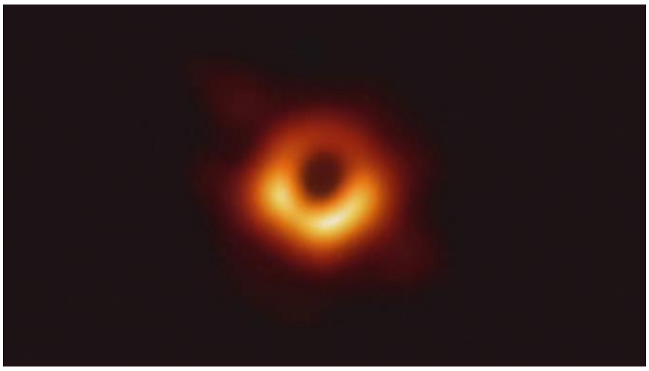
First picture of a black hole

What is a black hole?

In 1915, Albert Einstein published his manuscript on the theory of general relativity, which would constitute one of the two main pillars of physics as we know it today (the second being quantum mechanics). This theory governs the world of the infinitely large, and many experimental verifications carried out over the last century have so far confirmed its validity; the most recent major examples are the detection of gravitational waves and the subject of this article. Among the many implications of the relativistic paradigm is the prediction of the existence of extremely dense celestial bodies called black holes.

Portrait of Albert Einstein in 1904 at the Bern Patent Office (Credits: www.historytoday.com)

A black hole is an astrophysical object that usually results from the collapse of a star on itself: at some point in its evolution, the star exceeds a certain critical mass, and is no longer "strong" enough to support itself. This is followed by a fast degeneration into an extremely dense body with such an intense gravitational force that nothing can escape from it - not even light - hence the name "black hole". This impossibility is due to the fact that to compensate the monstrous attraction inside the black hole and thus escape from it, one would have to move at speeds higher than that of light, which is prohibited by special relativity (theory which is also the work of Einstein, published in 1905). The ultimate limit not to cross if one wishes to avoid being swallowed up is called the event horizon: it corresponds to the area around the black hole where the escape velocity is that of light. The theory predicts the presence of singularities at the centers of some black holes, *i.e.* breaks in the structure of space-time. There are different types of black holes, the heaviest ones are called "supermassive black holes" and are located in the centers of some of the most massive galaxies. It is such a black hole that has recently been "photographed" thanks to the international telescope network called the Event Horizon Telescope (EHT). Its name is M87*, it is located in the center of the elliptical galaxy M87 in the Virgo cluster, 55 million light years away from Earth. Its mass is 6.5 billion times that of our Sun.



First image of a black hole, M87 (Credits: Event Horizon Telescope Collaboration)*

But then, if no light can escape the black hole, how do you photograph it?

Although a black hole is by definition invisible, it is possible to observe its accretion disc: some matter in orbit around it that emits electromagnetic radiation due to its high temperature. This is the light zone that can be observed on images such as those in Christopher Nolan's film Interstellar, or more recently on the image that is the subject of this article!

More precisely, for M87*, it was the radio wave broadcasts that were studied and then "transcribed" into an image. Looking at this photograph, the brightest areas are those that emit the most radio radiation, and the black area in the center is the black hole.

Image of Gargantua, from the movie Interstellar, based on very precise simulations led by physicist Kip Thorne (Nobel 2017) (Credits: Paramount)

Why is the publication of this image important?

The publication of the M87* image is a first in the field of astronomy: to start, the EHT exists thanks to a genuine international collaboration and is a technological achievement in itself. Eight radio telescopes from around the world worked together for four days in April 2017 to match the accuracy of a telescope the size of our entire planet. This resulted in a resolution about 4000 times better than that of the Hubble Space Telescope. Observing M87* being a similar challenge to photographing an orange on the moon, it was absolutely necessary! To classify the data, the scientists used very long-base interferometry: this technique consists in marking each data with a specific time (measured using an atomic clock) when it is recorded. Once the data had been collected and classified, they had to be exploited in order to obtain the newly revealed image. Once again, this was a real scientific challenge that required the development of algorithms to sort the 5 petabytes of data.

Katie Bouman (the computer scientist who developed one of the data processing algorithms) when the image first appears. Happiness is palpable! (Credits: bbc.com)

The direct calculation of the mass of M87* is now possible with the image obtained, using the radius of its event horizon (or Schwarzschild radius).

Finally, one of the major advantages of the photography taken by the EHT is its great similarity with previous black hole simulations: it confirms that these models were very accurate, and further supports Einstein's theory of relativity.

Why M87?*

The EHT actually has two "targets": M87* and Sagittarius A*, the supermassive black hole in the center of the Milky Way, our galaxy. M87* attracts the attention of scientists first of all because of its size: it is one of the largest supermassive black holes known to date. But a second criterion placed him in the EHT's sights: his astrophysical jets. Jets are still very mysterious phenomena today: they are very fast clouds of matter that form along the axis of rotation of a compact astronomical object. In the case of M87*, the velocities reached by the jet particles are close to that of light. Coming from around the event horizon, the M87* jet was observed by NASA more than 1000 light years away from the black hole, reflecting the drastic energy supplied to the particles when they are ejected.

Sagittarius A*, on the other hand, was chosen mainly because it is at the center of our galaxy. The image of the latter should be broadcast in the near future by the EHT, but it is more difficult to obtain than that of M87* because of the "pollution" caused by the stars and the dust that separates it from us.

And then what?

Once the image of Sagittarius A* appears, the EHT plans to focus on improving its resolution. This will be done, in particular - and is already being done - by the arrival of new telescopes in the international network. Since the main purpose of this collaboration is to learn more about black holes, it can be expected that other "targets" will be observed in the future.

Sources

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- Singularities and Black Holes – Stanford Encyclopedia of Philosophy
- How Scientists Captured the First Image of a Black Hole – JPL, California Institute of Technology
- Astronomers Capture First Image of a Black Hole – Event Horizon Telescope