Ultra-Light

Hidden Photons

Theory and Searches

Jeremy Mardon, SITP, Stanford

The hidden photon

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

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

kinetic mixing ε with photon

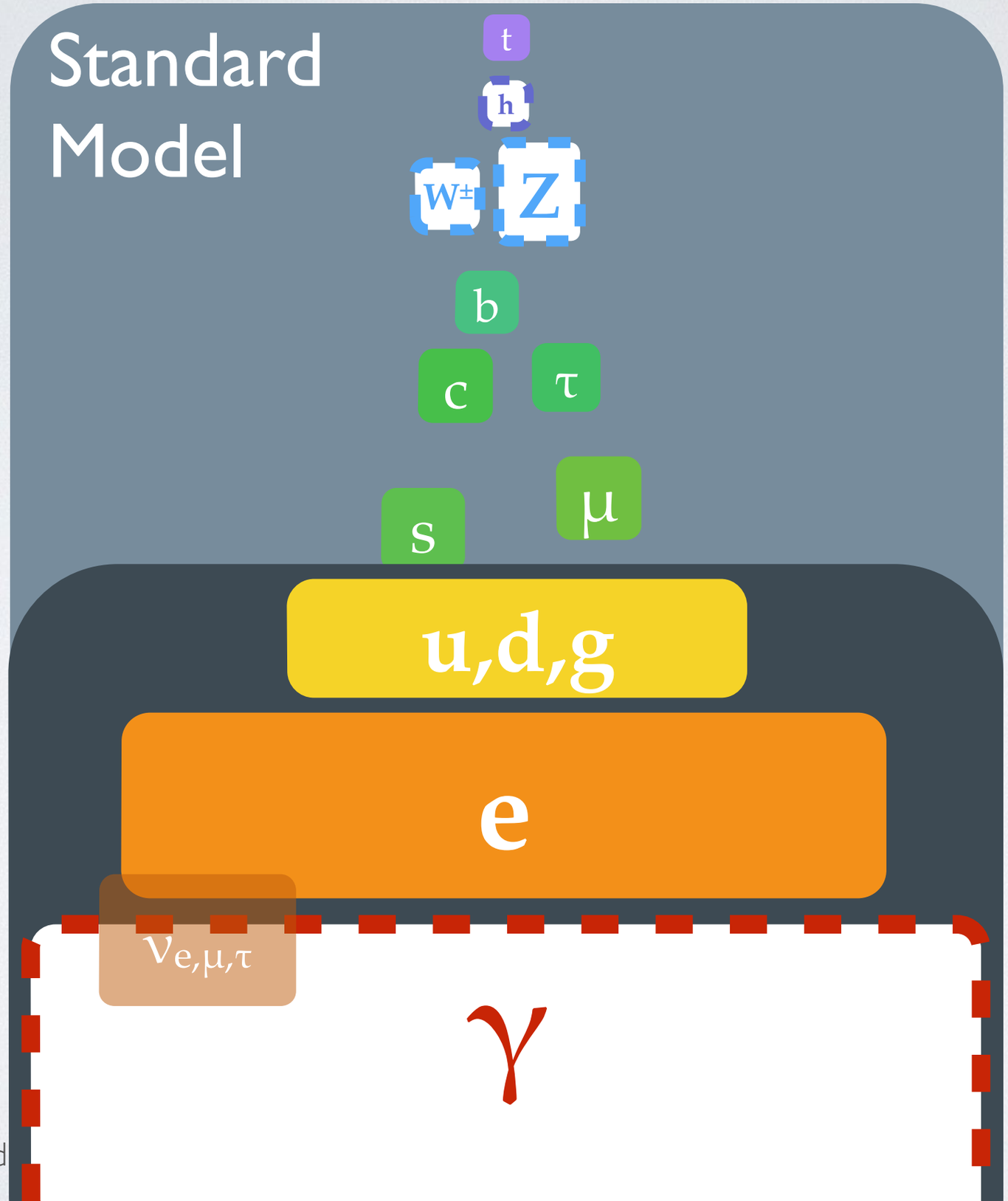
small mass (with no hierarchy problem)

The hidden photon

Why Not?

Jeremy Mardon, SITP, Stanford

Standard Model



SM extension

Standard Model

t

h

W±

Z

b

c

τ

μ

s

u,d,g

e

$\nu_{e,\mu,\tau}$

γ

?

?

?

?

?

?

?

?

?

?

hidden sectors

SM extension
e.g. SUSY

Standard
Model

t

h

W±

Z

b

c

τ

?

hidden

Low energy, high precision probes

u,d,g

e

$\nu_{e,\mu,\tau}$

γ

γ'

a

γ''

ULTRA-LIGHT HIDDEN PHOTON

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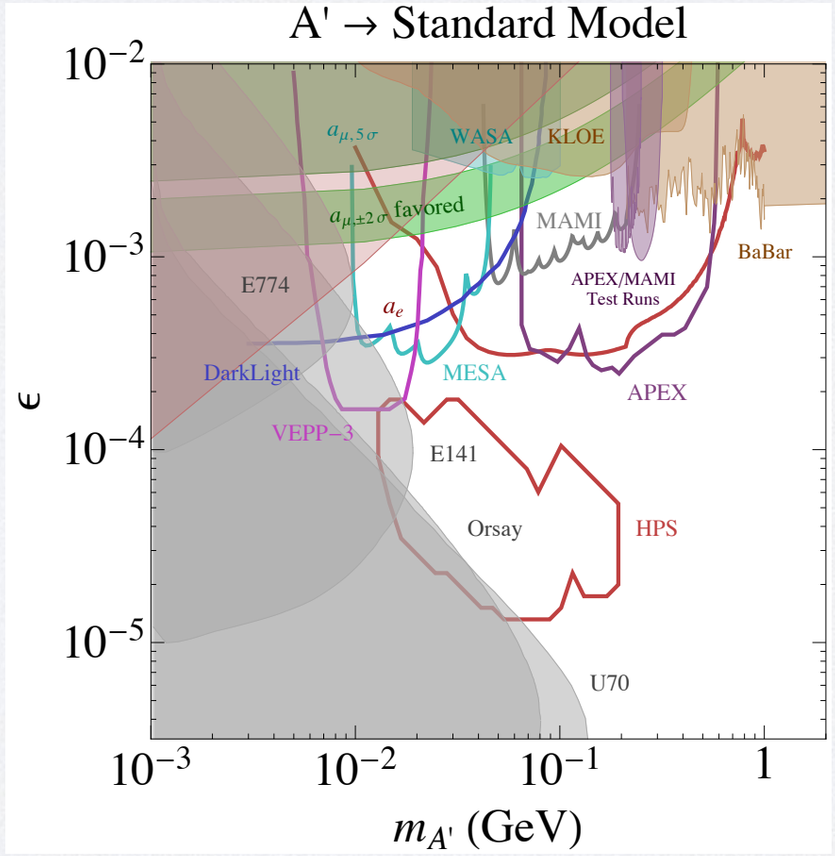

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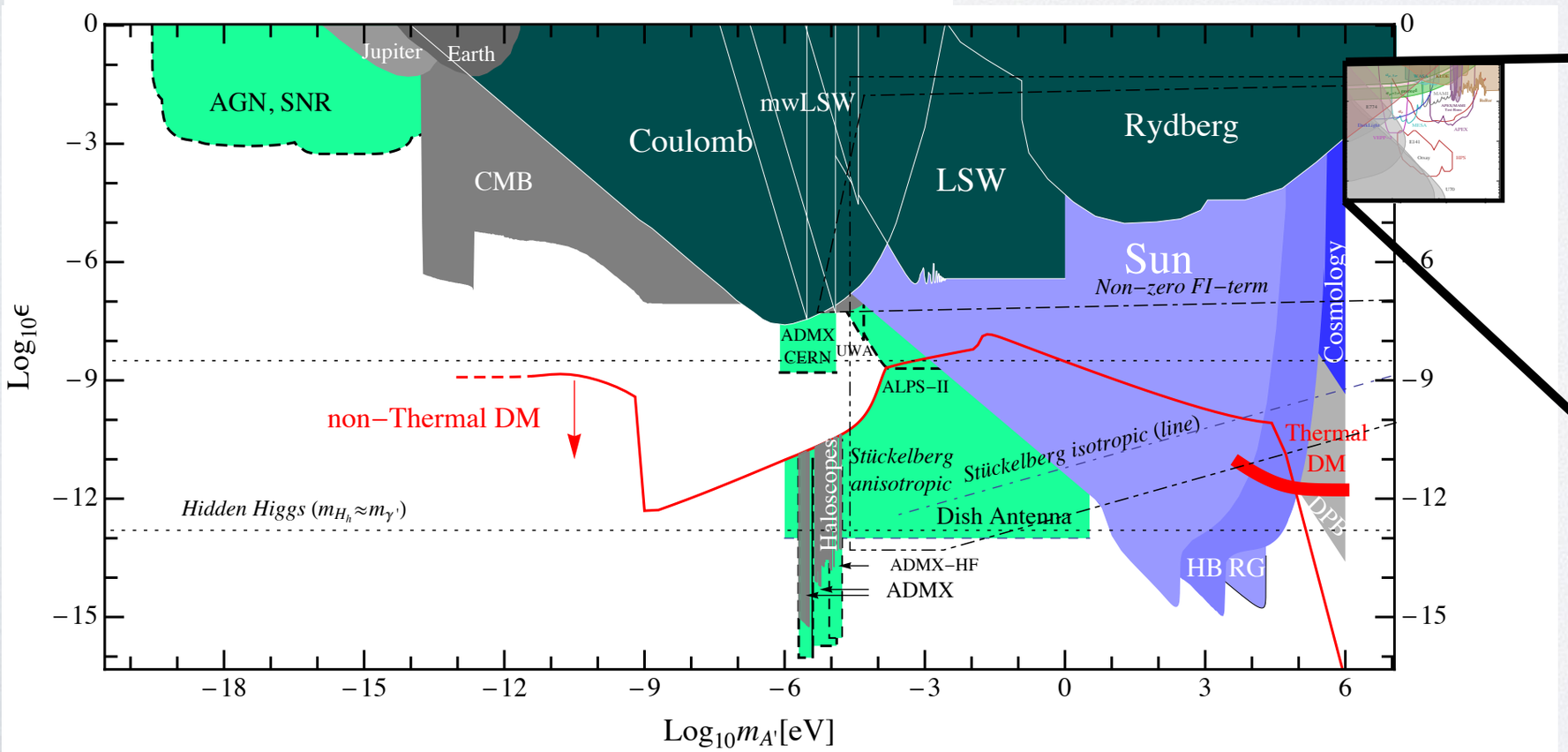

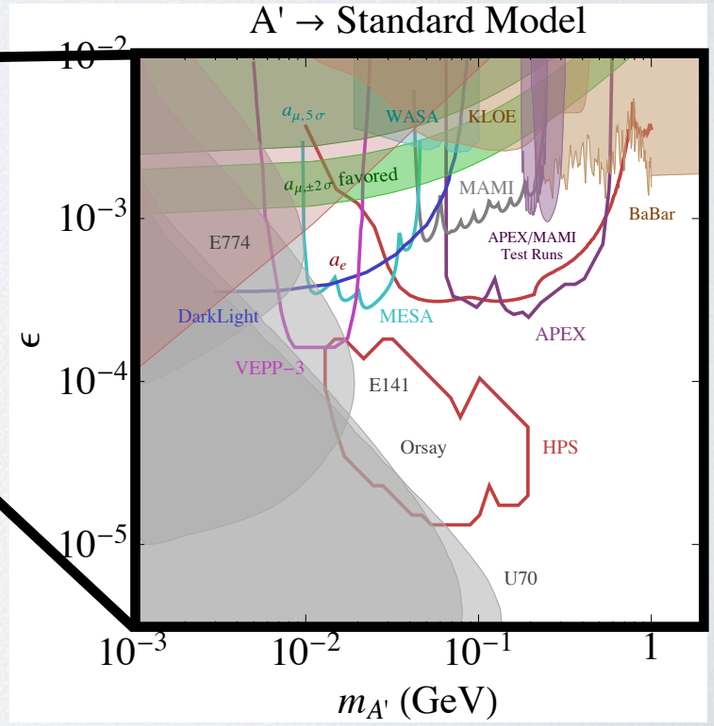

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ULTRA-LIGHT hidden photon

A new force / force carrier:

a copy of E&M, with a finite range & very weakly coupled

EM: — ***massless*** photon
— coupling strength e

EM′: — ***massive*** hidden photon
— coupling strength εe

ULTRA-LIGHT HIDDEN PHOTON

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

New massive particle
⬇
Dark matter candidate

ULTRA-LIGHT hidden photon

A new force / force carrier:
a copy of E&M, with a finite range & very weakly coupled

EM: — ***massless*** photon
— coupling strength e

EM′: — ***massive*** hidden photon
— coupling strength εe

Enhancing Light-Through-Walls Searches with Longitudinal Modes

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Searching for Hidden Photon Dark Matter with a Radio

Hidden Photon DM Sourced by Inflationary Fluctuations

work in progress with:

Peter Graham, Surjeet Rajendran & Yue Zhao

and experimental collaborators:

Sami Tantawi, Vinod Bharadwaj, Kent Irwin, Saptarshi Chaudhuri

building on work by:

… J. Redondo, J. Scholtz, M. Pospelov, J. Pradler, G. Rybka … (& others)

Jeremy Mardon, SITP, Stanford

Parametrically Enhanced Light-Through-Walls Searches for Hidden Photons using Longitudinal Modes

Jeremy Mardon, SITP, Stanford

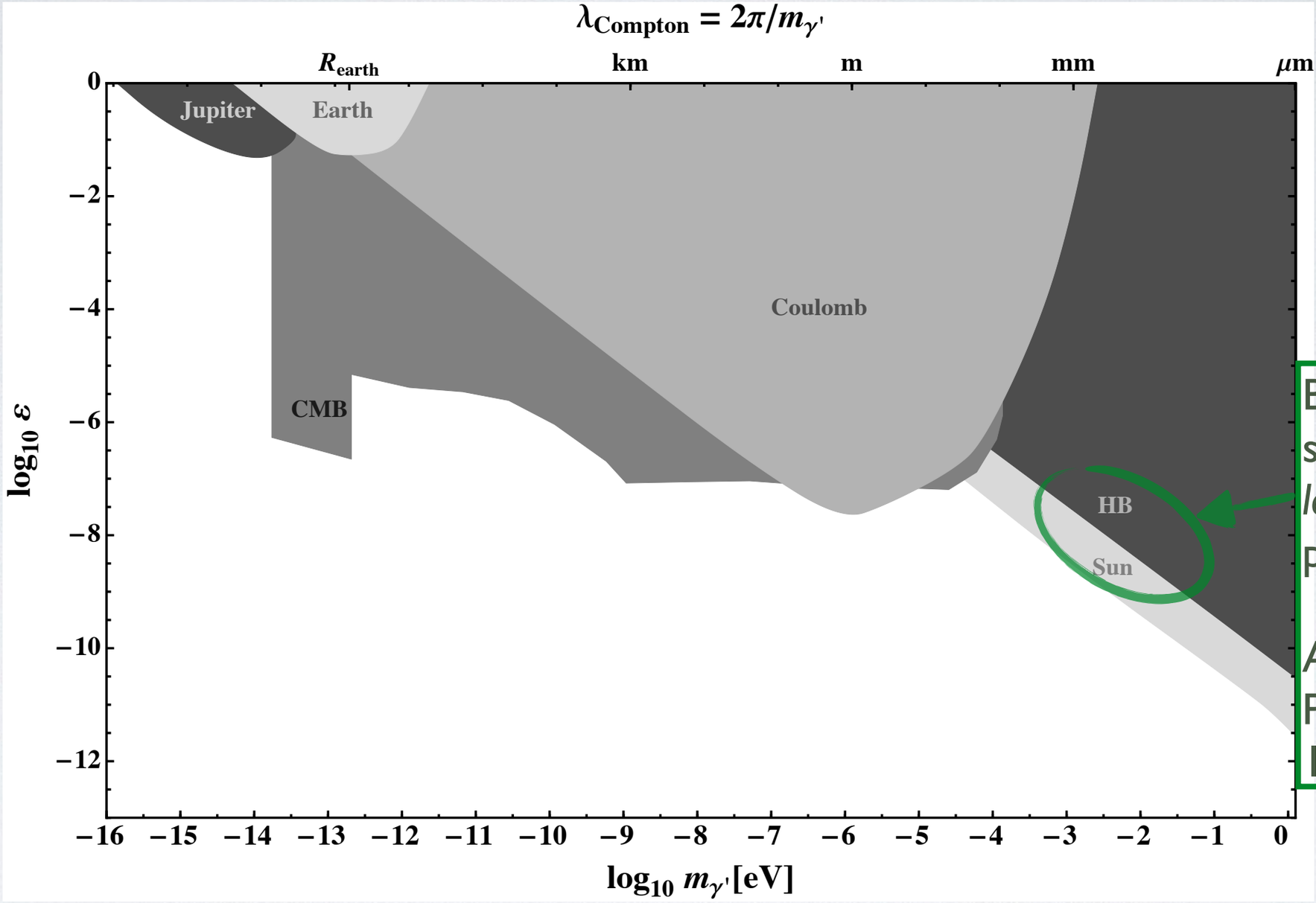
P.Graham, J.M., S. Rajendran & Y. Zhao 1406.xxxx

2 Important Points

1: all effects decouple when $m_{\gamma'} \to 0$

2: massive hidden photon has **2 transverse** modes + **1 longitudinal**

EXISTING BOUNDS

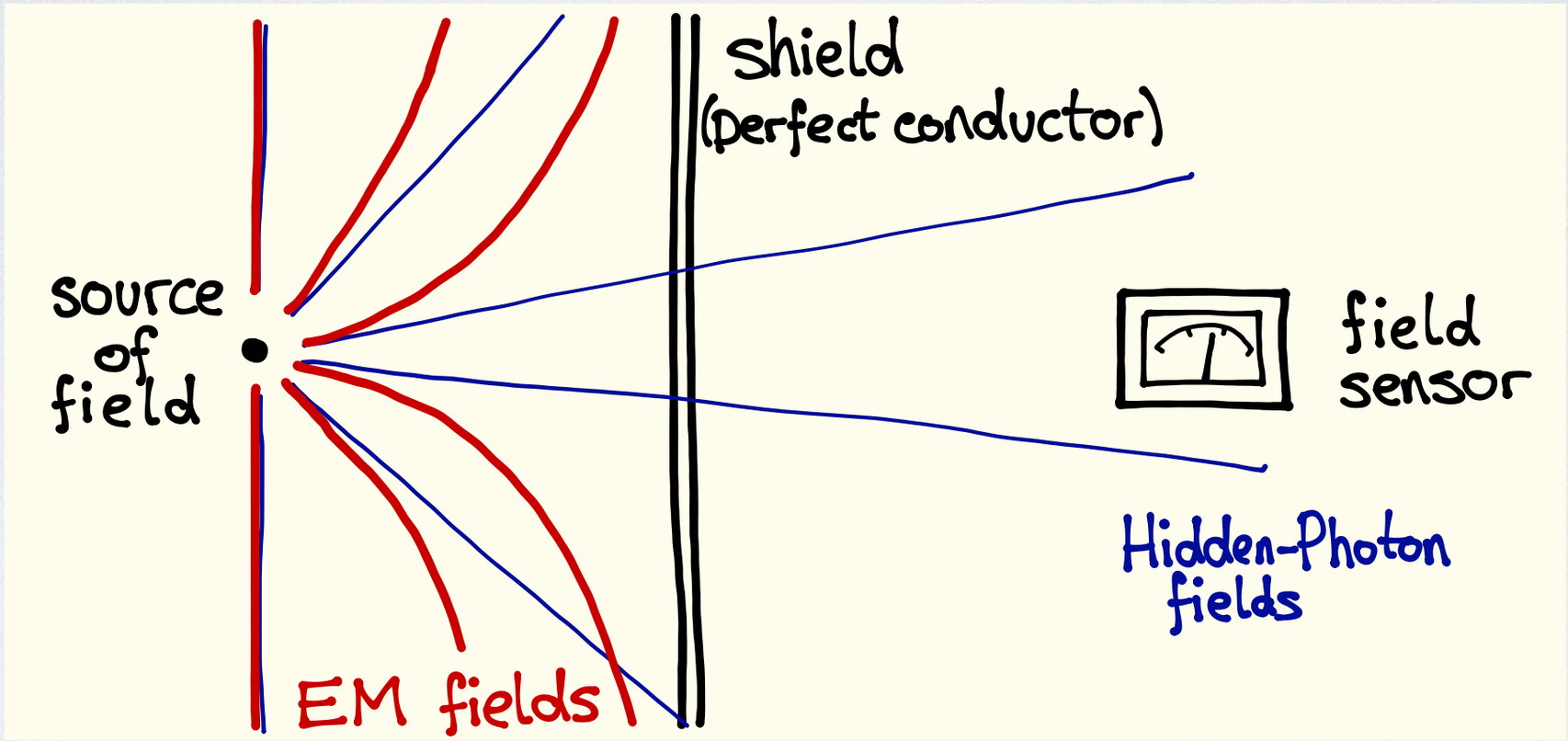


Bounds from stellar cooling by *longitudinal mode* production

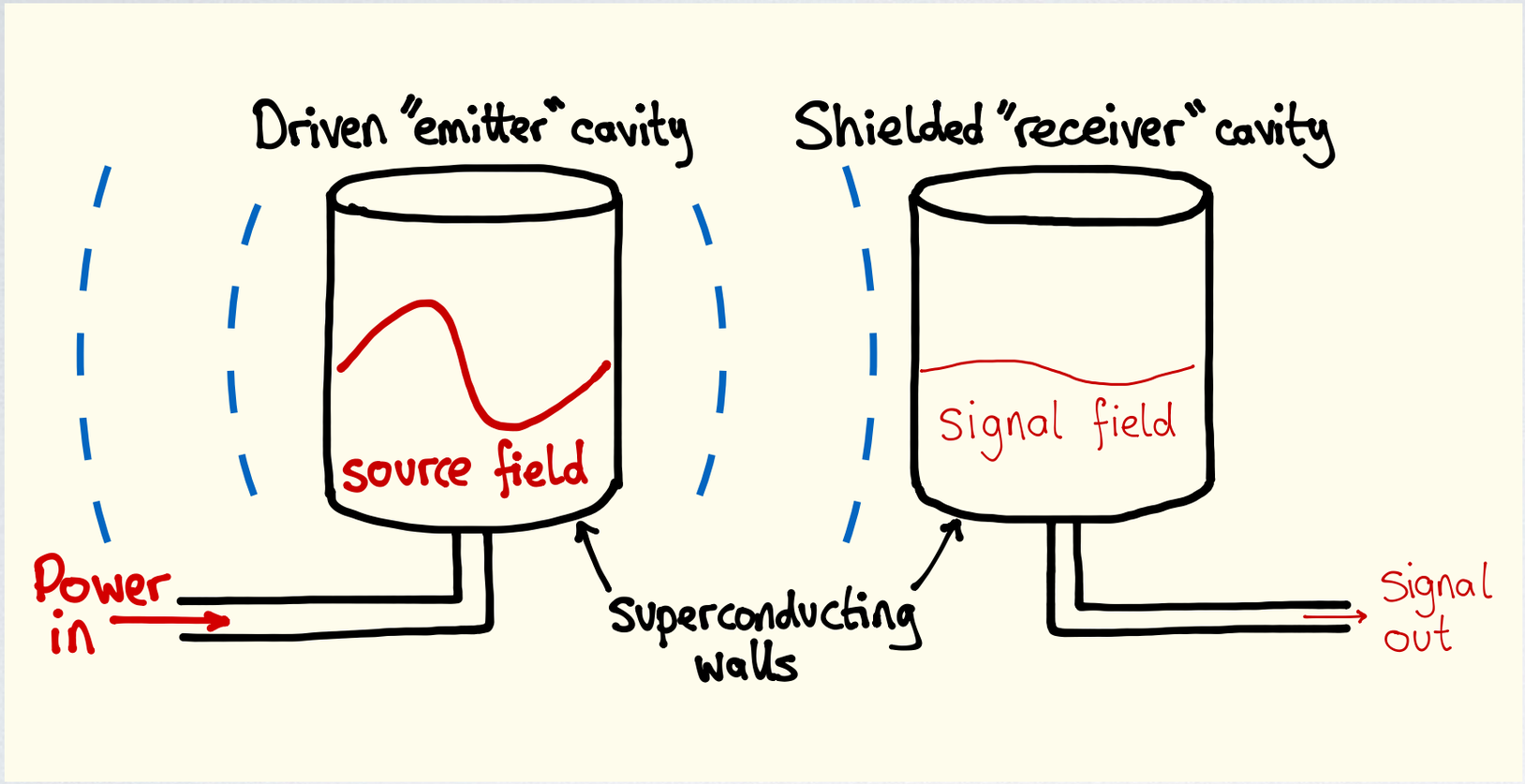
An, Pospelov & Pradler 1302.3884

LIGHT THROUGH WALLS SEARCHES

Fields leak through shields



MICROWAVE CAVITIES ARE IDEAL



Jaeckel & Ringwald
0707.2063

— amazing resonant enhancement: $Q \sim 10^{10}$
— 2 cavities can be tuned to same frequency
— self-shielding

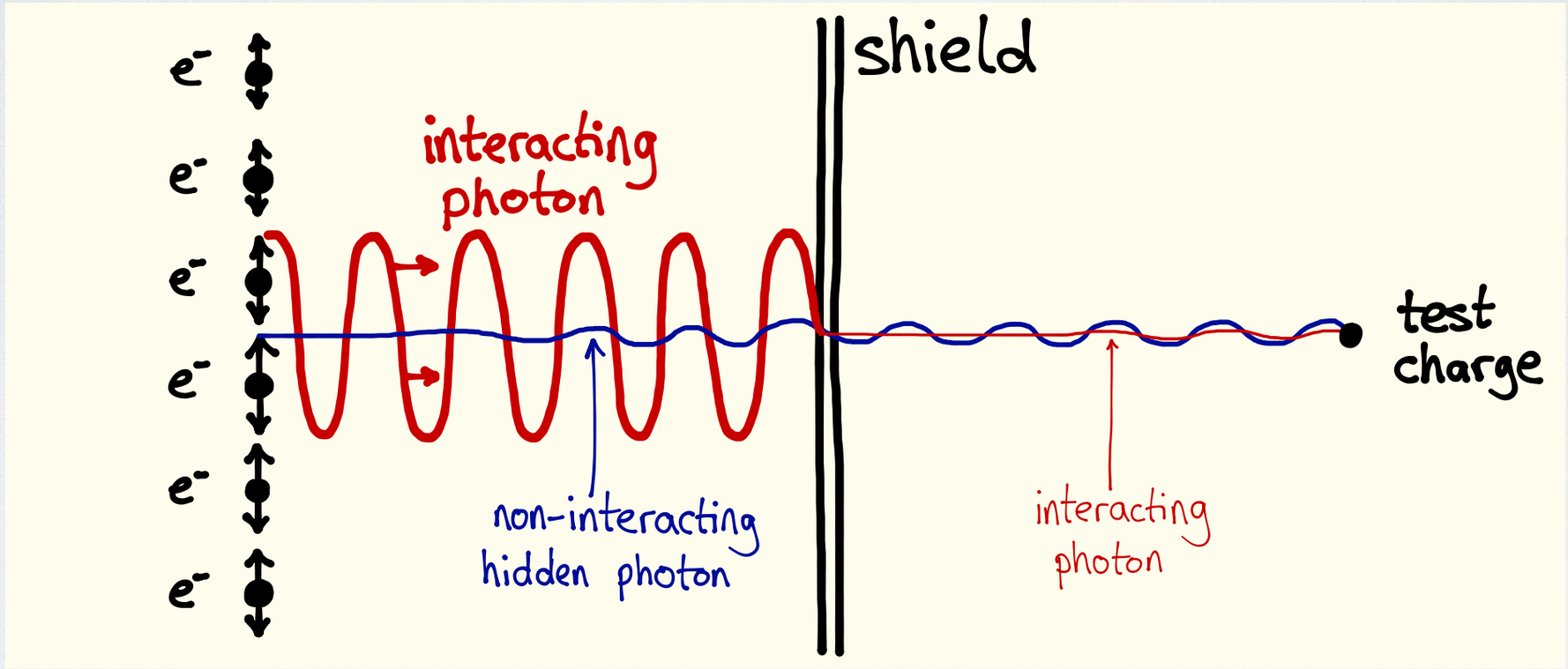
Early-stage experiments already carried out

Povey et al 1003.0964 ADMX 1007.3766 CROWS 1310.8098

With Transverse Modes

Can use interaction basis (as in neutrino oscillation)

oscillation into non-interacting component → pass through wall → oscillation back into interacting component



$$(E, B)_{\text{detected}} \sim Q\, \varepsilon^2\, (m_\gamma{}^4\, L^2/\omega^2)\, (E, B)_{\text{source}}$$

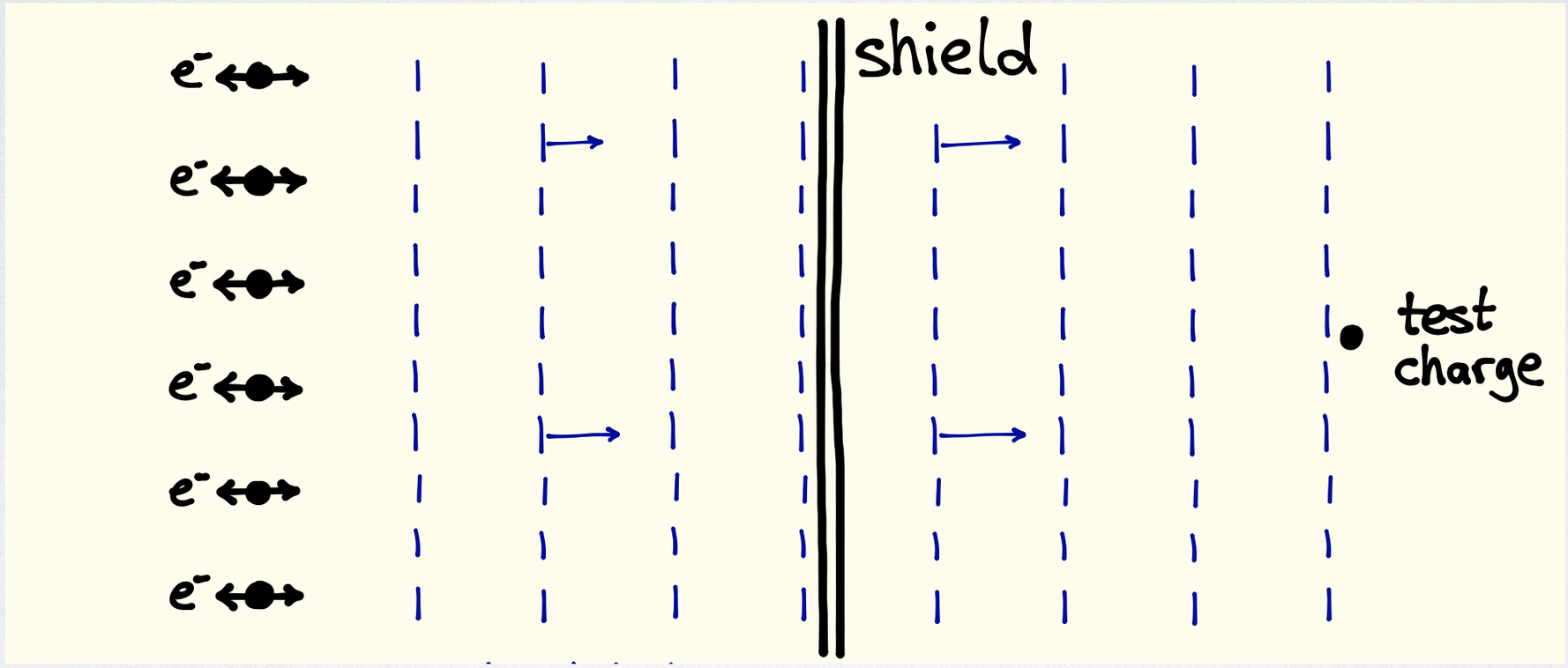
Ahlers et al 0706.2836
Jaeckel & Ringwald 0707.2063

With the Longitudinal Mode

Hidden photon longitudinal mode is also (weakly) produced

Passes through all shielding

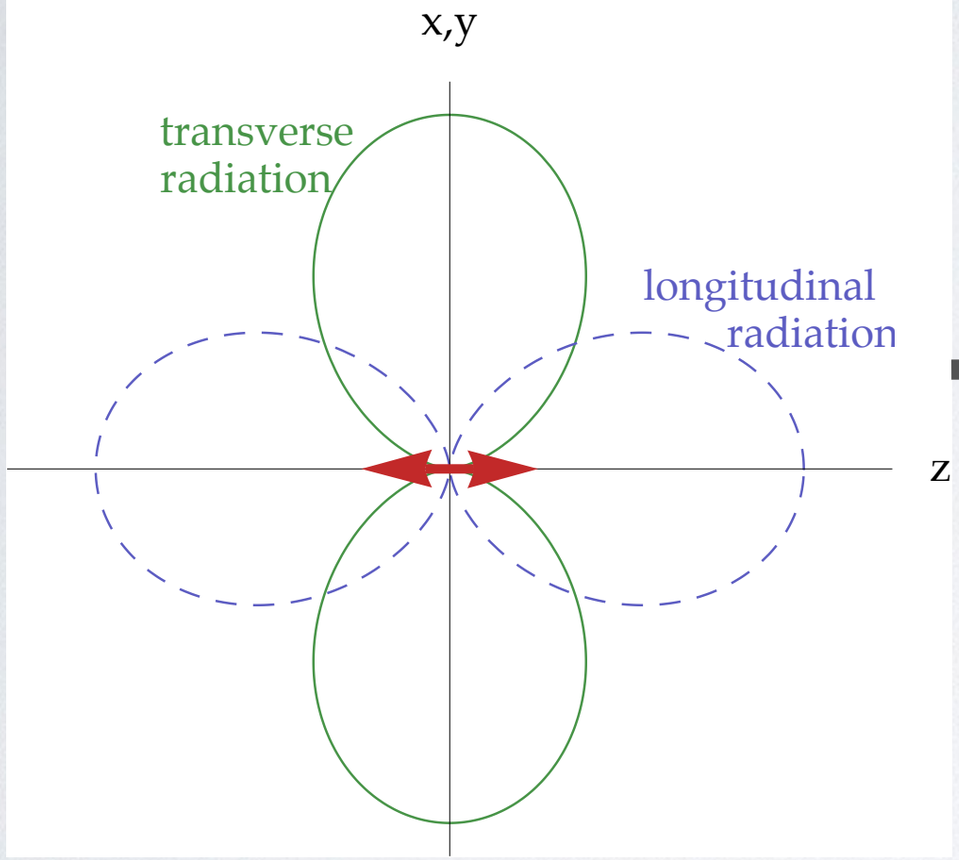
Parametrically stronger signal than transverse modes



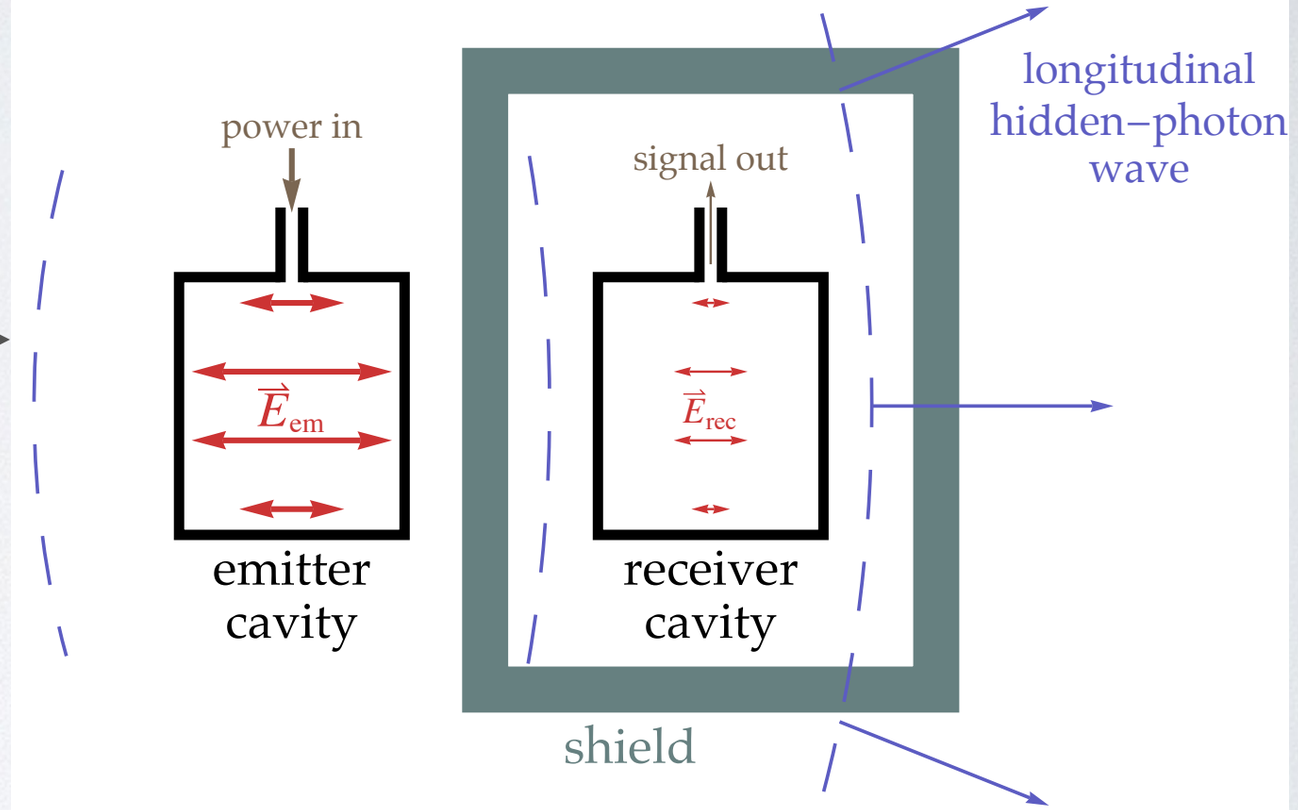
transverse:	$(E, B)_{\text{detected}} \sim Q\, \varepsilon^2\, (m_\gamma{}^4\, L^2/\omega^2)\, (E, B)_{\text{source}}$
longitudinal:	$(E, B)_{\text{detected}} \sim Q\, \varepsilon^2\, (m_\gamma{}^2/\omega^2)\, (E, B)_{\text{source}}$

USING THE LONGITUDINAL MODE

Radiation pattern of EDM



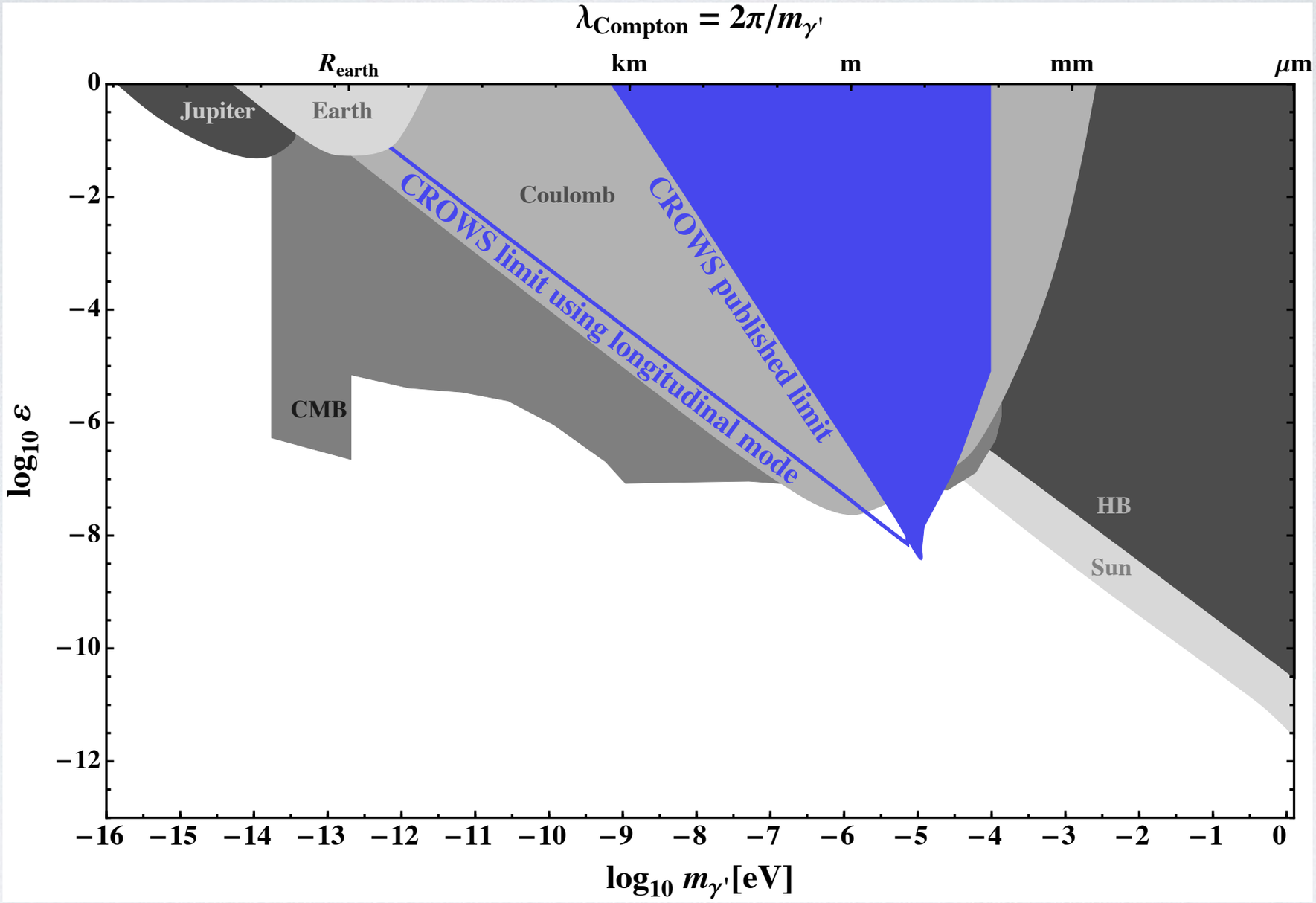
Cavity Orientation



transverse: $(E, B)_{detected} \sim Q\ \varepsilon^2\ (m_{\gamma'}{}^4\ L^2/\omega^2)\ (E, B)_{source}$

longitudinal: $(E, B)_{detected} \sim Q\ \varepsilon^2\ (m_{\gamma'}{}^2/\omega^2)\ (E, B)_{source}$

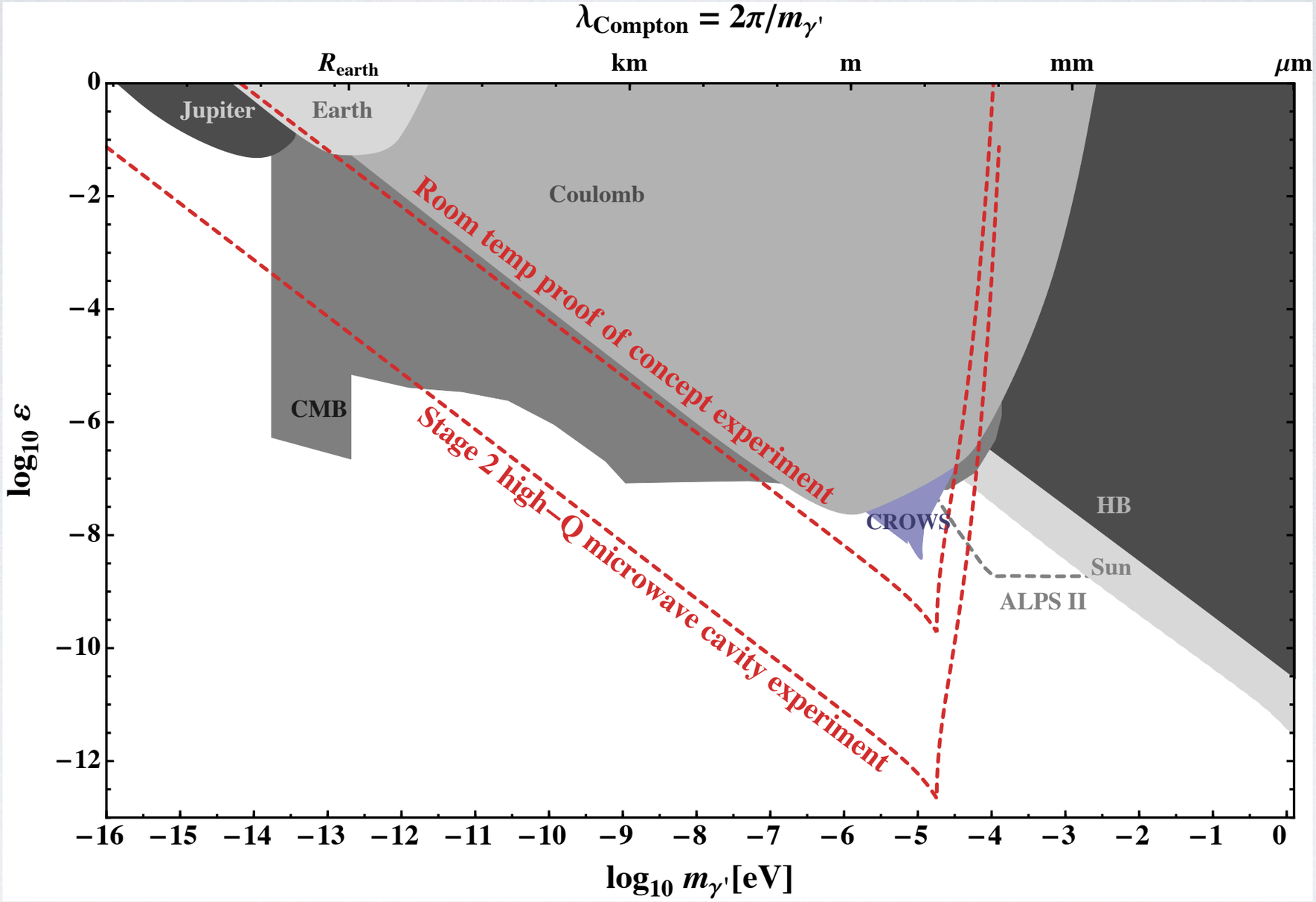
PARAMETRICALLY ENHANCED LIMIT



CROWS: 1310.8098

P.Graham, J.M., S. Rajendran & Y. Zhao 1406.xxxx

Reach

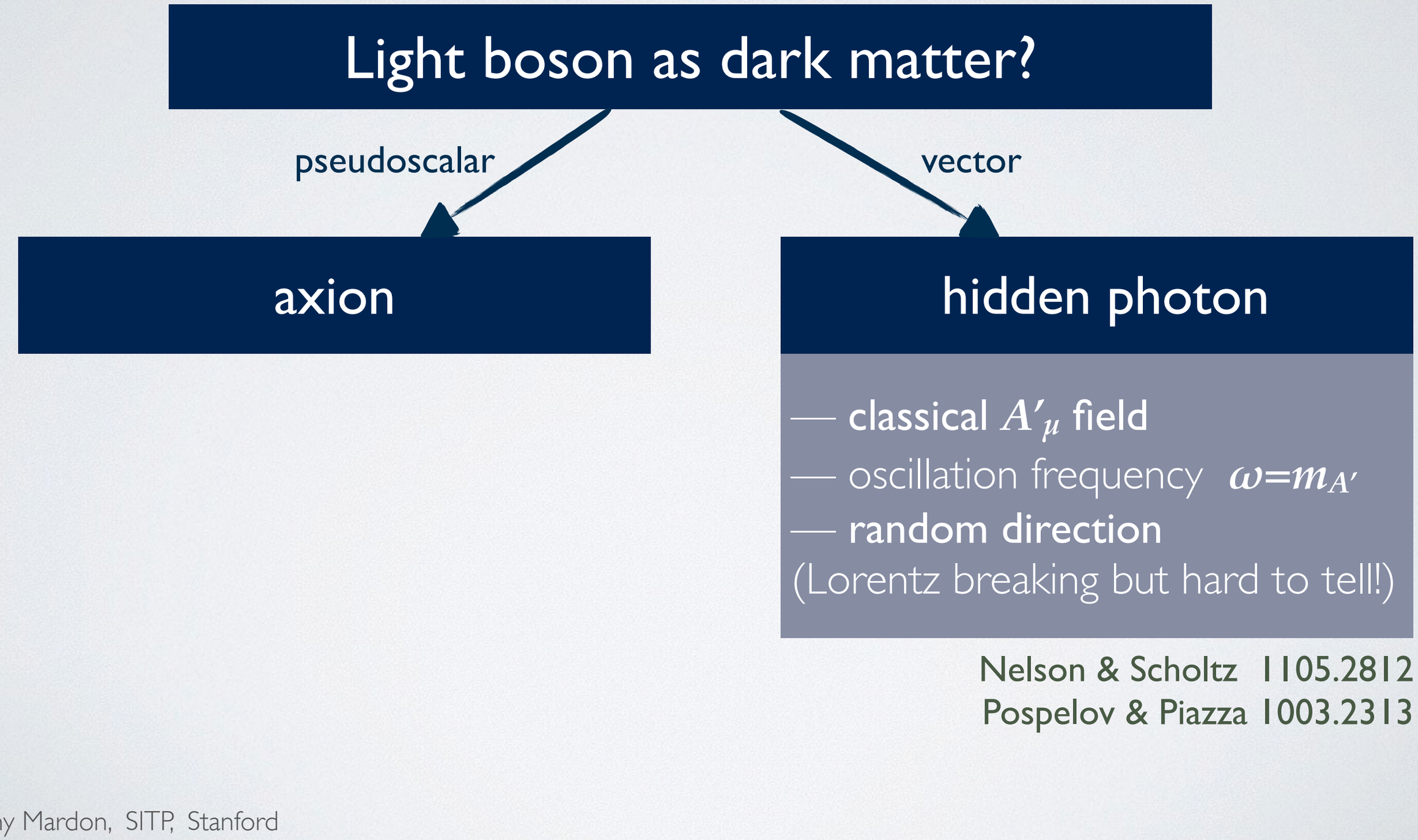


Graham, J.M., Rajendran & Zhao w. K. Irwin, S. Tantawi, V. Bharadwaj
in progress

Scanning for Hidden Photon Dark Matter with a High-Q Radio

Jeremy Mardon, SITP, Stanford

HIDDEN-PHOTONS AS DARK MATTER



Nelson & Scholtz 1105.2812
Pospelov & Piazza 1003.2313

HIDDEN-PHOTONS AS DARK MATTER

A "**hidden electric field**" that penetrates shielding

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

— cavity size restricts mass range

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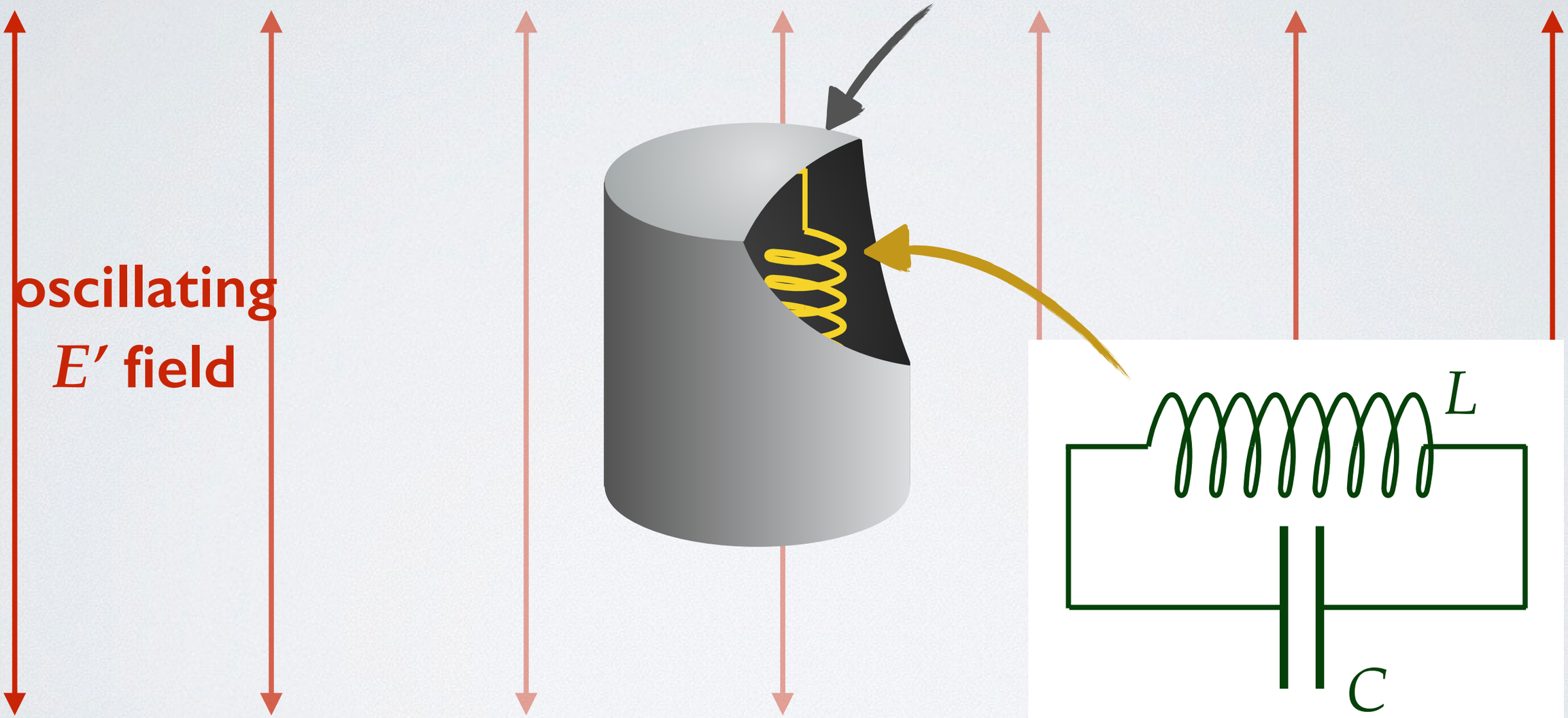
LC circuits

— can be high Q

— much wider and lower frequency range than cavities

EXPERIMENTAL SETUP

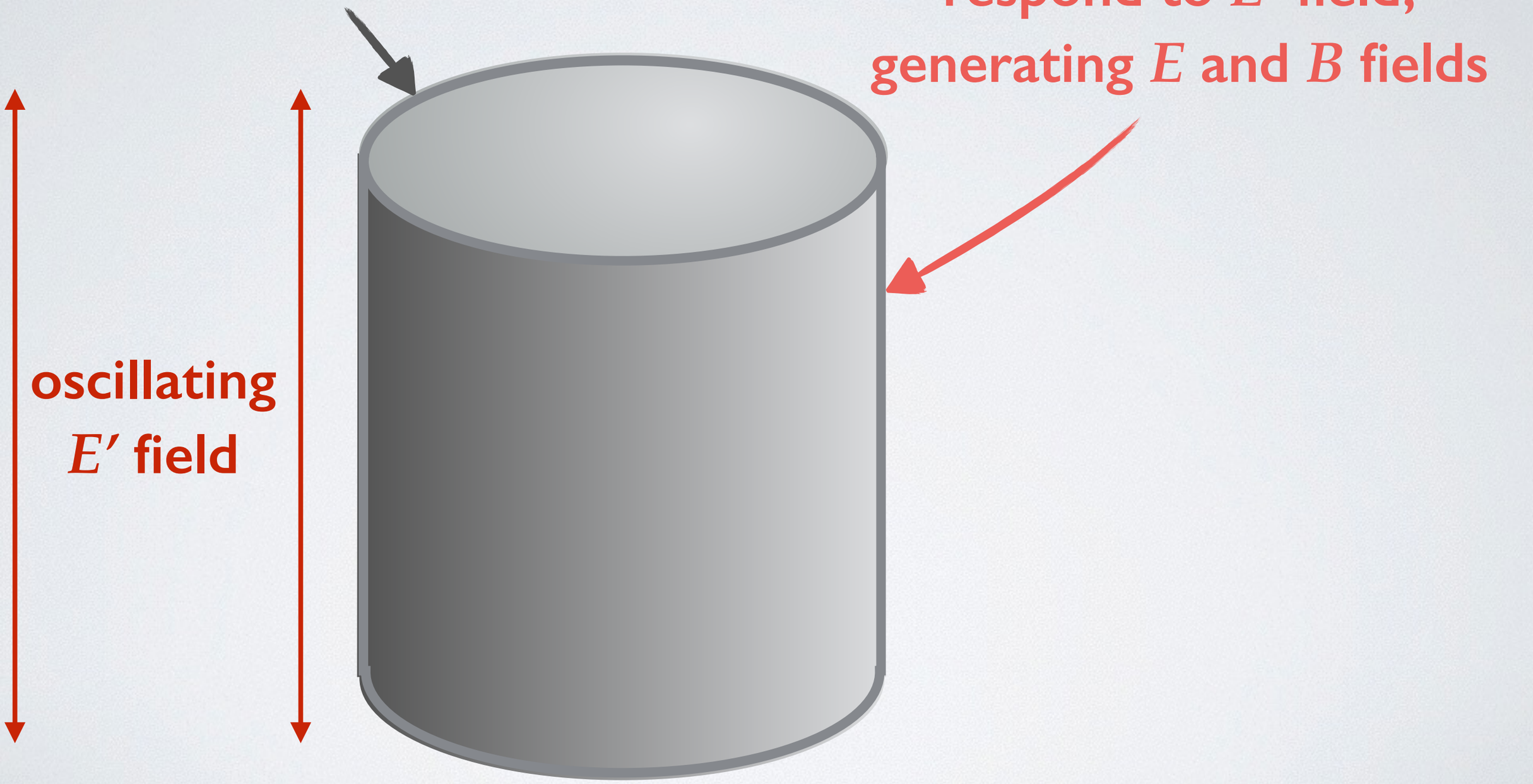
Metal box to shield backgrounds



Tunable resonant LC circuit (a radio)

THE SIGNAL INSIDE A SHIELD

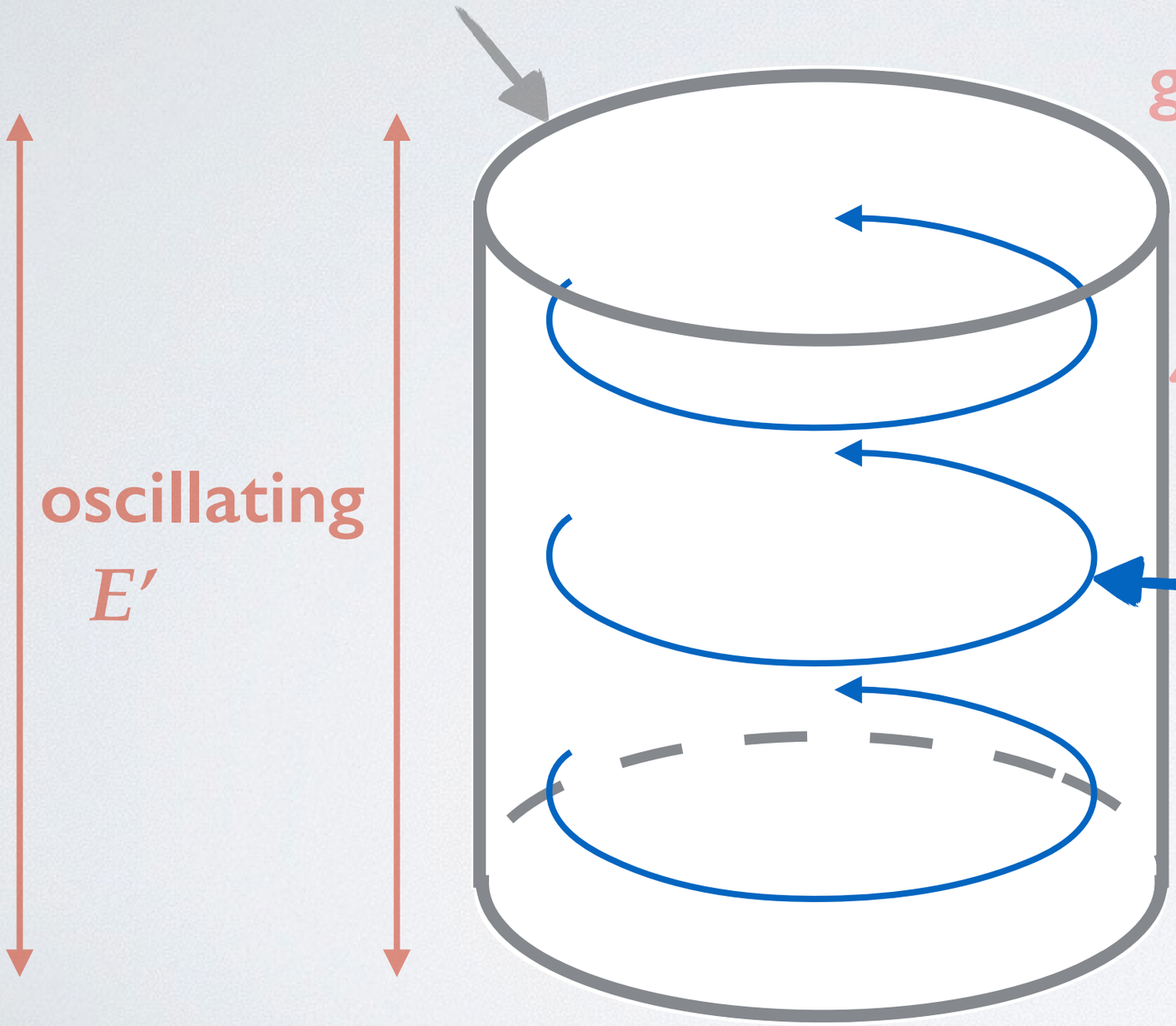
Metal box to shield backgrounds



THE SIGNAL INSIDE A SHIELD

Metal box to shield backgrounds

conduction electrons in wall respond to generating



net effect is a B field inside the box

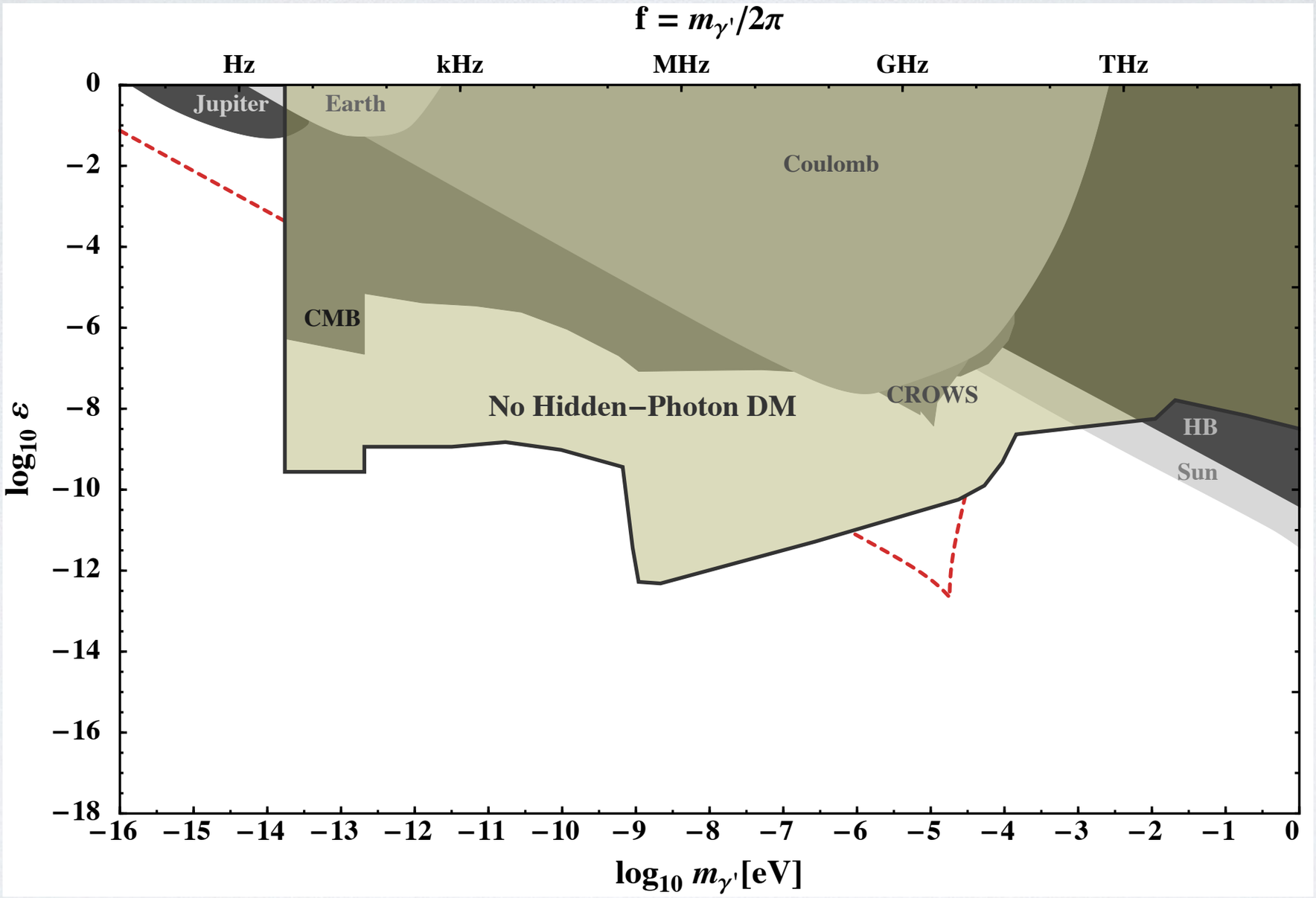
$$B \sim \varepsilon\,(m_{\gamma'} R) \times 10^{-5}\ \mathrm{T}$$

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

ASTROPHYSICAL CONSTRAINTS

Astro constraints from resonant conversion of hidden photons to plasma excitations

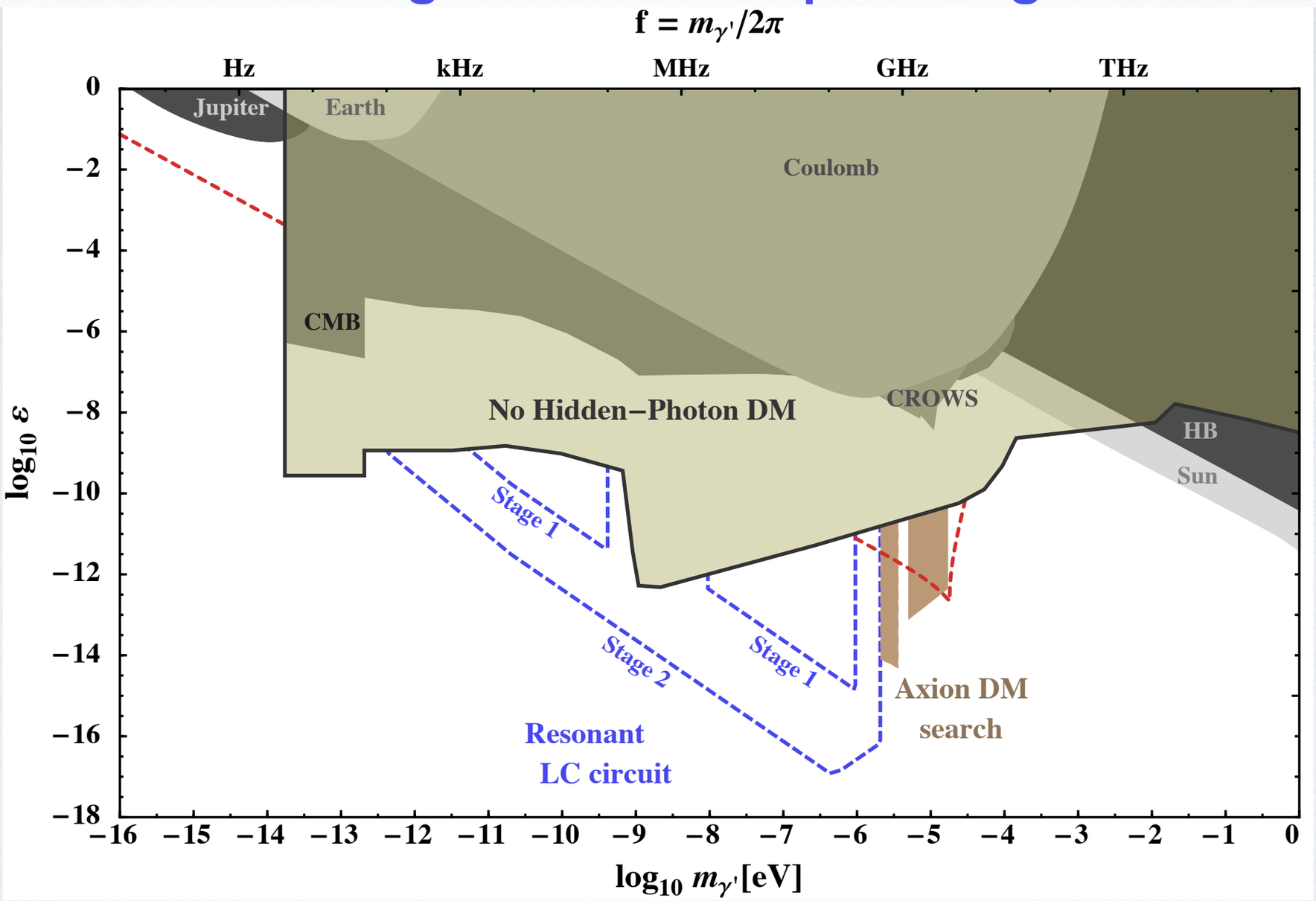
Arias et al 1201.5902



REACH

LC oscillator search: size ~ 1m Q~10^6 ~1 month scan per decade

Stage 1: room temp Stage 2: T~0.1K



Graham, J.M., Rajendran & Zhao w. S. Chaudhuri & K. Irwin
in progress

GENERATING DM ABUNDANCE

— Misalignment + large coupling to $\mathcal{R}$ Arias et al 1201.5902

— May be several other ways (work in progress)

— One novel possibility:

DM abundance generated purely gravitationally

Hidden-photon **longitudinal mode sourced by inflationary fluctuations**

Evolution automatically suppresses isocurvature fluctuations

— **BICEP-II** $\longrightarrow$ ω**~100 MHz**

— Lower infl. scale $\longrightarrow$ larger mass

P.Graham, J.M., S. Rajendran & Y. Zhao, preliminary

VECTOR DM GENERATED BY INFLATIONARY FLUCTUATIONS

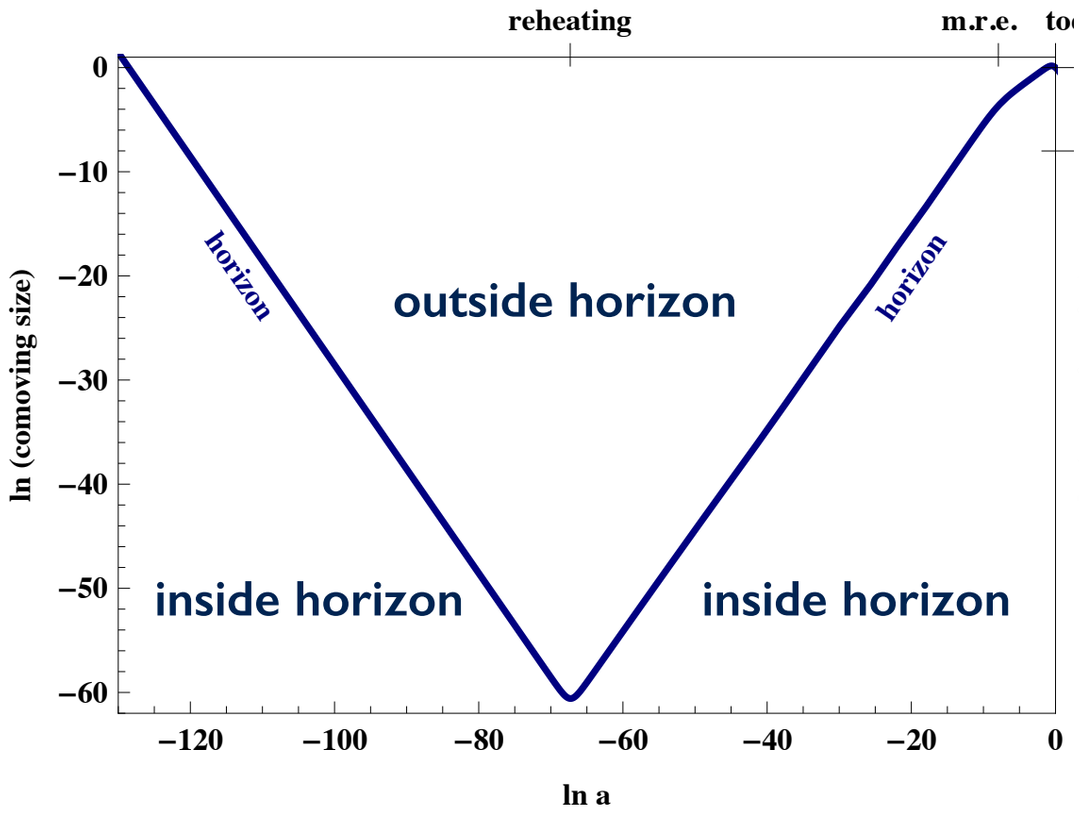
(preliminary)

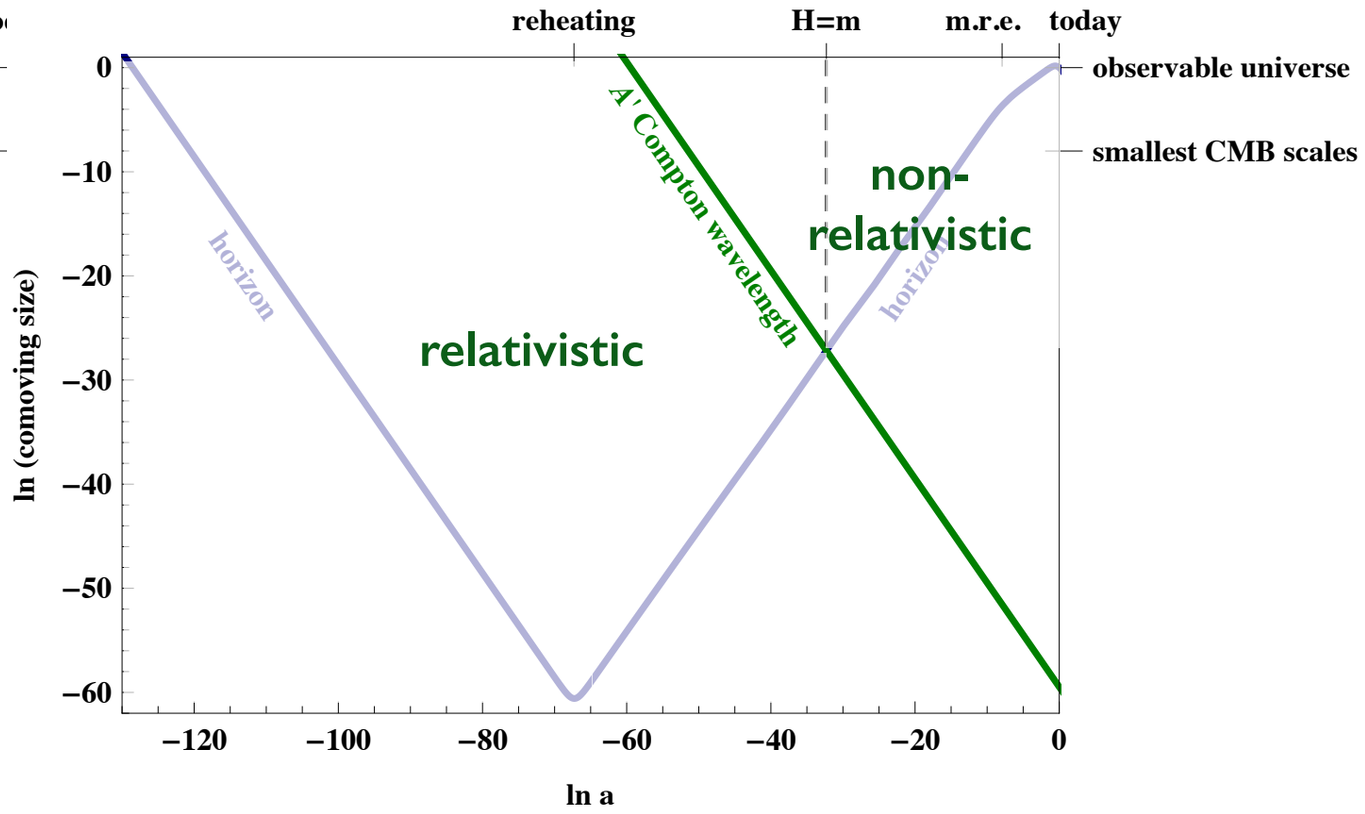
Jeremy Mardon, SITP, Stanford

COSMOLOGICAL EVOLUTION

(WITH STUCKELBERG MASS)

Evolution of A' modes in expanding universe





COSMOLOGICAL EVOLUTION

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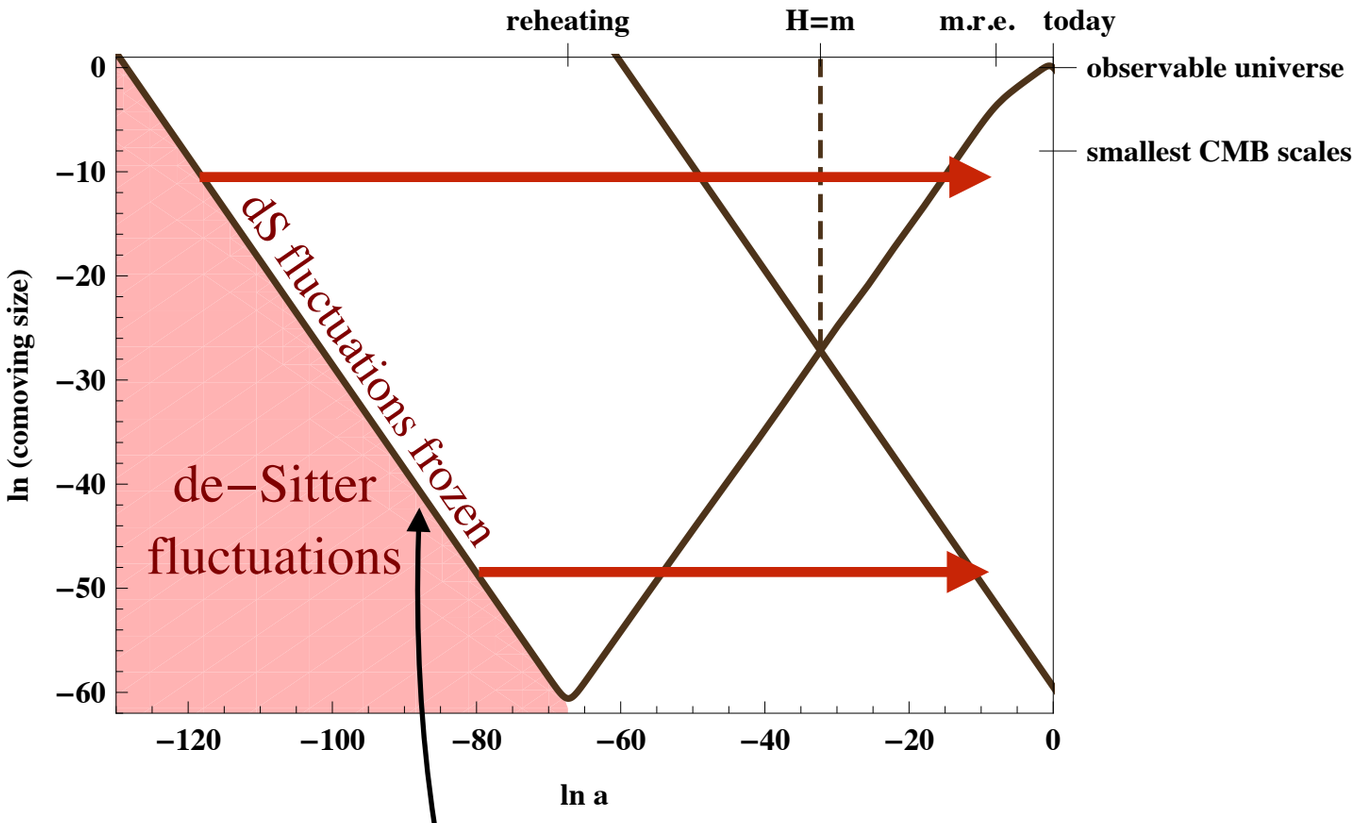
Evolution of A' longitudinal modes in expanding universe



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

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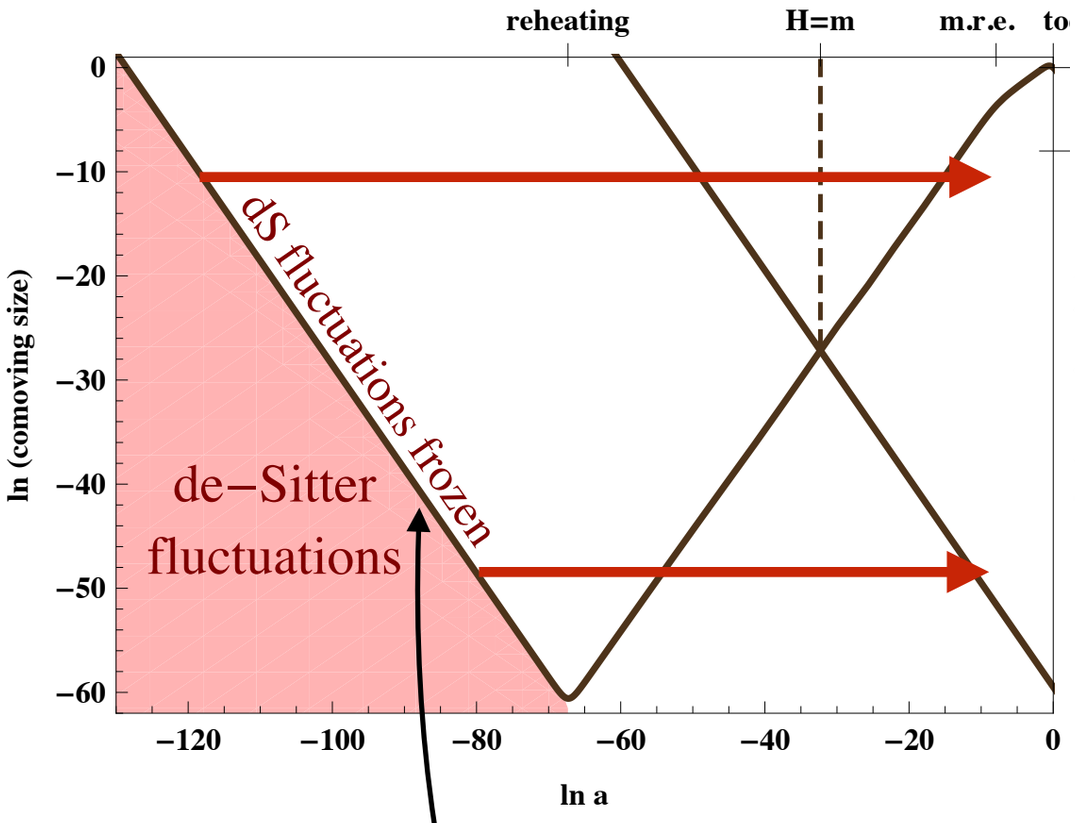

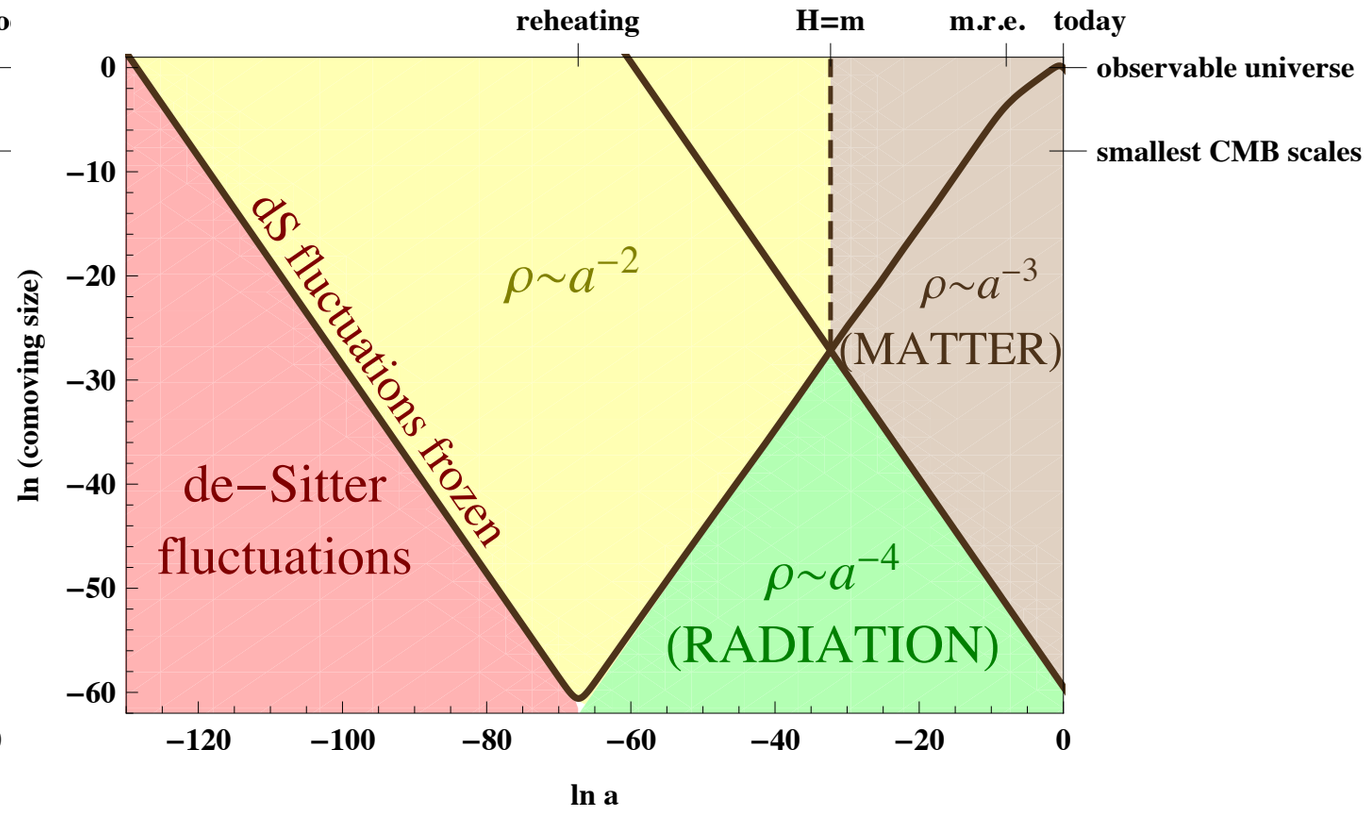

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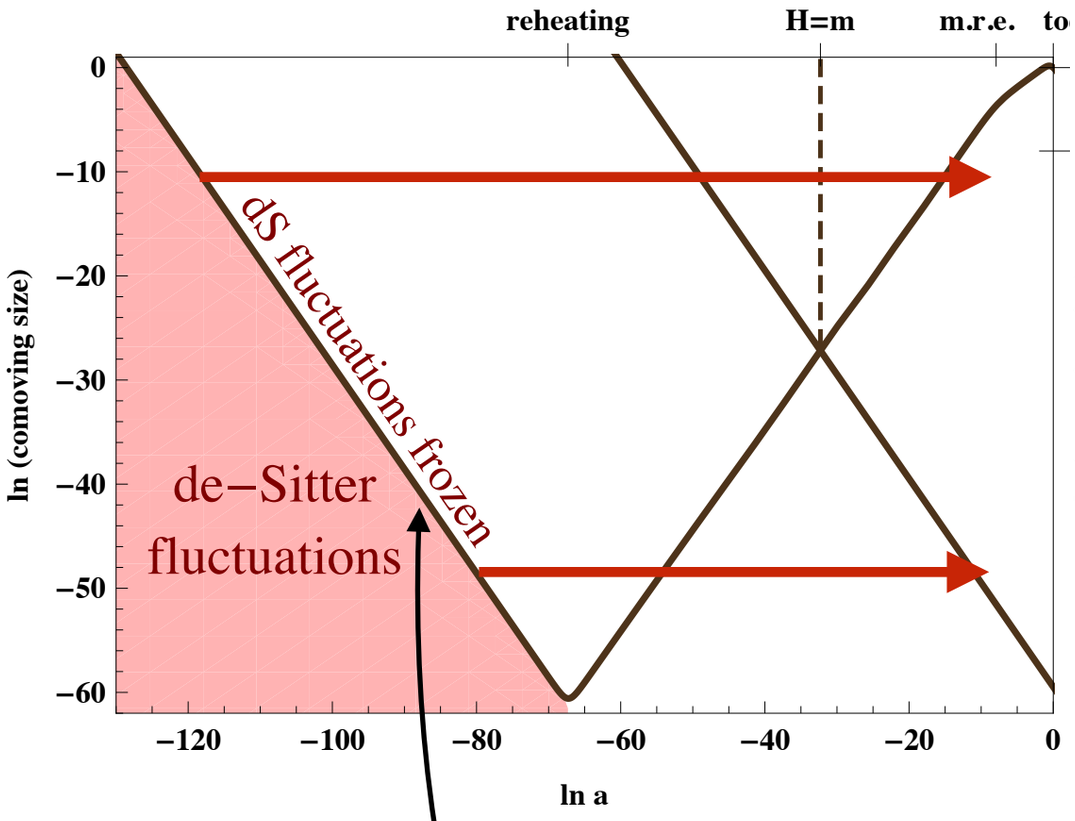

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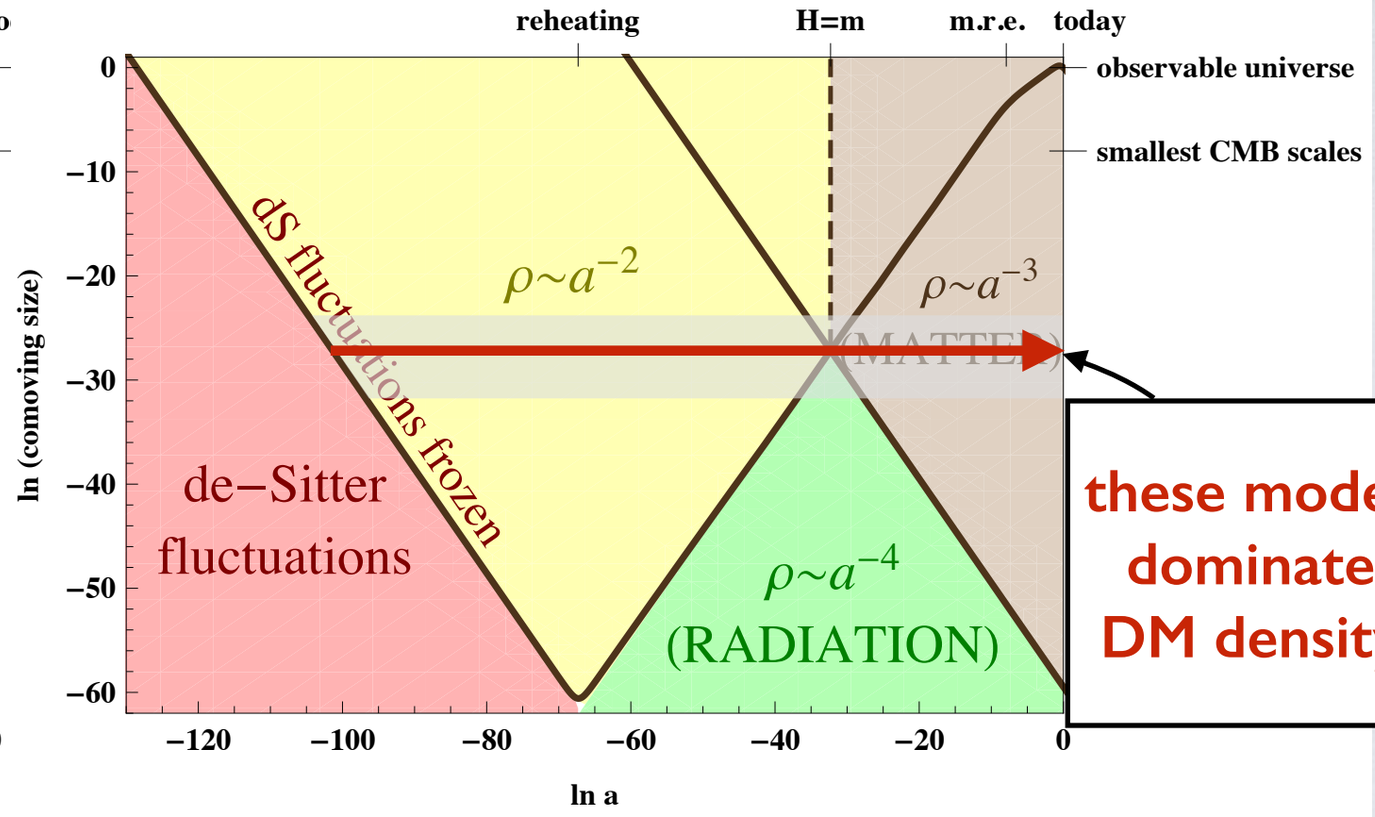

these modes dominate DM density

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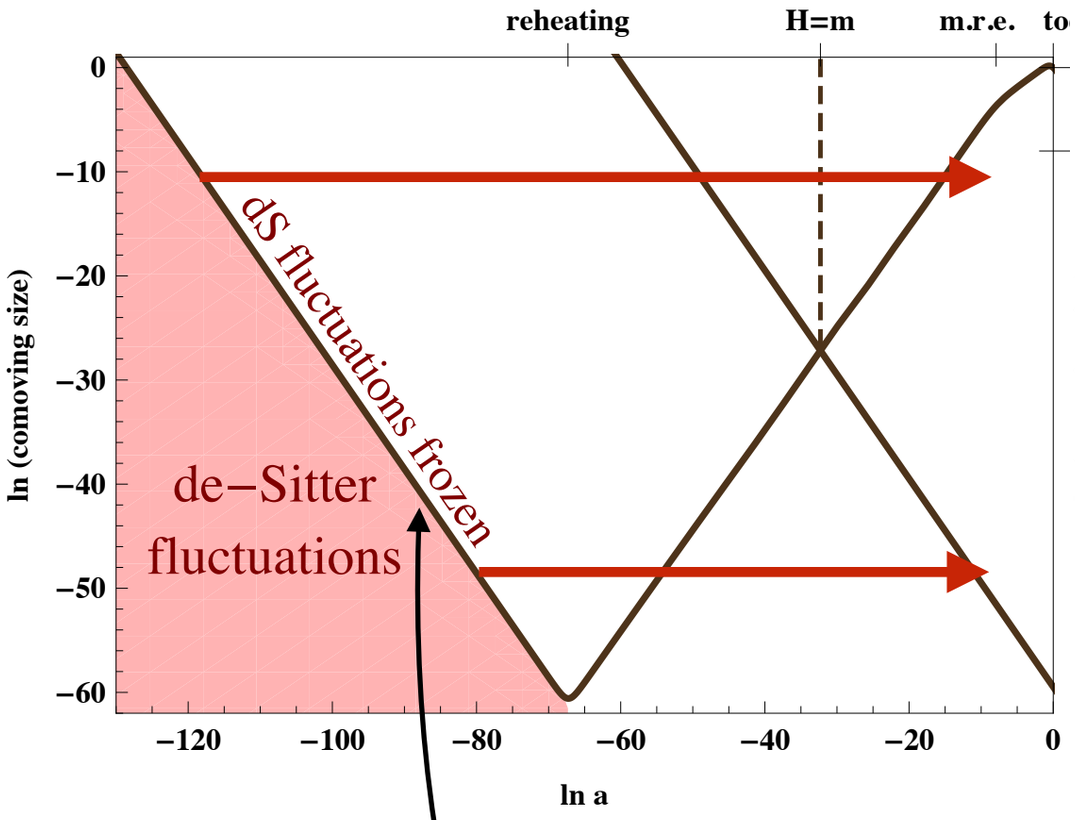
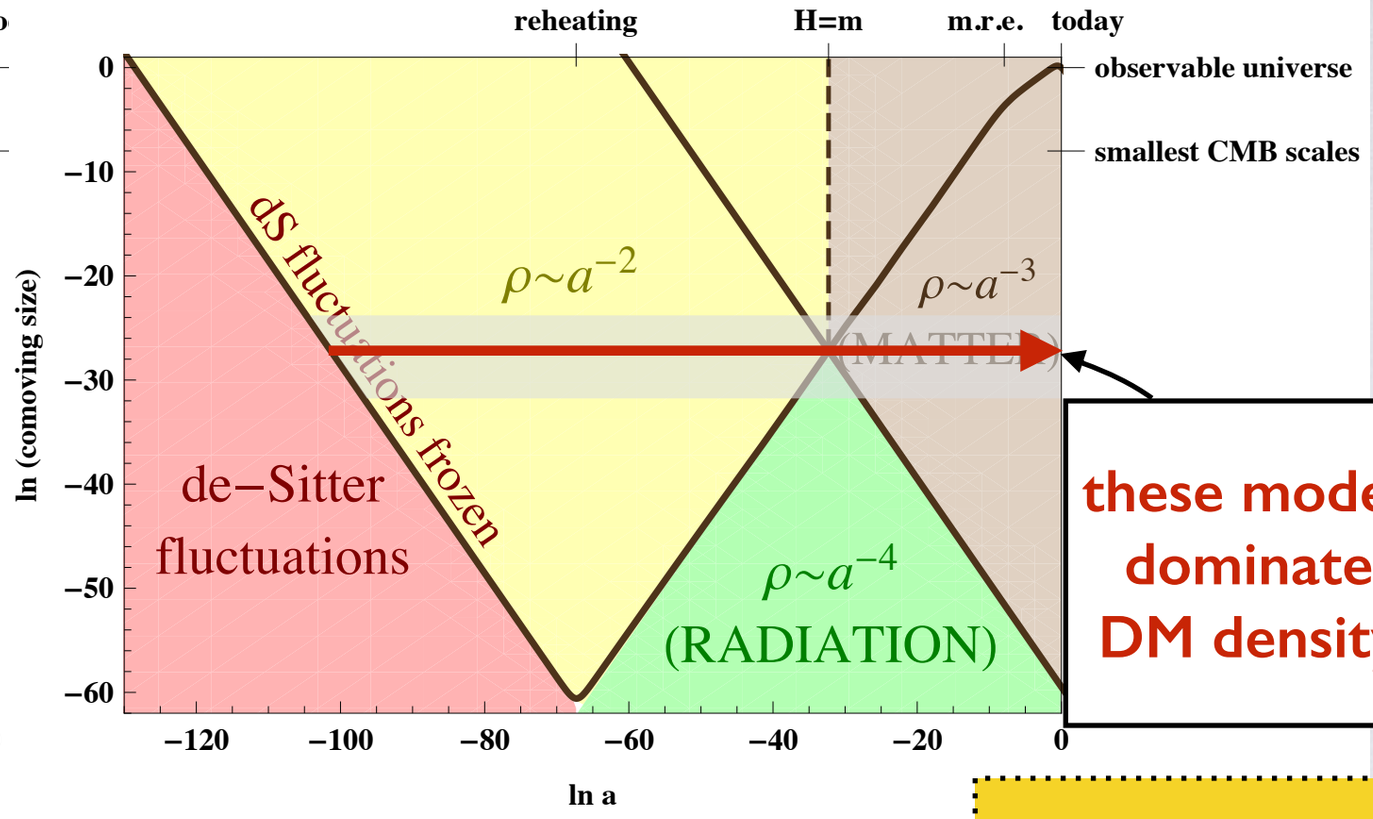




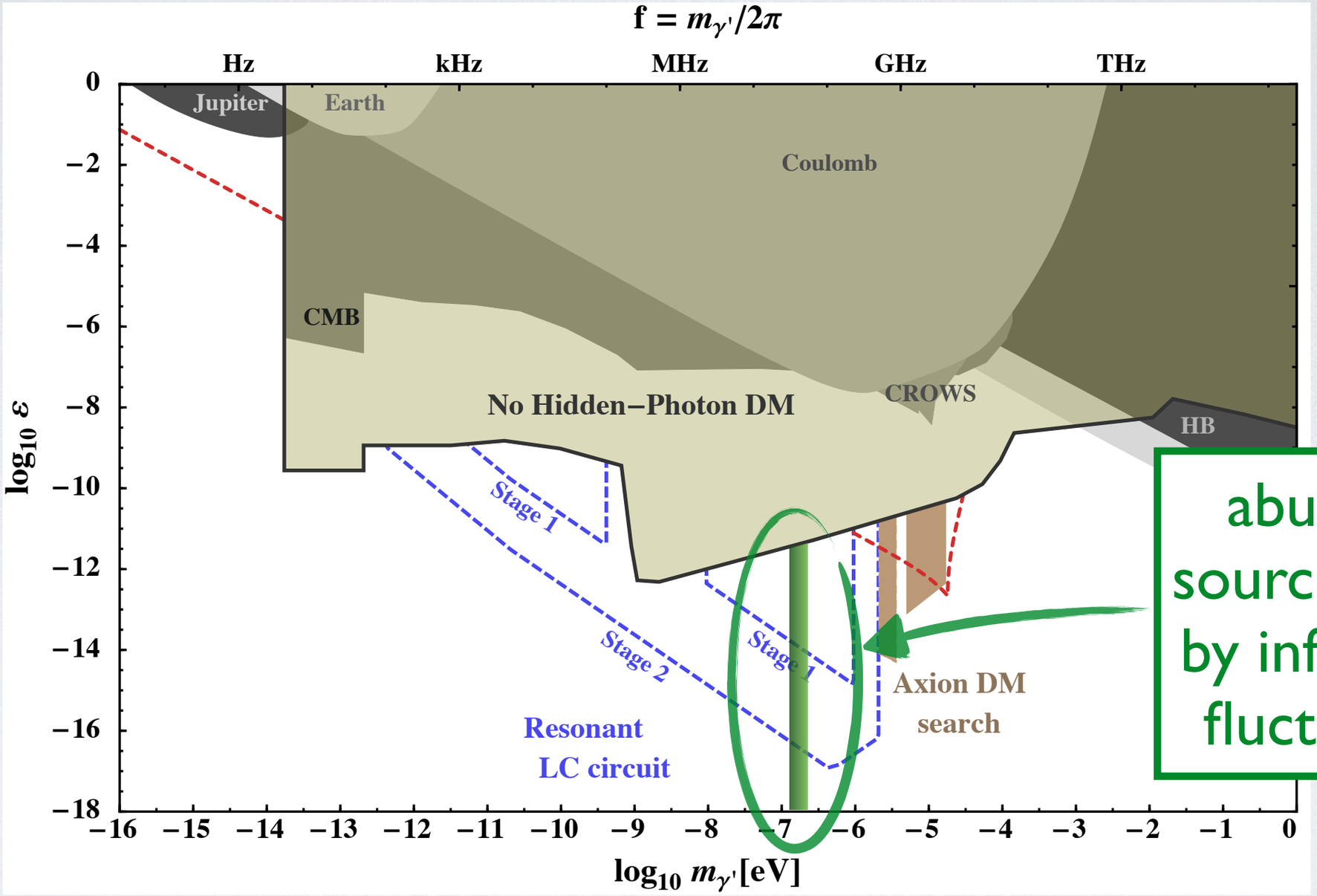
these modes dominate DM density

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

preliminary

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

Reach



abundance sourced purely by inflationary fluctuations?

P.Graham, J.M., S. Rajendran & Y. Zhao, preliminary

Conclusions

Hidden photons are a natural window into hidden sectors

— A natural window into hidden sectors

— Could be Dark Matter

— Why not?

Neat ways to probe with table-top-scale experiments:

— Longitudinal mode greatly improves reach of cavity-to-cavity experiments

— Searches using LC circuits will be powerful probes of hidden photon DM over a wide range of masses

Hidden photon DM has an unusual possible production mechanism: purely gravitational production via inflationary fluctuations