Landauer's Principle of Minimum Energy Might Place Limits on the Detectability of Gravitons of Certain Mass

Ioannis Haranas, Ioannis Gkigkitzis, Kristin Cobbett, and Ryan Gauthier

Abstract — According to Landauer's principle, the energy of a particle may be used to record or erase N number of information bits within the thermal bath. The maximum number of information N recorded by the particle in the heat bath is found to be inversely proportional to its temperature T . If at least one bit of information is transferred from the particle to the medium, then the particle might exchange information with the medium. Therefore for at least one bit of information, the limiting mass that can carry or transform information assuming a temperature $T = 2.73$ K is equal to $m = 4.718 \times 10^{-40}$ kg which is many orders of magnitude smaller than the mass of most of today's elementary particles. Next, using the corresponding temperature of a graviton relic and assuming at least one bit of information the corresponding graviton mass is calculated and from that, a relation for the number of information N carried by a graviton as a function of the graviton mass m_g is derived. Furthermore, the range of information number contained in a graviton is also calculated for the given range of graviton mass as given by Nieto and Goldhaber, from which we find that the range of the graviton is inversely proportional to the information number N . Finally, treating the gravitons as harmonic oscillators in an enclosure of size R we derive the range of a graviton as a function of the cosmological parameters in the present era.

Keywords — entropy; graviton; graviton mass; information; Landauer Principle; Landauer limit.

I. INTRODUCTION

The existence of any physical systems presupposes the registration of information just because it exists [1] and [2]. Dynamically evolved systems not only process but they also transform information. In this case the laws of physics determine the precise amount of information that a system can register or process or transfer as well as the exact number of logical operation that the system can perform. In Landauer's original paper [1], the author went on making the statement that information is physical but at the same time all this information is registered and processed by physical systems. Furthermore, the laws of physics that describe a certain system can involve information and information processing. On the other hand, Landauer's principle is a principle that defines the lower possible theoretical limit of energy consumption during a computation. At this point, we must say that even though non-equilibrium extensions as well as quantum extensions to the Landauer principle have not been considered yet, recently some GR corrections of Landauer's principle exist in the bibliography. Furthermore, Landauer's principle is a physical principle pertaining to the lower theoretical limit of energy consumption during a computation. Landauer's principle asserts that there is a minimum possible amount of energy required to change one bit of information, known as the Landauer's limit, and it is equal to:

$$E_{\min} = k_B T \ln 2 \quad (1)$$

where $k_B = 1.38 \times 10^{-23}$ J/K is Boltzmann's constant, and T is the temperature of the heat bath. Therefore, Landauer's energy formula is written in terms of the information number $N \neq 1$ where N is given in bits in the following way [3]:

$$E_{\min} = k_B N T \ln 2 \quad (2)$$

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Dr. I. Haranas, Department of Physics and Computer Science, Wilfrid Laurier University, Waterloo, Canada.
(corresponding e-mail: iharanas@wlu.ca)

Dr. I. Gkigkitzis, Department of Mathematics, NOVA, Annandale, USA.
(e-mail: gkigkitzis@nvcc.edu)

Kristin Cobbett, Department of Physics and Computer Science, Wilfrid Laurier University, Waterloo, Canada.
(e-mail: cobb2390@mylaurier.ca)

Ryan Gauthier, Department of Physics and Computer Science, Wilfrid Laurier University, Waterloo, Canada.
(e-mail: gaut0700@mylaurier.ca)

In a recent paper [4] the author postulates the idea of a new principle of mass-energy-information equivalence. He simply proposes that a bit of information is physical, and actually possesses a certain mass associated with it whereinf ormation stored. For example, at room temperature $T = 300$ K the mass corresponding to one bit of information is equal to $m_{N=1bit} = 3.190 \times 10^{-38}$ kg.

II. THE THEORY

In a private communication paper by [5], the author postulates and considers a particle with energy E in contact but not necessarily in thermal equilibrium with the thermal bath at temperature T . According to Landauer's principle, the energy of a particle may be used to record or erase N number of information bits within the thermal bath. The maximum number of information recorded by the particle in the heat bath is equal to:

$$N_{max} = \frac{mc^2}{k_B T \ln 2}. \quad (3)$$

Equation (3) can be considered as the maximum number of information content in bits of a particle at rest [5]. If at *least one bit* of information is transferred from the particle to the medium, then the particle might exchange information with the medium. In this case we can write that $N_{max} \geq 1$ should be true. Following [5] and using (3) we obtain the following relation for the mass of the particle:

$$m_0 \geq \frac{k_B T \ln 2}{c^2} \quad (4)$$

To get an idea with of the limiting mass that can carry or transform information to the medium following [5] the author obtains $m_0 \approx 2.0 \times 10^{-40}$ kg. In reference to this numerical result, we just have to say that in today's standard model the mass values of the elementary particles including that of neutrino with estimated mass are much heavier than the mass predicted above. At this point we remind the reader of the order of magnitude of the some of the elementary particle masses known today are in the range $10^{-31} \text{ kg} \leq m \leq 10^{-28} \text{ kg}$. Therefore, particles with masses smaller than $m_0 \leq 10^{-40} \text{ kg}$ will not transform/transmit information to the universe and therefore as a result they will not be detected. At this point, we say that Landauer's principle might result in detectability issues that are related to the smallness of the masses of certain elementary particles. Since we are interested in the relation of graviton to information some theory in relation to graviton will be given here. According to Einstein's theory of general relativity, linearization of Einstein's field equations demonstrates that small perturbations of the metric obey a wave equation [6]. These small disturbances referred as gravitational waves, and travel at the speed of light. However, various gravity theories predict a dispersive propagation [7]. The most considered form of dispersion assumes that these waves obey a Klein -Gordon equation of the form:

$$\left[\frac{1}{c^2} \frac{\partial^2}{\partial t^2} - \nabla^2 + \left(\frac{m_{gr} c}{\hbar} \right)^2 \right] \phi = 0 \quad . \quad (5)$$

The physical significance of this dispersive term is ascribed to the quantum of gravitation that has a non-zero rest mass m_{gr} or equivalently a non-infinite Compton wavelength give by the relation $\lambda = \hbar / m_{gr} c$ where ϕ is the potential function of the gravitational field. Theories like M -theory, loop quantum gravity, string theory and superstring theory and quantum field theory all predict the existence of graviton particles. In relation to quantum field theory gravitons are the elementary particles that mediate the force of gravity, and they are expected to be massless which results to an infinite range gravitational force. Furthermore, gravitons are bosons of spin-2 which is related to the stress energy momentum tensor, and can give rise to a force that is indistinguishable from gravitation simply because the massless spin-2 field is coupled to the stress-energy tensor in the same way that gravity field does [8]. Therefore, if a particle of spin 2 is discovered it must be graviton. Its detection will be an important step in the validation of the gravitational theories above and unify quantum mechanics with general relativity [6]. At the same time, we should say that the extreme weakness of the gravitational force makes the graviton detection a very hard issue. In a recent book the author suggests "the detection of a single graviton may in fact ruled out in the real universe" [9]. If this proves to be true, then issues will be raised immediately for the quantization of gravity. On the other hand,

attempts to extend the standard model by including gravitons have failed at high energies because of the infinities arising at quantum effects, which means that gravitation is nonrenormalizable [10]. This also means that quantum mechanics and gravity are incompatible at these energies and thus the situation becomes tenable.

Concluding in relation to the mass of the graviton, we say that in a recent paper [11] the authors indicate a link between the cosmological constant and the graviton mass m_{gr} . Theory predicts that particles that travel with the speed of light have practically zero mass $m \geq 10^{-68}$ kg. This result is in excellent agreement with the current experimental mass bound of photon and graviton, something that suggests that entropic gravity might result of a softly broken recent local symmetry [12]. Moreover, cosmological holography postulates all the information content of the universe is encoded at the cosmological horizon, an idea first proposed by 't Hooft, [13]. In a more recent paper forwarded by Smoot the author postulates all the information content in our universe is encoded at the cosmological horizon [14].

III. GRAVITON RELIC TEMPERATURE

At this point, we will use Landauer's principle and calculate the corresponding mass of a graviton if a graviton in the relic graviton background exchanges information with the medium at least one bit of information. For that we will use the result for the graviton relic temperature and therefore we feel that we touch upon the corresponding formulation is necessary for the reader. Following [15] a graviton thermal background is expected to exist and has decoupled from the photon bath around the Planck time, and ever since cooling at a rate $T_{gr} \propto \frac{1}{R(t)}$ [15]. To be more specific in [15] the authors claim that photons cooled

less quickly because they have been heated by the annihilation of heavy species, and therefore the current graviton temperature is given by:

$$T_{gr} = \left(\frac{g_{*s}(t_0)}{g_{*s}(t_{pl})} \right)^{1/3} T_\gamma \quad (6)$$

where: $g_{*s}(t_{pl})$ is the relativistic degrees of freedom in the fluid (with $m < kT/c^2$) at the Planck time and $g_{*s}(t_0) = 3.91$ today and g_{*s} is given by [15] as follows:

$$g_{*s} \cong \sum_{\text{Bosons}_i} g_i \left(\frac{T_i}{T_\gamma} \right)^3 + \sum_{\text{Fermions}_i} \frac{7}{8} \left(\frac{T_i}{T_\gamma} \right)^3 + \dots \quad (7)$$

In previous estimates of the background graviton entropy the authors have assumed $g_{*s}(t_{pl}) \sim g_{*s}(10^{12} \text{ eV}) = 106.75$ [16] and [17]. Therefore, the corresponding graviton relic temperature as calculated in [15] is give by:

$$T_{gr} = 0.61_{-0.52}^{+0.2} \text{ K}. \quad (8)$$

Using the above temperature instead as the temperature via which the graviton can now exchange information and if it exchanges *at least* one bit of information with the surrounding medium we find that the quantifiable mass of the graviton to be equal to:

$$m_{gr} \geq \frac{k_B T \ln 2}{c^2} = 6.438 \times 10^{-41} \text{ kg} \quad (9)$$

We find that the calculated graviton mass exchanging one information bit with the medium is an order of magnitude less than the mass limit predicted in [5], in which the author used the cosmic microwave background radiation temperature instead. This is the lower bound mass limit required for a relic background graviton at $T = 0.61$ K to transform information to the medium. Therefore, we conclude that at one bit of information gravitons in the range $10^{-69} \text{ kg} \leq m_{gr} \leq 10^{-55} \text{ kg}$ [18], will not be detected. As an example, we also say the according to [19] the mass of the lightest neutrino has been estimated to

$m_\nu = 0.086 \text{ eV} = 1.5 \times 10^{-37} \text{ kg}$ which is four orders of magnitude heavier than the mass predicted above. Next using the temperature of the graviton in [18] we can write the number of information bits as a function of the graviton mass in the following way [3]:

$$N = \frac{m_{gr} c^2}{k_B T \ln 2} = 1.542 \times 10^{40} m_{gr} \quad (10)$$

This is the number of information bits, which various graviton masses will be able to transfer to the medium because of their masses and temperatures. This has been calculated under the assumption that all gravitons have a temperature equal with that of the graviton relic $T = 0.61 \text{ K}$. We can easily see that the number of information bits is a linear function of the mass of the graviton particle in the following way:

$$N = 1.542 \times 10^{40} m_{gr} . \quad (11)$$

Considering the graviton mass range given $10^{-69} \text{ kg} \leq m_{gr} \leq 10^{-55} \text{ kg}$ [18] we find that the corresponding number of information contained within the graviton falls in the range:

$$1.542 \times 10^{-29} \text{ bits} \leq N \leq 1.542 \times 10^{-15} \text{ bits} . \quad (12)$$

From (11) we see that it takes a quantifiable graviton of mass $m_{gr} = 6.485 \times 10^{-41} \text{ kg}$ to contain and transfer one bit of information to the medium, which is impossible since the calculated graviton mass range is many orders of magnitudes smaller than the limiting mass i.e., (9). In our calculation, we have used the corresponding graviton temperature as calculated in [15], but the mass is still many orders of magnitude when compared with that mass of most elementary particles. In reference to (12) in [3], certain cosmological scenarios involve fractional number of information bits. According to information theory, fractional information bits imply uncompressed data. This will also imply information that is not possible to be decompressed (or sometimes it has not been decompressed yet) through matter and energy. Thus, we may perceive matter in our universe as a system of specific information in which any interaction and law takes place with the exchange of specific amount of information under the assumption that matter is an entity analogous to a computer.

Next, it is known that the Compton wavelength or range of a boson λ in this case the graviton it is given by the following relation in [20]:

$$\lambda_{gr} = \frac{\hbar}{m_{gr} c} . \quad (13)$$

Using (4) for the mass of graviton, as function of the maximum number of information N that may be recorded by the particle in the bath, we can write the range of graviton in the following way:

$$\lambda_{gr} = \frac{\hbar c}{N k_B T \ln 2} \propto \frac{1}{N} . \quad (14)$$

In other words, the range of the graviton scales inversely proportional to the information number N . Thus, if a graviton contains a very small number of information bits is expected to have a very large range or Compton wavelength. In this aspect, we postulate that the less information a graviton carries the less will interact with the rest of the universe and therefore it will propagate at large cosmic distances, a direct result of Landauer's principle. Therefore, we propose that the information bit might be an alternative way via which graviton particles and matter could interact with the rest of the universe. Thus, we can picture information as a new way via which matter interacts with the rest of the universe telling matter how to interact. Using the values predicted for the mass of graviton according to [18] we find that the graviton range λ falls in the range:

$$3.513 \times 10^{26} \text{ m} \leq \lambda \leq 3.513 \times 10^{12} \text{ m} . \quad (15)$$

Taking into account that the radius of the universe is $R_{uni} = 4.4 \times 10^{26} \text{ m}$ [21] and [22] we say the range of such gravitons of the appropriate mass can be equal to the radius of the visible universe and the solar system respectively. In [23] the authors applied this idea to investigate the data from the Hulse-Taylor

binary pulsar and from the pulsar PSR B1534+12. From their analysis of the data, they found the graviton range to be $\lambda \geq 2.60 \times 10^{12}$ m which is almost identical to our lower bound in (15). This result was under the assumption that, some linearized theories, allow for massive gravitons of mass m_{gr} to propagate freely via the Klein-Gordon equation. If the graviton had a rest mass, the decay rate of an orbiting binary would be affected [24]. As the decay rates of binary pulsars agree very well with GR, the errors in their measurements provide a limit on a graviton mass.

IV. GRAVITON ENTROPY OF GRAVITONS IN AN ENCLOSURE

In proceeding with calculation of the range of a graviton as a function of cosmological parameters and information an expression for the entropy in the universe is necessary. To be more specific we need an expression with the help of which the entropy attributed to one or N_{gi} as gravitons can be obtained. In [25] the author embraces the idea that gravitons can often be seen inside the horizon of a black hole, where the statistical black hole entropy can be treated as an ensemble of n non-interacting massless particles with angular frequency ω [23]. His expression can equally apply at a generic size enclosure (“box”) of dimension R . On the other hand, there are proposals presented in the literature that are physically possible, but we are still lacking a complete theory of quantum gravity. In his paper [25] the author proceeds in obtaining a physically reasonable “phenomenological” formula for the frequency of trapped gravitons motivated by the techniques of perturbative quantum field theory, i.e. perturbation around a Minkowski spacetime. Next the author in a statistical mechanics treatment of gravitons in a box derives that the trapped gravitons have a discrete spectrum with angular frequency given by:

$$\omega_{\ell n} \simeq \frac{c}{2R} (2 + \ell + 2n) \pi \quad \ell \geq 2 \quad n \in \mathbb{N} \quad (16)$$

In the literature of statistical black hole entropy, we can often see gravitons inside the horizon depicted as an ensemble of n non-interacting massless particles with (continuum) angular frequency ω (Bekenstein 1975). Following [25] we write the entropy of gravitons treated as a system of N_{gi} oscillators in an enclosure of dimension R is the following way:

$$S_{gr} = -k_B N_{gr_i} \left[\ln(1 - e^{-x/2}) + \ln(1 - e^{-x}) \right] + \frac{\pi \hbar N_{gr_i}}{2TR} e^{-x/2} \frac{(1 + 3e^{-x/2})}{(1 - e^{-x})}. \quad (17)$$

where:

$$x = \frac{\pi \hbar}{k_B TR}, \quad (18)$$

where again R is the dimension of the “box” and is N_{gr_i} the number of gravitons enclosed. Taking (18) to the Hubble horizon i.e., $R_H = c/H$ we obtain that:

$$x = \frac{\pi \hbar H}{k_B T}. \quad (19)$$

In the present era $x \ll 1$ has an extremely small value and therefore expanding (17) to first order we obtain that:

$$S_{gr} \cong \left[\frac{2\pi \hbar}{RTx} + \left(\frac{3k_B}{4} + \frac{5\pi \hbar}{48RT} \right) x + \left(k_B \ln \left(\frac{2}{x^2} \right) - \frac{3\pi \hbar}{4RT} \right) \right] N_{gr_i}. \quad (20)$$

Using the value of x and after some algebra we can write (20) in the following form:

$$S_{gr} \cong 2k_B \left[1 + \frac{5}{96} x^2 + \frac{1}{2} \ln \left(\frac{2}{x^2} \right) \right] N_{gr_i}, \quad (21)$$

for which we can say that the entropy for a total number of gravitons N_{gr_i} treating gravitons as oscillators in an enclosure of size R and temperature T and it is equal to an *effective* k_B Boltzmann constant, by twice

the value of the square bracket in the above equation. It is the proportionality factor that relates the average relative kinetic energy of the gravitons in the graviton gas with the thermodynamic temperature of the gas. Equating (20) to the equation of the entropy of a system in terms of the information number N i.e., $S = N_{tot} k_B \ln 2$ and solving for the number of information N corresponding to an number of gravitons N_{gr_i} we obtain that:

$$N_{tot} \cong \frac{2}{\ln 2} \left[1 + \frac{5}{96} x^2 + \frac{1}{2} \ln \left(\frac{2}{x^2} \right) \right] N_{gr_i} \quad (22)$$

Taking R to be the Hubble radius $R_H = c/H_0$ and first assuming one graviton $N_i = 1$. Equation (21) after some simplifications takes the form:

$$N = \frac{2}{\ln 2} \left[1 + \left(\frac{\pi \hbar H_0}{k_B T} \right)^2 + \frac{1}{2} \ln \left(2 \left(\frac{k_B T}{\pi \hbar H_0} \right)^2 \right) \right] \quad (23)$$

Next substituting (22) into (15) we can write the range λ_{gr} of one graviton in the following way:

$$\lambda_{gr} = \frac{\hbar c}{k_B T \ln 2 \left[\frac{2}{\ln 2} \left[1 + \left(\frac{\pi \hbar H_0}{k_B T} \right)^2 + \frac{1}{2} \ln \left(2 \left(\frac{k_B T}{\pi \hbar H_0} \right)^2 \right) \right] \right]} \quad (24)$$

Given that in the present era the second term in the denominator square bracket is $\left(\frac{\pi \hbar H_0}{k_B T} \right)^2 \ll 1$, equation (24) can be written as:

$$\lambda_{gr} = \frac{\hbar c}{2 k_B T \left[1 + \frac{1}{2} \ln \left(2 \left(\frac{\pi \hbar H}{2 k_B T} \right)^2 \right) \right]} \quad (25)$$

For a graviton that carries at least one bit of information the possibility of an infinity range implies a temperature of the thermal bath that is equal to:

$$T = \frac{\pi \hbar H}{k_B e \sqrt{2}} = \frac{\pi}{e \sqrt{2}} \left(\frac{\hbar H}{k_B} \right) = \frac{\pi}{e \sqrt{2}} \left(\frac{E_{min_{qua}}}{k_B} \right), \quad (26)$$

where we have used that $E_{min_{qua}} = \hbar H$ is the so-called minimum quantum energy of the graviton [24]. Next, let us now consider the total number of gravitons in the universe as its given in [27]:

$$N_i(gr) = \frac{c^3}{G \hbar \Lambda} = \frac{1}{\ell_{pl}^2 \Lambda}, \quad (27)$$

where Λ is the cosmological and ℓ_{pl} is the Planck length. Substituting (27) in (21) we obtain that the total number of information for the total number of gravitons in the universe to be equal to:

$$N_{tot} \cong \left(\frac{2}{\ell_{pl}^2 \Lambda} \right) \left[1 + \frac{1}{2} \ln \left(2 \left(\frac{k_B T}{\pi \hbar H_0} \right)^2 \right) \right] \quad (28)$$

Using (27) we obtain in a statistical sense an average graviton range if all gravitons have the same mass to be equal to:

$$\langle \lambda_{gr} \rangle = \frac{\ell_{pl}^2 A}{2k_B T} \frac{\hbar c}{\left[1 + \frac{1}{2} \ln \left(2 \left(\frac{k_B T}{\pi \hbar H_0} \right)^2 \right) \right]}. \quad (29)$$

Next let us assume that the graviton can have an “infinite” range, would imply that the denominator of (29) should be equal to zero for two different possibilities for the thermal bath temperature, i.e. $T = 0$ and also T equal to (26) above. Similarly, and infinite range will require a Hubble constant that is equal to:

$$H = \frac{e\sqrt{2}}{\pi} \left(\frac{k_B T}{\hbar} \right). \quad (30)$$

In flat universe the Hubble constant depends on the information number N in the following way [25], [28]:

$$H = \sqrt{\frac{\pi}{\ln 2}} \frac{1}{t_{pl} \sqrt{N}} \quad (31)$$

Equating (31) and (30) we write this temperature of the bath as a function of information number N in the following way:

$$T = \frac{\pi^{3/2}}{e \ln 2 \sqrt{2}} \left(\frac{\hbar}{k_B t_{pl} \sqrt{N}} \right), \quad (32)$$

where $t_{pl} = \sqrt{\frac{G\hbar}{c^5}}$ is the Planck time, and therefore, (32) can be further written in following way:

$$T = \frac{\pi^{3/2}}{e \ln 2 \sqrt{2}} \left(\frac{T_{pl}}{\sqrt{N}} \right), \quad (33)$$

where $T_{pl} = \sqrt{\frac{\hbar c^5}{G k_B^2}} = 1.416 \times 10^{32}$ K is the Planck temperature. Next assuming that the universe is an enclosure of the size equal to today's Hubble radius we calculate its total entropy using that $S_{tot} = N_{tot} k_B \ln 2$ [28]. For that we substitute (28) for the total number of gravitons in the universe in the equation for the S_{tot} and therefore we obtain that:

$$S_{tot} = \frac{2k_B \ln 2}{\ell_{pl}^2 A} \left[1 + \frac{1}{2} \ln \left(2 \left(\frac{k_B T}{\pi \hbar H_0} \right)^2 \right) \right]. \quad (34)$$

Calculating (34) to in the present era we find that the total number of information to be:

$$S_{tot} = 68.223 \left(\frac{k_B c^3}{G \hbar A} \right) = \frac{68.223 k_B}{\ell_p^2 A} = 2.371 \times 10^{123} k_B = 3.270 \times 10^{100} \text{ J/K}. \quad (35)$$

The above entropy is approximately 9.114 times larger than the one calculated by Egan and Lineweaver [15] at the visible horizon of the universe, namely $S_{hor} = 2.60 \times 10^{122} k_B = 3.588 \times 10^{99} \text{ J/K}$. This is the contribution of the term in the square bracket in the calculation of the entropy in a first order approximation. In this case if we use (40) in [15] namely:

$$S_H = \frac{k_B c^3 A_H}{4G\hbar} \quad (36)$$

Equating (34) and (35) and solving for the radius of the horizon we obtain:

$$R_U = \left[\frac{2 \ln 2}{\pi \Lambda} \left(1 + \frac{1}{2} \ln \left(\frac{2 k_B^2 T^2}{\pi^2 \hbar^2 H_0^2} \right) \right) \right]^{1/2}, \quad (37)$$

At this point we say that today's radius of the universe is calculated using the black body background radiation temperature $T = 2.725$ K. On the other hand, using the individual graviton relic background temperature as given in [15] i.e. $T = 0.61$ K and substituting in the above equation we find the following values for the radius of the universe to be:

$$R_U = 5.115 \times 10^{26} \text{ m}, \quad (38)$$

where the use of the microwave background radiation temperature results to a value for the radius of the universe, which is very close to the one above, as given in [30]:

$$R_U = 4.50 \times 10^{26} \text{ m}, \quad (39)$$

But in [15] the value of the radius of the universe is calculated to be $R_u = 1.550 \times 10^{26}$ m. At his point, using (26) and in the present era we estimate the temperature required such that the graviton has an infinite range, and we find that:

$$T_{\lambda_{gr} \rightarrow \infty} = 1.433 \times 10^{-29} \text{ K}. \quad (40)$$

This is an extremely low temperature. To obtain an idea of such a low temperature let us consider the mass universe of $M_U = \frac{c^3}{GH_0} = 1.762 \times 10^{53}$ kg [29], to be a black hole and calculate the temperature of such black hole to be:

$$T_{BH} = \frac{\hbar c^3}{8\pi k_B G M_U} = \frac{\hbar H_0}{8\pi k_B} = 6.400 \times 10^{-31} \text{ K}. \quad (41)$$

Similarly using (14) and solving for the number of information N we obtain that:

$$N = \frac{\hbar c}{\lambda_{gr} k_B T \ln 2}. \quad (42)$$

Assuming that the range of the graviton is at least equal to the visible horizon of the universe i.e., $\lambda_{gr} = R_U = \frac{c}{H_0}$ (42) gives that the number of information in the present era in the equation below:

$$N = \frac{\hbar H_0}{k_B T \ln 2} = \frac{1}{\ln 2} \left(\frac{E_{qua_{min}}}{E_{ther}} \right). \quad (43)$$

Using the temperature of microwave background radiation i.e. $T = 2.725$ K as well as the temperature of the graviton relic as given in (9) $T = 0.61$ K [15] (43) results in the following values for the information N :

$$9.294 \times 10^{-30} \text{ nats} \leq N \leq 4.152 \times 10^{-29} \text{ nats}. \quad (44)$$

At this point we say that $N = O(10^{-29})$ is the same order of magnitude of information that is given in (12) and for the specific graviton mass that is equal to $m_{gr} \geq 10^{-69}$ kg. This can also suggest two different ways that a graviton of certain mass either by mass or by the graviton relic temperature of $T = 0.61$ K can carry the same order of magnitude of information bits a direct consequence of as derive from Landauer's principle. Using (33) and the numerical value of the temperature of the thermal bath we estimate the amount

of information in one single graviton to be equal to:

$$N = \frac{\pi^3}{4e^2 \ln 2} \left(\frac{T_{pl}}{T_{\lambda_{gr} \rightarrow \infty}} \right)^2 = 1.495 \times 10^{122} \text{ nats.} \quad (45)$$

This number is almost the same order of magnitude as the total number of gravitons in the universe being equal to:

$$N_{gr}(tot) = 3.626 \times 10^{121} \text{ nats.} \quad (46)$$

With reference to [27] the authors have derived an expression for the total number of gravitons contained inside the observable horizon $N_{g_{tot}}$ as a function of the number of information N in the following way:

$$N_{g_{tot}} = \frac{\ln 2}{3\pi} N = 0.073N, \quad (47)$$

where N is the number of the total information in the universe. Looking at (45) it might be worth trying to understand the possible meaning of this numerical result. For example, highly repetitive input such as the orbit of a planet or particle can effectively be compressed, for instance, such as in biology a biological data collection of the same or closely related species can be compressed. The basic task can be achieved through a context free physics. However, just as the human eye is more sensitive to subtle variations in luminance than it is to the variations in color, it is very likely that our perception is restricted to the use of several compression formats that lead to paradoxes, such as a graviton having information context greater than the universe. Inspired by the close connection between machine learning and compression where a system can predict the posterior probabilities of a sequence given its entire history for optimal data compression, we may expect that a particle such as the graviton, can read the history of the universe and has more bits of information as predicted posterior probabilities of the system (the concept of "general intelligence. [31], [32] and [33]. When we study the universe, our rational perception resembles the psychoacoustics of our ears where not all data in an audio stream can be perceived by the human auditory system. But as a lossy compression, it reduces redundancy by first identifying perceptually irrelevant sounds, that is, sounds that are very hard to hear. Another hypothesis we can make is that perhaps the universe manifests only certain aspects of its information context that can be measured or identified by our scientific methods. Something like it happens to speech encoding, an important category of audio data compression. The range of frequencies needed to convey the sounds of a human voice are normally far narrower than that needed for music, and the sound is normally less complex. As a result, speech can be encoded at high quality using a relatively low bit rate. Perhaps the information context of the universe has an intrinsic mechanism that "hides" away more of the information bits—keeping just enough to reconstruct an "intelligible" universe to the observer rather than the full realization range of events, that can be modeled even beyond quantum probabilities.

V. CONCLUSIONS

In this paper the idea that the max number of bits of information N recorded by one particle in a heat bath is inversely proportional to the particle's temperature T . Furthermore if at least one bit of information it is transferred from the particle to the medium, then the corresponding particle might exchange information with the medium. If the particle exists in our universe and the temperature to be the same of that of black body radiation $T = 2.73$ K, the corresponding mass of the particle carrying at least one bit of information is equal $m = 4.718 \times 10^{-40}$ kg which is many orders of magnitude smaller than the mass of most of today's elementary particles. Next, using the corresponding graviton temperature i.e. and assuming at least one bit of information i.e., $N = 1$ the corresponding graviton mass is calculated. Moreover, using the above-mentioned result, we derive a relation for the number of information N carried by a graviton as a function of the graviton mass m_{gr} . Furthermore, the range of information number contained in a graviton is also calculated for the given range of graviton mass as given by Nieto and Goldhaber and, we find that the range of the graviton is inversely proportional to the information number N . Finally, adopting a treating and gravitons as oscillators in an enclosure of size R we derive the graviton range as a function of cosmological constant, graviton relic temperature and the Hubble parameter in an effort to relate the range of a graviton to basic cosmological and thermodynamic parameters such as the Hubble parameter and Boltzmann's constant.

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