NATURE | NEWS

Quantum bounce could make black holes explode

If space-time is granular, it could reverse gravitational collapse and turn it into expansion.

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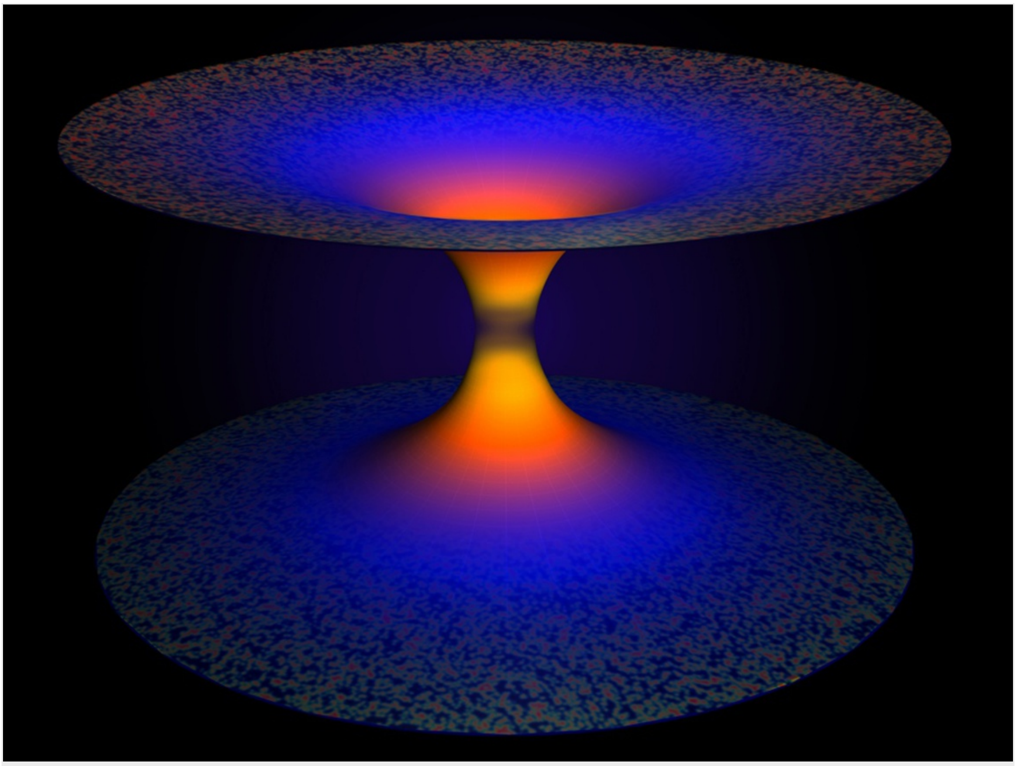

A. Corichi/J.P. Ruiz

The collapse of a star into a black hole could be a temporary effect that leads to the formation of a 'white hole', suggests a new model based on a theory known as loop quantum gravity.

Black holes might end their lives by transforming into their exact opposite — 'white holes' that explosively pour all the material they ever swallowed into space, say two physicists. The suggestion, based on a speculative quantum theory of gravity, could solve a long-standing conundrum about whether black holes destroy information.

The theory suggests that the transition from black hole to white hole would take place right after the initial formation of the black hole, but because gravity dilates time, outside observers would see the black hole lasting billions or trillions of years or more, depending on its size. If the authors are correct, tiny black holes that formed during the very early history of the Universe would now be ready to pop off like firecrackers and might be detected as high-energy cosmic rays or other radiation. In fact, they say, their work could imply that some of the dramatic flares commonly considered to be supernova explosions could in fact be the dying throes of tiny black holes that formed shortly after the Big Bang.

Albert Einstein’s general theory of relativity predicts that when a dying star collapses under its own weight, it can reach a stage at which the collapse is irreversible and no known force of nature can stop it. This is the formation of a black hole: a spherical surface, known as the event horizon, appears, shrouding the star inside from outside observers while it continues to collapse, because nothing — not even light or any other sort of information — can escape the event horizon.

Because dense matter curves space, ‘classical’ general relativity predicts that the star inside will continue to shrink into what is known as a singularity, a region where matter is infinitely dense and space is infinitely curved. In such situations, the known laws of physics cease to be useful.

Many physicists, however, believe that at some stage in this process, quantum-gravity effects should take over, arresting the collapse and avoiding the infinities.

In a loop
One of the leading approaches to merging quantum theory and gravity, pioneered by, among others, theoretical physicist Carlo Rovelli of Aix-Marseille University in France, posits that it is not just gravity but space-time itself that is quantized, woven from tiny, individual loops that cannot be subdivided any further. The loops in this 'loop quantum gravity' — a theoretical attempt that has yet to find experimental support — would be so tiny that to any observer space-time looks smooth and continuous. In the new work[1], Rovelli and his Aix-Marseille colleague Hal Haggard have calculated that the loop structure would halt the collapse of a black hole.

The collapsing star would reach a stage at which its inside can shrink no further, because the loops cannot be compressed into anything smaller, and in fact they would exert an outward pressure that theorists call a quantum bounce, transforming a black hole into a white hole. Rather than being shrouded by a true, eternal event horizon, the event would be concealed by a temporary 'apparent horizon', says Rovelli. (Theoretical physicist Stephen Hawking of the University of Cambridge, UK, has recently suggested that true event horizons would be incompatible with quantum physics.)

Other loop-quantum theorists have made similar calculations for cases in which it is not just a star that is collapsing but an entire universe[2, 3]. They found that the universe could bounce back, and suggested that our own Universe's Big Bang could in fact have been such a 'big bounce'. Rovelli and Haggard have now shown that the quantum bounce does not require an entire universe to collapse at once. "We think this is a possible picture," says Rovelli. "We have found that the [transformation] process can be completely contained in a limited region of space-time. Everything outside behaves following the classical Einstein equations."

Information paradox
If black holes turn into white holes and release all of their innards out again, it could provide a solution to one of the most troublesome questions of fundamental physics. Hawking calculated in the 1970s that a black hole should emit radiation out of its event horizon, slowly losing energy and shrinking in the process until it completely disappears. This 'Hawking radiation' means that information carried by the matter that fell into the black hole would then seem to vanish forever. This would violate one of the fundamental principles of quantum theory, according to which information cannot be destroyed.

If the new work sheds any light on this black-hole information paradox, "it would be important", says theoretical physicist Steven Giddings of the University of California, Santa Barbara. "Understanding how information escapes from a black hole is the key question for the quantum mechanics of black holes, and possibly for quantum gravity itself."

The authors acknowledge that some of the conclusions in their paper have yet to be fleshed out with detailed calculations. Other physicists, including Joseph Polchinski of the University of California, Santa Barbara, also worry that the scenario involves quantum effects that are unrealistically large.

Theoretical physicist Donald Marolf of the University of California, Santa Barbara, cautions that the quantum bounce could violate one of the most fundamental principles of physics: that entropy, a measure of the amount of disorder in a system, can increase but can never decrease. He says that the outgoing material from the white hole, initially packed into a small region, would seem to have a smaller entropy than the black hole itself. Rovelli and Haggard maintain that in their scenario entropy would not decrease.

Nonetheless, the work puts the idea of a quantum bounce on a surer footing, says Abhay Ashtekar of Pennsylvania State University in University Park, another one of the founders of loop quantum gravity. But he says that he would like to see more detailed calculations before he is convinced.

All in the timing
Rovelli notes that he and Haggard must calculate more carefully how much time it takes for the black hole to transform into a white hole. Their current, rough estimate — a few thousandths of a second — is crucial to pin down, because the intense gravitational field of a black hole stretches light waves and dilates time, so that an outside observer would see the transformation occur over a much longer time.

If the time, as seen by an outside observer, were too short, then all the black holes that ever formed ought to have exploded and vanished, contradicting astrophysical observations. On the other hand, if the observed time were too long, the transformation to white hole would be inconsequential because black holes would already have fizzled out owing to Hawking radiation. The team calculates that for a black hole the mass of the Sun, it would take about a thousand trillion times the current age of the Universe to convert into a white hole.

In a recent paper[4], Giddings proposes that information may escape black holes in a less explosive fashion, made possible by the grainy quantum structure of space-time. This would cause fluctuations in the geometry of the region just outside the black hole that could be detectable by the future Event Horizon Telescope, a global network of radio telescopes, when it studies the pattern of light surrounding Sagittarius A*, the supermassive black hole at the centre of our Galaxy.

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References

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