

On E.D.Jones' MICROCOSMOLOGY*

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Abstract

By taking seriously the limits on observability which come from combining relativistic quantum mechanics with general relativity, Ed Jones has shown that the current measurements of the cosmological constant density $\Omega_\Lambda \sim 0.7$ imply that the temperature scale at which it becomes possible to discuss cosmological models is $\sim 5 \text{ Tev}$ ($5.8 \times 10^{16} \text{ }^\circ\text{K}$). This is self-consistent with the assumption that the number of Planck masses which make some sort of “phase transition” to this state is $N_{Pk} \sim 4 \times 10^{61}$. We review Jones' argument and the *bit-string physics* calculation which gives the baryon-photon ratio at nucleosynthesis as $\sim 2/256^4$, the dark matter-baryon ratio as ~ 12.7 , and hence $\Omega_m \sim 0.3$, in agreement with current observations. Accepting these values for the two energy densities $\Omega_\Lambda + \Omega_m \sim 1$ in accord with recent analyses of fluctuations in the CMB showing that space is flat to about 6%. We conclude that experiments with particle accelerators in the 5-10 Tev range must either show that current theory can adequately describe the currently observed structure of our universe or force us to revise our ideas about physics at a very fundamental level.

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I. INTRODUCTION

It has been known for some time that standard general relativistic cosmology can describe current astronomical observations in remarkable detail.[25, 26] Retrodicting from these results to earlier times, one finds extremely hot and dense radiation and matter ~ 13 *Gyr* ago. Conditions were such that no current experimental or astronomical systems are available to test what the “laws of physics” were then, or even whether such laws “existed”. As E.D.Jones realized some time ago, one way to make progress in gaining a limited understanding of this “pre-physics” era is to take seriously the limitations that the shortest measurable length and time, and the largest measurable elementary mass and temperature place on physical cosmology. In this paper we review and discuss the remarkable discoveries that he made. We emphasize their fundamental character and independence of special assumptions.

E.D.Jones[10] discovered that a *neo-operational* [19] approach imposes fundamental limits on the measurement of short distances in such a way that we can *predict* that there must be a *positive* cosmological constant. Further, his preliminary calculation gave the cosmological constant energy density, relative to the critical density, of $\Omega_\Lambda = 0.6 \pm 0.1$. The basic idea is that we must find some way to connect the inchoate, pre-geometrical, pre-physical state of the universe by a “phase transition” to a state in which contemporary physics — explicitly, relativistic quantum mechanics and general relativity — can be consistently employed. The connection will be made by using one scaling parameter. This scaling parameter is fixed by requiring energy density equilibrium between the virtual energy density which thermalizes at some mass scale m and the virtual energy density $\rho_\epsilon = \frac{3\epsilon}{4\pi r_\epsilon^3}$ which is “left behind” when the (extremely rapid) transition to ordinary space, time and particles is complete. Here $r_\epsilon = \hbar c/\epsilon$. Since this residual virtual energy ϵ necessarily decouples from other contributions to

the FRW equations for the evolution of the universe, Jones' interpretative postulate is to identify it with the cosmological constant density, i.e. $\rho_\epsilon = \rho_\Lambda$.

The limiting concepts we apply to obtain limits on observability are the uncertainty principle, the black hole surface area, and the cosmological event horizon. We make contact with experimental practice by assuming that we know four basic universal constants in standard units. These are:

(1) Newton's gravitational constant $\mathbf{G}_\mathbf{N}$, which can be fixed if we know the escape velocity of a particle from a system of radius R , and mass m , i.e.

$$\frac{\mathbf{G}_\mathbf{N}m}{R} = \frac{1}{2}v_{escape}^2 \quad (1)$$

(2) Boltzman's constant \mathbf{k} from the basic law of statistical mechanics connecting entropy, S , to the number of degrees of freedom W , i.e.

$$S = \mathbf{k} \ln W \quad (2)$$

(3) Planck's constant \mathbf{h} (or $\hbar = h/2\pi$), as in

$$E = \mathbf{h} \nu \quad (3)$$

(4) Einstein's limiting velocity \mathbf{c} , as in the mass-energy relation

$$E = m \mathbf{c}^2 \quad (4)$$

II. Shortest length; largest density; highest temperature

If there is a largest *elementary* fermion mass m_X , the shortest geometrical length in (special) relativistic quantum mechanics to which we can examine its (or any) structure is the Compton radius

$$R_Q(m_X) = \frac{\hbar}{2m_X c} \quad (5)$$

Wick pointed out long ago[27] that if we try to measure the structure of a system which couples to some mass μ , combining special relativity with the quantum energy-time uncertainty principle tells us that at distances less than $\hbar/\mu c$, which requires us to use available energies greater than μc^2 , such a particle can be produced with a finite

probability. For particles of mass m_X that satisfy the CPT theorem — no exceptions are known — and have a conserved quantum number which allows anti-particles to be defined (which includes all known fermions), examining the structure of m_X with *any* probe of energy greater than $2m_Xc^2$ will necessarily produce a pair consisting of m_X and its anti-particle with some finite probability. But the m_X produced will be indistinguishable from the m_X probed, and can appear *anywhere* within a distance $\hbar/2m_Xc$ of the target particle. Thus, in relativistic quantum mechanics (in contrast to non-relativistic quantum mechanics which in principle allows any short distance to be examined by using probes of high enough momenta) there is an absolute shortest distance, set by the largest elementary mass. Below this limit the concepts of point geometry simply *dissolve*.

In contrast, general relativity *starts* with geometrical concepts and would seem to be able (until we come to cosmology) to describe systems with arbitrarily large masses. However, if the mass is concentrated within a volume whose surface area is (for spherical symmetry) $4\pi R_G(m)^2$, we must use more care. “Inside” the *black hole* defined by this area and calculable from the Schwarzschild radius

$$R_G(m) = \frac{2mG_N}{c^2} \tag{6}$$

where G_N is Newton’s gravitational constant, there is no known way to *measure* geometrical structure. Only the mass, and (if it has them) charge and magnetic moment can be measured by means of *exterior* observations. Consequently, in regions where the mass concentrations are small enough, we can use (if available) systems with small enough mass-energies to probe geometrical structure down to arbitrarily short lengths. Thus, by itself, general relativity seems to be able to use geometrical concepts consistently in any regions *outside* of black holes.

But any theory of *quantum gravity* must, at least in a limiting sense, combine both relativistic quantum mechanics and general relativity in a single theory. Since the shortest length observable in the first theory is inversely proportional to the mass considered, while the shortest length observable in the second theory is proportional to the mass considered, this requirement tells us (in the absence of new concepts) that there must be a finite limiting length for *any* theory of quantum gravity. We

define this by setting the Schwarzschild radius equal to the Compton radius, i.e.

$$R_{min}^{QG} = R_G(m) = R_Q(m) \quad (7)$$

This leads immediately, to the requirement that $4m^2 = \hbar c/G_N \equiv M_P^2$.

The limiting mass M_P calculated in this way was first arrived at by Planck (using h), and is now (using \hbar) called the *Planck mass*. Planck's original argument was simply that G_N , k , c , and h were clearly universal constants. Since their dimensions in terms of (sometimes fractional) powers of mass, length, time, and temperature are *independent*, these constants collectively define what are certainly universal, and perhaps fundamental dimensional units for physics. But the numerical values so predicted were discouraging. The *Planck mass* in SI units is approximately 2.18×10^{-8} kilograms. Even today there is no known elementary particle with this mass. The corresponding *Planck length* $L_P \equiv \hbar/M_P c = 1.62 \times 10^{-35}$ m, *Planck time* $T_P \equiv \hbar/M_P c^2 = 5.39 \times 10^{-44}$ sec and *Planck temperature* $\Theta_P \equiv M_P c^2/k = 1.42 \times 10^{32}$ °K. These sounded ridiculous if one wished to relate them to available methods of measuring masses, lengths, times and temperatures. But as *limiting* quantities, they make sense. To our knowledge, Jones' simple calculation, which at least for us makes this interpretation compelling, originated with him.

That it makes no sense using current theory to talk of lengths less than the Planck length (or times less than the Planck time, or elementary masses greater than the Planck mass, or temperatures higher than the Planck temperature) is hardly a novel conclusion. But Ed Jones' demonstration of the fact, which we have just summarized, is so straightforward that we think it deserves wide circulation.

What is, perhaps, less familiar is that the same physical principles prohibit meaningful discussion of physical matter at any density greater than the Planck density, i.e. a Planck mass in a Planck volume which must exist for at least a Planck time, that is for at least $[\frac{\hbar G_N}{c^5}]^{\frac{1}{2}}$. We define this limiting density scale by

$$\rho_P \equiv \frac{M_P}{\frac{4\pi}{3} L_P^3} = \frac{3}{4\pi} [c/\hbar]^3 M_P^4 \quad (8)$$

From now on we will use units in which $\hbar = 1 = c = 1 = k = 1$, so that any mass μ can stand (ambiguously) for either a mass or an energy or a temperature; any inverse

mass μ^{-1} can stand (ambiguously) for a length or a time. We see that in these units $\frac{3}{4\pi}\mu^4$ is the energy density of mass-energy μc^2 in a spherical volume whose radius is its Compton wavelength.

We now show that in these units $\frac{3}{4\pi}M_P^4$ is, indeed, the limiting energy density. Consider first masses less than a Planck mass inside a Planck volume. For such systems, the Compton wavelength exceeds the Planck length, and the limiting density is achieved only when the contained mass is equal to the Planck mass. Consider next systems with a mass greater than the Planck mass which we try to confine within a Planck volume. For such systems, the Schwarzschild radial coordinate defined by the horizon area exceeds the size of the system we are attempting to construct, and to assume that it is confined within a smaller radial coordinate is, again, meaningless. Although the radial coordinate does not measure proper distance, it nonetheless sets the radial scale of the geometry relative to the horizon. So only the limiting case of systems at the Planck density (or less) whose volume just exceeds the volume measured by the Schwarzschild radius (or is greater) have any hope of being given observational meaning. Since these two cases exhaust the possibilities, no system with greater than the Planck density can be given operational meaning. Q.E.D.

For completeness, we also note that the same considerations we used to establish limits on elementary masses, lengths and times also limit the maximum temperature to the Planck temperature. At first sight, this is not completely obvious. We are allowed massless radiation, and hence could define temperature by the Planck distribution in, for example, an Einstein-De Sitter universe that contains only gravitation and electromagnetic radiation. However radiation, by itself, cannot come to equilibrium even when the individual frequency modes are quantized using the $E = h\nu$ prescription for each degree of freedom. These modes could be initially set to any arbitrary distribution. Without some interaction between the modes this arbitrary initial distribution will never come to the Planck distribution. Hence, there is no way to define “temperature”.

To obtain insight on how relativistic quantum mechanical temperature measurement necessarily gets connected to a mass scale it is useful to go back to the classic paper by Bohr and Rosenfeld[4] which provided the initial operational justification for

“second quantization” of the electromagnetic field. They derived the commutation relations between electric and magnetic field strengths by applying the uncertainty principle to the material apparatus which measures them. This derivation can avoid any discussion of the particulate structure of matter because the only universal constants they invoke are \hbar and c . Thus the theory they discuss is scale invariant and their analysis need only use wavelengths so long that the classical description of matter can be invoked consistently. However, as they point out, when wavelengths of the order of \hbar/mc are required, which is true at mass scale m , their derivation breaks down. We then need to use the coupling between the matter field and the electromagnetic field in order to study the meaning of measurement. This, in turn, brings in the scattering of light by light due to the creation (real or virtual) of particle-antiparticle pairs. This coupling then provides transitions between electromagnetic modes and in the black body situation leads, sooner or later, to the Planck distribution. Clearly this same mechanism can achieve thermalization in the cosmological context. Once more this ties us to some finite mass scale, and the arguments already given limit us to temperatures below the Planck temperature.

Since any system we consider, including our observed universe, cannot be described using current physics if it exceeds the Planck density, we next ask whether assigning the Planck density to our universe at some stage in its history makes sense. Consider first the case when the universe that starts at this density has one Planck mass. But then its event horizon, or radial scale factor in the FRW metric, coincides with the Schwarzschild radius for that mass. There is no space “outside” this radius which can allow us to define the volume which this mass occupies, so the concept of density remains vacuous. However, if this universe has a larger radial parameter (and hence a lower density) allowing it to become a “black hole” surrounded by an “ergo-sphere” made up of particles and anti-particles and radiation at some mass-energy-temperature scale $m < M_P$, it becomes a possible starting point for a universe which becomes describable at an event horizon parameterized by $R_H \sim 1/m$. Jones realized that these arguments are closely related to the Dyson-Noyes argument[18, 20], as we now show.

Dyson[6] pointed out that if there are $Z_{e^2} = \alpha_{e^2}^{-1} \simeq 137$ electromagnetic inter-

actions within the Compton wavelength of a single charged particle-antiparticle pair (i.e. $\hbar/2mc$), there is enough energy to create another pair. Whether these interactions are virtual, or real (eg in a system with enough energy and appropriate internal momenta to concentrate $2mc^2Z_{e^2}$ of that energy within this Compton wavelength), in a theory for which like charges attract rather than repel each other still more energy can then be gained by creating another pair; the system collapses to negatively infinite energy. Dyson concluded that the renormalized perturbation theory for QED is not uniformly convergent beyond 137 terms. Note that this bound can be written as $Z_{e^2}\alpha_{e^2} = 1$. Noyes[18, 20] noted that for electron-positron pairs, this critical energy corresponds approximately to the threshold for producing a pion. This fact provides a physical interpretation of the reason for the failure of QED: QED ignores strong interactions mediated by pions, or more generally by quarks and anti-quarks which bind to yield pions.

For gravitation the corresponding coupling constant $\alpha_m = G_N m^2 = m^2/M_P^2$ and the critical condition becomes

$$Z_m \alpha_m = 1 \text{ or } Z_m = \frac{M_P^2}{m^2} \quad (9)$$

where Z_m represents the number of gravitational interactions within \hbar/mc defining this critical condition. That is, for quantum gravitational perturbation theory, the cutoff mass-energy corresponds to the Planck mass rather than the pion mass, which makes sense.

III. Plancktons: The Pre-physics - Physics Transition

To see how a dense system like that discussed at the end of the last section might make sense in a cosmological context, consider first a system which starts from a Planck's mass worth of quantized mass-energy (at some mass scale m where we have confidence that currently accepted physics is applicable) distributed in a radial shell with radially inward-directed momentum. Such a system, assuming no changes in the physics along the way, would have a finite chance of making it down to the Planck density scale before rebounding (or whatever). This suggests that we might, in some sense, be able to describe a universe which "starts" with one *Planckton* (which

we define as a Planck mass in a Planck volume and hence necessarily at the Planck temperature). If our current physics is not capable of describing a single Planckton, it is still possible to envisage some non-adiabatic expansion process which would allow the virtual energy “contained” in this Planckton to be distributed throughout a large volume at some small enough mass scale and event horizon large enough so that *after this expansion* this universe *will be describable* using currently understood physics. This assumes, of course, that the mass scale m is low enough that we have confidence that current theory can describe Z_m gravitational interactions within volumes contained within the event horizon whose linear measure is $\sim 1/m$, and that the Dyson-Noyes analysis applies.

Of course the universe described in the last paragraph is not *our* universe, which is known to contain (and have contained for twelve thousand million years or more) a lot more than one Planckton’s worth of mass. However, since we are postulating a non-adiabatic transition from the Planck density to situations we *can* describe, it makes just as much sense to start from N_{Pk} Plancktons as to start from one. Of course this whole assemblage would have to be at the Planck density or just below it; on another occasion we hope to be able to discuss whether such an assemblage can be consistently described as a state of *Plancktonic matter*. This idea allows us to think of the initial expansion as starting from a virtual energy state and making a transition to a real energy state at some mass scale m , *leaving some of that virtual energy behind*.

Assume that the event horizon at which this residual virtual energy ϵ has observable consequences can be characterized by a radial parameter which we call $R_H(\epsilon) \sim 1/\epsilon$. Further assume that the transition point corresponds to some expansion factor Z_ϵ from the Planck length, i.e.

$$R_H(\epsilon) \equiv Z_\epsilon L_P = \frac{Z_\epsilon}{M_P} \sim \frac{1}{\epsilon} \quad (10)$$

Here ϵ is the energy *per Planckton*. One might note that this defines the expansion factor in terms of R_H , which will give a measure of the square root of the area of the horizon, NOT a radial distance. This is a key feature of holographic interpretations of the physical properties of horizons[3]. This relationship also associates the energy

per Planckton with the expansion scale of this horizon from the Planck length.

The corresponding energy density scale which this residual virtual energy has at the moment when the phase transition is complete is $\rho_\epsilon = N_{Pk} \frac{3}{4\pi} \epsilon^4$. Since this came from N_{Pk} Plancktons, each confined within a volume scale given by a single Planckton, we can also write down the event horizon (scale factor, “Schwarzschild radius of the universe”) $R_H(\epsilon)$ defined by this mass scale as

$$R_H(\epsilon) = G_N N_{Pk} \epsilon \Rightarrow 1 \sim \frac{N_{Pk} \epsilon^2}{M_P^2} = \frac{N_{Pk} M_P^2}{M_P^2 Z_\epsilon^2} \Rightarrow N_{Pk} = Z_\epsilon^2 \quad (11)$$

Jones now assumes that the bulk of the energy which started out as N_{Pk} Plancktons thermalizes at mass scale m and that the corresponding energy density $\rho_m = \frac{3}{4\pi} m^4$ is in energy equilibrium with the residual energy ρ_ϵ at the moment of completion of the phase transition. Hence

$$N_{Pk} \epsilon^4 = m^4 \Rightarrow \frac{N_{Pk}}{Z_\epsilon^4} = \frac{m^4}{M_P^4} = \frac{1}{Z_m^2} \Rightarrow Z_m^2 = Z_\epsilon^2 \quad (12)$$

Thus the Dyson-Noyes factor Z_m (which allows for operationally definable coordinates in the quantum domain) coincides with the residual virtual energy expansion scale factor Z_ϵ . This is true only at the completion of the non-adiabatic phase transition (at which point there are also operationally definable coordinates in the gravitational/geometrical domain). Hence we conclude that

$$Z_\epsilon = Z_m = Z = N_{Pk}^{\frac{1}{2}} \quad \text{and} \quad m^2 = \epsilon M_P \quad (13)$$

Jones also points out that this fact is over-constrained because Z_ϵ and Z_m each corresponds to the entropy (number of degrees of freedom) of each of the systems, which must also be equal at equilibrium. We also note that the mass scale at which the transition becomes complete is the geometric mean between the residual virtual energy and the Planck mass. Since the system starts in the pre-physics regime in which geometric structure cannot be specified, in the resulting thermalized state, prior to further evolution, “where” in the earlier state any Planckton’s worth of energy “came from” also cannot be specified. Hence the virtual energy which is momentarily in density equilibrium with the mass-energy at mass scale m is *uniformly* distributed. Consequently the universe describable using current physics *starts out*

with no structure even though it is much too large for the regions to be causally connected. Thus, Jones’ use of fundamental physical principles solves the “horizon problem” *without* having to postulate the unknown “physics” implicit in the currently popular “inflationary” scenarios.

We now complete the Jones argument. Note that since the residual energy density must be positive, and since the transition — whatever the details — must be extremely rapid, it can be seen that ρ_ϵ corresponds to the cosmological constant density “boundary condition” ρ_Λ in the FRW equations. That it is positive is required for logical consistency, because this corresponds to a “negative pressure” (expansive force)[8] which makes the transition *irreversible*.

We can now check this conclusion by comparison with cosmological observations. Putting together the algebraic results already established and the definition of the cosmological constant energy density in terms of the critical density ($\rho_\Lambda = \Omega_\Lambda \rho_c = \Omega_\Lambda \rho_\epsilon$), we have that the basic scale parameter

$$Z = \left(\frac{\rho_P}{\Omega_\Lambda \rho_c}\right)^{\frac{1}{4}} = \left(\frac{0.7}{\Omega_\Lambda}\right)^{\frac{1}{4}} \left(\frac{0.71}{h_0}\right)^{\frac{1}{2}} \times 6.564 \times 10^{30} \quad (14)$$

For the Planck density we use Eq. 8, which works out to be $\rho_P = 6.906 \times 10^{117} \frac{GeV/c^2}{cm^3}$. For the critical energy density we use[25] $\rho_c = 1.054 \times 10^{-5} h_0^2 GeV/c^2 cm^{-3}$. Finally we accept $\Omega_\Lambda = 0.7$ for the normalized cosmological constant density and $h_0 = 0.71$ for the normalized Hubble constant, as is indicated in Eq. 14. It is then easy to calculate the thermalization mass scale from the Dyson-Noyes relation (Eq. 9) as

$$m = Z^{-\frac{1}{2}} M_P = \left(\frac{\Omega_\Lambda}{0.7}\right)^{\frac{1}{8}} \left(\frac{h_0}{0.71}\right)^{\frac{1}{4}} \times 4.766 TeV/c^2 \quad (15)$$

The positive cosmological constant, let alone its value, was still a matter of debate two or three years ago, resting as it did solely on the measured luminosity and red shifts of a number of distant type Ia supernovae (IaSne). These results have recently been improved[26]. As was pointed out this spring by Frieman[9], lingering doubts can be set to rest by the fact that a completely different type of evidence now shows that $\Omega_\Lambda = 0.7$, consistent with the Type Ia supernova data. The new evidence is simply that *fluctuations* in the cosmic microwave background radiation show that our universe is *flat* to about 6%, i.e. that $\Omega_m + \Omega_\Lambda = 1$ where Ω_m is the normalized

mass-energy density. Since it is known from a number of different types of data that $\Omega_m = 0.3$, the value $\Omega_\Lambda = 0.7$ follows immediately.

We now assert that Jones has *proved* his contention that $\Omega_\Lambda = 0.7$ implies a mass scale of $\sim 5 \text{ Tev}/c^2$ ($(5.8 \times 10^{16} \text{ }^\circ K)$ or visa versa. To our knowledge, this is the first time that the Planck mass has been directly and *quantitatively* connected to any observable phenomenon. We emphasize that although the Jones argument connects a conventional FRW universe to a denser situation where conventional concepts loose operational meaning, *all* that he requires is that normal scaling holds across the phase transition, and depends on only one scale factor. That there is only one independent scale factor is the conclusion acceptance of Occam's razor would establish directly.

We also wish to emphasize that our reproduction of E.D.Jones calculation here makes no claim to novelty, and is presented prior to the posting of his own paper because of an unexpected delay in the presentation of his own way of looking at the problem. We stress that his thinking contains novel elements not discussed here and that our cruder discussion should not be used as a substitute for his work as soon as that becomes available.

IV. Relation to Bit-String Physics

We have seen that Jones' calculation depends on one fundamental dimensionless scaling parameter, the number of Plancktons ($N_{Pk} = Z^2 \sim 4.3 \times 10^{61}$) which thermalize at mass scale $m \sim 5 \text{ Tev}$ leaving behind energy density ϵ per Planckton. Since $m^2 = \epsilon M_P$ (Eq. 12), any fundamental, dimensionless theory which allows us to (a) identify within its structure the Planck mass and three other dimensionless structural constants which bear a known, and mutually independent, connection to, e.g. c , \hbar and k and (b) calculate Z (or m or ϵ) would allow us to say we have a first order, fundamental understanding of physical cosmology. Where could we find or how could we construct such a theory?

The candidate theory we examine here is bit-string physics[23]. We choose this construction both because Jones' theory is historically connected to the research program that led to bit-string physics (specifically, by his use of the Dyson-Noyes argument), and because the only places where his prediction that $\Omega_\Lambda \sim 0.6$ appear

are in papers stimulated by his private communication of that result to HPN[21, 22]. Bit-string physics in turn arose out of the combinatorial hierarchy of Amson, Bastin, Kilmister and Parker-Rhodes[24], which in turn came out Bastin and Kilmister's[2] interest in Eddington's search for a fundamental theory[11]. One reason this research program looks promising is, among other things, because of Eddington's contention that dimensionless numbers like $\alpha_{e^2} = \hbar c/e^2 \approx 137$ get into physics only when we start from a logical or mathematical "pre-physics" and/or "pre-geometry" construction. Then such dimensionless numbers could arise *prior* to development of procedures we can relate to conventional measurement and which give quantitative meaning to dimensional symbols like \hbar, c and e^2 in any consistent system of physical units. To one of us (HPN), the program universe construction which was created as part of the research program on the combinatorial hierarchy sounds suspiciously like Jones' postulated "non-adiabatic process" which takes the universe from the Planck scale up to a scale where current physics clearly applies.

Unfortunately, none of this fundamental work on the combinatorial hierarchy or bit-string physics has as yet led to a *reliable, quantitative* connection to mainstream physics. Critically viewed, one might say that this work consists of a few numerical coincidences which are still in search of what might deserve to be called a speculative physical theory. We contrast this with Jones' theory, which we hope the first three sections have shown *does* constitute a theory based on a few fundamental and generally accepted principles in mainstream physics. Despite these critical remarks, we include a brief discussion of the connection to bit-string physics here in the hope that this discussion may help in planning future research.

We start with the best succinct, accurate and published statement of what the *combinatorial hierarchy* is. This is due to McGoveran[13]:

The Combinatorial Hierarchy is generated from two recursively generated sequences. The first is governed by the recursion formula $n_{i+1} = 2^{n_i} - 1$ (a formula familiar to those who have studied the Mersenne primes), and begins with the term $n=2$ leading to the sequence 3, 7, 127, $2^{127} - 1, \dots$ The cumulative cardinals of this series (ignoring the initial term) also

form a series which has interpretive significance, namely 2, 3, 10, 137, $\sim 1.7016... \times 10^{38} + 137, \dots$

The second recursively generated sequence is governed by the formula $m_{i+1} = m_i^2$. These two sequences have various justifications. Perhaps the clearest presentation has been given by Clive Kilmister (correspondence to H.P.Noyes date Oct. 16, 1978), paraphrased here as follows:

Definition:

By a combinatorial hierarchy is meant a collection of levels selected as follows:

- a) the elements of level L are a basis of a vector space V/Z_2
- b) the elements at Level L+1 are non-singular (i.e. invertible) linear operators mapping V/Z_2 into V/Z_2
- c) each element A at level L+1 are mapped to a subset S of the elements at Level L by the correspondence: the proper eigenvalues of A [i.e, $Av = v$] are exactly the linear subspace generated by S.
- d) each element at level L+1 is chosen independent, allowing the process to be repeated for level L+2, L+3, L+4, ...

Theorem 1:

There is a unique hierarchy (up to isomorphism) with more than 3-levels and it has the following successive numbers of elements: 2, 3, 7, 127, $2^{127} - 1$ and terminates at level 4 due to the fact that the operators have m^2 elements if the vectors are m-fold and 2^n (required for V/Z_2) increases too fast.

What strikes some of us when we encounter the cumulative sequence is that the third term $137 \approx \hbar c/e^2 = \alpha_{e^2}$ is the inverse fine structure while the number of elements in the terminating level $2^{127} + 136 \approx 1.7016 \times 10^{38} \approx \hbar c/G_N m_{proton}^2 = M_P^2/m_{proton}^2$ is the square of the ratio of the Planck mass to the proton mass. Note that one is the Dyson-Noyes number characterizing electromagnetic interactions, and

the other the corresponding Dyson-Noyes number for the gravitating particles which constitute most of the known particulate mass of the universe (if the “dark matter” can be shown *not* to be particulate, or about 10% of the total mass of the universe if the “dark matter” *is* particulate). This looks promising for a cosmology based on this construction. But progress toward a physical theory has been distressingly slow. A historical summary has been published[20]. Perhaps the most encouraging results are the derivation of the Sommerfeld formula and calculation of the next four significant figures (beyond 137) in the inverse fine structure constant by McGoveran[15, 17] and his various combinatorial corrections to other results, reprinted and discussed in[16]. All of these corrections improve the fit to experiment.

Despite the vagueness of the contact between bit-string physics and relativistic quantum particle dynamics, the structure already discussed suggests a way to calculate two cosmological parameters[21]. The first is the dark matter to ordinary matter ratio. In the hierarchy construction, we do not encounter the connection to electromagnetism until we have constructed level 3 (i.e. the level characterized by $137 = 127 + 10$ cumulative elements). However, one string in level 4 interacts gravitationally with everything. This strongly suggests that that the first two levels $10 = 3 + 7$ do not interact electromagnetically but do interact gravitationally, and could therefore be used to represent dark matter, whether it is particulate or non-particulate. Then, if we use a constructive algorithm with an arbitrary, stochastic element (as is done, for example, in *program universe* — see[20] for details), the usual assumption that in the absence of further information all elements receive equal weight immediately predicts that the dark matter to electromagnetically interacting matter ratio is $127/10 = 12.7$. At the time of nucleosynthesis, it is also plausible to assume that the the dark matter to electromagnetically interacting (at the fundamental level) matter, can be approximated by the dark matter to baryonic matter ratio, so we make that further assumption. The final step needed to connect to cosmological observation (see, e.g.[25, 26]) is the photon number to baryon number ratio at the time of nucleosynthesis.

To get the photon/baryon ratio, we need only slightly more detail about our constructive algorithm than has already been invoked. As is discussed in more detail

in the paper already cited[21], the most likely bit-strings a stochastic construction yields, i.e. those (when of even length $2N$) with the number of zeros (N_0) equal to the number of ones (N_1) — hence $N_0 = N_1$, $N_0 + N_1 = 2N$, are also the prime candidates for representing photon labels (quantum numbers). The next most likely strings have $N_0 = N_1 \pm 1$ or, with equal probability $N_0 = N_1 \mp 1$. Note that these strings with an odd number of ones, conserve this characteristic when “interacting” with the photon (even number of ones) strings as modeled by our basic operation of addition in Z_2 . This in turn suggests a conserved quantum number such as baryon number. Further, the more detailed interpretation of the basic *progam universe* algorithm in the reference already cited[20] seems to yield the type of driving terms (two-body scatterings) needed for a finite particle number relativistic quantum mechanical scattering theory[1].

The basic processes needed to estimate the photon baryon ratio in the cosmological context of nucleosynthesis we are discussing are then the probability of a photon-photon scattering process with a similar process as “spectator” (in the few body sense) compared to a photon-baryon scattering process with the same spectator. In the first case there are four photons in the initial (and final) state, and in the second there is one baryon and three photons in the initial (and final) state. At this stage in the construction (level 4 completed) the labels are strings of length 256. To change the photon label to a baryon label in one of the four photon labels, obtaining the next most probable process, can only happen in one out of 256^4 ways, giving a baryon-photon ratio of $1/256^4 \sim 2.3 \times 10^{-10}$. When first presented[21], this result was in comfortable agreement with what was then known about this number from cosmic abundances of the primordial nuclei, and predicted a value of Ω_m which was, perhaps, a little low, but amazingly good for such a speculative calculation.

Recent observations, particularly of the primordial deuterium to hydrogen ratio as inferred from the absorption spectra when the interstellar and intergalactic deuterium is illuminated by very early quasars, have tightened the allowed values of the baryon-photon ratio and moved the median up nearly a factor of two, as estimated by Fields and Sarkar[7]. Their recommended limits now just exclude HPN’s value and suggest that there may have been an error in his reasoning. The error was that the $1/256^4$

value ignored the fact that *both* the case when N_1 exceeds N_0 by one *and* the case when it is one less should have been counted, providing the “missing” factor of two. If accepted, this correction has the added advantage of moving the prediction of Ω_m closer to the median of the observed value. See[21] for the details of the original calculation. We conclude here that HPN’s calculation does provide a weak indication that bit-string physics predicts $\Omega_m \sim 0.3$, but that more work is badly needed before much confidence can be placed in it.

If one accepts the bit-string prediction that $\Omega_m \sim 0.3$ *and* the empirical fact[9] that space is flat to about 6%, we can then use the constraint for flat space $\Omega_\Lambda + \Omega_m = 1$ to say that bit string physics *predicts* $\Omega_\Lambda \sim 0.7$. Then, as we have seen in our discussion in the first three sessions Jones’ MICROCOSMOLOGY shows that the dark energy density at the current time can be understood, that thermalization/baryon number conservation/physical space-time all became meaningful at a mass scale $m \sim 5TeV$, and all started from a pre-physics, pre-geometry universe characterized by a virtual energy of $N_{Pk} \sim 4 \times 10^{61}$ Planck masses.

Clearly this puts a high premium on tightening up the connection between bit-string physics and mainstream physics to the point where it can enter the field as a respectable contender for the research interest of the physics and astrophysics community. Where to begin is a matter of taste. One possibility, which HPN favors, is to try to show that dark matter is particulate with a unique mass of $m_D \sim 5 Tev/c^2$ and *only* gravitational interactions. Searches for dark matter in this range are already under way; having a prediction to confirm or refute might help the experimenters. On the theoretical side, we note that bit-string physics can already claim to have provided a kind of strong-electromagnetic unification by arguing that the pion mass can be approximately calculated as twice the inverse fine structure constant in units of the electron mass. To get weak-gravitational unification, we might argue by analogy with the weak-electromagnetic unification (including the Coulomb force) which gives the heavy vector mesons (W,Z) and one or more massive Higgses, that electromagnetic-gravitation unification (including Newton’s gravitational force) might give a massive scalar at $\sim 5 Tev/c^2$. This is, admittedly, a long shot, but might provide amusement for those with appropriate skills.

V. Conclusions

Accepting the growing consensus that current observations inescapably require that $\Omega_\Lambda = 0.7$ to 20% or better, Jones' reasoning allows him to use this value to state that the mass-energy-temperature scale at which "pre-physics" makes a transition to observable space, time and particles is $\sim 5 \text{ Tev}$! In other words, the next generation of particle accelerators will either substantiate the view that we *already* have in hand enough physics to understand the basic structure parameters of the currently observed universe *quantitatively*, or the next generation of high energy particle physics machines (if constructed) will necessarily provide graphic evidence that fundamental revision of our basic concepts is needed. We trust we have made it clear that bit-string physics has the basic logical structure needed to provide the one theoretical scaling factor on which Jones' theory rests. Optimists will go further and think that it already provides weak support for MICROCOSMOLOGY.

Acknowledgment

We are most grateful to E.D.Jones for permitting us to post this discussion of his theory before his own paper is readily available. We emphasize again that our paper should not be used as a substitute for his original work, particularly since we have used a number of short cuts and simplifications in our presentation, and tied it to bit-string physics in a way that has not been discussed with him.

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