Migdal effect in solid state dark matter detectors

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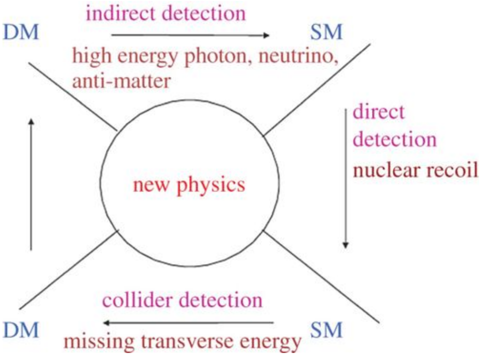
Outline

- Direct detection and current status
- Why look into the Migdal effect and what is it
- Migdal in semiconductors

Dark matter detection

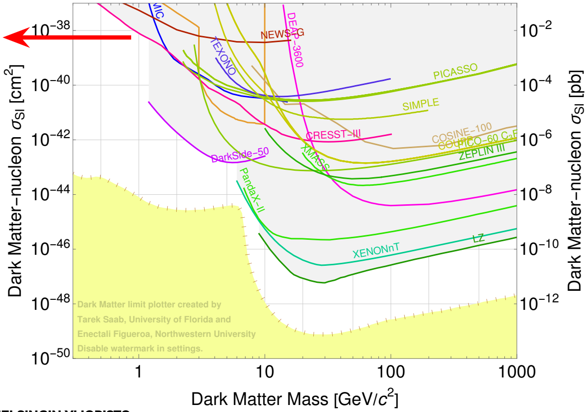
- From gravitational effects, we know that dark matter exists
- Beyond the SM, particle mass e-22 eV to e15 GeV
- Assuming coupling to SM, three detection methods



Observables in direct detection

- Detectors usually observe scintillation light, ionization, vibrations
- Scintillation and ionization available only above some energy threshold
- In elastic nuclear recoils, scintillation and ionization result from collisions between the recoiling nucleus and the neighbouring nuclei
- In Migdal, the recoiled atom gets excited/ionized itself. This is possible for a smaller energy

Direct detection status



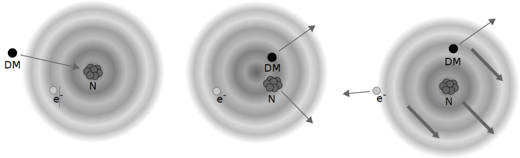
Two ways to go:

- Towards the neutrino floor ⇒ larger exposures
- Exploring small mass region ⇒ Migdal(, electron recoils, phonons)

Source: SuperCDM

The Migdal effect

- Deposited energy in elastic NR $E_N \sim m_\chi^2 v_\chi^2 / m_N$
- Inelastic scattering: a portion of this energy is directly deposited to the electrons, enabling detecting light DM
- Migdal: DM transfers momentum to nucleus and electrons get ionized or excited, then emitting photon when de-excited



Source: Quantum universe

- Calculations done for some "free" atom detectors

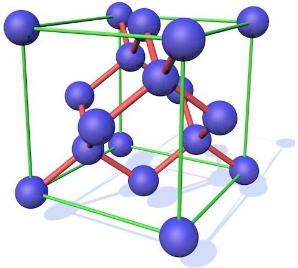
Migdal in semiconductors

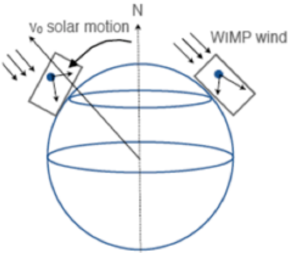
$$R \sim \int_{\mathbf{v}} \int_{\mathbf{k}_e} \int_{\mathbf{q}} f(\mathbf{v})\,(\mathbf{q}\cdot\mathbf{k}_e)\mathrm{Im}(-\epsilon^{-1}(\mathbf{k}_e,\omega))\,S(\mathbf{k}_e,\mathbf{q},\mathbf{v})|M|^2$$

- Velocity distribution $f(\mathbf{v})$
- Structure function S captures the effect of the material on nuclear scattering
- Free ion approximation of S corresponds to a Dirac delta
- More dominant angular dependence arises from the energy loss function (ELF) $\mathrm{Im}(-\epsilon^{-1})$

Directional dependency

- ELF $\mathrm{Im}(-\epsilon^{-1})$ from density functional theory (DFT) calculations
- Collaborating with Gianni Profeta's material physics group at University of L'Aquila
- Anisotropies in it can lead to modulation effects





Source: arXiv 1310.8327

Summary

- We need to extend direct detection into smaller cross sections and smaller masses
- Migdal effect to reach smaller mass ranges
- Exploring whether the crystal detectors have directional dependencies

Thank you for listening!

Event rate integrals

$$\frac{\mathrm{d}R}{\mathrm{d}\omega} = \frac{(2\pi)^2 M}{\omega^4} \int_{(-v_{esc}-w)/v_{lab}}^{(v_{esc}-w)/v_{lab}} \mathrm{d}\cos\theta_k \int_0^{10^4} \mathrm{d}k \int_{-1}^{1} \mathrm{d}\cos\theta_q \int_0^{10^4} \mathrm{d}q$$

$$\times\, q^3 k^2 \cos\theta_k^2 ELF(\omega, k) \left(\exp\left[\frac{-(w + v_{lab}\cos\theta_q)^2}{v_0^2}\right] - \exp\left[\frac{-v_{esc}^2}{v_0^2}\right]\right)$$

$$w = \frac{q}{2\mu} + \frac{\omega}{q} \qquad \left(-\frac{k\cos\theta_q}{2m_N} + \frac{k^2}{2m_N q}\right)$$

$$M = \frac{1}{N_{esc} v_0 \sqrt{\pi}} 2A^2 \alpha \rho_T \sigma_n \rho_\chi Z^2 / (\mu^2 m_N^2 m_\chi)$$

$$N_{esc} = \mathrm{erf}(v_{esc}/v_0) - 2v_{esc}\exp(-v_{esc}^2/v_0^2)/\left(\sqrt{(\pi)}v_0\right)$$