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

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**Abstract**

This paper presents the Horizon Model (HM) of cosmology, designed to resolve the cosmological constant problem by equating the vacuum energy density with that of the observable universe. Grounded in quantum information theory, HM proposes the first element of reality emerging from the Big Bang singularity as a Planck-sized qubit. The model views the Big Bang as the opening of a white hole, with spacetime and matter/energy emerging from the event horizon. Using the Schwarzschild solution and the Holographic Principle, HM calculates the number of vacuum qubits needed to equalize densities, and compares this to published estimates of the observable universe's Shannon entropy (S). With this information, HM can calculate the state of the vacuum as a function of S. Results at S=1 (t=0) and $\boldsymbol{S = 1.4610^{104}}$ bits (t=now) are presented. At t=0, the radius of the event horizon is predicted to be $\boldsymbol{\sim 10^{-26}}$ m in excellent agreement with the ad-hoc requirement of the current cosmic inflation paradigm. At t=now, HM predicts Hubble flow within $\boldsymbol{0.8\sigma}$ of the Planck collaboration measurement and can resolve the Hubble tension with a small adjustment of the vacuum energy density. HM predictions of the vacuum pressure ($\boldsymbol{\sim 10^{-10}}$ Pa) are in good agreement with pressure measurements made on the lunar surface by NASA and the Chinese space program. Aligned with current research for spacetime emerging from surfaces, HM suggests new theoretical directions, potentially leading to a quantum theory of gravity.

**Keywords:** Cosmic inflation, Hubble tension, Gravitation, Emergent spacetime, Dark energy.

## 1 Introduction

The standard model of cosmology ($\Lambda$CDM) 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$^3$). Because the Planck region is a region of pure probability and Heisenberg uncertainty it is not subject to measurement. It is therefore outside the observable universe and General Relativity can not apply to distances $\leq l_p$.

The Planck region is of intense interest to the theoretical community working to develop a quantum theory of gravity because it is assumed that General Relativity

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

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

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.

In this paper I am introducing a white hole model for 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 must 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 white hole model for 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.

It will be shown below that General Relativity and the quantum world come together on the white hole horizon surrounding a single Planck sized qubit and that this elemental horizon has a radius of $2l_p$.

In the sections below I will demonstrate that the vacuum energy density, $\rho_{vac}$, is inversely proportional to the number of qubits within the horizon. This then is used to calculate the number of qubits required for $\rho_{vac}$ 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 cosmic 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]Di Valentino et al (2021) 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

[2]Expansion of spacetime.
[3]This corresponds to an e-fold volume expansion relative to $l_p^3$ of $\geq 60$.
[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 $5\sigma$.

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 ( $\simeq 22\mu g$). From the definition of the Planck units, $R_s = (2l_p)$. Thus, the surface area of an event horizon around a single 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), 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. According to the white hole hypothesis, $A_{pq}$ is the universal holographic surface area associated with a single qubit of information. The generalized Holographic 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)

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

This is the entropy-area law published by Hawking Hawking (1975) and Bekenstein Bekenstein (1973). The fact that $R = 2l_p$ explains the factor of 4 in the Hawking/Beckenstein equations.

From the Holographic Principle, 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 $\propto I_q^{1/2}$,

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

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

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

$$\begin{aligned} T_{vac} &= T_p M_p / M_{vac} = T_p I q^{-1/2} \\ &= 1.42x10^{32} I_q^{-1/2} K = 1.22x10^{19} GeV. \end{aligned} \tag{6}$$

The measured rate of expansion of the observable universe is characterized by the Hubble "constant", $H_0$. HM assumes that the expansion of the observable (local) universe is driven by the expansion of the non-local vacuum horizon. 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 local spacetime, so $H_0 = H_{vh}$,

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

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

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

## 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

$$\begin{aligned} S &= 3.1^{+3.0}_{-1.7} x10^{104} k \text{ ,or, Shannon entropy} \\ &= 4.47^{+4.3}_{-2.4} x10^{104} bits. \end{aligned}$$

**Table 1** Non-local vacuum at t=0 (the"inflaton") with $\Delta S_{EL}$ 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] | 6.38E+25 | 1.46E+26 | 4.08E+25 |
| N=e-fold of E | 59.42 | 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 |
| $T_{vac}(GeV)$ | 6.11E+10 | 2.47E+10 | 2.00E+10 |
| $\Omega_{vac}$, [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 $4/3\pi l_p^3$.
[2]Normalized to the current value of $\rho_{crit} = 4.84 GeV/m^3$.

In the standard model $\Omega_{vac} \equiv \rho_{vac}/\rho_{crit}$ is a constant [6]. But in HM, from equation(5) $\Omega_{vac}$ is a parameter depending on $I_q^{-1}$. As explained in the Introduction, there are $4x10^{16}$ qubits in the vacuum for every bit of local entropy, S. The state of the vacuum as a function of $\Omega_{vac}$ and the local entropy S can therefore be calculated from 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, $\rho_{crit}$).*

# 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, $\Delta S_{EL}$, as estimated by Egan and Lineweaver Egan and Lineweaver (2010).

Defining N as the e-fold expansion of the volume of the inflaton relative to the Planck volume ($4/3\pi l_p^3$), the analysis of the Planck collaboration of their 2018 measurements of the Cosmic Microwave Background (CMB) puts a constraint on N =54±2.55 Planck Collaboration. Constraints (2020). Table 1 shows that the white hole model predictions have N = $59^{+1.2}_{-1.0}$. So, the white hole model predictions are within $1.8\sigma$ of the Planck collaboration 2018 measurements.

The results for S=$4.47x10^{104}$ bits (t=now) when calculated with the $\Delta S_{EL}$ provided by Egan and Lineweaver 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 $\Delta S_{EL}$ artificially adjusted to reproduce the measurement uncertainty.

From the 2018 Planck Collaboration measurements of $\rho_{crit}$ (Planck Collaboration. Parameteers (2020)) the $\Lambda$CDM experimental value for

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

The basic equations of HM will fit this measurement exactly by artificially adjusting the uncertainties in S, $\Delta S_\Omega$, 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 $\Delta S_\Omega$

[6]The assumption that it is constant is responsible for the cosmological constant problem
[7]The reason that $\Omega_{vac} = \Omega_{tot}$ and not $\Omega_\Lambda$, is that in the HM matter/energy as well as spacetime emerge from the vacuum horizon.

**Table 2** Non-local vacuum at t=now with $\Delta S_{\Omega}$ 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 |
| $A_S(m^2)$ | 2.34E+53 | 2.60E+51 | 2.57E+51 |
| $R_{vh}(m)$ | 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 |
| $\Omega_{vac}$ | 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 $\Delta S_{SH}$ 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 |
| $A_S(m^2)$ | 2.02E+53 | 5.66E+51 | 5.66E+51 |
| $R_{vh}(m)$ | 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 |
| $\Omega_{vac}$ | 1.16 | 0.03 | 0.03 |
| $H_{vh}(km/s/Mpc)$ | 73.00 | 1.00 | 1.00 |

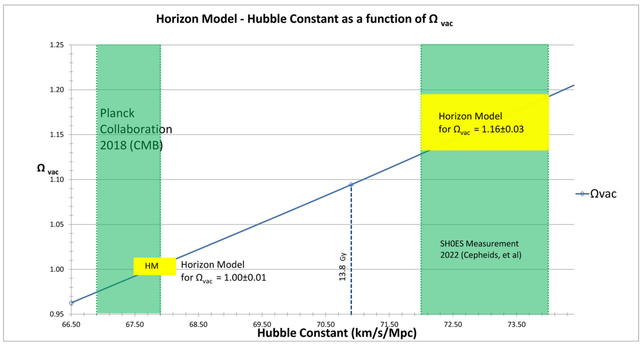


**Fig. 1** *Horizon Model (HM) values of the Hubble constant as a function of $\Omega_{vac}$. With $\Omega_{vac} = \Omega = 1.00 \pm 0.01$, the HM value for H $(67.87 \pm 0.38)$ is within $0.8\sigma$ of the Planck collaboration measurement. The HM values for H are in perfect agreement with the SH0ES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

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).

# 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 (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 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) Planck Collaboration. Constraints (2020). 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 and explains the "exponential" nature of cosmic 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 a mass of $4^{+2}_{-1}x10^{17}$ kg, an energy density of $2.2^{+2.1}_{-1.2}x10^{105}GeV/m^3$, a temperature of T=$6.1^{+2.5}_{-2}x10^{10}$GeV and exerts a repulsive pressure of $P_{vac} = 3^{+3}_{-2}x10^{95}$ Pa. The large uncertainties in these results reflect the large uncertainties, $\Delta S_{EL}$, in the estimates of local entropy by Egan and Lineweaver (2010).

The Planck collaboration measurements of $H_0 = 67.39 \pm 0.54 km/s/Mpc$ Planck Collaboration. Parameteers (2020) were derived from the CMB anisotropies and are, therefore, indicative of the Hubble flow in the early universe. An alternative measurement of $H_0 = 73 \pm 1 km/s/Mpc$ 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 $0.8\sigma$.

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 $\Omega_{vac}$ 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 $1.16 \pm 0.03$.

For this change in $\Omega_{vac}$ 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 $\Omega_{vac}$ to increase by $16 \pm 0.03\%$.

## 4.2 Consistency of HM with the emergent spacetime program

The Horizon Model (HM) aligns with the growing body of research suggesting that spacetime, as we perceive it, is not fundamental but rather an emergent phenomenon arising from a deeper, non-spatiotemporal reality. This concept, known as "emergent spacetime," draws inspiration from various fields, including quantum gravity, string theory, and holography.

A central idea in this program is the Holographic Principle (Susskind (1995), t'Hooft (1993)), which posits that the description of a volume of space can be encoded on a lower-dimensional boundary to that region. This principle found a concrete realization in the AdS/CFT correspondence, conjectured by Juan Maldacena Maldacena (1998). This duality proposes a relationship between a theory of gravity in a (d+1)-dimensional Anti-de Sitter (AdS) space and a conformal field theory (CFT) living on its d-dimensional boundary. The AdS/CFT correspondence has provided a powerful framework for studying quantum gravity and the emergence of spacetime, leading to numerous insights (Gubser et al (1998), Witten (1998), Aharony et al (2000), Maldacena (2004)).

One significant insight stemming from this research is the potential resolution of the black hole information paradox. Stephen Hawking's conclusion that "Elementary quantum gravity interactions do not lose information or quantum coherence" Hawking (2005) supports the HM's assumption of indestructible qubits. Raphael Bousso's work Bousso (2002) further strengthens the holographic perspective by providing evidence that the area of any surface limits the information content of adjacent spacetime regions, a bound that HM appears to satisfy.

Variations of the AdS/CFT correspondence have also been explored. In 2001, Andrew Strominger Strominger (2001) proposed a scenario where 3D+1 spacetime emerges from a spherical shell surrounding a 3D deSitter sphere. Furthermore, Ryu and Takayanagi Ryu and Takayanagi (2006) utilized the Holographic Principle and AdS/CFT correspondence to develop a method for calculating the entanglement (Von Neumann) entropy of $\mathrm{CFT}_{d+1}$ from the entropy of quantum many-body systems in $\mathrm{AdS}_{d+2}$.

Mark Van Raamsdonk's influential 2010 paper Mark Van Raamsdonk (2010) proposed a deep connection between the structure of spacetime and the entanglement of underlying quantum systems, a notion central to HM. Van Raamsdonk concluded, "It is fascinating that the intrinsically quantum phenomenon of entanglement appears to be crucial for the emergence of classical spacetime geometry." This statement strongly resonates with the HM's proposition that spacetime emerges from the horizon of a white hole surrounding a region of non-local, fully entangled qubits.

Further supporting this view, Cao, Carroll, and Michalakis Cao et al (2017) explored how spatial geometry can be recovered from bulk entanglement. Brian Swingle Swingle (2018) reviewed the idea that spacetime and gravity can emerge from entanglement, suggesting that tensor networks can define a discrete geometry encoding entanglement, which, in a continuum limit, obeys General Relativity.

Erik Verlinde's work Verlinde (2011) also foreshadows many features of the HM. Verlinde argued that Newton's law of gravitation naturally arises in a theory where space emerges through a holographic scenario, emphasizing that "..the central notion needed to derive gravity is information."

Carlos Silva Silva (2024) contends that spacetime can only emerge from quantum correlations, raising fundamental questions: "...how could physics exist beyond spacetime, and how could things exist, and become entangled, without some loci where and when they happen and change?" HM directly addresses these questions by positing that *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, emerge from the horizon of that white hole.*

# 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.

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 blob 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 blob 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 $6.1^{+2.5}_{-2}x10^{10}$ GeV and a volume with an e-fold expansion relative to $4/3\pi l_p^3$ of $N = 59.4^{+1.2}_{-1.0}$. This is within $1.8\sigma$ of the Planck collaboration 2018 measurements of the constraints on N $=54 \pm 2.55$ Planck Collaboration. Constraints (2020). The large uncertainties in the white hole model results reflect the uncertainties in the estimates of the local S by Egan and Lineweaver, $\Delta_{EL}$ Egan and Lineweaver (2010).

The $\Delta_{EL}$ provided by Egan and Lineweaver are too large to permit meaningful comparison with measurements. So the uncertainties in $\Delta_{EL}$ 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 $\Delta_{\Omega}$, 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 $\Delta_{\Omega}$ is $67.9 \pm 0.4$ which is within $0.8\sigma$ of the $H_0$ value measured by the Planck collaboration Planck Collaboration. Parameteers (2020).

The HM predictions for the vacuum pressure with $\Delta_{\Omega}$ is $7.77 \pm 0.09x10^{-10}$ Pa while with $\Delta_{SH}$ 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 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 blob of $4x10^{16}$ entangled 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 [8] resulting from the interaction among $4x10^{16}$ entangled qubits?

This paper presents the observational credentials for a model that proposes a quantized event horizon as the source of spacetime/gavity. It is clear that theoretical research into the questions posed by this model hold promise of leading to a quantum theory of gravity Yang (2016).

# 6 Acknowledgments.

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

# 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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[8] 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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