Dark Matter and Neutrino Masses in a 2HDM-U(1) Model

Téssio Melo
Ph.D. student - IIP/UFPB

Dark Universe Workshop
São Paulo, Brazil - October 21-25, 2019

based on **J. High Energ. Phys. (2017) 2017: 92**, with D. Cogollo, M. Lindner, Farinaldo Queiroz, W. Rodejohann
and on **Phys. Lett. B (2019) 795, 319-326**, with D. Camargo, M. Campos, F. Queiroz

UNIVERSIDADE
FEDERAL DA
PARAÍBA

2HDMs

Popular extensions of the SM

$$\Phi_1 = \begin{pmatrix} \phi_1^+ \\ \phi_1^0 \end{pmatrix} \qquad \Phi_2 = \begin{pmatrix} \phi_2^+ \\ \phi_2^0 \end{pmatrix}$$

- Supersymmetry requires two Higgs doublets
- CP violation $\longrightarrow$ Baryogenesis
- Dark matter
- Axion
- ...

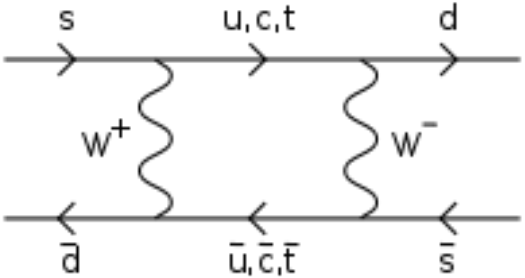
2HDMs

Flavor Changing Neutral Currents (FCNC)

FCNC processes very suppressed experimentally

Example: K - $\bar{K}$ oscillation

Loop suppressed in SM



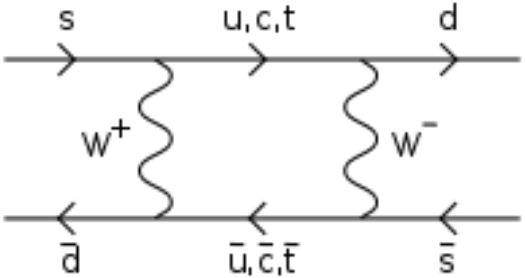
2HDMs

Flavor Changing Neutral Currents (FCNC)

FCNC processes very suppressed experimentally

Example: K - $\bar{K}$ oscillation

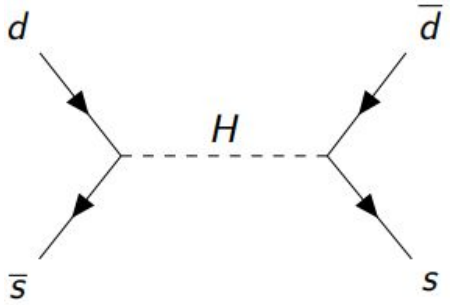
Loop suppressed in SM



In models with extra neutral scalars

$$-\mathcal{L}_{Y_{2HDM}} = y^{1d}\bar{Q}_L\Phi_1 d_R + y^{1u}\bar{Q}_L\widetilde{\Phi}_1 u_R + y^{1e}\bar{L}_L\Phi_1 e_R + \\ + y^{2d}\bar{Q}_L\Phi_2 d_R + y^{2u}\bar{Q}_L\widetilde{\Phi}_2 u_R + y^{2e}\bar{L}_L\Phi_2 e_R + \text{h.c.}$$

Oscillation at tree level



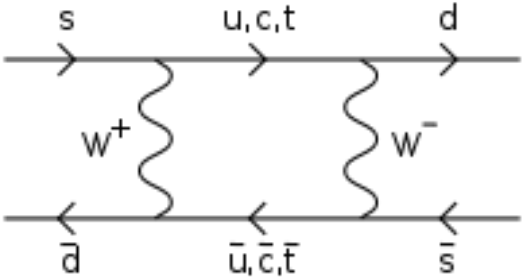
2HDMs

Flavor Changing Neutral Currents (FCNC)

FCNC processes very suppressed experimentally

Example: K - $\bar{K}$ oscillation

Loop suppressed in SM

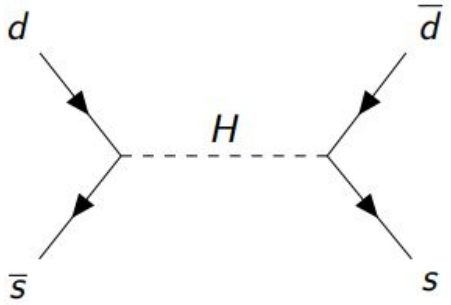


In models with extra neutral scalars

$$-\mathcal{L}_{Y_{2HDM}} = y^{1d}\bar{Q}_L\Phi_1 d_R + y^{1u}\bar{Q}_L\widetilde{\Phi}_1 u_R + y^{1}\bar{L}_L\Phi_1 e_R +$$
$$+ y^{2d}\bar{Q}_L\Phi_2 d_R + y^{2u}\bar{Q}_L\widetilde{\Phi}_2 u_R + y^{2e}\bar{L}_L\Phi_2 e_R + \text{h.c.}$$

Problem

Oscillation at tree level



2HDMs

Usual solution to FCNC problem: Z2 symmetry $\quad \Phi_1 \to -\Phi_1 \quad \Phi_2 \to \Phi_2$

$$-\mathcal{L}_{Y_{2HDM}} = y^{1d}\bar{Q}_L\Phi_1 d_R + y^{1u}\bar{Q}_L\widetilde{\Phi}_1 u_R + y^{1e}\bar{L}_L\Phi_1 e_R + \\ + y^{2d}\bar{Q}_L\Phi_2 d_R + y^{2u}\bar{Q}_L\widetilde{\Phi}_2 u_R + y^{2e}\bar{L}_L\Phi_2 e_R + \text{h.c.}$$

There are 4 possibilities

Modelo	u_R	d_R	e_R
Tipo I	Φ_2	Φ_2	Φ_2
Tipo II	Φ_2	Φ_1	Φ_1
Tipo X	Φ_2	Φ_2	Φ_1
Tipo Y	Φ_2	Φ_1	Φ_2

Scalar Potential

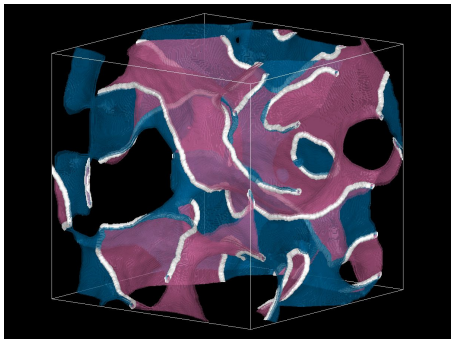
Explicit breaking of Z2

$$V(\Phi_1,\Phi_2) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 - m_{12}^2\left(\Phi_1^\dagger\Phi_2 + \Phi_2^\dagger\Phi_1\right)$$
$$+ \frac{\lambda_1}{2}\left(\Phi_1^\dagger\Phi_1\right)^2 + \frac{\lambda_2}{2}\left(\Phi_2^\dagger\Phi_2\right)^2 + \lambda_3\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_2^\dagger\Phi_2\right)$$
$$+ \lambda_4\left(\Phi_1^\dagger\Phi_2\right)\left(\Phi_2^\dagger\Phi_1\right) + \frac{\lambda_5}{2}\left[\left(\Phi_1^\dagger\Phi_2\right)^2 + \left(\Phi_2^\dagger\Phi_1\right)^2\right]$$

Scalar Potential

$$V\left(\Phi_1,\Phi_2\right) = m_{11}^2\Phi_1^\dagger\Phi_1 + m_{22}^2\Phi_2^\dagger\Phi_2 + \frac{\lambda_1}{2}\left(\Phi_1^\dagger\Phi_1\right)^2 + \frac{\lambda_2}{2}\left(\Phi_2^\dagger\Phi_2\right)^2 + \lambda_3\left(\Phi_1^\dagger\Phi_1\right)\left(\Phi_2^\dagger\Phi_2\right) + \lambda_4\left(\Phi_1^\dagger\Phi_2\right)\left(\Phi_2^\dagger\Phi_1\right) + \frac{\lambda_5}{2}\left[\left(\Phi_1^\dagger\Phi_2\right)^2 + \left(\Phi_2^\dagger\Phi_1\right)^2\right]$$

Domain Wall Problem



2HDM - U(1)

A more appealing solution to the FCNC problem is to use a U(1) gauge symmetry

Basic requirement: scalar doublets have different U(1) charges

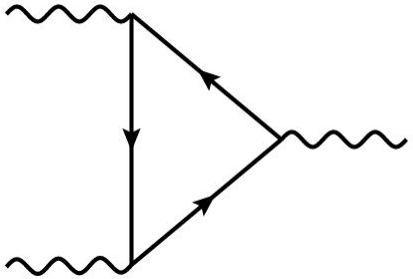
$$Q_{X1} \neq Q_{X2}$$

2HDM - U(1)

Two Higgs Doublet Models free from FCNC

Fields	u_R	d_R	Q_L	L_L	e_R	N_R	Φ_2	Φ_1
Charges	u	d	$\frac{(u+d)}{2}$	$\frac{-3(u+d)}{2}$	$-(2u+d)$	$-(u+2d)$	$\frac{(u-d)}{2}$	$\frac{5u}{2}+\frac{7d}{2}$
$U(1)_A$	1	-1	0	0	-1	1	1	-1
$U(1)_B$	-1	1	0	0	1	-1	-1	1
$U(1)_C$	1/2	-1	$-1/4$	3/4	0	3/2	3/4	9/4
$U(1)_D$	1	0	1/2	$-3/2$	-2	-1	1/2	5/2
$U(1)_E$	0	1	1/2	$-3/2$	-1	-2	7/2	$-1/2$
$U(1)_F$	4/3	2/3	1	-3	-4	$-8/3$	1/3	17/3
$U(1)_G$	$-1/3$	2/3	1/6	$-1/2$	0	-1	$-1/2$	$-3/2$
$U(1)_{B-L}$	1/3	1/3	1/3	-1	-1	-1	0	2
$U(1)_Y$	2/3	$-1/3$	1/6	$-1/2$	-1		1/2	$\neq h_2$
$U(1)_N$	0	0	0	0	0		0	$\neq h_2$

Gauge Anomalies

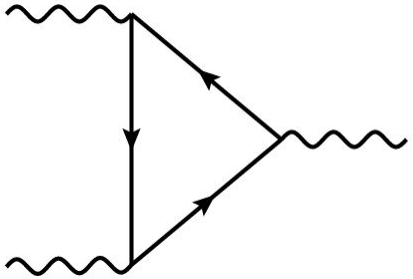


2HDM - U(1)

Two Higgs Doublet Models free from FCNC

Fields	u_R	d_R	Q_L	L_L	e_R	N_R	Φ_2	Φ_1
Charges	u	d	$\frac{(u+d)}{2}$	$\frac{-3(u+d)}{2}$	$-(2u+d)$	$-(u+2d)$	$\frac{(u-d)}{2}$	$\frac{5u}{2}+\frac{7d}{2}$
$U(1)_A$	1	-1	0	0	-1	1	1	-1
$U(1)_B$	-1	1	0	0	1	-1	-1	1
$U(1)_C$	1/2	-1	$-1/4$	3/4	0	3/2	3/4	9/4
$U(1)_D$	1	0	1/2	$-3/2$	-2	-1	1/2	5/2
$U(1)_E$	0	1	1/2	$-3/2$	-1	-2	7/2	$-1/2$
$U(1)_F$	4/3	2/3	1	-3	-4	$-8/3$	1/3	17/3
$U(1)_G$	$-1/3$	2/3	1/6	$-1/2$	0	-1	$-1/2$	$-3/2$
$U(1)_{B-L}$	1/3	1/3	1/3	-1	-1	-1	0	2
$U(1)_Y$	2/3	$-1/3$	1/6	$-1/2$	-1		1/2	$\neq h_2$
$U(1)_N$	0	0	0	0	0		0	$\neq h_2$

Gauge Anomalies



Three RH-neutrinos

Type I seesaw

Dark matter

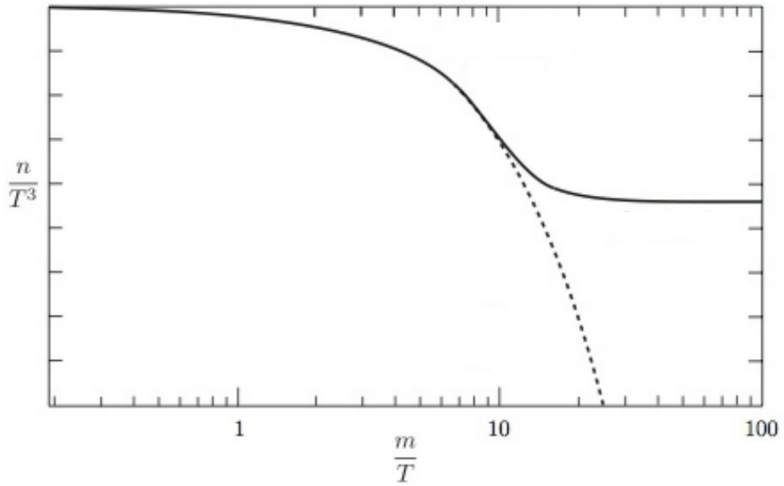
Vectorlike fermion charged under U(1)

$$\mathcal{L}_{DM} = i\bar{\chi}\not{D}\chi - m_\chi\bar{\chi}\chi$$

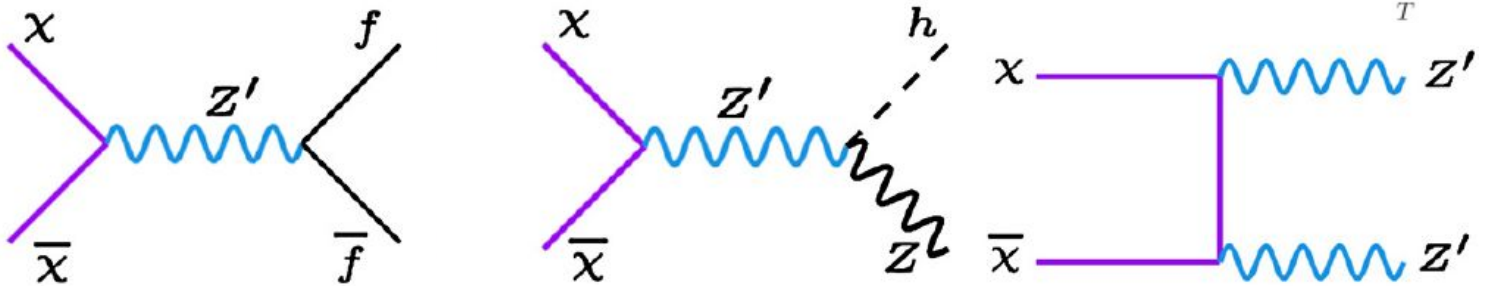
Dark matter

Vectorlike fermion charged under U(1)

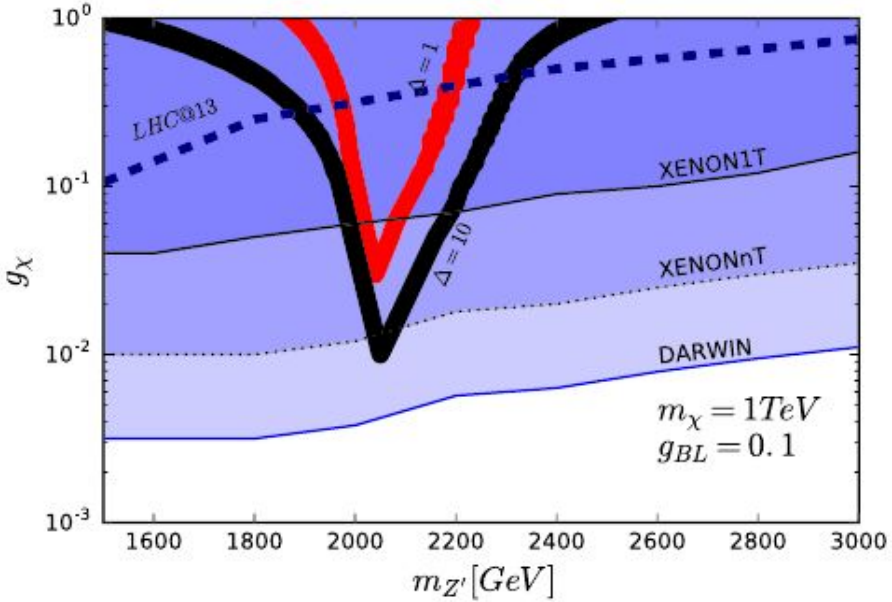
$$\mathcal{L}_{DM} = i\bar{\chi}\not{D}\chi - m_\chi\bar{\chi}\chi$$

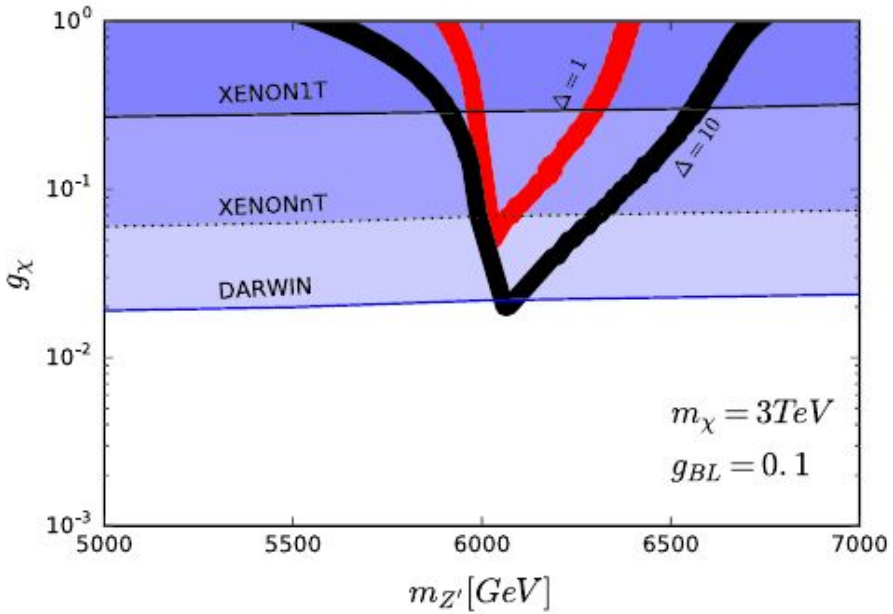


Thermal production



Dark matter


LHC@13
$\Delta = 1$
$\Delta = 10$
XENON1T
XENONnT
DARWIN
$m_\chi = 1TeV$
$g_{BL} = 0.1$
g_χ
$m_{Z'}[GeV]$


XENON1T
$\Delta = 1$
$\Delta = 10$
XENONnT
DARWIN
$m_\chi = 3TeV$
$g_{BL} = 0.1$
g_χ
$m_{Z'}[GeV]$

Conclusion

We have presented a version of the 2HDM which is more appealing than the usual one and very rich phenomenologically

Neutrino masses and dark matter are addressed

The models survives the current constraints and future experiments will probe a large portion of its parameter space

Thanks!