Mysterious and Exotic Dead Star: Black Hole

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ABSTRACT According to the classical theory, known to most people, a Black Hole is a region of space-time from which gravity prevents anything to escape- including light. The theory of General Relativity predicts that a sufficiently compact mass will deform space-time to form a black hole. Around the black hole, there is a mathematically well defined surface or boundary called the Event Horizon that marks the point of no return. According to Quantum Theory, some particles may leak out of it through Quantum Tunneling behavior. Thus, the Black Hole may lose mass and eventually, they may completely evaporate!

***Key words*:** Black Holes, Evaporating Black Holes, Accretion Disks, Event Horizon, Hawking Radiation, Firewall, Dark Stars.

It is said that sometimes the fact is stranger than fiction, and this can't be truer, 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 i.e. a fact.

The idea behind "black holes" has been around in the scientific community for more than 200 years. The name "Dark Stars" was introduced by John Mitchell (see [1, 2] for references.), in 1783, in a paper in the Philosophical Transactions of the Royal Society, London. He explained that if a star was sufficiently massive and compact, it would have such a strong gravitational field that even 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. Mitchell also 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 never reach us, we would still feel their gravitational attraction. Such objects are what we now call black holes. A few years later, a similar suggestion was made by the French mathematician Laplace. Both Mitchell and Laplace 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 surface. But according to the then accepted notion, light was a wave phenomena. How then could gravity slow down light (a wave), and make it fall back??? This was impossible, according to the then accepted ideas of light and space-time [1].

But the beginning of the twentieth century brought with it the revolutionary ideas of the wave-particle duality; Einstein's General Theory of Relativity, the Heisenberg's Uncertainty Principle and the Quantum Physics. Thus, now according to the theory of general relativity, space and time were no longer separate and independent entities. Instead, they were just different aspects of a single entity called space-time. This space-time, according to the general relativity, was not flat, but was warped and curved by the matter and energy in it. In order to understand this, consider 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 space-time near the Sun. General Relativity was confirmed [3,4].

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 space-time according to General Relativity is rather similar. A star will curve and distort the space-time 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 space-time, that light can't get out of. Such objects were given the name, black holes, by the American physicist, John Wheeler. The name caught on quickly as it suggested something dark and mysterious.
From the outside, you can't tell what is inside a black hole. You can throw old furniture, a brand new BMW, or even the worst politicians into a black hole, and all the black hole will remember, is the total mass, and the state of rotation.

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 the Niagara Falls in a boat. 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 forever. 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 boat, than the back. There's a danger that the boat will be ripped 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 lengthwise, and squashed in sideways…

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, because light from you would never get out of the black hole to reach the observer's eyes. 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 forever. Because, apart from its mass and rotation you can't say what's inside a black hole. This means that a black hole contains a lot of information that is hidden from the outside world.

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, $E = m c^2$.

So, if there is too much of 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 on one shelf in the library. The mass of books goes on increasing but the shelf can hold only a particular amount onto it. Eventually, the shelf will break down, collapsing onto the ground. Similar is the case with black holes, more and more mass is added to it and eventually it collapses onto itself.

Nothing can ever escape the gravitational pull of a Black Hole. Once anything goes inside a Black Hole, it is lost forever… or so it was thought… but this is not the entire truth. Particles do leak out of a Black Hole…

It was found that particles may leak out of a black hole. The reason is that on a very small scale, things are a bit fuzzy. At the quantum level, there is always a finite uncertainty in the way the things behave. There are tons of interactions happening all around a Black Hole every moment. There might be huge masses getting sucked into the black hole. These masses wouldn't just fall into it so simply. Instead, they will rotate around the black hole and form an accretion disk. This is not very simple to understand, but to get an idea of how this happens, imagine trying to get onto a moving merry go round. Would you simply jump onto it? If you do, you will fall off instantly, so instead you move around trying to match the angular speed of the merry go round and once you are at the exact same speed, you can jump onto it without the fear of falling off. Something similar happens around a black hole. It is in a state of continuous rotation. So if a particle is falling in, it has to rotate with an equivalent angular speed. The rotation of the black hole is somewhere between several rotations per second to several thousand rotations per second!!! So the in falling matter has to get highly accelerated to match with such rotation. In doing so, it gets heated up to several tens of thousands of Kelvin temperature, creating a sort of firewall all around the black hole.

According to quantum mechanics, there is no absolute nothingness. Even in space, in the vacuum state, there are tiny pairs of particles and anti particles popping in and out of existence continuously. But they disappear the moment they appear. So to bring them into existence, a huge amount of energy must be provided to space.

Imagine the space around the black hole. The gargantuan energy of the black hole is enough to pull this particle- anti particle pair into existence, just near the surface or the event horizon of the black hole. This pair may annihilate the moment it is formed. Or they may be pulled into the black hole due to the gravitational pull. In either case, the energy used up will be restored. But the momenta of the particles will be in mutually opposite directions. So there is a possibility that one of them falls into the black hole while the other escapes the gravitational pull. Thus in a way, we can say that only half of the energy used up to form the pair was returned. The other half was gone. And thus the black hole has lost some energy. (The radiation leading to this energy loss is called Hawking Radiation [5] (which is yet to be confirmed), after the theoretical physicist Stephen Hawking, who first introduced this theory.) And according to Albert Einstein, energy has an equivalent mass associated with it. Thus the black hole has lost some mass. This process occurs on the entire surface of the black hole. So each moment the black hole is losing some mass. Thus a black hole would eventually evaporate entirely!!!

After a very rigorous mathematical treatment, scientists have come to a conclusion that this rate of loss of mass of a black hole depends upon its size [5]. The larger the black hole, the slower it will evaporate and a smaller black hole will lose mass at a faster rate. 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 as massive as a cruise ship would disappear in a bright flash in less than a second.

Scientists have searched for mini black holes of this mass, but have not found any, so far. So they are trying to widen their search by creating other possibilities. There is a chance that we might be able to create micro black holes in the extra dimensions of space time. According to the string theory, the universe we experience, is just a three dimensional surface, in a higher dimensional space. We wouldn't see these extra dimensions, because light wouldn't propagate through them. Gravity, however, would affect the extra dimensions. 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 [6], the Large Hadron Collider, at CERN, in Switzerland. (Remember the newspaper and Television News Channel Headlines…Breaking News: The LHC might produce Black Holes which would destroy the Earth… these were not completely false but these mini black holes would leak out particles at such a fast rate, that they would evaporate within some 10^{-27} seconds… so it would be pretty harmless.) This LHC 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 we could try to recognize.

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!!!

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Sometimes life isn't about what you want to do, but what you ought to do.

~ Chetan Bhagat