Dark Matter – The Seeds of Birth for Cosmic Structures

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Abstract: One of the greatest challenges to modern day physicists is to unravel the mystery of the birth and contents of the universe, for only 5% of the Universe is known and the laws of physics are applicable to that part only, the rest 95% is the unknown Universe comprising Dark matter responsible for formation of stars, galaxies and their clusters and Dark energy responsible of giving it accelerated expansion .Physicists are also searching for elusive dark matter particles without which our existence could not have taken place as dark matter formed the seeds for the birth of cosmic structures and is the hidden scaffolding on which entire cosmos structures are built upon.

Index Terms **- Dark energy, Dark matter, Einstein's General relativity equations, Friedman's equations, CMB radiation, gravitational lensing, Λ-CDM model of cosmos.**

I. INTRODUCTION

The universe currently best described by the concordance model is a Lambda CDM model (Λ-CDM) where Lambda denotes the cosmological constant (Dark energy) in the Einstein's equations of general relativity. Lambda has a constant density always even as the space- time fabric of the universe expands and CDM is the cold and dark matter, which includes normal baryonic and non-baryonic dark matter, in this model the universe is 13.8 billion years old and is made up of 4% baryonic matter 23% non-baryonic dark matter and 73% dark energy. Cosmological model is basically a mathematical description of the universe and attempts to explain its current behavior and evolution and its future, these models are prepared on the basis of direct observations and astronomical studies. Dark matter though inferred through observations has not been detected yet, cosmologist can only speculate about its nature whether it is hot (comprising of fast-moving particles nearing speed of light) or cold (slow moving with a fraction of speed of light), the current belief is that it is cold, the most part because if it was hot then the structure formation in the Universe would not have taken place. It is called is dark matter because it is not in the form of matter in regular stars and planets that are visible to us. Astronomical observations show that there is far less visible matter in the universe to make the required 27% from the observations, secondly it is not in the form of normal matter called the baryonic matter which we would be able to detect by the absorption of radiation passing through them, It cannot be anti-matter because matter and anti-matter when they come together they produce Gamma Rays which we would be able to detect and finally we can rule out large primordial black holes being dark matter because total amount of matter in the large primordial black holes is far less than the total amount of dark matter present out there. Most commonly used idea is that the dark matter is not baryonic but it is made up of more exotic particle like WIMPS (weakly interacting massive particles) or Axions.

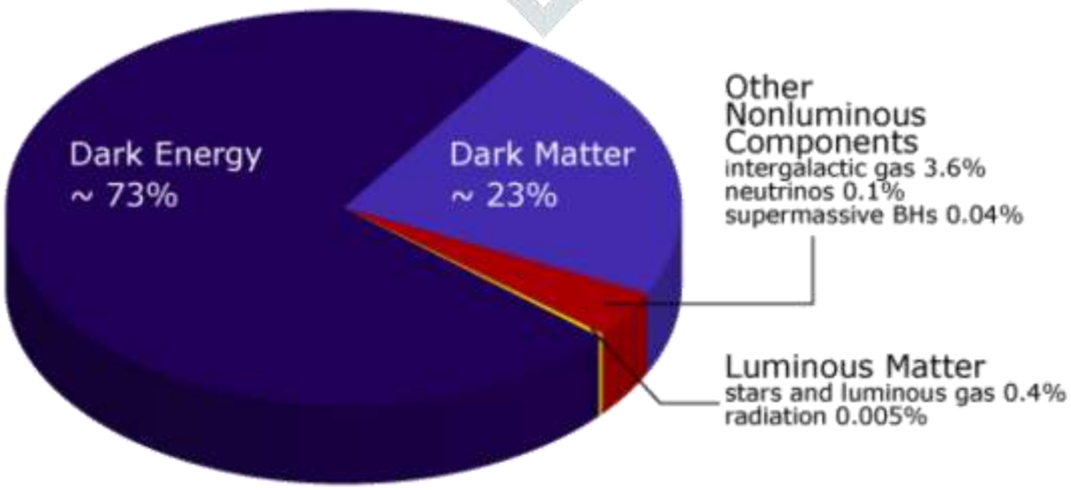

Figure 1: Composition of Universe – note that normal matter and radiation form only about 4% of total and out of that 4% roughly 90% or 3.6% is intergalactic gas and stars and planets constitute only 0.4 % of total.

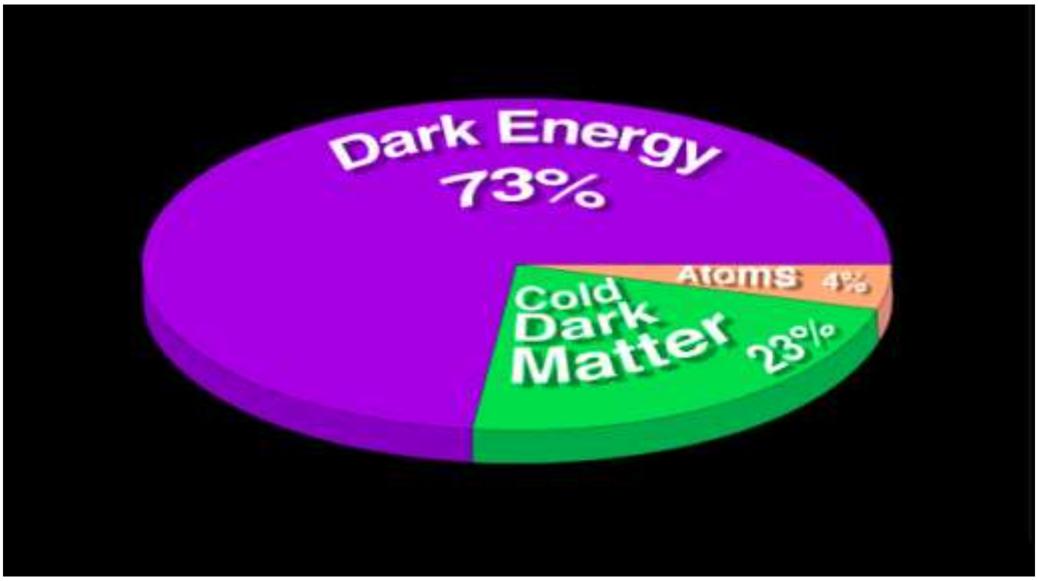

Figure 2: Λ-CDM Model composition: Λ (Dark energy-73%), CDM (Dark matter, non-baryonic-27%), normal baryonic matter - 4%

Figure 3: Energy Content and Matter Content of the Universe

II. Discovery of Dark Matter

Swiss astronomer Fritz Zwisky in 1933 while studying the motion of COMA cluster of galaxies (a few hundred light years away) found that motion of galaxies in the cluster was such that it could not be entirely due to the matter that could be seen by virtue of their light. He concluded that there had to be some additional stuff he called "Dark matter" (was first to coin this term) that was responsible for the gravity that was pushing and pulling these galaxies around .The gravity of the matter in these galaxies was too small for their fast orbits and he estimated that clusters should have 400 times mass than visually observable mass. This hidden Dark mass was the reason for additional gravity responsible for such fast orbits of galaxies in the COMA cluster. Zwicky's observation is based on the fact that a certain amount of mass is needed to produce the measured amount of light (the *mass-to-light ratio*).

Vera Ruben and Kent Ford of the Carnegie Institution of Washington in seventies studying spiral galaxies were trying to know how they rotate as we can gather lot of information about galaxy by its rotation. This can also be seen in our solar system where the planets closer to our Sun are moving faster than the planets farther away from our Sun. Isaac Newton gave formula to calculate sun's gravity which means that we can in turn get the mass of the sun, similarly in galaxy if we can measure how they rotate and how rapidly gas clouds move near the edges of the galaxies ,we can calculate the mass of the entire galaxies but since we cannot see the Nebula (A nebula is an enormous cloud of dust and gas occupying the space between stars) , we can measure their Doppler's shift which gives their velocity, it was expected that the gas far away from center of the galaxy would be moving slower just like more distant planets from sun move slowly in their orbits but we got the opposite for many galaxies the farther you went out from the center the faster the clouds were moving and at best velocity is flattened out with distance whereas that should have declined ,that means the gravity of the galaxy was constant throughout the disc and not dropping from the center as we expected, this was bizarre for there is simply not enough matter far out from center to account for faster rotation rates. Vera Rubin made their observations on the Andromeda galaxy; the vast Andromeda spiral seemed to be rotating altogether wrong to them. The stars at the edges were moving just as fast as the stars near the centre, apparently violating Newton's Laws of Motion. According to Newton's laws of gravitation $F=GMmr^2$, the farther a star is from the center, less is the force exerted on it and thus the slower its expected orbital speed.

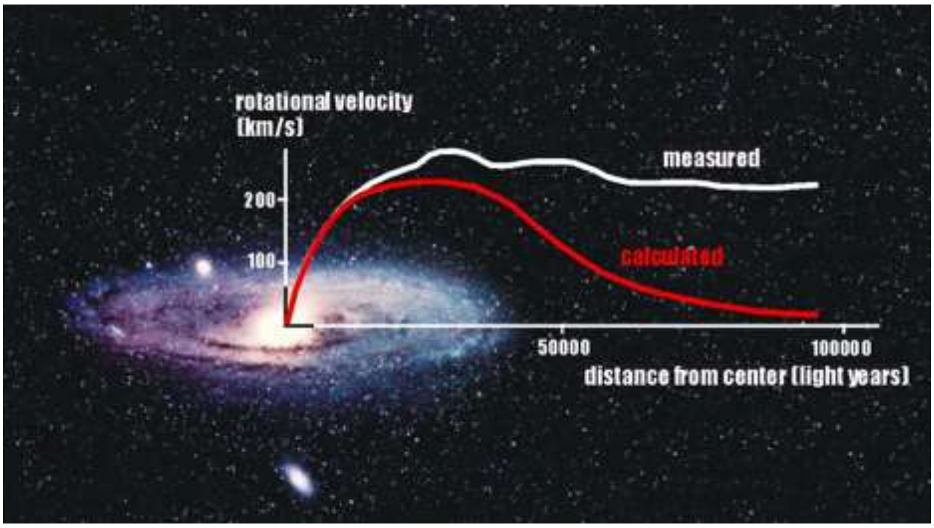

Figure 4: Rotation curve of a galaxy; following Kepler's law the rotational velocity should decrease with distance from the visible disk (red curve), but the observation (white curve) shows an almost constant velocity out to very large radii.

Rubin and Ford used the spectrometer to study the spectrum of light coming from the stars in different parts of spiral galaxies. Stars on one side approach us while those on the other side move away as the disk is inclined to our line of vision. Due to Doppler's effect, when a source of light moves toward us, we see a decrease in the wavelengths of the light (a shift toward the blue end of the spectrum), and when the source moves away, we see an increase in the wavelengths (Red shifted -a shift toward the red end). The observations made by Vera Rubin and Kent Ford were showing that stars far from centre of galaxy in the area where matter was less were moving as fast as the stars nearer to the centre of galaxy where matter was much more, this seemed wrong as the visible matter did not have sufficient gravity to give such fast orbital speeds to these outer stars in the galaxy, this could only be possible if there was huge amount of unseen matter which was providing extra gravity force to these stars to increase their orbital speeds. Calculations showed that galaxies must contain about ten times (or 90% of mass in the observable universe) as much "dark" mass as can be accounted for by the visible stars. This was a far more accurate number for dark matter content than Fritz Zwisky had given.

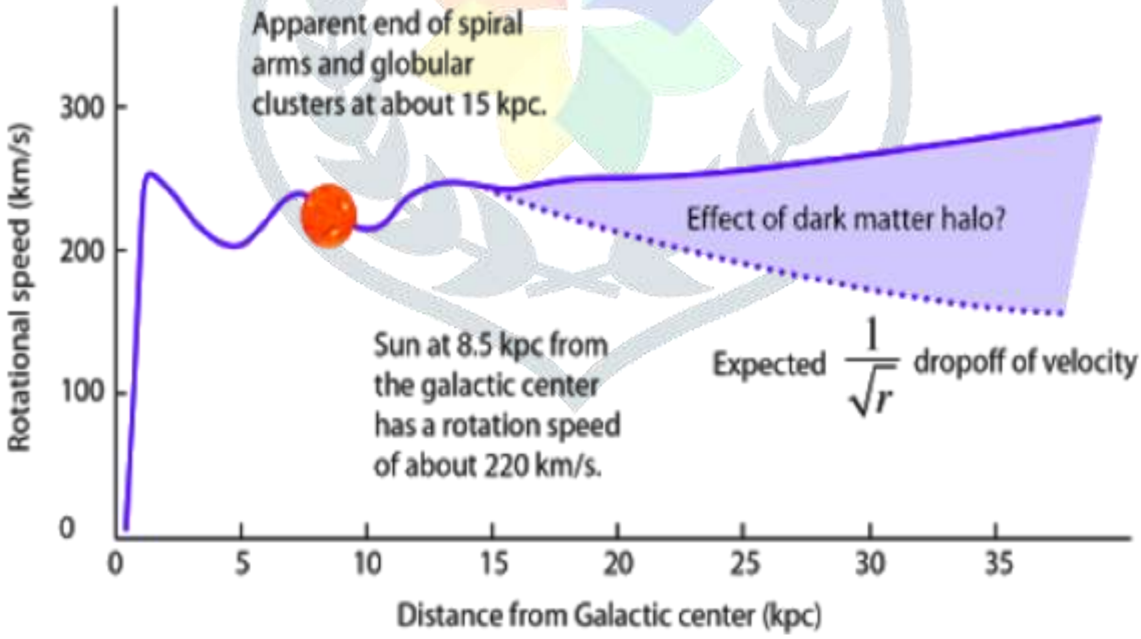

Figure 5

To conclude there is approximately five times less mass than derived from gravitational influence for a Universe to be stable. The huge missing mass is a kind of non-baryonic (protons, neutrons) Dark matter. These observations were noted in elliptical galaxies also besides spiral ones

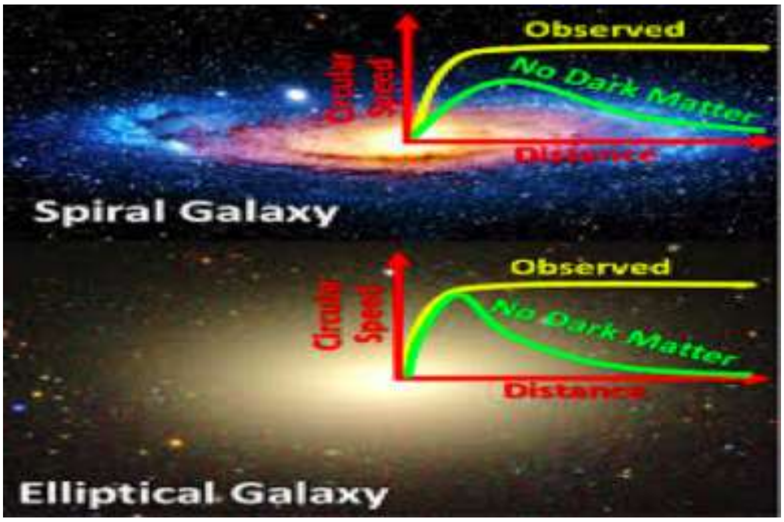

Figure 6

And could this motion be explained by a modification in general relativity equations of Einstein for galaxies million and billions light years across:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

$R_{\mu\nu}$ = R_{icci} tensor curvature
R = R_{icci} scalar curvature
$g_{\mu\nu}$ = metric tensor
$T_{\mu\nu}$ = stress-energy tensor
c = speed of light in a vacuum
G = universal gravitational constant
π = the famous constant from geometry
The left-hand side of above equation describes the curvature of space-time and right-hand side of equation represents mass and energy that cause the curvature of space-time fabric. As stated by John Wheeler matter and energy cause space-time to curve and curved space-time tells matter how to move.

These equations of general relativity have been shown to be very accurate for describing massive objects that are at very short distances of several light years to few thousand light years across but when it comes to galaxies where we are looking at a radius of few million light years and in clusters of galaxies that are billions of light years across ,it could be possible that gravity behaves very differently at thousands and millions of light years across than say one light year apart, and is there therefore a better and more accurate theory than Einstein's General theory of relativity?

In 1983, Mordehai Milgrom an Israeli physicist published a hypothesis showing that modification of Newtonian mechanics could perfectly explain above anomalous observations. However, the Israeli physicist challenges the concept of dark matter. Milgrom's theory is called "MOND"(Modified Newtonian Dynamics), which defies the presence of Dark matter and provides an alternate answer to issue of flat rotational curves of spiral galaxies by allowing small changes in Newton's theory. MOND is based on a modification of Newton's second law at very low acceleration, although it hasn't been successful in replacing the dark matter hypothesis.

Milgrom noticed that in the center of galaxies no dark matter needs to be invoked because there is enough ordinary matter to explain the motion of these stars, only in the outskirts is the motion of stars so fast that if we need to invoke dark matter, what he found that if we calculate using just the laws of Newton the acceleration due to gravity at the point where ordinary matter is no longer sufficient or we need to invoke dark matter to explain the orbital velocity of stars , this acceleration was same for every galaxy.

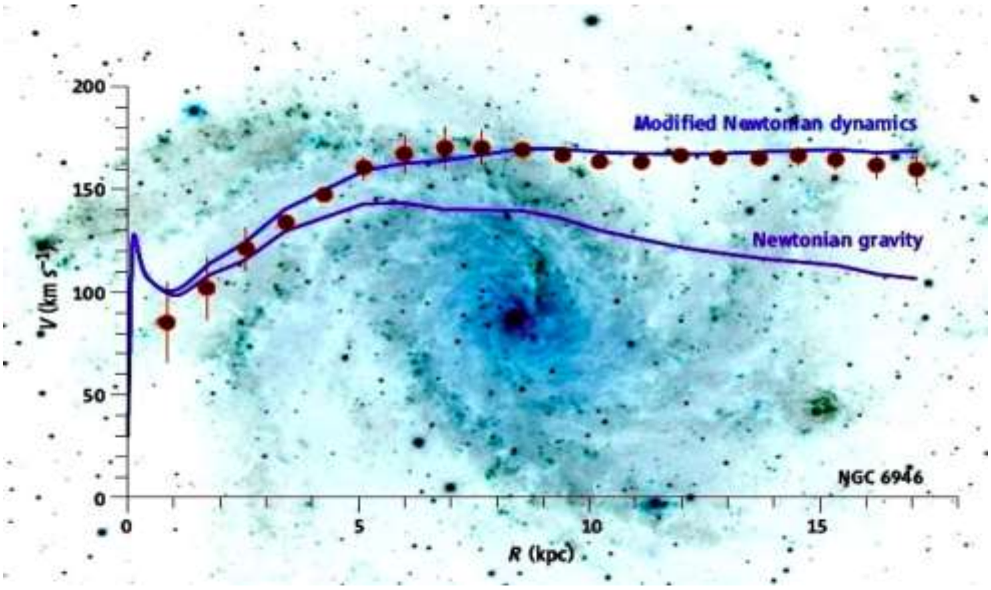

Figure 7

In other words, there was some critical value of acceleration such that if the acceleration was larger than that value (1.2×10^{-10} m/s^2), we do not need dark matter. So Milgrom said that may be there is no dark matter, maybe we need to modify the theory of gravity such that if acceleration is greater than a certain value then gravity decreases by $1/r^2$ as Newton's equations indicate but at a smaller acceleration gravity decreases by 1/r instead of $1/r^2$, that is gravity is more effective or has higher force than theorised. At high acceleration,

$$F = \frac{GMm}{\mu\left(\frac{\mathring{a}}{a}\right) r^2}$$

Where μ is an interpolating function and $\frac{\mathring{a}}{a}$ is new fundamental constant. The remarkable thing is that if we invoke Milgrom's hypothesized modification of gravity it fits the data observed in the galaxy almost perfectly.

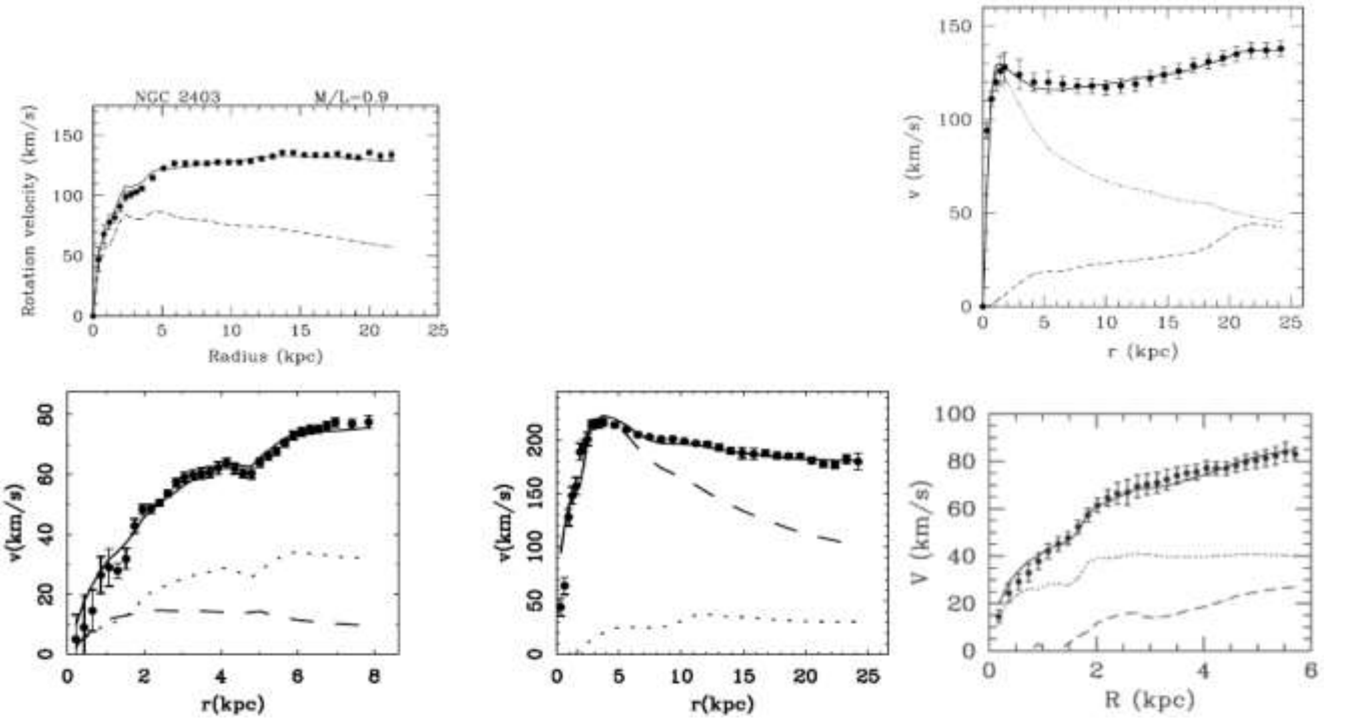

Figure 8: Observed rotation curves of five galaxies, (data points) compared with the MOND predictions (solid lines going through the data points). The three leftmost from [Begeman, Broeils, & Sanders, 1991](), the lowest-right from [Swaters, Sanders, & McGaugh, 2010](), and the upper right from [Sanders, 2006](). Other lines in the figures are the Newtonian curves for various baryonic components.

It fits our observation of motion of stars not just in our own Milky Way galaxy but in almost every other galaxy, so the idea that we don't need dark matter and that Newton's laws work fine within a certain radius, Milgrom's hypothesis is called modified Newtonian dynamics or MOND, both ideas of MOND and dark matter equally work well in explaining stars motion in galaxies but since we have not yet detected dark matter particle Milgrom may be correct.

Problems with Mond Theory

The problem with Milgrom's hypothesis or MOND arises when we try to explain the behavior of cluster of galaxies. The problem is that whereas Milgrom's theory explains the motion of stars within a galaxy exceptionally well it does not explain the motion of clusters of galaxies. Take the example of the Bullet cluster which are two colliding cluster of galaxies, is not explained by Milgrom's theory. In this cluster ordinary matter in the form of interstellar gas can be seen by Chandra X-Ray telescope but while gravitational lensing indicates that majority of the mass is located where less ordinary matter can be seen, so there must be unseen dark matter in these areas as indicated by the gravitational lensing, this is a very strong evidence of dark matter being a particle as this cannot be explained by Milgrom's modifications , many scientists have worked hard to make MOND work in these cases of cluster of galaxies but have been unsuccessful, so most proponents of MOND agree that you cannot altogether reject the idea of dark matter particle, may be both MOND and dark matter particle ideas are correct, MOND may explain the behavior of stars within galaxies few thousand of light years across and dark matter may explain behavior of cluster of galaxies million and billions of light years across, so proponents of MOND believe that motion of stars within galaxy can be explained by MOND by modifications of Newton's gravity and the behavior of cluster of galaxies by some type of matter such as neutrons or unseen dark matter particles such as Axions and WIMPS.

III. PROOF OF DARK MATTER

There are at least five significant cases besides the observations and studies of Fritz Zwisky on COMA cluster and of Vera Ruben and Kent Ford on Andromeda galaxy, described below involving gravity where deficit of matter is about five times the baryonic mass in the universe. I would discuss these cases along with certain phenomena taking place in the universe.

Cosmic microwave background radiation or the CMB is the radiation which is reaching to us from all around the universe when the universe was 3,80,000 years old and was at 3000 degree Kelvin, before this universe was a hot soup of matter and radiation and it was opaque to radiation as photons would be scattered by free electrons and could only travel short distances, however as the universe expanded its temperature cooled down to 3000 degree Kelvin then the electrostatic attractive force of the positive protons could overcome the kinetic energy of the electrons and thus the electrons got locked up with the proton in the form of the hydrogen atom, matter became neutral and this allowed photons to travel freely across the universe in the form of radiation and it is this radiation which is reaching us now the form of cosmic microwave background radiation, the space time fabric of the universe has since start of cosmic microwave background radiation expanded by a factor of about 1100 and due to this stretching of space time fabric the wavelength of the radiation has also got stretched by a same factor and the temperature therefore has dropped from 3000 degree Kelvin 2.7 kelvin due to energy loss.

Dicke and his astrophysicist colleagues at Princeton University reasoned that the Big Bang must have scattered not only the matter that coagulated into galaxies later but also must have released a tremendous blast of radiation. With the proper instruments, this radiation can be detected and measured, albeit as microwaves, due to a massive redshift since it started due to this stretching of space- time fabric; they had even calculated that its temperature would be about three degrees above the absolute zero.

Penzias and Wilson who were awarded a Nobel Prize for their discovery of CMB radiation found the first physical evidence of the Big Bang in the form of cosmic microwave background radiation the afterglow of the beginning of the universe; this was a direct proof of the Big Bang.

WMAP (Wilkinson Microwave Anisotropy Probe**)** mission gave us the first full-sky detailed map of microwave background radiation in the universe, this was later on refined by Plank satellite. WMAP is a super advanced version of lenses with giant antenna with two reflecting telescopes. It was used to map the afterglow of the Big Bang, and after a year of recording the first results were mapped. Note that the temperature variation on the Earth covers about 100°C while those measured by WMAP range only over about 0.0004 °C, WMAP shows that actually there are many small variations in temperature as tiny red spots are where matter is beginning to clump together and where clusters of galaxies would form eventually, this is vital evidence and clues as to how stars galaxy and clusters come into being. It also allows astronomers to get exact age of the universe for the first time to an accurate figure of 13.8 billion years, it has taken us close to the birth of the universe and it is revealing the edges of the universe.

Below is WMAP report on NASA website. The illustrations are NASA graphics:

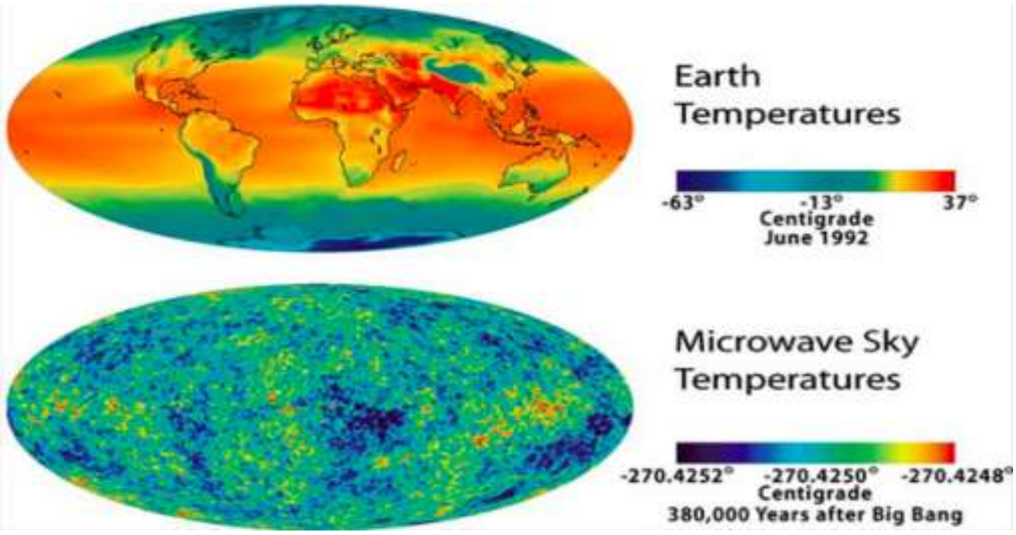

Figure 9

The wavelengths of radiation detected by WMAP were in the microwave region of the electromagnetic spectrum as depicted in the NASA graphic below.

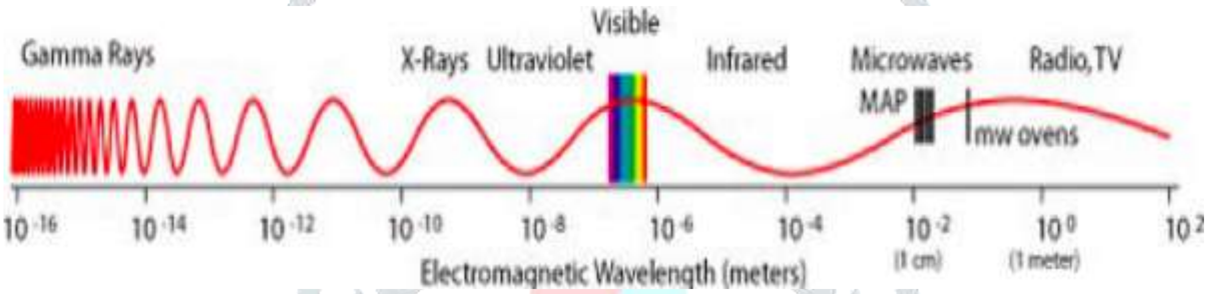

Figure 10

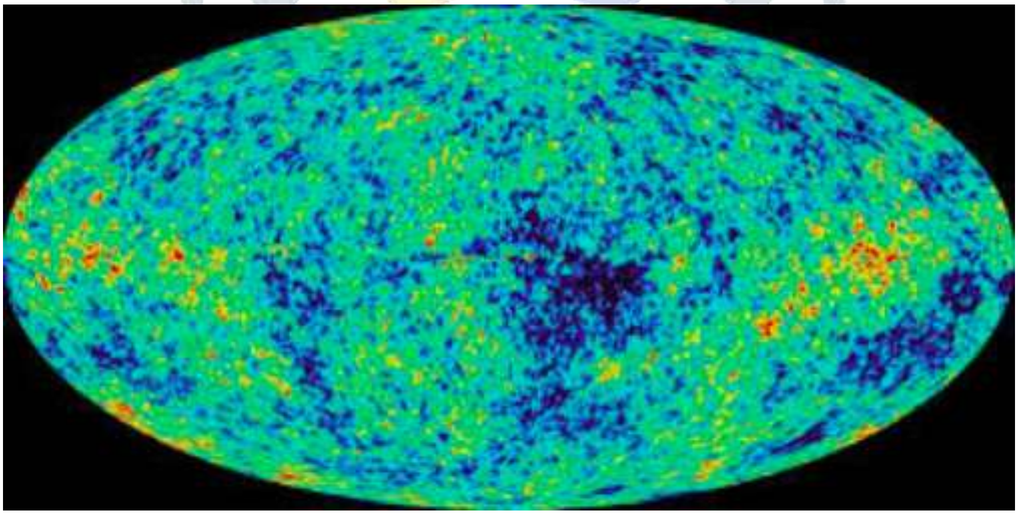

Figure 11

Before the time of cosmic microwave background radiation the universe was in a hot soup of matter and radiation in which density fluctuations could not grow as any increase in density was neutralized due to scattering by high kinetic energy electrons, however since the dark matter does not interact with normal matter or radiation, the density fluctuations in the dark matter had grown into substantial gravitational wells and at the time of CMB universe which was mostly hydrogen gas provided a medium for sound waves to travel as acoustic oscillations similar to sound waves travelling in the atmosphere on earth, these oscillations show a series of peaks in the power spectrum of the CMB that are related to preferred wavelengths which were governed by the distribution of baryonic (normal) and non-baryonic (Dark) matter. These dark matter high density gravitational wells would pull the normal matter in them and the extreme gravity of these dark matter wells would compress the normal matter this would increase the pressure to such an extent that it would heat it up and the extreme pressure developed would then overcome the gravity of dark matter well and force the normal matter out, this cycle would repeat thus causing normal matter to vibrate in these extreme gravity dark matter wells giving rise to baryonic acoustic oscillations and the temperature fluctuations of the normal matter in these waves gives rise to peaks in the CMB power spectrum , the waves are therefore the oscillations in the normal matter as they move in and out of the dark matter gravitational potential wells, this observed power spectrum of the CMB is compared with the power spectrum from a simulated computer program using the (Λ -CDM) model of the universe and the theory of acoustic waves. Input parameters of dark matter dark energy normal matter are varied to find a perfect match to the observed power spectrum of the CMB and the best fit has been found to contain 68% dark energy 27% dark matter and only 5% normal matter.

Second proof of dark matter comes from **Gravitational lensing.** Just as a lens placed in the path of ray of light causes light rays to bend similarly gravity also bends light rays and this is called gravitational lensing. Einstein in his theory of general relativity had predicted this phenomenon which was later confirmed during solar eclipse of 1919. Gravity is defined as curvature of space-time in general theory of relativity. The space -time fabric gets warped, depressed by the introduction of mass in it and this causes curvature in it and since light travels kissing the space-time fabric, light also bends around the heavy masses. This bending of light around heavy masses is called gravitational lensing.

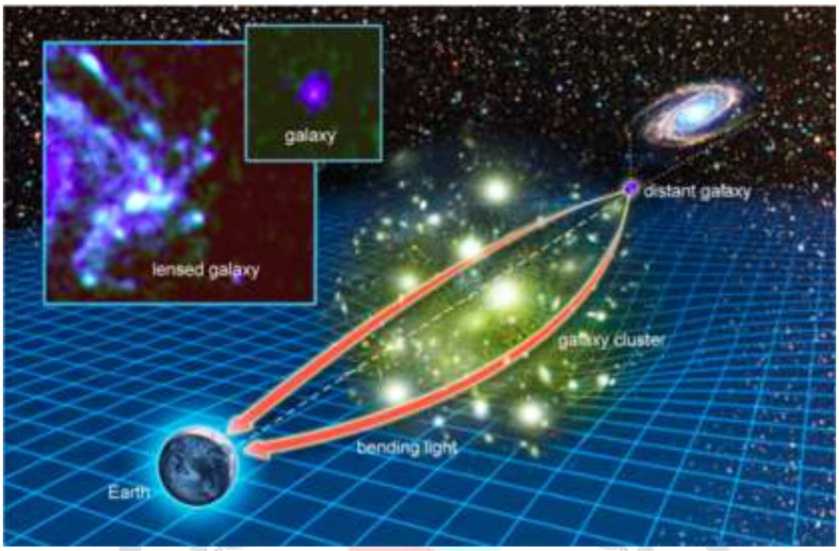

Figure 12: The gravity of a gigantic cluster of galaxies has bent and magnified the light of the distant spiral galaxy Sp1149, making its spiral arms visible and available for study by astronomers. Normally, gravitational lensing distorts the structures of distant galaxies beyond recognition. The inset labeled "galaxy" shows how Sp1149 would look without lensing.

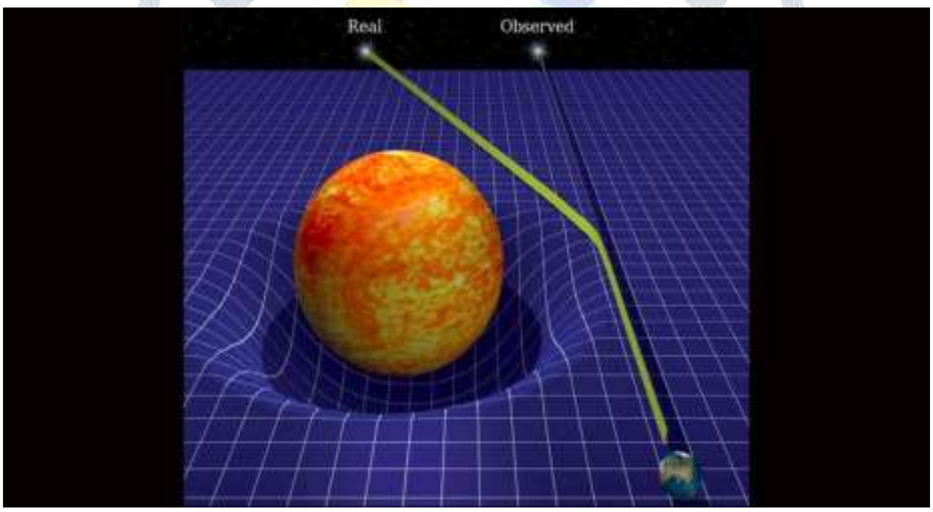

Figure 13

This was seen during total solar eclipse in 1919, normally we are not able to see the light coming from a distant star behind the sun in the extreme light of the sun, however during total solar eclipse when the light of the sun is blocked totally, the light from the star behind the sun is visible due to bending of its rays due to curvature caused in the space-time fabric by the mass of the sun, the apparent position of the star is though shifted by an angle which depends upon the mass of the sun. Similarly, many clusters of galaxies show arcs of light, (when bending of light ray does not happen at a single point but path of light ray forms a continuous curve around distributed masses in the cluster of galaxies) which are the gravitational lensed images of galaxies lying behind this cluster. The angle by which light rays have been bent by a massive object is given by formula of general relativity $\Theta = \frac{4GM^2}{R}$ where M is the mass of cluster of galaxy, c is speed of light, G is the gravitational constant and R is Impact distance, angle theta is proportional to mass of the bending object in this case cluster of galaxies and inversely proportional to how close the light rays gets to the bending object (the cluster of galaxies), distance R ,can be calculated from the redshifts of the remote lensed galaxy from the Hubble's law, now the cluster of galaxy comprises of many galaxies which are 90% gas and 10% stars and planets and other celestial objects. Also, we know the mass to light ratio for the galaxies i.e., how much light is emitted by galaxy of certain mass, so from the total light emitted by a galaxy we can know its mass and total mass of gas in the galaxy can be known by the X-ray emission of the galaxy. X-rays are emitted by hot gas in the galaxy when the high energy rays coming out from the thermonuclear reaction in the stars of the galaxy knock off the electrons from the gas and impart them their energy and the gravity contracts gas cloud and this heats up the gas so that electrons are ejected from the atom of the gas as high energy X-rays. So, we can know the total mass of gas and stars and other celestial objects in the galaxy and thus get the total mass of the cluster of galaxies. Therefore, knowing the mass of the cluster and its distance R, we can calculate angle theta from the above equation, however it is observed that bending angle theta is far greater than the angle theta calculated from the equation above, which means that normal visible matter is too less in the cluster of these galaxies and the mass of galaxy cluster calculated from observed angle of lensing is much greater. It is seen that the observed and the calculated value of theta are matching when we add approximately add 5 times mass to the existing masses in the cluster of galaxies, this extra invisible matter must be dark matter.

Another proof of dark matter comes from the observation from the **Galaxy clusters**. The observations show that the kinetic energy of the galaxies in the cluster is approximately 5 times larger than the potential energy and these high kinetic energies of the galaxies in the cluster should make them move too fast to remain in the cluster and in fact they should've ejected out of cluster billions of years ago. The virial theorem which relates total kinetic energy T of a self-gravitating body due to motions of its constitution parts to the gravitational potential energy U of the body (2T +U=0) predicts that the kinetic energy should be just half the potential energy.

$$\frac{GMm}{R^2} = \frac{mv^2}{R}$$

$$M = \frac{Rv^2}{G}$$

So, the velocity of Galaxy is proportional to square root of its mass, that is higher velocities can be obtained by having additional mass.

Example of a stable cluster of galaxies: Abell 2537, radial velocity of this cluster can be determined from the redshift and this also determines the distance to this cluster from the Hubble's law. The geometry of the cluster can be ascertained by knowing the center of the galaxy and also the distribution of the galaxies with respect to center, the individual radial velocity of the galaxies can be known from the spectroscopy data and the mass of the galaxy can be determined from the known mass -brightness ratio , the position of the galaxy within the cluster, together with its mass determines the total potential energy of that galaxy and the total potential energy of the cluster is then determined by summing up the individual potential energies of the constituent galaxies, also the intragalactic gas lying between the galaxies has a mass which is similar to that of galaxies, cluster pulls the gas together which heats up the gas to emit X-rays and from the brightness of the X-rays mass of the gas can be determined , radial velocity of a galaxy can be determined from the spectroscopy observations and this when subtracted from the average velocity of the cluster shall give us the relative speed of each galaxy with respect to the center of the cluster, the mass of each galaxies known to us we can determine the total kinetic energy of a galaxy and the total kinetic energy of the cluster which according to the virial theorem should be half that of the potential energy .However observations from the cluster show that kinetic energy is approximately five times the potential energy if this be the case then these high kinetic energy of the galaxies should make them eject from their cluster billions of years ago but this has not happened which indicates that some extra invisible matter is present in the cluster which is providing additional gravity to hold the galaxies in their place by providing a strong gravitational pull and also providing the required mass to give them faster acceleration giving them faster velocities, the amount of matter required to keep galaxies moving at these fast velocities in their place in the cluster is approximately 5 times the total mass of the cluster, this invisible mass is present in the form of halo in the cluster with density distribution that peaks at the cluster center. Addition of at least five times the observed mass of the cluster in the form of dark matter makes the clusters stable and prevents the galaxies from ejecting out of cluster at high observed velocities.

Rotational Curves of the Galaxies: Spiral galaxies show that the stars in the spiral arms have much greater speeds then can be obtained with normal matter present in these galaxies, we know from the formula: $\frac{GMm}{R^2} = \frac{mv^2}{R}$

$$M = \frac{Rv^2}{G}$$

If M and G are constant then if we increase R, velocity has to decrease this means that stars at a greater distance from the center of galaxy should be moving slower which is contrary to the observation, in fact the stars in the outer spiral arms of the galaxy are moving at same speed to those near the center of the galaxy (Vera Ruben and Kent Ford of the Carnegie Institution of Washington in 70s), this is only possible if there is huge amount of additional invisible matter present which is providing additional gravity force allowing stars to move at such high velocities in the outer spiral arms of the galaxy, it is calculated that addition of about five times additional mass in the form of dark matter halo with the density distribution that peaks at the center of galaxy is required to fit in the observations.

Another strong evidence in the favor of existence of dark matter come from the time required for the **Structures growth in our universe**, we know from Einstein's equations of general relativity and from the Friedmann's equations suggesting the rate of expansion of universe and its age thereby around 13.8 billion years. In the universe some 3,80,000 years after the Big Bang at the time of cosmic microwave background radiation era, density differences between regions were of 1 part in hundred thousand that is to say that normal matter was smooth to around one parts in 100,000. Cosmic structures in the universe grow through gravitational accretion that is regions with a slightly higher density attract matter by gravitational attraction to become more dense and the growth happens from smaller structures to bigger structures in the universe, 3,80,000 years after the Big Bang the Universe became transparent to light, when its temperature cooled down to about 3000 degree Kelvin and this led to decrease in the kinetic energy of electrons much below electrostatic force of attraction of the protons thus allowing protons to capture electrons and making a neutral hydrogen atom this process allowed photons and thus radiation to travel freely in space which is reaching us today in the form of cosmic microwave background radiation, nucleo-synthesis then took place after the universe had become transparent to light and matter became neutral. Hubble's Space Telescope recorded redshifts of some of the remotest galaxies indicate that the earliest galaxies had been formed by the time universe was less than 1 billion years old, this implies that stars were in existence well before that .Simulated computer models indicate that first stars were created before 200 million years after Big Bang (WMAP report on NASA website) and galaxies came into existence about 1 billion years after the big bang and thereafter the clusters of galaxies in a few billion years, but the universe 3,80,000 years after the big bang was smooth to one parts in hundred thousand and this small difference in density could not have created enough gravity to pull the matter together and form structures from stars to galaxies to cluster of galaxies in just few billion years after the big bang, gravity from normal method would have required many billions of years just to form galaxy which the red shifts from Hubble telescope indicate had formed well before 1 billion years after the birth of universe. This means there was insufficient time for gravity arising from normal matter to form stars galaxies and clusters, something else was providing helping hand by providing additional gravitational attraction to normal matter by pulling it together and making up for the lost time. This additional matter which kick-started the formation of structures and enabled normal matter to catch up for the lost time has been estimated to be five times the normal matter and since this is invisible and does not interact with normal matter or radiation it has all the hallmarks of a dark matter in place. So, unlike normal matter dark matter would have clumped together well before the time of CMB to form extreme gravitational accretion areas or wells which would attract normal matter and speed up formation of structures. In fact, dark matter had already provided the seeds for the structure formations in the universe in the form of dark matter gravitational wells. Stars, galaxies and clusters of galaxies were formed around these dark matter gravitational wells. Thus, the dark matter has provided seeds for formation of our universe. Computations with the Lambda CDM model of the universe have also demonstrated this process.

Probable particles proposed for Dark matter are:

- *Massive Compact Halo Objects (MACHOs)* are normal matter that do not emit (much) light including black holes.
- *Weakly Interacting Massive Particles (WIMPs)* are large more exotic particles that interact with gravity, but not the other forces of nature including electromagnetism.
- *Axions* are extremely light particles with no electrical charge.
- WIMPs and axions are the most accepted probable Dark matter candidates.
- Many experiments have attempted (and will attempt) to detect dark matter. They include:
  1. The planned *LUX-ZEPLIN (LZ)* detector in South Dakota.
  2. The *PICO Experiment* and *SuperCDMS* detector at the *Sudbury Neutrino Observatory Laboratory (SNOLAB)* in Canada.
  3. The *XENON1T* and planned *XENONnT* experiments near L'Aquila, Italy.
  4. The *Axion Dark Matter experiment (ADMX)* located at the University of Washington.

So far none of these experiments have found definitive evidence for a dark matter particle, although they have put limitation on what such a particle could be like.

IV. CONCLUSION

(1) It is called Dark matter as it is not in the form of normal baryonic matter found in stars and galaxies. Observations show that there is too little matter to make 27% required by the observations.

(2) It is non baryonic and it does not react and cannot be seen with Electromagnetic radiation, it is invisible to light and other forms of Electromagnetic radiation.

(3) It is not antimatter because we do not see the signature in the form of γ rays that are produced when antimatter annihilates matter.
(4) One of the candidates could be primordial black holes found very early in the Universe. But dark matter is not also made from black holes as matter in the black holes is 700 times less than the estimated dark matter in the Universe.
(5) Possibility is that Dark matter is made up of other exotic particles such as axions and WIMPS (Weakly interacting massive particles) roughly hundred times mass of a proton.
(6) Scientists are confident that it exists because of gravitational effects it exerts on galaxies and galaxy clusters.
(7) Content of Dark matter has decreased and Dark energy has increased since Big Bang, the birth of the Universe.
(8) Structure forming by gravity works when bulk of the matter in the Universe is dark matter, once dark energy takes over and becomes more dominant than dark matter structures can no longer form because dark energy is a repulsive force pushing things away from each other where gravity was the thing pulling them together.
(9) Dark matter has had a profound effect on the universe, it is the seed for the formation of stars, mega structures which however would not have got enough time for formation in the early Universe as energy blasted out by stars and galaxies just could not aggregate matter due to all that heat without dark matter.

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