General Relativity Honors Physics II Project

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Isaac Newton was responsible for bringing the thought of gravitational forces into existence. "It was occasioned by the fall of an apple, as he sat in a contemplative mood" (William Stuckley, Memoirs of Sir Isaac Newton). Gravity during his time was a complete mystery and throughout his lifetime, Newton searched for truth in mathematics. He developed a set of equations that worked in nature and were considered the solution to all gravitational fields.

The year of 1915 brought forth an incredible breakthrough in the area of relativity and the development of gravity. Albert Einstein had already established many theories and breakthroughs in his life; however he sought to find an answer to relate all the known forces of the Universe. His work had been very recognized in the area of special relativity which related reference frames and the properties of light. From the year of 1907 and 1915, Einstein realized that gravity, did not agree with all the other forces that had already been discovered, hence marking his departure on a search to research the effects of gravitational masses in space-time.

Introduction

General Relativity was developed to observe the gravitational attraction between masses and how they resultantly warp space and time. Einstein believed he could relate it somehow to the other forces in nature like the electromagnetic forces in order to create a grand unified theory. Gravity is still a huge mystery and the effects of its have not been directly discovered. Many theories such as elementary particles called *gravitons* have also been proposed. *Gravitons* have complicated properties but, are basically elementary particles that could only be visible at relative velocities. Gravitons in string theory are connected strands of energy which could move from one dimension into a parallel one if two atoms collided at velocities near the speed of light. They are also what could be in charge for gravitational waves, gravitation lensing and the effects of huge masses on light. One theory, which is widely accepted today, is the effect of space-time curvatures. Space could be treated as a material and matter is another material that stretches space and causes folds and turns. Space and time could be pictured as a trampoline, with the nylon material being stretched. When a mass is placed on top of the trampoline, the nylon stretches and causes curves in the fabric. Let's say the sun is represented by a bowling ball which pulls the material downwards. Now place a tennis ball to represent the earth. The tennis ball curves the material somewhat but not as much because it has less matter and is less dense. The bowling ball pulls the tennis ball towards it. Gravity works pretty much the same way. Now place a tennis ball near the bowling ball, but give it a perpendicular velocity. The ball will rotate around the denser mass, which is the way planets revolve around the sun and satellites around planets. The big mass causes an attractive force on the other one towards its center of mass, and the directionally changing tangential velocity associated with the mass, causes a centripetal acceleration.

Newtonian Mechanics and History

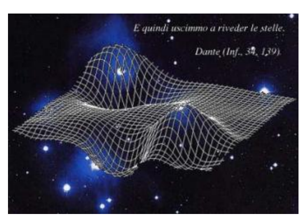
Isaac Newton had developed several theories to explain the actions of the cosmos and how they were related to objects on the earth. Newton, being a young and curious scientist, was sitting next to a tree, when an apple fell on his head, causing him an epiphany. Newton began to question the effects of gravity and the forces that controlled the universe and the rotations of the planets. He developed accurate measurements that related forces and masses through acceleration, and figured out that all objects have equal and opposite forces. He also found nature's inherent laziness or resistance to change.

Newton described energy in terms of mass and their respective velocities. Mass was a property of the universe and the amount of matter present was what drove the forces of gravitational attraction between different objects.

Early works

The discoveries of general relativity were mainly because of Einstein, but were truly paved by his scientific predecessors. Michael Faraday, a young electrochemist and physicist, was able to make amazing discoveries in chemistry and physics. One of the main laws in electricity and magnetism was discovered by the self-educated scientist. His curiosity began when he visualized a magnet get deflected by a passing current. Later, through his work, he had predicted light to be an electromagnetic wave, for which he was mocked. Maxwell, a contemporary mathematician fought through the complex mathematics of Faraday's work and discovered the speed of light.

Le Chatelier, a young female chemist, helped in the discovery that the energy associated with the motion of a mass was not directly related to the object's velocity, rather the square of that velocity by experimenting with the effects of metallic spheres dropping into clay. She measured how deep the crater formed by these masses was at a certain distance, and then doubled the distance but discovered 4 times the depth. Later it was Einstein that figured out that Energy was directly associated with mass and the speed of light squared in his very famous equation,



$E = mc^2$

A Macroscopic View

The Cosmos are concentrated matter of gas, liquids, solids or plasma. Gravity exists between all atoms and their gravitational pull is related by their distances and masses. Gravity gets concentrated to what is called a singularity, or a single point. This concentration of masses is why most objects in the universe appear to be spherical (in the macroscopic universe), and why our planets and sun are spheres themselves. Gravities of giant masses act as single points pulling on each other with equal and opposite forces. For the planets, this is from their center of mass radially outward. Planets have acceleration towards each other caused by these gravitational field forces of attraction, but also have tangential velocities which cause them to have changing directional velocities and centripetal accelerations. These are the reasons for the motions of the cosmos and orbits of the planets. Newton figured this out through simple experimentations, but he was struck with some orbits which could not be explained. Mercury had a radical orbit which did not follow these laws directly. For many centuries, these questions could not be fully explained,

however, they would be answered when Einstein began to question the effects of gravity at relative velocities, or velocities near the speed of light (c= $3x10^{8}\,{}^{m}/_{s}$).

Special Relativity

Albert Einstein realized that Newtonian mechanics failed at the velocities of such magnitude or near such magnitude. Picture an object A moving at a velocity v_a in the (+) $\hat{x}$. The object, relative to a stationary observer B moves constantly at a velocity v_a in the (+) $\hat{x}$. Now picture, object A moving with the same velocity in the same direction but object B now moves with a velocity v_b in the same direction. Object A has a relative velocity $v_a - v_b$ because to object B, object A moves apparently slower, if $v_b < v_a$.

Since reference frames had been established, physicists began to believe that time was absolute and that all values changed according to time. Einstein though, began to wonder about the properties of light and their behavior. He realized that if an object moved close to the speed of light next to another source of light moving at a similar speed, light did not apparently contract its velocity due to the reference frame of the observer. He saw that light maintained its velocity and that only other parts of the system were changing. Time was “dilating” or shortening so that light could maintain its velocity in a vacuum. The advent of special relativity brought upon a revolutionary change in physics and added a new concept now known as time dilation. Experimentation for this is very difficult because reaching relativistic speeds requires incredible amounts of energy. Take an astronaut who travels near the speed of light for a year and returns to earth, the time for him would have seemed to be only a year, but for a person on the earth, it would be more like 700 years depending on the speed the astronaut was traveling. Special relativity also determined the equivalence principle relating mass and energy in the most famous equation, $E = mc^2$. Mass, just like for Newton was the driving variable in the strength of gravitational attraction between two distinct sources. “Mass, or more generally, energy is the source of gravitational field and its sphere of influence as an attractive force extends to infinite distances just like the electric charge of the electromagnetic force.”(pg 197 – On the Path of Albert Einstein) Although, much more was to be discovered. He found that since there are particles in nature that behave like waves and gravity acts with distance, therefore the gravitational fields must be caused by other presences. The geometry of the mathematics just did not coincide with the theoretical discoveries. He was forced to adapt an established geometric system in which he used tensors to describe energy. He called this an *energy tensor,* which described all physical aspects of what was going on. This meant that not only mass was a gravitational source, but so were energy, momentum, pressure, and tension. All these put together could describe the actual sources for gravitational waves in his newly adapted geometric system. For these systems, light had very special properties and behaved strangely in nature. Sometimes light behaved as a wave but other times it had the properties of particles with mass themselves. Light though, Einstein believed was a sort of universal boundary, meaning nothing could travel faster than its speed, as had been determined by the mathematician Maxwell earlier on. Einstein called this period "The Great Revolution." (The Elegant Universe, video)

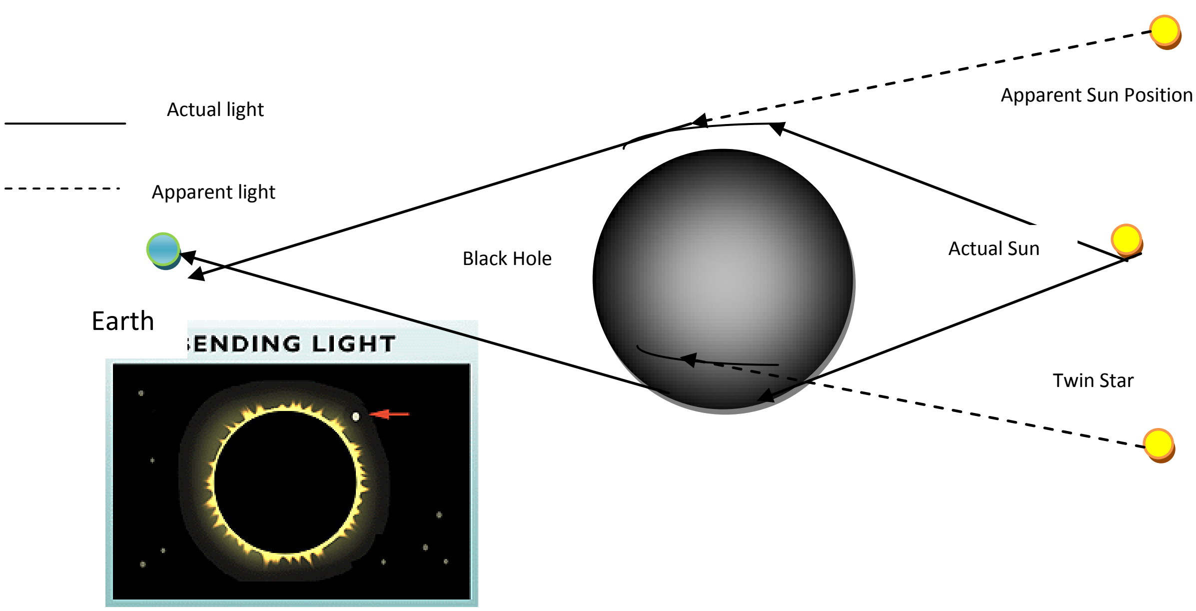
<u>Effects of Special Relativity on Gravity</u>

Light was discovered to be the fastest possible velocity of anything. It was described as "celeretous" or Latin for swift. The word was used to choose the variable used in Physics.

The speed of light c is a universal limit. According to Newtonian mechanics, gravity acted instantaneously throughout the universe. What this meant was that if the motion of the planets was observed around the sun, and suddenly the sun were to vanish, then, the planets would begin to soar out in tangential directions to where the center of the mass of the sun stood immediately after it disappeared. The sun blasts powerful electromagnetic radiation from its core to the earth but that takes about 8 minutes to reach the earth's atmosphere at the speed it travels. Nothing can exceed that speed, meaning that gravity cannot exceed that speed either. Considering that gravitational waves travel at the speed of light, the effect of the disappearance of the sun would not be felt on earth until about 8 minutes after it vanished. The planets would still soar off into infinite space but not immediately, there would be some time until the gravitational wave reached the earth. "Gravitational effects cannot propagate with infinite speeds." (Gravitation & Space-time, pg 17) These discoveries lead Albert Einstein to think of space as a sort of elastic sheet that would bend or curve in the presence of a mass. This "sheet" can carry waves of energy called gravitational waves, explaining the phenomena of black holes, and gravitational lensing.

Gravitational Lensing

Cosmologists were plagued for centuries by the discoveries they saw in the cosmos. When they analyzed stars, they found similar stars which seemed to be twins in two different locations pretty much parallel to another. This phenomenon was later explained by general relativity as gravitational lensing and also led to the discovery of immensely concentrated masses which are now known as black holes. Light travels through the same medium in which masses are present in the universe. When something very massive is present, the curve it inflicts on space is incredibly large and steep. Light also bends in the presence of a curved space-time continuum. Black holes are stars so massive that they do not allow light to escape their gravitational field. Black holes will curve light substantially as light travels close to its surface in a perpendicular direction to its center of mass. Imagine a star far away. Now imagine a huge black hole between the earth and the star. Light leaves from the star far away and travels orthogonally to the black hole which curves its light. The light gets skewed around the black hole and focused back on the surface of the earth. This appears as two different stars in the sky with very similar properties. The twin stars observed in the sky are actually, the same star. This effect can occur at several different positions all showing the same star.



Gravitational Waves

Gravitational waves are like pulses propagating at the speed of light. Most objects in the universe are round so these are commonly radial ripples in space-time, like dropping a stone in a puddle of water. Pulsars are also known as neutron stars which are heavily dense masses which emit light from their poles. The light emitted from these poles has been measured to account for gravitational waves. Pulsar stars revolve closely around each other and apparently lose energy. Conservation of energy laws state that no energy can be lost, therefore gravitational energy waves could account for any energy loss.

Black holes

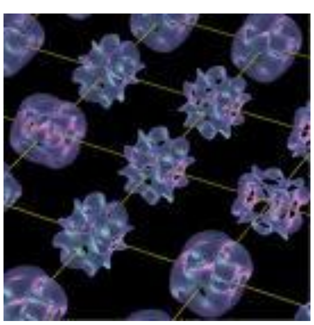
Black holes were said to be immensely dense matter that had such a strong gravitational force, that its gravitational pull would not allow any light to escape. This would mean that the escape velocity of such a massive star would have to exceed the speed of light. These stars are not only heavy though, they have to be very compact to form. When these stars collapse into almost forming point particles because they cave into their own gravitational fields, they release very strong gravitational fields. Accelerating masses can emit gravitational waves of energy that could also account for the lost energy of pulsating binary stars.

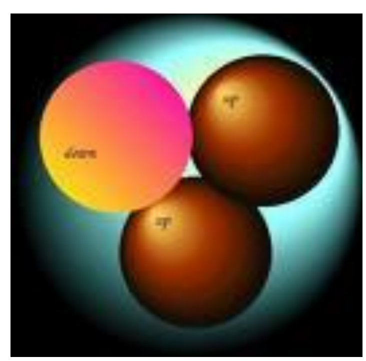
General relativity's collapse

Einstein's predictions were outstandingly accurate at macroscopic levels and redefined all the works of Isaac Newton which had already been accepted. Some discrepancies showed that Newton's work was not always accurate. Therefore general relativity worked well at all level's that had been seen for his time. It answered many questions and corrected any mistakes in Newton's work. Its predictions were also tested with amazing accuracy. However, quantum mechanics were not around during Einstein's time and presented a problem to his theories. General relativity coped with the universe and tried to connect everything, all forces and galactic interactions until the atomic level. The introduction of quantum theories showed flaws with general relativity, or better yet, had incomplete predictions and conclusions. In order to deal with the inconclusive consequences of relating general relativity to quantum mechanics, many theories have now attempted to deal with such discrepancies. The best theory in modern physics, which is still inconclusive, is string theory, which seems to solve many of the chaotic problems posed by quantum levels to general relativity.

String Theory

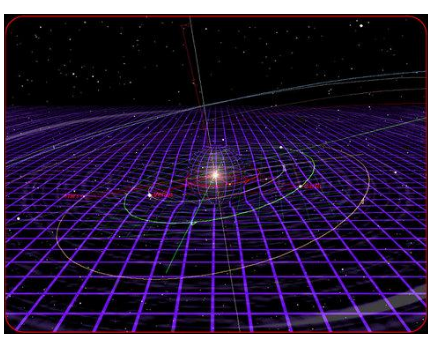
Zooming in from the outskirts of the universe, the Milky Way galaxy appears from a distance. Approaching the Milky Way and heading towards the center of the solar system reveals an amazing place called the earth. A spherical magnificence made of oceans, mountains, plateaus, and endless composite elements. Elements are made up of atoms joint by strong and weak nuclear forces surrounded by electrons. Inside these atoms are neutrons and protons which further reveal the presence of quarks. These sub-atomic particles oscillate chaotically inside the protons. But what is within these quarks (size $\approx 1 femtometer = 10^{-15}\ meters$) ?

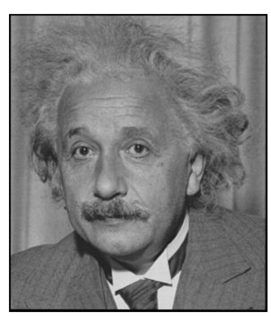




Physics today, attempts to solve the mysteries of quantum mechanics. To the naked human eye, it is impossible to visualize atoms, quarks, and similar elementary particles because by the time the light reflected from these tiny masses reaches a human eye, the momentum carried by light has already moved the particles from their position. This is called the *Heisenberg uncertainty principle*. Quarks though, are known to oscillate at certain frequencies within a proton, and inside them, physicist predict vibrating strings of energy. These strands of energy can either be circular (oval too) or linear. They are constantly in motion and account for all the matter in the universe. The strings resonate at different frequencies and make up all the properties of the universe, such as mass, charge, composition, etc... The strings also allow scientists to move back into the big bang, before this universe burst into existence, removing the problems of singularity and extreme temperatures of the first seconds of the universe. The only way these could exist though, would be in a world of 11 dimensions instead of the 4 people comfortably accept in their daily lives.

General Relativity serves as a connection to the underlying mysteries of the universe. Thanks to the work of many great scientists, including Albert Einstein himself, science today discovers incredible coincidences and mathematical connections in the Microverse and Macroverse. Perhaps someday, all doubts will be fulfilled; however, proof requires much determination and work. Einstein spent his life arriving to his conclusions but discovered how the universe works in relative frameworks, opening the gates for today's scientists to figure out the rest.





Scientiae, Orbis. On the Path of Albert Einstein. Coral Gables, FL: Plenum Press, 1979.
Pgs 15-39

Ohanian, Hans C. . Gravitation and Spacetime. 1st. New York : W.W. Norton & Company, Inc, 1976.
Pgs (1-10)

Romer , Robert H. . Energy An Introduction to Physics. San Francisco: W.H Freeman and Company , 1976.
(pgs 172 – 200)

PBS, video. The Elegant Universe. Physics. 2003.

"General Relativity." (1995) 22 Sep 2008
<http://archive.ncsa.uiuc.edu/Cyberia/NumRel/GenRelativity.html>.

University of Illinois, "Albert Einstein and the Theory of Relativity." 22 Sep 2008
<http://csep10.phys.utk.edu/astr161/lect/history/einstein.html>.

Gockeler & Schucker, Differential Geometry, gauge Theories, and gravity. Sydney: Cambridge, 1987.

Pais, Jannsen. "General Relativity." Wikipedia 26 Oct 2008
<http://en.wikipedia.org/wiki/General_relativity>.

Young, Hugh. "Newtonian Mechanics and Relativity."University Physics. 11th. 2004.