Time Travel and the Universe / 3/26/2011

This will be a journey in time and space. The way I'd like to start is by telling you that you should not trust your intuition and common sense too much, because what I am hoping to convince you with, would defy those. When I was in the Air Force, although only as a programmer, not a pilot, I did go through some training that pilots go through, and one of the first things a pilot learns about is vertigo situation. When you fly a jet 2000 miles an hour, a lot of funny things can happen, especially when you make a turn, you could experience 4-6 g forces and your common sense goes to the crapper – always trust your instruments more than your intuition. If you think the earth is bellow you and the gauges tell you it's above, you'd better turn around.

Here is another example, when you throw a ball of feathers weighing ½Lb and a ball of lead weighing 20Lb from the 5th floor, but your intuition tells you that the lead will hit the ground first, and you could be right, but only because of air resistance. Astronaut David Scott tried that experiment on the moon, where there is no air, and they both hit the ground at the same time, so sometimes what seems logical is not. We'll defer the discussion of gravity for a bit later. Einstein had said once that common sense is the collection of biases you accumulate until the age of 18. Since most of you are younger, I hope after this lecture you'll add more biases that are known as universal truths, at least for now.

The first thing I'll try to convince you with, is that time is not an absolute term, and even before that, I'll attempt a simpler one: Space is not an absolute thing. Imagine that I stand on a train, moving at a constant 90 miles an hour on a straight rail, and I bounce a ping-pong ball on a table. The ball goes up and down; let's say within 1 second and hits the exact same spot on the table. Johnny, my friend, who stands outside the train, does not think the ball hit the same spot, because the train had traveled 40 meters between the first and second bounce. So an event that has the same space coordinates for the traveler has different coordinates for the outside observer. (board drawing)

Now let's try to tackle time instead of location, but before we do, let's talk a bit about some physics principles, relating to speed. If a train travels at a uniform speed of 30 miles an hour in relation to the railroad along a straight line, and a man walks inside the train at 4 miles an hour in the same direction, the outside observer will see as if the man is traveling at 34 miles an hour. The best example is if you ever experienced walking on one of those moving strips in a large airport, it doubles your speed when you look to the sides. If you walk the other way, you may look like you're standing still or even moving backward, to the outside observer. We're using an intuitive principle of adding or subtracting velocities.

Let's talk about the speed of light, or as I like to call it 'the speed of life', and I'll explain later. If you sit on a train that's moving 60 miles an hour and you shine a flash light toward the direction the train moves in, and we assume that the speed of light is c miles an hour (c - is usually denoted in miles/sec or Km/sec), you would think that the beam from your flashlight moves at c+60 miles per hour. You will then be wrong, because observations have shown that the light always travels in the same speed (in vacuum we assume), regardless of whether the source of light moves or stands still. There are many interesting implications to this fact, but before going any further, I'd like to note that the first person we know of, who determined that the speed of light is finite (as oppose to instantaneous), and even made an attempt of measuring it, was the Danish Astronomer Ole Christensen Roemer in 1676. Roemer noticed that the Jupiter's moons were being eclipsed by the giant planet at different intervals, depending on the time of the year. One possible but improbable explanation was that they speed and slow down occasionally, but the more plausible explanation was that because of the varying distances between earth and Jupiter over the course of the year, the vision of those eclipses reaches us at different intervals. His calculation was off at 140,000 miles per second. Today we know that the speed is about 186,000 miles per second of 300,000 kilometers per second. The most accurate measure to date is: 299,792,458 meters/second.

The reason I call it the speed of life, is because if an observer, say 10 light years away from us, is watching us right now, he or she would see events that occurred on earth 10 years ago, and the pace those images of our lives would appear, is in accordance with the speed of light, so in ten year our current events would have traveled and reached the observer, so life events flow at the speed of light.

In 1887 Albert Michelson, who later became the first American to win a Nobel prize for Physics, together with Edward Morely, ran a series of experiments to measure the speed of light using the speed in which the earth is moving around the sun (about 20 miles per second) and measuring the light moving toward the earth motion, with it and in perpendicular to it – to their surprise they found out that the speed of light had remained constant.

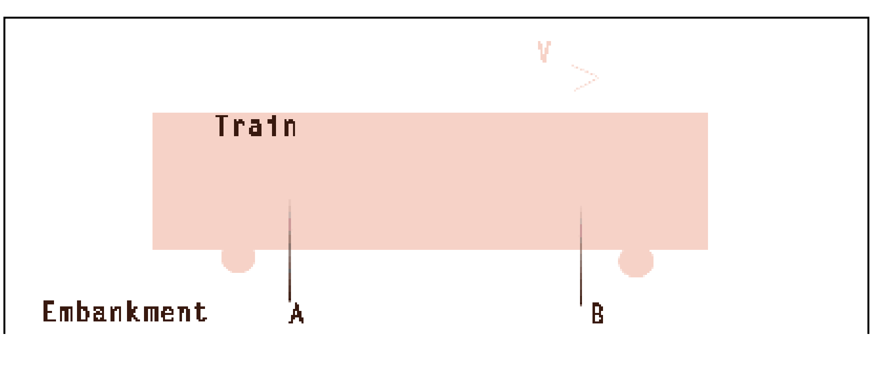
This revelation is already against 'logic' of the addition of speeds principle, but what I am hoping to convince you with, will dwarf the principle we've just 'broken'. The two assumptions I will make are as follows:

Assumption 1 as we've discussed: The speed (velocity) of the propagation of light is finite and is approximately 300,000 km/second in vacuum, regardless of whether the source of light or the observer is moving toward one another, away from one another or in any other directions.

Assumption 2: The laws of physics (nature) are the same in all inertial systems (systems that are at rest or moving in straight line with a constant speed in relation to other system). We call this the principle of equivalence.

We'll go back to our favorite train ride and we'll plant poles A and B on the embankment of the train, as shown in figure 1.

Figure 1.



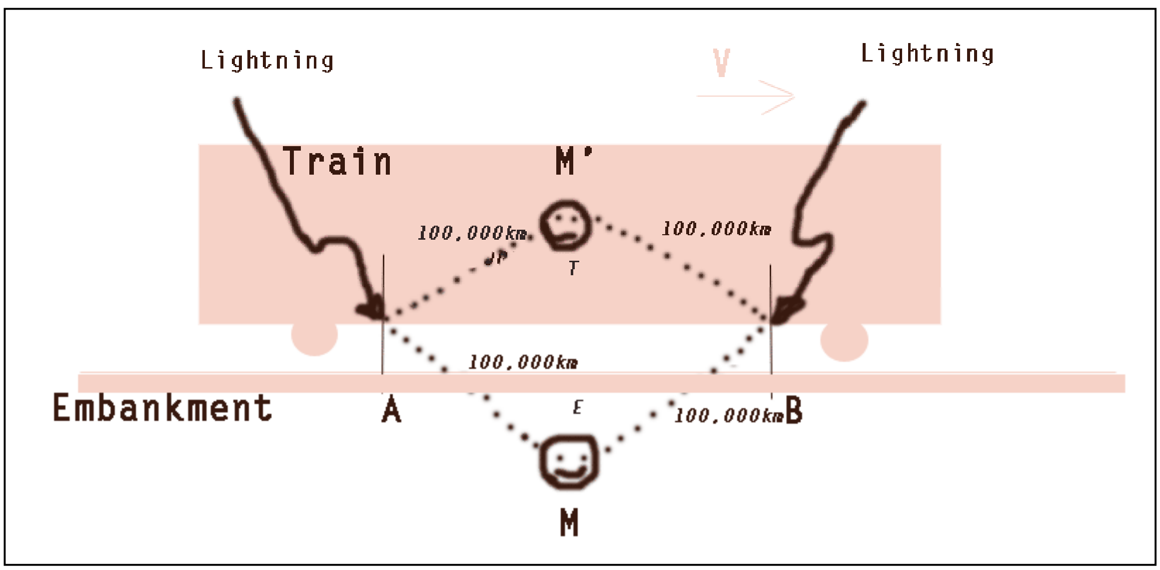
We'll then put a person on the train and call him or her T, and on the embankment one called E, and this time the train is made of glass (so you can see through it). Since this is only a 'thought' experiment we can go wild with the speeds so:

v – The velocity (speed) of the train is 200,000 km/second from left to right
c – The velocity (speed) of light in vacuum is 300,000 km/second (approximately)
M, M' – are midpoint between AB (M is on the embankment, M' on train)

The whole train, embankment and space around them has vacuum (so we equip our persons with breathing apparatus, although air only reduced the speed of light by 90 kilometers per second).

Lightning according to E strikes A and B simultaneously. In other words, E saw a lightning hitting A and B at exactly the same time, while he was standing at point M. See figure 2.

Figure 2



In fact E saw the lightning strike on A and B 1/3 of a second after the lightning hit, because it took the rays that much time to travel from points A to M, and B to M (same distance of 100,000 km)

T also observed the lightning strike. The lightning strike when T was in the position M', which is aligned with M. Since T is traveling at 200,000 km/second away from A and toward B, the lightning from A is 'chasing' (propagation of light we call it) and the lightning from B is hurtling toward T. In order to calculate the time it takes those lightning to reach T, we need simple equations:

(1) Lightning that hit A – the time t seconds is our unknown:

t*300000=t*200000 + 100000 ; since distance=time*velocity, we simply add the initial distance (100,000) and the distance T travels in t seconds and equate it to the distance the light is traveling in t seconds. t will then be: 1 second, so T saw the lightning from A 1 second after it hit A.

(2) Lightning that hit B – We'll do similar calculation for the lightning from B and we'll call the unknown time: t' ; t'*300000+t'*200000=100000; This time we add the distances because the light and T approach each other. t' then is: 1/5 of a second.

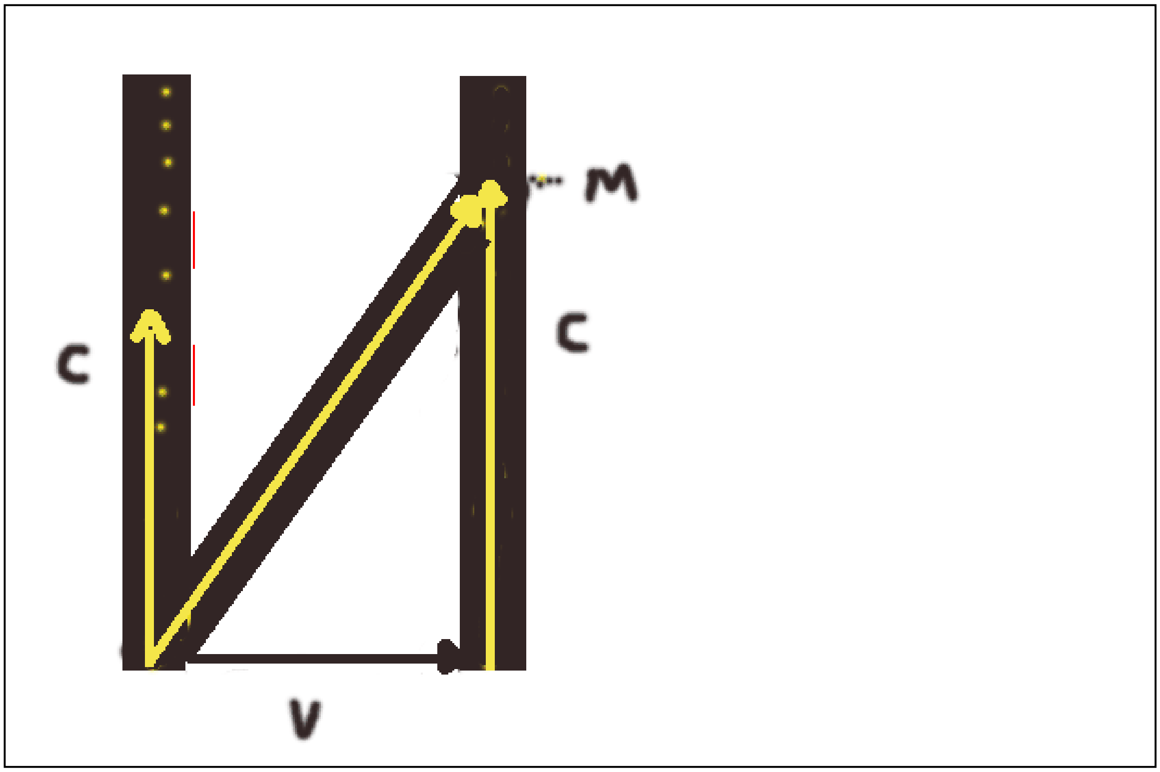
<u>Conclusion:</u> The event of lightning strike on A and B was simultaneous for E, and was not so for T. T will see the light from B a lot sooner than he'll see the light from A (0.2 s vs. 1 s)

This is an astounding revelation, contradictory to our intuition. We have shown that simultaneity is not the same for different observers, but it's dependent on their motion in respect to one another. With simultaneity disagreeable, it also leads to disagreement on length of objects in the direction of their motion, because length is measured by simultaneously 'clocking' both ends of an object – we'll have more to say about that later. It's even more startling if you think for instance about a rigid metal rod with a length of 300,000 kilometers and two observers one at each end. One moves the rod to the right. Since nothing can move faster than light, the other end, which is supposed to move to the left, does not do it instantaneously, so there is an effect on the rigidity of bodies.

My next task is to convince you that time slows down if we move. The faster we move, the less time we consume, in relation to an outside observer. At the same time I'll show you how much slower time moves as a function of the speed.

For this purpose we'll device a clock made of a hollow tube in the size of c (300,000 kilometers) with two mirrors at the top and bottom. The clock is large for the simplicity of the calculations. A beam of light is bouncing up and down the tube, so it travels each direction in exactly one second. We have two such clocks, one we load on a truck that travels in a high-speed v, and the other we leave next to us observing the truck. After what seems to us, the stationary observers, as 1 second, the truck is v kilometers away from us. The following figure 3 shows the two clocks, the truck travel of v and an overlay of our stationary clock leaning toward the traveling clock. The overlaid clock is our view, as outside observers, of the time passage inside the truck (how we view the driver's clock)

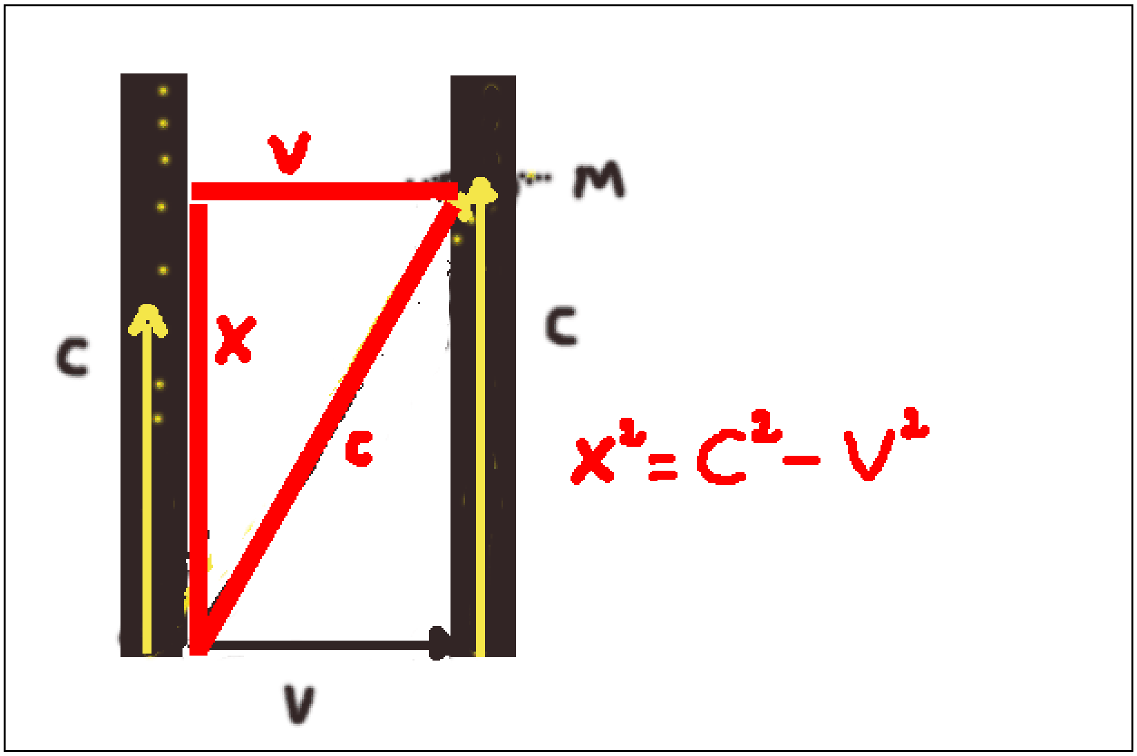
Figure 3



Remember the earlier example, if the beam of light was a ping-pong ball bouncing up and down in the tube, the driver sees it going up and down in a straight line, but the outside observer sees the ball going up diagonally (and down diagonally to the movement side).

We can obviously see why the overlaid (diagonal) clock's light beam cannot reach the top of the traveling clock, so according to our stationary clock 1 second has passed (the beam in the diagonally overlaid clock reached the top), but according to the traveling clock, the beam of light has only reached the point M, so therefore less than one second has passed for the truck driver. We can also see that the faster v, the less time would the moving clock have shown. Let's try to calculate how much slower the clock on the truck runs. I drew a red overlay on the diagram and called it: figure 4, which shows us a right angle triangle with a hypotenuse of c and one side of v. The time line on the moving clock is the equivalent of the X drawn in figure 4.

Figure 4.



Using the Pythagorean theorem we get:

$X=\sqrt{c^2 - v^2}$; If we take c outside the square root, we get: $X=c\sqrt{1-(v^2/c^2)}$

It is customary to simplify the notation by defining: $1/\sqrt{1-(v^2/c^2)}$ as the symbol: γ (Gamma, or the Lorentz factor), so we can then write: $X= c/\gamma$.
We call this effect on time: *Time Dilation*, so in order to calculate the time dilation for objects in motion we use: γ in a way that $Td = T/\gamma$, where T is the time at the stationary clock (or proper time) and Td is the dilated time on the moving clock. Here is an example:

The moving object moves at half the speed of light: c/2, so:

$\gamma= 1/\sqrt{1-(c/2)^2)/c^2}=1/\sqrt{3/4} \approx 1.155$

So if 10 seconds had passed in our stationary clock, only $10/1.155\approx 8.66$ seconds passed on the moving clock.

Let's take a more extreme case, so suppose that the object in motion has 99% of the speed of light, or about 184,000 miles per second or 297,000 kilometers per second.

$\gamma = 1/\sqrt{1-(0.99c)^2)/c^2} \approx 50$, so if we travel in space for one year at 99% of the speed of light, the time passed on earth would be 50 years. And this shows you how you can reach the future, now if we want to get to the year 3011 in one year, I'll leave it as an optional exercise for you to find the necessary speed.

As a result of the time dilation, there is another effect, which I briefly mentioned earlier. That effect is called length contraction, and that means that the moving objects become shorter in the direction of their movement to the outside observer. The lengths measured in the direction of motion are closely related to the time dilation. For instance, as the truck driver's clock ticks 1 second we can see on figure 5 that he, the driver, will say he has traveled γv kilometers, but we, the observers, will measure a distance of v, after 1 second of "our" time has passed. To summarize we can say that both us and the driver agree that he moves at a speed of v, but since we disagree on timing events, and a distance is: (time X speed), we, therefore, must also disagree on distances measured.

Figure 5.

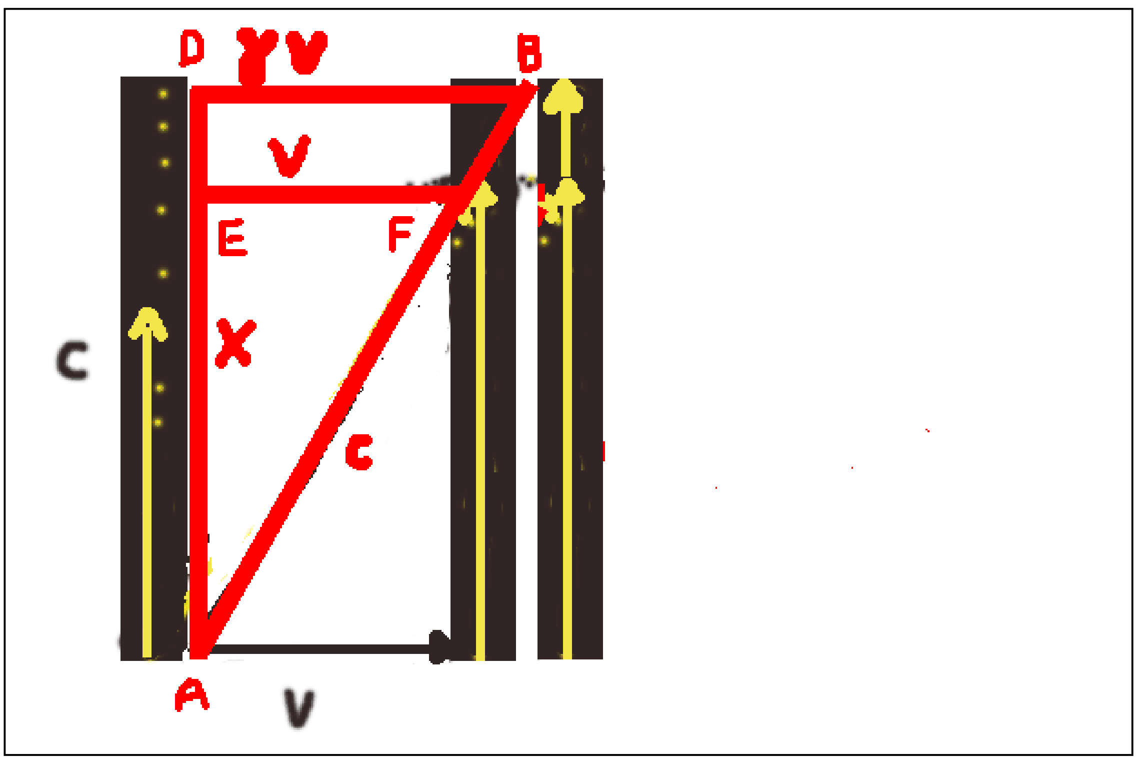


Figure 5 has an extension of the truck movement so that one second elapsed on the truck driver's clock. Note that the triangle ABD is similar to the triangle AFE (same angles), and we've already calculated that: X=AE= c/γ, and we know from geometry that the ratio between the corresponding sides of similar triangles is equal. So since: AD=C=γAE, then AB=γC and BD=γV, and therefore the truck driver views the distance as: γv after his one second elapsed, and the stationary observer sees the distance v (v*1sec). For any other distance at the moving truck, the simultaneity required to check the length, as mentioned earlier, will be different inside the truck and outside, so will always result with measuring shorter distance from the outside.

Not surprisingly we see a contraction by: γ, so another optional home exercise, if I may, please find the speed that will give us a length contraction of half the length.

GENERAL RELATIVITY

If our intuition was shaken so far, we'll add to it a bit more with the principles of general relativity. Since we've shown that time is not absolute, we'll add it as a dimension to a coordinate system, as the fourth dimension, and rather than referring to space, we'll call it space-time. Einstein was disturbed because while conceiving his idea of special relativity, the requirement of dealing with constant velocities in straight lines were quite restricting; after all, to achieve a constant velocity you need to accelerate at some point.

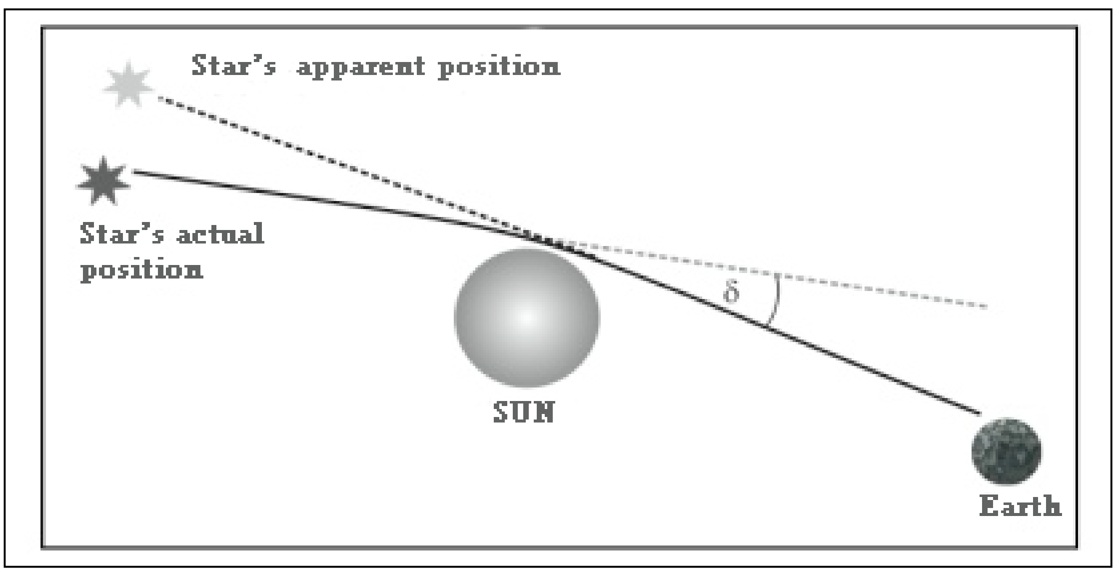
With the process of thought, and through observations, Einstein extended the principle of equivalence and realized that it is impossible for someone inside a closed chamber to tell if that chamber is accelerating uniformly in an empty space, or resting in a gravitational field, like on earth for instance. In other words, there is no physical experiment that can distinguish between the two, as is the case with uniform straight-line movement. Einstein further discovered that time slows down when measured close to a gravitational field. In order to show that, I'll describe another thought experiment.

Let's imagine a space rocket as long as c (300,000 kilometers) resting freely in space, and one observer with a flashlight on top, and another observer at the bottom. The observer on top sends a light signal every second according to his clock toward the bottom. The bottom observer also measures one second between the signals, because they have identical clocks. Now the rocket starts accelerating upward uniformly. The ceiling observer proceeds with the one-second interval signals, but since the rocket gains more speed during the travel of the signal, the bottom observer will see those signals at increasingly shorter intervals (remember light travels at a constant speed regardless of movement, but the distance it needs to travel becomes shorter, to reach the bottom). So the one-second intervals the top observer generates will arrive at shorter intervals to the bottom person. Because of the principle of equivalence we can replace the rocket's acceleration by placing it in a gravitational field (like on earth for instance), so our conclusion is that time slows down when you're closer to a gravitational field. This effect is quite small; a clock would slow down by one minute per year if placed on the sun, vs. an equivalent clock on earth. An experiment with a water tower and clocks placed at the top and bottom was conducted in 1962. Those clocks were extremely accurate, and indeed the bottom clock ran slower as predicted by general relativity.

By this time you may think that Scientists and myself are quite crazy, after all the fastest speed achieved by humans so far, is less than 0.005% of the speed of light, and a gravitational field that visibly affects time is nowhere near our earth, so why bother with relativity at all? A simple application you may be familiar with, would not be possible without corrections for relativity's effects. A GPS would miss it's mark by several miles had we not account for those effects. The twelve satellites that circle the earth, move at several tens of thousands of miles an hour and are about 12,000 miles above earth. Their clocks must be accurate to a billionth of a second with their location for triangulation purpose, so both the effects of gravitation and speed need to be considered by the GPS device that needs four signals, from four different satellites, at any given time, to calculate its location. There are other uses from astronomy to nano technology where relativity impacts calculations.

Einstein's general relativity predicted that massive gravitational fields had an impact on the direction light travels. This was confirmed the first time in 1919, during a solar eclipse, scientists observed a star whose light traveled near our sun, had its light deflected (or bent) by the sun in a way that it appeared to have been at a different location than it really was, as is shown in figure 6.

Figure 6



Without getting into the actual equations, I'll just mention that the theory accurately predicted the angle: δ. The expedition to the eclipse over in west Africa and northern Brazil came about 4 years after the theory was published, and this discovery of the light shift had been sensational for the world. Here is a sample headline

LIGHTS ALL ASKEW IN THE HEAVENS

Men of Science More or Less Agog Over Results of Eclipse Observations.

EINSTEIN THEORY TRIUMPHS

Stars Not Where They Seemed or Were Calculated to be, but Nobody Need Worry.

A BOOK FOR 12 WISE MEN

No More in All the World Could Comprehend It, Said Einstein When His Daring Publishers Accepted It.

General relativity postulates that gravitational field is nothing but a curvature of space-time caused by body masses in a similar fashion that would happen if placed on a trampoline. It further proclaims that the movement of those bodies like stars and planets are along what's called geodesic lines in the curved space-time continuum.

Geodesic lines are the shortest paths between a pair of points on a sphere. They are part of a great circle, a circle whose center is the sphere's center. Airlines fly along geodesic lines, because they are shorter than other routes. For example the 'straight' line between Madrid and New York is 3,707 miles, and the geodesic is: 3,605 miles.

MORE ANOUT THE UNIVERSE

This leads us to the third topic I wanted to explore which is some revelations about the universe and how they were discovered or hypothesized. The ancient Greeks believed the earth was the center of the universe, some even thought earth to be a disk, not a sphere, held by giant turtles. We've come a long way since then. Every child now knows that the earth is one of the planets revolving around the sun. The number of visible stars to the naked eye in the night sky is about 5000, though with today's powerful telescopes we can observe about 100 Billion stars similar to our sun in our Galaxy, called the Milky Way. We can also observe about 100 Billion galaxies, so I'd also leave it for you to calculate how many potential planets exist in the observable universe. To calculate distance to far-away stars we use something called parallax, which is the effect of seeing objects differently when they are at different distance from us, as we are moving in relation to them. For example, if we ride a car and there are trees along the road, those trees will 'fly' by us much faster than say buildings that are 1 mile away from the road. In the same fashion we use nearby stars and the change of their position in relation to further ones, to measure distances between earth and those far-away stars. Aside from the sun, which is only 90 million miles away from us, the nearest star to us is called Proxima Centaury, or Alpha Centaury, and is about 4 light years away from us or approximately 24 Trillion miles. The parallax method can be used when there is some movement, however, with very far stars, they may look fixed and other methods like star brightness must be deployed. For some sense of distance let me mention that our galaxy, The Milky Way, is shaped as a spiral and is about 100,000 light years across. The problem of judging distance by light intensity is that stars have different luminosities.

The American astronomer Edwin Hubble showed in 1924 that there are other galaxies besides our own. Hubble classified star types according to their luminosity for nearby stars, for which parallax used to measure distance. In that way he was able to detect similar luminosity stars much further away, and then use their apparent brightness to measure the distance. One of the most useful tools astronomers use is a prism that breaks down light to its spectrum of colors. The missing colors of the spectrum of light emitted from different stars tell us the composition of their atmosphere. In addition, scientists found out that when viewing the spectrum of stars in remote galaxies the color spectrum had been shifted toward the red. Using a phenomenon called The Doppler effect, they were able not only to determine that those stars were moving away from us, but also the speed in which they were moving.

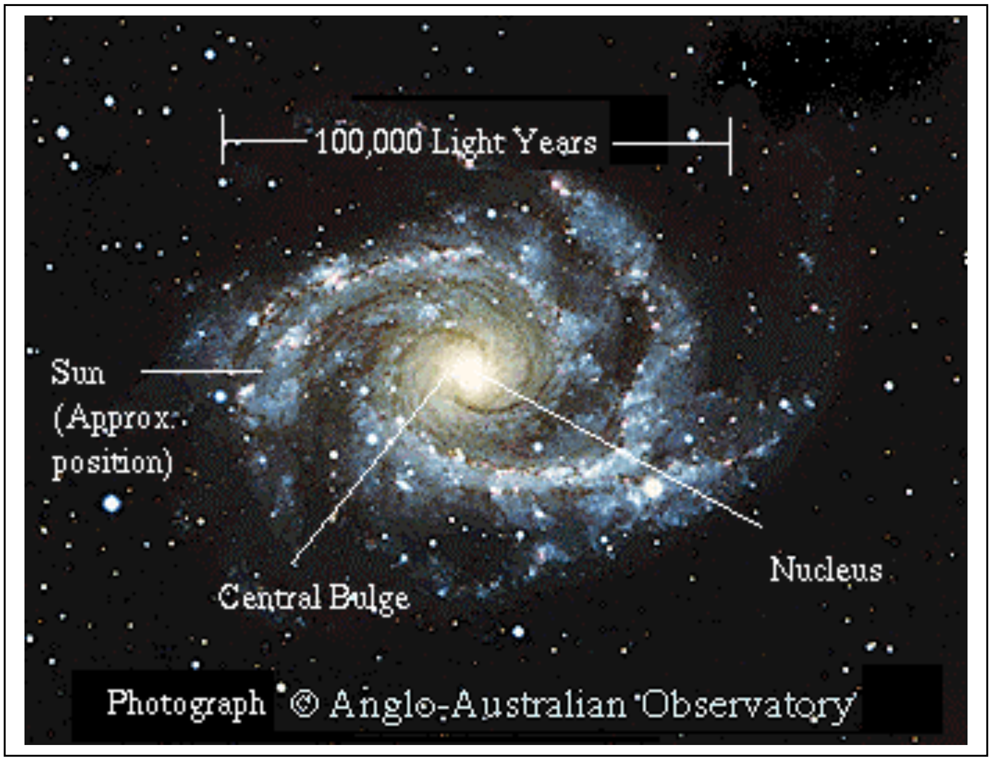
A quick word on the Doppler effect, when a car moves toward us or away, its sound changes, especially when the horn is used. This is because the sound waves flow more or less frequent, depending on the direction. This change in frequency allows us to measure speed, and this is how the police can catch you speeding, even if they are far away from you. The same effect happens to light waves (which are 40 to 80 millionth of a centimeter for visible light). The light wave becomes elongated when the source of light moves away, so the spectrum is shifted toward the red (longer side). Another measure that the spectrum allows is the temperature of the star.

Hubble discovered to his and other scientists' surprise not only that the vast majority of galaxies were moving away from us (color red-shifted rather than blue), but also that the further the galaxy is, the faster it moves away. This discovery established the theory of our expanding universe, which is so far uncontested. If the universe were static, there would have been no force to counter gravity, in which case the universe had to collapse inward – It's interesting to note that scientists could have come to this conclusion two hundred years before they did. There are in fact 3 possible outcomes to how the end of the universe will look like. The first predicts that at some point the expansion will stop and gravity will cause it to contract, the second predicts that gravity will slow it down a bit, but the expansion will not stop, and the third predicts that gravitation will slows it significantly, but will not stop it completely.

In 1922, the Russian astronomer, Alexander Friedman, made two simple assumptions about the universe. The first was that the universe looks the same no matter what direction you look at, and the second was that the first assumption is true regardless of your observation point – Both assumptions are true on a large scale. This was a prediction that was verified by Hubble's findings later.

The term Black Hole was coined only in 1969, however, the phenomenon has been known for a while. In 1783, John Mitchell of Cambridge, England, had published an article saying that stars that were sufficiently massive and compact, create such enormous gravity that even light would not escape it, an observation that was shortly and independently corroborated by the French scientist Marquis De Laplace. We call the outer boundary of a Black Hole, The Event Horizon, the point at which anything would be sucked forever into it. It's interesting to note that our Milky Way galaxy has a massive black hole at its center, it's more than a million times the mass of our sun, and the star rotating it (which is one of the ways to discover Black Holes), does that at a dizzying 2% of the speed of light, or 3700 miles per second. In general, the visible stars of all the galaxies cannot even account for 1% of the mass required to hold the universe at its current state, so we strongly believe that there are different types of dark matter/energy that account for the invisible but strongly felt gravitation effects.

Our sun is an average yellow star near the inner edge of one of the spiral arms of the Milky Way. The galaxy rotates around its center completing an orbit once every several hundred million years.



A Supernova is when a massive star collapses under its own gravity and its outer regions explode with tremendous force. The Chinese recorded one in the year 1054, about 5000 light years away from earth. The light was so intense that you could read at night, and it was also visible during the day for months – Its remnants are what we call the Crab Nebula. A Supernova 500 light years away, could rival the sun's light (and the sun is only 8 light minutes away). If a supernova occurs close enough to us, it could annihilate life on earth with its radiation. The last supernova in the Milky Way occurred before the telescope was invented, 1604. The prime candidate for the next one is a star called: Rho Cassiopeae, which is classified as a yellow Hyper-giant (one out of 7 such stars know in our galaxy). In a Supernova explosion some of the heavier elements deflected from a star back into the galaxy space, later form new stars like the sun and like our solar planets. Our sun in fact is a 2nd or 3rd generation such star that was formed some 5 Billion years ago.

In recent years scientists have discovered that the rate of expansion of the universe is accelerating, which is a puzzle. If the big-bang was an explosion, how can the particles blown off, accelerated, in fact the opposite should happen.

Hubble Telescope's images:

http://www.youtube.com/watch?v=fgg2tpUVbXQ&feature=related