

Trapped surfaces solved the riddle

Whether black holes could form under realistic conditions was a question that puzzled Roger Penrose. The answer, as he later recalled, appeared in the autumn of 1964 during a walk with a colleague in London, where Penrose was professor of mathematics at Birkbeck College. When they stopped talking for a moment to cross a side street, an idea flashed into his mind. Later that afternoon, he searched for it in his memory. This idea, which he called trapped surfaces, was the key he had unconsciously been searching for, a crucial mathematical tool needed to describe a black hole.

A trapped surface forces all rays to point towards a centre, regardless of whether the surface curves outwards or inwards. Using trapped surfaces, Penrose was able to prove that a black hole always hides a singularity, a boundary where time and space end. Its density is infinite and, as yet, there is no theory for how to approach this strangest phenomenon in physics.

Trapped surfaces became a central concept in the completion of Penrose's proof of the singularity theorem. The topological methods he introduced are now invaluable in the study of our curved universe.

A one-way street to the end of time

Once matter begins to collapse and a trapped surface forms, nothing can stop the collapse from continuing. There is no way back, as in the story told by physicist and Nobel Laureate Subrahmanyan Chandrasekhar, from his childhood in India. The story is about dragonflies and their larva, which live underwater. When a larva is ready to unfold its wings, it promises it will tell its friends what life is like on the other side of the water's surface. But once the larva passes through the surface and flies away as a dragonfly, there is no return. The larvae in the water will never hear the story of life on the other side.

Similarly, all matter can only cross a black hole's event horizon in one direction. Time then replaces space and all possible paths point inwards, the flow of time carrying everything towards an inescapable end at the singularity (figure 2). You will not feel anything if you fall through the event horizon of a supermassive black hole. From the outside, no one can see you falling in and your journey towards the horizon continues forever. Peering into a black hole is not possible within the laws of physics; black holes hide all their secrets behind their event horizons.

Black holes govern the paths of stars

Even though we cannot see the black hole, it is possible to establish its properties by observing how its colossal gravity directs the motions of the surrounding stars.

Reinhard Genzel and Andrea Ghez each lead separate research groups that explore the centre of our galaxy, the Milky Way. Shaped like a flat disc about 100,000 light years across, it consists of gas and dust and a few hundred billion stars; one of these stars is our Sun (figure 3). From our vantage point on Earth, enormous clouds of interstellar gas and dust obscure most of the visible light coming from the centre of the galaxy. Infrared telescopes and radio technology were what first allowed astronomers to see through the galaxy's disc and image the stars at the centre.

Using the orbits of the stars as guides, Genzel and Ghez have produced the most convincing evidence yet that there is an invisible supermassive object hiding there. A black hole is the only possible explanation.