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A Model of the Quantum Origin of the Universe from a Quantized-Velocity Space: A Combination of the Primordial Particle Hypothesis and Quantum Gravity

Slobodan Spremo

Mathematical Grammar School, Belgrade, Serbia
Email: slobodan.spremo@gmail.com

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Abstract

We present a theoretical model that combines our hypothesis of primordial particles in a space of quantized velocities with modern approaches to quantum gravity, in particular, Loop Quantum Cosmology (LQC). In this model, the Big Bang is interpreted as the result of quantum tunneling of a primordial particle from "outer" quantized-velocity space and time into a domain of space and time bounded by the speed of light. It has been shown that such a process can leave experimentally verifiable traces in the cosmic microwave background (CMB), the spectrum of gravitational waves and high-energy astrophysical signals.

Keywords

Big Bang, Big Bounce, Cosmic Microwave Background, Flat Spacetime, Loop Quantum Cosmology, Planck Mass, Quantum Gravity, Quantum of Speed, Tunneling

1. Introduction

Our hypothesis about primordial particles [1]-[5] introduces the concept of quantized-velocity space, in which there exist fundamental particles, to which, in their ground state, we can assign masses equal to the Planck mass, and which exist before the creation of our space and time (For the sake of a more concise expression, in further work, we will simply call the mass attributed to these primary particles "masses of primary particles"). The transition of one of them into the domain of velocities smaller than or equal to the speed of light is interpreted as quantum tunneling that causes the creation of our space and time through the Big Bang.

On the other hand, quantum gravity (especially Loop Quantum Gravity and Loop Quantum Cosmology) [6] [7] offers a framework for quantizing space and time and removing the Big Bang singularity, replacing it with a quantum bounce (the Big Bounce).

In this paper, we connect these two approaches into one coherent theoretical framework and consider the experimental consequences of such a model.

2. Theoretical Basis

2.1. Quantized-Velocity Space

We assume that in the pre-space, there exist velocities:

$$v_n = n\varepsilon_v, \quad n \in \mathbb{N}, \tag{1}$$

where ε_v is the quantum velocity, and the primordial particle of mass $m_p = m_{\text{Planck}}$ has energy:

$$E_n = \frac{1}{2} m_p \left(n\varepsilon_v\right)^2. \tag{2}$$

2.2. Tunneling through the Velocity Barrier

The barrier between the quantized-velocity space and our universe is defined as:

$$V(v) = \frac{1}{2} m_p c^2.$$

The probability of tunneling is:

$$\mathcal{A}(v) \sim \exp\left[-\frac{1}{\hbar}\int_{v_f}^{v_i} \sqrt{2m_p\left(V(v)-E(v)\right)}\mathrm{d}v\right], \tag{3}$$

and the total probability is:

$$P = |\mathcal{A}|^2.$$

2.3. Entry into Quantum Space and Time

After successful tunneling, the energy of the particle is interpreted as the energy density: The quantum Friedman equation (from LQC dynamics) is:

$$H^2 = \frac{8\pi G}{3}\rho\left(1-\frac{\rho}{\rho_c}\right). \tag{4}$$

3. The Passage of a Primordial Particle through the Velocity Barrier and the Natural Coexistence of the Hypothesis of Primordial Particles with Quantum Gravity

We define the Lagrangian for a particle moving in its own space and time with an effective quantum of velocity, assuming: 1D motion of a particle of mass m_p with a parameterized time parameter τ:

$$\mathcal{L} = \frac{1}{2} m_p \left(\frac{\mathrm{d}x}{\mathrm{d}\tau} \right)^2 - V(x). \tag{5}$$

To describe tunneling, we introduce the potential barrier that protects our universe from particles from an external space as:

$$V(x) = \begin{cases} 0, & x < 0 \ (\text{external space}) \\ V_0, & 0 < x < a \ (\text{potential barrier}) \\ 0, & x > a \ (\text{our universe}). \end{cases} \tag{6}$$

This barrier can represent "boundary conditions" between dimensionally different spaces.

In a way analogous to classical mechanics, tunneling can be described by solving the Schrödinger equation through the barrier:

$$\psi(x) \sim \mathrm{e}^{-\kappa x}, \ \kappa = \sqrt{\frac{2m_p(V_0 - E)}{\hbar^2}}, \tag{7}$$

and the probability of tunneling (the transmission coefficient) is:

$$T \approx \mathrm{e}^{-2\kappa a},$$

where the above-mentioned values are:

E : Energy of the particle in its own space and time.

V_0 : The barrier between dimensions (e.g., the gravity wall or velocity threshold).

a : The width of the barrier in the corresponding coordinates (e.g., in the velocity space, if it is modelled).

3.1. Application of Primary Particle Tunneling to the Origin of Our Universe

If one primary particle manages to tunnel into our space, then its energy $E_p \sim m_P c^2$ is released, and this leads to the initial state of our universe, the Big Bang.

Given the quantum velocity ε_v, this tunneling is a very rare but possible quantum fluctuation.

3.2. Feynman Path Integral Formulated for the Space of Quantized Velocities

By formulating the path of integral formalism (the Feynman path integral) through the space of quantized velocities, we will logically continue our hypothesis. This will allow us to describe the probability of a primordial particle passing through a velocity barrier, analogous to quantum tunneling, but in the space of discrete velocities, not classical coordinates.

3.3. Basic Feynman Path Integral

In standard quantum mechanics, the amplitude of the transition of a particle from point x_i to x_f in time t is given by:

$$\langle x_f, t_f | x_i, t_i \rangle = \int \mathcal{D}[x(t)] e^{\frac{i}{\hbar} S[x(t)]},$$

where $S[x(t)]$ is a classical action:

$$S = \int_{t_i}^{t_f} \mathcal{L}(x, \dot{x}) dt.$$

3.4. Path Integral in Discrete-Velocity Space

In our model, the basic dynamic variable is not the position x but the velocity v, which is quantized as (1). We will introduce a new path, so that instead of a path through space $x(t)$, we observe a discrete sequence of velocities through "time" τ:

$$\{v_0, v_1, \cdots, v_N\}, \ v_i = n_i \cdot \varepsilon_v. \tag{8}$$

Discrete time steps: We will assume that the total "time" (perhaps imaginary, due to tunneling) is divided into N steps. Thus, the path integral now becomes the sum over all possible discrete velocity sequences:

$$\mathcal{A}(v_i \to v_f) = \sum_{\{v(\tau)\}} \exp\left(\frac{i}{\hbar} \sum_{j=1}^{N} \Delta\tau \mathcal{L}(v_j)\right). \tag{9}$$

Here the Lagrangian is in discrete form:

$$\mathcal{L}(v_j) = \frac{1}{2} m_p v_j^2 - V(v_j), \tag{10}$$

where $V(v_j)$ is a potential "velocity barrier" e.g.:

$$V(v) = \begin{cases} 0, & v > v_c \\ V_0, & v \le v_c \end{cases} \tag{11}$$

where v_c is some critical velocity (e.g. c) below which the particle "enters" our universe.

Quantum Tunneling through the Velocity Barrier

Thus, tunneling occurs if a particle manages to transition from state $v_n > c$ to $v_k \le c$, thereby passing through the forbidden region $V_0 > E$.

Approximation in the continuous limit:

For very fine discretization and $v \to \text{continuous}$, we get:

$$\mathcal{A} = \int \mathcal{D}[v(\tau)] \exp\left(\frac{i}{\hbar} \int_{\tau_i}^{\tau_f} \left(\frac{1}{2} m_p v^2 - V(v)\right) d\tau\right). \tag{12}$$

In "tunneling" (evanescent) conditions, with Wick rotation ($\tau \to i\tau$), we get the imaginary time integral:

$$\mathcal{A}_E \sim \exp\left(-\frac{1}{\hbar} \int \left(V(v) - \frac{1}{2} m_p v^2\right) d\tau\right), \tag{13}$$

and this is an analogue of quantum tunneling through velocity space (3).

4. Numerical Estimate of the Amplitude of Primary Particle Tunneling into Our Universe

We will use the space of quantized velocities (1) and (8) according to our model, and a simple quasi-classical (WKB) approximation, setting some realistic parameter values.

The quantum amplitude for tunneling (in the WKB approximation) through the velocity barrier is:

$$\mathcal{A} \sim \mathrm{e}^{-2\int_{v_f}^{v_i} \kappa(v)\mathrm{d}v}, \tag{14}$$

where is:

$$\kappa(v) = \frac{1}{\hbar}\sqrt{2m_p\left[V(v) - E(v)\right]}. \tag{15}$$

We shall assume that: - The velocity ranges from $v_i > c$ to $v_f = c$ (the boundary of our universe), - $E(v) = \frac{1}{2}m_p v^2$, - $V(v) = V_0 = \text{constant}$ in the barrier (for $v \le v_i$).

Tunneling occurs in the region $v \in [c, v_i]$, where $E(v) < V_0$.

We will assume the following values as numerical settings:

- The Planck mass, *i.e.* the mass of the primordial particle: $m_p = m_{\text{Planck}} = 2.18 \times 10^{-8}\ \text{kg}$.
- Planck's constant: $\hbar = 1.055 \times 10^{-34}\ \text{J} \cdot \text{s}$.
- The critical velocity (the boundary velocity for our universe): $c = 3 \times 10^8\ \text{m/s}$.
- The initial velocity of the primordial particle: $v_i = 5 \times 10^8\ \text{m/s}$.
- The quantum velocity: $\varepsilon_v = 10^7\ \text{m/s}$.
- The height of the barrier: Let:

$$V_0 = \frac{1}{2}m_p v_b^2,\ \ v_b = 5.5 \times 10^8\ \text{m/s}$$

Thus, the barrier is slightly higher than the energy of the particle, and this creates the conditions for tunneling. Tunneling between $v_f = c = 3 \times 10^8$ and $v_i = 5 \times 10^8$, in steps of $\varepsilon_v = 10^7$:

That is, a total of $N = 20$ steps.

At each step, we approximate:

$$\kappa_n = \frac{1}{\hbar}\sqrt{2m_p\left(V_0 - \frac{1}{2}m_p v_n^2\right)}$$

Then:

$$S \approx 2\sum_{n=1}^{N} \kappa_n \cdot \varepsilon_v \Rightarrow \mathcal{A} \sim \mathrm{e}^{-S}$$

Result (calculated):

Using these values:

- $m_p = 2.18 \times 10^{-8}\ \text{kg}$ - $\varepsilon_v = 10^7\ \text{m/s}$ - $\hbar = 1.055 \times 10^{-34}\ \text{J} \cdot \text{s}$ - velocity: $v_n = c + n \cdot \varepsilon_v$, $n = 1, \cdots, 20$

We calculate:

$$S \approx \sum_{n=1}^{20} \frac{2\times10^{7}}{1.055\times10^{-34}} \cdot \sqrt{2\cdot 2.18\times10^{-8}\cdot\left(V_0 - \frac{1}{2}m_p v_n^2\right)}$$

We include $V_0 = \frac{1}{2}m_p\left(5.5\times10^{8}\right)^2$.

We get:

$$S \approx 1.4\times10^{5} \Rightarrow \mathcal{A} \sim \mathrm{e}^{-1.4\times10^{5}} \approx 0.$$

Interpretation:

- The probability of tunneling is extremely small, but not zero, which is very important, because from this we can draw the following two conclusions: - If there is an infinite number or quasi-continuum of primary particles in the external quantized-velocity space, at least one can tunnel, and that event would trigger the Big Bang. - This low probability supports the idea of a spontaneous and rare origin of the universe as an extremely rare but inevitable fluctuation in the quantized-velocity space.

Physical meaning:

- If $\mathcal{A}_E$ is not zero, there is a non-zero probability that the particle passes from the world with $v > c$ to our world with $v \le c$. - This enables spontaneous quantum "breaking" of the velocity barrier and entering the space where classical relativity rules, *i.e.* our universe.

This is also confirmed by the total probability with given parameter values (Planck mass, barrier height, quantum velocity, etc.), which is:

$$\boxed{P_{\text{total}} \approx 0}$$

5. Formulation of an Extended Quantum-Gravity Model Incorporating Our Hypothesis of Primordial Particles as an Initial Condition of Quantum Cosmology

The goal of this model is to create a combination: primordial particle hypothesis: primordial particles in quantized-velocity space → tunneling → creation of the universe; and on the other hand quantum gravity: quantization of space and time (e.g., Loop Quantum Cosmology, LQC) → dynamic metrics → Big Bounce or quantum Big Bang.

Assumption: The velocity-quantized space of primordial particles

- We assume: - The space before our universe is a space of quantized velocities $\{v_n\}$, where $v_n = n\cdot\varepsilon_v$; - In that space there are primordial particles of mass m_p that behave quantum mechanically; - Particles have energy as in (2):

$$E_n = \frac{1}{2}m_p v_n^2$$

- Certain velocities $v_n > c$ are allowed in that space.

- Tunneling in metric bounded space

Tunneling is the passage through an effective barrier:

$$V(v) = \frac{1}{2} m_p v_b^2$$

where $v_b > c$, and the barrier acts as a quantum threshold for entry into our universe.

The tunneling leads into space and time where: - Velocity limit $v \le c$, - Beginning of spatial and temporal geometry.

- Entering the quantum-gravitational conditions

When the particle "passes" the barrier: - It is no longer just a particle, but becomes a source of curvature of space and time, - Quantum gravity is engaged: space and time are quantum generated around it.

In Loop Quantum Cosmology (LQC), quantum cosmological dynamics is described by a modified Friedman equation (4):

$$H^2 = \frac{8\pi G}{3} \rho \left(1 - \frac{\rho}{\rho_c}\right),$$

where: ρ is the energy density of the primordial particle, $\rho_c \sim \rho_{\text{Planck}}$ is the critical density from quantum gravity.

This equation predicts the Big Bounce, not the singularity.

6. Result and Discussion

We hypothesized that primordial particles exist in their own flat space and time while moving at velocities much faster than that of light. This "outer space" is a quantized-velocity space. In this space, "collisions" of these particles are possible, and with some of them there exists the possibility that one primordial particle slows to a velocity slightly higher than that of light, *i.e.* for quantum velocity ε_v higher than c. At the same time, its energy increases rapidly and it tunnels through the quantum barrier (exponentially suppressed probability).

Upon entering the domain where $v \le c$, it becomes a source of quantum curvature. A quantum-generated space and time is initiated via the LQC formalism, so that our universe emerges with Planck conditions as a boundary.

Our hypothesis provides a natural mechanism for initial entropy and time.

It is possible for many other universes to arise in a similar way (each "Big Bounce" is a consequence of the tunneling of some new primordial particle).

We expect that experimental confirmation of our hypothesis is possible through a quantum spectral signature in the cosmic microwave background (CMB).

7. We Propose a Potential Experimentally Verifiable Predictive Model

We combine:

- Tunneling of a primordial particle from a quantum-velocity space;
- Initiating quantum space and time via Loop Quantum Cosmology (LQC);
- Predictions in early cosmology, including quantum traces [8]-[11].

7.1. Experimental Predicted Consequences

1) Spectral deviations in the CMB (cosmic microwave background)

Prediction: - Tunneling from the quantized space leads to a discrete structure of the initial fluctuation. - Anomalies are expected in low multipoles ($\ell < 30$), e.g., quadrupole depression. Observations: - Planck, WMAP: already noted certain deviations in low ℓ . - Suggestion: look for discrete-frequency artifacts corresponding to ε_v .

2) Limits on quantum velocity ε_v

Prediction: - If ε_v is not extremely small, it could leave a trace in the gravitational wave forest.

Experimentally: - LISA, Pulsar Timing Arrays → traces of discrete structure in primordial gravitational waves.

3) Imbalance between inflationary potential and initial kinetics

Prediction: - The initial kinetic energy of the particle can cause asymmetry in the development of inflation.

Test: - Compare predicted asymmetric models with Planck's CMB maps of hemispheric asymmetry.

4) Temporal quantization and dispersion of high-energy photons

If time is also quantized (as we propose in our works):

- We may expect energy-dependent delays of high-energy photons from distant sources (e.g. GRB "gamma-ray burst").

Test: - Observation of GRBs (e.g. by Fermi LAT) → look for delays dependent on E^2 ili E^3 .

7.2. Predictive Model

We can formally write a simple model:

1) Spectral index of initial fluctuations

$$P(k) \sim k^{n_s - 1} \cdot \left(1 + \delta \cdot \sin\left(\frac{2\pi k}{k_v}\right)\right),$$

where $k_v \sim \frac{2\pi}{\varepsilon_v}$ is the wave number associated with the velocity quantum.

2) Effective density

$$\rho_{\text{eff}} = \frac{1}{2} m_p v^2 \cdot \mathrm{e}^{-2S(v)}.$$

7.3. Testability

| Observation | Expected traces | Experiment | CMB spectra | Low-frequency anomalies, discrete oscillatory patterns | Planck, Simons Observatory | Gravitational waves | Discrete structure in the primordial background signal | LISA, NANOGrav | Gamma-ray bursts (GRBs) | Delay of high-energy photons | Fermi LAT, CTA | Inflationary asymmetry | Hemispheric irregularity in temperature maps | Planck, CMB-S4 |.

7.4. Conclusions

We have formulated an experimentally verifiable quantum-cosmological model according to which:

A primordial particle tunnels out of a quantized-velocity space;

Space and time with quantum properties are born;

Traces remain in the CMB, gravitational waves, and high-energy signals.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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