Black holes: from theory to the first image - Prof. Éric Gourgoulhon

Prof. Éric Gourgoulhon is a senior researcher at the Laboratory for the Universe and Theories (LUTH) at the Paris Observatory, part of the French National Centre for Scientific Research (CNRS). As a theoretician in the field of Astrophysics, his research interests include gravitational waves, neutron stars, and black holes.

Under this capacity, he came to EPFL last Wednesday 13th of November to talk about the path to obtaining the first image of a black hole. Black holes are physical objects that we know little about. They have increasingly become of interest in both the Astrophysics community and in popular culture due to the science fiction opportunity that this void of knowledge provides.

Historical Overview

How were black holes hypothesised?

Everything has a gravitational field, including stars, planets and other astronomical objects. By considering Newtonian mechanics, it is possible to compute the velocity that one would need to escape that astronomical object, a quantity that goes by the name of "escape velocity".

It is possible to imagine that there could exist a region in space that is very massive, and its escape velocity is larger than the speed of light. This would mean that light would not be able to escape this region, hence, it would be invisible for us. This observation was made by several scientists in the 18th century, including John Mitchell and Pierre-Simon Laplace. They postulated the existence of such an object from which light could not escape, defining for the first time the concept of a black hole.

However, their observations were brushed aside when Young's double slit experiment demonstrated light's wave-like behaviour, making the particle description of light obsolete. Since no one knew how waves behave in a gravitational field, to think about the possibility of black holes was not evident.

Black holes came back into the limelight when the wave-particle duality of light became accepted. In the 20th century, Einstein published his Theory of Special Relativity. In this theory, he postulated that nothing can travel faster than the speed of light. This incurred changes in the definition of a black hole, leading to what we generally comprehend as a black hole today: a region of space from which not just light, but nothing can escape.

Properties of black holes

Do black holes really eat up everything around them?

Despite the fact that nothing can escape from a black hole, they are not "space vacuums" i.e. they do not just eat up everything around them. There is a certain distance at which an object with sufficient velocity can orbit in a stable manner around the black hole. This is why there exists a "boundary", known as event horizon, which only if crossed will mean that the object has reached the point of no escape.

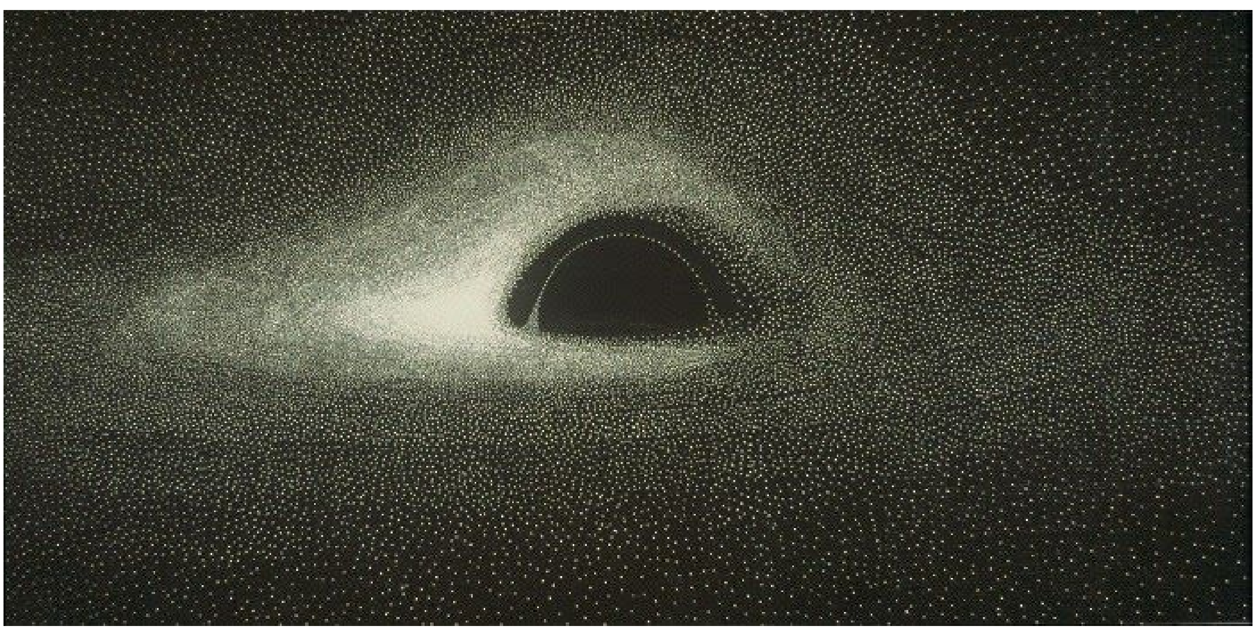
Another surprising property is that black holes are not necessarily very dense. Furthermore, only 2 numbers are needed to characterise a black hole: their mass, and their angular momentum. This means that black holes are extremely smooth objects. As opposed to what one might think , the mass of a black hole is not the amount of matter it contains (as we do not know what there actually is inside a black hole). It is rather a description of the external gravitational field that is felt by objects near the black hole. This is why this mass is measurable. The angular momentum of the black hole can also be measured by using the precession that a gyroscope would have if it were in orbit around the black hole.

Imaging black holes

Black holes have very interesting properties, as we have seen, but how exactly does one image a black hole, if they are invisible?

Consider a black hole in a binary system. This means that it is in orbit around a star which is also itself orbiting the black hole. The black hole will be accreting mass from the companion star, due to its massive gravitational field, i.e. it will be stripping the star of its mass. When this happens, the black hole is surrounded by this accumulated mass, forming something known as an accretion disk. This accretion disk is visible, so that is how one views the black hole, by looking at its "silhouette".

This is how the first theoretical computer image of a black hole was constructed in 1979 by Jean-Pierre Luminet. This first simulation demonstrated what a black hole with an accretion disk would look like.



The simulation of a black hole published in 1979 by Jean-Pierre Luminet.

With technological advances, computational power also increased, leading to progress in the black hole simulation field as well. The first film of a black hole was produced in 1991 by Jean-Alain Marck, and in 2007 Alain Riazuelo imaged an isolated black hole (without an accretion disk) on a starry background.

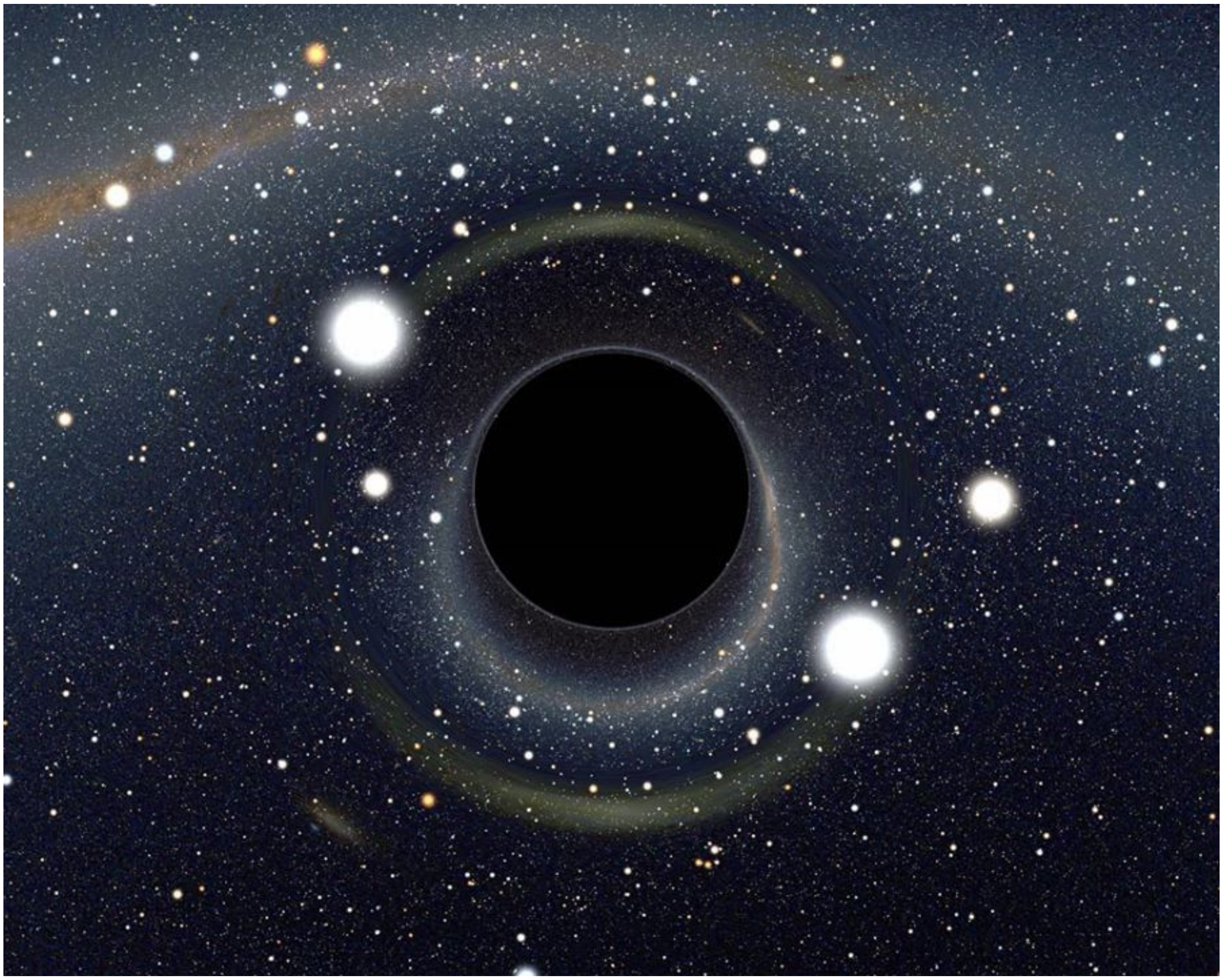
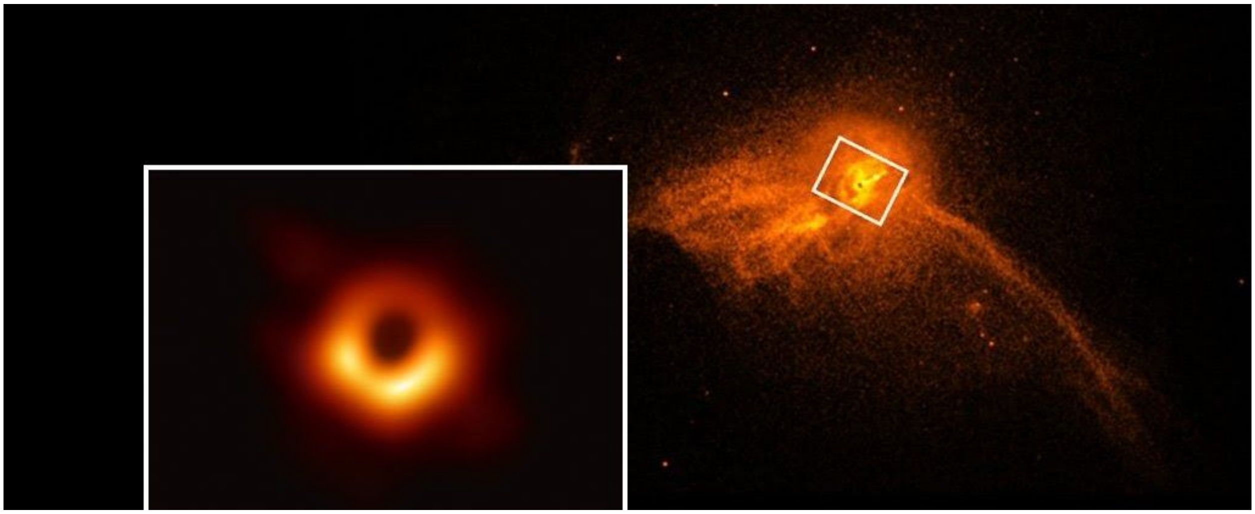


Image by Alain Riazuelo (CNRS), showing an isolated black hole on a starry backdrop.

However, all these are just theoretical simulations of black holes. What about the real deal?

The breakthrough for black hole imaging happened last April, when the Event Horizon Telescope (EHT) collaboration released the first real image of the "silhouette" of a black hole, M87, residing at the center of galaxy M87 in the*

Virgo cluster. It was taken by using a technique called Very Long Baseline Interferometry (VLBI), which consists of using various radio telescopes around the Earth and combining their data in order to observe distant objects.



First image of a black hole, taken by the Event Horizon Telescope.

The Event Horizon Telescope is a network of radio telescopes around the world, which combined have approximately the same angular resolution as a telescope the size of the Earth. This is why it is possible to resolve the supermassive black hole in the center of the M87 galaxy. However, the data obtained was not an image per se, it had to be reconstructed statistically into an image, and there was insufficient coverage to get a unique image from the data. Maybe in the future, as the Event Horizon Telescope continues to look at black holes and technology continues to improve, the images will be more accurate.

The next target for the EHT is the black hole at the center of our galaxy, Sgr A. It is known that there is a black hole there due to the observed orbits of stars around the galactic center, as measured by the GRAVITY instrument on ESO's Very Large Telescope (Chile). It would be the first time we would see what there is at the center of our galaxy if they image it successfully! Soon enough we will have sharper images of black holes, which will also be important for other applications in Physics, such as testing Einstein's Theory of General Relativity.*

This conference was part of the joint public astronomy conferences by EPFL-Unige (University of Geneva). These conferences take place on a yearly basis since 2005, when the agreement was signed by both universities. Prof. Gourgoulhon's talk marked the 14th iteration of these public conferences. We are looking forward to exploring another fascinating astronomical subject next year!

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