Three-component dark matter system in a radiative seesaw model

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M.Aoki, D.Kaneko, J.Kubo, Front. Phys. 5, 53, 2017(arXiv:1711.03765 [hep-ph])

Introduction

- Problems with Standard Model
  - **Neutrino mass generation**
  - **Dark matter**
  - etc...

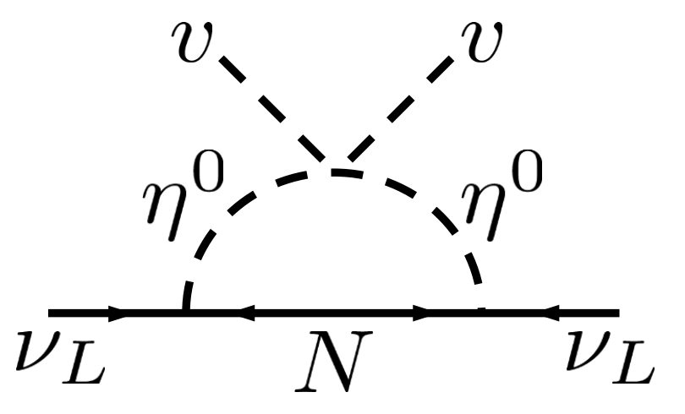
▷ **Radiative seesaw mechanism** is one of the attractive way to realize the tiny masses of the neutrinos and dark matter.

Ma model (E. Ma:Phys. Rev. D **73** (2006) 077301)

Z_2 symmetry

field	statistics	$SU(2)_L$	$U(1)_Y$	Z_2
$L=(\nu_L,l_L)$	F	2	$-1/2$	+
l_R^c	F	1	1	+
N	F	1	0	−
$H=(H^+,H^0)$	B	2	1/2	+
$\eta=(\eta^+,\eta^0)$	B	2	1/2	−

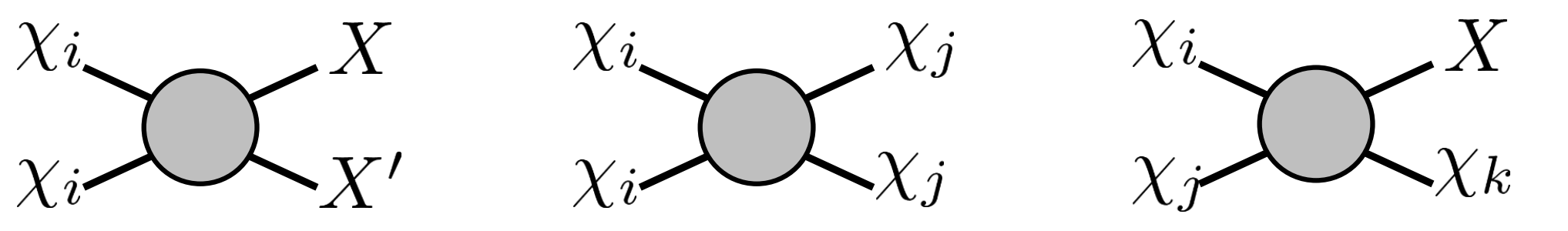
- **Dirac mass term is forbidden** ⋯ ⋯ $\cancel{\frac{Y_\nu v}{\sqrt{2}}\nu_L N_R}$
  - · Neutrino mass is generated at one loop and neutrino mass can be explained by TeV scale particles because of a loop factor.
- **One dark matter can be stable** ⋯ $\eta_R^0(\eta_I^0), N_1$
  - · If we consider that N_1 is dark matter, the relic abundance $\Omega_{\rm obs}$ is not explained by the LFV constraints.



▷ **Depending on symmetry, there are some particles that are stable.**

Multicomponent dark matter system

Three type of annihilation processes



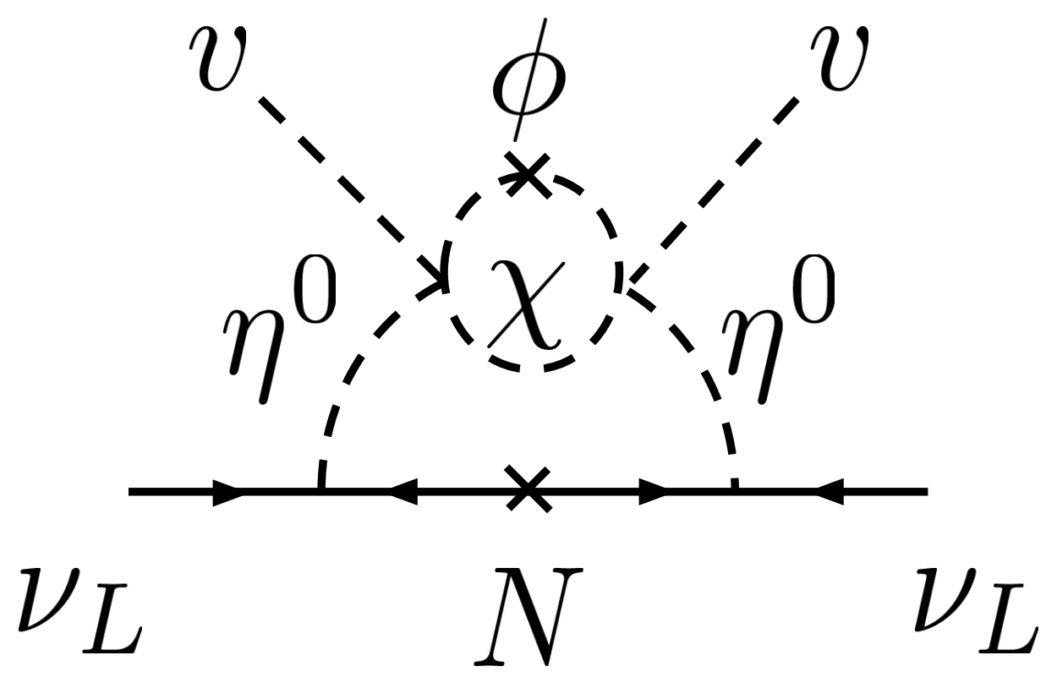
Standard | Conversion | Semi-annihilation

Non-standard annihilation processes effect relic abundance.

By imposing $Z_2\times Z_2'$ symmetry, we suggest **the two-loop radiative seesaw model with three-component dark matter**.

Three-component dark matter model

field	statistics	$SU(2)_L$	$U(1)_Y$	Z_2	Z_2'	L
(ν_l,l_L)	F	2	$-1/2$	+	+	1
l_R^c	F	1	1	+	+	-1
N_R^c	F	1	0	−	+	0
$H=(H^+,H^0)$	B	2	1/2	+	+	0
$\eta=(\eta^+,\eta^0)$	B	2	1/2	−	+	-1
χ	B	1	0	+	−	0
ϕ	B	1	0	−	−	1



Lagrangian

$$\mathcal{L}_Y = Y^e_{ij}H^\dagger L_i l^c_{Rj} + Y^\nu_{ik}L_i\epsilon N^c_{Rk} - \frac{1}{2}M_k N^c_{Rk}N^c_{Rk} + h.c$$

Potential

$$\begin{aligned} V_\lambda =& \lambda_1(H^\dagger H)^2 + \lambda_2(\eta^\dagger\eta)^2 + \lambda_3(H^\dagger H)(\eta^\dagger\eta) + \lambda_4(H^\dagger\eta)(\eta^\dagger H) \\ &+\gamma_1\chi^4 + \gamma_2(H^\dagger H)\chi^2 + \gamma_3(\eta^\dagger\eta)\chi^2 + \gamma_4|\phi|^4 + \gamma_5(H^\dagger H)|\phi|^2 \\ &+\gamma_6(\eta^\dagger\eta)|\phi|^2 + \gamma_7\chi^2|\phi|^2 + \frac{\kappa}{2}\left[(H^\dagger\eta)\chi\phi + h.c\right] \\ V_m =& m_1^2 H^\dagger H + m_2^2\eta^\dagger\eta + \frac{1}{2}m_3^2\chi + m_4^2|\phi|^2 + \frac{1}{2}m_5^2\left[\phi^2 + (\phi^*)^2\right] \end{aligned}$$

- The lepton number L is softly broken by the ϕ mass term.
- $(H^\dagger\eta)^2$ is forbidden by L.

DM candidates

particle	(Z_2,Z_2')
N_1 , η^0	(−,+)
χ	(+,−)
$\phi_R(\phi_I)$	(−,−)

We discuss the three DM system of N_1, ϕ_R, χ.

$$(m_{N_1}, m_{\phi_R} > m_\chi \sim 62\text{ GeV})$$

The condition to make three DMs stable

- $\boldsymbol{m_{\phi_R} < m_N}$ **case**

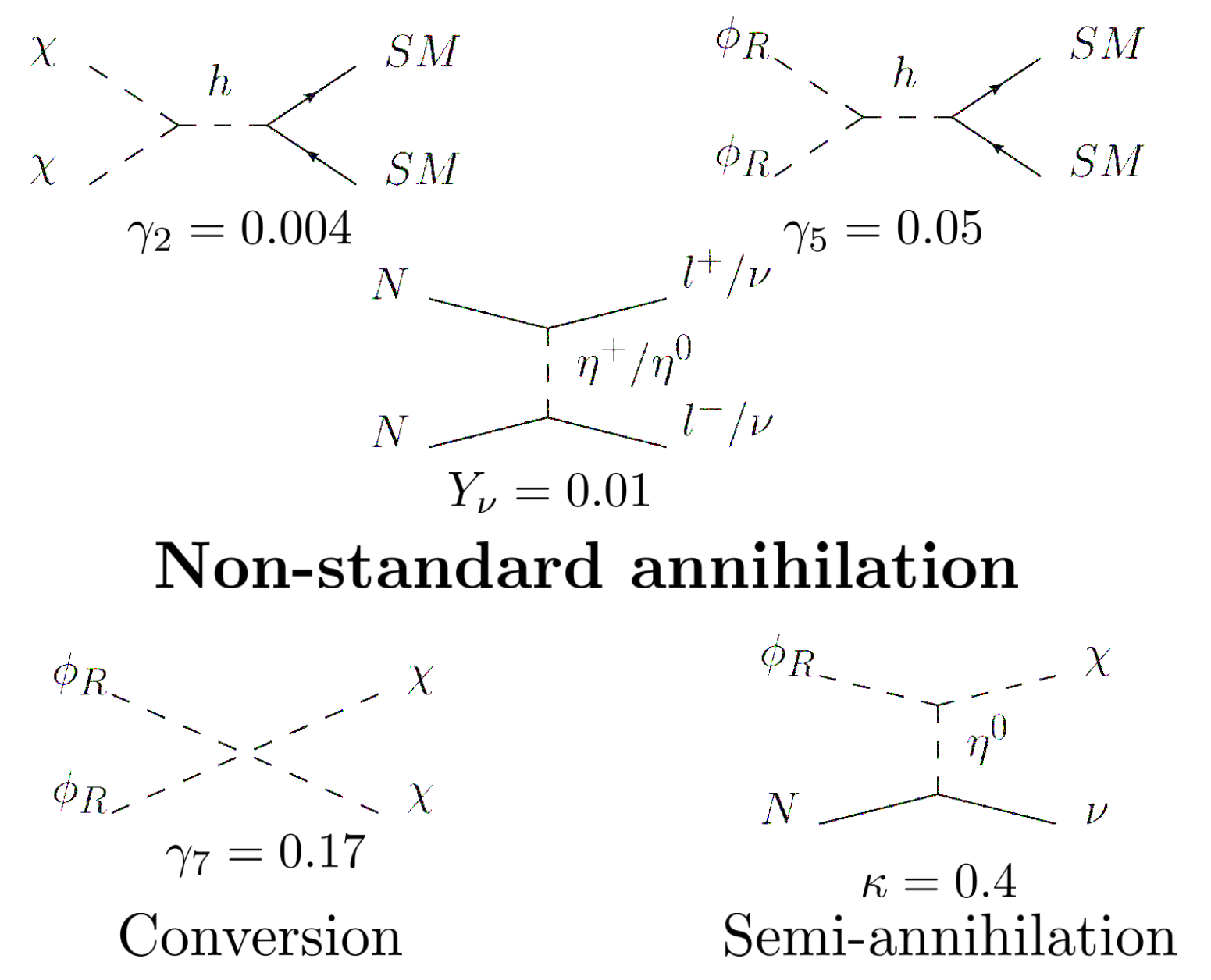
  $m_{N_1} < m_{\phi_R} + m_\chi$

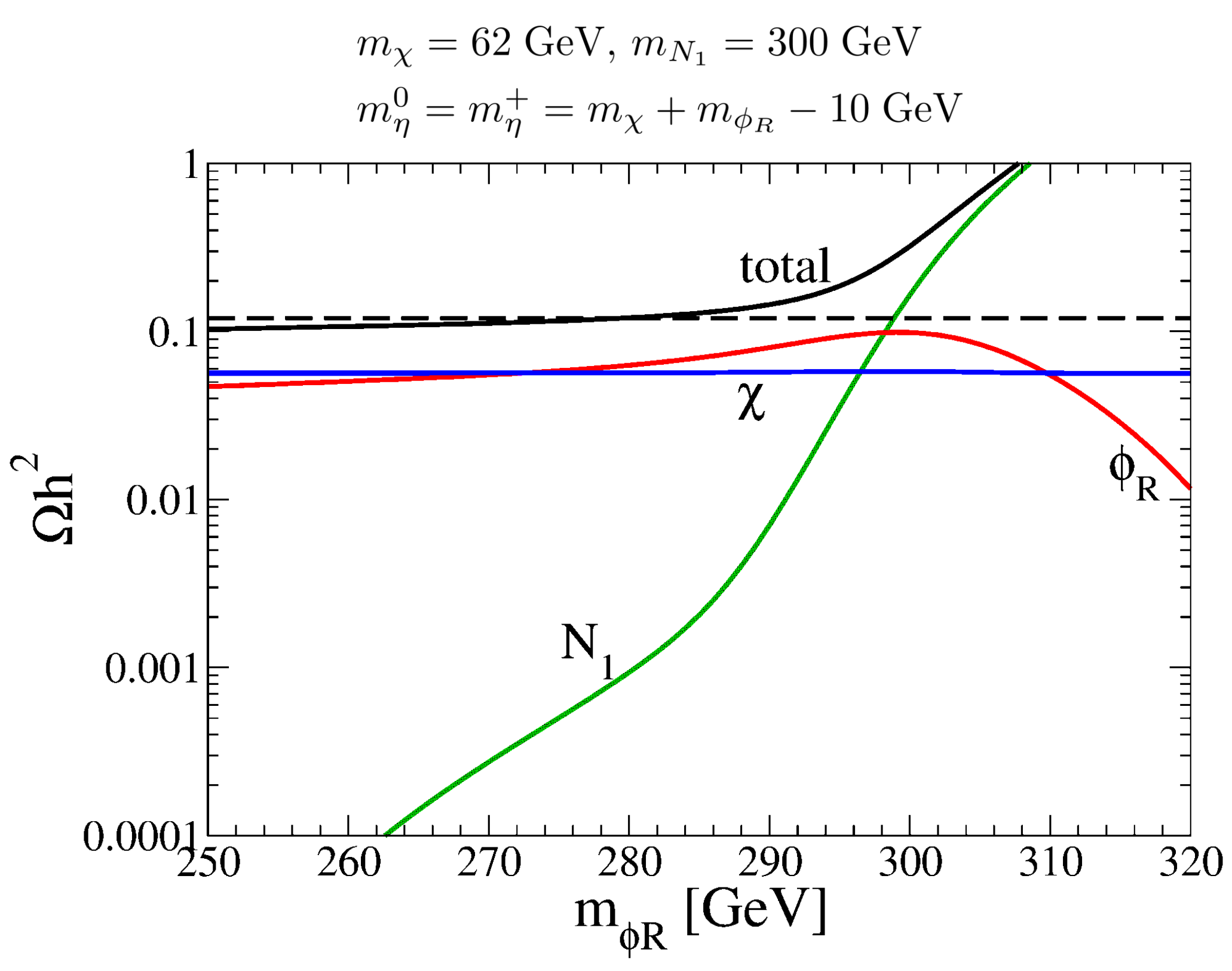
- $\boldsymbol{m_{\phi_R} > m_N}$ **case**

  $m_{\phi_R} < m_{N_1} + m_\chi$

Relic abundance

Standard annihilation

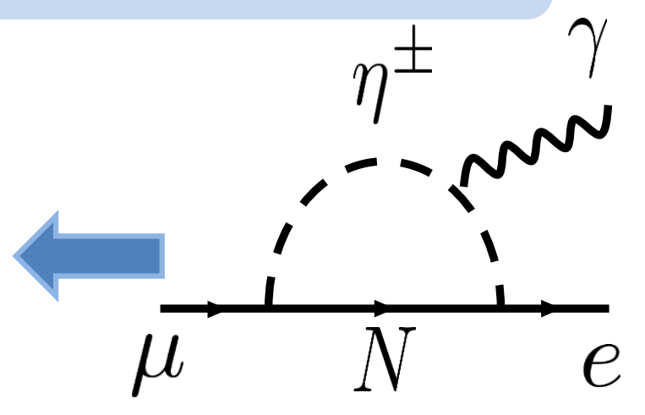




By the semi-annihilation($N\phi_R\to\chi\nu, N\chi\to\phi_R\nu$), $\Omega_{N_1}h^2$ can decrease.

- Ma model with dark matter of N_1
  Since there is only Standard annihilation, $\Omega_{N_1}h^2$ becomes larger than $\Omega_{\rm obs}h^2\sim 0.12$ because of small Y_ν.

$Y_\nu < \mathcal{O}(10^{-2})$ ⇐



Direct detection

- In this model, **only ϕ_R and χ** scatter with the nucleus.
  - ▷ **Effective cross section**

$$\sigma_\chi^{\rm eff} = \frac{1}{\pi}\left(\frac{\gamma_2\hat{f}m_N}{m_\chi m_h^2}\right)^2\left(\frac{m_N m_\chi}{m_N+m_\chi}\right)^2\left(\frac{\Omega_\chi h^2}{\Omega_{\rm total}h^2}\right)\sim 10^{-47}\text{ cm}^2$$

$$\sigma_{\phi_R}^{\rm eff} = \frac{1}{\pi}\left(\frac{(\gamma_5/2)\hat{f}m_N}{m_{\phi_R}m_h^2}\right)^2\left(\frac{m_N m_{\phi_R}}{m_N+m_{\phi_R}}\right)^2\left(\frac{\Omega_{\phi_R}h^2}{\Omega_{\rm total}h^2}\right)$$

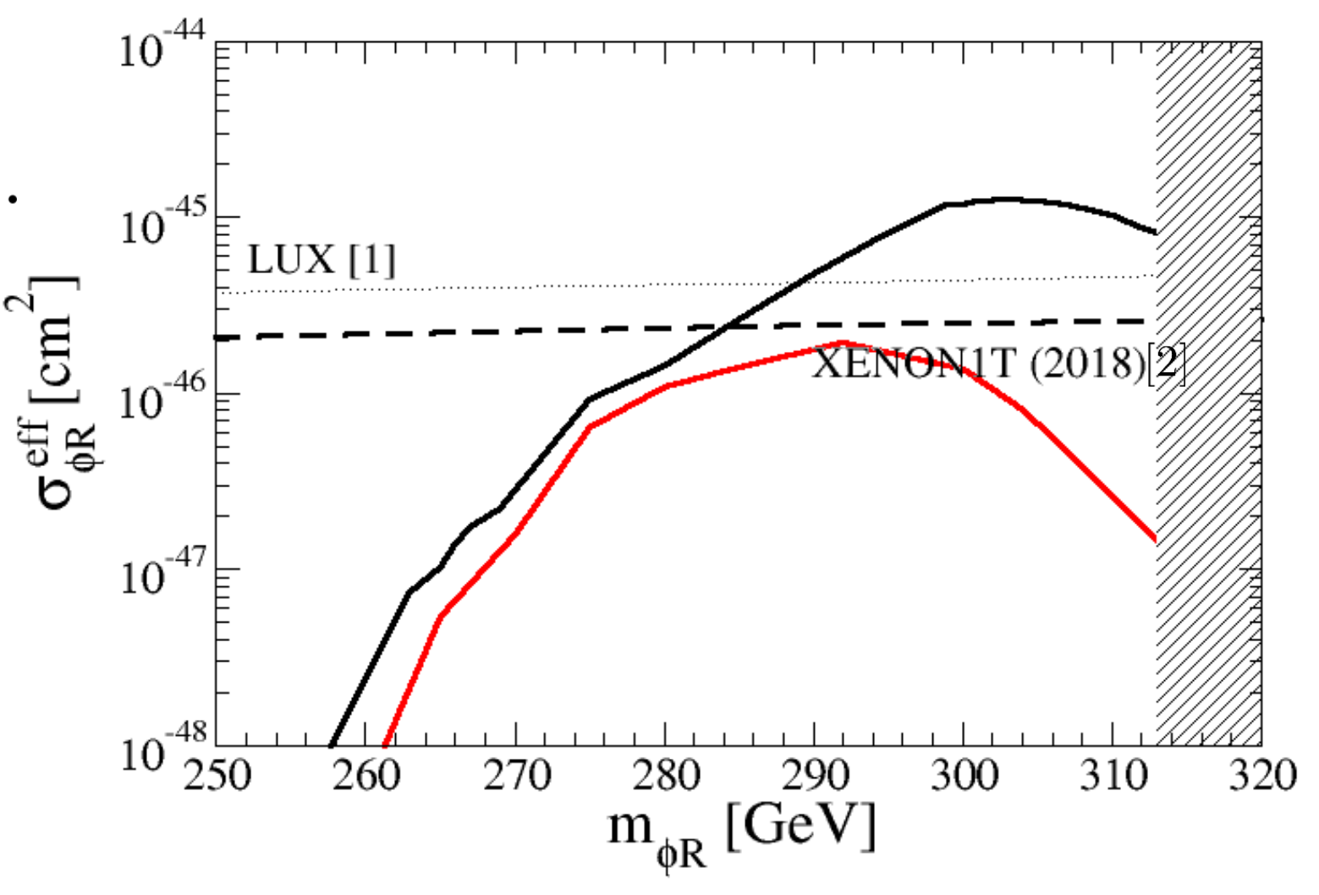
$\hat{f}$: the usual nucleonic matrix element $\hat{f}\sim 0.3$

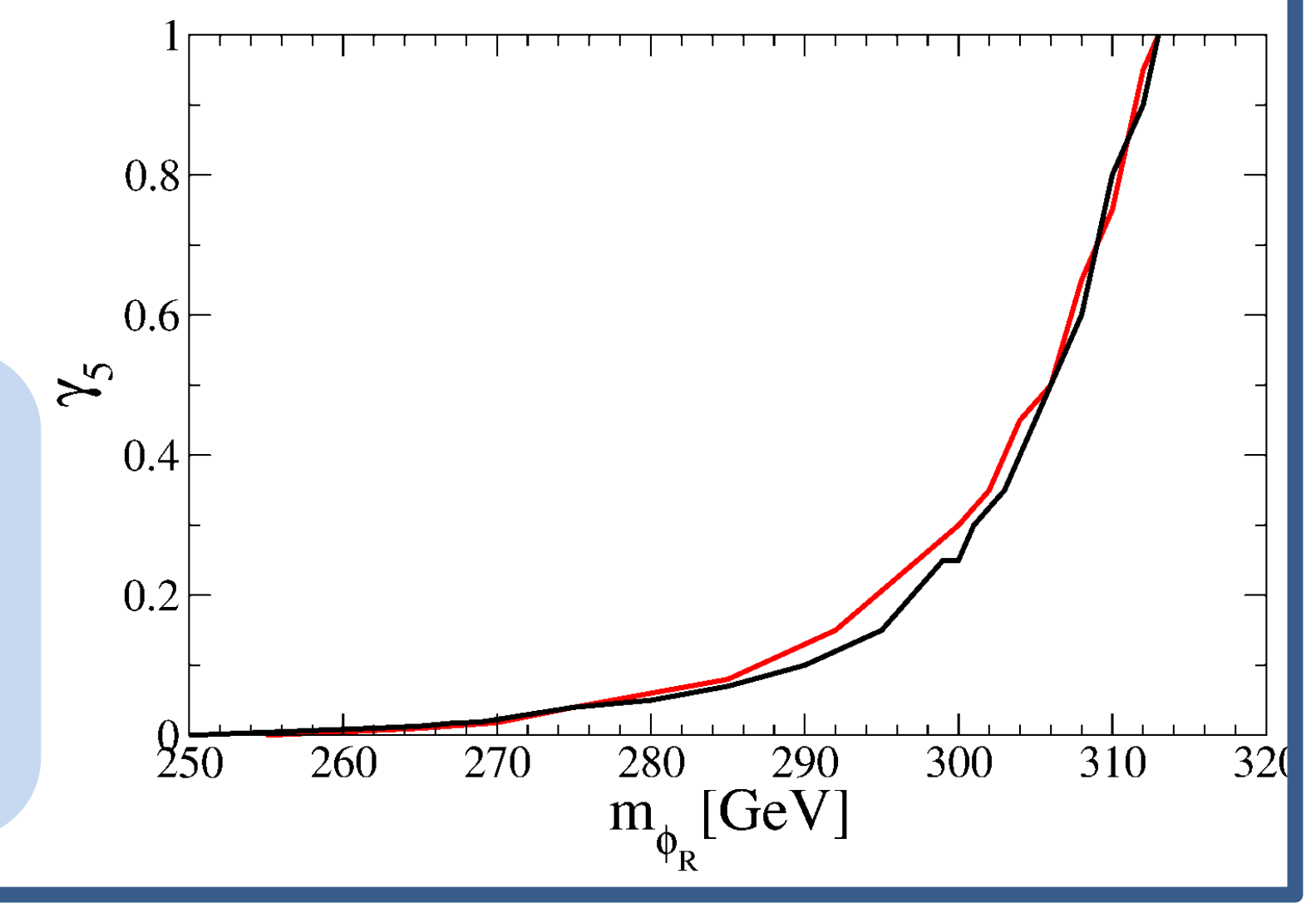
m_N : nucleon mass $m_N\sim 0.93$ GeV

$m_{\eta^0_{R,I}} = m_{\eta^+} = m_\chi + m_{\phi_R} - 10$ GeV : Black line

$m_{\eta^0_{R,I}} = m_{\eta^+} = m_\chi + m_{\phi_R} - 1$ GeV : Red line

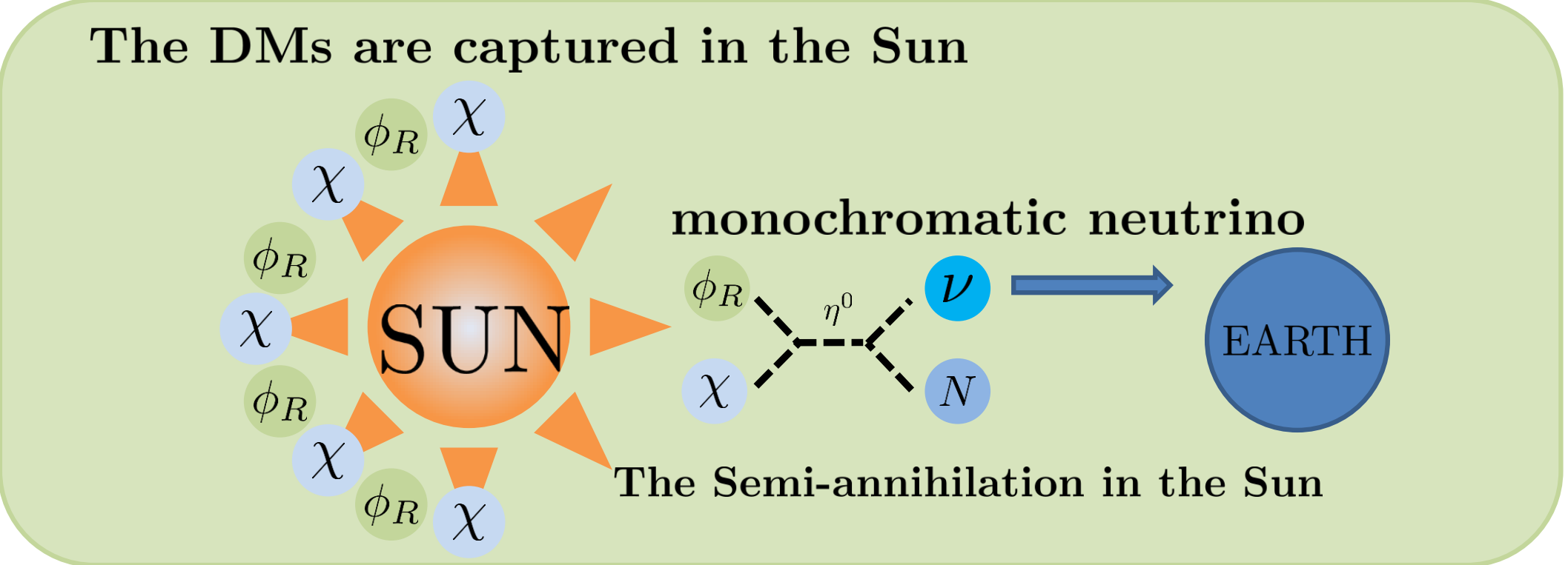
- $\boldsymbol{m_{\phi_R} < m_N}$ **case**
  When m_{ϕ_R} becomes larger, **the Semi-annihilation** $(N_1\phi\to\chi\nu)$ becomes smaller and γ_5 has to be large to reducing $\Omega_{\phi_R}h^2$.
- $\boldsymbol{m_{\phi_R} > m_N}$ **case**
  The γ_5 becomes larger but $\Omega_{\phi_R}h^2$ becomes small. ⟹ $\sigma_{\phi_R}^{\rm eff}$ decreases.





Indirect detection

- We consider the neutrino flux from the Sun as a possibility to detect the semi-annihilation process of DMs.

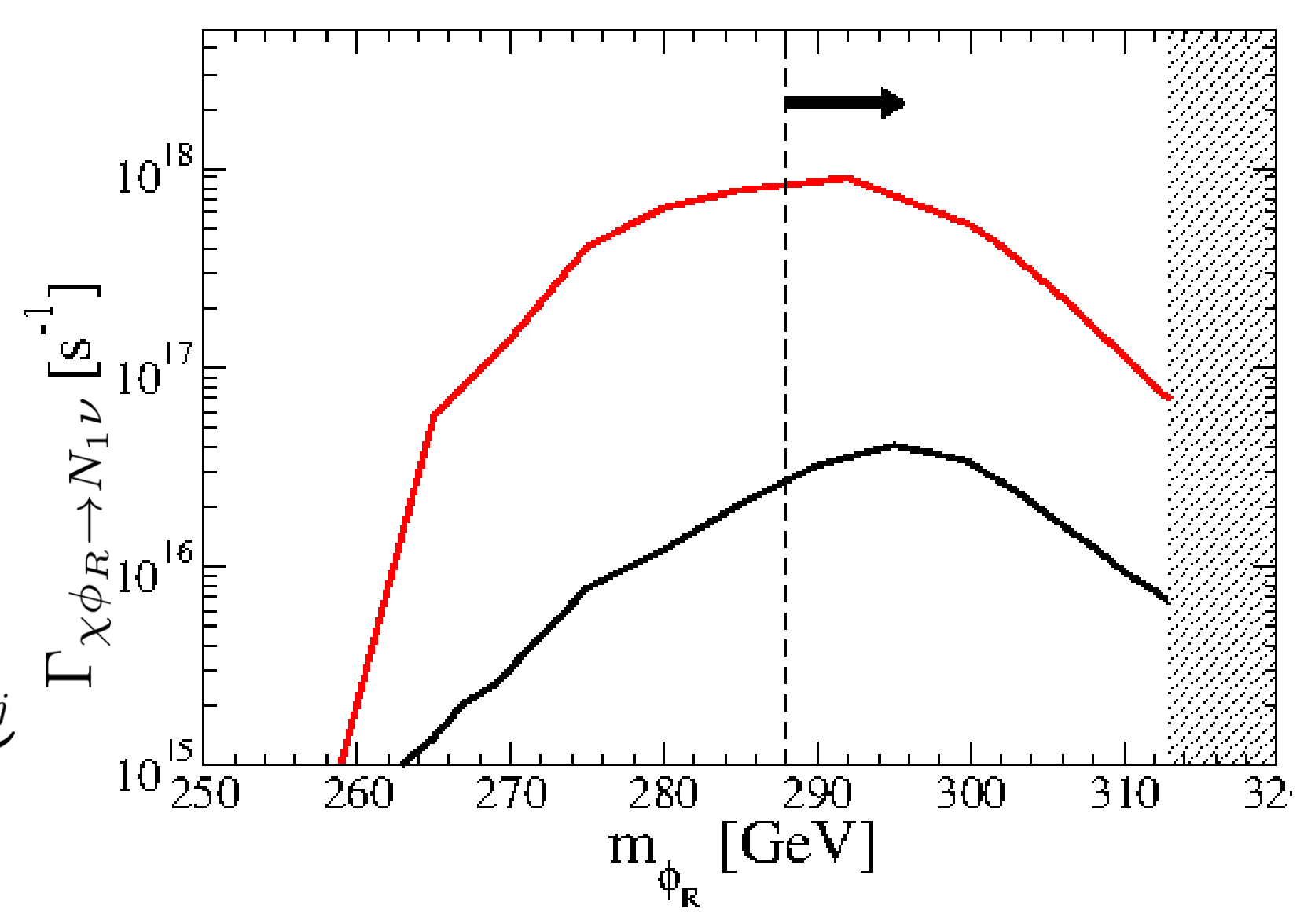


- The time dependence of number of captured DM in the Sun

$$\dot{n}_i = C_i - \underbrace{C_A(ii\to\text{SM})n_i^2}_{\text{Standard}} - \sum_{m_i>m_j}\underbrace{C_A(ii\to jj)n_i^2}_{\text{Conversion}} - \underbrace{C_A(ij\to k\nu)n_i n_j}_{\text{Semi-annihilation}}$$

- Semi-annihilation rate in the Sun

$$\Gamma_{\chi\phi_R\to N_1\nu} = C_A(\chi\phi_R\to N_1\nu)n_{\phi_R}(t)n_\chi(t)$$



In the red line, **semi-annihilation rate $(\chi\phi_R\to N_1\nu)$ is increased by resonance**.

IceCube: DM DM $\to W^+W^-\sim 1.13\times10^{21}$ s^{-1} [3]

The semi-annihilation rate in the Sun is at least 10^2 times smaller than the IceCube upper limits of continuous energy of neutrino.

But **the neutrino generated by semi-annihilation in our model has monochromatic energy.**

Summary

We discussed the multi-component dark matter model with radiative seesaw mechanism.

- Under the $Z_2\times Z_2'$ symmetry, three DMs can be stable.
- Semi-annihilation decreases the relic abundance of right-handed neutrino Ω_{N_1}.
- In the future direct detection experiment, there is a possibility that the DM is detected.
- The possibility of the observation of the semi-annihilation in the Sun can increase with an increasing resolution of energy and angle.

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[2] XENON1T E. Aprile:Phys. Rev. Lett. **119** (2017) no.18, 181301
[3] M. G. Aartsen:Eur. Phys. J. C **77** (2017) no.3, 146