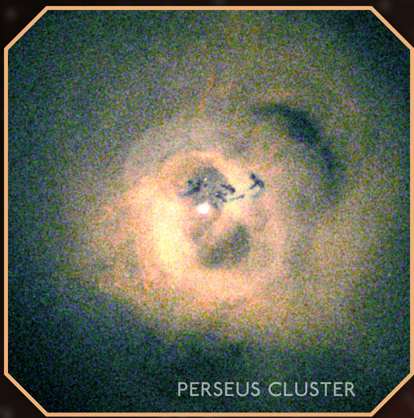
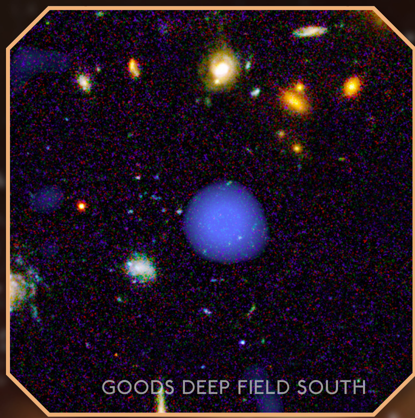
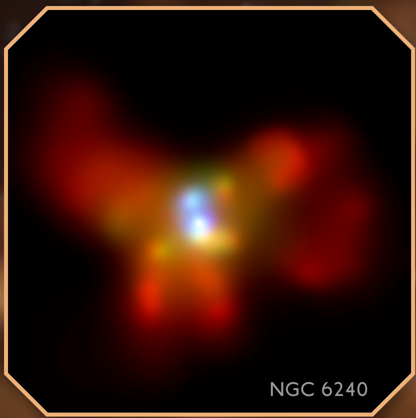
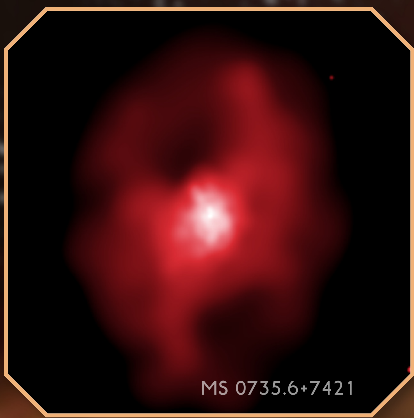
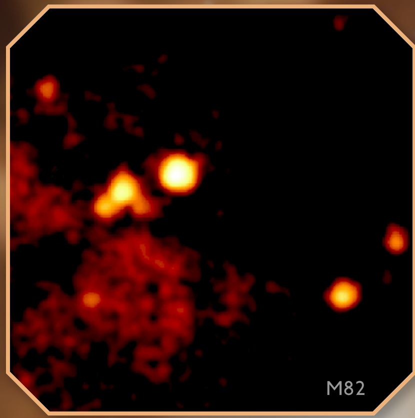
EXPLORING BLACK HOLES


PERSEUS CLUSTER

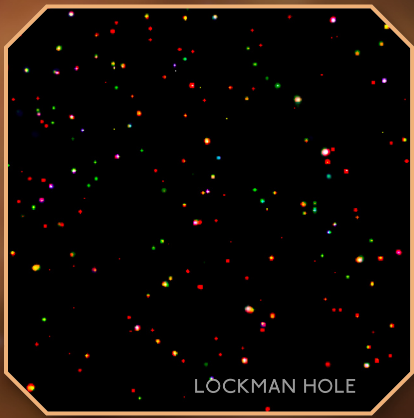

GOODS DEEP FIELD SOUTH

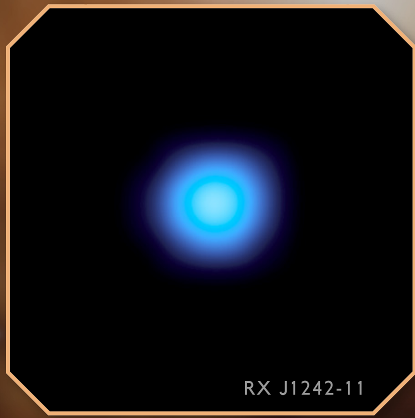

NGC 6240

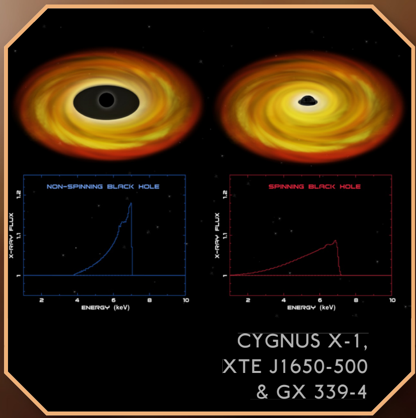

MS 0735.6+7421


M82


SAGITTARIUS A*


LOCKMAN HOLE


RX J1242-11



CYGNUS X-1,
XTE J1650-500
& GX 339-4

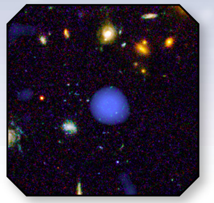
WHAT IS A BLACK HOLE? When a star runs out of nuclear fuel, it will collapse. If the core, or central region, of the star has a mass that is greater than three Suns, no known nuclear forces can prevent the core from forming a deep gravitational warp in space called a black hole.

A black hole does not have a surface in the usual sense of the word. There is simply a region, or boundary, in space around a black hole beyond which we cannot see. This boundary is called the event horizon. The radius of the event horizon (proportional to the mass) is very small, only 30 kilometers for a non-spinning black hole with the mass of 10 Suns.

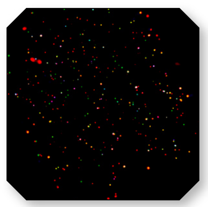
Anything that passes beyond the event horizon is doomed to be crushed as it descends ever deeper into the gravitational well of the black hole. No visible light, nor X-rays, nor any other form of electromagnetic radiation, nor any particle, no matter how energetic, can escape.

EXPLORING BLACK HOLES WITH CHANDRA X-RAY OBSERVATORY

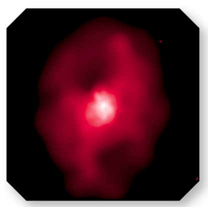
With its unique properties, Chandra is peerless as a black hole probe - both near and far. Not even Chandra can "see" into black holes, but it can tackle many of their other mysteries. Using Chandra, scientists have found evidence for mid-sized black holes, found hidden populations, and estimated how many black holes are in the Universe. They have studied their dining habits and how fast they spin. They found a black hole that generated the deepest note ever detected in the Universe, and another that generated the most powerful explosion. They found direct evidence for a star that was torn apart by a supermassive black hole. They observed two supermassive black holes orbiting in the same galaxy, destined for a titanic collision. Chandra observations strongly confirmed the reality of the "event horizon". Expect more startling revelations about the lives of black holes as Chandra continues its mission to explore our Universe!



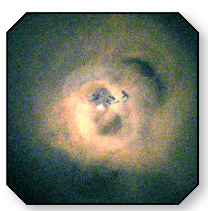
GOODS DEEP FIELD SOUTH: A deep, multiwavelength study of the Great Observatory Origins Deep Survey (GOODS) field, locating several supermassive black holes in young galaxies as far as 13 billion light years from Earth.
Together with the Hubble Space Telescope and the Spitzer Space Telescope, Chandra has found evidence of a hidden population of supermassive black holes in the Universe. Some of these objects appear as X-ray sources without optical counterparts in composite Hubble-Chandra images. Chandra-Spitzer images from the survey demonstrate that these mysterious X-ray sources are also detected at infrared wavelengths, indicating that the galaxies around these supermassive black holes are heavily obscured by dust. Combined data from Chandra, Spitzer and Hubble should soon yield a much more complete census of the number of black holes in the early Universe.



LOCKMAN HOLE: A region of the sky away from the Galactic plane that provides a relatively clear view to objects ranging from nearly a billion to over 12 billion light years from Earth.
This Chandra image of the Lockman Hole region is a mosaic that shows hundreds of X-ray sources, many of which are supermassive black holes in distant galaxies. These and other data have enabled astronomers to study the rate at which these enormous black holes grow by pulling in gas from their surroundings. On average, the most massive black holes appear to have grown rapidly until they attained a mass of a few hundred million to a few billion Suns and then stopped. Intense heating released by their rapid growth could have produced a blowback effect that cleared away much of the gas and dust around the black hole. In contrast, smaller supermassive black holes grow more slowly and retain most of the gas and dust around them.

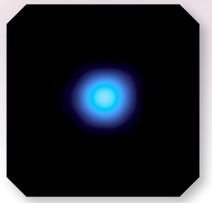


MS 0735.6+7421: A cluster of galaxies about 2.6 billion light years from Earth.
Chandra's image shows two cavities - each about 600,000 light years in diameter - in the hot, X-ray emitting gas that pervades the MS0735 cluster. The cavities appear on opposite sides of a large galaxy at the center of the cluster. This indicates that these cavities came from an enormous eruption in the vicinity of the galaxy's supermassive black hole that launched jets of high-energy particles. These jets blasted through the galaxy into the surrounding hot, intergalactic gas, pushing it aside to carve out the cavities. Chandra has discovered evidence of similar outbursts in Perseus and other galaxy clusters, but the cavities in MS 0735 are easily the largest. To create an eruption of the size in MS 0735, the supermassive black hole must have swallowed about 300 million solar masses worth of gas over the last 100 million years.

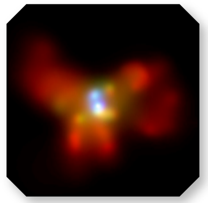


PERSEUS CLUSTER: A galaxy cluster about 250 million light years from Earth.
Chandra's 53-hour observation of the central region of the Perseus galaxy cluster has revealed wavelike features that appear to be sound waves. The features were discovered by using a special image-processing technique to bring out subtle changes in brightness. These sound waves are thought to have been generated by explosive events occurring around a supermassive black hole (bright white spot) in Perseus A, the huge galaxy at the center of the cluster. The image also shows two vast, bubble-shaped cavities filled with high-energy particles and magnetic fields. These cavities create the sound waves by pushing the hot X-ray emitting gas aside. The pitch of the sound waves translates into the note of B flat, 57 octaves below middle-C. This frequency is over a million billion times deeper than the limits of human hearing.

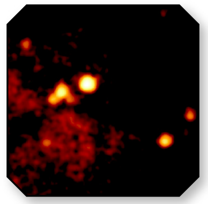
Did you know that black holes come in different sizes? Astronomers have long known about two categories: stellar-mass (about a dozen times more massive than the Sun) and supermassive black holes (millions or even billions of solar masses). In recent years, Chandra and other telescopes have found evidence for a middle-size black hole category now called "intermediate-mass" black holes with masses equal to hundreds or thousands of Suns. Theories for the formation of intermediate-mass black holes involve the collapse of extremely massive stars, or merger of many stellar-mass black holes.



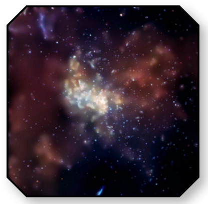
RX J1242-11: A galaxy about 700 million light years from Earth.
Observations with Chandra and other X-ray observatories confirmed that a powerful X-ray outburst had occurred in the center of RX J1242-11, which appears to be a normal galaxy in a ground-based optical image. This X-ray outburst, one of the most powerful ever detected in a galaxy, is evidence for the catastrophic destruction of a star that wandered too close to a supermassive black hole. After a close encounter with another star, the doomed star takes a path toward the giant black hole where the black hole's enormous gravity stretches the star until it is torn apart. Only a few percent of the disrupted star's mass is swallowed by the black hole, while the rest is flung away into the surrounding galaxy where it emits X-rays.



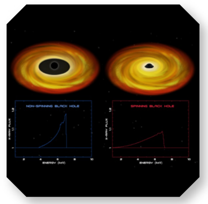
NGC 6240: An extremely luminous galaxy about 400 million light years from Earth.
The peculiar butterfly shape of NGC 6240 was caused by the collision of two smaller galaxies. Chandra's high-resolution image of the galaxy's central region revealed not one, but two active giant black holes. Over the course of the next few hundred million years, the two supermassive black holes, which are about 3,000 light years apart, will drift toward one another and merge to form one larger supermassive black hole. The relatively recent merger (30 million years) that formed this galaxy triggered a dramatic increase in the rate of star formation and supernova explosions. This activity heated the gas (seen in the reddish lobes) to multimillion degree temperatures, making it glow in X-rays.



M82: A starburst galaxy (central region) about 11 million light years from Earth.
Using Chandra's superior resolution, astronomers have discovered a new type of black hole. The bright source near the center of the image is associated with the black hole. It is located 600 light years away from the dynamic center of M82 and may have a mass of more than 500 suns. This mid-mass black hole may represent the missing link between smaller stellar black holes and the supermassive variety found at the centers of most galaxies. The source was seen to increase dramatically in intensity over a period of three months after which it decreased in intensity. A pattern of variability such as this indicates that the source is a black hole.



SAGITTARIUS A* (Sgr A*): The supermassive black hole at the center of our Galaxy, about 26,000 light years from Earth.
This Chandra image of Sgr A* and the surrounding region was made from 164 hours of observation time over a two-week period. During this time the black hole flared up in X-ray intensity half a dozen or more times. The cause of these outbursts is not understood, but the rapidity with which they rise and fall indicates that they are occurring near the event horizon, or point of no return, around the black hole. Also discovered were more than two thousand other X-ray sources and huge lobes of 20 million-degree gas (the red loops in the image at approximately the 2 o'clock and 7 o'clock positions). The lobes indicate that enormous explosions occurred near the black hole several times over the last ten thousand years.



CYGNUS X-1, XTE J1650-500 & GX 339-4: Three stellar black holes in the Milky Way galaxy, located between 8,000 and 15,000 light years from Earth.
Spectral observations by Chandra of Cygnus X-1 and GX 339-4, and XMM-Newton of XTE J1650-500 allowed astronomers to study iron atoms as they orbited close to the black holes. The orbits of these particles reveal details of the curvature of space around the black hole, and how fast the black hole is spinning. As shown in the illustration, the gravity of a black hole shifts X-rays from iron atoms to lower energies, producing a distinctive, strongly skewed X-ray signal. The data do not require that Cygnus X-1 is spinning, whereas the other two black holes are spinning rapidly. One possible explanation for the differences in spin among stellar black holes is that they are born spinning at different rates. Another is that the gas flowing into the black hole spins it up.

MORE ON BLACK HOLES

CHANDRA X-RAY CENTER

How are black holes created? In general, black holes are created whenever enough matter is squeezed into a small enough space. To turn the Earth into a black hole, we would have to compress all its mass into a region the size of a marble! Stellar mass black holes are formed when a massive star (about 25 times the mass of the Sun) runs out of fuel and its core collapses. The formation of supermassive black holes is more mysterious. They may be created when stellar mass black holes merge and gobble up matter in their vicinity, or by the collapse of giant clouds of dust and gas.

Can you see a black hole? No light of any kind, including X-rays, can escape from inside the event horizon of a black hole. The X-rays Chandra observes from the vicinity of black holes are from matter that is close to the event horizon of black holes. Matter is heated to millions of degrees as it is pulled toward the black hole, so it glows in X-rays.

How do you find black holes if you can't see them? Searching for black holes is a tricky business. One way to locate black holes is to search for the X-radiation from a disk of hot gas swirling toward a black hole. Friction between particles in the disk heats them to many millions of degrees, and they produce X-rays. Such disks have been found in binary star systems composed of a normal star in a close orbit around a stellar-mass black hole and, on a much larger scale, around the supermassive black holes in the centers of galaxies.

What happens to objects when they get too close to a black hole? Objects can orbit a black hole without any serious consequences as long as the size of their orbit is much greater than the diameter of the event horizon of a black hole, which is about 30 kilometers for a stellar black hole, and many millions of kilometers for a supermassive black hole. But, if any object gets too close, its orbit will become unstable and the object will fall into the black hole.

Is all matter in the disk around a black hole doomed to fall into the black hole? No, sometimes gas will escape as a hot wind that is blown away from the disk at high speeds. Even more dramatic are the high-energy jets that X-ray and radio observations show exploding away from the vicinity of some supermassive black holes. These jets can move at nearly the speed of light in tight beams and can travel hundreds of thousands of light years.

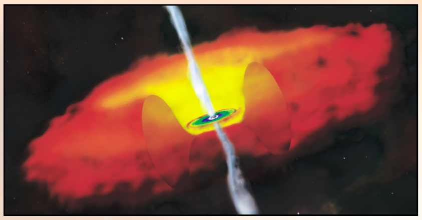


Illustration of a Black Hole This artist's conception shows a black hole surrounded by a disk of hot gas, and a large doughnut or torus of cooler gas and dust. Jets of high energy particles are propelled away from the vacinity of the black hole by intense electric magnetic fields. Illustration: CXC/M. Weiss

Do black holes grow when matter falls into them? Yes, the mass of the black hole increases by the amount of mass that was captured. For a stellar-mass black hole the radius of the event horizon increases by about 3 kilometers for every solar mass that is captured.

Are there limits to black hole growth? Theoretically, black holes can grow without limit. However, in the Universe, black holes do not have an infinite food supply! Sooner or later they will consume all the matter within their gravitational reach. Material further away may be affected by the gravitational field of the black hole, as we on Earth are affected by the massive black hole in the center of the Milky Way, but will not fall past its event horizon.

Can matter ever come back out of a black hole? No, even if matter was able to move at the speed of light, it could not escape once it falls past the event horizon. This is because the gravitational field inside a black hole is so strong that space is curved in on itself. Anything that falls into a black hole is able to travel in one direction only - towards the singularity (a point of infinite density where the laws of physics as we know them break down) at the center. Stephen Hawking showed that quantum theory implies that black holes should emit radiation. This radiation is predicted to be exceedingly weak and undetectable, except for hypothetical black holes with the mass less than that of a comet, and has yet to be observed.

MORE INFORMATION ON BLACK HOLES IS AVAILABLE AT
http://chandra.harvard.edu/xray_sources/blackholes.html
http://chandra.harvard.edu/photo/category/blackholes.html

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