Decays of Long Lived Lightest Supersymmetric Particles in the Galactic Halo

Milind V. Diwan
Brookhaven National Laboratory, Upton, NY

ABSTRACT

If dark matter neutral LSPs in the galactic halo decay into two body final states containing photons or neutrinos they could be detected even if the decay rates are very small, $\sim 10^{-32}s^{-1}$. I calculate mass and lifetime bounds from current astrophysical data on monochromatic photons and neutrinos and suggest that the poorly explored region between 10 GeV and 1 TeV be explored for signs of supersymmetry from space.

In this note I describe a calculation of the possibility of detecting two body decays of very long lived lightest supersymmetric particles (LSP or $\tilde{\chi}_1^0$). If the lifetime is long enough then these LSPs could form a significant component of the dark matter. It is proposed that the two body decays $\tilde{\chi}_1^0 \to \tilde{G}\gamma$, $\tilde{\chi}_1^0 \to \tilde{G}\nu$, $\tilde{\chi}_1^0 \to J\nu$, and $\tilde{\chi}_1^0 \to \nu\gamma$ of the LSPs that form the local galactic halo could be detected even if the decay rates are very small. $\tilde{G}$ and J are the gravitino and the Majoron, respectively, that arise in some SUSY models. For example, the first two of these decays have been suggested in the context of low energy gauge mediated SUSY breaking models [1], though with small lifetimes. The decays to a Majoron and a neutrino or a neutrino and a photon could take place in R-parity violating models in which the violation is very small [2]. Regardless of the theoretical prejudice, if LSPs do form majority of the dark matter it must be interesting to detect them and to probe their lifetime at the same sensitivity as proton decay. Such experiments will be important even if supersymmetry is detected at present or future colliders because the measured density in the galactic halo will provide important information about the early history of the universe.

For this calculation I will assume that the LSP has a mass of about 50 GeV and that all of the local halo consists of LSPs. The local galactic halo has a density of about $0.2 - 0.4\ \mathrm{GeV/cm^3}$ [3]; therefore there are about $\rho = 6 \times 10^{-3}\ \mathrm{cm^{-3}}$ of LSPs around us. As these LSPs decay through two body decays monochromatic gammas or neutrinos with energy ~25 GeV will result. The flux of these particles on the earth will be

$$\phi \approx \frac{\rho}{\tau} \times \lambda(1 - e^{-R/\lambda})$$

where R is the radius of the local halo around the galaxy, τ is the effective lifetime of the two body decay, and λ is the attenuation length of photons through the galaxy. Since the galaxy is mostly transparent to these photons the formula simplifies to $\frac{\rho R}{\tau}$. This flux will be diffuse or uniform over all angles. I will assume $R \approx 30\ \mathrm{kpc}$ or approximately 3 times the distance of the sun from the galactic center. Then the flux can be written as

$$\phi = (\frac{50\ \mathrm{GeV}}{M_\chi}) \times \frac{5.5 \times 10^{20}\ \mathrm{cm^{-2}}}{\tau}$$

where M_χ is the mass of the supersymmetric particle.

Consider an electro-magnetic calorimeter with a surface area of about $10\ \mathrm{m} \times 10\ \mathrm{m}$ and angular acceptance of π str in orbit around the earth; the rate of gamma events per year will be

$$N_\gamma = \frac{1}{4} 1.8 \times 10^{34}/\tau$$

where τ is the decay lifetime in seconds. Thus if we require about 10 events in the 25 GeV peak then lifetimes of the order of $\sim 10^{32}$ sec could be reached.

Currently there is only one experiment that could look at such photons from outer space [4]. The EGRET experiment has observed the diffuse spectrum of gamma rays up to 10 GeV. The diffuse background spectrum at 10 GeV has been determined to be $10^{-8}\ \mathrm{cm^{-2}s^{-1}sr^{-1}GeV^{-1}}$. This background flux has been explained to be mainly from interactions of cosmic ray nucleons on galactic matter with significant components from electron bremsstrahlung, inverse Compton, and unresolved point sources (blazars) [5]. The energy resolution of EGRET at 10 GeV is about 1 GeV and the solid angle acceptance is approximately 0.15π str [6]. If we assume that a diffuse monochromatic flux about 10 times larger than the background at 10 GeV could be considered a signal for supersymmetric particles then EGRET is sensitive to a flux of about $5 \times 10^{-8}\ \mathrm{cm^{-2}s^{-1}}$. Thus EGRET rules out long lived LSPs of up to 20 GeV with lifetimes less than $\sim 3 \times 10^{28}$ s. Since LSPs up to ~20 GeV are already ruled out by LEP data [7] it is desirable to push the mass limit to higher values. The background from unresolved point sources is clearly a function of the angular resolution and the size of the detector. A new larger detector (the GLAST experiment) with much better angular and energy resolution is being considered [8]. This detector will also have acceptance to photons up to 300 GeV. Such a detector will indeed be able to explore much of this physics. If a signal is detected then its variation across the galactic plane could be measured.

We will now consider terrestrial experiments to detect the monochromatic neutrinos using upward going muons or energetic electrons. The two largest neutrino detectors with the most amount of data so far are Kamioka and IMB. Neither of these detectors can measure the momentum of high energy muons that pass through the detector, and so the best limits from these detectors come from the electron data. We will consider the sensitivity of the Kamioka detector only since the data above 10 GeV is published [9]. The Kamioka detector has had a total exposure of 8.2 kTon-yr including fiducial cuts, and the spectrum of contained electrons has 6 events between 10 GeV and 50 GeV. These events are consistent with background from atmospheric neutrinos. We will assume that a mono-energetic peak of events approximately 10 times the observed background constitutes a signal (or about 10 events in the peak). Then using the charged current neutrino (anti-neutrino) cross section of $\sim 0.7 \times 10^{-38} E_\nu$ $\mathrm{cm^2 GeV^{-1}}$ ($\sim 0.3 \times 10^{-38} E_{\bar{\nu}}$ $\mathrm{cm^2 GeV^{-1}}$) we obtain the following lifetime limits independent of the mass of the LSP:

$$\tau(\tilde{\chi}_1^0 \to X\nu_e) > 1.5 \times 10^{24}\ \mathrm{s} \qquad (1)$$
$$\tau(\tilde{\chi}_1^0 \to X\bar{\nu}_e) > 0.7 \times 10^{24}\ \mathrm{s}$$

where X is any light neutral particle. The Super-Kamioka detector, which started operating recently [10], has approximately 5 times the mass of the Kamioka detector; it also has much better energy resolution and particle identification, and so it should be able to reach 10 times longer lifetimes.

It is interesting to note that there is a lack of data about both neutrinos and photons of astronomical origins between 10 and a few hundred GeV. Since supersymmetric particles are postulated to have masses in this range, careful examination of both neutrinos and photons of a few tens of GeV is quite important. A cosmic ray muon detector to measure the momentum of upward going muons could partially fill this gap [11]. As an example consider a detector of size about $30\ \mathrm{m} \times 30\ \mathrm{m}$ and an angular acceptance of about $\pi/2$ str. The detector would be composed of an iron toroid magnet with a total momentum kick of about 1 GeV with tracking chambers to measure the muon bend. Water Cherenkov detectors placed above and below the iron toroid would detect the time and the direction of the muon. Such a detector would have an effective fiducial mass greater than 50 kT for 20 GeV muon neutrinos. Although it would be difficult to detect a mono-energetic peak with such a detector without any knowledge of the event vertex, an excess of high energy ($> 10\ \mathrm{GeV}$) muon events above the atmospheric neutrino background will clearly signal interesting physics.

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