

Multi-component Dark Matter in Two Loop Radiative Seesaw Model

Hiroshi TAKANO (Kanazawa Univ.)

collaborated with

Mayumi AOKI, Jisuke KUBO, Taishi OKAWA (Kanazawa Univ.)

Outline

1 loop radiative seesaw model (Z_2 symmetry)

Small coupling, too much DM density

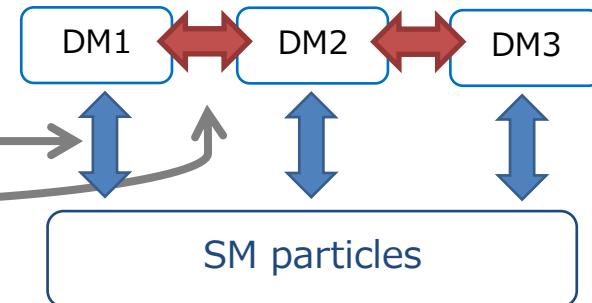
↓ additional Z_2 symmetry

2 loop extension ($Z_2 \times Z'_2$ symmetry)

Loop generated coupling, Multi-component DM

Multi-component DM

- Effects for the relic density
- Direct detection probability
- Indirect detection probability



Ma model

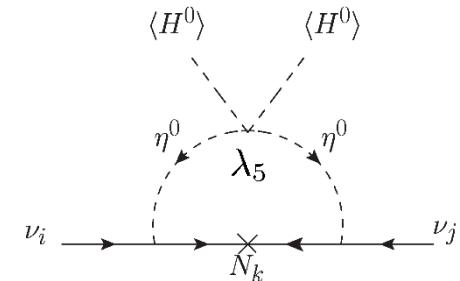
E.Ma, Phys. Rev. D73, 077301 (2006)

SM + inert doublet scalar η
right handed neutrino N_R^c

$$\lambda_5[(\eta^\dagger H)^2 + h.c.] , M_k N_{Rk}^c N_{Rk}^c$$

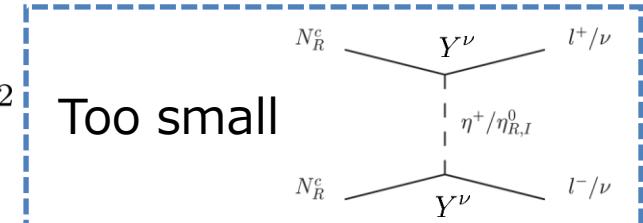
$$(M_\nu)_{ij} \sim -\frac{\lambda_5}{16\pi^2} \sum_k \frac{Y_{ik}^\nu Y_{jk}^\nu v_h^2}{M_k} \text{ for } m_\eta \simeq M_k$$

field	$SU(2)_L$	$U(1)_Y$	Z_2
N_R^c	1	0	-
(η^+, η^0)	2	$1/2$	-



Dark matter

- Inert scalar doublet $\eta_{R,I}^0 \sim$ Inert Doublet Model
- Right handed neutrino N_R^c
 - ✓ Relic density $\Omega_{\text{DM}} h^2 \sim 0.12 \rightarrow |Y^\nu| \sim 1$
 - ✓ Lepton Flavor Violation $Br(\mu \rightarrow e\gamma) \lesssim 2.4 \times 10^{-12} \rightarrow |\eta^+/\eta_{R,I}^0| \lesssim 10^{-2}$
 - Neutrino mass $M_\nu \lesssim \mathcal{O}(10^{-1}) \text{ eV} \rightarrow |\lambda_5| \sim 10^{-5}$



Two loop extension of Ma model

M. Aoki, J Kubo, H.Takano Phys. Rev. D 87, 116001 (2013)

Ma model + inert singlet scalars

χ, ϕ

$Z_2 \times Z'_2 \times L$ symmetry

$$\lambda_5 [(H^\dagger \eta)^2 + h.c.]$$

soft breaking of L

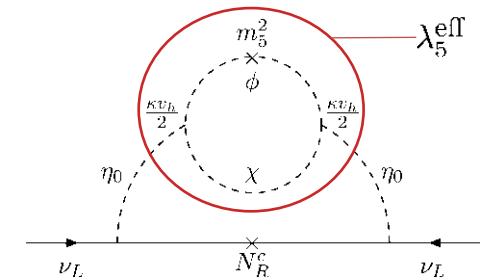
$$\frac{1}{2} m_5^2 [\phi^2 + (\phi^*)^2]$$

$$\lambda_5^{\text{eff}} \sim -\frac{\kappa^2}{64\pi^2} \frac{m_5^2}{m_{\phi_R}^2 - m_\chi^2}$$

$$m_{\text{new}} = \mathcal{O}(100) \text{GeV}, \quad m_5 = \mathcal{O}(10) \text{GeV}, \\ \kappa = \mathcal{O}(10^{-1}), \quad Y^\nu = \mathcal{O}(10^{-2})$$

$$\lambda_5^{\text{eff}} = \mathcal{O}(10^{-5}), \quad (M_\nu)_{ij} = \mathcal{O}(0.1) \text{eV}$$

field	$SU(2)_L$	$U(1)_Y$	L	Z_2	Z'_2
N_R^c	1	0	0	-	+
$\eta = (\eta^+, \eta^0)$	2	1/2	-1	-	+
χ	1	0	0	+	-
ϕ	1	0	1	-	-



Multi-component DM

Candidate: $(Z_2, Z'_2) = (-, +)$ N_R^c or $\eta_{R,I}^0$

$(Z_2, Z'_2) = (+, -)$ χ

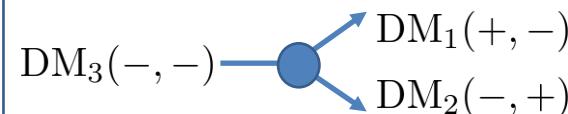
$(Z_2, Z'_2) = (-, -)$ $\phi_{R,I}$

- ✓ 3 component DM of N_R^c, ϕ_R, χ
- ➡ Additional N_R^c annihilation

$Z_2 \times Z'_2$ DM

Q. H. Cao, E. Ma, J. Wudka, C.-P. Yuan
arXiv:0711.3881 [hep-ph]

$\text{DM}_1(+, -), \text{DM}_2(-, +), \text{DM}_3(-, -)$

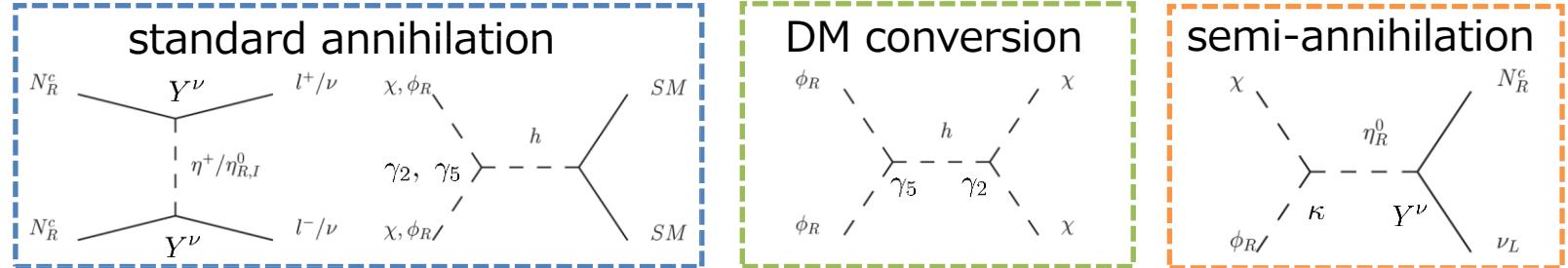


$m_3 > m_1 + m_2$: 2 component DM

$m_3 < m_1 + m_2$: 3 component DM

Thermal process

3 types of annihilation process $(M_N > m_{\phi_R} > m_\chi)$



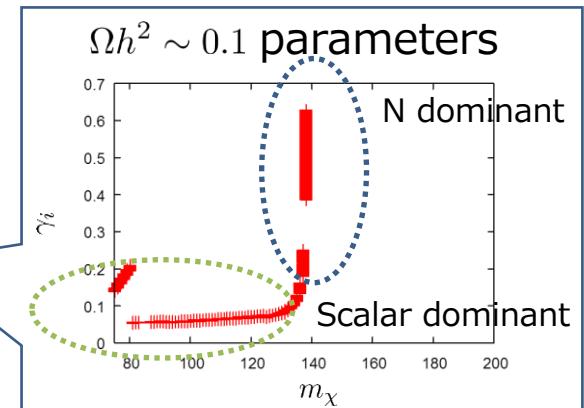
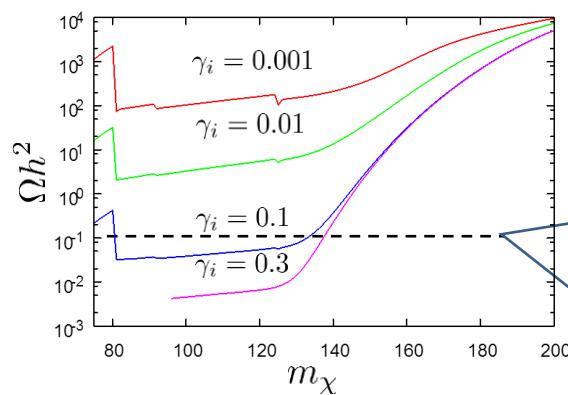
Large N mass \rightarrow reducing N density

Parameter search

$$\kappa = \mathcal{O}(10^{-1}), \quad Y^\nu = \mathcal{O}(10^{-2}) \quad \gamma_2 = \gamma_5 = \gamma_i$$

particle	mass[GeV]
$N_{2,3}$	1000
η_R	$m_\chi + m_{\phi_R} - 10$
N_1	200
ϕ_I	$m_{\phi_R} + 10$
ϕ_R	$m_\chi + 50$
χ	75 to 200

$\rightarrow m_5 = \mathcal{O}(10)\text{GeV}$

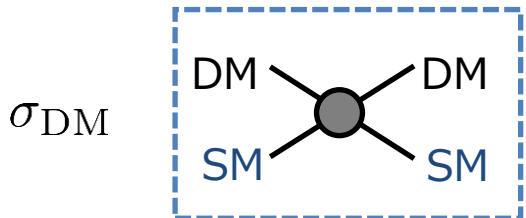


Direct detection

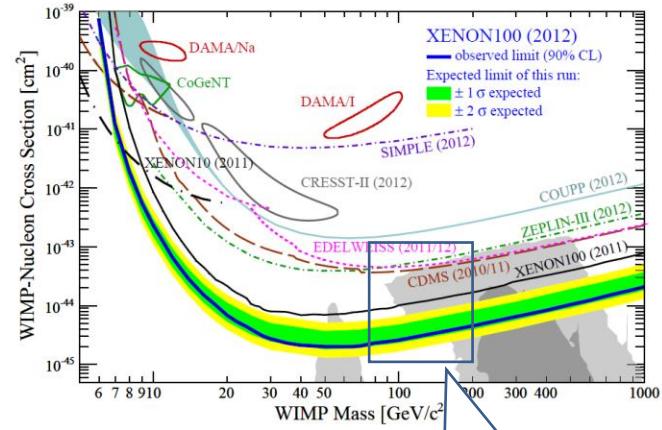
1 component DM

Event rate $\propto \sigma_{\text{DM}} n_{\text{DM}}$

→ bound for cross section



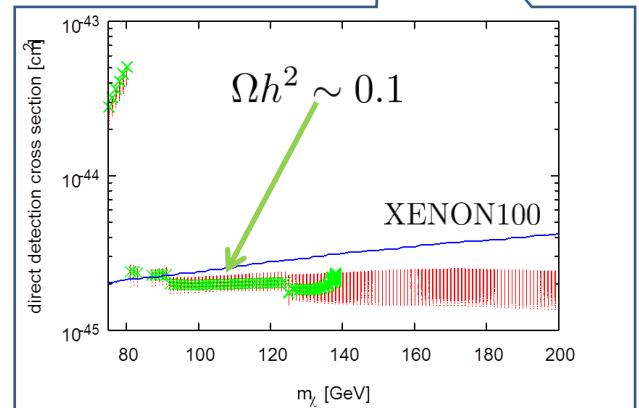
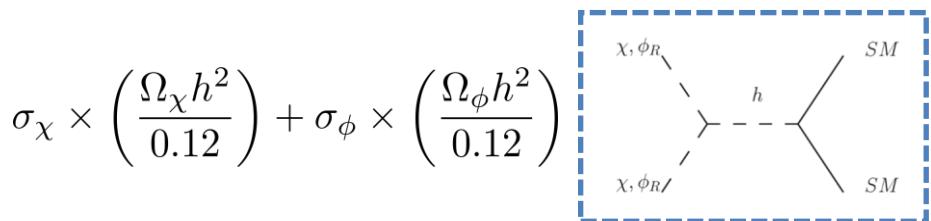
$$\sigma_{DM} \lesssim 10^{-45} [\text{cm}^2] \quad \text{for } m_{DM} = \mathcal{O}(100) \text{ GeV}$$



Multi-component DM

Event rate $\propto \sum_i \sigma_i n_i$

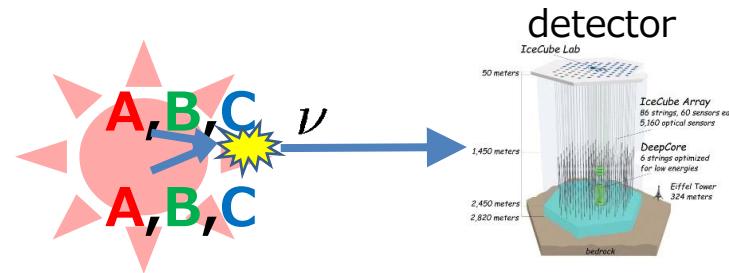
→ sum of effective cross section



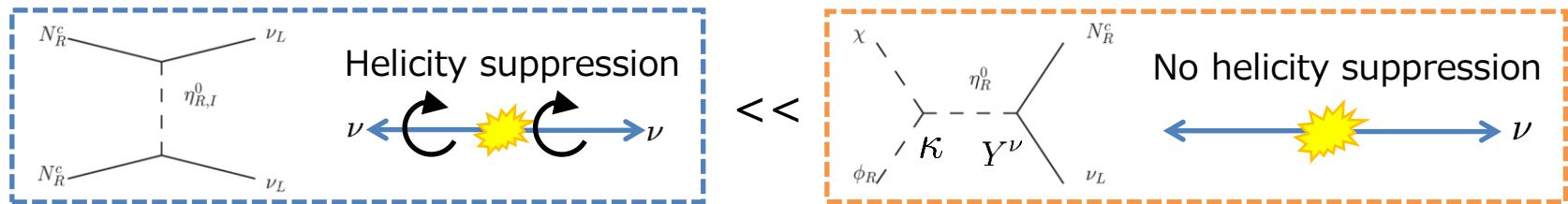
Indirect detection

Neutrino from the Sun

$$\dot{N}_i = C_i - C_A(ii \leftrightarrow \text{SM})N_i^2 - C_A(ii \leftrightarrow jj)N_i^2 - C_A(ij \leftrightarrow k\text{SM})N_i N_j$$



Monochromatic neutrino production



Detection rate

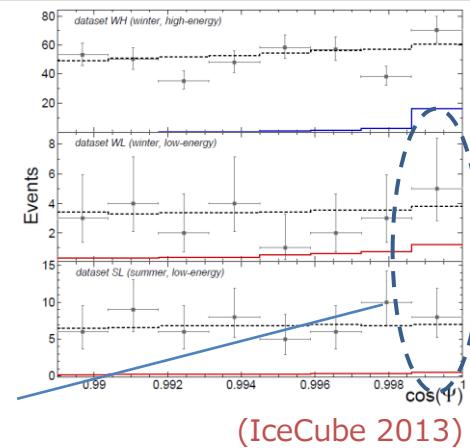
$$\Gamma_{\text{detect}} = AP(E_\nu)\Gamma_{\text{inc}}$$

Detector area $A \simeq 1\text{km}^2$

Detection probability $P(E_{\nu(\bar{\nu})}) \simeq 2.0(1.0) \times 10^{-11} \left(\frac{L}{\text{km}}\right) \left(\frac{E_{\nu(\bar{\nu})}}{\text{GeV}}\right)$

Incoming flux $\Gamma_{\text{inc}} = \Gamma/4\pi R_\odot^2$ ($L \sim 1\text{km}$)

BG signal $\sim O(10)\text{events}$

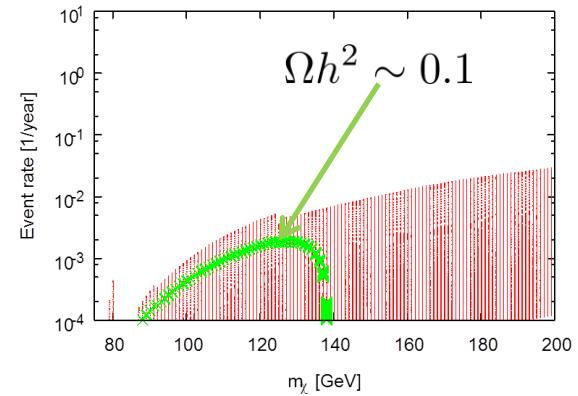
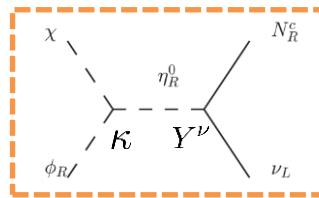


Indirect detection

Numerical result

$$m_{\eta_R^0} = m_\chi + m_{\phi_R} - 10 \text{GeV}$$

Event rate $\lesssim 10^{-3} [1/\text{year}]$
 << BG signal $\sim \mathcal{O}(10)$ events



Enhancement of semi-annihilation

- η_R^0 resonance

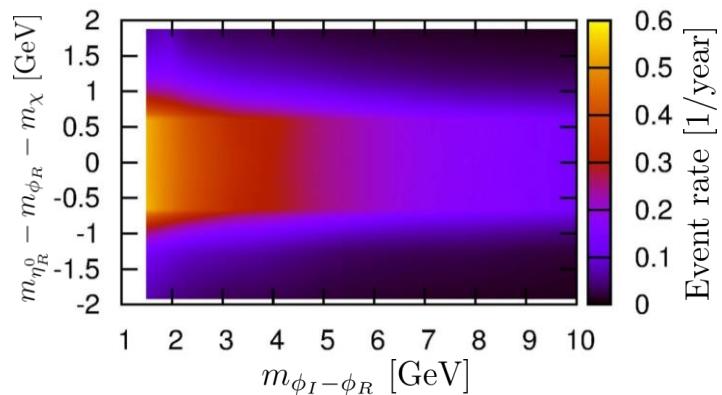
small $|m_{\eta_R^0} - m_\chi - m_{\phi_R}| \rightarrow$ large $\sigma(\chi\phi_R \rightarrow N_R^c\nu)$

- Coupling enhancement

$(M_\nu)_{ij} \sim \lambda_5^{\text{eff}} Y^\nu Y^\nu \sim \kappa^2 Y^\nu Y^\nu m_5^2$

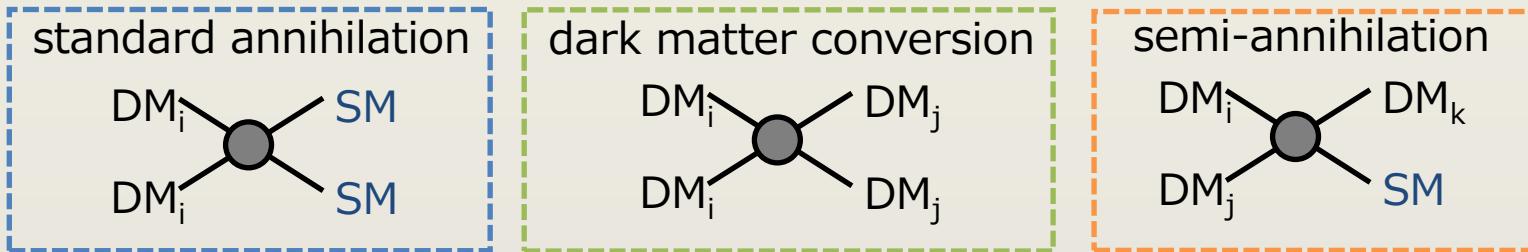
small $|m_5^2| = \frac{1}{2}|m_{\phi_R}^2 - m_{\phi_I}^2| \rightarrow$ large κY^ν

fixed $m_\chi = 100 \text{GeV} \rightarrow$ Event rate $\lesssim 1 [1/\text{year}]$



Summary

- 2 loop extension of Ma model
small $|\lambda_5| \sim 10^{-5}$ generated by 1 loop correction
- multi-component DM
 - 3 types of annihilation process



- Direct detection
 - constraint for $\sigma_{DM} \rightarrow \sum_i \sigma_i \left(\frac{\Omega_i h^2}{0.12} \right)$
 - Indirect detection
 - Monochromatic neutrino from semi-annihilation
 - η_R^0 resonance enlarge the event rate
- in progress**
- Quantitative comparison with the experimental value
 - other neutrino source? (from Earth, G.C.)

