# Gamma Rays from Super Heavy Dark Matter in the Halo

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### Abstract

Super-heavy (SH) quasistable relic particles created in the early universe, can produce ultra high energy cosmic rays (UHECRs) and play some role as cold dark matter candidates. Since SH particles are likely to cluster in the galactic halo, most of the UHECRs detected at the Earth would be gamma rays, generated by the decay of neutral pions resulting from the fragmentation process following the decay of a SH particle. Ultra high energy electrons (UHEEs) are also produced at the same time due to the decay of charged pions. The resulting gamma ray flux from SH particles in the halo will be the superposition of the primary gamma rays from neutral pions and gamma rays produced as synchrotron radiation of the UHEEs in the galactic magnetic field. We present here our results of this combined emission and more specifically we calculate the contribution of the synchrotron radiation, which could give important informations about SH particles as sources of UHECRs.

## 1 Introduction:

The origin of cosmic rays with energy in excess of $10^{19}$ eV is still unknown. A cosmological origin for these particles would imply the presence of the so called GZK cutoff (Greisen, 1966; Zatsepin, & Kuzmin, 1966) at energy $E \sim 5 \times 10^{19}$ eV, which is not observed (Takeda et al., 1998). On the other hand if these particles are produced locally (within $50 - 100$ Mpc) then the sources should be visible in some wavelength (assuming a small intergalactic magnetic field, according with the existing upper limits (Kronberg, 1994; Blasi, Burles, & Olinto, 1999)) while no trivial association with known sources has been found so far.

These problems have fueled the interest in a new class of models, the so called *top-down* models, in which the UHECRs are produced by the decay of very massive particles (generically named X-particles) either produced by topological defects or as relics of some process occurred in the very early universe (Berezinsky, Kachelriess, & Vilenkin, 1997; Birkel, & Sarkar, 1998; Kuzmin, 1997; Berezinsky, 1998; Chung, Kolb, & Riotto, 1998a,b). We consider here the latter case, where X particles are related to super heavy quasistable relic particles. These particles are likely to cluster in the galactic halo, therefore the flux of UHECRs produced by the decay of SH particles is dominated by the gamma ray component and has some peculiar features discussed in (Dubovsky, & Tinyakov, 1998; Berezinsky, Blasi, & Vilenkin, 1998; Berezinsky, & Mikhailov, 1998). The main characteristic of this model is the anisotropy in the arrival directions, introduced by the asymmetric position of the sun in the galaxy with respect to the spherically symmetric distribution of SH particles.

Together with the neutral pions, responsable for the gamma ray component, charged pions are also produced. They rapidly decay into electrons and neutrinos. In this paper we concentrate our attention on the results of our calculations of the gamma radiation emitted by synchrotron emission of the UHEEs in the magnetic field of our Galaxy. We find that the fluxes in the energy region between $100$ MeV and $10^4$ GeV can be of interest for next generation gamma ray satellites (e.g. GLAST) and for current high energy experiments (e.g. MILAGRO). We also compare these fluxes with the existing upper limits in the $10^5 - 10^8$ GeV region.

## 2 The Gamma Ray fluxes:

In this section we outline the calculations which are discussed in detail in (Blasi, 1999). The rate of decay of SH particles in the halo is parametrized as the distribution of dark matter proposed in (Kravtos, et al., 1997; Navarro, Frenk, & White, 1996) and used in (Berezinsky, Blasi, & Vilenkin, 1998):

$$\dot{n}_X(R) = \frac{\dot{n}_0}{(R/r_0)^\gamma \left[1 + (R/r_0)^\alpha\right]^{(\beta-\gamma)/\alpha}} \tag{1}$$

where $\dot{n}_0$ is a normalization, $R$ is the distance to the galactic center and $r_0$ is a distance scale between $5$ and $10$ kpc. The parameters $(\alpha, \beta, \gamma)$ define the model of dark matter distribution in the galactic halo. Although we carried out the calculations for different models, as found in (Blasi, 1999), after the normalization to the observed fluxes of UHECRs the predictions appear to be very weakly dependent on the specific distribution of SH particles in the halo. However, as discussed in (Berezinsky, Blasi, & Vilenkin, 1998) different models give different anisotropies in the arrival directions. The decay of a SH particle typically results in the production of a quark-antiquark pair ($X \to q\bar{q}$) and UHECRs are produced in the hadronic cascade due to the fragmentation of quarks. We use here the MLLA limiting spectrum for the fragmentation function, in its classical QCD form (Dokshitzer, et al., 1991) and its supersymmetric generalization (Berezinsky, & Kachelriess, 1998). The calculation of the flux of primary gamma rays is carried out as in (Berezinsky, Blasi, & Vilenkin, 1998), assuming that a fraction $\sim 1/3$ of the pion content in the hadronic cascade is in the form of neutral pions, which then decay in gamma rays. Analogously $\sim 2/3$ of the pion content is in the form of charged pions which are responsable for the production of electrons, radiating gamma rays through synchrotron emission.

The typical energy of the synchrotron gamma rays in the magnetic field of the Galaxy is given by

$$E_\gamma = 1.5 \times 10^3 B_\mu \left( \frac{E_e}{10^{10} GeV} \right)^2 GeV \tag{2}$$

where $E_e$ is the electron energy in GeV and $B_\mu$ is the magnetic field in $\mu$Gauss. The calculation of the synchrotron emission has been done assuming the following profile for the magnetic field

$$B(r, z) = B_0(r) exp(-z/z_0) \tag{3}$$

where $B_0(r) = 3(r_\odot/r)\mu G$ for $r < 4$ kpc and constant otherwise, $r$ is the radial distance in the disc, $r_\odot$ is the distance of the sun from the galactic center ($8.5$ kpc) and $z$ is the height above the disc. $z_0$ is assumed to be $0.5$ kpc, but the results are weakly dependent on the specific value.

The results of our calculations of the combined flux of gamma radiation due to neutral pion decay and sunchrotron emission of UHEEs are plotted in Fig. 1 (in the form of gamma ray flux per unit surface, time and solid angle multiplied by $E_\gamma^{1.75}$). The fluxes of UHECRs are normalized to the observed flux at $5 \times 10^{19}$ eV, and this automatically determines the normalization in the synchrotron flux. The two solid lines are obtained using the SUSY-QCD fragmentation function while the dashed lines are obtained using the ordinary QCD fragmentation function. The thick lines refer to $m_X = 10^{14}$ GeV and the thin lines to $m_X = 10^{13}$ GeV. The points with arrows are the upper limits from the HEGRA (Karle, et al., 1995), Utah-Michigan (Matthews, et al., 1991), EASTOP (Aglietta, et al., 1996) and CASA-MIA (Chantell, et al. 1997) experiments. The dash-dotted line is the isotropic gamma ray background as measured by EGRET (Chen, Dwyer, & Kaaret, 1996; Sreekumar, et al., 1998). The broken line labelled *GLAST* is the sensitivity limit of the GLAST experiment assuming a 2.5 sterad opening angle.

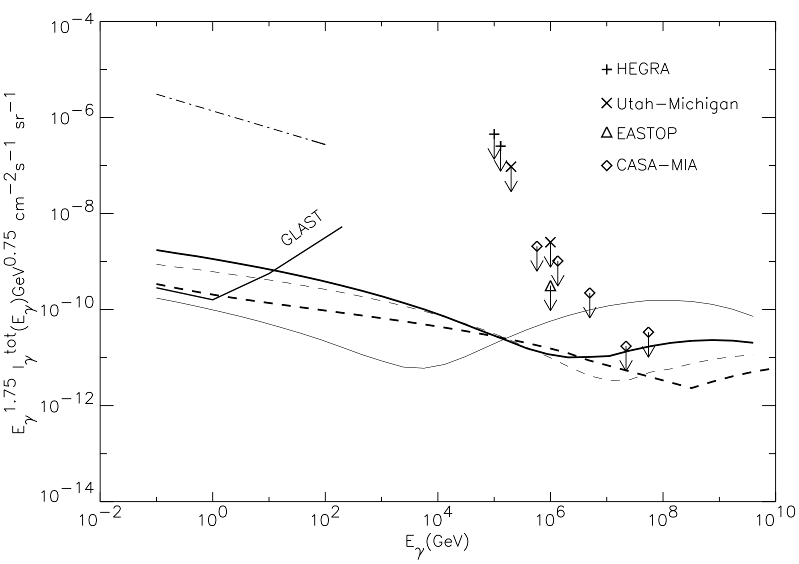


**Figure 1:** Flux of gamma rays from SH particles in the halo for different fragmentation functions and different values of $m_X$ (see text).

All the curves plotted in Fig. 1 are compatible with the existing upper limits with the exception of the one obtained with $m_X = 10^{13}$ GeV and a SUSY-QCD fragmentation function, which exceeds the CASA-MIA limit at $\sim 10^8$ GeV. The sensitivity of the MILAGRO experiment in the range of energies $250 - 10^4$ GeV (not plotted in the figure) is comparable with our best case scenario in Fig. 1. Some additional comments on the curves in Fig. 1 are needed: the fluxes per unit solid angle have been obtained assuming an isotropic distribution and dividing by $4\pi$. However both the fluxes of primary gamma rays and synchrotron gamma rays are anisotropic, due to the asimmetric position of the sun in the galaxy and due to the magnetic field configuration. In general the two fluxes have different patterns of anisotropy. For this reason, the fluxes plotted in Fig. 1, when calculated more carefully, taking into account the real angular distribution of the radiation, could be larger than the ones obtained here (Blasi, & Olinto, 1999).

## 3 Conclusions:

We calculated the flux of gamma radiation produced by the decay of SH particles in the halo of our Galaxy. The total flux is the sum of the primary gamma ray flux, due to the decay of neutral pions and the secondary gamma ray flux, produced as a result of synchrotron emission of UHEEs in the galactic magnetic field. If the magnetic field in the galactic halo is $\sim 1\mu G$ then UHEEs with energy between $10^{17}$ eV and $m_X/2$ very rapidly loose all their energy in the form of gamma rays with energy $\leq 10^6 - 10^8$ GeV. The resulting diffuse gamma ray emission above $100$ MeV, dominated by the synchrotron component, is of the order of $10^{-8}$ photons $cm^{-2}s^{-1}sr^{-1}$ in our best case scenario. This flux is above the detectability limit of next generation gamma ray satellites like GLAST, though in the same energy region there is a large background. The possibility to isolate the signal could increase if a peculiar anisotropy pattern will be found (Blasi, & Olinto, 1999). The background is supposed to be smaller at higher energies $E_\gamma \geq 500$ GeV because of two reasons: first of all, if the isotropic diffuse gamma ray background detected by EGRET has extragalactic origin, then it is plausible to assume that most of the gamma rays above $500$ GeV would be absorbed on the infrared universal background. Second, if the most important galactic process of high energy gamma ray production is represented by $pp$ collisions, then the expected gamma ray spectrum would be very steep compared with the flat spectrum obtained by the synchrotron emission of UHEEs, and the latter should dominate above some energy. For this reason we propose to look in the region $E_\gamma \geq 500$ GeV for a possible evidence of the gamma rays generated by the SH particles, since this could give an important clue to the origin of UHECRs and to the physics of the early universe, responsable for the formation of these SH relics.

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