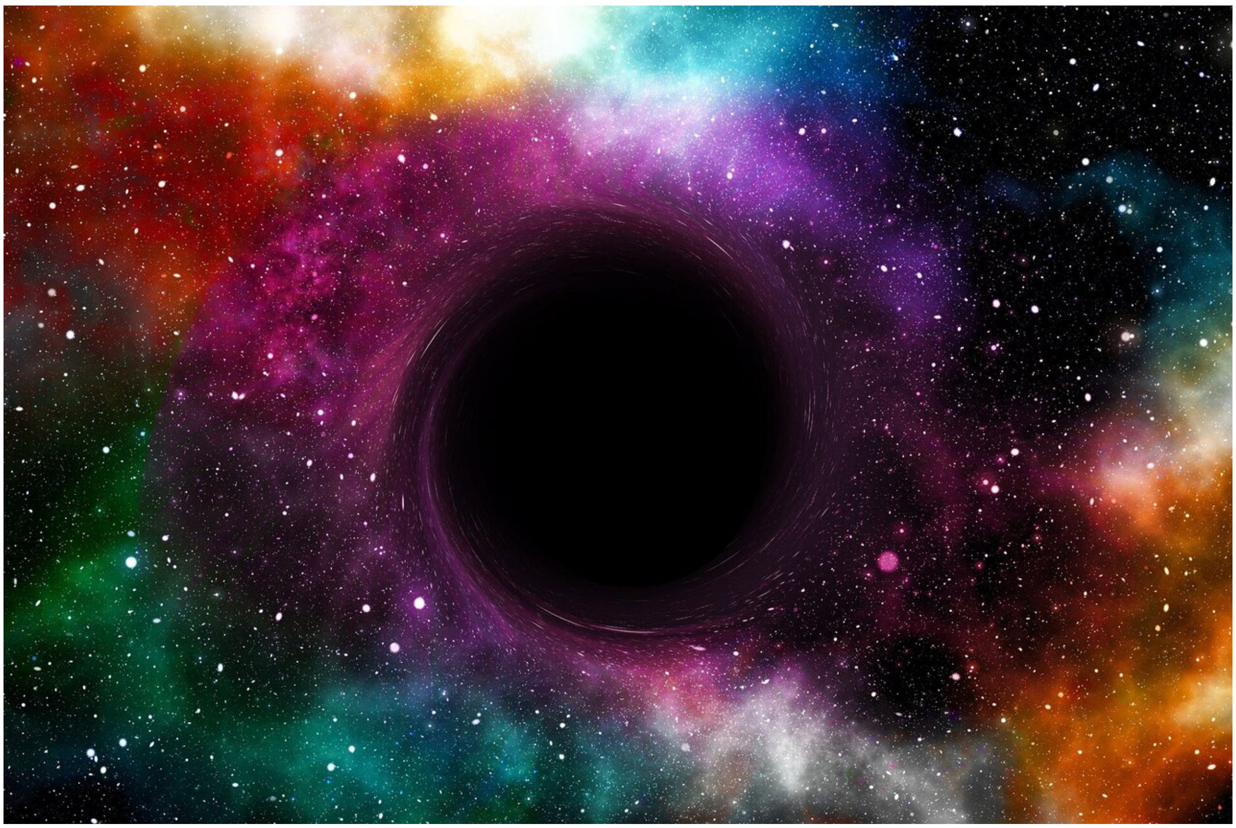
Black holes? They are like a hologram

June 4 2020



What researchers have done is apply the theory of the holographic principle to black holes. In this way, their mysterious thermodynamic properties have become more understandable: focusing on predicting that these bodies have a great entropy and observing them in terms of quantum mechanics, you can describe them just like a hologram: they have two dimensions, in which gravity disappears, but they reproduce an object in three dimensions. Credit: Gerd Altmann for PIxabay

According to new research by SISSA, ICTP and INFN, black holes could be like holograms, in which all the information to produce a three-dimensional image is encoded in a two-dimensional surface. As affirmed by quantum theories, black holes could be incredibly complex, and concentrate an enormous amount of information in two dimensions, like the largest hard disks that exist in nature. This idea aligns with Einstein's theory of relativity, which describes black holes as three dimensional, simple, spherical and smooth, as depicted in the first-ever image of a black hole that circulated in 2019. In short, black holes appear to be three dimensional, just like holograms. The study, which unites two discordant theories, has recently been published in *Physical Review X*.

The mystery of black holes

For scientists, black holes pose formidable theoretical challenges for many reasons. They are, for example, excellent representatives of the great difficulties of theoretical physics in uniting the principles of Einstein's general theory of relativity with those of the quantum physics of gravity. According to the relativity, black holes are simple bodies without information. According to quantum physics, as claimed by Jacob Bekenstein and Stephen Hawking, they are the most complex existing systems because they are characterized by enormous entropy, which measures the complexity of a system, and consequently contain a lot of information.

The holographic principle applied to black holes

To study black holes, the two authors of the new study, Francesco Benini (SISSA Professor, ICTP scientific consultant and INFN researcher) and Paolo Milan (SISSA and INFN researcher), used a 30-year-old idea called the holographic principle. The researchers write, "This revolutionary and somewhat counterintuitive principle proposes that the behavior of gravity in a given region of space can alternatively be described in terms of a different system, which lives only along the edge of that region and therefore in a one less dimension. And, more importantly, in this alternative description (called holographic), gravity does not appear explicitly. In other words, the holographic principle allows us to describe gravity using a language that does not contain gravity, thus avoiding friction with quantum mechanics."

What Benini and Milan have done is apply the theory of the holographic principle to black holes. In this way, their mysterious thermodynamic properties have become more understandable: Focusing on predicting that these bodies have a great entropy and observing them in terms of quantum mechanics, you can describe them just like a hologram—they have two dimensions, in which gravity disappears, but they reproduce an object in three dimensions.

From theory to observation

This study is only the first step toward a deeper understanding of these cosmic bodies and of the properties that characterize them when quantum mechanics crosses with general relativity. Everything is more important now at a time when observations in astrophysics are experiencing an incredible development. Just think of the observation of gravitational waves from the fusion of black holes, the result of the collaboration between LIGO and Virgo, or indeed, that of the black hole made by the Event Horizon Telescope that produced this extraordinary image. In the near future, we may be able to test our theoretical predictions regarding quantum gravity, such as those made in this study, by observation. And this, from a scientific point of view, would be something absolutely exceptional.

More information: Francesco Benini et al, Black Holes in 4-D N=4 Super-Yang-Mills Field Theory, *Physical Review X* (2020). DOI:

10.1103/PhysRevX.10.021037