Estimates on macroscopic force due to dark matter coherent scattering

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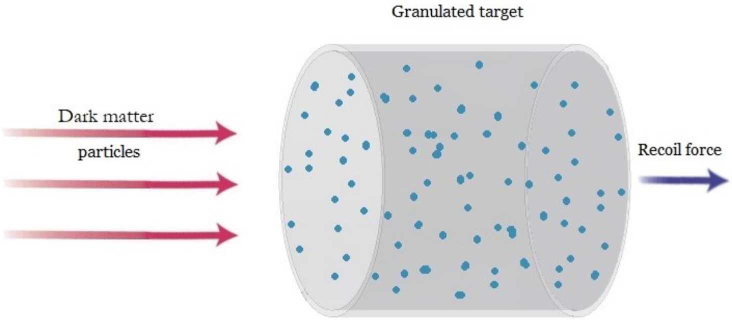
Cracow, 2018

Contents

Dark matter particles detection due to coherent scattering

The goal

Detection of dark matter particles by measuring a macroscopic recoil force acting on a target

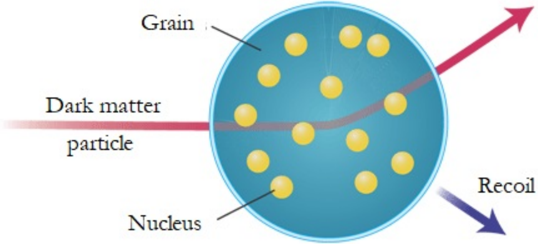


Dark matter particles detection due to coherent scattering

For coherent scattering

$$a \lesssim \lambda_{DM}, \qquad (1)$$

where a — size of granule/pore.



Materials of the target

Properties of the Sample Powders

Name	Grain Density δ (gcm^{-3})	Shape	Material
Alumina (0.1 μm)	3.9	irregular	Al_2O_3
Silica beads (1.7 μm)	2.2	spherical	SiO_2
Silica sand (13 μm)	2.645	irregular	SiO_2
Silica sand (19 μm)	2.645	irregular	SiO_2
Silica sand (73 μm)	2.645	irregular	SiO_2

Dark matter candidates

- WIMPs
- neutrino (e, μ, τ, sterile, heavy)
- axions
- dark photon
- supersymmetric particles
- Q-balls
- Kaluza-Klein particles
- strangelets
- techni-baryons
- cryptons
- magnetic monopoles
- MACHO (black holes, dwarfs, etc)
- mirror particles

Dark matter candidates

- WIMPs
- heavy neutrino
- axions
- dark photon

Too heavy

- supersymmetric particles
- Q-balls
- Kaluza-Klein particles
- strangelets
- techni-baryons
- cryptons
- magnetic monopoles

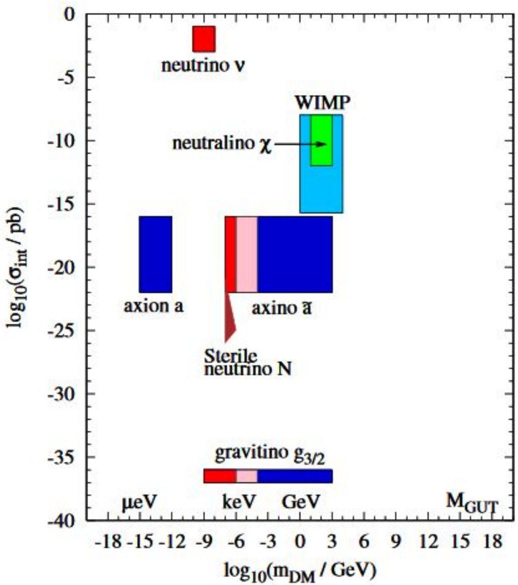
Not enough

- neutrino (e, μ, τ)
- MACHO (black holes, dwarfs, etc)

Too weak interaction

- mirror particles
- sterile neutrino

WIMP dark matter candidates



Local dark matter density

Label	Reference	Description	Sampling	$\rho_{\rm dm}$ [GeV cm^{-3}]
a) Local measures ($\rho_{\rm dm}$)				
		Latest measurements		
MB12	Moni Bidin et al. (2012)	CSF	412	0.023 ± 0.042 [0 ± 0.042]
BT12	Bovy & Tremaine (2012)	CSF	412	0.3 ± 0.11
G12	Garbari et al. (2012)	VC	2×10^3	$0.85^{+0.57}_{-0.5}$
G12*	Garbari et al. (2012)	VC + Σ_b	2×10^3	$0.33^{+0.26}_{-0.075}$
S12	Smith et al. (2012)	CSF	10^4	0.19 [0.57]
Z13	Zhang et al. (2013)	CSF	10^4	0.25 ± 0.09
BR13	Bovy & Rix (2013)	CSF + MAP	10^4	0.22 ± 0.07 [0.3 ± 0.094]
b) Global measures assuming spherical symmetry ($\rho_{\rm dm,ext}$)				
S10	Salucci et al. (2010)	NP	–	0.43 ± 0.15
CU10	Catena & Ullio (2010)	NFW; SP	–	0.385 ± 0.027
WB10	Weber & de Boer (2010)	NFW/ISO; WP	–	0.2 - 0.4
I11	Iocco et al. (2011)	gNFW; WP; ML	–	0.2 - 0.56
M11	McMillan (2011)	NFW; SP	–	0.4 ± 0.04

Parameters of dark matter particles

Candidates	Mass, eV
Axion	10^{-6}–10^{-4}
Neutrino	0.1–10
Axino	10^{2}–10^{12}
Dark photon	10^{6}–10^{9}

Candidates	The most likely/Average $n \cdot \mathrm{cm}^{-3}$	$n_{\mathrm{min}} \cdot \mathrm{cm}^{-3}$	$n_{\mathrm{max}} \cdot \mathrm{cm}^{-3}$
Axion	10^{13}	10^{11}	10^{14}
Neutrino	$3 \cdot 10^{7}$	$2 \cdot 10^{6}$	$5 \cdot 10^{9}$
Axino	0.1	$2 \cdot 10^{-5}$	$8 \cdot 10^{6}$
Dark photon	3	0.01	$9 \cdot 10^{2}$

L. Roszkowski et al. 2018 [1]
L. Marsicano et al. 2018 [4]

Neutrino case

Amplitudes of coherent scattering

$$A_{\nu_{\mu,\tau}} = -\frac{Gm_\nu}{4\sqrt{2}\pi}(A-Z)N_A, \tag{2}$$

$$A_{\nu_e} = \frac{Gm_\nu}{4\sqrt{2}\pi}(3Z-A)N_A, \tag{3}$$

where Z and A — charge and atomic number, m_ν — neutrino mass, and N_A — number of atoms in the granule:

$$N_A = \frac{\rho}{Am_p}\frac{4\pi}{3}a^3. \tag{4}$$

Neutrino case

Cross section

$$\sigma = \frac{G^2 m_\nu^2}{\pi} N_A^2 k_L^2 \tag{5}$$

where $k_L = 3Z - A$ for ν_e and $k_L = Z - A$ for ν_μ, ν_τ.

Acceleration

When momentum transfer $q \sim 2m_\nu v$, the acceleration:

$$w = \frac{1}{AN_A m_p}\frac{dq}{dt} = 10^{-22}\frac{k_L^2}{A^2} \tag{6}$$

Results

The minimum detectable acceleration (for $m = 1\text{g}$)

$$w_{\mathsf{min}} = 4.2 \cdot 10^{-18}\mathsf{cm} \cdot \mathsf{s}^{-2} \quad (7)$$

S. Schreppler at el. (2014) [3]

Candidates	Average $w \cdot \mathsf{cm} \cdot \mathsf{s}^{-2}$	Best $w \cdot \mathsf{cm} \cdot \mathsf{s}^{-2}$
Axion	$2 \cdot 10^{-19}$	$6 \cdot 10^{-16}$
Neutrino	10^{-22}	$8 \cdot 10^{-20}$
Axino	10^{-33}	$6 \cdot 10^{-25}$
Dark photon	—	$3.4 \cdot 10^{-36}$

Conclusion

- Some kinds of DM particles can be theoretically detected by measurements of macroscopic recoil force due to coherent scattering
- How will estimations change for dark matter which consists of different particles?
- Can the radiative scattering be more efficient for DM detection?

Thank you for your attention!

References

- L. Roszkowski, E. M. Sessolo, S. Trojanowski, Rept. Prog. Phys. **81** (2018) no.6, 066201 doi:10.1088/1361-6633/aab913 [arXiv:1707.06277 [hep-ph]].
- T. Omura, A. M. Nakamura Astroph. J., **860** (2018) no.2 doi:10.3847/1538-4357/aabe81
- S. Schreppler et al., Science **1486** (2014), 344 doi: 10.1126/science.1249850
- L. Marsicano et al., [arXiv:1807.05884 [hep-ex]].