# Detecting Dark Blobs

**Dorota M Grabowska**

UC Berkeley and LBL

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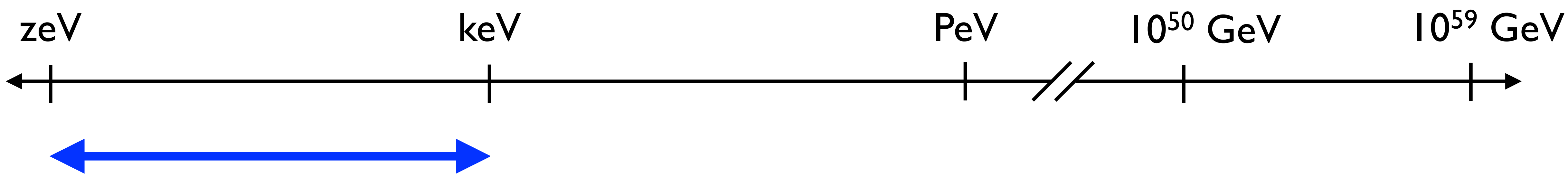


Ultra Light DM

Axions, ALPS, etc

*Need classically coherent fields to compensate for weak coupling*

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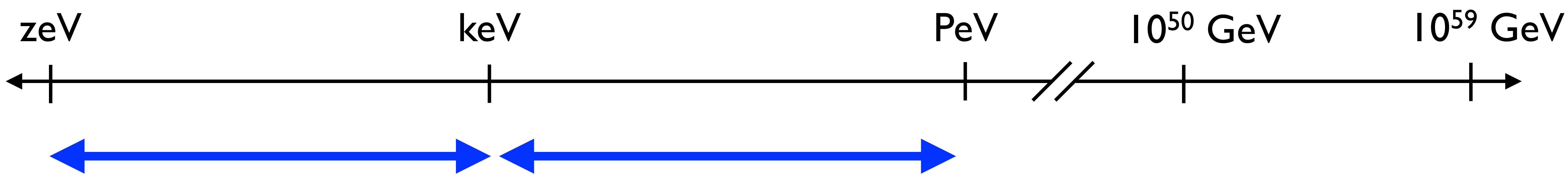


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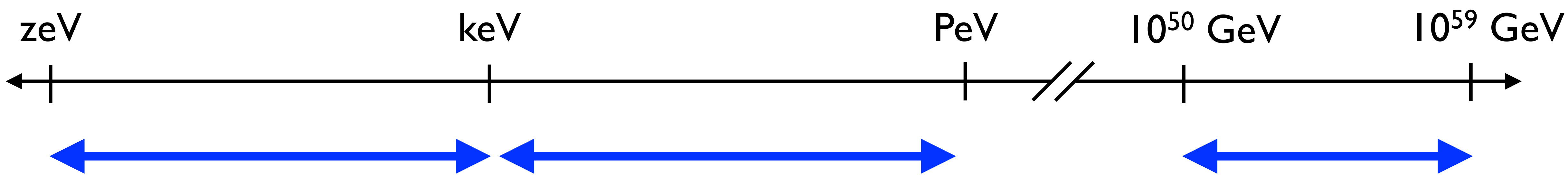


| Ultra Light DM | Particle DM | Macroscopic DM ($M_\odot \sim 10^{57}$ GeV) |
|---|---|---|
| Axions, ALPS, etc | WIMPs, Hidden Sector, Asymmetric, etc | Primordial Black Holes, MACHOS, etc |
| *Need classically coherent fields to compensate for weak coupling* | *Need high number density to compensate for small cross sections* | *Need high mass to detect gravitationally* |

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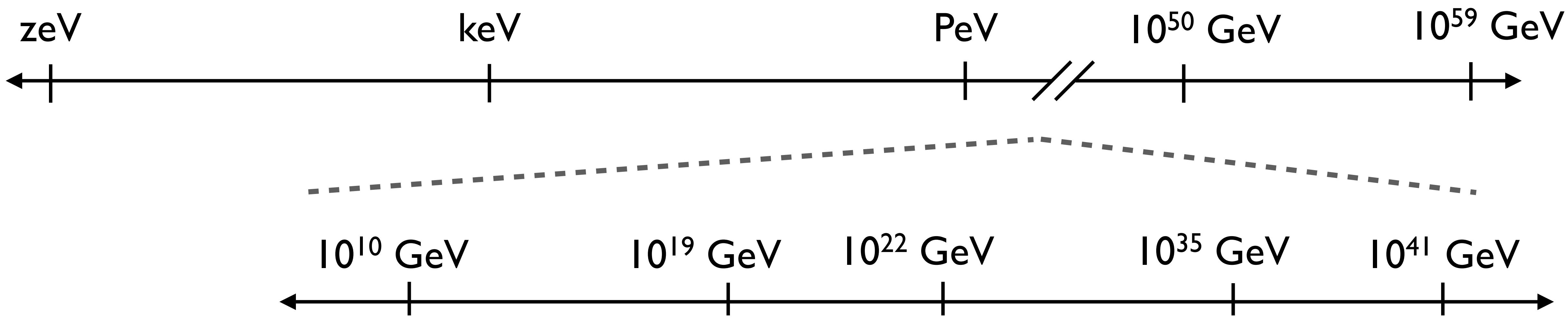

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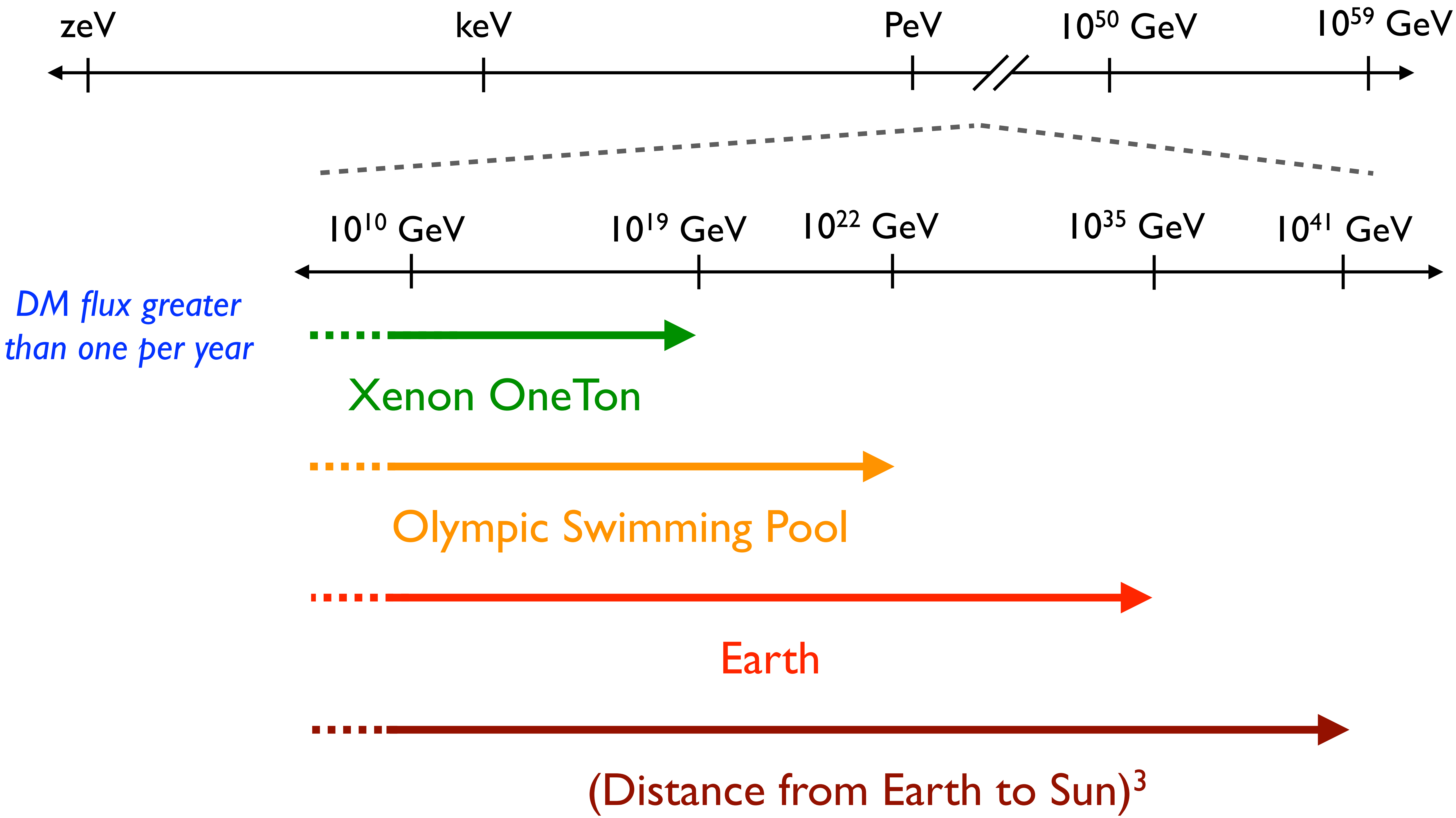

# Plan and Outline

**Goal:** Convince you of two key points

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**Outline:** Discuss formation, detection of one model

3. Illustrative model: strongly interacting dark sector

4. Discuss formation: dark nucleosynthesis

5. Present several detection methods: MACRO, hydrophones, and NMR

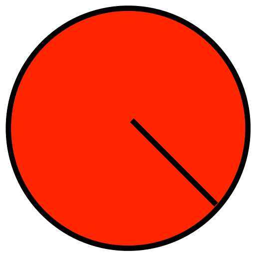
# Strongly Interacting Dark Sector

*"Dark QCD"*

General Properties

- Theory confines at energy scale $\Lambda_X$
- Spectrum contains massive particle with $m_x \sim \Lambda_x$

*"Dark Nucleon"*



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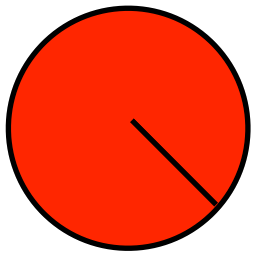

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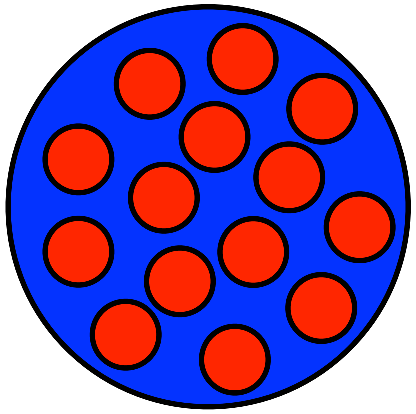
- Massive particles form bound states with $M_x \sim N_x \, \Lambda_x$

*"Dark Nucleus"*



$R_x \sim N_x^{1/3}/\Lambda_x$

- Relic abundance set by dark baryon asymmetry

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*Semi-empirical mass formula*

Treat dark nuclei as drop of liquid to determine how binding energy depends on number of constituents

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**Binding energy unbounded from above!**

# Formation of Dark Nuclei

*Freeze out of Dark Fusion*

Dark nuclei size is only limited by how long fusion lasts during early universe

- Need to compare fusion rate to Hubble expansion

$$\frac{\Gamma}{H} \sim 0.2 \left(\frac{g^*(T)}{10.2}\right)^{1/2} \left(\frac{100 \text{ MeV}}{\Lambda_\chi}\right)^{7/2} \left(\frac{10^{17}}{N_X}\right)^{5/6} \left(\frac{T}{\text{MeV}}\right)^{3/2} \left(\frac{T_\chi}{T}\right)^{1/2}$$

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*Relativistic DoF at decoupling* *Photon Temperature*

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*Dark Sector Temperature*

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*Number of Constituents*

- Generically find exponentially large constituents bound into dark nuclei

$$M_X \sim 10^{15}\ \mathrm{GeV} \left(\frac{g^*(T)}{10.2}\right)^{3/5} \left(\frac{100\ \mathrm{MeV}}{\Lambda_\chi}\right)^{16/5} \left(\frac{T}{\mathrm{MeV}}\right)^{9/5} \left(\frac{T_\chi}{T}\right)^{3/5}$$

# Progress

**Goal:** Convince you of two key points

1. Viable DM candidates in this mass region

- Macroscopically large composite Dark Matter object: **BLOB**
- See Hardy et al (arXiv: 1411.3739) and Moira, Lou and Zurek (arXiv: 1707.02313 and 1707.02316) for detailed analysis

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2. Detectable with existing experimental methods

   - MACRO
   - Hydrophones
   - NMR

# Coupling to Standard Model

Focus on coupling to nucleons and electrons

- Scalar Coupling
- PseudoScalar Coupling

$$\mathcal{L} \supset \frac{m_\varphi^2}{2}\varphi^2 + g_\chi \varphi\, \bar{\chi}\chi + g_f \varphi\, \bar{\psi}_f \psi_f + \frac{\partial_\mu \varphi}{F_f}\, \bar{\psi}_f \gamma_\mu \gamma_5 \psi_f$$

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Three types of experimental signatures

- Ionization and Scintillation
- Localized energy deposition
- Spin Precession

# Non-relativistic Potentials

Consider only long range mediator

- Classical treatment using non-relativistic potentials

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Scalar Coupling

$$V(r) \sim \frac{e^{-m_\varphi r}}{r}$$

*Spin Independent*

PseudoScalar Coupling

$$V(r) \sim \frac{\hat{\sigma}\cdot\hat{r}}{F_f}\frac{e^{-m_\varphi r}}{r^2}(1 + m_\varphi r)$$

*Spin Dependent*

# Ionization and Scintillation Signals

**Ionization/Scintillation:** Depends on momentum transfer during ***SINGLE*** collision

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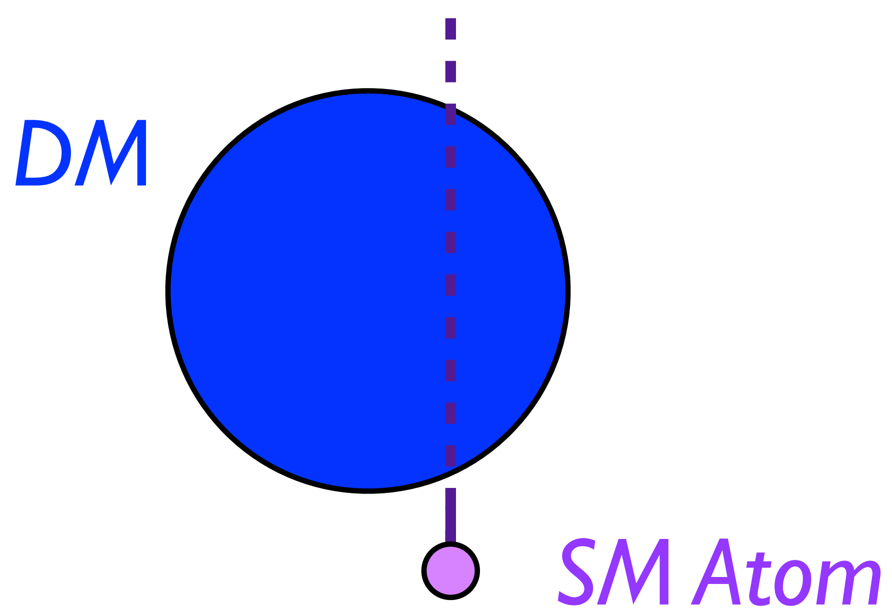

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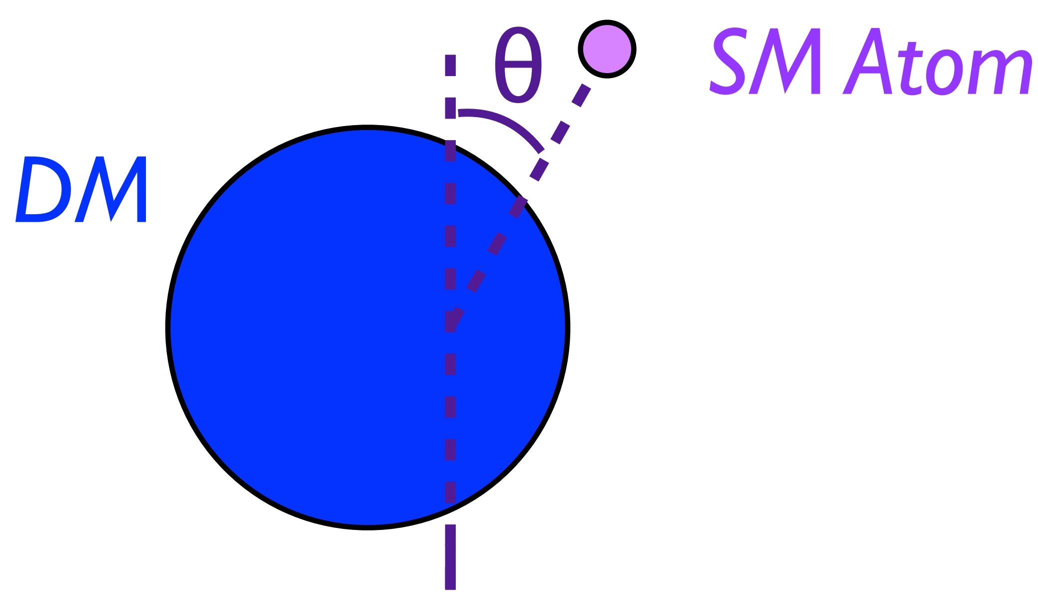

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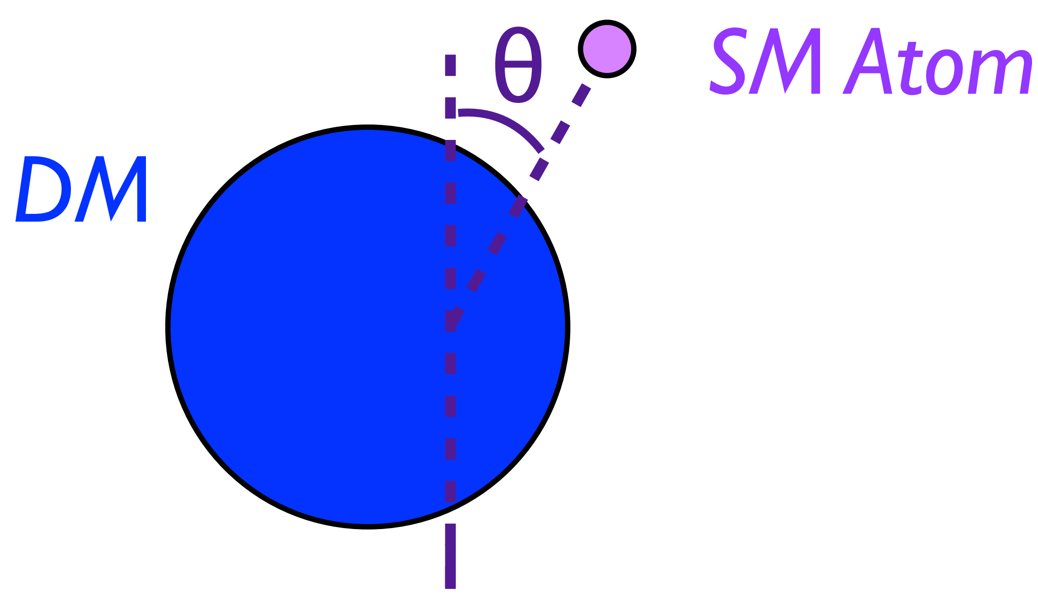


*Scalar*

$$\Delta p \sim 0.1 \frac{g_\chi g_f N_f}{v} \left(\Lambda_\chi M_X^2\right)^{1/3}$$

*PseudoScalar*

$$\Delta p \sim 0.01 \frac{g_\chi}{v} \left(\frac{\Lambda_\chi^5 M_X}{F_f^3}\right)^{1/3}$$

# MACRO

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**Blobs:** Produce signal similar to magnetic monopole for sufficiently high energy deposition

- Momentum transfer depends on $g_X$ and $g_f$ or $F_f$, which have independent constraints
- Sensitivity limited to $M_X < 10^{24}$ GeV due to total exposure

# Mediator Coupling Constraints

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**$g_f$ Bound:** Fifth force and inverse square law test

- Constrained by precision gravity tests such as torsion balances or lunar laser ranging
- Constraints exist for mediator ranges of $(10^{-5} - 10^{14})$ m

**$F_f$ Bound:** White dwarf cooling, SN 1987A neutrino emission

- Analogous to Axion-like particle bounds

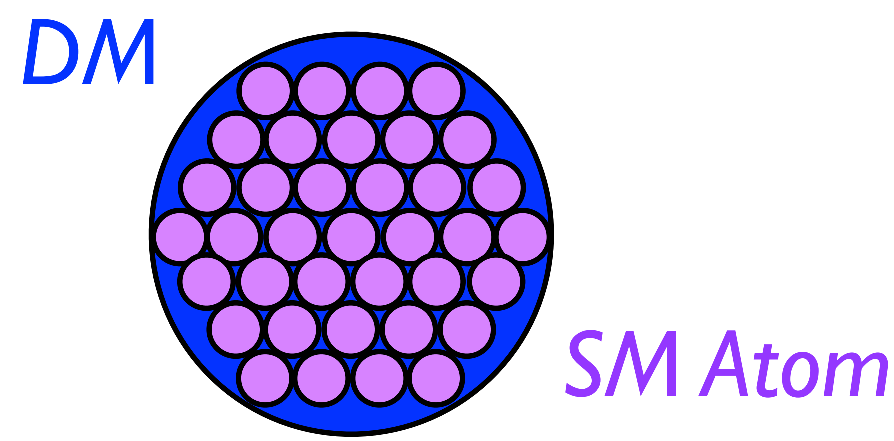
# Hydrophones

*Localized energy deposition*

**General Idea:** Blobs deposit large amounts of energy without necessarily causing ionization/scintillation

- Large blob radius allows multiple SM atoms to experience significant change in momentum

$$\Delta E_{\mathrm{Tot}} \sim \left(\frac{R_X}{R_0}\right)^2 \Delta E^{\mathrm{Max}}_{\mathrm{Single}}$$



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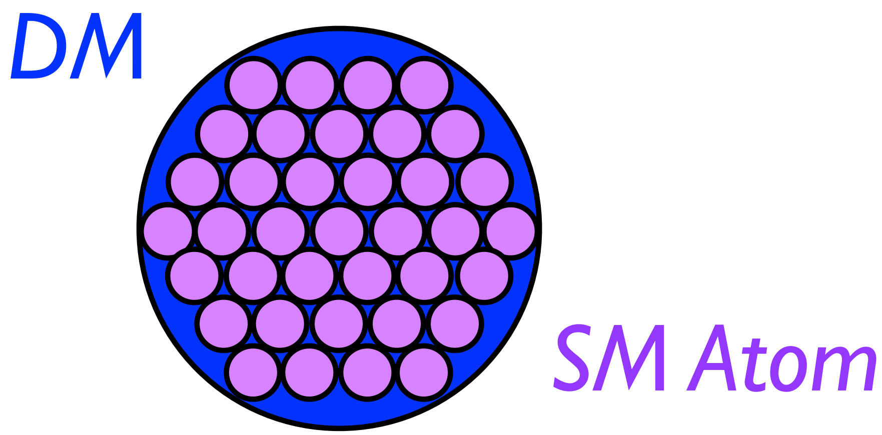


- **Example:** Hydrophones in tank of water are sensitive to energy deposition of ~ 10 keV/Angstrom

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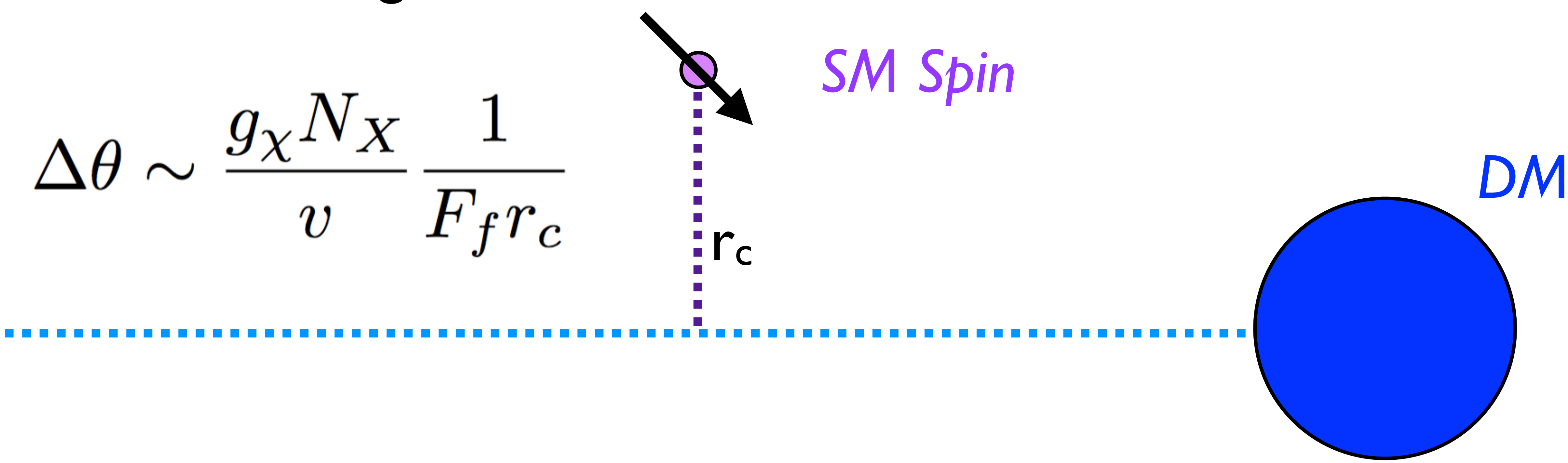

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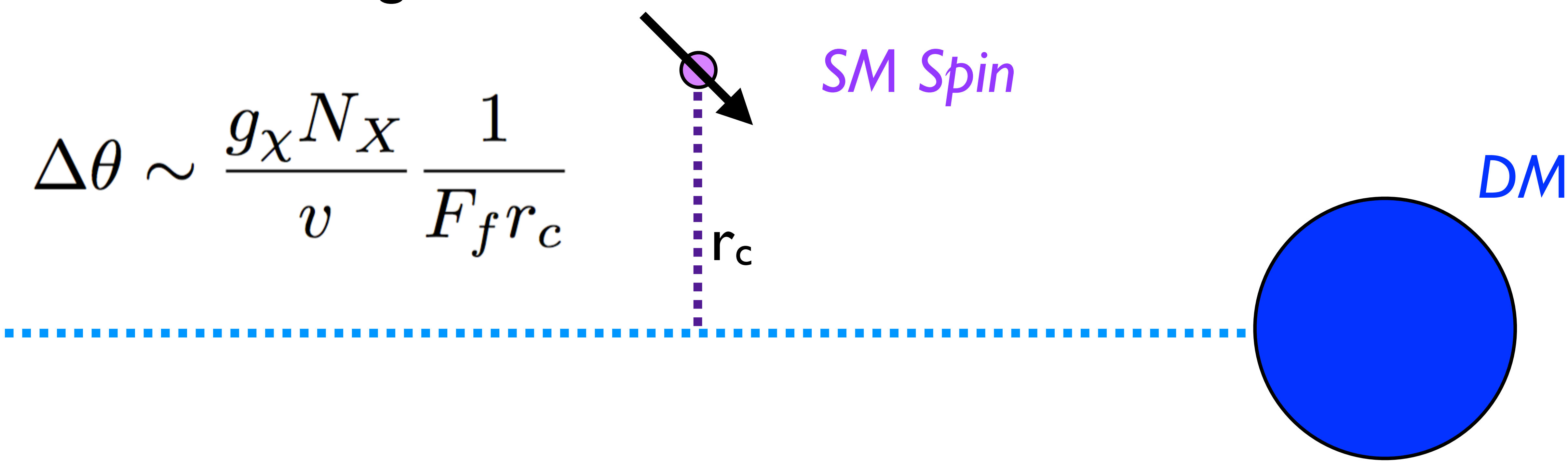
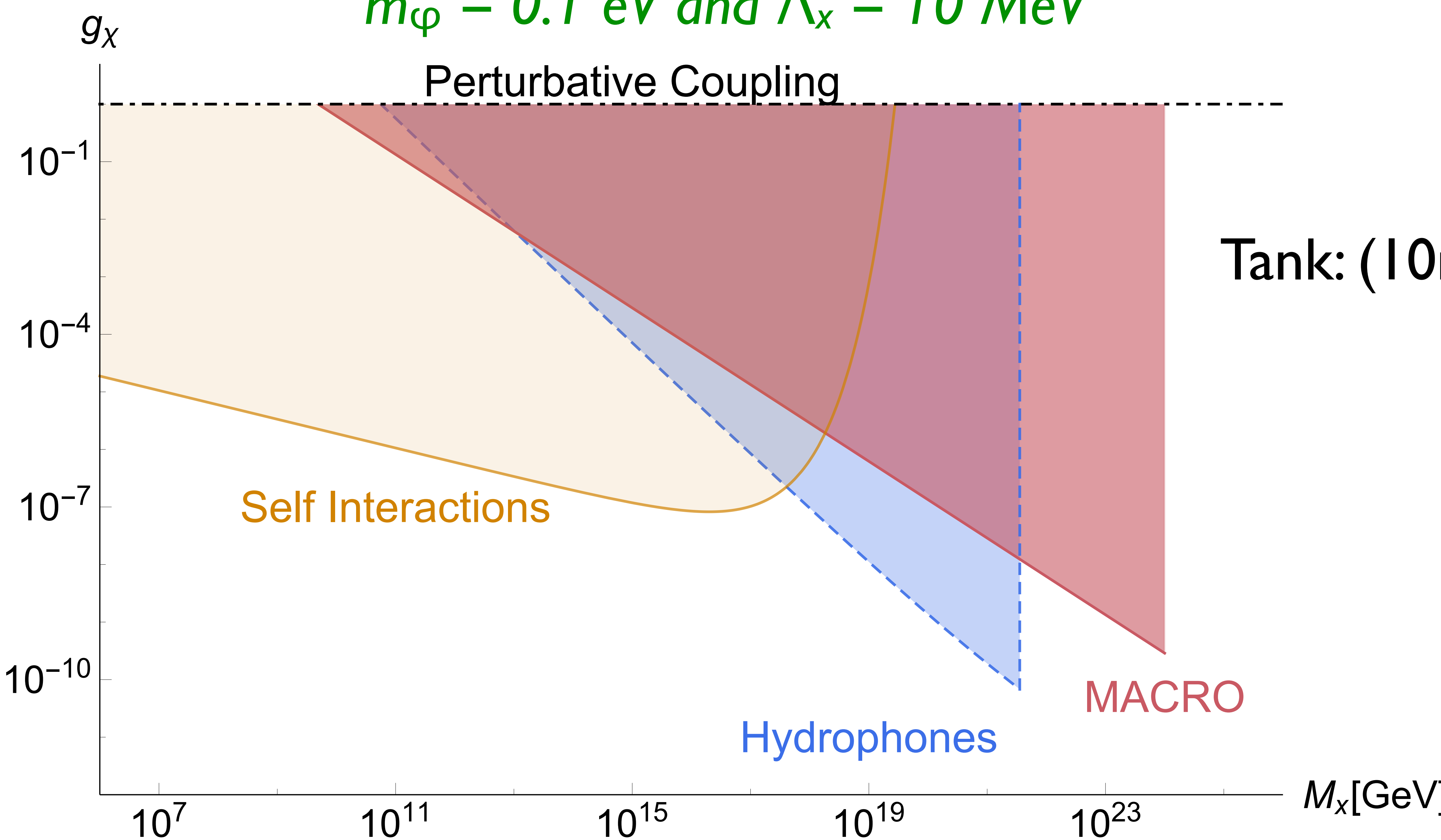



- **Example:** SQUID in CASPEr is sensitive to $\Delta M \sim 0.1$ fT

# Scalar Mediator to Nucleons

$m_\varphi = 0.1$ eV and $\Lambda_x = 10$ MeV

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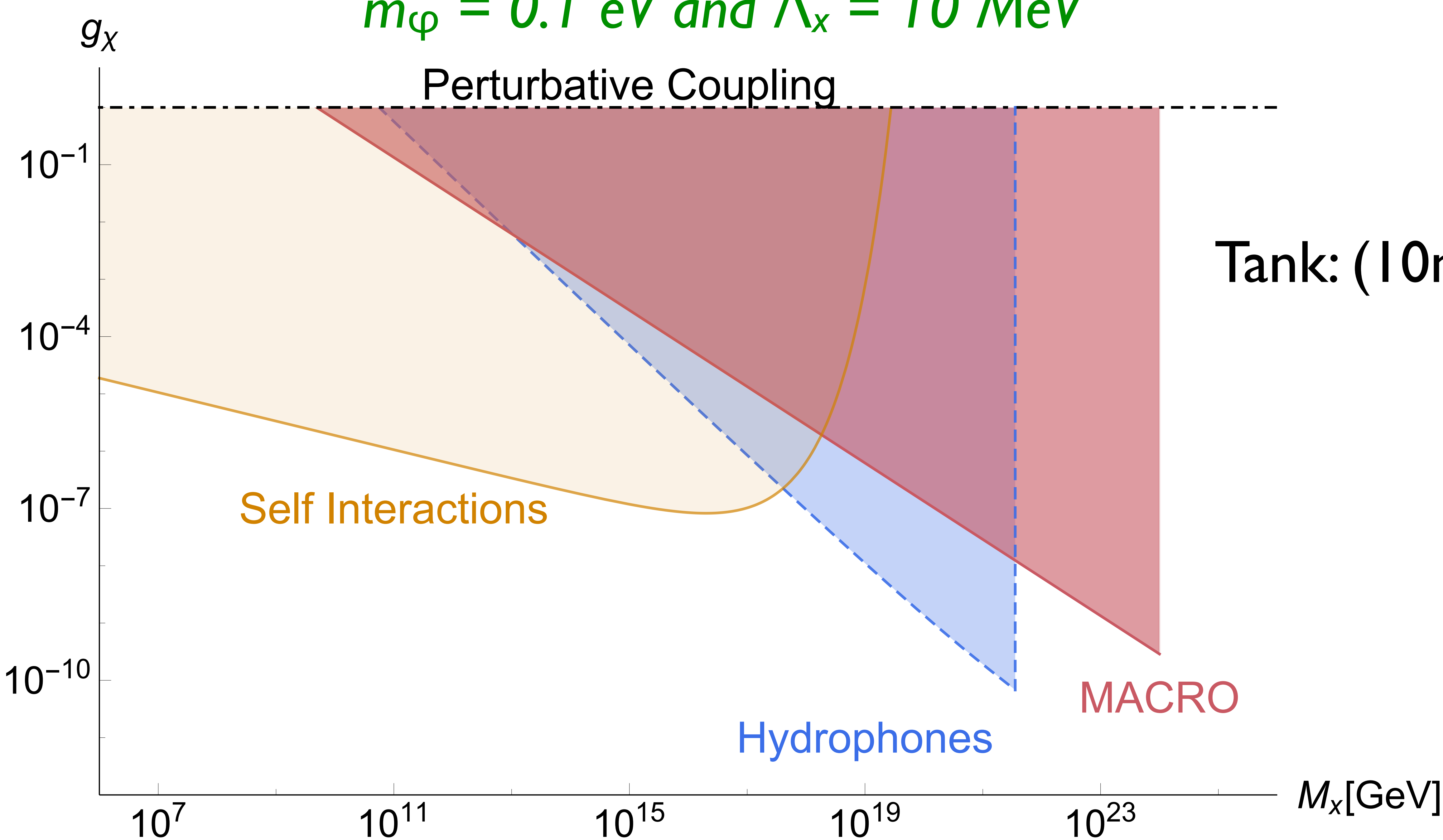


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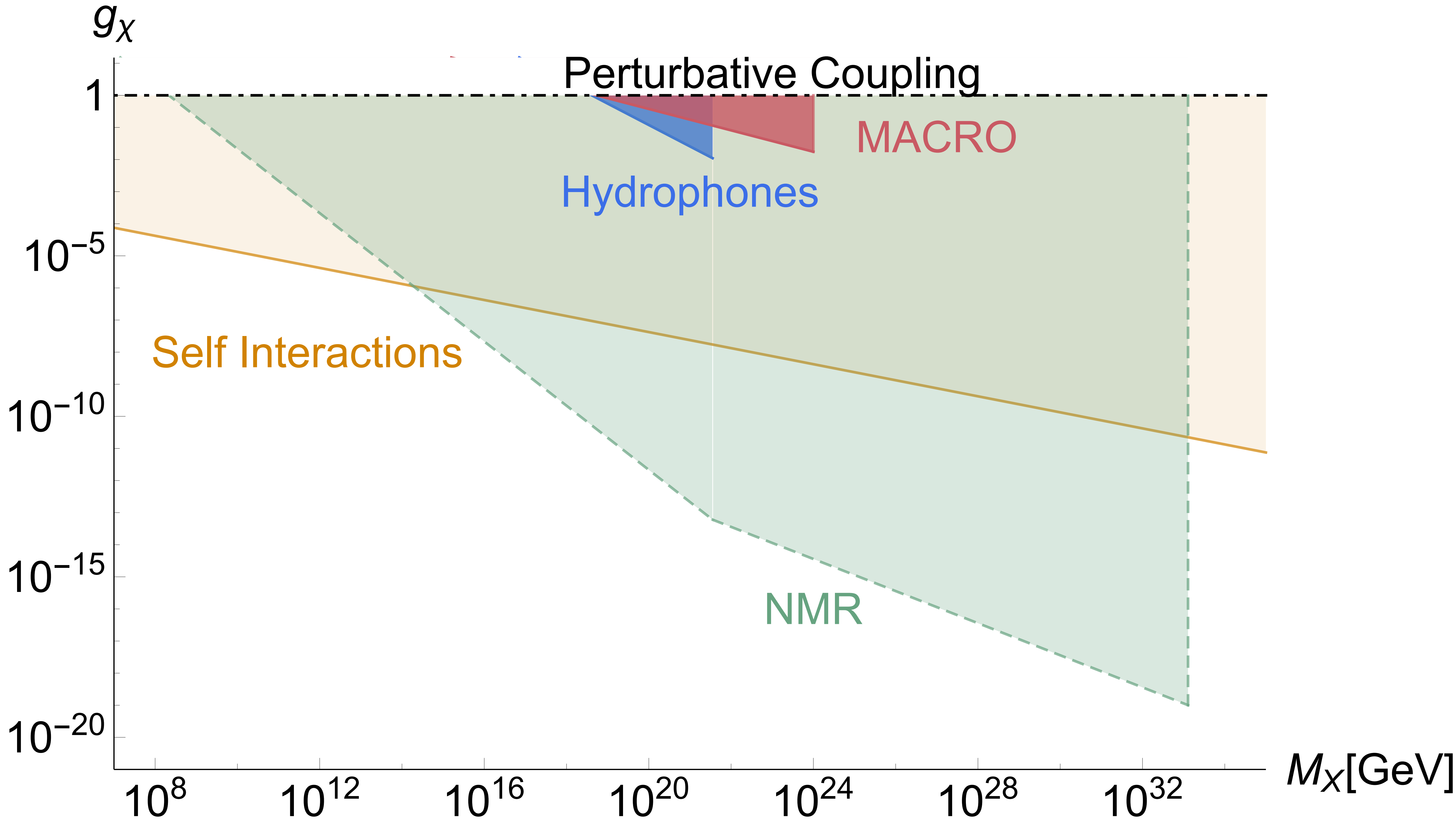
$$\Delta E_{\mathrm{MACRO}} \sim g_\chi^2 \left(\frac{M_X}{10^{10}\ \mathrm{GeV}}\right)^{4/3} \mathrm{eV} \qquad \Delta E_{\mathrm{HYDRO}} \sim 10\, g_\chi^2 \left(\frac{M_X}{3\times 10^{11}\ \mathrm{GeV}}\right)^{2} \mathrm{keV}$$

# PseudoScalar Mediator to Electrons

$m_\varphi = 10^{-14}$ eV and $\Lambda_\chi = 100$ MeV



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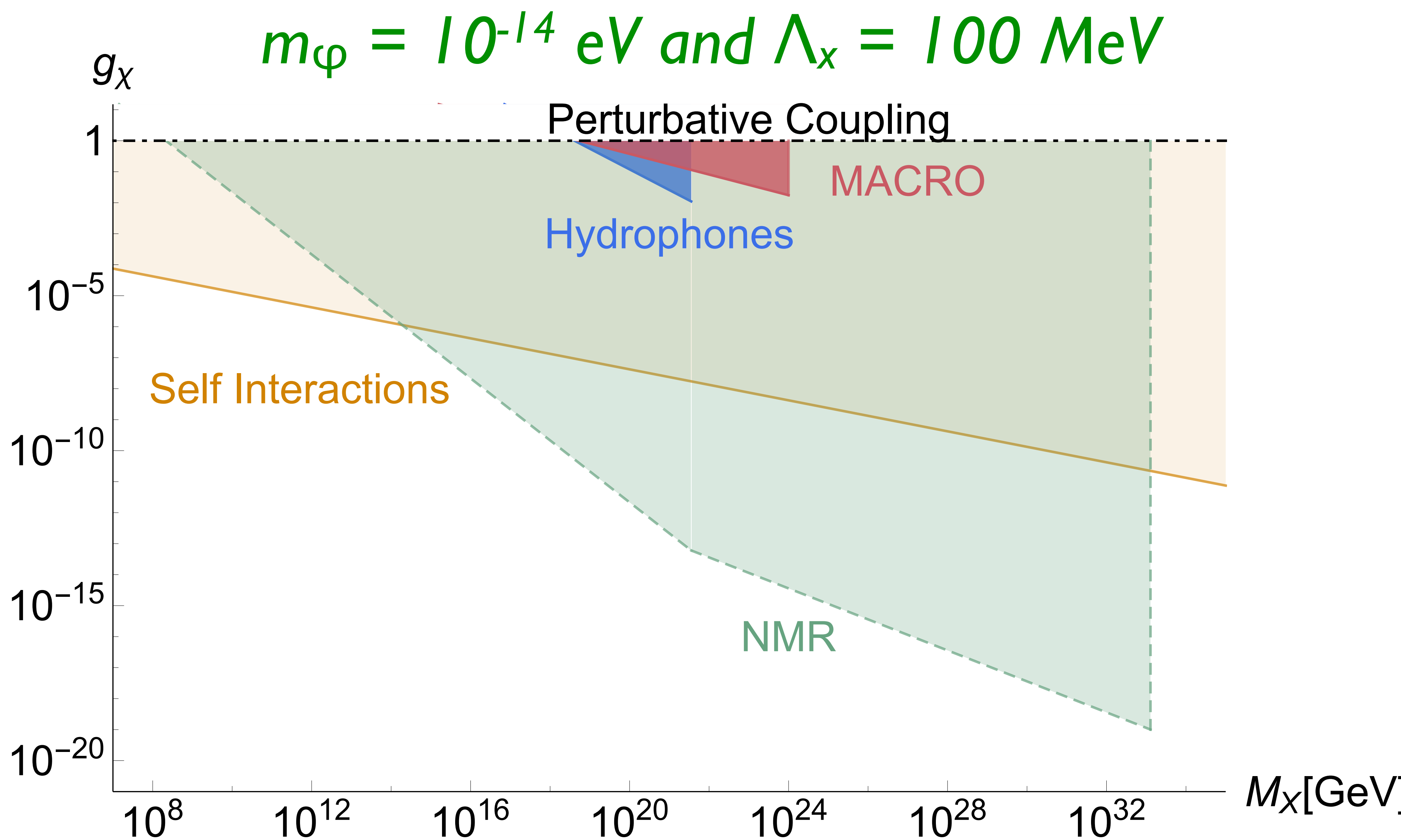


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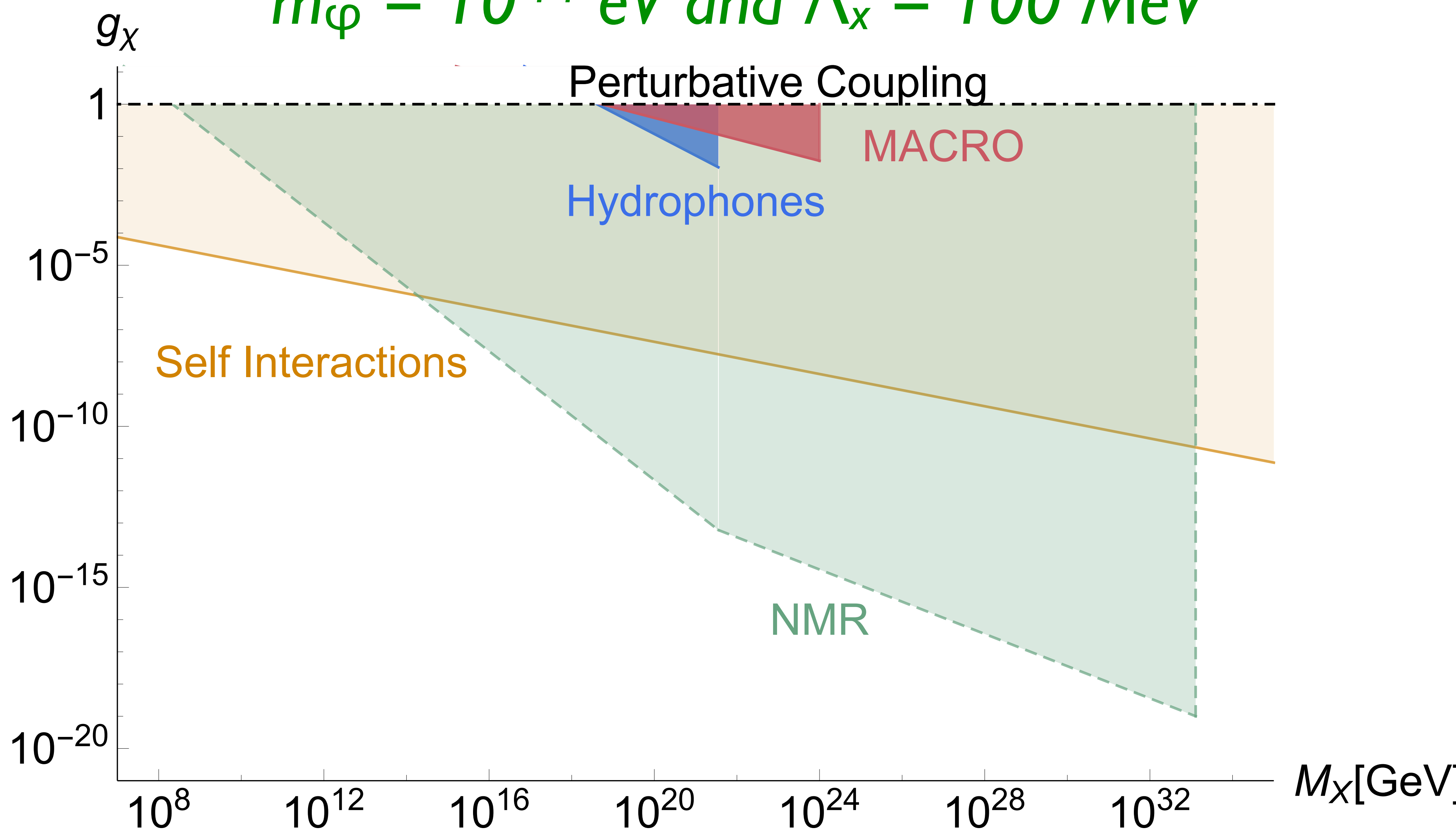


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$$\Delta M_{\mathrm{NMR}} \sim 10^{-16}\, g_\chi \left(\frac{M_X}{10^{9}\ \mathrm{GeV}}\right)\left(\frac{10\,\mathrm{m}}{r_c}\right) \mathrm{Tesla}$$

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2. Detectable with existing experimental methods
   - Ionization and Scintillation signals (MACRO)
   - Localized energy deposition (Hydrophones, etc)
   - Spin Precession (CASPEr and other NMR experiments)