How to help keV right-handed neutrino dark matter?

Hiroyuki Ishida (NCTS)

@5th International Workshop on Dark Matter, Dark Energy and Matter-Antimatter Asymmetry

Introduction

- To consider new physics,
  - Neutrino masses
  - Dark matter candidate
  - Matter-antimatter asymmetry

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- To consider new physics,
  - Neutrino masses
  - Dark matter candidate
  - Matter-antimatter asymmetry

  + concept of minimality

   the νMSM!

The νMSM

[Asaka, Blanchet, Shaposhnikov (2005)]
[Asaka, Shaposhnikov (2005)]

- The most economical extension : SM + 3RHνs

$$\mathcal{L}_N = i\bar{\nu}_{RI}\partial\!\!\!/\nu_{RI} - F_{\alpha I}\bar{L}_\alpha H\nu_{RI} - \frac{M_N}{2}\overline{\nu^c_{RI}}\nu_{RI} + \text{h.c.}$$

∗Key assumption

Dirac masses : $M_D \ll$ Majorana masses : $M_N \lesssim \Lambda_{\rm EW}$

∗Seesaw mechanism [Minkowski (1977):Yanagida(1979):Gell-Mann,Ramond,Slansky (1979): Glashow (1980):Mohapatra,Senjanovic(1980)]

$$M_\nu = -M_D M_N^{-1} M_D^T \to 0.1\ \text{eV}\left(\frac{F}{10^{-7}}\right)^2\left(\frac{1\ \text{GeV}}{M_N}\right)$$

Tiny neutrino masses can still be explained
by the seesaw mechanism with small Yukawa coupling

The νMSM

[Asaka, Blanchet, Shaposhnikov (2005)]
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- Mass spectrum of RHνs

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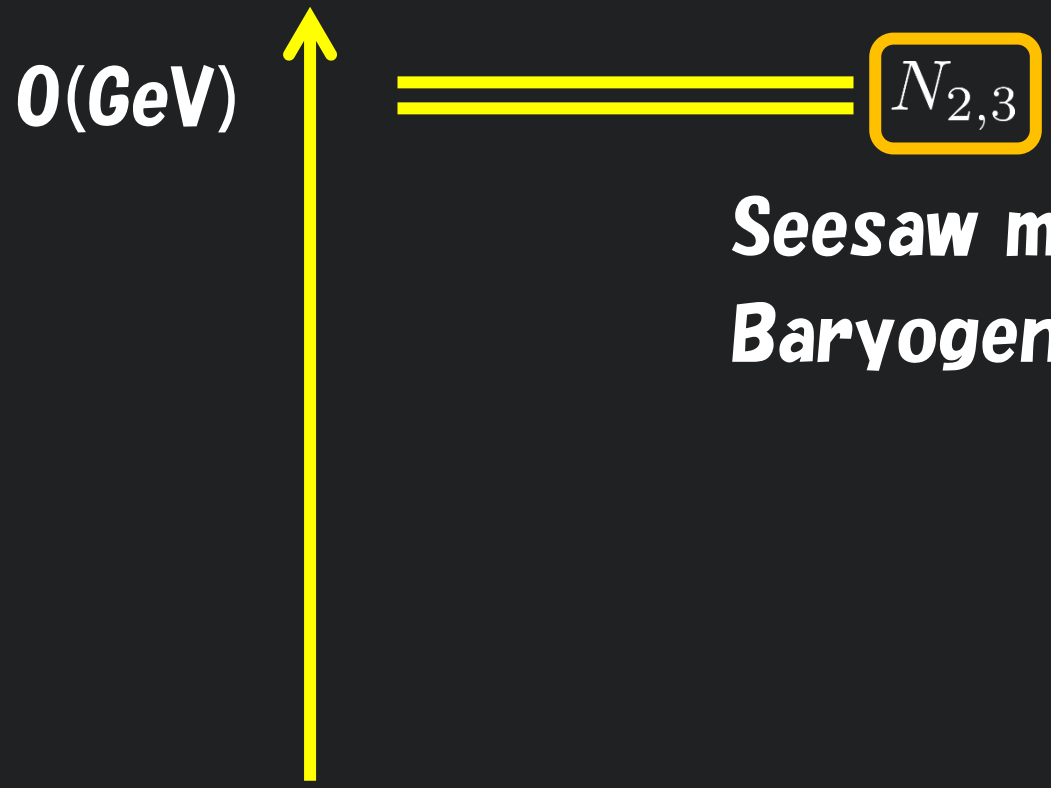

Seesaw mechanism
Baryogenesis

The νMSM

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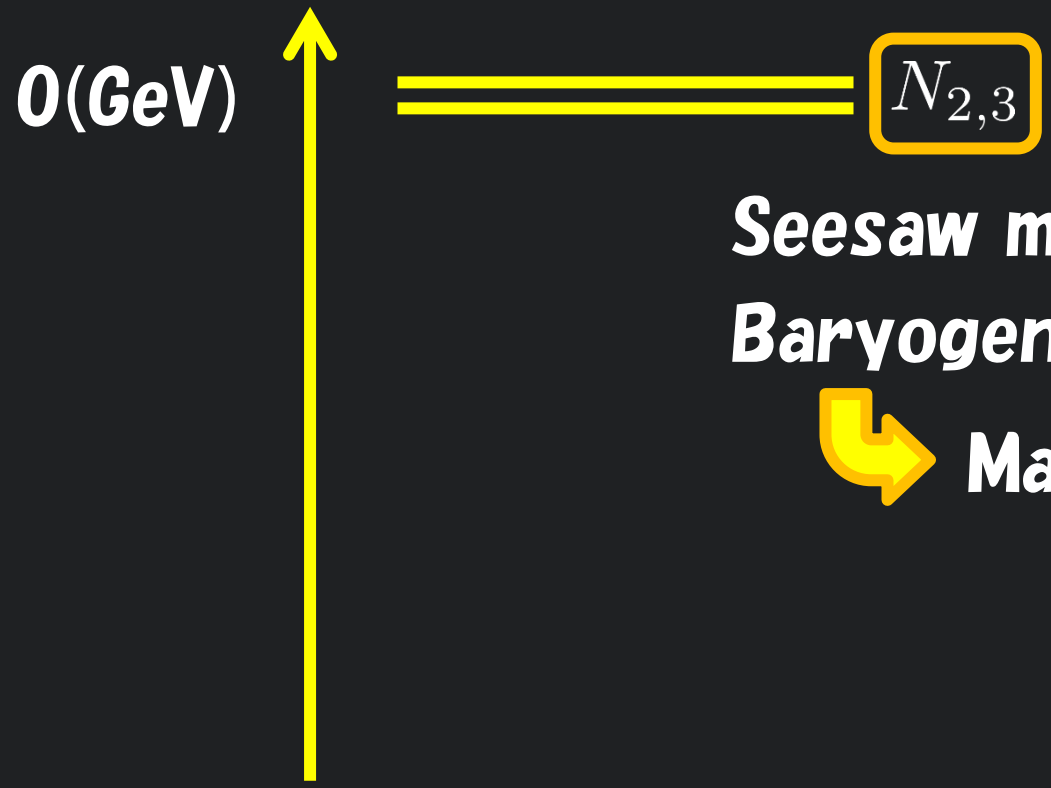

Seesaw mechanism

Baryogenesis

↳ Mass degeneracy

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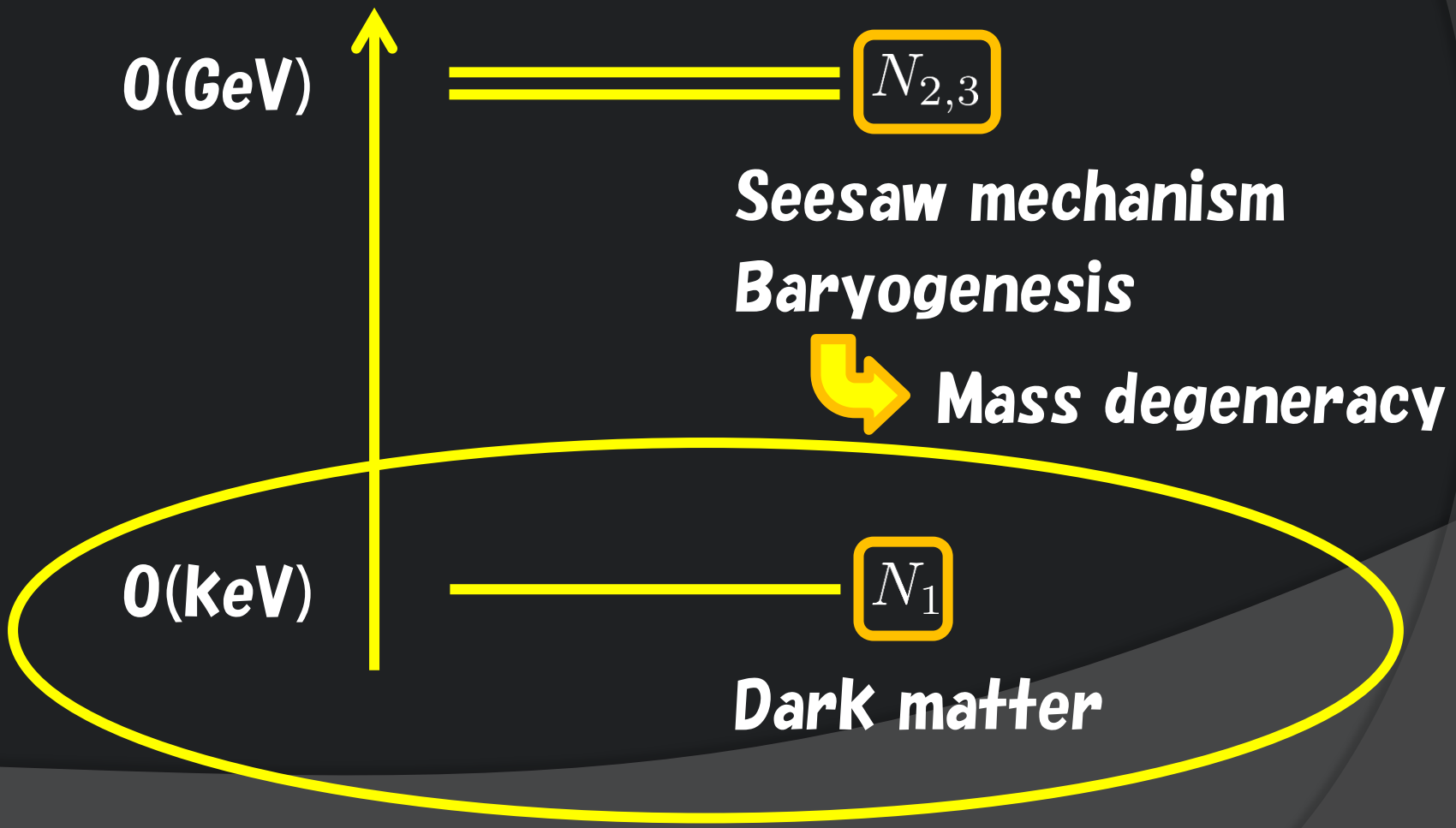

The νMSM

[Asaka, Blanchet, Shaposhnikov (2005)]
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- Physical states of neutrinos
  - active neutrinos : $\nu_i = U^{\dagger}_{\rm MNS}\nu_{L\alpha} - U^{\dagger}_{\rm MNS}\Theta\nu^C_{RI}$
  - sterile neutrinos : $N^C_I = \nu^C_{RI} + \Theta^{\dagger}\nu_{L\alpha}$

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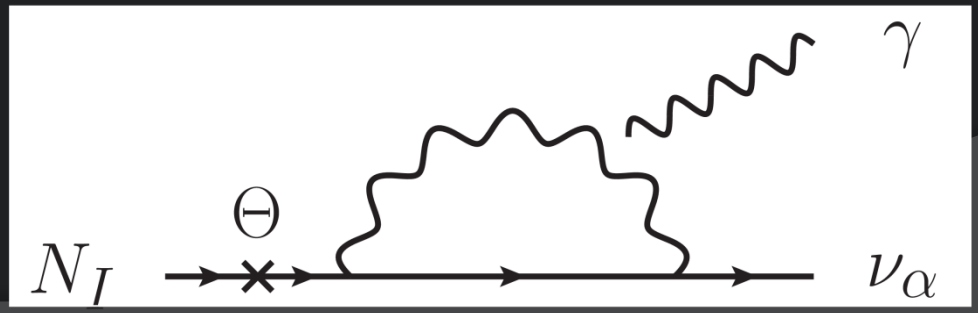
    - right-handed neutrinos
- Important parameter : $\Theta \equiv M_D/M_N$

Through this mixing,



The νMSM

[Asaka, Blanchet, Shaposhnikov (2005)]
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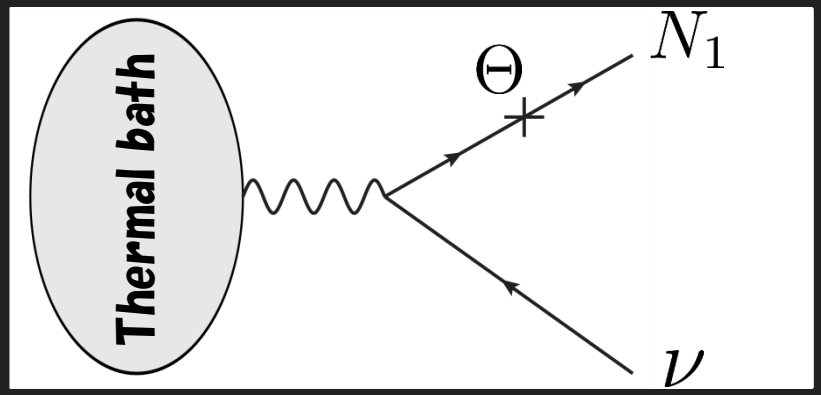
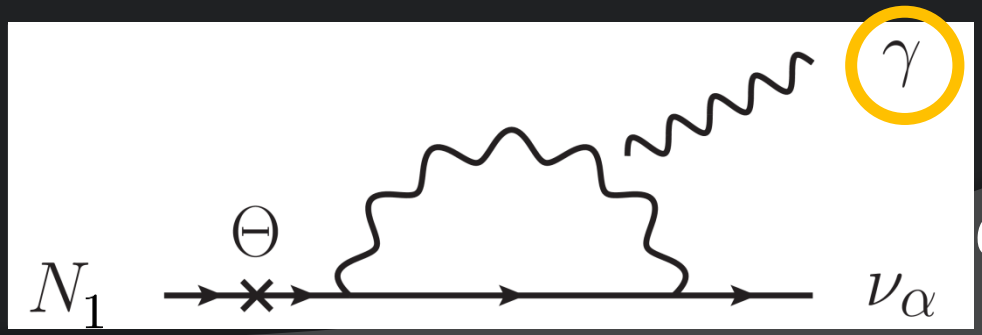
- DM in the νMSM
  - *simple production mechanism (Dodelson-Widrow)



[Dodelson and Widrow (1993)]

- Mixing ↑ - Production rate ↑
- Photon production rate ↑



X-ray observatory

The νMSM

[Asaka, Blanchet, Shaposhnikov (2005)]
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- Constraints on DM

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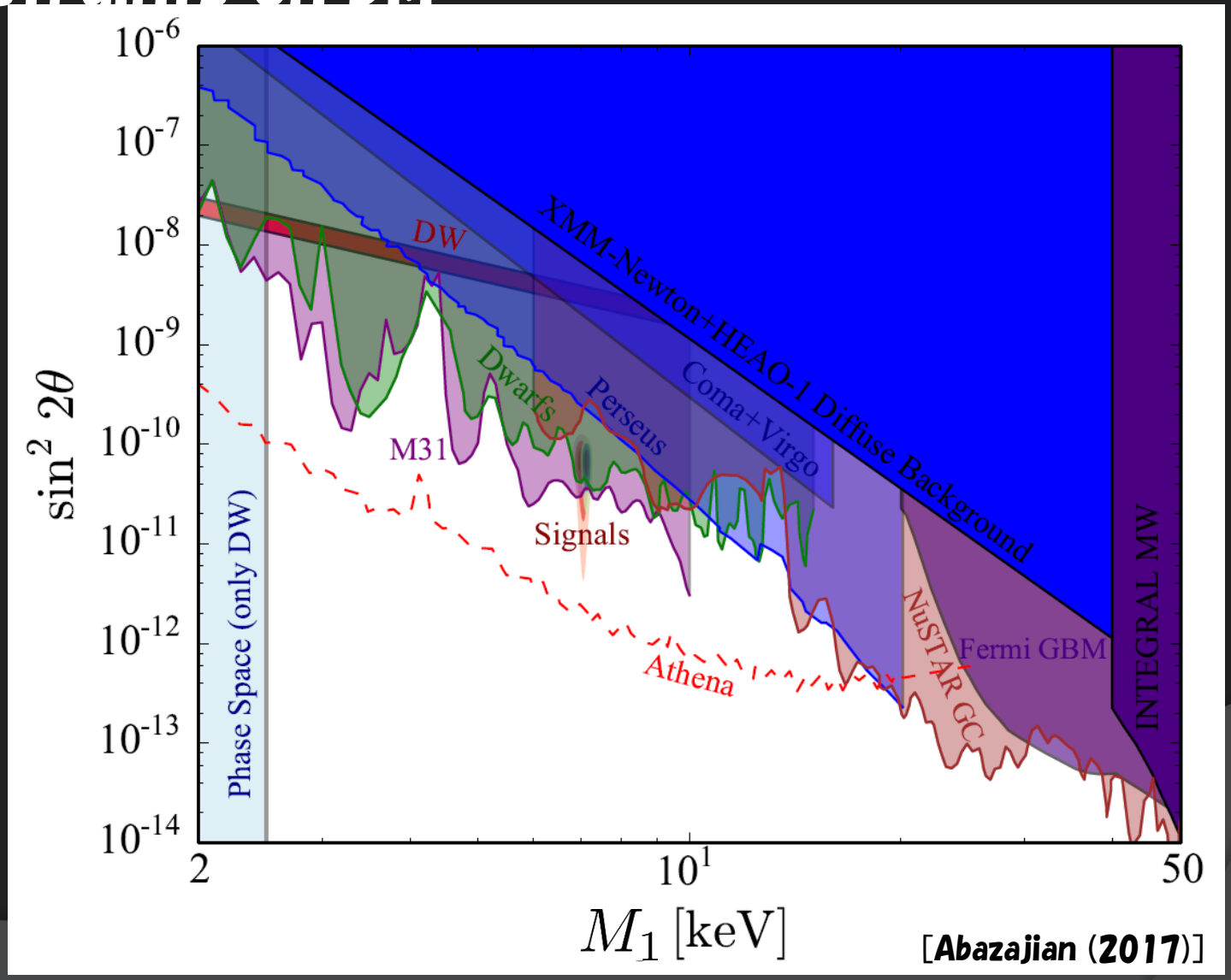

[Abazajian (2017)]

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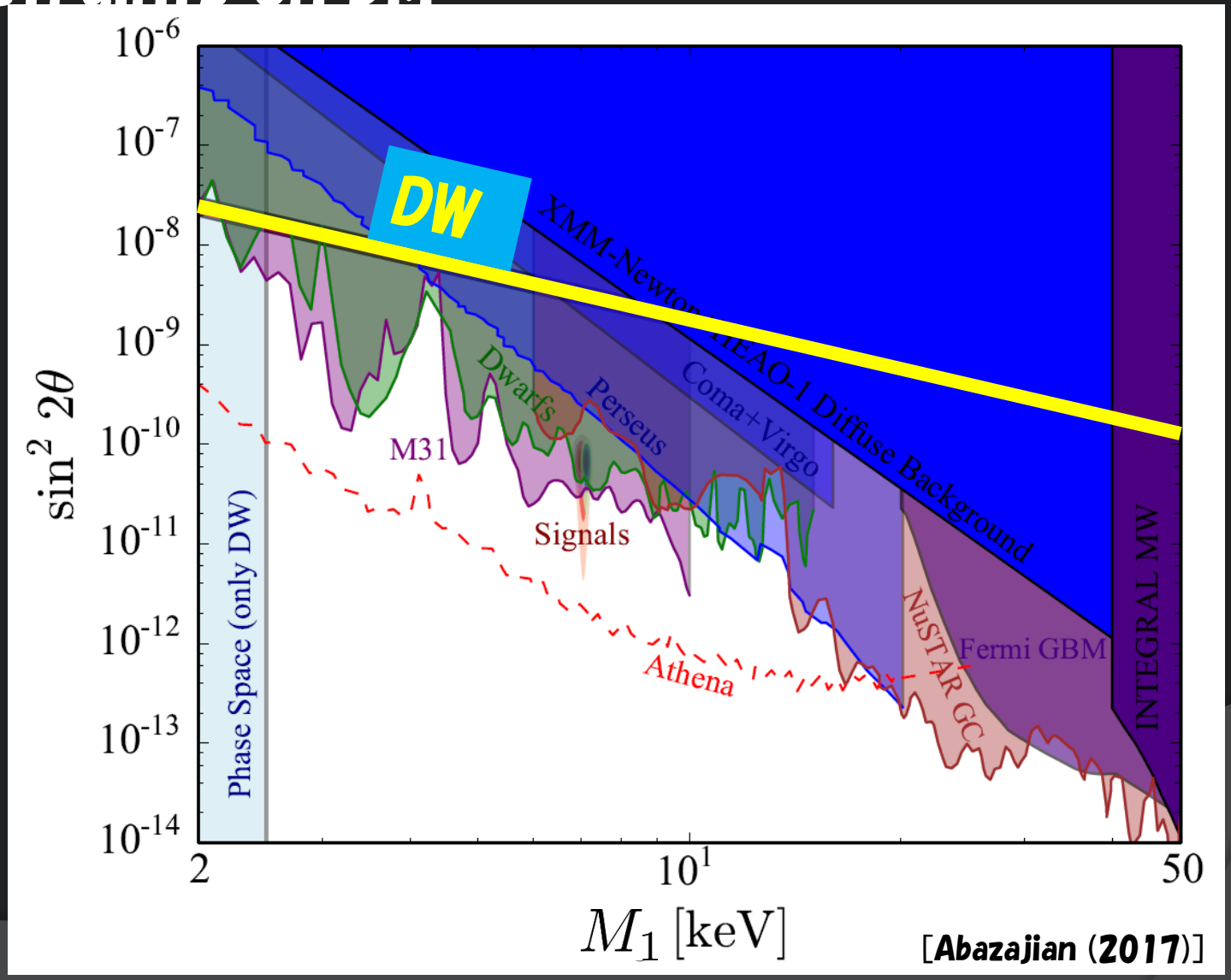

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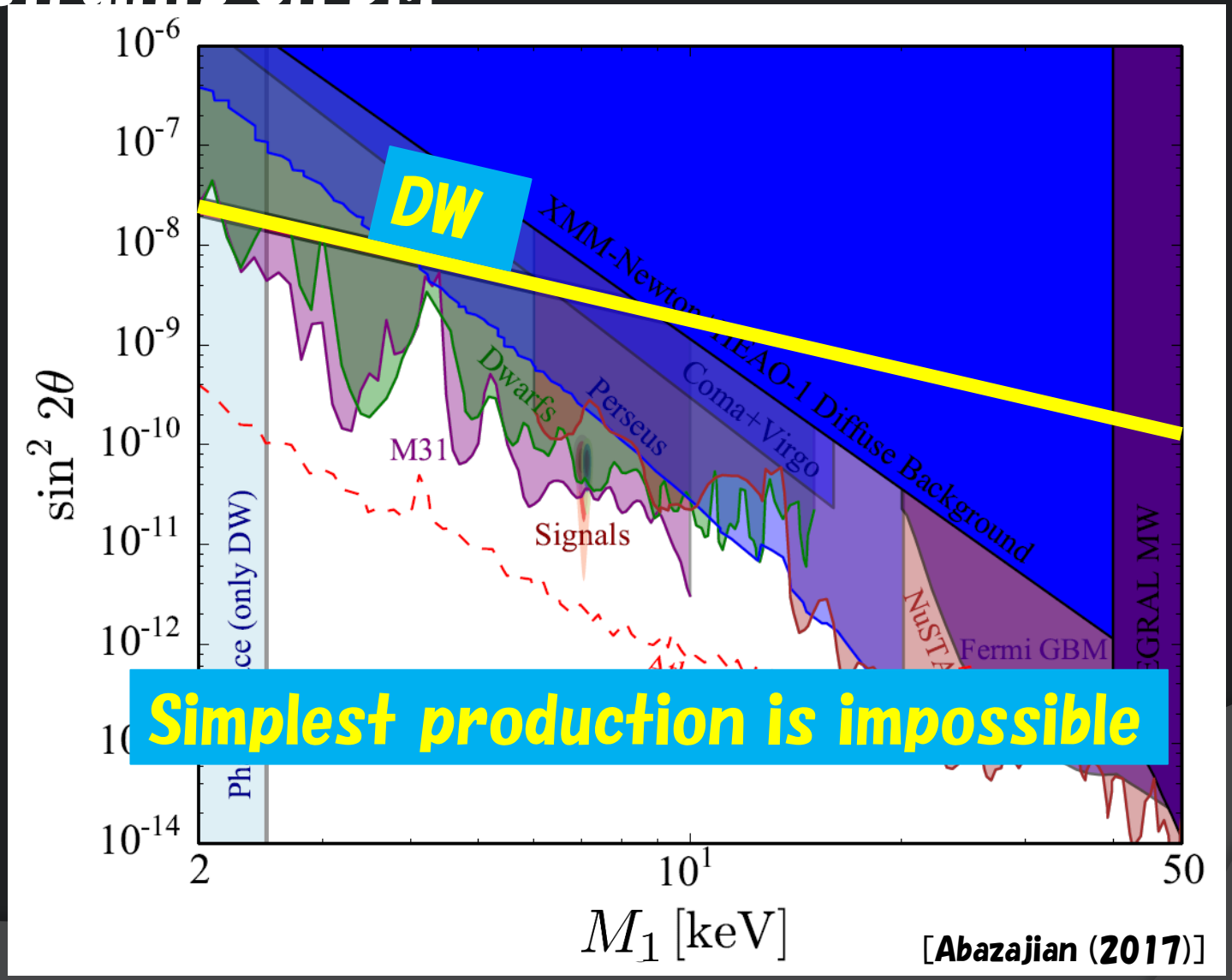
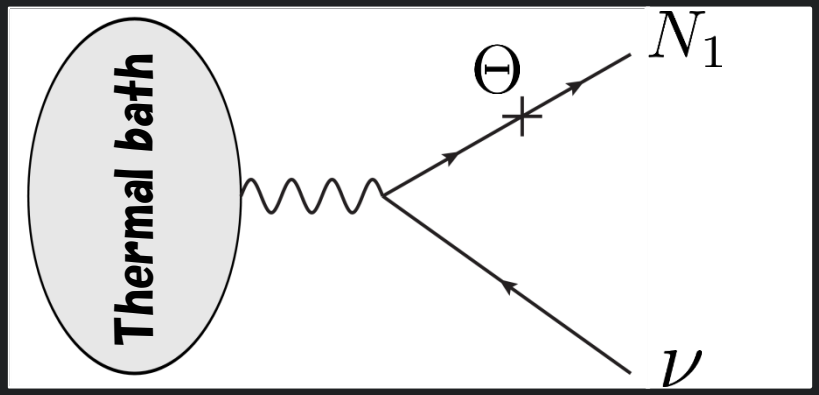


[Abazajian (2017)]

keV DM production

- Resonant production [Shi and Fuller (1998)]



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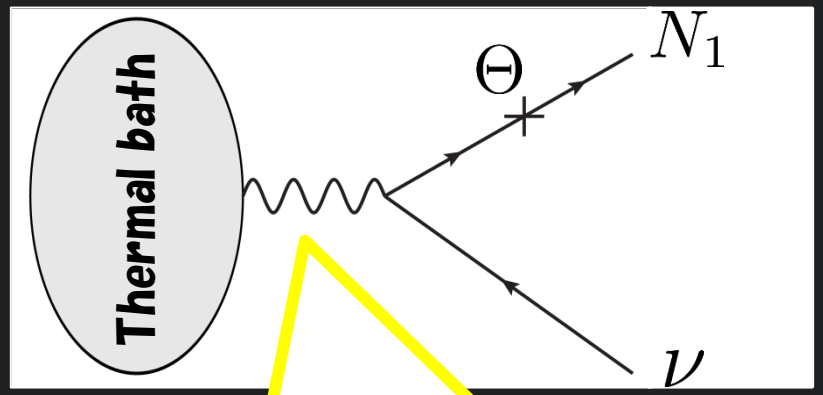

Large # of lepton asymmetry

keV DM production

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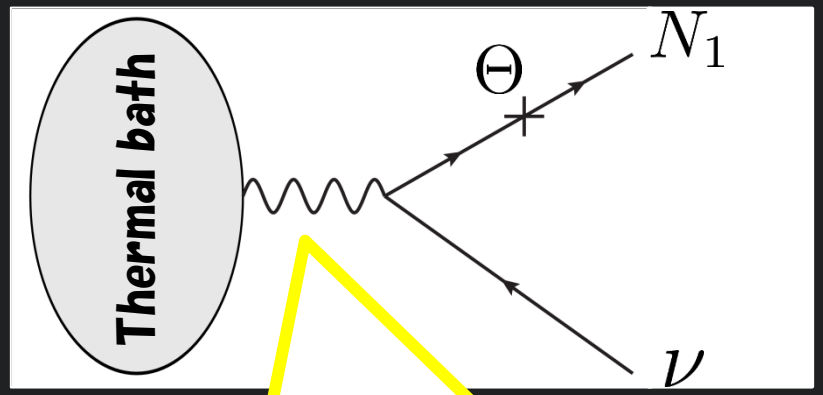

Large # of lepton asymmetry

*typical required amount of Lepton asymmetry

$$\eta_L \equiv n_L/n_\gamma \gtrsim 10^6 \ \eta_B$$

How to produce?

keV DM production

- Late time resonant leptogenesis
  - same idea as one leptogenesis for baryogenesis

[Pilaftsis and Underwood (2003, 2005)]

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resonant lepton asymmetry production after EWSB is possible!

keV DM production

- Late time lepton asymmetry production

keV DM production

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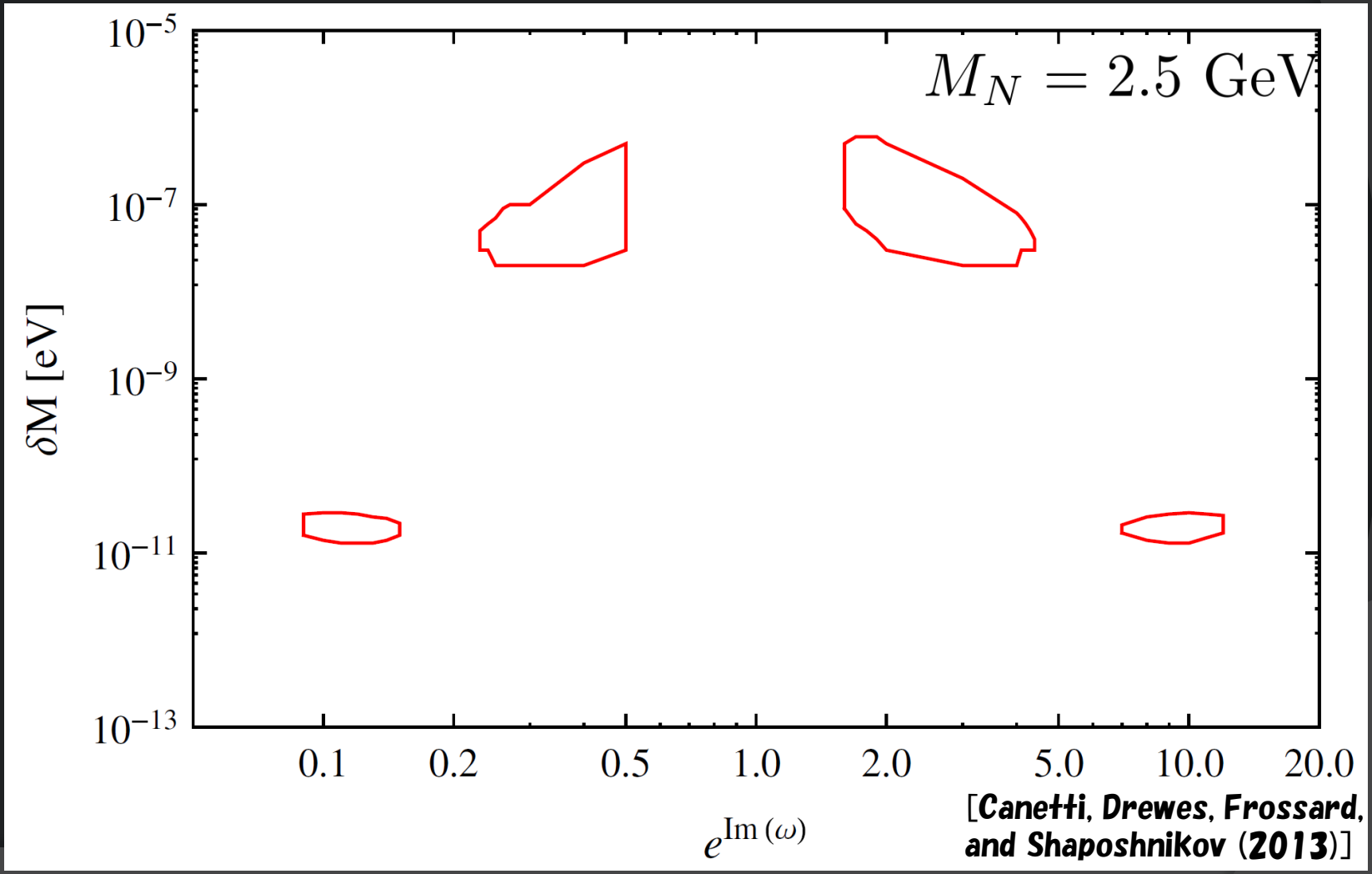


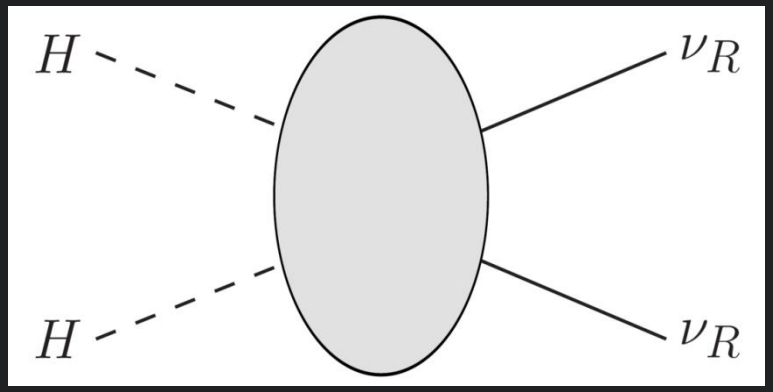
[Canetti, Drewes, Frossard, and Shaposhnikov (2013)]

keV DM production

- Higher dimensional production @high scale

[Asaka, Eijima, HI, Minogawa, Yoshii (2017)]

$$\mathcal{L}_{\rm HD} = \frac{A_{IJ}}{\Lambda} H^\dagger H \overline{\nu_{RI}^c} \nu_{RJ} + {\rm h.c.}$$



Produced amount of RHνs

$$\left[\rho_N^I\right]_{IJ} = \#\times\frac{M_P T_R}{\Lambda^2}\left[A^\dagger A\right]_{IJ}$$

$$\xrightarrow{\Lambda\to M_P} \#\times\frac{T_R}{M_P}\left[A^\dagger A\right]_{IJ}$$

Higher dimensional operator effect

[Asaka, Eijima, HI, Minogawa, Yoshii (2017)]

- Effect on (constraint from) DM production

If $$\sum_{\alpha} |\Theta_{\alpha 1}|^2 \ll 8 \times 10^{-8} \left(\frac{M_1}{1\ \mathrm{keV}} \right)^{-2}$$

↳ DW mechanism does not work at all

↳ Production via HD operators becomes more important!!

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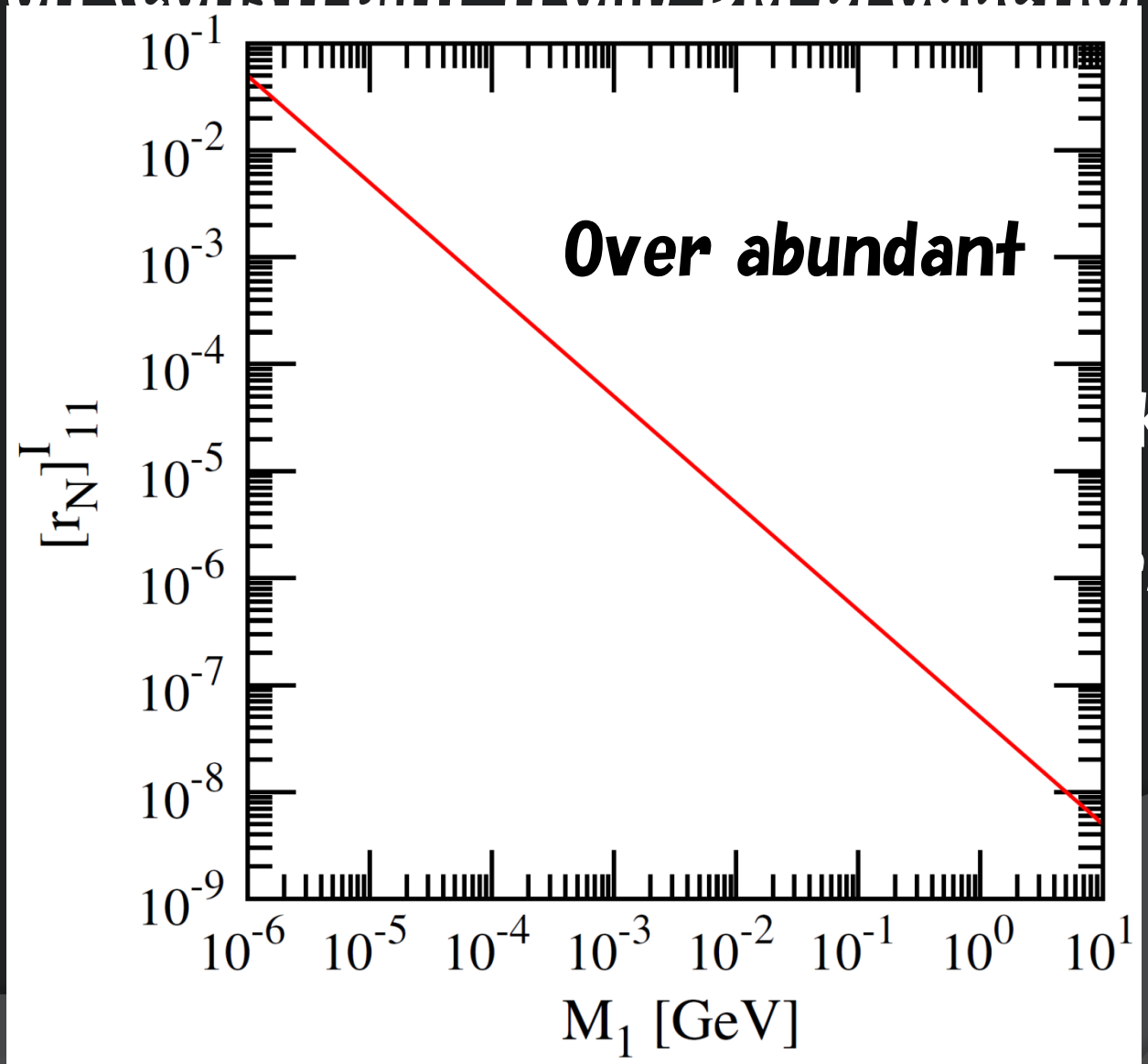

k at all

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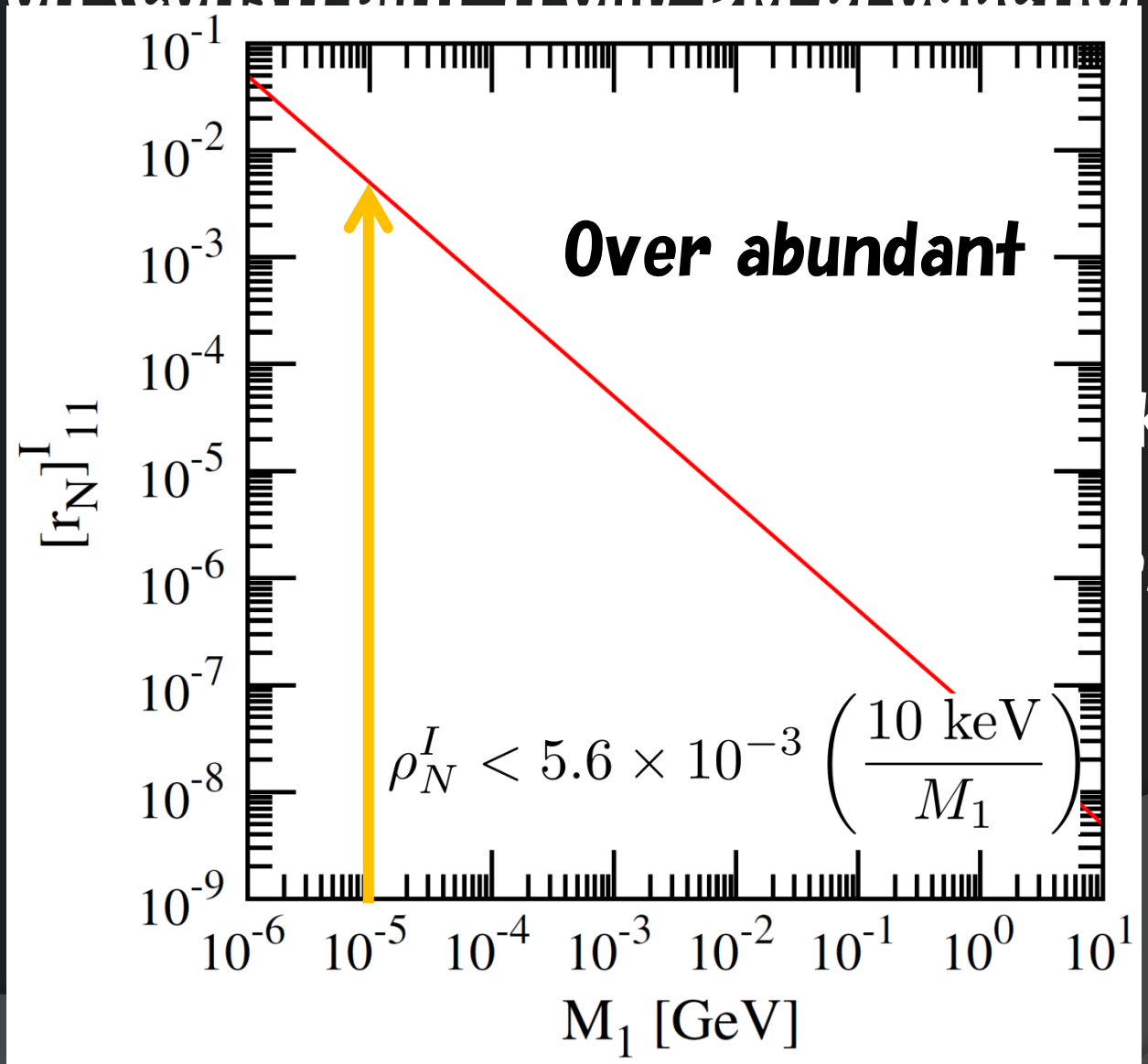

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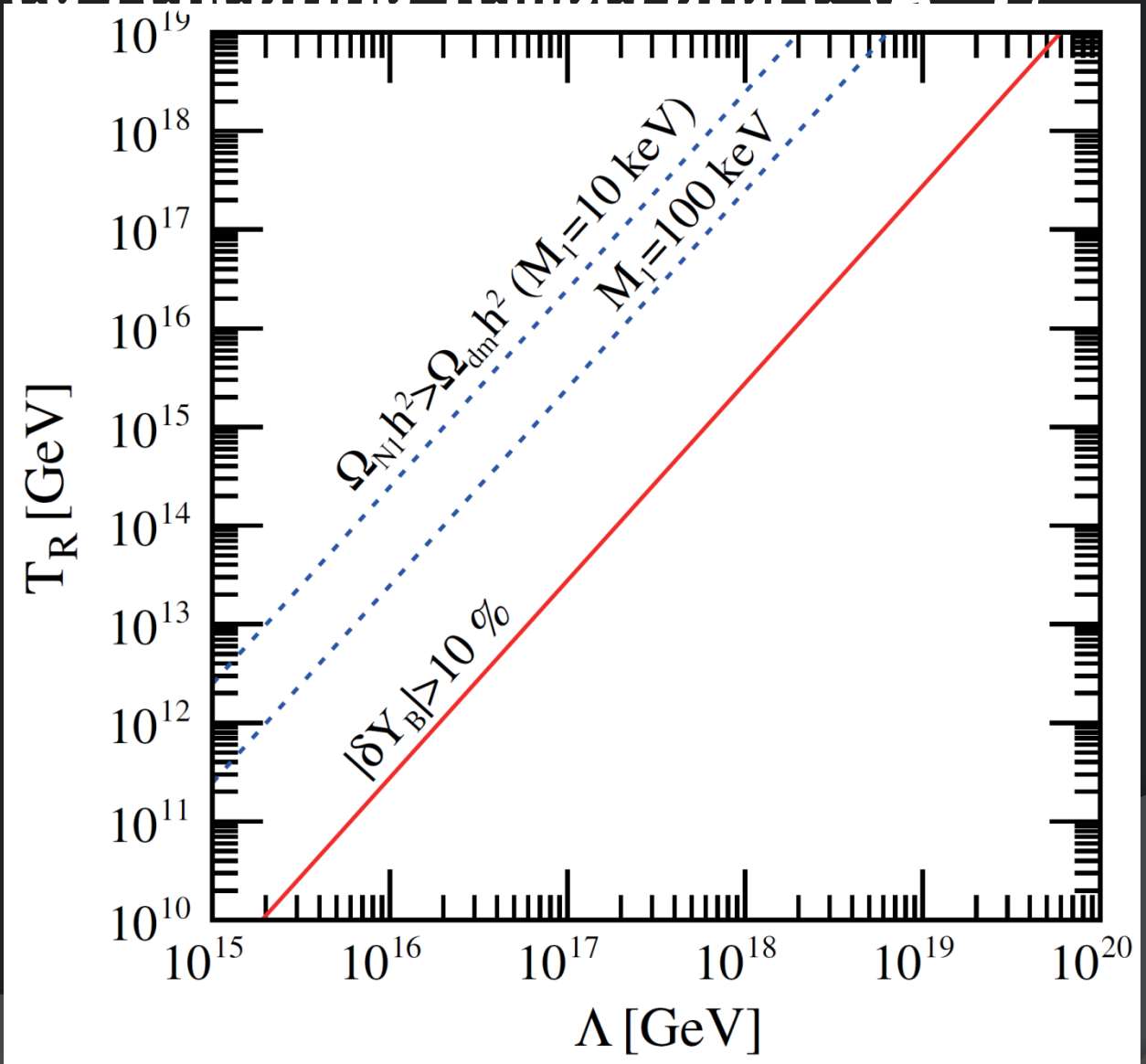

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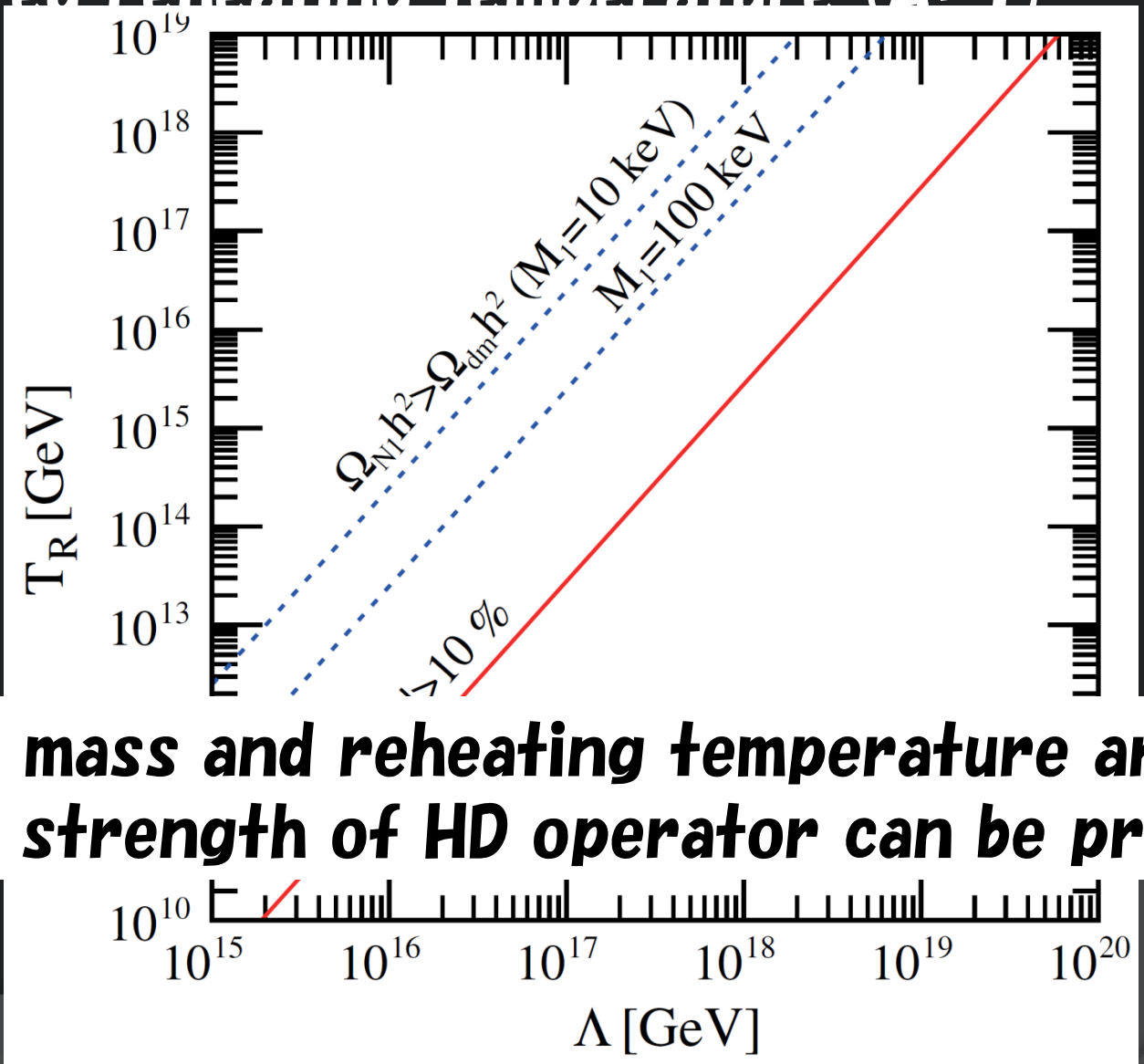


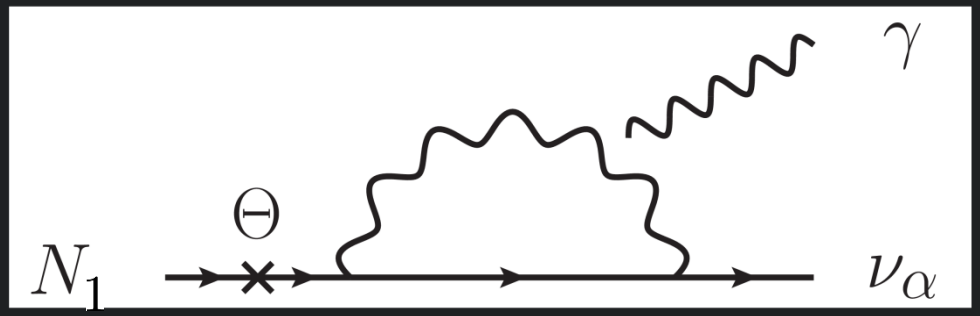
Once DM mass and reheating temperature are given coupling strength of HD operator can be predicted!

Higher dimensional operator effect

[Asaka, Eijima, HI, Minogawa, Yoshii (2017)]

- When $T_R = 10^{13}\ \mathrm{GeV}\,, A = \mathcal{O}(1)\,, \Lambda = M_P$

$$M_{N_1} \simeq 5\ \mathrm{GeV}$$



$$-F_{\alpha 1}\bar{L}_\alpha H \nu_{R1}$$

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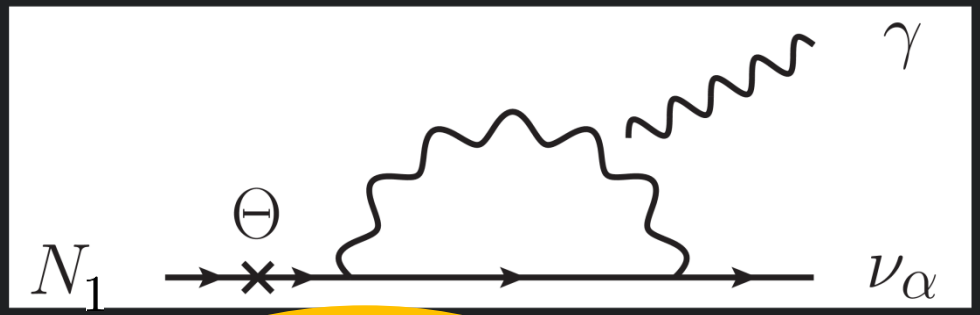

Z_2 need to be imposed

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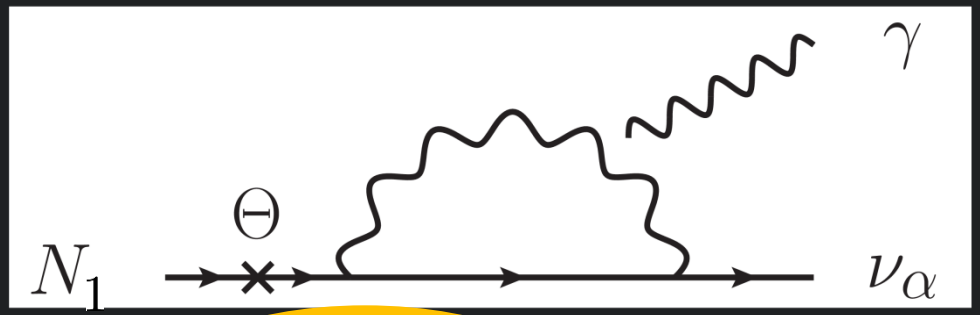

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$\frac{A_{11}}{\Lambda} H^\dagger H \overline{\nu_{R1}^c} \nu_{R1}$ is invariant under Z_2

This DM production becomes important!

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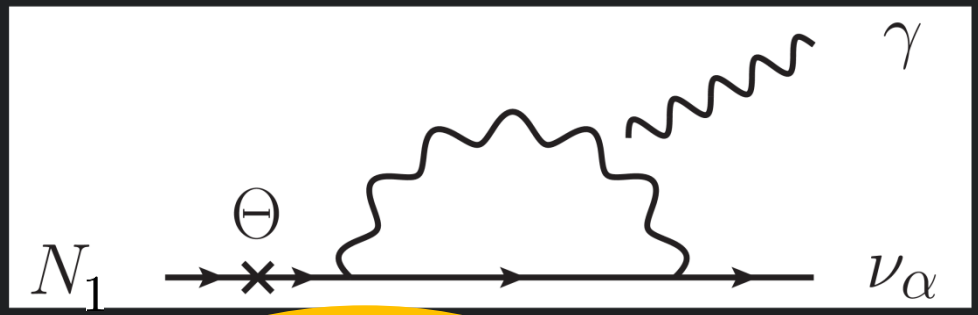

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This DM production becomes important!

Test might become difficult…

Summary

- keV right-handed neutrino is still one of the possibilities of DM candidate

  * Simplest production does not work

    - Resonant production

      Highly tuned parameters are required

    - Higher dimensional operator production

      What is the underlying theory?

Welcome to discuss about alternative possibilities!

Thank you for your attention!