GRAVITATIONAL REDSHIFT

1.1 A brief history of gravity

The first philosopher who ever wondered about the nature of gravity was Aristotle (384-322 BC). He thought that the natural state of all the objects on Earth, believed at centre of the Universe, was at rest, and therefore all the moving objects will always come to a halt. The heavens, however, were believed to move naturally and endlessly in a complex circular motion, and for this reason, he thought that they had to be made of a different substance unknown to Earth - aether. Aristotle believed that everything on the Earth was made up of four elements: earth, air, fire and water. Therefore, aether had to be the fifth element that distinguished the heavens from Earth; a superior element incapable of any change other than the circular motion. His, was also the idea that heavier bodies fall faster than lighter ones when their shapes are the same, a mistaken view that was accepted until Galileo conducted his experiment with weights dropped from the Leaning Tower of Pisa more than 1800 years later.

Galileo (1564-1642), with the German astronomer Johannes Kepler, initiated the scientific revolution that flowered in the later work of Sir Isaac Newton. Like Kepler, he believed that all the planets including the Earth orbited the Sun, which at the time was against the belief of the Church. For this reason, more than any other person, Galileo deserves to stand as a symbol of the battle against the Church authority for freedom of inquiry. During his teaching career, he observed how Aristotle had mistaken in believing that the speed of fall was proportional to the weight, by dropping objects from the Leaning Tower. By careful measurement he discovered the law of falling bodies, the parabolic path of projectiles and the harmonic motion of pendulums, turning physics from speculative to exact experimental science. At the beginning of the seventeenth century, Galileo, after hearing of lenses invented in Holland, built the first telescope with which he first discovered lunar mountains and craters, the sunspots, four satellites of Jupiter, the phases of Venus and confirmed his preference for the Copernican system. Despite the numerous discoveries in astronomy and intuition about the nature of gravity, Galileo, missed the key idea that unites both fields embracing and all bodies in the Universe.

Fifty years later, Newton (1643-1727) published his book *Principia* in which he describes the three laws of motion, still largely used today, and marking the beginning of, what today is called, Newtonian mechanics with his law of gravitation. In his book, Newton marries the laws of motion, experimented on Earth, with the planets orbiting the Sun, helped by his incredible vision that all planets are simply ever falling objects. However, although the effects of gravitational forces had been completely discovered, the actual cause and nature still remain unveiled; Newton himself, attributed the origin of these forces to the same mysterious intrinsic property of matter. This idea was maintained for the next three hundred years; some remarkable comment was made by James Clerk Maxwell (1831-1879), the interpreter of the electromagnetism, in which he inquired how could two bodies know of the presence of each other without any action made on the surrounding medium.

At the beginning of the twentieth century, Albert Einstein (1879-1955), was working on his *Special theory of Relativity* when he had, what he called, the happiest thought of his life, namely that an observer in free fall would experience no gravitational pull. As a consequence he proposed the *Equivalence Principles*, which states the equivalence of a gravitational field with an uniformly accelerated frame, and therefore, he extended his special theory of relativity to accelerated frames in his *General theory of Relativity* in which, he also included his gravitational field equation. With his *Equivalence Principle*, Einstein eliminated completely the problem of a gravitational force acting between two bodies, and attributed gravity to the distortion of space and time in the vicinity of the two bodies. During the late years of his life, Einstein tried to understand the nature of the interactions between matter, electromagnetic forces and spacetime in his last effort, the *unified field theory*, which still remain unfinished today.

Being Gravity, one of the first queries that confronted men, and still being one of the problems that the greatest scientists are trying to solve, it certainly deserves the recognition of the longest unsolved problem that human history has ever encountered.

1.2 Classical theory of gravitational redshift

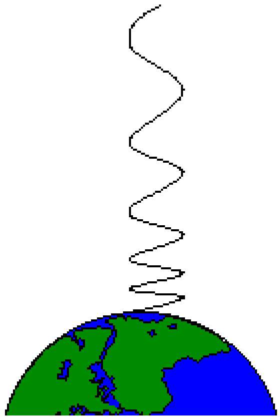

Fig. 1.1 - Effect of large masses on electromagnetic signals coming from outer space.

Gravitational redshift is the effect that gravity does on electromagnetic waves when entering or exiting a gravitational field. From Figure 1.1, it is possible to notice that the frequency is higher near the mass where the gravitational pull is stronger, and it is lower where away from the mass, where the pull is weaker. This can be shown by substituting the expression for the gravitational acceleration g into the formula for the gravitational redshift. This is:

$$\Delta f = \frac{GM}{Rc^2} f_t \quad \text{but} \quad g = \frac{GM}{R^2} \quad \text{hence} \quad \Delta f = \frac{gR}{c^2} f_t \qquad (1.0)$$

The leftmost expression for the gravitational redshift, assumes that the signal is coming from outer space, therefore the redshift is taking place along the whole travelled distance or infinity. The rightmost expression, can be use to calculate the redshift of a signal transmitted at a certain height, by substituting the radius of the mass R with the travelled distance of the signal H. The formula can be derived imagining a photon of light falling on the mass. The mass of the photon is:

$$m_p = \frac{hf}{c^2} \qquad (1.1)$$

where the product h, the Planck's constant, and f, the frequency of the photon, represent the photon energy. When the photon falls for a distance H inside the gravitational field of the mass, it gains a potential energy equal to mgH. Thus, its total energy, at the end if its path is the sum of its initial energy and its final energy:

$$hf_2 = hf_1 + mgH$$

which, when inserting the photon mass (1.1), it becomes:

$$hf_2 = hf_1 + \frac{hf}{c^{2\mathrm{gH}}} \quad \text{or} \quad f_2 - f_1 = \frac{gR}{c^2} f_1 \qquad (1.2)$$

In the case of a signal coming from outer space instead, the derivation of the formula can be tackled using the potential energy of a mass on the surface of the Earth or any other large mass. That is:

$$PE = \frac{-GMm}{R}$$

where M is the large mass and m is the smaller mass, which, when substituted with the photon mass (1.1), it becomes:

$$PE = \frac{-GMhf}{c^{2\mathrm{R}}}$$

Once again, the total energy of the photon is the sum of its original energy and the energy gained by the gravitational pull of the large mass:

$$hf_2 = hf_1 - \frac{GMhf_1}{c^2 R} \quad \text{or} \quad f_2 - f_1 = \frac{-GM}{Rc^2} f_1$$

which is the same expression (1.0) but with a minus sign in front which shows that the frequency decreases as the signal leave the mass.

Experiments on testing the gravitational redshift on Earth, was carried out by Robert V. Pound and Glen A. Rebka in 1960 at Harvard University. They demonstrated that a beam of very high energy gamma rays was slightly redshifted when launched up the elevator shaft of the Jefferson Tower physics building. The gamma ray was emitted from the decay of a cobalt atom ^{57}Co to iron ^{57}Fe at ground level with a frequency 3.5×10^{18} Hz. At the top of the 22.5m high tower, the redshift can be calculated by using Equation 1.2, this results in about 8.6 kHz, which was measured within the ten percent. [3]

In 1964-65 the experiment was repeated by R. V. Pound and J. L. Snider and proved within 1%. [4]

1.2.1 The effect of the Moon

This paragraph tries to explain what would happen to the energy of the same photons when the Moon or another large mass comes out at a certain distance. As shown in Figure 1.2, the total acceleration constant g would decrease due to the opposite attraction of the other mass, hence, as indicated by the rightmost expression in 1.0, also the frequency variation Δf must decrease. Referring to Figure 1.1 (previous page), if the Moon is placed at point A, the frequency at that point is expected to increase for the grater pull of the Moon than the Earth, whilst the frequency at point B on Earth is expected to decrease, because the Moon would weakly interfere with the signal in the opposite direction. The final signal would appear as slightly shifted toward point A.

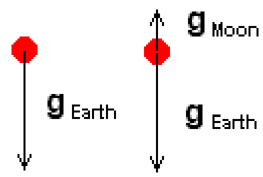

Fig. 1.2 - Effect of the Moon on gravitational redshift on Earth.

1.3 Spacetime theory of gravitational redshift

When Einstein published his first paper on Special Relativity, he introduced the world to a new dimension, the dimension of time. With his theory, he found that space and time are locked together, and cannot be separated. In other words, if space exist, than time is essential for objects to move within it. Since then, the concept of spacetime and the fourth dimension had begun. One of the following papers he published was General Relativity, where he extended his previous paper and the Equivalence Principle to described how gravity can be considered as distortion of space time, which makes a freely falling body to be in its natural state. He imagined a large mass to distort spacetime in the same way a mass placed on top of a rubber sheet distorts the rubber sheet making any other mass in the vicinity to fall towards it as shown in Figure 1.3. He then spent the rest of his life trying to understand how mass and spacetime interact, that is, which force makes spacetime distort.

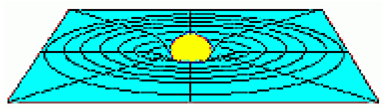

Fig. 1.3 - Rubber sheet model for gravity.

1.3.1 Multidimensional objects

The problem with spacetime is that it is a four dimensional object, hence, there is great difficulty in understanding how it can be imagined using the only three dimensions available in space. Today, however, these concepts are often used in other fields like Computer science. Computer programmers use the idea of multidimensional memory cell, which they call arrays. One array, is simply a memory cell in which they can store data. A one dimensional array, is a row of these cells which makes up a line. A two dimensional array is many rows aligned next to one another to make up a plane. A three dimensional array, is many plane aligned next to one another to make up a square solid. The pattern here is that, the last object that has been created is multiplied by the number of the next dimension, hence, if the array was 3 cell long, then the three dimensional array is $3\times3\times3=27$ cells. Consequently, the four dimensional array is $27\times3=81$ cells, which is the solid formed by the three dimensional object lined up again along a row this time 3 solids long. A five dimensional array is then many of these rows aligned next to one another to form a plane of solids, and so on.

There is absolutely no difference, if instead of arrays, instants (non necessarily in time) are considered. A one dimensional object, is simply a line (x-axis) formed by a succession of frames (points) at which the object has been considered (Figure 1.4*a*). A two dimensional object, is the same line framed at different instants along another perpendicular line (y-axis) to form a plane (Figure 1.4*b*). A three dimensional object, is that plane framed along another line (z-axis), still perpendicular, to form a square solid (Figure 1.4*c*). Therefore, a four dimensional object, is that solid framed at different instants, again placed along the first line (x-axis) to form yet another line (Figure 1.4*d*), and from here the pattern repeats itself up to infinite dimensions. What all this means, is that to represent spacetime as four dimensional object, it is simply possible to imagine it as a three dimensional object, and if the fourth (time) needs to be added, then the whole object can be

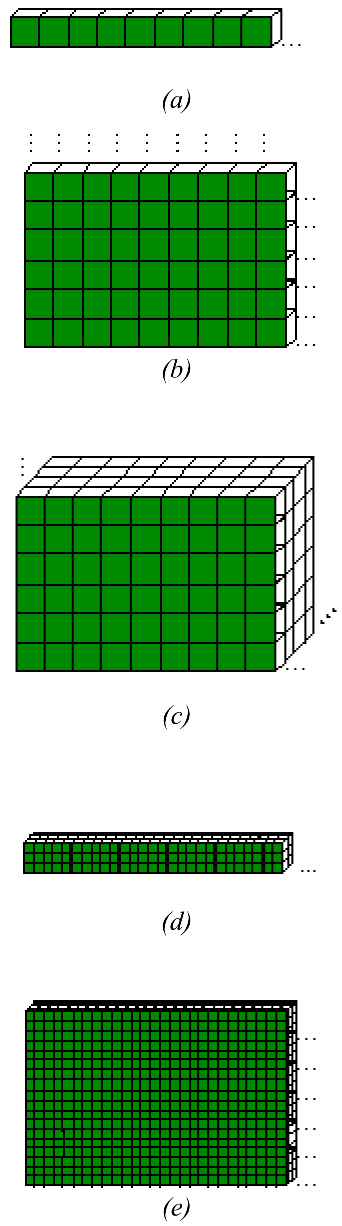

Fig. 1.4 - (*a*) One dimensional object, (*b*) two dimensional object, (*c*) three dimensional object, (*d*) four dimensional object, (*e*) five dimensional object.

considered constant as a single line and framed at different instants placing the values obtained into yet another line to form a graph containing the fourth dimension alone. It is the same technique used in partial differentiation.

1.3.2 Three dimensional spacetime model

The first step to deriving the distorted spacetime in three dimensions is to start from its representation in one dimension and try to develop it to the others two remaining. Figure 1.5*a* shows, the same rubber sheet model shown in Figure 1.3 but with only one dimension. As indicated, the figure suggests that at the middle, where the slope of spacetime is horizontal, there is an equilibrium point. Indeed, in real life, an equilibrium point exists at the centre of every mass, therefore, the drawing can be slightly improved if these two locations are overlapped as shown in Figure 1.5*b*.

In order to visualise spacetime as a three dimensional object, it is essential to immerse the mass into the rubber sheet, since all masses are actually immersed into spacetime. The first step, is then to insert the model into a coordinate system choosing the equilibrium point as the origin as shown in Figure 1.5*c*. Bearing in mind that the mass is buried into the spacetime medium, than the same thing seen in one direction would be also seen in all other directions. Starting with the horizontal, the same line above is mirrored below the axis, again shown in Figure 1.5*c*. Then, to better the idea of the mass being plunged into the rubber sheet, a number of layer, corresponding to distorted axis, can be added at both the top and the bottom of the origin, considering that the farther the layers are from the mass, the less the distortion caused by the mass would be, up to a point where the layer would be perfectly straight again (Figure 1.5*d*). Repeating the same procedure for the vertical direction, the resulting model is shown in Figure 1.5*e*, where, it is clearly visible, that the initial curvature of spacetime in the original model, has changed into a stretching inwards the mass. By repeating again the procedure, for the third axis, perpendicular to the page, the final three dimensions model is obtained as shown in Figure 1.6, where the mass would be at the centre inside the picture. Each line, represents

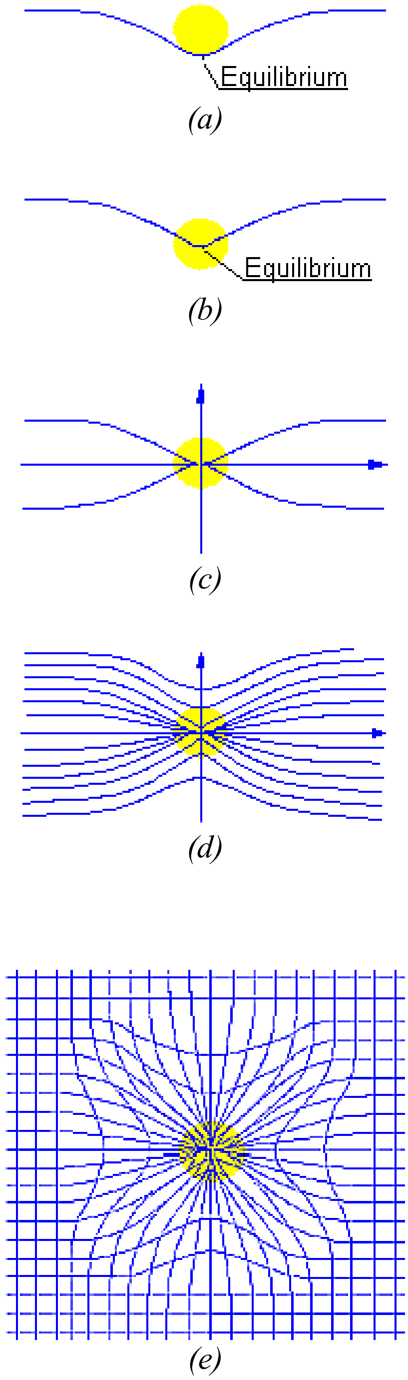

Fig. 1.5 - (*a*) One dimensional spacetime gravity model, (*b*) overlap of the two equilibrium points, (*c*) immerse the mass into the rubber sheet by first inserting the model into a coordinate system, (*d*) add layers of rubber and (*e*) repeat for vertical direction to obtain two dimensional model for gravity.

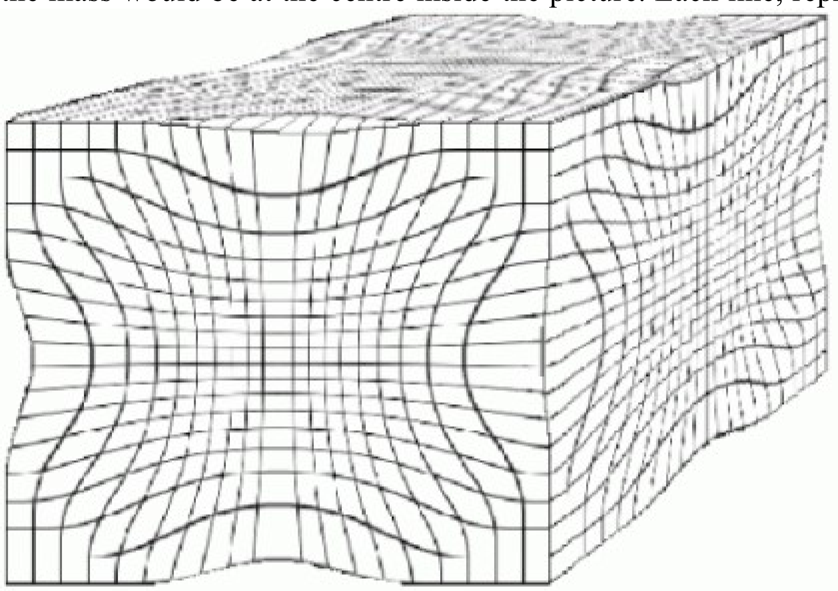

Fig. 1.6 - Final three dimensional version of spacetime distortion around a spherical mass (left).

a coordinate that gets distorted by the mass inside, by the same mysterious force that interacts with spacetime by curving it in the original rubber sheet model proposed by Einstein. The eight corners of the figure, are not distorted as they are further away from the mass than the sides which are instead distorted. This is because, being the mass spherical, then the distortion caused by it, all around it, must be spherical too. Moreover, the faces of the cube, should also be slightly distorted inward (concave), as their plane is not distant enough from the mass to not suffer any distortion.

1.3.3 Latticework of clocks

Events are specified by a place and a time of happening, and in spacetime physics these are determined by imagining a cubical latticework, with identical clocks placed at each intersection (Figure 1.7). These clocks are synchronised in light travel time, which means that each clock indicates the time employed by light to reach its point from another reference point. To synchronise these clocks, an imaginary flash of light is made started from the reference clock, which spreads out in all directions as a sphere. Whenever this flash of light reaches a nearby clock, it sets the time for that clock to read, so if a clock is 10 meters away, then it will read 10 meters of light travel time.

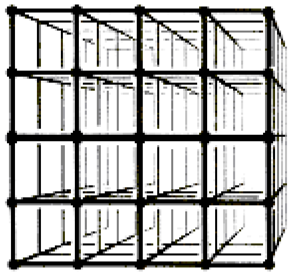

Fig. 1.7 - Latticework used to determine events in spacetime. Each intersection between two or more sticks is represented by a clock.

The previous paragraph describes how to derive, from the two dimensional spacetime curvature, to the three dimensional stretched model for gravity. What the model in fact represents, is that a mass placed within the lattice, would cause it to stretch inwards as shown in Figure 1.5*e*. When a ray of light enters the gravitational field of the mass, it will find that the clocks at each of the encountered intersections, get more and more distant as it approaches the mass. On the other hand, it is universally recognised that the speed of light is constant, therefore, the travelling beam of light cannot accelerate to reach the next clock in time such that its speed is measured to be constant.

Considering the drawing of Figure 1.7, if the lattice is stretched from either sides, the space between two nodes or clocks increases, while the two clocks will still read the same time. A beam of light reaching the first clock in the direction of the stretching, must arrive at the next clock at the time indicated on the clock, without accelerating. It does this, because space is not the only thing that gets stretched, in fact, as the two clocks get further apart, they will always read the same time, which means that also the time between the two clocks gets stretched of the same amount. Therefore, to an observer placed between the two clocks, the speed of light will measure the same as an observer placed somewhere else simply because his clock will run slow. As a consequence of this statement, time near a large mass, must run slower on the surface than on a ship in orbit around the mass. Ref. [1][2].

1.3.4 Gravitational redshift

The previous paragraph, explained how the speed of light stays constant whatever happens to the spacetime medium. In this paragraph it is shown that if the frequency of light is also assumed to be constant, then some consistency between the gravitational redshift formula

(Equation 1.0) and spacetime arises. At the end of the day, frequency is the rate at which the electromagnetic field changes direction, hence, if the speed at which the electromagnetic field travel through space does not change, than why should the frequency. In an antenna, the current is forced to alternate the direction to produce changes in the electromagnetic field, and therefore propagate through space. The frequency at which the current alternates is determined by the time constants within the oscillator device, which in turn depend on spacetime. However, once the electromagnetic wave leaves the antenna, that frequency is held throughout the entire journey. Thus, supposing that the frequency is constant is not a totally unjustifiable assumption.

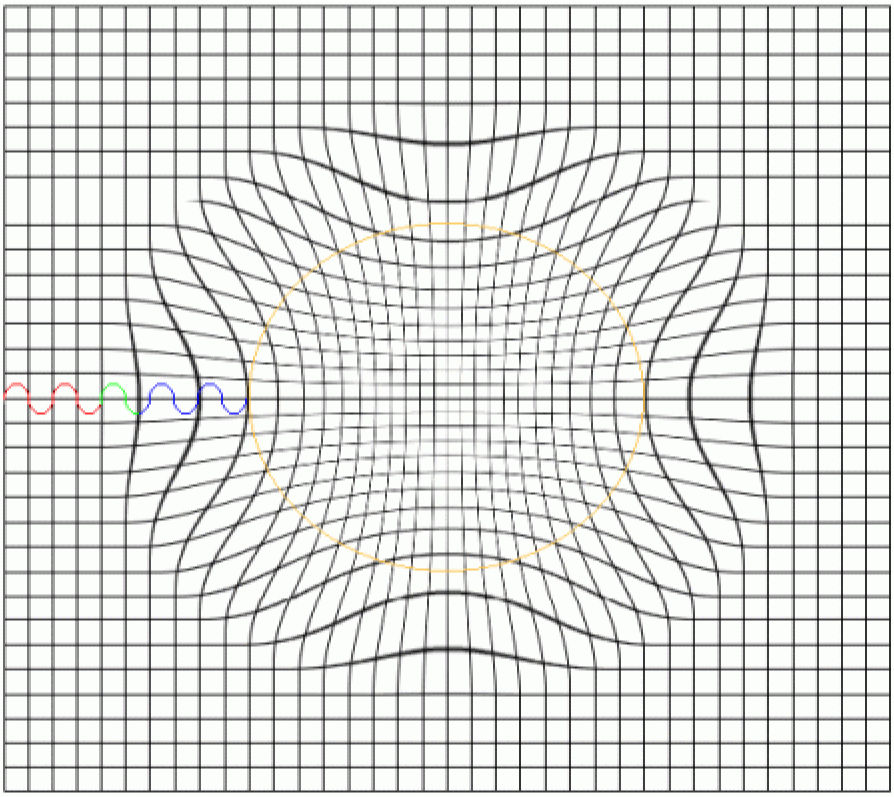

Fig 1.8 - Cross section of latticework of three dimensional model for gravity.

Figure 1.8, shows a cross section of the latticework across the mass at the centre, and a signal coming from outer space whose frequency is left constant throughout the gravitational field. As spacetime in the vicinity of large masses is stretched, than both units to measure time or space are also stretched, hence, either the clock to measure frequency or the meter to measure the wavelength, would measure a higher frequency or a shorter wavelength respectively. Considering time for a start, and assuming that each small square in Figure 1.8 represents one second, from the figure it is possible to see that with the same second two different frequencies are measured depending how close the observer is to the mass.

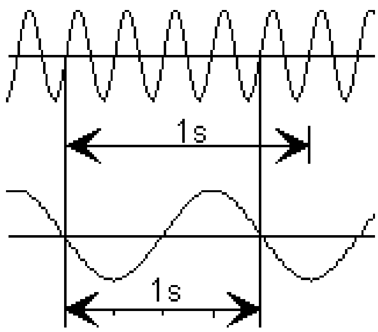

Fig 1.9 - One small square of Figure 1.9, is reported to show consistency with the gravitational redshift equation.

To look it more closely, in Figure 1.9 it is reported one small square only, and in it, there are also two sinwave with different frequency. This has been done to show that for a given gravitational field, the redshift caused by it, is proportional to the frequency as expected by Equation 1.0. Thus, looking at the top wave first and measuring its frequency with the bottom non stretched second, it results 4 Hz, whilst the bottom signal, measured with the same second results 1 Hz. Now, repeating the measurements using the top stretched second, as the two signals approach the mass, it is possible to see that the top signal is now 5 Hz, whilst the bottom is 1.25 Hz. Summarising, the top signal was 4 Hz and has become 5 Hz, hence, Δf is 1 Hz, at the same time, the bottom signal was 1 Hz and has become 1.25 Hz hence Δf is ¼ Hz. This clearly agrees shows that the higher the frequency the higher the shift caused on the signal in agreement with the previous statement about Equation 1.0, and also, again as expected, the ratio $\Delta f/f$ is constant for both signals.

In order to be absolutely sure that the model agrees completely with the formulas, a further check needs to be done by, this time, using space instead of time. To do this, it is simply necessary to measure the wavelength rather than the frequency, and prove that the redshift is also proportional to the wavelength, as:

$$\Delta \lambda = \frac{GM}{Rc^2} \lambda_2 \tag{1.3}$$

which can be proved in the same way as the frequency, but substituting the energy of the photon hf by hc/λ. The fact that this time there is the final wavelength (λ_2) rather than the initial (f_1) as in Equation 1.0 does not make any difference as it is simply a matter of choosing which end is the transmitter. The positive sign means that as the frequency increases, the wavelength decreases. So, still referring to Figure 1.9, but considering the square to be one meter instead of one second, the top signal wavelength, would measure 0.25 meters, and the bottom signal 1 meter. Then, getting closer to the mass, the same meter would stretch to become slightly longer as shown with the top double arrow headed second. With that meter, the top signal measures 0.2 meters, and the bottom signal measures 4/5 m or 0.8 meters. Again, for the top signal where λ was 0.25 meters, $\Delta\lambda$=0.25-0.2=0.05m and for the bottom signal, where λ was 1 meter, $\Delta\lambda$=1-0.8=0.2m, which prove that the longer the wavelength the greater the shift as expected by the formula. Moreover, the ratio $\Delta\lambda/\lambda_2$=0.25 is always constant and so is $\Delta\lambda/\lambda_1$=0.2 as expected.

As it has been shown, the three dimensional latticework model for gravity, could really be mathematically described by the same formulas used for the gravitational redshift with the only assumption that frequency is not affected by gravity as for the speed.

1.3.5 The Moon effect

Again, this short paragraph, consider the effect that the Moon would do on a signal coming from outer space. Looking at Figure 1.8, if another mass is placed at the left of the signal, the latticework between the two masses would stretch even further resulting in an overall frequency increase. More precisely, the end of signal near the new mass would increase substantially, while the other end near the mass at the centre, would increase only slightly for being further away from the new mass (Moon). This second point, is in opposition of what the classical theory predicts as seen in paragraph 1.2.1. However, both theories agree on the mathematical point of view, which is, that the difference in frequency Δf between the two ends must decrease.

1.3.6 Relationship between the two models

Once the necessary steps to transform the two dimensional curved spacetime model for gravity, into the stretched three dimensional model have been illustrated, the next reasonable step is to find any relationship between the two.

Relating to the three dimensional model, as it was mentioned in the previous paragraph, and as illustrated in Figure 1.8, the small squares of the lattice, get more and more stretched as they approach the mass. In fact, there should be the maximum stretch somewhere near the surface of the mass, and the minimum at infinity, with a decrement equal to the inverse square law until the relaxed distance between two nodes of the lattice is restored. In the same way, the curvature of spacetime in the original model, is proportional to the gravitational pull that would affect another mass in the vicinity. Therefore, as for the three dimensional model, the slope of the curvature should decrease with inverse square law as it leaves the mass. By consequence of both obeying the same law, the degree of stretching in the three dimensional model, is proportional the slope of the curvature in the two dimensional model without any mathematical change.

The experiments carried out to test the gravitational redshift, launch a high frequency signal vertically to measure its frequency at a certain altitude. From the spacetime point of view, from Figure 1.8, the two measurements are taken at different positions along the stretching, therefore, located in different squares with different degree of stretching. Consequently, the difference in the frequency measured at the two ends of the launched signal, tells us how steeply the degree of stretching changes at that point, or, for the two dimensional model, they would tell us about the slope of the curve at that point.

GRAVITY

2.1 A hint to gravity

Let us imagine we have a sphere of radius *R* filled with energy *E*. The sphere initially would have an energy density of:

$$\rho = \frac{E}{Volume} = E \frac{3}{4\pi R^3} \tag{2.0}$$

then we start compressing the sphere in all directions making the radius *R* of the sphere smaller, and hence the energy density greater. Now let us assume that there is a maximum energy density that spacetime can have, and let us assume that we reached that density by compressing our sphere to its limits. What we would have is simply a very dense sphere of energy as shown in Figure 2.1, that would be impossible to shrink further. But I am not done with assumptions, and I will assume that I have a much greater force, even greater than the force that spacetime has to keep it from shrinking. Well, if I compress the sphere even further, and spacetime cannot stand more energy than that, the only thing that spacetime can do is to shrink with the energy it contains, hence producing something as shown in Figure 2.2. This figure is the same as Figure 1.5e which was derived from General Relativity as discussed in paragraph 1.3.2.

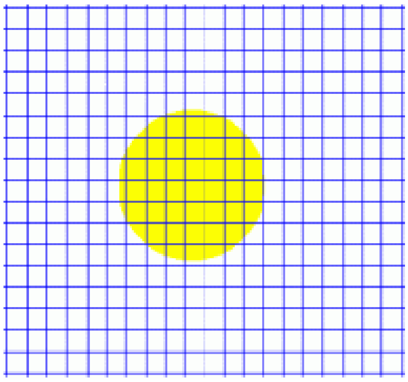

Fig 2.1 - Sphere of energy compressed to the limit.

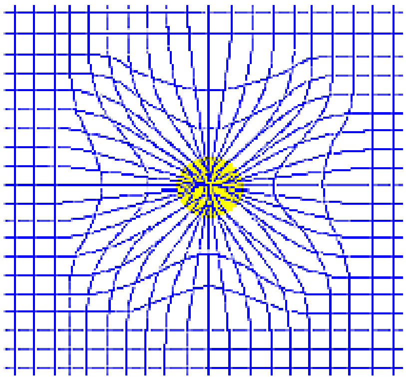

Fig 2.2 - Same as Figure 1.5e, but this time it shows a sphere full of energy compressed with a force greater than the stiffness of spacetime. The volume of the two sphere is the same, and so is the density.

If this was the case then we would be able to measure the stiffness of space time; we know the force we applied, and we know the displacement we have shrank spacetime. Hence:

$$F = -kx \rightarrow k = -\frac{F}{x} \tag{2.1}$$

Hugh D. Young in his book University Physics states "*all nuclei have approximately the same density*". The idea that comes to mind now is; what if what we have described so far is the nucleus of an atom? What if there was a fight between the nuclear force that compress the nucleus together and spacetime that limiting its density prevents it from collapsing into a dimensionless point? Obviously one nucleus on its own would not have enough force to distort spacetime considerably, but many atoms put together as in large masses might just have that force. In this case we would still be able to measure the stiffness of spacetime as we know the force of the nucleus and the displacement. The force is simply the sum of all the forces of all the nuclei that make up the mass, the displacement would be the gravitational redshift ($\Delta\lambda/\lambda$) caused by the mass/energy itself, something like:

$$k = -\frac{\lambda}{\Delta\lambda} \sum_{n=1}^{N} F_{nucleus} \tag{2.2}$$

where N is the number of atoms present in the mass.

Attention must be paid to the fact that the density we would measure is higher than the maximum density that spacetime can hold.

That is because the unit we use to measure the density is outside the sphere, and hence not compressed making the volume appear smaller when in fact is the same as the sphere before compression.

2.1.1 The assumption

Now let us discuss the assumption we made about the limit of energy density that spacetime can take. To do this we will look at the reason why waves propagate and we will start from the easiest, that is a rope.

Everyone knows that if we start to oscillate one end of a rope the waves propagate through the rope to reach the other end which in turn oscillates in the same manner. When we oscillate one end of the rope, all we do is to oscillate around a middle point, and from there all other points along the rope are pulled by the preceding point and start to oscillate as well. Therefore there is an interaction between all points along the rope, that makes all points to oscillate around the same middle point.

The same observation can be done with water waves, molecules of water, that cannot be pulled apart at liquid temperature, pull other molecules to oscillates around a middle point that is the level of the water in the tank or the sea level if we are thinking at waves in the sea.

Now let us look at sound waves. Sound waves propagate through a medium (let it be air) because molecules of air are pushed and pulled by areas of high and low pressure. Hence the pressure of a section area or shell inside the wave oscillates around a value of pressure that stands in the middle between the high and the low pressure.

In the same way, waves of electricity propagate through a copper wire. Areas of high voltage with many electrons push electrons towards areas of low voltage with very few electrons and vice versa.

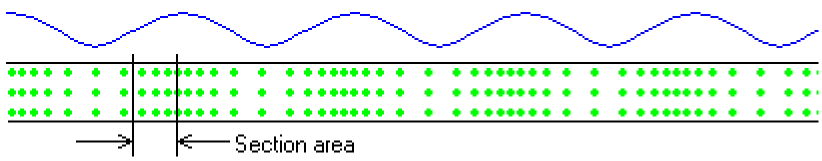

Fig 2.3 – High frequency electric signal propagating through a copper wire. Single electrons oscillates around a fixed point. In the same way a section area along the wire will alternate moments of many and few electrons with the same frequency of the travelling wave.

A small section area (or volume) inside the wire (see Figure 2.3) will alternate moments of many electrons with moments with few electrons, with a frequency equal to the frequency of the travelling wave. The number of electrons in the section area depends on the voltage applied to the wire.

Therefore, in order to propagate, waves need a tendency towards an average or middle value, or even better they need some sort of potential/internal energy that is stored in the medium they travel. This energy gets released to the neighbouring section areas making the wave travel along the medium.

Electromagnetic waves behave in the same way, the only difference is that each spherical shell or section area vary in the intensity of electromagnetic field even if they do not have a medium..

Many system have the natural tendency towards increasing disorder, the measure of this disorder is called entropy. Consider a thermally insulated box divided by a partition into two compartments each having volume V (Figure 2.4). Initially one compartment contains *n* moles of an ideal gas at temperature T, and the other compartment is evacuated. The system has the ability to do work, hence has energy. We then break the partition, and the gas expands to fill both compartments spreading like a sound wave.

For this initial state the heat Q = 0, the work W = 0, and the change in internal energy ΔU = 0. Therefore, because it is an ideal gas ΔT = 0. In order to obtain an isothermal expansion from V to 2V at temperature T, heat must be supplied to keep the internal energy constant. The gas does work during this substitute expansion, the total heat supplied equals to the total work, which is:

$$W = Q = nRT \ln 2$$

If we did not supply the system with heat, the final state would have a lower internal energy than the initial condition. So it seems that this tendency towards "disorder" is in fact a tendency towards a lower energy state of the whole system. All hot objects tend to cool down eventually to 0°K if not heat is supplied, and so is air pressure, it will tend to zero if molecules are left free in space.

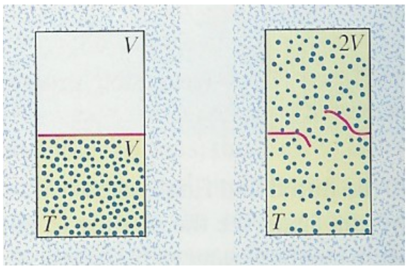

Fig 2.4 – Entropy is the measure of the disorder of a system.

The system just described is not very different from the section area described for sound and electric waves above, hence waves need some sort of energy stored in the medium in order to propagate. This energy gets released as the system tends to go towards a more natural state or "disorder". For an isolated systems the work done during this process can be in the form of heat, while for waves the work done on other particles (by collision or repulsion/attraction) makes the wave travel along the medium.

So it seems that in general free energy tends to zero and if this was not the case, than waves would not propagate. In conclusion, we can say that if energy in free spacetime has the tendency to zero. As a consequence it is not so crazy assume that spacetime must also have an upper limit of energy density that it can take, otherwise there would be no reason for this tendency to exist at all.

In fact this would explain the repulsive and the attractive force of molecular bonds. The attractive force would be the electric force and the repulsive force would be the limit of energy density that spacetime can take, which behaves like a spring pushing outwards when two atoms get too close.

2.1.2 Exploring further

In this paragraph we will look at what would happen if the force of equation 2.1 is the gravitational force of the mass of Earth, hence assuming that somehow the stretching of spacetime by the mass of Earth causes a force equal to the force needed to accelerate an object with the mass of Earth on Earth. Hence if:

$$x = \frac{\Delta\lambda}{\lambda} \qquad \text{and} \qquad F = Mg$$

where M is the mass of Earth, and from equation 1.0 we know that:

$$\frac{\Delta\lambda}{\lambda} = \frac{gR}{c^2}$$

this yields:

$$k=-\frac{Mg\lambda}{\Delta\lambda}\rightarrow k=-\frac{Mgc^2}{gR}=-\frac{Mc^2}{R}=-\frac{E}{R}$$

This equation tells us that the stiffness of spacetime depends on the rest mass energy and the radius of the mass itself.

Calculating it for different masses, like for our Sun and the Earth, we obtain different results, which means that the assumption we made is incorrect as we expect *k* to be the same for all masses.

2.2 Thoughts on time

Consider the well known equation of time dilation for moving bodies.

$$t = \frac{t_0}{\sqrt{(1 - \upsilon^2 / c^2)}}$$

This equation tells us that as we approach the speed of light time runs slower. In fact at the speed of light, the time interval t gets infinitely bigger that the time interval at rest t_0. Basically it seems that time flows at the speed of light when we are at rest, and stand still when we travel at the speed of light. It can be considered like a string where at one end we travel in space but stand still in time, and at the other end we travel in time but stand still in space. In real life we stand somewhere on this string near the latter end.

Our eyes see the light that a body reflects, and we perceive movement whenever the light coming from the body changes its angle hence direction or its frequency (for colours). Thus a body reflects light in all directions, and this can be thought as a collection infinitesimally thin shells of electromagnetic fields that leave the body at the speed of light getting bigger and bigger as the travel further from the body itself.

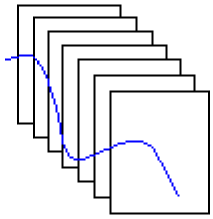

Fig 2.5 – Light seen as a flow of frames that travel at the speed of light.

If we think a beam of light as made up of a collection of frames that flow in one direction (see Figure 2.5) and we imagine a body travelling in the same direction at the speed of light, we would see the body to stand always in the same frame hence we would not be able to experience the body movement as the light coming from it would never leave him and therefore never change. He would be static in time. As a conclusion we could say that light and time travel at the same speed, or maybe we could even say that they are the same thing, or that light is a disturbance of time. Maybe if we could create a space with no electromagnetic waves of any kind, that space would be timeless.

We know that space and time are locked together in the sense that we cannot separate them. If we have space then we need time to move within that space and vice versa, one on its own just does not make sense. But if time is light, as we stated earlier, than a distortion of spacetime, like gravitational waves, would simply be an electromagnetic wave/field, and this could explain why we never detected a gravitational wave. Personally, I expect the lattice of spacetime in the universe be fluctuating constantly like the surface of the sea on Earth, in fact the gravitational waves that we are looking for, would just be the background radiation of the universe.

The other statement was that light is a disturbance of time, or we could even say that time is the medium of light. We know that space and time are locked together, but they still are two different things, hence we might just be able to distort them separately. We know that moving charges produce a magnetic field around them, hence a magnetic field could be produced by a fast travelling body even if its net charge is null as its positive and negative charges cancel themselves out. At the end of the day a body is still made up if charges. In conclusion a distortion of time, like speed, could produce a magnetic field, whilst a distortion of space could produce gravity. However this last statement is not evidenced by any experiment as no gravitational wave has been detected yet and no body with a null net charge has ever reached such speeds.

Another thought on light is that if the temperature of an ideal gas is given by the kinetic energy of its molecules, which in turn is proportional to the speed of the molecules, and the speed of light is the ultimate limit, then an ideal gas travelling at the speed of light must cool down as its molecules cannot travel in any other direction otherwise they would be travelling faster than light. This is similar to a body that would stand still in time, hence a body travelling at the speed of light must cool down to zero degree Kelvin.

2.3 Infinite Universe

A finite Universe can be thought as a confined space in which lay a finite number of galaxies as shown in Figure 2.6. It would be a collapsing Universe as the gravitational force of each galaxy attracts all other galaxies inwards towards a point which position depends on the distribution of the galaxies themselves.

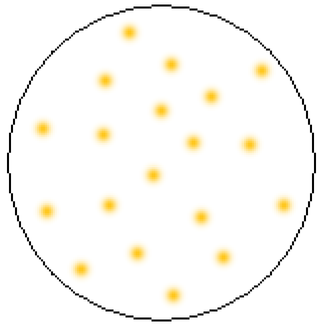

Fig 2.6 – Finite Universe.

However, an infinite Universe would have an infinite number of galaxies lying outside this border, each with a gravitational force attracting the galaxies inside the border outwards. Hence, when the galaxies are spaced apart enough, the resultant gravitational force for each galaxy inside the border would be outward, making the Universe "appear" expanding and accelerating outward.

For simplicity, consider an infinite array of galaxies all spaced apart the same distance, all having the same mass and arranged like a regular lattice (Figure 2.7). Each galaxy will experience the same gravitational attraction in all directions, in this way the Universe would be in static equilibrium. Now take one galaxy and displace it from one place to another leaving a hole one side, and filling a space another. We have now broken the equilibrium of our Universe, where we left the hole the galaxies will start expanding outward as their resultant force would not be balanced any more by the missing galaxy. On the other hand, that same galaxy that left the hole one side is now filling a space the other side, forming a cluster of galaxies which gravitational pull is inward towards the extra galaxy.

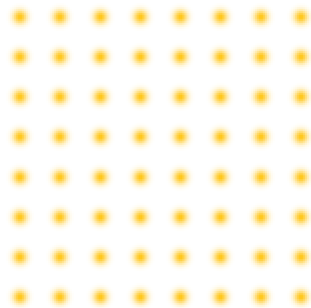

Fig 2.7 – Infinite regular array of galaxies.

In math parlance let us consider the one dimensional version of

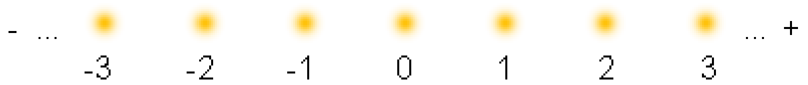

Fig 2.8 – Infinite line of galaxies.

the Universe as shown in Figure 2.8 below. The figure shows an infinite line of galaxies all spaced equally from each other and all having the same mass. Now, we know that the equation for the gravitational force acting on two isolated masses is:

$$F = G\frac{m_0 m_1}{r^2}$$

where r is the distance between each galaxy. Hence, the force acting on the galaxy placed at position zero along the infinite line towards the positive direction would be:

$$F_{+ve} = Gm_0 \sum_{n=1}^{\infty} \frac{m_n}{(nr)^2}$$

and the force acting in the negative direction would be:

$$F_{-ve} = Gm_0 \sum_{n=-1}^{-\infty} \frac{m_n}{(nr)^2}$$

which means that $F_{+ve}=F_{-ve}$ and the galaxies are in equilibrium. However, if we take the galaxy at position -1 out of the line, then the two forces would be:

$$F'_{+ve} = Gm_0 \sum_{n=1}^{\infty} \frac{m_n}{(nr)^2} \quad \text{and}$$

$$F'_{-ve}=Gm_0\sum_{n=-2}^{-\infty}\frac{m_n}{(nr)^2}=F_{-ve}-\frac{Gm_0 m_{-1}}{(-r)^2}$$

Therefore, $F'_{+ve}>F'_{-ve}$ which means that m_0 will experience a force towards the positive direction along the infinite line, and so do all other galaxies placed along the positive direction of the line. As far as the negative direction, it is simply a matter of applying the same reasoning to the galaxy placed at position -2 and so on. We will conclude that for m_{-2} the force pulling towards the negative direction is greater than the force acting towards the positive direction. That is same for all the galaxies placed along the negative direction, and extending it for all other dimensions of space you can see how the surrounding stars would be expanding when we are left with a hole and collapsing when we have an extra galaxy.

In conclusion, if the Universe is a random distribution of galaxies, than we would expect it to expand in some places and contract in others, so we were just lucky as it seems we ended up in an expanding hole.

2.3.1 The beginning

The next step now is to explore the possibility for the Universe to have a beginning. The question that comes to mind is how an infinite Universe could begin its existence.

The first and easiest answer to this question is that time, like space, is infinite and therefore does not have a beginning nor an end. This however does not leave us with much space for discussions denying us all the fun.

Assuming that there was a beginning we can imagine the fabric of spacetime to be full of fluctuations in the same way there are waves and currents in the sea or a lake. This fluctuations of spacetime produce energy, and from energy to mass is merely a question of extending the theory of evolution, hence we would have that, in due time, energy would evolve into mass. At the end of the day mass is simply energy that is somehow locked into itself.

On the other hand, the sea is full of waves because there are currents and winds that agitate its surface (assuming that there would not be bodies in the sea). In the same way the fabric of spacetime is fluctuating because there are stars and galaxies that shake its fabric producing what we know today as gravitational waves.

If we suppose that there are no celestial bodies in the Universe, as it would be if there was a beginning, then the lattice of spacetime would have no reason for fluctuating. Again we could assume that two very distant regions of spacetime would have a slightly different potential or stretching and would one day meet to produce the first lump of energy. This assumption is, however, quite unsatisfactory as would not answer the question why there should be two regions with different stretching. The last possibility we are left with is that there was a "divine pinch" in the fabric of spacetime, and from there everything evolved to what we are today.