Into a Black Hole

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Can you hear me.

It is a great pleasure for me to be back again in Chile, to celebrate the sixtieth birthday of an old friend, and esteemed colleague, Claudio Bunster, whom I have known for almost forty years. Claudio has done so much for science in general, and for science in Chile in particular. Being in the city of Valdivia where CECs, the center he created, is located, is quite meaningful to me.

It is said that fact is sometimes stranger than fiction, and nowhere is this more true than in the case of black holes. Black holes are stranger than anything dreamt up by science fiction writers, but they are firmly matters of science ~fact. Not that science fiction was slow to climb on the band-wagon after black holes were discovered.. I remember going to the premier of a Walt Dizny film, The Black Hole, in the 1970s. It was about a spaceship, that was sent to investigate a black hole that had been discovered. It wasn't a very good film, but it had an interesting ending. After orbiting the black hole, one of the scientists decides, the only way to find out what is going on, is to go inside.So he gets into a space probe, and dives into the black hole. After a screen writer's depiction of Hell, he emerges into a new universe. This is an early example of the science fiction use of a black hole as a wormhole, a passage from one universe to another, or back to another location in the same universe. Such wormholes, if they existed, would provide short cuts for Interstellar space travel, which otherwise would be pretty slow and tedious, if one had to keep to the Einstein speed limit, and stay below the speed of light.

In fact, science fiction writers should not have been taken so much by surprise.The idea behind black holes, has been around in the scientific community for more than 200 years. In 1783,a Cambridge don, John Michell, wrote a paper in the Philosophical Transactions of the Royal Society of London,about what he called dark stars. He pointed out that a star that was sufficiently massive and compact, would have such a strong gravitational field that light could not escape. Any light emitted from the surface of the star, would be dragged back by the star's gravitational attraction, before it could get very far. Michell suggested that there might be a large number of stars like this. Although we would not be able to see

them, because the light from them would not reach us, we would still feel their gravitational attraction. Such objects are what we now call black holes, because that is what they are, black voids in space. A similar suggestion was made a few years later, by the French scientist the Marquis de La~plass, apparently independently of Michell.
Interestingly enough, La~plass included it in only the first and second editions of his book, The System of the World, and left it out of later editions. Perhaps he decided that it was a crazy idea.

Both Michell and La~plass thought of light as consisting of particles, rather like cannon balls, that could be slowed down by gravity, and made to fall back on the star. But a famous experiment, carried out by two Americans, Michelson and Morley in 1887, showed that light always traveled at a speed of one hundred and eighty six thousand miles a second, no matter where it came from. How then could gravity slow down light, and make it fall back. This was impossible, according to the then accepted ideas of space and time. But in 1915, Einstein put forward his revolutionary General Theory of Relativity. In this, space and time were no longer separate and independent entities. Instead, they were just different directions in a single object called spacetime. This spacetime was not flat, but was warped and curved by the matter and energy in it. In order to understand this, considered a sheet of rubber, with a weight placed on it, to represent a star. The weight will form a depression in the rubber, and will cause the sheet near the star to be curved, rather than flat. If one now rolls marbles on the rubber sheet, their
paths will be curved, rather than being straight lines. In 1919, a British expedition to West Africa, looked at light from distant stars, that passed near the Sun during an eclipse. They found that the images of the stars, were shifted slightly from their normal positions. This indicated that the paths of the light from the stars, had been bent by the curved spacetime near the Sun. General Relativity was confirmed.

Consider now placing heavier and heavier, and more and more concentrated weights on the rubber sheet. They will depress the sheet more and more. Eventually, at a critical weight and size, they will make a bottomless hole in the sheet, that particles can fall into, but nothing can get out of.

What happens in spacetime according to General Relativity, is rather similar. A star will curve and distort the spacetime near it, more and more, the more massive and more compact the star is. If a massive star that has burnt up its nuclear fuel, cools and shrinks below a critical size, it will quite literally make a bottomless hole in spacetime, that light can't get out of. Such objects were given the name, black holes, by the American physicist, John Wheeler, who was one of the first to recognize their importance, and the problems they pose. The name caught on quickly.It suggested something dark and mysterious, But the French, being French, saw a more riskay meaning. For years, they resisted the name, troo noir, claiming it was obscene. But that was a bit like trying to stand against ~le week end, and other franglay. In the end, they had to give in.Who can resist a name that is such a winner.

From the outside, you can't tell what is inside a black hole. You can throw television sets, diamond rings, or even your worst enemies into a black hole, and all the black hole will remember, is the total mass, and the state of rotation. John Wheeler called this, A Black Hole Has No Hair. To the French, this just confirmed their suspicions.

A black hole has a boundary, called the event horizon. It is where gravity is just strong enough to drag light back, and prevent it escaping. Because nothing can travel faster than light, everything else will get dragged back also. Falling through the event horizon, is a bit like going over Niagra Falls in a canoe. If you are above the falls, you can get away if you paddle fast enough, but once you are over the edge, you are lost.There's no way back.
As you get nearer the falls, the current gets faster. This means it pulls harder on the front of the canoe, than the back. there's a danger that the canoe will be pulled apart. It is the same with black holes. If you fall towards a black hole feet first, gravity will pull harder on your feet than your head, because they are nearer the black hole. The result is, you will be stretched out longwise, and squashed in sideways.. If the black hole has a mass of a few times our sun, you would be torn apart, and made into spaghetti, before you reached the horizon. However, if you fell into a much larger black hole, with a mass of a million times the sun, you would reach the horizon without difficulty. So, if you want to explore the inside of a black hole, choose a big one. There is a black hole of about a million solar masses, at the center of our Milky way galaxy.

Although you wouldn't notice anything particular as you fell into a black hole, someone watching you from a distance, would never see you cross the event horizon. Instead, you would appear to slow down, and hover just outside. You would get dimmer and dimmer, and redder and redder, until you were effectively lost from sight. As far as the outside world is concerned, you would be lost for ever. Because black holes have no hair, in Wheeler's phrase, one can't tell from the outside what is inside a black hole, apart from its mass and rotation. This means that a black hole contains a lot of information that is hidden from the outside world.But there's a limit to the amount of information, one can pack into a region of space. Information requires energy, and energy has mass, by Einstein's famous equation, E = m c squared. So if there's too much information in a region of space, it will collapse into a black hole, and the size of the black hole will reflect the amount of information. It is like piling more and more books into a library. Eventually, the shelves will give way, and the library will collapse into a black hole.

If the amount of hidden information inside a black hole, depends on the size of the hole, one would expect from general principles, that the black hole would have a temperature, and would glow like a piece of hot metal. But that was impossible, because as everyone knew, nothing could get out of a black hole. Or so it was thought, but I discovered that particles can leak out of a black hole. The reason is, that on a very small scale, things are a bit fuzzy. This is summed up in the uncertainty relation, discovered by Werner Heisenberg in 1923, which says that the more precisely you know the position of a particle, the less precisely you can know its speed, and vice versa. This means that if a particle is in a small black hole, you know its position fairly accurately. Its speed therefore will be rather uncertain, and can be more than the peed of light, which would allow the particle to escape from the black hole. The larger the black hole, the less accurately the position of a particle in it is defined, so the more precisely the speed is defined, and the less chance there is that it will be more than the speed of light,. A black hole of the mass of the sun, would leak particles at such a slow rate, it would be impossible to detect. However, there could be much smaller mini black holes. These might have formed in the very early universe, if it had been chaotic and irregular. A black hole of the mass of a mountain, would give off x-rays and gamma rays, at a rate of about ten million Megawatts, enough to power the world's electricity supply. It wouldn't be easy however, to harnass a mini black hole. You couldn't keep it in a power station, because it would drop through the floor, and end up at the center of the Earth. About the only way, would be to have the black hole in orbit around the Earth.

People have searched for mini black holes of this mass, but have so far, not found any. This is a pity, because if they had, I would have got a Nobel prize. Another possibility however, is that we might be able to create micro black holes in the extra dimensions of space time. According to some theories, the universe we experience, is just a four dimensional surface, in a ten or eleven dimensional space. We wouldn't see these extra dimensions, because light wouldn't propagate through them, but only through the four dimensions of our universe. Gravity, however, would affect the extra dimensions, and would be much stronger than in our universe. This would make it much easier to form a little black hole in the extra dimensions. It might be possible to observe this at the LHC, the Large Hadron Collider, at Cern, in Switzerland. This consists of a circular tunnel, 27 kilometers long.Two beams of particles travel round this tunnel in opposite directions, and are made to collide. Some of the collisions might create micro black holes. These would radiate particles in a pattern that would be easy to recognize. So, I might get a Nobel prize, after all.

As particles escape from a black hole the hole will lose mass, and shrink.This will increase the rate of emission of particles. Eventually, the black hole will lose all its mass, and disappear. What then happens to all the particles and unlucky astronauts, that fell into the black hole. They can't just re-emerge when the black hole disappears. The particles that come out of a black hole, seem to be completely random, and to bear no relation to what fell in. It appears that the information about what fell in, is lost, apart from the total amount of mass, and the amount of rotation. But if information is lost, this raises a serious problem that strikes at the heart of our understanding of science. For more than 200 years, we have believed in Scientific determinism, that is, that the laws of science, determine the evolution of the universe. This was formulated by La~plass as, If we know the state of the universe at one time, the laws of science will determine it at all future and past times. Napoleon is said to have asked La~plass how God fitted into this picture. La~plass replied, Sire, I have not needed that hypothesis. I don't think that La~plass was claiming that God didn't exist. It is just that He doesn't intervene, to break the laws of Science. That must be the position of every scientist. A scientific law, is not a scientific law, if it only holds when some supernatural being, decides to let things run, and not intervene.

In La~plass's determinism, one needed to know the positions and speeds of all particles at one time in order to predict the future. But according to the uncertainty relation, the more accurately you know the positions, the less accurately you can know the speeds, and vice versa. In other words, you can't know ~both the positions, ~and the speeds, accurately. How then can you predict the future accurately? The answer is, that although one can't predict the positions and speeds separately, one ~can predict what is called, the quantum state. This is something from which both positions and speeds can be calculated, to a certain degree of accuracy. We would still expect the universe to be deterministic, in the sense that if we knew the quantum state of the universe at one time, the laws of science should enable us predict it at any other time.

If information were lost in black holes, we wouldn't be able to predict the future, because a black hole could emit any collection of particles. It could emit a working television set, or a leather bound volume of the complete works of Shakespeare, though the chance of such exotic emissions is very low. It is much more likely to be thermal Radiation, like the glow from red hot metal. It might seem that it wouldn't matter very much if we couldn't predict what comes out of black holes.There aren't any black holes near us. But it is a matter of principle. If determinism breaks down with black holes, it could break down in other situations. There could be virtual black holes that appear as fluctuations out of the vacuum, absorb one set of particles, emit another, and disappear into the vacuum again. Even worse, if determinism breaks down, we can't be sure of our past history either.The history books and our memories could just be illusions. It is the past that tells us who we are. Without it, we lose our identity.

It was therefore very important to determine whether information really was lost in black holes, or whether in principle, it could be recovered. Many people felt that information should not be lost, but no one could suggest a mechanism by which it could be preserved. The arguments went on for years. Finally, I found what I think is the answer. It depends on the idea of Richard Feinman, that there isn't a single history, but many different possible histories, each with their own probability. In this case, there are two kinds of history. In one, there is a black hole, into which particles can fall, but in the other kind, there is no black hole. The point is, that from the outside, one can't be certain whether there is a black hole, or not. So there is always a chance that there isn't a black hole. This possibility is enough to preserve the information, but the information is not returned in a very useful form. It is like burning an encyclopedia.. Information is not lost if you keep all the smoke and ashes, but it is difficult to read. Kip Thorne and I had a bet with John Preskill, that information would be lost in black holes. When I discovered how information could be preserved, I conceded the bet.I gave John Preskill an encyclopedia. Maybe I should have just given him the ashes.

What does this tell us about whether it is possible to fall in a black hole, and come out in another universe. The existence of alternative histories with black holes, suggests this might be possible. The hole would need to be large, and if it was rotating, it might have a passage to another universe.But you couldn't come back to our universe. So, although I'm keen on space flight, I'm not going to try that.

The message of this lecture, is, that black holes ain't as black as they are painted. They are not the eternal prisons they were once thought. Things ~can get out of a black hole, both to the outside, and possibly, to another universe. So, if you feel you are in a black hole, don't give up. There's a way out.

I would like to thank the organizers of this meeting again, for inviting me, to this beautiful country, which I discovered about ten years ago.My stay in Chile is not over, and I look forward to the coming days.,

Thank you for listening.
