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Decaying SUSY dark matter and 130 GeV Fermi Gamma-ray Line

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There has been interest in a tentative signal of 130 GeV gamma-ray line from the galactic center, which could be interpreted as a signature of dark matter annihilation or decay. We show that it is possible to explain the signal with supersymmetric dark matter with R-parity violation. In particular, we focus on decaying gravitino and axino dark matter. We also comment on the recent observation of an X-ray line from galactic clusters.

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1. 130 GeV gamma-ray line from Galactic Center

Recently, studies on the four-year Fermi data have found excess of 130 GeV gamma-ray line from the Galactic Center (GC) [1, 2, 3, 4, 5]. While up until now it is not entirely clear what the origin of the excess is, one of the most enticing possibilities is its interpretation as a dark matter (DM) annihilation/decay signature.

We attempt to interpret this signal utilizing decaying DM within the supersymmetric (SUSY) framework. SUSY is a well-motivated beyond-the-Standard-Model scenario where elegant solutions of problems such as hierarchy and unification are provided. The common wisdom is to impose R-parity, such that the lightest SUSY particle (LSP) can be a stable DM candidate. However, if R-parity violation (RPV) is small, and the LSP interacts weakly with other particles, the LSP is long-lived enough to be a candidate of DM. In addition, it is possible to detect the decay signature of DM from observations of astrophysical objects.

2. R-parity violation

Let us describe the framework of RPV briefly. The superpotential terms that violate R-parity are:

$$W = \lambda_{ijk} L_i L_j E_k + \lambda'_{ijk} L_i Q_j D_k + \lambda''_{ijk} U_i D_j D_k + \mu_i L_i H_u, \tag{2.1}$$

where the first three terms are called trilinear RPV, while the last one is of bilinear type. L_i, E_i, Q_i, D_i, U_i and H_u are the matter superfields of the Minimal Supersymmetric Standard Model (MSSM). λ_{ijk}, λ'_{ijk}, λ''_{ijk} are dimensionless coupling constants while the μ_i's carry mass dimension one. The indices i and j (j and k) of λ_{ijk} (λ''_{ijk}) are antisymmetric due to gauge symmetries. $\lambda''_{ijk} = 0$ is imposed by assuming baryon number conservation as the UUD operators are irrelevant to our study of decaying DM.

The bilinear RPV require more elaborate discussion. One can rotate away $\mu_i L_i H_u$ by redefining L_i and H_d as $L'_i = L_i - \varepsilon_i H_d$ and $H'_d = H_d + \varepsilon_i L_i$ with $\varepsilon_i \equiv \mu_i/\mu$, where μ is the Higgsino mass parameter. In general, the soft terms do not vanish along with the redefinition, and this leads to non-zero sneutrino VEVs, $\langle\tilde{\nu}_i\rangle$, which can be written as

$$\langle\tilde{\nu}_i\rangle = -\frac{m^2_{L_i H_d}\cos\beta + B_i \sin\beta}{m^2_{\tilde{\nu}_i}} v, \tag{2.2}$$

v being the Higgs vacuum expectation value (VEV). It is common to parametrize the strength of bilinear RPV in terms of $\kappa_i \equiv \langle\tilde{\nu}_i\rangle/v$.

The sneutrino VEV induces mixings between the gaugino and lepton sectors. In the neutralino-neutrino sector, such mixings induce neutrino masses, and therefore impose an upper bound on the value of sneutrino VEV (strength of bilinear RPV).

3. Models of decaying dark matter

We propose KSVZ-type axino DM in order to explain the observed monochromatic 130 GeV gamma-ray line [6]. The relevant interaction Lagrangian of the axino is

$$\mathscr{L}_{\tilde{a}\lambda A} = i\frac{\alpha_Y C_Y}{16\pi f_a}\bar{\tilde{a}}\gamma_5[\gamma^\mu,\gamma^\nu]\tilde{B}B_{\mu\nu} + i\frac{\alpha_W C_W}{16\pi f_a}\bar{\tilde{a}}\gamma_5[\gamma^\mu,\gamma^\nu]\tilde{W}^a W^a_{\mu\nu}. \tag{3.1}$$

C_Y, C_W are model-dependent coupling constants of order unity and f_a is the Peccei-Quinn scale. $\tilde{a}$ is the axino and $\tilde{B}(\tilde{W}^a)$ is the bino (wino) fields. Axino decays via the gaugino-lepton mixing induced from bilinear RPV. It is possible to obtain a large branching ratio of axino decay to photon and neutrino ($\tilde{a} \to \gamma\nu$). For example, when $C_W = 0$, the branching fraction is given as $\mathrm{Br}(\tilde{a} \to \gamma\nu)$: $\mathrm{Br}(\tilde{a} \to Z\nu) \simeq \cos^2\theta_W : \sin^2\theta_W$, which is equivalent to around 80 % for $\mathrm{Br}(\tilde{a} \to \gamma\nu)$. The decay rate is

$$\tau_{\tilde{a}} \simeq 8 \times 10^{26}\,\mathrm{sec}\, C_Y^{-2} \left(\frac{m_{\tilde{a}}}{260\,\mathrm{GeV}}\right)^{-3} \left(\frac{f_a}{10^{13}\,\mathrm{GeV}}\right)^{2} \left(\frac{m_{\tilde{B}}}{1\,\mathrm{TeV}}\right)^{2} \left(\frac{\kappa}{10^{-11}}\right)^{-2}. \tag{3.2}$$

The range of parameters to explain the excess lies in $\tau_{\mathrm{DM}}/\mathrm{Br}(\mathrm{DM} \to \gamma\nu) = (1-3) \times 10^{28}$ sec and $\mathrm{Br}(\mathrm{DM} \to \gamma\nu) \simeq 0.01 - 1$. Overproduction of antiprotons can be avoided as the hadronic decay branching ratio in this model is sufficiently small [7].

Another potential decaying SUSY DM candidate is gravitino. We consider the case where trilinear R-parity is broken [8, 9]. In particular, we focus on the trilinear RPV operators of *LLE* type so that overproduction of antiproton does not occur. Gravitino can undergo tree-level decay mediated by a slepton, e.g. right-handed stau. In this case, the three-body decay rate can be approximated by

$$\Gamma(\psi_{3/2} \to \bar{\tau}\nu_i e_j) \simeq \frac{|\lambda_{ij3}|^2}{90(32)^2\pi^3} \frac{m_{3/2}^7}{M_{\mathrm{Pl}}^2 m_{\tilde{\tau}_R}^4}. \tag{3.3}$$

M_{Pl} is the reduced Planck mass. Gravitino also undergoes one-loop decay to a photon and a neutrino. The decay rate scales as

$$\Gamma(\psi_{3/2} \to \gamma\nu_i) \sim \frac{\alpha\lambda_{ijj}^2 m_{3/2} m_j^2}{M_{\mathrm{Pl}}^2} \tag{3.4}$$

As an example, by choosing $m_{\tilde{\tau}_R} = 3$ TeV, the branching ratio of the radiative decay is 10 %. In order to explain the 130 GeV excess, λ_{133} has to be $O(10^{-6})$. Other astrophysical constraints, such as diffuse gamma-ray constraints are also satisfied.

Let us also mention the relevance of the gravitino model to the recently observed X-ray line from galaxy clusters and Andromeda galaxy. It has been observed that there is an excess of X-ray emission at around 3.55 keV, which if interpreted as DM decaying to photon, corresponds to DM with lifetime $\sim 10^{28}$ sec [10, 11]. Gravitino or axino with loop diagrams similar to the above mentioned decaying gravitino scenario have been shown to be compatible with the X-ray excess [12, 13].

4. Conclusion

We have shown two SUSY models with extremely weakly interacting particle as DM (i.e. axino and gravitino) that could explain the observed 130 GeV gamma-ray line signal. We have also briefly discussed the application of the presented models to another recently observed excess of signal. Finally, we suggest readers to refer to the original papers for discussions of the models' cosmological aspects, which are not discussed here.

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