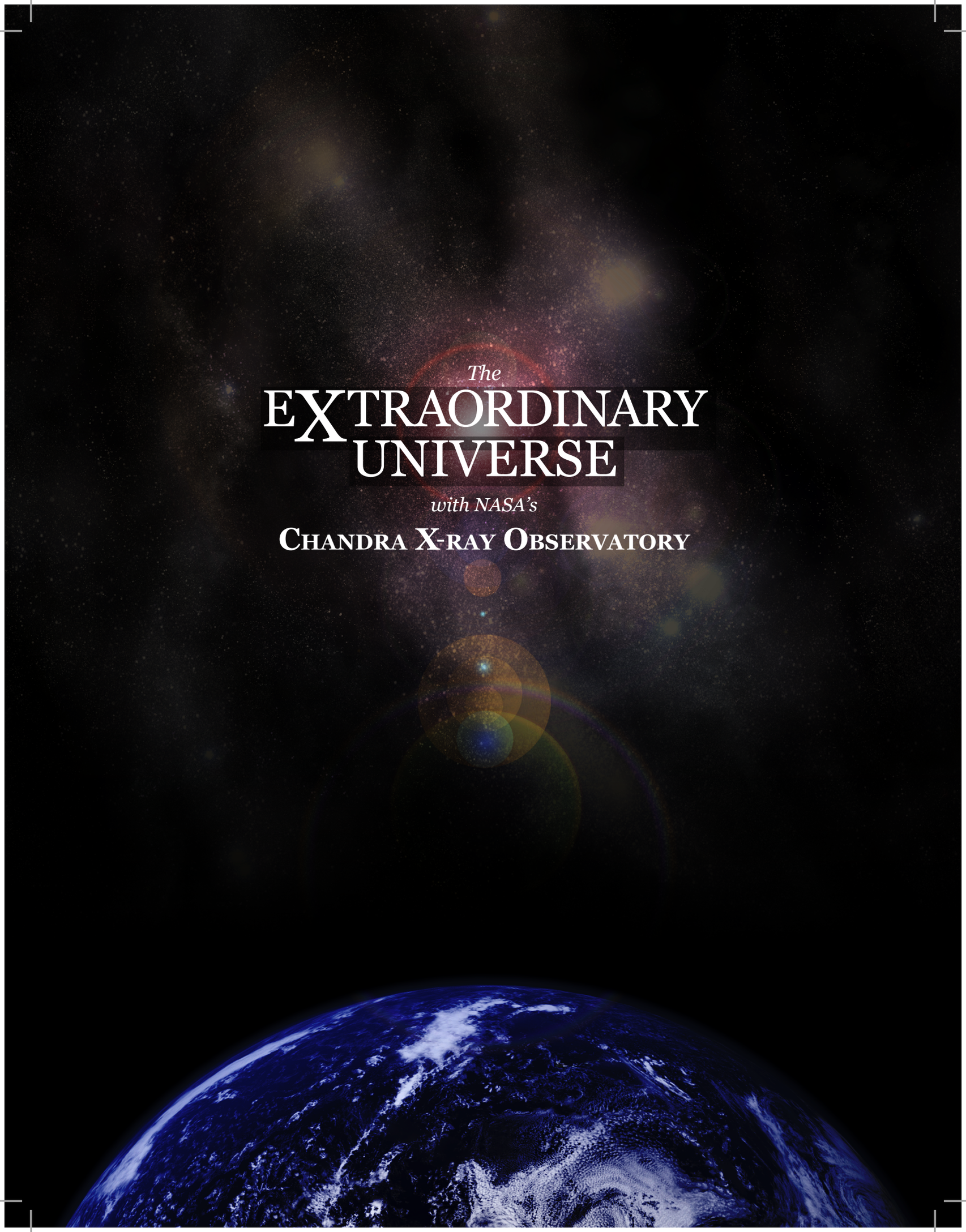
The

EXTRAORDINARY UNIVERSE

with NASA's

CHANDRA X-RAY OBSERVATORY



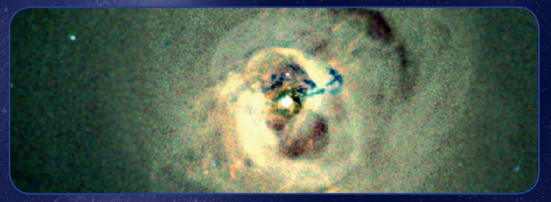
Cool Stories from the Hot Universe

In more than a decade of operation, NASA's Chandra X-ray Observatory has had a widespread, transformative impact on 21st century astrophysics. With its unrivaled ability to create high-resolution X-ray images, Chandra has enabled astronomers to investigate phenomena from comets to cosmology. Discoveries are accumulating at a rapid rate as Chandra makes observations of hundreds of objects each year. Here we profile a dozen significant scientific advances made from research using Chandra.

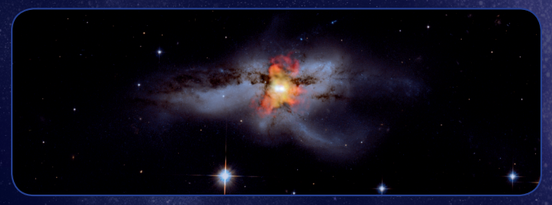
Dark Energy: Chandra observations of the rate at which galaxy clusters grow by pulling in surrounding galaxies and gas imply that the growth of these immense structures has been stifled by the accelerated expansion of the universe. The prime candidate for the cause of this acceleration is the prevalence throughout space of an invisible energy called dark energy.

Dark Matter: Observations of the Bullet Cluster and other clusters with Chandra and optical telescopes have provided the most direct evidence yet that the universe contains six times as much dark matter as normal matter. The presence of dark matter is revealed through its gravitational pull on normal matter such as electrons and protons, but it has so far escaped detection by any type of telescope.

Black Hole Census: Chandra surveys have led to the discovery of hundreds of supermassive black holes that produce X rays as they pull in surrounding gas. These sources can explain essentially all the "diffuse" X-ray glow first observed more than 40 years ago, resolving a long standing puzzle. The supermassive black hole census also provides insight into when these objects first formed, and how they grow over cosmic time.



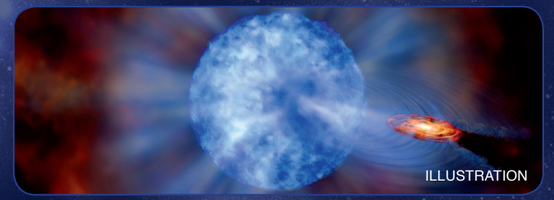
Black Hole Blowback: Chandra images of galaxy clusters have revealed dramatic evidence for the repetitive and far reaching explosive activity associated with rotating supermassive black holes. This activity involves the highly efficient conversion of the gravitational energy of infalling gas into powerful jets of high-energy particles. Black hole blowback plays a key role in the evolution of massive galaxies.



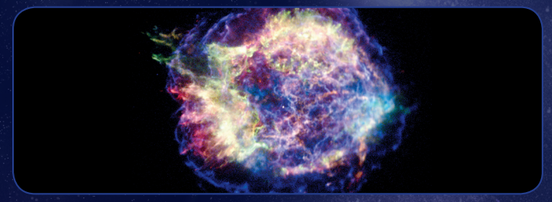
Binary Black Holes: Chandra discovered two supermassive black holes in the same galaxy that are destined to merge, providing evidence on how supermassive black holes grow in the centers of galaxies. Over the course of the next few hundred million years, the two supermassive black holes, which are about 3000 light years apart, will drift toward one another and merge to form one larger supermassive black hole.

Black Hole in the center of Milky Way Galaxy: Chandra measured the energy output and flaring from Sagittarius A* (Sgr A*), the supermassive black hole at the center of our own galaxy. The rapidity of the variations in the X ray emission indicates that they are occurring near the event horizon, or point of no return, around the black hole, and the low intensity of the X-rays suggests that Sgr A* is a starved black hole.

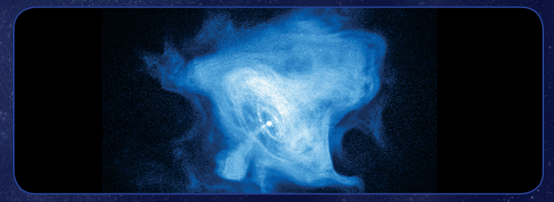
Galactic Center: This Chandra image reveals the exotic center of the Milky Way. Hundreds of small dots show emission from material around black holes, neutron stars and white dwarfs. A supermassive black hole resides within the bright, blue-white region in the center. Diffuse X-ray light comes from gas heated to millions of degrees by outflows from the supermassive black hole, winds from giant stars, and stellar explosions.



Large Stellar Mass Black Holes: Observations with Chandra, NASA's Swift satellite and optical telescopes have revealed the existence in nearby galaxies of two black holes with masses twice that of known stellar mass black holes. The companion stars for these black holes are very large, with masses more than 30 times that of the Sun, and will likely evolve into black holes.

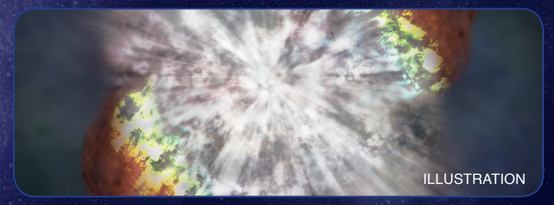


Supernovas and Supernova Remnants: Chandra images and spectra have allowed scientists to investigate the dynamics of shock waves generated by supernovas and how they accelerate electrons and protons to near the speed of light, to trace the amount and distribution of heavy elements expelled by the explosions, and to explore the mechanisms of the explosions.

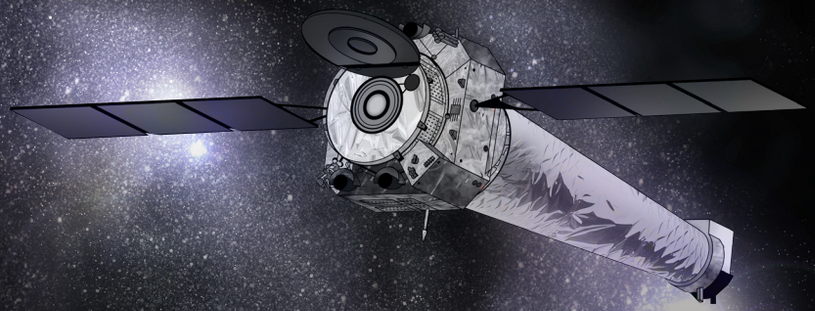


Pulsar Rings and Jets: Chandra images of the Crab Nebula and other supernova remnants have revealed spectacular rings and jets surrounding a central neutron star and embedded in glowing, magnetized clouds of energetic particles called pulsar wind nebulas. The X-ray images show that a magnetized, rapidly rotating neutron star can generate voltages millions of times greater than those of lightning bolts.

Young Sun-like Stars: A long Chandra observation of a rich cluster of young stars in the Orion Nebula showed that young Sun like stars produce violent X ray outbursts, or flares, that are much more frequent and energetic than anything seen today from our 4.6 billion year old Sun. This could have implications for the formation of planets and the existence of a habitable zone around stars.



A New Kind of Supernova: Chandra and optical observations of the supernova SN 2006gy, one of the most luminous supernovas ever recorded, indicate that it was a long-predicted but never observed type of thermonuclear supernova that occurs only in extremely massive stars that are greater than 150 times the mass of the Sun. Such stars may have been much more common when the universe was very young.



NASA's Chandra X-ray Observatory has transformed our view of the high-energy universe with its ability to make exquisite X-ray images of star clusters, supernova remnants, galactic eruptions, and collisions between clusters of galaxies. Chandra has probed the geometry of space-time around black holes, traced the dispersal of calcium and other elements by supernovas, and revealed that whirling neutron stars only twelve miles in diameter can generate streams of high-energy particles that extend for light years. Chandra has found cosmic generators millions of times more powerful than neutron stars—rapidly spinning, supergiant black holes in the centers of galaxies. There, energy from the rotation of the black hole and surrounding gas is converted into powerful jets and winds that can influence the destiny of an entire galaxy.

On an even greater scale, Chandra has helped to confirm that galaxies and the universe are dominated by other forms of darkness, called dark matter and dark energy. In the distant past, dark matter pulled material together to form galaxies and galaxy clusters, but now, it appears that dark energy—which may be a much different phenomenon—has stopped the process and is causing the universe to expand at an ever-increasing rate. The nature of dark matter and dark energy is still a deep mystery.

As Chandra expands the realm of the known, it continues to raise new questions and point the way for future exploration.

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