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A Cosmological Calculation Suggesting a Threshold for New Physics at 5 Tev*

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Abstract

A calculation by E.D.Jones of the cosmological mass scale for the phase transition from pre-geometric to physical description as about 5 Tev could be interpreted as a prediction of an effective threshold for novel physical effects in particle-particle collisions.

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E.D.Jones [1, 2] has sketched a compelling cosmological scenario resting on basic physical principles. Starting from the fact that the validity of current physics is bounded, at best, by the Planck length and the Planck density, he assumes only scaling laws are needed to take the universe from some pre-geometric, pre-physical situation by an "extremely rapid" transition to a much less dense phase in which space, time, particles and temperature carry their usual meaning. He and we refer to the end of this transition as *thermalization*. The only parameter which is unknown is the "number of Plancktons" — a *Planckton* is a Planck's mass worth of mass-energy at the Planck density and temperature — with which, in a poetic sense, our universe "starts out". An initial presentation of Jones' ideas by Noyes, et. al. is available[2], with the *caveat* that Jones' own views could differ in ways that have not yet been spelled out. What makes Jones' work so exciting is that with this minimal input he is able to show that a currently acceptable value of $\Omega_\Lambda = 0.7$ for the cosmological constant density normalized to the critical density implies that the mass scale at which thermalization becomes meaningful is about 5 Tev. In this paper we present a calculation leading to this result and discuss some of the implications.

That an explicitly gravitational effect has such a low mass scale is exciting because 5 Tev is well within the energy range that can be explored once the large hadron collider (LHC) comes on line. In an alternative approach Thomas[3, 4] has shown that in 10 dimensional string theories with 6 compactified dimensions and an appropriate choice of the string coupling constant, black hole effects in hadron-hadron collisions could become observable at energies as low as 1 Tev, and would rapidly come to dominate over conventional scattering and particle production at energies above this threshold. If the threshold is as low as 4 Tev, effects might also become detectable in very high energy neutrino-induced, lateral cosmic ray showers[5] when experimental programs currently under construction collect enough data. In this paper we argue that Jones' cosmological calculation might provide us with an estimate of the energy scale for significant elementary particle gravitational effects in our universe. Whether this might signal the threshold explored by Thomas and others, or some even more fundamental reason to question the adequacy of conventional physics at this mass scale is briefly discussed below.

Basic operational[6, 7] criteria for what we mean by physical measurement limit the highest mass-energy density at which physical cosmology could possibly be meaningful[2] to the Planck density $\frac{3}{4\pi}M_P^4$. Here M_P is the Planck mass and we have used units in which $\hbar = 1 = c = 1 = k$; in these units Newton's gravitational constant is given by $G_N = 1/M_P^2$ and the Planck length is $1/M_P$. Because there is no way to measure geometry, or any type of geometrical structure at that limit, the only meaningful parameter we can assign to the universe if it "starts" at the Planck density is the number of Plancktons N_{Pk}. The same considerations which forced us to deny the possibility of physical description under these extreme and necessarily hypothetical conditions require us (following Jones) to envisage an "extremely rapid" transition from this pre-geometrical, pre-physical "state" to a physically describable situation. This transition is given explicit form by *defining* the expansion parameter $Z \equiv M_P/\epsilon$ which takes the universe from the Planck scale $1/M_P$ to a universe with an event horizon $R_H(\epsilon) = 1/\epsilon$. When the scale factor of the universe reaches this value the Freedman-Robertson-Walker (FRW) cosmological equations become appropriate; this fact shows that the parameter ϵ has physical significance.

The next step is to note that because no Planckton can be localized in the pre-geometric situation with which we must start, each must contribute uniformly to every volume element within the event horizon. This gives us an alternative way to calculate the event horizon as the gravitational horizon due to a total mass of $N_{Pk}\epsilon$, that is a horizon with radial parameter $G_N N_{Pk}\epsilon = \frac{N_{Pk}\epsilon}{M_P^2}$. Then we have that

$$1/\epsilon = R_H(\epsilon) = \frac{N_{Pk}\epsilon}{M_P^2} \Rightarrow 1 = \frac{N_{Pk}\epsilon^2}{M_P^2} = \frac{N_{Pk}M_P^2}{M_P^2 Z^2} \Rightarrow N_{Pk} = Z^2 \tag{1}$$

Thus the number of Plancktons N_{Pk} is not a separate parameter. It is simply the square of the expansion factor, i.e. $N_{Pk} = Z^2 = M_P^2/\epsilon^2$.

So far all we have done is to envisage some sort of "expansion" of the "virtual energy" which in some sense "existed" before the transition was complete to a density where normal space, time and particles can be defined and provide an appropriate physical description. But how are we to pick a physical criterion which will mark the transition from (at best) scaling laws to normal physics? Jones' answer is that the mass scale at which this happens is fixed by requiring (momentarily, i.e. at the "end" of the phase transition) energy density equilibrium between the residual energy parameterized by ϵ and the mass scale, which we call m_θ. The energy ϵ itself is only the residual virtual energy *per Planckton* "left behind" when the bulk of the virtual energy makes a phase transition to conventional energy at the mass scale m_θ and temperature θ. Because of the lack of structure at the Planck density, each of the N_{Pk} Plancktons must contribute ϵ energy to each element of volume used in computing the residual energy density. Hence we require that

$$\frac{3}{4\pi}m_\theta^4 = N_{Pk}\frac{3}{4\pi}\epsilon^4 \ or \ m_\theta^4 = Z^2\epsilon^4 \tag{2}$$

Of course the thermalized energy emerging from this momentary equilibrium can be localized down to the mass scale $1/m_\theta$ once the residual virtual energy decouples.

We now show that this scenario defines ϵ as a physically meaningful parameter. The scenario only makes sense if we can argue that the virtual energy "left behind" does, indeed, decouple from the conventional energy independent of any specific mechanism used to "explain" how a pre-physical state expands to a low enough density so that the phase transition to an FRW state can take place. But whatever that "mechanism" is, our postulate that it represents, in some sense, an expansion from the limiting (unmeasurable) Planck density to a much lower density where measurement has at least a conceptual foundation requires that at the termination of the process it should still be represented (momentarily) by an "equation of state" with a "negative pressure", i.e. opposing the gravitational self-attraction of the normal matter. This means (on the grounds of continuity if nothing else) that, if the transition is "sufficiently rapid", the residual energy density $\frac{3}{4\pi}\epsilon^4$ left behind can simply be identified with a *positive* cosmological constant density $\Omega_\Lambda\rho_c$; here ρ_c is the critical density which would close the FRW universe in the absence of a cosmological constant. The positivity of the cosmological constant follows from the fact that in the FRW universe this sign goes with negative pressure. "Sufficiently rapid" amounts to a basic postulate of the scenario defined by limiting the effects of the residual energy at the transition point to the identification with the cosmological constant. Since a positive cosmological constant in the FRW universe we have now described prevents collapse back to higher density, the transition is necessarily *irreversible*. As a consequence the

Jones scenario makes the mass parameter ϵ a physical observable. Explicitly

$$\frac{3}{4\pi}\epsilon^4 = \Omega_\Lambda \rho_c = \frac{3}{4\pi}\left(\frac{\Omega_\Lambda}{0.7}\right)\left(\frac{h_0}{0.71}\right)^2 \times 5.385 \times 10^{-124} M_P^4 \tag{3}$$

Here we adopt for the value of the critical density[8] $\rho_c = 1.054 \times 10^{-5} h_0^2 \; Gev/c^2 \; cm^{-3}$. For a normalized Hubble constant of $h_0 = 0.71$, we find that $\rho_c = 7.694 \times 10^{-124} M_P^4$ in our units. As Eq. 3 indicates, we take $\Omega_\Lambda = 0.7$, a value which is often quoted. Inserting $\epsilon^4 = M_P^4/Z^4$ into Eq. 3 and solving for Z we then find that, for $\Omega_\Lambda = 0.7$ and $h_0 = 0.71$, $Z = 6.564 \times 10^{30}$. We now solve the energy density equilibrium equation (Eq. 2) for m_θ and find that $m_\theta = 4.766 \; Tev/c^2$.

Note further that, since $M_P/\epsilon = Z = M_P^2/m_\theta^2$, we have that

$$m_\theta^2 = \epsilon M_P \tag{4}$$

or in words, the mass scale for thermalization is the geometric mean between the cosmological constant "dark energy" mass and the Planck mass, *independent of Z*! This expression also shows us that the number of Compton wave lengths of size $1/m_\theta$ across the universe of size $1/\epsilon$ is the same as the number of Planck lengths of size $1/M_p$ across each Compton wave length $1/m_\theta$. But this is the geometrical, counting equivalent of our argument given above that for uniform density, each Planckton must contribute mass ϵ to each volume element at mass scale m_θ, providing consistency with the intuitive geometrical picture.

To relate these cosmological considerations to elementary particle physics we now introduce what at first sight will appear to be an unrelated line of reasoning. Long ago Dyson[9] pointed out that if there are $Z_{e^2} = \alpha_{e^2}^{-1} \simeq 137$ electromagnetic interactions 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 $2mc^2 Z_{e^2}$ 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[10, 11] noted that for electron-positron pairs, this critical energy corresponds approximately to the threshold for producing a pion because $2m_e \times 137 \approx m_\pi$. This fact provides a physical interpretation of the reason for the failure of QED: QED ignores strong interactions mediated by pions, or more generally mediated by quarks and anti-quarks which bind to yield pions as the lowest mass hadronic states.

For gravitation and any mass m the coupling constant corresponding to $e^2/\hbar c = \alpha_{e^2}$ is $\alpha_m = G_N m^2 = m^2/M_P^2$ and the critical condition becomes

$$Z_m \alpha_m = 1 \text{ or } Z_m = \frac{M_P^2}{m^2} \tag{5}$$

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 in an elementary particle context. But this means that at the moment of the phase transition at mass scale m_θ in the cosmological context we have been discussing, $Z_{m_\theta} = M_P^2/m_\theta^2 = Z$. That is, at the mass scale m_θ — which we can predict, given the cosmological constant density or equivalently the expansion factor Z from the Planck density — this same Z is *also* the Dyson-Noyes gravitational saturation parameter for particles of mass m_θ. Recall now that above we showed that, at this mass scale, there are just enough systems of this mass and Compton wavelenght $1/m_\theta$ to, geometrically, fit into the event horizon defined by ϵ. But each such Compton wavelength itself defines an event horizon within which (barring the existence of some heavier mass) no structure can be defined using particle probes. This again establishes the self-consistency of the scenario provided that *at the moment of thermalization* there are no heavier particulate masses which can be given physical meaning.

If one accepts HPN's reasoning that explains the Dyson breakdown of perturbative QED at 137 terms as due to the production of pions of mass $m_\pi \approx 2m_e/\alpha_{e^2} \approx 274 m_e$, we might by analogy say that perturbative gravitational theory breaks down at around 5 Tev because it leaves out the production of some (currently unknown) particle of mass m_θ. One obvious candidate is that this mass is the characteristic mass of particulate dark matter, which at least to a first approximation has only gravitational interactions. This was already suggested earlier[2], but not supported by the arguments given here. If this identification is correct, particulate dark matter searches might eventually pick it up. Of course, if this interpretation is to be consistent, such a particle would have to have a structure which would stabilize it for several Gigayears, which requires a theory that we do not pursue further here. Obviously it could have interesting gravitational effects at LHC energies, but could *not* be a black hole; conventional black holes of this mass would be unstable due to Hawking radiation. Theorists using string theory explore the possibility of detecting black hole production at the LHC ([3, 4] and others there cited) and in very high energy neutrino-induced lateral cosmic ray showers (eg[5] and others there cited), might find it profitable to take account of this cosmological significance of the 5 Tev energy range in their parameter studies.

In conclusion we note that the three parameters of Jones' theory of *Microcosmology*, namely ϵ, $Z^2 = N_{Pk}$ and m_θ, emphasize different ways of looking at the theory once we accept it as an overall description of our universe. From an empiricist's point of view, measuring ϵ determines (at least approximately) the number of Plancktons with which our universe starts out and predicts the mass-energy-temperature scale at which the FRW description first becomes appropriate. Like any boundary condition, this leaves unanswered the question *why* this parameter describes our universe.

If we take the basic parameter to be N_{Pk}, the unanswered question remains the same, but this point of view raises the possibility of exploring to what extent the cosmological consequences of the choice of the single parameter N_{Pk} set constraints on the physical parameters (eg. elementary particle coupling constants) by requiring them to be consistent with cosmological thermalization starting at 5 Tev.

If we focus our attention on m_θ, we naturally are led to ask *why* this particular energy is singled out. Many theoretical speculations are possible. One suggestion[2], already discussed briefly above, is that m_θ is the mass of particulate dark matter. Then the saturation of the low energy gravitational interaction, or bound on range of validity of perturbative quantum gravity, would correspond to the threshold for production of this particle. Here we assume the correctness of our interpretation that the Dyson calculation of the bound on the validity of perturbative QED corresponds to the threshold for pion production, and infer that particulate dark matter plays the same role in gravitational theory. Clearly this also would imply that 5 Tev is a significant threshold for new physics. An alternative already mentioned is that what has been cosmologically calculated by Ed Jones is in fact the threshold for black hole production allowed by a particular choice of the number of compactified dimensions and string coupling constant[3, 4].

Independent of any specific theory, we emphasize the fact that 5 Tev is well within the range which will be opened up to *experimental* study once the large hadron collider (LHC) comes on line without endorsing any specific theoretical interpretation. We believe that Jones' cosmological calculation greatly strengthens the expectation that *fundamental new physics* can be expected to emerge from the work at that installation.

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