Could gravitons from prior Universe survive quantum bounce to reappear in present Universe*

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Abstract

We ask the question if an entropy $S = E/T$ with a usual value ascribed of initial entropy $S \sim 10^5$ of the onset of inflation can allow an order of magnitude resolution of the question of if there could be a survival of a graviton from a prior to the present universe, using typical Planckian peak temperature values of $T \sim 10^{19}$ GeV. We obtain the values consistent with up to 10^{38} gravitons contributing to an energy value of $E \sim 10^{24}$ GeV if we assume a relic energy contribution based upon each graviton initially exhibiting a frequency spike of 10^{10} Hz. The value of $E \sim 10^{24}$ GeV is picked from looking at the aftermath of what happens if there exists a quantum bounce with a peak density value of $\rho_{maximum} \sim 2.07 \cdot \rho_{Planck}$ as has been considered recently by P. Malkiewicz and W. Piechocki [15] in the LQG bounce regime radii of the order of magnitude of $\ell \sim 10^{-35}$ meters. In this paper estimates specifically avoids using $S = (E - \mu N)/T$ are done, by setting vanishing chemical potential $\mu = 0$ for ultra high temperatures. Finally we compare briefly the obtained results with the ones recently investigated by G. 't Hooft [20] and Ł.A. Glinka [21, 22].

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1 Introduction

Recently, a big bounce has been proposed as an alternative to singularity conditions that Hawking and Ellis [1], and others use. The 1st problem is though that there as of yet appears to be no fundamental argument presented in either traditional Friedmann metric GR or LQG for preservation of the same value for Planck constant or the fine structure constant from prior universes (before ours) and the present universe. Ashtekar [2], in conversations with the author in the inaugural opening of the Penn State gravity center (2007) told that the universe preserves most of its "memory" in cosmological cycles, but the proof of this assertion does not show up in Rovelli's book on Quantum Gravity [3]. The driving force for this present investigation is due to a conversation the author had with Steinhardt, and 't Hooft at the meeting Frontiers of Fundamental Physics [FFP11] in July 2010 in a parallel session about LQG, and new developments in it.

2 What are necessary first principles to consider in graviton/GW detection?

Modeling how much information may be carried by an individual graviton can be achieved by measuring the graviton via instrumentation. Normalized energy density of gravitational waves, as given by Maggiore [4] is

$$\Omega_{gw} \equiv \frac{\rho_{gw}}{\rho_c} \equiv \int_{\nu=0}^{\nu=\infty} d(\log\nu)\Omega_{gw}(\nu) \Rightarrow \\ \Rightarrow h_0^2\Omega_{gw}(\nu) \simeq 3.6\left[\frac{n_\nu}{10^{37}}\right]\left(\frac{\nu}{1kHz}\right)^4. \tag{1}$$

Where n_μ is a frequency-based count of gravitons per unit cell of phase space. Is Eq. (1) above fundamental physics? And what is the significance of the n_ν and ν terms with regards to if gravitons could have been cycled from a prior to the present universe? The rest of the document will attempt to answer the question of what ultra high frequency inputs into the n_ν as well as ν term are relevant to, assuming that the quantum bounce model of a 'recycled' universe is in part, correct.

2.1 Estimating the size of contribution to energy in $S = E/T$, assuming a frequency $\nu \sim 1010 Hz$ for relic gravitons, if the standard chemical potential is effectively $\mu = 0$ at the onset of creation

As suggested earlier by Beckwith [5], gravitons may have contributed to the re-acceleration of the universe one billion years ago. When q becomes negative, the rate of acceleration of the universe is actually increasing, rather than slowing down [5, 6]. The suggestion Beckwith made for implementing re acceleration involves correct use of the de celebration parameter, and also looking at the behavior of gravitons. The use of Eq. (2) below to have re acceleration in the application Beckwith made is dependent upon 'heavy gravity' and the rest mass of gravitons in four dimensions having a small mass term.

$$q = -\frac{\ddot{a}a}{\dot{a}^2}. \tag{2}$$

We wish next to consider what happens not a billion years ago, but at the onset of creation itself. If a correct understanding of initial graviton conditions is presented, it **may** add more credence to the idea of a small graviton mass, in a rest frame, which may give backing, in part, to Beckwith's use of Eq (1.2) for re acceleration of the universe, in a manner usually associated with Dark Energy. Here, we are making use of refining the following estimates. In what follows, we will have even stricter bounds upon the energy value (as well as the mass) of the graviton based upon the geometry of the quantum bounce, with a radii of the quantum bounce on the order of $\ell_{Planck} \sim 10^{-35}$ meters [5, 7].

$$\begin{gathered} m_{graviton}|_{RELATIVISTIC} < 4.4 \times 10^{-22} h^{-1} eV/c^2 \\ \Leftrightarrow \lambda_{graviton} \equiv \frac{\hbar}{m_{graviton} c} < 2.8 \times 10^{-8} meters \end{gathered} \tag{3}$$

For looking at the onset of creation, with a bounce; if we look at $\rho_{max} \propto 2.07 \rho_{Planck}$ for the **quantum bounce** with a value put in for when $\rho_{Planck} \approx 5.1 \times 10^{99} grams/meter^3$, where

$$E_{eff} \propto 2.07 \cdot \ell^3_{Planck} \cdot \rho_{Planck} \approx 5 \times 10^{24} GeV \tag{4}$$

Then, taking note of this, one is obtaining having a scaled entropy of $S = E/T \sim 10^5$ when one has an initial Planck temperature. One needs, then to consider, if the energy per-given graviton is, if a frequency $\nu \propto 10^{10} Hz$ and $E_{graviton-effective} \propto 2 \cdot h\nu \approx 5 \times 10^{-5} eV$, then

$$S = E_{eff}/T \sim \frac{10^{38} \times E_{graviton-effective}(\nu \approx 10^{10} Hz)}{T \sim 10^{19} GeV} \approx 10^5. \tag{5}$$

Having said that, the $E_{graviton-effective} \propto 2 \cdot h\nu \approx 5 \times 10^{-5} eV$ is 10^{22} greater than the rest mass energy of a graviton if $E \sim m_{graviton}[red-shift \sim .55] \sim (10^{-27} eV)$ grams is taken when applied to Eq. (2) above.

2.2 Making sense of the factor of 10^{38} in Eq. (5). I.e. how to reconcile Eq. (5) with $S \sim n$ used by Y. Jack Ng for DM particles in his entropy/particle counting algorithm?

Note that J. Y. Ng uses the following [8]. I.e. for DM, $S \sim n$, but this is for DM particles, presumably of the order of mass of a WIMP, i.e. $m_{WIMP} \approx 100 \cdot GeV \sim 10^{11} eV$, as opposed to a relic graviton mass – energy relationship:

$$m_{graviton}(energy - \nu \approx 10^{10} Hz) \approx m_{WIMP} \times 10^{-16} \sim 10^{-5} eV \qquad (6)$$

If one drops the effective energy contribution to $\nu \sim 10^{0} \sim 1 Hz$, as has been suggested, then the relic graviton mass- energy relationship is:

$$m_{graviton}(energy - \nu \approx 10^{0} Hz) \approx m_{WIMP} \times 10^{-26} \sim 10^{-15} eV \qquad (7)$$

Finally, if one is looking at the mass of a graviton a billion years ago, with

$$m_{graviton}(red - shift - .55) \approx m_{WIMP} \times 10^{-38} \sim 10^{-27} eV \qquad (8)$$

I.e. if one is looking at the mass of a graviton, in terms of its possible value as of a billion years ago, one gets the factor of needing to multiply by 10^{38} in order to obtain WIMP level energy-mass values, congruent with Ng's $S \sim n$ counting algorithm. I.e. the equivalence relationship for entropy and 'particle count' may work out well for the WIMP sized DM candidates, and may break down for the graviton mass-energy problem.

2.3 The electroweak generation regime of Space-time for entropy and early universe graviton production before electroweak transitions

A typical value and relationship between an inflaton potential $V[\phi]$, and a hubble parameter value, H is

$$H^2 \sim \frac{V[\phi]}{m_{Planck}^2}. \qquad (9)$$

Also, if we look at the temperature occurring about the time of the Electroweak transition, if $T \leq T^{\star}$ when $T^{\star} = T_c$ was a critical value, (of which we can write $\frac{v(T_c)}{T_c} > 1$, where $v(T_c)$ denotes the Higgs vacuum expectation value at the critical temperature T_c., i.e. $\frac{v(T_c)}{T_c} > 1$ according to C. Balazs et al (2005) [9] and denotes that the electroweak transition was a *strongly first order phase transition*) then one can write, by conventional theory that

$$H \sim 1.66 \cdot [\sqrt{\widetilde{g}_\phi}] \cdot \left[\frac{T^2}{m_{Planck}^2} \right]. \tag{10}$$

Here, the factor put in, of is the number of degrees of freedom. Kolb and Turner [10] put a ceiling of about $\widetilde{g}_\phi \approx 100 - 120$ in the early universe as of about the electro weak transition. If, however, $\widetilde{g}_\phi \sim 1000$ or higher for earlier than that, i.e up to the onset of inflation for temperatures up to $T \approx T_{Planck} \sim 10^{19} GeV$, it may be a way to write, if we also state that $V[\phi] \approx E_{net}$ that if

$$S \sim 3 \frac{m_{Planck}^2}{T} \left[H = 1.66 \cdot \sqrt{\widetilde{g}_\phi} \cdot \frac{T^2}{m_{Planck}} \right]^2 \sim 3 \cdot [1.66 \cdot \sqrt{\widetilde{g}_\phi}]^2 T^3. \tag{11}$$

Should the degrees of freedom hold, for temperatures much greater than $T^\star$, and with $\widetilde{g}_\phi \approx 1000$ at the onset of inflation, for temperatures, rising up to, say $T \sim 10^{19} GeV$, from initially a very low level, pre inflation, then this may be enough to explain how and why certain particle may arise in a nucleated state, without necessarily being transferred from a prior to a present universe.

I.e. the suggestion being presented is that a more standard thermodynamic dependence of entropy upon temperature, i.e. $S \propto T^3$ for values of degrees of freedom may be envisioned if one has $S \propto T^3$ when $\widetilde{g}_\phi \approx 1000$ or even higher even if $T \sim 10^{19} GeV \gg T^\star$ is envisioned, in place of $S \neq T^3$ if $T \sim 10^{19} GeV \gg T^\star$, and assuming that $\widetilde{g}_\phi \neq 1000$, i.e. that an upper limit of $\widetilde{g}_\phi \approx 100 - 110$ in degrees of freedom is all that is permitted.

Furthermore, if one assumes that $S \propto T^3$ [10] when $\widetilde{g}_\phi \approx 1000$ or even higher even if $T \sim 10^{19} GeV \gg T^\star$, then there is the possibility that when could also hold, if there was in pre inflationary states very LOW initial temperatures, which rapidly built up in an interval of time, as could be given by $0 < t < t_{Planck} \sim 10^{-44}$ *seconds* which has the following 'vacuum nucleation' interpretation which will be given below, as exemplified by the example of a harmonic system having, in a time interval $0 < t < \breve{T}$ an infusion of energy, into what is otherwise a typical harmonic oscillatory system. Observe the following argument as given by Mukhanov and Winitzki [11] as to additional particles being 'created' due to an infusion of energy in an oscillator, obeying the following equations of motion

$$\begin{aligned}&\ddot{q}(t)+\omega_0^2 q(t)=0, \quad \text{for} \quad t<0 \text{ and } t>\breve{T};\\ &\ddot{q}(t)-\Omega_0^2 q(t)=0, \quad \text{for} \quad 0<t<\breve{T}.\end{aligned} \tag{12}$$

Given $\Omega_0 \breve{T} > 0$, with a starting solution of $q(t) = q_1 \sin(\omega_0 t)$ if $t < 0$, Mukhanov state that for $t > \breve{T}$

$$q_2 \approx \frac{1}{2}\sqrt{1+\frac{\omega_0^2}{\Omega_0^2}} \cdot \exp\left\{\Omega_0 \breve{T}\right\} \tag{13}$$

The Mukhanov et. al argument leads to an exercise which Mukhanov et. al [11] claims is solutions to the exercise yields an increase in number count, as can be given by first setting the oscillator in the ground state with $q_1 = {\omega_0}^{-1/2}$, with the number of particles linked to amplitude by $n = (1/2)(q_0^2\omega_0 - 1)$, leading to

$$n = (1/2)\left(1+\frac{\omega_0^2}{\Omega_0^2}\right) \cdot \sinh^2\left\{\Omega_0 \breve{T}\right\} \tag{14}$$

I.e. for non zero $\Omega_0 \breve{T}$, Eq. (14) leads to exponential expansion of the numerical state. For sufficiently large $\Omega_0 \breve{T}$, Eq. (12) and Eq. (14) are equivalent to placing of energy into a system, leading to vacuum nucleation. A further step in this direction is given by Mukhanov [11] on p. 82 of his book leading to a Bogoliubov particle number density of becoming exponentially large

$$n \sim \sinh^2[m_0 \eta_1]. \tag{15}$$

Eq. (12) to Eq. (14) are, for sufficiently large $\Omega_0 \breve{T}$ a way to quantify what happens if initial thermal energy are placed in a harmonic system, leading to vacuum particle 'creation' Eq. (15) is the formal Bogoliubov coefficient limit of particle creation. Note that $\ddot{q}(t) - \Omega_0^2 q(t) = 0$, for $0 < t < \breve{T}$ for corresponds to a thermal flux of energy into a time interval $0 < t < \breve{T}$. If $\breve{T} \approx [t_{Planck} \propto 10^{-44}\ sec]$ or some multiple of t_{Planck} and if $\Omega_0 \propto 10^{10}\ Hz$, then Eq. (12), and Eq. (14) plus its generalization as given in Eq. (15) may be a way to imply either vacuum nucleation , or transport of gravitons from a prior to the present universe. Having said that, the problem of Heavy Gravity raises its ugly head in the following field theory example.

3 Massive Graviton field theories, and the limit $m_{graviton} \longrightarrow 0$

As given by Maggiore [4], the massless equation of the graviton evolution equation takes the form

$$\partial_\mu \partial^\mu h_{\mu\nu} = \sqrt{32\pi G}\left(T_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}T^\mu_\mu\right). \tag{16}$$

When $m_{graviton} \neq 0$, the above becomes

$$\left(\partial_\mu \partial^\mu - m_{graviton}\right) h_{\mu\nu} = \left(\sqrt{32\pi G} + \delta^+\right)\left(T_{\mu\nu} - \frac{1}{2}\eta_{\mu\nu}T^\mu_\mu + \frac{\partial_\mu \partial_\nu T^\mu_\mu}{3m_{graviton}}\right). \tag{17}$$

The mismatch between these two equations, when $m_{graviton} \longrightarrow 0$, is largely due to $m_{graviton}h^\mu_\mu \neq 0$ in the limit $m_{graviton} \longrightarrow 0$, which in turn is due to setting $m_{graviton}h^\mu_\mu = -\left(\sqrt{32\pi G} + \delta^+\right) \cdot T^\mu_\mu$. The mismatch between these two expressions is one of several reasons for exploring what happens for semi-classical models when $m_{graviton} \neq 0$, $m_{graviton} \sim 10^{-65}$ $grams$, noting that in QM, a spin 2 $m_{graviton} \neq 0$ has five degrees of freedom, whereas the $m_{graviton} \longrightarrow 0$ gram case has only two helicity states. Note that string theory treats gravitons as "excitations" of a closed string, as given by Keifer [12], with a term added to a space-time metric, $\bar{g}_{\mu\nu}$, such that $g_{\mu\nu} = \bar{g}_{\mu\nu} + \sqrt{32\pi G} f_{\mu\nu}$ with $f_{\mu\nu}$ a linkage to coherent states of gravitons. This is partly in relation to the Venziano [13] expression of $\Delta x \geq \frac{\hbar}{\Delta p} + \frac{\ell_s^2}{\hbar}\Delta p$, where $G \sim g^2 \ell_s^2$. Kieffer [12] gives a correction due to quantum gravity in p. 179 of the order of $\left(\frac{m}{m_{Planck}}\right)^2$. If the mass, $m_{graviton} \sim 10^{-65}$ $grams$, it will be hard to measure as an individual "particle". But, if $m_{graviton} \sim 10^{-65}$ $grams$ exists, as a macro effect one billion years ago, i.e. as a substitute for DE, it also would be potentially relevant toward information exchange between a prior to the present universe, provided that there was no cosmic singularity and that the LQG quantum bounce hypothesis has some validity. , Note that the author has been informed by J. Dickau of research by [14] de Rham and Gabadadze which in the authors opinion clears up the problem of ghosts and heavy gravity (massive Gravitons). However, the issue of if a graviton could survive a quantum bounce in LQG [15] stands alone as a problem which the author believes has been removed from being impossible to entertain, to one which cannot be ruled out.

4 Conclusions

A way to obtain traces of information exchange, from prior to present universe cycles is finding a linkage between information and entropy. If such a parameterization can be found and analyzed, then Lloyd's [16] shorthand for entropy,

$$I = \frac{S_{total}}{k_B \ln 2} = [\sharp operations]^{3/4} = [\rho \cdot c^5 \cdot t^4 / \hbar]^{3/4}, \tag{18}$$

could be utilized as a way to represent information which can be transferred from a prior to the present universe . The question to ask, if does Eq. (18) permit a linkage of gravitons as information carriers, and can there be a linkage of information, in terms of the appearance of gravitons in the time interval of, say $0 < t < t_{Planck}$ either by vacuum nucleation of gravitons / information packets along the lines of Eq. (12) and Eq. (14) or by reconciling the counting algorithm questions put up in section A II.

4.1 Further research questions for investigative inquiry and how to link our inquiry to the overall geometry of the universe

The problem of reconciling the existence of a graviton mass with quantum mechanics , in spin two particles usually having zero mass appears to be resolvable, and may imply a linkage between DE and DM [5] Furthermore, the radius of the universe problem, as presented by Roos [17], will yield rich applications of the Friedmann equations used in this document, once there are falsifiable experimental criteria for determining both the Hubble Parameter $H = \frac{\dot{a}}{a}$ on the basis of choices of Friedman equations, and $\Omega = \rho(t)/\rho_c$, using variables chosen and described in this present paper. Both are pertinent to the problem of re-acceleration of the Universe parameter set in Eq (2), [17]

$$r_U = \frac{1}{H\sqrt{|\Omega - 1|}}. \tag{19}$$

Specifically, the author is convinced that analyzing Eq. (19) will be tied in, with appropriate analysis of the following diagram The relation between and the spectrum is often expressed as written by Grishchuk [19], as

$$\Omega_g \approx \frac{\pi^2}{3}\left(\frac{\nu}{\nu_H}\right)^2 h^2(\nu, \tau). \tag{20}$$

The importance of understanding the radius of the universe question, and making sense of Eq. (19) lies in reconciling the conflicting estimates put in

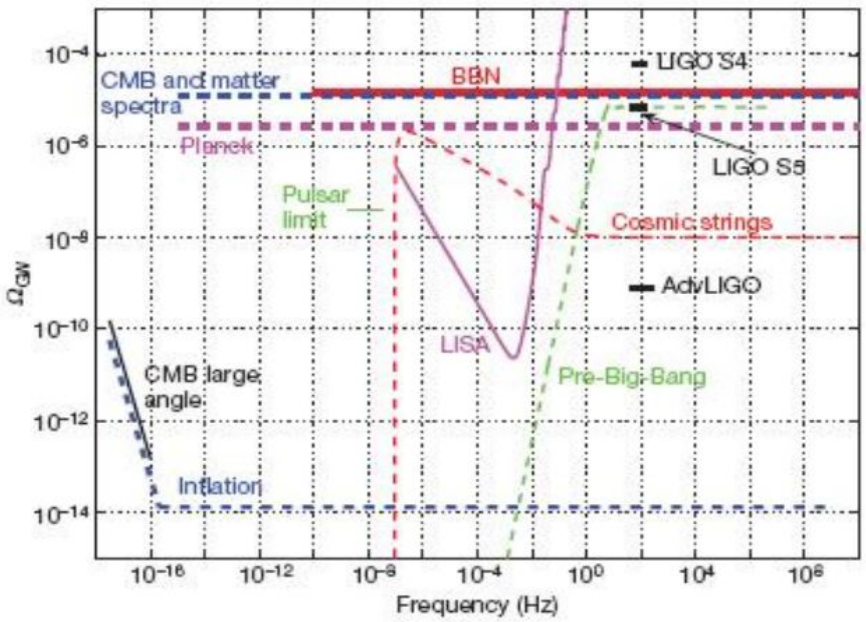

Figure 1: This figure from B.P. Abbott et al. [18] (2009) shows the relation between Ω_g and frequency.

section A II. Above. If one can get an answer to reconciling the estimates put in Section 1.2, one has gone a long way toward answering, or laying the ground work to answering the question as to the classical nature of gravitons, or if they have a semi classical interpretation.

Recently G.'t Hooft [20], has been written, that gravitons can attain mass by spontaneous local symmetry breaking. "The question is whether this can happen in a Lorentz-invariant way". The author submits that when 't Hooft writes that *"These arguments should not be regarded as opposed to, but rather complimentary to the AdS/CFT approach to solve QCD using superstring theory [5], where the* $3+1$ *dimensional theory is mapped onto a 5 dimensional AdS theory. There, the massless graviton in 5 dimensions is mapped onto a massive graviton in 4 dimensions"*, that one is actually considering, as an example, mapping of higher dimensional contributions of gravitons before the electro weak transition, into the time space $0 < t < t_{Planck}$ which may lead to the construction of newly nucleated graviton states, contributing to, in one sense or another to the different scenarios as given in subsection 1.2 above. If a quantum bounce, is the only way, without higher dimensions to answer the issues in subsection 1.2, then one has to ask if enough experimental evidence exists to confirm if Eq. (12) to Eq. (15) are implying nucleation of gravitons in a relic sense AFTER a LQG big bounce regime of energy transfer, or of an actual transmission of gravitons from a prior universe.

4.2 Further inquiry as to if the chemical potential, as given by approaches zero in the onset of inflation/ super inflation

Beckwith has very deliberately set $S \equiv \frac{E-\mu N}{T} \to \frac{E}{T}$ with $\mu \neq 0$ approaching zero. Note that in the approach to quantum cosmology recently investigated and developed by L. Glinka [21, 22], in his quantum rendition of a graviton gas has manifestly $\mu \neq 0$, as the consequence of the rigorous computation based on rules of thermodynamics. Glinka calculates entropy basing upon a partition function received due to quantum field theory including the bosonic Bogoliubov transformation, explicitly with $\mu \neq 0$ results. This quantum gas approach is strictly speaking based on quantum information and quantum statistics. The author thinks that Glinka's work is sound, but has decided to set $\mu \neq 0$ to $\mu = 0$ for the following reason. The main benefit of chemical potentials is in applications of BBN and/ or neutrino physics, i.e. a good example of such is given by Raffelt [23] as of neutrino physics, BBN, and cosmology. At the very onset of inflation which is where the analysis of setting $S \equiv \frac{E-\mu N}{T} \to \frac{E}{T}$ occurs, Beckwith is very deliberately setting initial nucleation at or before the BBN/neutrino physics contributions to cosmology.

If the author, Beckwith, is wrong, he will be quite happy to amend his work along the lines given by Lukasz Glinka 2007 work [21]. However, in lieu of the absence of either a neutrino physics/ BBN contribution, he is attempting to come up with falsifiable experimental results using initially $S \equiv \frac{E-\mu N}{T} \to \frac{E}{T}$ and also attempting to make sense of if there is a way to distinguish between the criteria given in subsection 1.2 of this document.

A Entropy generation via Ng's infinite quantum statistics

The author brings up entropy development as given by [5, 8]. Furthermore, information counts, as discussed in this appendix tie in with information packing as brought up in the conclusion of the present paper. How do relic high frequency gravitational waves inter relate experimentally with the nucleation of short wave length relic gravitons? A small graviton creation volume, V, for relic gravitons of a high frequency (short wave length) right after the big bang would be consistent Graviton volume V for nucleation is tiny, well inside inflation. So the log factor drops out of entropy S if V is chosen properly for both Eq. (19) and Eq. (20). Ng's [8] result begins with a modification of the entropy/partition function Ng used in an approximation of temperature and its variation with respect to a spatial parameter, starting with temperature $T \approx R_H^{-1}$ (R_H can be thought of as a representation of the region of space of the particles in question). Furthermore, assume that the volume of space to be analyzed is of the form $V \approx R_H^3$ and look at a preliminary numerical factor we shall call $N \sim (dfracR_H \ell_{Planck})^2$, where the denominator is Planck length (on the order of 10^{-35} centimeters). We also specify a "wavelength" parameter $\lambda \approx T^{-1}$. So the value of and of $\lambda \approx T^{-1}$ are approximately of the same order of magnitude. Now this is how Jack Ng [8] changes conventional statistics: he outlines how to get $S \approx N$, which with additional arguments we refine to be (where $S \approx < n >$ is graviton density). Begin with

$$Z_N \sim \frac{1}{N!}\left(\frac{V}{\lambda^3}\right)^N \tag{21}$$

This, according to Ng, leads to entropy of the limiting value of, if $S = \log Z_N$

$$\log\left[\frac{V}{N\lambda^3}\right] + \frac{5}{2} \longrightarrow N \cdot \left(\log\left[\frac{V}{\lambda^3}\right] + \frac{5}{2}\right) \approx N \tag{22}$$

But $V \approx R_H^3 \approx \lambda^3$, so unless N in Eq. (22) above is about 1, S (entropy) would be < 0, which is a contradiction. Now Eq. (22) is where [8] introduces removing the N! term in Eq. (21) above, removing the expression of N inside the Log expression in Eq. (22).

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