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Irreversible Thermodynamics of Cosmological Matter Creation

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Abstract

In this paper, we derive the expression of the internal energy of the universe, and we then study the physics of the very early universe from a thermodynamic point of view. In the process, we obtain interesting new physics about the actual time frames of the known key stages of the evolution of the universe in relation to the entropy of the universe. This then has the implication for the understanding of cosmology as we know it, and in particular the time frame of the large-scale structure formation as pointed out in the recent results from the James Webb Space Telescope (JWST). We complete the paper by studying the isothermal irreversible expansion of the universe and thus obtain the relation between irreversible particle creation and the Hubble parameter.

Keywords

Internal Energy, Very Early Universe, James Webb Space Telescope Isothermal Irreversible Expansion, Hubble Parameter

1. Introduction

The physics of the standard model is proven to have some fundamental problems that need to be cleared because of its incompleteness to give the final answer to the problem of quantum gravity, and as a result the nature of the composition of matter at the quantum scale. Paudel [1] described this theory as a set of mathematical formulae and measurements describing elementary particles and their interactions. Like, the atomic periodic table, it categorizes the elementary particles—fermions and bosons. Thus, its inherently imperfections lead to fundamental problems in the understanding of quantum cosmology, and thus the very early universe.

At the quantum scale, there are two promising theories, one for quantizing matter known as string theory, and one for quantizing gravity known as Loop Quantum Gravity. Kubeka [2] showed that these two theories could complement each other to form a possible quantum vacuum geometry. Cicoli *et al.* [3] among others give an overview of the application of applications of string theory to cosmology, and discussed the evolution of the universe from primordial times to the present-day accelerated expansion. In the process, he discussed inflation in string theory, the impact of string theory on post-inflationary dynamics, dark energy and the cosmological constant, and pre-big-bang scenario. The current study puts this evolutionary characteristic of our universe into perspective in the context of the emergent universe using the thermodynamic constraints of our universe as discussed in [4], and thus interesting picture of the dynamics of the pre- and post-big bang scenarios of universe is obtained in relation to its entropy evolution.

This emergent thermodynamic picture seems to give some theoretical insight to the new observation data from the James Webber Telescope. This indicates that our current knowledge of cosmology might be incorrect with regard to time frame of the structure formation which the data suggest that this process might have occurred much earlier than we thought and with much bigger galaxies having been formed much earlier [5] [6]. Also, another new data from the James Webber Telescope by [7] found that we might be living inside a Black Hole which is in essence is aligned with the direction of this study as it claims that our universe is actually a white hole. The study by [7] found that the assumption of isotropic universe is in question, because two third (about 263) of the galaxies have been found to be rotating clockwise.

The results of our study also suggest that matter creation through quantum fluctuations might have started before the Big Bang, thus proposing a new perspective on the timing of the fundamental stages of matter creation. According to this view, these stages would have occurred before the supersymmetry breaking at the Big Bang, contrary to what is suggested by the standard model. This is purely from the analysis of the entropy evolution of the universe. It is important to note that this does not change or affect the physics of Big Bang Nucleosynthesis (BBN) as we know it [8]. It just affects the entropic time frame of the origin of matter creation during quantum fluctuations.

This paper is arranged as follows: in Section 2, we derive the internal energy of the universe, and in Section 3, we analyze the variations of internal energy, entropy, and temperature during the early universe key stages. Then in Section 4, we analyze the implications to large structure formation, and in Section 5, we study the properties of isothermal irreversible expansion of the universe. Then lastly in Section 6, we derive irreversible particle creation formula and implication to the Hubble parameter in the thermodynamic framework.

2. The Internal Energy of the Universe

The conservation internal energy of the modified white hole is $U = H - PV$

which in this formalism is the internal energy of the universe. From [4], the enthalpy H, pressure P and the thermodynamic volume V are given by Equations (22), (16), and (23) respectively, and thus we obtain the internal energy of the universe by

$$U=\frac{\left[T-\frac{1}{2}\frac{a}{\sqrt{\frac{S}{\pi}}}+\frac{1}{4}\frac{ab\pi}{S}\right]\left[-\frac{2\left[1-a\pi\ln\frac{S}{\pi}-\frac{ab\pi}{\sqrt{\frac{S}{\pi}}}\right]\left[\frac{1}{2}\frac{b}{\sqrt{\frac{S}{\pi}}\pi}-\frac{1}{\pi}\right]}{\left[b\sqrt{\frac{S}{\pi}}-\frac{S}{\pi}\right]^{2}}+\frac{2\left[-\frac{a\pi}{S}+\frac{1}{2}\frac{ab}{\left[\frac{S}{\pi}\right]^{\frac{3}{2}}}\right]}{b\sqrt{\frac{S}{\pi}}-\frac{S}{\pi}}\right]}{2\sqrt{\frac{S}{\pi}}-b}+\frac{2\left[1-a\pi\ln\frac{S}{\pi}+\frac{ab\pi}{\sqrt{\frac{S}{\pi}}}\right]}{b\sqrt{\frac{S}{\pi}}-\frac{S}{\pi}} \quad (1)$$

Figure 1 and Figure 2 below depict the dynamics of the internal energy throughout the history of the evolution of our universe as a function of increasing entropy. The van der Waals particle variables a, b modeling the dynamics of matter in the universe do not necessarily affect the shape of the Figure 1, and Figure 2 and thus of the universe.

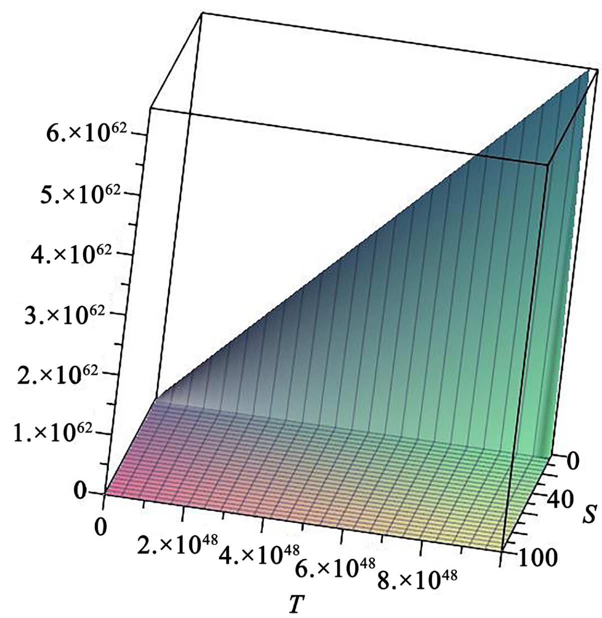

Figure 1. Internal energy of the universe.

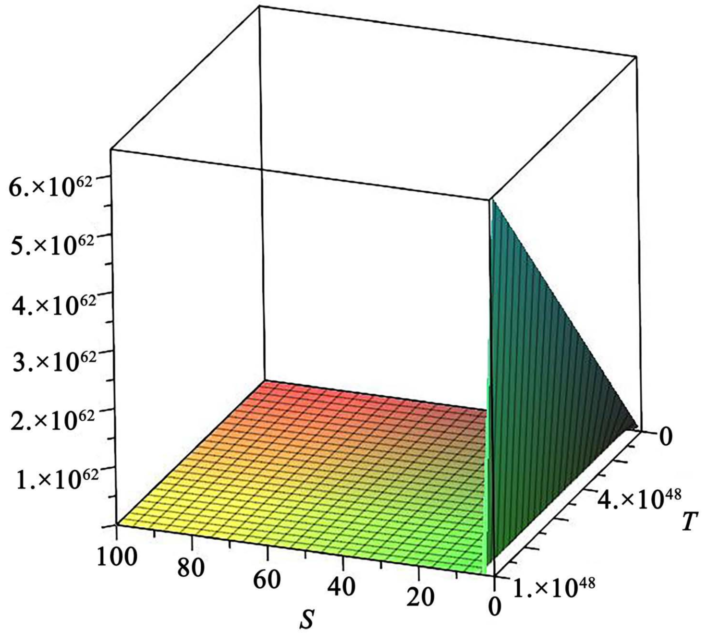

Figure 2. Internal energy of the universe showing its dynamics moments after the big bang.

Taking $a = 1$ to be the maximum particle (matter) energy density, and $b = 0.3$ the separation volume between the particles. The separation volume has the range from 0 to 0.3 on which the attraction force is strong enough to produce observed cosmological results. We observe from **Figure 1** below that the internal energy of the universe moment after the big bang decreases linearly from the order of 10^{62} to 0, and the temperature decreased sharply from the order of 10^{48} to about 3 when the entropy was between 0 and 0.4. Then from **Figure 2**, we observe that the internal energy then dropped-off to 0 when the entropy was 0.4, and temperature was about 3 K, and since then the internal energy of the universe has remained constant at 0 throughout the remaining evolutionary phase of universe (The FLRW universe).

3. Variations of Internal Energy, Entropy, and Temperature during the Early Eniverse's Key Stages

3.1. Inflationary Quantum Fluctuations

In this phase inflationary quantum fluctuations where very high and grew exponentially as result of the inflaton. During this phase time was 10^{-35} s, the temperature was 10^{27} K, and the internal energy was 10^{23} J. But however, at the same temperature, we found that the internal energy was of the order of 10^{42} *i.e.* 1.6×10^{42} J and that the entropy was 0.

3.2. Quark-Gluon Plasma

As the universe cooled down, the temperature decreased, but internal energy was still substantial, and quarks and gluons began to form hadrons. At this phase, time was 10^{-6} s, the temperature was of the order of 10^{12}, and the internal energy was of the order of 10^{19} J. But however, at the same temperature, we found that the internal energy was of the order of 10^{27} *i.e.* 1.6×10^{27} J and while the was entropy was still at 0.

3.3. Baryogenises

In this phase, the temperature dropped to 10^{10} K at 1 s, and internal energy to 10^{17} J. During this phase, nucleosynthesis reactions begun. However, we found that the internal energy for this phase was of the order of 10^{25} *i.e.* 1.6×10^{25} and while the entropy was still at 0.

3.4. Recombination

This phase marked the formation of neutral hydrogen atoms at 380,000 s with a significant decrease in temperature at 3000 K, and with the internal energy of the order of 10^{14} J. However, we found that the internal energy at this temperature was of the order of 10^{21} *i.e.* 1.95×10^{21} J while the entropy was still at 0.

3.5. Discussions

From the above and from the literature analysis, we note that the observed higher temperatures differences for the various stages of matter creation might be due to the exponentially growing quantum vacuum fluctuations energy facilitated by the cosmological constant. In addition, from the observation, it is evident that the universe did not start from the big-bang singularity, rather from a highly self-perturbed and fluctuating quantum vacuum [9]. Furthermore, from the above results we note that the analysis puts these key stages at the moment where H is infinitely positive and fluctuating [9]. This quantum gravity enthalpy was very high and fluctuated from positive infinity near $S = 0$ and dropped to just below 300 at about 275 when the $S = 0.1$, then it increases asymptotically to infinity again near $S = 0.4$ the infinitesimally quantum gravity self-perturbations started to occur, and the perturbations growth increased so much so that they generated infinite heat resulting in H increasing infinitely near $S = 0.1$.

At $S = 0.4$ there was enthalpy phase transition (*i.e.* big bang), and thus supersymmetric breaking occurred instantly at that moment. The supersymmetric breaking was of the stringy like quantum geometric vacuum coupled to graphs like geometric gravity as discussed in [2]. This infinitely hot soup of highly self-perturbed and self-created quantum matter was created exponentially, and the creation was facilitated by the Higgs boson within the stringy like geometric structures as they vibrate in fundamental particles frequency modes. The Higgs bosom is inherent to the quantum vacuum geometry [2].

The extremely high standard model entropies for the; Inflationary quantum fluctuations of the order of 10^{30}, quark-gluon plasma of the order of 10^{25}, baryogenesis of the order of 10^{23}, and Recombination of the order of 10^{20}, are for the supersymmetric quantum fluctuating spherical cloud of newly created matter inside stringy like structures of the quantum vacuum geometry. Thus, the decreasing entropies of these newly created quantum matter are in relation to the increasing temperatures created by these self-generated quantum matter creating fluctuations of the vacuum geometry facilitated and driven by the cosmological constant [4] till the point of supersymmetric breaking.

From **Figure 1** and **Figure 2**, we observe that after $S = 0.4$, the universe attained the internal energy value of 0 after the supersymmetric breaking of gravity, other fundamental forces, and spewing of the created quantum matter *i.e.* electrons, protons, neutrons, and photons (electromagnetic radiation). At this stage, the universe became transparent because of the electromagnetic radiation and as the universe evolved it cooled very rapidly to about 3K as discussed above. The effect of this supersymmetric breaking was that the negative gravitational force cancels out the positive energy of matter. The inflation phase ended at $S = 4.3$ pass the big-bang [4] from there the universe evolve as we know for large structure formation.

This is a new and a particularly important picture about the creation of our universe building on what we already know from the standard model of particle physics and creation of matter cosmology. Putting this into correct perspective, this might bring answers to some of fundamental problem in the standard model and the current problems with the understanding of cosmology as we know it today.

4. Large Structure Formation

The analysis of this paper also strengthens the new discoveries from observation by James Webb Space Telescope (JWST) [5] that the structure formations and in particular galaxies might have formed much earlier (in what is called "anciant galaxies") and faster [6] than we knew because matter creation actually happened during quantum vacuum geometry fluctuations pre big bang. Thus, the period immediately post the big-bang was mostly characterised by large structure formation and evolution. [5] highlighted that "Explaining the early emergence of massive galaxies requires either an extremely efficient conversion of baryons into stars at $z > 10$ or a more rapid assembly of baryons than anticipated in ΛCDM." This could be explained by our analysis above about stages of matter creation being at between $S = 0$ and $S = 0.4$.

In [4] we also confirm the Hubble tension due to the gravitational potential of a modified white/universe which is almost linearly increasing to infinity. This accelerated expansion of the universe/Hubble parameter was also confirmed by [10] by offering a stronger evidence from observations that this acceleration is faster than current known prediction of theoretical models. The enthalpy energy density [4] suggest the second phase transition just before the horizon at $S = 11.9$ just near the while hole horizon $S = 12.566$ inside the white hole , this phase transition is gravitational and this could be the results of the effects of the formed primordial black wholes. This gravitational phase transitions facilitated the large structure formation we now observe. This gravitational phase transitions could also be interpreted as the cosmic dawn beyond [11] which we won't be able see further in our past. From recent James Webb Space Telescope observational results [6], we then get the impression that we are living inside a black hole.

5. Isothermal Irreversible Expansion of the Universe

From [12] Equation (23) we have the expression for the volume of the universe. Since our universe is an isolated system, thus the external pressure $P_{ext} = \text{constant}$. We do the isothermal analysis when the universe became transparent and the temperature cooled to about $T = 3\ \text{K}$ (constant) from when $S = 0.4$. Thus the amount of work done in the evolution of our universe is

$$W = -\frac{T}{V_f}\left(V_f - V_i\right), \tag{2}$$

The initial volume V_i is at $S = 0.4$ and the final volume V_f is at $S = \infty = 1000$ (say), and thus the total work done is approximated as

$$W = \frac{31899.67665}{-1.271263610} = -25092.88900. \tag{3}$$

For $S = 1000000(\text{say})$ we have $W = -8.044559959 \times 10^6$, and this then imply that the more the universe grow older, less and less amount of work is needed for the expansion of the universe until it is constant = 0 and equal the internal energy of the universe.

The negative sign implies that the universe does not receive any heat from its surroundings or outside. This amount of work done by the dynamic universe is facilitated by the cosmological constant, dark energy, and dark matter for its evolution and irreversible expansion. Below, we considered the isothermal irreversible expansion for $U - S$ when $T = 3$.

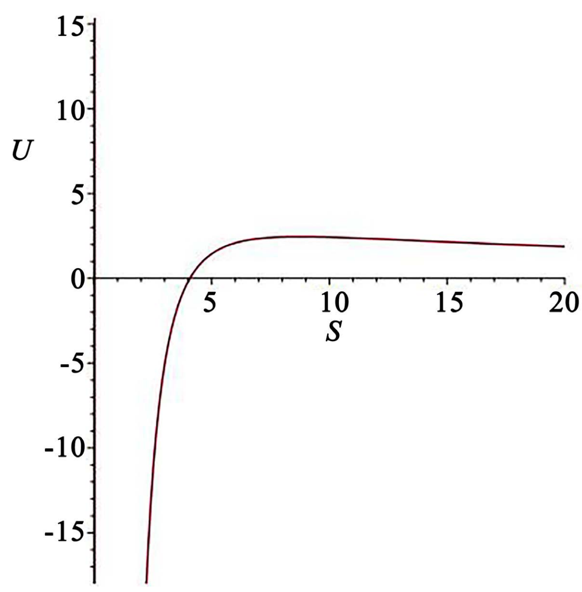

Figure 3. Isothermal irreversible expansion for internal energy $U - S$, for $T = 3$, $U = -18..15$, and $S = 0..20$.

Figure 3 shows the discontinuity in the internal energy at $S = 0.4$. Thereafter, it increased exponentially due to the self-pertubative quantum geometry between $S = 0.4$ and the boundary of the quantum regime $S = 4.4$ [9]. Thereafter it flattened out isothermal from the horizon $r = 2M$ $S = 12.566$ to a constant value of about 1.5. From [9] **Figure 2**, we note that the dynamical behaviour of the total internal energy of the universe is analogous to that of the enthalpy approaching the same constant 1.5.

Also, we observe from [4] **Figure 2** as expected, that the dynamic behaviour of the thermodynamic volume of the universe follows proportionally that of the dynamic behaviour of the internal energy and thus of the enthalpy of the universe inside the horizon and outside the horizon. Below, we considered the isothermal irreversible expansion plots for $U - S$ for the critical temperature $T_c = \frac{8a}{27b} = 0.9876543209$, and $T = 0.25$ (below T_c), and $T = 5$ (above T_c). In [4], we shown that the modified white hole geometry satisfied the $P - V$ criticality, and thus our universe as well.

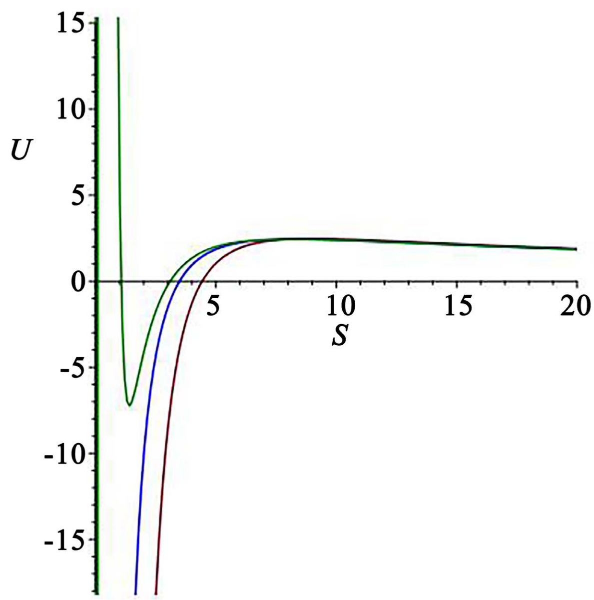

Figure 4. Isothermal irreversible expansion for internal energy $U - S$, for $T = 0.25$ (Green), $T_c = 0.9876543209$ (Blue), $T = 5$ (Red), $U = -18..15$, and $S = 0..20$.

Figure 4 shows the isothermal irreversible expansion of the very early universe from the perspective of entropy and temperature relationship, thermodynamic equilibrium, phase transitions, and cooling and expansion. Therefore, it illustrates how the change in temperature led to changes in internal energy and entropy.

However, a more critical analysis of **Figure 4** is that, we note that there is a critical temperature T_c, that below it, it seems that, the entropy-internal energy relation for our universe as an isolated system not violated, and thus the second law of thermodynamics. Because, this is analogous to starting from different initial conditions to that we know of our universe where the second law of thermodynamics not violated. But what we have now is the second law violated between $S=0$ and $S=1.5$, and then from $S=1.5$ onwards, the second law is upheld.

Then below T_c, we have the second law of thermodynamics upheld throughout the history of the universe from when $S=0$. Thus, this imply that for temperatures above and below T_c, we get two possible different quantum vacuum states, from where our universe might have evolved. However, the current irreversible isothermal properties of the universe as confirmed by cosmological observations, and of the cosmic microwave background, indicate that our universe evolved from the quantum vacuum state with thermodynamic properties below T_c as described above and in [2] [4] [9].

6. Irreversible Particle Creation and the Hubble Parameter

From [12], we obtain the particle creation $\dot{n}$ given by

$$\dot{n} = -\frac{a}{V^2}\dot{V} \tag{4}$$

where

$$n = \frac{a}{V} \tag{5}$$

From [9], Equation (13) we have the radial relation between the internal energy of the universe and the Hubble parameter given by

$$dU = U\int \mathcal{H}(U), \tag{6}$$

where $U = \frac{r_+}{2}$, and $\mathcal{H}(U) = \frac{d^2 r_+}{dr_+}$. dr_{r_+} scales analogous to the FLRW scale factor. The thermodynamic V is given by Equation (23) in [4], and the pressure P in U comes in through the expression of the temperature T in the equation of state of the universe Equation (3) in [9], and P is then given by Equation (4) in [9]

$$P = P(V,T) + ann_a \tag{7}$$

and from [13] where $n = n_a + n_c$, and n_c is the particle density from the Bose-Einstein condensate, and n_a is the active particle density with momentum distribution. From [12] the energy creation φ is then given by

$$\varphi = \frac{\mathcal{H}}{n}\dot{n} \tag{8}$$

Thus Equation (6) is the relation for the irreversible particle creation and the Hubble parameter $\mathcal{H}$.

7. Conclusion

The entropy analysis of this study reviles a much richer structure of quantum cosmology from the perspective of quantum vacuum matter creation fluctuations as outlined by standard theory of particle physics. This picture suggests that matter creation might have started before the big bang, contrary to what we know from standard cosmology, which suggests that matter creation started after the big bang. This result is without any loss of generality to the standard model theory, but it only places matter creation into correct cosmological perspective in relation to the new data findings from the James Webber Tellescope, which suggest that galaxy formation must have occurred much earlier than we thought, and in fact much bigger galaxies have been observed much earlier than we know.

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Data Availability

The data and codes underlying this article will be shared on reasonable request to the corresponding author.

Conflicts of Interest

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

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