Baryon number asymmetry and dark matter in the neutrino mass model with an inert doublet

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1.Introduction

Problems we can't understand with SM

- Neutrino mass?
- Dark matter?
- Baryon number asymmetry?

◆ The radiative neutrino mass model with an inert doublet scalar can explain these problems if dark matter is identified with the lightest neutral component of the inert doublet.
◆ Recently, the new data of the neutrino oscillation such as a non−zero value of θ_{13} have been established by the reactor experiments.

Using the parameters which satisfy with these new data, we reexamine whether the baryon number asymmetry can be realized in this model.

2.The radiative neutrino mass model with an inert doublet scalar

Z_2 symmetry

even parity / odd parity

SM particles + a scalar doublet H_2 + three right−handed neutrinos N_i

Inert doublet

$$H_2 = \begin{pmatrix} H^+ \\ (H_0 + iA_0)/\sqrt{2} \end{pmatrix}$$

Since the scalar doublet H_2 has no vacuum expectation value, Z_2 symmetry is guaranteed.

Z_2 invariant interaction and potential

$$-\mathcal{L}_{RH} = h_{i\alpha}\bar{N}_i\tilde{H}_2^\dagger L_\alpha + \frac{1}{2}m_{N_i}N_iN_i + h.c.$$

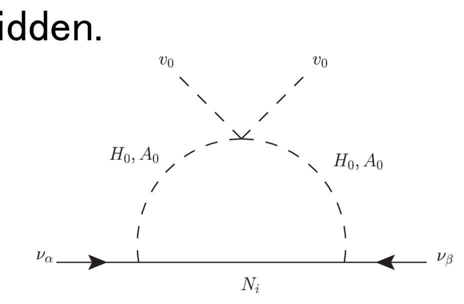
$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + h.c.\right]$$

	$SU(2)_L$	$U(1)_Y$	Z_2
H_2	1/2	1	odd
N_i	0	0	odd

Neutrino masses

The Dirac mass term at tree level is forbidden.

The small neutrino masses can be realized by loop contribution.



The neutrino mass matrix

$$\mathcal{M}^\nu_{\alpha\beta} = \sum_{i=1}^{3} h_{i\alpha}h_{i\beta}\left[\frac{\lambda_5 v_0^2}{16\pi^2 m_{N_i}}\frac{m_{N_i}^2}{m_{H_2}^2 - m_{N_i}^2}\left(1 + \frac{m_{N_i}^2}{m_{H_2}^2 - m_{N_i}^2}\ln\frac{m_{N_i}^2}{m_{H_2}^2}\right)\right]$$

$$|\lambda_5| \ll 1 \qquad m_{H_2}^2 \equiv \mu_2^2 + \frac{\lambda_3+\lambda_4}{2}v_0^2$$

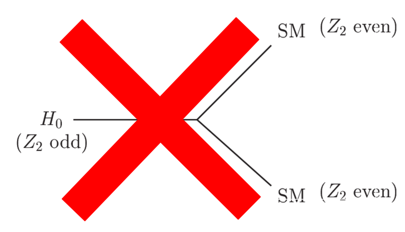
Even if masses of the right−handed neutrinos are $\mathcal{O}(1)$ TeV, small neutrino masses are realized.

New physics is expected in lepton sector at TeV regions.

Dark matter

We assume the neutral component H_0 of the inert doublet is the lightest of Z_2 odd particles.

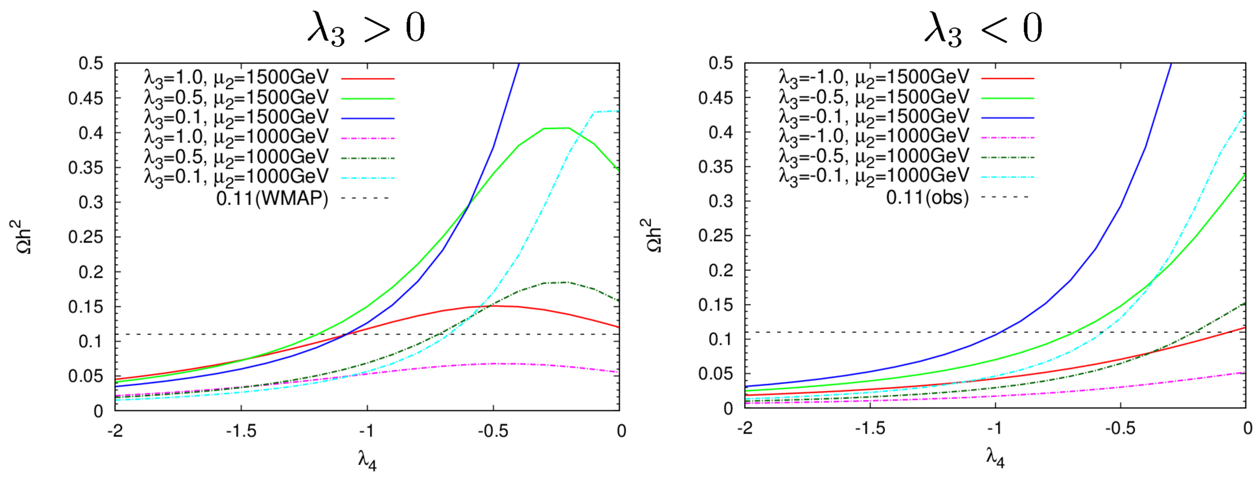
H_0 decay is forbidden under Z_2 symmetry.



➡ H_0 can be the dark matter candidate.

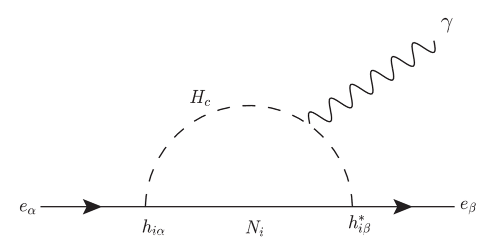
$\mu_2 = 1000, 1500$ GeV, $|\lambda_5| = 10^{-5}$

$\lambda_3 > 0$ $\lambda_3 < 0$



The required relic abundance is realized for $|\lambda_3 + \lambda_4| = \mathcal{O}(1)$.

Lepton flavor violating processes (LFV)



$$\mathrm{Br}(\mu \to e\gamma) < 2.4\times 10^{-12}\ (\mathrm{MEG})$$
$$\mathrm{Br}(\tau \to \mu\gamma) < 4.4\times 10^{-8}\ (\mathrm{BaBar})$$

DM abundance depends on not only neutrino yukawa couplings but also scalar couplings.

We don't need to consider this constraint for small neutrino yukawa couplings.

3.Baryon number asymmetry

Lepton flavor structure

To fix the flavor structure, we assume that

$$h_{ie} = 0, \quad h_{i\mu} = h_i, \quad h_{i\tau} = q_i h_i, \qquad (i = 1, 2);$$
$$h_{3e} = h_3, \quad h_{3\mu} = -q_2 h_3, \quad h_{3\tau} = -q_3 h_3$$

In case of $q_{1,2,3} = 1$, the neutrino mass matrix can be diagonalized by PMNS matrix

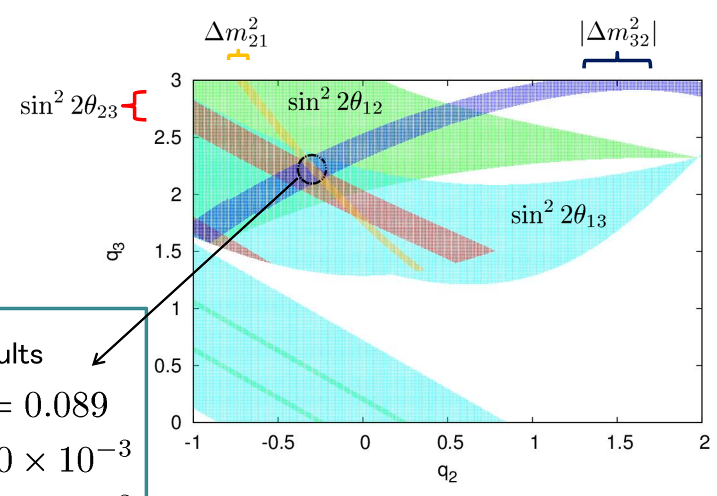
$$U_{PMNS} = \begin{pmatrix} \frac{2}{\sqrt{6}}, & \frac{1}{\sqrt{3}}, & 0 \\ \frac{-1}{\sqrt{6}}, & \frac{1}{\sqrt{3}}, & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{6}}, & \frac{-1}{\sqrt{3}}, & \frac{1}{\sqrt{2}} \end{pmatrix}$$

tri-bi maximal mixing

parameters	2σ
Δm_{21}^2 $[10^{-5}\mathrm{eV}^2]$	7.27-8.01
$\lvert\Delta m_{31}^2\rvert$ $[10^{-3}\mathrm{eV}^2]$	2.38-2.68
$\sin^2\theta_{12}$	0.29-0.35
$\sin^2\theta_{23}$	0.38-0.66
$\sin^2\theta_{13}$	0.019-0.030

D.V. Forero, et el., Phys. Rev. D86 (2012)073012.

Input parameters
$q_1 = 0.85$
$|\lambda_5| = 10^{-5}$
$|h_1| = 3.0\times 10^{-8}$
$m_{H_2} = 1000$ GeV
$m_{N_1} = 2000$ GeV
$m_{N_2} = 6000$ GeV
$m_{N_3} = 10000$ GeV



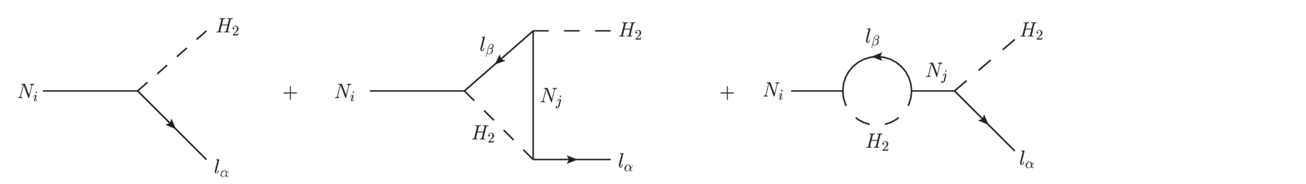
This takes non−zero value from the recent experimental results for θ_{13}. We look for the values of q_1, q_2, q_3 so as to satisfy all the neutrino oscillation data.

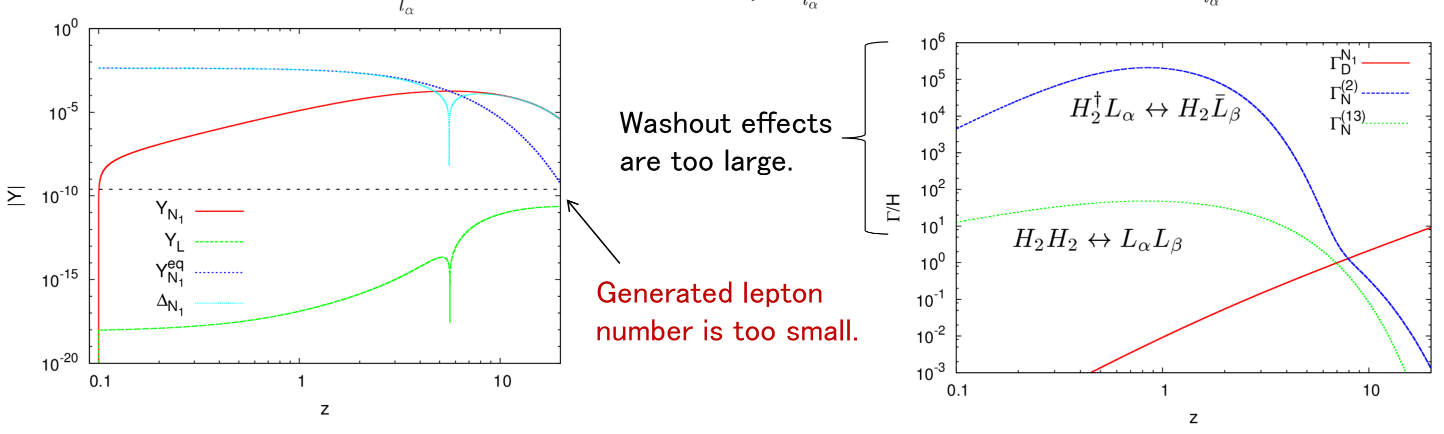
(We only consider the case of normal hierarchy here.)

The results
$\sin^2 2\theta_{13} = 0.089$
$|h_2| = 3.50\times 10^{-3}$
$|h_3| = 1.60\times 10^{-3}$

Baryon number asymmetry

Baryon number asymmetry can be realized through TeV scale leptogenesis.





Washout effects are too large.

Generated lepton number is too small.

The washout effects are too large to realize our universe.

To obtain enough baryon number, the washout processes should be suppressed.

4.Resonant leptogenesis

To suppress the washout processes, we make neutrino Yukawa couplings smaller.

- Too small neutrino masses $\quad \mathcal{M}^\nu_{\alpha\beta} \propto \sum_{i=1}^{3} h_{i\alpha}h_{i\beta}\lambda_5$

The constraint of DM direct search experiments

$$|\lambda_5| \gtrsim 5.0\times 10^{-6}\left(\frac{m_{H_0}}{1\ \mathrm{TeV}}\right)\left(\frac{m_{A_0} - m_{H_0}}{150\ \mathrm{keV}}\right)$$

If we make λ_5 larger, we can recover neutrino masses.

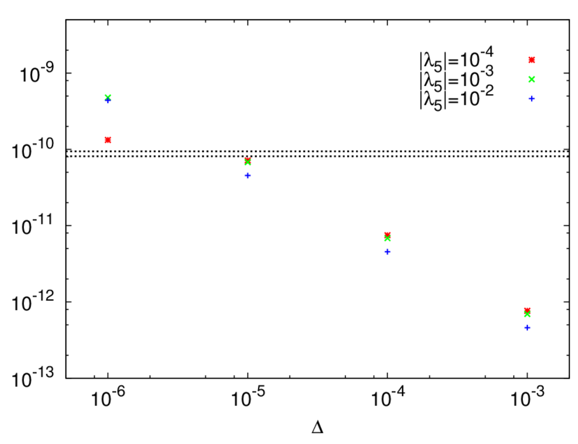
But

- Too small CP asymmetry $\quad \epsilon \propto \dfrac{\left[\mathrm{Im}\left(\sum_{\alpha=e,\mu,\tau} h_{1\alpha}h_{i\alpha}^*\right)^2\right]}{\sum_{\alpha=e,\mu,\tau} h_{1\alpha}h_{1\alpha}^*}$

The contribution from the interference term between tree and self−energy diagram

$$\epsilon \propto \frac{(m_{N_1}^2 - m_{N_2}^2)m_{N_1}\Gamma_2}{(m_{N_1}^2 - m_{N_2}^2)^2 + m_{N_1}^2\Gamma_2^2} \qquad m_{N_2} = (1+\Delta)m_{N_1}$$

If we make the right−handed neutrino masses almost degenerate, the CP parameter becomes lager value.



We can obtain the required baryon asymmetry in the case of $\Delta \sim \mathcal{O}(10^{-5})$.

This is rather mild degeneracy compared with the ordinary case.

Summary

We reexamined the baryon number asymmetry in the radiative neutrino mass model with an inert doublet which can explain the DM relic abundance and the small neutrino masses.

Lepton number asymmetry is too small !!

◆ The nearly degenerated right−handed neutrino masses can realize the observed baryon asymmetry. This degeneracy is milder than the ordinary resonant leptogenesis.
◆ We need examine the inverted hierarchy case.