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Black Holes: Why study them? What makes them so fascinating?

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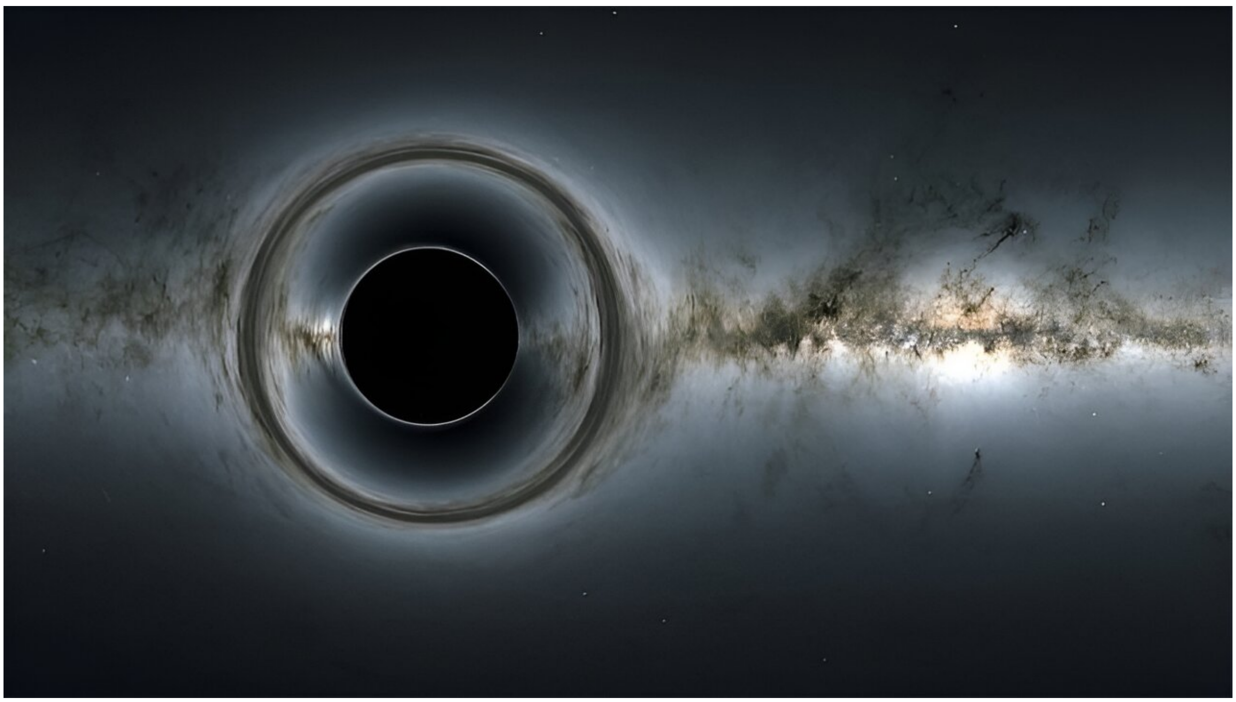

Simulation of a black hole. Credit: NASA/ESA/Gaia/DPAC

Over the last few months, Universe Today has explored a plethora of scientific fields, including impact craters, planetary surfaces, exoplanets, astrobiology, solar physics, comets, planetary atmospheres, planetary geophysics, cosmochemistry, meteorites, radio astronomy, extremophiles, and organic chemistry, and how these various disciplines help scientists and the public better understand our place in the cosmos.

Here, we will discuss the fascinating and mysterious field of black holes with Dr. Gaurav Khanna, who is a Professor in the Department of Physics at the University of Rhode Island, regarding the importance of studying black holes, the benefits and challenges, exciting aspects of studying black holes, and how upcoming students will pursue studying black holes.

So, what is the importance of studying black holes?

"Gravity is the oldest known, but the least understood force in nature," Dr. Khanna tells Universe Today. "For students of gravity, black holes are among the most interesting objects to study because gravity is the dominant force there—in fact, it is infinitely strong! Then there are astrophysical reasons of interest in black holes. They play important roles in galaxies, perhaps even in the large-scale behavior of the universe and more.

"The other thing to note about black holes is that they are very 'simple' especially when compared to stars and other astrophysical objects. This is a consequence of the so-called 'no hair' theorem that states that black holes can be fully characterized by only three attributes—their mass, charge and spin. That simplicity makes them particularly appealing to study and research."

Black holes are known for exhibiting gravity so strong that light can't even escape, and while Albert Einstein's theory of general relativity in 1915 is often credited with first proposing the concept of black holes, the concept of an object whose size and gravity would not allow light to escape was first proposed in a November 1784 letter by English philosopher and clergyman, John Mitchell.

In this letter, Mitchell referred to these objects as "dark stars" since he postulated that stars whose diameters exceeded 500 times that of our sun's diameter would trigger the formation of these objects. Additionally, he suggested that gravitational waves influencing nearby celestial bodies would enable these objects to be detected.

Fast forward to Einstein's theory of general relativity, which also predicted both the existence of black holes and gravitational waves, both of which continued to be scrutinized throughout the 20th century, which includes what's called the "golden age of general relativity" during the 1960s and 1970s. This includes the first object accepted by the scientific community as a black hole, called Cygnus X-1, which was discovered in 1964. However, it took another 52 years for the existence of gravitational waves to be confirmed through a black hole merger, which was accomplished by the LIGO Scientific Collaboration.

Therefore, given the extensive history combined with key discoveries only occurring within the last few years, what are some of the benefits and challenges of studying black holes?

Dr. Khanna tells Universe Today, "As I stated above, studying black holes, which are a consequence of Einstein's relativity theory, offers insight on the nature of gravity, space and time at the most fundamental levels. As physicists, we are yet to develop a complete understanding of the quantum nature of gravity, and black holes are the key to unlocking that mystery.

"On the challenges, I'd say that the clearest one perhaps is that black holes can only be observed indirectly. Unlike stars, since they don't emit radiation themselves, it is difficult for astronomers to collect data on them. At best, we can observe their influence on their environment (like gas, stars, etc.) and infer their properties and behavior.

"On the theoretical side, while it is indeed true that black holes are very 'simple' compared to stars, there are still challenges. The mathematics and physics that describe them is fairly advanced and even computer simulations involving them are challenging, requiring massive processing power and memory."

While it took over 100 years between Einstein introducing his theory of general relativity in 1915 and the confirmation of gravitational waves in 2016, it only took another three years for astronomers to publish the first direct image of a black hole at the center of the Messier 87 galaxy.

The results were published in *The Astrophysical Journal Letters* and based on observations taken in 2017 by the powerful Event Horizon Telescope (EHT). While Messier 87 is located approximately 53 million light-years from Earth, the closest hypothesized black hole, Gaia BH1, is located approximately 1,560 light-years from Earth. In 2022, astronomers published a direct image of Sagittarius A*, which is the supermassive black hole at the center of our Milky Way Galaxy.

Dr. Khanna tells Universe Today, "I suppose I'd probably refer to my recent work on how very rapidly rotating black holes attempt to 'grow hair' but ultimately fail. The project is interesting because it appears to suggest a violation of the 'no hair' theorem that I mentioned earlier, but it ultimately doesn't. So, it is provocative, but then relieving!

"More importantly, we are now using the main context of that research to develop a new observational 'signature' or test for rapidly rotating black holes, aka near-extremal black holes. Such black holes have several peculiar properties and aspects and are an area of active research."

Black holes are studied by astronomers, physicists, and astrophysicists, who use a combination of theory and observations to construct what black holes might look like, and in rare cases, as discussed, obtain direct images of them. Regarding theory, researchers use mathematical calculations and computer models to simulate what black holes might look like, and then have used powerful ground-based telescopes like EHT to obtain the few direct images of black holes.

It is important to note that these direct images don't capture the black hole itself, but the gases that are encircling the black hole's event horizon, or the unofficial boundary where light can't escape the black hole.

But what advice can Dr. Khanna offer upcoming students who wish to pursue studying black holes?

Dr. Khanna tells Universe Today, "I would offer them a lot of encouragement! There is a lot to do in this space and many mysteries to solve. New observations are going to open many new doors and brand-new avenues for research. This is among the best times to be a black hole astrophysicist!"

Dr. Khanna continues, "The one thing that I could say perhaps that isn't as much emphasized elsewhere is about computing as a tool to study black holes. Mostly there is heavy emphasis on learning advanced mathematics as the background for serious research in black holes—and for good reason—that continues to be critical for every student of Einstein's relativity theory which is the foundation for black hole physics.

"In recent years, computer simulations have advanced rapidly, and one can now make major discoveries about deep questions using computational tools. In the long run, computer programming would be a very promising tool for advancing research in this field and many others as well."

Provided by Universe Today