Multicomponent Dark Matter and the Inert Doublet Model

Amalia Betancur

In collaboration with: Andrés Rivera and Guillermo Palacio

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- Motivation
- The models
- Phenomenology:

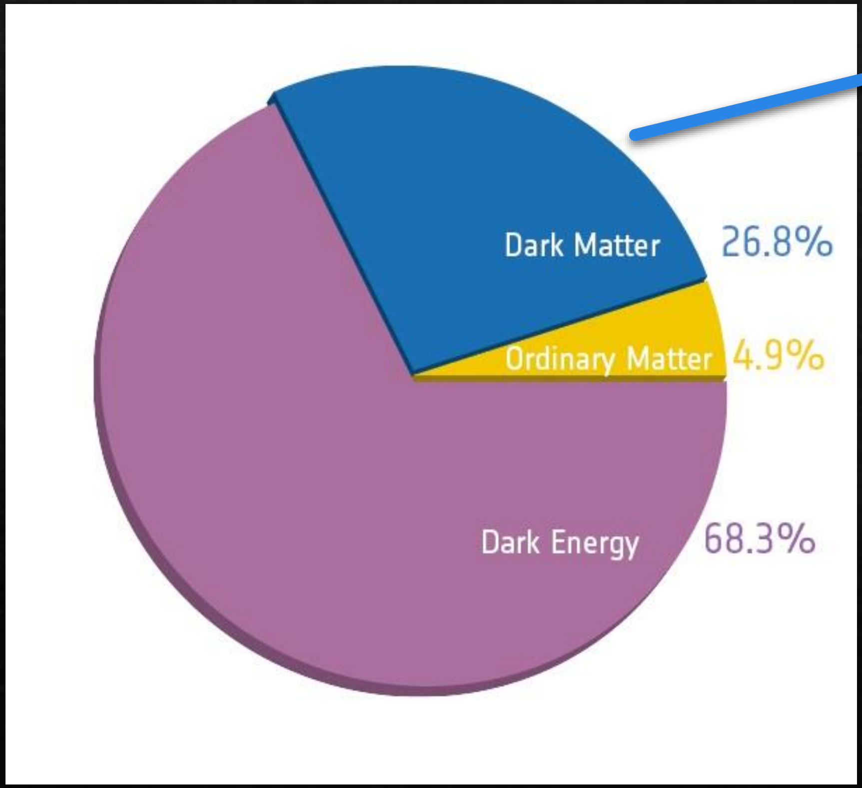
Relic density

Direct detection

Indirect detection

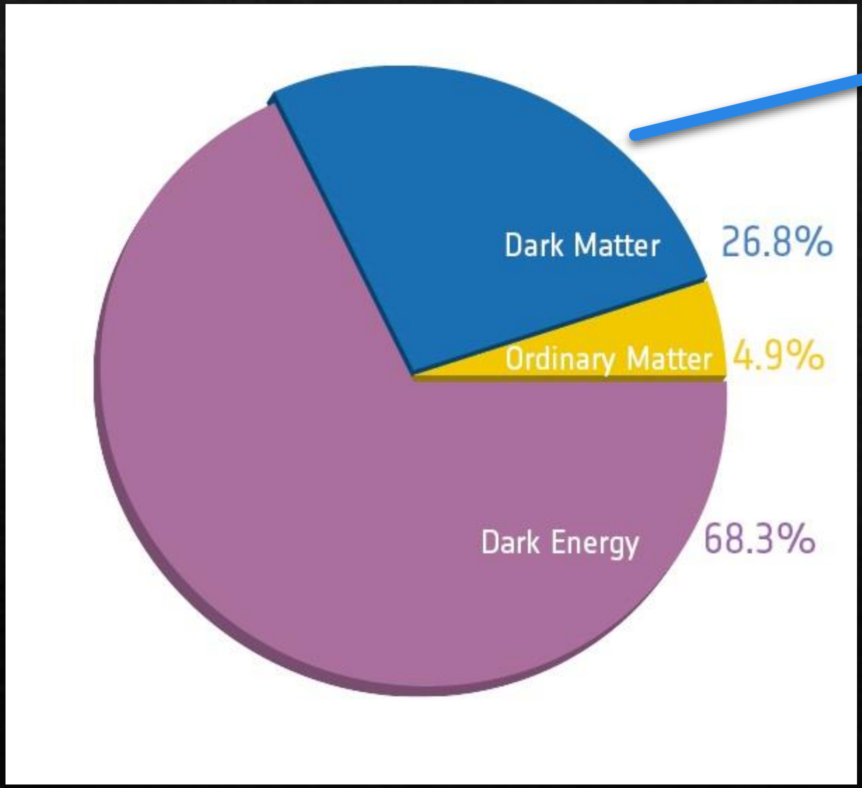
- Conclusions

Motivation for Multicomponent Dark Matter



χ_1^0

Motivation for Multicomponent Dark Matter



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$\nu_e \; \nu_\mu \; \nu_\tau$

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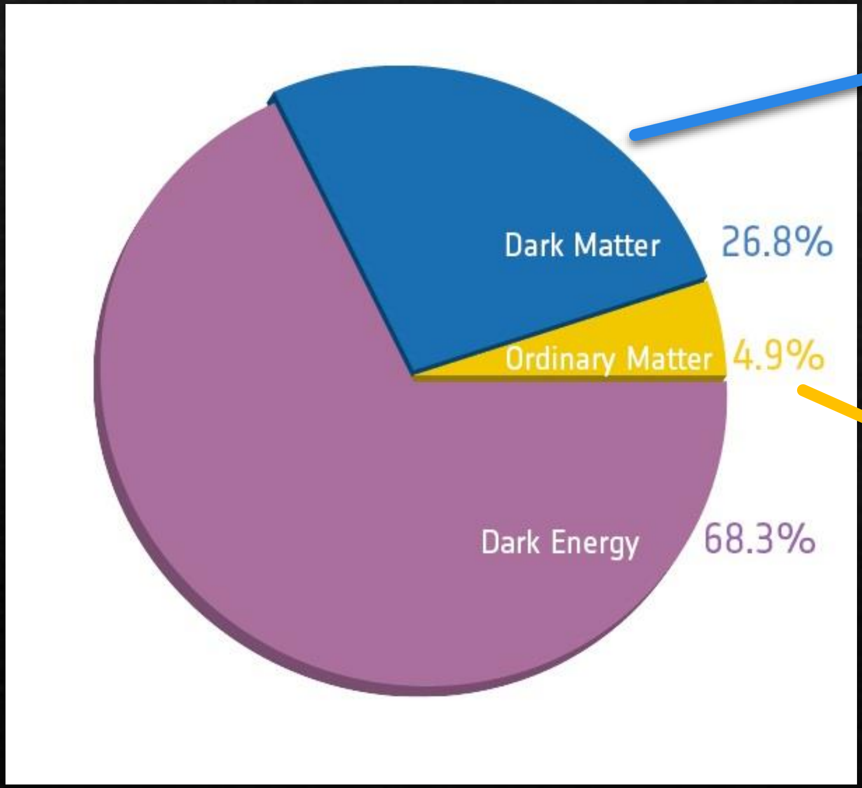

$$\chi_1^0$$

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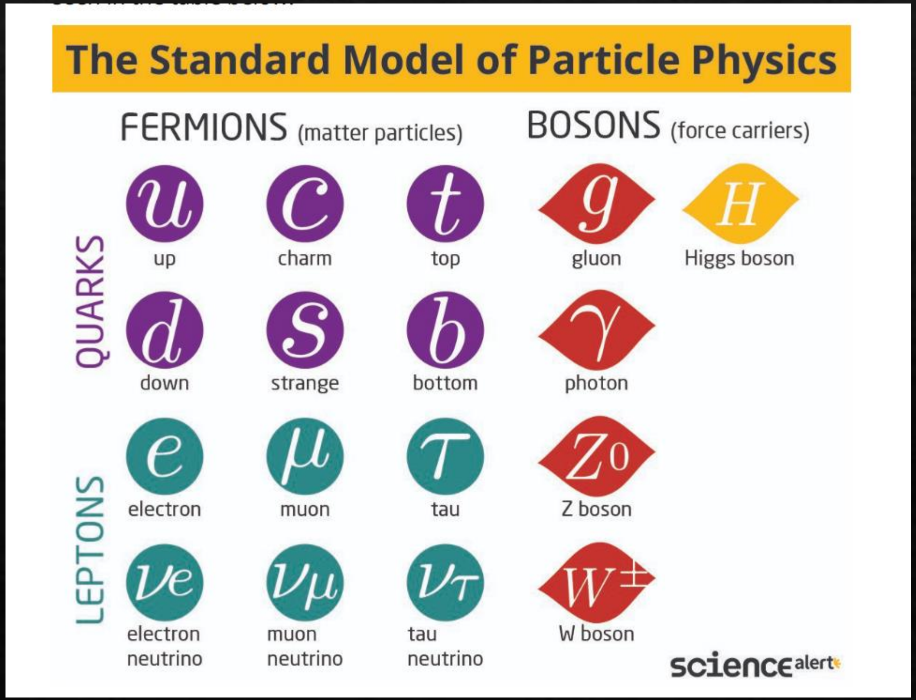

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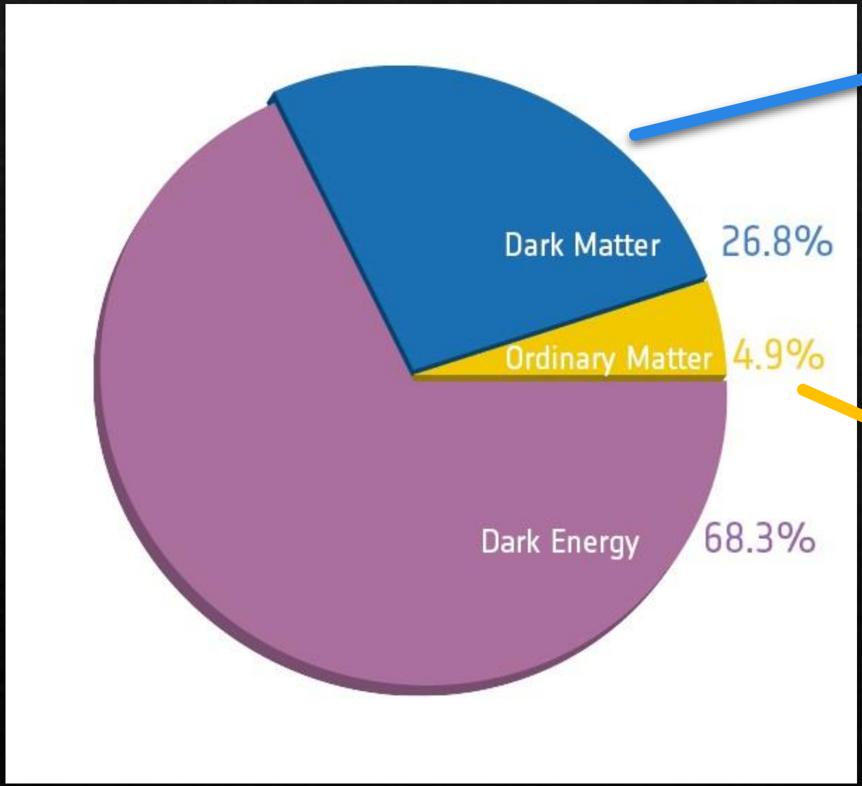
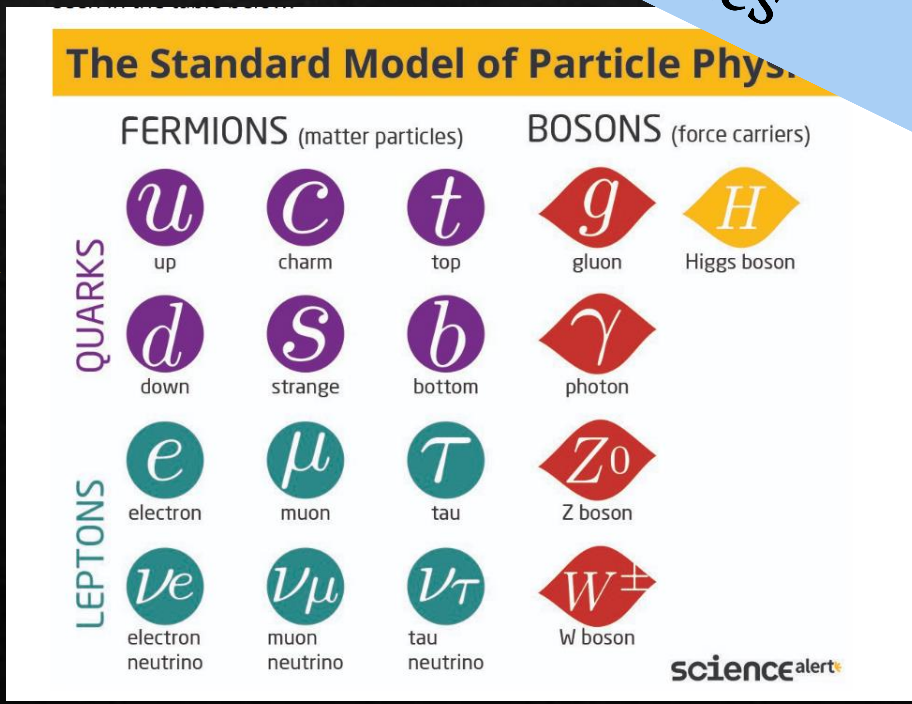


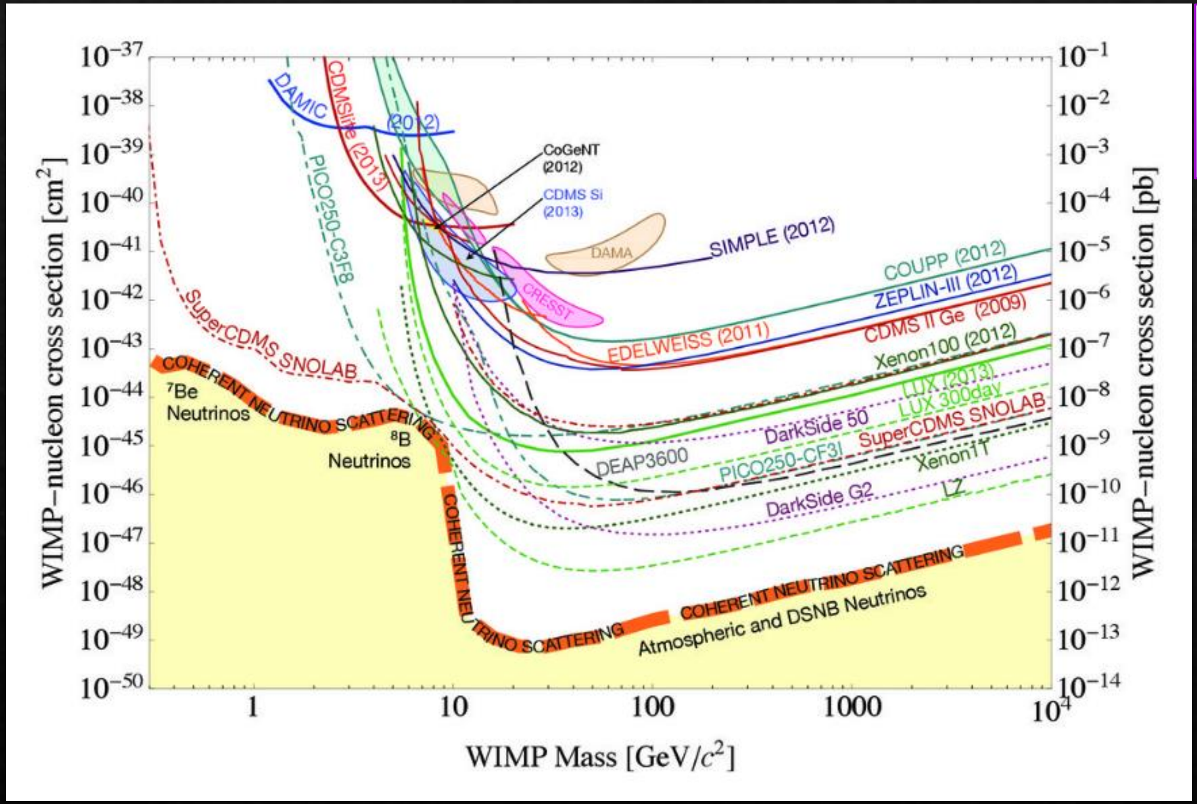
χ_1^0

$\nu_e \ \nu_\mu \ \nu_\tau$

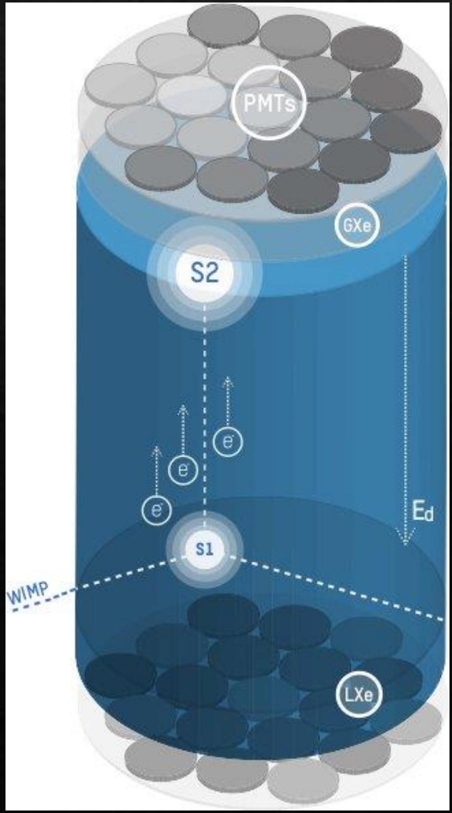
DM could be made up of a myriad of particles



Advantages of Multicomponent dark sectors: Direct detection constraints



WIMP direct detection cross section is getting more constrained



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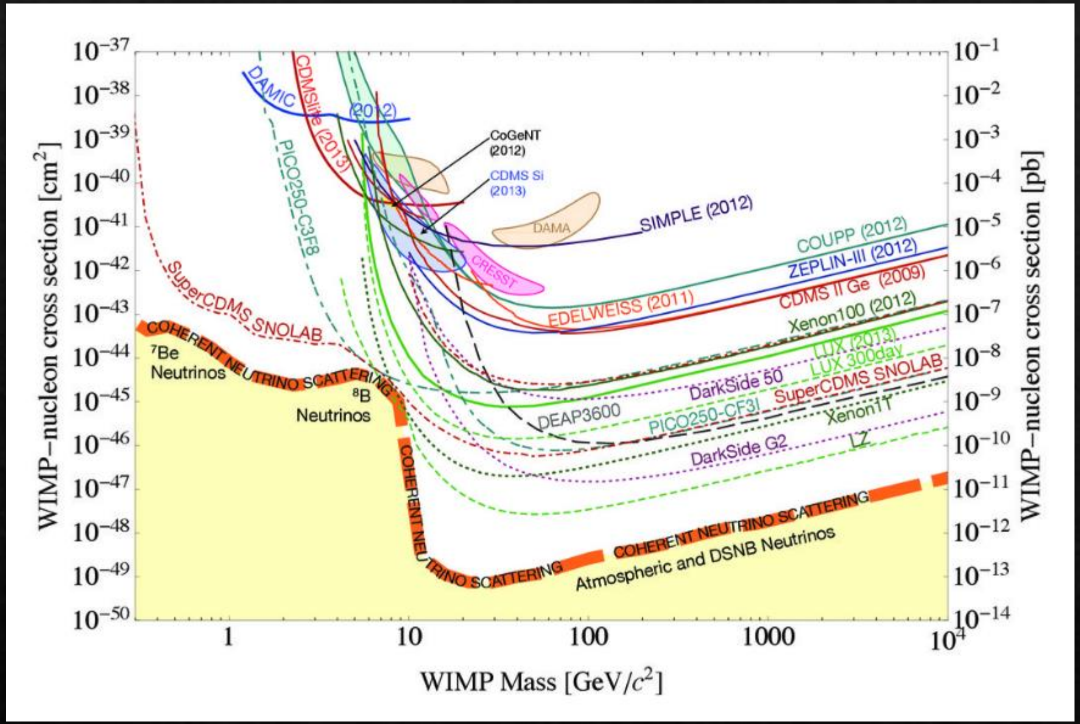

WIMP direct detection cross section is getting more constrained

Multicomponent dark matter is less constrained because direct detection restrictions must be rescaled

The Inert Doublet Model

- Extend the scalar sector with a new doublet and a new Z_2 symmetry:

$$H_2 = \begin{pmatrix} H^+ \\ \frac{H^0 + iA^0}{\sqrt{2}} \end{pmatrix}$$

DM candidate

$$m_{H^0}^2 = \mu_2^2 + \lambda_L v^2$$

$$\lambda_L = \frac{\lambda_3 + \lambda_4 + \lambda_5}{2}$$

New gauge interactions

New Higgs interactions

$$\mathcal{V}_\mathrm{I} = \lambda_3 |H_1|^2 |H_2|^2 + \lambda_4 |H_1^\dagger H_2|^2 + \frac{\lambda_5}{2} \left[(H_1^\dagger H_2)^2 + \mathrm{h.c.} \right]$$

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Interesting phenomenology but hard to probe around the electroweak scale!

Fermion sector, the recipe

- Extend the fermion sector with a new Z_2' symmetry

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- Singlet-doublet
- Doublet-triplet
- Singlet-triplet

The fermion sector

Singlet-Doublet

$\Psi \, , \; N$

Doublet-Triplet

$\Psi \, , \; \Sigma$

Singlet-Triplet

$N \, , \; \Sigma$

The fermion sector

Singlet-Doublet

$\Psi\ ,\ N$

Doublet-Triplet

$\Psi\ ,\ \Sigma$

Singlet-Triplet

$N\ ,\ \Sigma,\ \Omega$

New scalar that mixes with the Higgs, not scalar DM

The fermion sector

Model 1:
Singlet-Doublet

$\Psi \ , \ N$

Model 2:
Doublet-Triplet

$\Psi \ , \ \Sigma$

Model 3:
Singlet-Triplet

$N \ , \ \Sigma, \ \Omega$

New scalar that mixes with the Higgs, not scalar DM

Fermion Mixing

χ_1^0 → Dark matter candidate plus other fermionic guys

Phenomenology

- Check theoretical constraints for all models.

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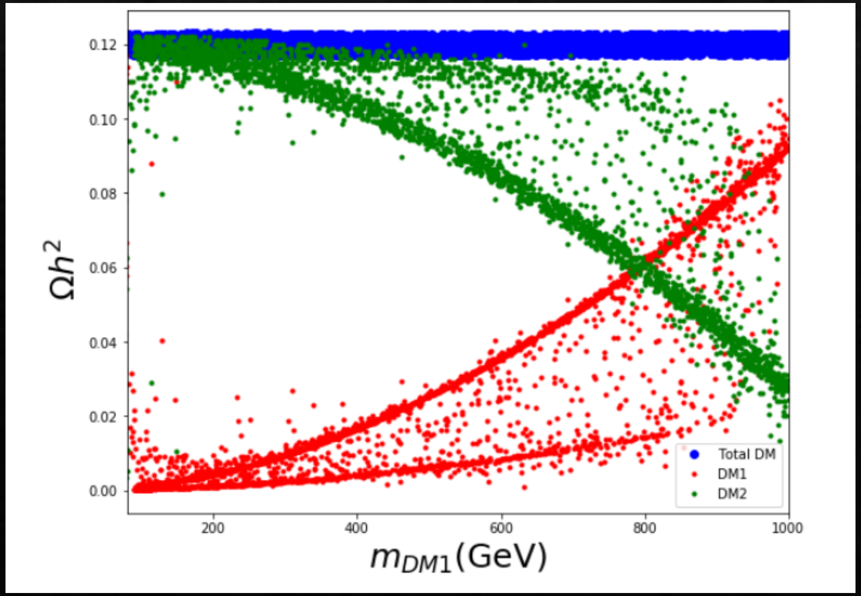
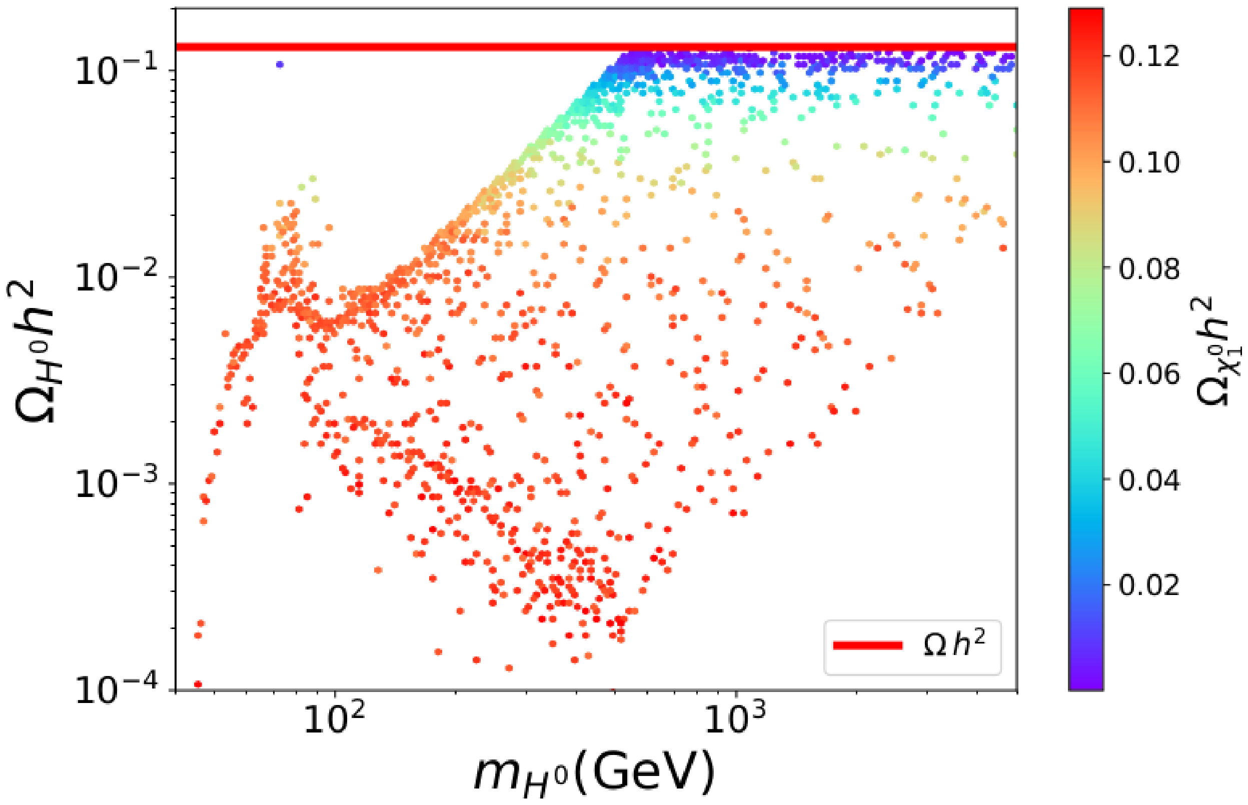
Implement all models in SARAH use SPheno, MicrOmegas and MadGraph. Perform checks!

Relic density Model 1: Singlet Doublet

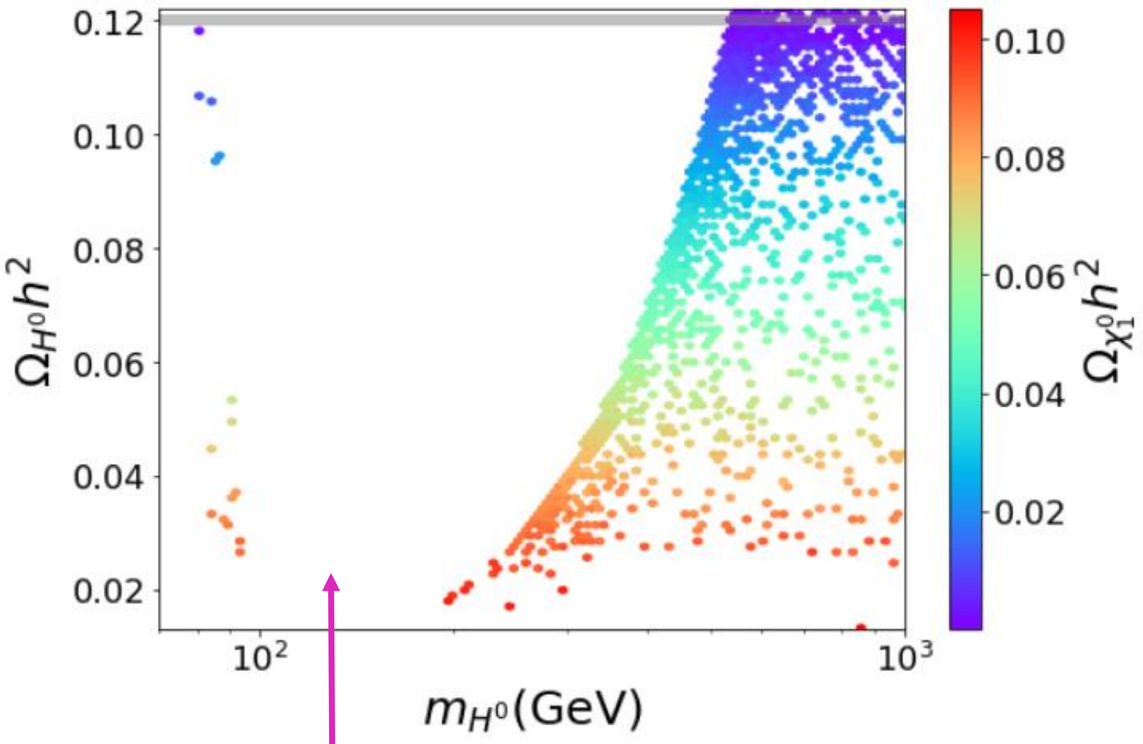


All points yield the correct relic abundance (amount of dark matter)



Relic density Model 2: Doublet Triplet

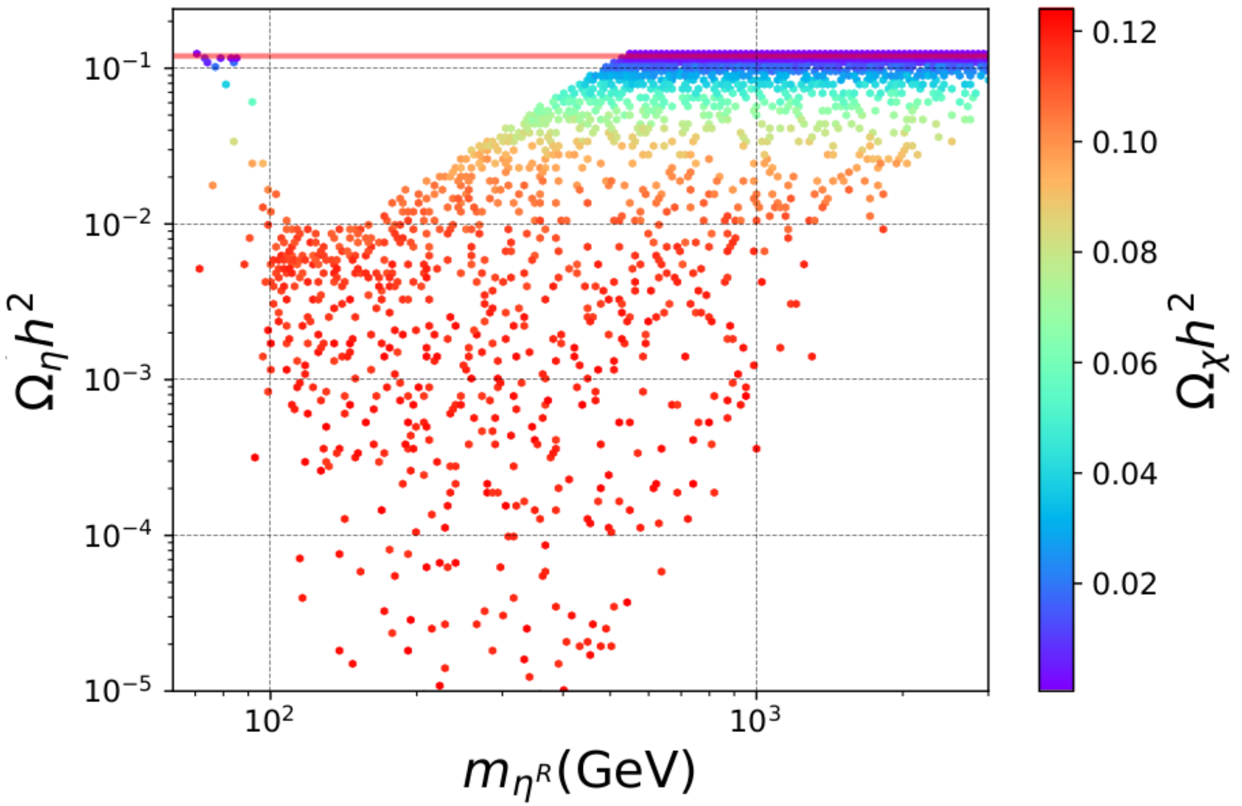
All points yield the correct relic abundance (amount of dark matter)



Due to large gauge interactions from the fermion sector and scalar sector it is not possible to recover this region

Relic density Model 3: Singlet Triplet

All points yield the correct relic abundance (amount of dark matter)



Relic density

DM1 scalar

DM2 fermion

Relic density

Can they communicate?

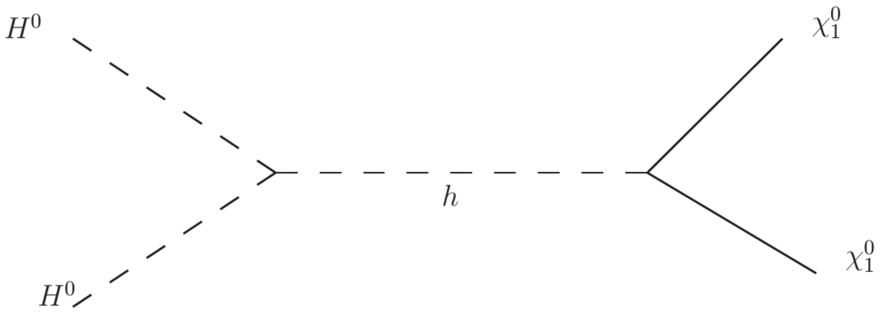
DM1 scalar

DM2 fermion

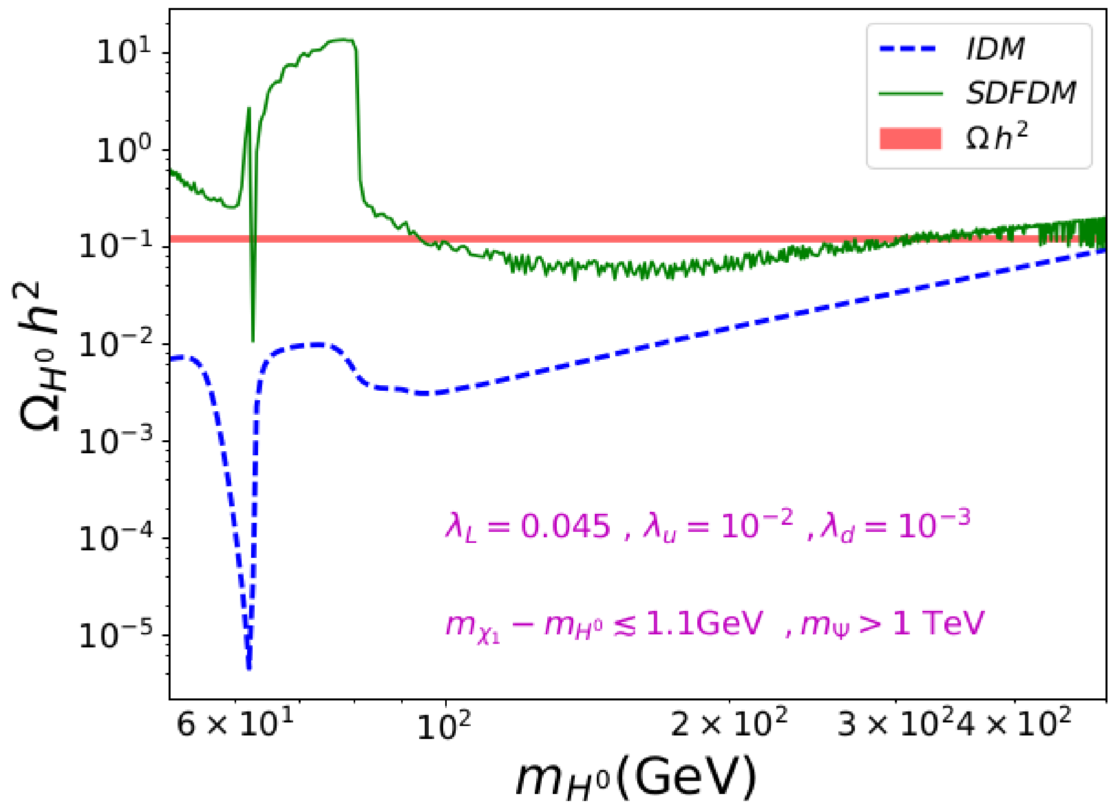
Relic density
Dark Matter conversion

Can they communicate?

DM1 scalar | Higgs Boson | DM2 fermion

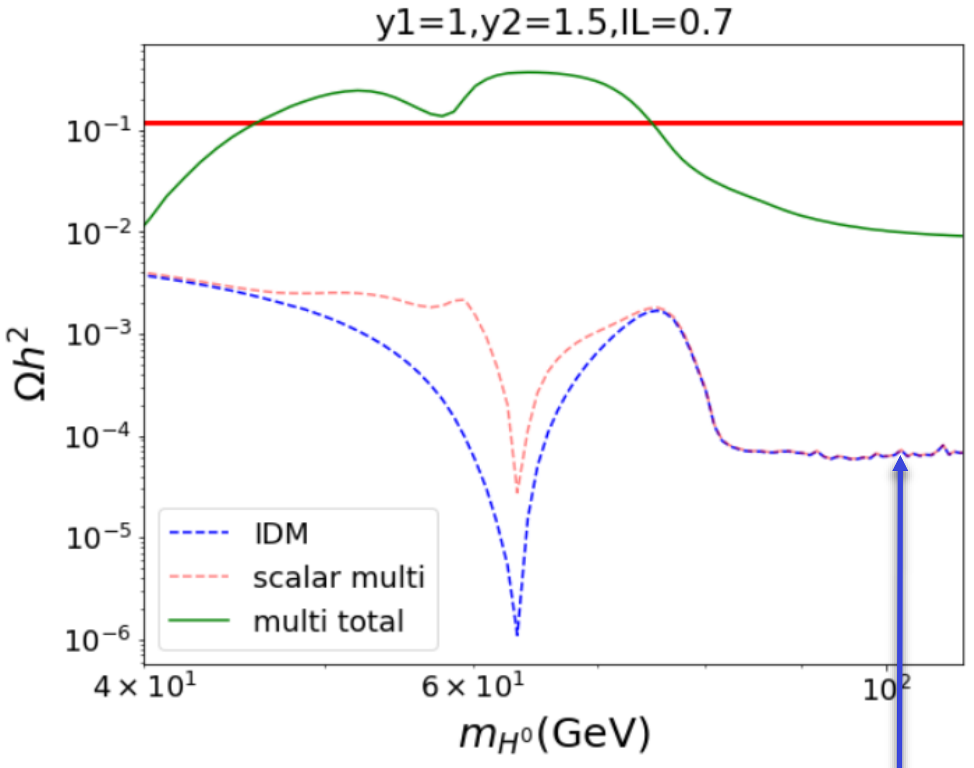


Dark matter conversion singlet-doublet



Similar to the Singlet-Triplet

Dark matter conversion doublet-triplet



Gauge interactions dominate over the Higgs interactions

Direct Detection

- In multi-component dark sectors, direct detection is suppressed because it depends on the local relic abundance of the dark matter candidate and limits must be reinterpreted due to an expected different nucleon recoil rate.

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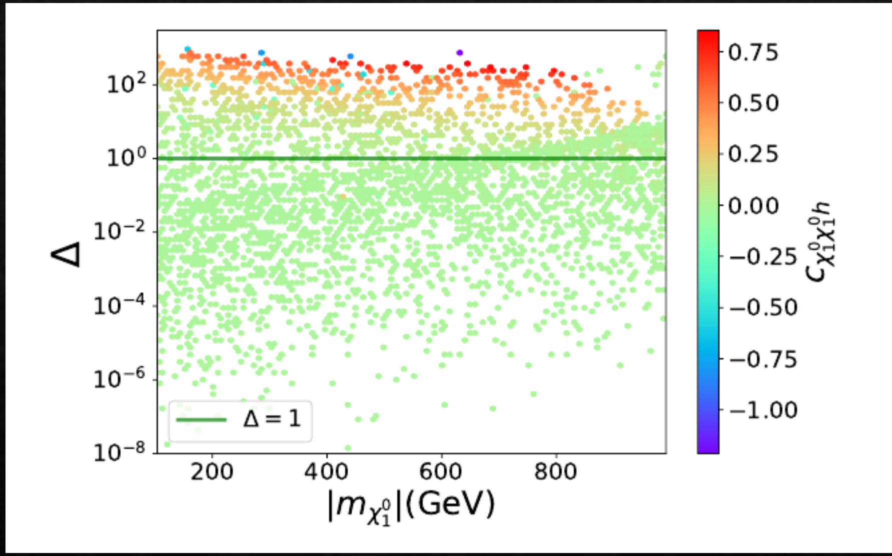
$$R < R_{\text{exp}}$$

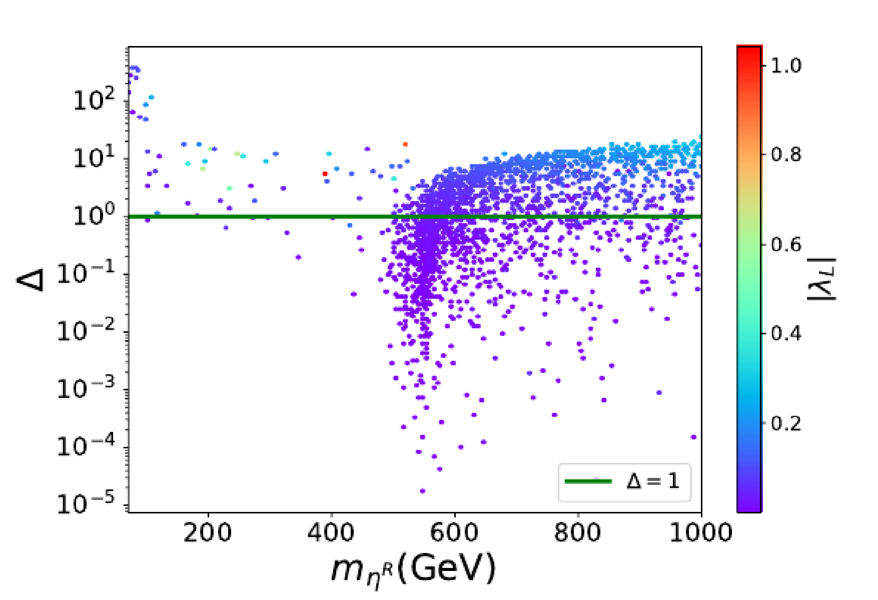
$$\Delta = \frac{\sigma^{SI}_{H^0}}{\sigma^{SI}_{X_e}(M_{H^0})}\left(\frac{\Omega_{H_0}}{\Omega}\right) + \left(\frac{\sigma^{SI}_{\chi^0_1}}{\sigma^{SI}_{X_e}(m_{\chi^0_1})} + \frac{\sigma^{SD}_{\chi^0_1}}{\sigma^{SD}_{X_e}(m_{\chi^0_1})}\right)\left(\frac{\Omega_{\chi^0_1}}{\Omega}\right) < 1$$

Direct Detection limits from Xenon1T

Doublet-Triplet



Singlet-Triplet



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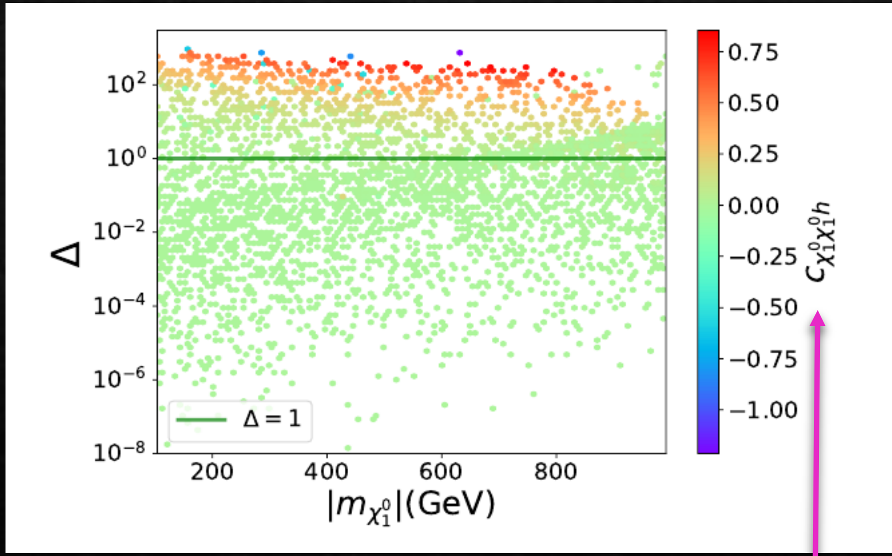
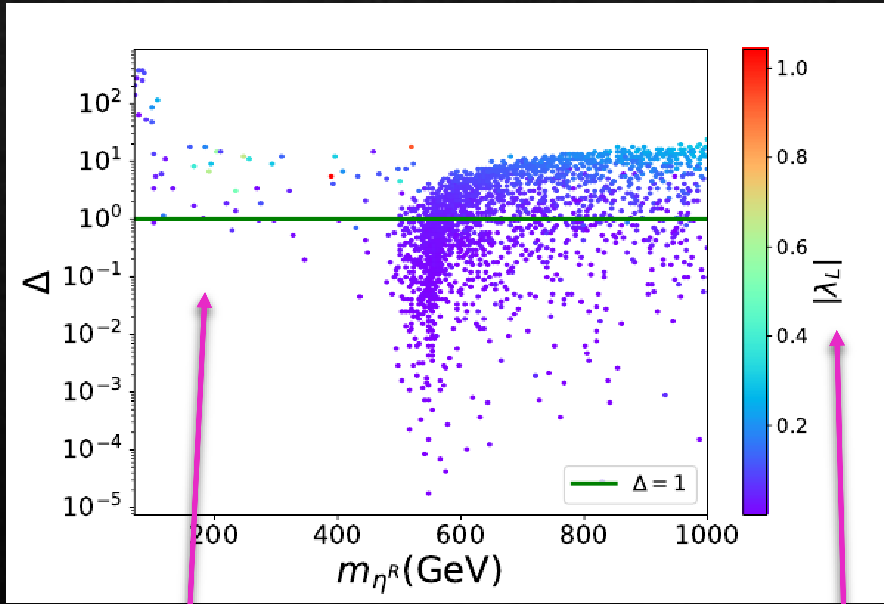


Higgs coupling to fermion DM <0.08

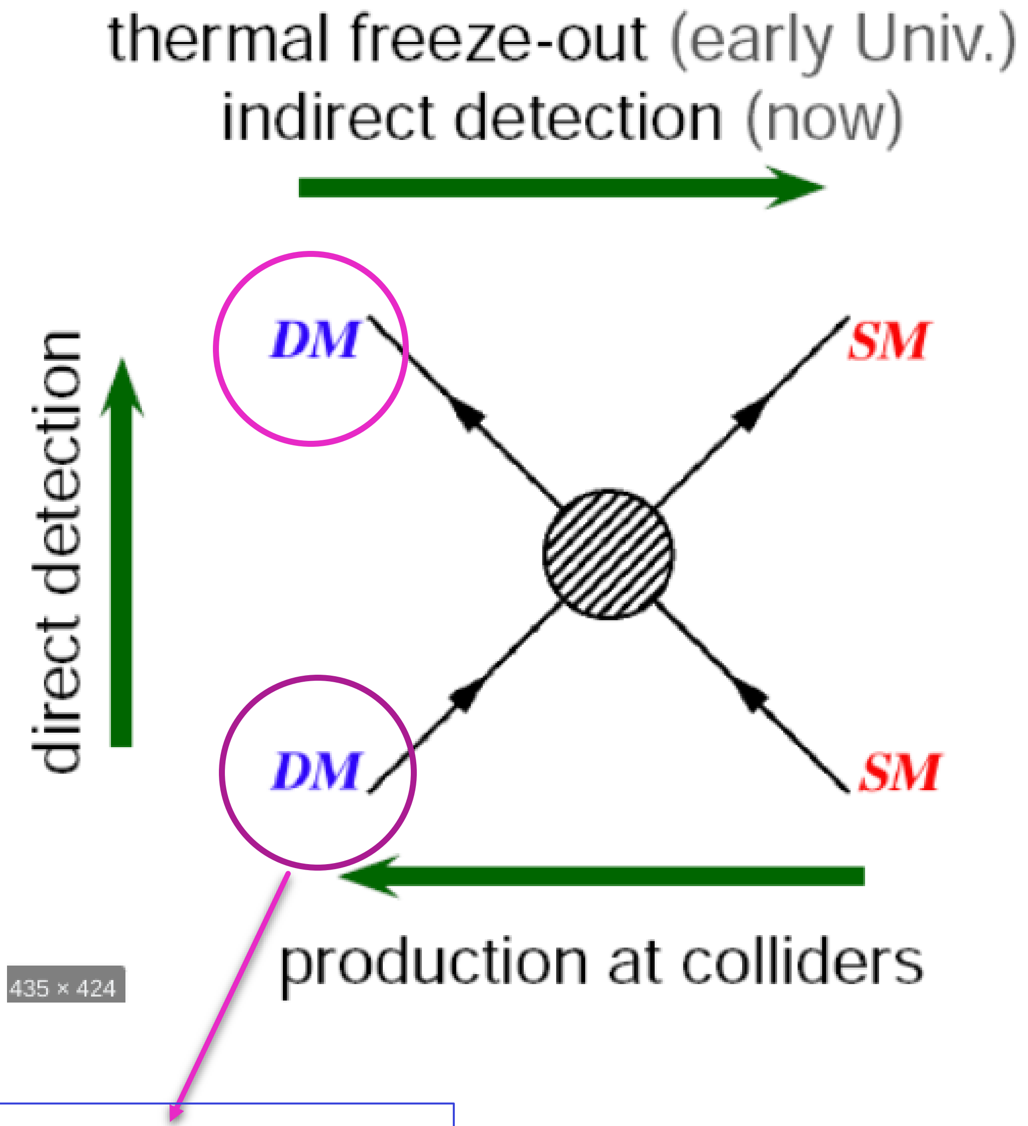
Singlet-Triplet



Restrictions on the scalar mass

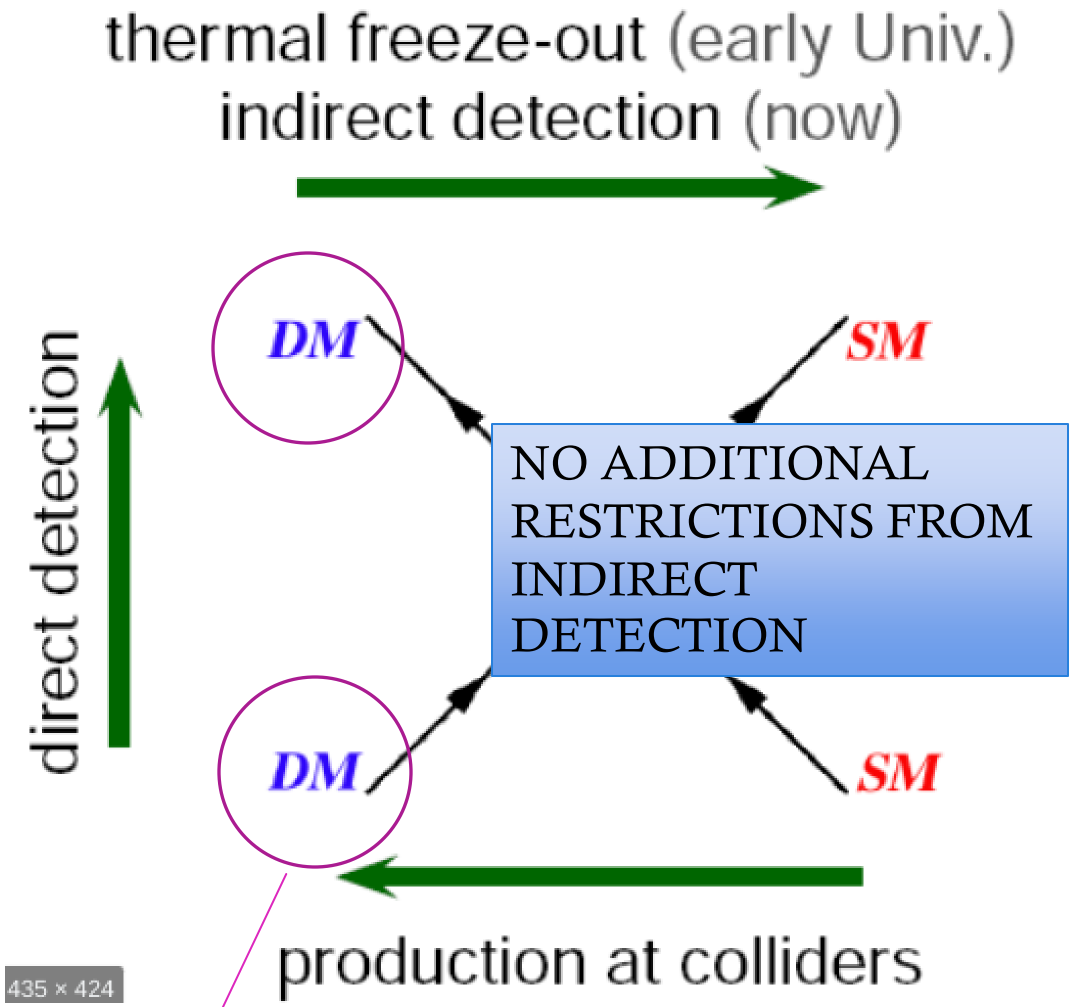
Higgs coupling to scalar DM <0.2

Indirect detection



Double suppression from smaller density of each species

Indirect detection



Double suppression from smaller density of each species

Conclusions

- Multicomponent dark sectors are interesting scenarios of Dark Matter.
- For the Inert Doublet Model it is possible to recover the intermediate regime when another stable fermionic Dark Matter candidate is included.
- It is possible for the two DM candidates to communicate through the Higgs portal, thus altering each other's relic density
- Direct detection places constraints in the Higgs coupling to both scalars and fermions for two of the models while the thermally averaged cross sections of the models are out of bounds of current experiments.

Thank you

Bibliography

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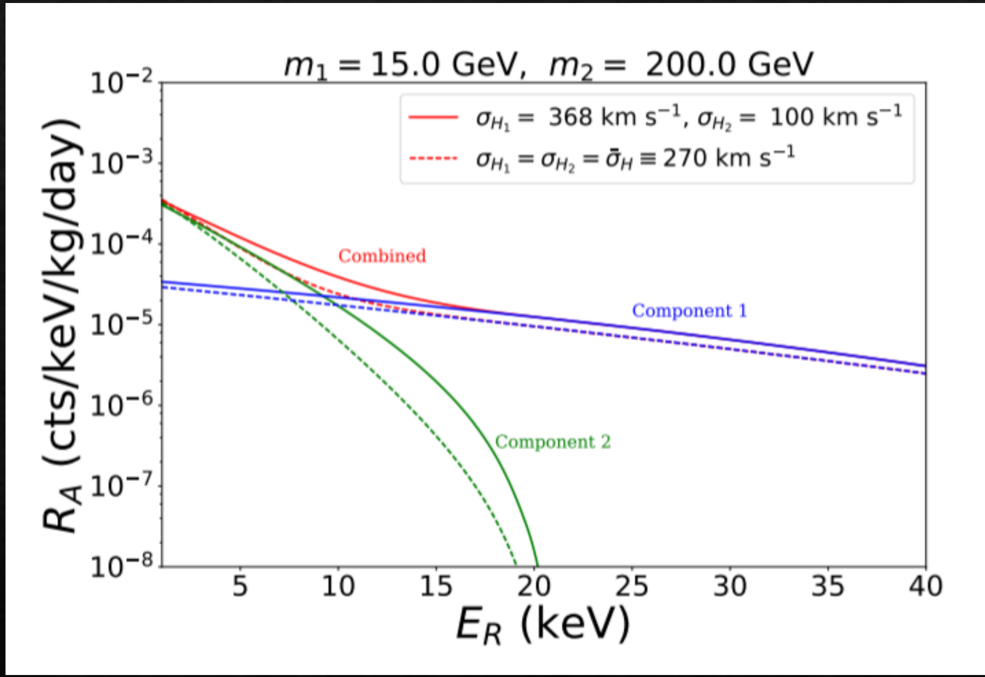
[4] SPheno 3.1: extensions including flavour, CP-phases and models beyond the MSSM, W. Porod, F. Staub.

Advantages of Multicomponent dark sectors: Direct detection constraints



It is even possible to differentiate between the dark matter candidates

Herrero García, et. Al 2018

DM conversion trough gauge interactions