New Ultra-light Force Carriers

Precision Tests, Dark Matter, and a New Direct Detection Experiment

work with:

Peter Graham, Surjeet Rajendran & Yue Zhao

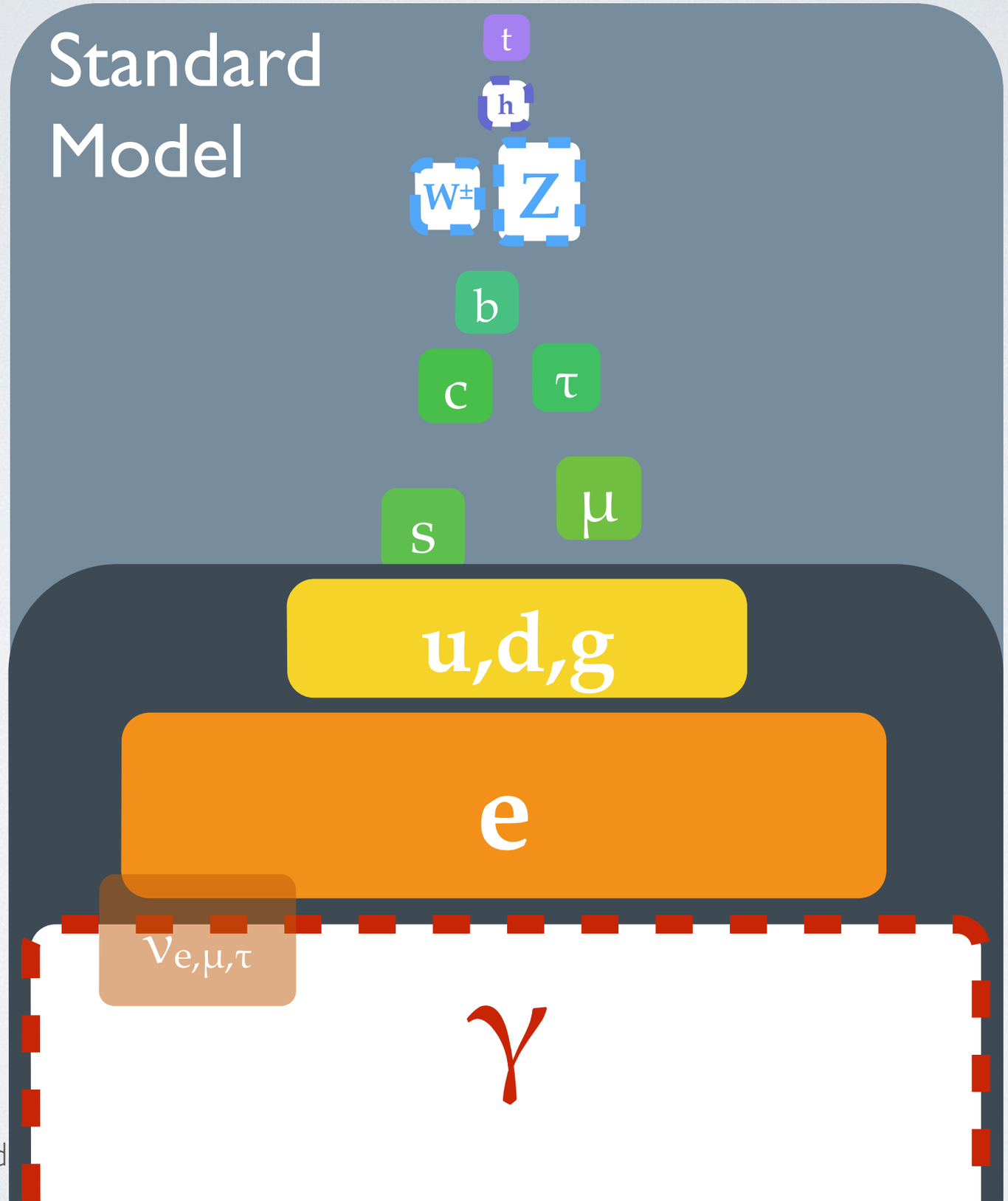
and experimental collaborators:

Sami Tantawi, Vinod Bharadwaj, Kent Irwin, Saptarshi Chaudhuri

Jeremy Mardon, SITP, Stanford

Hidden Photons

Jeremy Mardon, SITP, Stanford


Standard Model
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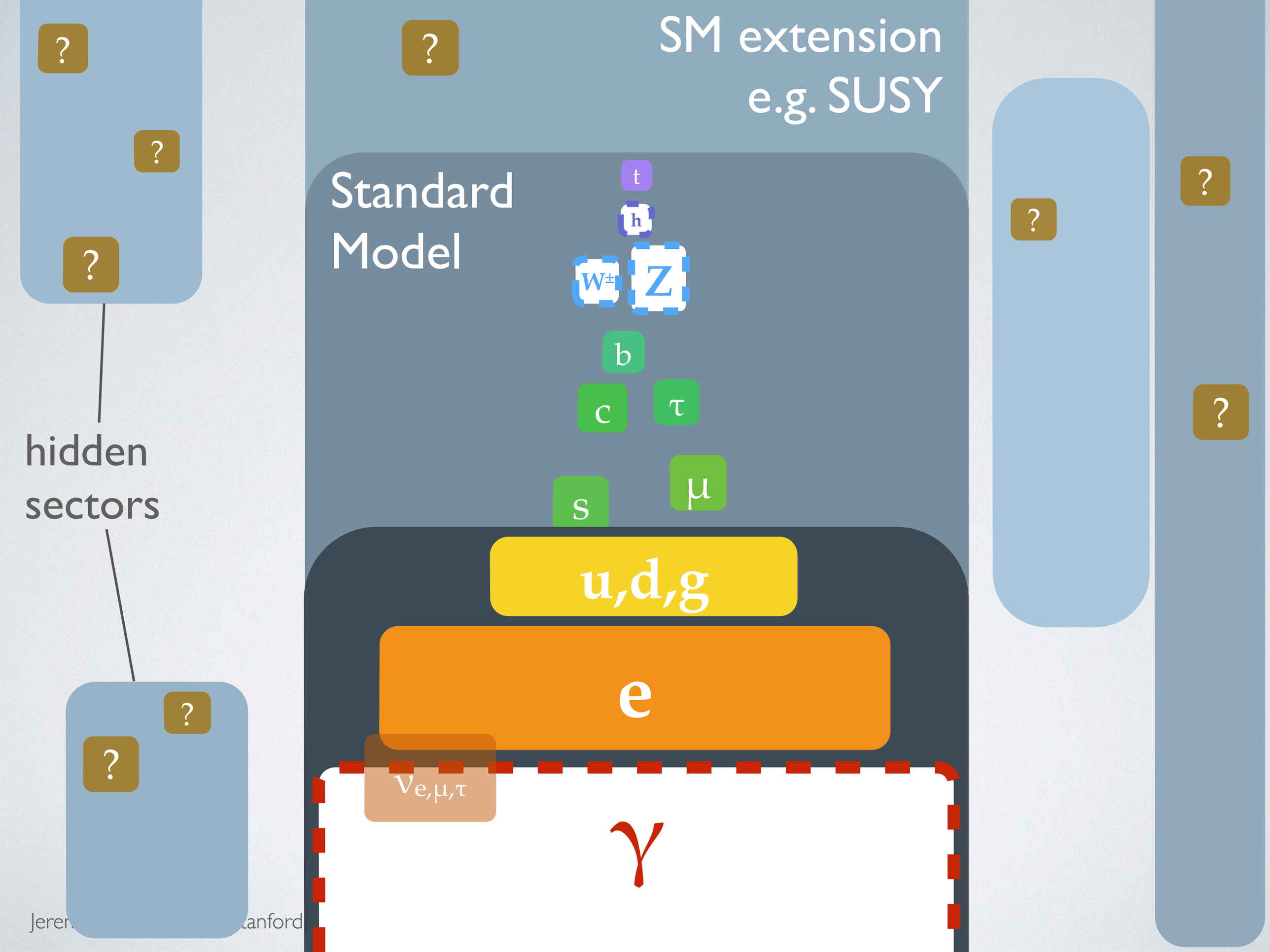
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SM extension e.g. SUSY
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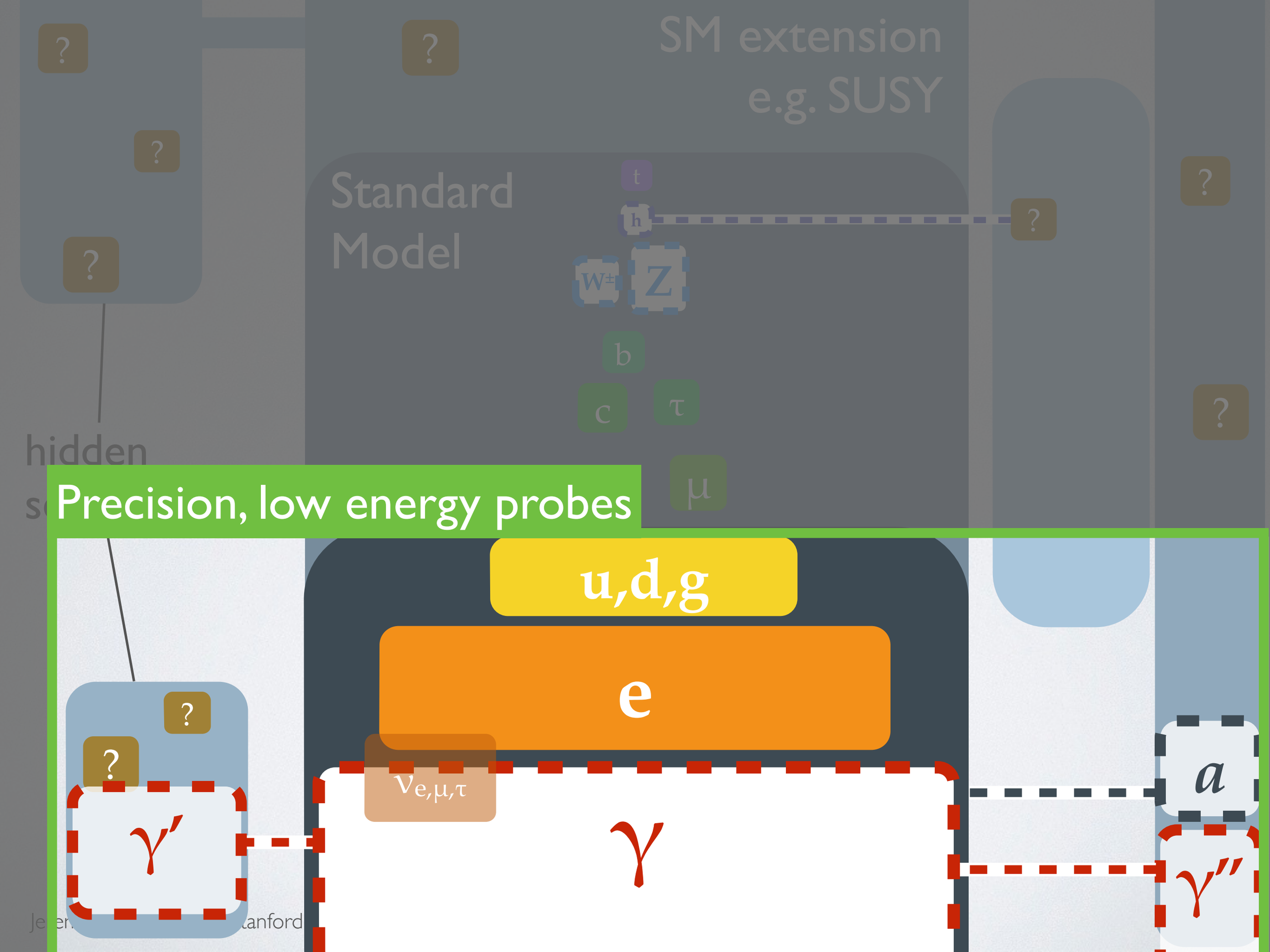
SM extension
e.g. SUSY
Standard
Model
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hidden
Precision, low energy probes
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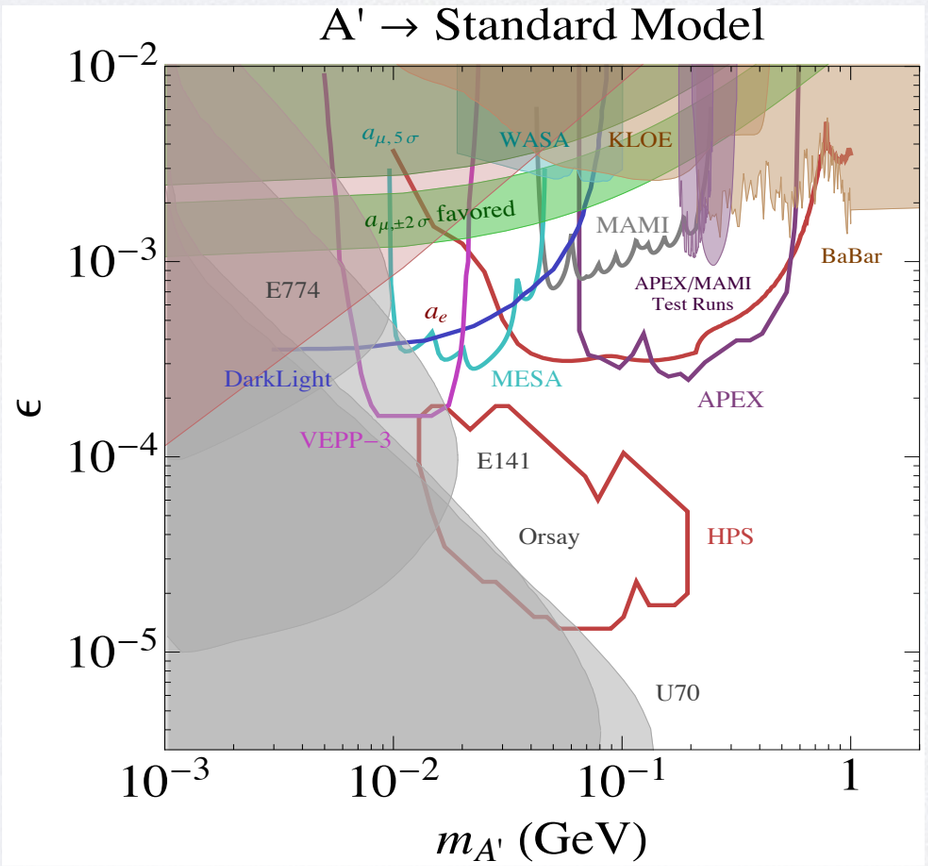
ULTRA-LIGHT HIDDEN PHOTON

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

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

kinetic mixing ε
with photon

small mass
(with no hierarchy problem)



SNOWMASS 1401.6077

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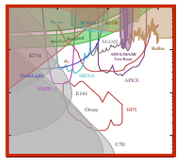

SNOWMASS 1401.6077

ULTRA-LIGHT HIDDEN PHOTONS

To a particle theorist

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

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

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To an experimental physicist

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 PHOTONS

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

New massive particle
⬇
Dark matter candidate

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

EM: — *massless* photon
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EM′: — *massive* hidden photon
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Parametrically Enhanced Light-Through-Walls Searches for Hidden Photons

P.Graham, J.M., S. Rajendran & Y. Zhao 1407.4806

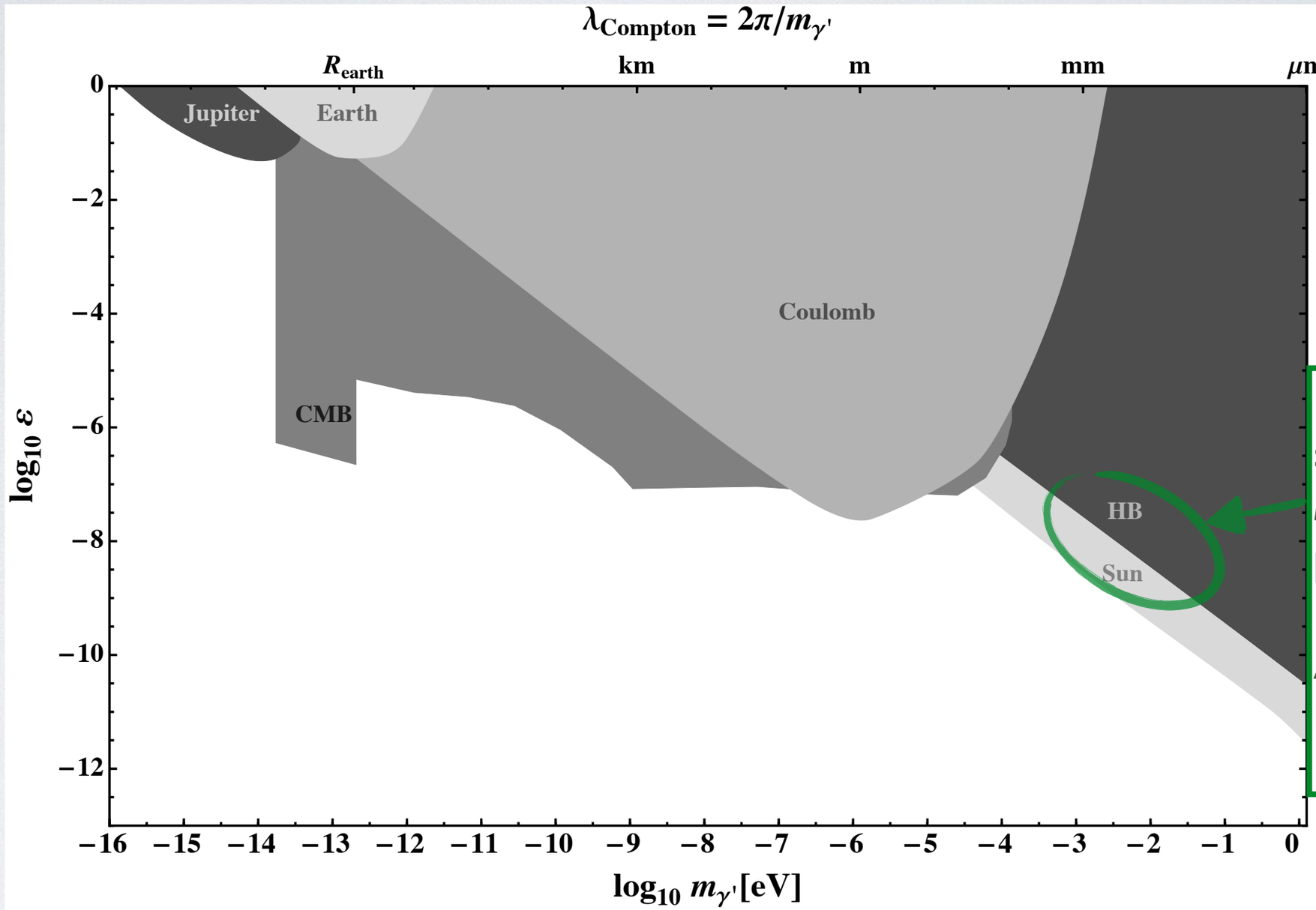
Jeremy Mardon, SITP, Stanford

2 Important Points

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

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

EXISTING BOUNDS



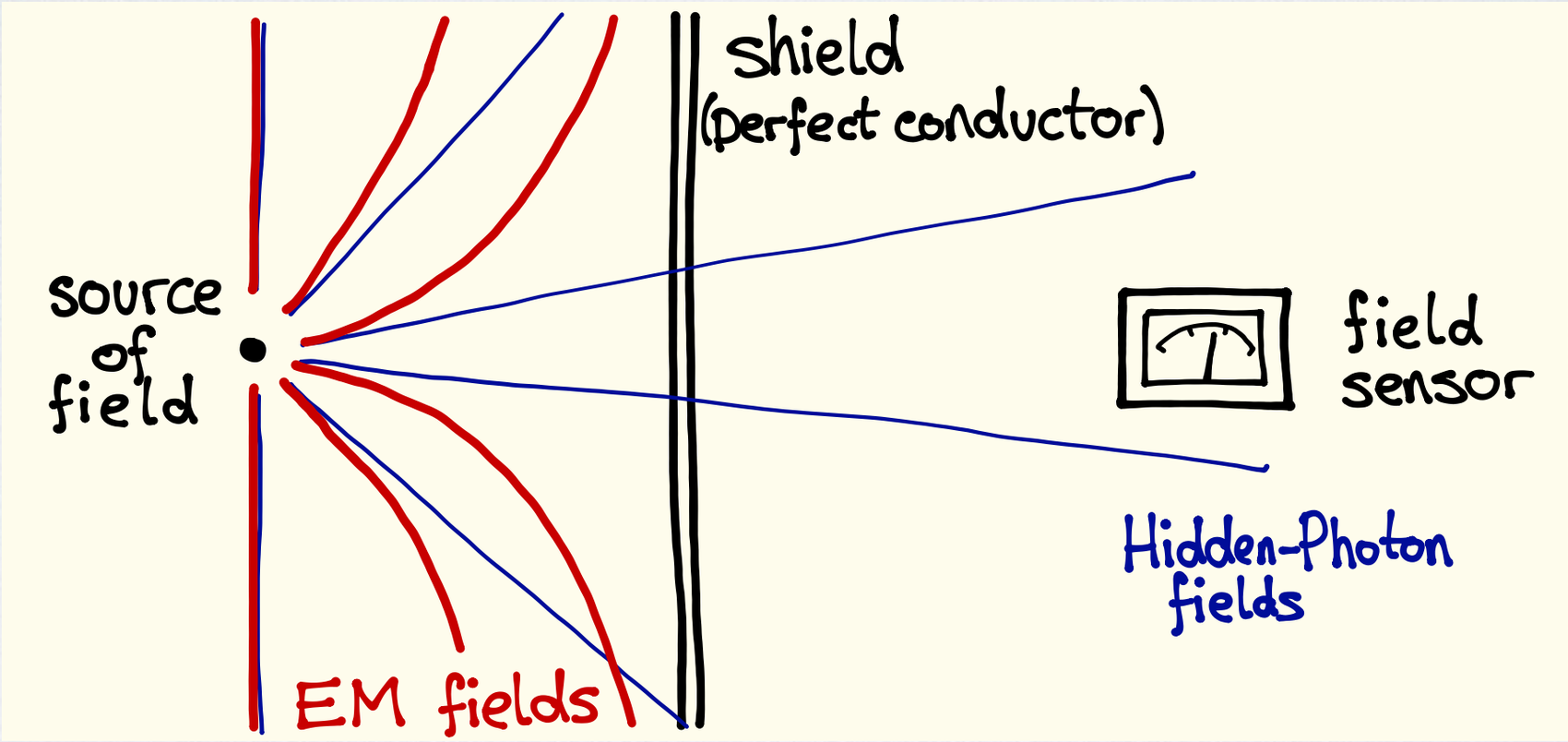
Bounds from stellar cooling by *longitudinal mode* production

An, Pospelov & Pradler 1302.3884

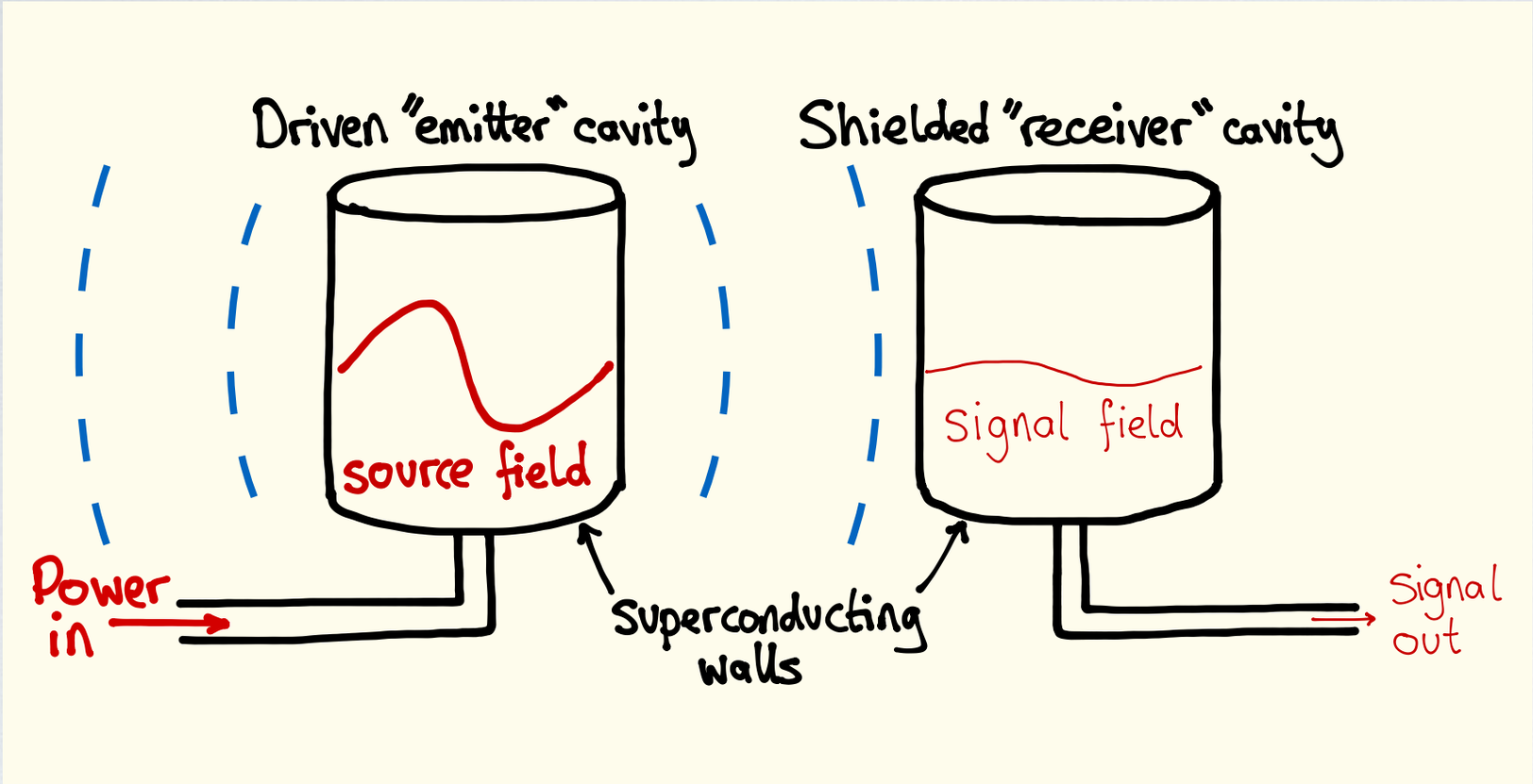
Jaeckel & Ringwald 1002.0329

LIGHT THROUGH WALLS SEARCHES

Fields leak through shields



MICROWAVE CAVITIES ARE IDEAL



Jaeckel & Ringwald 0707.2063

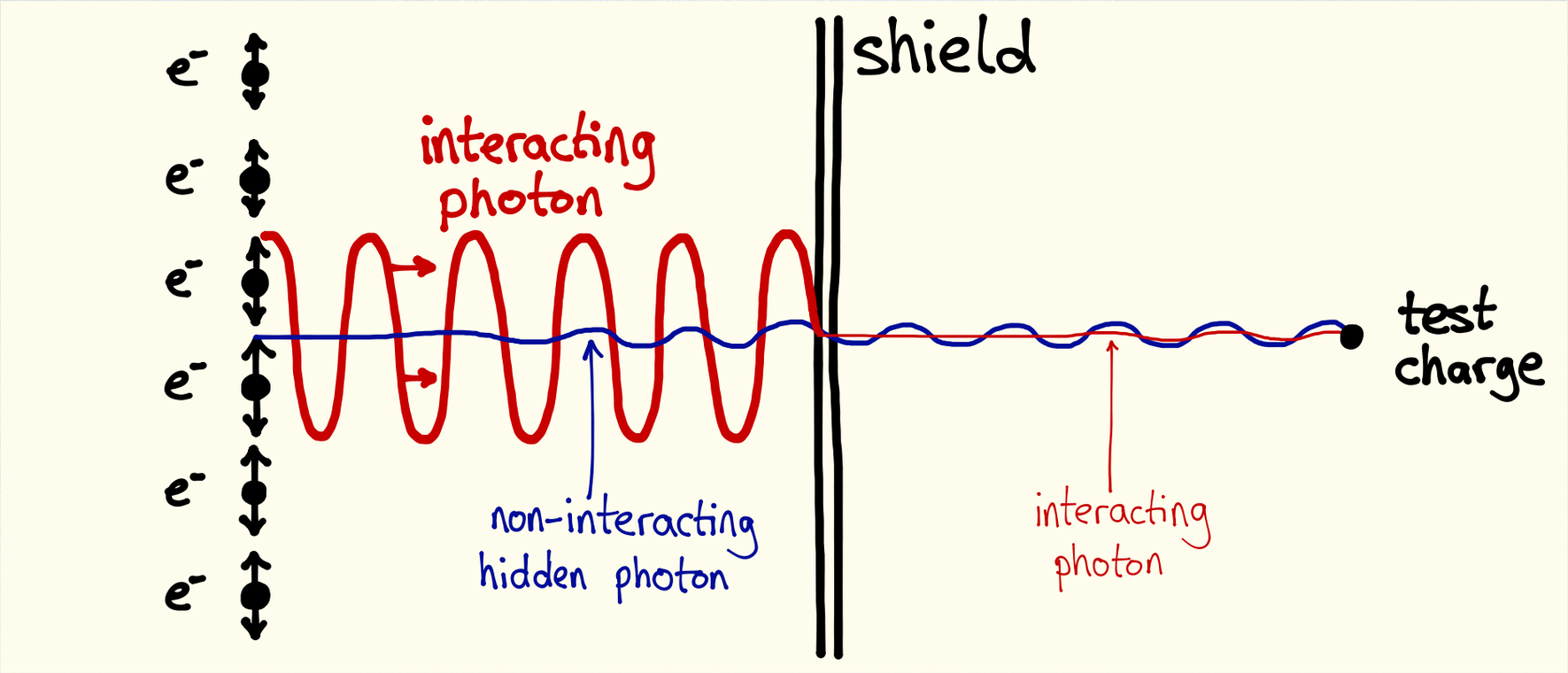
— amazing resonant enhancement: $Q \sim 10^{10}$
— 2 cavities can be tuned to same frequency
— self-shielding

Early-stage experiments already carried out

Povey et al 1003.0964 ADMX 1007.3766 CROWS 1310.8098

With Transverse Modes

Can be treated as an oscillation phenomenon

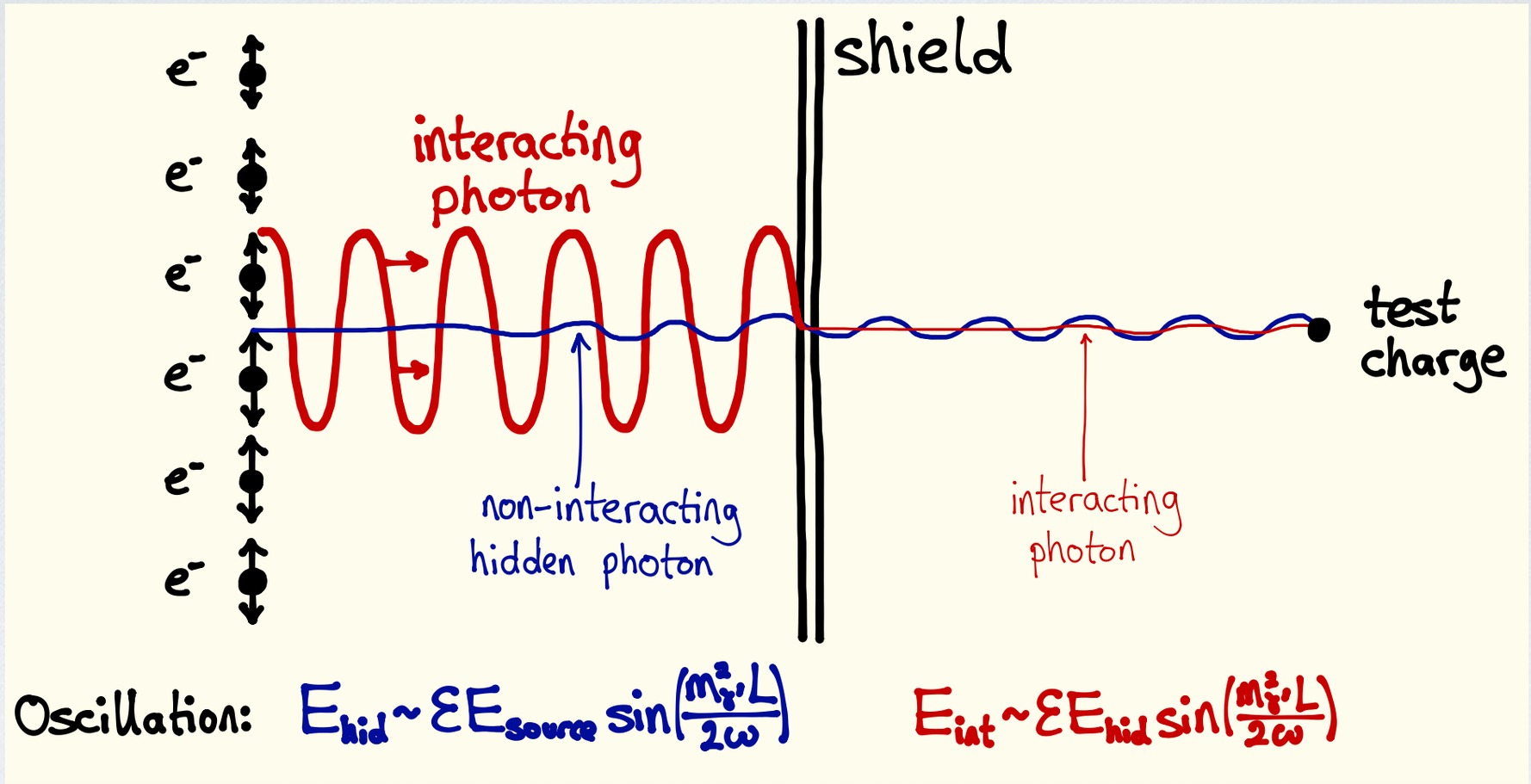


oscillation into non-interacting component → pass through wall → oscillation back into interacting component

Ahlers et al 0706.2836
Jaeckel & Ringwald 0707.2063

With Transverse Modes

Can be treated as an oscillation phenomenon



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

resonant enhancement

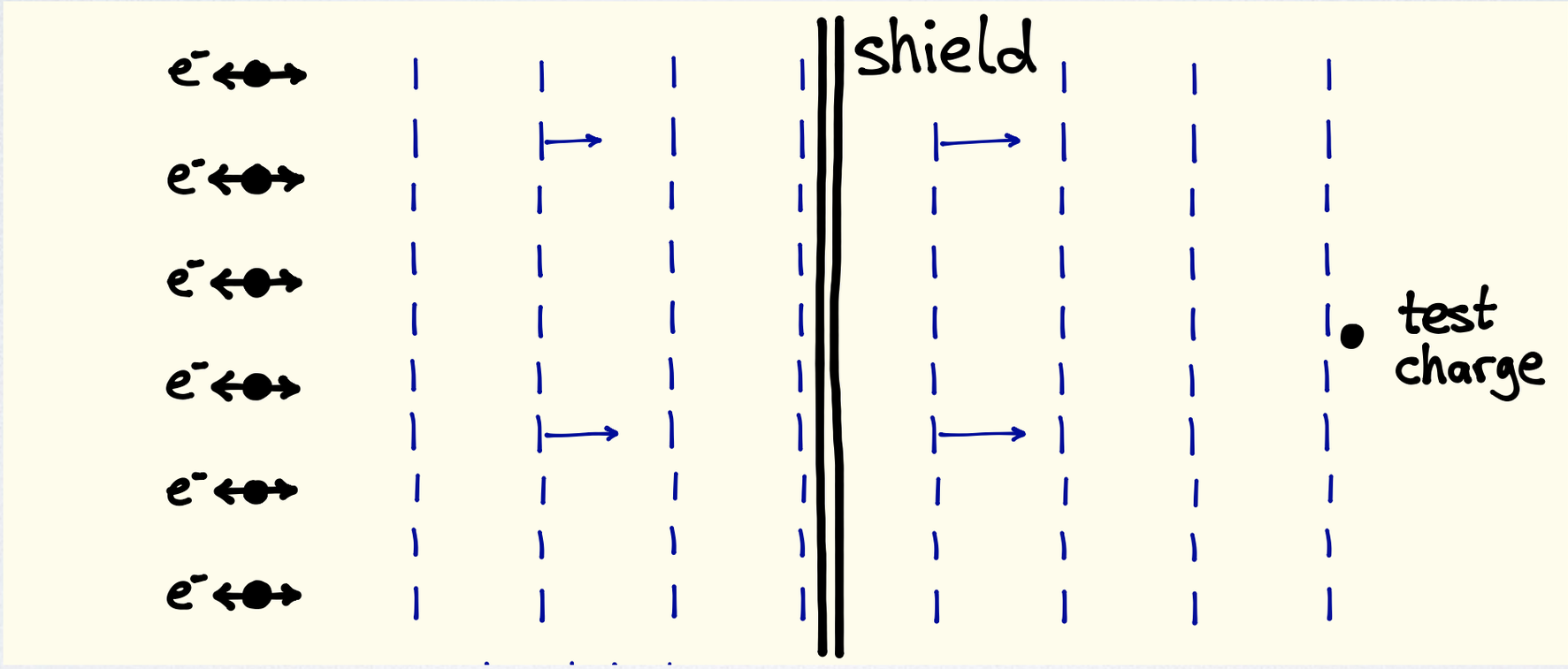
mixing

oscillation angle

Ahlers et al 0706.2836
Jaeckel & Ringwald 0707.2063

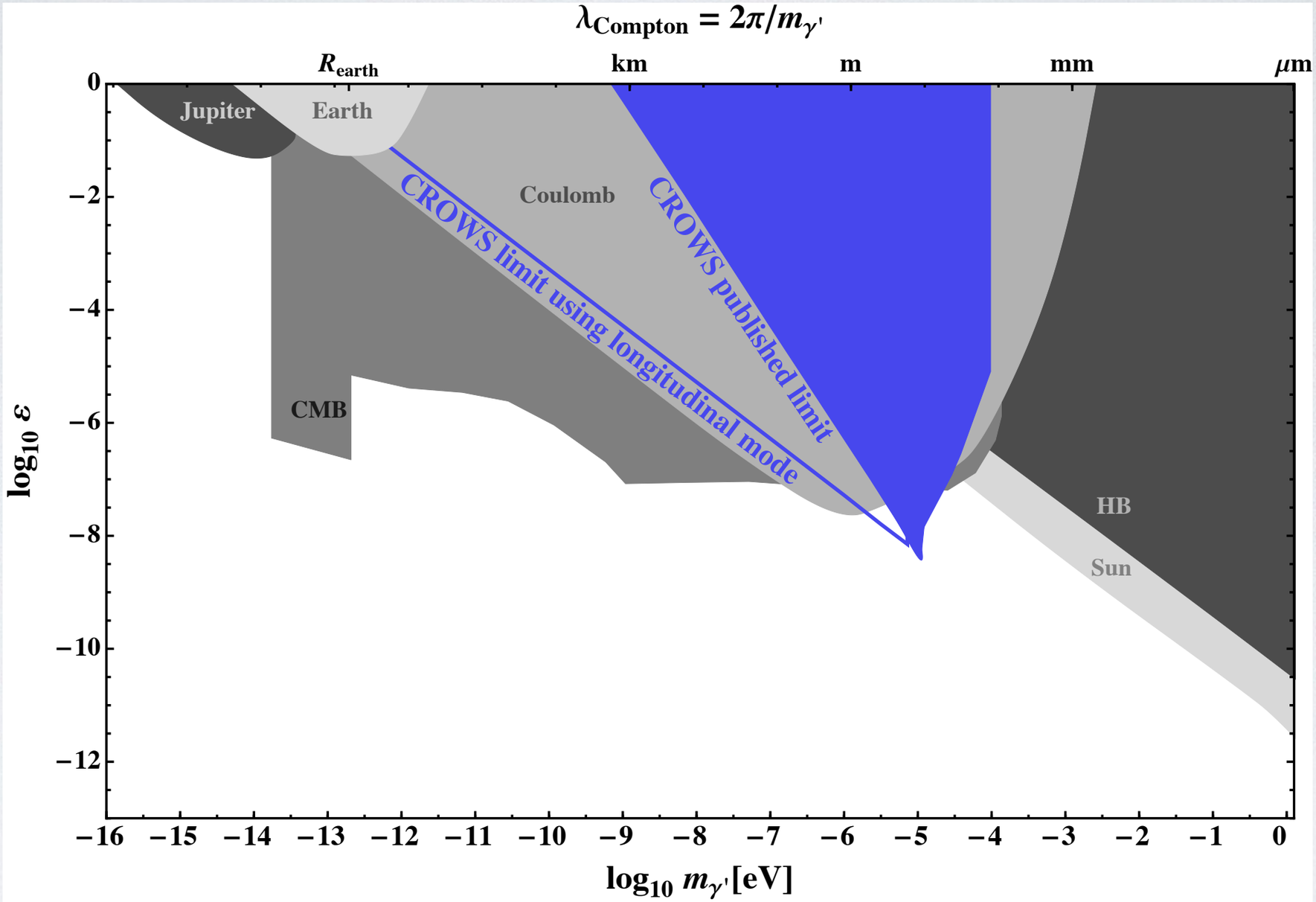
WITH THE LONGITUDINAL MODE

Hidden photon longitudinal mode is also produced
Passes through all shielding
No oscillation (no photon longitudinal mode to mix with)
Parametrically stronger signal than transverse modes



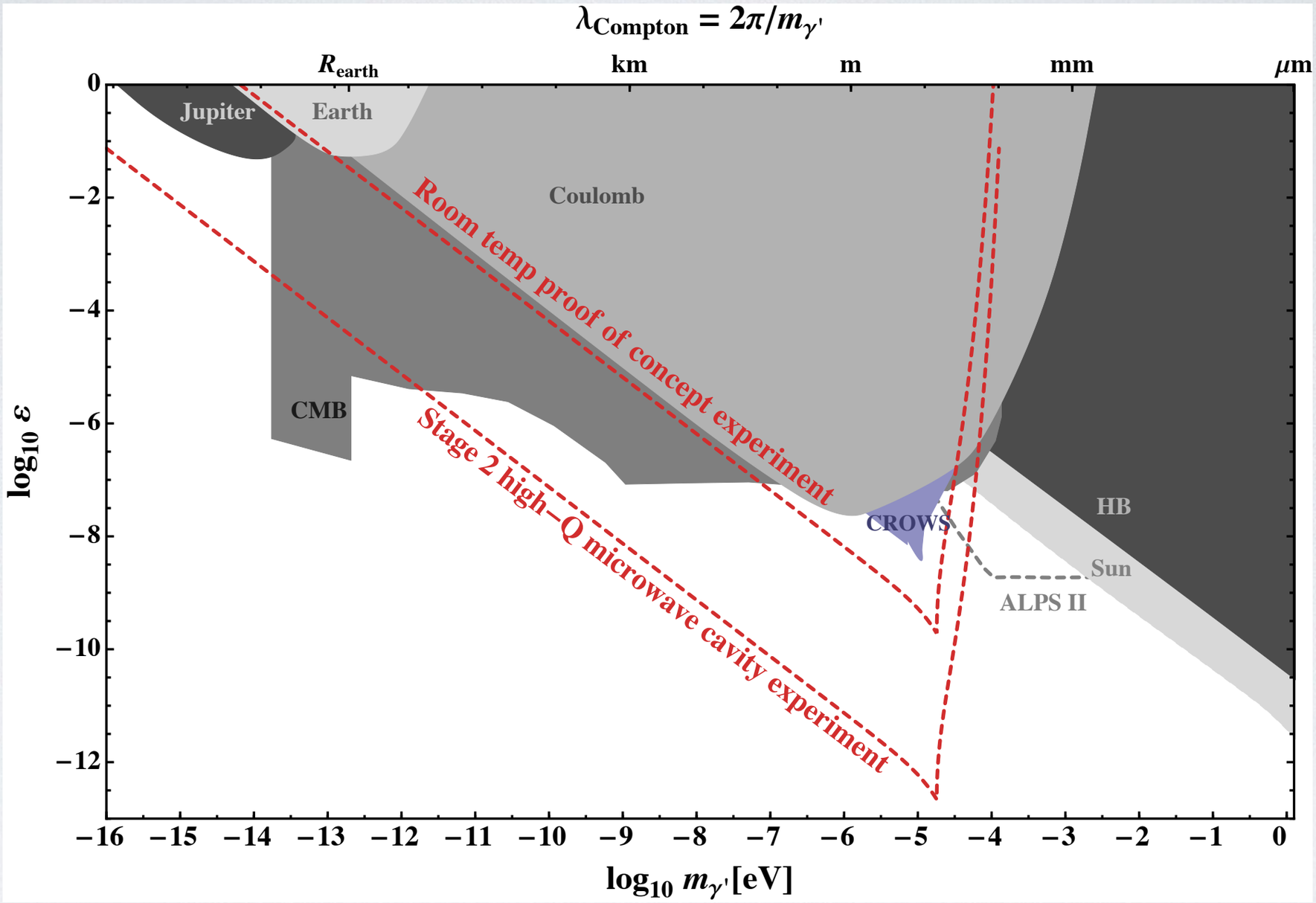
transverse:	$(E, B)_{\text{detected}} \sim Q\, \varepsilon^2 (m_{\gamma'}^4 L^2/\omega^2)\, (E, B)_{\text{source}}$
longitudinal:	$(E, B)_{\text{detected}} \sim Q\, \varepsilon^2 (m_{\gamma'}^2/\omega^2)\, (E, B)_{\text{source}}$

PARAMETRICALLY ENHANCED LIMIT



P.Graham, J.M., S. Rajendran & Y. Zhao 1407.4806

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

Light boson as dark matter?

pseudoscalar → **axion**

vector → **hidden photon**

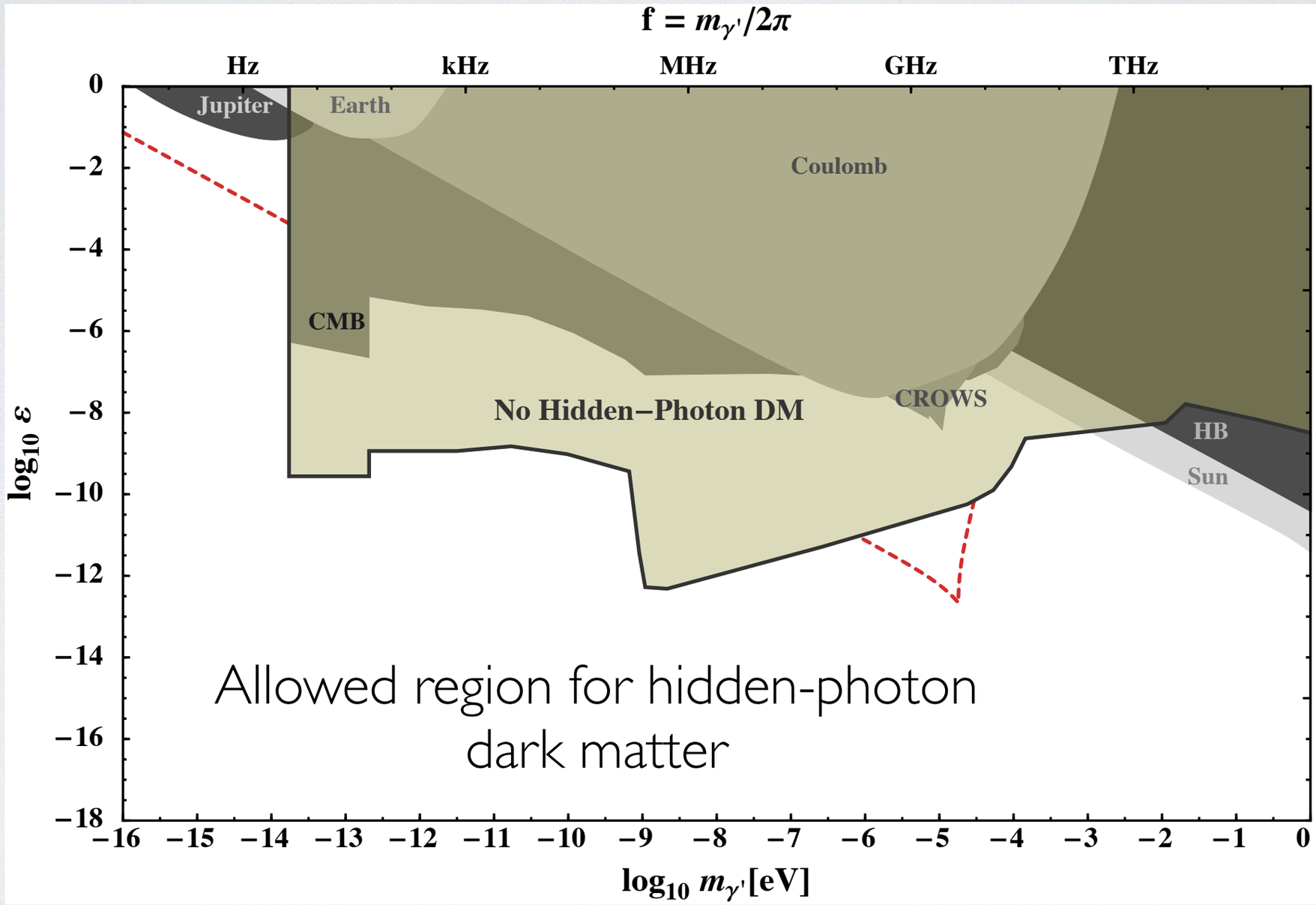
— **classical A'_μ field**
— oscillation frequency $\omega = m_{A'}$
— **random direction**
(Lorentz breaking but hard to tell!)

Nelson & Scholtz 1105.2812

ASTROPHYSICAL CONSTRAINTS

Astro constraints from resonant conversion of hidden photons to plasma excitations

Arias et al 1201.5902



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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Arias et al 1201.5902

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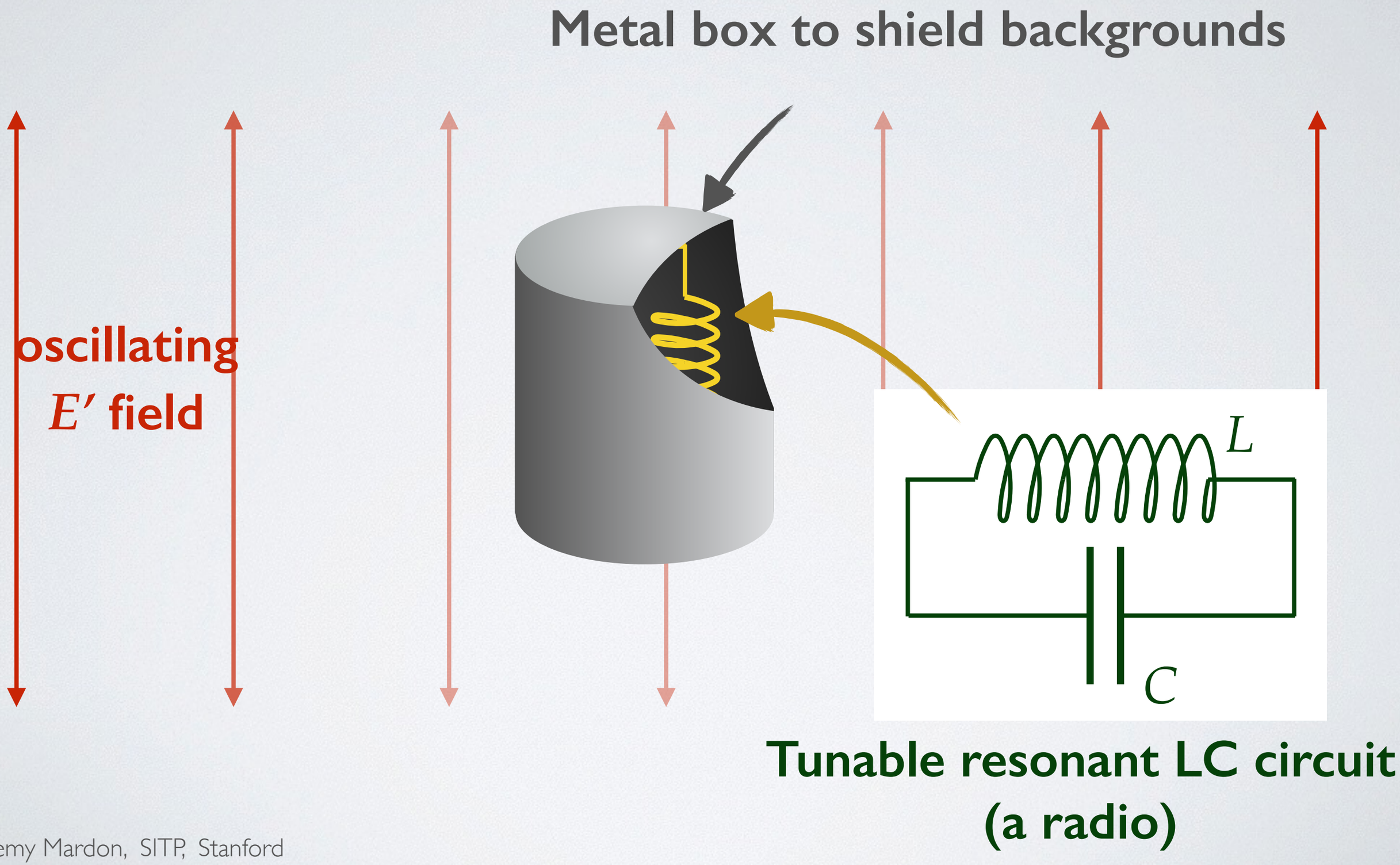
LC circuits

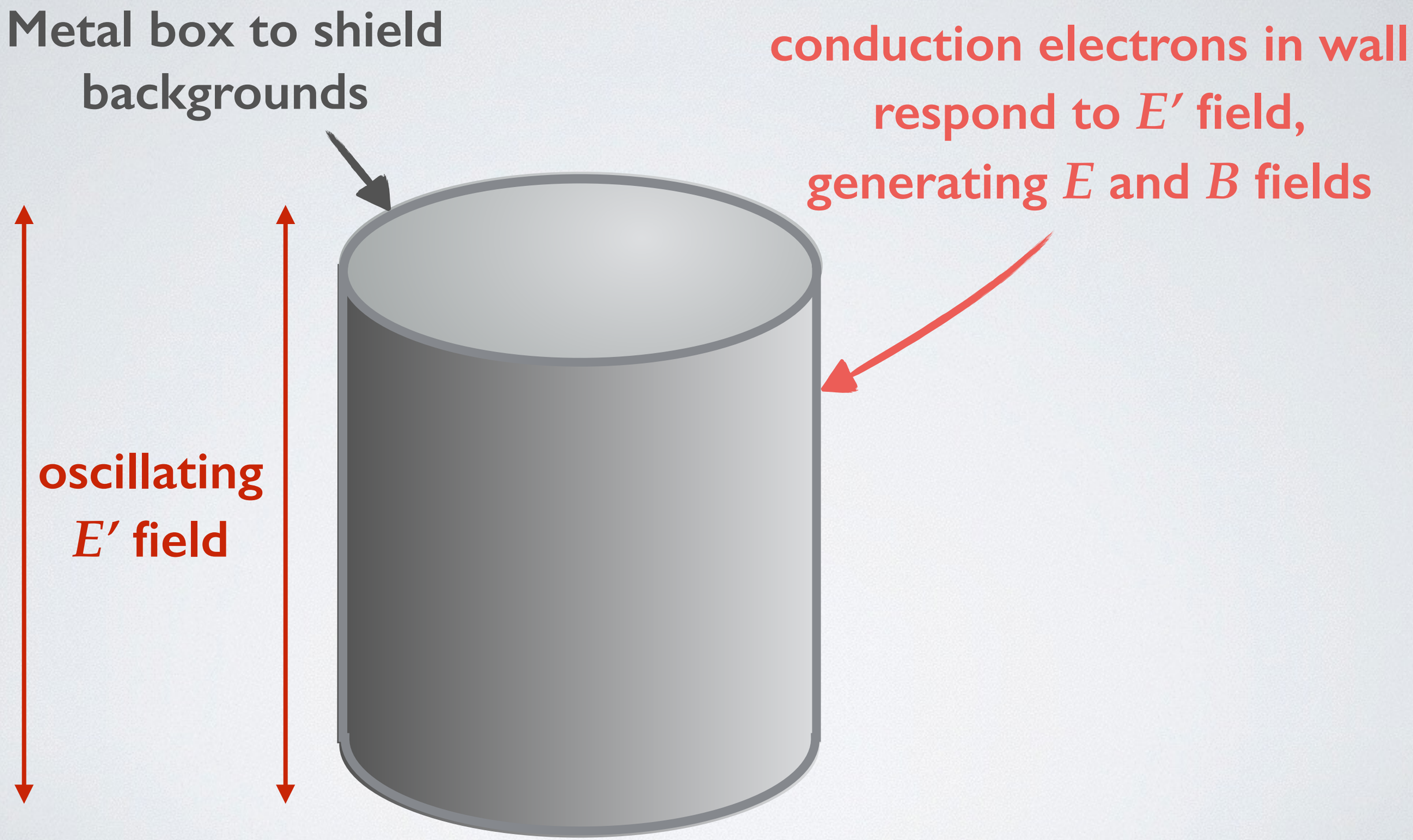
— can be high Q

— much wider and lower frequency range than cavities

EXPERIMENTAL SETUP



THE SIGNAL INSIDE A SHIELD



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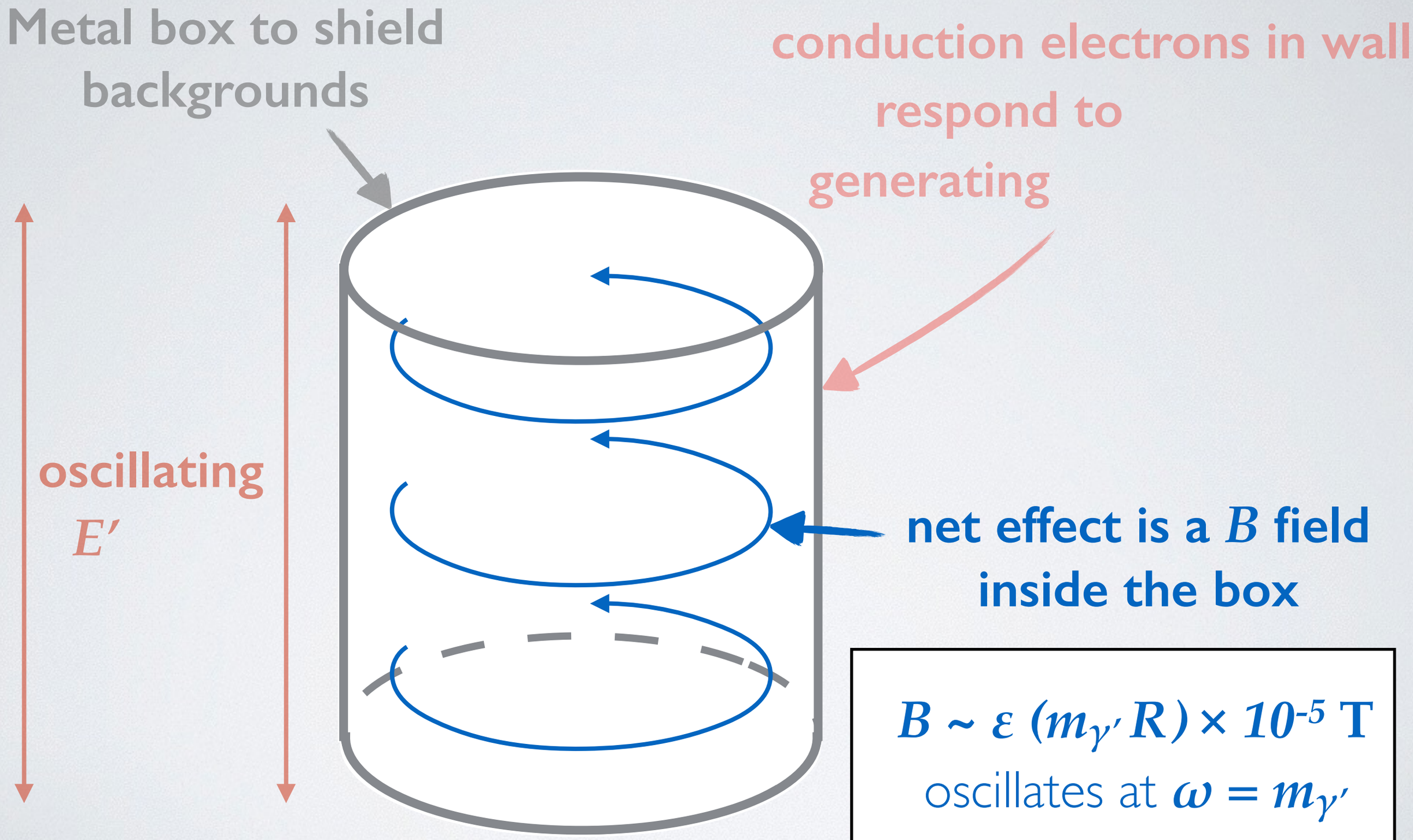


$$B \sim \varepsilon\,(m_{\gamma'} R) \times 10^{-5}\ \mathrm{T}$$

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

REACH

— Experiment to be done at Stanford over the next few years by K. Irwin's group

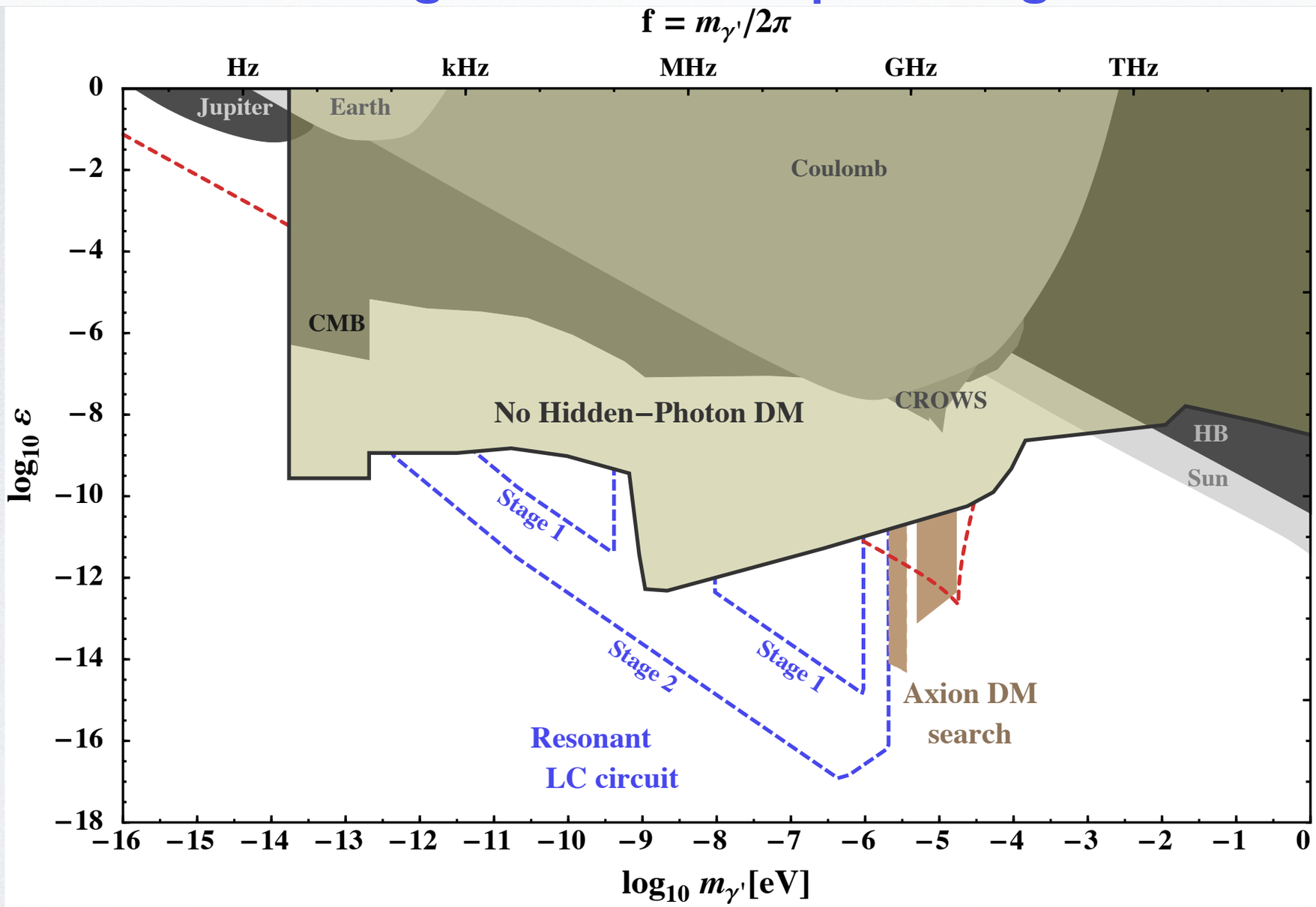
— Currently writing experimental white paper

Graham, J.M., Rajendran & Zhao (theory)
S. Chaudhuri & K. Irwin (experiment)
in progress

REACH

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

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



P. Graham, J.M., S. Rajendran, Y. Zhao, S. Chaudhuri & K. Irwin

in progress

CONCLUSIONS

Hidden photons are a natural window into hidden sectors

Ultra-light hidden photons are both:

— new force carriers

— a dark matter candidate

New ways to probe both aspects with small-scale experiments:

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

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

Cavity-to-cavity searches already being pursued by several groups

LC-circuit dark matter search to be done at Stanford over next several years

BACKUP: GENERATING THE RELIC ABUNDANCE

(preliminary)

Jeremy Mardon, SITP, Stanford

Generating DM abundance

Where did the hidden-photon abundance come from?

One possibility (preliminary):

DM abundance generated purely from its gravitational coupling

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

Evolution automatically suppresses isocurvature fluctuations

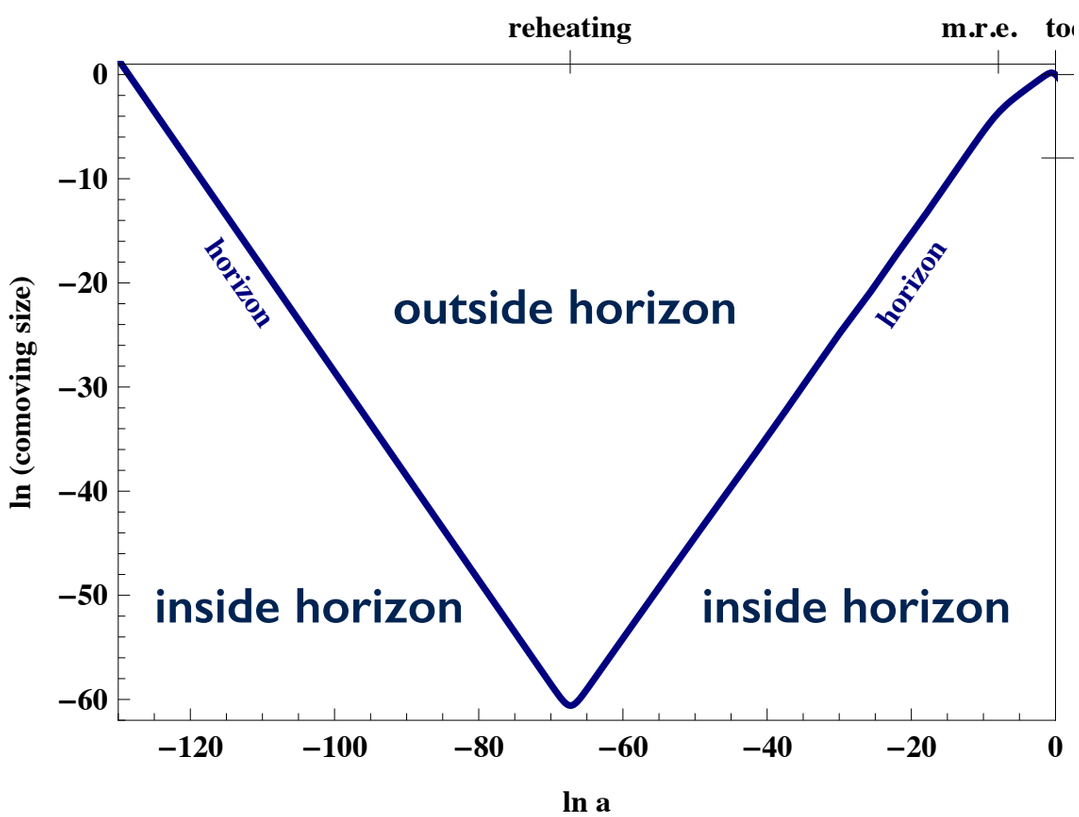
— **BICEP-II** $\longrightarrow$ ω~100 MHz

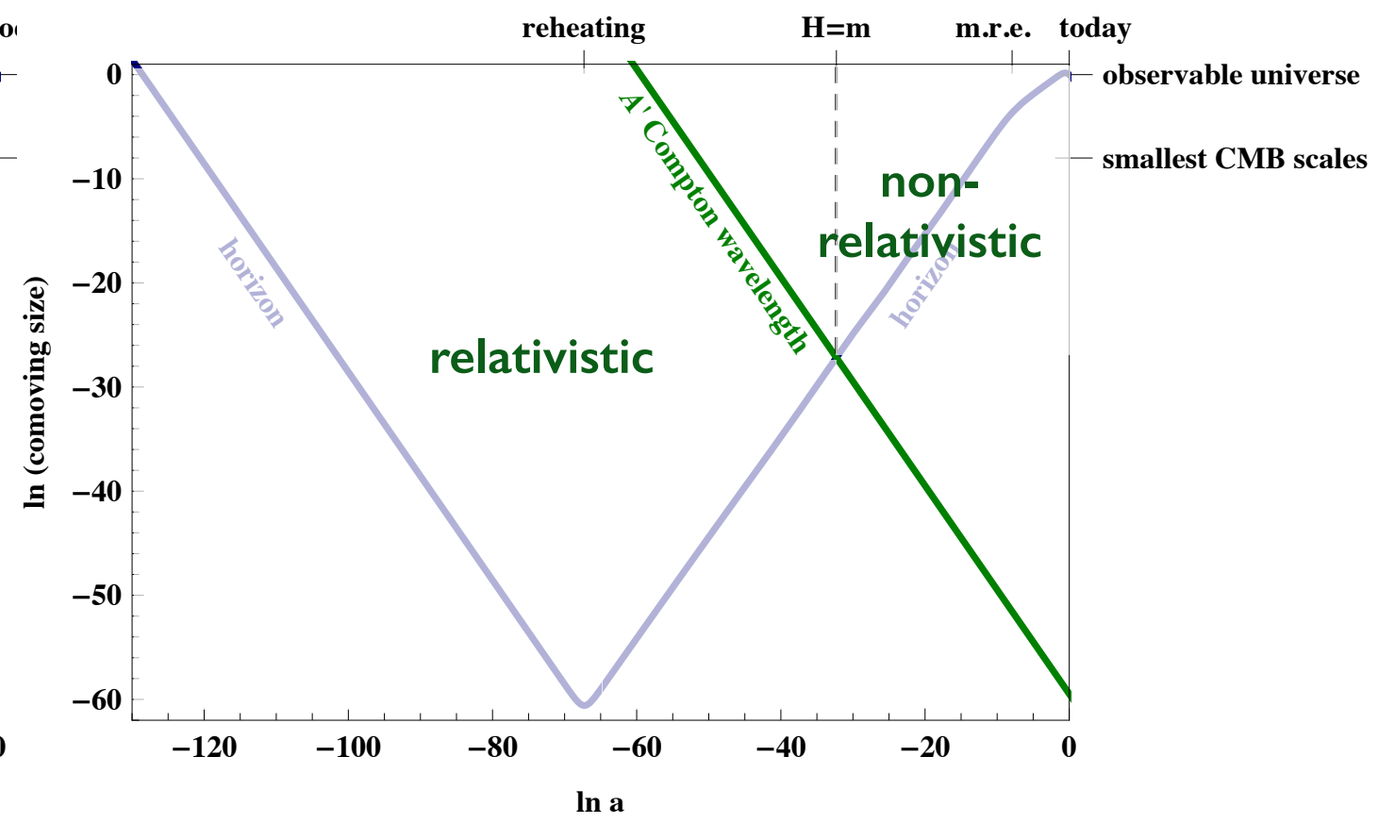
— Lower infl. scale $\longrightarrow$ larger mass

Cosmological evolution

(with Stuckelberg mass)

Evolution of A' modes in expanding universe

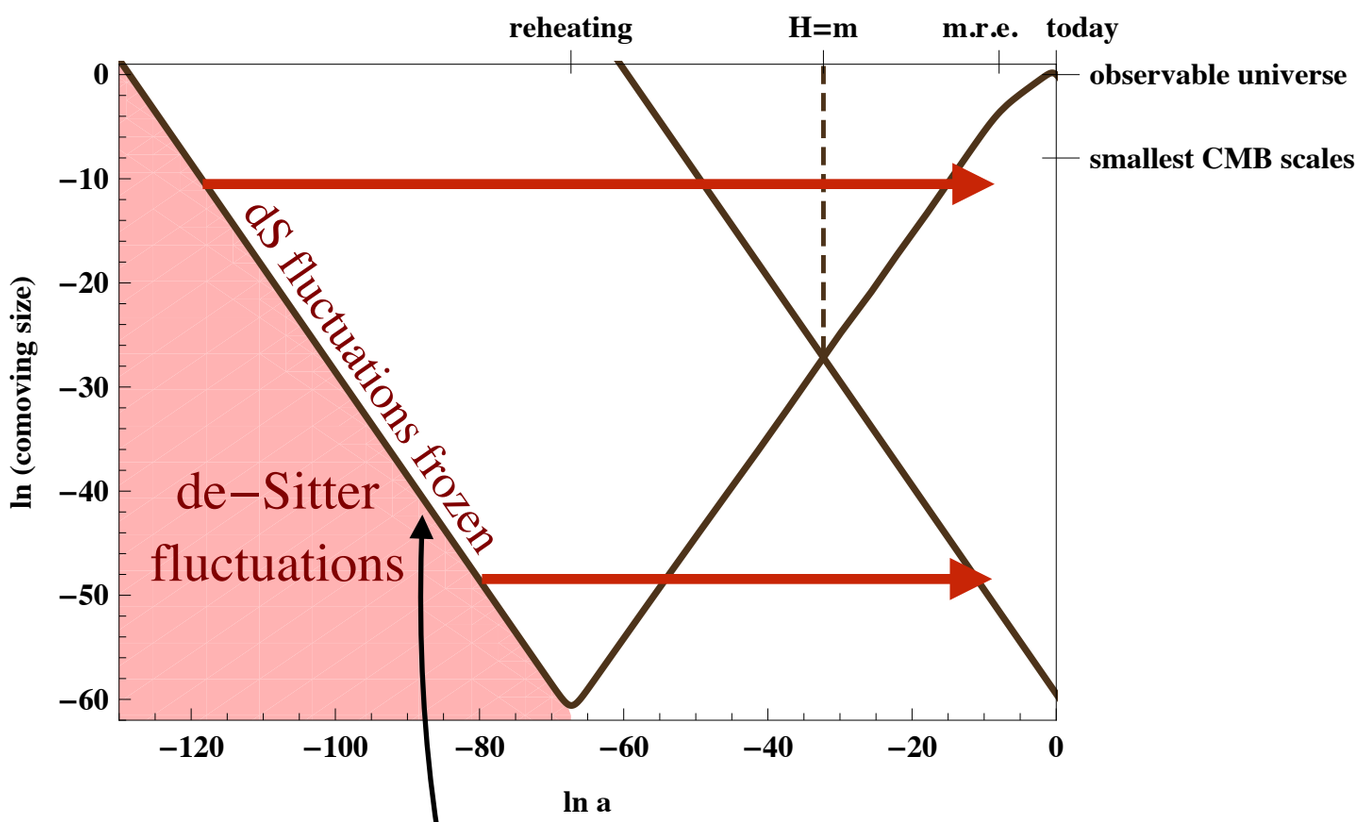




Cosmological evolution

(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)

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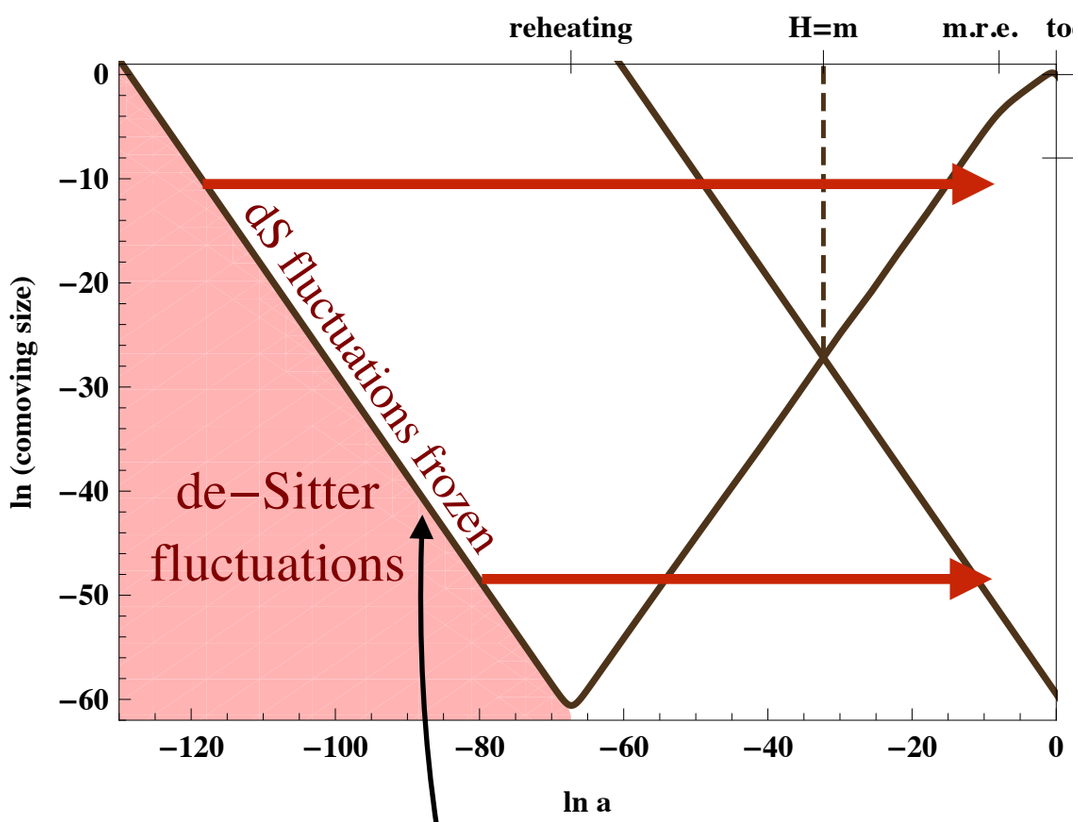

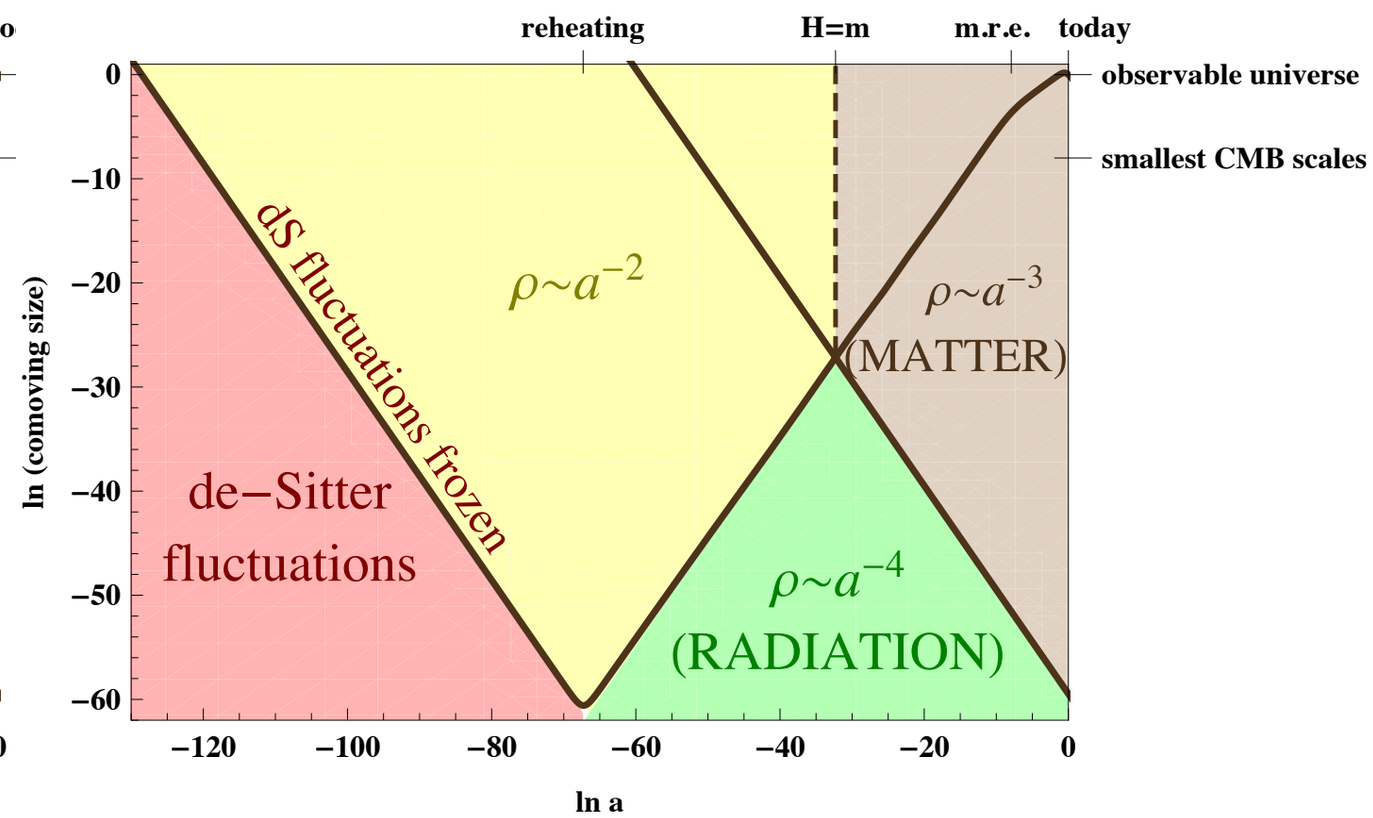

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(WITH STUCKELBERG MASS)

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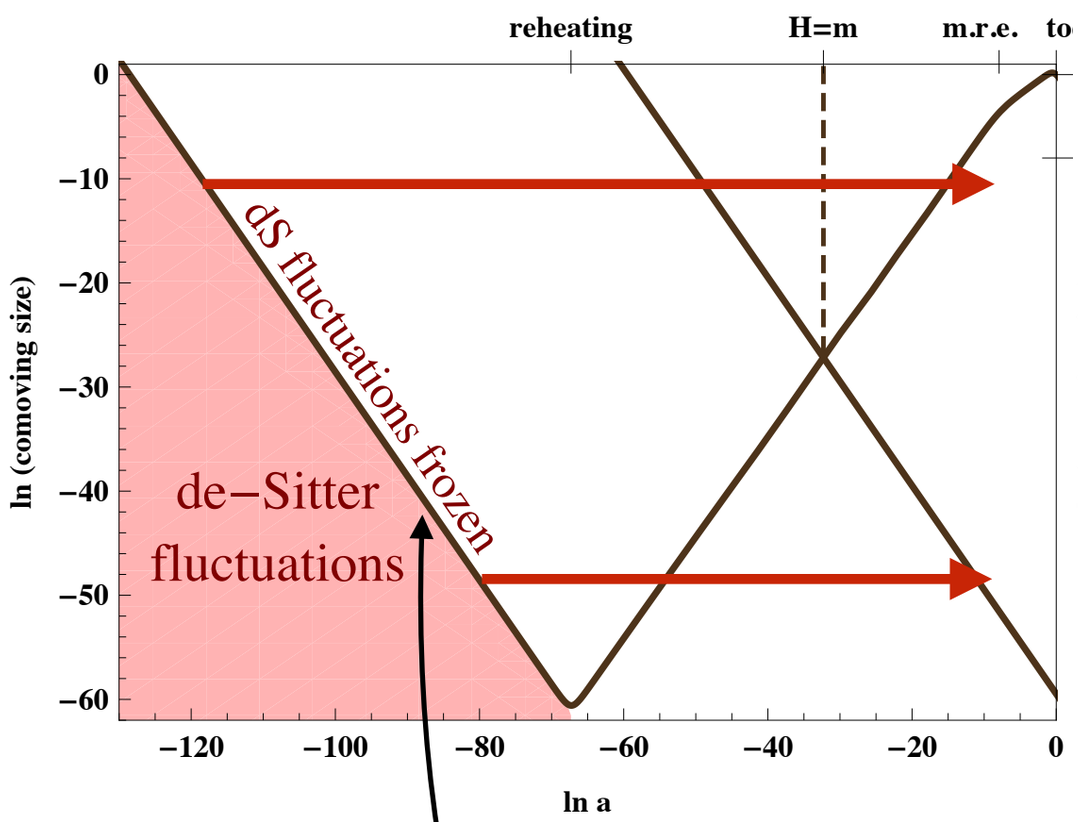
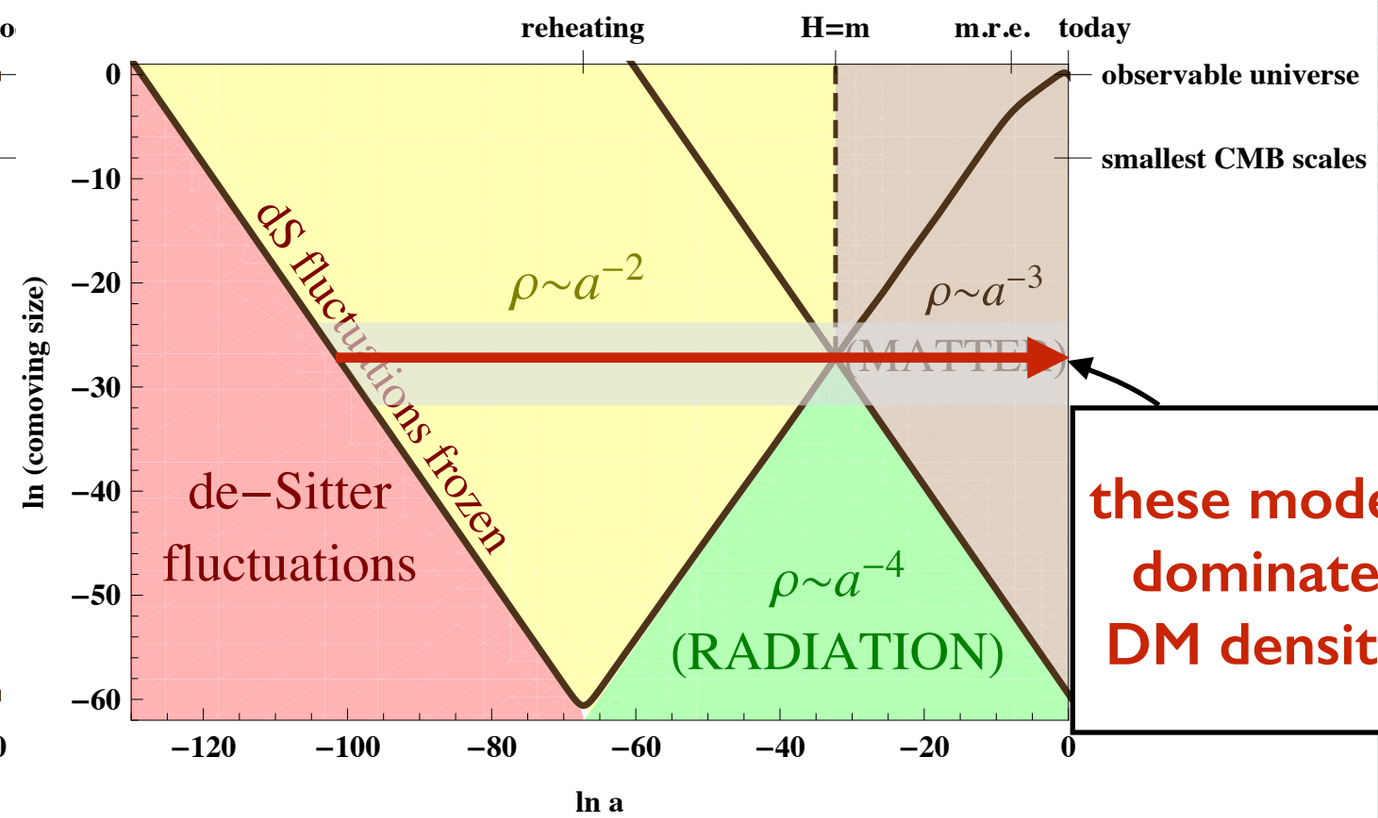
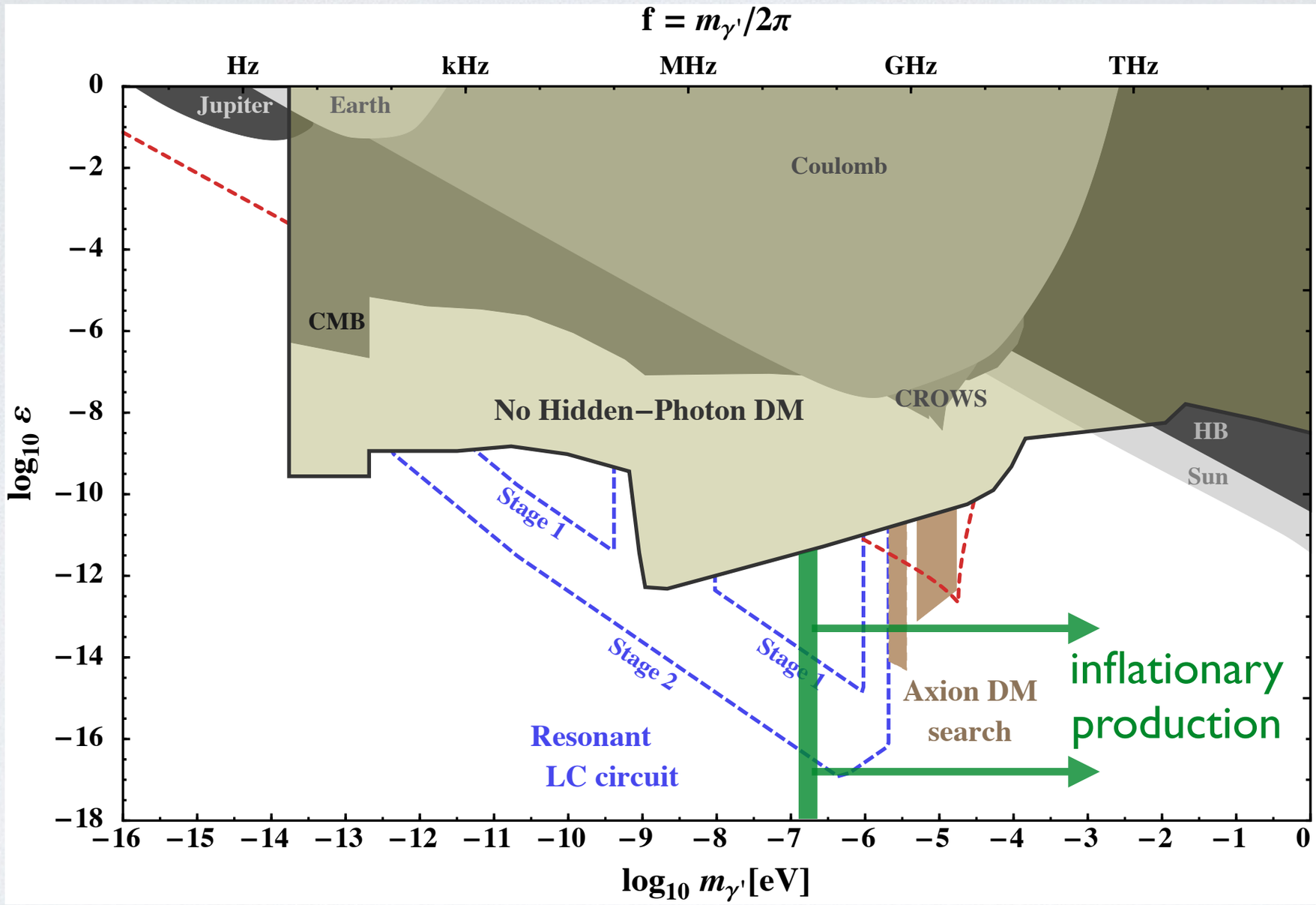




these modes dominate DM density

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

REACH



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

Cosmological evolution

(with Stuckelberg mass)

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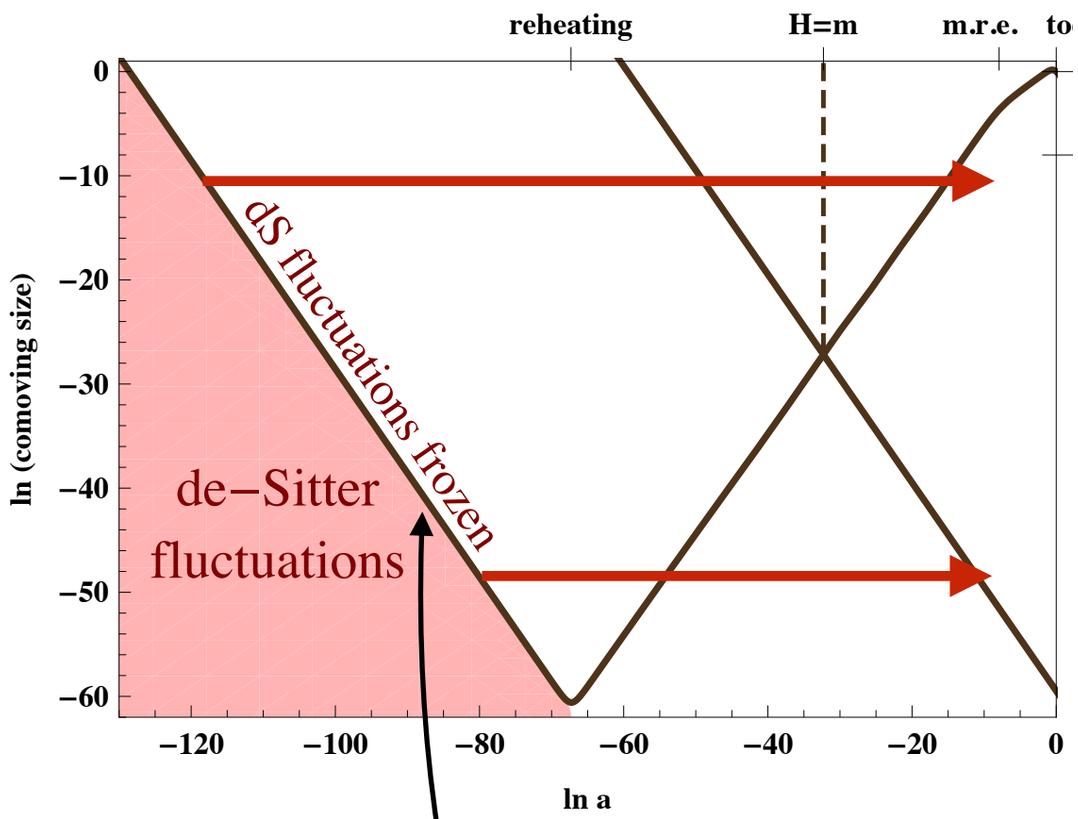

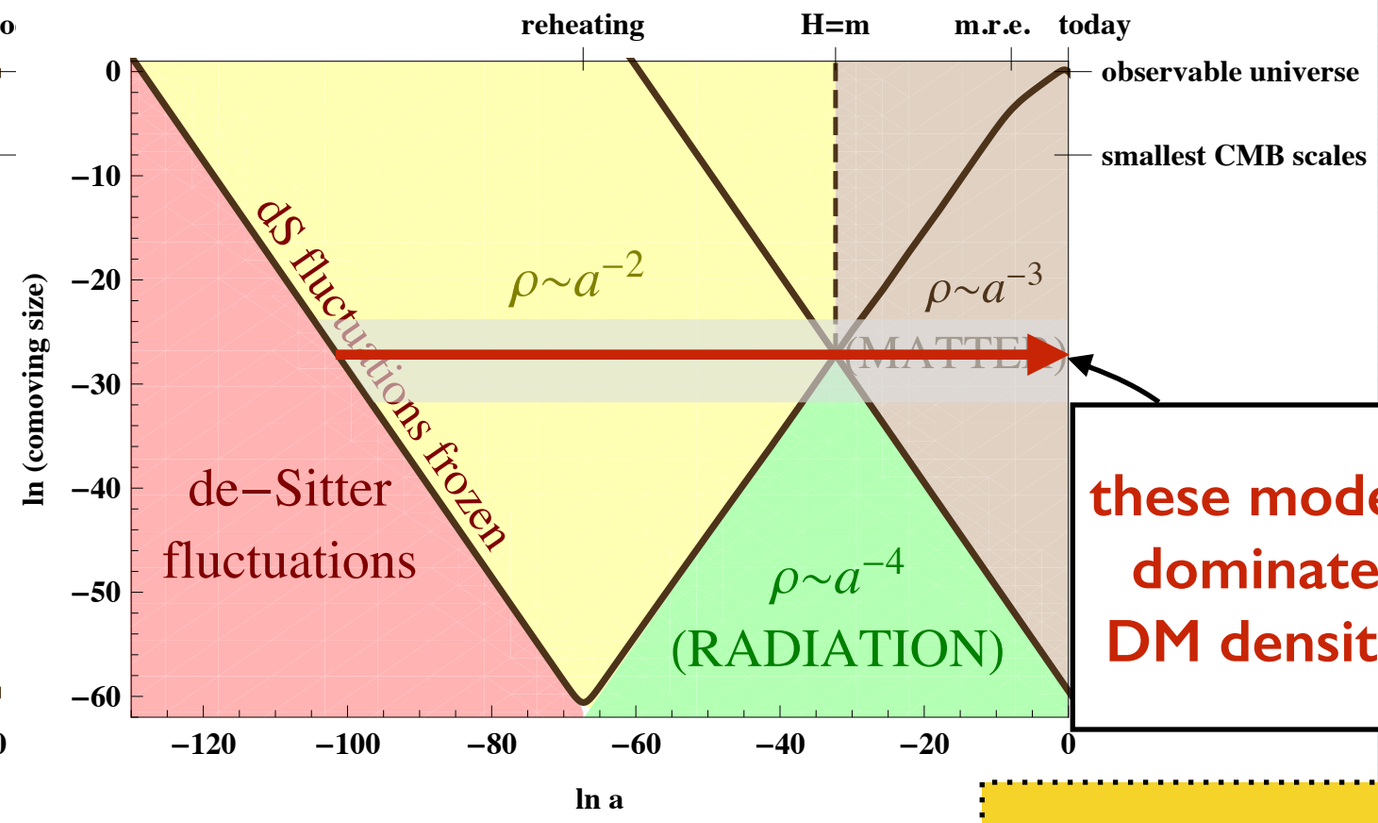

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preliminary

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