Black Holes

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H2

Introduction to Black Holes

The concept of the term black hole is quite misunderstood in today's society. Hollywood portrays black holes as these enormous cosmic vacuums that suck in anything within a one-hundred mile radius of them. But in reality, this is typically not true of a black hole. A black hole is a cold remnant of former stars, so dense that matter-not even light-is able to escape their powerful gravitational pull (National Geographic 2011). Even though not much information is known about black holes, what is known shows that they are a fascinating part of outer space.

"The Physics of Black Holes"

The Discovery of the Black Hole

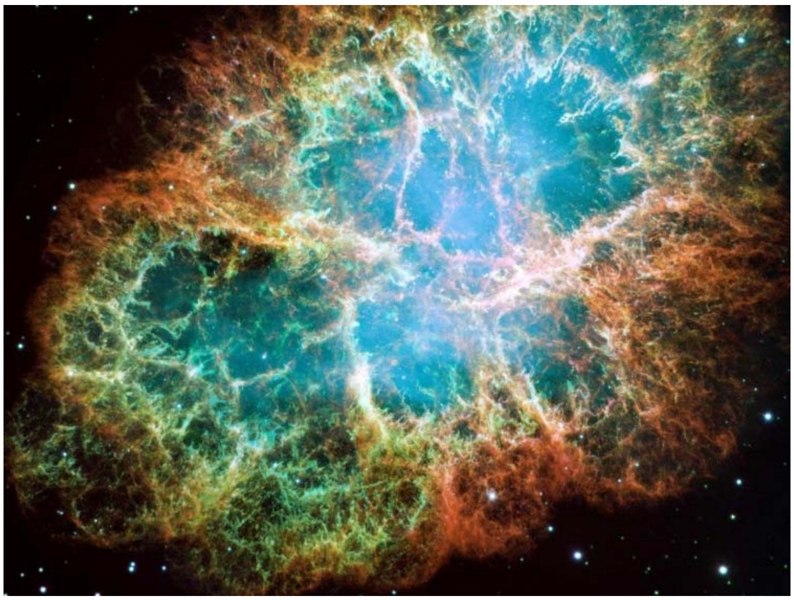
Many scientists have played a role in the discovery of black holes. Until fairly recently it was thought that the first person to predict the existence of black holes was the world famous French mathematician and astronomer Pierre Laplace in 1795, but it is now clear that the first person to suggest the existence of black holes was John Mitchell, an English geologist (Al-Khalili 1999). Although Mitchell is considered the "father of seismology", he used the escape velocity of the sun to suggest the existence of a black hole. Mitchell calculated the escape velocity on the sun to be six-hundred and twenty kilometers per second, based on the sun's size and density. Based on this information, he calculated that the speed of light was five-hundred times the escape velocity of the sun. Therefore a star having the same density as the sun, but a mass five-hundred times of it would have an escape velocity equal to the speed of light. At this point in history, light was viewed as a stream of particles and not as electromagnetic radiation as it is today. Using this assumption of light as particles, Miller concluded that the particles of light would not be fast enough to escape the gravitational pull of this giant star, and therefore a black or "invisible star" would be the result (Al-Khalili 1999). The problem with Mitchell's theory is that he used Newton's theory of gravity and not Einstein's theory of relativity in his calculations. The first person to actually develop theory about the concept of black holes is Karl Schwarzschild in 1916. Using Einstein's theory of relativity and his calculations of the gravitational field of stars, he concluded that if a huge mass, such as a star, were to be concentrated down to the size of an infinitesimal point, the effects of Einstein's relativity would get fairly extreme ("Discovered Black Holes" 2003). He predicted that if this did occur and a star did shrink down to that small of a size that the star's gravity would remain the same and the planets around it would remain in their same orbits. He discovered the Schwarzschild Radius, which is the maximum radius a body with a specific mass can have without letting light escape and modeled by the equation:

$$R_s = \frac{2MG}{c^2}$$

The American physicist John Wheeler was actually credited with coining the name black hole in 1968, and also contributed vast amounts of research to today's knowledge of black holes.

Formation of Black Holes

The formation of a black hole is a somewhat complicated process. To start, there are two different types of black holes. The first type of black hole is the stellar-mass black hole. This black hole is formed from the death of a massive star: when these stars run out of nuclear fuel to power themselves they often detonate into a supernova ("Relentless Pull" 2011), scattering most of a star into space but leaving behind a large remnant in which fusion can no longer take place (National Geographic 2011). This is modeled in "Supernova in Space". The star then collapses down to a critical size, since there are no forces to counteract the force of gravity on the star. At this critical size, the escape velocity would be equal to the speed of light and according to Einstein's Theory of Relativity, the gravitational force on the collapsed star would be infinite (Al-Khalili 1999). Thus, a budding black hole with zero volume and infinite density emerges, enveloping the star in the Schwarzschild Radius. Once through the Radius, there is no way for anything to escape, and the star collapses into a single point, known as singularity. The second category of black holes is the supermassive black holes, and it is

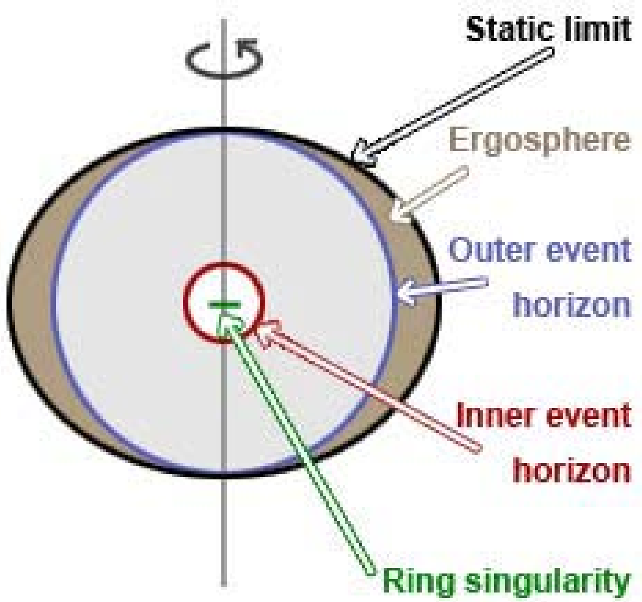


"Supernova in Space"

unknown how this type of black hole forms. Scientists theorize that this type of black hole could be formed by the merging of multiple stellar-mass black holes, or that these supermassive black holes originated as stellar-mass black holes that over billions of years grew supermassive by consuming stars and gas.

Features of Black Holes

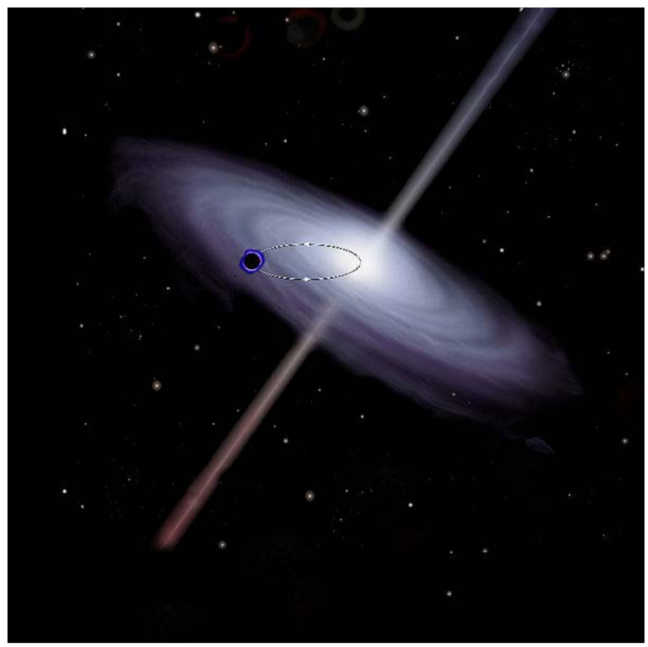
In space, rotating black holes are the only type of black hole to be identified. Rotating black holes are composed of four major parts: the static limit, the ergosphere, the event horizon, and the central singularity. The static limit is actually outside of the black hole and the outer limit of the ergosphere. At the static limit, objects that are moving counter-spinward at the speed of light are stationary with respect to the rest of the universe. This is because the space here is being dragged at exactly the speed of light relative to the rest of space. Outside this limit space is still dragged, but at a rate less than the speed of light (Wikipedia 2011). The second major part of a rotating black hole is the ergosphere, which is the region right outside of a rotating black hole, and inside of the static limit. The ergosphere is elliptically shaped, touching the event horizon at the poles of the black hole and then stretching out a distance equal to one radius of the event horizon of that particular black hole. The ergosphere, along with the static limit are only present in rotating black holes. In



"Black Holes: Gravity's Relentless Pull" the ergosphere, spacetime is dragged along in the direction of the rotation of the black hole at a greater speed than the speed of light. Spacetime is any mathematical model that combines space and time into a single continuum (Wikipedia 2011).This is known as the Lense-Thirring effect or frame dragging. Due to this dragging effect, objects have to move faster than the speed of light in order to appear stationary in relation to the rest of the universe. If an object enters the ergosphere, it can still escape the gravitational pull of the black hole, since it has not yet passed through the Schwarzschild Radius or the event horizon. Theoretically, an object can actually gain up to 29% of the energy of a rotating black hole by escaping the ergosphere. This process is known as the Penrose Process and is a possible explanation for why energetic phenomena such as gamma ray bursts occur (Wikipedia 2011). The third and probably most important part of a black hole is the event horizon. The event horizon is an imaginary sphere that measures how close to the singularity of a black hole an object can safely get. In the event horizon, all lightlike paths (paths that light could take) and hence all paths in the forward light cones of particles within the horizon, are warped so as to fall farther into the hole (Hehl 1998). Because of this, someone observing an object passing through the event horizon will never actually see the moment it crosses through it; it will seem like the event horizon is still farther off in the distance. Once an object passes through the horizon, there is no escape from the pull of the black hole. The radius of the event horizon is equal to the Schwarzschild radius. In the equation for the Schwarzschild radius, the size of the radius is proportional to the mass of the planet or star. For example, the Schwarzchild radius of Earth is the size of a marble, meaning that Earth would have to be compressed that much to turn into a black hole (“Relentless Pull” 2011). In nonrotating black holes, there is a single event horizon, and in rotating black holes, there is an inner and an outer event horizon. The fourth major part of a black hole is the singularity or the central singularity. This singularity is a point or an area where all matter is squeezed into which has infinitely small volume. At this point, the spacetime curvature becomes infinite. In nonrotating black holes, the singularity is a single point, but in rotating black holes, the singularity is an area inside the black hole.

Classifications of Black Holes

There are three major criteria that are used in classifying black holes: the mass of black hole, the spin of the black hole, and the magnetic field of the black hole. Two different mass-categories are used to characterize black holes today: stellar-mass and supermassive. Stellar-massive black holes are the most well know type of black holes. They originate from the death of a star, as previously mentioned, and are typically just a few times heavier than our sun ("Relentless Pull" 2011). Supermassive black holes, on the other hand, are about as heavy as a small galaxy. It is not known how these supermassive black holes are formed. Based on the spin of a black hole and the electric charge of a black hole, there are three more classifications. The first is the Schwarzschild Black Hole. It was originally proposed by Karl Schwarzschild and is classified as containing no magnetic field and zero spin. This type of black hole is composed of a singular event horizon and a point of singularity. The second type is the Kerr Black Hole. Named after scientist Roy Kerr, these black



"Stellar-Mass Black Hole"

holes have both spin and a magnetic field, and are the most common type of black hole found in space. The Kerr Black Holes are composed of a two-ringed event horizon, an ergosphere, a static limit, and a central ring of singularity instead of a finite point. The last type of black hole is the Reidner-Nordstrom Black Hole. This black hole has no spin, but does contain a magnetic field. This group is characterized by singularity and a two-ringed event horizon (Matthew 2011).

Entering a Black Hole

The question often arises about what happens when someone "falls into" or enters a black hole. The experiencing of falling into a black hole is unique in that the person who actually falls into the black hole sees and feels something totally different from someone who is watching that person fall into the black hole. The experience is quite horrifying for the person who falls into this hole. Inside a black hole, the gravitational force is changing so much that it produces a tidal effect, similar to the tidal effect that the moon produces on the Earth's oceans, but to a much higher degree. The person who falls into the black hole will feel this effect across their body and will ultimately be ripped to shreds, long before they reach the point of singularity. In stellar-mass black holes, these tidal forces are so strong that a person would be killed long before he or she reaches the event horizon, but in larger black holes, such as a supermassive black hole, the tidal forces are not nearly as strong, and although a person would still be ripped to shreds, they would be able to make it past the event horizon (Al-Khalili 1999). A strange occurrence happens after someone passes the event horizon: space and time interchange with one another. It is believed that inside a black hole, space and time are so warped, that the distance from the event horizon to the singularity is not a distance in space, but instead a "time direction" (Al-Khalili 1999). The Schwarzschild Radius is a distance measured from outside of a black hole; the inside of the black hole cannot be measured in distance, but instead in time. The time it takes to reach the singularity from the event horizon is proportional to the mass of the black hole. For example, in a typical stellar-mass black hole, it would take one ten-thousandths of a second to reach singularity from the event horizon, but in a supermassive black hole, it would take several minutes to reach this point (Al-Khalili 1999). The amount of time is also dependent on how much the object struggles to escape the black hole. According to Russian physicist and leading black hole expert, Ivor Novikov, if a person were to fire rockets inside a black hole's event horizon in an attempt to escape, they would reach singularity faster than usual, and would therefore be ripped to shreds sooner. For the person watching the black hole from the outside, a strange event occurs. When watching someone fall through a black hole, the person falling appears to slow down as they approach the unseen event horizon, until they actually appear to freeze. This is known as "frozen time", and occurs because the light reaching you has been redshifted into such long wavelengths that it quickly goes beyond the visible spectrum (Hehr 1998). To the person observing the falling person, the person seems to slow down, but to the person falling it seems as if he is speeding up. After a small amount of time, the falling person's image fades away and disappears as he falls further into the black hole. Also, time really does slowdown in strong gravitational fields. If the person watching the other person falling into the black hole were to aim a telescope at the person's watch, the hands on the watch would actually be moving slower than the observer's watch (Al-Khalili 1999).

Growth and Death of Black Holes

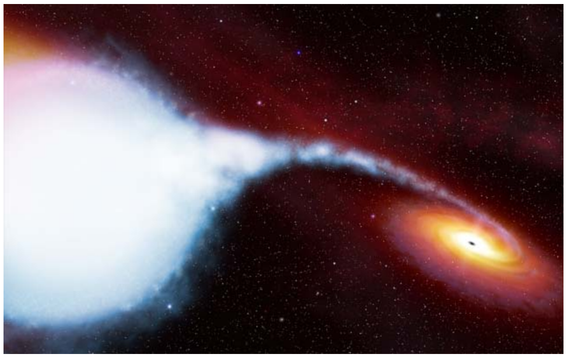
Throughout their "life", black holes grow in mass by swallowing nearby material that passes through the black hole's event horizon. Black holes can also theoretically grow by colliding with another black hole. Once they pass through one another's event horizon, the black holes will violently merge into one larger black hole. With not even another black hole being able to topple another black hole, one might think that black holes live forever. This is a false assumption as proved by scientist Steven Hawking using the laws of quantum mechanics to study the region close to a black hole horizon ("Relentless Pull" 2011). Hawking theorizes that a process known as evaporation occurs. In this process, tiny particles and light are created and destroyed on a subatomic scale. In doing this, there is a chance that some of the particles and light could escape, if they were outside of the event horizon. Then, the Penrose process occurs, where the matter and light that escapes takes along energy from the black hole. The most famous of the Einstenian equations is needed to explain the next part.

$$E = mc^2$$

The obvious is that since the mass of the particle or light is gone, that the black hole becomes a very tiny bit smaller, but what also occurs is that the black hole needs to replace the energy taken away by that particle. Therefore, it converts mass into energy to replace that taken by the particle, and in return decreases the mass of itself. Over millions and billions of years, a black hole becomes so small that it evaporates, resulting in its "death" ("Relentless Pull" 2011).

Detecting Black Holes

Compared to the rest of space, stellar-black holes are very small. Due to this, and the fact that the light that would allow for someone to see black holes cannot escape from the black hole, black holes are difficult to spot. The way that most scientists identify black holes is by looking at binary systems of stars. If only one star is visible, than either a neutron star or a black hole is part of the binary system. If a black hole is near a star, it will begin to suck the gas off of the star. As the gas enters the black hole, it will gain kinetic energy and heat up, forming an accretion ring around the black hole (NASA 2010). This matter in the accretion disk is so hot, that the disk emits X-rays, which typically are emitted at a random sequence. From this accretion disk, scientists can typically tell the size of the black hole. This is the process that scientists have to go through to find a black hole.



"Cygnus X-1"

<u>Known Black Holes</u>

There are many known black holes today. The longest one is Cygnus X-1, which is located in a binary system along with its companion star HDE 226868. Cygnus X-1 is a highly variable and irregular source with X-ray emissions that flicker about every hundredth of a second. This is the time required for light to travel through the black hole, and in that amount of time, light travels 3,000 kilometers (NASA 2010). Using the mass and luminosity of the star, the mass of Cygnus X-1 is calculated to be around seven solar masses. As of 2009, there are 20 X-ray emitting binaries with black holes, and there are twenty more binaries that are thought to contain black holes.

<u>Black Holes: Still Much to Learn</u>

It is clear that black holes are not quite the things that Hollywood and other people seem to portray them as. They are not just a cosmic vacuum cleaner that sucks up anything within a one-hundred mile radius of them; they play a unique role in space. Over the past century, many strives have been made in understanding black holes, starting with scientists such as Schwarzschild and including scientists such as Steven Hawking. But, there is still so much more to be learned about black holes, their characteristics, and how they function.

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