Universidad
Católica del Norte

lawphysics
Latin American Webinars on Physics

WIMP Dark Matter in a Type-II Scotogenic model

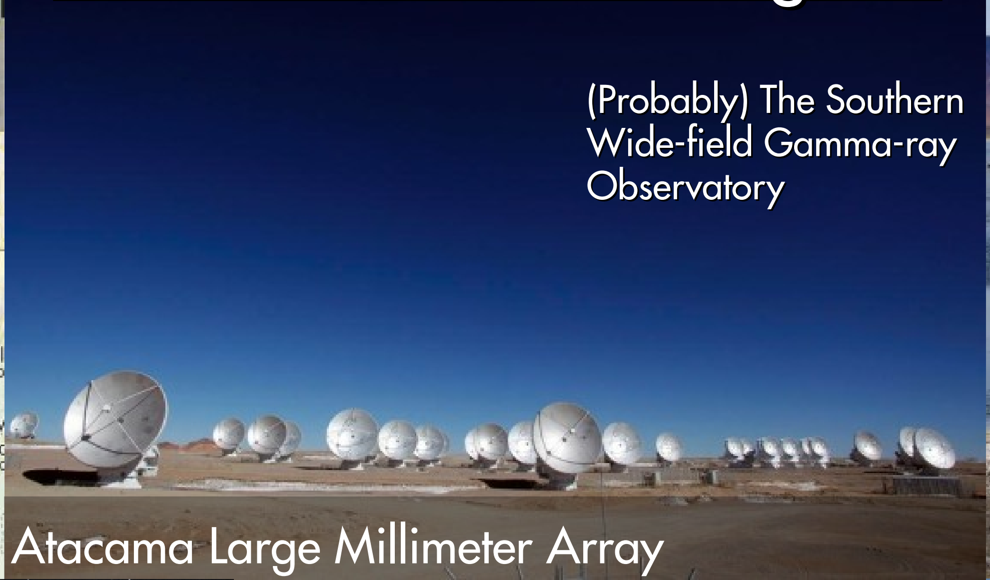
Roberto A. Lineros

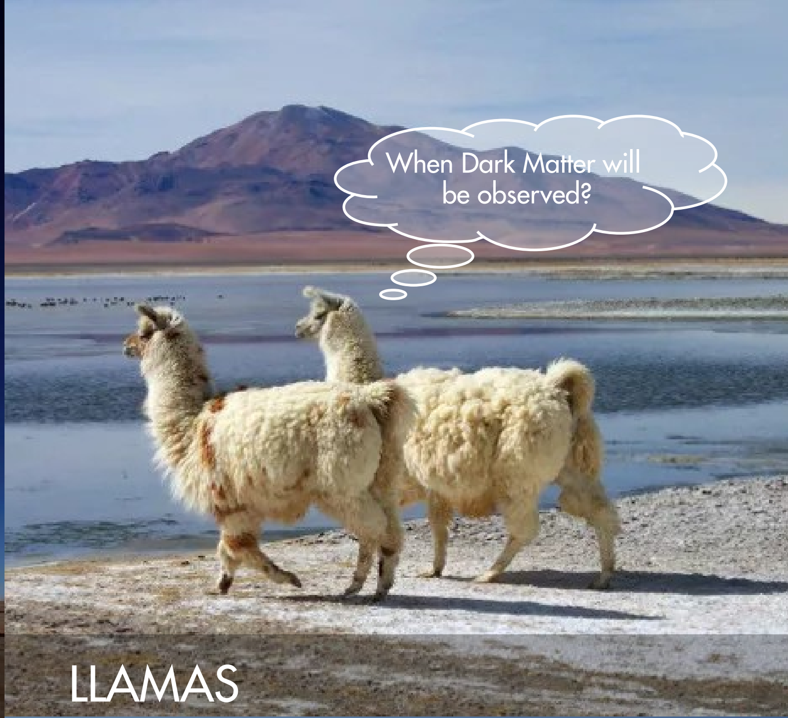
Departamento de Física, Universidad Católica del Norte

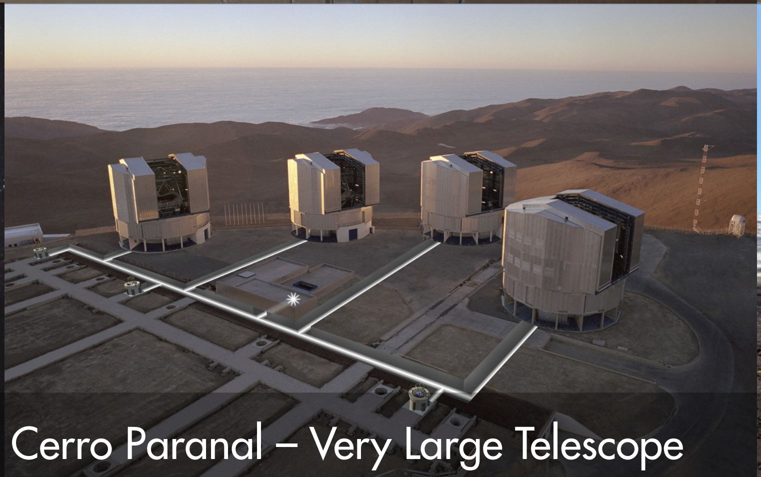
Work in collaboration with Mathias Pierre (IFT UAM/CSIC)
arxiv:2011.08195

Workshop on New Trends in Dark Matter
7 to 9 December 2020

Science around Antofagasta





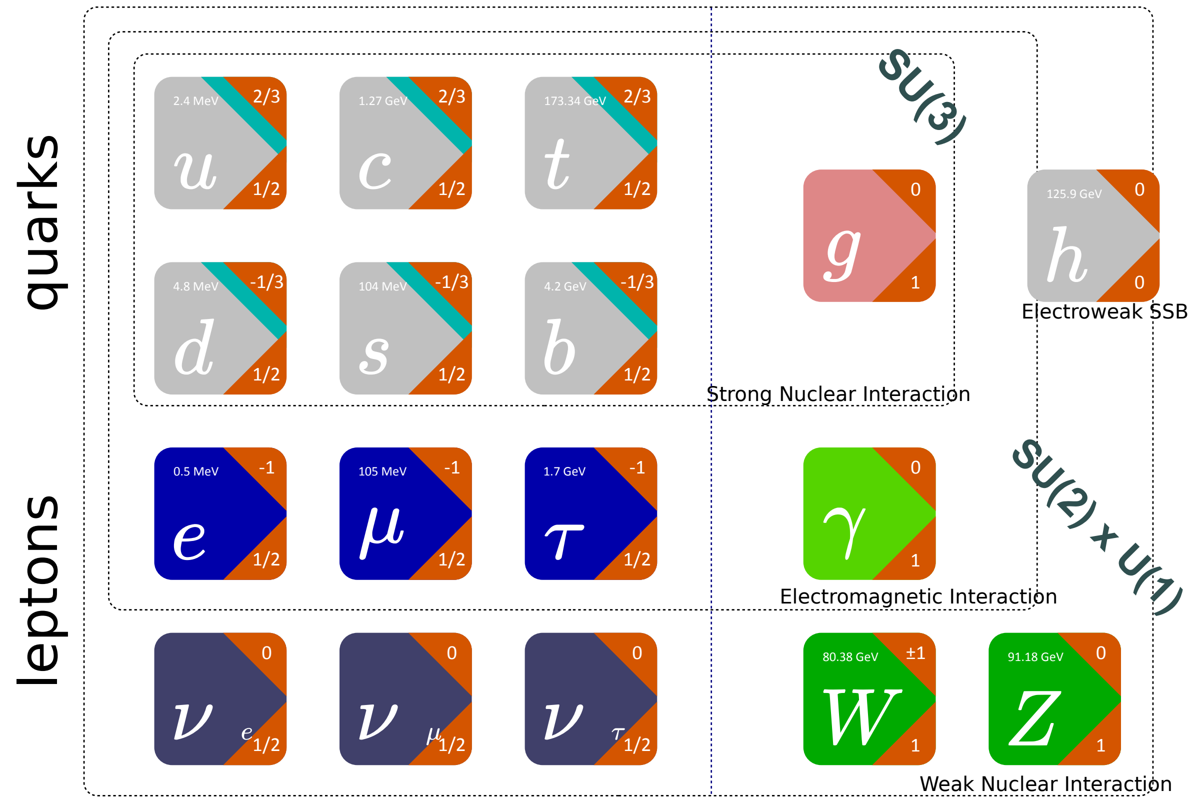


The Plan

1. Introduction
2. Dark Matter and Neutrinos
3. The Model
4. Conclusions

The Standard Model

SM matter families



Symmetries

- Lorentz
- $SU(3)_c$: Color
- $SU(2)_L$: Isospin
- $U(1)_Y$: Hypercharge

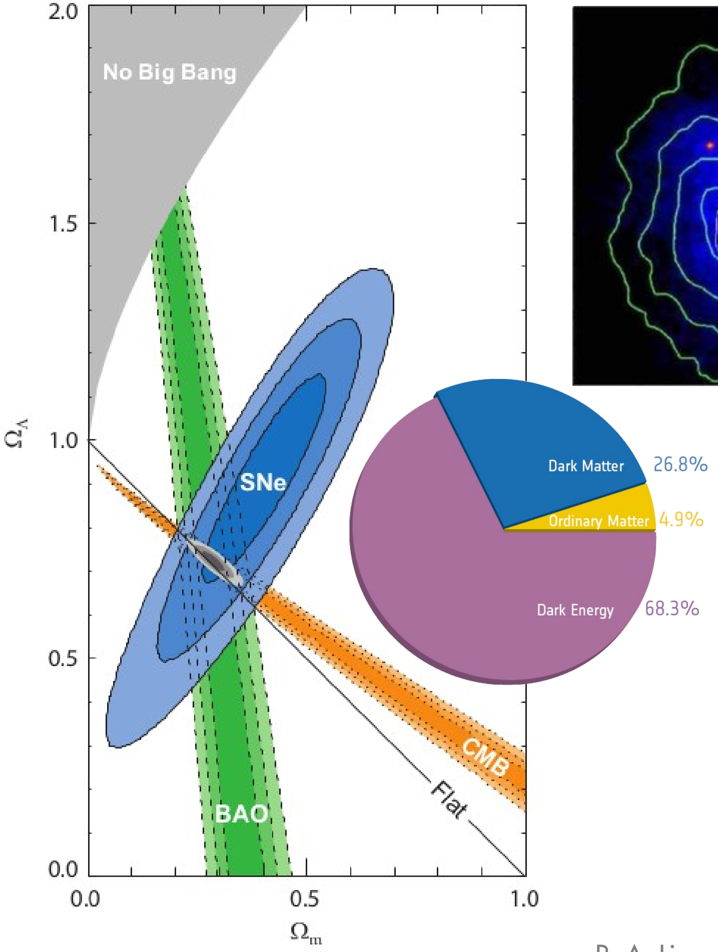
Matter content

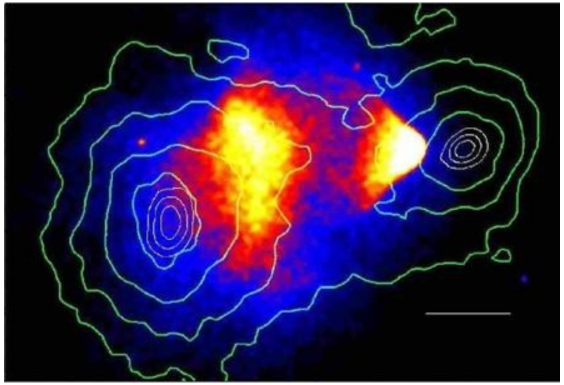
- 3 families quarks
- 3 families leptons

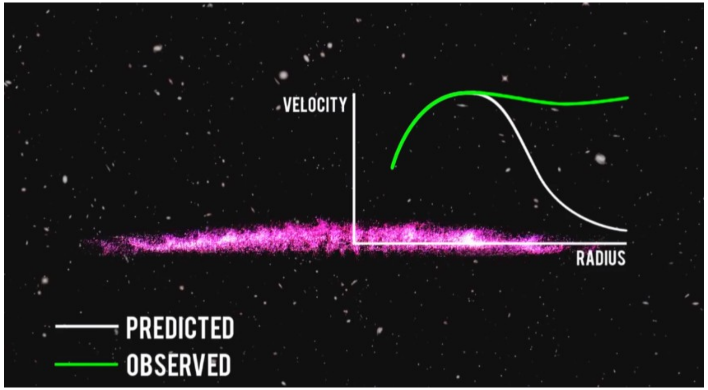
Higgs field

- $SU(2)_L x U(1)_Y \rightarrow U(1)_{EM}$
- Mass to fundamental particles

Dark Matter





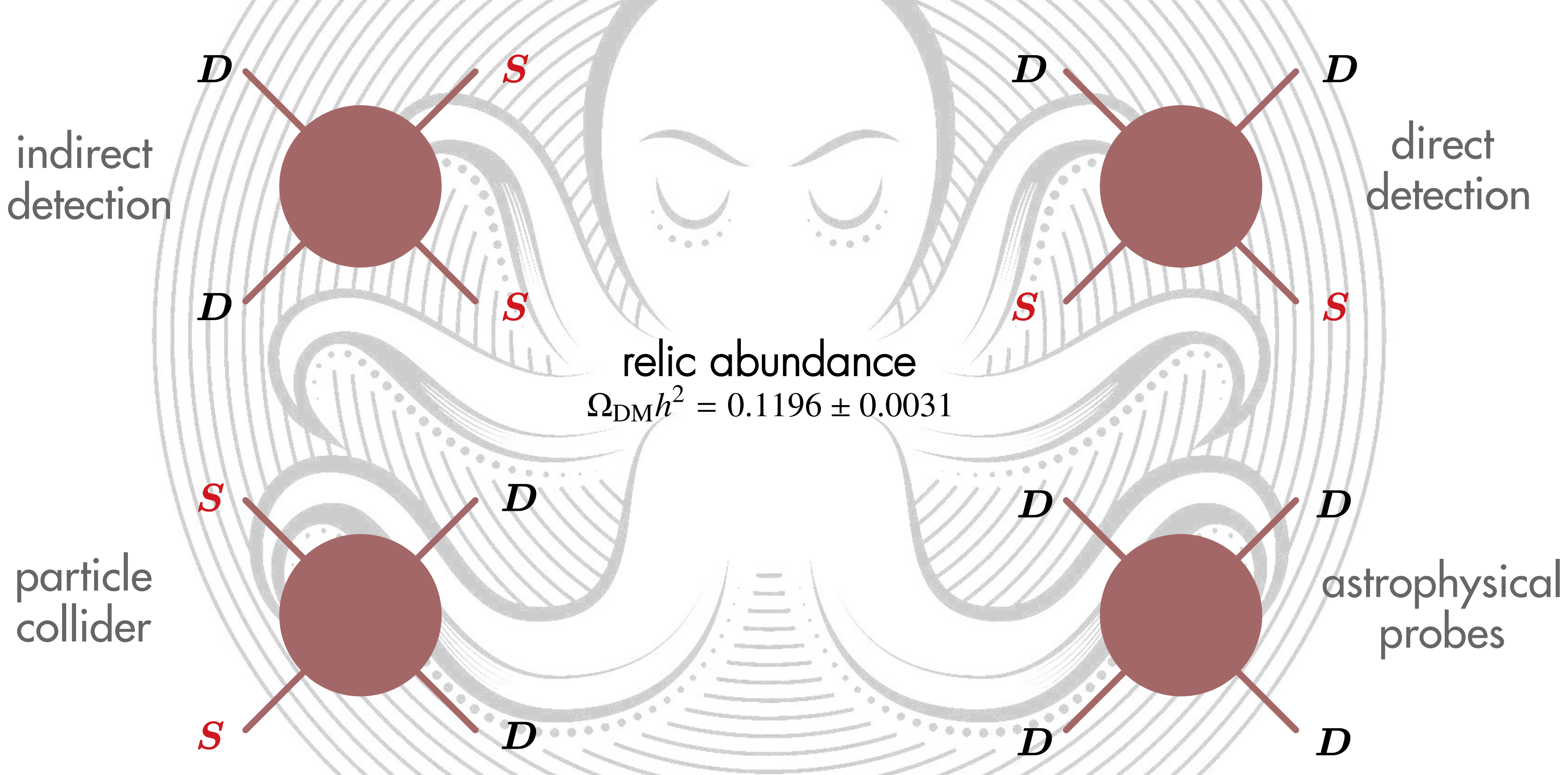


Observations support Dark Matter

- Dynamics of clusters and galaxies
- Structure formation
- CMB anisotropies
- Baryon Acoustic Oscillation

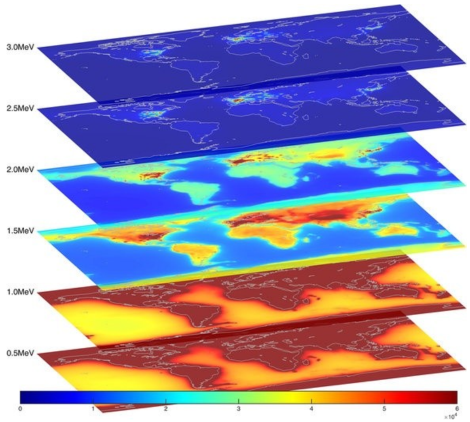
$$\Omega_{DM}h^2 = 0.1196 \pm 0.0031$$

Dark Matter Searches

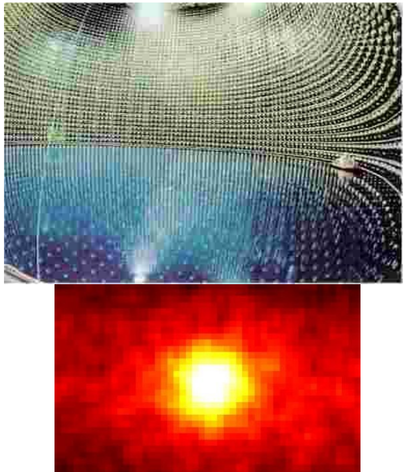


Design Credits: Vecteezy!

Neutrinos

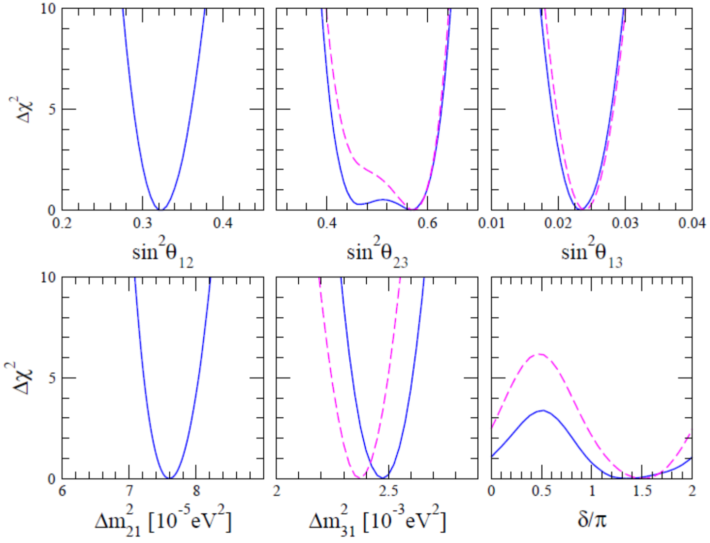


AGM2015: Antineutrino Global Map 2015



Super-K:
Neutrinos in the Sun

Forero, Tortola and Valle PRD 90 (2014) 093006



The SM predicts zero neutrino mass

Beyond SM physics is required to explain mass spectrum and mixing angles

Neutrino mass mechanisms

A large fraction of the models uses the 5-dim Weinberg operator to generate majorana neutrino masses

$$\mathcal{O}_{5ij} = \frac{1}{\Lambda} (L_i H)^T (L_j H)$$

This operator preserves SM symmetries but it breaks lepton number in **2 units**

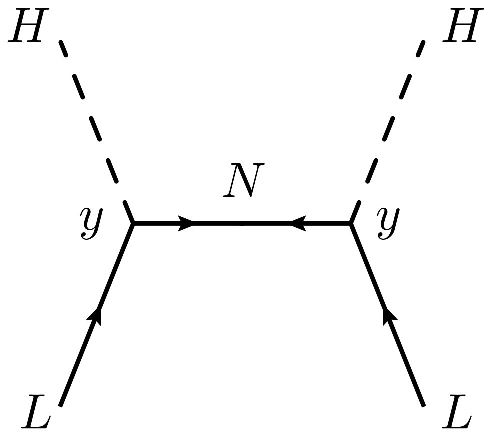
$$\mathcal{O}_{5ij} = \frac{v^2}{\Lambda} \nu_j \nu_i = M_{ij} \nu_j \nu_i$$

Neutrino mass mechanisms

The most known schemes are see-saw mechanisms

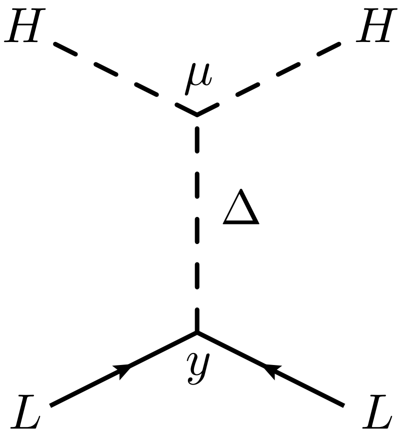
$\mathcal{O}_{5ij}$

Type-I



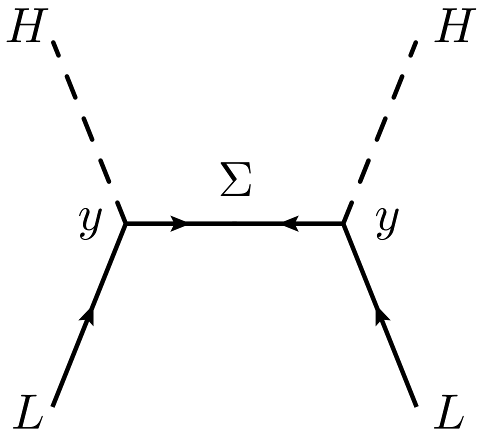
$$m_\nu \propto \frac{v^2 y^2}{M_N}$$

Type-II



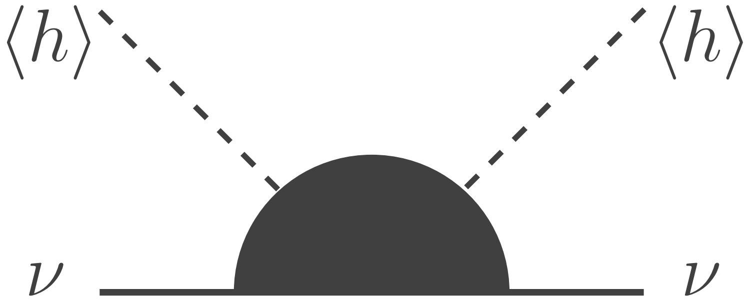
$$m_\nu \propto \frac{v^2 y \mu}{M_\Delta^2}$$

Type-III



$$m_\nu \propto \frac{v^2 y^2}{M_\Sigma}$$

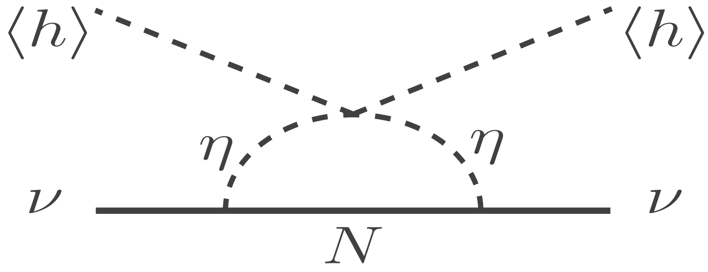
Radiative seesaw



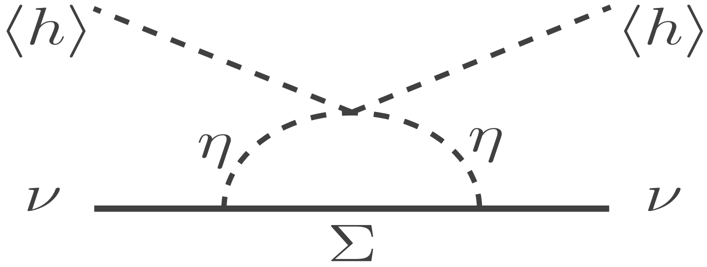
To connect neutrino mass mechanism and dark matter

(See Restrepo et al. JHEP arxiv:1308.3655)

We focus on scotogenic models:



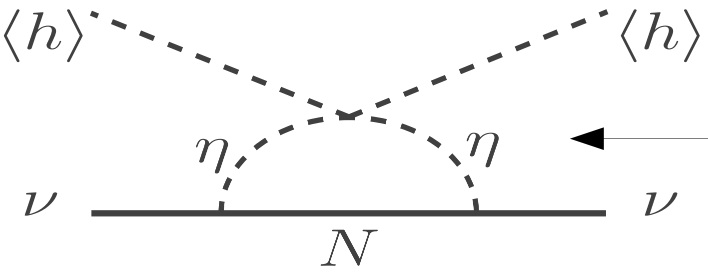
E. Ma, Phys.Rev.D73:077301,2006



E. Ma, D. Suematsu Mod.Phys.Lett.A24:583-589,2009

Scotogenic models

Type I

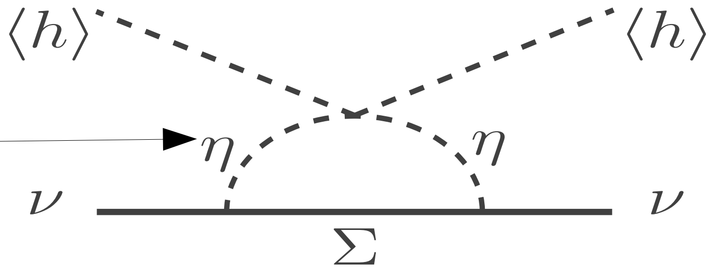


Fermion singlet

E. Ma, Phys.Rev.D73:077301,2006

Scalar SU(2) doublet

Type II



Fermion SU(2) triplet

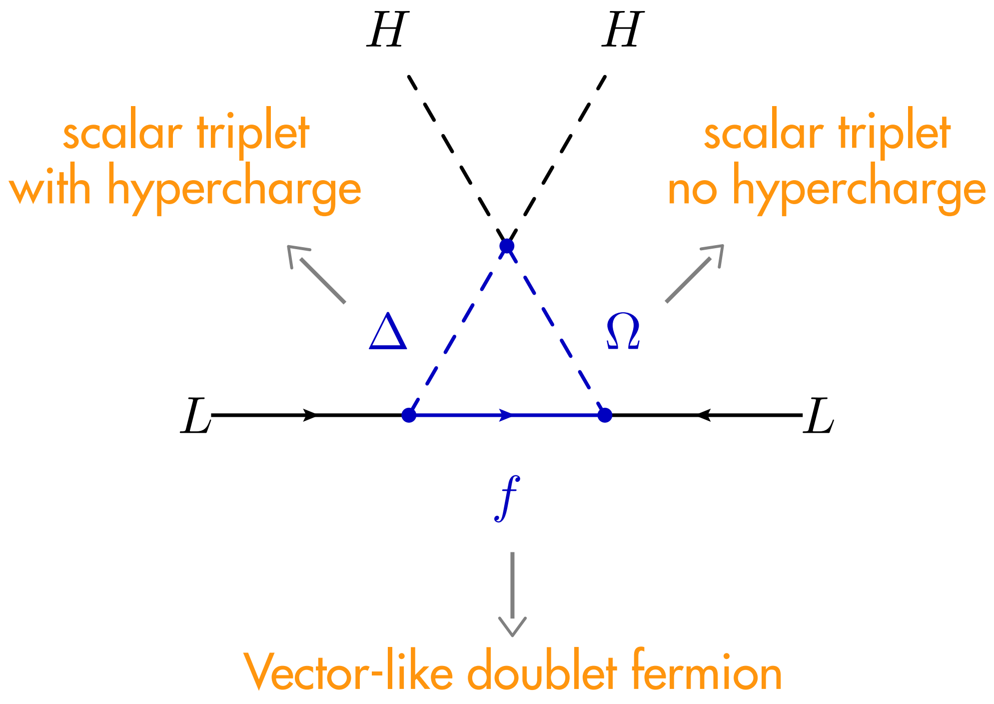
E. Ma, D. Suematsu Mod.Phys.Lett.A24:583-589,2009

DM candidates:

Type I: $N\,\eta^0\,\eta^A$

Type III: $\Sigma^0\,\eta^0\,\eta^A$

A type-II inspired Scotogenic model



The minimal construction of the model requires:

- 2 scalar triplets
- 2 fermion doublets (vector-like)

DM candidates:

$$S_1^0 \quad \tilde{S}^0 \quad f^0$$

CP-even scalar

CP-odd scalar

Dirac fermion

Charge assignment

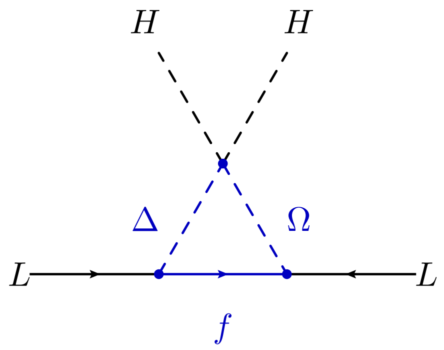
Field	L_i	f_L	f_R	Δ	Ω	H
Spin	1/2	1/2	1/2	0	0	0
Chirality	L	L	R	–	–	–
$\mathbf{SU(2)}_L$	**2**	**2**	**2**	**3**	**3**	**2**
$\mathbf{U(1)}_Y$	-1/2	1/2	1/2	1	0	1/2
$\mathbb{Z}_2$	+1	-1	-1	-1	-1	+1

The Z2 symmetry is the minimal addition to the model, besides the fields

After considering, neutrino masses, scalar potential minimization and stability, and minimal DM phenomenology.

The DM candidate is only one: S_1^0

The model's lagrangian



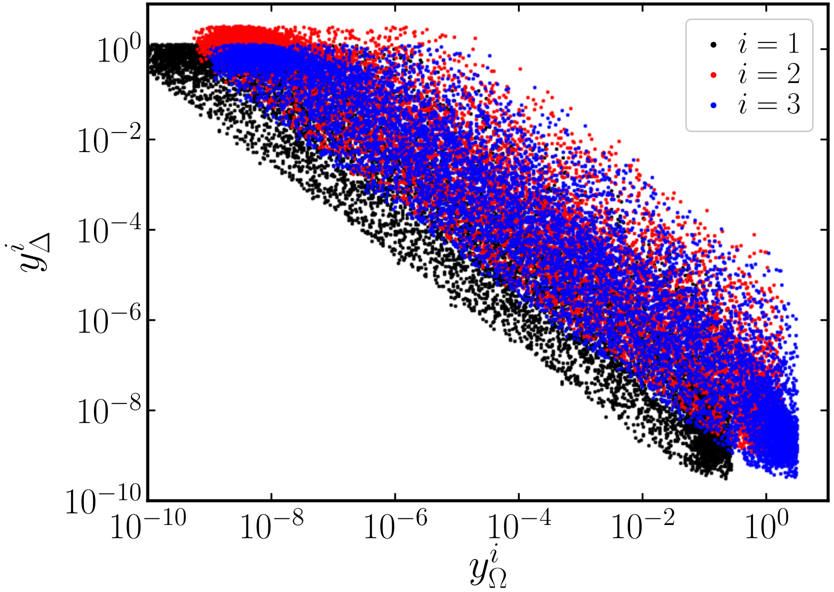
$$\mathcal{L} \supset -y^i_\Delta \left(\overline{f_R} \Delta L_i + \text{h.c.} \right) - y^i_\Omega \left(\overline{f^c_L} i \sigma_2 \Omega L_i + \text{h.c.} \right) - m_f \left(\overline{f_L} f_R + \overline{f_R} f_L \right) - V_\text{scalar}$$

$$\begin{aligned} V_\text{scalar} =& -\mu_h^2 |H|^2 + \lambda_h |H|^4 + \frac{m^2_\Delta}{2} \text{Tr}\left[\Delta^\dagger \Delta\right] + \frac{\lambda_\Delta}{4} \text{Tr}\left[\Delta^\dagger \Delta \Delta^\dagger \Delta\right] + \frac{\lambda'_\Delta}{4} \text{Tr}\left[\Delta^\dagger \Delta\right]^2 \\ &+ \frac{m^2_\Omega}{4} \text{Tr}\left[\Omega^\dagger \Omega\right] + \frac{\lambda_\Omega}{16} \text{Tr}\left[\Omega^\dagger \Omega\right]^2 + \frac{1}{8} \lambda_{\Delta\Omega} \text{Tr}\left[\Delta^\dagger \Delta\right] \text{Tr}\left[\Omega^\dagger \Omega\right] \\ &+ \frac{1}{2} \lambda_{H\Delta} H^\dagger \Delta \Delta^\dagger H + \frac{1}{2} \lambda'_{H\Delta} \text{Tr}\left[\Delta^\dagger \Delta\right] H^\dagger H + \frac{1}{2} \lambda_{H\Omega} H^\dagger \Omega \Omega^\dagger H \\ &+ \frac{1}{4} s_\kappa \kappa \left(H^T \widetilde{\Delta} \Omega H + \text{h.c.} \right) \end{aligned}$$

Neutrino masses

The scotogenic mechanism in this model gives non-zero mass to 2 neutrino, but one remains massless.

$$m_{ij} = \frac{1}{16\sqrt{2}\pi^2}\left(y_\Delta^i y_\Omega^j + y_\Omega^i y_\Delta^j\right) m_f\, F_{\rm loop}(m_{S^0_{1,2}}, m_{S^\pm_{1,2}}, m_f)$$

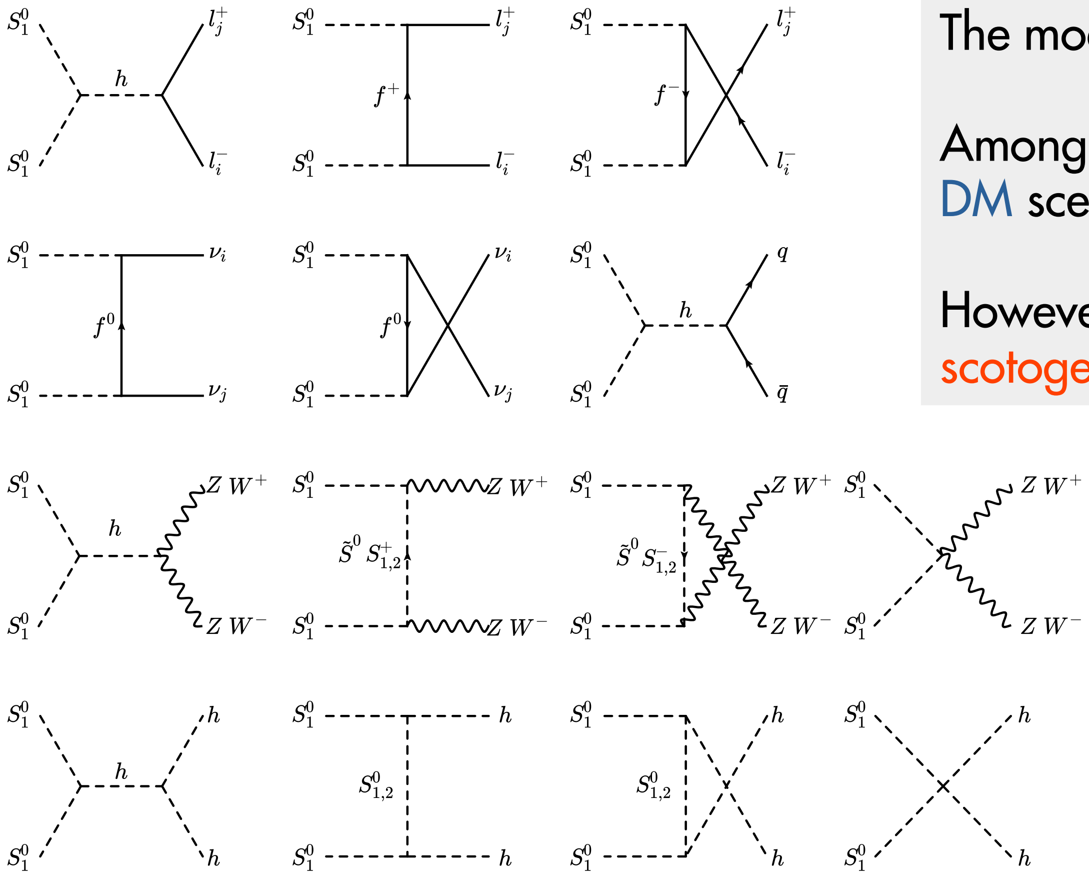


$$\begin{aligned} m_{\nu_1} &= 0 \\ m_{\nu_2} &= -2\hat{y}_\Delta \hat{y}_\Omega \sin^2(\phi_N) m_f F_{\rm loop} \\ m_{\nu_3} &= -2\hat{y}_\Delta \hat{y}_\Omega \cos^2(\phi_N) m_f F_{\rm loop} \end{aligned}$$

$$\phi_N \equiv \arctan\left[\left(\Delta m^2_{21}/\Delta m^2_{32}\right)^{1/4}\right]$$

$$\hat{y}_\Omega \equiv \frac{\sqrt{\Delta m^2_{21}}}{2\hat{y}_\Delta \sin^2(\phi_N) m_f F_{\rm loop}}$$

Indirect searches channels

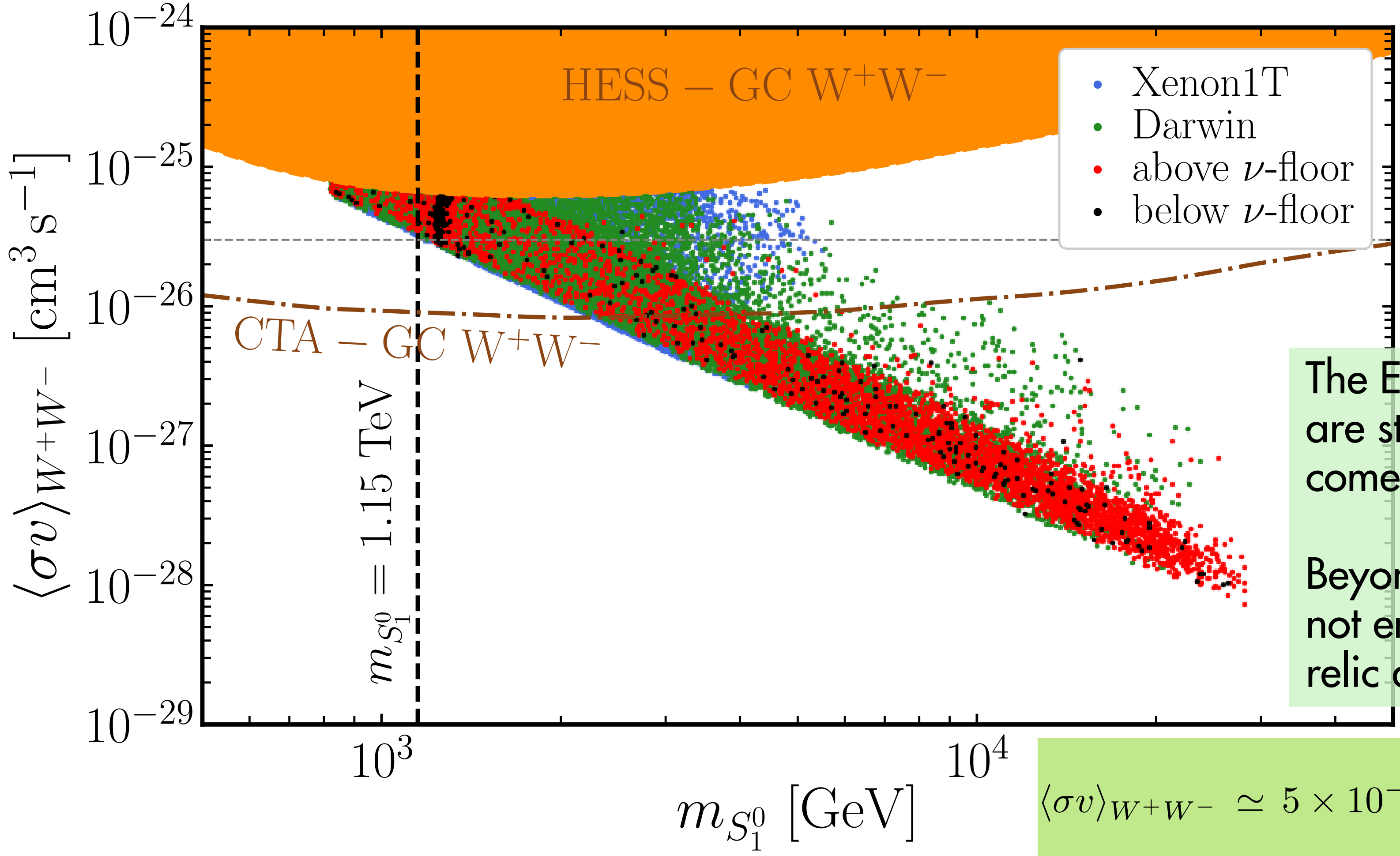


The model has many annihilation channels.

Among them some are shared with Minimal DM scenarios

However other are genuine due to the scotogenic construction

Indirect searches: W channel

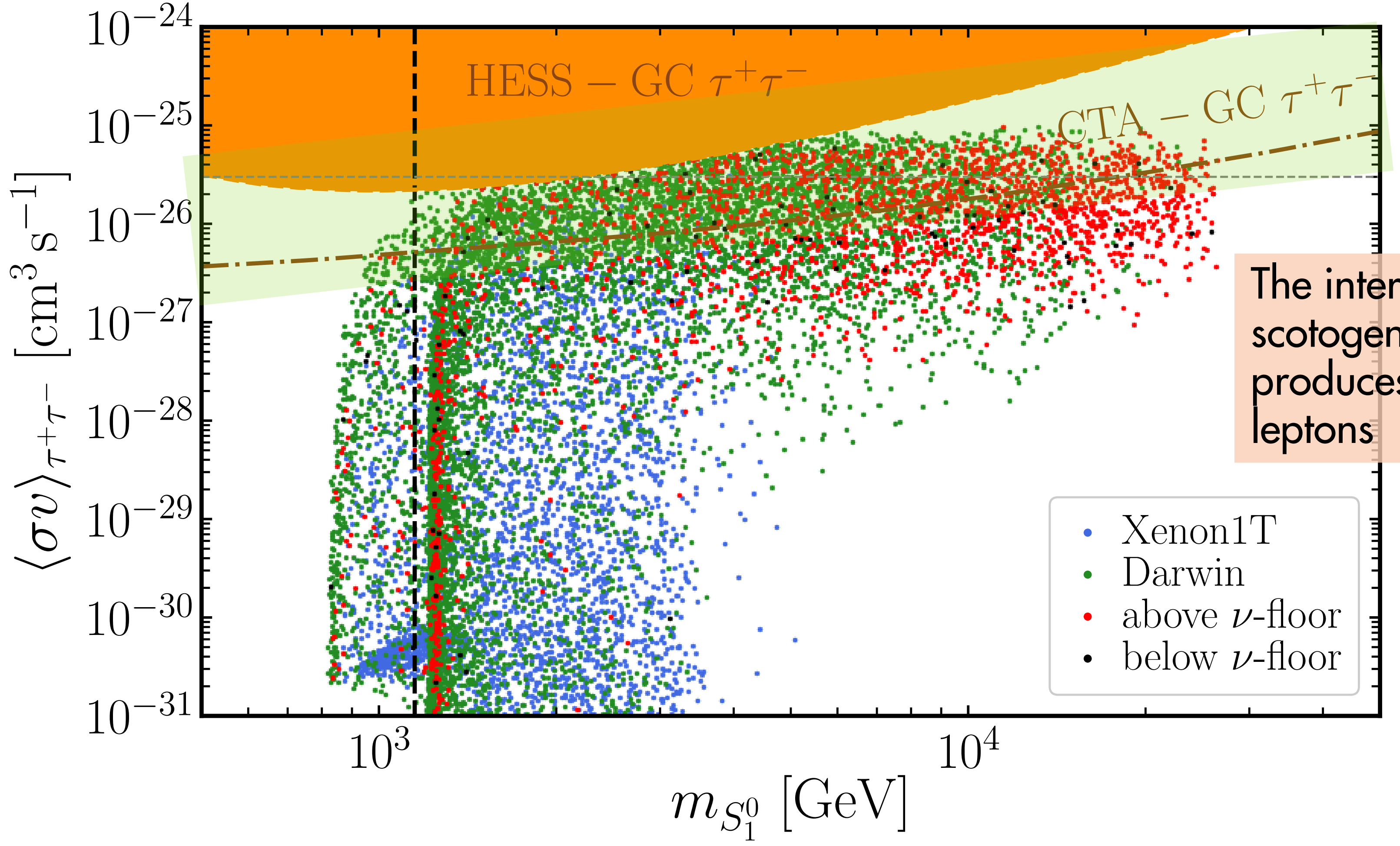


The ElectroWeak channel are strong due to DM comes from triplets.

Beyond ~1.5 TeV, those are not enough to explain DM relic abundance

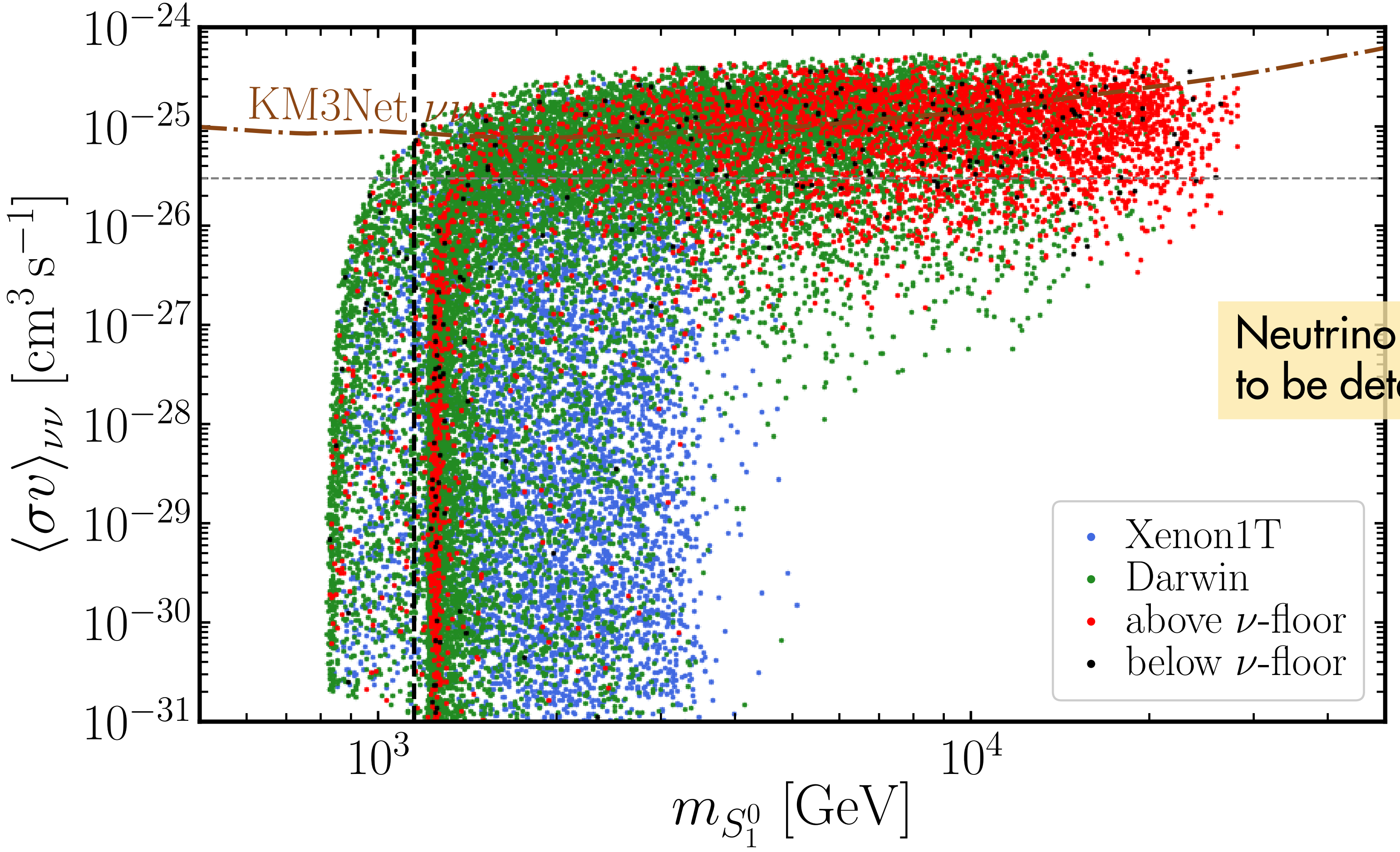
$$\langle \sigma v \rangle_{W^+W^-} \simeq 5 \times 10^{-26}\,\mathrm{cm}^3\,\mathrm{s}^{-1} \left(\frac{1.15\ \mathrm{TeV}}{m_{S_1^0}} \right)^2$$

Indirect searches: tau channel



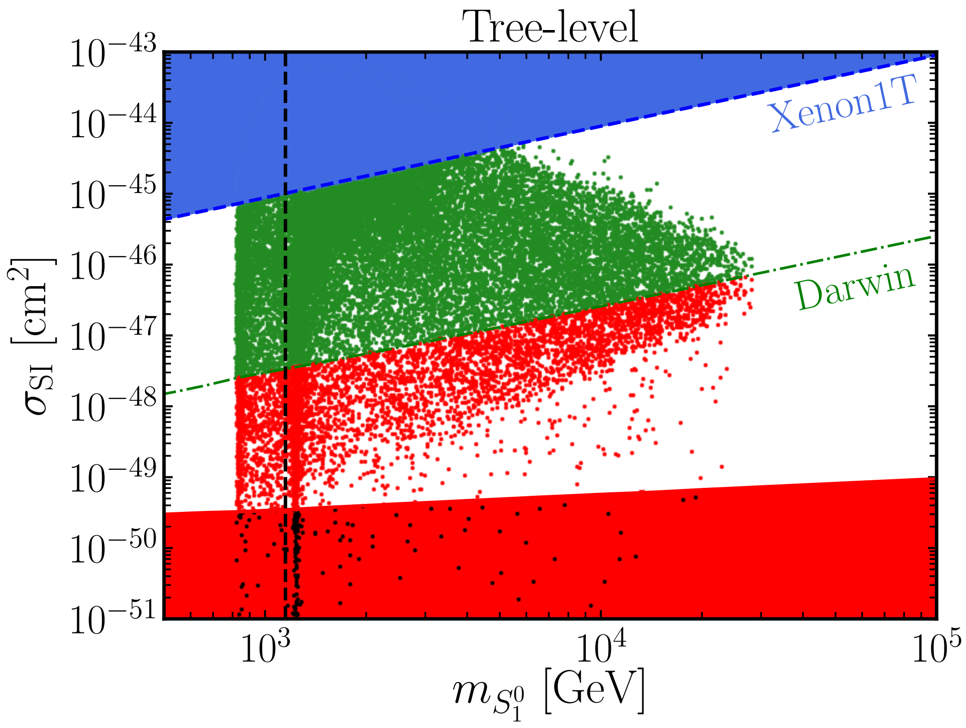
The interaction due to the scotogenic mechanism produces a large flux into leptons

Indirect searches: neutrinos

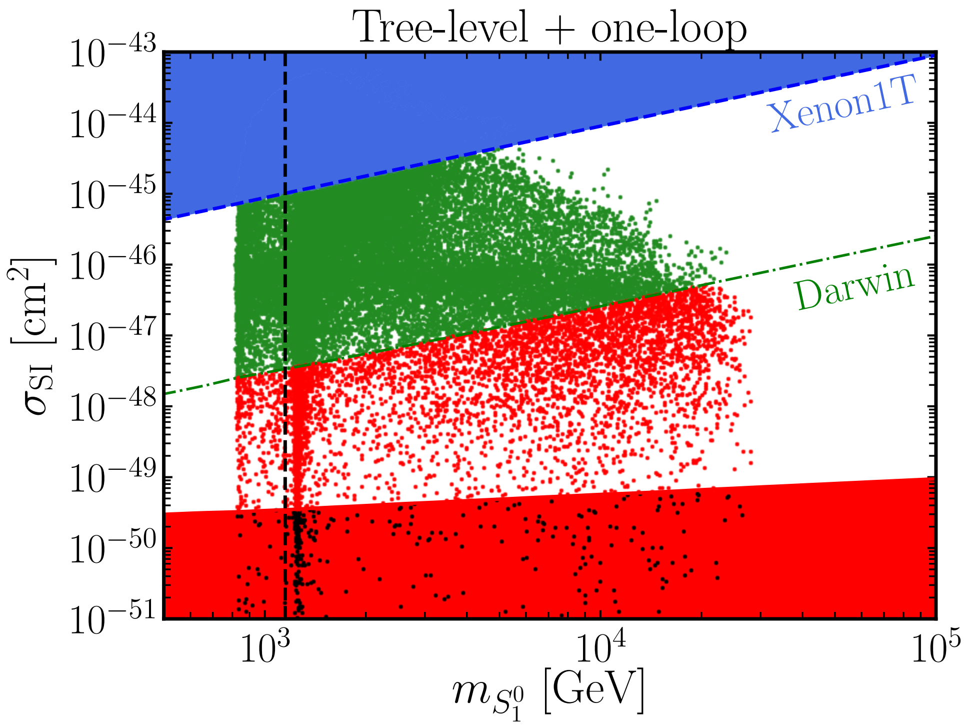


Neutrino flux large enough to be detected in KM3Net

Direct detection: Tree-level vs One-loop



Higgs portal



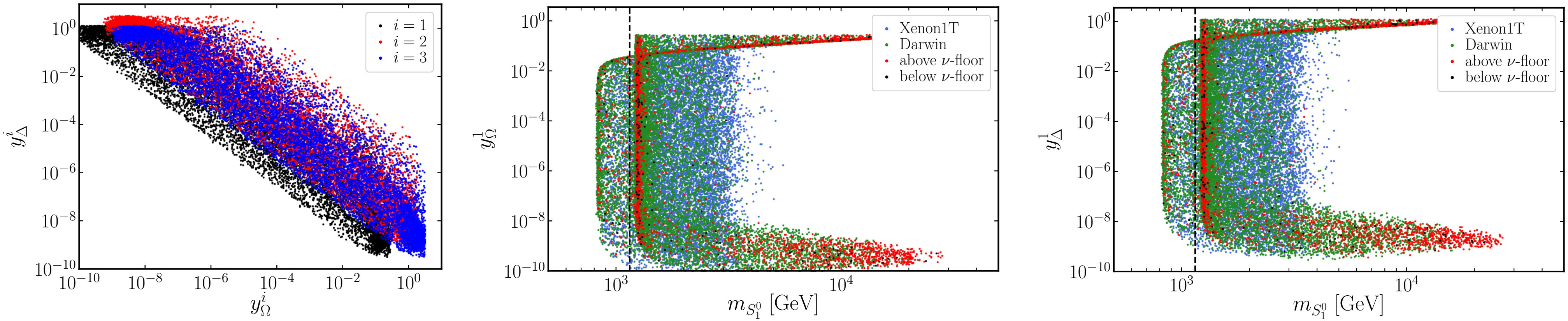
Higgs portal + electroweak loops

Conclusions

- Neutrinos observables and DM are keys to unveil New Physics
- Scotogenic mechanism connects DM stability and neutrino masses
- A type-II seesaw inspired scotogenic model provide an interesting TeV DM candidate
- The complementarity between CTA, KM3Net, and Darwin is key to explore the model.


Thanks

Neutrino masses



$$m_{\nu_1} = 0\,,$$

$$m_{\nu_2} = -2\hat{y}_\Delta \hat{y}_\Omega \sin^2(\phi_N) m_f F_{\rm loop}(m_{S^0_{1,2}}, m_{S^\pm_{1,2}}, m_f)\,,$$

$$m_{\nu_3} = -2\hat{y}_\Delta \hat{y}_\Omega \cos^2(\phi_N) m_f F_{\rm loop}(m_{S^0_{1,2}}, m_{S^\pm_{1,2}}, m_f)\,.$$