Antigravity and black holes

Dragan Slavkov Hajdukovic
CERN, Geneva, Switzerland
and Cetinje, Montenegro
dragan.hajdukovic@cern.ch

We speculate about impact of antigravity (i.e. gravitational repulsion between matter and antimatter) on the creation and emission of particles by a black hole. If antigravity is present a black hole made of matter may radiate particles as a black body, but this shouldn’t be true for antiparticles. It may lead to radical change of the radiation process predicted by Hawking and should be taken into account in preparation of the attempt to create and study mini black holes at CERN. Gravity, including antigravity is more than ever similar to electrodynamics and such similarity with a successfully quantized interaction may help quantization of gravity.

One of the most important theoretical predictions of Quantum Electrodynamics is that in a sufficiently strong external (classical i.e. unquantized) electromagnetic field, the (Dirac) vacuum becomes unstable and decays leading to a spontaneous production of electron- positron pairs (See [1] and References therein). The simplest field configuration is when the entire space is filled with a constant, homogenous electromagnetic field, characterized by the two constant vectors $E, B$. In the particular case of a constant pure electric field ($B=0$) the pair creation occurs for fields greater than a critical field value, $E_{cr}$, estimated to be

$$E_{cr} = \frac{2m^2c^3}{eh}$$

(1)

with corresponding critical acceleration

$$a_{cr} = \frac{2mc^3}{h}$$

(2)

There is a complex physics behind this phenomenon, but for the purpose of this paper it is sufficient to repeat a well known intuitive interpretation of pair creation in an electric field: in the vacuum short-living “virtual” e⁺ e⁻ pairs are continuously created and annihilated again by quantum fluctuations. These pairs can be separated spatially by the external electric field and so converted into real particles by the expenditure of the field energy. For this to become possible the potential energy has to vary by an amount $\Delta V = eE\Delta l > 2mc^2$ in the range of about one Compton wavelength $\Delta l = h/mc$ which leads to the value of the critical field strength in Equation (1).

Of course, the example of a constant external field is an idealisation, but it is an extremely useful example because it can be solved exactly, giving deep theoretical understanding of the phenomenon.
In principle every external field that can cause spatial separation of “virtual” particle-antiparticle pairs may lead to creation of particles. Let’s assume that there is antigravity defined as gravitational repulsion between matter and antimatter, while ordinary gravitational attraction stays valid in matter-matter and antimatter-antimatter interactions. If there is antigravity, a constant gravitational field and a constant electric field produce the same effect: particle and antiparticle from a “virtual” e⁺e⁻ pair are pushed in opposite directions. Thus we may expect that the known exact solution in a constant electric field remains valid if electrical fields \( E \) and \( E_{cr} \) are replaced by accelerations \( a \) and \( a_{cr} \), while charge \( e \) must be replaced by mass \( m \).

\[
E \rightarrow a \\
E_{cr} \rightarrow a_{cr} \\
e \rightarrow m
\]

In the case of a constant electric field the probability for pair production per unit time and volume is given by

\[
\frac{dN_{e^+e^-}}{dt \, d^3x} = \frac{\alpha E^2}{\pi^2} \sum_{n=1}^{\infty} \frac{e^{-n \pi E_{cr}/2E}}{n^3}
\]

where \( \alpha \) is the fine-structure constant and for simplicity Equation (4) is written in natural units (\( h = c = 1 \)). So, in principle, under assumption of antigravity, Equation (4) after substitution (3) must give an exact result for constant gravitational field. In principle gravitation as an universal interaction may do more than an electrical field; it may create both particle-antiparticle pairs of charged and neutral particles.

As it can be seen from Equations (1) and (2) very strong electrical and gravitational fields are needed for particle production. When gravitation is in question only a black hole may be the source of such a strong gravitational field. And of course it can't be a constant field. By the way in addition to the large number of black holes existing in the Universe, the production of mini black holes will probably be soon possible at LHC in CERN [2].

Before I continue let me point out a few self-evident facts. If there is antigravity a black hole made of matter (antimatter) acts as a nearly perfect reflector of incident antiparticles (particles). A matter (antimatter) black hole strongly repels all antiparticles (particles) produced inside or outside its horizon. So, a black hole may lose its mass much faster than predicted by Hawking [3] and antigravity may lead to a shorter life for black holes! In principle emission of a black hole is composed from both particles and antiparticles, but only for one of these two components the law of the black body radiation may stay valid (as predicted by Hawking); the other component must follow a different law. For instance a black hole made from matter may be considered as black body for the matter part of the radiation, but can’t be considered as a black body for emission of antiparticles. If we think about the Hawking process as a quantum tunnelling effect only particles must tunnel while antiparticles are simply repealed without tunnelling. So, the majority of the created particles are absorbed by the black hole and, contrary to antiparticles, only a tiny fraction is emitted. Similarly a black hole made of antimatter may be considered as a black body for the antimatter part of the radiation, but can’t be considered as a black body for the emission of particles.

As well known the Schwarzschild radius of a black hole with mass \( M \) is:

\[
R_s = \frac{2GM}{c^2}
\]
Now, let’s consider a sphere with a radius $R_H \neq R_S$ and let us suppose that there is a spherically symmetric distribution of mass $M$ inside this sphere. The question is for which value $R_H$ acceleration on the surface of the sphere is equal to the critical acceleration (2). Combining Equation (2) with Newton’s universal law of gravitation leads to:

$$R_H^2 = \frac{\lambda R_S}{4}$$  \hspace{1cm} (6)

where $R_S$ is the Schwarzschild radius (5) and $\lambda = h/mc$ is the Compton wavelength divided by $2\pi$. It is evident that

$$R_H = R_S, \text{ for } R_S = \frac{\lambda}{4} \text{ i.e. } M = \frac{\lambda c^2}{8G}$$

$$R_H < R_S, \text{ for } R_S > \frac{\lambda}{4} \text{ i.e. } M > \frac{\lambda c^2}{8G}$$

$$R_H > R_S, \text{ for } R_S < \frac{\lambda}{4} \text{ i.e. } M < \frac{\lambda c^2}{8G}$$  \hspace{1cm} (7)

The above Equation tells us that a (for us) physically comfortable situation $R_H>R_S$ occurs only for black holes with a mass smaller than $M = \frac{\lambda c^2}{8G} = 6.5 \times 10^{13}$ kg. In such a case the mass $M$ of the black hole is inside the Schwarzschild sphere, and the vacuum between the surfaces of the Schwarzschild sphere and a larger sphere with radius $R_H$ is in a strong gravitational field that may create particle-antiparticle pairs. So, the vacuum between two spheres is a potential “factory” for particle production by the gravitational field of a black hole. As a result a black hole may lose faster its mass and if so there is a little hope that primordial black holes still exist. But everything must be treated with caution because in this case radius $R_H$ may be much smaller than a Compton wavelength $\lambda$. Let’s note that because of uncertainty relations the lifetime of the virtual pair is only of the order of $\Delta t = h/mc^2$ and a virtual pair may become real if during this time it is separated by more than a Compton wavelength and if it has gained more kinetic energy than twice its rest mass. Hence the strong background field has to extend over a sufficiently large region to lead to an observable critical behaviour. An appealing example is strong external electric field produced by a nucleus of charge $Z$. For all $Z$ the maximum electric field strength (at the surface of the nucleus) is bigger than the critical electric field given by Equation (1) but the other conditions are satisfied only for nuclei (non existing in the nature) with $Z \approx Z_{cr} = 173$ [1]. However it may be argued that in a gravitational field virtual particles of a pair are definitely separated if one of them is inside and the other outside the horizon. So, inevitable conditions, in the case of an electric field may be relaxed in the case of the gravitational field.

A situation with $R_H<R_S$ is less clear. We may assume that at some stage of the gravitational collapse, mass $M$ of the black hole will be confined in a sphere of radius $R<R_H$. The volume enclosed by the surfaces of these two spheres, has sufficiently strong gravitational field and the linear size of the volume is not small compared with Compton wavelength $\lambda$. So, this volume may be an ideal “factory” for particle production by a black hole. Let us note that this volume grows with the progress of the collapse, allowing higher rate of creation of the particles. So, in a way, the collapse is opposed by the creation of particles. We may speculate that in the best case particle creation may stop the collapse to the extreme state of a singularity.
The aim of this short paper is just to promote some new ideas and raise questions. In forthcoming publications we may study in details some of the raised questions and ideas but in general, the community of theoretical physicists must pay more attention to the idea of antigravity and work seriously on it. Antigravity was already proposed as an explanation of different observed phenomena like CP violation in the neutral Kaon decay or accelerating expansion of the Universe. If confirmed existence of antigravity will become one of the most exciting discoveries in the human history opening an enormous field of research.

In the end, let’s note that gravity, after introduction of antigravity is more than ever similar to electrodynamics. Such an augmented level of similarity between gravitational and electromagnetic interactions (which are the most impressive example of successful quantization) may be helpful in quantization of gravity.

REFERENCES