IOSR Journal Of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 12, Issue 5 Ser. II (Sep. – Oct 2020), PP 53-59
www.Iosrjournals.Org

Exploration of Negative Mass as a Harbinger of Dark Energy

AryamanBabbar[1], Bhavik Agarwal
Student, Grade XII, Ryan International School, Rohini, Delhi, India
Student, Indraprastha Institute of Information Technology, Delhi

Abstract
Having intrigued the entire scientific community since its discovery by Edwin Hubble[2], redshift, in its own, seems to be presenting a multitude of mysteries that lie enclosed within itself. Collecting the data of galaxies at different distances from the Earth, which indirectly allows us to travel back in time because given the astronomical scales of the universe light travels pathetically slow, it has been observed that most galaxies have actually sped up in moving away from us.For that matter, any observer on anywhere in the universe will observe that galaxies far away from the observational point will continue to move further away from that point. If we keep classical mechanics in mind, we would think that since galaxies exert the gravitational force on one another, this retardation would probably slow the motion of the galaxies to the point, where the velocity becomes zero and over a period of years, the galaxies shall all come close to each other, resulting in the "gnaBgiB"[3]. However, a team of researchers led by Brian Schmidt[4], using supernovae, made the astonishing discovery that instead of retarding, the galaxies, have been accelerating away from each other. Till date, the cause of this acceleration remains fairly uncertain and has hence, been dubbed as "Dark Energy". In this paper, we attempt to provide a reason for this peculiar phenomenon.

***Key Words**: Dark Energy, gnaBgiB, Redshift, Blueshift, Hubble's law*

Date of Submission: 28-09-2020 Date of Acceptance: 10-10-2020

I. Methodology

Authors set forth a proposition that dark energy may be negative mass and this paper explores the testing of this hypothesis. While undertaking this archival research, hypothesis has been treated as a provisional conjecture to guide any further investigation in the field of astrophysics or may be treated as a working hypothesis. This hypothesis has been arrived upon by secondary analysis of existent data. Extrapolation of the hypothesis leads to the equation of Hubble's Law, a well-established result.

II. Introduction

Imagine that you are standing on a platform waiting for a train, which blows a horn signalling its arrival. While standing on the platform, it could be observed that the horn sounds a bit shriller than it does when the train blows the horn while it is on the platform. Also, it would be observed that when the train leaves the platform, the horn would sound less shrill to an observer, seated on a bench on the platform. This phenomenon has been attributed to the Doppler effect[5] of sound waves, which states that change in frequency of a wave is observed by the observer, who is moving relative to the wave source. This effect can be caused by the movement of the source as well as that of the observer along the line joining each other. Similar to sound, we know that light behaves like a wave, so light from a luminous object undergoes a Doppler-like shift if the source is moving relative to the observer.

---

[1] I acknowledge the immense motivation and cooperation of Mrs.ReenaSachdeva, my mentor, Mr.Rakesh Sharma, my class teacher and Ms.Mamta Nanda, Principal, Ryan International School.

[2] American astronomer who played a crucial role in establishing the field of extragalactic astronomy and is generally regarded as the leading observational cosmologist of the 20th century.

[3] Big Bang backwards

[4] Brian Schmidt received a PhD from Harvard University in 1993 and, moved to Australia the following year, where he was involved in building the High-Z Supernova Search Team, as a part of which he conducted his Nobel Prize-awarded work. Brian Schmidt is a Professor at the Australian National University in Weston Creek, Australia.

[5] It was first described (1842) by Austrian physicist Christian Doppler.

In 1929, Edwin Hubble[6] observed that the universe is expanding and that most of the galaxies are moving away from us. Consequently, owing to the motion of galaxies away from us, a Doppler-like shift in the light waves coming from the observed galaxies has been noted. Since most of the galaxies are moving away from us, the wavelength of light coming from these sources has been stretched, which has resulted in an increase in the wavelength of light emitted from that source, thus, shifting the light to redder wavelengths. This phenomenon iscalled redshift. Similarly, when a galaxy moves towards us, the wavelength of the light coming from the source is reduced and is thus shifted to bluer wavelengths. This phenomenon is called blueshift.

To measure redshift, you will need to know what lines to expect, and what their wavelengths are in the laboratory. For instance, if we know that the star we are looking at is composed of Hydrogen, we shall look up the laboratory wavelength of Hydrogen, which is 486.135nm. Now, when we shall point our spectrograph[7] towards the source and take the spectrum. For example, if the wavelength of hydrogen is observed to be 490.14nm, we say that the observed wavelength is 490.14nm. For any such pair of observed and laboratory wavelengths, redshift, denoted by z is given by

$$z = \frac{\lambda_{observed} - \lambda_{laboratory}}{\lambda_{laboratory}}$$

If the observed star/galaxy is moving away from the observer, then

$\lambda_{observed} < \lambda_{laboratory}$ and $z < 0$, this negative redshift is nothing but blueshift, i.e., the observed star/galaxy is moving towards us.

Since, the velocity of galaxies (which gives us the redshift) is far less than$c$,

$$z = \frac{\lambda_{observed} - \lambda_{laboratory}}{\lambda_{laboratory}} = \sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}} - 1 \approx \frac{v}{c}$$

As we have seen earlier, Edwin Hubble discovered that objects in space that are not bound gravitationally or chemically to each other, tend to move apart owing to the expansion of space. The distance between any two such objects gets bigger as time moves forward and the more space is between them, the faster it grows; thus, we can say that if the displacement vector, between any two such objects in space is $\vec{r}$, then the position vector at a time t, is a constant times $\vec{r}$.Moreover, the more is the initial separation between two such galaxies, more is the relative velocity of motion of the galaxies away from each other. This is known as Hubble's Law[8]. The mathematical expression of Hubble's law is-

$v = H_0 r$, where r is the distance between them.

The value of H_0, i.e. Hubble's constant comes out to be around 70 $kms^{-1}Mpc^{-1}$.

Now, this constant is constant in the sense that at any given time, all different galaxies have the same constant but the same constant is not constant at all times.

By default, we assume the scale factor of the present to be unity and it is certain that for objects in space that are not bound gravitationally or chemically to each other, $a(t)$ (which is the notation for scale factor as a function of time)at any moment previous to the present is less than unity. We can, in terms of $a(t)$, express redshift as

$z = \frac{1-a(t)}{a(t)}$, or

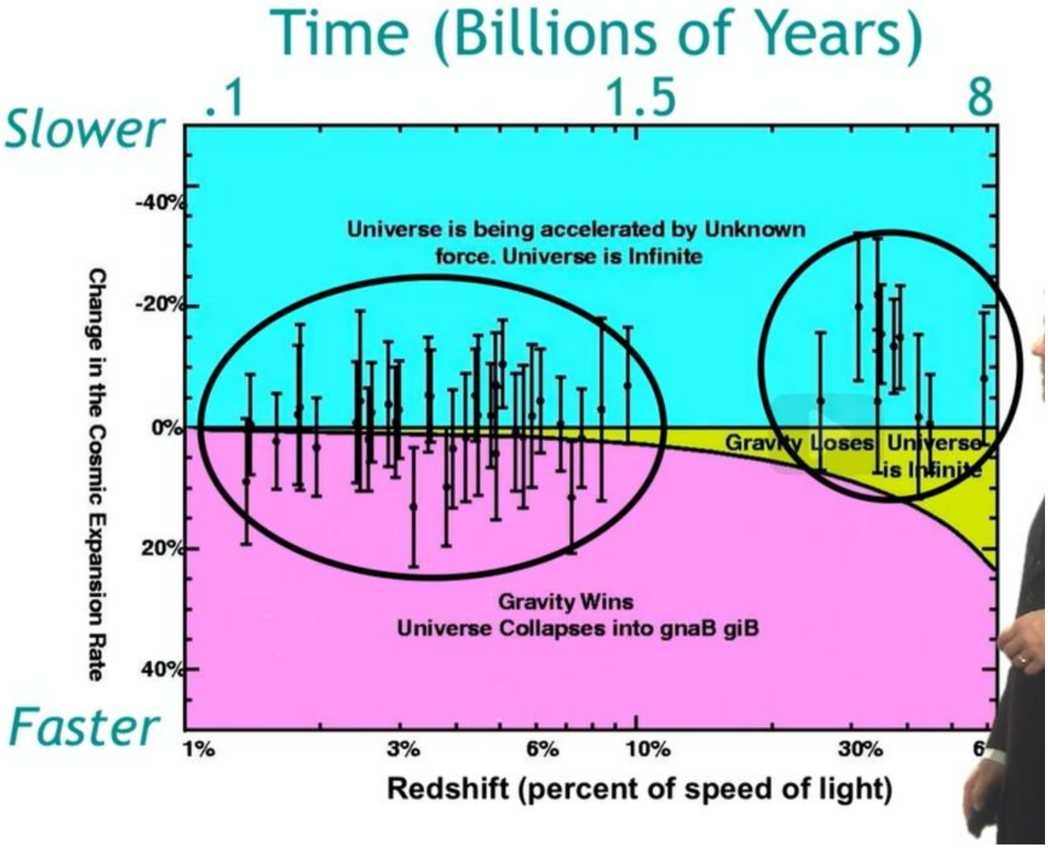
$$a(t) = \frac{1}{1+z}$$

Normally, we shall expect that even though the scale factor is increasing at the present, the rate of its increase shall decelerate, or even if it does not decelerate, it means that the gravitational force is not strong enough, which means that the rate of change of scale factor should, as a worst case scenario, remain a constant.

[6] In his revolutionary paper published in 1929, Hubble showed that most galaxies were actually moving away from us and that the universe was expanding.

[7] A spectrograph is an instrument used to obtain and record an astronomical spectrum.

[8] Hubble's law, also known as the Hubble–Lemaître law, is the observation in physical cosmology that galaxies are moving away from the Earth at speeds proportional to their distance.



Graph Plot 1

However, Schmidt's team i.e. the "High ZTeam"[9], observed, using supernovae, that instead of decreasing or remaining constant with time, the redshift increased with it. That is expansion of the universe is accelerated despite the force of gravity acting to bring the objects together. The above graph plot 1illustrates the findings[1].

The accelerating redshift means the accelerating expansion of the universe, which means that though Hubble's constant$H_0$is a constant at all parts of the universe at the same time, it is not actually a constant with time.

This accelerating movement of galaxies away from each other seemed to be a peculiar result that despite the action of gravity, there was an unknown force that acted against it, producing an acceleration. This force was dubbed as "Dark energy".

Conserving the energy of a particular part of the universe-

Since, the universe is isotropic, the same result shall be obtained by operating on any part of the universe.

$E_{total} = K + U$

$K = \frac{1}{2}mv^2$ and $U = -\frac{GmM}{r}$,now since the particle of mass m is moving away from the galaxy, when we shift our reference frame to the center of the galaxy, v shall be observed as the rate of change of position vector from the center of the galaxy

$\Rightarrow v = \dot{r}$ and we can for the purpose of this paper, assume each galaxy to be circular such that its center of mass lies at its center and the particle under observation to be at a position of $\vec{r}$ from there.

$U = -\frac{GmM}{r}$, now as we have assumed the galaxy to be circular, it is only the mass enclosed by an imaginary sphere centered at the center of the galaxy and with radius as r, that causes the gravitational potential energy.

$\Rightarrow M = \frac{4}{3}\pi r^3 \rho$, where ρ is the density

$$\Rightarrow U = -\frac{4}{3}\pi\rho G m r^2$$

$\Rightarrow E_{total} = \frac{1}{2}m\dot{r}^2 - \frac{4}{3}\pi\rho G m r^2$

[9]The High-Z SN Search Team is an international group of astronomers interested in using type Ia supernovae to trace the expansion of the Universe from the present day to 9 billion years in the Past.

Here, $\vec{r}$is changing with respect to time, as was previously discussed, $\vec{r} = \vec{r_0}.a(t)$. So, in order to simplify the change of $\vec{r}$, we shall introduce a metric, wherein the coordinates are moving according to $\vec{r} = \vec{r_0}.a(t)$. This metric accounts for the expansion of the universe and all objects, which are not bound chemically or gravitationally, hold the same position vector as time goes on.

In this new metric $\vec{r} = \vec{r_0}.a(t)$, so we shall replace $\vec{r}$

$\Rightarrow E_{total} = \frac{1}{2}m(r_0.\dot{a}(t))^2 - \frac{4}{3}\pi\rho G m(r_0.a(t))^2$

As r_0 is a constant,

$\Rightarrow E_{total} = \frac{1}{2}m{r_0}^2 a(\dot{t})^2 - \frac{4}{3}\pi\rho G m{r_0}^2 a(t)^2$

Since, energy is conserved, E_{total} , m and r_0 are constants, we can rearrange the equation as

$E_{total} = \frac{1}{2}m.a(t)^2{r_0}^2(\frac{a(\dot{t})^2}{a(t)^2} - \frac{8}{3}\pi\rho G)$

$\Rightarrow \frac{2E_{total}}{m.a(t)^2{r_0}^2} = \frac{a(\dot{t})^2}{a(t)^2} - \frac{8}{3}\pi\rho G$

$\Rightarrow \frac{8}{3}\pi\rho G - (\frac{-2E_{total}}{m.c^2{r_0}^2})\frac{c^2}{a(t)^2} = \frac{a(\dot{t})^2}{a(t)^2}$

Substituting $\frac{-2E_{total}}{m.c^2{r_0}^2}$as k, we obtain[3]

$$\frac{8}{3}\pi\rho G - \frac{kc^2}{a(t)^2} = \frac{a(\dot{t})^2}{a(t)^2}$$

Now, since, $c,\ G, a(t)$ are constant and since the universe is isotropic, ρ must be constant. This means that k must be a constant as well. This is the classical Friedmann[10] Equation.

$\frac{a(\dot{t})^2}{a(t)^2} = \frac{8}{3}\pi\rho G - \frac{kc^2}{a(t)^2} + \frac{\Lambda c^2}{3}$ Modified First Friedmann Equation

$\frac{a(\ddot{t})}{a(t)} = -\frac{4}{3}\pi G\left(\rho + \frac{3P}{c^2}\right) + \frac{\Lambda c^2}{3}$ Modified Second Friedmann Equation[4]

Above is the modified Friedmann equation. The modification in the form of addition of the term lambda was incorporated to account for the acceleration expansion of the universe[11].Lambda is the mathematical term for dark energy. According to second Friedmann equation, we obtain a positive value for cosmological constant as owing to its positive value we have the increase in the rate of increase of the scale factor, which means that universe's expansion rate is increasing. Without lambda, $a(\ddot{t})$ would be negative, because the pressure density ρ and the pressure P would slow down the expansion of the universe. So, lambda has to be positive to give us an accelerated expansion. We propose that this "dark energy" is negative mass.

III. Discussion

Consider two isolated galaxies such that, the relative velocity, as observed from one galaxy, of the other, is away from the galaxy from where the observation has been made.

[10]Alexander Friedmann, a Russian and Soviet physicist, is best known for his equations that demonstrate the expansion of the universe-The Friedmann equations.

[11] Einstein, in his theory of general relativity incorporated this term, however, most of the astronomers believed at that time universe is static. So, to "correct" the equation, he added a term lambda known as Einstein's cosmological constant, but a few years later, Edwin Hubble came with a remarkable discovery that universe isn't static; it is expanding. So, Einstein removed lambda again from the equation. But now, given the accelerated expansion of the universe, lambda has been added to the Friedmann equation.

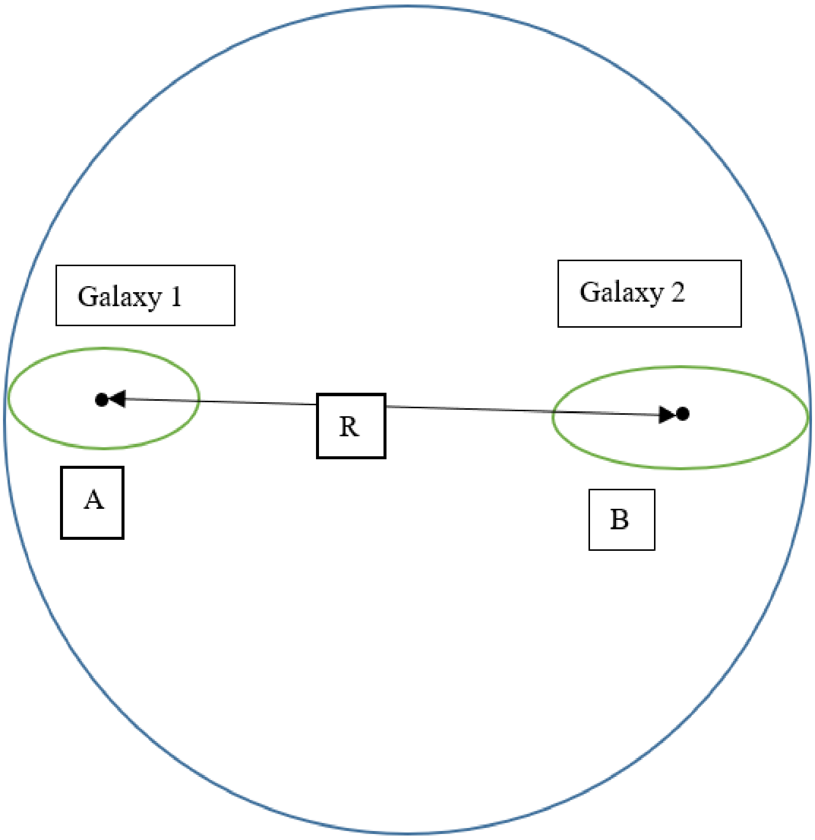


Figure 1

Consider the situation in Figure 1. Without loss of generality, assume that the observer is present at the center of galaxy 1, i.e. A. From that position, galaxy 2 is observed to be moving away. Now, assuming that the centers of both galaxies are actually the centers of gravity of each one, we can state that gravitational force acts along the line joining A and B which attracts each galaxy towards the other with a magnitude of

$$F = \frac{Gm_1m_2}{R^2}$$

where m_1 and m_2 are the masses of the two galaxies. So, in principle, if we do not take into consideration dark energy, every pair of galaxies must attract each other, thus, causing the entire universe to converge in a single point and reducing the scale factor as time proceeds.However, this is not the case. In fact, it has been observed that only a handful of galaxies move towards us and most move away from us.

Serial Number	Galaxy Name	Distance (from the Earth)	Redshift (z)
1.	Andromeda Galaxy	2.54 Million light years	−0.001001[5](minus sign indicates blueshift)
2.	M63 [6]	29.3 Million light years	0.0016[6]
3.	IC 1101[7]	1.2 Billion light years	0.077947[7]

Table 1

As indicated in the data given above in Table 1, galaxies which are far away from us move at a higher redshift as compared to those which are at a distance lesser than the galaxy in consideration. In fact, for Andromeda Galaxy[12], the redshift is negative, i.e. it is moving towards us. Since, the redshift has been

[12]The Andromeda Galaxy, our nearest major galactic neighbour, can be seen with the naked eye, even in areas with moderate light pollution.

increasing with distance, there a redshift gradient, which automatically translates to a speed gradient and that speed gradient is called the Hubble's Constant[13].

IV. Suggestions

In this paper, we suggest that the cause of dark energy – the energy that causes the galaxies to move away at an accelerating rate - is the gravitational repulsion caused by negative mass that is present between the galaxies.

We know that two objects, when placed at a distance (ignoring all other forces) from each other attract each other with a gravitational force. If one of the masses among the two were to be negative, the sign of the force would be changed, thus leading to a change in the direction of the force i.e. repulsion.

Consider figure 1. The sphere of diameter R depicted has a volume that is directly proportional to R^3. Moreover, assume that the distance R is far greater than the diameter of any of the two galaxies shown. Given the isotropic nature of the universe, the density of negative mass would be uniform and the magnitude of mass (M) of the negative mass can be given by

$$M = kR^3$$

According to Newton's Law of gravitation, $F = \frac{GMm}{r^2}$, thus, the repulsive force between each galaxy and the negative mass between them, in the sphere, is directly proportional to R^{14}, m^{15} and ρ^{16}.

Hence, relative acceleration between the two galaxies is directly proportional to ρR and because ρ is assumed to be a constant, the acceleration is directly proportional to R.

i.e. $a = cR$ (where 'c' is a constant)

$$\Rightarrow \frac{dv}{dt} = cR$$

$$\Rightarrow v\frac{dv}{dR} = cR$$

$$\Rightarrow vdv = cRdR$$

integrating on both sides from limit 0 to v and 0 to R,

$$\Rightarrow \int_0^v vdv = \int_0^R cRdR$$

$$\Rightarrow \frac{v^2}{2} = c\frac{R^2}{2}$$

taking the square root on both sides and isolating v yields,

$$v = \alpha R$$

where α is an arbitrary constant that is obtained by combining all other constants.

V. Conclusion

Now, it has already been mentioned that $v = H_0 r$ and the equation we arrived at corresponds to the Hubble's Law.

The data presented shows a negative redshift for Andromeda galaxy which does not correspond to either Hubble's law or our result, but we must bear in mind that the above calculations have been made keeping in mind that the distance between the two galaxies is far greater than their radius. In the mentioned case, the gravitational attraction prevalent between them can't be ignored and even overpowers the repulsion. In fact, there may exist many such galaxies in the universe that are coming close to each other, the reason of which is common: gravitational attraction dominates negative mass repulsion and in cases of positive redshift, negative mass repulsion overpowers positive mass attraction.

The above has been replicated through two simulations made on Blender [8] Platform.The first simulation[17] shows galaxies that are in close vicinity of each other coming together to form clusters over a period of millions and billions of years. These clusters, in turn, form bigger clusters over a period of billions of

---

[13]The Hubble constant is a unit that describes how fast the universe is expanding at different distances from a particular point in space. It is one of the keystones in our understanding of the universe's evolution — and researchers are mired in a debate over its true value.

[14]Direct proportionality to R (the diameter) of the force is obtained as the radius r (stated in Newton's Law of Gravitation) is directly proportional to R. Moreover, as M (magnitude of negative mass) is directly proportional to R^3, R^3 divided by R^2 yields R.

[15]Mass of the galaxy

[16]The density of negative mass

[17]https://drive.google.com/file/d/1u9s8jAGKxQyJN7WNJtrsWsRjcJfYzqS6/view?usp=sharing

years. In this case the gravitational attraction dominates the negative mass repulsion. Moreover, the negative mass between the two galaxies is repelled by the positive mass and in this case, given that there is more positive mass than negative mass, more of negative mass is pushed out of the vicinity.

The second simulation[18] shows galaxies that are sufficiently far apart for the negative mass repulsion to dominate over the positive mass attraction, thus, causing the galaxies to move away from each other, giving the notion of redshift.

As shown in the calculations above, this redshift corresponds to the relation obtained by Hubble's Law.

Bibliography

[1]. ANUAstro1x- Greatest unsolved mysteries of the universe (V3.5)
[2]. https://www.researchgate.net/publication/273784936_Hubble's_Law_and_the_expanding_universe
[3]. ANUAstro4x- Cosmology
[4]. https://www.researchgate.net/publication/265603209_Friedmann's_Equations_in_All_Dimensions_and_Chebyshev's_Theorem
[5]. http://ned.ipac.caltech.edu/cgi-bin/objsearch?objname=M+031&extend=no&hconst=73&omegam=0.27&omegav=0.73&corr_z=1&out_csys=Equatorial&out_equinox=J2000.0&obj_sort=RA+or+Longitude&of=pre_text&zv_breaker=30000.0&list_limit=5&img_stamp=YES
[6]. http://ned.ipac.caltech.edu/cgi-bin/objsearch?objname=messier+63&extend=no&hconst=73&omegam=0.27&omegav=0.73&corr_z=1&out_csys=Equatorial&out_equinox=J2000.0&obj_sort=RA+or+Longitude&of=pre_text&zv_breaker=30000.0&list_limit=5&img_stamp=YES
[7]. http://ned.ipac.caltech.edu/cgi-bin/objsearch?objname=IC+1101&extend=no&hconst=73&omegam=0.27&omegav=0.73&corr_z=1&out_csys=Equatorial&out_equinox=J2000.0&obj_sort=RA+or+Longitude&of=pre_text&zv_breaker=30000.0&list_limit=5&img_stamp=YES
[8]. https://www.blender.org/
[9]. https://web.mit.edu/edbert/reese.pdf
[10]. https://science.nasa.gov/astrophysics
[11]. https://www.edx.org/xseries/astrophysics
[12]. http://va-iitk.vlabs.ac.in
[13]. https://physion.software.informer.com/1.2/

[18] https://drive.google.com/file/d/1MOtMpMzFpFQpic4mDQn59-8okeZtYhOq/view?usp=sharing