Non-local Vacuum: A Door to New Physics

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Abstract

This paper presents a novel cosmological model that resolves key issues in inflationary theory as well as eliminating the cosmological constant (vacuum catastrophe) problem by proposing a white hole as the source of the observable universe. By linking spacetime and matter/energy to information-theoretic phenomena, this model describes the expansion of the universe in terms of increasing information. The emergence of qubits, or quantum bits of information, from the singularity drives the expansion of the white hole event horizon, which is the actual source of spacetime and classical gravity. The interior of the white hole is timeless and, therefore, non-local and is equated with the vacuum. The energy density of the vacuum is equal to the critical density of the observable universe ($\boldsymbol{\rho_{vac} = \rho_{crit}}$) when it contains $\boldsymbol{\sim 10^{121}}$ qubits. The entropy/information in the observable universe has been estimated elsewhere as $\boldsymbol{\sim 10^{105}}$ bits. At t=0, when the first bit of local reality emerged, the size of the white hole containing $\boldsymbol{\sim 10^{16}}$ qubits is $\boldsymbol{\sim 10^{-26}}$ meters. This explains the existence and magnitude of the ad-hoc expansion required by inflation theory. The model introduces a new cosmological parameter, $\boldsymbol{P = \rho_{vac}/\rho_{local}}$. The model calculations of the Hubble constant are functions of P that can be adjusted to resolve the Hubble tension. The model proposes dark energy to be the non-local energy driving the white hole expansion. The model of spacetime emerging from a surface surrounding a complex non-local Euclidean region of entangled qubits could provide an alternative to AdS/CFT (or dS/CFT), models used in the study of quantum gravity and quantum information science. Several experiments that could falsify the model are identified in the paper.

Keywords: Cosmology and the early universe, Inflation theory, Hubble tension, Gravitation, Quantum entanglement as a source of spacetime/classical gravity.

1 Introduction

1.1 Background

Recent measurements of the Hubble constant Planck Collaboration (2020) Riess et al (2022) that are statistically divergent from one another by 5σ has led to recognition of the need for new physics beyond the ΛCDM standard model of cosmology Richard Panek (March, 2020). There is also an outstanding cosmological constant (vacuum catastrophe) problem that requires new physics to resolve the disparity ($> 10^{120}$) between predictions of the energy density of the vacuum from quantum field theory and observations of the energy density of the universe embodied in ΛCDM Adler et al (1995) .

Measurements of the Cosmic Microwave Background (CMB) has led to the proposal of new physics in the form of the theory of inflation Guth (1981) Linde (1982). This theory postulates a period of exponential expansion of the universe following the Big Bang to explain the observed homogeneity in the CMB. The ad-hoc assumption was that the universe had a size of $\sim 10^{-26}$ meters before Hubble flow began Ellis and Wands (2023). This corresponds to an e-fold volume expansion, N, of approximately 60 relative to the Planck volume.

A series of loop-hole free Bell's-inequality experiments Hensen et al (2015) Giustina et al (2015) citeHR:sh15 established that physical reality includes a non-local reality where quantum entanglement takes place and the local 3D+1 spacetime from which we make our observations. Understanding the physics of this non-local reality is another example of the need for new physics beyond standard models.

In the rest of this paper, a logical/numerical model of cosmology, the Horizon Model (HM), is presented. This model produces the following new physics:
* the cosmological constant problem is eliminated;
* the Hubble tension is resolved by introducing a new cosmological parameter;
* the existence of inflation is *predicted* with magnitude $N = 61^{+1.2}_{-1.0}$;
* a specific non-local physical reality, the vacuum, is identified as the seat of quantum entanglement;
* dark energy can be interpreted as the non-local energy driving the white hole expansion.

1.2 Fundamentals of the Horizon Model.

In 1990, John Archibald Wheeler, mentor to many distinguished theoretical physicists, was reported to have coined the aphorism "it from bit" Misner et al (2009). This expressed his belief, derived from decades of research in quantum theory, that *all things physical are information-theoretic in origin.* Following his guidance, the HM is an information-theoretic model that attempts to explain the origins of physical reality.

1.2.1 Horizons

A fundamental assumption of the HM is that the observable universe is bounded by horizons that shield or limit the observable from the unobservable elements of physical reality.

The non-local singularities at the center of the black holes (BH) of mass/energy M are shielded from observation (from within the local universe) by the spherical event horizons surrounding them. These BH event horizons, according to General Relativity (GR) are located at a distance from their singularity that is dependent on M. This distance is denoted by the Schwarzchild radius, $R_s = 2GM/c^2$, where G is the universal gravitational constant, and c is the speed of light.

Observation of the far distant regions of the universe is limited by the particle horizon, which defines the limits imposed by the expansion of spacetime Liddle and Lyth (2000). Currently, the particle horizon is located at a distance from any observer of approximately 46.9 Gly (billions of light years).

The HM is built on the understanding that the non-local reality in which quantum entanglement occurs is unobservable (by the instruments of local science). It asserts that this non-local reality must therefore be shielded behind a horizon. The vacuum is another element of physical reality that is unobservable[1]and can therefore be considered to be shielded by a horizon. The HM equates these two horizons to the horizon of an *expanding white hole*, which is referred to below as the vacuum horizon.

Because the vacuum is equated with the non-local reality of quantum entanglement, the HM (an information theoretic model) considers the interior of the vacuum horizon to be quantized in the form of qubits. A key consequence of the non-locality of the vacuum is that it is a region where causality does not exist and can therefore be considered a region where time does not exist. It is the quantized vacuum horizon that is the actual source of spacetime, not the singularity or the vacuum itself. The invariance of the vacuum speed of light and the gravitational constant follow naturally from the HM because they are a properties of space alone and not spacetime. Locality (time) emerges from the vacuum horizon. This situation is schematically illustrated in Figure(1).

1.2.2 Vacuum Horizon

According to the Holographic Principle of Susskind Susskind (1995) and t'Hooft t'Hooft (1993), as well as the study conducted on the entropy/information associated with black holes by Hawking Hawking (1975) and Bekenstein Bekenstein (1973), a "bit" of information is associated with a unit of area on a horizon. The HM asserts that the first qubit entering the universe was the interior of the vacuum horizon surrounding the first element of reality that emerged from the Big Bang singularity. This is the original Planck region. According to GR, the Schwarzchild radius of a white hole is exactly the same as that of a black hole. For the Planck region, the radius of the Planck qubit comprising the horizon and its contained Planck region is $R_{pq} = 2GM_p/c^2$. From the definition of M_p, it follows that

$$R_{pq} = 2l_p = 3.23x10^{-35}m \text{ , with a corresponding area } A_{pq} = 1.31x10^{-68}m^2$$

. Thus, according to the white hole hypothesis, A_{pq} is the universal holographic surface area associated with a single qubit of information. The generalized Holographic

[1]The standard models equate the vacuum with the Planck region of length $\sim 10^{-35}m$ and this region is unobservable because it is a region of pure Heisenberg uncertainty.

principle relating the amount of information, S, enclosed within any spherical surface of area A becomes $S = \frac{Ac^3}{16\pi G\hbar}$ or, (in rationalized Planck units)

$$S = \frac{A}{4G}. \tag{1}$$

This is the entropy-area law published by Hawking Hawking (1975) and Bekenstein Bekenstein (1973),

Andrew Strominger has stated that "Understanding the microscopic origin of (1) is undoubtedly a key step towards understanding the fundamental nature of spacetime and quantum mechanics"'Strominger (2001). The white hole hypothesis and the HM provide the miscroscopic origin of equation (1) by identifying 4G ($1.31x10^{-68}m^2$) *as the surface area of the Schwartzchild event horizon surrounding a single qubit of information.*

The particle horizon at 46.5 Gly has a surface area of $2.43x10^{54}$ m^2. It is worth noting that, according to the Holographic Principle and the HM, the *maximum* amount of quantized information in the observable universe is $\simeq 2x10^{122}$ qubits.

A key consequence of the white hole nature of the vacuum is that, as the horizon expands, the energy density of the vacuum (ρ_{vac}) decreases. As the horizon expands, it continues to emit "new" spacetime; thus, there is no need for a cosmological constant in the field equations of GR. Therefore the white hole assumption eliminates the '"cosmological constant" problem for cosmology. The situation is more complex in terms of quantum physics.

Quantum experiments have verified the existence of tiny local electromagnetic effects, such as the Casimir force Lamoreaux (2005) Chan et al (2008), which quantum field theory explains as a result of shifts in the energy density of the vacuum. These shifts in vacuum energy density are due to the positioning of interacting bodies (conductors) of various shapes in the local electromagnetic field. In the HM, the vacuum is non-local, and the fields are assumed to reach their minima on the surface of the vacuum horizon. Thus, the importance to the HM of zero-point energy effects, such as the Casimir effect, is that it must be possible to alter the local spacetime conditions to effect the conditions on the vacuum horizon. In other words, these zero energy effects imply the possibility of feedback from the local to the vacuum horizon.

1.2.3 Local/Non-Local Entropy and Inflation.

The HM makes contact with observation through the identity of information with entropy. Egan and Lineweaver published a useful and detailed budget of entropy/information within the observable universe Egan and Lineweaver (2010). This study establishes the total entropy in the local universe at present as:

$$S = 3.1^{+3.0}_{-1.7}x10^{104}k \text{ ,or, a Shannon entropy/information } = 4.47^{+4.3}_{-2.4}x10^{104}bits \tag{2}$$

According to the ΛCDM model of cosmology, current observations establish that the matter/energy density of the universe is very close to the critical density of approximately 5 GeV/m^3 ($\Omega \simeq 1$). As shown in the next section, the HM uses the

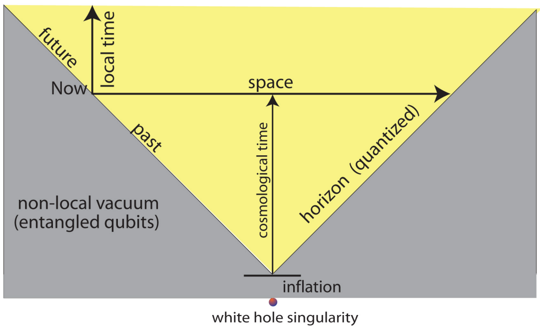

Fig. 1 Schematic of the Horizon Model. The non-local region inside the vacuum had instantaneously inflated to a size of $\sim 10^{-26}m$ before spacetime began .

Holographic Principle and the definition of an event horizon to calculate the total amount of information within the non-local vacuum, I_q. Assuming $\Omega = 1$, the result is $I_q = 1.78^{+2.17}_{-0.88}x10^{121}qubits$. Therefore, according to the HM, for every bit of observable local information there are $4^{+5}_{-2}x10^{16}$ qubits of non-local information in the universe. Considering t = 0 , the moment spacetime began, there were $4^{+5}_{-2}x10^{16}$ non-local qubits introduced into the physical reality of the non-local vacuum by the white hole singularity. From the Planck parameters, the area of the horizon surrounding this region is $5.2^{+6}_{-2}x10^{-52}m^2$.

This expansion of the vacuum horizon before spacetime began corresponds to the period of inflation proposed by Guth Guth (1981) and Linde Linde (1982) to explain the observed homogeneity in the Cosmic Microwave Background (CMB). The HM predicts that this period of inflation corresponds to a vacuum volume relative to the Planck region volume of $2.7^{+3.5}_{-1.0}x10^{26}$ or an e-fold expansion of $N = 61^{+1.2}_{-1.0}$. This is in good agreement with the expected volume expansion of the "inflaton" Ellis and Wands (2023). For the HM, the non-locality of the "inflaton" precludes the idea of stages or phases during the initial inflation Guth et al (2014). Heisenberg fluctuations within the bits of the expanding vacuum horizon could explain the small irregularities observed in the CMB.

1.2.4 Quantization of the vacuum horizon.

It is natural to assume that each bit of local reality (spacetime/gravity, matter/energy) emanates from a single bit of the vacuum horizon, that is, the vacuum horizon is quantized. In the previous section, it was shown that the first bit of local reality emanates from the horizon surrounding the "inflaton" when it had a surface area of $\sim 5.2x10^{-52}m^2$. Thus, the length associated with the vacuum horizon quantization is $\sim 2.3x10^{-26}m$ with an associated quantized time interval of $\sim 8x10^{-35}s$.

Paul Dirac wrote that "There is a limit to the fineness of our powers of observation and the smallness of the accompanying disturbance—a limit which is *inherent in the nature of things* and can never be surpassed by improved technique or increased skill on the part of the observer" (Dirac (1958),page 4, emphasis mine). Because the non-local vacuum is unobservable, the HM supports Dirac's idea and predicts the absolute limits of observation to be $\sim 10^{-26}m$ and $\sim 10^{-34}s$.

2 Numerical Model

2.1 Input data.

According to the Holographic Principle the total number of qubits in the vacuum, I_q, is proportional to the area of the vacuum event horizon; thus, $R_{vh} \propto I_q^{1/2}$. If R_{pq} is the radius of a single qubit, then:

$$R_{vh} = R_{pq} I_q^{1/2} = 2l_p I_q^{1/2} = 3.23x10^{-35} I_q^{1/2}\ m. \tag{3}$$

According to the Schwarzchild equation for the radius of the event horizon,

$$R_{vh} = 2GM_q/c^2 \text{ ; therefore, } M_q \propto I_q^{1/2}.$$

The volume of the vacuum,V_q, is $\propto R_{vh}^3$; thus, $\propto I_q^{3/2}$. Matter/energy density in the vacuum $\rho_{vac} = M_q/V_q$, so

$$\rho_{vac} \propto I_q^{-1}.$$

The volume of a single Planck qubit,V_{pq}, is $4/3\pi(2l_p)^3 = 1.41x10^{-103}\ m^3$; thus, the matter/energy density of a single qubit, $\rho_{pq} = M_p/V_q = 8.63x10^{121}\ GeV/m^3$ and $\rho_{vac} = 8.63x10^{121}/I_q\ GeV/m^3$. Therefore,

$$I_q^{1/2} = 9.29x10^{60}\ \rho_{vac}^{-1/2}. \tag{4}$$

Plugging this into Equation(3) yields

$$R_{vh} = 3.0x10^{26} \rho_{vac}^{-1/2}\ m \text{ ; where, } \rho_{vac} \text{ is in } GeV/m^3. \tag{5}$$

The primary assumption of the HM is that $\rho_{vac} = \rho$, where ρ is the matter/energy density in the observable (local) universe. According to the ΛCDM model of cosmology, ρ is currently approximately equal to the critical density for a flat universe, i.e., $\Omega_{tot} = \rho/\rho_{crit} = \Omega \simeq 1$ where $\rho_{crit} = 8.62x10^{-27}kg/m^3 = 4.84Gev/m^3$. With this value for ρ_{vac}, Equation (3) yields

$$R_{vh} = 1.36x10^{26}m = 14.42Gly$$

.

With the total entropy in the observable universe S, as expressed in Equation (2), the ratio of the number of non-local qubits to local bits of spacetime is

$$I_q/S = 4^{+5}_{-2}x10^{16} \tag{6}$$

. Assuming that the expansion of the vacuum horizon occurs at the speed of light, $R_{vh} = cH_{vh}^{-1}$, where H_{vh} is the Hubble "constant" for the vacuum expansion. Because spacetime expands with the vacuum horizon, it is reasonable to assume that the local Hubble "constant" $H = H_{hv}$. With this definition, Equation(5) can be rewritten as:

$$H(km/s/Mpc) = 978.7/R_{vh}\ (Gly). \tag{7}$$

It is indicative of the simplicity of the HM and its potential for unification that it requires only two inputs from the quantum world and two inputs from cosmology. The quantum inputs are the Planck mass and length ($\sim 10^{-8}kg$ and $\sim 10^{-35}m$), and the cosmological inputs are the total entropy in the observable universe and the present energy density of the universe ($\sim 10^{104}$ bits and $\sim GeV/m^3$).

2.2 Model equations.

The output of the HM can be summarized as a simple set of equations relating the state of the non-local vacuum to the total information/entropy, $S(bits)$, in the observable universe simultaneously. The ratio of qubits to S(bits) expressed in Equation (6) is assumed to be a constant independent of S.

The simple model equations were programmed into an Excel spreadsheet that was used to calculate the state of the vacuum as a function of S. The HM equations are listed in Table 1. The equations were normalized to yield $\Omega_{vac} = 1$ for S, the current value of local entropy. Note that $P = \Omega_{vac}$ when $\rho_{local} = \rho_{crit}$.The uncertainties (the Δs) reflect the large uncertainties cited by Egan and Lineweaver Egan and Lineweaver (2010) for $S = 4.47^{+4.3}_{-2.4}x10^{104}bits$.

As examples, the Table shows that, when the observable universe has a total entropy of S bits and where $Z = ln(S)$, the value of the virtual energy in the vacuum can be found from the equation $ln(Mass/Energy) = 63.06^{+0.4}_{-0.34} + Z/2$ (GeV). Furthermore, R_{vh} can be found from the equation $ln(R_{vh}) = 124.7^{+0.34}_{-0.40} - Z/2$.

The equation for the temperature, T (K), as shown in the table, is problematic and oversimplified. It assumes a simple equation of state with $w = -1$ so that the values of T are simply $\propto \rho^{-1}$. The length dependent parameters are related to the radius of the vacuum horizon.

2.3 State of physical reality at t = 0 (the "Inflaton").

The two limiting values of S(bits) of particular interest are the values at t = 0 ($S = 1$) and t = now (cosmological time). The state of physical reality at t = 0 is presented in Table 2. The table shows that the group of qubits that produced the first bit of local entropy/information in the universe contained $4^{+5}_{-2}x10^{16}$ Planck qubits. One of the assumptions of the HM is that this ratio of qubits/bit remains constant during the expansion of the universe.

Table 2 also shows the *prediction* by the HM that the first group of qubits (the "inflaton") had an e-fold expansion relative to the Planck volume of $N = 61^{+1.2}_{-1.0}$. This agrees with the theory of cosmic inflation which argues that an e-fold expansion

Table 1 State of the Vacuum as a Function of the Shannon Entropy of the Observable Universe .

Equations: ln(Parameter) = Z_0 + Z dependence, [1] ; where, $Z = ln(S(bits))$				
Parameter	Z_0	$+\Delta^2$	$-\Delta$	Z dependence
Total Qubits	38.22	0.79	0.68	+Z
$R_{vh}(m)$	-60.31	0.40	0.34	+Z/2
$V_{vac}(m^3)$	-179.48	1.19	1.02	+3Z/2
ln(V_{vac}/V_p),[3]	60.85	1.19	1.02	+3Z/2
Virtual Mass/Energy (GeV)	63.06	0.40	0.34	+Z/2
Virtual Mass/Energy (kg)	1.47	0.40	0.34	+Z/2
$\rho_{vac}(GeV/m^3)$	242.55	0.68	0.79	-Z
$\rho_{vac}(kg/m^3)$	180.95	0.68	0.79	-Z
T (K)	32.30	0.68	0.79	-Z
Ω_{vac}	240.97	0.68	0.79	-Z
$H_{vh}(km/s/Mpc)$	124.70	0.34	0.40	-Z/2

[1]e.g; ln(Ω_{vac} at Z) = 240.97-Z.

[2]The Δs are derived from the uncertainties in the entropy (S_{ob}) Egan and Lineweaver (2010).

[3]V_p is the Planck volume = 4.22E-105 m^3.

Table 2 Non-local Region (the Vacuum) at t=0 (the "Inflaton").

Parameter	Value $+\Delta^1$	$-\Delta$	
Total Qubits	3.98E+16	4.84E+16	1.96E+16
$A_S(m^2)$	5.23E-52	6.35E-52	2.57E-52
$R_{vh}(m)$	6.45E-27	3.15E-27	1.85E-27
$V_{vac}(m^3)$	1.12E-78	2.58E-78	7.17E-79
Volume Expansion,[2]	2.66E+26	6.11E+26	1.70E+26
$\ln(V_{vac}/V_p)$	60.85	1.19	1.02
Mass/Energy (GeV)	2.44E+27	1.19E+27	7.00E+26
Mass/Energy (kg)	4.34	2.12	1.25
$\rho_{vac}(GeV/m^3)$	2.17E+105	2.10E+105	1.19E+105
$\rho_{vac}(kg/m^3)$	3.86E+78	3.74E+78	2.12E+78
T (K)	1.06E+14	1.03E+14	5.82E+13
Ω_{vac}, [3]	4.48E+104	4.34E+104	2.46E+104
$H_{vh}(km/s/Mpc)$	1.44E+54	5.78E+53	4.71E+53

[1]e.g; ln(Ω_{vac} at Z) = 240.97-Z.

[2]Relative to the Planck volume, V_p.

[3]Normalized to the current value of ρ_{crit}.

of approximately N = 60 after the Big Bang is required to explain the observed homogeneity of the CMB Ellis and Wands (2023).

During inflation the temperature of the inflaton decreased from an initial temperature of $4x10^{30}K$ to $1^{+1}_{-0.5}x10^{14}K$.

From R_{vh} at t = 0, when the first bit of local reality emanates from the vacuum horizon, it follows that the horizon is quantized in areas of $A_S = 5.2^{+6.4}_{-2.6}x10^{-52}m^2$ or at a length scale of $2.3^{+2.5}_{-1.6}x10^{-26}m$. The corresponding quantized time intervals are $8^{+8.4}_{-5.3}x10^{-35}s$.

Table 3 Vacuum at Various Epochs During Its Expansion

Epoch,[1]	Z	Total Qubits	Radius meters	Radius light-years	Mass/Energy Density GeV/m^3	Mass/Energy Density kg/m^3	Ω_{vac}, [2]	$H_{vh}(km/s/Mpc)$
-	186.18	2.88E+97	1.73E+14	1.83E-02	3.00E+24	5.35E-03	6.21E+23	5.34E+13
Stars	186.82	5.45E+97	2.39E+14	2.52E-02	1.58E+24	2.82E-03	3.27E+23	3.88E+13
+	187.21	8.05E+97	2.90E+14	3.06E-02	1.07E+24	1.91E-03	2.22E+23	3.19E+13
-	187.28	8.64E+97	3.00E+14	3.17E-02	9.99E+23	1.78E-03	2.07E+23	3.08E+13
ISM/IGM[3]	188.83	4.07E+98	6.52E+14	6.89E-02	2.12E+23	3.78E-04	4.39E+22	1.42E+13
+	189.42	7.31E+98	8.74E+14	9.23E-02	1.18E+23	2.10E-04	2.44E+22	1.06E+13
-	192.64	1.83E+100	4.37E+15	4.61E-01	4.73E+21	8.43E-06	9.78E+20	2.12E+12
Gravitons[4]	198.39	5.77E+102	7.77E+16	8.20E+00	1.50E+19	2.66E-08	3.09E+18	1.19E+11
+	198.85	9.15E+102	9.78E+16	1.03E+01	9.44E+18	1.68E-08	1.95E+18	9.47E+10
-	201.38	1.15E+104	3.46E+17	3.66E+01	7.52E+17	1.34E-09	1.55E+17	2.67E+10
Dark Matter[5]	203.69	1.16E+105	1.10E+18	1.16E+02	7.46E+16	1.33E-10	1.54E+16	8.42E+09
+	205.99	1.15E+106	3.47E+18	3.67E+02	7.48E+15	1.33E-11	1.55E+15	2.67E+09
-	206.91	2.88E+106	5.49E+18	5.80E+02	2.99E+15	5.34E-12	6.19E+14	1.69E+09
Neutrinos[6]	206.94	2.97E+106	5.57E+18	5.88E+02	2.91E+15	5.18E-12	6.01E+14	1.66E+09
+	206.97	3.06E+106	5.65E+18	5.97E+02	2.82E+15	5.03E-12	5.84E+14	1.64E+09
-	206.95	3.02E+106	5.62E+18	5.93E+02	2.86E+15	5.09E-12	5.91E+14	1.65E+09
CMB	206.98	3.11E+106	5.70E+18	6.02E+02	2.78E+15	4.95E-12	5.74E+14	1.62E+09
+	207.01	3.20E+106	5.78E+18	6.10E+02	2.70E+15	4.81E-12	5.58E+14	1.60E+09
-	223.73	5.83E+113	2.47E+22	2.61E+06	1.48E+08	2.64E-19	3.06E+07	3.75E+05
Stellar BH	225.49	3.40E+114	5.96E+22	6.29E+06	2.54E+07	4.53E-20	5.25E+06	1.55E+05
+	226.51	9.37E+114	9.90E+22	1.05E+07	9.21E+06	1.64E-20	1.90E+06	9.36E+04
-	240.17	8.06E+120	9.18E+25	1.40E+10	10.709	1.91E-26	2.21	100.89
SMBH[7]	240.97	1.78E+121	1.37E+26	1.44E+10	4.837	8.62E-27	1.00	67.81
+	241.64	3.51E+121	1.92E+26	1.48E+10	2.458	4.38E-27	0.51	48.34

[1] The characterization of epochs and values of Z are derived from Table 1 of Egan and Lineweaver (2010).

[2] Relative to the current value of ρ_{crit}.

[3] Interstellar and Intergalactic media.

[4] Relic gravitons.

[5] WIMP dark matter.

[6] Relic neutrinos.

[7] Super Massive Black Holes.

2.4 State of the vacuum at various epochs during the expansion of the universe.

Egan and Lineweaver Egan and Lineweaver (2010) estimated the entropy of the universe (S) at various epochs (stages) of its expansion. (See Table 1 in Egan and Lineweaver (2010)). Table 3 presents the results of applying the equations in Table 1 to the various epochs identified in their study. These data show, for example, that at the emergence of the CMB, the vacuum horizon had a radius of approximately 600 light-years, and the energy density of the vacuum was approximately $2.8x10^{15} GeV/m^3$.

Table 4 Non-local Vacuum at t = Now With ΛCDM Ω Uncertainties.

Parameter	Value	max	min
Total Qubits	1.78E+121	1.80E+121	1.76E+121
$A_S(m^2)$	2.34E+53	2.36E+53	2.31E+53
Radius (m)	1.36E+26	1.37E+26	1.36E+26
Radius (Gly)	14.42	14.50	14.34
Volume(m^3)	1.06E+79	1.08E+79	1.05E+79
Mass/Energy (GeV)	5.16E+79	5.18E+79	5.13E+79
Mass/Energy (kg)	9.19E+52	9.24E+52	9.14E+52
$\rho_{vac}(GeV/m^3)$	4.85	4.90	4.79
$\rho_{vac}(kg/m^3)$	8.64E-27	8.73E-27	8.54E-27
Ω_{vac}	1.00	1.01	0.99
$H_{vh}(km/s/Mpc)$	67.87	68.25	67.50

2.5 State of the non-local vacuum at the present time (t = Now).

The large uncertainties in the data presented in the tables above (derived from the uncertainties in the estimates of S, Equation(2), are too large to permit meaningful comparison with measurements. To circumvent this limitation, the model is required to fit a particular measurement with the uncertainties in S artificially adjusted to reproduce the measurement uncertainty.

From the 2018 Planck Collaboration measurements of ρ Planck Collaboration (2020), the ΛCDM experimental value for

$$\Omega_{tot} = \Omega_\Lambda + \Omega_m = 0.685 \pm 0.007 + 0.315 \pm 0.007 = 1.00 \pm 0.01.$$

Thus, for the HM to fit this measurement

$$\Omega_{vac} = \Omega_{tot} \text{ ,i.e., } \rho_{vac} = \rho = 4.84 \pm 0.05 GeV/m^3$$

Plugging this value into Equation(5), we find

$$R_{vh} = 1.36 \pm 0.01 x 10^{26} m = 14.42 \pm 0.08 Gly.$$

For this value of R_{vh}, Equation (3)) gives

$$I_q = 1.78 \pm 0.02 x 10^{121} qubits.$$

Using these values as inputs, the state of the vacuum at the present time calculated by the HM is presented in Table 4.

As shown in Table 4 , the HM predicts that, when $\Omega_{vac} = 1.00 \pm 0.01$, $H_0 = H_{vac} = 67.87 \pm 0.38$ km/s/Mpc. This is in good agreement (0.7σ) with the value of the ΛCDM H_0 measured by the Planck collaboration in 2018 Planck Collaboration (2020): $H_0 = 67.39 \pm 0.54$ km/s/Mpc.

Table 5 Non-local Vacuum at t = Now With SH0ES H_0 Uncertainties.

Parameter	Value	max	min
Total Qubits	1.54E+121	1.58E+121	1.50E+121
$A_S(m^2)$	2.02E+53	2.08E+53	1.97E+53
Radius (m)	1.27E+26	1.29E+26	1.25E+26
Radius (Gly)	13.41	13.59	13.23
Volume(m^3)	8.55E+78	8.90E+78	8.21E+78
Mass/Energy (GeV)	4.79E+79	4.86E+79	4.73E+79
Mass/Energy (kg)	8.54E+52	8.66E+52	8.43E+52
$\rho_{vac}(GeV/m^3)$	5.61	5.76	5.46
$\rho_{vac}(kg/m^3)$	9.99E-27	1.03E-26	9.72E-27
Ω_{vac}	1.16	1.19	1.13
$H_{vh}(km/s/Mpc)$	73.00	74.00	72.01

Note that $\Omega_{vac} < 1$ indicates that $\rho_{vac} < \rho$. Because the qubits (information) are indestructible the vacuum horizon can only expand and $\rho_{vac} \geq \rho$ [2]. Thus, according to the HM, H_0 must be greater than 67.5 km/s/Mpc.

Incidentally, the first entry in Table 4 , $I_q = 1.78 \pm 0.05x10^{121}$ qubits, is all of the information assumed to emerge from the white hole singularity up to the present time. It is worth noting that this is about 10% of the holographic limit of $1.85x10^{122}$ qubits established by the area of the particle horizon. Thus, the information/entropy resulting from the creation and expansion of spacetime and matter/energy is only about 10% of the maximum amount of information possibly existing within the observable universe.

For $\Omega_{vac} = 1.00 \pm 0.01$, the size of the bits comprising the vacuum horizon is $A_S = 5.23 \pm 0.06x10^{-52}m^2$ and the uncertainty of the e-fold expansion of the "inflaton" is reduced to $N = 60.85 \pm 0.02$.

The Planck collaboration measurements of H_0 Planck Collaboration (2020) were derived from the CMB anisotropies and are, therefore, indicative of the Hubble flow in the early universe. An alternative measurement of H_0 was conducted by Reiss et al. on the SH0ES team using IR data from the Hubble Space Telescope. This measurement is derived from measurements of the red shifts of extra-galactic cepheids and other astronomical objects; which is indicative of the Hubble flow in the late universe Riess et al (2022).

$$\text{SH0ES measurement: } \mathrm{H}_0 = 73.0 \pm 1.0 \ \ \text{km/s/Mpc.}$$

These values for the SH0ES and Planck measurements of H_0 differ by 5σ. Both teams have examined their error budgets and have insisted that this difference is real. Therefore, Riess et al. believe Riess et al (2022) that the H_0 measurements provide strong evidence of the need for physics beyond ΛCDM. Riess has even been quoted as saying that cosmology is now in crisis Richard Panek (March, 2020).

Similar to the Ω measurement, the HM was adjusted to fit the SH0ES measurement and the corresponding uncertainties. The results are presented in Table 5.

The HM agrees exactly with the SH0ES measurement with the assumption that $\Omega_{vac} = 1.16 \pm 0.03$ and $R_{vh} = 13.4 \pm 0.2$ Gly .

[2] This is the origin of the second law of thermodynamics.

For $\Omega_{vac} = 1.16 \pm 0.03$, the size of the bits comprising the vacuum horizon is $A_S = 4.52 \pm 0.06x10^{-52}m^2$, and the uncertainty of the e-fold expansion of the "inflaton" is reduced to $N = 60.6 \pm 0.04$.

The HM values for $H_0 = H_{vac}(\Omega_{vac})$ are plotted together with the Planck and SH0ES measurements in Figure (2).

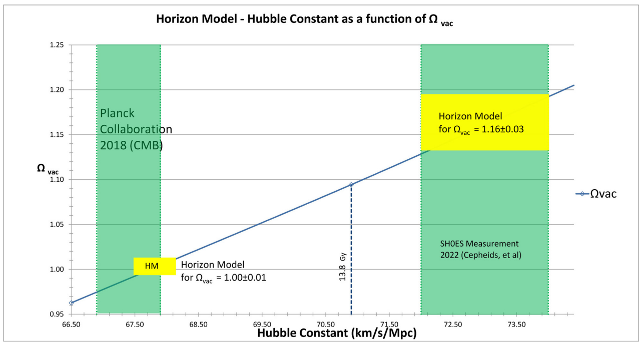

Fig. 2 *Horizon Model (HM) values of the Hubble constant as a function of* Ω_{vac}*. (P=*Ω_{vac} *when* $\rho_{local} = \rho_{crit}$*) With* $\Omega_{vac} = \Omega = 1.00 \pm 0.01$*, the HM value for H* (67.87 ± 0.38) *agrees very well with the Planck collaboration measurement. The HM values for H are in agreement with the SH0ES team measurement if* $\Omega_{vac} = 1.16 \pm 0.03$*. For a Hubble time of 13.8 Gyr,* $\Omega_{vac} = 1.094$*.*

3 Framework for New Physics.

3.1 Hubble Tension.

For the HM, the fact that the H_0 measurements from the two different epochs of CMB and cepheids are statistically different, is proof that $P \equiv \frac{\rho_{vac}}{\rho}$ increased over cosmological time. In the early universe, $\rho_{vac} = \rho$ and, therefore, $P = 1$. Furthermore, spacetime expanded according to the parameters established by the ΛCDM standard model. However, by the age of the cepheids, $\rho_{vac} > \rho$ and, therefore, $P > 1$. It seems plausible that $P > 1$ resulted in an acceleration of the Hubble flow and that $P > 1$ corresponds to an increase in the dark energy postulated to explain the white hole expansion.

According to the HM,

$$\rho_{vac} = \frac{M_p}{4/3\pi(2l_p)^3} I_q^{-1} = 0.03\frac{M_p}{l_p^3} I_q^{-1} = 0.03\frac{c^3}{\hbar G^2} I_q^{-1}(GeV/m^3).\ ^3, \quad (8)$$

and the SH0ES measurement discrepancy' is explained by $P = 1.16 \pm 0.03$.

[3] Where $\hbar = 6.582x10^{-25}GeVs$ and $G = 1.19x10^{-37}m^3GeV^{-1}s^{-2}$

Any variations in $\hbar$ and c must be constrained by the observed limits on variations in the fine-structure constant, $\alpha = \frac{e^2}{4\pi\epsilon_0\hbar c}$. Introducing α, Equation (8) becomes :

$$\rho_{vac} = \frac{3}{8}\frac{\epsilon_0\alpha}{e^2}\frac{c^4}{G^2}I_q^{-1}. \tag{9}$$

.

Assuming that $\frac{\epsilon_0\alpha}{e^2}$ is constant, for ρ_{vac} to increase by $16 \pm 3\%$, c would have to increase by $3.8 \pm 0.7\%$ or G would have to decrease by $7.1 \pm 1.2\%$ over the span of approximately 10^8 years, which is the estimated age of classical cepheids. These correspond to an average increase in c of 11 ± 2 cm/s per year or average decrease in G of $4.7 \pm 0.8x10^{-20}m^3kg^{-1}s^{-2}$ per year.

Equation(9) can be rewritten in terms of the Coulomb force, F_C, and gravitational force, F_G, acting between the qubits of mass M_P and electric charge q_P:

$$\rho_{vac} = \frac{3}{8}\frac{\epsilon_0}{q_P^2}\frac{F_C}{F_G}\frac{c^4}{G^2}I_q^{-1}. \tag{10}$$

. In these terms, $P = 1.16 \pm 0.03$ implies that the relative strengths of the electromagnetic and gravitational fundamental forces may have changed by that amount in the span of $\sim 10^8$ years . These are possible *ad hoc* explanations of the Hubble tension derived from the HM framework. However, a prediction from first principles would require new physics in the form of an understanding of $P(S)$ or, equivalently, $P(t)$, and the relationship between $P > 1$ and dark energy.

3.2 Non-local Vacuum.

The basic framework of the HM is based on the idea of a non-local vacuum that is a region of completely entangled qubits existing outside spacetime. Thus, the qubits do not change in terms of the local time. The indestructibility of the qubits (information) implies that separation (space) is maintained among them. The most likely physics for this separation is the balance between the electrostatic repulsion and gravitational attraction among the Planck size qubits. This physics describes the creation of an uncurved, 3-dimensional, (Euclidian) space that fills the interior of the vacuum. It is a natural consequence of the non-local vacuum that the vacuum speed of light is a universal constant simply because it is a property of space and not spacetime. The same is true for the universal gravitational constant and Planck's constant.

If the qubits are binary, what are they a superposition of? In terms of particles, the qubits might be a superposition of $[gravitons, photons]$. Any Hamiltonian derived to describe the energy-density of the vacuum must be, by definition, time-independent. These are some of the aspects of new physics required to understand the non-local vacuum.

However, the real challenge for new physics is to explain how an ensemble of $\sim 10^{16}$ spatial qubits (an "inflaton") produces a local bit of Minkowski spacetime (gravity) and matter/energy on the horizon. The situation is similar to the Holographic Principle acting in reverse: a hologram of $\sim 10^{16}$ 3-D qubits projects on to a bit of a holograph of 3D+1 spacetime. Is this the result of Heisenberg fluctuations within the qubits, or some property *emerging* (in a Complexity Science sense) from such a high degree of entanglement, or is it entirely new physics?

3.3 Vacuum Horizon.

The second basic element of the HM framework is that local reality originates from the quantized horizon surrounding the vacuum where local reality consists of spacetime and matter/energy. According to GR, , the physical reality of spacetime is a geometrical metric of the gravitational field. Thus, the quantized bits of the vacuum horizon result in quantized gravity and matter/energy.

New physics is required to determine the exact form of these quanta and how the quantized bits of the horizon produce one or the other. In other words, what are [0] and [1] and how does $\begin{bmatrix} 0 \\ 1 \end{bmatrix}$ become either [0] or [1]?[4]

The value of $P = 1.16 \pm 0.03$, which explains the Hubble tension, indicates that the size of the vacuum horizon bits decreased by $13.7 \pm 1.4\%$ over the 10^8 years. The new physics related to the emergence of matter/energy from these bits and how this could have changed with the size of the bits over the 10^8 years might be relevant to understanding "dark matter". (Evidently, this is highly speculative.)

In the HM picture, the non-local vacuum is outside spacetime. Therefore, all quantum fields have zero-point energies and all Hamiltonians obtain their time dependence on the vacuum horizon rather than in the vacuum itself. All wave function collapses occur on the vacuum horizon. Perhaps all quantum superposition occur within the unobservable vacuum. (Would this not be where Schrödinger's cat exists?)

In the HM, all world lines begin from quantized bits on the expanding vacuum horizon. New physics may flow from making this framework compatible with GR. HM defines the physical "Now" Muller (2016) as the vacuum horizon that exists everywhere in spacetime, with a depth of $\sim 10^{-34}$ s and a spatial uncertainty of $\sim 10^{-26}$ m. In this picture, "Now" is a quantum bit of the horizon where cosmological time stops and local time begins.

3.4 Some Precedents

The notion that spacetime emerges from a surface is not new. In 1997, Juan Maldacena invoked the Holographic Principle Susskind (1995) t'Hooft (1993) such that 3D+1 spacetime was defined on a surface bounding a bulk 5-dimensional Anti de Sitter (AdS) space. Maldacena conjectured that there is a correspondence between certain Conformal Field Theories (CFT) applied to the boundary in 3D+1 spacetime and the compactification of M/string theories on the 5D Anti de Sitter spacetime inside the boundary and he termed this the AdS/CFT correspondence Maldacena (1998). Though the AdS/CFT system represents only a fictitious universe, its study has led to a number of insights and advances in the search for a theory of quantum gravity. One of the insights important to the HM is the resolution of the black hole information

[4] One of these states must correspond to the quantum of gravity, the graviton.

paradox, leading Stephen Hawking to conclude that "Elementary quantum gravity interactions do not lose information or quantum coherence." Hawking (2005)

In 2001 Andrew Strominger introduced a variant of the AdS/CFT correlation by assuming that 3D+1 spacetime emerged from a spherical shell surrounding a 3D deSitter sphere Strominger (2001). In attempting to derive a dS/CFT correlation, Strominger considered the point of view of a time-like observer inside the sphere. This fictitious universe is much more closely aligned with the HM in that the non-local vacuum is spatially flat and is without matter; i.e., a deSitter space.. However, the establishment of any correlation between the highly complex conditions in the non-local vacuum and the bits of spacetime emerging from the vacuum horizon requires new physics and, most likely, advances in computational complexity Gefter (2014).

In 2006, Ryu and Takayanagi Ryu and Takayanagi (2006) used the Holographic Principle and AdS/CFT correspondence to calculate the entanglement (Von Neumann) entropy of CFT_{d+1} from the entropy of quantum many-body systems in AdS_{d+2}. In 2010, Mark Van Raamsdonk published a paper Mark Van Raamsdonk (2010) that invoked AdS/CFT duality to argue that the "emergence of spacetime in the gravity picture is intimately related to the quantum entanglement of degrees of freedom in the corresponding conventional quantum system." He concluded his paper with the following statement: "It is fascinating that the intrinsically quantum phenomenon of entanglement appears to be crucial for the emergence of classical spacetime geometry."

In 2013, Maldacena and Susskind extended the idea of the connection between spacetime and quantum entanglement noting that the GR solution for two distant black holes, whose interiors are connected via a wormhole (Einstein-Rosen bridge), can be interpreted as two black holes in a maximally entangled state Maldacena and Susskind (2013) Maldacena (November, 2016). Swingle published a review of the idea that spacetime and gravity can emerge from entanglements Swingle (2018). Inspired by the AdS/CFT duality, Swingle argues that networks of tensors can be used to define a discrete geometry that encodes entanglement, and with the assumption that a continuum limit can be taken, this geometry necessarily obeys GR.

Many of the features of the HM are foreshadowed in a paper by Erik Verlinde, where it is stated, "Starting from first principles and general assumptions we present a heuristic argument that shows that Newton's law of gravitation naturally arises in a theory in which space emerges through a holographic scenario. The universality of gravity suggests that its emergence should be understood from general principles that are independent of the specific details of the underlying microscopic theory. In this paper we will argue that the central notion needed to derive gravity is information." Verlinde (2011).

3.5 Relevance to current research

One of the advances resulting from the studies of the AdS/CFT system is the recognition that quantum information theory has an important role to play in the eventual development of a theory of quantum gravity. In support of this, the Simons foundation has funded the formation of the *It from Qubit* collaboration [5]. There are many points

[5] https://www.simonsfoundation.org/mathematics-physical-sciences/it-from-qubit/

of contact between the HM and studies undertaken by this collaboration. Most of these stem from the connection that the HM establishes among quantum information, quantum entanglement, and the emergence of gravity on the quantized holographic surface of the vacuum horizon.

Several recent papers have established that gravitationally mediated entanglement may be viewed as implying the existence of gravitons Danielson et al (2022), Carney (2022). Matsumara and Yamamoto have remarked that the generation of entanglement by gravity implies that gravitational interactions cannot be described by classical processes. Hence, the detection of gravity-induced entanglement can be a proof of the quantum signature of gravity Matsumura and Yamamoto (2020).

Many aspects and conclusions of the HM are supported by the analysis of Carlos Silva Silva (2024). Three quotes from Silva's paper are reproduced below.

"It is possible to argue that spacetime must be not fundamental, but an emergent entity in the context of quantum gravity, whose fundamental degrees of freedom, from which spacetime itself must to emerge, will correspond to quantum correlations only. Not correlations among things, but only quantum correlations."

"...it is considered that spacetime geometry must emerge holographically from a quantum theory living in a spatial dimension lower."

'"...such a kind of conceptual barrier is linked with the fact that it is difficult to completely leave the idea of the existence of spacetime in such a context (AdS/CFT), and in this way, we still need the existence of a locus (the boundary) from which the bulk itself will emerge. In fact, this is rooted in some deep questions that still haunt the issue of spacetime emergence: *how could physics exist beyond spacetime, and how could things exist, and become entangled, without some loci where and when they happen and change?* (emphasis mine)".

The HM answers Silva's questions by revealing: *physics exists beyond spacetime as the physics of non-locality and things exist and become entangled in the expanding interior of a white hole that is the non-local vacuum. Spacetime and, thus, the observable universe emerges from the horizon of that white hole.*

3.6 John Wheeler's Aphorism

As mentioned in the Introduction, John Wheeler's famous information-theoretic aphorism is *"it from bit"*. All physical sciences are encapsulated in the word *from* in that phrase. The framework of the HM extends Wheeler's aphorism to include *bit from qubits*, and all of the new science required to develop the HM is encapsulated in the word *from* in that context. A complete physics that includes the HM framework can be expressed in the aphorism *"it from bit from qubits"*.

4 Summary and Conclusions

The basic framework of the HM is that of a non-local vacuum filled with spatial binary qubits behind an expanding quantized white hole event horizon, which is the source of local reality (spacetime/gravity and matter/energy). This framework, when combined with quantitative estimates of the number of bits (entropy) in the observable universe, requires the existence of instantaneous inflation before the expansion of spacetime begins and calculates that it involves an e-fold volume expansion relative to the Planck volume of $N = 61^{+1.2}_{-1.0}$.

The framework automatically eliminates the "cosmological (vacuum catastrophe) problem" and provides a logical home for the non-local reality of quantum entanglement.

If the requirement from ΛCDM that $\Omega = 1.00 \pm 0.01$ is imposed on the HM, the assumption that $P(\equiv \frac{\rho_{vac}}{\rho_{local}}) = \rho_{vac}/\rho_{crit} = 1$ predicts a value of $H_{vac} = H_0 = 67.87 \pm 0.38$ km/s/Mpc and the uncertainty on the e-fold expansion of the "inflaton" is reduced to $N = 60.85 \pm 0.02$. This H_0 value agrees with the 2018 Planck Collaboration measurement Planck Collaboration (2020) to within 0.7σ. The area of a bit of the quantized vacuum horizon is predicted as $A_S = 5.23 \pm 0.06x10^{-52}m^2$.

The HM agrees perfectly with the SH0ES team measurement of H_0 Riess et al (2022) with the assumption that $P = 1.16 \pm 0.03$. With this assumption, $H_0 = 73 \pm 1.0$ km/s/Mpc; $N = 60.63 \pm 0.04$; and $A_S = 4.52 \pm 0.12x10^{-52}m^2$. For the HM, the Hubble tension implies that P increases over the cosmological time between the time of the CMB and the era of classical cepheids. Possible explanations for this increase within the HM framework include changes over time in the physical constants c or G (assuming that the fine-structure constant is truly constant). Numerically, over a time span of 10^8 years, the average changes required would be an increase in c of 11 ± 2 cm/s per year or a decrease in G of $4.7 \pm 0.8x10^{-20}$ m $kg^{-1}s^{-1}$ per year. Alternatively, the required change in ρ_{vac} results from a change in the relative strengths of the electromagnetic and gravitational forces ($\frac{F_C}{F_G}$) by the same amount. These are only possible *ad hoc* explanations. The new physics required by the HM is an understanding of how P varies with local entropy, $P(S)$ or, equivalently, $P(t)$, and how $P(t) > 1$ relates to an increase in dark energy.

Consequently as $P(t) > 1$, the size of the quantized bits of vacuum horizon A_S decreases. In the HM, these bits are the source of gravity (spacetime) and matter/energy. Therefore it is important to understand how matter/energy and gravity emerge from these quanta and how that might have changed over time.

In the HM, there is an ensemble of $\simeq 4x10^{16}$ non-local (entangled) binary qubits "behind" each quantum of the vacuum horizon (the explanation for "inflation"). The fact that information (a qubit) is indestructible leads the HM to postulate that the separation among them is responsible for the creation of 3-D space within the non-local (timeless) vacuum. However, it is necessary to understand how an ensemble of entangled spatial qubits produces a local quantum bit of the vacuum horizon from which matter/energy and gravity (time) emerge.

All the new physics required to expand on the framework of the HM is captured by an extension of John Wheeler's aphorism, namely, *'"it from bit from qubits"*.

The HM satisfies Popper's requirement for a legitimate scientific hypothesis that it is falsifiable. If new analyses or measurements of the CMB require inflation at $t = 0$ with $N < 55.8$, the model using Egan and Lineweaver's errors would be falsified by 5σ. The assumptions of the HM could be weakened by experimental proof of the existence of a naked singularity. It could also be falsified by any experiment that detects a granularity of spacetime at a length scale of less than $\sim 10^{-26}m$.

5 Acknowledgments.

I would like to thank Charles H. Lineweaver and the astrophysics team at the Australian National University for their careful analysis of the entropy/information budget in the observable universe and for providing open access to the data Egan and Lineweaver (2010). I would also like to thank the *Editage* company for their help in editing this manuscript.

6 Declarations.

The author did not receive financial support from any organization for the submitted work. The author has no competing interests to declare that are relevant to the content of this article.

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