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# An Exact Formula for Cosmic Entropy in Rh=Ct Cosmological Model

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# An Exact Formula for Cosmic Entropy in Rh=ct Cosmological Model

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**Abstract**

The question of the entropy of the universe is crucial and remains unanswered in cosmology. Assuming a flat universe, we derive, which we then demonstrate, an exact heuristic formula for the entropy of the apparent universe: $S_{Rh} = \frac{16\,\pi^2 Rh^2 E_{Pl}}{Rh\; l_{Pl}\, T_{Pl}} \frac{Tcmb}{T_{Pl}} \frac{t_{Rh}}{t_{Pl}}\ J.K^{-1}$ at the apparent horizon, i.e. at the Hubble radius. This approach forms part of a quantum thermodynamic cosmology framework of the Rh = ct type, which is in the field of classical mechanics, and could help to quantify the Planck era of Big Bang theory. It assumes that the universe would exist before Planck time at Planck temperature. Furthermore, it could shed new light on the standard cosmological model with regard to entropy.

**Keywords:** thermodynamics; cosmic entropy; Rh=ct cosmology; temperature of CMB; black hole; planck era

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## 1. Introduction

Einstein said about thermodynamics: "A theory is the more impressive the greater the simplicity of its premises is, the more different kinds of things it relates, and the more extended is its area of applicability. Therefore, the deep impression which classical thermodynamics made upon me. It is the only physical theory of universal content concerning which I am convinced that within the framework of the applicability of its basic concepts, it will never be overthrown." [1]

Entropy is a measure of the disorder or randomness of a system. According to the second law of thermodynamics, the entropy of an isolated system increases over time, or at best remains constant. This law gives time a fundamental direction, often referred to as the 'arrow of time'.

A major challenge in the standard cosmological model is explaining why the universe began its expansion with abnormally low entropy, which then increased dramatically to reach values much higher than those observed at decoupling (approximately 380,000 years after the Big Bang). This 'initial entropy problem' appears to contradict the observed cosmic microwave background (CMB), which indicates that the early universe was close to thermal and chemical equilibrium, a state typically associated with high entropy.

Assuming our universe is an isolated system at the temperature of the CMB and based on recent thermodynamic cosmology research of the Rh = ct type, we propose a formula for the entropy of our universe that is consistent with its energy at the apparent horizon.

## 2. Background

In 2015, Tatum et al. [2] proposed an equation for the CMB temperature, noted $T_{cmb}$, that has since been formally derived from the Stefan-Boltzmann law by Haug and Wojnow [3,4].

$$T_{cmb} = T_{Rh} = \frac{\hbar c}{k_b 4\pi\sqrt{R_h 2 l_{Pl}}} \quad (1)$$

Witch can be derived as follows:

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$$T_{cmb} = T_{Rh} = \frac{\hbar}{k_b 4\pi\sqrt{t_{Rh}\, 2t_{Pl}}} \quad (2)$$

Where $\hbar$ is the reduced Planck constant, $c$ is the speed of light in a vacuum, $k_b$ is Boltzmann's constant, the Hubble radius is defined by $R_h = \frac{c}{H}$ where $H$ is the Hubble parameter, $T_{Rh}$ is the temperature of the Hubble sphere, $l_{Pl}$ is the Planck length, $t_{Rh}$ is the Hubble time defined by $t_{Rh} = \frac{1}{H}$, and $t_{Pl}$ is the Planck time.

From Eq.2 we derive directly:

$$t_{Rh} = \frac{\hbar^2}{T_{cmb}^2 k_b^2 16\pi^2 2t_{Pl}} \quad (3)$$

These values, together with Planck's energy, $E_{Pl} = m_{Pl}c^2$ , where $m_{Pl}$ is Planck's mass, are necessary and sufficient to lead us to the formulation of the entropy $S_{Rh}$ of the apparent universe, i.e. at the Hubble radius, compatible with the energy contained in the Hubble sphere.

## 3. Heuristic Formulation of the Entropy of Our Apparent Universe

Firstly, we are in the field of classical thermodynamic cosmological models, so the previously proposed formulation of cosmic entropy, for example by Haug and Tatum[5], which falls within the field of general relativity in Rh=ct models, cannot be applied on the grounds that it does not correctly take into account the energy contained in the Hubble sphere, $E_{Rh} = \frac{c^4 Rh}{2G}$, where $G$ is the gravitational constant, but above all because its field of study is different. Indeed, it is not logical that $S_{Rh}\, T_{Rh}$ diverges from $E_{Rh}$ in our model.

*Note: It should be noted that Eq.1 is an adaptation of the Hawking temperature of black holes[2]. This leads to the idea that our universe is the interior of an expanding black hole and that, in thermodynamic cosmology, an isolated system can also be linked to the interior of a black hole. Thus, our universe is a simple part of an infinite flat universe populated by black holes, which themselves contain their own universes.*

For example, in Haug and Tatum's approach to the entropy of our apparent universe, the energy $E_{Rh}$ is correct at Planck temperature, which should be noted, but diverges by a factor of $10^{52}$ today in our model. We reject it for this reason: The law of conservation of energy must be applied when we are in the field of classical mechanics which imposes: $S_{Rh}\, T_{Rh} = E_{Rh}$.

The entropy $S_{Rh}$ proposed by Haug and Tatum [5], although logically incorrect for all $Rh$ in classical mechanics, has the advantage of being correct at Planck temperature. They assumed in Rh=ct cosmology the Bekenstein-Hawking formula for the entropy of a black hole as follows:

$$S_{Rh} = \frac{4\pi\, R_h^2}{4 l_{Pl}^2} \quad (4)$$

We have noticed that the geometric means, commonly used in our particular approach to Rh=ct thermodynamic cosmological models [2,6], between unit quantum values and Rh=ct model values.

We therefore replaced $l_{Pl}^2$ with $\sqrt{R_h^2 l_{Pl}^2} = R_h l_{Pl}$ to preserve the exact result at Planck temperature, when $R_h = c\, t_{Pl}$ . Despite this modification, $S_{Rh}T_{Rh}$ still diverged from $E_{Rh} = \frac{c^4 Rh}{2G}$ for more contemporary values of $Rh$. We then applied the principle of the ratio of quantum values to values in the Rh = c t model to count the number of Planck units. For example [7], $\frac{t_{Rh}}{t_{Pl}}$. When $S_{Rh}T_{Rh}$ was sufficiently close to $E_{Rh}$, we searched for constants, particularly simple powers of π, to arrive at this formula for the entropy of the apparent universe, which is compatible with its energy at the CMB temperature

$$S_{Rh} = \frac{16\,\pi^2 Rh^2 E_{Pl}}{Rh\, l_{Pl}\, T_{Pl}} \frac{Tcmb}{T_{Pl}} \frac{t_{Rh}}{t_{Pl}}\, J.K^{-1} \tag{5}$$

With $Rh = c\, t_{Rh}, l_{Pl} = c\, t_{pl}$ and $T_{Pl} = \frac{E_{Pl}}{k_B}$ Eq.5, i.e. the formula of cosmic entropy in this Rh = c t model, can simplify as follows:

$$S_{Rh} = 16\,\pi^2 k_B \frac{Tcmb}{T_{Pl}} \frac{t_{Rh}^2}{t_{Pl}^2}\, J.K^{-1} \tag{6}$$

It is important to emphasize and remember that, in this approach,

$$T_{cmb} = T_{Rh} = \frac{\hbar}{k_b 4\pi \sqrt{t_{Rh}\, 2t_{Pl}}}\, K \tag{7}$$

and

$$t_{Rh} = \frac{\hbar^2}{T_{cmb}^2 k_b^2 16\pi^2 2t_{Pl}}\, s \tag{8}$$

Then we can verify numerically $S_{Rh}T_{cmb} = S_{Rh}T_{Rh} = E_{Rh}$, i.e. the law of energy conservation:

$$S_{Rh}T_{Rh} = 16\,\pi^2\, k_B \frac{Tcmb}{T_{Pl}} \frac{t_{Rh}^2}{t_{Pl}^2} Tcmb = E_{Rh} = \frac{c^4 Rh}{2G}\, J \tag{9}$$

$$S_{Rh}T_{Rh} = 16\,\pi^2\, k_B \frac{T_{cmb}^2}{T_{Pl}} \frac{t_{Rh}^2}{t_{Pl}^2} = E_{Rh} = \frac{c^4 Rh}{2G}\, J \tag{10}$$

As $Tcmb$ decreases, the cosmic entropy $S_{Rh}$ of the universe increases. The temperature and the entropy of universe are transformed into Hubble volume and Hubble mass (i.e. energy). This is a global change in the state of the universe's temperature, affecting its volume and mass.

## 4. Demonstration of This Formula for Cosmic Entropy in This Model Rh=ct.

$$S_{Rh}T_{Rh} = 16\,\pi^2\, k_B \frac{T_{cmb}^2}{T_{Pl}} \frac{t_{Rh}^2}{t_{Pl}^2}\, J \tag{10}$$

With $T_{cmb} = \frac{\hbar}{4\pi\, k_b \sqrt{t_{Rh}\, 2t_{Pl}}}\, K$, we derive Eq.10 as follows:

$$S_{Rh}T_{Rh} = \frac{\hbar^2}{k_b\, T_{Pl}} \frac{t_{Rh}}{2t_{Pl}^3}\, J \tag{11}$$

With $T_{Pl} = \sqrt{\frac{\hbar\, c^5}{G\, k_B^2}}$ and $t_{Pl} = \sqrt{\frac{\hbar\, G}{c^5}}$, we derive Eq.11 as follows:

$$S_{Rh}T_{Rh} = \frac{\hbar^2}{\sqrt{\frac{\hbar\, c^5}{G}}} \frac{t_{Rh}}{2\sqrt{\frac{\hbar\, G}{c^5}\frac{\hbar\, G}{c^5}}} = \frac{c^5 t_{Rh}}{2\, G} = \frac{c^4\, ct_{Rh}}{2\, G} = \frac{c^4\, Rh}{2\, G} J \tag{12}$$

Since $E_{Rh} = \frac{c^4\, Rh}{2\, G}$, we have shown that $S_{Rh}T_{Rh} = \frac{c^4\, Rh}{2\, G} = E_{Rh}$ to satisfy the law of the conservation of energy in the Rh=ct model thanks to the formulas of $T_{Rh}$ and $t_{Rh}$.

## 5. Contribution of the Entropy $R_h = c\,t$ to the Duration and Energy in the Planck era.

It is widely accepted that the Planck era is characterized by Planck energy and Planck temperature. However, the concept of time in the Planck era is poorly defined. By setting $T_{cmb} = T_{Rh} = T_{Pl}$ , we calculate $t_{Rh} = \frac{t_{Pl}}{32\pi^2}$, i.e. a time shorter than the Planck time at Planck era. In an other hand, we also can calculate in this model that for $E_{Pl} = S_{Rh}T_{Rh} = S_{Rh}T_{cmb}$, we need to set $T_{cmb} = \frac{T_{Pl}}{8\pi}$.

## 6. Conclusion

The contribution of the universe entropy formula Rh=ct to this emerging quantum thermodynamic cosmological model is an important advance. It provides a reliable formula in this field of research, paving the way for new developments and perspectives on the issues faced by the contemporary standard cosmological model.

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