Direct *Deflection* of Particle Dark Matter

Asher Berlin

Light Dark Matter
Venice
November 21, 2019

1908.06982 with R. D'Agnolo, S. Ellis, P. Schuster, N. Toro

Direct Detection Below an MeV

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predictive cosmology

(freeze-in)

viable

(self-interactions, stellar cooling, 5^{th} forces)

detectable

(light mediator)

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millicharge-like on meter length scales

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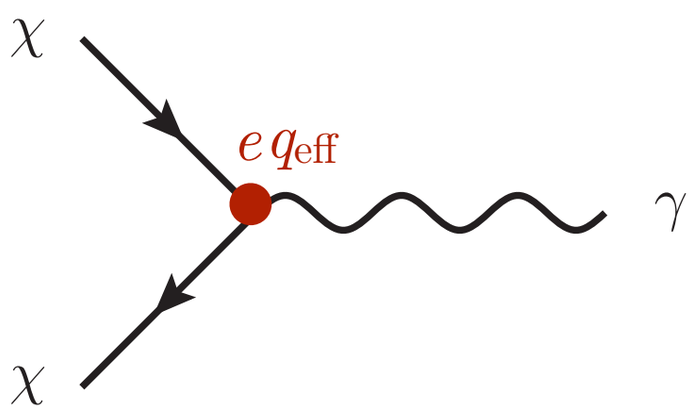

kinetically-mixed dark photon

$$m_{A'} \lesssim 10^{-9}\ \text{eV} \sim \frac{1}{100\ \text{m}}$$

Freeze-In

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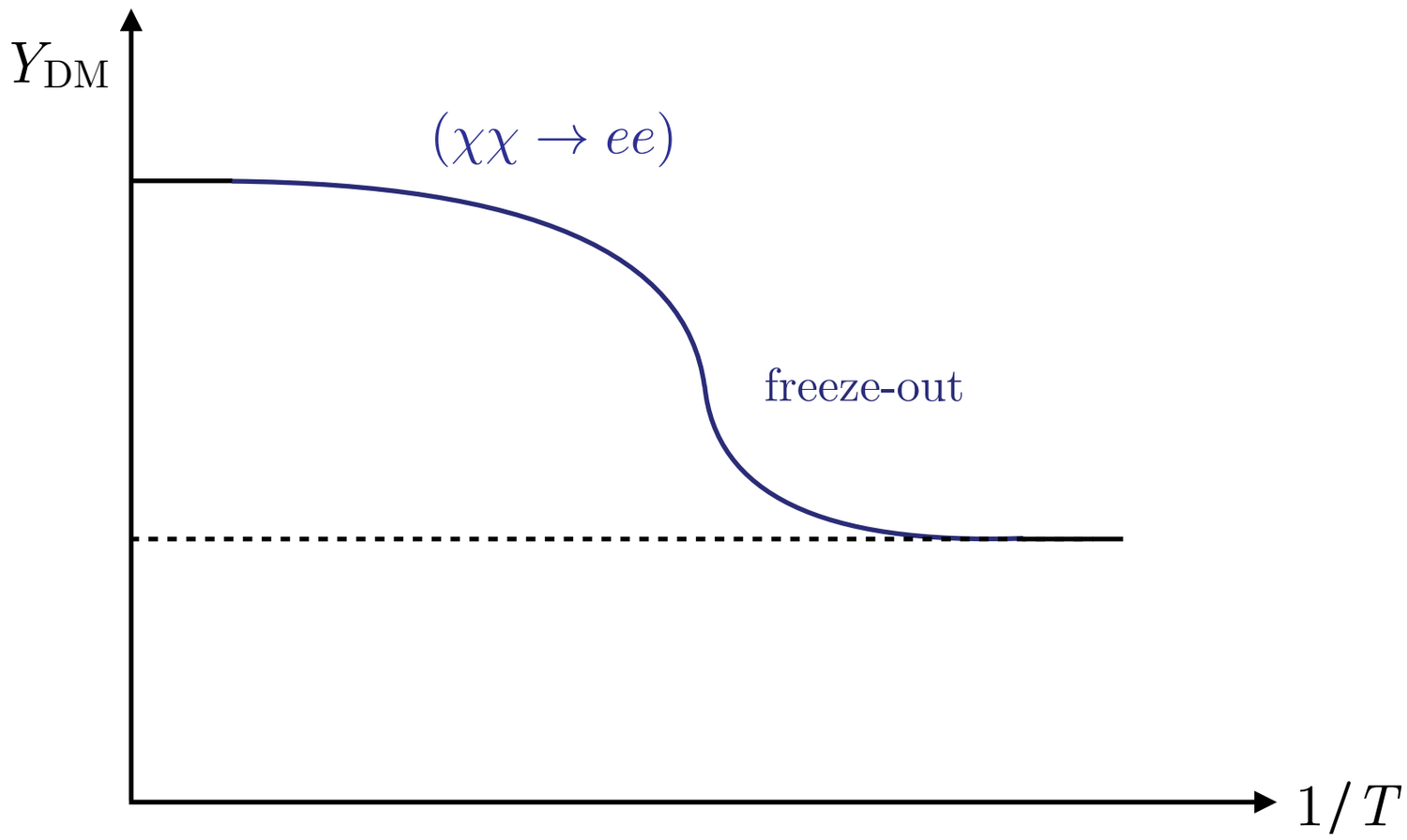

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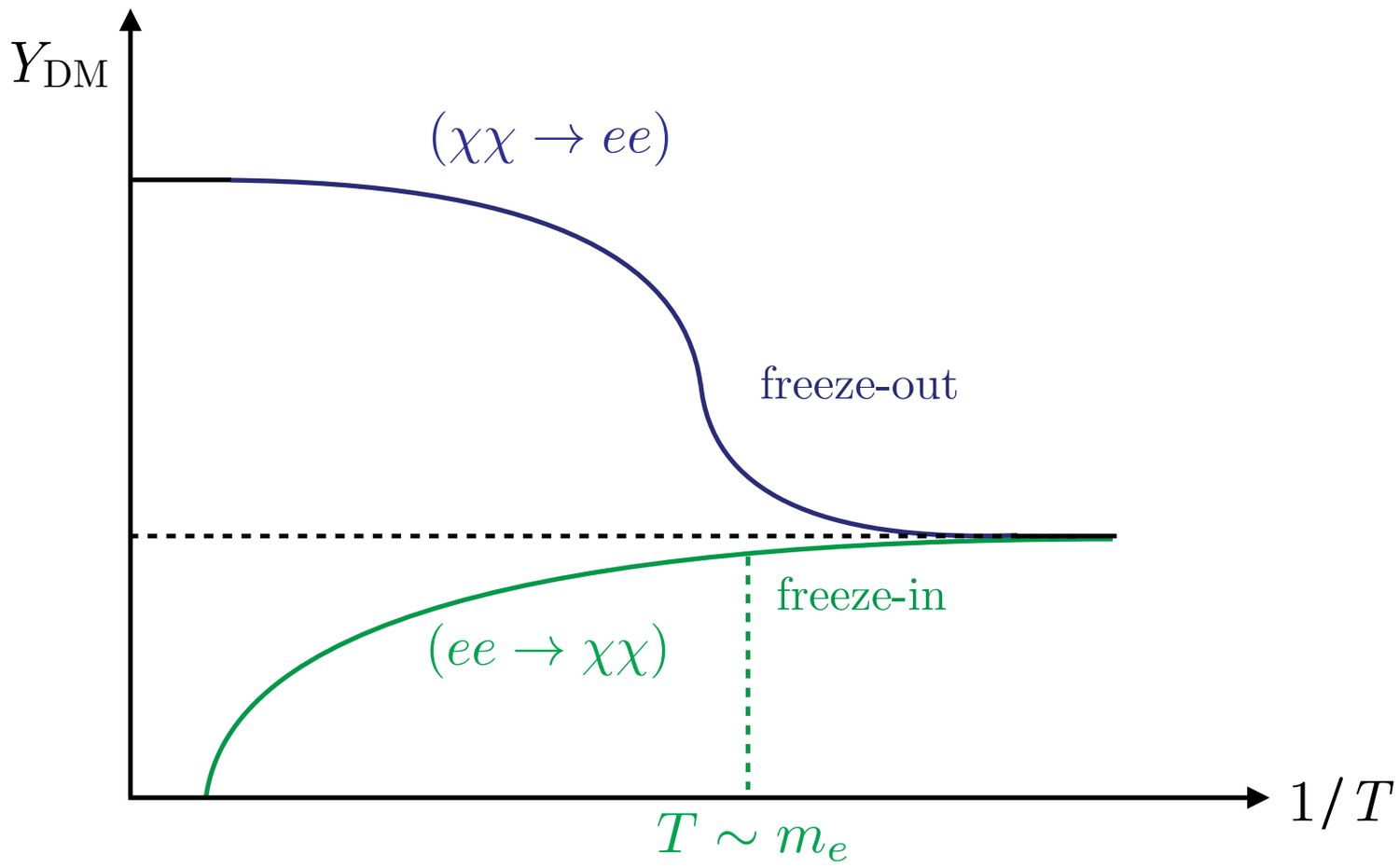
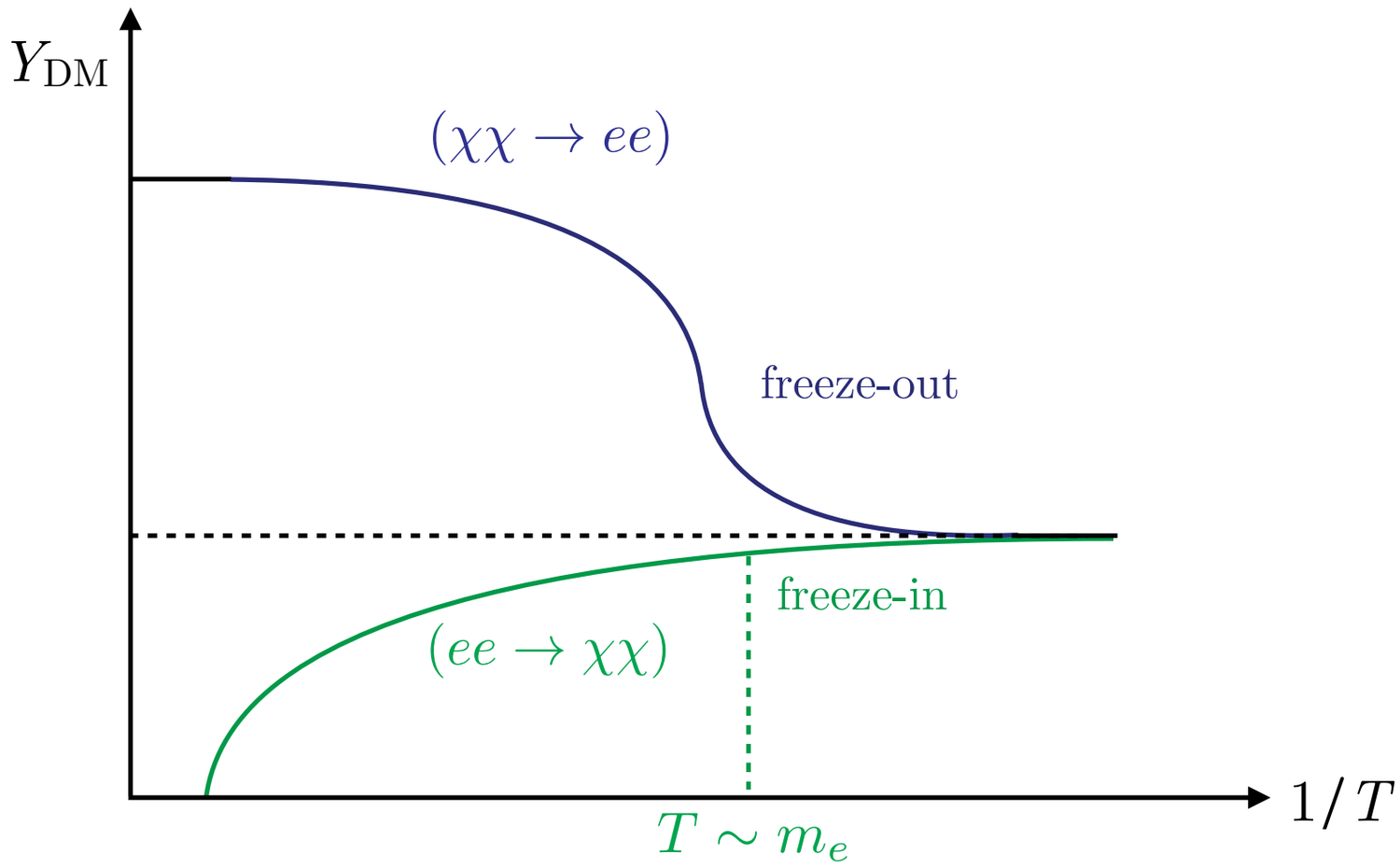
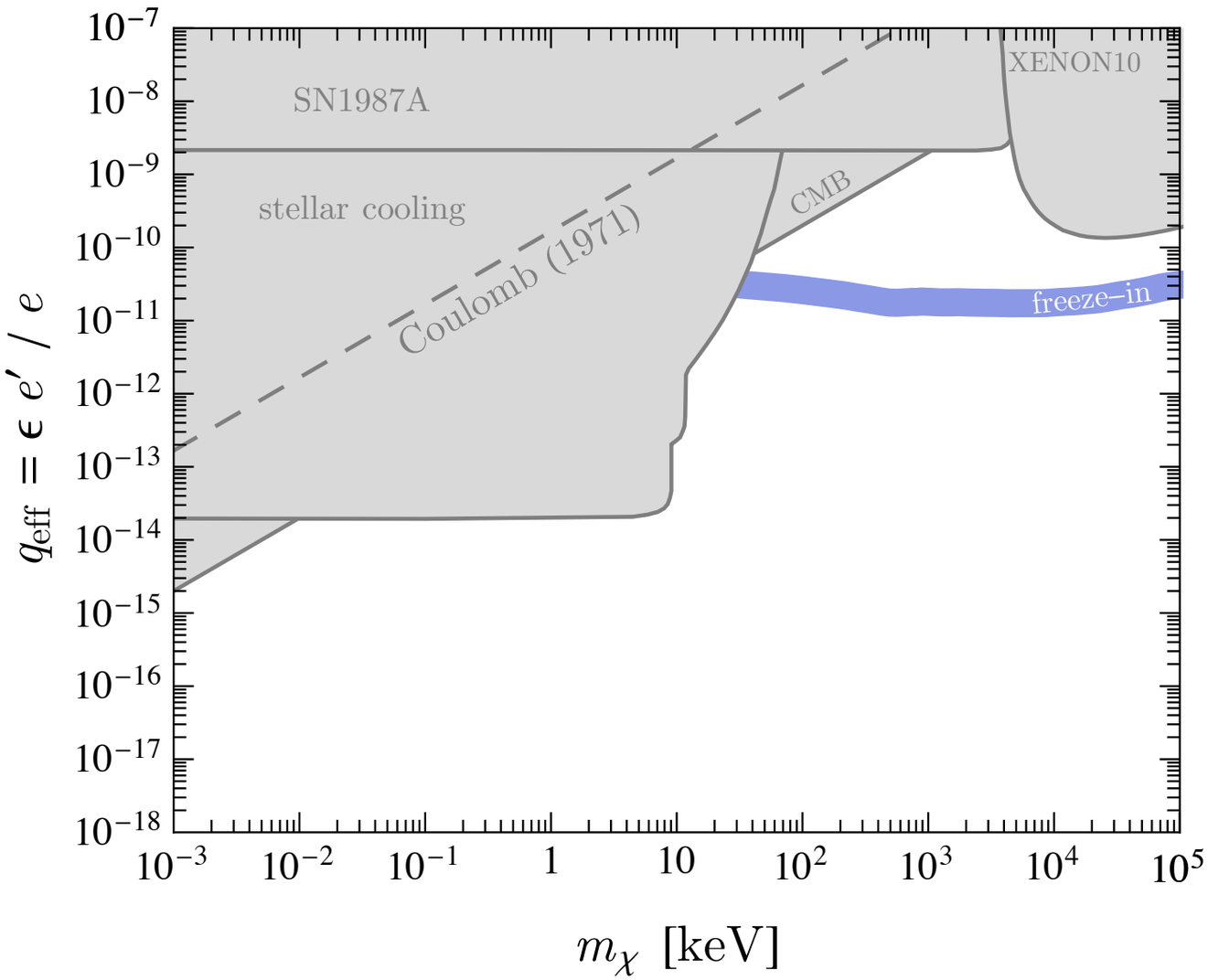


Freeze-In



$$q_{\rm eff} \sim \frac{1}{\alpha_{\rm em}} \left(\frac{m_e\, T_{\rm eq}}{m_\chi\, m_{\rm pl}} \right)^{1/2} \sim 10^{-11} \left(\frac{\rm MeV}{m_\chi} \right)^{1/2}$$

MilliCharged Dark Matter



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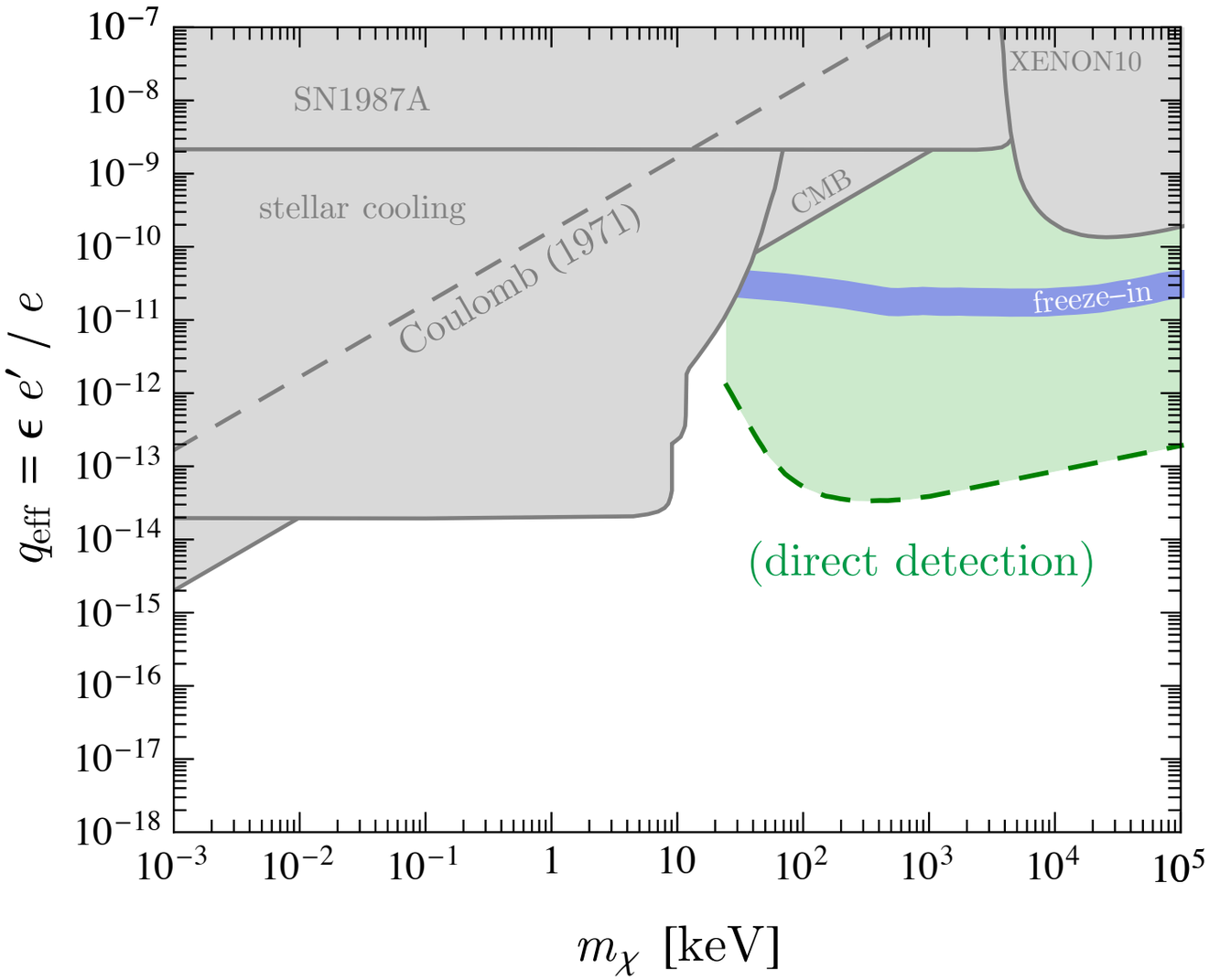
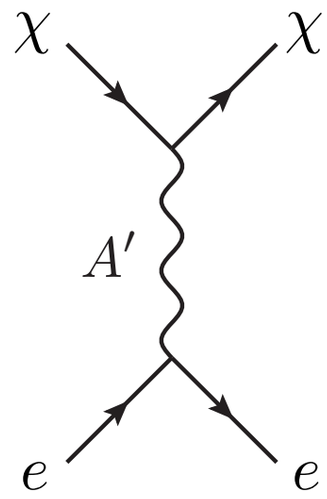
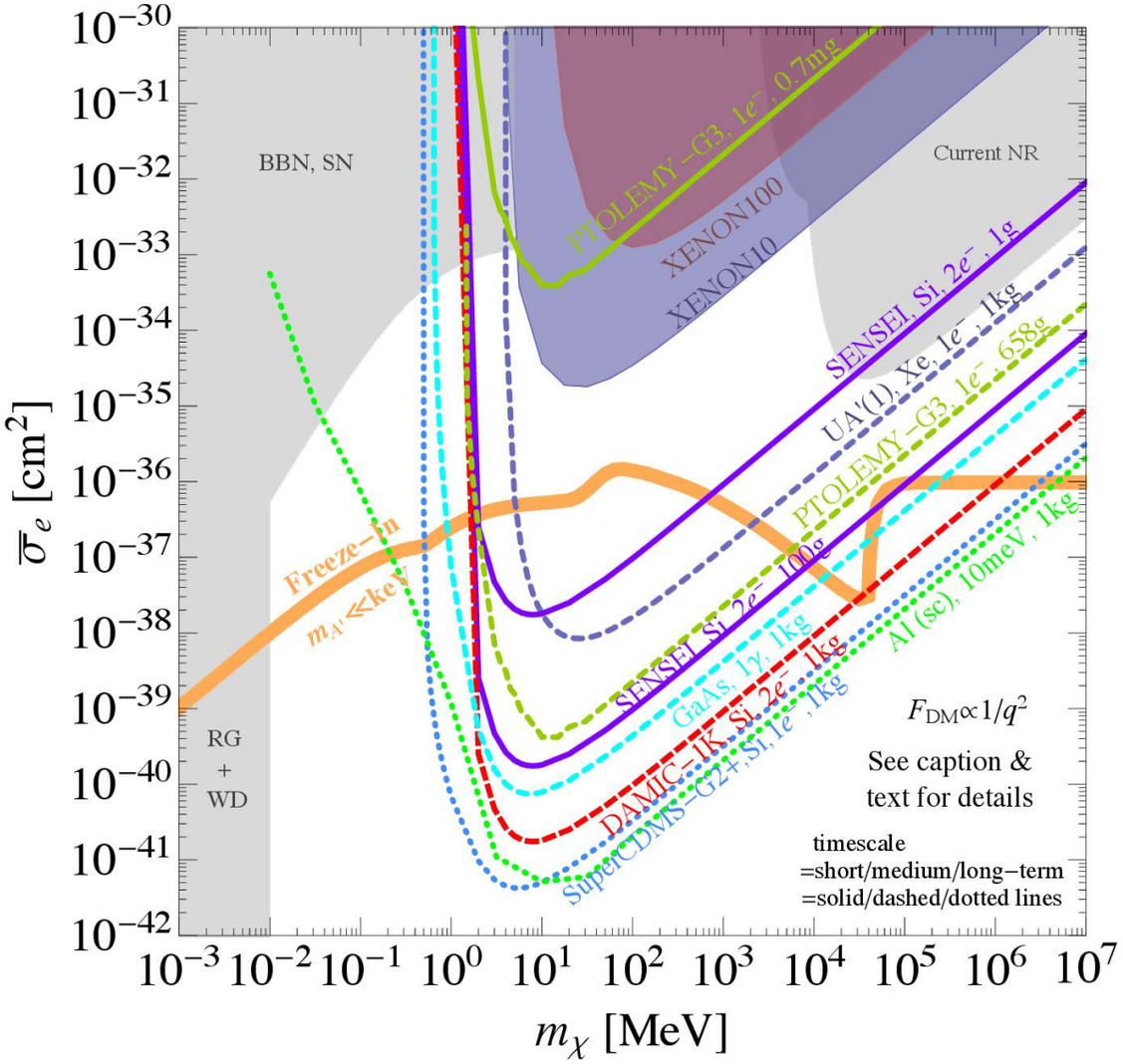




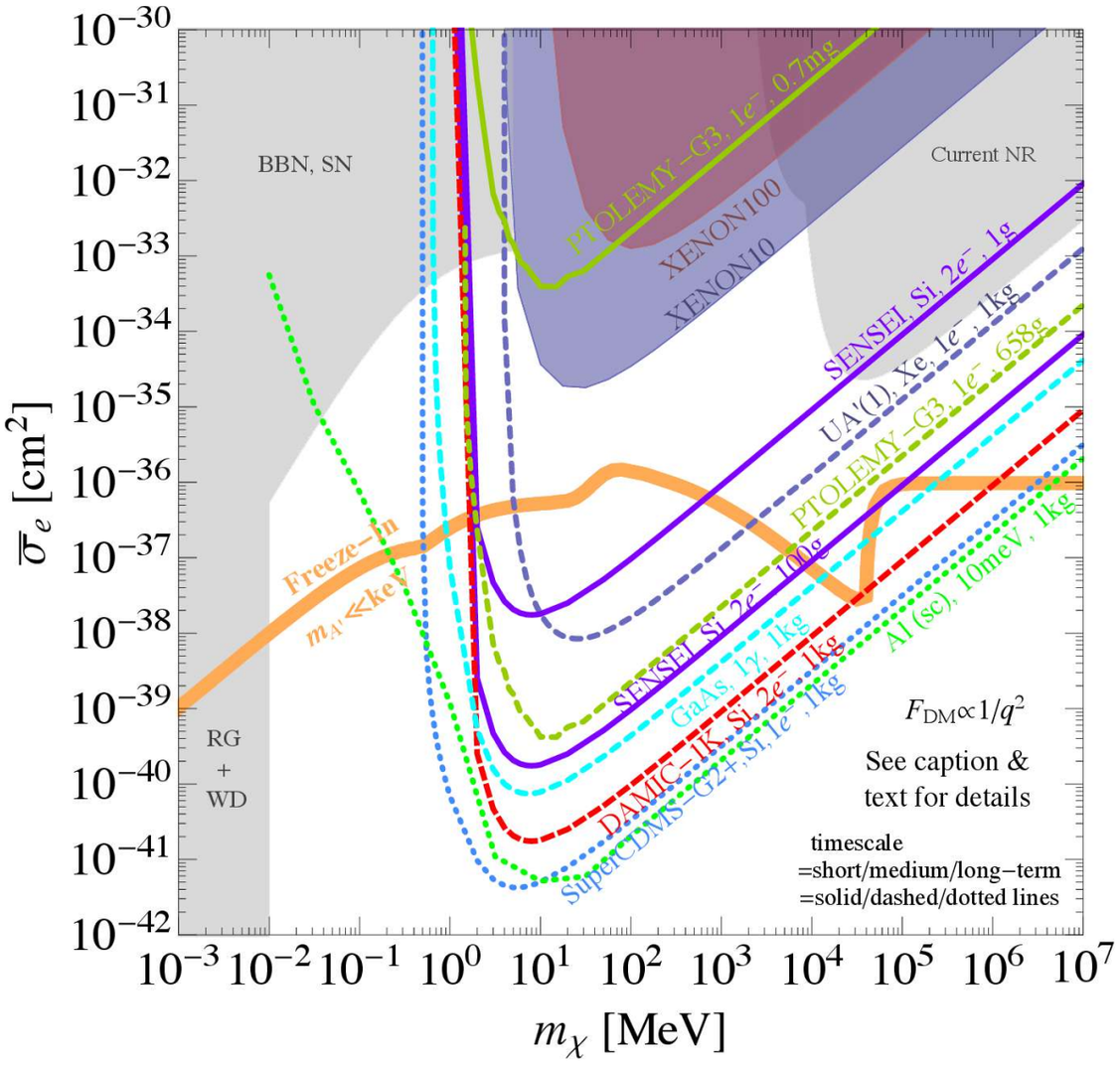
Direct Detection via Scattering



- new scattering targets
- new read-out technologies
- similar philosophy

arXiv:1707.04591

Direct Detection via Scattering



- new scattering targets
- new read-out technologies
- similar philosophy

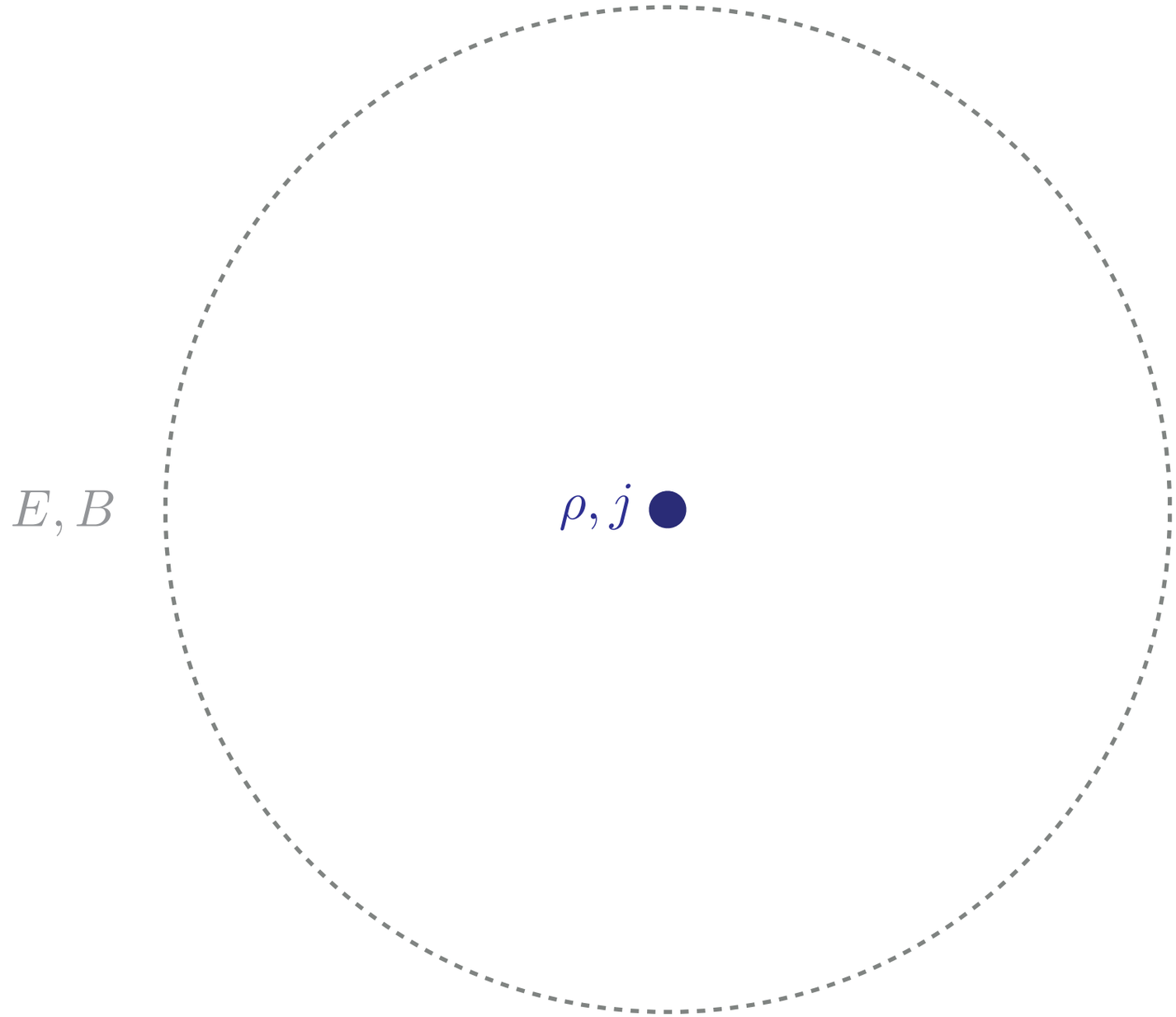
instead, take advantage of:

small mass $\rightarrow$ large number density, small momentum $\rightarrow$ easier to manipulate

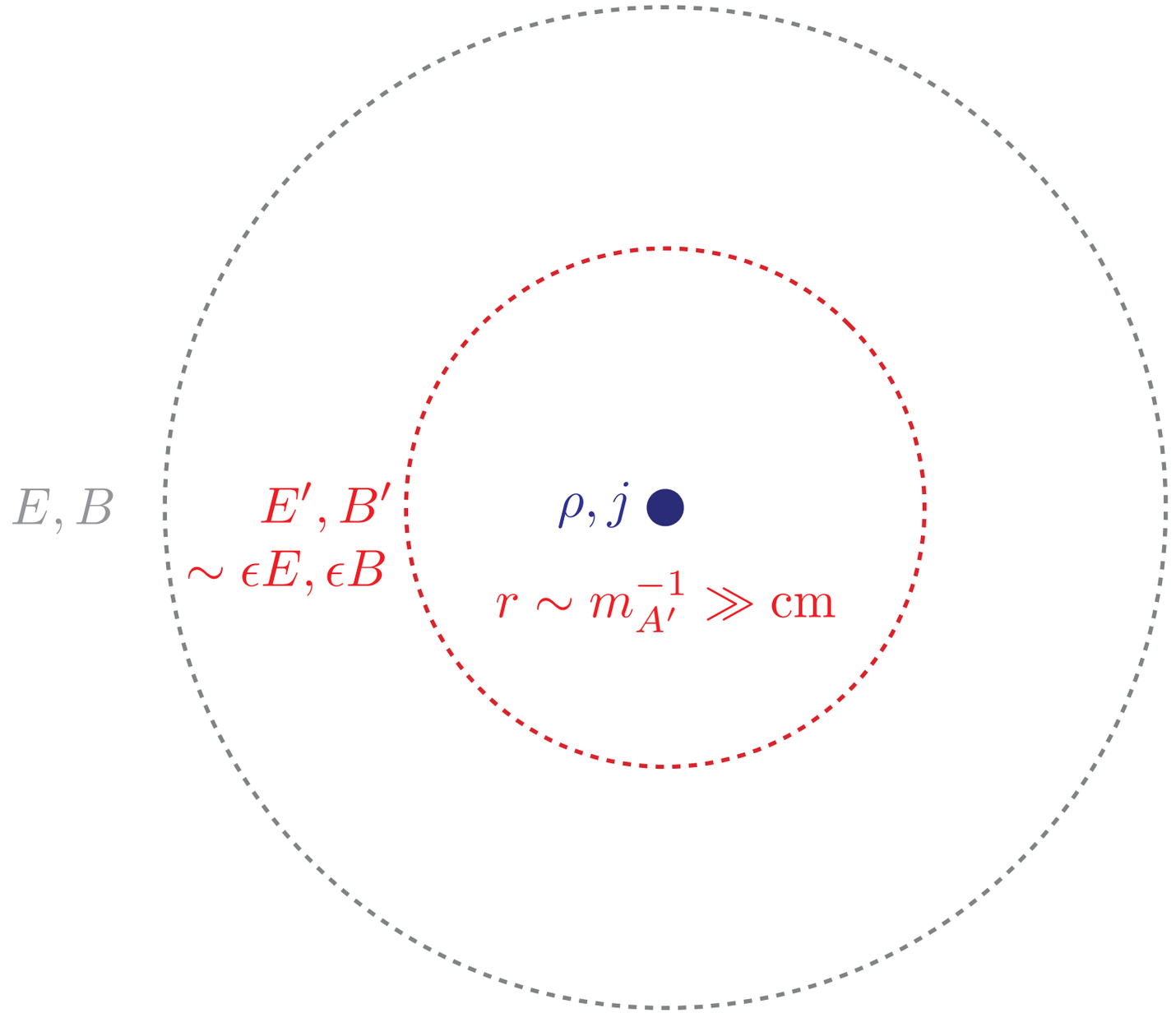
arXiv:1707.04591

New Observables

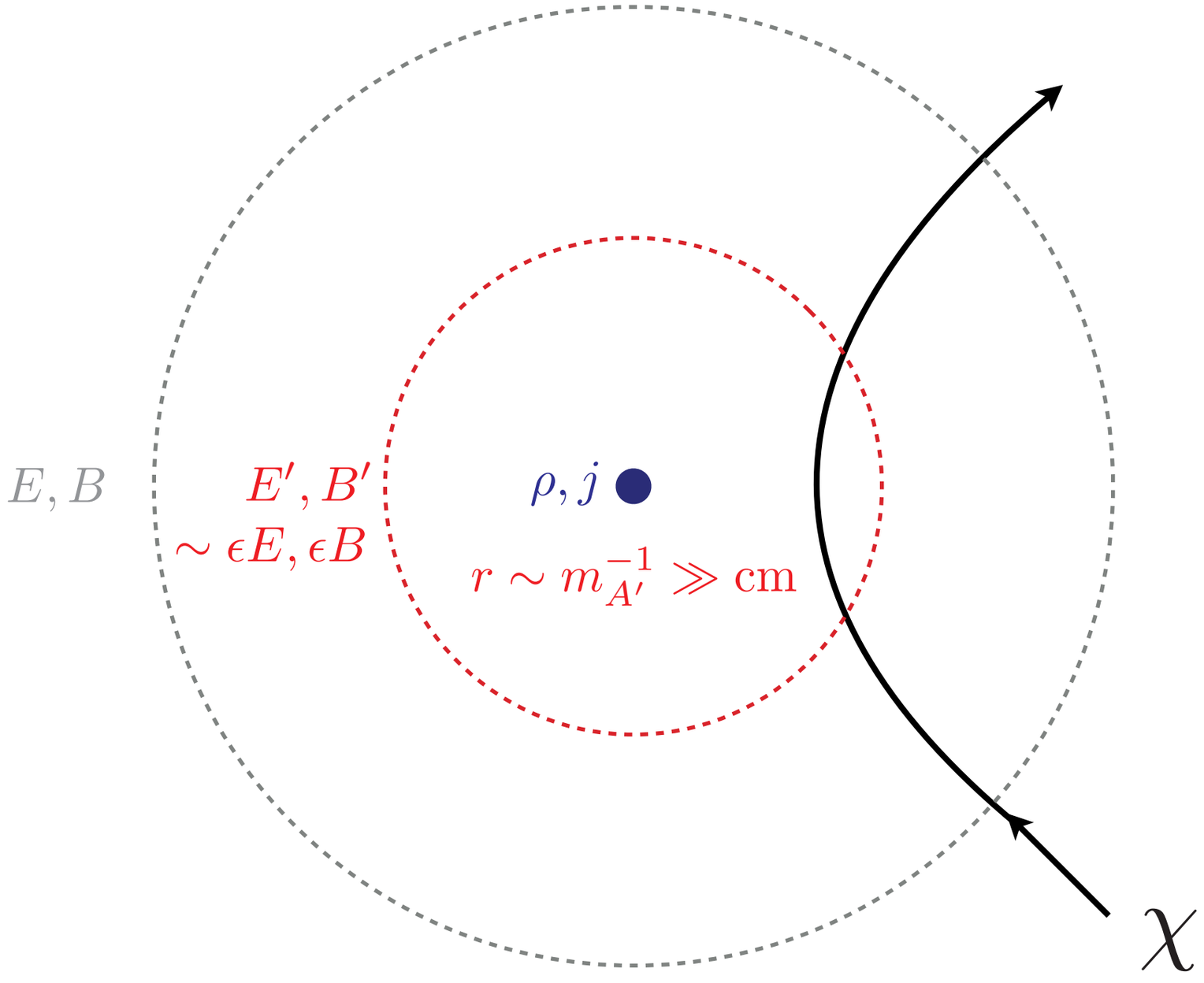
Electromagnetic Fields



Electromagnetic Fields



Electromagnetic Fields



Active Direct Detection

$$q_{\rm eff} \sim \epsilon e'/e \sim 10^{-11} \left(\frac{m_\chi}{\rm MeV}\right)^{-1/2}$$

(freeze-in)

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- bend it: $r_g \sim \dfrac{m_\chi\, v_\chi}{q_{\rm eff}\, e\, B} \sim \text{meter} \times \left(\dfrac{m_\chi}{\rm keV}\right)^{3/2} \left(\dfrac{10\ \rm T}{B}\right)$

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- stop it: $m_\chi\, v_\chi^2 \sim q_{\rm eff}\, e\, \Delta V \implies \Delta V \sim \text{MV} \times \left(\dfrac{m_\chi}{\rm keV}\right)^{3/2}$

Active Direct Detection

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(freeze-in)

($v_\chi \ll 1 \implies$ electric fields are more efficient than magnetic fields)

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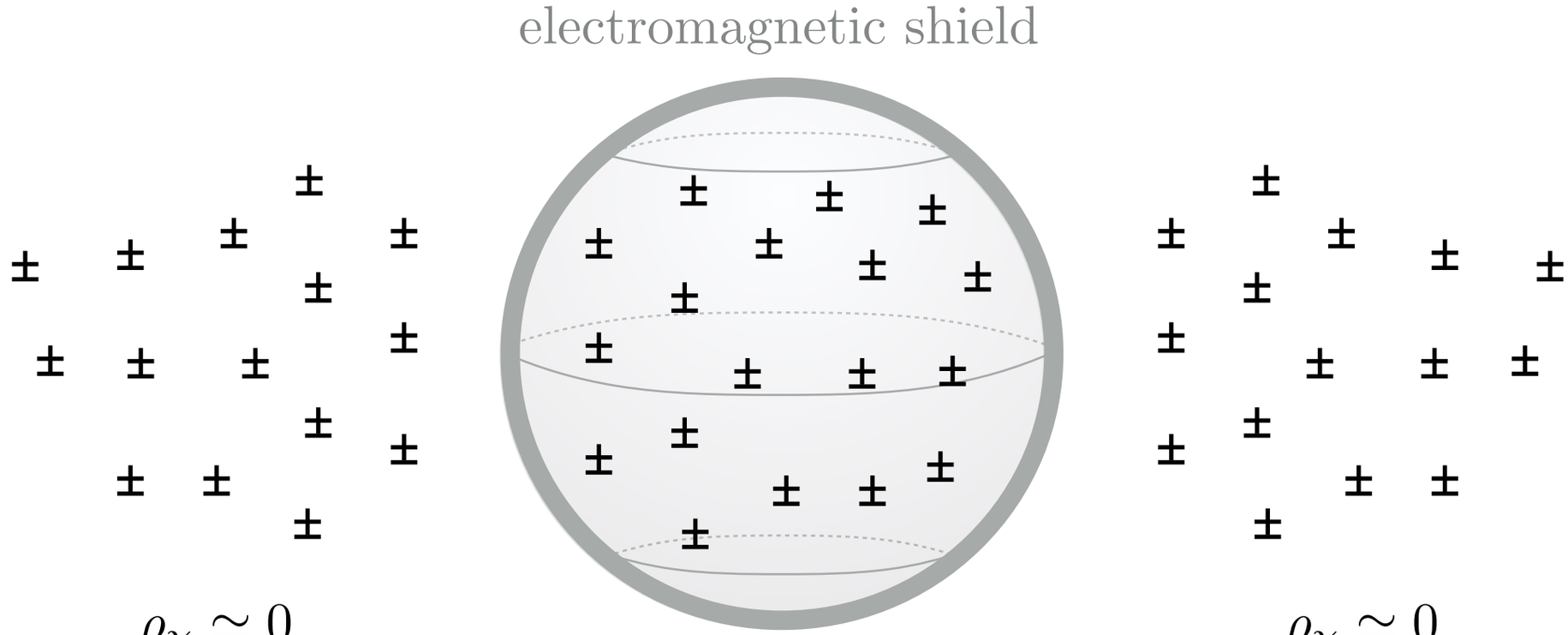
Inducing Dark Matter Waves

Debye Screening

Debye Screening

$\chi^{\pm}$



$\rho_\chi \simeq 0$

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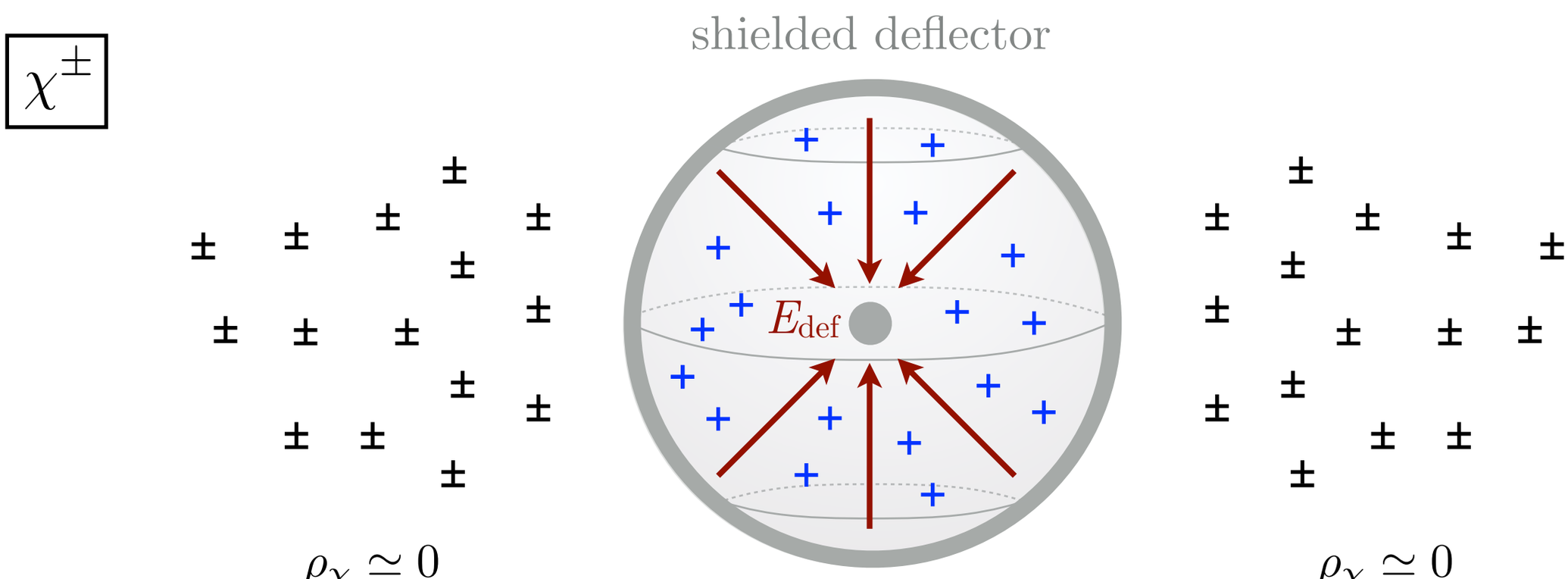
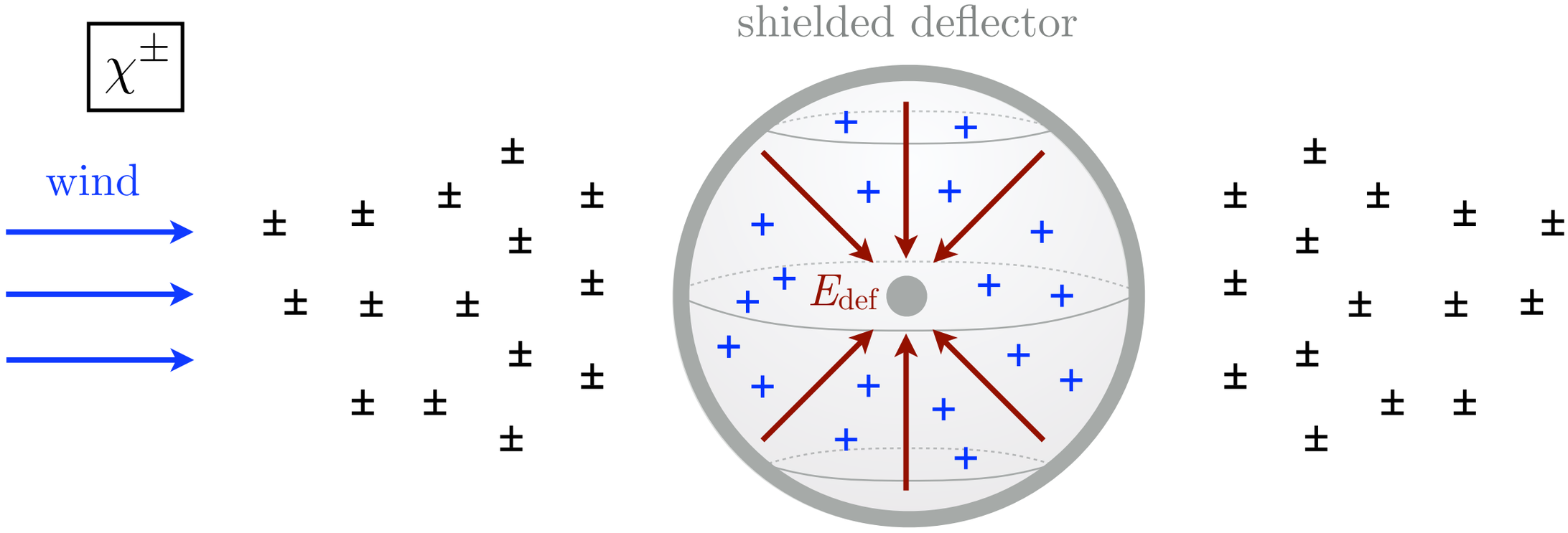
Debye Screening



$$\rho_\chi^{\rm Debye} \simeq -\frac{(e q_{\rm eff})^2\, \rho_{\rm DM}\, V_{\rm def}}{m_\chi^2\, v_\chi^2}$$

Non-Adiabatic Debye Screening



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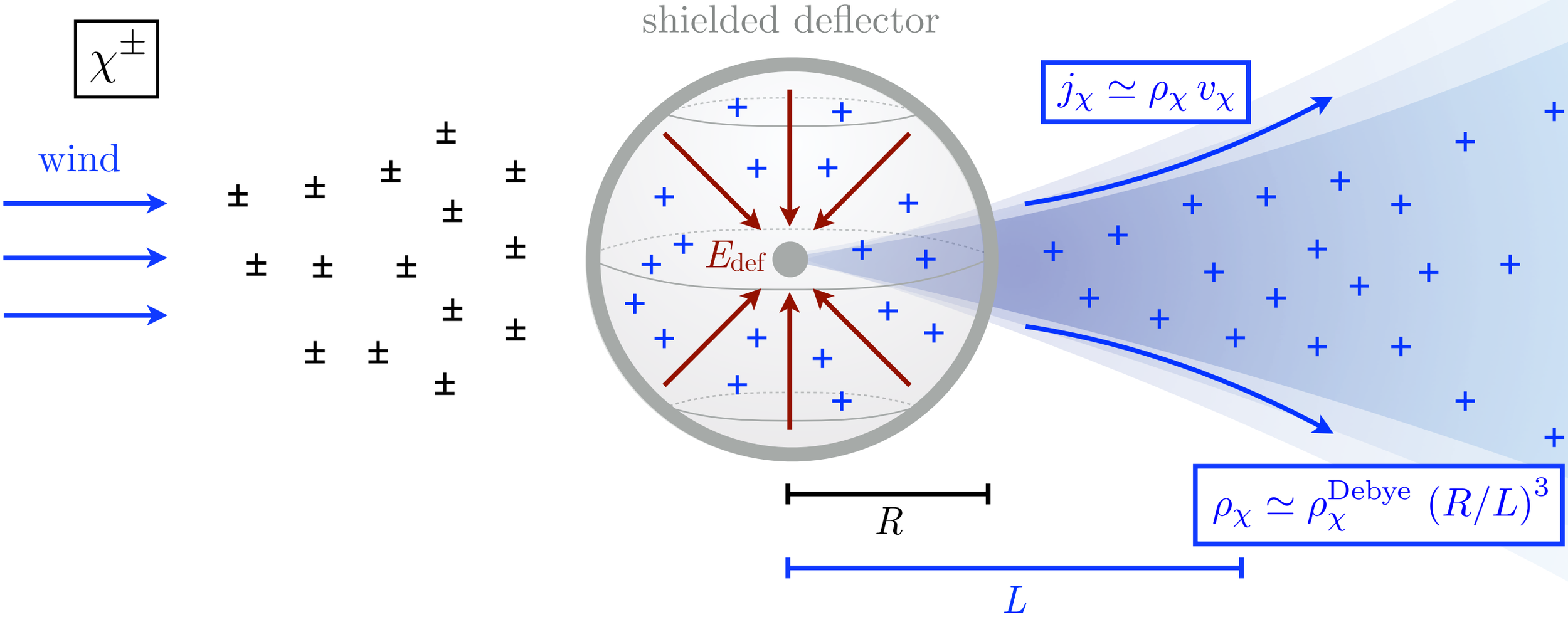

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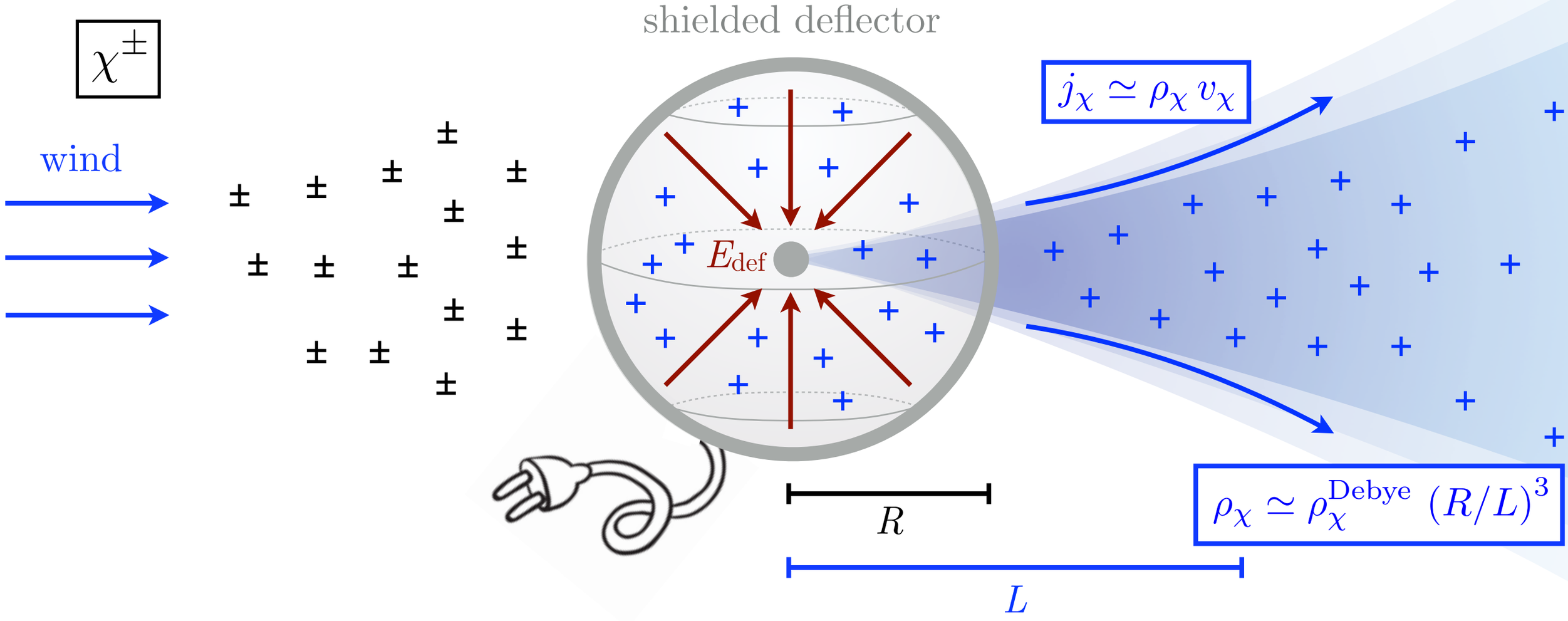
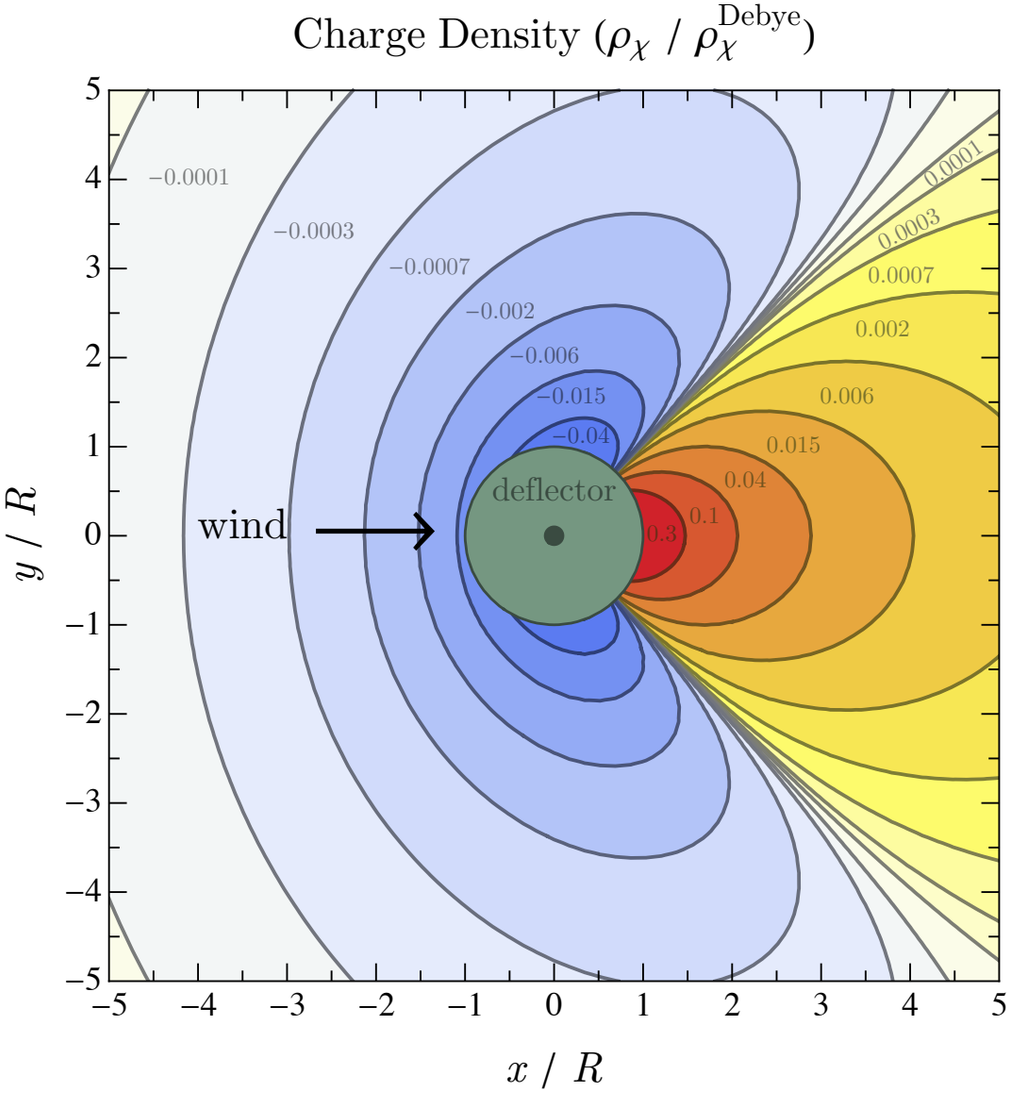
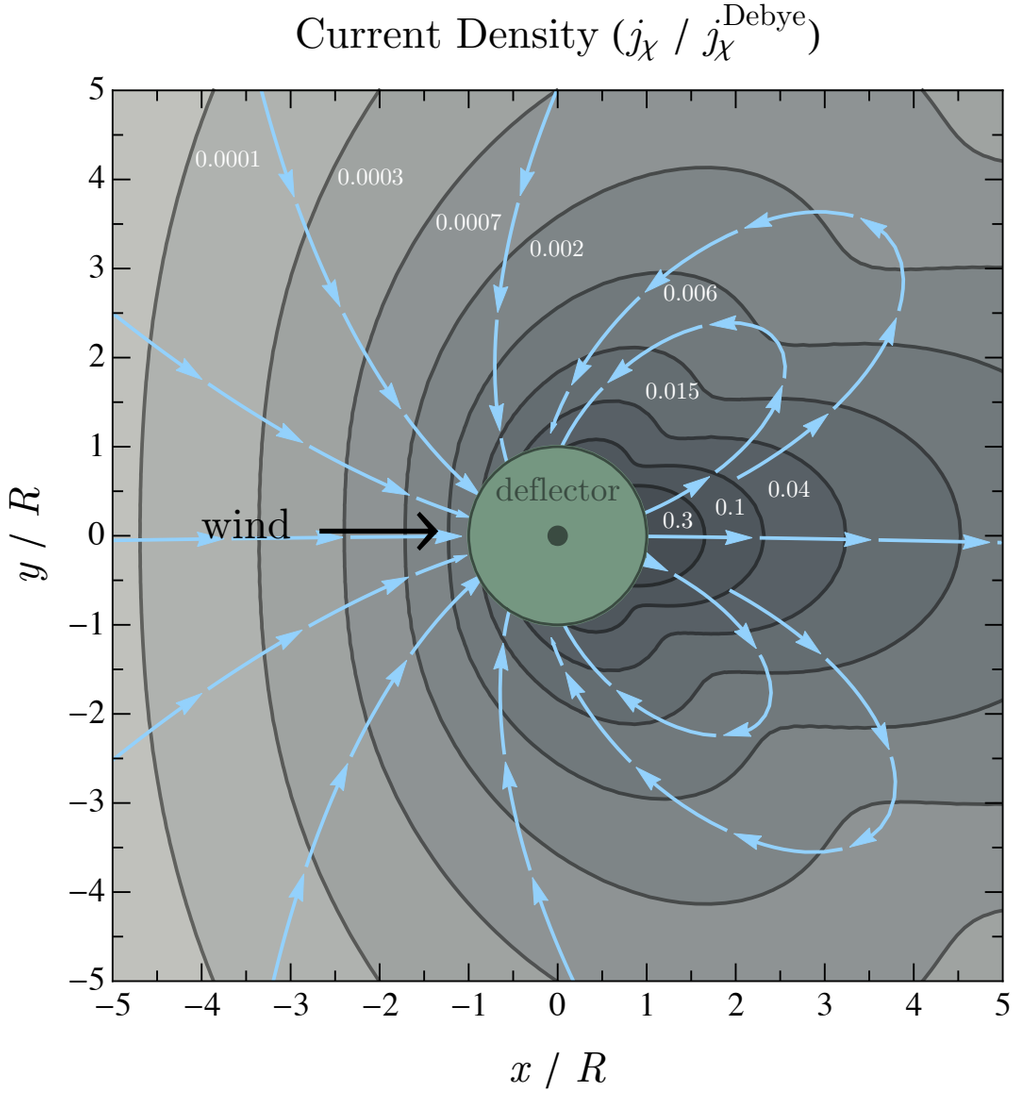


$$E_{\rm def} \to E_{\rm def}\, e^{i\omega t} \implies \rho_\chi \to \rho_\chi\, e^{i\omega t}\ ,\ j_\chi \to j_\chi\, e^{i\omega t}$$

Non-Adiabatic Debye Screening





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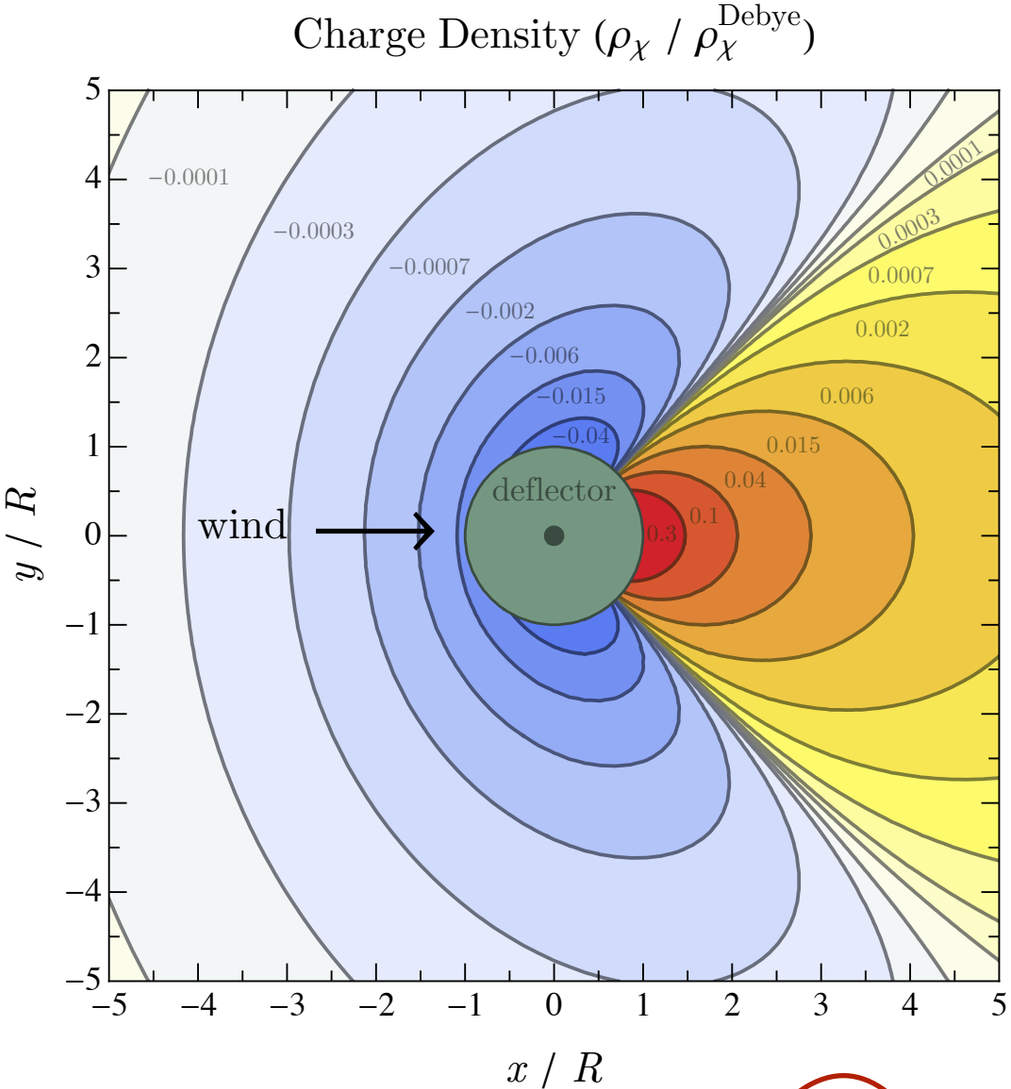

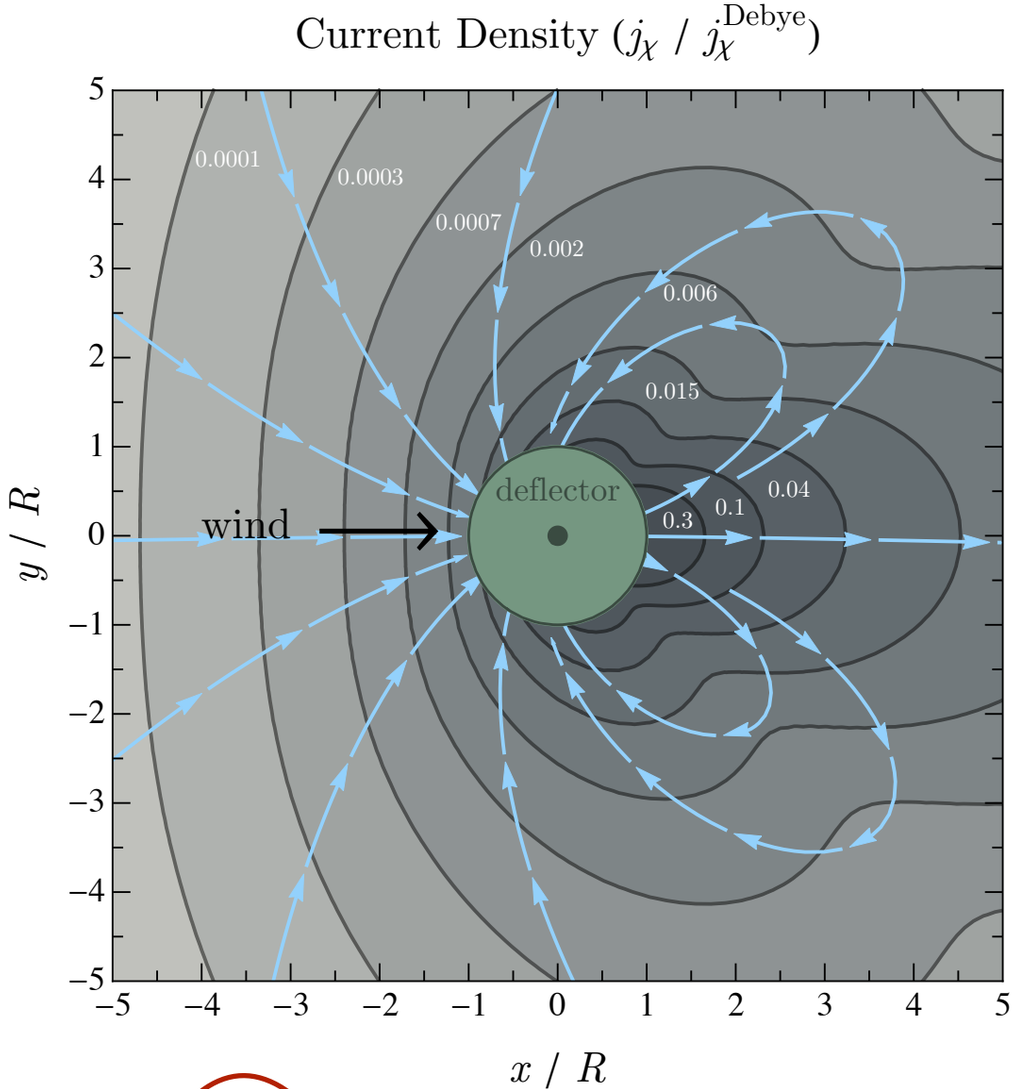

(ignore backreaction) $\omega_{\rm p} \ll \omega \ll \pi\, v_\chi / R$ (maximum deflection)

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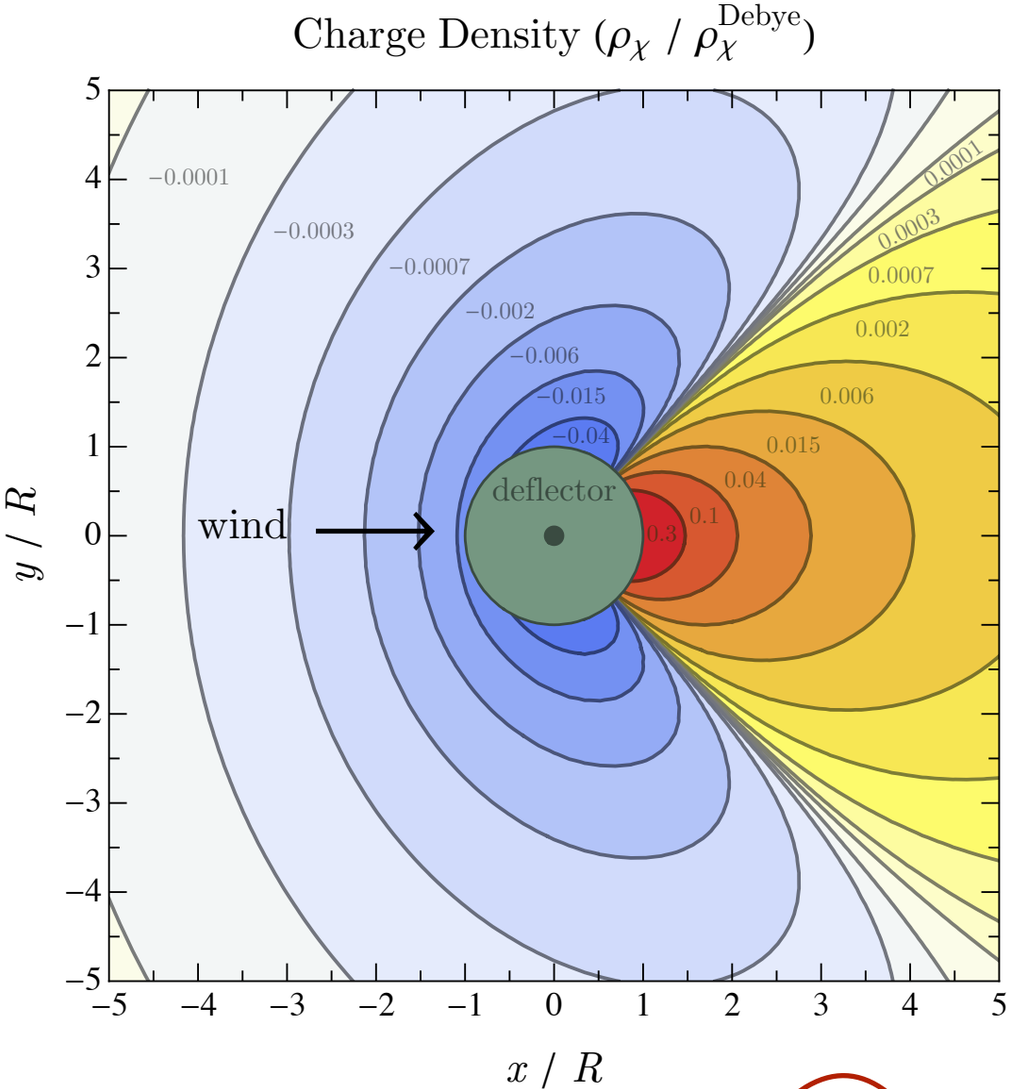

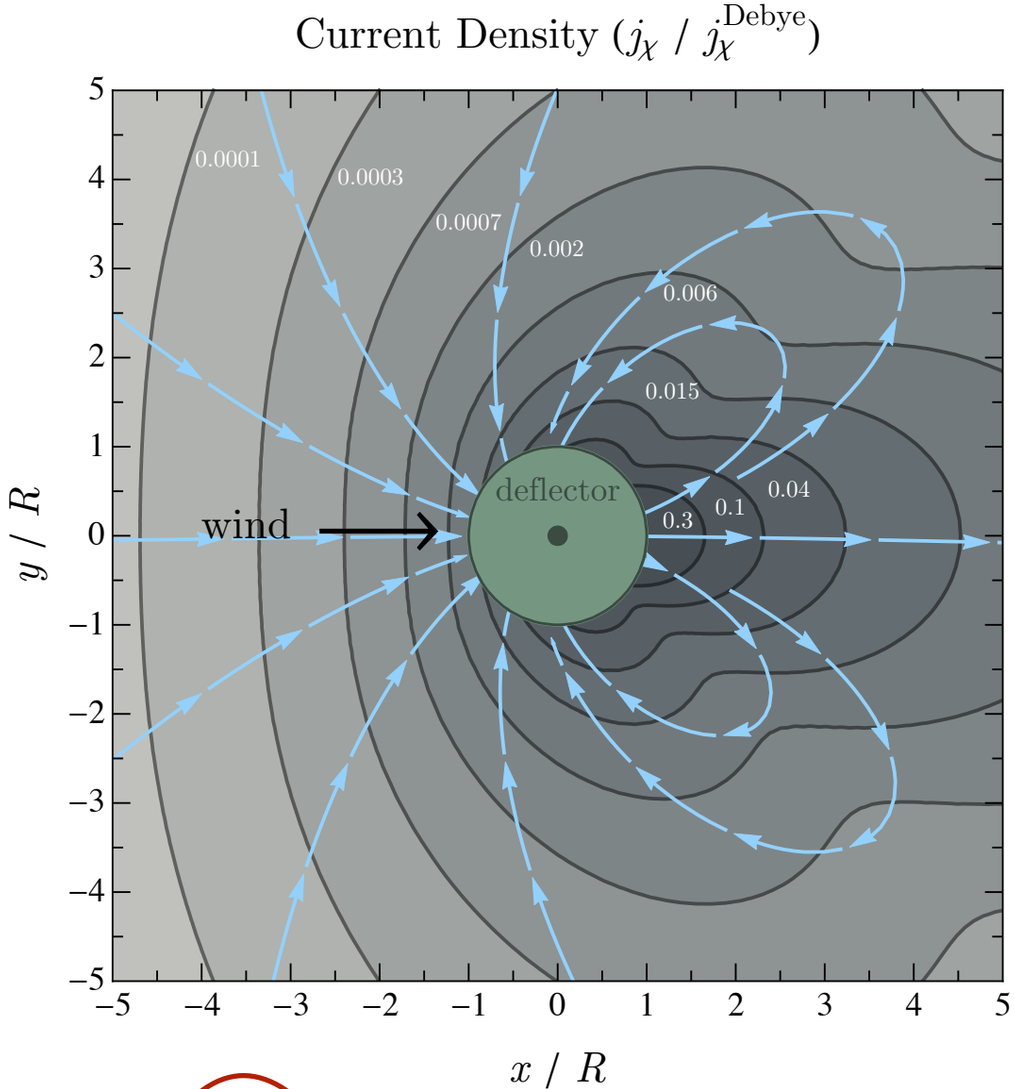

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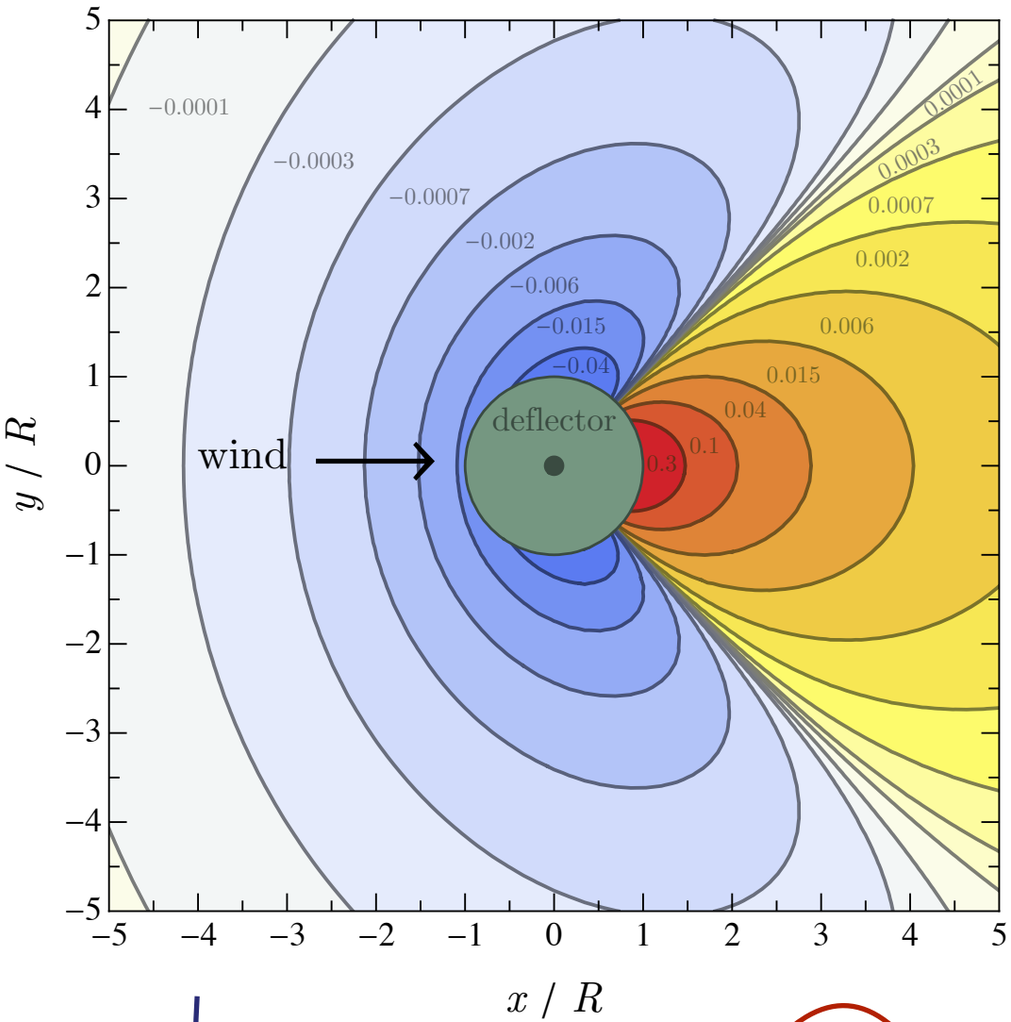
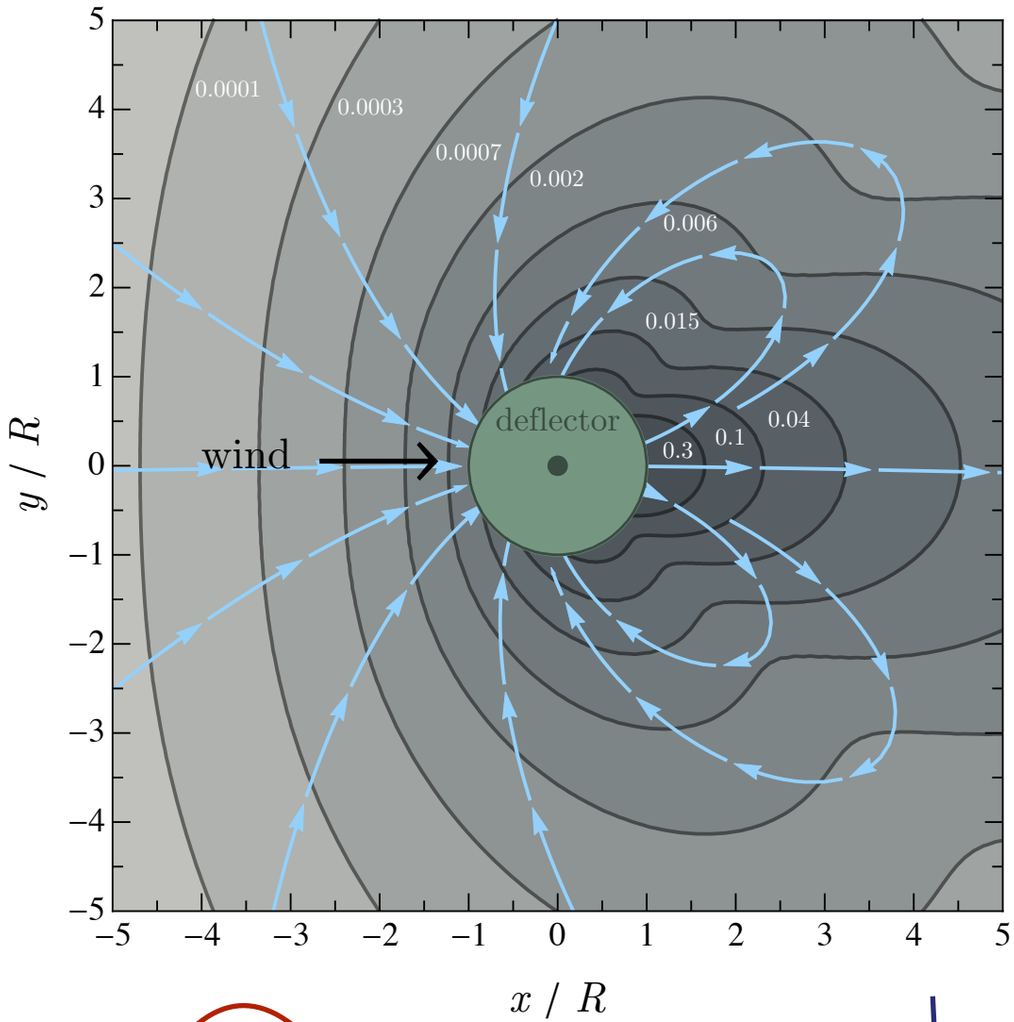
$$\Longrightarrow \ {\rm kHz} \times (m_\chi/{\rm eV})^{-1/4} \ll \omega \ll {\rm MHz} \times (R/{\rm meter})^{-1}$$

Non-Adiabatic Debye Screening

Charge Density (ρ_χ / $\rho_\chi^{\rm Debye}$)



Current Density (j_χ / $j_\chi^{\rm Debye}$)



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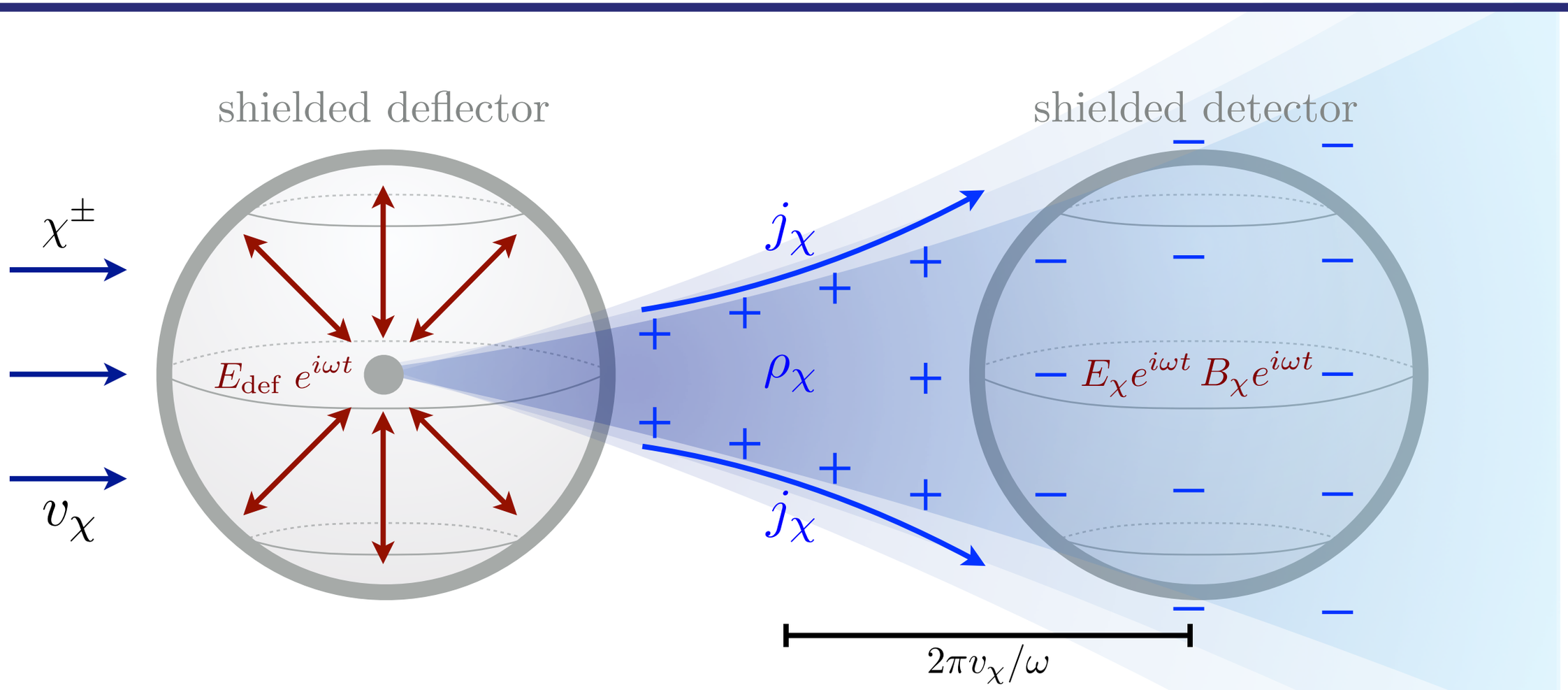
electric fields

100 kHz
(quasi-static)

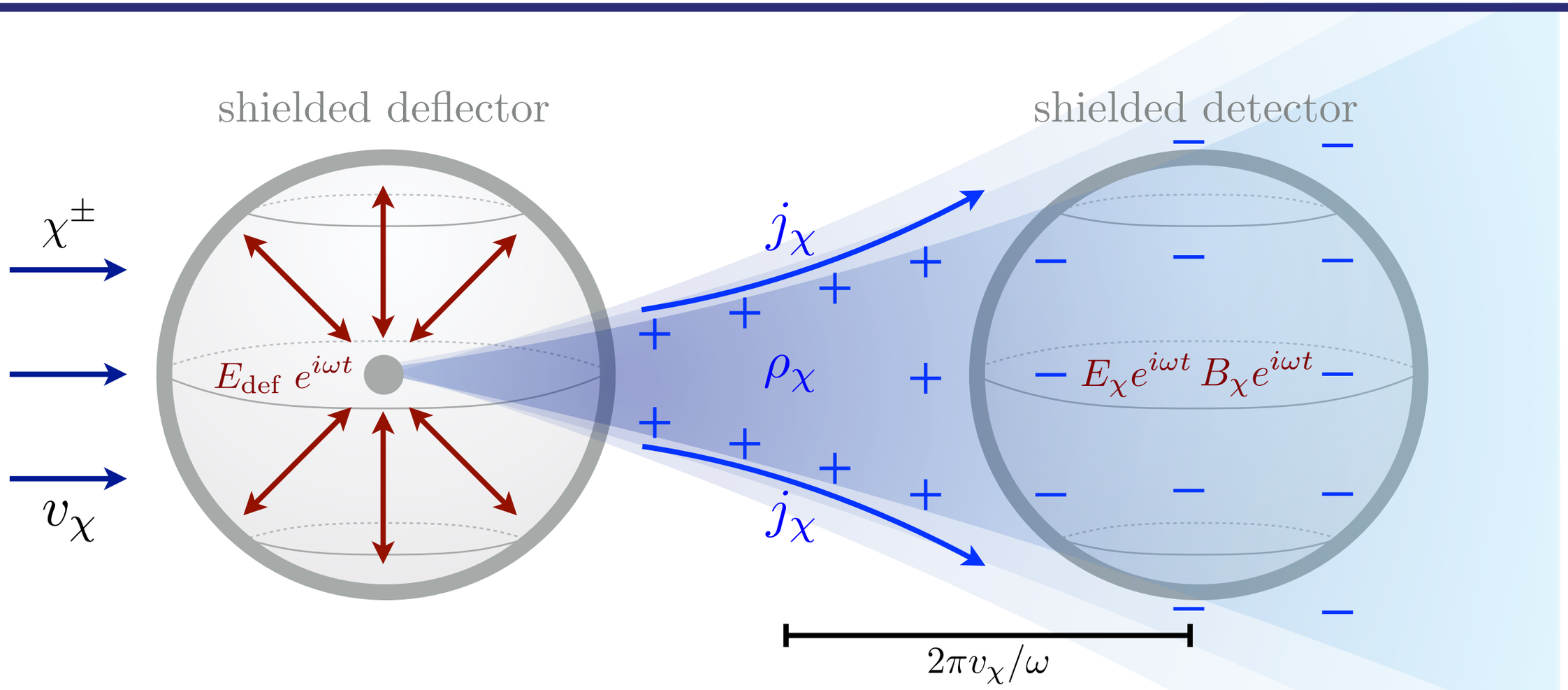
magnetic fields

Direct Deflection



(similar to light-shining-through-a-wall type experiments)

Direct Deflection



$$\text{quasi-static } (\omega \ll 1/R) \implies \begin{cases} E_\chi \sim \rho_\chi\, R\, e^{i\omega t} \\ B_\chi \sim v_\chi\, \rho_\chi\, R\, e^{i\omega t} \end{cases}$$

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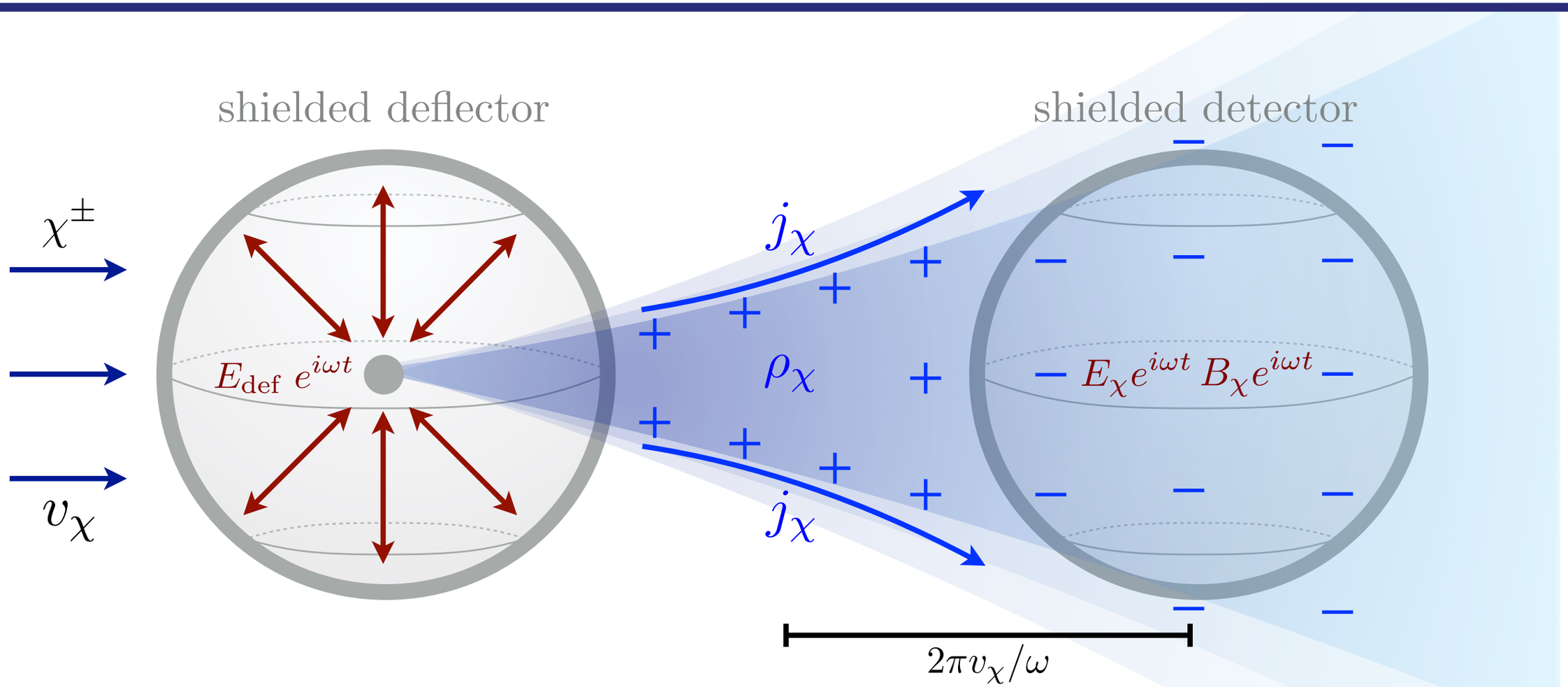

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$$E_{\rm def} \sim 10\ \text{kV/cm}\ ,\ \ R \sim \text{meter} \implies \begin{cases} E_\chi \sim 10^{-12}\ \text{kV/cm} \times (q_{\rm eff}/10^{-10})^2\, (m_\chi/\text{keV})^{-2} \\ B_\chi \sim 10^{-19}\ \text{T} \times (q_{\rm eff}/10^{-10})^2\, (m_\chi/\text{keV})^{-2} \end{cases}$$

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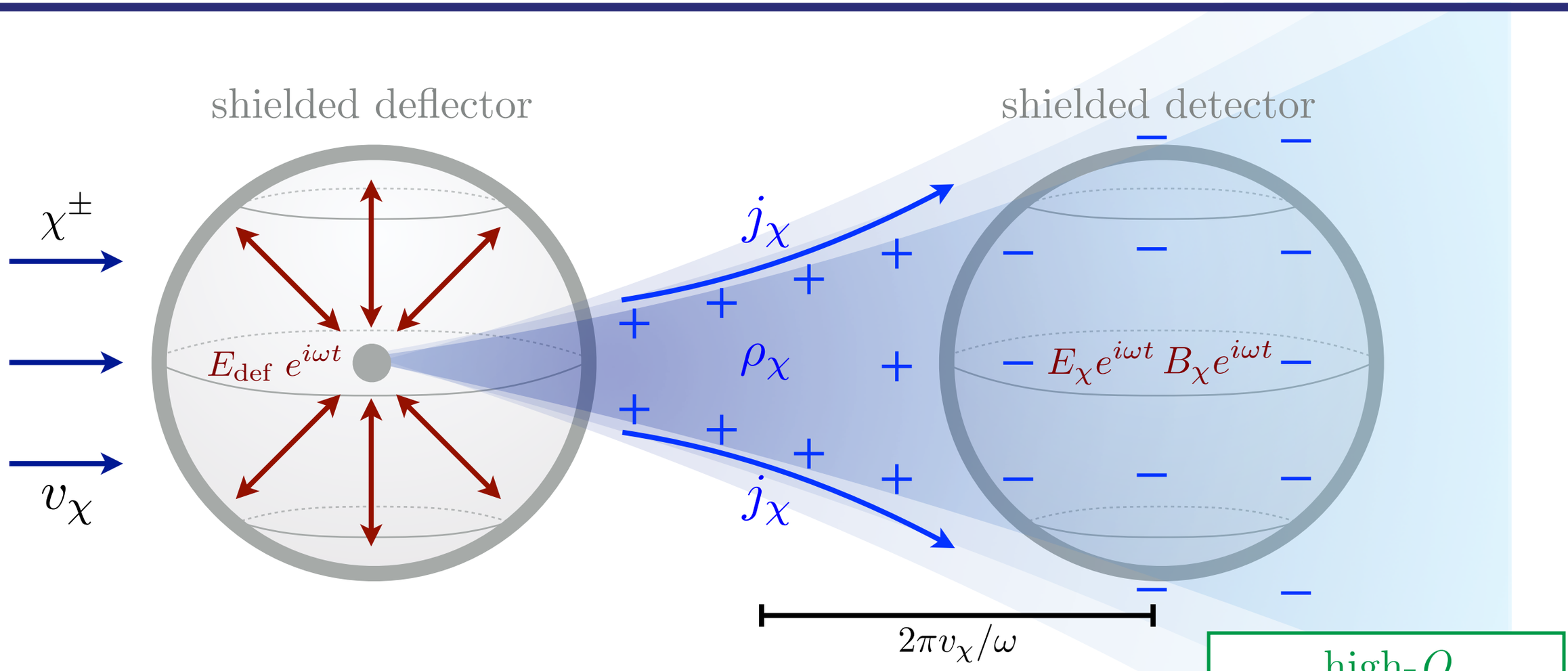

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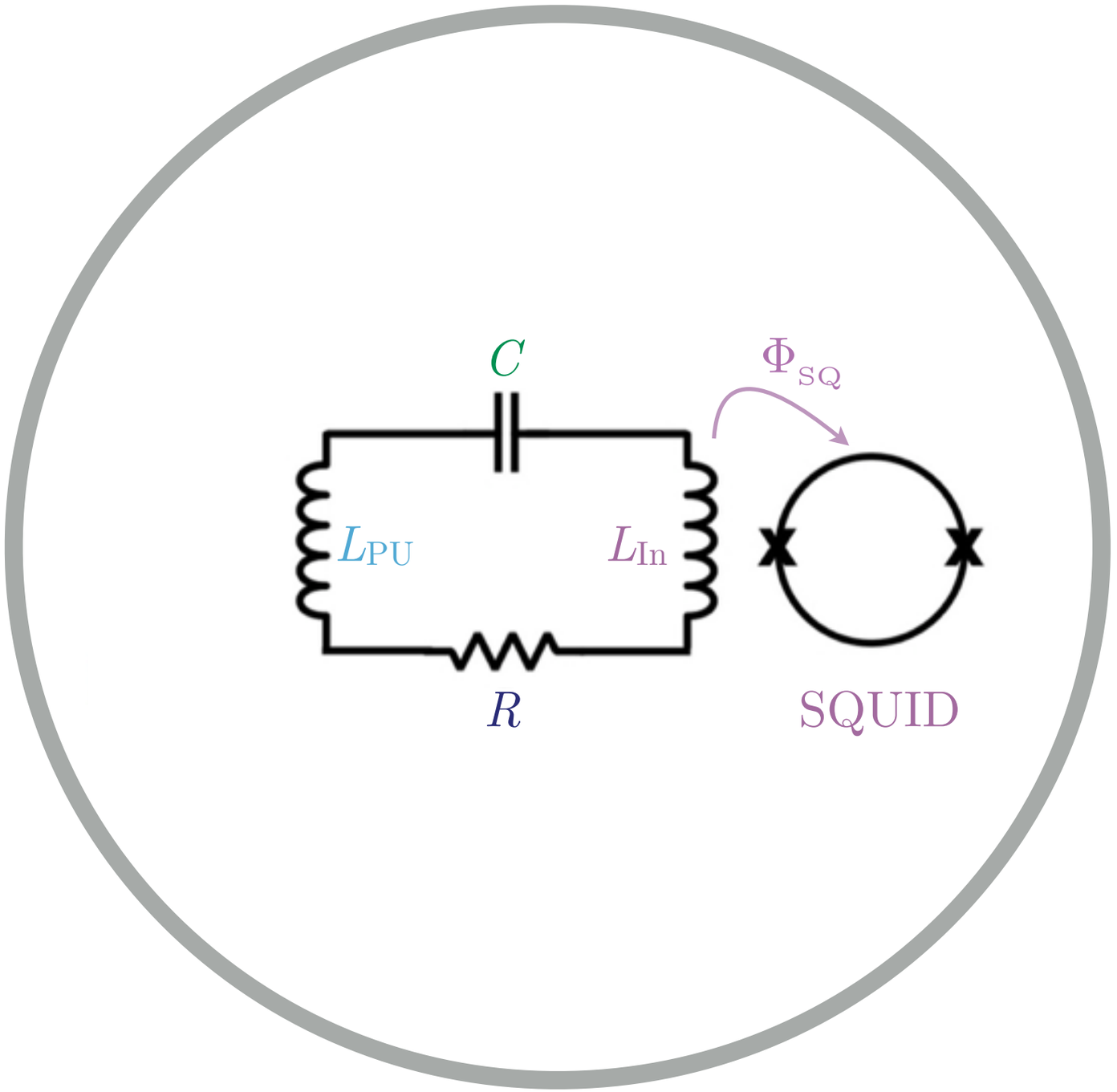
Detecting Dark Matter Waves

LC Resonators

LC Resonators

shielded detector



LC Resonators

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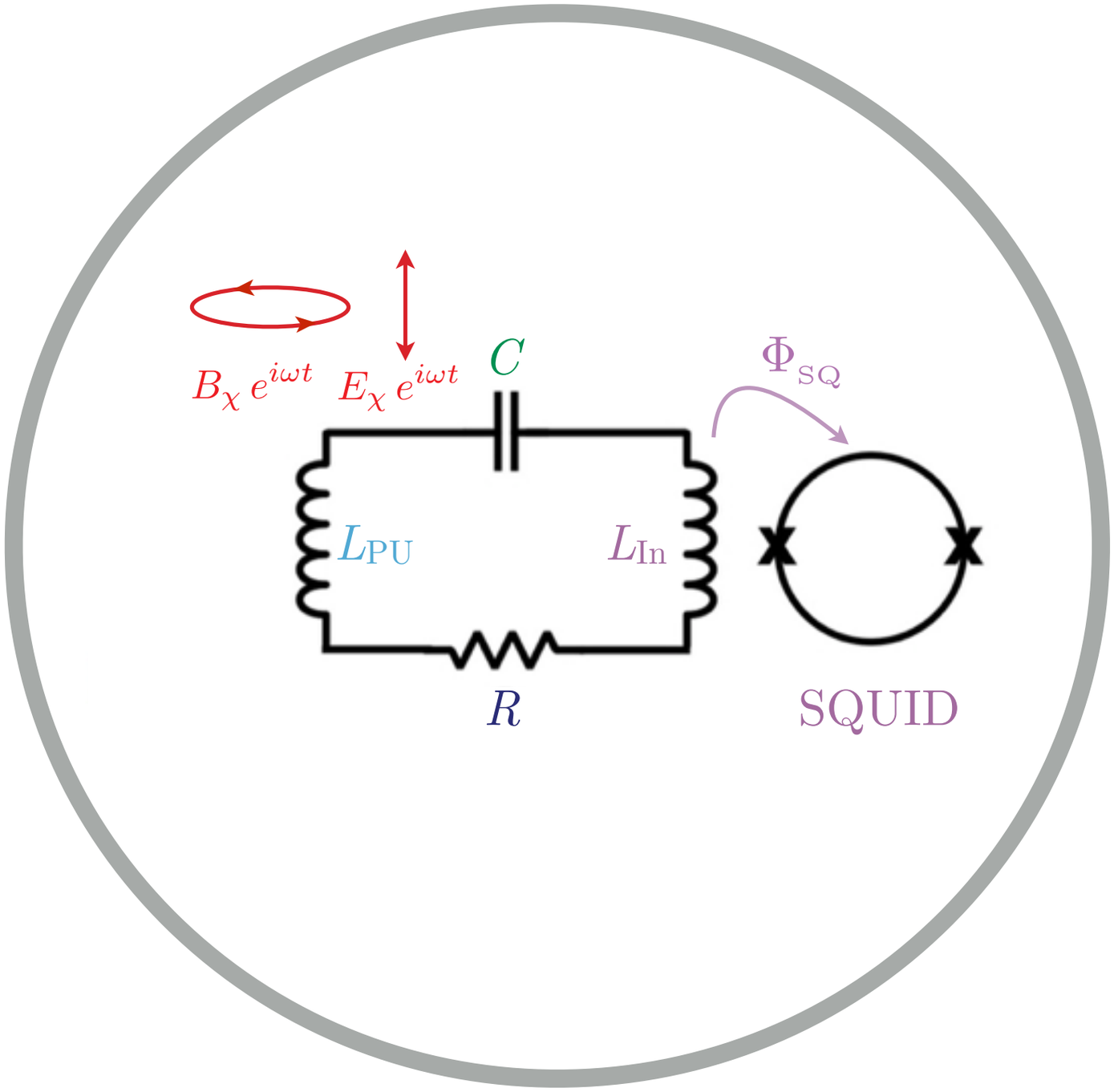

LC Resonators

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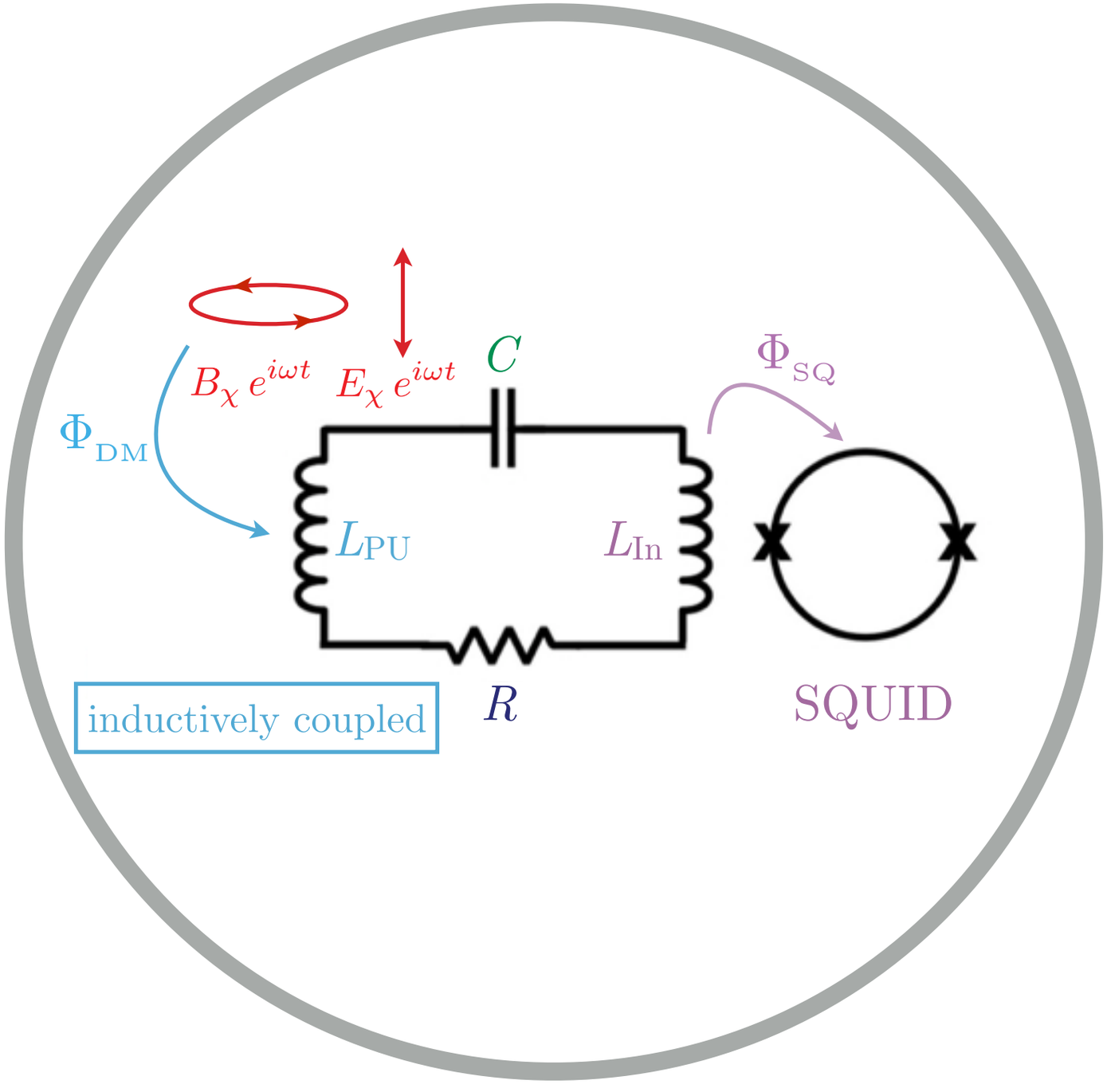

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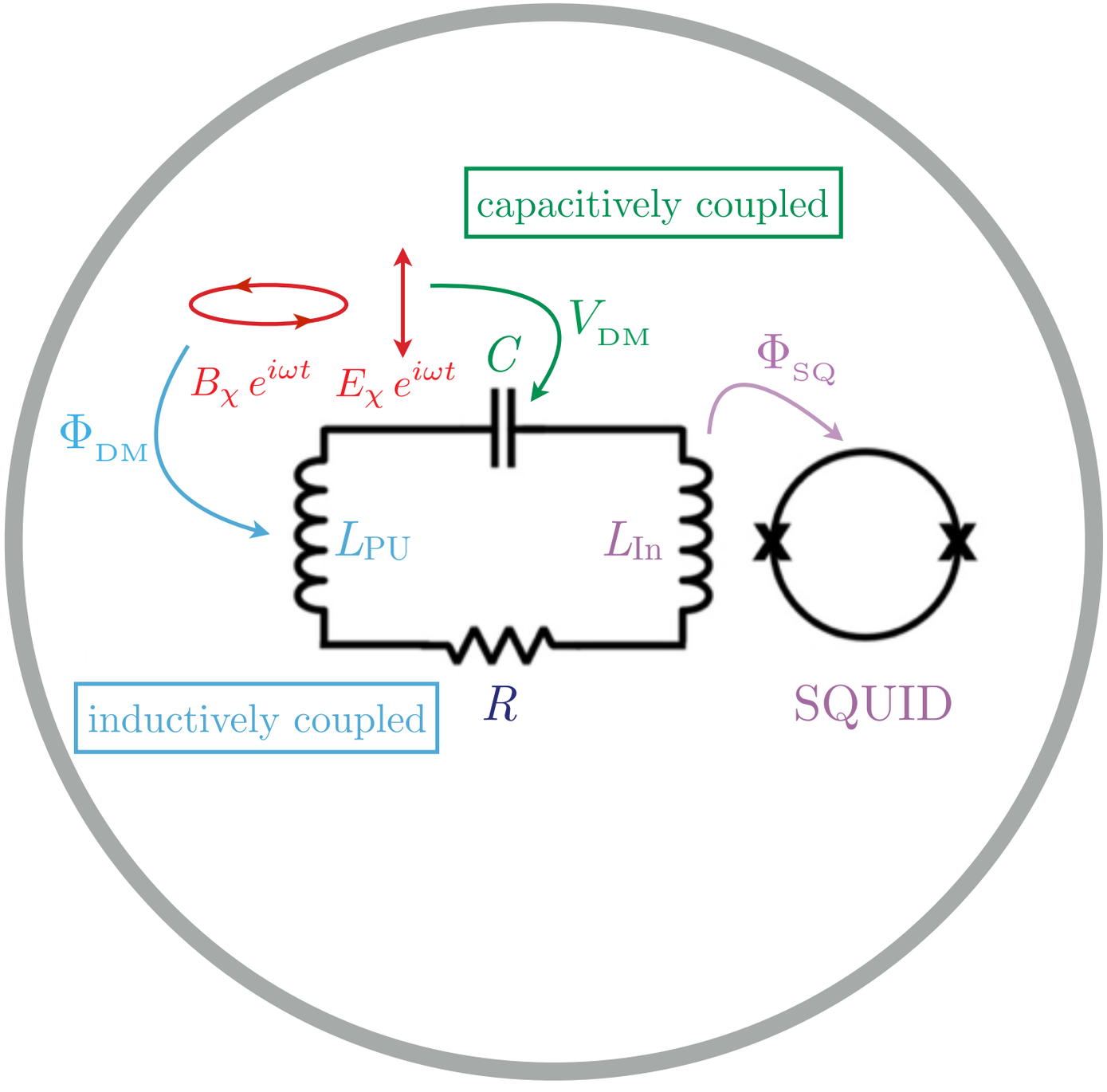

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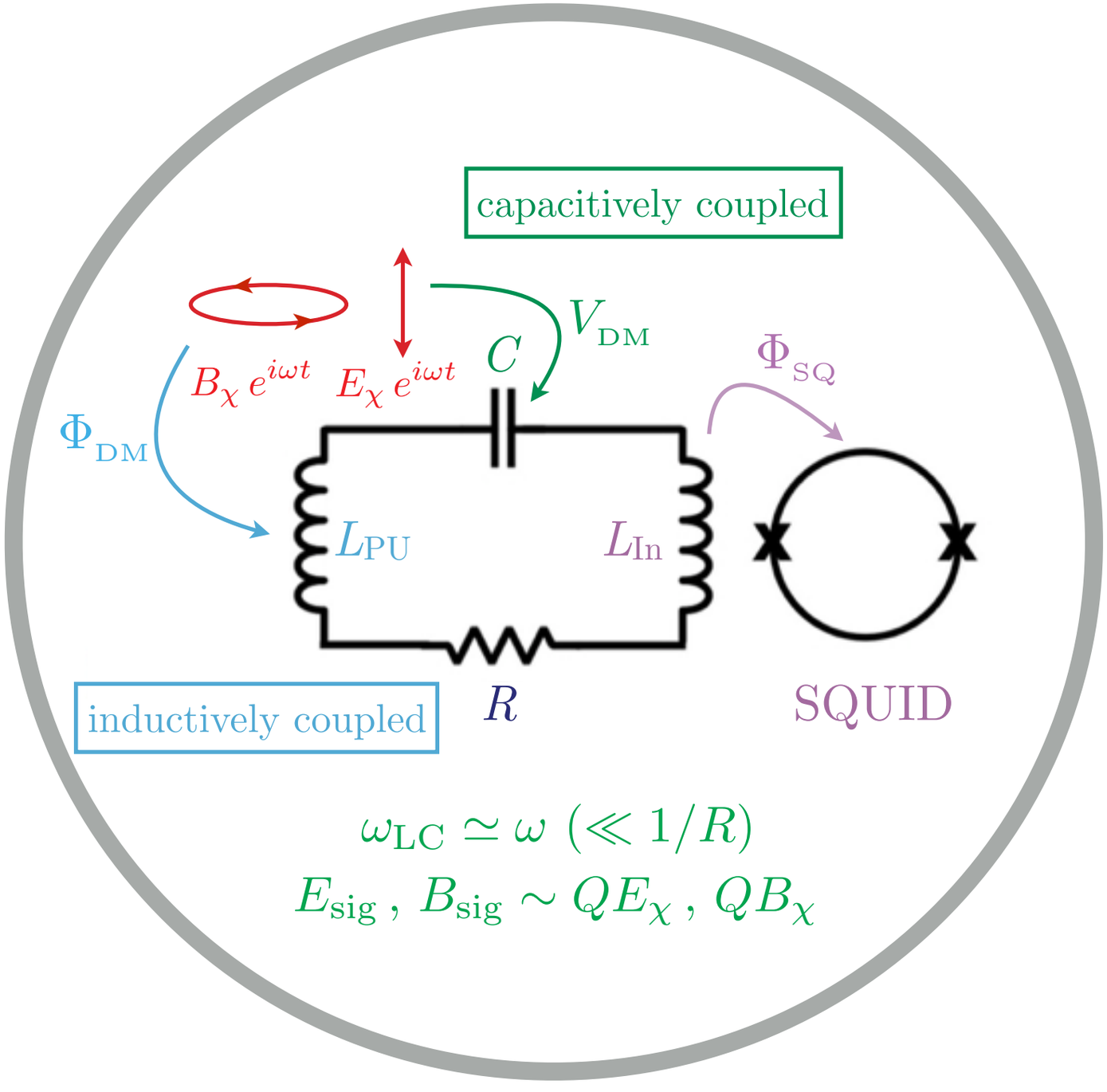

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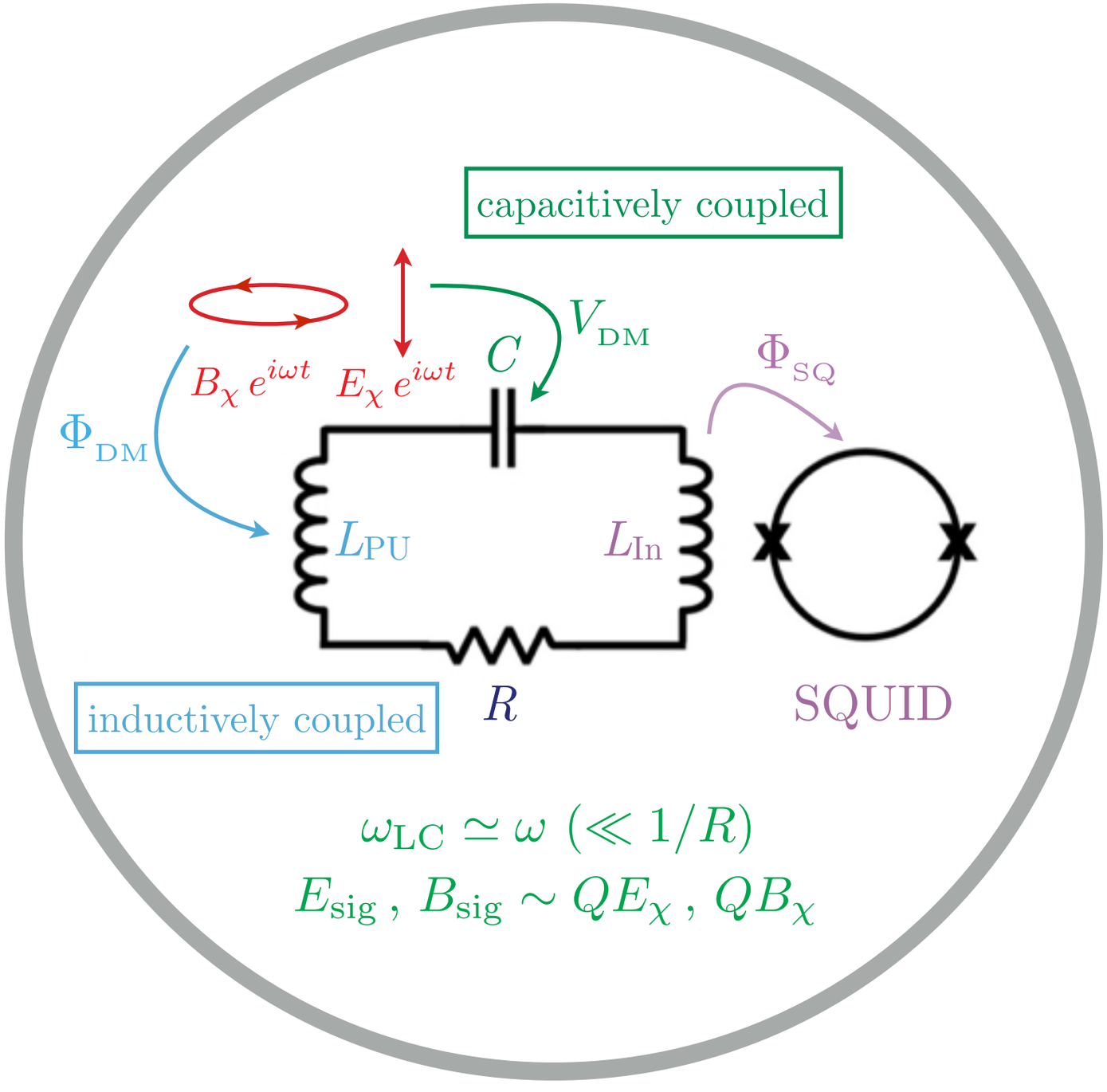


= DM Radio, Auriga...

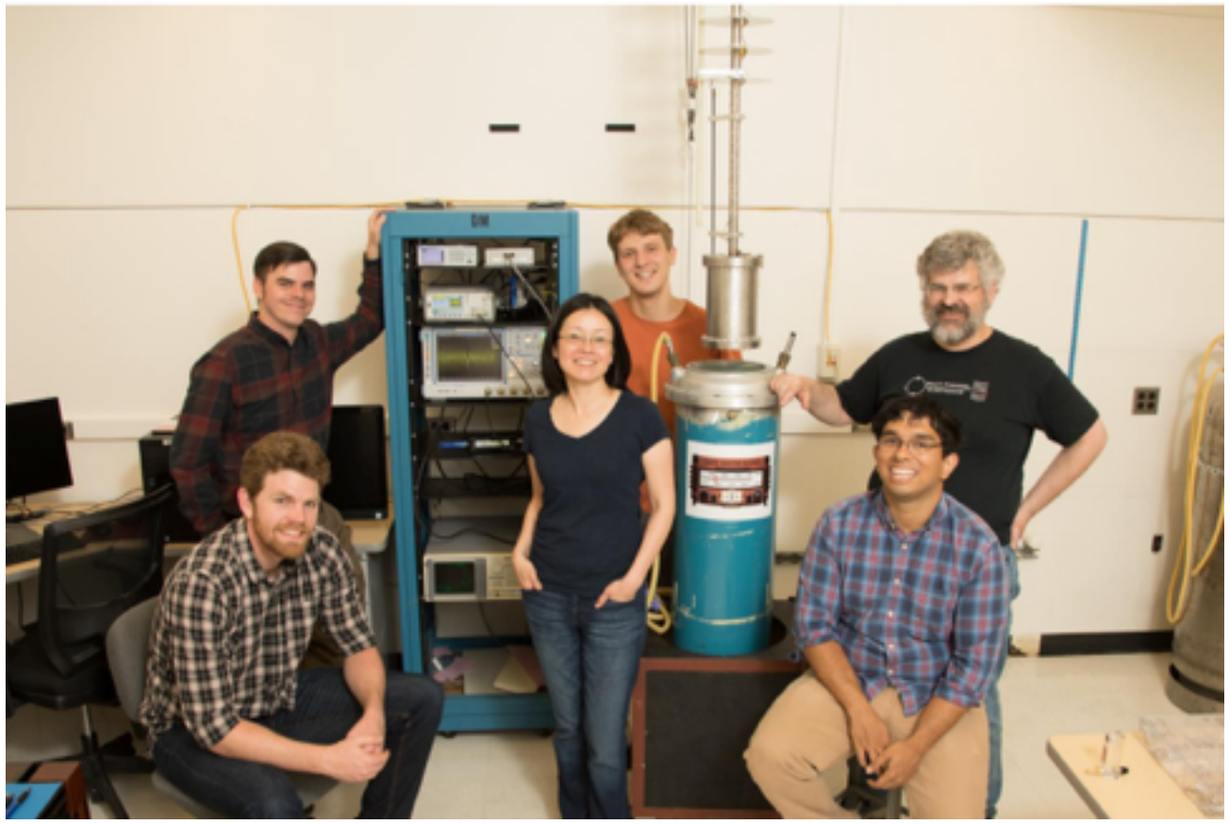
LC Resonators

Auriga

(gravity waves)

DM Radio

(effective currents via ultralight DM)



resolve thermal noise

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Auriga

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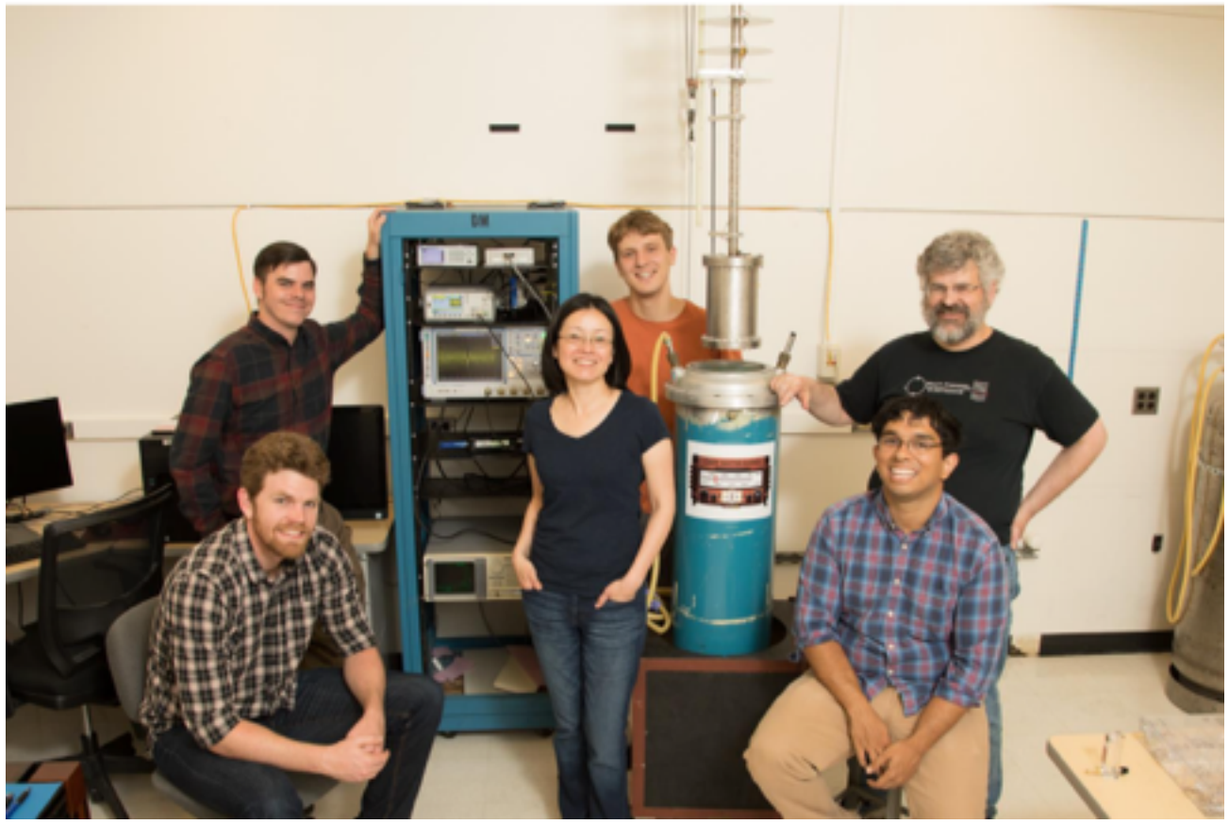
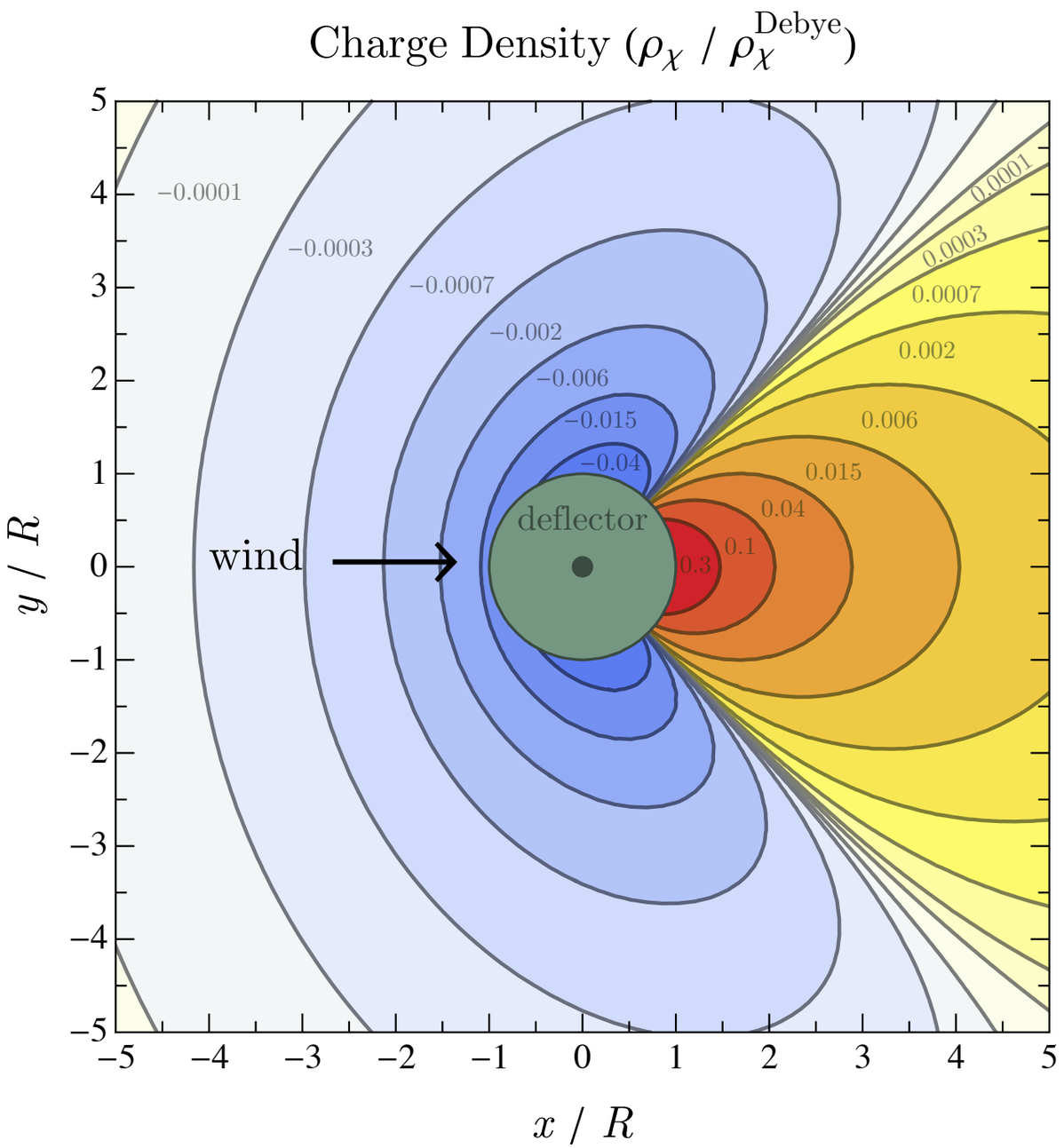


resolve thermal noise

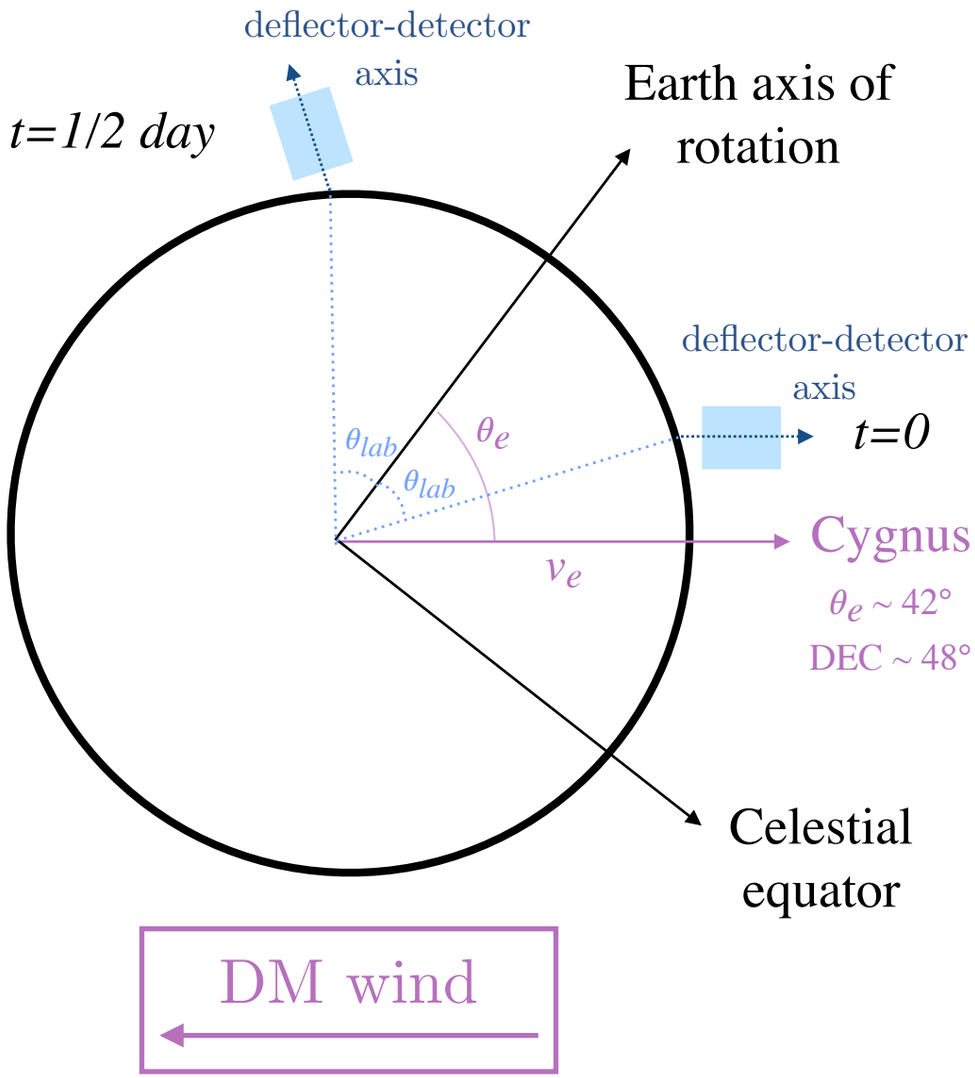
no need to scan or operate down at kHz frequencies $\Longrightarrow$ $Q > 10^6$

Directional Dependence

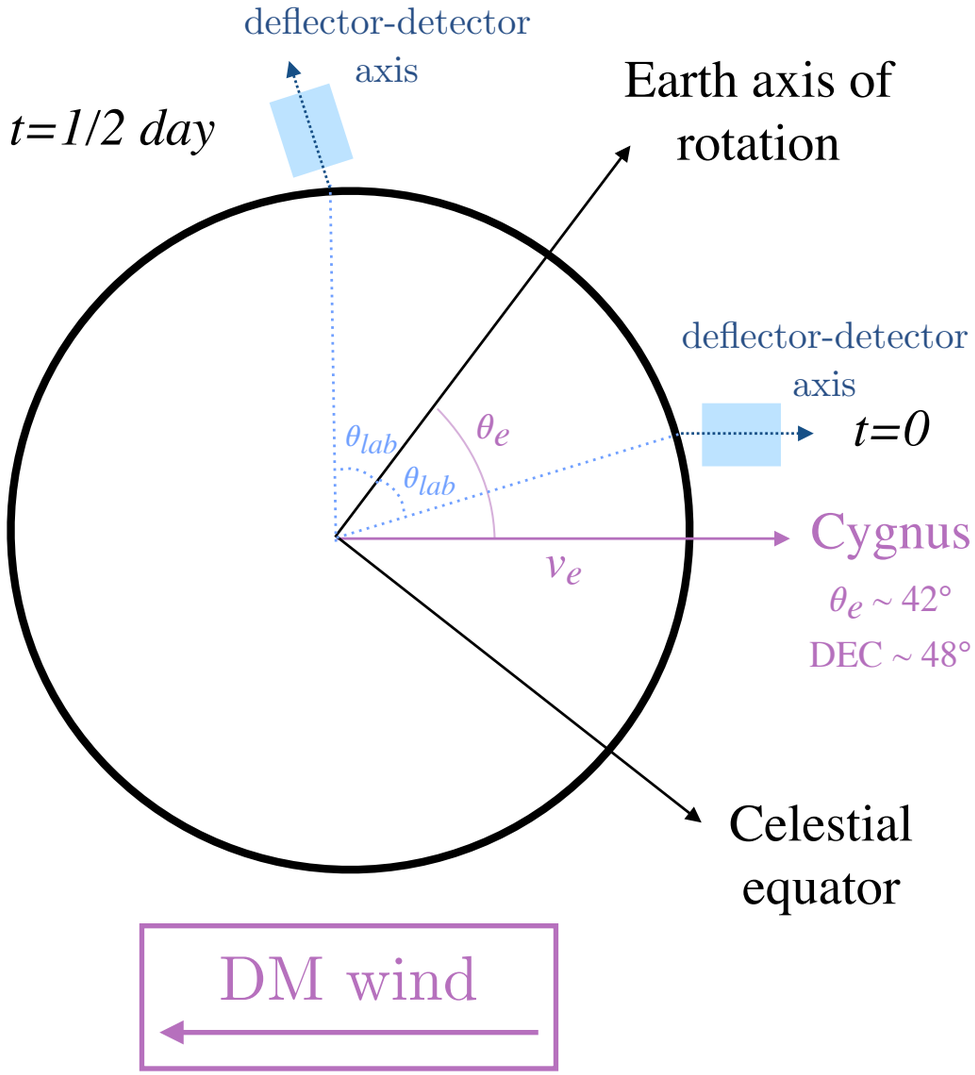


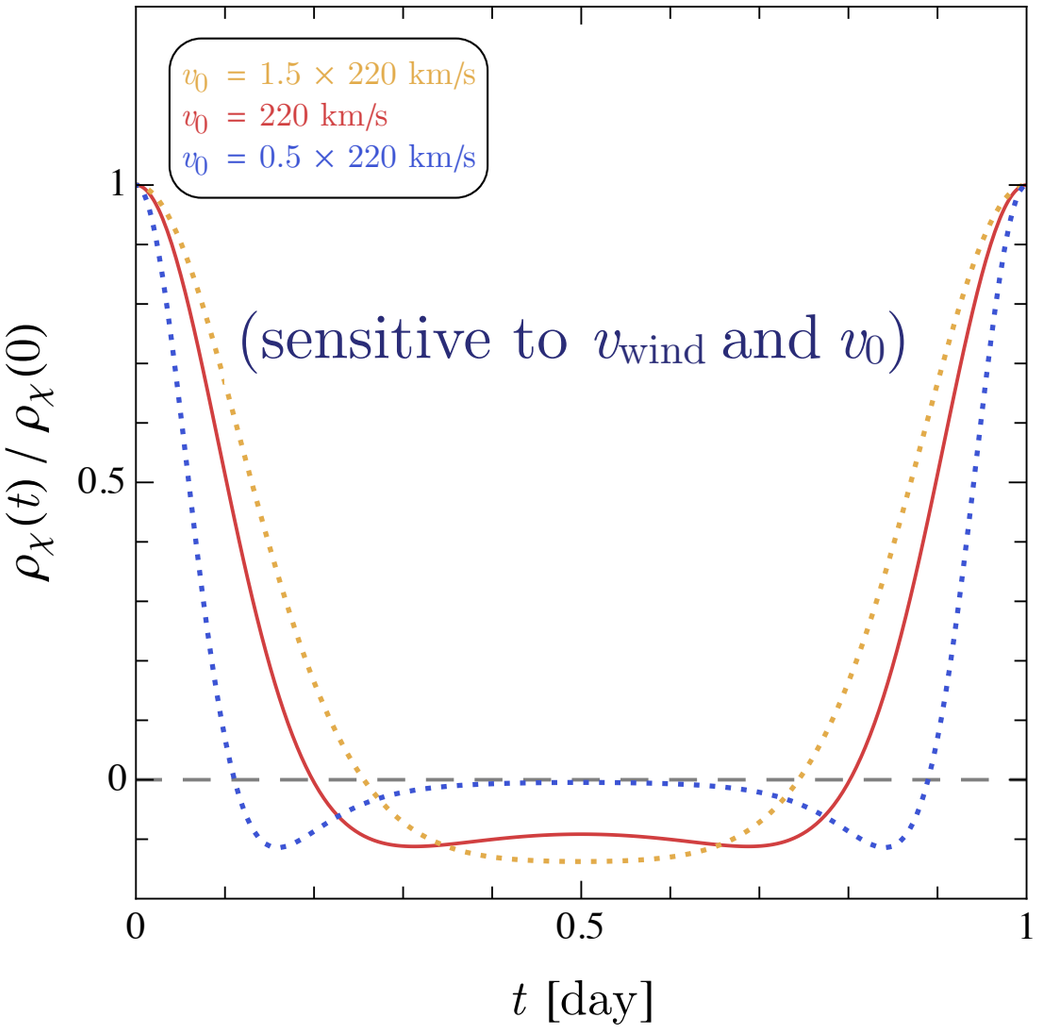
Daily Modulation

Daily Modulation



Daily Modulation





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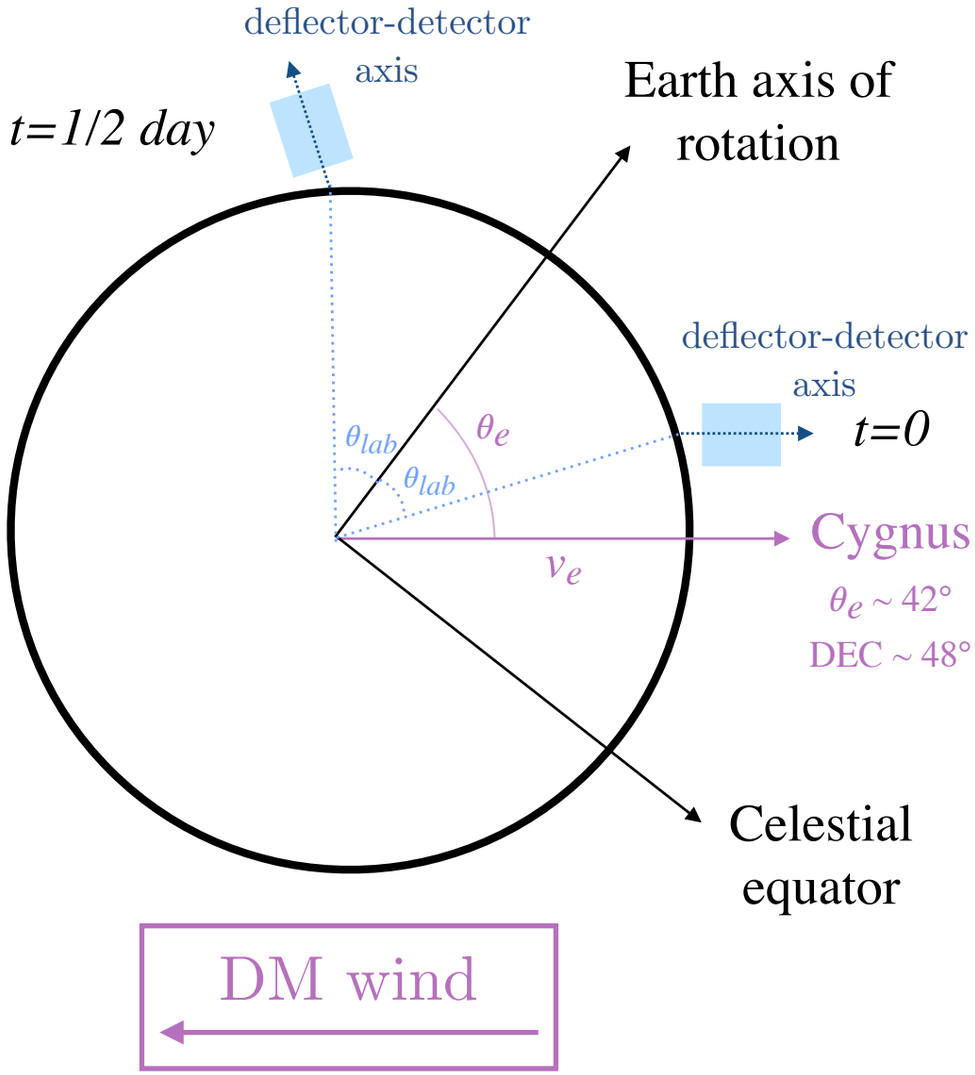
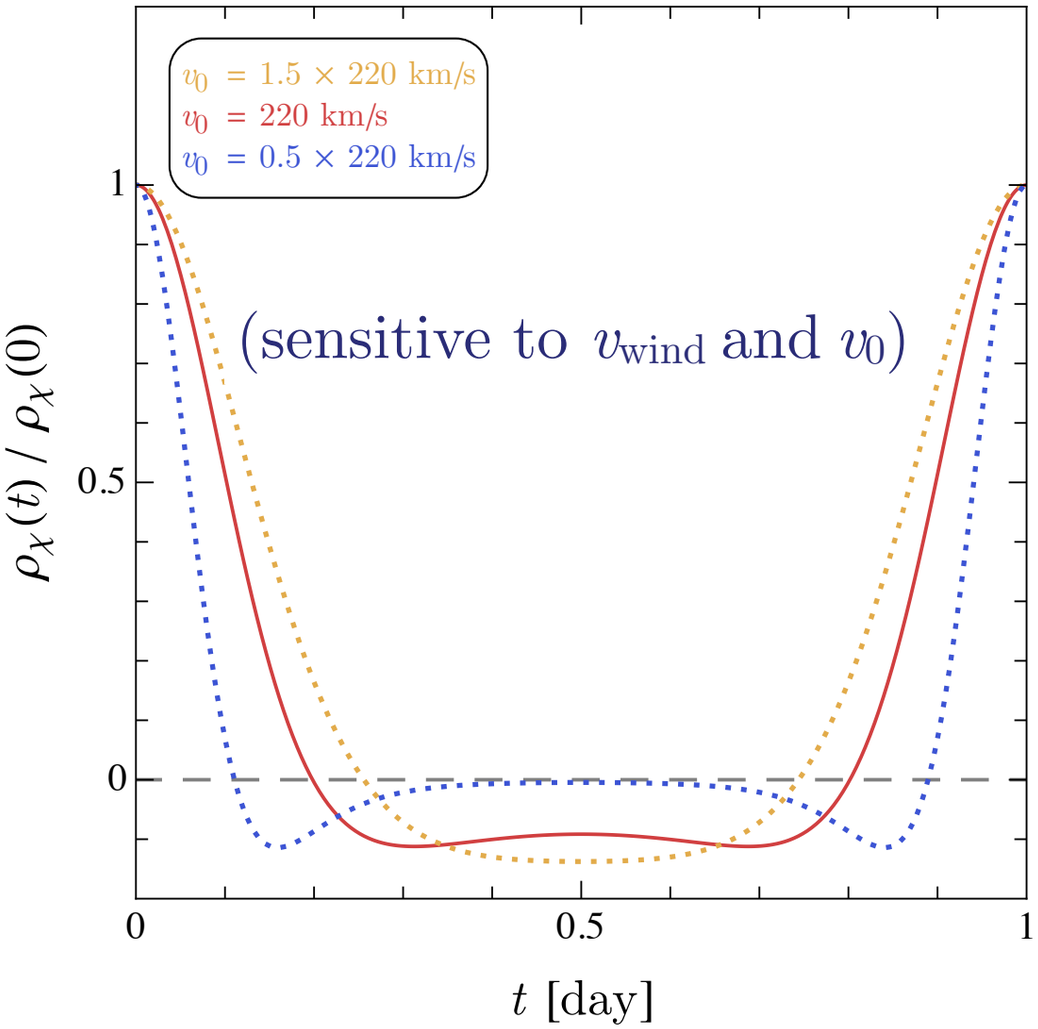




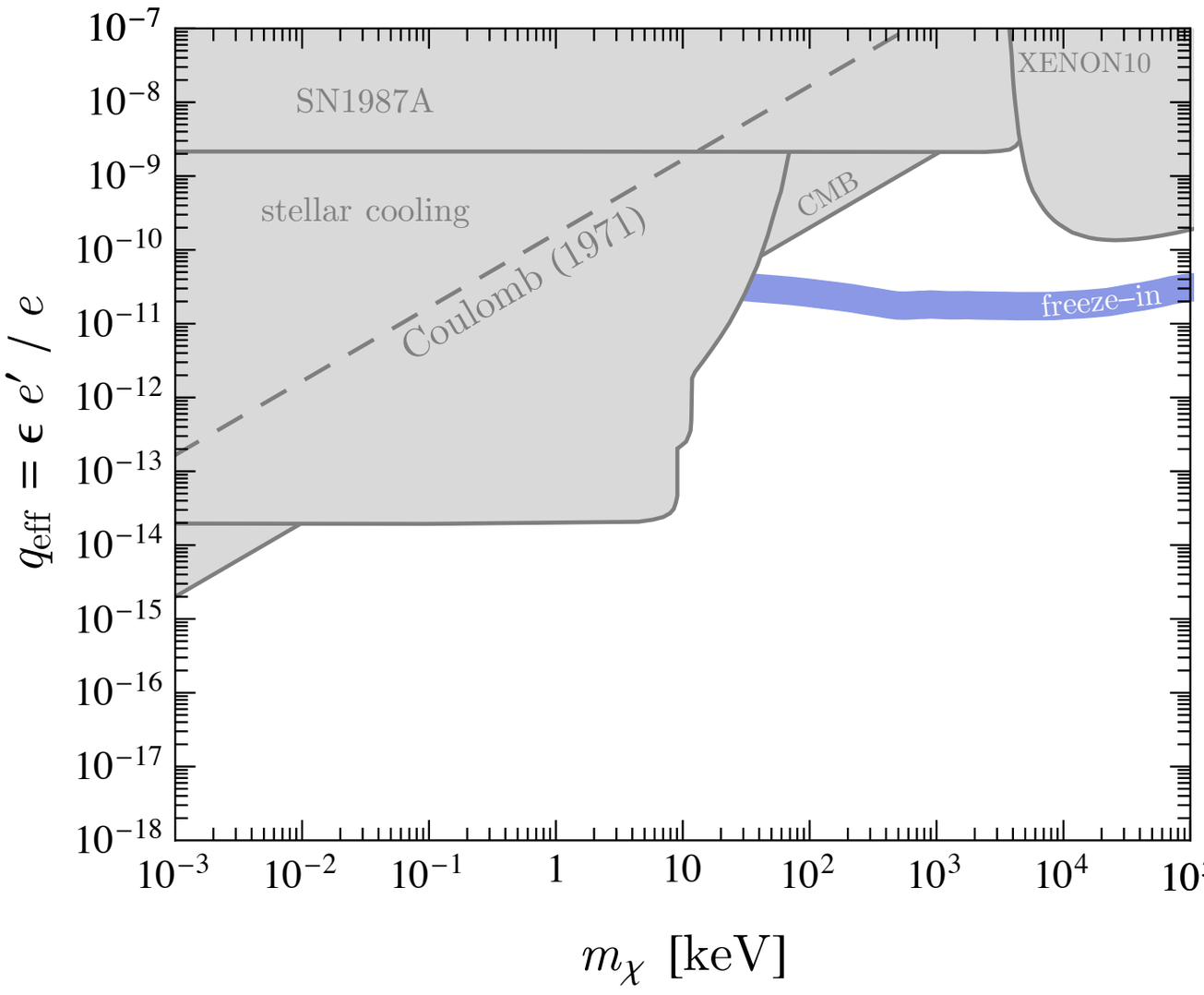
deflector: ω

signal: $\omega \pm \omega_\oplus$

arXiv:1807.10291

Reach Summary

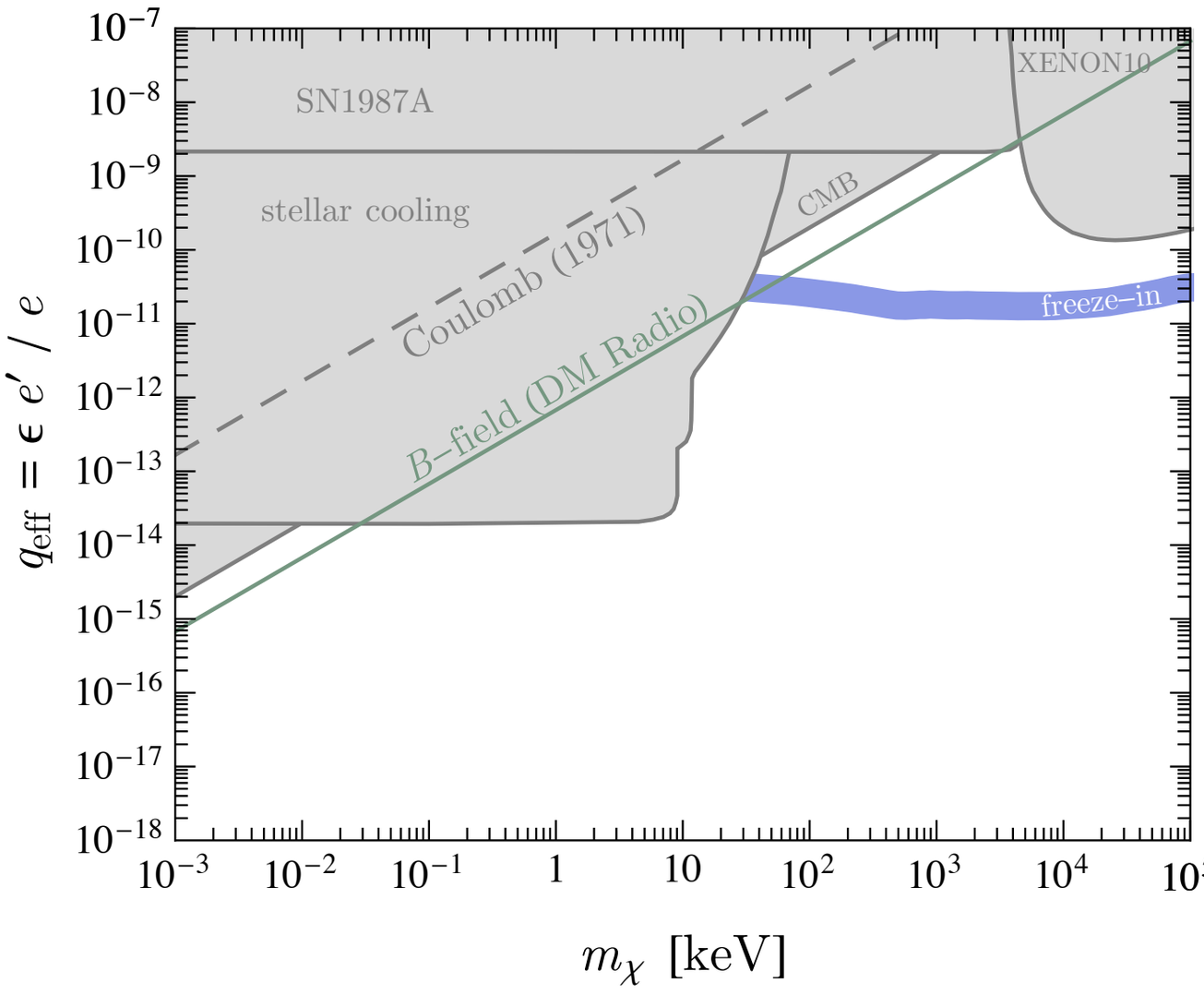
Reach Summary



$$\langle E_{\rm def}\rangle = 10\ \text{kV/cm}$$
$$\omega = 100\ \text{kHz}$$
$$t_{\rm int} = \text{year}$$

$$q_{\rm eff}(\text{reach}) \propto m_\chi\ V_{\rm sh}^{-\frac{7}{12}}\ \langle E_{\rm def}\rangle^{-\frac{1}{2}}\ \ (Q\,\omega\,t_{\rm int}/T_{\rm LC})^{-\frac{1}{4}}$$

Reach Summary



$$\langle E_{\rm def}\rangle = 10\ \text{kV/cm}$$
$$\omega = 100\ \text{kHz}$$
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$$q_{\rm eff}(\text{reach}) \propto m_\chi\ V_{\rm sh}^{-\frac{7}{12}}\ \langle E_{\rm def}\rangle^{-\frac{1}{2}}\ \ (Q\,\omega\,t_{\rm int}/T_{\rm LC})^{-\frac{1}{4}}$$

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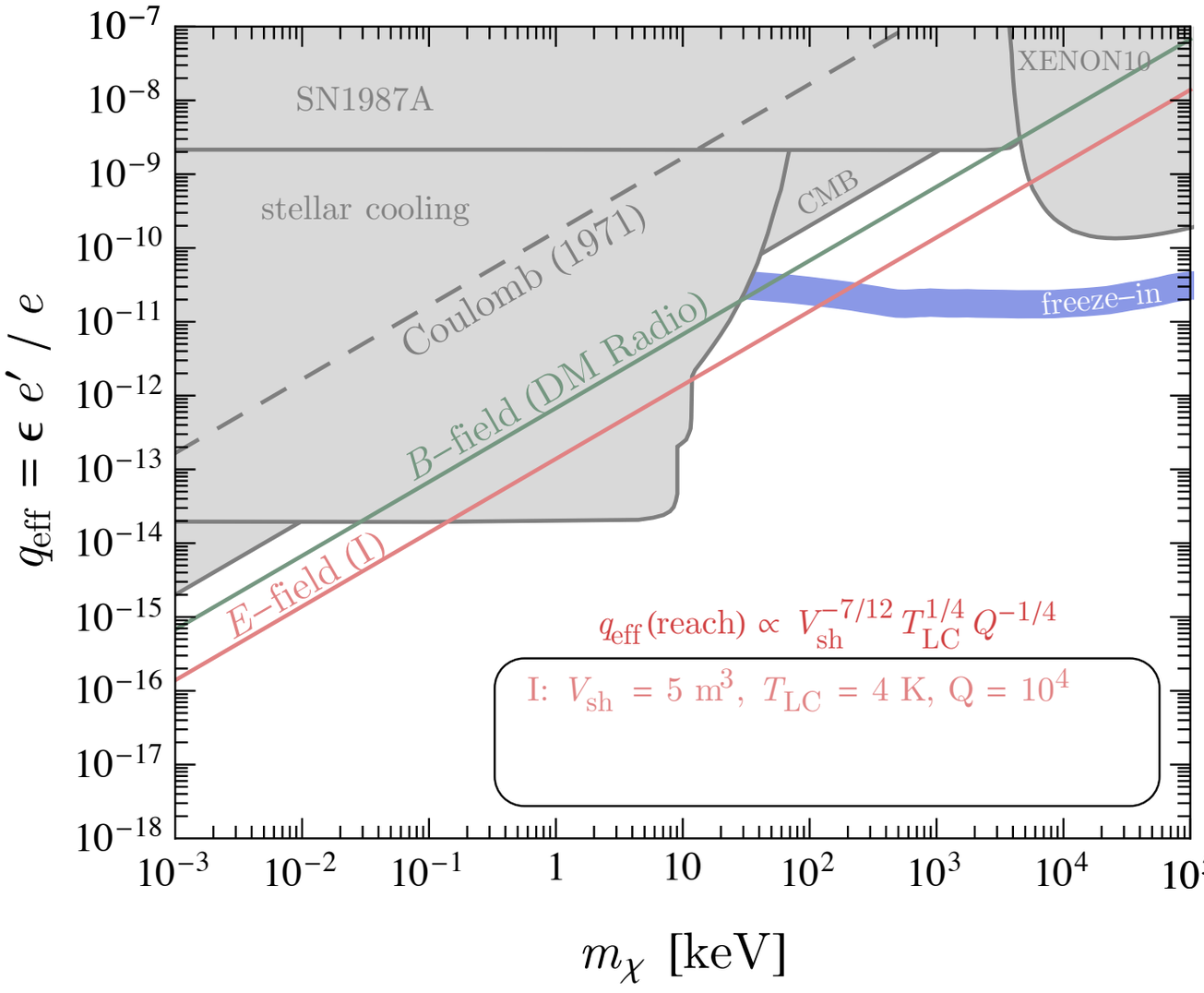

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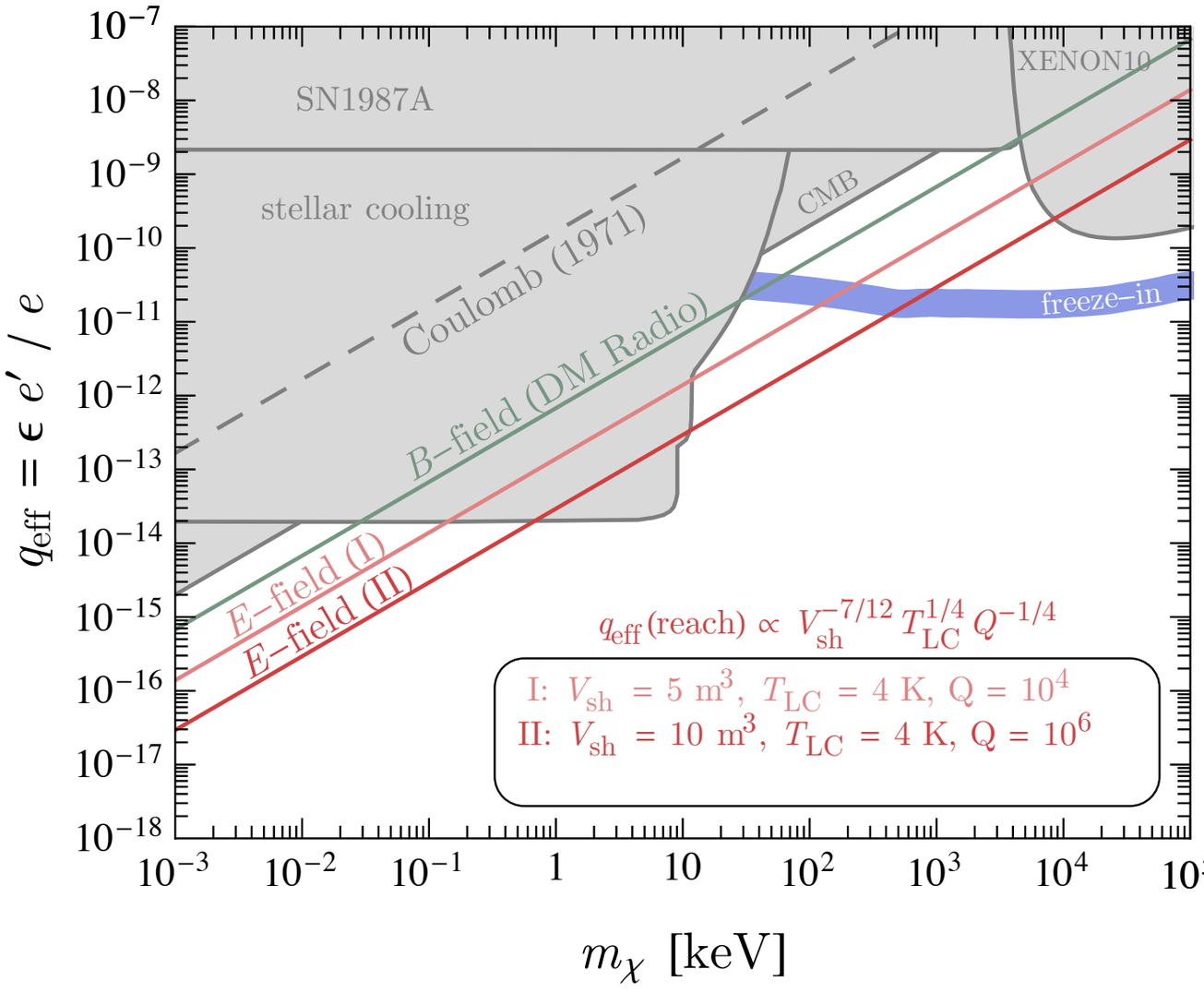
Reach Summary



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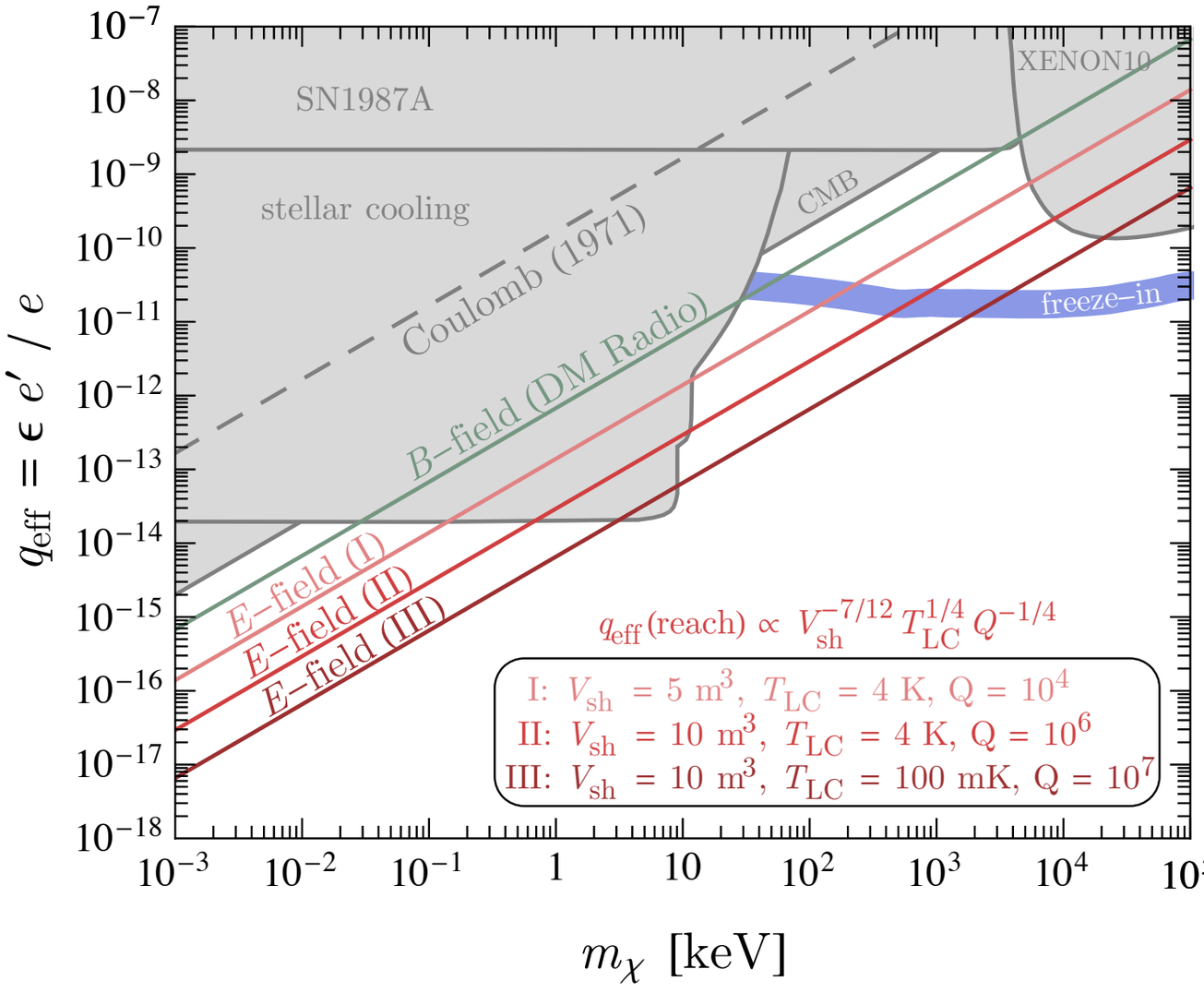
Reach Summary



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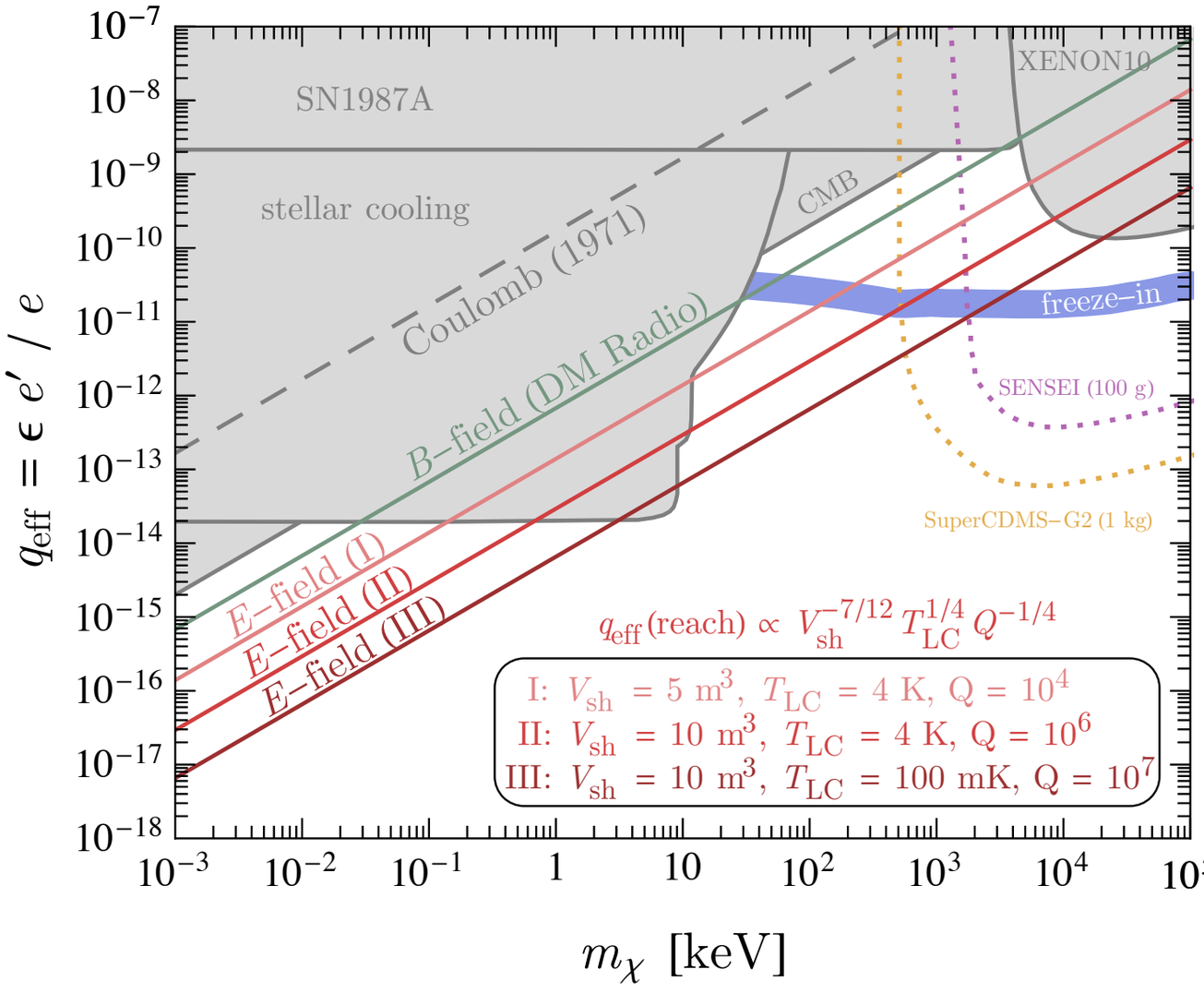
Reach Summary



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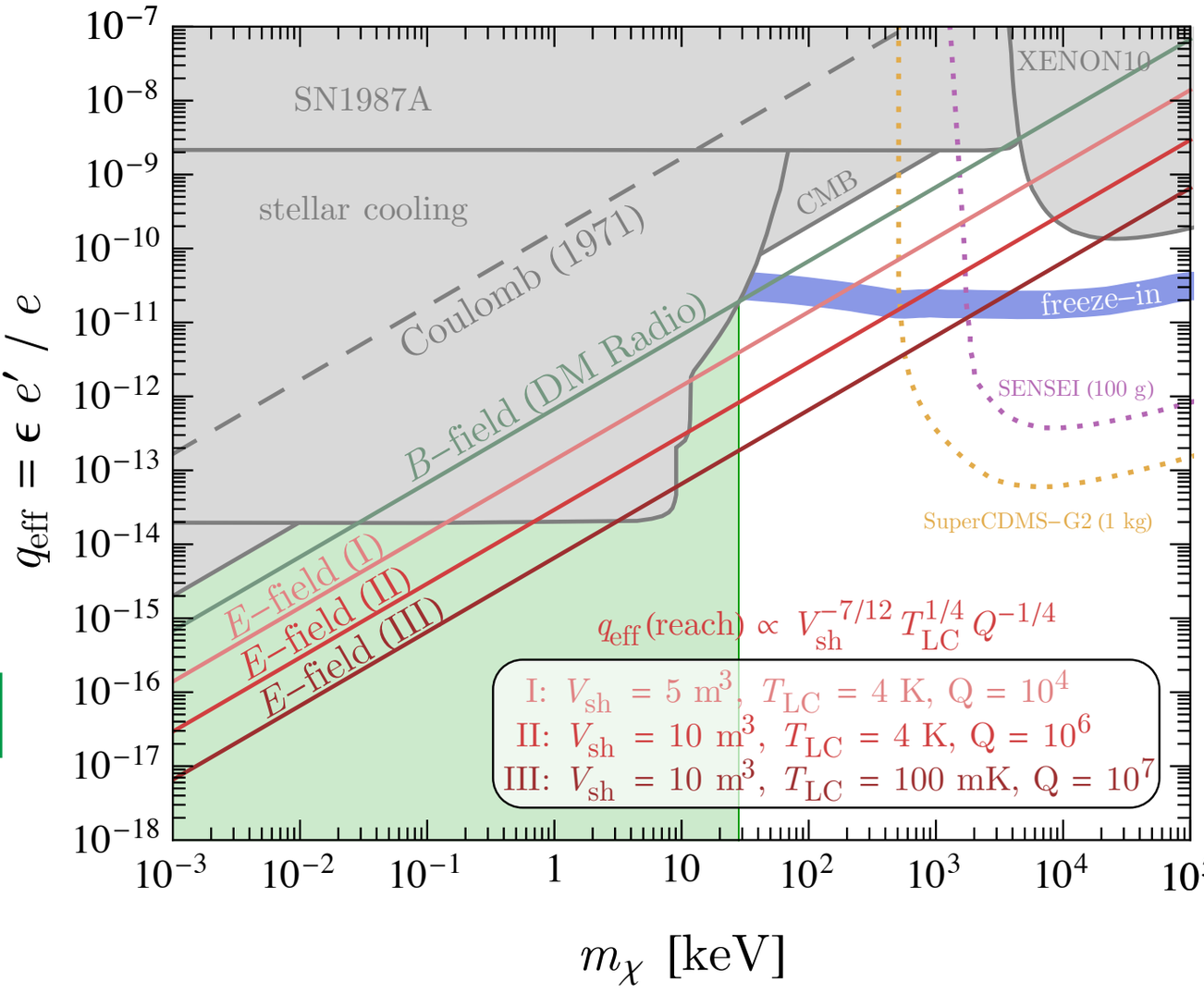
Reach Summary

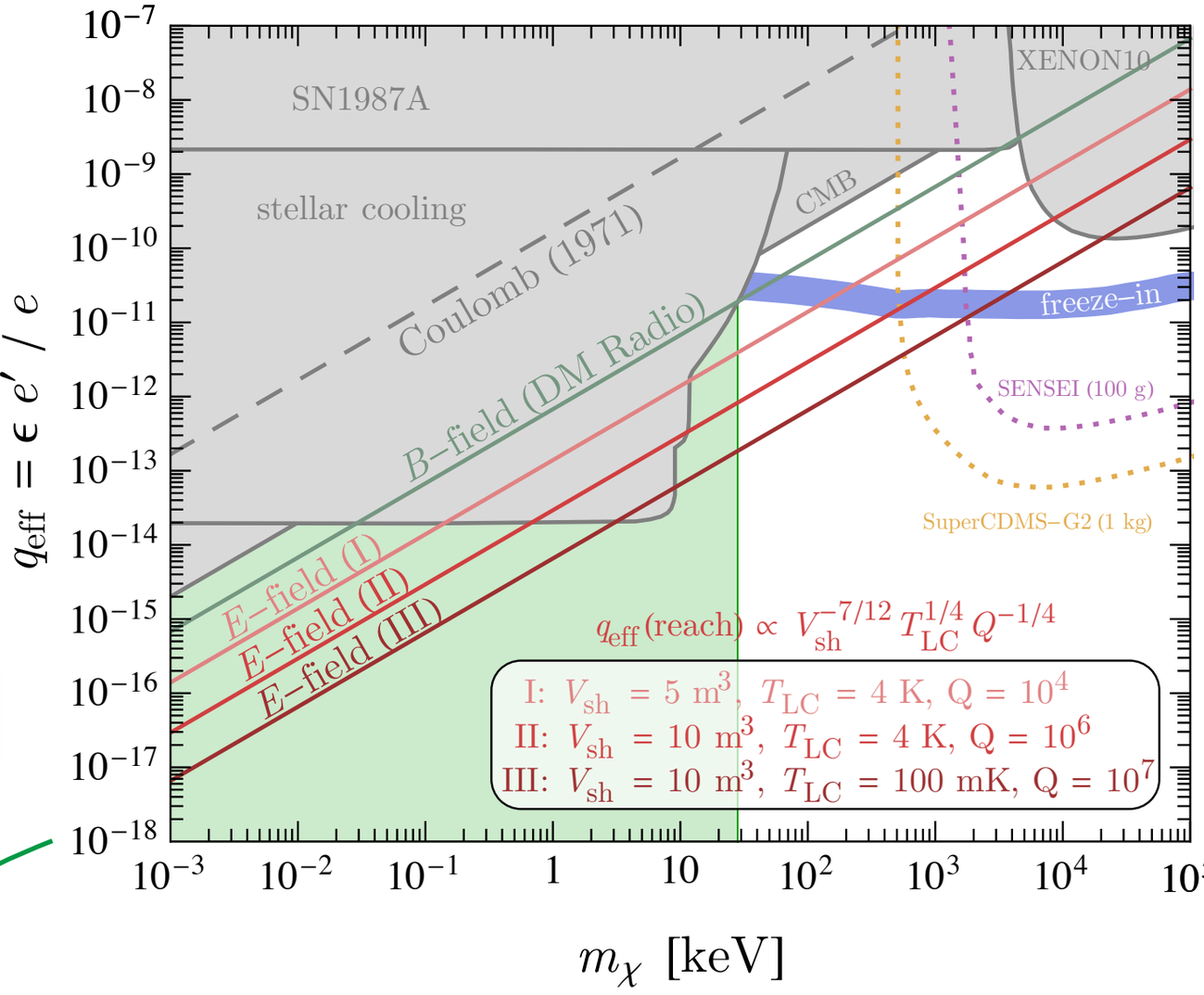


$\langle E_{\rm def}\rangle = 10$ kV/cm
$\omega = 100$ kHz
$t_{\rm int} =$ year

ultralight cosmology?

$$q_{\rm eff}({\rm reach}) \propto m_\chi\; V_{\rm sh}^{-\frac{7}{12}}\; \langle E_{\rm def}\rangle^{-\frac{1}{2}}\; (Q\,\omega\,t_{\rm int}/T_{\rm LC})^{-\frac{1}{4}}$$

Reach Summary



$\langle E_{\rm def}\rangle = 10$ kV/cm
$\omega = 100$ kHz
$t_{\rm int} =$ year

ultralight cosmology?

transition when
$m_\chi\, v_\chi \lesssim \text{meter}^{-1} \implies m_\chi \lesssim 10^{-7}$ keV

$$q_{\rm eff}(\text{reach}) \propto m_\chi\; V_{\rm sh}^{-\frac{7}{12}}\; \langle E_{\rm def}\rangle^{-\frac{1}{2}}\; (Q\,\omega\, t_{\rm int}/T_{\rm LC})^{-\frac{1}{4}}$$

Active Direct Detection

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- induced daily modulation

Active Direct Detection

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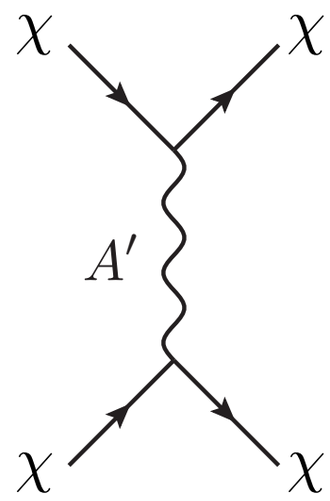
- electromagnetic focusing/trapping of dark matter

Active Direct Detection

- induced daily modulation
- electromagnetic focusing/trapping of dark matter
- deflection-detection for spin-coupled forces, ...

Back Up Slides

Self-Interactions



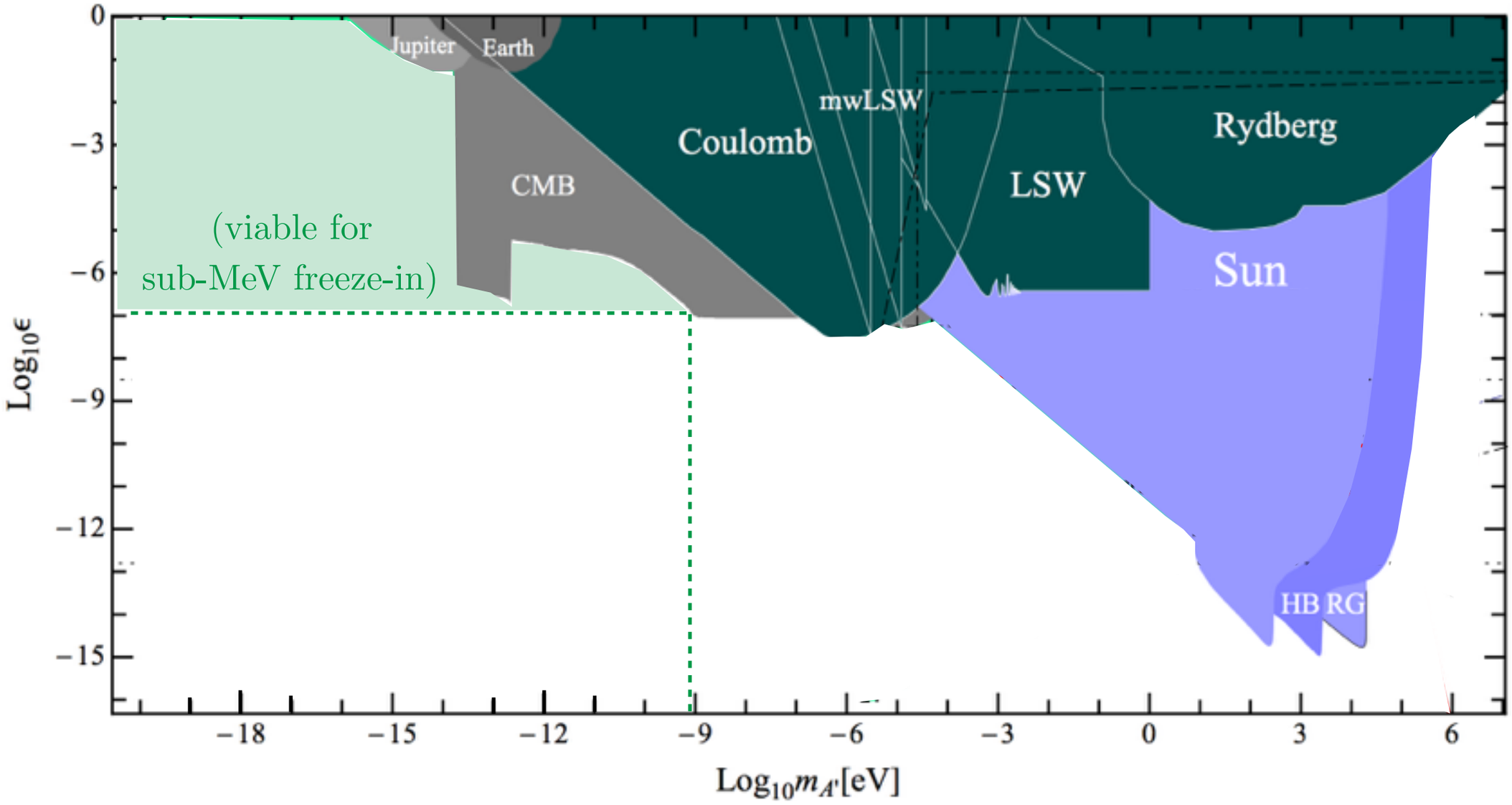
$$\text{galaxy clusters, ...} \implies \boxed{\alpha' \lesssim 10^{-10} \left(\frac{m_\chi}{\text{MeV}}\right)^{3/2}}$$

$$\text{freeze-in} \implies q_{\text{eff}} \sim \epsilon e'/e \sim 10^{-11} \left(\frac{m_\chi}{\text{MeV}}\right)^{-1/2} \implies \boxed{\alpha' \sim \frac{10^{-24}}{\epsilon^2} \left(\frac{m_\chi}{\text{MeV}}\right)^{-1}}$$

$$\therefore \ \text{SIDM} + \text{freeze-in} \implies \boxed{\epsilon \gtrsim 10^{-7} \left(\frac{m_\chi}{\text{MeV}}\right)^{-5/4}}$$

what does this imply
for the dark photon mass?

Parameter Space



$$m_{A'} \lesssim 10^{-9}\ \text{eV} \sim \frac{1}{100\ \text{m}}$$

long-range forces

arXiv:1704.05081
arXiv:1401.6077