Cosmic-ray-boosted dark matter in direct detection and neutrino experiments

Richard Diurba[a], Helena Kolešová[b], Gailyn Monroe[b]

[a]University of Bern, [b]University of Stavanger

Cosmic-ray boosted dark matter (CRDM)

- Direct detection experiments are blind to sub-GeV halo dark matter interacting with nucleons ($v \lesssim 540\,\mathrm{km/s}$ ⇒ elastic scattering with heavy nuclei in the detector dominant and light dark matter doesn't have enough kinetic energy to produce observable recoil)
- Light dark matter can be still detected if boosted by interactions with galactic cosmic rays! [1]

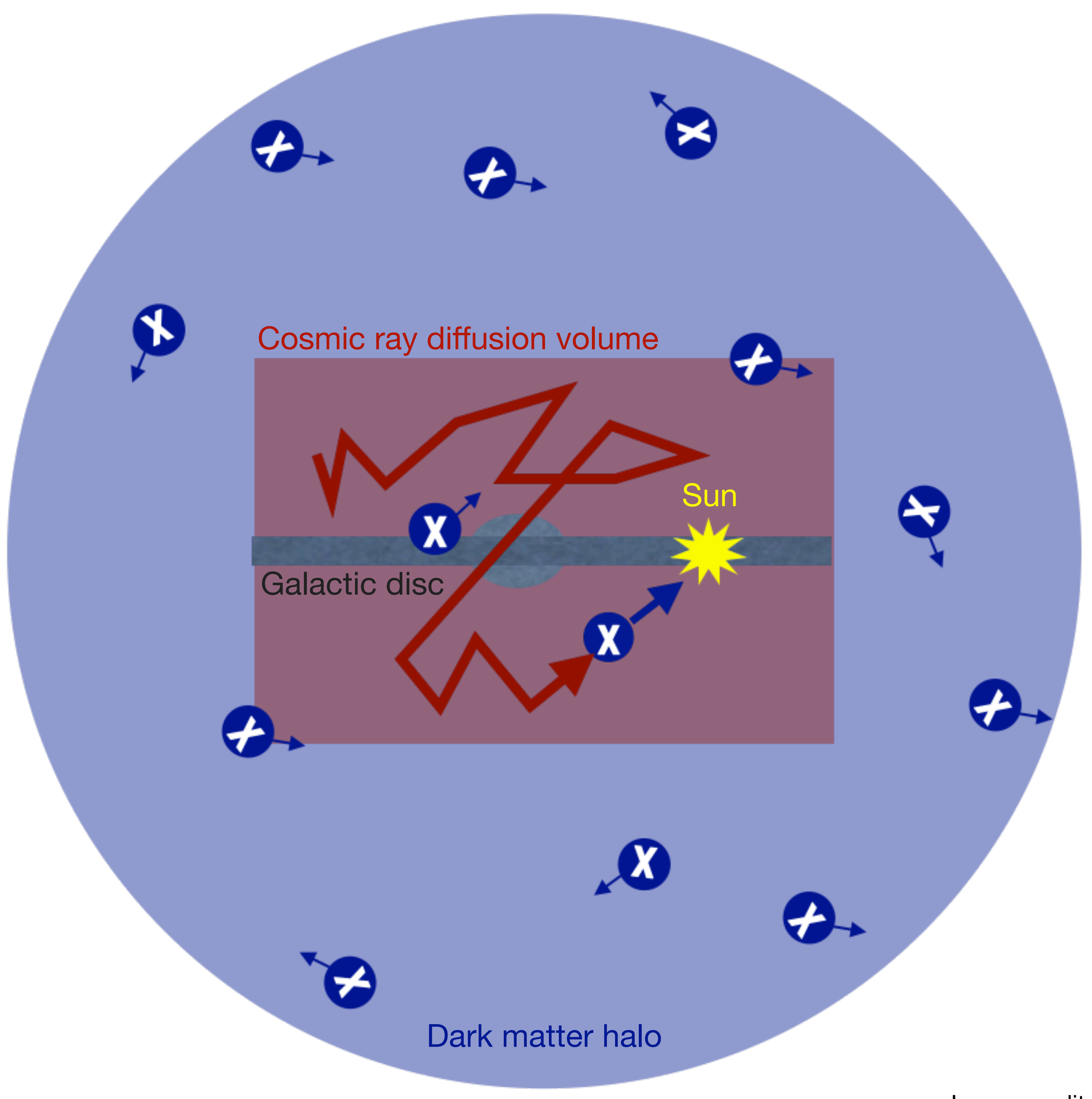


Image credit: Torsten Bringmann

Scattering of dark matter on nuclei

- Relativistic dark matter (similarly to neutrinos) would undergo also inelastic scattering with nuclei. For increasing dark matter kinetic energy and momentum transfer, different processes appear [3, 4, 5]:
  - Quasi-elastic scattering: scattering on individual nucleons
  - Excitation of hadronic resonances like Δ that further decays to nucleons and pions
  - Deep inelastic scattering: scattering on quarks and gluons

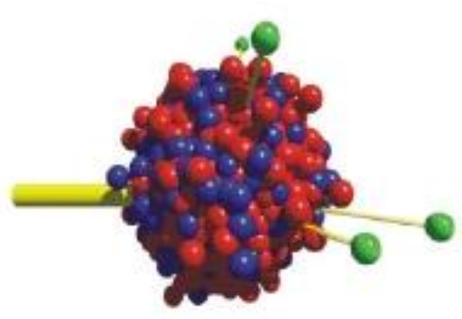


Image credit: GiBUU

- Need for numerical codes like GiBUU [4] (for neutrino-nucleus scattering) or GENIE [5] (also for dark matter)
- Benchmark model for interactions of dark matter χ with quarks implemented using GENIE [5]: mediator = heavy vector boson Z'

$$\mathcal{L} \ni g_{Z'} Z'_\mu \left(Q_\chi \overline{\chi} \gamma^\mu \chi + \sum_{q=u,d,s,c} Q_q \overline{q} \gamma^\mu q \right)$$

⇒ "Spin independent" elastic scattering of non-relativistic dark matter with nuclei. Dark matter-proton cross section in highly non-relativistic limit:

$$\sigma_{\mathrm{SI}}^{\mathrm{NR}} = \frac{g_{Z'}^4 (3Q_q)^2 Q_\chi^2 m_\chi^2 m_p^2}{\pi m_{Z'}^4 (m_\chi + m_p)^2},$$

cross sections for inelastic scattering calculated numerically

References

[1] T. Bringmann and M. Pospelov, "Novel direct detection constraints on light dark matter", Phys. Rev. Lett. **122** no. 17, (2019) 171801, arXiv:1810.10543 [hep-ph].

[2] XENON, E. Aprile *et al.*, "Dark Matter Search Results from a One Ton-Year Exposure of XENON1T", Phys. Rev. Lett. **121** no. 11, (2018) 111302, arXiv:1805.12562 [astro-ph.CO].

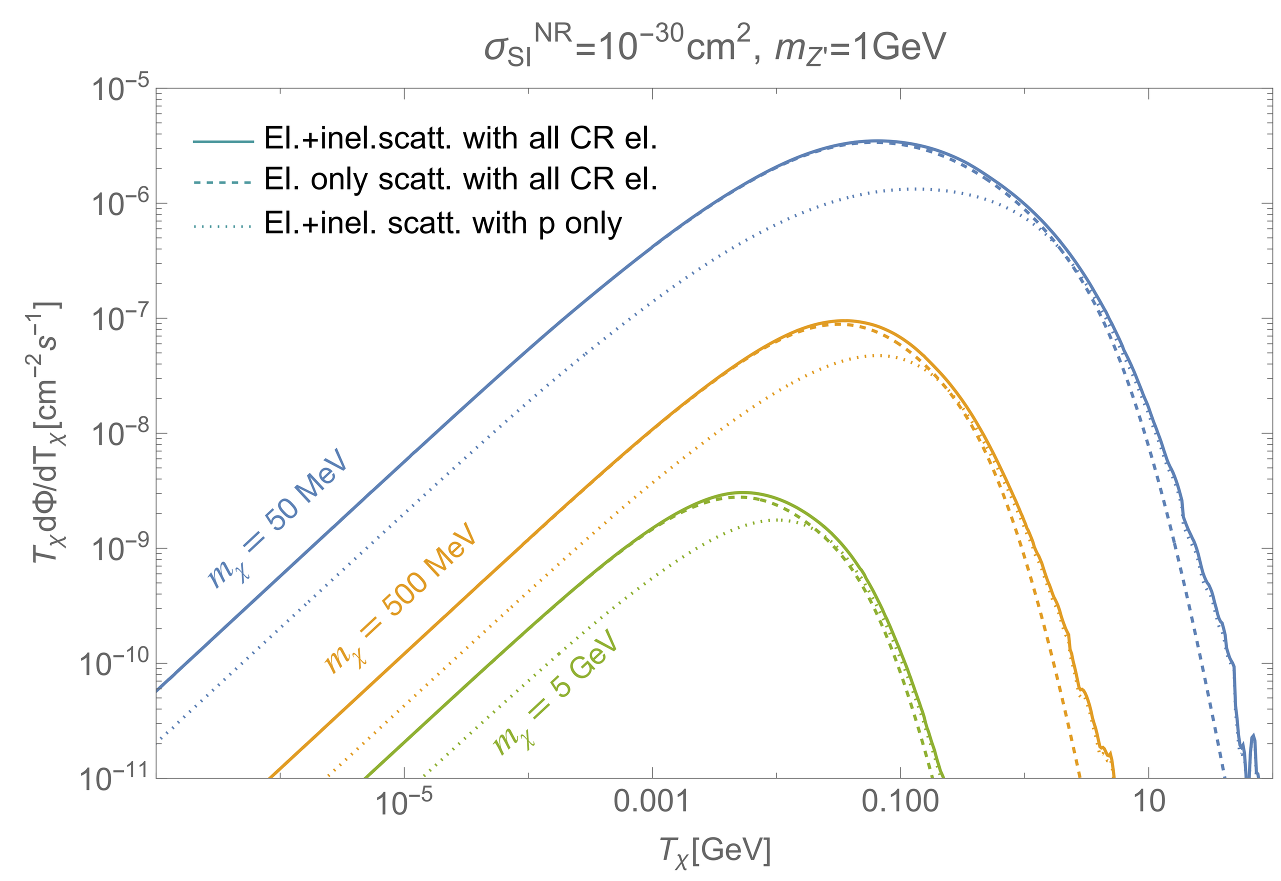
[3] J. Alvey, T. Bringmann, and H. Kolesova, "No room to hide: implications of cosmic-ray upscattering for GeV-scale dark matter", JHEP **01** (2023) 123, arXiv:2209.03360 [hep-ph].

[4] O. Buss *et al.*, "Transport-theoretical Description of Nuclear Reactions", Phys. Rept. **512** (2012) 1–124, arXiv:1106.1344 [hep-ph].

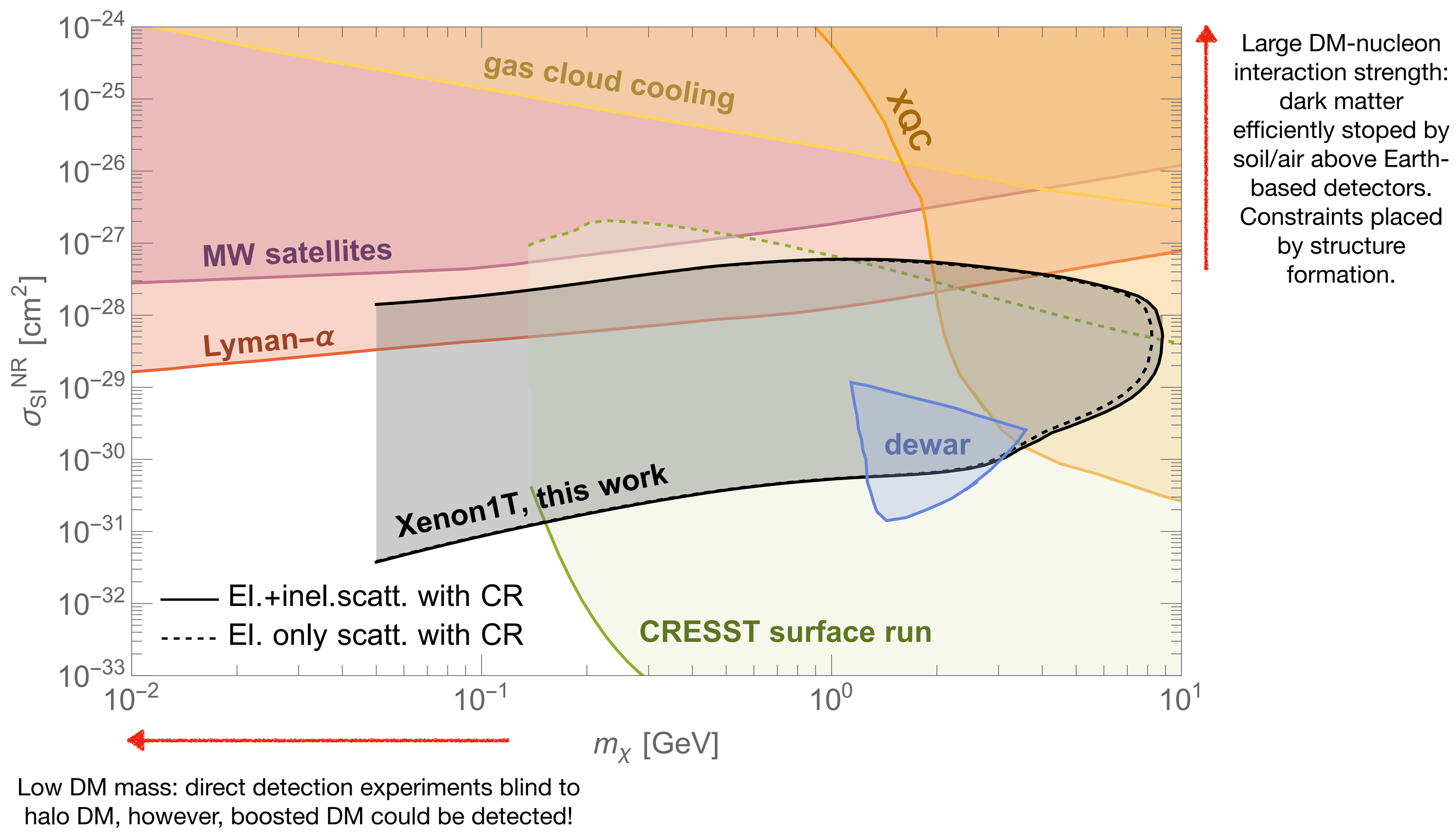
[5] J. Berger, "A Module for Boosted Dark Matter Event Generation in GENIE", arXiv:1812.05616 [hep-ph].

Results

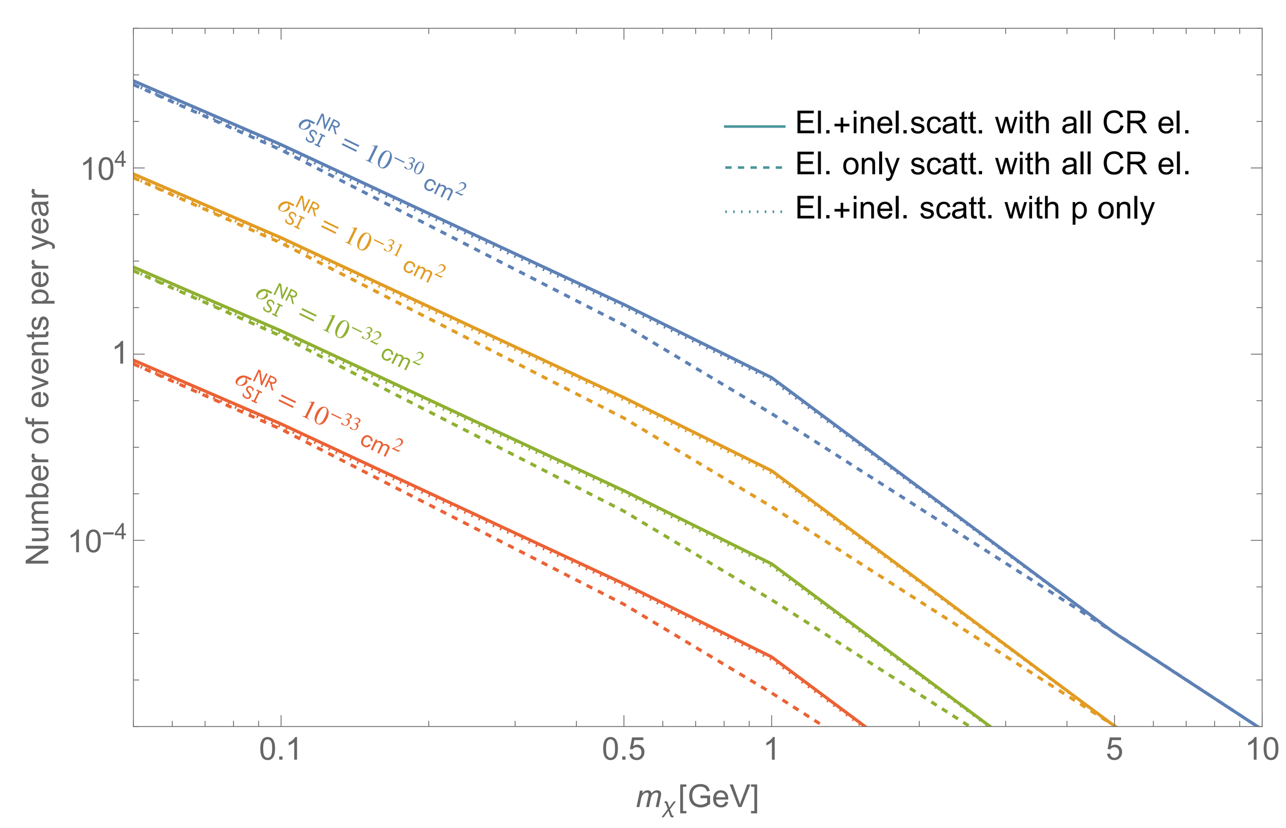
- Scattering of halo dark matter with cosmic-ray nuclei (the most abundant elements H, He, C and O included) results into flux of boosted dark matter coming to Earth.
- Inclusion of inelastic scattering increases the flux at large kinetic energies T_χ that comes dominantly from scattering with cosmic-ray protons.



- Exclusion limits by Xenon1T experiment [2] are not substantially affected by the increase of CRDM flux due to inelastic scattering since direct detection experiments are more sensitive to dark matter with lower T_χ



- Number of events that might be seen DUNE is increased when inelastic scattering is included. It turns out that mainly the boosting by cosmic-ray protons is important for detectability in DUNE.



- Outlook: exclusion limits that might be placed by DUNE. Estimate of the atmospheric neutrino background needed!

Acknowledgements

H.K. is supported by the Research Council of Norway under the FRIPRO Young Research Talent grant no. 335388.