Cosmic inflation from entangled qubits: a white hole model for emergent spacetime

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Abstract

This paper introduces the Horizon Model (HM) of cosmology, designed to resolve the cosmological constant problem by equating the vacuum energy density to that of the observable universe. The model is founded on the primacy of quantum information, proposing that the first element of reality that emerges from the Big Bang singularity is a Planck sized qubit. HM conceptualizes the Big Bang singularity as the opening of a white hole, with the non-local vacuum as its interior with spacetime and matter/energy emerging from the event horizon. Utilizing the Schwarzschild solution and the Holographic Principle, the model calculates the number of vacuum qubits required to equalize the densities. This number is then compared with estimates of the observable universe's Shannon bits (entropy) S. With this information, HM can calculate the state of the vacuum as a function of S. Results are presented for two specific values of S corresponding to t-0 and t=now. The results at t=0 closely align with the expectations of the cosmic inflation paradigm. For t=now, HM predicts Hubble flow within 0.8s of the Planck collaboration value and can resolve the Hubble tension. HM predictions of the vacuum pressure (10-10 Pa) are in good agreement with measurements. HM is closely aligned with current research being done by the emergent spacetime program, But research into how a non-local white hole with a quantized event horizon could be the source of spacetime and matter/energy holds promise of leading directly to a quantum theory of gravity.

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

1 Introduction

The standard model of cosmology (ΛCDM) is known to have a range of " serious theoretical issues"Bull et al (2016). This paper presents an alternative model of the Big Bang that resolves two of the more prominent of these issues.

According to the standard model the Big Bang is a naked singularity[1]where time, and therefore spacetime, goes to zero. In this model, the first element of physical reality emanating from the singularity is the Planck region. This is a quantum region associated with the vacuum having a size of $l_p \sim 10^{-35}$ m and the enormous energy density of $\rho_p \sim 10^{123}$ GeV/m^3 ($\sim 10^{96}$ kg/m^3).

This is a region of intense interest to the theoretical community working to develop a quantum theory of gravity because it is assumed that General Relativity (GR) and classical gravity flow directly from the Planck region. There are at least two problems associated with this assumption.

First, there is a disparity $> 10^{120}$ between predictions of the energy density of the vacuum from quantum field theory and observations of the energy density of the

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[1] Not shielded by a horizon like for a black or white hole.

universe embodied in ΛCDM. This has been called the “vacuum catastrophe”.Adler et al (1995) or ”cosmological constant problem”Martin (2012).

Secondly, the assumption that classical Hubble flow[2] began at the boundaries of the Planck region is contradicted by measurements of the Cosmic Microwave Background (CMB) that have led to the paradigm of cosmic inflation Guth (1981) Linde (1982). This paradigm postulates a period of exponential expansion of the universe to the ad-hoc size of of $\sim 10^{-26}$m [3] before Hubble flow began Ellis and Wands (2023) Baumann and McAllister (2014). There is no explanation for this “exponential” expansion or the size of $\sim 10^{-26}$ m.

In this letter I am introducing an alternative version of the Big Bang that eliminates both of these problems. John Wheeler had the insight, embodied in his famous aphorism “it from bit”, that the most fundamental element of reality is information Wheeler (1990). Taking Wheeler’s point of view, the Big Bang would be a source of information, i.e., the Planck region would be a quantum bit of information (a qubit) in the form of a binary probability.

The alternative view of the Big Bang is that it is not a naked singularity but represents the opening up of a white hole with an expanding horizon, In this view, the interior of the white hole is the vacuum, and time, and therefore spacetime, emerges from the horizon of the white hole. Since the quantum interior of the vacuum is timeless it is non-local and, therefore, all the qubits within it are entangled.

In the sections below I will demonstrate that the vacuum energy density, ρ_{vac}, is inversely proportional to the number of qubits within the horizon. This then is used to calculate the number of qubits required for ρ_{vac} to equal the energy density of the observable universe. This automatically eliminates the “cosmological constant problem”. That number turned out to be $\sim 10^{121}$ qubits.

This number is then compared with published estimates Egan and Lineweaver (2010) of the Shannon entropy [4] (information) in the observable universe, $S =\sim 10^{105}$ bits. Assuming that the ratio of vacuum qubits to Shannon bits has remained constant, when the first Shannon bit emerged from the vacuum horizon at t=0, the timeless vacuum had instantaneously inflated to contain $4x10^{16}$ qubits. This explains the “exponential” nature of cosmic inflation. Using the Schwartzchild solution of GR and the Planck units, I calculate that the size of the white hole at t=0 (the “inflaton”) to be $\sim 10^{-26}$ m. This is in good agreement with and explains the magnitude of inflation inferred from the CMB measurements.

I present calculations below of the size and mass of the white hole (vacuum), and quantities derived from them, as a function of S. Tables of these results calculated at t=0 (for the “inflaton”) and at t=now are included.

In this alternative view of the Big Bang, the energy density of the vacuum is the source of the “dark energy” driving the expansion of the white hole event (vacuum) horizon and therefore the expansion of spacetime. Also, in the alternative view, the Hubble tension[5] and the observed acceleration in spacetime expansion are related to changes in the vacuum energy density. I will speculate below how such changes might have come about. I will also discuss the relevance of this alternative view to current research in the emergent spacetime program.

For brevity’s sake I will refer to this alternative view of the Big Bang below as the Horizon Model (HM).

2 Numerical framework of HM

2.1 Basic equations

As noted above, HM incorporates John Wheeler’s insight that the most fundamental element of reality is quantum information in the form of a probability; i.e., a qubit. Wheeler (1990). The Big Bang is the source of the Planck region as the first element of physical reality. According to HM, this would be a qubit contained within a white hole. The Schwartzchild solution of the Einstein field equations is valid for any mass M. Therefore, the radius of the event horizon of a white or black hole containing a single Planck region would be $R_s = 2GM_p/c^2$, where G is the universal gravitational constant, c is the speed of light and M_p is the Planck mass. From the definition of the Planck units, $R_s = (2l_p)$. Thus, the surface area of an event horizon around a single

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[2] Expansion of spacetime.

[3] This corresponds to an e-fold volume expansion relative to l_p^3 of ≥ 60.

[4] Two microstates per macrostate.

[5] The fact that two different measurements of the Hubble flow representative of two different ages of the universe differ by 5σ.

Planck qubit is $16\pi\hbar c^{-3}G$, which, in rationalized units, is

$$A_{qp} = 4G = 1.31x10^{-68}m^2. \tag{1}$$

According to the Holographic Principle of Susskind Susskind (1995) and t'Hooft t'Hooft (1993), the amount of information within the vacuum (white hole event) horizon $I_q \propto A_{vac}$ so the radius of the vacuum horizon $R_{vac} \propto I_q^{1/2}$,

$$R_{vac} = R_s I_q^{1/2} = 2l_p I_q^{1/2} = 3.23x10^{-35} I_q^{1/2} m. \tag{2}$$

$$V_{vac} = 4/3\pi R_{vac}^3 I_q^{3/2} = 1.41x10^{-103} I_q^{3/2} m^3. \tag{3}$$

From the Schwartzchild equation, $M \propto R \propto A^{1/2}$. From the Holographic Principle $A^{1/2} \propto I_q^{1/2}$ so the mass/energy of the vacuum is $\propto I_q^{1/2}$,

$$M_{vac} = M_p I_q^{1/2} = 1.22x10^{19} I_q^{1/2} GeV. \tag{4}$$

$$\rho_{vac} = 1.22x10^{19} I_q^{1/2}/1.41x10^{-103} I_q^{3/2} = 8.65x10^{121} I_q^{-1} GeV/m^3. \tag{5}$$

The temperature of a white/black hole is inversely proportional to its mass. So

$$T_{vac} = T_p M_p/M_{vac} = T_p Iq^{-1/2} = 1.42x10^{32} I_q^{-1/2} K. \tag{6}$$

Assuming that the expansion of the vacuum horizon occurs at the speed of light, $\mathrm{R}_{vac} = cH_{vh}^{-1}$, where H_{vh} is the Hubble "constant" for the vacuum horizon expansion. In HM the vacuum horizon is the source of spacetime, so $H_0 = H_{vh}$,

$$H_0 = H_{vh} = 2.87x10^{62} I_q^{1/2} = 67.86\Omega_{vac}^{1/2} km/s/Mpc. \tag{7}$$

The repulsive pressure of the "dark energy" driving the expansion of the event horizon is, for equation of state w=-1,

$$\mathrm{P}_{vac} = \rho_{vac} 1.6x10^{-10} = 1.38x10^{112} I_q^{-1} = 7.77x10^{-10}\Omega_{vac}\ \mathrm{Pa}. \tag{8}$$

2.2 State of the vacuum as a function of local entropy S

HM is tied to observation by comparing the value of I_q to the Shannon entropy of the observable (local) universe. That entropy has been estimated Egan and Lineweaver (2010) to be

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

In the standard model Ω_{vac} is a constant [6]. In HM, Ω_{vac} is a parameter depending on I_q^{-1}. The state of the vacuum as a function of Ω_{vac} and the local entropy can be calculated with the basic equations above by substituting

$$I_q = 4x10^{16}\Omega_{vac}^{-1} S. \tag{9}$$

It is indicative of the simplicity of the HM and its potential for unification that it requires only two inputs from the quantum world (M_p, l_p) and two inputs from cosmology (S, ρ_{crit}).

3 Results

The two values of S that I will present results for here are S=1 (t=0), and S=$4.47x10^{104}$ bits (t=now). The state of the non-local vacuum at t=0 represents the state of the universe from which spacetime first emerged. In the inflation paradigm this state is sometimes referred to as the"inflaton". Table 1 presents the results of solving the above basic equations for S=1 with uncertainties in S, ΔS_{EL}, as estimated by Egan and Lineweaver Egan and Lineweaver (2010).

The results for S=$4.47x10^{104}$ bits (t=now) when calculated with ΔS_{EL} have uncertainties too large to permit meaningful comparison with measurements. For example, $\Omega_{vac} = 1.00^{+1.22}_{-0.49}$. 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_{crit} Planck Collaboration (2020). the ΛCDM experimental value for

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

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[6] The assumption that it is constant is responsible for the cosmological constant problem

Table 1 Non-local vacuum at t=0 (the“inflaton”) with ΔS_{EL} uncertainties.

Parameter	Value	$+\Delta$	$-\Delta$
I_q qubits	3.99E+16	4.83E+16	1.97E+16
I_q/S qubits/bit	3.99E+16	4.83E+16	1.97E+16
$A_S(m^2)$	5.24E-52	6.34E-52	2.59E-52
$R_{vh}(m)$	6.46E-27	3.14E-27	1.86E-27
$V_{vac}(m^3)$	1.13E-78	2.58E-78	7.22E-79
E=Volume Expansion,^{1}	2.67E+26	6.10E+26	1.71E+26
N=e-fold of E	60.85	1.19	1.02
Mass/Energy (GeV)	2.44E+27	1.19E+27	7.03E+26
Mass/Energy (kg)	3.91E+17	1.90E+17	1.13E+17
$\rho_{vac}(GeV/m^3)$	2.16E+105	2.10E+105	1.18E+105
P_{vac} (Pa)	3.46E+95	3.37E+95	1.90E+95
$T_{vac}(K)$	7.09E+23	2.87E+23	2.32E+23
Ω_{vac}, ^{2}	4.47E+104	4.35E+104	2.45E+104
$H_{vh}(km/s/Mpc)$	1.43E+54	5.80E+53	4.69E+53

[1] Relative to l_p^3.

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

Table 2 Non-local vacuum at t=now with ΔS_{Ω} uncertainties.

Parameter	Value	$+\Delta$	$-\Delta$
I_q qubits	1.78E+121	1.98E+119	1.96E+119
I_q/S qubits/bit	3.98E+16	4.43E+14	4.38E+14
$A_S(m^2)$	4.47E+104	4.98E+102	4.92E+102
$R_{vh}(m)$	1.36E+26	7.57E+23	7.53E+23
$R_{vh}(Gly)$	14.42	0.08	0.08
$V_{vac}(m^3)$	1.06E+79	1.78E+77	1.75E+77
Mass/Energy (GeV)	5.15E+79	2.86E+77	2.84E+77
Mass/Energy (kg)	8.26E+69	4.58E+67	4.56E+67
$\rho_{vac}(GeV/m^3)$	4.85	0.05	0.05
P_{vac} (Pa)	7.77E-10	8.64E-12	8.54E-12
Ω_{vac}	1.00	0.01	0.01
$H_{vh}(km/s/Mpc)$	67.87	0.38	0.37

Table 3 Non-local vacuum at t=now with ΔS_{SH} uncertainties.

Parameter	Value	$+\Delta$	$-\Delta$
I_q qubits	1.54E+121	4.31E+119	4.31E+119
I_q/S qubits/bit	3.44E+16	9.38E+14	9.38E+14
$A_S(m^2)$	4.47E+104	1.25E+103	1.25E+103
$R_{vh}(m)$	1.27E+26	1.76E+24	1.76E+24
$R_{vh}(Gly)$	13.41	0.19	0.19
$V_{vac}(m^3)$	8.55E+78	3.61E+77	3.61E+77
Mass/Energy (GeV)	4.79E+79	6.66E+77	6.66E+77
Mass/Energy (kg)	7.68E+69	1.07E+68	1.07E+68
$\rho_{vac}(GeV/m^3)$	5.61	0.15	0.15
P_{vac} (Pa)	8.98E-10	2.45E-11	2.45E-11
Ω_{vac}	1.16	0.03	0.03
$H_{vh}(km/s/Mpc)$	73.00	1.00	1.00

The basic equations of HM will fit this measurement exactly by artificially adjusting the uncertainties in S, ΔS_{Ω}, such that $\Omega_{vac} = 1.00 \pm 0.01$ [7]. The results are presented in Table 2. The values of T_{vac} are not included in this or in Table 3 because they drop below 10^{-10} K for $R_{vac} >\sim 10^8 m$.

To address the Hubble Tension, HM was required to fit the measurement of H_0 conducted by the SH0ES team Riess et al (2022). This was done by keeping the ΔS_{Ω} as is and reducing R_{vac} and therefore I_q in Equation(2), The results are presented in Table 3.

The HM values for H_{vac} are plotted together with the Planck and SH0ES measurements of H_0 in Figure (1).

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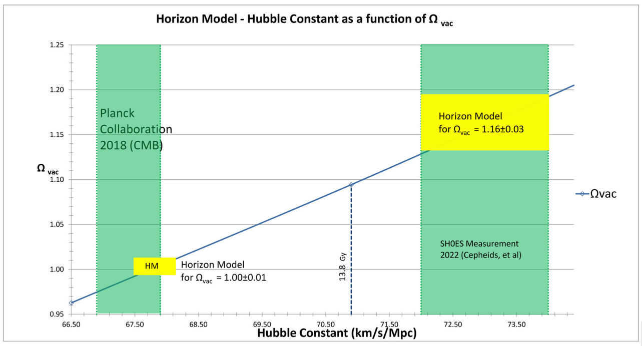
[7] The reason that $\Omega_{vac} = \Omega_{tot}$ and not Ω_{Λ}, is that in the HM matter/energy as well as spacetime emerge from the vacuum horizon.



[h]

Fig. 1 *Horizon Model (HM) values of the Hubble constant as a function of* Ω_{vac}. *With* $\Omega_{vac} = \Omega = 1.00 \pm 0.01$, *the HM value for H* ($67.87 \pm 0.38$) *is within* 0.8σ *of the Planck collaboration measurement. The HM values for H are in perfect agreement with the SH0ES team measurement* (73 ± 1) *if* $\Omega_{vac} = 1.16 \pm 0.03$. *For a Hubble time of 13.8 Gyr,* $\Omega_{vac} = 1.094$.

4 Discussion.

4.1 Numerical results.

The entropy-area law published by Hawking Hawking (1975) and Bekenstein Bekenstein (1973) states that the entropy S of a black/white hole having an event horizon of area A is $S = A/4G$. Basic equation(1) of HM identifies 4G as $A_{qp} = 1.31x10^{-68}m^2$. Andrew Strominger has stated that “Understanding the microscopic origin of (this formula) is undoubtedly a key step towards understanding the fundamental nature of spacetime and quantum mechanics” Strominger (2001). The HM provides the microscopic origin of (this formula) by identifying 4G *as the surface area of the Schwartzchild event horizon surrounding a single Planck mass qubit of information.*

The standard model of the Big Bang assumes that the expansion of spacetime began at the boundaries of the Planck region. This is in conflict with the paradigm of cosmic inflation that requires the universe to have exponentially expanded to a size of $\sim 10^{-26}$ m before spacetime expansion occurred Ellis and Wands (2023) Baumann and McAllister (2014). HM supports the inflation paradigm and calculates the properties of the inflation state (the ”inflaton”) as the properties of the vacuum at t=0 (S=1). In HM the vacuum is timeless (non-local) so the ”inflaton” appears simultaneously with the Big Bang singularity. This implies there are no stages of development for inflation. The properties of the ”inflaton” are listed in Table 1. The HM value for the size of the ”inflaton” is $R_{vh} = 6^{+3}_{-2}x10^{-27}m$. It has an energy density of $2.4^{+1.2}_{-0.7}x10^{105}GeV/m^3$, a temperature of T=$7^{+3}_{-2}x10^{23}$ K and exerts a repulsive pressure of P$_{vac}$ = $3^{+3}_{-2}x10^{95}$ Pa. The large uncertainties in these results reflect the large uncertainties in S Egan and Lineweaver (2010).

The Planck collaboration measurements of $H_0 = 67.39 \pm 0.54km/s/Mpc$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 $H_0 = 73 \pm 1km/s/Mpc$ was conducted by the SH0ES team Riess et al (2022) 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 Hubble flow in the later universe. As can be seen in Figure(1), HM fits the SH0ES result exactly by setting $\Omega_{vac} = 1.16 \pm 0.03$. With $\Omega_{vac} = 1.00 \pm 0.01$, HM fits the Planck measurement to within 0.8σ.

The second law of thermodynamics implies that local bits (information/entropy) are indestructible. If one assumes that qubits are also indestructible, then the only way for Ω_{vac} to increase would be for I_q/S to decrease. From Equation(9), I_q/S would have to decrease from $3.98 \pm 0.04x10^{16}$ to $3.44 \pm 0.09x10^{16}$ qubits/bit as $\Omega_{vac} = 1.0 \pm .01$ increases to 1.16 ± 0.03.

For this change in Ω_{vac} the vacuum pressure would change from $7.77 \pm 0.09x10^{-10}$ to $8.98 \pm 0.02x10^{-10}$ Pa. These are in agreement with measurements of the pressure on the lunar surface made (after sunset) during the Apollo missions and the Chinese lunar landings of $\sim 10^{-10}$ Pa Detian et al (2021).

Until the physics of I_q/S is understood, any attempt to explain these changes is only speculation. One such speculative explanation is that the physical constants c and G changed. Numerically, c and G would have had to both decrease by $7.23 \pm 1.40\%$ over the time span between the Planck and SH0ES measurements for Ω_{vac} to increase by $16 \pm 0.03\%$.

4.2 Consistency of HM with the emergent spacetime program

HM envisions spacetime emerging from a white hole event horizon quantized in units of area of $\sim 10^{-52}m^2$. 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 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 paradox, leading Stephen Hawking to conclude that "Elementary quantum gravity interactions do not lose information or quantum coherence"Hawking (2005) [8]. 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 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." Swingle published a review of the idea that spacetime and gravity can emerge from entanglements. He further 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 Swingle (2018). 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". He further argues that "..the central notion needed to derive gravity is information."Verlinde (2011). Carlos Silva has written a paper Silva (2024) that argues that spacetime is an entity that can only emerge from quantum correlations . His paper includes the following two quotes:

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

"..deep questions ... 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.)

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 matter/energy and, thus, the observable universe emerges from the horizon of that white hole.* Swingle said that General Relativity is compatible with spacetime expansion from a 2D surface as long as certain continuity conditions are met.

5 Summary and conclusions.

This paper presents the Horizon Model of cosmology (HM) that was developed for the express purpose of eliminating the cosmological constant (vacuum catastrophe) problem Martin (2012). It does this by assuming the energy density in the vacuum is equal to the energy density of the observable universe. The foundation of HM is based on the primacy of quantum information Wheeler (1990) leading to the understanding that the first element of reality emerging from the Big Bang singularity, the Planck region, is a qubit. The HM views the Big Bang singularity as the opening of a white hole and the vacuum as the interior of that white hole. It invokes the Schwartzchild solution and the Holographic Principle to calculate the number of qubits I_q required for that equality. HM is tied to observation by comparing I_q to published estimates of the number of Shannon bits (entropy), S, in the observable universe Egan and Lineweaver (2010). The HM can then be used to calculate the properties of the vacuum and the event horizon as a function of S.

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[8] This supports the assumption that qubits are indestructible.

The results for two particular values of S are presented here. Table 1 shows the results for S=1 corresponding to t=0 and Tables 2 and 3 list the results for S=$1.46x10^{104}$ bits corresponding to t=now.

The HM results for t=0 show that a bubble of $4x10^{16}$ non-local entangled qubits produced a quantized bit on the vacuum horizon from which the first bit of local spacetime emerged. This first bubble is logically equivalent to the "inflaton" of the cosmic inflation paradigm. According to HM, it had an energy density of $2^{+2}_{-1}x10^{105}GeV/m^3$, a temperature of $7^{+3}_{-2}x10^{23}$ K and a volume with an e-fold expansion relative to l_p^3 of $N = 60.9^{+1.2}_{-1.0}$. This is in good agreement with the cosmic inflation paradigm which requires $N > 60$ Ellis and Wands (2023). The large uncertainties in these results reflect the uncertainties in the estimates of S by Egan and Lineweaver, Δ_{EL} Egan and Lineweaver (2010).

The Δ_{EL} are too large to permit meaningful comparison with measurements. So the uncertainties in S were artificially adjusted to fix $\Omega_{vac} = 1.00 \pm 0.01 \Rightarrow \Delta_\Omega$ and to fit the SH0ES measurement of $H_0 = 73 \pm 1.0 \Rightarrow \Delta_{SH}$.

Using Δ_Ω, the vacuum horizon is quantized in bits of area $A_S = 5.23 \pm 0.06x10^{-52}m^2$.

The HM prediction for H_{vac} with Δ_Ω is 67.9 ± 0.4 which is within 0.8σ of the H_0 value measured by the Planck collaboration Planck Collaboration (2020).

The HM predictions for the vacuum pressure with Δ_Ω is $7.77 \pm 0.09x10^{-10}$ Pa while with Δ_{SH} it is $9 \pm 0.3x10^{-10}$ Pa. These are in agreement with measurements of the pressure on the lunar surface made by NASA and the Chinese space program of $\sim 10^{-10}$ Pa Detian et al (2021).

I am an experimenter/computer-modeler and this is obviously not a theoretical paper but HM does point to a new direction for theoretical research. In HM, 3D+1 spacetime and matter/energy emerge from a quantized 2D surface surrounding a region of entanglement. This is in keeping with current research on emergent spacetime. But the specific basic question raised by HM is: How could a 3D bubble of $4x10^{16}$ entangled (non-local) Planck sized binary qubits give rise to a quantized 2D horizon from which emerges time, gravity and matter/energy? Other supplementary questions present themselves. Could the qubits be a superposition of [gravitons,photons]? Is time created through Heisenberg fluctuations among the qubits? Is time an emergent property [9] resulting from the network of $4x10^{16}$ entangled qubits? Does HM meet Swingle's criteria for compatibility with General Relativity Swingle (2018)?

By the nature of HM, it is clear that theoretical research into these questions hold promise of leading directly to a quantum theory of gravity.

6 Acknowledgments.

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7 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.

8 Data availability statement

The data used in this paper are publicly available at https://iopscience.iop.org/article/10.1088/0004-637X/710/2/1825/meta

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[9] In the sense of Complexity Science $\Rightarrow$ the whole is greater that the sum of its parts because of the network among them.

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