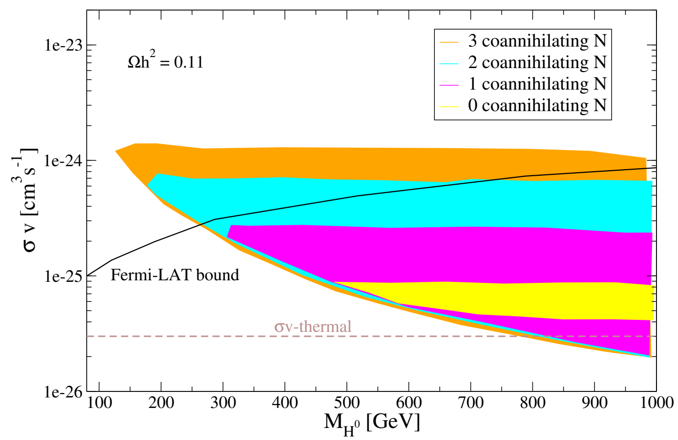
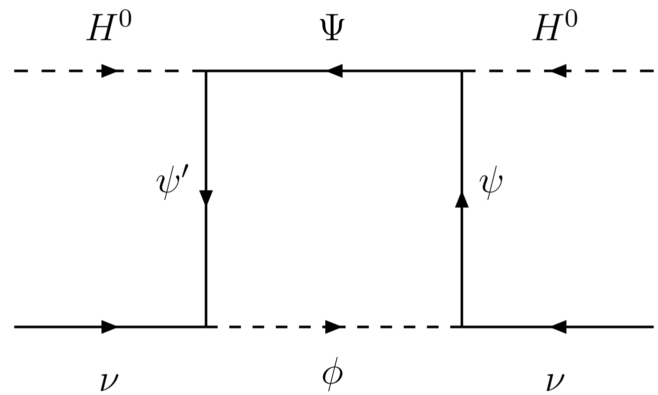
Models of neutrino masses and dark matter





Based on JCAP 1304 (2013) 044
and 1308.3655 (JHEP)

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Münster University

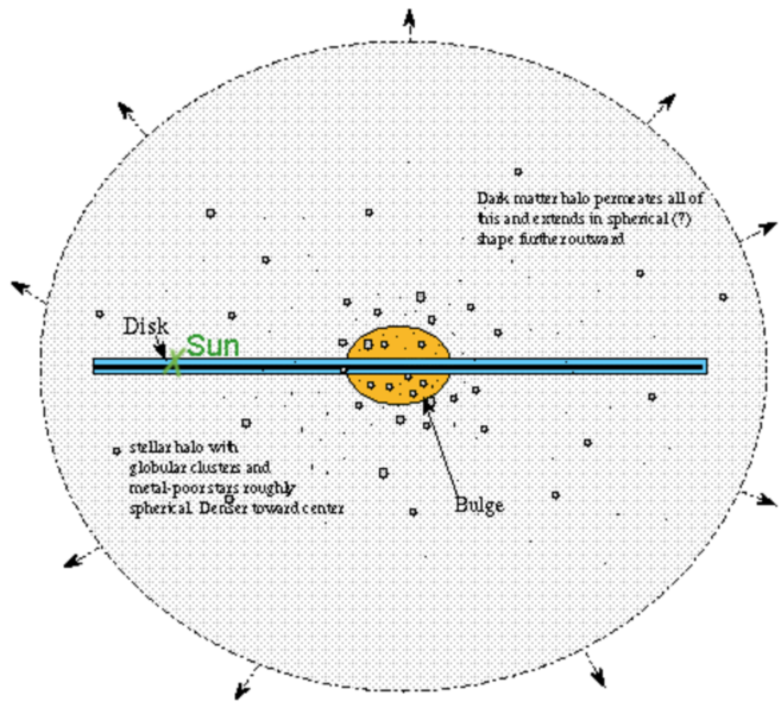
2013

Observations indicate that a large fraction of the matter in the Universe is not visible

It is observed via gravitational interactions

Proven principle $\longrightarrow$
e.g. Neptune discovery

The Sun moves faster than expected

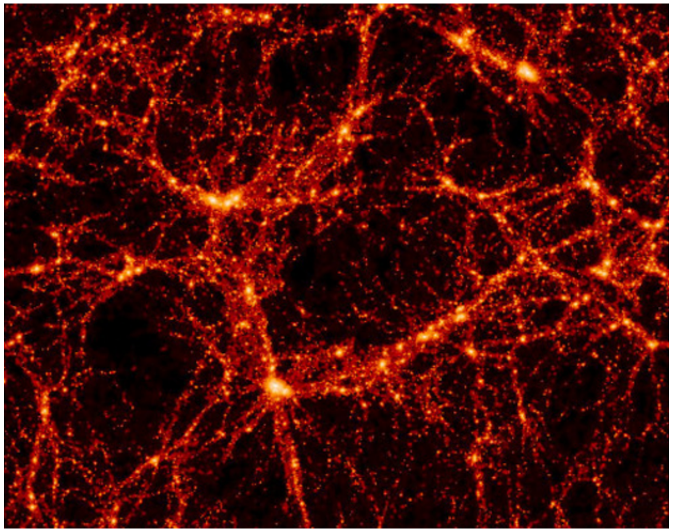


Something similar happens in other galaxies

Dark matter accounts for about 25% of the energy-density of the Universe

Additional evidence for DM comes from

Galaxy clusters
Large Scale Structure
Anisotropies in the CMB



The DM density is obtained from CMB data

$$\Omega_{dm} = 0.25$$
$$\Omega_{atoms} = 0.05$$

The existence of dark matter is a clear indication of physics beyond the SM

DM candidates should be neutral and stable

Neutrinos?

Neutrinos cannot explain the dark matter

$\Omega_\nu \ll \Omega_{dm}$

ν's are hot dm

The SM contains no dark matter candidates

New Physics !

Recent experiments demonstrated that neutrinos have non-zero masses

The flavor or a neutrino can oscillate

$\nu_\alpha \rightarrow \nu_\beta$

Solar, atm, reactor

Oscillation parameters are already known

Δm^2_{ij}, θ_{ij}

Physics beyond the SM is required

??

Most models try to address only one of these two issues

Many scenarios could account for the DM

SUSY, UED, minimal models

Different mechanisms might explain ν masses

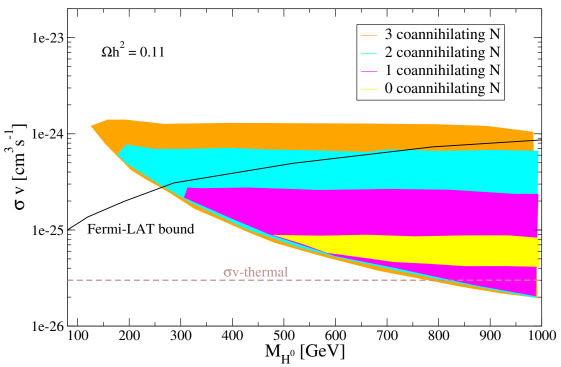
Seesaw, loops, flavor symmetries

Could dark matter and M_ν be related?

Can both be explained by physics at the TeV scale?

I will discuss models that simultaneously address dark matter and ν masses

1. A particular example



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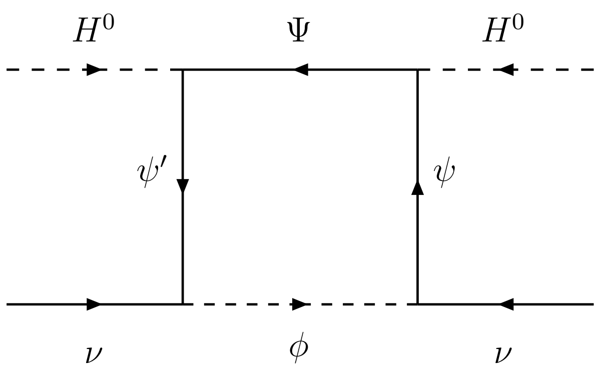
2. Many additional models



1308.3655 (JHEP)

The best known model of neutrino masses and dark matter is the radiative seesaw

It contains only two new fields

Ma, 2006

$H_2 = \binom{H^{\pm}}{H^0 + A^0}$, N_i

They are odd under a Z_2 symmetry

To prevent FCNC

To stabilize the dm

It has a very rich phenomenology

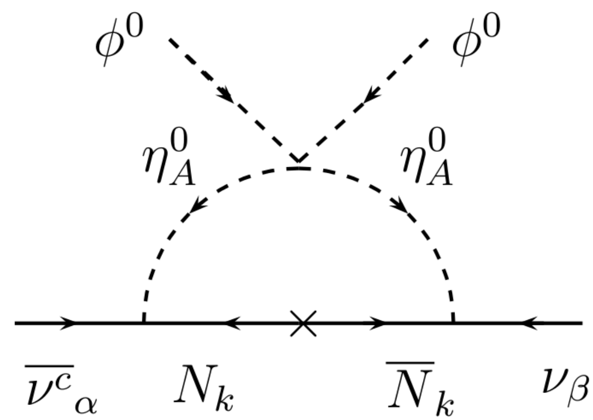
Many studies:

dm, ν, collider

In this model, neutrino masses are generated radiatively at the 1-loop level

No Dirac mass term
for L, N_i

Due to the Z_2
N_i is not a ν_R



Neutrinos acquire masses
at 1-loop

Small M_ν even for N_i, H_2
at the TeV scale

Without tiny couplings

In this model, the dark matter particle can be a scalar or a fermion

It contains two dark matter candidates

H^0: gauge, scalar, Yukawa
N_1: Only Yukawa int.

Ω_{N_1} tends to be larger than Ω_{dm}

Large Yukawa couplings
Constraints from $\mu \to e\gamma$

Ω_{H^0} tends to be smaller than Ω_{dm}

$H^0H^0 \to W^+W^-$
Similar to the Inert Higgs

For scalar dark matter the known viable regions feature $M_{H^0} > 500$ GeV

To compensate for the large value of $\langle \sigma v \rangle$

True for the Inert Higgs

The scalar mass splitting has to be small

$$M_{A^0} - M_{H^0} \ll M_{A^0}$$
$$M_{H^\pm} - M_{H^0} \ll M_{H^\pm}$$

Can we make the region $M_{H^0} < 500$ GeV viable?

With N_i coannihilations?

Coannihilations effects may decrease or increase the predicted relic density

They are relevant for small mass splittings

$\chi_1\chi_1 \to SM$
$\chi_1\chi_2 \to SM, \chi_2\chi_2 \to SM$

If $\langle\sigma v\rangle_{11} \ll \langle\sigma v\rangle_{22}$ coann. tend to decrease Ωh^2

Bino-like neutralino in SUSY

If $\langle\sigma v\rangle_{11} \gg \langle\sigma v\rangle_{22}$ coann. tend to increase Ωh^2

e.g. UED

In the radiative seesaw model it naturally happens that $\langle\sigma v\rangle_{H^0H^0} \gg \langle\sigma v\rangle_{NN}$

$\langle\sigma v\rangle_{H^0H^0}$ is determined by gauge interactions

$H^0H^0 \to W^+W^-$

$\langle\sigma v\rangle_{NN,H^0N}$ are determined by new Yukawa couplings

$h_{ij}\bar{L}_i N_j H_2^\dagger$

h_{ij} are constrained to be small

by neutrino masses

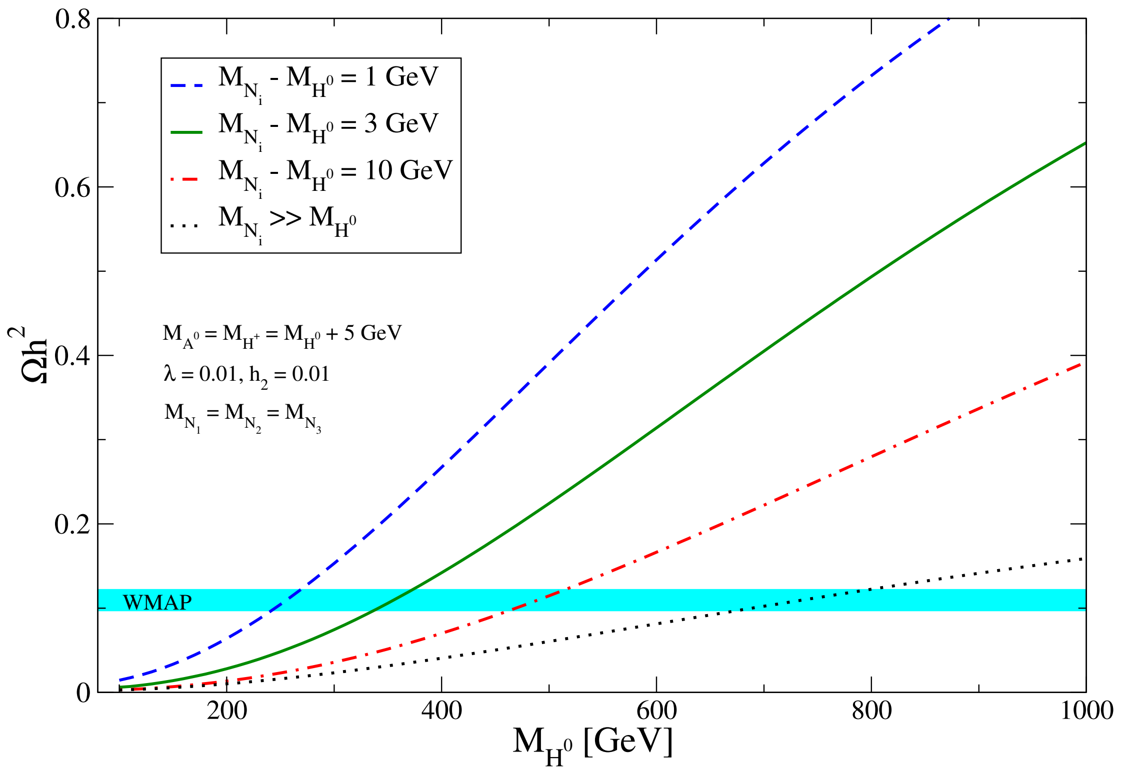
by $\mu \to e\gamma$

The relic density depends on the $H^0 - N_i$ mass splitting

$\Omega h^2_{H^0}$ increases when $\Delta M_{N_i - H^0}$ is reduced

New viable regions at lower masses

The mass splitting has to be small

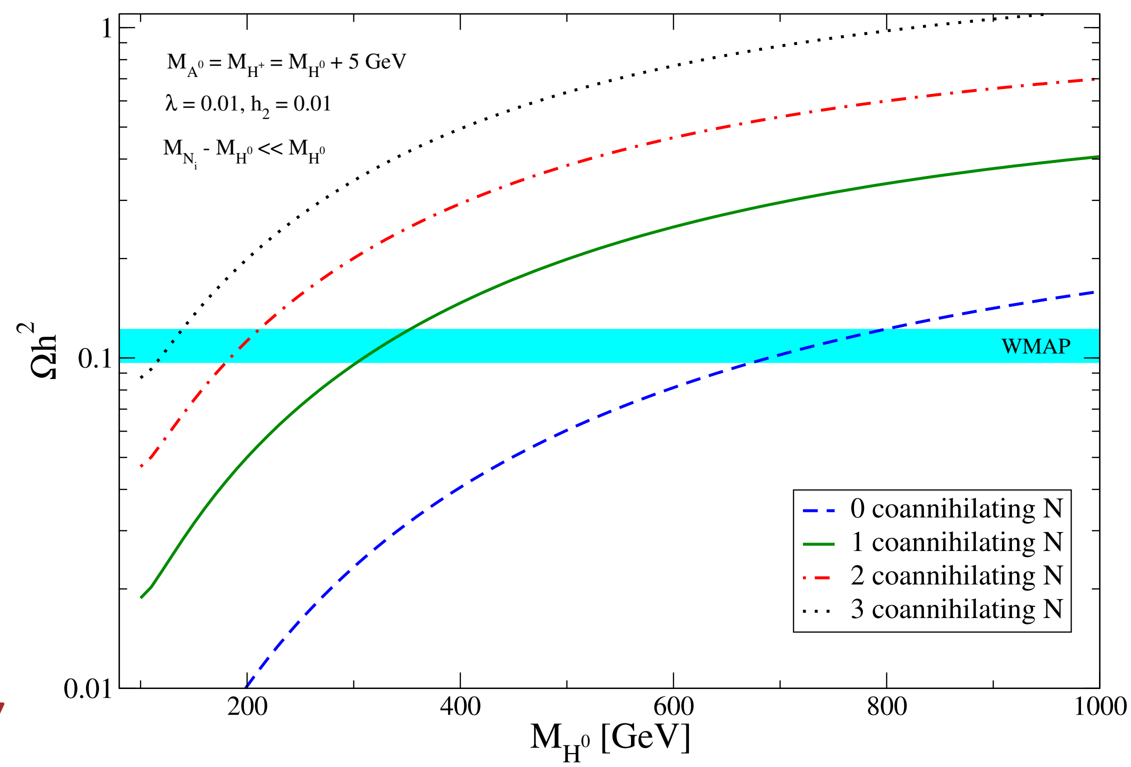


The relic density depends also on the number of coannihilating fermions

N_i in general are not degenerate

The effect is sizable even for 1 coann. N

M_{H^0} as low as 100 GeV becomes viable

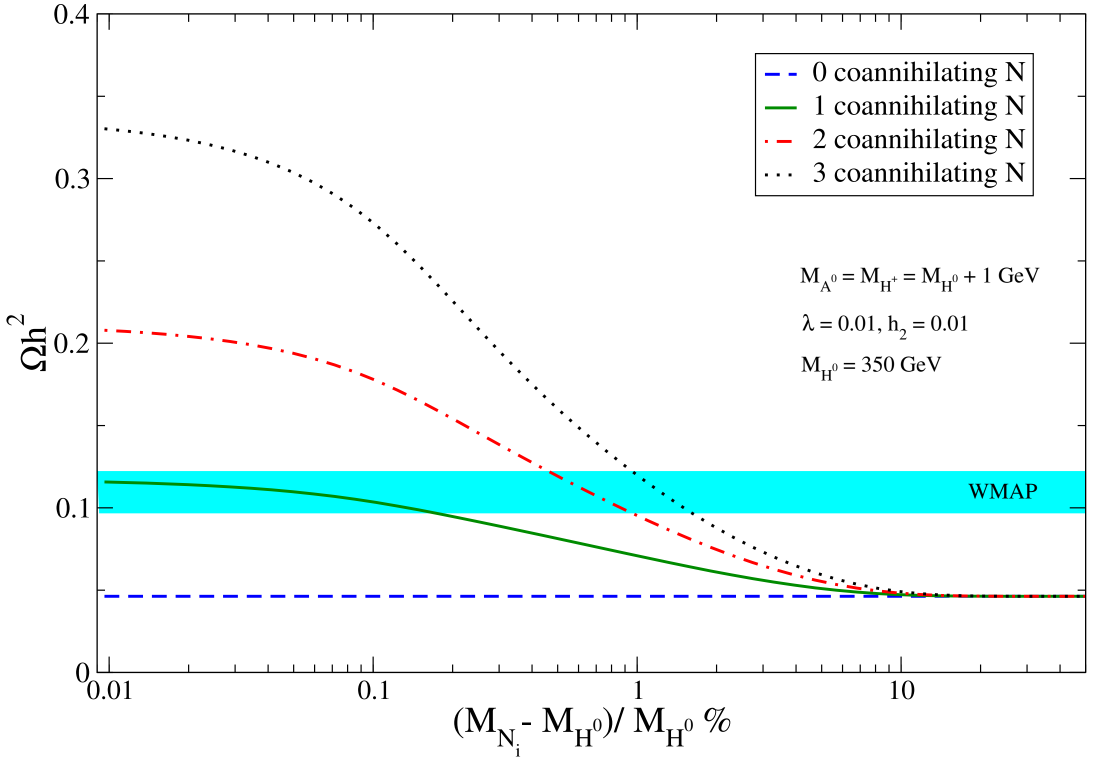


A mass degeneracy below 10% is required to obtain significant effects

Above 10% the effect is negligible

Ωh^2 tends to a constant for small mass splitting

Ωh^2 can increase by up to a factor 6 or so

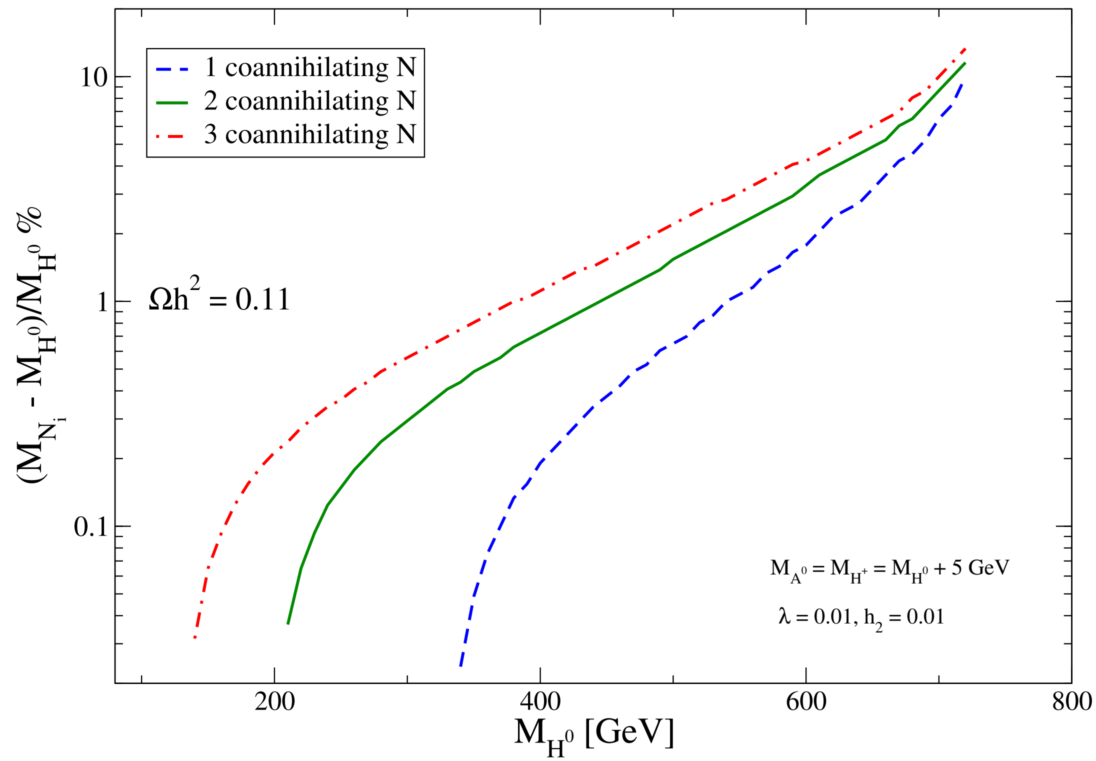


The viable regions now include dark matter masses below 500 GeV

They reach $\sim$ 300 GeV for 1 coann. N

About $\sim$ 200 GeV for 2 coann. N

And close to 100 GeV for 3 coann. N

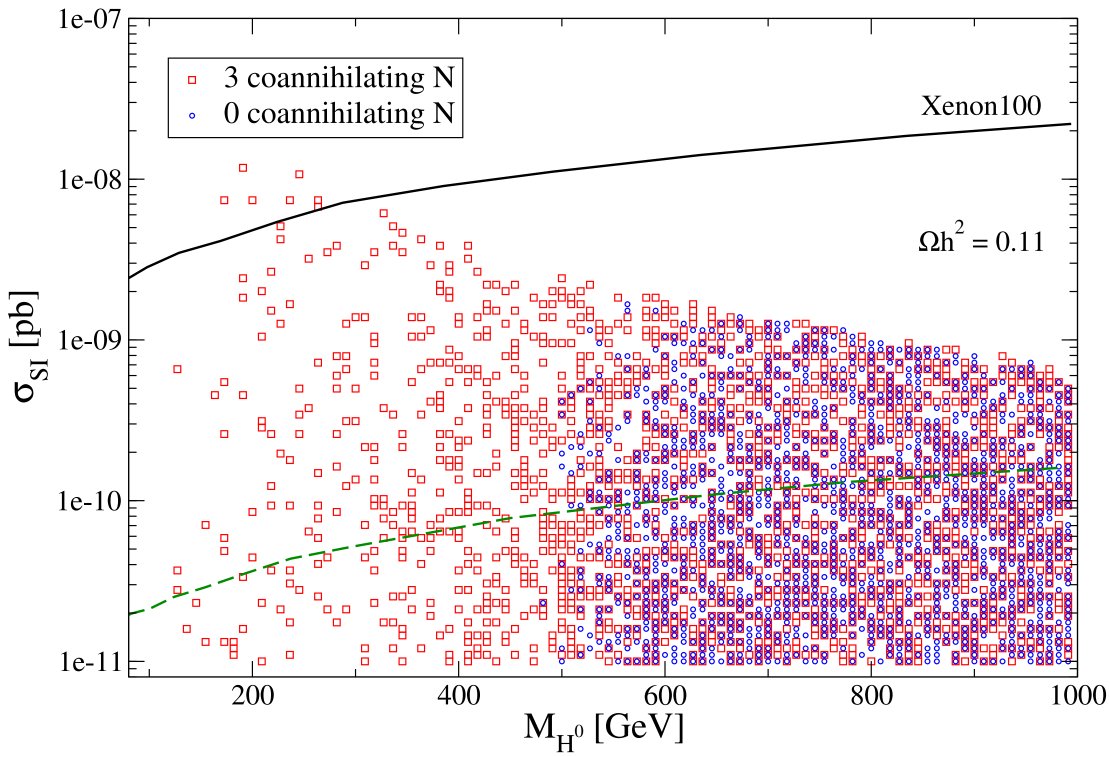


These effects have important implications for dark matter direct detection

More models at low masses

Larger values of the SI cross section

Some models are already excluded

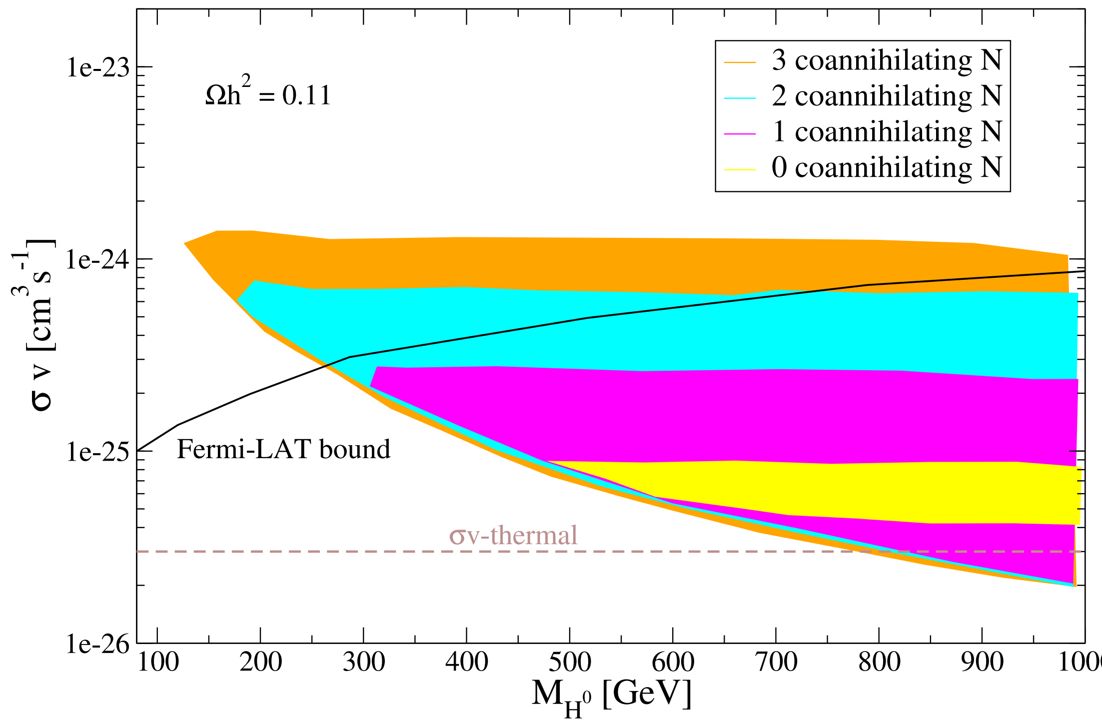


The annihilation rate today can be much larger than naively expected

$\langle \sigma v \rangle$ can reach values of 10^{-24} cm^3/s

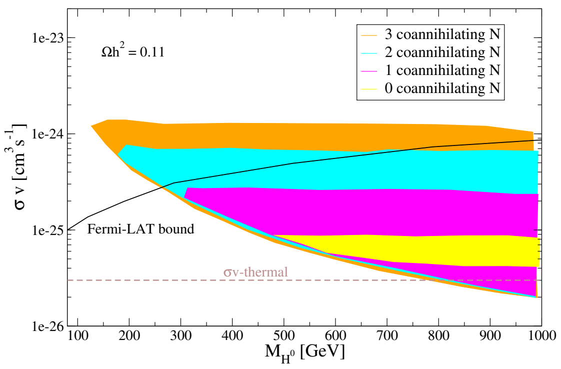
Part of the new region is ruled out

It could be relevant for current experiments



I will discuss models that simultaneously address dark matter and ν masses

1. A particular example



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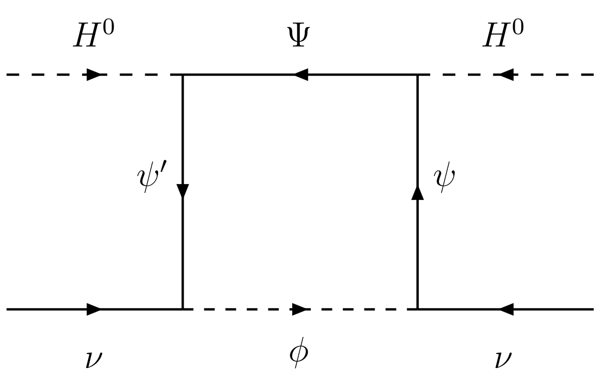
2. Many additional models



1308.3655 (JHEP)

We want to find other models analogous to the radiative seesaw

New particles at the TeV scale

Few of them
Small reps

That can account for the dark matter

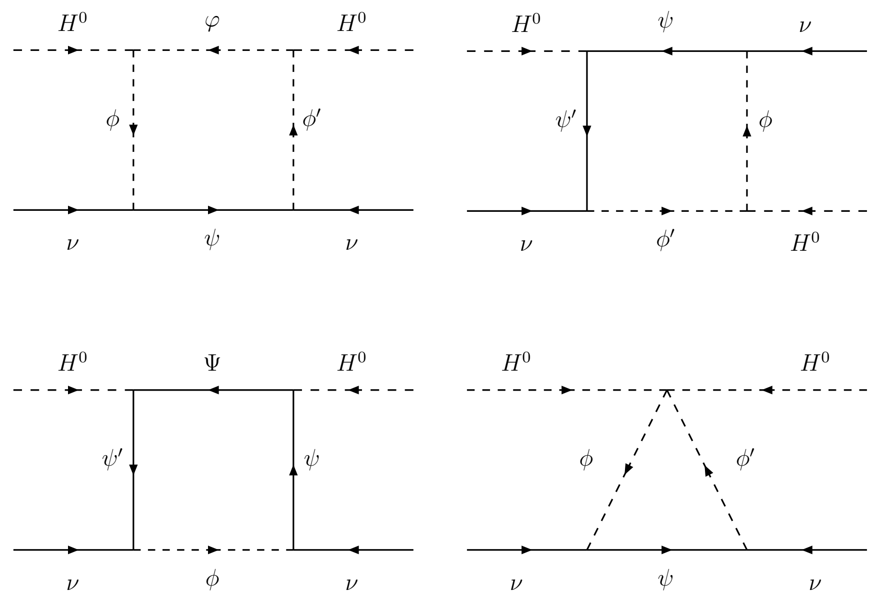
dm is a WIMP
stabilized by a Z_2

M_ν appears at the 1-loop level

Our starting point

The possible 1-loop realizations of the Weinberg operator are already known

Only 4 different topologies exist



Bonnet, Hirsch, Ota, Winter (2012)

The new fields transform as 1, 2 or 3 of SU(2)

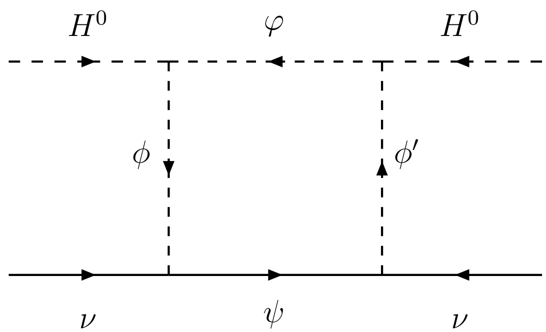
They give rise to $\sim$ 30 new field configurations

Modulo the hypercharge

We have obtained the full list of minimal models of ν masses and dark matter

All new fields are odd under a Z_2	DM stability
The spectrum should contain a neutral particle	$Y = -2T_3$ Few viable possibilities
It must be consistent with current experiments	$\Omega h^2 \rightarrow$ TeV masses Direct detection bounds

We found 12 models compatible with dark matter within the T1-1 topology



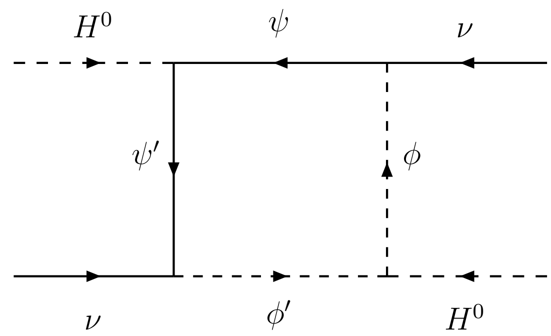
All of them allow for scalar dm

Only four admit fermionic dm

7 models include exotics

Model	Fields	α	Fermionic DM	Fermionic DD	Scalar DM	Scalar DD	Exotic Charges	# of N'plets
T1-1-A	1^S_α, $2^S_{\alpha-1}$, 1^F_α, $2^S_{\alpha+1}$	± 2	$\times$	$\times$	$2_{\pm 1}$	✓	✓	4
		0	1_0	✓	$1_0, 2_{\pm 1}$	✓	$\times$	3
T1-1-B	1^S_α, $2^S_{\alpha-1}$, 3^F_α, $2^S_{1+\alpha}$	± 2	$3_{\pm 2}$	$\times$	$2_{\pm 1}$	✓	✓	4
		0	3_0	✓	$1_0, 2_{\pm 1}$	✓	$\times$	3
T1-1-C	2^S_α, $1^S_{\alpha-1}$, 2^F_α, $1^S_{1+\alpha}$	± 1	$2_{\pm 1}$	$\times$	$1_0, 2_{\pm 1}$	✓	✓	4
T1-1-D	2^S_α, $1^S_{\alpha-1}$, 2^F_α, $3^S_{1+\alpha}$	1	2_1	$\times$	$1_0, 2_1, 3_2$	✓	✓	4
		-1	2_{-1}	$\times$	$2_{-1}, 3_0$	✓	$\times$	4
T1-1-F	2^S_α, $3^S_{\alpha-1}$, 2^F_α, $3^S_{1+\alpha}$	± 1	$2_{\pm 1}$	$\times$	$2_{\pm 1}, 3_0, 3_{\pm 2}$	✓	✓	4
T1-1-G	3^S_α, $2^S_{\alpha-1}$, 1^F_α, $2^S_{1+\alpha}$	± 2	$\times$	$\times$	$2_{\pm 1}, 3_{\pm 2}$	✓	✓	4
		0	1_0	✓	$2_{\pm 1}, 3_0$	✓	$\times$	3
T1-1-H	3^S_α, $2^S_{\alpha-1}$, 3^F_α, $2^S_{1+\alpha}$	± 2	$3_{\pm 2}$	$\times$	$2_{\pm 1}, 3_{\pm 2}$	✓	✓	4
		0	3_0	✓	$2_{\pm 1}, 3_0$	✓	$\times$	3

Within the T1-2 topology, 8 models are compatible with dark matter



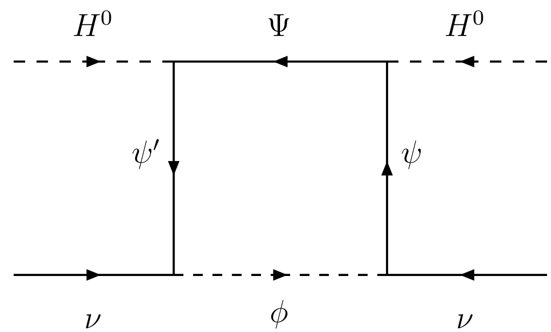
All models admit scalar dm

Four allow for fermionic dm

3 models include exotics

Model	Fields	α	Fermionic DM	Fermionic DD	Scalar DM	Scalar DD	Exotic Charges	# of N'plets
T1-2-A	$1^F_\alpha,\ 2^S_{1+\alpha},\ 1^S_\alpha,\ 2^F_{1+\alpha}$	0	$1_0, 2_1$	✓	$1_0, 2_1$	✓	×	4
		-2	2_{-1}	×	2_{-1}	✓	×	4
T1-2-B	$1^F_\alpha,\ 2^S_{1+\alpha},\ 3^S_\alpha,\ 2^F_{1+\alpha}$	0	$1_0, 2_1$	✓	$2_1, 3_0$	✓	×	4
		-2	2_{-1}	×	$2_{-1}, 3_{-2}$	✓	✓	4
T1-2-D	$2^F_\alpha,\ 1^S_{1+\alpha},\ 2^S_\alpha,\ 3^F_{1+\alpha}$	1	$2_1, 3_2$	×	2_1	✓	✓	4
		-1	$2_{-1}, 3_0$	✓	$1_0, 2_{-1}$	✓	×	4
T1-2-F	$2^F_\alpha,\ 3^S_{1+\alpha},\ 2^S_\alpha,\ 3^F_{1+\alpha}$	1	$2_1, 3_2$	×	$2_1, 3_2$	✓	✓	4
		-1	$2_{-1}, 3_0$	✓	$2_{-1}, 3_0$	✓	×	4

We found 8 models from the T1-3 topology that are consistent with dark matter



All models admit scalar dm

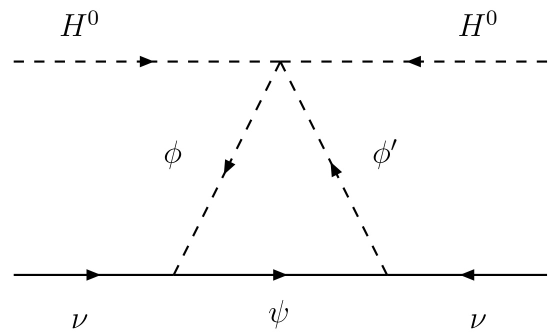
All allow for fermionic dm

2 models include exotics

Model	Fields	α	Fermionic DM	Fermionic DD	Scalar DM	Scalar DD	Exotic Charges	# of N'plets
T1-3-A	$1^F_\alpha,\ 2^F_{1+\alpha},\ 1^S_\alpha,\ 2^F_{\alpha-1}$	0	$1_0, 2_{\pm1}$	✓	1_0	✓	×	3
T1-3-B	$1^F_\alpha,\ 2^F_{1+\alpha},\ 3^S_\alpha,\ 2^F_{\alpha-1}$	0	$1_0, 2_{\pm1}$	✓	3_0	✓	×	3
T1-3-C	$2^F_\alpha,\ 1^F_{1+\alpha},\ 2^S_\alpha,\ 1^F_{\alpha-1}$	±1	$1_0, 2_{\pm1}$	✓	2_1	✓	×	4
T1-3-D	$2^F_\alpha,\ 1^F_{1+\alpha},\ 2^S_\alpha,\ 3^F_{\alpha-1}$	1	$2_1, 3_0$	✓	2_1	✓	×	4
		-1	$1_0, 2_{-1}, 3_{-2}$	✓	2_{-1}	✓	✓	4
T1-3-F	$2^F_\alpha,\ 3^F_{1+\alpha},\ 2^S_\alpha,\ 3^F_{\alpha-1}$	±1	$2_{\pm1}, 3_0, 3_{\pm2}$	✓	$2_{\pm1}$	✓	✓	4
T1-3-G	$3^F_\alpha,\ 2^F_{1+\alpha},\ 1^S_\alpha,\ 2^F_{\alpha-1}$	0	$2_{\pm1}, 3_0$	✓	1_0	✓	×	3
T1-3-H	$3^F_\alpha,\ 2^F_{1+\alpha},\ 3^S_\alpha,\ 2^F_{\alpha-1}$	0	$2_{\pm1}, 3_0$	✓	3_0	✓	×	3

Within the T3 topology, 7 models were found to be consistent with dark matter

All models allow scalar dm



Only two admit fermionic dm

4 models include exotics

Model	Fields	α	Fermionic		Scalar		Exotic Charges	# of N'plets
			DM	DD	DM	DD		
T3-A	1^S_α, $3^S_{2+\alpha}$, $2^F_{1+\alpha}$	0	2_1	×	$1_0, 3_2$	✓	✓	3
		-2	2_{-1}	×	3_0	✓	×	3
T3-B	2^S_α, $2^S_{2+\alpha}$, $1^F_{1+\alpha}$	$1, -3$	×	×	$2_{\pm 1}$	✓	✓	3
		-1	1_0	✓	$2_{\pm 1}$	✓	×	2
T3-C	2^S_α, $2^S_{2+\alpha}$, $3^F_{1+\alpha}$	$1, -3$	$3_{\pm 2}$	×	$2_{\pm 1}$	✓	✓	3
		-1	3_0	✓	$2_{\pm 1}$	✓	×	2
T3-E	3^S_α, $3^S_{2+\alpha}$, $2^F_{1+\alpha}$	$0, -2$	$2_{\pm 1}$	×	$3_0, 3_{\pm 2}$	✓	✓	3

These models of ν masses and dm offer an interesting approach to physics BSM

They address two pressing problems

M_ν at 1-loop
DM is an SU(2) n-plet

They are minimal and testable

Few new fields, a Z_2
$M \sim$ TeV $\rightarrow$ LHC

Most of them have not been studied

Work in progress