Strongly-interacting dark matter and CNO neutrinos with low-threshold detectors

Based on:

J. H. Davis, Phys.Rev.Lett. 119 (2017) 211302
D. G. Cerdeño, J. H. Davis, M. Fairbairn and A. C. Vincent, arXiv:1712.06522

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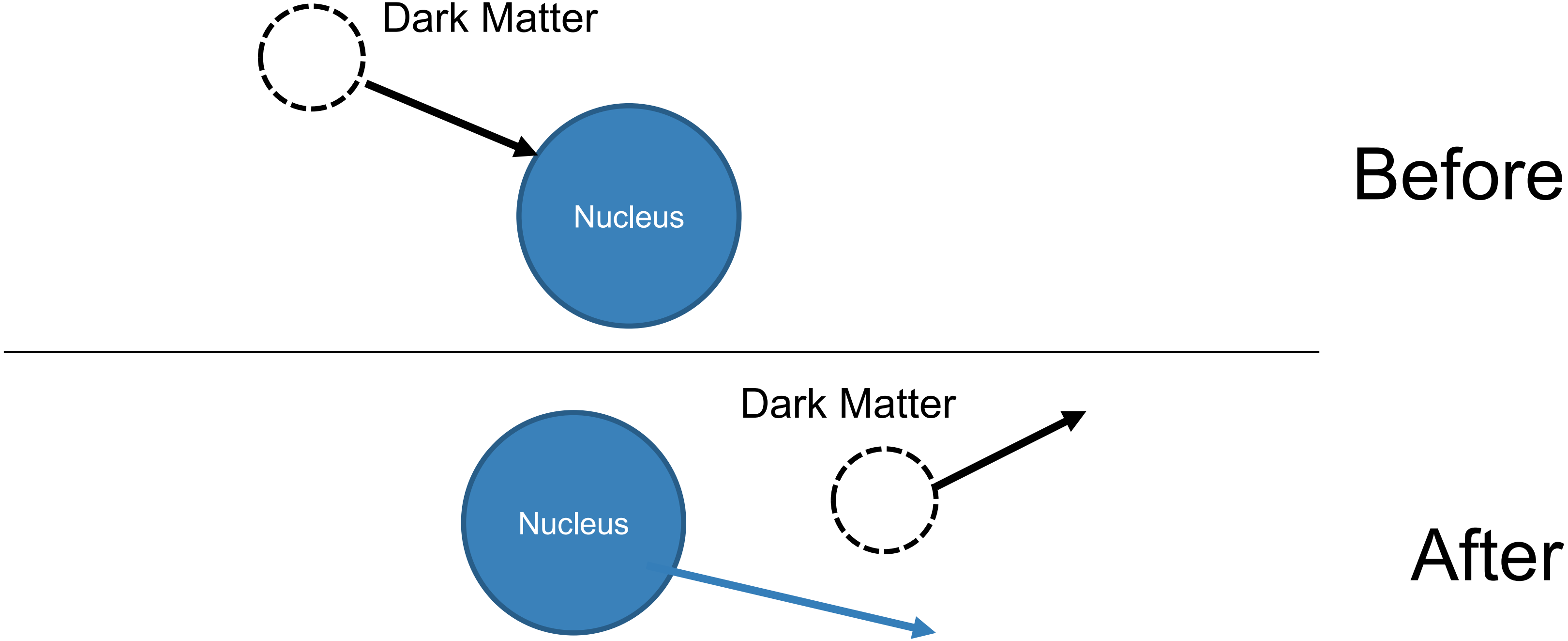
DMUK Meeting – Bristol - 17 January 2018

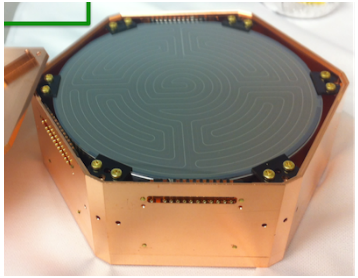
Direct detection



Direct detection experiments

Cryogenic Detectors

SuperCDMS
Looking for
ionization
and phonons



CRESST
Looking for
tiny temperature
changes

Liquid Noble Detectors

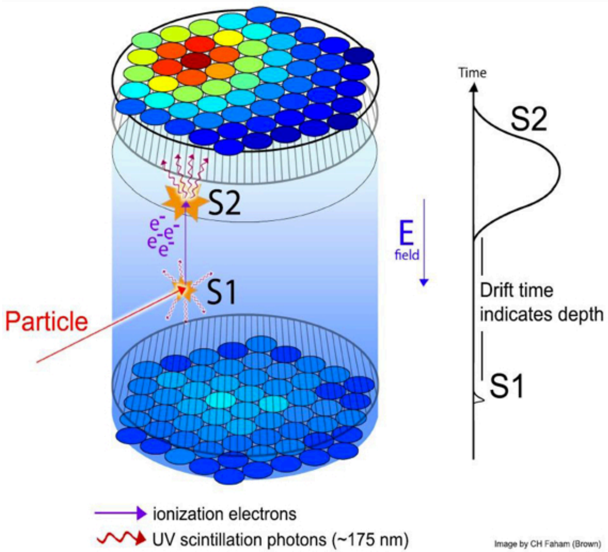
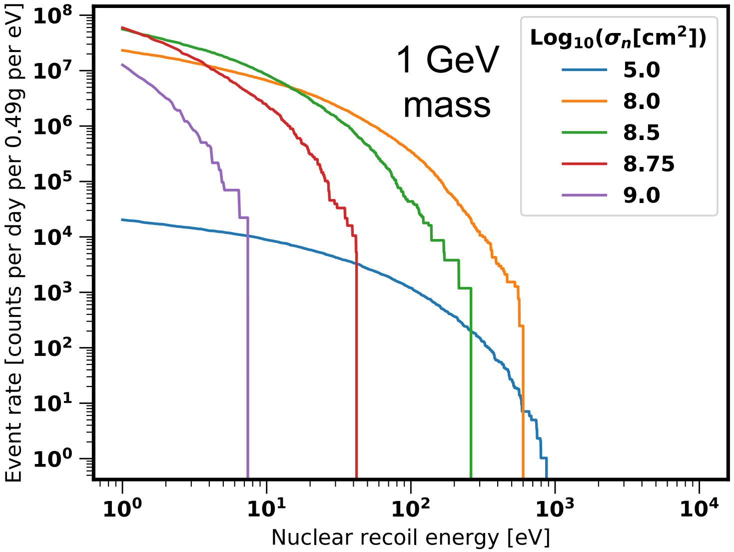
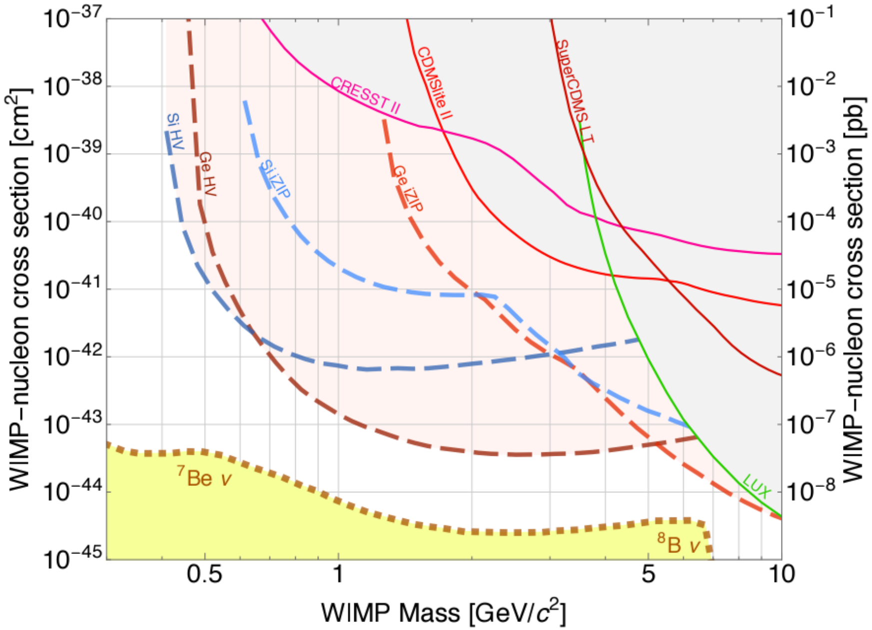


Image by CH Faham (Brown)

Dark matter with low-threshold detectors

Detectors which are sensitive to energies below a keV can detect sub-GeV mass dark matter, and more exotic models too.

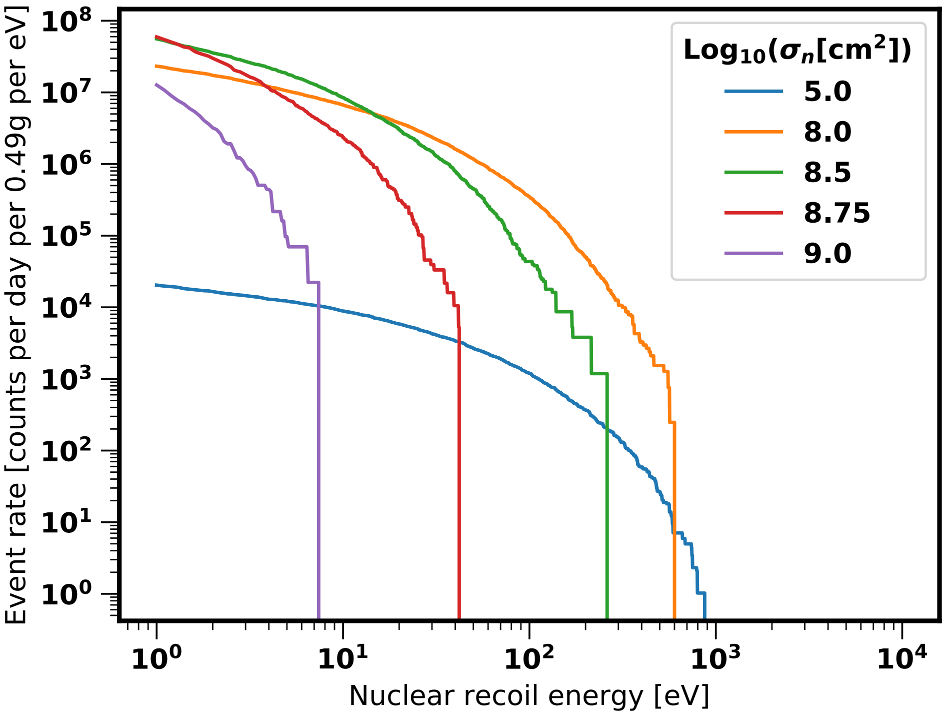




SuperCDMS-SNOLAB, arXiv:1610.00006

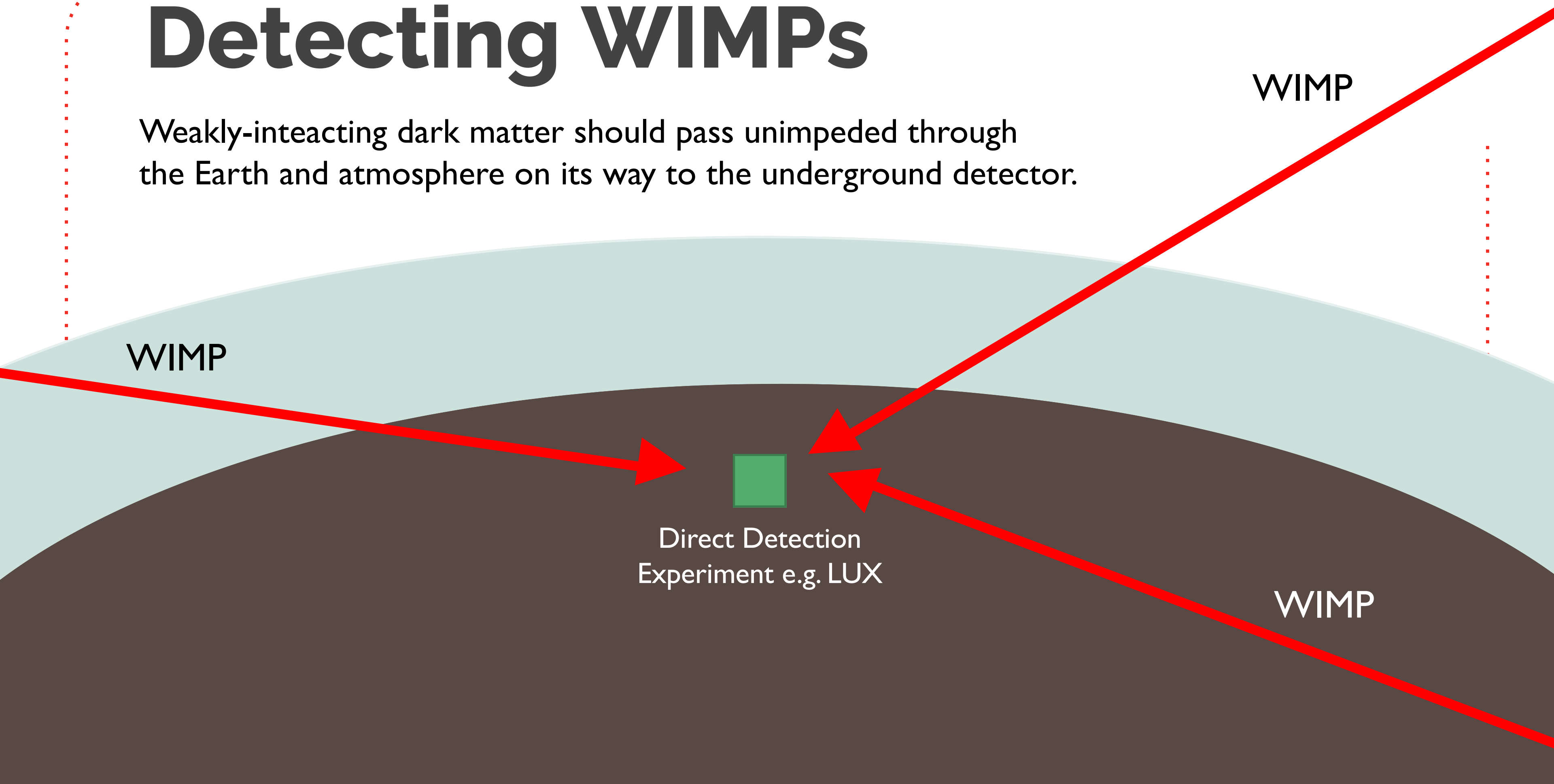
Strongly-interacting dark matter

- Increasing the DM-nucleon cross section leads to a larger expected recoil rate, until the cross section enters the SIMP-regime.
- Beyond this point the SIMPs lose energy due to interactions in the Earth or atmosphere, leading to lower-energy recoils in the detector.
- Could be dark atoms (astro-ph/0406355) or other composite states with e.g. a magnetic moment (arXiv;1201.4858).



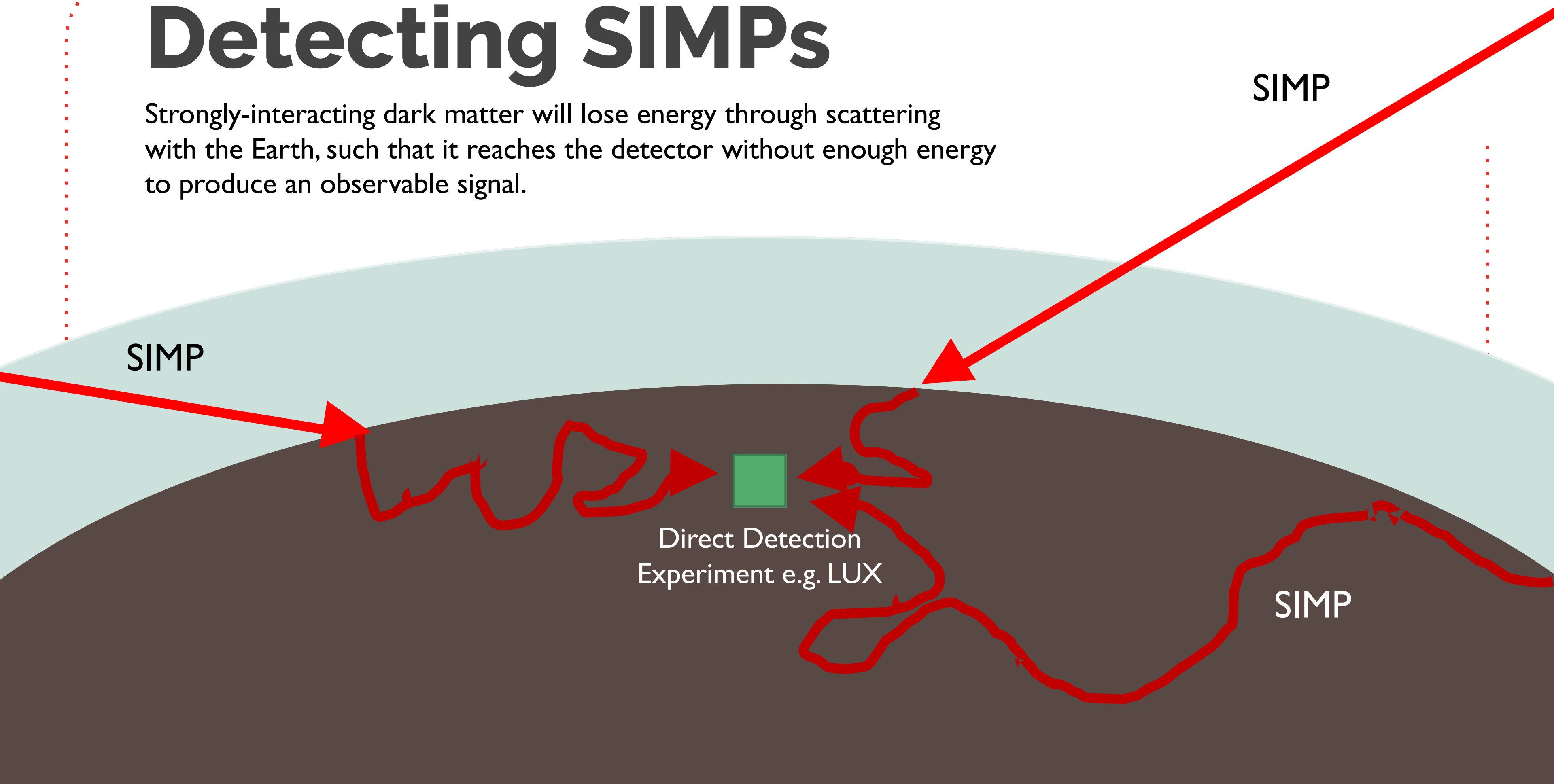
Detecting WIMPs

Weakly-inteacting dark matter should pass unimpeded through the Earth and atmosphere on its way to the underground detector.



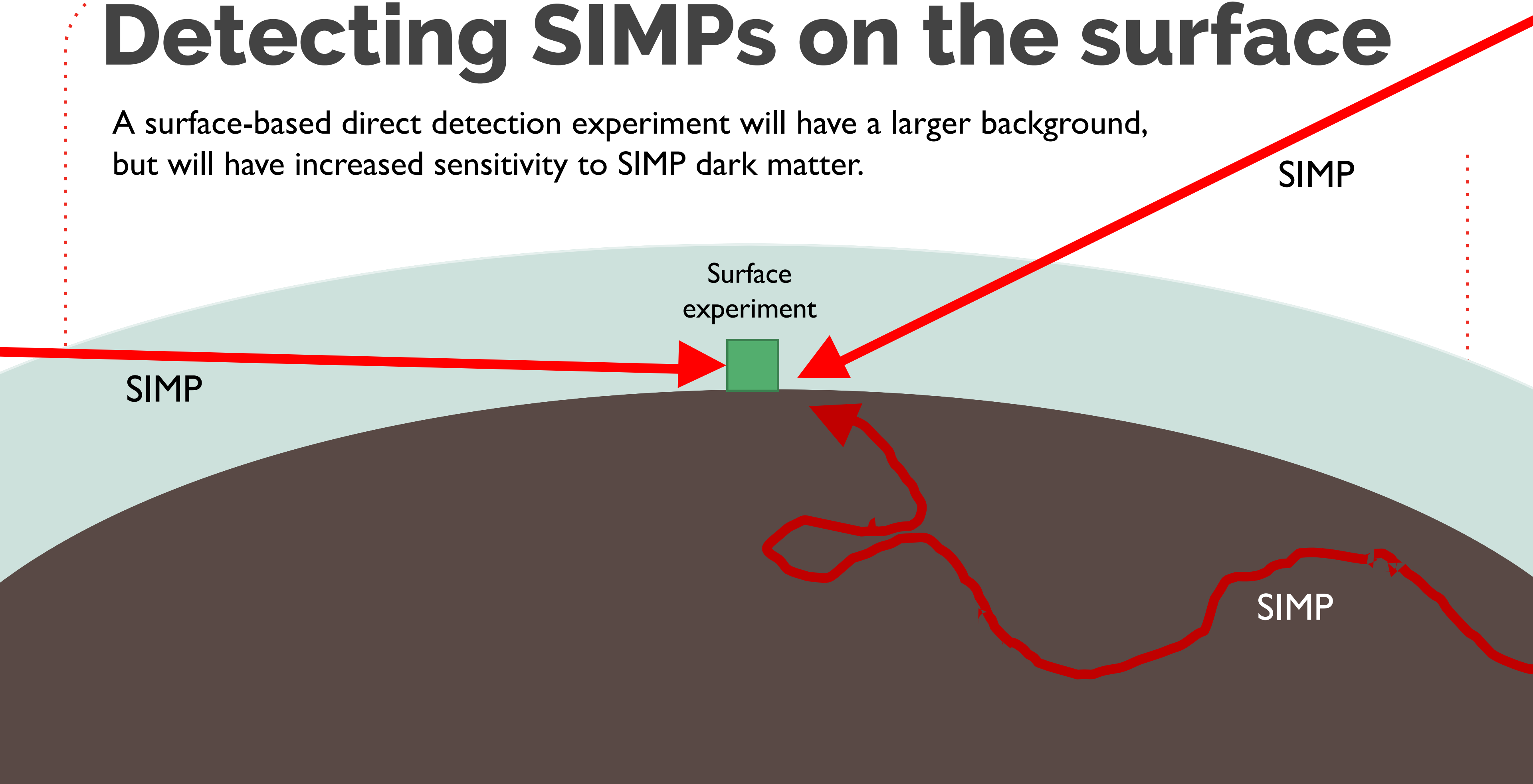
Detecting SIMPs

Strongly-interacting dark matter will lose energy through scattering with the Earth, such that it reaches the detector without enough energy to produce an observable signal.



Detecting SIMPs on the surface

A surface-based direct detection experiment will have a larger background, but will have increased sensitivity to SIMP dark matter.

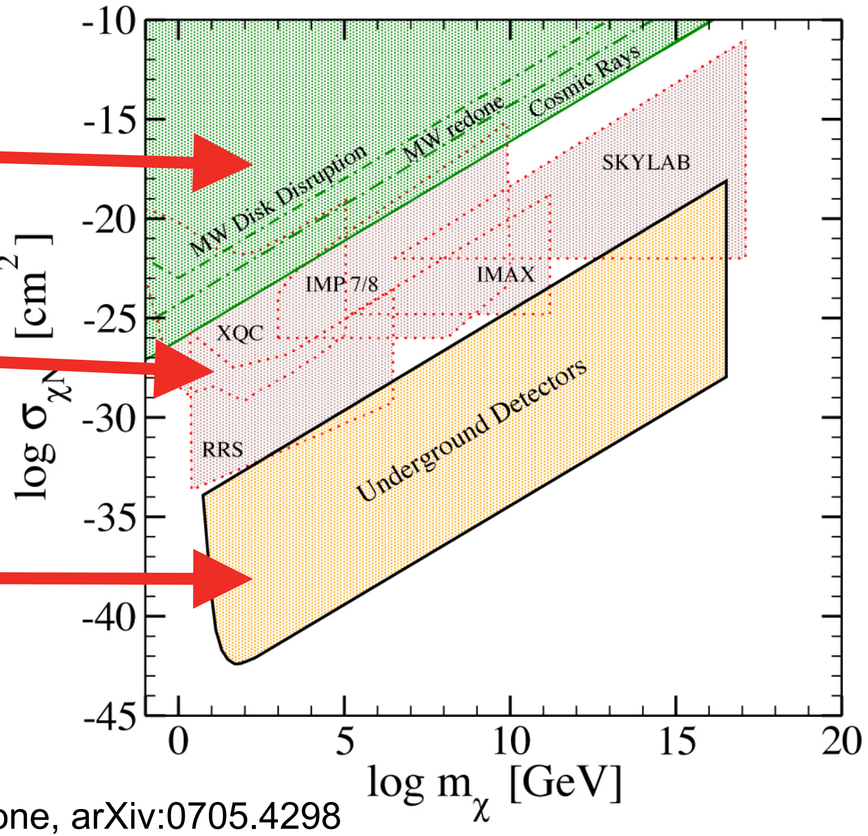


SIMP direct detection

Even larger cross sections are ruled out by astrophysical constraints.

At larger cross sections constraints come from balloon and rocket-borne experiments.

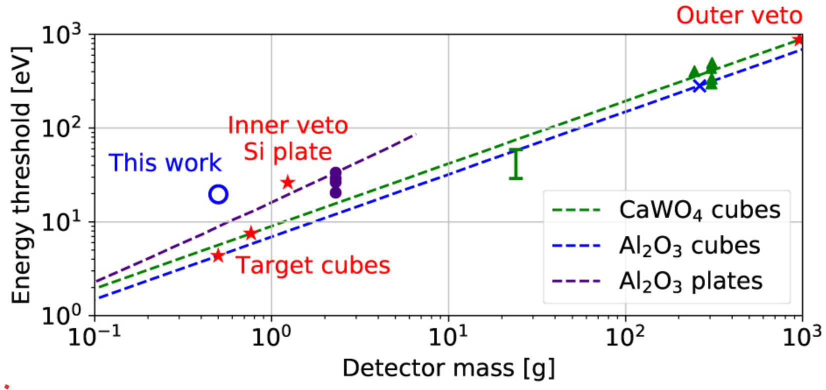
Direct detection experiments are not sensitive to larger DM-nucleon cross sections, in the so-called SIMP region.



Mack, Beacom and Bertone, arXiv:0705.4298

New results from a surface-based cryogenic detector

Gram-scale crystals mean that the experiment has an extremely low energy threshold, but at the expense of a smaller exposure.

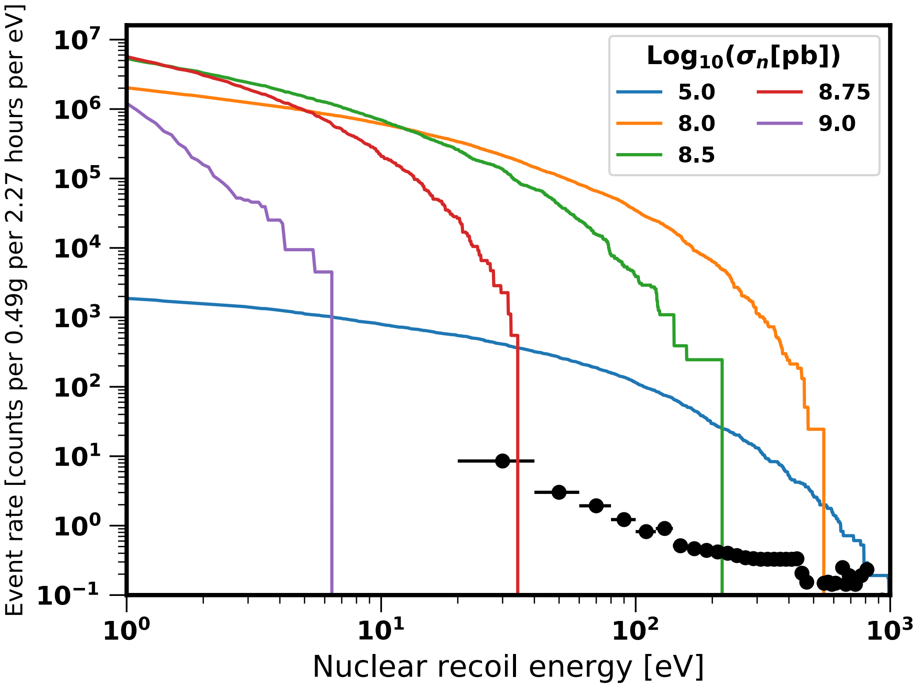


R. Strauss, **Eur.Phys.J. C77 (2017) 506**, arXiv:1704.04320

SIMPs in a surface-based cryogenic experiment

- The rate of events expected from SIMPs is far larger than the observed rate.
- Sensitivity to SIMPs is lost when the spectrum drops below the 20eV threshold due to SIMPs scattering in the shielding and atmosphere.

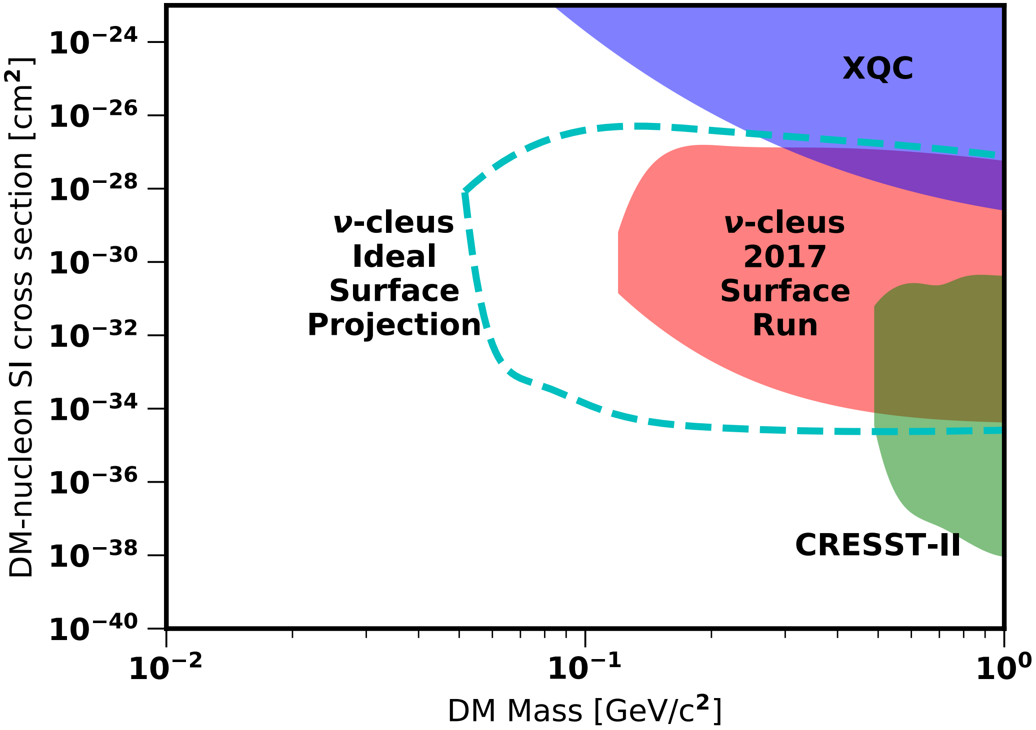
Data from: Results on MeV-scale dark matter from a gram-scale cryogenic calorimeter operated above ground, Eur.Phys.J. C77 (2017) no.9, 637 , arXiv:1707.067



New constraints on SIMP dark matter

- The red region shows SIMP cross sections and masses which can be ruled out with the data from this surface run.

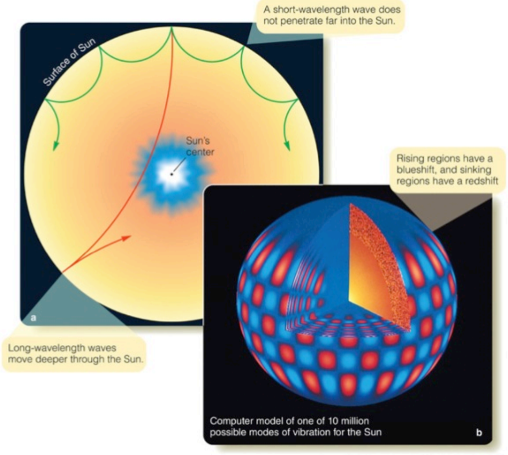
- The blue dashed line shows projections for a surface-based detector with a 4eV threshold.



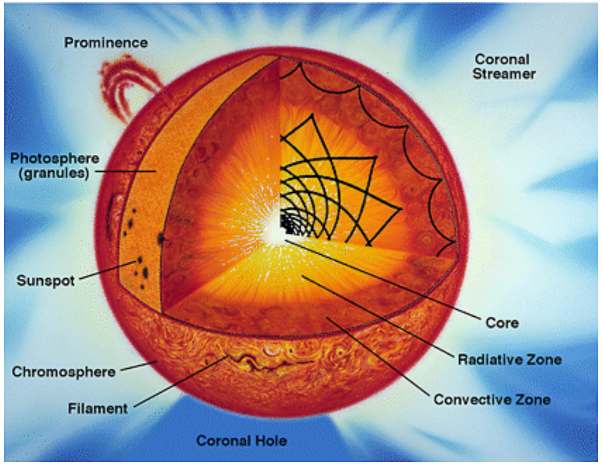
CNO Neutrino Grand Prix: The race to solve the solar metallicity problem

The solar metallicity problem

- Our knowledge of the Sun's composition comes from comparing simulations to data from probes such as **helioseismology** and electromagnetic **emission from the photosphere**.
- Helioseismology depends on the **whole Sun**.
- **The photospheric abundances depend on the solar surface** and are inferred by comparing absorption line measurements to models of the solar atmosphere.



Panel a: © 2016 Cengage Learning®; Panel b: AURA/NOAO/NSF



Helioseismology and the photosphere disagree

- Metallicity (C, N and O) measurements from the photosphere are consistent with the low-metallicity model.
- But, in order to fit to helioseismic data the surface metallicity needs to be larger i.e. the high-metallicity models.
- So models can fit either the photosphere metal abundances or helioseismic data but not both.
- We need more data.

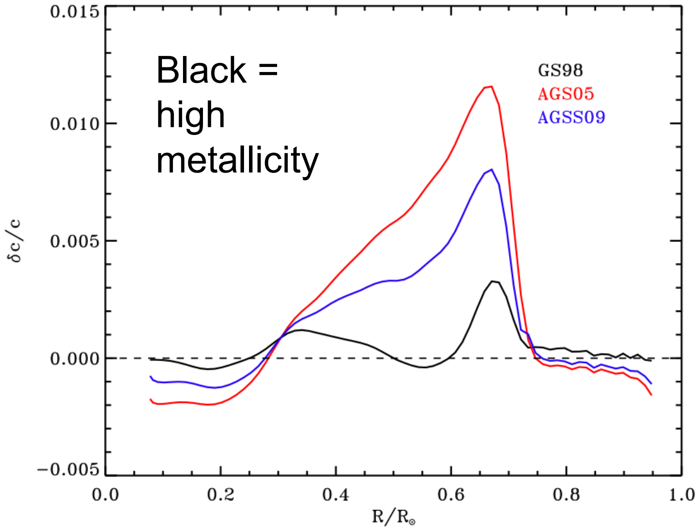
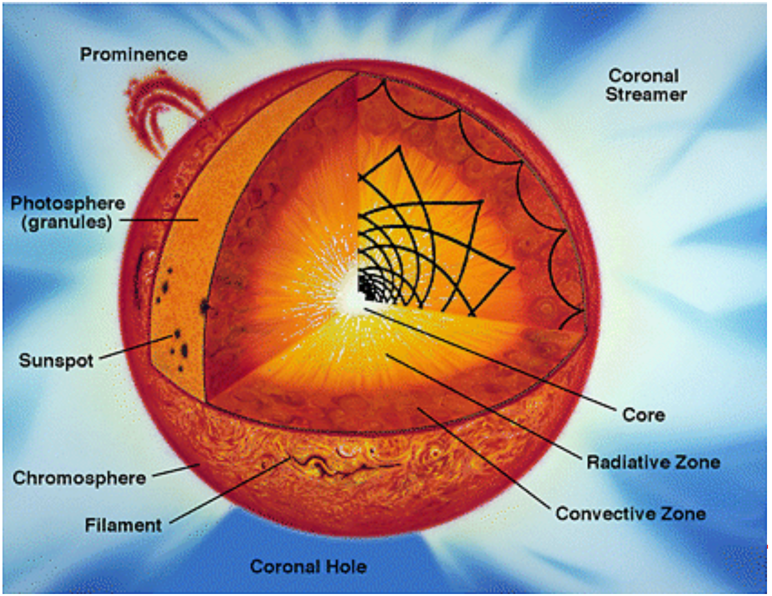


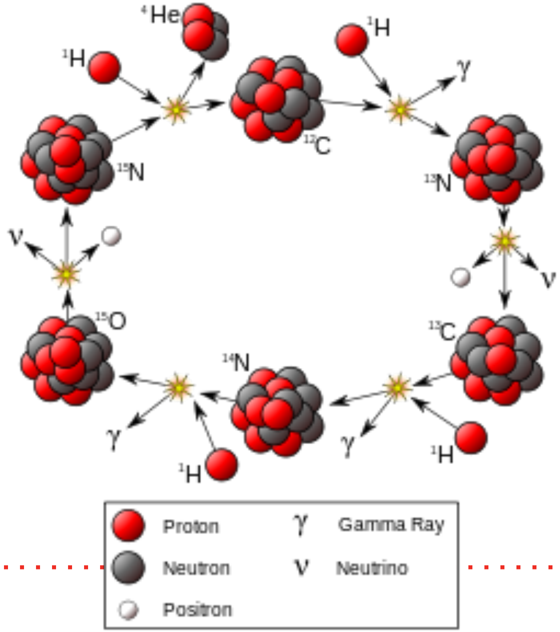
Figure 8: The differences between the helioseismic and predicted sound speeds as a function of depth (Serenelli et al. 2009). The standard solar models shown here only differ in the assumed chemical compositions: Grevesse & Sauval (1998) (black line, here denoted GS98), Asplund, Grevesse & Sauval (2005) (red line, AGS05) and the present work (blue line, AGSS09). Each model has independently been calibrated to achieve the correct solar luminosity, temperature and age. The base of the convection zone is at $R = 0.71\,R_\odot$, which is also where the discrepancy starts in earnest in all three cases.

Asplund et al., Ann.Rev.Astron.Astrophys. 47 (2009) 481-522

CNO Neutrinos – a solution

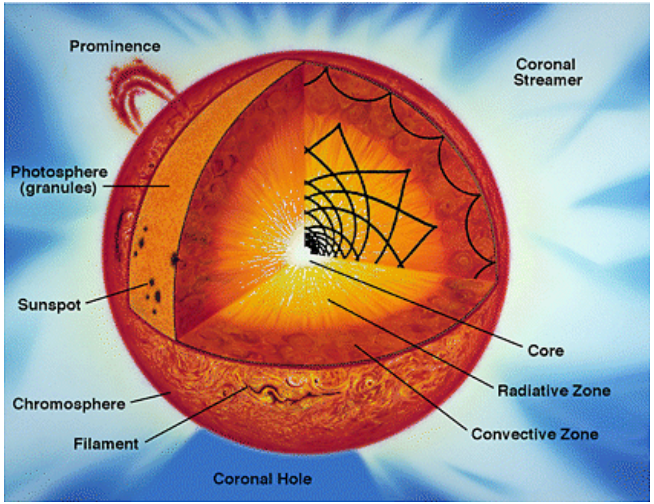
- A crucial extra measurement would be the metallicity in the solar core. One potential solution to the metallicity problem is that we do not understand conductivity and diffusion in the Sun. Changing this would lead to a different metal content in the core.
- The CNO neutrino flux depends sensitively on the metallicity of the solar core.

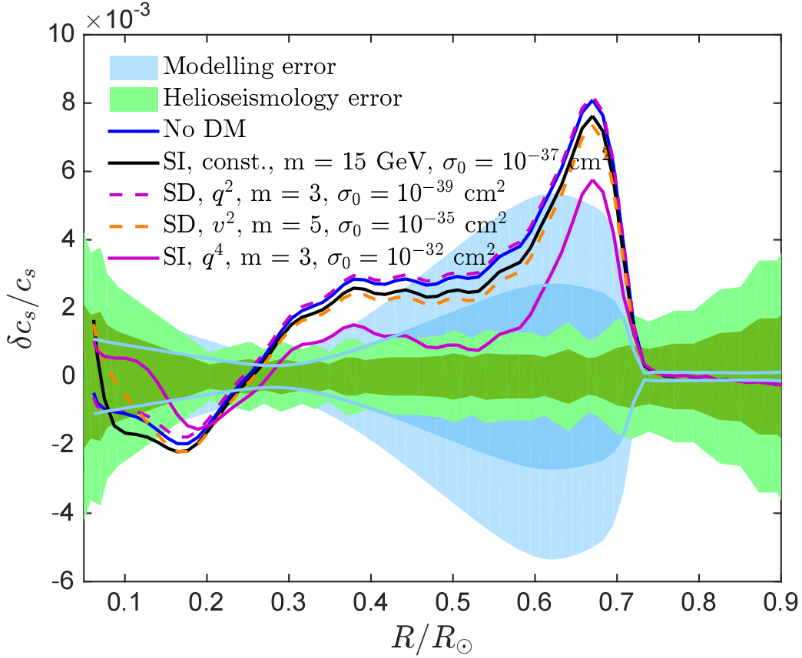




CNO neutrinos and new physics?

Measuring the CNO flux will tell us if the diffusion model is wrong, or whether something else is causing the discrepancy, potentially even **dark matter** (e.g. Frandsen and Sarkar, arXiv:1003.4505 or Vincent, Scott, and Serenelli, arXiv:1411.6626).

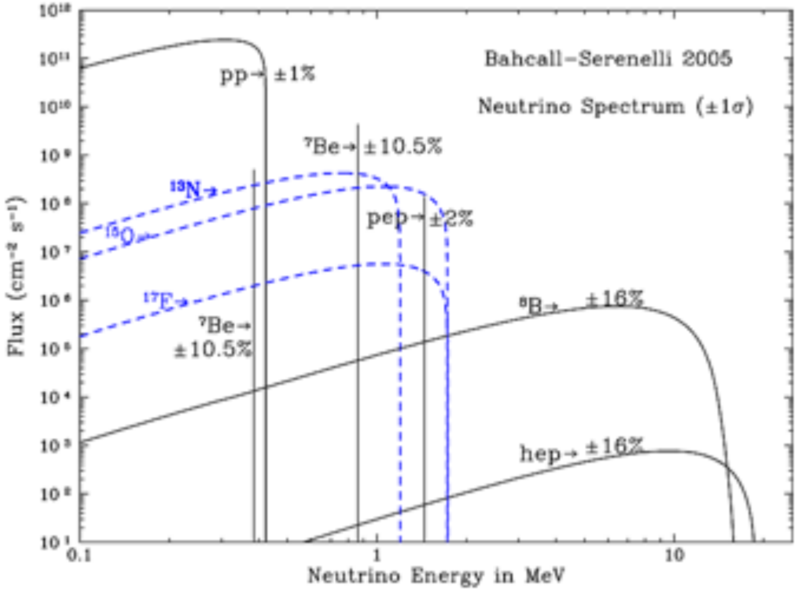


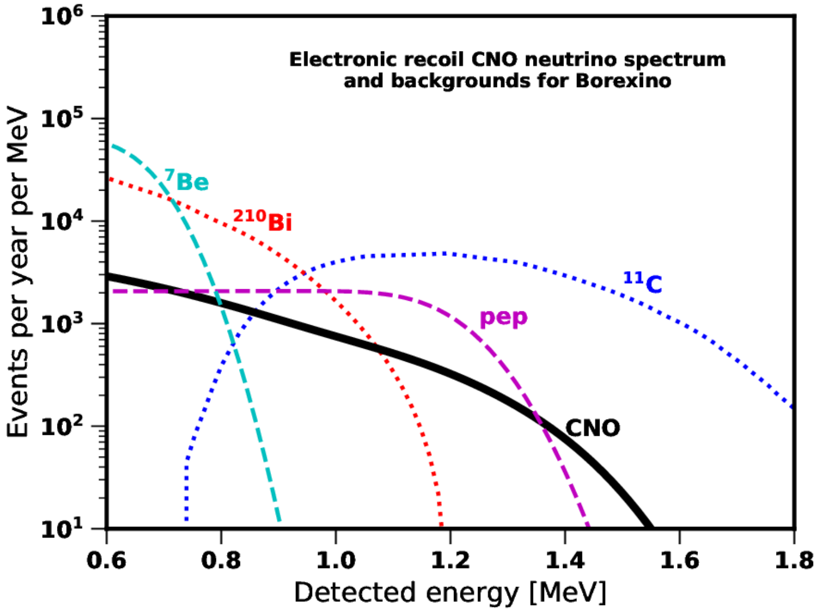


1605.06502

Detecting CNO Neutrinos

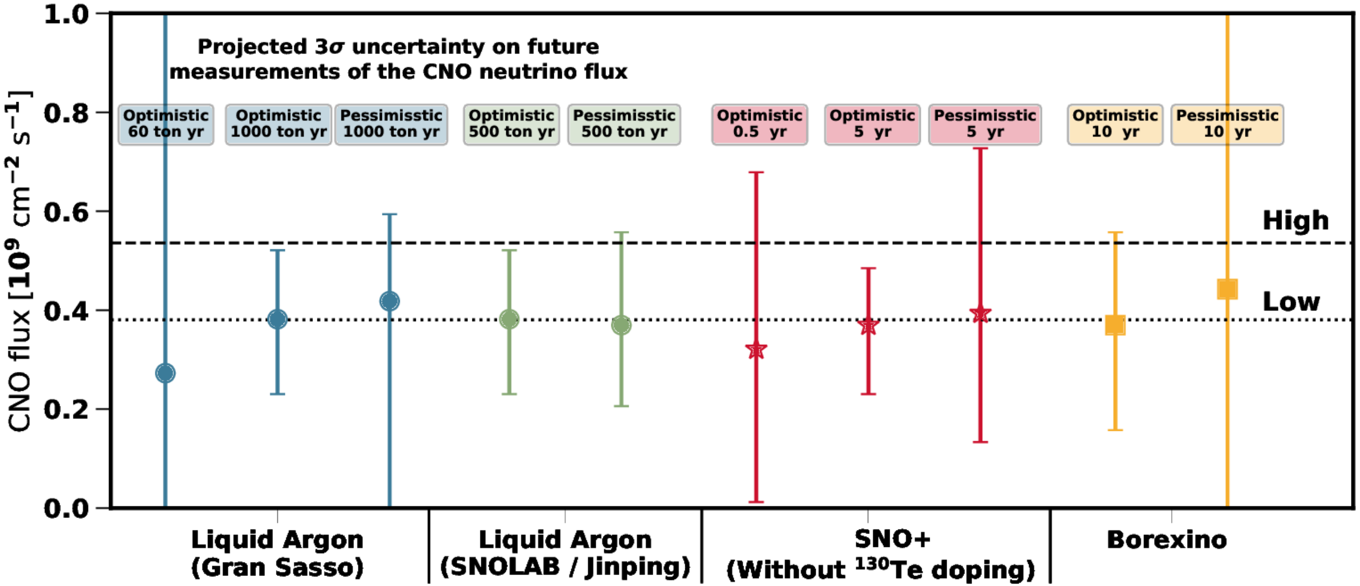
Measuring the CNO flux is extremely difficult as their spectrum is sub-dominant compared to the other solar neutrino sources e.g. berylium-7 or pep.





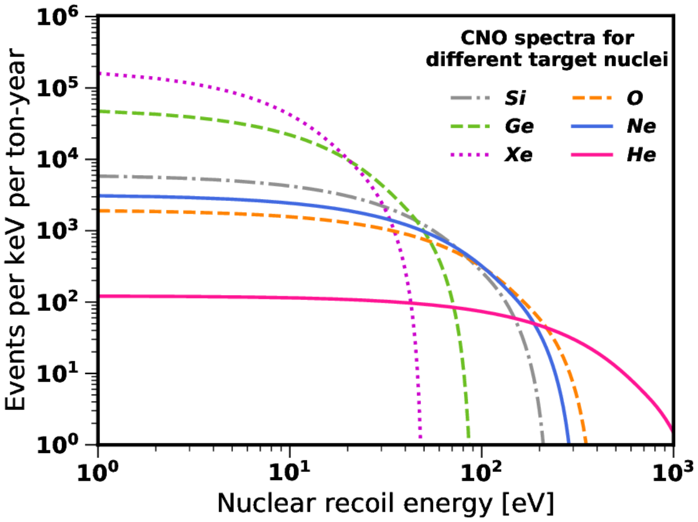
Measuring the CNO flux with electron-recoil experiments

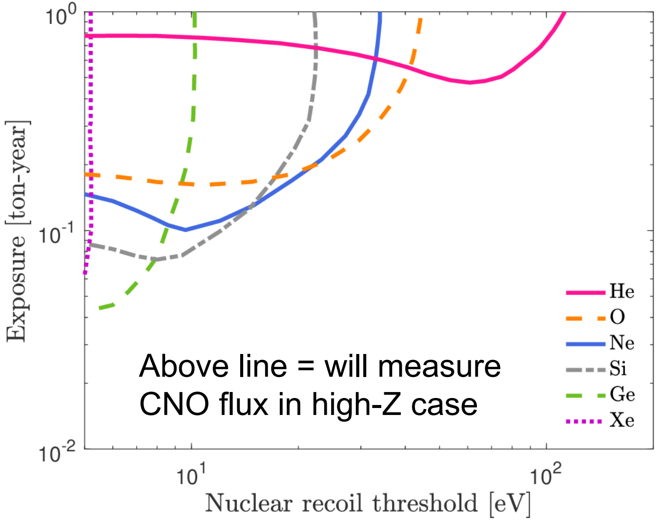
CNO neutrinos scattering with electrons lead to signals with energies up to around 1.4 MeV, which can be observed e.g. in liquid scintillator detectors. These tend to have large signal rates but also difficult backgrounds (e.g. beta-decay).



Measuring the CNO flux with nuclear-recoil experiments

Looking for nuclear-recoils could be a viable alternative, but experiments will need both a low threshold and a large exposure.

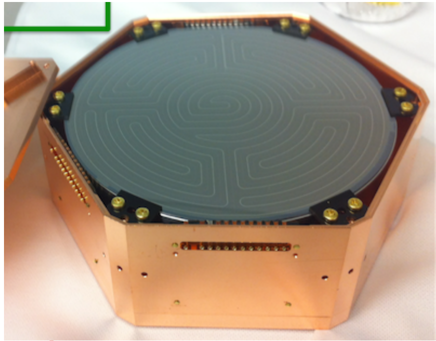


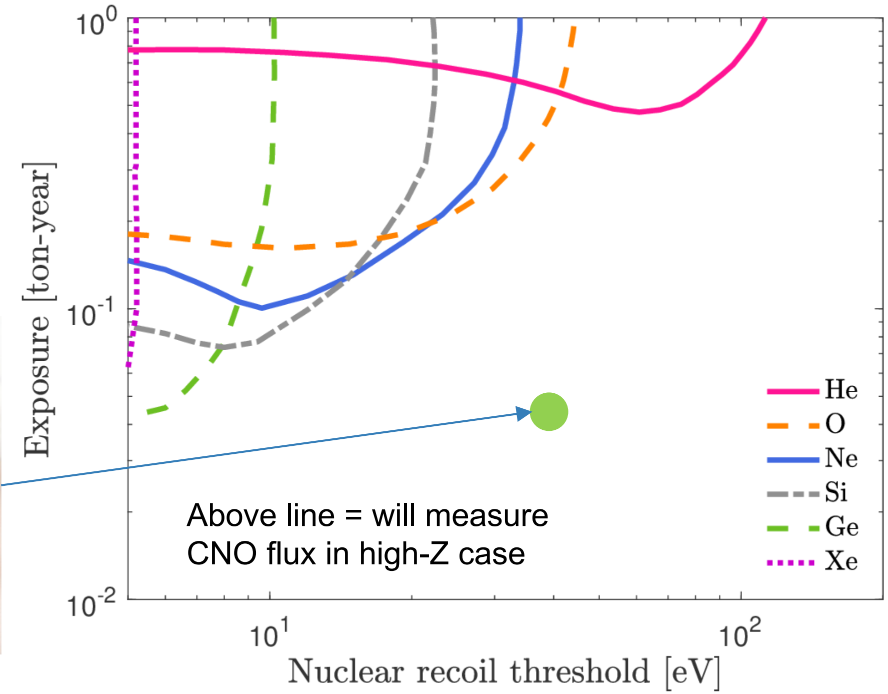


Above line = will measure CNO flux in high-Z case

Technologies for CNO-NR observation

SuperCDMS in SNOLAB looks to be the best hope with germanium.





Above line = will measure CNO flux in high-Z case

CRESST with its 0.5g sapphire crystal can get the required threshold with oxygen, but the exposure is far too small.

Conclusion

- Looking for nuclear-recoils with energies below a keV opens up new regions of dark matter parameter space towards low masses and also high cross sections.
- Such technology could also be used to measure the CNO neutrino flux, which would help towards solving the solar metallicity problem.
- This will require large exposures to be obtained by around the latter part of the next decade, at which point SNO+ will likely have got to a CNO flux measurement first.

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