Clear methods to differentiate between decaying and annihilating dark matter (DM) scenarios are still by and large unavailable. In this note, we study the potential astrophysical signatures of a new class of hidden sector decaying DM models, which can address the recent cosmic ray measurements. Such models may produce primary photons and/or neutrinos at large rates, correlated with the leptonic production. The photon and neutrino spectra will then contain sharp features at the TeV scale. We demonstrate the discovery potential for upcoming and future measurements by FERMI, HESS, AGIS and IceCube/DeepCore. We show that these models may be discovered in the near future. Specifically, measurements of diffuse gamma rays by FERMI can detect the start of a hard photon feature. We argue that these hard spectra can be produced by decaying dark matter and be consistent with current constraints, but are difficult to reconcile with models of annihilating DM. Consequently the measurement of a hard spectral feature, in correlation with the current cosmic ray measurements, will strongly favor decaying DM models. Finally we comment on the preliminary results from the Inner Galaxy presented by the FERMI collaboration.

A more promising situation may arise if hard spectral features are measured. Such features have not been conclusively observed in the electron spectra, but may appear in photon or neutrino measurements. For the remainder of this letter, we loosely define the hard photons or neutrinos that contribute to a sharp spectral feature, as ‘primary’. If discovered, this feature would be smoking gun evidence for DM. Here we point out that such a signal, if found to be correlated with the leptonic excess, also has the potential to differentiate between the decaying and annihilating scenarios. Indeed, annihilating DM models that address the leptonic excess and have a sizable branching fraction into primary photons or neutrinos, are already excluded assuming the DM profiles supported by current N-body simulations [2]. Conversely, in the decaying case, the photon or neutrino signals lie just below the sensitivity reach of current experiments. As we show, these may be measured in the near future thereby not only confirming the presence of DM, but also supporting the decaying DM scenario.

The interpretation of the cosmic ray data requires the DM to have mass $\sim$ few TeV. Many models have been put forth to explain the data (see [3] and refs. therein) nearly all of which bifurcate into annihilating and decaying DM scenarios. In order to explain the measurements, models of annihilating DM require a surprisingly large cross-section, three orders of magnitude larger than that of a thermal weakly interacting massive particle (WIMP). Such an enhancement can, in principle, be achieved at low velocities, for example, by the Sommerfeld effect [4], without altering the compelling features of the WIMP scenario. In practice, however, it may be difficult to obtain a large enough enhancement and even if achieved, annihilating DM models are in tension with various $\gamma$-ray and neutrino bounds [3, 5], and constraints from the recombination epoch [6].

The alternative of decaying DM solely replaces the need for the Sommerfeld enhancement. If dimension six operators are generated at or around the GUT scale [7], the decay of the DM particle naturally explains the observed signals, again without altering the predictions of the thermal WIMP scenario. In this case, the various constraints from $\gamma$-rays, neutrinos and the like are significantly weaker and such signals may be probed by a variety of experiments [8]. The drawback of many decaying DM models lies in the difficulty to naturally explain the lack of hadronic activity, without introducing significant fine-tuning or complicated and ad hoc structure. We present a new class of models where weak-scale DM decays into a hidden ‘dark’ sector which is broken at the GeV scale and which communicates with the SM through gauge kinetic mixing [9]. The lack of hadronic activity is explained through kinematics, much as in the model of [10].
Below we study one representative example of this class of models and show that DM may naturally decay into primary photons and/or neutrinos with large branching fractions. We study the current and prospective measurements of the spectra at FERMI, HESS, AGIS, SuperK and IceCube/DeepCore. Our best-fit of the model to the cosmic ray measurements is consistent with current constraints and within the sensitivity reach of the above experiments. We comment on the recent preliminary FERMI results in the diffuse photon spectrum which are consistent with the predictions of our model.

A Model. Let us briefly describe a natural model of decaying DM which predicts correlated high-energy gamma rays and neutrinos. To avoid overproduction of antiprotons, the DM must predominantly decay into light leptons. This can be achieved either through additional symmetries that forbid couplings to hadrons or through kinematical constraints. The former is more difficult to accomplish, especially for decaying DM where the symmetries must be present at the GUT scale, and typically requires some amount of fine-tuning. We concentrate on the case where weak-scale DM decays into a light state that subsequently decays into leptons, with antiprotons suppressed by kinematics [11]. The DM itself may or may not be charged under the SM gauge group. Here we take DM to be SM-charged, which results in a primary neutrino signal. Below we present a brief description of the model and refer the reader to [9] for a more comprehensive analysis of this and similar decaying DM models.

We work within the context of supersymmetric GUTs. The DM states, $\chi + \bar{\chi}$, are taken to be two chiral superfields with charges $(5, 0) + (\bar{5}, 0)$ under $SU(5)_{SM} \times U(1)_d$ where $SU(5)_{SM} \supset SU(3)_C \times SU(2)_W \times U(1)_Y$ is the GUT gauge group. The predicted signatures to be discussed below do not depend on the choice of GUT or dark gauge group. The $U(1)_d$ mixes with the SM through kinetic mixing,

$$-\frac{\epsilon}{2} \int d^2 \theta \, W_d W_Y.$$  

(1)

Here $W_d(W_Y)$ is the dark(hypercharge) field strength. This term can be generated by heavy bifundamental fields and $\epsilon$ is naturally of order $\epsilon \sim 10^{-3} - 10^{-4}$ [10, 12]. The above gauge mixing induces an effective Fayet-Iliopoulos term proportional to $\epsilon(D_Y)$, naturally triggering the spontaneous breaking of the $U(1)_d$ at the GeV scale [13]. If this is the dominant term for the breaking, the dark sector is, to a good approximation, supersymmetric. Conversely, the $U(1)_d$ breaking can be triggered by SUSY-breaking effects communicated through TeV scale fields charged under the dark sector [10]. In this case the dark spectrum is not supersymmetric and the dark gaugino can be heavier or lighter than the dark gauge boson.

A dimension six operator of the form,

$$\frac{\alpha_d}{4\pi M^2_{GUT}} \int d^2 \theta \, \chi^2 f W^2_d$$  

(2)

induces the DM decay. Here $\alpha_d = g^2_d/4\pi$ is the dark gauge coupling and $5_f$ denotes a SM multiplet. Such an operator is generated by integrating out GUT-scale fields, $X, Y$ [8, 9].

$$W = (M_{GUT} + X)Y + M_{GUT}X\bar{X} + \bar{X}\chi 5_f.$$  

(3)

where $X$ and $\bar{X}$ are singlets and $Y + \bar{Y}$ have charges $(1, 1) + (1, -1)$ respectively. There are other possible dimension six operators that can decay DM into the dark sector, and the choice of decay operator does not alter the qualitative conclusions of this work. The decay operator of Eq. (3) induces DM decay with a lifetime of order,

$$\tau \sim 10^{26} \sec \left(\frac{\alpha_d}{30^{-1}}\right)^2 \left(\frac{m_{DM}}{3 \text{ TeV}}\right)^{-5} \left(\frac{M_{GUT}}{10^{15} \text{ GeV}}\right)^4$$  

(4)

which is the right time scale to explain the astrophysical anomalies. We stress, however, that the DM lifetime is a free parameter of the theory.

As a consequence of Eq. (2), DM decays into a neutrino or sneutrino and two dark gauge bosons or gauginos. The production of primary neutrinos is a generic consequence of DM being electrically neutral while carrying hypercharge [14]. The other possibility of decaying into the neutral Higgs is disfavored due to the antiproton bound from PAMELA. The subsequent decay of the sneutrino depends on the MSSM spectrum. Here we assume that the sneutrino is the (SM) NLSP and can decay into a gravitino and a neutrino. If the sneutrino is heavier, its decay may produce antiprotons. The resulting antiproton spectrum, however, is expected to be rather soft due to the cascade decay. The production of the dark gauge bosons and gauginos is followed by their decay through the kinetic mixing. The gauge bosons decay into light SM leptons, $\gamma_d \rightarrow l^+ l^-$. To avoid the tension with the antiproton and gamma-ray bounds from the GC, the gauge boson mass, $m_{\gamma_d}$, is required to be sufficiently small, below $\sim$ GeV. The gauginos, on the other hand, decay to either dark gauge bosons or photons, as we describe in the next section.

There are several constraints on the model described above. If DM couples elastically to the Z, the model is ruled out by direct detection [15] by 2-3 orders of magnitude [16]. This constraint can be evaded by introducing a dark matter splitting, $\delta m_{DM} \gtrsim 100$ keV, such that DM couples inelastically to the Z. With a splitting, there is a strong constraint from neutrino telescopes on inelastic capture in the Sun, followed by annihilation into ZZ or $W^+ W^-$. This constraint can be evaded by taking a slightly larger splitting of $\delta m_{DM} \gtrsim 500$ keV. We evade these constraints by coupling DM to the SM Higgs:

$$W_{\text{split}} = m_N N^2 + m_{DM} \chi_2 \bar{X}_2 + \chi_2 H_d N$$  

(5)
where $N$ is a singlet with weak-scale mass $M_N$, and $\chi_2$ denotes the doublet component of $\chi$, where the DM resides. DM stability requires $M_N > M_{DM}$, and integrating out $N$ generates the required DM splitting.

If the dominant DM annihilation channel is to SM gauge bosons, its mass is constrained to be of order 1.1 TeV, in order to obtain the correct thermal abundance \([16]\). Such a low mass is inconsistent with the FERMI and HESS measurements. Interestingly, the same operator that generates the splittings to evade the direct detection bounds, Eq. \([5]\), also opens a new annihilation channels into Higgses which can easily dominate the DM annihilation cross-section. Consequently, the mass of the DM is a free parameter.

Another important constraint on this model is related to the lifetime of the triplet partner of the DM, $\chi_3$. There are strong constraints on colored particles with $\tau_3 \gtrsim 10^{17}$ sec because they form exotic atoms \([18]\). These constraints are evaded if the triplet partner decays through a dimension-5 operator, which we take to be in the Kähler potential,

$$\frac{1}{M_{\text{GUT}}} \int d^4 \theta \chi \tilde{\chi}^\dagger_s ,$$

where $s$ is a singlet. This operator decays $\chi$ in $\tau_3 \sim 1$ sec, but keeps the DM stable as long as $m_{DM} < m_s < m_{\chi_3}$. That $m_{\chi_3}$ is heavier than $m_{DM}$ is a generic consequence of RG evolution.

We note that there are a number of operators that must not be present, such as dimension-5 operators which induce prompt DM decays, and tree-level Yukawa couplings between DM and SM matter. All such operators are easily forbidden by symmetries at the GUT scale. Cosmology also places nontrivial and interesting constraints on the spectrum and lifetimes of light fields in the dark sector. For a detailed discussion of both GUT-scale symmetries and cosmological constraints on this model, we refer the reader to \([9]\). See also \([19]\) for discussions of the cosmology of light hidden sectors.

**Gamma-ray Signatures.** The measurement of a photon line or sharp spectral feature is considered to be a smoking gun signature for DM. Typically, such features are model dependent and are associated with the high end of the spectrum, set by the DM mass. Interestingly, within the context of the observed electronic activity, a measurement of this kind would point towards the decaying rather than annihilating DM scenario. Indeed, as was shown in \([3,5]\), annihilating DM models that provide explanations of the PAMELA and FERMI anomalies and which have sizeable branching fractions into primary photons or $\pi^0$’s are excluded. The exclusion holds under the assumption of DM profiles suggested by state-of-the-art N-body simulations. To ameliorate it, one would have to resort to currently unsubstantiated profiles (see however \([20]\)) which predict a significantly shallower or flatter density, $\rho$, at the GC. A key observation is then: if measurements of photons that are correlated with the PAMELA and FERMI results indicate the production of primary photons or photons from $\pi^0$’s, then decaying DM models are strongly favored.

Models of DM in which the DM decays or annihilates into a light hidden sector, predict gamma rays from several channels. Three irreducible sources of photons are FSR, ICS and synchrotron radiation. Concentrating on the high energy spectrum, the first two dominate, where FSR dominates at the high end of the spectrum while the ICS dominates at lower energies. Two additional sources of photons are those produced from $\pi^0 \rightarrow \gamma \gamma$ decays and primary photons. In this letter we concentrate on the latter. Whether primary photons are produced depends strongly on the dark spectrum. Assuming a light gravitino, if the dark gauginos are heavier than the dark gauge bosons, $m_{\tilde{\chi}_d} > m_{\tilde{\gamma}_d}$, the decay $\tilde{\gamma}_d \rightarrow \gamma + \tilde{G}$ dominates and no primary photons are produced. If, on the other hand, the dark gaugino is degenerate with or lighter than the dark gauge boson, it decays through the kinetic mixing to a SM photon and a gravitino:

$$\tilde{\gamma}_d \rightarrow \gamma + \tilde{G}.$$  \(7\)

Measurement of the primary photons produced through this decay is thus an indication of a light dark gaugino (or more generally a light fermion) in the dark sector. Conversely, the absence of such photons indicates a heavy fermionic spectrum, and in particular implies significant SUSY breaking in the dark sector. We stress that as opposed to the primary neutrino signal to be discussed in the next section, and which follows from the specific operator of Eq. \([2]\), the primary photon signal is rather generic for models where dark matter decays or annihilates into a light hidden sector, and the signal probes the lower end of the dark sector spectrum.

In the model discussed above, the $\chi$ supermultiplet is split, and we assume that the fermion plays the role of the DM. We use 3-body phase space spectra with flat matrix elements, which captures the model-independent part of the spectrum. The resulting primary photons arise from the two available decay channels:

$$\tilde{\chi} \rightarrow \bar{\nu} \tilde{\gamma}_d \gamma_d , \quad \tilde{\chi} \rightarrow \nu \tilde{\gamma}_d \tilde{\gamma}_d .$$  \(8\)

and the photon spectrum depends on the mass of the sneutrino, which we keep as a free parameter. We begin by fitting our model to the PAMELA, FERMI, and HESS electron and positron cosmic rays spectra, as shown in Fig. \([4]\). We obtain the best-fit values: $m_{\tilde{\chi}} = 3.3$ TeV, $m_{\tilde{\pi}} = 370$ GeV, $m_{\tilde{\gamma}_d} = 400$ MeV, and $\tau_\chi = 4 \times 10^{26}$ sec. Consequently, the dark photon decays into electrons and muons with branching fractions (0.75, 0.25) respectively. We use this best fit model for the gamma ray and neutrino analyses that follow.

We compute contributions to the photon flux from the primary photons described above, ICS, and FSR. No
π0's are produced due to the lightness of γd. To compute the ICS we propagate the electrons following the procedure described in [21]. Throughout the analysis we assume the MED propagation model [21] and Einasto DM profile [22],

$$\rho(r) = \rho_\odot \exp \left[ -\frac{2}{\alpha} (r/r_s)^\alpha - 1 \right]$$  \hspace{1cm} (9)

with \(r_s = 20 \text{ kpc}, \rho_\odot = 0.3 \text{ GeV/cm}^3\) and \(\alpha = 0.17\). Since we're studying decaying DM, the dependence on the choice of profile is significantly weaker than in the annihilating case. Our gamma ray results are relatively insensitive to varying \(\alpha\) in the range found in simulations, 0.12 – 0.2, and to interchanging Einasto with NFW [23]. The flux does not change by more than a factor of 3 around the GC nor does it vary by more than 10% for the diffuse gamma signal in the regions studied below.

We consider signals from both the center of the Galaxy and diffuse gammas. A measurement of the latter in the region \(0^\circ < l < 360^\circ, 10^\circ < |b| < 20^\circ\) was recently released by the FERMI collaboration [24]. The data and the predictions of the model are shown in Fig. 1. The blue dashed line corresponds to the primary photon spectrum resulting from the DM decays, the red dashed line corresponds to the contribution from FSR and the black corresponds to that from ICS. As can be seen, the primary photons dominate the high end of the spectrum, starting at \(~100\ \text{GeV}\). Since FERMI can measure the spectrum up to 300 GeV, it may only probe the tail of the primary photon contribution. Although it will be difficult for FERMI to disentangle the primary contribution from the ICS, it is possible that it will have enough sensitivity to resolve the turnover in the spectrum. Finally we note that a gauge boson with a mass larger than the 400 MeV presented here, can produce a more significant FSR signal. For complimentary studies of such signals see [25].

A remark is in order. As we mention before, the measurement of the hard spectrum is a strong indication of decaying DM. The normalization of the spectrum is such that if a signal resulting from annihilation is seen in the diffused gamma region, away from the GC, it must be over-produced at the center itself. This is the case, for instance, when DM annihilates into two τ's which consequently decays into π0's (see Fig. 8 of [3]). This statement is in sharp contrast to the decaying DM scenario since the photon flux depends on \(\rho^2\) in the former case and on \(\rho\) in the latter. Nevertheless, it is conceivable that the DM density will turn out to be shallower in which case the GC signal can be hiding below the background. A correlated measurement in the two regions would then imply the existence of decaying DM or some coincidence regarding the DM density at the GC.

Measurements from the GC and Galactic Ridge (GR) have been taken by the HESS collaboration and already place strong constraints on models of DM [26]. The GR is more sensitive since it measures a smaller flux in a larger region. Furthermore, it is less sensitive to the DM

FIG. 1: The electron fit and photon flux predictions for our best-fit model, using the Einasto DM profile with \(\alpha = 0.17\). The right plot shows the fitted curve to the \(\pi^+ + \pi^-\) flux measured by FERMI and HESS [24]. The middle curve shows the predicted spectrum from the Galactic Ridge. The red data points represent the corresponding HESS measurement [26] with 2σ error bars. The dashed blue line is the primary photon component predicted by our model, the FSR contribution is too small to be plotted, and the green line is the total flux, including a background modeled by a power-law and fitted to the HESS data. The signal is consistent with the current HESS data and can be constrained by further statistics. The black data points illustrate the projected reach for the AGIS experiment [29] with 2σ error bars. As can be seen, AGIS will decisively test this scenario. The left plot shows the diffuse photon prediction in the \(0^\circ < l < 360^\circ, 10^\circ < |b| < 20^\circ\) region. The blue points correspond to the recent FERMI measurement [24]. The dashed lines show the primary (blue), ICS (black), and FSR (red) contributions to the total flux, shown in green. As the FERMI data extends to higher energies it may be able to measure the turnover between the ICS and primary photon components of the signal.
FIG. 2: Neutrino constraints and discovery reach. The right plot shows the 95% C.L. muon flux limit from SuperK as a function of the opening angle around the Galactic Center. The green curve corresponds to our best-fit decaying DM model, while the blue curve illustrates the expected flux for an annihilating model with a large branching fraction of primary neutrinos. Our decaying model is consistent with the constraints, while the annihilating model is excluded. The left plot shows the neutrino flux as a function of the energy. The green curve corresponds to the predicted total signal and the dashed lines show the primary (blue) and soft (red) neutrino components. The data correspond to the AMANDA measurement (37). The black lines indicate the expected 1- (dashed) and 3- (solid) year 5σ signal.

profile since the GC itself (a 0.1° cone around the center) is subtracted. We show this measurement and the model prediction in Fig. 1a, where the error bars correspond to 2σ. The red dashed line is the signal and the green line corresponds to the total signal plus background, where the latter is found by fitting a power-law to the data. Our predicted signal is below the current HESS resolution. There is also a preliminary FERMI measurement from the GC (27) and we find that the predicted signal of our model is well below the data.

In addition to upcoming HESS results with improved sensitivity, there are two future Cherenkov telescope arrays under consideration: AGIS [28] and CTA [29]. Both arrays are expected to be significantly larger than HESS, with an order 5-10 improvement in sensitivity at the energies of interest. To demonstrate the capabilities of these experiments, we concentrate on AGIS and project a possible future measurement using an effective area of 1 km², energy resolution of 15% and 200 hours of measurement. We show the projected measurement on Fig. 1b, in black. The signal is found to be well above the expected sensitivity [30]. To conclude, we remark that the future location of AGIS will influence its ability to take measurements from the GC. It is therefore preferable to locate it in the southern hemisphere, such as the proposed site near the Félix Aguilar Observatory in Argentina.

Neutrino Signatures. The second smoking gun signature of DM is a neutrino line or a sharp spectral feature. While SuperKamiokande already places important constraints on DM models, the upcoming experiments IceCube, Antares and KM3NeT will have the potential to resolve features in the neutrino spectrum at the TeV scale and therefore discover DM. Here, by a sharp feature, we mean a feature which appears in one or a few measured bins. In our model (or in corresponding annihilating DM models), we therefore distinguish between primary neutrinos (which are accompanied by a sharp feature), produced directly from the decay or annihilation, and soft neutrinos that result from lepton and pion decays. Within annihilating DM scenarios that explain the lepton anomalies, primary neutrinos with a large branching fraction are already excluded. On the other hand, as we show below, the corresponding decaying scenarios are right below the sensitivity of current experiments and can easily be discovered by future ones.

As a first step, we must make sure that our model is not already excluded by the current neutrino bounds from SuperK. In Fig. 2a, we plot the neutrino flux of our best fit model as a function of opening angle around the GC, integrated over energies detectable at SuperK. In Fig. 2b, we plot the neutrino flux of our best fit model as a function of the opening angle around the Galactic Center. The green curve corresponds to the expected flux for an annihilating model with a large branching fraction of primary neutrinos. Our decaying model is consistent with the constraints, while the annihilating model is excluded. The left plot shows the neutrino flux as a function of the energy. The green curve corresponds to the predicted total signal and the dashed lines show the primary (blue) and soft (red) neutrino components. The data correspond to the AMANDA measurement (37). The black lines indicate the expected 1- (dashed) and 3- (solid) year 5σ signal.
a cone of 5° around the GC. The number of upward showering events is given by the expression [32]:

$$N^\mu_{\text{shower}} = \int dE_\nu \frac{d\phi_\nu}{dE_\nu} f(E_\nu) \epsilon(E_\nu).$$  \hspace{1cm} (10)

Here $\phi_\nu$ is the neutrino flux, $f(E_\nu)$ is the conversion probability of neutrinos into muons of detectable energy, and $\epsilon(E_\nu)$ is the showering probability extracted from the analysis of [32]. The result for our best fit model is

$$N^\mu_{\text{shower}} = 1.8 \times 10^{-16} \text{ cm}^{-2} \text{ s}^{-1}. \hspace{1cm} (11)$$

This is smaller than the expected background flux of atmospheric upward showering neutrinos, $N^\mu_{\text{bg}} = 3.4 \times 10^{-16} \text{ cm}^{-2} \text{ s}^{-1}$. SuperK has done an analysis on upward showering neutrinos from 1646 days of data, and they find no events in the above cone [33]. Our best fit model is therefore not excluded, but interestingly close to the current sensitivity.

The hard neutrino signal predicted by our model will be tested by upcoming neutrino experiments, such as IceCube and Antares. Here we focus on IceCube with DeepCore, which will have good sensitivity for TeV-scale neutrinos within the DeepCore fiducial volume [34]. The surrounding IceCube strings will be used to veto downward going muons, such that the main background is due to atmospheric neutrinos. The signal is then expected to become comparable to the background at high energies, because the neutrino-nucleon scattering cross-section rises as $\sigma_{\nu N} \sim E^2$ while the atmospheric neutrino background drops rapidly as $E^{-3}$. We estimate the future sensitivity of IceCube with DeepCore by following an approach along the lines of [35]. The number of neutrino events to be observed at IceCube, as a function of neutrino energy is given by the expression,

$$\frac{dN}{dE} = \frac{d\phi_\nu}{dE} \rho_{\text{ice}} N_A \sigma_{\nu N}(E) V(E) t_{\text{obs}},$$  \hspace{1cm} (12)

where $\rho_{\text{ice}} = 0.9 \text{ g/cm}^3$, $N_A = 6.022 \times 10^{23} \text{ g}^{-1}$, $t_{\text{obs}}$ is the run time, $\sigma_{\nu N}$ is the neutrino-nucleon scattering cross-section, and $V(E) \approx 0.04 \text{ km}^3$ is the effective volume of DeepCore for neutrino showers, roughly estimated from [34].

We compare our predicted signal at IceCube and DeepCore with the atmospheric neutrino background [35]. In order to estimate the energy resolution of IceCube, we bin the background in bins of size $\log(E_{\text{max}}/E_{\text{min}}) = 0.3$. In Fig. 2, we plot the AMANDA data [27] together with the flux sensitivity for 5$\sigma$ discovery in each bin, collecting events from the entire 2$\pi$ sky for 1 and 3 years of run time. We also plot the signal flux for our best-fit model. A 5$\sigma$ discovery is found to be possible at the highest bin of the predicted spectrum, above $E_\nu \gtrsim 1 \text{ TeV}$, after 1 year, and in 2 bins after 3 years. This is in sharp contrast to the soft neutrinos which populate lower energy bins and therefore cannot be discovered with this method. We see that IceCube with DeepCore has the potential to decisively test decaying DM with a primary neutrino component. It would be interesting to also estimate the reach of Antares for this scenario.

**Note Added.** While this work was in completion, new but very preliminary data from the Inner Galaxy region, $0.25^\circ < |\theta| < 4.75^\circ$, $0.25^\circ < |\phi| < 29.75^\circ$, was presented by the FERMI collaboration [38]. Interestingly, the results indicate a deviation from the naive expected background at high energy. Being preliminary, these data may well suffer from significant cosmic-ray contamination, especially at the high end of the spectrum. Nonetheless, we cannot resist to compare our predictions with the measurement, as we do in Fig. 3. In the figure, we plot two sets of curves for two different fits. The first (thick lower green line) is the best-fit model described above and the second (thin upper green line) corresponds to a lighter DM mass, resulting in a somewhat worse fit to the HESS electronic measurement. The ICS, hard and FSR contributions to the spectrum of the best-fit model are shown in dashed lines. A careful background analysis is warranted. Here we simply assume the dominance of $\pi^0$ decay at energies above $\sim 1 \text{ GeV}$ which can be approximated by a power-law spectrum. We therefore model the background by fitting a power-law to the data between 3 and 16 GeV.

With the above cautious remarks in mind, we note the following:

- If confirmed, the excess may indirectly imply the existence of DM [39].

- For our best fit model, with decay rate normalized to explain the PAMELA, FERMI, and HESS leptonic data, there is insufficient ICS to account for the excess at high energies $\gtrsim 100 \text{ GeV}$. The FSR that we find is also insufficient to account for the excess.

- For our best fit model, the primary photon component is consistent with the preliminary data at high-energies. Still, our model’s prediction is slightly below the data. We find two sources of tension: (i) fitting to the HESS electron measurement results in a high DM mass, setting the hardness of the photon spectrum, and (ii) the decay rate cannot be increased without introducing tension with the HESS GC/GR measurements. We expect the overall fit to improve should the data points move down following a complete analysis.

- Future improvement of the statistics may be capable of indicating a turnover in the spectrum.

- Ref. [40] presents an interesting analysis of the data and its implications to models of annihilating DM. We comment that the authors utilize a different fitting procedure from the one presented here. While
we fit our decaying model to the PAMELA, FERMI and HESS leptonic results, and present predictions for the photon and neutrino signals. [10] fit only to the diffuse gamma excess. The disagreement with regards to the ICS contribution may arise, in part, from different DM masses and different propagation models. It would be interesting to see if annihilating models can provide consistent fits to both the leptonic and diffuse gamma excesses.

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