The Unbearable Lightness of Being:

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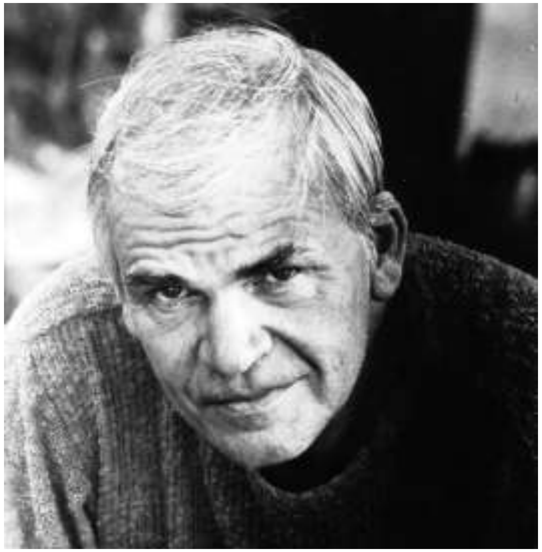


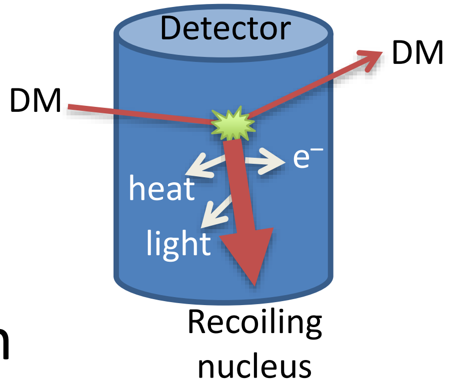
"But is heaviness truly deplorable and lightness splendid? [...] The heavier the burden, the closer our lives come to the earth, the more real and truthful they become. Conversely, the absolute absence of a burden causes man to be lighter than air, to soar into the heights, take leave of the earth and his earthly being, and become only half real, his movements as free as they are insignificant."

While most particle physicists complain about the heaviness of new physics, dark matter direct detection may be "a drama not of heaviness but of lightness".

Direct detection: Event rate

$$\frac{\mathrm{d}R}{\mathrm{d}E_\mathrm{R}} = \frac{\rho_0}{m_\mathrm{N}\, m_\mathrm{DM}} \int_{v_\mathrm{min}}^{\infty} \mathrm{d}v\, v\, f(v, v_\mathrm{E})\, \epsilon(E_\mathrm{R})\, \frac{\mathrm{d}\sigma}{\mathrm{d}E_\mathrm{R}}$$

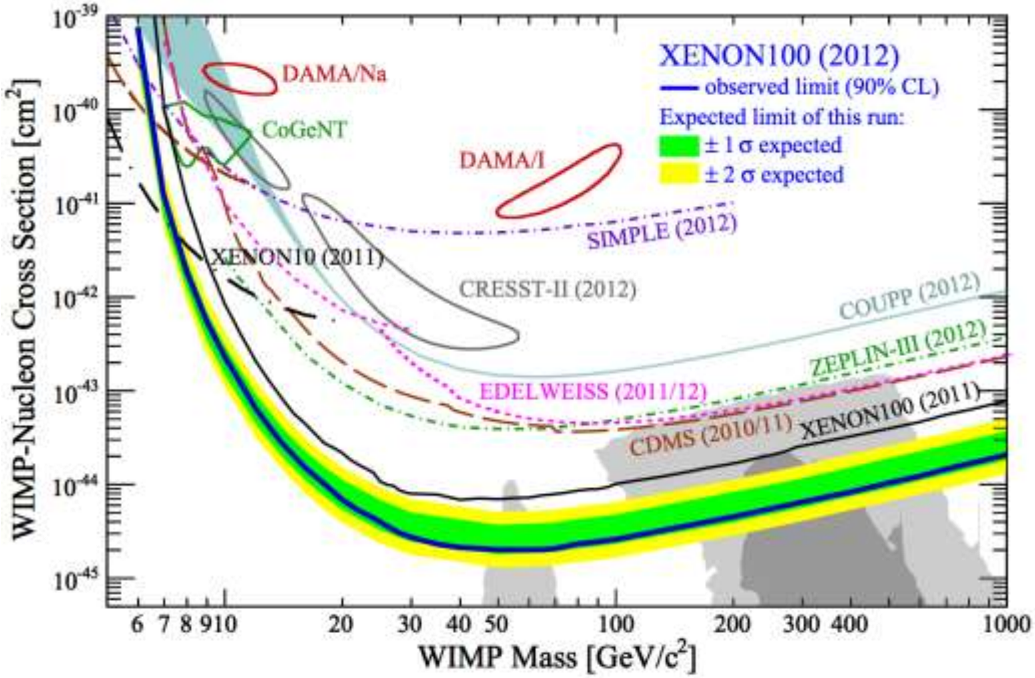
$$v_\mathrm{min} = \sqrt{m_\mathrm{N}\, E_\mathrm{R}/2\,\mu_\mathrm{N}^2}$$



There are three fundamental difficulties with the direct detection of light DM:

1. At very low recoil energies, the detector response and signal acceptance is difficult to determine.
2. The expected signal is close to the threshold and therefore difficult to distinguish from backgrounds.
3. Light DM experiments only probe the highly uncertain tail of the DM velocity distribution.

Direct detection: Results

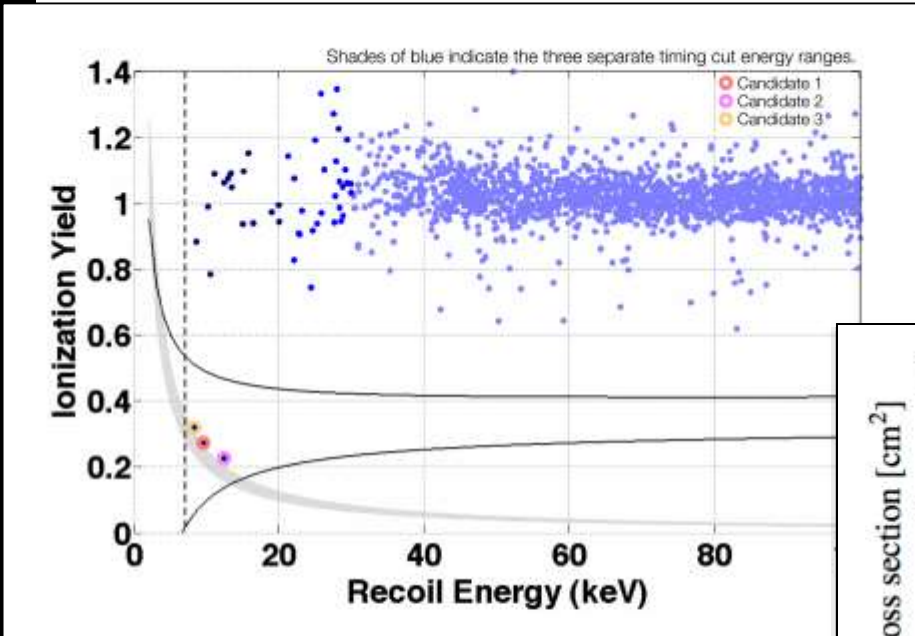


XENON100: 1207.5988

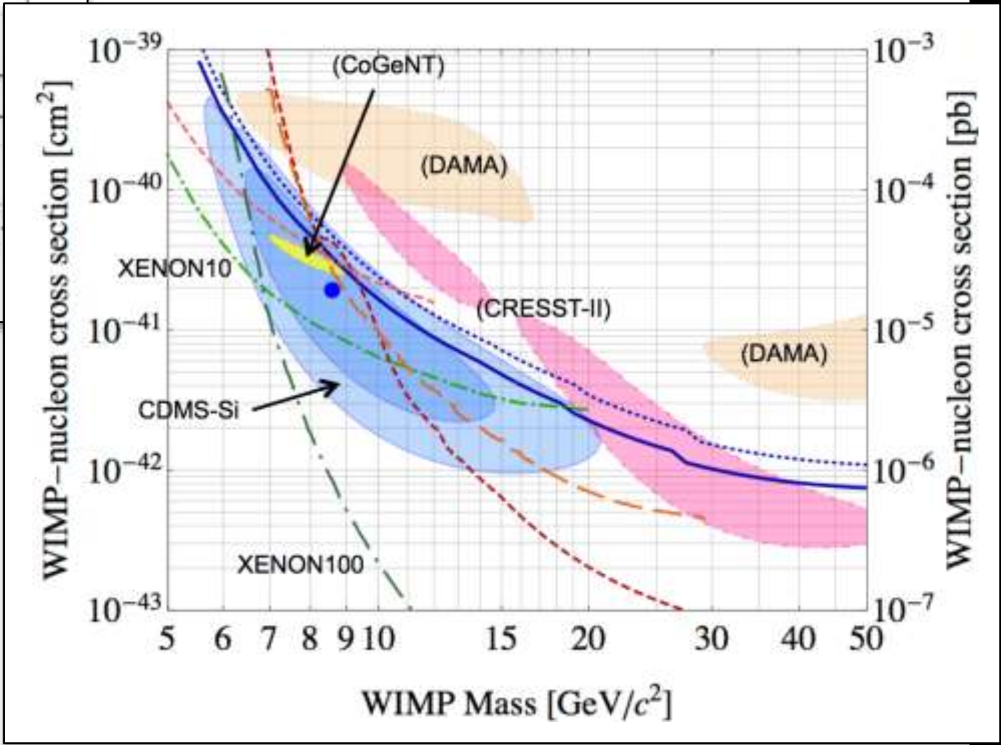
Standard assumptions:

1. Standard Halo Model (Maxwell-Boltzmann)
2. Contact interactions
3. Elastic scattering
4. Equal couplings to protons and neutrons

CDMS-II: Signal or background?



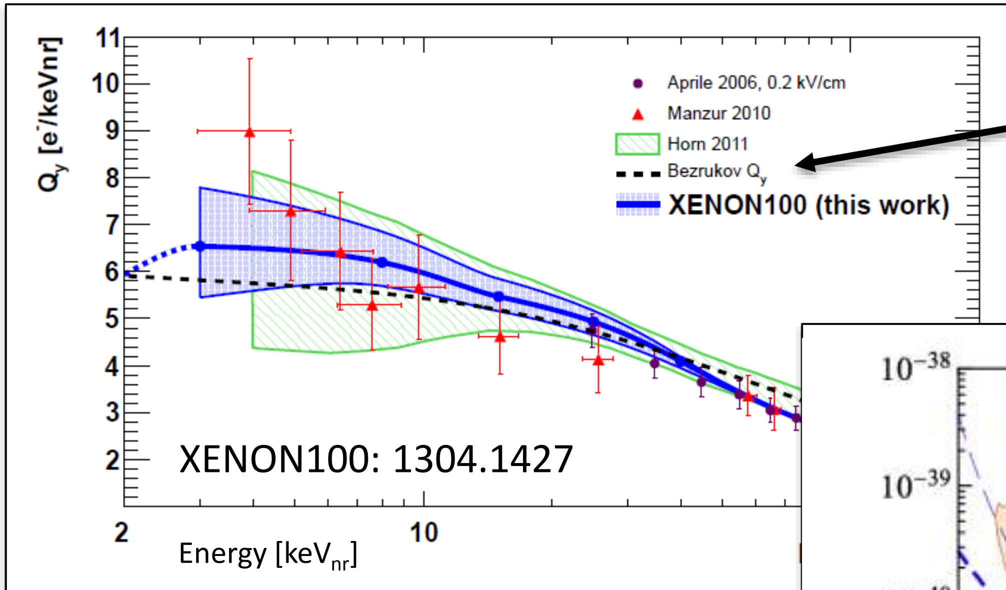
- 140 kg-days (July 2007- Sept 2008) with silicon detectors
- Three events passed all cuts (0.7 expected)



DM + background hypothesis preferred over known-background only hypothesis at 99.8% C.L.

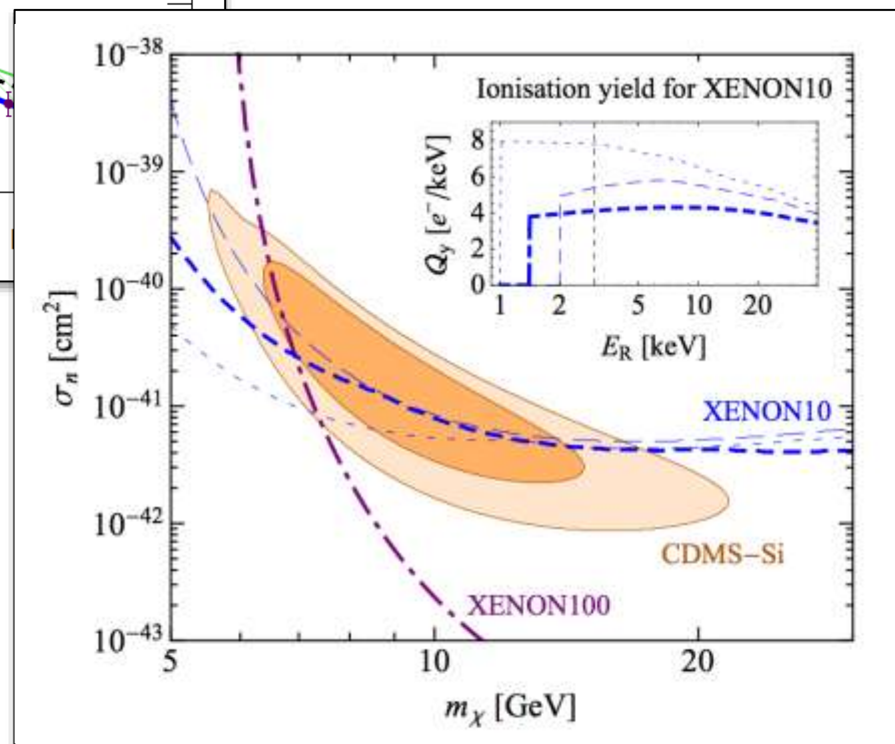
CDMS-II: 1304.4279

XENON10: Detector response



Bezrukov, FK, Lindner: 1011.3990

Frandsen, FK, McCabe, Sarkar, Schmidt-Hoberg: 1304.6066



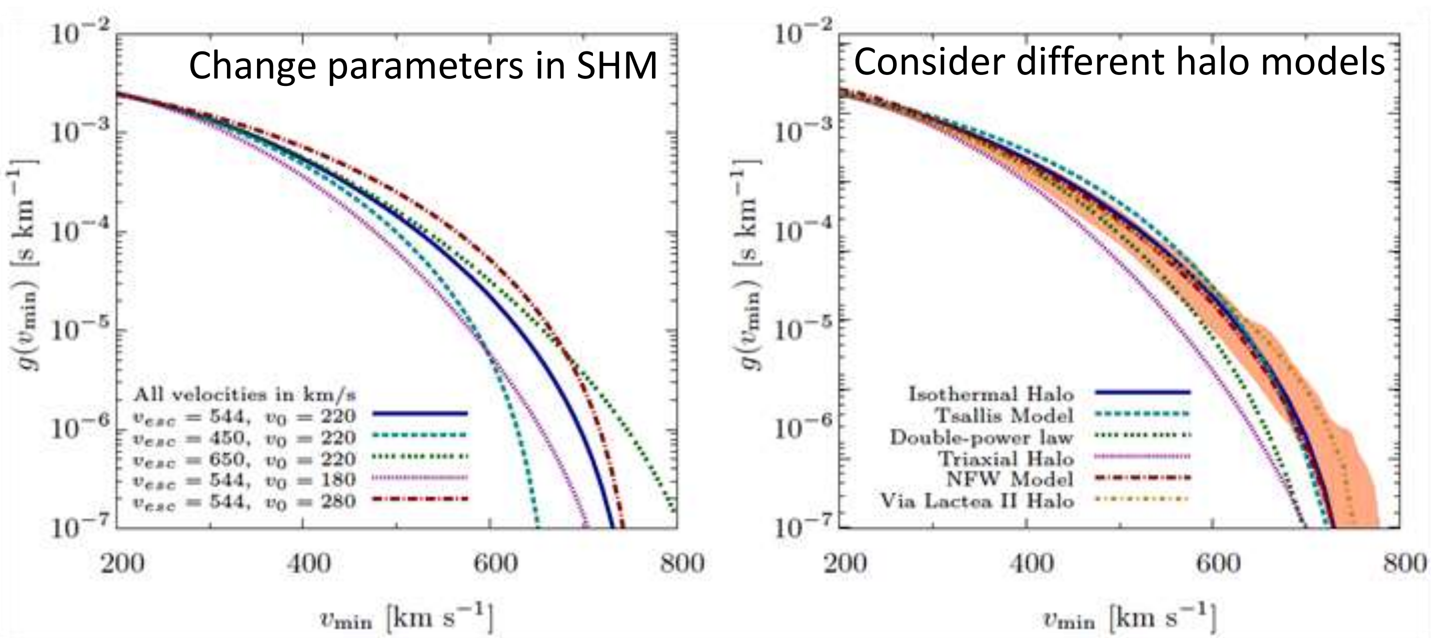
For the S2-only analysis, the energy scale $E_R(S2)$ depends sensitively on the ionization yield Q_y, which is difficult to measure and unknown below 3 keV.

CDMS vs XENON: Halo uncertainties

There is significant tension between CDMS and XENON. Can this be evaded by modifying the DM velocity distribution?

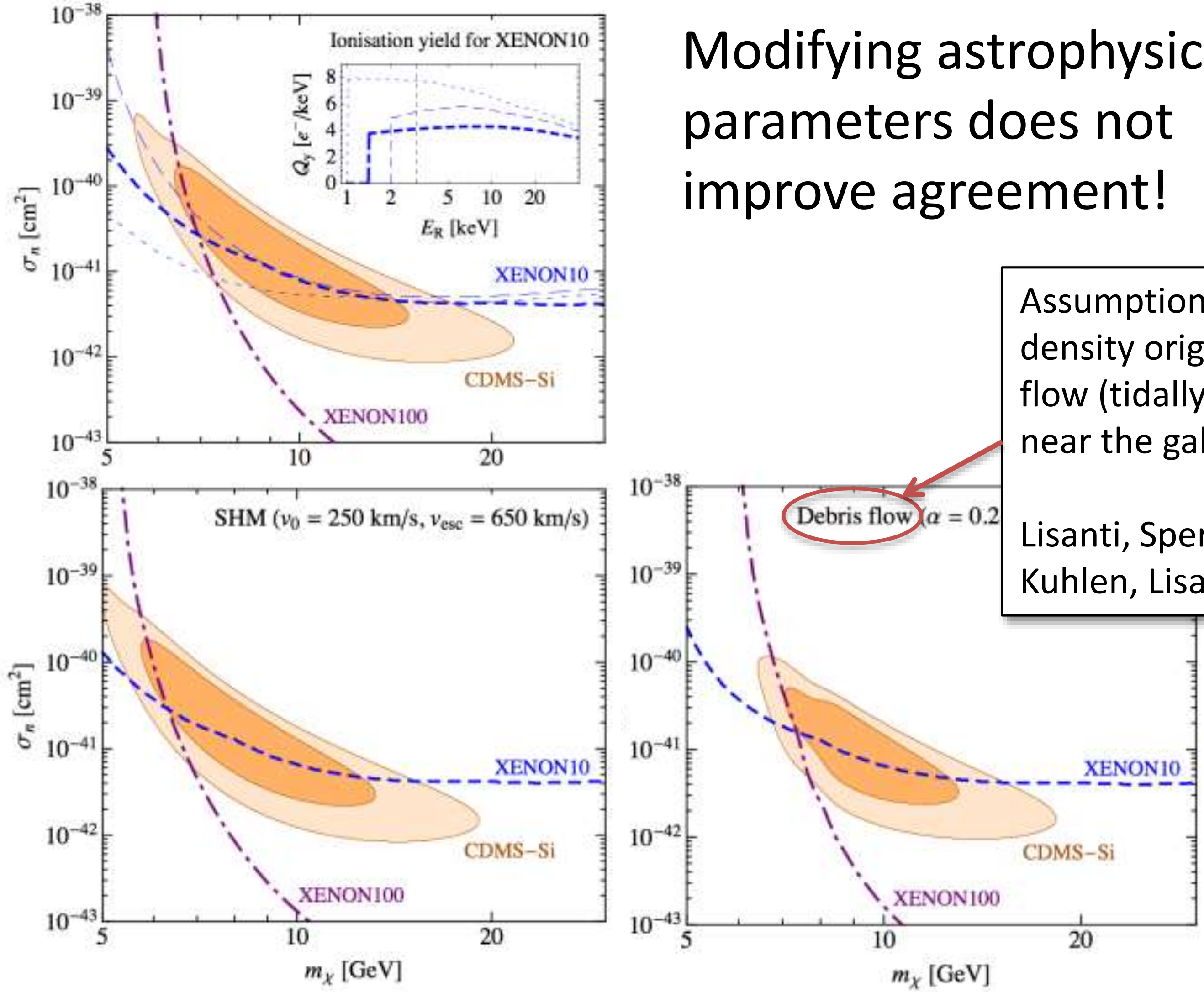
$$\frac{\mathrm{d}R}{\mathrm{d}E_\mathrm{R}} = \frac{1}{2\,\mu_n^2} C_\mathrm{T}^2(A,Z)\,F^2(E_\mathrm{R})\,\epsilon(E_\mathrm{R})\,\tilde{g}(v_\mathrm{min})$$

$$\tilde{g}(v_\mathrm{min}) \equiv \frac{\rho\,\sigma_n}{m_\mathrm{DM}} \int_{v_\mathrm{min}}^{\infty} \frac{f(\boldsymbol{v}+\boldsymbol{v}_\mathrm{E})}{v}\,\mathrm{d}^3v$$



Frandsen, FK, McCabe, Sarkar, Schmidt-Hoberg: 1111.0292

CDMS vs XENON: Halo uncertainties



Modifying astrophysical parameters does not improve agreement!

Assumption: 20% of the local DM density originates from a debris flow (tidally stripped from subhalos near the galactic centre).

Lisanti, Spergel: 1105.4166
Kuhlen, Lisanti, Spergel: 1202.0007

Mapping to v_{min}-space

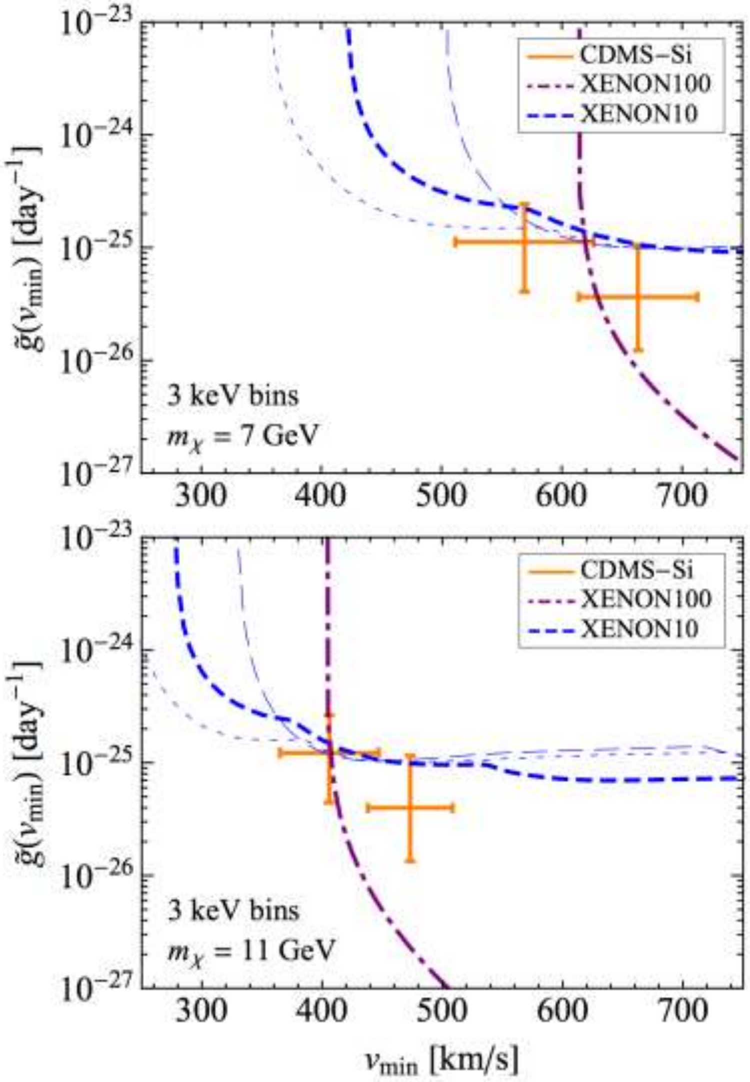
The differential event rate is proportional to the velocity integral $g(v_{min})$:

$$\tilde{g}(v_{\rm min}) = \frac{2\,\mu_n^2}{C_{\rm T}^2(A,Z)\,F^2(E_{\rm R})\,\epsilon(E_{\rm R})}\,\frac{{\rm d}R}{{\rm d}E_{\rm R}}$$

We can thus map experimental results into v_{min}-space.

Fox, Liu, Weiner: 1011.1915

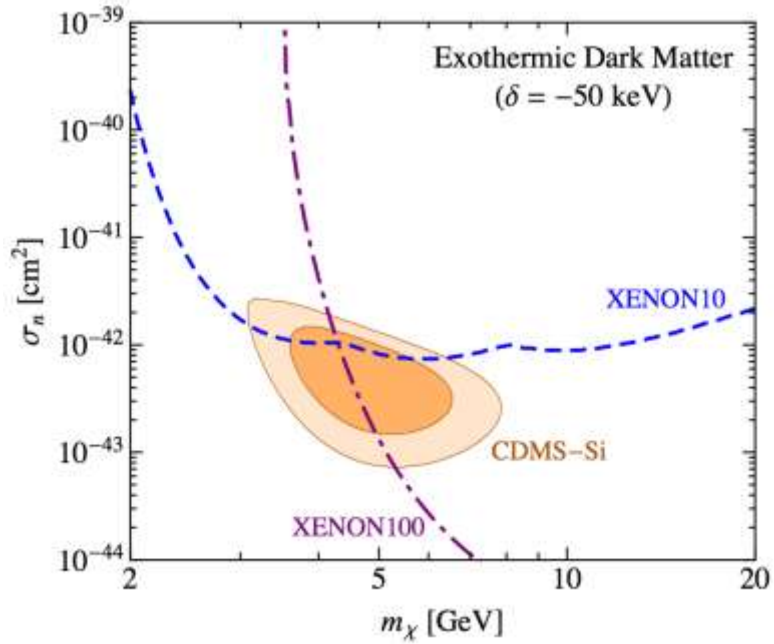
Since XENON10, XENON100 and CDMS-II probe overlapping regions of this space, the tension between them cannot be resolved by changing astrophysics.



Possible solutions

Since astrophysical uncertainties do not resolve the tension between CDMS-II and XENON10/100, we want to consider particle physics models beyond the standard assumption:

- Adding a momentum dependence ($\frac{d\sigma}{dE_\mathrm{R}} \rightarrow \left(\frac{q^2}{q^2_\mathrm{ref}}\right)^n \frac{d\sigma}{dE_\mathrm{R}}$) does not help, because $q \propto v_\mathrm{min}$.
- Inelastic collisions with down-scattering (exothermic DM) enhances rate for light targets.
- Partial destructive interference between protons and neutrons (isospin-dependent couplings) can suppress targets with large ratio A/Z.



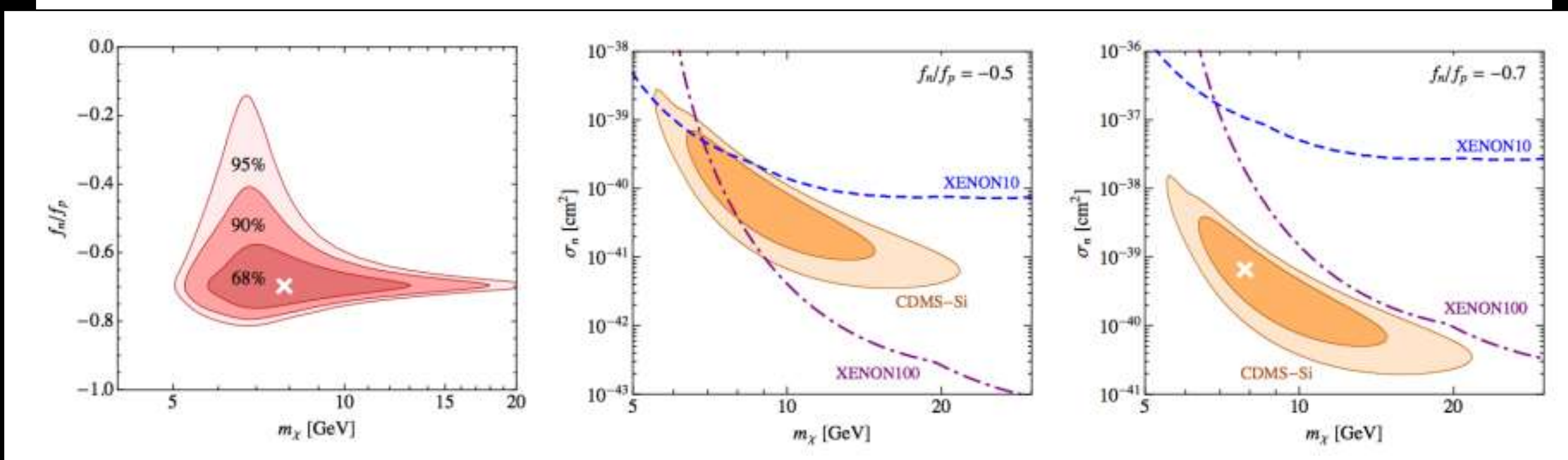
Isospin-dependent couplings

If we abandon the assumption of equal couplings to protons and neutrons, we have

$$\frac{\mathrm{d}R}{\mathrm{d}E_\mathrm{R}} \propto \left[Z + f_n/f_p(A-Z)\right]^2$$

If the interactions of DM are mediated by a new Z' gauge boson, it is possible to have $f_n/f_p < 0$.

Frandsen, FK, Sarkar, Schmidt-Hoberg, 1107.2118
Frandsen, FK, Preston, Sarkar, Schmidt-Hoberg, 1204.3839

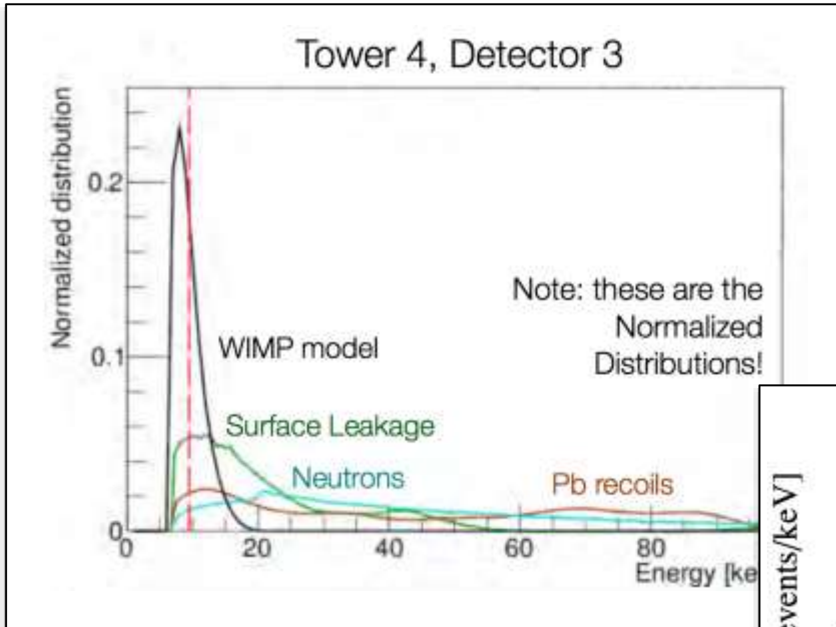


Conclusions

- The 3 events in CDMS-II Si point towards low-mass DM.
- The XENON10/100 experiments cannot currently exclude the entire parameter region favoured by CDMS-II.
- Nevertheless, the tension between these experiments is independent of astrophysical uncertainties .
- Allowing a momentum or velocity dependence in the DM scattering cross-section will not improve the agreement.
- The tension is reduced if scattering of DM on heavy targets is suppressed, e.g. because DM couplings are isospin-dependent.
- It is essential that experimental searches employ as many different target nuclei as is possible.

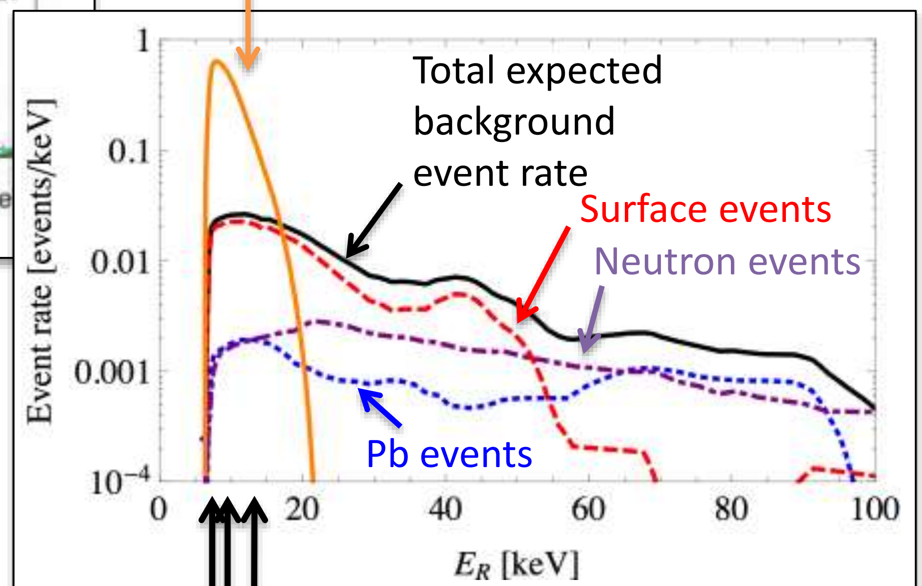
Backup

CDMS-II: Background estimate



CDMS-II: 1304.4279

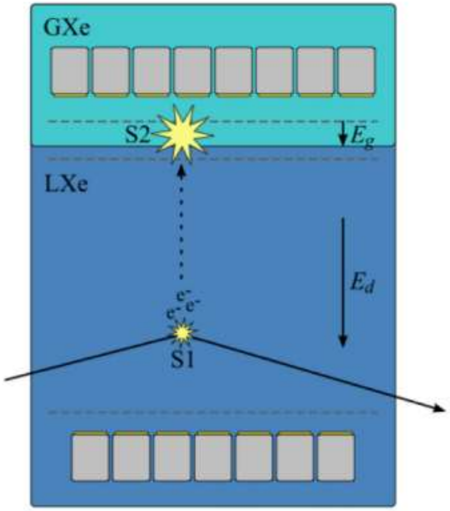
Expected signal event rate for σ_p = 2 x 10^{-41} cm^2 and m_χ = 8.6 GeV

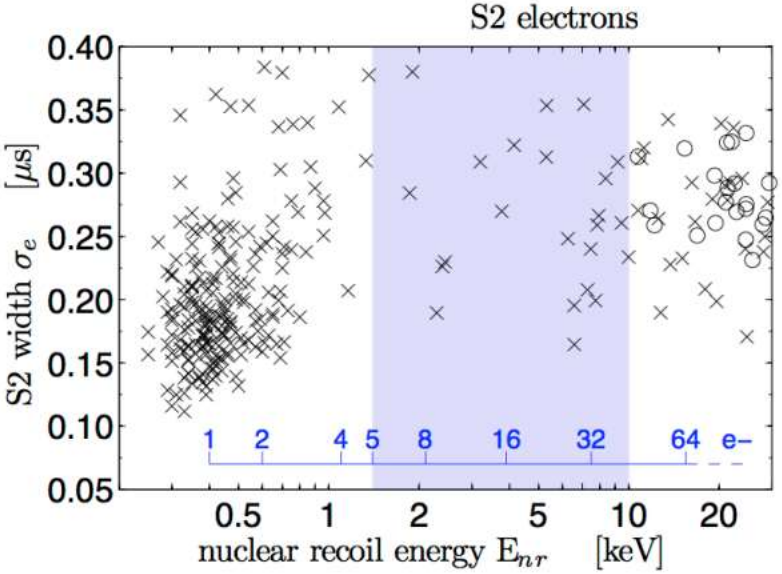


Observed events

Lowering the threshold in XENON

- Allow for events without primary scintillation (S1) signal.
- Pro: S2 can be detected down to much lower energies.
- Con: Loss of ability to discriminate electron recoils leads to large backgrounds (23 events in 12 days).

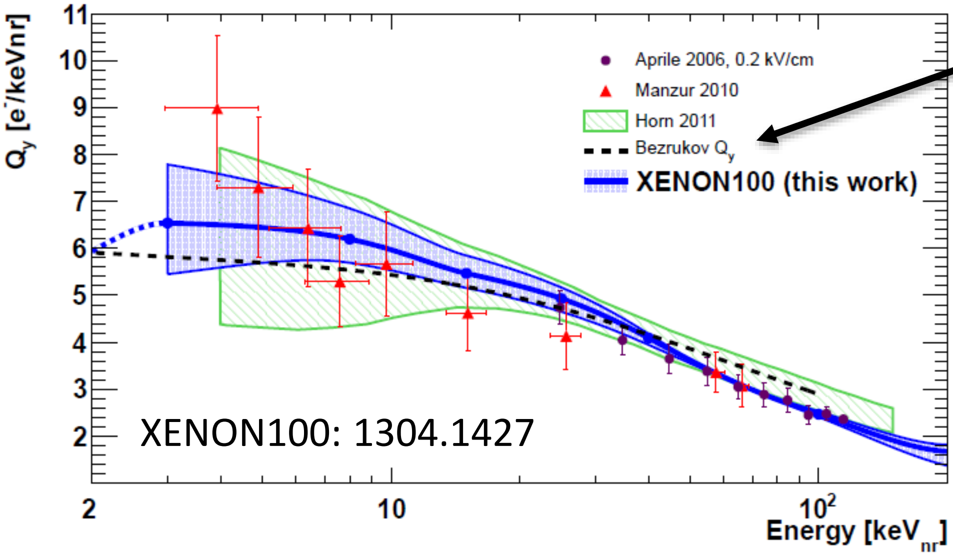




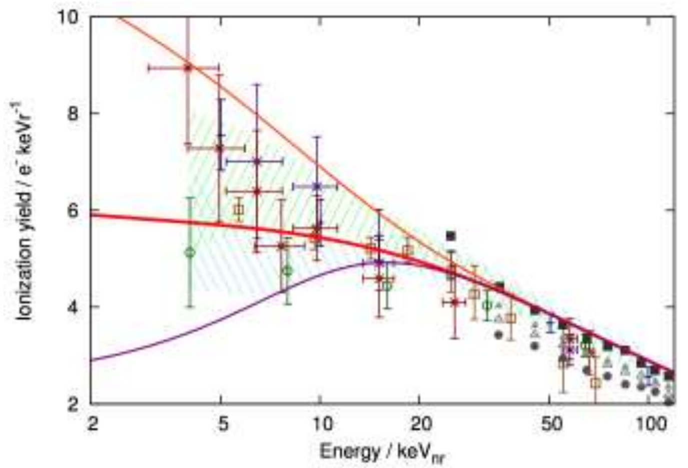
XENON10:
1104.3088

XENON10: Ionisation yield

For the S2-only analysis, the energy scale $E_R(S2)$ depends sensitively on the ionisation yield Q_y, which is difficult to measure and unknown below 3 keV.



Bezrukov, FK, Lindner: 1011.3990

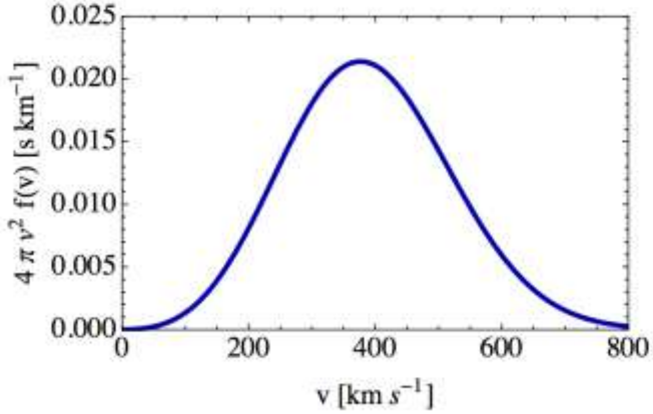


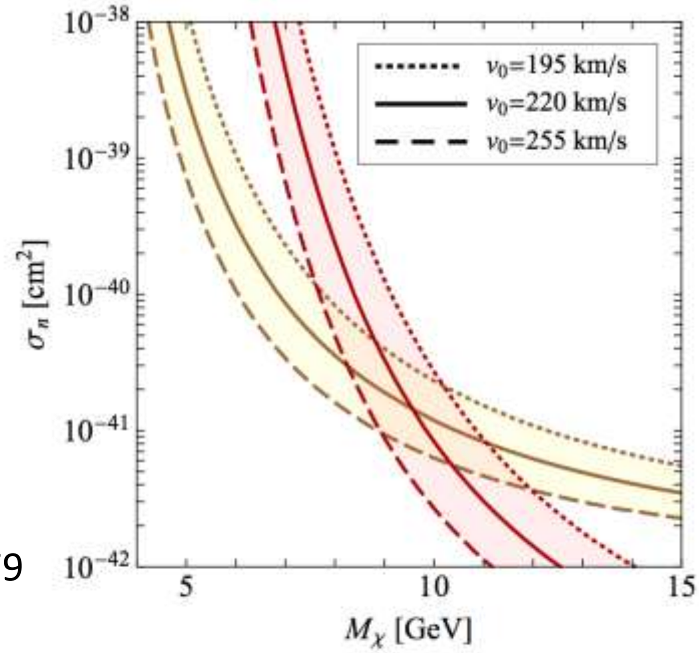
Standard Halo Model

The "Standard Halo Model" is a truncated Maxwell-Boltzmann velocity distribution.

$$f(v) = \begin{cases} N_0 \exp\left(-\frac{v^2}{v_0^2}\right) & v < v_{\text{esc}} \\ 0 & v > v_{\text{esc}} \end{cases}$$

v_0 = 200 … 250 km/s
(McMillan, Binney: 0907.4685)
v_{esc} = 498 … 608 km/s
(RAVE survey: astro-ph/0611671)





McCabe: 1005.0579

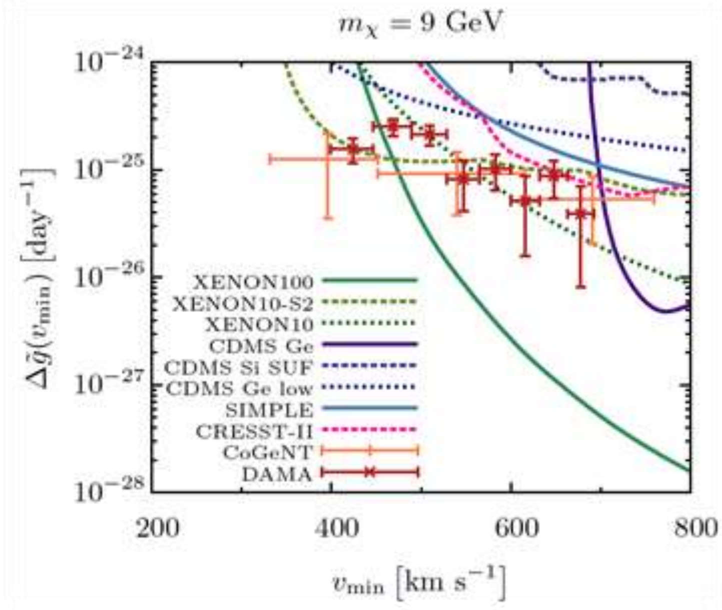
Including annual modulations

- Interpreting the annual modulations observed by DAMA and CoGeNT, allows us to infer the modulation amplitude of the velocity integral $\Delta g(v_{\min})$.
- To compare measurements of $\Delta g(v_{\min})$ to experimental bounds on $g(v_{\min})$, we would need to determine the modulation fraction $A(v_{\min})$.
- Without making any assumptions on the DM halo, we can only be sure that

$$A(v_{\min}) \leq 1$$

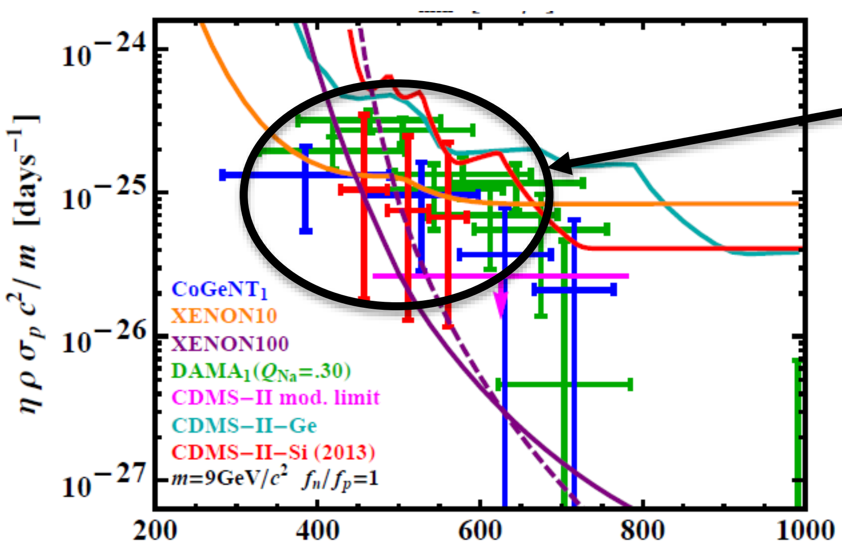
and consequently

$$\Delta g(v_{\min}) \leq g(v_{\min})$$



How about CDMS-Si?

2013: There is significant tension between CDMS-II Si and the annual modulation observed by CoGeNT and DAMA.



Del Nobile, Gelmini, Gondolo, Huh, arXiv:1304:6183

To explain all 3 experiments, the modulation fraction would have to be close to 100% - in tension with all known halo models.