Solar Dark Photon Absorption:

Strategy for Optimal Material Identification

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Dark Photons

Extra U(1)
gauge boson

Mediator between
DM and SM

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The model:

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}^2 - \frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}F_{\mu\nu}V^{\mu\nu} + \frac{m_V^2}{2}V_\mu V^\mu + eJ_{\text{em}}^\mu A_\mu$$

An, Pospelov, Pradler, arXiv:1304.3461

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Kinetic mixing

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Absorption of Solar Dark Photons

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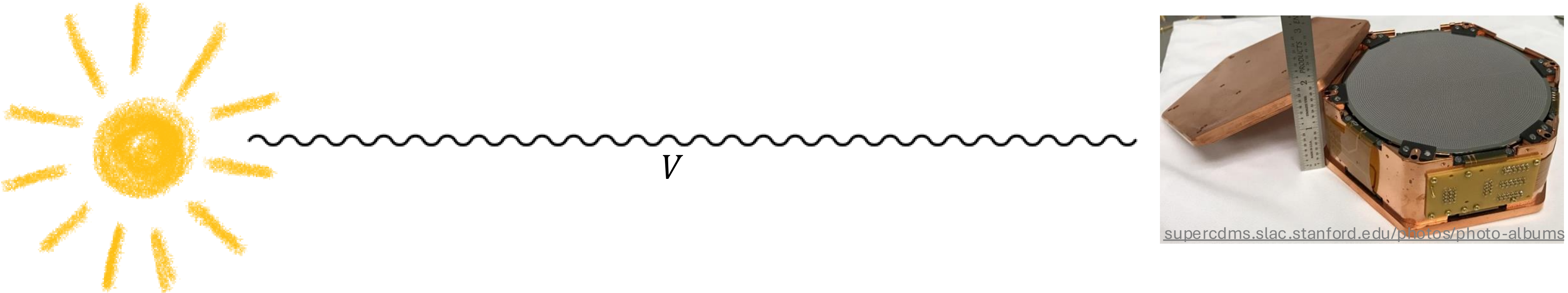
Production in the sun

Absorption in a detector



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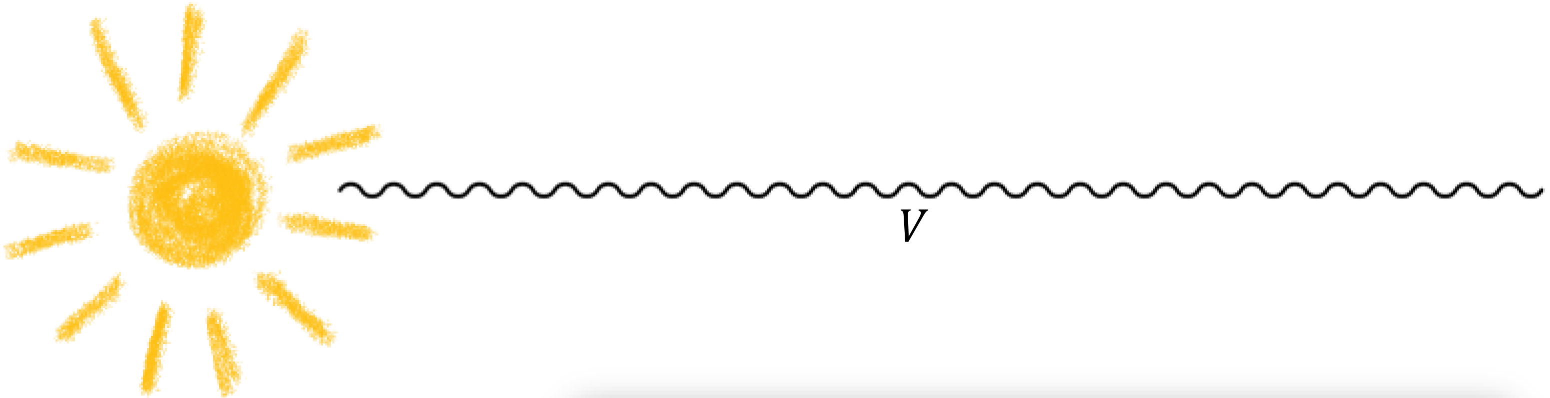

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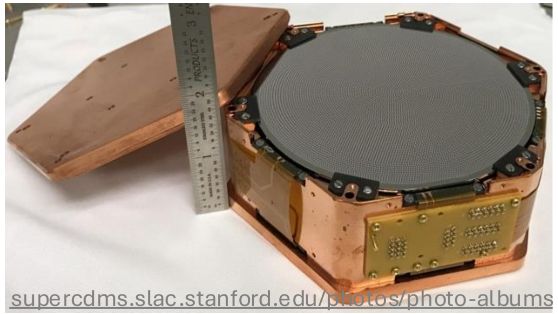
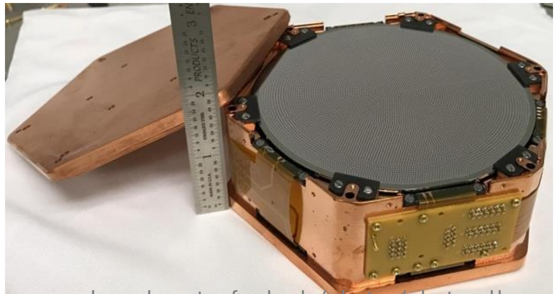


What is the best material for detecting dark photons?

Absorption of Solar Dark Photons

Production in the sun

Absorption in a detector



supercdms.slac.stanford.edu/photos/photo-albums

Main production mechanism:
Bremsstrahlung

Calculated by An et al., arxiv:1302.3884
and Redondo, arxiv:0801.1527

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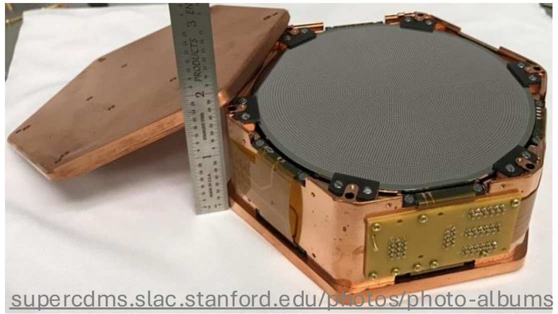

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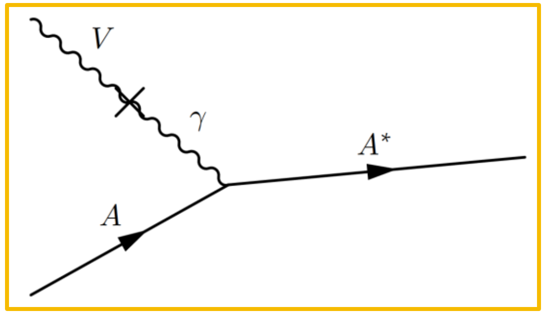

Detection Rates

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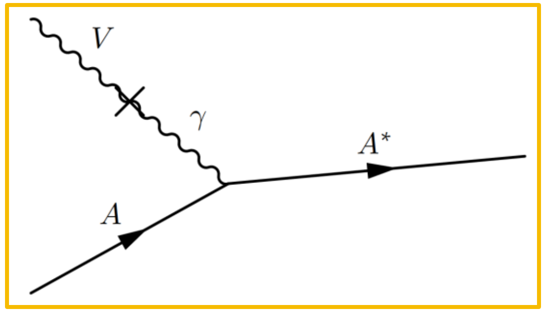

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Detection rate:

$$n = \int_{\omega_{min}}^{\omega_{max}} \frac{\omega d\omega}{|\boldsymbol{q}|} \left(\frac{d\Phi_L}{d\omega}\Gamma_L + \frac{d\Phi_T}{d\omega}\Gamma_T \right)$$

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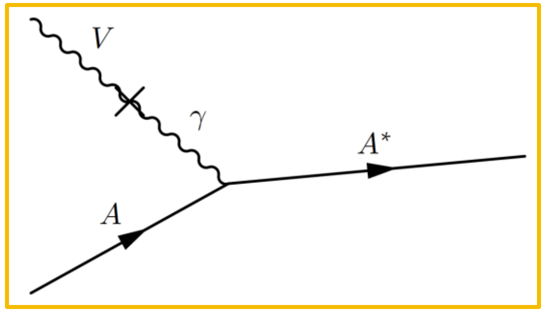

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$$n_T = \int_{\omega_{min}}^{\omega_{max}} \frac{d\omega}{\omega} \mathrm{Im} \left(\frac{-1}{(\varepsilon_r - 1)\omega^2 + m_V^2} \right) \kappa^2 m_V^4 \frac{\omega}{|\boldsymbol{q}|} \frac{d\Phi_T}{d\omega}$$

How to find the Best Material for Detecting Dark Photons?

Our Strategy to Find an Upper Limit on n_L and n_T

Kramers-Kronig relation:

$$\int_0^\infty \frac{d\omega}{\omega} \operatorname{Im} \chi(\omega, \boldsymbol{q}) = \frac{\pi}{2} \chi(0, \boldsymbol{q})$$

This holds if

1. $\lim_{\omega \to \infty} \chi(\omega, \boldsymbol{q}) = 0$
2. $\chi(\omega, \boldsymbol{q})$ analytic in the upper half plane $(\operatorname{Im} \omega > 0)$
3. $\operatorname{Im} \chi(\boldsymbol{q}, \omega)$ odd function of ω

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e.g. Energy Loss Function

$$\int_{\omega_{min}}^{\omega_{max}} \frac{d\omega}{\omega} \mathrm{Im}\left(\frac{-1}{\varepsilon_r(\boldsymbol{q}, \omega)}\right) \leq \frac{\pi}{2}\left(1 - \frac{1}{\varepsilon_r(\boldsymbol{q}, 0)}\right)$$

$$\int_{\omega_{min}}^{\omega_{max}} \frac{d\omega}{\omega} \mathrm{Im}\,\chi(\omega, \boldsymbol{q}) \leq \frac{\pi}{2}\chi(0, \boldsymbol{q})$$

Analytical Results

Longitudinal part:

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$$\boxed{\int_{\omega_{min}}^{\omega_{max}} \frac{d\omega}{\omega} \mathrm{Im}\, \chi(\omega, \boldsymbol{q}) \leq \frac{\pi}{2} \chi(0, \boldsymbol{q})}$$

Longitudinal part:

$$n_L = \underbrace{\int_{\omega_{min}}^{\omega_{max}} \frac{d\omega}{\omega} \mathrm{Im}\left(\frac{-1}{\varepsilon_r}\right)}_{\text{Energy loss function: response function}} \kappa^2 m_V^2 \frac{\omega}{|\boldsymbol{q}|} \frac{d\Phi_L}{d\omega}$$

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Energy loss function:
response function

$$n_L \leq \kappa^2 m_V^2 \frac{\pi}{2}\left(1 - \frac{1}{\varepsilon_r(0, \boldsymbol{q})}\right) \max_{\omega \in [m_V, \infty)} \left(\frac{\omega}{\sqrt{\omega^2 - m_V^2}} \frac{d\Phi_L}{d\omega}\right)$$

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Analytical Results

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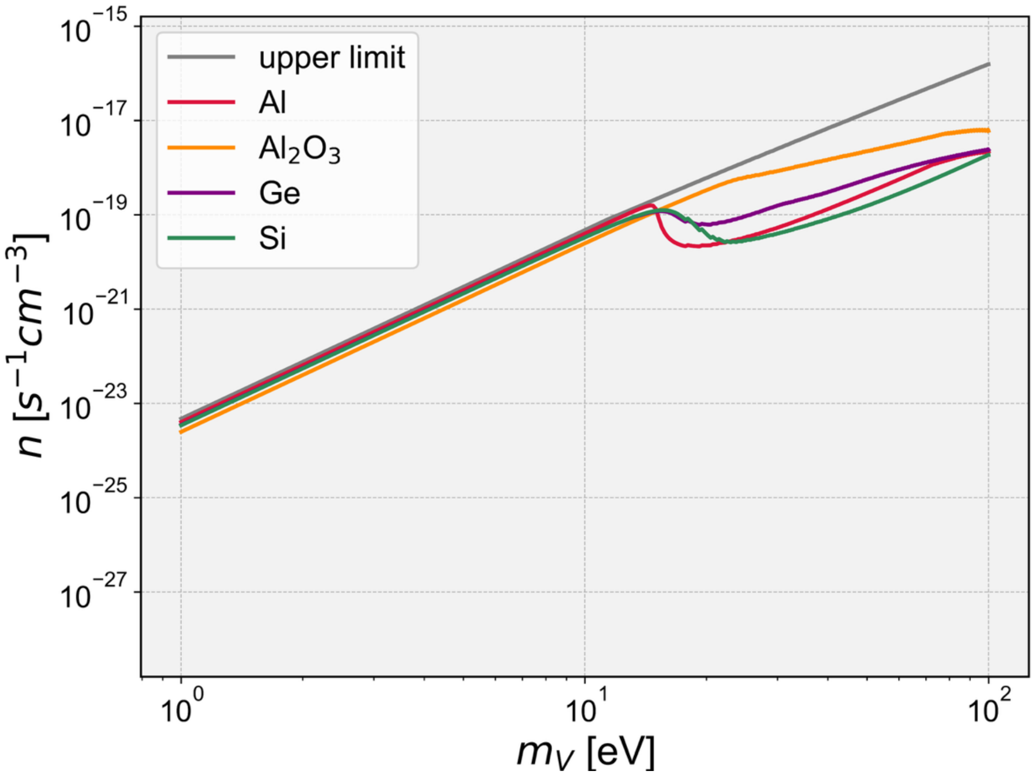
For $m_V^2 \ll \omega_p^2$ or $m_V^2 \geq 2\omega_p^2$:

$$n_T \leq \kappa^2 m_V^2 \frac{\pi}{2} \max_{\omega \in [m_V, \infty)} \left(\frac{\omega}{\sqrt{\omega^2 - m_V^2}} \frac{d\Phi_T}{d\omega}\right)$$

Comparison with Real Materials

Longitudinal part:



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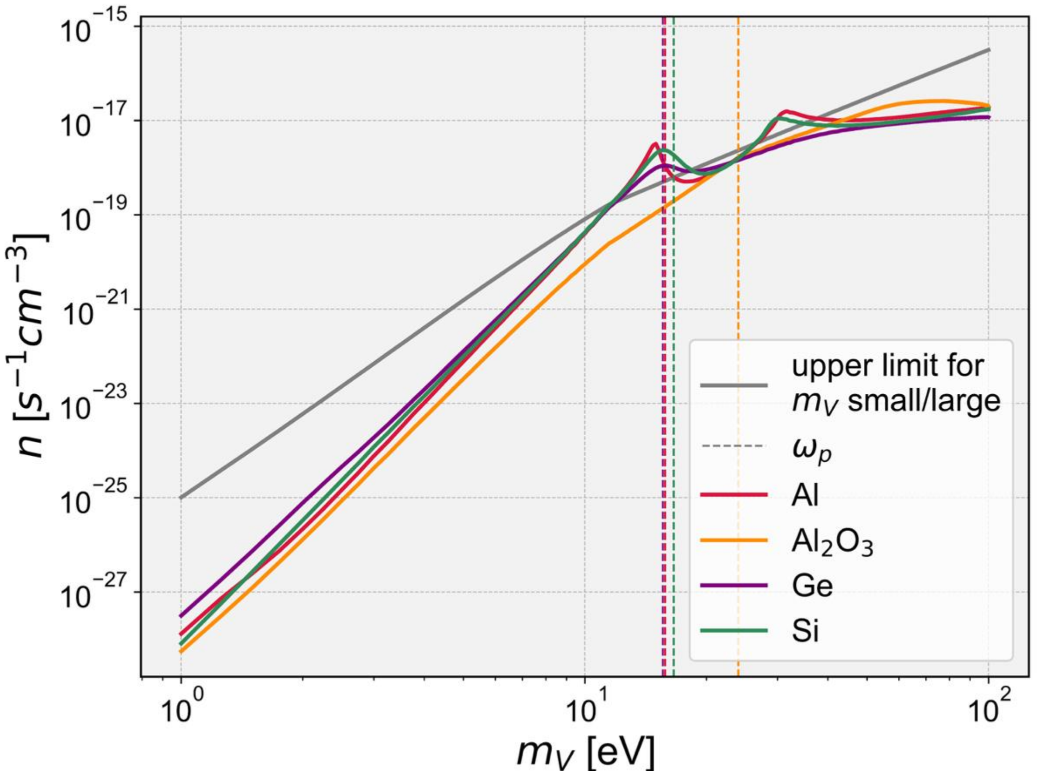

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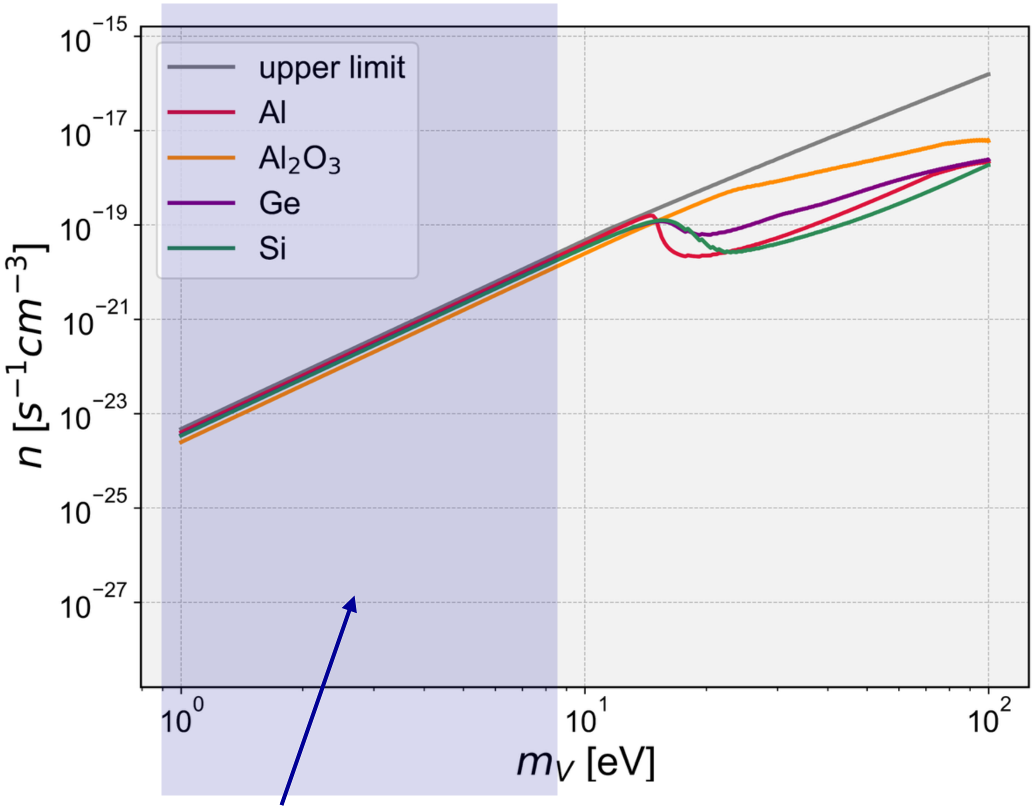

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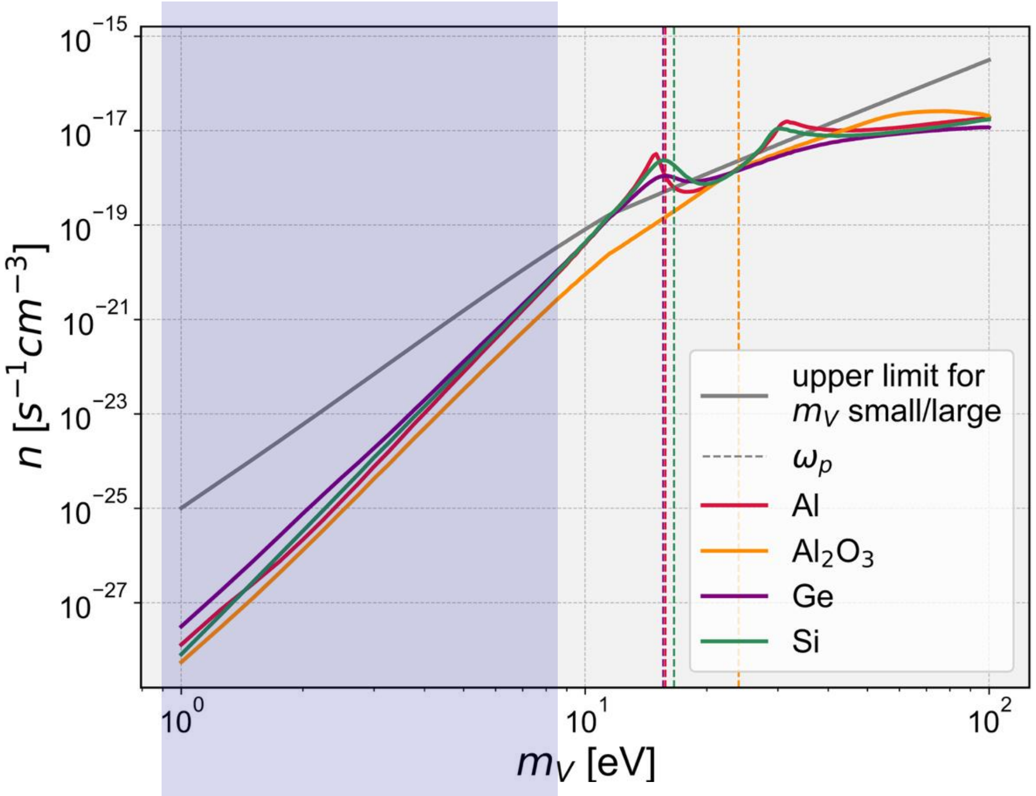

For $m_V \ll \omega_p$
longitudinal part dominates

Comparison with Real Materials

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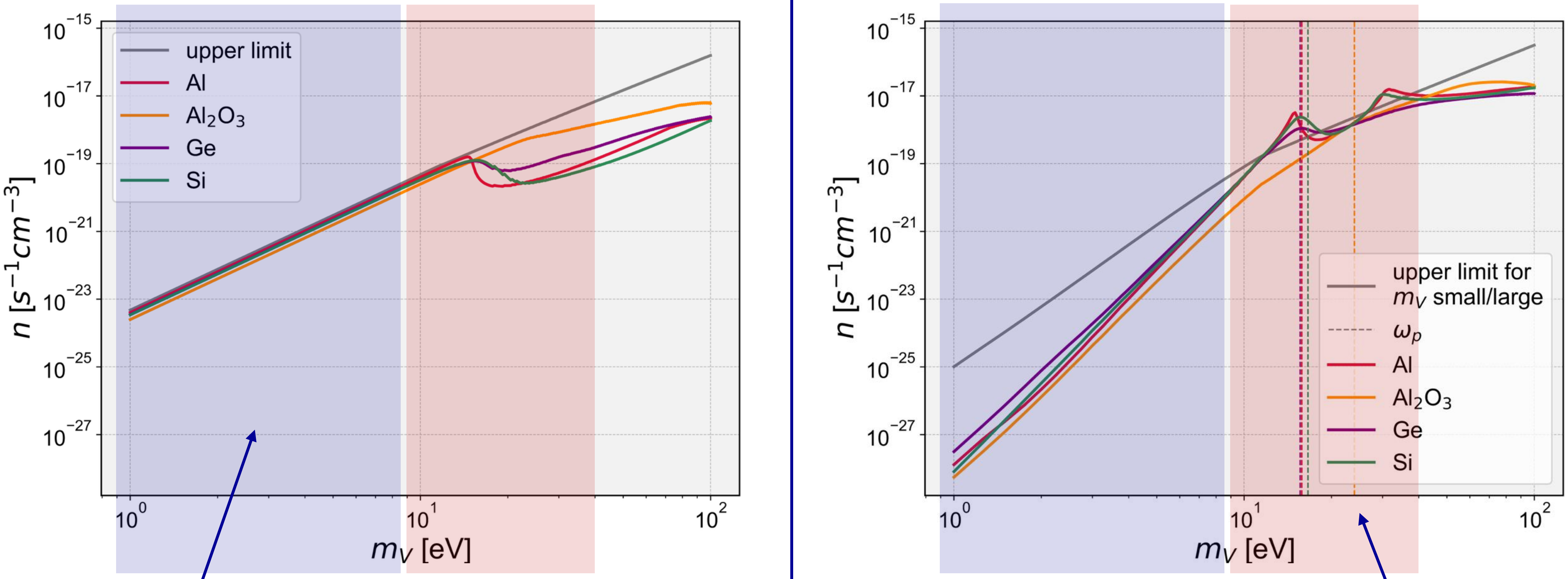
Transverse part:



For $m_V \ll \omega_p$ longitudinal part dominates

Highest detection rates for $m_V \approx \omega_p$

Strategy

Comparison with upper limits in three regions:

I. Longitudinal part dominates for $m_V \ll \omega_p$:
Rates high and parallel to upper limit

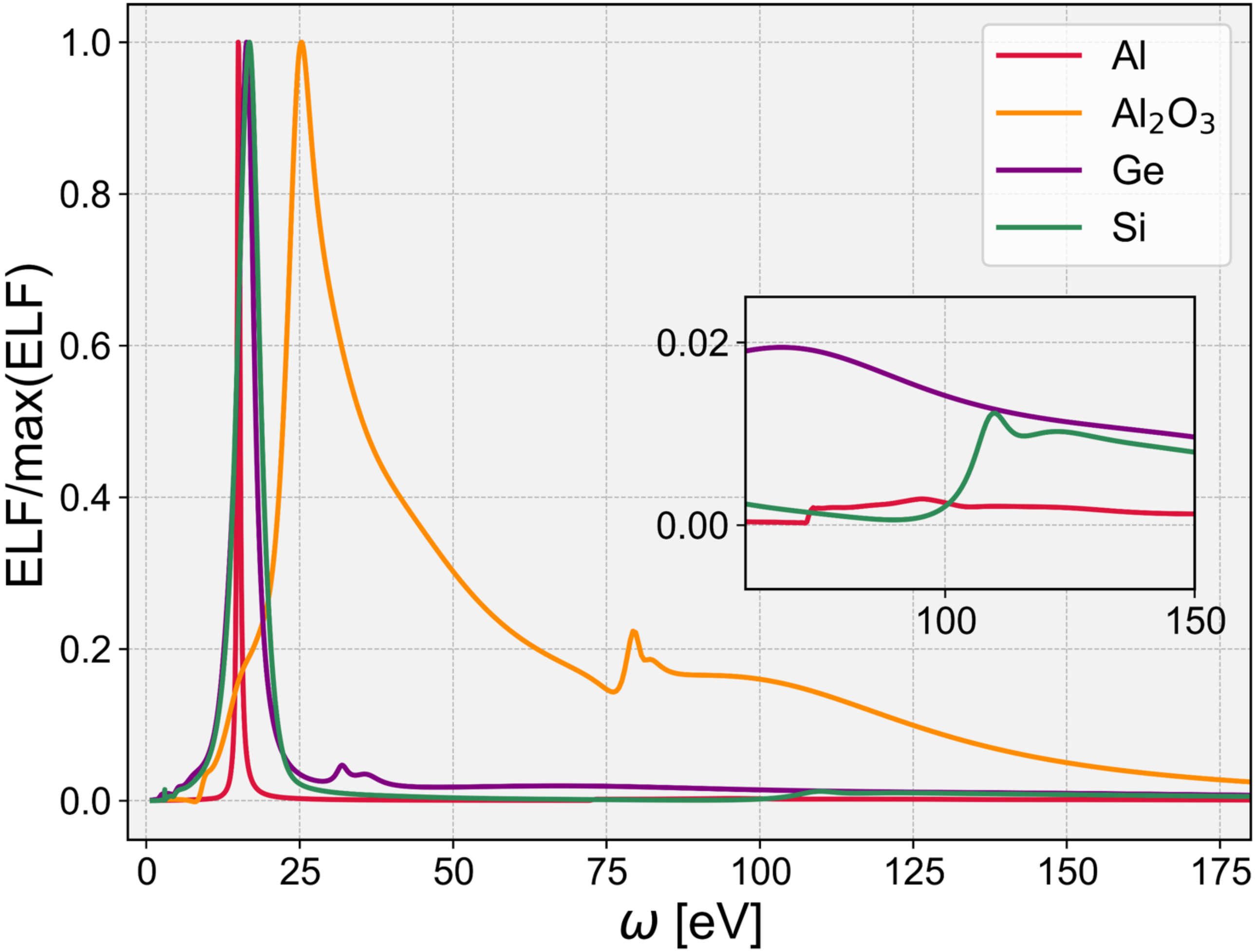
II. Transverse part dominates for $m_V \approx \omega_p$:
Ideally a peak at the plasma frequency

III. Both rates should not drop to fast for $m_V \gg \omega_p$

Thank you for your attention.

Backup

ELFs of Example Materials



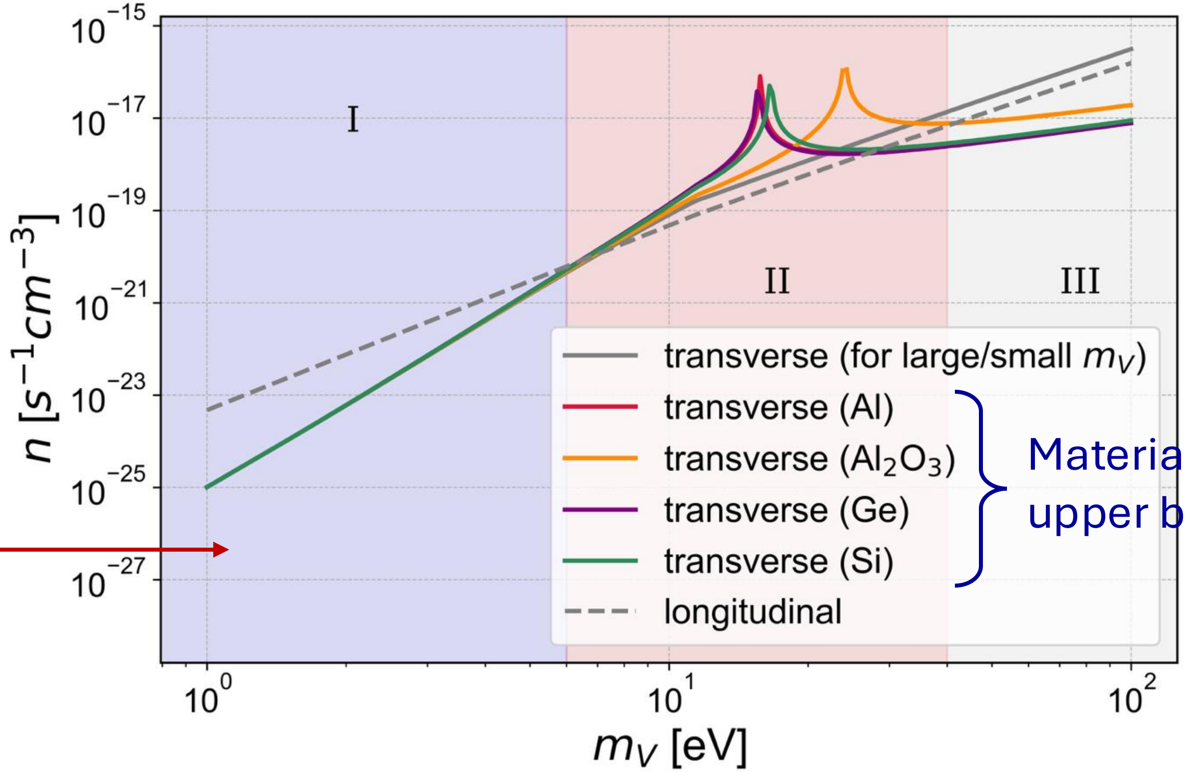
Parametrizations following the Drude-Lorentz oscillator model:

$$\mathrm{Im}\left(\frac{-1}{\varepsilon_r(\omega,0)}\right) = \sum_{i=1}^{N} A_i \frac{\omega_{p,i}^2 \gamma_i \omega}{\left(\omega^2 - \omega_{p,i}^2\right)^2 - \left(\gamma_i \omega\right)^2}$$

Novak et al. (2008): doi:10.1016/j.elspec.2007.11.002

Sun et al. (2016): doi:10.1063/1674-0068/29/cjcp1605110

Comparison of Upper Limits



Material-dependent upper bounds

For $m_V^2 \ll \omega_p^2$ transverse material-dependent and –indepent limits coincide

$m_V^2 \approx \omega_p^2$