DARK ENERGY DECODED

KARAN R.TAKKHI
Pune 411015, India
E-mail: karantakkhi007@gmail.com

ABSTRACT

The value of the cosmological constant obtained according to the quantum field theory is 10^{120} times larger than the observed small value of the cosmological constant. Such huge discrepancy with the cosmological constant, known as the cosmological constant problem would cause a vacuum catastrophe. Since the discrepancy involved with the cosmological constant is unimaginably very high, therefore, molecular diffusion model has been introduced in this paper as an alternative to dark energy in order to explain the accelerated expansion of the Universe. The molecular diffusion model considers the distribution of large-scale structures as molecules inside a vacuum chamber. Since large-scale structures are ensemble of atoms, therefore, they can be treated as distribution of molecules possessing finite amount of energy. Instead of considering that space is expanding, the manuscript emphasizes upon the recession of large-scale structures upon a stationary space-time continuum. Since the discrepancy with the cosmological constant is very large, therefore, instead of considering that empty space possesses energy, it would be much more prudent to consider that large-scale structures possess energy by the virtue of which they recede, quite similar to a molecule that recedes by the virtue of energy that it possesses, after all, "the diffusion or free expansion of gas molecules inside a vacuum chamber by the virtue of vacuum energy or dark energy" has never been heard of; such claim, if true, would only suggest that gas molecules do not possess any energy. The study shows that large-scale structures will attain a constant recessional velocity in distant future.

Key words: cosmology: theory - dark energy.

1 INTRODUCTION

The Universe is expanding towards the infinity and beyond at an accelerated rate instead of slowing down or even coming to a halt. A mysterious energy rightfully termed as dark energy is considered responsible for causing the Universe to expand at an accelerated rate. Dark energy introduced itself 5 billion years ago (Frieman, Turner and Huterer 2008) and since then the Universe has continued to expand at an accelerated rate; before this time the expansion of the Universe was decelerating due to the gravitational attraction of matter. The accelerated expansion of the Universe was discovered independently by the High-Z Supernova Search Team in the 1998 (Riess et al.) and by Supernova Cosmology Project team in the 1999 (Perlmutter et al.) by measuring the distance to Type Ia supernovae from their brightness (standard candles) and then comparing this distance with the supernovae's cosmological redshift. Dark energy fills the entire Universe just like the Cosmic Microwave Background Radiation (CMBR), but unlike the CMBR whose energy density decreases with time as the Universe expands, the energy density of dark energy remains constant.

Dark energy is hypothetical. The only indication for the existence of dark energy comes from the observations of distance measurements and their relation to the redshifts (Durrer 2011). There are many theories that try to tackle the dark energy problem. What type of energy it exactly is remains an unsolved mystery.

In 1917, Sir Albert Einstein had introduced a special term into his gravitational equation to account for a "static" Universe; a Universe that neither contracts nor expands; the average distance between the celestial objects remains same in a static Universe. The special term was the cosmological constant, denoted by Λ. This constant was introduced to overcome the gravitational attraction of matter that tends to contract and collapse the Universe. The fate of the Universe depends upon whether the cosmological constant is positive or negative. If positive, then gravitational repulsion or expansion is assured, and, if negative, then gravitational attraction or contraction would become inevitable.

In 1929, Sir Edwin Hubble gathered vital data from his observations of distant galaxies from Mount Wilson Observatory in California that proved that the Universe is expanding and is not static at all as was previously considered. The redshifts of the observed galaxies suggested that the distance between the galaxies was increasing, indicating that the galaxies were receding away from each other. This observation of expanding Universe against the idea of static Universe led to the abandoning of the cosmological constant idea.

Surprisingly, the independent observations of the distant Type Ia supernovae in 1998 and 1999 revealed that the Universe is not only expanding, but that expansion was accelerating. This observation made it imperative to bring back the discarded cosmological constant once again. In the simplest form the cosmological constant is equivalent to the energy density of empty space or vacuum (vacuum energy density). However, when the value of the cosmological constant is obtained according to the quantum field theory, a huge discrepancy is introduced. Quantum field theory provides the theoretical value of the cosmological constant to be extremely large ($\sim 2 \times 10^{110}$ erg cm^{-3}) as compared to the observed value of the cosmological constant which is extremely small ($\sim 2 \times 10^{-10}$ erg cm^{-3}) (Carroll 2001). The theoretically obtained value of the cosmological constant according to the quantum field theory is 10^{120} times greater than the observed small value of the cosmological constant. Such discrepant problem with the cosmological constant would lead to a vacuum catastrophe.

The main objective of this paper is to explain the accelerated expansion of the Universe by considering the molecular diffusion model. According to this model space is not expanding; space is stationary, therefore, more precisely, it is the recession of large-scale structures upon a stationary space-time continuum causing the distance between them to increase with time.

Since a huge discrepancy is involved, therefore, instead of considering that empty space possesses energy, the manuscript emphasizes upon the possession of energy by a large-scale structure by the virtue of which it recedes, just like a molecule that recedes by the virtue of energy possessed by it.

2 MOLECULAR DIFFUSION MODEL

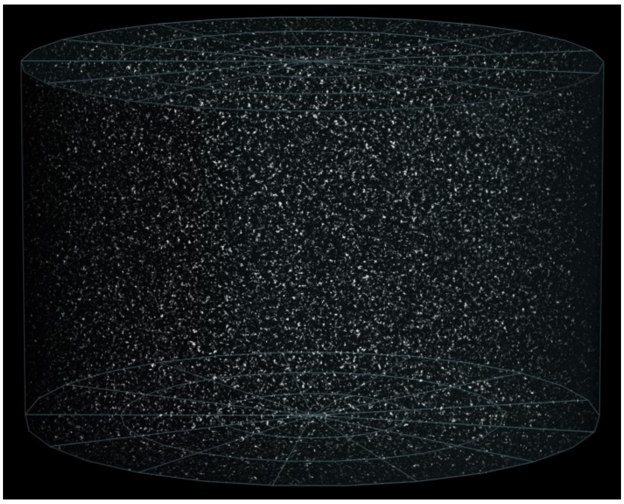

Figure 1. Large-scale structures within the observable Universe. When compared to the infinite volume of the Universe, the large-scale structures can be considered as distribution of molecules inside a vacuum chamber. Therefore, the large-scale structures just like molecules possess finite amount of energy by the virtue of which they diffuse or recede (expand freely) into the empty space just like molecules that diffuse or expand freely in an ultra-high vacuum chamber by the virtue of the energy that they possess. Since large-scale structures possess finite amount of energy, therefore, their recessional velocity must also become finite in the near future, instead of increasing forever.

Diffusion is the flow of molecules from the region of their higher concentration to the region of lower concentration in the presence of a gradient which can be a concentration gradient, a pressure gradient, a thermal gradient or a combination of these. Diffusion ceases only when the system has reached a homogenous state or a state of dynamic equilibrium. The celestial objects distributed within the observable Universe are concentrated within the observable Universe. Therefore, they must diffuse from the region of their higher concentration to the region of lower concentration, that is, from the observable Universe to the region beyond the observable Universe. Such diffusion will only cease when the Universe would have achieved a homogenous or uniform distribution of matter throughout its empty space.

As shown in figure 1, all large-scale structures (galaxies, galaxy clusters, superclusters, etc.) when compared to the gigantic volume of the infinite Universe resemble microscopic particles, almost like gas molecules in an infinite and ultra-high vacuum chamber. Therefore, instead of maintaining a fixed position within the Universe, the large-scale structures would most probably prefer to diffuse out or expand freely into the infinite realm by the virtue of the diffusion energy that they possess, after all, diffusion or recession of a molecule occurs due to the energy it possesses, and, the diffusion of molecules in an ultra-high vacuum chamber will be faster as compared to the diffusion of molecules inside a pressurized chamber; pressure affects the mean free path of the diffusing molecules, that is, a lower pressure increases the mean free path of the molecules and decreases the collision probability between them, whereas a higher pressure reduces the mean free path and increases the collision probability between the molecules.

In the past, the distance between celestial objects was less, or we can say that the mean free path was less, therefore, the collision probability between structures was significantly higher; structures readily collided and merged to form bigger structures. As time progressed, the distance between structures increased, that is, the mean free path of gravitationally bound structures increased gradually according to the low pressure of the surrounding space; increased mean free path has reduced the collision probability between the structures at present.

Gravity being the only force between the distant large-scale structures is not strong enough to retard the recession (diffusion or the recessional energy possessed by the receding large-scale structures is greater than the mutual gravitational force between them).

A large-scale structure such as galaxy cluster harbours more atoms throughout its volume. When compared to the colossal size of the infinite Universe we can consider such large-scale structure as a single molecule since it is an ensemble of many atoms all gravitationally bound due to the resultant mass of the ensemble. Therefore, the more the energy possessed by a large-scale structure more will be its recessional velocity; the energy possessed by a large-scale structure makes it diffuse or recede as a single molecule (diffusion of molecules occurs due to the energies of the diffusing molecules; the energy possessed by the molecule makes it recede).

In case of molecules which are just about to diffuse, if the molecular attractive force between the molecules is increased somehow, then such force will out power the energy that causes the molecules to diffuse, in such case the molecules would remain clumped together instead of diffusing out. The molecular attractive force is analogous to gravity between large-scale structures. The structures that cause its constituents to orbit are bound strongly by gravity, and the diffusing ability is out powered by such gravitational force (star causes planets to orbit around it, galaxy causes stars and gas clouds to orbit around it, and, galaxy cluster causes galaxies to orbit around it). Therefore, planets do not diffuse or recede out of a planetary system, stars do not diffuse out of a galaxy, and galaxies do not diffuse out of the cluster; such structures do not expand. On the other hand, the gravitationally self-bound large-scale structures which do not seem to orbit around any other large-scale structures (suggesting that they are not bound strongly by mutual gravitation) are able to out power the mutual gravitational force with the energy that they possess required for diffusion or recession, and therefore they diffuse or recede; structures such as galaxy clusters, field galaxies and superclusters.

Therefore, the diffusion or the recession of large-scale structures works effectively and efficiently for those structures that are separated by large distances; between field galaxies, between galaxy clusters and between superclusters. And, not within planetary systems, within galaxies and within galaxy clusters as these are gravitationally bound systems. Within gravitationally bound systems such as planetary systems, galaxies, galaxy clusters, the diffusion process is out powered by the gravitational force which is responsible for binding such systems; the gravitational force within such bound systems is more than the energy required for diffusion or recession. Therefore, we have the distance between galaxy clusters, field galaxies and superclusters increasing continuously, whereas the distance between stars in galaxies, galaxies within galaxy clusters and between planets and the central star in case of planetary systems remains significantly unchanged apparently.

In the molecular diffusion model, the space is not expanding, only the distance between the large-scale structures is increasing with time.

3 ENERGY THAT CAUSES THE DIFFUSION OR RECESSION OF A LARGE-SCALE STRUCTURE: WHY SHOULD A LARGE-SCALE STRUCTURE RECEDE ?

The energy possessed by an object moving with velocity v is given as,

$$E = \frac{1}{2}mv^2 \tag{1}$$

Equation (1) should also be valid if expressed in terms of velocity as,

$$v = \sqrt{\frac{2E}{m}} \tag{2}$$

Equation (2) suggests that an object possessing sufficient amount of energy will also possess velocity and therefore the object will recede. This is exactly what is observed in the case of a molecule, that is, if the molecule gains more energy than before, then according to equation (2) the velocity of the molecule will increase. Now, since a large-scale structure possesses sufficient amount of energy, therefore, such structure will recede with a velocity according to equation (2).

In an environment where gravitational force is stronger, like on Earth's surface, the energy possessed by an object will not cause the object to recede, as gravitational force takes over, however, a molecule is an exception in this case. Since the mass of a molecule is minuscule, therefore, a molecule is not influenced significantly by Earth's gravitational force; the energy possessed by a molecule turns out to be greater than the gravitational force acting upon it, and therefore the molecule recedes purely by the virtue of energy possessed by it. Similarly, in deep space environment the gravitational influence is significantly weaker; particularly between the large-scale structures that are separated by large distances. Therefore, the energy possessed by a large-scale structure will make it recede, just like a molecule, as the energy required for recession is greater than the gravitational influence between the receding large-scale structures.

4 IS SPACE BETWEEN LARGE-SCALE STRUCTURES EXPANDING OR ARE THE LARGE-SCALE STRUCTURES RECEDING ?

It is firmly believed that large-scale structures are stationary and only the distance between them is increasing at an accelerating rate, that is, the space between the structures is expanding at an accelerating rate causing the light emitted by them to get stretched (redshifted). However, if the space is stationary and the large-scale structures are receding away from each other just like molecules, then the light emitted by them would still undergo redshifting due to the involvement of actual recession rather than expansion of space.

Since the most distant structures possess higher recessional velocity as compared to the structures that are closer, therefore, the light from a very distant receding structure is redshifted to higher extent as compared to the light from a nearby receding structure. It must be noted that the amount of intervening space between the structures is increasing in both cases; whether space undergoes expansion, or if structures recede away from each other.

The next section shows that receding large-scale structures should attain a constant recessional velocity due to the finite amount of energy possessed by them.

5 ACCELERATED EXPANSION OF THE UNIVERSE WILL NOT CONTINUE FOREVER: WHAT WOULD BE THE FINAL RECESSIONAL VELOCITY THEN ?

Large-scale structures recede by the virtue of energy possessed by them, instead of energy being possessed by empty space. Since large-scale structures possess finite amount of energy, therefore, their recessional velocity must also be finite, instead of increasing continuously with time. Accelerated recession as observed is only possible if the structures are still in the process of attaining a finite velocity corresponding to the finite amount of energy possessed by them; just like a vehicle that keeps accelerating before attaining a constant velocity. The velocity keeps increasing every second as long as the permitted constant velocity is not attained.

As an example let us consider a galaxy cluster. Since the mass of galaxy clusters usually ranges between 10^{14} $M_\odot$ to 10^{15} $M_\odot$, therefore, it would be perfectly fine to consider a galaxy cluster with mass of about 2×10^{15} $M_\odot$ (4×10^{45} kg). From this mass we obtain the total number of protons making the cluster to be 2.3914×10^{72}.

The temperature of all galaxy clusters is dominated by the extremely hot (10^7 K to 10^8 K) intracluster medium (ICM) - the plasma that shines brightly in X-ray wavelength. This galaxy cluster is therefore no exception;

its temperature is dominated by ICM at 10^8 K (we are considering maximum temperature and mass as it will provide us with approximate recessional velocity that a massive galaxy cluster should attain). The energy per proton is given as,

$$E = \frac{3}{2}kT \tag{3}$$

where k is the Boltzmann constant and T is the temperature. Using equation (3), we obtain the energy per proton corresponding to a temperature of 10^8 K to be 2.0709 x 10^{-15} J. Total energy possessed by the galaxy cluster therefore equates to 4.9523 x 10^{57} J.

Now, using equation (2), we will obtain the finite value of recessional velocity that the cluster will attain, and this is found to be 1,573,578.724 m s^{-1} (1,573.57 km s^{-1}). The obtained velocity v of 1,573,578.724 m s^{-1} (1,573.57 km s^{-1}) corresponds to a redshift z of 0.005245262413. This is just an approximation, recessional velocities greater than the velocity of light are also possible if the energy possessed by the large-scale structure is sufficiently large.

For instance, if this galaxy cluster has to exhibit recessional velocity greater than the velocity of light, say, 4 x 10^8 m s^{-1} (z = 1.333333333 obtained from the relation $z = v / c$), then the energy possessed by the cluster must be 3.2 x 10^{62} J. It has been observed that the most distant celestial objects (billions of light-years away) exhibit such high recessional velocities as evident from their redshifts. Such distant structures reveal themselves to us as they were billions of years ago when the Universe was comparatively younger than it is today. Since the early Universe was much more energetic than it is today, therefore, it is very likely that the structures during that energetic era possessed surplus amount of energy that made them recede with such high recessional velocity. We do not know the present day recessional velocity of such distant celestial objects as we are observing them how those structures were billions of years ago. Therefore, it would be more accurate if we obtain the amount of energy possessed by a large-scale structure from its recessional velocity, after all, it is the energy possessed by the structure that is causing it to recede.

6 ENERGY POSSESSED BY RECEDING LARGE-SCALE STRUCTURES IS GREATER THAN THE GRAVITATIONAL INFLUENCE BETWEEN THEM

Let us consider two identical galaxy clusters, both are equally massive (2 x 10^{15} $M_\odot$ (4 x 10^{45} kg)), and both are dominated by the ICM at temperature of 10^8 K. The energy possessed by both galaxy clusters is 4.9523 x 10^{57} J (section 5) .These clusters are separated by a distance of 50 Mpc (1.5428 x 10^{24} m); typical distance between galaxy clusters. Now, since we are equating the energy possessed by the clusters with the gravitational influence between them, therefore, the result would be more accurate if we consider the gravitational binding energy and gravitational potential energy between the clusters.
The gravitational binding energy is given as,

$$G.B.E. = \frac{GM_1M_2}{2R} \tag{4}$$

Similarly, the gravitational potential energy is given as,

$$G.P.E. = -\frac{GM_1M_2}{R} \tag{5}$$

where M_1 and M_2 are the masses of the galaxy clusters and R is the distance between them.

The gravitational binding energy is found to be 3.4602 x 10^{56} J, whereas the gravitational potential energy is found to be -6.9204 x 10^{56} J. The recessional energy, or the energy possessed by the clusters required to recede is 14.31 times greater than the gravitational binding energy, and 7.15 times greater than the gravitational potential energy, therefore, instead of remaining gravitationally bound to each other, the clusters would diffuse or recede away from each other into the cosmic wilderness.

7 WHEN WOULD THE UNIVERSE COLLAPSE ?

The Cosmic Microwave Background Radiation (CMBR) corresponds to a temperature of 2.7260 $\pm$ 0.0013 K (Fixsen 2009). The temperature of surrounding space is therefore extremely low (-270.424°C). Surrounding space at such low temperature would act like an efficient heat sink. The large-scale structures that are receding by the virtue of energy possessed by them will become energy deficient in distant future, causing them to gradually slow down and stop. Gravity will take over and the inward collapse of matter will begin.

CONCLUSIONS

(1) The molecular diffusion model has been introduced in this paper as an alternative to dark energy.

(2) According to this model space is stationary and the distance between the large-scale structures is increasing due to their diffusion or recession by the virtue of the energy possessed by them.

(3) Large-scale structures recede upon a stationary space-time continuum with velocity corresponding to the total amount of energy that they possess; finite amount of energy suggests finite velocity that the receding structures will attain in distant future.

(4) Large-scale structures would continue to accelerate as long as they do not attain a constant velocity corresponding to finite amount of energy that they possess.

(5) The energy possessed by receding large-scale structures is greater than the gravitational influence between them. Therefore, they recede away from each other instead of remaining gravitationally bound.

(6) “Gas molecules diffusing or expanding freely inside a vacuum chamber by the virtue of vacuum energy or dark energy” has never been heard of. Such claim, if true, would only suggest that gas molecules do not possess any energy.

(7) Large-scale structure possessing recessional velocity greater than the velocity of light is practically possible if the total amount of energy possessed by them is sufficiently large.

(8) Accelerated recession of a large-scale structure upon a stationary space-time continuum as is believed in this paper should produce a gravitational wave.

(9) The Universe will begin to collapse once the receding large-scale structures become energy deficient. Energy deficient large-scale structures will slow down and eventually stop with their recession and gravity will finally take over.

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REFERENCES

Carroll S. M., 2001, LRR, 4, 1
Durrer R., 2011, RSPTA, 369, 5102
Einstein A., 1917, Sitz. Preuss. Akad. Wiss. Phys.-Math, 142, 87
Fixsen D. J., 2009, ApJ, 707, 916
Frieman J. A., Turner M. S., Huterer D., 2008, ARA&A, 46, 385
Hubble E. P., 1929, Proc. Natl. Acad. Sci., 15, 168
Perlmutter S., Aldering G., Goldhaber G., Knop R. A., Nugent P., et al., 1999, ApJ, 517, 565
Riess A. G., Filippenko A. V., Challis P., Clocchiatti A., Diercks A., et al., 1998, AJ, 116, 1009
vixra.org/abs/1712.0096
vixra.org/abs/1801.0144