The Black Hole Singularity

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*re*Evolution*ary* Physics

- Severing Space-Time
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- A Mathematical Point
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Mentor: David Finkelstein

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"A singularity represents the ultimate unknowable in science."- Paul Davies

This paper will explore some of the ideas concerning the exciting phenomena occurring at the center of a black hole, namely the singularity. With the hope of simplifying in my own mind and better construction of my thoughts, I will attempt to outline the behavior predicted by general relativity at the black hole's heart, and the actual occurrence due to, the not yet fully actualized, quantum gravity explanation.

No one knows for sure what happens at the center of a black hole. But, I would like to touch on a few of the ideas that have been suggested for such a fascinating object of imagination and speculation. The severing of space-time certainly might raise eyebrows from a few skeptic scientists. But the reality is, our equations, namely the theory of general relativity, predict the existence of a singularity at the center of a black hole. As Kip Thorne states: "It was a horrendous shock to most physicists, and still is to many, to discover that singularities are an inevitable consequence of Einstein's general relativistic laws."[1] The definition that I choose to describe a singularity, I will steal from Thorne's Black Holes and Time Warps:

singularity: A region of space-time where space-time curvature becomes so strong that the general relativistic laws break down and laws of quantum gravity take over.[2]

Ultimately, what is beyond the singularity be it a white hole and another new universe, remains a field of study that I choose to leave out of this short paper, not due to the lack of interest on my part, but on the pure speculation and lack of observed evidence. The predicted behavior near and around the peculiar point of truth, named the singularity, is much more likely to turn out correct, than the behavior beyond the singularity. Much more is known and can be explained in our current theories of gravity about the behavior near and before space-time reaches a singularity. This is due to the hard work of many scientists, too many, in fact, to mention here.

Singularities are predicted to exist inside black holes. From my understanding, the most popular type of singularity that exists is thought to be a mathematical point, inside a black hole, where an infinite density occurs, that is, where so much mass becomes concentrated in infinitesimally small point of volume: zero volume, in fact. This singularity is, alone predicted by Einstein's general relativistic laws.[3] Not only does volume become zero at a singularity, but time comes to a stop as well. Stephen Hawking states that the singularity would be an end to time for anything that falls into the black hole through the event horizon.[4]

Some messy fog surrounds the word singularity, which needs to be cleared. There exists this older idea of a 'singularity', in which the word was used to describe a black hole itself. The "Schwarzschild singularity" as it was called, was the name used to describe the black hole's critical circumference[5] and existed before the term 'black hole' was in popular usage.

[1]Kip Thorne. Black Holes and Time Warps. (W.W. Norton and Company, 1994), 524.
[2]Ibid, 557.
[3]Ibid, 451.
[4]Stephen Hawking. Black Holes and Baby Universes and Other Essays. (Bantam Books, 1994), 18.
[5]Kip Thorne. Black Holes and Time Warps. (W.W. Norton and Company, 1994), 244.

The discovery that 'Schwarzschild singularities" or black holes must exist was much harder coming than the idea of a singularity existing inside the black hole. Infinities are typically not good to find in one's equations describing nature. And many scientists felt opposed to embracing the idea of a black hole or 'singularity', as exemplified in this quote by John A. Wheeler, in his book Geons, Black Holes, and Quantum Foam: "But if I was going to fight against the idea of a true singularity [he means black hole], I had to understand the 'enemy'.[6] But as Wheeler was eventually convinced with the help of two graduate students and the previous work of David Finkelstein and Charlie Misner,[7] that black holes will truly trap all light, the idea of a singularity existing at the center of a black hole was eventually made convincing by the work of Roger Penrose and his singularity theorem.

The claim against singularities went somewhat like this: singularities lose the fight due to the hair of the black hole, that is, the small perturbations, deformities and characteristics of the impending, imploding star. With this argument in hand, two Russian physicists, Khalatnikov and Lifshitz claimed that the small random, perturbations will grow large when the imploding matter attempts to form a singularity.[8] This is where topology and Roger Penrose's singularity theorem saves the day for our friend, the singularity. Using this mathematical tool, topology, new to the research done by physicists, Penrose proved that singularities are inevitable. Thus the work of Roger Penrose and his creation of a singularity theorem, verified that indeed, if a black hole has an 'apparent horizon' then there exists a singularity inside the black hole.[9]

This raised fascinating questions about the ending of space-time, reality beyond space-time and the big-bang singularity. On an interesting Discovery Channel program, Professor Sandra Faber stated, "Some people believe you might pop out of a singularity in another part of the universe."[10] The speculation of the reality at the singularity has led to many new ideas and imaginative conclusions. Particularly, the ideas of quantum foam and the laws of quantum gravity controlling the fabric of space-time are at the center of the mystery of singularities. The support from John Wheeler is strong for the existence of a quantum foam, or 'fluctuations where there would be no left and right, no before and after'.[11] In the book, The Five Ages of the Universe, Adams and Laughlin explain how laws are needed for a better understanding of what happens at a singularity:

"For the enormous densities near the putative singularity inside a black hole, quantum mechanical effects must play a role. In spite of this necessity, however, we do not have a complete and self-consistent description of physical laws that simultaneously include both gravity and quantum mechanics.".[12]

Whether quantum foam or another exotic phenomena occurs, these ideas governing what happens when quantum gravity rules the effects, are purely theoretical, and are also not very

[6] John Wheeler. Geons, Black Holes and Quantum Foam. (W.W. Norton and Company, 1998), 229.
[7] Ibid, 295
[8] Kip Thorne. Black Holes and Time Warps. (W.W. Norton and Company, 1994), 457.
[9] Ibid, 463.
[10] "Super Massive Black Holes". Discovery Channel.
[11] John Wheeler. Geons, Black Holes and Quantum Foam. (W.W. Norton and Company, 1998), 248.
[12] Fred Adams and Greg Laughlin. The Five Ages of the Universe (Touchstone 1999), 137.

certain. The development of quantum gravity and the comprehension of what it tells us about singularities must be further explored before certainty can be expressed. Thorne explains this uncertainty: "... we might be on completely the wrong track in believing that singularities are made of quantum foam."[13] Only with a better theory of quantum gravity or quantum relativity, can we know for sure what happens at the singularity of a black hole.

Another intriguing consequence of singularity research is the idea of the existence of a 'naked' singularity. Emerging from the desire to probe and experiment with the singularity, an idea was forged that perhaps it is possible for a singularity to exist without a black hole surrounding it. Therefore, being naked, it has no horizon, and quite literally we could throw things into it and see what happens. We would not be trapped by the confines of a black hole and have all our information lost when trying to relay it to the outside world. From what I understand, it seems that naked singularities might exist via extremely non-spherical stellar implosions and via the evaporation of a black hole.[14] Penrose considers the notion of cosmic censorship, 'an important unsolved problem'.[15] Cosmic censorship, developed by Penrose, is a postulate ordering singularities to have clothing, particularly that they be dressed very nicely in a horizon. The censorship postulates that no imploding object will form a naked singularity. This cosmic censorship has not been proven, and would certainly be a nice postulate to break, considering the amazing consequences that could result from being able to experiment with these naked singularities. Personally I find it rather awesome that nature allows black holes, and to be able to cast my eyes upon a naked singularity, would simply be icing on the cake.

The richness of general relativity and the implications of its possible union with quantum mechanics only guarantees the true power and even greater richness awaiting scientists who take part in creating a more unified version of the two. Black holes and their mysterious singularities seem to be an excellent playground for quantum gravity and its comprehension. The fascination of the unknown events at a singularity, and the exploration of its character, further develops our paradigms of nature and advances our understanding of one the most peculiar and interesting features of our universe.

References

[1] Adams, Fred and Greg Laughlin. The Five Ages of the Universe. Touchstone 1999.

[2] Hawking, Stephen. Black Holes and Baby Universes and Other Essays. Bantam Books 1994.

[3] Penrose, Roger. The Emperor's New Mind: Concerning Computers, Minds, and the Laws of Physics. Penguin Books. Oxford University Press, 1989.

[4] Smolin, Lee. The Life of the Cosmos. Oxford University Press, 1997.

[13] Kip Thorne. Black Holes and Time Warps. (W.W. Norton and Company, 1994), 478.
[14] Ibid, 482.
[15] Roger Penrose. The Emperor's New Mind (Oxford University Press, 1989), 215.

[5] Super Massive Black Holes. Discovery Channel. Channel 44. 10:00pm Monday, December 03, 2001.

[6] Thorne, Kip. Black Holes and Time Warps: Einstein's Outrageous Legacy W.W. Norton and Company. 1994.

[7] Wheeler, John Archibald. Geons, Black Holes and Quantum Foam W.W. Norton and Company, 1998.