

# First imagery of black hole by the Event Horizon Telescope

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Astronomers have published the first reconstructed image of a black hole, from the center of galaxy Messier 87. Radio emissions collected in April 2017 by the Event Horizon Telescope (EHT) Collaboration reveal a bright ring of light bent by the gravitational field of a black hole 55 million light years away, 6.5 billion times more massive than the Sun and occupying a volume of space comparable to our entire Solar System.

The results from the planet-wide array of eight radio telescopes are the first direct measurements of the structure of a black hole and its surrounding environment. A new level of astronomical technique provides insight into the structure of the black hole itself and the nature of gravity under such extreme conditions. These measurements are the first step toward a deeper understanding of how spacetime warps in the presence of mass and energy, the basis of Einstein's theory of general relativity.

Two hundred researchers in Africa, Antarctica, Asia, Europe, North and South America labored for two years to make this discovery, while hundreds more made the upgrades to each of the observatories necessary to achieve the required angular resolution (the precision necessary to detect an object so far away with the degree of accuracy required).

These observations also provide the first, if limited, data of the dynamics of an accretion disk, the bright material surrounding and spiraling towards the black hole. The observations necessary to pin down the size of the black hole were taken over the course of a week and as a result provide the first direct look at how the matter around a black hole changes in time.

To complement the EHT measurements, NASA's Chandra, NuSTAR and Swift space telescopes participated in the observing campaign. While the

current scientific results do not incorporate their data, future calculations will be released combining radio and x-ray studies to provide a more complete picture of the interior of the Virgo galactic cluster's second brightest galaxy.

Further black hole images will be released in the coming months as researchers finish processing more data, both of the supermassive black hole at the center of Messier 87 (dubbed M87), as well as of Sagittarius A\*, the supermassive black hole at the center of our own Milky Way galaxy.

Strictly speaking, the graphic released is not a photograph of a black hole. A black hole is, by definition, not an object one can touch or see but rather a region of space with such intense gravity that no form of matter can escape, including light. Anything passing through this so-called event horizon forevermore becomes a part of the black hole itself.

One can, however, image the accretion disk. It is comprised of gas and dust—and planets and stars—that stray too close and are captured by a black hole's immense gravitational pull. The closer the material is to the black hole, the faster it circles around and the hotter and brighter it becomes. Accretion disks emit every frequency of electromagnetic radiation—from radio to visible light to gamma—and their emissions are the most common way to infer the presence of a black hole.

The gravitational pull of a black hole, in addition to creating a region of no return, warps spacetime so massively that light of the accretion disk isn't simply radiated directly away from the black hole. Some of it is instead curved back around the black hole, allowing one to see all sides of the accretion disk simultaneously. The same phenomenon occurs with the event horizon itself. General relativity lets us "see" both the front half and the back half of the event

horizon simultaneously, producing a “shadow” of a black hole that is 2.6 times the radius of the black hole itself. This shadow is what the EHT image reveals.

The peculiarities of black holes also make them easier to observe. The volume of a sphere (assuming its density doesn't change) is proportional to the cube root of its mass: double its mass and it only increases in size by 26 percent. But if you double the mass of a black hole, it *doubles* in size. M87 is 2100 times more distant than Sagittarius A\*, but it was suspected to be about 1500 times its mass, meaning the factors roughly cancel. Data from EHT confirmed this hypothesis and thus another aspect of general relativity.

Black holes were first theorized by Karl Schwarzschild in late 1915, when he showed that the unified structure of space and time proposed by Einstein, spacetime, could be contracted to a single point. The idea has been debated, refined and expanded upon for more than a century. Indirect evidence of black holes has existed since objects emitting powerful x-rays in our galaxy were discovered in the 1960s. Direct evidence was not acquired until the 2015 detection of gravitational waves.

Small black holes, those approximately the mass of our Sun, are formed when a large dying star implodes on itself in an event that can be seen across the entire Universe, a supernova. Larger black holes, those about ten times the mass of the Sun, are formed when these smaller black holes merge.

Supermassive black holes, on the other hand, those that are at the center of essentially every galaxy and which are millions or billions of times the mass of the Sun, were probably not formed through this process. They are too large and, since they are thought to be the seeds around which galaxies formed, too old to be the result of many thousands of mergers. It is unclear what physical processes generated such massive objects so early in the evolution of the cosmos.

Radio telescopes like EHT have been used for decades to study black holes. They are particularly suited for interferometry, which uses two or more telescopes in conjunction to make the effective size of the combined system the distance between the individual elements. EHT takes advantage of this by using observatories placed on opposite sides of Earth, making a telescope with the effective diameter of the entire planet.

The drawback of this technique is that it requires advanced mathematics and enormous computing power to produce an image that makes sense to the human eye. Those must be built up by comparing the radio wave data to models of the target being observed. Researchers using EHT built four independent models of M87 using our current knowledge of general relativity, fluid mechanics and plasma physics.

These were then compared to the approximately 5,000 terabytes of data collected by the telescope array that were aggregated using high speed fiber optic cables and physically shipping hard drives (when there was too much data to send over the internet). The model that most closely approximated the empirical data was then used to generate the images released to the world, as well as to understand the characteristics of the black hole and its accretion disk.

There are only two black holes that can be resolved by the world's current suite of radio telescopes: the two already mentioned, M87 and Sagittarius A\*. The natural next step involves launching radio telescopes into space to enlarge the separation between them and telescopes on the ground, making the detection of finer details in objects possible: this was first done in 1997 by Japan with the HALCA satellite and in 2011 by Russia with the Spektr-R satellite.

One can also look at higher frequencies, closer towards visible light. This means the telescopes need to have more precise radio “optics” and that the radio receivers and instrumentation must operate much more rapidly and record against a much more stable time signal to allow the technique to work.

Either way, the findings of the Event Horizon Telescope represent the first step of a new level of coordination and sophistication enabled through a powerful development of technique and international coordination. Only the realities of science funding under capitalism place limits on what can be achieved.

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