Black Hole Are Finally In Vogue

By Avi Loeb on October 13, 2020

*W*ith black holes, what you see is not what you get. The ring of light visible around a black hole's silhouette originates from a radius of about $5GM/c^2$, where G is Newton's constant, M is the black hole mass and c is the speed of light. This ring is larger than the event horizon of a non-spinning black hole by a factor of 2.5 or up to 5 with the addition of a spin. And so, truth-in-advertising, the *Event Horizon Telescope* did not actually image the event horizon of the supermassive black hole M87 but rather traced light from much farther out.

For a distant observer the difference between the light ring and the horizon is academic, but for an astronaut en route into M87, the difference is existential. Entering the "ultimate prison" walls associated with the horizon implies a death sentence, with no opportunity for sharing the experience with the outside world. After less than a day, the astronaut's body will reach the singularity and be torn apart by the gravitational tidal force.

In 1939, Albert Einstein wrote a paper in *Annals of Mathematics* doubting that black holes exist in nature. Now, black holes are in vogue. So much so, that the 2020 Nobel prize in physics was awarded to the study of black holes. This gave me reason to celebrate as the founding director of Harvard's Black Hole Initiative, which brings together astronomers, physicists, mathematicians and philosophers, all dedicated to research on black holes.

Karl Schwarzschild would have been delighted to join our celebration. Unfortunately, he died on the German-Russian front during World War I over a century ago and just half a year after deriving the non-spinning black hole solution to Einstein's equations.

One of the recipients of the 2020 Nobel Prize in physics, Roger Penrose, demonstrated that black holes are a robust prediction of Einstein's general theory of relativity and in doing so invented a new mathematical tool to depict spacetimes, called Penrose diagrams. He also showed that it is possible to extract energy from a spinning black hole as if it was a flywheel, through the so-called Penrose Process. His cosmic censorship hypothesis protects our ability to forecast the future throughout the universe from the pathology of black hole singularities, where the spacetime curvature blows up and Einstein's theory breaks down. This conjecture asserts that all singularities are hidden behind an event horizon so that matter approaching them has no causal effect on what happens outside the horizon. Just as in Las Vegas, "whatever happens inside the horizon, stays inside the horizon".

The two other Nobel laureates in physics this year, Reinhard Genzel and Andrea Ghez, demonstrated that a black hole weighing four million Suns resides at the center of our own Milky Way galaxy. The discovery of quasars more than half a century ago implied that supermassive black holes form generically at the centers of galaxies. By monitoring the

motion of massive stars around the center of our own galaxy in real time, as if they were planets orbiting a star, they demonstrated the existence of a black hole there. Prior to their work, it was unclear whether a black hole is associated with the stationary radio source, Sagittarius A*. Not only that they measured the mass of the black hole but they also tested Einstein's theory of gravity. The stars they discovered move in two orbital planes. In a new paper with Giacomo Fragione, we showed that the black hole spin must therefore be small or else it would blur the strict orbital planes of the stars over their lifetime. The teams of Genzel and Ghez were engaged in intense competition, elevating their efforts to great heights. This was a wonderful demonstration of how rivalry promotes good science.

One of the stars traced by Genzel and Ghez, labeled S2, completes an orbit around the Galactic center every 16 years. The related advice I gave astronomy students is to focus their PhD project on a source like S2 that evolves over a timescale of a decade or two, so that they will continue to learn new things about the source throughout their careers.

If Stephen Hawking was alive, he would have been a worthy contender for this year's Nobel prize, since his work paralleled that of Penrose on classical general relativity, with the addition of the quantum mechanical aspect of black hole evaporation.

Black holes are simple and complex at the same time. They are described by mass, charge and spin, yet – as Jacob Bekenstein first recognized - they carry a huge entropy. It would be remarkable to have a field trip to the nearest black hole and study it up close. The journey would be practical over a human lifetime if there is one in the Solar system.

Even though black holes are the darkest objects when left on their own, they appear as the brightest sources of light when dressed up with matter, perfect symbols of Halloween. Outflows from supermassive black holes shape the evolution of entire galaxies. These beasts stop growing only because they become so energetic that they shove their food off their dining table. One gets a lot more out of black holes than expected based on their small size.

ABOUT THE AUTHOR

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(Credit: Nick Higgins)