

Gauged Lepton number

with *dark matter* and *dark baryogenesis*



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Focus on

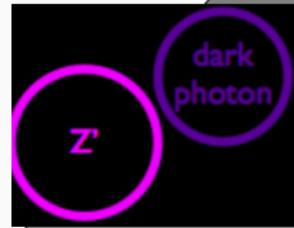
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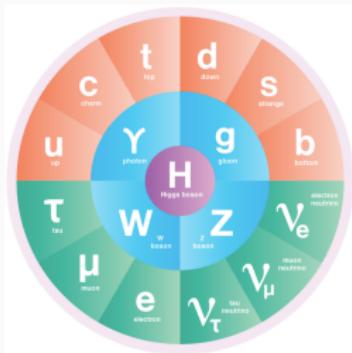
In collaboration with

Leonardo Leite, Orlando Peres, William Novelo (UNICAMP), David Suárez (UdeA)

Dark sectors







Local $U(1)\chi$

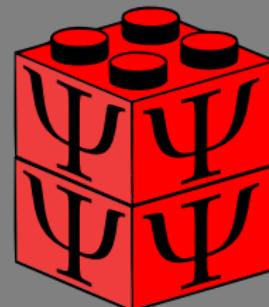
$$\mathcal{L} = -\frac{1}{4} V_{\mu\nu} V^{\mu\nu} + i \sum_i \psi_i^\dagger \mathcal{D} \psi_i - h (\psi_1 \psi_2 \Phi + \text{h.c.})$$

Anomalons: SM-singlet Dirac fermion
dark matter $m_\Psi = h\langle\Phi\rangle$

LHC production:

Gauged Symmetry: $\mathcal{X} \rightarrow D$:

Gauged Symmetry: $\mathcal{X} \rightarrow X$:



$$\bar{\Psi}\Psi = \psi_1\psi_2 + \psi_1^\dagger\psi_2^\dagger \rightarrow \psi_\alpha\psi_\beta\Phi^{(*)}, \quad \alpha = 1, \dots, N \rightarrow N > 4$$



Local $U(1)\chi$

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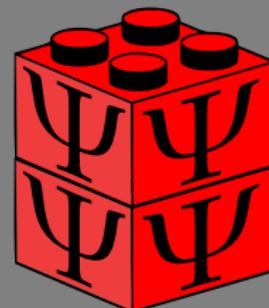
Anomalons: SM-singlet Dirac fermion
dark matter $m_\Psi = h\langle\Phi\rangle$

LHC production:

$$F_{\mu\nu}, V^{\mu\nu}$$

Gauged Symmetry: $\mathcal{X} \rightarrow B$: $q\bar{q} \rightarrow Z' \rightarrow \text{jets}$

Gauged Symmetry: $\mathcal{X} \rightarrow L$:



$$\bar{\Psi}\Psi = \psi_1\psi_2 + \psi_1^\dagger\psi_2^\dagger \rightarrow \psi_\alpha\psi_\beta\Phi^{(*)}, \quad \alpha = 1, \dots, N \rightarrow N > 4$$



Local $U(1)_{\mathcal{X}}$

$$\mathcal{L} = -\frac{1}{4} V_{\mu\nu} V^{\mu\nu} + i \sum_i \psi_i^\dagger \mathcal{D} \psi_i - h (\psi_1 \psi_2 \Phi + \text{h.c.})$$

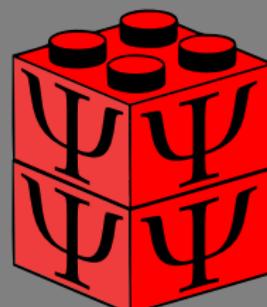
Anomalons: SM-singlet Dirac fermion
dark matter $m_\Psi = h\langle\Phi\rangle$

LHC production:

$$F_{\mu\nu} V^{\mu\nu}$$

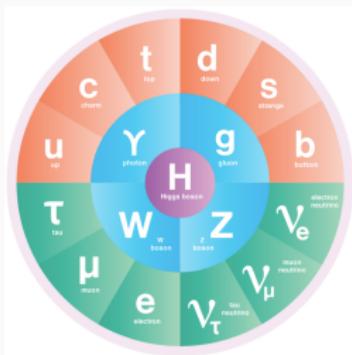
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$$\alpha = 1, \dots N \rightarrow N > 4$$



$$F_{\mu\nu} V^{\mu\nu}$$

Local $U(1)_{\mathcal{X}}$

$$\mathcal{L} = -\frac{1}{4} V_{\mu\nu} V^{\mu\nu} + i \sum_i \psi_i^\dagger \mathcal{D} \psi_i - y (\psi_1 \psi_2 S + \text{h.c})$$

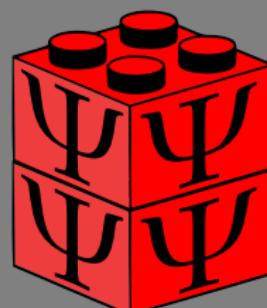
Anomalons: SM-singlet Dirac fermion

CP violation Yukawa y

LHC production:

Gauged Symmetry: $\mathcal{X} \rightarrow B: q\bar{q} \rightarrow Z \rightarrow \text{jets}$

Gauged Symmetry: $\mathcal{X} \rightarrow L:$



$$\bar{\Psi}\Psi = \psi_1\psi_2 + \psi_1^\dagger\psi_2^\dagger \rightarrow \psi_\alpha\psi_\beta\Phi^{(*)},$$

$$\alpha = 1, \dots N \rightarrow N > 4$$

Anomaly cancellation

Any local Abelian extension of the Standard Model can be reduced to a set of integers which must satisfy the gravitational anomaly, $[SO(1, 3)]^2 U(1)_Y$, and the cubic anomaly, $[U(1)_X]^3$ conditions:

$$\sum_{\alpha=1}^N z_\alpha = 0, \quad \sum_{\alpha=1}^N z_\alpha^3 = 0, \quad (1)$$

- From a list of $N - 2$ integers, e.g., for N even

$$\mathbf{q} = [l_1, l_2, \dots, l_n, k_1, k_2, \dots, k_n], \quad n = (N - 2)/2. \quad (2)$$

in the range $[-m, m]$, build two vector-like solutions of N integers,

$$\mathbf{x} = [l_1, k_1, \dots, k_n, -l_1, -k_1, \dots, -k_n] \quad \mathbf{y} = [0, 0, l_1, \dots, l_n, -l_1, \dots, -l_n] \quad (3)$$

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- Obtain a (some times) non vector-like solution with $z_{\max} = 2m$

$$\mathbf{z} = \mathbf{x} \oplus \mathbf{y} = \left(\sum_{i=1}^N x_i y_i^2 \right) \mathbf{x} + \left(\sum_{i=1}^N x_i^2 y_i \right) \mathbf{y}, \quad (4)$$

- From a list of $N - 2$ integers, e.g., for N even

$$\mathbf{q} = [l_1, l_2, \dots, l_n, k_1, k_2, \dots, k_n], \quad n = (N - 2)/2. \quad (2)$$

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The parameter space to be explored with $z_{\max} = 20$ ($m = 10$) has 96 153 non vector-like solutions

$$\# \text{ of } \mathbf{q} \text{ lists} = (2m + 1)^{N-2} = \begin{cases} 9261 \rightarrow 3 & N = 5 \\ 194841 \rightarrow 38 & N = 6 \\ \vdots & \vdots \\ 1.6 \times 10^{13} \rightarrow 65910 & N = 12, \quad \text{instead } 10^{19} \end{cases} \quad (5)$$

- From a list of $N - 2$ integers, e.g., for N even

$$\mathbf{q} = [2, 3, -1, -3], \quad n = 6. \quad (2)$$

in the range $[-3, 3]$, build two vector-like solutions of 6 integers,

$$\mathbf{x} = [2, -1, -3, -2, 1, 3] \quad \mathbf{y} = [0, 0, 2, \dots, 3, -2, \dots, -3] \quad (3)$$

- Obtain a (some times) non vector-like solution with $z_{\max} = 2 \times 3 = 6$

$$\mathbf{z} = \mathbf{x} \oplus \mathbf{y} = \left(\sum_{i=1}^N x_i y_i^2 \right) \mathbf{x} + \left(\sum_{i=1}^N x_i^2 y_i \right) \mathbf{y}, \quad (4)$$

The parameter space to be explored with $z_{\max} = 20$ ($m = 10$) has 96 153 non vector-like solutions

$$\# \text{ of } \mathbf{q} \text{ lists} = (2m+1)^{N-2} = \begin{cases} 9261 \rightarrow 3 & N = 5 \rightarrow [1, -2, -3, 5, 5, -6] \\ 194841 \rightarrow 38 & N = 6 \\ \vdots & \vdots \\ 1.6 \times 10^{13} \rightarrow 65910 & N = 12, \quad \text{instead } 10^{19} \end{cases} \quad (5)$$

<https://pypi.org/project/anomalies/>

The screenshot shows the PyPI project page for 'anomalies' version 0.2.5. At the top, there's a search bar with the placeholder 'Search projects' and a magnifying glass icon. To the right of the search bar is a user icon labeled 'restrepo'. Below the header, the project name 'anomalies 0.2.5' is displayed in large blue text. Underneath the name is a button with the command 'pip install anomalies' and a pip icon. To the right of this button is a green button with a checkmark and the text 'Latest version'. Further to the right, the release date 'Released: Sep 6, 2022' is shown. In the bottom left corner of the main content area, there's a link 'Anomaly cancellation'. In the bottom right corner, there's a blue button labeled 'Manage project'. The overall background is dark blue.

Navigation

Project description

Release history

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Project links

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Statistics

GitHub statistics:



Project description

Anomalies

Python package: [passing](#) Upload Python Package: [passing](#) DOI: [10.5281/zenodo.5526558](#)

Implement the anomaly free solution of [arXiv:1905.13729](#) [PRL]:

Obtain a numpy array `z` of `N` integers which satisfy the Diophantine equations

```
>>> z.sum()
0
>>> (z**3).sum()
0
```

The input is two lists `l` and `k` with any $(N-3)/2$ and $(N-1)/2$ integers for N odd, or $N/2-1$ and $N/2-1$ for N even ($N > 4$). The function is implemented below under the name: `free(l,k)`

The screenshot shows a Jupyter Book interface with the following components:

- Header:** A navigation bar with icons for search, refresh, and download.
- Left Sidebar:** A sidebar titled "jupyter {book}" containing the book's title "Advanced Computation" and a search bar.
- Content Area:** The main content area displays the following text:

```
chunkszie=
```

Implementation.

 - Use the official module to find solutions
 - filter the chiral ones with a maximum integer of 32
 - Build a function suitable for multiprocessing

Functions

```
import numpy as np
import itertools
import sys
from anomalies import anomaly
import numpy as np
import time
import warnings
warnings.filterwarnings("ignore")

global zmax
zmax=32

z=anomaly.free

def _get_chiral(q,q_max=np.inf):
    #Normalize to positive minimum
    if 0 in q:
        #q=q[q!=0]
    return None,None
```

zenodo

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September 24, 2021

Dataset Open Access

Set of N integers between -30 and 30 with sum and cubic sum up to zero for 4<N<13

Diego Restrepo

Anomalies

Solutions obtained with the python package: [anomalies](#), based on the method to find anomaly free solutions of the standard model extended with an Abelian Dark Symmetry with N right-handed singlet chiral fields described in [arXiv:1905.13729 \[PRL\]](#).

Data scheme

- 'I': integer lists → input to obtain the 'solution' by using the [anomalies](#) package
- 'K': integer lists → input to obtain the 'solution' by using the [anomalies](#) package
- 'solution': list → of integers, z_i which satisfy $\sum_{i=1}^N z_i = 0$ and $\sum_{i=1}^N z_i^3 = 0$
- 'n': integer → number of integers in 'solution', N .

USAGE

```
#Example of JSON file usage in Python with pandas (see also json module)
>>> import pandas as pd
>>> df=pd.read_json('solutions.json.gz')
>>> df[:2]
      1          k      solution    gcd   n
0   [1, 2]  [0, -3]  [1, 5, -7, -8, 9]    1  5
1  [-2, -1]  [0, -1]  [2, 4, -7, -9, 10]    1  5
```

Data:

2 296 615 solutions with $5 \leq N \leq 12$ integers until '|32|' [JSON]

141 views 351 downloads See more details...

Indexed in

OpenAIRE

Publication date: September 24, 2021

DOI: DOI [10.5281/zenodo.7380817](https://doi.org/10.5281/zenodo.7380817)

Keyword(s):

Anomaly free Diophantine equations Abelian symmetry Gauge Symmetry

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Versions

Version v2 Sep 24, 2021
10.5281/zenodo.7380817

<https://pypi.org/project/yukawa/>

The screenshot shows the PyPI project page for 'yukawa 0.0.2'. The top navigation bar includes links for Help, Sponsors, Log in, and Register. A search bar is located at the top left. The main title 'yukawa 0.0.2' is displayed prominently. Below the title, there is a button with the command 'pip install yukawa' and a download icon. To the right of the title, there is a green button labeled 'Latest version' with a checkmark. A release note indicates the package was released 'about 9 hours ago'. The project description section states: 'Get massive fermions from a given scalar Abelian charge'. The 'Project description' sidebar contains links for 'Project description' (which is highlighted in blue), 'Release history', and 'Download files'. The 'Project links' sidebar includes a link to the 'Homepage'. The 'Statistics' sidebar shows GitHub statistics: 'Stars: 0'. The 'Project description' main content area includes a heading 'Yukawa couplings with spontaneous symmetry breaking (SSB)', status indicators for Python packages (both passing), and a brief description of the project's purpose. The 'Install' section shows the command '\$ pip install yukawa'.

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yukawa 0.0.2

`pip install yukawa`

✓ Latest version

Released: about 9 hours ago

Get massive fermions from a given scalar Abelian charge

Navigation

- Project description
- Release history
- Download files

Project links

- Homepage

Statistics

GitHub statistics:

★ Stars: 0

Project description

Yukawa couplings with spontaneous symmetry breaking (SSB)

Python package passing Upload Python Package passing

Given a list of integers as the Abelian charges of fermions, check if there is a scalar which which can generate Yukawa couplings and non-zero masses for all them after the SSB-

Install

```
$ pip install yukawa
```

USAGE

Simplest secluded model with SM-singlet massive chiral fermions from SSB: $U(1)_D$

$$\mathcal{L} = i\psi_i^\dagger \not{\partial} \psi_i - \frac{1}{4} V_{\mu\nu} V^{\mu\nu} + \sum_{i < j} h_{ij} \psi_i \psi_j \phi^{(*)} + \text{h.c} \quad (6)$$

96 153 \rightarrow 5 196 multi-component DM ($N = 8, 12$) \rightarrow 28 with two Dirac-fermion DM

Simplest secluded model with SM-singlet massive chiral fermions from SSB: $U(1)_D$

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96 153 \rightarrow 5 196 multi-component DM ($N = 8, 12$) \rightarrow 28 with two Dirac-fermion DM

$$z = [1, 2, 2, 4, -5, -5, -7, 8] \rightarrow \phi = 3 \rightarrow [(1, 2), (2, -5), (-5, 8), (4, -7)] \quad (7)$$

Simplest secluded model with SM-singlet massive chiral fermions from SSB: $U(1)_D$

$$\mathcal{L} = i\psi_i^\dagger \mathcal{D}\psi_i - \frac{1}{4} V_{\mu\nu} V^{\mu\nu} + \sum_{i < j} h_{ij} \psi_i \psi_j \phi^{(*)} + \text{h.c} \quad (6)$$

$96\,153 \rightarrow 5\,196$ multi-component DM ($N = 8, 12$) $\rightarrow 28$ with two Dirac-fermion DM

$$z = [1, 2, 2, 4, -5, -5, -7, 8] \rightarrow \phi = 3 \rightarrow [(1, 2), (2, -5), (-5, 8), (4, -7)] \quad (7)$$

$$\mathcal{L} \subset \Psi^T \left[\begin{array}{cccccc} 1 & 2 & 2 & -5 & -5 & 8 \\ 0 & h_{(1,2)} & h'_{(1,2)} & 0 & 0 & 0 \\ h_{(1,2)} & 0 & 0 & h_{(2,-5)} & h_{(2,-5)} & 0 \\ h'_{(1,2)} & 0 & 0 & 0 & 0 & 0 \\ 0 & h_{(2,-5)} & 0 & 0 & 0 & h_{(-5,8)} \\ 0 & h_{(2,-5)} & 0 & 0 & 0 & h'_{(-5,8)} \\ 0 & 0 & 0 & h_{(-5,8)} & h'_{(-5,8)} & 0 \end{array} \right] \Psi \phi^{(*)} + h_{(4,-7)} \psi_4 \psi_{-7} \phi^* \quad (8)$$

Standard model extended with $U(1)_{\chi=\textcolor{blue}{X} \text{ or } \textcolor{red}{D}}$ gauge symmetry

Fields	$SU(2)_L$	$U(1)_Y$	$U(1)_{\chi=\textcolor{red}{D} \text{ or } \textcolor{blue}{X}}$
Q_i^\dagger	2	-1/6	Q
d_{Ri}	1	-1/2	d
u_{Ri}	1	+2/3	u
L_i^\dagger	2	+1/2	L
e_{Ri}	1	-1	e
H	2	1/2	h
χ_α	1	0	z_α

Φ	1	0	ϕ
--------	----------	---	--------

Table 1:

$i = 1, 2, 3, \alpha = 1, 2, \dots, N$

Standard model extended with $U(1)_{\mathcal{X}=\textcolor{blue}{L} \text{ or } \textcolor{red}{B}}$ gauge symmetry

Fields	$SU(2)_L$	$U(1)_Y$	$U(1)_{\mathcal{X}=\textcolor{red}{B} \text{ or } \textcolor{blue}{L}}$
Q_i^\dagger	2	-1/6	Q
d_{Ri}	1	-1/2	d
u_{Ri}	1	+2/3	u
L_i^\dagger	2	+1/2	L
e_{Ri}	1	-1	e
H	2	1/2	$h = 0$
χ_α	1	0	z_α
$(L'_L)^\dagger$	2	1/2	$-x'$
L''_R	2	-1/2	x''
e'_R	1	-1	x'
$(e''_L)^\dagger$	1	1	$-x''$
Φ	1	0	ϕ
S	1	0	s

Table 1: minimal set of new fermion content: $L = e = 0$ for $\mathcal{X} = \textcolor{red}{B}$. Or $Q = u = d = 0$ for $\mathcal{X} = \textcolor{blue}{L}$.
 $i = 1, 2, 3, \alpha = 1, 2, \dots, N'$

Anomaly cancellation: $\mathcal{X} = \textcolor{blue}{L}$ or B

The anomaly-cancellation conditions on $[\text{SU}(3)_c]^2 \text{U}(1)_X$, $[\text{SU}(2)_L]^2 \text{U}(1)_X$, $[\text{U}(1)_Y]^2 \text{U}(1)_X$, allow us to express three of the X -charges in terms of the others

$$\textcolor{red}{u} = -\textcolor{blue}{e} - \frac{2}{3}\textcolor{blue}{L} - \frac{1}{9}(x' - x'') , \quad \textcolor{red}{d} = \textcolor{blue}{e} + \frac{4}{3}\textcolor{blue}{L} - \frac{1}{9}(x' - x'') , \quad \textcolor{red}{Q} = -\frac{1}{3}\textcolor{blue}{L} + \frac{1}{9}(x' - x'') , \quad (9)$$

while the $[\text{U}(1)_X]^2 \text{U}(1)_Y$ anomaly condition reduces to

$$(\textcolor{blue}{e} + \textcolor{blue}{L})(x' - x'') = 0 . \quad (10)$$

- Previously: $x' = x''$
- We choose instead ($h = 0$):

$$\textcolor{blue}{e} = -\textcolor{blue}{L} , \quad (11)$$

so that ($\textcolor{blue}{L}$ is still a free parameter)

$$\textcolor{red}{Q} = -\textcolor{red}{u} = -\textcolor{red}{d} = -\frac{1}{3}\textcolor{blue}{L} + \frac{1}{9}(x' - x'') . \quad (12)$$

If $\textcolor{red}{B} = 0 \rightarrow \text{U}(1)_{\textcolor{blue}{L}}$

Anomaly cancellation: $\mathcal{X} = \textcolor{blue}{L}$

The gravitational anomaly, $[\text{SO}(1, 3)]^2 \text{U}(1)_Y$, and the cubic anomaly, $[\text{U}(1)_X]^3$, can be written as the following system of Diophantine equations, respectively,

$$\sum_{\alpha=1}^N z_\alpha = 0, \quad \sum_{\alpha=1}^N z_\alpha^3 = 0, \quad (13)$$

where

$$z_1 = -x', \quad z_2 = x'', \quad \textcolor{blue}{z_{2+i} = L}, \quad i = 1, 2, 3 \quad (14)$$

\rightarrow

$$9Q = - \sum_{\alpha=1}^5 z_\alpha = -x' + x'' + \textcolor{blue}{L} + L + L, \quad (15)$$

$L = 0 \rightarrow \text{U}(1)_{\textcolor{red}{B}}$ but $Q = 0 \not\rightarrow \text{U}(1)_{\textcolor{blue}{L}}$

$U(1)_{\textcolor{blue}{L}}$ selection

- $B = 0$ with $L = 6$

$$(6, 6, 6, -8, -10, 5, 13, -9, -9)$$

$U(1)_{\textcolor{blue}{L}}$ selection

- $B = 0$ with $L = 6$
- Electroweak-scale vector-like fermions with $\Phi = 18$:

$$(L'_L)^\dagger L''_R \Phi \rightarrow x' = 8, x'' = -10$$

$$(6, 6, 6, \textcolor{red}{-8}, \textcolor{red}{-10}, 5, 13, -9, -9)$$

$U(1)_{\textcolor{blue}{L}}$ selection

- $B = 0$ with $L = 6$
- Electroweak-scale vector-like fermions with $\Phi = 18$:
 $(L'_L)^\dagger L''_R \Phi \rightarrow x' = 8, x'' = -10$
- $L + L + L - x' + x'' = 0$

$$(6, 6, 6, \textcolor{red}{-8}, \textcolor{red}{-10}, 5, 13, -9, -9)$$

$U(1)_{\textcolor{blue}{L}}$ selection

- $B = 0$ with $L = 6$
- Electroweak-scale vector-like fermions with $\Phi = 18$:

$$(L'_L)^\dagger L''_R \Phi \rightarrow x' = 8, x'' = -10$$

$$\textcolor{blue}{L} + \textcolor{blue}{L} + \textcolor{blue}{L} - \textcolor{red}{x}' + \textcolor{red}{x}'' = 0$$

- Dirac-fermionic DM:

$$(\chi_L)^\dagger \chi'_R \Phi^* \rightarrow z_3 = 5, z_4 = 13$$

$$(\textcolor{blue}{6}, \textcolor{blue}{6}, \textcolor{blue}{6}, -8, -10, \textcolor{teal}{5}, \textcolor{teal}{13}, -9, -9)$$

$U(1)_L$ selection

- $B = 0$ with $L = 6$
- Electroweak-scale vector-like fermions with $\Phi = 18$:
 $(L'_L)^\dagger L''_R \Phi \rightarrow x' = 8, x'' = -10$
- $L + L + L - x' + x'' = 0$
- Dirac-fermionic DM:
 $(\chi_L)^\dagger \chi'_R \Phi^* \rightarrow z_3 = 5, z_4 = 13$
- (Two generations) Majorana-fermionic DM:
 $(\chi''_i)^\dagger \chi''_j \Phi \rightarrow z_5 = -9, z_6 = -9$

$(6, 6, 6, -8, -10, 5, 13, -9, -9)$

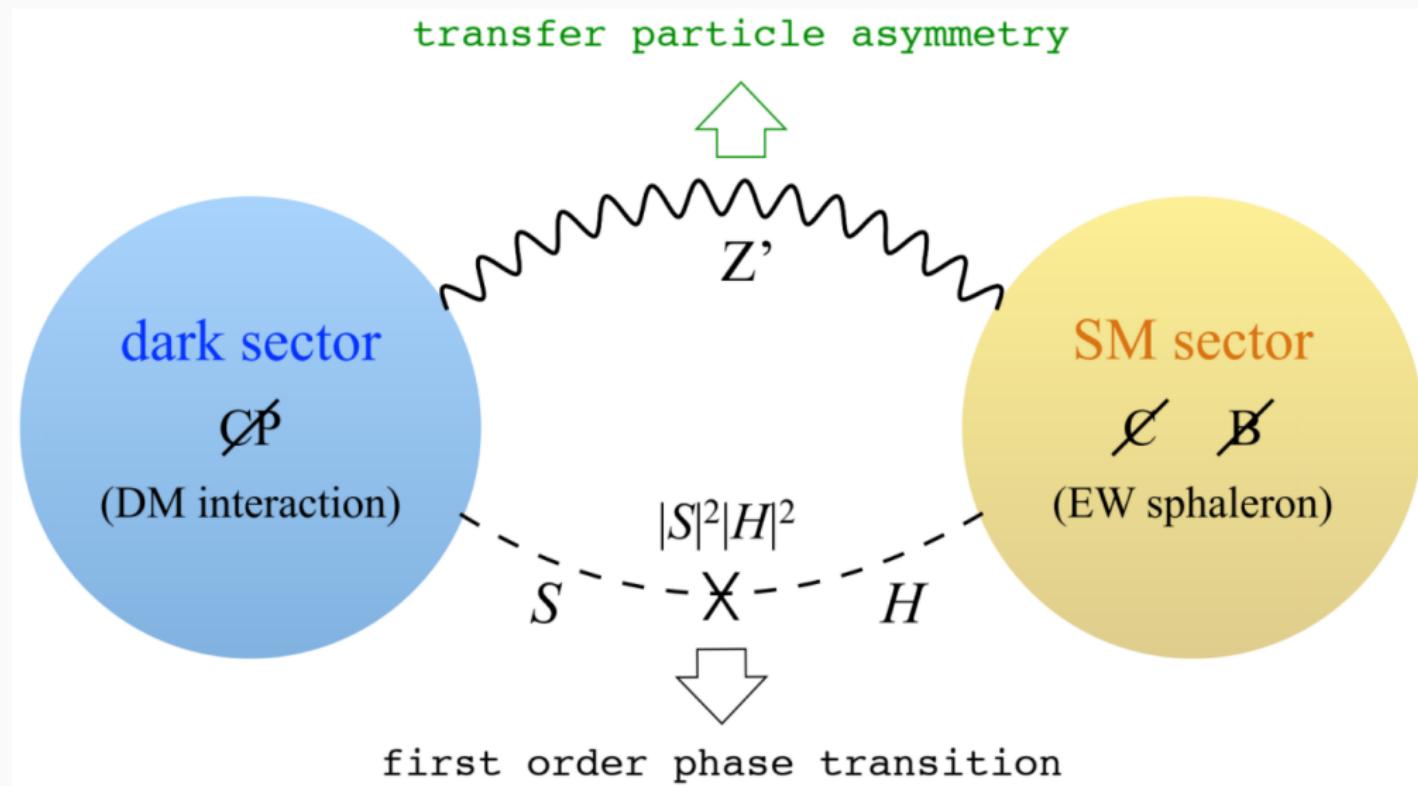
U(1)_L selection

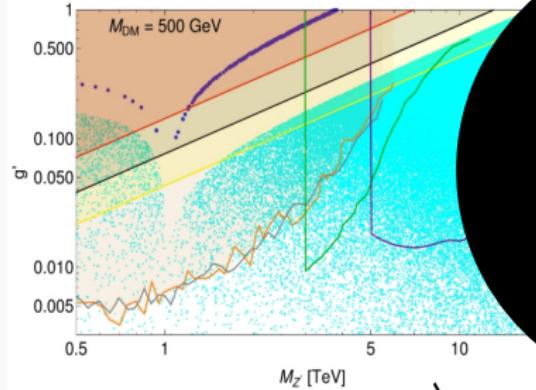
- $B = 0$ with $L = 6$
 - Electroweak-scale vector-like fermions with $\Phi = 18$:
 $(L'_L)^\dagger L''_R \Phi \rightarrow x' = 8, x'' = -10$
 - $L + L + L - x' + x'' = 0$
 - Dirac-fermionic DM:
 $(\chi_L)^\dagger \chi'_R \Phi^* \rightarrow z_3 = 5, z_4 = 13$
 - (Two generations) Majorana-fermionic DM:
 $(\chi''_i)^\dagger \chi''_j \Phi \rightarrow z_5 = -9, z_6 = -9$
- $(6, 6, 6, -8, -10, 5, 13, -9, -9)$

Unique solution with 2 DM particles from 96 153!

l	k	solution	gcd	n	zmax	hidden
$[-2, -3, 0]$	$[1, 2, 3, 2]$	$[5, 6, 6, 6, -8, -9, -9, -10, 13]$	4	9	13	$\{[\{'S': 18, '\Psi': [(-9, -9), (-8, -10), (5, 13)]]\}\}$
$[2, 0, 3]$	$[-2, 1, -3, -1]$	$[2, 3, 3, 3, 6, -8, -11, -15, 17]$	12	9	17	$\{[\{'S': 9, '\Psi': [(2, -11), (6, -15), (-8, 17)]]\}\}$
$[-4, -2, 1]$	$[2, -4, 4, -2]$	$[1, -2, 6, 6, 6, -9, -9, -16, 17]$	16	9	17	$\{[\{'S': 18, '\Psi': [(-9, -9), (1, 17), (-2, -16)]]\}\}$
$[3, -2, -4]$	$[-2, -1, -2, 3]$	$[1, 2, 3, -6, -6, 15, 16, -19]$	2	9	19	$\{[\{'S': 18, '\Psi': [(1, -19), (3, 15), (2, 16)]]\}\}$

Dark sector baryogenesis



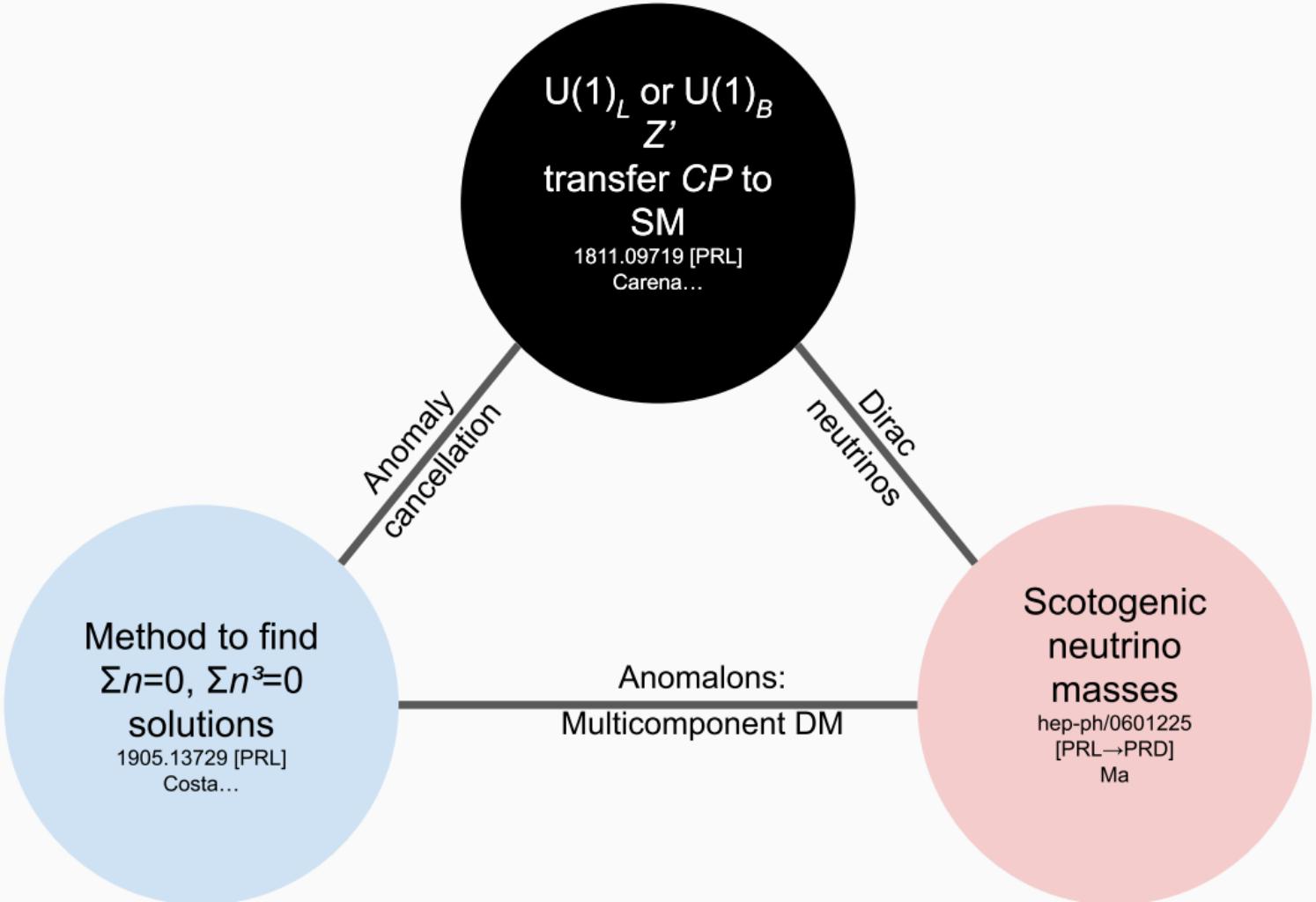


Anomaly cancellation

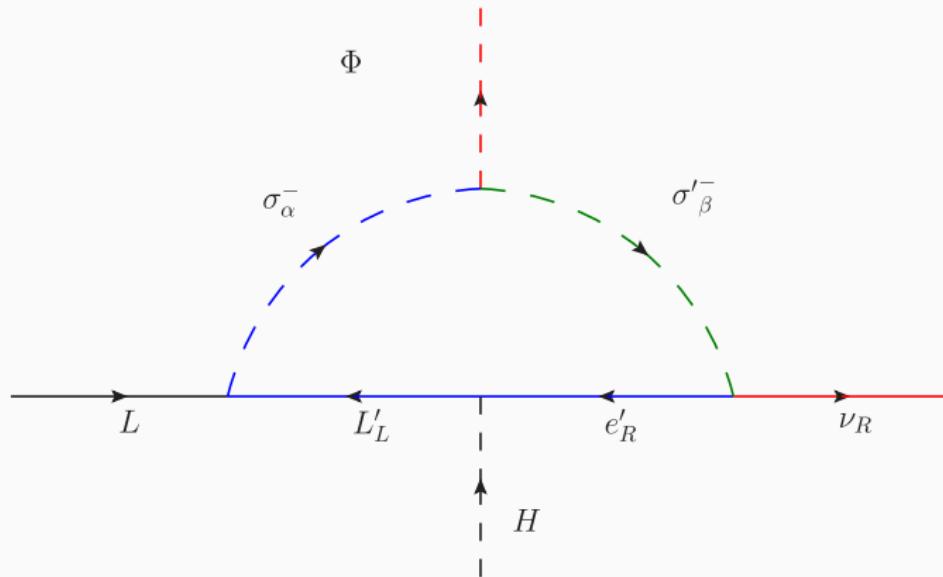
Dirac neutrinos

Anomalons:

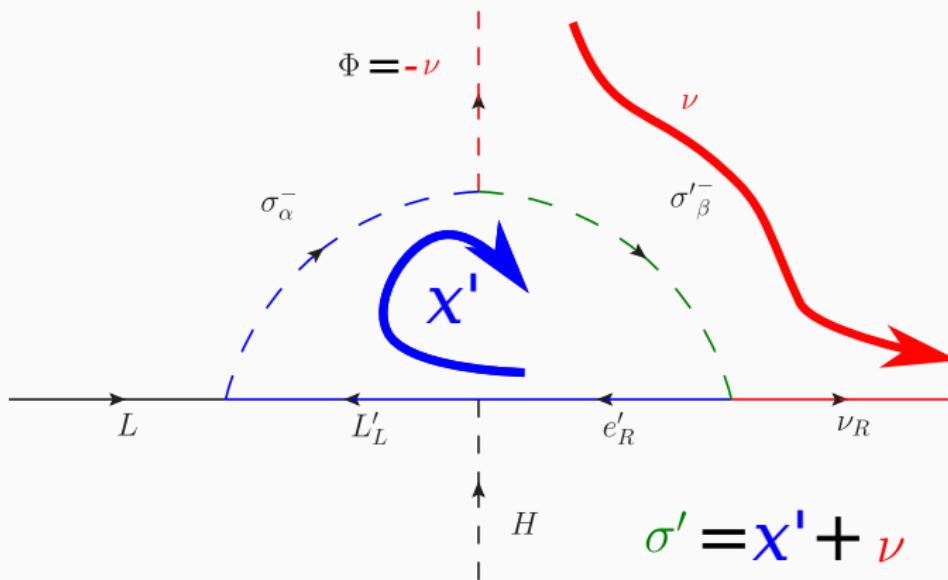
DM



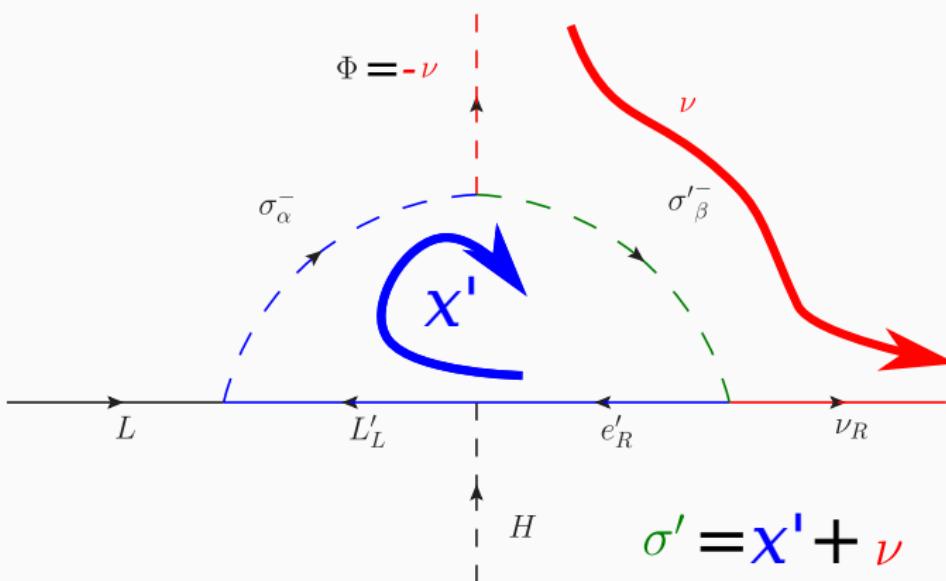
with Andrés Rivera (UdeA) and Walter Tangarife (Loyola U.)



with Andrés Rivera (UdeA) and Walter Tangarife (Loyola U.)



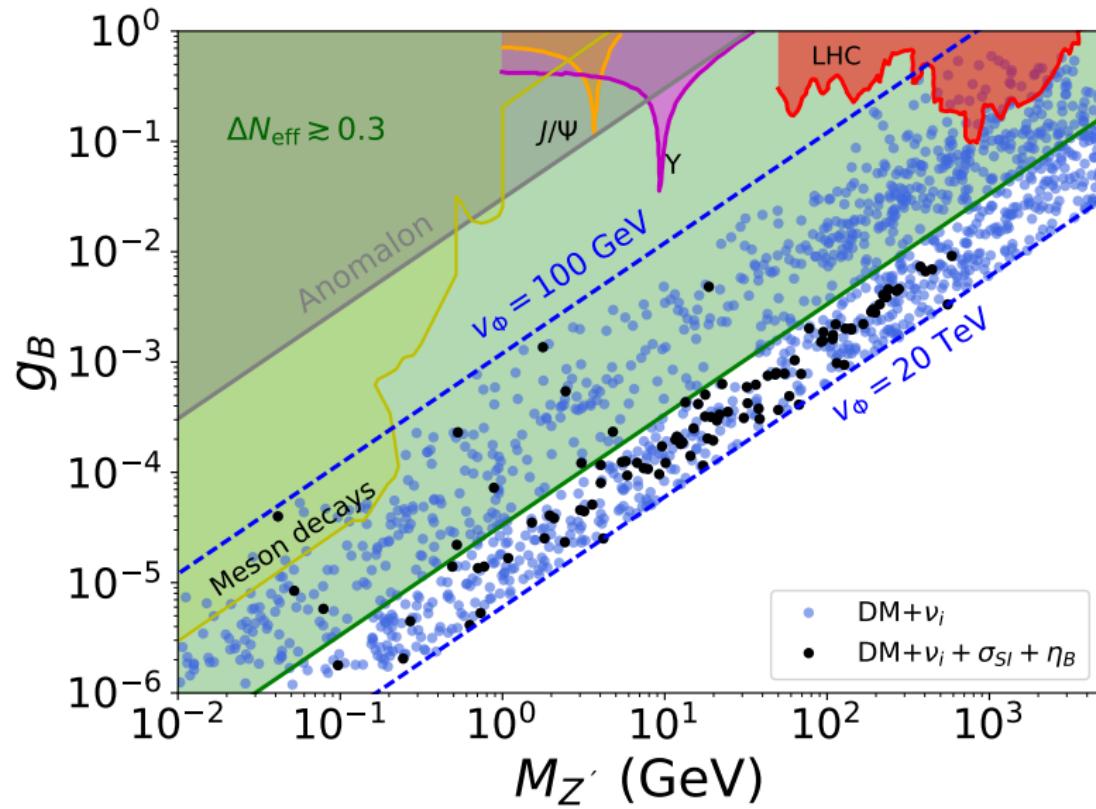
with Andrés Rivera (UdeA) and Walter Tangarife (Loyola U.)



Field	$SU(2)_L$	$U(1)_Y$	$U(1)_B$
u_{Ri}	1	2/3	$u = 1/3$
d_{Ri}	1	-1/3	$d = 1/3$
$(Q_i)^\dagger$	2	-1/6	$Q = -1/3$
$(L_i)^\dagger$	2	1/2	$L = 0$
e_R	1	-1	$e = 0$
$(L'_L)^\dagger$	2	1/2	$-x' = -3/5$
e'_R	1	-1	$x' = 3/5$
L''_R	2	-1/2	$x'' = 18/5$
$(e''_L)^\dagger$	1	1	$-x'' = -18/5$
$\nu_{R,1}$	1	0	-3
$\nu_{R,2}$	1	0	-3
χ_R	1	0	6/5
$(\chi_L)^\dagger$	1	0	9/5
H	2	1/2	0
S	1	0	3
Φ	1	0	3
σ_α^-	1	1	3/5
$\sigma'^-_α$	1	-1	-12/5

- SARAH→SPheno→MicroMegas
- η_B calculation code
- Python notebook with the scan

Black points: Dirac neutrinos with proper DM and baryon assymetry



Conclusions

A methodology to find all the *universal* Abelian extensions of the standard model is designed

All of the extensions can be reformulated as the solution of

$$\sum_{\alpha=1}^N z_\alpha = 0,$$

$$\sum_{\alpha=1}^N z_\alpha^3 = 0,$$

which we fully scan until $N = 12$ and $|z_{\max}| = 20$

Once the physical conditions are established, the full set of self-consistent models are found from a simple data-analysis procedure