Crystal responses to general dark matter-electron interactions

- We develop a novel framework allowing predictions of excitation rates in germanium and silicon crystals caused by dark matter (DM) electron interactions.
- We do this by using the fact that both gravitationally bound DM in our galaxy and the electrons in the detector are non-relativistic, which allows us to expand the matrix element in non-relativistic effective operators (shown in the table to the right).
- Using published data from experimental collaborations we can compute exclusion limits on interaction types that were previously not possible to model. As examples, we show exclusion limit plots for the Lagrangians in the lower right corner.

Einar Urdshals, arXiv: 2105.02233

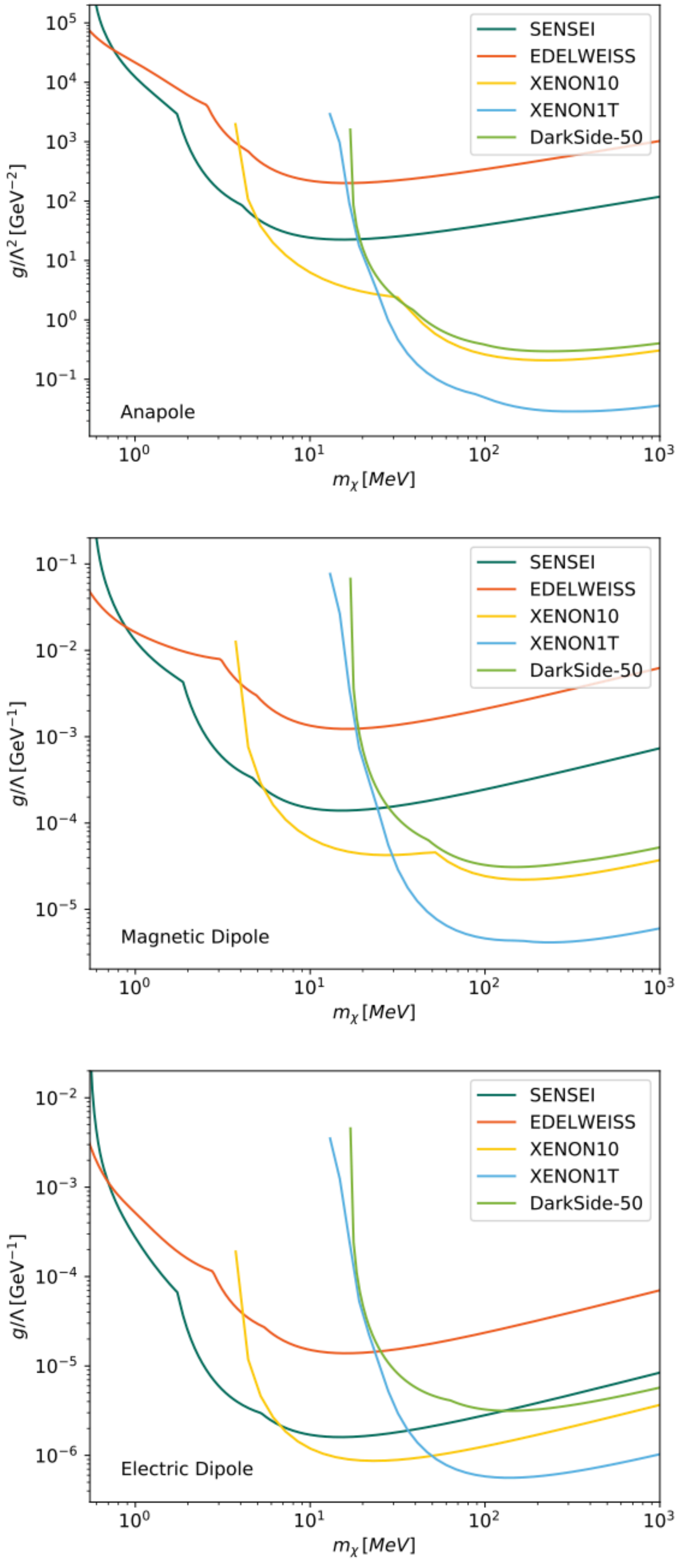

FIG. 9. 90% C.L. exclusion limits on the DM-electron coupling from data reported by SENSEI@MINOS [58] and EDELWEISS [59] and interpreted within the anapole (top panel), magnetic dipole (central panel) and electric dipole (bottom panel) DM models. For comparison, in each panel we also report the 90% C.L. exclusion limits found in [41] from the null result of experiments operating xenon (XENON10 and XENON1T) and argon (DarkSide-50) detectors.

$$\mathcal{O}_1 = \mathbb{1}_{\chi e} \qquad \mathcal{O}_9 = i\mathbf{S}_\chi \cdot \left(\mathbf{S}_e \times \frac{\mathbf{q}}{m_e}\right)$$

$$\mathcal{O}_3 = i\mathbf{S}_e \cdot \left(\frac{\mathbf{q}}{m_e} \times \mathbf{v}_{\rm el}^\perp\right) \qquad \mathcal{O}_{10} = i\mathbf{S}_e \cdot \frac{\mathbf{q}}{m_e}$$

$$\mathcal{O}_4 = \mathbf{S}_\chi \cdot \mathbf{S}_e \qquad \mathcal{O}_{11} = i\mathbf{S}_\chi \cdot \frac{\mathbf{q}}{m_e}$$

$$\mathcal{O}_5 = i\mathbf{S}_\chi \cdot \left(\frac{\mathbf{q}}{m_e} \times \mathbf{v}_{\rm el}^\perp\right) \qquad \mathcal{O}_{12} = \mathbf{S}_\chi \cdot \left(\mathbf{S}_e \times \mathbf{v}_{\rm el}^\perp\right)$$

$$\mathcal{O}_6 = \left(\mathbf{S}_\chi \cdot \frac{\mathbf{q}}{m_e}\right)\left(\mathbf{S}_e \cdot \frac{\hat{\mathbf{q}}}{m_e}\right) \qquad \mathcal{O}_{13} = i\left(\mathbf{S}_\chi \cdot \mathbf{v}_{\rm el}^\perp\right)\left(\mathbf{S}_e \cdot \frac{\mathbf{q}}{m_e}\right)$$

$$\mathcal{O}_7 = \mathbf{S}_e \cdot \mathbf{v}_{\rm el}^\perp \qquad \mathcal{O}_{14} = i\left(\mathbf{S}_\chi \cdot \frac{\mathbf{q}}{m_e}\right)\left(\mathbf{S}_e \cdot \mathbf{v}_{\rm el}^\perp\right)$$

$$\mathcal{O}_8 = \mathbf{S}_\chi \cdot \mathbf{v}_{\rm el}^\perp \qquad \mathcal{O}_{15} = i\mathcal{O}_{11}\left[\left(\mathbf{S}_e \times \mathbf{v}_{\rm el}^\perp\right) \cdot \frac{\mathbf{q}}{m_e}\right]$$

TABLE I. Interaction operators defining the non-relativistic effective theory of spin 1/2 DM-electron interactions [41, 44, 45]. $\mathbf{S}_e$ ($\mathbf{S}_\chi$) is the electron (DM) spin, $\mathbf{v}_{\rm el}^\perp = \mathbf{v} - \boldsymbol{\ell}/m_e - \mathbf{q}/(2\mu_{\chi e})$, where $\mu_{\chi e}$ is the DM-electron reduced mass, $\mathbf{v}_{\rm el}^\perp$ is the transverse relative velocity and $\mathbb{1}_{\chi e}$ is the identity in the DM-electron spin space.

$$\mathscr{R}_{\rm crystal} = \frac{n_\chi N_{\rm cell}}{128\pi m_\chi^2 m_e^2} \int {\rm d}(\ln \Delta E) \int {\rm d}q\, q\, \widehat{\eta}(q, \Delta E) \times \sum_{l=1}^{r} \Re\left(R_l^*(q, v)\overline{W}_l(q, \Delta E)\right) , \tag{45}$$

$$\overline{W}_l(q, \Delta E) = (4\pi)^2 V_{\rm cell} \frac{\Delta E}{q^2} \sum_{\Delta \mathbf{G} ii'} \int_{\rm BZ} \frac{{\rm d}^3k}{(2\pi)^3} \int_{\rm BZ} \frac{{\rm d}^3k'}{(2\pi)^3} B_l \times \delta(|\mathbf{k} - \Delta\mathbf{G} - \mathbf{k}'| - q) \times \delta(\Delta E - E_{i\mathbf{k}} + E_{i'\mathbf{k}'}) . \tag{47}$$

$$\mathscr{L}_{\rm anapole} = \frac{g}{2\Lambda^2}\, \bar{\chi}\gamma^\mu\gamma^5\chi\, \partial^\nu F_{\mu\nu} , \tag{27}$$

$$\mathscr{L}_{\rm magnetic} = \frac{g}{\Lambda}\, \bar{\psi}\sigma^{\mu\nu}\psi\, F_{\mu\nu} , \tag{28}$$

$$\mathscr{L}_{\rm electric} = \frac{g}{\Lambda}\, i\bar{\psi}\sigma^{\mu\nu}\gamma^5\psi\, F_{\mu\nu} , \tag{29}$$