Supersymmetry *Entière*
Preons, Particles and Inflation

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Abstract

A scenario of particles with unbroken supersymmetry has been proposed recently, a supersymmetric preon model. It offers an economic basis for constructing the standard model particles and going beyond it to supergravity. The model predicts that the standard model's superpartners do not exist in nature. The article is largely a review of selected papers. The model is tentatively explored towards quark and lepton structure. The supersymmetric Wess-Zumino and Starobinsky type of models of inflation are discussed. Both are found to agree well with the Plank 2018 CMB data, thus giving experimental support to supersymmetry on an energy scale of 10^{13} GeV. Some future directions are hinted.

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1 Introduction

It is commonly stated that the CERN LHC has 'failed' to discover supersymmetry (SUSY). However, LHC has given strong support for the standard model of particles (SM). Accordingly, I have proposed model that is supersymmetric and the constituents of which build the standard model. Supersymmetry functions on the constituent, or preon, level and it is unbroken, or spontaneously broken. The SUSY preon model contains all the fields and their superpartner fields in its supermultiplets. This has the consequence that, within this model, no standard model superpartners (like squarks, sleptons, gluinos etc.) exist in nature. This is the crucial test of the SUSY peon scheme. Other tests are many phenomenological calculations, which differ from the SUSY SM ones.

In the preon model, quarks and leptons are represented as three preon bound states. The number of elementary superfield fermion fields is $N_F = 2$, whereas in the supersymmetric standard model $N_F = 16$ (2 quarks in 3 colors, 2 leptons and their superpartners, for the first generation in both models). On the other hand, the physics on preon level is largely open. To get some idea of it, I overview results obtained by studying the Kerr-Newman metric for complex values of radial coordinate. I explore and collect ideas that would make it possible to approach a model of SM particles with bound preons and which makes contact with gravity.

The proper case of comparing this supersymmetric model with available experimental data is at present the CMB data of Planck 2018. The CMB measurements open a window to energies well above any accelerator energy and only a few decades below Planck scale. The agreement between the gravity driven model and data is good. The connection of the leading inflationary model to supersymmetry is elucidated.

The article is organized as follows. In section 2.1 I give motivation for the preon model. The construction of scalars, quarks and leptons as composite states of supersymmetric preons is presented in section 2.2. In section 3.1 a graviton condensate model and in section 3.2 an over-spinning black hole model of the microscopic black hole interior are overviewed and discussed. A possible mechanism for white hole formation is black hole to white hole tunneling process which is treated in section 4 together with supersymmetry compatible Starobinsky and Wess-Zumino models of inflation. The possibility of primordial black holes making substantial part of dark matter is considered. Conclusions are given in the final section 5. Section 2 contains summary of previous original work while sections 3 - 4 form an exploratory overview of some recent literature on model building for black holes that might give support the preon model. The leading thought of the article is supersymmetry - unbroken. Sections 3.2 - 3.5 may be omitted on first reading. The article is intended to be pedagogical and self-contained. An Appendix, in two sections A.1 - A.2, is included to cover basic material of gravity, which may show current and future directions on the subject.

2 Preons

2.1 Why Preons?

When one wants to go beyond the standard model one has to consider what is the most important element missing from the SM. Here it is assumed this would be gravity. Admittedly, it also is the most difficult problem in all of theoretical physics. Therefore it is safer to start with something reasonably simple and generally accepted like vacuum solutions of Einstein equations. Or in other words, global internal symmetries are not allowed by quantum gravity [3]. In such a scheme the SM particles, quarks and leptons carrying baryon and lepton number, may not be the best particles for supersymmetric model building.

A model for quark and lepton constituents was introduced in [4, 5, 6, 1]. I consider the supersymmetric[1] model scheme with these properties

[1] Supersymmetry was anticipated in passing in [4].

- the quantum numbers of basic objects must be those available for vacuum solutions of Einstein equations: mass, spin and charge (no-hair),
- supersymmetry, the unbroken global spacetime symmetry, is valid for preons; the basic superfields are members of a supermultiplet which includes the graviton, photon, a spin $\frac{1}{2}$ preon, and their superpartners, and
- scalar particles, preons, quarks and leptons are classified using the quantum group SLq(2) representations [7, 8].

I believe this structure of the preon model brings clarity as compared to the case of traditional approach to supersymmetry and grand unification as follows. The crucial distinctive feature of the present model is that

- it inholds matter-radiation unification, or supersymmetry, built in on preon level. This means e.g. that the photon has a superpartner with the same quantum numbers, but spin $\frac{1}{2}$ lower (see (2.3)), and
- secondly, at energies above

$$\Lambda_{cr} \sim 10^{16}\text{GeV} \tag{2.1}$$

there are only two interactions, gravity and electromagnetism.[2] The weak and strong interactions are stellar and terrestrial level inreactions (to be derived from (2.4)).

I presume that quantum gravity, when available, will organize the preons in bound states in three generations. Alternatively, there may be a new very strong gauge interaction between the preons, like e.g. in [9, 10, 11, 12]. In those cases introducing supersymmetry as indicated above fails.

2.2 Supersymmetric Preon Model

In the present scenario, at the energy of the order $\Lambda_{cr} \sim 10^{16\pm1}$ GeV quarks and leptons ionize, or make a phase transition, into their constituents, preons. Below this critical point, I consider the standard model a well behaving renormalizable theory with a UV momentum cutoff Λ_{cr}. Above this transition energy unbroken supersymmetry enters the scene: it is defined for preons, which are now unbound and massless.

Compared to main stream theory parameters, Λ_{cr} is of the order of the grand unified theory gauge coupling unification energy and the proton decay mediating X-boson mass lower limit, corresponding to a proton lifetime of 10^{32} years. If gravitational waves of quantum feature were detected (several years ago) the energy scale would be 10^{16} GeV.

In this simple supersymmetric preon model there is the graviton G and its spin $\frac{3}{2}$ superpartner gravitino $\tilde{G}$

$$G = \begin{pmatrix} \rightarrow \\ \leftarrow \end{pmatrix} \text{ and } \tilde{G} = \begin{pmatrix} \rightarrow \\ \leftarrow \end{pmatrix} \tag{2.2}$$

[2] Because of asymptotic freedom of quantum chromodynamics this may be considered as an approximation to a grand unified theory.

This the graviton supermultiplet.

In addition there are the massless fields the photon γ and its neutral spin $\frac{1}{2}$ superpartner, the photino, denoted $\tilde{m}^0$. The second superpair is the spin $\frac{1}{2}$, charge $\frac{1}{3}$ light preon m^+ and two scalar superpartners $\tilde{s}_i^+$, i = 1, 2. All fields γ, $\tilde{m}^0$, m^+ and $\tilde{s}_i^+$ have two degrees of freedom:

$$\gamma = \left(\begin{array}{c} \rightarrow \\ \leftarrow \end{array} \right) \text{ and } \tilde{\mathrm{m}}^0 = \left(\begin{array}{c} \uparrow \\ \downarrow \end{array} \right), \ \mathrm{m}^+ = \left(\begin{array}{c} \uparrow \\ \downarrow \end{array} \right) \text{ and } \tilde{\mathrm{s}}^+_{1,2} \tag{2.3}$$

where the horizontal and vertical arrows refer to helicity and spin, respectively, and $+$ and 0 refer to charge in units of $\frac{1}{3}$ electron charge. The $\tilde{m}^0$ is a Majorana fermion. The γ and the $\tilde{m}^0$ form the gauge, or vector, supermultiplet and the m^+ and the $\tilde{s}^+_{1,2}$ form the chiral supermultiplet. The R-parity for fields in (2.3) is simply $P_R = (-1)^{2(spin)}$. The m^+ and $\tilde{m}^0$ are assumed to have zero, or light mass of the order of the first generation quark and lepton mass scale.[3]

The supermultiplet construction (2.2) together with (2.3) define matter-radiation unification, or preunification, in terms of spacetime symmetry rather than internal symmetry.

Assuming a generic attractive interaction, or potential, the preons combine freely without extra assumptions into standard model fermion composite states. They form a three member combinatorial system, modulo three [5]. For the same charge preons fermionic permutation antisymmetry factor ϵ_{ijk} must be included. These arguments lead heuristically to four bound states made of preons, which form the first generation quarks (q) and leptons (l) (dropping the tildes)

$$\begin{aligned} u_k &= \epsilon_{ijk} m_i^+ m_j^+ m^0 \\ \bar{d}_k &= \epsilon_{ijk} m^+ m_i^0 m_j^0 \\ e &= \epsilon_{ijk} m_i^- m_j^- m_k^- \\ \bar{\nu} &= \epsilon_{ijk} \bar{m}_i^0 \bar{m}_j^0 \bar{m}_k^0 \end{aligned} \tag{2.4}$$

More details are given in [1, 5] and references therein.

Bound states of scalar constituents do not make a spectrum like fermions. A neutral, very light two body bound state is expected to exist

$$a_i^0 = \tilde{s}_i^+ \ \tilde{s}_i^-, \quad i = 1, 2 \tag{2.5}$$

Scalar bound states can also be formed from the fermions

$$\begin{aligned} b^0 &= m^+ m^- \\ c^0 &= m^0 m^0 \\ h^\pm &= m^\pm m^0 \end{aligned} \tag{2.6}$$

The states (2.5) and (2.6) (and other possible states including mixtures) are candidates for the Higgs and axion, which are important in spontaneously broken symmetries of the standard model. Finally, the model allows an unbound scalar charge $\frac{1}{3}$ field.

[3] A different kind of supersymmetric preon model has been presented in [13, 14].

3 Particles and Holes

Lacking experimental data on black holes, one has to experiment with models as in this section. To this end, I consider what role black holes may have in fundamental particle structure. This idea is, for better or worse, not new [15, 16, 17].

3.1 Graviton Condensate Singularity

Let us begin with a brief overview of the model of [18]. The authors propose a model which includes spacetime phase transition and graviton condensate inside a spinning black hole. The radii of the two horizons of a Kerr-Newman black hole [19] are

$$r_{\pm} = m \pm \sqrt{m^2 - a^2 - q^2} \tag{3.1}$$

where m is its mass, a its angular momentum per mass J/m and q its charge. When $m^2 < a^2 + q^2$ (3.1) may loose its physical meaning unless a complex radius is introduced: with complex radius (3.1) has wider meaning so rewrite it as follows

$$r_{\pm} = m \pm \sqrt{m^2 - a^2 - q^2} = m \pm i\sqrt{a^2 + q^2 - m^2} \equiv (r_R, \pm r_I) \tag{3.2}$$

For a light low energy particle $a \gg q, m$ and therefore $r_I \approx ia$. As the energy of the particle increases the imaginary radius r_I decreases. After the value $m = a^2 + q^2$ r_I becomes real and the particle makes a phase transition into a Kerr-Newman black hole. The time-like space between the two horizons is realized imaginary space encrusted by real space outside the horizon. r_R of a real KN black hole describes its origin as a 2D spherical surface in 3D space. The r_I determines the boundary of the realized imaginary space, appearing as its two horizons.

In the Dvali-Gomez model [20] a graviton in a Schwarzschild black hole consisting of Bose-Einstein condensate (BEC) of N gravitons has a mass $m = M/N = 1/M$. The spin of the graviton is 2 and charge 0, thus

$$r_I = ia = 2iM \tag{3.3}$$

The module of graviton's $r_I = 2M$ is the radius of the Schwarzschild black hole. The graviton's r_R

$$r_R = m = \frac{1}{M} \tag{3.4}$$

is the Compton wavelength of the black hole of mass M.

The singularity of the black hole in the center extends up to the horizon [21] making it a firewall.

In [21] it is shown that the gravitons of the Bose-Einstein condensate model [20] can be described by the complex Kerr-Newman metric. The hole is slightly naked firewall. Most notably, both particles and black holes are derivable from the complex KN metric. The module of gravitons r_I is the same as the radius of the BEC black hole. The r_R of a KN black hole gives the position of the origin of the imaginary space, which shrunk to real axis, and it appears as a 2D sphere centered at the origin. The real valued r_I gives the boundary of the real valued imaginary space, appearing as its two horizons.

The imaginary radius of a Dirac particle has both positive and negative values. To have meaning for the negative value the origin of the complex space of the Dirac particle has to be a 2-dimensional surface centered at the origin. The particle appears as an Schwarzschild black hole with radius $R_i = 2r_I$ [21]

$$R_i = 2r_I = 2i\sqrt{a^2 + q^2 - m^2} \tag{3.5}$$

This Schwarzschild black hole has a mass $M_i = r_I = i\sqrt{a^2 + q^2 - m^2}$ and Hawking temperature $T_i = \left(4i\sqrt{a^2 + q^2 - m^2}\right)^{-1}$.

A point particle moves forward in four dimensional spacetime along the time dimension. This motion looks different in the hidden three dimensional imaginary space. The energy moves on the horizon of the imaginary Schwarzschild black hole at the speed of light

$$\theta = \frac{ct}{|R_i|} \approx \frac{ct}{2a} = mt \tag{3.6}$$

where θ is the phase angle of the particle's wave function.

Let the particle consist of small pieces of mass dm_j which move on the origin surface at half speed of light thus keeping the same phase angle. The energy of the particle is in uniform circular motion around the origin having a radius $|R_i|/2$. The spin of the particle has a dynamic angular momentum origin in the hidden imaginary space [21]

$$L = \sum_{j=1} dm_j c \frac{|R_i|}{2} \tag{3.7}$$

The gyromagnetic ratio has the value two, as given by the Dirac equation. Each preon could be a black hole of this kind. But it is difficult to think of this model as confining preons in the interior.

3.2 Dirac–Kerr-Newman Fermion

In general relativity little is known of microscopic systems, which could be considered for modeling of elementary particles. Let us study in more detail the candidate geometry of the previous section 3.1: a rotating black hole [22]. The safest fact about black holes is the existence of a horizon though some discussion is still going on of its detailed structure. The inside of the hole is fully open and the singularity is a point where the classical theory will certainly break down. Therefore something new has to be made up to describe the inside. It is known that fermions generate a strong repulsive force under conditions like in the center of a black hole. The singularity is in this case said to be replaced by a bounce. A heuristic scheme is proposed on this basis. A black hole spacetime is divided in the radial coordinate in three regions (i) the region $r < M_{\mathrm{Pl}}^{-1}$ is the quantum (and non-linear) gravity region. It may be characterized by a 'potential' inside the hole such that $V(r \sim 0) \sim \infty$ due to quantum effects, or fermionic repulsive interaction, (ii) boundary region with $V(r = 2M) \sim \infty$ due to the horizon, (iii) in the interior region $M_{\mathrm{Pl}}^{-1} < r < 2M$ the system is classical and non-linear.

The simplest assumption for the interior $M_{\mathrm{Pl}}^{-1} < r < 2M$ is Minkowski space [23]. A dynamical model for the Minkowski interior with Kerr-Newman exterior solution was developed in [24, 25], which I attempt to summarize below.

The Kerr-Newman solution has been used as a model for the electron after the discovery [22] that it has the gyromagnetic ratio $g = 2$. This leads to the question are the Dirac equation and the Kerr-Newman solution somehow connected? In this subsection I disclose a model by Burinskii [26] which connects the Dirac equation and the spinor (twistor) structure of the Kerr solution. The Burinskii model is based on the assumption that the Dirac equation and the Kerr solution are complementary to each other. The Dirac spinors fit together with the structure of the Kerr spinning particles. The combined Dirac–Kerr-Newman system is indistinguishable from the behavior of the Dirac electron. I refer to [26] for details, and discuss here only the Kerr-Schild metric used in the model.

The angular momentum per unit mass $a = J/m$ is important for elementary particles. For an electron a is huge, about 10^{22} (in units $\mathrm{G} = \mathrm{c} = \hbar = 1$). This is so big that the black hole horizons disappear. This is called over-rotating Kerr geometry.

The source of a Kerr spinning particle is classical naked ring singularity. The ring represents a string which is able to have excitations generating the spin and mass of the extended object. The ring is a focal line of the principal null vector congruence which is a bundle of light-like rays (Riemann tensor eigenvectors). Towards the end of this section we build a regular field model for the Kerr source such that the source forms a flat metric bubble with a superconducting interior vacuum and an exterior with an exact Kerr solution.

The form of the metric is determined by a null vector field $k^\mu(\mathrm{x})$ which is tangent to the vortex of light-like rays. The metric is called the Kerr-Schild form of Kerr-Newman metric

$$g^{\mu\nu} = \eta^{\mu\nu} + 2H(r,\theta)k^\mu k^\nu \tag{3.8}$$

where $\eta^{\mu\nu}$ is the Minkowski metric, the vector potential for the charged Kerr-Newman solution is

$$A_\mu = \mathcal{A}(x)k_\mu \tag{3.9}$$

and the function $H(r,\theta)$ is

$$H(r,\theta) = \frac{mr - e^2/2}{r^2 + a^2\cos^2\theta} \tag{3.10}$$

where r, θ are ellipsoidal coordinates

$$x + iy = (r + ia)e^{i\phi}\sin\theta, \quad z = r\ \cos\theta, \quad t = \rho - r \tag{3.11}$$

The complexification $(x, y, z) \to (x, y, z + ia)$ to the source of the Coulomb potential at origin yields

$$\Phi(x, y, z) = \mathcal{R}e\frac{q}{\tilde{r}} \tag{3.12}$$

where $\tilde{r} = \sqrt{x^2 + y^2 + (z - ia)^2}$ is complex. On the real slice (x, y, z) this solution gains a singular ring for $\tilde{r} = 0$. The radius of the ring is a and it is located in the plane $z = 0$. The solution can be presented in the oblate spheroidal coordinate system $(\tilde{r}, \theta)$ where $\tilde{r} = r + ia\ \cos\theta$. The space is seen to have twofold structure with the ring-like singularity as the branch line. For each real point (t, x, y, z) there are two points, one lying on the positive sheet with $r > 0$ and the other on the negative sheet with $r < 0$.

The potential (3.12) corresponds exactly to the electromagnetic field of the KN solution. The complex shift $\vec{a} = (a_x, a_y, a_z)$ indicates the angular momentum of the KN solution.

3.3 Gravitating Bag Model

The Dirac equation inside the KN soliton has been analyzed [27] with the results that the KN solution shares many features with the hadronic bag models. The gravitating bag has to preserve the external KN field. The bag models are based on semiclassical theory including elements of quantum theory based on Minkowski spacetime without gravity. To resolve the conflict between gravity and quantum theory the following solution is proposed [29, 30]: inside the bag there is flat spacetime and outside the bag there is exact KN model solution.

The Kerr-Schild form of metric is (3.8) and (3.10). The variables r and θ are ellipsoidal coordinates and the null vector field $k_\mu(x)$ forms a vortex polarization of Kerr spacetime. Between the negative sheet $r < 0$ and the positive sheet $r > 0$ there is the surface $r = 0$, a bridge connecting the two sheets. The disk $r = 0$ is spanned by the Kerr singular ring $r = 0$ and $\cos\theta = 0$. The null vector fields are different on these sheets and are thus denoted as $k^{\mu\pm}(x)$ making two different congruences $\mathcal{K}^\pm$ with metrics $g^\pm_{\mu\nu} = \eta_{\mu\nu} + 2Hk^\pm_\mu k^\pm_\nu$.

A regularization of the two-sheeted Kerr geometry was suggested by Lopez [28]. The singular region and the negative sheet were excised and replaced by a regular core manifold having flat metric $\eta_{\mu\nu}$. This core forms a vacuum bubble. It is glued to the external manifold, the Kerr-Newman solution, which it must match at the boundary $r = R$ as follows

$$H_{r=R}(r) = 0 \tag{3.13}$$

which gives

$$R = r_e = \frac{e^2}{2m} \tag{3.14}$$

The bubble covers the Kerr-Newman singular ring and forms a thin rotating disk of radius[4]

$$r_C \sim a = \frac{\hbar}{mc} \tag{3.15}$$

[4] The electron radius can be estimated by considering the electron's charge inside a sphere and

The oblateness of the disk $r_e/r_C \sim e^2$ is the fine structure constant $\alpha \sim 1/137$. The bubble model is a soliton structure of a vacuum bubble with domain wall boundary. Classical gravity controls the external spacetime and quantum theory makes a pseudo-vacuum state inside the soliton with the Higgs mechanism breaking the symmetry.

The discrepancy between gravity and quantum theory is avoided by three principles: (i) spacetime is flat inside the core, (ii) outside the core there is the Kerr spacetime and (iii) the boundary between inside and outside of the core is determined by the Lopez condition (3.13).

The effectiveness of these principles (i)-(iii) define uniquely the form of the soliton and the following properties [29, 30, 31, 32, 33]: (a) The Higgs field is an oscillon, oscillating with a frequency $\omega = 2m$ and (b) angular momentum is quantized as $J = \frac{n}{2}, n = 1, 2, 3, \ldots$

A tentative model for preon physics is a construction by Burinskii where the electron, or a light preon in this article, is considered an over-spinning Kerr black hole with a superconducting bag vacuum with supersymmetric scalar potential [24]. The scalar and U(1) part of the Lagrangian is

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{2}\big(\mathcal{D}_\mu\Phi\big)\big(\mathcal{D}^\mu\Phi\big)^* - V(\Phi) \tag{3.16}$$

where $\mathcal{D}_\mu = \nabla_\mu + ieA_\mu$, Φ is the Higgs field, $F_{\mu\nu} = \partial_\nu A_\mu - \partial_\mu A_\nu$ and $V(\Phi) \sim (\Phi^*\Phi - \langle|\Phi|\rangle_0^2)^2$ is a potential derived from a superpotential $W(\Phi_i)$. In fact, a preonic scalar field scheme must be introduced which includes three fields $\Phi^i, i = 1, 2, 3$ with the Higgs field being Φ^1. The potential V is

$$V(r) = \sum_i |\partial W/\partial\Phi_i|^2 \tag{3.17}$$

and the superpotential is

$$W(\Phi^i, \bar{\Phi}^i) = \Phi^2\big(\Phi^3\bar{\Phi}^3 - \eta^2\big) + \big(\Phi^2 + \mu\big)\Phi^1\bar{\Phi}^1 \tag{3.18}$$

where μ and η are real constants. (3.18) gives the necessary concentration of the Higgs field inside the bag. Using the condition $\partial W/\partial\Phi_i = 0$ one gets two vacuum states $V = 0$:

(i) internal vacuum $r < R - \delta$ where $|H| = \eta$,

(ii) external vacuum $r > R + \delta$ where $|H| = 0$ and

(iii) transitional area $R - \delta < r < R + \delta$ with a spike of potential $V > 0$.

The requirements (i)-(iii) above concerning the structure of the vacua establish the stability of the bag. The wave length of a Kerr fermion is brought to Compton scale $\hbar/2m$ because of high spin/mass value $\sim 10^{22}$ [24]. This makes gravity meeting the quantum world consistent with the uncertainty relations.

neglecting its angular momentum. In Reissner–Nordström metric the radius of the sphere r_q can be defined, in SI units, by $r_q = \sqrt{q^2G/4\pi\epsilon_0 c^4}$ where q is the electron's charge and ϵ_0 is the vacuum permittivity. This gives $r_q = 1.4 \times 10^{-36}$m. The size of the Kerr-Newman ring singularity is $r_a = J/mc$ which gives with electron's mas and spin $r_a = 1.9 \times 10^{-13}$m.

A supersymmetric source matching the Kerr solution has now been indicated. More complicated models have been studied in the literature but the above considerations are characteristic of the present situation. The model discussed above can be considered as modeling a preon or, rather, confining three preons as a bound state. The stability of the three preon state in the black hole to white hole tunneling, see next section 4, would have to be established.

3.4 Kruskal-Szekeres Spacetime

The Kruskal-Szekeres (KS) coordinates extend the Schwarzschild solution to maximally large spacetime manifold available. It turns out that there is our universe and "another" universe which includes a white hole. The KS coordinates (T, X) are defined in terms of Schwarzschild coordinates (t, r, θ, ϕ) as follows

$$\begin{aligned} T &= \left(\frac{r}{2m} - 1\right)^{1/2} e^{r/2m} \sinh\left(\frac{t}{2m}\right) \\ X &= \left(\frac{r}{2m} - 1\right)^{1/2} e^{r/2m} \cosh\left(\frac{t}{2m}\right) \end{aligned} \tag{3.19}$$

for the exterior region $r > 2m$, and

$$\begin{aligned} T &= \left(\frac{r}{2m} - 1\right)^{1/2} e^{r/2m} \cosh\left(\frac{t}{2m}\right) \\ X &= \left(\frac{r}{2m} - 1\right)^{1/2} e^{r/2m} \sinh\left(\frac{t}{2m}\right) \end{aligned} \tag{3.20}$$

for the interior region $0 < r < 2m$.

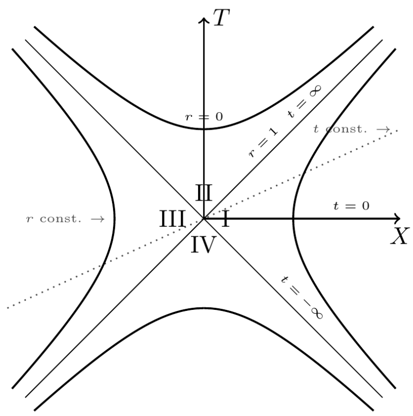

Figure 1: Kruskal-Szekeres diagram illustrated for 2m = 1. The quadrants I and III are the two exterior regions, II is the black hole interior and IV the white hole interior. The ±45° lines are the event horizons. The hyperbolas which bound the top and bottom of the diagram are the physical singularities.

The Schwarzschild radius in KS coordinates is given implicitly from

$$T^2 - X^2 = \big(1 - \frac{r}{2m}\big)\ e^{r/2m} \tag{3.21}$$

for both interior and exterior regions. This is in terms of the Lambert function W

$$\frac{r}{2m} = 1 + W\Big(\frac{X^2 - T^2}{e}\Big) \tag{3.22}$$

The Lambert function is defined by the equation $x = W(x)e^{W(x)}$. The metric in terms of (T, X) is

$$ds^2 = \frac{32m^3}{r}\ e^{-r/2m}\big(-dT^2 + dX^2\big) + r^2 d\Omega^2 \tag{3.23}$$

The event horizons are given by $T = \pm X$ for $r = 2m$. The curvature singularity is on the hyperbola $T^2 - X^2 = 1$.

The coordinate transformation equations (3.19) and (3.20) are defined for $r > 2m$ and $-\infty < t < \infty$. In this region r is an analytic function of T and X. It can be extended at least to the first singularity at $T^2 - X^2 = 1$. The metric (3.23) is defined for $-\infty < X < \infty$ and $-\infty < T^2 - X^2 < 1$.

We analyze what happens to an arbitrary point P near the singularity of a Schwarzschild black hole [34, 35]. The geometry of the interior is homogenous in a third spatial coordinate x, which was originally time-like coordinate t outside the horizon. The gravitational field $g_{\mu\nu}(\tau, x, \theta, \phi)$ in the line element can be written in the form

$$ds^2 = g_{\tau\tau}(\tau)d\tau^2 - g_{xx}(\tau)dx^2 - g_{\theta\theta}(\tau)d\Omega^2 \tag{3.24}$$

where the angular coordinate values satisfy $0 \le \theta \le \pi$ and $0 \le \phi \le 2\pi$. The coordinate x values are in a finite part of the cylinder's axis $]x_{min,x_{max}}[$ and the temporal coordinate τ's range is determined dynamically resulting as $-\sqrt{2m} < \tau < \sqrt{2m}$. Putting (3.24) into Einstein equations one obtains the solution for the line element

$$ds^2 = \frac{4\tau^4}{2m - \tau^2}d\tau^2 - \frac{2m - \tau^2}{\tau^2}dx^2 - \tau^4 d\Omega^2 \tag{3.25}$$

The value $\tau = 0$ corresponds to locations where cylinder's radius goes to zero. The region $-\sqrt{2m} < \tau < 0$ is the interior of a BH. It is the the region II of Kruskal-Szekeres diagram figure 1. This can be shown by a change of variables $t_s = x$ and $r_s = \tau^2$.

The next step of this analysis is done by changing the variables as follows

$$g_{\tau\tau} = N^2\frac{a}{b},\quad g_{xx} = \frac{b}{a},\quad g_{\theta\theta} = a^2 \tag{3.26}$$

The solutions in these variables are

$$a(\tau) = \tau^2,\quad b(\tau) = 2m - \tau^2,\quad N^2(\tau) = 4a(\tau) \tag{3.27}$$

This is the BH interior solution (3.25). From (3.27) we see that the solution can be continued from negative values past $\tau = 0$ without loss of regularity. The gravitational field $g_{\mu\nu}(\tau, x, \theta, \phi)$ evolves regularly over the central singularity to the region $0 < \tau < \sqrt{2m}$.

We cite a simple model for quantum fluctuating line element ds_q which deviates from the classical line element in the vicinity of the classical singularity. We replace $a(\tau)$ in (3.27) by [34]

$$a(\tau) = \tau^2 + l \tag{3.28}$$

where $l \ll m$ is a quantity depending on l_{Pl}, to be fixed later. Now the line element ds_l is

$$ds_l^2 = \frac{4(\tau^2 + l)^2}{2m - \tau^2} d\tau^2 - \frac{2m - \tau^2}{\tau^2 + l} dx^2 - (\tau^2 + l)^2 d\Omega^2 \tag{3.29}$$

This line element has no singularities. The curvature of this pseudo-Riemann spacetime is bounded by the value of the Kretschmann invariant $K(\tau)$ in (3.32), see below.

I assume that Kerr black holes should also have finite curvature at the classical singularity, in spite of the different horizon and singularity structure, as compared to Schwarzschild black holes. It has been shown that a transformation

$$r = r + ia\ \cos\theta \tag{3.30}$$

$$v' = v - ia\ \cos\theta \tag{3.31}$$

takes the Schwarzschild metric to the Kerr metric, with a few subtleties [36]. In fact the situation is better, in the limit $m \to 0$ the Minkowski spacetime results from Kerr metric in agreement with the superpotential (3.18) internal vacuum state.

3.5 Physical Picture

The values $\tau \sim 0$ give the maximal curvature and smooth out the central singularity at $r = 0$. High curvature leads to quantum particle creation which includes gravitons. Their energy-momentum tensor back-reacts on the classical geometry changing its evolution. The value of l can be estimated from the boundedness of curvature at Planck scale. This can be estimated from the Kretschmann invariant $K(\tau)$ [40] for high mass is to order $\mathcal{O}(l/m)$

$$K(\tau) = R_{\mu\nu\sigma\rho} R^{\mu\nu\sigma\rho} \sim \frac{9l^2 - 24l\tau^2 + 48\tau^4}{(l + \tau^2)^8} m^2 \tag{3.32}$$

The maximum value of (3.32) is $K^2(0) = 9m^2/l^6$. In this case the cylindrical tube has a finite thickness, which causes a bounce at the small value l.

The approximate quantum geometry (3.29), which is able to cross the singularity, is constructed to approach the classical geometry (3.25) in the limit

$l \to 0$. The value of l can be estimated from the condition that the curvature is bound at the Planck scale: $l \sim l_{\rm Pl}\ (m/M_{\rm Pl})^{1/3}$.

In a semi-classical description the infalling matter near the singularity consists of a superposition of quantum states, $\sum \psi(m, s, q)$. These are Fock space states of (2.3) in the present model. According to (4.1) the lightest preons have the largest tunneling probability. Light preon fermions therefore fulfill the condition of over-rotating Kerr geometry discussed in subsection 3.2. In terms of the Kruskal-Szekeres diagram in figure 1 the tunneling corresponds folding the XT-plane around the T-axis.

The black to white hole tunneling introduces a special particle 'recycling' or 'reshuffling' (bounce) universe. This seems to get support from recent observations of black holes in the galactic center [37]. Alternatively, the universe may have started from one or more suitable sized black KN holes tunneling in white holes and then preons. The mechanism for producing preon is rather laborious in the present scenario. A third possibility, perhaps the least likely, is that the big bang initial state is given in terms of the supermultiplet field in a major role.

This ends the analysis of Schwarzschild black hole to white hole transition with finite curvature. So there is finite probability for a small mass, e.g. of the order of 100 MeV, to go through the black to white hole transition. It is suggestive to assume that this produces a high spin/mass ($a = J/m$) value $\sim 10^{22}$. The limit $m \to 0$ where the curvature goes to zero corresponds to Minkowski spacetime. However, to have finite a, m cannot go to zero. So there is a mass gap. The last emitted particles, when $T > \Lambda_{cr}$, are a preons. When $T \leq \Lambda_{cr}$ the preons combine into quarks and leptons. The standard model reigns the scene.

The quark and lepton generation question can be roughly estimated assuming the three preons, approximated as preon dipreon, forming bound system. The wave equation of the system is in a first approximation of type Klein-Gordon equation with boundary conditions like $\Psi(r = 2M) = \Psi(r = 0) = 0$, where M is of the order light fermion mass, like 100 MeV. With proper parameters one (or more) energy states can be obtained.

4 Cosmological Inflation

4.1 Cosmological Tunneling

The over-spinning state of a Kerr black hole cannot be obtained by dropping material of certain angular momentum into a Kerr black hole (see e.g. [38]). How, then, can one create a horizonless white hole? A possibility for white hole formation is black hole to white hole tunneling process [39, 40, 41]. A stellar mass object ($m > 3M_\odot$) is in classical GR thought to collapse into a black hole. A quantum gravitational process may, however, disrupt that. In quantum tunneling the classical equations are violated for a short period of time. The classical causal structure is altered so that the dynamics of the local apparent horizon is modified. Therefore the apparent horizon may not evolve into an event horizon.

The information, originally trapped inside the black hole and containing only mass, spin and charge, is now radiated by the white hole. The radiation can only be in the form of supermultiplet (2.3) fields. After a some time the white hole evaporates leaving a spin 0 or $\frac{1}{2}$ remnant preon and later, with decreasing temperature, the phase transition into standard model particles takes place.

For a macroscopic black hole the tunneling probability is small. It becomes larger for smaller mass near the end of the evaporation. The tunneling probability factor P is

$$\begin{aligned} P &\sim e^{-S_E/\hbar} \sim e^{-Gm^2/\hbar c} \\ &\sim e^{m/M_{\text{Pl}}} \end{aligned} \tag{4.1}$$

where S_E is the Euclidean action of the tunneling process. P is of the order of unity when $0 < m \lll M_{\text{Pl}}$ with masses close to zero favored. The tunneling probability is no longer suppressed as the black hole approaches the end of its evaporation. The transition may produce a long-lived white hole with Planck size horizon and very large interior when $m \to M_{\text{Pl}}$. On the other hand, if $m \to 0$ is allowed by quantum gravity light particles may be copiously produced. This may open a way to create over-spinning, light and very short lived white holes.

Some estimates for time scales of quantum processes can be given [41]. The deaths of a black and white holes are quantum phenomena. White hole is formed when a black hole is dying [42]. The lifetime of a black hole is estimated from Hawking radiation. It is $\tau_{BH} \sim m_0^3$ where m_0 is the initial mass of the hole. The lifetime of a white hole is longer $\tau_{WH} \sim m_0^4$. Thus

$$\tau_{WH} = \frac{m_0}{M_{\text{Pl}}}\tau_{BH} \tag{4.2}$$

The time of the tunneling process from white to black hole is of the order of the current mass at transition time [43]. The horizon area and mass of the black hole decrease when the hole is emitting Hawking radiation. The transition occurs when the BH mass reaches the value M_{Pl}.

Consider the possibility that white hole remnants form part of dark matter in the universe. A local dark matter density of $\sim 0.01 M_\odot/pc^3$ is approximately one Planck remnant per 10,000 km^3. These objects are still observable if their lifetime larger than the Hubble time, i.e. $m_0^4 > T_H$. But one expects remnants to be produced by already evaporated black holes the lifetime of which is therefore $m_0^3 < T_H$. Now we have an estimate for possible values of m_0

$$10^{10} g < m_0^3 < 10^{15} g \tag{4.3}$$

These masses of primordial black holes may have produced dark matter now in the form of remnants. The corresponding Schwarzschild radii are between

$$10^{-18} cm < R_0 < 10^{-13}\text{cm} \tag{4.4}$$

The prevailing theory of primordial black hole (PBH) formation indicates that BHs of given mass were formed when their Schwarzschild radii were of the order of the cosmological horizon, which was in the range 4.4 at the end of inflation. These black holes are with us as remnants. They have ended their Hawking evaporation but the resulting white holes have not yet dissipated. For the above black/white hole discussion to be relevant for our particle model enough PBHs must have been produced at the end of inflation. This should not be a problem with the observed mass ratio DM/SMM ~ 5 where SMM denotes ordinary SM matter.

4.2 LISA and Primordial Black Holes

The nature of dark matter is an open question in astro-particle physics. Of the various for candidates of DM the primordial black hole proposal is rather natural because the energy density is very high during inflation. This possibility has gained increasing interest after the observation of gravitational waves (GW) produced in the merger of two $\sim 30\ M_{\odot}$ black holes. PBHs are generated in the early universe by enhancing the comoving curvature perturbations ζ at small scales during inflation. The perturbations are transfered to radiation after inflation through the reheating process, producing PBHs upon horizon re-entry. A collapse to PBHs takes place during the radiation era in regions where the density contrast [44]

$$\Delta(\vec{x}) = 4/9a^2H^2\nabla^2\zeta(\vec{x}) \tag{4.5}$$

is larger than a critical value Δ_c which depends on the shape of the power spectrum.

The comoving curvature perturbation power spectrum is defined as follows

$$\langle\zeta(\vec{k_1})\zeta(\vec{k_2}\rangle' = \frac{2\pi^2}{k_1^3}\mathcal{P}_\zeta(k_1) \tag{4.6}$$

where the prime means dropping the $(2\pi)^3$ times the Dirac delta function for momentum conservation. The variance of $\Delta\vec{x}$ is defined as

$$\sigma^2_\Delta(M) = \int_0^\infty \mathrm{d\ln k\ W^2(k, R_H)}\mathcal{P}_\Delta(\mathrm{k}) \tag{4.7}$$

where $W(k, R_H)$ is a window function to smooth out $\Delta(\vec{x})$ on the comoving horizon length $R_H \sim 1/aH$ and $\mathcal{P}_\Delta(k) = (4k^2/9a^2H^2)^2\mathcal{P}_\zeta(k)$. The fraction of mass β_M of the universe which ends up as PBHs at the time of formation is

$$\beta_M = \int_{\Delta_c}^\infty \frac{\mathrm{d}\Delta}{\sqrt{2\pi}\sigma_\Delta}e^{-\Delta^2/2\sigma^2_\Delta} \simeq \frac{\sigma_\Delta}{\Delta_c\sqrt{2\pi}}e^{-\Delta_c^2/2\sigma^2_\Delta} \tag{4.8}$$

It corresponds to a present fraction of dark matter $\rho_{DM}f_{PBH}(M) \equiv \mathrm{d}\rho_{\mathrm{PBH}}/\mathrm{d\ln M}$ in the form of PBHs of masses M

$$f_{PBH}(M) \simeq \Big(\frac{\beta_M}{7\cdot 10^{-9}}\Big)\big(\frac{\gamma}{0.2}\big)\Big(\frac{106.75}{g_*}\Big)^{1/4}\Big(\frac{M_\odot}{M}\Big)^{1/2} \tag{4.9}$$

where $\gamma \simeq 0.2$ accounts for the efficiency of the collapse and g_* is the number of effective relativistic degrees of freedom.

Now we come to the key point of this subsection. If there are large comoving curvature perturbations generated during the last stages of inflation they inevitably act as a second order source of primordial gravitational waves at horizon re-entry. Using entropy conservation one can relate the mass M of a PBH to the peak frequency of the gravitational waves which collapse to form a PBH

$$M \simeq 50\,\gamma \left[\frac{\text{Hz}}{10^9 f}\right]^2 M_\odot \tag{4.10}$$

The Laser Interferometer Space Antenna (LISA) has the maximum sensitivity at $f \simeq 3.4$ mHz. The corresponding mass 4.10 is $M \simeq 10^{-12} M_\odot$. Current observational constraints on the PBH abundances around this mass are absent, making $f_{BPH}(M) \simeq 1$ possible. If dark matter consits of PBHs with masses $\sim 10^{-12} M_\odot$, then LISA can measure the power spectrum of gravitational waves predictably associated with the production of PBHs.

4.3 Starobinsky Inflation

A quick formula for the early universe is suggested as follows. The inflationary phase of the universe is driven by gravitation (see (4.14) below). It would, in the present scenario, be that black hole matter of dense graviton condensate of section 3.1 expanded the required number of e-folds, like 50 or so. Towards the end of inflation bubbles and turbulence began to appear in the form of Kerr-Newman black holes and preon-antipreon pairs. Preons combined module three and were trapped inside the remnant black holes. Recent cosmic microwave background (CMB) measurements, like Plank 2018, have given valuable information of scalar spectral index, n_s, the tensor-to-scalar ratio, r, and the non-Gaussianity parameter, f_{NL}. Cosmological inflation models and CMB measurements offer a lookout of physics at energy scale far above any accelerator energy and a few orders of magnitude below Planck scale, or the scale where quantum gravitational effects begin to show up.

There is another mechanism for black hole production besides tunneling of the previous subsection 4.1. Black holes may have been formed before the big bang assuming a cosmological bounce model [45]. In this case white hole remnants were formed by evaporating black holes in the contracting phase of the previous eon [46]. The lifetime of these remnants is of the order $\tau_{WH} \sim m_0^4$. The internal volume of the remnant at birth is of the order $V_{WH} \sim m_0^4$ [40]. A remnant must have a lifetime bigger than the Hubble time, $\tau_{WH} > T_H$, to be alive at present. The internal volume of the remnant at bounce time must have been

$$V_{WH} \sim m_0^4 \sim \tau_{WH} > T_H \tag{4.11}$$

The energy density of remnants, in case all dark matter is white hole remnants, must be of the order of the matter density ρ_M which is related to T_H by the

Friedmann equation

$$\frac{1}{T_H^2} \sim \frac{\dot{a}}{a} \sim \rho_M \tag{4.12}$$

The current remnant density ρ is of the order

$$\rho \sim \rho_M \, \frac{1}{T_H^2} \tag{4.13}$$

ρ is also the number density provided the mass of each remnant is of Planckian magnitude. Entropy considerations are given in [46]. The present preon model, with its black hole framework as described in sections 3.1 or rather 3.2, sets itself rather naturally in cosmological considerations about primordial black holes and dark matter.

Several models of inflation have been proposed some time ago and experimental results from the sky have become more and more accurate. It was noted in [47, 48] that quantum corrections to general relativity are important in the early universe. They lead to R^2, with R being the curvature of spacetime, corrections in the Einstein-Hilbert action. In situations where curvature is large these corrections lead to an effective cosmological constant causing an inflationary de Sitter era. In addition, predictions for corrections to the microwave background were obtained in detailed calculations. The simplest Starobinsky action is

$$S_{Staro} = \frac{M_{\rm Pl}^2}{2} \int \mathrm{d^4x}\sqrt{\mathrm{-g}}\Big(\mathrm{R} + \frac{\mathrm{R}^2}{6\mathrm{m}^2}\Big) \tag{4.14}$$

where m ($\sim 3 \cdot 10^{13}$ GeV) is the inflaton mass as the only parameter. Note that it is entirely based on gravitational interactions but it is non-renormalizable. Starobinsky inflation is equivalent to Higgs inflation in supergravity because both models lead to indistinguishable predictions. The potential of the Starobinsky inflation in terms of the canonical inflaton field ϕ

$$V(\phi) = \frac{3}{4} M_{\rm Pl}^2 m^2 \Big[1 - \exp\big(-\sqrt{2/3}\ \phi/M_{\rm Pl}\big)\Big]^2 \tag{4.15}$$

The charasteristic features of this scalar potential are: it is bounded from below, it has an absolute minimum at $\phi = 0$ and it has a plateau which leading to slow roll of inflaton in the inflationary period. The inflation potential drives the inflation and its quantum fluctuations generate deviations from flatness, isotropy and homogeneity.

The Starobinsky model predicts for spectral tilt n_s and tensor-scalar ratio the values $n_s = 1-2/N$ and $r = 12/N^2$ where N is the number e-folds. The 2018 CMB data from the Planck satellite [49] give r<0.064 (95 percent confidence) and $n_s = 0.9649 \pm 0.0042$ (68 percent confidence level).

In [50] the Starobinsky action is extended by the following assumptions (i) introduce four dimensional $N = 1$ supergravity, (ii) inflaton belongs to a massive $N = 1$ vector supermultiplet, and (iii) the kinetic terms of the vector supermultiplet have Born-Infeld (BI) structure, inspired by superstrings and D-branes. These conditions lead to a specific $F(R)$ gravity model. With minimal coupling to gravity the BI action is

$$S_{BI} = -b^{-2} \int \mathrm{d}^4\mathrm{x} \Big[\sqrt{-\mathrm{g}} - \sqrt{-\det\big(\mathrm{g}_{\mu\nu} + \mathrm{b/e} \cdot \mathrm{F}_{\mu\nu}\big)} \, \Big] \tag{4.16}$$

This BI structure of the action also occurs in string theory with bosonic part of open superstrings, D3-branes and partial supersymmetry breaking from N=2 to N=1 supersymmetry. The full action of the self-interacting massive vector supermultiplet of BI structure is complicated, the reader is directed to [50].

4.4 Wess-Zumino Inflation

Starting from the early model of supersymmetry, the Wess-Zumino model [51], one is interested to know whether the CMB data can be tried on it. The data disfavor simple models of inflation with monomial potential ϕ^n. Instead potentials with concave regions like $\phi^2(v-\phi)^2$ may provide reasonable inflation if $v >> M_{\mathrm{Pl}}$ and $\phi_0 \sim v/4$. This form can be interpreted as coming from the minimal Wess-Zumino model with superpotential W and scalar potential V as follows for real fiels Φ [52, 53]

$$W = \frac{1}{2}\mu\Phi^2 - \frac{1}{3}\lambda\Phi^3, \quad V = |\frac{\partial W}{\partial \Phi}|^2 \tag{4.17}$$

The W-Z model field Φ is, however, complex and it can be written as modulus and phase $\Phi = \frac{1}{\sqrt{2}}\phi\ \exp(i\theta)$. The scalar potential becomes now

$$V = A\big(\phi^4 - 2\cos(\theta) v\phi^3 + v^2\phi^2\big) \tag{4.18}$$

This reduces to hilltop form when $\theta = 0$: $V = A(\phi^2(v-\phi)^2$. For the phenomenological analysis a two field form of $\Phi = (\psi + i\sigma)/\sqrt{2}$ is used. The parameters n_s and r were calculated using perturbation theory, quantum field theory techniques and numerically integrating two-point scalar field perturbations in Fourier space. The model gives for $N = 50$ foldings and $v = (5-10)M_{\mathrm{Pl}}$ with initial conditions near $\sigma = 0$ axis results which are very close to what the Starobinsky model gave in subsection 4.3.

5 Conclusions

The present supersymmetric preon model is based on the proposal that the physical domain of supersymmetry is the preon level instead of quark and lepton level. Consequently both the particles/fields and the superpartners are in the basic supermultiplet. Supersymmetric models possess diffeomorphism invariance and they are (D = 10) low energy limits of string theory. Therefore the model has rich enough structure for quantitative study on the way towards quantum gravity.

Summarizing, the model

1. is an economic way to build the standard model fermions, a possible mechanism for three generations is indicated,
2. has no supersymmetric standard model superpartner issue, i.e. no squarks or sleptons etc. exist,
3. contains matter-radiation unification in terms of a spacetime symmetry rather than internal symmetry as traditionally. Weak and strong interactions are, on log scale, late time interactions to provide for chemistry and biology,
4. is due to unbroken symmetry more constrained than models with broken super- and grand unified symmetry,
5. includes a tentative connection between quantum realm and classical relativity defined by boundary condition (3.13),
6. is amenable to the idea of preons being confined inside a Kerr-Newman white hole having a Compton wavelength of correct order of magnitude of light quarks and leptons,
7. includes the parameter $\Lambda_{cr} = 10^{16}$ GeV, in (2.1), which agrees with the energy scale at the end of the inflationary era and with the coupling constant grand unification energy,
8. provides a prolific framework for discussing black/white hole processes, dark matter finds a natural explanation as being formed of primordial black holes, and
9. underlays description of inflation: the supergravity equivalent Starobinsky and the supersymmetric Wess-Zumino models of inflation agree with the Planck 2018 CMB data.

The parameter l in (3.28) is introduced by hand and must be replaced by an expression of future quantum gravity. As far as the gravitating bag idea discussed in subsection 3.3 can be shown to be rigorously true and consistent with section 2.2, even approximately, there may be a reasonably comprehensible doorway to an extension of semi-classical quantum gravity. The question of quantizing spacetime itself, like e.g. in loop quantum gravity [54] or causal dynamical triangulation [55], is beyond the scope of this article.

The preon model complies with both the inflationary and bounce models of cosmology. In the very early universe an abundance of black holes is expected. The black holes tunneled into white holes which emitted all content until three preon remnants were formed as standard model fermions during early reheating. Matter dominated universe is possible in the present model.

The supersymmetry phenomenology for standard model particles is to be recalculated with the unbroken symmetry to start with. The next step is to go to local supersymmetry [56]. It is hoped that the present preon model provides a new avenue towards better understanding of the roles of all four interactions. This article is intended to serve as an affirmative feasibility study of a research proposition which is hoped to receive community response.

A Brief Recap of Gravity Theories

A.1 Graviton and Diffeomorphism Invariance

Let us consider gravity from the point of view of symmetry and helicity states. The needed gauge symmetry is linearized general coordinate invariance. The helicity of the graviton is two. Demanding consistent graviton self-interactions leads us to general relativity with full general coordinate invariance [57, 58]. Further, helicity two implies the equivalence principle [58].

It is often said that Poincaré group is the gauge symmetry of gravity. Strictly speaking, gauge symmetries are redundancies of description rather than fundamental properties. One can always fix the gauge and eliminate the gauge symmetry, without changing the physics of the system. If a system does not have gauge invariance it is always possible to introduce redundant variables and restore gauge symmetry. This procedure is called Stueckelberg trick [61]. Using it one can make any Lagrangian invariant under general coordinate diffeomorphism. Therefore this symmetry is not adequate for defining general relativity. The principle of equivalence is in a similar position in general relativity.

Discuss now briefly local supersymmetry following [60]. Let the supersymmetry parameter depend on spacetime coordinate

$$\begin{aligned} \delta_\epsilon B &= \bar{\epsilon}(x) F \\ \delta_\epsilon F &= \epsilon(x) \partial B \end{aligned} \tag{A.1}$$

The commutator of two infinitesimal transformations δ_ϵ yields

$$[\delta_{\epsilon_1}, \delta_{\epsilon_2}] B \propto (\bar{\epsilon}_1 \gamma^\mu \epsilon_2)(x) \partial B \tag{A.2}$$

The factor $(\bar{\epsilon}_1 \gamma^\mu \epsilon_2)(x)$ is an element of the infinitesimal version of the group of local diffeomorphism on spacetime. Therefore locally supersymmetric theory is necessarily diffeomorphism invariant. The best known diffeomorphism invariant theory is, of course, general relativity.

Instead of coordinate invariance, equivalence principle or geometry the basic principle of general relativity may be taken this statement [57]:

"... general relativity is the theory of a non-trivially interacting massless helicity two particle. The other properties are consequences of this statement, and the implication cannot be reversed".

A.2 Weinberg Rationale

One may perceive the action for any locally supersymmetric model as follows

$$\mathcal{L} = \mathcal{L}_G + \mathcal{L}_g + \mathcal{L}_c + \mathcal{L}_i \tag{A.3}$$

where the terms are for gravity, gauge field, chiral fields and interactions, respectively. The gravity term is written using supergravity fields (2.2). The gauge term includes the photon and its superpartner. The matter term contains the chiral supermultiplet and the potential term that the the preons undergo (at this tender stage one may restrain writing all terms explicitly). In (A.3) the 4D electromagnetic gauge theory is added to gravity, unlike in the gauge/gravity duality.

The supergravity equation, equivalent to the Einstein equation, is derived from the variation of (A.3). All the terms are now of the same field theory origin, supergravity.

The model of section 2.2 is intended to serve as a guide to defining mathematical expressions for the next, or beyond standard model level particle description. Any realistic theory of quantum gravity may differ from the present model but it is hoped that the present definition of supersymmetry in section 2.2 may give, if properly understood, a useful clue on the road forward. Fair enough, there seems to be a goal indicated by Weinberg [59], call it the Weinberg rationale:

"Gravity exists, so if there is any truth to supersymmetry then any realistic supersymmetry theory must eventually be enlarged to a supersymmetric theory of matter and gravitation, known as supergravity. Supersymmetry without supergravity is not an option, though it may be a good approximation at energies below the Planck Scale.",

In the first sentence of the above quotation, the leap from gravity to supergravity is too long. Gravity is basically neither supersymmetric nor microscopic. Therefore one has to define microscopic matter fields to which the graviton (2.2) is coupled. Altogether, preons of section 2.2 build the standard model with the minimum number of elementary fields and, as an agreeable bonus, supergravity can be formulated. Secondly, superstrings are hinted

"Supergravity is itself only an effective nonrenormalizable theory which breaks down at the Planck energies. So if there is any truth to supersymmetry then any realistic theory must eventually be enlarged to superstrings which are ultraviolet finite. Supersymmetry without superstrings is not an option.",

and finally the non-perturbative M-theory looms to us

"Superstring theory is itself only a perturbative theory which breaks down at strong coupling. So if there is any truth to supersymmetry then any realistic theory must eventually be enlarged to the non-perturbative M-theory, a theory involving higher dimensional extended objects: the super p-branes. Supersymmetry without M-theory is not an option.".

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