Mini Review on the Beginning of the Quantum Universe

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Abstract

This article is a phenomenological, introductory mini review on some early cosmology, three-dimensional Chern-Simons quantum gravity, and unbroken supersymmetry-based preon model for visible/dark particles. As an unforeseen result, we obtain justification that three a priori very distinct ideas, namely Hartle-Hawking cosmological initial condition, Chern-Simons quantum gravity, and unbroken global supersymmetry of preons provide the necessary concepts for initiating the universe in a self-consistent manner and unifying all particles and the four forces. This combined model is a novel and noteworthy candidate for physics beyond the Standard Model (BSM).

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Contents

1 Introduction

The Standard Model of particles (SM) describes all the accelerator experimental results well and it gives a premonition of being valid at even higher energies. Going beyond the Standard Model (BSM) has turned out to be time-consuming task, the main reason being insufficient data of cosmological phenomena such as dark matter, baryon asymmetry, quantum gravity. In this situation one may try to look for an insightful change within the SM, or rather in the Minimally Supersymmetric SM (MSSM).

A priori, there does not appear to be any connection between the three distinct ideas considered in this review: 1. Hartle-Hawking no-boundary condition (by H. and H.), 2. 3D quantum gravity (by A. Castro et al.), and 3. supersymmetric preons as fundamental particles (by myself and others). A combined model of 1.–3. is a novel, noteworthy candidate for BSM physics. This solves many important shortcomings of the Standard Model as given in section 7.

To handle the classical initial singularity of the quantum universe more explicitly, its initial state must be defined. We assume the Hartle-Hawking no-boundary condition for the wave function of the universe.

Second, gravitation is based on a non-perturbative and all-order perturbatively calculable Chern-Simons (CS) quantum gravity model.

Below the quark-lepton level, there is a topological level of supersymmetric Chern-Simons preons[1]. All matter is now defined by a supersymmetric vector multiplet.

[1] We have also used the term *chernon* for preons.

The resulting combined model of this survey is a novel, noteworthy candidate for BSM physics (not presented anywhere before to the best of our knowledge). It solves many important shortcomings of the Standard Model as discussed in 7.

The remainder of this paper is organized as follows. In section 2 we briefly review the Hartle-Hawking no-boundary wave function and Wheeler-deWitt equation. Some simple inflationary cases are discussed in section 3 . Three dimensional Chern-Simons gravity with calculational capability is introduced in section 4 for the very early quantum universe. The Chern-Somons particle model for the visible matter and the dark sector is summarized in section 6 . Finally, concluding remarks are presented in section 7. This note is intended to be a brief, readable "pocket book" introduction to quantum gravity phenomenology. All text is based on published material. The novelty of this study lies in the composition of the sources. Readers interested in the subject must go to the brief list of references - and references therein - for the calculations. However, much remains to be determined .

2 The No-Boundary Wave Function

2.1 Ground State of the Universe and Quantum Creation

A competent review of the Hartle-Hawking no-boundary concept is [1], which we follow. Ground states can be defined in quantum mechanics by considering a Euclidean path integral, and integrating from configurations of vanishing action in the infinite (Euclidean) past,

$$\psi_0(x,0) = \int \mathcal{D}x \, e^{-\frac{1}{\hbar} I_E[x(\tau)]} \,, \tag{2.1}$$

where we ignored an overall normalisation factor and where Euclidean time τ is related to physical time via $t = -i\tau$. The Euclidean action I_E is related to Lorentzian action via $I_E = -iS$. An integral from the infinite Euclidean past defines the ground (vacuum) state of the system. In other words, the integration over Euclidean time is an alternative method to implement the ground state as initial state. In addition, the replacement $t = -i\tau$ takes one from quantum oscillatory behavior towards semiclassical physics.

What is the analogous definition when gravity is included? What should be the role of the infinite Euclidean past? As discussed by Hartle and Hawking [2], there are two natural choices (i) Euclidean flat space, and (ii) compact Euclidean metrics. Euclidean flat space can be used for scattering amplitudes, where fields are defined at infinity. In cosmology, instead, we only measure the universe at late (finite) times, and we do so from the inside of the universe. Therefore option (ii) is more appropriate for cosmology, as proposed by Hartle and Hawking. Note that this prescription then obviates the need to insert an initial state explicitly, the idea being that the Euclidean integral places the universe in its ground state.

The no-boundary proposal assumes a fully quantum view of spacetime: actual spacetime exists only in interaction with either itself or matter. The interactions between different constituents of the universe result in our perception of classical spacetime with classical laws of evolution. Going back in time towards the putative big bang, one will necessarily encounter departures from classical evolution.

The wave function is a function of three-dimensional spatial slices. The path integral over compact metrics may then be seen as an amplitude from a slice where the 3−dimensional volume goes to zero, to a final slice with metric h_{ij},

$$\Psi_{HH}[h_{ij}] = \mathcal{N} \int_{\mathcal{C}} \mathcal{D}g_{\mu\nu}\, e^{-I_E[g_{\mu\nu}]}\,, \tag{2.2}$$

where the integral is over all (inequivalent) compact metrics $\mathcal{C}$ that contain a surface with metric h_{ij}. $\mathcal{N}$ here is a normalization factor. This definition may be interpreted as a transition amplitude from zero to a given final size. This is the amplitude of the universe to tunnel from nothing to the final state. Nothing means absolute nothing: no space, time or matter.

According to definition (2.2) one has certain consequences. First, the wave function is real valued. Nevertheless, this can lead to the definition of probabilities. The second is that from a sum of Euclidean metrics, our Lorentzian universe must somehow come out. This is because the saddle points of the path integral (2.2) will turn out to be complex. Third, by definition big bang singularity is avoided. This is possible because the geometry is not forced to remain Lorentzian in regions where the universe shrinks to zero size. The origin of the geometry can be viewed as a point on the surface of a sphere, called the South Pole (see figure 1).

2.2 Wheeler-DeWitt Equation

The Hamiltonian form of the action of General Relativity is given by [3]

$$S = \int \mathrm{d}^3x \; \mathrm{d}t \left[\dot{h}_{ij}\pi^{ij} - N\mathcal{H} - N^i\mathcal{H}_i\right] \tag{2.3}$$

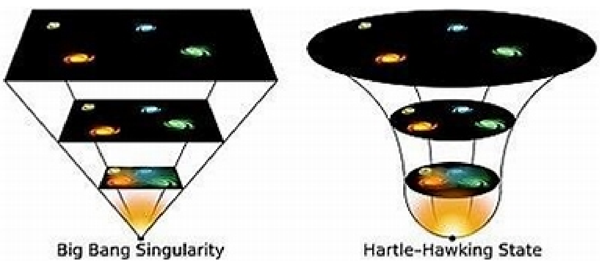

Figure 1: Big Bang Universe and Hartle-Hawking Universe.

where $\pi^{ij} = \frac{\delta \mathcal{L}}{\delta h^{ij}} = -\frac{\sqrt{h}}{2}\left(K^{ij} - h^{ij}K\right)$ are the momenta conjugate to h_{ij}. The Hamiltonian is a sum of constraints, with lapse N and shift N^i being Lagrange multipliers. There is a momentum constraint:

$$\mathcal{H}^i = -2D_j\pi^{ij} + \mathcal{H}^i_{matter} = 0\,, \tag{2.4}$$

and the Hamiltonian constraint

$$\mathcal{H} = 2G_{ijkl}\pi^{ij}\pi^{kl} - \frac{1}{2}\sqrt{h}({}^3R - 2\Lambda) + \mathcal{H}_{matter} = 0\,, \tag{2.5}$$

where G_{ijkl} is the DeWitt metric [4]

$$G_{ijkl} = \frac{1}{2\sqrt{h}}\left(h_{ik}h_{jl} + h_{il}h_{jk} - h_{ij}h_{kl}\right)\,. \tag{2.6}$$

These constraints are essentially equivalent to the $0i$ and 00 components of the classical Einstein equations. The constraints play a central role in the canonical quantisation procedure.

Canonical quantization amounts to imposing the constraints as operator equations, in the field representation with substitution

$$\pi^{ij} \to -i\frac{\delta}{\delta h_{ij}} \tag{2.7}$$

and is similarly for matter momenta. This results in four equations: the momentum constraint

$$\mathcal{H}^i\Psi = 2iD_j\frac{\delta\Psi}{\delta h_{ij}} + \mathcal{H}^i_{matter}\Psi = 0\,, \tag{2.8}$$

and Wheeler-DeWitt equation [4, 5] for the wavee function of the universe

$$\mathcal{H}\Psi(h_{ij},\Phi_{matter}) = \left[-G_{ijkl}\frac{\delta}{\delta h_{ij}}\frac{\delta}{\delta h_{kl}} - \sqrt{h}({}^3R - 2\Lambda) + \mathcal{H}_{matter}\right]\Psi = 0\,. \tag{2.9}$$

or

$$\hat{H}\Psi = 0 \to \hbar^2\frac{\partial^2\Psi}{\partial q^2} + 12\pi^4(\Lambda q - 3)\Psi = 0\,. \tag{2.10}$$

This section presents two remarks. Time is treated as a complex number. In the early universe, time behaves as a spatial dimension. This removes the distinction between time and space and allows the geometry of the universe to be smooth and finite in all directions. Imaginary time replaces the singular boundary of the big bang.

Classicalization is explained by a Wentzel-Kramers-Brillouin (WKB) semi-classical phenomenon and decoherence due to interactions (see [1] for details.

3 Simple Inflationary Examples

We briefly review a simplified inflationary case of the universe following [1]. It is known that path integrals can be well approximated by their saddle points. Compact and regular saddle point solutions actually exist.

The relevant situation is gravity coupled to a scalar field ϕ with a potential $V(\phi)$ and action

$$S = \int_{\mathcal{M}} \mathrm{d}^4x\sqrt{-g}\left(\frac{R}{2} - \frac{1}{2}g^{\mu\nu}\partial_\mu\phi\partial_\nu\phi - V(\phi)\right) + \int_{\partial\mathcal{M}} \mathrm{d}^3y\sqrt{h}K\,. \tag{3.1}$$

We will assume Friedmann-Lemaître-Roberston-Walker (FLRW) backgrounds

$$\mathrm{d}s^2 = -\tilde{N}^2(t)\mathrm{d}t^2 + a^2(t)\mathrm{d}\Omega_3^2\,, \tag{3.2}$$

where $\tilde{N}$ is the lapse function and $\mathrm{d}\Omega_3^2$ the metric on the unit three-sphere. This symmetry reduced setting is an example of minisuperspace.

We redefine the time coordinate $\tilde{N}\mathrm{d}t = -i\mathrm{d}\tau$. $\tau \subset \mathbb{R}$ corresponds to Euclidean time, it will be useful to consider $\tau \subset \mathbb{C}$ in general. Then the metric ansatz is

$$\mathrm{d}s^2 = \mathrm{d}\tau^2 + a^2(\tau)\mathrm{d}\Omega_3^2\,, \tag{3.3}$$

and the Euclidean action $I_E = -iS$ becomes

$$I_E = 2\pi^2\int \mathrm{d}\tau\left(-3aa'^2 - 3a + a^3\left(\frac{1}{2}\phi'^2 + V\right)\right)\,, \tag{3.4}$$

where $' \equiv \mathrm{d}/\mathrm{d}\tau$. The equations of motion are

$$\phi'' + 3\frac{a'}{a}\phi' - V_{,\phi} = 0\,, \tag{3.5}$$

$$a'' + \frac{a}{3}\left(\phi'^2 + V\right) = 0\,, \tag{3.6}$$

while the constraint, arising from time reparameterisation invariance, is

$$a'^2 - 1 = \frac{a^2}{3}\left(\frac{1}{2}\phi'^2 - V\right)\,. \tag{3.7}$$

which is known as Friedmann equation. Using this equation, we can simplify the action when it is evaluated using the solution of the equations of motion

$$I_E^{on-shell} = 4\pi^2\int \mathrm{d}\tau\,\left(-3a + a^3V\right)\,. \tag{3.8}$$

The no-boundary wave function is the path integral

$$\Psi(b,\chi) = \int_{\mathcal{C}} \mathcal{D}a\mathcal{D}\phi\, e^{-I_E(a,\phi)} \sim \sum e^{-I_E(b,\chi)}\,, \tag{3.9}$$

depends on b and χ, which are the (late-time) values of the scale factor and scalar field on the final hypersurface. We assume this can be approximated by (the sum of) saddle point contributions. These saddle points must satisfy several mathematical and physical requirements [6]: evidently, they must satisfy the equations of motion and constraints. Moreover, we would like them to be physically meaningful, and for this reason they should yield normalisable wave functions. Moreover, they should lead to physically sensible results, implementing the idea that matter fields were in their ground states in the early universe.

The solutions $(a(\tau), \phi(\tau))$, must satisfy several conditions [7, 8]. The solution must be compact, we must have $a(0) = 0$ somewhere. The time coordinate was defined such that $\tau = 0$ corresponds to the South Pole of the solution. There the solution should also be regular. The Friedmann equation (3.7) then implies $a'(0) = \pm 1$, implying that the geometry must be Euclidean at the South Pole. The choice of sign for a' is important. For normalizability we must choose $a'(0) = +1$. Equation (3.6) indicates that $a = \tau + \mathcal{O}(\tau^3)$. In addition, the equation of motion for ϕ, Eq. (3.5), shows that no-boundary solutions can be characterised by the value of the scalar field at the South Pole, $\phi_{SP} = \phi(0)$, which is complex in general.

On the final hypersurface we must have

$$a(\tau_f) = b \quad \text{and} \quad \phi(\tau_f) = \chi, \tag{3.10}$$

where b, χ are the arguments of the wave function. It is necessary for the fields to obtain the specified values simultaneously. Otherwise, no solution exists.

The phases of the very early universe, $0 \leq t \leq 10^{-32}$ s, in the preon model are 1. nucleation, 2. appearance of the scalar field, and 3. scalar field produces preon–anti-preon pairs, and 4. reheating producing SM fermions (more details in [9] together with the baryon asymmetry mechanism). During the nucleation of the universe, only scalar fields may have a non-zero energy density. This follows from the equation of continuity $\dot{\rho} + 3\frac{\dot{a}}{a}(\rho + p) = 0$. At the zero-scale factor, this equation remains regular only if $\rho + p$ vanishes, and only a scalar field can be achieved, when its kinetic energy is zero. Other matter fields must be created during the reheating.

The black hole information paradox is diluted in the present scenario. Black holes with an initial mass less than approximately 10^{15} g have completely evaporated in about 13.8 billion years. When the surface temperature of a decaying hole reaches a temperature of approximately $\Lambda_{cr} \sim E_R \sim 10^{15}$ GeV falling quarks and leptons transform into preons with vacuum quantum numbers. These in turn form scalars. The stuff ultimately ends up at a point, the South Pole. The Pole begins the process of the previous paragraph (inflation) in phase 2 producing matter and radiation as in the present universe. The baryon asymmetry may be slightly different from what has now been observed. Stellar size holes radiate sparsely and may rather swallow more material (if available).

4 Quantum Gravity

The CS model of quantum gravity by Castro et al. [10, 11] and the supersymmetric model for (left handed) particles in [12] were reviewed and their actions were compared [13]. The first model is summarized below. In section 6 the particle model is described.

In Euclidean space, fermions ψ and $\bar{\psi}$ are independent and they transform in the same representation of the Lorentz group. Their index structure is [16]

$$\psi^\alpha, \quad \bar{\psi}^\alpha. \tag{4.1}$$

We will take γ_μ to be the Pauli matrices, which are hermitian, and

$$\gamma_{\mu\nu} = \frac{1}{2}[\gamma_\mu, \gamma_\nu] = \mathrm{i}\epsilon_{\mu\nu\rho}\gamma^\rho. \tag{4.2}$$

The three dimensional Euclidean $\mathcal{N} = 2$ vector superfield V has the following content

$$V: \qquad A_\mu,\ \sigma,\ \lambda,\ \bar{\lambda},\ D, \tag{4.3}$$

where A_μ is the gauge field, σ is the auxiliary scalar field, λ, $\bar{\lambda}$ are two-component complex Dirac spinors, and D is an auxiliary scalar. This is simply the dimensional reduction of the $\mathcal{N} = 1$ vector multiplet in four dimensions, and σ is the reduction of the fourth component of A_μ. All fields are valued in Lie algebra $\mathfrak{g}$ of gauge group G. For $G = U(N)$ our convention is that $\mathfrak{g}$ is a Hermitian matrix. It follows that the gauge covariant derivative is given by

$$\partial_\mu + \mathrm{i}[A_\mu, .] \tag{4.4}$$

while the gauge field strength is

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + \mathrm{i}[A_\mu, A_\nu]. \tag{4.5}$$

The question of gravity-matter coupling was resolved in [17]. The major result of [10] is the expression of the one-loop determinant (or partition function) of a massive scalar field minimally coupled to a background metric, $g_{\mu\nu}$, as a gauge invariant object of the Chern-Simons connections, $A_{L/R}$

$$Z_{\text{scalar}}[g_{\mu\nu}] = \exp\frac{1}{4}\mathbb{W}[A_L, A_R]\ . \tag{4.6}$$

The object $\mathbb{W}[A_L, A_R]$, coined the Wilson spool, is a collection of Wilson loop operators W

$$\mathrm{Tr_R Pexp}\Big(\mathrm{i}\int_\gamma \mathrm{A}_\mu \mathrm{dx}^\mu\Big) \tag{4.7}$$

where γ is a closed loop in space-time and R is a representation of the gauge group G, wrapped many times around cycles of the base geometry. Supersymmetric localization for the evaluation of Wilson loop expectation values [16] with the Wilson spool inserted into the path integral allows a precise and efficient calculation of the quantum gravitational corrections to Z_{scalar} at any order of perturbation theory of Newton's constant G_N. The equality in (4.6) is expected to apply to the three-dimensional gravity of either sign of the cosmological constant.

5 Trans-Planckian Censorship Conjecture

In the context of early universe cosmology, effective field theories face challenges due to the expansion of space (for a review, see [14]). In the standard treatment of linear cosmological perturbations, the fluctuating fields are expanded in Fourier modes in comoving coordinates, and each mode is an independent harmonic oscillator. If we now consider a mode which today has a wavelength in the range of current observations, then if we go back sufficiently far into the past, the wavelength of this mode can become smaller than the Planck length.

In a uniformly expanding universe with the scale factor $a(t)$, it should not be possible for a sub-Planckian region to become larger than the Hubble horizon $1/H(t)$ where $H = \dot{a}/a$. In other words, in Planck units [15]:

$$\frac{t_f}{t_i} \leq \frac{1}{H(t_f)} \tag{5.1}$$

Having introduced a topological CS theory for energies near the Planck scale we have to take a new look at concepts like distance, particularly the Planck scale. The concept of length need not be defined in topological spaces. Second, at the classical singularity, we have applied the Hartle-Hawking no-boundary condition thus avoiding the singularity. The Trans-Planckian Censorship Conjecture (TCC) posits that physical processes in our observable universe should not involve modes that originate with wavelengths smaller than the Planck length. This conjecture is motivated by concerns about preserving the consistency of effective field theories and avoiding trans-Planckian paradoxes.

If we trust that the topological quantum gravity (TQG) of section 4 is all order finite it should describe physics at least to certain extent beyond the Planck scale. Thus the value of TCC may be limited. In string theory, the string length may not be an untroubled concept from the point of view of TQG. On the other hand, linking the Hartle-Hawking initial conditions to topological quantum field theory is a demanding task.

6 Particle Model

The localization procedure [16] is not only a calculational method but the vectormultiplet $\{A_\mu, \sigma, \mathfrak{D}, \lambda, \bar{\lambda}\}$ of section 4 should also be realized on the topological matter sector of the particle model. In fact, this kind of supersymmetric matter structure was anticipated on phenomenological basis some time ago in [18, 12, 9]. The setup for this scenario is recapped below:

Unbroken supersymmetry was adopted for fundamental particles. The divisive point between the Minimal Supersymmetric SM and our model (for visible and dark matter) as follows: supersymmetry is unbroken and superpartners are included in constructing the Standard Model particles. There are no squarks or sleptons to be dicovered.[2] This can be achieved only if Standard Model

[2] The MSSM leads rather to particle "double counting".

fermions are split into three preons. A binding mechanism for the preons was constructed using the spontaneously broken 3d Chern-Simons theory.

Preons are free particles above the energy scale Λ_{cr}, numerically abou t $\sim 10^{10} - 10^{16}$ GeV. It is close to the reheating scale T_R and the grand unified theory (GUT) scale. At Λ_{cr} preons undergo a phase transition by an attractive Chern-Simons model interaction into composite states of Standard Model quarks and leptons, including gauge interactions. preons have undergone "second quarkization".

To make the preon scenario compatible with the SM we consider the following Lagrangians 6.1 anf 6.2. To include charged matter we define the charged chiral field Lagrangian for fermion m^-, complex scalar s^- and the electromagnetic field tensor $F_{\mu\nu}$[3]

$$\mathcal{L}_{QED} = -\frac{1}{2}\bar{m}^-\gamma^\mu(\partial_\mu + ieA_\mu)m^- - \frac{1}{2}(\partial s^-)^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \ . \tag{6.1}$$

We assign color to the neutral fermion $m \to m_i^0$ $(i = R, G, B)$. The color sector Lagrangian is then

$$\mathcal{L}_{QCD} = -\frac{1}{2}\sum_{i=R,G,B}\left[\bar{m}_i^0\gamma^\mu(\partial_\mu + igG_\mu^a t_a)m_i^0\right] - \frac{1}{4}G_{\mu\nu}^a G_a^{\mu\nu} \ . \tag{6.2}$$

We now have the supermultiplets shown in table 1.

Multiplet	Particle, Sparticle
chiral multiplets spins 0, 1/2	s^-, m^-; σ_i, m_i^0; a, n
vector multiplets spins 1/2, 1	m^0, γ; m_i^0, g_i

Table 1: The particle s^- is a charged scalar particle. The particles m^-, m^0 are charged and neutral, respectively, Dirac spinors. The a is axion and n axino [19, 20, 21]. m^0 is color singlet particle and γ is the photon. m_i and g_i (i = R, G, B) are zero charge color triplet fermions and bosons, respectively.

Note that in table 1 there is a zero charge quark triplet m_i but no gluon octet. Instead, supersymmetry demands that the gluons appear only in triplets at this stage (before reheating) of cosmological evolution. We obtain the dark sector from the axion multiplet {a, n} in table 1 (if axion(s) are found).

The matter-preon correspondence for the first two flavors (r = 1, 2; i.e., the first generation) is indicated in table 2 for the left-handed particles.

[3] The next two equations are in standard 4D form. They are not used quantitatively below.

SM Matter 1st gen.	Preon state
ν_e	$m_R^0 m_G^0 m_B^0$
u_R	$m^+ m^+ m_R^0$
u_G	$m^+ m^+ m_G^0$
u_B	$m^+ m^+ m_B^0$
e^-	$m^- m^- m^-$
d_R	$m^- m_G^0 m_B^0$
d_G	$m^- m_B^0 m_R^0$
d_B	$m^- m_R^0 m_G^0$
W-Z Dark Matter	Particle
boson (or BC)	s, axion(s)
e'	axino n
meson, baryon o	$n\bar{n}, 3n$
nuclei (atoms with γ')	multi n
celestial bodies	any dark stuff
black holes	anything (neutral)

Table 2: Visible and Dark Matter with corresponding particles and preon composites. m_i^0 $(i = R, G, B)$ is color triplet, $m^{\pm}$ are color singlets of charge $\pm 1/3$. e' and γ' refer to dark electron and dark photon, respectively. BC stands for Bose condensate. preons obey anyon statistics.

After quarks are formed by the process described in [9] the SM octet of gluons emerges because it is known that fractional charge states have not been observed in nature. To make observable color neutral, integer charge states (baryons and mesons) we proceed as follows. The local $SU(3)_{color}$ octet structure is formed by quark-antiquark composite pairs as follows (with only the color charge indicated):

$$\text{Gluons}: \mathrm{R\bar{G}}, \mathrm{R\bar{B}}, \mathrm{G\bar{R}}, \mathrm{G\bar{B}}, \mathrm{B\bar{R}}, \mathrm{B\bar{G}}, \frac{1}{\sqrt{2}}(\mathrm{R\bar{R}} - \mathrm{G\bar{G}}), \frac{1}{\sqrt{6}}(\mathrm{R\bar{R}} + \mathrm{G\bar{G}} - 2\mathrm{B\bar{B}}) \ . \tag{6.3}$$

With the gluon triplet the first hunch is that they form, with octet gluons now available, the $3 \otimes 3 \otimes 3 = 10 \oplus 8 \oplus 8 \oplus 1$ bosonic states with spins 1 and 3. However, these three gluon coupling states require a separate investigation.

Finally, we briefly and heuristically introduce the weak interaction - the scalar sector is rather complex. After the SM quarks, gluons and leptons are formed at scale Λ_{cr} there is no observable supersymmetry in nature. To avoid a more complicated vector supermultiplet in table 1, we append the Standard Model electroweak interaction in our model as an $SU(2)_Y$ Higgs extension with the weak bosons presented as composite pairs, such as gluons in (6.3).

The Standard Model and dark matter are formed by preon composites in the very early universe at temperature of approximately the reheating value T_R. Because of spontaneous symmetry breaking in three-dimensional QED_3

by a heavy Higgs-like particle the Chern-Simons action can provide by Möller scattering mediated by two particles (the Higgs scalar and the massive gauge field) a binding force stronger than Coulomb repulsion between equal charge preons. The details of preon binding and a mechanism for baryon asymmetry in the universe are presented in [9, 22].

Chern-Simons theory with larger groups such as $G = U(N_c)$ with fundamental matter and flavor symmetry group $SU(N_f) \times SU(N_f)$ have been studied, for example [23], but they are beyond the scope of this review.

7 Conclusions and Outlook

Starting from the beginning of time without singularity we obtain a rather comprehensive picture of the cosmological evolution of the universe from nothing to the present time.

Properties of the scenario include

- perturbative and perturbatively all order calculable quantum gravity,
- there are no initial or black hole singularities due to no-boundary condition,
- the no-boundary condition describes the existence of the universe in a self consistent manner,
- time is treated as a complex number,
- classicalization is explained by the Wentzel-Kramers-Brillouin (WKB) semiclassical phenomenon and decoherence due to interactions,
- cosmic expansion is possible by inflation or ekpyrotic model,
- mechanism for baryon asymmetry has been constructed,
- dark sector is predicted, see table 1 (axion, n),
- "light" black hole radiates back the same matter (as preons) it has swallowed earlier (depending on the flux of falling matter),
- dark sector is obtained, see table 1 (axion, n),
- Standard Model of particles is obtained after reheating,
- flavor symmetry is $SU(N_f)$ extendable,
- all particles and interactions originate equally on the topological level (near the Planck scale) from the **supermultiplets** of table 1 and the **CS action** of (A.2) (this is the novelty of the article),
- numerical techniques are available.

The present discussion is a preliminary one. The details of this framework must be systematically studied. For example, why do the dimensions of spacetime approach zero as we move towards the initial state of the universe?

A single CS basic action to build all particles and interactions combined with Hartle-Hawking initial conditions for cosmic expansion indicates an element of a theory of "everything" - to the extent it can be defined.

A Chern-Simons Action

In accordance with the split structure of the isometry group, one describes Euclidean dS_3 gravity with a pair of $SU(2)$ Chern-Simons theories [10]

$$S = k_L\, S_{CS}[A_L] + k_R\, S_{CS}[A_R] \ , \tag{A.1}$$

with

$$S_{CS}[A] = \frac{1}{4\pi}\mathrm{Tr}\int\left(\mathrm{A}\wedge \mathrm{dA} + \frac{2}{3}\mathrm{A}\wedge\mathrm{A}\wedge\mathrm{A}\right) \ , \tag{A.2}$$

and the trace taken in the fundamental representation. This topological expression is a key element for unification. The other is unbroken supersymmetry.

The gravitational Chern-Simons term I_{GCS} is

$$I_{\mathrm{GCS}} = \frac{1}{2\pi}\mathrm{Tr}\int\left(\omega\wedge \mathrm{d}\omega + \frac{2}{3}\omega\wedge\omega\wedge\omega\right) + \frac{1}{2\pi\ell_{\mathrm{dS}}^2}\mathrm{Tr}\int \mathrm{e}\wedge\mathrm{T} \ , \tag{A.3}$$

with T the torsion two-form and ℓ_{dS} is deSitter radius.

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