Particles, Forces and the Early Universe - a mini review

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Abstract

The aim of this mini review is this unforeseen result: we show that three a priori very distinct ideas, namely unbroken global supersymmetry of preons, Hartle-Hawking cosmological initial condition, and Chern-Simons quantum gravity, provide the necessary concepts for initiating the universe in a self-consistent manner and unifying all particles and the four forces.

Keywords: Composite particles, Supersymmetry, Chern-Simons model, Hartle-Hawking wave function, Quantum gravity, Gravitational wave polarization

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1 Introduction

The Standard Model of particles (SM) describes all the accelerator experimental results remarkably 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. In this situation one may try to look for an insightful change within the SM, or rather in the Minimally Supersymmetric SM (MSSM). Unlike in MSSM, we postulate unbroken global supersymmetry and take LHC data at face value, i.e. there are no squarks or sleptons. This constraint can be fulfilled by splitting quarks and leptons in three parts called preons.[1]

We believe below the quark-lepton level length scale, there is a topological level of supersymmetric preons. All matter is now defined in supersymmetric multiplets, the vector and the chiral multiplets. The binding force between preons is a 3D Chern-Simons interaction, which is engineered stronger than Coulomb repulsion between like charge preons. We indicate doubts on the validity of the minimal supersymmetric standard model (MSSM).

A priori, there does not appear to be any connection between the three distinct ideas considered in this review:
(1) supersymmetric preons as fundamental particles,
(2) Hartle-Hawking no-boundary condition, and
(3) all order finite 3D quantum gravity.

Let us outline these points briefly. Particle are constructed from supersymmetric constituents. Requiring supersymmetry to be unbroken we are lead to consider preons, instead of quarks and leptons, as fundamental particles.

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

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

Gravitation is based on a recent non-perturbative and all-order perturbatively calculable Chern-Simons (CS) quantum gravity model. The parity violating CS interaction leads to different intensities to polarization states of gravitational waves (GW) provided the source is symmetric. These waves may come from times as early as before inflation started, $t \lessapprox 10^{-35}$s. We also discuss production of classical GWs.

The resulting combined model of this survey is a novel, testable 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 5. Furthermore, we give arguments in favor of the Fayet conjecture of "$Matter \longleftrightarrow Forces$" [1].

This article is organized as follows. The Chern-Simons particle model for the visible matter and the dark sector is summarized in section 2.[2] In section 3 we briefly review the Hartle-Hawking no-boundary wave function and Wheeler-deWitt equation. Three dimensional Chern-Simons gravity with calculational capability is introduced in section 4 for the very early quantum universe. Finally, concluding remarks are presented in section 5.

This note is intended to be a brief, readable "pocket book" introduction to selected concepts in quantum gravity phenomenology. All text is based on published material. Readers interested in the subject profoundly should go to the brief list of references - and references therein - for the calculations. However, many details remain to be determined.

2 Particle Model

The fundamental particles, preons, are set in vector and chiral supermultiplets [2]. The divisive point between the Minimal Supersymmetric SM and our model (for visible and dark matter) is as follows: supersymmetry is unbroken and superpartners are also included in constructing the Standard Model particles. Consequently, there are no squarks or sleptons to be dicovered.[3] This can be achieved only if Standard Model fermions are split into three preons. A binding mechanism for the preons has been constructed using the spontaneously broken 3D Chern-Simons theory [3].

Preons are free particles above the energy scale Λ_{cr}, numerically about $\sim 10^{10} - 10^{16}$ 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".

[2] Section 2 is based on this authors work. Sections 3 and 4 are from authors cited.
[3] The MSSM leads rather to particle "double counting".

To make the preon scenario compatible with the SM we considered originally [4] the following Lagrangians 2.1 and 2.2. To include charged matter we define the charged chiral field Lagrangian for fermion m^-, complex scalar s^- and the electromagnetic field tensor $F_{\mu\nu}$[4]

$$\mathcal{L}_{QED} = -\frac{1}{2}\bar{m}^-\gamma^\mu(\partial_\mu + ieA_\mu)m^- - \frac{1}{2}(\partial s^-)^2 - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} \ . \tag{2.1}$$

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

$$\mathcal{L}_{QCD} = -\frac{1}{2}\sum_{i=R,G,B}\left[\bar{m}_i^0\gamma^\mu(\partial_\mu + igG_\mu^a t_a)m_i^0\right] - \frac{1}{4}G_{\mu\nu}^a G_a^{\mu\nu} \ . \tag{2.2}$$

We now have the supermultiplets shown in table 1.[5]

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

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 [5, 6, 7]. 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.

[4] The next two equations are in standard 4D form. They are not used quantitatively below.
[5] The indices of particles in tables 1 and 2 are corrected from those in [2].

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 [8] 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):

$$\text{Gluons}: \mathrm{R\bar{G}, R\bar{B}, G\bar{R}, G\bar{B}, B\bar{R}, B\bar{G}}, \frac{1}{\sqrt{2}}(\mathrm{R\bar{R} - G\bar{G}}), \frac{1}{\sqrt{6}}(\mathrm{R\bar{R} + G\bar{G} - 2B\bar{B}}) \ . \tag{2.3}$$

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 (2.3).

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 [3, 8].

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 [9], but they are beyond the scope of this review.

3 No-Boundary Wave Function

We review first the ground state and, secondly, the dynamical equation of the wave function of the universe.

3.1 Ground State of the Universe

A pedagogic review of the Hartle-Hawking no-boundary concept [10] is Lehners' article [11], which we follow closely in this section. In quantum theory, ground states can be defined by solving a proper quantum differential equation or considering a Euclidean path integral. The latter is integrated from configurations of vanishing action in the infinite (Euclidean) past,

$$\psi_0(x, 0) = N \int \mathcal{D}x \, e^{-\frac{1}{\hbar} I_E[x(\tau)]} \,, \tag{3.1}$$

where N is a normalization factor and where Euclidean time τ is related to physical time via $t = -i\tau$. The connection between the Euclidean and the Lorentzian actions is given by $I_E = -iS$. An integral from the infinite Euclidean past defines the ground (vacuum) state of the system, which is taken as the initial state. Furthermore, the replacement $t = -i\tau$ shifts one from quantum oscillatory behavior towards semiclassical physics.

When gravity is switched on, according to Hartle and Hawking [10] there are two natural choices (i) Euclidean flat space for scattering amplitudes, and (ii) compact Euclidean metrics. In cosmology one only measures the universe at late (finite) times. More importantly, one does so from the inside of the universe. Clearly, option (ii) is more appropriate for cosmology. An advantage in (ii) is that there is no need to insert an initial state explicitly. The Euclidean integral takes care of the universe in its ground state.

As discussed in Lehners' review [11], the no-boundary proposal assumes a fully quantum view of spacetime: the actual spacetime exists only in interaction with either itself or matter. Our perception of classical spacetime comes from interactions between different constituents and bodies, including ourselves, in the universe.

The arguments of wave function are now three-dimensional spatial slices. The path integral is an amplitude from the initial slice with zero three-dimensional volume, to a final slice with metric h_{ij},

$$\Psi_{HH}[h_{ij}] = N \int_{\mathcal{C}} \mathcal{D}g_{\mu\nu}\, e^{-I_E[g_{\mu\nu}]}\,, \tag{3.2}$$

where the integral is calculated over all (inequivalent) compact metrics $\mathcal{C}$ and N is a normalization factor. The meaning of this amplitude is for the universe to tunnel from nothing to the final state. The initial state "nothing" contains no space, time or matter.

The wave function (3.2) is real valued but it can lead to the definition of probabilities. The present Lorentzian universe will come out because the saddle points of the path integral (3.2) are complex. The big bang singularity is avoided because the initial geometry is Euclidean and the universe shrinks to zero size, i.e. the point universe can be called the "South Pole" (see figure 1). The energy density there has its maximal value.

3.2 Wheeler-DeWitt Equation

The discussion of subsection 3.1 can also be done using the Hamiltonian form of the action of General Relativity (GR), given by [12]

$$S = \int \mathrm{d}^3x\ \mathrm{d}t \left[\dot{h}_{ij}\pi^{ij} - N\mathcal{H} - N^i\mathcal{H}_i\right] \tag{3.3}$$

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

$$\mathcal{H}^i = -2D_j\pi^{ij} + \mathcal{H}^i_{matter} = 0\,, \tag{3.4}$$

and the Hamiltonian constraint

$$\mathcal{H} = 2G_{ijkl}\pi^{ij}\pi^{kl} - \frac{1}{2}\sqrt{h}(^3R - 2\Lambda) + \mathcal{H}_{matter} = 0\,, \tag{3.5}$$

where G_{ijkl} is the DeWitt metric [13]

$$G_{ijkl} = \frac{1}{2\sqrt{h}}\left(h_{ik}h_{jl} + h_{il}h_{jk} - h_{ij}h_{kl}\right)\,. \tag{3.6}$$

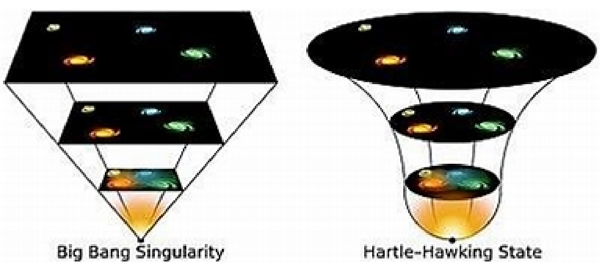

Figure 1: Big Bang Universe and Hartle-Hawking Universe.

Canonical quantization makes the constraints as operator equations with the familiar substitution

$$\pi^{ij} \to -i\frac{\delta}{\delta h_{ij}} \tag{3.7}$$

and correspondingly for matter momenta. We get four equations: the momentum constraint

$$\mathcal{H}^i\Psi = 2iD_j\frac{\delta\Psi}{\delta h_{ij}} + \mathcal{H}^i_{matter}\Psi = 0\,, \tag{3.8}$$

and Wheeler-DeWitt equation [13, 14] for the wave function of the universe

$$\mathcal{H}\Psi(h_{ij},\Phi_{matter}) = \left[-G_{ijkl}\frac{\delta}{\delta h_{ij}}\frac{\delta}{\delta h_{kl}} - \sqrt{h}(^3R - 2\Lambda) + \mathcal{H}_{matter}\right]\Psi = 0\,. \tag{3.9}$$

or

$$\hat{H}\Psi = 0 \to \hbar^2\frac{\partial^2\Psi}{\partial q^2} + 12\pi^4(\Lambda q - 3)\Psi = 0\,. \tag{3.10}$$

In the early universe, time is treated as a complex number and it behaves like a spatial dimension. This allows a smooth and finite geometry in all directions of the universe. Imaginary time wipes away the singular boundary of the big bang.

When the South Pole tunnels into expanding phase, infinitesimally thin slices of three dimensional space are formed. Likewise, quantum gravity is 3D (to be described in the next section 4). The slices grow quickly into finite thickness slices occuring in (3.2). At the same time, preon-antipreon pairs are are created from the topological neighborhood of the Pole. Preons form quarks and leptons due to the spontaneously broken symmetry created, attractive Yukawa-like force [8, 3]. After inflation comes reheating as in the concordance model. From reheating on, our model will adapts to the standard models of cosmology and particles. Classicalization is obtained in a Wentzel-Kramers-Brillouin (WKB) process (see [11] for details). Gravity has become classical GR.

4 Quantum Gravity

We first review quantum gravity, which is expected to be in a major role in the very early universe. We consider a three dimensional model, which should comply with the considerations of the previous section 3.

4.1 Wilson Spool

The recent CS model of quantum gravity by Castro et al. [15, 16] is briefly summarized below. In Euclidean space, fermions ψ^α and $\bar{\psi}^\alpha$ are independent.

Their transformation properties go under the same representation of the Lorentz group [17]. We take the γ_μ matrices to be the hermitian Pauli matrices, and $\gamma_{\mu\nu}$ is defined

$$\gamma_{\mu\nu} = \frac{1}{2}[\gamma_\mu, \gamma_\nu] = \mathrm{i}\epsilon_{\mu\nu\rho}\gamma^\rho. \tag{4.1}$$

The three dimensional Euclidean $\mathcal{N} = 2$ vector superfield V includes the following fields (note that the charge and color indices in table 1 can be dropped in case of gravity)

$$V: \quad A_\mu,\ \sigma,\ \lambda,\ \bar{\lambda},\ D, \tag{4.2}$$

where A_μ is the gauge field, σ and D are auxiliary scalar fields, and λ, $\bar{\lambda}$ are two-component complex Dirac spinors. The superfield 4.2 is as described in [17] "*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.*" The relevant gauge covariant derivative is then

$$\partial_\mu + \mathrm{i}[A_\mu, ..]. \tag{4.3}$$

The usual gauge field strength is

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

The question of gravity-matter coupling was resolved in [18]. Further, the major result of [15] is the expression for the partition function (technically, the one-loop determinant) of a massive scalar field minimally coupled to a background metric $g_{\mu\nu}$ [18]

$$Z_{\text{scalar}}[g_{\mu\nu}] = \exp\frac{1}{4}\mathbb{W}[A_L, A_R]\ . \tag{4.5}$$

Conveniently, it is a gauge invariant object of the Chern-Simons connections $A_{L/R}$. The object $\mathbb{W}[A_L, A_R]$, coined the Wilson spool [16], is a collection of Wilson loop operators W [18]

$$W_R = \mathrm{Tr_R Pexp}\Big(\mathrm{i}\int_\gamma \mathrm{A}_\mu \mathrm{dx}^\mu\Big). \tag{4.6}$$

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 in the evaluation of Wilson loop expectation values [17] 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. – More detailed description of Castro et al. [15, 16] is beyond the scope of this note.

Gravitational waves have two polarization states propagating with the speed of light. Parity violation, due to Levi-Civita tensor $\epsilon_{\mu\nu\rho}$ in (A.1), causes the two polarization states to have different intensities. As to the power spectrum, highest frequency GWs should have strongest intensity due to very early preon-preon (Abelian) Möller scattering above energies $\Lambda_{cr} \sim 10^{10} - 10^{16}$ GeV when preons formed a hot gas. All GWs from the time period $t_{\text{Planck}} \leq t \leq 10^{-35}$ s are maximally redshifted by a factor is approximately $z \sim 10^{27} - 10^{30}$, which pushes the GW wavelengths far beyond the observable range. The NANOGrav detector [19] has the low-frequency end at $f \sim 10^{-9} Hz$, corresponding the wavelength of approximately $\lambda_{max} \sim 3 \times 10^{17}$ m, or roughly 30–32 light years. Wavelengths larger than λ_{max} cause background noise in the detector. LISA detectors [20] in turn are designed to measure GWs in the range of 0.1 mHz – 1 Hz.

In addition to direct detection of GWs, the next decade CMB data may reveal them through the polarization pattern in the CMB B-modes [21, 22], which are difficult to detect. Detection and parametrization of GWs is a subject of itself, see e.g. [23].

4.2 Mathematical Supplement

We have not yet discussed the possible compatibility of Chern-Simons theory and the Hartle-Hawking no-boundary proposal. Quite promisingly, Kodama showed [24] that the Ashtekar-Hamilton-Jacobi equation of General Relativity has the Chern-Simons action as a solution with nonzero cosmological constant. It was therefore expected that when the theory is canonically quantized the quantum constraint equations would have a solution of the form $exp(iS_{CS})$.

The Kodama state has been, however, a subject of debate. In 2003, Witten published a paper arguing that the Kodama state is unphysical, e.g. it has negative energies [25]. A few years later, Randono generalized the Kodama state [26, 27]. He concluded that the Immirzi parameteris generalized to a real value, the theory matches "*with black hole entropy, describes parity violation in quantum gravity, and is CPT invariant, and is normalizable, and chiral, consistent with known observations of both gravity and quantum field theory*" [26, 27]. The physical inner product resembles the MacDowell–Mansouri formulation of gravity, which may include torsion [28, 29].

Some years after the Kodama paper, Louko [30] studied the CS and Hartle-Hawking compatibility problem in more general spacetimes, namely in Bianchi type IX (homogeneous but anisotropic) quantum cosmology with S^3 spatial surfaces. He showed that "*among the classical solutions generated by S_{CS}, there is a two-parameter family of Euclidean space times that have a regular closing of the NUT-type [31]. This implies that, in this model, a wave function of the semiclassical form $exp(iS_{CS})$ can be regarded as compatible with the no-boundary proposal of Hartle and Hawking*".

In 2022, Alexander et al. introduced Ashtekar [32] formalism in their approach to quantum gravity. In this formalism the dynamical variables are Yang-Mills gauge field having the SU(2) gauge group. Now the Wheeler-DeWitt equation can be solved exactly. The ground state is the Chern-Simons-Kodama (CSK) state. They "*seek to find a new CSK state that includes fermionic matter* *on the same footing as gravity (...). In this work, we explore a quantization of gravity with the inclusion of fermionic matter by solving both the gravitational and fermionic Hamiltonian constraint. We find an exact wave function that has interesting connections to the CSK state with the inclusion of torsion. We then seek to make contact with the Hartle-Hawking/Vilenkin wave functions of quantum cosmology from this exact wave function.*"

In 2003, Oda showed [33] that "*the Kodama state has its origin in topological quantum field theory so that this state has a large gauge symmetry which includes both the usual gauge symmetry and diffeomorphisms. Accordingly, the Kodama state automatically satisfies the quantum Ashtekar constraints.*" A related article is [34].

We leave the Kodama state, CS-HH compatibility and other such problems and accept sections 3 and 4 as phenomenological tools for the present. In the next section 4.3 we review the classical case.[6]

4.3 General Relativity Modified by Chern-Simons Term

In the following we reiterate subsection 4.1 for classical astronomical situations including a 3D CS interaction (to be promoted to four dimensions) to General Relativity. This has been studied by Jackiw and Pi [35]. Their modification of GR is the the three-dimensional Chern-Simons term $CS(\Gamma)$

$$CS(\Gamma) = \frac{1}{4\pi^2} \int d^3x \ \varepsilon^{ijk} \ (\frac{1}{2} \ {}^3\Gamma^p_{iq} \, \partial_j {}^3\Gamma^q_{kp} + \frac{1}{3} {}^3\Gamma^p_{iq} \ {}^3\Gamma^q_{jr} \ {}^3\Gamma^r_{kp}). \tag{4.7}$$

Latin letters range over three values, indexing coordinates on a three manifold. Greek letters denote analogous quantities in four dimensions. The superscript 3 denotes three-dimensional objects.

The Chern-Simons topological current, a four-dimensional quantity, is

$$K^\mu = 2\varepsilon^{\mu\alpha\beta\gamma} \left[\frac{1}{2} \ \Gamma^\sigma_{\alpha\tau} \, \partial_\beta \ \Gamma^\tau_{\gamma\sigma} + \frac{1}{3} \ \Gamma^\sigma_{\alpha\tau} \, \Gamma^\tau_{\beta\eta} \Gamma^\eta_{\gamma\sigma} \right], \tag{4.8}$$

It satisfies the equation

$$\partial_\mu K^\mu = \frac{1}{2} {}^*R^\sigma{}_\tau{}^{\ \mu\nu} \ R^\tau{}_{\sigma\mu\nu} \equiv \frac{1}{2} {}^*RR, \tag{4.9}$$

where $R^\tau{}_{\sigma\mu\nu}$ is the Riemann tensor

$$R^\tau{}_{\sigma\mu\nu} = \quad \partial_\nu \ \Gamma^\tau_{\mu\sigma} - \partial_\mu \ \Gamma^\tau_{\nu\sigma} \ + \Gamma^\tau_{\nu\eta} \Gamma^\eta_{\mu\sigma} - \Gamma^\tau_{\mu\eta} \Gamma^\eta_{\nu\sigma}, \tag{4.10}$$

and its dual is ${}^*R^\tau{}_\sigma{}^{\mu\nu}$

$${}^*R^\tau{}_\sigma{}^{\mu\nu} = \frac{1}{2} \ \varepsilon^{\mu\nu\alpha\beta} R^\tau{}_{\sigma\alpha\beta}. \tag{4.11}$$

Note that the zero component of K^μ, i.e. K^0, is not related to the Chern-Simons term (4.7).[7]

[6] It is possible that quantum gravitational waves are not found.

[7] Extending the Einstein theory with a Chern-Simons term can be done in different ways.

We now choose the following Einstein-Hilbert action [35]

$$\mathrm{I} = \frac{1}{16\pi G}\int d^4x\left(\sqrt{-g}R + \frac{1}{4}\theta^* RR\right) = \frac{1}{16\pi G}\int d^4x\left(\sqrt{-g}R - \frac{1}{2}v_\mu K^\mu\right), \tag{4.12}$$

where θ is the CS coupling field, and $v_\mu \equiv \partial_\mu \theta$ is the embedding coordinate. The variation of the first term in the integrand with respect to $g_{\mu\nu}$ produces the usual Einstein tensor $G^{\mu\nu} \equiv R^{\mu\nu} - \frac{1}{2}\, g^{\mu\nu}R$. The variation of the second, topological term gives a traceless symmetric, second-rank tensor, which we call the four-dimensional Cotton tensor $C^{\mu\nu}$

$$C^{\mu\nu} = \frac{-1}{2\sqrt{-g}}\left[v_\sigma\left(\varepsilon^{\sigma\mu\alpha\beta}D_\alpha R^\nu_\beta + \varepsilon^{\sigma\nu\alpha\beta}D_\alpha R^\mu_\beta\right) + v_{\sigma\tau}\left({}^*R^{\tau\mu\sigma\nu} +^* R^{\tau\nu\sigma\mu}\right)\right] \tag{4.13}$$

The above deformation of Einstein's equation finally reads

$$G^{\mu\nu} + C^{\mu\nu} = -8\pi G T^{\mu\nu}. \tag{4.14}$$

For consistency, let us take the covariant divergence of (4.14). The Bianchi identity enforces $D_\mu G^{\mu\nu} = 0$. In the right hand side, diffeomorphism invariance of matter degrees of freedom implies that $D_\mu T^{\mu\nu} = 0$. But the covariant divergence Cotton tensor is non-zero [35]

$$D_\mu C^{\mu\nu} = \frac{1}{8\sqrt{-g}} v^{\nu *} RR. \tag{4.15}$$

Thus the extended theory (4.14) possess solutions that are necessarily confined to spaces with vanishing ${}^*RR = 2\partial_\mu K^\mu$. The results of [35] indicate that diffeomorphism symmetry breaking effects are barely visible. Parity violation due to Levi-Civita tensor $\epsilon_{\mu\nu\rho}$ causes again the two polarization states to have different intensities. This effect should occur in astronomical situations but milder because of tensor modes of GR.

5 Conclusions

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 particles and their structures of hugely various sizes..

Properties of the scenario include:

- the universe begins in a topological preon state, the standard model of particles is obtained before reheating, thereafter standard model of cosmology operates,
- the no-boundary condition describes the existence of the universe in a self consistent manner,
- there are no initial or black hole singularities due to no-boundary condition,

- candidate particles are predicted for the dark sector,
- the one family flavor symmetry is $SU(N_f)$ extendable,
- non-perturbative and perturbatively all order calculable quantum gravity is conjectured,
- classicalization is explained by the Wentzel-Kramers-Brillouin (WKB) semi-classical phenomenon and decoherence due to interactions,
- mechanism for baryon asymmetry has been constructed,
- polarization states of primordial gravitational waves have different intensity, their power spectrum is weighted towards high frequency due to preon Möller scattering,
- *CS action (A.1) is key to all quantum interactions and particle structure, which is the novel discovery of this mini review.*

On the other hand, in section 4 tensor supermultiplet is needed in addition of CS terms. Both components occur in string theory.

We have constructed a model with single Chern-Simons basic action to build a model of all particles (first generation) and interactions. This is combined with Hartle-Hawking initial conditions for the very early cosmic expansion, which indicates an element of a model of "everything" – to the extent it can be defined.

A Chern-Simons Action

An instructive introduction to CS theory is [36].

The Abelin CS action can be written in terms of A_μ as

$$S_{CS}[A] = \frac{k}{4\pi}\int_M d^3x \epsilon^{\mu\nu\rho} A_\mu \partial_\nu A_\rho. \tag{A.1}$$

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 [15]

$$S = k_L\, S_{CS}[A_L] + k_R\, S_{CS}[A_R]\ , \tag{A.2}$$

with

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

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

$$I_{\mathrm{GCS}} = \frac{1}{2\pi}\mathrm{Tr}\int \left(\omega\wedge \mathrm{d}\omega + \frac{2}{3}\omega\wedge\omega\wedge\omega\right) + \frac{1}{2\pi\ell_{\mathrm{dS}}^2}\mathrm{Tr}\int \mathrm{e}\wedge\mathrm{T}\ , \tag{A.4}$$

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

In the last but one paragraph of subsection 4.1 the cosmological numbers were obtained by using generative AI (Scholar CPG).

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