Bounds upon Graviton Mass – using the difference between graviton propagation speed and HFGW transit speed to observe post-Newtonian corrections to gravitational potential fields

Updated to take into account early universe cosmology and Penrose's cyclic conformal cosmology

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The author presents a post-Newtonian approximation based upon an earlier argument in a paper by Clifford Will as to Yukawa revisions of gravitational potentials, in part initiated by gravitons having explicit mass dependence in their Compton wave length. Prior work with Clifford Will's idea was stymied by the application to binary stars and other such astrophysical objects, with non-useful frequencies topping off near 100 Hertz, thereby rendering Yukawa modifications of Gravity due to gravitons effectively an experimental curiosity which was not testable with any known physics equipment. This work improves on those results.

Key words: Graviton mass, Yukawa potential, Post Newtonian Approximation

1. Introduction

Post-Newtonian approximations to General Relativity have given physicists a view as to how and why inflationary dynamics can be measured via deviation from simple gravitational potentials. One of the simplest deviations from the Newtonian inverse power law is a Yukawa potential modification of gravitational potentials. It is apparent that a graviton's mass (assuming it is massive) would factor directly into the Yukawa exponential term modification of gravity. This present paper tries to indicate how a smart experimentalist could use a suitably configured gravitational wave detector as a way to obtain more realistic upper bounds for the mass of a graviton, and explores how to use this idea as a template to investigate modifications of gravity along the lines of a Yukawa potential modification as given by Clifford Will. **Appendix A** summarizes why we think gravitons should be massive, i.e. having a small rest mass. We will show how our findings dovetail with a larger than Planck length radius of the initial universe, and its connections with both cyclic conformal cosmology (Penrose) and recycled information (from previous cycles) into a new universe. Presumably the information transferred via massive Gravitons will be responsible for setting Planck's constant at a particular value at the onset of a new universe.

Secondly, this paper will address an issue of great import to the development of experimental gravity. Namely, if an upper mass to the graviton mass is identified; can an accelerator physicist use the theoretical construction Eric Davis posited in his book in the section "Producing Gravitons via Quantization of the coupled Maxwell-Einstein fields" for obtaining an experimental bound to the graviton mass, to refine our understanding of graviton Synchrotron radiation. A brief review of Chen, Chen, and Noble's application of the Gersenshtein effect will be made, to potentially improve their statistical estimates of the range of graviton production.

2. Giving an upper bound to the mass of a graviton.

The easiest way to ascertain the mass of a graviton is to investigate if or not there is a slight difference in the speed of graviton 'particle' propagation and that of HFGW in transit from a 'source' to the detector. Visser's (1998) mass of a graviton paper presents a theory which passes the equivalence test, but which has possible problem with depending upon a non-dynamical background metric. Note that gravitons are assumed by both Visser, and also in Clifford Will's write up of experimental GR, to have mass

This document also accepts the view that there is a small graviton mass, which the author has estimated to be on the order of 10^{-60} kilograms. This is small enough so the following approximation is valid. Here, v_g is the speed of graviton 'propagation', λ_g is the Compton wavelength of a graviton with $\lambda_g = h/m_g c$, and $f \approx 10^{10}$ Hertz in line with L. Grischuck's treatment of relic HFGWs. In addition, the high value of relic HFGWs leads to naturally fulfilling $hf >> m_g c^2$ so that

$$v_g/c \approx 1 - \frac{1}{2}\cdot\left(c/\lambda_g \cdot f\right)^2 \qquad (1)$$

But equation (1) above is an approximation of a much more general result which may be rendered as

$$(v_g/c)^2 \equiv 1-(m_g c^2/E)^2 \tag{2}$$

The terms m_g and E refers to the graviton rest mass and energy, respectively. Now Physics researchers can ascertain what E is, with experimental data from a gravitational wave detector, and the next question needs to be addressed, relating to Visser's model. Namely; if D is the distance between a detector and the source of a HFGW/ Graviton emitter source

$$1-v_g/c = 5\times 10^{-17}\cdot\left[\frac{200Mpc}{D}\right]\cdot\left(\frac{\Delta t}{1\sec}\right) \tag{3}$$

The above formula depends upon, $\Delta t = \Delta t_a - (1+Z)\cdot\Delta t_e$ with where Δt_a and Δt_e are the differences in arrival time and emission time of the two signals (HFGW and Graviton propagation), respectively, and Z is the redshift of the source.

Specifically, the situation for HFGW is that for early universe conditions, that $Z \geq 1100$, in fact for very early universe conditions in the first few milliseconds after the big bang, that $Z \sim 10^{25}$. This is an enormous number.

The first question which needs to be asked is, if the Visser non-dynamical background metric is correct, for early universe conditions so as to avoid the problem of the limit of small graviton mass does not coincide with pure GR, and the predicted perihelion advance, for example, violates experiment . A way forward would be to configure data sets so in the case of early universe conditions that one is examining appropriate $Z >> 1100$ but with extremely small Δt_e times, which would reflect upon generation of HFGW before the electro weak transition, and after the INITIAL onset of inflation.

I.e. a Gravitational wave detector system should be employed as to pin point experimental conditions so to high accuracy, the following is an adequate presentation of the difference in times, Δt. I.e.

$$\Delta t = \Delta t_a - (1+Z)\cdot\Delta t_e \quad \to \Delta t_a - \varepsilon^{+} \approx \Delta t_a \tag{4}$$

The closer the emission times for production of the HFGW and Gravitons are to the time of the initial nucleation of vacuum energy of the big bang, the closer we can be to experimentally using equation (4) above as to give experimental criteria for stating to very high accuracy the following.

$$1-v_g/c \cong 5\times 10^{-17}\cdot\left[\frac{200Mpc}{D}\right]\cdot\left(\frac{\Delta t_a}{1\sec}\right) \tag{5}$$

More exactly this will lead to the following relationship which will be used to ascertain a value for the mass of a graviton. By necessity, this will push the speed of graviton propagation very close to the speed of light. In this, we are assuming an enormous value for D

$$v_g / c \cong 1 - 5\times10^{-17} \cdot \left[\frac{200Mpc}{D}\right] \cdot \left(\frac{\Delta t_a}{1\sec}\right) \qquad (6)$$

This equation (6) relationship should be placed into $\lambda_g = h / m_g c$, with a way to relate this above value of $(v_g / c)^2 \equiv 1 - (m_g c^2 / E)^2$, with an estimated value of E as an average value from field theory calculations, as well as to make the following argument rigorous, namely

$$\left[1 - 5\times10^{-17} \cdot \frac{200Mpc}{D} \cdot \frac{\Delta t_a}{1\sec}\right]^2 \cong 1 - \left(\frac{m_g c^2}{E}\right)^2 \qquad (7)$$

A suitable numerical treatment of this above equation, with data sets could lead to a range of bounds for m_g, as a refinement of the result given by Clifford Will for graviton Compton wavelength bounded behavior for a lower bound to the graviton mass, assuming that h is the Planck's constant.

$$\begin{aligned} \lambda_g &\equiv \frac{h}{m_g c} > 3\times10^{12} km \cdot \left(\frac{D}{200Mpc} \cdot \frac{100Hz}{f}\right)^{1/2} \cdot \left(\frac{1}{f\Delta t}\right)^{1/2} \\ &\cong 3\times10^{12} km \cdot \left(\frac{D}{200Mpc} \cdot \frac{100Hz}{f}\right)^{1/2} \cdot \left(\frac{1}{f\Delta t_a}\right)^{1/2} \end{aligned} \qquad (8)$$

The above equation (8) gives an upper bound to the mass m_g as given by

$$m_g < \left(\frac{c}{h}\right) \Big/ 3\times10^{12} km \cdot \left(\frac{D}{200Mpc} \cdot \frac{100Hz}{f}\right)^{1/2} \cdot \left(\frac{1}{f \cdot \Delta t_a}\right)^{1/2} \qquad (9)$$

Needless to say, an estimation of the bound for the graviton mass m_g, and the resulting Compton wavelength λ_g would be important to get values of the following formula for experimental validation

$$V(r)_{gravity} \cong \frac{MG}{r} \exp(r/\lambda_g) \qquad (10)$$

Clifford Will gave for values of frequency $f \equiv 100$ Hertz enormous values for the Compton wavelength, i.e. values like $\lambda_g > 6\times10^{19} km$. Such enormous values for the Compton wavelength make experimental tests of equation (10) practically infeasible.

Values of $\lambda_g \approx 10^{-5}$ centimeters or less for very high HFGW data makes investigation of equation (10) above far more tractable.

3. Application to Gravitational Synchrotron radiation, in accelerator physics

Eric Davis, quoting Pisen Chen's article written in 1994 estimates that a typical storage ring for an accelerator will be able to give approximately $10^{-6} - 10^{3}$ gravitons per second. Eric uses Chen's article about Photon conversion into Gravitons, to suggest a way we can use accelerators as a somewhat focused graviton source. Quoting Pisen Chen's 1994 article, the following for graviton emission values for a circular accelerator system, with m the mass of a graviton, and M_P being the Planck mass. N as mentioned below is the number of 'particles' in a ring for an accelerator system, and n_b is an accelerator physics parameter for bunches of particles, which for the LHC is set by Pisen Chen to the value of 2800, and N for the LHC is about 10^{11}. And, for the LHC Pisen Chen sets γ at 0.88×10^{2}, with $\rho[m] \approx 4300$. Here, $m \sim m_{graviton}$ acts as a mass charge.

$$N_{GSR} \sim 5.6 \cdot n_b^2 \cdot N^2 \cdot \frac{m^2}{M_P^2} \cdot \frac{c \cdot \gamma^4}{\rho} \tag{11}$$

The immediate consequence of the prior discussion would be to obtain a more realistic set of bounds for the graviton mass, which could considerably refine the estimate of 10^{11} gravitons produced per year at the LHC, with realistically 365 x 86400 *seconds* = 31536000 *seconds* in a year, leading to 3.171×10^{3} gravitons produced per second. Refining an actual permitted value of bounds for the accepted graviton mass, m, as given above, while keeping $M_P \sim 1.2209 \times 10^{19}$ *GeV*/c^2 would allow for a more precise value for gravitons per second which significantly enhances the chance of actual detection, since right now for the LHC there is too much general uncertainty about where to place a detector for actually capturing / detecting a graviton. Note that Eric Davis explicitly uses Pisen Chen's calculations of $10^{-6} - 10^{3}$ gravitons produced to make a feasibility argument as to non zero graviton mass.

4. Conclusion, falsifiable tests for the Graviton are closer than the physics community thinks

The physics community now has an opportunity to experimentally infer the existence of gravitons as a knowable and verifiable experimental datum with the onset of the LHC as an operating system. Even if the LHC is not used, Pisen Chen's parameterization of inputs from the table right after his equation (8) as inputs into equation (11) above will permit the physics community to make progress toward the detection of Gravitons for, say the Brookhaven laboratory site circular ring accelerator system. See **Appendix B** for that table. Tony Rothman's statement about needing a detector the size of Jupiter to obtain a single experimentally falsifiable set of procedures is defensible only if the wave-particle duality induces so much uncertainty as to the mass of the purported graviton, that worst case model building and extraordinarily robust parameters for a Rothman style graviton detector have to be put in place.

A suitably configured detector can help with bracketing a range of masses for the graviton, as a physical entity subject to measurements, without needing to be so massive. Such an effort requires obtaining rigorous verification of the approximation used to the effect that $\Delta t = \Delta t_a - \left(1+Z\right)\cdot \Delta t_e \quad \to \Delta t_a - \varepsilon^{+} \approx \Delta t_a$ is a defensible approximation. Furthermore, having realistic estimates for distance D as inputs into equation (9) above is essential.

The expected pay offs of making such an investment would be to determine the range of validity of equation (10) , i.e. to what degree is gravitation as a force is amendable to post Newtonian approximations.

The author asserts that equation (10) can only be realistically be tested and vetted for sub atomic systems, and that with the massive Compton wavelength specified by Clifford Will cannot be done with low frequency gravitational waves.

Furthermore, a realistic bounding of the graviton mass would permit a far more precise calibration of equation (11) as given by Pisen Chen in his 1994 article. We refer the reader to **Appendix C** for how we expect that Eq. (11) and **Appendix A**, Eq. (A4) may be combined to yield experimentally falsifiable tests for a massive graviton.

Note that **Appendix D** gives the details of how Yurov links both initial inflation and the speed up of acceleration of the universe a billion years ago. In addition a brief mention of Padmanabhan's contruction of the present era infaton is mentioned. Notice that the inflaton for today is given by Padmanabhan , which Beckwith views as important to understand what Yurov meant by linking initial inflation with the expansion of the universe speeding up today, i.e. Yurov's second inflation. Also, if gravitons are linkable to DE, as stated by Beckwith's Journal of cosmology publication (2011), in the present era, and if gravitons are super partnered with Gravitinos as stated by Beckwith (2013), Kauffman's non zero initial radius becomes essential, and we also have a description of how the fine structure constant over time, as given by Appendix C, Eq. (C2) , could be invariant. That in turn would lead to Planck's constant being invariant from cosmological cycle to cycle without invoking the Anthropic principle. As well as also keeping track of how the following would be possible at the electro weak era.

Note, from Valev,

$$\begin{aligned} & m_{graviton}\Big|_{RELATIVISTIC} < 4.4\times 10^{-22} h^{-1} eV/c^2 \\ & \Leftrightarrow \lambda_{graviton} \equiv \frac{\hbar}{m_{graviton}\cdot c} < 2.8\times 10^{-8}\, meters \end{aligned} \tag{12}$$

Extending M. Marklund *et al*. and Valev , some gravitons may become larger , i.e. due to red shifting as given by Clifford Will.

$$\lambda_{graviton} \equiv \frac{\hbar}{m_{graviton}\cdot c} < 10^{4}\, meters \text{ or larger} \tag{13}$$

The author maintains that the information necessary for both Eq. (12) and Eq. (13) plus space-time geometry , as well as DM and DE linked as given by Beckwith(2013) states require the finite initial radius result (Kauffman) with initially in the electro weak era, tiny HFGW as given by Eq.(12) super partnered with gravitinos. We hope for experimental confirmation, as soon as possible. Appendix A gives a crucial lower bound for the initial radius of the universe. Appendix C makes the case for a non zero Graviton mass super partered to (via SUSY) to Gravitinos. The non zero Gravitino mass leads credence to a non zero initial energy necessary for a the initial cosmological radii, R, being non zero, and Appendix D makes the case for linking non zero graviton mass as linked to the expansion of the universe, via a mechanism linking initial inflation with the speed up of inflation as stated by Yurov, which the author wishes to improve upon.

Appendix A: Indirect support for a massive graviton

We follow the recent work of Steven Kenneth Kauffmann, which sets an upper bound to concentrations of energy, in terms of how he formulated the following equation put in below as Eq. (A1). Equation (A1) specifies an inter-relationship between an initial radius R for an expanding universe, and a "gravitationally based energy" expression we will call $T_G(r)$ which lead to a lower bound to the radius of the universe at the start of the Universe's initial expansion, with manipulations. The term $T_G(r)$ is defined via Eq.(A2) afterwards. We start off with Kauffmann's

$$R \cdot \left(\frac{c^4}{G} \right) \geq \int_{|r''| \leq R} T_G(r + r'') d^3 r'' \tag{A1}$$

Kauffmann calls $\left(\frac{c^4}{G} \right)$ a "Planck force" which is relevant due to the fact we will employ Eq. (A1) at the initial instant of the universe, in the Planckian regime of space-time. Also, we make full use of setting for small r, the following:

$$T_G(r + r'') \approx T_{G=0}(r) \cdot const \sim V(r) \sim m_{Graviton} \cdot n_{Initial-entropy} \cdot c^2 \tag{A2}$$

I.e. what we are doing is to make the expression in the integrand proportional to information leaked by a past universe into our present universe, with Ng style quantum infinite statistics use of

$$n_{Initial-entropy} \sim S_{Graviton-count-entropy} \tag{A3}$$

Then Eq. (A1) will lead to

$$R\cdot\left(\frac{c^4}{G}\right)\geq\int_{|r''|\leq R}T_G\left(r+r''\right)d^3r''\approx const\cdot m_{Graviton}\cdot\left[n_{Initial-entropy}\sim S_{Graviton-count-entropy}\right]$$

$$\Rightarrow R\cdot\left(\frac{c^4}{G}\right)\geq const\cdot m_{Graviton}\cdot\left[n_{Initial-entropy}\sim S_{Graviton-count-entropy}\right] \qquad \text{(A4)}$$

$$\Rightarrow R\geq\left(\frac{c^4}{G}\right)^{-1}\cdot\left[const\cdot m_{Graviton}\cdot\left[n_{Initial-entropy}\sim S_{Graviton-count-entropy}\right]\right]$$

Here, $\left[n_{Initial-entropy}\sim S_{Graviton-count-entropy}\right]\sim 10^5$, $m_{Graviton}\sim 10^{-62}\, grams$, and

1 Planck length = l_{Planck} **= 1.616199 × 10**$^{-35}$ **meters**

where we set $l_{Planck}=\sqrt{\frac{\hbar G}{c^3}}$ with $R\sim l_{Planck}\cdot 10^{\alpha}$, and $\alpha>0$. Typically $R\sim l_{Planck}\cdot 10^{\alpha}$ is about $10^3\cdot l_{Planck}$ at the outset, when the universe is the most compact. The value of *const* is chosen based on common assumptions about contributions from all sources of early universe entropy, and will be more rigorously defined in a later paper.

Appendix B: Graviton paper table from Pisen Chen

Storage Rings	**PEP-11**	**LEP-1**	**LEP-II**	**HERA**	**LHC**
$\varepsilon\left[GeV\right]$	**9**	**50**	**100**	**880**	**7000**
$\gamma\left[10^3\right]$	**18**	**100**	**100**	**7.5**	**.88**
$N\left[10^{10}\right]$	**3.8**	**45**	**45**	**10**	**10**
n_b	**1700**	**4**	**4**	**210**	**2800**
$l\left[cm\right]$	**3.46**	**6.24**	**6.24**	**27.7**	**18.4**
$\rho\left[m\right]$	**500**	**4300**	**4300**	**1035**	**4300**
Gravitational SR					
$\omega_0\left[kHz\right]$	**600**	**70**	**70**	**290**	**70**
$N_{GSR}\left[10^{-7}\sec^{-1}\right]$	**1.3**$\times10^3$	**38**	**150**	**6**$\times10^6$	**18**$\times10^8$
Resonant conversion					
$\omega_c\left[10^9\,GHz\right]$	**3.5**	**70**	**560**	**.12**	**4.8**$\times10^{-5}$
$N_{\mathrm{Res}}\left[10^{-7}\sec^{-1}\right]$	**.1**	**.1**	**,3**	10^3	**2**$\times10^5$

Appendix C: How to get stricter bounds to Eq. (A4) above

We follow the recent work of Steven Kenneth Kauffmann, which sets an upper bound to concentrations of energy, in terms of how he formulated Eq. (A4) as stated earlier in Appendix A above. The methodology for obtaining a specific set of initial conditions to specify a lower non zero bound for obtaining a radii of the universe, initially requires a specific set of initial conditions. The first is to state how a graviton would have non zero mass, initially, as discussed by Beckwith in 2011 in the journal of cosmology, as well as the assumption that a gravitino would be super partnered with gravitons according to a mass conservation expression given as in the following section in Beckwith, 2013, sent to the Rencontres De Moriond conference. i.e. the section entitled

2. Forming $m_{3/2}$ for a Gravitino and linking it to Massive Graviton Contributions in electro weak era: For the Machian relationship

We assume that the mass between gravitons and gravitinos is super parterned and that the number of gravitons, i.e. about 10^{50} in the electro weak era , reflects in about $10^{8}-10^{12}$ gravitinos, each gravitino with at least 10^{38} times the mass of a graviton. Each of the gravitinos is initially up to 1 TeV in mass, and if mass is initially the same as energy, the presence of non zero energy will show up in the formulation of $T_G(r)$ of Eq. (A2) as having a non zero value. Since $T_G(r)$ has a non zero value, this super partnering of gravitinos with non zero mass gravityons insures that there is a lower non zero bound for the initial radii, R. We now below document how to obtain a super partner relationship between gravitons and gravitinos which will lead to a non zero $T_G(r)$

The idea was to mix results in Salvoy's 1983 documet with

$$\begin{aligned} M_{electro-weak} &= N_{electro-weak}\cdot m_{3/2} = N_{electro-weak}\times 10^{38}\cdot m_{graviton} \\ &= N_{today}\cdot m_{graviton} \approx 10^{88}\cdot m_{graviton} \end{aligned} \qquad \text{(C1)}$$

Then the electro weak regime would have and entropy value of $N_{electro-weak}\sim 10^{50}$ for gravitons which would be compared with $N_{initial}\sim 10^{8}-10^{12}$ for gravitinos, with $m_{3/2}$ 10^{38} times larger in mass than the graviton , whereas the $m_{3/2}$ is a gravitino mass value. With (C2) below being the initial entropy value in electro weak regime which grows to 10^{88} today, i.e. via use of Ng's re statement of entropy

$$N_{electro-weak}\sim 10^{50} \qquad \text{(C2)}$$

The first and second eqn. above form our relationship for making a linkage of massive gravitons linked to SUSY gravitinos This would lead to , say

$$\sum m_{BOSONS} - \sum m_{FERMIONS} = 0 \qquad \text{(C3)}$$

Table 1, mass of different particles and cosmological parameters (rounded off)

M_{Planck}	$M_{TEV}\sim M_{DM}\sim M_{Gravitino}$	M_{DE}	$M_{Graviton}$
$10^{-8}\,kg\sim 10^{16}\,TeV$	$10^{-24}\,kg = 10^{12}\,eV$	$10^{-16}\,M_{DM}$	$10^{-65}\,kg$

The net up shot of the super partner pairing of gravitons and gravitinos is to obtain a non zero $T_G(r)$ due top no zero gravitons leading up to possibly an upper gravitino mass value with this mass being initially energy . The minimum energy for $T_G(r)$ will then entail the lower bound to the initial radii, R are not zero. Now to the problem How to insure that the graviton has non zero mass.

To start, we can first review briefly what was done by Beckwith in 2011, in the Journal of Cosmology. In this publication, Beckwith outlined how there may be a contribution via a minimally massive graviton as to re acceleration of the universe. Here the value of $m_{Graviton} \sim 10^{-62}\, grams$ to get a speed up of acceleration of cosmological expansion a billion years ago. This though, does not cleave to the essence of the problem, though, as seen in growing neutrino mass theories and cosmology, there conceivably could be growing mass for early universe gravitons. The author thinks not, and appeals to what was done in another publication, a talk in Italy 2011 (see pages 36-43) where a variant of Penrose cyclic conformal cosmology is employed as a means to recycle prior universe information in order to have a uniform Planck's constant, per cycle – via a consistent small graviton mass.

Note that recently in La Thuile, Italy (2013) in Rencontres De Moriond, Beckwith outlined a relationship between Gravitons and Gravitinos which implies that at or before the electro weak era, i.e. that due to a revision of SUSY, the up to TeV mass of gravitinos at or before the electro weak era with Gravitinos super partnered with gravitons leads to a non zero initial cosmological radius. Furthermore, as stated in FXQI, in a discussion by Tom Ray, *No singularity at the Schwarzchild radius not only confirms the quantum nature of the cosmological initial condition, it implies non-quantization of classical space-time. For if the quantum field does not collapse, the universal wavefunction, which is continuous (Kauffmann concludes, " ... only the universe itself, with its cosmological redshift, is actually capable of 'containing' the arbitrarily high frequencies of a quantum field") is physically real and dark energy isn't't".*

This end result leads to a finite initial radius of space-time, not zero, with enough information transported from a prior universe to the present so as to preserve the continuity of physical constants from space-time collapse to rebirth, again and again. Note that the almost infinite amount of energy within a radii within a Planck value (but not smaller) is enough to get Gravitinos formed which are super partered via re done SUSY as stated by Beckwith (2013) to obtain during the Electro weak regime massive Gravitons obeying the equation of state , as given by Maggiore

$$\left(\partial_{\mu}\partial^{\varpi} - m_{graviton}\right)\cdot h_{\mu\nu} = \left[\sqrt{32\pi G} + \delta^{+}\right]\cdot\left(T_{\mu\nu} - \frac{1}{3}\eta_{\mu\nu}T^{\mu}_{\mu} + \frac{\partial_{\mu}\partial_{\nu}T^{\mu}_{\mu}}{3m_{graviton}}\right) \quad \text{(C4)}$$

Furthermore, we state that both the Graviton and Gravitino would have to be consistent, with respect to the well known De Broglie matter-wave hypothesis, with the resultant consistency of a constant fine structure constant ,which does not vary over time, as given by Beckwith (2010a,b), so that there would be constant fine structure values, as given by

$$\tilde{\alpha} \equiv e^2 / \hbar \cdot c \equiv \frac{e^2}{d} \times \frac{\lambda}{hc} \quad \text{(C5)}$$

The idea that Planck's constant would remain consistent is also stated by R. Penrose in his recent book. Accordingly; the author views that a minimum entropy of 10^5 as a transfer mechanism from prior to present space time is important and should be reviewed, as it gives constant values equal to the present value of Planck's constant from cycle to cycle. Cyclic conformal cosmology, and tests confirming its initial CMBR pattern, would do much to add such a plausible explanation showing how consistency in Planck's constant from cycle to cycle can be maintained. Lastly; the author appeals to a calculation given by Giovanni, to the effect that if the Penrose supposition of

$$\begin{aligned} &10^{10^{90}} \approx 10^{Final-entropy-Gravitons=S_{FINAL-GRAVITONS}} \\ &\sim Phase \quad space \quad due \quad to \quad Gravitons \end{aligned} \quad \text{(C6)}$$

is true (as given by Penrose) then the relationship given by Giovanni in his book for entropy that the present entropy of the universe, i.e. about $10^{88} - 10^{90}$ is obtained by integrating from 10-^ 11 Hertz down to 10^-19 Hertz would do much to argue for a constant graviton mass, as given above. Furthermore, this could be with work also connected with what the author referred to as first and second inflation, as given by his work in 2010. This would be a project warranting serious investigation. First inflation is the typical inflation given in cosmology, whereas the 2nd inflation is the speed up of the universe, as referenced in Beckwith's 2011 publications.

Appendix D What if an inflaton partly re-emerges in space-time dynamics? At z ~ . 423?

In this section, the author will give further elaboration of a suggestion by Yurov as to linking of initial inflation with the speed up of expansion of the universe, commencing up to today. This section will be focused upon saying something about the inflaton which may be basic as to why the universe has a speed up of inflation. We review, in doing so, the work by Padmanabhan.

Padmanabhan has written up how the 2nd Friedman equation which for **z ~ . 423** may be simplified to read as

$$\dot{H}^2 \cong \left[-2\frac{m}{a^4} \right] \quad \text{(D1)}$$

would lead to an inflaton value of , when put in, for scale factor behavior as given by $a(t) \propto t^{\lambda}, \lambda = (1/2) - \varepsilon^{+}, 0 \le \varepsilon^{+} << 1$, of, for the inflaton and inflation of (Padmanabhan)

$$\phi(t) = \int dt \cdot \sqrt{-\frac{\dot{H}}{4\pi G}} \quad \text{(D2)}$$

Assuming a decline of $a(t) \propto t^{\lambda}, \lambda = (1/2) - \varepsilon^{+}, 0 \le \varepsilon^{+} << 1$, Eq. (D3) yields

$$\phi(t) \sim \sqrt{\frac{2m}{4\pi G}} \cdot \left[2\varepsilon^{+}\right] \cdot t^{2\cdot\varepsilon^{+}} \qquad \text{(D3)}$$

As the scale factor of $a(t) \propto t^{\lambda}, \lambda = (1/2) - \varepsilon^{+}, 0 \le \varepsilon^{+} << 1$ had time of the value of roughly $a(t) \propto t^{\lambda}, \lambda = (1/2) - \varepsilon^{+}, 0 \le \varepsilon^{+} << 1$ have a power law relationship drop below $a(t) \propto t^{1/2}$, the inflaton took Eq. (D3) 's value which may have been a factor as to the increase in the rate of acceleration, as noted by the q (z) factor , given in Beckwith's Journal of cosmology publication . Note that there have been analytical work projects relating the inflaton, and its behavior to entropy via noting that inflation stopped when the inflaton field settled down into a lower lower energy state. The way to relate an energy state to the inflaton is , if $a(t) = a_0 t^{\lambda}$, then in the early universe, one has a potential energy term of (Padmanabhan)

$$V(\phi) = V_0 \cdot \exp\left[-\sqrt{\frac{16\pi G}{\lambda}} \cdot \phi(t)\right] \qquad \text{(D4)}$$

A situation where both $\lambda = (1/2) - \varepsilon^{+}$ grows smaller, and, temporarily, $\phi(t)$ takes on Eq. (D3)'s value, even if the time value gets large, and also, if acceleration of the cosmic expansion is taken into account, then there is infusion of energy by an amount dV. The entropy dS ≃dV/T, will lead, if there is an increase in V, as given by Eq. (D4) a situation where there is an effective increase in entropy. If there is, as will be related to later, in page eight, circumstances, where $S \approx N =$ number of graviton states (as stated by Y. Ng)

Linking the two analytically, partly due to Yurov's suggestion about an explicit linkage between initial and final inflation (initial inflation being what happens right after Planck scale time , and final inflation being the speed up of acceleration seen as of the present era) would in the mind of the author, clinch the case for a non zero graviton mass. The Yurov suggestion about linking initial and final inflation (as stated above) will be worked upon seriously by the author in future publications and is crucial to making initial and final graviton mass, about the same order of magnitude.

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