Low-Mass Dark Matter Inelastic Direct Detection via the Migdal Effect

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2103.05890

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low mass dark matter

- lots of interest in detecting low-mass (sub-GeV) dark matter
- but low-mass DM-nucleon scattering is hard to detect, since nuclear recoils are below threshold
- new strategies are being studied
  - electron scattering, low threshold, cosmic ray upscattering, the Migdal effect
- focus has been mostly on elastic scattering
- but inelastic scattering is a natural feature of many scenarios

- what happens to the Migdal effect with inelastic low-mass DM scattering?
- upshot→ parameter degeneracy, and new exothermic search opportunities

why inelastic scattering?

- consider an example → DM is charged under spontaneously broken U(1) gauge symmetry
- arises in many models of new low-mass physics involving dark photons

- DM must be a complex particle to have a vector coupling to a gauge boson
  - symmetry gives you two particles with the same mass
- symmetry breaking generically splits DM into two real particles

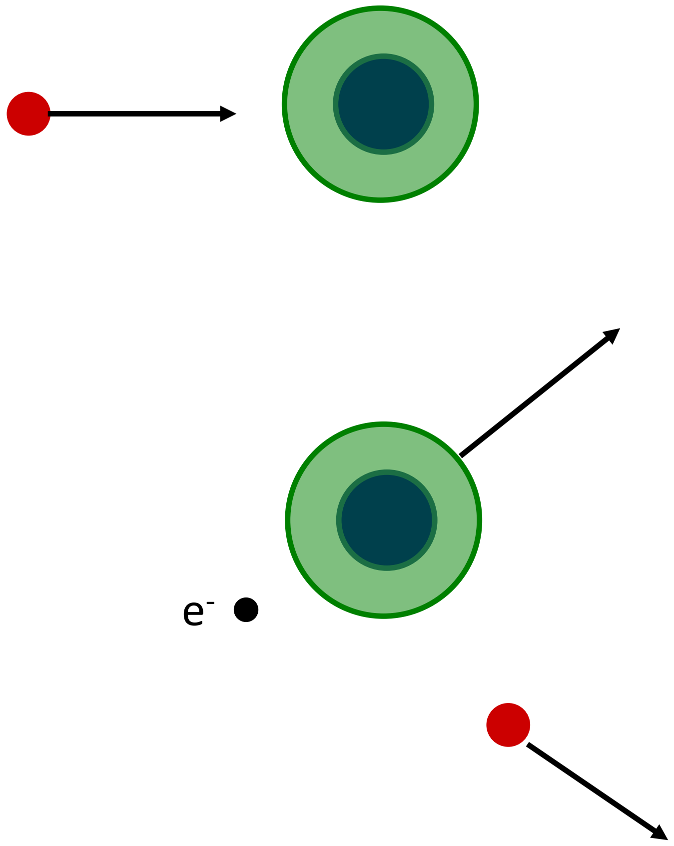
- but vector current for a real particle vanishes

- so tree-level matrix element is off-diagonal

what is the Migdal effect?

(equation-free version)

- basic idea → when nucleus recoils, can leave an e^- behind
- small probability, but easier to detect
  - larger quenching factor
  - more energy
- this is already a species of inelasticity in DM-atom scattering
- ejected electron takes away a little momentum, but significant energy
  - loses energy, and then usually an electron reabsorbed



details

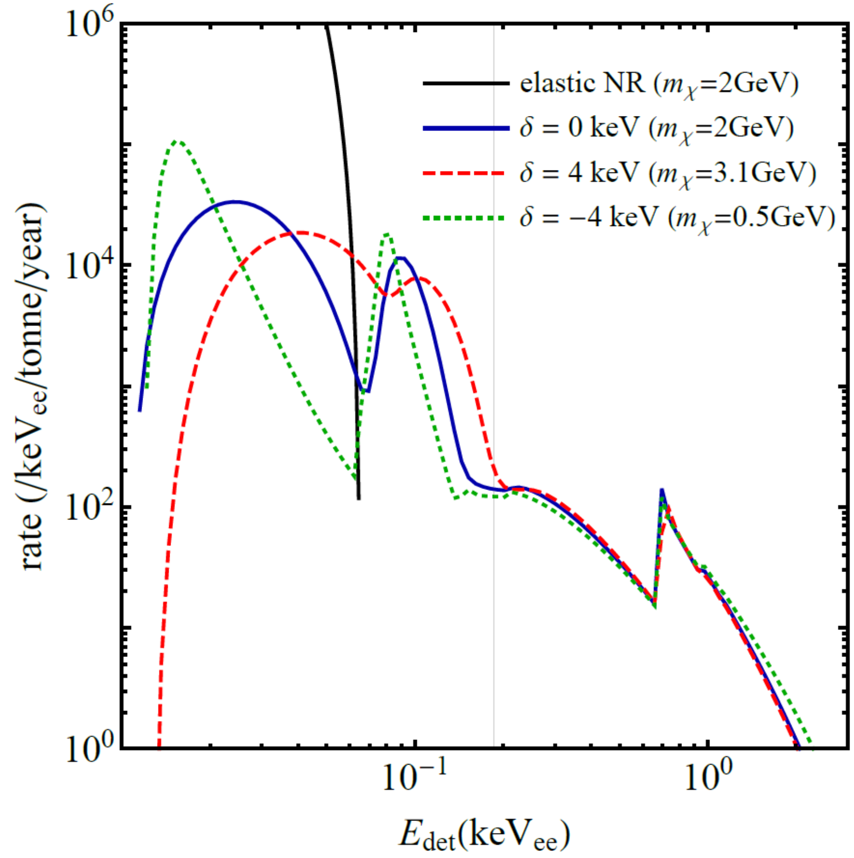
- mostly follow Ibe, Nakano, Shoji, Suzuki (1707.07258)
- we focus on Xe-based detectors
- brem and e^- excitation subleading
- isolated atom approximation is reasonable
  - more complicated for other materials
- total inelasticity δ' includes mass splitting and Migdal e^- energy
- ionization probabilities p^c
- we consider n = 3, 4, 5 shells

$$\frac{d^3R}{dE_R dE_e dv} = \frac{d^2R}{dE_R dv} \times \frac{1}{2\pi} \sum_{n,\ell} \frac{d}{dE_e} p^c_{q_e}(n,\ell \to E_e)$$

$$E_R = \frac{\mu^2}{m_A} v^2 \left[1 - \frac{\delta'}{\mu v^2} - \sqrt{1 - \frac{2\delta'}{\mu v^2}} \cos\theta_{cm} \right]$$

spectrum degeneracy

- degeneracy between m_χ, δ, and σ
- why?
- spectrum characterized by threshold, height and cutoff
- threshold fixed by reabsorption energy
- cutoff set by kinetic energy needed to produce inelasticity
  - $E_{max} \sim (1/2)\, m_\chi\, v^2_{max} - \delta$
  - degeneracy between m_χ (kinetic energy) and δ (inelasticity)
- σ then sets the height



δ = mass splitting in keV

σ = (1, 0.0084, 28) × 10^{-40} cm^2

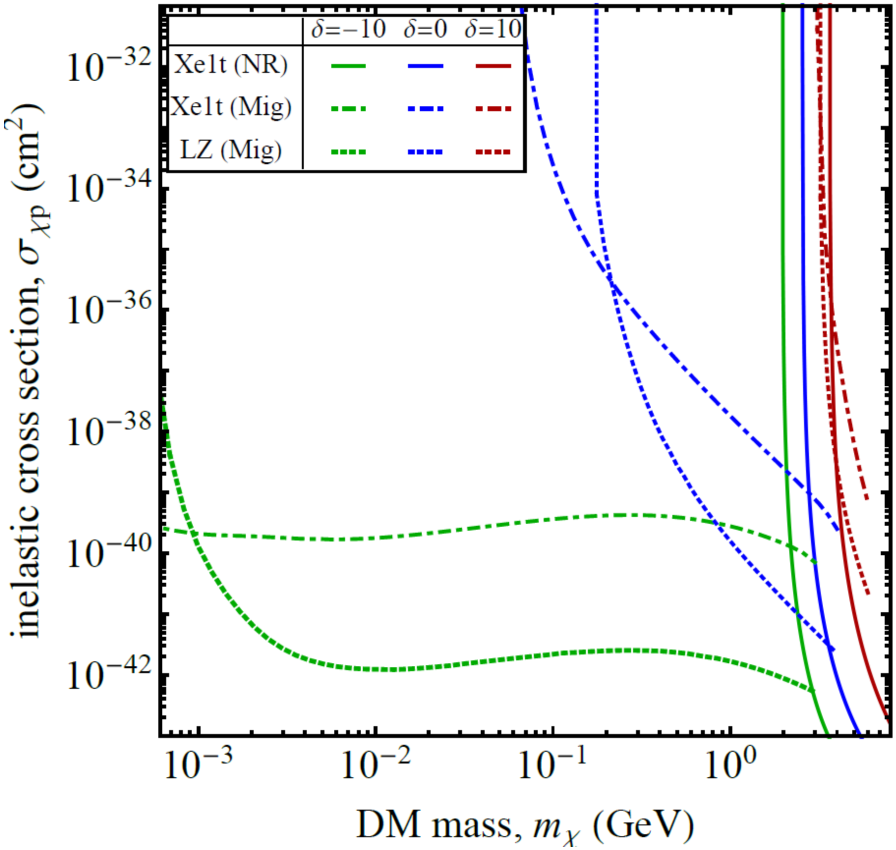
bounds and sensitivities

- S2 only analysis
- sensitivity for exothermic scattering down to very low mass

- why?
- δ transferred to e⁻, with nucleus absorbing recoil

- won't work with just exothermic DM-nucleus scattering
  - light DM takes away energy

- need a three-body process



conclusion

- direct detection experiments are set to probe low-mass dark matter
- Migdal effect provides a good prospects
- but inelasticity is a generic feature, so should consider its effect

- → parameter degeneracy makes it hard to distinguish m_χ, δ and σ
- → Migdal effect leads to great sensitivity to exothermic scattering

Mahalo!

Backup Slides

details of analysis

- Xe1t energy range = 0.186 – 3.8 keV_{ee}
- exposure = 22 T day
- number of events observed = 61
- expected bgd = 23.4

- LZ looks like it will have worse sensitivity to exothermic at low mass, but that's because of our assumed threshold
  - 0.5 - 4 keV_{ee} , 5.6 kT day
- should wait to see what threshold they eventually report