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A Non Reductionist Model for Fundamental Physics

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Much of twentieth century physics has rested on a reductionist approach. However the author's own fuzzy spacetime model and very recent work has pointed to an approach where fundamental phenomena emerge as a result of collective effects. This is discussed in concrete terms and it is also pointed out that Nobel Laureate Laughlin has strongly endorsed the new paradigm shift.

1. INTRODUCTION

Reductionism has been at the heart of twentieth century Theoretical Physics. Its origins however can be traced back to the seventh century B.C. Indian thinker Kanada who declared that all substances were made up of ultimate subconstituents in perpetual vibration [1]. A few centuries later the Greeks brought up this idea of atomism, through their atoms were static. These concepts were revived after a couple of millennia with the atomic theory of the nineteenth century. Since then, there has been a progressive downward cascade propelled by the belife that we could understand the universe by studying its ultimate subconstituents. This spirit is very much evident in Einstein's concepts of locality in which an an arbitrarily small part of the universe can be studied without reference to other parts of it. A few decades later Wheeler observed that our studies of the inaccessible Planck scale of 10^{-33} *cms* were really like an understanding of bulk properties of matter by studying the subconstituent molecules [2]. Indeed it is this philosophy of reductionism which has propelled the most recent studies such as String Theory or other Quantum Gravity approaches. Decades of labour has gone into these endeavours and the research output has been enormous.

2. A PLANCK SCALE MODEL

Against the above background, we consider a model of spacetime with an underpinning at the Planck scale. Indeed the differentiable spacetime of Classical Physics, including General Relativity and Quantum Mechanics and Quantum Field Theory has had to be abandoned in favour of such a Planck scale description, due to the failure of decades of efforts to provide a unified description of General Relativity and Quantum Mechanics, or alternatively

Gravitation and Electromagnetism. Modern Quantum Gravity approaches as also Super String Theory (including M-Theory) and the author's own noncommutative spacetime model work at the Planck scale (Cf.ref.[3] for a discussion and several other references).

We recall that the Planck scale is given by

$$l_P = \left(\hbar G / c^3\right)^{\frac{1}{2}} \sim 10^{-33} cms \tag{1}$$

with corresponding expressions for the Planck time t_P and Planck mass m_P,

$$t_P \sim 10^{-42} sec, \; m_P \sim 10^{-5} gms$$

We next consider a collection of N' Planck oscillators [4], without specifying N'. We then use the well known relations (Cf. ref. [3])

$$\omega^2 = \frac{K}{m} = \frac{kT}{ml^2} \tag{2}$$

In (2) R is of the order of the radius of the universe while K is the analogue of the spring constant, T is the effective temperature while l is the analogue of the Planck length, m the analogue of the Planck mass and ω is the frequency. We do not yet give l and m their usual values as given in (1) for example, but rather try to deduce these values.

We now use the well known result that the individual minimal oscillator particles are black holes or mini universes as shown by Rosen [5]. So using the well known Beckenstein temperature formula for these primodial black holes [6], that is

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

in (2) we get,

$$Gm^2 \sim \hbar c \tag{3}$$

which is another form of (1). We can easily verify that (3) leads to the value $m = m_P \sim 10^{-5}$ *gms*. In deducing (3) 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 (3).

We now make two interesting comments. Cercignani and co-workers have shown [7, 8] that when the gravitational energy becomes of the order of the electromagnetic energy in the case of the Zero Point oscillators, that is

$$\frac{G\hbar^2\omega^3}{c^5} \sim \hbar\omega \tag{4}$$

then this defines a threshold frequency above which the oscillations become chaotic.

Secondly from the parallel but unrelated theory of phonons [9, 10], which are also bosonic oscillators, we deduce a maximal frequency given by

$$\omega^2 = \omega_{\max}^2 = \frac{c^2}{l^2} \tag{5}$$

In (5) 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 $\omega_{\max}$ in (5) are meaningless. We can easily verify that (4) and (5) give back (3).

Finally we can see from (2) that, given the value of l_P and using the value of the radius of the universe, viz., $R \sim 10^{27} cms$, we can deduce that,

$$N' \sim 10^{120} \tag{6}$$

In a sense the relation (3) can be interpreted in a slightly different vein as representing the scale at which all energy- gravitational and electromagnetic becomes one.

We now use the well known fact that there are $N \sim 10^{80}$elementary particles in the universe. So using (6) we conclude that there would be $n \sim 10^{40}$ Planck oscillators constituting an elementary Particle.

We now use equations like (2) but this time for the n Planck oscillators constituting an elementary particle like the pion. This time we have

$$r = \sqrt{nl_P^2}$$

$$\omega = \left(\frac{Kl_P^2}{m_P}\right) = \omega_{\max}\frac{l_P}{r}, \tag{7}$$

$\omega_{\max}$ denoting the frequency at the Planck scale. From (7) we can immediately see that $r \sim l$, now an elementary particle Compton lenght, while ω yields the mass m of an elementary particle like the pion, instead of the maximal mass, the Planck mass. Similarly we get the elementary particle Compton time $t \sim 10^{-23}$ *secs*. From (7) it follows that the elementary particle is the lowest energy state of n Planck oscillators and is therefore stable, unlike the mass m_P which is the highest possible energy state. This would explain why the universe is made up of stable elementary particles, rather than the Planck masses.

Another deduction from (2) and (7) is

$$M = \sqrt{N'} m_P = Nm \tag{8}$$

where $M \sim 10^{55}$ *gms* is the mass of the universe. There is a contrast to be seen in (8) - the description in terms of the Planck oscillators or masses is different compared to teh description in terms of the elementary particles. This is because the universe can be considered as a coherent system of N' Planck oscillators, whereas the N elementary particles do not form a coherent system in this sense. We will returnto this important point shortly.

3. FLUCTUATIONS AND EMERGENCE

A fruitful model in the above context which correctly predicted in 1997 a dark energy driven accelerating universe with a small cosmological constant was obtained when we considered fluctuations which are $\sqrt{N'}$ for the Planck oscillators and $\sqrt{N}$ elementary paticles within the respective Compton scales. This means that Planck or elementary particles are created from the background dark energy and also destroyed in a random fashion. The net result is the appearance of $\sqrt{N'}$ or $\sqrt{N}$ new entities, given N such entities (Cf.[11, 12]). So we have, for elementary particles,

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

whence on integration we get, (remembering that we are almost in the continuum region),

$$T = \frac{\hbar}{mc^2}\sqrt{N} \tag{9}$$

We can easily verify that the equation is indeed satisfied where T is the age of the universe. Further (9) leads immediately to the supposedly empirical and accidental Wey-Eddington relation,

$$R = \sqrt{N} l \tag{10}$$

Next by differentiating (10) with respect to t we get

$$\frac{dR}{dt} \approx HR \tag{11}$$

where H in (11) can be identified with the Hubble Constant, and is given consistently by,

$$H = \frac{Gm^3c}{\hbar^2} \tag{12}$$

All this shown that in this formulation, the correct mass, radius, Hubble constant and age of the universe can be deduced given N as the sole cosmological or large scale parameter. Equation (12) can be written as

$$m \approx \left(\frac{H\hbar^2}{Gc}\right)^{\frac{1}{3}} \tag{13}$$

Equation (13) 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 micro physics. We will touch upon this micro-macro nexus again. In our formulation, equation (13) is no longer a mysterious coincidence but rather a consequence of the theory.

As (12) and (11) are not exact equations but rather, order of magnitude relations, it follows, on differentiating (11) that a small cosmological constant Λ is allowed such that

$$\Lambda < 0\ (H^2)$$

This is consistent with observation an shows that Λ is very small - this has been a puzzle, the so called cosmological constant problem becaue in conventional theory, it turns out to be huge [14]. But it poses no problem in this formulation. Further it was shown that from the above we can deduce

$$\frac{Gm}{lc^2} = \frac{1}{\sqrt{N}} \propto T^{-1} \tag{14}$$

Equation (14) shows gravitation in a completely different light [15, 3] - G is expressed in terms of the so called microphysical constants, m, l and c as also the number of elementary particles N in the universe - it is thus seen as a distributional energy over the particles of the universe. In fact (14) can be rewritten as

$$\frac{Gm^2N}{R} = mc^2 \tag{15}$$

Equivalently we can deduce that

$$\frac{Gm^2}{e^2} \sim \frac{1}{\sqrt{N}},$$

another well known but supposedly accidental empirical relation (but which, is deduced here and shows that Gravitation can be described in terms of electromagnetism over the N particles of the universe). (15) shows that the entire inertial energy of an elementary particle equals its total purely gravitational energy due to all particles in the universe. This distributional and not fundamental nature of gravitation resembles to a certain extent Sakharov's interpretation of gravitation as a residual energy [16].

It must also be observed that (14) gives an inverse time dependence of the gravitational constant on time. Such a dependence can be infered by an observationof binary pulsars, solar system orbits and also from palaeontological evidence, although slightly different variations have been suggested [17]. In fact the above time dependence also explains the otherwise inexplicable anomalous accelerations of the Pioneer spacecrafts [18].

Another interesting observation is that using (14) and (3) we can deduce that

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

This relation was independently recovered a little earlier. In any case the above considerations explain the otherwise inexplicable Weinberg formula (13) [13]. As Weinberg observed, "... it should be noted that the particular combination of $\hbar$, H, G, and c appearing (in the formula) is very much closer to a typical elementary particle mass than other random combinations of these quantities; for instance, from $\hbar$,G, and c alone one can form a single quantity $(\hbar c / G)^{1/2}$ with the dimensions of a mass, but this has the value 1.22×10^{22} MeV/c^2 , more than a typical particle mass by about 20 orders of magnitude !

"In considering the possible interpretations (of the formula), one should be careful to distinguish it from other numerical "coincidences" ... In contrast, (the formula) relates a single cosmological parameter, H, to the fundamental constants $\hbar$, G, c and m, and is so far unexplained." We can now see that there is really no puzzle: (14) shows that the gravitational constant G itself depends on N, just as H is a cosmological parameter in (13).

What the above results mean is that we have to view the universe no longer in reductionist terms but from a holistic, Machian point of view where large scale parameters like the Hubble constant or the number of elementary particles or the radius of the universe and the supposed microphysical parameters are interlinked. No wonder that gravitation has posed such a puzzle, and indeed as noted by Witten, "the existence of gravity clashes with our description of the rest of Physics by Quantum Fields", this latter being a reductionist approach.

4. DISCUSSION

As indicated above, all the so called mysterious large number relations including the Weinberg formula (13) have been deduced from the theory. It is difficult to escape the conclusion that there is an underlying mechanism outlined in the previous section which yields all these otherwise mysterious coincidences. The picture is one of what may be called collective phenomena and fluctuations therein, rather than being the usual reductionist theory.

The has been pointing out that the universe is not rigid, but rather "thermodynamic", and that the so called conservation laws are in fact stochastic (Cf.also ref.[19, 12]). To elaborate further, if we consider differentiable spacetime and point particles, we are really taking the thermodynamic limit as can be seen from teh Weyl-Eddington relation (10) above. As the number of particles N in the universe tends to infinity then the fuzzy Compton scale $l \to 0$ and that is the description of spacetime used in Classical Physics and Quantum Field Theory. In this limit, we recover from the above the Big Bang scenario as

$$\frac{dN}{dt} = \frac{\sqrt{N}}{t} \to \infty$$

This however is only an approximation. In an accurate picture we have small departures from the usual spacetime approaches, and this includes non commutativity and non differentiability by virture of a minimum scale - the Planck scale.

For example such a "thermodynamic" treatment of light leads to our deducing the value of the velocity of light, as also giving the photon a small small mass $\sim 10^{-65}\,gms$ [20, 21]. It must be stressed again that in this approach we consider collective phenomena. For instance, from (5) which otherwise describes phonons, we can recover the correct value of the velocity of light and photon mass with the correct value of the photon Compton length l which turns out to be the radius of the universe.

Similarly in our Planck scale underpinning for the universe, it turns out that the entire universe is a coherent collection of $N' \sim 10^{120}$ oscillators. So also an elementary particle like the pion is a collection of $n \sim 10^{40}$ Planck oscillators at the elementary particle Compton scale. However the elementary particles in the universe are on a different footing compared to the underpinning Planck oscillators. This can be brought out by using considerations of Quantum Statistical Mechanics [22].

A state can be written as

$$\psi = \sum_n c_n \phi_n \tag{16}$$

in terms of basic states ϕ_n which could be eigen states of energy for example, with eigen values E_n. It is known that (16) can be written as

$$\psi = \sum_n b_n \phi_n \tag{17}$$

where $|b_n|^2 = 1$ if $E < E_n < E + \Delta$, and = 0 otherwise under the assumption

$$\overline{(c_n, c_m)} = 0, n \neq m \tag{18}$$

(In fact n could stand for not a single state but for a set of states n_1 and so also m). Here the bar denotes a time average over a suitable interval. This is the well known Random Phase Axiom and arises due to the total randomness amongst the phases c_n. Also the expectation value of any operator 0 is given by

$$< 0 >= \sum_n | b_n |^2 (\phi_n, 0\phi_n) / \sum_n | b_n |^2 \tag{19}$$

(17) and (19) show that effectively we have incoherent states $\phi_1, \phi_2, \cdots$ once averages time intervals for the phases c_n in (18) vanish owing to their relative randomness. At this level of description the coherence is lost. As seen earlier, for elementary particles we need $n \sim 10^{40}$ Planck oscillators leading from the Planck scale to the Compton scale. The ϕ_n, of (16) denote the Planck oscillators while the bounded states in (17) denote elementary particles, the time average in (18) being over the Compton time. The random phase is symbolized by the zitterbewegung effects within the Compton time. In fact for the mass of the universe, (19) gives the last of equations (8) in terms of elementary particles, and not the second of equations (8) which gives the mass of the universe in terms of the coherent underpinning at the Planck scale.

This new non reductionist, but rather emergent view of the universe has recently been endorsed by Nobel Laureate R.B. Laughlin who makes a very strong argument against reductionism in his book “A Different Universe” [23, 24], According to Laughlin this paradigm shift to the new model of fundamental physics is symbolised by Klitzing’s experiments bringing out the Quantum Hall Effect, in which the resistence is a combination of fundamental constants viz. the individual quantum of electric charge e, the Planck constant h and the speed of light. As he points out, this demonstrates that the supposedly basic building blocks of the universe can be measured with breathtaking accuracy, without dealing with the building blocks themselves, but rather wlith macroscopic collective phenomena. Laughlin goes goes on to criticise the current status of fundamental physics including Quantum Field theory, very much in the spirit of the author's own work as briefly outlined above.

Finally it may be mentioned that work on Fuzzy Spacetime has been carried out by M.S. El Naschie, G. Iovane and other authors (Cf. for example [25, 26]).

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