

# Influence of Quadratic Axion-Matter Interaction on the Direct Detection of Dark Matter

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# 1. Introduction

- Axions and gluon-coupled ALPs present the coupling

$$\frac{\phi}{f_a} \frac{g_s^2}{32\pi^2} G^{\mu\nu} \tilde{G}^{\mu\nu}$$

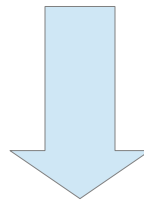
- At low energies, this coupling produces a potential for ALPs that gets modified by **nucleon densities**

$$V(\phi) = -m_\pi^2 f_\pi^2 \left\{ \left( \epsilon - \frac{\sigma_N \rho}{m_\pi^2 f_\pi^2} \right) \left| \cos\left(\frac{\phi}{2f_a}\right) \right| + \mathcal{O}\left(\left(\frac{\sigma_N \rho}{m_\pi^2 f_\pi^2}\right)^2\right) \right\}$$

$$\sigma_N = \sum_{q=u,d} m_q \frac{\partial m_N}{\partial m_q} \sim 59 \text{ MeV} \quad [\text{Hook, Huang 2017}]$$

- For small values of the field ( $f_a \gg \phi$ ) the effective Lagrangian for ALPs reads

$$\mathcal{L} = \frac{1}{2}(\partial\phi)^2 - \frac{1}{2}m^2\phi^2 - \frac{\lambda}{2}\phi^2\rho \quad \begin{cases} m^2 = \frac{m_\pi^2 f_\pi^2 \epsilon}{4f_a^2} \\ \lambda = \frac{\sigma_N}{4f_a^2} \end{cases}$$



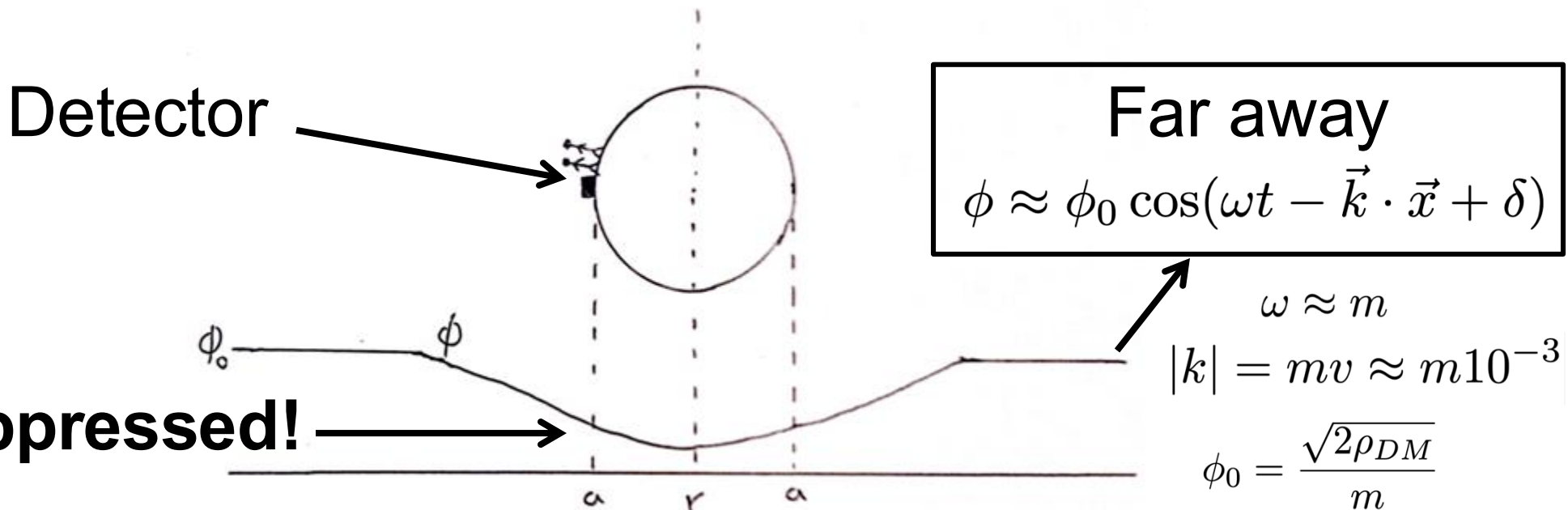
$$\left(\square + m^2 + \lambda\rho\right)\phi = 0$$

[Hees et al. 2018,  
Balkin et al. 2022,  
Banerjee et al. 2023,  
Bauer et al. 2024]

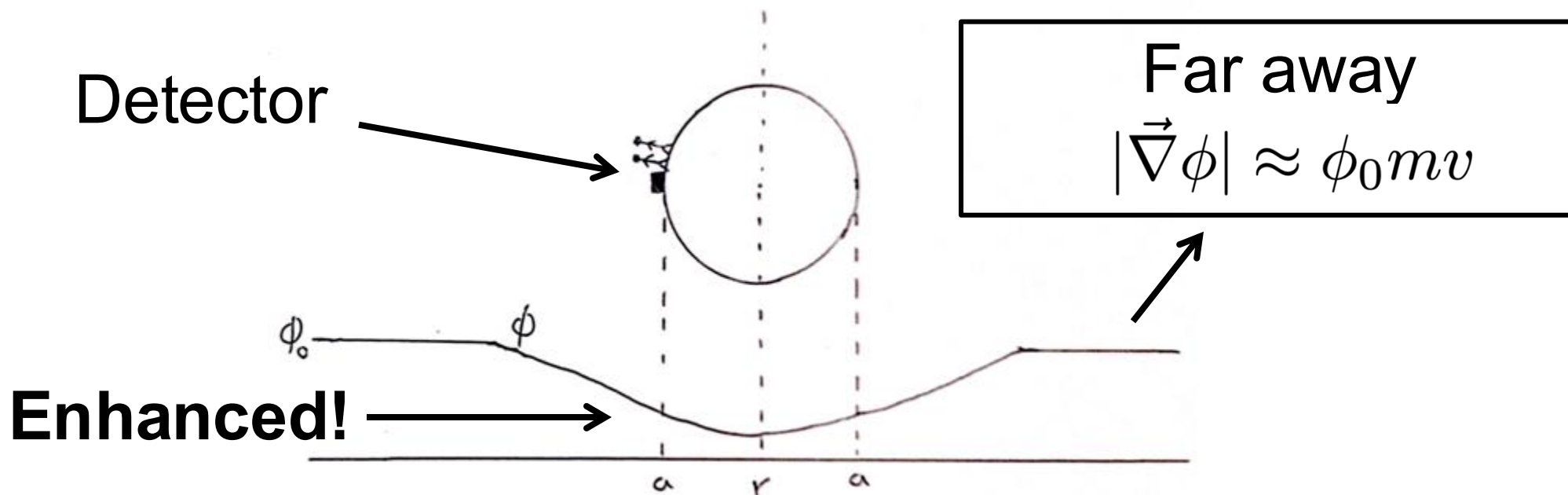
- Interesting phenomenology!
- Nucleon densities modify the ALP's field distribution.
  - Can be generated through other portals.

## 2. Modification of direct detection sensitivities

- Some experiments aim for interactions that are **proportional to the field** (e.g. CASPER-Electric ( $g_d \phi \bar{N} \sigma_{\mu\nu} \gamma_5 N F^{\mu\nu}$ ) or BREAD ( $\frac{1}{4} g_{\phi\gamma\gamma} \phi F_{\mu\nu} \tilde{F}^{\mu\nu}$ )).
- Sensitivity estimates with  $\phi_0$  too naive!  $\Rightarrow$  Earth affects!  $\Rightarrow$  Should be done with  $\phi(a)$ .

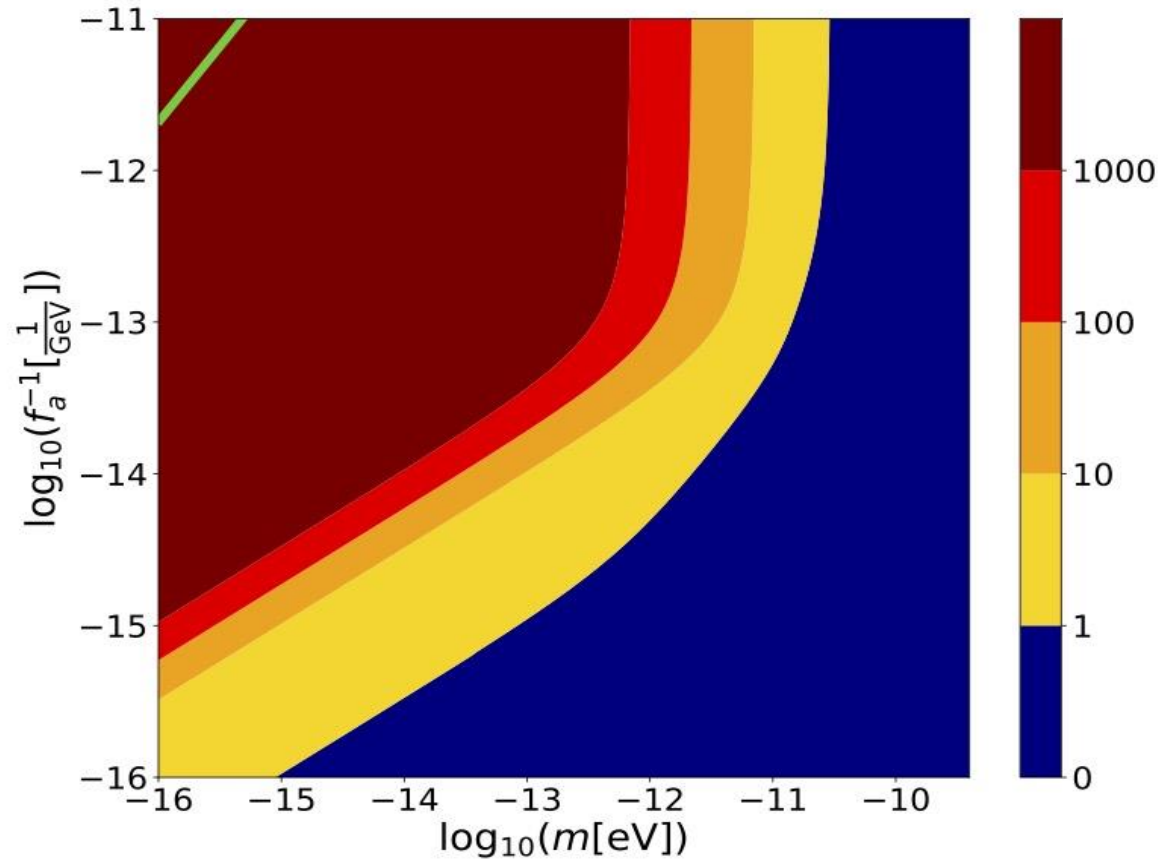


- Other experiments aim for interactions that are **proportional to the field's gradient** (e.g. CASPEr-Wind (  $g_{\phi NN} \partial_\mu \phi \bar{N} \gamma^\mu \gamma_5 N$  )).
- Sensitivity estimates with  $|\vec{\nabla} \phi| \approx \phi_0 m v$  too naive!  
Earth affects!  $\longrightarrow$  Should be done with  $|\vec{\nabla} \phi(a)|$ .



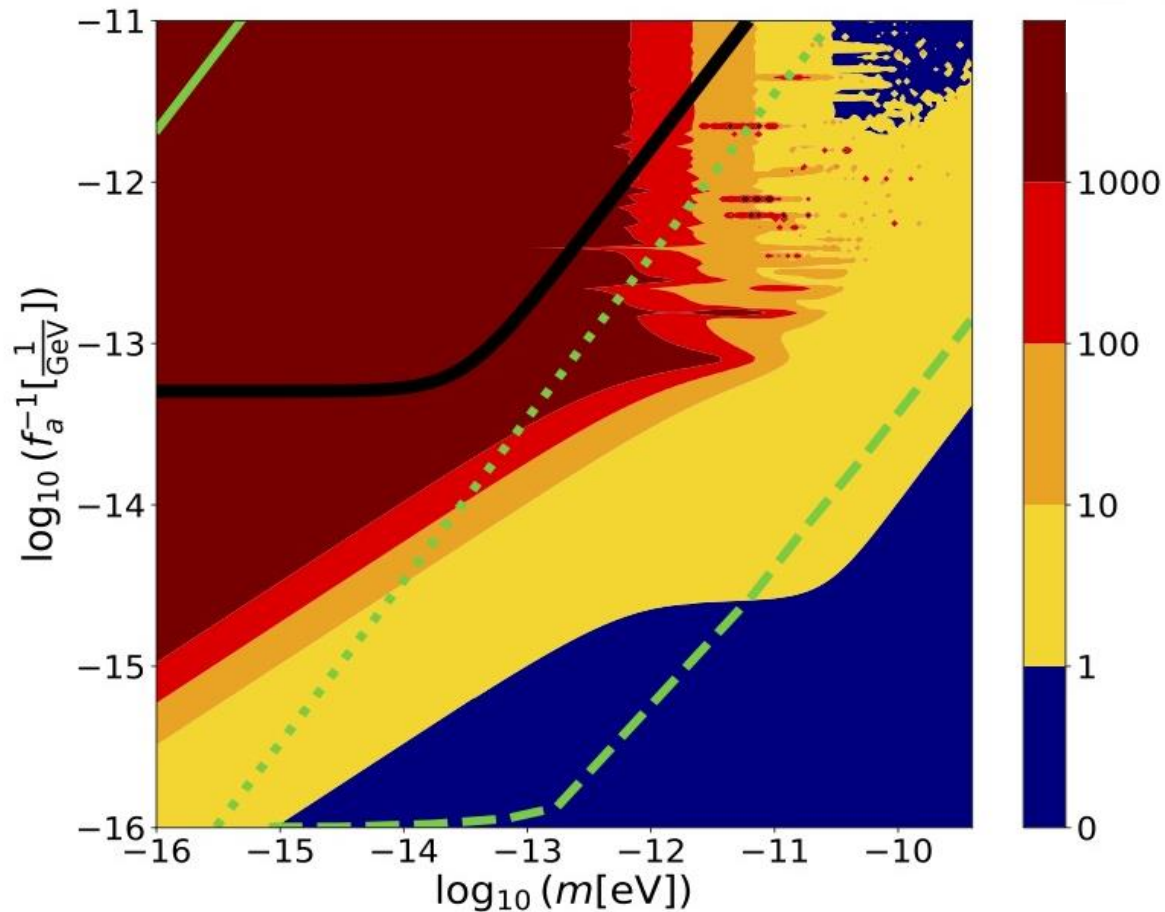
## 2.1 Repulsive coupling ( $\lambda > 0$ )

$$\frac{\int P_{rr}^{\text{modified}}(\omega, a, 0, 0) d\omega}{\int P_{rr}^{\text{free}}(\omega, a, 0, 0) d\omega}$$



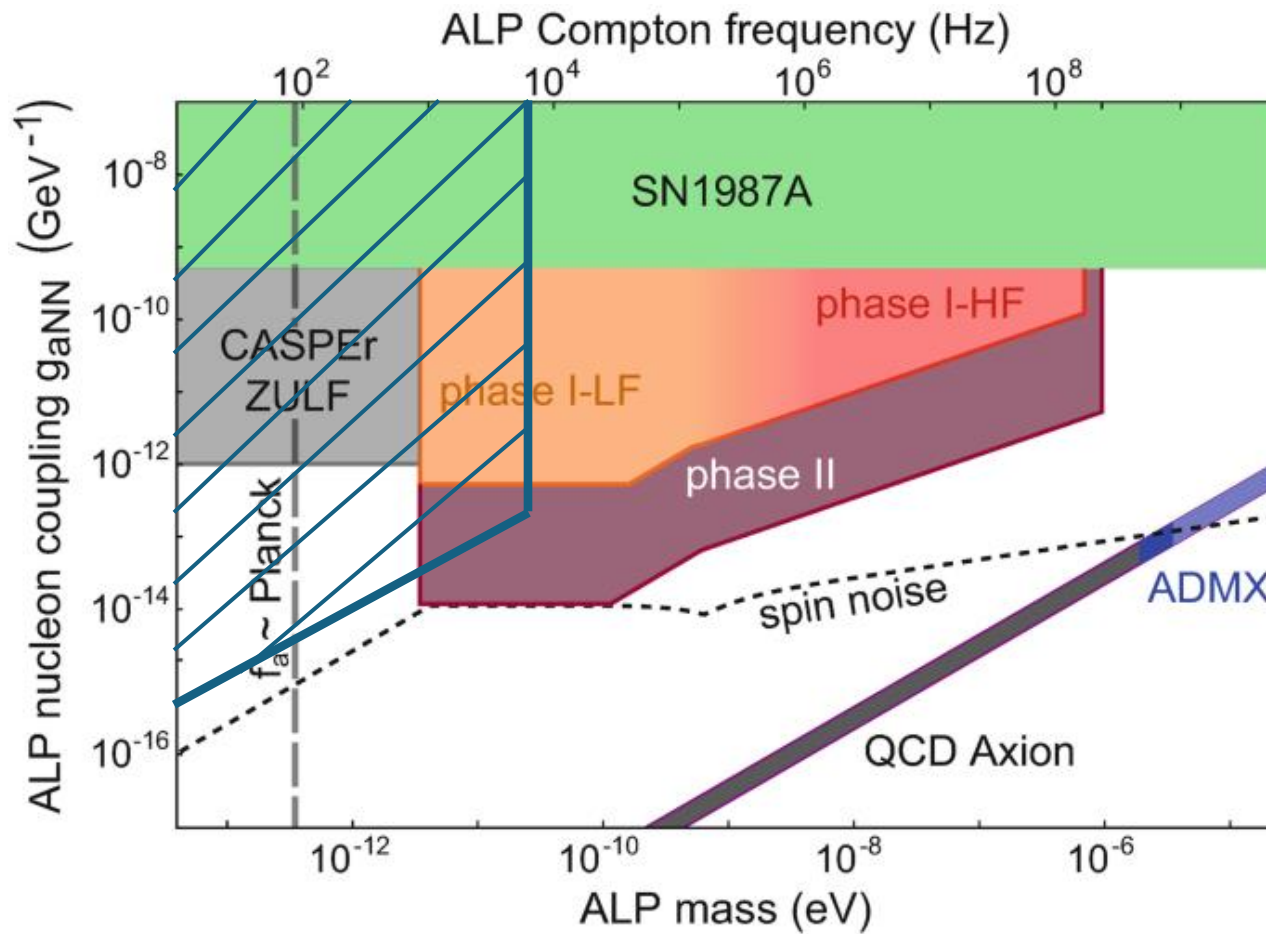
Enhanced sensitivity

## 2.2 Attractive coupling ( $\lambda < 0$ )



Interesting profile due to bound states

## 2.3 Enhanced sensitivity region in CASPEr-wind



# 3. Conclusions

- The presence of the Earth can affect sensitivities of direct detection.
- Enhanced sensitivities for experiments that aim for a gradient coupling, e.g. CASPEr-wind.

**Thank you for listening!**