130 GeV Fermi gamma-ray line from dark matter decay

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Abstract

The 130 GeV gamma-ray line based on tentative analyses on the Fermi-LAT data is hard to be understood with dark matter annihilation in the conventional framework of the MSSM. We point out that it can be nicely explained with two body decay of a scalar dark matter ($\tilde{\phi}_{\text{DM}} \to \gamma\gamma$) by the dimension 6 operator suppressed with the mass of the grand unification scale ($\sim 10^{16}$ GeV),

$$\mathcal{L} \supset |\tilde{\phi}_{\text{DM}}|^2 F_{\mu\nu} F^{\mu\nu}/M_{\text{GUT}}^2,$$

in which the scalar dark matter $\tilde{\phi}_{\text{DM}}$ develops a TeV scale vacuum expectation value. We propose a viable model explaining the 130 GeV gamma-ray line.

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A thermally produced weakly interacting massive particle (WIMP) would be the most promising dark matter (DM) candidate explaining 23 percent of the mass-energy density in the present universe \[1\]. It might be closely associated with a new physics at the electroweak (EW) energy scale beyond the standard model in particle physics. In this sense, the ongoing indirect DM searches, which cover the EW energy scales, are expected to provide a hint toward the fundamental theory in particle physics as well as in cosmology.

Recent tentative analyses \[2-4\] based on the data from the Fermi Large Area Telescope (Fermi-LAT) \[5, 6\] exhibited a sharp peak around 130 GeV in the gamma-ray spectrum coming from near the galactic center (GC). The authors pointed out the gamma-ray excess could be a result from DM annihilation to a photon pair.\(^1\) Since DM should carry no electromagnetic charge,\(^2\) the annihilation, \(\chi\chi \rightarrow \gamma\gamma\) is possible only through radiative processes. If the sharp peak of the gamma-ray around 130 GeV really originates from DM annihilation, the annihilation cross section and the mass of DM would be \(\langle \sigma v \rangle_{\chi\chi \rightarrow \gamma\gamma} = (1.27 \pm 0.32^{+0.18}_{-0.28}) \times 10^{-27} \text{ cm}^3/\text{s} (2.27 \pm 0.57^{+0.32}_{-0.31}) \times 10^{-27} \text{ cm}^3/\text{s}\) and \(m_{\text{DM}} = 129.8 \pm 2.4^{+13}_{-13} \text{ GeV}\), respectively, when the Einasto (NFW) DM profile employed \[3\]. It is almost one order of magnitude smaller than the total cross section for the thermal production of DM needed for explaining the present DM density (\(\sim 10^{-6} \text{ GeV/cm}^3\)), which is about \(3 \times 10^{-26} \text{ cm}^3/\text{s}\) \[1\]. Indeed, the cross section of order \(10^{-27} \text{ cm/s}\) is much larger than the expected estimation of one-loop suppressed processes, assuming a thermal relic DM \[3\].

On the other hand, at the tree level, DM may annihilate into other final states, e.g. \(W^+W^-, ZZ, b\bar{b}, \tau^+\tau^-, \mu^+\mu^-\), etc, which can produce secondary continuous \(\gamma\)-ray spectrum through hadronizations or final state radiations. Thus, one can derive the constraints on the DM annihilation cross sections for those channels from the Fermi-LAT \(\gamma\)-ray observation data. Current limits on those annihilation modes are at the level of \(\mathcal{O}(10^{-26} - 10^{-25}) \text{ cm}^3/\text{s}\) for \(m_{\text{DM}} \approx 130 \text{ GeV}\). For more details, see Refs. \[11-16\]. Moreover, produced \(W\) and \(Z\) bosons can also lead to a sizable primary contribution to the antiproton flux measured by PAMELA \[17\], which provides another constraint of \(\mathcal{O}(10^{-25}) \text{ cm}^3/\text{s}\) on the DM annihilation into \(W^+W^-\) and \(ZZ\) \[18, 19\]. Consequently, any annihilating DM model to explain the 130 GeV \(\gamma\)-ray signal should also satisfy such limits.

Actually, the full one-loop calculations of the neutralino annihilation into two photons \[20-22\] show that the annihilation cross section of order \(10^{-27} \text{ cm}^3/\text{s}\) is impossible in the region of 20 GeV – 4 TeV DM mass in the minimal supersymmetric standard model (MSSM). In fact, the neutralino in the MSSM can be annihilated also into one photon plus one \(Z\) boson through one-loop induced processes, and this gamma-ray can cause the excess of the observed flux. Unlike the case of \(\chi\chi \rightarrow \gamma\gamma\), the emitted photon energy is estimated as

\(^1\) In Refs. \[4, 8\], it is argued that the gamma-ray line can be still explained with an astrophysical origin, associated with hard photons in the “Fermi bubble” regions.

\(^2\) The possibility that DM is a milli-charged particle has been studied in Refs. \[4, 10\].
\( E_\gamma = m_{DM}(1 - m_Z^2/4m_{DM}^2) \) for \( \chi \chi \to \gamma Z \). From the 130 GeV photon energy, hence, the DM mass of 144 GeV is predicted. [If the \( Z \) boson is replaced by an unknown heavier gauge field \( X \), the DM mass can be raised more.] Even in such a case, the cross section of \( \chi \chi \to \gamma Z \) is just about \( 10^{-28} \text{ cm}^3/\text{s} \) in the MSSM \([22,23]\), which is still smaller than \( 10^{-27} \text{ cm}^3/\text{s} \).

Renouncing the possibility of thermal production of the neutralino DM required to explain the observed DM relic density, the annihilation cross sections \( \langle \sigma v \rangle_{\chi \chi \to \gamma \gamma} \) and \( \langle \sigma v \rangle_{\chi \chi \to \gamma Z} \) can be of order \( 10^{-27} \text{ cm}^3/\text{s} \) or even larger. In this case, however, the mass difference between the chargino and the neutralino should be of order 10 GeV or less \([18,24]\). Moreover, such large neutralino annihilation cross sections for the one-loop suppressed processes are necessarily accompanied by much larger annihilation cross section into \( W^+W^- \) of order \( 10^{-25} \text{ cm}^3/\text{s} \) or even larger \([18]\). As discussed above, the large annihilation cross section, \( \langle \sigma v \rangle_{\chi \chi \to \gamma \gamma} \), is constrained by the current Fermi-LAT limits on continuum photon spectrum \([12–16]\).

If the neutralino is wino- or higgsino-like, one might think that the cross section of \( \chi \chi \to \gamma \gamma \) could be enhanced by nonperturbative effects, called “Sommerfeld effect.” It turns out, however, that the cross section \( \langle \sigma v \rangle_{\chi \chi \to \gamma \gamma} \) cannot reach \( 10^{-27} \text{ cm}^3/\text{s} \), unless the mass of the neutralino is of TeV or hundreds of GeV scales \([25,27]\), which is exceedingly heavier than 130 GeV. In addition, the nonperturbative effects on heavy wino- or higgsino-like DM also enhance the annihilation cross sections into \( W^+W^- \) and \( ZZ \), \( \langle \sigma v \rangle_{\chi \chi \to \gamma \gamma} \), which are inevitably constrained by the Fermi-LAT continuum photon limits \([12–16]\) and the PAMELA antiproton flux limits \([18,19]\).

Thus, the 130 GeV gamma-ray is quite hard to explain with DM annihilation, if the framework is restricted within the MSSM; we need to consider a possibility of the presence of a new DM sector, introducing a new DM and its interactions with ordinary charged particles. The basic reason for the difficulty is the charged superparticles’ masses circulating in the loop cannot be light enough to enhance the cross section, because they should be heavier than the neutralino DM. Hence, if a new interaction coupling between a new DM and charged particles is introduced, which is larger enough than the weak coupling, we may obtain the required cross section \( \langle \sigma v \rangle_{\chi \chi \to \gamma \gamma} \) with relatively heavy (130 + a few\times10 GeV) charged particles in the loop. Of course, the out-going interaction of the photons should be still given by the electromagnetic interaction. In order to reconcile the difference between the demanded cross sections for 130 GeV gamma-ray by DM annihilation and for the thermal relic DM, one may introduce two quite different interactions such that a photon annihilation interaction with \( \langle \sigma v \rangle_{\chi \chi \to \gamma \gamma} \sim 2 \times 10^{-27} \text{ cm}^3/\text{s} \) is separated from the interaction explaining the thermal relic with \( \sum \langle \sigma v \rangle \sim 3 \times 10^{-26} \text{ cm}^3/\text{s} \) \([28,30]\). However, we will not pursue such an ambitious job in this Letter.

Instead, in this Letter we will discuss the possibility that the gamma-ray line at 130 GeV is explained by DM decay. By comparing the differential photon flux by DM decay (\( \Phi_{\text{dec}} \)
with that by annihilation ($\Phi_{\text{ann}}$)

\[
\frac{d\Phi_{\text{dec}}}{dE_\gamma d\Omega} = \frac{\Gamma}{4\pi r_\odot} \left( \frac{\rho_\odot}{2m_{\text{DM}}} \right) \int_{\text{l.o.s.}} ds \frac{1}{r_\odot} \left( \frac{\rho_{\text{halo}}(r)}{\rho_\odot} \right) \frac{dN_{\text{dec}}}{dE_\gamma},
\]

\[
\frac{d\Phi_{\text{ann}}}{dE_\gamma d\Omega} = \frac{\langle \sigma v \rangle}{8\pi r_\odot} \left( \frac{\rho_\odot}{m_{\text{DM}}} \right)^2 \int_{\text{l.o.s.}} ds \frac{1}{r_\odot} \left( \frac{\rho_{\text{halo}}(r)}{\rho_\odot} \right)^2 \frac{dN_{\text{ann}}}{dE_\gamma},
\]

one can estimate the decay rate $\Gamma$, needed for explaining the gamma-ray excess, where $dN_{\text{dec(ann)}}/dE_\gamma$ is the differential photon energy spectrum, $\rho_{\text{halo}}(r)$ is the DM halo density profile, $\rho_\odot \approx 0.4$ GeV cm$^{-3}$ is the local DM halo density, $r_\odot \approx 8.5$ kpc is the distance from the GC to the Sun and $\int_{\text{l.o.s.}} ds$ is the integral along the line of sight (l.o.s.). The morphology of the signal from DM decay is linearly proportional to the DM density profile, while that from DM annihilation has the density square dependence. Consequently, the decay case tends to show a less steep increase of the signal towards the GC compared with the annihilation case, although the morphology of the signal still has uncertainty by the DM halo density profile itself. In addition, for decaying DM more $\gamma$-ray flux is generically expected from the galactic halo compared to annihilating DM. However, the Fermi collaboration has observed no $\gamma$-ray excess from the galactic halo: it just reported the lower limits on the partial DM lifetime $\tau_{\gamma\nu}$ [3]. Although the best-fit values for the lifetime are in tension with the limit from the Fermi collaboration, however, the required lifetime to explain the 130 GeV $\gamma$-ray signal marginally satisfies the experimental limit allowing $2\sigma$ level error bars [33]. Moreover, there still exist the large uncertainty of the DM distribution around the GC, and also large statistical and systematic uncertainties at the moment. To confirm which scenario explains the 130 GeV $\gamma$-ray line, more improvement in observation is therefore essential in the near future. In Ref. [34], it was shown that both of decaying and annihilating DM explanations similarly give good $\chi^2$-fits for DM halo profiles more enhanced around the GC (with $\alpha > 1$), compared to the original form of NFW profile (with $\alpha = 1$).

In Eq. (1), we set the DM mass in the decay case as two times heavier than the annihilation case to obtain the same resulting gamma-ray fluxes around $E_\gamma = 130$ GeV. Thus, the decay rate leading to the same gamma-ray flux by the annihilation with $\langle \sigma v \rangle_{\chi\chi \rightarrow \gamma\gamma} \sim 2 \times 10^{-27}$ cm$^3$/s is estimated as [3, 6]

\[
\Gamma_{\chi \rightarrow \gamma\gamma} \sim 10^{-29} \text{ s}^{-1},
\]

by which the life time of DM becomes sufficiently longer than the age of the universe ($\sim 10^{16}$ s). Note that the required annihilation cross section for $\chi\chi \rightarrow X\gamma$ is approximately twice of that for $\chi\chi \rightarrow \gamma\gamma$; the required decay rate for $\chi \rightarrow X\gamma$ is also approximately twice of that for $\chi \rightarrow \gamma\gamma$.

If the gamma-ray excess should be explained by DM decay, the sharp peak of the gamma-ray would imply two body decay of the DM, since the three body decay would make the spectrum broad and the intensity much weaker. In the case of $\chi \rightarrow \gamma X$, the emitted photon energy is estimated as $E_\gamma = (1 - m_X^2/m_{\text{DM}}^2)m_{\text{DM}}/2$. For $E_\gamma \approx 130$ GeV, thus, the required
DM mass is around \( m_{\text{DM}} \approx 288 \) (1138) GeV for \( X = Z \) (1000 GeV), which is heavier than that in the annihilation case. Thus, in the decaying DM case the DM mass can be much heavier than 260 GeV, say upto \( \mathcal{O}(\text{TeV}) \).

In Ref. [35], radiative DM decays to gamma-ray were extensively studied. For fermionic DM decay, the author considered the following renormalizable interactions:

\[
- \mathcal{L}_{\text{eff}} = \overline{\psi}_{\text{DM}} \gamma^\mu \left[ g_L^P P_L + g_R^P P_R \right] IV_\mu + \overline{\psi}_{\text{DM}} \left[ g_L^N P_L + g_R^N P_R \right] l \Sigma + h.c.,
\]

where “\( g \)”s and “\( y \)”s denote the coupling constants, and \( P_{L,R} \) the projection operators. \( V_\mu \) and \( \Sigma \) are superheavy vector and scalar fields with the masses \( m_V \) and \( m_\Sigma \), respectively, which radiatively mediate DM decay. \( N \) and \( l \) indicate neutral and charged fermions, respectively. We suppose \( m_{\text{DM}} < 2m_l \) to disallow the three body decays of DM kinematically at tree level. Note that for producing the photons radiatively, the vector field \( V_\mu \) (and also \( \Sigma \)) should carry an electromagnetic charge like the “\( X \)” or “\( Y \)” gauge bosons in the SU(5) grand unified theory (GUT). The interactions of Eq. (3) yield the estimation of the life time for the fermionic DM \( \psi_{\text{DM}} \) [35]:

\[
\tau_{\psi_{\text{DM}} \rightarrow \gamma N} \approx 1.7 \times 10^{27} \frac{s}{\left[ \sum (\eta g_{L}^P g_{L}^N - g_{R}^P g_{R}^N) \right]^2 \left( \frac{260 \text{ GeV}}{m_{\psi_{\text{DM}}}} \right)^5 \left( \frac{m_V}{10^{14} \text{ GeV}} \right)^4},
\]

provided \( m_V \ll m_\Sigma \). Thus, the life time can be of order \( 10^{29} \) sec. e.g. for a charged gauge boson slightly heavier than \( 10^{14} \) GeV. In many GUT models, however, the mass of the heavy gauge bosons carrying electromagnetic charges should be well above a few times \( 10^{15} \) GeV for longevity of the proton [36]. Note that in the decaying DM case, as discussed above, the DM mass can be much heavier than 260 GeV. In Eq. (4), thus, \( m_V \) could be raised upto \( 10^{15} \) GeV scale for fermionic DM of TeV scale mass. However, it is not yet enough to reach the conventional SUSY GUT scale (\( \approx 2 \times 10^{16} \) GeV). On the other hand, if \( m_V \gg m_\Sigma \), the life time of the fermionic DM becomes [35]

\[
\tau_{\psi_{\text{DM}} \rightarrow \gamma N} \approx 5.9 \times 10^{28} \frac{s}{\left[ \sum (\eta g_{L}^P g_{L}^N - g_{R}^P g_{R}^N) \right]^2 \left( \frac{260 \text{ GeV}}{m_{\psi_{\text{DM}}}} \right)^5 \left( \frac{m_\Sigma}{10^{14} \text{ GeV}} \right)^4}.
\]

Thus, \( \Sigma \) with \( 10^{14} \) GeV mass still affects the gauge coupling unification, unless \( \Sigma \) composes an SU(5) multiplet with other fields.

One could also explore the possibility of a scalar DM decaying to two gammas. In that case, however, the resulting effective dimension five operator \( (\phi_{\text{DM}} F_{\mu \nu} F^{\mu \nu}/M_*) \) should be extremely suppressed for its life time of \( 10^{29} \) s [35]: the suppression factor \( (1/M_*) \) should be much smaller than \( 1/M_P \), where \( M_P \) denotes the reduced Planck mass (\( \approx 2.4 \times 10^{18} \) GeV). Thus, let us consider the case that a scalar DM decays to two photons via the dimension six operator:

\[
- \mathcal{L}_{\text{eff}} = c_{\text{eff}} \frac{\tilde{\phi}_{\text{DM}}^* \tilde{\phi}_{\text{DM}}}{M_*^2} F_{\mu \nu} F^{\mu \nu},
\]
where the scalar DM, \( \tilde{\phi}_{DM} \) is assumed to develop a vacuum expectation value (VEV). With Eq. (6), the decay rate of \( \tilde{\phi}_{DM} \) is estimated as

\[
\Gamma_{\tilde{\phi}_{DM} \rightarrow \gamma\gamma} \approx \frac{c_{\text{eff}}^2}{4\pi} \left( \frac{\langle \tilde{\phi}_{DM} \rangle}{M^2_*} \right)^2 m_{\tilde{\phi}_{DM}}^3.
\]

(7)

Now we attempt to achieve this DM decay rate by constructing a simple supersymmetric (SUSY) model. The scalar DM, \( \tilde{\phi}_{DM} \) can be regarded as the scalar component of a superfield \( \Phi \). In this Letter, we simply assume that \( \tilde{\phi}_{DM} \) and also its fermionic superpartner \( \Phi_{DM} \) are non-thermally produced. Let us consider the following superpotential:

\[
W \supset \kappa N \Phi^2,
\]

(8)

where \( N \) and \( \Phi \) are MSSM singlets, and \( \kappa \) is a dimensionless coupling constant. The \( R \) and hyper charges of the relevant superfields are presented in Table I. We suppose that waterfall fields, which are not explicitly specified here, decay eventually to the scalar and fermionic components of \( \Phi \) through \( N \): \( N^c \rightarrow \Phi_{DM}\tilde{\phi}_{DM} \), \( \tilde{N}^* \rightarrow \Phi_{DM}\Phi_{DM} \), and \( \tilde{N}^* \rightarrow \tilde{\phi}_{DM}\tilde{\phi}_{DM} \) by the above \( \kappa \) coupling and the corresponding “A-term.” By the soft SUSY breaking A-term corresponding to the \( \kappa \) term in Eq. (8) and the soft mass terms in the scalar potential, \( \tilde{\phi}_{DM} \) and \( \tilde{N} \) can develop VEVs at the minimum:

\[
\langle \tilde{\phi}_{DM} \rangle \sim \langle \tilde{N} \rangle \sim \frac{m_{\tilde{\phi}_{DM}}^{3/2}}{\kappa} \sim \mathcal{O}(1) \text{ TeV}.
\]

(9)

We assume that the mass of \( \tilde{\phi}_{DM} \) determined by the soft terms is about 260 GeV. The A-term and the VEVs of \( \tilde{\phi}_{DM} \) and \( \tilde{N} \) (and also instanton effects) break U(1)\( _R \) completely. However, the above singlet fields are still hard to be coupled to the ordinary MSSM fields carrying non-negative integer \( R \) charges: since \( N \) and \( \Phi \) carry positive fractional \( R \) charges, the ordinary \( R \) parity violating terms (and also the terms leading to the dimension 5 proton decay), which require the presence of a spurion field carrying the \( R \) charge of \( -1 \) (\( -2 \)), should be extremely suppressed in this framework. As a result, such U(1)\( _R \) breaking leaves intact e.g. the proton stability.

| Superfields | \( N \) | \( \Phi \) | \( X \) | \( X^c \) | \( Y \) | \( Y^c \) |
|-------------|-------|------|------|------|------|------|
| U(1)\( _R \) | 4/3   | 1/3  | 1    | 1    | 2/3  | 4/3  |
| U(1)\( _Y \) \( [=U(1)_{em}] \) | 0     | 0    | \( q \) | \(-q\) | \(-q\) | \( q \) |

TABLE I: \( R \) and hyper charges of the superfields. The ordinary MSSM matter (Higgs) superfields including the Majorana neutrinos carry the unit (zero) \( R \) charges.
FIG. 1: Scalar dark matter decaying to two photons. By radiative mediations of the superheavy particles $X$ and $Y$, the scalar dark matter component $\tilde{\phi}_{DM}$ can decay into two photons with the decay rate of $O(10^{-29})$ s$^{-1}$. Similar diagrams contributed by the virtual superheavy scalar partners of $X$, $Y$ are also possible.

$\tilde{\phi}_{DM}$ cannot be absolutely stable in this scenario, because of the following additional terms in the superpotential:

$$W_{\gamma\gamma} = \lambda_{\gamma\gamma} \Phi X Y + M_X X X^c + M_Y Y Y^c,$$

where $M_X$ and $M_Y$ are the mass parameters of the GUT scale ($\sim M_{\text{GUT}} \approx 10^{16}$ GeV). The $U(1)_R$ and $U(1)_Y$ charges of the superfields $X^{(c)}$ and $Y^{(c)}$ are presented in Table I. If the model is embedded in an ordinary GUT such as $SU(5)$ and $SO(10)$ GUTs, they should carry also $SU(3)_c$ and/or $SU(2)_L$ quantum numbers and be accompanied with other (colored) particles to compose proper irreducible representations and their conjugations of a GUT. On the other hand, if the gauge group is given by “flipped SU(5)” or just that of the standard model at the GUT scale, $X^{(c)}$ and $Y^{(c)}$ can still remain as singlet fields with $q = \pm 1$ without any other supplementary particles $[37]$.

The DM component, $\tilde{\phi}_{DM}$ eventually decays into two photons with the desired decay rate. See Figure I. The loop-suppression factor, which gives a small $c_{\text{eff}}$ in Eq. (7), could be easily compensated by a relatively large VEV of $\tilde{\phi}_{DM}$ ($\sim O(1)$ TeV), the coupling $\lambda_{\gamma\gamma}$ of order unity, and a proper choice of charge $q$ such that Eq. (7) can be fulfilled without any serious fine-tuning. In a similar way, $\tilde{\phi}_{DM}$ can decay into $\gamma Z$: one photon is replaced with $Z$ in the diagram of Figure I. For $m_{\tilde{\phi}_{DM}} = 260$ GeV, the energy of this single photon is given by

$$E_\gamma = \frac{m_{\tilde{\phi}_{DM}}}{2} \left(1 - \frac{m_X^2}{m_{\tilde{\phi}_{DM}}^2}\right) \approx 114$ GeV.

Considering the coupling difference and the reduced phase space factor, one can easily estimate relative decay rate:

$$\frac{\Gamma_{\tilde{\phi}_{DM}\rightarrow\gamma Z}}{\Gamma_{\tilde{\phi}_{DM}\rightarrow\gamma\gamma}} \approx 0.26.$$
Since only one photon is produced by the decay mode $\tilde{\phi}_{DM} \rightarrow \gamma Z$, the final photon flux is just 0.13 times of the 130 GeV gamma-ray flux. Thus, we predict another peak around $E_\gamma = 114$ GeV although the 114 GeV second peak is much less significant than the primary peak around 130 GeV.

On the other hand, the fermionic component of $\Phi$, $\Phi_{DM}$ cannot decay via a dimension 5 operator: it is because $\Phi_{DM}$ can decay to a photon plus a neutral fermion through a dimension 5 operator only when a neutral fermion lighter than $\Phi_{DM}$ exists as seen in Eqs. (4) and (5). However, we do not have such a neutral fermion. Note that in general a fermionic DM cannot decay to only two photons via a dimension 6 operator.

Only with the interactions in Eq. (10) and the above field contents, other terms yielding a dimension 6 operator, e.g. $\Phi^3 LH_u$ cannot be generated from the renormalizable superpotential. By introducing more fields, however, $\Phi^3 LH_u$ might be induced, since the given symmetries admit it: its suppression mass parameter, which is determined by the masses of such additional fields, would be model-dependent. Even in that case, the expected signal $\tilde{\phi}_{DM}^* \rightarrow l^- \tilde{H}^+$ (or $\nu \tilde{H}^0$) is kinematically constrained by the mass of the Higgsino: if the Higgsino is heavier than $\tilde{\phi}_{DM}$, $\tilde{\phi}_{DM}$ can decay only to three or more particles, which is much suppressed if the suppression factor is of order $M_{GUT}^2$ or heavier. The other possible decay channel $\tilde{\phi}_{DM}^* \rightarrow \nu \Phi_{DM}$ might be detectable only in neutrino observatories such as Super-Kamiokande and IceCube. The current limits from the Super-Kamiokande data are $\tau_{DM} \approx 10^{24-25}$ sec. [38], which is easily evaded if this decay mode originates from the dimension 6 operator $\Phi^3 LH_u$ suppressed by at least $M_{GUT}^2$. In one year, the expected sensitivities of IceCube are around $\tau_{DM} \approx 10^{26}$ sec. [38, 39]. Consequently, it is difficult to observe the neutrino signal from $\tilde{\phi}_{DM}^* \rightarrow \nu \Phi_{DM}$ in near future. Of course, the bare superpotential can always contain $\Phi^3 LH_u/M_{P}^2$. However, the $M_P^2$ suppression results in too weak expected signals.

If $X$ and $Y$ are accompanied with some other colored particles to be embedded in certain GUT multiplets, $\tilde{\phi}_{DM}$ can decay into two gluons, $gg$, through the similar diagram to that of Figure 1: two photons are replaced with two gluons. Then, these gluons can lead to a sizable primary contribution to the antiproton flux. Thus, this decay mode $\tilde{\phi}_{DM} \rightarrow gg$ is constrained by the PAMELA antiproton flux data [17]. Even though the direct constraint on $gg$ channel has not been studied yet and the antiproton flux constraints depend on the propagation models, we can estimate the limit as $\Gamma_{\tilde{\phi}_{DM} \rightarrow gg}^{-1} \approx 10^{26-27}$ s from the limits on the $W^+W^-$, $ZZ$, $hh$, and $q\bar{q}$ channels [40].

In conclusion, we have confirmed that the recently noticed 130 GeV gamma-ray line based on the Fermi-LAT data is hard to explain with DM annihilations in the conventional MSSM framework. We raised the possibility that it originates from two body decay of a scalar DM ($\tilde{\phi}_{DM} \rightarrow \gamma \gamma$) by a dimension 6 operator suppressed with the mass of the grand unification scale ($\mathcal{L} \supset |\tilde{\phi}_{DM}|^2 F_{\mu \nu} F^{\mu \nu}/M_{GUT}^2$). The scalar DM needs to develop a VEV of TeV scale. We proposed a model realizing the possibility, in which superheavy particles with GUT scale
masses radiatively mediate the DM decay.

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