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Recent Result of the AMS-02 Experiment and Decaying Gravitino Dark Matter in Gauge Mediation

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Abstract

The AMS-02 collaboration has recently reported an excess of cosmic-ray positron fractions, which is consistent with previous results at PAMELA and Fermi-LAT experiments. The result indicates the existence of new physics phenomena to provide the origin of the energetic cosmic-ray positron. We pursue the possibility that the enhancement of the positron fraction is due to the decay of gravitino dark matter. We discuss that such a scenario viably fits into the models in which the soft SUSY breaking parameters are dominantly from gauge-mediation mechanism with superparticle masses of around 10 TeV. Our scenario is compatible with 126 GeV Higgs boson, negative searches for SUSY particles, and non-observation of anomalous FCNC processes. We also point out that the scenario will be tested in near future by measuring the electric dipole moment of the electron and the lepton flavor violating decay of the muon.

1 Introduction

The AMS-02 collaboration has recently released their first result of the cosmic-ray positron fraction [1]. The anomalous excess over the expectation based on the simple comic-ray propagation models has been seen again, and its energy spectrum is consistent with the previous results of the PAMELA [2] and Fermi-LAT [3] experiments. The AMS-02 collaboration has also reported a fact that the positron flux at the energy region of the excess shows no appreciable anisotropy to date. This fact may indicate that the positrons are not due to some astrophysical activities on the galactic plane but are from exciting dark matter phenomena in the halo, though it is clearly premature to make a definite statement because of limited statistics.

When the excess of the positron fraction is interpreted as a dark matter signal, a decaying gravitino with its mass being $\mathcal{O}(1)\,\mathrm{TeV}$ could be a promising candidate for dark matter [4, 5] (for earlier discussions on decaying gravitino dark matter see references [6]). The lifetime of the gravitino is then required to be $\mathcal{O}(10^{26})$ sec., which is realized by introducing a tiny R-parity violation. The introduction of this violation is in fact favored from the viewpoint of cosmology; we can evade the serious gravitino problem [7] because the required violation is large enough to allow other sparticles to decay before the era of Big-Bang Nucleosynthesis (BBN). On the other hand, the violation is small enough not to wash out the baryon asymmetry of the universe created in the early universe, so that models with the decaying gravitino are consistent with the successful leptogenesis scenario [8].

In this letter, we revisit the model of decaying gravitino dark matter in light of the recent results of the AMS-02 experiment and the discovery of the Higgs particle at the LHC experiments [9, 10]. As we show, the desirable gravitino mass and the observed Higgs boson mass at around $126\,\mathrm{GeV}$ can be explained simultaneously in the models of direct gauge mediation with the messenger masses just below the scale of the Grand Unified Theory (GUT). We also show that the gravitino mass at around $\mathcal{O}(1)\,\mathrm{TeV}$ allows us to construct a simple model of the R-parity breaking which is appropriate for the favored gravitino lifetime, $\mathcal{O}(10^{26})\,\mathrm{sec}$.

This letter is organized as follows. In section 2, we reassure that the decaying gravitino with a mass at around $1\,\mathrm{TeV}$ well fits the anomalous excess of the positron fraction observed at the AMS-02. In section 3, we discuss the models with gauge mediation at the GUT scale which explain both the favored gravitino mass of $\mathcal{O}(1)\,\mathrm{TeV}$ and the observed Higgs boson mass, $m_h \simeq 126\,\mathrm{GeV}$. We also discuss the flavor changing neutral current and CP-violation in the lepton sector. In section 4, we give a simple model of R-parity breaking which leads to the appropriate gravitino lifetime.

The final section is devoted to our conclusions.

2 Positron Fraction

We first discuss the excess of positron fractions reported by the AMS-02 collaboration and its implication to the decaying gravitino dark matter. There are several ways to introduce R-parity violating interactions which make the gravitino meta-stable. In this letter, we consider the simplest possibility, namely the violation through the LH_u operator as an example, where L and H_u are the lepton doublet and the up-type higgs superfields, respectively. The relevant part of the superpotential and soft SUSY breaking terms are therefore given by as follows;

$$W = \mu H_u H_d + \mu'_i H_u L_i, \tag{1}$$
$$\mathcal{L}_{\text{soft}} = (B\mu\, H_u H_d + B'_i \mu'_i H_u \tilde{L}_i + h.c.) - \tilde{L}_i^\dagger m_{Lij}^2 \tilde{L}_j - m_{H_d}^2 |H_d|^2,$$

where H_d is the down-type higgs superfield. Then, the gravitino dark matter decays into a Z boson plus a neutrino, a Higgs boson plus a neutrino, and a W boson plus a charged lepton with the relative ratio of about 1:1:2, as was explicitly shown in reference [5].

We next summarize our procedure to calculate the positron fraction $R = \Phi_{e^+}/(\Phi_{e^+} + \Phi_{e^-})$, where Φ_{e^+} and Φ_{e^-} are positron and electron fluxes, respectively. The fluxes consist of the contribution from the decaying gravitino dark matter and the background contribution: $\Phi_{e^+} = [\Phi_{e^+}]_{\text{DM}} + [\Phi_{e^+}]_{\text{bkg}}$. For the contribution from the dark matter, we have solved the diffusion equation in order to take account of the effect of electron/positron propagations inside our galaxy. The energy spectrum of the electron/positron from the dark matter $f_{e^\pm}$ evolves as [11]

$$\frac{\partial f_{e^\pm}(E,\vec{r})}{\partial t} = K(E)\left[\nabla^2 f_{e^\pm}(E,\vec{r})\right] + \frac{\partial}{\partial E}\left[b(E)\, f_{e^\pm}(E,\vec{r})\right] + Q(E,\vec{r}), \tag{2}$$

where the function K is expressed as $K = K_0\, E_{\text{GeV}}^\delta$ with E_{GeV} being the energy in units of GeV and $b = 1.0 \times 10^{-16}\, E_{\text{GeV}}^2$ [GeV/sec]. In our numerical calculation, we have fixed the parameters δ and K_0 to be 0.55 and 5.95×10^{-3} [kpc^2/Myr], respectively. The diffusion zone is assumed to be a cylinder with a radius of 20 [kpc] and a half-height of 1 [kpc], and we set $f_{e^\pm} = 0$ at the boundary. The fluxes from the dark matter are then obtained as $[\Phi_{e^\pm}]_{\text{DM}}(E) = (c/4\pi) f_{e^\pm}(E,\vec{r}_\odot)$.

The source term Q expressing the production of primary electrons/positrons from decaying gravitino dark matters is given by the following formula,

$$Q(E,\vec{r}) = \frac{\rho_{\text{DM}}(\vec{r})}{m_{3/2}\, \tau_{3/2}} \left[\frac{dN_{e^\pm}}{dE}\right]_{\text{decay}}, \tag{3}$$
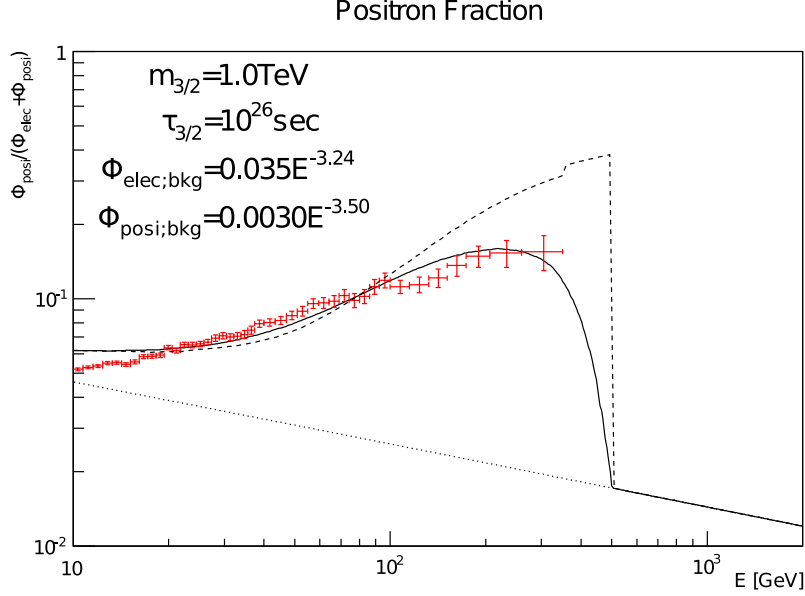
Figure 1: *The positron fraction expected in the decaying gravitino dark matter scenario with the bilinear term of the R-parity violation. The solid line corresponds to the $L_2 H_u$ interaction, while the dashed line to the $L_1 H_u$. As a reference, the fraction without dark matter contribution is drawn with a dotted line. The recent results from the AMS-02 experiment is shown with the red data points.*

where $\tau_{3/2}$ and $m_{3/2}$ are the lifetime and the mass of the gravitino, respectively. In addition, $\rho_{\rm DM}$ is the dark matter mass density of our galaxy for which we adopt the NFW profile $\rho_{\rm DM}(\vec{r}) = \rho_{\odot}(r_{\odot}/r)(r_c + r_{\odot})^2/(r_c + r)^2$ [12], where $\rho_{\odot} \simeq 0.4$ [GeV/cm^3] is the local halo density, $r_c \simeq 20$ [kpc] is the core radius, and $r_{\odot} \simeq 8.5$ [kpc] is the distance between the galactic center and our solar system. In the above expressions, $[dN_{e^{\pm}}/dE]_{\rm decay}$ is the energy distributions of the electron/positron from single decay process, and are calculated by using PYTHIA6 package [13].

The background contributions are approximated to the form $[\Phi_{e^{\pm}}]_{\rm bkg} = C_{\pm} \cdot (E_{\rm GeV})^{\delta_{\pm}}$, where $[\Phi_{e^{\pm}}]_{\rm bkg}$ is in the unit of [GeV cm^2 sec sr]$^{-1}$. Parameters for electrons are determined with fitting against the result of total electron flux reported by PAMELA collaboration [14] to be $(C_-, \delta_-) = (0.035, -3.24)$. For positrons, $C_+ = 0.088 C_-$ and $\delta_+ = \delta_- - 0.26$ are used.

The result is shown in Fig. 1. As a benchmark point, the mass and lifetime of the dark matter are fixed as $(m_{3/2}, \tau_{3/2}) = (1.0\,{\rm TeV}, 10^{26}\,{\rm sec})$. Two patterns of the gravitino decay are shown: the solid line (the dashed line) shows the case where the gravitino exclusively decays into the second (first) generation leptons, i.e., R-parity is broken only in the second (first) generation leptons.

First it should be noted that the data points below 10 GeV are not taken into consideration because the fraction in the region is subjected to the solar modulation [15]. Also, fractions around 10 GeV could be modified by the change of the background contribution. Considering these two uncertainties, the AMS-02 results are explained well by the solid line, i.e., when the gravitino decays into the second generation. On the contrary, when the decay is into the first generation leptons, the slope becomes steeper due to the electrons produced primarily, and it is difficult to explain the AMS-02 result.

Decays of the gravitino through the LH_u operator, on the other hand, also produce other particles such as anti-protons and gamma-rays. Furthermore, high-energy electrons from the decay of the gravitino produce gamma-rays through the inverse Compton scattering with cosmic microwave backgrounds and infra-photons from star lights [16]. Since no excesses are reported so far at observations of these particles, models involving the decaying gravitino are severely constrained. First, let us consider the constraint from the observation of cosmic-ray anti-protons. According to reference [17], with use of the most conservative limit (dark matter decay only), it turns out that the lifetime of the gravitino should be longer than 10^{26} sec. when the gravitino mass is around 1 TeV. If we used shallower profiles than the NFW one, the limit is expected to be milder [18]. Next, we consider the constraint from gamma-ray observations. According to the most conservative limit (dark matter decay only) in reference [19], the lifetime has to be longer than about 10^{26} sec. In any case, the lower limit on the lifetime is almost the same as that required to explain the excess of positron fractions. An attractive solution to this problem is the use of the $LL\bar{E}$ operator instead of LH_u, where we do not have to worry about the constraint from the observation of cosmic-ray anti-protons, while that from gamma-ray observations becomes much milder than the case of LH_u [20].

Finally, let us comment on the mass of the gravitino. The decaying gravitino should be heavier than $520\,\text{GeV}$ in order to explain the rightmost data point of the AMS-02 result, which is for the energy of 260–350 GeV. Meanwhile, if the gravitino mass is heavier than 1 TeV, the lifetime which can explain the result tends to be shorter than 10^{26} sec. since the number density of the gravitino is smaller. This is somewhat disfavored for the constraints from the gamma-ray and anti-proton fluxes. The AMS-02 result indicates that the mass of the decaying gravitino dark matter should be $\sim 1\,\text{TeV}$, which provides precious information to model building behind the physics of the dark matter.

3 Gravitino Dark Matter in Gauge Mediation

In the previous section, we have seen that the AMS-02 result is well explained in the model with unstable gravitino dark matter with the mass of ~ 1 TeV. However, such a model is usually severely constrained by the flavor violating processes, like the K-$\bar{K}$ mixing, lepton flavor violating (LFV) processes, and so on. In particular, if the gravity mediation contribution dominates the soft SUSY breaking sfermion masses, the off-diagonal elements of the sfermion mass-squared matrices are expected to be unsuppressed compared to the diagonal ones. If so, our scenario is not compatible with the constraints from the flavor violating processes. In addition, in the light of the recently observed Higgs mass, the scenario gives too small Higgs mass (unless the tri-linear scalar coupling is relatively large); the stop masses should be as large as ~ 10 TeV to realize the lightest Higgs mass as large as 126 GeV [21].

If the gauge-mediation contribution gives an extra contribution to the soft SUSY breaking parameters, the above problems may be solved. In particular, if the gauge mediation contributions to the sfermion masses are significantly larger than the gravitino mass and are as large as ~ 10 TeV, we obtain viable scenario as we see below.

We parameterize the messenger sector as

$$W_{\text{mess}} = (M_{\text{mess}} + F_{\text{mess}}\theta^2)\Psi_i\bar{\Psi}_i, \tag{4}$$

where $\Psi_i(\bar{\Psi}_i)$ are messenger fields in fundamental (anti-fundamental) representation of $SU(5)$ GUT gauge group. The indices i runs to $1 - N_{\text{mess}}$, with N_{mess} being the number of the messengers. The gravitino mass is bounded from below:

$$m_{3/2} \geq \frac{F_{\text{mess}}}{\sqrt{3}M_P}. \tag{5}$$

The equality is satisfied in the direct gauge mediation models; in such a model, the messenger scale is around the GUT scale taking $m_{\text{soft}} \sim 10$ TeV.

The bino, wino and gluino masses are given by

$$M_{\tilde{B}} \simeq N_{\text{mess}}\frac{\alpha_1}{4\pi}\left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right), \tag{6}$$

$$M_{\tilde{W}} \simeq N_{\text{mess}}\frac{\alpha_2}{4\pi}\left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right), \tag{7}$$

$$M_{\tilde{g}} \simeq N_{\text{mess}}\frac{\alpha_3}{4\pi}\left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right), \tag{8}$$

where α_1, α_2 and α_3 are gauge coupling constant squareds of $SU(3)_C$, $SU(2)_L$ and $U(1)_Y$ divided by 4π, respectively. (Here, we take a normalization of $U(1)_Y$ as the

$SU(5)$ GUT normalization.) In addition, the messenger-scale values of the sfermion masses are

$$m_Q^2 \simeq \left(\frac{4}{3}\alpha_3^2 + \frac{3}{4}\alpha_2^2 + \frac{1}{60}\alpha_1^2\right) \frac{N_{\text{mess}}}{8\pi^2} \left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right)^2, \tag{9}$$

$$m_{\bar{U}}^2 \simeq \left(\frac{4}{3}\alpha_3^2 + \frac{4}{15}\alpha_1^2\right) \frac{N_{\text{mess}}}{8\pi^2} \left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right)^2, \tag{10}$$

$$m_{\bar{D}}^2 \simeq \left(\frac{4}{3}\alpha_3^2 + \frac{1}{15}\alpha_1^2\right) \frac{N_{\text{mess}}}{8\pi^2} \left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right)^2, \tag{11}$$

$$m_L^2 \simeq \left(\frac{3}{4}\alpha_2^2 + \frac{3}{20}\alpha_1^2\right) \frac{N_{\text{mess}}}{8\pi^2} \left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right)^2, \tag{12}$$

$$m_{\bar{E}}^2 \simeq \frac{3}{5}\alpha_1^2 \frac{N_{\text{mess}}}{8\pi^2} \left(\frac{F_{\text{mess}}}{M_{\text{mess}}}\right)^2, \tag{13}$$

where $Q, \bar{U}, \bar{D}$ are squarks and $L, \bar{E}$ are sleptons. The soft masses of the up- and down-type Higgses (H_u and H_d) are same as m_L^2.

The mass spectrum we anticipated can be easily obtained. For instance, taking $M_{\text{mess}} = 10^{15}$ GeV, $F_{\text{mess}}/M_{\text{mess}} = 3000$ TeV, and $N_{\text{eff}} = 1$, the low-energy values of gluino and squark masses are abut 20 TeV while the slepton masses are $\sim$ 10 TeV. Furthermore, assuming the direct gauge mediation, the gravitino mass becomes about 1 TeV. (Notice that the gravitino mass as large as 1 TeV can be realized with smaller value of M_{mess} if we do not consider the direct gauge mediation.)

Let us estimate the rates of flavor and CP violations which are important probes of the SUSY particles even if the masses of superparticles are quite large [22, 23, 24]. First, we consider the leptonic ones on which the experimental bounds are expected to be drastically improved. Even though all the superparticles are relatively heavy, the rates of LFV processes may become sizable. This is because the off-diagonal elements of the sfermion mass-squared matrices are expected to be of $O(m_{3/2}^2)$, which are $\sim$ 1 % of the diagonal elements in the present setup. If the masses of sleptons, Higgsinos, and the electroweak gauginos are 10 TeV while the 1-2 elements of the slepton mass-squared matrices are 10^{-2} of the diagonal elements, for example, $Br(\mu \to e\gamma)$ is estimated to be 1×10^{-15}, 6×10^{-15}, and 2×10^{-14}, for $\tan\beta = 5, 10$, and 20, respectively. Thus the rate of the $\mu \to e\gamma$ process can be below the current bound. In addition, using the fact that $Br(\mu \to e\gamma)$ is approximately proportional to $\tan^2\beta$, $Br(\mu \to e\gamma)$ may be within the reach of MEG-upgrade experiment (which is expected to reach $Br(\mu \to e\gamma) \simeq 6 \times 10^{-14}$ [25]) in particular when $\tan\beta$ is large.

Another important check point is the so-called ϵ_K parameter, which often gives the most stringent constraint on supersymmetric flavor and CP violations. Assuming that off-diagonal elements of the squark mass-squared matrices are given by $(1 \text{ TeV})^2$,

for example, the SUSY contribution to the ϵ_K parameter becomes smaller than the present bound $(1 \times 10^{-3}$ [26, 27]) if the mass scale of the colored superparticles is larger than ~ 20 TeV. (Here, the phases in the MSSM parameters are tuned to maximize the SUSY contribution to ϵ_K.) Such a value of the colored superparticle masses can be easily realized as we have mentioned.

We also comment on the electric dipole moment (EDM) of the electron. Assuming that the supergravity contribution provides the B parameter of $O(m_{3/2})$, we expect that the CP violating phase in the μ parameter (in the bases where the VEVs of the Higgs bosons and the gaugino masses are real) is sizable. Taking the masses of non-colored superparticles to be 10 TeV, for example, the electron EDM is estimated to be 0.3×10^{-27}, 0.6×10^{-27}, and 1×10^{-27} $e$cm for $\tan \beta = 5$, 10, and 20, respectively, which are around the current bound [27]. (Here, we have tuned the phase of the μ parameter to maximize the electron EDM.) The future experiments, which may improve the bound by ~ 3 orders of magnitude [28], have a good chance to observe the electron EDM.

Now, we estimate the size of μ' and soft masses required for the gravitino decay with $\sim 10^{26}$ sec. In the case that R-parity is broken by bi-linear operator, we need a small VEV of a left-handed sneutrino, inducing chargino, neutralino/lepton mixing. Then, the gravitino decays into the SM gauge bosons and leptons through the mixing. The sneutrino get a VEV trough the potential

$$\mathcal{L}_{\text{soft}} \ni \tilde{B}_i^2 \tilde{L}_i H_u - m_i^2 \tilde{L}_i H_d^* + h.c. - m_{\text{GMSB}}^2 |\tilde{L}|^2, \tag{14}$$

where $\tilde{B}_i^2 = -\epsilon_i B\mu + \epsilon_k B_k' \mu \delta_{ik}$ and $m_i^2 = (\delta m_L^2)_{ik} \epsilon_k^* - \epsilon_i \delta m_{H_d}^2$. The rotation parameters ϵ_i are determined by the ratio of μ and μ_i' as $\epsilon_i = \mu_i/\mu$, and $m_{\text{GMSB}}^2 = m_L^2$ are the soft masses induced by gauge mediation. Other mass parameters, B, B', $\sqrt{|\delta m_L^2|}$ and $\sqrt{|\delta m_{H_d}^2|}$ of ~ 1 TeV are induced by the supergravity effects. The sneutrino VEV is given by

$$\kappa_i \equiv \frac{\langle \tilde{\nu}_i \rangle}{v} \simeq (\tilde{B}_i^2 \sin \beta - m_i^2 \cos \beta)/m_{\text{GMSB}}^2. \tag{15}$$

For the gravitino of ~ 1 TeV, the life-time of 10^{26} sec. is explained by $\kappa_i \sim 10^{-10}$ [5]. This requires ϵ_i to be $\sim 10^{-9}$, i.e., the coefficient of the R-parity violating bi-linear term μ_i' should be $\sim 10^{-5}$ GeV ($\mu \sim 10$ TeV in the parameter space of our interest). This $\mu_i' \sim 10^{-5}$ GeV can be explained consistently with the seesaw mechanism; μ' is induced by the small vacuum expectation value of the right-handed sneutrino through the operator $L H_u \langle \bar{N}_R \rangle$. An explicit model realizing the small $\langle \bar{N}_R \rangle$ is discussed below. Note that the NLSP also decays into SM particles through the

mixing with the life-time much less than 1 sec, and hence, the BBN constraint can be avoided [7].

4 A Model of R-parity Violation

In the previous section, we have shown that the small value of the R-parity violating parameter of $\mu' = O(10^{-5})\,\text{GeV}$ is needed to explain the AMS-02 result. Here, we show that such a value of the μ' parameter may arise in the model with a discrete R-symmetry, as we show below.

Let us consider a model with a discrete R-symmetry, $\mathbb{Z}_{5R}$ (see Table. 1). With the given charge assignments, the relevant superpotential terms are given by,

$$
\begin{aligned}
W &= y_u H_u \mathbf{10}\,\mathbf{10} + y_{d,e} H_d \mathbf{10}\,\mathbf{5}^* + y_\nu H_u \mathbf{5}^* \, \bar{N}_R + \mu H_u H_d + y_M \phi \bar{N}_R^2/2 \\
&\quad - \frac{c_4}{M_{\text{PL}}^2} \phi^4 \bar{N}_R + \frac{c_7}{M_{\text{PL}}^4} \phi^7 + y_X X \left(\phi^2 + c_H \frac{\mu}{M_{\text{PL}}} H_u H_d - c_W \frac{\langle W_0 \rangle}{M_{\text{PL}}} \right) \, , \quad (16)
\end{aligned}
$$

where ϕ and X are gauge singlets and y's and c's are dimensionless constants.[#1] We assume here that there is a spontaneous discrete R-symmetry breaking sector which generates $m_{3/2} = \langle W_0 \rangle /M_{\text{PL}}^2 \neq 0$.[#2] It should be noted that the above superpotential breaks $U(1)_{B-L}$ and R-parity explicitly, although the usual R-parity violating terms $LL\bar{E}$, $LQ\bar{D}$, $\bar{U}\bar{U}\bar{D}$ and LH_u are suppressed by $\mathbb{Z}_{5R}$.

From the above superpotential, we find a stable vacuum at around,

$$
\langle \phi \rangle = \left(c_W \frac{\langle W \rangle}{M_{\text{PL}}} \right)^{1/2} = (c_W m_{3/2} M_{\text{PL}})^{1/2} \, , \tag{17}
$$

$$
\langle \bar{N}_R \rangle = \frac{c_4}{y_M} \frac{\langle \phi \rangle^3}{M_{\text{PL}}^2} = \frac{c_4}{y_M} \left(\frac{c_W^3 m_{3/2}^3}{M_{\text{PL}}} \right)^{1/2} \, ,
$$

$$
\langle X \rangle = -\frac{y_M \langle \bar{N}_R \rangle^2}{4 y_X \langle \phi \rangle} + \frac{2 c_4}{y_X M_{\text{PL}}^2} \langle \phi \rangle^2 \langle \bar{N}_R \rangle + \frac{7 c_7}{2 y_X M_{\text{PL}}^4} \langle \phi \rangle^5 \sim m_{3/2} \left(\frac{m_{3/2}}{M_{\text{PL}}} \right)^{5/2} \tag{18}
$$

For $c_W = \mathcal{O}(1)$, $c_4/y_M = \mathcal{O}(1)$ $m_{3/2} = \mathcal{O}(1)\,\text{TeV}$, we find

$$
\langle \phi \rangle = \mathcal{O}(10^{11})\,\text{GeV} \, ,
$$

$$
\langle \bar{N}_R \rangle = \mathcal{O}(10^{-5})\text{GeV} \, . \tag{19}
$$

[#1] Here, we absorbed the allowed mass term of ϕ^2 by the shift of X. We also assume that the size of μ is controlled by another symmetry than $\mathbb{Z}_{5R}$ symmetry.

[#2] For example, the discrete R-symmetry is spontaneously broken in the supersymmetric Yang-Mills theories by the gaugino condensations [29]. If X appears in the gauge kinetic functions of the Yang-Mills theories, we need several gaugino condensations to stabilize X.

Table 1: *The charge assignments under the discrete $\mathbb{Z}_{5R}$ symmetry are presented here. We have used $SU(5)$ GUT representations for the MSSM matter fields, i.e.* $\mathbf{10} = (Q_L, \bar{U}_R, \bar{E}_R)$, $\mathbf{5}^* = (\bar{D}_R, L_L)$ *and* $\bar{N}_R$ *the right-handed neutrino.*

	H_u	H_d	$\mathbf{10}$	$\mathbf{5}^*$	$\bar{N}_R$	ϕ	X
$\mathbb{Z}_{5R}$	1	1	3	3	3	1	0

At around this vacuum, we obtain the masses of the right-handed neutrino,

$$M_N \propto \langle \phi \rangle = \mathcal{O}(10^{11})\,\text{GeV} \ , \tag{20}$$

which are appropriate for the see-saw mechanism [30]. Furthermore, we also obtain the effective bi-linear R-parity violating term,

$$\mu' = \langle \bar{N}_R \rangle \quad = \quad \mathcal{O}(10^{-5})\,\text{GeV} \ , \tag{21}$$

which is appropriate for the decaying gravitino dark matter discussed in the previous section.

In addition to the superpotential terms in Eq. (16), there are R-parity breaking terms such as,

$$W = \frac{1}{M_{\text{PL}}^3}\phi \langle W_0 \rangle H_u \mathbf{5}^* \ , \tag{22}$$

which gives a similar contribution to the LH_u term from the $\langle \bar{N}_R \rangle LH_u$ term. The trilinear R-parity breaking terms have, on the other hand, the charge -1 under $\mathbb{Z}_{5R}$, and hence, they are proportional to $(m_{3/2}/M_{\text{PL}})^{3/2} = \mathcal{O}(10^{-22})$. Thus, the trilinear R-parity breaking terms generated by the vacuum expectation values in Eq. (17) are negligibly small.

5 Summary

In this letter, we have shown that the anomalous increase of the positron fraction recently observed by the AMS-02 experiment can be well explained in the unstable gravitino scenario if $m_{3/2} \gtrsim 520$ GeV and $\tau_{3/2} \simeq 10^{26}$ sec. Even with such a value of the gravitino mass, we argued that the dangerous SUSY contribution to the flavor violating processes may be suppressed enough if the gauge mediation mechanism provides the dominant contribution to the sfermion masses of ~ 10 TeV. We have also proposed a model to give the R-parity violating interaction required to explain the AMS-02 signal.

Here, we concentrated on the case where the gravitino decays into lepton and electroweak gauge boson (or Higgs) with the interaction given in Eq. (14). With other types of R-parity violating interaction, however, gravitino may decay into different final states. In particular, if the $LL\bar{E}$-type R-parity violating operator exists in the superpotential, the gravitino decays into purely leptonic final state, with which the constraints from the anti-proton flux can be easily avoided. More detailed analysis on the related issues will be given elsewhere.

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