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Is there life inside black holes? Physicist **Paul Wesson** explores a startling discovery

WE ALL know what happens if you fall into a black hole. It's not pretty – you get ripped limb from limb before vanishing down the plughole.

However, there is a way for you to live inside a black hole: find one that has five dimensions. Life inside a 5D black hole is known to be rather more sustainable than it is in the 4D version. In the 4D case, you would experience "tidal" forces that vary so vastly over short distances that your body would be pulled apart. But in the 5D case, there is no physical plughole, and the tidal forces are negligible, so you could happily explore without fear of dismemberment. And, according to the results of my research, you may be doing that right now. A mathematical analysis says that our universe may well be a 5D black hole (*General Relativity and Gravitation)*, vol 37, p 1339).

To a cosmologist this is not as weird as you might think. That's because it arises from the very common consideration that our universe has more than the four dimensions we are familiar with (three of space, one of time).

A fifth dimension is not a mere flight of fancy. People have been looking at adding an extra dimension to Einstein's general theory of relativity since the 1920s, when Theodor Kaluza and Oskar Klein suggested relativity, which deals with the nature of space-time, could be united with electromagnetism by using a fifth dimension. Einstein, for one, thought this a good idea, and there are several reasons for modern physicists to agree (see "The power of five", page 34).

> "Appreciating that the universe is a 5D black hole is a mind-bendingly hard thing to do"

The 5D version of relativity even passes experimental tests, fitting all the evidence that has verified the 4D theory. 4D relativity's predictions have been tested in a number of astronomical experiments that measure phenomena such as gravitational lensing – in which the gravitational pull of massive objects such as a galaxy bends starlight on its journey to Earth. In 1995, Dimitri Kalligas and his colleagues at Stanford University in California showed that the modern, 5D version of relativity is in agreement with these observations (*Astrophysical Journal*, vol 439, p 548). That's not really so surprising to theorists, who know the older 4D theory works very well within the new 5D theory; the new theory gives no reason to expect a 5D universe to look drastically different to a 4D one.

In fact, such a universe seems to be more natural than its 4D counterpart. Consider, for example, theories of how our universe began. People have long sought alternatives to the classic big bang, which involves a singularity (otherwise known as a breakdown in the laws of physics) as you roll the clock back towards time zero. One solution to this problem involves creating a "big bounce": there are solutions to the equations of general relativity where the bang is in fact the result of a collapsing universe that bounces back just before reaching the singularity stage. However, this idea works better in 5D than 4D.

The reason for this has to do with ▶

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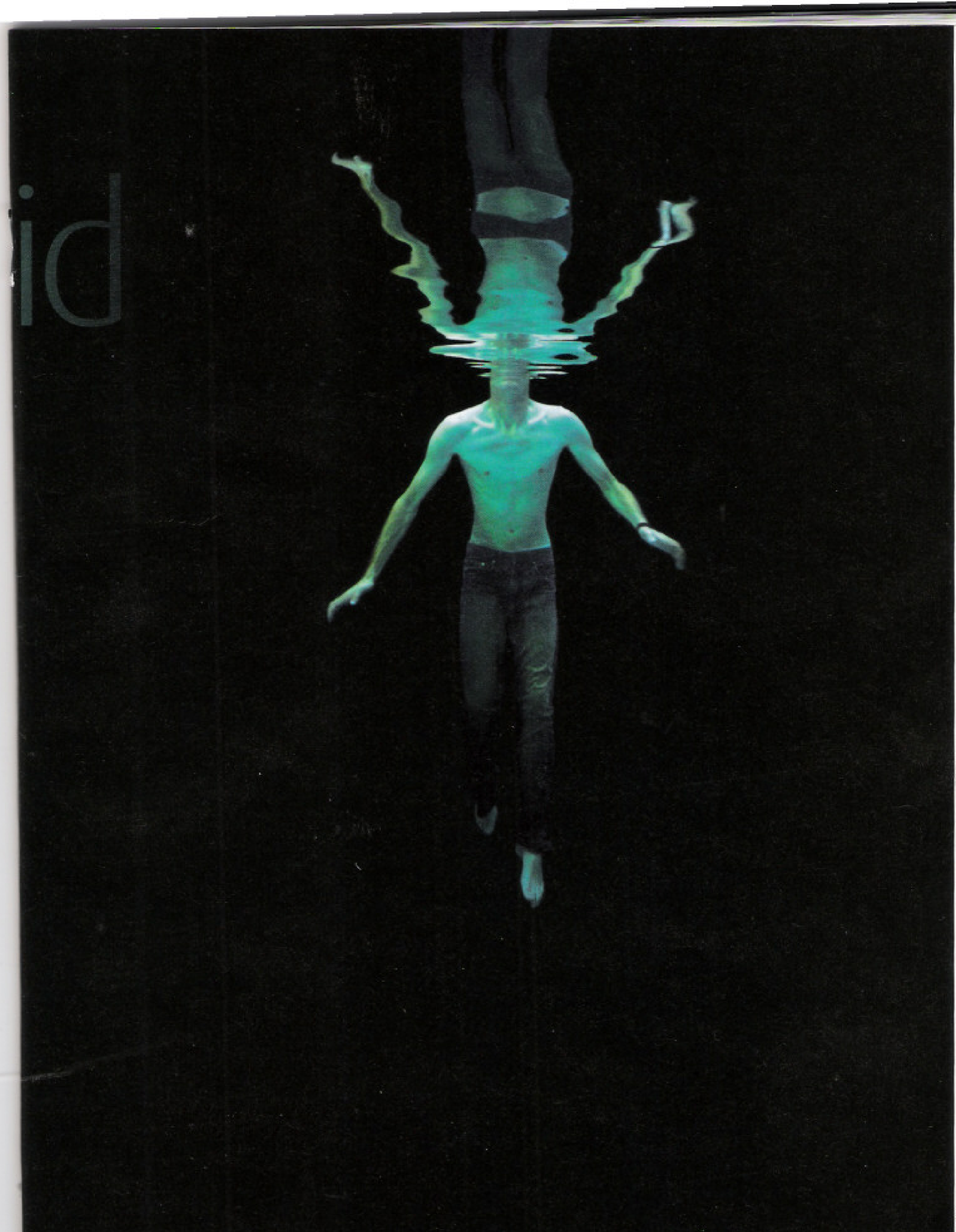


matter. In 4D cosmological models the existence of matter is simply assumed, with no possibility of analysing where it came from. In the 5D model, however, the bounce appears to be associated with the creation of particles. I showed this in work with Hongya Liu, a colleague at Waterloo, where we also studied other aspects of the model, and how they fit with observations (*The Astrophysical Journal*, vol 562, p 1). My University of Waterloo colleague Tomas Liko showed last year that this creation of matter is consistent with what physicists call a phase change (*International Journal of Modern Physics*, vol A20, p 2037). Just as bubbles form in a pot of boiling water on your stove, so particles of matter formed from energy in the cauldron of the big bounce.

The physical attributes of the 5D bouncing universe are certainly intriguing. But its mathematical properties – especially its "invariants" – seem to be even more worthy of attention: this is where we see how we might be living in a black hole.

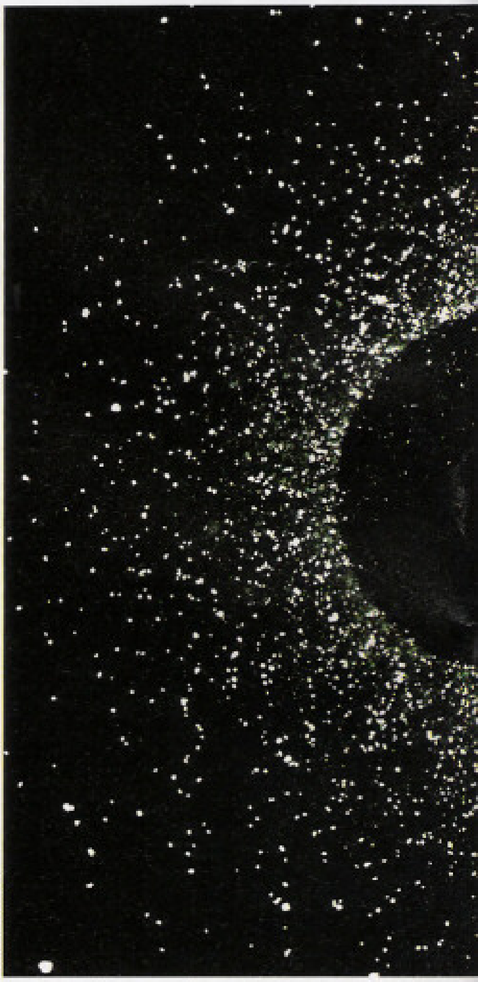
Invariants are an important facet of general relativity theory. Even though the appearance of things, such as length or time may change, in relativity you can calculate certain geometrical characteristics that are immutable. As an illustration, think of your mass. Your body can take on different configurations – you might be sitting down, or standing up, or doubled up with laughter – but your mass does not change: it is an invariant. The invariants of relativity theory are more complicated than this, but share the same property of being essentially the same no matter how we change the appearance and shape of things.

An invariant much used by theoretical cosmologists is one known as the Kretschmann scalar. In loose language, this measures the averaged out value of the gravitational field at some point in space, basically by summing all of the gravitational influences from elsewhere. Given any solution of the gravitational field equations formulated by Einstein, we can summarise its content by writing down the Kretschmann scalar. It is rather like having a rough mathematical fingerprint for each model of the universe.

The mathematics of the 5D big-bounce model is typified by a particular value of the Kretschmann scalar: $72C^2/A^8$. Here C measures the gravitational curvature of the model in five dimensions, while A measures the rate of change of the distances between particles as space expands due to the the bounce.

The significance of this number became apparent last year when I was working with a PhD student called Sanjeev Seahra, again at the University of Waterloo. We were looking at the geometry of black holes, and how we might understand their nature in theories that incorporate extra dimensions. To a theorist, 5D black holes are considerably more complicated than their 4D counterparts, thanks to the fifth dimension that runs at right angles to space-time. As a result, the laws governing the black hole's properties contain many more variables.

"It is rather like having a rough mathematical fingerprint for each model of the universe"



The power of five

One of the most important challenges facing physics is to unify general relativity, Einstein's description of space and time, with quantum mechanics, which describes the physics of matter. And physicists generally think that they need more than four dimensions to accomplish this.

The problem is that general relativity only deals with the force we call gravity. There are three other known forces: the strong force responsible for nuclear interactions; the weak force responsible for radioactivity; and the electromagnetic force. We believe that all these forces emerged from a single force in the extremely high energy conditions of the very early universe.

Our best ideas about these forces also suggest that they involve dimensions other than the ones we generally interact with. So to get to the root of where these forces come from, we need to develop multidimensional theories that not only explain them but, at high energies, join up with gravity to give a unified theory.

Of course, that's easier said than done. Adding extra dimensions to general relativity leads to a rapid proliferation in the number of viable theories – hence we have 10D supersymmetry, 11D supergravity and 26D string theory, and so on. Which one lies in the right direction? For now, the sensible way out is to look at general relativity using only the most basic extension of Einstein's 4D theory – to five dimensions.

Sticking to just five dimensions keeps our venture within the realms of experimental science. Within the four dimensions we perceive we live at low energies and without travelling anywhere near the speed of light. If there are more than four dimensions, in general it is highly unlikely that we will ever be able to have experiences (that is, do experiments) that get much beyond the fifth dimension. Getting to grips with the true nature of the forces affecting particles requires huge, high-energy particle accelerators, and for the next hundred years or more, even our most powerful machines are unlikely to access phenomena at energies higher than those involved in the fifth dimension. So, for our scientific (rather than philosophical) purposes, five dimensions are really enough to be going on with.

All the same, it is worth getting to grips with them. Black holes are in many respects the basic "object" in Einstein's theory, and we certainly need to understand 5D black holes before we can have much faith in the algebra governing any of the higher dimensional universes that interest many physicists. And hard though it is, it is possible to calculate the Kretschmann scalar of a 5D black hole – I know because we published it last year (*General Relativity and Gravitation*, vol 37, p 1339). In similar nomenclature to that used above, the result is $72C^2/R^8$. Here the 5D curvature C depends on the black hole mass, and R is a radius measure.

You do not have to be Einstein to see that the result for a 5D black hole agrees with that for the big-bounce universe, provided we swap the radius in the black-hole solution for the distance measure in the cosmological solution. The question is, is the coincidence of these numbers due to chance or to some deep physics?

At this stage it is worth pointing out that the Kretschmann scalar of a 4D black hole of mass M as measured at radius r from the singularity at its centre is – in suitable units – $48M^2/r^6$. That is, for a 4D black hole the numbers come out different. It is conceivable that a bouncing universe and a 5D black hole could have identical Kretschmann scalars by coincidence alone, but given the number of parameters involved, it is very unlikely. Much more likely is that there is some kind of similarity between the two objects.

Seahra and I fully understood that it would take a lot more work to make the argument convincing. After all, the Kretschmann scalar only measures the averaged-out, coarse-grained gravitational properties of a model. To prove true correspondence, you need to show explicitly how the fine-grained properties of one model match those of the other model. So we set about it.

This requires what in technical terms is called a coordinate transformation. In 5D, this consists of five equations that between them cover time, the three directions of ordinary space and the extra dimension, mapping each from one model to the other. After a lot of pencil-and-paper algebra, we found the necessary equations, and then checked the results by computer. We have now shown that, from a mathematical viewpoint, the universe may actually be a 5D black hole.

Intriguingly, we are already fairly sure our universe contains 4D black holes – most astronomers agree that there is one at the centre of the Milky Way, for example. And as long ago as 1972, it was noted that there are similarities between the universe and a 4D black hole (see "Trick of the light"). What we have now is the proof that, by going to 5D, the correspondence is mathematically exact.

To appreciate that the universe is a 5D black hole is mind-bendingly hard. But our studies of gravity and the interaction of particles are constantly leading us to models with more than 4 dimensions. We are led to consider the idea of a set of "Russian doll universes", with each world embedded in another world of higher dimensions. There is as yet no way to know what we will discover when we probe these higher-dimensional universes. But even our stalwart 5D model has brought new physics and a new view of the cosmos. Next time you stare up at the night sky, stop and consider the fact that you may actually be surveying the star-speckled interior of a five-dimensional black hole. ●

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"The question is, is the coincidence of these numbers due to chance, or to some deep physics?"

Trick of the light

If you happen to be standing near the event horizon of a black hole, and have a flashlight, try this experiment. Switch on the light. You should see the beam circumnavigate the black hole and come right back to you, held in a circle by the intense gravitational field. Now move far away from the black hole, and shoot the light beam off into the universe. What happens?

In Einstein's theory of general relativity, space and time are welded together to form space-time, and the curvature of space-time corresponds to the strength of the gravitational field. This in turn depends on the amount of matter present, as well as the strengths of other fields. If the universe has a positive 3D curvature (like a ball) – a situation allowed by certain solutions of Einstein's equations – the flashlight beam will travel on a curved trajectory, pulled by the large amount of matter present. The beam may even circle the universe more than once.

Raj Pathria of the University of Waterloo first noted a correspondence between the behaviour of light beams near 4D black holes and in universes with positive 3D curvature in 1972 (*Nature*, vol 240, p 298). And, he pointed out, a 4D black hole and a 4D universe both have singularities – in space and time, respectively. While astronomers now believe that there is not enough matter in the universe to make its 3D (ordinary space) part curve positively, Pathria's work on the parallels between black holes and universes still seems curiously prescient: perhaps all he really lacked was an extra dimension.