

# Doublet-Triplet Fermionic Dark Matter

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European Union  
European Social Fund



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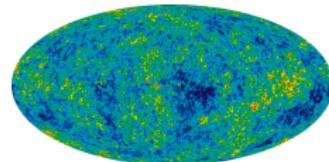
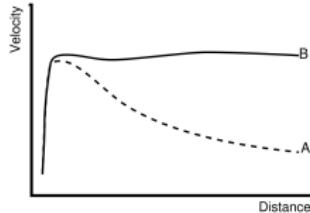
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# Why dark matter



Three key observations:

- Velocity curves of spinning galaxies.
- Gravitational lensing.
- Cosmic microwave background.

**There is extra mass in the universe!**

# WIMPs and the WIMP miracle

WIMP=Weakly Interacting Massive Particle.

- Lifetime much larger than the age of the universe.
- Electrically neutral (because it's dark).
- Interacts weakly.
- Massive (cold dark matter).
- Relic abundance  $\Omega_{DM} h^2 \approx 0.1 \Rightarrow \langle \sigma v \rangle \sim 10^{-8} \text{ GeV}^{-2}$  (for  $M_{DM} \sim 100 \text{ GeV}$ ), “**WIMP miracle**”!

- Electroweak scale WIMP.
- No co-annihilations or resonant effects (natural Dark Matter).
- Vanishing WIMP-nucleon interactions (at least at tree level).

# The model

*Assumptions:*

- Vectorial E/M interactions.
- Anomaly free gauge (and gravitational) interactions.
- The new fermions are  $SU(3)_C$  singlets.
- $Z_2$ -parity symmetry.

*Model details:*

- Two doublets with opposite hypercharges and one triplet with zero hypercharge.
- The lightest neutral fermion is an equal admixture of the two doublets.
- Vanishing tree level interaction with nucleons.

# The Symmetry

$$\begin{aligned}\mathcal{L}_{\text{Yuk-mass}}^{DM} = & Y_1 \epsilon^{ab} T^A H_a (\tau^A)_b^c \bar{D}_{1c} - Y_2 T^A H^{\dagger a} (\tau^A)_a^c \bar{D}_{2c} \\ & - \frac{1}{2} M_T T^A T^A - M_D \epsilon^{ab} \bar{D}_{1a} \bar{D}_{2b} + H.C.\end{aligned}$$

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$$\mathbf{Y}_1 = \mathbf{Y}_2 = \mathbf{Y} = \frac{\mathbf{m}}{v}$$

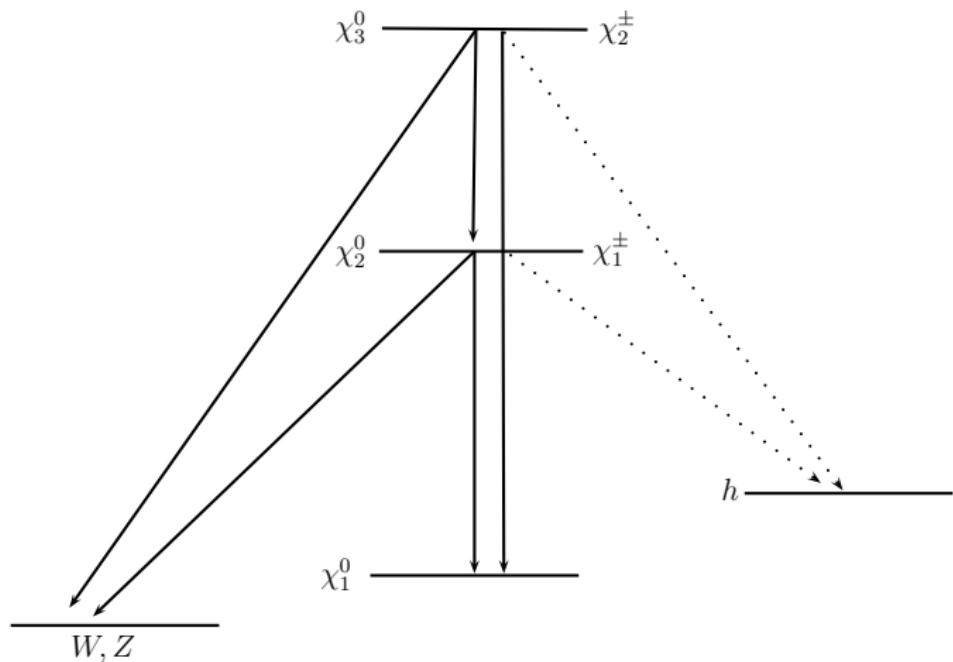
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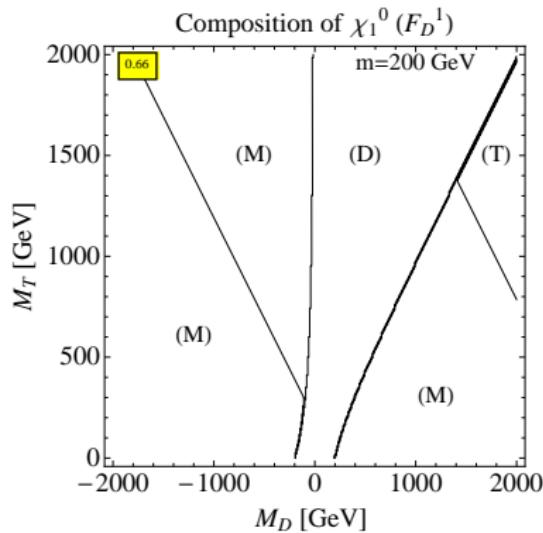
Yukawa sector invariant under rotations of  
 $\mathcal{H} = \begin{pmatrix} H \\ H^\dagger \end{pmatrix}$  and  $\bar{\mathcal{D}} = \begin{pmatrix} \bar{D}_1 \\ \bar{D}_2 \end{pmatrix}$ .

# Spectrum



# WIMP composition

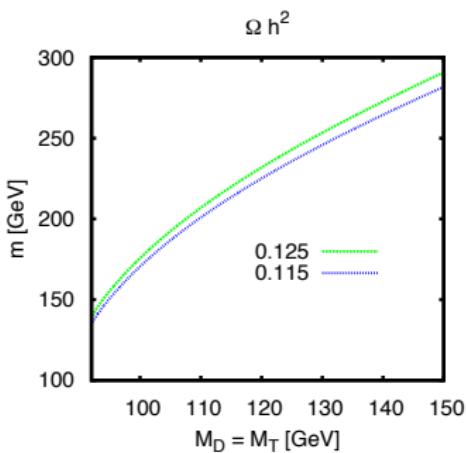
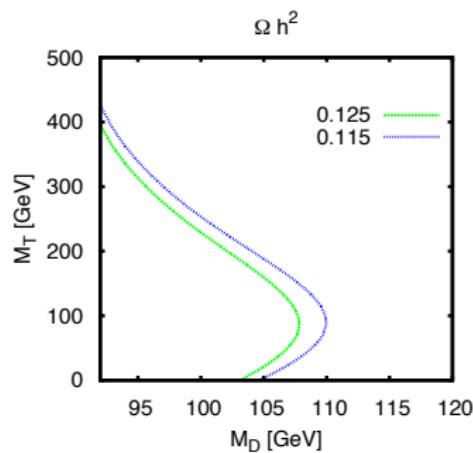
$$|\chi_1^0\rangle = A |T^3\rangle + B |\bar{D}_1^1\rangle + C |\bar{D}_2^2\rangle$$



$A = 0$  means that the WIMP is an equal admixture of  $\bar{D}_1^1$  and  $\bar{D}_2^2$ .  
**Vanishing tree level interaction with Z and Higgs boson.**

# Relic abundance

Relic abundance<sup>1</sup>:  $\Omega_{DM} h^2 \sim 0.12$



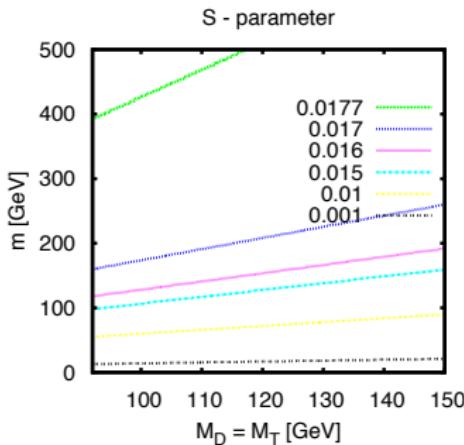
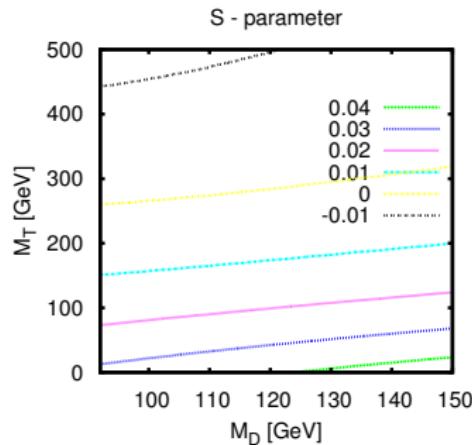
$92 \lesssim M_D \lesssim 110$  GeV and  $M_T \lesssim 420$  GeV for  $m \sim 200$  GeV.

**There exists low mass WIMP for high Yukawa coupling.**

<sup>1</sup>P. A. R. Ade *et al.* [Planck Collaboration], Astron. Astrophys. **571** (2014)

# Electroweak corrections

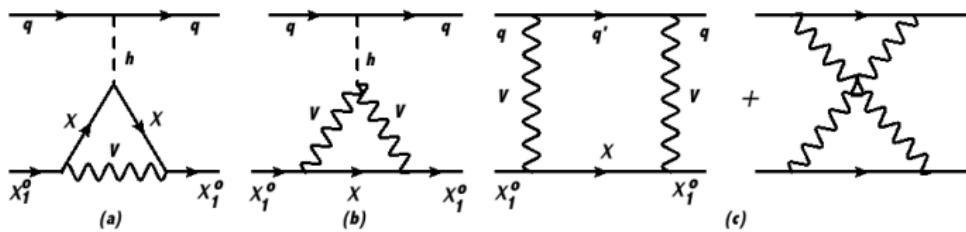
From experimental fits we know that  $S = 0.04 \pm 0.09$  and  $T = 0.07 \pm 0.08$



$T$  and  $U$  are suppressed, because  $Y_1 = Y_2$ .

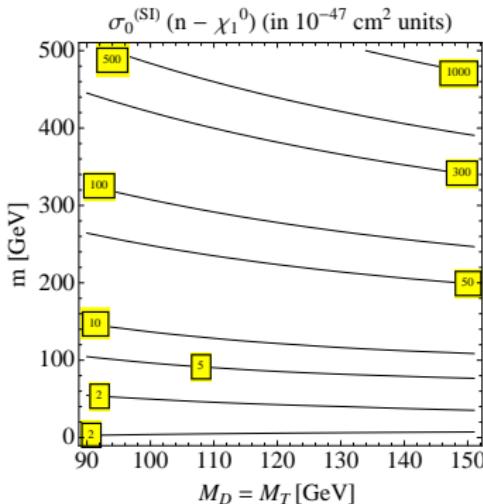
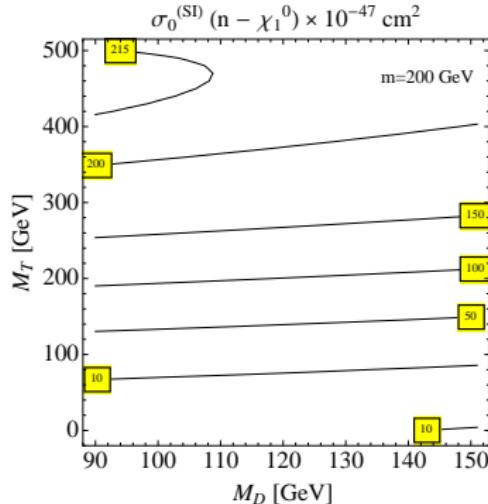
# Direct detection I

The tree level cross section vanishes. So, we need make a calculation at one-loop level.



# Direct detection II

Spin independent cross section:



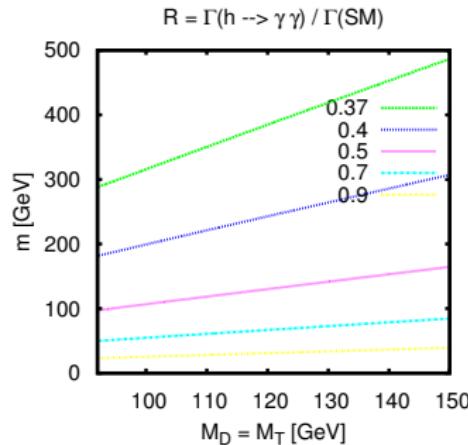
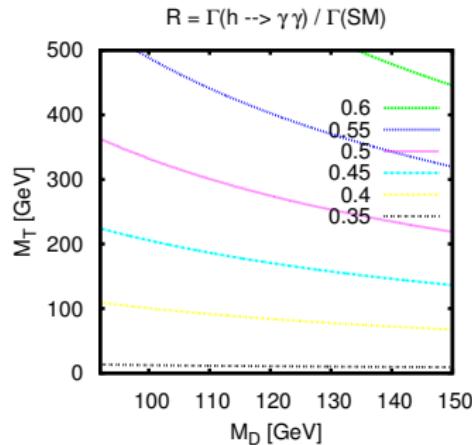
Latest experiments<sup>2</sup> show that  $\sigma_0^{(SI)} \lesssim 2 \times 10^{-45} \text{ cm}^2$  for a WIMP at 100 GeV.

<sup>2</sup>[LUX Collaboration], Nucl. Instrum. Meth. A **704** (2013) 111  
[arXiv:1211.3788 [physics.ins-det]].

$h \rightarrow \gamma\gamma$

CMS<sup>3</sup>:  $R = 1.13 \pm 0.24$

ATLAS<sup>4</sup>:  $R = 1.17 \pm 0.27$



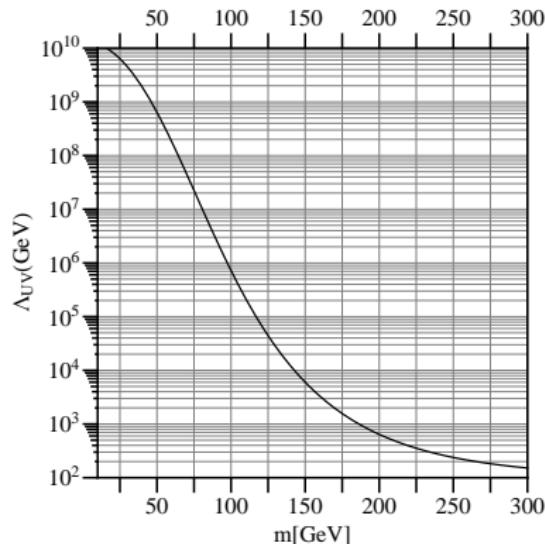
$0.35 \lesssim R \lesssim 0.5$ .

<sup>3</sup>[CMS Collaboration], Eur. Phys. J. C **74** (2014) 10, 3076 [arXiv:1407.0558 [hep-ex]]

<sup>4</sup>[ATLAS Collaboration], Phys. Rev. D **90** (2014) 11, 112015 [arXiv:1408.7084 [hep-ex]].

# Vacuum stability

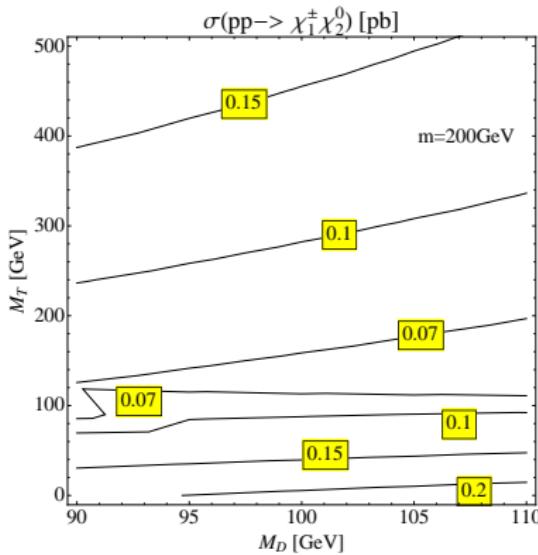
We need to find the energy scale ( $\Lambda_{UV}$ ) that this mode needs completion, by demanding that the SM vacuum has survived until today.



Completion is needed at  $\sim 600$  GeV! Possible solution is the addition of some scalar particles (maybe a SUSY extension of this model).

# Production

LHC studies<sup>5</sup> for  $pp \rightarrow W^* \rightarrow \chi_1^\pm \chi_2^0$  have shown  $\sigma \sim 0.1 - 1 \text{ pb}$ .



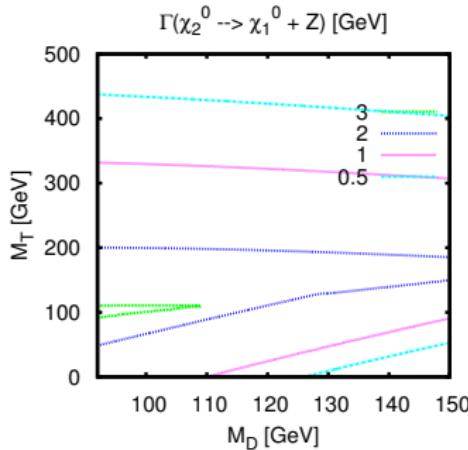
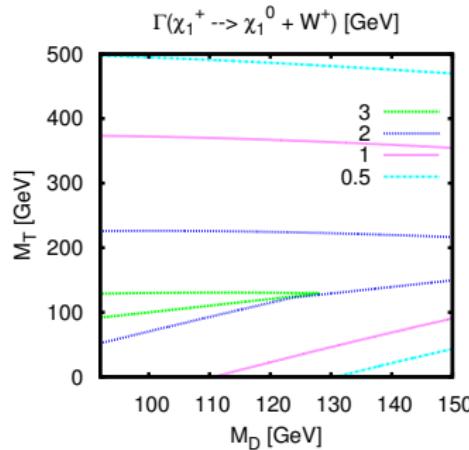
At  $20 \text{ fb}^{-1}$  **1400-4000 events!**

<sup>5</sup> ATLAS Collaboration, ATLAS-CONF-2013-035, ATLAS-COM-CONF-2013-042 and CMS Collaboration, CMS-PAS-SUS-13-006.

# Decays

For pure doublet WIMP the only available channels are:

$$\begin{aligned}\chi_2^0 &\rightarrow \chi_1^0 Z \\ \chi_1^+ &\rightarrow \chi_1^0 W^+\end{aligned}$$



# Conclusions

- Electroweak scale WIMP.
- Near future detectability by direct detection experiments.
- Production in near future experiments at LHC.
- Suppression of branching ratio of  $h \rightarrow \gamma\gamma$ .
- SM vacuum instability.

# Future directions

- Neutrinos from  $\chi_1^0$  annihilations in the Sun.
- Other models with similar behavior (“Blind spot” models).
- Solution of the vacuum stability and the  $h \rightarrow \gamma\gamma$  suppression problem.