

What happens in black holes? Hawking's final paper released

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Stephen Hawking's last scientific paper has been released by physicists who worked with the late cosmologist on his career-long effort to understand what happens to information when objects fall into black holes. Co-author on the paper Malcolm Perry, a professor of theoretical physics at Cambridge, said it was "at the centre of Hawking's life" for more than 40 years. In the days before he died, 'he knew the final result', said Perry.



Exclusive
What happens

Stephen Hawking's final scientific paper has been released by physicists who worked with the late cosmologist on his career-long effort to understand what happens to information when objects fall into black holes.

The work, which tackles what theoretical physicists call "the information paradox", was completed in the days before Hawking's death in March. It has now been written up by his colleagues at Cambridge and Harvard universities and posted online.

Malcolm Perry, a professor of theoretical physics at Cambridge and a co-author on the paper entitled Black Hole Entropy and Soft Hair, said the information paradox was "at the centre of Hawking's life" for more than 40 years.

The origins of the puzzle can be traced back to Albert Einstein. In 1915, the physicist published his theory of general relativity, a tour-de-force that described how gravity arises from the space-time-bending effects of matter, and so why the planets circle the sun. But Einstein's theory made important predictions about black holes too, notably that a black hole can be completely defined by only three features: its mass, charge, and spin.

Nearly 60 years later, Hawking added to the picture. He argued that black holes also have a temperature. And because hot objects lose heat into space, the ultimate fate of a black hole is to evaporate out of existence. But this throws up a problem. The rules of the quantum world demand that information is never lost, come what may. So what happens to all the information contained in an object – the nature of a moon's atoms, for instance – when it tumbles into a black hole?

"The difficulty is that if you throw something into a black hole it looks like it disappears," said Perry. "How could the information in that object ever be recovered if the black hole then disappears itself?"

In the latest paper, Hawking and his colleagues show how some information at least may be preserved. Toss an object into a black hole and the black hole's temperature ought to change. So too will a property called entropy, a measure of an object's internal disorder, which rises the hotter it gets.

The physicists, including Sasha Hajnal-Corob at Cambridge and Andrew Strominger at Harvard, show that a black hole's entropy may be recorded by photons that surround the black hole's event horizon, the point at which light cannot escape the intense gravitational pull. They call this sheen of photons "soft hair".

"What this paper does is show that 'soft hair' can account for the entropy," said Perry.

"It's telling you that soft hair really is doing the right stuff."

It is not the end of the information paradox though. "We don't know that Hawking entropy accounts for everything you could possibly throw at a black hole, so this is really a step along the way," said Perry. "We think it's a pretty good step, but there is a lot more work to be done."

Days before Hawking died, Perry was at Harvard working on the paper with Strominger. He was not aware how ill Hawking was and called to give the physicist an update. It may have been the last scientific exchange Hawking had. "It was very difficult for Stephen to communicate and I was put on a loudspeaker to explain where we had got to. When I explained it, he simply produced an enormous smile. I told him we'd got somewhere. He knew the final result."

Among the unknowns that Perry and his colleagues must now explore are how information associated with entropy is physically stored in soft hair and how that information comes out of a black hole when it evaporates.

"If I throw something in, is all of the information about what it is stored on the black hole's horizon? That is what is required to solve the information paradox. If it's only half of it, or 99%, that is not enough, you have not solved the problem," said Perry.

"It's a step on the way, but it is definitely not the entire answer. We have slightly fewer puzzles than we had before, but there are definitely some perplexing issues left," he added. Marika Taylor, professor of theoretical physics at Southampton University, and a former student of Hawking's, said: "Understanding the microscopic origin of this entropy – what are the underlying quantum states that the entropy counts? – has been one of the great challenges of the last 40 years."

"This paper proposes a way to understand entropy for astrophysical black holes based on symmetries of the event horizon. The authors have to make several non-trivial assump-

tions so the next steps will be to show these assumptions are valid,” she added.

Juan Maldacena, a theoretical physicist at the Institute for Advanced Studies at Princeton, said: “Hawking found that black holes have a temperature. For ordinary objects we understand temperature as due to the motion of the microscopic constituents of the system. “In some physical systems that have special symmetries, the thermal properties can be calculated in terms of these symmetries. This paper shows that near the black hole horizon we have one of these special symmetries.”