

How the Haug-Tatum Cosmology Model Entropic Energy Might Be Directly Linked to Dark Energy

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Abstract

Haug and Tatum have recently developed a cosmological model which links cosmic age, the Hubble constant, cosmic temperature, cosmological redshift and the Planck length in a manner fully consistent with general relativity. Furthermore, they have employed the Bekenstein-Hawking formula for black hole entropy and the “entropic gravity” and “entropic force” concepts of Erik Verlinde in order to attempt a mathematical model of the phenomena currently attributed to “dark energy”. Within the Haug-Tatum model, the entropic force is treated as a real force, since such forces are connected to real energy when they do work. This energy connected to the cosmological entropic force can therefore be regarded as “entropic energy”. When applied to this model, the current epoch entropic energy density is shown to be approximately $7.5 \times 10^{-10} \text{ J}\cdot\text{m}^{-3}$. Thus, there is a close approximation to the current observed energy density of the “cosmological constant”. Our entropic energy density decay curve over the last 14 billion years of this model is presented in anticipation of the pending deep space dark energy survey results. Whether this “entropic energy” concept can be supported or refuted by observations, and whether cosmological “entropic energy” is what is currently called “dark energy,” is yet to be determined.

Keywords

Dark Energy, Entropic Energy, Entropic Force, Entropic Gravity, Cosmic Entropy, Cosmology Models, $R_H = ct$ Model, Haug-Tatum Cosmology, Black Holes, DESI

1. Introduction and Background

Beginning with type Ia supernova observations reported in 1998-1999 [1]-[3], it

was realized that the expansion of our universe is not decelerating. This was a shocking discovery, because it could not be readily explained by general relativity without proposing the existence of an energy (and force) in opposition to the gravitational attraction which must be present between widely-separated galaxies, galaxy clusters and superclusters. A simple theoretical fix was to assume the presence of an exceedingly small “cosmological constant” energy (and force) otherwise unseen within the cosmic vacuum. The energy attributed to this newly-discovered gravitationally-repulsive phenomenon was named “dark energy.”

Despite intensive study over the last couple of decades, the precise nature and evolution of cosmological dark energy has remained a mystery. To put it simply, no one yet knows what dark energy is, or why it arises. Although current estimates of its average energy density in the present epoch suggest a value of approximately 10^{-9} Joule per cubic meter of the cosmic vacuum, this remarkably small value cannot yet be explained by quantum field theorists with respect to our understanding of the quantum vacuum. The apparent discrepancy between observation and theory has been reported to be on the order of about 10^{120} . This discrepancy is often referred to as the “cosmological constant problem” [4] [5].

Efforts to understand possible inter-relationships between attractive gravity and gravitationally-repulsive dark energy have taken many different directions. One of the more intriguing approaches has been taken by Erik Verlinde [6] [7]. His approach suggests the possibility that gravitational interactions could be emergent phenomena of entropy. Thus, one can think of “entropic forces” not only at play in Brownian motion [8], but also potentially acting on the horizon of our universe [9].

The treatment of cosmological entropic forces must undoubtedly be model-dependent. The reasoning underlying such a statement has to do with the fact that entropic forces presently described in nature as real forces (e.g., with respect to polymers, colloidal suspensions, osmosis, etc.) are understood to be emergent phenomena resulting from the tendency of a thermodynamic system to maximize its entropy. Thus, a derivation of the nature and magnitude of entropic force and entropic energy within a cosmological model depends upon model assumptions concerning its geometry and thermodynamics, including its time-dependent temperature and entropy.

The 2015 Tatum *et al.* FSC model [10]-[12] and its successor Haug-Tatum Cosmology (HTC) model [13]-[17] are expanding, spherically symmetric systems which follow the Stefan-Boltzmann law, the observed $T_t = T_0(z + 1)$ temperature-vs-redshift relation, and the $R_H = ct$ principle [18]. They also follow a time-dependent Cosmic Microwave Background (CMB) temperature formula:

$$T_t \cong \frac{\hbar c^3}{8\pi G k_B \sqrt{M_t M_{pl}}} \cong \frac{\hbar c}{4\pi k_B \sqrt{R_t R_{pl}}} \quad (1)$$

where T_t is cosmic temperature at time t , M_t is cosmic mass (equal to the Friedmann critical mass) at time t , M_{pl} is the Planck mass, R_t is cosmic radius at time t ,

and R_{pl} is the Planck radius equal to two Planck lengths. All other symbols are the well-known physical constants.

Equation (1) has not only been shown to be derivable using the Stefan-Boltzmann law, but it has also been independently derived using the geometric mean approach of Haug and Tatum [19]. The idea behind this is simple; in a black hole Hubble sphere, the minimum possible wavelength is linked to the Planck scale and the maximum wavelength is linked to the time-dependent radius, or potentially even the circumference, of the Hubble sphere. Thus, the CMB temperature at any point in cosmic time could simply be related to the geometric mean of these wavelengths. This explains the $\sqrt{R_t R_{pl}}$ term, which is the geometric mean of the Hubble radius at time t and the radius of the Planck mass black hole. It is important to be aware that the Lambda-CDM model cannot predict the current CMB temperature [20]. Furthermore, by its assumption of Equation (1), the HTC “growing black hole” variant of $R_H = ct$ model is considerably different in comparison to the better-known Melia $R_H = ct$ model [21] which, to our knowledge, also cannot predict the current CMB temperature. Equation (1) is both consistent with the Stefan-Boltzmann law and with pure geometrical principles when one treats the Hubble sphere as a growing black hole, as we do.

As would be expected for a “growing black hole” variant of $R_H = ct$ model, HTC naturally assumes the Bekenstein-Hawking formula for the entropy of a black hole:

$$S_{BH} = \frac{A}{4l_p^2} = \frac{4\pi R_H^2}{4l_p^2} \quad (2)$$

So, the total model entropy increases over cosmic time because the Hubble radius grows steadily at the speed of light. Thus, the HTC model can derive an entropic force and entropic energy simulating that of dark energy in a completely different manner than the Lambda-CDM standard model of cosmology.

It is the purpose of this note to show our derivation of the HTC entropic force as a possible dark energy force equivalent, and to show how its corresponding entropic energy density might be directly linked to the observed value of the dark energy density, namely approximately 10^{-9} Joule per cubic meter of the cosmic vacuum [22] [23]. A brief discussion of the potential significance of these HTC model derivations will follow.

2. Relating HTC Cosmic Entropy to Entropic Gravity and Entropic Force Theories by a Concept of “Entropic Energy”

Herein, we show our model formulae for the entropic force and its associated critical energy. As seen by critical mass and Hubble radius formulae in one of our recent publications (see again [14]), both time-dependent parameters are derivable from Equation (1) above, when assuming that the critical mass is equal to the time-dependent mass M_t and the Hubble radius is equal to the time-dependent

radius R_c ,

Thus, our formula for critical mass at a given time t is:

$$M_{c,t} = \frac{c^2 R_H}{2G}, \quad (3)$$

And our formula for the corresponding Hubble radius at a given time t is:

$$R_H = ct \quad (4)$$

The magnitude of the entropic force in our model can be given by:

$$F = \frac{M_{c,t} c^2}{R_H} = \frac{E_{c,t}}{R_H} \quad (5)$$

where $M_{c,t}$, is the critical mass (mass equivalent) given above and

$E_{c,t} = M_{c,t} c^2 = \frac{c^4 R_H}{2G}$ is the critical energy, or what we can now also call the

“entropic energy.” One can readily see that we use the Schwarzschild formula relationship between critical mass and Hubble radius in our “growing black hole” variant of $R_H = ct$ model. In such a model, the growing matter mass-energy is equal in magnitude, but opposite in sign, to the growing vacuum energy. This vacuum entropic energy is what we think could be equivalent to a “repulsive” vacuum energy long-suspected to be synonymous with “dark energy.” We theorize that this energy within the vacuum creates an outward radiation pressure counterbalancing the Hubble sphere gravitational attraction force at all times t . As this critical energy spreads over a bigger and bigger surface (the cosmic horizon) as well as volume (the Hubble volume), we believe that it acts by its outward radial entropic force. Since HTC is a subclass of $R_H = ct$ model, we can see from the equations that what we now refer to as entropic energy grows linearly with the growth of R_H over time. However, the Hubble volume grows according to R_H^3 , so that the entropic energy density in our model decreases (*i.e.*, “decays”) over time, as opposed to remaining constant. Given our current estimated values of M_c and R_H , our formula for the current entropic energy density is calculated as:

$$\rho_e = \frac{E_c}{\frac{4}{3}\pi R_H^3} \approx 7.5 \times 10^{-10} \text{ J} \cdot \text{m}^{-3} \quad (6)$$

For earlier cosmic times and smaller Hubble radii, we use $E_{c,t} = \frac{c^4 R_H}{2G}$ and

the time-dependent Hubble volume as a function of $R_H = ct$. Note that R_H is the only variable in both the entropic energy and in the Hubble volume, so the entropic energy density in the HTC model declines according to $R_H = ct$. See **Figure 1**. One can readily see, by the above time-dependent equations, and by **Figure 1**, that total entropic energy shows a steady growth proportional to the growing Hubble radius and that entropic energy density exponentially decays according to the cubic Hubble radius volume.

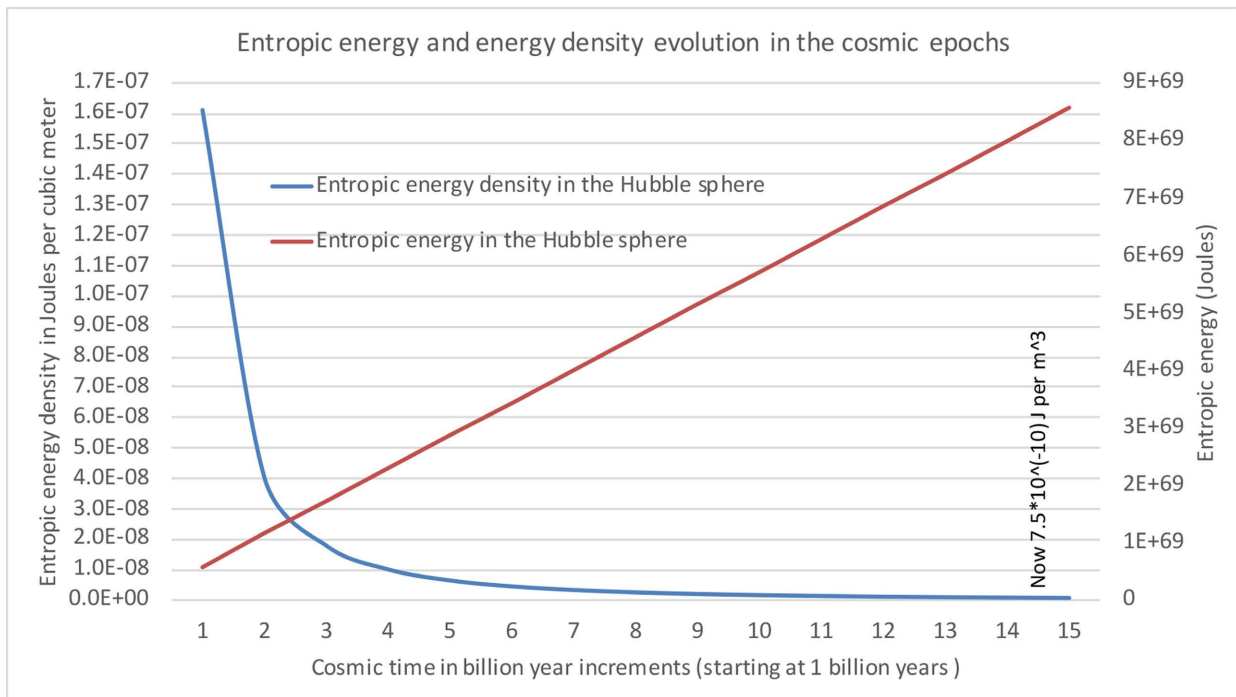


Figure 1. This figure shows HTC entropic energy density (blue decay curve) as a function of cosmic age in one billion-year increments following the cosmic Planck epoch (not shown). It is calculated according to Equation (6). The red line is corresponding total entropic energy in Joules.

3. Discussion

The entropic energy which we introduce herein can be seen as a kind of radiation pressure energy which grows as the vacuum volume grows with cosmic expansion. Through its entropic force, it provides the counterbalancing force to the attractive gravity force of traditional mass and energy within the Hubble sphere. The entropic energy density in our model was much greater in past cosmic epochs, but is smoothly decreasing over forward cosmic time. During the cosmic Planck epoch, our model suggests that it was at approximately the Planck energy density, whereas in the current cosmic epoch, our model shows it to be approximately $7.5 \times 10^{-10} \text{ J}\cdot\text{m}^{-3}$, and to have decayed very slowly and subtly to this present value in the last few billion years. The difference between its Planck energy density and the current observed energy density is on the order of about 10^{120} . Thus, this entropic energy appears to behave qualitatively and quantitatively much like cosmic dark energy undergoing energy density decay as the universe expands. That it does so may also explain why HTC models cosmological redshift in a way which appears to solve the Hubble tension problem. See again, for example, references [13]-[17]. As such, our HTC model may be regarded as a model of vacuum dark energy with rapid energy density decay in the early universe and very gradual and subtle decay in the late universe to the present. To put it most simply, ours is a scalar model of dark energy decay, as opposed to an unchanging cosmological constant model. We see no theoretical reason why the cosmic vacuum must be unchanging in its energy density over the great span of cosmic time. This has been true for both the

FSC and HTC models.

The concept of an “entropic force” to characterize the study of entropy in large N-body particle interactions has a rich and varied history. Radial and/or non-radial entropic forces, for example, have been derived from studies of polymers, colloidal suspensions and osmosis and treated as “real forces,” as mentioned by Roos. See again [8]. The extension of the “entropic force” concept to theoretical work in gravity and cosmology appears to have been greatly advanced by Erik Verlinde. See again [6] [7]. It has been suggested by Verlinde and Roos that the mysterious cosmological “dark energy” could even be an emergent property manifestation of cosmic entropy. For example, in the theoretical study of dark energy one could conceivably derive an outward radial entropic force for an expanding spherically symmetric cosmological model with well-defined thermodynamic formulae for time-dependent CMB temperature and total entropy. The FSC and HTC models nicely fit this profile.

The potential for such theoretical study would be in the comparison between derivable parameters from a given cosmology model and what can be observed concerning such parameters. In the case of a dark energy comparison, observables of particular interest include precision measurements of the Hubble constant and observation-based best estimates of the current value of the cosmological constant. With respect to the latter estimates, there is general agreement on an observed vacuum energy density of approximately 10^{-9} Joule per cubic meter of cosmic vacuum [22] [23]. The Planck Collaboration, for example, indicates a current estimated value of $5.3566 \times 10^{-10} \text{ J}\cdot\text{m}^{-3}$. Thus, there is a close approximation between the HTC theoretical value and the best observational value to date.

With respect to the publications of Verlinde and Roos, the implication of a radial entropic force responsible for universal expansion is that there is an associated entropic energy linked to such a force. And yet, when we search the cosmology literature for something called “entropic energy”, we find nothing particularly useful at the present time. Since we have successfully used the HTC model to solve the Hubble tension problem within $R_H = ct$ cosmology, this note shows how HTC derives a current entropic energy density value in-line with the current best estimate of the cosmological constant value. Thus, we have shown herein how the HTC entropic force and energy might be directly linked to what is currently called “dark energy.” Naturally, due to the speculative nature of this note, we eagerly await the final results of the Dark Energy Spectroscopic Instrument (DESI) study and other pending dark energy observations before any firm conclusions can be drawn. Although preliminary results of the early portion of the DESI study are suggestive of dark energy decay, we await confirmation of this and look forward to comparing our **Figure 1** graph with the final DESI results.

4. Summary and Conclusion

Herein, we have applied the “entropic gravity” and “entropic force” concepts of Erik Verlinde to the new HTC model formulae for cosmic entropy and vacuum

energy density to derive a time-dependent entropic “dark energy” equivalent. The entropic force is treated as a real force, so the associated energy doing the work of cosmological expansion can be referred to as “entropic energy” within our model. When applied to this model, the current epoch entropic energy density is shown to be approximately $7.5 \times 10^{-10} \text{ J}\cdot\text{m}^{-3}$. Thus, there is a close approximation to the current observed energy density pertaining to the “cosmological constant”. Furthermore, the entropic energy density decay curve over the last 14 billion years of this model is presented in anticipation of the pending deep space dark energy survey results. If the current preliminary impression of subtle dark energy decay can be finally confirmed by DESI or other pending dark energy observations, we can then compare our theoretical model of dark energy decay with the observational findings. Naturally, whether our “entropic energy” concept can be supported or refuted by observations, and whether cosmological “entropic energy” is what is currently called “dark energy,” is yet to be determined.

Conflicts of Interest

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

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