Photon-photon photoproduction in the photon universe model

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Abstract

We propose a theoretical analysis of the fundamental hypothesis of the photon universe model: the photon-photon photoproduction.

Keywords: dark matter, visible matter, photon-photon collision, model Photon universe, galaxy, missing mass, rotation curve, MOND, Astrophysics of High Energies.

1. Introduction.

The Photon Universe model, as an exercise by Fermi (1901-1954), was introduced (**[1]**, **[2]**) as an alternative to existing models in order to study the problem of missing mass (rotation curves of galaxies).

Through the use of the model it was proved:

(a) to theoretically estimate the total mass (visible and hidden) of a galaxy **[1]**, **[5]**;

(b) to estimate the total Mass of the Observable Universe **[2]**;

(c) to estimate the value of the Radius Limit of a galaxy **[3]**;

(d) to predict the trend of the rotation curve **[4]**;

(e) to derive, theoretically, the value of the parameter a_0 introduced *ad hoc* in the MOND model, **[5]**.

All the estimates obtained fall within the values currently known in the literature.

What we have presented, as already observed **[5]**, is an "interpretative model of the rotation curves of galaxies that highlight the problem of the "hidden mass" (**[6]**, **[7]**, **[8]**) such that:

(a) does not change the Newtonian law of motion (contrary to the MOND theory),

(b) does not use an unknown phenomenology (or particle) as the source of the "hidden mass" (or energy) but hypothesizes a photon-photon photoproduction (contrary to the theory of dark matter)".

This article aims to carefully analyze the fundamental hypothesis of the Photon Universe Model **[1]**:

we consider the collision of a high-energy photon with a CMBR microwave background photon which gives rise to a mass (with large-scale gravitational effects),

to which we added **[2]**:

the possible collision of a high-energy photon with a photon of the EBL background which gives rise to a mass (with large-scale gravitational effects) is also considered.

Summarizing, in our model, both the CMBR photon gas and the EBL photon gas are both considered as possible targets of high energy photons **[1]**, **[2]**.

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2. Photon-photon photoproduction

By the term photoproduction we mean a process in which two photons collide and produce an electron-positron pair. The phenomenon, whose genesis is the subject of historical reflection **[9]**, can now be verified experimentally due to the substantial improvement of the technology necessary to set up the experimental apparatus **[11]**.

Although the phenomenon is extremely interesting, still a few years ago it could be written that "the creation of an electron-positron pair in the collision of two real photons, indicated with the name of Breit-Wheeler process, has never been directly observed in a laboratory ever since its prediction in 1934, despite its fundamental importance in quantum electrodynamics and high-energy astrophysics, [...] However, several proposals have emerged to study this process in the laboratory in recent years" **[10]**.

In fact, recent experimental analyzes show that the collected data are "within the uncertainties, in line with the expected expectations of the Breit-Wheeler process" **[11]**.

On the creation and annihilation of pairs it is useful to report the following: "of all the processes of creation and annihilation of particles, only three have played, at least until now, a fundamental role in High Energy Astrophysics. The first concerns the creation, absorption, and diffusion of neutrinos [...], the second [is] the process of photoproduction of pions in the collision between a nucleon and a photon [...], the third process of great importance [is] the creation and annihilation of electron/positron pairs […]. The fundamental process of making pairs is:

$$\gamma + \gamma \rightleftarrows e^+ + e^- \qquad \text{(i)}$$

[…] other processes which may involve couples […] have smaller cross sections […]. The cross section [of relation (i)] is, as an order of magnitude,

$$\sigma_T = 8\pi\left(e^2/(m_e c^2)^2\right)/3 \approx 0{,}66\cdot 10^{-24}\, cm^2$$

while the other processes […] must have smaller cross sections" **[12]**.

Of the two processes indicated by (i), we are interested in the photon-photon photoproduction process and the creation of an electron-positron pair:

$$\gamma + \gamma \rightarrow e^+ + e^- \qquad \text{(ii)}$$

which has an energy threshold; the process (ii), based on the attention paid to the initial or final states, is seen either as an absorption of photons or as the creation of electron-positron pairs, **[13]**.

The theoretical analysis of (ii) **[13]** is of scientific interest because the reaction limits the maximum energy of the photons that can reach the Earth from great distances.

Pointing with $\varepsilon_1 = \frac{h\nu_1}{m_e c^2}$ and $\varepsilon_2 = \frac{h\nu_2}{m_e c^2}$ the energies of the incident photons (expressed in the unit mass of the electron), we arrive at the well-known relationship

$$\varepsilon_1 \cdot \varepsilon_2 = \frac{2(m_e c^2)^2}{1-\cos(\theta)} \qquad \text{(iii)}$$

where θ is the collision angle (in a suitable reference).

From the analysis of the equations it follows that the condition for (ii) to take place is that $\varepsilon_1 \cdot \varepsilon_2 \geq 1$ and, in particular, the threshold condition of equality is obtained when the two photons are in opposition ($\theta = \pi$).

The total cross section (ratio between the number of electrons, or positrons, created in the unit of time and the flux of unpolarized photons), which is independent of the reference used, is given by **[13]**:

$$\sigma_{\gamma\gamma}(\varepsilon') = \frac{3\sigma_T}{16(\varepsilon')^2}\left[\left(2 + \frac{2}{(\varepsilon')^2} - \left(\frac{1}{(\varepsilon')^4}\right)\right)\ln\left(\frac{1+\beta'}{1-\beta'}\right) - 2\beta'\cdot\left(1+\frac{1}{(\varepsilon')^2}\right)\right] \qquad \text{(iv)}$$

where $(\varepsilon')^2=\frac{\varepsilon_1\cdot\varepsilon_2}{2}\cdot(1-\cos(\theta))$ and $(\beta')^2=1-(\frac{1}{(\varepsilon')^2})$ and $\sigma_T=\frac{8\pi}{3}\cdot r_0^2$ where $r_0=\frac{e^2}{m_e c^2}$ present in the literature (**[12]**, **[13]**, **[14]**).

By studying the cross section (iv), a maximum follows for ε'~1,4 and that, important information, the higher energy photons interact much more effectively with the less energetic photons (**[12]**, **[13]**), thus being able to estimate the following relationship **[13]**:

$$\varepsilon_1\approx\frac{2}{\varepsilon_2}\cdot(\frac{2}{1-\cos(\theta)})\geqslant\frac{2}{\varepsilon_2} \qquad \text{(v)}$$

concluding that the most probable processes occur between photons with energies $\varepsilon_1\approx 2/\varepsilon_2$ **[13]**. The vastness and complexity of the Universe makes it possible to evaluate different photons as targets for high energy photons: the CMBR background is the dominant background but requires projectile photons with extremely high energy; the EBL fund, used as a target, requires projectile photons with lower energy. As an example we report the following orders of magnitude **[12]**: if the target photon is in the infrared (0.1 eV) the projectile photon must have at least an energy of 10 TeV; with target photons of the CMBR background (10^{-3} eV) the production of pairs becomes possible when the projectile photon has an energy of the order of 10^{15} eV.

3. Conclusion.

In this article we have analyzed the validity of the photoproduction hypothesis which underlies the Universe of Photons model. The hypothesis of using CMBR and EBL photons as targets is proved theoretically by the fact that the more energetic photons interact more effectively with the less energetic photons for the purpose of producing an electron-positron pair.

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