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How a New Type of $R_h = ct$ Cosmological Model Outperforms the Λ-CDM Model in Numerous Categories and Resolves the Hubble Tension

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Abstract

This paper provides a brief overview of how the Haug and Tatum cosmological Model (HTC) outperforms the Λ-CDM model in numerous categories. In particular, we show why the HTC model is a strong competitor to the Λ-CDM model. For example, HTC appears to resolve the Hubble tension by making use of newly-discovered fundamental relationships between the CMB temperature, the Hubble parameter, and cosmological redshift. Moreover, HTC appears to better explain certain early universe telescopic observations than the Λ-CDM model.

Keywords

$R_h = ct$ Cosmology, Black Hole Cosmology, CMB Temperature, Hubble Parameter, Hubble Tension, Λ-CDM Model, Cosmic Age, Early Galaxy Formation, High-Precision Cosmology

1. The Haug and Tatum $R_h = ct$ Cosmological Model

The Haug and Tatum cosmological model (HTC) [1] has integrated some newly-discovered fundamental relationships between certain cosmological parameters such that it even appears to resolve the Hubble tension. In the following sections, we will explore different aspects of the model and compare each with the Λ-CDM model. HTC is a variant of the $R_h = ct$ cosmology model which satisfies the Friedmann [2] equation, making it consistent with Einstein's [3] general relativity. One of the fundamental breakthroughs of this model is its ability to provide a robust mathematical framework relating the CMB temperature to other cosmological parameters, all in accordance with general relativity. For an in-depth study of the model, one must consult the many references we provide in this paper. To facilitate such study, we herein summarize the key features and compare them with the Λ-CDM model. Based on our analysis so far, HTC appears to outperform the Λ-CDM model, although there may still be challenges as we continue to test it with pending observational studies.

There are multiple subclasses of the $R_H = ct$ model. The most well-known $R_H = ct$ model is likely the Melia [4] [5] model. The Melia model and HTC differ on a series of points. The HTC model is a black hole universe model; this is not the case for the Melia model. The cosmological redshift has a very different mathematical function in the two models; in the HTC model, it is given by $z = \sqrt{\frac{R_{H_0}}{R_t}} - 1$. Also, the Melia model, like the Λ-CDM model, cannot predict the current CMB temperature and has no direct mathematical relation between the CMB temperature and the Hubble parameter. However, the Melia and HTC models have much more in common than they do in comparison to Λ-CDM. Both, for example, predict a current cosmic age of approximately 14.6 billion years and scale in a similar way, according to the $R_H = ct$ principle. For more details, please see Section 13.

2. HTC Can Precisely Predict T_0

The current CMB temperature T_0 is the most precisely measured cosmological parameter. For example, the recent Dhal *et al.* [6] study reports a CMB temperature of $T_0 = 2.725007 \pm 0.000024\ \text{K}$. Unfortunately, Λ-CDM cannot predict T_0, as pointed out by Narlikar and Padmanabhan [7]:

"*The present theory is, however, unable to predict the value of* T *at* $t = t_0$. *It is therefore a free parameter in SC* (*Standard Cosmology*)."

The standard model has made attempts to predict the current CMB temperature; this goes all the way back to Gamow in 1948 [8] [9]. However, as we have recently discovered, the modern standard model formula predicts the wrong CMB temperature, $T \approx 23\ \text{K}$ (using today's high-precision inputs), versus the observed 2.725 K; see [10]. We believe that the reason the standard model fails is that it has not been able to derive a relationship between the CMB temperature and H_0 that is consistent with observations. Furthermore, we suspect that the standard model is overly complex and that a linear $R_H = ct$ cosmology is actually what is needed. This point of view appears to be supported by recent studies seriously questioning the accelerated expansion of the universe. Please see Section 13 for more details and references.

In sharp contrast to T_0 being a free parameter in Λ-CDM, HTC can accurately predict the current CMB temperature according to:

$$T_0 = \frac{\hbar c}{k_b 4\pi \sqrt{R_h 2 l_p}} \approx 2.725\ \text{K} \tag{1}$$

Equation (1) was first introduced within $R_h = ct$ cosmology by Tatum *et al.* [11]. It was later fundamentally derived from the Stefan-Boltzmann law by Haug and Wojnow [12]. Since then, it has also been derived using a geometric mean approach by Haug and Tatum [13], which also seems valid in $R_h = ct$ black hole cosmology.

3. Λ-CDM Cannot Derive $T_t = T_0(1+z)$, Whereas HTC Does So

HTC reference [1] gives distance-vs-redshift scaling according to $z = (R_h/R_t)^{\frac{1}{2}} - 1$. When used in combination with Equation (1), the following well-known observational relation can be easily derived:

$$T_t = T_0(1+z) \tag{2}$$

Whereas, in standard cosmology, the $T_t = T_0(1+z)$ relation appears to be mostly an assumption based upon observations [14]-[16], rather than a prediction based on derivation and then confirmed by observations, as in the HTC model.

4. A Radiation Density Parameter That Is Calculated More Precisely than Λ-CDM

The HTC model predicts an exact CMB radiation density parameter value of $\Omega_\gamma = \frac{\rho_\gamma}{\rho_{cr}} = \frac{1}{5760\pi} \approx 5.52621330180192 \times 10^{-5}$. The value of this parameter can be calculated to any desired precision, depending only upon how many decimal places of π one wishes to use; one can see the derivation in Haug [17]. This value also falls well within the 95% confidence interval given by the Particle Data Group (PDG)[1], which is 5.08×10^{-5} to 5.68×10^{-5} (2STD). Thus, in this case as well, the HTC model is just as good, if not better, in terms of precision.

More precise observations of the CMB radiation density ρ_γ, as well as the critical density ρ_{cr}, are needed to distinguish between the two models based on observational data. The HTC model predicts a critical energy density with much lower uncertainty than the Λ-CDM model or any other major cosmological model of which we are aware; see [18].

5. Number Density of CMB Photons

The Λ-CDM model predicts the number density of CMB photons as:

$$n_{\gamma 0} = \frac{30\zeta(3)}{\pi^4} \frac{a_b T_0^3}{k_b} \tag{3}$$

wherein $\zeta(s)$ is the Riemann zeta function. The best-estimated PDG value is $n_{\gamma 0} = 410.73(27)$. The same equation and estimate are fully consistent with our HTC cosmological model. However, in addition, we can predict the number density of CMB photons directly from the Hubble parameter without any knowledge of the CMB temperature, using the newly-derived equation by Haug [17], fully consistent with and rooted in HTC:

[1]See https://pdg.lbl.gov/2023/reviews/rpp2023-rev-astrophysical-constants.pdf.

$$n_{\gamma 0} = \frac{\zeta(3)}{\pi^5 64\sqrt{2}\left(\frac{c}{H_0} l_p\right)^{\frac{3}{2}}} = 410.71 \pm 0.26 \text{ photons per cm}^3 \quad (4)$$

when using the Hubble parameter $H_0 = 66.8711 \pm 0.0019$ km/s/Mpc estimated by Haug and Tatum, which resolves the Hubble tension within HTC.

The Λ-CDM model has no method to predict the number density of CMB photons directly from the Hubble parameter. Furthermore, if we use the Hubble constant estimated by Riess *et al.* [19], $H_0 = 73.30 \pm 1.04$ km/s/Mpc, and plug it into the formula above, we obtain a predicted CMB photon number density more than six sigma away from the value calculated from the CMB temperature itself (PDG). This clearly indicates that the Hubble tension in the Λ-CDM model also manifests as tension in the predicted CMB photon number density. Such tensions do not exist within HTC, wherein everything remains consistent due to the recently-discovered mathematical duality between the current CMB temperature and the HTC Hubble parameter value. Consequently, in HTC, one can choose whether to estimate the number density of CMB photons using the CMB temperature or using the HTC Hubble parameter value.

6. HTC Appears to Resolve the Hubble Tension

In Λ-CDM cosmology, the Hubble tension has not yet been satisfactorily resolved, as noted by Valentino *et al.* [20]. Haug and Tatum, however, have recently demonstrated that the Hubble tension appears to be resolved within HTC. By using the measured CMB temperature, Haug and Tatum [1] demonstrated that, through either a simple but tedious trial-and-error method or a more sophisticated and automated "intelligent search" algorithm, one can readily find the single optimal value of H_0 which allows their redshift function to match the full distance ladder of supernovae (SNe Ia) in the PantheonPlusSH0ES database. Haug [21] has further discussed this and even provided an additional mathematical proof that the Hubble tension is resolved within the HTC model. In **Figure 1**, we show the graph of the predicted redshifts in HTC versus the actual observed redshifts across the full PantheonPlusSH0ES distance ladder. We simply start out with the measured CMB value of Fixsen [22] $T_0 = 2.72548\text{ K} \pm 0.00057\text{ K}$ and then, by the trial-and-error method, or alternatively by the closed-form solution method (both methods described in the papers just mentioned), find the one single optimized value of $H_0 = 66.8943 \pm 0.0287$ km/s/Mpc value which gives a near-perfect match between observed redshifts and our HTC-predicted redshifts. Naturally, there is a very small residual uncertainty in H_0 due to the minimal residual uncertainty in T_0. We have, of course, also incorporated the latest NIST CODATA uncertainties in the physical constants used.

Moreover, if one starts out by already assuming the CMB temperature and HTC H_0 values, one can also use the observed full distance redshift ladder of the Union2 supernovae database to extract the Planck length value matching the NIST

CODATA; this is yet another convincing way that HTC resolves the Hubble tension; see [23]. Such a result also demonstrates that HTC is mathematically linked to the Planck scale. We reiterate that all of these parameters are mathematically connected within HTC.

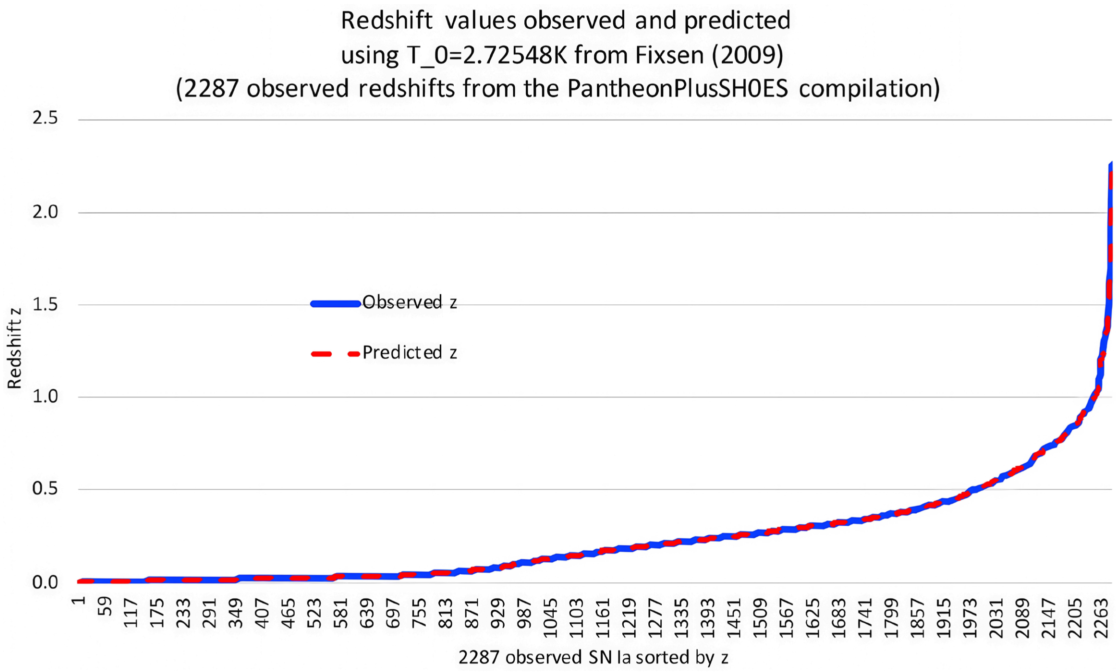

Figure 1. This figure shows the near-perfect match between HTC predicted redshifts and the observed redshifts of all 2287 type Ia supernovae in the full distance ladder of the PantheonPlusSH0ES database. The only other necessary observational input is the CMB temperature given by Fixsen (2009) of 2.72548K. The observed data are sorted by redshift (blue line). The red line represents our HTC predictions matching with $H_0 = 66.8943$ km/s/Mpc, which we extracted from the data using our trial-and-error statistical method (see [1]) or, alternatively, the closed-form solution method.

The mathematical proof given by Haug [21] demonstrates that the predictions in the HTC model must be exact, except that one naturally needs to take into account the uncertainty in the Planck length, that is in G as $l_p = \sqrt{\frac{G\hbar}{c^3}}$. Thus, no matter the SNe Ia database, this will lead to a single H_0 parameter that needs to be determined, and it will always be $H_0 = 66.8943 \pm 0.0287$ km/s/Mpc when using the Fixsen 2009 CMB temperature of $T_0 = 2.72548\text{ K} \pm 0.00057\text{ K}$. We refer to the papers cited above for an in-depth study of exactly how our analysis is performed.

7. Λ-CDM Has Much Higher Uncertainty in Comparison to HTC in Measured H_0

Despite considerable recent improvements in the measurements of H_0, there is still significant uncertainty in the measured Hubble constant value. The Planck Collaboration study [24] gives $H_0 = 67.4 \pm 0.5$ km/s/Mpc. In contrast, the

SH0ES study of the local universe by Riess *et al.* [19] gives $H_0 = 73.04 \pm 1.04$ km/s/Mpc. These two very different results are the basis for the Hubble tension in standard cosmology, which we have already shown that HTC appears to resolve in favor the Planck Collaboration value.

Fortunately, HTC also dramatically improves the precision of H_0. This is possible because, unlike the Λ-CDM model, HTC has established an exact mathematical relationship between H_0 and T_0 (derivable from Equation (1)). As a result, we can simply use the most precisely measured value of either T_0 or H_0 and calculate the other parameter. For example, if we use the Dhal *et al.* [6] study, which provides a high-precision CMB temperature, we obtain $H_0 = 66.8711 \pm 0.0019$, km/s/Mpc, see [1] [25]. This is a dramatic improvement in precision in comparison to the Planck Collaboration and Riess *et al.* measurements.

8. HTC Provides for Markedly Increased Precision in Predictions of a Series of Cosmological Parameters

Since HTC has achieved much higher precision in H_0, we can significantly increase the precision in predicting any of the usual cosmological parameters in which uncertainty in H_0 has been the main source of uncertainty. **Table 1**, for example, shows a sampling of cosmological parameters for which HTC provides for greatly reduced uncertainty compared to what is currently possible in the Λ-CDM model. An important question, of course, is whether any of this can be

Table 1. This table shows a sampling of the many cosmological parameters that can be predicted from the HTC model simply by using its precise H_0 value. The uncertainty in these predictions is vastly reduced in comparison to what has been achieved in the Λ-CDM framework. The reason for this is the HTC Hubble parameter formula which links a given CMB temperature value (Dhal's 2.725007 K in this example) with its corresponding Hubble parameter value.

Property:	Formula:	References
Hubble constant	$H_0 = \mho T_0^2 = 66.8711 \pm 0.0019$ km/s/Mpc	[1] [25]
Hubble radius	$R_h = \frac{c}{H_0} = \frac{c}{\mho T_0^2} = 1.383352 \pm 0.000004 \times 10^{26}$ m	
Hubble time	$t_h = \frac{1}{H_0} = \frac{1}{\mho} T_0^2 = 14622028851 \pm 421876$ years	[27] [28]
Critical density	$\rho_c = \frac{3H_0^2}{8\pi G} = \frac{3T_0^4 \mho^2}{8\pi G} = 8.399481 \pm 0.000296 \times 10^{-27}\ \mathrm{kg \cdot m^{-3}}$	[18]
Cosmic Hubble sphere entropy	$S_{BH} = \frac{A}{l_p^2} = \frac{4\pi R_h^2}{l_p^2} = \frac{4\pi c^2}{\mho^2 T_0^4 l_p^2} = 9.2057 \pm 0.0007 \times 10^{122}$	[29]
CMB photon radiation parameter	$\Omega_\gamma = \frac{1}{5760\pi} \approx 5.52621330180192 \times 10^{-5}$	[17]
Number density CMB photons	$n_\gamma = \frac{\zeta(3)}{\pi^5 64\sqrt{2}\left(\frac{c}{H_0} l_p\right)^{\frac{3}{2}}} = 410.71 \pm 0.26$ photons per cm^3	[17]

supported by observations. We believe this is already the case. To give but one example, the approximately 14.6 billion-year HTC cosmic age estimate provides about 800 million more years for early galaxy formation than predicted by the Λ-CDM model, which aligns much better with deep space telescopic observations made by JWST. See Section 10 for more details and specific references on this topic. The $\mho = \frac{k_b^2 32\pi^2 G^{1/2}}{c^{5/2}\hbar^{3/2}}$ in the table is a composite constant that we represent with the Latin symbol for Upsilon; see [25] [26].

9. Λ-CDM Operates with Three Different Distances for a Given Red-Shift, whereas They Are Unified in HTC

In the Λ-CDM model, for an object at a given observed redshift, there are potentially three different distances, each governed by a different Λ-CDM distance-vs-redshift formula. These are: the luminosity distance; the angular diameter distance; and the co-moving distance. These distances can be quite different, even for the same z value. This remarkable fact could be an artifact of the Λ-CDM concept of accelerated expansion, in order to keep the model internally consistent. In HTC, the luminosity distance, angular diameter distance, and co-moving distance are derived to be one and the same for any given redshift. This is because HTC uses only a single derived distance-vs-redshift formula. It should be remembered that HTC, like any $R_h = ct$ cosmology, models cosmic coasting at constant velocity rather than cosmic acceleration. Researchers should ask themselves how such a simple model, with only one distance for a given redshift, can fit the entire distance ladder of all supernovae without the need for cosmic acceleration. While HTC certainly needs to undergo more observational testing, and may require some modifications, it performs remarkably well in all aspects that we have examined so far.

10. Λ-CDM Appears to Be Less Compatible with Recent Early Universe Observations than HTC

Melia [30], who has a different type of $R_h = ct$ model than ours, recently pointed out that:

"*JWST's recent discovery of well-formed galaxies and supermassive black holes only a few hundred million years after the Big Bang seriously challenges the timeline predicted by Λ-CDM.*"

Like Melia, we believe that the current early universe observations strongly support the $R_h = ct$ principle of cosmic coasting at constant velocity, which extrapolates to a greater current cosmic age than estimated by Λ-CDM. Haug and Tatum have recently shown that, within HTC, the age of the universe appears to be 14,622,028,851 ± 421,876 years. This is more than 800 million years greater than predicted by the Λ-CDM model. The discovery of surprisingly large and well-formed galaxies in the early universe, therefore, appears to be more in-line with HTC [27] [28].

11. HTC Is Consistent with Both the Standard Friedmann Equation and Our Thermodynamic Friedmann Equation

Haug and Tatum [18] have introduced a thermodynamic version of the Friedmann equation, in which the critical Friedmann universe behaves according to:

$$T_t = \left(\frac{8\pi G\rho_{c,t}}{3\mho^2}\right)^{\frac{1}{4}} = \frac{1}{k_b\sqrt{\pi}}\left(\frac{\rho_{c,t}c^5\hbar^3}{16}\right)^{1/4} \quad (5)$$

wherein $\mho = \frac{k_b^2 32\pi^2 G^{1/2}}{c^{5/2}\hbar^{3/2}}$ is our composite Upsilon constant. This is fully compatible with the standard critical Friedmann equation. So, we now have a direct mathematical relationship between the CMB temperature and other cosmological parameters. The thermodynamic Friedmann equation is simply the Friedmann equation expressed through the CMB temperature rather than simply the Hubble constant. The Λ-CDM model is unlikely to achieve this, as it would require predicting T_0 in the first place, which it cannot do, owing to its lack of a rigorous mathematical relationship between T_0 and H_0.

12. HTC Has No Horizon Problem

Measurements of the CMB anisotropy show that the observable universe has a remarkably uniform thermal blackbody radiation spectrum in all observational directions. Melia [4] [31] has clearly shown that the horizon problem emerges only within the Λ-CDM model and not within $R_h = ct$ cosmology. Since HTC is clearly a $R_h = ct$ model variant, there is also no horizon problem in HTC.

The rationale for Melia's conclusion concerning $R_h = ct$ models is remarkably straightforward. As best explained in his reference [31], there are now two phase transitions during the Λ-CDM model expansion which appear to present a horizon problem for Λ-CDM. The first of these could be solved, in theory, by an unobservable inflationary epoch of accelerated early cosmic expansion from about 10^{-36} seconds to about 10^{-33} seconds following the Big Bang. This would be according to the well-known theory of cosmic inflation. The second of these phase transitions would likely have been an electroweak phase transition (EWPT) event occurring at a critical temperature of 159.5 ± 1.5 GeV, at approximately 10^{-11} seconds following the Big Bang. Such an event would, by virtue of the apparent uniformity of the vacuum expectation value of the Higgs field, present the second horizon problem within the Λ-CDM model. This event would be well beyond the inflationary epoch and require an entirely different Λ-CDM horizon problem solution. As Melia nicely explains, neither phase transition "would have created observable sub-horizon features in the $R_h = ct$ model". This would be because such phase transition events in the early $R_h = ct$ universe would have occurred within a causally-connected region now filling the entire visible $R_h = ct$ universe of today.

13. New Observational Evidence That Cosmic Expansion Is Not Actually Accelerating

The accuracy and precision of the HTC $R_h = ct$ model, in comparison to the Λ-CDM model, suggests to the present authors that there may well be sources of systematic error in their local universe Type Ia supernovae distance estimates. For example, references [1] and [23] imply that the HTC redshift vs distance relations might be more accurate at greater cosmological distances than those used by Λ-CDM model proponents. This might explain why the HTC model strongly favors the CMB-based measurement of the Hubble parameter value and strongly disfavors the Λ-CDM value. See again these references for details, including the statistical methods used.

Furthermore, there is recent observational evidence according to Son *et al.* [32] that Λ-CDM model proponents appear to have had a strong progenitor age bias in their supernova cosmology. Such observational evidence is reported by the same authors to be in alignment with recent DESI BAO measurements. Son *et al.* draw the following conclusions:

"*When the three cosmological probes* (*SNe*, *BAO*, *and CMB*) *are combined*, *we find a significantly stronger* (>9σ) *tension with the ΛCDM model than that reported in the DESI papers*, *suggesting a time-varying dark energy equation of state in a currently non-accelerating universe.*"

Thus, the new Son *et al.* paper appears to be strengthening the arguments of the many $R_h = ct$ model proponents, including the present authors, who have long disputed claims of cosmic acceleration.

14. For Further Study

To what extent the apparent inaccuracy of the "local universe" Hubble parameter measurement method depends upon not using the HTC-derived redshift versus distance formula, or not having adequately corrected for progenitor age bias in supernova cosmology, is a subject for future study. As we will summarize in a paper in current production, some of the latest astrophysical studies used to measure the current value of the Hubble parameter clearly show a stepwise progression more closely approximating the HTC prediction and the Planck CMB measurement. It is gradually becoming more apparent that previously-unrecognized biases in supernova cosmology are in need of adjustment.

15. Summary and Conclusions

We have compared numerous categories within the HTC model and the Λ-CDM model. From these comparisons, we must conclude that HTC is a simpler and yet more powerful and integrated cosmological model than Λ-CDM. HTC can predict T_0, while Λ-CDM cannot. HTC resolves the Hubble tension (in favor of the Planck Collaboration measurement), which remains an unresolved problem within Λ-CDM. Furthermore, we believe that the Hubble tension itself indicates a breakdown in the Λ-CDM model's ability to describe the cosmos. HTC also significantly reduces uncertainty in cosmological parameters, such as H_0, R_h, t_h, and M_c. Furthermore, the predicted age of the universe in HTC is more than 800 million years greater than that in Λ-CDM, a result which appears to be more consistent with the discovery of "surprisingly early" developed galaxies in recent JWST studies.

Despite these initial successes, there are likely still a number of outstanding issues in our model. However, we must bear in mind that literally thousands of researchers have been working on the Λ-CDM model for several decades, whereas the HTC model in particular, and $R_h = ct$ models in general, are newer and less well-explored. It would be a mistake, we think, to dismiss such an alternative model based upon prejudice. Instead, especially in light of the new evidence against cosmic acceleration provided by Son *et al.*, we believe that HTC should be currently viewed as an intriguing alternative to Λ-CDM, one that many more researchers could, and probably should, explore.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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