Linking direct detection and relic abundance in WIMP effective models

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Direct detection probes physics at the ***keV*** scale…..

….a pretty large amount of extrapolation needed to get some info about the cut-off scale of the Standard Model

If convincing high-energy physics ultraviolet completion of the SM available

TOP-DOWN

If no idea

BOTTOM-UP

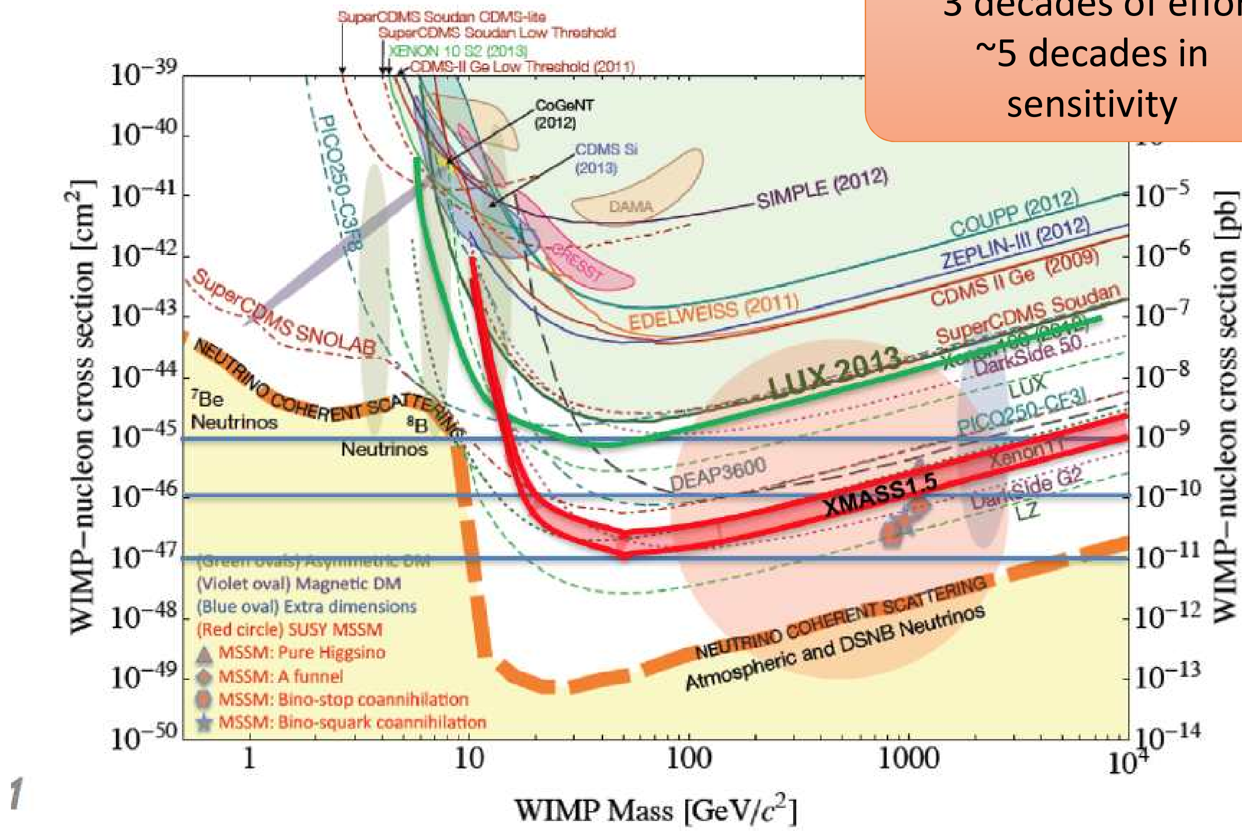
Both approaches should be pursued

Plan of the talk

- Explicit example of a low-energy non-relativistic effective model explaining consistently a DM direct detection excess: DAMA+pSIDM
- A possible first step in the bottom-up stair toward new physics: the connection between WIMP direct detection and the WIMP annihilation cross section (→ thermal relic density, indirect detection)

WIMP direct searches: spin-independent interaction+Maxwellian distribution

~3 decades of effort
~5 decades in
sensitivity

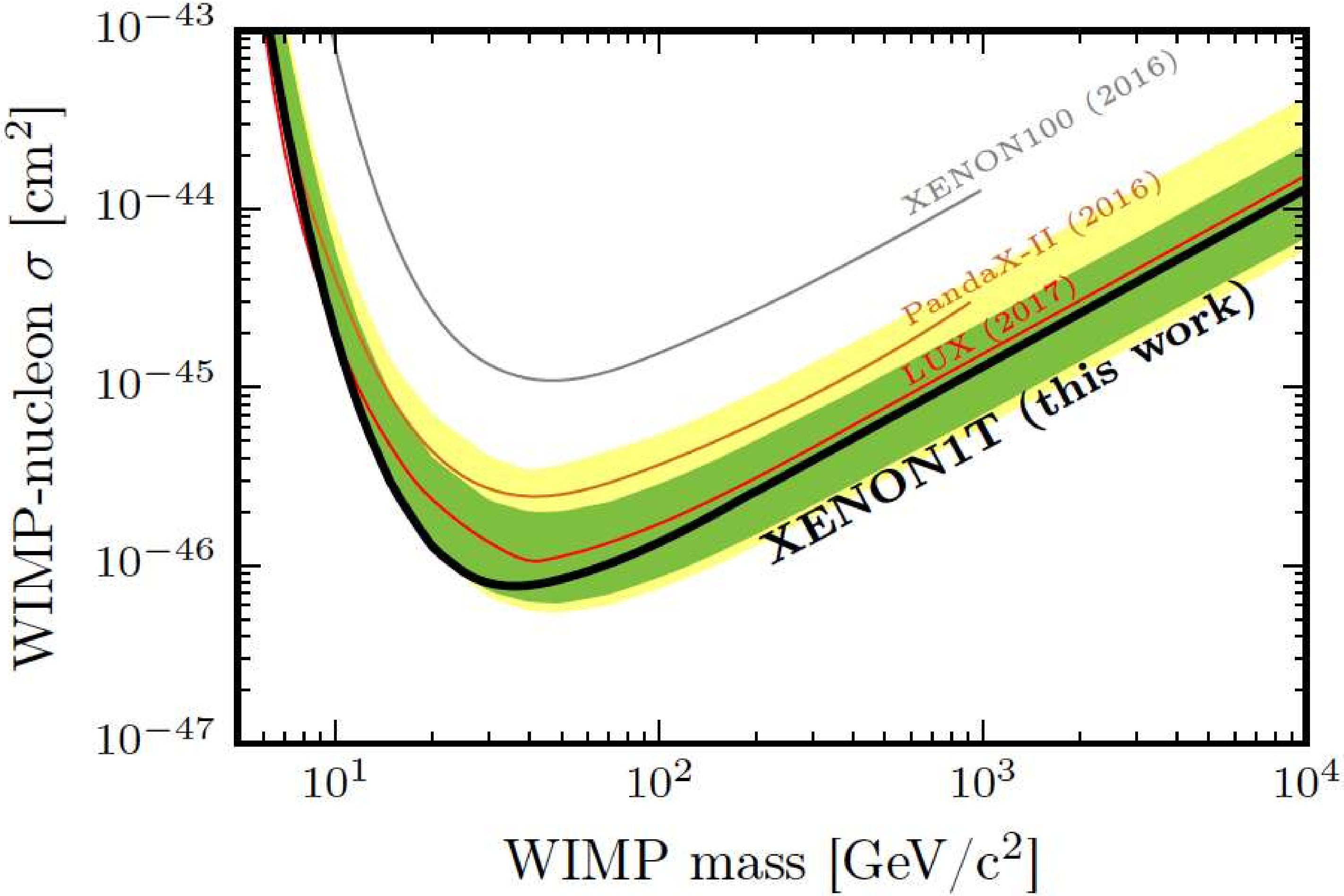


Will the race discover DM before eventually reaching the irreducible background of solar and atmospheric neutrinos???

(from Y. Suzuki talk @IDM 2016, July 2016)

First DM results from XENON1T

(complete LUX exposure reached in 34.2 live days)



Aprile et al, 1705.06655

N.B.: theoretical predictions for the WIMP direct detection rate depend on two main ingredients:

1) a scaling law for the cross section, in order to compare experiments using different targets

   Traditionally spin-independent cross section (proportional to (atomic mass number)^2) or spin-dependent cross section (proportional to the product $\mathbf{S}_{WIMP} \cdot \mathbf{S}_{nucleus}$ *) is assumed*

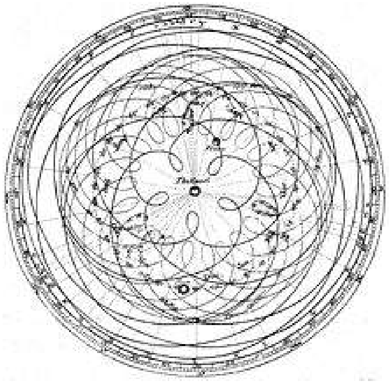
2) a model for the velocity distribution of WIMPs

   Traditionally a Maxwellian distribution is assumed

Indeed, spin-independent and spin-dependent cross sections are predicted for the neutralino in supersymmetry and numerical simulations of galaxy formation support the choice of a Maxwellian for the velocity distributions.

However a bottom-up approach would also be desireable,especially if no hints come from high-energy physics about the fundamental properties of the WIMP particle. Indeed two questions arise:

- what is the most general class of scaling laws for a WIMP-nucleus cross section?
- the detailed merger history of the Milky Way is not known, allowing for the possibility of the presence of sizeable non–thermal components for which the density, direction and speed of WIMPs are hard to predict, *especially in the high velocity tail of the distribution*: do we need to assume a Maxwellian velocity distribution?



In light of this several epicycles added to the usual scenario:

- Halo-independent
- Non-standard coupling
- Inelastic scattering
- Isospin violation
- ….

- Indeed, combining a halo-independent approach and/or a non-standard coupling (other than SI or SD) and/or inelastic scattering (different kinematics) and/or isospin violation compatibility among any of the “excesses” and constraints from null experiments can be achieved (S.S. and K.H. Yoon, JCAP 1602 (2016) no.02, 050; S.S.,K.H. Yoon and J.H. Yoon, JCAP 1507 (2015) no.07, 041; S.S. and J. H. Yoon, Phys.Rev. D91 (2015) no.1, 015019; S.S. and K.H. Yoon, JCAP 1408 (2014) 060)
- “Proofs of concept”

One explicit example: explaining the DAMA effect with pSIDM (proton-philic Spin-dependent Inelastic Dark Matter, i.e. a WIMP that scatters inelastically off protons and couples to their spin)

S.Scopel and K.Yoon, JCAP 1602(2016)050
S. Scopel and H. Yu, JCAP 1704 (2017) no.04, 031

One of the most popular scenarios for WIMP-nucleus scattering is a spin-dependent interaction where the WIMP particle is a χ fermion (either Dirac or Majorana) that recoils through its coupling to the spin of nucleons N=p,n:

$$\mathcal{L}_{int} \propto \vec{S}_\chi \cdot \vec{S}_N = c^p \vec{S}_\chi \cdot \vec{S}_p + c^n \vec{S}_\chi \cdot \vec{S}_n$$

(for instance, predicted by supersymmetry when the WIMP is a neutralino that couples to quarks via Z-boson or squark exchange)

A few facts of life:

Nuclear spin is mostly carried by odd-numbered nucleons. Even-even isotopes carry no spin.

• the DAMA effect is measured with Sodium Iodide. Both Na and I have spin **carried by an unpaired proton**

Isotope	Spin	Z (# of protons)	A-Z (# of neutrons)	Abundance
^{23}Na	3/2	11	12	100 %
^{127}I	5/2	53	74	100 %

Germanium experiments carry only a very small amount of ^{73}Ge, the only isotope with spin, **carried by an unpaired neutron**

Isotope	Spin	Z (# of protons)	A-Z (# of neutrons)	Abundance
^{73}Ge	9/2	32	41	7.7 %

Xenon experiment contain two isotopes with spin, **both carried mostly by an unpaired neutron**

Isotope	Spin	Z (# of protons)	A-Z (# of neutrons)	Abundance
^{129}Xe	½	54	75	26%
^{131}Xe	3/2	54	77	21%

→several authors have considered the possibility that $c_n << c_p$: in this case the WIMP particle is seen by DAMA but does not scatter on xenon and germanium detectors

However another class of Dark Matter experiments (superheated droplet detector and bubble chambers) **all use nuclear targets with an unpaired proton**:

Experiment	Target	Type	Energy thresholds (keV)	Exposition (kg day)
SIMPLE	$C_2Cl\,F_5$	superheated droplets	7.8	6.71
COUPP	$C\,F_3\,I$	bubble chamber	7.8, 11, 15.5	55.8, 70, 311.7
PICASSO	$C_3\,F_8$	bubble chamber	1.7, 2.9, 4.1, 5.8, 6.9, 16.3, 39, 55	114
PICO-2L	$C_3\,F_8$	bubble chamber	3.2, 4.4, 6.1, 8.1	74.8, 16.8, 82.2, 37.8

Isotope	Spin	Z (# of protons)	A-Z (# of neutrons)	Abundance
^{19}F	1/2	9	10	100
^{35}Cl	3/2	17	18	75.77 %
^{37}Cl	3/2	17	20	24.23 %
^{127}I	5/2	53	74	100

These experiments are sensitive to c_p , so for $c_n \ll c_p$ spin-dependent scatterings on Fluorine have been shown to lead to tension with the DAMA (C. Amole et al., (PICO Coll.) PLB711, 153(2012), E. Del Nobile, G.B. Gelmini, A. Georgescu and J.H. Huh, 1502.07682)

N.B. All only sensitive to the energy threshold, which for bubble and droplets nucleation is controlled by the pressure of the liquid

One way to evade Fluorine constraints for a WIMP with spin-dependent coupling to protons: **inelastic scattering**

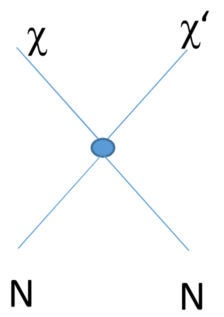
→ proton-philic Spin-dependent Inelastic Dark Matter, pSIDM

Inelastic Dark Matter

D. Tucker-Smith and N.Weiner, Phys.Rev.D 64, 043502 (2001), hep-ph/0101138

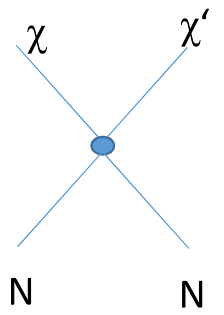
Two mass eigenstates χ and χ' very close in mass: $m_\chi - m_{\chi'} \equiv \delta$ with χ +N→ χ +N forbidden

"Endothermic "scattering (δ>0)



Kinetic energy needed to "overcome" step → rate no longer exponentially decaying with energy, maximum at finite energy E_*

"Exothermic" scattering (δ<0)



χ is metastable, δ energy deposited independently on initial kinetic energy (even for WIMPs at rest)

S.Scopel and K.Yoon, JCAP 1602(2016)050

$$v_{\rm min} = \frac{1}{\sqrt{2 m_N E_R}} \left| \frac{m_N E_R}{\mu_{\chi N}} + \delta \right|$$

(minimal speed needed to deposit energy E_R)

$v_{min} > v^*_{min}$ $$v^*_{\rm min} = \sqrt{\frac{2\delta}{\mu_{\chi N}}}$$

(minimal speed to overcome mass splitting)

$A_{sodium}=23$ $A_{Fluorine}=19$

$m_{Sodium} > m_{Fluorine} \rightarrow \mu_{\chi N}^{Sodium} > \mu_{\chi N}^{Sodium}$

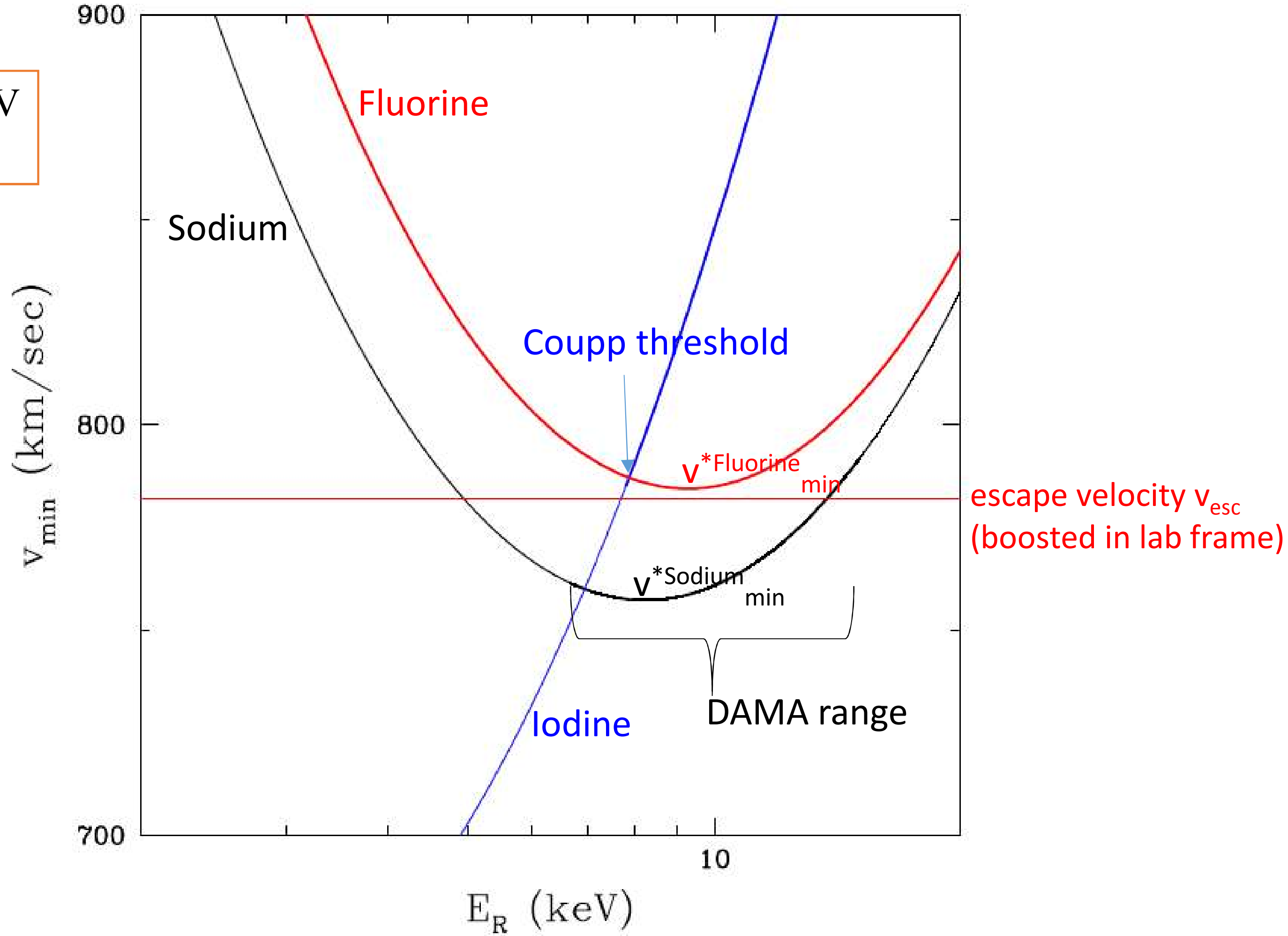
$\rightarrow v^{*Sodium}_{min} < v^{*Fluorine}_{min}$

what if $v^{*Sodium}_{min} < v_{esc} < v^{*Fluorine}_{min}$?

(N.B. v_{esc} in lab frame)

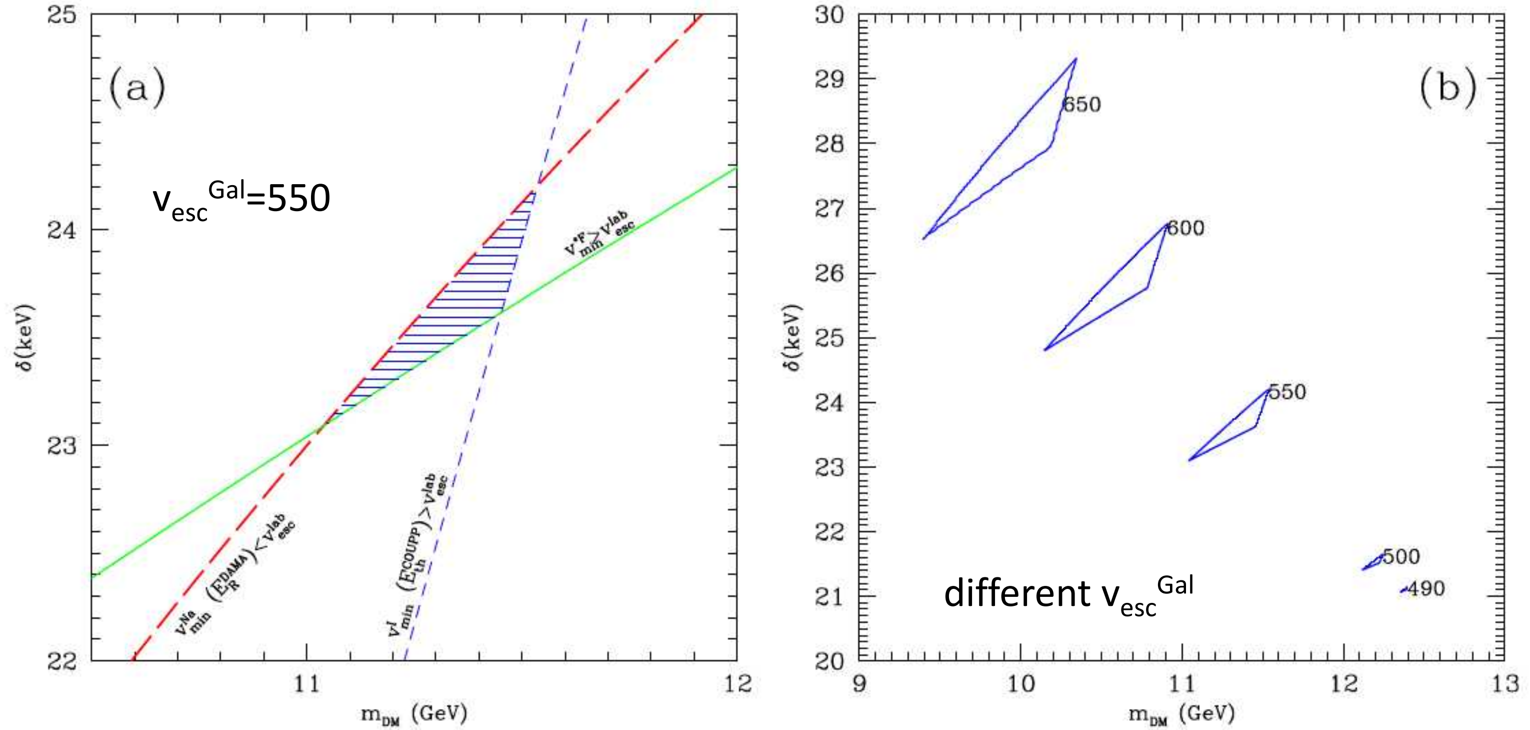
S.Scopel and K.Yoon, JCAP 1602(2016)050

m_χ = 11.4 GeV
δ=23.7 keV



depending on m_χ and δ, can drive Fluorine (and Iodine in COUPP) beyond v_{esc} while Sodium remains below → no constraint on DAMA from droplet detectors and bubble chambers

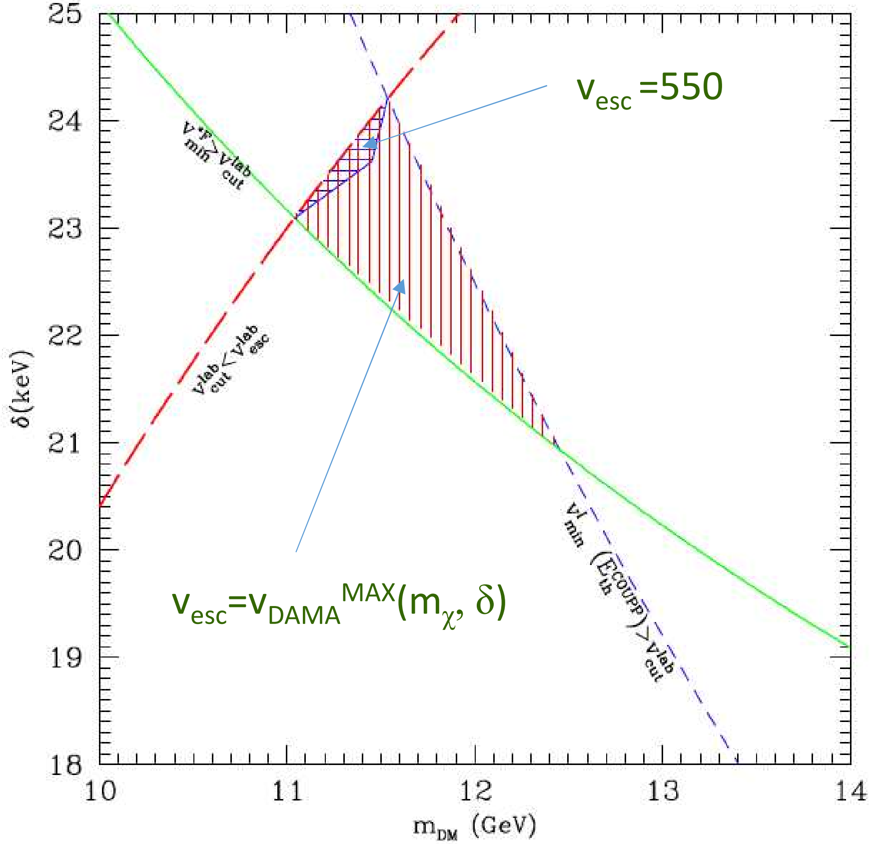
S.Scopel and K.Yoon, JCAP 1602(2016)050



very tuned region. but this is just kinematics

S.Scopel and K.Yoon, JCAP 1602(2016)050

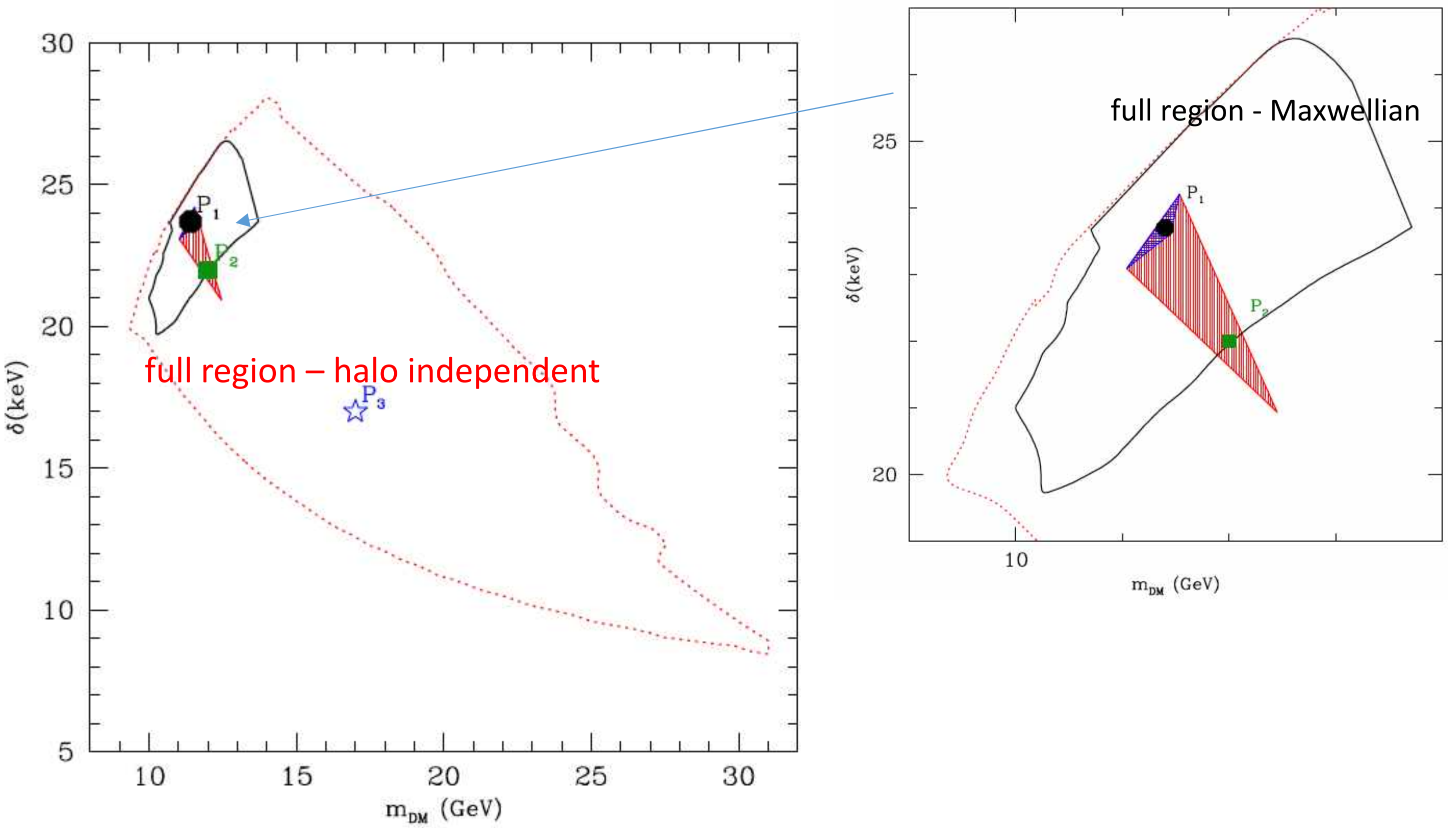
taking $v_{esc}=v_{DAMA}^{MAX}(m_\chi, \delta)$ the kinematic region enlarges considerably



(assuming the “minimal” halo functions that explains DAMA, i.e. f(v) drops when v is beyond the v_{min} range corresponding to the DAMA effect energy range)

S.Scopel and K.Yoon, JCAP 1602(2016)050

when including also the dynamics the two regions (Maxwellian and halo-independent) enlarge even more



That's fine: we have now an effective model (valid at the *keV* scale) that explains DAMA (or any other excess) in a way which is consistent to the constraints of other experiments. So what?

- Obvious step forward: find a possible ultraviolet completion!

Of course that would be OK. But don't actually need it to discuss correlations with indirect detection and the relic abundance. For that, just need a *relativistic* effective model valid at the scale ~2 m_χ

An intrinsic limitation of DM direct detection: don't know the WIMP incoming flux

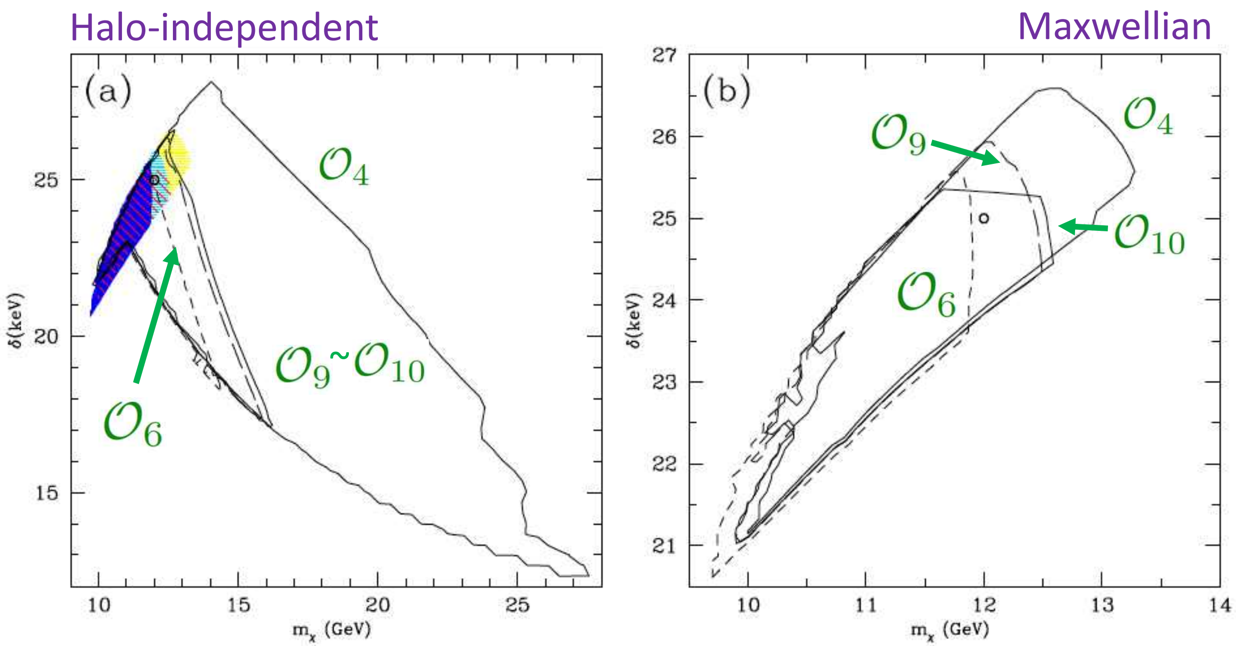
In particular the six-dimensional phase space WIMP distribution $f(x,y,z, v_x, v_Y, v_Z)$ is not know (technically, it's what we are looking for…)

WIMP local density: $$\rho_\chi(x_\odot, y_\odot, z_\odot) = \int d^3v f(x_\odot, y_\odot, z_\odot, v_x, v_y, v_z)$$

WIMP velocity distribution: $$f(\vec{v}) = \frac{1}{\rho_\chi(x_\odot, y_\odot, z_\odot)} f(x_\odot, y_\odot, z_\odot, v_x, v_y, v_z)$$

most general *relativistic* spin-dependent EFT's yielding a *non-relativistic* EFT corresponding to the pSIDM scenario

	Relativistic EFT	Non-relativistic limit	$\sum_i \mathcal{O}_i$	cross section scaling
$\mathcal{O}_4^{AA}$	$\bar\chi_1\gamma^\mu\gamma^5\chi_2\bar{\mathcal{N}}\gamma_\mu\gamma^5\mathcal{N}$+h.c.	$-4\vec{S}_\chi\cdot\vec{S}_{\mathcal{N}}$	-4$\mathcal{O}_4$	$W^{\tau\tau'}_{\Sigma''}(q^2)+W^{\tau\tau'}_{\Sigma'}(q^2)$
$\mathcal{O}_9^{VA}$	$\bar\chi_1\gamma^\mu\chi_2\bar{\mathcal{N}}\gamma_\mu\gamma^5\mathcal{N}$+h.c.	$+\frac{2}{m_{WIMP}}i\vec{S}_\chi\cdot\left(\vec{S}_{\mathcal{N}}\times\vec{q}\right)$	$\simeq 2\frac{m_{\mathcal{N}}}{m_{WIMP}}\mathcal{O}_9$	$\simeq q^2W^{\tau\tau'}_{\Sigma'}(q^2)$
$\mathcal{O}_9^{TA}$	$\bar\chi_1 i\sigma_{\mu\nu}\frac{q^\nu}{m_M}\chi_2\bar{\mathcal{N}}\gamma^\mu\gamma_5\mathcal{N}$+h.c.	$4i(\frac{\vec{q}}{m_M}\times\vec{S}_\chi)\cdot\vec{S}_{\mathcal{N}}$	$4\frac{m_{\mathcal{N}}}{m_M}\mathcal{O}_9$	$q^2W^{\tau\tau'}_{\Sigma'}(q^2)$
$\mathcal{O}_9^{AT}$	$\bar\chi_1\gamma^\mu\gamma_5\chi_2\bar{\mathcal{N}}i\sigma_{\mu\nu}\frac{q^\nu}{m_M}\mathcal{N}$+h.c.	$4i\vec{S}_\chi\cdot(\frac{\vec{q}}{m_M}\times\vec{S}_{\mathcal{N}})$	$-4\frac{m_{\mathcal{N}}}{m_M}\mathcal{O}_9$	$q^2W^{\tau\tau'}_{\Sigma'}(q^2)$
$\mathcal{O}_{10}^{SP}$	$i\bar\chi_1\chi_2\bar{\mathcal{N}}\gamma^5\mathcal{N}$+h.c.	$i\frac{\vec{q}}{m_{\mathcal{N}}}\cdot\vec{S}_{\mathcal{N}}$+h.c.	$\mathcal{O}_{10}$	$q^2W^{\tau\tau'}_{\Sigma''}(q^2)$
$\mathcal{O}_6^{PP}$	$\bar\chi_1\gamma_5\chi_2\bar{\mathcal{N}}\gamma^5\mathcal{N}$+h.c.	$-\frac{\vec{q}}{m_{WIMP}}\cdot\vec{S}_\chi\frac{\vec{q}}{m_{\mathcal{N}}}\cdot\vec{S}_{\mathcal{N}}$	$-\frac{m_{\mathcal{N}}}{m_{WIMP}}\mathcal{O}_6$	$q^4W^{\tau\tau'}_{\Sigma''}(q^2)$
$\mathcal{O}_6^{T'T'}$	$\bar\chi_1 i\sigma^{\mu\alpha}\frac{q_\alpha}{m_M}\gamma_5\chi_2\bar{\mathcal{N}}i\sigma_{\mu\beta}\frac{q^\beta}{m_M}\gamma_5\mathcal{N}$+h.c.	$4\frac{\vec{q}}{m_M}\cdot\vec{S}_\chi\frac{\vec{q}}{m_M}\cdot\vec{S}_{\mathcal{N}}$	$4\frac{m_{\mathcal{N}}^2}{m_M^2}\mathcal{O}_6$	$q^4W^{\tau\tau'}_{\Sigma''}(q^2)$



Momentum dependence leads to smaller allowed regions

S. Scopel and H. Yu, JCAP 1704 (2017) no.04, 031

From direct detection data to suppression scale (a very simple halo-independent recipe)

A given experimental excess gives info on the generalized halo function:

$$\tilde{\eta}(v_{min}) \equiv \frac{\rho_\chi}{m_\chi}\sigma_0 \eta(v_{min}) \qquad \tilde{\eta}(v_{min}) = \frac{\rho}{m_\chi}\sigma \int_{v_{min}}^{\infty} f(v)\, dv$$

$$v_{\rm min} = \frac{1}{\sqrt{2 m_N E_R}} \left| \frac{m_N E_R}{\mu_{\chi N}} + \delta \right|$$

(minimal speed to deposit energy E_R)

M*aximize η* and *minimize* cross section taking:

$$f(\vec{v}) = \delta(v_s - v_{min})$$

(v_s = maximal value of the v_{min} range corresponding to the signal)

$$\tilde{\eta}^{max}(v_{min}) = \tilde{\eta}^{fit}\theta(v_s - v_{min})$$

N.B. corresponds to fitting the experimental halo function to a constant value, works only if this is compatible to data

Then use: $\tilde{\eta}^{fit} = \frac{\rho_\chi}{m_\chi}\sigma\frac{1}{v_s}$ to get lower bound on σ and an upper bound on the EFT cut-off scale

N.B.: direct detection only sensitive to the product density times cross section

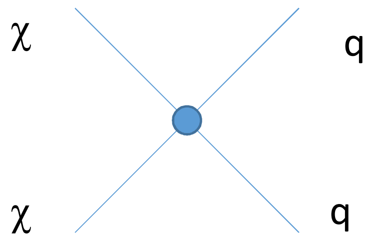
If the DM density ρ_χ is a fraction ς of the total amount measured in the neighborhood of the Sun ρ_{loc} , a direct detection experiment can only get estimates on $\varsigma\sigma$ rather then σ

WIMP miracle: assume that the DM particle is a thermal relic

$\longrightarrow$ once the EFT cut-off scale is fixed should be used to calculate the relic abundance and get the rescaling factor

From direct detection to thermal relic abundance

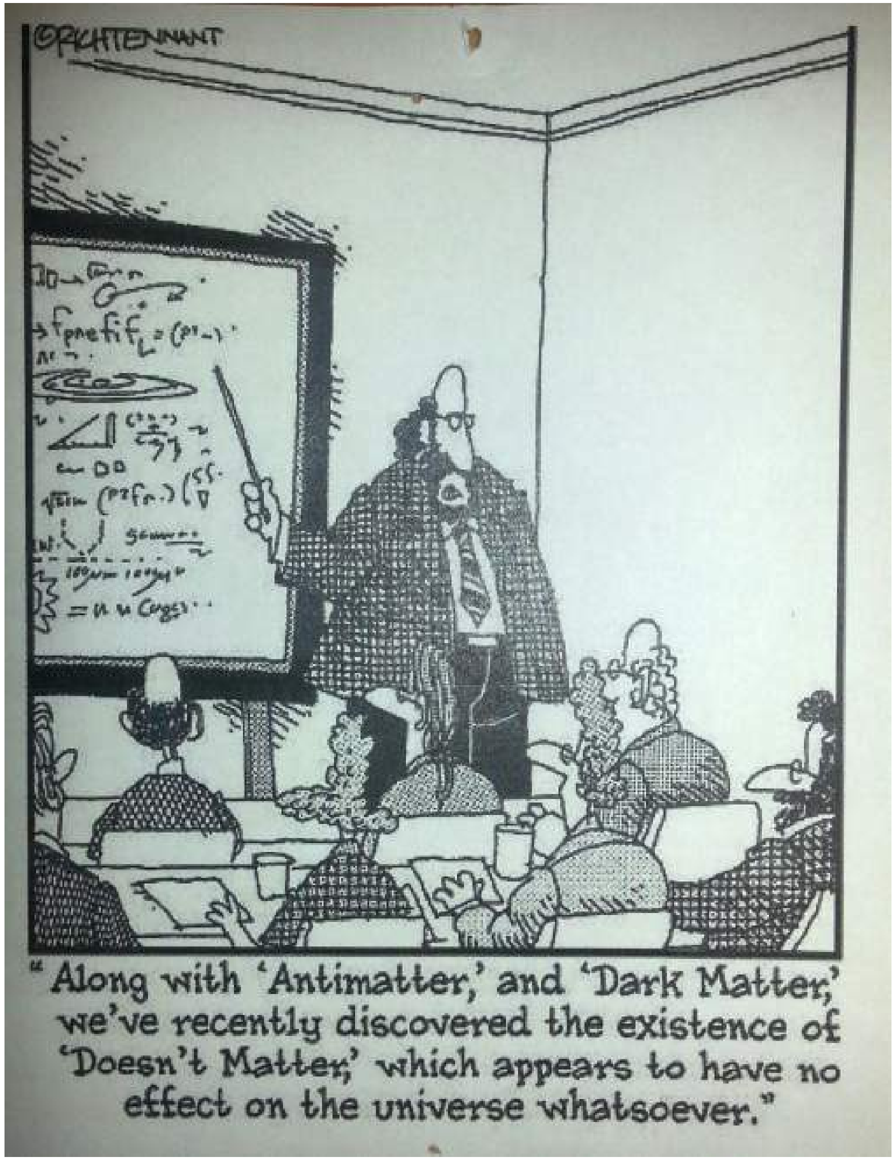
If the same current dominates the EFT up to the annihilation scale at freeze out (E_{CM}~2 m_{χ}) ,can calculate the WIMP thermal relic abundance



$$\Omega h^2 \simeq \frac{< \sigma v >_0}{< \sigma v >}$$

$$< \sigma v >_0 \simeq 2 \times 10^{-9}\,\mathrm{GeV}^{-2}$$

$$< \sigma v >= \frac{1}{\Lambda^4} \sum_q |c_q|^2 < \tilde{\sigma v} >_q$$



How to handle subdominant DM candidates?

Actually, one should rescale the local DM density ρ_χ used to extract Λ:

$$\rho_\chi \to \xi \rho_\chi$$

with the rescaling factor:

$$\xi \equiv \frac{\Omega_\chi h^2}{(\Omega h^2)_{obs}} \simeq \frac{\Lambda^4}{\sum_q |c_q|^2 \frac{<\sigma \tilde{v}>_q}{<\sigma v>_0}}$$

In this case a direct detection experiment measures the combination $\varsigma\sigma_{ref,p}$ with:

$$\sigma_{ref,p} \simeq \frac{\mu^2}{\pi} \frac{c_p^2}{\Lambda^4}$$

$$\xi \sigma_{ref,p} = \frac{\mu^2}{\pi} \frac{c_p^2}{\sum_q |c_q|^2 \frac{<\sigma \tilde{v}>_q}{<\sigma v>_0}} = \frac{\mu^2}{\pi} \frac{c_p^2}{\tilde{\Lambda}^4} = \frac{\mu^2}{\pi} \frac{1}{\tilde{\Lambda}_p^4}$$

<u>dependence on Λ cancels out</u>

Expected effective scale:

$$\tilde{\Lambda}_{p,th} = \left(\frac{\sum_q c_q^2 < \sigma \tilde{v} >_q}{c_p^2 < \sigma \tilde{v} >_0} \right)^{\frac{1}{4}} = \left(\frac{\sum_q r_q^2 < \sigma \tilde{v} >_q}{(c_p/c_u)^2 < \sigma \tilde{v} >_0} \right)^{\frac{1}{4}} = \tilde{\Lambda}_{p,\Omega_0}$$

$\tilde{\Lambda}_{p,\Omega}$ is just the $\tilde{\Lambda}_p$ fixed by the observed by the relic abundance, and would be measured also if $\Omega h^2 << (\Omega h^2)_{obs}$; $r_q = c_q/c_u$

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A direct detection experiment is bound to measure the corresponding "effective scale" :

$$\tilde{\Lambda}_{p,exp} = \frac{\Lambda}{\xi^{1/4} c_p^{1/2}} = \left(\frac{\mu_{\chi\mathcal{N}}^2}{\pi(\xi\sigma_{ref})_{exp}} \right)^{\frac{1}{4}}$$

If the velocity distribution is known a given experimental excess fixes $\varsigma\sigma$ and so $\tilde{\Lambda}_{p,exp}$, which for a given effective model is bound to be equal to $\tilde{\Lambda}_{p,\Omega}$ irrespective to the actual value of Ω_0

The bottom line: a DM experiment is bound to measure an effective scale corresponding to $\Omega=\Omega_0$ even if $\Omega<\Omega_0$

$$\tilde{\Lambda}_{p,exp} = \tilde{\Lambda}_{p,\Omega_0}$$

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On the other hand, if f(v) is not fixed, can get a lower bound on ςσ and so an upper bound on Λ_p

$$\tilde{\Lambda}^{max}_{p,exp} > \tilde{\Lambda}_{p,\Omega_0} > \tilde{\Lambda}^{min}_{p,\Omega_0}$$

Minimized with respect to the free parameters of the EFT (r_q's)

N.B. consistency test , not just a requirement that $\Omega \leq \Omega_0$ when the parameters of the EFT are fixed by direct detection

Actually, the acceptable values of $\Lambda_{p,exp}$ are those for which $\Omega \geq \Omega_0$ when ς=1 ("overclosure" is fine, "underclosure" is not)

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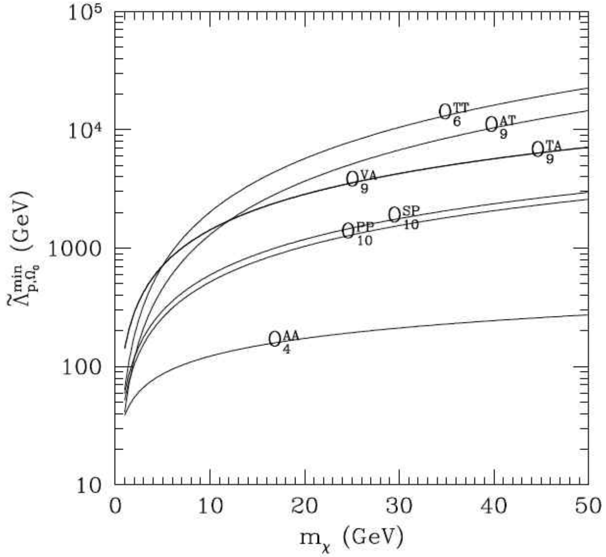
pSIDM generalized to spin-dependent EFT models with momentum dependence

	Relativistic EFT	Non-relativistic limit	$\sum_i \mathcal{O}_i$	cross section scaling
$\mathcal{O}_4^{AA}$	$\bar{\chi}_1\gamma^\mu\gamma^5\chi_2\bar{\mathcal{N}}\gamma_\mu\gamma^5\mathcal{N}$+h.c.	$-4\vec{S}_\chi \cdot \vec{S}_\mathcal{N}$	-4$\mathcal{O}_4$	$W_{\Sigma''}^{\tau\tau'}(q^2) + W_{\Sigma'}^{\tau\tau'}(q^2)$
$\mathcal{O}_9^{VA}$	$\bar{\chi}_1\gamma^\mu\chi_2\bar{\mathcal{N}}\gamma_\mu\gamma^5\mathcal{N}$+h.c.	$+\frac{2}{m_{WIMP}} i\vec{S}_\chi \cdot \left(\vec{S}_\mathcal{N} \times \vec{q}\right)$	$\simeq 2\frac{m_\mathcal{N}}{m_{WIMP}}\mathcal{O}_9$	$\simeq q^2 W_{\Sigma'}^{\tau\tau'}(q^2)$
$\mathcal{O}_9^{TA}$	$\bar{\chi}_1 i\sigma_{\mu\nu}\frac{q^\nu}{m_M}\chi_2\bar{\mathcal{N}}\gamma^\mu\gamma_5\mathcal{N}$+h.c.	$4i(\frac{\vec{q}}{m_M} \times \vec{S}_\chi) \cdot \vec{S}_\mathcal{N}$	$4\frac{m_\mathcal{N}}{m_M}\mathcal{O}_9$	$q^2 W_{\Sigma'}^{\tau\tau'}(q^2)$
$\mathcal{O}_9^{AT}$	$\bar{\chi}_1\gamma^\mu\gamma_5\chi_2\bar{\mathcal{N}} i\sigma_{\mu\nu}\frac{q^\nu}{m_M}\mathcal{N}$+h.c.	$4i\vec{S}_\chi \cdot (\frac{\vec{q}}{m_M} \times \vec{S}_\mathcal{N})$	$-4\frac{m_\mathcal{N}}{m_M}\mathcal{O}_9$	$q^2 W_{\Sigma'}^{\tau\tau'}(q^2)$
$\mathcal{O}_{10}^{SP}$	$i\bar{\chi}_1\chi_2\bar{\mathcal{N}}\gamma^5\mathcal{N}$+h.c.	$i\frac{\vec{q}}{m_\mathcal{N}} \cdot \vec{S}_\mathcal{N}$+h.c.	$\mathcal{O}_{10}$	$q^2 W_{\Sigma''}^{\tau\tau'}(q^2)$
$\mathcal{O}_6^{PP}$	$\bar{\chi}_1\gamma_5\chi_2\bar{\mathcal{N}}\gamma^5\mathcal{N}$+h.c.	$-\frac{\vec{q}}{m_{WIMP}} \cdot \vec{S}_\chi \frac{\vec{q}}{m_\mathcal{N}} \cdot \vec{S}_\mathcal{N}$	$-\frac{m_\mathcal{N}}{m_{WIMP}}\mathcal{O}_6$	$q^4 W_{\Sigma''}^{\tau\tau'}(q^2)$
$\mathcal{O}_6^{T'T'}$	$\bar{\chi}_1 i\sigma^{\mu\alpha}\frac{q_\alpha}{m_M}\gamma_5\chi_2\bar{\mathcal{N}} i\sigma_{\mu\beta}\frac{q^\beta}{m_M}\gamma_5\mathcal{N}$+h.c.	$4\frac{\vec{q}}{m_M} \cdot \vec{S}_\chi \frac{\vec{q}}{m_M} \cdot \vec{S}_\mathcal{N}$	$4\frac{m_\mathcal{N}^2}{m_M^2}\mathcal{O}_6$	$q^4 W_{\Sigma''}^{\tau\tau'}(q^2)$

$\tilde{\Lambda}_{p,exp}$ (maximal value in allowed param. Space)

Non–relativistic operator	Halo–independent	Maxwellian
$\mathcal{O}_4$	163	20.4
$\mathcal{O}_6$	23.0	2.79
$\mathcal{O}_9$	27.5	3.27
$\mathcal{O}_{10}$	3.01	0.32

$\tilde{\Lambda}_{p,\Omega_0}$ (minimum value)



Only the standard spin-dependent interaction passes the consistency test:

$$\tilde{\Lambda}^{max}_{p,exp} > \tilde{\Lambda}_{p,\Omega_0} > \tilde{\Lambda}^{min}_{p,\Omega_0}$$

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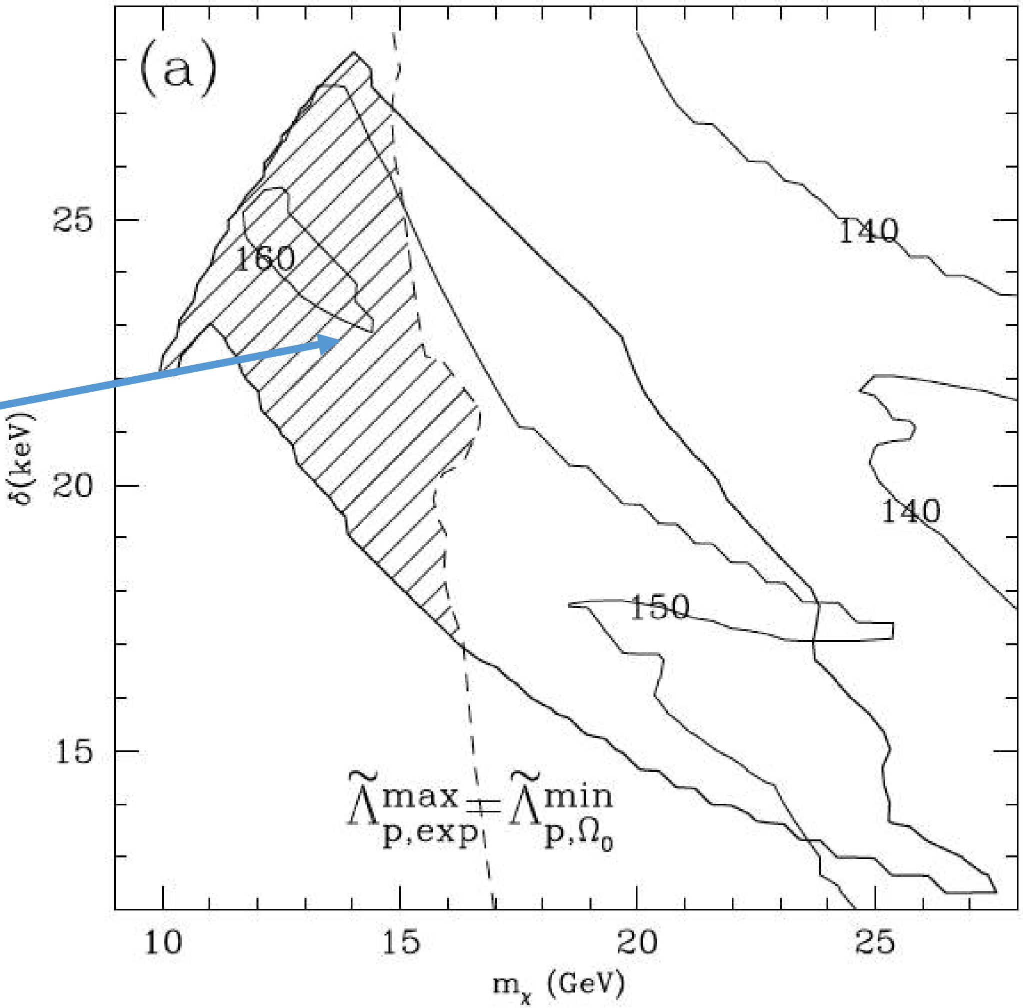
pSIDM, standard spin coupling



DAMA+thermal relic

$(\tilde{\Lambda}^{max}_{p,exp} \geq \tilde{\Lambda}^{min}_{p,\Omega_0})$

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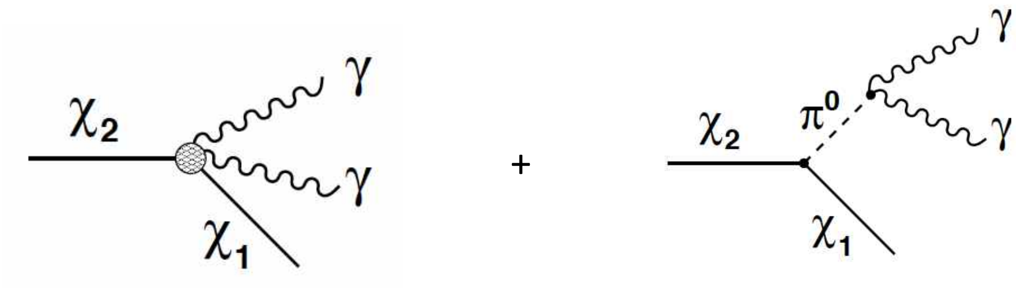
One complication in the pSIDM scenario: χ_2 states decay to χ_1's too slowly if only the effective operator that drives direct detection is present



$$\Gamma_{\gamma\gamma} = 7.2 \times 10^{-56} \left(\frac{\delta}{10\ \mathrm{keV}}\right)^9 \left(\frac{10\ \mathrm{GeV}}{\tilde{\Lambda}}\right)^4 \mathrm{GeV}$$

Age of the Universe: $1.5 \times 10^{-42}\ \mathrm{GeV}^{-1}$

Downscatterings of χ_2 states are excluded by bubble chambers and droplet detectors, must assume some additional decay mechanism to get rid of them!

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Conclusions

• Without any hint from the LHC about the underlying fundamental physics and without a detailed knowledge of the merger history of our Galaxy it appears useful to adopt a bottom-up approach in the analysis of direct detection experimenta data. In this way a much wider parameter space opens up.

• First explorations show that indeed compatibility between excesses and constraints can be achieved → **full correlation with indirect signals and relic abundance needs still to be worked out**

• **pSIDM (proton-philic spin-dependent Inelastic Dark Matter) works just fine for DAMA and complies to the constraints from other experiments**

• Direct detection is sensitive to the product of local density times cross secti   on → insensitive to the cut-off scale of the effective theory

• given an experimental excess can get a consistency test on the possibility that the same EFT drives direct detection and the relic density → OK only for vanilla pSIDM (i.e. usual spin-spin coupling)