Exchange driven freeze out of dark matter

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We introduce a novel mechanism where processes that preserve the number density of the dark sector set the relic density of a thermal particulate dark matter. In a relatively degenerate multipartite dark sector, if there is a considerable time lapse between the freeze out of various species, then a process like exchange between dark sector constituents can play the pivotal role of driving freeze out and setting dark matter relic density. As a proof of principle, we present simple scalar models with viable dark matter in the GeV scale to demonstrate this phenomenon.

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I. INTRODUCTION

The overwhelming evidence from various astrophysical and cosmological observations establish that around 25% of the energy budget of the Universe is made of dark matter (DM) [1,2]. The assumption that DM is a particulate thermal relic is one of the leading candidate. In this framework, DM remains in thermal equilibrium at a very early stage of the thermal history of the Universe; however, due to the combined effect of depletion in its number density through annihilation and the expansion of the Universe, it gets frozen out resulting in the DM relic density observable today.

The description of thermal freeze out of DM is usually driven by $2 \rightarrow 2$ number changing processes, where a pair of stable DM candidate annihilates to Standard Model (SM) states [3–9]. It so happens that a particle having weak scale mass and coupling could produce the observed relic density [10], and this outcome is often referred to as the WIMP (weakly interacting massive particles) miracle. This framework has received considerable attention within a large class of particle physics models [11–13] and has been explored widely. However, the framework of WIMP is progressively in tension by the nonobservations of it in different dark matter experiments. Subsequently, there have been new proposals like $3 \rightarrow 2$ annihilation [14–16], secluded DM [17], codecaying DM [18], cospinning [19–21], forbidden DM [22] etc. that addresses some of

the shortcomings of the vanilla WIMP framework. Nevertheless, it is not surprising to expect these models to have a multiparticle dark sector [23–27], whose stability is ensured by imposing one or more discrete symmetry. Depending on the number of particles and unbroken discrete symmetries in the theory, either there will be a single or multicomponent DM. Assuming that, these dark sector particles couple to SM states in the primordial soup, then the main underlying process that set the thermal DM relic density is shown in Fig. 1. To keep the discussion tractable, we assume that there are two particles in the dark sector ϕ_1 and ϕ_2 with the former being the major component of the present day DM relic density. Depending on the stabilizing symmetry, ϕ_2 may either be a minor component of the DM or an associated unstable state of the dark sector. We will be considering both of these scenarios later.

The chronology of the decoupling time of the processes, shown in Fig. 1, will determine freeze out behavior of the species under consideration. In the standard paradigm, the freeze out of the processes in Fig. 1 happens almost simultaneously, and the annihilation channels of individual

FIG. 1. The main processes that are operative at the time DM freeze out in a multipartite dark sector. The arrow below indicates the decoupling time ordering of the processes that may lead to exchange driven freeze out of DM. While for reverse freeze-out time ordering between (b) and (c) the annihilation of ϕ_2 will drive the freeze out of ϕ_1 .

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species [Figs. 1(a) and 1(c) for ϕ_1 and ϕ_2 , respectively] are primarily responsible for setting their relic density [4–9]. It has been already pointed out that, if there is a substantial gap in the freeze out time of these processes then non-annihilation channels may regulate the relic density of DM [19–21]. It is in this context, we propose, for the first time, a mechanism where exchange processes [shown in Fig. 1(b)] play the pivotal role in setting DM relic density.

In Sec. II, we describe the basic formalism of an exchange driven freeze out mechanism. In Sec. III, we present a simple scalar DM model, where the framework has been realized, before concluding in Sec. IV.

II. BASIC FRAMEWORK

In this section, we will lay out the basis formalism of an exchange driven freeze out mechanism. Within this framework, we will assume that the annihilation of the major DM constituent ϕ_1 , shown in Fig. 1(a), decouples earliest in the thermal history compared to all the other relevant processes. This early freeze out implies a suppression in the annihilation cross section, which may be indicative of the null results in the DM experiments. The successful thermal freeze out of ϕ_1 can still be achieved through the combined effect of the exchange $\phi_1\phi_1 \rightarrow \phi_2\phi_2$ and subsequent annihilation of the ϕ_2 to SM state. This is in contrast with studies of a multiparticle dark sector [26,28,29], where the relic density is primarily set by annihilation processes. Interestingly, Ref. [30] has considered a related but distinct framework, where the DM states annihilate to relatively heavier unstable intermediate states that subsequently decay to SM. The endothermic annihilation of the DM to the intermediate state controls its relic density.

The comoving number density of ϕ_1 freezes once either of both processes turns inoperative. Crucially, the mode of freeze out hinges on the time ordering of decoupling of processes shown in Figs. 1(b) and 1(c). If the interaction rate of exchange process goes below the Hubble expansion rate before the other one, then the exchange process will determine the freeze out. This is an atypical feature of this framework, where a non-number changing process drives the freeze out. While for the reverse time ordering, annihilation of ϕ_2 will regulate the freeze out of ϕ_1 . Interestingly, here the decoupling of the annihilation of one species sets the relic abundance of a different state.

The evolution of the number density (n) of the dark sector species can be obtained by solving the coupled Boltzmann equation for the dark sector states, that can be schematically written as

$$\dot{n}_i + 3\mathcal{H}n_i = -\sum_j \left\{ \langle\sigma v\rangle_i^{\text{anh}} (n_i^2 - (n_i^{\text{eq}})^2) + \langle\sigma v\rangle_{i \rightarrow j}^{\text{ex}} \left(n_i^2 - (n_i^{\text{eq}})^2 \left(\frac{n_j}{n_j^{\text{eq}}} \right)^2 \right) \right\}, \quad (1)$$

where i, j include all the particles in the spectrum, n_k^{eq} represents the equilibrium number density, $\mathcal{H}$ is the Hubble expansion rate. The first term in the rhs of Eq. (1) is related to annihilation processes with $\langle\sigma v\rangle_i^{\text{anh}}$ being the thermally averaged annihilation cross section, and the second term is the contribution of exchange process.

As is usually the case, if the major DM component ϕ_1 is the lightest state in the dark sector, then the $\phi_1\phi_1 \rightarrow \phi_2\phi_2$ exchange process is endothermic, and its thermally averaged cross section has an exponential suppression [21],¹

$$\langle\sigma v\rangle_{1 \rightarrow 2}^{\text{ex}} \approx \left(\frac{m_2}{m_1} \right)^3 e^{-2x\delta} \langle\sigma v\rangle_{2 \rightarrow 1}, \quad (2)$$

where $x = m_1/T$, and $\delta = (m_2 - m_1)/m_1$ is a measure of the degree of degeneracy in the dark sector spectrum.

In the exchange driven freeze out regime, we can keep aside all the suppressed cross sections and considering the fact that the ϕ_2 remains in equilibrium at the time of freeze out of ϕ_1 , Eq. (1) reduces to

$$\dot{n}_1 + 3\mathcal{H}n_1 = -\langle\sigma_{11 \rightarrow 22} v\rangle (n_1^2 - (n_1^{\text{eq}})^2). \quad (3)$$

Interestingly, Eq. (3) is quite similar to the Boltzmann equation for the traditional WIMPs. The solution of Eq. (3) has already been studied extensively in the literature [6–9,31].

On the other hand, if the annihilation of ϕ_2 freezes before the exchange process, then the freeze out of ϕ_1 is determined by the related freeze out of ϕ_2 .² Therefore, retaining relevant terms, the Eq. (1) trims down to the following coupled system of differential equations:

$$\dot{n}_1 + 3\mathcal{H}n_1 = -\langle\sigma_{11 \rightarrow 22} v\rangle \left(n_1^2 - (n_1^{\text{eq}})^2 \left(\frac{n_2}{n_2^{\text{eq}}} \right)^2 \right) \quad (4a)$$

$$\dot{n}_2 + 3\mathcal{H}n_2 = -\langle\sigma_{22} v\rangle (n_2^2 - (n_2^{\text{eq}})^2). \quad (4b)$$

The coupled Boltzmann equation (4b) can be solved numerically to get the required relic abundance.

An approximate analytical solution of the coupled Boltzmann equation (1) in the exchange and ϕ_2 annihilation dominated regime may be obtained by comparing the relevant event rate with the Hubble parameter through the following equation:

$$\begin{aligned} n_1 \langle\sigma v\rangle^{\text{ex}} &= \mathcal{H}, & \text{exchange} \\ n_2 \langle\sigma v\rangle^{\text{anh}} &= \mathcal{H}, & \phi_2 \text{ annihilation.} \end{aligned} \quad (5)$$

This gives an estimate of the freeze out temperature (x_f) of the ϕ_1 up to a normalizing factor (c) in the event rate.

¹Such a forbidden channel has been considered earlier in the context of the annihilation of sub-GeV DM [22] and in the coscattering scenario [21].

²This mechanism is similar to the sterile coannihilation framework discussed in the context of light dark matter [32].

$$x_f \approx \begin{cases} \frac{1}{2\delta} \ln \left(\frac{M_{\text{pl}} m_1 \langle \sigma v \rangle_{2 \rightarrow 1}^{\text{ex}} (1+3\delta) x_f^{1/2}}{26.14 c \sqrt{g_{\text{eff}}(x_f)}} \right), \\ \text{exchange} \\ \frac{1}{\delta+1} \ln \left(\frac{M_{\text{pl}} m_1 \langle \sigma v \rangle_2^{\text{anh}} (1+3\delta/2) x_f^{1/2}}{26.14 c \sqrt{g_{\text{eff}}(x_f)}} \right). \\ \phi_2 \text{ annihilation} \end{cases} \quad (6)$$

Note that, in Eq. (6) g_{eff} is the effective number of relativistic degrees of freedom at the time of freeze out.

The relic density can now be computed assuming that the comoving number density of the ϕ_1 remains constant since freeze out. The approximate expression for the major component of DM relic density for the two regime can be written as

$$\Omega h^2 \approx \begin{cases} \frac{0.27 \text{ pb}}{\langle \sigma v \rangle_{2 \rightarrow 1}^{\text{ex}}} \frac{c x_f e^{x_f(2\delta-1)} (1-3\delta)}{\sqrt{g_{\text{eff}}(x_f)}}, \\ \text{exchange} \\ \frac{0.27 \text{ pb}}{\langle \sigma v \rangle_2^{\text{anh}}} \frac{c x_f e^{x_f \delta} (1-3\delta/2)}{\sqrt{g_{\text{eff}}(x_f)}}. \\ \phi_2 \text{ annihilation} \end{cases} \quad (7)$$

Matching with a full numerical solution of Eq. (1) implies $c \sim \mathcal{O}(1)$. With $g_{\text{eff}} \sim 100$ from Eq. (6), the experimentally observed value of relic density could be reproduce for $x_f \sim 20$, implying DM freeze out in the nonrelativistic regime. This signifies that exchange driven and ϕ_2 annihilation driven freeze out yield a cold dark matter as preferred from the large scale structure of the Universe.

III. MINIMAL SETUP

To construct the minimal multiparticle dark sector, we augment the SM with two real scalar SM singlet fields ϕ_1 and ϕ_2 . Depending on the stabilizing symmetry of the dark sector, one can obtain a single component or two component DM. Regions of parameter space of these generic constructions demonstrate the phenomenon of exchange driven freeze out.

A. Model 1: Multicomponent DM

The most economic Lagrangian is obtained when one considers two discrete symmetries $\mathbb{Z}_2$ and $\mathbb{Z}'_2$ under which ϕ_1 and ϕ_2 are charged, respectively, while the SM remains even under both [26]. The most general renormalizable Lagrangian including the Higgs portal coupling to the SM can be written as

$$-\mathcal{L}_{\text{int}} = \frac{\lambda_1}{2} \phi_1^2 H^\dagger H + \frac{\lambda_{1s}}{4!} \phi_1^4 + \frac{\lambda_{2s}}{4!} \phi_2^4 + \frac{\lambda_2}{2} \phi_2^2 H^\dagger H + \frac{\lambda_e}{4} \phi_1^2 \phi_2^2, \quad (8)$$

where H denotes the SM Higgs doublet. In writing above equation, we have omitted mass term for ϕ_1 and ϕ_2 . We assume the masses of ϕ_1 and ϕ_2 are m_1 and m_2 , respectively. Clearly, both ϕ_1 and ϕ_2 will be stable leading to a two component DM.

The standard two component DM framework with $\mathbb{Z}_2 \times \mathbb{Z}'_2$ symmetry is mostly disfavored by the results of direct detection experiments except in the tuned Higgs resonance region or for DM mass $\gtrsim 800$ GeV [26]. Interestingly, in the regime where the annihilation cross section of the lighter species, say ϕ_1 , is quite small, the freeze out of ϕ_1 can still be achieved by the combined effect of conversion of ϕ_1 to ϕ_2 and subsequent annihilation of ϕ_2 to SM states. In this region where $\lambda_1 \ll \lambda_2, \lambda_e$, the model demonstrates the phenomenon of exchange driven freeze out explained above. Depending on relative strength and hence, the freeze out chronology, either the exchange process or the ϕ_2 annihilation will set the relic density of ϕ_1 .

Assuming that ϕ_1 is the major constituent of DM, a detailed numerical solution is obtained using the full set of coupled Boltzmann equations involving the number densities of both ϕ_1 and ϕ_2 . The temperature variation of relativistic degrees of freedom have been included following [33]. The cross section of the all the relevant channels can be written as

$$\begin{aligned} \sigma v_{\phi_1 \phi_1 \rightarrow f \bar{f}} &= \frac{1}{4\pi s \sqrt{s}} \frac{N_c \lambda_i^2 m_f^2}{(s - m_h^2)^2} (s - 4m_f^2)^{\frac{3}{2}} \\ \sigma v_{\phi_1 \phi_1 \rightarrow h h} &= \frac{\lambda_i^2 \sqrt{s - 4m_h^2}}{16\pi s \sqrt{s}} \left(1 + \frac{3m_h^2}{(s - m_h^2)} - \frac{4\lambda_i v^2}{(s - 2m_h^2)} \right)^2 \\ \sigma v_{\phi_2 \phi_2 \rightarrow \phi_1 \phi_1} &= \frac{\sqrt{s - 4m_{\phi_1}^2}}{8\pi s \sqrt{s}} \left(\frac{v^2 \lambda_1 \lambda_2}{(s - m_h^2)} + \lambda_e \right)^2 \\ \sigma v_{\phi_1 \phi_1 \rightarrow V V} &= \frac{s_f \sqrt{s} \lambda_i^2 \sqrt{1 - 4m_V^2}}{16\pi (s - m_h^2)^2} \left(1 + \frac{12m_V^4}{s^2} - \frac{4m_V^2}{s} \right), \end{aligned} \quad (9)$$

where $s_f = \{2, 1\}$ for $\{W, Z\}$. We have utilized Eq. (9) in the nonrelativistic limit to solve the Boltzmann equation. Throughout the discussion, the annihilation cross section of ϕ_1 has been kept small by fixing it at $\lambda_1 = 10^{-5}$.

In Fig. 2, the evolution of comoving number densities of ϕ_1 and ϕ_2 is shown by red and blue lines, respectively. The dot-dashed lines represent their respective equilibrium values. For the solid curve, exchange processes control the DM relic abundance. Whereas the simultaneous departure of both dashed blue and red lines from the equilibrium curve indicates that the annihilation of ϕ_2 drives the freeze out of ϕ_1 . The apparent decrement of the ϕ_2 number density after it departs from equilibrium curve is due to the process $\phi_2 \phi_2 \rightarrow \phi_1 \phi_1$.

The two distinct possibilities of our numerical solution have been depicted in Fig. 3. In the left and right panel, we

FIG. 2. Evolution of comoving number densities with time. The red and blue lines indicate evolution of comoving number densities of ϕ_1 and ϕ_2 . For the solid and dashed lines, exchange and ϕ_2 annihilation processes drive the decoupling of ϕ_1 . Note that μ is the reduced mass of two dark matter. The chosen values of m_1 and m_2 are 100 and 105 GeV, respectively. We set $\lambda_1 = 10^{-5}$ for all the contours.

show the variation of the relic abundance with λ_e and λ_2 , respectively. In each plot, there are three distinctive regions, the region in between two gray vertical lines represents the part of the parameter space where the relic density of ϕ_1 and hence, that of DM is set by exchange [Fig. 3(a)] or ϕ_2 annihilation [Fig. 3(b)] processes. When either of λ_e or λ_2 become comparable to λ_1 then annihilation of ϕ_1 regulates the relic density. In both of the panels, flatness of the relic density towards the left edge before the vertical lines implies this. While for larger values of the λ_e or λ_2 , depending on their relative strength, either exchange or ϕ_2 annihilation will control the dark matter relic density. In Fig. 3(a), for $\lambda_e \gtrsim 1$, the freeze out of ϕ_2 control the relic

density while in Fig. 3(b), for $\lambda_2 \gtrsim 1$, the exchange process will drive the freeze out.

In the exchange driven freeze out regime, the large value of λ_2 results in a large spin-independent ϕ_2 -nucleon cross section [34–36]. This leads to a strong constraint from direct detection limits in spite of the fact that the ϕ_2 is a minor constituent of the total DM relic density. For instance, the limit on such Higgs portal coupling from the recent results of the XENON1T experiment [37] effectively rules out this possibility in the ~ 100 GeV mass scale within the minimal model. However, note that the effective spin-independent ϕ_2 -nucleon cross section is given by

$$\sigma_{2,n}^{\text{eff}} = \frac{\Omega_2}{\Omega_t} \sigma_{2,n}. \quad (10)$$

The spin independent ϕ_2 -nucleon direct detection cross section, $\sigma_{2,n}$ reads

$$\sigma_{2,n} = \frac{\lambda_2^2 f_n^2 \mu_n^2 m_n^2}{4\pi m_h^4 m_2^2}, \quad (11)$$

where $\mu_n = m_n m_2 / (m_n + m_2)$, m_n is the mass of the nucleon and nucleon form factor, $f_n \approx 0.28$ [35,36]. The first factor of the rhs of the Eq. (10) represents the fraction of relic density shared by ϕ_2 , and as mentioned earlier, ϕ_2 comprises a very small fraction of the total DM density. Thus, in the ϕ_2 annihilation dominated region, the lower rate of ϕ_2 annihilation cross section together with the reduction factor $\Omega_2/\Omega_t \ll 1$ is enough to suppress the effective direct detection coupling to an extent to be able to evade the present XENON1T bound. This has been demonstrated in Fig. 4 where the light blue, orange, and green lines correspond to DM relic density contours for $m_1 = 100, 300$, and 500 GeV, respectively. The dashed lines of Fig. 4 show direct detection

FIG. 3. Different phases of freeze out for the models. For model 1, in both the left and right panel red solid, dashed, and dot dashed lines represent total relic density ($\Omega_t h^2$), the contribution of ϕ_1 ($\Omega_1 h^2$), and the contribution of ϕ_2 ($\Omega_2 h^2$), respectively, while the blue dashed lines correspond to model 2. We assume $\lambda_1 = 10^{-5}$, $m_1 = 100$ GeV, and $\delta = 1\%$. The black solid band represents the central value of DM relic density, measured by Planck [10]. (a) Exchange driven freeze out regime in $\Omega h^2 - \lambda_e$ plane. The chosen value of λ_2 is 0.5. (b) ϕ_2 annihilation dominated freeze out regime in $\Omega h^2 - \lambda_e$ plane. The chosen value of λ_e is 0.5.

FIG. 4. Phenomenological consequences of model 1 in $\lambda_2 - \lambda_e$ plane for $m_1 = 100, 300$, and 500 GeV are shown by light blue, orange, and green lines, respectively. The solid lines represent $\Omega_c h^2 = 0.12$ contours [10]. The dashed lines illustrate upper limit on the couplings for the aforementioned masses from XENON1T experiments. The three shaded regions show the allowed parameter space from both the overclosure of relic density and direct detection. For the hatched region, the exchange process drives the freeze out of ϕ_1 , whereas for the nonhatched region, annihilation of ϕ_2 determines the same. The numerical value of the other relevant parameters is mentioned in Fig. 3.

upper limit on λ_2 for the aforementioned masses. The three shaded regions are consistent with both the direct detection and relic density over closure bounds. Further, in Fig. 4, the pink hatched patch denotes the exchange driven freeze out region which remains forbidden by the direct detection bound. Interestingly, the allowed ϕ_2 annihilation region resurrects the two component $\mathbb{Z}_2 \times \mathbb{Z}_2$ model with DM masses in the 100 GeV range, which is otherwise ruled out in conventional scenarios [26]. It is to be noted that in the above discussion, we have chosen $\delta = 1\%$, signifying the amount of fine-tuning required in this framework.

In passing, we note that one can consider the heavier of the two species as the major DM constituent, which would ease the exponential suppression in Eq. (2) [38]. However, such a framework seems to be mostly ruled out from direct detection constraints.

B. Model 2: Single-component DM

In a setup where the two SM singlet scalars ϕ_1 and ϕ_2 are charged under the same $\mathbb{Z}_2$ symmetry, keeping the rest of the SM even leads to a multipartite dark sector with a single stable DM candidate [24,25]. The most general renormalizable Lagrangian consistent with the charge assignment is given by

$$-\mathcal{L}_{\text{int}} = \left(\frac{\lambda_1}{2} \phi_1^2 + \frac{\lambda_2}{2} \phi_2^2 + \lambda_{12} \phi_1 \phi_2 \right) H^\dagger H + \frac{\lambda_{1s}}{4!} \phi_1^4 + \frac{\lambda_{2s}}{4!} \phi_2^4 + \frac{\lambda_{e1}}{4} \phi_1^2 \phi_2^2 + \frac{\lambda_{e2}}{3!} \phi_1^3 \phi_2 + \frac{\lambda_{e3}}{3!} \phi_1 \phi_2^3, \quad (12)$$

FIG. 5. $\Omega_c h^2 = 0.12$ contours for model 2 in $\lambda_2 - \lambda_e$ plane for $m_1 = 100, 300$, and 500 GeV are depicted by light blue, orange, and green lines, respectively. For the hatched region, exchange processes drive the DM freeze out, whereas for the nonhatched region, annihilation of ϕ_2 determines the same. We have taken $\lambda_1 = \lambda_{12} = 10^{-5}$ and $\delta = 5\%$.

where H denotes the SM Higgs doublet. The lighter state represents the stable DM candidate. In our discussion, we will assume $m_1 < m_2$; therefore, ϕ_1 represents the lightest stable particle (LSP) and is the sole DM candidate within this setup, while ϕ_2 is the next to lightest stable particle (NLSP) that can decay to the LSP. In addition to the processes shown in Fig. 1, coannihilation and decay of the NLSP are the major features that distinguish this from model in Sec. III B. The thermally averaged cross sections for all the relevant annihilation and coannihilation channels can be read out from (9). Conventionally, the annihilation and coannihilation set the DM relic density. However, here we will assume that these processes are suppressed enough to induce a considerable time lapse between the freeze out of the LSP annihilation process with the exchange and NLSP (ϕ_2) annihilation. This enables the exchange processes and NLSP (ϕ_2) annihilation to drive the freeze out of LSP (ϕ_1). Furthermore to keep the discussion tractable, we assume $\lambda_{e1} = \lambda_e$. Unlike the multicomponent DM model, there are two more exchange channels ($\phi_1 \phi_1 \rightarrow \phi_1 \phi_2$ and $\phi_1 \phi_2 \rightarrow \phi_2 \phi_2$) that are operative here. As is evident from Eq. (2), the exponential suppression associated with these channels would be smaller than the $\phi_1 \phi_1 \rightarrow \phi_2 \phi_2$ channel. We have incorporated all these channels in our numerical simulation.

The different phases of the freeze out shown by the blue dashed lines of Fig. 3, which are obtained using a full numerical simulation of the dark sector, are represented by the Lagrangian given in Eq. (12). Clearly, when $\lambda_1, \lambda_{12} < \lambda_{e/2} \sim \lambda_{2/e}$ then either exchange processes or the annihilation of ϕ_2 predominantly drive the thermal freeze out of the DM; hence, we set $\lambda_1 = \lambda_{12} = 10^{-5}$. The relic density allowed contours for DM masses 100, 300, and 500 GeV have been depicted in Fig. 5. The hatched region denotes

the exchange driven freeze out parameter space, while for the nonhatched region, annihilation of ϕ_2 drives the freeze out.

The spin-independent direct detection cross section of the DM would be considerably smaller due to the smallness of the Higgs portal coupling λ_1 . However, in both the exchange and ϕ_2 annihilation driven regime, the lifetime of ϕ_2 can be quite large, having potential implications for early Universe cosmology. For the DM mass in the 100 GeV scale and $\delta = 5\%$, a lower limit on $\lambda_{12} \geq 10^{-6}$ ($\ll \lambda_e, \lambda_2$) is obtained from BBN constraints.

IV. CONCLUSION

In this paper, we propose a new paradigm of thermal freeze out of DM. In a relatively degenerate dark sector, if the annihilation cross section of the major constituent of DM relic density is suppressed then the exchange process within the dark sector and subsequent annihilation of other species drives the freeze out. Depending on the time ordering of freeze out, either exchange processes or

annihilation of second lightest species can set the relic density of DM. We have demonstrated that for a simple multiparticle Higgs portal DM model, this mechanism can be readily realized to saturate the DM relic density constraints while being consistent with direct detection bounds.

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