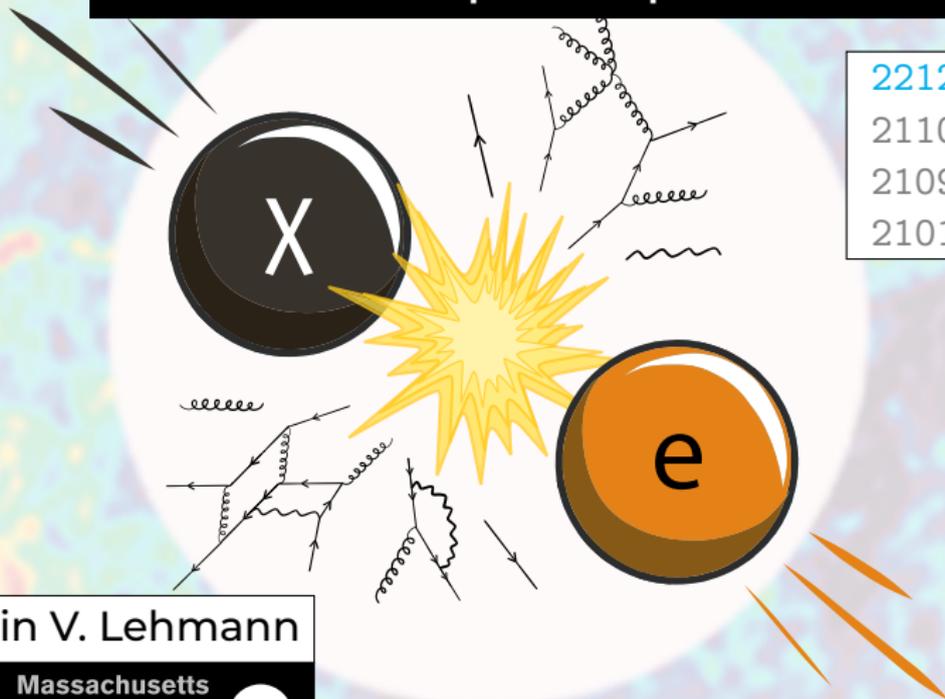


# Directional detection of dark matter with anisotropic response functions



2212.04505

2110.01586

2109.04473

2101.08263

Benjamin V. Lehmann

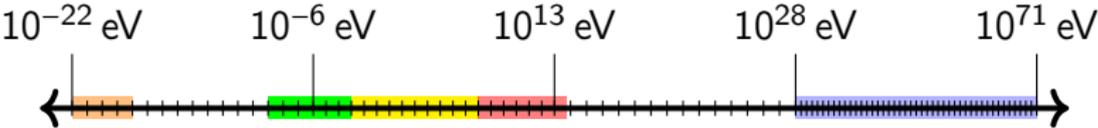


Massachusetts  
Institute of  
Technology

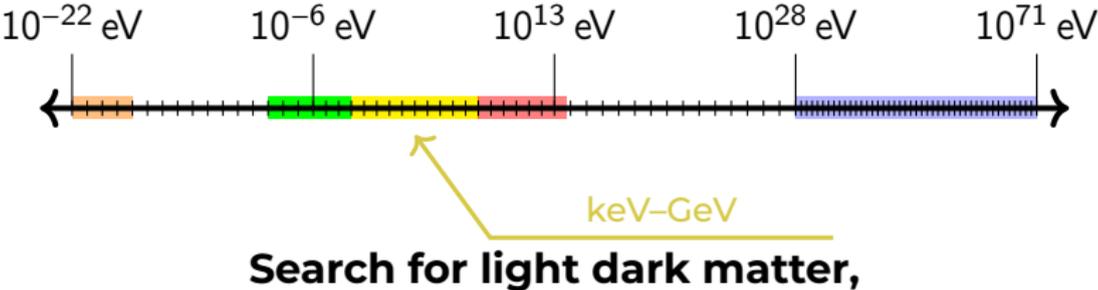


with Christian Boyd, Yonit Hochberg, Yoni Kahn, Eric David Kramer, Noah Kurinsky & To Chin Yu

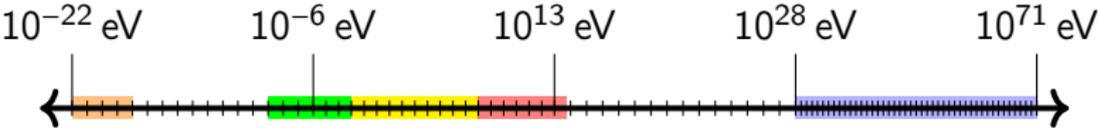
# This talk in one slide



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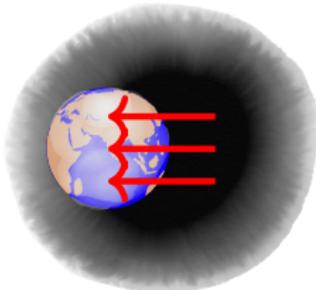
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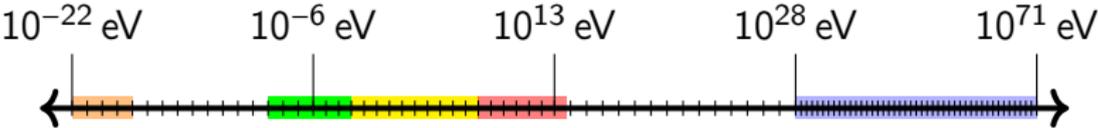
keV-GeV

**Search for light dark matter,  
directionally,**

background



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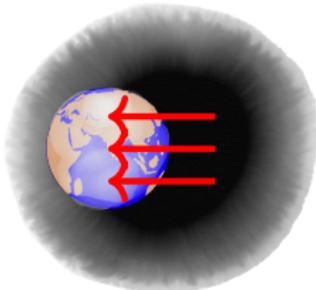


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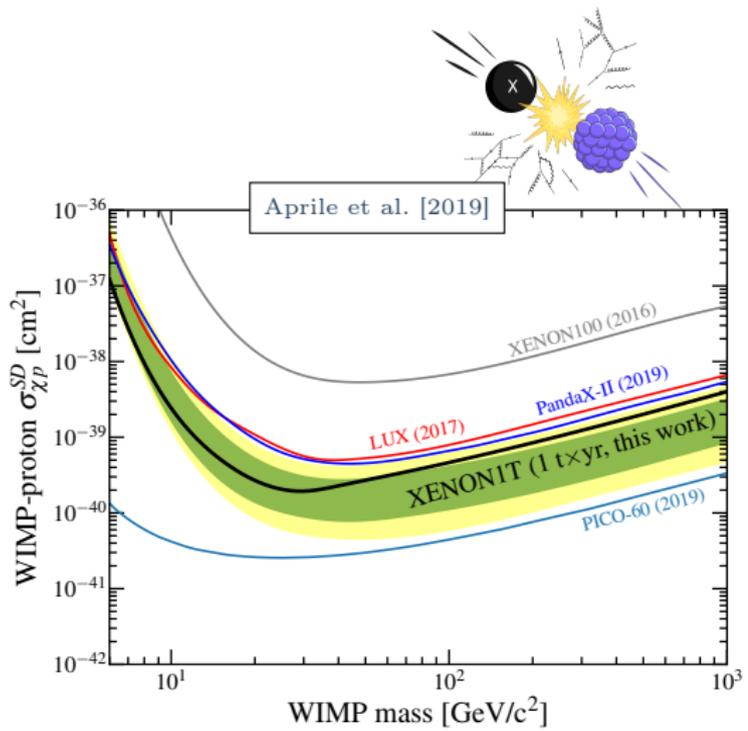
**Search for light dark matter,  
directionally, with anisotropic dielectrics.**

background

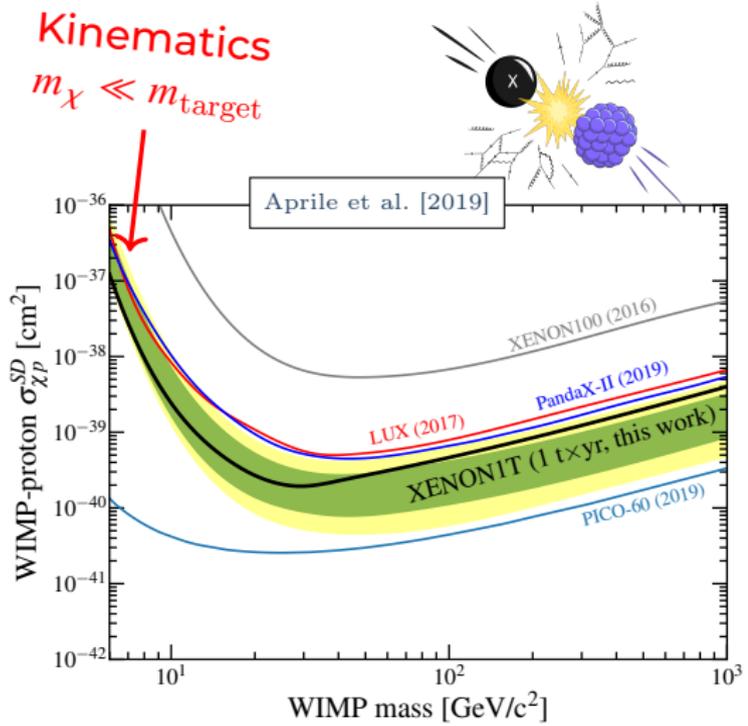
common stuff



# Sub-GeV DM

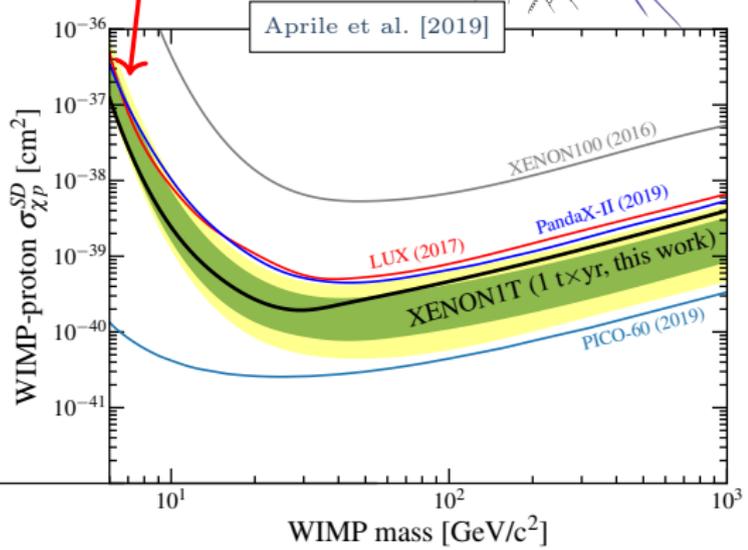
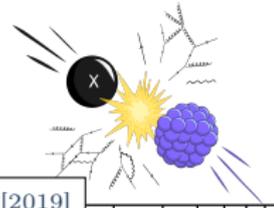


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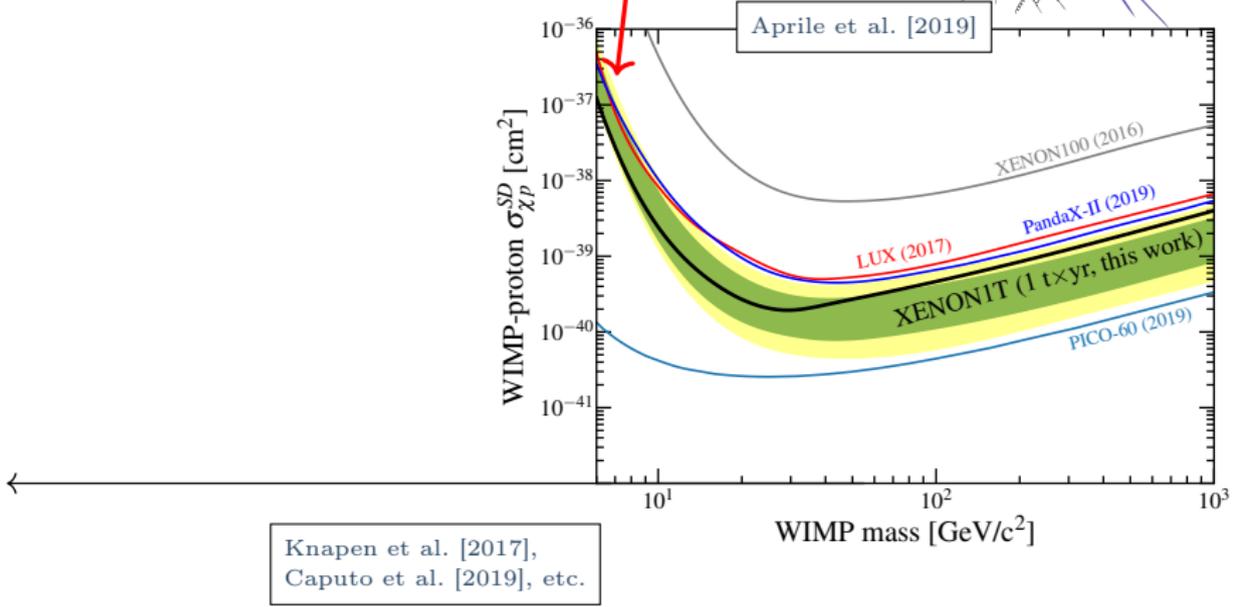
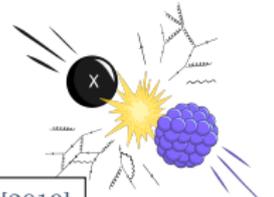
# Sub-GeV DM

Kinematics  
 $m_\chi \ll m_{\text{target}}$



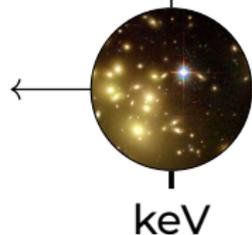
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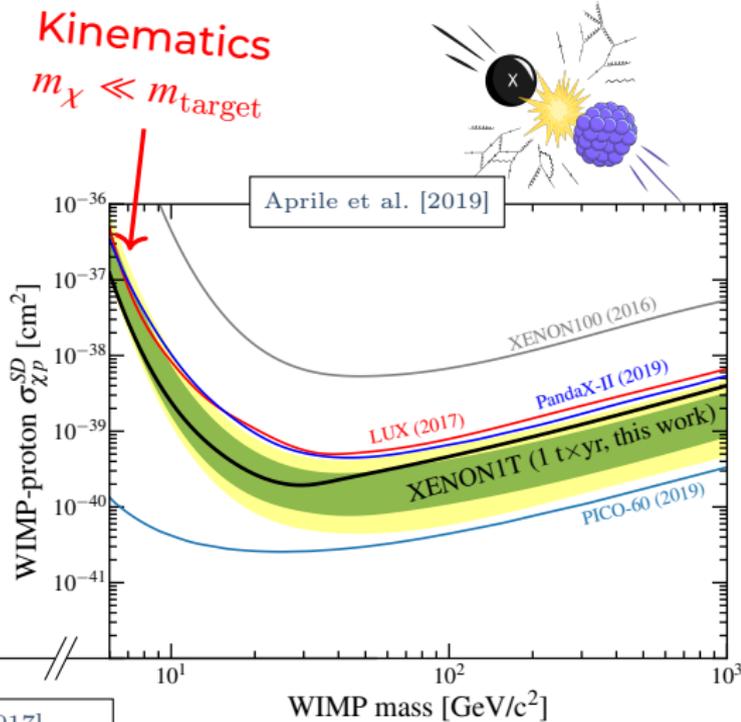


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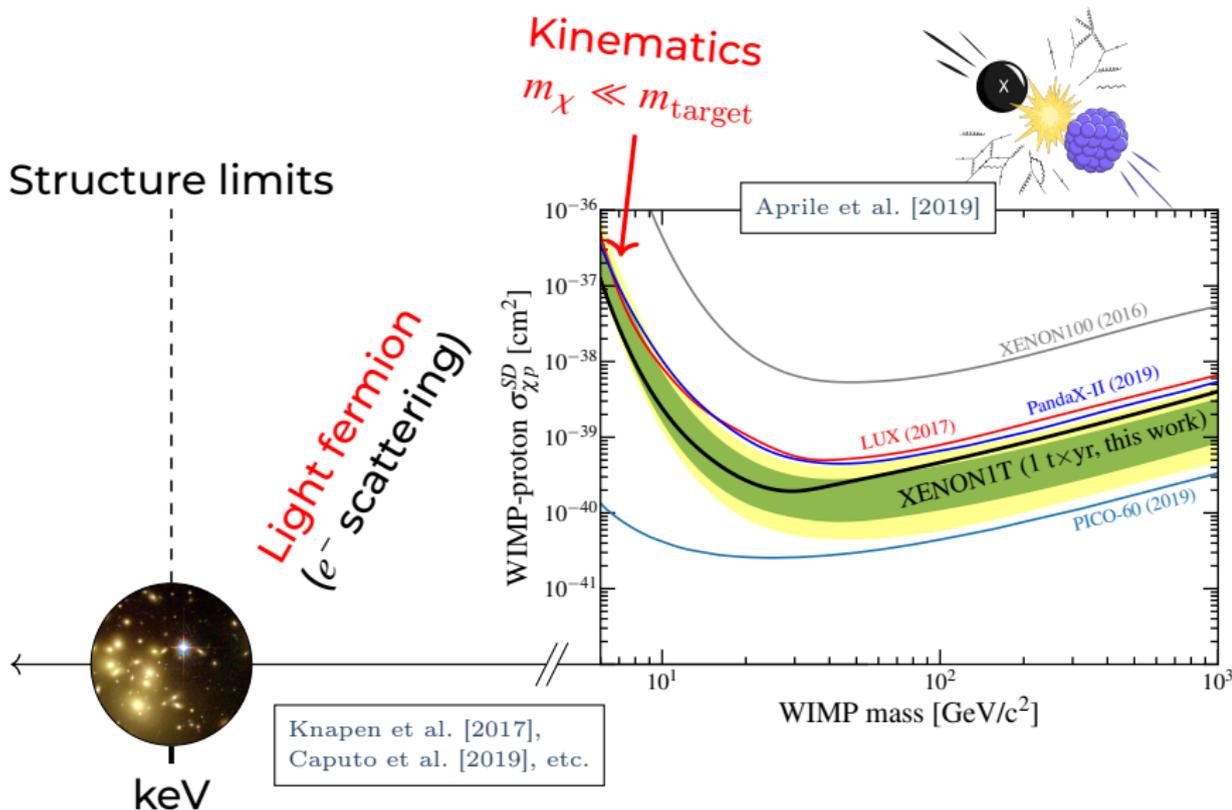
Structure limits



Knapen et al. [2017],  
Caputo et al. [2019], etc.



# Sub-GeV DM



Electrons are not free: **condensed matter matters**

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$$|x\rangle|\Psi\rangle_{\text{detector}} \rightarrow |x'\rangle|\Psi'\rangle_{\text{detector}}$$

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Predict scattering rate from **response function**

$$\Gamma = \int \frac{d^3\mathbf{q}}{(2\pi)^3} |V(\mathbf{q})|^2 \left[ \underbrace{2 \frac{q^2}{e^2} \text{Im} \left( -\frac{1}{\epsilon(\mathbf{q}, \omega_{\mathbf{q}})} \right)}_{\text{"Loss function"} \mathcal{W}} \right]$$

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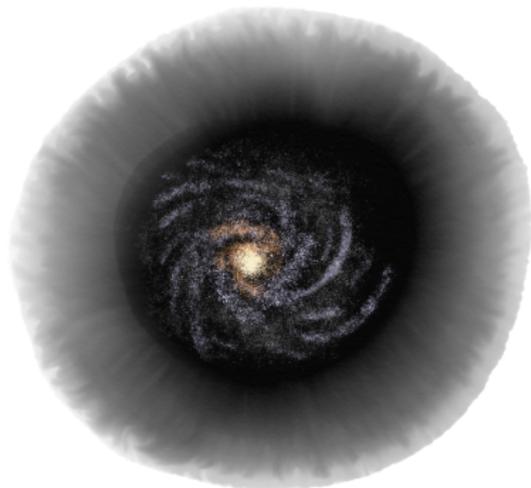
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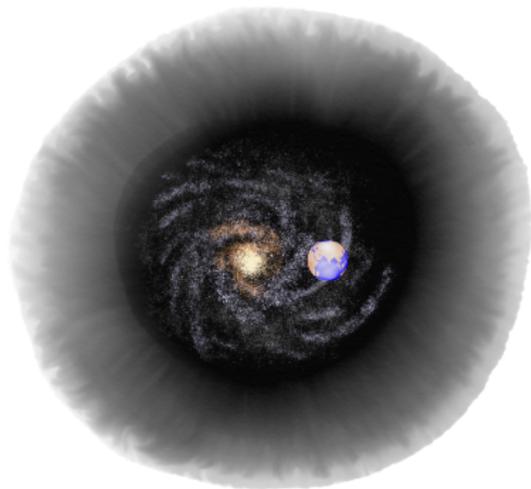
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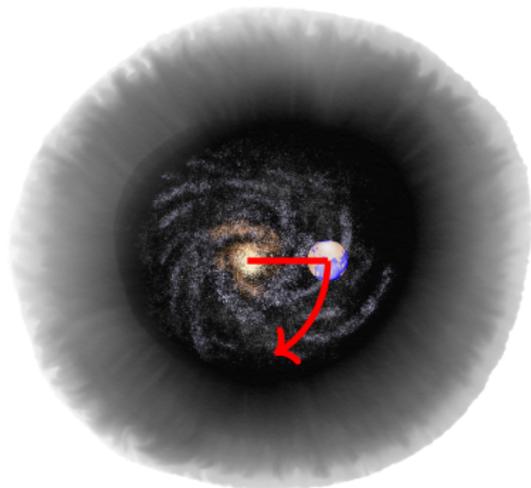
# Directional sensitivity



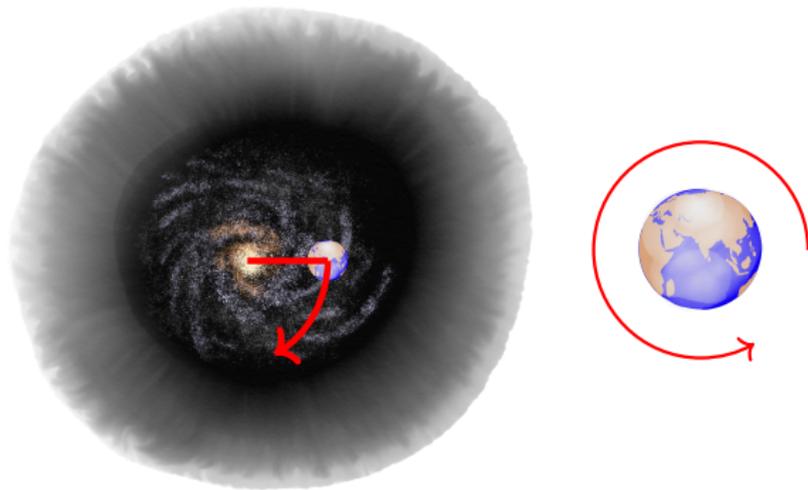
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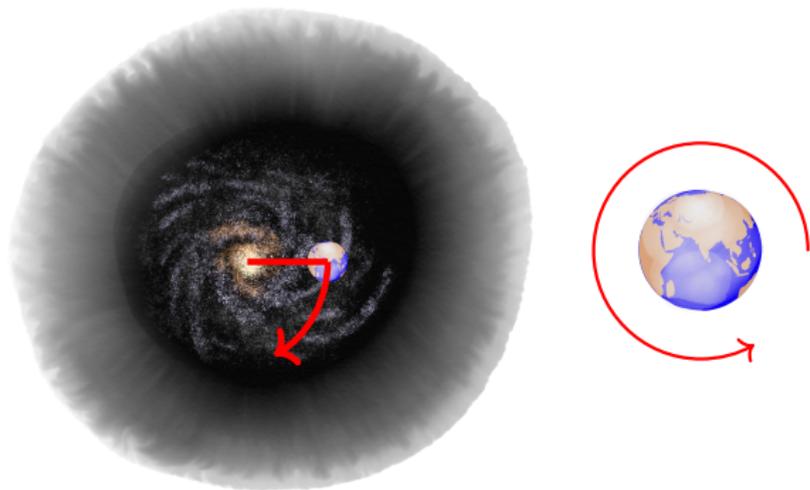
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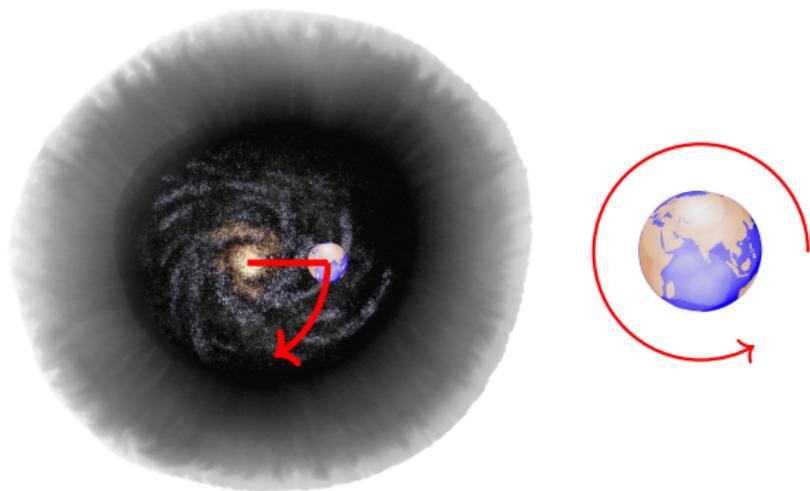


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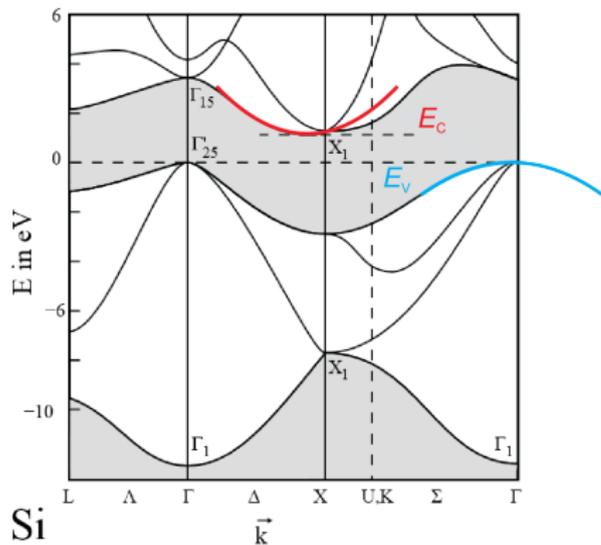
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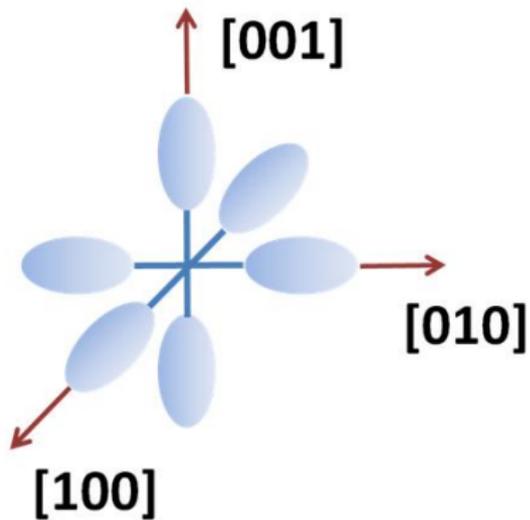
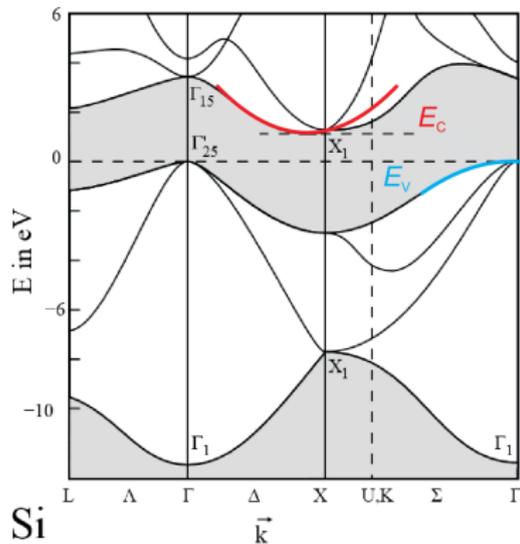


Anisotropic sensitivity  $\rightarrow$  daily modulation in rate  
**Cut through background:** scale with exposure

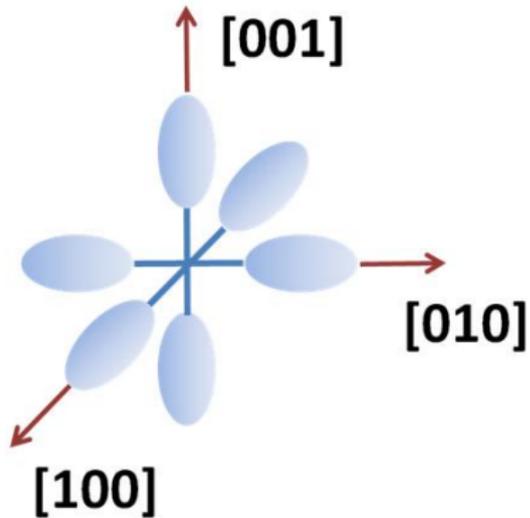
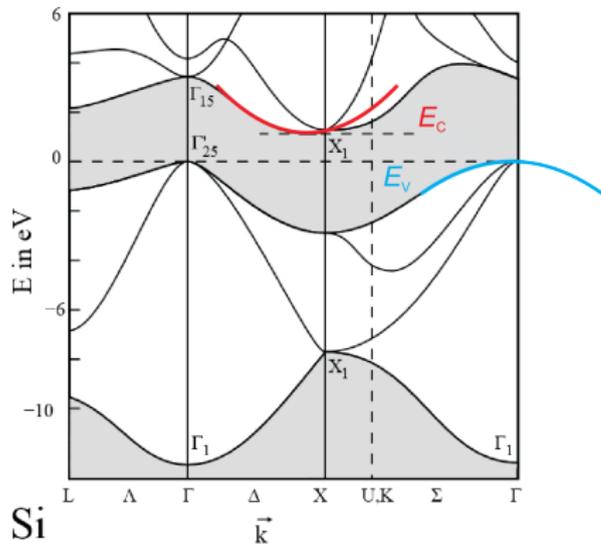
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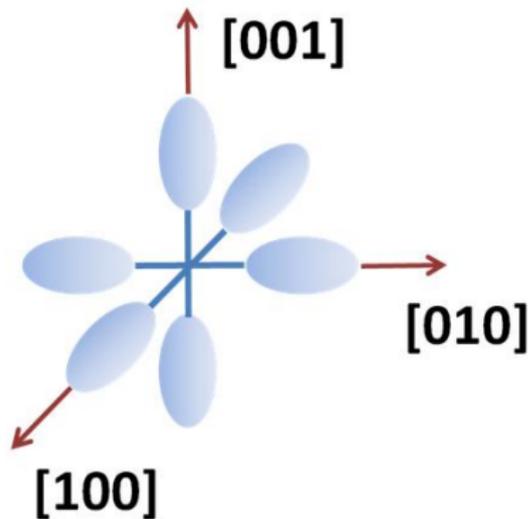
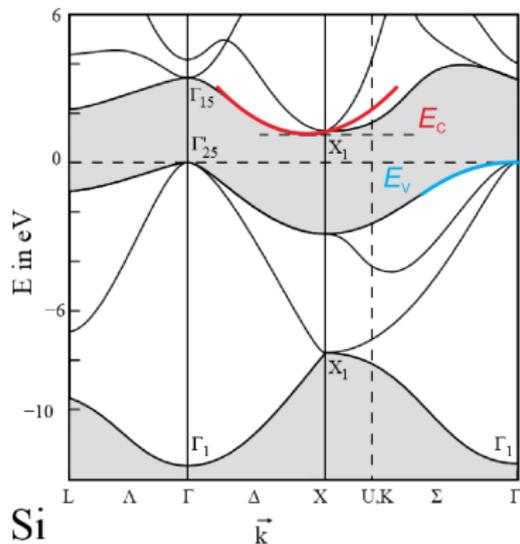
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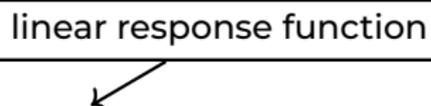
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See e.g. Mahan [2013]

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**Random phase approximation (RPA)**

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# Understanding $\chi$ — plasmons

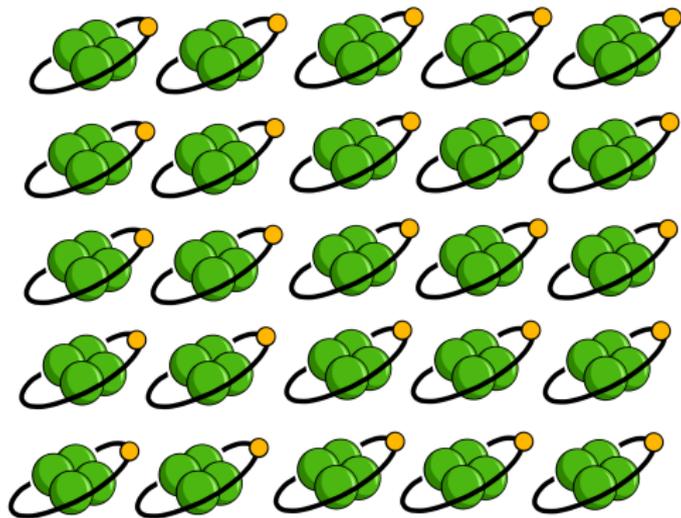
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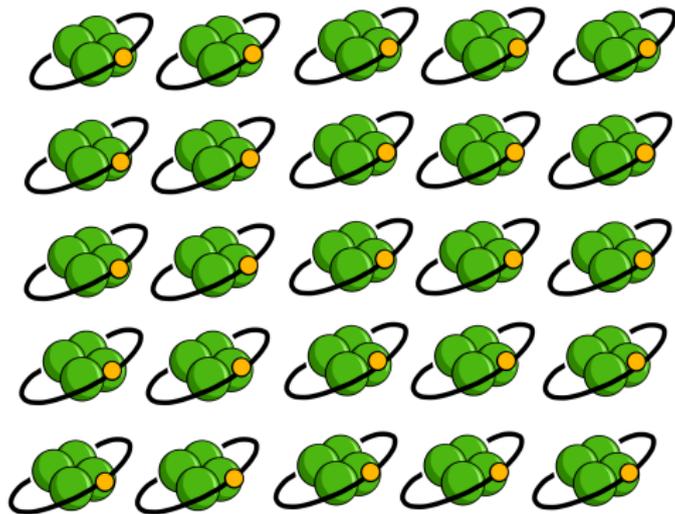


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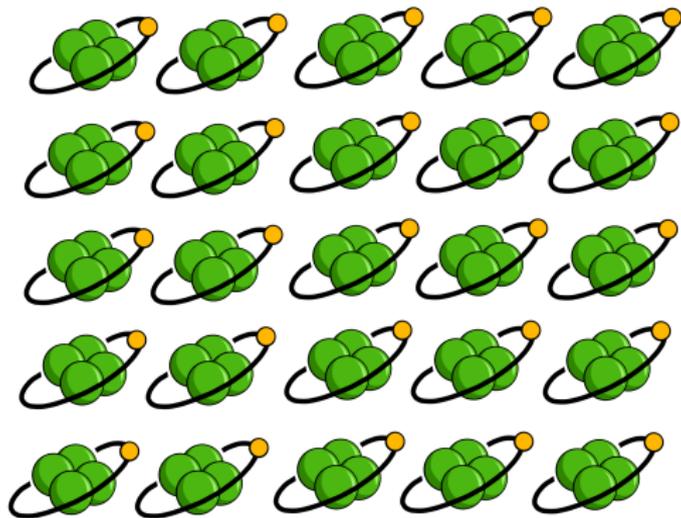
A **collective oscillation** of electrons

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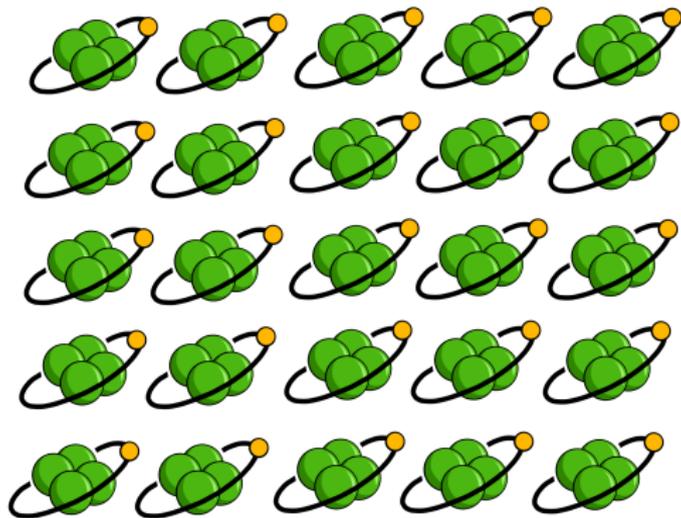
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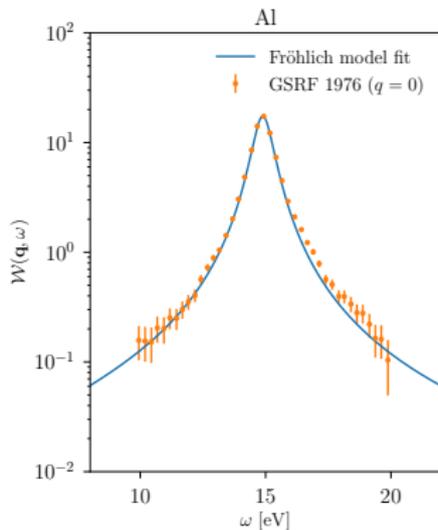
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A **collective oscillation** of electrons

Shows up as a resonance in the **loss function**

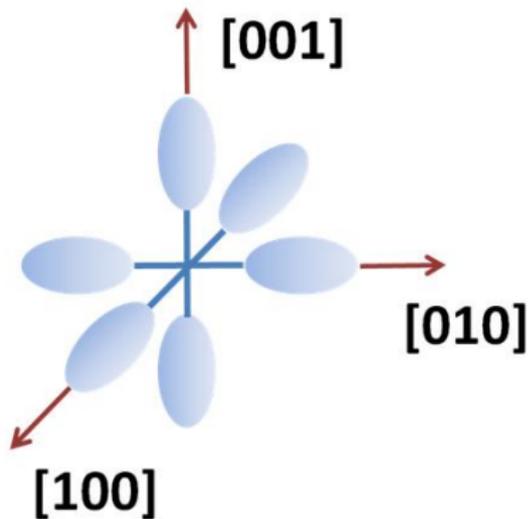
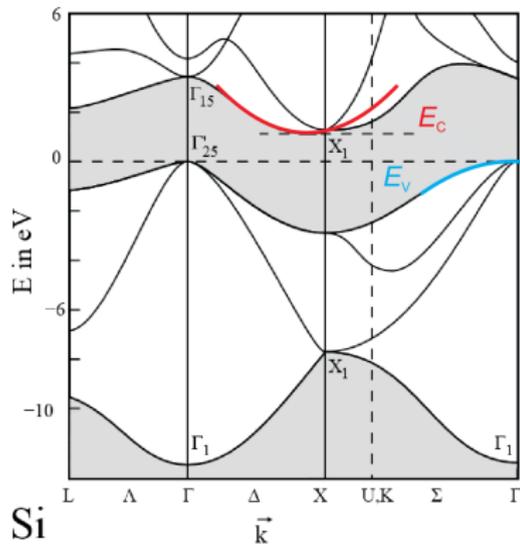
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# Anisotropic response function

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**Anisotropic case.**  $E_{\mathbf{q}}^{\text{iso}} = \frac{q^2}{2m} \longrightarrow E_{\mathbf{q}}^{\text{ani}} = \frac{q_x^2}{2m_x} + \frac{q_y^2}{2m_y} + \frac{q_z^2}{2m_z}$

Transform back to isotropic in  $k$ -space

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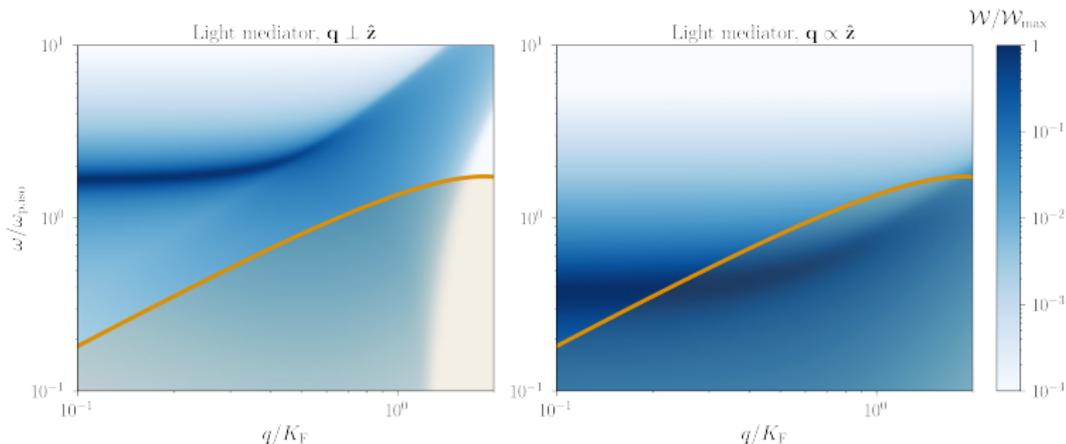
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# Anisotropic loss function

$$m_z/m_{xy} = 20, \quad m_x m_y m_z = m_e^3$$

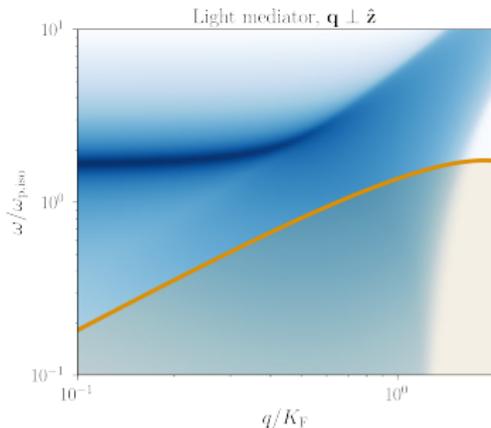


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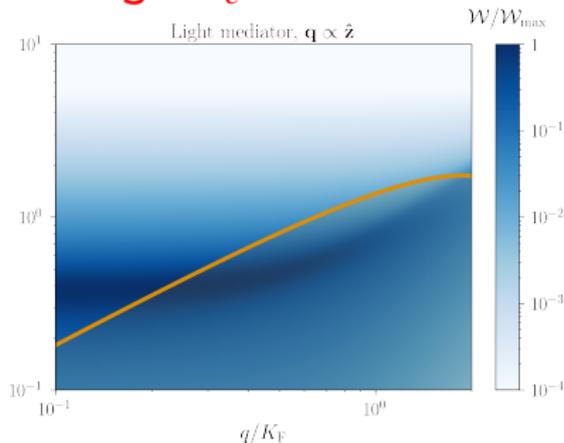
$$m_z/m_{xy} = 20,$$

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Low- $m_e$  direction



High- $m_e$  direction



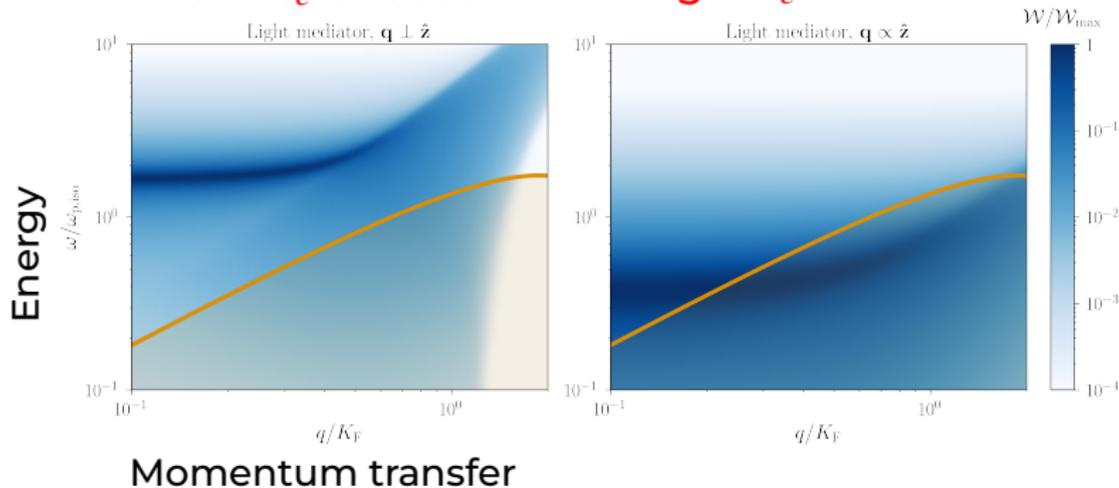
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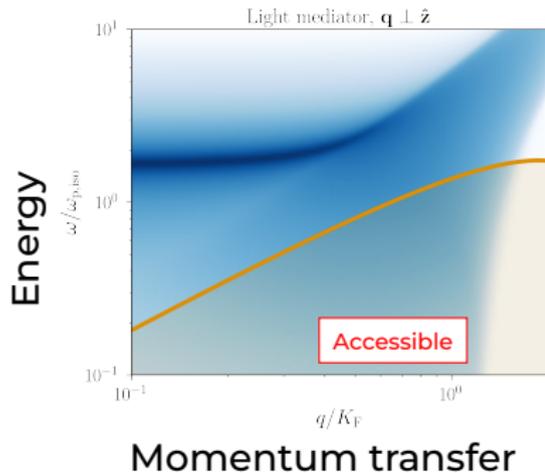


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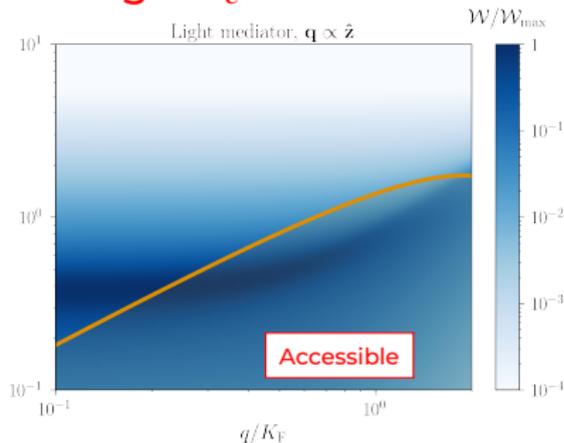
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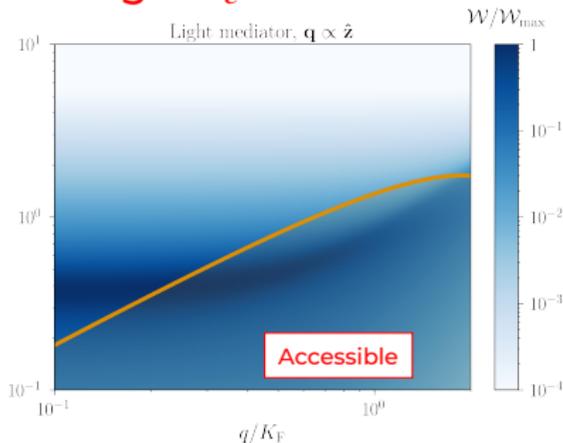
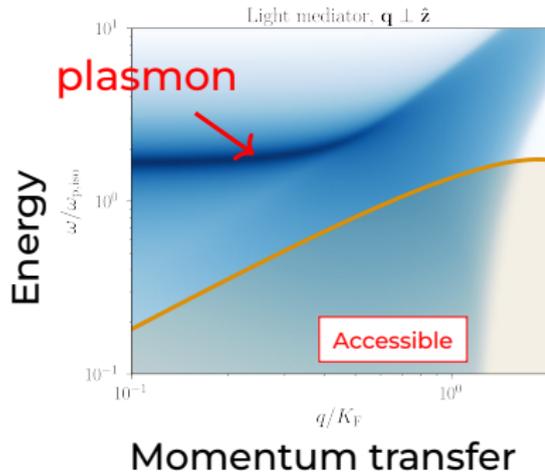
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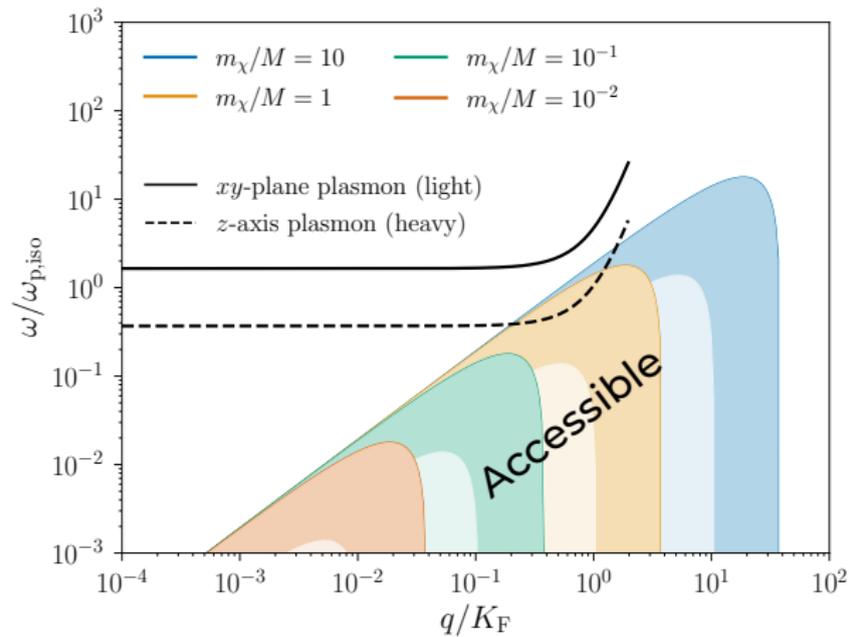
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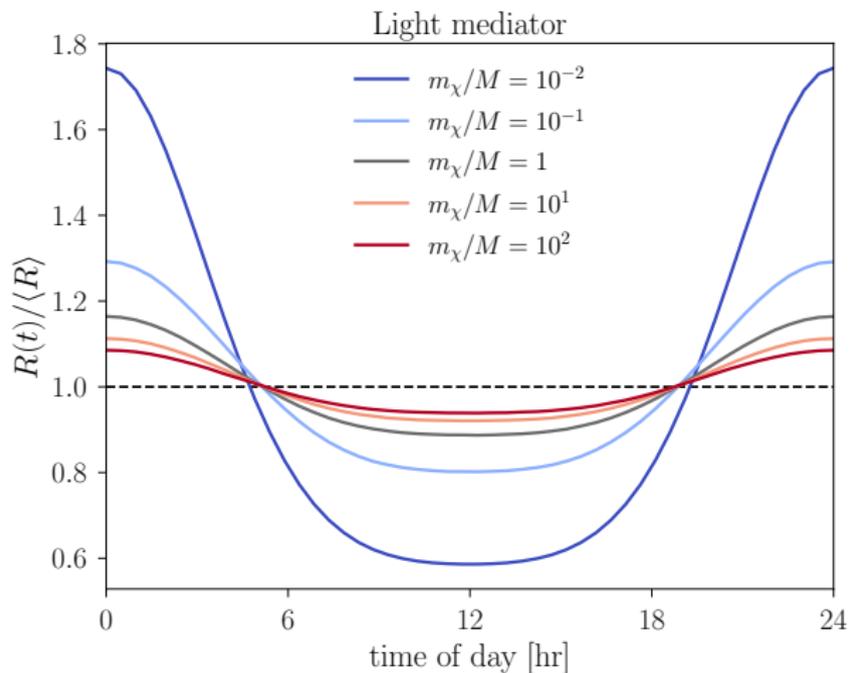
High- $m_e$  direction



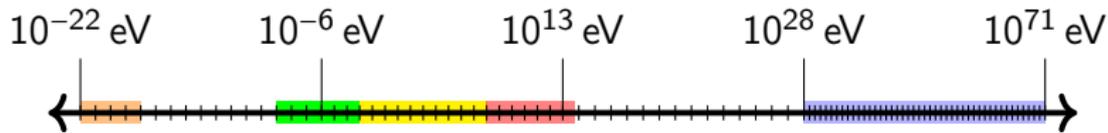
# Anisotropic plasmon threshold



# Daily modulation in the rate

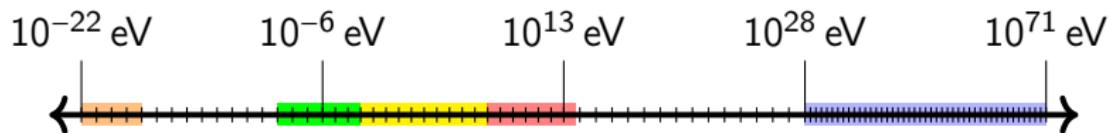


# Conclusions



**Search for light dark matter,  
directionally, with anisotropic dielectrics.**

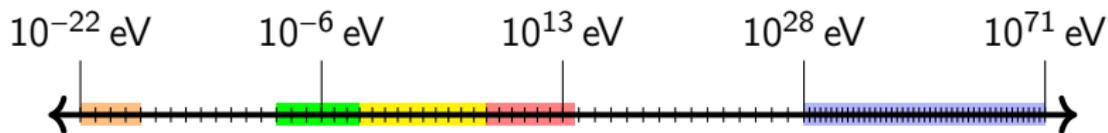
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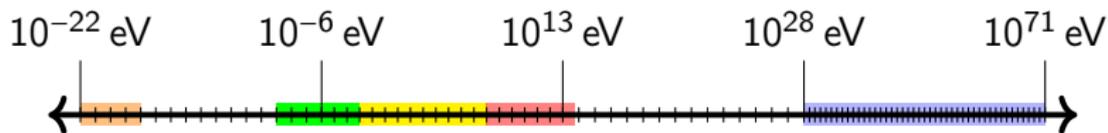
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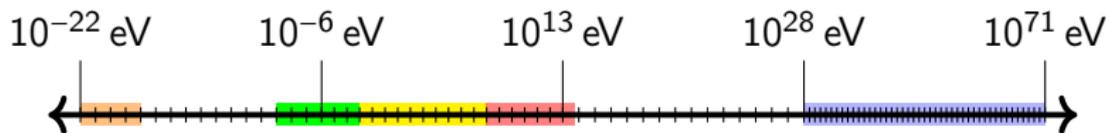
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