Why and How do Black Holes Radiate?

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Abstract

I propose a phenomenological model for the radiation of black holes. The radiation consists of thermal Hawking radiation and a leptonic component which is a consequence of quantum number neutralization assuming the no-hair theorem. The latter component grows relatively stronger with increasing black hole mass and can be tested in principle.

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1 Introduction and Summary

The purpose of this note is to propose a quantum mechanical model for the total radiation of black holes and to present a no-hair theorem based mechanism to the origin of black hole radiation, which usually is considered thermal Hawking radiation. I discuss the logical structure of the model rather than any numerical predictions. A compatible decay model of black holes of Planck mass has been introduced in [1, 2].

Due to the gravitational attraction of the black hole particles fall through the horizon inside the hole. At and above the Planck scale the particle enters the grand unified theory (GUT) energy domain. Most arguments of this note apply also if only the standard model is considered. Inside the hole the fallen particle tends to loose its other quantum numbers but charge (mass and spin) due to the no-hair theorem. Quantum number, like lepton or baryon number, neutralization takes place via black hole radiation as follows. For example, a fallen electron inside the hole can observe a virtual electron-positron pair being formed just outside the horizon. The positron is taken inside the hole neutralizing the electron into energy like photons or ultimately gravitons. Thus a fallen electron causes another electron being emitted from the hole. The same happens to a fallen proton except that it first decays into an electron and a pion.

A model of corpuscular structure of black holes is needed for the basis of the model of radiation. Such a model has been presented in [3].

In the last phase of radiation before disappearance the basic element in the present model is the gravon [1], a critical state which connects the black hole state to a quantum field theory. Instead of vanishing totally after enough of radiation a micro black hole, with mass of about the Planck mass value, triggers the operators of the standard model (SM) or a grand unified quantum field theory like SO(10). Thereafter the black hole energy decays into SO(10) particles and finally into standard model particles. Primordial black holes (PBH) with mass about 10^{15} g will be evaporating today and their abundance is constrained by the flux of gamma-rays, for a comprehensive treatment see [5].

The SO(10) GUT gets support from a different direction, and time, in the universe. In [4] the authors study Starobinsky inflation in a renormalizable grand unified theory based on the SO(10) gauge group with no scale supergravity theory (SUGRA).

In this note I discuss the physical motivation and description of the model. Section 2 discusses the radiation mechanisms of black holes. Section 3 mentions briefly thoughts of black holes being condensates of gravitons and other massless fields. In section 4 I describe the gravon qualitatively. Section 5 summarizes briefly an SO(10) GUT inflation model with a rich multiplet structure. I finish in section 6 with conclusions. Sections 3 and 5 are very brief surveys of work done by other authors. They are included for consistency of the framework and as directions of future work. Full quantization of general relativity (GR) is beyond the scope of this note.

2 Black Hole Total Radiation

Particles falling into a black hole through the horizon is a "no-drama" event. The hole is supposed to have no hair, though. When a proton, or other baryon, falls into a black hole it should neutralize (barber) its baryon number into energy like gravitons.

Within the standard model this takes place by absorbing an antiproton of a virtual pair from just outside the horizon, which gives minimal growth of mass of the hole. In a GUT the fallen proton inside the hole may first decay into lighter particles, $p \to e^+\pi$, and subsequently the positron lepton number is neutralized leading to substantially faster growth of the hole mass. When a hole is bombarded by baryons the radiation of the hole is predicted to have a thermal Hawking and leptonic component consisting dominantly of the lightest leptons. While a BH gets cooler with increasing mass the relative amount of the leptonic component is expected to increase with the mass of the hole. Thus black hole radiation has a component which is a necessary consequence of general relativity alone.

3 Structure of Black Holes

Using the concepts of the previous section one is lead to consider a corpuscular model for black holes and gravity. Such a model has been proposed in [3]. There is a recent review of results obtained by various authors in [6]. The basic idea is that a black hole is a Bose-Einstein condensate (BEC) of gravitons.

The authors in [7] consider massless scalar gravitons instead of real ones and write a Klein-Gordon equation for them with a real scalar current in Minkowski space

$$\Box\phi(x) = qJ(x) \tag{1}$$

Later an interesting concept called the horizon wave function (HWF) is introduced starting from the energy eigenvalue equation

$$\hat{H}|\, \psi_E \,\rangle = E|\, \psi_E \,\rangle \tag{2}$$

Any state ψ_{S} can be presented using these energy eigenstates

$$|\, \psi_{\mathrm{S}} \,\rangle = \sum_E c(E)|\, \psi_E \,\rangle \tag{3}$$

Inverting the expression of the Schwarzschild radius,

$$r_{\mathrm{H}} = 2G_{\mathrm{N}}E = 2\frac{L_{\mathrm{Planck}}}{M_{\mathrm{Planck}}}E \tag{4}$$

one obtains E as a function of r_{H}. This expression is then used to define the horizon wave function by elevating the coefficient c(E) into a wave function

$$\psi_{\mathrm{H}}(r_{\mathrm{H}}) \propto c(E) = c\left(M_{\mathrm{Planck}} r_{\mathrm{H}}/2L_{\mathrm{Planck}}\right) \tag{5}$$

whose normalization is determined by the inner product

$$\langle\, \psi_{\mathrm{H}} \mid \phi_{\mathrm{H}} \,\rangle = 4\,\pi \int_0^\infty \psi_{\mathrm{H}}^*(r_{\mathrm{H}})\phi_{\mathrm{H}}(r_{\mathrm{H}})r_{\mathrm{H}}^2 dr_{\mathrm{H}} \tag{6}$$

Starting from the HWF one then goes to define the probability density of finding a gravitational radius $r = r_{\mathrm{H}}$ corresponding to the given quantum state ψ_{S} as

$$\mathcal{P}_{\mathrm{H}}(r_{\mathrm{H}}) = 4\,\pi\, r_{\mathrm{H}}^2\, |\psi_{\mathrm{H}}(r_{\mathrm{H}})|^2 \tag{7}$$

It is seen that the HWF takes the classical concept of the Schwarzschild radius into the quantum domain. The gravitational radius turns out to be necessarily "fuzzy", since it is related to a quantity, the energy of the particle, that is naturally uncertain.

Provided the BEC model of the black holes s valid the above discussion indicates a possible avenue for further development of the present model.

4 The Gravon and Decay of Black Holes

The universe is described by classical general relativity at large distances and by grand unified quantum field theory of particles at microscopic scales. The gravon [1] is a critical connecting state between microscopic black holes and quantum fields. As seen from the quantum field side it is the equivalent of quantum state vector collapse into the classical theory. Seen from the classical side the black hole looses (barbers) its horizon and makes a transition into quantum fields. The horizon requires proper mathematical treatment, see section 3, but the physical picture given here should be clear.

The decay of a micro black hole can be approximated by a heavy Higgs-like scalar (or a fermion) decay. SO(10) is a GUT group in which a 16 dimensional spinorial representation (**16**) can accommodate all one generation quarks and leptons. Therefore at the energy considered, all particles have zero mass, all interactions have the same strength, all gauge bosons (**45**) can be produced freely and all quarks can transform into leptons. The Higgs come in the representations (**10**), (**16**) and (**45**).

5 Inflation

In [4] the authors study inflation in a renormalizable grand unified theory based on the SO(10) gauge group with no scale SUGRA. The authors show that a renormalizable Wess-Zumino superpotential of SO(10) GUT along with no-scale Kähler potential can produce Starobinsky kind of inflationary potential with specific choice of superpotential parameters.

The Higgs supermultiplets the authors consider are **10**, **210**, **126** ($\overline{\mathbf{126}}$). Among these, the **210** and **126** ($\overline{\mathbf{126}}$) are responsible for breaking of SO(10) symmetry down to minimal supersymmetric standard model (MSSM). The **210** supermultiplet alone can give different intermediate symmetries [8] depending upon which of its MSSM singlet field takes a *vev*. Then **126** ($\overline{\mathbf{126}}$) breaks this intermediate symmetry to MSSM. Successful inflationary potential can be achieved in the case of $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$, $SU(5) \times U(1)$ and flipped $SU(5) \times U(1)$ symmetry. The other possible intermediate symmetries of Pati-Salam $(SU(4)_C \times SU(2)_L \times SU(2)_R)$ or $SU(3)_C \times SU(2)_L \times U(1)_R \times U(1)_{B-L}$ gauge groups do not give phenomenologically correct inflationary potentials.

At the end of inflation reheating can occur via non-perturbative decay of inflaton to bosons of the intermediate scale model. After the end of reheating, when universe cools down, the finite temperature potential can have a minimum which corresponds to MSSM and the universe rolls down to this minimum at temperature $<< T_R$ (reheat temperature).

The Starobinsky model, based on one loop quantum gravity, is known to fit all the CMB data available today. From the point of view of the present model it would be interesting to know whether the calculation of [4] could yield similar results without assuming supersymmetry.

6 Conclusions

The present note contains a proposal of a model for black hole radiation and decay. According to the model the ratio of Hawking radiation to leptonic radiation intensity decreases with increasing black hole mass. Planck mass black hole decay and black hole radiation are different kind of processes. These are testable in principle.

The general conclusion is that the GUT based on SO(10) provides very much what is wanted for a description of the universe from big bang to collapse of matter into non-singular black holes. It seems one can handle the whole life cycle of particles in the (bouncing) universe using the SO(10) based GUTs and the black hole model of this note.

Targets of future research include the following. The the use of grand unified theories inside black holes and black hole radiation mechanisms should be analyzed in quantitative detail. Secondly, corpuscular models of the structure of black holes need to be set on solid basis. Thirdly, the dynamical details of the present simple black hole model and the more involved supersymmetric inflationary model mentioned in section 5 should be compared and studied.

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