A neutrino floor for the Migdal effect

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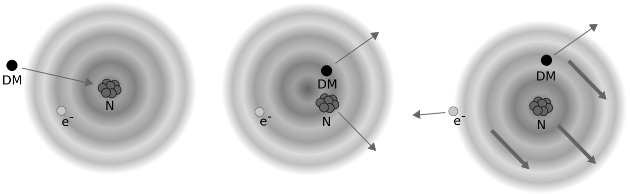
Migdal, 1939

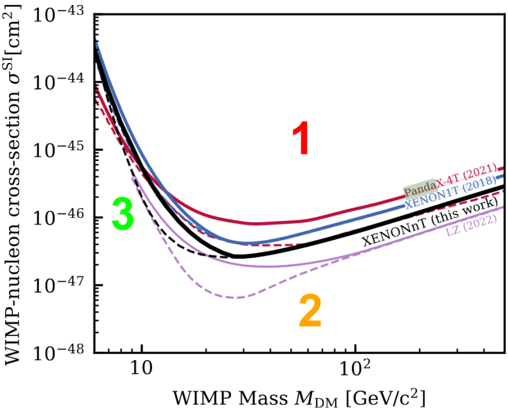
In nuclear collisions involving large energy transfer there must occur ionization of the recoil atoms. If the velocity acquired by the nucleus is not too large, then it can carry its electrons off with it, and ionization takes place only in the outer, weakly bound shells. For large velocities, on the other hand, the nucleus recoils right out of its electronic shells instead of carrying them with it.

Dolan, Kahlhoefer, McCabe, 17'



Light dark matter may induce nuclear recoils below the experimental threshold, but leaving a detectable ionization signal via the Migdal effect

Direct detection of dark matter



× 1: Ruled out by several experiments

× 2: Dark matter signal masked by atmospheric/solar neutrinos, but reachable in the near future

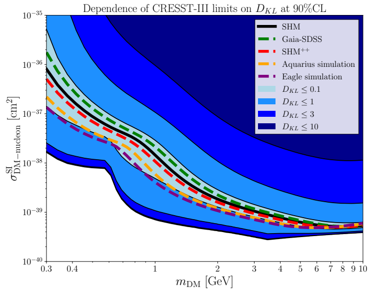
✓ 3: Unexplored region, hard to reach in the near future

In reality, these limits are subject to a couple of theoretical assumptions

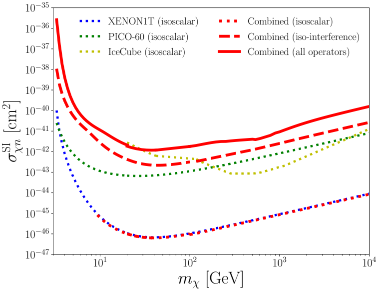
? The dark matter velocity distribution on Earth follows a Maxwell-Boltzmann

? The dark matter-nucleus interaction is given by a coherent operator, and the dark matter couples equally to neutrons and protons

Herrera, Rappelt, 24'



Brenner, Herrera, Ibarra, Kang, Scopel, Tomar, 22'

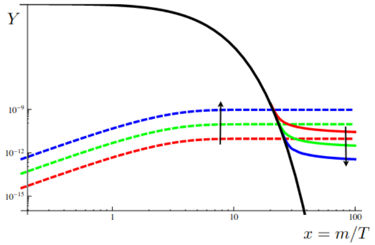


Relaxing these assumptions relaxes the limits...

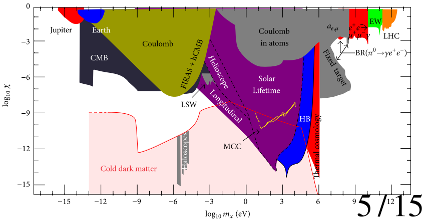
Light dark matter

- Phenomenologically viable, although neglected in "traditional" WIMP models → **Lee-Weinberg-Hut bound**.
- However, light scalar particles can account for thermal dark matter via exchange of **new fermions and light bosons** (**Boehm, Fayet, 03'**)
- **Asymmetric dark matter**: E.g 3 → 2 processes in the dark sector yield MeV thermal dark matter (**Hochberg, Kuflik, Volansky, Wacker, 14'**)
- Dark matter may also be produced non-thermally, **freezing-in** instead of freezing-out

Hall, Jedamzik, March-Russell, West '19

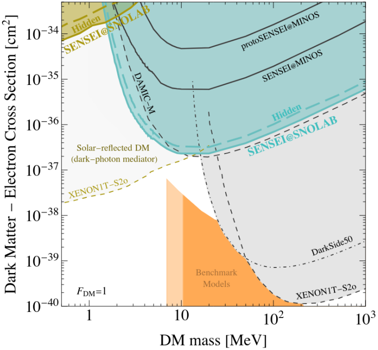


Jaeckel '13

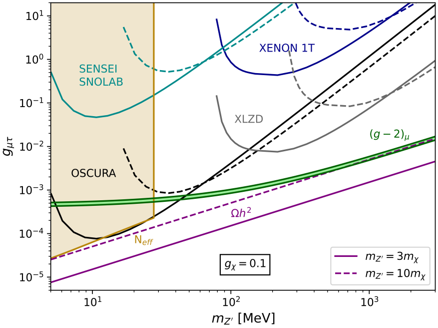


Direct detection of light dark matter through electron recoils

SENSEI, 23'



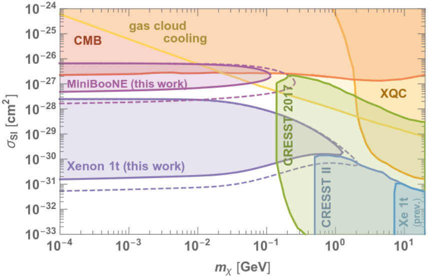
Figueroa, Herrera, Ochoa, 24'



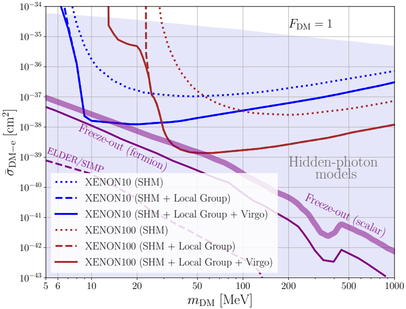
- Light dark matter may scatter off electrons in the atom directly
- Current experiments are orders of magnitude less stringent to electron recoils than to nuclear recoils
- Next generation experiments (**XLZD**, **OSCURA**) will be able to probe motivated models, but we are still far from that

Direct detection of high-speed light dark matter

Bringmann, Pospelov, 19'



Herrera, Ibarra, 21'



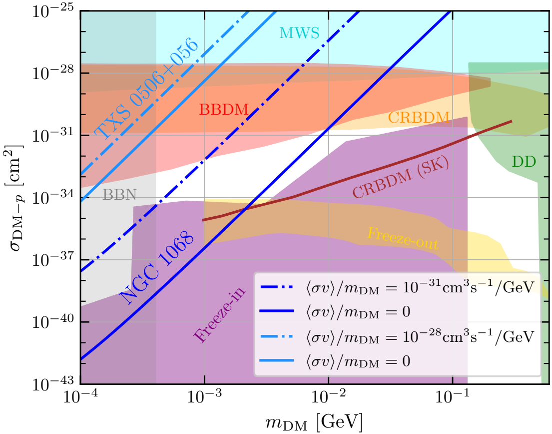
- A fraction of the dark matter flux on Earth may have larger velocities than the escape velocity of the Milky Way

  $\rightarrow$ Extended sensitivity to low-mass dark matter

- E.g: **Cosmic-ray boosted dark matter**, **non-galactic dark matter**, Boosted dark matter from annihilations/decays...

Indirect bounds on light dark matter

Herrera, Murase, 23'



- Cosmological and astrophysical observables constrain dark matter scattering with baryons

- Strongest bounds arise from **cosmic-ray cooling** in Active Galactic Nuclei, **cosmic-ray boosted dark matter** at Super-Kamiokande, and BBN

All these approaches constrain light dark matter with relatively large cross section, well above the current sensitivity of direct detection experiments at the GeV scale

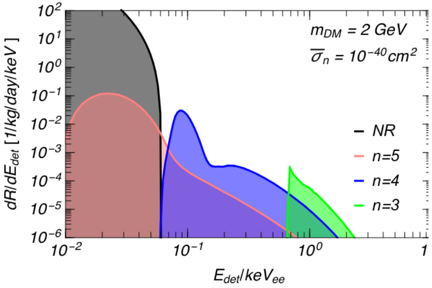
They are subject to astrophysical/cosmological uncertainties, or they only probe dark matter coupling to electrons

Alternative to constraint light dark matter with weak cross sections?

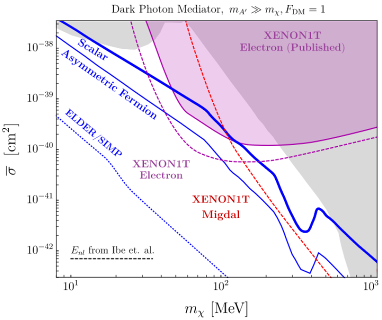
Make use of the Migdal effect

The Migdal effect in dark matter direct detection

Ibe, Nakano, Shoji, Suzuki, 17'



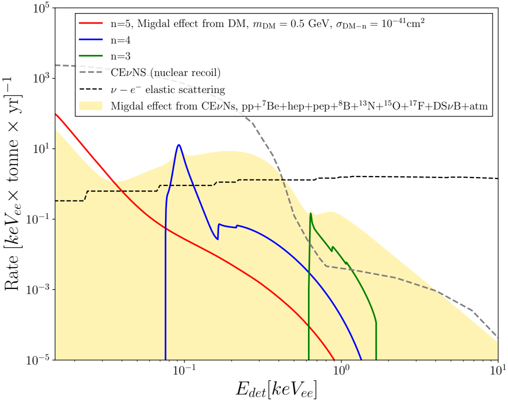
Baxter, Kahn, Krnajic, 17'



- The **electromagnetic** signal occurs at larger energy than the **nuclear** recoil signal
- Current experiments probe some **thermal** light dark matter models

Where is the neutrino floor in the parameter space of the Migdal (or electron recoil) dark matter signal?

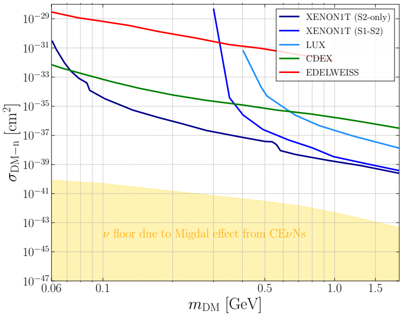
Herrera, 23’

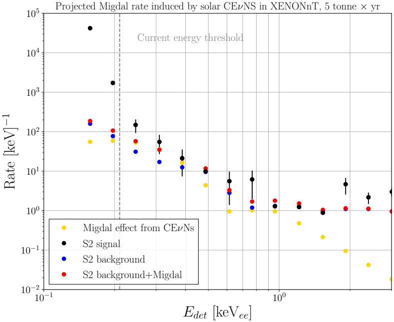


$$\frac{d\sigma_{\nu N-\nu N^* e^-}}{dE_R} = \frac{G_F^2 m_A}{4\pi} Q_V^2 \left(1 - \frac{m_A E_R}{2E_\nu^2}\right) \times \left|Z_{\rm ion}\ (E_{\rm er})\right|^2$$

- The **Migdal** signal from neutrinos can overcome the **nuclear** recoil signal and the **electron** scattering signal at certain energies

Herrera, 23’

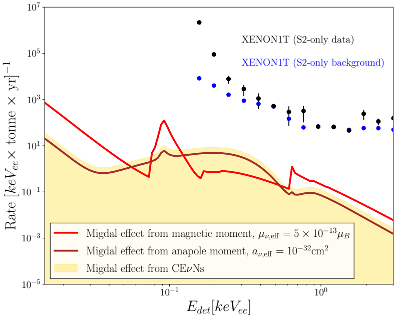


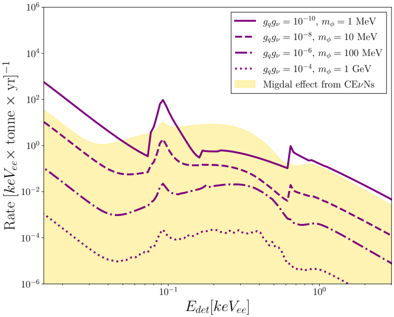


- The **neutrino floor** is ∼ 4 orders of magnitude away from current sensitivity to the Migdal effect from light dark matter
- The Migdal ionization signal might be **detectable** with 5 yr exposures at liquid xenon experiments and S2-like threshold and background
- However, this relies on being able to separate the nuclear recoil and electron ionization signal at energies of 0.1 – 1 keV

Migdal effect from neutrino BSM interactions

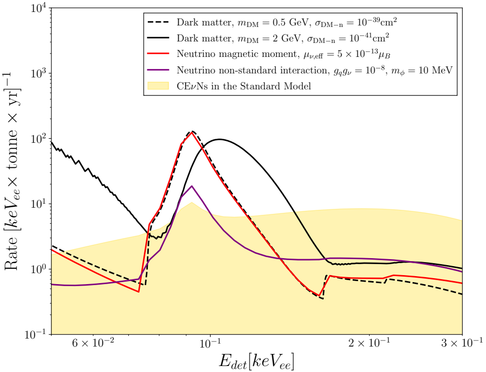
Herrera, 23'





- The **anapole moment** scattering rate has the same shape as the weak rate
- The **magnetic moment** interaction has an ionization rate with distinct shape, due to the enhancement of the cross section at small neutrino energy
- For new light mediators, the dominant rate arises from the pp chain, while for heavy mediators the $8B$ dominates, which smoothes out the peaks in the spectrum

Herrera, 23'



- New physics can induce a **distinct peak** in the ionization spectrum around 0.1 keV, arising from the ionization of $n = 4$ electrons by pp neutrinos, which is absent in the weak interaction spectrum
- It can be hard to discriminate among different models in most cases

Conclusions

- There is a neutrino floor for light dark matter searches induced by the Migdal effect from solar neutrinos
- The Migdal ionization signal from neutrinos can dominate over the nuclear recoil and electron scattering signal at certain energies
- We propose to search for peaks in the ionization spectrum of liquid xenon around ~ 0.1 keV, a clean signature that can provide hints of new physics from both dark matter and neutrinos

Thanks for your attention

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