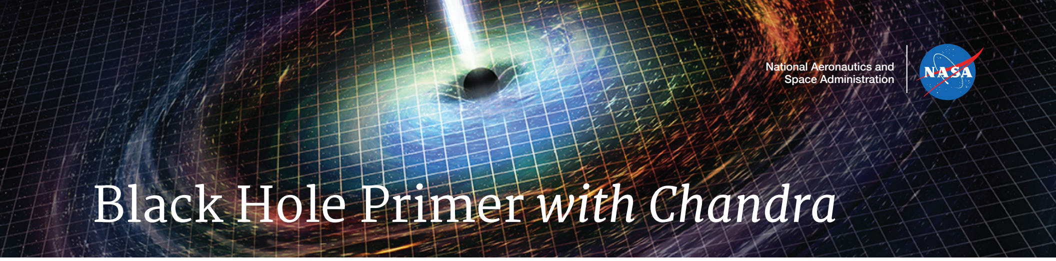


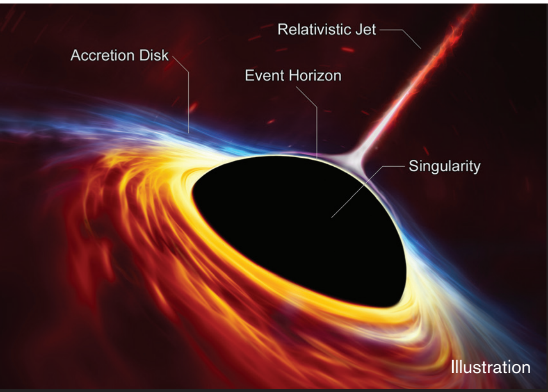
Black Hole Primer *with Chandra*

What is a black hole?

When some stars run 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 a region, or boundary, in space around a black hole beyond which we cannot see, known as the event horizon. Black holes come in different sizes, ranging from tens to millions or even billions of times the mass of the Sun.

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.



Anatomy of a Black Hole

Supermassive black holes with the mass of many millions of stars are thought to lie at the center of most large galaxies.

The evidence comes from optical and radio observations which show a sharp rise in the velocities of stars or gas clouds orbiting the centers of galaxies. High orbital velocities mean that something massive is creating a powerful gravitational field which is accelerating the stars. X-ray observations indicate that a large amount of energy is produced in the centers of many galaxies, presumably by the in-fall of matter into a black hole.

Accretion Disk
A disk of gas and dust that can accumulate around a center of gravitational attraction, such as a normal star, a white dwarf, neutron star, or black hole. As the gas spirals in due to friction, it becomes hot and emits radiation.

Event Horizon
Imaginary spherical surface surrounding a black hole, with radius equal to the Schwarzschild radius, within which no event can be seen heard, or known about by an outside observer.

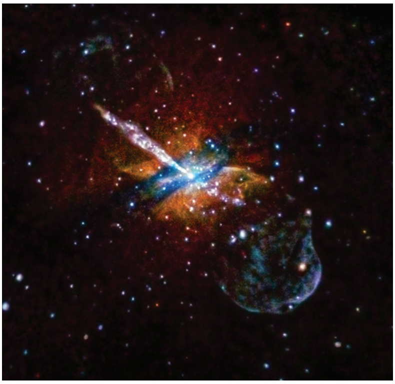
Relativistic Jet
A powerful jet generated by a black hole of radiation and particles traveling close to the speed of light.

Singularity
A point in the universe where the density of matter and the gravitational field are infinite, as in the center of a black hole.

Chandra, Black Hole Hunter

With its unique properties, NASA's Chandra X-ray Observatory is an exceptional black hole probe—both near and far. Chandra can't "see" into black holes, but it can tackle many of their 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 stars that were torn apart by a supermassive black hole. They have observed two supermassive black holes orbiting in the same galaxy, destined for titanic collisions. A few visual highlights include:

One of the most important black holes to study is the one found at the center of our Milky Way galaxy. Known as Sagittarius A*, this black hole is about 4 million times the mass of the Sun and Chandra has revealed much about its behavior and history.



The galaxy Centaurus A is well known for a spectacular jet of outflowing material, seen pointing from the middle to the upper left in this image, that is generated by a giant black hole at the galaxy's center.

Galaxies can merge and when they do, the supermassive black holes at their centers may also collide. This is the case of NGC 6240 where Chandra finds two giant black holes—the bright point-like sources in this middle of the image—are only 3,000 light years apart.

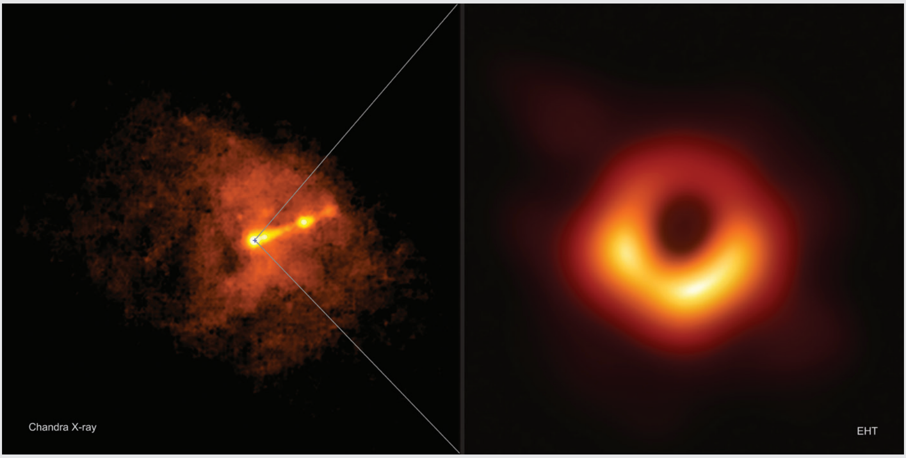
Chandra Captures X-rays in Coordination with EHT

The Event Horizon Telescope (EHT), a network of radio antennae around the globe, captured the first image of a black hole event horizon. This black hole is located in Messier 87, or M87, which is about 60 million light years from Earth. Chandra studied M87 many times over its 20-year mission and sees a much wider field-of-view than the EHT. The "+" marks the spot in the Chandra image on the left for the location of the EHT image on the right (not to same scale).

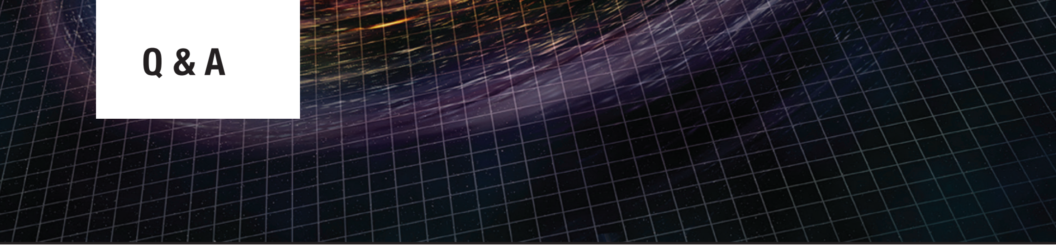
Astronomers used NASA's Chandra X-ray Observatory to obtain data of M87 during the April 2017 observing run by the EHT. These X-ray data, in combination with the new radio image from the EHT and other observations, will help scientists learn more about high-energy emission and the physics of accretion and ejection at the event horizon, the boundary between what can and cannot escape the gravitational pull of a black hole.

Chandra can view the full length of the jet of high-energy particles launched by the intense gravitational and magnetic fields around the black hole at M87. This jet (seen in detail from Chandra, below left), extends more than 1,000 light years from the center of the galaxy.

- The Event Horizon Telescope (EHT), a network of radio antennae around the globe, has captured the first image of a black hole event horizon.
- This black hole is located in Messier 87, or M87, which is about 60 million light years from Earth.
- Chandra has studied M87 many times over its 20-year mission and sees a much wider field-of-view than the EHT.
- By combining Chandra data with the EHT image, scientists can learn more about the giant black hole and its behavior.



Credit: Left: NASA/CXC/SAO; Right: Event Horizon Telescope Collaboration.



Q & A

How are black holes created?

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 our 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 X-ray telescopes 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 with Chandra if you can't see them?

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.

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.

More questions and answers at http://chandra.si.edu/blackhole