The Black Hole Paradox (Review Paper)
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Abstract:
It is said that nothing escapes from a black hole: anything that crosses the boundary called event horizon gets trapped because of the enormous gravitational pull exhibited by it. Even light is not fast enough to escape a black hole. Black holes are named so from the fact that even light can’t escape from it thus making its appearance like a black hole in the space. Even though black holes can’t be observed, the astronomers can study the effects of black holes in their surroundings. Existence of black holes has been theorized for more than 200 years. Investigation about black holes has been made possible greatly by the ESO telescopes and astronomical community. The previous century has witnessed major breakthroughs about the black holes. However, the most recent and intriguing theory about these has been given by Stephen Hawking and Jacob Bekenstein in 1974. According to them, black holes should slowly radiate away energy, which poses a problem from the no-hair theorem. One would expect the Hawking radiation to be completely independent of the material entering the black hole. Hawking pointed out that the out flowing particles—now known as Hawking radiation—would have completely different properties. As a result of which once the black hole was gone, the information carried by anything that had previously fallen into the hole would be forever lost from the universe. But this result clashes against the laws of physics that says that information like mass-energy is conserved, and thus creating the Black Hole Paradox.

Keywords: Chandrasekhar limit, Ads/CFT correspondence, baby universe, Hawking radiation.

I. INTRODUCTION AND LITERATURE REVIEW:
The existence of black holes has been theorized for more than 200 years. Investigation about them has greatly been made possible by ESO telescopes and the astronomical community. The past century has witnessed several major breakthroughs about these black holes, however the most recent and intriguing theory about these has been given by Stephen Hawking and Jacob Bekenstein in 1974. According to them, black holes slowly radiate away energy, which poses a problem. This is called Hawking radiation. According to the no-hair theorem, one would expect this Hawking radiation to be completely independent of matter that had ever entered into the black hole. As pointed out by the renowned Stephen Hawking, these outflowing particles from a black hole (Hawking Radiation) would have completely random properties. As a result of which, once any black hole is gone, the information carried by anything that had fallen into the black hole would be forever lost from the universe. But, this result clashes against the laws of physics that says information like mass-energy is conserved, and thus creating a paradox called the Black Hole Paradox. This review paper deals with this paradox.

II. CONTENT:
Now in order to actually delve deeper and know about the no-hair theorem and the Black Hole Paradox, let us extend our discussion a bit more to the phenomenon of formation of black holes. This idea dates back to a time when there were two theories about light: the particle theory (forwarded by Newton) and the wave theory (forwarded by Huygens). Now we know that both are correct and are interconnected by the wave particle duality of quantum mechanics. Under the light of wave theory, light must not respond to gravity, but if made of particles, travelling with a finite speed (as discovered by Roemer), light is bound to get affected by gravity. On this assumption, John Mitchell from Cambridge wrote a paper in 1783 stating that a star sufficiently massive and compact would exert such a strong gravitational field that any light emitted from the surface of that star would not be able to escape into space and would be dragged back by the enormous gravitational pull before it could get very far. Although we would not be able to visually see them, as the light from them would not reach us, still we would be able to feel their gravitational attraction. Such objects are called black holes. As black holes are assumed to originate from huge stars, first we need an understanding about the life cycle of a star. A star is formed when a large amount of gas (mostly hydrogen) starts to collapse on itself and the molecules collide with each other more and more frequently and with more and more speeds owing to gravity. Eventually the star will become so hot, that these hydrogen atoms coalesce to form helium atoms, a reaction called nuclear fusion. The immense heat radiations released in the process is what makes the star shine. This being like a controlled hydrogen bomb explosion, the extra heat released due to the process increases the pressure of the gas until and unless it becomes enough to balance the force of gravitational attraction, and it is only then that the gas stops contracting. Eventually after millions and billions of years the star will run out of its hydrogen and other fuel reserves. Now, what happens after that was only understood at the end of 1920s. In 1928, Subrahmanyan Chandrasekhar, proposed that when the star becomes small, the particles get very near to each other, and so according to Pauli’s exclusion principle they must have very different velocities. This makes them move apart from each other and so tends to make the star expand. A star thus maintains itself at constant radius by balance between gravity and repulsion arising from the exclusion principle, also called the electron degeneracy pressure, just as earlier in its life was balanced by the
pressure due to heat. However, eventually Subrahmanyan Chandrasekhar realized that when the star will become sufficiently dense, the attraction due to gravity will then surpass the repulsion that this exclusion principle can provide, and eventually such a giant star could collapse to a singular point mass (which was thought to be simply impossible by many scientists of that era). He calculated that a cold star of more than about one and a half times the mass of the Sun (this mass is called the Chandrasekhar limit) would not be able to support itself against its own gravity. If a star’s mass is less than the Chandrasekhar limit (now it is approximately accepted as 1.4 times the mass of the sun), it can settle down as a ‘white dwarf’ or a ‘neutron star’. Stars with masses above the Chandrasekhar limit, on the other hand, have a big problem when they come to the end of their fuel reserve.

American scientist, Openheimer, in 1939 suggested that the gravitational field of the star changes the path of light rays in space-time from what they would have been, had the star not been present. Because of the immense gravitational force exerted by these collapsing stars, even light is forced to bend and this phenomenon can be precisely observed during an eclipse of the sun, when light from distant stars are found to deviate from their probable path of travel. As the star contracts, the gravitational field at the surface gets stronger and the light cones get bent more inwards. Eventually when the star shrinks to a certain critical radius, the gravitational field at the surface becomes strong enough such that even light cones are forced to bend inwards so much that the light can no longer escape the enormous gravity and travel beyond the event horizon of the star. Thus if light cannot escape, nothing else can, since no particle having real mass can travel beyond the speed of light. Hence everything in the vicinity of the shrunk star is dragged into it. So there is a set of events, a region of space-time from which nothing escapes to reach a distant observer, which is called by the scientists as a Black Hole. Its boundary, called the event horizon coincides with the path of light rays unable to escape from the black hole. During the gravitational collapse of a star to form a black hole, the movements would be very rapid. Hence it won’t be very long before all the energy is carried away by gravitational waves and the star would settle down to a stable state. One might suppose that this final stationary stage would depend on all the complex features of the original star – like its mass, rotation, densities at various parts and the complicated movements of various gases within the star. And if black holes were as varied as the objects that would collapse to form them, then it might be very difficult to make any predictions about black holes in general. However, in 1967, Canadian scientist Werner Israel revolutionized the study of black holes, showing that according to the general theory of relativity, non-rotating black holes must be very simple; perfectly spherical, size depending only on their mass and any two such black holes with the same mass are identical. Later researchers gave the view that any non-rotating star, however complicated its shape and internal structure, would always end up after a gravitational collapse as a perfectly spherical black hole, whose size would depend only on its mass. Further calculations supported this view, and soon it came to be adopted generally. In 1963, Roy Kerr, a New Zealander, found a set of solutions of equations of general relativity, that described the rotating black holes. These ‘Kerr’ black holes rotate at a constant rate, their shape and size depending only on their mass and rate of rotation. Later researches by various scientists proved this Kerr solutions to be accurate. The size and shape of a black hole would depend only on its mass and rate of rotation and not on the nature of the body or bodies that had collapsed to form it. This result became known by the maxim: ‘A black hole has no hair.’ The no-hair theorem states that black holes can exhibit only three properties- mass, angular momentum and electric charge. It is of great practical importance, because it greatly restricts the possible types of black holes. It also means that a very large amount of information about the original body that had collapsed to form the black hole and everything else that had fallen into it must be lost when a black hole is formed, because afterwards all we can possibly measure about the body is its mass and rate of rotation. This violates the principle of conservation of mass and rate of rotation. This creates a paradox, called the black hole paradox. Thus we can see that the black hole paradox is result of combination of quantum mechanics and general relativity. Calculations show that information is lost in a black hole. This is controversial because it violates a core precept of modern physics- that in principle the value of a system at one point in time should determine its value at any other time. A fundamental postulate of Copenhagen interpretation of quantum mechanics states that complete information about a system is encoded in its wave function up to when the wave function collapses. Since the evolution of a wave function is determined by a unitary operator, it implies that information is conserved in quantum sense. The two main principles, Quantum determinism, and Reversibility states that information must always be preserved. Stephen Hawking and Jacob Bekenstein put forward theoretical arguments based on the principles of quantum mechanics and general relativity. Hawking’s calculations showed that black hole radiation does not preserve information. Hawking was convinced with the black hole thermodynamics and the no-hair theorem that quantum information can be destroyed. But holographic principles shows that Hawking’s conclusion was incorrect. Hawking made a bet in 2004, where he agreed to the fact that black hole evaporation does in fact preserve information.

III. RESULTS AND DISCUSSION:

Various ideas have been brought up since 1997 to solve this paradox. After the proposal of the AdS/CFT correspondence, the physicists predominantly believe that information is preserved and Hawking radiation is not precisely thermal but receives quantum corrections. Other possibilities include the information being contained in a Planckian remnant or a modification of the laws of quantum mechanics, allowing non-unitary time evolution. Stephen Hawking, in 2004, published a theory paper stating that quantum perturbations of the event horizon could allow information to escape from a black hole, which would resolve the black hole paradox. All
the postulated solutions have its own drawbacks. But only one of them does not seem to violate any of the basic principles. It states that the information is not lost in a black hole but it is stored in a baby universe. This baby universe is completely separated from our universe. This concept can be supported by the Einstein-Cartan theory of gravity. This theory extends the general relativity of matter to spin momentum. But as stated earlier all the solutions postulated till date has certain drawbacks, the drawback with this solution is that, Einstein-Cartan theory is too difficult to be tested.

IV. CONCLUSION:

Further researches can be done on baby universe and on the composition of black hole radiation. And these researches might be able to solve The Black Hole Paradox. Andrew Strominger, a physicist at Harvard University in Cambridge rightly said, “The Black Hole Paradox was responsible for more sleepless nights among theoretical physicists than any other paper in history.”

V. REFERENCES:

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