Novel Method for Detecting Ultralight Dark Matter

In preparation

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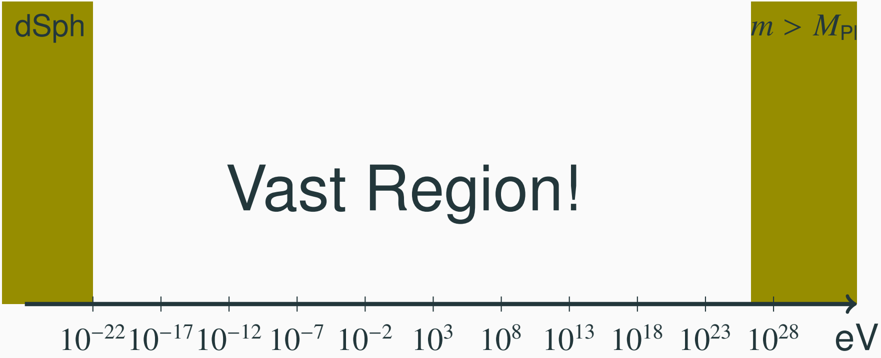
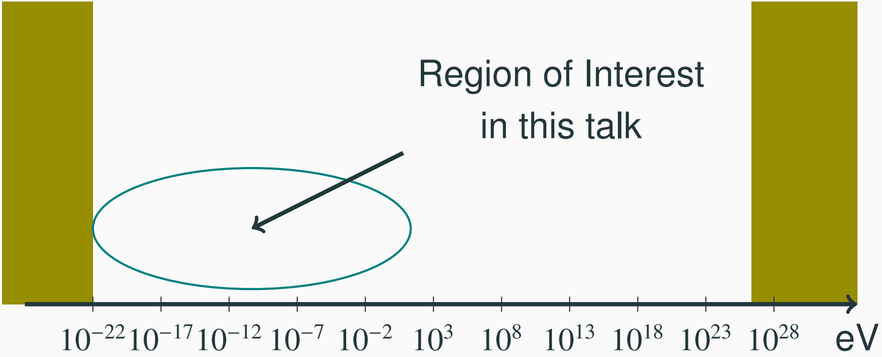
Introduction

- Dark matter is one of the most rigid new physics
- Which mass range?

Particle DM Mass Range



Particle DM Mass Range



Ultralight DM

- DM for 10^{-22} eV $\lesssim m_{\text{DM}} \lesssim$ eV
- Must be Bosonic
- Several interesting astrophysical signature
    - *e.g.* Hu, *et al.*, 2000
- Moduli d.o.f.? ALP?

Most Important Point

- Does DM have non-gravitational interaction? How could we detect them?
    - Production - $\times$
    - Indirect Detection - $\times$ (or $\triangle$)
    - **Direct Detection**

Direct Detection

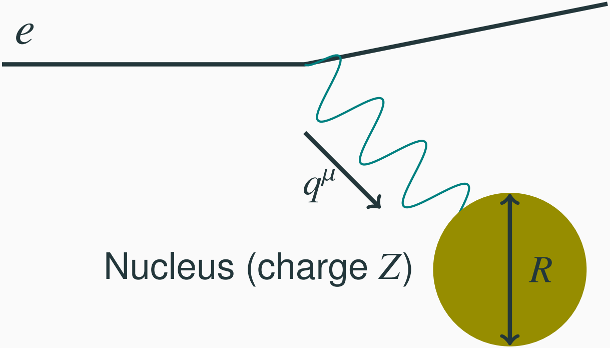
- One recoil may be small
    - Not enough to detect itself
- However, n_{DM} is quite large
- **What is an appropriate target?**
    - Measurement must be precise enough
    - Large enhancement

Enhancement Effect

- The cross section gets enhanced by
  - Stimulated emission
    - We don’t include since DM distribution is unknown
  - **Coherent effect on the target**

Coherent Effect

- e.g. Coulomb scattering



- For $qR < 1$, $\sigma \propto Z^2$!

Coherent Effect

- Naively, $\sigma \propto N_{\text{targ}}^2$
  - The interaction must be "spin-independent"
- The larger, the better
- **Use planets as the target!**, $N \sim 10^{50\text{–}58}$
  - Measurement is very accurate, $\Delta v / v \Delta t \lesssim 10^{-(17\text{–}19)}\ \text{s}^{-1}$

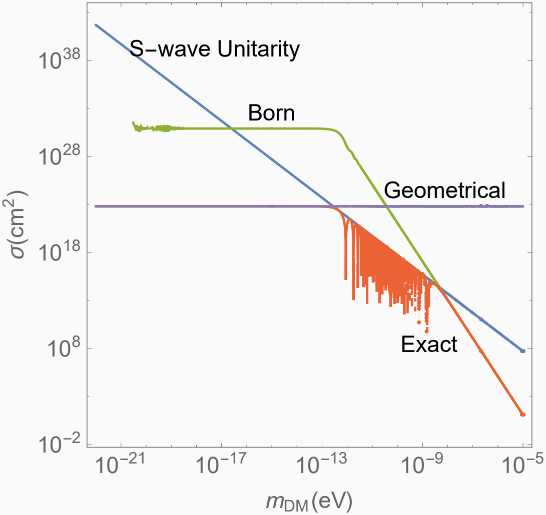
Real Cross Section

- Unfortunately, simple N_{targ}^2 scaling is wrong
- What happens in the coherence:
  $\mathcal{A}_{\text{tot}} = \sum e^{ik\Delta r_i}\mathcal{A}_i \sim N\mathcal{A} \quad (k\Delta r_i \to 0)$
  - Each scattering must be nearly independent
  - The incident wave is too disturbed for large N

Real Cross Section

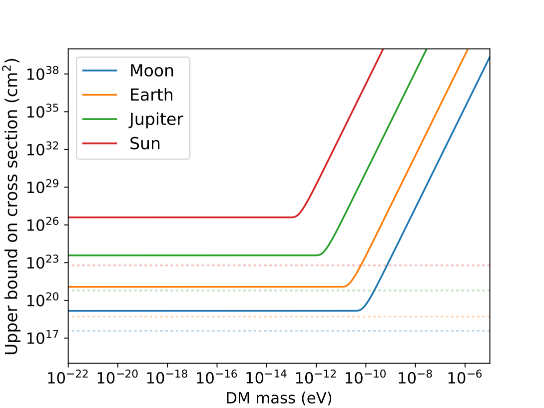
- How the planets look like to DM?
  - Uniform sphere → **Constant potential sphere**
- **Schrödinger eq. with** $V(r) = V_0\Theta(R-r)$
  - V_0 must be $V_0(\rho_{\text{targ}})$
    - Matching V_0 for small enough r with N^2 enhancement

Real Cross Section (for the Sun)



Final Result

- For the best target, we need one order more
  - $\sigma \sim {m_{\mathrm{DM}}}^2/\Lambda^4, \Lambda \sim 10^{13}$ GeV ($m \lesssim 10^{-14}$ eV)



Summary

- For ultralight DM $m \ll$ eV, the celestial bodies in the solar system can be good targets for the direct detection
- We need a few order more accuracy, but then we may reach as much as 10^{13} GeV