In this paper, we show that the extremely-high energies of some cosmic-ray particles can be related to the strong increase of their gravitational masses when they have been generated.

Key words: Cosmic-ray particles Energy, Gravitational Mass, Mini-blackholes.

1. Introduction

The energy spectrum of cosmic-ray particles extends to $\sim 10^{70}$ eV [1]. The origin of these ultra-high-energy cosmic-ray particles is not yet firmly established [1, 2, 3-6]. Actually, this is one of the great challenges of modern Astrophysics [7, 8]. In this paper, we show that the extremely-high energies of these cosmic particles can be related to the strong increase of their gravitational masses when they have been generated.

2. Theory

In 1974, Stephen Hawking showed that black holes could emit particles (neutrinos, electrons, protons, nucleons, etc.) and so evaporate [9]. The Hawking’s theory [9, 10] establishes that the internal temperature ($T$) of a black hole, its lifetime ($\tau$) and the number ($N$) of particles emitted from it, are respectively given by

$$T \approx \frac{10^{26}}{m}, \quad \tau \approx 10^{-27} \, m^{3} \quad (1)$$

and

$$N \approx 10^{11} m \quad (2)$$

where $m$ (in grams) is the inertial mass of the black hole.

In a previous paper [11] it was shown that there is a correlation between the gravitational mass, $m_{g}$, and the rest inertial mass $m_{i0}$, which is given by

$$\chi = \frac{m_{g}}{m_{i0}} = \left( 1 - 2 \left( \frac{\mathcal{U}n_{r}}{m_{i0}c^{2}} \right)^{2} - 1 \right) \quad (4)$$

where $U$ is the electromagnetic energy absorbed or emitted by the particle; $n_{r}$ is the index of refraction of the particle and $c$ is the light speed.

In the particular case of thermal radiation, it is usual to relate the energy of the photons to the temperature, through the relationship $\langle h\nu \rangle \approx kT$, where $k = 1.38 \times 10^{-23} \, J/K$ is the Boltzmann’s constant. Thus, in that case, the energy absorbed by a particle will be $U = \eta \langle h\nu \rangle \approx \eta kT$, where $\eta$ is a particle-dependent absorption coefficient ($\eta \geq 0.1$, see [12]). Therefore, Eq.(4) can be rewritten in the following form:

$$m_{g} \approx \frac{2 \eta kTn_{r}}{c^{2}} = 10^{-41} \, T; \quad (n_{r} \sim 1) \quad (6)$$

According to Eq. (1), the temperature ($T$) of mini black holes can be very high, in such way that the term $\eta kTn_{r}/m_{i0}c^{2}$ in Eq. (5), can become very greater than 1. In this case, Eq. (5) shows that, the gravitational masses of the particles emitted from a mini black hole will be given by:

$$m_{g} \approx -2 \frac{\eta kTn_{r}}{c^{2}} \approx -10^{-41} T; \quad (n_{r} \sim 1) \quad (6)$$

Thus, these particles will have energy, $E$, expressed by [11]:

$$E = \frac{m_{g}c^{2}}{\sqrt{1-v^{2}/c^{2}}} \approx \frac{10^{-41} Tc^{2}}{\sqrt{1-v^{2}/c^{2}}} \quad (7)$$

For $v < c$, Eq. (7) reduces to

$$E \approx 10^{-24} T \quad (8)$$

In the case of mini black holes with inertial masses $m < 1000 \, g$, the temperature, $T$, according to Eq.(1), is $T > 10^{23} \, K$. Then, Eq. (8), tells us that the particles emitted from these mini black holes can have energy, $E$, given by

$$E > 0.1 \, joule \approx 10^{16} \, eV \quad (9)$$

This energy corresponds to the extremely-high energies of the spectrum of the cosmic-ray particles. Consequently, we can conclude that, possibly the ultra-high-energy cosmic-ray particles can have originated in mini black holes.

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* In 1971 Hawking shows that many mini black holes ($m < 10^{-6} \, g$) with masses down to $\sim 10^{-4} \, g$ could have been created in the initial stages of the formation of the Universe [13].
References


