The origin of the Ultra-high-energy cosmic-ray particles

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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 ~10^{20} 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 shown 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 (τ) and the number (N) of particles emitted from it, are respectively given by

$$T \approx \frac{10^{26}}{m} \tag{1}$$

$$\tau \approx 10^{-27} m^3 \tag{2}$$

and

$$N \approx 10^{11} m \tag{3}$$

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

$$\chi = \frac{m_g}{m_{i0}} = \left\{1 - 2\left[\sqrt{1+\left(\frac{Un_r}{m_{i0}c^2}\right)^2} - 1\right]\right\} \tag{4}$$

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 $k = 1.38\times10^{-23}\,J/K$ 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 η is a particle-dependent absorption coefficient ($\eta \cong 0.1$, see [12]). Therefore, Eq.(4) can be rewritten in the following form:

$$\frac{m_g}{m_{i0}} \approx \left\{1 - 2\left[\sqrt{1+\left(\frac{\eta kTn_r}{m_{i0}c^2}\right)^2} - 1\right]\right\} \tag{5}$$

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:

$$m_g \approx -2\left(\frac{\eta kTn_r}{c^2}\right) \approx -10^{-41}T \quad ; \quad (n_r \sim 1) \tag{6}$$

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

$$E = \frac{m_g c^2}{\sqrt{1-v^2/c^2}} \approx \frac{10^{-41}Tc^2}{\sqrt{1-v^2/c^2}} \tag{7}$$

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

$$E \approx 10^{-24} T \tag{8}$$

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

$$E > 0.1\,joule \approx 10^{19}\,eV \tag{9}$$

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* $(m << 10^9\,g)$ with masses down to ~10^{-5}g could have be created in the initial stages of the formation of the Universe [13].

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