Looking for starlight underground

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ongoing work with David Curtin

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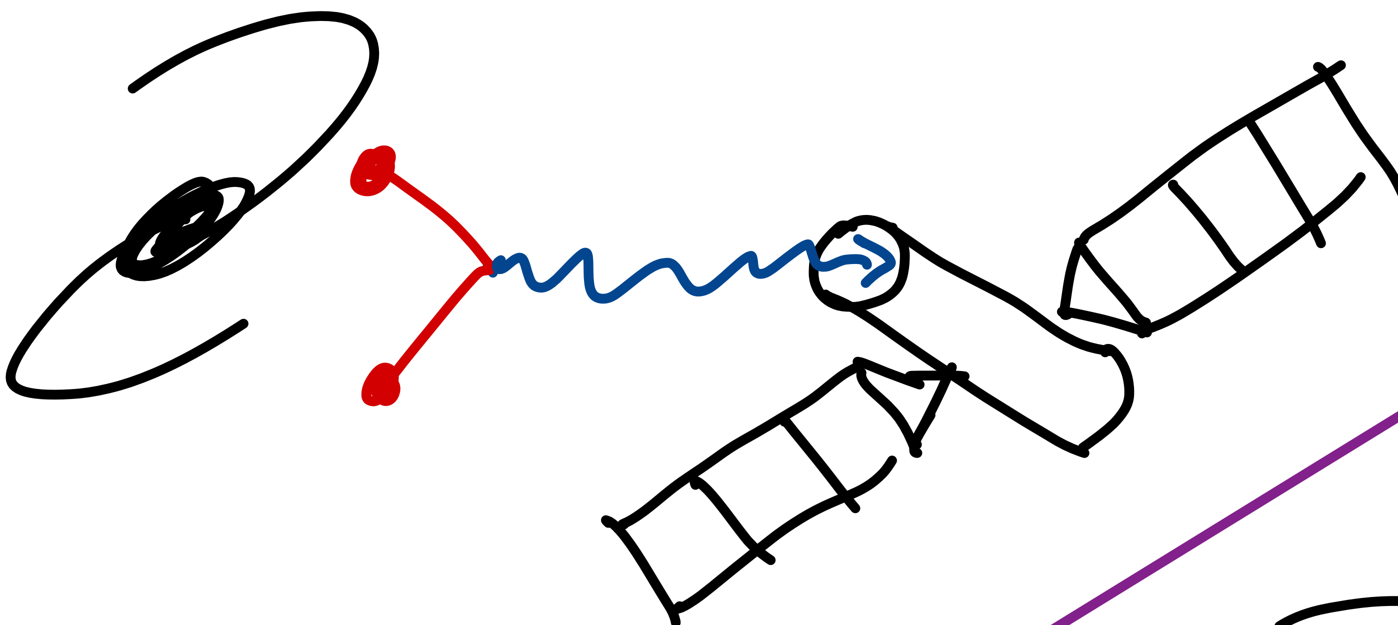
How we look for dark matter

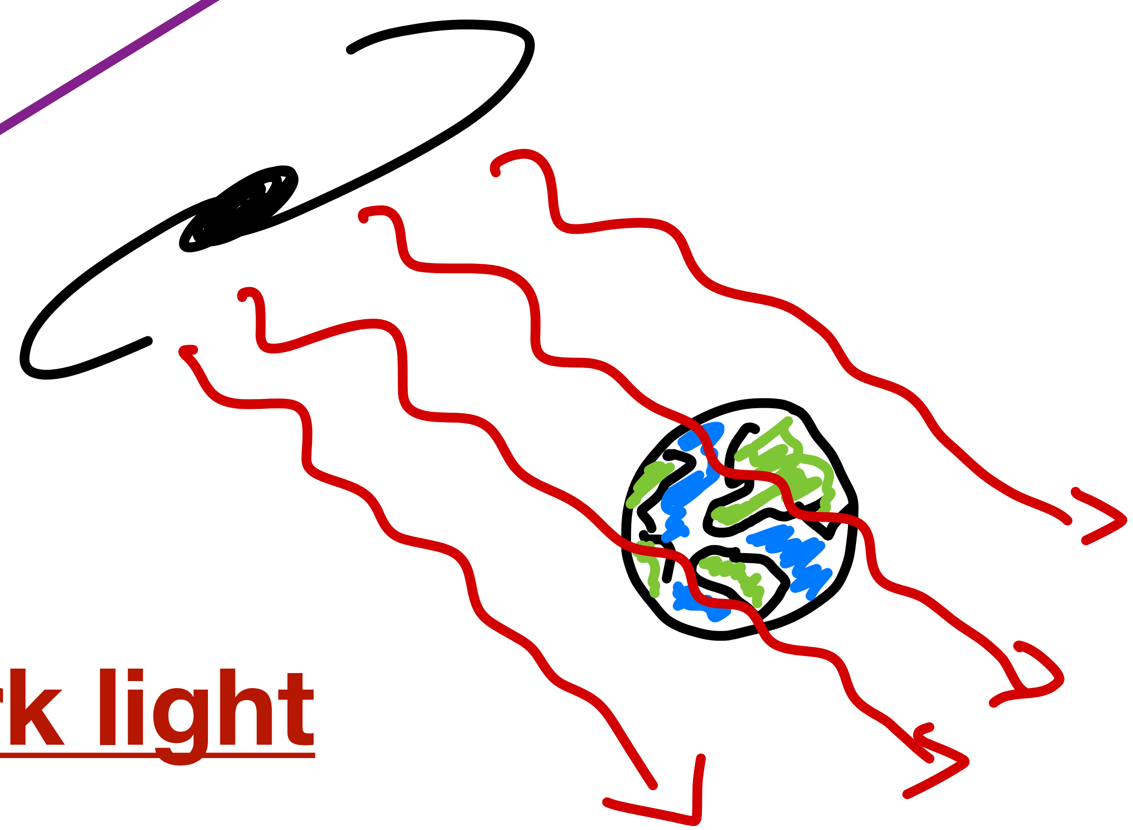
How we look for visible matter

Can dark matter shine?

Indirect detection



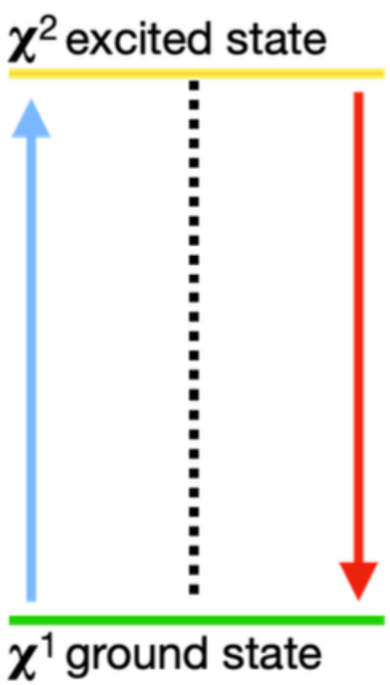
Little visible light

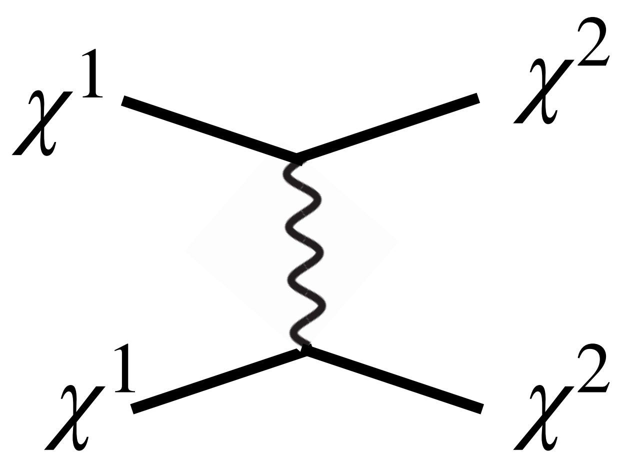


Lots of dark light

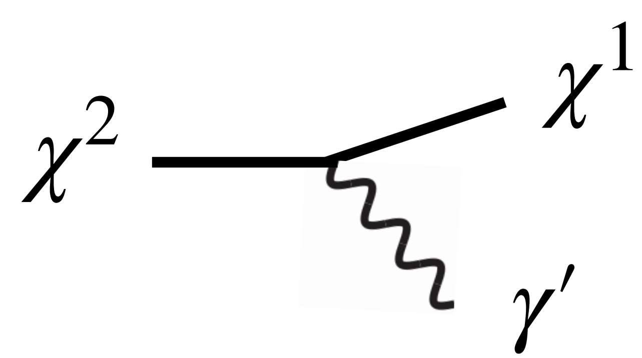
Inelastic dark matter

Toy model: two-level system



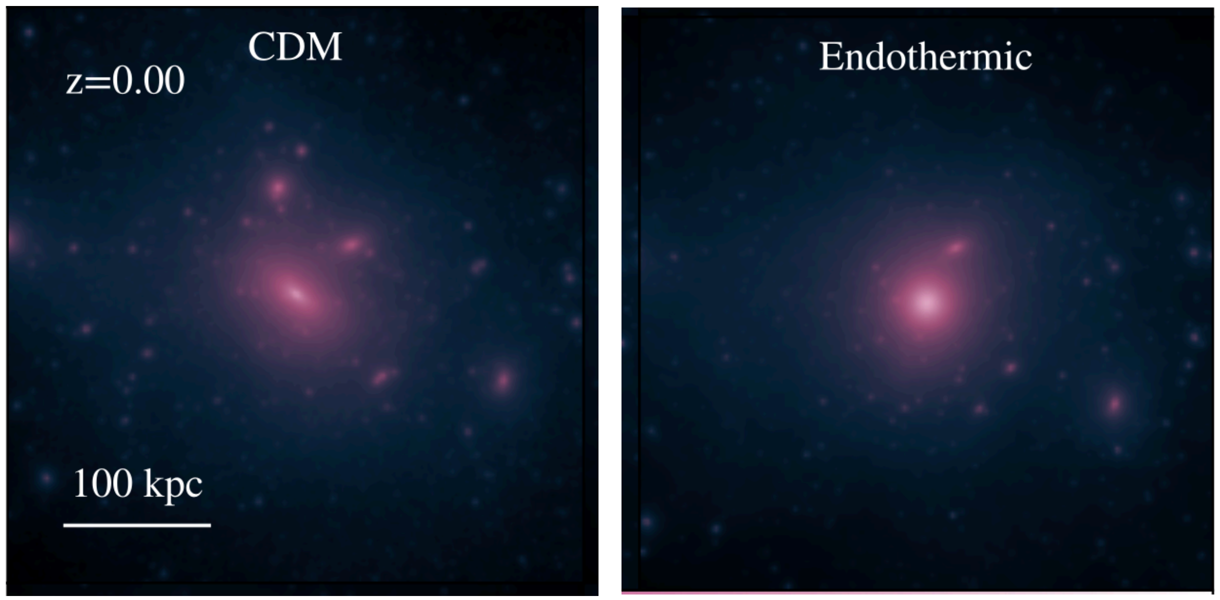


Upscattering



De-excitation

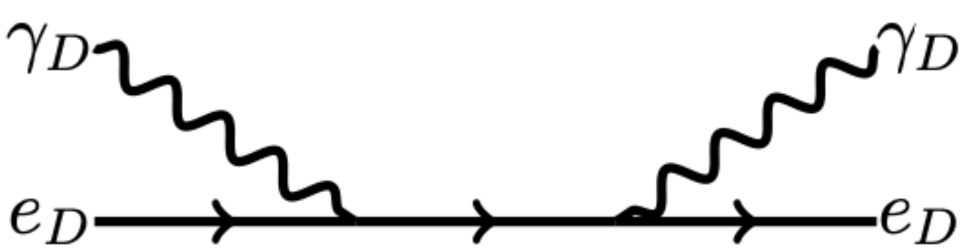
O’Neil et al, [2210.16328]



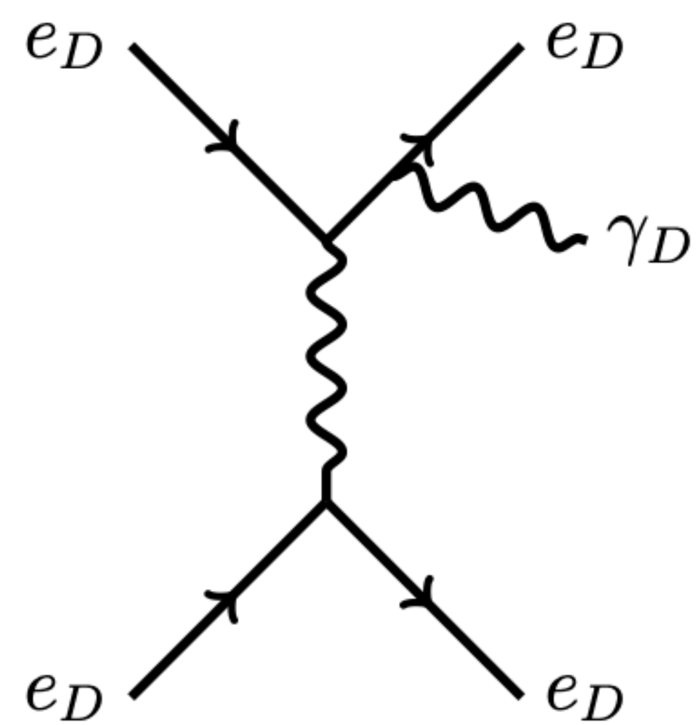
Dissipative dark sectors

Simple model with a dark electron and a dark photon

Chang et al, [1812.07000]



Compton scattering

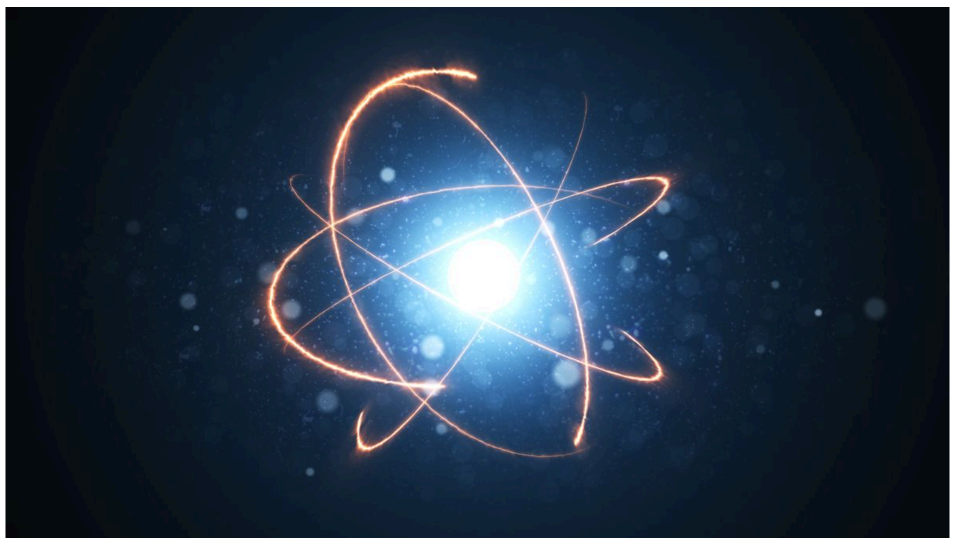


Bremsstrahlung

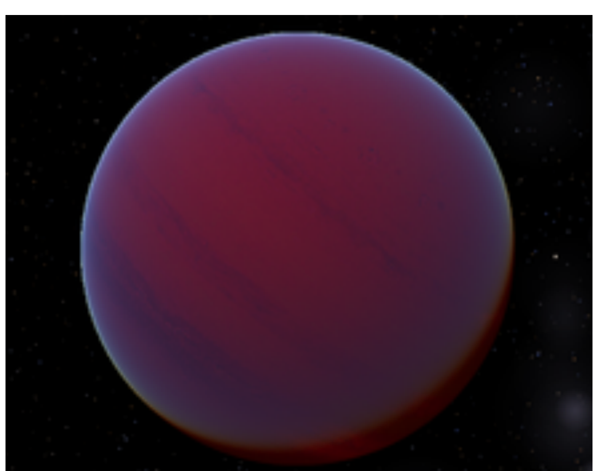
Gas fragmentation and formation of compact objects

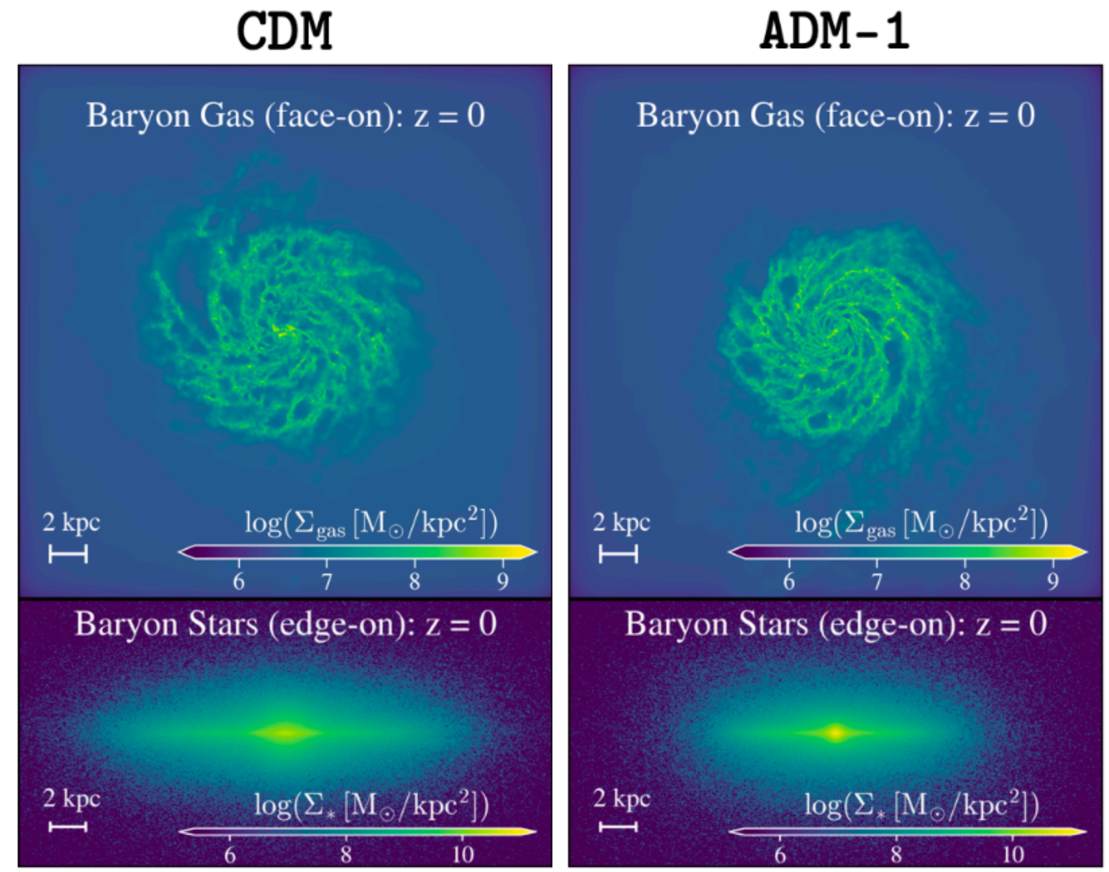
Atomic dark matter

Dark proton, dark electron, and dark photon **Kaplan et al [0909.0753]**

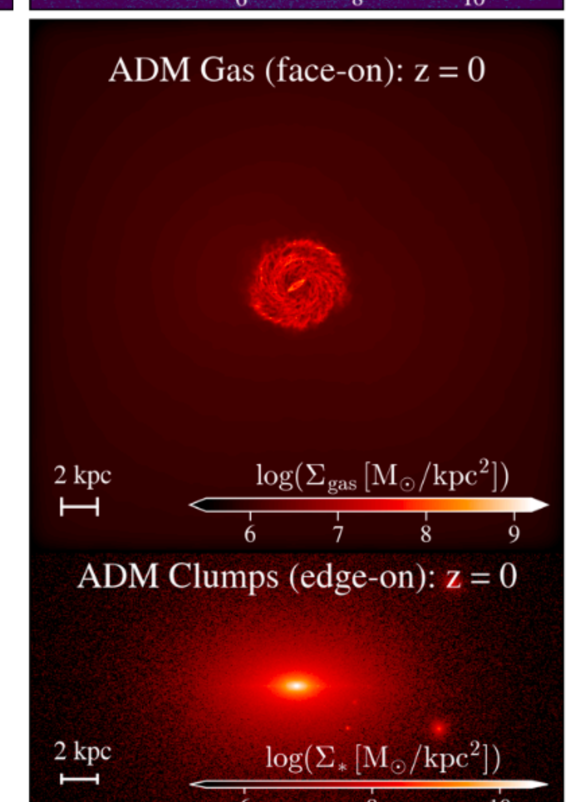


Dark "brown dwarfs"





Roy et al [2304.09878]



Mirror world

Visible sector

Dark sector

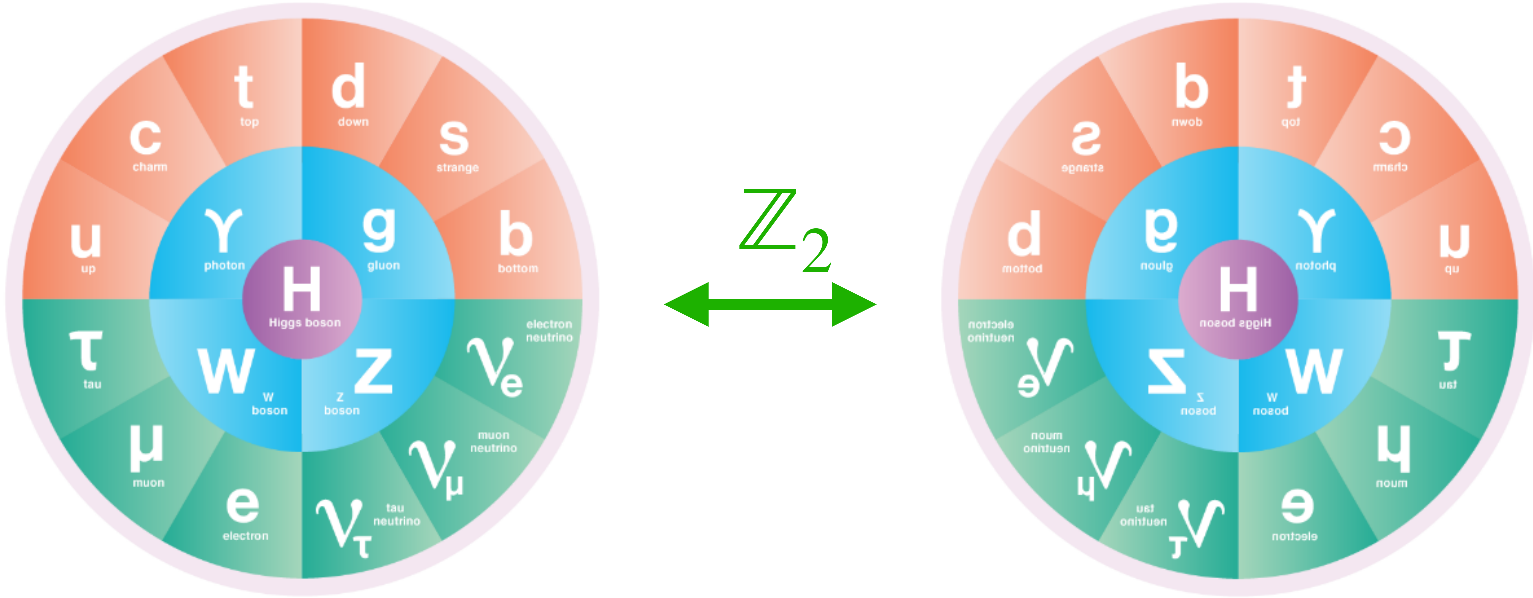
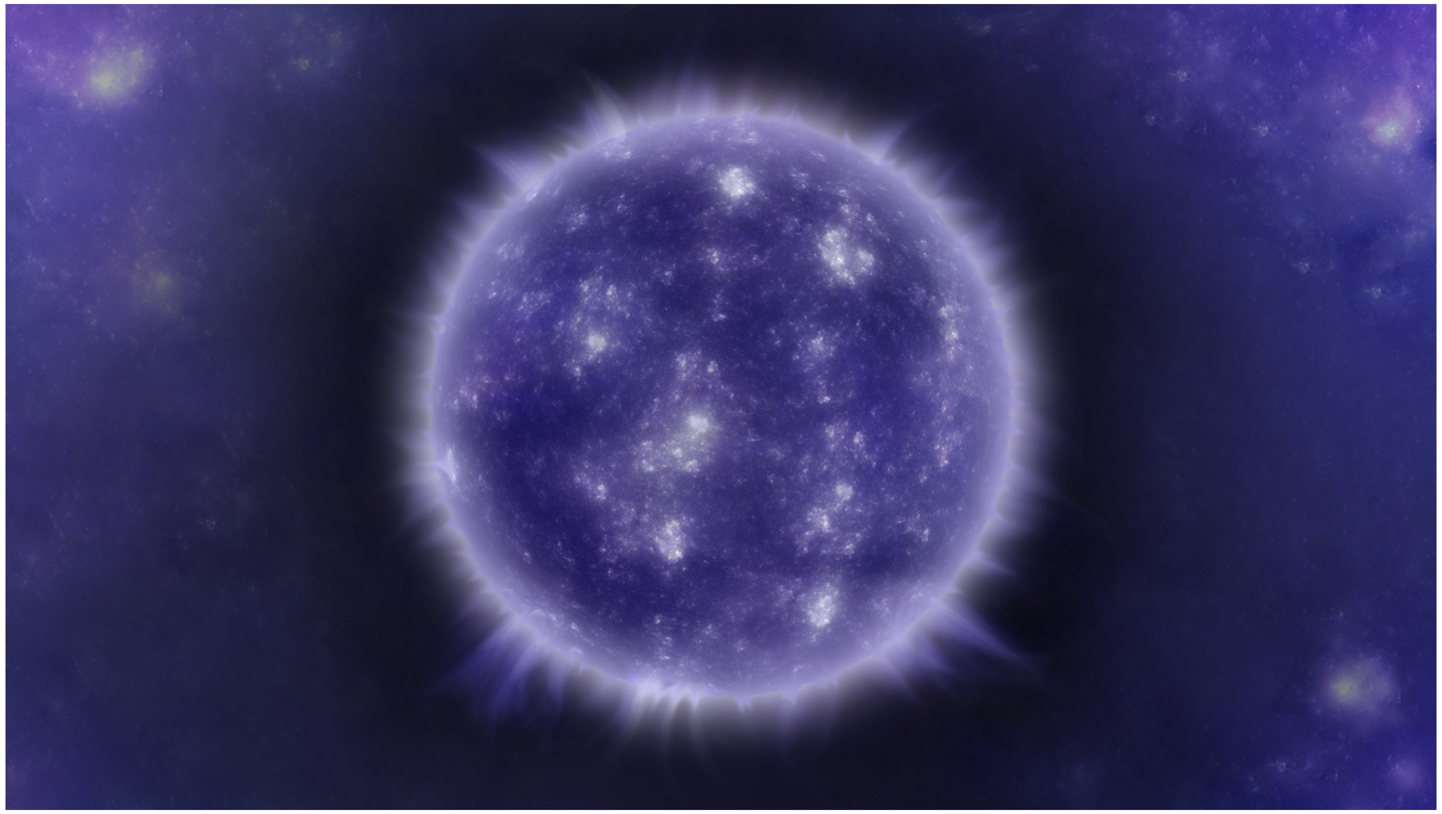


image source: Symmetry magazine

Dark Big Bang Nucleosynthesis, fusion-supported stars



Mohapatra & Teplitz [9603049]

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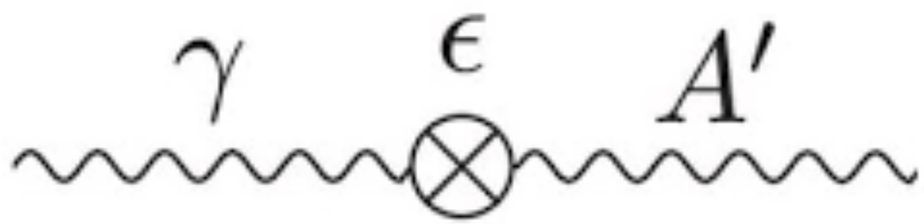
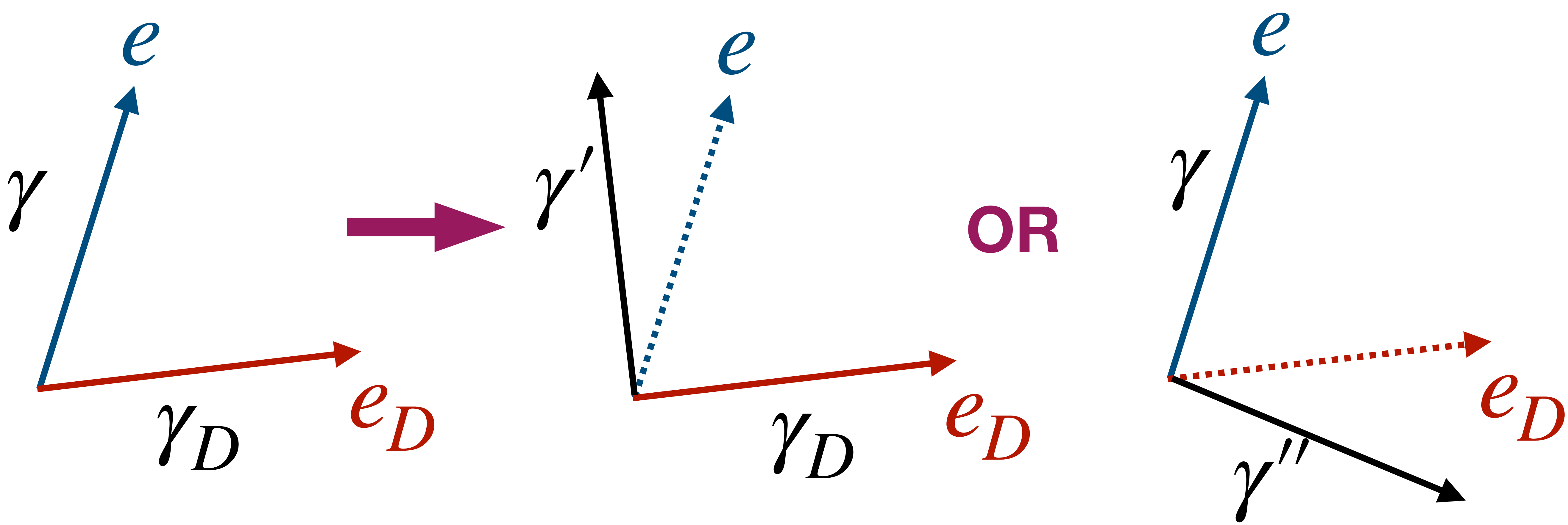
Dark photons

May “kinetically mix” with the visible photon



Kinetic terms are not diagonal

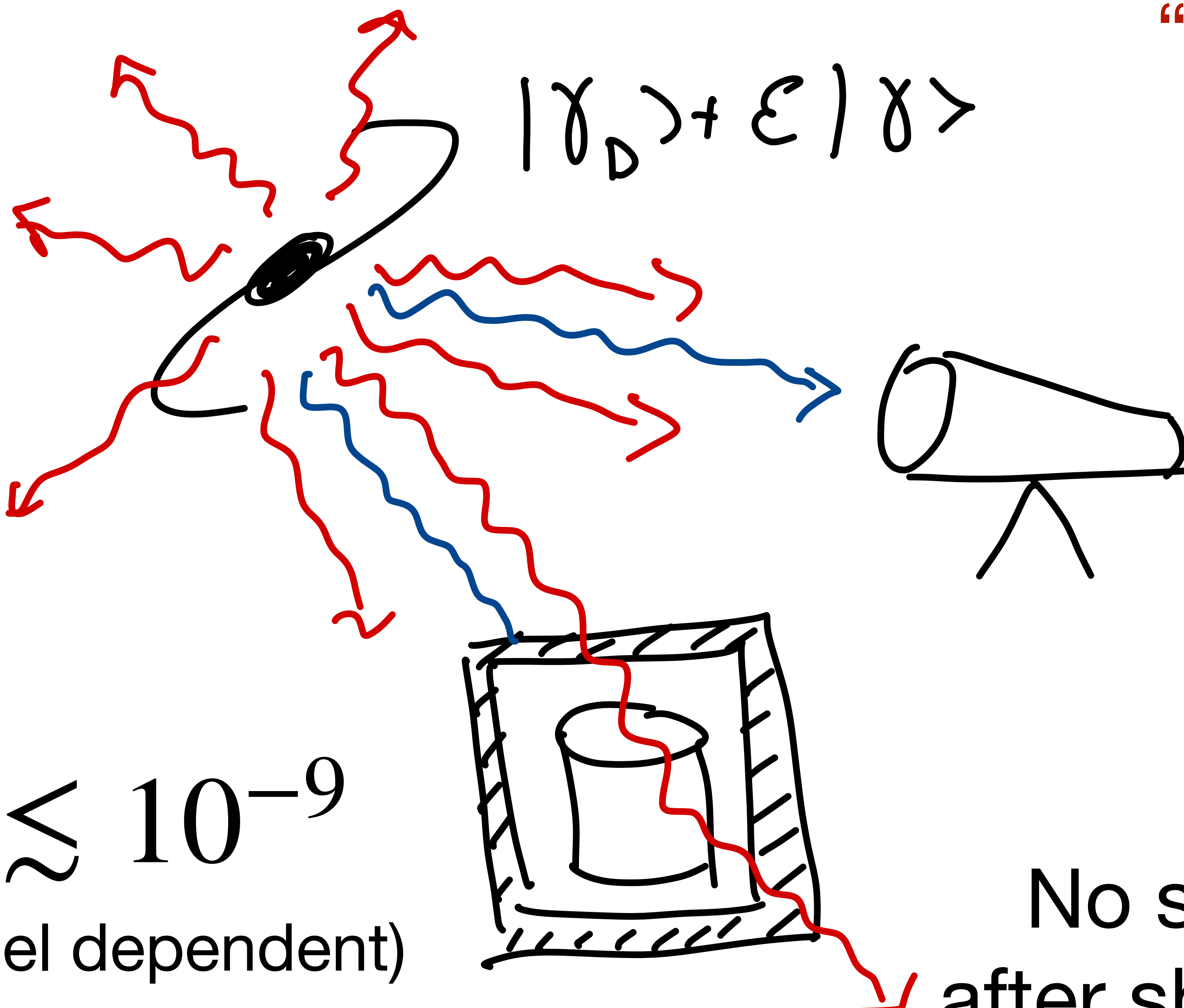


Interaction basis “SM millicharged” “DM millicharged”

Detecting massless dark photons

If dark matter shines in dark photons

"DM millicharged"



Overwhelmed by foregrounds

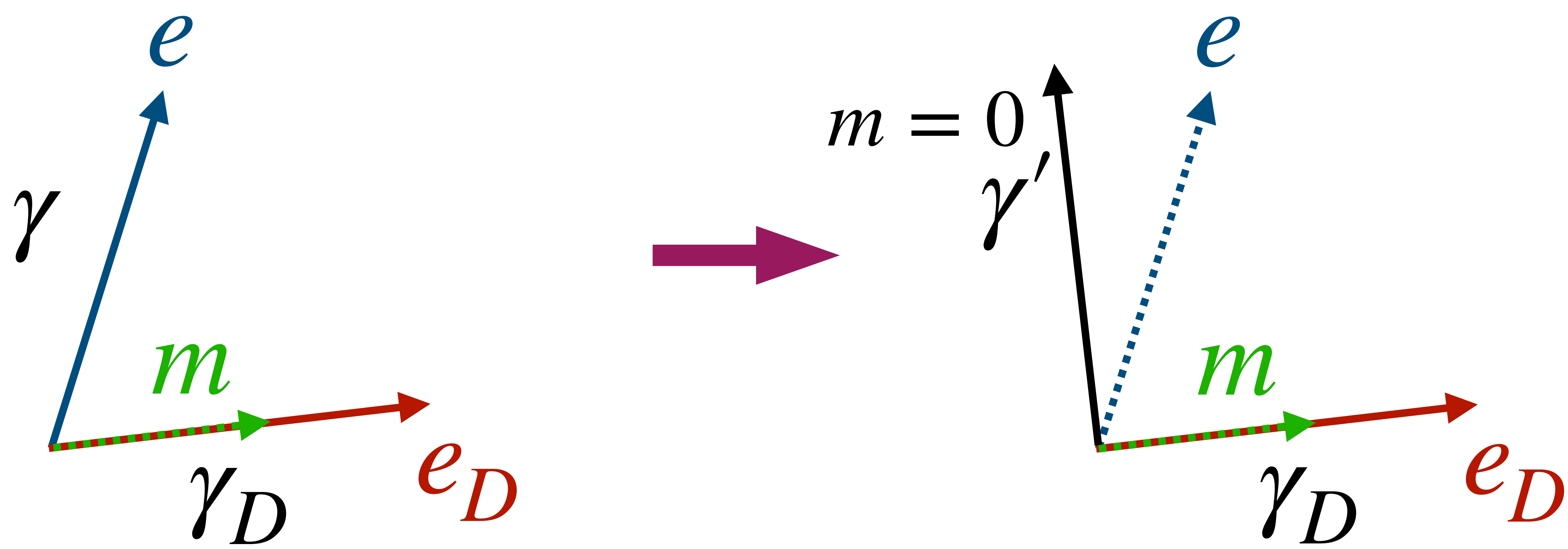
$$\epsilon \lesssim 10^{-9}$$

(model dependent)

No signal after shielding

Massive dark photons

Mass term for the dark photon —> special direction



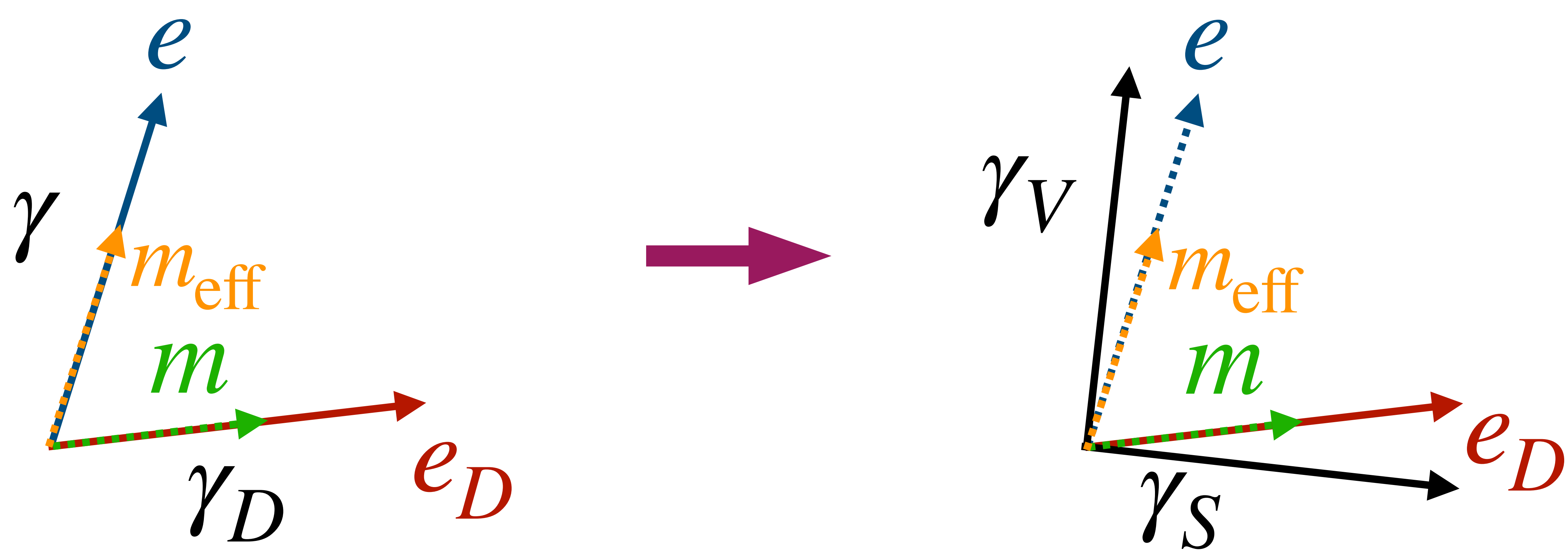
Interaction basis

Mass basis

Photon - dark photon oscillations (similar to neutrinos)

Massive dark photons in a medium

Effective mass term for the visible photon

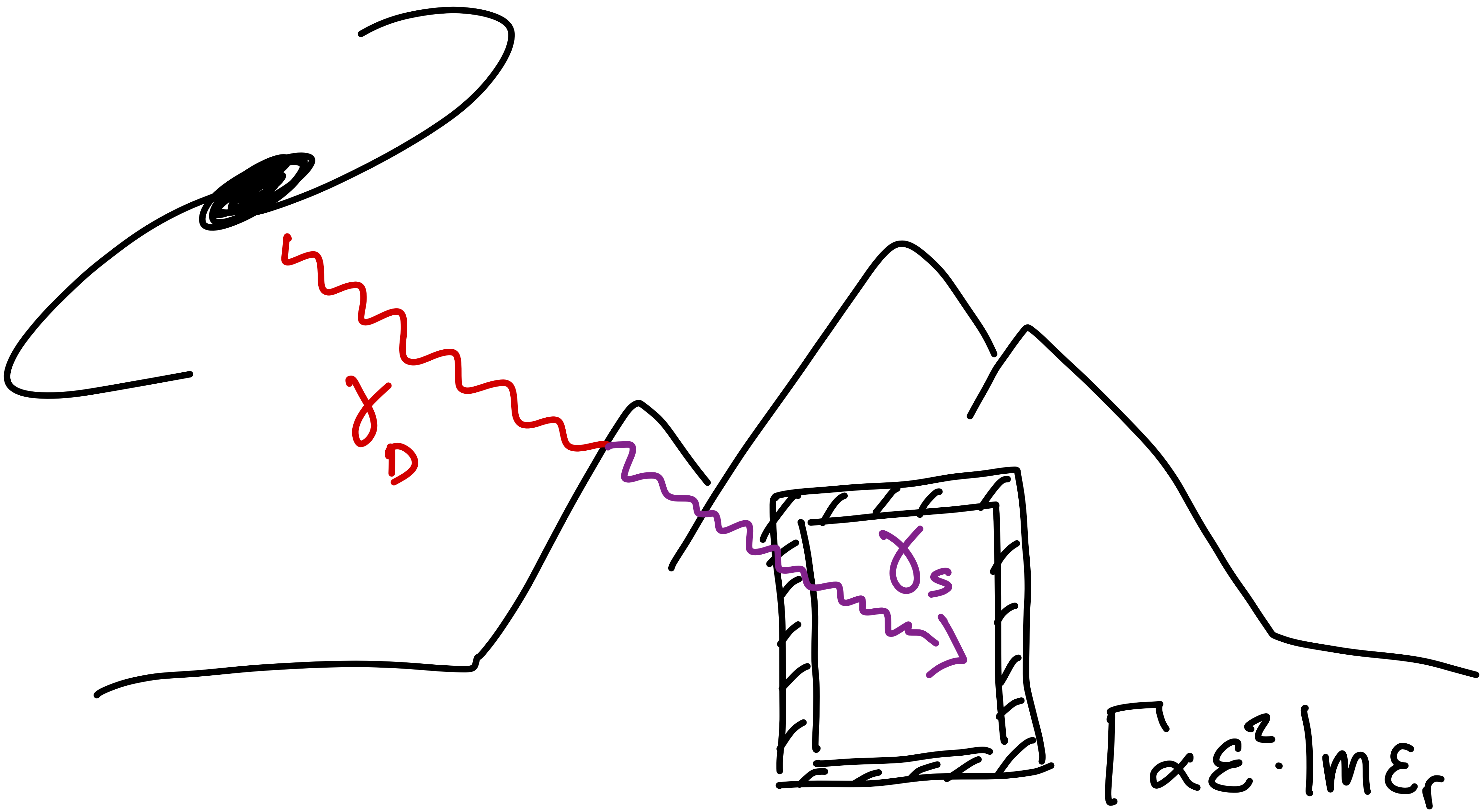


Interaction basis
Propagation basis

Two propagating eigenstates:

- Visible photon, $\ell_{\gamma_V} \propto 1/\text{Im}\,(m^2_{\text{eff}})$
- Sterile photon, $\ell_{\gamma_S} \sim \ell_{\gamma_V}/\epsilon^2$

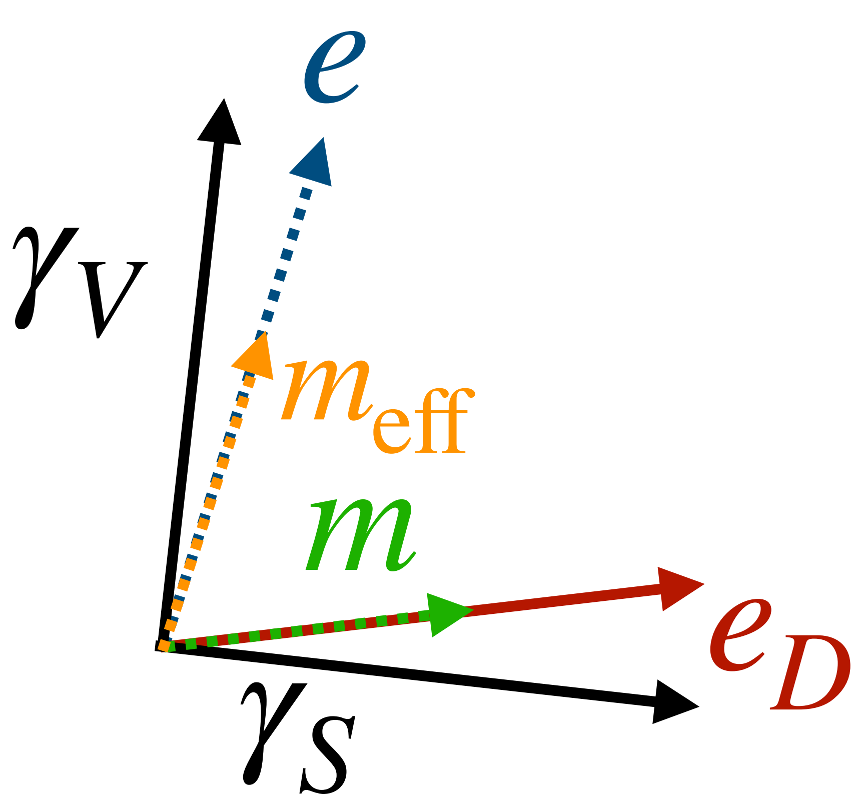
Massive dark photon absorption



Still some signal after shielding!

Resonant oscillations

Photon-dark photon mixing can be resonantly enhanced



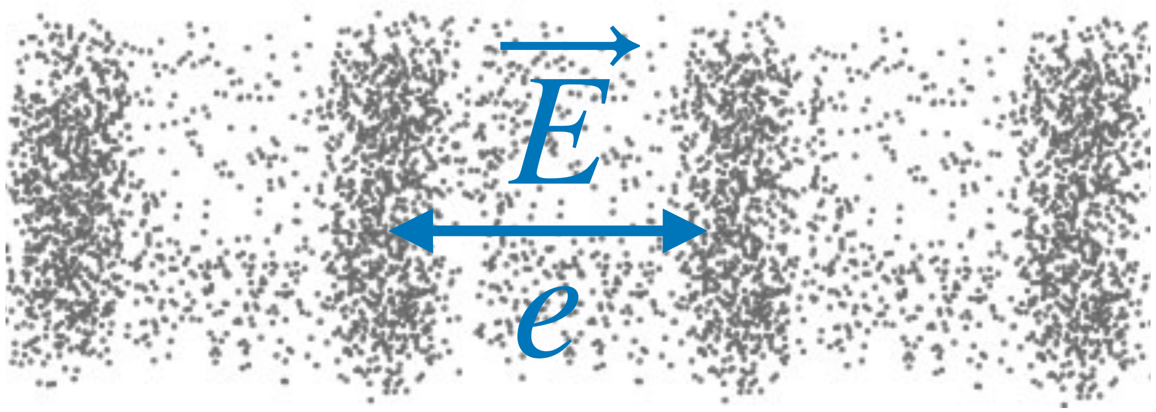
Resonant oscillations when

$$m^2 = m^2_{\rm eff}$$

- $m^2_{\rm eff} < 0$ in dielectrics: no resonance
- $m^2_{\rm eff} = \omega_p = \dfrac{e^2 n_e}{m_e} > 0$ in a conductor: resonance

Longitudinal modes

Conductors support longitudinal photon modes



Plasmon dispersion relation

$$\omega = \omega_p$$

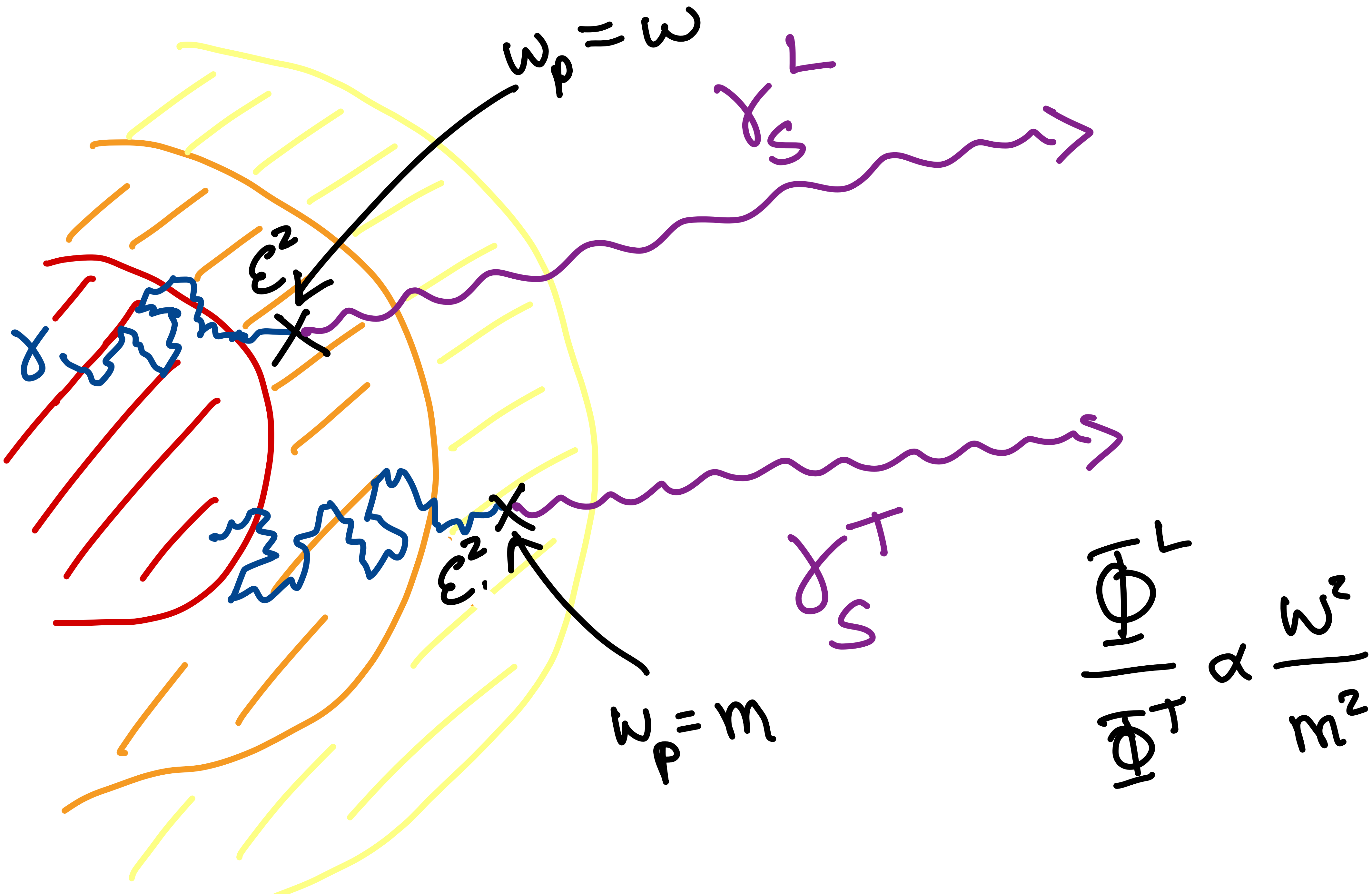
Longitudinal dark photons mix with plasmons:

- Resonance at $\omega_{\gamma_D} = \omega_p$
- Enhanced amplitude $\theta_L = \dfrac{\omega^2}{m^2}\theta_T$
- Enhanced absorption $\Gamma_L \propto \dfrac{\omega^2}{m^2}\Gamma_T$

Look for longitudinal modes when $m \ll \omega$!

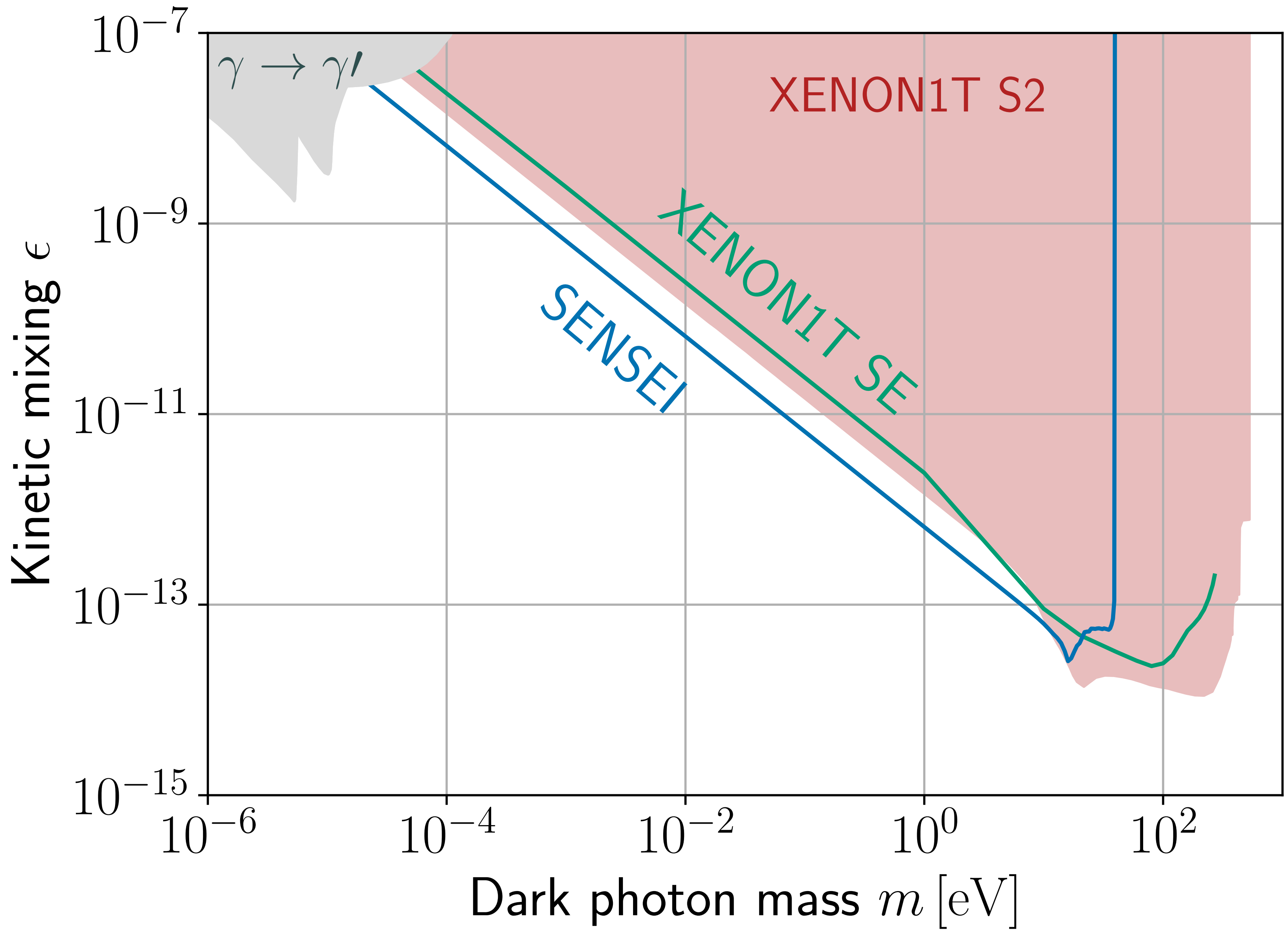
Solar emission of dark photons

Resonant $\gamma \to \gamma_D$ conversion in the solar plasma



Predominantly in longitudinal modes for $m \ll \omega$

Absorption of solar dark photons



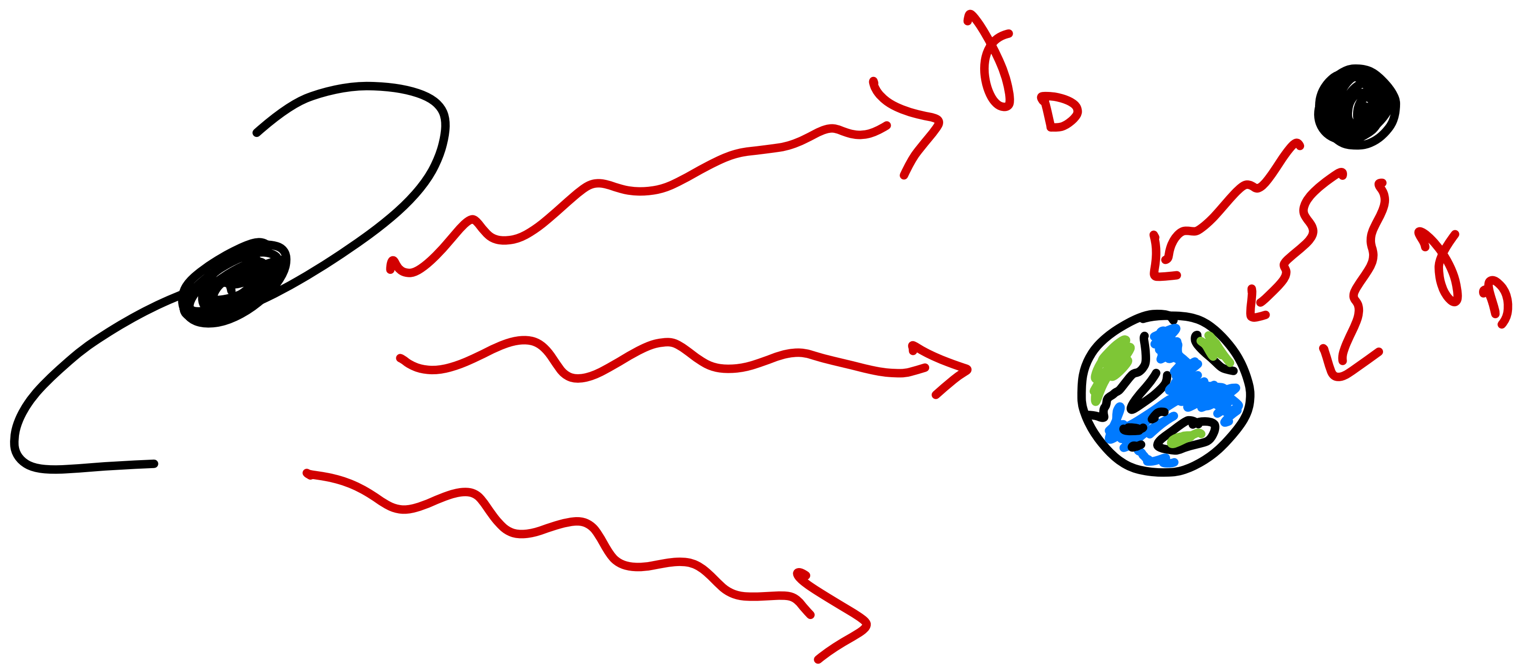
XENON1T S2: limits from **An et al [2006.13929]**

SENSEI: own recast of **Adari et al [2312.13342]**

XENON1T SE: own recast of **Aprile et al [2112.12116]**

Dark galaxy emission

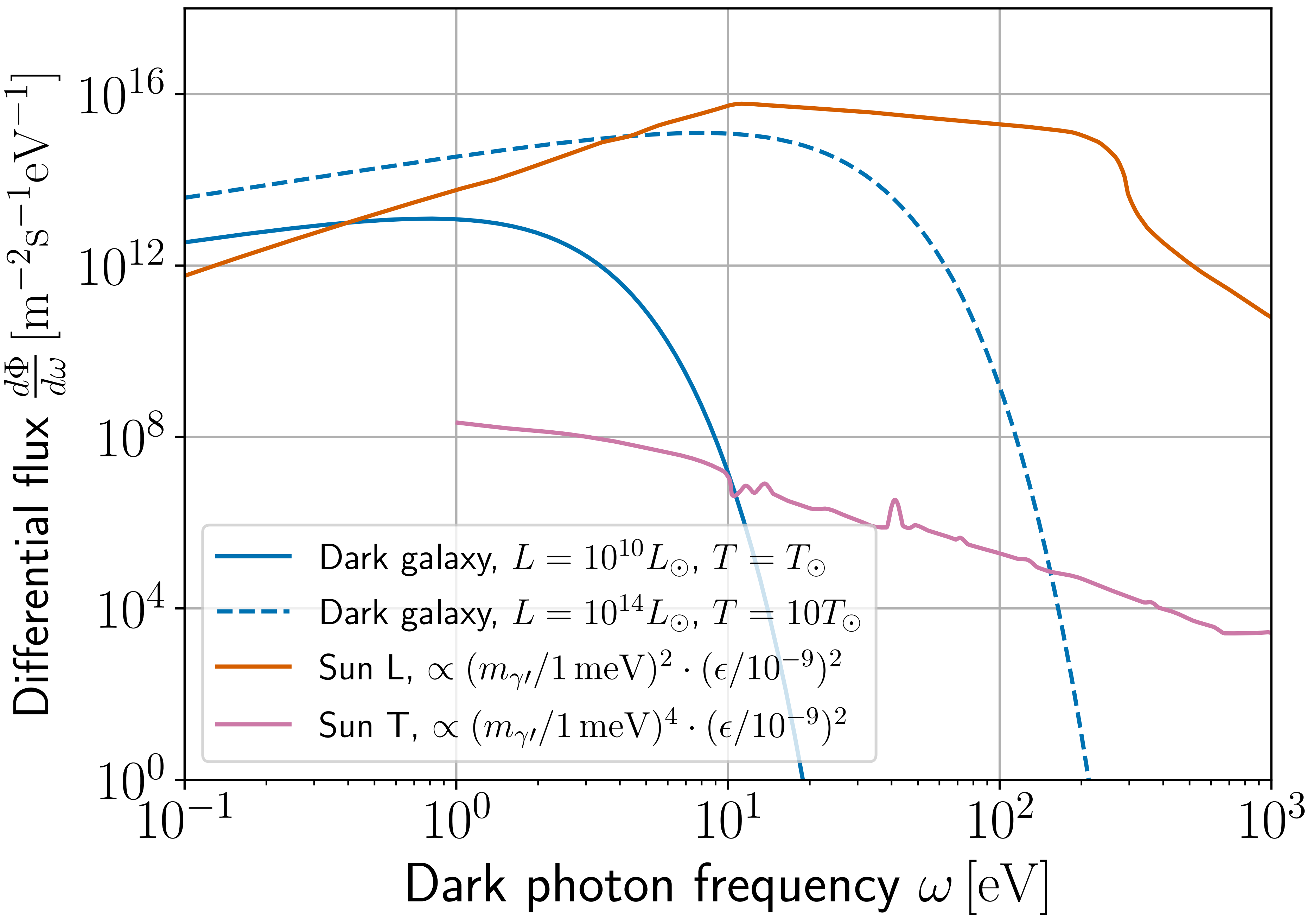
Details of the spectrum are very model dependent



Parametrized as a black body spectrum

- Temperature T
- Total luminosity L
- Located at the galactic center $d \simeq 8\,\mathrm{kpc}$
- Equal amount of longitudinal and transverse modes

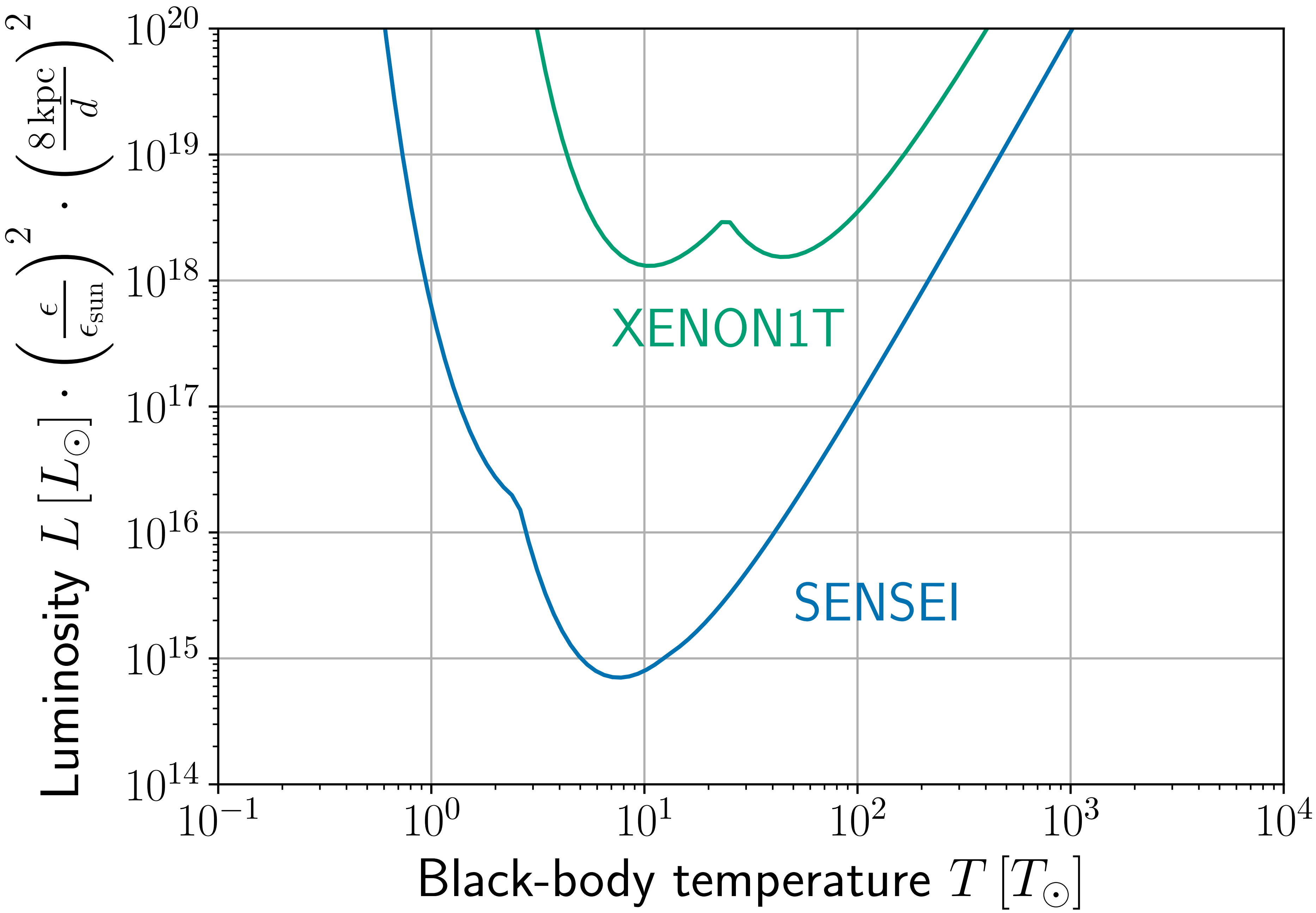
Total dark photon flux at earth



Solar emission decreases as ϵ^2

Dark galaxy is independent of ϵ!

Absorption of dark starlight



For each m, saturate the limit on ϵ from solar emission

As a reference, the Milky Way has $L \sim 10^{10} L_\odot$

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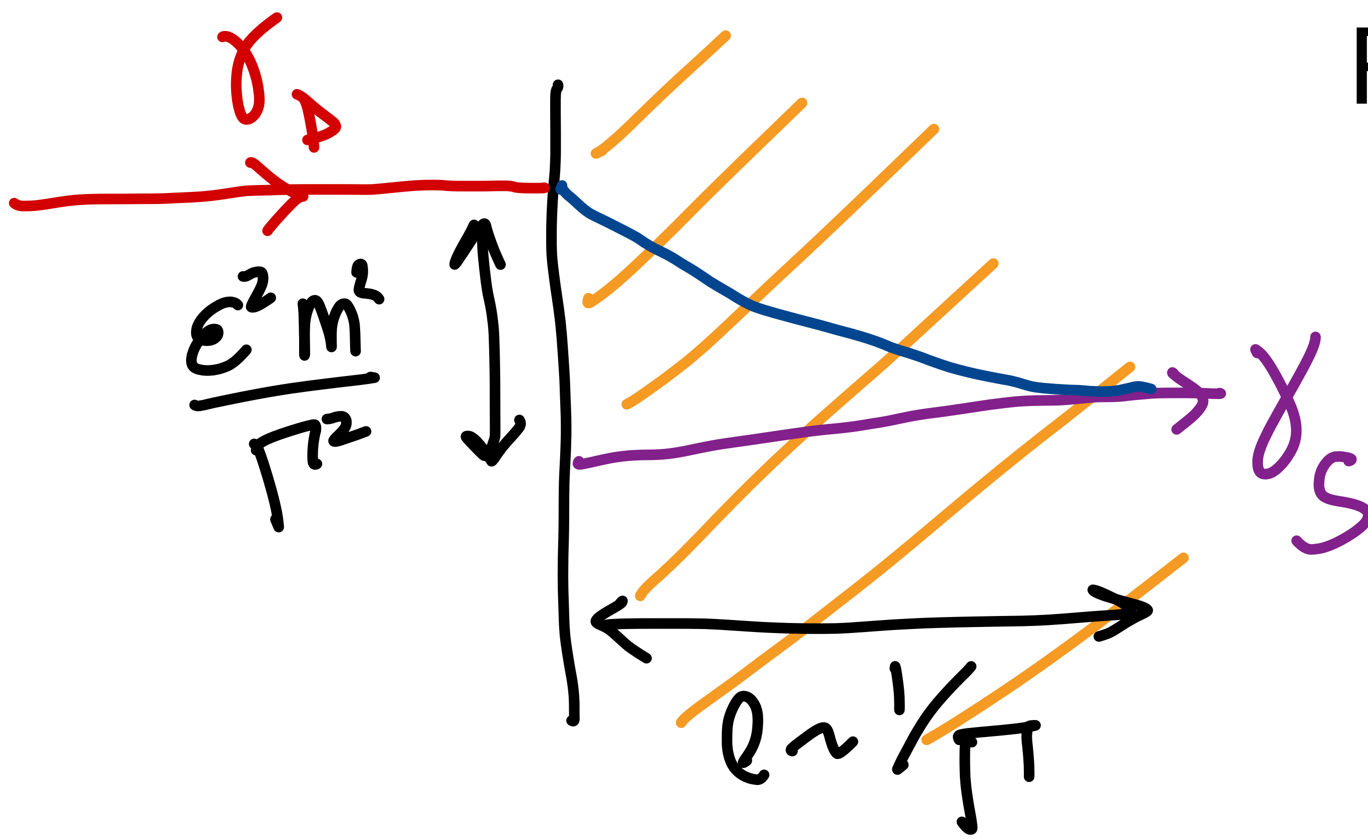
Resonant conversion

Resonant detector material (i.e. conductor)



Resonant frequency

$$\omega = \omega_p$$

Width of resonance

$$\delta\omega \sim \Gamma$$

Event rate:

$$R \simeq \left.\frac{d\Phi^L}{d\omega}\right|_{\omega_p} \cdot \frac{\epsilon^2 m^2}{\Gamma^2} \cdot \Gamma \cdot S$$

(flux) (conv. prob.) (width) (surface area)

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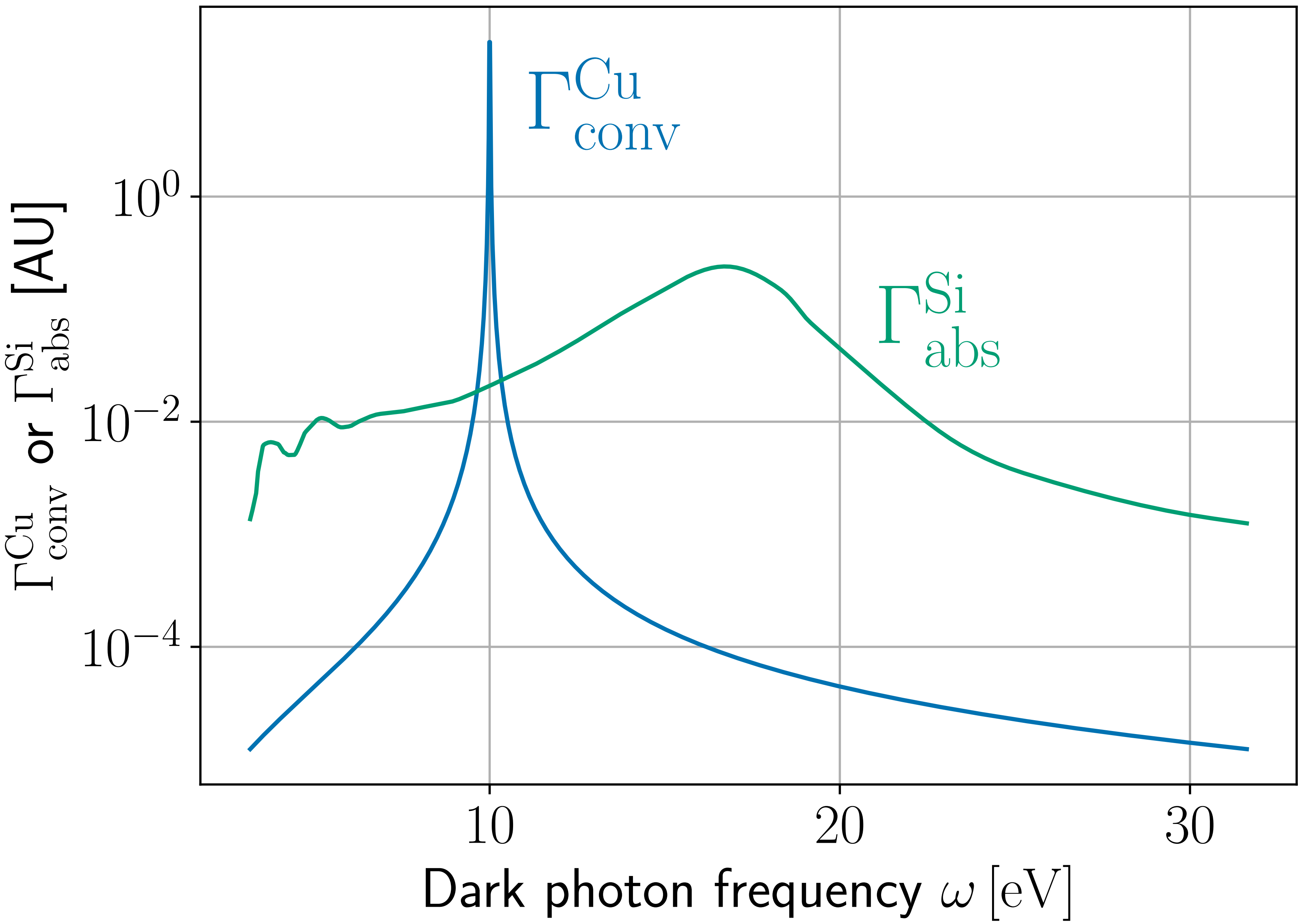
Resonant conversion vs absorption

Rates per unit volume

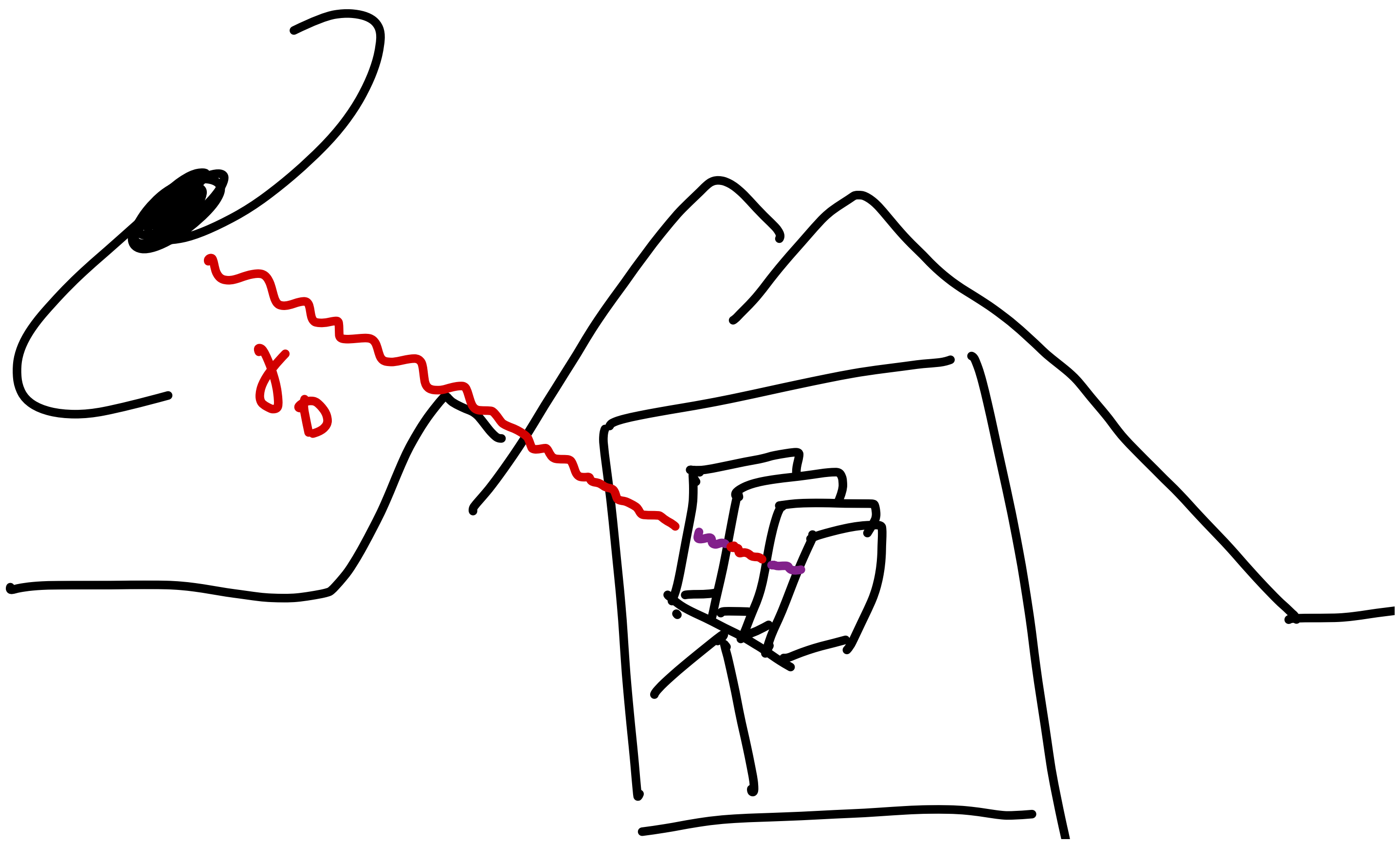


Similar integrated rate, but absorption is volumetric

conversion is at surface

Dark photon telescope

Series of instrumented thin layers of conductor



Example: copper

$$\omega_p \sim 10\,\mathrm{eV}$$

$$\ell = 1/\Gamma \lesssim \mathrm{mm}$$

(ultra pure, cooled)

Pros:	Cons:
Direccionality	Heat conductivity
Narrow frequency response	Readout?

Summing up

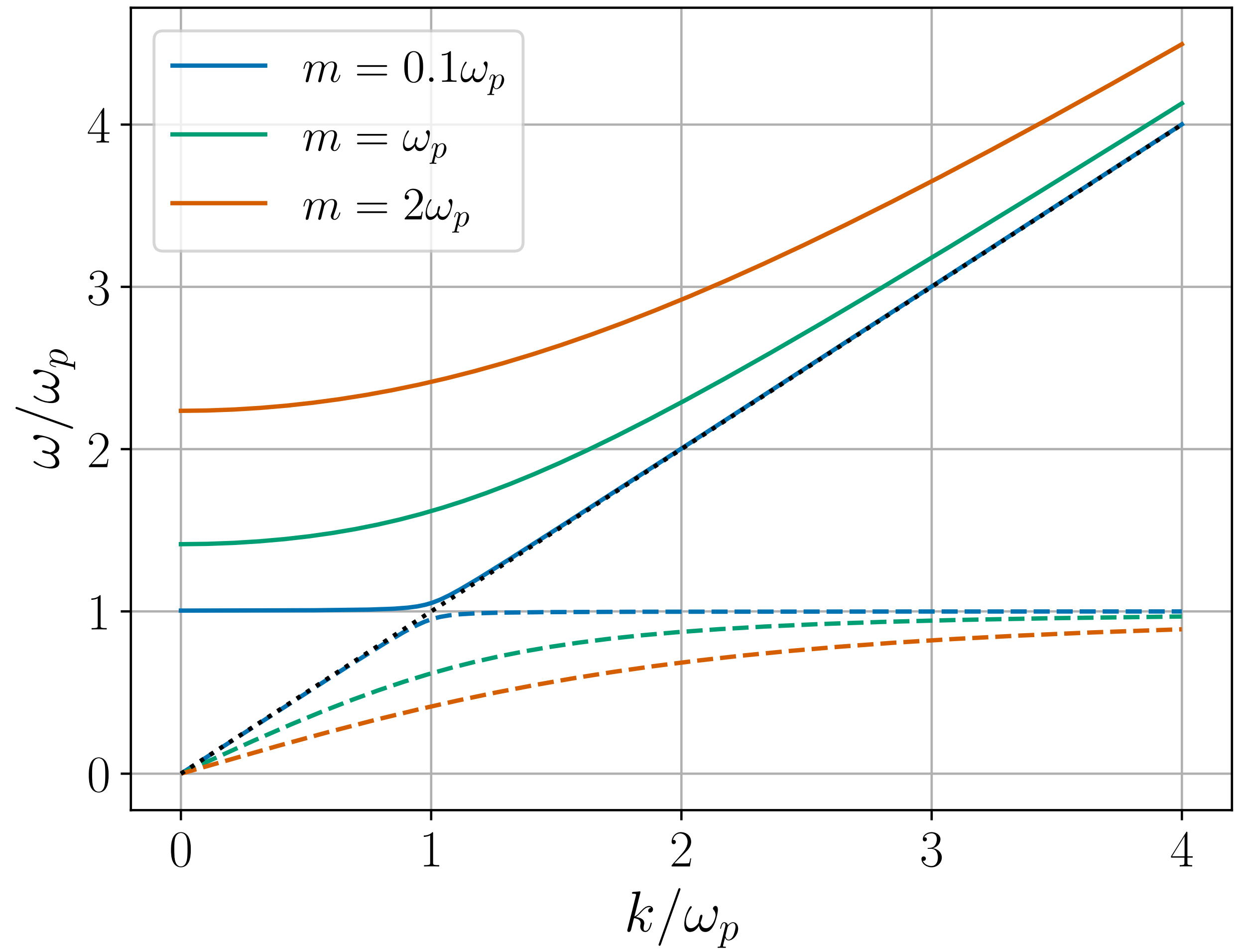
- Dissipative dark sectors may be detected by the dark radiation they emit.

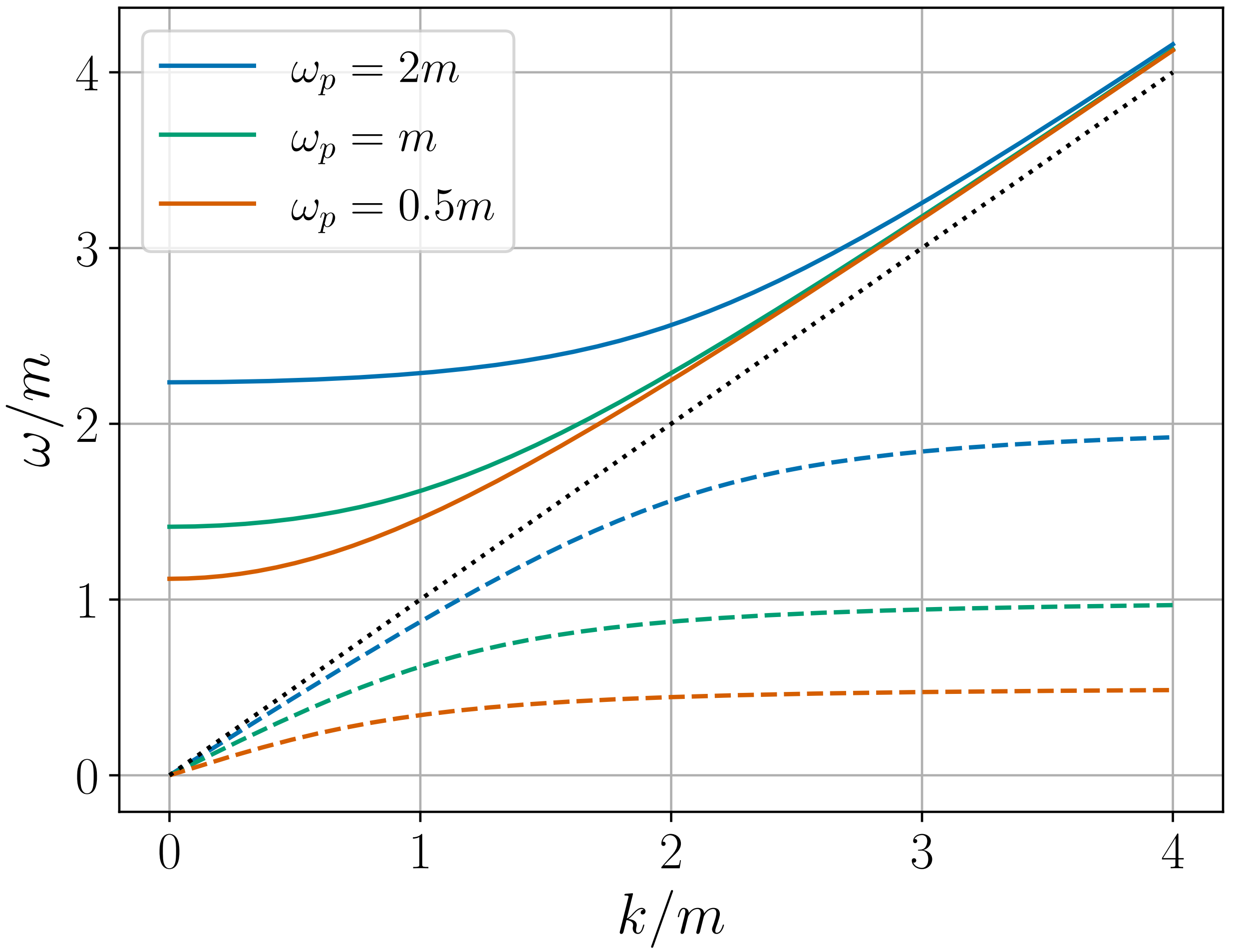
- Combine techniques of dark matter direct detection and astronomy:

“Dark astronomy”

Backup

Massive photon dispersion relation





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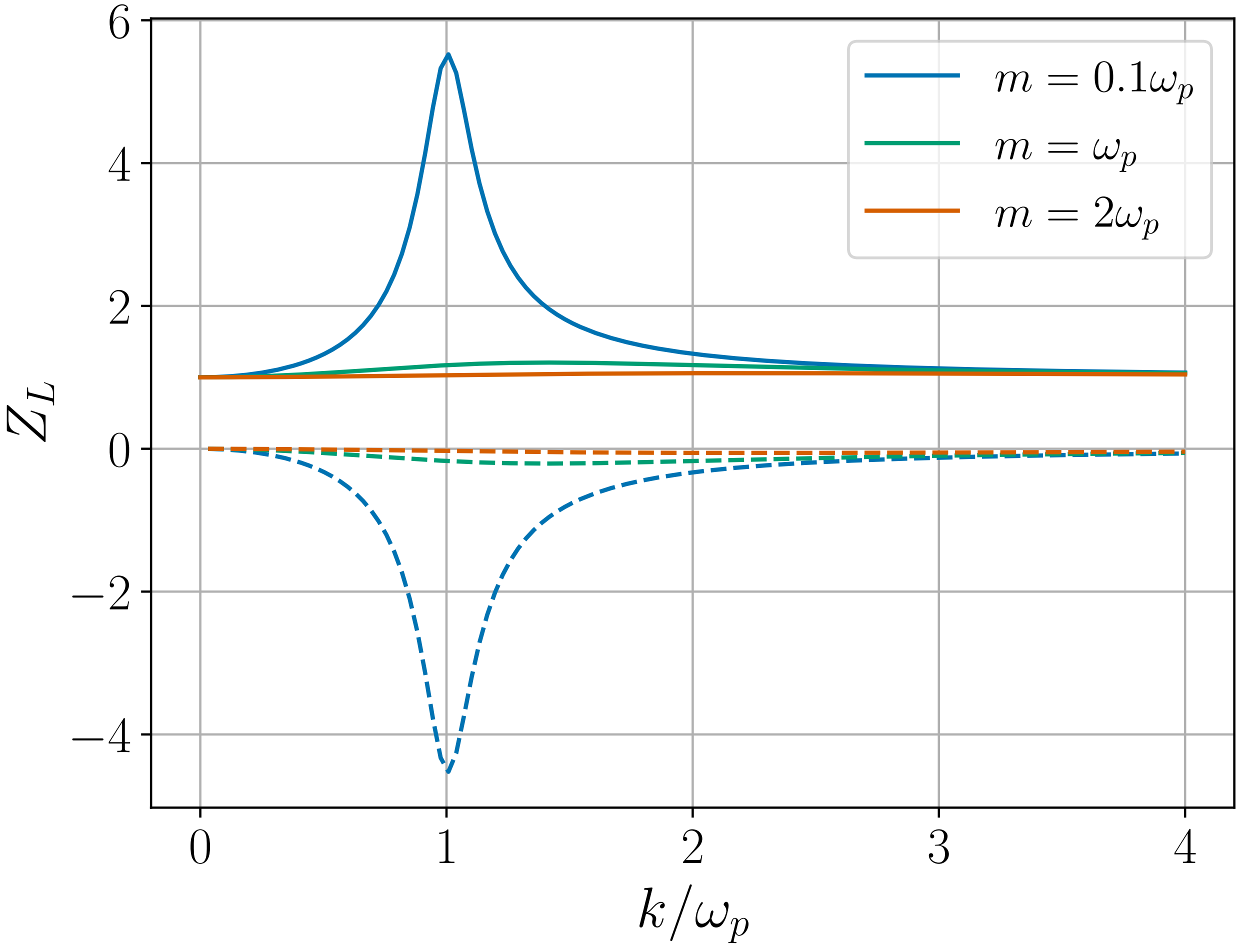
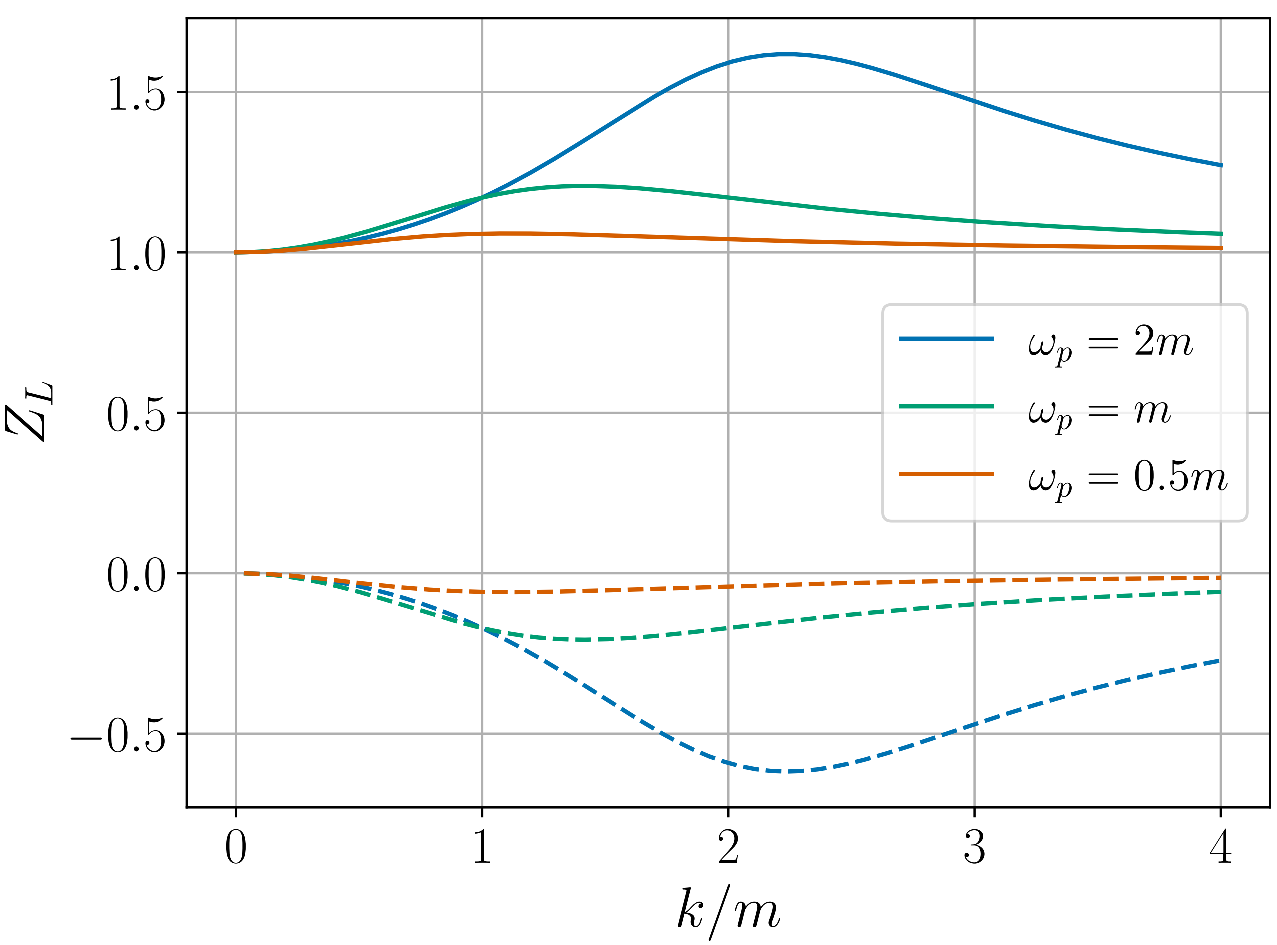
Massive photon renormalization factor





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Massive photon emission of sun-like star