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A Study of Dirac Fermionic Dark Matters

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We study pure weak eigenstate Dirac fermionic dark matters (DM). We consider WIMP with renormalizable interaction. According to results of direct searches and the nature of DM (electrical neutral and being a pure weak eigenstate), the quantum number of DM is determined to be $I_3 = Y = 0$. There are only two possible cases: either DM has non-vanishing weak isospin ($I \neq 0$) or it is an isosinglet ($I = 0$). In the first case, the Sommerfeld enhancement is sizable for large I, producing large $\chi^0\overline{\chi^0} \to VV$ rates. In particular, we obtain large $\chi\bar{\chi} \to W^+W^-$ cross section, which is comparable to the latest bounds from indirect searches and m_χ is constrained to be larger than few hundred GeV to few TeV. It is possible to give correct relic density with m_χ higher than these lower bounds. In the second case, to couple DM to standard model (SM) particles, a SM-singlet vector mediator X is required from renormalizability and the SM gauge quantum numbers. To satisfy the latest bounds of direct searches and to reproduce the DM relic density at the same time, resonant enhancement in DM annihilation diagram is needed. Thus, the masses of DM and the mediator are related. Furthermore, this model is not sufficient to explain the deviation in muon $g-2$.

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We investigate a renormalizable DM model by introducing a pure weak eigenstate Dirac fermion as a DM candidate [1]. The Z boson interaction produces a tree-level spin independent elastic cross sections giving a normalized cross section $\sigma_N^Z \simeq I_3^2 \times 10^{-40}\text{cm}^2$, for m_χ ranges from few GeV to few TeV. The magnitude of the cross section exceeds most of the experimental upper bounds [2]. This forces us to consider two cases of heavy DM with quantum numbers: (i) $I \neq 0, I_3 = Y = 0$, and (ii) $I = Y = 0$.

1. Case I: $\mathbf{I \neq 0, I_3 = Y = 0}$ case

In this case, the DM possesses non-vanishing weak isospin I but with zero hypercharge. The DM pair can annihilate into a W boson pair and then can contribute to the relic density of DM and indirect processes from milky way satellites. It is known that we need to take into account Sommerfeld enhancement effect, when the velocity is very small (see Fig. 1(a)-(c)) [3]. We first give the results of case I. In Fig. 2(a) we show our results on relic abundance for $I = 1,2,3$ and compare to the experimental result $\Omega_{\text{nbm}}h^2 = 0.1187 \pm 0.0017$ [4]. Solid (dashed) lines are results with (without) the Sommerfeld factor. We see that the observed relic density can be reproduced in all three cases with TeV DM masses. The Sommerfeld enhancement become more prominent in the large I case. In Fig. 2(b) to (d) we show the results of galactic $\langle\sigma v\rangle$ on WIMP annihilation for $\chi^0\bar{\chi}^0 \to W^+W^-, Z^0Z^0, Z^0\gamma, \gamma\gamma$ channels for WIMP candidates with different isospin ($I = 1,2,3$) and compare them to the milky way satellites data on the W^+W^- rate [5]. The signatures of the enhancement are sizable $Z^0Z^0, Z^0\gamma, \gamma\gamma$ rates. It will be interesting to search for these processes.

2. Case II: $\mathbf{I = Y = 0}$ case

In this case, the DM candidate is a pure weak isospin singlet Dirac fermion. To reproduce the observed relic density, we need to couple χ to SM fermions f. We consider renormalizable

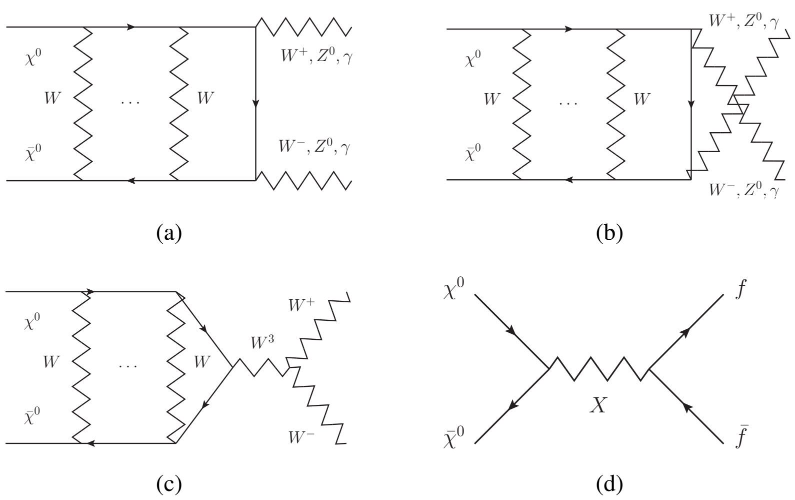

Figure 1: (a) to (c): $\chi^0\bar{\chi}^0 \to VV$ annihilation diagrams with the Sommerfeld effect in Case I. (d): $\chi\bar{\chi} \to f\bar{f}$ annihilation through an X exchange in Case II.

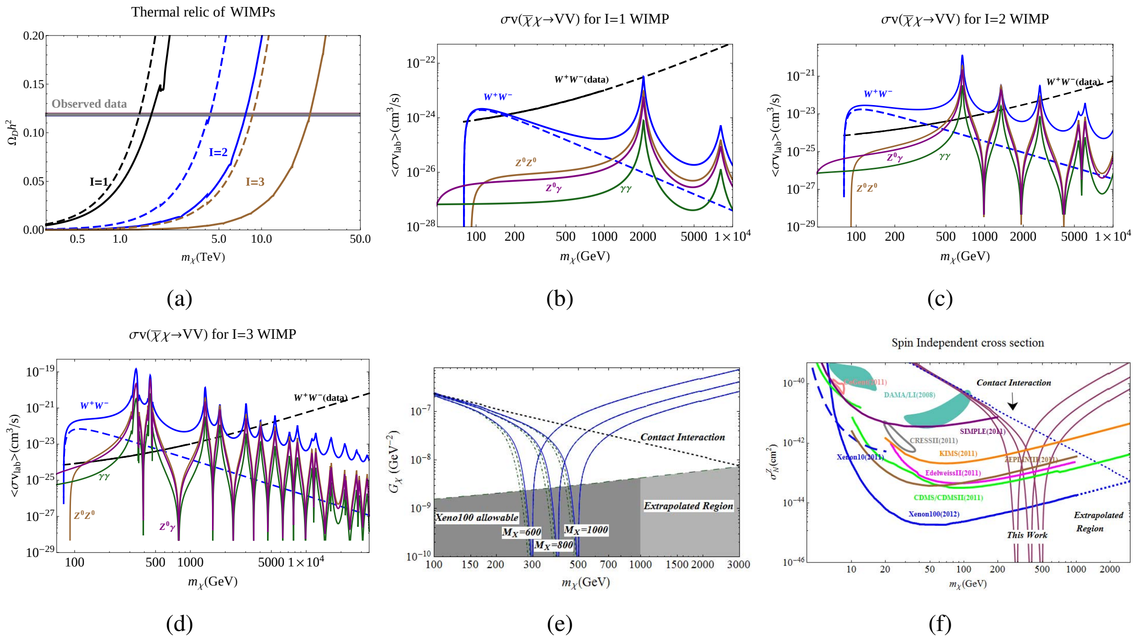

Figure 2: (a) to (d): $\chi^0\bar{\chi}^0 \to VV$ annihilation diagrams with the Sommerfeld effect in Case I. (e): The relic density allowed $G_\chi \equiv g_\chi g_f^V/{M_X}^2$ as a function of m_χ for different M_X in Case II. The shadow region are Xenon100 allowed region. (f): The SI elastic scattering cross sections of our model for $M_X = 600, 800, 1000$ GeV in Case II are compared to experimental limits [2].

interaction only. Therefore, an additional gauge singlet particle X is necessary to mediate the $\chi\bar{\chi} \to f\bar{f}$ annihilation process (see Fig. 1(c)). In Fig. 2(e), we plot the relic density allowed $G_\chi \equiv g_\chi g_f^V/{M_X}^2$, where g_χ (g_f^V) is the $X-\chi(f)-\bar{\chi}(\bar{f})$ coupling. We also plot the G_χ of the contact interaction case. The contact interaction case is ruled out for $m_\chi \lesssim 3$ TeV, if the BW effect is absent. However, with the present of the BW effect, the model can survive from the direct search bound with m_χ even as low as few hundreds GeV. The corresponding elastic cross section for DM and nuclei is shown in Fig. 2(f). The muon $g-2$ puzzle could be a hint for some unknown contributions from physics beyond the SM. It will be interesting to explore the connection with the DM sector. We find that our model is not sufficient to explain the deviation [1].

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