ARC CENTRE OF EXCELLENCE FOR DARK MATTER PARTICLE PHYSICS

Early Career Research Workshop
Feb. 2021

Light Inelastic Dark Matter Detection

THE UNIVERSITY OF MELBOURNE

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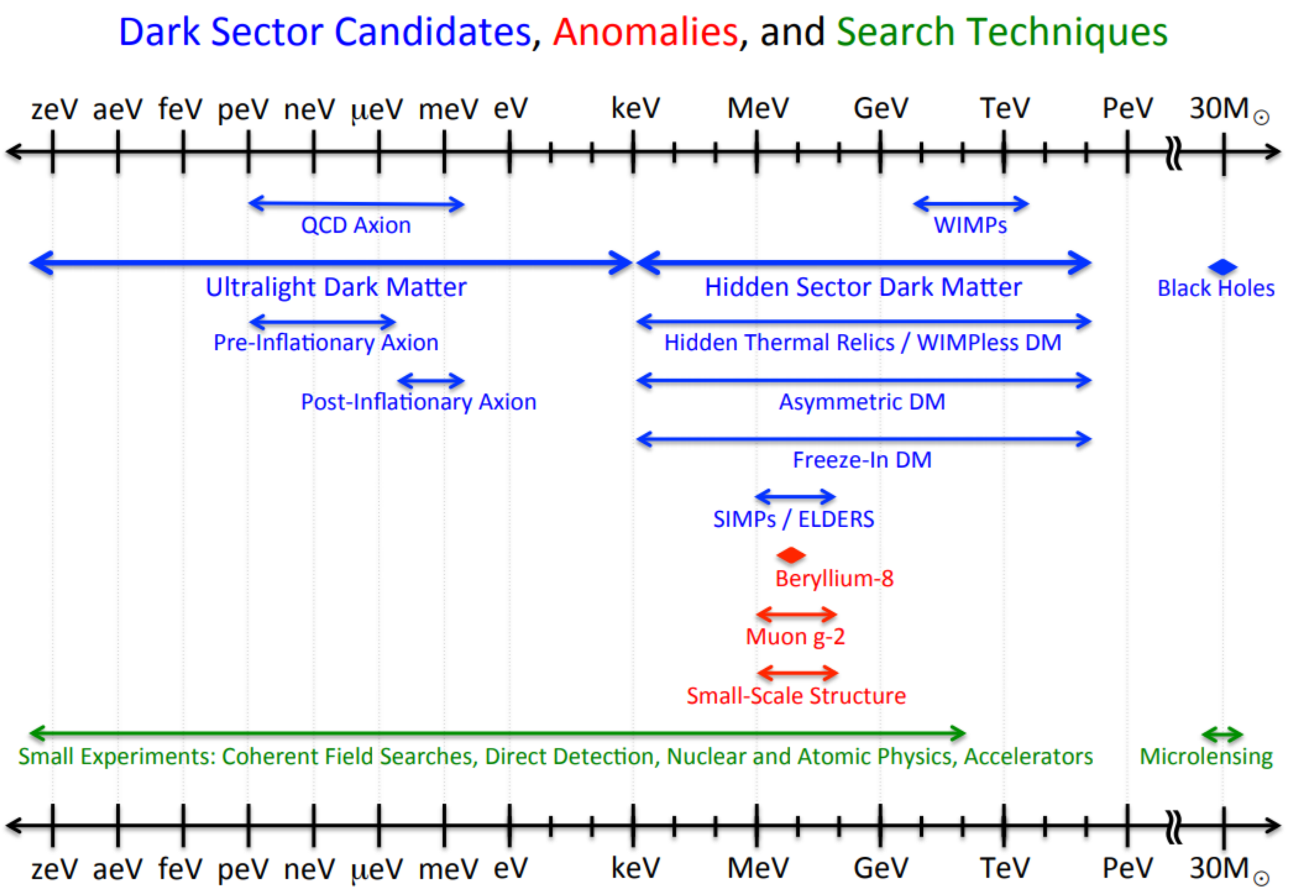
The mass/energy landscape

There has been a concerted effort to extend our horizons beyond WIMPs, notably in the direction of lighter masses.



From US Cosmic Visions arXiv:1707.04591

Methods for probing lighter dark matter
(an incomplete list)

Existing direct detection:

- Cosmic ray dark matter (arXiv:1810.10543)
- The Migdal effect (arXiv:1707.07258)
- Bremsstrahlung (arXiv:1607.01789)
- Electron scattering (arXiv:1703.00910)

Cosmology/Astrophysics/other

- DM-proton CMB (arXiv:1712.07133)
- Reverse direct detection (arXiv:1810.07705)
- Neutron star heating (arXiv:1704.01577)
- Boosted dark matter (arXiv:1405.7370)
- Colliders (arXiv:1903.01400)

Improved (traditional) direct detection:

- Diamond detectors (arXiv:1901.07569)
- Single charge germanium (arXiv:1804.10697)
- Single charge xenon (e.g. ALBECA)
- Helium detectors (arXiv:1302.0534)

New Ideas

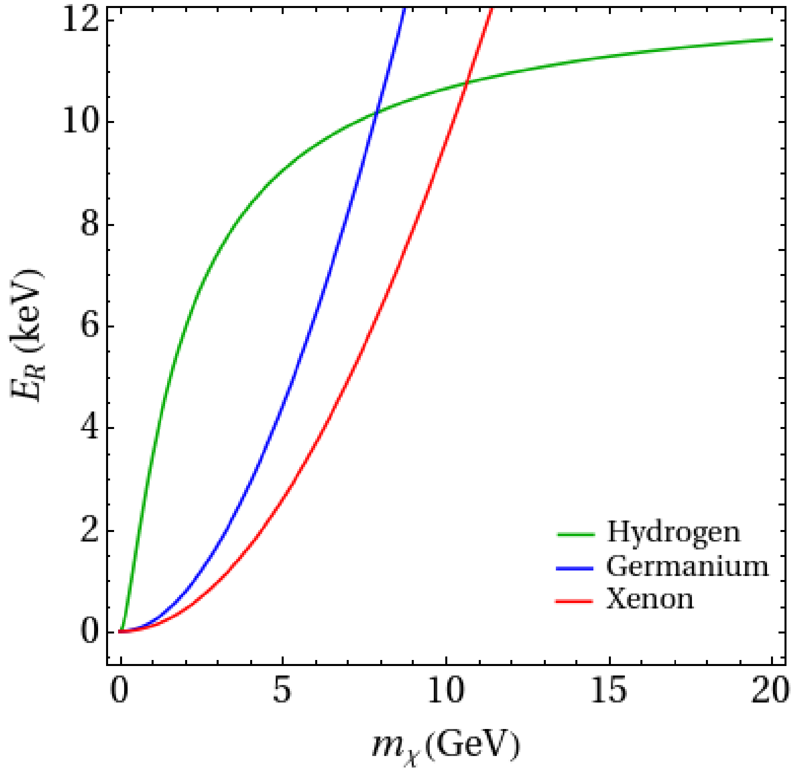
- Plasmons (arXiv:2002.06937)
- Multi-exciton/rotons in LHe (arXiv:1611.06228)
- Absorption (arXiv:1608.01994)
- Chemical bond breaking (arXiv:1608.02940)
- Spin-flip avalanche (arXiv:1701.06566)

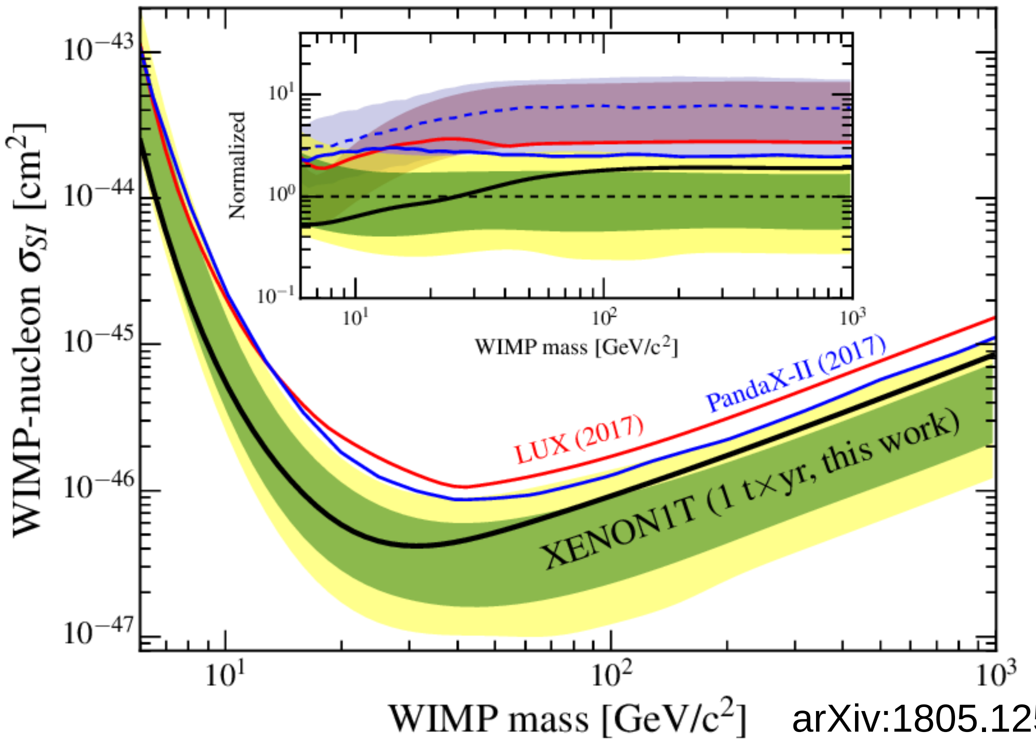
Direct detection's kinematic problem

- Light dark matter does not pack much of a punch:

$$E_{R_{\max}} = \frac{2\mu_T^2}{m_T} v_{\max}^2$$

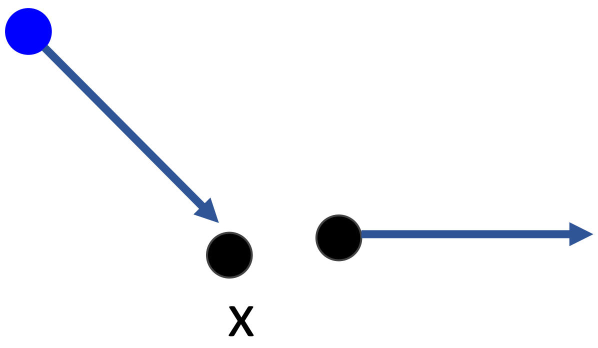
take v_{max} = 760 km/s



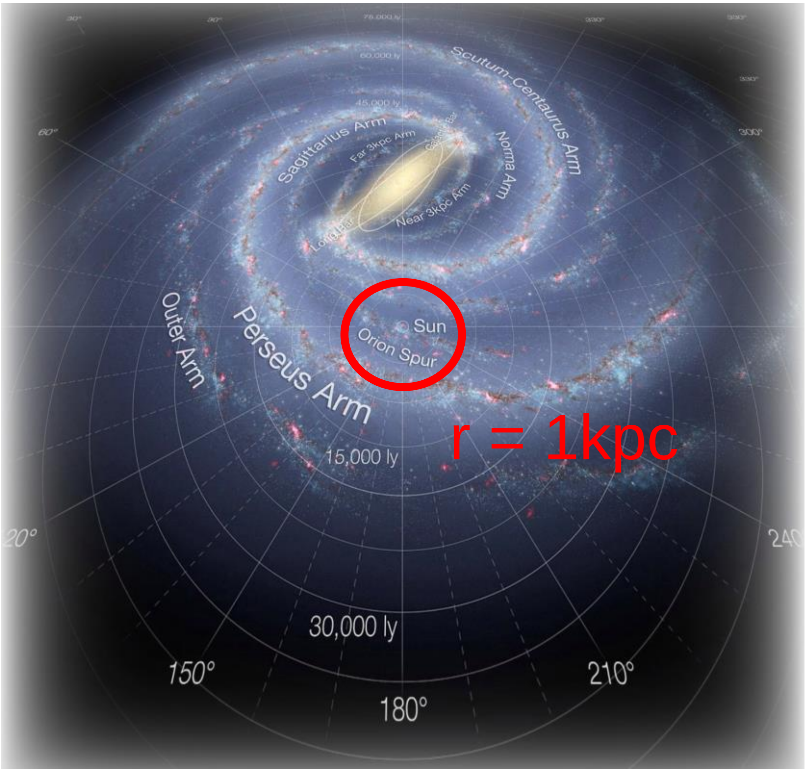


arXiv:1805.12562

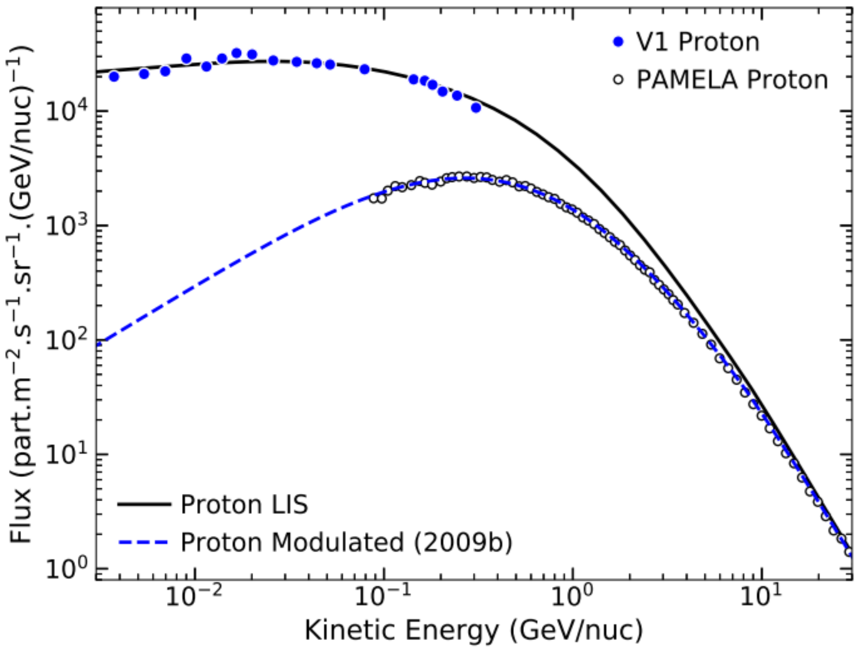
Cosmic-ray dark matter



- A local population of CRDM will be created through collisions with the LIS



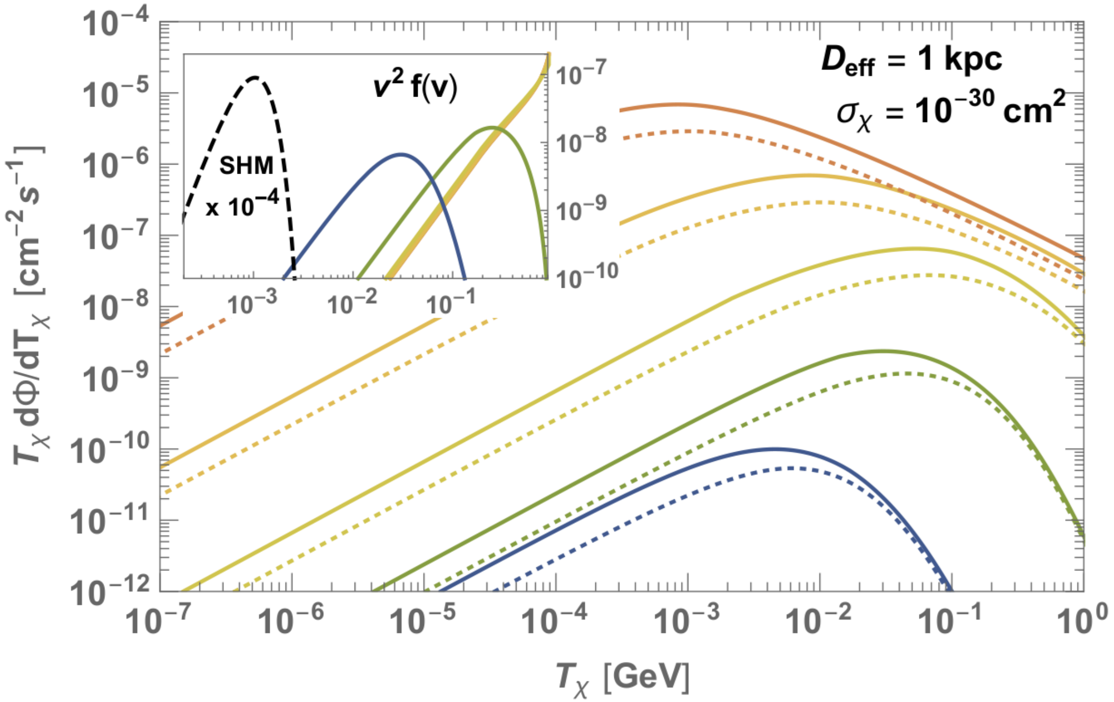
Local Interstellar Spectrum (LIS)



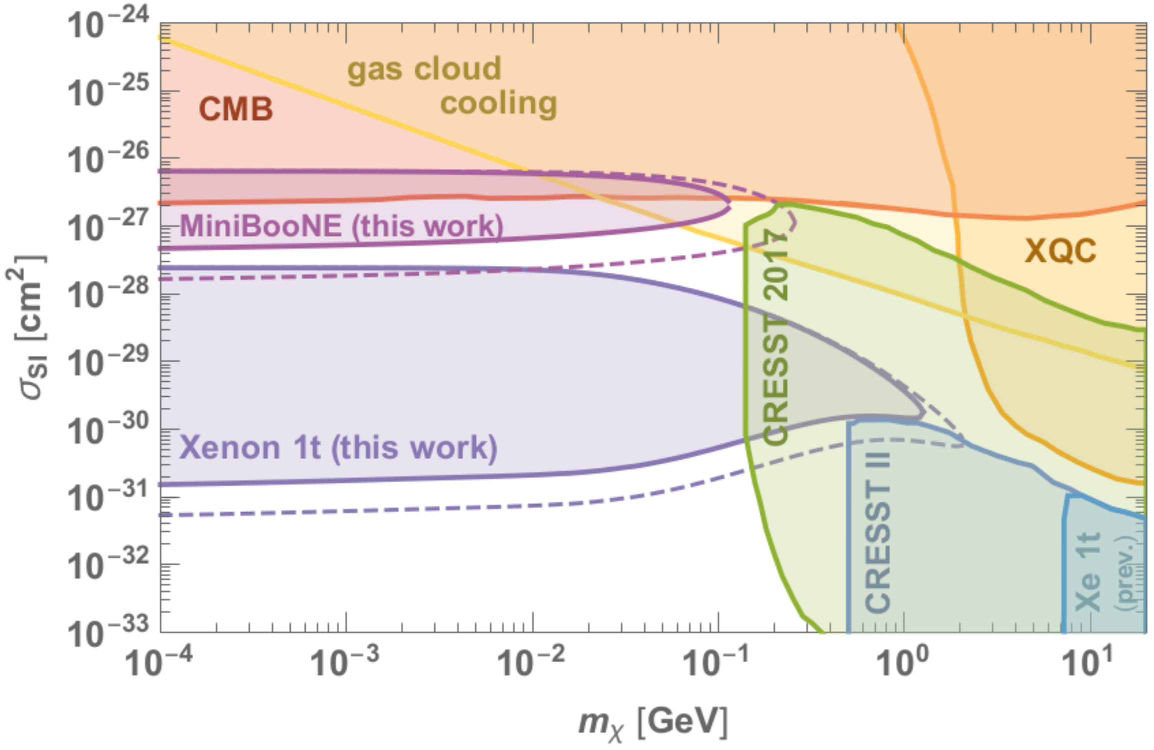
D. Bisschoff et al. arXiv:1902.10438

Cosmic-ray dark matter

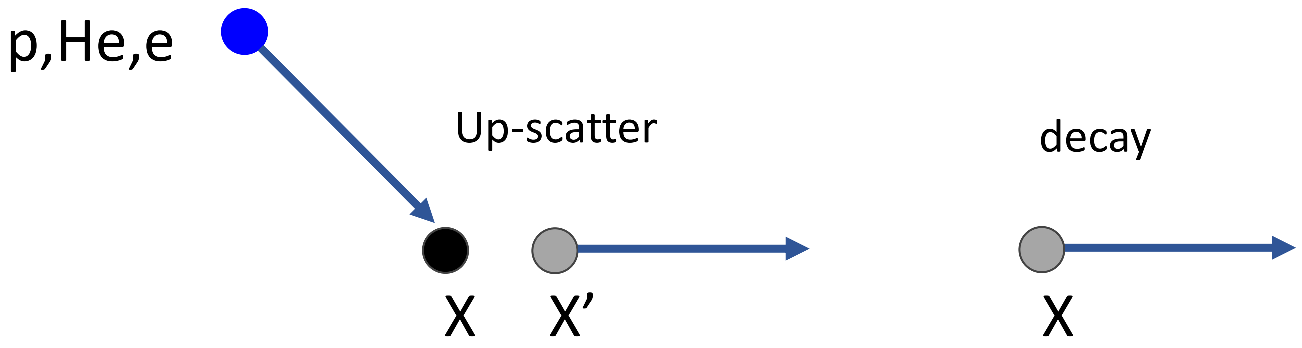
Spectrum of CRDM

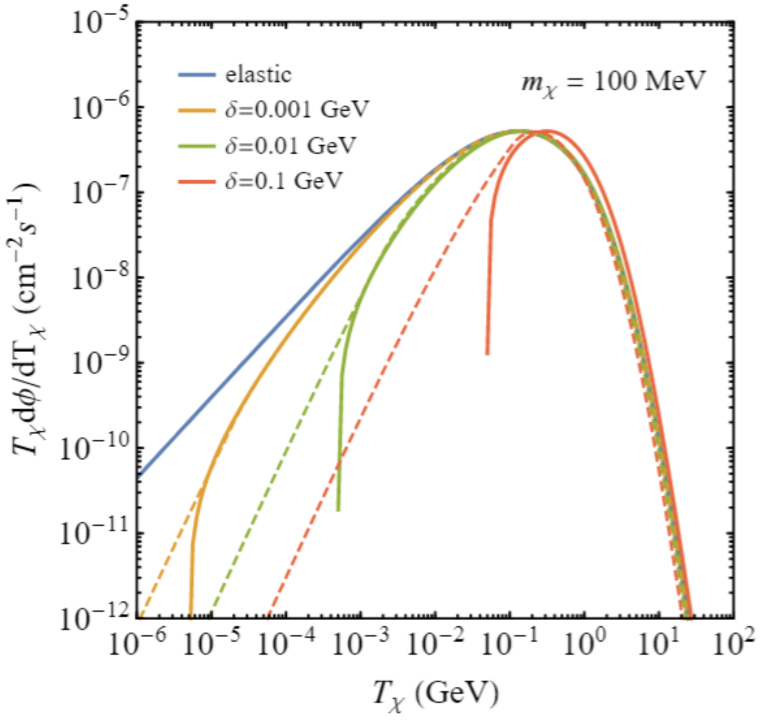


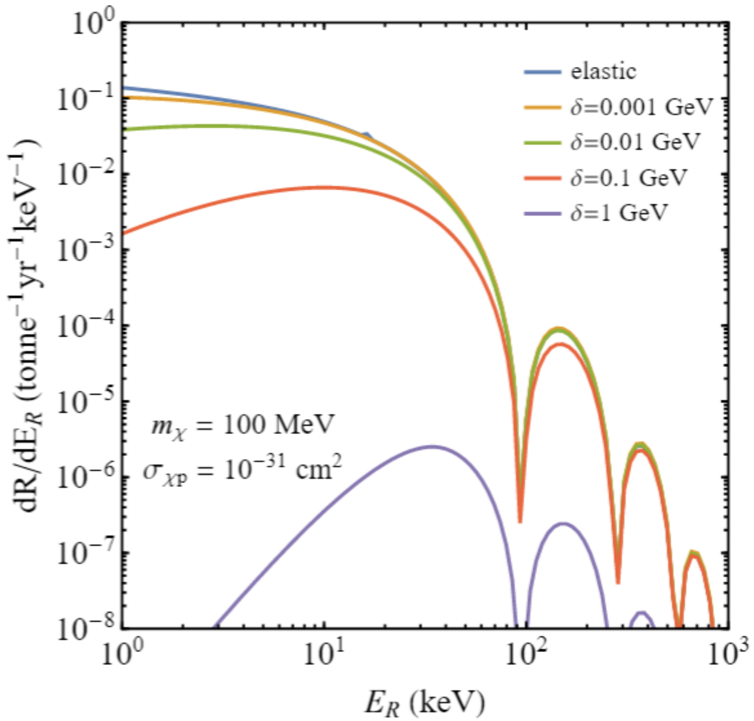
Spin independent bounds

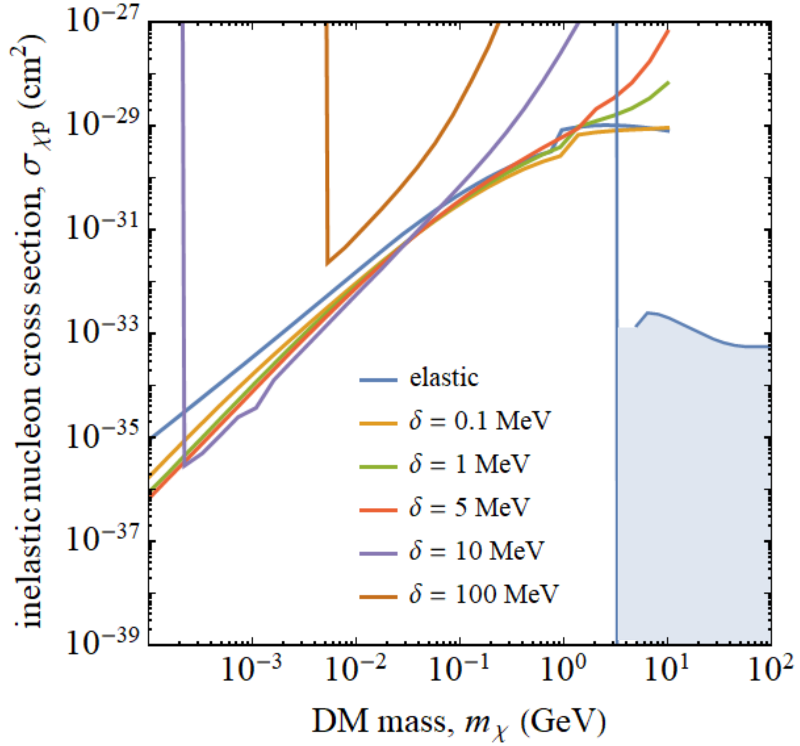


Inelastic cosmic-ray dark matter







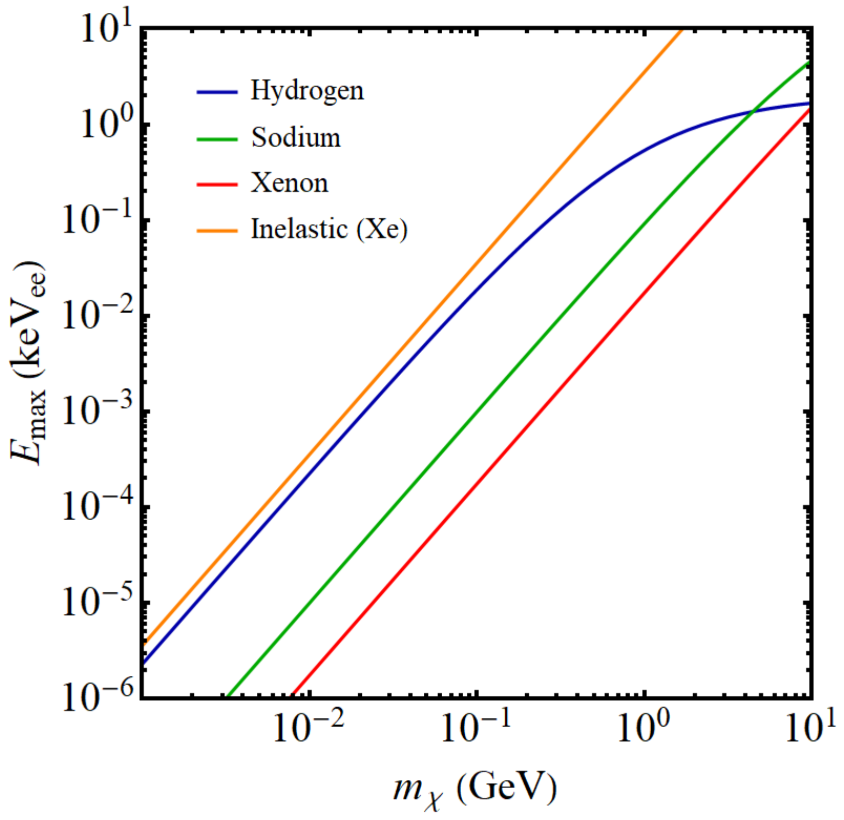


Why the Migdal channel?

1. Kinematic advantage:

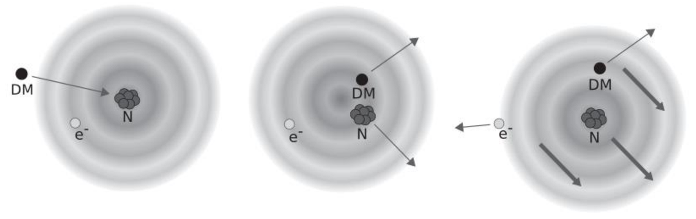
Nuclear: $$E_{R_{\max}} = \frac{2\mu_T^2}{m_T} v_{\max}^2$$

Electronic (Migdal/Decay): $$E_{EM_{\max}} = \frac{\mu_T}{2} v_{\max}^2$$

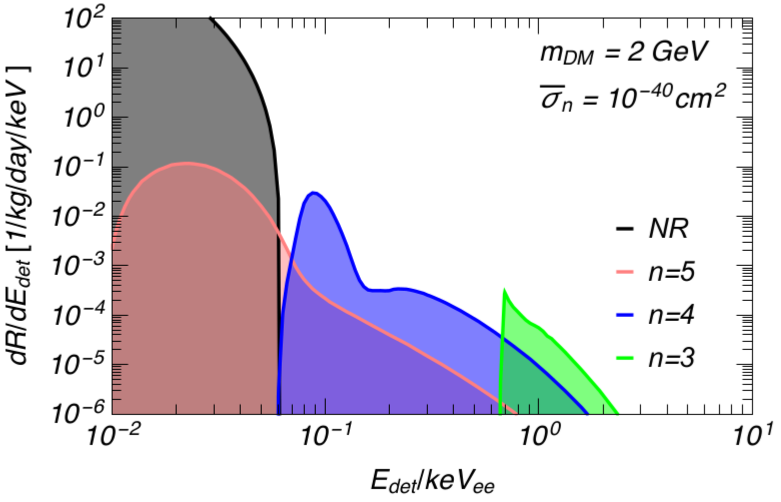


2. Electronic recoil energy isn't quenched (nuclear recoils result in more heating)

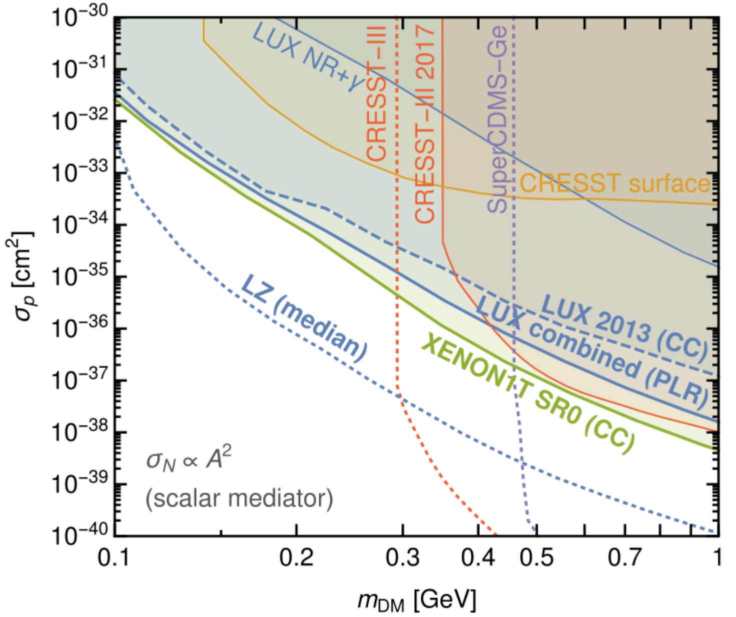
Migdal rates and Limits



Dolan et al.



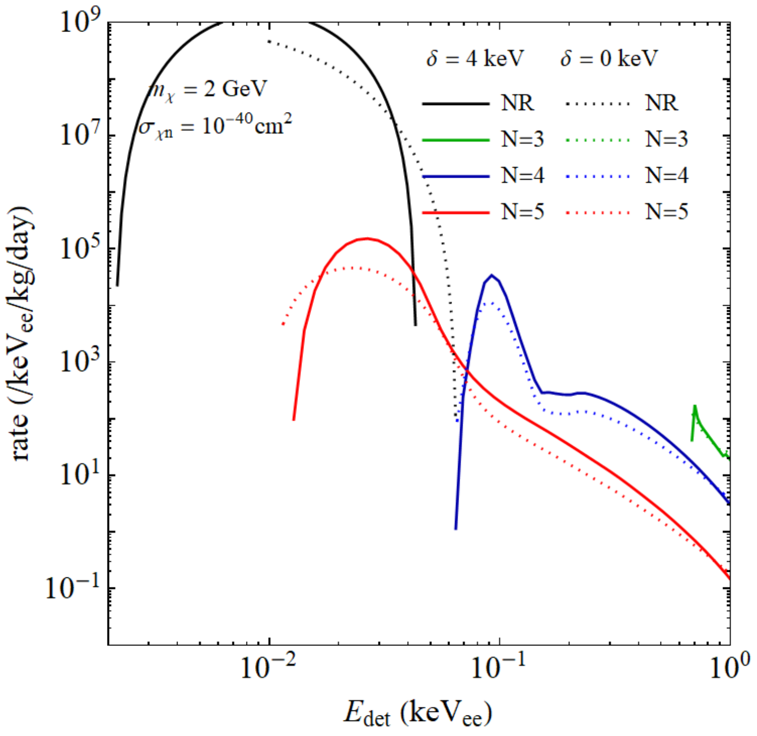
M. Ibe, W. Nakano, Y. Shoji, and K. Suzuki, arxiv:1707.07258



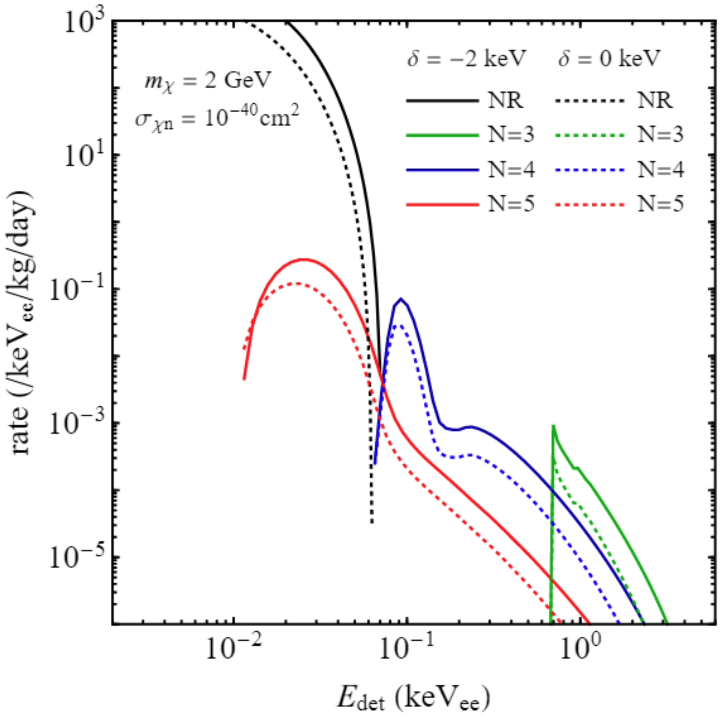
M. J. Dolan, F. Kahlhoefer, and C. McCabe, (PRL)
arXiv:1711.09906

The Migdal effect with inelastic DM

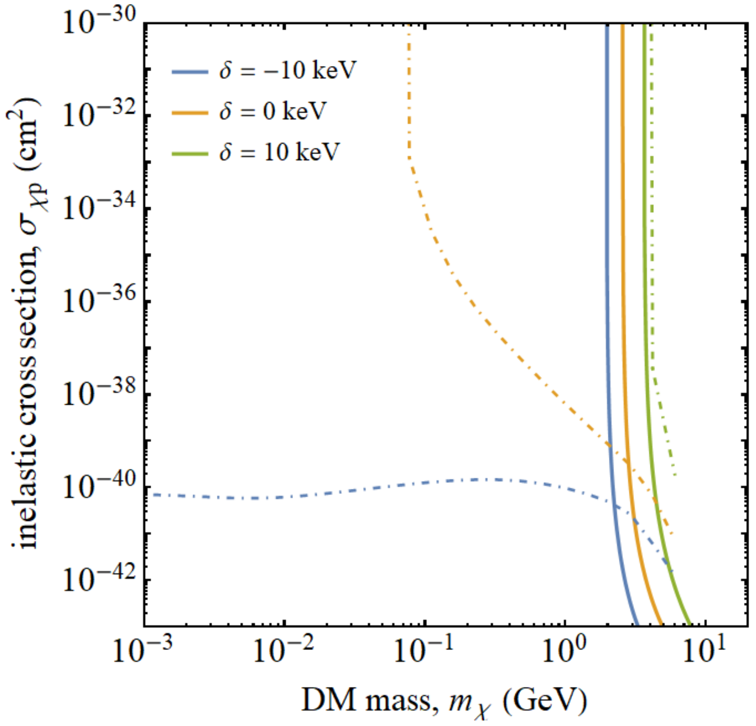
endothermic



exothermic

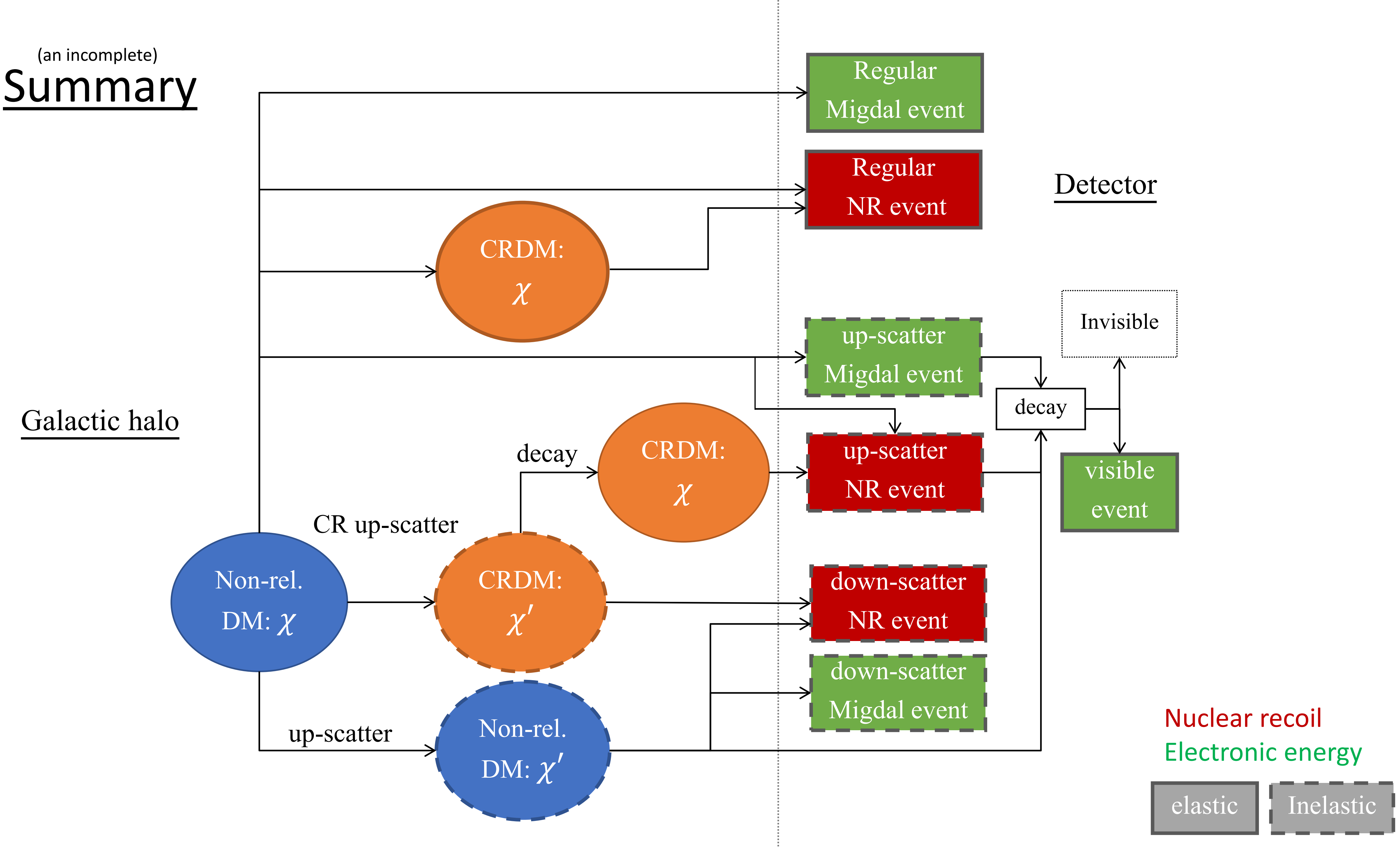


Xe1t bounds



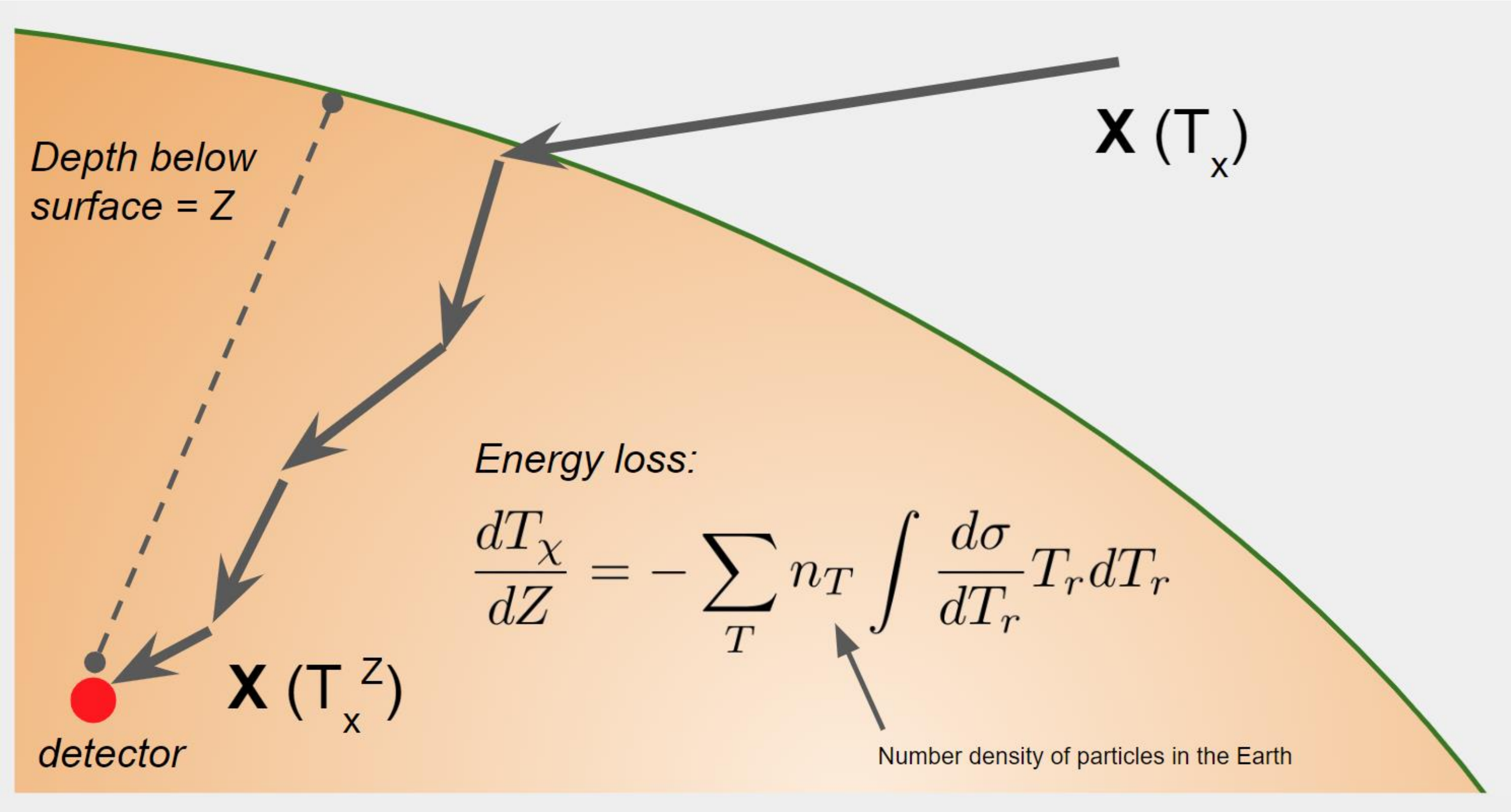
(an incomplete)

Summary



Attenuation of dark matter

- For the relevant cross sections we must consider the effects of attenuation by overburden (see, for example, Starkman et al. PRD 1990)
- Dark matter loses energy as it collides with matter:



See more recent treatments:
Kouvaris (arXiv:1802.04764) and
Hooper (arXiv:1802.03025)

Attenuation of CRDM

- Now we must integrate the energy loss equation numerically

$$\frac{dT_\chi}{dx} = -\sum_T n_T \int \frac{d\sigma}{dT_r} T_r dT_r$$

- Assume that above 1 GeV inelastic scattering dominates and attenuates all CRDM