Chapter 25
The Dark Energy Universe

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Abstract Some 75 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 decelarating universe. The new model introduces a dark energy driven accelarating 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.

25.1 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 mat-

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ter 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 [21] "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 50 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 [13], 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 magnetic poles we encounter. Such monopoles have failed to show up even after 75 years.

Some of these problems 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 [5, 28].

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.

25.2 Cosmology

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

$$Nm = M \tag{25.1}$$

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 electromagnetic considerations.

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

We next invoke the well known relation [3, 8, 20]

$$R \approx \frac{GM}{c^2} \tag{25.2}$$

where M can be obtained from (25.1). We can arrive at (25.2) in different ways. For example, in a uniformly expanding Friedman Universe, we have

$$\dot{R}^2 = 8\pi G\rho R^2/3$$

In the above if we substitute $\dot{R} = c$ at R, the radius of the universe, we get (25.2). We now use the fact that given N particles, the (Gaussian) fluctuation in the particle number is of the order $\sqrt{N}$ [3, 4, 14–17], 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,

$$\frac{dN}{dt} = \frac{\sqrt{N}}{\tau} \tag{25.3}$$

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

$$T = \frac{\hbar}{mc^2}\sqrt{N} \tag{25.4}$$

We can easily verify that the Eq. (25.4) is indeed satisfied where T is the age of the Universe. Next by differentiating (25.2) with respect to t we get

$$\frac{dR}{dt} \approx HR \tag{25.5}$$

where Hin (25.5) can be identified with the Hubble Constant, and using (25.2) is given by,

$$H = \frac{Gm^3c}{\hbar^2} \tag{25.6}$$

Equations (25.1), (25.2) and (25.4) 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 quantum vacuum background. Equation (25.6) can be written as

$$m \approx \left(\frac{H\hbar^2}{Gc}\right)^{\frac{1}{3}} \tag{25.7}$$

Equation (25.7) has been empirically known as an "accidental" or "mysterious" relation. As observed by Weinberg [26], this is unexplained: it relates a single cosmological parameter H to constants from microphysics. In our formulation, Eq. (25.7) is no longer a mysterious coincidence but rather a consequence of the theory.

As (25.6) and (25.5) are not exact equations but rather, order of magnitude relations, it follows, on differentiating (25.5) that a small cosmological constant $\wedge$ is allowed such that

$$\wedge \leq 0(H^2)$$

This is consistent with observation and shows that $\wedge$ is very small—this has been a puzzle, the so called cosmological constant problem because in conventional theory, it turns out to be huge [27]. But it poses no problem in this formulation. This is because of the characterization of the ZPF or quantum vacuum as independent and primary in our formulation this being the mysterious dark energy. Otherwise we would encounter the cosmological constant problem of Weinberg: a $\wedge$ 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 [3, 14],

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

On using (25.2) in the above, we recover the well known Gravitation- Electromagnetism ratio viz.,

$$e^2/Gm^2 \sim \sqrt{N} \approx 10^{40} \tag{25.8}$$

or without using (25.2), we get, instead, the well known so called Weyl-Eddington formula,

$$R = \sqrt{N}l \tag{25.9}$$

(It appears that (25.9)) was first noticed by H. Weyl [24]. Infact (25.9) is the spatial counterpart of (25.4). If we combine (25.9) and (25.2), we get,

$$\frac{Gm}{lc^2} = \frac{1}{\sqrt{N}} \propto T^{-1} \tag{25.10}$$

where in (25.10), we have used (25.4). Following Dirac (cf.also [6]) 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 (25.10) in (25.6), we can see that

$$H = \frac{c}{l} \quad \frac{1}{\sqrt{N}} \tag{25.11}$$

Thus apart from the fact that H has the same inverse time dependence on T as G, (25.11) shows that given the microphysical constants, and N, we can deduce the Hubble Constant also, as from (25.11) or (25.6).

Using (25.1) and (25.2), we can now deduce that

$$\rho \approx \frac{m}{l^3} \quad \frac{1}{\sqrt{N}} \tag{25.12}$$

Next (25.9) and (25.4) give,

$$R = cT \tag{25.13}$$

Equations (25.12) and (25.13) 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,

$$H = c/R$$

which follows from (25.11) and (25.9), then we recover (25.2). 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 (25.6), (25.12) or (25.9) 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 by observation.
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 [12, 13]. The trio got the 2011 Nobel for Physics.

25.3 Discussion

1. We observe that in the above scheme if the Compton time $\tau \to \tau_P$, we recover the Prigogine Cosmology [7, 25]. 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 $\tau \to 0$ (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 Eqs. like (25.4) or (25.6) or (25.8) or (25.9).
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

$$|\Delta x|^2 =< \Delta x^2 >= \nu \cdot \Delta t$$

$$\nu = \hbar/m, \nu \approx lv \tag{25.14}$$

This way we could explain a process similar to the formation of Benard cells [7, 22]—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 [23]. This would be described by

$$r = \sqrt{N\Delta x^2} \tag{25.15}$$

$$ka^2 \equiv k\Delta x^2 = \frac{1}{2}k_B T \tag{25.16}$$

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

$$\omega_0^2 = \frac{k}{m} \tag{25.17}$$

$$\omega = \left(\frac{k}{m}a^2\right)^{\frac{1}{2}}\frac{1}{r} = \omega_0\frac{a}{r} \tag{25.18}$$

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 (25.17) and (25.16) gives $k_B T \sim m_P c^2$, which ofcourse agrees with the temperature of a black hole of Planck mass. Indeed, Rosen [10] 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 (25.15), 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

$$l = \sqrt{n} l_P, \ \tau = \sqrt{n} \tau_P, \tag{25.19}$$

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

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 [18, 19]).

We now use the well known result alluded to that the individual minimal oscillators are black holes or mini Universes as shown by Rosen [10]. So using the Beckenstein temperature formula for these primordial black holes [11], that is

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

we can show that

$$G m^2 \sim \hbar c \tag{25.20}$$

We can easily verify that (25.20) leads to the value $m \sim 10^{-5} gms$. In deducing (25.20) 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 (25.20).

We now make two interesting comments. Cercignani and co-workers have shown [1, 2] that when the gravitational energy becomes of the order of the electromagnetic energy in the case of the Zero Point oscillators, that is

$$\frac{G \hbar^2 \omega^3}{c^5} \sim \hbar \omega \tag{25.21}$$

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

$$\omega \leq \omega_{max}.$$

Secondly as we can see from the parallel but unrelated theory of phonons [4, 9], which are also bosonic oscillators, we deduce a maximal frequency given by

$$\omega_{max}^2 = \frac{c^2}{l^2} \tag{25.22}$$

In (25.22) 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 ω_{max} in (25.22) are again meaningless. We can easily verify that using (25.21) in (25.22) gives back (25.20).

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 (25.10) 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. [22]).

References

1. Cercignani C, Galgani L, Scotti A (1972) Phys Lett 38A:403
2. Cercignani C (1998) Found. Phys Lett 11(2):189–199
3. Hayakawa S (1965) Suppl of PTP commemmorative issue pp. 532–541.
4. Huang K (1975) Statistical Mechanics. Wiley Eastern, New Delhi, pp. 75ff.
5. Linde AD (1982) Phys Lett 108B:389
6. Melnikov VN (1994) Int J Theor Phys 33(7):1569–1579
7. Nicolis G, Prigogine I (1989) Exploring complexity. Freeman, New York, W.H
8. Nottale L (1993) Fractal space-time and microphysics: towards a theory of scale relativity. World Scientific, Singapore
9. Reif F (1965) Fundamentals of statistical and thermal physics. McGraw-Hill Book Co., Singapore
10. Rosen N (1993) Int J Theor Phys 32(8):1435–1440
11. Ruffini R, Zang LZ (1983) Basic concepts in relativistic astrophysics. World Scientific, Singapore, p. 111ff.
12. Science, December 1998.
13. Science, December 2003.
14. Sidharth BG (1998a) Int J Mod Phys A 13(15):2599ff.
15. Sidharth BG (1998b) Int J Theor Phys 37(4):1307–1312
16. Sidharth BG (1998c) Frontiers of quantum physics (1997) Lim SC et al. (eds.) Springer Verlag, Singapore.
17. Sidharth BG (1999) Proceeding of the eighth marcell grossmann meeting on general relativity (1997) Piran T (ed.) World Scientific, Singapore, pp. 476–479.
18. Sidharth BG (2001) Chaotic universe: from the planck to the hubble scale. Nova Science, New York
19. Sidharth BG (2002) Found. Phys Lett 15(6):577–583
20. Sidharth BG (2003) Chaos Solitons Fractals 16(4):613–620
21. Sidharth BG (2007) Encounters: abdus salam in new advances. Physics 1(1):1–17
22. Sidharth BG (2008) The thermodynamic universe. World Scientific, Singapore
23. Sidharth BG (2010) Int J Theor Phys 49(10):2476–2485

24. Singh J (1961) Great ideas and theories of modern cosmology. Dover, New York, pp. 168ff.
25. Tryon EP (1973) Is the universe a vacuum fluctuation? Nature 246:396–397
26. Weinberg S (1972) Gravitation and cosmology. Wiley, New York, p. 61ff.
27. Weinberg S (1979) Phys Rev Lett 43:1566
28. Zee A (1982) Unity of forces in the universe (Vol. II). World Scientific, Singapore, p. 40ff.