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Cosmic Entropy and Conversation of Energy of the Type $ST = E$

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Abstract

We will discuss how the entropy of the growing black hole Hubble sphere in $R_{H_t} = ct$ cosmology, as described by Haug and Tatum, is fully consistent with the conservation of energy in the form $ST = E$.

Keywords

Black Hole Entropy, Hubble Sphere Entropy, Energy Conservation, Quantum Gravity

1. Background

The Bekenstein-Hawking [1]-[3] entropy is normally given by:

$$S = k_b \frac{A}{4l_p^2} \tag{1}$$

For a black hole Hubble sphere, the surface area is $A = 4\pi R_{H_t}^2$, where R_{H_t} is the Hubble radius at time t. The idea to look at the Hubble sphere as a black hole where the Hubble radius is equal to the Schwarzschild radius is not new. Pathria [4] already in 1972 pointed out similarities between a black hole and the Hubble sphere. A series of papers have been discussing black hole cosmology since that time, see [5]-[16]. The critical Friedmann [17] mass in the universe is given by $M_{cr} = \frac{c^2 R_H}{2G}$, solved for the Hubble radius R_H we get:

$$R_H = \frac{2GM_{cr}}{c^2} \tag{2}$$

which is basically identical to the formula for the Schwarzschild radius: $R_s = \frac{2GM}{c^2}$. Even if there is no direct evidence that the Hubble radius is the radius of a black hole, there is a considerable amount of indirect evidence. Haug and Tatum [18] have recently examined a series of properties in black hole cosmology versus the Λ-CDM model, which seem to favor black hole cosmology. That said, this is clearly an ongoing debate where no consensus has yet been reached.

Furthermore, we will here consider cosmological models in which the radius of the Hubble sphere grows as $R_{H_t} = ct$, see for example [19]-[21] for more information about this model class. Here we will focus on a black hole $R_{H_t} = ct$ consistent with what has been presented by Haug and Tatum [22]. The entropy in the $R_{H_t} = ct$ model can therefore be expressed as:

$$S = k_b \frac{4\pi R_{H_t}^2}{4l_p^2} \tag{3}$$

and the entropy at R_{H_0} is

$$S = k_b \frac{4\pi R_{H_0}^2}{4l_p^2} = k_b \frac{\pi R_{H_0}^2}{l_p^2} \approx 2.29\times 10^{122} k_b$$

This represents the entropy of the black hole universe in the $R_{H_t} = ct$ model as described by Haug and Tatum [23]-[26]. However, they were not very clear in their interpretation of this entropy. It seems to correspond to the total entropy of the universe at time t. When $t = 0$ (now), this value is very close to the number of operations since the beginning of the universe, as estimated by Lloyd [27]: $\frac{t_{H_0}^2}{t_p^2} \approx 7.29\times 10^{121}$. The difference between this value and S is simply a factor of π. Haug [28] has also calculated similar numbers for the total number of operations in the universe since its beginning, see also **Appendix A**. Haug in that paper clearly also demonstrates the Bekenstein-Hawking entropy basically is identical to the number of operations since the beginning of the universe until now.

According to Haug's [29] [30] quantum gravity theory, the universe is updating itself every Planck time. This means the Hubble sphere entropy at the Planck time window now must be:

$$S_{t_p} = k_b S \frac{t_p}{t_{H_0}}$$

$$S_{t_p} = k_b \frac{4\pi R_{H_t}^2}{4l_p^2} \frac{\frac{l_p}{c}}{\frac{R_H}{c}}$$

$$S_{t_p} = k_b \frac{4\pi R_{H_t}^2}{4l_p R_{H_t}}$$

$$S_{t_p} = k_b \frac{4\pi R_{H_t}}{4l_p}$$

$$S_{t_p} = k_b 2\pi \frac{l_p}{\bar{\lambda}_{cr}} \approx 2.68\times 10^{61} k_b \tag{4}$$

where $\bar{\lambda}_{cr} = \frac{\hbar}{M_{cr}c}$ is the reduced Compton [31] [32] wavelength of the Hubble sphere. This means the entropy is nothing more than the reduced Compton frequency of the Hubble sphere per Planck time, multiplied by $k_b 2\pi$. This is essentially the same as the number of operations in the universe per Planck time if one instead views the Hubble sphere as a quantum gravity computer; see Haug [28]. The number of operations in the Hubble sphere is basically the same as the entropy, and this number keeps increasing, but is distributed over a larger and larger volume as the Hubble sphere expands, since the volume grows proportionally to $R_{H_t}^3$, while the total energy grows proportionally to R_{H_t}, and the same applies to the number of states (operations). The energy in the universe related to this entropy is given by:

$$S_{t_p} T = E_{cr} \tag{5}$$

where $E_{cr} = \frac{c^5}{2GH_0}$. The temperature related to each entropic state is actually the Hawking-Planck temperature as we are now at the Planck scale. The smallest building blocks of the universe are Planck mass particles that have Hawking-Planck temperature $T_{Haw,p} = \frac{\hbar c}{2\pi l_p}\frac{1}{k_b}$.

This means we have full conservation of energy in the Haug and Tatum entropy:

$$S_{t_p} T_{Haw,p} = k_b \frac{\pi R_{H_t}}{l_p}\frac{\hbar c}{2\pi l_p}\frac{1}{k_b} = \frac{c^5}{2GH_0} = E_{cr} \tag{6}$$

where E_{cr} is the critical Friedmann energy: $E_{cr} = \frac{c^5}{2GH_0}$. In other words, the Haug and Tatum way to describe entropy in a $R_{H_t} = ct$ universe is clearly is consistent with conservation of energy. We also simply have:

$$E_{cr} = \frac{S_{t_p}}{k_b}\frac{m_p c^2}{2\pi} \tag{7}$$

and naturally also:

$$\frac{S_{t_p}}{k_b} = \frac{E_{cr}}{\frac{m_p c^2}{2\pi}} \approx 2.68\times 10^{61} \tag{8}$$

In other words, each micro state in the entropy has the energy of a Schwarzschild micro black hole. One can think of these micro black holes as the very building blocks of everything. The Planck scale can actually be detected indirectly from any gravity observation, see [33]-[35], that is without relying on traditional Max Planck [36] [37] dimensional analysis and knowledge off G or $\hbar$.

Figure 1 shows the total number of entropic states from the beginning of the universe at any time t, represented by the blue line: $\frac{S}{k_b}$. The red line represents the number of entropic states within the given Planck time window at time t: $\frac{S_{t_p}}{k_b}$. The entropic states since the beginning of the universe are proportional to $R_{H_t}^2$, while the entropic states in the Planck time window grow linearly and are proportional to R_{H_t}. The energy in this universe is also proportional to R_{H_t}, as given by $E_{cr,t} = \frac{c^4 R_{H_t}}{2G} = \frac{c^5 t}{2G}$. Thus, the conservation of energy in relation to $E_{cr,t}$ is naturally expressed as $S_{t_p} T_{Haw,p} = E_{cr,t}$. Tatum and Haug [25] calls $E_{cr,t}$ correctly also for the entropic time varying energy.

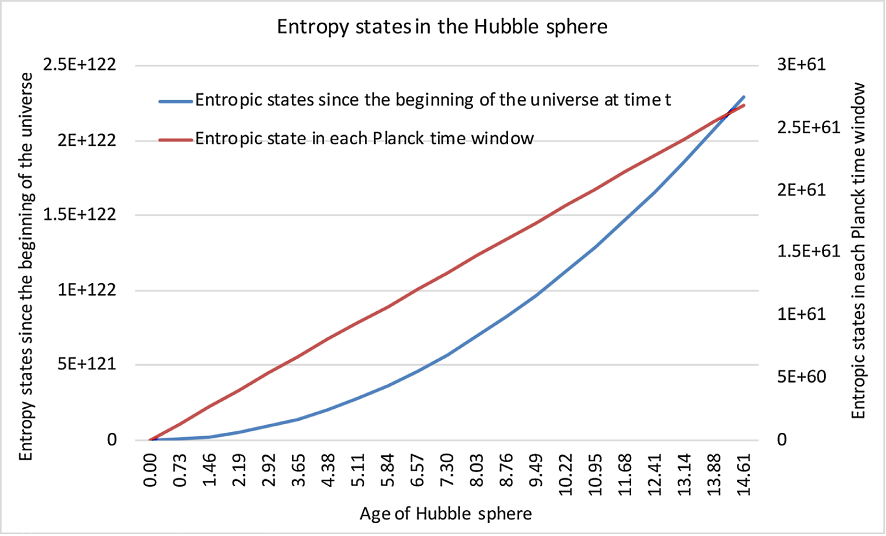

Figure 1. The figure shows the entropic states in the Hubble sphere in $R_{H_t} = ct$ cosmology as we move through the age of the Hubble sphere up to the present. The blue line represents the Bekenstein-Hawking entropy formula where the radius is $R_{H_t} = ct$. This is the total entropy since the beginning of the universe at time t. The blue line also represents the entropy at any time t, more precisely the entropy within the Planck time window at time t. The latter expresses the conservation of energy in the form $S_{t_p} T_{Haw,p} = E_{cr}$.

2. The CMB Photons Contribution to the Cosmic Entropy

There is consensus among cosmologists that 95% confidence interval (2STD) for the current CMB photon density is about $\Omega_\gamma = \frac{\rho_\gamma}{\rho_{cr}} = 5.38 \pm 0.3 \times 10^{-5}$ (see PDG[1]). In our $R_H = ct$ cosmology, we find that the exact CMB photon density since decoupling is equal to $\Omega_\gamma = \frac{\rho_\gamma}{\rho_{cr}} = \frac{1}{5760\pi} \approx 5.52 \times 10^{-5}$, see [38]. Let us define S_{cmb} as the part of the total cosmic entropy that is associated with the CMB

[1] https://pdg.lbl.gov/2023/reviews/rpp2023-rev-astrophysical-constants.pdf

photons. We must then have that the total CMB energy in the Hubble sphere is:

$$E_{cmb} = E_{cr}\Omega_{\gamma} = \frac{c^4 R_{H_t}}{2G}\frac{1}{5760\pi} = \frac{c^4 R_{H_t}}{11520\pi G} \tag{9}$$

This means we must have:

$$\begin{aligned} S_{cmb,t_p} T_{Haw,p} &= E_{cmb} \\ S_{cmb,t_p} T_{Haw,p} &= E_c \Omega_{\gamma} \\ S_{cmb,t_p} &= \frac{E_c \Omega_{\gamma}}{T_{Haw,p}} \\ S_{cmb,t_p} &= k_b \frac{\frac{c^4 R_{H_t}}{2G}\frac{1}{5760\pi}}{\frac{\hbar c}{2\pi l_p}} \\ S_{cmb,t_p} &= k_b \frac{R_{H_t}}{l_p}\frac{1}{5760} \approx 2.047\times 10^{34}\ \mathrm{J\cdot K^{-1}} \end{aligned} \tag{10}$$

The number of entropic states we can link to the CMB photons in the universe now $t=0$ is then:

$$\frac{S_{cmb,t_p}}{k_b} = \frac{R_{H_t}}{l_p}\frac{1}{5760} \approx 1.48\times 10^{57} \tag{11}$$

If we now divide this by the total number of entropic states in Hubble sphere over the Planck time window ($k_b S_{t_p} \approx 2.68\times 10^{61}$) we get:

$$\frac{\frac{S_{cmb,t_p}}{k_b}}{\frac{S_{t_p}}{k_b}} \approx \frac{1.48\times 10^{57}}{2.68\times 10^{61}} \approx 5.62\times 10^{-5} \tag{12}$$

In other words, our theory is fully consistent with observed CMB photon density. Note that each entropic state still has a temperature equal to the Hawking-Planck temperature. The reason for this is that the scientifically defined NOW must correspond to the Planck time window in any quantized gravity (quantum gravity) model. A CMB photon cannot be observed within this interval, since its wavelength is so long (microwave spectrum, $\approx 8\times 10^{-4}$ m and 2.8×10^{-12} s). That is CMB photons can only be detected over time intervals much longer than the Planck time window ($t_p \approx 10^{-44}$ s)-that is they cannot be observed in the scientifically defined NOW in quantum gravity. Nevertheless, this (Equation (11)) still represents the equivalent number of entropic states arising from the total CMB energy within the Hubble sphere.

Haug and Tatum [25] have, in another paper, correctly connected the Bekenstein-Hawking entropy in $R_H = ct$ cosmology to the CMB, in full agreement with the findings of this work. This has enabled them to predict the cosmic entropy from the beginning of the universe to the present with much greater precision than anyone has achieved in the past. However, this paper goes beyond their results by clarifying how the entropy used in $R_H = ct$ cosmology is fully consistent with the conservation of energy principle $ST = E$. We also emphasize that the cosmic entropic states are not directly associated with CMB photon energy but are instead linked to something far more fundamental: the Planck scale. Nevertheless, as demonstrated, we can readily determine how much the CMB photons contributes to the total cosmic entropy—it is only about 5.62×10^{-5} of the total, fully consistent with the observed CMB photon density.

The number of entropic states will in our model also be basically identical to the reduced Compton frequency in the Hubble sphere, see [28]. This is yet another finding pointing to the validity of the model and how it is closely connected to fundamental aspects of the quantum world.

3. Response to Prior Work

Wojnow [39], in a recent paper, presents multiple arguments and in our view incorrectly claims that the entropy in relation to $R_H = ct$ models, as discussed by Haug and Tatum, is not consistent with the conservation of energy. This is not correct as demonstrated in the section above.

Wojnow assumes that the CMB temperature alone, multiplied by the entropy of the universe, should yield the critical Friedmann [17] energy of the universe, $S_{R_H} T_{cmb} = E_{cr}$. To make this work, he introduces a ad-hock adjustment to the Bekenstein-Hawking entropy formulation. In the paper of Wojnow also seems to fail to understand that the entropy:

$$S = k_b \frac{4\pi R_{H_t}^2}{4l_p^2} \tag{13}$$

indeed is valid for any time in the $R_{H_t} = ct$ universe, but this is the total entropy since the beginning of the universe at any time t in the black hole $R_{H_t} = ct$ model. This is not the entropy of the whole Hubble sphere just now in this Planck time window, which is:

$$S_{t_p} = S\frac{t_p}{t_H} = k_b \frac{4\pi R_{H_t}^2}{4l_p^2}\frac{t_p}{t_H} = k_b \frac{\pi R_{H_t}}{l_p} = k_b 2\pi \frac{l_p}{\bar{\lambda}_c} \approx 2.68\times 10^{61} k_b \tag{14}$$

see also Haug [28] that describes this entropy per Planck time (operations per Planck time) as the reduced Compton frequency of the Hubble sphere per Planck time (see also **Appendix A**). Gravity is at the deepest level quantum gravity that can be described as done by Haug [29] [40]. To then go from the total entropy in the lifetime of the universe to the entropy now (the current Planck time) the total entropy must be multiplied by $\frac{t_p}{t_{H_t}}$.

Wojnow [39] seems to claim that the whole cosmic entropy consists of CMB photons. This is not consistent with observations, where the CMB photon density is only of the order $\Omega_\gamma = \frac{\rho_\gamma}{\rho_{cr}} = 5.38 \pm 0.3\times 10^{-5}$ (95% confidence interval reported by PDG). The correct way to determine the contribution of the CMB to the total cosmic entropy is given in Section 2 of this paper. Wojnow's model does not seem to be consistent with the Bekenstein-Hawking entropic states $\approx 10^{122}$, nor with the number of states in the Planck time window ($\approx 10^{61}$). The number of entropic states in the Wojnow model is of the order 10^{92}. These represent the number of entropic states if one hypothetically assumes that all the states of the universe have only CMB energy, but this is clearly not the case: elementary particles have much shorter wavelengths and much higher energies. At the depth of gravity, we also encounter quantum gravity, where all states likely have something close to the Planck energy, or in our model the Planck energy divided by 2π, with the factor 2π related to the Schwarzschild metric.

The CMB temperature is naturally not directly related to the entropy of the full Hubble sphere, as the CMB temperature constitutes only a very small fraction of the total energy in the Hubble sphere. By making this mistake, Wojnow arrives at a entropy formula that does not seem consistent with observations, such as the fact that only a very small part of the universe consists of CMB photons. In addition, Wojnow suggests that the entropy is related to the geometric mean, without providing any reasoning for this claim, other than referring to the fact that the CMB temperature is indeed related to the geometric mean, as pointed out by Haug and Tatum [41]-[43]. One can, in fact, use any temperature, multiply it by an unknown entropy S, and then set $ST = E_{cr}$ to solve for S. For example, we could even take my current room temperature ($T_{room} = 293.15\text{ K}$) and claim that one must have:

$$ST_{room} = E_{cr}$$

and then, when solving for the entropy, obtain:

$$S = \frac{E_{cr}}{T_{room}} \approx 2.84 \times 10^{67} \tag{15}$$

which implies that the number of entropic states must then be $\frac{S}{k_b} = 2.06 \times 10^{90}$.

This also does not match the Bekenstein-Hawking entropic states or the number of entropic states in the universe within the Planck time window. It simply gives the number of entropic states in the universe if one assumes that each entropic state has room temperature, but this does not provide any new insight into the cosmos—it is merely a play with numbers and formulas.

4. Discussion

We will claim that each entropy state related to black holes is directly related to the Planck scale. We will also conjecture that it is meaningless to try to analyze, for example, the CMB temperature or any other temperature at the Planck scale in the universe today. Any temperature corresponding to an energy considerably smaller than the Planck energy will have a wavelength that cannot, even hypothetically, be observed within the Planck-time window.

In the Schwarzschild metric, when down at the Planck scale, there can only be one temperature that is the same for each microstate in the entropy: the Hawking-Planck temperature $T_{Haw,p} = \frac{m_p c^2}{k_b 2\pi} = \frac{\hbar c}{k_b 2 l_p}$. Only at the very beginning of a black hole universe is the total temperature of the universe equal to a Planck temperature in $R_{H_t} = ct$ cosmology, but that is not what we are typically interested in, except when describing the entropy during the very first Planck-time window after the black hole universe began, when there was only one microstate.

As entropic states occur at the Planck scale and Planck time, they must be studied through the mathematical lens of the Planck regime. For example, trying to bring in the present CMB temperature $T_{cmb} \approx 2.7255\ \mathrm{K}$ in relation to entropic states has little or no meaning, as it is not related to the entropic states. These are instead connected to the most elementary of all particles: Schwarzschild Planck-mass black holes, which, as we know from Hawking radiation theory, have an extremely short lifetime, not much longer than the Planck time. Thus, we claim that the entropic microstates likely pop in and out of existence. Furthermore, it is well known that the total energy from the CMB background contributes only about $\Omega_\gamma = \frac{\rho_\gamma}{\rho_{cr}} = 5.38 \pm 0.3 \times 10^{-5}$ (see PDG) to the total energy of the universe.

5. Conclusion

The Haug and Tatum's way of describing entropy in a black hole $R_H = ct$ universe in multiple papers is fully consistent with conservation of energy in the form $ST = E$. However, the relevant entropy in relation to the critical Friedmann energy of the Hubble sphere is the entropy in this Planck time window, not the entropy from the start of the universe until now. So more precisely the Hubble sphere entropy over the Planck time S_{t_p} multiplied by the temperature of each micro state in the entropy, which is the Hawking-Planck temperature is equal to the critical Friedmann energy: $S_{t_p} T_{Haw,p} = E_{cr}$. The relevant temperature for each elementary (gravitational) state in the universe is the Hawking-Planck temperature, and not the CMB temperature. The CMB temperature accounts for only a very small fraction of the total energy in the universe, which is evident from the CMB photon energy density parameter, equal to $\Omega_\gamma = \frac{1}{5760\pi}$.

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Data Availability Statements

No new data has been generated in this study.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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Appendix A

Haug [28] has suggested that the Hubble sphere could operate as a quantum gravity computer. We recommend reading that paper, but in short, he assumes that every elementary particle ticks at the reduced Compton frequency of that particle. For the whole Hubble sphere, one can find the reduced Compton frequency simply by taking the reduced Compton wavelength of the critical universe mass, which is given by:

$$\lambda_{cr} = \frac{\hbar}{M_{cr}c} \approx 3.79\times10^{-96}\ \text{m} \tag{16}$$

This is much shorter than the Planck length, even though we assume the shortest possible physical wavelength is the Planck length. This is still consistent, since the Compton wavelength of a composite object is the aggregate of all the Compton wavelengths of the elementary particles making up that composite object. We have

$$M_{cr} = m_1 + m_2 + m_3 + \cdots + m_n$$

$$\bar{\lambda}_{cr} = \frac{1}{\sum_{i=1}^{n}\frac{1}{\bar{\lambda}_i}} \tag{17}$$

We can easily extend this to take into account effects such as binding energies. One can simply say the binding energy is equal to $E_b = \frac{m}{c^2}$ and then incorporate the binding energy as one of the masses aggregated above.

The reduced Compton frequency per second must be $f = \frac{c}{\lambda_{cr}} \approx 7.9\times10^{103}$. For entropy, we are interested in the reduced Compton frequency per Planck time, which must be $f_{t_p} = \frac{c}{\lambda_{cr}}t_p = \frac{l_p}{\lambda_{cr}} \approx 4.27\times10^{60}$, which is exactly a 2π difference from the number of entropic states calculated earlier. The 2π difference comes from properties of the Schwarzschild metric. Each entropic state can be seen as a microstate that again corresponds to the number of operations in a Hubble sphere quantum gravity computer per Planck time window. Entropy and operations are simply two different labels for what at the ultimate depth of reality simply is the reduced Compton wavelength over the Planck time window.