

# Neutrino portals to Dark Matter

## Brief Introduction

*Mayumi Aoki (Kanazawa University)*

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**Nuria Rius** (Valencia University)

**Sterile Neutrino Portal to DM**

**Emiliano Molinaro** (CP3-Origins, University of Southern Denmark)

**The scotogenic FIMP at the LHC**

**Pasquale Di Bari** (University of Southampton)

**Unifying leptogenesis, DM and high energy neutrinos**

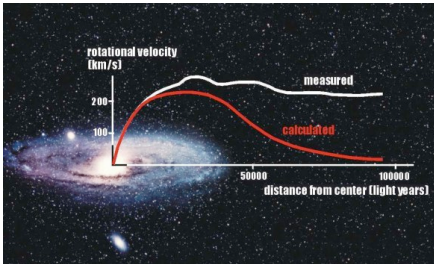
# DARK MATTER

► Nature of Dark Matter

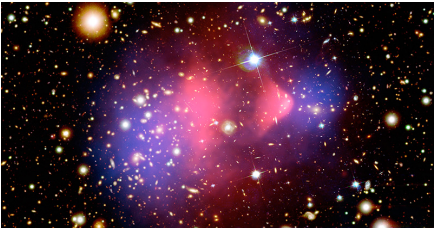
- Stable
- Massive
- Neutral



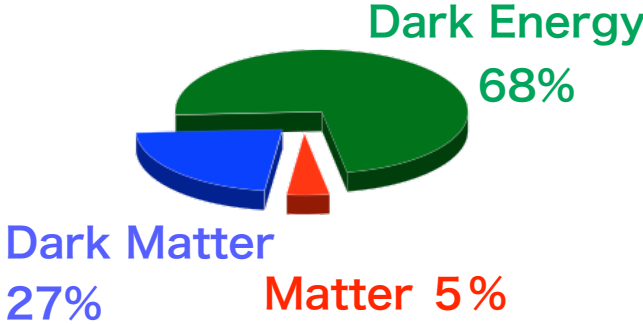
Gravitational lens



Galaxy rotation curves



Bullet Cluster



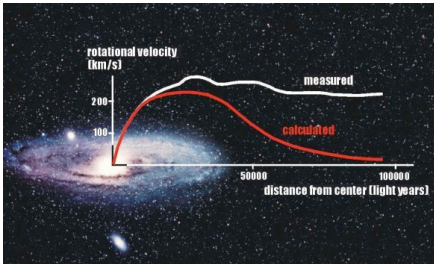
# DARK MATTER

➤ Nature of Dark Matter

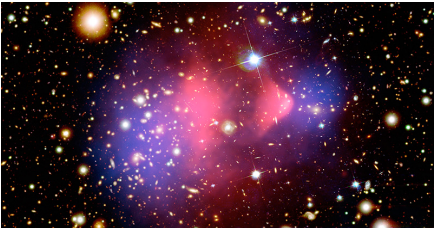
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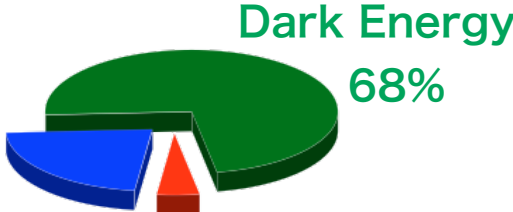
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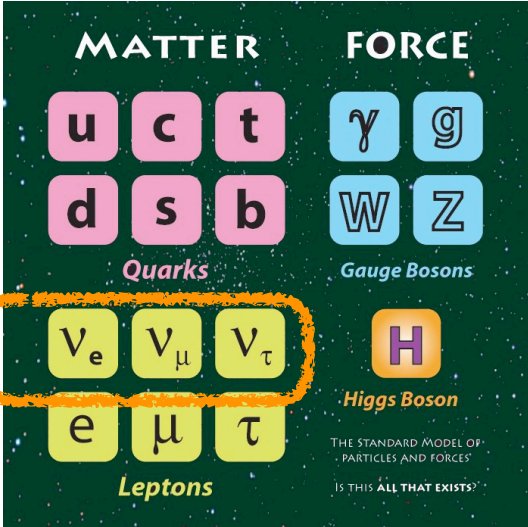
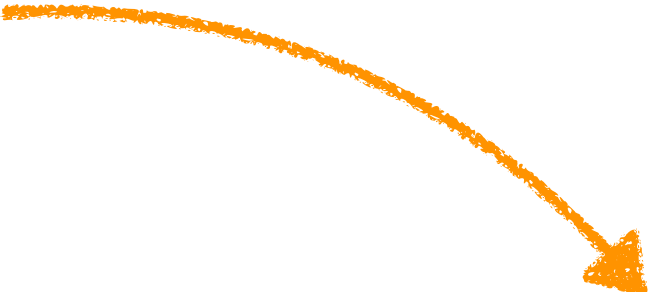


Dark Matter 27%  
Matter 5%

➤ Standard Model

*good candidate*

- weakly interacting
- small mass
- stable

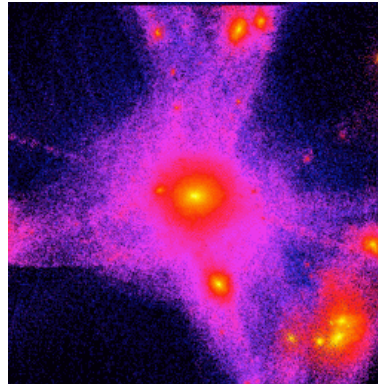


THE STANDARD MODEL OF PARTICLES AND FORCES  
IS THIS ALL THAT EXISTS?

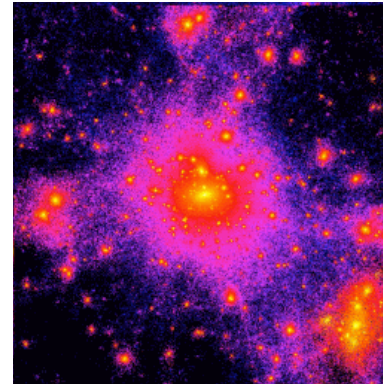
# BEYOND NEUTRINO DM

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Hot



Cold



**Not enough structure**

→ Needs some more new particles

- ▶ Beyond the SM
  - Neutrino mass
  - Baryon asymmetry
  - Inflation
  - :

# NEUTRINOS MASS AND DARK MATTER

## ▶ Type-I seesaw mechanism

$$m_\nu \sim \frac{y^2 v^2}{M}$$

### ▶ High scale

- ▶  $y \sim 1, M \sim 10^{14} \text{ GeV}$
- ▶ Thermal leptogenesis

### ▶ EW scale

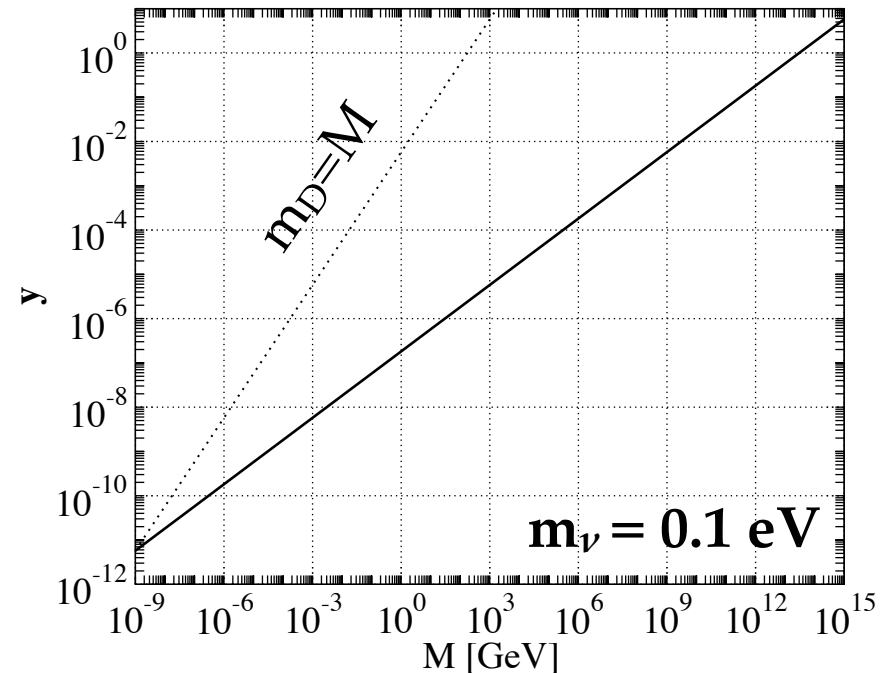
- ▶  $y \sim y_e, M \sim 1 \text{ TeV}$
- ▶ Collider reach

### ▶ Low scale

$\nu$ MSM

- ▶ keV scale Warm DM

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



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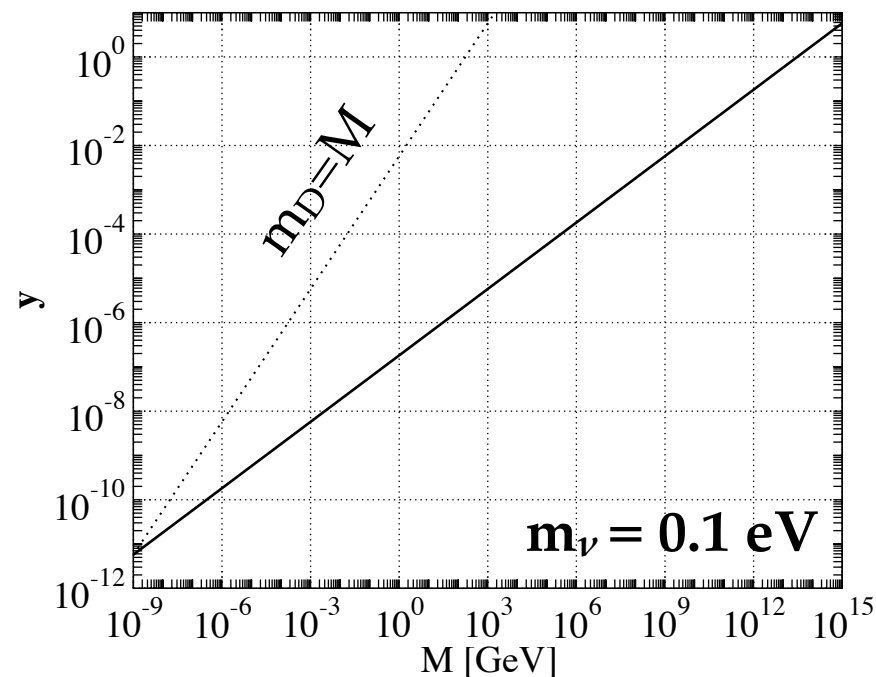
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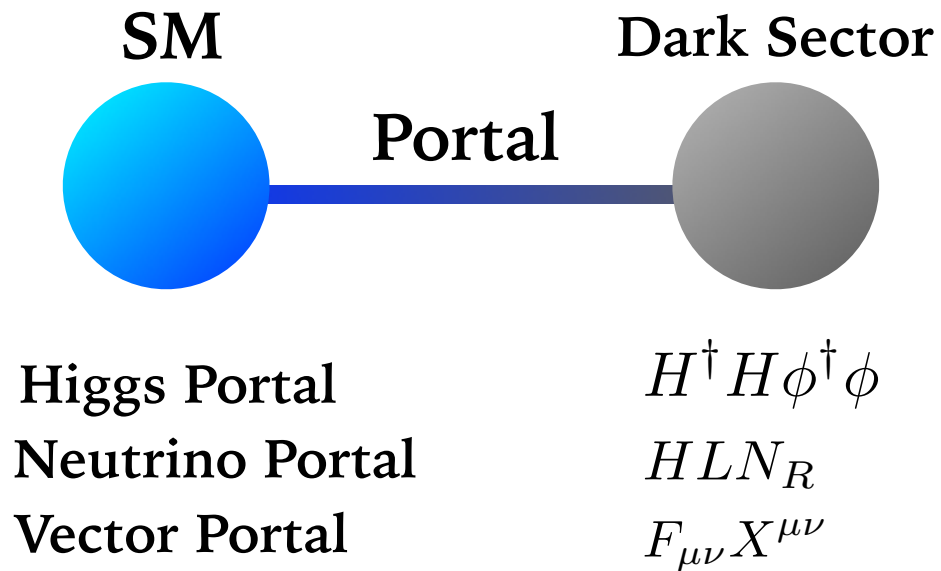
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Asaka, Blanchet, Shaposhnikov (2005)

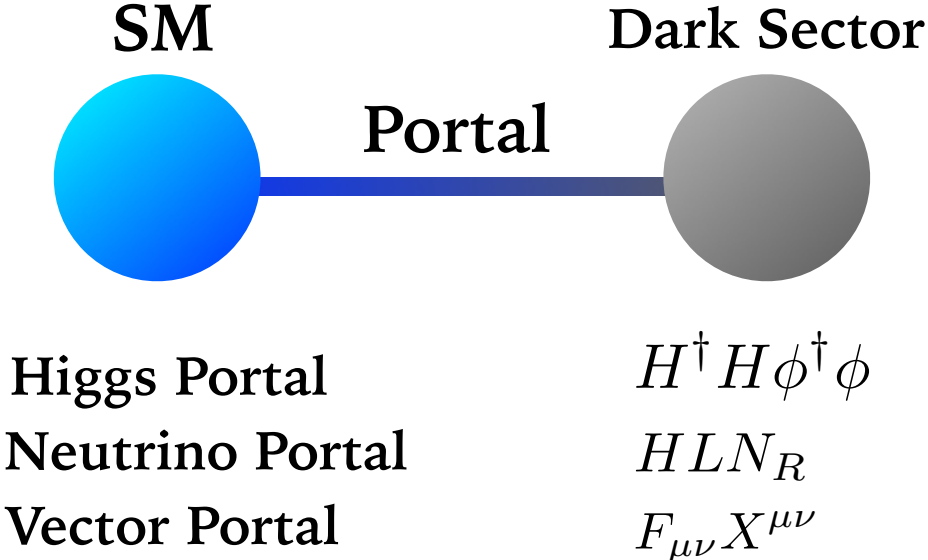


# PORTAL TO DARK SECTOR

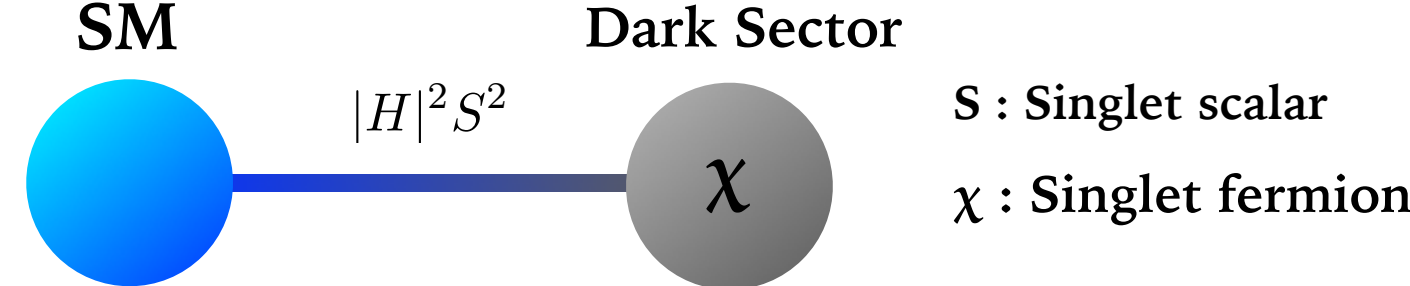
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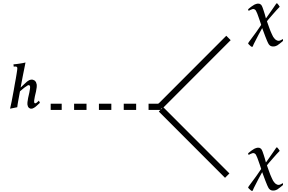
# PORTAL TO DARK SECTOR



► Higgs Portal



- e.g.)
- DM Direct search
  - Invisible decay of Higgs boson



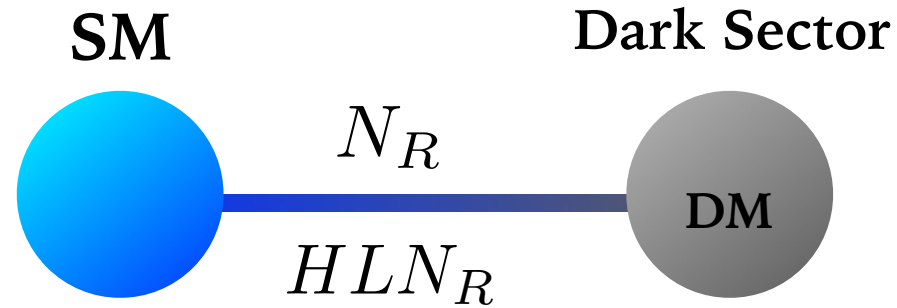
Ko et al. (2012)



# PORTAL TO DARK SECTOR

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## ► Neutrino Portal

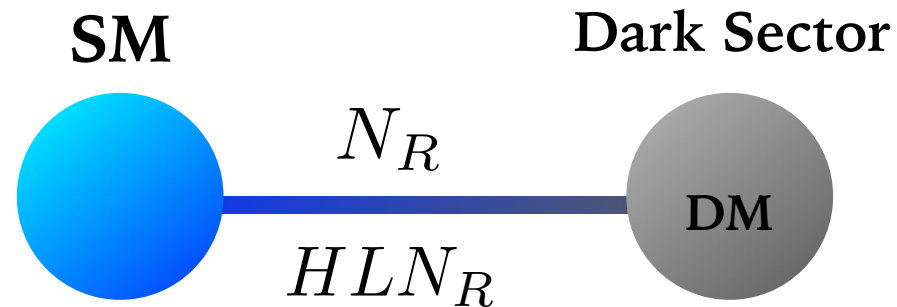


→ Type-I seesaw mechanism

# PORTAL TO DARK SECTOR

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## ► Neutrino Portal



→ Type-I seesaw mechanism

## ► ~ TeV - PeV scale seesaw

**Nuria Rius**

- $U(1)_{B-L}$  symmetry
- Exact symmetry

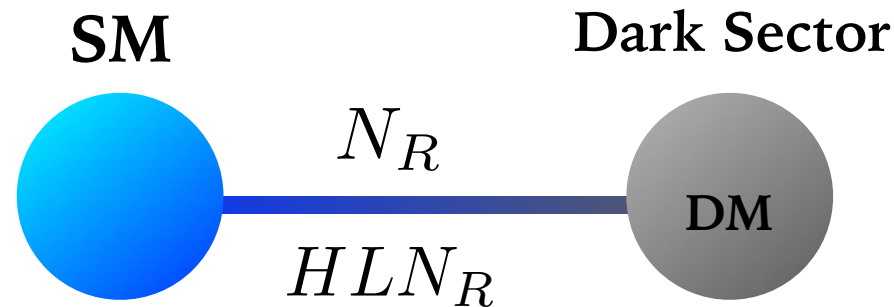
**Pasquale Di Bari**

- $N_R$  DM

# PORTAL TO DARK SECTOR

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## ► Neutrino Portal



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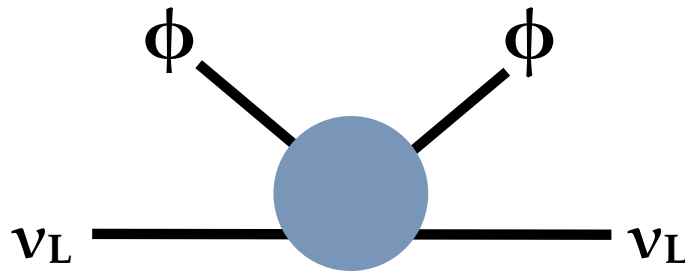
**Pasquale Di Bari**

- $N_R$  DM
- High-energy Neutrino

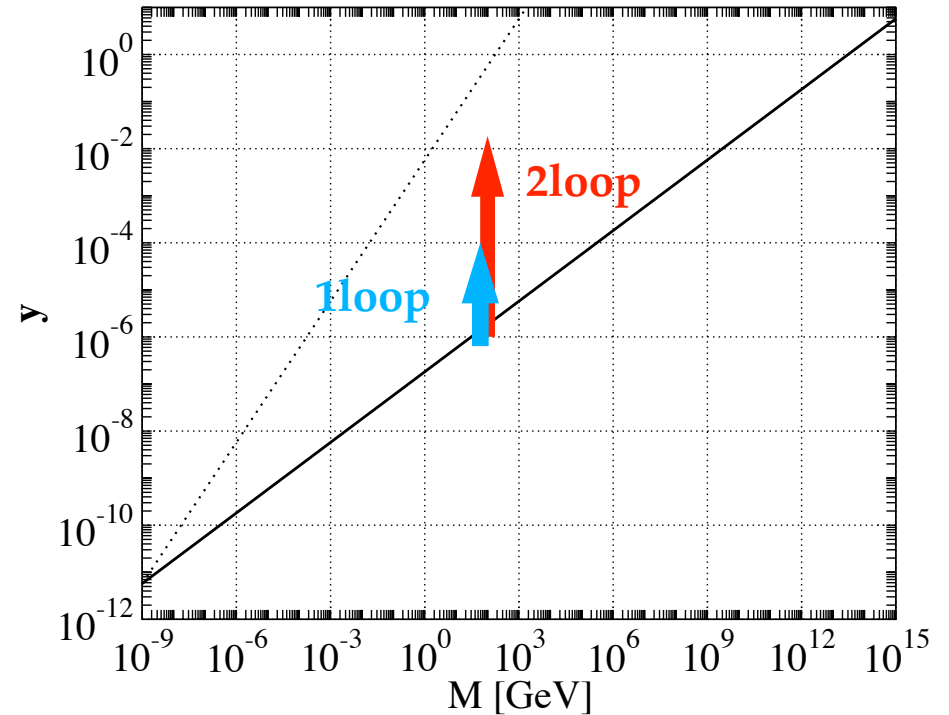
# RADIATIVE NEUTRINO MASS GENERATION

## ► Radiative Seesaw Model

D=5 operator



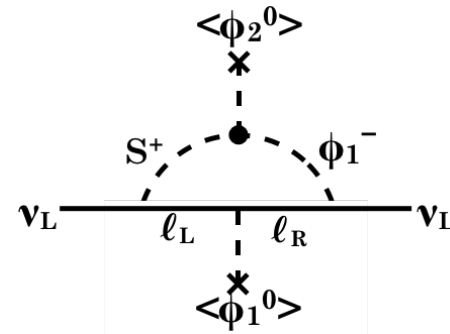
$$N \text{ loop} : m_{\nu}^{ij} = \left( \frac{1}{16\pi^2} \right)^N \frac{f_{ij}}{\Lambda} \langle \phi^0 \rangle^2$$



**Tiny neutrino masses would be explained in a natural way by TeV-scale dynamics.**

► Zee model [1980, 1985](#)

$$\text{SM} + \Phi_2 + S^{\pm}$$



# RADIATIVE SEESAW MODEL WITH DM

- **Symmetry guarantees**
  - ✓ Radiative generation of  $\nu$  mass
  - ✓ DM stability

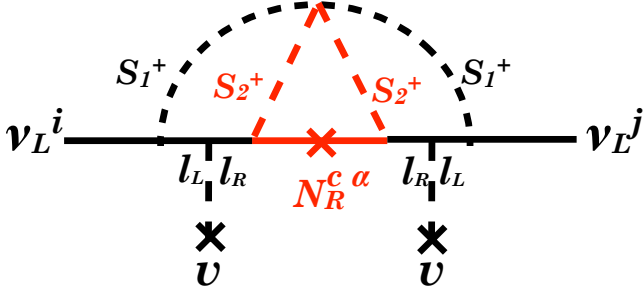
- **Mosel with  $Z_2$  symmetry** Krauss, Nasri, Trodden (2003)

$SM + N_R + S_1^\pm + S_2^\pm$

$S_1^\pm, S_2^\pm$ : singly charged singlet scalars

~~$LHN_R$~~

$N_R$  : WIMP DM



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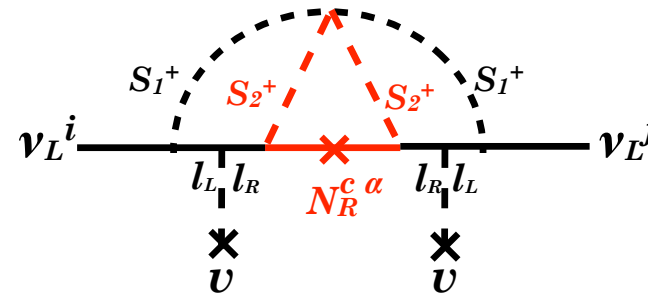
- **Model with  $Z_2$  symmetry** Krauss, Nasri, Trodden (2003)

$$\text{SM} + N_R + S_1^\pm + S_2^\pm$$

$S_1^\pm, S_2^\pm$ : singly charged singlet scalars

$$L \cancel{H} N_R$$

$N_R$ : WIMP DM



- Many models have been proposed along this line.



**Emiliano Molinaro**

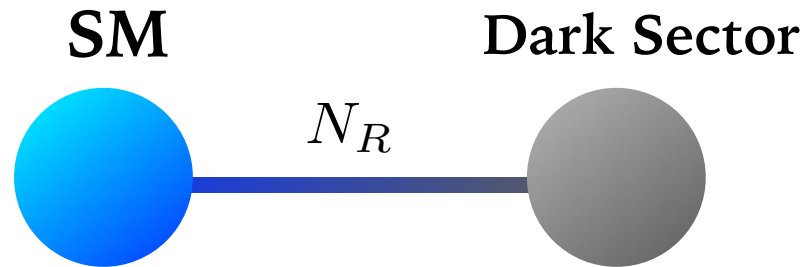
Feebly interacting massive particle (FIMP) DM scenario

$$M \sim 10 \text{keV}, y \sim 10^{-9}$$

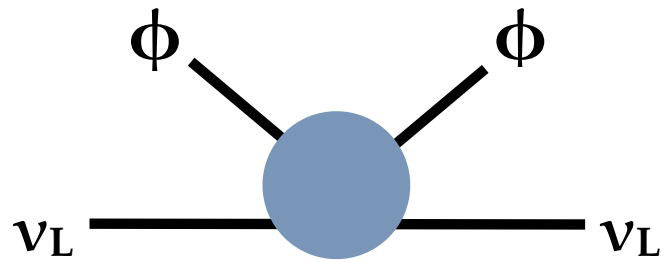
# CONNECTION BETWEEN NEUTRINO MASS GENERATION AND DM

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## ► Neutrino Portal



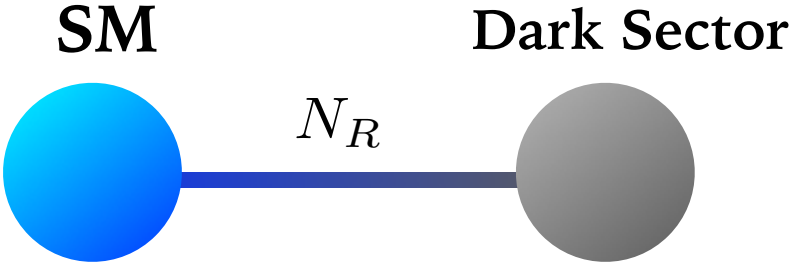
## ► Radiative Seesaw Model



- Flavor Structure
- LFV
- LNV
- Majorana Nature
- DD/ID of DM/new particles
- ⋮
- ⋮

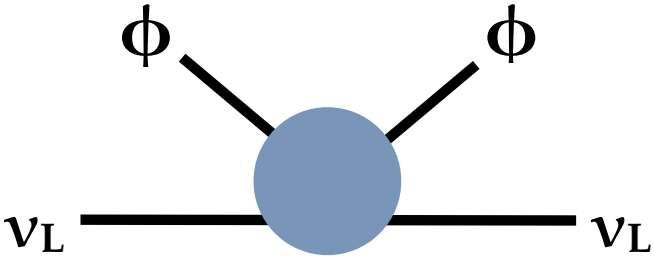
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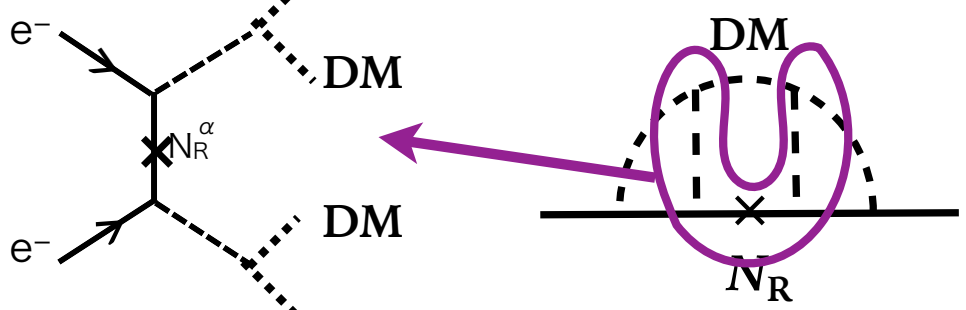


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► Radiative Seesaw Model



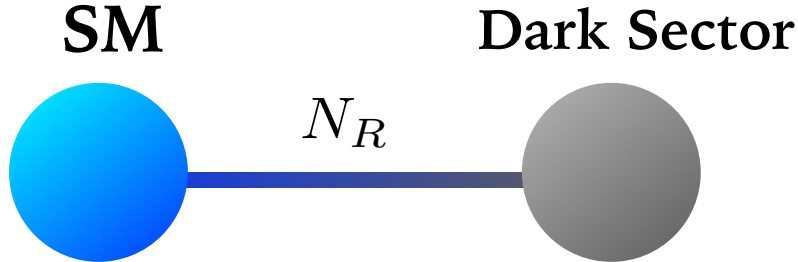
e.g.) sub-diagram





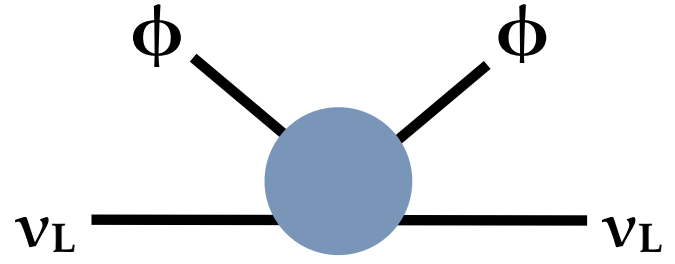
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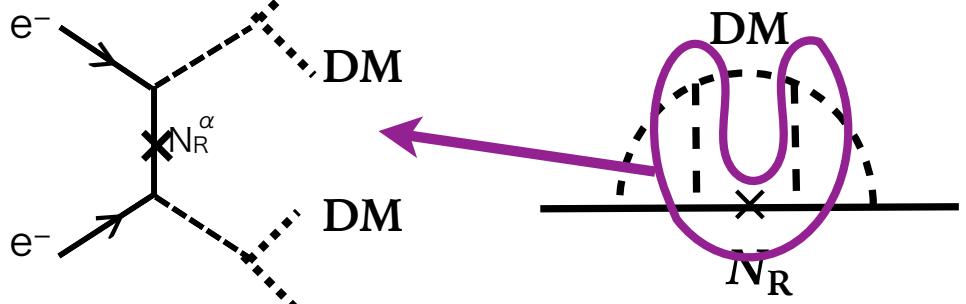


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► Radiative Seesaw Model



e.g.) sub-diagram



**Any new ideas to proof  
the connection would be welcome.**

# CONTRIBUTIONS

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**Emiliano Molinaro** (CP3-Origins, U. of Southern Denmark)

**The scotogenic FIMP at the LHC**

**Pasquale Di Bari** (University of Southampton)

**Unifying leptogenesis, DM and high energy neutrinos**