The Dark Energy Universe

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Abstract

Some seventy five years ago, the concept of dark matter was introduced by Zwicky to explain the anomaly of galactic rotation curves, though there is no clue to its identity or existence to date. In 1997, the author had introduced a model of the universe which went diametrically opposite to the existing paradigm which was a dark matter assisted decelerating universe. The new model introduces a dark energy driven accelerating universe though with a small cosmological constant. The very next year this new picture was confirmed by the Supernova observations of Perlmutter, Riess and Schmidt. These astronomers got the 2011 Nobel Prize for this dramatic observation. All this is discussed briefly, including the fact that dark energy may obviate the need for dark matter.

1 Introduction

By the end of the last century, the Big Bang Model had been worked out. It contained a huge amount of unobserved, hypothesized "matter" of a new kind - dark matter. This was postulated as long back as the 1930s to explain the fact that the velocity curves of the stars in the galaxies did not fall off, as they should. Instead they flattened out, suggesting that the galaxies contained some undetected and therefore non-luminous or dark matter. The identity of this dark matter has been a matter of guess work, though. It could consist of Weakly Interacting Massive Particles (WIMPS) or Super Symmetric partners of existing particles. Or heavy neutrinos or monopoles
or unobserved brown dwarf stars and so on.

In fact Prof. Abdus Salam speculated some two decades ago [1] "And now we come upon the question of dark matter which is one of the open problems of cosmology. This is a problem which was speculated upon by Zwicky fifty years ago. He showed that visible matter of the mass of the galaxies in the Coma cluster was inadequate to keep the galactic cluster bound. Oort claimed that the mass necessary to keep our own galaxy together was at least three times that concentrated into observable stars. And this in turn has emerged as a central problem of cosmology.

"You see there is the matter which we see in our galaxy. This is what we suspect from the spiral character of the galaxy keeping it together. And there is dark matter which is not seen at all by any means whatsoever. Now the question is what does the dark matter consist of? This is what we suspect should be there to keep the galaxy bound. And so three times the mass of the matter here in our galaxy should be around in the form of the invisible matter. This is one of the speculations."

The universe in this picture, contained enough of the mysterious dark matter to halt the expansion and eventually trigger the next collapse. It must be mentioned that the latest WMAP survey [2], in a model dependent result indicates that as much as twenty three percent of the Universe is made up of dark matter, though there is no definite observational confirmation of its existence.

That is, the Universe would expand up to a point and then collapse. There still were several subtler problems to be addressed. One was the famous horizon problem. To put it simply, the Big Bang was an uncontrolled or random event and so, different parts of the Universe in different directions were disconnected at the very earliest stage and even today, light would not have had enough time to connect them. So they need not be the same. Observation however shows that the Universe is by and large uniform, rather like people in different countries showing the same habits or dress. That would not be possible without some form of faster than light intercommunication which would violate Einstein’s Special Theory of Relativity.

The next problem was that according to Einstein, due to the material content in the Universe, space should be curved whereas the Universe appears to be flat.

There were other problems as well. For example astronomers predicted that there should be monopoles that is, simply put, either only North magnetic poles or only South magnetic poles, unlike the North South combined mag-
netic poles we encounter. Such monopoles have failed to show up even after seventy five years.

Some of these problems as we noted, were sought to be explained by what has been called inflationary cosmology whereby, early on, just after the Big Bang the explosion was super fast [3, 4].

What would happen in this case is, that different parts of the Universe, which could not be accessible by light, would now get connected. At the same time, the super fast expansion in the initial stages would smoothen out any distortion or curvature effects in space, leading to a flat Universe and in the process also eliminate the monopoles.

Nevertheless, inflation theory has its problems. It does not seem to explain the cosmological constant observed since. Further, this theory seems to imply that the fluctuations it produces should continue to indefinite distances. Observation seems to imply the contrary.

One other feature that has been studied in detail over the past few decades is that of structure formation in the Universe. To put it simply, why is the Universe not a uniform spread of matter and radiation? On the contrary it is very lumpy with planets, stars, galaxies and so on, with a lot of space separating these objects. This has been explained in terms of fluctuations in density, that is, accidentally more matter being present in a given region. Gravitation would then draw in even more matter and so on. These fluctuations would also cause the cosmic background radiation to be non uniform or anisotropic. Such anisotropies are in fact being observed. But this is not the end of the story. The galaxies seem to be arranged along two dimensional structures and filaments with huge separating voids.

From 1997, the conventional wisdom of cosmology that had concretized from the mid sixties onwards, began to be challenged. It had been believed that the density of the Universe is near its critical value, separating eternal expansion and ultimate contraction, while the nuances of the dark matter theories were being fine tuned. But that year, the author proposed a contra view, which we will examine.

2 Cosmology

To proceed, as there are $N \sim 10^{80}$ such particles in the Universe, we get, consistently,

$$Nm = M$$  \hspace{1cm} (1)
where $M$ is the mass of the Universe. It must be remembered that the energy of gravitational interaction between the particles is very much insignificant compared to the above electromagnetic considerations.

In the following we will use $N$ as the sole cosmological parameter.

We next invoke the well known relation \[ R \approx \frac{GM}{c^2} \] \[(2)\]
where $M$ can be obtained from (1). We can arrive at (2) in different ways. For example, in a uniformly expanding Friedman Universe, we have

\[
\dot{R}^2 = \frac{8\pi G\rho R^2}{3} \]

In the above if we substitute $\dot{R} = c$ at $R$, the radius of the universe, we get \[(2)\]. Another proof can also be given.

We now use the fact that given $N$ particles, the (Gaussian) fluctuation in the particle number is of the order $\sqrt{N}$ \[7, 8, 9, 10, 11, 12\], while a typical time interval for the fluctuations is $\sim \hbar/mc^2$, the Compton time, the fuzzy interval within which there is no meaningful physics as argued by Dirac and in greater detail by Wigner and Salecker. So particles are created and destroyed - but the ultimate result is that $\sqrt{N}$ particles are created just as this is the nett displacement in a random walk of unit step. So we have,

\[
\frac{dN}{dt} = \frac{\sqrt{N}}{\tau} \]

whence on integration we get, (remembering that we are almost in the continuum region that is, $\tau \sim 10^{-23}\text{sec} \approx 0$),

\[
T = \frac{\hbar}{mc^2} \sqrt{N} \]

(4)

We can easily verify that the equation \[(1)\] is indeed satisfied where $T$ is the age of the Universe. Next by differentiating (2) with respect to $t$ we get

\[
\frac{dR}{dt} \approx HR \]

(5)

where $H$ in (5) can be identified with the Hubble Constant, and using (2) is given by,

\[
H = \frac{Gm^3c}{\hbar^2} \]

(6)
Already this shows an exponential inflationary behaviour with acceleration while Equation (1), (2) and (4) show that in this formulation, the correct mass, radius, Hubble constant and age of the Universe can be deduced given \( N \), the number of particles, as the sole cosmological or large scale parameter. We observe that at this stage we are not invoking any particular dynamics - the expansion is due to the random creation of particles from the ZPF background. Equation (6) can be written as

\[
m \approx \left( \frac{H \hbar^2}{Gc} \right)^{\frac{1}{3}}
\]

Equation (7) has been empirically known as an "accidental" or "mysterious" relation. As observed by Weinberg [13], this is unexplained: it relates a single cosmological parameter \( H \) to constants from microphysics. We will touch upon this micro-macro nexus again. In our formulation, equation (7) is no longer a mysterious coincidence but rather a consequence of the theory. As (6) and (5) are not exact equations but rather, order of magnitude relations, it follows, on differentiating (5) that a small cosmological constant \( \Lambda \) is allowed such that

\[
\Lambda \leq 0(H^2)
\]

This is consistent with observation and shows that \( \Lambda \) is very small —— this has been a puzzle, the so called cosmological constant problem alluded to, because in conventional theory, it turns out to be huge [14]. But it poses no problem in this formulation. This is because of the characterization of the ZPF as independent and primary in our formulation this being the mysterious dark energy. Otherwise we would encounter the cosmological constant problem of Weinberg: a \( \Lambda \) that is some \( 10^{120} \) orders of magnitude of observable values!

To proceed we observe that because of the fluctuation of \( \sim \sqrt{N} \) (due to the ZPF), there is an excess electrical potential energy of the electron, which in fact we identify as its inertial energy. That is [9, 7],

\[
\sqrt{N}e^2/R \approx mc^2.
\]

On using (2) in the above, we recover the well known Gravitation-Electromagnetism ratio viz.,

\[
e^2/Gm^2 \sim \sqrt{N} \approx 10^{40}
\]
or without using (2), we get, instead, the well known so called Weyl-Eddington
formula,
\[ R = \sqrt{N}l \]  \hspace{1cm} (9)
(It appears that (9) was first noticed by H. Weyl [15]). Infact (9) is the
spatial counterpart of (4). If we combine (9) and (2), we get,
\[ \frac{Gm}{lc^2} = \frac{1}{\sqrt{N}} \propto T^{-1} \]  \hspace{1cm} (10)
where in (10), we have used (4). Following Dirac (cf.also [16]) we treat \( G \) as
the variable, rather than the quantities \( m, l, c \) and \( \hbar \) which we will call micro
physical constants because of their central role in atomic (and sub atomic)
physics.
Next if we use \( G \) from (10) in (6), we can see that
\[ H = \frac{cl}{\sqrt{N}} \]  \hspace{1cm} (11)
Thus apart from the fact that \( H \) has the same inverse time dependance on
\( T \) as \( G \), (11) shows that given the microphysical constants, and \( N \), we can
deduce the Hubble Constant also, as from (11) or (6).
Using (11) and (2), we can now deduce that
\[ \rho \approx \frac{m}{l^3} \frac{1}{\sqrt{N}} \]  \hspace{1cm} (12)
Next (9) and (4) give,
\[ R = cT \]  \hspace{1cm} (13)
Equations (12) and (13) are consistent with observation.
Finally, we observe that using \( M, G \) and \( H \) from the above, we get
\[ M = \frac{c^3}{GH} \]
This relation is required in the Friedman model of the expanding Universe
(and the Steady State model too). In fact if we use in this relation, the
expression,
\[ H = \frac{c}{R} \]
which follows from (11) and (2), then we recover (2). We will be repeatedly
using these relations in the sequel.
As we saw the above model predicts a dark energy driven ever expanding and accelerating Universe with a small cosmological constant while the density keeps decreasing. Moreover mysterious large number relations like (6), (12) or (9) which were considered to be miraculous accidents now follow from the underlying theory. This seemed to go against the accepted idea that the density of the Universe equalled the critical density required for closure and that aided by dark matter, the Universe was decelerating.

However, as noted, from 1998 onwards, following the work of Perlmutter, Schmidt and Riess, these otherwise apparently heretic conclusions have been vindicated.

It may be mentioned that the observational evidence for an accelerating Universe was the American Association for Advancement of Science’s Breakthrough of the Year, 1998 while the evidence for nearly seventy five percent of the Universe being Dark Energy, based on the Wilkinson Microwave Anisotropy Probe (WMAP) and the Sloan Sky Digital Survey was the Breakthrough of the Year, 2003 [17, 2]. The trio got the 2011 Nobel for Physics.

3 Discussion

1. We observe that in the above scheme if the Compton time \( \tau \rightarrow \tau_P \), we recover the Prigogine Cosmology [18, 19]. In this case there is a phase transition in the background ZPF or Quantum Vacuum or Dark Energy and Planck scale particles are produced.

On the other hand if \( \tau \rightarrow 0 \) (that is we return to point spacetime), we recover the Standard Big Bang picture. But it must be emphasized that in neither of these two special cases can we recover the various so called Large Number coincidences for example Equations like (1) or (6) or (8) or (9).

2. The above ideas lead to an important characterization of gravitation. This also explains why it has not been possible to unify gravitation with other interactions, despite nearly a century of effort.

Gravitation is the only interaction that could not be satisfactorily unified with the other fundamental interactions. The starting point has been a diffusion equation

\[
|\Delta x|^2 = \langle \Delta x^2 \rangle = \nu \cdot \Delta t
\]

\[
\nu = \hbar / m, \nu \approx lv
\]

This way we could explain a process similar to the formation of Benard cells [20, 18] – there would be sudden formation of the “cells” from the background
dark energy, each at the Planck Scale, which is the smallest physical scale. These in turn would be the underpinning for spacetime. We could consider an array of $N$ such Planckian cells. This would be described by

$$r = \sqrt{N\Delta x^2}$$

(15)

$$ka^2 \equiv k\Delta x^2 = \frac{1}{2}k_BT$$

(16)

where $k_B$ is the Boltzmann constant, $T$ the temperature, $r$ the extent and $k$ is the spring constant given by

$$\omega_0^2 = \frac{k}{m}$$

(17)

$$\omega = \left(\frac{k}{ma^2}\right)^{\frac{1}{2}} \frac{1}{r} = \omega_0 \frac{a}{r}$$

(18)

We now identify the particles or cells with Planck masses and set $\Delta x \equiv a = l_P$, the Planck length. It may be immediately observed that use of (17) and (16) gives $k_BT \sim m_Pc^2$, which of course agrees with the temperature of a black hole of Planck mass. Indeed, Rosen [22] had shown that a Planck mass particle at the Planck scale can be considered to be a Universe in itself with a Schwarzchild radius equalling the Planck length. We also use the fact alluded to that a typical elementary particle like the pion can be considered to be the result of $n \sim 10^{40}$ Planck masses.

Using this in (15), we get $r \sim l$, the pion Compton wavelength as required. Whence the pion mass is given by

$$m = m_P/\sqrt{n}$$

which of course is correct, with the choice of $n$. This can be described by

$$l = \sqrt{nl_P}, \tau = \sqrt{n\tau_P},$$

(19)

$$l_P^2 = \frac{\hbar}{m_P\tau_P}$$

The last equation is the analogue of the diffusion process seen, which is in fact the underpinning for particles, except that this time we have the same Brownian process operating from the Planck scale to the Compton scale (Cf. also [23] [24]).
We now use the well known result alluded to that the individual minimal oscillators are black holes or mini Universes as shown by Rosen [22]. So using the Beckenstein temperature formula for these primordial black holes [25], that is

\[ kT = \frac{\hbar c^3}{8\pi G m} \]

we can show that

\[ Gm^2 \sim \hbar c \]  

(20)

We can easily verify that (20) leads to the value \( m \sim 10^{-5}\)gms. In deducing (20) we have used the typical expressions for the frequency as the inverse of the time - the Compton time in this case and similarly the expression for the Compton length. However it must be reiterated that no specific values for \( l \) or \( m \) were considered in the deduction of (20).

We now make two interesting comments. Cercignani and co-workers have shown [26, 27] that when the gravitational energy becomes of the order of the electromagnetic energy in the case of the Zero Point oscillators, that is

\[ \frac{G\hbar^2 \omega^3}{c^5} \sim \hbar \omega \]  

(21)

then this defines a threshold frequency \( \omega_{\text{max}} \) above which the oscillations become chaotic. In other words, for meaningful physics we require that

\[ \omega \leq \omega_{\text{max}}. \]

Secondly as we can see from the parallel but unrelated theory of phonons [8, 28], which are also bosonic oscillators, we deduce a maximal frequency given by

\[ \omega_{\text{max}}^2 = \frac{c^2}{l^2} \]  

(22)

In (22) \( c \) is, in the particular case of phonons, the velocity of propagation, that is the velocity of sound, whereas in our case this velocity is that of light. Frequencies greater than \( \omega_{\text{max}} \) in (22) are again meaningless. We can easily verify that using (21) in (22) gives back (20).

In other words, gravitation shows up as the residual energy from the formation of the particles in the universe via Planck scales (Benard like) cells.

3. It has been mentioned that despite nearly 75 years of search, Dark Matter has not been found. More recently there is evidence against the existence
of Dark Matter or its previous models. The latest LHC results for example seem to rule out SUSY.

On the other hand our formulation obviates the need for Dark Matter. This follows from an equation like (10) which shows a gravitational constant decreasing with time. Starting from here it is possible to deduce not just the anomalous rotation curves of galaxies which was the starting point for Dark Matter; but also we could deduce all the known standard results of General Relativity like the precession of the perihelion of mercury, the bending of light, the progressive shortening of the time period of binary pulsars and so on (Cf.ref.[20]).

4. Epilogue: The idea of a perfect vacuum began to get frayed in the 19th century. In the 20th century with the advent of Quantum Theory the concept of a Quantum Vacuum came into being. This Quantum Vacuum is seething with energy and activity, and it is there everywhere. With this background we can see the following:

Around 1997 I had put forward a radically different model. In this, there wasn’t any Big Bang, with matter and energy being created instantaneously. Rather the universe is permeated by an energy field of a kind familiar to modern physicists. The point is, that according to Quantum theory which is undoubtedly one of the great intellectual triumphs of the twentieth century, all our measurements, and that includes measurements of energy, are at best approximate. There is always a residual error. This leads to what physicists call a ubiquitous Zero Point Field or Quantum Vacuum. We will return to this “Dark Energy” soon. Out of such a ghost background or all pervading energy field, particles are created in a totally random manner, a process that keeps continuing. However, much of the matter was created in a fraction of a second. There is no “Big Bang” singularity, though, which had posed Wheeler’s greatest problem of physics. The contents of this paper went diametrically opposite to accepted ideas, that the universe, dominated by dark matter was actually decelerating. Rather, driven by dark energy, the universe would be expanding and accelerating, though slowly. I was quite sure that this paper would be rejected outright by any reputable scientific journal. So I presented these ideas at the prestigious Marcell Grossmann meet in Jerusalem and another International Conference on Quantum Physics. But, not giving into pessimism, I shot off the paper to a standard International journal, anyway. To my great surprise, it was accepted immediately!

There is a further cosmic footprint of this model: a residual miniscule energy in the Cosmic Microwave Background, less than a billion billion billion
billionth of the energy of an electron. Latest data has confirmed the presence of such an energy. All this is in the spirit of the manifest universe springing out of an unmanifest background, as described in the Bhagvad Gita. There are several interesting consequences.

Firstly it is possible to theoretically estimate the size and age of the universe and also deduce a number of very interesting interrelationships between several physical quantities like the charge of the electron, the mass of elementary particles, the gravitational constant, the number of particles in the universe and so on. One such, connecting the gravitational constant and the mass of an elementary particle with the expansion of the universe was dubbed as inexplicable by Nobel Laureate Steven Weinberg. But on the whole these intriguing interrelationships have been considered by most scientists to be miraculous coincidences.

With one exception. The well known Nobel Prize winning physicist Paul Dirac sought to find an underlying reason to explain what would otherwise pass off as a series of inexplicable accidents. In this model, there is a departure from previous theories including the fact that some supposedly constant quantities like the universal constant of gravitation are actually varying very slowly with time. Interestingly latest observations seem to point the finger in this direction.

However my model is somewhat different and deduces these mysterious relations. Further, it sticks its neck out in predicting that the universe is not only expanding, but also accelerating as it does so. This went against all known wisdom. Shortly thereafter from 1998 astronomers like Perlmutter and Kirshner began to publish observations which confirmed exactly such a behavior. These shocking results have since been reconfirmed. The universe had taken a U Turn.

When questioned several astronomers in 1998 confided to me that the observations were wrong! After the expansion was reconfirmed, some became cautious. Let us wait and see. At the same time, some rushed back to their desks and tried to rework their calculations. The other matter was, what force could cause the accelerated expansion? The answer would be, some new and inexplicable form of energy, as suggested by me. Dark Energy. Later the presence of dark energy was confirmed by the Wilkinson Microwave Probe (WMAP) and the Sloane Digital Sky Survey. Both these findings were declared by the prestigious journal Science as breakthroughs of the respective years.

The accelerated expansion of the universe and the possibility that supposedly
eternally constant quantities could vary, has been the new paradigm gifted to science, a parting gift by the departing millennium. A 2000 article in the Scientific American observed, “In recent years the field of cosmology has gone through a radical upheaval. New discoveries have challenged long held theories about the evolution of the Universe... Now that observers have made a strong case for cosmic acceleration, theorists must explain it.... If the recent turmoil is anything to go by, we had better keep our options open.”

On the other hand, an article in Physics World in the same year noted, “A revolution is taking place in cosmology. New ideas are usurping traditional notions about the composition of the Universe, the relationship between geometry and destiny, and Einstein’s greatest blunder.”

It is this greatest blunder of Einstein which got the Nobel Prize for Physics in 2011 for three US astronomers, Perlmutter, Reiss and Schmidt who observed the accelerated expansion of the universe in 1988.

References

[1] Sidharth, B.G. (2007). *Encounters: Abdus Salam* in *New Advances in Physics* Vol.1, No.1, March 2007, pp.1–17.

[2] Science, December 2003

[3] Zee, A. (1982). *Unity of Forces in the Universe Vol.II* (World Scientific, Singapore), p.40ff.

[4] Linde, A.D. (1982). *Phys.Lett.* 108B, 389.

[5] Sidharth, B.G. (2003). *Chaos, Solitons and Fractals* 16, (4), pp.613–620.

[6] Nottale, L. (1993). *Fractal Space-Time and Microphysics: Towards a Theory of Scale Relativity* (World Scientific, Singapore), pp.312.

[7] Hayakawa, S. (1965). *Suppl of PTP Commemorative Issue* pp.532-541.

[8] Huang, K. (1975). *Statistical Mechanics* (Wiley Eastern, New Delhi), pp.75ff.

[9] Sidharth, B.G. (1998). *Int.J. of Mod.Phys.A* 13, (15), pp.2599ff.
[10] Sidharth, B.G. (1998). *International Journal of Theoretical Physics* Vol.37, No.4, pp.1307–1312.

[11] Sidharth, B.G. (1998). *Frontiers of Quantum Physics (1997)* Lim, S.C., et al. (eds.) (Springer Verlag, Singapore).

[12] Sidharth, B.G. (1999). *Proc. of the Eighth Marcel Grossmann Meeting on General Relativity (1997)* Piran, T. (ed.) (World Scientific, Singapore), pp.476–479.

[13] Weinberg, S. (1972). *Gravitation and Cosmology* (John Wiley & Sons, New York), p.61ff.

[14] Weinberg, S. (1979). *Phys.Rev.Lett.* 43, pp.1566.

[15] Singh, J. (1961). *Great Ideas and Theories of Modern Cosmology* (Dover, New York), pp.168ff.

[16] Melnikov, V.N. (1994). *Int.J.of Th.Phys.* 33, (7), pp.1569–1579.

[17] Science, December 1998.

[18] Nicolis, G. and Prigogine, I. (1989). *Exploring Complexity* (W.H. Freeman, New York), p.10.

[19] Edward P. Tryon (1973). *Is the Universe a Vacuum Fluctuation?* in *Nature* Vol.246, December 14 1973, pp.396-397.

[20] Sidharth, B.G. (2008). *The Thermodynamic Universe* (World Scientific), Singapore.

[21] Sidharth, B.G. (2010). *Int.J.Th.Ph* Vol.49(10), 2010, pp.2476-2485.

[22] Rosen, N. (1993). *Int.J.Th.Phys.*, 32, (8), pp.1435–1440.

[23] Sidharth, B.G. (2002). *Found.Phys.Lett.* 15, (6), pp.577–583.

[24] Sidharth, B.G. (2001). *Chaotic Universe: From the Planck to the Hubble Scale* (Nova Science, New York).

[25] Ruffini, R. and Zang, L.Z. (1983). *Basic Concepts in Relativistic Astrophysics* (World Scientific, Singapore), p.111ff.
[26] Cercignani, C. (1998). *Found.Phys.Lett.* Vol.11, No.2, pp.189-199.

[27] Cercignani, C., Galgani, L. and Scotti, A. (1972). *Phys.Lett.* 38A, pp.403.

[28] Reif, F. (1965). *Fundamentals of Statistical and Thermal Physics* (McGraw-Hill Book Co., Singapore).