WISPy cold dark matter

- searching for axions and other weakly interacting light candidates -

Javier Redondo

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LMU
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN
ARNOLD SOMMERFELD CENTER FOR THEORETICAL PHYSICS
MAX-PLANCK-GESELLSCHAFT

Outline

- Strong CP problem and axions

- axion-like particles BSM

- WISPy cold dark matter

- axion - photon mixing

- radiation from a magnetised mirror

- cavity experiments

- dish antennas

The Strong CP problem

- Topological term in QCD cannot be neglected (‘t Hooft) (explains eta’ mass)

$$\mathcal{L}_\theta = \frac{\alpha_s}{8\pi}\mathrm{tr}\left\{G_a^{\mu\nu}\widetilde{G}_{a\mu\nu}\right\}\theta$$

Violates P and T (and thus CP, since CPT is conserved)

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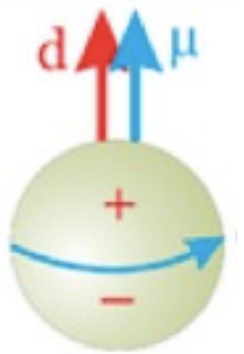

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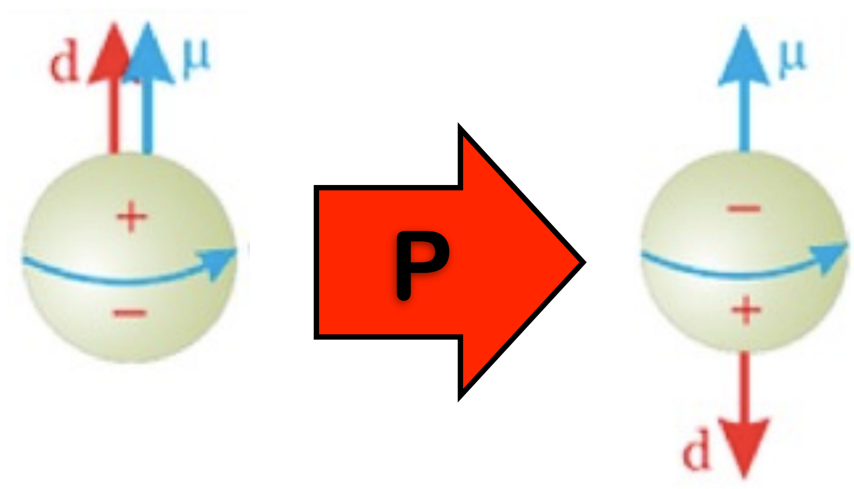

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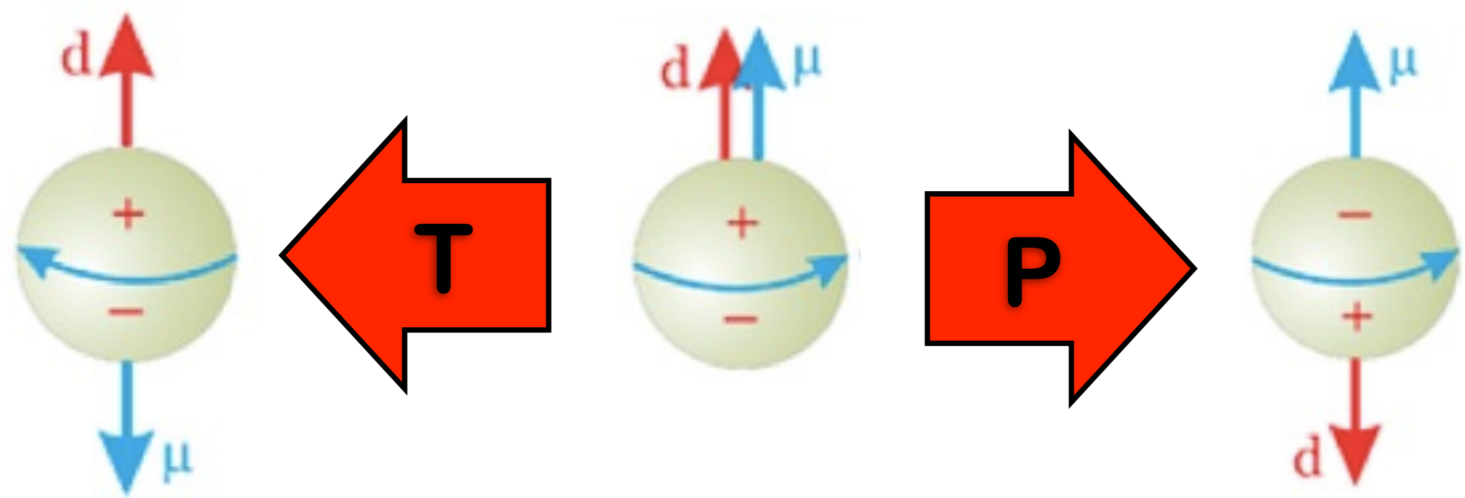

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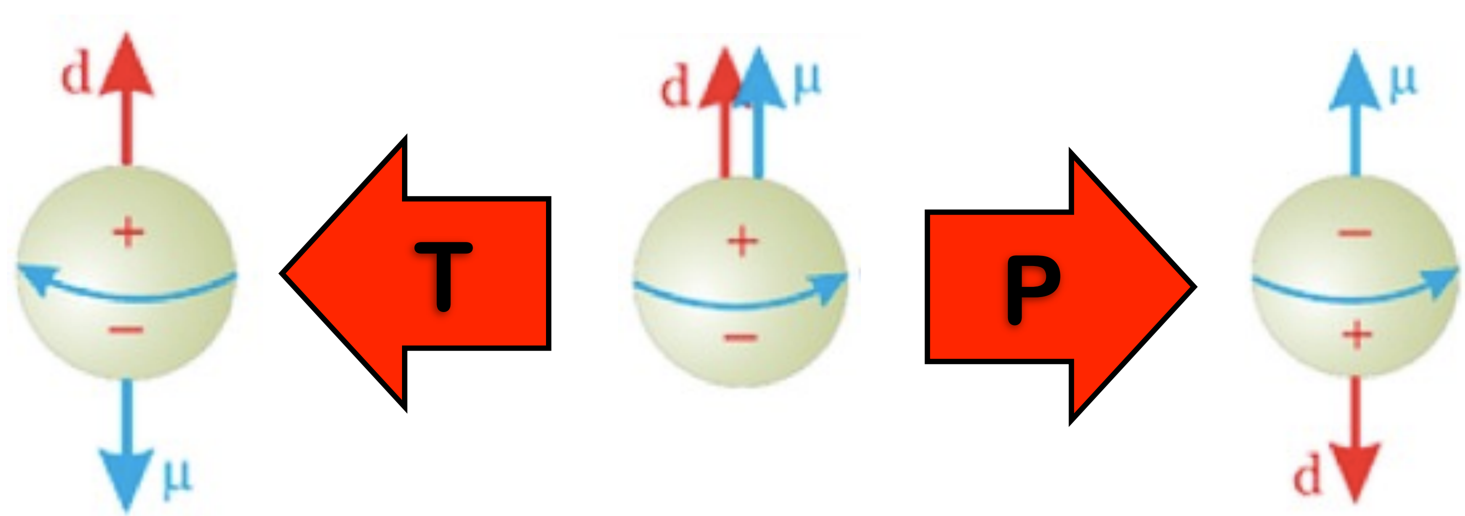

Prediction is $d_n \sim 10^{-15} \theta\, \mathrm{ecm}$ **but ... Experiments do not find it**

Experimental limit
$d_n < 2.6 \times 10^{-26}\, \mathrm{ecm}$

$\theta \lesssim 10^{-11}$

Why ?????

Quinn, PRL'77
Weinberg PRL '78
Wilczek PRL '78

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took two nobel prizes to realize that this implies a NEW PARTICLE

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$$f_a$$

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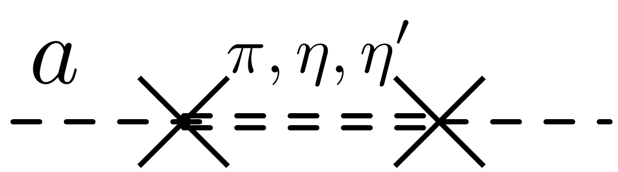
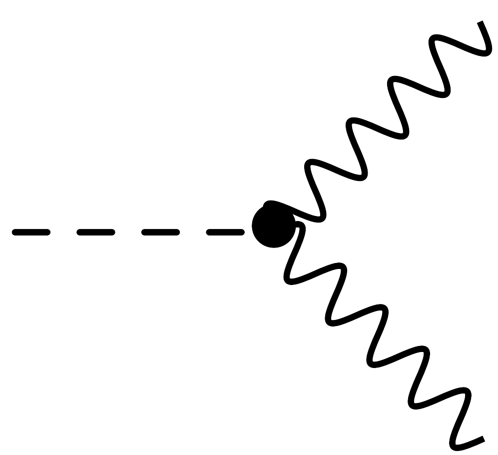


$$m_a \simeq 6\,\mathrm{meV}\,\frac{10^9\,\mathrm{GeV}}{f_a}$$



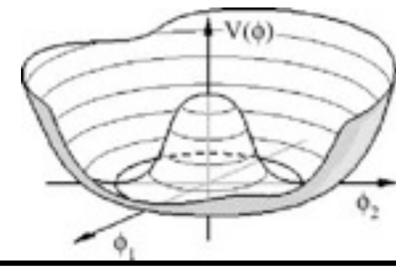
$$\frac{\alpha}{8\pi}(F_{\mu\nu}\widetilde{F}^{\mu\nu})c_{a\gamma\gamma}\frac{a}{f_a}$$

$$g_{a\gamma} = c_{a\gamma\gamma}\frac{\alpha}{2\pi f_a}$$

0^-

pseudo Goldstone bosons

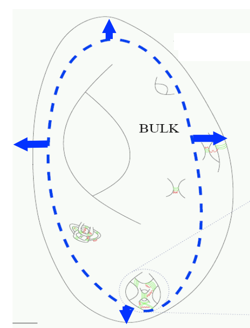
Global continuous symmetry spontaneously broken at high energy scale M



$\pi^0\ \eta'\ \eta\ a$ MAJORONS R-AXION FAMILONS

String 'axions'

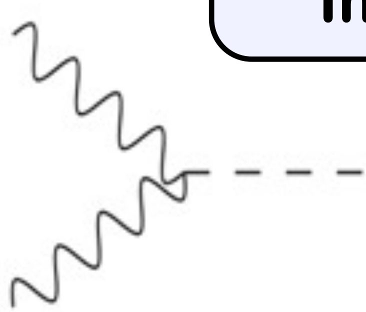
Sizes and deformations of extra dimensions, gauge couplings



DILATONS RADION MODULI

String Axiverse! O(100) candidates!

Important remark!



$g \sim \alpha/2\pi M$ ⟺ ? ⟺ mass m_ϕ

but QCD axions... $m_a \simeq 6\,\mathrm{meV}\,\frac{10^9\,\mathrm{GeV}}{f_a}$

Axion-like particles (ALPs) BSM 0^-

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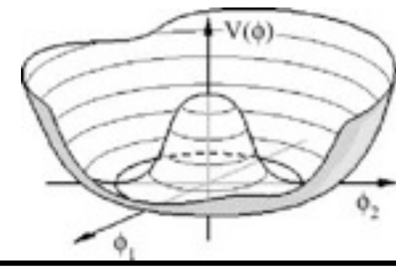

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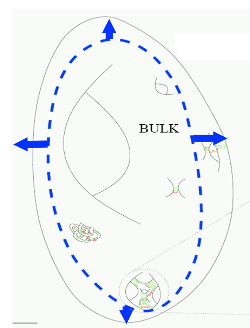

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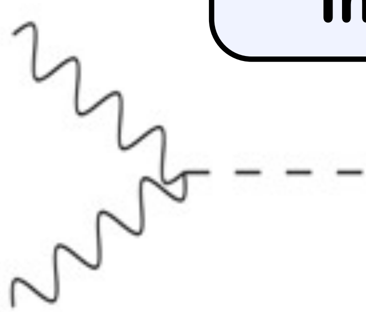

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axion cold dark matter

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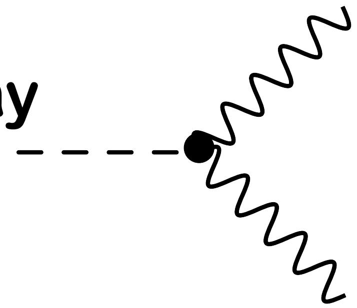

$$\tau \sim \frac{1}{g_{a\gamma}^2 m_a^3} \propto \frac{1}{m_a^5}$$

only low mass axions can be DM!

axion cold dark matter

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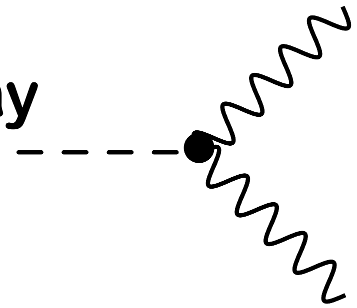

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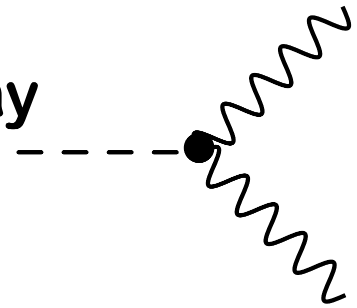

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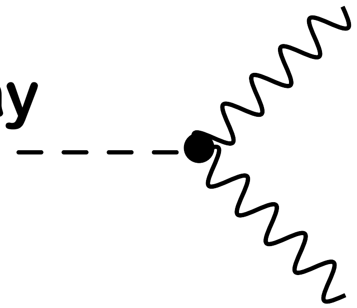

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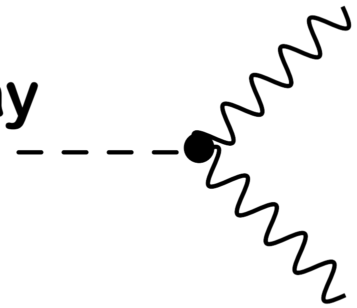

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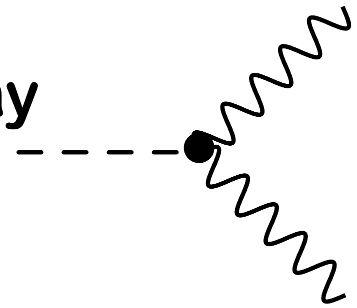

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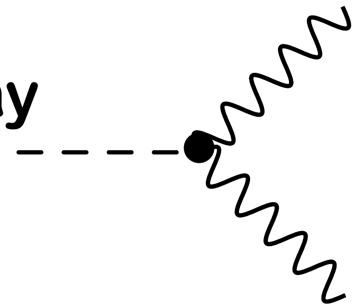

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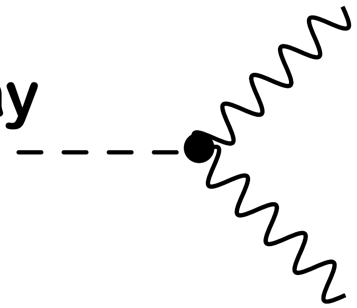

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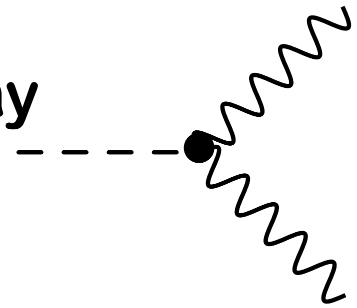

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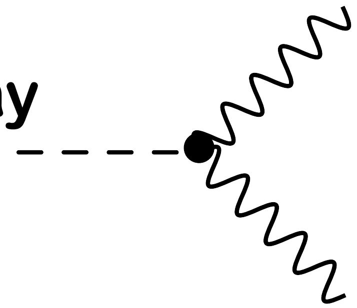

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At PQ phase transition

axion cold dark matter

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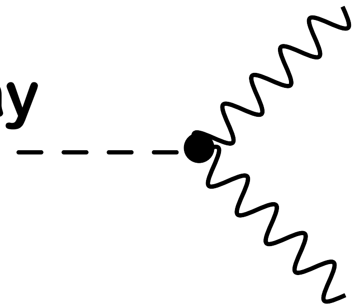

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~~$m_a \sim \text{eV}$???~~

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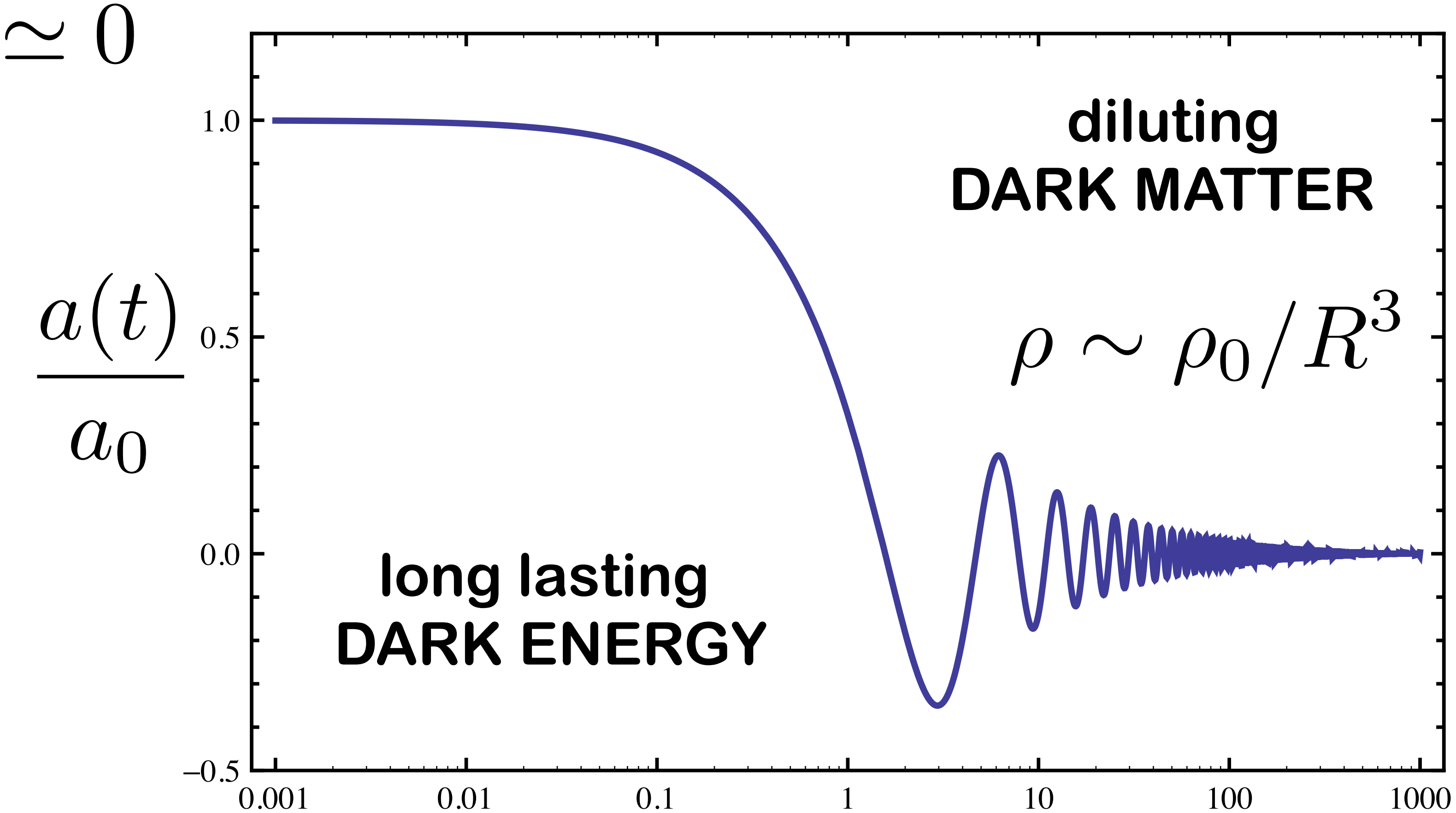
At PQ phase transition

→ high f, more energy... and small mass!

the lonely scalar field evolution

$$\ddot{a} + 3H\dot{a} + (k^2 + V'(a)) \simeq 0$$



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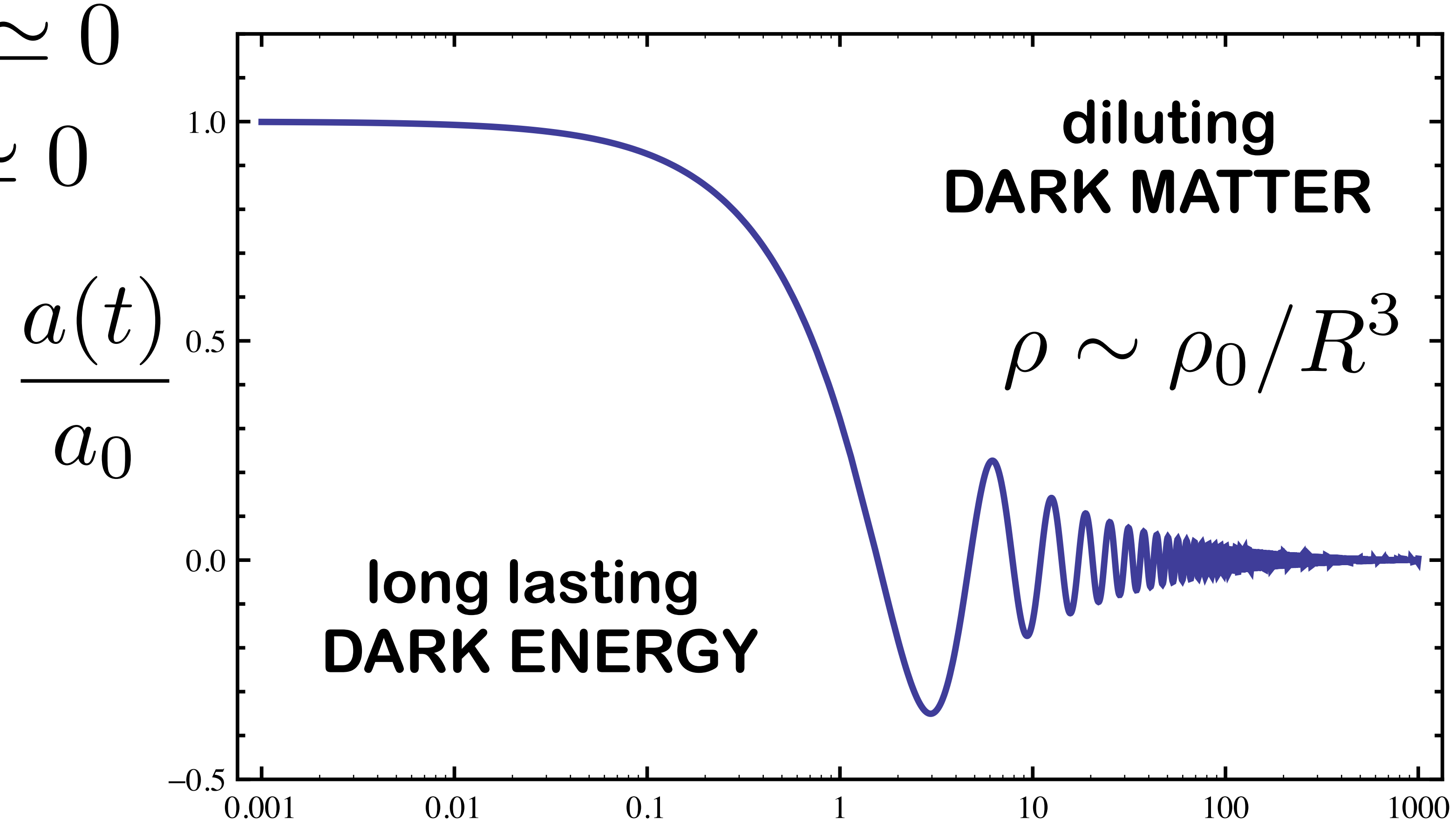

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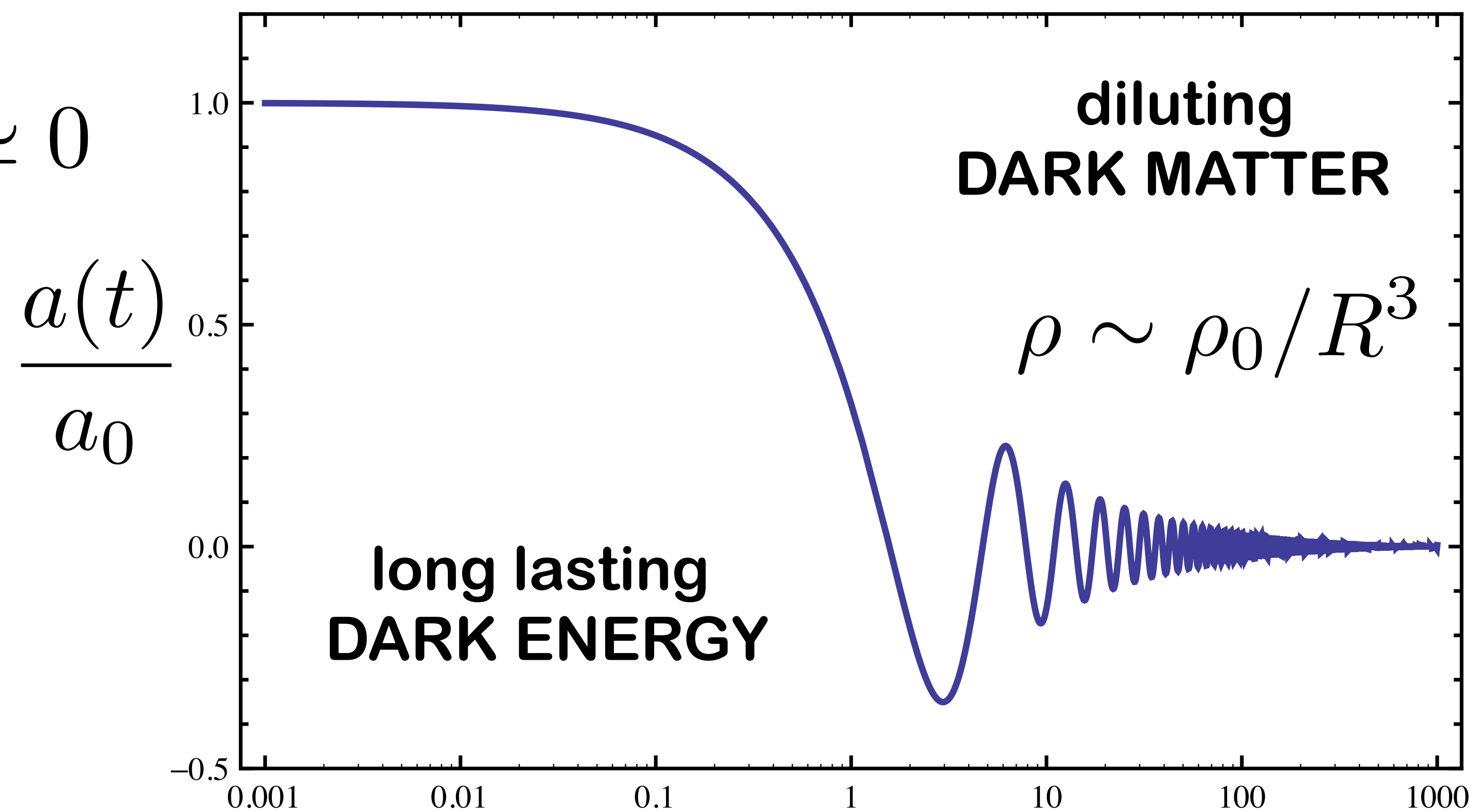

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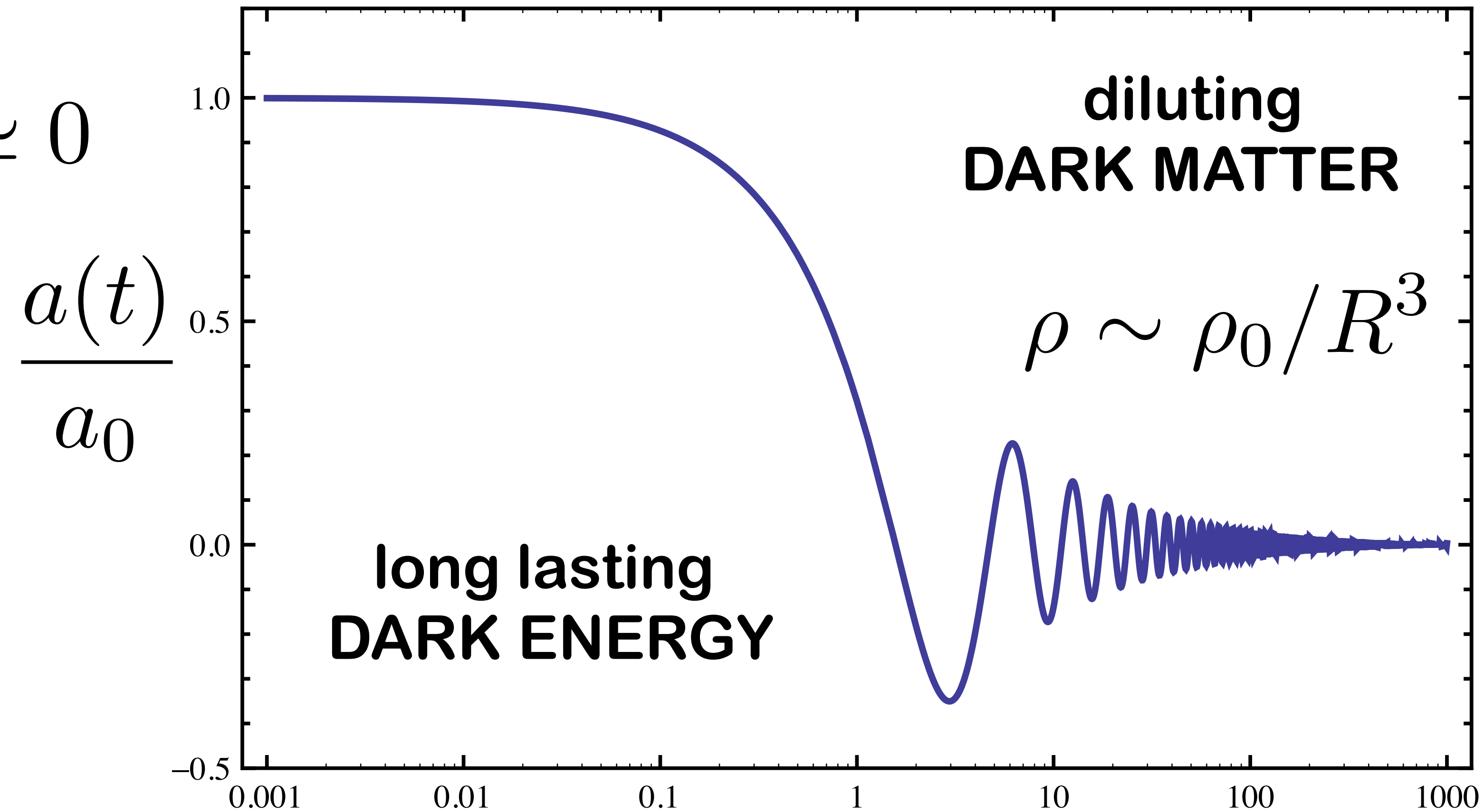

this time is given by

$$t \sim \frac{1}{\sqrt{k^2 + m_a^2}} \sim \min\{\lambda, \frac{1}{m_a}\}$$

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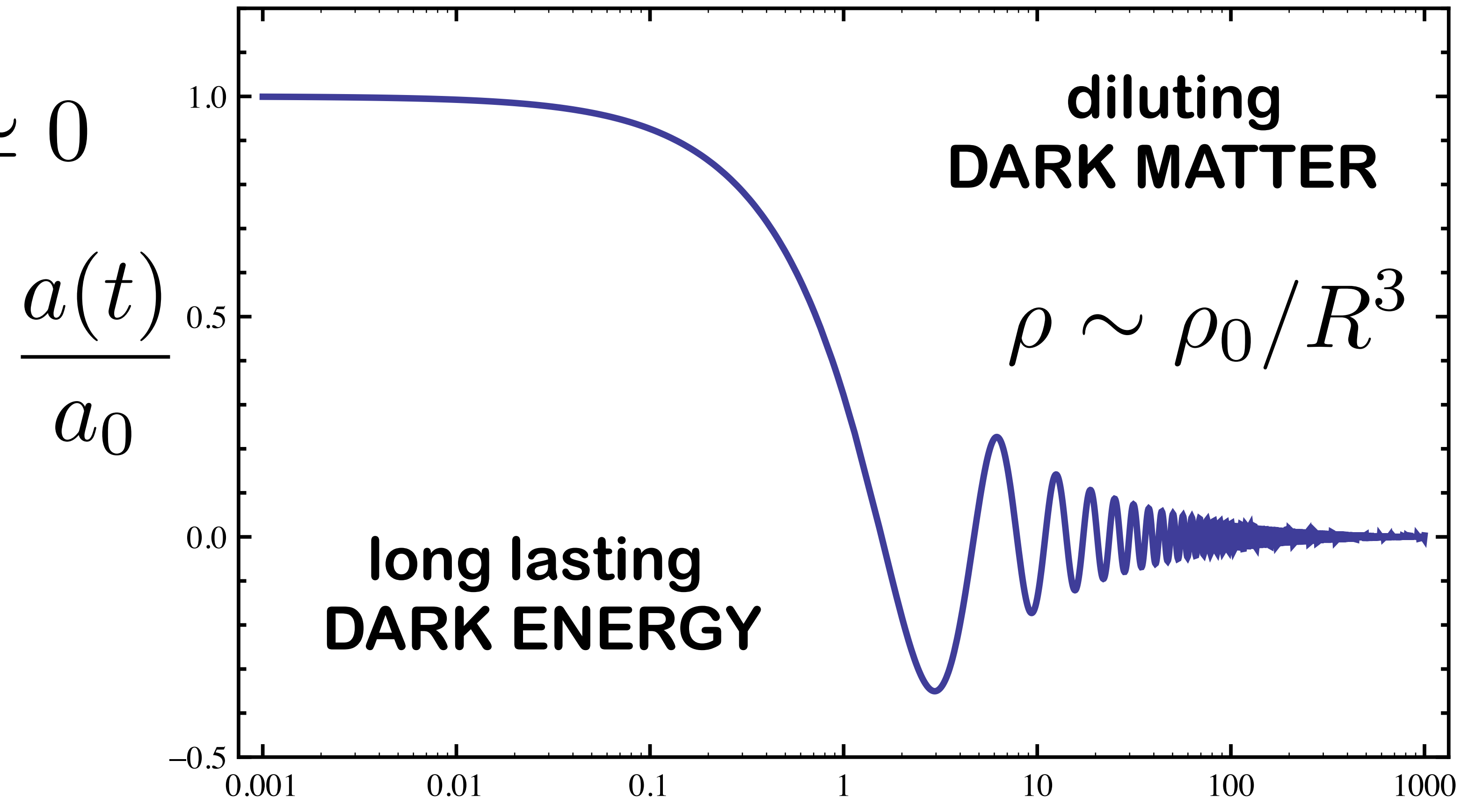

short wavelengths (hotter axions)
start being diluted earlier!
and thus more

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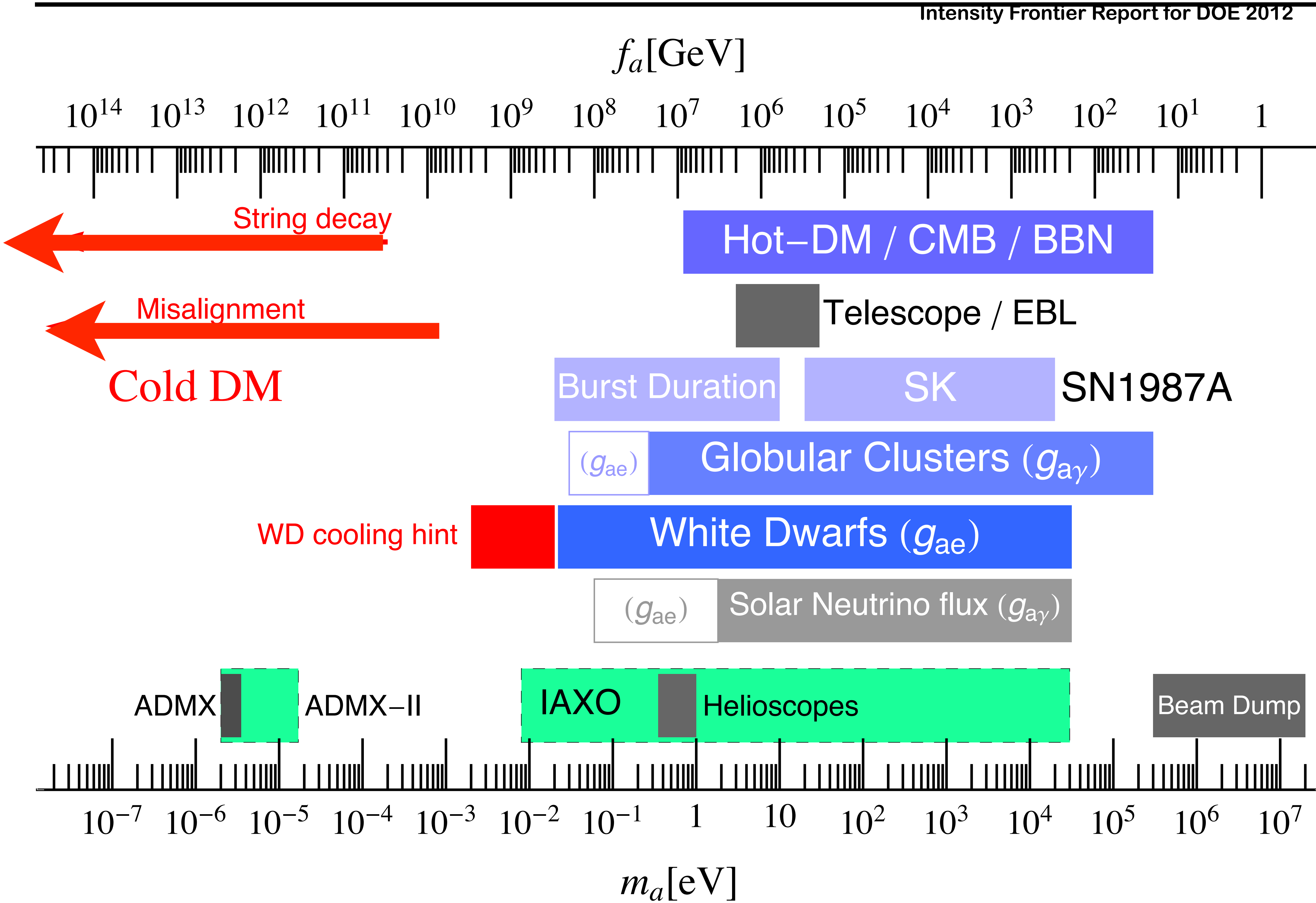
where axion CDM lie ?



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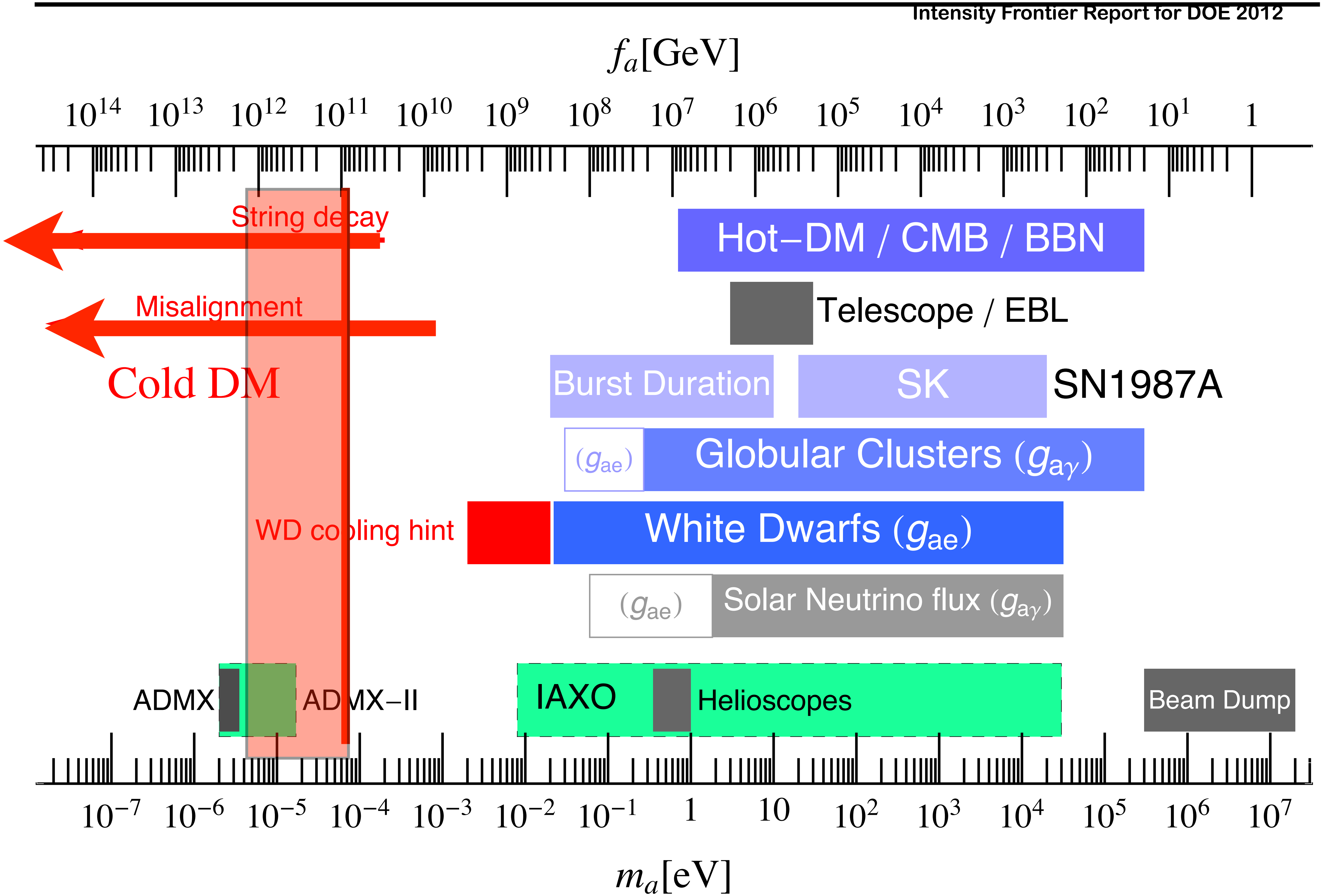
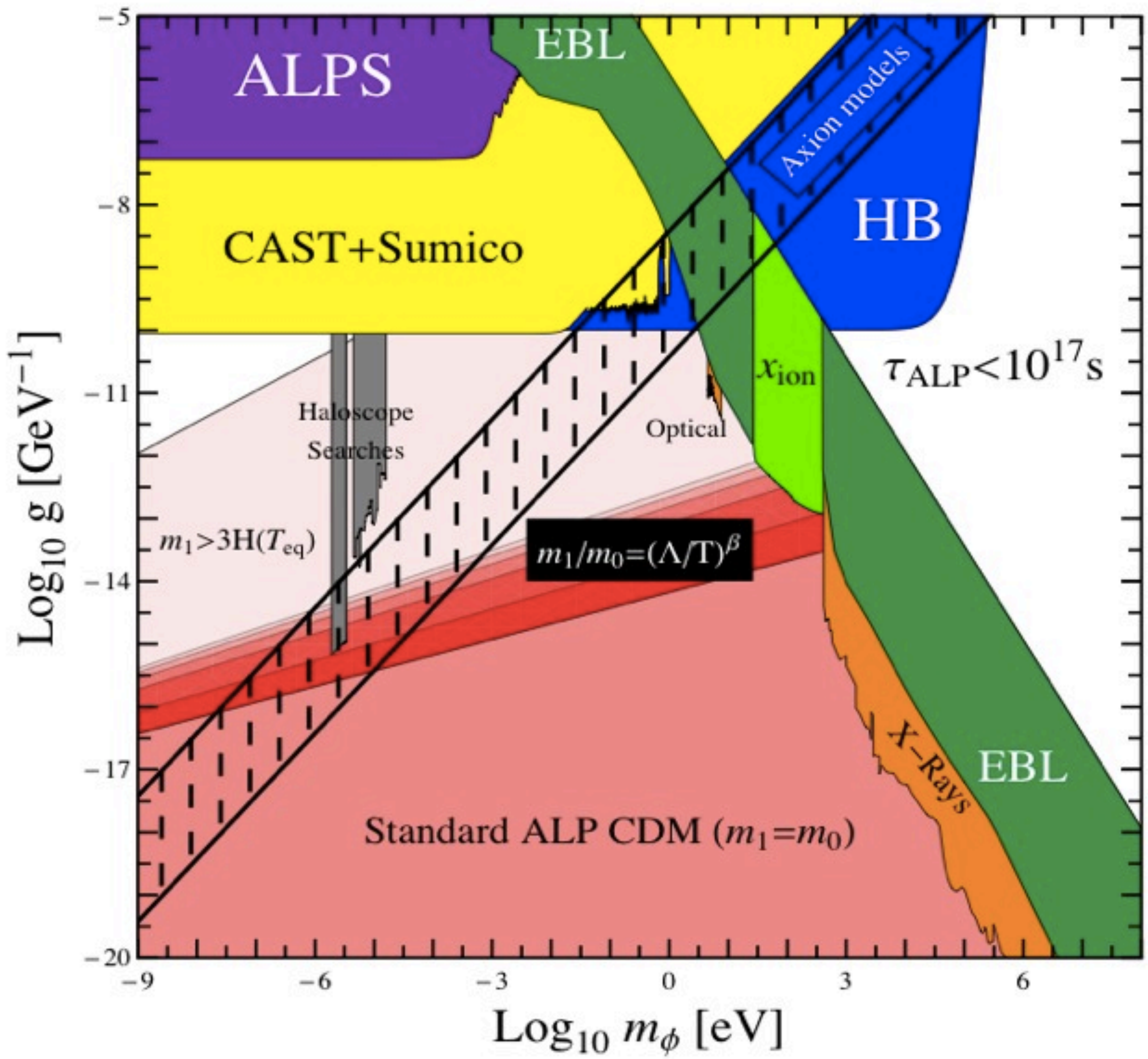


WISPy cold dark matter

Arias et al, JCAP 1206



axion - photon mixing in a magnetic field

Raffelt, PRD'88

$$\mathcal{L}_I = \frac{g_{a\gamma}}{4} F_{\mu\nu} \widetilde{F}^{\mu\nu} a = -g_{a\gamma} \mathbf{B} \cdot \mathbf{E}\, a$$

axion - photon mixing in a magnetic field

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Not axions, nor photons are propagation eigenstates!

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radiation from a mirror

Horns et al, arXiv:1212.2970

$$E_a = \omega_a \chi \cos(\omega_a t + kz).$$

Note: measuring these photons,
we measure the TOTAL DM energy,
DM mass and the velocity distribution!
also with directional sensitivity!
Irastorza et al. 2012

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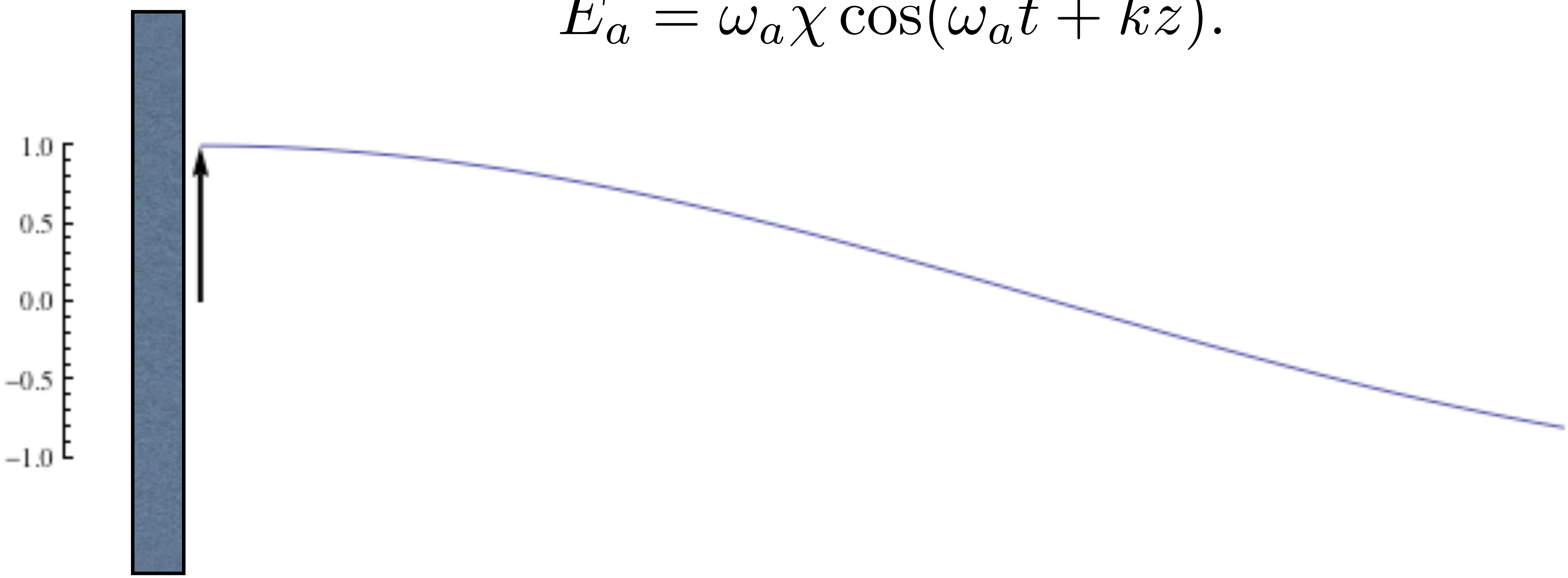

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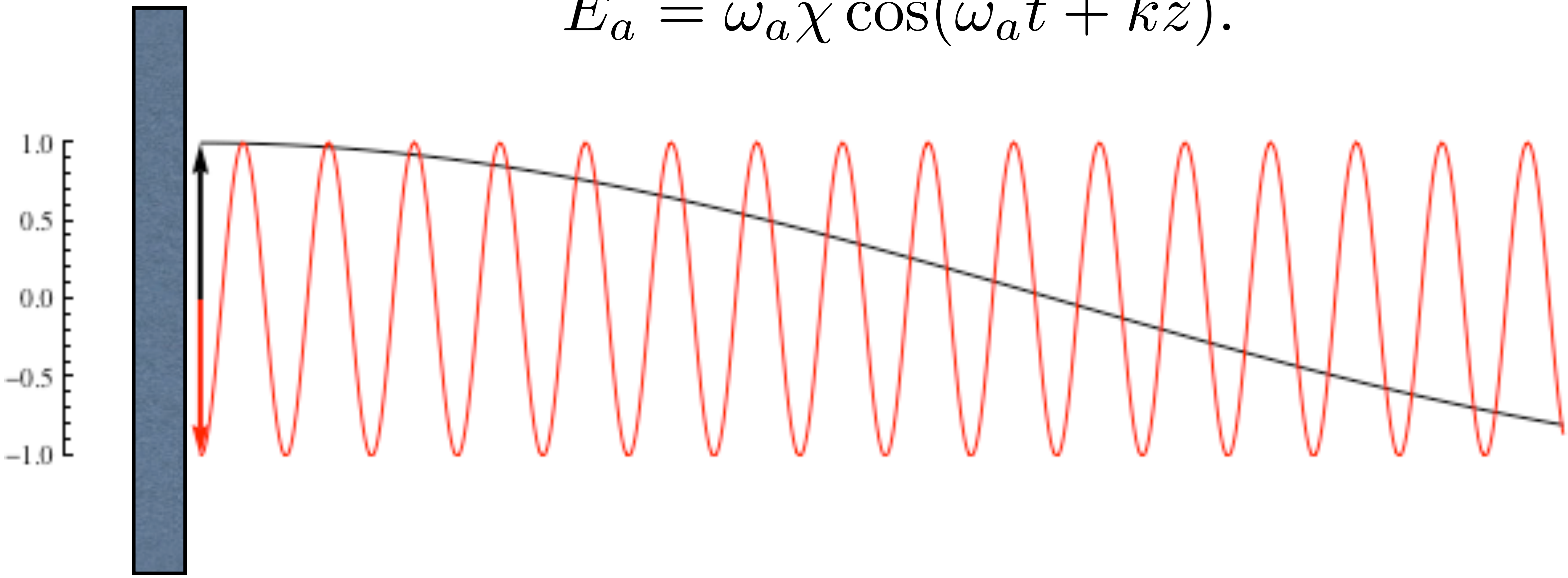

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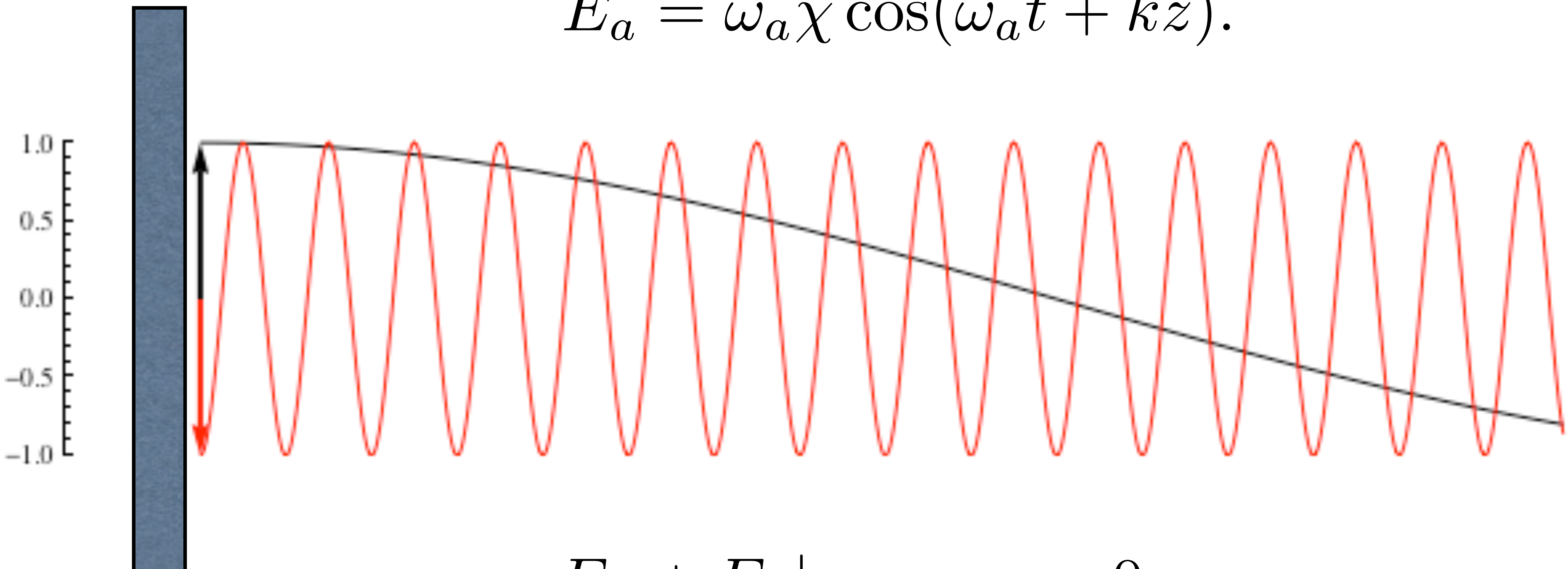

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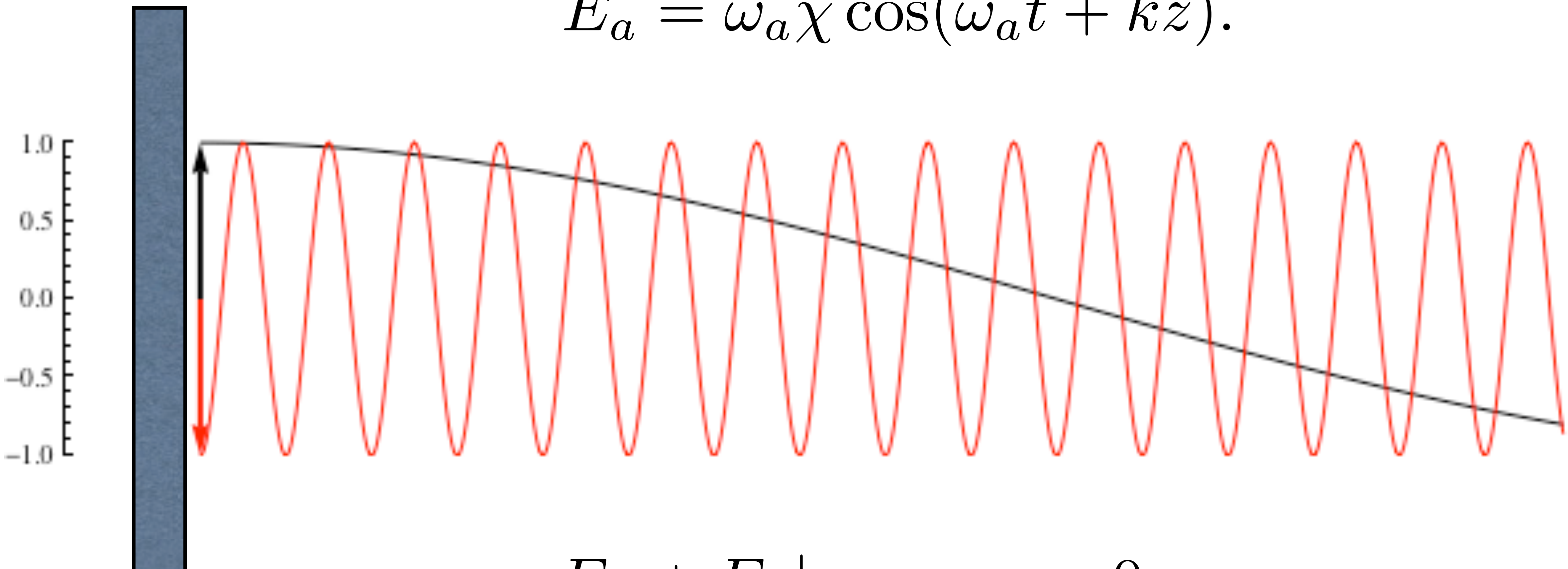

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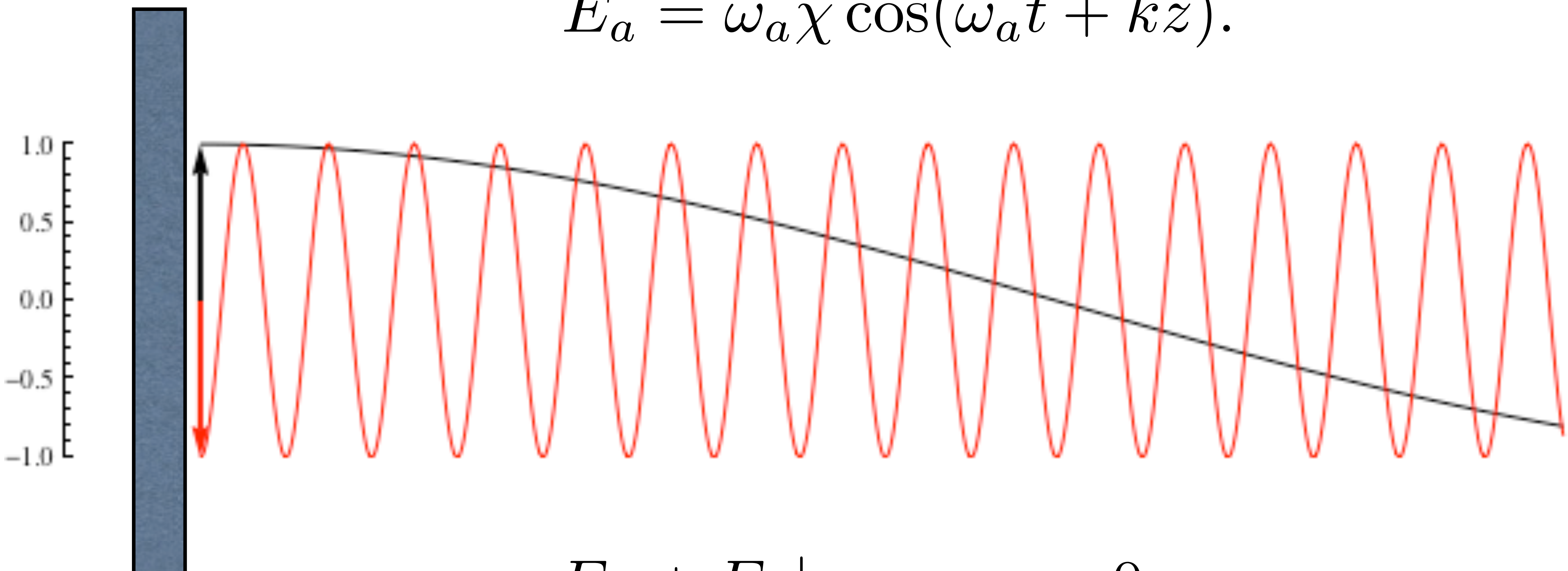

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Photons radiated from the mirror with $\omega_\gamma = \omega_a = m_a(1 + v^2/2)$

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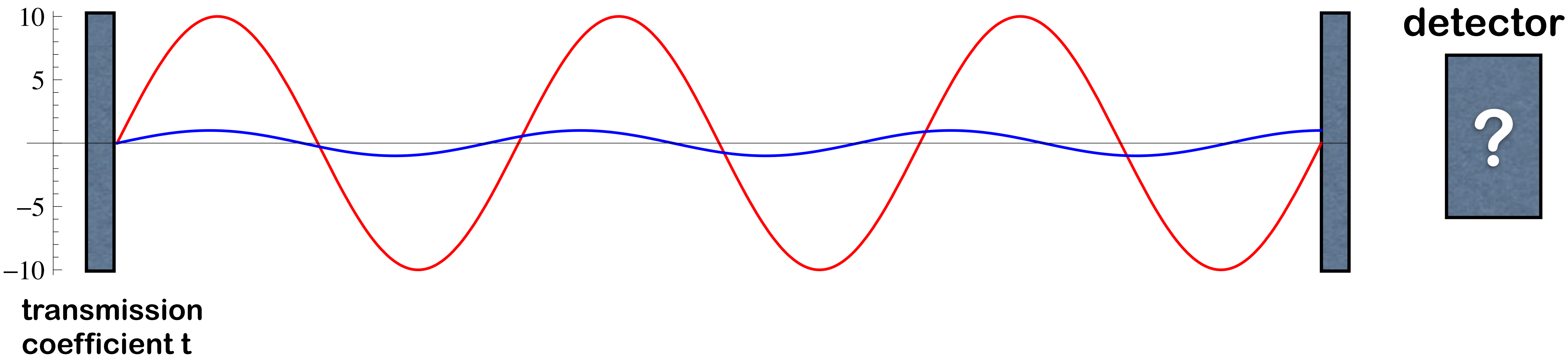
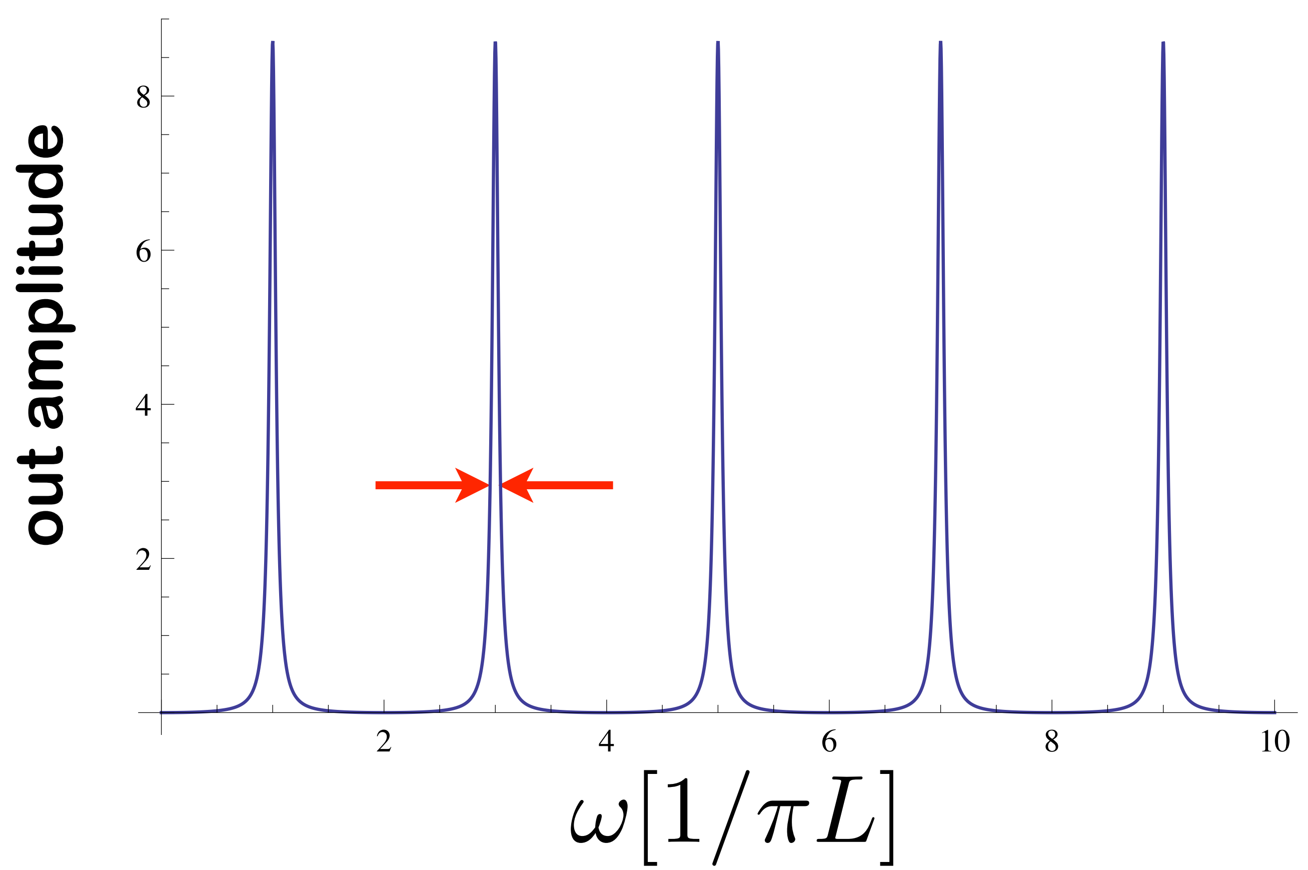
cavity searches (haloscopes)

Sikivie PRL '83

- Use two facing mirrors (simplistic resonant cavity in 1D)





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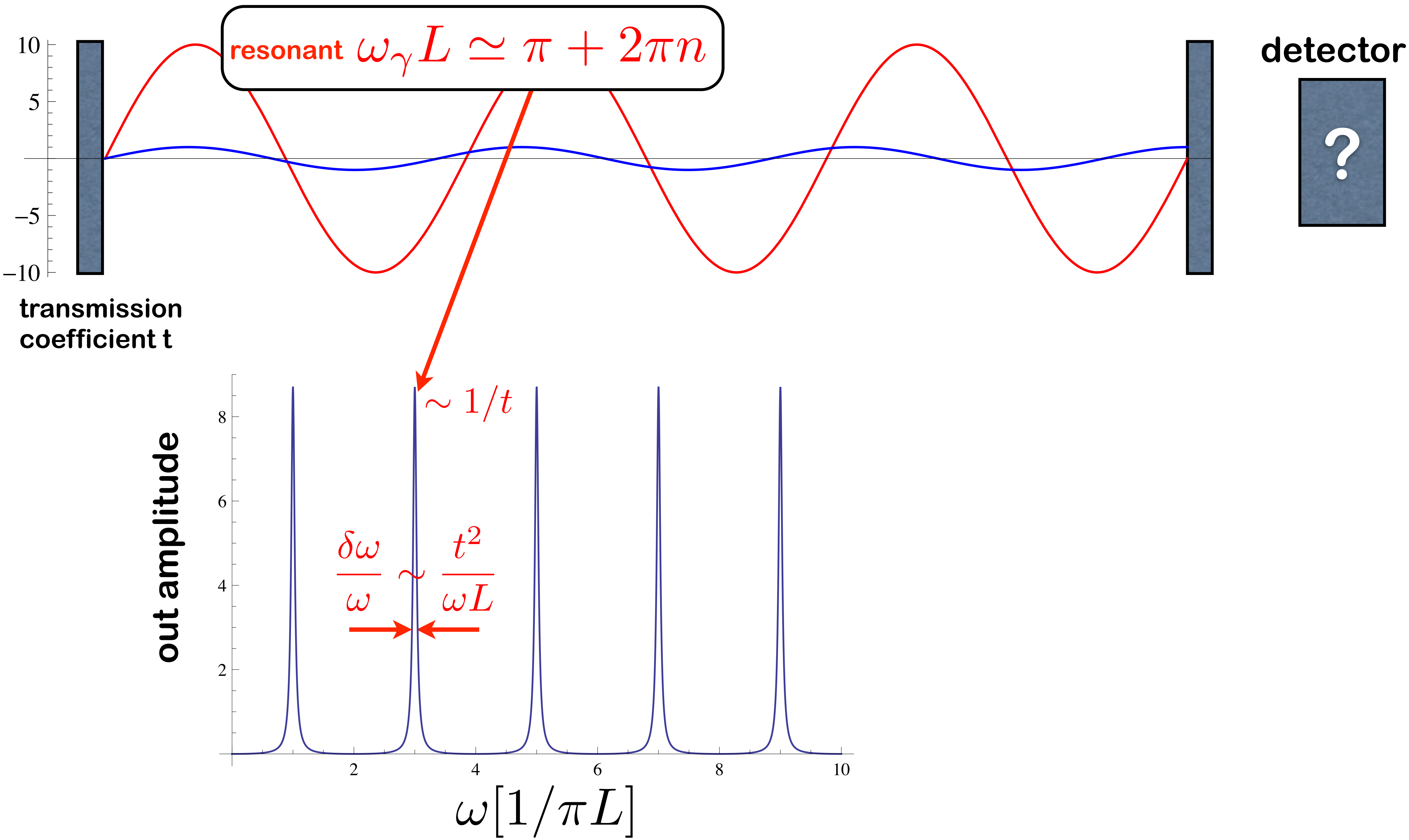

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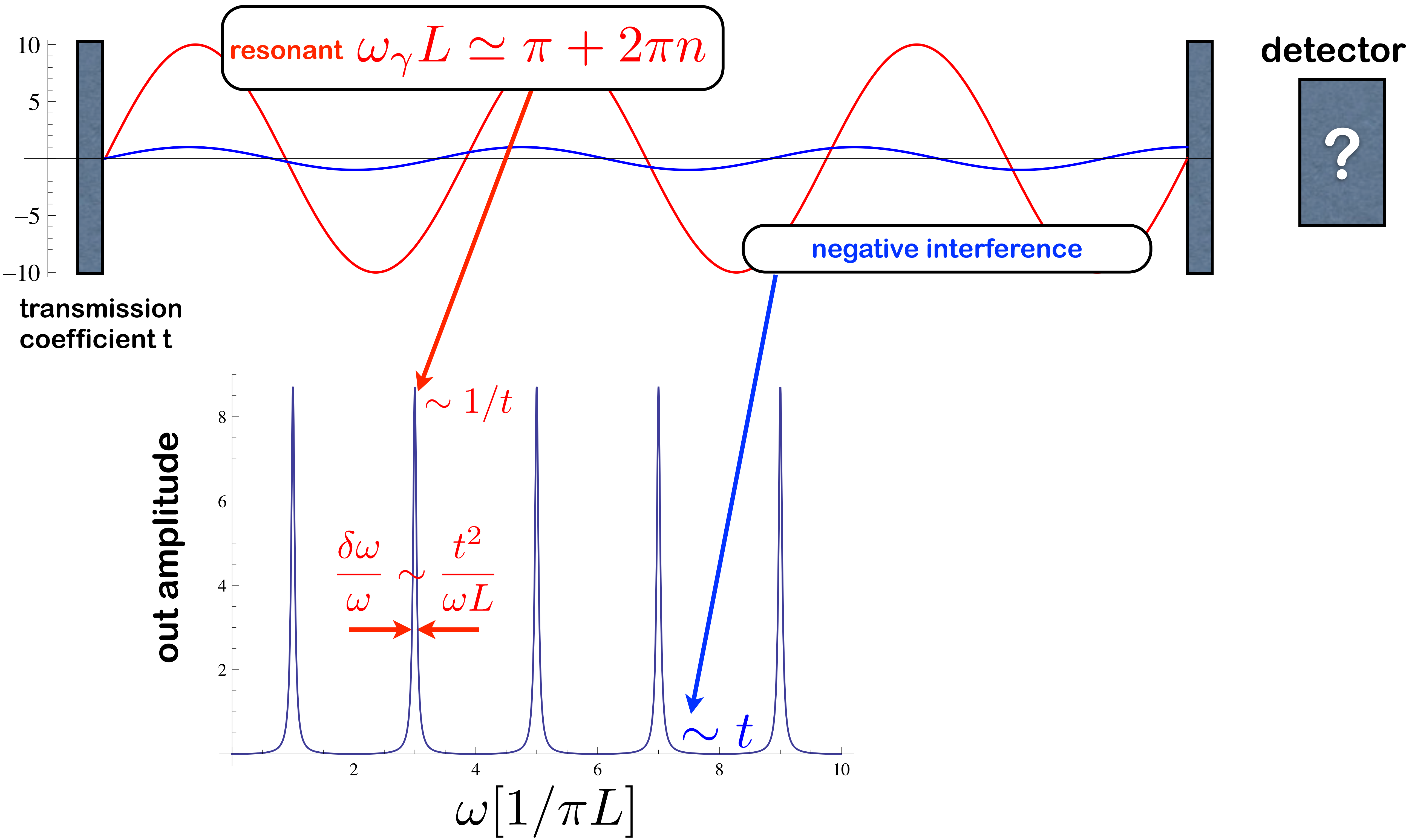

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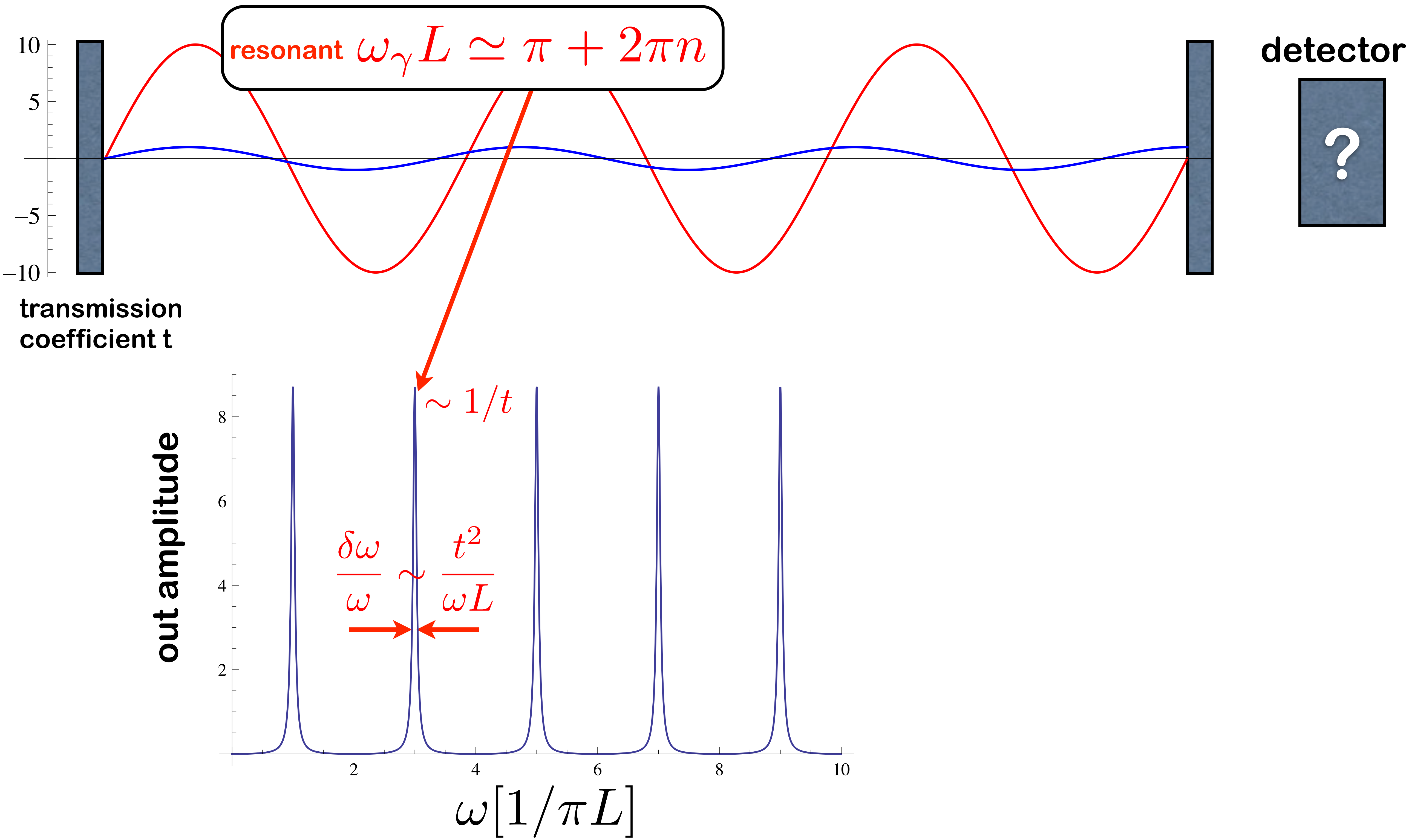

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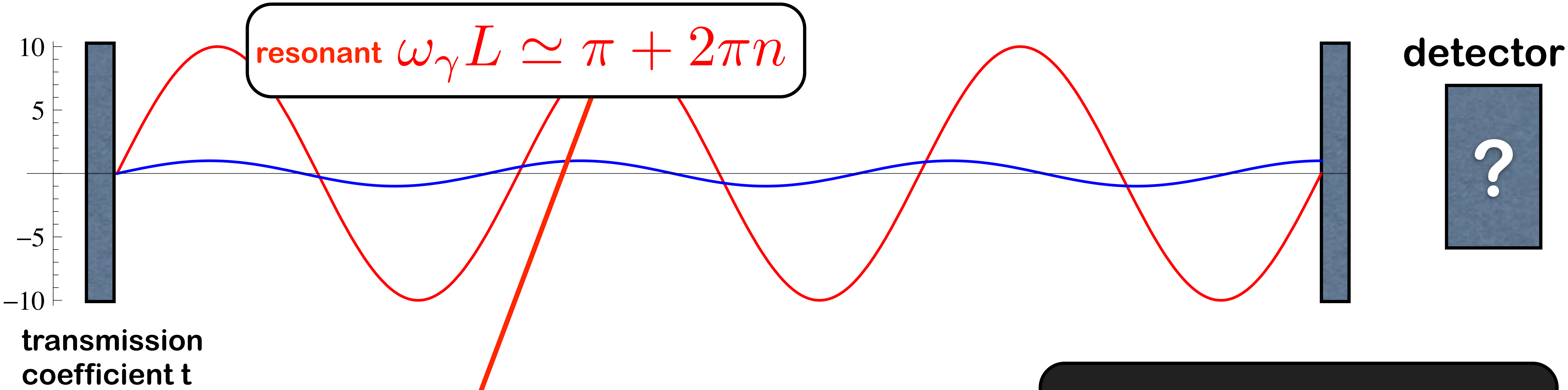

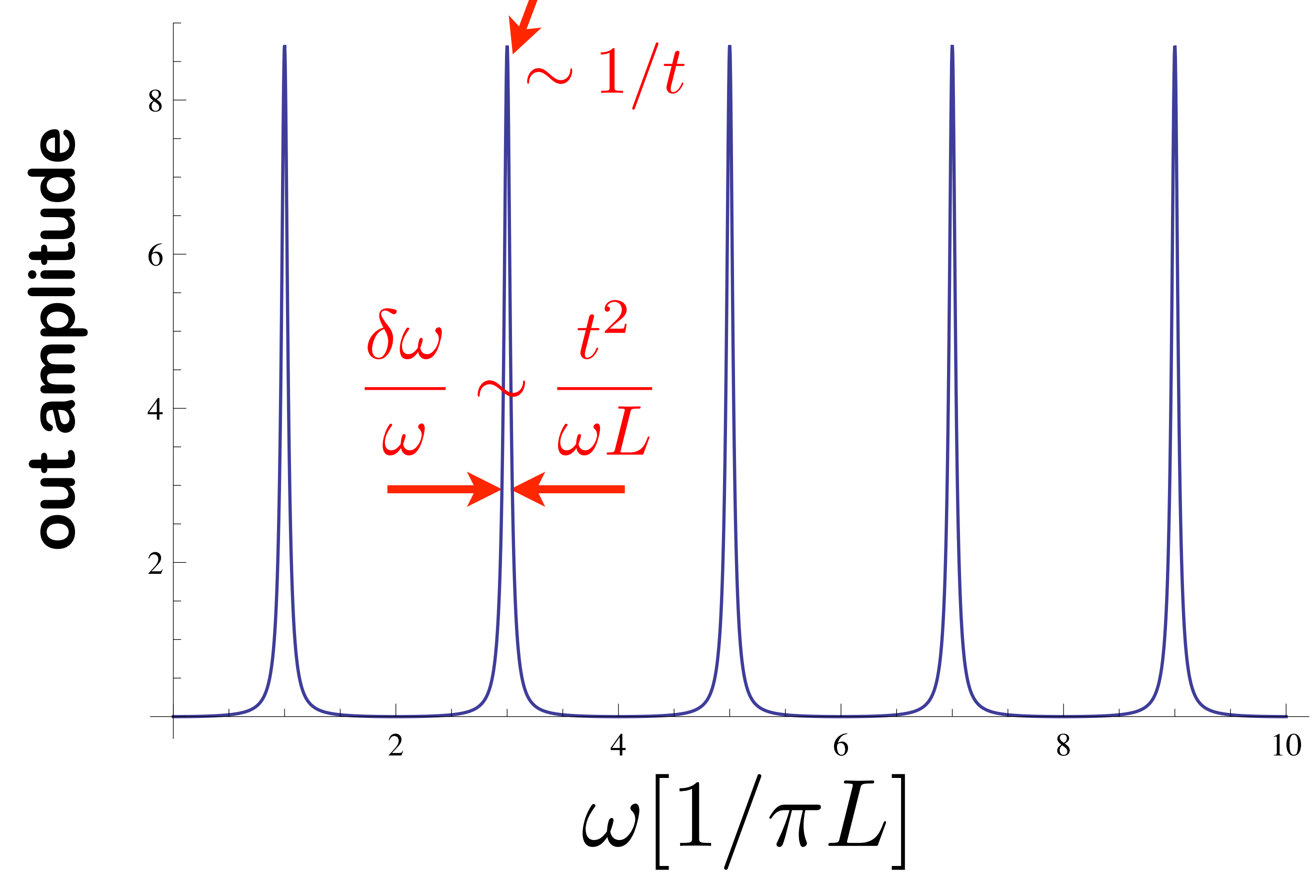

dark matter distribution

$$\frac{\delta\omega}{\omega} \sim \frac{v^2}{2} \sim 10^{-6}$$

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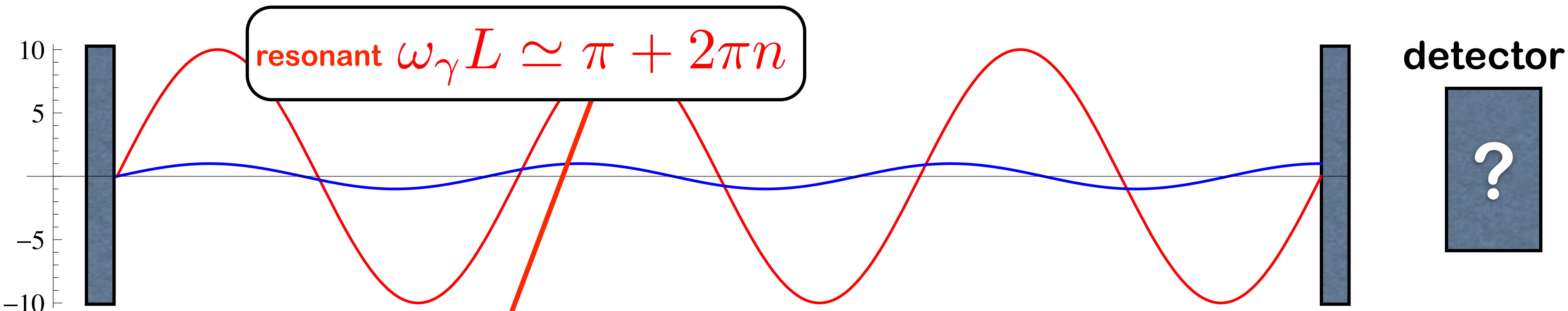
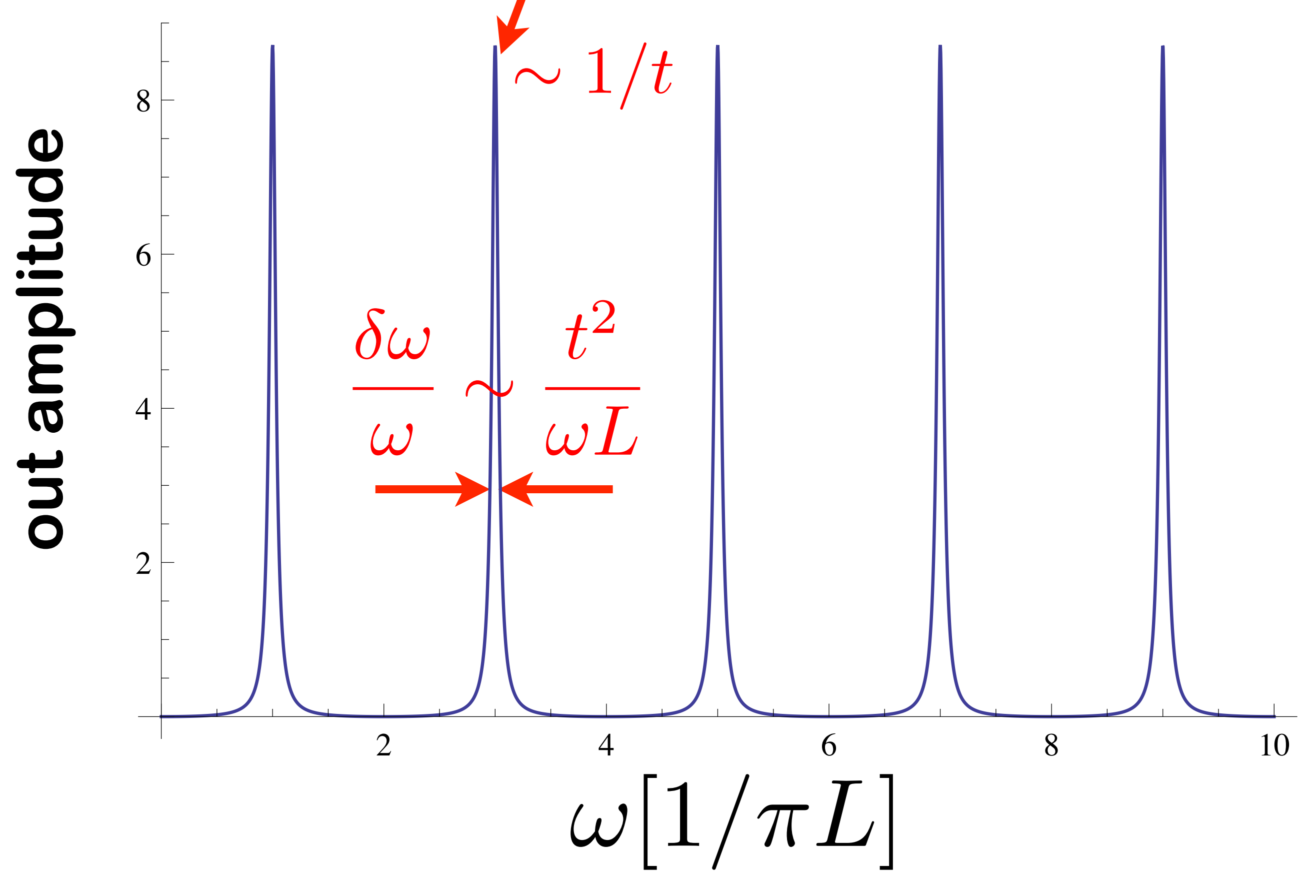


transmission coefficient t



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chose

$$m_a L = \pi$$

$1/t$ **large**

$$t^2 \sim 10^{-6}$$

cavity searches II: ADMX

http://www.phys.washington.edu/groups/admx/home.html

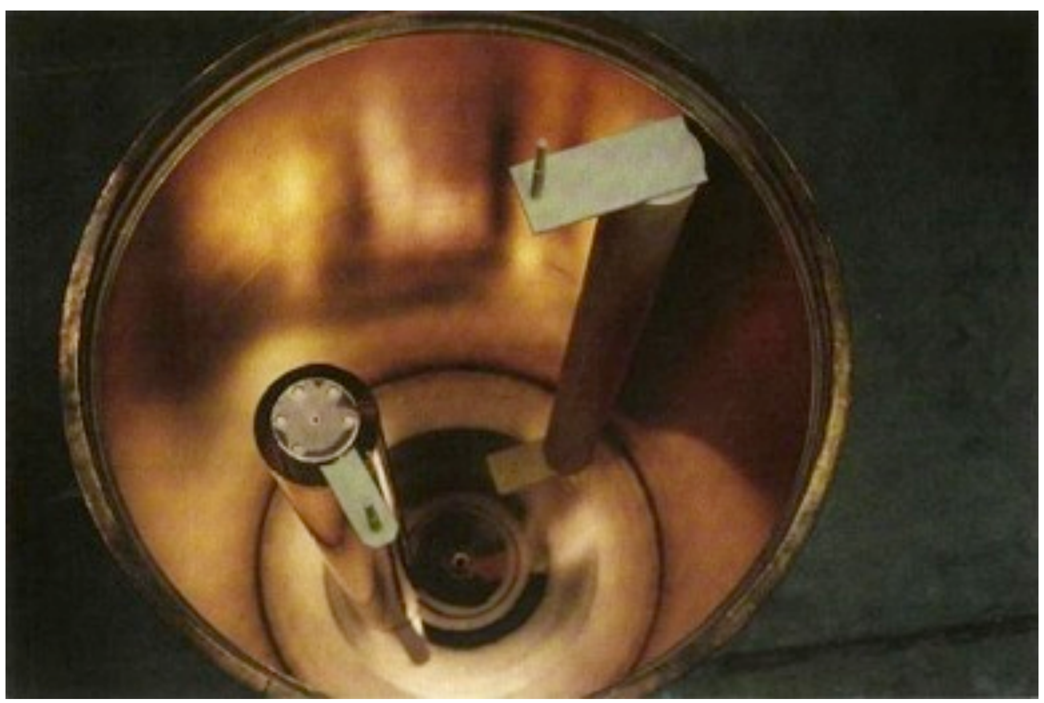
- Problem! We don't know the axion mass!!!!!!!!! $L = \pi/m_a?$

$$L_0, L_0 + \delta, L_0 + 2\delta, ..., L_0 + n\delta$$

slow scan, adjusting the length!

- ADMX (University of Washington) ...

(the 3D version is more complicated...)



8T field, 1mL,0.5mD

$$m_a \sim 1/L \sim \mu\mathrm{eV}$$

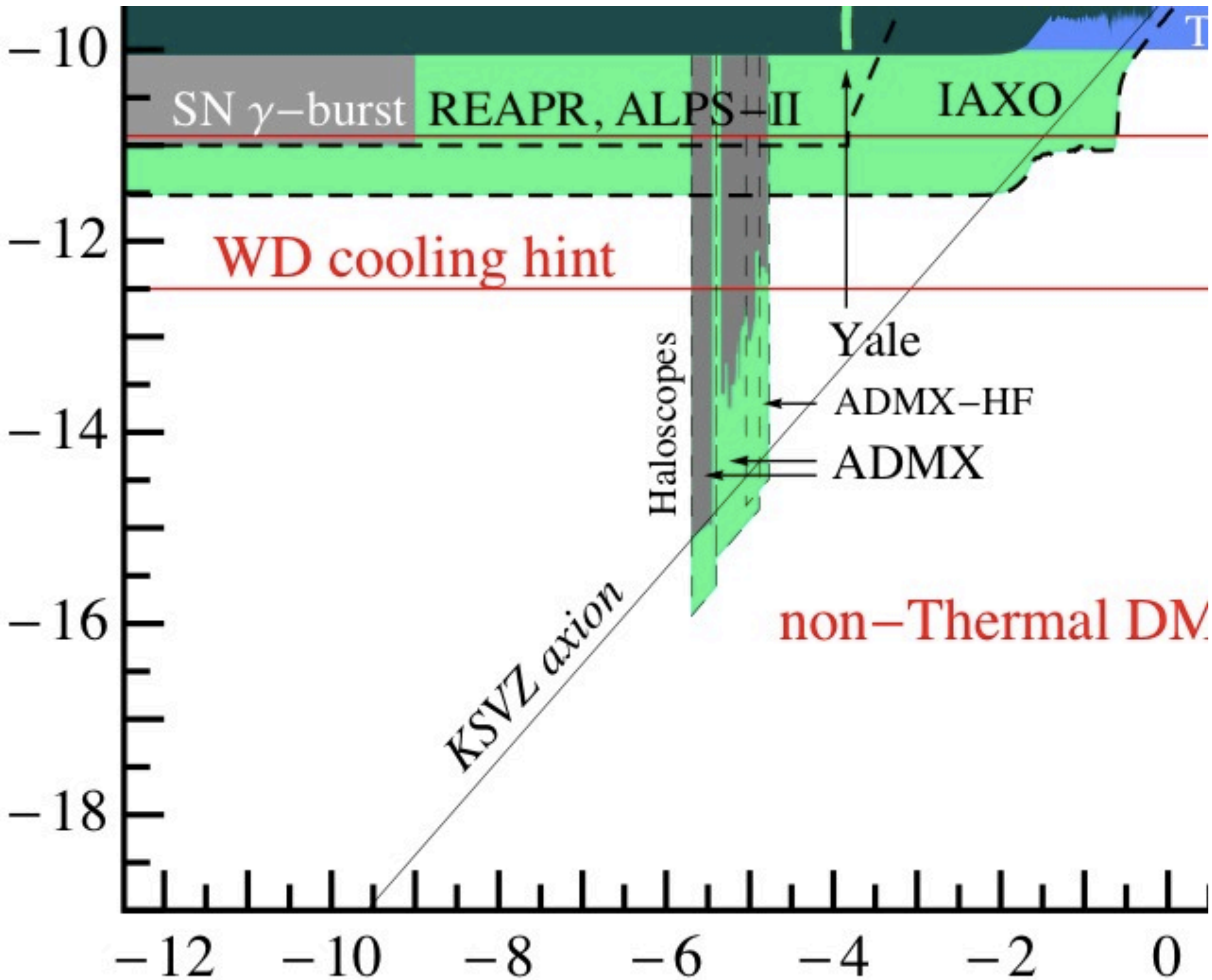
Once you have the right cavity ...
the only problem is detector noise

measurement time vs. different measurents

ADMX is now fighting to cool down
the cavity/amplifier to liquid 3He

the definitive experiment! ... ???

cavity searches II: ADMX and relatives



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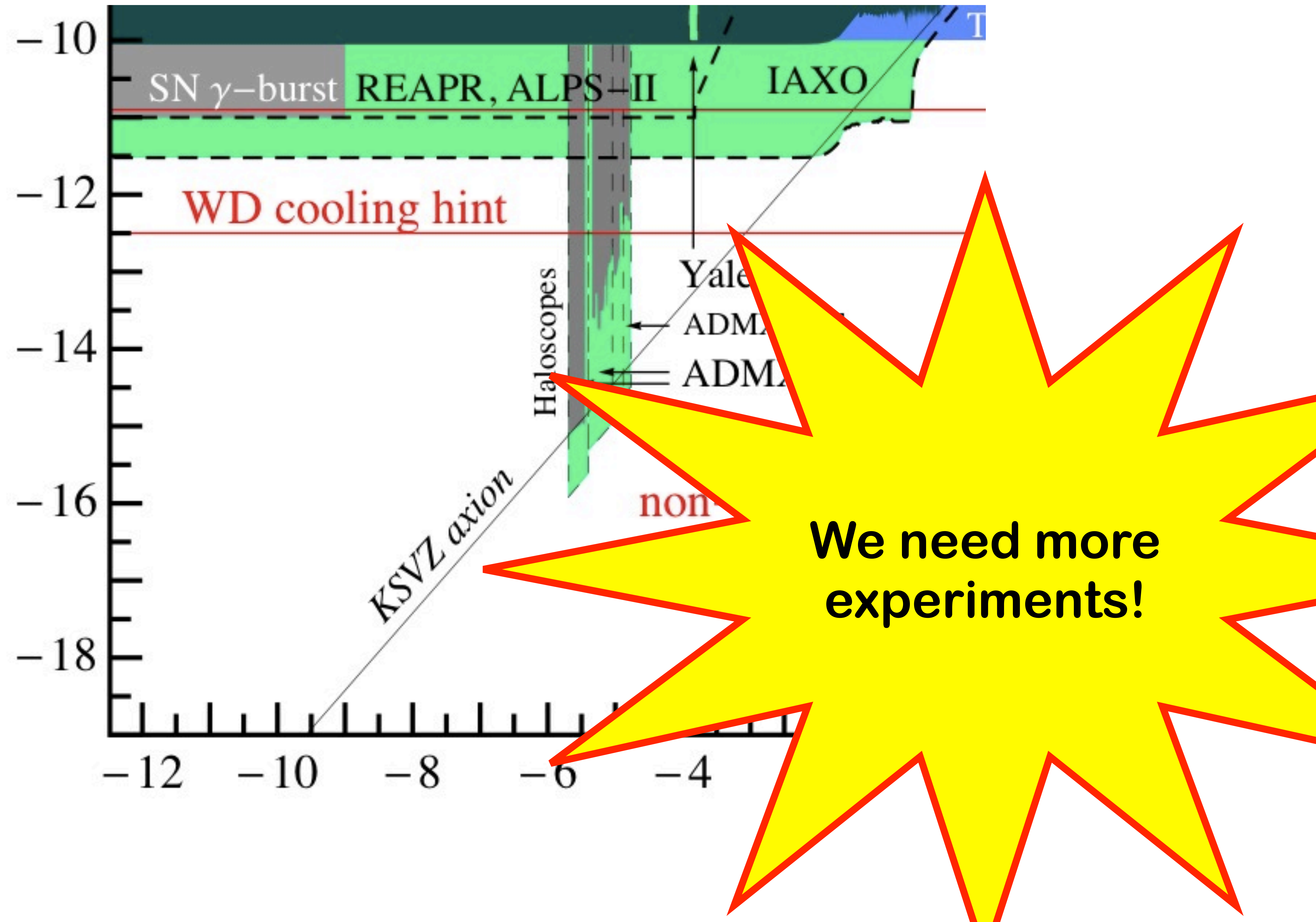
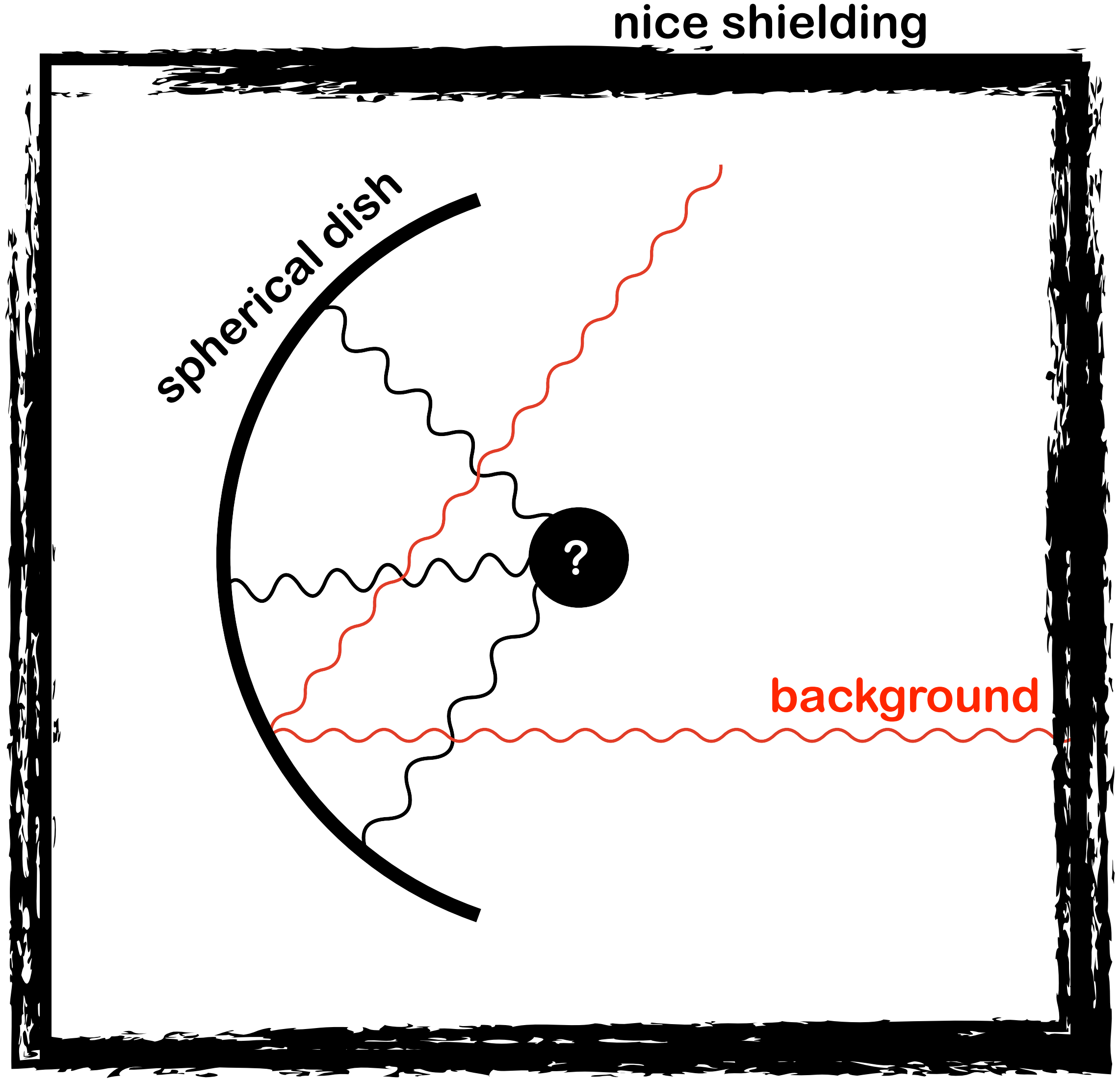


dish antenna searches (broadband!)

Horns et al, arXiv:1212.2970



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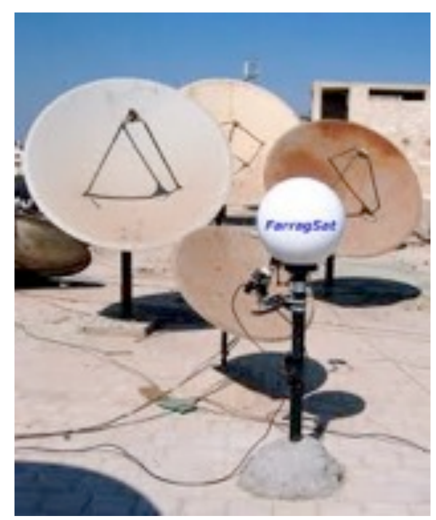
- concentrate emission using a spherical dish antenna!



Comparing both methods...

$$P_{\rm center} \approx A_{\rm dish} \langle |\mathbf{E}_{{\rm DM},||}|^2 \rangle \sim \chi^2 \rho_{\rm CDM} A_{\rm dish}$$

$$P_{\rm resonant\ cavity} = \kappa \chi^2 m_a \rho_{\rm CDM} Q V_{\rm cavity} \mathcal{G}_0 (\alpha')^2 .$$

$$\frac{P_{\rm center}}{P_{\rm cavity}} \sim \frac{A_{\rm dish} m_a^2}{10^6}$$

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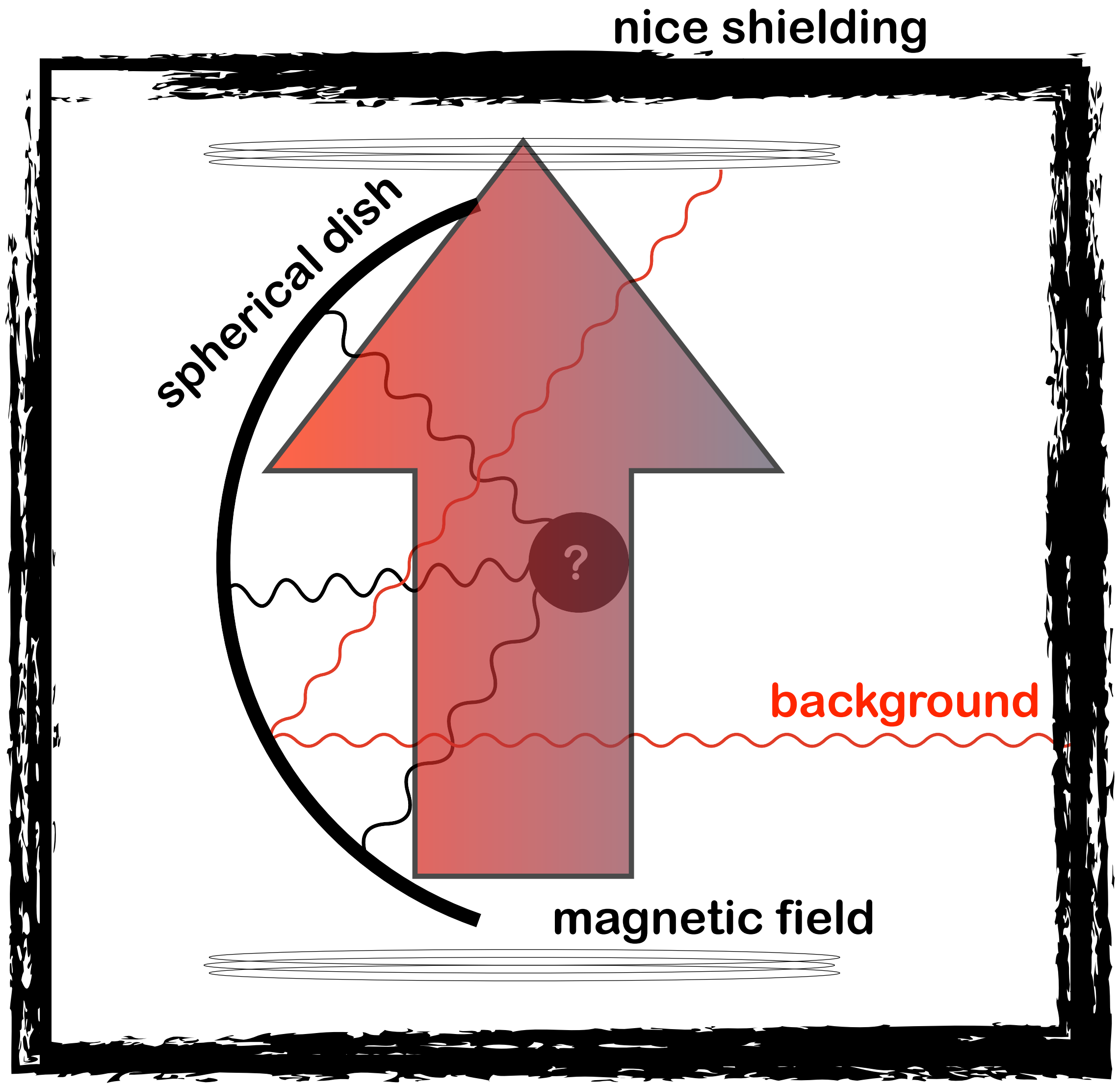

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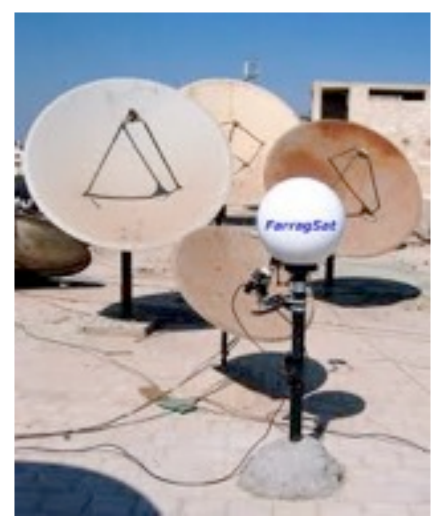

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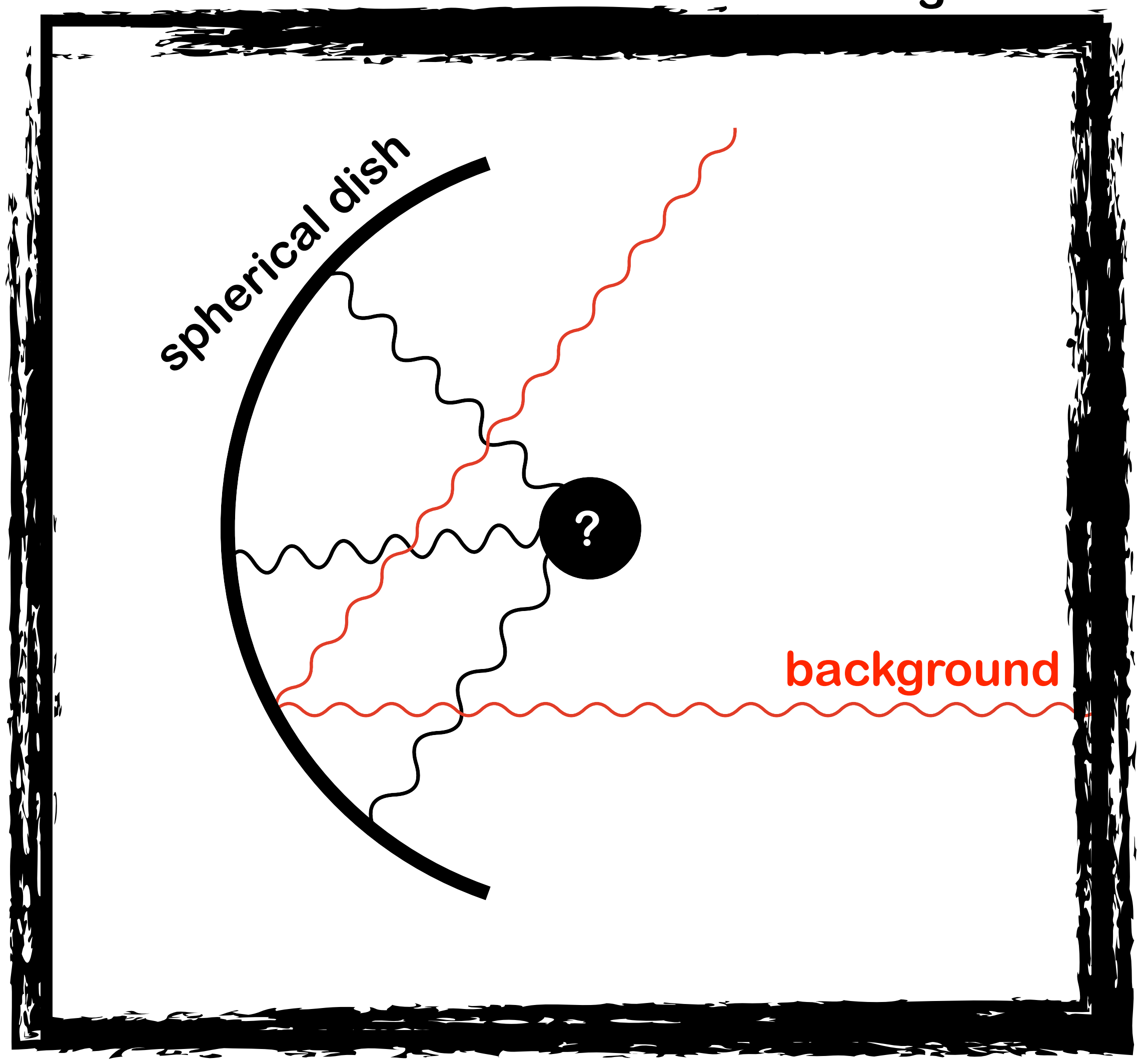

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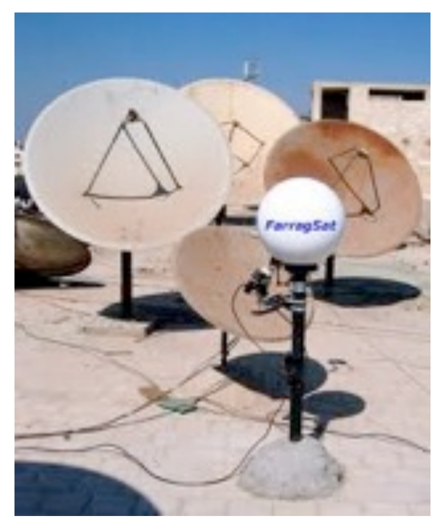

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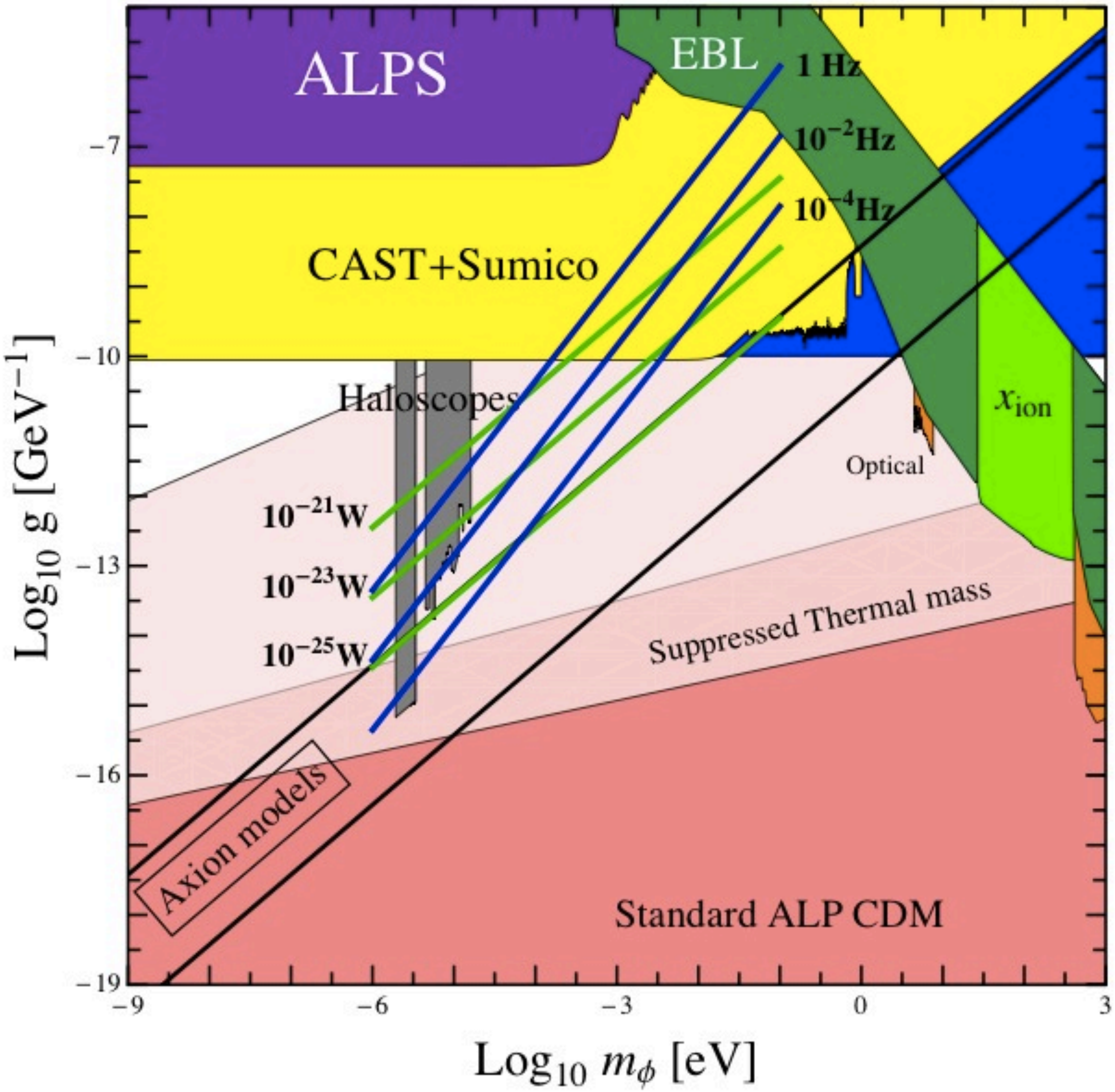


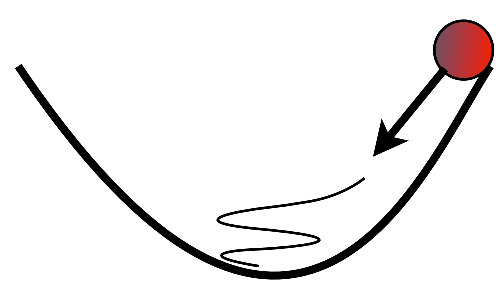
1 m^2 dish
5T magnet

to take home

- No nEDM, dark matter is there... axions?
- WISPy cold dark matter
- cavity experiments (ADMX) hunt in the micro-eV
- new experiments!
- higher masses are motivated, but difficult!
- new broadband proposal with dish antennas

Light Dark Matter: non-thermal relics

Any light boson features the realignment mechanism (like axions)



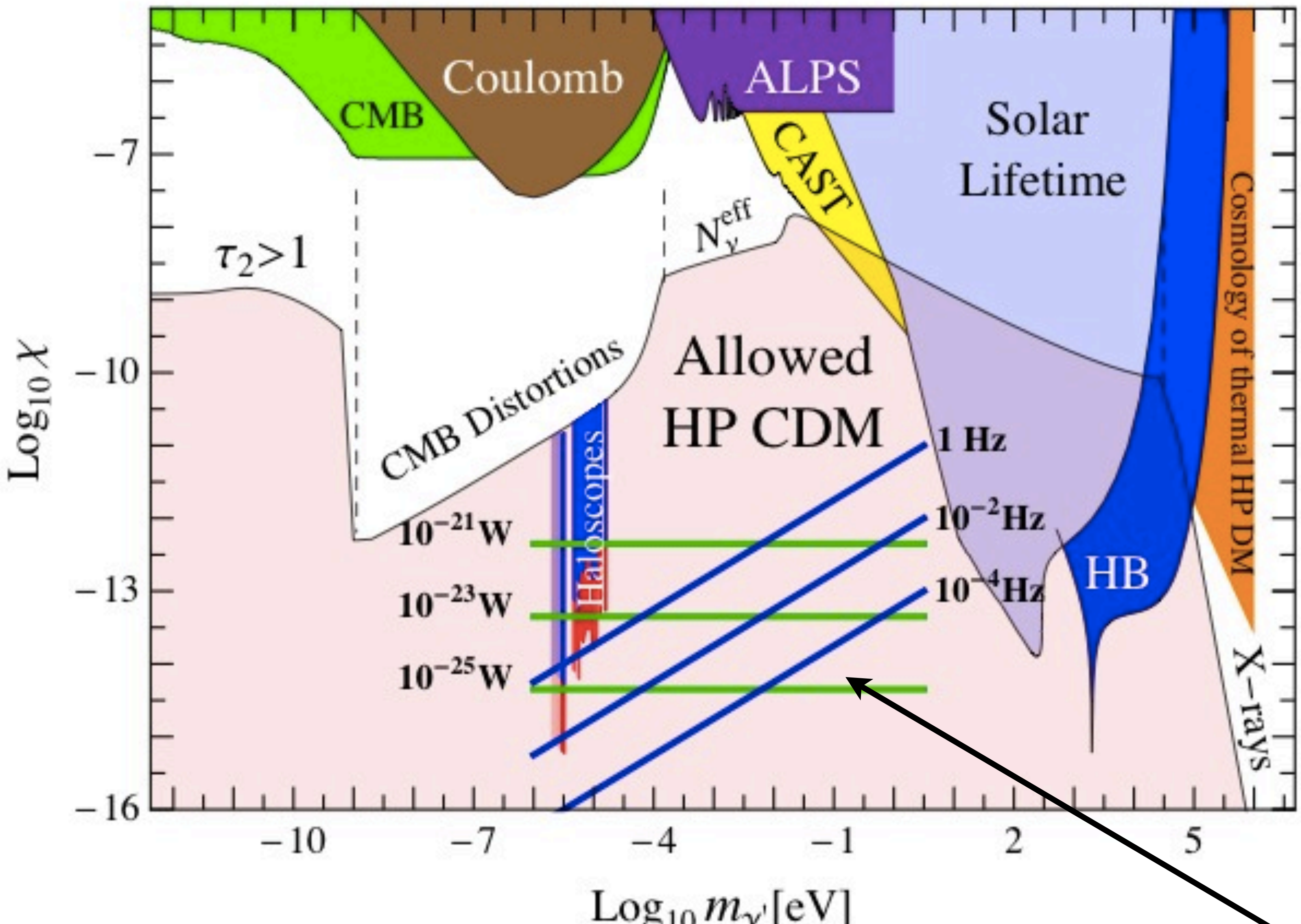
Hidden photons can be also Cold Dark Matter

Nelson et al, PRD84 ; Arias et al, JCAP 1206

dish antenna searches (broadband!)

Horns et al, arXiv:1212.2970

kinetic mixing



HP mass

1 m^2 dish
5T magnet