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Singularities in Space

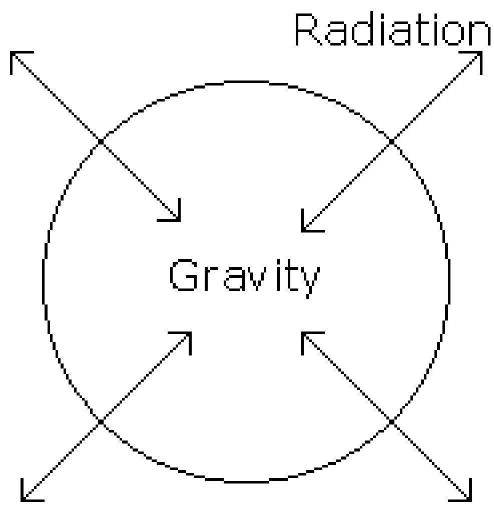
Countless images of our galaxy riddle textbooks and television shows, all depicting a large glow, or sphere of light at the center, but why? Why represent the Milky Way as a sphere with flat plane of light surrounding it in a wheel type shape? Why does a galaxy such as ours rotate as it does? These may seem as just random pondering of someone looking too close at a fourth grade textbook; however, these questions delve considerably deeper into modern physics than first believed, for at the center of our galaxy lies a massive black hole. This enormous entity creates the trademark spin we all think of when we ponder our galaxy and induces the “arms” on one which our very own solar system sits. At one point or another virtually every educated person in the world has heard that a black hole has been referenced as a *singularity* in space, and true to its ambiguous technical name black holes are still largely unknown. It is a simple question, but a most complex answer; what truly is a black hole? The origin of these singularities must be addressed to further understand such a pivotal part of our solar system. What factors are needed for a singularity to come into existence?*(Shapiro and Teukolsky 1983)* How does the Chandrasekhar limit factor into the creation of the black hole, and how does it differ with neutron stars?*(Daintith and Martin 2010)* How does the event horizon work, and the Schwarzschild radius concerning a black holes size?*(Zeilik 2002)* Quite simply what are the physics behind a black hole once it is established? Just as the Heisenberg uncertainty principle demonstrates the limited knowledge of exactly what happens on the atomic level, so do black holes demonstrate just how much is unknown in the next frontier, space.

In the very simplest terms black holes originate from the death of stars. Although all stars have a life cycle, these cycles vary greatly depending on their size. Only the extremely massive stars, on the magnitude of 10 solar masses and greater have the required mass to produce a black hole. However, all stars start about the same. The first step in a stars life is an interstellar cloud of dust and particles. A common misbelief by a great amount of people is that space is truly a vacuum, when in reality space is filled with gas, albeit at a extremely low density. *(Shklovskii 1978)* Overtime these particles start to clump together due to a thermodynamic difference between the Hydrogen and H_2 shells. Due to this alter in temperature the shells interact with each other, and once the shells reach approximately a density of 1,000 atoms per cubic centimeter they will collapse under their own gravity, and only then will the cloud then proceed to condense due to gravitational force. (Shklovskii 1978) Once the cloud condenses sufficiently it will become a protostar. The outer edges of the interstellar cloud are becoming opaque, and creating a spinning inner core. The light and heat that are created at the center of the protostar are created from the gravitational energy, due to the kinetic energy the molecules possess which in collisions they create an increasing temperature and give of light. The protostar will continue to condense and grow hotter for a period of time on the magnitude of a million years, depending on the size. Eventually the protostar will develop into a pre-main sequence star, due to the shedding of the outer cloud. In the pre-main sequence phase the star is still increasing temperature and density due to gravitational force, collapsing in towards the core. The core of the pre-main sequence will continue for an extended period of time, on a scale of millions of years. Only when the core of the star reaches approximately eight million degrees kelvin at which thermonuclear fusion can occur and the star can begin its main sequence stage in life. *(Zeilik 2002)* Due to the massive size needed to create a black hole, greater than 10 solar masses, the life time of a black hole degree star will use up its fuel hundreds of times faster than that of a star of similar mass to our sun. For instance the sun will remain in its main sequence stage for about 10^{10} years while a massive star will only remain in this stage for approximately 10^{7} years. *(Joshi 2007)* All the same a massive star undergoes similar activity as smaller stars, all resulting in fusion. Fusion is what gives every star in the universe their power, it is the warmth felt from our sun. Quite simple it is pushing two atoms together to make a new one. Due to the massive size of the "black hole stars" they burn brighter and are hotter than their smaller counter parts and can create heavier elements, but in the end they will run out of fuel to fuse together. This fusion is the reason stars are considered main sequence or in stellar equilibrium; the gas pressure pushing out equals the gravitational pressure pushing in. At the point when majority of the hydrogen is utilized to create helium the core of a heavier star will continue to increase in temperature to then induce helium fusion. Incredibly massive stars will continue to fuse atoms together making heavier and heavier elements from helium to carbon, carbon to silicon, and so on until the core is iron and nickel. *(Phillips 1994)* The star will continue this type of thermonuclear fusion to oppose the gravitational collapse inward, due to the radiation and gas pressures pushing out. The gravitational force pushing inward will eventually become larger than the gas pressure pushing outward and the result is an explosion, this explosion is known as a supernova.

As represented in Figure 1. The radiation and gas pressure pushing outwards equals that of the gravitational pressure pushing in; when the nuclear fuel inside the star runs out, as said before the result is a supernova.

Figure 1. Star Pressures

Charles Sturt University. 2011. Last modified November. http://hsc.csu.edu.au/



The interesting fact is that stars cannot manufacture heavier elements than iron and nickel through pure fusion because they cannot create high enough temperatures and pressures to push iron atoms together; the secret to elements such as gold and mercury is through the event of a supernova. *(Joshi 2007)* During a supernova the star will explode the outer layers of hydrogen, helium, ect. and the inner core, or remnant, will then collapse due to nothing in the universe containing enough energy to oppose the gravitational force pressing in. *(Zeilik 2002)* While these outer layers are shed this remnant will collapse inward at velocities around 70,000 m/s. Due to the massive size of the remnant left behind the star then creates a singularity and a black hole. *(Shklovskii 1978)*

However for a massive star a black hole is not the only end to life. According to recent research considerably smaller stars have been found that are about the size of the earth, but contain the mass of a star as big as our sun. Pushing a large mass in a small volume will create an incredibly dense object, as common sense dictates. The interesting thing about these interstellar objects is that they are completely made up of neutrons, and indicates their name Neutron stars. These neutron stars are the final stage of life for many massive stars but there is a key point at which a neutron star will develop as opposed to a white dwarf; which many main sequence stars will come to. That point is known as the Chandrasekhar limit. It is a commonly held number of 1.4 solar masses that dictates the limit. The lower bound is now known, but the upper bound for a neutron star becomes a tad more hazy. A generally held number is that of 3 solar masses and below create a neutron star, but a number of 5 solar masses is a firm upper bound. This is due to the reason why a neutron star develops as opposed to a black hole, which is neutron degeneracy. As stated before at the point of the supernova the remnant will then collapse inward, and in a black hole case nothing will be able to oppose that inward force, but in a star under five solar masses neutron degeneracy will provide just enough energy pushing outward. *(Joshi 2007)*

To everyday people black holes are some strange cool space thing that scientists discovered and they know that its black; taking the name as a definition. Other than the belief that these heavenly bodies are spherical and indeed black, the only other largely known fact is that they have some sort of event horizon. Now at this point, or curvature, interesting things happen concerning all states of matter in our universe. *(Frolov and Novikov 1989)* Contrary to that of the neutron star, a black hole has no material difference at this horizon than the space around it. If a human being were to “fall” into the gravity well of a black hole they would literally be ripped apart at the very atoms, with their feet atomized first, working all the way to the head; however, an observer would never know what happened to the individual whom went into the black hole unless they were to “jump” in as well due to strange reactions with light. The enormous amount of gravitational force beyond the event horizon in space is enough to even withhold light from escaping; that is the escape velocity exceeds the speed of light. So as to the previous assumption that black holes are indeed "black," well it is actually the warping of light around the black hole that produces this name, for the black hole itself seemingly absorbs all the light that travels to the event horizon. As to the previous example of a person falling into a black hole, the same goes for the observer, no light would escape to "show" the observer what happened. *(Zeilik 2002)* Astronomers use this key concept to actually study the sizes of black holes and their locations, for it is impossible to actually "see" a black hole, the astronomers study the distortions in star paths and distortions in spacetime as clues to the location of a black hole. Studies such as these are the very reasons why many of the scientific community believe there to be a super massive black hole at the very center of our galaxy.

Stars in general have incredible life cycles differing in many ways due in large to their mass. Again this mass dependence will be key. As stated before, after the supernova the remnant of a massive star will then collapse inward in free-fall. At some point in time the inward collapse will then change the star into a black hole, due to the point reached named the Schwarzschild radius. In essence at this Schwarzschild radius the first event horizon is created, because at that point the black hole will manifest and from then on the even horizon will change according to time. As with the event horizon this is the radius at which light cannot even escape the pull of gravity. Essentially given a certain amount of mass, how much compression would be needed so that the gravity would not allow light to escape near the object? *(Phillips 1994)*

This is given by the Schwarzschild equation [1]:

$$R_{Sch}=2GM/C^2$$

As seen in the Schwarzschild equation [1], G represents the universal gravitation constant, M represents the mass, and C is the speed of light in a vacuum. The radius is directly dependent on the mass of the star, the more massive the star the larger the radius will become. *(Phillips 1994)*

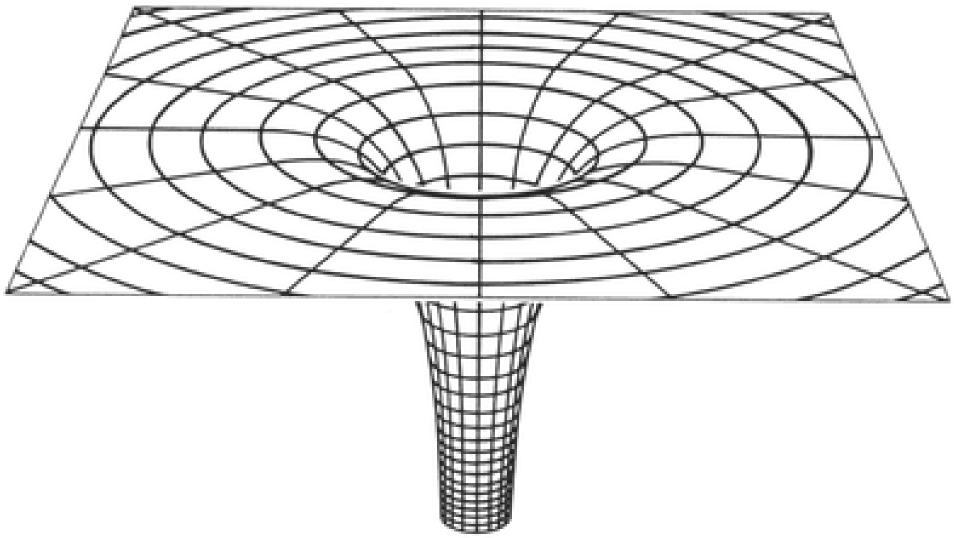
As the runaway gravitational collapse reaches the Schwarzschild radius the star will appear to become redshifted and then extinguish altogether. The main thing to understand is that this process will take on the magnitude of years to take place; it is not something that happens overnight. Once at this point the gravitational collapse does not stop, it continues on until the star then reaches a point of zero volume. *(Zeilik 2002)*

A singularity, probably the most ambiguous type of description a person could use for a black hole. What truly does a singularity mean? As described before the remnant left after supernova will then experience a runaway collapse inward, overtime this continuous uninhibited collapse will eventually result in a volume of zero while maintaining the original mass. This can only be achieved if the density then goes to infinity, which then creates the trademark singularity that is so used to describe these mysterious voids. *(Daintith and Martin 2010)* The star itself warps the spacetime around it.

According to general relativity space and time are unified in a certain points of events, each containing four different variables; three of which give the point, and the fourth to give the time. This four dimensional analysis of space gives a certain type of fabric surface which can be visualized for easier understanding of gravity and such things as the event horizon. According to Einstein large objects in this region make depressions in the fabric therefore creating such gravity wells, and are what we experience as gravity. This visualization can be used to understand the variations in paths of stars due to black holes, and understand how singularities warp spacetime around them. *(Shapiro and Teukolsky 1983)* This is due to spacetime warping sharply downward into a single point as seen in Figure 2.

Figure 2. Spacetime Warping

Astrosociety. 2011. Last modified November 21. http://www.astrosociety.org/index.html



Also seen in figure 1, the circular depression will then imitate the motion of gravity and objects revolving around the center. As objects come closer to the singularity they will dip down into the well and then circle around and around funneling downwards unless velocity is maintained. As the further the well goes the greater the gravity will become.

As established before the event horizon acts as a sort of one-way door, particles and light can enter, but nothing known to man can escape the grasp of gravity at that point. Therefore logic seems to dictate that black holes must at some point reach a point of equilibrium, or a stationary state. Then arises the popular saying, “black holes have no hair.” Which is attempting to make a metaphor out of the observable quantities associated with a black hole. First through intensive solving of Maxwell’s equations in general relativity it can be shown that black holes are constrained to three observable quantities; mass, electrical charge, and angular momentum. First, the mass is observable by the approximate size and gravitational pull of the black hole. The electric charge can be observed because just like traditional electromagnetism, like charges repel. Therefore charge is always conserved and can be shown to demonstrate the charge of a black hole. Finally the angular momentum can be observed compared to some point in space and the singularity. The metaphor arises in the saying due to the fact that all other observable quantities of matter entering the event horizon is now lost; therefore no hair. *(Novikov and Frolov 1989)* The important thing to discern from the previous explanations is that they mainly address a stationary non-changing black hole; this allows the assumptions for the no-hair theorem. The calculations concerning the event horizon, the electric fields and magnetic fields of the black hole become exponentially harder with rotating, non-symmetric black holes.

Thorough examination of the external spacetime and even approaching the event horizon of a black hole has been explored and naturally the next step is to delve past the event horizon and explore what is inside a black hole. For it has been shown that black holes actually emit neutrinos, small unseen particles that travel through material, called neutrino jets. How can this be? What is actually happening inside of the singularity? These are answers that can be calculated concerning the internal physical fields of a black hole, but as to the exact "substance" inside of the singularity little is known. *(Novikov and Frolov 1989)* As evident from the multitude of different sizes of stars, some black holes contain a greater mass than others. As hinted at in the beginning of the paper the super massive black hole at the center of the galaxy is most likely on the scale of 100-1000 solar masses; large indeed. Now it has been shown that some of the smaller black holes approximately under 10 solar masses actually evaporate away. This was discovered by Stephen Hawking, and is explained through the radiation of a black hole.

A black hole of very low mass will radiate just as a black body would, around the temperature of $1.2 \times 10^{26} M^{-1}$ degree kelvin. Because of this the black hole will actually lose some of its mass and it will eventually reach 0. Knowing this it once again represents another aspect of these singularities still misunderstood. *(Shklovskii 1978)*

Singularities in space, or black holes do not just come into existence; many different variables come into play in their creation, and it is a star that creates these massive entities. These differences can range from mass, charge, density, composition and momentum, have such a profound effect on what will happen to the star itself, only through a certain path can a black hole be born. As to the exact nature of a black hole, extensive research has been done and more will come; but at this point in time everything discovered has been pure theory. Black holes can be proven through mathematics, shown in space through astronomy, the internal structure of a the spacetime inside a black hole can be formulated, but the true nature of the singularity is still unknown.

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