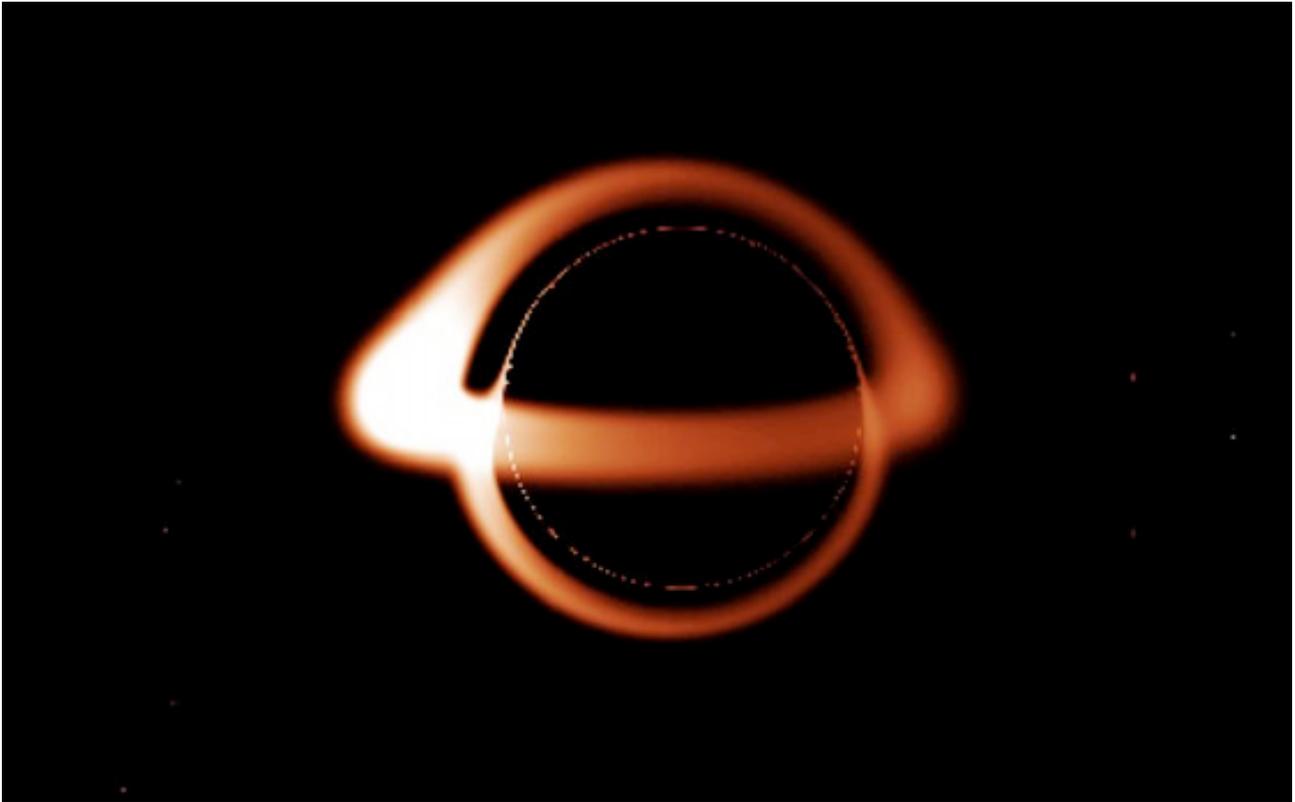




## A look beyond the horizon of events



### A proposed solution to calculating black hole thermodynamics

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Black holes are still very mysterious celestial bodies which, according to the majority of physicists, do not, however, escape the laws of thermodynamics. As a result, these physical systems possess an entropy though no real agreement has been reached about the microscopic origin of this propriety and how it should be calculated. A SISSA/Max Planck Institute (Potsdam) group has achieved important results in this calculation by applying a new formalism (Group Field Theory) of Loop Quantum Gravity (LQG), a very popular approach in the area of quantum gravity. The result is consistent with the famous Bekenstein/Hawking law, whereby the entropy of a black hole is proportional to a quarter of its surface area, while it avoids many of the assumptions and simplifications of previous LQG theory attempts. Additionally, it lends support to the holography hypothesis, whereby the black hole that appears three-dimensional can be mathematically reduced to a two-dimensional projection.

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In principle, nothing that enters a black hole can leave the black hole. This has considerably complicated the study of these mysterious bodies on which generations of physicists have debated ever since 1916, the year their existence was hypothesized as a direct consequence of Einstein's Theory of Relativity. There is, however, some consensus in the scientific community on the fact that black holes possess an entropy, because their existence would otherwise violate the second law of thermodynamics. In particular, Jacob Bekenstein and Stephen Hawking have suggested that the entropy – which we can basically consider a measure of the inner disorder of a physical system – of a black hole is proportional to its area and not to its volume, as would be more intuitive. This assumption also gives rise to the "holography" hypothesis of black holes, which (very roughly) suggests that what appears to be three-dimensional might in fact be an image projected onto a distant two-dimensional cosmic horizon just like a hologram which, despite being a two-dimensional image, appears to us as three-dimensional.

As we cannot see beyond the event horizon (the outer boundary of the black hole), the internal microstates that define its entropy are inaccessible: so how is it possible to calculate this measure? The theoretical approach adopted by Hawking and Bekenstein is semiclassical (a sort of hybrid between classical physics and quantum mechanics) and introduces the possibility (or necessity) of adopting a quantum gravity approach in these studies, in order to obtain a more fundamental comprehension of the physics of black holes.

Planck's length is the (tiny) dimension at which space-time stops being continuous as we see it, and takes on a discrete graininess made up of quanta, the "atoms" of space-time. The Universe at this dimension is described by quantum mechanics. Quantum gravity is the field of enquiry that investigates gravity in the framework of quantum mechanics: this force is a phenomenon that has been very well described within classical physics, but it is unclear how it behaves at the Planck scale.

Daniele Pranzetti and colleagues, in a new study published in Physical Review Letters, present an important result obtained by applying a second quantization formulation of Loop Quantum Gravity (LQG) formalism. LQG is a theoretical approach within the problem of quantum gravity, and Group Field Theory is the "language" through which the theory is applied in this work.

"The idea at the basis of our study is that homogenous classical geometries emerge from a condensate of quanta of space introduced in LQG in order to describe quantum geometries" explains Pranzetti. "This way, we obtained a description of black hole quantum states, suitable to describe also 'continuum' physics, that is, the physics of space-time as we know it".

### ***Condensates, quantum fluids and the universe as a hologram***

A "condensate" is a collection of 'atoms' - in this case space quanta – all of which share the same properties so that, even though there are huge numbers of them, we can nonetheless study their collective behavior simply, by referring to the microscopic properties of the individual particle. So now the analogy with classical thermodynamics seems clearer: just as fluids at our scale appear as continuous materials despite their consisting of a huge number of atoms, similarly, in quantum gravity, the fundamental constituent atoms of space form a sort of fluid, that is, continuous space-time. A continuous and homogenous geometry (like that of a spherically symmetric black hole) can, as Pranzetti and colleagues suggest, be described as a condensate, which facilitates the



underlying mathematical calculations, keeping in account an a priori infinite number of degrees of freedom .

“We were therefore able to use a more complete and richer model compared with what done in the past in LQG, and obtain a far more realistic and robust result”, continues Pranzetti. “This allowed us to resolve several ambiguities afflicting previous calculations due to the comparison of these simplified LQG models with the results of semiclassical analysis, as carried out by Hawking and Bekenstein”. Another important aspect of Pranzetti and colleagues’ study is that it proposes a concrete mechanism in support to the holographic hypothesis, whereby the three-dimensionality of black holes could be merely apparent: all their information could be contained on a two-dimensional surface, without having to investigate the structure of the inside (hence the link between entropy and surface area rather than volume).

The other two authors of the study are Daniele Oriti, of the Max Planck Institute for Gravitational Physics in Potsdam, Germany, and Lorenzo Sindoni, former SISSA research fellow, now also at the Max Planck Institute in Potsdam.

#### **USEFUL LINKS:**

- **Link to the original paper in Physical Review Letters:**  
<https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.116.211301>

#### **IMAGES:**

- **Predicted appearance of non-rotating black hole - Credits: Brandon Deffise Carter**  
(Wikimedia commons: <https://goo.gl/dWaCxS>)

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