On the Quantum Origins of the Universe

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I devise a novel minimalistic-bootstrap program and attempt to derive the Hamiltonian acting on the wavefunction of the Universe. A new cosmological *denkökonomie* is presented and a new path to general relativity from elementary quantum mechanics is charted.

The quantum-first program—the idea that spacetime emerges from the wavefunction of the Universe—has recently been proposed by Carroll [cite]. This Everettian view is austere: if the Universe as a whole is quantum mechanical, then it must *always* obey the Schrödinger equation. Instead of quantizing gravity it makes more sense to find gravity within quantum mechanics (QM). In this Letter, I propose a novel bootstrap technique in an attempt to calculate the universal Hamiltonian and derive general relativity (GR) through self-consistency constraints. Inspired by Chew's "nuclear democracy," I advocate a universal democracy unifying the concepts of Lemaître's primordial atom hypothesis with the "one-particle universe" picture of Wheeler and Feynman. Undergirding this work is the Turokian vision of physics: the Universe as a whole is simple and simple phenomenon demand simple explanations. I turn to decades of tantalizing clues in the literature. A compendium of clues is assembled. Deep regularities and unexpected simplicity in the structure of known physical law is pointed out. Three general principles are put forth for the bootstrap. A Schrödinger equation with Wheeler-DeWitt form is derived and solved exactly.

I. THE EINSTEIN-SCHRÖDINGER EQUATION

Throughout this story I refer to a curious collection of clues. These are the puzzle pieces used in the formulation of general principles for the bootstrap. As the scheme unfolds, several technical hurdles appear and the process is repeated.

- **Scale Symmetry** The primordial fluctuations in the cosmic microwave background are (nearly) scale-invariant and admit a power-law form.
- The classical action of the standard model is consistent with scale symmetry if the Higgs mass term is dropped. This suggests the mass term could emerge from the vacuum expectation value of a new scalar field in a fully scale invariant theory [Turok].
- Power-like phenomena are ubiquitous in thermal systems near a phase transition. Many such systems all share the same scale invariant limit under the renormalization group (RG) flow [cite].
- In the AdS/CFT correspondence, a holographic gauge gravity duality, bulk fields in AdS_5 have equations of motion with power-like solutions [Maldacena].
- In biadjoint scalar field theory, (a gauge gravity duality known as the double copy) the equations of motion have power-like solutions [White].

The study of scale symmetry in physics has very old roots. It is the symmetry that forms the basis of the AdS/CFT and is a critical tool (the RG) in curing the standard model of its infinities. Power-laws are unreasonably ubiquitous in the character of physical law. They form what I call the *inescapable pattern.* Maybe their origin is fundamental? Symmetry of the *form* of the laws of physics under some physically well-motivated transformation is arguably the most successful apparatus of physical reasoning ever invented. As such, the first principle is:

> ***Turok's principle of scale-invariance*** The form of the laws of physics remain unchanged at all scales.

This is to say the outcome of experiments do not change as the size of the universe changes. It also is a statement that the laws hold at the singularity. *Nature has no fundamental scale.* As a consistency constraint, both with the first principle and the ADM formulation of GR [cite], the second principle is:

> ***Guth's zero-energy principle*** The total energy of the Universe is exactly zero for all scales.

As a matter of principle the infinite energies at the singularity cancel. The bootstrap immediately reads,

$$\hat{H}\Psi = 0. \tag{1}$$

It follows from Turok's principle that Ψ is scale invariant and takes the form of a power-law: $\Psi(r) = Ar^{\alpha}$, where r is the universal radius (or scale factor) with A and α yet-to-be worked out parameters. One may now immediately write down the following *timeless equation*:

$$\left(\frac{-\hbar^2}{2M}\frac{d^2}{dr^2} + \frac{\hbar^2}{2M}\frac{\alpha(\alpha-1)}{r^2}\right)\Psi = 0. \tag{2}$$

Let us scrutinize. Equation 2 is inconsistent with QM. As stated Ψ is real, it has no complex phase. There is neither a Born rule nor a global $U(1)$ phase symmetry. The equation is valid for both signs of α, but the integral of Ψ diverges for $\alpha > 0$ as $r \to \infty$ and for $\alpha < 0$ as $r \to 0$. This equation is strangely paradoxical. The mass M is the mass of the universe in the Lemaîtrian picture. The scalar field $V(r)$ is generally *repulsive*—it is a centrifugal potential (and amusingly Machian). More strange is the fact that there exists a map between the *reduced radial equation* and equation 2. Send $u(r) \to \Psi$, $m \to M$, $l \to -\alpha$, $E \to 0$, and $V_0(r) \to 0$. m is the mass of a free particle in a ball with radius $R \to \infty$, $V_0(r)$ is the potential energy, E is the total energy of the system, and l is the centrifugal term. The remaining term is the so-called fictitious effective potential, $V(r) = \alpha(\alpha-1)r^{-2}$. In this setup, it is anything but fictitious. The kinetic energy term always carries the opposite sign of $V(r)$. The Universe becomes a point-like particle. It is the source charge for $V(r)$, which diverges as $r \to 0$. That is, $V(r)$ regulates M at the singularity by canceling the kinetic term, and with it, dynamics. This comes at a great cost. As written, there is no unitary evolution of the wavefunction—the relevant degrees of freedom are "hidden,"—information is lost at the singularity.

Into the impossible we go [Keating].

II. THE ALGEBRA OF PHYSICAL INFORMATION

Let us now quest to expand our inventory of clues.

- **Hawking Radiation** Through a Bogoliubov transformation (into the Dirac sea), Hawking demonstrated that a negative energy virtual particle (the antiparticle of a virtual pair) can tunnel through the event horizon where the Killing vector (which encodes time translations) is spacelike. In the blackhole interior the particle can exist on-shell with a timelike momentum vector, even though its energy relative to infinity, as measured by the time translation Killing vector, is negative. The positive energy particle of the pair escapes to infinity as thermal radiation described by the Hawking-Unruh temperature. This means the final state of the black hole is independent of its initial state—unitarity is (seemingly) violated [Hawking].
- **Entropic Gravity** Jacobson has derived GR from the Clausius relation: $\delta Q = T\delta S$, where T is the Hawking-Unruh temperature (which relates the temperature of curved spacetime to acceleration) and S is the Bekenstein-Hawking entropy (which counts the degrees of freedom of curved spacetime) [Jacobson]. Further works by Padmanabhan suggest deep Machian connections between gravity and thermodynamics [cite]. Further still, is Verlinde's thermodynamic derivation of Newtonian gravity by identifying the number of degrees of freedom N with the area of an accelerating 2-sphere [Verlinde, ?].
- **The UV-IR Connection** A fundamental measurement limit appears to be a model-independent feature of quantum gravity [Hossenfelder]. Numerous thought experiments including Heisenberg's scope and several variants [cite, cite], recover a generalized uncertainty principle (GUP) of the form:

$$\Delta x \gtrsim \frac{1}{\Delta p} + G\Delta p. \tag{3}$$

As pointed out by Adler and Santiago, the GUP is invariant under the replacement

$$l_{pl}\Delta p \leftrightarrow \frac{1}{l_{pl}\Delta p}, \tag{4}$$

which relates short distances and high energies to large distances and low energies (l_{pl} is the Planck length). Additional clues of UV/IR mixing occur in stringy theories [cite] and quantum cosmology [Turok]. There are two fundamental scales in quantum gravity: the Planck length and the length scale defined by the dark energy. Both coincide with a horizon—beyond of which nothing is observable. Perhaps they are related?
- **The Spinorial Connection** More abstractly is what I deem the most incredible mathematical fact: $SU(2)$, the quantum symmetry group of the simplest logical object—a binary alternative (or qubit)—is locally isomorphic to the three-dimensional rotation group $SO(3)$ [cite]. Weizsäcker, student of Heisenberg, believed so strongly this was the reason the world has three spatial dimensions that he devoted the rest of his career to *emerging* spacetime from a primitive spinorial wavefunction [cite]. Indeed the information-theoretic reductionist view espoused by entropic and holographic gravity programs begins with him.

Centrifugal forces arise as either (i) artifacts from curvilinear coordinates or (ii) from acceleration through an angle. We have no notion of a coordinate system. $V(r)$ is no artifact. From astronomical observations the Universe is not rotating. The only remaining possibility: acceleration through *internal* rotational degrees of freedom. There are two steps required to make the model consistent with QM: (i) we need a complex phase for the Born rule, and (ii) the Hilbert space of states, $\mathcal{H}$, must be an inner-product space of square-integrable functions. Turok's principle constrains the integration region to all space. The Universe can have any arbitrary size. It follows $\mathcal{H}$ is infinite-dimensional. Conceptually it makes sense to adopt a particle-universe duality. Equation 2 has two physically equivalent interpretations: it describes (i) the probability of finding a particle of mass M a distance r from the origin, and (ii) the probability of an observer occupying a universe of mass M with scale-factor r.

The idea here is Chewian: by introducing Guth's principle, we aim to emerge gravity for internal consistency. This leads to the conjecture that the unique self-consistent completion of equation 2 is a non-perturbative theory of quantum gravity.

Let us now inspect the symmetries of equation 2. It is invariant under the reflections $\alpha \to -\alpha$ and $r \to -r$. If we restrict $\alpha \in \mathbb{R}$, we obtain a complex phase: $\Psi(-r) = e^{i\pi\alpha}\Psi(r)$. This mirror symmetry, together with the observation of missing rotational degrees of freedom are beautiful clues: they are guiding us to the topology of the inner-product space. Indeed, we have yet to mathematically define what the radius r is *of*. Let us reach into our bag of clues for the path forward.

The third principle is:

> ***Weizsäcker's principle of measurement*** The information obtained from any physical measurement lives on the Lie group manifold $U(2) \cong SU(2) \times U(1) \cong \mathbb{S}^3 \times \mathbb{S}^1$.

$SU(2) \times U(1)$ is the symmetry group of qubits with unitary norm and has the topological representation of the Cartesian product of the 3-and-1-sphere. This was Weizsäcker's starting point in his Wheelerian 'it-from-bit' formulation of quantum mechanics. Let us construct $SU(2)$ with the Clifford algebra $\mathcal{C}\ell(\mathbb{R}^3)$. The algebra generated by $\mathcal{C}\ell(\mathbb{R}^3)$ is isomorphic to the Pauli matrices σ_k and span the space of observables of the two-dimensional complex Hilbert space representing spin along the ith coordinate axis in $\mathbb{R}^3$. A point in 3-space can therefore be represented by the Pauli vector matrix,

$$\vec{\sigma} \cdot \vec{r} = \begin{pmatrix} x_3 & x_1 - ix_2 \\ x_1 + ix_2 & -x_3 \end{pmatrix}. \tag{5}$$

The eigenvalues are $\pm|\vec{r}|$ where $|\vec{r}|$ is the Euclidean length. Substitute $\vec{\sigma} \cdot \vec{r}$ in the generic power-law $\psi(a) = a^\alpha$ and take the trace: $\operatorname{Tr}\psi(\vec{\sigma} \cdot \vec{r}) = (1 + e^{i\pi\alpha})|\vec{r}|^\alpha$. Relabeling the radial component r as the Euclidean length yields a solution to equation 2. Letting $\theta = \alpha\pi$ the wavefunction now reads:

$$\psi(r, \theta) = (1 + e^{i\theta})r^{\theta/\pi}. \tag{6}$$

The Born rule along with the global $U(1)$ phase symmetry is restored. We know $SU(2)$ is a double-cover for $SO(3)$. Briefly, this means that for any arbitrary $U \in SU(2)$ there is a 2-to-1 map, $f : U \to R$ with $R \in SO(3)$, where $f(U) = f(-U)$ and $U(4\pi) = R(2\pi)$. That is, two full-rotations in $SU(2)$ correspond to a single rotation in $SO(3)$. These two groups differ only at their boundaries and are therefore locally isomorphic, i.e., they have isomorphic Lie algebras, $\mathfrak{su}(2) \simeq \mathfrak{so}(3)$. This fact is critical in what is to come. There are two unique solutions to equation 2, $\psi_0 \equiv \psi(r, \theta)$ and $\psi_1 \equiv \psi(r, -\theta)$. After some thought, the only self-consistent Hilbert space of states is the *binary inner-product space*:

$$\langle\psi_0|\psi_0\rangle = \int_0^{\lambda_1}\int_0^{2\pi} \psi_0\psi_0^* d\theta dr \tag{7}$$

$$= 4\pi \int_0^{\lambda_1} \left(\frac{r^4 - 1}{\ln r}\right)\left(\frac{\pi^2 + 8\ln^2 r}{\pi^2 + 4\ln^2 r}\right) dr \tag{8}$$

and

$$\langle\psi_1|\psi_1\rangle = \int_{\lambda_0}^{\infty}\int_0^{2\pi} \psi_1\psi_1^* d\theta dr \tag{9}$$

$$= 4\pi \int_{\lambda_0}^{\infty} \left(\frac{r^4 - 1}{r^4 \ln r}\right)\left(\frac{\pi^2 + 8\ln^2 r}{\pi^2 + 4\ln^2 r}\right) dr \tag{10}$$

where λ_0 is a UV-cutoff and λ_1 is an IR-cutoff. The above integrals converge. Unitary evolution of the wavefunction (through the internal rotational degree of freedom θ) is restored. We need only calculate the UV-IR cutoffs to compute probability amplitudes.

The internal angular degree of freedom θ is not of the 2-sphere while the radial degree of freedom r *is* of the 2-sphere. The complex phase $e^{i\theta} \in U(1)$ is a compactified unit circle at each point on the 2-sphere. Topologically this is the principle fiber bundle, $\mathbb{S}^2 \times \mathbb{S}^1$. The pair of square-integrable spaces read $L^2(\mathbb{S}^2_0 \times \mathbb{S}^1) = \operatorname{span}\{\psi(r, \theta),\ \theta \in (0, 2\pi),\ 0 \le r \le \lambda_1\}$ and $L^2(\mathbb{S}^2_\infty \times \mathbb{S}^1) = \operatorname{span}\{\psi(r, -\theta),\ \theta \in (0, 2\pi),\ \lambda_0 \le r \le \infty\}$. $\mathbb{S}^2_0$ is a 2-sphere that extends from 0 to λ_1 and $\mathbb{S}^2_\infty$ is a 2-sphere that extends from λ_0 to infinity. We have made use of very basic but non-trivial mathematical facts of the rotational symmetry of 3-space, and its double cover—the symmetry group of qubits—to integrate over all space as dictated by Turok's principle.

Several puzzles remain. We now have two Schrödinger equations, one for each sign of θ. This means we have to introduce two new mass terms: m_0 and m_1. We also had to introduce two fundamental length scales: λ_0 and λ_1 ($\lambda_0 \lll \lambda_1$) to ensure absolute convergence. These scales define the boundary of the *observable* universe, beyond of which no measurement can be made. The Lie group manifold $U(2)$ has a pair of horizons, λ_1 corresponding to the boundary of $\mathbb{S}^2_0$ and λ_0 to the boundary of $\mathbb{S}^2_\infty$. Another puzzle is the nature of the state vectors. What states do they map to? Let us inspect m_0 and m_1 as the source charges of the centrifugal scalar potentials,

$$V_0(r, \theta) = \frac{\hbar^2}{2m_0 r^2}\left[\frac{\theta}{\pi}\left(\frac{\theta}{\pi} - 1\right)\right] \tag{11}$$

and

$$V_1(r, \theta) = \frac{\hbar^2}{2m_1 r^2}\left[\frac{\theta}{\pi}\left(\frac{\theta}{\pi} + 1\right)\right], \tag{12}$$

with respect to their so-called probability densities $\rho_0(r) \equiv \int_0^{2\pi} \psi_0\psi_0^* d\theta$ and $\rho_1(r) \equiv \int_0^{2\pi} \psi_1\psi_1^* d\theta$. Another puzzle still is the nature of the internal degree of freedom θ. What does it mean physically to integrate over a full rotation? We come back to this in a moment.

The behavior of m_1 is highly counter-intuitive: its probability density $\rho_1(r)$ scales like $1/r^4$, asymptotically approaching a maximum at λ_0, despite the fact that $V_1(r, \theta)$ is repulsive for $\theta > 0$ and pushes the particle *away* from the origin. This bizarre particle has a negative kinetic energy and roles up its scalar potential—m_1 has a *negative* pressure. It is clear ψ_1 encodes the state of an expanding universe. $\rho_1(r)$ describes the probability of expansion as a function of size. The smaller the radius, the greater the probability the universe is in the expanding state. ψ_0 therefore encodes the contracting state. It is thus natural to identify the $U(1)$ fiber as time curled up into a 1-sphere—the fundamental representation of a cyclic cosmology. We have found ourselves in good trouble: $V_0(r,\theta)$ has an attractive phase from $(0,\pi]$, a repulsive phase from $[\pi, 2\pi)$, and is zero when $\theta = 0$ and $\theta = \pi$. The scalar field V_0 can not drive the contraction. For the model to retain internal consistency, gravitational attraction, and more generally Einstein's field equations, must emerge to provide a gravitational collapse. Integration over a rotation of 2π corresponds to both a full contraction and a full expansion. A complete cycle thus corresponds to a rotation of 4π. One may now collect both Schrödinger equations in a single spinorial equation:

$$\left(-\frac{1}{2}(\hat{p}\cdot\vec{\sigma})^2 + V(r,\mathbf{\Phi})\right)\Psi = 0 \tag{13}$$

where for simplicity we have set $\hbar = m_0 = m_1 = 1$. The scalar field $V(r,\mathbf{\Phi}) = \frac{1}{\pi r^2}\mathbf{\Phi}$ with $\mathbf{\Phi} = (\theta/2)\text{diag}(\theta/\pi + 1, \theta/\pi - 1)$ and $\vec{\sigma}$ is the Pauli vector. The solution to the above equation (up to a diagonal normalization matrix) is the *biconformal spinor*:

$$\Psi = \begin{pmatrix} (1+e^{i\theta})r^{\theta/\pi} \\ (1+e^{-i\theta})r^{-\theta/\pi} \end{pmatrix}. \tag{14}$$

Alas, the wavefunction of the universe is CPT symmetric, in resounding agreement with Turok's proposal [cite]. One interprets the biconformal spinor as a universe-antiuniverse pair with a *cosmic charge.* Notice if we move the $1/2$ out of $\mathbf{\Phi}$ and multiply equation 13. on both sides by $A/2$, where A is the surface area of a 2-sphere, we get $\hat{H} = -\frac{A}{4}(\hat{p}\cdot\vec{\sigma})^2 + \mathbf{\Phi}$. The Hamiltonian can thus be interpreted as describing the energy of a coupled pair of self-accelerating 2-spheres with intrinsic spin. One is therefore forced to abandon the point-like assumptions of m_0 and m_1—they are *extended spin-1/2 objects.* One final task remains: the derivations of m_0, m_1, λ_0, and λ_1.

Recall Weizsäcker's principle states all physical information lives on the Lie group manifold $\mathbb{S}^3\times\mathbb{S}^1$, yet the state vectors are functions on the principle fiber bundle $\mathbb{S}^2\times\mathbb{S}^1$, which is locally isomorphic to the total space $\mathbb{S}^3$. Now rewrite the squared-modulus as the state-space densities with $s = \pm 1/2$ and $dt = s^{-2}\cos^2(\frac{\theta}{2})d\theta \implies \rho_0(r) = \int_{U(1)} dt \exp\left(\frac{\theta}{\pi}\ln r^2\right)$ and $\rho_1(r) = \int_{U(1)} dt \exp\left(-\frac{\theta}{\pi}\ln r^2\right)$. Express the pair as surface densities on the base space $\mathbb{S}^2$ by the scale transformation $r\to\frac{\sqrt{4\pi}}{\lambda}r$, with λ adopting the subscript of the densities: $\rho_0(A) = \int_{U(1)} dt \exp\left(\frac{\theta}{\pi}\ln\frac{A}{\lambda_0^2}\right)$ and $\rho_1(A) = \int_{U(1)} dt \exp\left(-\frac{\theta}{\pi}\ln\frac{A}{\lambda_1^2}\right)$. Each density encodes the Hopf fibration: mapping every point on $\mathbb{S}^2_0$ and $\mathbb{S}^2_\infty$ to a phase circle of $\mathbb{S}^3$ by the embedding $\mathbb{S}^1\hookrightarrow\mathbb{S}^3$. The entropy of the expanding and contracting states are therefore *defined* (for consistency) as

$$S_1 = \ln\left(\frac{A}{\lambda_0^2}\right) \text{ and } S_0 = -\ln\left(\frac{A}{\lambda_1^2}\right), \tag{15}$$

respectively. The densities are expressible as $\rho_0 = \int_{U(1)} e^{\alpha S_1}dt$ and $\rho_1 = \int_{U(1)} e^{\alpha S_0}dt$. The entropy of the expanding state is measured *relative* to the horizon of the contracting state, and vice versa. $dS \geq 0$ is thus respected for both states and diverge, as required by the infinite-dimensionality of $\mathcal{H}_0$ and $\mathcal{H}_1$. The total entropy of the system is $S = k_B(S_0+S_1) = k_B\ln\left(\lambda_1^2/\lambda_0^2\right)$. Thus $dS = 0$ for all cycles. The total number of observable microstates are $\Omega \equiv \lambda_1^2/\lambda_0^2$. As we shall soon see, this implies every dimensionful quantity corresponding to the horizon at λ_0 (in the UV) has a dual to the horizon at λ_1 (in the IR). Let us now reach back into our satchel of clues.

It is easy to check $m\ddot{r} + \nabla V(r) = 0$ has hyperbolic solutions, where the overdots are derivatives of the cosmic radius with respect to the internal observers' proper time, t. It is therefore reasonable to assume the horizons accelerate uniformaly in all directions. One can write down the temperature of a uniformly accelerating 2-sphere with the Hawking-Unruh temperature:

$$T = \frac{\hbar\ddot{r}}{2\pi c k_B}. \tag{16}$$

In the bulk, where the metric is globally Euclidean ($dr^2 = dx^2+dy^2+dz^2$), the comoving observer is surrounded in all directions by thermal radiation emitted from the surface of the accelerating 2-sphere. From the equivalence principle m_0 and m_1 have identical inertial and gravitational masses; $g = \ddot{r}$ is the surface gravity. It follows the masses are stretched across the horizon per unit area. We now have enough data to calculate m_0 by dimensional analysis. Of course, we already know what the answer needs to be for consistency: the Planck mass, the smallest possible blackhole. We perform the calculation in three (novel) steps: (i) decorate the 2-sphere with $2\pi k_B$ entropy per unit (Planck) area: $2\pi k_B/l_{pl}^2$, (ii) multiply by the temperature per unit length of the accelerating 2-sphere: T/l_{pl}, and (iii) identify this relation with the ideal gas law, $PV = k_B T$. Now write down the pressure:

$$P_0 = \tilde{\rho}_0\ddot{r} = \frac{c^2 g}{G l_{pl}}. \tag{17}$$

$\tilde{\rho}_0$ has units of $[Mass][Length]^{-2}$. The above is nothing but Newton's 2nd law: $F = m_{pl}g$. The horizon $\lambda_0 = l_{pl}$ is thus the Compton wavelength of $m_0 = m_{pl}$. The unit surface density $\tilde{\rho}_0$ is constant as the 2-sphere accelerates. This extended object is an infinitely thin 2-brane with spherical symmetry that becomes more massive as it expands, less massive as it contracts, and glows like a black body as it accelerates. The wavefunction of the Universe Ψ has the T-duality: $r \leftrightarrow r^{-1}$. It is therefore impossible to escape the conclusion that stringyness,—and more generally holography—is required for the self-consistency of quantum gravity. Matching the surface densities $\rho_0 \leftrightarrow \tilde{\rho}_0$, it becomes clear why Verlinde's holographic Newtonian gravity works.

The purely repulsive component of the Hamiltonian carries the negative cosmic charge (the source term of V_1) which inflates $\tilde{\rho}_0$ to a radius less than (or equal to) λ_1 and then pops it—converting its surface tension to standard model particles—and possibly D2-branes. One therefore matches $\rho_1 \leftrightarrow -\tilde{\rho}_1$. The derivation of m_1 is dual to m_0 by swapping the Planck length with the inner cosmic horizon R (generated by the Compton wavelengths of the source charges). The steps are: (i) decorate the dual accelerating 2-sphere with $2\pi k_B$ entropy per unit R area: $2\pi k_B/R^2$, (ii) multiply by the temperature per unit Planck length: T/l_{pl}, and (iii) identify this relation as $PV = k_B T$ with $V = l_{pl} R^2$. Now introduce the cosmological term $\Lambda = 1/R^2$ and write down the pressure:

$$P_1 = -\tilde{\rho}_1 \ddot{r} = -\frac{\Lambda \hbar g}{c\lambda_0}. \tag{18}$$

The above is nothing but Newton's second law: $-F = m_1 g$ where $m_1 = \Lambda\hbar\lambda_0/c$. The Compton wavelength is $\lambda_1 = 1/\lambda_0\Lambda$. The cosmological constant can thus be written as $\Lambda = m_1 c/\hbar\lambda_0 = 1/\lambda_0\lambda_1$. By *definition* m_1 is the least massive possible particle—it is the mass-gap in the Yang-Mills sense and the vacuum energy density per unit Planck volume—which is constant as the 2-brane expands. If one evaluates the above at the Planck acceleration, $P_1|_{g=c^2/\lambda_0} = p_{10} = -\frac{\Lambda c^4}{G} = -\rho_\Lambda$, one obtains the dark energy equation-of-state (up to a factor of 8π, which we move over to the geometric side of Einstien's field equations. Here we use a reduced vacuum energy density (rho-lambar) $\rho_\Lambda = \rho_\Lambda/8\pi$.) The above equation reproduces the dark energy equation-of-state parameter $w = -1$. If one evaluates $P_0|_{g=c^2/\lambda_1} = p_{01} = +\rho_\Lambda$, one obtains Newton's third law: $p_{01} = -p_{10}$ and the opposite charge, $w = +1$. Acceleration becomes quantized. In the Noetherian sense, the time-translation symmetry of $\hat{H}\Psi = 0$ corresponds to a global conservation of energy and the time-reversal symmetry corresponds to a global conservation of entropy. (*If observations of the cosmic current w converge to anything other than exactly ± 1, our model is falsified.*) What is more, m_1 is the source charge of V_1—a spin-0 scalar boson that must be the inflaton. V_0 corresponds to yet another spin-0 boson.

One may now write the Bekenstein-Hawking entropy as

$$S_{BH} = s^2 e^{S_1} \simeq dim\ \mathcal{H}_{BH} \tag{19}$$

where $s = \pm 1/2$ and S_1 is the entropy of the expanding state. The blackhole Hilbert space is a locally factorizable finite-dimensional space, embedded in a larger infinite-dimensional Hilbert space $\mathcal{H}_1$. The whitehole is embedded in the contracting state space $\mathcal{H}_0$ and has entropy $s^2 e^{S_0}$. The biconformal spinor Ψ is dual to the black-and-whitehole interiors, which is to say the interior of a blackhole is the contracting state and the interior of a whitehole is the expanding state. Weizsäcker's principle is the continuum limit of a qubit at each point in 3-space—*as an observable consequence, empty space gains the form of information and information gains the form of substance.* To answer Caroll's question of what is in the entropy in entropic gravity *of*: it is the entropy of empty space, which is a material substance governed by the Schrödinger equation of the Universe: $\hat{H}\Psi = 0$. This is all the justification one needs to import Jacobson's argument and derive GR—leaving the model internally consistent.

A plethora of puzzles remain. In a proceeding companion paper, I investigate the *geometry of physical information.* To conclude: I hope to have made this story clear, deep, and beautiful. Happy questing to the curious reader. Now go forth and calculate.