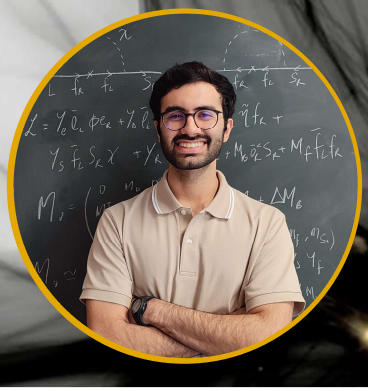

The Dark Side of Neutrinos

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PhD Programme: Neutrinos: a window to the Universe

Supervisors:

Filipe Joaquim (CFTP/IST)
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2022: MSc in Physics

MSc Thesis:
h to ϒγ as a Novel Probe for New Physics

Supervisor:
Rahul Srivastava

MSc Thesis

Highlighted Publications:

- **Axion framework with color-mediated Dirac neutrino masses**
  A. Batra, H.B. Câmara, F.R. Joaquim, N. Nath, R. Srivastava, J.W.F. Valle
  Published in: Phys.Lett.B 868 (2025) 139629
- **Axion paradigm with color-mediated neutrino masses**
  A. Batra, H.B. Câmara, F.R. Joaquim, R. Srivastava, J.W.F. Valle
  Published in: Phys.Rev.Lett. 132 (2024) 5, 051801
- **Dark linear seesaw mechanism**
  A. Batra, H.B. Câmara, F.R. Joaquim
  Published in: Phys.Lett.B 843 (2023) 138012
- **Phenomenology of the simplest linear seesaw mechanism**
  A. Batra, P. Bharadwaj, S. Mandal, R. Srivastava, J.W.F. Valle
  Published in: JHEP 07 (2023) 221
- **h→ϒγ Decay: Smoking Gun Signature of Wrong-Sign hbb Coupling**
  A. Batra, S. Mandal, R. Srivastava
  e-Print: 2209.01200 [hep-ph]

Full Publication List

Talks at international conferences:

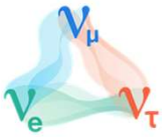
- **FLASY 2025** - 11th Workshop on Flavour Symmetries and Consequences in Accelerators and Cosmology (Roma Tre, Italy)
- **Corfu2024** - Workshop on Standard Model and Beyond (Corfu, Greece)
- **ISAPP 2024** - Particle Candidates for Dark Matter (SGGS, Padua, Italy)
- **PLANCK2024** - The 26th International Conference "From the Planck Scale to the Electroweak Scale" (IST, Lisboa, Portugal)

UIDB/00777/2020,
UIDP/00777/2020,
CERN/FIS-PAR/0019/2021,
UI/BD/154391/2023

The problems: the **Standard Model** cannot explain:

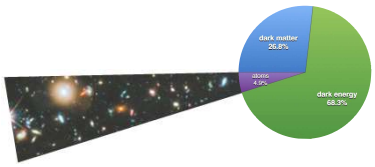
Neutrino flavour oscillations

- Neutrinos can change from one type to the other while they propagate.
- This is only possible if they have non-zero masses.



Observed Dark Matter abundance

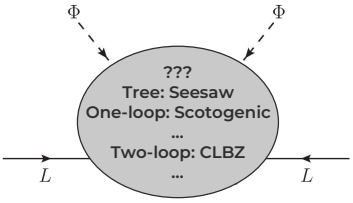
- Cosmological evidence suggests that 26.8% of the total matter in the Universe appears in the form of dark matter.



Neutrino masses

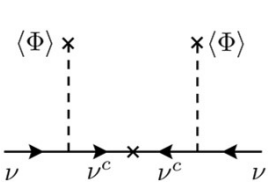
The unique lowest-dimensional effective operator that can be added to the Standard Model is the dimension-five **Weinberg operator**. This operator leads to **Majorana masses** for neutrinos after electroweak symmetry breaking.

$$-\mathcal{L}^{d=5}_{\text{Maj.}} = \frac{\kappa_{\text{Maj.}}}{\Lambda}\,(\bar{L}^c\tilde{\Phi}^*)(\tilde{\Phi}^\dagger L) + \text{H.c.}$$



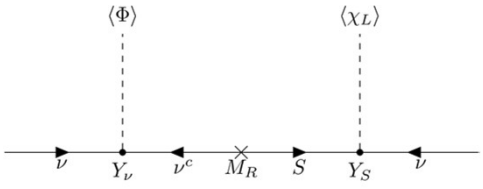
Popular solutions

Type-I Seesaw Model



$$m_\nu \sim \frac{v_\Phi^2}{M_R}$$

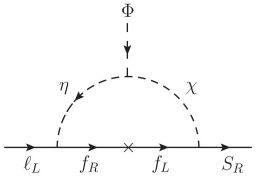
Linear Seesaw Model



$$m_\nu \sim \frac{v_\Phi v_\chi}{M_R}$$

- The **Type-I Seesaw** is by far the **simplest solution** to the neutrino mass problem.
- A major drawback of this model is the large mass scale of the right-handed neutrinos, far away from the reach of current experiments.
- **The Linear Seesaw**, despite being more complicated, is a **low-scale solution** that offers more testability prospects at ongoing experiments.

Our approach:



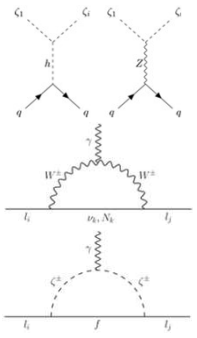
The **lepton number symmetry** is violated by the scalar potential term:

$$V_{\text{soft}} = \kappa\,(\eta^\dagger\Phi)\,\chi + \text{H.c.}\,,$$

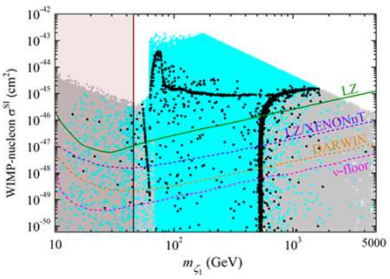
	Fields	$SU(2)_L \otimes U(1)_Y$	$U(1)_L$	$\mathcal{Z}_2$
Fermions	L	$(\mathbf{2},-1)$	1	+
	e_R	$(\mathbf{1},2)$	1	+
	ν_R	$(\mathbf{1},0)$	1	+
	S_R	$(\mathbf{1},0)$	-1	+
	$f_{L,R}$	$(\mathbf{1},0)$	-1	-
Scalars	Φ	$(\mathbf{2},1)$	0	+
	η	$(\mathbf{2},1)$	-2	-
	χ	$(\mathbf{1},0)$	0	-

We propose a model where the **low-scale linear seesaw** neutrino mass generation mechanism is seeded by cosmologically stable dark matter particles accounting for both **neutrino flavour oscillations** and the observed **dark matter** abundance.

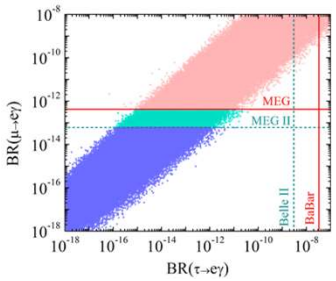
The results



Dark matter direct detection



Charged lepton flavour violation



The **scalar dark matter** particles can interact with normal matter directly through the Higgs or Z boson. Furthermore, the new particles can mediate **charged lepton flavour violating decays** with sizable branching ratios. Therefore, our model can be probed through these processes at various current and upcoming experiments.