Resonant Conversion of Wave DM in the Ionosphere

arxiv : 2405.xxxxxx

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CAGE meet. Annecy, 21/05, Carl Beadle

ULDM : Ultra-Light Dark Matter

$$10^{-24}\mathrm{eV} \lesssim m_{\mathrm{DM}} \lesssim 1\mathrm{eV}$$

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$$10^{-9}\mathrm{eV} \lesssim m_{\mathrm{DM}} \lesssim 10^{-8}\mathrm{eV}$$

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Axions:

$$\mathcal{L} \supset -\frac{1}{4}\, g_{a\gamma\gamma}\, a\, F^{\mu\nu}\tilde{F}_{\mu\nu}$$

KM DPs:

$$\mathcal{L} \supset \frac{1}{2}\,\epsilon\, F^{\mu\nu} F'_{\mu\nu}$$

ULDM: Ultra-Light Dark Matter

We can treat both in a similar way!

One need only modify Maxwell's equations.

$$\mathcal{J}^{\nu}_{\text{eff}} \equiv -g_{a\gamma\gamma}\partial_{\mu}a\,\tilde{F}^{\mu\nu}$$

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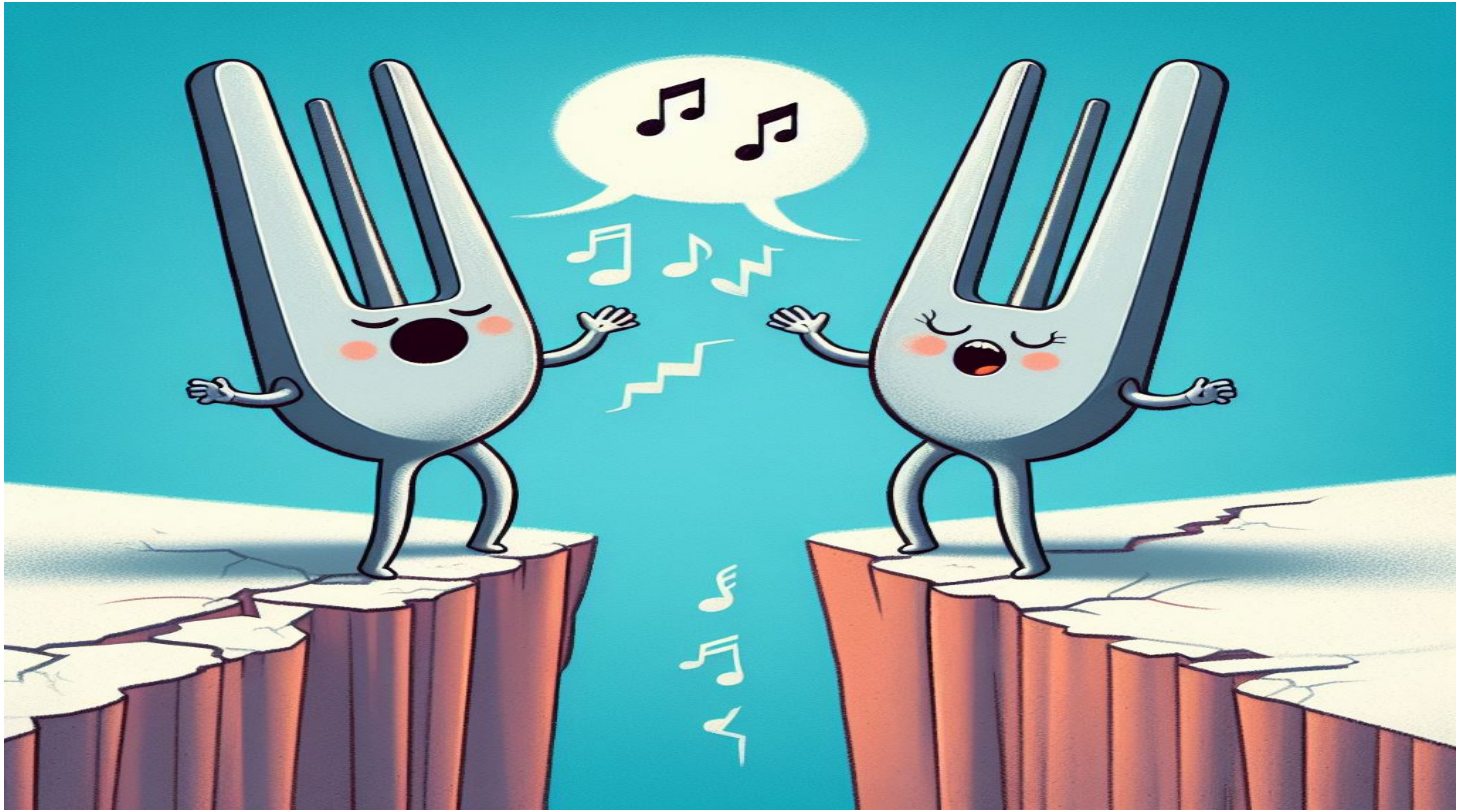
Low mass and requiring to be DM leads to high occupation number,

which allows us to use a classical treatment.

$$\begin{aligned} \nabla \cdot \mathbf{D} &= \rho + \rho_{\text{eff}}\,, & -\partial_t \mathbf{D} + \nabla \times \mathbf{H} &= \mathbf{J} + \mathbf{J}_{\text{eff}}\,, \\ \nabla \cdot \mathbf{B} &= 0, & \partial_t \mathbf{B} + \nabla \times \mathbf{E} &= \mathbf{0}. \end{aligned}$$

Typically, resonant conversions are used to overcome the small couplings.



Prop. : Use the ionosphere!

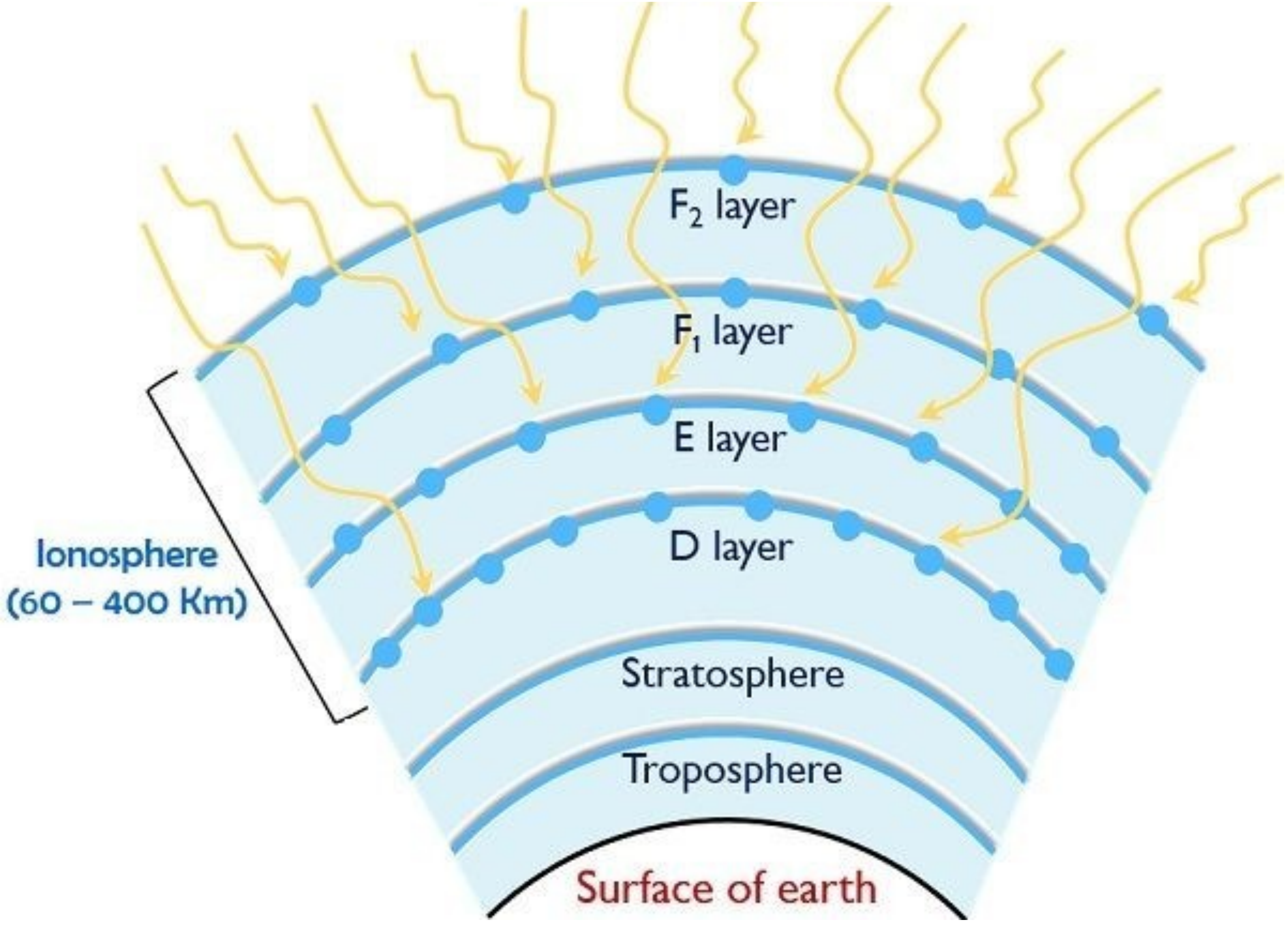
We have a natural resonator we can exploit.

Created by ionising UV & X-ray radiation.

Been known about for donkey's years.

(1839) ~ Gauss postulates existence.

(1901) ~ Marconi transatlantic radio signal (E-layer).



Sourced from: https://rifat-cou.medium.com/sky-wave-propagation-3bd094c73241

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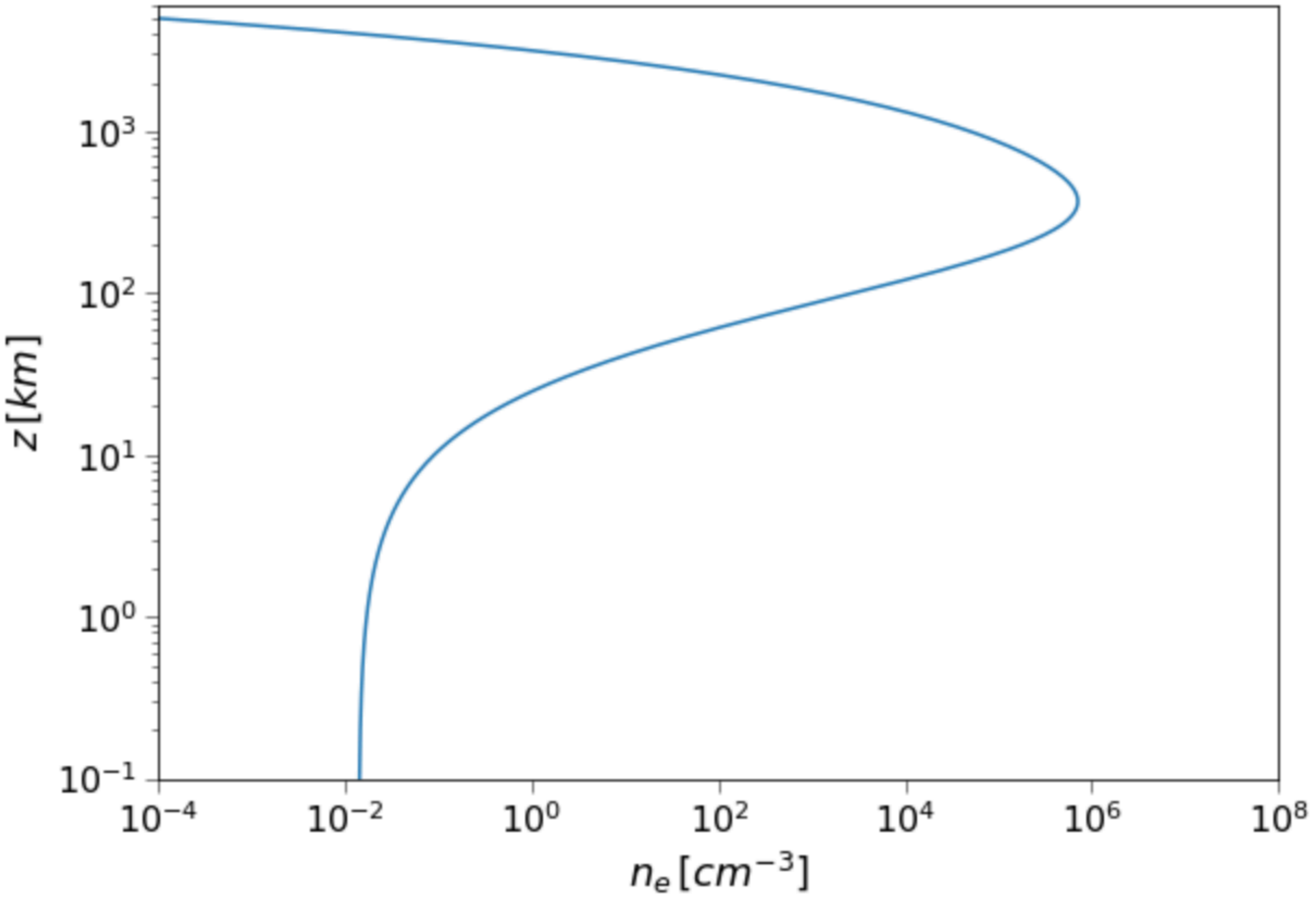
3) The electron number density follows a benchmark shape known as the Chapman profile



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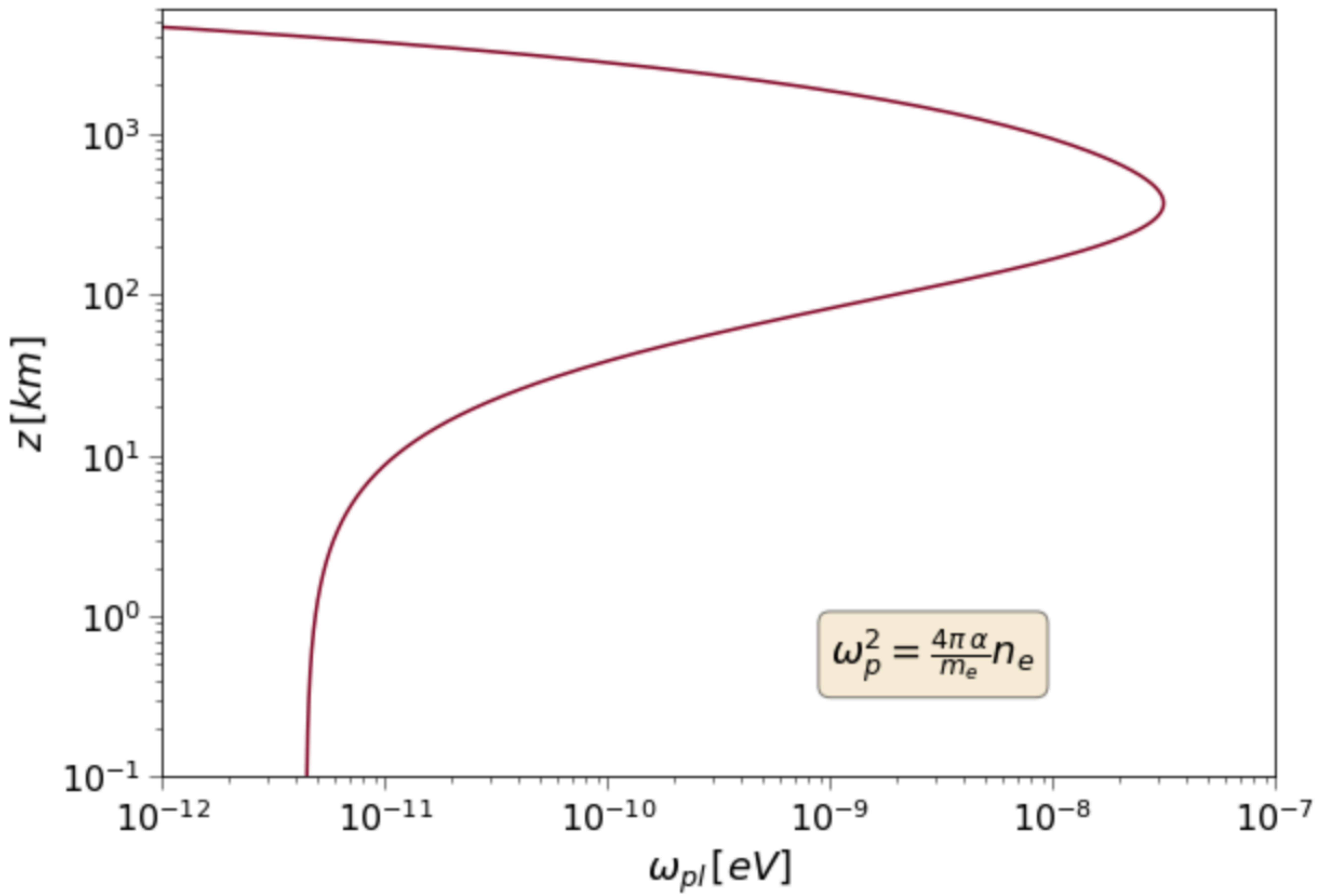
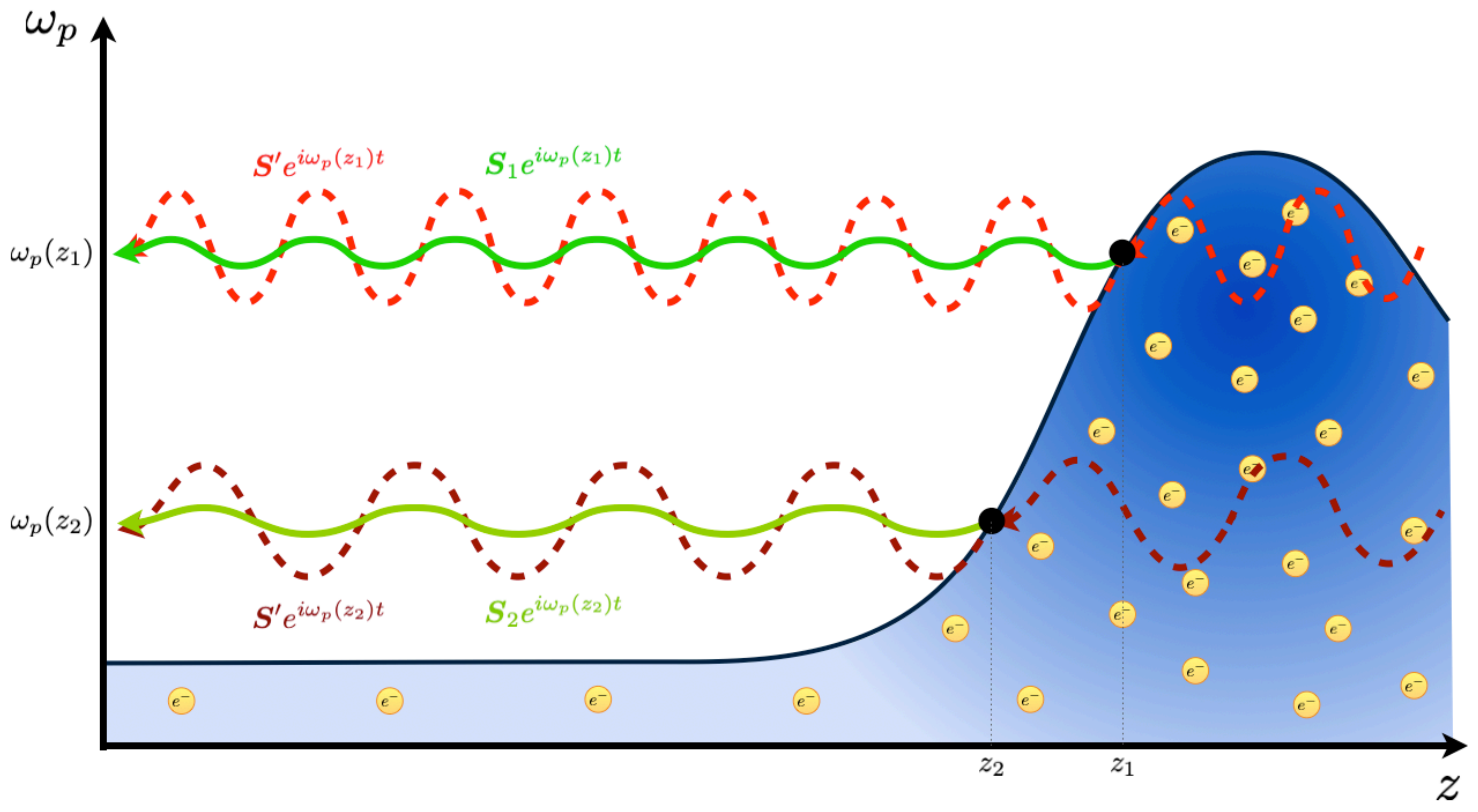


1D cavity



ω_p
$\boldsymbol{S}'e^{i\omega_p(z_1)t}$
$\boldsymbol{S}_1 e^{i\omega_p(z_1)t}$
$\omega_p(z_1)$
$\omega_p(z_2)$
$\boldsymbol{S}'e^{i\omega_p(z_2)t}$
$\boldsymbol{S}_2 e^{i\omega_p(z_2)t}$
z_2
z_1
z

1D cavity

We can treat the ionosphere and Earth system as a driven cavity

$$\left[\nabla^2 + \omega^2 \left(1 - \frac{1}{\omega^2 + i\nu\,\omega}\,\omega_p^2\right)\right]\mathbf{E}_T = i\,g_{\rm eff}\,m_{\rm DM}^2\,\omega\,\mathbf{V}$$

Axion:

$$g_{\rm eff} = g_{a\gamma\gamma}\,|\mathbf{B}_T|/m_a$$

$$\mathbf{V} = a\hat{\mathbf{B}}_T$$

DP:

$$g_{\rm eff} = \epsilon$$

$$\mathbf{V} = \mathbf{A}'_T$$

1D cavity

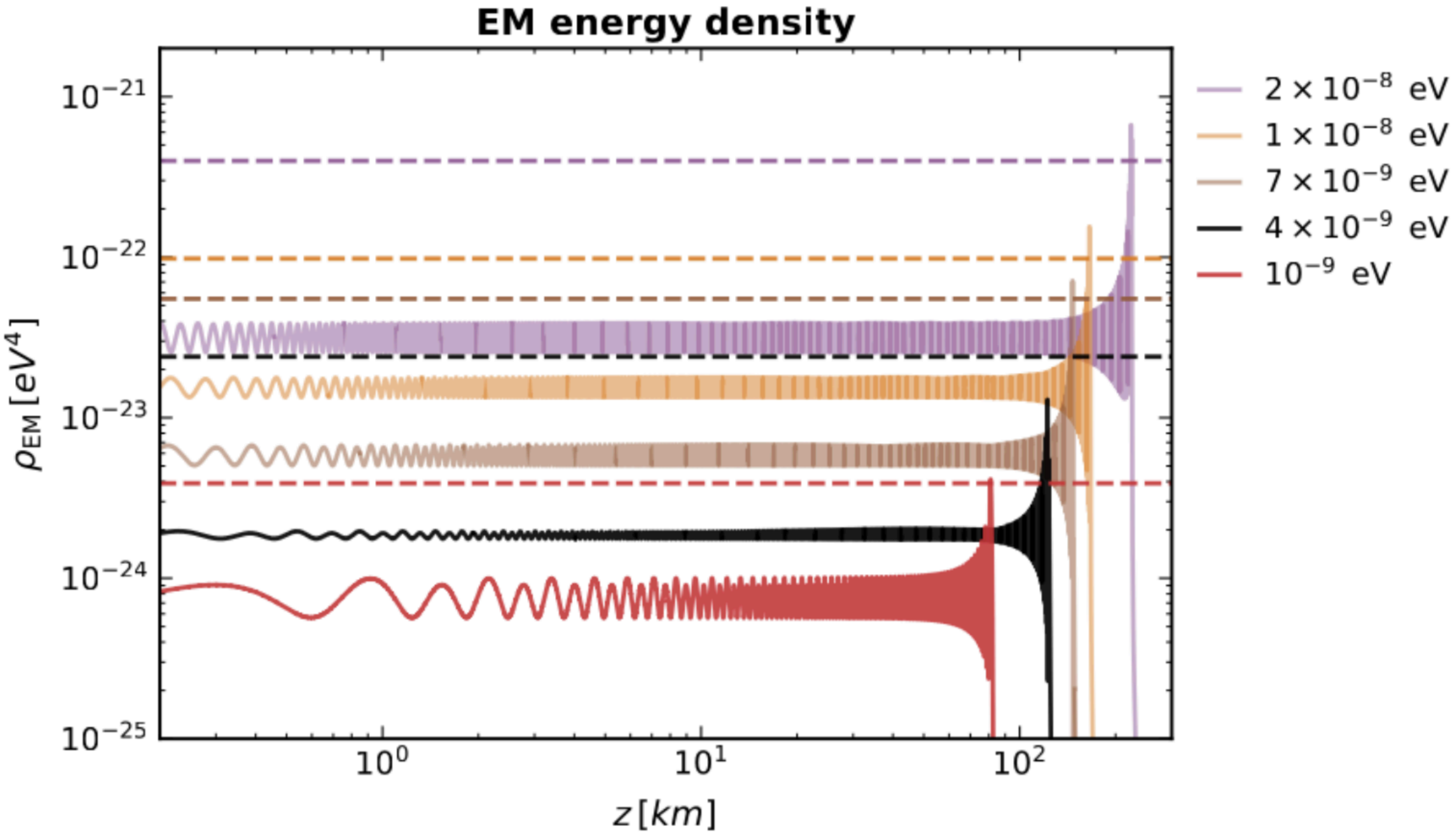
Little to no scale separation in this problem …

The characteristic scale of variation of the plasma is comparable to the dB wavelength of the DM, almost everywhere …

$$\left|\frac{\partial \log \omega_p^2}{\partial z}\right|^{-1} \gtrsim H \sim \lambda_{\rm dB}$$

Means that a numeric solution is the best way forward

1D cavity

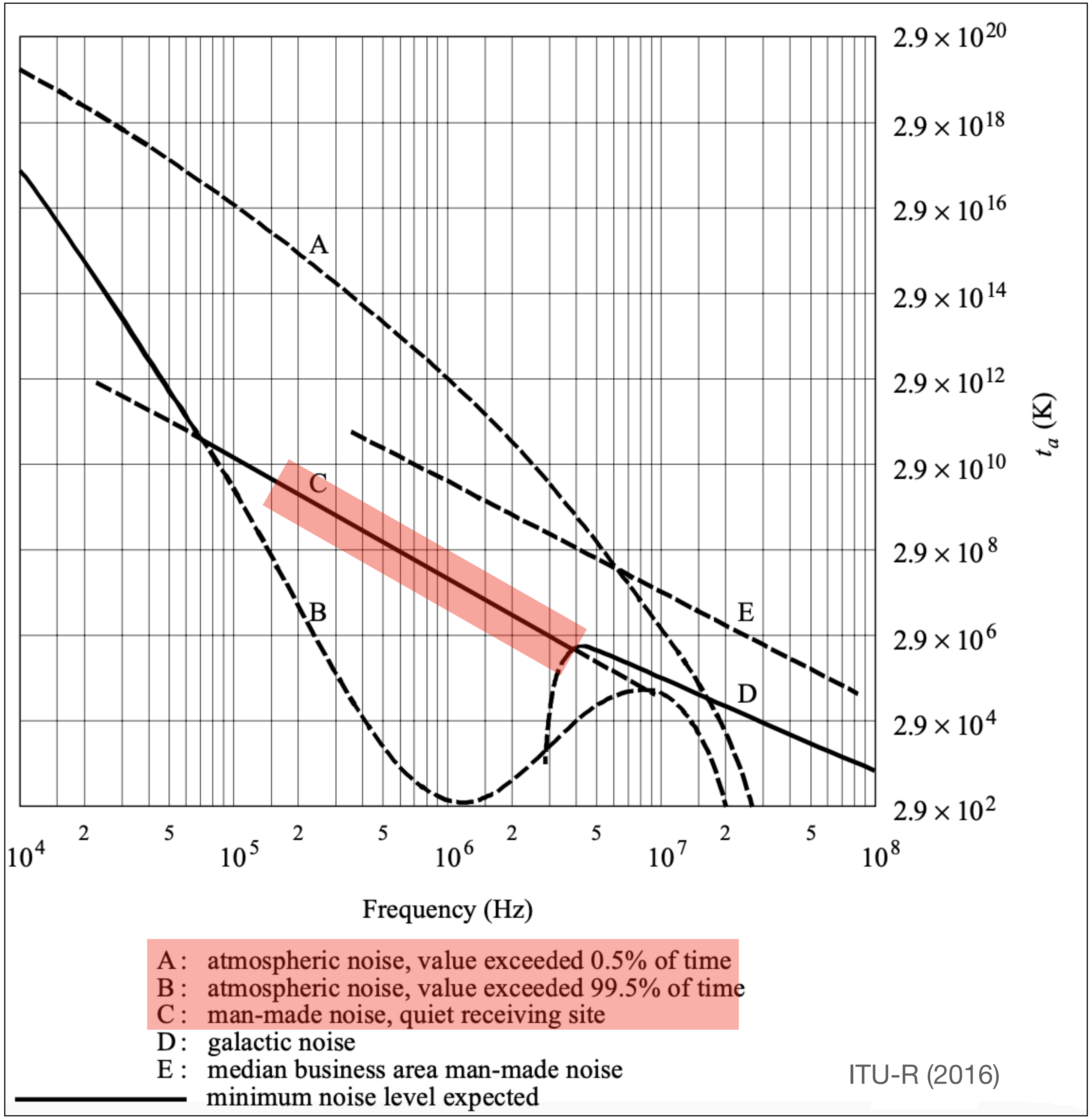


EM energy density
$\rho_{EM}\,[eV^4]$
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{0}
10^{1}
10^{2}
$z\,[km]$
2×10^{-8} eV
1×10^{-8} eV
7×10^{-9} eV
4×10^{-9} eV
10^{-9} eV

Noise

Noise

ITU provides us with estimates for our noise



ITU-R (2016)

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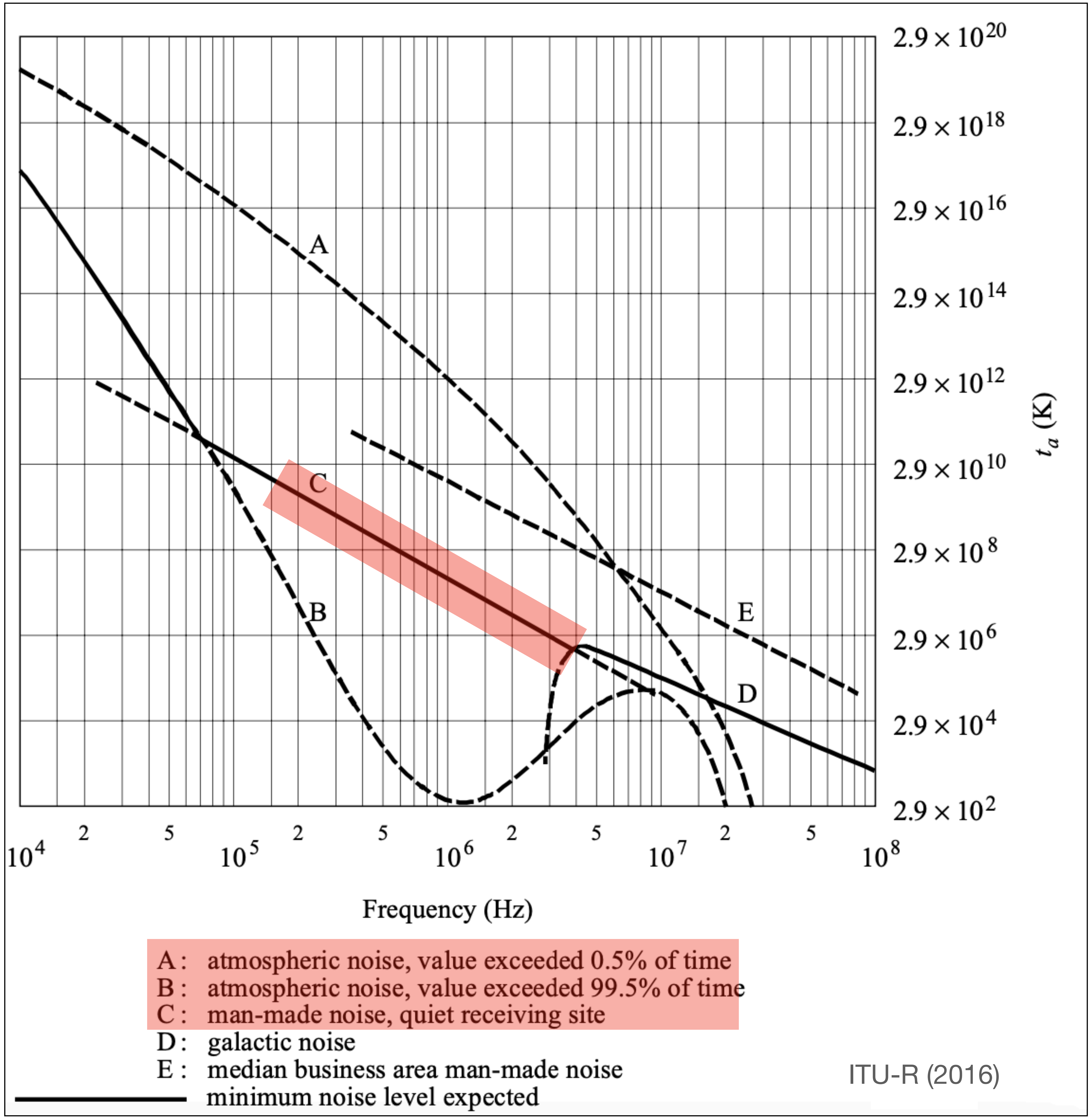
$$10^5\,\mathrm{K} \lesssim T_n \lesssim 10^9\,\mathrm{K}$$



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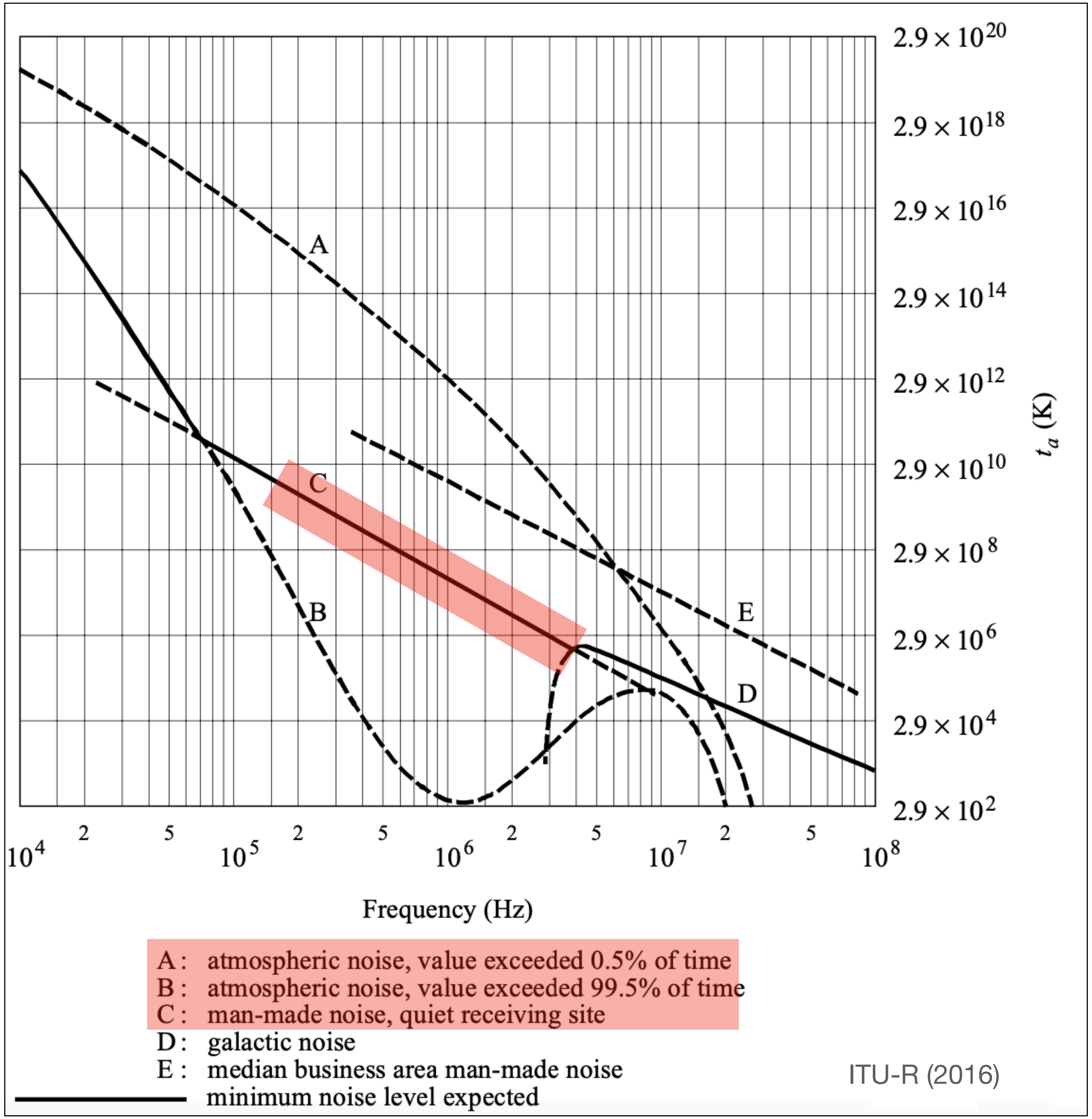
We can map from temperature to a noise PSD using:

$$S_n(\nu) \approx \frac{32}{3}\pi^2\,\nu^2\,T_n(\nu)$$



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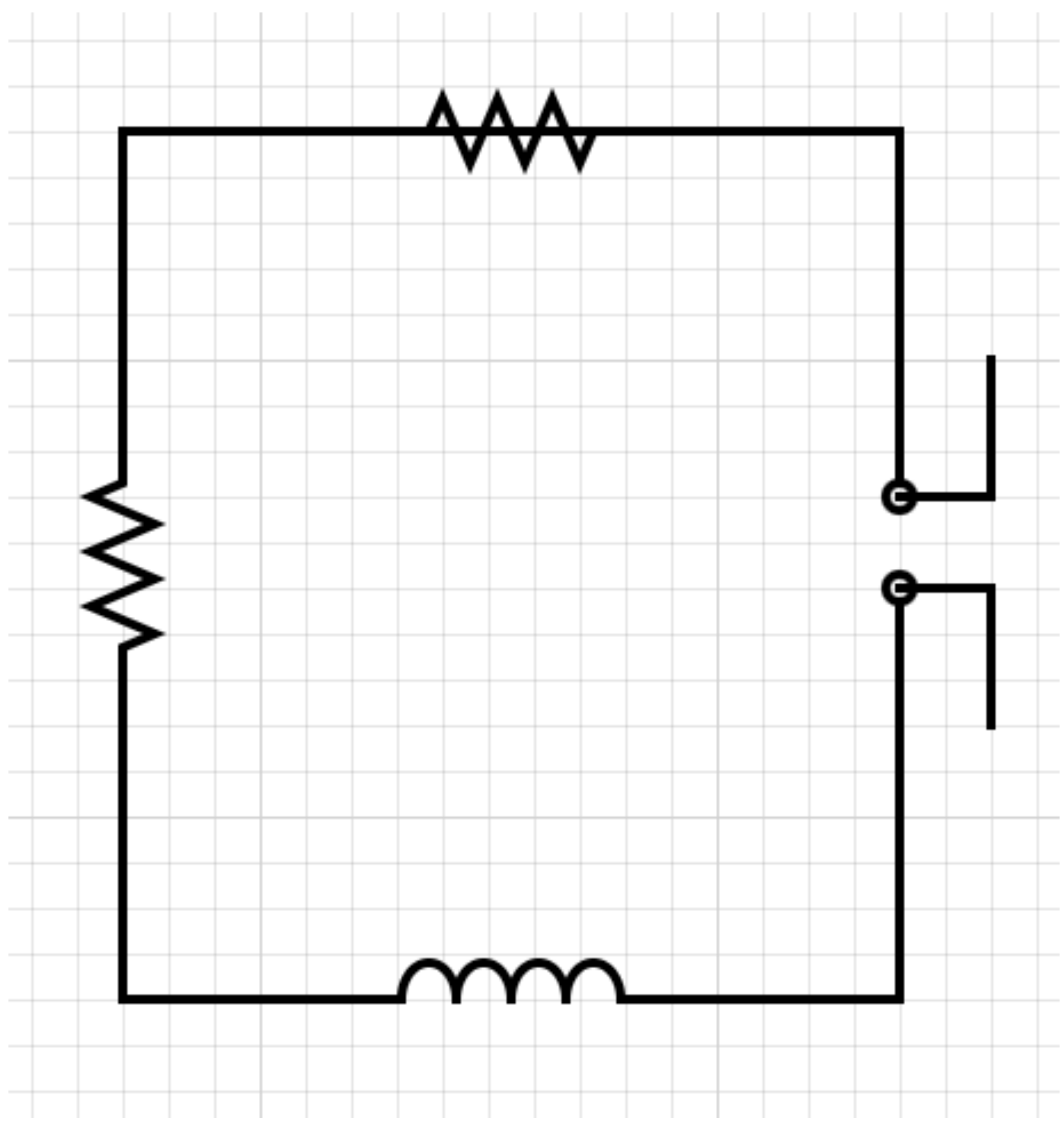
Antenna: Electrically short dipole antenna

We model a prospective antenna and read-out as a simple RLC-circuit



$$P_L = \int \mathrm{d}\omega \, \frac{\omega^2 \, h^2}{R_L \, L^2 \, \left[\left(\omega^2 - \omega_0^2\right)^2 + \omega^2 \, \Delta\nu^2\right]} S_E\left(\omega\right)$$

$$\omega_0^2 \equiv \frac{1}{C_A L}$$

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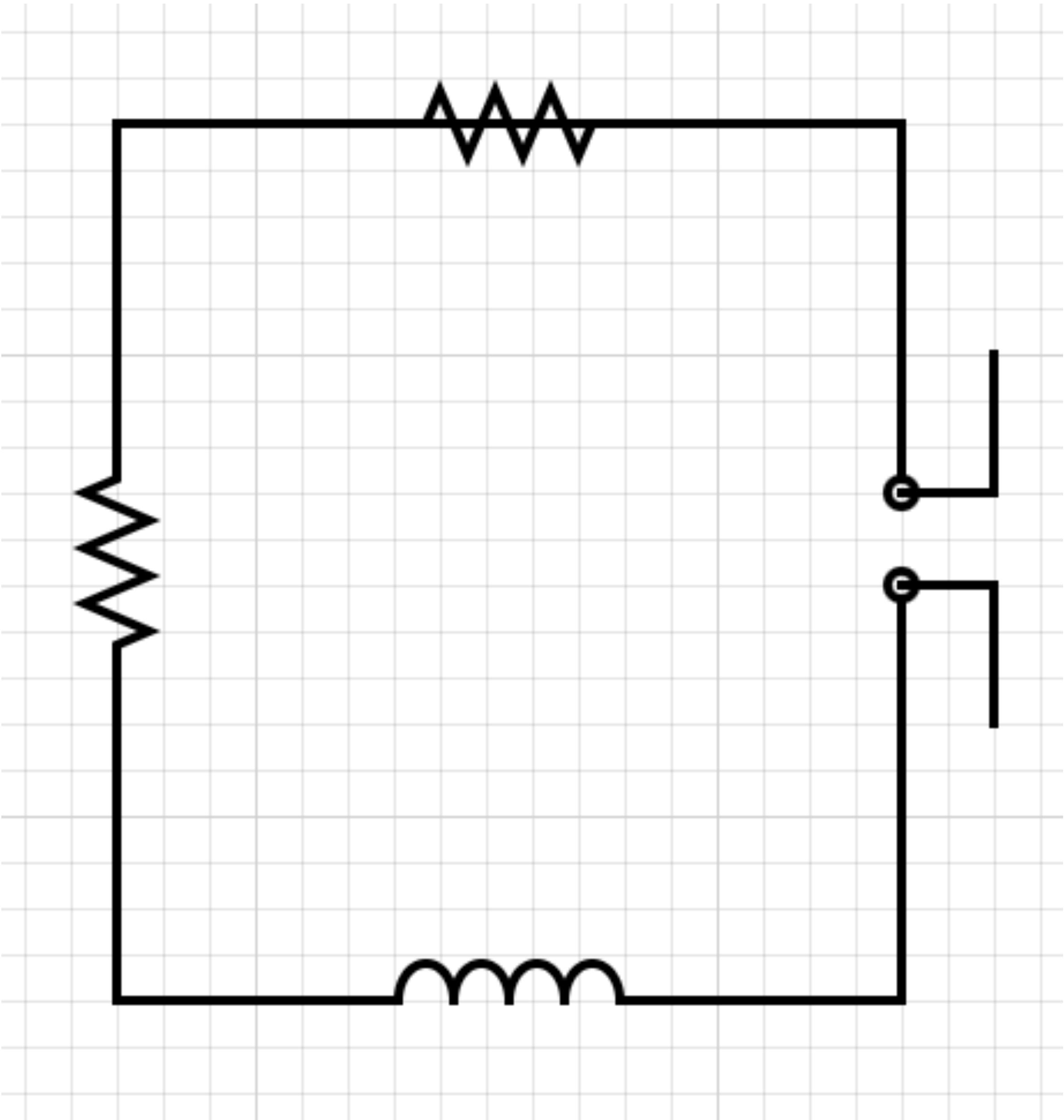

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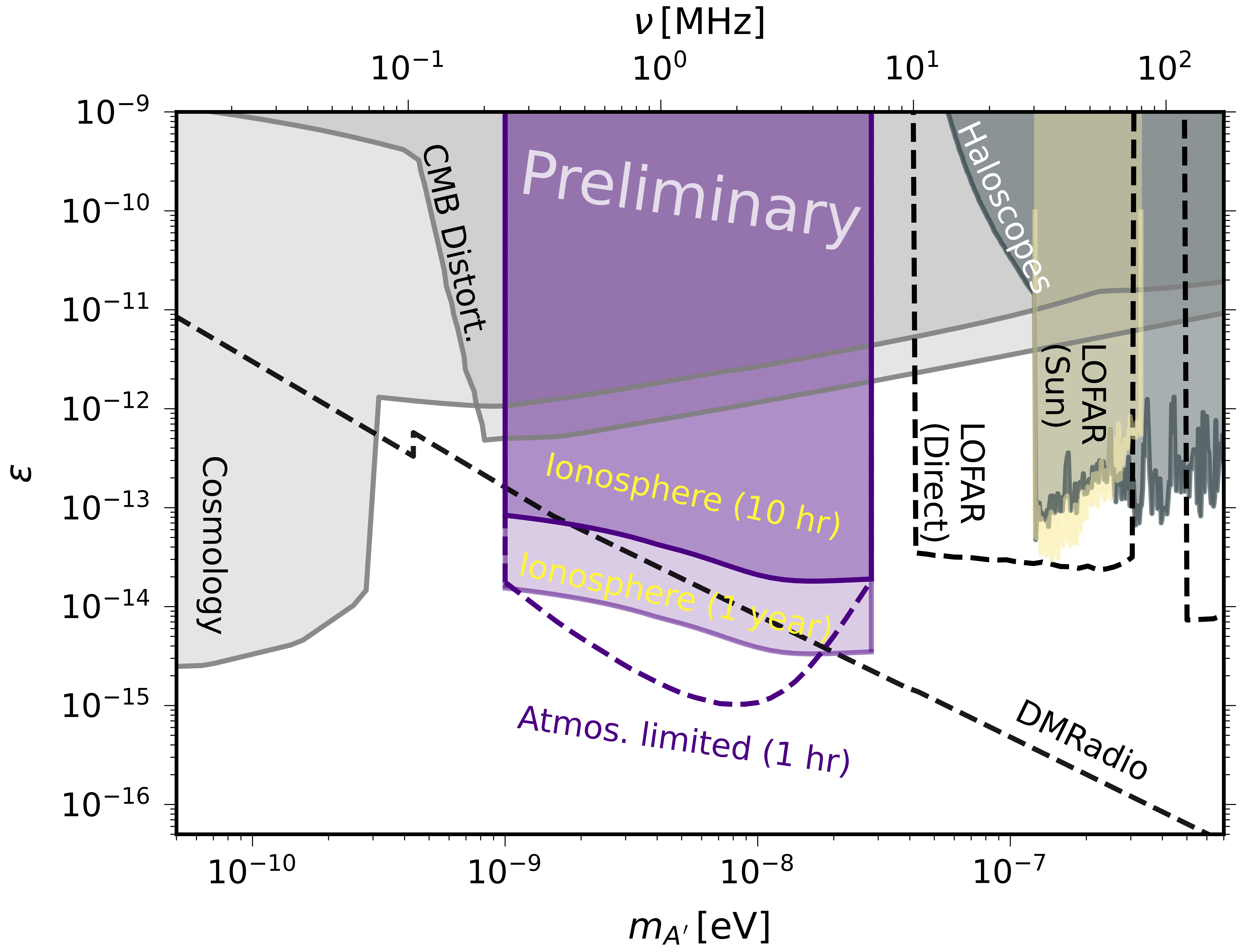
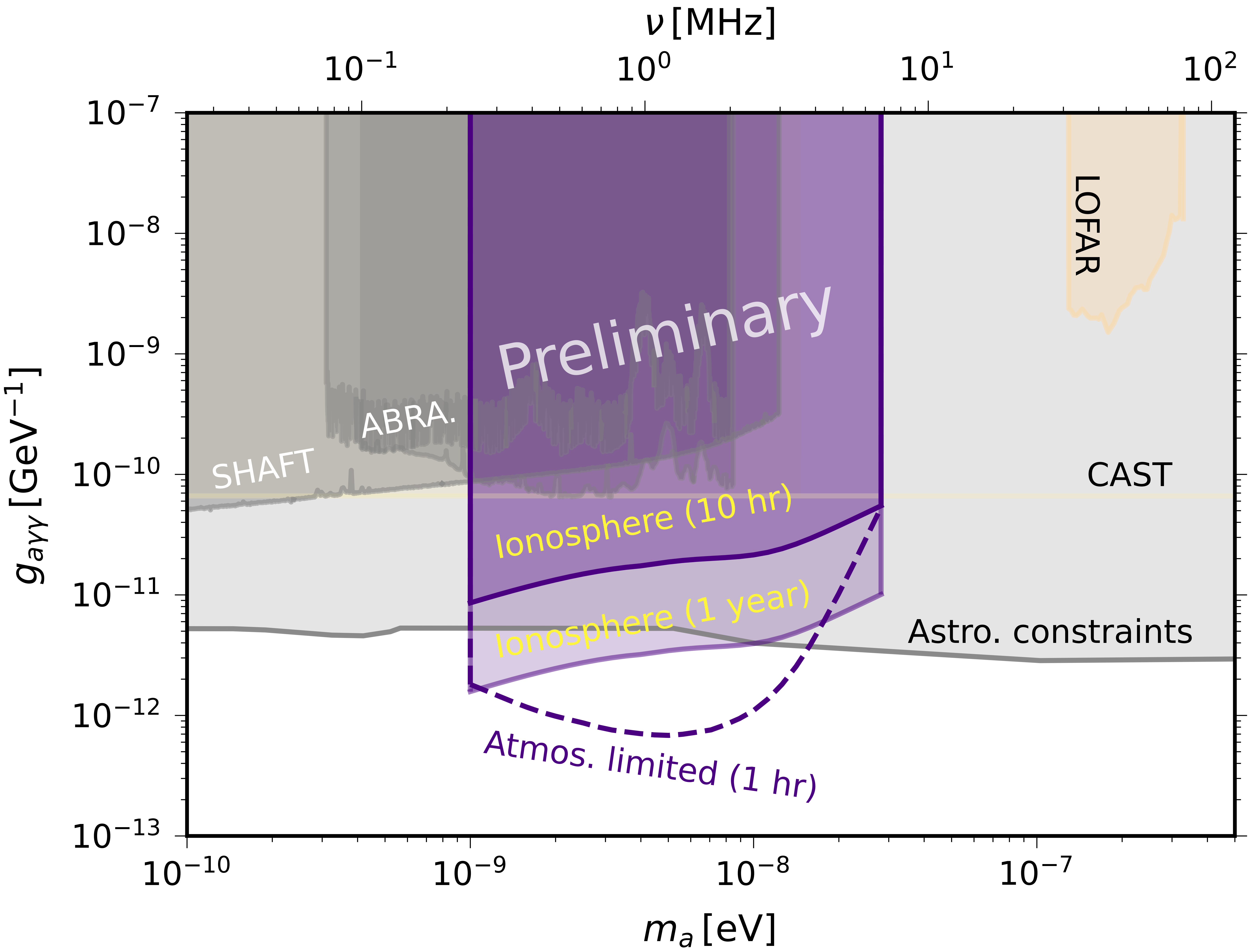
$$\mathrm{SNR} = \left[t_{\mathrm{int}} \int_0^\infty d\nu \left(\frac{\mathcal{S}_{\mathrm{Sig}}}{\mathcal{S}_{\mathrm{N}}} \right)^2 \right]^{1/2}$$

Projections : DP



Projections : Axions



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Thanks for listening!