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Heavy decaying dark matter and large–scale anisotropy of high-energy cosmic rays

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The hypothesis of dark matter (DM) consisting of heavy long-living particles has attracted significant attention in the context of inflationary cosmology [1, 2]. There are several scenarios of effective DM particles production on various stages of early Universe evolution. There are several sources of constraints for the heavy DM parameters. The mass is subjected to cosmological constraints and the lifetime of the DM particles can be effectively constrained with the observed fluxes of various high-energy particles. In the present work we use the recent upper-limits on the cosmic-ray flux anisotropy to obtain the conservative constrains on the lifetime of the heavy DM with masses $10^7 \leq M_X \leq 10^{16}$ GeV. We also discuss the role of the various observables in a search for the heavy decaying dark matter (DM) signal. This study complements our previous works [3, 4], where constraints on the heavy decaying DM lifetime were obtained using the high-energy gamma-ray and neutrino flux upper limits.

We consider DM consisting of scalar particles X decaying through the primary channel $X \to q\bar{q}$. The final products of the decay cascade are photons, protons, neutrino etc. In this study we are interested in the decay products that can contribute to the cosmic-ray flux anisotropy observed at Earth – that is photons and protons. We follow the method of fragmentation functions and DGLAP equations described in Refs. [5] in calculation of the decay spectra. We use the numerical code provided by the authors of Ref. [5]. The details were reviewed in our previous works [3, 4]. The large–scale anisotropy predicted by the DM models is calculated for the total flux of the high-energy cosmic rays, which is dominated by the isotropic contribution of charged particles. The possible decay of the DM gives only a small anisotropic admixture to the total flux. With the good accuracy this contribution consists only of the galactic photon and proton fluxes.

For the galactic flux calculation we use Navarro–Frenk–White DM distribution and Burkert distribution. For galactic gamma-ray flux we take into account only prompt photon spectra of DM decay and allow for the modification of this spectra due to interactions with CMB photons, simulated by the numerical code of Ref. [6]. In turn, the galactic proton contribution is affected by the galactic magnetic field, which deflects the protons and therefore washes out the anisotropy pattern. We conservatively assume that only protons with energies above 10^{19} eV contribute to the flux anisotropy (the protons with these energies are not affected by magnetic field).

For any DM mass M_X the lifetime τ can be constrained using the upper-limits on the anisotropy observables. We use the data from EAS-TOP [7], IceCube [8], KASCADE [9], KASCADE-Grande [10], Yakutsk [11], and Pierre Auger [12] experiments. All data is interpreted in terms of amplitude of the first harmonic r_1 of the Fourier analysis in right ascension. We also employ the result of joint Telescope Array and Pierre Auger full-sky anisotropy study [13] presented in the form of separate upper-limits on the Laplace series coefficients a_{lm}. We conservatively assume that all the anisotropy is given by the DM decay. The results are shown in Fig. 1. As one can see all the anisotropy constraints lie in the parameter area which is already excluded by the high-energy gamma-ray and neutrino limits.

In general, the obtained results indicate that current EAS experiments are more sensitive to the photons from DM decay than to the respective anisotropy. The large–scale anisotropy if observed at a particular energy not accompanied by the gamma-rays should be attributed to physics other than the DM decay. In other words, until the gamma-rays of the respective energies are detected the DM signal should not interfere with the study of astrophysical large–scale anisotropy. Some of the future experiments may be more sensitive to anisotropy than to gamma-ray DM signal. For instance in Ref. [14] the anisotropy detection prospects from the DM decay signal allowed by current photon limits were found favourable for EUSO experiment at ultra-high energies.

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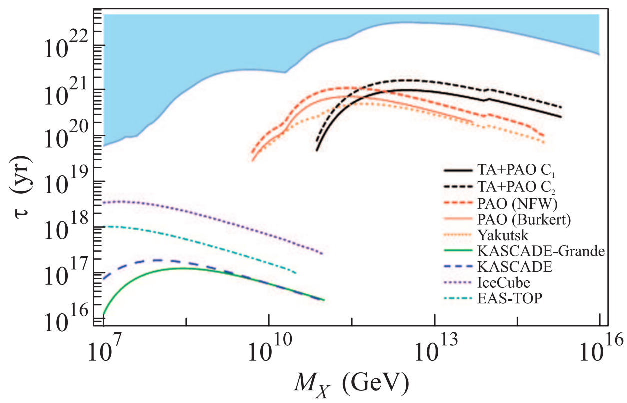

Fig. 1. (Color online) 95 % C.L. exclusion plot for mass M_X and lifetime τ of DM particles. The constraints are obtained assuming NFW DM profile with the data of Telescope Array and Pierre Auger full-sky analysis; data of Pierre Auger, Yakutsk, IceCube, EAS-TOP, KASCADE and KASCADE-Grande partial-sky analysis (for KASCADE-Grande C.L. is 99 %). White area is excluded by the photon and neutrino constraints of Refs. [3, 4]. For comparison we show the constraints obtained assuming Burkert DM profile using the data of Pierre Auger partial-sky analysis

At the same time planned photon sensitivity improvements in the currently running experiments – Pierre Auger and Telescope Array would make them even more effective in search for the signal of heavy decaying DM.

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