On a possible solution to gamma-ray overabundance arising in dark matter explanation of cosmic antiparticle excess

2016 J. Phys.: Conf. Ser. 675 012026

(http://iopscience.iop.org/1742-6596/675/1/012026)

On a possible solution to gamma-ray overabundance arising in dark matter explanation of cosmic antiparticle excess

V V Alekseev[1], K M Belotsky[2], Yu V Bogomolov[1], R I Budaev[2], O A Dunaeva[1], A A Kirillov[1,2], A V Kuznetsov[1], M N Laletin[2], A D Lukyanov[1], V V Malakhov[2], A G Mayorov[1,2], M A Mayorova[2], A F Mosichkin[1], A A Okrugin[1], S A Rodenko[2] and A M Shitova[1]

[1] Yaroslavl State P.G. Demidov University, 150000 Sovietskaya st. 14, Yaroslavl, Russia
[2] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia

E-mail: `maxim.n.laletin@gmail.com`

Abstract. As we are going to show, some self-interacting dark matter models may provide an intriguing solution to the "cosmic antiparticle excess vs. isotropic diffuse gamma-ray background" problem (an overproduction of diffuse gamma rays, arising in any reasonable decaying or annihilating dark matter model explaining high-energy charged cosmic antiparticles anomalous abundance).

1. Introduction

The existence of dark matter – an unknown substance, which compose almost 26% of our Universe [1], but only perceptible by virtue of its gravitational effects – can hardly surprise scientific community nowadays, however its nature and origin still remain a mystery. Though an enormous amount of hypothesis were proposed to explain this phenomenon a mostly conventional conception of dark matter is a quite massive particle with vanishingly weak interaction with ordinary matter (except the strongly interactive massive particle (SIMP) models, which are however strongly disfavored by experimental searches [2]) and rather rarefied local distribution. Observational facts force us to think that dark matter behaves like an ideal gas, though there's a not only tempting, but a pretty reasonable (from the particle physics point of view) idea, that dark matter should posess some new fundamental interaction. Probably the first thing that comes to mind is the possibility of dark matter annihilations or decays, rarely taking place due to this new interaction. Such an obsessive idea has been actively studied for many decades and is commonly used to explain a broad variety of astrophysical effects, the hints of which we possibly observe (like gamma-ray bursts, emission lines in gamma-ray spectrum of the Galactic center, anomalous abundance of high-energy antiparticles in cosmic rays and etc.), or, on the other hand, to impose constraints on various Standard Model extensions, predicting candidates for dark matter.

Another interesting concept is that dark matter particles can scatter on each other rather than annihilate. It was shown that a new QCD-like strong self-interaction is able of solving the so called "cusp-core" problem [3] and a new wave of interest towards self-interacting dark matter models was caused by the recent observation of Abell 3827 galaxy cluster [4]. However, in order to stay consistent with cosmological and astrophysical observations one should permit only a small fraction of dark matter (e.g. a different species of dark matter) to interact with each other noticeably, while the major part of dark matter reveals the properties of collisionless gas. Except for the strong self-interaction model, which we mentioned, it would be an indeed beautiful theory, in which dark matter particles are charged under an unknown $U(1)$ interaction (or "dark" electromagnetism). Besides suitable conditions for a plenty of indirect (see e.g. [5]) or even direct (see e.g. [6]) dark matter effects it was noted in [7] that this model can also provide a solution for the "cusp-core" problem. Furthermore, the authors of the considering article proposed an exceptionally new idea, that self-interacting dark matter can cool down due to "dark radiation" emission and form a disk-like structure, possibly coinciding with the Galactic plane. Though this idea may seem unrealistic or superfluous at first sight in this work we are going to show, that if self-interacting dark matter also experience decays or annihilation to Standard Model quarks and leptons, such approach can solve the "charged antiparticle excess vs. diffuse gamma-ray background" problem [8, 9].

2. Charged antiparticles from dark matter decays and diffuse gamma-ray overabundance

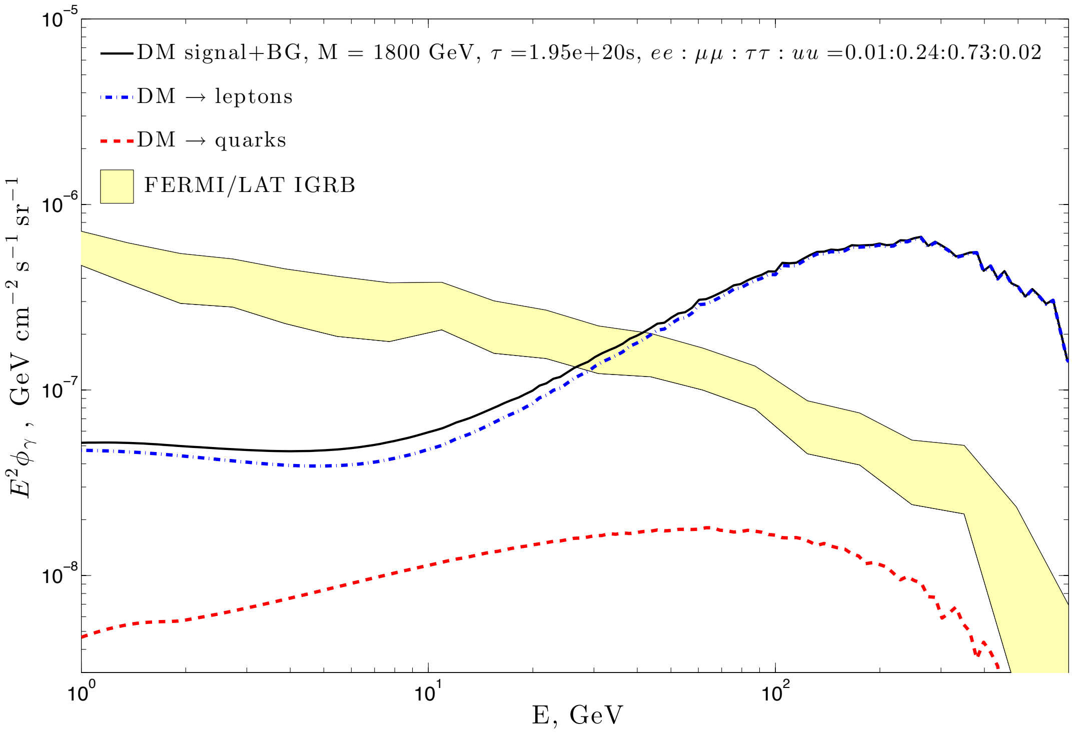

Figure 1. Diffuse gamma-ray flux predicted by the average decaying dark matter model, explaining positron and antiproton excess in cosmic rays (see [9]). The flux is averaged over the solid angle corresponding to the range of Galactic coordinates $20° \leq b \leq 90°$ and $0° \leq l < 360°$, in which FERMI/LAT measures IGRB. The uncertainties of IGRB are related to the arbitrary choice of foreground model.

Let us briefly remind here the basics of “charged antiparticle excess vs. diffuse gamma-ray background” problem (see [9] for a detailed review). Any rational dark matter model (assuming isotropical distribution of metastable or annihilating fraction) capable of high-energy cosmic antiparticle excess explanation (seen by PAMELA and AMS-02 in positrons [10, 11] and antiprotons [12, 13]) predicts a tremendous amount of high-energy gamma rays as well and thus contradicts with FERMI/LAT data on isotropic diffuse gamma-ray background (IGRB) [14].

One should note that this problem can not be solved neither by model parameter tuning nor propagation parameters variation. Though we’ve considered only decaying dark matter we strongly suppose that the same problem strikes also annihilating dark matter scenario.

3. Dark matter disk model (DDDM) and the solution of gamma-ray overproduction problem

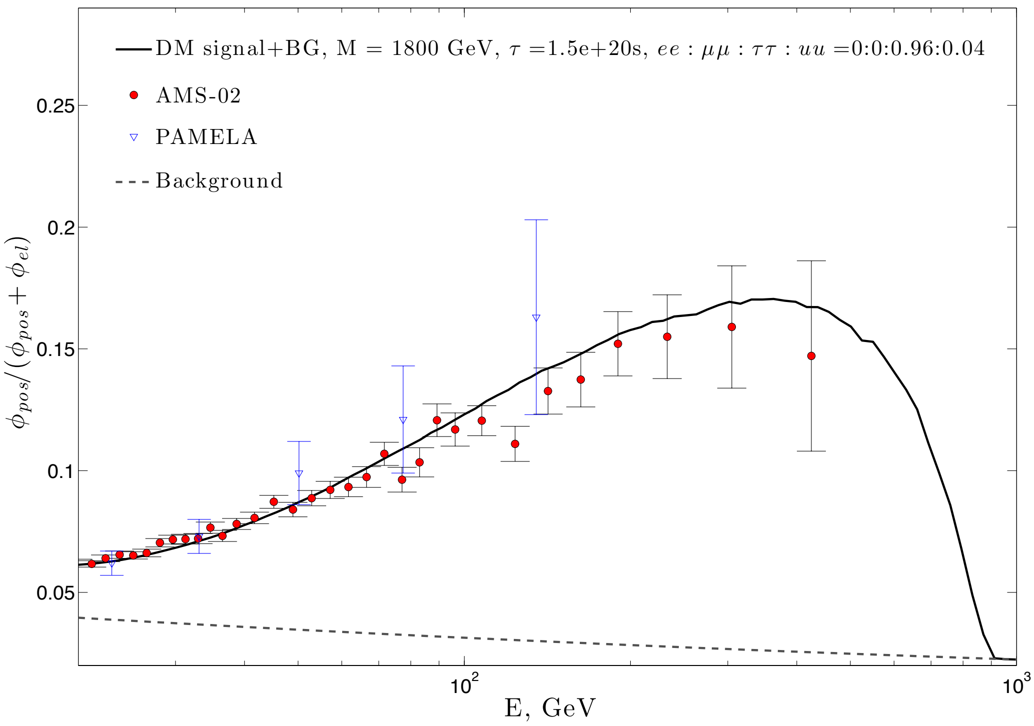

Figure 2. Fraction of positrons in cosmic rays, predicted by the double-disk decaying dark matter model and compared to AMS-02 and PAMELA data. The values of model parameters corresponds to those listed in the *top left* part of the plot.

If decaying or annihilating component of dark matter posess long-range self-interaction, which allows it to cool down due to energy exchange with “dark radiation” bath, then a dark matter disk formation seems possible. Since charged particles (and antiparticles) responsible for anomalous effects in cosmic rays observations can reach the Solar system only from the sources located in the magnetic halo, while gamma rays come to us from the whole large dark matter halo, one can easily see that squeezing decaying dark matter into a disk, following the shape and size of baryonic disk, can significantly reduce the amount of isotropic diffuse gamma rays, while preserving almost the same flux of charged antiparticles. In figures 2-4 we show our results for the same dark matter model, mentioned in section 2, but placed in the thin disk.

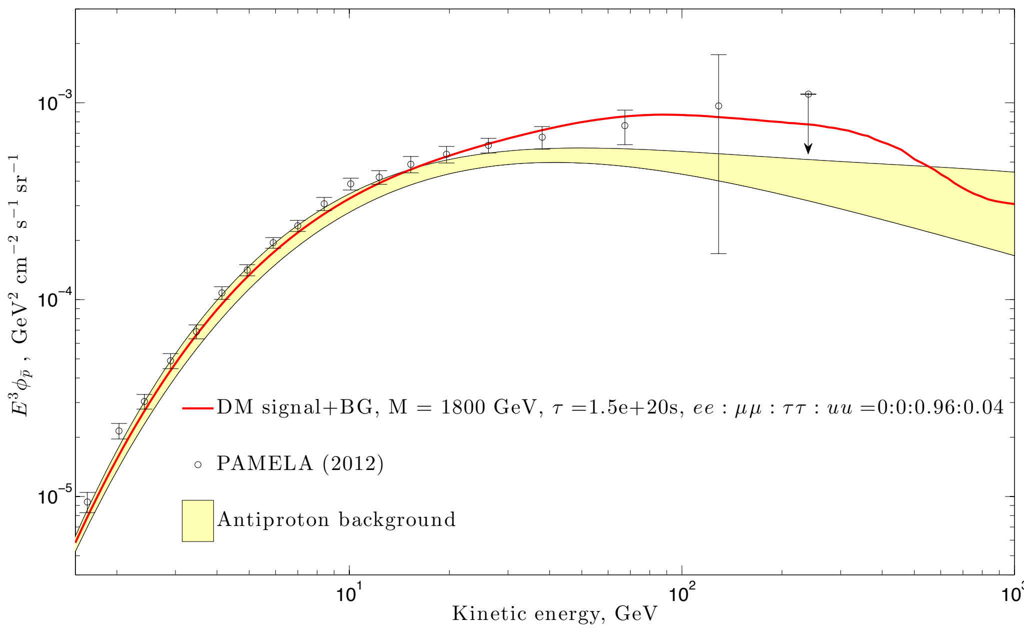

Figure 3. Antiproton flux, predicted by the double-disk decaying dark matter model and compared to the PAMELA data.

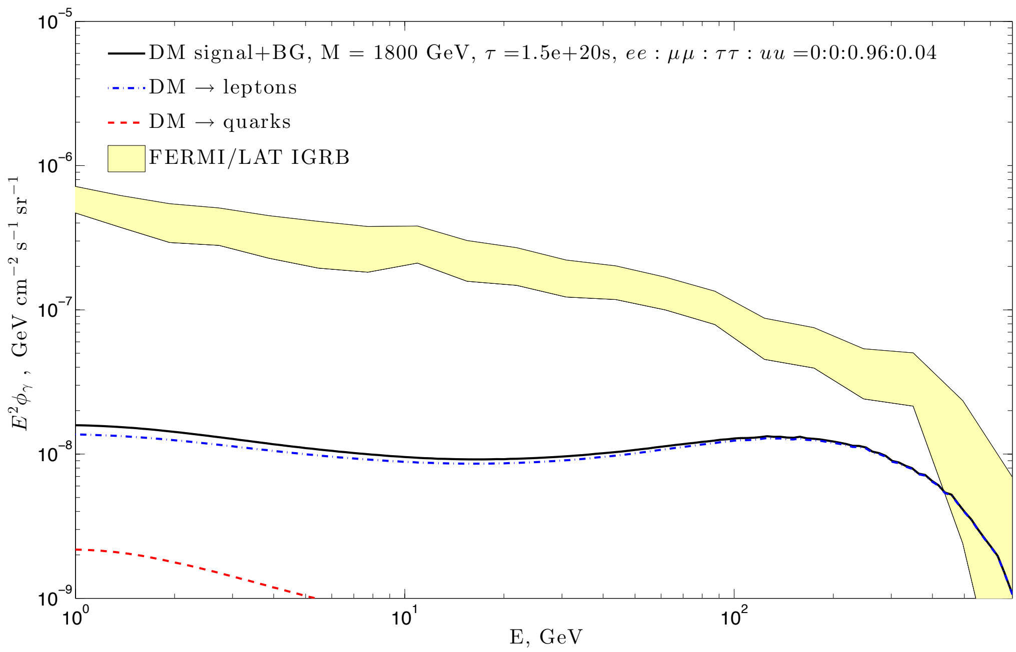

Figure 4. Diffuse gamma-ray flux, predicted by the double-disk decaying dark matter model and compared to the FERMI/LAT data. The separate contributions from leptonic (blue dot-dashed) and hadronic (red dashed) decaying modes are also presented.

4. Conclusion

In this work we have applied the double-disk dark matter concept to the decaying dark matter model and worked out a possible solution to the "cosmic antiparticle excess vs. isotropic diffuse gamma-ray background" problem. However our approach is mostly phenomenological and a more detailed theoretical study of decaying (or annihilating) double-disk dark matter model is needed. Furthermore, we should accurately verify the consistency of our model with cosmological and astrophysical observations (first of all, we should check the predicted gamma-ray flux from the Galactic center and the Oort limit on the local amount of matter). Also we believe that a small anisotropy in high-energy cosmic positron flux may appear in our model. All these questions should be the aim of our future research.

Acknowledgments

The research is financed by the grant of the Russian Science Foundation (Project No. 15-12-10039). The work by MEPhI group (K M Belotsky, R I Budaev, M N Laletin, V V Malakhov, M A Mayorova and S A Rodenko) on the calculation of cosmic ray fluxes from dark matter decays was performed within the framework of the Center of FRPP supported by MEPhI Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013).

References

[1] Adam R *et al.* (Planck Collaboration) 2015 *arXiv:1502.01582*
[2] Ericksek A L *et al.* 2007 *Phys. Rev.* D **76** 042007
[3] Spergel D N and Steinhardt P J 2000 *Phys. Rev. Lett.* **84** 3760
[4] Harvey D *et al.* 2015 *Science* **347** 6229 1462
[5] Belotsky K, Khlopov M and Kirillov A 2014 *Adv. High Energy Phys.* **2014** 651247
[6] Cudell J R and Wallemacq Q 2015 *JCAP* **1502** 011
[7] Fan J *et al.* 2013 *Phys. Dark Univ.* **2** 139
[8] Alekseev V *et al.* 2015 *Physics Procedia* **74C** 48
[9] Alekseev V *et al.* 2015 High-energy cosmic antiparticle excess vs. isotropic gamma-ray background problem in decaying dark matter Universe (*these proceedings*)
[10] Adriani O *et al.* (PAMELA Collaboration) 2013 *Phys. Rev. Lett.* **111** 081102
[11] Accardo L *et al.* (AMS Collaboration) 2014 *Phys. Rev. Lett.* **113** 121101
[12] Adriani O *et al.* (PAMELA Collaboration) 2012 *JETP Lett.* **96** 621
[13] AMS Days at CERN and Latest Results: *http://www.ams02.org/2015/04/ams-days-at-cern-and-latest-results-from-the-ams-experiment-onthe- international-space-station*
[14] Ackermann M *et al.* (Fermi LAT Collaboration) 2015 *Astrophys. J.* **86** 799