

Cosmic Time as an Emergent Property of Cosmic Thermodynamics

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Abstract

This paper, in conjunction with recent Flat Space Cosmology (FSC) publications, provides theoretical support for cosmic time being an emergent property of cosmic entropy and temperature. Therefore, if Verlinde's "emergent gravity" theory is correct, both time and gravity are most fundamentally emergent properties of cosmic thermodynamics. Since emergent properties within complex systems with a huge number of degrees of freedom are often not definable at the smallest scales, these results suggest that quantum time and quantum gravity may be no more definable than consciousness within two connecting neurons. String theorists now struggling to define quantum space-time and quantum gravity should bear this in mind.

Keywords

Flat Space Cosmology, Cosmology Theory, Emergent Gravity, Dark Matter, Cosmic Entropy, Entropic Arrow of Time, Universal Temperature, Black Holes

1. Introduction and Background

A common dictionary definition of time is that it is "the measure of duration". However, this definition is somewhat unsatisfying, because "duration" is simply a synonym for "time". Einstein's definition of time as "what a clock measures" is correct, of course, but gets us no closer to a fundamental understanding of time. The difficulty with the philosophical question "What is time?" is that one cannot define time in a fundamental way using only words, because any word definition of time invariably must use another word which can only be defined in terms of time [1].

The only alternative to defining time in words is to use a more rigorous form

of symbolic logic, namely mathematics. Mathematics is essentially rigorous logic without the use of words, with the only exception to rigor being that some beginning set of assumptions ultimately derived from word logic is necessary as a starting point of any mathematical derivation. As proven in Godel's theorem, all mathematical systems must start with at least one unprovable assumption.

Aside from issues concerning starting assumptions, even with the use of mathematical equations, it is not necessarily easy to define time in a fundamental way. Every student of elementary physics learns the equation $vt = s$, where v stands for velocity, t stands for time, and s stands for distance travelled. Algebraic rearrangement defines time by $t = s/v$ (*i.e.*, time as distance divided by velocity). However, this equation gets us no closer to a fundamental meaning of time than a word definition, because the physics definition of velocity can only be given in terms of time. When we search all other Gallilean and Newtonian physics equations incorporating a time symbol t , we invariably find at least one other variable within each equation which can only be defined in terms of time.

It was not until the 19th and early 20th centuries that time could be redefined in a non-Newtonian way. The first important breakthrough appears to have been Maxwell's discovery of a fundamental velocity (*i.e.*, speed of light c) which was entirely derivable from Faraday's laws of electromagnetism, *which did not incorporate a time variable!* Then, in 1905, Einstein conclusively proved that c is a fundamental constant of nature which is completely unshackled from the Newtonian concept of absolute time, and the tautological time definitions that come with it.

Of even greater importance, for the purposes of this introduction, was Ludwig Boltzmann's concept of entropy, which also did not incorporate a time variable. Entropy allowed for a probabilistic, but inevitable, sequence progression (*i.e.*, *progressive change*) within highly complex systems with many degrees of freedom, including the cosmos itself. Unfortunately, Boltzmann didn't live long enough to see the potential cosmic consequences of his second law definition, because the universe in his day was widely believed to be infinite, eternal and unchanging.

It was not until Edwin Hubble's discovery of an expanding universe that Einstein and the rest of the scientific world recognized the importance of understanding universal parameters in terms of their fundamental relationship to cosmic time. This opened the way for thinking of cosmic time as being somehow deeply connected to cosmic entropy. The idea of a cosmic "entropic arrow of time" was seriously entertained, although, until recent developments, no one had any idea how to mathematically define cosmic entropy in terms of cosmic time, particularly for infinite universe theories or cosmic models with no definable finite horizon.

The recent developments began with the Bekenstein-Hawking definition of black hole entropy [2] [3] and its possible application to cosmological models according to

$$S_t \cong \frac{\pi R_t^2}{L_p^2} \quad (1)$$

wherein S_t represents cosmic entropy at time t , R_t represents the cosmic radius at time t , and L_p represents the Planck length. Furthermore, the Hawking-Penrose conjecture that a universe smoothly expanding from a singularity could be modeled as a time-reversed black hole was another development. Such a model implies an ever-expanding, but definable and finite, cosmic horizon with a surface area which is directly proportional to the total entropy of the cosmic system at each point in cosmic time. Finally, the Flat Space Cosmology (FSC) model incorporated into spatially-flat universe Friedmann equations [4] completed this development using the inspiration of the Hawking-Penrose conjecture. The purpose of the current paper is to show how algebraic rearrangements from this July 2018 *Journal of Modern Physics* FSC paper may provide for a more fundamental understanding of cosmic time.

2. Results

An entropic arrow of cosmic time is rigorously defined in FSC according to the following equation

$$t \cong \left(\frac{L_p}{c\sqrt{\pi}} \right) \sqrt{S_t} \quad (2)$$

wherein t represents cosmic time, L_p represents the Planck length, c is speed of light and \sqrt{S} is the square root of Bekenstein-Hawking's entropy S at time t [see Equation (1)]. As detailed in the FSC references [4] and [5], Bekenstein-Hawking's entropy is a unitless ratio, and the correct-scaling entropy term in FSC is \sqrt{S} . The reason for this is simply that cosmic entropy in terms of \sqrt{S} scales in exactly the same way as cosmic time t (60.63 logs of 10 from the Planck scale). Furthermore, the FSC "Universal Temperature" T_U scale [5], which is defined in a one-to-one correspondence to the Kelvin scale T by $T_U = T^2$, scales *downward* from the Planck scale temperature by 60.63 logs of 10 as time scales *upward* from the Planck scale time by 60.63 logs of 10. This allows for a *thermodynamic arrow of time in the form of*

$$t \cong \left(\frac{\hbar L_p c^4}{32\pi^2 k_B^2 G} \right) T_U^{-1} \cong \left(\frac{\hbar L_p c^4}{32\pi^2 k_B^2 G} \right) T^{-2} \quad (3)$$

wherein T_U and T are defined as above and the other terms are well-known constants.

3. Discussion

The above FSC definitions of cosmic time are in terms of cosmic entropy \sqrt{S} , cosmic Universal Temperature T_U , and temperature T in the Kelvin scale. Thus, in this cosmological model, *cosmic time appears to be fundamentally an emergent property of cosmic thermodynamics*. Furthermore, Erik Verlinde has re-

cently suggested very persuasively that gravity and its manifestations (including dark matter and dark energy) are also emergent properties of cosmic entropy [6] [7]. The paper entitled “Clues to the Fundamental Nature of Gravity, Dark Energy and Dark Matter” [Tatum, *et al.* (2018)] shows how FSC appears to be the cosmological model correlate to Verlinde’s “emergent gravity” theory. Furthermore, as detailed in the July 2018 *Journal of Modern Physics* paper entitled “A Potentially Useful Dark Matter Index” [8], there now appear to be at least four recent observational studies [9] [10] [11] [12] in support of Verlinde’s “emergent gravity” theory, particularly with respect to observations currently attributed to “dark matter.” In addition, our own July 2018 *Journal of Modern Physics* paper entitled “Equivalence between a Gravity Field and an Unruh Acceleration Temperature Field as a Possible Clue to ‘Dark Matter’” [13] provides further theoretical support for “dark matter” not actually being particulate in nature. Thus, it appears likely that additional persuasive evidence in support of Verlinde’s “emergent gravity” theory will be forthcoming. For the time being, one must keep an open mind. However, if Verlinde’s theory is correct, *both time and gravity are most fundamentally emergent properties of cosmic thermodynamics.*

4. Summary and Conclusions

The current paper, in conjunction with recent FSC publications, provides theoretical support for cosmic time being an emergent property of cosmic entropy and temperature. Therefore, if Verlinde’s “emergent gravity” theory is correct, both time and gravity are most fundamentally emergent properties of cosmic thermodynamics. Since emergent properties within complex systems with a huge number of degrees of freedom are often not definable at the smallest scales, quantum time and quantum gravity may be no more definable than consciousness within two connecting neurons. String theorists now struggling to define quantum space-time and quantum gravity should bear this in mind.

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Conflicts of Interest

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

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