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Hadronically decaying heavy dark matter and high-energy neutrino limits

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The idea that dark matter consists of heavy long-living particles was proposed in the context of inflationary cosmology [1, 2]. There are several mechanisms of production of these particles that are able to yield the observed relic abundance. The heavy dark matter candidate X has two main parameters: mass M_X and lifetime τ. However, there are several sources of constraints for the heavy dark-matter parameters: the mass is subject to cosmological constraints [3], and the lifetime of the dark-matter particles can be effectively constrained using the observed fluxes of various high energy particles or limit on these fluxes.

This study is mainly inspired by the publication of the new refined sample of the IceCube high-energy neutrino data along with the updated exposure of this experiment [4]. In that work the stringent cuts were employed to eliminate the atmospheric neutrino background. The resulting data set contains only two events with PeV order energy, both consistent with the astrophysical neutrino Monte-Carlo. This fact together with the non-observation of higher energy events allows the IceCube collaboration to place limits on the astrophysical neutrino flux and to constrain several models of astrophysical neutrino origin. In this work we use the same data sample to place limits on the neutrino flux from the decay of dark matter with masses $10^7 \le M_X \le 10^{16}$ GeV and to constrain its lifetime. For comparison we also derive constrains using Pierre Auger Observatory data [5] that reports non-detection of neutrino with energies $E_\nu \gtrsim 10^{17}$ eV. This study complements our previous research [6], where heavy decaying dark matter parameters were constrained by the high energy gamma-ray limits.

We consider dark matter consisting of heavy scalars X decaying through the channel $X \to q\bar{q} \to \nu_i \ (\bar{\nu}_i)$. We assume that all quark flavors are coupled to X similarly. The decay through this channel can be described irrespectively of the particular form of X-quarks coupling, since the most important physical phenomenon of relevance is hadronisation, see Refs. [7] for the details of this approach. The resulting spectrum of neutrino from the decay of X-particle takes into account DGLAP evolution [8, 9]. We use the code of Ref. [7] to solve DGLAP equations numerically in the leading order of $\alpha(s)$.

The resulting neutrino flux that reaches the Earth consists of the galactic and extragalactic parts. The enhancement of the signal is related to the fact that the anisotropic galactic flux exceeds the isotropic extragalactic contribution, it is also important that the largest high-energy neutrino observatories – IceCube and Pierre Auger can observe the enhanced neutrino flux from the Galactic Center region which is located in the southern sky. For the galactic neutrino flux calculation we use the Navarro–Frenk–White dark matter distribution [10]. For the extragalactic flux we take into account cosmological redshifting but neglect the interaction of neutrino with cosmic media.

The method of constraining the dark-matter parameters with neutrino limits slightly differs from that using with the gamma-ray limits. The exposure of neutrino observatory depends on the neutrino energy, therefore flux limits depend on neutrino spectrum. The quantity one needs to compare with the observation is the total number of neutrino events that would be detected in the given experiment under the assumption of the given neutrino spectrum. For each mass M_X the lifetime τ is subject to constrain. We use the standard technique of Ref. [11] which implies that we vary τ until the predicted number of events N_{th} reaches from below the number N_{limit} specified for a given number of observed events N_{obs}, number of background events N_{bg} and given confidence level. The constraints on the parameter space $\{M_X, \tau\}$ are presented in Fig. 1 together with the constraints of works [12, 13] as well as the gamma-ray constraints obtained in our previous work [6]. We should note that the present constraints are conservative since we consider the total predicted neutrino flux as a product of the dark-matter decay and do not allow for the possible astrophysical or cosmogenic contribution. One can see that the gamma-ray constraints overlap the neu-

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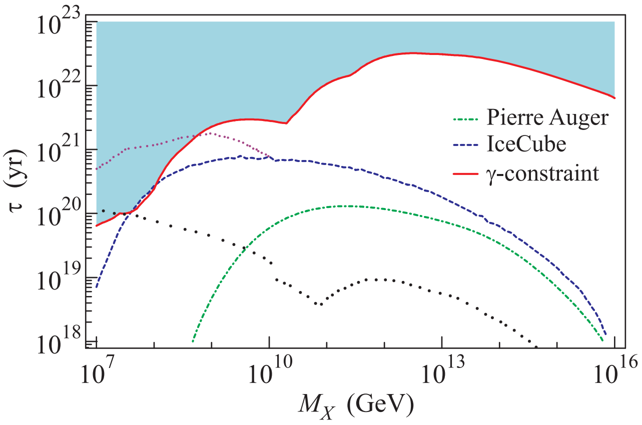

Fig. 1. (Color online) 90 % C.L. exclusion plot for mass M_X and lifetime τ of dark-matter particles. White area is excluded. For comparison we present the constraints obtained with photon limits [6] (solid thin red line). We also show the constraint obtained in the dark matter model with $X \to \nu\bar{\nu}$ decay channel [12] (black dots) and constraint for $X \to b\bar{b}$ channel which assumes that the IceCube events are of astrophysical origin [13] (purple dots)

trino ones in almost all dark-matter mass range except the narrow region around $M_X \sim 10^8$ GeV, where the neutrino constraints are slightly stronger. Nevertheless, neutrino observations remain crucial for the dark-matter indirect detection. For example the ratio of neutrino flux to photon flux have the certain value for each dark matter decay model and could be an additional criterion for distinguishing between various hypotheses of photon and neutrino fluxes origin.

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