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► **To cite this version:**

Espen Gaarder Haug. The Hawking temperature as a minimum temperature, the Planck temperature as the maximum temperature and the CMB temperature as a geometric mean temperature. 2023. hal-04308132v1

HAL Id: hal-04308132

<https://hal.science/hal-04308132v1>

Preprint submitted on 29 Nov 2023 (v1), last revised 2 Dec 2023 (v2)

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The Hawking temperature as a minimum temperature, the Planck temperature as the maximum temperature and the CMB temperature as a geometric mean temperature.

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November 26, 2023

Abstract

We will illustrate how the Hawking temperature, seems to represent simply the minimum temperature above zero anywhere in the Hubble sphere. It serves as the temperature gap, so to speak – the minimum temperature above zero – and therefore, also the energy gap. This do not exclude that it in addition represent radiation from the black hole. Secondly, the Planck temperature is likely the maximum temperature at any localized subatomic point in the universe. Additionally, we demonstrate that the CMB temperature is simply a form of geometric mean temperature between the minimum and maximum temperatures. This observation suggests a leaning toward re-consideration of $R_H = ct$ cosmological models, as well as black hole cosmological models, even if this possibly also can be consistent with the Λ -CDM model. Most importantly, this contributes to the growing literature in recent years, asserting not only the measurability of the CMB temperature but its accurate predictability as well and to tighten the relationship between such as CMB and the Hubble constant and other aspects related to the Hubble sphere.

Keywords: Hawking temperature, Planck temperature, CMB temperature, geometric mean, Compton wavelength, Hubble sphere.

1 All electromagnetic energy the kilogram mass of any mass can be expressed through the Compton wavelength

Arthur Holy Compton [1] in 1923 gave us a formula for the Compton wavelength of a particle

$$\lambda = \frac{h}{mc} \quad (1)$$

Further the reduced Compton wavelength is equal to $\bar{\lambda} = \frac{\hbar}{mc}$, where \hbar is the reduced Planck constant $\hbar = \frac{h}{2\pi}$. Since pure energy can be expressed as equivalent rest-mass energy $m = \frac{E}{c^2}$ then we can also write

$$\bar{\lambda} = \frac{\hbar}{mc} = \frac{\hbar}{\frac{E}{c^2}c} = \frac{\hbar c}{E} \quad (2)$$

Haug [2] has recently in length discussed and demonstrated how the Compton wavelength likely is the true matter wavelength and how the de Broglie wavelength likely only is a mathematical derivative of this. We ask the reader to go to that paper for in depth discussion on this. Even if not agreeing on this one simply need to understand the formulas just represented are valid.

2 The maximum and minimum temperature and its link to the shortest and longest reduced Compton wavelength

The Planck [3, 4] temperature is given by

$$T_p = \frac{1}{k_b} \sqrt{\frac{\hbar c^5}{G}} = \frac{E_p}{k_b} = \hbar f_p \frac{1}{k_b} = \hbar \frac{c}{l_p} \frac{1}{k_b} \approx 1.42 \times 10^{32} k \quad (3)$$

This means the Planck temperature is the Planck frequency times the Planck constant, which is the Planck energy expressed as a temperature by dividing the Planck energy by the Boltzmann constant. The Planck length is assumed by many physicists [5–8] to be the shortest meaningful length. This also means the Planck frequency is the highest possible frequency and this again indicates the Planck energy is the highest possible energy for a photon: $E_p = m_p c^2 = \hbar \frac{c}{l_p} = \hbar f_p$, where f_p is the Planck frequency. Further since the Planck temperature simply is the Planck energy converted to temperature scale of kelvin by dividing it by the Boltzmann constant this implies that the Planck temperature is likely the highest possible temperature as also suggested by multiple researchers [9], even if some still question whether the maximum temperature could be somewhat lower [10] or somewhat higher [11] than the Planck temperature. It has recently been demonstrated that the Planck length is closely related to gravity as the Planck length and other Planck units can be extracted directly from gravitational observations without knowledge of G or \hbar , see [12, 13].

The reduced Compton wavelength of the Planck energy is

$$\bar{\lambda} = \frac{\hbar}{m_p c} = \frac{\hbar c}{E_p} = l_p \quad (4)$$

If the maximum temperature is linked to the shortest possible reduced Compton wavelength, and considering that the Planck energy is likely the highest localized energy possible, then the lowest possible energy must be linked to the longest possible wavelength in the universe. We assert that the longest possible wavelength is the diameter of the Hubble sphere. This implies that the minimum temperature is related to what we can call the Hubble frequency, and it must be given by:

$$T_{min} = \hbar \frac{c}{2R_H} \frac{1}{k_b} \approx 8.3 \times 10^{-30} k \quad (5)$$

The term $\frac{c}{2R_H}$ can be referred to as the Hubble frequency $f_H \approx 1.09 \times 10^{-18}$ per second. Consequently, the minimum temperature is simply given by $T_{min} = \hbar f_H \frac{1}{k_b}$. This represents the smallest frequency above zero that one can observe, as no wavelength can be longer than the diameter of the universe.

In the Λ -CDM model, the diameter of the universe extends far beyond the Hubble radius R_H due to the assumption of the expansion of space, including accelerated expansion. However, there is a series of alternative cosmological models within the linear $R_H = ct$ category, as illustrated in, for example, [14–18]. Another concept to consider is the idea that the Hubble sphere is a black hole with an event horizon equal to the Hubble radius. In this scenario, no wavelength can clearly be longer than the diameter of the Hubble sphere, or at the very least, the circumference of the Hubble sphere. This imposes a maximum limit on the wavelength of electromagnetic radiation and, consequently, a minimum energy above zero – a sort of energy gap, the lowest even theoretical measurable energy above zero. The notion that the observable universe could be inside a black hole is not a recent idea. It was proposed as early as 1972 by Patheria [19] and later in 1994 by Stuckey [20]. This idea despite being in conflict with the Λ -CDM model continues to be a topic of ongoing discussion, as evidenced by recent publications such as [21–23].

We observe that if we multiply this minimum temperature by $\frac{1}{2\pi}$, it is surprisingly identical to the Hawking temperature [24] when the mass in the Hawking temperature is the critical Friedmann mass $M_c = \frac{c^3}{2GH_0}$:

$$T_{Hw} = \frac{\hbar c^3}{k_b 8\pi G M_c} = \hbar \frac{c}{2R_H} \frac{1}{k_b} \frac{1}{2\pi} = \hbar f_H \frac{1}{k_b} \frac{1}{2\pi} \approx 1.32 \times 10^{-30} k \quad (6)$$

The difference of $\frac{1}{2\pi}$ between the prediction from 5 and the Hawking temperature formula could have multiple reasons. Even if not ideal it is not unnormal to adjust the end result with a factor like 2π , for example Adler et al. [25] had to do so and simply called it a calibration factor. For example, the maximum reduced Compton wavelength could be seen as the circumference of the Hubble sphere instead of the Hubble radius, making the difference simply a factor of 2. There could also be differences due to Hawking radiation being derived from the Schwarzschild metric. Other metrics, such as the recent Haug and Spavieri metric [26], can likely also be used to derive similar temperatures; then there will possibly be small differences from the Hawking temperature. We do not have the final answer as to why there is a small difference of 2π in the formulas so we will like Adler et al for the moment call it a calibration factor.

For now, let's assume that the Hawking temperature and the minimum temperature calculated from this alternative method, based on the Compton wavelength and the Compton frequency, indeed represent the minimum temperatures inside a black hole. This would mean that the Hawking temperature possibly does not solely represent radiation emitted from the black hole, but could instead or at least in addition be the minimum temperature (above zero) that can be observed at any point inside the Hubble sphere.

3 The CMB temperature as a geometric mean related to the maximum and minimum temperature in the Hubble sphere

Mean temperature plays an important role in various fields, including climate science, fluid dynamics, and biophysics [27]. To our knowledge, mean temperatures have not been linked to the CMB temperature, except naturally that the 2.725k can by words be called a type mean temperature in all empty space of the Hubble sphere. To establish a more solid theoretical connection to CMB as a mean temperature, a solid mathematical and physical foundation is necessary. It is not sufficient to simply take the mean of some temperatures and call it the mean temperature; as we will see one must comprehend the Planck temperature, cosmic

temperature, and their relationship to the only variable that differentiates different energy levels—namely, the electromagnetic wavelength. Additionally, we know from mathematics and statistics that various types of means exist.

The geometric mean traces back to the Pythagoreans, who defined the three most commonly used means even of our time—namely, arithmetic mean, geometric mean, and harmonic mean (see [28]). The geometric mean, indicating a central tendency of a finite set of real numbers by using the product of their values, has wide applications across diverse fields, from economics, finance, engineering, nuclear medicine, informatics, ecology, surface and groundwater hydrology, geoscience, geomechanics, machine learning, and chemical engineering, see [29]. The geometric mean is utilized for various applications and challenges also in physics. For instance, Henderson [30] demonstrated the use of geometric mean as useful for problems in gas dynamics, Zhang et al. [31] employed the geometric mean density of states in one-dimensional nonuniform systems, and Yamagami [32] relied on the geometric mean of states and transition amplitudes, see also [33]. The potential role of geometric means in average temperatures should not be surprising. The reason the connection between maximum and minimum temperatures in the Hubble sphere has not been linked to the geometric mean before is likely that it has only recently been understood that the reduced Compton wavelength plays a much more central role in energy, matter, and even gravity than previously thought.

Assume the measured CMB temperature is somehow related to some type of mean value between the maximum and minimum allowed temperature in the Hubble sphere. The longest possible reduced Compton wavelength in the universe, or at least in a $R_H = ct$ universe as well as a black hole Hubble sphere, is the diameter of the Hubble sphere, so we have

$$\bar{\lambda}_{Maximum} = 2R_H. \quad (7)$$

Further the shortest possible reduced Compton wavelength is assumed to be the Planck length so we have

$$\bar{\lambda}_{Minimum} = l_p. \quad (8)$$

The geometric mean of the shortest and longest reduced Compton wavelength is given by

$$\bar{\lambda}_{gm} = \sqrt{\bar{\lambda}_{Maximum}\bar{\lambda}_{Minimum}} = \sqrt{2R_H l_p} \quad (9)$$

we can call this wavelength: $\bar{\lambda}_{gm}$, the geometric mean reduced Compton wavelength of the observable universe. The temperature from this wavelength we find by taking the energy of its frequency and simply divide by the Boltzman constant, it gives

$$T_{gm} = \hbar \frac{c}{\lambda_m} \frac{1}{k_b} = \hbar f_m \frac{1}{k_b} \approx 34.27k \quad (10)$$

If we divide this by a calibration factor of 4π , we obtain the CMB temperature of

$$T_{gm} = \hbar \frac{c}{\lambda_m} \frac{1}{k_b 4\pi} = \hbar f_m \frac{1}{k_b 4\pi} \approx 2.725k \quad (11)$$

Which is close to measured values; see, for example, [34–37] (see also the appendix). We are convinced that this is not simply a coincidence. The CMB temperature seems indeed to simply be related to the geometric mean of the shortest and longest wavelengths, possibly in the observable universe. Since the only thing that differentiates the different energy levels of electromagnetic radiation (a single beam of photons) is the wavelength, an energy that is the geometric mean of the shortest and longest wavelength, expressed as temperature (simply by dividing it by the Boltzmann constant), can be termed the geometric mean temperature. This indicates that the CMB temperature is simply the geometric mean temperature between

the lowest and highest possible temperatures in the Hubble sphere, but through the reduced Compton wavelength of the energies. In our view, this is quite revolutionary, as it also points in the direction that $R_H = ct$ cosmological models as well as black hole cosmological models seem to be supported over the Λ -CDM model, but as we will see also the Λ -CDM should not yet be excluded.

This clearly also seems to be related to recent breakthroughs in the theoretical foundation of the CMB temperature linked to the Planck scale. Tatum et al. [38, 39] proposed the following formula for the CMB temperature in 2015:

$$T_{CMB} = \frac{\hbar c^3}{k_b 8\pi G \sqrt{M_c m_p}} \quad (12)$$

In the Hawking temperature formula, the M in the denominator is simply changed to $\sqrt{M_c m_p}$, where M_c is the critical mass in the Friedmann universe. Tatum et al also re-wrote their formula on the form

$$T_{CMB} = \frac{\hbar c^3}{k_b 4\pi \sqrt{R_h R_{pl}}} \quad (13)$$

Recently, it has been proven that this formula is derivable from the Stefan-Boltzmann law [40]. Furthermore, it has been demonstrated that rewriting this formula to find the Hubble constant and then determining the Hubble constant from published CMB temperature studies dramatically increases the accuracy in predicting the Hubble constant, see [41]. Tatum et al define R_{pl} as the Schwarzschild radius of the Planck mass, so this means $R_{pl} = R_s = \frac{2Gm_p}{c^2} = 2l_p$ which again mean their formula easily also can be re-written as

$$T_{CMB} = \frac{\hbar c^3}{k_b 4\pi \sqrt{2R_h l_p}} = \hbar f_m \frac{1}{k_b} \frac{1}{2\pi} \approx 2.725k \quad (14)$$

Where f_m is the reduced Compton frequency of an energy with a wavelength consisting of the geometric mean wavelength from the lowest and highest possible temperatures in the Hubble sphere. The Tatum et al formula is identical to formula 11 after dividing formula 11 by a calibration factor of 4π . Our methodology in this paper arrives at the same formula starting out from a very different angle: by focusing on the Compton wavelength and Compton frequency in matter and energy and by taking the geometric mean between the maximum and minimum reduced Compton wavelength, we then examine the temperature to which this leads. This provides a new perspective on the Hawking temperature, potentially being the minimum temperature in a black hole and the Planck temperature the maximum temperature and the average temperature inside the black hole simply to be the geometric mean temperature in the way described in detail above

4 Possible mechanisms for why the CMB temperature is linked to the Planck temperature.

Adler, Chen, and Santiago [25] claim that, "In the current standard viewpoint, small black holes are believed to emit black body radiation at the Hawking temperature." This is something we agree on, and Haug [42, 43] has recently indicated, based on quantum gravity theory, that all matter ultimately consists of Planck mass particles popping in and out of existence, lasting only the Planck time. These Planck mass particles have the mathematical properties of micro black holes, and their energy is released into energy. They are likely also related to the predicted quantum fluctuations in vacuum energy, so to say. This provides us with a possible

underlying deeper theory of why the Cosmic Microwave Background (CMB) temperature is related to the Planck temperature.

The Planck temperature, the maximum temperature existing all over in space, is present only in Planck-sized areas of space, popping in and out of existence. Even an electron or proton is enormous in terms of spatial dimensions compared to the radius of a Planck mass particle micro black hole. All our measurements of the CMB are from simply photons radiating from the Planck mass soup vacuum energy popping in and out of existence. Our approach seems fully consistent with a new way to quantize general relativity theory; Einstein's field equation can be re-written as [43]:

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = \frac{8\pi l_p^2}{\hbar c} T_{\mu\nu}. \quad (15)$$

This re-written form of the field equation gives all the same results as before, but it leads for example a re-written Schwarzschild metric of the form

$$\begin{aligned} ds^2 &= - \left(1 - \frac{2GM}{c^2 r}\right) c^2 dt^2 + \left(1 - \frac{2GM}{c^2 r}\right)^{-1} dr^2 + r^2 g\Omega^2 \\ ds^2 &= - \left(1 - \frac{2l_p}{r} \frac{l_p}{\bar{\lambda}_M}\right) c^2 dt^2 + \left(1 - \frac{2l_p}{r} \frac{l_p}{\bar{\lambda}_M}\right)^{-1} dr^2 + r^2 g\Omega^2 \end{aligned} \quad (16)$$

where $\bar{\lambda}_M$ is the reduced Compton wavelength of the mass M , and $g\Omega^2 = (d\theta^2 + \sin^2\theta d\phi^2)$. The term $\frac{l_p}{\bar{\lambda}_M}$ is the reduced Compton frequency per Planck time that represent the quantization of gravity. This new way to rewrite the Schwarzschild metric provides exactly the same predictions as the standard Schwarzschild solution, but it offers a deeper insight, in our view. It shows that gravity is ultimately linked to the Planck scale and establishes a connection between gravitational objects such as the Earth, the Sun, and even the mass or energy of the Hubble sphere and the Planck scale.

Again it is important to be aware that the Planck length can be found from gravity observations without any knowledge of G or even \hbar , see [12]. Already in 1984 Cahill [44, 45] suggested the Planck units could be more fundamental than the gravity constant, he simply solved the Planck mass formula $m_p = \sqrt{\frac{\hbar c}{G}}$ with respect to G and got $G = \frac{\hbar c}{m_p^2}$. However already in 1987 Cohen [46] that did the same pointed correctly out that this just led to a circular problem as no one at that time had demonstrated a way to find Planck units independent of G , so to express G from the Planck units would just lead to a circular problem. This view have been held until recently, see for example the interesting paper by McCulloch [47]. However the recent resolution to this unsolved problem makes it today fully possible to find Planck units from gravity observations with no knowledge off G and \hbar . In our view this means the Planck scale now indirectly has been detected. This also indirectly explains why we surprisingly can predict the the CMB temperature from simply theoretical combined with practical knowledge off the shortest and longest possible wavelength in the Hubble sphere.

Another view more consistent with the Λ -CDM model is that Planck mass particles (black holes) existed only just after the Big Bang, and that these particles evaporated into today's known particles. Lloyd Motz [48–50] was likely the first to suggest the existence of a very fundamental particle with a mass equal to the Planck mass. However, he knew the Planck mass was way too big compared to any observed particles, such as protons and electrons. Motz tried to overcome this challenge by claiming that the Planck mass particles created just after the Big Bang had radiated most of their energy away and that this energy is the origin of the creation of particles such as protons and electrons. Others have suggested a similar idea that there were plenty of Planck mass-type particles just after the Big Bang; see De [51]

but that such super-heavy particles have radiated away most of their energy. One possibility is therefore that the Cosmic Microwave Background (CMB) is somewhat a remnant of that epoch. Only further scrutinizing of the CMB temperature can provide a final conclusion to these answers. What is most important is that both the Stefan-Boltzmann law and this new geometric mean temperature approach essentially lead to the same conclusion and to the formula initially suggested by Tatum et al . The CMB temperature can clearly also be predicted and described theoretically and not only be measured. This theoretical relation unknown to most astrophysics at the time of writing seems to bind the different properties of the observable universe more closely together than before. We think it would be a mistake to reject all the recent years theoretical findings about the CMB temperature, for example, based on that it also having been linked to what would be considered alternative cosmological models.

A third alternative that seems to be possibly consistent with this is that the universe is a black hole where the Hubble horizon has been and is growing at $R_H = ct$, in other words, yet another class of $R_H = ct$ cosmological models. Our new theoretical understanding of the Cosmic Microwave Background (CMB) should naturally be carefully scrutinized by multiple researchers over time to check which cosmological models, as well as quantum gravity models, it best fits in with, or if even our theoretical CMB framework needs modification. However, one should not ignore that already in the current stage, the framework for theoretically predicting CMB has been laid since its initial start in 2015 seems to be extremely accurate at predicting the CMB temperature. It also establishes a close link between CMB temperature, the Hubble constant, and other entities of the universe; see [38, 41].

5 Conclusion

The Planck temperature is likely the maximum possible temperature anywhere in the observable universe, at least if we ignore what may be happening inside black hole singularities. We have also explained how the minimum temperature is linked to energy with a wavelength equal to the Hubble diameter of the Hubble sphere. The Planck temperature is again linked to the shortest possible reduced Compton wavelength the Planck length, and we have demonstrated the minimum temperature can be considered a energy with reduced Compton wavelength equal to the photon wavelength of the diameter of the Hubble sphere. Interestingly and surprisingly, the CMB temperature seems to be related to an energy level that is simply the geometric mean between the minimum and maximum energy levels, or more precisely, to an energy related to the geometric mean of the shortest and longest possible reduced Compton wavelength in the universe. This seems to imply that the Hawking temperature is, in fact, a minimum temperature (above zero) anywhere in the Hubble sphere. Our findings strengthen the support for having a solid theoretical framework for theoretically predicting and understanding the CMB temperature, rather than solely observing it.

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Declarations

Conflict of interest

The author declares no conflict of interest.

Appendix Wien's Law versus Planck's law for getting to the CMB temperature

The CMB temperature has not been measured directly. Instead, it is the radiation frequency that is measured. There is a whole spectrum of radiation frequencies, but the peak frequency can be easily transformed into temperature by utilizing Wien's (approximation) law or the more exact Planck's law. The transformation from the measured peak wavelength to CMB temperature can be achieved by utilizing Wien's law. According to Wien's law, we can determine that

$$b = \frac{hc}{5k_b} \quad (17)$$

and the CMB temperature is then given as

$$T_{CMB} = \frac{b}{\lambda_{peak}} = \frac{hc}{5k_b} \frac{1}{\lambda_{peak}} \quad (18)$$

For a peak wavelength of 1.0634 mm this gives a CMB temperature of $T_{CMB} = 2.706k$

From Planck's-Law we get

$$b = \frac{ch}{k_b(5 + W_0(-5/e^5))} \approx 0.002897773 \quad (19)$$

where W_0 is the Lambert W function. If the peak wavelength is 1.0634 mm this gives a CMB temperature of approximately

$$T_{CMB} = \frac{b}{\lambda_{peak}} \approx 2.725k \quad (20)$$

This mean transforming measured peak wavelength from the CMB spectrum to CMB temperature using Wien's law will underestimate the CMB temperature by approximately 0.019k compared to using the more exact Planck's law.