Flat Space Cosmology

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A New Model of the Universe Incorporating Astronomical Observations of Black Holes, Dark Energy and Dark Matter

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and

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Preface

When one combines the observational results of the past three decades with those pending in the current decade, it appears that there has never been a better time to be an astrophysicist or cosmologist. Most would agree that we are fortunate to be living in an observational and theoretical 'Golden Age' with respect to understanding our place in the universe.

Over the previous decade, both of us, working at opposite ends of the world, have been involved on the theoretical side as cosmologists. Making use of the internet, we joined forces in 2015 after one of us (E.T.T.) published two papers in *Journal of Cosmology* commenting on initial Planck satellite survey findings. We were both simultaneously struck by something not widely recognized or discussed at the time.

The results of the Planck survey which *were* widely discussed crystalized the suspicion that our observable universe is at, or very near, what is called 'critical density.' To put it simply, the observations indicated that the total observable mass of the universe is a tiny fraction less than what would be necessary to decelerate the universal expansion into a 'Big Crunch' in the distant future. To use the vernacular for 'critical density,' the observable universe is spatially flat to an extraordinary degree (perhaps to within one part in 10^{60}!).

The critical density confirmation was indeed impressive, but what captured our attention more than anything else was the observational implications concerning the ratio of the mass of the observable universe to its radius. One can readily check these numbers for oneself by looking up 'Observable Universe' on Wikipedia. The current best estimate of the mass of *ordinary* matter is 1.5×10^{53} kg and the current best estimate of the radius of the observable universe is 4.4×10^{26} m. If we compare these two numbers in the form of the ratio of the mass M to the radius r (M/r ratio), we get approximately 3.4×10^{26} kg/m for the observable universe. *What is particularly interesting about this number is that it is the same order of* *magnitude as the M/r ratio of a black hole!* A theoretical Schwarzschild black hole, for instance, has a *M/r* ratio of $c^2/2G$, which is approximately 6.73×10^{26} kg/m.

Moreover, the *M/r* ratio comparison becomes even more compelling when we consider that the observable universe has at least 5–6 times the mass of ordinary matter in the form of dark matter. Thus, our observations would imply a total matter mass of about 10^{54} kg within the observable radius of 4.4×10^{26} m. Using the Schwarzschild formula, $r_s = 2GM/c^2$, and plugging in 10^{54} kg for *M*, we can see that the Schwarzschild radius r_s should be about 1.485×10^{27} m for an object with a mass of 10^{54} kg. One can appreciate the significance of this comparison (4.4×10^{26} m versus 1.485×10^{27} m) by realizing that 'any object whose radius is smaller than its Schwarzschild radius is called a black hole' (as noted in the referenced Wikipedia entry for 'Schwarzschild radius').

Lest we be accused of jumping to unwarranted conclusions, we are not asserting that our universe is a black hole *in the usual sense of the term*. After all, it is clearly expanding rather than collapsing. However, our realization that it actually does have the approximate density of a 13.7 billion light-year radius black hole (9.5×10^{-27} kg/m^3) was the primary inspiration and jumping off point for the publications collected in this book. *The question worth asking is whether or not our universe could be something very much like a time-reversed black hole-like object. If one prefers, such an object can be referred to as a 'white hole'* instead. Furthermore, as discussed in the first chapter, the prior theoretical work of Hawking and Penrose, rigorously *proving* the similar, if not identical, physical nature of astrophysical and cosmological 'singularities,' clearly opens the door for exploring this question. Hawking was one of the first to consider such a question, although, to our knowledge, he never pursued it with a formal cosmological model.

This book offers readers the opportunity to quickly familiarize themselves with the unique cosmological model we first published in 2015. For reasons discussed at length in the summarizing first chapter, our model is called 'Flat Space Cosmology' (FSC) because it models a time-reversed (*i.e.,* expanding) black hole-like object at *perpetual* critical density. We don't believe that current observations of critical density are an inexplicable strange coincidence, but rather an important clue as to how our remarkably fractal-like universe actually works. To use computer programmer jargon, this particular cosmological 'coincidence problem' is not a 'bug' but rather a 'feature.'

The summary first chapter contains the FSC model assumptions and many of its derivations correlating closely with cosmological observations. The second chapter explains why FSC appears to be superior to standard inflationary cosmology in at least eleven different categories. All ensuing chapters are excerpts from identically-entitled, peer-reviewed, FSC papers published in the same chronological order from 2018 to the present. They each address individual key features of the FSC model in logical sequence. The only exceptions are timely chapters 12 and 16, which introduce the reader to a plausible dark matter theory. This leads us to believe that intergalactic dark matter may have been significantly underestimated in terms of its percentage of the critical density. The FSC model and the intriguing dark matter theory are brought together in Chapter 14 to suggest that the total matter mass-energy and dark energy percentages may in fact be closer to 50:50, rather than the present estimate of 32:68. If so, the additional cosmological 'coincidence problem' of similar orders of magnitude for matter energy and dark energy might actually be an important clue as to the nature of dark energy with respect to matter energy. Are matter energy and dark energy within a *scaling* cosmic vacuum possibly two sides of the same cosmological coin? Could a continuous link between cosmic vacuum energy density and matter energy density have something to do with quantum nonlocality through *instantaneous* (*i.e.,* faster than light!) conservation of cosmic energy? We suspect this may be the case in our matter-generating quintessence model. If so, it would not be the first time that matter and energy were found to be deeply interconnected. Significantly, as discussed in this book, the FSC model does not have the well-known vacuum energy density 'cosmological constant problem' that deeply troubles proponents of the concordance model (*i.e.,* standard ΛCDM cosmology).

The final two chapters focus entirely on dark matter and dark energy. These are two of the remaining great mysteries of the universe. The FSC model has something to say about both topics. We trust that you will find both concluding chapters to be interesting!

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February, 2021

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CHAPTER 1

A Heuristic Model of the Evolving Universe Inspired by Hawking and Penrose

Abstract: A heuristic model of universal expansion is presented which uses, as its founding principle, Stephen Hawking's singularity theorem. All assumptions of this model are intrinsically linked to Hawking's theorem and its implications with respect to the time-symmetric properties of general relativity. This is believed to be the first mathematical model constructed in such a way, and it is remarkably accurate with respect to current astrophysical observations. The model's origin, basic assumptions and selected observational correlations are presented in this chapter, including its accurate derivation of the observed Hubble parameter value.*

Keywords: Flat Space Cosmology; Cosmology Theory; Hubble Parameter; Cosmic Flatness; Cosmic Entropy; Black Holes; $R_h = ct$ Model

1. INTRODUCTION AND BACKGROUND

A heuristic mathematical model of the evolving universe, for the purpose of this chapter, is one which tracks its *global* parameters (Hubble parameter, radius, mass, energy, entropy, average temperature, temperature anisotropy, *etc*.) as a function of cosmic time. For it to be useful, such a model should be consistent with everything we currently observe about the universe as a global object, and extend these parameters indefinitely into

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the past and future. In assembling such a model, it is particularly useful to start with a founding principle on which some or, preferably, all of the starting assumptions can be based. For this particular model, the founding principle is based upon the groundbreaking work of Roger Penrose [1] and Stephen Hawking [2][3] concerning the similar theoretical nature of astrophysical and cosmological singularities. This founding principle is Hawking's singularity theorem.

Hawking's singularity theorem implies that our universe, following time-symmetric properties of general relativity, could be treated mathematically as if it were a cosmological black hole-like object moving *backwards in time* (*i.e., expanding from* a singularity state as opposed to *collapsing to* a singularity state). Unfortunately, although Hawking's theorem was rigorously logical, he never actually put together a predictive mathematical cosmological model based upon his theorem. *What is presented in this chapter is believed to be the first such model.*

This author (E.T.T.) was sufficiently intrigued by the initial Planck satellite survey results and the potential implications of Hawking's singularity theorem that he teamed up with two Indian physicists (U.V.S. Seshavatharam and S. Lakshminarayana) in 2015 to publish the seminal papers [4][5][6] on this model. For reasons to be discussed below, this model is called 'Flat Space Cosmology' (FSC). The current five basic assumptions of FSC are presented below.

2. FIVE BASIC ASSUMPTIONS OF FLAT SPACE COSMOLOGY

1. The cosmic model is an ever-expanding sphere such that the cosmic horizon always translates at speed of light c with respect to its geometric center at all times t. The observer is operationally-defined to be at this geometric center at all times t.
2. The cosmic radius R_t and total mass M_t follow the Schwarzschild formula $R_t \cong 2GM_t/c^2$ at all times t.
3. The cosmic Hubble parameter is defined by $H_t \cong c/R_t$ at all times t.
4. Incorporating our cosmological scaling adaptation of Hawking's black hole temperature formula, at any radius R_t, cosmic temperature T_t is inversely proportional to the geometric mean of cosmic total mass

M_t and the Planck mass M_{pl}. R_{pl} is defined as twice the Planck length (*i.e.,* as the Schwarzschild radius of the Planck mass black hole). With subscript t for any time stage of cosmic evolution and subscript pl for the Planck scale epoch, and, incorporating the Schwarzschild relationship between M_t and R_t,

$$\left.\begin{array}{l} k_B T_t \cong \dfrac{\hbar c^3}{8\pi G\sqrt{M_t M_{pl}}} \cong \dfrac{\hbar c}{4\pi\sqrt{R_t R_{pl}}} \\ \left\{\begin{array}{ll} M_t \cong \left(\dfrac{\hbar c^3}{8\pi G k_B T_t}\right)^2 \dfrac{1}{M_{pl}} & (A) \\ R_t \cong \dfrac{1}{R_{pl}}\left(\dfrac{\hbar c}{4\pi k_B}\right)^2 \left(\dfrac{1}{T_t}\right)^2 & (B) \\ R_t T_t^2 \cong \dfrac{1}{R_{pl}}\left(\dfrac{\hbar c}{4\pi k_B}\right)^2 & (C) \\ t \cong \dfrac{R_t}{c} & (D) \end{array}\right. \end{array}\right\} \tag{1}$$

5. Total cosmic entropy follows the Bekenstein-Hawking black hole entropy formula [7][8]:

$$S_t \cong \frac{\pi R_t^2}{L_p^2} \tag{2}$$

The rationale for these basic assumptions is closely tied to Hawking's singularity theorem as it might pertain to a time-reversed Schwarzschild cosmological black hole-like object. From the centrally-located observer's point of view, outwardly-moving photons traveling along geodesics at the cosmic boundary (*i.e.,* the fastest-moving 'particles' of the expansion) are infinitely redshifted and thus define the observational event horizon. Therefore, as given in assumption 3, the truly *global* Hubble parameter value can always be defined as speed of light c divided by the ever-increasing Schwarzschild radius R_t. While the first equation of assumption 4 closely resembles Hawking's black hole temperature formula, it is modified so that cosmological mass scales in

Planck mass units. This is thought to be more appropriate for a scaling cosmological model, as opposed to the relatively static thermodynamics of an astrophysical (*i.e.,* stellar) black hole.

As described in some detail in the seminal FSC papers, the first three assumptions allow for perpetual Friedmann's critical density (*i.e.,* perpetual global spatial flatness) of the expanding FSC cosmological model from its inception. It should be emphasized that these assumptions were not adopted for this particular purpose. However, this unexpected and fortuitous outcome is perhaps the most important feature of this model. By dividing the Schwarzschild mass (defined in terms of cosmic radius R_0) by the spherical volume, and substituting $c^2/R_0^{\,2}$ with $H_0^{\,2}$, Friedmann's critical mass density $\rho_0 = 3H_0^2 / 8\pi G$ is achieved for *any* given moment of theoretical observation (note the subscript '0') in cosmic time. So, *perpetual Friedmann's critical density and global spatial flatness from inception is a fundamental feature of the FSC model. Our model was named for this important feature*.

This perpetual spatial flatness feature, as well as the finite properties of light-speed expansion of the cosmic horizon, obviates the need for an inflationary solution to the cosmological 'flatness problem' and the 'horizon problem.' It also avoids the disturbing and incredible 'infinite multiverse' implications inherent within inflationary cosmic models. The problems of the required new physics of the 'inflaton' field, and of the 'past-incomplete' nature [9] of inflationary models, are also avoided in the FSC model. Many of these differentiating features of FSC with respect to standard inflationary models were discussed at length in a recent FSC summary paper [10] (see Chapter two).

Based upon the relations proceeding from the top equation of assumption 4, and the model Hubble parameter definition of assumption 3, the following FSC log graph can be presented in **Figure 1**.

An overlay of cosmic epochs evolving from the Planck scale epoch, as believed to be the case from particle physics experiments and quantum field theory, is presented in **Figure 2**.

In both figures, there is a tight correlation between cosmic temperature and time elapsed since the Planck scale epoch (not shown) at approximately the 10^{-43} second mark of cosmic expansion.

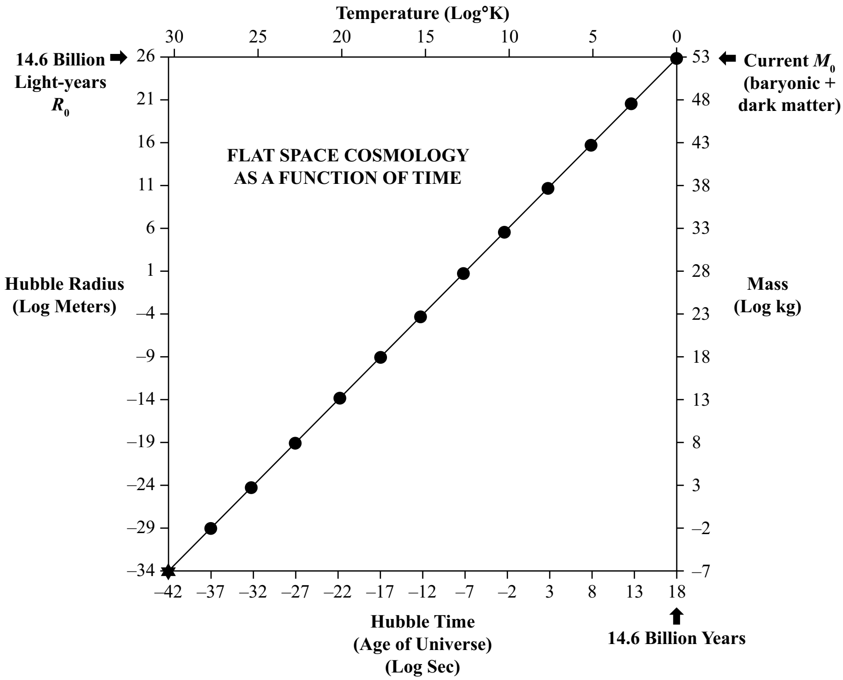

Figure 1 Cosmic Radius and Mass versus Cosmic Time and Temperature.

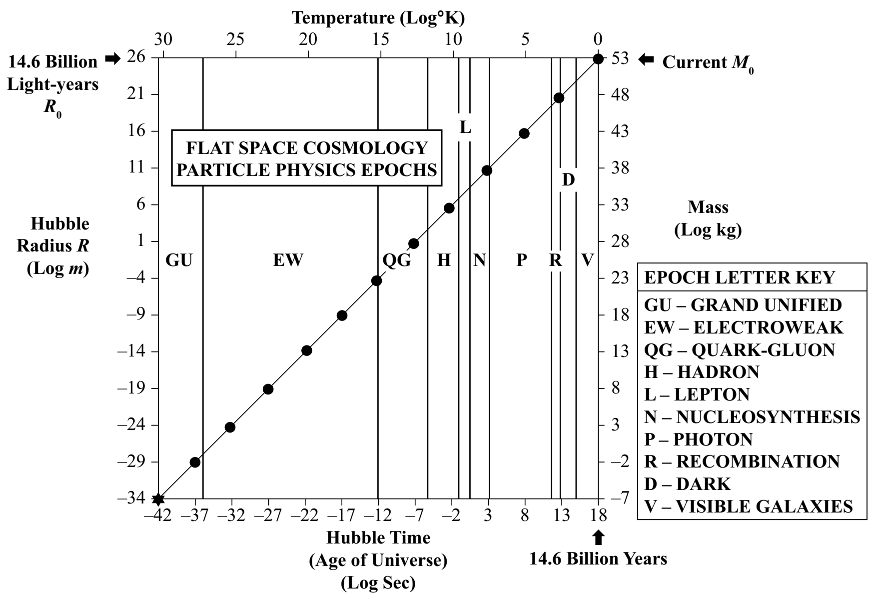

Figure 2 Particle Physics Epochs as a Function of Cosmic Temperature.

3. FSC CORRELATIONS TO ASTRONOMICAL OBSERVATIONS

The following temperature-dependent cosmological parameters can be easily calculated in the FSC model. The only free parameter in any of these equations is the cosmic temperature. Furthermore, by incorporating the values of T_0, $\hbar$, c, G, k_B, and π to as many decimal places as known, any of these FSC parameters can be shown to closely match astronomical observations.

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

$$H \cong \frac{32\pi^2 k_B^2 T^2 G^{1/2}}{\hbar^{3/2} c^{5/2}} \qquad H_0 \cong \frac{32\pi^2 k_B^2 T_0^2 G^{1/2}}{\hbar^{3/2} c^{5/2}} \tag{4}$$

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

$$M \cong \frac{\hbar^{3/2} c^{11/2}}{64\pi^2 k_B^2 T^2 G^{3/2}} \qquad M_0 \cong \frac{\hbar^{3/2} c^{11/2}}{64\pi^2 k_B^2 T_0^2 G^{3/2}} \tag{6}$$

$$Mc^2 \cong \frac{\hbar^{3/2} c^{15/2}}{64\pi^2 k_B^2 T^2 G^{3/2}} \qquad M_0 c^2 \cong \frac{\hbar^{3/2} c^{15/2}}{64\pi^2 k_B^2 T_0^2 G^{3/2}} \tag{7}$$

Current parameters are calculated in the right-hand column, which incorporates the currently-observed T_0 value of 2.72548 K. Accordingly, the theoretical current FSC Hubble parameter value at this temperature is:

$$H_0 = 2.167862848658891 \times 10^{-18}\ \text{s}^{-1}\ (66.89325791854758\ \text{km.s}^{-1}.\text{Mpc}^{-1})$$

This derived theoretical global H_0 value fits the 2018 Planck Collaboration observational global H_0 value of 67.36 +/– 0.54 km.s^{-1}.Mpc^{-1} (68% confidence interval for TT, TE, EE + lowE + lensing) [11] and the DES 2018 H_0 value of 67.77 +/– 1.30 km.s^{-1}.Mpc^{-1} (SN + BAO) [12]. Since the Planck observational value was obtained with the aid of extraordinarily precise observations of the CMB black body radiation spectrum, this may be as close as we can come in the foreseeable future to a truly *global* Hubble parameter measurement. And yet, the above theoretical H_0 calculation is based *solely* upon this one carefully-measured parameter: $T_0 = 2.72548$ K. This is a remarkable result!

Therefore, one should have great confidence that the following cosmological parameters incorporating the FSC-derived H_0 value are also highly accurate.

$$t_0 \cong \frac{1}{H_0} = 4.61283794 \times 10^{17} \text{ s } (14.61694684 \times 10^{9} \text{ sidereal years})$$
$$(\text{multiplying by 1 sidereal year per } 3.155814954 \times 10^{7} \text{ s})$$

This value is simply the reciprocal of the above-derived Hubble parameter value, as one would expect for the perpetually spatially-flat FSC cosmic model in comparison to the standard inflationary model. For reasons not elaborated here, *any* inflationary model would be *expected* to calculate a slightly younger cosmic age. 13.8 billion years is now consensus for the standard inflationary model.

$$R_0 \cong \frac{c}{H_0} = 1.38289402 \times 10^{26} \text{ m } (14.617201 \times 10^{9} \text{ light-years})$$
$$(\text{multiplying by 1 Julian light-year per } 9.4607304725808 \times 10^{15} \text{ m})$$

This current cosmic radius value correlates with current cosmic time by $R_0 = ct_0$. Therefore, FSC is a $R_h = ct$ cosmological model. Later discussion in this chapter will focus on the extremely good statistical fit between $R_h = ct$ models and the accumulated Type Ia supernovae light curve data purported to 'prove' the existence of cosmic acceleration.

$$Vol_0 = \frac{4\pi}{3}\left(\frac{c}{H_0}\right)^3 = 1.10778456 \times 10^{79} \text{ m}^3$$

$$M_0 = \frac{c^3}{2GH_0} = 9.31126529 \times 10^{52} \text{ kg}$$

This total mass number can be compared very favorably to a rough estimate made from astronomical observations. The visible matter consists of roughly 100 billion galaxies averaging roughly 100 billion stars each, of average star mass equal to roughly 1.4×10^{30} kg (70 percent of solar mass), totaling to roughly 1.4×10^{52} kg. The 2015 Planck Collaboration report indicates a universal matter ratio of approximately 5.5 parts dark matter to one part visible (baryonic) matter. This brings the total estimated matter in the observable universe to approximately 9.1×10^{52} kg. A recent study [13] of average mass density of intergalactic dust gives a value of approximately 10^{-30} kg.m^{-3}. Since this is approximately one part intergalactic dust to 10^4 parts galactic and peri-galactic matter, intergalactic dust does not appreciably modify the estimated total observational mass of matter given above. Accordingly, this observational estimate is remarkably close to the above FSC theoretical calculation of total cosmic mass attributed to positive energy (*i.e.,* gravitationally attractive) matter.

According to the FSC Friedmann equations (referenced below), the positive matter mass-energy is equal in absolute magnitude, and opposite in sign, to the negative (dark) energy at all times. This is a 50/50 percentage ratio as opposed to the approximately 30/70 ratio implied by yet unproven, and supposedly dark energy-dominating, cosmic *acceleration*. However, without definitively proving cosmic acceleration, standard inflationary cosmology cannot claim this 30/70 ratio! (Please see the discussion and relevant references in the last two paragraphs of this section).

$$M_0 c^2 = \frac{c^5}{2GH_0} = 8.3685479 \times 10^{69} \text{ J}$$

$$\rho_0 = \frac{3H_0^2}{8\pi G} = 8.40530333 \times 10^{-27} \text{ kg.m}^{-3} \text{ (critical mass density)}$$

This closely approximates the observational cosmic mass density calculation of critical density.

$$\rho_0 c^2 = \frac{3H_0^2 c^2}{8\pi G} = 7.554309896 \times 10^{-10} \text{ J.m}^{-3} \text{ (critical mass-energy density)}$$

This closely approximates the observational cosmic mass-energy density and the observational vacuum energy density. They are equal in absolute magnitude, and opposite in sign, in FSC.

A recent paper [14] has integrated the FSC model into the Friedmann equations containing a Lambda Λ cosmological term. Thus, FSC has been shown to be a scalar dynamic Λ dark energy model of the *w*CDM type, wherein equation of state term *w* is always equal to –1.0 (See Chapter 11). Furthermore, it is well-known that a sufficiently realistic $R_h = ct$ model, such as FSC, can fit within the tightest constraints of the Supernova Cosmology Project (SCP) data. Figure 5 of the following link from the SCP is offered as proof: https://dx.doi.org/10.1088/0004-637x/746/1/85 [15]. One can readily see (by the "Flat" line intersection) that a realistic spatially-flat universe model such as FSC is an excellent fit with all such SCP observations to date.

Currently, there is no certainty about the percentage of the critical density which is attributable to dark matter. Those with knowledge of the observational studies of the ratio of dark matter to visible matter realize the difficulty of determining a precise *co-moving* value for this ratio at the present time. Galactic and peri-galactic distributions of dark matter can be surprisingly variable, as evidenced by the 29 March 2018 report in *Nature* [16] of a galaxy apparently completely lacking in dark matter! Although the 2015 Planck Collaboration consensus is a large-scale approximate ratio of 5.5 parts dark matter to one part visible matter, this can only be considered as a rough estimate of the actual *co-moving* ratio, particularly if this ratio varies significantly over cosmic time. A 9.2-to-1 actual ratio in approximately co-moving galaxies (*i.e.,* those within about one hundred million light-years of the Milky Way galaxy) remains a possibility, and would change the ratio of total matter mass-energy to dark energy to essentially unity (*i.e.,* 50% matter mass-energy and 50% dark energy). Thus, the intersection zone of tightest constraints shown in the above-mentioned SCP figure should then correlate with 0.5 Ω_m and 0.5 Ω_Λ. This is one of several important testable predictions discriminating the FSC model from the standard inflationary cosmology model. Precise dark matter measurements of approximately co-moving galaxies are in order, for comparison with the CMB observational Planck Collaboration result.

The question of dark energy density dominance over total matter energy density remains in doubt, at the present time, in the scientific literature. Several recent papers [17][18][19][20][21] have clearly shown that cosmic acceleration, as opposed to the cosmic coasting of $R_h = ct$ models, is not yet *proven*. These are not, of course, refutations of the existence of dark energy as may be defined by general relativity. Rather, they are statistical analyses placing some doubt on dark energy *dominance*, and thus cosmic *acceleration*. These papers are well worth reading.

4. SUPERIORITY OF FSC OVER INFLATIONARY COSMOLOGY

As detailed in the recent FSC summary paper [10] (see Chapter two), there are at least eleven categories in which FSC appears to be superior to standard inflationary cosmology. What makes FSC so powerful in this regard is its ability to make very specific predictions for observations which can be used to falsify the theory if FSC is incorrect. To date, FSC as a global parameter observational predictor has not been falsified.

Standard inflationary cosmology, on the other hand, has largely been cobbled together from observations, and would be difficult to falsify because it makes few falsifiable predictions. The reader should remember that the various theories of cosmic inflation contained *ad hoc* adjustments to accommodate observations [22][23], and that the presumed 'inflaton' energy field of inflation was invented before the actual cosmological vacuum energy now called dark energy was discovered approximately two decades later. It is notable that, rather than attempt to apply the newly-discovered dark energy as a scalar quantity also at work in the early universe, standard inflationary cosmologists have generally assumed the dark energy field to be something entirely distinct from their theoretical inflaton energy field. There has also been an assumption that the post-inflationary energy density of the vacuum must have been a *constant* over the great span of cosmological time. And yet, the theoretical/observational discrepancies created by this 'cosmological constant problem' [24][25] are considered by many to be the most embarrassing problem in all of physics.

The reader is referred to Chapter two for a detailed description as to why FSC is superior to standard inflationary cosmology in the following eleven categories: Cosmic Dawn Early Surprises; Predictions Pertaining to Primordial Gravity Waves; Predicting the Magnitude of CMB Temperature Anisotropy; Predicting the Hubble Parameter Value; Quantifiable Entropy and the Entropic Arrow of Time; Clues to the Nature of Gravity, Dark Energy and Dark Matter; Cosmological

Constant Problem; Dark Matter and Dark Energy Quantitation; Quantum Cosmology; Predicting the Value of Equation of State Term *w*; Requirements for New Physics.

5. SUMMARY AND CONCLUSIONS

This chapter has introduced the reader to the heuristic FSC cosmology model. Like all useful heuristics, FSC provides a means for accurately calculating a variety of parameters. The founding principle for the construction of this model is Hawking's singularity theorem. Accordingly, all assumptions of this model are intrinsically linked to Hawking's theorem and its implications with respect to widely-accepted time-symmetric properties of general relativity. Black holes and black hole-like objects are now known to exist. Furthermore, we know that such objects range over a remarkably wide, fractal-like, scale. Our universe may simply be the largest of these objects which can be observed, albeit from the inside!

Beginning with the work of Penrose and Hawking, the black hole-like properties of the universe have continued to fascinate and surprise us. Our current 'Golden Age' of astrophysical observations and new theories certainly promises even more surprises ahead.

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CHAPTER 2

Why Flat Space Cosmology is Superior to Standard Inflationary Cosmology

Abstract: Following recent Cosmic Microwave Background (CMB) observations of global spatial flatness, only two types of viable cosmological models remain: inflationary models which almost instantaneously attain cosmic flatness following the Big Bang; and non-inflationary models which are spatially flat from inception. Flat Space Cosmology (FSC) is the latter type of cosmological model by virtue of assumptions corresponding to the Hawking-Penrose implication that a universe expanding from a singularity could be modeled like a time-reversed black hole. Since current inflationary models have been criticized for their lack of falsifiability, the numerous falsifiable predictions and key features of the FSC model are herein contrasted with standard inflationary cosmology. For the reasons given, the FSC model is shown to be superior to standard cosmology in the following eleven categories: Cosmic Dawn Early Surprises; Predictions Pertaining to Primordial Gravity Waves; Predicting the Magnitude of CMB Temperature Anisotropy; Predicting the Hubble Parameter Value; Quantifiable Entropy and the Entropic Arrow of Time; Clues to the Nature of Gravity, Dark Energy and Dark Matter; Cosmological Constant Problem; Dark Matter and Dark Energy Quantitation; Quantum Cosmology; Predicting the Value of Equation of State Term *w*; Requirements for New Physics.*

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Keywords: Cosmology Theory; Cosmic Inflation; Dark Energy; Cosmic Flatness; CMB Anisotropy; Cosmic Entropy; Emergent Gravity; Black Holes; FSC; Cosmic Dawn; $R_h = ct$ Model

1. INTRODUCTION AND BACKGROUND

The BOOMERanG experiment, Wilkinson Microwave Anisotropy Probe (WMAP) and Planck satellite studies of the Cosmic Microwave Background (CMB) have established beyond reasonable doubt that our universe is spatially flat [1][2][3]. All non-flat cosmologies have thus been consigned to the waste basket of history. Andrew Lange, principle investigator for BOOMERanG, the first study to confirm universal flatness, was decidedly circumspect in his answer to the question on everyone's mind: 'Is this final confirmation that cosmic inflation theory is correct?'

One would do well to remember Lange's admonition that one can never *prove* the correctness of cosmic inflation by confirming spatial flatness in the CMB. He emphasized that there might ultimately be other cosmology theories with a non-inflationary mechanism for achieving CMB flatness. While many scientists at the time considered Lange to be unnecessarily conservative with his answer, others have since reiterated this point of view. Physicist Philip Gibbs, for instance, put it this way: 'The problem… is that no particular model of inflation has been shown to work yet. It is possible that that work has not yet been completed *or that a more recent specific model will be shown to be right*' (our italics) [4].

Given Lange's concerns, physicist Brian Keating and others have set out on a different tack by looking for inflationary B-mode polarization in the CMB. His recent book [Keating (2018)] is an excellent glimpse into this new and exciting phase of experimental cosmology. Unfortunately, no primordial gravity waves of inflation have yet been discovered. In 2014, the BICEP2 team jumped the gun and prematurely announced a confirmatory result, only to be proven wrong by a Planck study overlay of B-mode polarizing interstellar dust.

While more sensitive searches for primordial gravity waves of cosmic inflation are being conducted, other cosmologists have taken up the cause of searching for non-inflationary mechanisms to explain cosmic spatial flatness. Some, including the present authors, have wondered if the universe has always been spatially flat since inception. Certainly, to this point, there is no observational proof otherwise. Even inflationary cosmologists agree that once the universe reaches critical density, it can remain spatially flat for the rest of time. We must remember that inflationary models must achieve spatial flatness to within one part in approximately 10^{60} *before* the first 10^{-32} second of cosmic time for inflation to achieve the degree of flatness now observed in the CMB [5]. This is a crucial realization. The only difference between an inflationary universe and a perpetually flat universe from inception is what happens within that first 10^{-32} second of cosmic time.

Flat Space Cosmology (FSC) is a remarkably accurate cosmological model which was initially developed as a heuristic mathematical model of the Hawking-Penrose implication [6][7] that a universe smoothly expanding from a singularity can be theoretically treated *within the rules of general relativity* as a time-reversed black hole. Thus, it is perhaps not surprising that FSC makes predictions that closely fit with Planck survey observations. For instance, the Planck Collaboration reported an *observed* global Hubble parameter value of 67.8 +/– 0.9 $km.s^{-1}.Mpc^{-1}$ (68% confidence interval) and FSC *predicts* a current global Hubble parameter value of 66.9 $km.s^{-1}.Mpc^{-1}$, which fits the lower end of the Planck survey range. This FSC calculation is based only upon one free parameter measurement, namely Fixsen's fitting of WMAP data for the CMB temperature peak with a black body at 2.72548 K. This CMB temperature number, plugged into FSC equations first published in 2015 [8][9][10][11], allows for a variety of cosmic parameter predictions fitting very tightly with observations. The five assumptions of FSC, closely adhering to the Hawking-Penrose implication, and the FSC observational correlations, were presented in Chapter one.

It is the purpose of this chapter to present the predictions and features of FSC which prove its superiority to standard inflationary cosmology. These predictions and features have been embedded in FSC since its inception in 2015.

2. PREDICTIONS AND SUPERIORITY OF THE FSC MODEL

In terms of observational correlations and/or falsifiability, FSC appears to be superior to standard inflationary cosmology in the following eleven categories:

2.1 COSMIC DAWN AND THE FORMATION OF THE FIRST STARS, QUASARS AND GALAXIES

As noted in several recent papers [12][13][14], standard inflationary cosmology cannot easily explain the surprisingly early formation of the first stars, quasars and galaxies. As detailed in Chapter three [15], temperature curve differences between the two models are such that cosmic dawn, correlating to *z* redshifts of approximately 15–20, occurred in the FSC model much earlier after the Planck epoch than in standard inflationary cosmology. A comparison of the two temperature curves is shown in **Figure 1**.

The top line is the radiation temperature curve in standard inflationary cosmology and the bottom line is the radiation temperature curve in FSC.

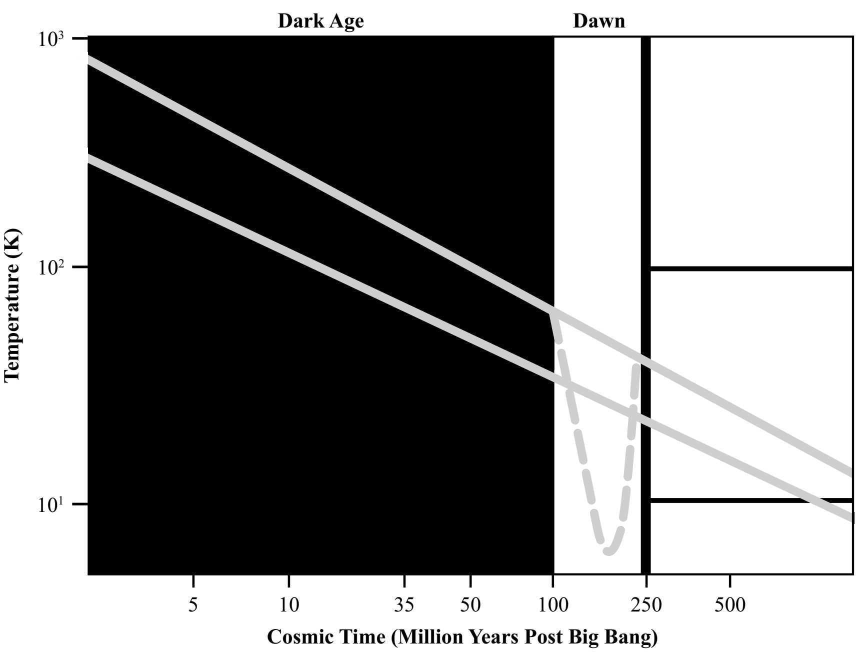

Figure 1 Temperature vs Time in Standard Model (top) and FSC (bottom).

As first presented in Bowman's 2018 publication [16], the dashed curve represents the primordial atomic hydrogen gas temperature.

One should note how cosmic time differs with respect to a given model's radiation temperature. Judging from these temperature curve differences, cosmic dawn in FSC could have been as early as about 35–65 million years after the Planck epoch as opposed to the standard inflationary cosmology cosmic dawn at about 100–250 million years. The nadir of the primordial hydrogen gas temperature, correlating to a z value of about 17, would have been at about 50 million years and about 180 million years, respectively. Thus, FSC, by the relative length (14.6 billion years vs 13.8 billion years) and slope of its temperature curve, allows for considerably more time between the formation of the first stars (at cosmic dawn) and the formation of the first quasars and galaxies.

2.2 PREDICTIONS PERTAINING TO PRIMORDIAL GRAVITY WAVES

FSC is a steadily expanding cosmology model, which would not be expected to produce inflationary B-mode primordial gravity waves. There is nothing 'explosive' about the FSC early universe in comparison to the standard inflationary early universe. Thus, FSC predicts that inflationary B-mode primordial gravity waves will never be detected. Such unequivocal detection of inflationary waves would falsify FSC. The continued failure to detect such waves, if the sensitivity of detection methods can be made sufficiently high, would strongly favor FSC over standard inflationary cosmology.

2.3 PREDICTING THE MAGNITUDE OF CMB TEMPERATURE ANISOTROPY

The angular power spectrum of the CMB clearly fits with a spatially flat universe. As noted following the BOOMERanG Collaboration report [17] of CMB anisotropy observations, their results are 'closely fitting the theoretical predictions for a spatially flat cosmological model with an exactly scale invariant primordial power spectrum for the adiabatic growing mode' [18]. Furthermore, the COBE DMR experiment [19] measured a CMB RMS temperature variation of 18 micro-Kelvins. This translates to a *dT/T* anisotropy value of (0.000018)/2.725 equal to 0.66×10^{-5} (nearly one part in one hundred thousand). This measurement fits within the range of FSC temperature anisotropy predictions for the beginning and ending of the recombination/decoupling epoch [20]. This result clearly favors FSC. See Chapters six and nine for details.

2.4 PREDICTING THE HUBBLE PARAMETER VALUE

In standard inflationary cosmology, the Hubble parameter value can only be determined by observation. That is to say that there is no theoretical ability within standard cosmology to derive a Hubble parameter value. The FSC model, on the other hand, *predicts* the current global H_0 value to be 66.9 kilometers per second per megaparsec (see Chapter one). This fits the 2018 Planck Collaboration [21] and 2018 DES [22] Hubble parameter values. Therefore, this category strongly favors FSC in comparison to standard inflationary cosmology.

2.5 QUANTIFIABLE ENTROPY AND THE ENTROPIC ARROW OF TIME

One of the problems within the standard inflationary model is in quantifying cosmic entropy. Entropy is typically defined in terms of the total number of possible microstates and the probability of a given set of conditions with respect to that number of microstates. These values are impossible to quantify in an infinite-sized inflationary universe or multiverse. FSC, on the other hand, is a *finite* model with a spherical horizon surface area. And, since the Bekenstein-Hawking definition of black hole entropy applies to the FSC model, values for cosmic entropy can be calculated for any time, temperature or radius of the FSC model. Thus, the 'entropic arrow of time' is clearly defined and quantified in the FSC model. The quantifiable entropy in the FSC model allows for model correlations with cosmic entropy theories, such as those of Roger Penrose [23] and Erik Verlinde. Thus, the entropy rules of FSC potentially allow for falsifiability. This feature favors the FSC model, particularly with respect to Verlinde's 'emergent gravity' theory (see below).

2.6 CLUES TO THE FUNDAMENTAL NATURE OF GRAVITY, DARK ENERGY AND DARK MATTER

The reader is referred to Chapter five with the above title for an in-depth discussion of how cosmic entropy in the FSC model may provide for tantalizing clues with respect to the fundamental nature of gravity [24]. In short, the FSC model appears to be the cosmological model correlate to Verlinde's emergent gravity theory [25][26]. Verlinde's landmark paper from 2011 provides strong theoretical support for gravity being an *emergent property* of cosmic entropy. Chapter five makes a case for the correctness of Verlinde's theory. As discussed, if gravity is an emergent property of cosmic entropy, then one might entertain the possibility that dark energy and dark matter could also be emergent properties of cosmic entropy. For instance, perhaps galactic and peri-galactic features attributed to dark matter (such as plate-like galactic rotation and gravitational lensing) could be an unexpected large-scale effect of the entropy of the known galactic baryonic matter. If this turns out to be the correct interpretation, then gravity, dark energy and dark matter might be as difficult to define at the quantum level as 'quantum consciousness' within two connected neurons.

The recent observations of Brouwer, *et al*. [27] appear to be in support of Verlinde's theory as it pertains to dark matter. The discovery of quantum gravity not at all connected to entropy at the quantum level would falsify Verlinde's theory. At present, standard inflationary cosmology, by virtue of its inability to precisely define cosmic entropy, has no capacity to incorporate Verlinde's theory or any other cosmic entropy theory. This appears to favor FSC, particularly in light of the above-mentioned recent observational findings.

2.7 COSMOLOGICAL CONSTANT PROBLEM

The 'cosmological constant problem' is a longstanding problem in theoretical physics. It underscores standard cosmology's inability to unify general relativity with quantum field theory (QFT). Excellent expositions on this subject have been provided by Weinberg [28] and Carroll [29]. QFT theorists calculate a cosmological constant value which differs from observational measurements of the vacuum energy density by a magnitude of approximately 10^{121}! Suffice it to say, this discrepancy is so large that it is often referred to as the most embarrassing problem in all of theoretical physics.

In standard inflationary cosmology it has been assumed that the post-inflationary energy density of the cosmic vacuum must be constant, rather than scalar, over the remainder of cosmic time. However, general relativity does indeed allow for the vacuum energy density to be a dynamic scalar over time. Cosmological models incorporating scaling vacuum energy density are called 'quintessence' models. FSC is one such model. In FSC, the vacuum energy density scales downward by 121.26 logs of 10 over the cosmic time interval since the Planck mass epoch. Perhaps of even greater interest is that the Bekenstein-Hawking cosmic entropy value scales upward in direct proportion to the expanding surface area of the cosmic horizon. If one were to count the current number of Planck mass radius microstates (tiles with an area of $4L_p^{\,2}$) within the area of the FSC horizon, the model indicates this entropy number to be a factor of $10^{121.26}$ greater than the 4π value calculated for the Planck mass epoch. Thus, by its implication of a possible relationship between vacuum energy (*i.e.,* dark energy) and total cosmic entropy (as detailed in Chapter five), FSC offers a possible explanation for the magnitude difference between the Planck epoch vacuum energy density calculated by QFT theorists and today's observed vacuum energy density of approximately 10^{-9} J.m^{-3}. Since the FSC model stipulates these values, and standard inflationary cosmology has no basis for deriving them, the FSC model appears to be superior with respect to potentially resolving the cosmological constant problem.

2.8 DARK MATTER AND DARK ENERGY QUANTITATION

As reported by the Planck Collaboration, the ratio of dark matter to visible (baryonic) matter is observed to be approximately 5.5 parts dark matter to one part visible matter. However, there are already significant differences observed between the dark matter-to-visible matter ratios in the galaxies quite near to us (essentially co-movers) and the above dark matter-to-visible matter ratio determined from Planck CMB observations. *Perhaps this ratio* *is scalar over the great span of cosmic time. If the co-mover ratio is ultimately found to be approximately 9.2, as predicted by FSC, one can then conclude that total matter energy density at present is equal in absolute magnitude to dark energy density*. This equality of opposite sign energy densities is what one would expect for a spatially-flat universe. Otherwise, if one energy density dominated the other, there should be detectable global spatial curvature corresponding to the dominating energy density. One could, in fact, make a strong case that the spatial flatness of the CMB proves the equality of total matter and dark energy densities at the time of the recombination/decoupling epoch. This should nullify any Planck Collaboration conclusions (such as dark energy dominance) which are obviously contrary to their own observations of spatial flatness.

Despite the fact that FSC and standard inflationary cosmology differ somewhat with respect to the percentages of total matter versus dark energy predicted for the co-moving universe, there is one thing about this energy density partition on which everyone agrees: it is truly remarkable that total matter energy density and dark energy density are *of the same order of magnitude at the present time*. As physicist I. I. Rabi once famously remarked, 'Who ordered that?!' This is often referred to as the 'cosmological coincidence problem.' Standard cosmology simply accepts this coincidence problem with no further explanation or rationale. However, FSC *stipulates* perpetual equality of absolute magnitude of these two energy densities as a requirement for a perpetually spatially-flat universe. One can consider this expectation of energy density equality to be a falsifiable FSC prediction with respect to future measurements of total matter energy density in comparison to dark energy density. *An in-depth statistical analysis of approximate co-movers with the Milky Way should give us a better idea of the dark matter to visible matter ratio in the current epoch.*

With respect to standard cosmology's current belief in cosmic acceleration due to dark energy, the reader is referred to references [30] thru [34]. Cosmic acceleration is clearly not proven at the present time, despite the indisputable presence of dark energy as definable within general relativity. There are relative differences in luminosity distance and angular diameter distance formulae in standard inflationary cosmology and $R_h = ct$ modified Milne-type models (like FSC). Two comparative graphs from Chapter four and FSC reference [35] are shown in **Figure 2** and **Figure 3**.

Figure 2 Relative luminosity distances vs. redshift *z* for standard (thin) and Milne (thick).

Figure 3 Relative angular diameter distances vs. *z* for standard (thin) and Milne (thick).

The significance of the relative luminosity distance and relative angular diameter distance comparisons between these two competing models is paramount. An observer of distant Type Ia supernovae expects particular luminosity distances and angular diameter distances to correspond with particular redshifts. If, instead, he or she observes greater-than-expected luminosity distances (*i.e.,* unexpected 'dimming' of the supernovae) or greater-than-expected angular diameter distances, this can easily be misinterpreted by a standard inflationary model proponent as indicative of cosmic acceleration. However, *entirely predictable supernova luminosity distances within a realistic Milne-type universe containing matter, as opposed to a standard model universe, could be one possible explanation* *for the Type Ia supernovae observations since 1998. Obviously, cosmic acceleration would not then be required to explain these observations.* This possibility, combined with the standard model tension problem presented above (*i.e.,* spatial flatness and dark energy dominance cannot *both* be true at the same time), and the FSC *stipulation* of what standard model proponents refer to as the 'coincidence problem,' strongly favors FSC with respect to its predictions concerning dark matter and dark energy quantitation.

2.9 QUANTUM COSMOLOGY

The FSC model, by virtue of its appropriately scaling cosmic temperature equation (the first equation given in assumption four of Chapter one), can be considered the first successful quantum cosmology model [Tatum, *et al.* (2015)]. By incorporating the values of T_0, $\hbar$, c, G, k_B and π to as many decimal places as known, the FSC parameters can be shown to closely match astronomical observations. For convenience, the most important FSC quantum cosmology equations are repeated here:

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

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

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

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

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

Current parameters are calculated in the right-hand column. The only free parameter in any of these equations is the cosmic temperature. The right-hand column incorporates the currently-observed Fixsen WMAP T_0 value of 2.72548 K. *It is truly remarkable that, using only current best measurements of the CMB temperature, the derived H_0 value can be calculated and fitted to the lower end of the 2018 Planck Collaboration and DES observational measurements!*

No quantum model exists for standard inflationary cosmology. This obviously favors the FSC model.

2.10 PREDICTING THE VALUE OF EQUATION OF STATE TERM

For reasons given in Chapter 11, the FSC model requires that the equation of state w term have a perpetual value of exactly –1.0. This fits the quantum field theory stipulation that the vacuum pressure p corresponding to the zero-state vacuum energy must always be equal in magnitude to the vacuum energy density ρ (*i.e.,* $p = \rho$). A dark energy dominant universe (as currently believed in standard cosmology) would not meet this quantum field theory stipulation and would have a w value other than exactly –1.0. These are falsifiable predictions for both models. Standard model cosmologists believe our current universe to contain an extremely small *net* negative energy. In other words, they believe in *slight* cosmic acceleration (as opposed to constant velocity light speed expansion), despite current observations of global spatial flatness. However, *if our universe began from a zero-energy state, as is often assumed, and the universe now has a non-zero energy density, however small, this would appear to violate conservation of energy!* Thus, there is tension in the standard cosmology model of dark energy dominance, because the Planck Collaboration has reported $w = -1.006 +/- 0.045$. A final consensus value of exactly –1.0, which seems highly likely at the present time, would be in support of FSC and falsify the current belief in dark energy dominance within standard cosmology.

2.11 REQUIREMENTS FOR NEW PHYSICS

Cosmic inflation theory was invented before the spatial-flattening effects (on positively-curved space-time) of cosmic vacuum energy (dark energy) were discovered in 1998 [36][37][38]. Guth [39] and others [40][41] believed at the time of its invention that a special energy field with inflating features (called by Guth the 'inflaton') was required within the initial 10^{-32} second of universal expansion. It was believed that this energy field was necessary in order to flatten out a presumed highly-curved space-time during and immediately following the inception of expansion. Thus, inflation appeared to be a clever solution to the cosmological 'flatness problem,' as well as the cosmological 'horizon problem.' The latter problem was presumed at the time to exist because most cosmologists believed, without any real evidence, that the universe is infinite and thus otherwise difficult to explain in terms of its remarkable homogeneity in all observational directions. Nevertheless, one of the founders of cosmic inflation, Paul Steinhardt, has pointed out some serious flaws in inflationary theory [42].

For reasons given in Chapter one, FSC solves these cosmological problems without requiring an inflationary epoch. In contrast to inflationary models, in which the total cosmic mass generation is exclusively limited to within a tiny fraction of a second of the Big Bang, *the FSC model is a perpetual mass-generating model* with some similarities to the model presented in the 2019 publication entitled 'A Perpetual Mass-Generating Planckian Universe' by Sapar [43]. This concept of perpetual mass generation has a long tradition going back at least to Hoyle, although Hoyle's particular mass-generating theory was falsified by the discovery of the cosmic microwave background in the 1960s. Here it is important to emphasize that the mystery of mass generation is inherent in *all* cosmology models. FSC simply models perpetual mass generation while inflationary models imply, without any real evidence, that all universal matter was nearly instantaneously created.

It is speculated in Chapters 13 and 14 that negative energy (*i.e.,* gravitationally-repelling energy) within the cosmic vacuum may be continually increasing as an offset to the ongoing production of gravitationally-attracting positive energy in the form of matter. This would be in keeping with the spatial curvature rules of general relativity. One should remember that, according to general relativity, a flat space-time is flat precisely because it contains net zero total energy. Furthermore, a globally and perpetually spatially-flat universe which begins from a net zero total energy state (Guth's 'free lunch' idea) would presumably maintain net zero total energy throughout its expansion. Otherwise, a fully self-contained universe, such as a FSC universe, would violate conservation of energy.

Despite the ongoing mystery of mass generation in all cosmology models, for the arguments made above, and for the perpetual mass-generation rationale offered in Dr. Sapar's paper, this category appears to favor FSC in comparison to standard inflationary cosmology.

3. SUMMARY AND CONCLUSIONS

Following recent precise CMB observations of global spatial flatness, only two types of viable cosmological models remain: inflationary models which almost instantaneously attain cosmic flatness following the Big Bang; and non-inflationary models which are spatially flat from inception. FSC is the latter type of cosmological model by virtue of assumptions corresponding to the Hawking-Penrose implication that a universe expanding from a singularity could be modeled like a time-reversed black hole. Since current inflationary models have been criticized for their lack of falsifiability, the numerous falsifiable predictions and key features of the FSC model are herein contrasted with standard inflationary cosmology. For the reasons given, the FSC model is shown in this chapter to be superior to standard cosmology in the following eleven categories: Cosmic Dawn Early Surprises; Predictions Pertaining to Primordial Gravity Waves; Predicting the Magnitude of CMB Temperature Anisotropy; Predicting the Hubble Parameter Value; Quantifiable Entropy and the Entropic Arrow of Time; Clues to the Nature of Gravity, Dark Energy and Dark Matter; Cosmological Constant Problem; Dark Matter and Dark Energy Quantitation; Quantum Cosmology; Predicting the Value of Equation of State Term *w*; Requirements for New Physics.

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