MATTER ASYMMETRY GENESIS IN THE Z_3 DM-COMPANION MODEL

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THE 5TH WORKSHOP ON FRONTIERS OF PARTICLE PHYSICS,
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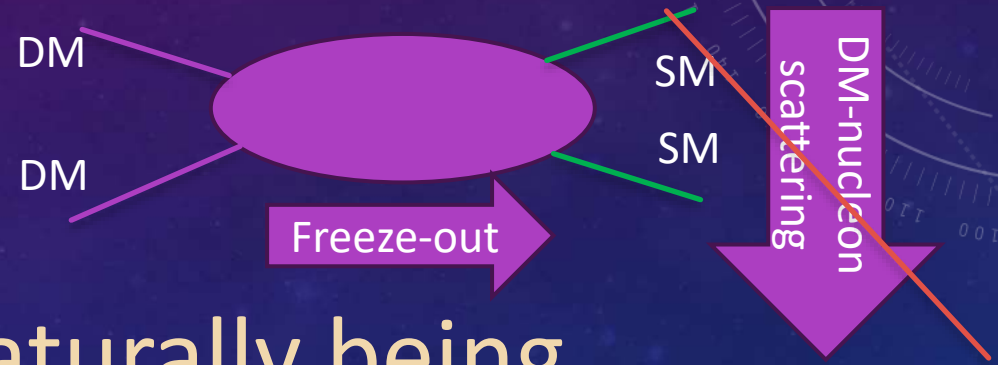
BASED ON THREE WORKS IN COLLABORATION WITH

JUN GUO(郭俊), SHAOLONG CHEN（陈绍龙） & PENG ZHANG（张鹏）

OUTLINE

- Z_3 symmetric DM-companion model

Break the typical WIMP DM connection by symmetry



- Semi-annihilation DM naturally being asymmetric DM & seeding matter asymmetry

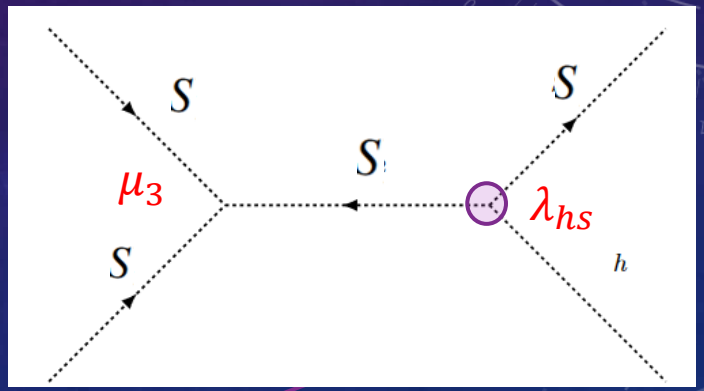
Adding a lepton portal

Z_3 SYMMETRIC DM-COMPANION MODEL

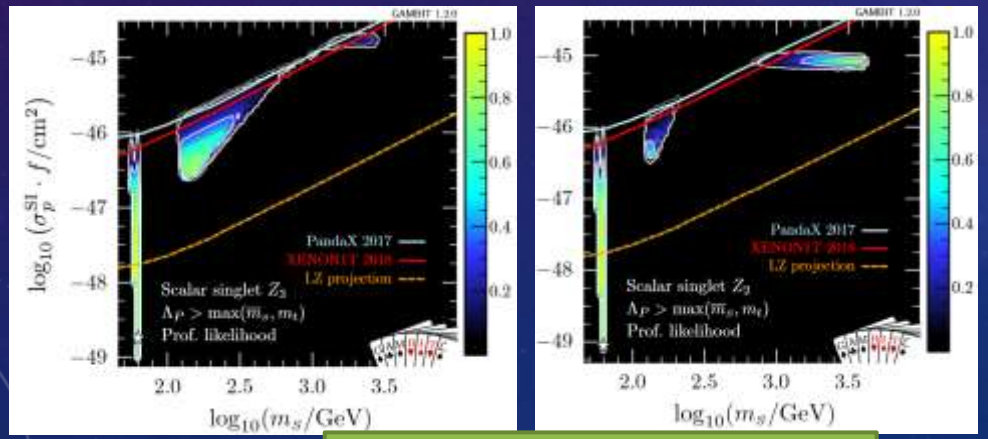
- The simplest Z_3 DM model: a complex scalar DM with Higgs portal

$$V_{\mathbb{Z}_3} = \mu_H^2|H|^2 + \frac{1}{2}\lambda_h|H|^4 + \lambda_{hS}S^\dagger S|H|^2 + \mu_S^2 S^\dagger S + \lambda_S(S^\dagger S)^2 + \frac{\mu_3}{2}(S^3 + S^{\dagger 3}),$$

$$S \to \exp\left(i\frac{2\pi}{3}\right)S$$



- New-1: Semi-annihilation $SS \to Sh$
- New-2: Alleviate the constraint of DM direct detection, widening the relatively light region



From GAMBIT, EPJC 2018

- The usual Higgs portal is still necessary, but λ_{hs} can be smaller by increasing μ_3

Can we have more fun?E.g., to Improve the embarrassing situation of WIMP DM?

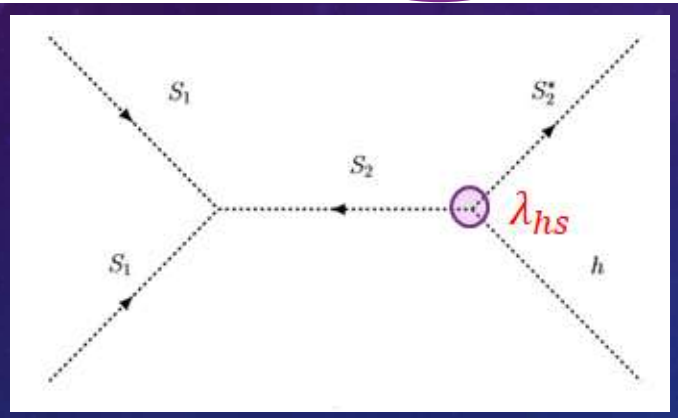
Z_3 SYMMETRIC DM-COMPANION MODEL

J. Guo, Z. Kang and P. Zhang, PLB (2022)

A new way to untie WIMP DM freeze-out & DM-nucleon scatter

- DM with a Z_3-symmetric companion

$$-\mathcal{L}_{Z_3} \supset m_1^2 S_1 S_1^* + m_2^2 S_2 S_2^* + \lambda_{1h}|S_1|^2|H|^2 + \lambda_{2h}|S_2|^2|H|^2 + \left(\frac{A_1 S_1^3}{3} + \frac{A_2 S_2^3}{3} + \frac{1}{2}A_{12} S_1^2 S_2 + \frac{1}{2}A_{21} S_1 S_2^2 + c.c\right),$$



- Fermionic Z_3 DM ***has no*** DM Higgs portal!

$$-\mathcal{L}_{Z_3} \supset + m_S^2|S|^2 + M_\Psi \bar{\Psi}\Psi + \lambda_{sh}|S|^2|H|^2 + \left(\frac{A_s}{3}S^3 + \lambda_L \overline{\Psi^C} P_L \Psi S + \lambda_R \overline{\Psi^C} P_R \Psi S + c.c.\right),$$

- If extend the original model by one more copy of DM S_1, then this DM companion S_2 furnishes the symmetric portal to SM
- Now the Higgs portal for DM can/should be turned off, by hand
- To allow DM semi-annihilate away, we require **the window: $m_{S_2} + m_h < 2m_{S_1} < 2m_{S_2}$**

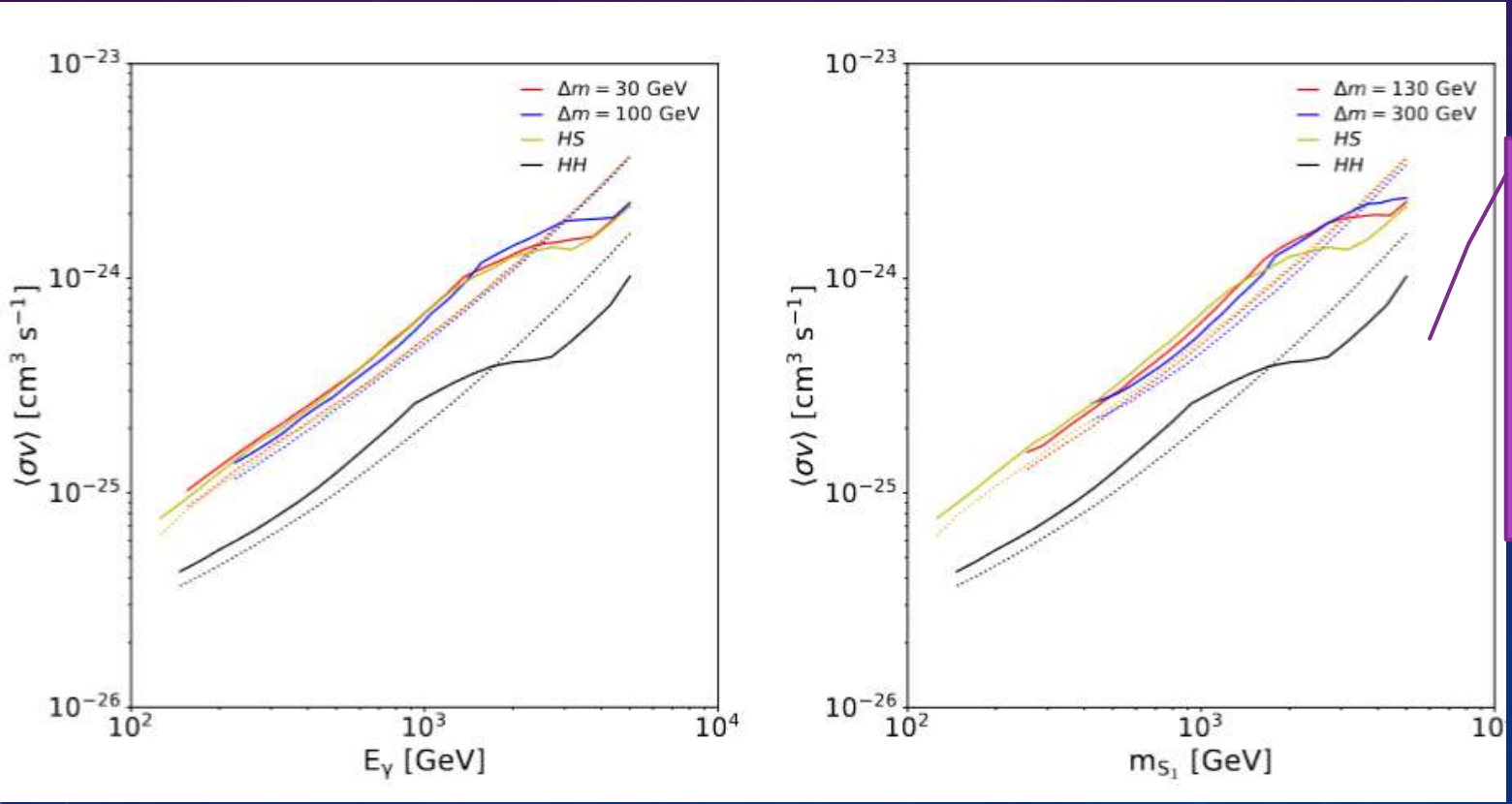
The idea can be implemented in any Z_N model for $N > 2$

Due to the accidental Z_2 for fermion, companion is also stable in this model

FUNS WITH Z_3 DARK MATTER MODELS

J. Guo, & Z. Kang , to appear

- Highly hidden in the sky?
  - Cosmic ray signal via on/off shell Higgs bosons:$S_1 S_1 \to S_2(\to S_1 h) + h$



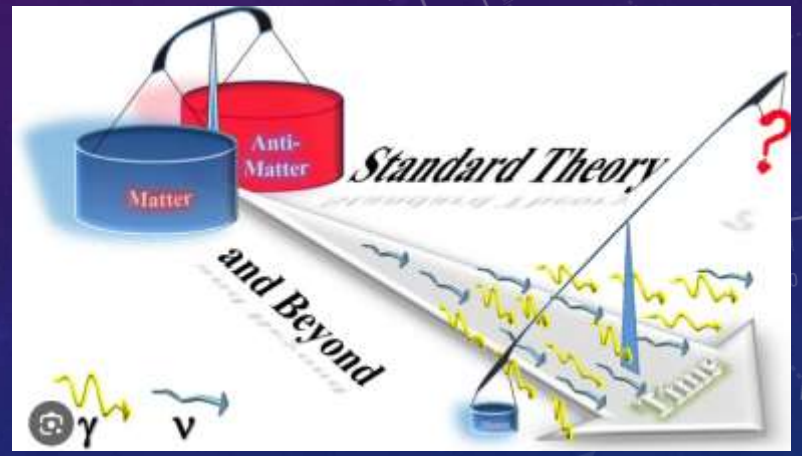
- The 14&6-year FRMI-LAT data cannot yield meaningful constraint in the heavy region
- in the deep coannihilation region, this signal rate may be highly suppressed

SEMI & ASYMMETRIC-ANNIHILATING DARK MATTER

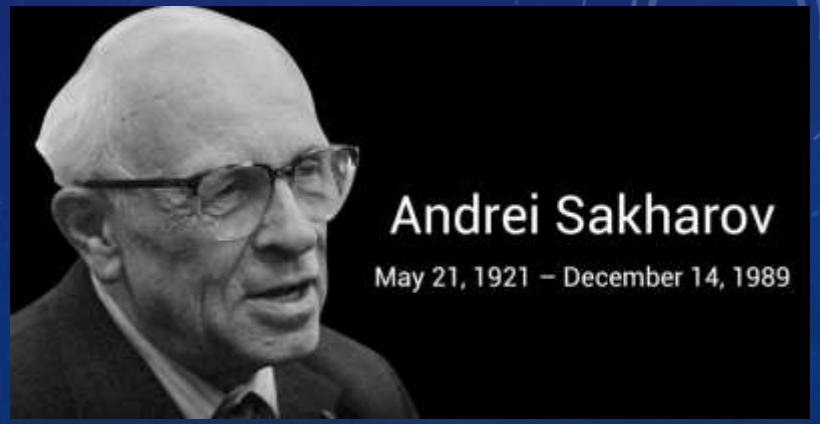
- Maximally asymmetric visible world
  - asymmetry to save the world

    Were in a symmetric early universe, the nucleon-antinucleon large annihilation rate would lead to negligible matter fraction

  - a tiny asymmetry at $T \gtrsim 1\mathrm{GeV}$ to prevent over-annihilation:



- Origin of asymmetry in BSM & Sakharov's 3 conditions (1967)
  - B violation
  - C &CP violation
  - out-of-equilibrium (freeze-out, first order phase transition)



SEMI & ASYMMETRIC-ANNIHILATING DARK MATTER

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Connect to dark matter?
idea traced back to
asymmetric dark matter

- Asymmetry first generated in the dark matter, carrying generalized B/L number
- Translated to the visible sector via proper operators, e.g., DM^2
- Related to but different than the models where DM directly annihilates into L/B to produce matter asymmetry

Natural dark Sakharov's 3 conditions in semi-annihilation models

- dark matter number (not self-conjugate by $Z_{N\geq 3}$) & its violation (S^3 term)
- CP violation: readily & safely present in the dark sector
- WIMP freeze out from the plasma departures from equilibrium

TRANSFER TO THE VISIBLE SECTOR

SL Chen, ZK Liu, Z. Kang and P. Zhang, to appear

- A lepton portal extension to the DM-companion model
  - an extra doublet scalar companion η

$$-\mathcal{L}_{extra} \supset + y_{ij}\overline{L_{Li}}\tilde{\eta}\Psi_{Rj} + \lambda_\eta H^\dagger H \eta^\dagger \eta + g\eta^\dagger H S + m_\eta^2 \eta^\dagger \eta,$$

The portal generalize lepton number to dark sector

A ``derivation" to the two-loop neutrino mass model by E. Ma

Fileds	$SU(2)$	$U(1)_Y$	$\mathcal{Z}_3$
H	2	1/2	1
L_L	2	-1/2	1
$\Psi^i_{R,L}$	1	0	w
$\eta = \begin{pmatrix} \eta^\dagger \\ \eta^0 \end{pmatrix}$	2	1/2	w
S	1	0	w

  - $S - \eta^0$ mixture→neutrino+DM, transferring DM asymmetry to leptons
  - Further transfers to baryon asymmetry? Depends on DM! see later

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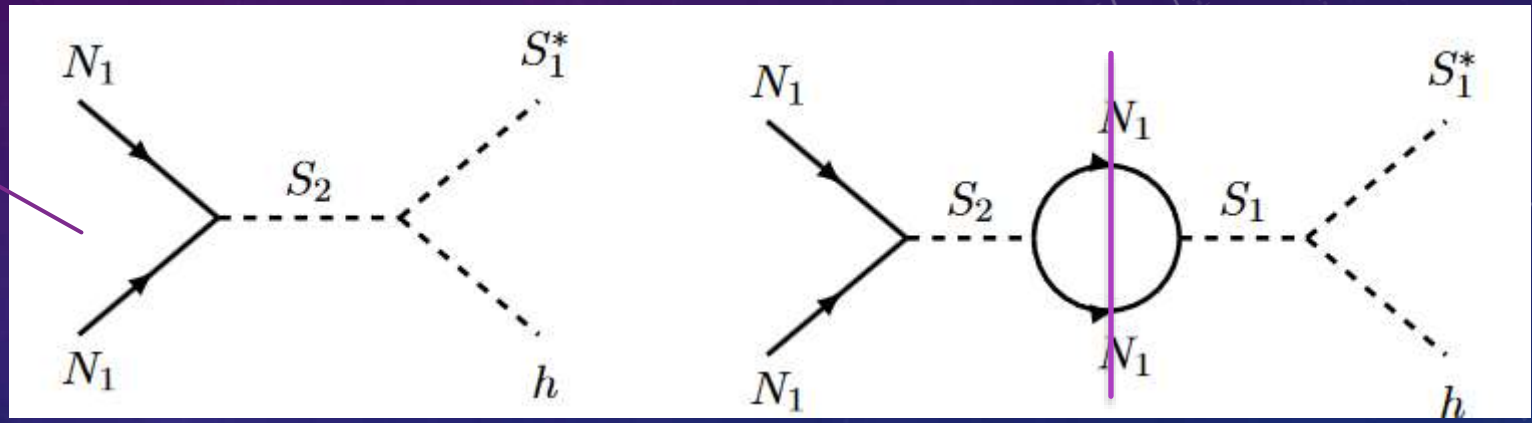
Non-zero CP-violation parameter thanks to thermal motion

- tree-loop interference

A resonant pole is needed for multi-TeV scale DM



- Zero CP violation in the static limit: initial & loop particles are the same

$$\epsilon = \frac{|M|^2_{N_1N_1\to S_1^*h} - |M|^2_{\overline{N_1N_1}\to S_1h}}{|M|^2_{N_1N_1\to S_1^*h} + |M|^2_{\overline{N_1N_1}\to S_1h}} = -\frac{Im[\lambda_0^*\lambda_1]}{4\pi|\lambda_0|^2}\frac{\sqrt{s(s-4m_{N1}^2)}(s-2m_{N1}^2)}{(s-m_{S_2}^2)m_{N_1}^2}$$

- way out: Thermal average consistently defined below

$$\epsilon_T \equiv \langle\epsilon(s)\rangle = \frac{4m_{N_1}^2}{n_a^{eq}n_b^{eq}}\int d\Pi_a f_a^{eq} d\Pi_b f_b^{eq}\epsilon(a+b\to i+j).$$

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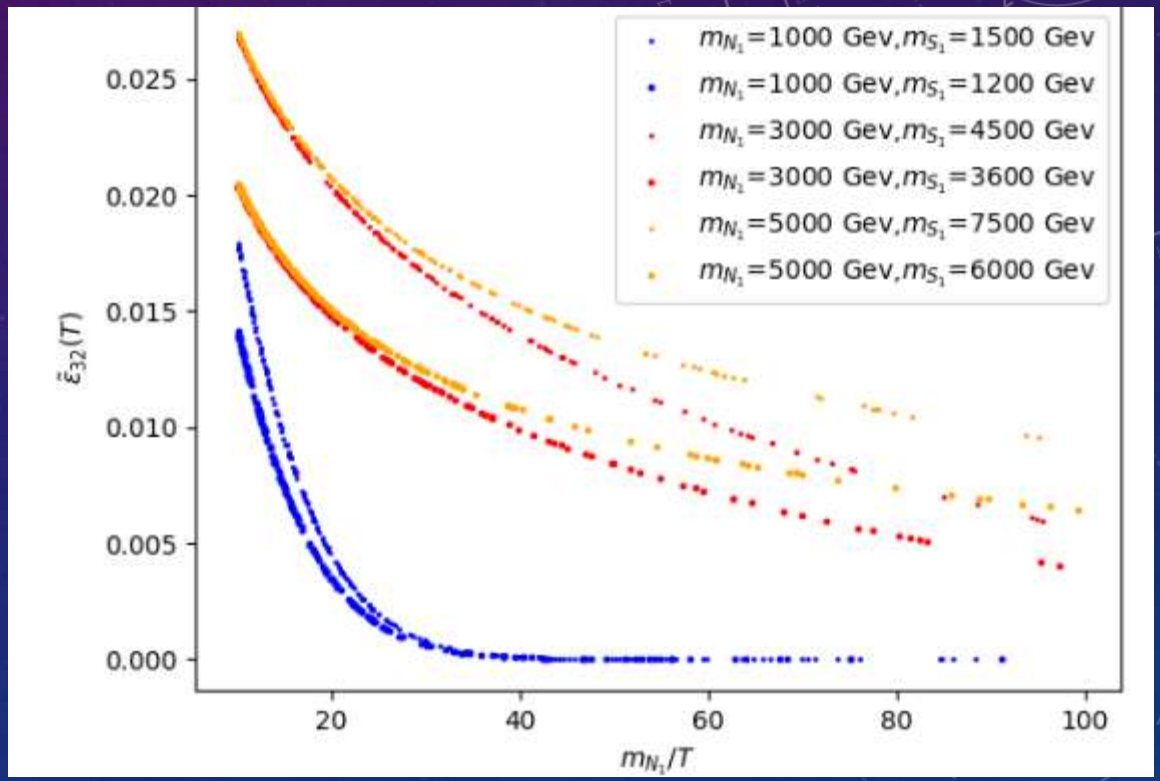
Non-zero CP-violation parameter thanks to thermal motion

- nonrelativistic suppression is mild, $\sim\mathcal{O}(0.001)-\mathcal{O}(0.01)$

$$\langle\tilde{\epsilon}_{32}(T)\rangle \approx \frac{e^{2z}}{8g_N^2(15/8+z)^2 z\pi\sqrt{\frac{\pi}{2}}} \int_{2z}\sqrt{x}e^{-x}\sqrt{x^2-4z^2}\frac{x\sqrt{(x^2-4z^2)(x^2-2z^2)}}{(x^2-y^2)}dx$$

- Resonant enhancement $\sim\mathcal{O}(10)$ from the coupling part is reasonable

$$\frac{\mathrm{Im}[\lambda_0^*\lambda_1]}{|\lambda_0|^2} = \frac{\mathrm{Im}[\lambda_{R2}^*\lambda_{sh12}\lambda_{R2}\lambda_{R2}\lambda_{R1}^*\lambda_{sh1}^*]}{|\lambda_{R1}\lambda_{sh12}^*|^2} \to \frac{|\lambda_{R1}||\lambda_{R2}||\lambda_{sh1}|}{|\lambda_{sh12}|}e^{i\beta}$$



This coupling can be very small due to DM annihilation with resonant enhancement

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Boltzmann equations

- evolutions of number density of the (anti)DM-(anti)companion system

$$\begin{aligned}\frac{\mathrm{d}Y_{N_1}}{\mathrm{d}z_N} = \frac{m_N^3}{z_N^2 H(m_N)}[&2Y_{S_1^*}Y_h\langle\sigma_a v\rangle - 2Y_{N_1}Y_{N_1}\langle\sigma_b v\rangle + Y_{S_1}\frac{z_N^3}{m_N^3}\Gamma_D - Y_{v_1}e^{-\frac{z_N\Delta m}{m_N}}\frac{z_N^3}{m_N^3}\Gamma_D \\ &+ Y_{S_1}Y_h\langle\sigma_c v\rangle - Y_{N_1}Y_{\overline{v_1}}\langle\sigma_c v\rangle + 2Y_{S_2^*}Y_h\langle\sigma_a v\rangle - 2Y_{N_1}Y_{N_1}\langle\sigma_b v\rangle \\ &+ Y_{S_2}\frac{z_N^3}{m_N^3}\Gamma_D - Y_{v_1}e^{-\frac{z_N\Delta m}{m_1}}\frac{z_N^3}{m_N^3}\Gamma_D + Y_{S_2}Y_h\langle\sigma_c v\rangle - Y_{N_1}Y_{\overline{v_1}}\langle\sigma_c v\rangle],\end{aligned}$$

$$\begin{aligned}\frac{\mathrm{d}Y_{S_1^*}}{\mathrm{d}z_1} = \frac{m_1^3}{z_1^2 H(m_1)}[&Y_{N_1}Y_{N_1}\langle\sigma_b v\rangle - Y_{S_1^*}Y_h\langle\sigma_a v\rangle + Y_{v_1}e^{-\frac{z_1\Delta m}{m_1}}\frac{z_1^3}{m_1^3}\Gamma_D - Y_{S_1}\frac{z_1^3}{m_1^3}\Gamma_D \\ &+ Y_{N_1}Y_{\overline{v_1}}\langle\sigma_c v\rangle - Y_{S_1}Y_h\langle\sigma_c v\rangle],\end{aligned}$$

The only accessible channel of asymmetric companion decay is into neutrino, **without washing-out**

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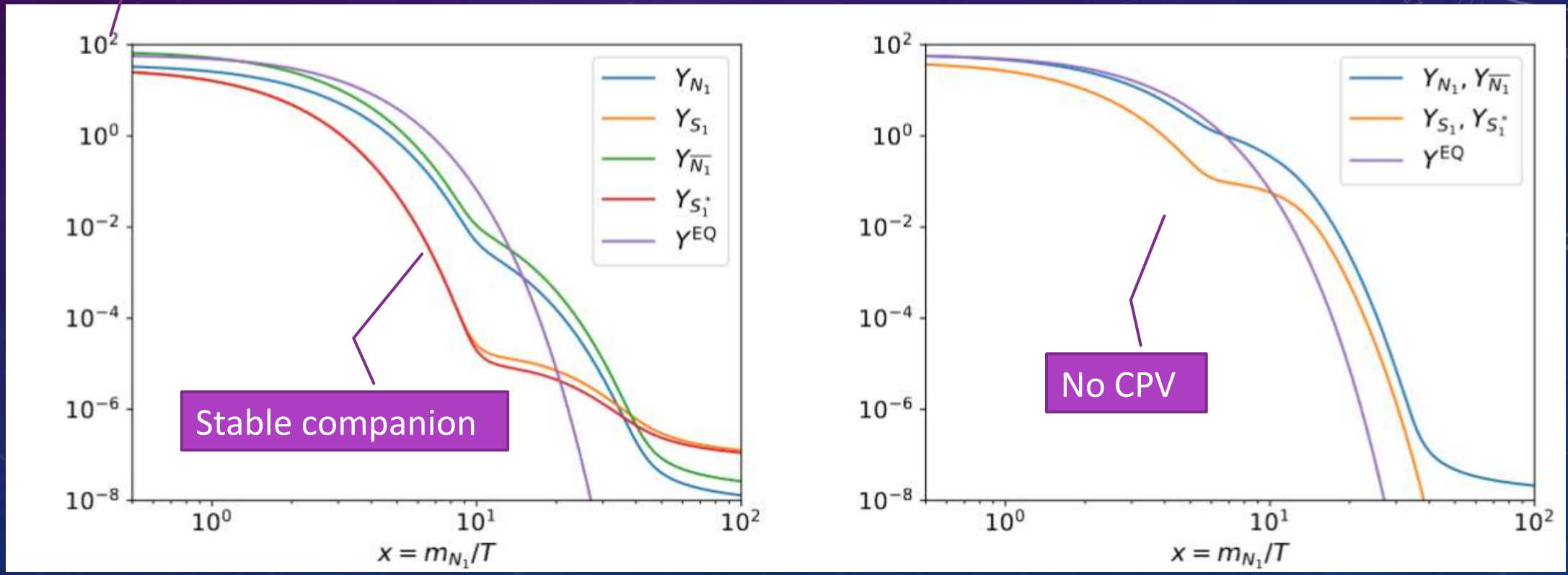
- BEs, beyond the coannihilation region
  - Asymmetry evolution samples

Asymmetry ~DM yield



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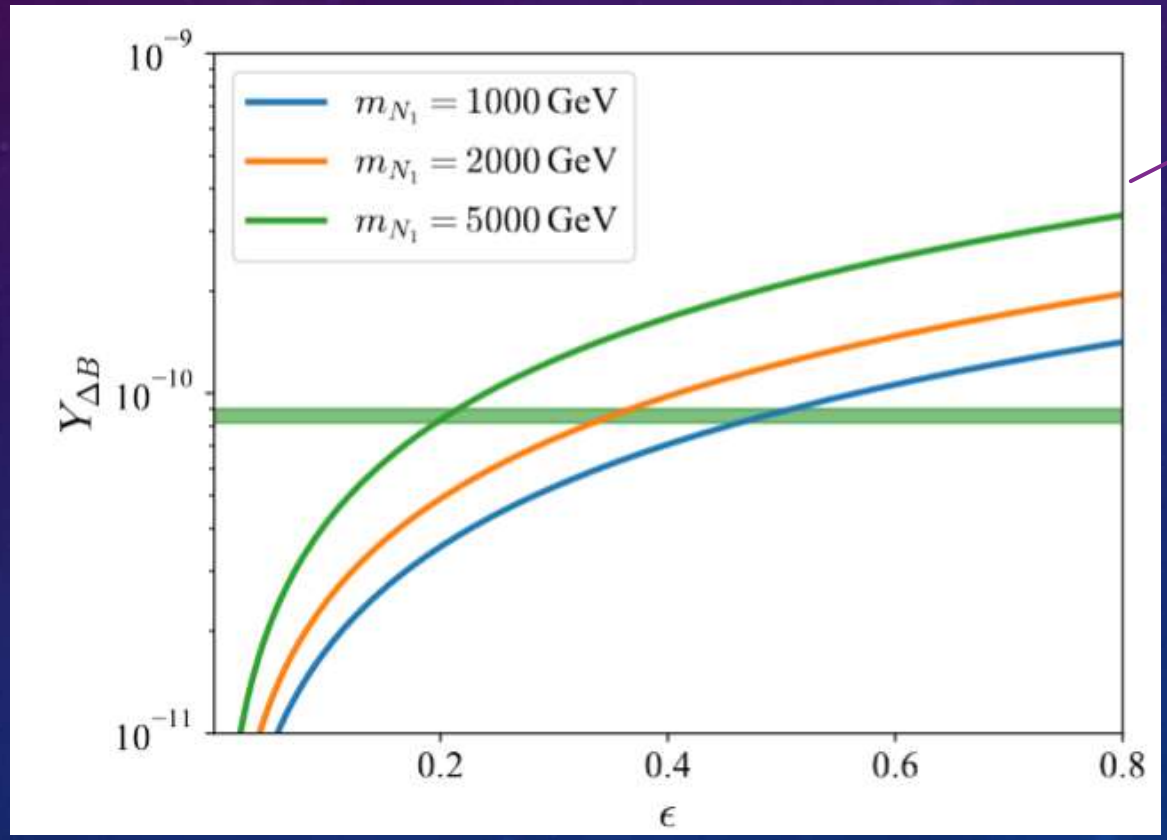
Results

- matter asymmetry versus thermally averaged CP violation parameter

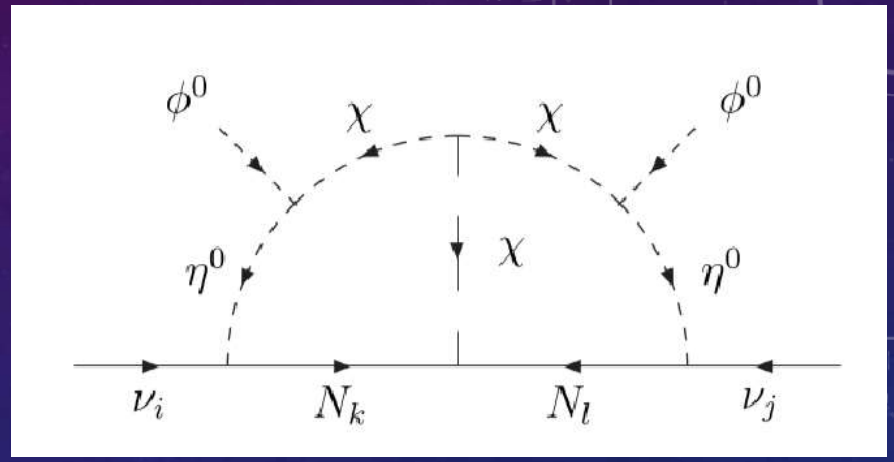


For the interesting multi-TeV scale DM, $\epsilon \sim 0.1$ works

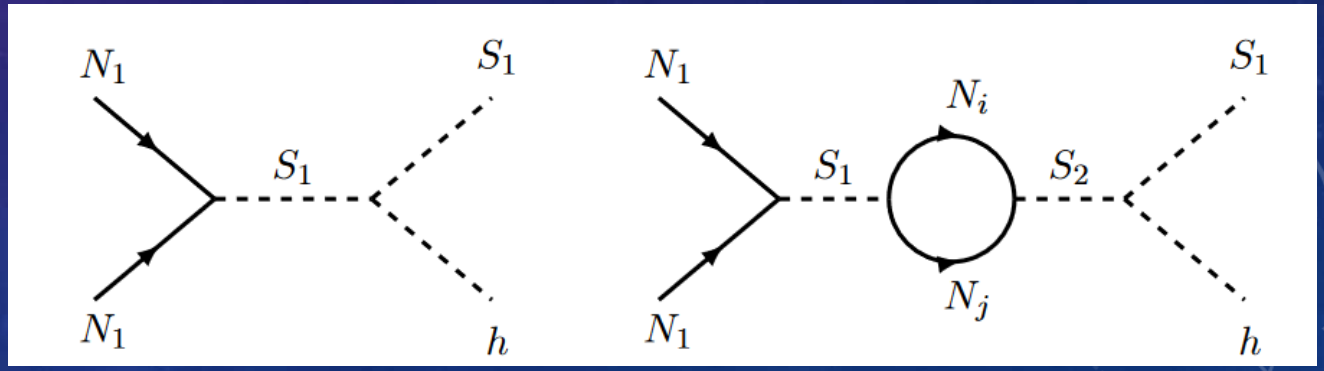
Thank you for your attention!

FUTURE WORK (WISH LIST LAST YEAR)

- Neutrino & matter asymmetry
  - a part of two-loop neutrino model
  - ingredients for matter asymmetry



- $\mathrm{DM}-\mathrm{DM}$ not DM-anti-DM annihilation (dark number violation)
- CP violation in the dark sector or from the neutrino sector
- Departure from equilibrium during DM freeze-out
- transforming DM asymmetry to matter via leptons



Thank you for your attention!