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A Solution to the Cosmological Constant Problem Using the Holographic Principle (A Brief Note)

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Abstract

This paper integrates a quantum conception of the Planck epoch early universe with FSC model formulae and the holographic principle, to offer a reasonable explanation and solution of the cosmological constant problem. Such a solution does not appear to be achievable in cosmological models which do not integrate black hole formulae with quantum formulae such as the Stephan-Boltzmann law. As demonstrated herein, assuming a constant value of Lambda over the great span of cosmic time appears to have been a mistake. It appears that Einstein's assumption of a *constant*, in terms of vacuum energy *density*, was not only a mistake for a statically-balanced universe, but also a mistake for a dynamically-expanding universe.

Keywords

Quantum Cosmology, Planck Scale, Cosmological Constant, Black Holes, Holographic Principle, Flat Space Cosmology, AdS-CFT, ER = EPR, Cosmology Model

1. Introduction and Background

It appears that the correct mathematical treatment of our visible universe as an expanding black hole-like global object was first *successfully* achieved in 2015 [1] [2]. To achieve this, a thermodynamic formula *slightly different* from the Hawking black hole temperature formula was necessary. This was accomplished primarily due to the incorporation of a geometric mean refinement of Hawking's black hole temperature formula taking the following form:

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

wherein T_t is time-dependent cosmic temperature, M_t is temperature-dependent cosmic mass, R_t is temperature-dependent cosmic Schwarzschild radius, R_{pl} is the Planck radius (to be defined below), and all other symbols are well-known physical constants. A stunning result was the *prediction*, in 2015, of today's most precise (*i.e.*, low uncertainty) Hubble constant measurement derived from a CMB temperature study reported in 2023 by Dhal *et al.* [3]. In the current paper, we will hereafter refer to Equation (1) as the Tatum *et al.* thermodynamic formula.

Although implied by the assumptions of the 2015 Flat Space Cosmology (FSC) model, their quantum cosmology equations were not published explicitly until 2018 [4]. These equations are repeated herein for the convenience of the reader:

$$R \cong \frac{\hbar^{3/2}c^{7/2}}{32\pi^2 k_B^2 T^2 G^{1/2}} \qquad R_0 \cong \frac{\hbar^{3/2}c^{7/2}}{32\pi^2 k_B^2 T_0^2 G^{1/2}} \tag{2}$$

$$H \cong \frac{32\pi^2 k_B^2 T^2 G^{1/2}}{\hbar^{3/2}c^{5/2}} \qquad H_0 \cong \frac{32\pi^2 k_B^2 T_0^2 G^{1/2}}{\hbar^{3/2}c^{5/2}} \tag{3}$$

$$t \cong \frac{\hbar^{3/2}c^{5/2}}{32\pi^2 k_B^2 T^2 G^{1/2}} \qquad t_0 \cong \frac{\hbar^{3/2}c^{5/2}}{32\pi^2 k_B^2 T_0^2 G^{1/2}} \tag{4}$$

$$M \cong \frac{\hbar^{3/2}c^{11/2}}{64\pi^2 k_B^2 T^2 G^{3/2}} \qquad M_0 \cong \frac{\hbar^{3/2}c^{11/2}}{64\pi^2 k_B^2 T_0^2 G^{3/2}} \tag{5}$$

$$Mc^2 \cong \frac{\hbar^{3/2}c^{15/2}}{64\pi^2 k_B^2 T^2 G^{3/2}} \qquad M_0 c^2 \cong \frac{\hbar^{3/2}c^{15/2}}{64\pi^2 k_B^2 T_0^2 G^{3/2}} \tag{6}$$

The right-hand column equations are for correlation with current cosmological observations, using the 2009 Fixsen Cosmic Microwave Background (CMB) temperature of 2.72548 K as T_0, the only observational input [5]. The remarkably good correlations between these FSC quantum cosmology equations and current observations have been well-documented [6] The FSC model has proven to be quite useful in its predictive capacity [7] [8].

It is the purpose of the present paper to show how the FSC model can employ the holographic principle to offer a solution of the cosmological constant problem, whereas this appears to be extremely difficult or impossible using the standard ΛCDM cosmology model. This difficulty can be expressed by quantifying the discrepancy between the quantum field theory estimate of the value of the cosmological constant and observational estimates of its value. The discrepancy is a factor roughly on the order of 10^{121}! This has often been referred to as the most embarrassing problem in all of modern physics [9] [10].

2. The Solution

It is theorized that the Big Bang may have started with what is likely to be the smallest possible micro black hole, the Planck mass particle, m_P. Since the Planck mass has a density at or near what is referred to as the "Planck density," one customarily derives its value according to m_P/l_P^3, which equals 5.155×10^{96} $kg \cdot m^{-3}$ using the NIST 2018 CODATA [11] [12]. However, we can also treat the

Planck mass particle as a micro black hole with a Schwarzschild radius of two Planck lengths ($2l_P$). In FSC, this is referred to as the "Planck radius" R_{pl} [see Equation (1)]. If we divide the m_P value of 2.17643424 × 10^{-8} kg by the volume of a sphere of Schwarzschild radius $2l_P$, we get a result of 1.538322 × 10^{95} kg·m^{-3}. This corresponds to a Planck energy density value of 1.382584 × 10^{112} J·m^{-3}. These are almost certainly more realistic values for a micro black hole Planck density, and will be taken as such in the calculations below.

Furthermore, given its Schwarzschild radius $2l_P$, we can assume that the sphere of the Planck mass micro black hole has a surface area of $4\pi R_{pl}^2$, which is $16\pi l_P^2$. This implies a starting Hubble surface area value for the Planck epoch black hole universe of 1.3130 × 10^{-68} m^2. We can then compare this starting Hubble horizon surface area value with that of the current Hubble surface. This would be according to the $4\pi R_0^2$ spherical surface formula. In FSC, the current Hubble radius value R_0 is 1.382894 × 10^{26} *m*. Thus, the current value of $4\pi R_0^2$ would be 2.40318 × 10^{53} m^2. Interestingly, the ratio of 2.40318 × 10^{53} m^2 to 1.3130 × 10^{-68} m^2 is 1.8303 × 10^{121}, which also can be expressed as $10^{121.26}$. This is the longstanding FSC magnitude of the cosmological constant problem. This can hardly be a coincidence with respect to the magnitude of the standard cosmology problem.

It is reasonable to treat the expanding cosmic black hole horizon at radius R_t (the time-dependent Schwarzschild radius correlated to the increasing Schwarzschild mass M_t) as a membrane of area $4\pi R_t^2$. One can view this boundary surface (hereafter referred to as the "boundary") as continually radiating a Hawking temperature (see Haug & Tatum for details). Thus, this temperature smoothly declines as the cosmic black hole smoothly grows in mass and expands adiabatically.

We can also, according to the holographic principle of Susskind and 't Hooft [13], treat the boundary as a conceptually separate entity in comparison to the black hole interior (hereafter referred to as the "bulk"). Therefore, we are entitled to view the boundary as starting out, in the Planck mass epoch, with the Planck energy value of a single Planck mass micro black hole equal to $m_P c^2$ equal to 1.9561 × 10^9 J. The Planck epoch temperature T_P of this $16\pi l_P^2$ membrane is equal to 5.65 × 10^{30} K (see Haug & Tatum, their Equation (6)), which can be compared to a $4\pi l_P^2$ (*i.e.*, according to a single Planck length Schwarzschild radius) boundary membrane temperature of $h^{1/2}c^{5/2}G^{-1/2}k_b^{-1}$ equal to 1.4168 × 10^{32} *K*, the classical Planck temperature (see Buczyna *et al.* reference [12] on Planck units).

One can now use the holographic principle to create a one-to-one correspondence of energy densities between the boundary and the bulk. The energy density within the current boundary surface area should be the Planck energy density of 1.382584 × 10^{112} J·m^{-3} (as calculated above for the micro black hole epoch) divided by 1.8303 × 10^{121} for the current cosmological epoch, to obtain the current FSC energy density within the boundary and bulk. The resulting energy density is 7.554 × 10^{-10} J·m^{-3} (see reference [6]). This is also quite consistent with the current *observed* cosmological constant value of Pvac = 5.3566 × 10^{-10} J·m^{-3} from the 2015 Planck Collaboration data set [14]. In the FSC model, another cosmological conundrum, called the cosmological *coincidence* problem, is also solved. This is because, in FSC, the matter and vacuum densities are *always* highly correlated. This *cannot* be true for the standard ΛCDM model.

3. Discussion

The standard ΛCDM cosmological model is vexed by many conundrums, not the least of which are the cosmological constant problem and the cosmological coincidence problem. There has been a suspicion, for several decades now, that this may be because the ΛCDM model is not a fully-integrated quantum cosmology model. This appears to be true. On the other hand, the FSC model of Tatum *et al.* has derived some extremely useful Planck scale quantum cosmology formulae which, so far, appear to be accurate over a wide cosmic time and temperature range. An exciting recent development was Haug & Wojnow's derivation of the Tatum *et al.* thermodynamic formulae of Equation (1) using the Stephan-Boltzmann law [15].

Thus, FSC appears to be usefully integrating the general relativity of black holes with certain quantum formulae. This is what is meant by referring to FSC as a "quantum cosmology model." It may be the first of many similar models to follow. To this author's knowledge, no particularly useful quantum cosmology model preceded FSC, presumably because there was insufficient development of the appropriate cosmic thermodynamic formulae, which have always been a key feature of FSC.

The purpose of the present paper has been to use the black hole holographic principle of Susskind and 't Hooft to provide a solution to the cosmological constant problem. Maldacena's AdS-CFT and ER = EPR hypotheses [16] [17] and the related holographic principle appear to have been the biggest cosmological breakthroughs in recent decades. They have a firmly-established mathematical basis, so that cosmologists can have some confidence in their careful application or, at the least, a direction in which to look for a new breakthrough, such as presented herein.

Importantly, in just the last few years, some respected physicists and cosmologists have joined in the speculation that our universe might very well be an evolving and expanding black hole-like object [18] [19] [20] [21]. It is good to now have them joining the conversation. Siegel's summary on this topic is especially nice. Lineweaver and Patel make some excellent points as well. Objections that such speculations should be forbidden by general relativity are simply short-sighted. Black holes and related objects, such as white holes, are clearly allowed by general relativity and still too mysterious for us to forestall a debate on related cosmological models. The apparent successes of the FSC Schwarzschild cosmological model are also in support of this viewpoint. Our visible universe has a surprising number of mathematical similarities to a gigantic black hole. As discussed in a comprehensive summary of the FSC model peer-reviewed publications [22], not the least of these are the mass-to-radius ratio and the current average density of the visible universe. For instance, the mass-to-radius ratio of the visible universe (if we include dark matter mass) and a Schwarzschild black hole are both in the range of $c^2/2G$ [23] [24]. Furthermore, the visible universe appears to be at or very near critical density. Surprisingly, this is the *average* density of a Schwarzschild black hole with a radius of approximately 14 billion light-years or very slightly larger (14.62 billion light-years in the FSC model). As a perpetual matter-generating model, FSC specifically models a universe at perpetual critical density. It appears, from CMB observations, that our visible universe has shown this spatial flatness feature (*i.e.*, critical density) as far back in cosmic time as we can observe to date. Thus, it appears to be an effective model for what we can see at present.

In their holographical principle hypothesis, Susskind and ‘t Hooft make separate distinctions between the horizon boundary of a black hole and its bulk. If their principle is correct, there is a one-to-one correspondence between properties of the boundary (a two-dimensional membrane of curved space-time) and the conventional 3-D bulk. As shown above, the original Planck mass energy (not density) within the boundary membrane is what is dispersed throughout the Hubble horizon boundary membrane during cosmic expansion. The resulting energy *density* dilutional effect is quantitively the same as observed in the 3D bulk. So, as often mentioned in previous papers, there is no cosmological constant problem in FSC. Finally, although some theorists [25] have speculated that there is no need to introduce a cosmological constant, the current paper accepts the presence of such a constant, despite its small value. Otherwise, it would be most difficult to explain why the universal expansion is not decelerating.

As for a way to potentially falsify the solution presented in the present paper, the best way to do so would be to measure the cosmic vacuum energy density so precisely that the calculated model density presented herein is *consistently* five or more standard deviations outside of the observational determination. At present, this does not appear to be the case. The two numbers are very close to one another, and there is yet too much uncertainty in the value of the Hubble constant. However, the coming decade of more precise dark energy observations and more precise Hubble constant determinations should be a good test of the hypothesis presented herein.

4. Summary and Conclusions

The current paper integrates a quantum conception of the Planck epoch early universe with FSC model formulae and the holographic principle, to offer a reasonable theoretical explanation and solution of the cosmological constant problem. Such a solution does not appear to be achievable in cosmological models which do not integrate black hole formulae with quantum formulae, such as the Stephan-Boltzmann law.

Einstein's "cosmological constant" was created *only* to achieve a statically-balanced universe (*i.e.*, neither contracting nor expanding). This was a mistake which he admitted to as his greatest blunder [26]. What was particularly erroneous about his blunder is well-described by Bodanis. The assumption that our universe could be kept perpetually in static balance by any sort of energy force in opposition to that of attractive gravity was simply unrealistic in the face of any perturbations to such a precarious balance.

However, in a dynamically-expanding universe, assuming the value of Lambda to remain constant *over the great span of cosmic time*, in terms of energy *density*, also appears to have been a mistake. At the very least, this possibility has been a topic of serious discussion in a number of recent scientific papers [27] [28] [29] [30]. And now, with the aid of the FSC model, the cosmological constant problem appears to be understandable and solved. We humbly and respectfully request that other investigators in the field carefully consider the above mathematical arguments and accept or attempt to refute the results.

Dedications and Acknowledgements

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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