Dark matter and leptogenesis in a non-SUSY model for neutrino masses

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Motivation

We have now some clues to new physics beyond the standard model (SM) such as

- neutrino mass
- dark matter
- baryon number asymmetry in the universe

Since the explanation of these is expected to open a window on new physics, it will be useful to find a model which can explain these three points simultaneously.

As such an example, we consider a model for neutrino masses which can contain a cold dark matter candidate automatically.

Original idea (Radiative see-saw model)

Ma ('05)
Kubo, Ma, Suematsu ('06)

Small neutrino masses can be related to weak scale physics, if they are generated by one-loop radiative effects.

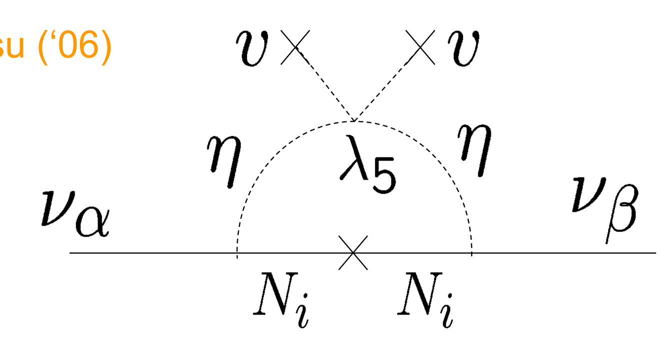
A Z_2 symmetry is imposed.

SM fields
even Z_2 charge

New fields

An additional doublet scalar field η
odd Z_2 charge

Right handed neutrinos N_i $(i=1,2,3)$
odd Z_2 charge



$$m_0 \gtrsim M_i \sim \sum_{i=1}^{3} \frac{\lambda_5 h_{\alpha i} h_{\beta i}}{8\pi^2} \frac{v^2}{M_i}$$

If $\lambda_5 \ll 1$ is satisfied, required small neutrino masses are generated even for $M_i = O(1\text{TeV})$.

The lightest right-handed neutrino with odd Z_2 charge is stable and then can be a cold dark matter candidate.

We improve these problems by extending the model.

An extension of the model

It is an interesting idea to relate neutrino masses to dark matter. However, in this model

- A very small coupling such as $\lambda_5 = O(10^{-9})$ is required to yield suitable neutrino masses for right-handed neutrinos with weak scale masses.
- Lepton flavor violating processes (*e.g.* $\mu \to e\gamma$) cannot be sufficiently suppressed for Yukawa couplings required for the explanation of dark matter abundance.
- Masses of right-handed neutrinos are TeV scale and then sufficient CP asymmetry required in thermal leptogenesis seems difficult to be realized.

A modified model

Kubo, Suematsu ('06)
Suematsu ('07)

New particle contents added to the SM

- a U(1)' vector gauge boson
- an additional doublet scalar η
- a singlet scalar ϕ
- three singlet fermions N_i $(i=1,2,3)$

U(1)' charge assignment

	Q_α	$\bar{U}_\alpha$	$\bar{D}_\alpha$	L_α	$\bar{E}_\alpha$	H
$U(1)'$	$2q$	$-2q$	$-2q$	0	0	0
Z_2	$+1$	$+1$	$+1$	$+1$	$+1$	$+1$

	$\bar{N}_{1,2}$	$\bar{N}_3$	η	ϕ
$U(1)'$	0	q	$-q$	$-2q$
Z_2	$+1$	-1	-1	$+1$

$U(1)' \to Z_2$

After U(1)' breaking by $\langle\phi\rangle \neq 0$, we have a desired discrete symmetry as its remnant.

We can explain the origin of the required discrete symmetry. Additionally,

- Since dark matter annihilates through Z' exchange processes, neutrino Yukawa couplings can be small enough to suppress the flavor violating processes sufficiently.
- Several terms in Lagrangian are favorably controlled by U(1)' symmetry :

$$\frac{\lambda_5 \phi}{M_*}(\eta^\dagger H)^2 + \text{h.c.} \qquad M_1 \bar{N}_1^2 + M_2 \bar{N}_2^2 + \lambda\phi \bar{N}_3^2$$

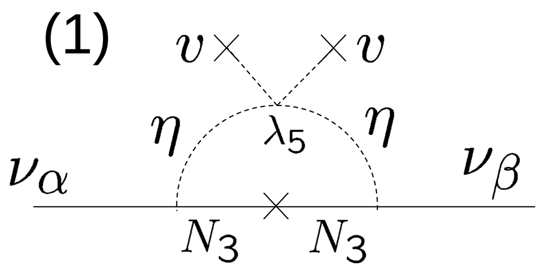
If $M_*, M_{1,2} \gg \langle\phi\rangle$ is satisfied, small neutrino masses can be obtained even for $\lambda_5 = O(1)$ and the CP asymmetry required for thermal leptogenesis can be generated.

Main results of the model

Neutrino mass generation

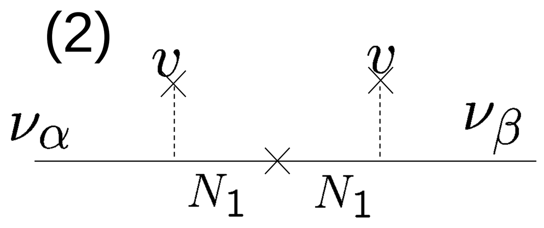
Two types of mass generation
(1) radiative seesaw and (2) ordinary seesaw

(1)



$$\simeq \frac{\lambda_5}{8\pi^2\lambda}\frac{v^2}{M_*} h_{\alpha 3} h_{\beta 3}$$

(2)



$$\simeq \frac{v^2}{M_1} h_{\alpha 1} h_{\beta 1}$$

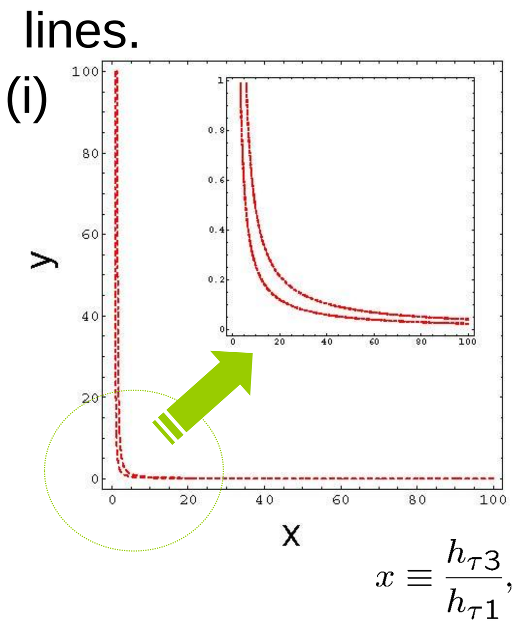
Mass eigenvalues $m_3 > m_2 > m_1 = 0$

Two possibilities

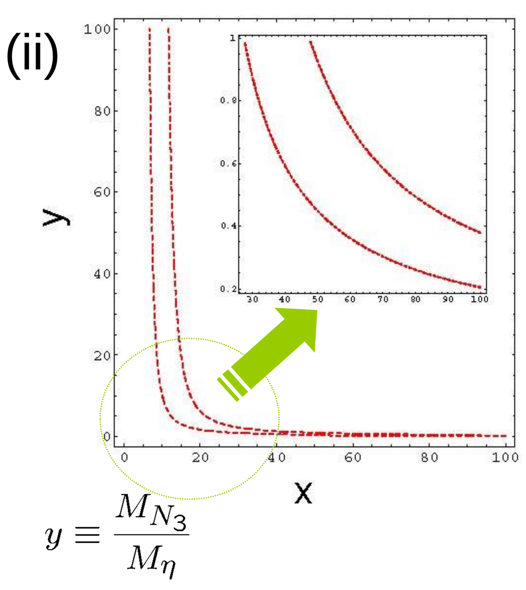
(i) radiative seesaw $\to m_2$, ordinary seesaw $\to m_3$
(ii) radiative seesaw $\to m_3$, ordinary seesaw $\to m_2$

Neutrino oscillation data can be consistently explained in the regions sandwiched by dashed lines.

(i)



(ii)



$x \equiv \frac{h_{\tau 3}}{h_{\tau 1}}$, $y \equiv \frac{M_{N_3}}{M_\eta}$

Leptogenesis

Two heavy right-handed neutrinos are contained in the model and then lepton number asymmetry can be produced. The CP asymmetry required to yield the sufficient baryon number asymmetry is

$$\varepsilon \simeq -7.2 \times 10^{-8} \kappa^{-1}$$

The model can generate the CP asymmetry :

(i) $\varepsilon = -9.8 \times 10^{-8} \left(\frac{10^{10}\kappa^{-1}\text{GeV}}{M_2}\right)\left(\frac{M_1}{10^8\text{GeV}}\right)^2 \kappa^{-1}$

(ii) $\varepsilon = -2.2 \times 10^{-8} \left(\frac{10^{10}\kappa^{-1}\text{GeV}}{M_2}\right)\left(\frac{M_1}{10^8\text{GeV}}\right)^2 \kappa^{-1}$

If $M_1 \ll M_2$ Is satisfied, this CP asymmetry can have a suitable value to explain baryon number asymmetry in the universe.

Cold dark matter

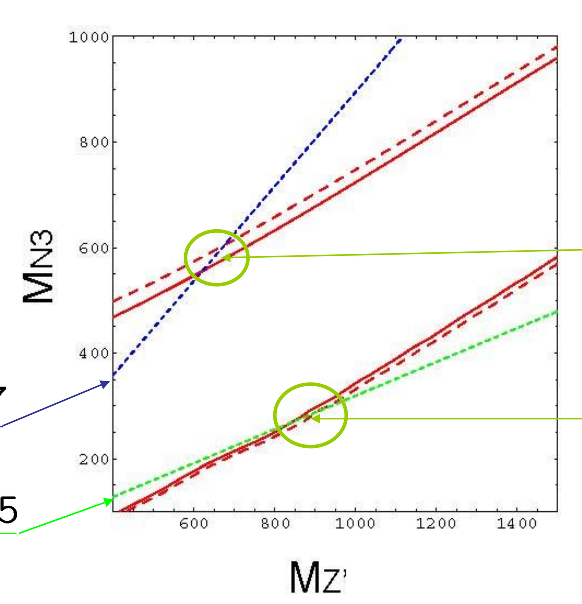
The model has two candidates for cold dark matter.

- N_3 case

Dominant annihilation processes

$N_3 N_3 \to \bar{f} f$ (S channel Z' exchange process)

Sufficient annihilation is possible even for small Yukawa couplings consistent with the FCNC constraints.



$M_{N_3} = \lambda\langle\phi\rangle$
$M_{Z'} = 2\sqrt{2}g' q\langle\phi\rangle$

WMAP allowed regions sandwiched by solid and dashed lines

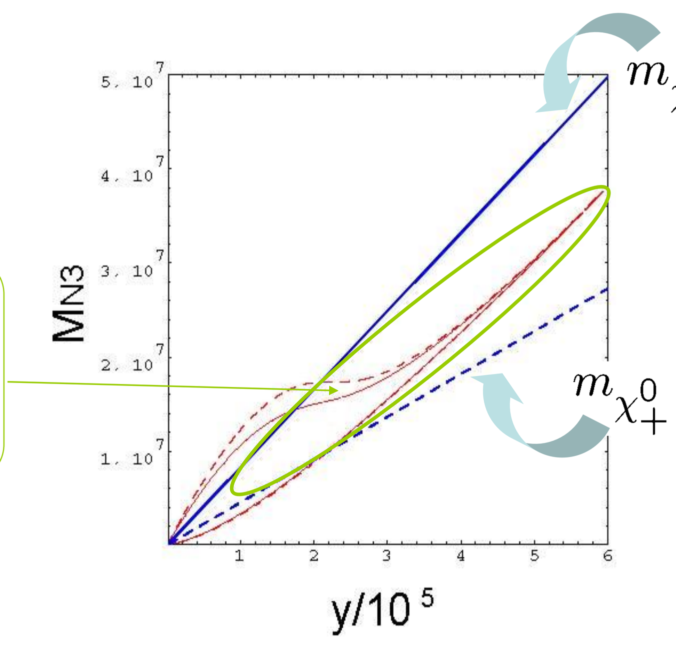
- χ_L^0 case

$$\chi_L^0 = \text{lighter one of } \chi_\pm^0 = \frac{1}{\sqrt{2}}(\eta^0 \pm \eta^{0*})$$

Annihilation occurs through weak gauge Interactions such as

$$\chi_L^0 \chi_L^0 \to W^+ W^-, \quad \chi_+^0 \chi_-^0 \to Z^* \to \bar{f} f$$

Severe conditions should be imposed to suppress these processes suitably.



Discussion and summary

- We have proposed a model for neutrino masses which could present a simultaneous explanation for cold dark matter and baryon number asymmetry in the universe through leptogenesis.
- A discrete symmetry which guarantees stability of dark matter can be induced from U(1)' local gauge symmetry. Its interaction makes it possible to explain the required CDM abundance without conflict with constraints from lepton flavor violating processes.
- We need to extend the model to explain the hierarchy problem which is put aside in this study. However, the present trial may be considered as a first step toward such a study.