When Freeze-Out Occurs Due to a Non-Boltzmann Suppression: A Study of Degenerate Dark Sector

ANIRBAN BISWAS[1], SOUGATA GANGULY[2] AND SOUROV ROY[3]
SCHOOL OF PHYSICAL SCIENCES, INDIAN ASSOCIATION FOR THE CULTIVATION OF SCIENCE, INDIA
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ABSTRACT

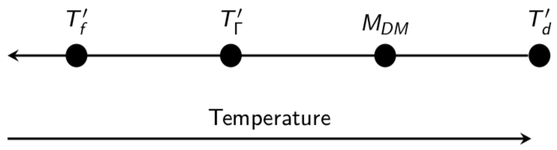
In a degenerate/quasi degenerate dark sector, chemical imbalance can also be generated from a mechanism which is analogous to the radioactive decay law, known as co-decaying dark matter. Here, we have studied the dynamics of a thermally decoupled dark sector in a hidden $U(1)_X$ extension of the Standard Model (SM). We compute the relic density as well as the temperature evolution by taking into account all the $3 \to 2$ processes in our model. We have also investigated the constraint arising from various direct and indirect searches. We have found that for degenerate scenario, all the existing bounds can easily be evaded but the bounds are significant for quasi degenerate scenario.

BASIC MECHANISM

Conditions

- ✓ Dark sector is decoupled from the visible sector when it is relativistic.
- ✓ Dark sector contains multiple species, which are degenerate (or nearly degenerate).
- ✓ Dark sector contains a metastable mediator which decays to SM out of equilibrium so that the dark sector is not thermalised with SM bath.

Time scale



Set-up

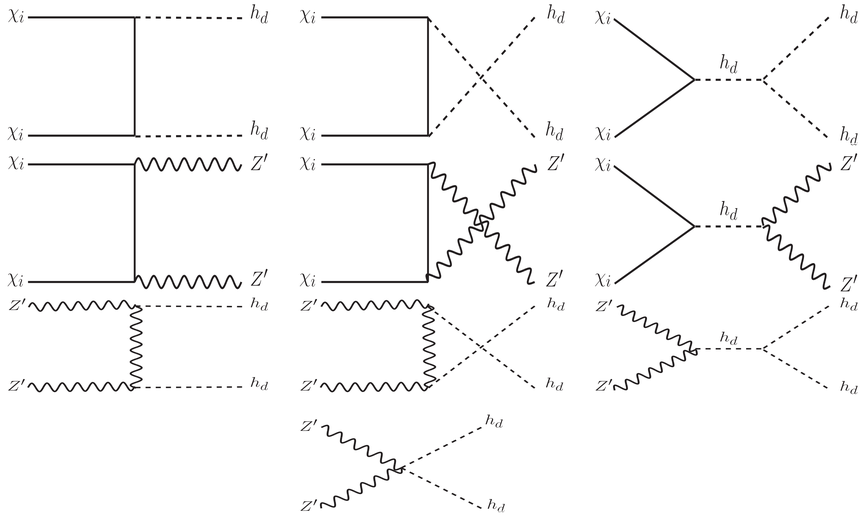
- Let us consider, a decoupled dark sector with two dark sector particles A and B which are degenerate. The dark sector is in thermal equilibrium with different temperature (say T') and B can decay out-of-equilibrium to SM.
- When they are non-relativistic, their number densities are not exponentially suppressed because of their degeneracy $\implies$ $\mu \simeq M_{DM} - \mathcal{O}(T')$.

THE MODEL AND DARK MATTER ANNIHILATION CHANNELS

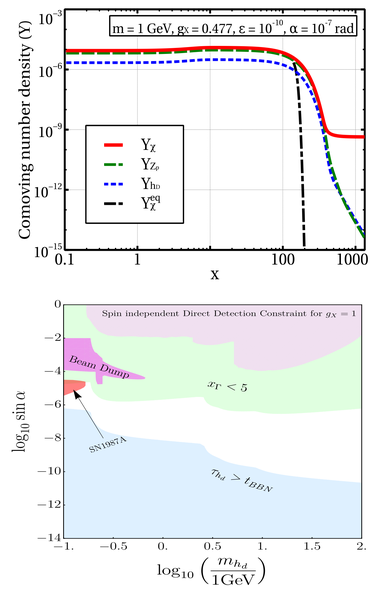
Field Content

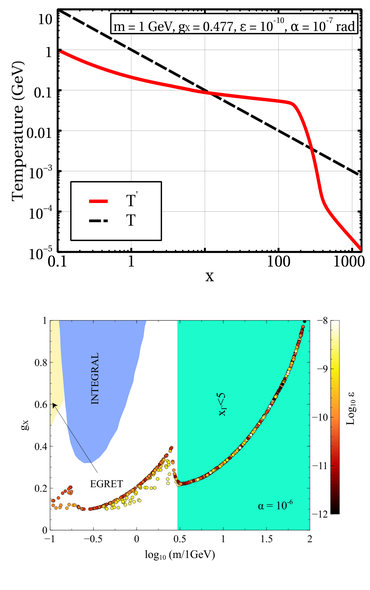
- We have considered the gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \otimes U(1)_X$.
- ξ_{1L} $(1,\ 1,\ 0, 1)$.
- ξ_{2L} $(1,\ 1,\ 0, -1)$.
- A complex scalar η $(1,\ 1,\ 0,\ 2)$.
- We impose a $\mathbb{Z}_2$ symmetry and ξ_{1L} is $\mathbb{Z}_2$ odd but ξ_{2L} is $\mathbb{Z}_2$ even $\implies$ $\eta\,\overline{\xi^c_{1L}}\xi_{2L}$ is forbidden.

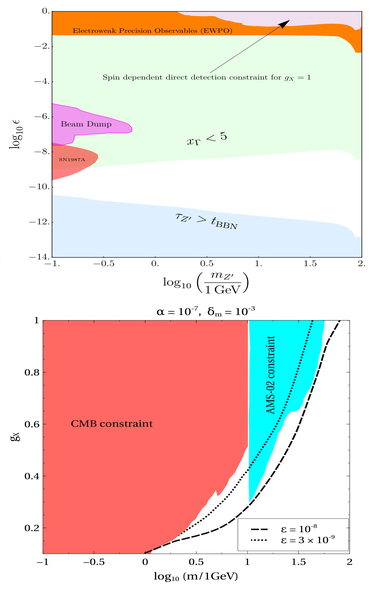
DM annihilation channels



RESULTS







SUMMARY AND CONCLUSIONS

- The out-of-equilibrium decay of long-lived mediator particle such as Z' and h_d leading to delayed freeze-out of Dark Matter and this is known as "Co-Decaying Dark Matter".
- The dark sector enters into the "Cannibal" phase due to the presence of $3 \to 2$ processes and during this phase the temperature evolution changes significantly.
- We have investigated the allowed region of parameter space from ν and γ ray signals from DM annihilation via one step cascade process.
- The bounds from direct, indirect, laboratory and astrophysical searches can be easily evaded in case of degenerate dark sector. However for non-degenerate dark sector, a certain region of the parameter space is significantly constrained from the measurement of diffuse γ ray flux by INTEGRAL, CMB anisotropy, and positron flux by AMS-02 experiment.

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CONTACTS

1. anirban.biswas.sinp@gmail.com
2. tpsg4@iacs.res.in
3. tpsr@iacs.res.in

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