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The Emergent Entangled Informational Universe

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The dream of capturing the workings of the entire universe in a single equation or a simple set of equations is still pursued. A set of five new equivalent formulations of entropy based on the introduction of the mass of the information bit in Louis de Broglie's hidden thermodynamics and on the physicality of information, is proposed, within the framework of the emergent entangled informational universe model, which is based on the principle of strong emergence, the mass-energy-information equivalence principle and the Landauer's principle. This model can explain various process as informational quantum processes such energy, dark matter, dark energy, cosmological constant and vacuum energy. The dark energy is explained as a collective potential of all particles with their individual zero-point energy emerging from an informational field, distinct from the usual fields of matter of quantum field theory, associated with dark matter as having a finite and quantifiable mass; while resolving the black hole information paradox by calculating the entropy of the entangled Hawking radiation, and shedding light on gravitational fine-grained entropy of black holes. This model explains the collapse of the wave function by the fact that a measure informs the measurer about the system to be measured and, this model is able to invalidate the many worlds interpretation of quantum mechanics and the simulation hypothesis.

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1. INTRODUCTION

The dream pursued by Albert Einstein and many physicists who still pursued the dream of capturing the workings of the entire universe in a single equation or a simple set of equations is still pursued. A set of five new equivalent formulation expressing the notion of entropy able to reconcile quantum formalism and relativistic formalism can explain various processes as informational quantum processes, i.e., energy, black holes, dark matter, dark energy, cosmological constant and vacuum energy. Those equations are based on key concepts such as Landauer's principle [1], Louis de Broglie's hidden thermodynamics [2], mass-energy-information equivalence principle [3], principle testable by an experimental protocol as given in [4], leading to the fundamentality of quantum information considered as physical with a finite and quantifiable mass.

In the first part of this work entitled "Structural basis", some theoretical considerations are examined such as the definition of quantum information, quantum entanglement, some considerations on quantum non-locality as well as the notion of fundamentality of temperature and information, considered as the two fundamental building blocks of the universe. This section examines in detail the processes of emergence that give birth to degrees of freedom from which emerge the temperature and the information, both giving birth to the notion of energy according to Landauer's principle [1].

Moreover, this section offers an explicative informational process about the physical process of the collapse of the wave function based on the definition of the quantum measurement where a measure informs the measurer about the system to be measured, the measurer shares one or more degrees of freedom (information) with the system under considerations, and both are entangled together by the sharing of degrees of freedom [5].

In the second part of this work, concerning the "Generalization" of the approach of entropic information theory, the mass of the bit of information of Melvin Vopson's mass-energy-information equivalence principle [3], is introduced into Louis de Broglie's equations of hidden thermodynamics [2] leading to different equations of entropy formulation such as the relations of Boltzmann, Einstein, Planck, Avogadro and the fine structure formulation, as various new expressions of the notion of entropy [6].

Also, in the second part of this work, is explained how, after injecting the temperature of Hawking radiation [7] into one of the new equations of entropy, this new formula can calculate the entropy of the entangled Hawking radiation up to the quantum system [5]. This new formulation of black hole entropy related to the work of Casini [8] and Bousso on Bekenstein bound [9-17], can calculate the Bekenstein-Hawking entropy; as the black hole entropy saturates exactly the Bekenstein bound so it is equal to the Bekenstein bound which is itself according to Casini's work equal to the von Neumann entropy itself equal to that of the Hawking radiation, which with the degrees of freedom of black holes produces a pure state, while the Hawking radiation being entangled with the fields inside black holes, allowing us to extract information that resides from the semiclassical viewpoint, in the black hole interior; at the end of evaporation, the full von Neumann entropy is again 0 , so no information is lost!. The black hole entropy horizon law turns out to be a special case of the Ryu–Takayanagi conjecture [18,19] which is a conjecture viewed as a general formula for the fine-grained entropy of quantum systems coupled to gravity.

In the third part of this work on the "Dark Side", entropic information theory is able to explain dark matter as the mass of the number of bits in the observable universe and is able to explain dark energy by the energy associated with this number of bits of information by the application of Landauer's principle [20]. The energetic content of the emergent entangled informational universe appears in two forms: an empty component (dark energy) and a matter component (dark matter).

The zero-point energy of the vacuum considered as dark energy is explained as a collective potential of all particles with their individual zero-point energy emerging from an informational field, distinct from the usual fields of matter of quantum field theory, associated with dark matter as having a finite and quantifiable mass.

The approach of entropic information theory bridges the precipice of the cosmological constant problem by considering the mass of the information bit instead of the Planck mass in the calculation of the cosmological constant, reducing the discrepancy of 120 orders of magnitude in the prediction of vacuum energy from a quantum perspective.

2. METHODS

Part One: Entropic information theory: Structural Bases

2.1 Information

2.1.1 Landauer's principle

Regarding information, Landauer's principle [1] is introduced, as a simple logical consequence of the second law of thermodynamics, the second law which states that the entropy of an isolated system increases or always remains the same; indeed, the change in entropy (delta S) is equal to the heat transfer (delta Q) divided by the temperature (T). For a given physical process, the entropy of the system and environment will remain a constant if the process can be reversed. Landauer's principle applies to all systems of nature, so any system, of temperature T, in which information is "erased" by a physical process will produce thermal energy per bit "erased" with a corresponding increase in information from the environment surrounding that system [21]. "Landauer showed that information is physical since the erasure of a bit of information in a temperature system, T, results in the release of a minimum, k T ln(2) of energy in the system environment" [22,23]. "This limit is the minimum amount of energy possible needed to erase a bit of information, known as the Landauer's limit. Landauer's principle is fully compatible with the laws of thermodynamics" [22,24,25,26]. "Landauer's principle can be derived from microscopic considerations [27] as well as well-established properties of Shannon–Gibbs–Boltzmann entropy" [22]. "Landauer's principle applies to both classical and quantum information. Landauer's principle has now been verified experimentally for classical bits and quantum qubits" [27,28]. "This important physical prediction that links information theory and thermodynamics was verified experimentally for the first time in 2012" [29]. The principle therefore appears fundamental and universal in its application. About these perspectives, the information is therefore directly related to the fundamental physics of nature.

2.1.2 Quantum information

Quantum information is considered as the basic entity of study in quantum information theory and can be manipulated using quantum information processing techniques; quantum information is information about the state of a quantum system, information is something physical that is encoded in the state of a quantum system [30]. Indeed, Gleason's theorem says that a quantum state is completely determined by knowing only the answers to all possible yes/no questions, a yes/no question is presumably a self-adjoint operator with two distinct eigenvalues.

2.1.3 Yes/No questions

At the bottom level of what we call the Reality is the "it from bit" perspective route. "It from bit" perspective symbolizes the idea that every item of the physical world has at bottom — at a very deep bottom, in most instances — an immaterial source and explanation; that what we call reality arises in the last analysis from the posing of yes-no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and this is a participatory universe" [31]. But "It's one thing to say that measurement requires information. It's another thing to say that the thing being measured is created by the observer doing the measuring" [32]. The notion of information can be defined in a precise and relevant way; indeed, it can be said that following the entropic information theory approach "Information is a quantum state change due to the modification of a degree of freedom in the quantum system considered [20]."

2.1.4 Entanglement

As seen in [20], quantum information can be measured using Von Neumann's entropy. Entropy is considered a measure of entanglement. Entropy provides a tool that can be used to quantify entanglement. Von Neumann entropy is a measure of the statistical uncertainty represented by a quantum state. In quantum physics, certain states, called entangled states, show certain statistical correlations between measurements on particles that cannot be explained by classical theory. An entangled system is defined as a system whose quantum state cannot be factored as a product of the states of its local constituents. That is, they are not individual particles but an inseparable whole. In quantum entanglement, one constituent cannot be described in detail without considering the other or others. The entanglement process is carried out when two particles are linked together, regardless of the separation from one to the other. In quantum mechanics, even if these entangled particles are not physically connected; they are always able to instantly share information. Following entropic information theory, quantum entanglement can be defined as the physical phenomenon that occurs when a group of particles is generated, interacts or shares spatial proximity such that one or more degrees of freedom are shared at the quantum level between each particle in the group; a particle cannot be described independently of the quantum state of others because they share degrees of freedom, even when the particles are separated by a great distance.

2.1.5 Quantum nonlocality

Quantum nonlocality is sometimes understood as being equivalent to entanglement. However, this is not the case. Quantum entanglement can be defined only within the formalism of quantum mechanics, i.e., it is a model-dependent property. In contrast, nonlocality refers to the impossibility of a description of observed statistics in terms of a local hidden variable model, so it is independent of the physical model used to describe the experiment. Non-locality means that measuring the properties of a quantum particle in one location can instantaneously affect the properties of another, even if the two particles are in different locations. Quantum nonlocality does not allow for faster-than-light communication [33], and hence is compatible with special relativity and its universal speed limit of objects. A semi-classical perspective can explain the notion of the entanglement; indeed, entanglement of photons can be explained in terms of the relativistic properties of space-time as defined by Einstein as well as by quantum mechanics. Yet, regarding photons and the theory of special relativity, all photons moving at the speed of light, the separation between those two points would be zero from the perspective of those photons. Those entangled photons which share one or more degrees of freedom at the quantum level between each photon cannot be described independently of the quantum state of the others because they share degrees of freedom. We can say thus that quantum theory is local in the strict sense defined by special relativity and, as such, the term "quantum nonlocality" is sometimes considered a misnomer.

2.1.6 Measure

The correlation predicted by quantum mechanics is due to the quantum entanglement of the pair, with the idea that their state is determined only at the point where a measurement is made on one or the other. This idea is entirely consistent with Heisenberg's uncertainty principle, one of the most fundamental concepts in quantum mechanics [34].

Here, we can understand the implication of the concept of information in the measurement problem, a measure informs the measurer, to be informed, the measurer needs information; taking information from the system during the measurement process; with measurement, the new system to consider is the system: "measurer-the thing to be measured", both parts of the system under consideration share one or more degrees of freedom, being entangled [5].

2.2 Degrees of Freedom

Energy has properties by which we can describe it. It has degrees of freedom. “Each spin can be taken to represent a bit, and each spin flip corresponds to a bit flip. Almost any interaction between degrees of freedom is sufficient to perform universal quantum logic on these degrees of freedom” [35,36]. The historical and scientifical approaches has been used to constitute a definition of degrees of freedom, where degrees of freedom refer to the number of independent variables needed to specify the state of a system, or more accurately, each of a number of independently variable factors affecting the range of states in which a system may exist, in particular any of the directions in which independent motion can occur.

The definition of degrees of freedom can be reformulated into “minimum number of coordinates required to specify a configuration based on the possible directions of movement of the system”. As indicated in the definition used, degrees of freedom depend on coordinates, depend on minimum number of ultimate coordinates required to specify a configuration. The ultimate basis of the universe is the level of ultimate positional coordinates which can give rise to degrees of freedom, by a process of emergence from the formation of a physical significance relative to the minimum number of coordinates required to specify a configuration. See Appendix A. to be able to see an explanatory diagram about the emergent entangled informational universe.

2.3 Emergence

2.3.1 Introduction

In science, an emergent process occurs when we observe that an entity has property that its parts do not have alone. The concept of emergence is based on the underlying concept that "the whole is greater than the sum of all its parts." An example of an emergent physical property is temperature. Temperature is not something that exists at the molecular level. At the molecular level, there is only movement, and this movement is what is perceived on a larger scale as temperature. A single particle has no temperature. It has a certain energy or speed, but it is not possible to translate this into temperature. Only when it comes to random velocity distributions of many particles does a well-defined temperature emerge. An emergence occurs when an entity has properties its parts do not have on their own, properties or behaviors that emerge only when the parts interact in a wider whole.

2.3.2 Weak and Strong emergence

The notion "emergence" may generally be subdivided into two perspectives, "weak emergence" and "strong emergence". Weak emergence, in terms of physical systems, is a type of emergence where the interacting members retain their independence, in which the emergent property is amenable to computer simulation or similar forms of after-the-fact analysis; independence is considered as crucial for these simulations. If the interacting members are not independent, a new entity is formed with new, emergent properties: this is called strong emergence, which it is argued cannot be simulated [37]. “The whole is other than the sum of its parts”. It is argued then that no simulation of the system can exist, for such a simulation would itself constitute a reduction of the system to its constituent parts [38]. Strong emergence describes the direct causal action of a high-level system upon its components; qualities produced this way are irreducible to the system's constituent parts [39]. This concept of emergence dates from at least the time of Aristotle [40]. Emergent structures are patterns that emerge via the collective actions of many individual entities. To explain such patterns, according to Aristotle [40], emergent structures are more than the sum of their parts assumes that the emergent order will not arise if the various parts simply act independently of one another. The emergence is interpreted as the impossibility in practice to explain the whole in terms of the parts. Now, one can understand the emergence of degrees of freedom from the minimum number of ultimate positional coordinates required to specify a configuration, configurations putted in relation to the possible directions of movement of the system, from which emerge the two fundamental building blocks of our universe, i.e., temperature and information. See Appendix A. to be able to see an explanatory diagram about the emergent entangled informational universe.

2.4 Temperature

After taking in account to information as fundamental building block of the universe talking now about Temperature as second fundamental building block of the universe. Regarding the third law of thermodynamics which states that absolute zero temperature, 0 K, cannot be reached by a finite number of steps, we can say that temperature is a fundamental aspect of nature.

2.5 Energy

2.5.1 Introduction

The application of Landauer's principle to the two fundamental building blocks of the universe, i.e., temperature and information, leads to an important consideration, the two ultimate building blocks of the emerging universe, i.e., temperature and information, produce the emergence of the notion of energy by Landauer's principle which identifies temperature as the only parameter linking information to energy as Energy = k T ln (2). Emerging from the minimum required ultimate coordinates forming a specific configuration, degrees of freedom give birth to temperature and information as the two fundamental building blocks of the universe whose relationship gives birth to energy, a relationship dictated by Landauer's principle. See Appendix A to be able to see an explanatory diagram about the emergent entangled informational universe.

2.5.2 Vacuum energy

Having considered temperature and information as the fundamental physics of nature, and after having considered their relationship that gives birth to energy, let us look at vacuum and the energy associated with it. The vacuum state is associated with the lowest possible energy state, which has measurable effects detected such as the Casimir effect.

A vacuum can be thought of not as empty space, but as the combination of all zero-point fields. In quantum field theory, this combination of fields is called the vacuum state, its associated zero-point energy is called the vacuum energy, and the value of the average energy is called the vacuum expectation value (VEV) also called its condensate. One of the most widely used examples of an observable physical effect resulting from an operator's vacuum expectancy value is the Casimir effect.

2.5.3 Casimir effect

In the Casimir effect, two flat plates placed very close together restrict the wavelengths of quanta which can exist between them. This in turn restricts the types and hence number and density of virtual particle pairs which can form in the intervening vacuum and can result in a negative energy density. Since this restriction does not exist or is much less significant on the opposite sides of the plates, the forces outside the plates are greater than those between the plates. This causes the plates to appear to pull on each other, which has been measured as the Casimir effect. More accurately, in the Casimir effect, the vacuum energy caused by the virtual particle pairs is pushing the plates together, and the vacuum energy between the plates is too small to negate this effect since fewer virtual particles can exist per unit volume between the plates than can exist outside them. The Casimir effect shows that quantum field theory allows the energy density in certain regions of space to be negative relative to the ordinary vacuum energy, and it has been shown theoretically that quantum field theory allows states where the energy can be arbitrarily negative at a given point [41].

2.5.4 Negative energy

The work of Casini and Bousso [8-17] on Bekenstein [42] bound sheds light on the Casimir effect

$$S_V = S(\rho_V) - S(\rho_V^0) \tag{1}$$
$$= -\left(\mathrm{tr}(\rho_V \log \rho_V)\right) + tr(\rho_V^0 \log \rho_V^0),$$

$$K_v = \mathrm{tr}(K\rho_V) - \mathrm{tr}(K\rho_V^0), \tag{2}$$

With these definitions, the bound reads

$$S_V \le K_V, \tag{3}$$

which can be rearranged to give:

$$\mathrm{tr}(\rho_V \log \rho_V) - \mathrm{tr}(\ \rho_V \log \rho_V^0) \ge 0, \tag{4}$$

This is simply the statement, following Casini's and Bousso work [8-17], of positivity of quantum relative entropy, which proves the Bekenstein bound as valid.

This construction allows us to make sense of the Casimir effect where the localized energy density is lower than that of the vacuum, i.e., a negative localized energy. The localized entropy of the vacuum is nonzero, and so, the Casimir effect is possible for states with a lower localized entropy than that of the vacuum i.e., a negative localized energy. Negative energies and negative energy density are consistent with quantum field theory.

In physics, the negative energy is a concept used to explain the nature of certain fields, including the gravitational field and various quantum field effects.

Part Two: Entropic information theory: Generalization

2.6 Entropy

2.6.1 Introduction

Entropy is almost universally simply called S or the statistical entropy or the thermodynamic entropy which have equally meaning.

In general, entropy is related to the number of possible microstates according to Boltzmann's principle:

$$S = k \ln(W), \tag{5}$$

Where:

S is the entropy of the system,
k is Boltzmann's constant,
W is the number of microstates.

Boltzmann entropy formula can be derived from Shannon entropy formula when all states are equally probable.

$$S = -k \sum p_i \ln(p_i) = k \sum \frac{\ln(W)}{w} = k \ln(W), \quad (6)$$

So, you have W microstate equiprobable with probability $p_i = \frac{1}{w}$.

The entropy of a thermodynamic system in equilibrium measures the uncertainty as to which of all its internal configurations compatible with its macroscopic thermodynamic parameters (temperature, pressure, etc.) is actually realized.

The entropy makes it possible to estimate the quantity of information lost when one summarizes the microscopic information by the macroscopic information.

"Statistical entropy is a probabilistic measure of uncertainty or ignorance; information is a measure of a reduction in that uncertainty" [43].

2.6.2 Coarse- and Fine-grained entropy

In general, a fine-grained description of a system is a detailed description of its microscopic behavior. A coarse-grained description is one in which some of this fine detail has been smoothed over.

Coarse graining is at the core of the second law of thermodynamics. It is important to recognize that a critical property of a coarse-grained description is that it is “true” to the system, meaning that it is a reduction or simplification of the actual microscopic details.

Where fine grained entropy is the entropy of the density matrix calculated by the standard methods of quantum field theory in curved spacetime. In the literature, this is often simply called the von Neumann entropy. It is Shannon’s entropy with distribution replaced by density matrix. It is invariant under unitary time evolution.

$$S = -tr\,[\rho \log(\rho)] \quad (7)$$

Entanglement entropy is a measure of “quantumness” that vanishes for classical states, and it is large when quantum correlations are important. It is also a measure of complexity [44].

2.6.3 New entropic perspective

We start this entropic information theory generalization by introducing the mass of information bit formula into the hidden thermodynamics of Louis De Broglie:

About the hidden thermodynamics of isolated particles, it is an attempt to bring together the three furthest principles of physics: the principles of Fermat, Maupertuis, and Carnot, that De Broglie has had his final idea. Entropy becomes a sort of opposite to action with an equation that relates the only two universal dimensions of the form [45]:

$$\frac{action}{h} = -\frac{entropy}{k} \quad (8)$$

Where:

k: Boltzmann's constant
h: Planck constant

With $action = Energy * Time$
and $Energy = mc^2$

$$\frac{action}{h} = \frac{mc^2t}{h} = -\frac{entropy}{k} = \frac{k \ln(w)}{k} \quad (9)$$

We introduce the mass of bit of information into this relation as being:

$$mass_{bit} = \frac{k\,T \ln(2)}{c^2} \quad (10)$$

Where:

k: Boltzmann's constant
T: the temperature at which the bit of information is stored.
t: Time required to change the physical state of the information bit.
c: speed of light

$$\frac{action}{h} = \frac{mc^2t}{h} = \frac{\frac{k\,T\ln(2)}{c^2}c^2t}{h} = -\frac{entropy}{k} = \frac{k\,ln\,(w)}{k} \quad (11)$$

$$\frac{action}{h} = \frac{mc^2t}{h} = \frac{k\,T\,\ln(2)t}{h} = -\frac{entropy}{k} = \ln(W) \quad (12)$$

$$\ln(W) = \frac{k\,T\,\ln(2)t}{h} \quad (13)$$

We obtain the validity proof by the Landauer limit as

$$\frac{k\,T\ln(2)t}{h} = \frac{mc^2t}{h} \qquad (14)$$

$$k\,T\ln(2) = m\,c^2 \qquad (15)$$

Indeed, the Landauer limit is the minimum possible amount of energy required to erase one bit of information, known as the Landauer limit:

As $E = mc^2$

$$E = k\,T\ln(2) \qquad (16)$$

Landauer's principle can be derived from microscopic considerations [46] as well as derived from the well-established properties of the Shannon-Gibbs-Boltzmann entropy [22]. The principle thus appears to be fundamental and universal in application. Landauer's principle applies both to classical and to quantum information.

2.6.4 New formulation of entropy

Moreover, as Entropy:

$$S = k\ln(W) \qquad (17)$$

We obtain a new value for the general entropy S formula based on the hidden thermodynamics of de Broglie with the introduction of mass of bit of information:

$$k\ln(W) = k\frac{k\,T\ln(2)t}{h} \qquad (18)$$

$$S = k^2\frac{T\ln(2)t}{h} \qquad (19)$$

With $S\ entropy$ expressed in the number of bits of information

Based on that view, the entropic information theory approach is founded on the bit of information such as the number of bits of the system, the number of bits necessary to specify the actual microscopic configuration among the total number of microstates allowed and thus characterize the macroscopic states of the system under consideration.

The entropic information theory approach can formulate a set of five equivalent equations expressing entropy, Boltzmann, Einstein, Planck, Avogadro and fine structure formulation as seen in Fig. 1.

2.7 Black Hole

2.7.1 Black hole entropy from Entropic Information approach

The theory of entropic information enters the problematic of the black hole by introducing Hawking's temperature into equations wherein the mass of the bit of information has been implemented.

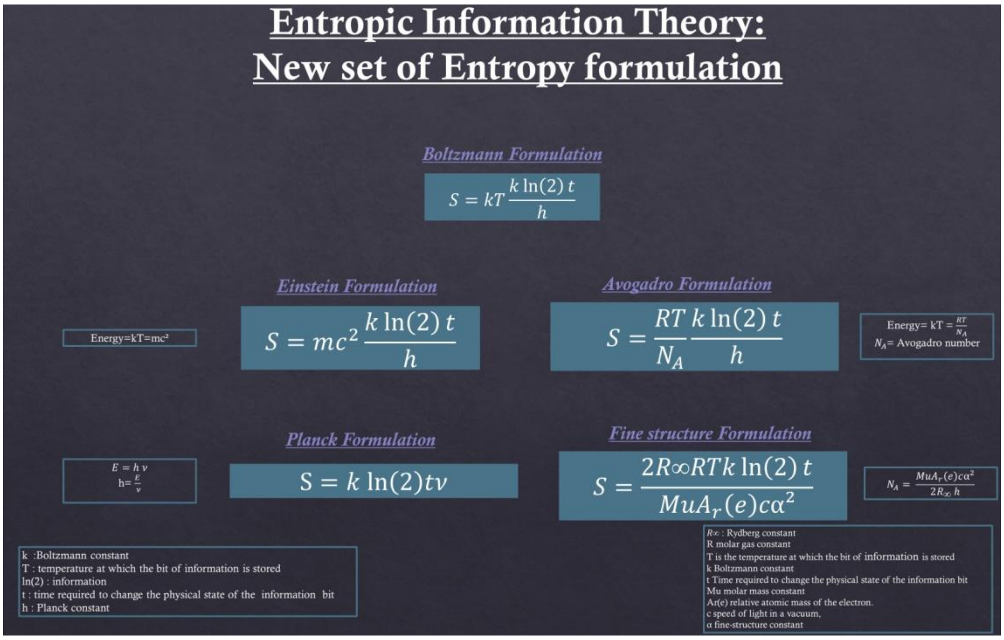

Fig. 1. Set of five equivalent equations expressing entropy according to entropic information theory

We start from this equation obtained by the introduction of mass bits of information into the hidden thermodynamics of Louis de Broglie. See (13):

wherein we inject the Hawking Temperature represented by this formula:

$$T_H = \frac{1}{k}\frac{\hbar c^3}{8\pi GM} \tag{20}$$

With (17), we obtain the black hole entropy formula from entropic information approach, at the hawking temperature, based on the mass of bit of information,

$$S = k\ln(W) = k\ \frac{c^3 \ln(2)\, t}{16\pi^2 GM} \tag{21}$$

The ln 2 factor comes from defining the information as the logarithm to the base 2 of the number of quantum states [16].

Introduction of the Hawking temperature formula which express itself by all the constant in modern physics bringing together: relativity, with c, the speed of light, gravitation, with G gravitational constant, quantum physics with $\hbar$ reduced Planck's constant and thermodynamics with k Boltzmann's constant.

2.7.2 The Bekenstein–Hawking entropy

The Bekenstein–Hawking area law claims that the area of the black hole horizon is proportional to the black hole's entropy.

$$S = \frac{k}{4}\left(\frac{c^3}{\hbar G}\right)A = k\ \frac{A}{4l_p^2} \tag{22}$$

The Bekenstein Hawking entropy formula, since it increases under time evolution, should be viewed as the coarse-grained entropy formula for the black hole [47].

The black-hole entropy is proportional to the area of its event horizon A. This area relationship was generalized to arbitrary regions via the Ryu–Takayanagi formula, which relates the entanglement entropy of a boundary conformal field theory to a specific surface in its dual gravitational theory [48].

The Bekenstein–Hawking entropy is a statement about the gravitational entropy of a system.

The Bekenstein–Hawking entropy is a measure of the information lost to external observers due to the presence of the horizon.

$$S = k\ln(W) = k\ \frac{c^3 \ln(2)\, t_{evap}}{16\pi^2 GM} = \frac{k}{4}\left(\frac{c^3}{\hbar G}\right)A \tag{23}$$

With A, the area of the black hole horizon: $16\,\pi(\frac{GM}{c^2})^2$

$$S = k\ln(W) = k\ \frac{c^3 \ln(2) t_{evap}}{16\pi^2 GM} = \frac{1}{4}\ k\ \frac{16\pi G^2 M^2 c^3}{\hbar c^4 G} \tag{24}$$

$$k\ \frac{c^3 \ln(2) t_{evap}}{16\pi^2 GM} = \frac{1}{4}\ k\ \frac{16\pi G^2 M^2 c^3}{\hbar c^4 G} \tag{25}$$

Simplification by $\frac{1}{4}$,

$$k\frac{c^3 \ln(2) t_{evap}}{4\pi^2 GM} = k\frac{16\pi G^2 M^2 c^3}{\hbar c^4 G} \tag{26}$$

Simplification by k,

$$\frac{c^3 \ln(2) t_{evap}}{4\pi^2 GM} = \frac{16\pi G^2 M^2 c^3}{\hbar c^4 G} \tag{27}$$

Simplification on left term by $\boldsymbol{c^3}$ *and G*

$$\frac{c^3 \ln(2) t_{evap}}{4\pi^2 GM} = \frac{16\pi GM^2}{\hbar c} \tag{28}$$

$$c^3 \ln(2)\, t_{evap} = \frac{64\pi^3 G^2 M^3}{\hbar c} \tag{29}$$

$$t_{evap} = \frac{64\pi^3 G^2 M^3}{\hbar c^4 \ln(2)} \tag{30}$$

With $\frac{2GM}{c^2} = R$

$$t_{evap} = \frac{32\pi^3 GRM^2}{\hbar \ln(2) c^2} \tag{31}$$

Again with $\frac{2GM}{c^2} = R$

$$t_{evap} = \frac{16\pi^3 R^2 M}{\hbar \ln(2)} \tag{32}$$

The entropic information theory approach concerning the black hole entropy can express based on the mass of information bit a new black hole entropy formula as reformulation of Bekenstein-Hawking entropy formula with a time of evaporation of the black hole as see in Fig. 2.

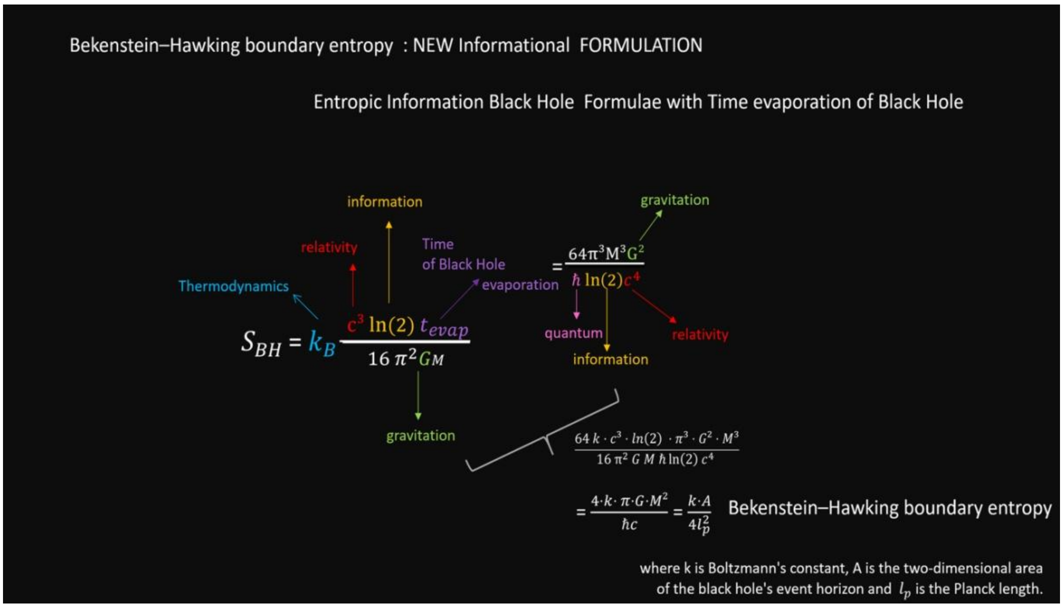

Fig. 2. Black holes entropic information formula with the time of evaporation of the black hole (t_{evap}) as new formulation of The Bekenstein–Hawking entropy additionally including the information notion, able to calculate the entropy of the entangled Hawking radiation; where k=Boltzmann constant, c=speed of light, $\hbar$ = reduced Planck's constant, G=Gravitational Constant, M= mass of the black hole

2.7.3 The Bekenstein bound

In physics, an upper limit on the thermodynamic entropy S, or Shannon entropy H, that can be contained within a given finite region of space which has a finite amount of energy is the Bekenstein bound (named after Jacob Bekenstein)—or conversely, the maximal amount of information required to perfectly describe a given physical system down to the quantum level [49]. Furthermore, generally, the entropy is proportional to the number of bits necessary to describe the state of the system considered. This result, which was demonstrated by Jacob Bekenstein corresponds to the interpretation in terms of bits of information.

The universal bound originally founded by Jacob Bekenstein in 1981 as the inequality [50,51].

$$S \leq \frac{2\pi kRE}{\hbar c} \qquad (33)$$

It implies that the information of a physical system, or the information necessary to perfectly describe that system, must be finite if the region of space and the energy are finite. In computer science this implies that non-finite models such as Turing machines are not realizable as finite devices.

In informational terms, the relation between thermodynamic entropy S and Shannon entropy H is given by:

Relation between S & H

$$S = k\,H\ln(2) \qquad (34)$$

The black holes entropic information formula given as follows:

$$S = k\ln(W) = \frac{kc^3\ln(2)t_{evap}}{16\pi^2 GM} \qquad (35)$$

As S, Boltzmann entropy can be derived from Shannon entropy H and following the relation between thermodynamic entropy and Shannon entropy S=k H ln(2); we obtain:

$$S = k\ln(W) = k\frac{c^3\ \ln(2)\,t_{evap}}{16\pi^2 GM} = k\frac{2\pi RE}{\hbar c} = k\ H\ln(2) \qquad (36)$$

With following S= k H ln(2)

$$\frac{c^3 t_{evap}}{16\pi^2 GM} = \frac{2\pi RE}{\hbar c\ln(2)} \qquad (37)$$

where S is the entropy, k is Boltzmann's constant, R is the radius of a sphere that can enclose the given system, E is the total mass–energy including any rest masses, ħ is the reduced Planck constant, and c is the speed of light.

With $\frac{c^2}{2\,GM} = \frac{1}{R}$

$$\frac{ct_{evap}}{8\pi^2 R} = \frac{2\pi cRM}{\hbar \ln(2)} \tag{38}$$

Simplification by c,

$$\frac{t_{evap}}{8\pi^2 R} = \frac{2\pi RM}{\hbar \ln(2)} \tag{39}$$

We obtain,

$$t_{evap} = \frac{16\pi^3 R^2 M}{\hbar \ln(2)} \tag{40}$$

With $\frac{2GM}{c^2} = R$

$$t_{evap} = \frac{32\pi^3 GRM^2}{\hbar \ln(2) c^2} \tag{41}$$

With $\frac{2GM}{c^2} = R$

$$t_{evap} = \frac{\boldsymbol{64\pi^3 G^2 M^3}}{\hbar \boldsymbol{c^4} \ln(2)} \tag{42}$$

With A, the area of the black hole horizon: $16\,\pi(\frac{GM}{c^2})^2$

$$t_{evap} = \frac{\boldsymbol{4\pi^2} M}{\hbar \ln(2)} A \tag{43}$$

To inject in $k\frac{c^3\ \ln(2) t_{evap}}{16\pi^2 GM}$,

$$S = k\frac{c^3\ \ln(2)\,\boldsymbol{4\pi^2} M}{16\pi^2 GM\,\hbar \ln(2)} A \tag{44}$$

The black hole scale is browsed to take in account some of them to make our calculations on to prove the validity of entropic information formula in regard to classic method to determine the black hole parameters [52].

As a side note, it can also be shown that the Boltzmann entropy is an upper bound to the entropy that a system can have for a fixed number of microstates meaning:

$$S \leq k \ln(W) \tag{45}$$

With W reflecting the degree of freedom of a system as seen upper.

We must take in account that the Bekenstein–Hawking boundary entropy of three-dimensional black holes exactly saturates the bound.

$$S = k \ln(W) = k\ \frac{c^3 \ln(2) t_{evap}}{16\pi^2 GM} = \frac{1}{4}\ k\ \frac{16\pi G^2 M^2 c^3}{\hbar c^4 G} \tag{46}$$

$$= \frac{k}{4}\left(\frac{c^3}{\hbar G}\right) A\ =\ k\ \frac{A}{4 l_p^2} =\ k\ \frac{2\pi RE}{\hbar c} = k\,H \ln(2)$$

Casini proves the thermodynamics interpretation in the form of Bekenstein bound as valid. Indeed, we know following the work of Casini in 2008 [8] about the Von Neumann entropy and the Bekenstein bound, that the proof of the Bekenstein bound is valid using quantum field theory [9-17].

For example, given a spatial region V, Casini defines the entropy on the left-hand side of the Bekenstein bound as:

$$S_V = S(\rho_V) - S(\rho_V^0) = -\mathrm{tr}\,(\rho_V \log \rho_V) + \mathrm{tr}(\rho_V^0 \log \rho_V^0) \tag{47}$$

Sv where S (ρ_V) is the Von Neumann entropy of the reduced density matrix ρ_V associated with V, V in the excited state ρ, and S (ρ_V^0) is the corresponding Von Neumann entropy for the vacuum state ρ^0.

Casini defines the right-hand side of the Bekenstein bound as the difference between the expectation value of the modular Hamiltonian in the excited state and the vacuum state,

$$K_V = \mathrm{tr}\,(K\,\rho_V) - \mathrm{tr}\,(K\,\rho_V^0) \tag{48}$$

With these definitions, the bound reads SV ≤ KV, which can be rearranged to give:

$$\mathrm{tr}\,(\rho_V \log \rho_V) - \mathrm{tr}\,(\rho_V \log \rho_V^0) \geq 0 \tag{49}$$

This is simply the statement of positivity of quantum relative entropy, which proves the Bekenstein bound.

2.7.4 Von Neumann entropy

Diving into Casini's work with the black hole's entropic information formula, we obtain new enlightening about black hole fine-grained entropy.

The ingenious proposal of Casini [53] is to replace 2 π R E, by:

$$K_V = \mathrm{tr}\,(K\,\rho_V) - \mathrm{tr}\,(K\,\rho_V^0) \tag{50}$$

Indeed, in [9-17], Casini's work, on the right-hand side of the Bekenstein bound, a difficult point is to give a rigorous interpretation of the quantity 2 π R E, where R is a characteristic length scale of the system and E is a characteristic energy. This product has the same units as the generator of a Lorentz boost, and the natural analog of a boost in this situation is the modular Hamiltonian of the vacuum state K = − log (ρ_V^0).

With these definitions, the bound reads

$$\mathrm{Sv} \le K_V \tag{51}$$

The version of the Bekenstein bound is $\mathrm{Sv} \le K_V$, namely:

$$S(\rho_V) - S(\rho_V^0) \le \mathrm{tr}(K\,\rho_V) - \mathrm{tr}(K\,\rho_V^0) \tag{52}$$

is equivalent to

$$\mathrm{Sv} \equiv S(\rho_V|\rho_V^0) \equiv \mathrm{tr}(\rho_V(\log\rho_V - \log\rho_V^0)) \ge 0 \tag{53}$$

As black holes entropic information formula is equal to Bekenstein universal bound.

$$\frac{kc^3\ln(2)t_{evap}}{16\pi^2GM} = \frac{2\pi kRE}{\hbar c} \tag{54}$$

As the difference between the expectation value of the modular Hamiltonian in the excited state and the vacuum state $K_V = \mathrm{tr}\,(K\,\rho_V) - \mathrm{tr}\,(K\,\rho_V^0)$ is equal to Bekenstein universal bound.

We obtain:

$$\mathrm{Sv} = S\,(\rho_V|\rho_V^0) = S(\rho_V) - S(\rho_V^0) \tag{55}$$

$$= -\mathrm{tr}\,(\rho_V \log\rho_V) + \mathrm{tr}(\rho_V^0 \log\rho_V^0)$$

$$= \mathrm{tr}\left(\rho_V\,(\log\rho_V - \log\rho_V^0)\right)$$

$$= K_V = \mathrm{tr}\,(K\,\rho_V) - \mathrm{tr}\,(K\,\rho_V^0)$$

$$= \frac{2\pi kRE}{\hbar c}$$

$$= \frac{kc^3\ln(2)t_{evap}}{16\pi^2GM}$$

2.7.5 Hawking radiation

In Quantum field theory in curved spacetime (QFTCS), a single emission of Hawking radiation involves two mutually entangled particles. The thermal aspect of Hawking radiation comes from separating entangled outgoing Hawking quanta and interior Hawking quanta. A quantum of Hawking radiation is emitted by the outgoing particle escaping; the black hole swallows the infalling particle.

The Hawking radiation temperature is [7]:

$$T_H = \frac{1}{k}\frac{\hbar c^3}{8\pi GM} \tag{56}$$

The Bekenstein–Hawking luminosity of a black hole, under the assumption of pure photon emission (i.e., that no other particles are emitted) and under the assumption that the horizon is the radiating surface is:

$$P = \frac{\hbar c^6}{15360\,\pi G^2M^2} \tag{57}$$

where P is the luminosity, i.e., the radiated power, ħ is the reduced Planck constant, c is the speed of light, G is the gravitational constant and M is the mass of the black hole.

The time that the black hole takes to dissipate is:

$$t_{evap} = \frac{5120\,\pi G^2M^2}{\hbar c^4} = \frac{480\,c^2V}{\hbar G} \approx 2.1\;10^{67}\;years\;\left(\frac{M}{M_\odot}\right)^3 \tag{58}$$

where M and V are the mass and (Schwarzschild) volume of the black hole. A black hole of one solar mass ($M_\odot$ = 2.0× 10^{30} kg) takes more than 10^{67} years to evaporate

Using the entropic information formula of black hole entropy:

$$S_{BH} = k\,\frac{c^3\ln(2)\,t_{evap}}{16\pi^2GM} \tag{59}$$

With a time of evaporation formula:

$$t_{evap} = \frac{64\pi^3G^2M^3}{\hbar c^4\ln(2)} \tag{60}$$

We obtain for a black hole 1.989×10^{30}kg a time of evaporation of 1,178007186570708 x 10^{74} seconds equal to 3,7354363×10^{66} years. Result remarkably close to the result associate to the Bekenstein–Hawking luminosity approach where the result is 10^{67} years to evaporate.

Assume that in a finite time in the past a black hole has been formed and in the future; will be fully evaporated away in some finite time. The black hole will only emit a finite amount of information encoded within its Hawking radiation. The Hawking radiation is to put in relation with the (finite) entropy and thus the (non-zero) temperature of the black hole: the Hawking temperature. Hence the absence of the Hawking radiation would lead to violations of thermodynamical laws.

Hawking radiation occurs in an inertial frame where spatial distance doesn't come into it, and, where the horizon of a black hole is compact.

Hawking radiation is thermal radiation following Boltzmann distribution.

Hawking radiation is in a pure state, is that this is in apparent contradiction to the fact that Hawking radiation is also said to be thermal. The apparent contradiction is solved when one realizes that in a general curved spacetime there is no unique definition of the vacuum state and therefore the whole Hilbert.

Consequently, an observer at infinity will see a thermal bath of particles (i.e., in a mixed state) coming from the horizon, even though the quantum fields are in the local vacuum state near the horizon."

2.7.6 Ryu and Takayanagi conjecture

The Ryu–Takayanagi conjecture is a conjecture within holography that posits a quantitative relationship between the entanglement entropy of a conformal field theory and the geometry of an associated anti-de Sitter spacetime [18,19]. The formula characterizes "holographic screens" in the bulk; that is, it specifies which regions of the bulk geometry are "responsible to particular information in the dual CFT" [54].

The Ryu–Takayanagi formula calculates the entropy of quantum entanglement in conformal field theories on Bekenstein-Hawking entropy of black holes in the context of Juan Martín Maldacena's holographic principle, in which conformal field theories on a surface form a gravitational theory in a closed volume.

"The Bekenstein–Hawking area law, while claiming that the area of the black hole horizon is proportional to the black hole's entropy, fails to provide a sufficient microscopic description of how this entropy arises. The holographic principle provides such a description by relating the black hole system to a quantum system which does admit such a microscopic description. In this case, the CFT has discrete eigenstates, and the thermal state is the canonical ensemble of these states [48]. The entropy of this ensemble can be calculated through normal means, and yields the same result as predicted by the area law. This turns out to be a special case of the Ryu–Takayanagi conjecture" [55].

The first version of the fine-grained entropy formula was discovered by Ryu and Takayanagi [52]. It was subsequently refined and generalized by several authors [56-63]. Originally, the Ryu-Takayanagi formula was proposed to calculate holographic entanglement entropy in anti-de Sitter spacetime, but the present understanding of the formula is much more general. It requires neither holography, nor entanglement, nor anti-de Sitter spacetime. Rather it is a general formula for the fine-grained entropy of quantum systems coupled to gravity [47].

The black-hole entropy is proportional to the area of its event horizon A. The black hole entropy horizon law which turns out to be a special case of the Ryu–Takayanagi conjecture. The black-hole entropy area relationship was generalized to arbitrary regions via the Ryu–Takayanagi formula, which relates the entanglement entropy of a boundary conformal field theory to a specific surface in its dual gravitational theory [48], but the current understanding of the formula is much more general. As being a general formula for the fine-grained entropy of quantum systems coupled to gravity [47].

Part Three: Entropic information theory: Dark Side.

2.8 Information and Dark Matter

Vopson even went so far as to speculate that the dark matter that holds galaxies together could also be composed of information. He said that since for more than 60 years we have been trying unsuccessfully to understand what dark matter is, it could very well be information. It is well-accepted that the matter distribution in the Universe is ~5% ordinary baryonic matter, ~27% dark matter and ~68%, dark energy [64].

How many bits of information are there in the content of the observable universe?

Going back as far as the late 1970s, this question has been addressed in several studies and several answers have been given. For example, using the Bekenstein–Hawking formula for the black-hole entropy [49,65] the information content of the universe has been calculated by Davies [66]

$$I \approx \frac{2\pi G M_u^2}{hc} = 10^{120} \text{ bits} \quad (61)$$

Where:

G is the gravitational constant,
Mu is the mass of the universe enclosed within its horizon,
h is Planck's constant,
c is the speed of light.

Wheeler's approach which estimated the number of bits in the present universe at T = 2.735 K from entropy considerations, resulting in 8×10^{88} bits content [31]. Or Lloyd which took a similar approach and estimated the total information capacity of the universe as [67]

$$I = \frac{S}{\mathrm{k} \ln(2)} \approx (\rho c^5 t^4)^{3/4} \approx 10^{90} \text{ bits} \quad (62)$$

Where:

S is the total entropy of the matter dominated universe,
k is the Boltzmann constant,
ρ is the matter density of the universe,
t is the age of the universe at present,
c is the speed of light,

The entropic information approach can calculate an estimation of the bits of information contained in the observable universe from the new formulation of entropy, entropy based on the mass of the information bit given as follows:

$$S = k^2 \frac{T \ln(2)\, t}{h} \quad (63)$$

With Einstein mass–energy equivalence, Energy= mc², this is

$$S = mc^2 \frac{k \ln(2)\, t}{h} \quad (64)$$

We use the mass of the universe and the age of this one for the calculations as

$mass_{univ} = 2.78 \text{ x} 10^{54}\ kg$

$t_{univ} = 4.361170766 \text{ x } 10^{17}\ seconds$

$$\frac{2.78\text{x } 10^{54}\text{x } 299792458^2\text{x } 1.380649\text{x}10^{-23}\text{x} \ln(2) \text{ x } 4.361170766\text{x } 10^{17}}{6.6267015\text{x } 10^{-34}} \quad (65)$$

$= 1.5736228 \text{ x}10^{99}$ bits

The Estimation of the number of bits of information in the observable universe based on entropic information entropy new alternative formulation: $S = mc^2 \frac{k\ln(2)t}{h}$, with $mass\text{-}univ$= 2.78 $\text{x } 10^{54}$. kg and $t\text{-}univ$= 4.361170766 $\text{x } 10^{17}\ seconds$ is 1.5736228 $\text{x } 10^{99}$ bits.

N.B: The relationship between thermodynamic entropy S and Shannon entropy H given by $S = \mathrm{k\,H} \ln(2)$ is not used to convert the result into informational terms because the result of the entropic information theory approach to entropy is expressed in informational terms, indeed it is the mass of the information bit that has been implemented to the initial equation considered, so the results of the entropy are expressed in the number of bits. The theory of entropic information is based on the number of bits of the system, the number of bits necessary to specify the real microscopic configuration among the total number of microstates allowed and thus characterize the macroscopic states of the system considered.

This number of 1.5736228 $\text{x } 10^{99}$ bits estimated by calculation from entropic information theory is remarkably close to an estimate of the information bit content of the universe with 10^{94} bits that would be sufficient to account for all the dark matter missing in the visible universe following Vopson using the reasoning developed following [68]. Taking the estimated mass of our Milky Way galaxy as ~ $7 \times 10^{11}\ M_\odot$ solar masses [69], and using the mass of the sun $M_\odot$ ~ 2×10^{30} Kg, then the estimated dark matter mass in our galaxy is $M_{\text{Dark\_Matter}}$ ~ $3.78 \times 10^{12}\ M_\odot$ = 7.56×10^{42} Kg. Assuming that all the missing dark matter is made up of bits of information, then the entire Milky Way galaxy has Nbits (Milky Way) = $M_{\text{Dark\_Matter}}$ / m_{bit}(T=2.73K) = 2.59×10^{82} bits. The estimated number of galaxies in the visible universe is ~ 2×10^{12} [70], so the estimated total number of bits of information in the visible universe is ~ 52×10^{93} bits. Remarkably, this number is reasonably close to another estimate of the Universe information bit content of ~10^{87} given by Gough in 2008 using Landauer's principle via a different approach [71].

Vopson estimated that around 5,2 × 10^{94} bits would be enough to account for all the missing dark matter in the observable universe [68,72,73]. The estimated bit content of the observable universe from entropic information is 10^{99} $b$its. Note that 10^{99} bits is significantly less than the theoretical maximum information content of the universe of 10^{123} Bits provided by applying the holographic principle [49,74] to the universe. In the maximum information scenario, corresponding to the universe being a single black hole, 10^{123} elementary squares of Planck length are needed to cover the surface of the current known universe.

2.9 Landauer's Principle and Dark Energy

From [71], we can read that Landauer's principle was originally proposed to describe the energy dissipation when information is overwritten in computer systems and subsequently used to predict the future limits to shrinking computer circuit size [75-81]. Moreover, Landauer showed that any erasure of information is necessarily accompanied by heat dissipation [1]. A corresponding minimum $\mathrm{k}\ T\ ln(2)$ of heat energy has to be dissipated into the surrounding environment to increase the environment's thermodynamic entropy in compensation, and in accord with the second law of thermodynamics. The total amount of information is conserved as the surrounding environment effectively contains the erased information, although clearly no longer in a form that the computer can use. More generally, Landauer's principle applies to all systems in nature so that any system, temperature T, in which information is 'erased' by some physical process will output $k\,T\,ln(2)$ of heat energy per bit 'erased' with a corresponding increase in the information of the environment surrounding that system. Information is therefore directly bound up with the fundamental physics of nature. This strong interdependence between nature and information is emphasized by astrophysicist John Wheeler's slogan "it from bit" and computer scientist Rolf Landauer's maxim "information is physical" Landauer's principle is fully compatible with the laws of thermodynamics [21,22,24,25].

Information entropy is equivalent to thermodynamic entropy when the same degrees of freedom are considered. The information entropy of the physical world is thus the number of bits needed to account for all possible microscopic states. Then each bit of information is equivalent to $\Delta S = \mathrm{k}\,T\ ln(2)$ of thermodynamic entropy leading to Landauer's principle that $\Delta S\ T = \mathrm{k}\,T\ ln(2)$ of heat is dissipated when a computer logic bit is erased [81].

Landauer's principle identifies temperature as the only parameter connecting information to energy.

The equivalent energy of the total information is given by $N_{bits}\ k_B\ T\ ln(2)$.

The equivalent Landauer energy of these elementary bits would be defined in a form and value identical to the characteristic energy of the cosmological constant.

We obtain the equivalent Landauer energy of a fundamental bit of information in a universe at temperature, T_{univ} ., ρ_{tot} is the total density of matter in the universe (baryon + dark).

$$k_B\ T_{univ}\ln(2) = \sqrt[4]{\frac{15\ \rho_{tot}\hbar^3 c^5}{\pi^2}}\ln(2) \tag{66}$$

This Landauer bit energy is defined identically to the characteristic energy of the cosmological constant, the cosmological constant is closely associated with the concept of dark energy. The right-hand side of this equation is identical to equation 17.14 of [82] for the characteristic energy of the cosmological constant—with the sole addition of ln(2) to convert between entropy units—between natural information units, nats, and bits. Information bit energy might then explain the low milli-eV (0.003 eV) characteristic energy of Λ, which Peebles [82] considered to be too low to be associated with any relevant particle physics [83].

The dark energy density in the universe is about 7× 10^{-30} g/cm3 on average according to Wikipedia. This is uniform throughout the Hubble volume of the entire universe i.e., the volume of the universe with which we are in causal contact. The Hubble volume is 10^{31} ly^3 i.e., cubic light years. This gives 8.46732× 10^{84} cm3 as the volume of the universe. Using the mass-energy equivalence, you find that the total dark energy content in the entire universe is around 10^{69} Joules.

We use the value obtained by the informational entropy for the estimation of the number of bits corresponding to all the mass content of the whole observable universe.

$$\frac{2.78\text{x } 10^{54}\text{x } 299792458^2\text{x } 1.380649\text{x}10^{-23} \text{ x} \ln(2) \text{ x } 4.361170766\text{x } 10^{17}}{6.6267015\text{x } 10^{-34}} \quad (67)$$

$= 1.5736228 \text{ x } 10^{99}$ bits

The Estimation of the number of bits of information in the observable universe based on entropic information entropy new alternative formulation: $S = mc^2 \frac{k\, ln(2)t}{h}$, with $mass\text{-}univ$=2.78 × 10^{54} . kg and $t\text{-}univ$=4.361170766 ×10^{17} $seconds$ is 1,5736228 x 10^{99} bits.

With the formula of total information equivalent energy, given by Landauer's principle:

$$N_{Bits}\, k\, T_{univ}\, \ln(2) \quad (68)$$

$T_{univ} = 2.725\, K$

We obtain,

$$1.5736228 \text{ x } 10^{99} \text{ x } 1.380649 \text{ x } 10^{-23} \text{ x } 2.725 \text{ x } \ln(2) = 4.1037027 \text{ x } 10^{76} \text{ Joules} \quad (69)$$

The estimation of the energy associated with the number of bits of information of the observable universe based on the entropic information theory and the Landauer's principle $N_{Bits}\, k\, T_{univ}\, ln(2)$ with temperature of universe, $T_{univ} = 2.725\, K$ is $4.1037027 \text{ x } 10^{76}$ Joules

The entropic information theory can provide a quantitative account for dark energy, accounting for the present energy value, $\sim 10^{69}$ Joules. The entropic information theory provides an estimation of $4.1 \text{ x}10^{76}$ Joules remarkably close to this estimation.

2.10 Dark Energy and Cosmological Constant

Now, let's dive into cosmology, where the cosmological constant (lambda: Λ), alternatively called Einstein's cosmological constant, is a constant term that can be added to Einstein's field equations of general relativity. In the field equation considered as a "source term", it can be thought of as equivalent to the mass of empty space or the energy density of space, or the energy of vacuum. It is closely associated with the concept of dark energy.

In physical cosmology, the energy of the cosmological vacuum appears as the cosmological constant in the Einstein equation or Einstein field equation, fundamental equation of general relativity. General relativity predicts that energy is equivalent to mass, and therefore, if the vacuum energy is "really there", it should exert a gravitational force.

The cosmological constant require that empty space takes the role of gravitating negative masses which are distributed all over the interstellar space' as first stated by Einstein [84,85].

The point is dark energy is a "negative pressure" form of energy causing universe expansion.

According to entropic information theory approach, this "negative pressure" form of energy has been explained by the injection of the mass of the bit of information in the hidden thermodynamics' formula of louis de Broglie leading to an explanation of the negative energy by the presence of the negative sign in the indicated formula $\frac{action}{h} = -\frac{entropy}{k}$.

In the Hidden Thermodynamics of Louis de Broglie, see [34]

$$\frac{action}{h} = -\frac{entropy}{k} \quad (70)$$

By the application of Landauer's principle formula, entropic information theory approach has calculated the dark energy as being the energy associated to the number of bits of information of the observable universe based on entropic information theory new alternative entropy formulation.

The equivalent Landauer energy of these elementary bits would be defined in a form and value identical to the characteristic energy of the cosmological constant [39]. This Landauer bit energy is defined identically to the characteristic energy of the cosmological constant. Estimation of the energy associated with the number of bits of information in the observable universe based on entropic information theory is considered as being the estimation of dark energy. This estimate of dark energy is associated with the equivalent Landauer energy for each bit of information or bit of entropy, an association based on Landauer's principle. This equivalent Landauer energy is defined identically to the characteristic energy of the cosmological constant. Dark energy is therefore associated with the cosmological constant. See Table 1 about value over time and temperature of dark energy (DE) considered as Λ, cosmological constant according to the formula of dark energy based on Landauer's principle from the entropic information theory with this formula: $mc^2 \frac{k\, ln(2)t}{h}$ k T ln(2).

Table 1. Value over time and temperature of the dark energy (DE), Λ, cosmological constant from the formula of dark energy based on Landauer's principle from the entropic information theory : $mc^2\,\frac{k\,ln(2)t}{h}$ k T ln(2)

Time	13.8 billion years	380000 years	3 mins
t(sec)	4.3520E+17	1,1984E+13	180
Temperature (T)	2.725	3000	1,00E+9
masse (m)	2.78E+54	2.78E+54	2.78E+54
c^2	8.988E+16	8.988E+16	8.988E+16
Boltzmann constant (k)	1.38E-23	1.38E-23	1.38E-23
ln(2)	0.69347	0.69347	0.69347
Planck constant h	6,63E-34	6,63E-34	6,63E-34
Dark Energy (DE), Λ $mc^2\,\frac{k\ln(2)t}{h}$ k T ln(2)	4.2771E+99	1.2966E+98	6,4919E+92

The dark energy can be associated to the cosmological constant and the cosmological constant can be formulated to be equivalent to the zero-point radiation of space, i.e., the vacuum energy [86].

2.11 Cosmological Constant and Zero-Point-Energy

The zero-point-energy is usually supposed to contribute to the cosmological constant. The mismatch between the small cosmological constant compared with the huge zero-point-energy is considered as one of the most serious problems in physics.

Essentially, a non-zero vacuum energy is expected to contribute to the cosmological constant, which affects the expansion of the universe.

Using quantum field theory one can calculate the quantum mechanical vacuum energy (or zero-point energy) for any quantum field. The result of this calculation can be as high as 120 orders of magnitude larger than the upper limits obtained via cosmological observations.

In quantum mechanics, the vacuum energy is not zero due to quantum fluctuations. The ground state energy of the harmonic oscillator is $\frac{\hbar\omega}{2}$ in contrast to the classical harmonic oscillator whose ground state energy is zero.

The formalism of quantum field theory makes it clear that the vacuum expectation value summations are in a certain sense summation over so-called "virtual particles".

Quantum fields can be described as an infinite collection of harmonic oscillators, so naively the vacuum energy, which would be a sum over all the harmonic oscillator ground state energies, should be infinite. But, in practice, we would expect the sum to be cut off at some energy scale above which the true (presently unknown) fundamental theory must be invoked.

The cosmological constant Λ was introduced by Albert Einstein into general relativity in 1917. Including the cosmological constant, Einstein's field equations are:

$$R_{\mu v} - \frac{1}{2} g_{\mu v} R + \Lambda G_{\mu v} = -\frac{8\pi G}{c^4} T_{\mu v} \quad (71)$$

The cosmological constant can be interpreted as the energy density of the vacuum. Specifically, if we introduce

$$T_{\mu v}^{vacuum} = \frac{c^4 \Lambda}{8\pi G} g_{\mu v} \quad (72)$$

Then (71) can be rewritten as

$$R_{\mu v} - \frac{1}{2} g_{\mu v} R + \Lambda G_{\mu v} = -\frac{8\pi G}{c^4}\left(T_{\mu v} + T_{\mu v}^{vacuum}\right) \quad (73)$$

if we compare (72) with the energy-momentum tensor of a perfect fluid,

$$T_{\mu v} = \left(\rho + \frac{p}{c^2}\right) u_\mu u_v - p g_\mu \quad (74)$$

then we would conclude that the energy density of the vacuum is:

$$c^2 \rho_{vac} = \frac{c^4 \Lambda}{8\pi G} \quad (75)$$

and the equation of state of the vacuum is $p = \rho c^2$

The current astrophysical data can be interpreted as being consistent with a nonzero value of the cosmological constant. The latest data can be found in the table of Astrophysical constants and parameters in [37]. This table includes the following two entries,

$$\frac{c^2}{3H_0^2} = 6.3 \ \pm 0.2 * \ 10^{51}\, m^2 \tag{76}$$

$$\Omega_\Lambda = 0.685^{+\,0.017}_{-0.016} \tag{77}$$

where $\Omega_\Lambda \equiv \frac{\rho_{vac}}{\rho_{c,0}} = \frac{\Lambda c^2}{3H_0^2}$ and H_0 is the present-day Hubble parameter.

The vacuum energy density is given by (75) and the critical density today is given by $\rho_{c,0}\,\frac{3H_0^2}{8\pi G}$

Hence

$$\Omega_\Lambda = \frac{\rho_{vac}}{\rho_{c,0}} = \frac{\Lambda c^2}{3H_0^2} \tag{78}$$

Employing the numbers given in eq. (76) and (77), it follows that:

$$\Lambda = \frac{3H_0^2}{c^2}\ \Omega_\Lambda = (1.09 \pm 0.04)\text{x}\, 10^{-52}\ m^{-2} \tag{79}$$

Using (79), we obtain,

$$\rho_{vac} = \frac{\Lambda c^2}{8\pi G} = \frac{(1.1\text{x}\, 10^{-52}\ m^2)\ (3\text{x}\ 10^8\ ms^{-1})^2}{8\pi(6.673\text{x}\ 10^{-11}\ m^3kg^{-1}s^{-2})} = 5.9\ \text{x}10^{-27}\ kg\ m^{-3} \tag{80}$$

Thus, the numerical value of the vacuum energy is:

$$\rho_{vac}c^2 = 5.31\ \text{x}\ 10^{-10}\ J = 3.32\ GeV\ m^{-3} \tag{81}$$

after using the conversion $1\ Ev = 1.6\ \text{x}\ 10^{-19}\ J$ and $1\ Gev = 10^9\ eV$.

In order to see whether this vacuum energy is large or small, we need to invoke quantum mechanics. In quantum mechanics, there is a natural association between length scales and energy scales. The key conversion factor is:

$$\hbar c = 197\ MeV\ fm = 1.97\ \text{x}\ 10^{-7}\ eVm \tag{82}$$

where $1\ fm = \ 10^{-15}\ m.$

Thus

$$1\ m = \ \hbar c(5.08\ \text{x}\ 10^{-6}\ eV^{-1}) \tag{83}$$

Using this conversion factor, we can write,

$$\rho_{vac}c^2 = \frac{3.32\ \text{x}\ 10^9\ eV}{(\hbar c)^3\ (5.08\ \text{x}\ 10^{-6})^3} = \frac{(2.24\ \text{x}\ 10^{-3}\ eV\ )^4}{(\hbar c)^3} \tag{84}$$

Given our lack of knowledge of the fundamental theory above the Planck energy scale, a reasonable first guess would be to cut off the vacuum energy sum at the Planck scale. Thus, the “prediction” of quantum mechanics is that the energy density of the vacuum due to vacuum fluctuations should be roughly given by:

$$\rho_{vac}^{QM}\ c^2 \sim \frac{M_{PL}c^2}{L_{PL}^3} = \left(\frac{\hbar c^5}{G}\right)^{\frac{1}{2}} \left(\frac{c^3}{\hbar G}\right)\ c^2 = \left(\frac{\hbar c^5}{G}\right)^{2} \frac{1}{(\hbar c)^3} = \frac{(M_{PL}c^2)^4}{(\hbar c)^3} \tag{85}$$

Putting in the numbers,

$$\rho_{vac}^{QM}\ c^2 \sim \frac{(1.22\ \text{x}\ 10^{19}\ GeV\ )^4}{(\hbar c)^3} = \frac{(1.22\ \text{x}\ 10^{28}\ eV\ )^4}{(\hbar c)^3} \tag{86}$$

Thus, the quantum mechanical prediction for the vacuum energy is given by (86). How good is this prediction? Let us compare this to the observed vacuum energy given in (84),

$$\frac{\rho_{vac}c^2}{\rho_{vac}^{QM}c^2} = \left(\frac{2.24\ \text{x}\ 10^{-3}}{1.22\text{x}\ 10^{28}}\right)^4 = 1.13\ \ \text{x}10^{-123} \tag{87}$$

The observed vacuum energy density is a factor of 10^{123} smaller than its predicted value!

This is by far the worst prediction in the history of physics!!

So, how do we fix this?

It is believed that there exists some mechanism that makes Λ small but non-zero.

The order of the obtained result is dictated by the utilization of the Planck mass in the calculation, indeed, with the $M_{PL} = 2.177\text{x}\ 10^{-8}\ kg$ which multiply the value of conversion between kilograms and electron volt, $1\ kg = 5.60958616721986\ \ \text{x}\ 10^{35}\ eV$, we obtain:

$$M_{PL} = \ 5.60958616721986\ \ \text{x}10^{35}\ \text{x}\ \ 2.177\ \text{x}\ 10^{-8} = 1.221297\ \text{x}\ 10^{-28}\ \ \ eV \tag{88}$$

But if we do the calculation with the replacement of M_{PL} by $M_{bit} = 2.91 \text{ x } 10^{-40} \, kg \; at \; T = 2.73 \, K$ [3] multiply by the value of conversion, kg to eV:

1kg=5.60958616721986 $\text{x } 10^{35}$ eV, we obtain

$$2.91 \text{ x}10^{-40}\text{x } 5.60958616721986 \text{ x}10^{35} = 0.00016323895 \; eV \quad (89)$$

$$\frac{\rho_{vac}c^2}{\rho_{vac}^{QM}c^2} = \left(\frac{2.24 \text{ x } 10^{-3}}{1.6323895 \text{ x } 10^{-4}}\right)^4 = (13.7222151944)^4 = 3.54565848944 \;\; \text{x}10^4 \quad (90)$$

By taking account of the mass of the bit of information instead of the Planck mass in the cosmological constant calculation we have reduced the discrepancy of 120 orders of magnitude in the prediction of the vacuum energy from a quantum perspective.

One way to envisage the dark energy is that it seems to be linked to the vacuum of space. In other words, it is an intrinsic property of the vacuum. The larger the volume of space, the more vacuum energy (dark energy) is present and the greater its effects.

3. RESULTS AND DISCUSSION

3.1 Entropic Information Theory: Structural Basis

After giving the physical explanation of the notion of energy by the fundamentality of temperature and information and the emergence process engaged, the entropic information theory approach gives the physical explanation of the collapse of the wave function and some definition in informational perspective of quantum foundation terms with the concept of Information defined as “a quantum state change due to the modification of a degree of freedom in the quantum system considered”; while the entanglement process can be defined as “the physical phenomenon that occurs when a group of particles is generated, interacts or shares spatial proximity such that one or more degrees of freedom are shared at the quantum level between each particle in the group; a particle cannot be described independently of the quantum state of others because they share degrees of freedom, even when the particles are separated by a great distance”.

Following entropic information theory, this considers the quantum measurement of a quantum system as an interactive and informative process that reduces uncertainty on the quantum system by exploiting quantum entanglement sharing some degrees of freedom between the measurer and the system to be measured. This definition of quantum measure is consistent with the given definitions of information and entanglement. It is a process in which the measure informs the measurer, the measurer needs to be informed about the system under considerations; to be informed about the system, the measurer needs information from the system to be measured, the measurer take information out the system under considerations, the measurer shares one or more degrees of freedom (information) with the system under considerations, and both are entangled together by the sharing of degrees of freedom [5]. This gives an explicative informational process about the physical process of the collapse of the wave function based on the definition of the quantum measurement, invaliding the Many worlds interpretation of quantum mechanics.

The entropic information theory is based on the ultimate positional coordinates which are the ultimate aspect of the universe, the ultimate basis, ultimate basis from which the degrees of freedom emerge, degrees of freedom as being defined as a physical significance emerging from a minimum number of positional coordinates required to specify a configuration. From those minimum required configurations putted in relation to the possible directions of movement of the system, emerge the two fundamental building blocks of our universe, i.e., temperature and information. See Appendix A: to be able to see an explanatory diagram about the emergent entangled informational universe. Temperature and Information are being perceived, as a physical significance in relation to degrees of freedom. Temperature can be considered as a fundamental aspect of nature, in reference to the third law of thermodynamics. Information can be equally considered as a fundamental aspect of nature in accord to the second law of thermodynamics and the Landauer’s principle. Degrees of freedom, temperature and information are considered as emergent properties and having a physical significance but not physical existence. The physical existence born by the emergence of energy from the relation between the two fundamentals building blocks of the universe, i.e., temperature and information according to the Landauer’s principle, Landauer’s principle which establishes the temperature as the unique parameter which bound information to energy, by the formula $Energy = k\,T\ln(2)$. Energy being considered as a process that emerges from the relationship between temperature and information, relative to the formula of Landauer's principle.

Emergent Entangled informational Universe must be considered as an emergent system, a system based on emergence process where emergence occurs when an entity has properties its parts do not have on their own, properties or behaviors that emerge only when the parts interact in a wider whole.

In mathematics, the simplest example concerning emergence is 1+1=2, 2 being emergent in regard to 1.

3.2 Entropic Information Theory: Generalization

After having developed a set of five new equivalent formulation of the notion of entropy, the thermodynamics aspect of black holes has been aborded by the injection of the Hawking temperature into the equation of "Boltzmann formulation", one of those formulas, this made possible to the entropic information formula of black holes to calculate the entropy of the entangled Hawking radiation down to the quantum system, describing black hole. The black holes entropic information formula saturates exactly the universal bound. The black holes entropic information formula is equal to the universal bound originally found by Jacob Bekenstein [61,9] which is equal by Casini's work [8] to the difference between the expectation value of the modular Hamiltonian in the excited state and the vacuum state.

Naive definitions of entropy and energy density in Quantum Field Theory suffer from ultraviolet divergences. In the case of the Bekenstein bound, ultraviolet divergences can be avoided by taking differences between quantities computed in an excited state and the same quantities computed in the vacuum state [87]. We must take note that the first version of the fine-grained entropy formula discovered by Ryu and Takayanagi is a general formula for the fine-grained entropy of quantum systems coupled to gravity [47].

The formula about black hole entropic information is a new formulation of Bekenstein-Hawking entropy, new formulation based on information; it is equal to Bekenstein bound, as Bekenstein-Hawking entropy saturates exactly the Bekenstein bound and equal to Von Neumann entropy which is the fine grained entropy, as in Casini's work, the von Neumann entropy calculates the Bekenstein bound, moreover the black hole entropy horizon law turns out to be a special case of the Ryu–Takayanagi conjecture, conjecture viewed as a general formula for the fine-grained entropy of quantum systems coupled to gravity.

Finally, we obtain.

$$\mathrm{Sv} = S(\rho_V|\rho_V^0) = S(\rho_V) - S(\rho_V^0) \quad (91)$$

$$= -\operatorname{tr}(\rho_V \log \rho_V) + \operatorname{tr}(\rho_V^0 \log \rho_V^0)$$

$$= \operatorname{tr}\left(\rho_V (\log \rho_V - \log \rho_V^0)\right)$$

$$= K_V = \operatorname{tr}(K\,\rho_V) - \operatorname{tr}(K\,\rho_V^0)$$

$$= \frac{2\pi kRE}{\hbar c}$$

$$= k\,\frac{4\,\pi\,G\,M^2}{\hbar c}$$

$$= 4\,\frac{A}{4l_p^2}$$

$$= \frac{kc^3 \ln(2) t_{evap}}{16\pi^2 GM}$$

$$= k\,H\ln(2)$$

$$= k\,\ln(W)$$

with $t_{evap} = \frac{64\,\pi^3 G^2 M^3}{\hbar\, c^4 \ln(2)}$

with A, the area of the black hole horizon: $16\,\pi(\frac{GM}{c^2})^2$

with l_p: Planck length

See the global equation concerning the entropic information theory approach in relation to the work of Casini as shown in Fig. 3.

About the Hawking radiation, Hawking radiation is in a pure state, is that this is in apparent contradiction to the fact that Hawking radiation is also said to be thermal. The apparent contradiction is solved when one realizes that in a general curved spacetime there is no unique definition of the vacuum state and therefore the whole Hilbert. Consequently, an observer at infinity will see a thermal bath of particles (i.e., in a mixed state) coming from the horizon, even though the quantum fields are in the local vacuum state near the horizon.

But if the overall system is pure, the entropy of one subsystem can be used to measure its degree of entanglement with the other subsystems.
"In fact, this is precisely what happens with Hawking radiation. The radiation is entangled with the fields living in the black hole interior [47]."

In fact, if we had a very complex quantum system which starts in a pure state, it will appear to thermalize and will emit radiation that is very close to thermal. In particular, in the early stages, if we computed the von Neumann entropy of the emitted radiation it would be almost exactly thermal because the radiation is entangled with the quantum system.

“In other words, if the black hole degrees of freedom together with the radiation are producing a pure state, then the fine-grained entropy of the black hole should be equal to that of the radiation $S_{black\_hole} = S_{rad}$ [47]."

"The Hawking radiation, are allowing us to extract information that resides (from the semiclassical viewpoint) in a distant spacelike-separated region: the black hole interior [88]."

"Importantly this fundamental nonlocality is not solely a feature of black hole physics; instead, it is an essential aspect of holography [88]".

“The entropy deliverable to an asymptotic observer by a spacetime causally explored to an inner boundary of area A cannot be greater than A=4G$\hbar$ [89].”

The black hole von Neumann entropy never gets bigger that the thermodynamic entropy set by the horizon area law.

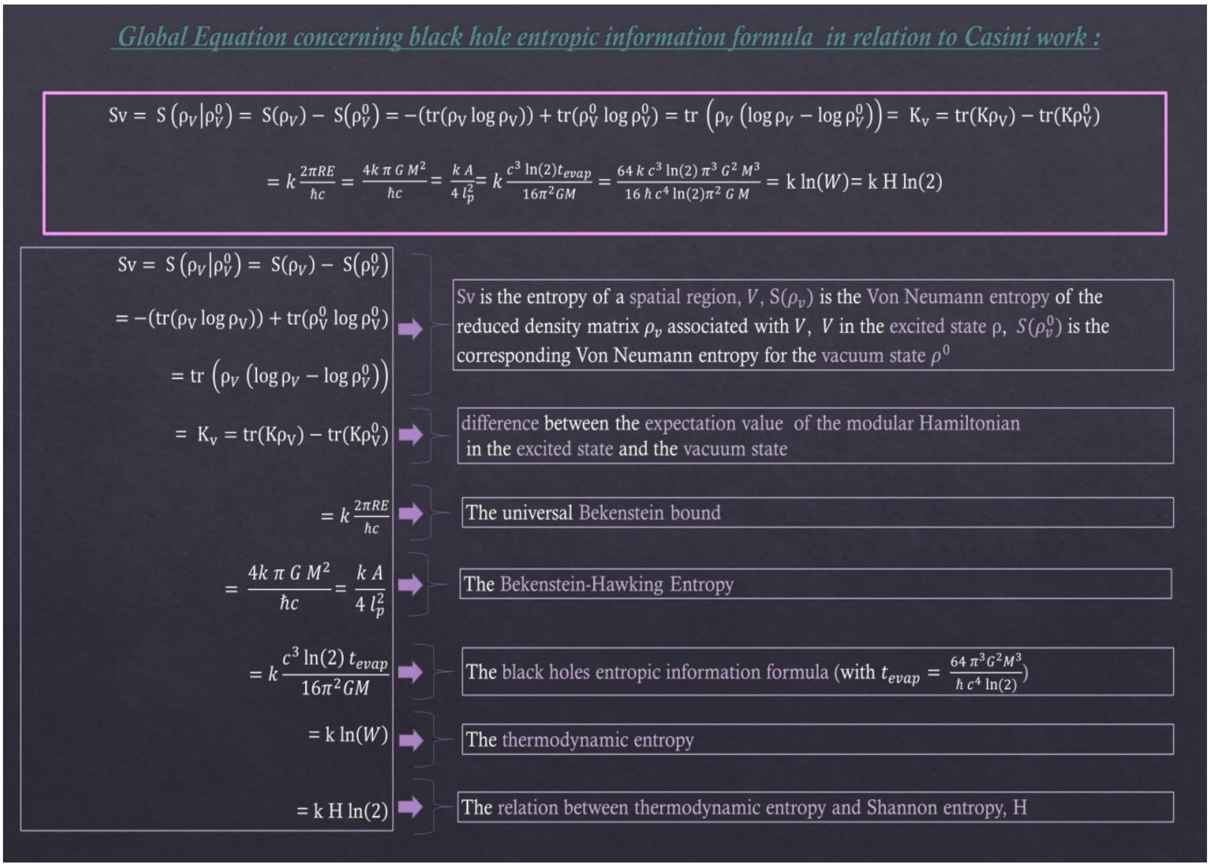

Fig. 3. Global equation concerning black holes entropic information formula in relation to casini’s work on von neumann entropy and bekenstein bound

3.3 Entropic Information Theory: Dark Side

The notion of negative energy, in relation to vacuum, is examined in more detail, in the light of Casini [8] and Bousso's work on the Bekenstein bound [9-17], both works giving meaning to the Casimir effect. The negative energy phenomenon is explained using Louis de Broglie's hidden thermodynamic formula, $\frac{action}{h} = -\frac{entropy}{k}$, used in the entropic information theory approach, itself in relation to Casini's work.

One way to envisage the dark energy is that it seems to be linked to the vacuum of space. In other words, it is an intrinsic property of the vacuum. The larger the volume of space, the more vacuum energy (dark energy) is present and the greater its effects.

The zero-point energy of the vacuum considered as dark energy is explained as a collective potential of all particles with their individual zero-point energy emerging from an informational field, distinct from the usual fields of matter of quantum field theory, associated with the dark matter as having a finite and quantifiable mass associated with the number of bits of the observable universe.

Dark matter emerging by the Landauer's principle, from the two fundamental building blocks of our universe, i.e., temperature and information and dark matter giving rise, according to the Landauer's principle, to Dark energy, the zero-point energy of the vacuum considered.

By taking account of the mass of the bit of information instead of the Planck mass in the cosmological constant calculation we have reduced the discrepancy of more of less 120 orders of magnitude in the prediction of the vacuum energy from a quantum perspective.

4. CONCLUSION

In the first part of this work, after having defined some fundamental notion of quantum mechanics in informational terms as quantum information, quantum entanglement , quantum measurement, and after having given an explanatory informational perspective of the process of the collapse of the wave function based of the fact that a measure informs the measurer, invaliding the Many worlds Interpretation of quantum mechanics, this entropic information theory approach explains how physical existence arises by the emergence of energy from the relationship between the two fundamental building blocks of the universe, temperature, and information, with respect to the second law of thermodynamics and according to the formula of Landauer's principle which establishes temperature as the only parameter linking information to energy. Having explained the process of emergence at the base of the notion of energy, we can notice that an important consequence of the emergent entangled Informational Universe where interacting members are not independent, being entangled, sharing degrees of freedom (information), that no simulation of the system can exist, the process of strong emergence doesn't permit the simulation of the system, for such a simulation would itself constitute a reduction of the system to its constituent parts. The simulation hypothesis is so invalided. Still according to the model of the entropic information theory, the amount of information in the universe is constant; only changes the proportion of its known or decoded state regarding its ignored or hidden state, indeed, information is one and the same thing, however it can exist in two forms: ignored or known, i.e., hidden or decoded. This emergent entangled informational universe is an informational system i.e., a system wherein the information notion is the global explanatory keystone concept, considered as an entangled system i.e., a system where there are not individual parts but are an inseparable whole, and as an emergent system i.e., system where the whole is greater than the sum of all its parts.

In the second part of this work, with the help of one of a set of five new equivalent equations expressing the notion of entropy, regarding black holes thermodynamics and black holes entropy, the equation of "Boltzmann formulation" when is applied to black hole thermodynamics by the injection of Hawking Temperature to it, can resolve the information paradox and can express the gravitational fine-grained entropy of the black holes. It can calculate the Bekenstein-Hawking entropy; as the black hole entropy saturates exactly the Bekenstein bound so it is equal to the Bekenstein bound which is itself according to Casini's work equal to the von Neumann entropy, itself equal to that of the Hawking radiation, which with the degrees of freedom of black holes produces a pure state, while the Hawking radiation being entangled with the fields inside black holes, allowing us to extract information that resides from the semiclassical viewpoint, in the black hole interior; at the end of evaporation, the full von Neumann entropy is again 0 , so no information is lost!. The black hole entropy horizon law turns out to be a special case of the Ryu–Takayanagi conjecture, and Ryu–Takayanagi conjecture is a conjecture viewed as a general formula for the fine-grained entropy of quantum systems coupled to gravity.

In the third part of this work, an equivalent reformulation of the “Boltzmann formulation” equation, the “Einstein formulation” equation has estimated the dark matter component, by calculating the number of bits content of the observable universe and validated by Landauer's principle. The estimate of dark energy is based on the estimation of the energy associated with the number of bits content of the observable universe, with respect Landauer’s principle. The equivalent energy of the total information, given by $N_{bits}\ k\ T\ ln(2)$, is proportional to both the total number of bits and the temperature, and therefore proportional to the volume of the universe as in the volume model, and proportional to the surface of the universe in the holographic model. The dark energy is associated to the cosmological constant being expressed into the Landauer energy equivalent, which can be defined in a form and value identical to the characteristic energy of the cosmological constant. The dark energy component is equally associated to vacuum energy, zero-point field energy. By taking account of the mass of the bit of information instead of the Planck mass in the cosmological constant calculation the entropic information theory approach has reduced the discrepancy of 120 orders of magnitude in the prediction of the vacuum energy from a quantum perspective. The zero-point energy of the vacuum considered as dark energy is explained as a collective potential of all particles with their individual zero-point energy emerging from an informational field, distinct from the usual fields of matter of quantum field theory, associated with dark matter as having a finite and quantifiable mass.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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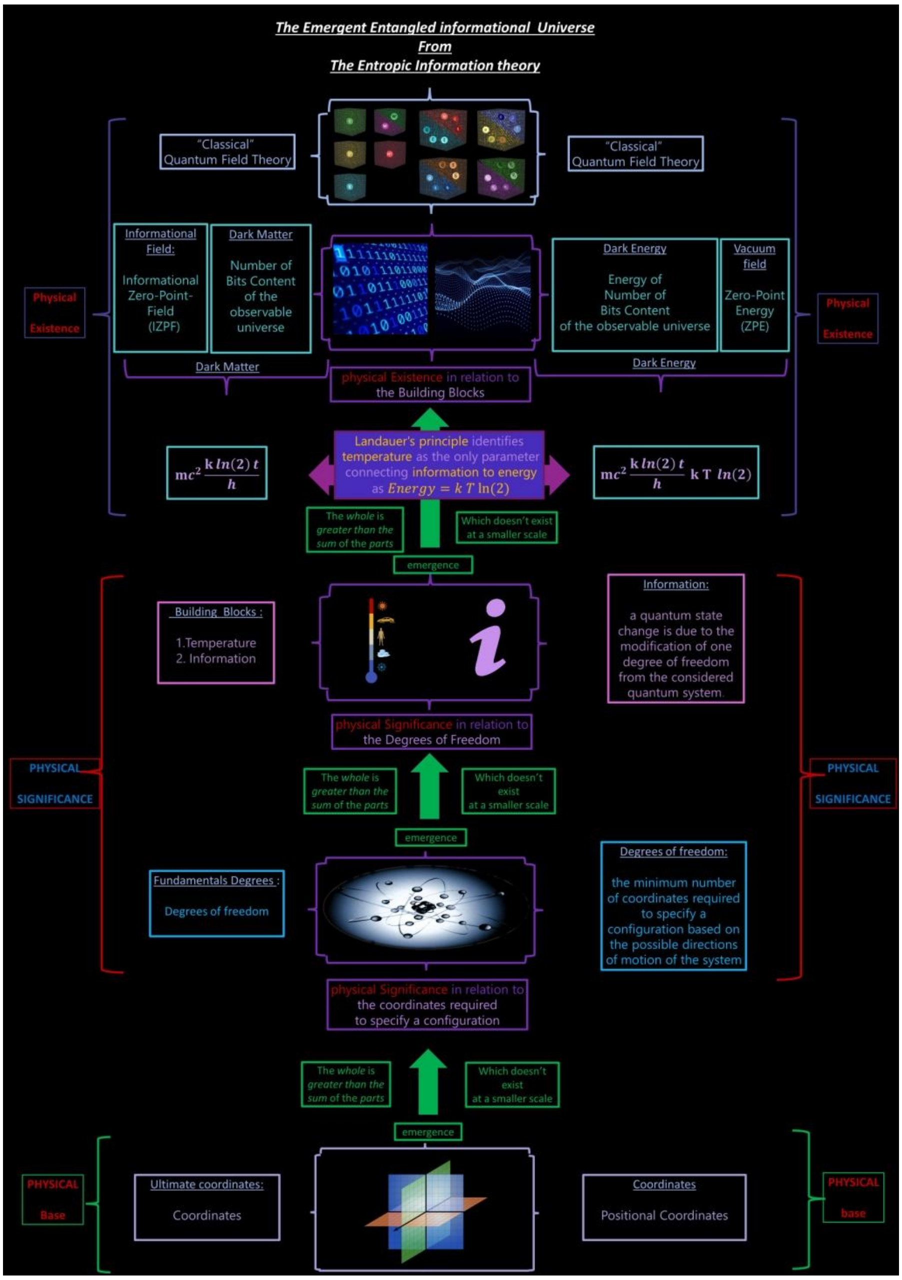
APPENDIX

Appendix A : explanatory diagram about the emergent entangled informational universe



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