Non-adiabatic evolution of dark sector in the presence of $U(1)_{L_\mu - L_\tau}$ gauge symmetry

Ananya Tapadar
intat@iacs.res.in
Indian Association for the Cultivation of Science

Dark Sectors of Astroparticle Physics (AstroDark-2021): Axions, Neutrinos, Black Holes and Gravitational Waves

Introduction

- Decades after the first observational evidences, the origin and composition of the dark matter (DM) is still illusive.
- Few possibilities of DM: Weakly interacting massive particle (WIMP), Feebly interacting massive particle (FIMP), Axionic DM, Secluded sector DM etc.
- Secluded sector DM: Energy exchange is possible between Dark Sector and Visible Sector.
- Our objectives are:
  - search of DM production mechanisms in such non-adiabatic scenario.
  - investigate detection prospects of hidden sector particles.

Model

- We have considered $U(1)_X \otimes U(1)_{L_\mu - L_\tau}$ extension of the SM gauge group.
- Tree level kinetic mixing between Z' and $Z_{L_\mu - L_\tau}$.
- The Lagrangian of our model:

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{K.E.} + \mathcal{L}_{int} + \frac{1}{2}\hat{m}^2_{\mu\tau}\hat{Z}^\rho_{\mu\tau}\hat{Z}_{\mu\tau\rho} + \frac{1}{2}\hat{m}'^2\hat{Z}'^\rho\hat{Z}'_\rho + \frac{\sin\delta}{2}\hat{Z}^{\rho\sigma}_{\mu\tau}\hat{Z}'_{\rho\sigma}$$

- Mass basis of Z' and $Z_{L_\mu - L_\tau}$: interaction of dark vector boson with DM and SM bath:

$$\mathcal{L} \supset -g_X\bar{\chi}\gamma^\rho\chi Z'_\rho + \epsilon\left(\bar{\mu}\gamma^\rho\mu + \bar{\nu}_\mu\gamma^\rho P_L\nu_\mu - \bar{\tau}\gamma^\rho\tau - \bar{\nu}_\tau\gamma^\rho P_L\nu_\tau\right)Z'_\rho$$

- Model parameters: m_χ, $m_{Z'}$, α_X, ϵ.
- Interested region: relativistic Z', i.e. $m'_Z \lesssim 10 m_\chi$.

Dark sector dynamics

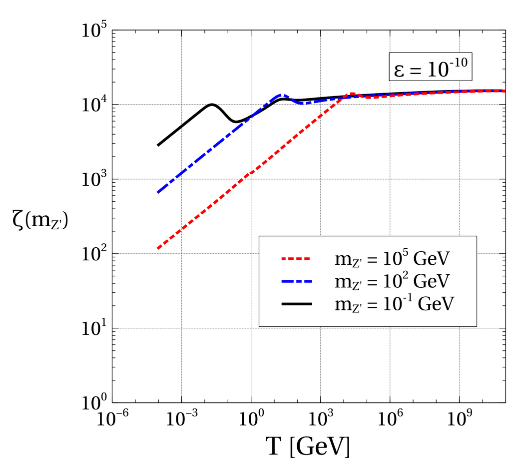
- Early era $\rightarrow$ dark sector particles are produced from SM bath.

processes:

$f\bar{f} \rightarrow \gamma(Z,h)Z'$, $f(\bar{f})\gamma(Z,h) \rightarrow f(\bar{f})Z'+$ charged current interactions.

- Numerical analysis: Dependence of HS temperature on SM sector temperature:

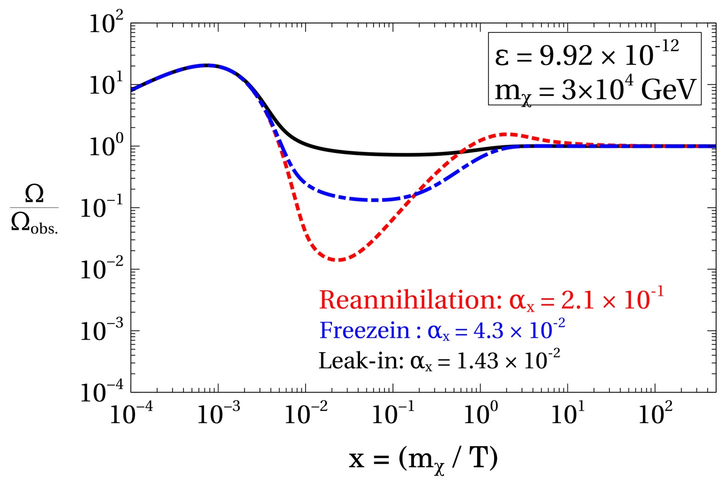
$$\boxed{T' = \zeta(m'_Z)\sqrt{\epsilon}T^{3/4} \sim 10^4\sqrt{\epsilon}T^{3/4}}$$



- Boltzamn Equation:

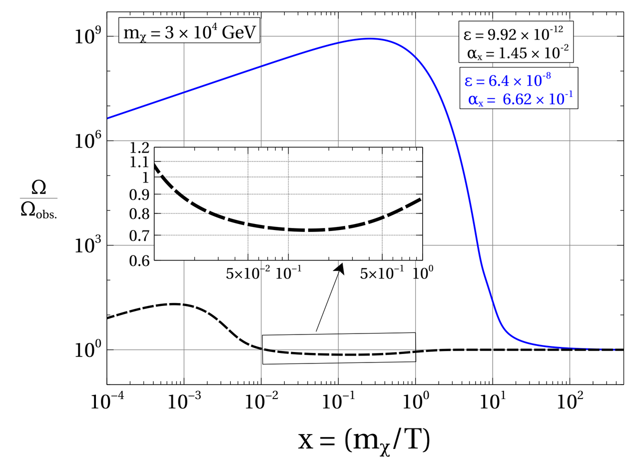
$$\frac{dn_{\chi_{tot}}}{dt} + 3Hn_{\chi_{tot}} = \frac{1}{2}\langle\sigma v\rangle^{T'}_{\bar{\chi}\chi\rightarrow Z'Z'}\left(n_{\chi_{eq_{tot}}}(T')^2 - n^2_{\chi_{tot}}\right) + 2\sum_f\langle\sigma v\rangle^{T}_{f\bar{f}\rightarrow\bar{\chi}\chi}n^2_{f_{eq}}(T)$$

Leak-in — Freeze-in



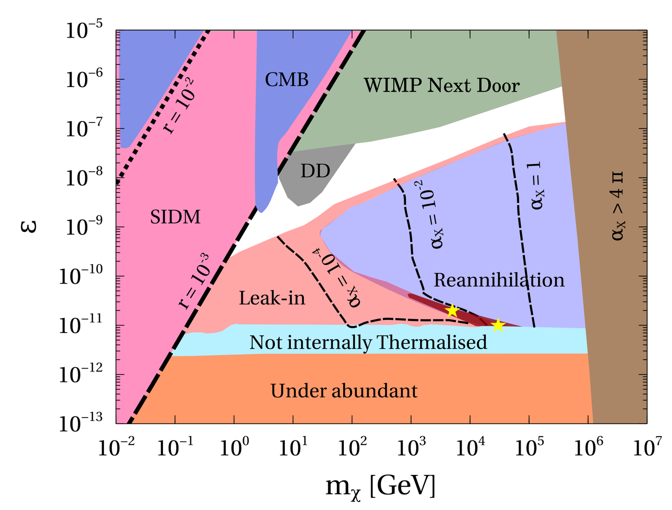
- DM decouples from internal thermal bath early and freezes out: LEAK-IN.
- DM decouples lately and again produced from SM bath: FREEZE-IN.
- After decoupling much lately from interanal thermal bath, DM are produced rapidly from SM bath and attain quasi-static equilibrium(QSE). At later time DM decouples from this QSE and freezes out: REANNIHILATION.

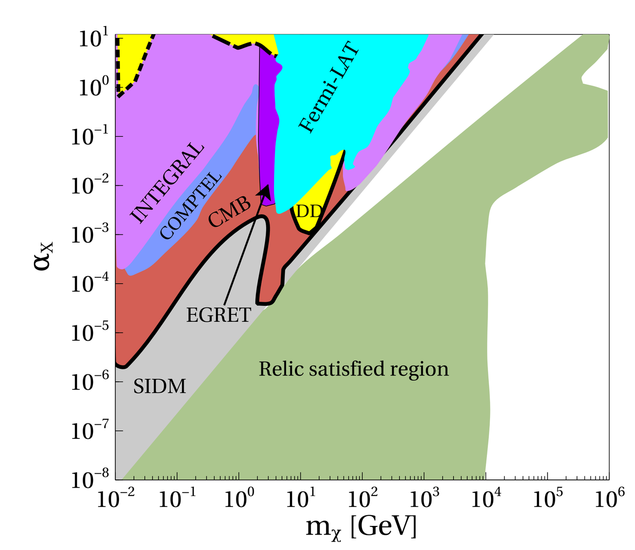
- Large ϵ : DM remains in thermal equilibrium for long time, DM production does not effect final relic, known as Late Leak-in.
- Small ϵ : freeze-in term effects in final relic abundance of DM, known as Early Leak-in.



Constraints on HS

- Model parameter space can be constrained theoretically:
  - HS is not internally thermalized $\rightarrow \epsilon \lesssim 10^{-11}$.
  - WIMP next door: HS and VS will be in thermal equilibrium $\rightarrow \epsilon \gtrsim 10^{-6}$.
  - Under abundant: DM production at early era is low, therefore it can never attain observed relic density $\rightarrow \epsilon \lesssim 10^{-12}$.
  - Pertubative region: observed relic density of DM can be satified for $\alpha_X > 4\pi$.





- Constraints from experiments:

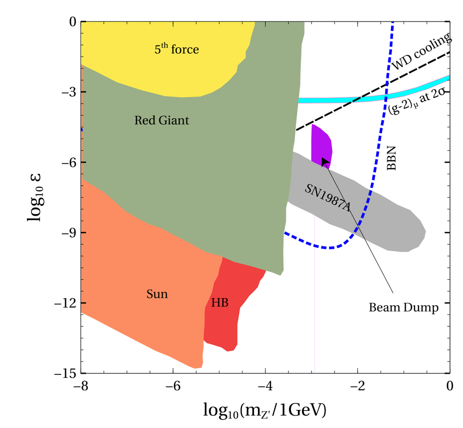
Direct detection:

- $\mathrm{XENON1T}$, $\mathrm{XENON10T}$, $\mathrm{CRESST-III}$: interaction of DM with quarks through radiatively generated $Z - Z'$ and $Z - \gamma$ kinetic mixing.

Indirect detection:

- Bullet cluster observation $\rightarrow$ self interaction of DM.
- Gamma ray signals: Fermi-LAT, INTIGRAL, EGRET, COMPTEL due to DM annihilation.
- CMB: production of charged SM particle ($\mu^\pm$,$\tau^\pm$,$e^\pm$) from Z' decay.

Constraints on the $L_\mu - L_\tau$ portal



- BBN: $Z' \leftrightarrow \bar{\nu}_\mu\nu_\mu$, $Z' \leftrightarrow \bar{\nu}_\tau\nu_\tau$.
- Neutrino luminosity after $1\mathrm{s}$ of Supernova $1987\mathrm{A}$: presence of extra light degrees of freedom can enhance the rate of cooling of $\mathrm{SN1987A}$.
- Fifth force experiments: light Z' can modify the coloumb potential.
- Observations of steller cooling and white dwarf cooling.
- Beam Dump experiment.
- Recent measurement of muon $g-2$ by Fermilab.

Result and Conclusion

- Non-adiabatic evolution of HS is one of possible nature of DM.
- Leak-in, Freeze-in, Re-annihilation all three are possible in a single frame work.
- A huge parameter space still allowed even after constraining model parameter space by direct detection and inderect detections.

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References

1. A.Tapadar,Sougata Ganguly,Sourov Roy *Non-adiabatic evolution of dark sector in the presence of $U(1)_{L_\mu - L_\tau}$ gauge symmetry*, arxiv: 2109.13609
2. Jared A. Evans, Cristian Gaidau, Jessie Shelton *Leak-in dark matter* JHEP01(2020)032.
3. $XENON$ collaboration, Dark Matter Search Results from a One Ton-Year Exposure of XENON1T, Phys.Rev.Lett.121(2018)111302 [1805.12562].
4. Fermi-LAT collaboration, Fermi-LAT Observations of the Diffuse Gamma-Ray Emission: Implications for Cosmic Rays and the Interstellar Medium, Astrophys.J.750(2012)3 [1202.4039].
5. Muon $g-2$ collaboration, *Final Report of the Muon E821 Anomalous Magnetic Moment Measurement at BNL*, Phys.Rev.D73(2006)072003 [hep-ex/0602035].
6. H. K. Dreiner, J.-F. Fortin, J. Isern and L. Ubaldi, /textitWhite Dwarfs constrain Dark Forces, Phys.Rev.D88(2013)043517 [1303.7232].