Singularities and Black Holes—in Other Universes

A spacetime singularity is a breakdown in spacetime. It's geometry is a topic of ongoing physical and philosophical research to amplifie both the nature and significance of such pathologies. When it is the fundamental geometry that breaks down, spacetime singularities are often viewed as an end, or "edge", of spacetime itself .

Black holes are regions of spacetime from which nothing , not even light, can escape. A typical black hole is the result of the gravitational force becoming so strong that one would have to travel faster than light to escape its pull. Such black holes generically contain a spacetime singularity at their center; thus we cannot fully understand a black hole without also understanding the nature of singularities

Black holes implies as dangerous destructive entities that never give up what falls into their grasp. But what if black holes are protective—shielding us from the unpredictable effects of places where our physical consciousness of the universe breaks down? This question might sound flippant, but in fact, it is at the heart of a decades-long physics puzzle known as "cosmic censorship," one that researchers may finally be close to answering.

Interior black holes, physics as we know it ends. Current theory of gravity, Einstein's general theory of relativity, predicts its own failure at points in spacetime called "singularities." According to the equations, at these points, gravitational fields behave unpredictably, often intensifying to impossibly, infinitely high levels where the equations themselves cannot describe what happens.

The foundational tenets of physics executes that the real , physical world continues to make sense inside black holes. They tend to interpret this disruption of the math to mean that some as yet unknown physics, which likely involves quantum mechanics, takes over near the singularities. But until they have found a theory that unifies gravity and quantum physics, exactly what happens at those points cannot be known.

Gratefully, with the singularities tucked inside the black holes, we do not have to worry about their potentially intangible effects on the external world. But what if these singularities could show up outside—on their own? The implications could be huge. Because we do not yet have a complete theory to describe what happens in singularities, we cannot trust the story that general relativity tells us. "Naked singularities cause general relativity to lose its predictive power," says Yen Chin Ong, a physicist at Yangzhou University in China, who has studied the nature of singularities in gravitational theories.

During the 1960s, British physicist Roger Penrose was in the midst of work on the mathematics of black holes and singularities that would later achieve him the 2020 Nobel Prize in Physics. At that time, no one had turned up any compelling evidence that the equations of general relativity could clarify these uncovered singularities in a physically sensible universe. They only ever materialized cloaked inside a black hole. Penrose pieced together clues that suggested a conjecture—an informed guess, not an airtight proof—that general relativity would never make that prediction. This conjecture is known as cosmic censorship: somehow the math must work out so that nature censors those "naked" singularities from existence.

In the first few decades after Penrose's initial work, theoretical studies corroborated the idea that cosmic censorship would hold. Then, in 2010, physicists Luis Lehner and Frans Pretorius used a computer simulation to show that the outer surface of black holes could break into pieces and leave behind naked singularities. The fracturing comes with a curious twist, though. It happens through a process, the so-called Gregory-Laflamme instability, that can only happen in universes with more than three dimensions of space. In other words, these sorts of singularity-revealing instabilities should be impossible in our universe's three dimensions as described by general relativity.

Though having dilation, the result still has meaning. With this one example as a starting point, researchers can look for similar processes and ask, "Does something like that happen in our mysterious universe?" If the answer is no, they can ask, "Why not?" Pau Figueras, a physicist at Queen Mary University of London, says that this direction does not equate to a full proof but that it is still initiative. "If this particular process is the only way to violate cosmic censorship," he says, "and astrophysical black holes do not suffer from it, then this offers a way to prove that [Penrose's] conjecture is true in astrophysical spacetimes."

The strong cosmic censorship conjecture, introduced by Penrose five decades ago, asserts that, in self-consistent theories of gravity, Cauchy horizons inside dynamically formed black holes should be unstable to remnant perturbation fields that fall into the newly born black holes.

According to Figueras, the field has gained momentum in the past decade, thanks largely to advances in computing that have made it possible to calculate how black holes evolve and, in some cases, fall apart to reveal singularities. "It's not only that the computers needed weren't available 20 years ago," he says. "We didn't understand how to simulate general relativity and hence black holes in computers." The result, he says, is that yes, naked singularities are more common than expected—in universes with extra dimensions.

A full proof or conclusive refutation of Penrose's cosmic censorship conjecture remains elusive. Whether or not the conjecture holds, though, the puzzle itself is no longer the

main point for most theorists, Ong says. “It is what we can learn along the way, what insights we can gain, what tools we can develop,” he adds. “The journey will be important, not just the destination.”