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How current CMB temperature related to cosmological redshift can be extracted from observations of 580 type Ia supernovae

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Abstract

We will demonstrate that the formula proposed by Tatum et al. for the Cosmic Microwave Background (CMB) temperature: $T_0 = \frac{hc}{4\pi\sqrt{R_H}2lp}$ 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 redshift scaling of: $z = \frac{\sqrt{R_H}}{\sqrt{R_t}} - 1 = \frac{T_t}{T_0} - 1$. 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.

Most importantly, we demonstrate how a rigorous mathematical approach can be used to extract a current CMB temperature of $2.726 \pm_{0.074}^{0.072} K$ from the 580 type Ia supernova data points in the Union2 database. Using redshift formula $z = \frac{\sqrt{R_H}}{\sqrt{R_t}} - 1$ incorporated into our new “CMB redshift prediction formula,” we find that the above current CMB temperature value is a remarkably good match for this particular data set. We therefore predict the likelihood that this approach and the above current CMB temperature value will also produce a best fit with future observed type Ia supernova redshifts. If so, we think that there are also obvious implications for the optimal value of a CMB-derived Hubble constant. If all goes well, perhaps sometime in the not-too-distant future, cosmologists will treat the above CMB temperature method as a “gold standard” for future applications.

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

1 The CMB temperature prediction formula

Tatum et al. [1] 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 et. al [2] of $66.6_{-3.3}^{+4.1} \text{ km/s/Mpc}$. Symbols m_p and l_p are respectively the Planck mass and the Planck length [3, 4], 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 as 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 [5, 6] temperature formula: $T_{Hw} = \frac{\hbar c^3}{k_b 8\pi G M}$, 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 [7, 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:

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

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 Extracting the current CMB temperature from 580 type Ia supernovae

Here we use the observed redshifts from 580 supernova data points in the Union2 database to determine the current CMB temperature ($z = 0$). The methodology employed is as follows: from the cosmological redshifts, we first predict the CMB temperatures for each observed z value, by using the standard and well-known relation $T_t = T_0(1 + z)$. Since our goal is to find T_0 a priori, we start with a wild guess. For instance, we might start with $T_0 = 4K$, or even $T_0 = 10K$, which is naturally far off from the currently observed CMB temperature of

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

approximately $2.72K$. We start with a wild guess because we will later use optimization to determine if there exists a T_0 that leads to an estimation error near zero, using the redshift prediction formula $z = \sqrt{\frac{R_h}{R_t}} - 1$. This can be achieved using optimization algorithms such as Newton-Raphson or the bisection method.

Next, we calculate the radius of the Hubble sphere going back in time for each z value. This is done by assuming a FSC-like $R_h = ct$ cosmology and solving Eq. (2) for R_t . This gives:

$$R_t = \left(\frac{\hbar c}{T_t k_b 4\pi} \right)^2 \frac{1}{2l_p} \quad (10)$$

and since we also have $T_t = T_0(1+z)$ we can replace T_t with this and get:

$$R_t = \left(\frac{\hbar c}{T_0(1+z)k_b 4\pi} \right)^2 \frac{1}{2l_p} \quad (11)$$

Because we are assuming that we do not know T_0 , we will not rely upon measured CMB temperatures. However we can now input this expression for R_t into our red-shift formula (Eq. 9) and we get:

$$z_{pre} = \sqrt{\frac{R_h}{R_t}} - 1 = \sqrt{\frac{R_h}{\left(\frac{\hbar c}{T_0(1+z_{obs})k_b 4\pi} \right)^2 \frac{1}{2l_p}}} - 1 \quad (12)$$

We can now minimize the errors between z_{pred} and z_{obs} by adjusting the unknown T_0 value. This can be accomplished through pure trial-and-error, or more efficiently by using “intelligent” trial-and-error systems such as the Newton-Raphson method or the bisection method. The results from these approaches are the same, except that, by naive trial-and-error, one will waste more time finding the optimal CMB temperature. To do this, we also need $R_h = \frac{c}{H_0}$, which is the current Hubble radius, and therefore, we also need the current value of H_0 , which we take from the very recent study of Sneppen et. al [28], $H_0 = 67 \pm 3.6 \text{ km/s/Mpc}$. Thus, H_0 affects the value; it is actually this relatively new theoretical relationship between H_0 and CMB, first implied by Tatum et al. [1] in 2015 and later proved to be derivable from the Stefan-Boltzmann law [7, 8], that makes this method possible.

Figure 1 illustrates the trial-and-error procedure. Assume that we initially have guessed a CMB temperature of $4K$. This is the green line in the figure, that we see is far above the observed redshift represented by the blue line. However, at least it looks like it correlates well. Still, the $4K$ prediction is way off. Given that the redshift predictions are proportional to the current CMB temperature, we must guess a lower CMB temperature. Assume that we now guess $T_0 = 1.5K$, we then get the predictions presented by the purple line. It becomes obvious that our $1.5K$ prediction is now too low compared to the observed redshifts. We now know that the CMB temperature needed in order to minimize the prediction errors must be between $4K$ and $1.5K$. We, therefore, now guess $3K$, and the redshift predictions we get from this are much closer to observed, but still too high.

We can continue ‘manually’ like this, or we can resort to efficient search algorithms that are used for similar statistical problems in many scientific fields. Among the most commonly used algorithms are the Newton-Raphson algorithm or the bisection method. One can also use the goal seek function in Excel, which is likely based on the bisection method. These trial-and-error methods are simply a form of calibration method. The question is whether there exists a single CMB temperature, denoted as T_0 , for the current epoch of the cosmos that can make our “CMB redshift prediction formula” match the observed redshifts with precision.

Effectively, we are calibrating our new cosmological redshift prediction equation relative to the observed 580 supernova redshifts by finding what value of T_0 minimizes our prediction error. Only one parameter is adjusted (optimized), namely the “unknown” current CMB temperature, so that the errors between the sum of $\sum_i^n (z_{pred,i} - z_{obs,i})$ are minimized. This approach results in a predicted CMB temperature $T_0 \approx 2.726219274$ K from the 580 supernova observations in the Union2 database. We are not claiming that the current CMB temperature is exactly this (although it could be); rather, this is what it appears to be, based on the observed supernova redshifts in combination with the $H_0 = 67$ km/s/Mpc.

When we also take into account the uncertainty in the value of H_0 (67 ± 3.6 km/s/Mpc), as reported in the study of Sneppen et. al, we get a one standard deviation (STD) confidence interval of 2.652 K to 2.798 K for the current CMB temperature.

As different Hubble constant measurement studies and methods yield considerable uncertainty in H_0 , this uncertainty could be even larger. Moreover, there is the unexplained Hubble tension; see for example [29–32]. However, we do not attempt to solve the Hubble tension in this paper, although it cannot be excluded that the improved theoretical understanding of the relationship between the Hubble constant, CMB temperature, and cosmological redshift utilized herein might also provide valuable insights into that issue. Nevertheless, using our new theoretical and radically-different approach, we can closely approximate the recent CMB temperature observations [33–36].

The predictions from Eq (12) are now perfectly aligned with the observational blue line in Figure 1. That is, the redshift formula we have presented is perfectly capable of matching observed cosmological redshifts.

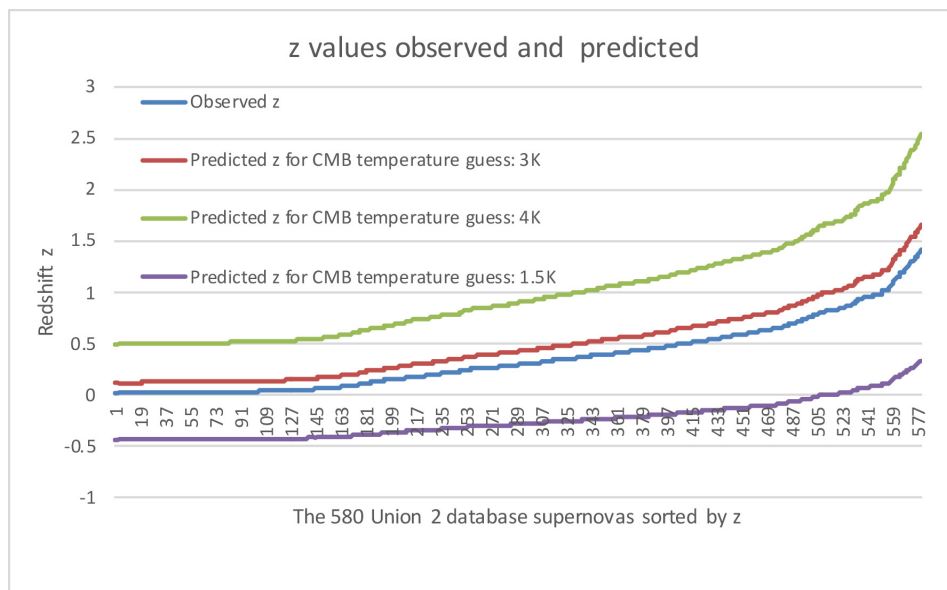


Figure 1: This figure shows observed redshift values from 580 type Ia supernovae, sorted by redshift. In addition, it shows the predicted redshifts for various qualified guesses on the current CMB temperature. We note that the predictions and observations are highly correlated, but they do not match. The predicted redshifts are too high when using CMB temperatures 4K and 3K and too low when using 1.5K. However, by using efficient trial-and-error algorithms, we can quickly find the current CMB temperature that gives the best fit, as shown in the next figure.

It is interesting that, by incorporating only the current CMB temperature, our redshift prediction function can perfectly match observations. It is important to note that we are

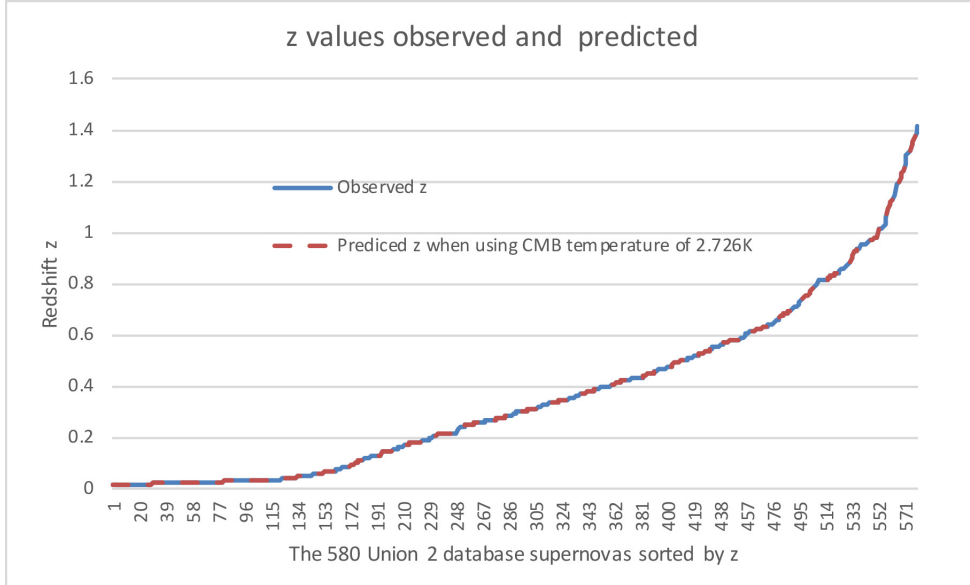


Figure 2: This figure shows observed redshift values from 580 type Ia supernovae, sorted by redshift, and assuming a current CMB temperature of $2.726K$. There is a match between observed and predicted redshifts for this particular CMB temperature.

using the same T_0 for all supernovae, rather than different T_0 values for different supernovae. This basically demonstrates that our framework is consistent and robust. It is fully consistent with the empirically-tested relation $T_t = T_0(1+z)$ and also with $R_h = ct$ cosmology. It is our recommendation that the astrophysics community pay attention to this and investigate to what degree it is or is not consistent with the Λ -CDM model. Could it be that the Λ -CDM model needs further adjustments? Or could it be that $R_h = ct$ models are actually more realistic in some respects? Only further research can settle these questions. In either case, researchers should be made aware of the recent progress in our theoretical understanding of CMB temperature and its relationship to cosmological redshift and the Hubble constant.

5 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 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 $\beta = \frac{1}{2}$. This may even require gaining a new perspective on understanding and investigating cosmological redshift. Further theoretical and observational studies are needed in order to reach a final consensus. At this stage, we can acknowledge that tremendous recent progress has been made in cosmology with respect to understanding the CMB temperature and its relationship to cosmological redshift and the Hubble constant. Nevertheless, there is still much to be discovered.

In this paper, we have demonstrated, from the observed redshifts of 580 type Ia supernovae

(the Union2 database), how one can predict a CMB temperature with a 1STD confidence interval of $2.652K$ to $2.798K$. Furthermore, we predict that future type Ia supernovae will show a similar excellent fit with a current CMB temperature of $2.726K$. Given its derivation, our CMB redshift prediction formula is, of course, also fully consistent with the $T_t = T_0(1+z)^\beta$ formula, so long as β is either zero or $1/2$.

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Declarations

Conflict of interest

The authors declare no conflict of interest.

Data availability statements

The supernova Union-2 database that we have used can be found here: https://supernova.lbl.gov/Union/figures/SCPUnion2.1_mu_vs_z.txt.