



Standard Model Matter Emerging from Spacetime Preons

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Abstract

I consider a statistical mechanical model for black holes as atoms of spacetime with the partition function sum taken over area eigenvalues as given by loop quantum gravity. I propose a unified structure for matter and spacetime by applying the area eigenvalues to a black hole composite model for quarks and leptons. Gravitational baryon number's non-conservation mechanism is predicted. Argument is given for unified field theory based on gravitational and electromagnetic interactions only. The standard model of non-Abelian gauge interactions is briefly discussed.

Keywords

Quantum Black Hole, Statistical Mechanics, General Relativity, Loop Quantum Gravity, Hawking Radiation, Davies-Unruh Effect, Standard Model

Subject Areas: Particle Physics

1. Introduction

In this note I continue elaborating the statistical mechanical model for black holes discussed in [1]. The partition function is redefined as a sum over black hole stretched horizon area eigenvalues as given by Loop Quantum Gravity (LQG) [2] [3]. I propose a unified picture for matter based on the preon model for quarks and leptons [4] and the horizon model for atoms of spacetime [5]. Originally there were no phenomenological reasons to introduce the preon model. The reason was to find a common concept of origin for particles and spacetime, as described below. The history of quantum gravity indicates the need for some new ideas.

This note is organized as follows. In section 2 I present briefly the horizon model of black holes. In section 3 the main point of this schematic model, consistent quantum structure of matter and spacetime, is discussed. I apply a previous model for composite quarks and leptons, the constituents of which are defined by mass, spin and charge. The mass scale of preons is found to start from zero using the area eigenvalues of LQG. A reason for point-like particles is indicated. The model predicts a mechanism of the gravitational decay of the proton. This

decay is due to an explicit preon rearrangement interaction instead of a general black hole quantum number erasure process. The preon model includes the electromagnetic U(1) gauge interaction and provides the fermion quantum number basis for the non-Abelian color and weak interactions. Finally in section 4 I give a brief discussion of results and conclusions. Being a scheme proposal the presentation is very concise throughout.

2. LQG Spacetime Area Eigenvalues

I consider a micro black hole dressed by a stretched horizon, which is a membrane hovering about a Planck length outside the event horizon and which is both physical and hot.

The energy of a black hole from the point of view of an observer on its stretched horizon is called Brown-York energy [6]

$$E = \frac{ac^2}{8\pi G} A \tag{2.1}$$

where a is the constant proper acceleration of an observer on the stretched horizon and A is the area of the horizon. In LQG the area eigenvalues are

$$A = \gamma l_{\text{Pl}}^2 \sum_p \sqrt{j_p(j_p + 1)} \tag{2.2}$$

where the sum is over punctures p of the spin network, l_{Pl} is the Planck length, γ is the Barbero-Immirzi parameter and the values of j_p are $0, \frac{1}{2}, 1, \frac{3}{2}, \dots$. For canonical treatments of quantum geometry and black holes, see [7] [8].

For the BH spacetime phenomenological model the partition function for a spin network with N punctures is, for details, see [5].

$$Z(\beta) = \sum_n \exp(-\beta E_n) = \sum_{n_1 n_2 \dots n_N} \exp\left(-\beta T_0 \sum_{p=1}^N \sqrt{n_p(n_p + 2)}\right) \tag{2.3}$$

where $T_0 = \frac{a}{16\pi} \gamma$ and $n_p = 2j_p$, with $n_p = 0, 1, 2, \dots$. The resulting $Z(\beta)$ is [5]

$$Z(\beta) = \frac{1}{y-1} \left[1 - \left(\frac{1}{y}\right)^N \right] \tag{2.4}$$

where

$$y = y(\beta) = \left[\sum_{n=1}^{\infty} \exp(-\beta T_0 \sqrt{n(n+2)}) \right]^{-1} \tag{2.5}$$

When $y = 1$ one has simply $Z(\beta) = N$.

The average energy at temperature $T = 1/\beta$ can be calculated from the partition function (3)

$$E(\beta) = -\frac{\partial}{\partial \beta} \ln Z(\beta) \tag{2.6}$$

of the black hole which yields

$$E(\beta) = \left(\frac{1}{y-1} - \frac{N}{y^N - 1} \frac{1}{y} \right) \frac{dy}{d\beta} \tag{2.7}$$

In LQG it is assumed that the number of punctures on the stretched horizon is very large, say about 10^{122} . Therefore for $y > 1$ (2.7) simplifies to

$$E(\beta) = \frac{1}{y-1} \frac{dy}{d\beta} \tag{2.8}$$

For $y < 1$, y^N approaches zero for large N and one gets

$$E(\beta) = \frac{N}{y} \frac{dy}{d\beta} \quad (2.9)$$

There is a jump in energy of the hole when $y = 1$. Since y depends on temperature according to (2.5) one sees that the hole undergoes a phase transition at the critical temperature T_C defined by the solutions of

$$\sum_{n=1}^{\infty} \exp\left(-\frac{T_0}{T_C} \sqrt{n(n+2)}\right) = 1 \quad (2.10)$$

Below the critical temperature T_C the punctures of the stretched horizon are in vacuum and there is no black hole. Above T_C the punctures get “excited” and provide the possibility of falling back to vacuum with Hawking radiation being emitted simultaneously.

From $T_0 = \frac{a}{16\pi} \gamma$ and $x = T_0/T_C \cong 0.508$ (obtained numerically) and choosing $\gamma = 8x \cong 4.06$ one gets

$$T_C = \frac{a}{2\pi} \quad (2.11)$$

which is the Davies-Unruh temperature felt by an observer on the stretched horizon with constant acceleration a .

In Schwarzschild spacetime the line element includes the function $f(r) = 1 - \frac{2M}{r}$ and the acceleration is

$$a = \frac{1}{2} f^{-1/2} \frac{df}{dr} = \left(1 - \frac{2M}{r}\right)^{-1/2} \frac{M}{r^2} \quad (2.12)$$

Right outside the horizon $r = 2M$ and (2.11) and (2.12) the lowest temperature of the hole as seen by an observer is

$$T_C = \left(1 - \frac{2M}{r}\right)^{-1/2} \frac{1}{8\pi M} \quad (2.13)$$

This temperature corresponds according to the Tolman relation a far away observer temperature

$$T_{\infty} = \sqrt{f} T_C = \frac{1}{8\pi M} \quad (2.14)$$

which is the Hawking temperature.

3. Model of Matter and the Unified Picture

The statistical model of Section 2 for spacetime offers a possibility to study the matter sector from a novel point of view to build a consistent, unified picture of matter and spacetime based on black holes. This goal would imply some internal structure at scale of the order of l_{pl} for quarks and leptons. Such a model has been proposed in [4].

The basic idea of [4] is that the quarks and lepton are made of black holes, called maxons, with characterized by three quantum numbers: mass, spin and charge. Their values are: mass is the Planck mass, spin 1/2 and charge 0 or 1/3. In addition there is “color” (i, j, k) as a permutation index. The first generation quarks and leptons are the following bound states

$$\begin{aligned} u_k &= \varepsilon_{ijk} m_i^+ m_j^+ m_k^0 \\ \bar{d}_k &= \varepsilon_{ijk} m_i^+ m_j^0 m_k^0 \\ e &= \varepsilon_{ijk} m_i^- m_j^- m_k^- \\ \bar{\nu} &= \varepsilon_{ijk} \bar{m}_i^0 \bar{m}_j^0 \bar{m}_k^0 \end{aligned} \quad (3.1)$$

Charge quantization $\{0, 1/3, 2/3, 1\}$ and particle permutation symmetry pull out of vacuum these standard model particles. States in (3.1) with only two identical maxons provide an index for quark three-valued color. I assume that these states are bound by gravitational (or other Planck scale) force between preons. Properties of this interaction need to be modeled as a future project. The question of existence of free single maxons depends

on the details of the model.

The construction (3.1) is matter-antimatter symmetric on maxon level, which is desirable for early cosmology. The model makes it possible to create from vacuum a universe with only matter: combine e.g. six m^+ , six m^0 and their antiparticles to make the basic β -decay particles, see **Figure 1**. Corresponding antiparticles occur equally well.

The maxon mass scale is the Planck scale and (3.1) would be superheavy particles. To get the standard model particles the large mass difference has to be explained. It is accomplished from (2.2) by setting $j_p = 0$, which leads by (2.1) to zero mass “cold” black hole. This $j_p = 0$ maxon may interact with the Higgs field and gain a light mass. Above the critical temperature, defined by (2.10), maxons should have a phase transition into Hawking radiating black holes.

The mass scale change is significant. It may be understood, using non-relativistic quantum mechanics as a guide, by assuming that when a maxon gets zero mass the spacetime geometry changes so that the maxon is trapped inside a rigid wall potential well of depth l_{pl} and width of the order of inverse l_{pl} . Secondly, I may think that there are three maxons as in (3.1) in the hole. The maxons seem to behave almost classically in the sense that they are localized. This is a crucial point, between quantum mechanics and geometry of spacetime, that needs to be developed quantitatively. At this point the generalized uncertainty principle (GUP), eg. $\Delta x \geq 1/\Delta p + l_{pl}^2 \cdot \Delta p$, should also be mentioned. This would need more consideration and is left for future task (beyond the general result $\Delta x_{min} = 2l_{pl}$). For a review of GUP questions, see eg. [9].

Spin 3/2 quarks and leptons are implied by this model.

The baryon number (B) is not conserved [10]-[12] in this model: a proton may decay at Planck scale temperature by a preon rearrangement process into a positron and a pion, see **Figure 2**. This is expected to be independent of the details of the preon interactions. Baryon number minus lepton number is conserved. One may speculate now that the ultimate grand unified theory is a preon theory with gravitational and electromagnetic interactions only. Basically, I have followed the guide of [10] that “black holes should be subject to the same rules of quantum mechanics as ordinary elementary particles or composite systems”.

The large mass reduction from Planck scale to zero would also imply shrinkage of the BH from three spatial dimensions to a point. Thus point-like particles would be dynamical consequence of quantum gravity.

Maxon				Particle
m^+	m^+	m^+	m^+	P
m^-	m^-	m^-	m^-	e
m^0	m^0	m^0	m^0	
m^0	m^0	m^0	m^0	V
m^0	m^0	m^0	m^0	n
m^+	m^+	m^-	m^-	

Figure 1. Maxons, antimaxons and four particles.

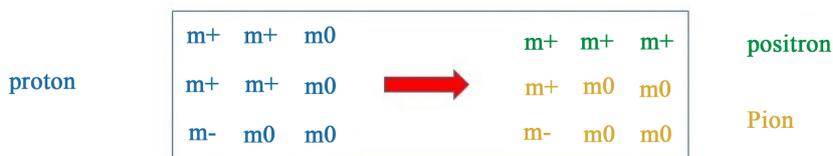


Figure 2. Proton decay by maxon rearrangement.

The standard model gauge bosons and the Higgs would be elementary (but their composite nature is not ruled out). The three generations would be due to a gravitational mechanism or a new symmetry. Note that I have assumed the standard model on top of the present preon model. On the other hand, starting from the preon model, one can “derive” the SM from (3.1) and **Figure 1**: one gets color and the weak isodoublet quantum numbers, for fermions and therefore the correct N in $SU(N)$ for strong and weak interaction gauge groups.

In the early universe at high temperature the standard model quarks and leptons would not be formed immediately. Instead all matter would be in black holes interacting gravitationally and electromagnetically. Quarks and leptons would appear later when the temperature decreases substantially. Electroweak and QCD interaction come to play rather late.

Some fraction of primordial black holes should remain black making dark matter. Their masses are expected to be around 30 solar masses. In [13] the authors discuss the possibility that LIGO has detected dark matter in black hole mergers..

4. Conclusion

There are at present a number of competing candidate theories for quantum gravity like string theory, loop quantum gravity, causal dynamical triangulation, and others. The model of Sections 2 and 3 goes deep into the structure of the physical universe and can be considered as a promising candidate for a unified scheme of “everything”, in the sense discussed here. In the scenario briefly outlined above, LQG area eigenvalues and the composite quark and lepton model look promising ingredients on the road towards the origin of spacetime, gravity and matter.

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