Neutrino lines from Dark Matter

Camilo Garcia Cely, ULB

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In collaboration with Chaimae El Aisati, Thomas Hambye, Julian Heeck and Laurent Vanderheyden.
Based on arXiv:1706.06600 and JCAP 1703 (2017) no.03, 054

Outline

- Motivation: why neutrino lines?
- Part I: neutrino lines from annihilating dark matter
- Part II: neutrino lines from the decay of Majoron dark matter

Indirect detection of DM with photon lines

- One looks for DMDM $\rightarrow \gamma\gamma$.
- Photons point to the place where they come from.
- Monochromatic photons (lines) stand out of the featureless astrophysical background.

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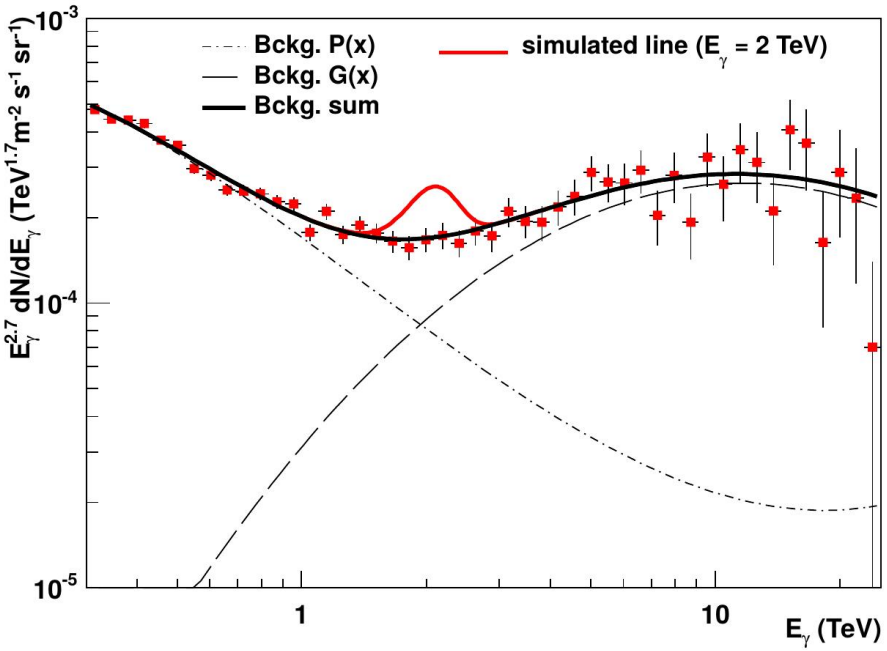
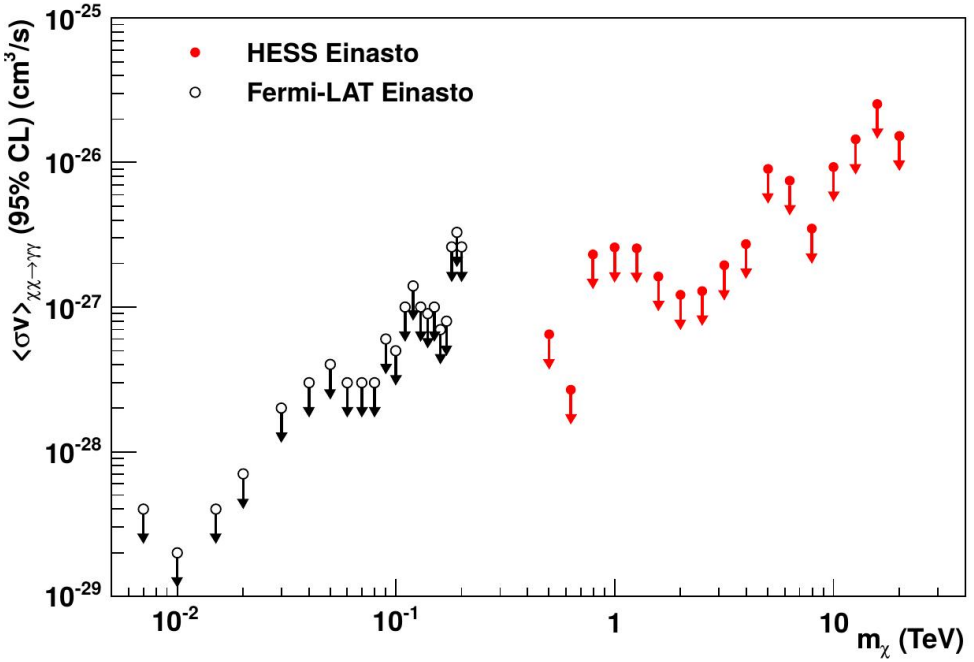
HESS collaboration 2013





Dark matter indirect searches with neutrino lines

- Neutrinos are similar to photons. They point to the direction where they were produced.
- With current resolutions, neutrino lines can be disentangled from the atmospheric and astrophysical background.

El Aisati, CGC, Hambye, Vanderheyden, 2017

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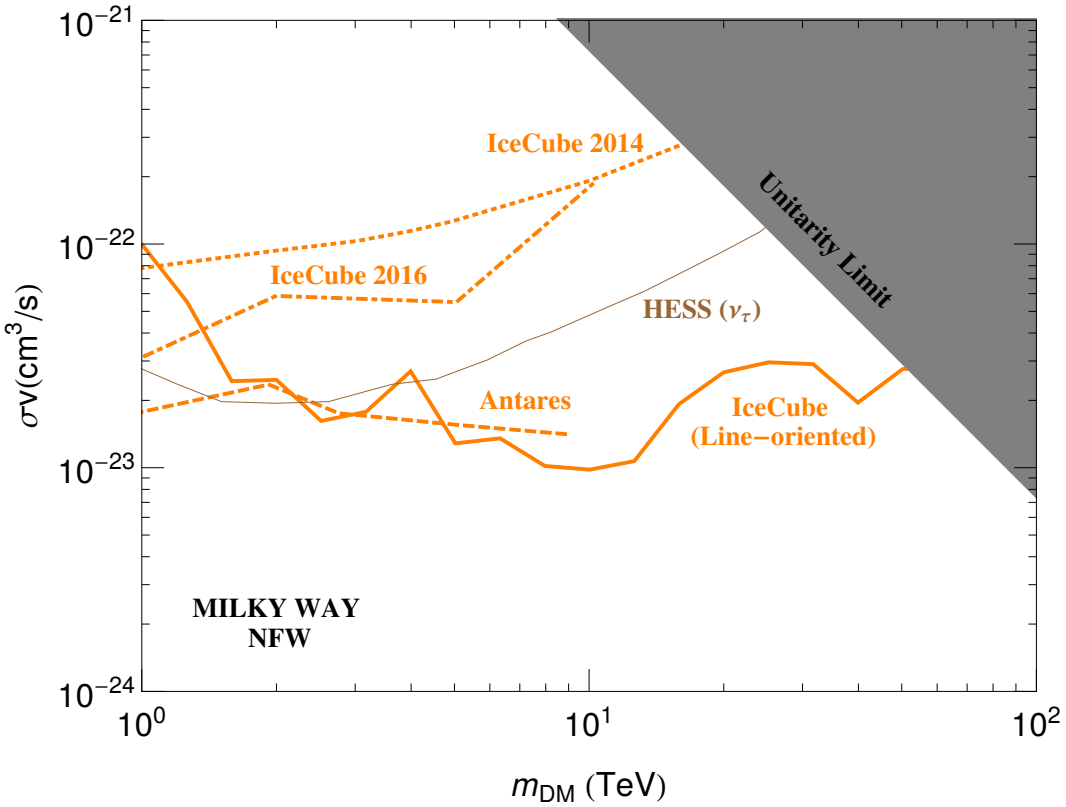

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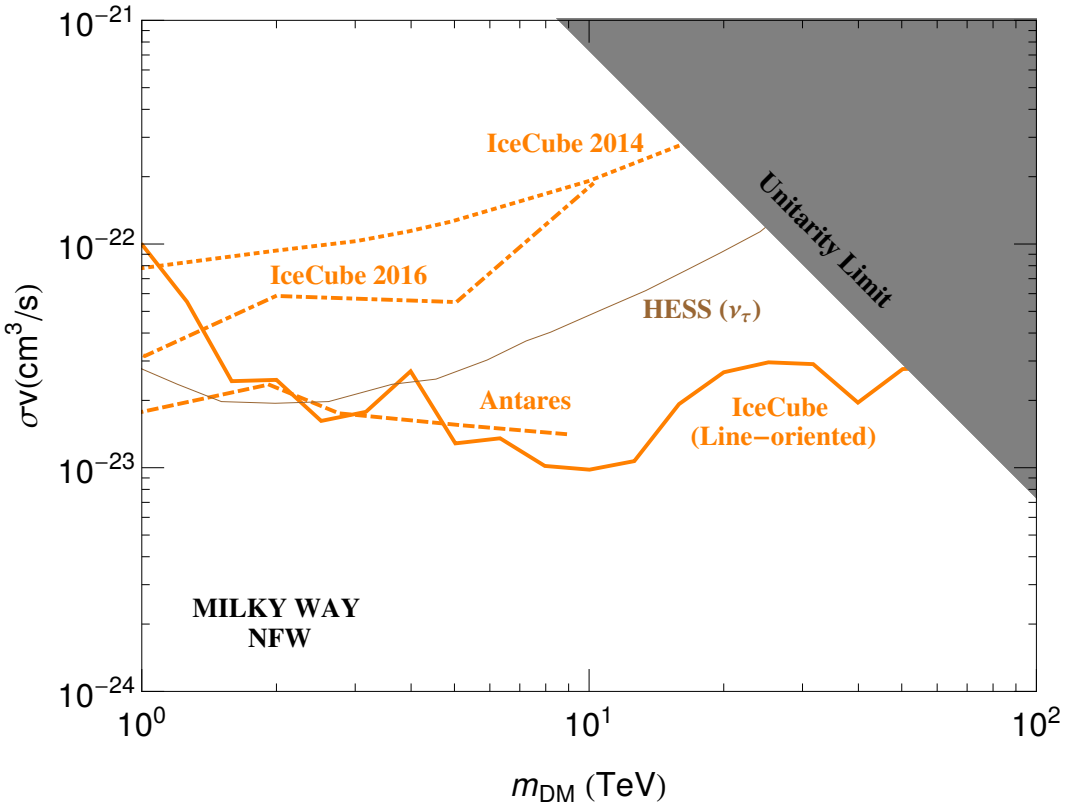


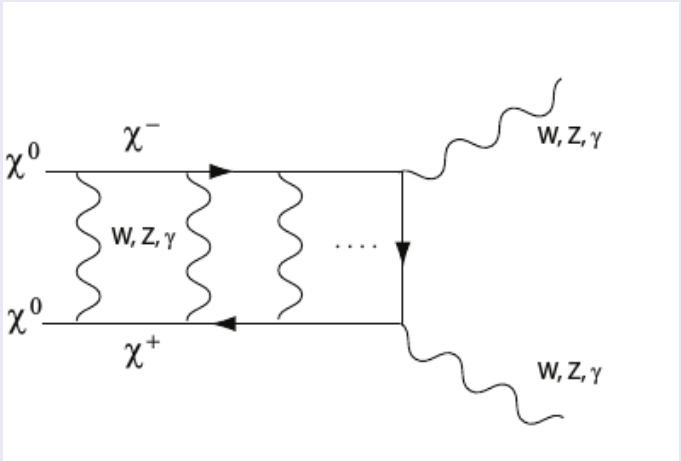
IceCube observations will improve these limits in the near future.

El Aisati, CGC, Hambye, Vanderheyden, 2017

Dark matter indirect searches with neutrino lines

What sort of models can be probed in the near future?

- Question partially addressed. Lindner, Merle, Niro, 2010.
- Consider *simple* models where the annihilation into neutrinos fixes the freeze-out process: $\sigma v \sim 3 \times 10^{-26}\,\mathrm{cm}^3/\mathrm{s}$ in the Early Universe.
- Calculate the Sommerfeld effect and see what are the neutrino indirect detection prospects.



Hisano et al, 2004

In practice, this means that today $\sigma v \gg 3 \times 10^{-26}\,\mathrm{cm}^3/\mathrm{s}$.

Annihilation into into neutrino lines

Final state $\nu\bar{\nu}$

Final state $\nu\nu$

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Lepton Number	Hypercharge	Angular Momentum J
0	0	≥ 1

- Annihilations are p-wave suppressed for scalar or Majorona DM: $\sigma v \ll 3 \times 10^{-26}\,\mathrm{cm}^3/\mathrm{s}$.
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Final state $\nu\nu$

Lepton Number	Hypercharge	Angular Momentum J
2	2	≥ 0

- At the TeV scale, it requires a DM particle with hypercharge
- Too large neutrino masses might be induced by the same process leading to DM annihilations.

Classification of simple models

Annihilation Channel	DM		Mediator		m_ν OK at 1-loop?	Suppressed by v_{EW}/m_{DM}?	$\ell^+\ell^-$	Model
$\overline{\text{DM}}\text{DM} \to \bar{\nu}\nu$	Dirac	T_0	s-chann. vector	S	Yes	No	$=$	F_1
		T_0	t-chann. scalar	D				F_2
		S	s-chann. vector	S				F_3
		S	t-chann. scalar	D				F_4
DMDM $\to \nu\nu$	Real Scalar	D	s-chann. scalar	T_2	$\pm$	No	/	S_1^r
		S	t-chann. Majorana	D	No	Yes		S_2^r
		D		S		No		S_3^r
		D		T_0		No		S_4^r
		D		T_2		Yes		S_5^r
		T_0		D		Yes		S_6^r
		T_2		D		Yes		S_7^r
	Majorana	D	s-chann. scalar	T_2	$\pm$	No		F_1^m
		S	t-chann. scalar	D	No	Yes		F_2^m
		D		S		No		F_3^m
		D		T_0		No		F_4^m
		D		T_2		Yes		F_5^m
		T_0		D		Yes		F_6^m
		T_2		D		Yes		F_7^m
	Complex Scalar	S	t-chann. Majorana	D	Yes	Yes		S_1
		T_0		D				S_2
	Dirac	S	t-chann. scalar	D	Yes	Yes		F_4
		T_0		D				F_2

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Two benchmark models

Model F_1: Dirac DM coupled to a heavier Z'

Model S_1^r: Scalar DM coupled to a scalar triplet with $Y = 2$.

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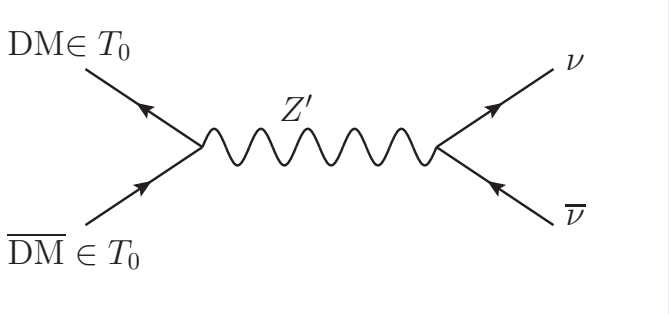
We want Sommerfeld effect $\rightarrow$ Take DM in a triplet with $Y = 0$.



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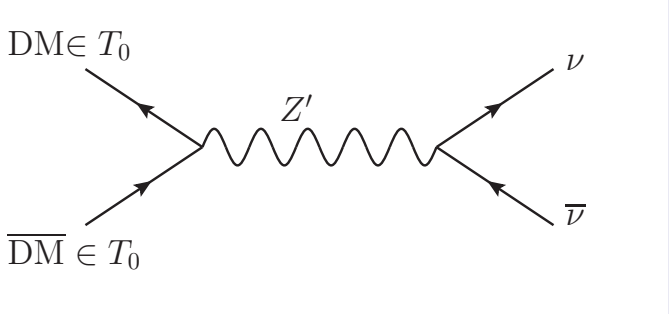

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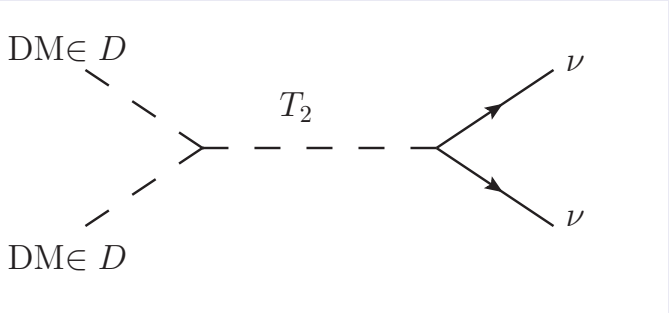

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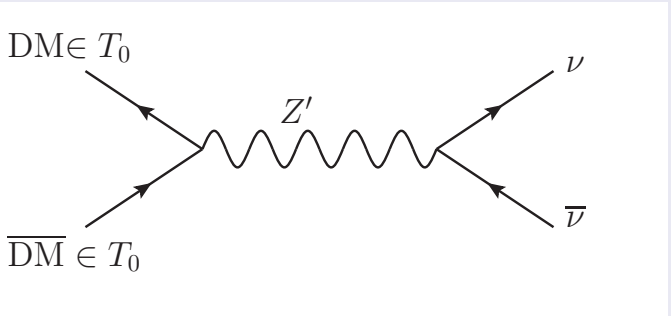

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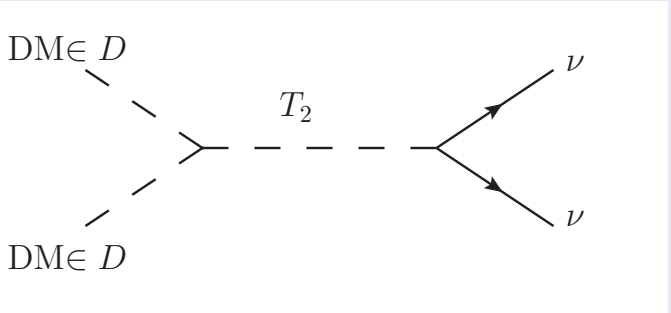


Type-II seesaw mechanism $\rightarrow$ Neutrino masses at tree level.

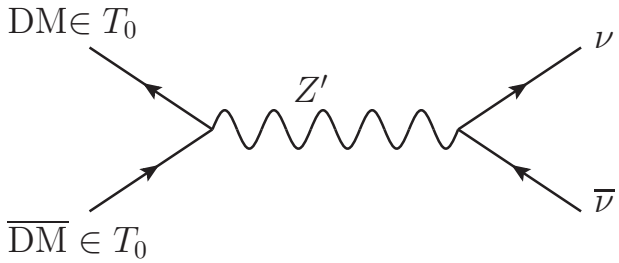
El Aisati, CGC, Hambye, Vanderheyden, 2017

Model F_1

DM belongs to ψ, a hyperchargeless triplet T_0

$$\mathcal{L}_{Z'} \supset g_D Z'_\mu \left(\overline{\psi} \gamma^\mu \psi + Q \overline{L_\alpha} \gamma^\mu L_\alpha \right) .$$

At freeze-out $\sigma v \sim 2.3 \times 10^{-26}\,\mathrm{cm}^3/\mathrm{s}$.



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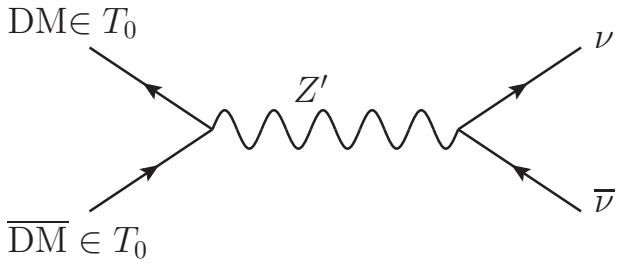

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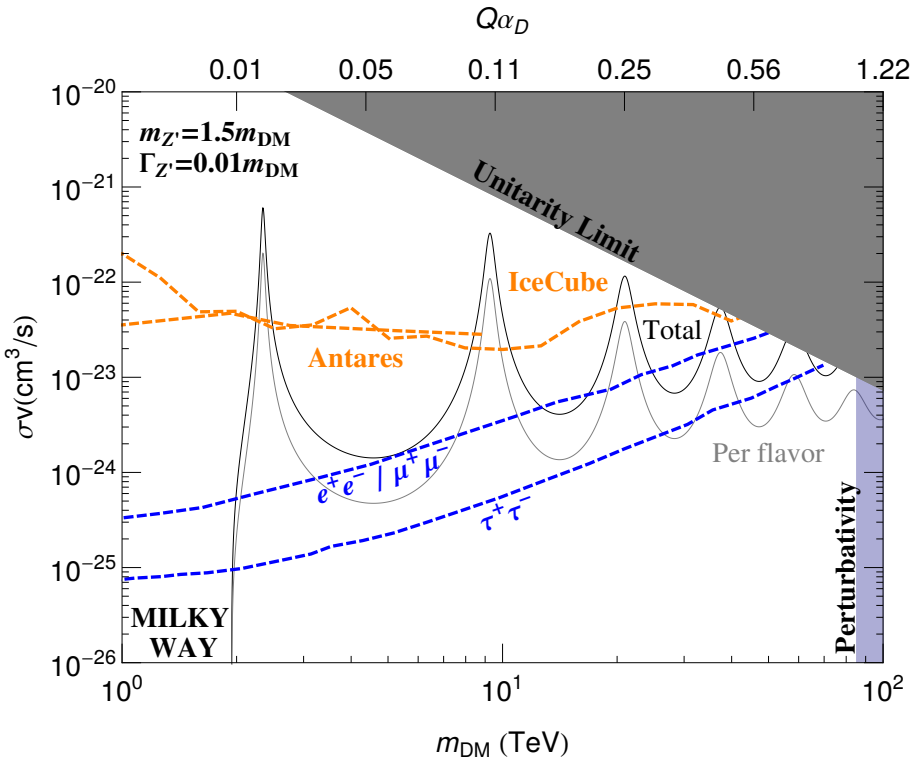

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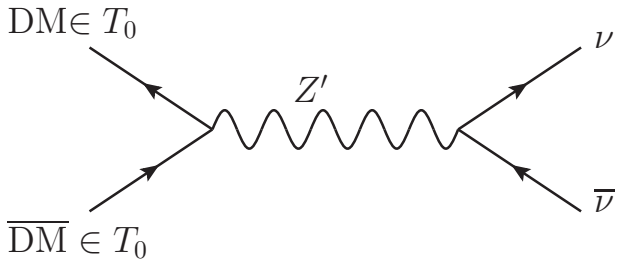

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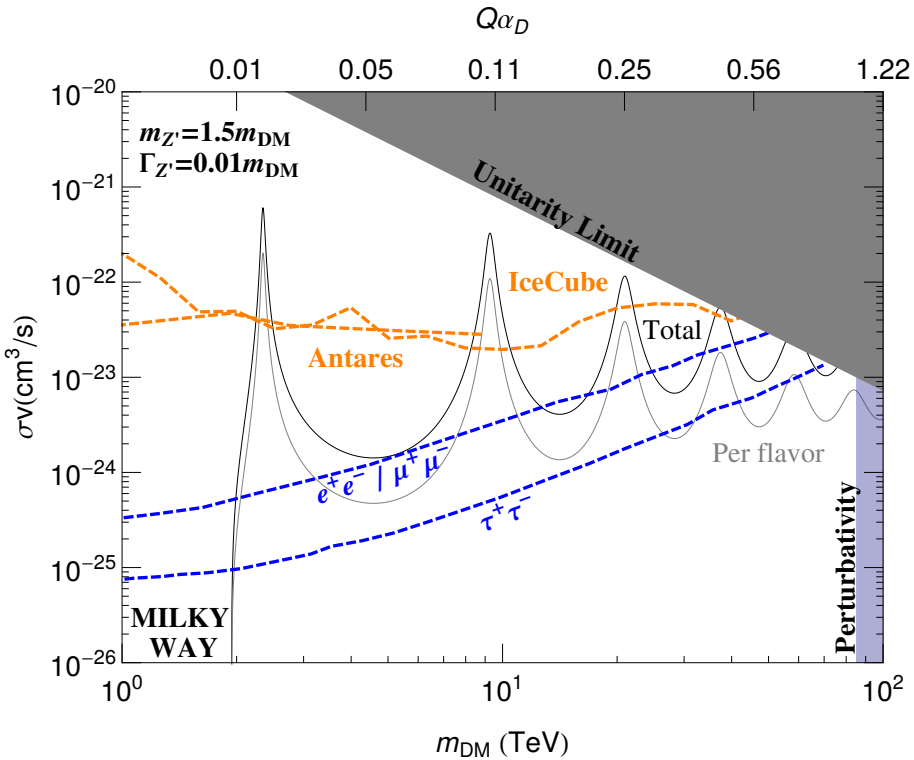

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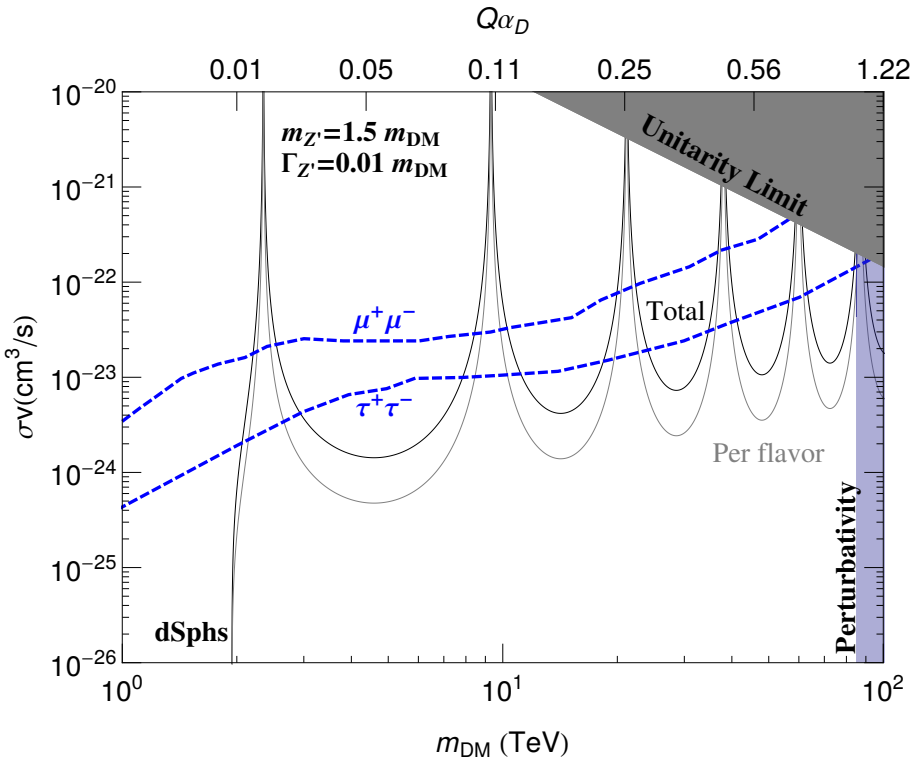
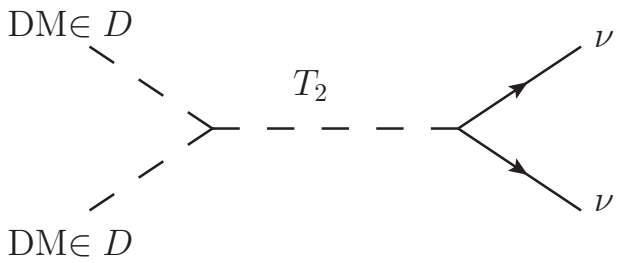


In dwarf galaxies ($v \sim \times 10^{-5} c$)

Model S_1^r

DM belongs to $\phi_D = \begin{pmatrix} H^+ \\ (H^0 + iA^0)/\sqrt{2} \end{pmatrix}$

$$\mathcal{L} = \mu\, \phi_D \phi_T \phi_D - Y^L_{\alpha\beta}\, \overline{L_\alpha} \phi_T L^c_\beta + h.c.$$



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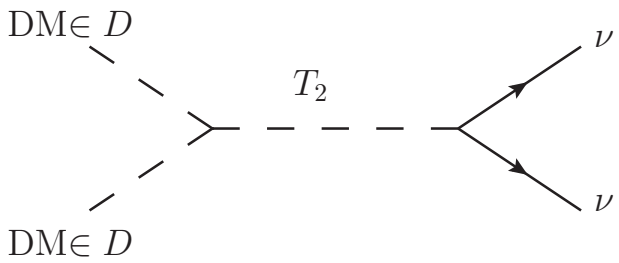

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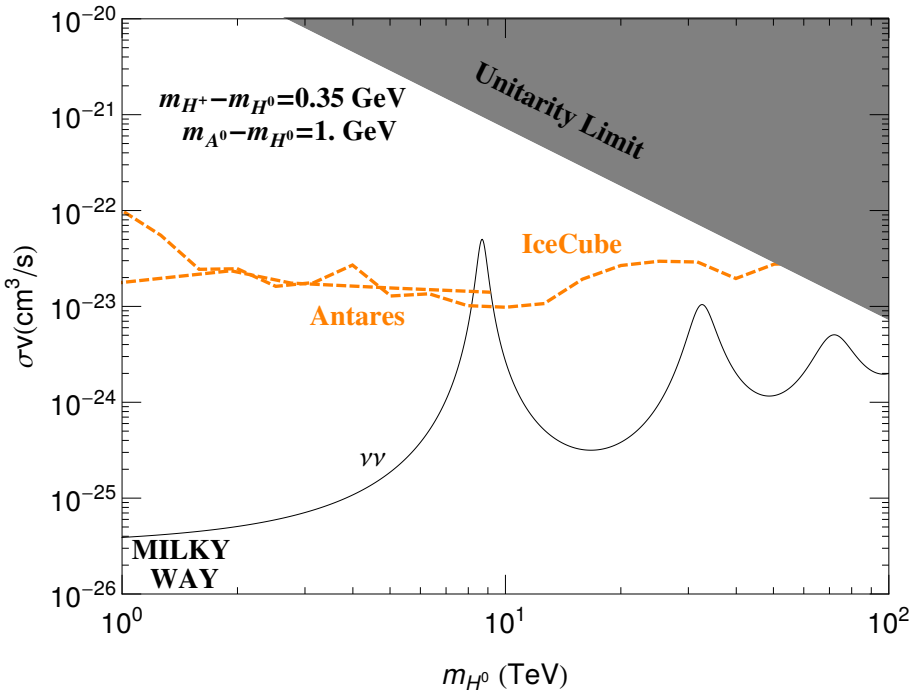

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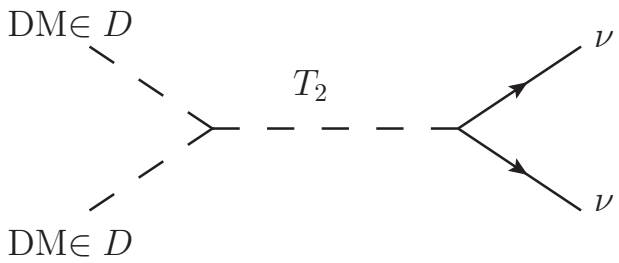

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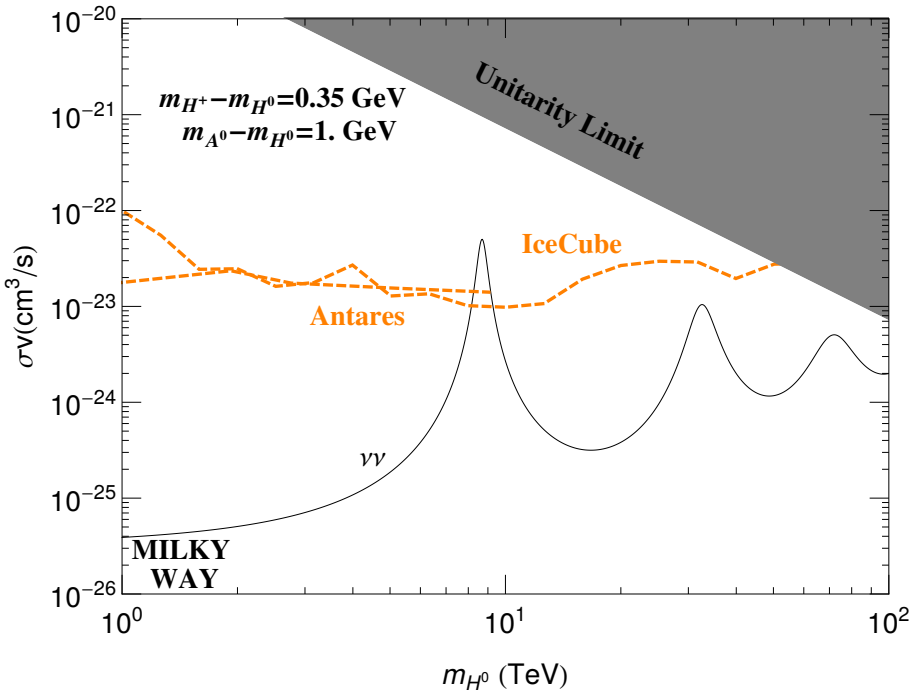

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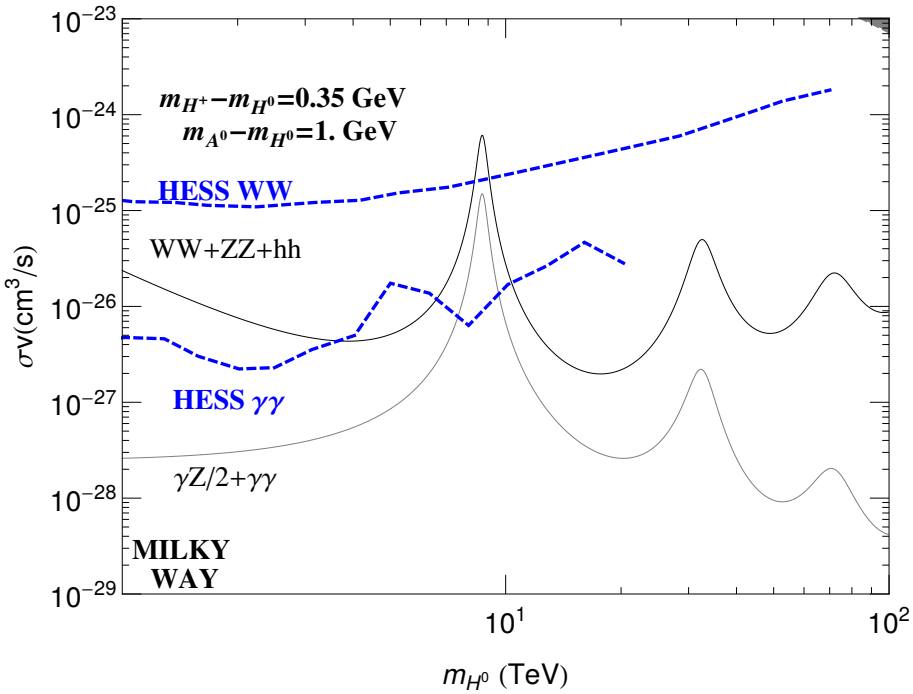
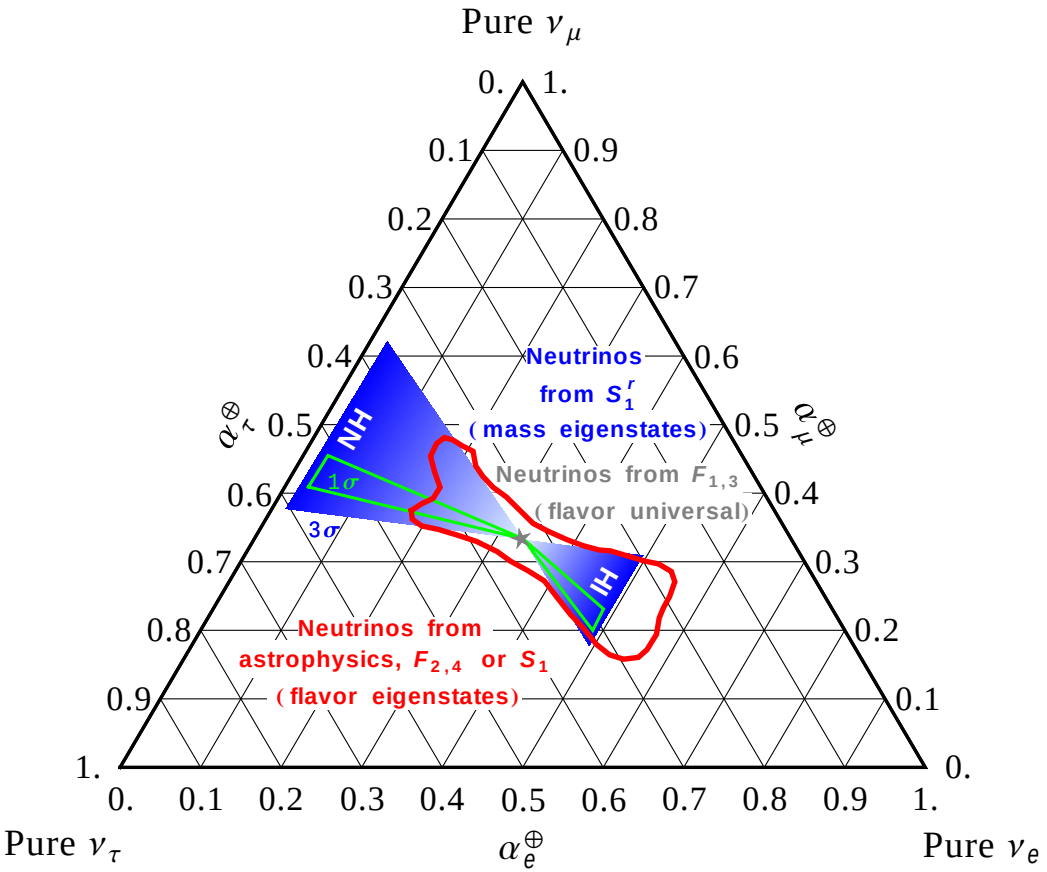


No charged leptons.

The flavor triangle

In contrast to photons, neutrinos carry flavor



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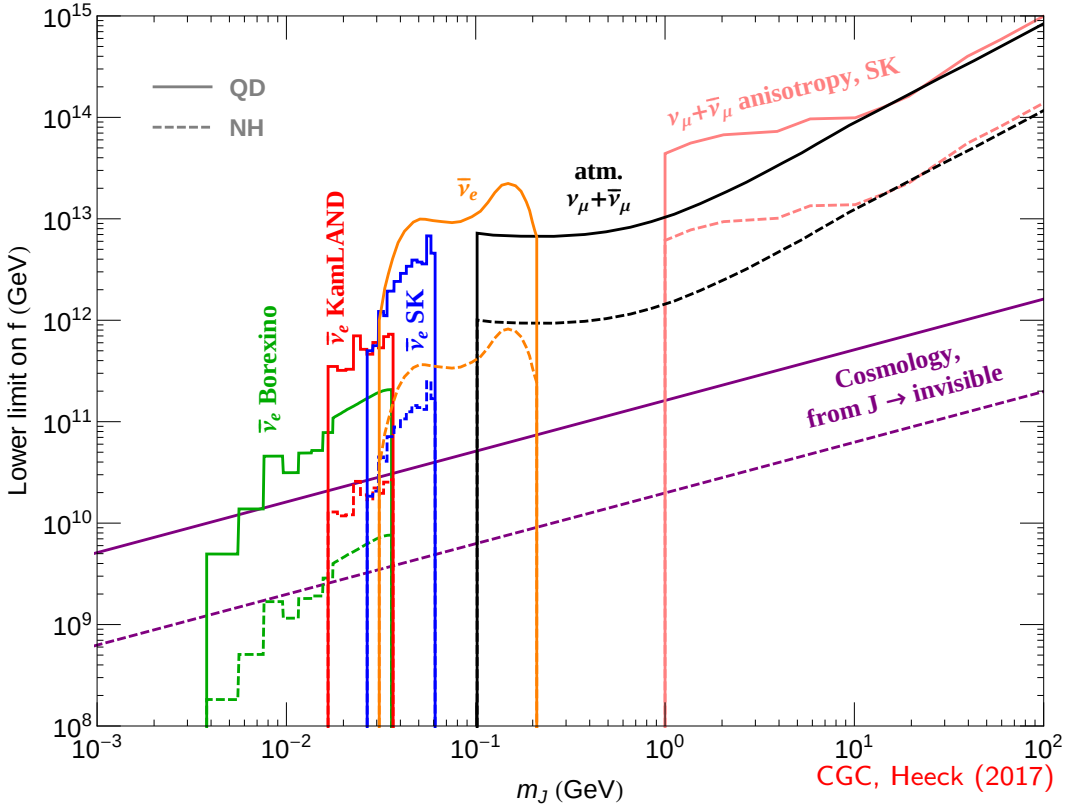
Majoron DM



- Neutrino experiments can be used as DM detectors.

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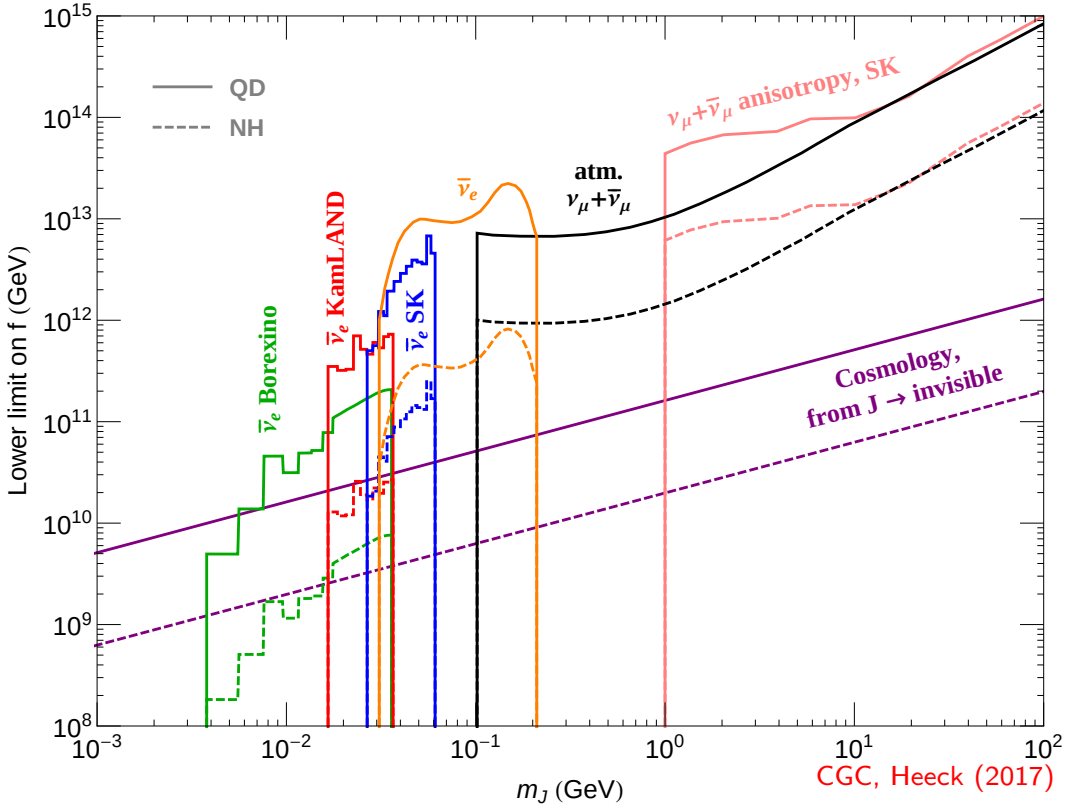

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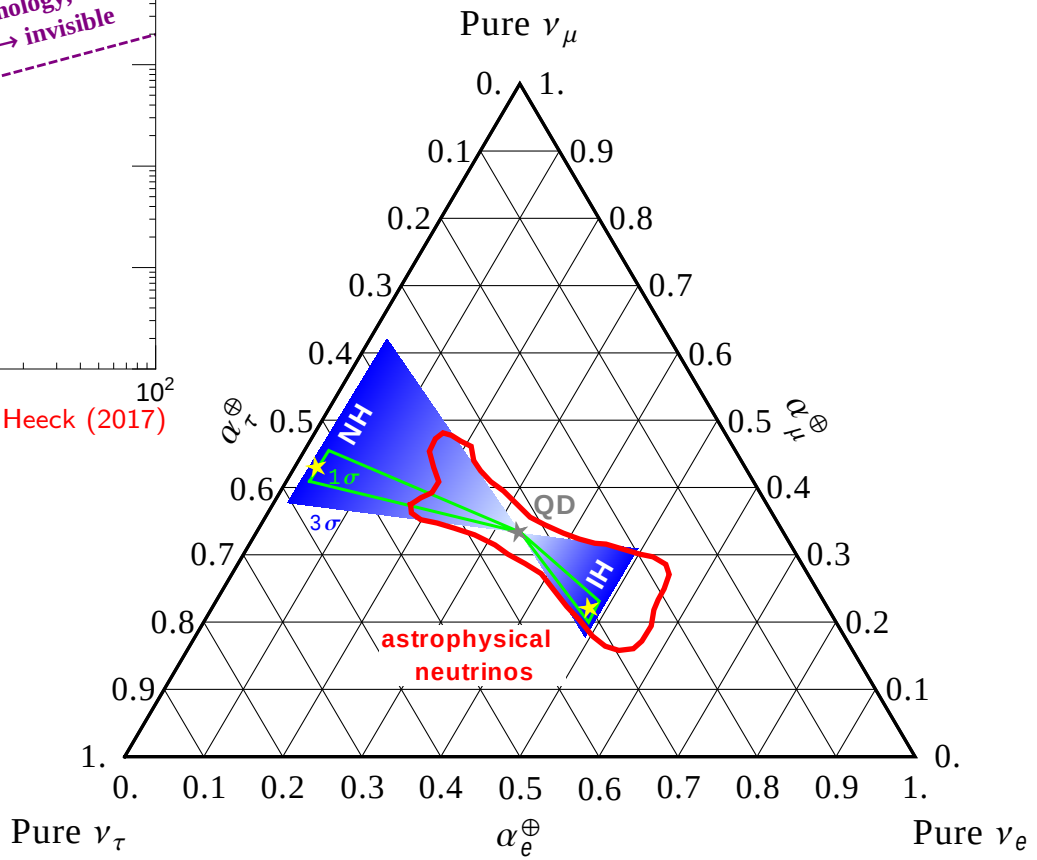

- Neutrinos from Majoron decay are mass eigenstates, which leads to very particular flavor ratios at Earth.

Conclusions

- Multi-TeV DM models predict a significant annihilation cross sections due to the Sommerfeld effect. Much above the canonical thermal value.
- I discussed models whose main signature is the annihilation into neutrino lines. They can be probed in the near future.
- Majoron DM is a consistent model that provides neutrino lines as its most important signature.

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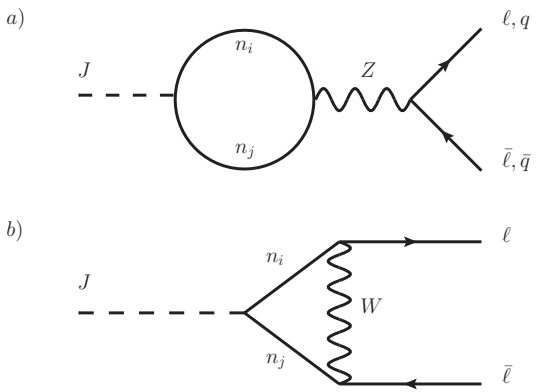
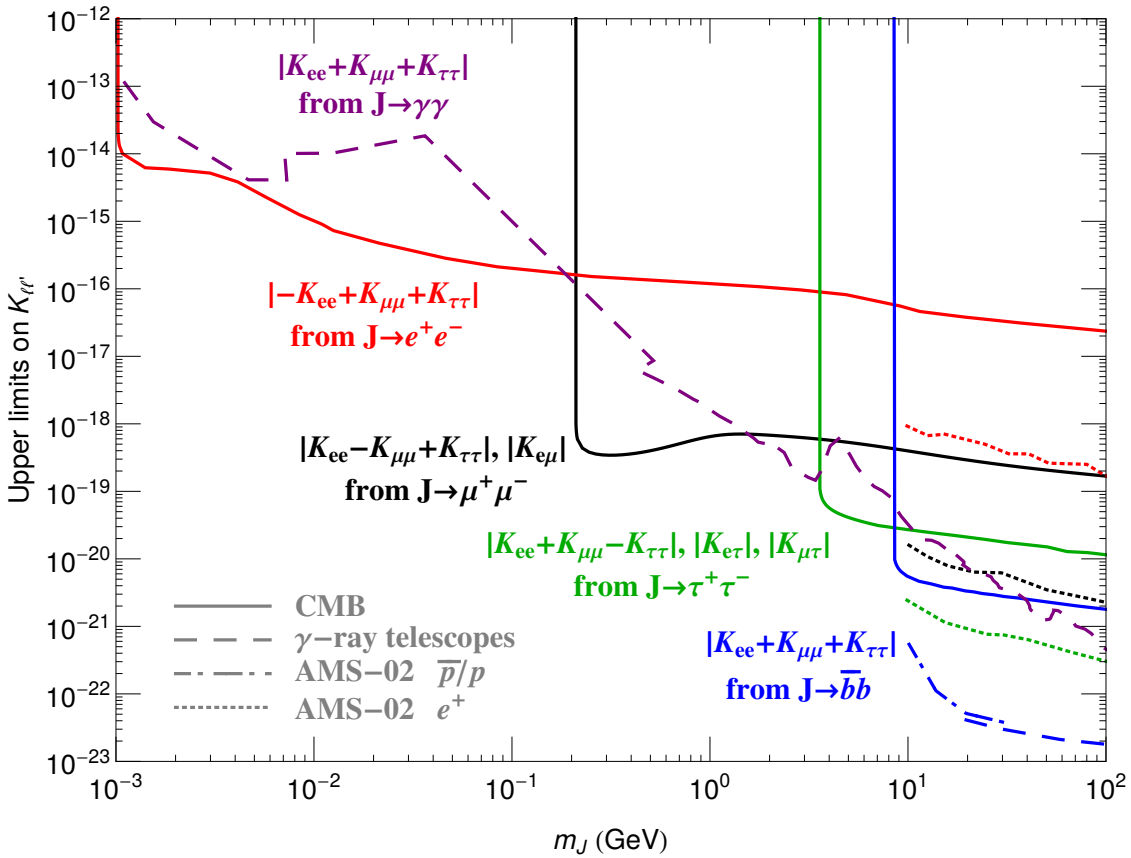
Thanks for your attention!

Charged final states

There are final states taking place at one-loop and two-loop level. They depend on different parameters. CGC, Heeck (2017)





General calculation of the rates for DM DM $\to \gamma\gamma$

Journal of Cosmology and Astroparticle Physics

General calculation of the cross section for dark matter annihilations into two photons

Camilo Garcia-Cely[a] and Andres Rivera[b,a]

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Abstract

Assuming that the underlying model satisfies some general requirements such as renormalizability and CP conservation, we calculate the non-relativistic one-loop cross section for any self-conjugate dark matter particle annihilating into two photons. We accomplish this by carefully classifying all possible one-loop diagrams and, from them, reading off the dark matter interactions with the particles running in the loop. Our approach is general and leads to the same results found in the literature for popular dark matter candidates such as the neutralinos of the MSSM, minimal dark matter, inert Higgs and Kaluza-Klein dark matter.