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► **To cite this version:**

Espen Gaarder Haug, Eugene Tatum. CMB temperature related to cosmological red-shift. 2024. hal-04368837v1

HAL Id: hal-04368837

<https://hal.science/hal-04368837v1>

Preprint submitted on 1 Jan 2024 (v1), last revised 16 Feb 2024 (v3)

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CMB temperature related to cosmological red-shift

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January 1, 2024

Abstract

We will demonstrate that the formula proposed by Tatum et al. to predict the Cosmic Microwave Background (CMB) temperature: $T_0 = \frac{\hbar c}{4\pi\sqrt{R_H}2l_p}$ in relation to observed (and theoretical) redshift fits the well-known formula $T_t = T_0(1+z)^\beta$, only when we have $\beta = 0$ or $\beta = \frac{1}{2}$. However, if one chooses $\beta = 0$, it seems to imply that one must also accept the scaling $z = \frac{\sqrt{R_H}}{\sqrt{R_t}} - 1 = \frac{T_t}{T_0} - 1$. On the other hand, if one chooses $\beta = \frac{1}{2}$, then it allows for the scaling $z = \frac{R_H}{R_t} - 1 = \frac{T_t^2}{T_0^2} - 1$. Only careful further empirical and theoretical studies can likely clarify whether it is best to set $\beta = 0$ or $\beta = \frac{1}{2}$, especially as one should investigate this for different $R_H = ct$ models, particularly those related to growing black hole models. Additionally, it is important to consider the compatibility of these models with the Λ -CDM model.

Keywords: Cosmological red-shift, z , CMB temperature.

1 The CMB temperature prediction formula

Tatum et al. [1, 2] presented the following formula for the Cosmic Microwave Background (CMB) temperature in 2015:

$$T_{CMB,0} = \frac{\hbar c^3}{k_b 8\pi G \sqrt{M_H m_p}} = \frac{\hbar c}{k_b 4\pi \sqrt{R_H} 2l_p} \approx 2.72_{-0.069}^{+0.082}, \text{ k} \quad (1)$$

when using the current Hubble constant value given by Kelly and et. al [3] of $66.6_{-3.3}^{+4.1}$ (km/s)/Mpc. Symbols m_p and l_p are respectively the Planck [4, 5] mass and the Planck length, k_b is the Boltzmann constant, \hbar is the reduced Planck constant and G is Newton's gravitational constant. M_H and R_H represent the current Hubble mass and current Hubble radius, respectively. The current value $R_H = \frac{c}{H_t}$ one can get by using the current CMB-determined Hubble constant H_0 , and the current mass inside the Hubble sphere of the model we will describe is the Friedmann critical mass $M_H = \frac{c^2 R_H}{2G}$; see [1] for more in-depth discussion. This formula is quite similar to Hawking's [6, 7] temperature formula: $T_{Hw} = \frac{\hbar c}{k_b 8\pi G M}$, except that one

replaces M with $\sqrt{M_H m_p}$. Despite its likely great potential significance, this formula has received little attention from the wider astrophysics community. The likely reasons are that it has not been published in one of the more prestigious established journals, and secondly, until recently, there have been no papers providing strong mathematical or other proofs of its foundation.

However, recently, Haug and Wojnow [8] have shown that formula (1) can be derived from the Stefan-Boltzmann [9, 10] law. Furthermore, Haug and Tatum [11] have derived the same formula from a geometric-mathematical approach, demonstrating its consistency with a geometric mean temperature between the lowest and highest possible current temperatures in the Hubble sphere. All of these approaches seem to create a consistent and interesting framework, particularly in line with growing black hole models such as the FSC Schwarzschild metric model, but likely also other growing black hole models that can be built around other metrics, such as the Kerr [12], Kerr-Newman [13, 14] or the recent Haug-Spavieri [15] metric.

An actively discussed class of cosmological models, in comparison to the Λ -CDM model, is the so-called $R_H = ct$ models. See, for example, [16–22]. The FSC model, originating with the referenced Tatum et al. 2015 paper, falls within the category of growing black hole $R_H = ct$ models, which is a subclass of $R_H = ct$ models. Thus, there is also thermodynamics related to the current and past CMB temperature in this cosmological model. A generalized version of formula (1) can be:

$$T_t = T_{CMB}(t) = \frac{\hbar c}{k_b 4\pi \sqrt{R_t 2l_p}} \quad (2)$$

where R_t is the black hole radius at any stage in the growing black hole universe. In this model the universe starts out with a Planck mass Schwarzschild radius of $R_s = \frac{2Gm_p}{c^2} = 2l_p$ and then expands one Planck length in radius per Planck time. Thus, one can also say that it increases by one-half a Planck mass per Planck time.

2 Cosmological red-shift from CMB temperatures

In general, for many cosmological models, we have:

$$z = \frac{R(t_0)}{R(t)} - 1 \quad (3)$$

where $R(t)$ is the scale factor dependent on the cosmological model, and t_0 is the reference time, which is now. In the Λ -CDM model, light is red-shifted based on the idea of the expansion of space and cosmic time. The redshifted wavelength can be treated as stretching as space-time expands. In $R_H = ct$ models, there is expansion of space and space-time corresponding to a constant horizon speed of light c . In such models, one can possibly also mathematically treat the redshift as a relativistic Doppler redshift in a pre-existing space, as outlined in reference [1]. In the FSC Tatum et al. model, we have $R_0 = R(t_0) = \frac{c}{H_0} = R_H$, which is simply the Hubble radius $R_H = \frac{c}{H_0}$ at present. The Hubble radius is the distance light has traveled since the beginning of the black hole universe, which in the FSC model started as a Planck mass black hole and today is the Hubble sphere with mass equal to the mass in the critical Friedmann [23] universe $M_H = M_c = \frac{c^2 R_H}{2G}$.

This means that, in $R_H = ct$ cosmological models, and particularly growing black hole models, we can have:

$$1 + z = \frac{a_{\text{now}}}{a_{\text{then}}} = \frac{R_H}{R_t} = \frac{\left(\frac{\hbar c}{k_b 4\pi \sqrt{R_t 2l_p}}\right)^2}{\left(\frac{\hbar c}{k_b 4\pi \sqrt{R_H 2l_p}}\right)^2} = \frac{T_t^2}{T_0^2} \quad (4)$$

where $R_H = \frac{c}{H_0}$ and $R_t = \frac{c}{H_t}$. Alternatively, we could write this as:

$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}} = \frac{R_H - R_t}{R_t} = \frac{R_H}{R_t} - 1 = \frac{\left(\frac{\hbar c}{k_b 4\pi \sqrt{R_t 2l_p}}\right)^2}{\left(\frac{\hbar c}{k_b 4\pi \sqrt{R_H 2l_p}}\right)^2} - 1 = \frac{T_t^2}{T_0^2} - 1 \quad (5)$$

Solving for T_t gives:

$$T_t = T_0(1 + z)^\beta = T_0(1 + z)^{\frac{1}{2}} \quad (6)$$

In the current paper we provide some detail about its derivation and additional discussion. Tatum and Seshavatharam have been aware that the formula $T_t = T_0(1 + z)$ is also likely valid, and have used it in a recent paper [24]. But then this has some potential implications, as discussed in the section below.

3 Comparison of $T_t = T_0\sqrt{1 + z}$ versus $T_t = T_0(1 + z)$

The Λ -CDM model has, for many years, been using the following redshift formula:

$$T_t = T_0(1 + z) \quad (7)$$

As there has been considerable uncertainty as to whether this really is the best model of CMB temperature versus cosmological red shift z , Lima et al. [25] in 2000 suggested the following generalization of the formula:

$$T_t = T_0(1 + z)^{1-\beta} \quad (8)$$

where β is an unknown constant that, if set to zero, yields the standard formula $T_t = T_0(1 + z)$; however, it has also been suggested that β can be other than zero. Chluba [26] has suggested that: *“decay of vacuum energy leads to ‘adiabatic’ photon production (or destruction), such that the CMB temperature scales like $T_t = T_0(1 + z)^{1-\beta}$.”*

Research based on observations suggests that β should be close to zero. For example, see [27]. However, this is still uncertain, as measuring CMB temperatures at high redshifts (z) is subject to significant uncertainties. Additionally, measuring cosmological redshift can be challenging because there are no direct observations of the emitted photons; we can only observe the received photons. This means that cosmological redshift is always seen through the lens of a mathematical model, and it is never entirely free of assumptions. On the other hand, measuring phenomena such as Doppler redshift or gravitational redshift on Earth provides much better control because we can directly compare the wavelengths of the emitted and received photons with minimal reliance on model assumptions. We mention this because one can then easily imagine how much more difficult it must be to know the exact cosmological redshift, as one can never have a direct observation of the emitted photon wavelength. Based on knowledge of ‘standardized’ objects as well as decades of impressive research in cosmology, one can make an educated guess; nevertheless, there could still remain some uncertainties.

If we set $\beta = 0$ then we can “only”¹ make $T_t = T_0(1 + z)$ compatible with CMB equations (1) and (2) in the following manner:

$$z = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} = \frac{\sqrt{R_H} - \sqrt{R_t}}{\sqrt{R_t}} = \frac{\sqrt{R_H}}{\sqrt{R_t}} - 1 = \frac{\left(\frac{hc}{k_b 4\pi \sqrt{R_t} 2l_p}\right)}{\left(\frac{hc}{k_b 4\pi \sqrt{R_H} 2l_p}\right)} - 1 = \frac{T_t}{T_0} - 1 \quad (9)$$

In that case $T_t = T_0(1 + z)$ would give the same result as in the previous sections, except we now also must have $z = \frac{\sqrt{R_H}}{\sqrt{R_t}} - 1$ which is an alternative possibility that should be carefully investigated, as this potentially could have an impact on how one interprets the need for space expansion in accordance with the Λ -CDM and $R_H = ct$ models.

Riechers et al. [27] have reported the Cosmic Microwave Background (CMB) temperature from the cosmic epoch at $z = 6.34$, resulting in a temperature range of $16.4 - 30.2K$ within one standard deviation uncertainty. In other words, even the one standard deviation, which represents only about 68% probability for the CMB temperature to be inside that range, is very wide. The two standard deviation CMB temperature range is much broader. Therefore, we can conclude that the formula $T_t = T_0(1 + z)$ is not sufficiently well-tested, given the very large uncertainty. The formula $T_t = T_0\sqrt{1 - z}$ predicts a CMB temperature of $T_t = 2.725K\sqrt{1 - 6.34} \approx 7.4K$ which is well inside the 95% confidence interval of the above report (using two standard deviations); however, as we have also shown, the FSC framework at present also appears to be consistent with $T_t = T_0(1 + z)$. Only further investigation can help us to decide on the optimal choice, even if observations appear to currently favor $\beta = 0$.

4 Conclusion

In the context of growing black hole cosmology models such as $R_H = ct$, we now have a robust theoretical framework for predicting the Cosmic Microwave Background (CMB) temperature, using a known Hubble constant value [8], or vice versa [1]. This can be done both for the present and past cosmic epochs (presumably), as well as in relation to cosmological redshifts. This framework initially emerged from the FSC cosmological model proposed by Tatum et al. However, it is worth exploring whether it can also be applied to other black hole $R_H = ct$ models. The theory appears to be compatible with the relationship $T_t = T_0(1 + z)^\beta$, but only when $\beta = 0$ or $\beta = \frac{1}{2}$. Further theoretical and observational studies are needed in order to reach a final consensus. This may even require gaining a new perspective on understanding and investigating cosmological redshift. At this stage, we can acknowledge that tremendous progress has been made in cosmology and in understanding the CMB temperature. Nevertheless, there is still much to be discovered.

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¹There could naturally be additional methods not discovered here, for example based on new cosmology or other metrics.

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Declarations

Conflict of interest

The authors declare no conflict of interest.