# The Standard Model is very successful but...

- Neutrinos have masses ($\nu$SM)
- Dark matter (no viable explanation) - MH? FS?
- Matter / antimatter asymmetry (no viable explanation) - MH? FS?
- Hierarchy problem (fine-tuning between parameters)
- Strong CP problem (fine-tuning between parameters)
- Gauge couplings (additional free parameters) - GUT?
- Flavour problem (many additional free parameters) - FS?

BSM solutions involve additional fields and symmetries, like MH and FS.

# The Standard Model

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Chiral spin $1/2$ fermions (left and right)
Quarks: colour triplets of $SU(3)_C$
Left fermions are doublets of $SU(2)_L$
Spin 0 scalar, doublet of $SU(2)_L$

# The Standard Model (1 generation)

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Quarks ($Q$, $u_R$, $d_R$): colour triplets of $SU(3)_C$
LH fields ($Q$ and $L$): doublets of $SU(2)_L$
$e_R$ just $U(1)_Y$
($\nu$SM: add $\nu_R$, complete singlet)

Scalar $H$ also doublet of $SU(2)_L$
$\langle H \rangle$ breaks $SU(2)_L \times U(1)_Y \to U(1)_{em}$

Mass terms: $m_f F_\alpha f_R$ not invariant under $SU(2)_L$

But $y_f(\epsilon^{\alpha\beta} H_\alpha F_\beta) f_R$ is...
$y_f \langle H \rangle F f_R \to m_f F f_R$ with $m_f = y_f \langle H \rangle$

# Multi-Higgs models

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Quarks ($Q$, $u_R$, $d_R$): colour triplets of $SU(3)_C$
LH fields ($Q$ and $L$): doublets of $SU(2)_L$
$e_R$ just $U(1)_Y$
($\nu$SM: add $\nu_R$, complete singlet)

Scalars $H_i$, doublets of $SU(2)_L$
Potential $V(H_i)$, Yukawa couplings, with each $H_i$...
Proliferation of parameters? Symmetries!

# The Standard Model (3 generations)

Gauge group: $SU(3)_C \times SU(2)_L \times U(1)_Y$

Quarks ($Q^i$, $u_R^j$, $d_R^k$): colour triplets of $SU(3)_C$
LH fields ($Q^i$ and $L^i$): doublets of $SU(2)_L$
$e_R^j$ just $U(1)_Y$
($\nu$SM: add $\nu_R^k$, complete singlet)

Scalar $H$ also doublet of $SU(2)_L$
$\langle H \rangle$ breaks $SU(2)_L \times U(1)_Y \to U(1)_{em}$

Mass terms: $M_{ij} F_\alpha^i f_R^j$ not invariant under $SU(2)_L$

But $Y_{ij}(\epsilon^{\alpha\beta} H_\alpha F_\beta^i) f_R^j$ is...
$Y_{ij}\langle H \rangle F^i f_R^j \to M_{ij} F^i f_R^j$
Proliferation of parameters? Symmetries!

# Papers with PhD student Miguel Levy

## Citation Summary

Exclude self-citations

| | Citeable | Published |
|---|---|---|
| Papers | **7** | **6** |
| Citations | **94** | **89** |
| h-index | **5** | **5** |
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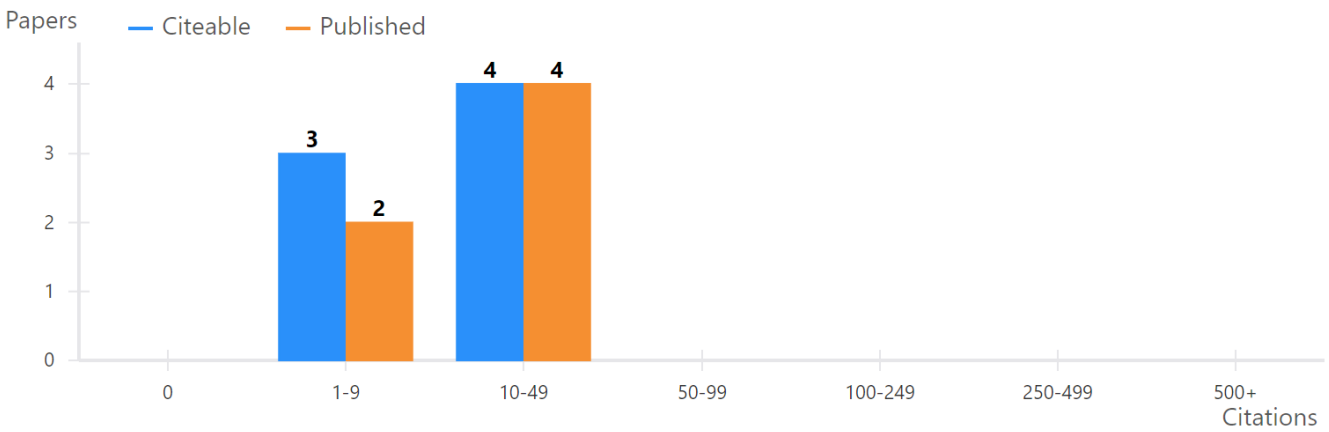


### A Modular $SU(5)$ Littlest Seesaw

#1

Ivo de Medeiros Varzielas (Lisbon, CFTP and Lisbon, IST), Steve F. King (Southampton U.), Miguel Levy (Lisbon, CFTP and Lisbon, IST) (Sep 27, 2023)

e-Print: 2309.15901 [hep-ph]

pdf cite claim reference search 5 citations

# Papers with Master student Diogo Ivo

Regular Article - Theoretical Physics | Open Access | Published: 07 May 2022

## Softly-broken $A_4$ or $S_4$ 3HDMs with stable states

Ivo de Medeiros Varzielas & Diogo Ivo

*The European Physical Journal C* **82**, Article number: 415 (2022) | Cite this article

# Papers with Master student João Lourenço

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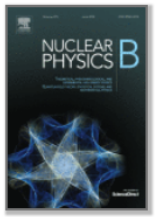
Nuclear Physics B

Volume 979, June 2022, 115793




## Two A4 modular symmetries for Tri-Maximal 2 mixing

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# Multi-Higgs and Flavour with symmetries

## Conclusion

- Models with Multi-Higgs and symmetries are a very natural extension of the Standard Model
- Models with Family Symmetry are a very natural extension of the Standard Model
- Viable research opportunities for interested students