Ultra-Light Hidden-Photon Dark Matter

or

How to listen to DM on the radio

work in progress with:

Peter Graham, Surjeet Rajendran & Yue Zhao

and experimental collaborators:

Kent Irwin, Saptarshi Chaudhuri

Jeremy Mardon, SITP, Stanford

OUTLINE

1. Ultra-light hidden photons

2. Ultra-light hidden photons as DM today

3. Searching for DM with a radio in a Faraday cage

4. Generating the DM abundance (preliminary)

ULTRA-LIGHT HIDDEN PHOTONS

Jeremy Mardon, SITP, Stanford

"ULTRA-LIGHT HIDDEN PHOTONS"

Hidden Photons:

Kinetically-mixed, massive, $U(1)'$ gauge boson A':

$$\mathcal{L} = \mathcal{L}_{SM} - {}^{1}\!/_{4}\, F'^{\,2} - 2\varepsilon F_{\mu\nu} F'^{\mu\nu} + {}^{1}\!/_{2}\, m_{A'}^{2} A'^{\,2}_{\mu}$$

gauge kinetic term

naturally small coupling to SM via kinetic mixing with photon

technically natural small mass

Ultra-light:

Macroscopic Compton wavelength

$$\lambda_{Compton} = 1\ \mathrm{m} \times (10^{-6}\ \mathrm{eV}/m_{A'})$$

A THOUGHT ON TINY MASSES

$$\lambda_{Compton} = 1\ \mathrm{m} \times (10^{-6}\ \mathrm{eV}/m_{A'})$$

How to generate $m_{A'} \lesssim 10^{-6}$ eV ?

Stuckelberg mass vs. **Higgs mechanism**

— $m_{A'}$ generated at string scale

— $m_{A'}$ generated dynamically
— New hidden sector particles
— Decouple as $g_D \to 0$

WHAT DOES THIS NEW FIELD DO?

Lagrangian is not diagonal

$$\mathcal{L} = \mathcal{L}_{SM} - {}^1/_4 F'^2 - 2\varepsilon F_{\mu\nu} F'^{\mu\nu} + {}^1/_2 m_{A'}^2 A'^2_\mu$$

Diagonalize

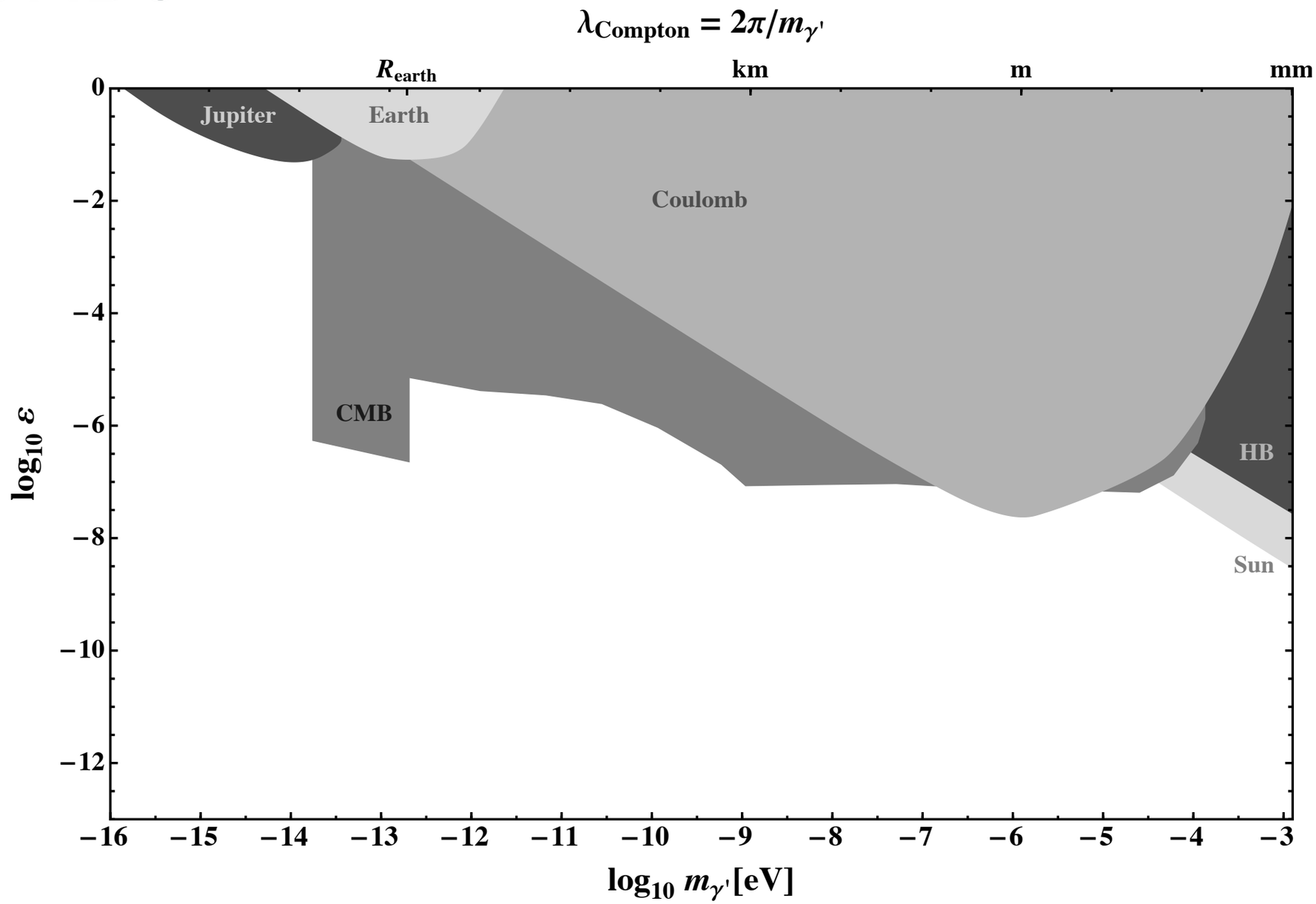
— *massless* photon
— coupling strength e

— *massive* hidden photon
— coupling strength εe

Long-range
Couples to charge like a photon
⬇
Modification of EM

What does this new field do?

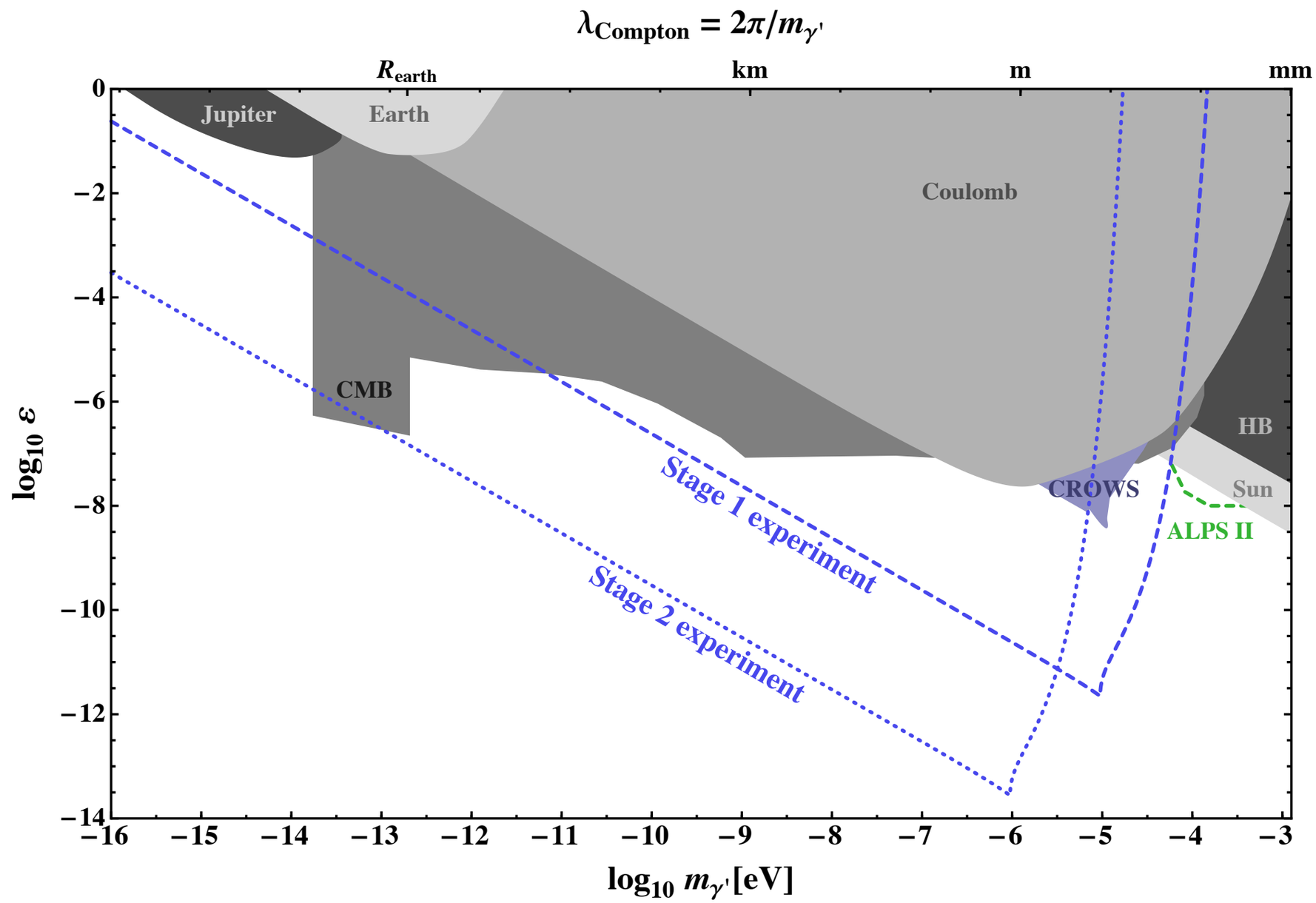
Bounds



Jaeckel & Ringwald 1002.0329
An, Pospelov & Pradler 1302.3884

What does this new field do?

Searching with cavities



P.Graham, J.M., S. Rajendran & Y. Zhao 1405.xxxx
Graham, J.M., Rajendran & Zhao w. K. Irwin, S. Tantawi, V. Bharadwaj 14xx.xxxx
Building original idea of Jaekel & Ringwald 0707.2063

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Long-range
Couples to charge like a photon
⬇
Modification of EM

New massive particle
⬇
Dark matter candidate?

HIDDEN PHOTONS AS DARK MATTER

Jeremy Mardon, SITP, Stanford

HIDDEN-PHOTONS AS DARK MATTER

DM can be as light as 10^{-22} eV (set by size of dwarf galaxies)

Must be a boson if $m \lesssim$ keV (or too much degeneracy pressure)

pseudoscalar → axion

vector → hidden photon

— classical A'_μ field

— oscillation frequency $\omega = m_{A'}$

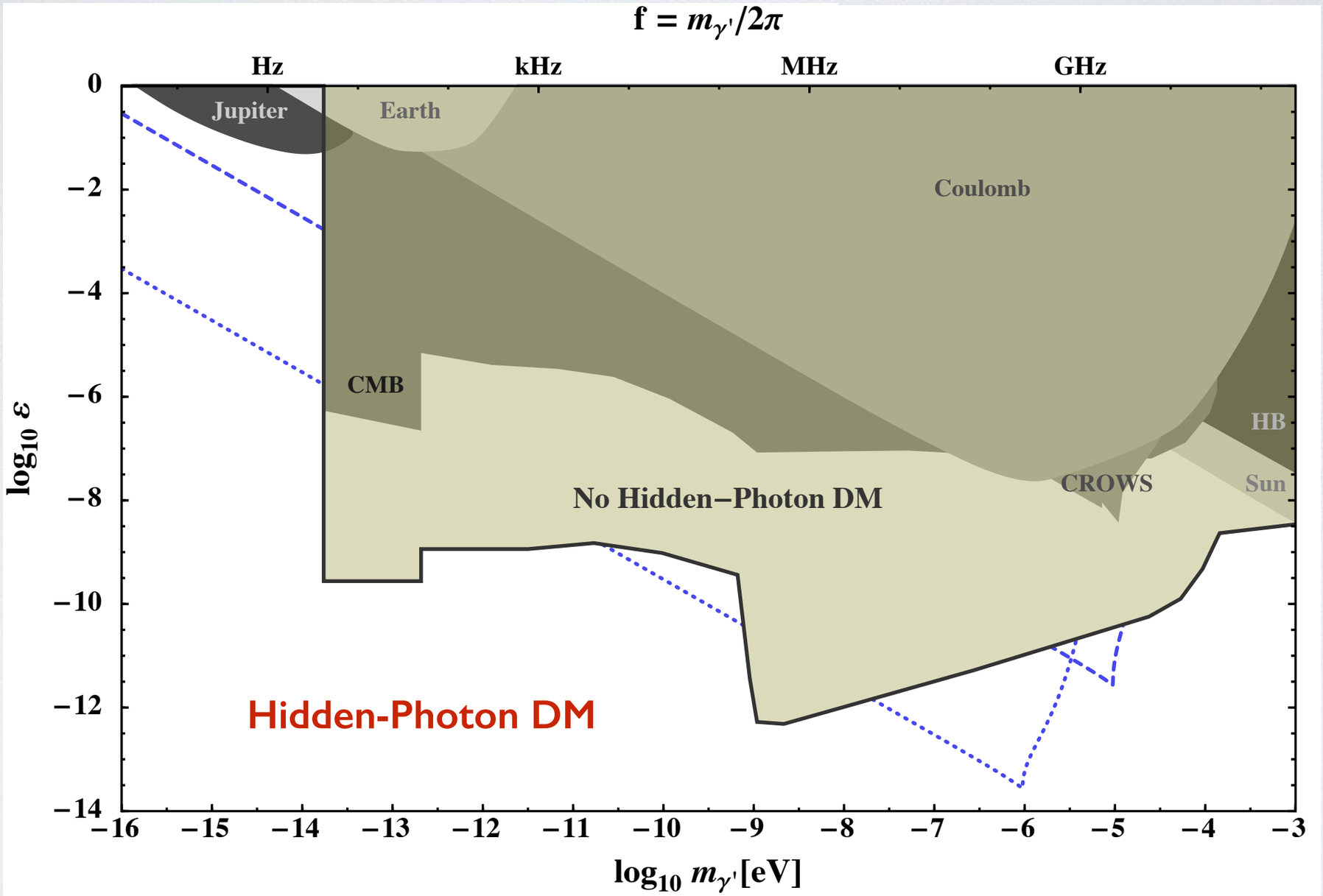
— random direction

(Lorentz breaking but hard to tell!)

Nelson & Scholtz 1105.2812

ASTROPHYSICAL CONSTRAINTS

(resonant conversion of hidden photons to plasma excitations)



Arias et al 1201.5902

DM DETECTION WITH A RADIO INSIDE A FARADAY CAGE

Jeremy Mardon, SITP, Stanford

HIDDEN-PHOTONS AS DARK MATTER

Like an electric field that penetrates conducting shields

— $E' \approx \sqrt{\rho_{\rm DM}} \approx$ **2000 V/m**

Has fixed frequency

— $\omega = m_{\gamma'}$, $\delta\omega/\omega = 10^{-6}$

Can excite an electromagnetic resonator

<u>electromagnetic cavities</u>

— ADMX is automatically sensitive!

Arias et al 1201.5902

— restricted to $m_{\gamma'} \sim 10^{-4}$-10^{-6} **eV**

(set by cavity size)

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Arias et al 1201.5902

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LC circuits

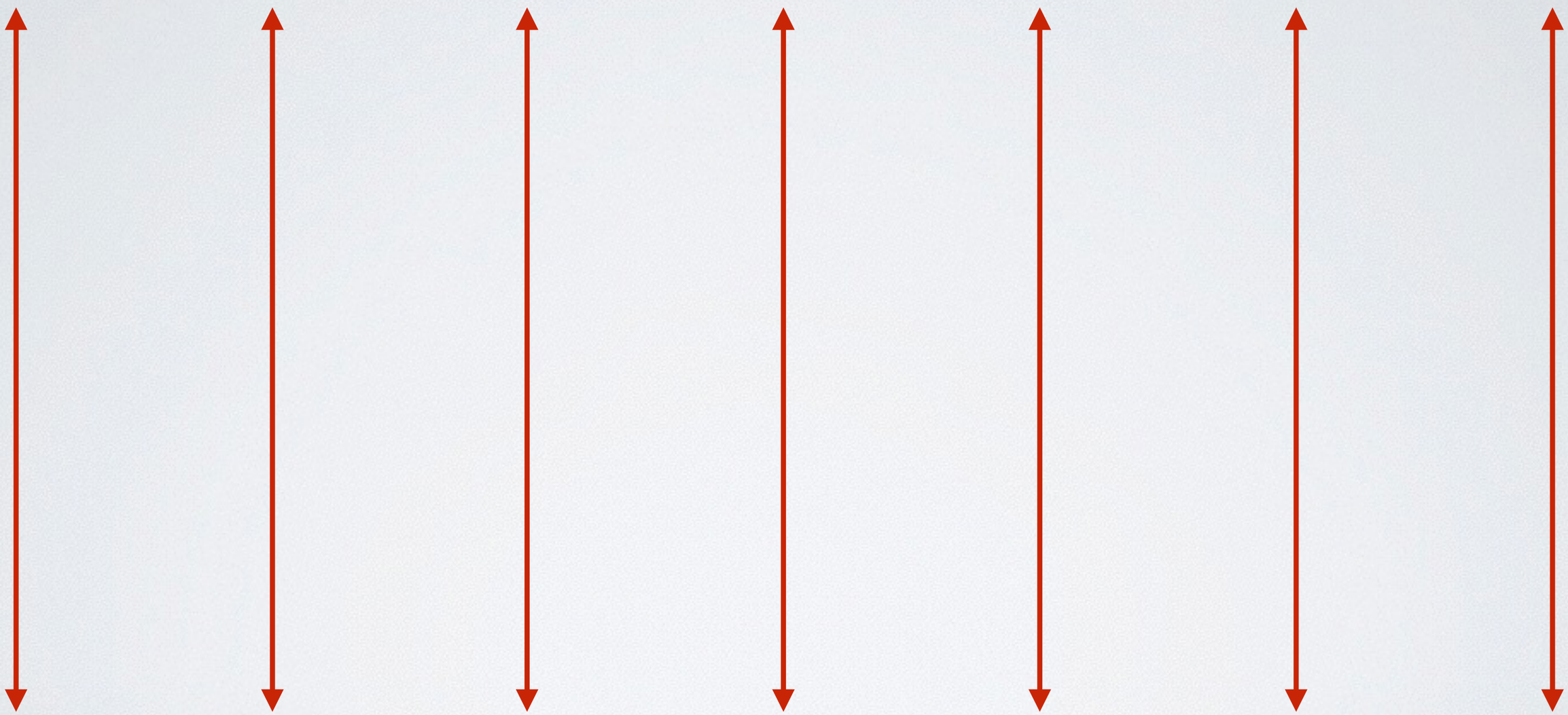
— resonators

— much wider and lower frequency range than cavities

⟶ can probe much lower masses

EXPERIMENTAL SETUP

oscillating E' field (dark matter)



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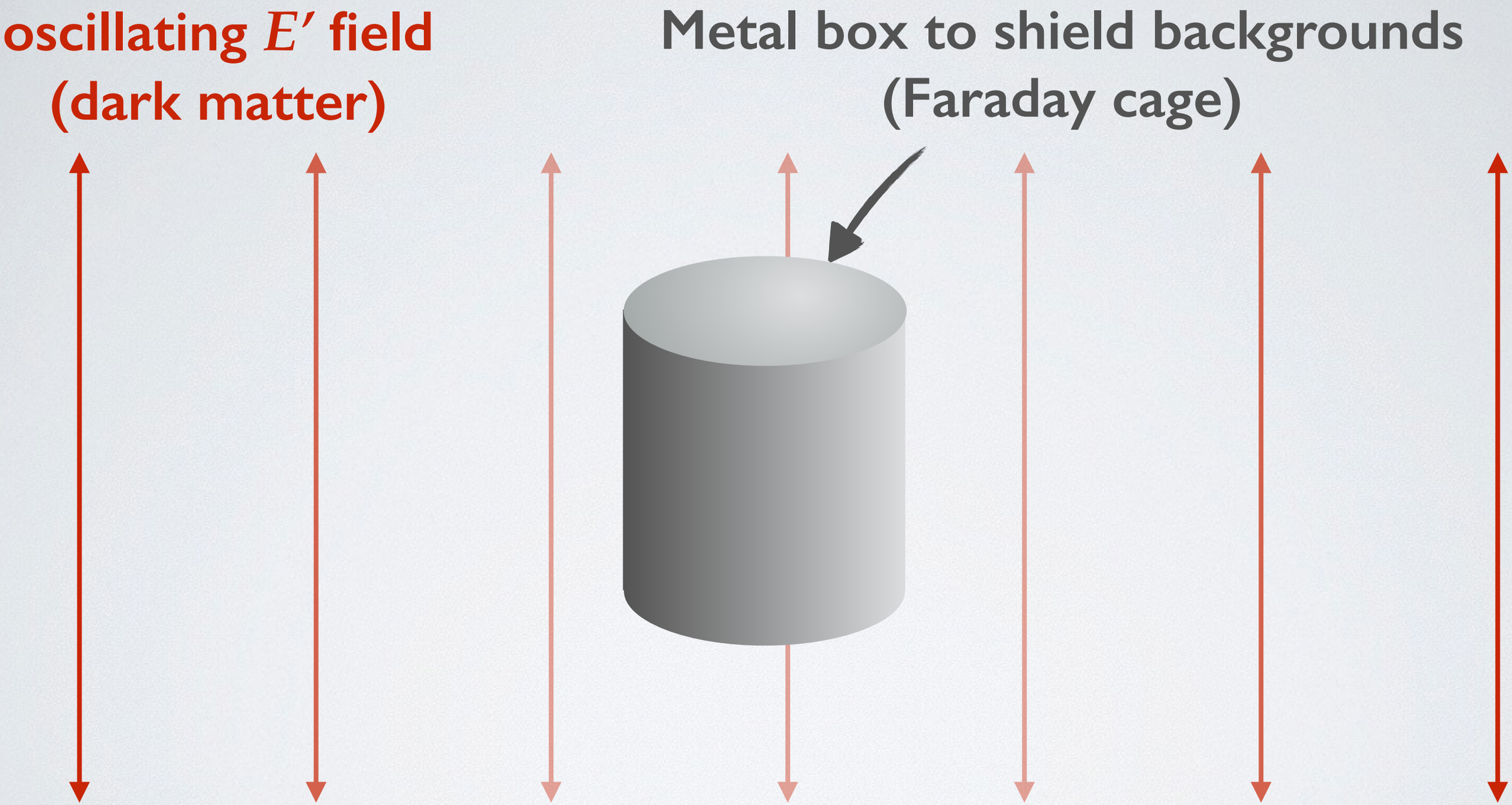
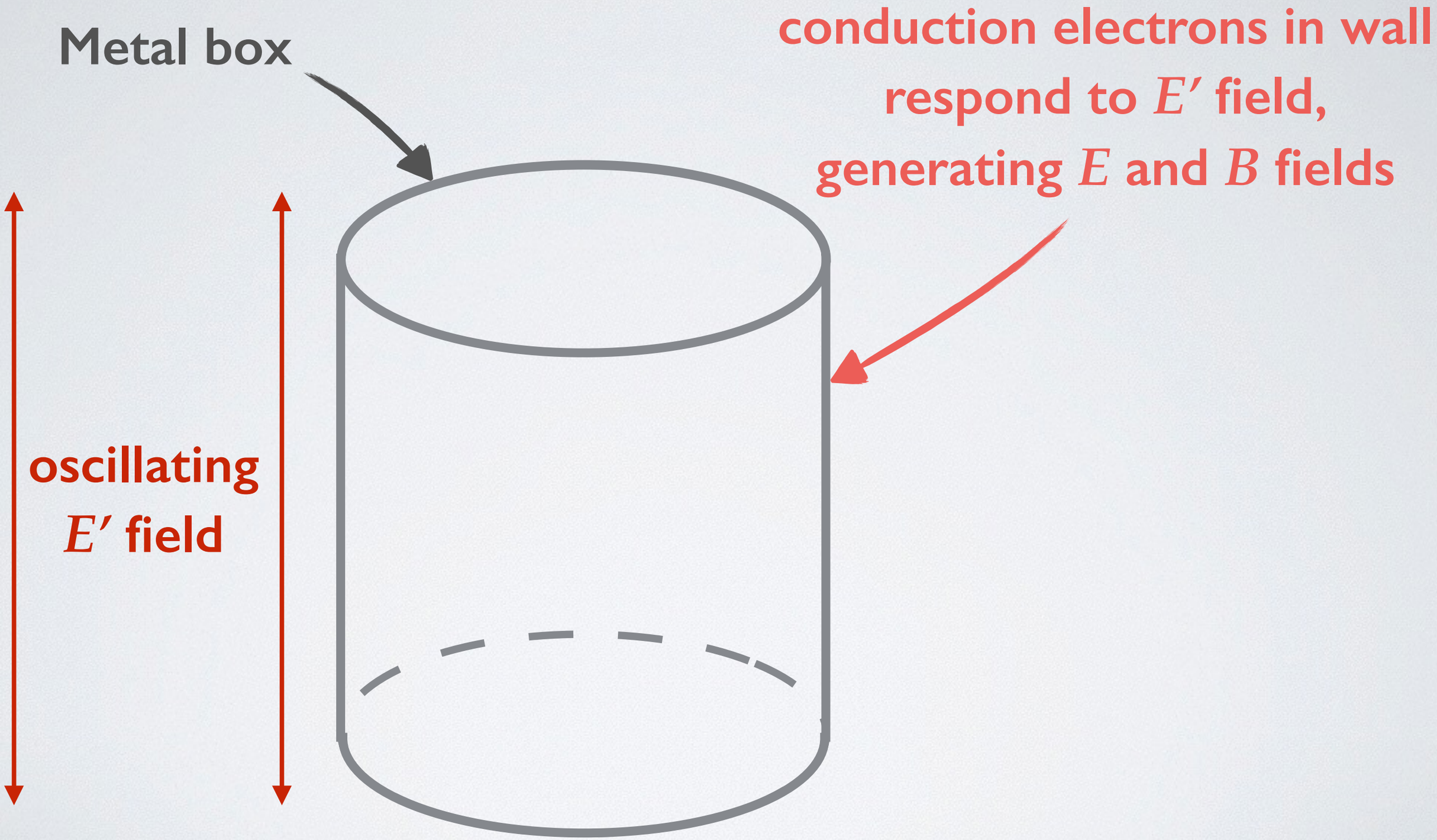


THE SIGNAL INSIDE THE BOX



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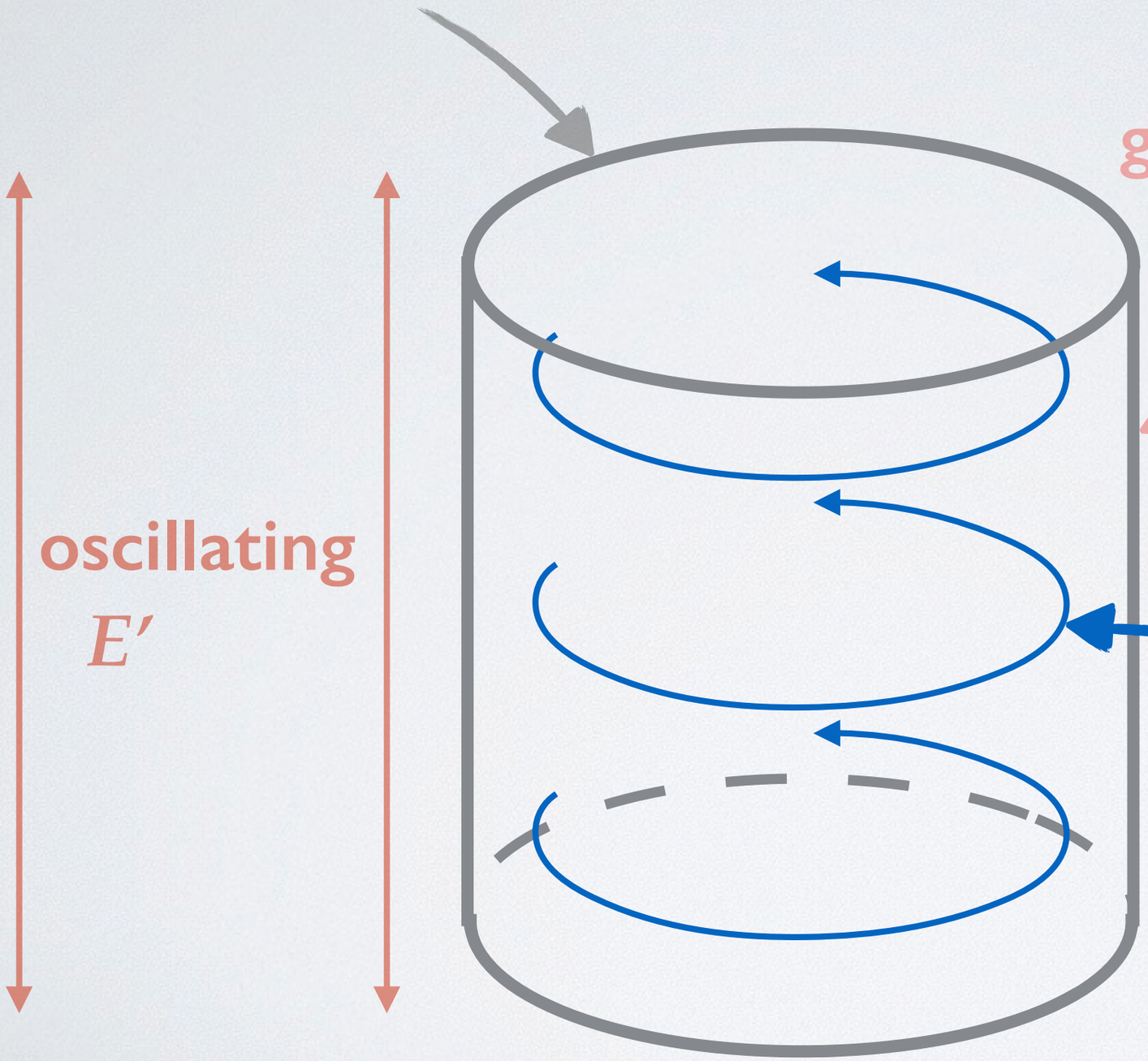


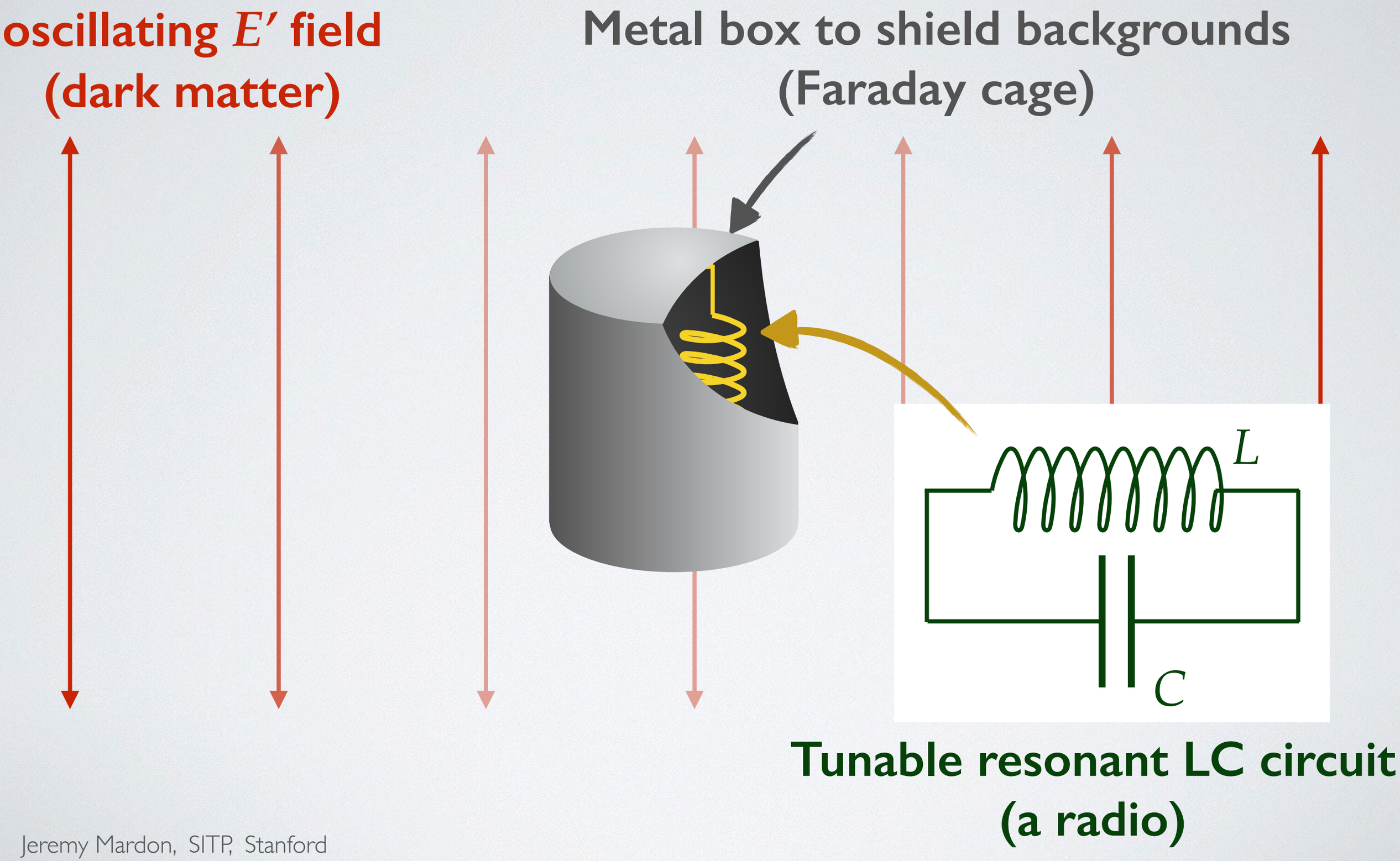
conduction electrons in wall respond to generating

net effect is a B field inside the box

$$B \sim \varepsilon\,(m_{\gamma'} R) \times 10^{-5}\ \mathrm{T}$$

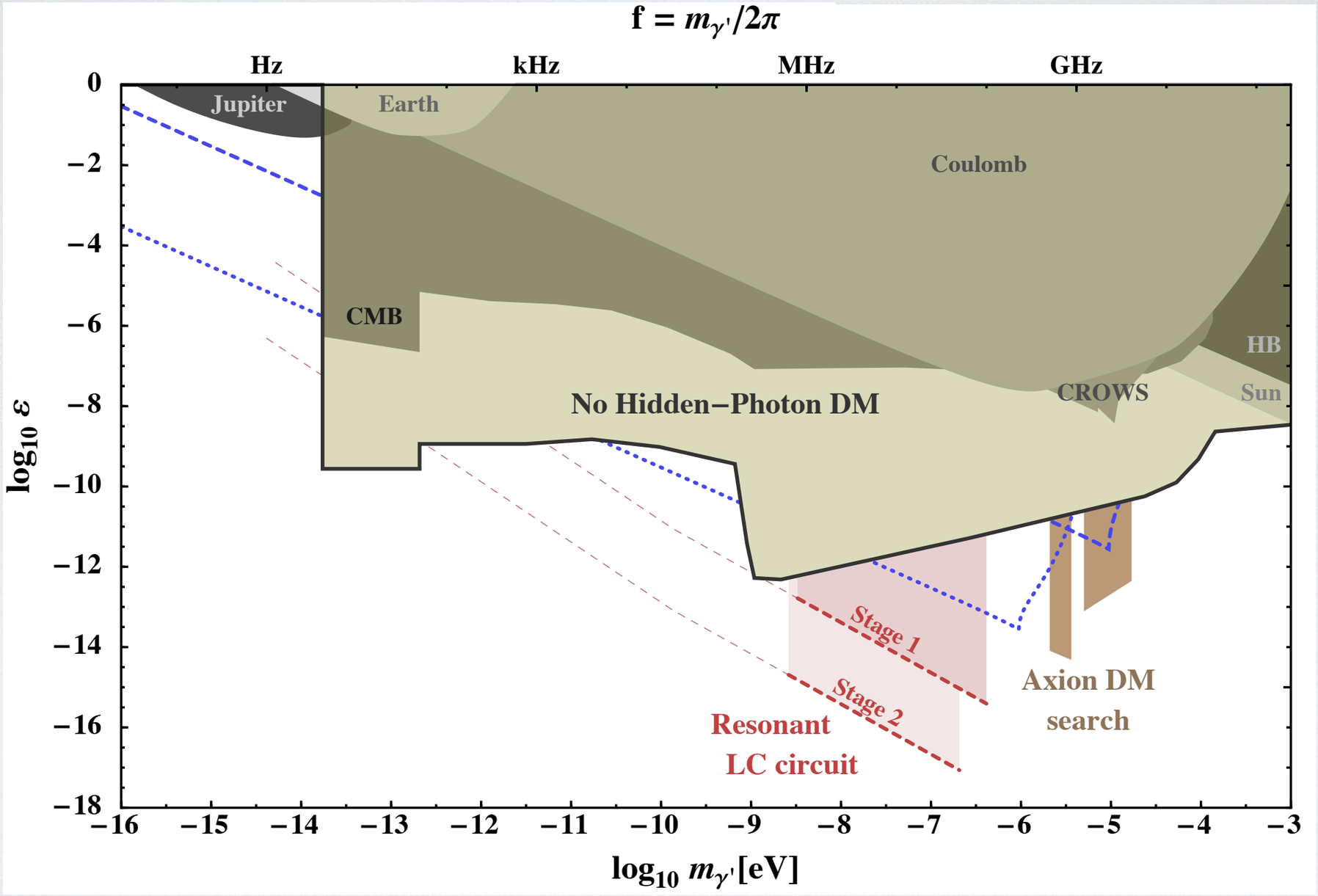
oscillates at $\omega = m_{\gamma'}$

EXPERIMENTAL SETUP



EXPECTED REACH

Stage 1: size ~50 cm, T= 4K, Q=10^6, 1 year scan



Stage 2: size ~1 m, T= 10mK, Q=10^6, 1 year scan

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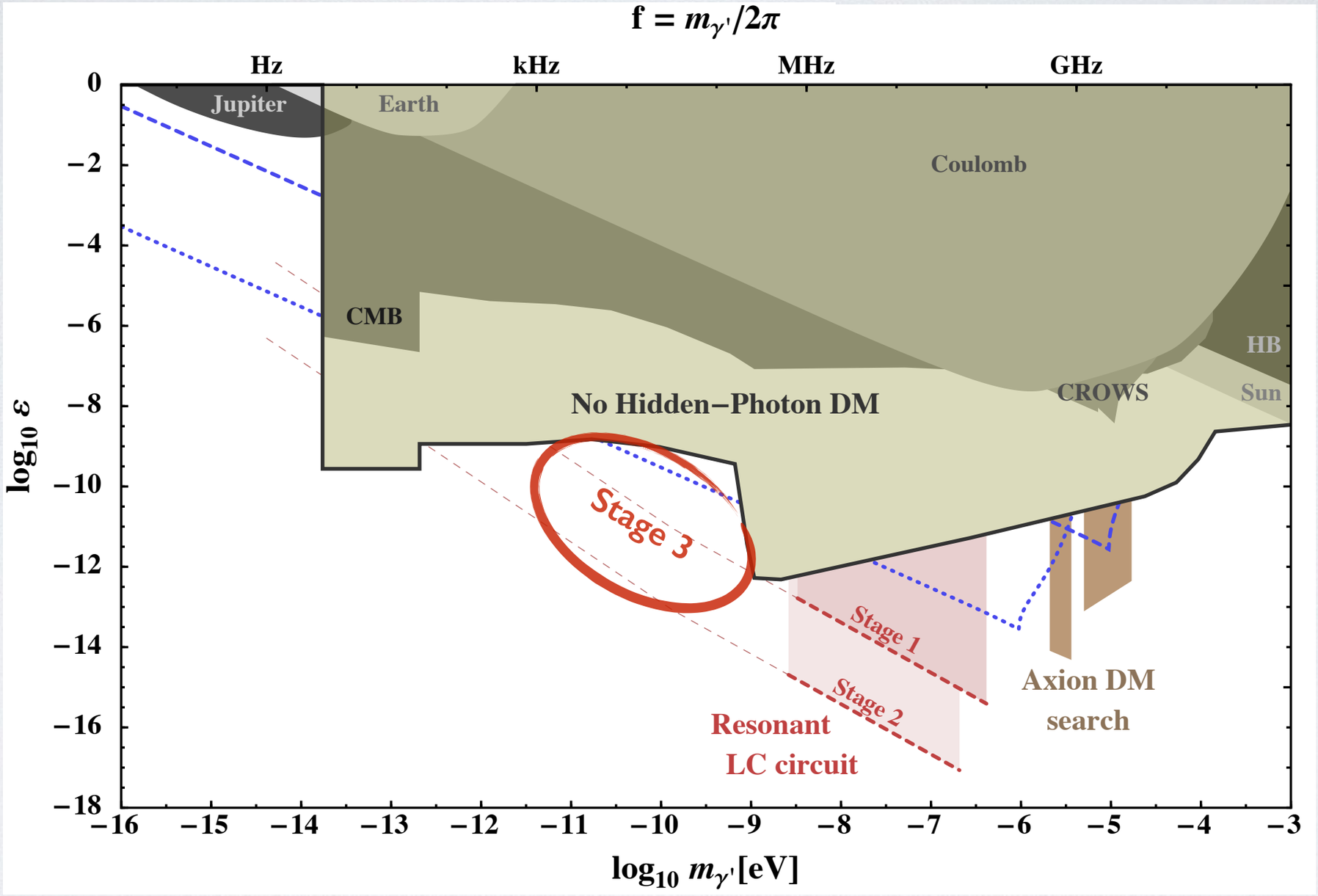


Stage 2: size ~1 m, T= 10mK, Q=10^6, 1 year scan

GENERATING THE RELIC ABUNDANCE

(preliminary)

Jeremy Mardon, SITP, Stanford

Generating A' DM abundance

— Previous literature seems to be incorrect

— Cosmological evolution of A' is a little unusual

— **We believe correct relic abundance *can* be generated**

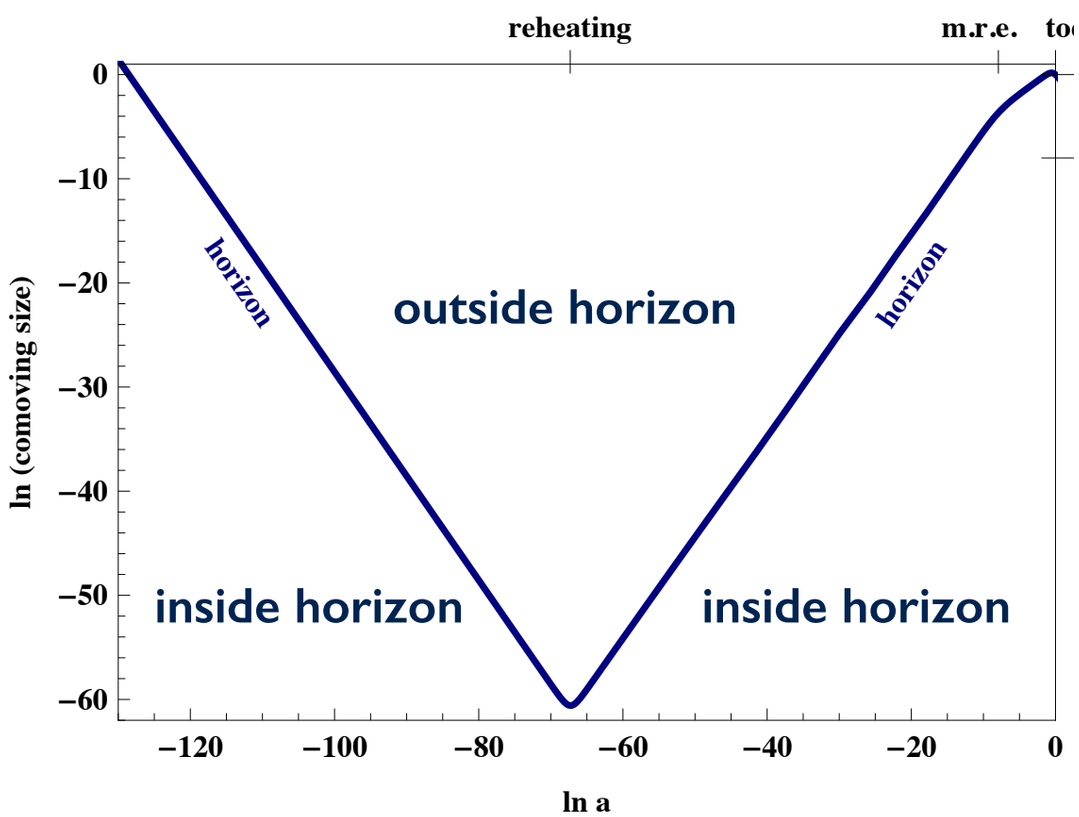
  — Several possibilities

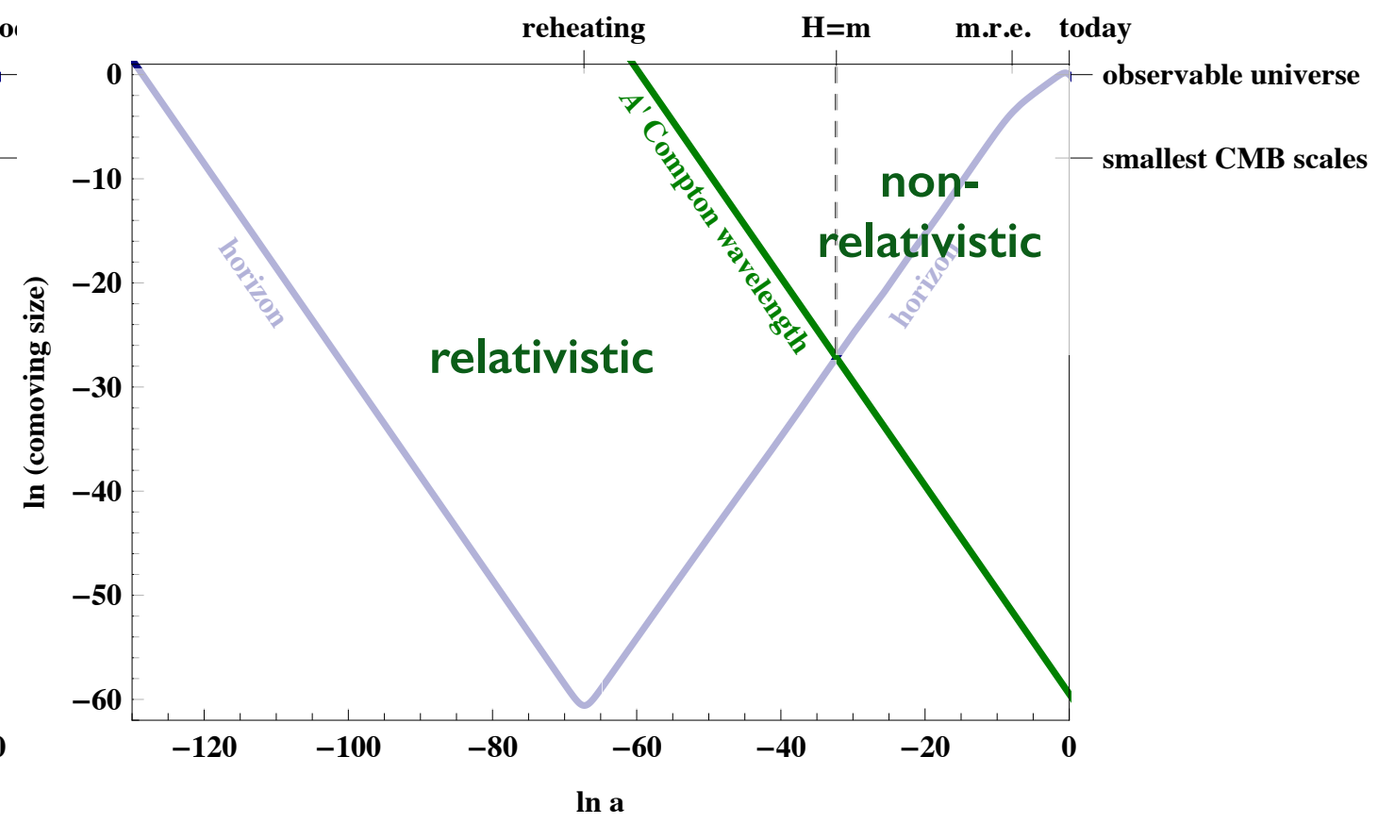
  — Will discuss one with an interesting prediction

Cosmological evolution

(with Stuckelberg mass)

Evolution of A' modes in expanding universe

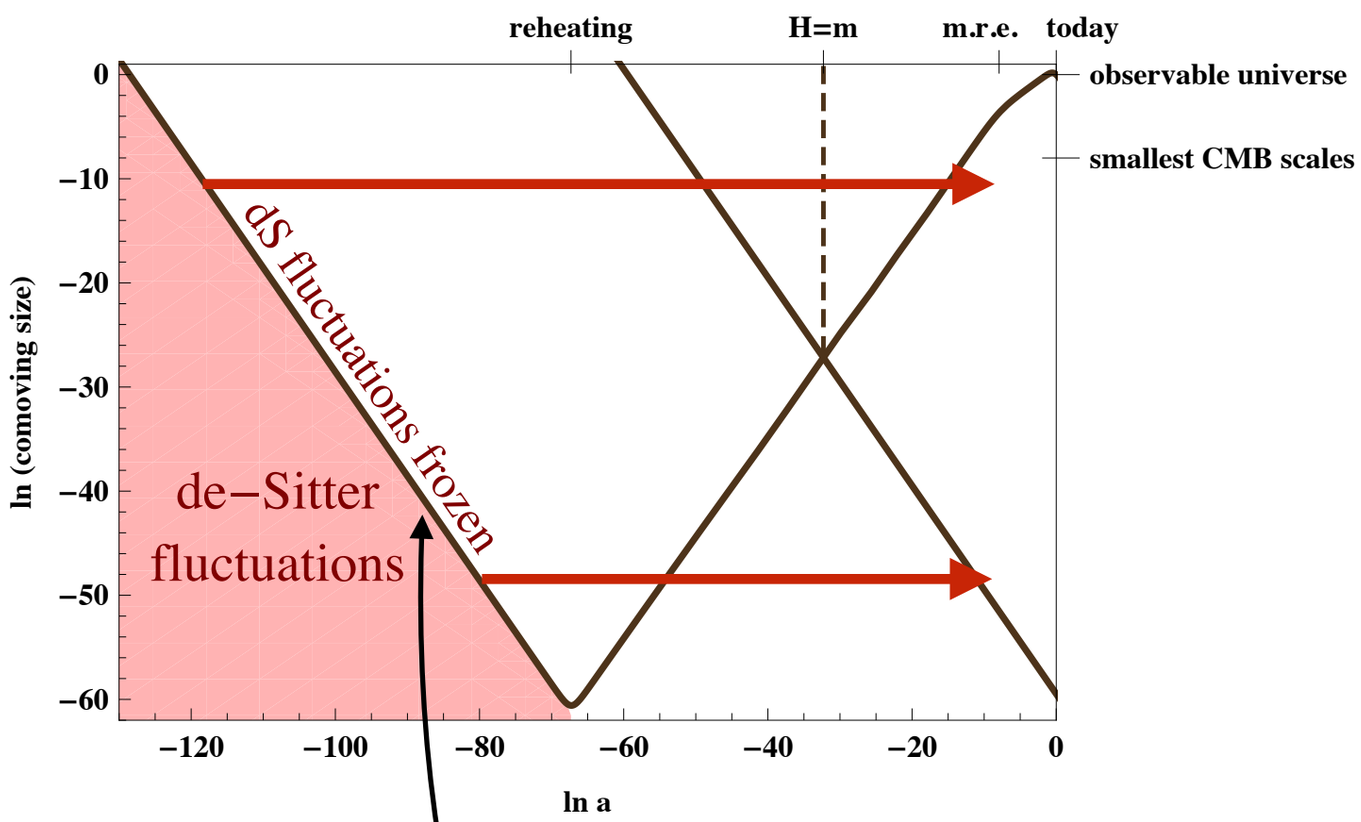




Cosmological evolution

(with Stuckelberg mass)

Evolution of A' **longitudinal modes** in expanding universe

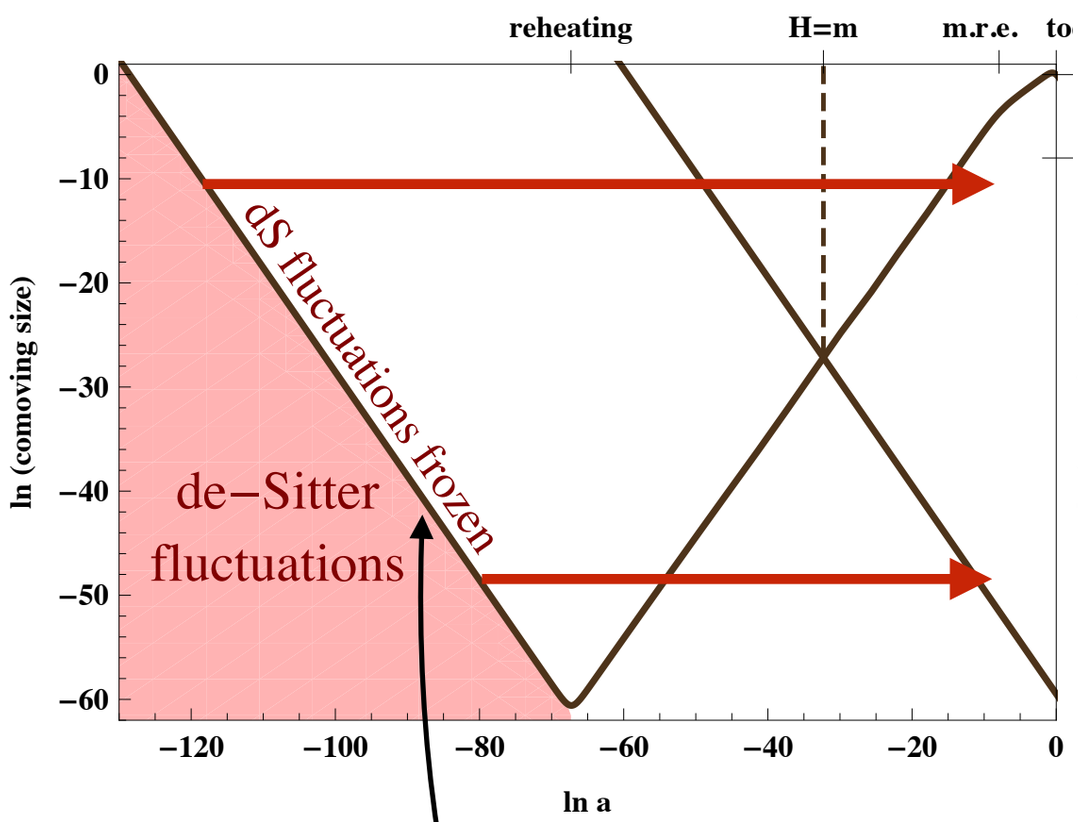


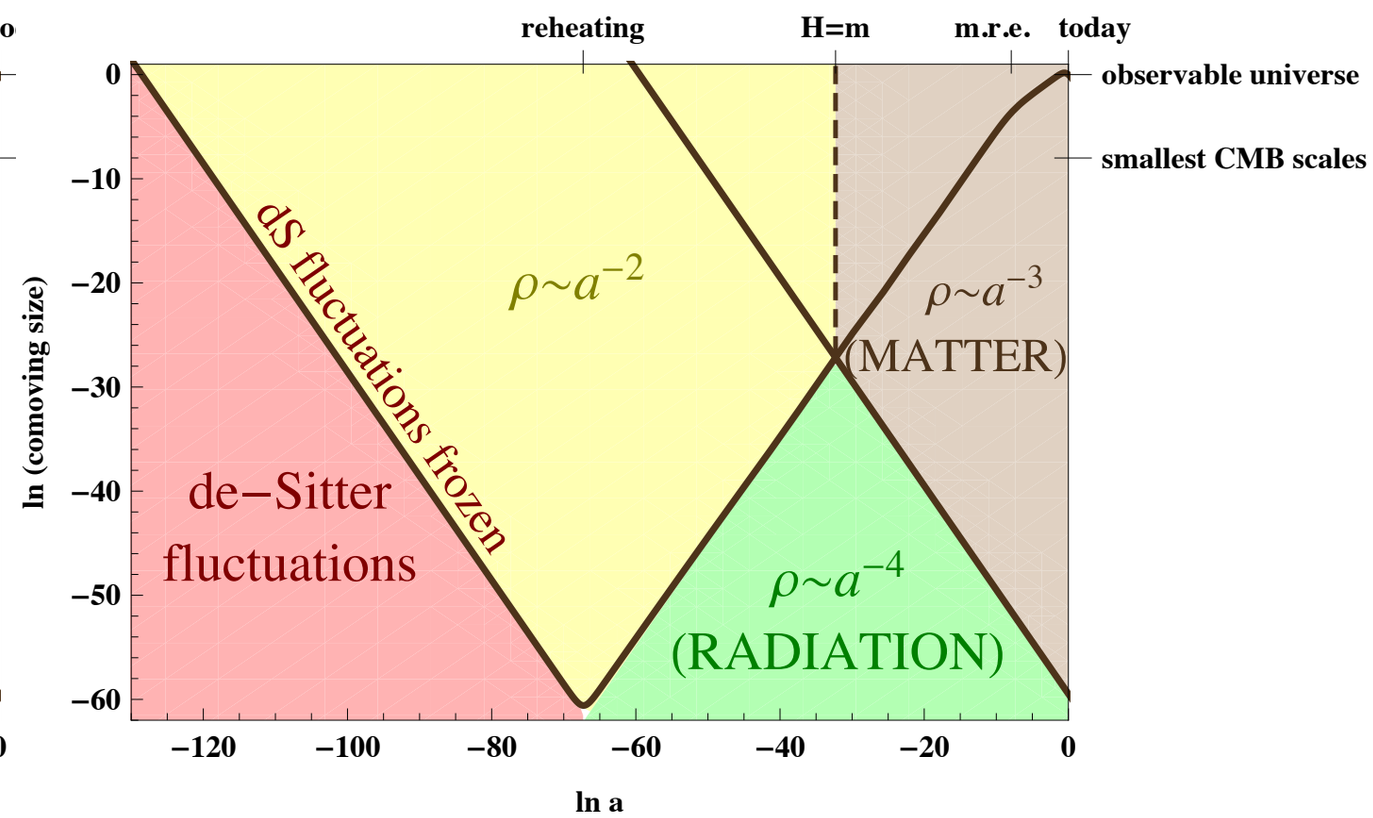
$$[d\rho/d\ln k]_{exit} \sim H_I^4$$

Cosmological evolution

(with Stuckelberg mass)

Evolution of A' longitudinal modes in expanding universe





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COSMOLOGICAL EVOLUTION

(WITH STUCKELBERG MASS)

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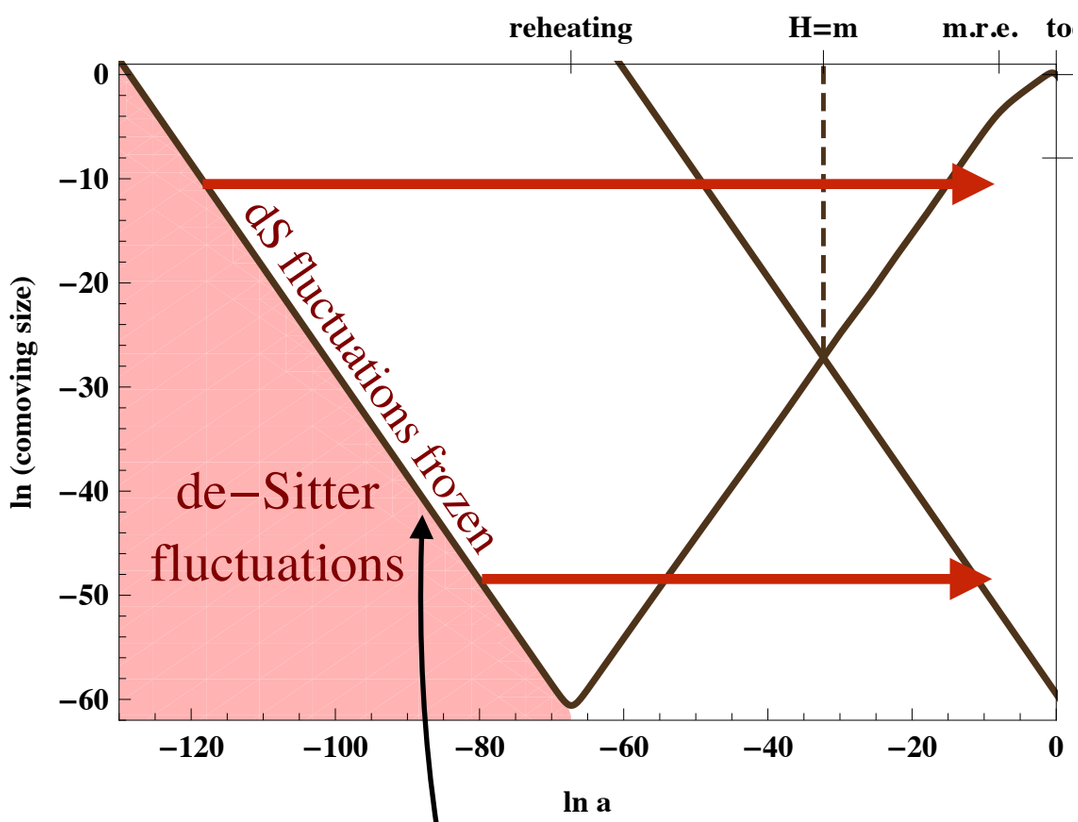

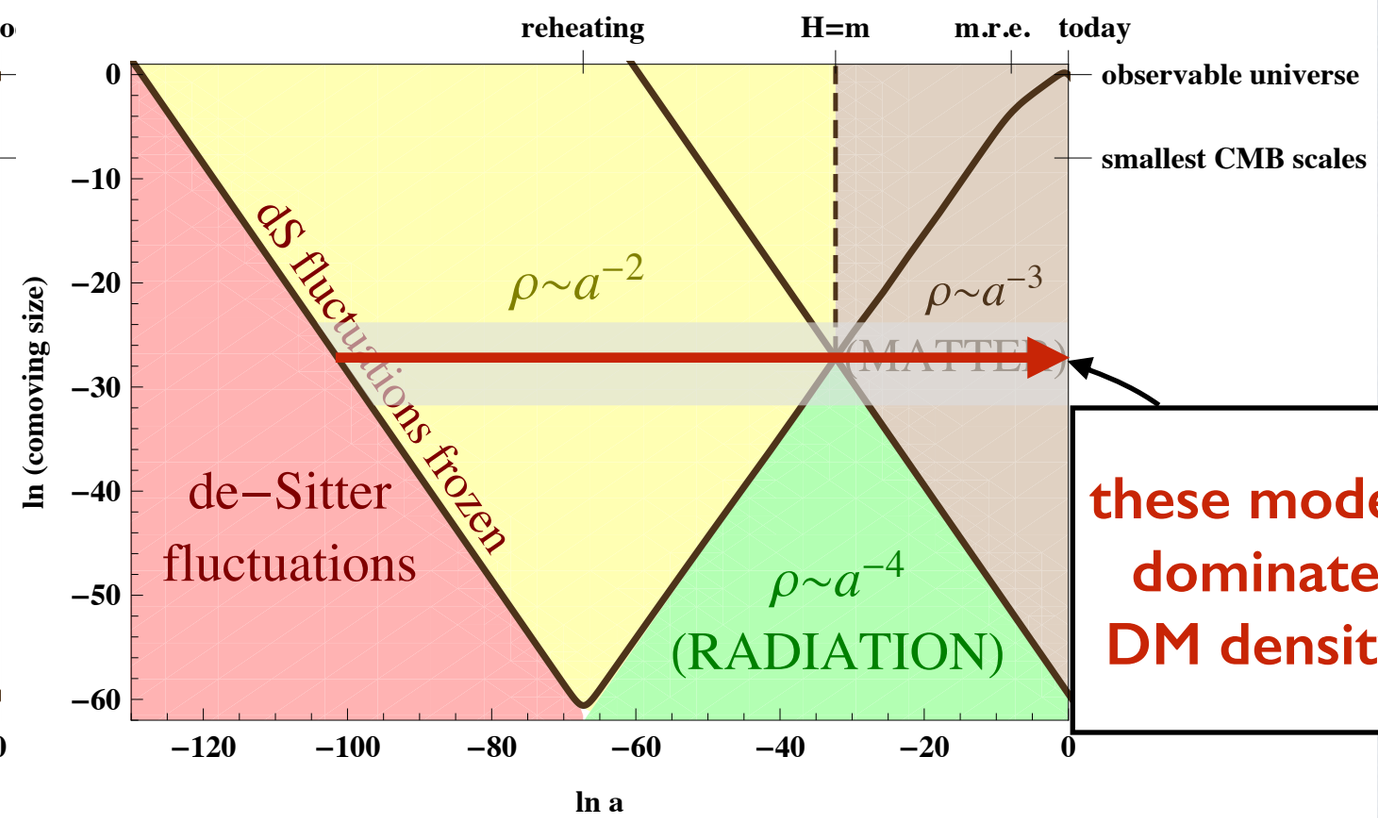

these modes dominate DM density

$$[d\rho/d\ln k]_{exit} \sim H_I^4$$

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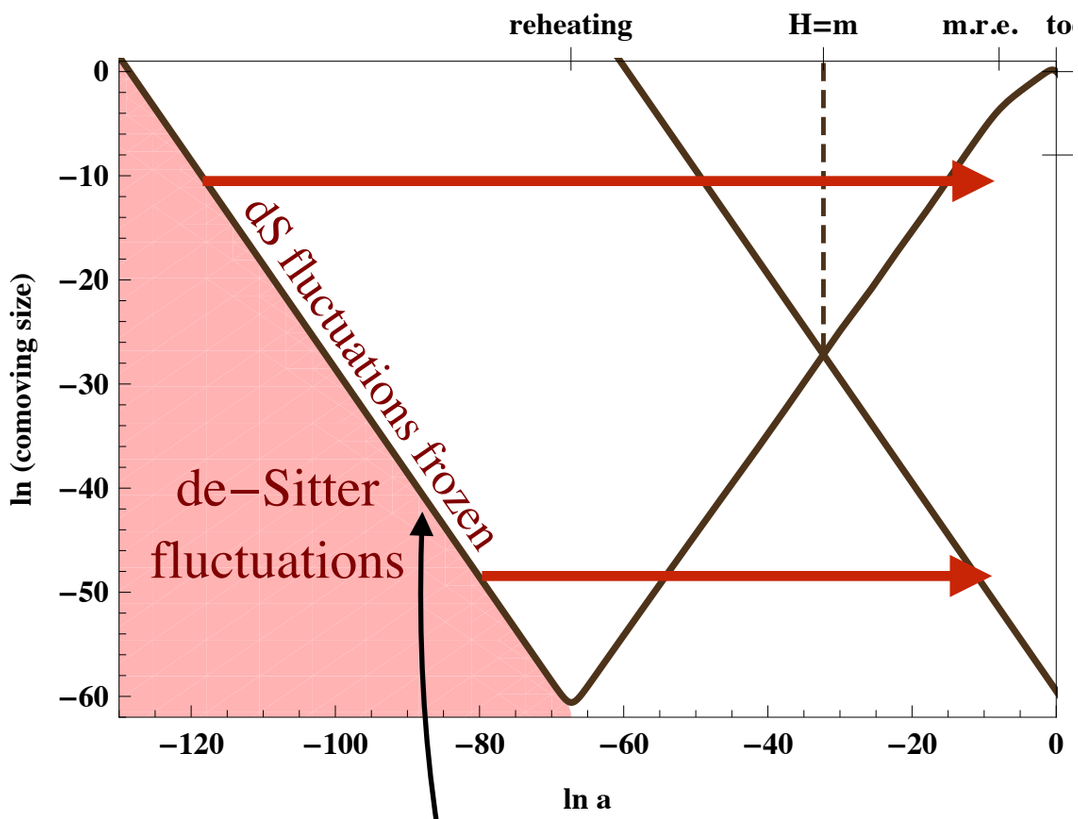
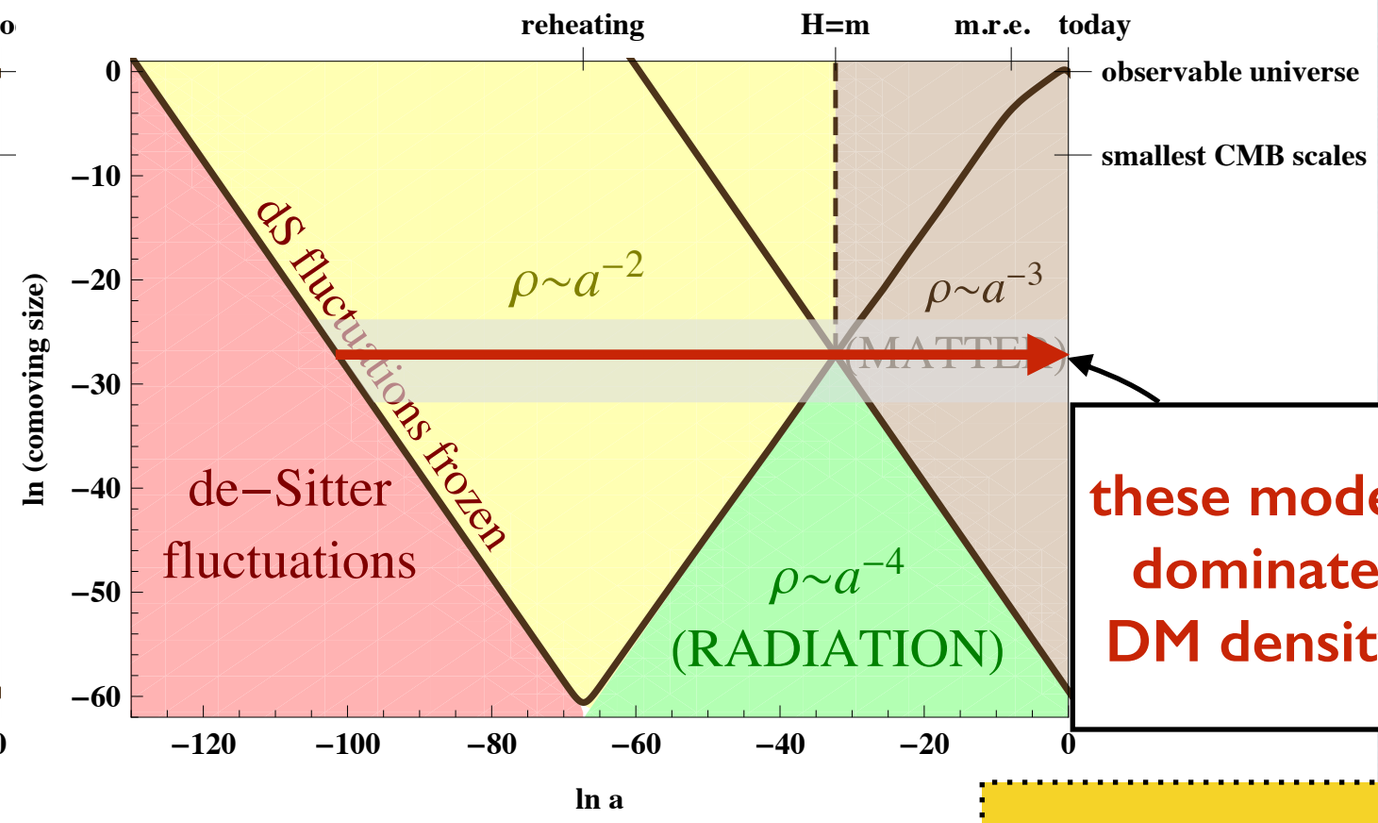




these modes dominate DM density

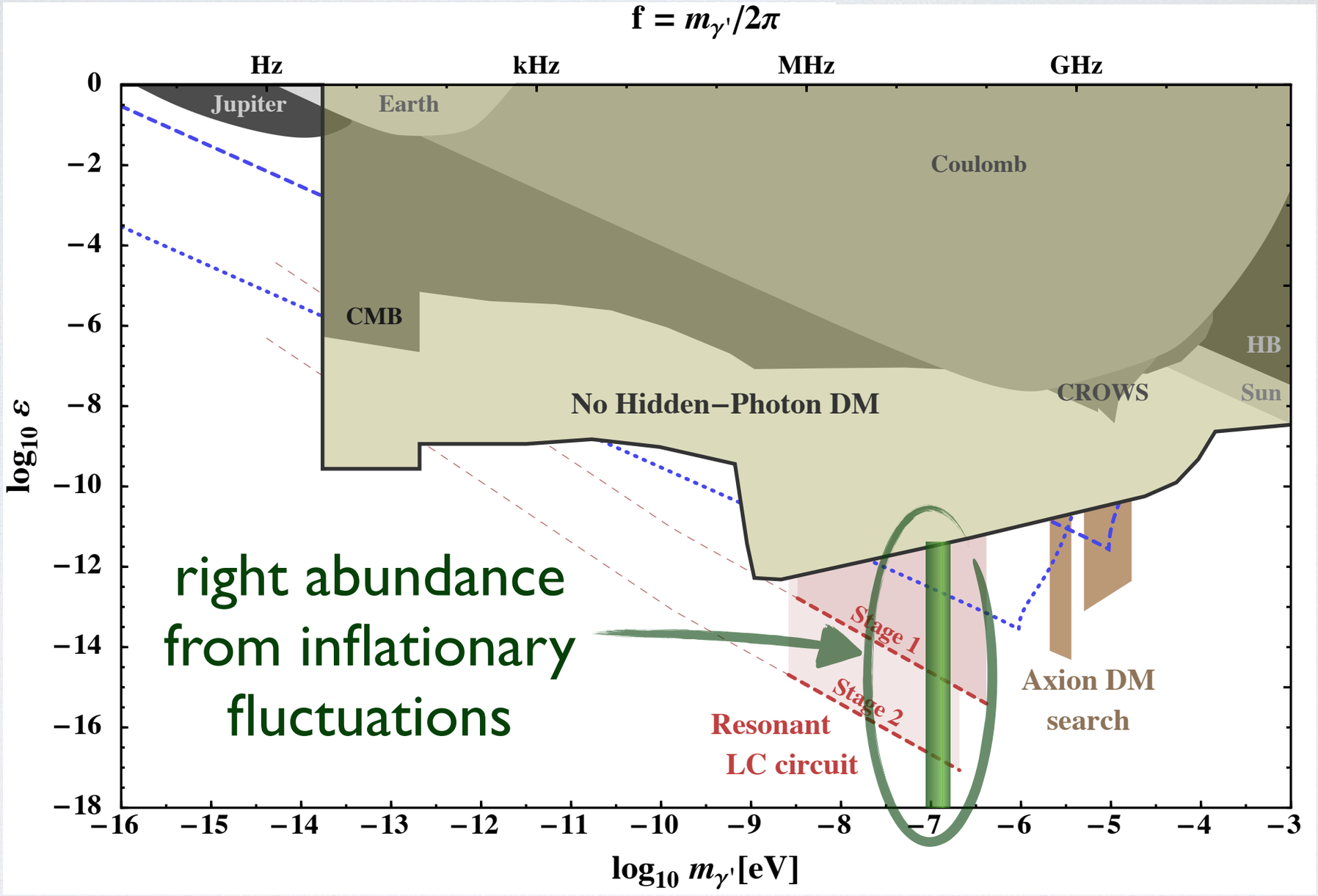
$[d\rho/d\ln k]_{exit} \sim H_I^4$

preliminary

with $H_I = 10^{14}$ GeV ,
get correct DM abundance if $m_{A'} \sim 10^{-7}$ eV

EXPECTED REACH

Stage 1: size ~50 cm, T= 4K, Q=10^6, 1 year scan



Stage 2: size ~1 m, T= 10mK, Q=10^6, 1 year scan

CONCLUSIONS

An ultra-light hidden photon is an interesting DM candidate

Can detect with a shielded LC circuit

Sensitive to a cosmologically interesting mass range!

Hope to see experimental results in a year or two

THANK YOU