Terrestrial effects on sub-GeV dark matter direct detection via electron scatterings

IPA 2018

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Sub-GeV dark matter direct detection

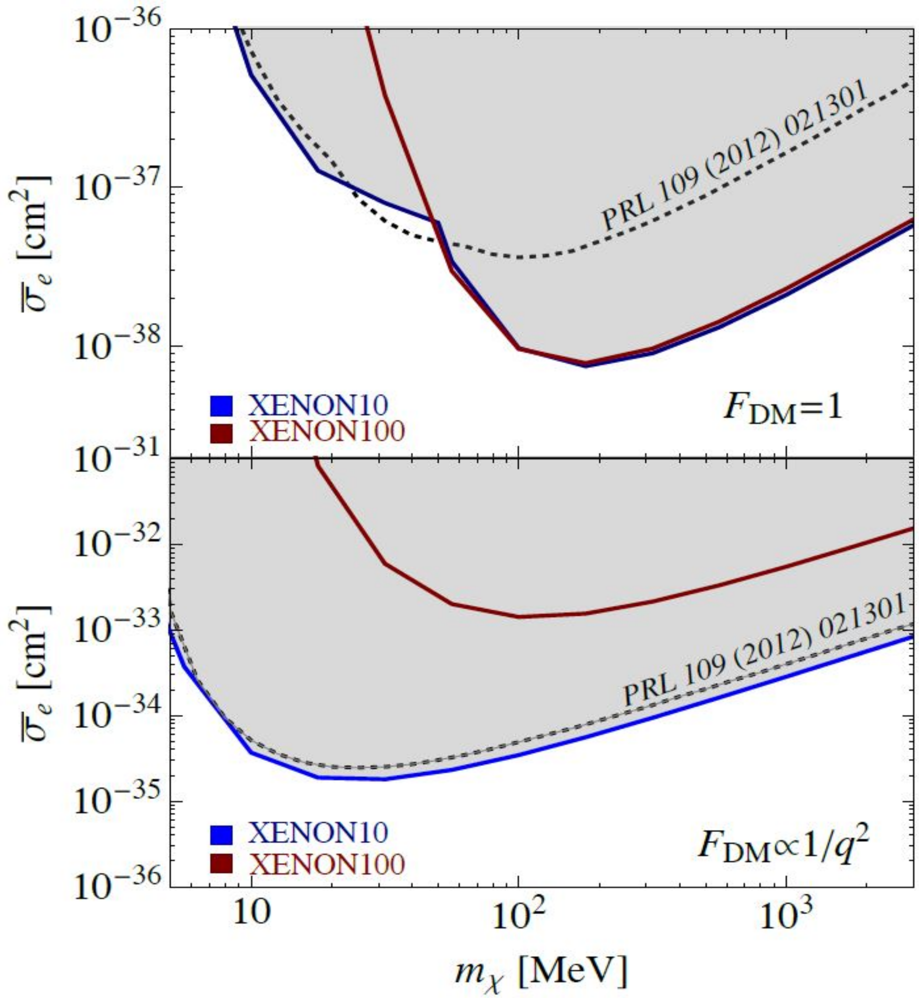
- Nuclear recoil energies produced by sub-GeV dark matter are too low to measure

$$E_{\rm NR}^{\rm max} \sim 2~{\rm eV}\left(\frac{m_\chi}{100~{\rm MeV}}\right)^2\left(\frac{10~{\rm GeV}}{m_N}\right)$$

↓

Can look for electron recoils induced by sub-GeV dark matter

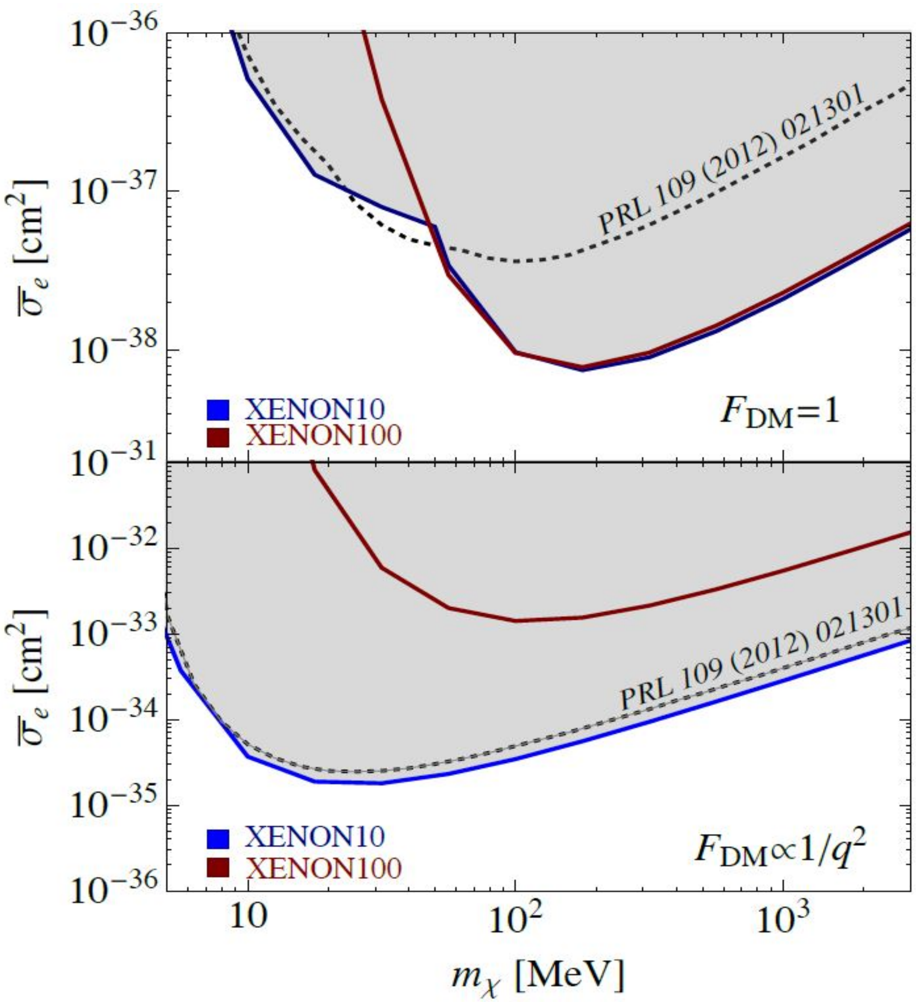
Existing constraints



* Essig, Volansky and Yu (1703.00910)

What happens as we increase the cross section ?

Existing constraints



What happens as we increase the cross section ?

- Dark matter can scatter off the nuclei and the electrons in the overburden (earth or atmosphere)
- Can become invisible to the detector above a critical cross section

* Essig, Volansky and Yu (1703.00910)

The model

- Dark photon (A') model

$$\mathcal{L}_{A'} = -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}\frac{\epsilon}{\cos\theta_W}B^{\mu\nu}F'_{\mu\nu} - \frac{1}{2}m_{A'}^2 A'^{\mu}A'_{\mu}$$

$$\overline{\sigma}_e \simeq \begin{cases} \frac{16\pi\mu_{\chi e}^2 \alpha\alpha_D\epsilon^2}{m_{A'}^4}, & m_{A'} \gg \alpha m_e \\ \frac{16\pi\mu_{\chi e}^2 \alpha\alpha_D\epsilon^2}{(\alpha\, m_e)^4}, & m_{A'} \ll \alpha m_e \end{cases}, \text{and} \quad F_{DM}(q) \simeq \begin{cases} 1\,, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 m_e^2}{q^2}\,, & m_{A'} \ll \alpha m_e \end{cases}$$

- Differential cross section with nuclei :

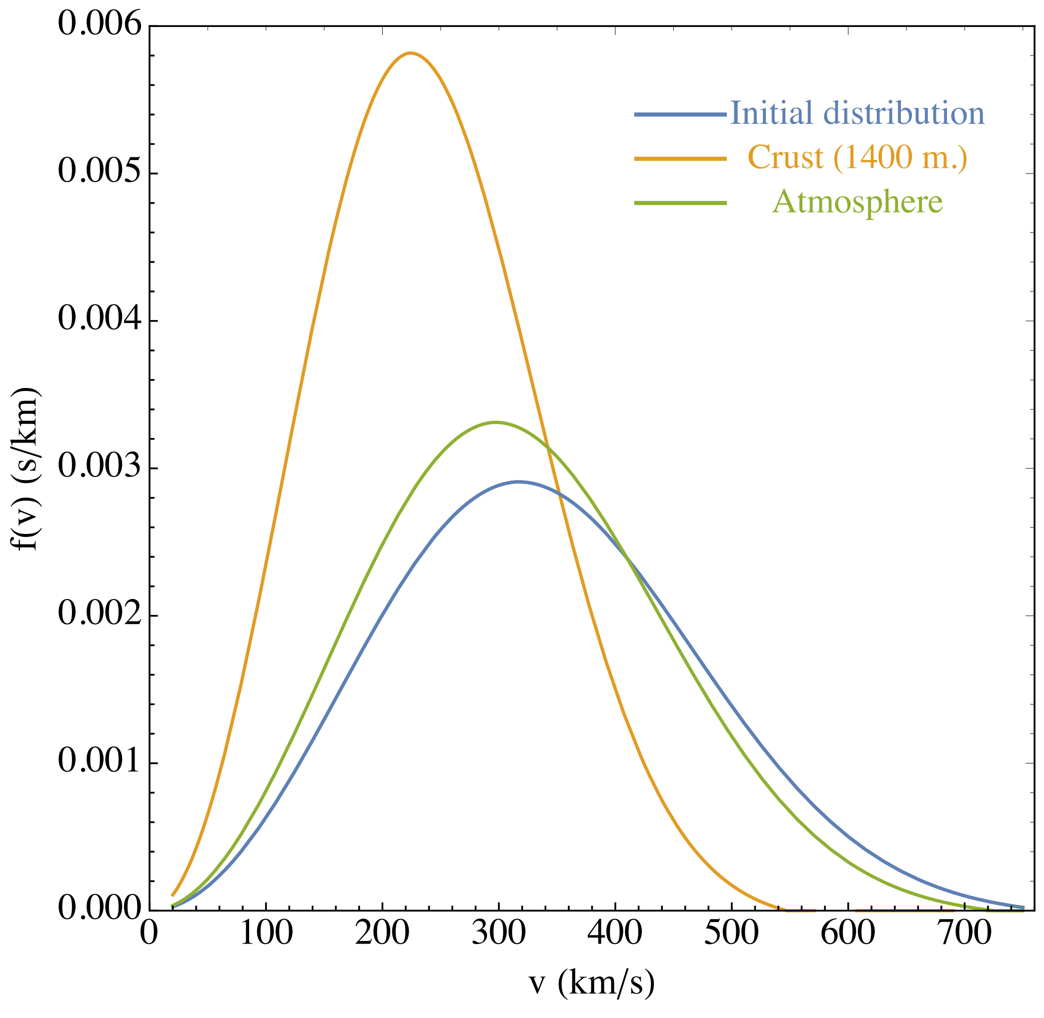
$$\frac{d\sigma}{dE_{NR}} = \left(\frac{\overline{\sigma}_e}{2\mu_{\chi e}^2 v^2}\right) \times m_N Z^2 \times F_{DM}(q)^2$$

Estimation of the stopping power

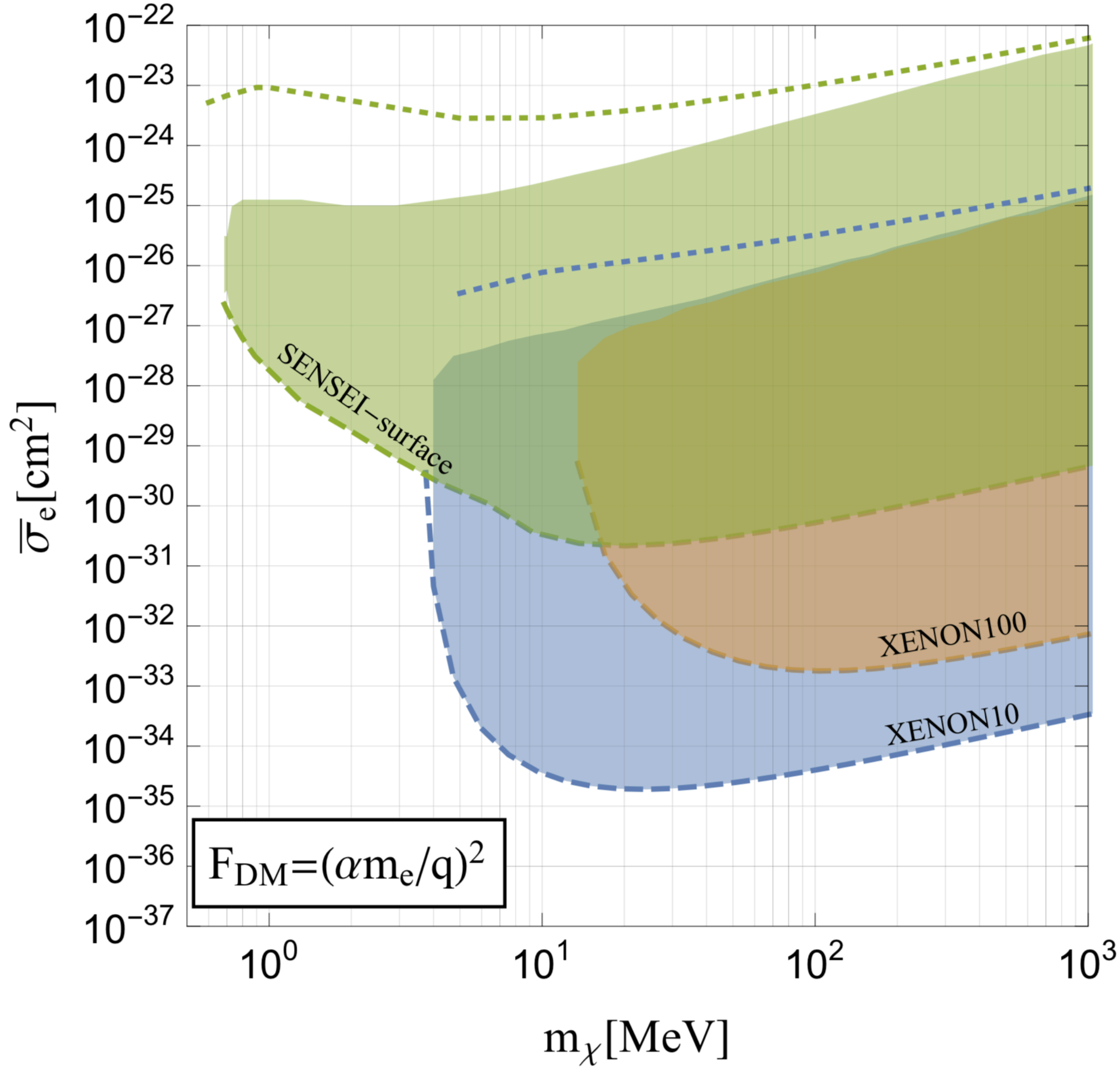
- **Monte Carlo simulations :**
  - Simulate the DM particles traveling through the Earth's crust or the atmosphere. (Reference : Emken and Kouvaris 1706.02249)
  - Analysis includes deflections in the trajectory.

- **Semi- analytic method :**
  - Calculate the final velocity distribution of the DM particles after passing through the crust or the atmosphere.
  - Analysis assumes no deflections in the trajectory.

Effect on the velocity distribution functions



Results: Ultralight mediator



Conclusions

- The semi-analytic method is a good approximation for calculating the stopping power for heavier dark matter. For low mass dark matter, deflections dominate and hence the analytic approximation breaks down.
- The terrestrial effect has to be taken into account while calculating the limits for a particular experiment.
- The upper limits from these terrestrial effects could open parameter space previously thought to be closed.