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► To cite this version:

Espen Gaarder Norwegian University of Life Sciences Haug, Stéphane Wojnow. How to predict the temperature of the CMB directly using the Hubble parameter and the Planck scale using the Stefan-Boltzman law. 2023. hal-04269991

HAL Id: hal-04269991

<https://hal.science/hal-04269991v1>

Preprint submitted on 3 Nov 2023

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How to predict the temperature of the CMB directly using the Hubble parameter and the Planck scale using the Stefan-Boltzman law

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November 3, 2023

Abstract

Based on recent progress in quantum gravity and quantum cosmology we are presenting also a way to estimate the temperature in cosmos, the Hubble sphere, from a relation between the Planck temperature and the Hubble scale. Our analysis predict the Hubble sphere temperature of $2.72k$ with the one standard deviation confidence interval between $2.65k$ and $2.80k$, which correspond well with the measured temperature observed from the cosmic microwave background (CMB) of about $2.72k$. This add evidence to that there is a close connection between the Planck scale, gravity and the cosmological scales as anticipated by Eddington already in 1918.

1 The Hawking temperature of the Hubble sphere

Quantum cosmology has garnered increased attention in recent years, see for example [1–8]. In this paper, we will demonstrate the existence of a link between the Planck temperature and the temperature within the Hubble sphere, which is further corroborated by the measured temperature of the cosmic microwave background.

In this section, we will first establish the mathematical relationship for the Hawking temperature across the entire Hubble sphere in the critical Friedmann universe. Then, in the next section, we will establish the connection between the Hawking temperature and the Planck temperature. By employing the Stefan-Boltzmann [9, 10] law, we will predict the temperature of the Hubble sphere, which we demonstrate to closely align with the measured temperature of the cosmic microwave background (CMB). This means the CMB temperature not only can be measured but predicted from quantum cosmology, something that is rather remarkable in our view.

The Hawking [11] temperature of a black hole is given by:

$$T_{\text{Hw}} = \frac{\hbar c^3}{k_b 8\pi G M}, \quad (1)$$

where M represents the mass of the black hole, k_b is the Boltzmann constant, and G is Newton's gravitational constant and \hbar is the reduced Planck constant also known as the Dirac constant. The Friedmann [12] equation is given by:

$$H_0^2 = \frac{8\pi\rho + \Lambda c^2}{3}, \quad (2)$$

where $\rho = \frac{M}{\frac{4}{3}\pi R_H^3}$, and the Hubble radius $R_H = \frac{c}{H_0}$, where H_0 is the Hubble constant. In the special case where the cosmological constant, Λ , is set to zero, and we then solve the Friedmann equation for mass, we get:

$$M_c = \frac{c^2 R_H}{2G}. \quad (3)$$

This is known as the mass of the critical Friedmann universe. Be aware that when we say 'mass' here, it can be considered equivalent to the mass in the Friedmann model, as it does not distinguish between effects from mass or energy. This means that energy is treated as mass equivalent since we naturally have $M = \frac{E}{c^2}$. We solve (Eq. 3) for R_H , which gives:

$$R_H = \frac{2GM_c}{c^2}. \quad (4)$$

This means the Hubble radius is mathematically identical to the Schwarzschild [13] radius of a black hole with a mass equal to the critical mass of the Hubble sphere. Patheria [14] and Stuckey [15] has even suggested that we possibly live inside a black hole, a controversial idea discussed even in recent literature [16–18]. We will not delve into a discussion about whether we could live inside a black hole or not, but we will focus on the mathematics and demonstrate that, starting from the critical Friedmann universe, we can surprisingly predict the correct temperature of the cosmic microwave background, in full alignment with observations, we will later discuss also why this can be.

Let us now input the critical mass of the Hubble sphere into the Hawking temperature formula. This gives:

$$T_{\text{HW}} = \frac{\hbar c^3}{k_b 8\pi G M_c} = \frac{\hbar c^3}{k_b 8\pi G \frac{c^3}{2GH_0}} = \frac{\hbar H_0}{k_b 4\pi} \approx 1.38 \times 10^{-30} k. \quad (5)$$

However, it's important to note that this temperature has never been observed. Nevertheless, if we take this literally, this is the radiation emitted from the Hubble sphere. As energy flows out of the Hubble sphere, there should also be a possibility to predict what this means for inside the Hubble sphere. This is what we aim to explore in the next section.

2 The Hubble sphere and its temperature derived from the Planck temperature

Planck mass particles have been suggested by multiple authors to possibly be the most fundamental particles in the universe; see, for example, Motz [19] and Haug [20]. It is also assumed that the Planck scale somehow will play a central role in quantum gravity. Einstein [21] already in 1916 suggested that the next step in gravity theory would be a unified quantum gravity theory, something he worked on much of the rest of his life, but unfortunately

without a big break through. Eddington [22] in 1918 was likely the first to suggest that such a quantum gravity theory had to be somehow linked to the Planck scale through the Planck length. Most researchers working on quantum gravity today seem to be of the opinion that the Planck scale will play an important role in such a theory; see, for example, [23–25].

It is worth noting that as early as 1987, Cohen [26] pointed out that it would likely be impossible to find the Planck length independent of deriving it from G , c , and \hbar . This view was held until at least 2016, as seen in the interesting paper by McCulloch [27]. However, in recent years, it has been demonstrated that we can find the Planck length independent of any knowledge of G or \hbar ; see [28, 29]. It has also been shown that the Planck length can be derived from cosmological redshift without knowledge of G or \hbar ; see [30]. Haug [31] has additionally recently demonstrated that a series of cosmological phenomena and entities, such as the critical mass of the universe divided by the Hubble radius, is identical to the Planck mass divided by twice the Planck length. Furthermore, the Hubble constant can be expressed as $H_0 = \frac{\bar{\lambda}_c c}{l_p^2}$, where $\bar{\lambda}_c$ is the reduced Compton wavelength of the critical mass of the universe. The reduced Compton wavelength of the critical mass in the universe can also be found without knowledge of the kilogram of the critical mass or the Planck constant; see [30].

If there is indeed a link between the Planck scale and the cosmic scale, then one could expect, or at least hope, that other observed phenomena of the cosmos, such as the cosmic microwave background temperature, possibly also have a link to the Planck scale. In this section, we will demonstrate that we can indeed predict the CMB temperature of about 2.72 Kelvin from the Planck temperature when utilizing a combination of the Hawking temperature with the Stefan-Boltzmann law.

The luminosity of the Hubble sphere according to the Stefan-Boltzmann law must be given by

$$L_H = 4\pi R_H^2 \sigma T_H^4 \quad (6)$$

where T_H is what we will call the Hubble sphere Temperature. Next, we will utilize the idea that the most elementary of all particles are likely Planck mass particles. The Planck mass is normally considered to have a mass of $m_p = \sqrt{\frac{\hbar c}{G}} \approx 2.17 \times 10^{-8}$ kg. This is much higher than any known atom. However, Haug [20] has recently suggested that the Planck mass particle only lasts the Planck time and that the particle then has a mass of $m_p t_p \approx 1.17 \times 10^{-51}$ if observed over a second, which corresponds well with a survey of existing and proposed classical and quantum approaches to the photon mass, as seen in Spavieri et al [32]. Only if observed inside the Planck time window the mass is the Planck mass, that is this mass is special as it is observer window time dependent as discussed in [33]. Going into depth about the different views on the potential photon mass is outside the scope of this article; we mention this to avoid any automatic rejection of the idea that the Planck mass particle can be the most elementary particle in the universe. It could actually be linked to photons. Even if photons are assumed to be massless, it could be that photons acquire this mass during collisions with other photons. It is well known within the standard literature that photon-photon collisions likely give rise to mass, as shown in, for example, Pike et al. [34]. For the moment simply assume there is a Planck mass particle playing a central role in the universe and possibly as the ultimate building block of all matter.

The energy passing through a sphere with a radius equal to the Planck length is given by:

$$E = \frac{L_H}{4\pi l_p^2}. \quad (7)$$

The radiant flux absorbed by the Planck sphere's cross-section πr^2 is thus expressed as:

$$\Phi_{abs} = \pi l_p^2 E = \pi l_p^2 \frac{L_H}{4\pi l_p^2} = \pi l_p^2 \frac{4\pi R_H^2 \sigma T_H^4}{4\pi l_p^2} = \frac{\pi}{4} R_H^2 \sigma T_H^4. \quad (8)$$

The Planck temperature, as given by Max Planck [35, 36], is $T_p = \frac{1}{k_b} \sqrt{\frac{\hbar c^5}{G}} = \frac{m_p c^2}{k_b} = \frac{\hbar c}{l_p k_b}$. Furthermore, the Hawking temperature of a Planck mass is determined by Hawking radiation and is given by:

$$T_{Hw,p} = \frac{\hbar g}{2\pi c k_b}. \quad (9)$$

The acceleration at the Planck mass at the Schwarzschild radius of the Planck mass is $g = \frac{Gm_p}{r_s^2} = \frac{Gm_p}{(2l_p)^2}$, which leads to:

$$T_{Hw,p} = \frac{\hbar g}{2\pi c k_b} = \frac{\hbar \frac{Gm_p}{r_s^2}}{2\pi c k_b} = \frac{\hbar c}{8\pi l_p k_b} = \frac{T_p}{8\pi}. \quad (10)$$

This is also identical to: $\frac{\hbar c^3}{8\pi G m_p k_b} = \frac{T_p}{8\pi}$. The same result can be obtained from the Unruh [37] temperature when applied to a Planck mass particle:

$$T_{Unn,p} = \frac{\hbar a}{2\pi c k_b} = \frac{\hbar \frac{c^2}{4l_p}}{2\pi c k_b} = \frac{\hbar c}{8\pi l_p k_b} = \frac{T_p}{8\pi}. \quad (11)$$

Since the Stefan–Boltzmann law involves a fourth power, it has a stabilizing effect on the exchange, and the flux emitted by Planck particles (Planck spheres) should be approximately equal to the flux absorbed, especially close to the steady state, where we have:

$$4\pi l_p^2 \sigma T_{Hwp}^4 = \pi l_p^2 E = \pi l_p^2 \frac{4\pi R_H^2 \sigma T_H^4}{4\pi l_p^2} = \pi R_H^2 \sigma T_H^4. \quad (12)$$

This gives:

$$\begin{aligned} T_{Hwp}^4 &= T_H^4 \frac{R_H^2}{4l_p^2} \\ T_{Hwp} &= T_H \sqrt{\frac{R_H}{2l_p}} \end{aligned} \quad (13)$$

and

$$\begin{aligned} T_H &= T_{Hwp} \sqrt{\frac{2l_p}{R_H}} \\ T_H &= \frac{T_p}{8\pi} \sqrt{\frac{2l_p}{R_H}} \approx 2.72k. \end{aligned} \quad (14)$$

As there is considerable uncertainty in both the Hubble constant, considerable effort has been put into measuring it as accurately as possible. See, for example, [38–45]. If we use the recent Hubble constant value given by Kelly et al. [46] of $66.6_{-3.3}^{+4.1}$ (km/s)/ Mpc (see also [47, 48]), we get a predicted Hubble temperature using (Eq. 14) to be $2.72k$ with a one standard deviation confidence interval of $2.65k$ to $2.8k$. This is well in line with the measured cosmic microwave background temperature. For example, Fixsen [49] used

the Wilkinson Microwave Anisotropy Probe data to obtain a cosmic microwave background (CMB) temperature of $2.7260 \pm 0.0013k$. Similarly, in a recent 2023 study, Dahl et al. [50] found a CMB temperature of $2.725007 \pm 0.000024k$ (see also [51]).

However, the Hubble tension [45, 52], which implies an unexplained difference in the Hubble constant when inferred from local measurements and when inferred from the cosmic microwave background (CMB), suggests that there may be a larger uncertainty in the CMB temperature than indicated in the studies just referenced. An important point could be that the black body is at a distance from the CMB. Our new approach here could potentially open up new avenues for investigating the cause of the Hubble tension, as our approach appears to directly link the Hubble constant to the Planck temperature and the cosmic microwave background. However, this is beyond the scope of this paper, but we mention it because we believe it's important to remain open to possible adjustments in the standard cosmological model as we make progress in understanding the cosmos and its connections to the Planck scale.

We have utilized the critical universe solution (The Friedmann equation when the cosmological constant is set equal to zero), so it represent the universe before taking into account accelerating expansion. The Λ -CDM model features a positive cosmological constant due to accelerating expansion that are assumed caused by dark energy, prompting us to inquire about how our model appears to predict the temperature of the cosmic microwave background so precisely. The reason for this may be that the temperature measured thus far for the cosmic microwave background (CMB) is more closely related to the early universe as discussed by for example by [53–55]. Alternatively, it could indicate a shift toward a new cosmology. However, further investigation by multiple researchers over time will be required to confirm this.

Interestingly, we can apply a similar law between the Hawking temperature of the Hubble sphere and the Hubble temperature, we get:

$$T_H = T_{Hw} \sqrt{\frac{R_H}{2l_p}} \approx 2.72k. \quad (15)$$

This means we also we have:

$$T_H = T_{Hw} \sqrt{\frac{R_H}{2l_p}} = \frac{T_p}{8\pi} \sqrt{\frac{2l_p}{R_H}} \approx 2.72k. \quad (16)$$

Tatum et al. [56] has independently suggested that the Hawking temperature can be used to find the Hubble temperature by providing the formula:

$$T_H = \frac{\hbar c^3}{k_b 8\pi G \sqrt{M_c m_p}}. \quad (17)$$

That is, they has altered the M in the denominator to $\sqrt{M_c m_p}$ in the Hawking temperature formula. From a deeper analysis, we can see that his formula is identical to (Eq. 16), as we have:

$$T_H = T_{Hw} \sqrt{\frac{R_H}{2l_p}} = T_{Hw} \sqrt{\frac{\frac{2GM_c}{c^2}}{\frac{2Gm_p}{c^2}}} = T_{Hw} \sqrt{\frac{M_c}{m_p}} = \frac{\hbar c^3}{k_b 8\pi G M_c} \sqrt{\frac{M_c}{m_p}} = \frac{\hbar c^3}{k_b 8\pi G \sqrt{M_c m_p}}. \quad (18)$$

However it is important to notice also that there was no independent way to find the Planck mass independent off G when they published this in 2015, this means they not could

have used or result (for predictions) we soon will show (Eq. 20) that likely can be seen as the true depth of quantum cosmology in relation to the CMB temperature. It is first in recent years been demonstrated how to find the Planck units totally independent on knowledge off G and \hbar , see [28, 29].

This means that the formula initially somehow speculatively suggested by Tatum et al. is fully consistent with our more formal analysis where the formula is derived based on the Stefan-Boltzmann law. Many ideas in physics began somewhat ad hoc and speculatively before being fully formalized mathematically and rooted in physical ‘laws’. For example, FitzGerald [57] merely described length contraction in words and stated it as a possible explanation for the null result in the Michelson and Morley experiment [58]. Later, Lorentz [59] formalized length contraction in his transformations, and naturally, Einstein [60] further naturally improved the theory of relativity.

Haug [28] has demonstrated that the Schwarzschild radius from a deeper perspective is always identical to $r_s = 2l_p \frac{l_p}{\lambda}$. Furthermore, since the Hubble constant always equals $H_0 = \frac{\bar{\lambda}_c c}{2l_p^2}$, and the Hubble radius is equal to $R_H = \frac{c}{H_0}$, we must also have $R_H = 2l_p \frac{l_p}{\bar{\lambda}_c}$, where $\bar{\lambda}_c$ is the reduced Compton wavelength of the critical universe mass. This means we can also express the Hubble temperature as:

$$T_H = \frac{T_p}{8\pi} \sqrt{\frac{2l_p}{R_H}} = \frac{T_p}{8\pi} \sqrt{\frac{\bar{\lambda}_c}{2l_p}} \approx 2.72k. \quad (19)$$

Further since the Planck temperature is given as $T_p = \hbar \frac{c}{l_p} \frac{1}{k_b}$, we can also re-write this as:

$$T_H = \frac{T_p}{8\pi} \sqrt{\frac{2l_p}{R_H}} = \frac{1}{k_b} \hbar \frac{c}{8\pi l_p} \sqrt{\frac{\bar{\lambda}_c}{2l_p}} \approx 2.72k. \quad (20)$$

Again, both the Planck length and the reduced Compton wavelength of the critical mass of the universe can be found independently of G and c . Equation (20) can be seen as the deepest quantum form describing the CMB temperature, it is only dependent on the Planck constant, the Planck length and the reduced Compton wavelength, all related to the quantum scale of the world.

That there is a link to the Planck scale even for cosmological observable phenomena also seems to be in line with a recent but simple Planck quantization of Einstein’s field equation (see [61]):

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = \frac{8\pi l_p^2}{\hbar c} T_{\mu\nu}. \quad (21)$$

This rewritten field equation is simply the deeper level of Einstein’s field equation as it gives all the same predictions as Einstein’s original field equation, but delving into it further is outside the scope of this paper. This paper was simply to demonstrate that there is also a connection between the Planck temperature and the temperature in the Hubble sphere, which again corresponds very well to the measured CMB temperature.

3 Conclusion

We have demonstrated a close connection between the Planck temperature and the Hubble sphere temperature. By combining the Planck temperature with the Stefan-Boltzmann law and insights from the Hawking or Unruh temperature, we can predict the temperature within

the Hubble sphere to fall between $2.65k$ and $2.8k$ with a 68.3% confidence interval. This prediction is based on the Hubble constant, which is reported as $66.6_{-3.3}^{+4.1}$ (km/s)/ Mpc in a recent study by Kelly et al. [46].

Our finding, which suggests that the Hubble sphere temperature can be predicted from the Planck temperature, aligns with recent advancements in quantum gravity and quantum cosmology. These developments provide additional evidence that gravity, at a deeper level, is intricately linked to the Planck scale as foreseen by Eddington already in 1918.

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Declarations

Conflict of interest

The authors declares no conflict of interest.

Authors' contributions

Both authors contributed to the research writing and review of the manuscript.

Availability of data and materials

The study contains no new data.