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Institut de Physique Nucléaire de Lyon (IPNL)

Model Independent Bounds in Direct DM Searches

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based on:

M.Cirelli, E.Del Nobile, P.Panci

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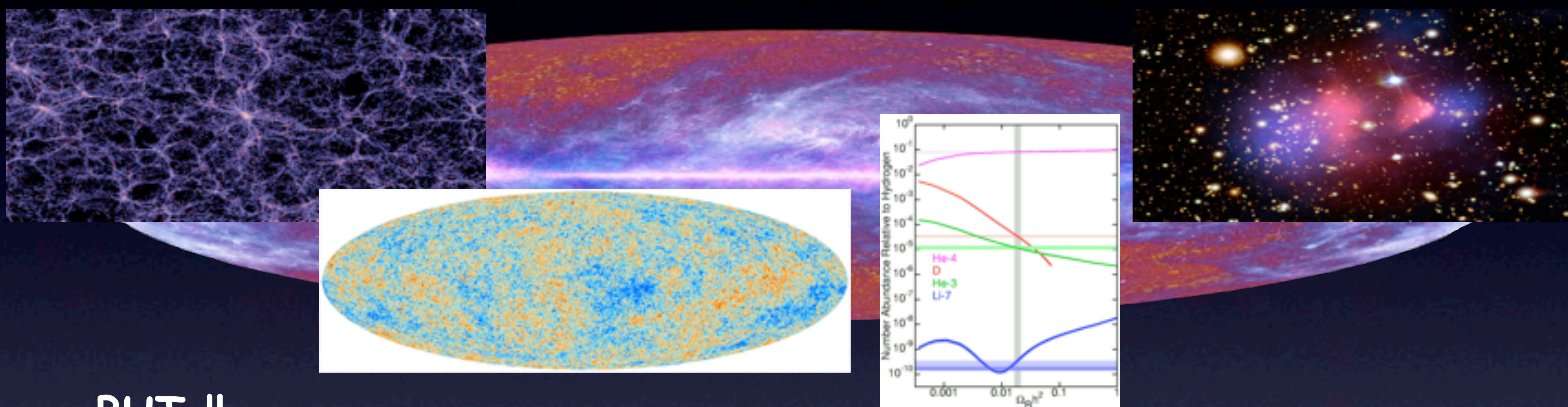
DM Open Questions

There is a compelling and strong evidence of non-baryonic matter in the Universe, ranging from galactic to cosmological scale



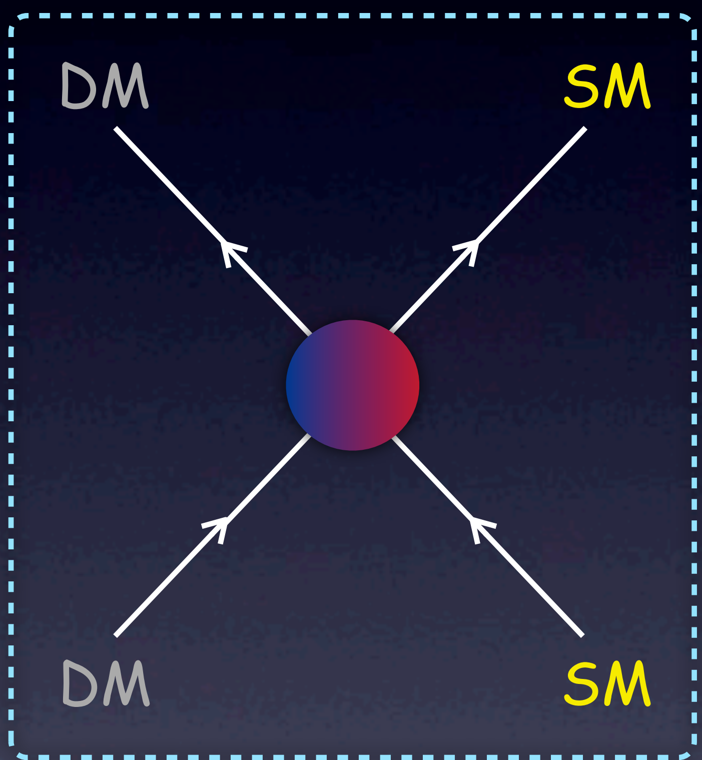
BUT !!

The microphysics of this new kind of matter is unknown yet

- ☑ DM candidate: axions, neutralinos, technicolor particles, wimpzillas, etc...
- ☑ Underlying theory: supersymmetry, technicolor, mirror models, etc...
- ☑ DM density profile: cuspy profile (NFW, Einasto), cored profile (isothermal)
- ☑ Nuclei nuclear response: Helm form factor, etc...

Dark Matter Detection

production at collider
LHC



direct detection
DAMA/Libra, CoGeNT, CRESST.... (Xenon, CDMS, Edelweiss....)

- I'll review how to write the DM-nucleon ME as a linear combination of NR operators
- I'm going to present you a new framework for "scaling" a bound given on a certain benchmark interaction to any other kinds of interactions in a model independent way

indirect detection

γ from ann/dec in GC or halo and from synchrotron emission
FERMI, radio telescopes....

e^+ from ann/dec in Galactic Center or halo
PAMELA, FERMI, HESS, AMS-II, balloons....

$\bar{p}$ from ann/dec in Galactic Center or halo
PAMELA, AMS-II

$\bar{d}$ from ann/dec in Galactic Center or halo
AMS-II, GAPS....

$\bar{\nu}, \nu$ from ann/dec in Galaxy and massive bodies
SuperK, Icecube....

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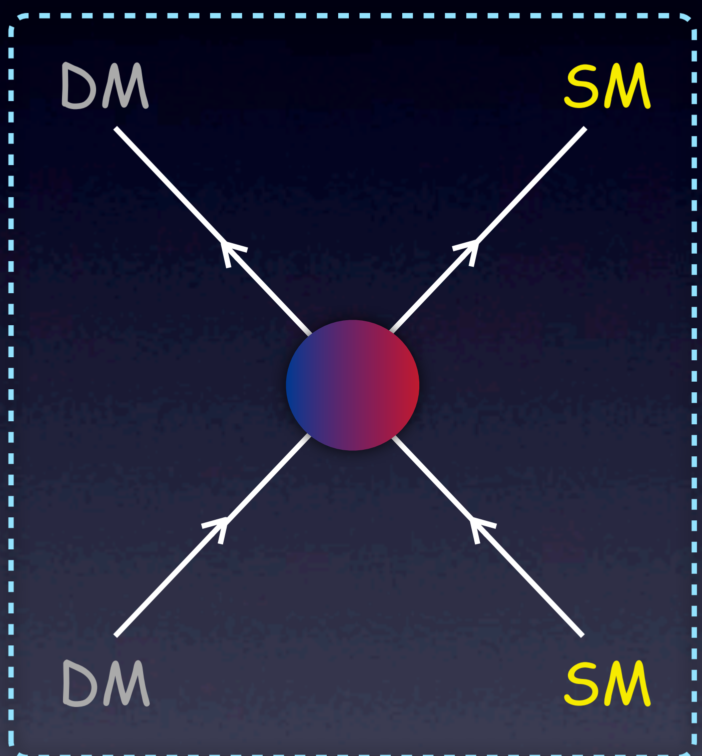

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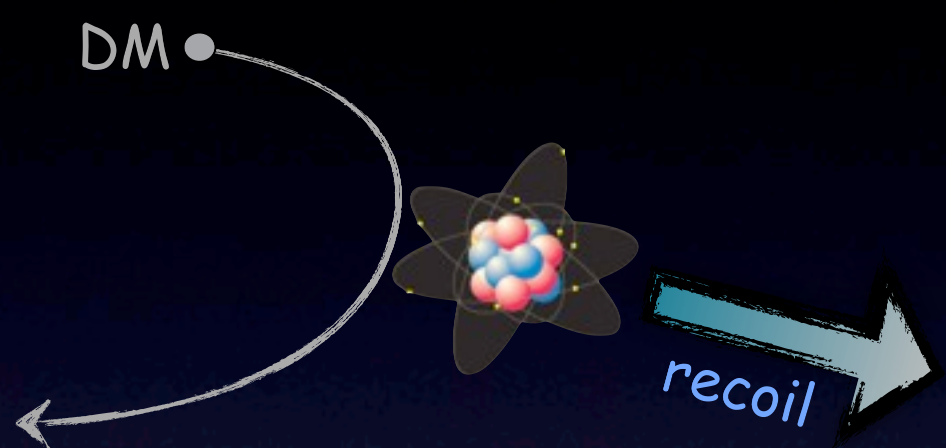
Direct Detection: Overview

Direct searches aim at detecting the nuclear recoil possibly induced by:



- elastic scattering:
  $$\chi + \mathcal{N}(A,Z)_{\rm rest} \to \chi + \mathcal{N}(A,Z)_{\rm recoil}$$

- inelastic scattering:
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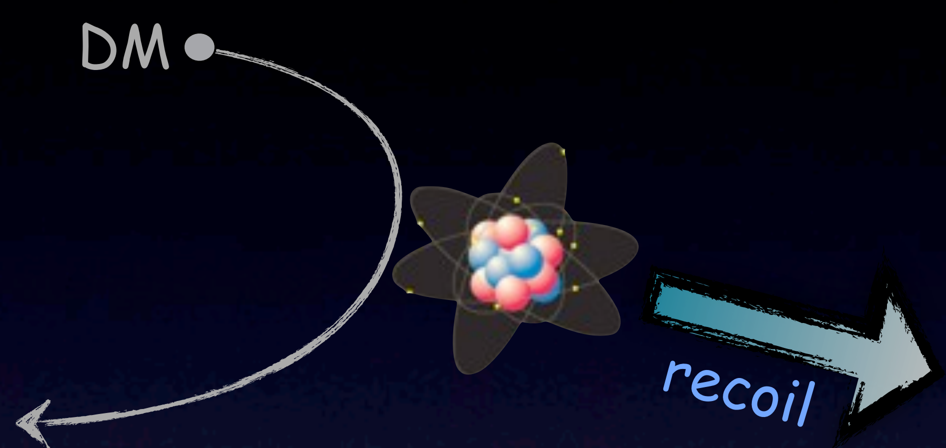

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DM signals are very rare events (less then 1 cpd/kg/keV)

Experimental priorities for DM Direct Detection:

- ✓ the detectors must work deeply underground in order to reduce the background of cosmic rays
- ✓ they use active shields and very clean materials against the residual radioactivity in the tunnel (γ, α and neutrons)
- ✓ they must discriminate multiple scattering (DM does not scatter twice in the detector)

Direct Detection: Overview

DM local velocity $v_0 \sim 10^{-3}c$ $\Rightarrow$ the collision between $\chi \,\&\, \mathcal{N}$ occurs in deeply non relativistic regime

$$E_{\rm R} = \frac{1}{2} m_\chi v^2 \, \frac{4 m_\chi m_{\mathcal{N}}}{(m_\chi + m_{\mathcal{N}})^2} \left(\frac{1 - \frac{v_{\rm t}^2}{2v^2} - \sqrt{1 - \frac{v_{\rm t}^2}{v^2}} \cos\theta}{2} \right), \qquad \begin{cases} v_{\rm t} = 0 & \text{elastic} \\ v_{\rm t} = \sqrt{\frac{2\delta}{\mu_{\chi\mathcal{N}}}} \neq 0 & \text{inelastic} \end{cases}$$

DM kinetic energy

Kinematics factor

scatter angle

threshold velocity

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Theoretical differential rate of nuclear recoil in a given detector

$$\frac{\mathrm{d}R_{\mathcal{N}}}{\mathrm{d}E_{\rm R}} = N_{\mathcal{N}} \frac{\rho_\odot}{m_\chi} \int_{v_{\rm min}(E_{\rm R})}^{v_{\rm esc}} \mathrm{d}^3 v \, |\vec{v}| \, f(\vec{v}) \frac{\mathrm{d}\sigma}{\mathrm{d}E_{\rm R}}$$

- ✔ $N_{\mathcal{N}} = N_a / A_{\mathcal{N}}$: Number of target
- ✔ $v_{\rm min}(E_{\rm R}) = \sqrt{\frac{m_{\mathcal{N}} E_{\rm R}}{2\,\mu_{\chi\mathcal{N}}^2}} \left(1 + \frac{\mu_{\chi\mathcal{N}}\,\delta}{m_{\mathcal{N}} E_{\rm R}} \right)$: Minimal velocity
- ✔ $\rho_\odot / m_\chi$: DM number density
- ✔ $v_{\rm esc}$: DM escape velocity (450 - 650 km/s)

DM Velocity Distribution

"Violent relaxation" lead to fast mixing of the DM phase-space elements
DM particles are frozen in high entropy configuration: ~ Maxwell-Boltzmann-like

"Statistical Mechanics of Violent Relaxation in Stellar System", Mon.Not.Roy.Astrom.Soc. (1966) **136**, 101

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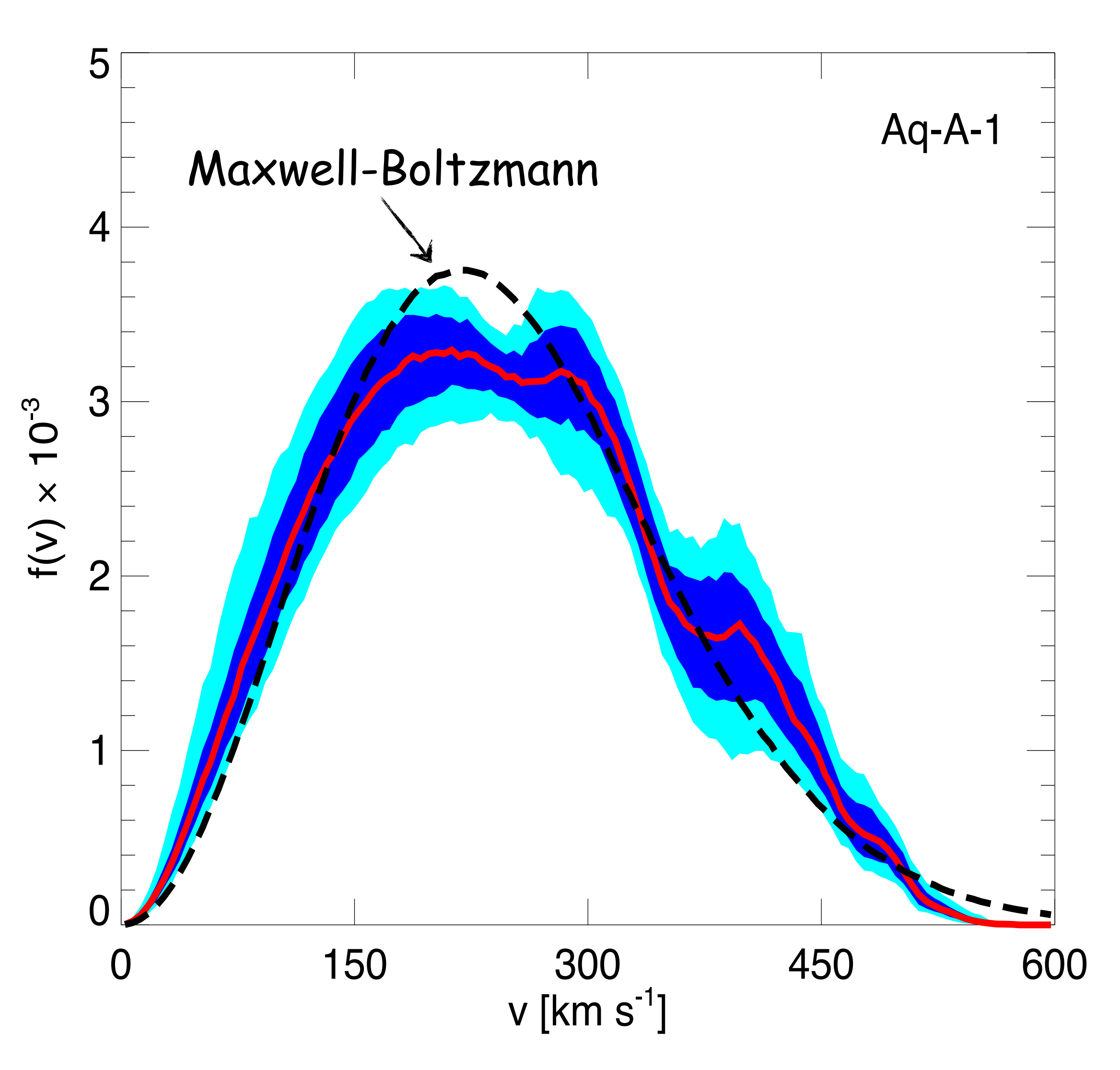
Recent Numerical Simulations

- This has been roughly confirmed by some numerical simulations
- There are deviations due to the DM assembly history of the Milky Way
- The geometry of the halo is not exactly spherical, but tends to a triaxial configuration



"Phase Space Structure in the Local DM Distribution", Mon.Not.Roy.Astrom.Soc. (2009) **395**, 797

DM Velocity Distribution

The velocity distribution in the Earth frame $f_\oplus$ is related to the velocity distribution in the Galactic frame $f_{\rm gal}$ through a Galileian transformation

$$f_\oplus(\vec{v},t) = f_{\rm gal}\left(\vec{v} + \vec{v}_\odot + \vec{v}_\oplus(t)\right)$$

velocity distribution in the Earth's frame

$$f_{\rm gal}(\vec{v}) = \begin{cases} k\exp\left(-\frac{v^2}{v_0^2}\right) & v < v_{\rm esc} \\ 0 & v > v_{\rm esc} \end{cases}$$

e.g: Maxwell-Boltzmann distribution

The Earth is moving around the Sun and the Sun around the GC

$$\vec{v}_{\rm obs}(t) = \vec{v}_\odot + v_\oplus\left[\vec{\varepsilon}_1\cos w(t-t_1) + \vec{\varepsilon}_2\sin w(t-t_1)\right]$$

drift velocity of the Sun

time dependent Earth's velocity projected in the GP

$\vec{v}_\odot \simeq (0,220,0) + (10,13,7)$ km/s

$v_\oplus \simeq 29.8$ km/s

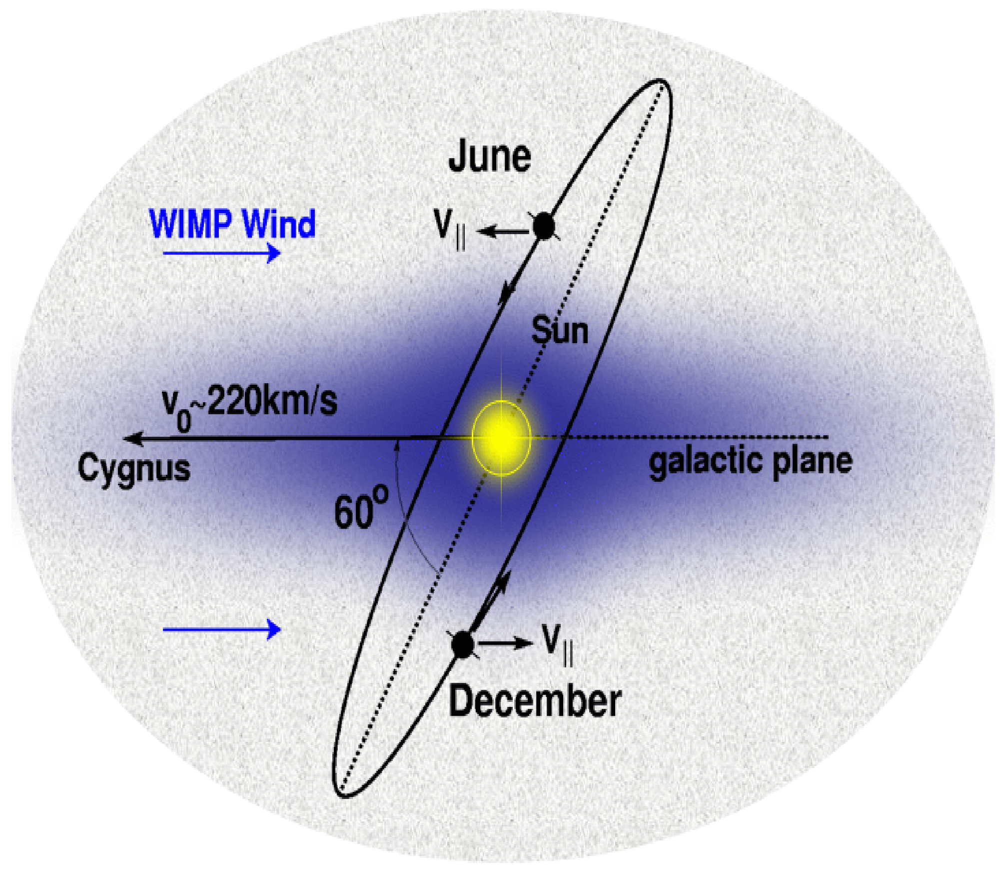
$|\vec{v}_\oplus| / |\vec{v}_\odot| \simeq 0.05$

$\vec{\varepsilon}_1 \simeq (0.9931, 0.1170, -0.0103)$

$\vec{\varepsilon}_2 \simeq (-0.0670, 0.4927, -0.8676)$

$t_1 \simeq 21^{\rm st}$ March

$w = 2\pi/\text{year}$



Looking for annual modulation is very challenge from the exp. point of view

Differential Cross Section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}E_{\mathrm{R}}}(v, E_{\mathrm{R}}) = \frac{1}{32\pi}\frac{1}{m_\chi^2 m_{\mathcal{N}}}\frac{1}{v^2}\boxed{|\mathcal{M}_{\mathcal{N}}|^2} \longrightarrow \text{Matrix Element (ME) for the DM-nucleus scattering}$$

$v \ll c \quad \Rightarrow$ the framework of relativistic quantum field theory is not appropriate

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Non relativistic (NR) operators framework

NR d.o.f. for elastic scattering

- $\vec{v}$: DM-nucleon relative velocity
- $\vec{q}$: exchanged momentum
- $\vec{s}_N$: nucleon spin ($N = (p, n)$)
- $\vec{s}_\chi$: DM spin

The DM-nucleon ME can be constructed from Galileian invariant combination of d.o.f.

$$|\mathcal{M}_N| = \sum_{i=1}^{12} \boxed{\mathfrak{c}_i^N(\lambda, m_\chi)}\, \mathcal{O}_i^{\mathrm{NR}}$$

functions of the parameters of your favorite theory (e.g. couplings, mixing angles, mediator masses), expressed in terms of NR operators

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Contact interaction ($q \ll \Lambda$)

$$\mathcal{O}_1^{NR} = \mathbb{1}\,,$$

$$\mathcal{O}_3^{NR} = i\,\vec{s}_N \cdot (\vec{q} \times \vec{v}^\perp)\,, \quad \mathcal{O}_4^{NR} = \vec{s}_\chi \cdot \vec{s}_N\,,$$

$$\mathcal{O}_5^{NR} = i\,\vec{s}_\chi \cdot (\vec{q} \times \vec{v}^\perp)\,, \quad \mathcal{O}_6^{NR} = (\vec{s}_\chi \cdot \vec{q})(\vec{s}_N \cdot \vec{q})\,,$$

$$\mathcal{O}_7^{NR} = \vec{s}_N \cdot \vec{v}^\perp\,, \quad \mathcal{O}_8^{NR} = \vec{s}_\chi \cdot \vec{v}^\perp\,,$$

$$\mathcal{O}_9^{NR} = i\,\vec{s}_\chi \cdot (\vec{s}_N \times \vec{q})\,, \quad \mathcal{O}_{10}^{NR} = i\,\vec{s}_N \cdot \vec{q}\,,$$

$$\mathcal{O}_{11}^{NR} = i\,\vec{s}_\chi \cdot \vec{q}\,, \quad \mathcal{O}_{12}^{NR} = \vec{v}^\perp \cdot (\vec{s}_\chi \times \vec{s}_N)\,.$$

Long-range interaction ($q \gg \Lambda$)

$$\mathcal{O}_1^{lr} = \frac{1}{q^2}\mathcal{O}_1^{NR}\,, \quad \mathcal{O}_5^{lr} = \frac{1}{q^2}\mathcal{O}_5^{NR}\,,$$

$$\mathcal{O}_6^{lr} = \frac{1}{q^2}\mathcal{O}_6^{NR}\,, \quad \mathcal{O}_{11}^{lr} = \frac{1}{q^2}\mathcal{O}_{11}^{NR}\,.$$

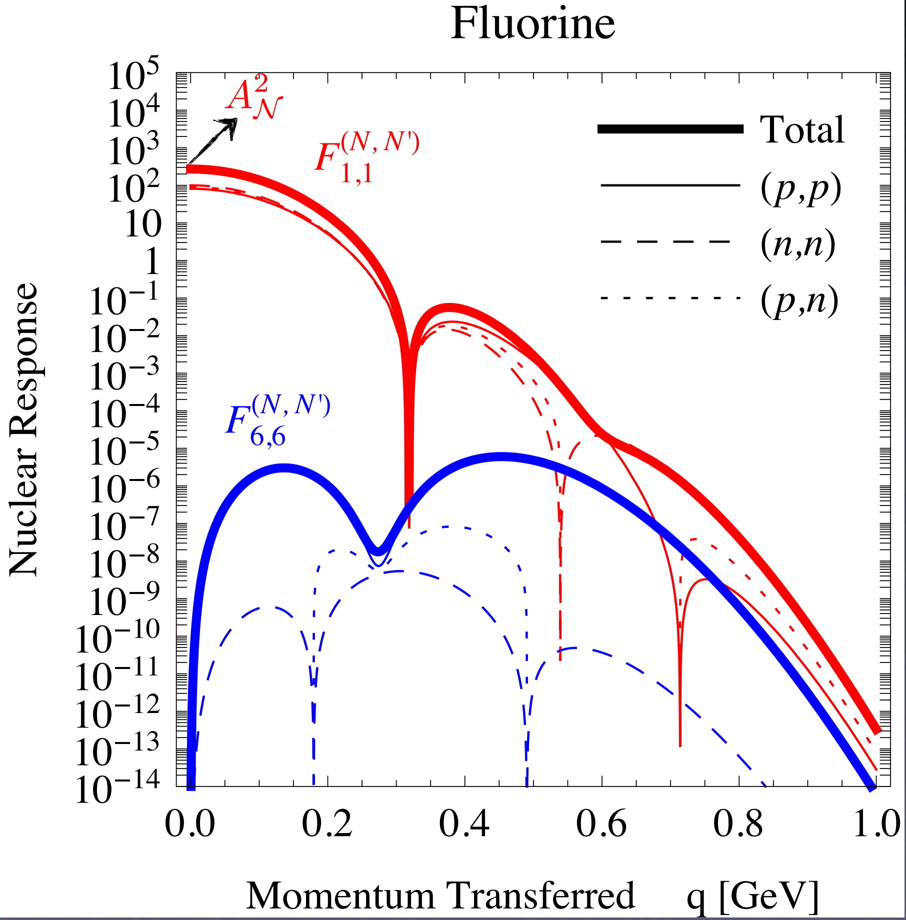
Differential Cross Section

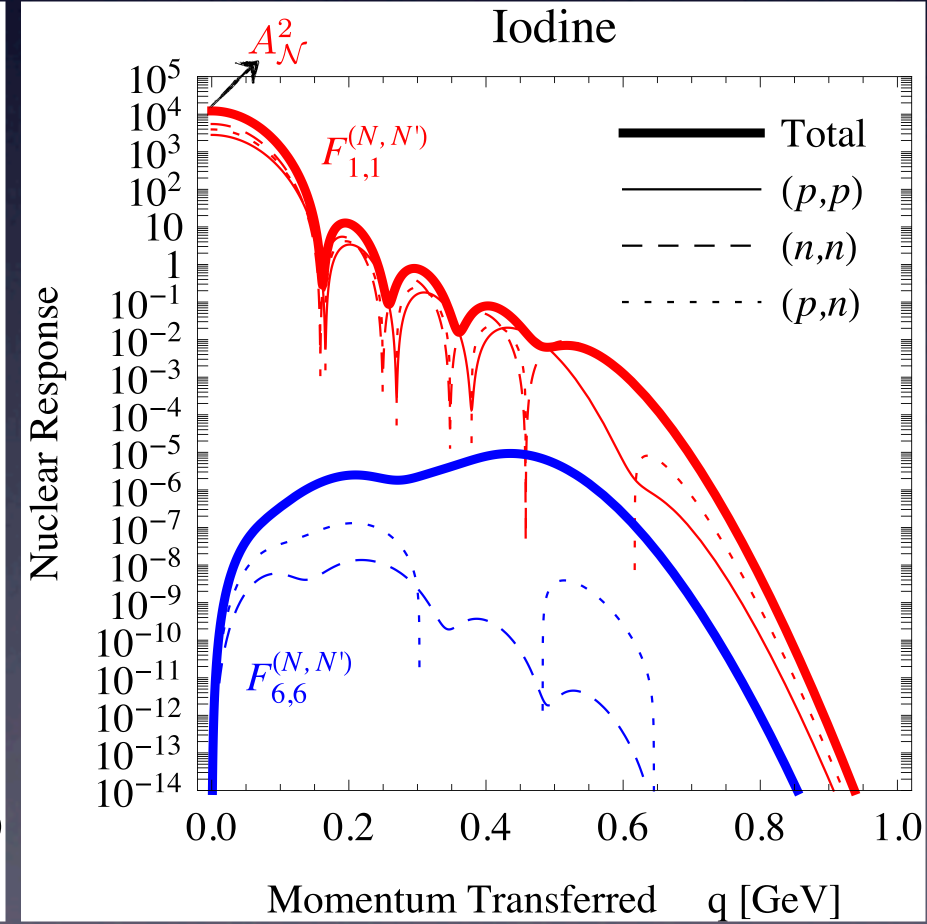
Nucleus is not point-like

There are different Nuclear Responses for any pairs of nucleons & any pairs of NR Operators

$$|\mathcal{M}_N|^2 = \frac{m_N^2}{m_N^2} \underbrace{\sum_{i,j=1}^{12}}_{\text{pairs of NR operators}} \underbrace{\sum_{N,N'=p,n}}_{\text{pairs of nucleons}} \mathfrak{c}_i^N \mathfrak{c}_j^{N'} \underbrace{F_{i,j}^{(N,N')}(v,q^2)}_{\text{Nuclear response of the target nuclei}}$$

Some Form Factors for Common Target Nuclei in Direct Searches





Contact interaction (q << Λ)

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Long-range interaction (q >> Λ)

$$\mathcal{O}_1^{lr} = \frac{1}{q^2}\mathcal{O}_1^{NR}, \quad \mathcal{O}_5^{lr} = \frac{1}{q^2}\mathcal{O}_5^{NR},$$
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"The Effective Field Theory of Dark Matter Direct Detection", JCAP **1302** (2013) 004

Rate of Nuclear Recoil

$$\frac{\mathrm{d}R_{\mathcal{N}}}{\mathrm{d}E_{\mathrm{R}}} = N_{\mathcal{N}} \frac{\rho_{\odot}}{m_\chi} \frac{1}{32\pi} \frac{m_{\mathcal{N}}}{m_\chi^2 m_N^2} \sum_{i,j=1}^{12} \sum_{N,N'=p,n} \mathfrak{c}_i^N \mathfrak{c}_j^{N'} \int_{v_{\min}(E_{\mathrm{R}})}^{v_{\mathrm{esc}}} \mathrm{d}^3 v \frac{1}{v} f_{\oplus}(v)\, F_{i,j}^{(N,N')}(v, q^2)$$

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“Standard” Spin Independent (SI) Interaction

Effective Lagrangian

$$\mathcal{L}_{\mathrm{SI}}^N = \lambda_{\mathrm{SI}}^N \cdot \bar{\chi}\chi \, \bar{N} N$$

free parameter
expressed in $[1/\mathrm{GeV}^2]$

DM-nucleon Matrix Element in the NR limit

$$\left|\mathcal{M}_{\mathrm{SI}}^N\right| = {}_{\mathrm{out}}\langle N, \chi | \, \mathcal{L}_{\mathrm{SI}}^N \, | N, \chi \rangle_{\mathrm{in}} = \underbrace{4 \, \lambda_{\mathrm{SI}}^N m_\chi m_N}_{\mathfrak{c}_1^N} \underbrace{1}_{\mathcal{O}_1^{\mathrm{NR}}}$$

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Rate of nuclear recoil for the SI Interaction

$$\frac{\mathrm{d}R_{\mathcal{N}}}{\mathrm{d}E_{\mathrm{R}}} = N_{\mathcal{N}} \frac{\rho_\odot}{m_\chi} \frac{m_{\mathcal{N}}}{2\mu_{\chi p}^2}\, \sigma_{\mathrm{SI}}^p\, \mathcal{I}(E_{\mathrm{R}}) \sum_{N,N'=p,n} F_{1,1}^{(N,N')}(q^2)$$

Total DM-nucleon Cross Section

$$\sigma_{\mathrm{SI}}^p = \frac{\lambda_{\mathrm{SI}}^2}{\pi}\mu_{\chi p}^2$$

with $\lambda_{\mathrm{SI}} \equiv \lambda_{\mathrm{SI}}^p = \lambda_{\mathrm{SI}}^n$

"Standard" velocity integral

$$\mathcal{I}(E_{\mathrm{R}}) = \int_{v_{\min}(E_{\mathrm{R}})}^{v_{\mathrm{esc}}} \mathrm{d}^3 v\, \frac{1}{v} f_\oplus(v)$$

Customary Helm Form Factor

$$\simeq A_{\mathcal{N}}^2\, F_{\mathrm{Helm}}^2(q^2)$$

Rate of Nuclear Recoil

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Comparison with the Experimental data

exposure

$$N_k^{\mathrm{th}} = w_k \int_{\Delta E_k} dE_{\mathrm{det}} \, \epsilon(E_{\mathrm{det}}) \int dE' \, \mathcal{K}(E_{\mathrm{det}}, E') \sum_{\mathcal{N}=\mathrm{Nucleus}} \frac{dR_{\mathcal{N}}}{dE_R} \left(E_R = \frac{E'}{q_{\mathcal{N}}} \right)$$

takes into account the response and energy resolution of the detector

runs over the different species in the detector (e.g. DAMA and CRESST are multiple-target)

quenching factor: accounts for the partial recollection of the released energy

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Uncertainties in Direct DM Searches

- ☑ Local DM energy Density & Geometry of the Halo (e.g: spherically symmetric halos with isotropic or not velocity dispersion, triaxial models, co-rotating dark disk and so on......)
- ☑ Nature of the interaction & Nuclear Responses (e.g: SI & SD scattering, long-range or point like character of the interaction and so on......)
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- ☑ Experimental uncertainties (e.g: detection efficiency close to the lower threshold, energy dependence of the quenching factors, channeling in crystals and so on......)

Expected Number of Events

$$N_k^{\rm th}(\lambda, m_\chi) = X \sum_{i,j=1}^{12} \sum_{N,N'=p,n} \mathfrak{c}_i^N(\lambda, m_\chi)\mathfrak{c}_j^{N'}(\lambda, m_\chi)\, \tilde{\mathcal{F}}_{i,j}^{(N,N')}(m_\chi, k)$$

as a linear combination of integrated form factors

$$X = \frac{\rho_\odot}{m_\chi}\frac{1}{32\pi}\frac{1}{m_\chi^2 m_N^2}$$

integrated form factors

$$\tilde{\mathcal{F}}_{i,j}^{(N,N')}(m_\chi, k) = w_k \sum_{\mathcal{N}=\text{Nucleus}} N_\mathcal{N} m_\mathcal{N} \int_{\Delta E_k} \mathrm{d}E_{\rm det}\, \epsilon(E_{\rm det}) \int \mathrm{d}E'\, \mathcal{K}(E_{\rm det}, E') \int_{v_{\rm min}\left(\frac{E'}{q_\mathcal{N}}\right)}^{v_{\rm esc}} \mathrm{d}^3 v \frac{1}{v} f_\oplus(v) F_{i,j}^{(N,N')}(v, q^2)$$

once computed the integrated form factors, one can easily derive the expected number of events for any kinds of interactions, whose particle physics in completely encapsulated in the coefficient $\mathfrak{c}_i^N$

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Model independent Bounds in direct DM searches

- ✓ I'm going to present a new framework for "scaling" a bound given on a certain benchmark interaction to any other kinds of interactions
- ✓ For example the model dependent bounds presented by the experimental collaborations can also be applied to other class of models

Benchmark interaction

Contact interaction

$$\mathcal{O}_1^{\rm NR} = \mathbb{1}\,,$$

$$\mathcal{O}_3^{\rm NR} = i\,\vec{s}_N \cdot (\vec{q} \times \vec{v}^{\perp})\,, \quad \mathcal{O}_4^{\rm NR} = \vec{s}_\chi \cdot \vec{s}_N\,,$$

$$\mathcal{O}_5^{\rm NR} = i\,\vec{s}_\chi \cdot (\vec{q} \times \vec{v}^{\perp})\,, \quad \mathcal{O}_6^{\rm NR} = (\vec{s}_\chi \cdot \vec{q})(\vec{s}_N \cdot \vec{q})\,,$$

$$\mathcal{O}_7^{\rm NR} = \vec{s}_N \cdot \vec{v}^{\perp}\,, \quad \mathcal{O}_8^{\rm NR} = \vec{s}_\chi \cdot \vec{v}^{\perp}\,,$$

$$\mathcal{O}_9^{\rm NR} = i\,\vec{s}_\chi \cdot (\vec{s}_N \times \vec{q})\,, \quad \mathcal{O}_{10}^{\rm NR} = i\,\vec{s}_N \cdot \vec{q}\,,$$

$$\mathcal{O}_{11}^{\rm NR} = i\,\vec{s}_\chi \cdot \vec{q}\,, \quad \mathcal{O}_{12}^{\rm NR} = \vec{v}^{\perp} \cdot (\vec{s}_\chi \times \vec{s}_N)\,.$$

LR interaction

$$\mathcal{O}_1^{\rm lr} = \frac{1}{q^2}\mathcal{O}_1^{\rm NR}\,, \quad \mathcal{O}_5^{\rm lr} = \frac{1}{q^2}\mathcal{O}_5^{\rm NR}\,,$$

$$\mathcal{O}_6^{\rm lr} = \frac{1}{q^2}\mathcal{O}_6^{\rm NR}\,, \quad \mathcal{O}_{11}^{\rm lr} = \frac{1}{q^2}\mathcal{O}_{11}^{\rm NR}\,.$$

Among all the NR interactions we choose the simplest:

(a model where DM interact with only protons with a constant cross section)

$\mathfrak{c}_1^p = \lambda_{\rm B}$, while $\mathfrak{c}_1^N = 0$

Benchmark DM-nucleon ME

$$|\mathcal{M}_{p,\rm B}| = \lambda_{\rm B}\mathcal{O}_1^{\rm NR}$$

Events for the benchmark model

$$N_{k,\rm B}^{\rm th} = X\,\lambda_{\rm B}^2\,\tilde{\mathcal{F}}_{1,1}^{(p,p)}(m_\chi, k)$$

benchmark DM constant

Benchmark interaction

Contact interaction

$\mathcal{O}_1^{NR} = \mathbb{1}$,

$\mathcal{O}_3^{NR} = i\,\vec{s}_N \cdot (\vec{q} \times \vec{v}^\perp)$, $\mathcal{O}_4^{NR} = \vec{s}_\chi \cdot \vec{s}_N$,

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LR interaction

$\mathcal{O}_1^{lr} = \frac{1}{q^2}\mathcal{O}_1^{NR}$, $\mathcal{O}_5^{lr} = \frac{1}{q^2}\mathcal{O}_5^{NR}$,

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Benchmark DM-nucleon ME

$$|\mathcal{M}_{p,B}| = \lambda_B \mathcal{O}_1^{NR}$$

Events for the benchmark model

$$N_{k,B}^{th} = X\,\lambda_B^2\,\tilde{\mathcal{F}}_{1,1}^{(p,p)}(m_\chi, k)$$

benchmark DM constant

Determination of the maximal value of λ_B allowed by the experimental data-set

Likelihood Ratio Test Statistic (TS)

$$\mathrm{TS}(\lambda_B, m_\chi) = -2\ln\left(\mathcal{L}(\vec{N}^{obs}\,|\,\lambda_B)/\mathcal{L}_{bkg}\right)$$

likelihood of obtaining the set of observed data

bkg. likelihood

for any given value of m_χ, a 90% CL lower bound on the free parameter can be obtained by solving

$$\mathrm{TS}(\lambda_B, m_\chi) = \chi^2_{90\%\,CL} \simeq 2.71$$

Benchmark interaction

Contact interaction

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Events for the benchmark model

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benchmark DM constant

Determination of the maximal value of $\lambda_{\rm B}$ allowed by the experimental data-set

Likelihood Ratio Test Statistic (TS)

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likelihood of obtaining the set of observed data

bkg. likelihood

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$$\mathrm{TS}(\lambda_{\rm B}, m_\chi) = \chi^2_{90\%\,\rm CL} \simeq 2.71$$

The functions TS that allow the users to compute the bound $\lambda_{\rm B}^{\rm CL}$ at the desired CL are provided here:

http://www.marcocirelli.net/NROpsDD.html

Rescaling Functions

For any model the bound must be drawn at the same CL:

$$\mathrm{TS}(\lambda, m_\chi) = \mathrm{TS}(\lambda_{\mathrm{B}}, m_\chi)$$

For null-results Exps. a solution is:

$$\sum_k N_k^{\mathrm{th}}(\lambda, m_\chi) = \sum_k N_{k,\mathrm{B}}^{\mathrm{th}}(\lambda_{\mathrm{B}}, m_\chi)$$

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$$\tilde{\mathcal{Y}}_{i,j}^{(N,N')}(m_\chi) = \frac{\sum_k \tilde{\mathcal{F}}_{i,j}^{(N,N')}(m_\chi, k)}{\sum_k \tilde{\mathcal{F}}_{1,1}^{(p,p)}(m_\chi, k)}$$

"Scaling" Functions
- nuclear physics
- astrophysics
- experimental details

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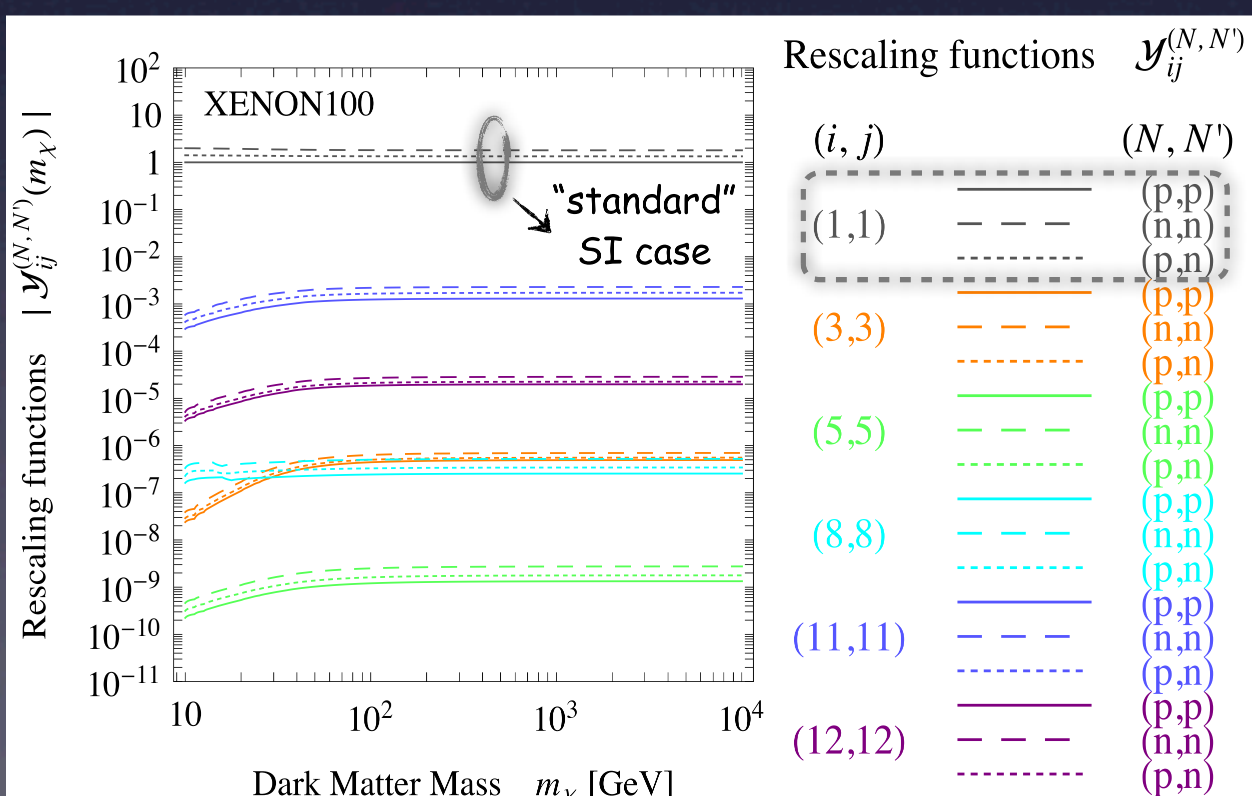

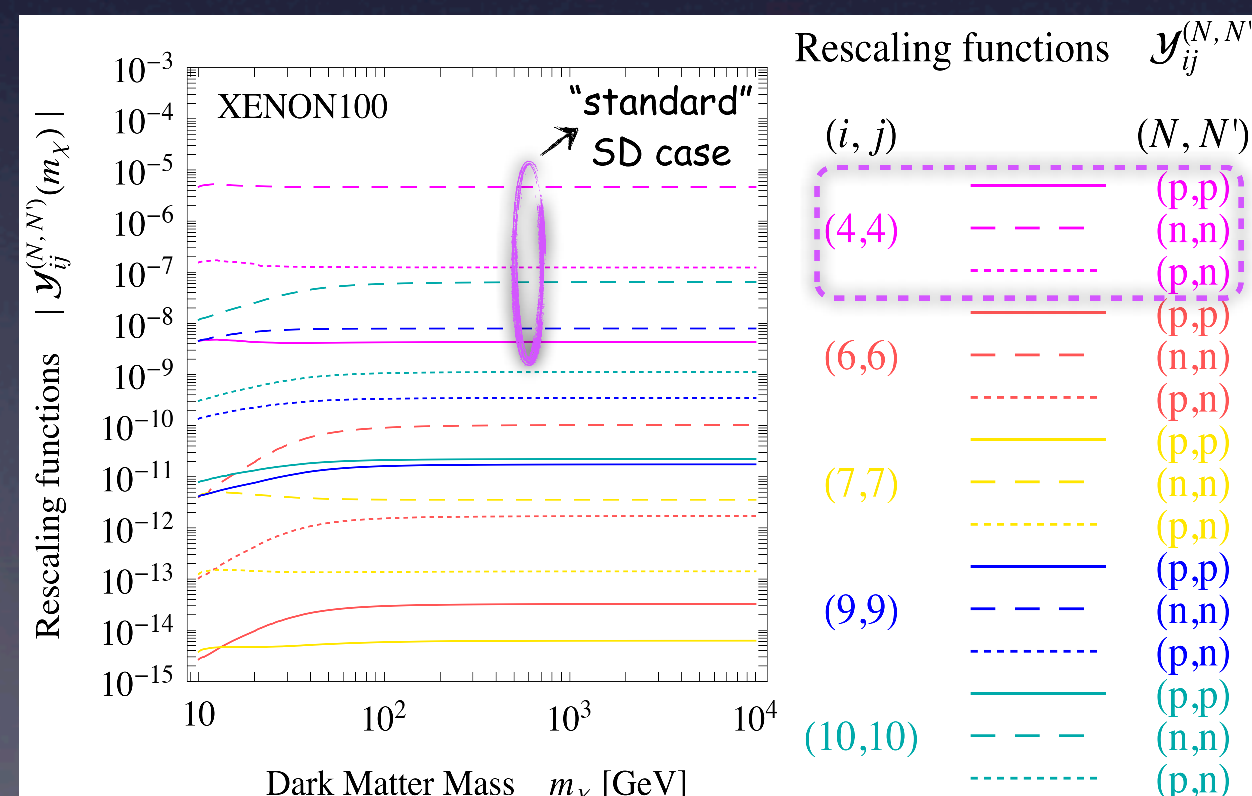

Example: SI & SD Interactions

SI DM-nucleon effective Lagrangian

$$\mathcal{L}^N_{\mathrm{SI}} = \lambda_{\mathrm{SI}} \cdot \bar{\chi}\chi\, \bar{N}N$$

Total SI DM-nucleon Cross section

$$\sigma^p_{\mathrm{SI}} = \frac{\lambda^2_{\mathrm{SI}}}{\pi}\mu^2_{\chi p}$$

DM-nucleon reduced mass

SD DM-nucleon effective Lagrangian

$$\mathcal{L}^N_{\mathrm{SD}} = \lambda_{\mathrm{SD}} \cdot \bar{\chi}\gamma^\mu\gamma^5\chi\, \bar{N}\gamma_\mu\gamma^5 N$$

Total SD DM-nucleon Cross section

$$\sigma^p_{\mathrm{SD}} = 3\frac{\lambda^2_{\mathrm{SD}}}{\pi}\mu^2_{\chi p}$$

DM-nucleon reduced mass

Example: SI & SD Interactions

SI DM-nucleon effective Lagrangian

$$\mathcal{L}_{\rm SI}^{N} = \lambda_{\rm SI} \cdot \bar{\chi}\chi \, \bar{N} N$$

Total SI DM-nucleon Cross section

$$\sigma_{\rm SI}^{p} = \frac{\lambda_{\rm SI}^2}{\pi} \mu_{\chi p}^2$$

DM-nucleon reduced mass

Non-relativistic SI DM-nucleon ME

$$|\mathcal{M}_{\rm SI}^{N}| = \underbrace{4\,\lambda_{\rm SI} m_\chi m_N}_{\mathfrak{c}_1^N} \, \mathbf{1}$$

$\mathbf{1} \rightarrow \mathcal{O}_1^{\rm NR}$

SD DM-nucleon effective Lagrangian

$$\mathcal{L}_{\rm SD}^{N} = \lambda_{\rm SD} \cdot \bar{\chi}\gamma^\mu\gamma^5\chi \, \bar{N}\gamma_\mu\gamma^5 N$$

Total SD DM-nucleon Cross section

$$\sigma_{\rm SD}^{p} = 3\frac{\lambda_{\rm SD}^2}{\pi} \mu_{\chi p}^2$$

DM-nucleon reduced mass

Non-relativistic SD DM-nucleon ME

$$|\mathcal{M}_{\rm SD}^{N}| = \underbrace{16\,\lambda_{\rm SD} m_\chi m_N}_{\mathfrak{c}_4^N} \, \vec{s}_\chi \vec{s}_N$$

$\vec{s}_\chi \vec{s}_N \rightarrow \mathcal{O}_4^{\rm NR}$

Example: SI & SD Interactions

SI DM-nucleon effective Lagrangian

$$\mathcal{L}_{\rm SI}^{N} = \lambda_{\rm SI} \cdot \bar{\chi}\chi\, \bar{N} N$$

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DM-nucleon reduced mass

Non-relativistic SI DM-nucleon ME

$$|\mathcal{M}_{\rm SI}^{N}| = \underbrace{4\,\lambda_{\rm SI} m_\chi m_N}_{\mathfrak{c}_1^N}\, \mathbf{1} \rightarrow \mathcal{O}_1^{\rm NR}$$

Quadratic form for the SI DM-nucleon interaction

$$\lambda_{\rm B}^2 = \sigma_{\rm SI}^{p} \sum_{N,N'=p,n} 16\pi\, m_\chi^2 \frac{m_N^2}{\mu_{\chi p}^2}\, \tilde{\mathcal{Y}}_{1,1}^{(N,N')}(m_\chi)$$

SD DM-nucleon effective Lagrangian

$$\mathcal{L}_{\rm SD}^{N} = \lambda_{\rm SD} \cdot \bar{\chi}\gamma^\mu\gamma^5\chi\, \bar{N}\gamma_\mu\gamma^5 N$$

Total SD DM-nucleon Cross section

$$\sigma_{\rm SD}^{p} = 3\frac{\lambda_{\rm SD}^2}{\pi}\mu_{\chi p}^2$$

DM-nucleon reduced mass

Non-relativistic SD DM-nucleon ME

$$|\mathcal{M}_{\rm SD}^{N}| = \underbrace{16\,\lambda_{\rm SD} m_\chi m_N}_{\mathfrak{c}_4^N}\, \vec{s}_\chi \vec{s}_N \rightarrow \mathcal{O}_4^{\rm NR}$$

Quadratic form for the SD DM-proton interaction

$$\lambda_{\rm B}^2 = \sigma_{\rm SD}^{p} \frac{256}{3}\pi\, m_\chi^2 \frac{m_N^2}{\mu_{\chi p}^2}\, \tilde{\mathcal{Y}}_{4,4}^{(p,p)}(m_\chi)$$

Summary & Conclusions

What have we learned till now?

- DM signals are not dominant, and in general one should look for subdominant channels on top of the astrophysical bkg in indirect searches and some unknown radioactive bkg in underground detectors

Good news: This is a Golden Age for indirect, direct searches and colliders !!

- There are many experiments that are currently taking data, in particular:
  - Direct DM Searches: long-standing DAMA results, CoGeNT, CRESST & CDMS-Si hints
  - Indirect DM Searches: possible indication of gamma-ray lines in the FERMI data

Bad news: The situation in direct searches is quite confusing

- as on top of the positive results, the constraints coming from null results are very stringent and they exclude the "Standard" SI contact interaction

But the uncertainties in DD are very big !!

- In this talk I have been focussed on the uncertainties coming from the nature of the interactions

Model independent Bounds in direct DM searches

- We have seen that it is possible to draw the exclusion lines on the free parameters of any kind of DM-nucleon interactions in a model independent way thanks to ready-made scaling functions
- We encourage the experimental collaborations to release, when possible, their own TS for a given benchmark interactions and a complete list of rescaling functions like we did

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Advertisement

You want to compute the bounds on your favorite DM-nucleus interactions, go in the website on the bottom of this slide and use our tools

Tools for model-independent bounds in direct dark matter searches

Data and Results from 1307.5955 [hep-ph], JCAP 10 (2013) 019.

If you use the data provided on this site, please cite:
M.Cirelli, E.Del Nobile, P.Panci,
"Tools for model-independent bounds in direct dark matter searches",
arXiv 1307.5955, JCAP 10 (2013) 019.

This is **Release 1.0** (July 2013). *Log of changes at the bottom of this page.*

Test Statistic functions:

The TS.m file provides the tables of TS for the benchmark case (see the paper for the definition), for the four experiments that we consider (XENON100, CDMS-Ge, COUPP, PICASSO).

Rescaling functions:

The Y.m file provides the rescaling functions $Y_{ij}^{[N,N']}$ and $Y_{ij}^{r[N,N']}$ (see the paper for the definition).

Sample file:

The Sample.nb notebook shows how to load and use the above numerical products, and gives some examples.

Log of changes and releases:

[23 jul 2013] First Release.
[08 oct 2013] Minor changes in the notations in Sample.nb, to match JCAP version. No new release.

Contact: Eugenio Del Nobile <delnobile@physics.ucla.edu>, Paolo Panci <panci@cp3-origins.net>

http://www.marcocirelli.net/NROpsDD.html