Hidden Photon Dark Matter

Theory and Searches

Jeremy Mardon, SITP, Stanford

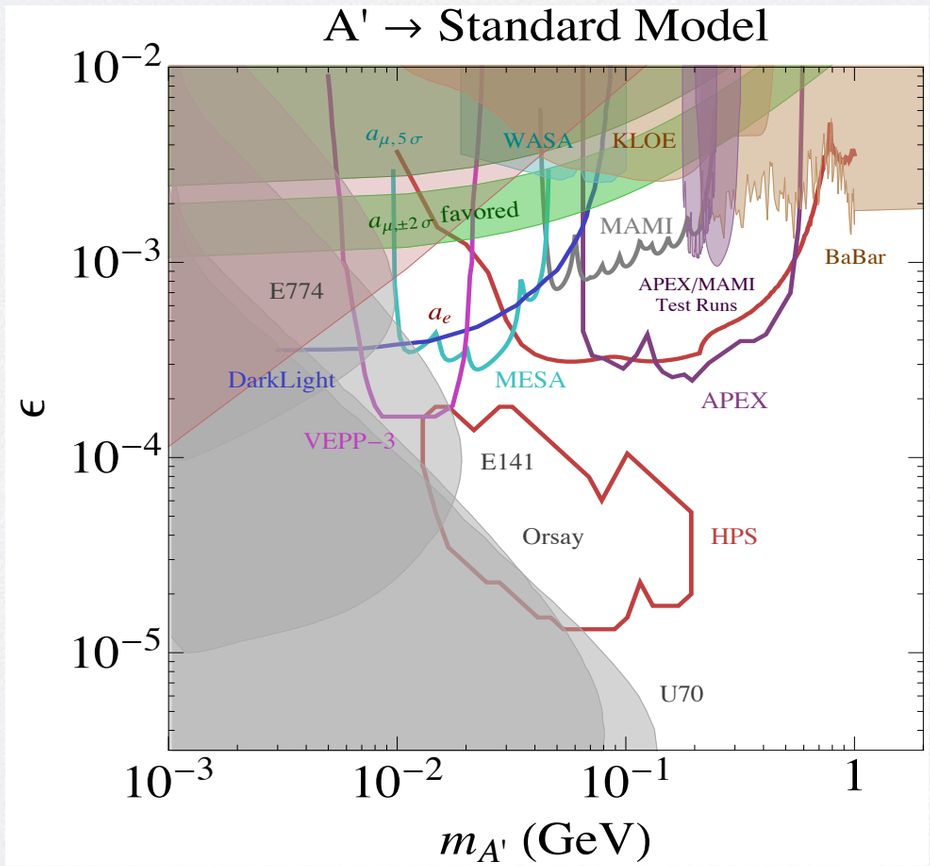
ULTRA-LIGHT HIDDEN PHOTON

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

ULTRA-LIGHT HIDDEN PHOTONS

PHENOMENOLOGICALLY

A new force / force carrier:

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

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

New light particle
⬇
Cosmo/astro effects

Stores energy in non-relativistic waves/particles
⬇
Dark matter

HIDDEN-PHOTONS AS DARK MATTER

Light boson as dark matter?

pseudoscalar → axion

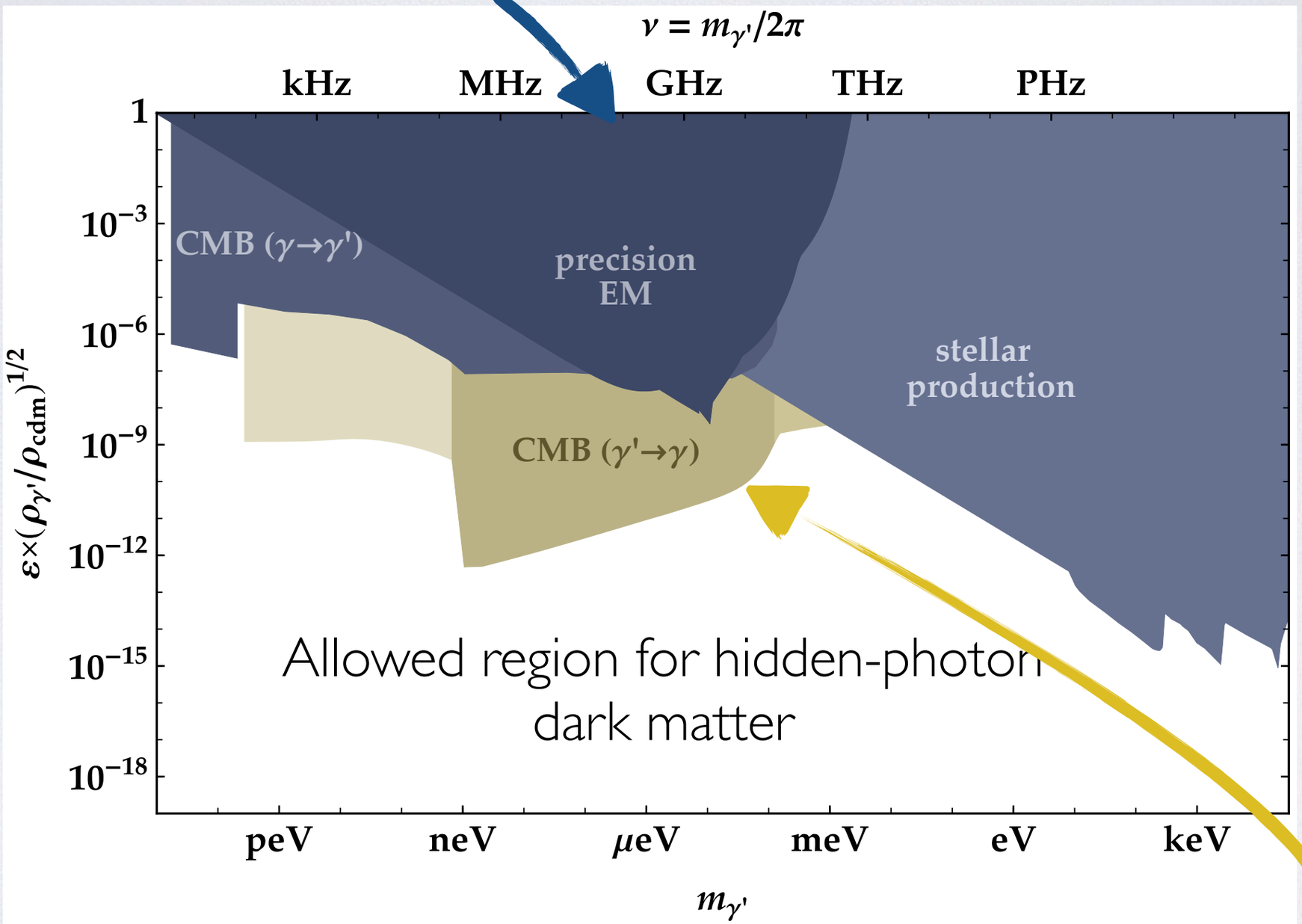
vector → hidden photon

— classical A'_μ field
— oscillation frequency $\omega = m_{A'}$
— random direction

Pospelov Ritz & Voloshin 0807.3279
Nelson & Scholtz 1105.2812

CONSTRAINTS

hidden photons excluded
(independent of relic abundance)



hidden photon excluded as dark matter

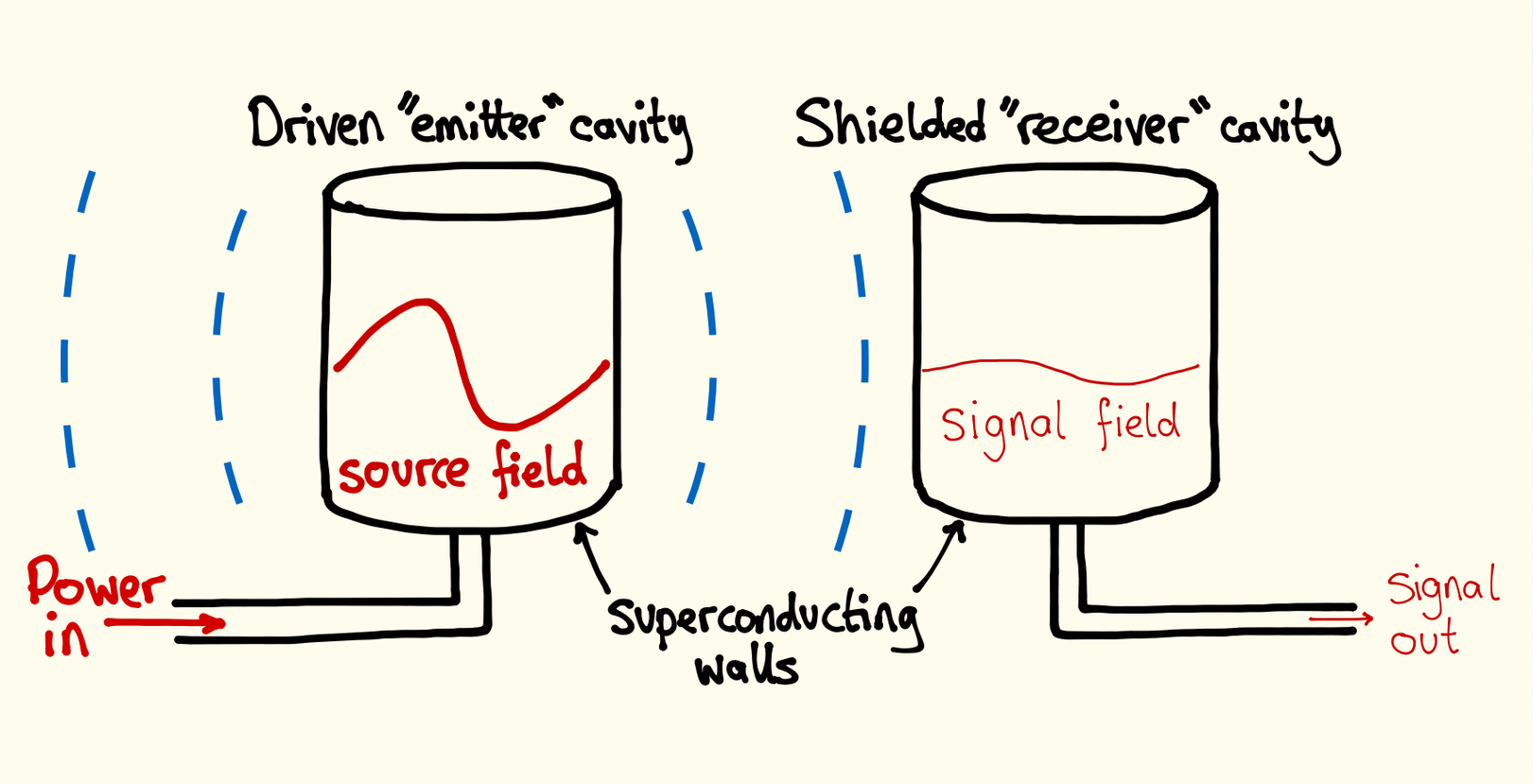
Arias et al 1201.5902

Light-Through-Walls Searches for Hidden Photons

Jeremy Mardon, SITP, Stanford

MICROWAVE CAVITY SEARCH

The hidden photon is an **unshieldable** addition to Electromagnetism



Jaeckel & Ringwald 0707.2063

— 2 cavities can be tuned to same frequency

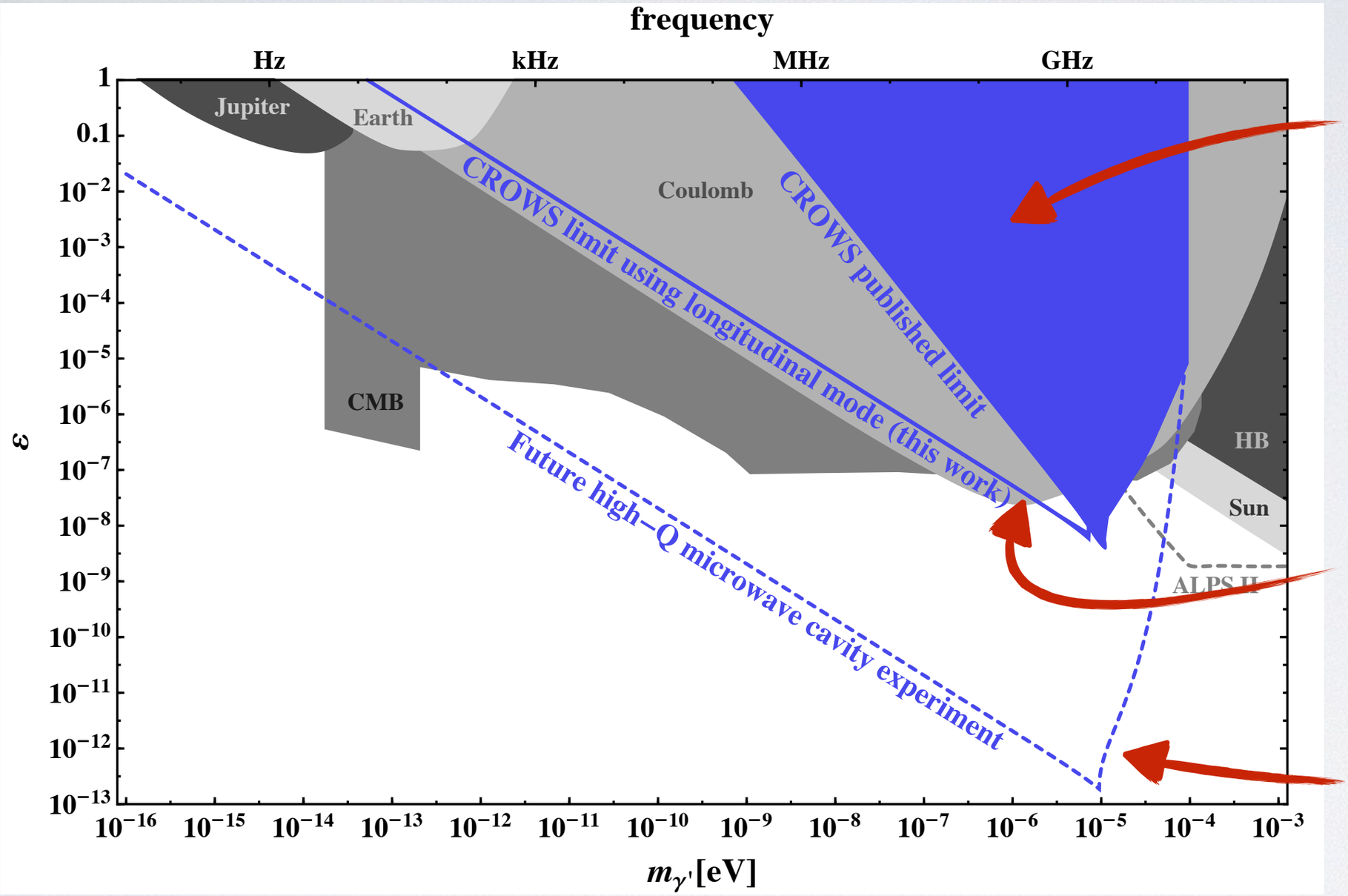
— amazing resonant enhancement: $Q \sim 10^{10}$

— self-shielding from backgrounds

Early-stage experiments already carried out

Povey et al 1003.0964 ADMX 1007.3766 CROWS 1310.8098

REACH



Published bound
CROWS collaboration
1310.8098

Reanalyzed bound including longitudinal mode
Graham, J. M., Rajendran & Zhao
1407.4806

Potential reach
proposal with Sami Tantawi & Vinod Bharadwaj

Searching for Hidden Photon Dark Matter

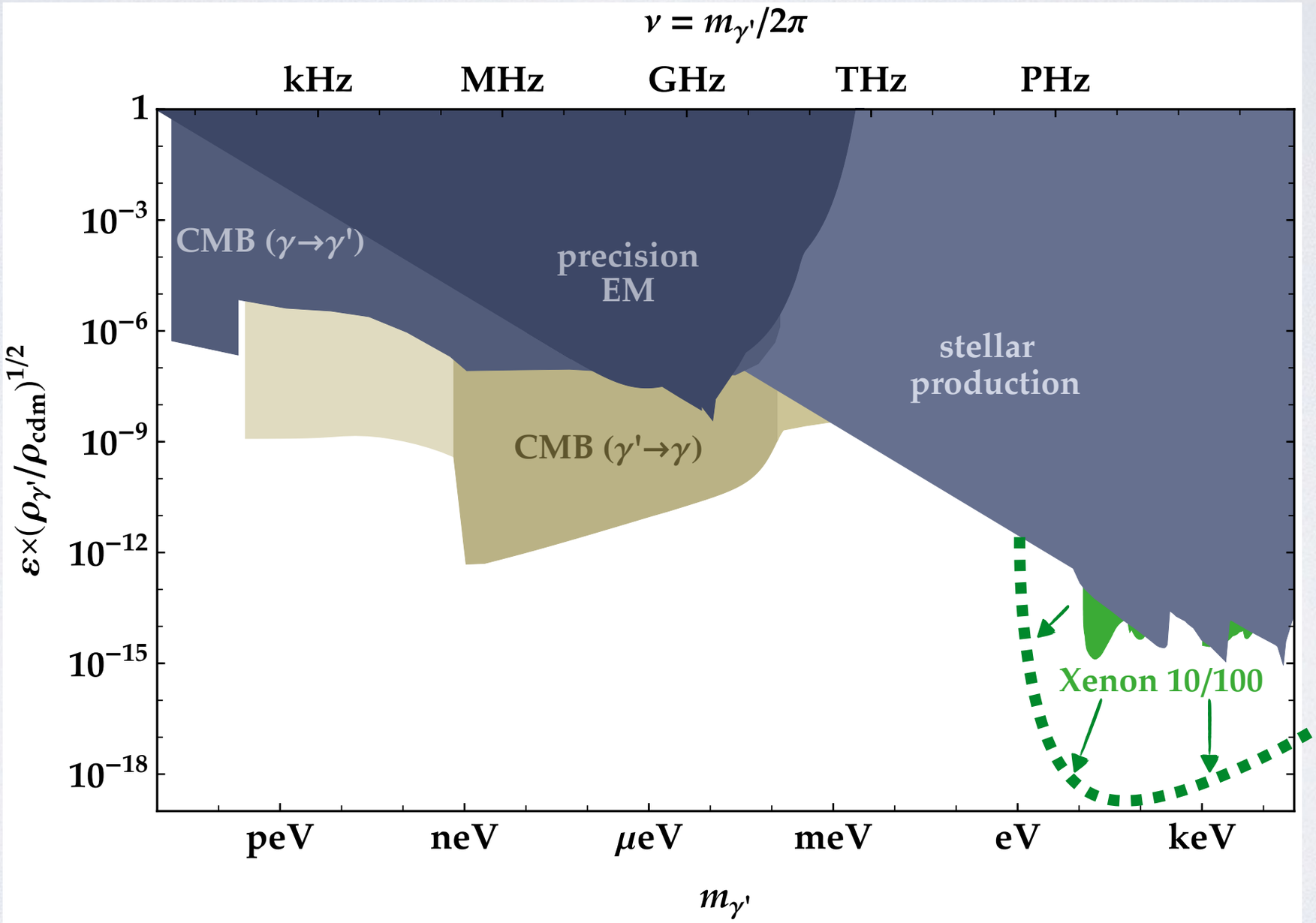
Jeremy Mardon, SITP, Stanford

Detecting hidden photon DM

1. **Absorption of individual hidden photons** in detectors

(Hidden-photoelectric effect)

An et al 1412.8378



DETECTING HIDDEN PHOTON DM

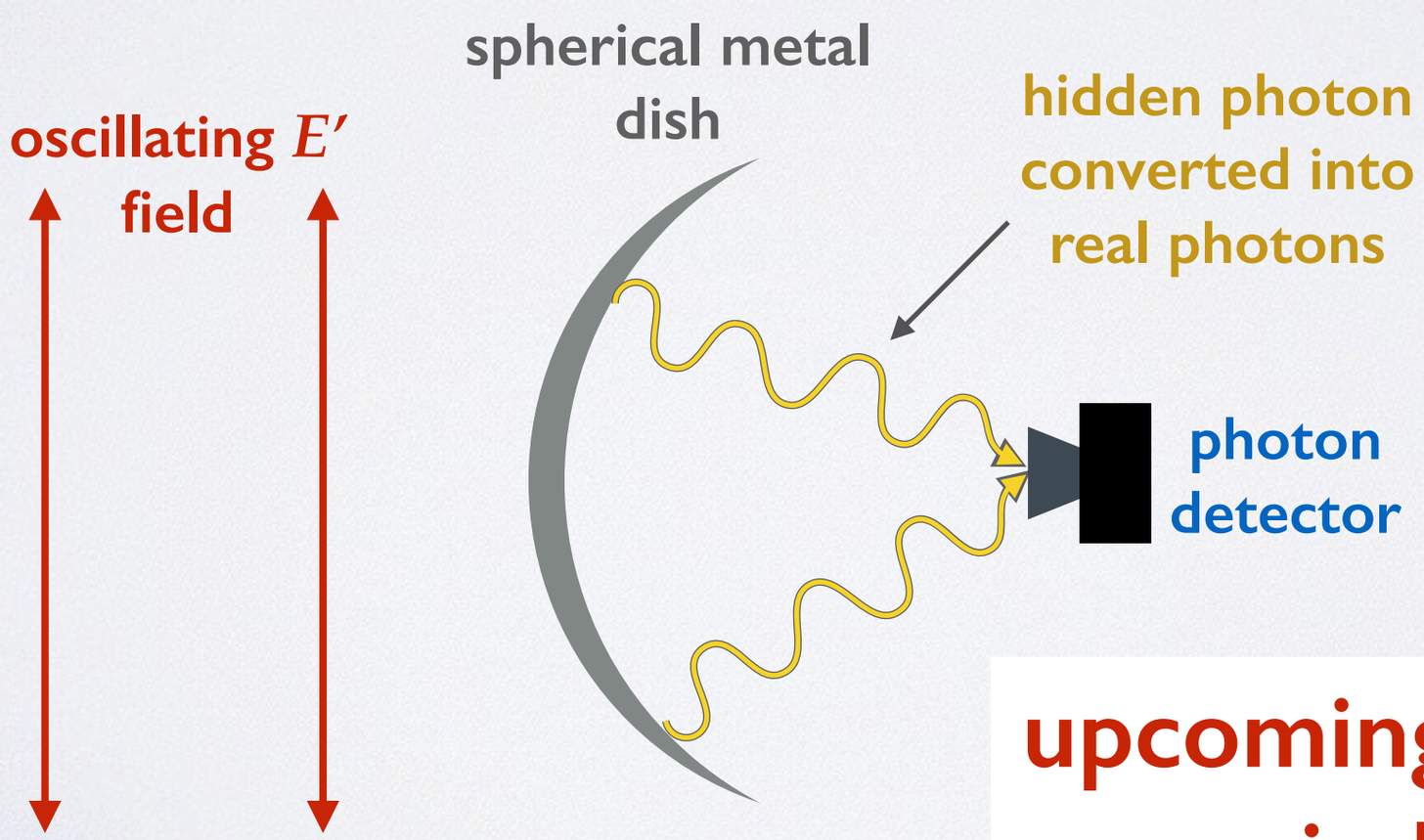
2. Dish antenna

Arias et al 1201.5902

Hidden photon DM:

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

Oscillates with **fixed frequency** $\omega = m_{\gamma'}$



upcoming experiment in Europe

DETECTING HIDDEN PHOTON DM

3. Resonant searches

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!

Redondo et al 1201.5902

— cavity size restricts mass range

Detecting hidden photon DM

3. Reso

A "

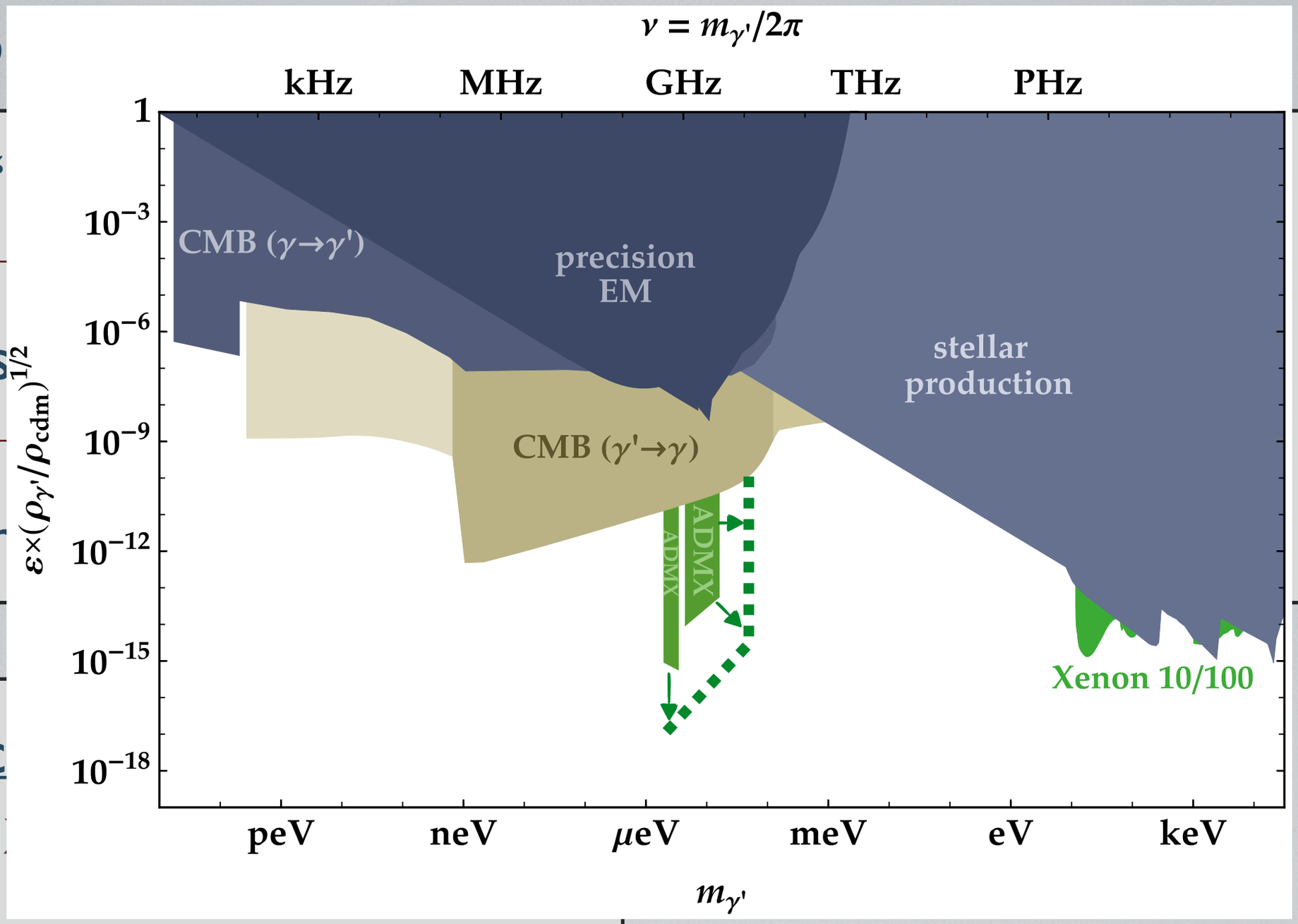
Has

Car

elec

— ADM

— cavity size restricts mass range



DETECTING HIDDEN PHOTON DM

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Arias et al 1201.5902

— cavity size restricts mass range

LC circuits

— can be high Q

— much wider and lower frequency range than cavities

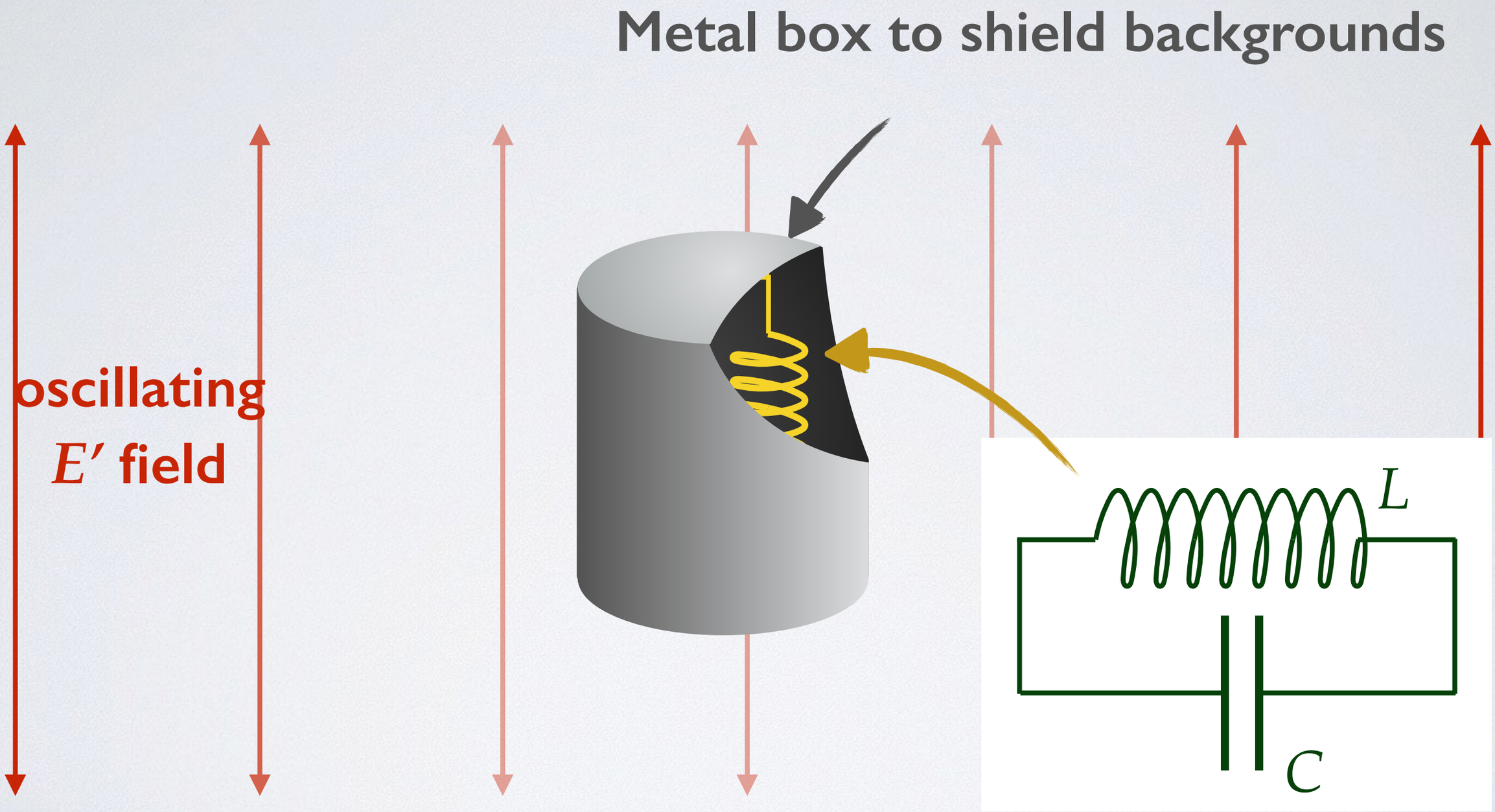
Scanning for Hidden Photon Dark Matter with a High-Q Radio

"A Radio for Hidden-Photon Dark Matter Detection"

Saptarshi Chaudhuri, Peter Graham, Kent Irwin, J. M., Surjeet Rajendran & Yue Zhao

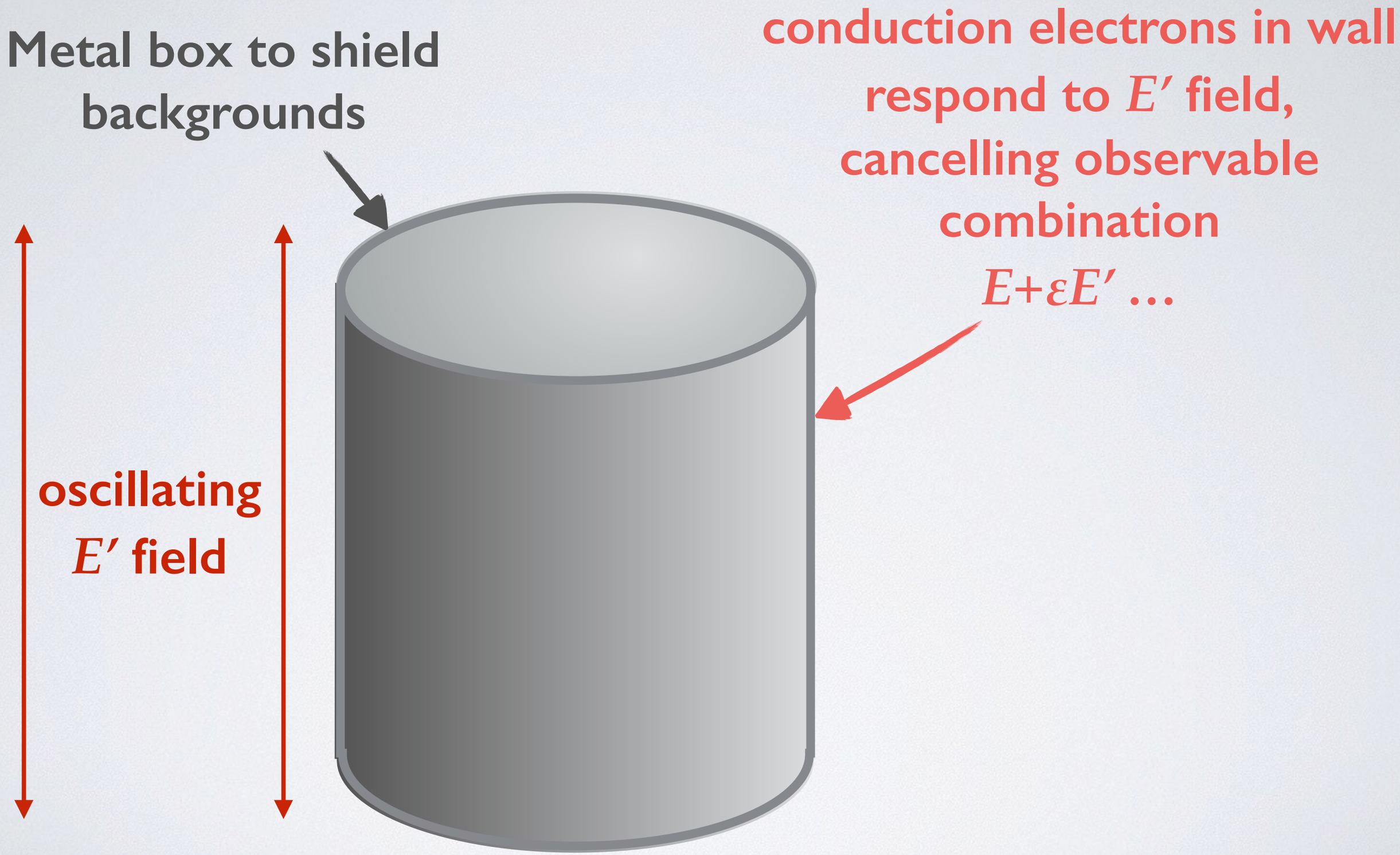
arXiv:1411.7382

EXPERIMENTAL SETUP



Tunable resonant LC circuit
Read out with SQUID

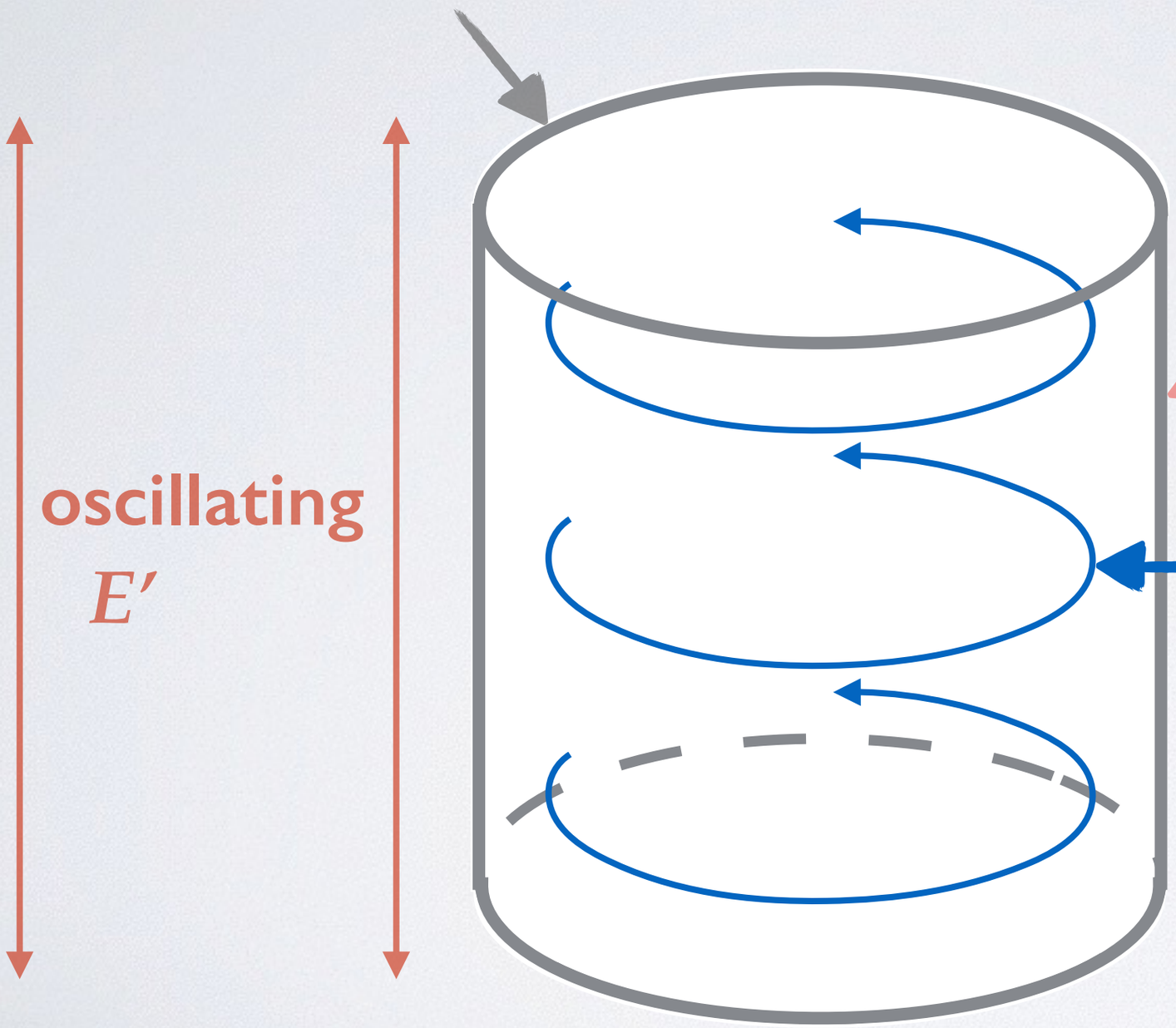
THE SIGNAL INSIDE A SHIELD



THE SIGNAL INSIDE A SHIELD

Metal box to shield backgrounds

conduction electrons in wall respond to cancelling observable combination $E+\varepsilon E'$



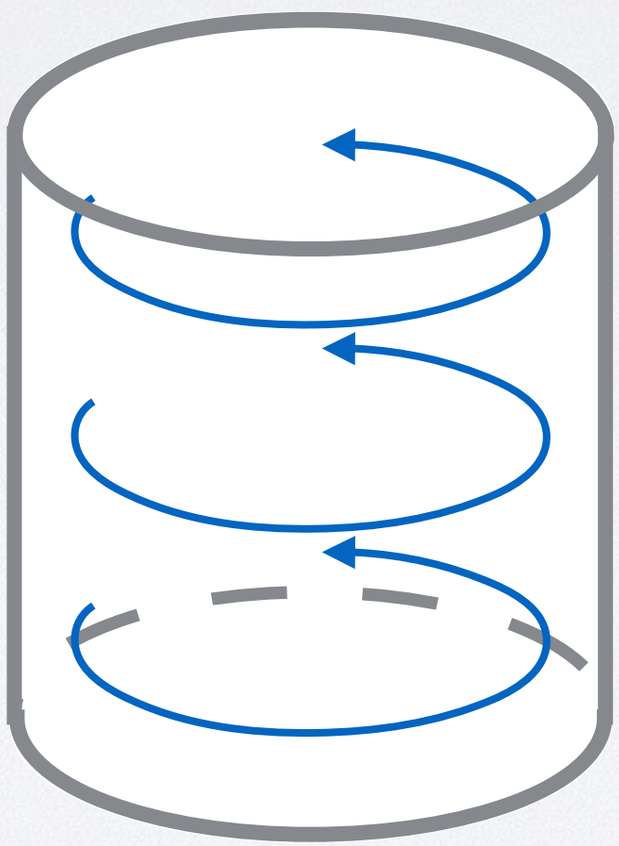
…but generating real B field inside the shield

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

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

DM RADIO CONCEPT

- Inductor designed to pick up induced B-field
- Piezo-adjusted capacitor to tune resonant frequency
- Read out with SQUID
- Scan over frequency looking for signal



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

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

Confirming a signal

Excellent **cross-checks** are possible:

— always at same **fixed frequency**

— **orientation dependence** is characteristic of vector

— phase and directional **coherence over ~1000 wavelengths**

— could **map out phase and direction** over time

THE DM RADIO COLLABORATION

Experiment

Kent Irwin (PI)
Saptarshi Chaudhuri
Dale Li
Christopher Williams
Betty Young
Max Silva-Feaver
Sarah Stokes Kernasovkiy

Theory

Peter Graham
Jeremy Mardon
Surjeet Rajendran
Yue Zhao

SLAC

Stanford University

REACH

STAGE I

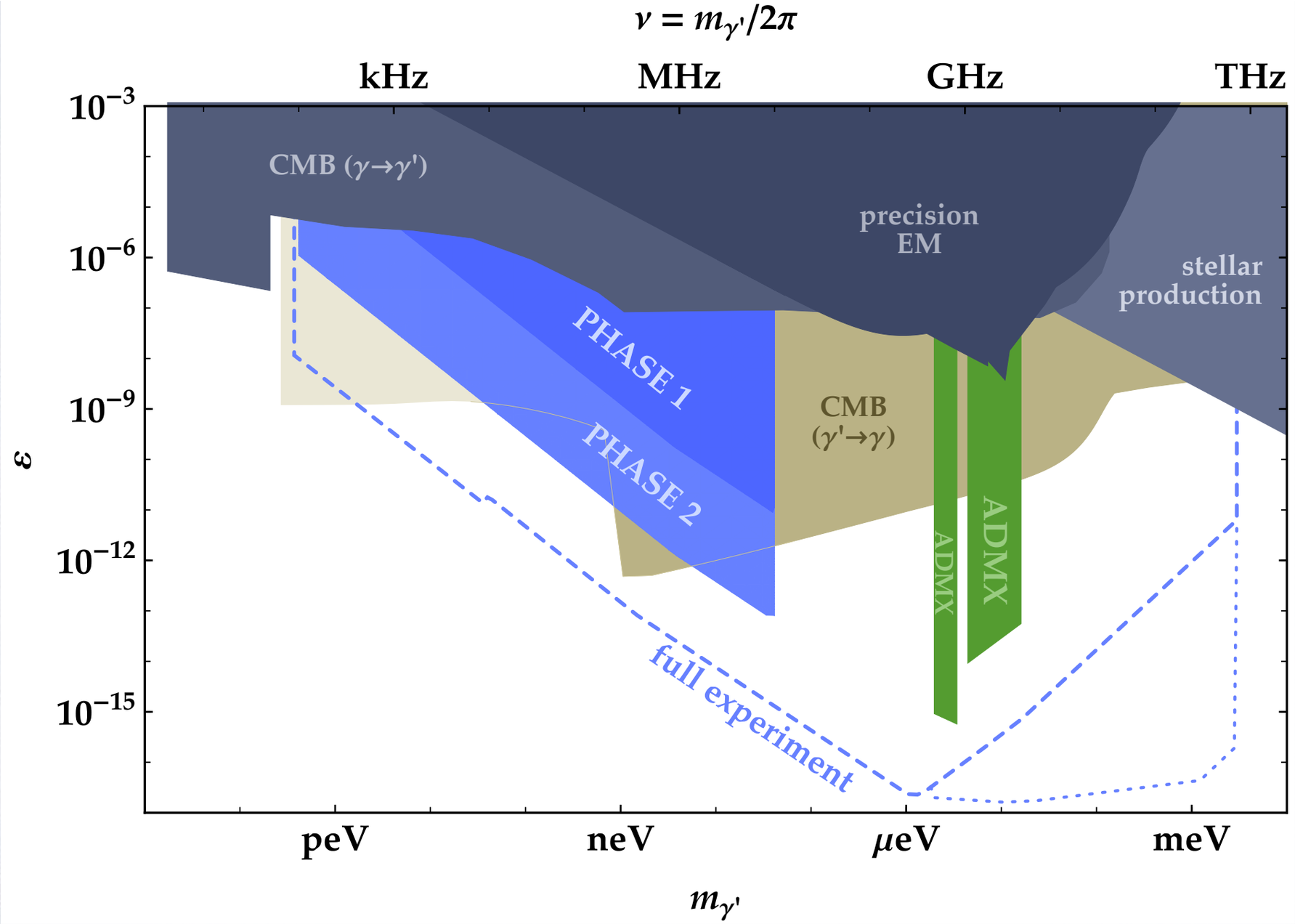
size ~ 350ml — 1m $Q \sim 10^6$

T~4K, thermal noise limited

FULL DESIGN

size ~ 1m $Q \sim 10^6$

T~0.1K, thermal noise limited



Hidden photon

DARK MATTER FROM INFLATION

"Vector Dark Matter from Inflationary Fluctuations"

Peter Graham, J. M. & Surjeet Rajendran

arXiv:1504.02102

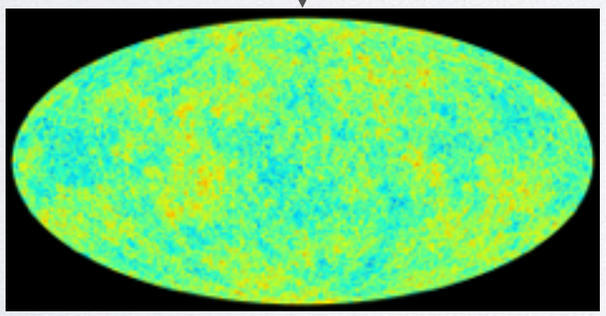
Inflation

⇒ coherent particle production

scalar

inflaton fluctuations

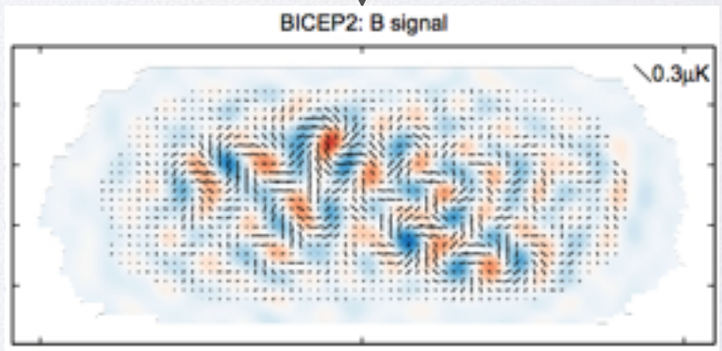
adiabatic density perturbations



tensor

metric fluctuations

primordial gravity waves



Inflation

⇒ coherent particle production

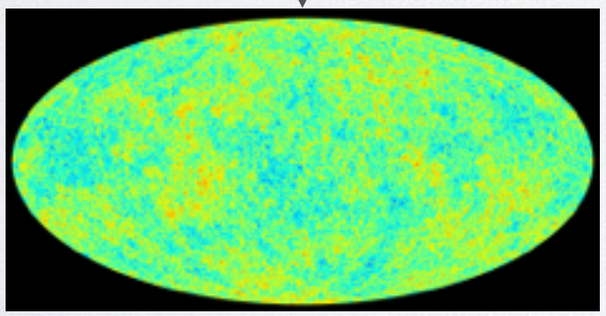
scalar

massive vector

tensor

inflaton fluctuations

adiabatic density perturbations

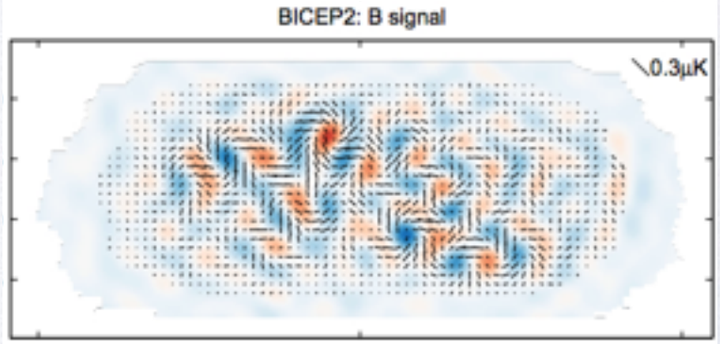


cold relic matter

DARK MATTER

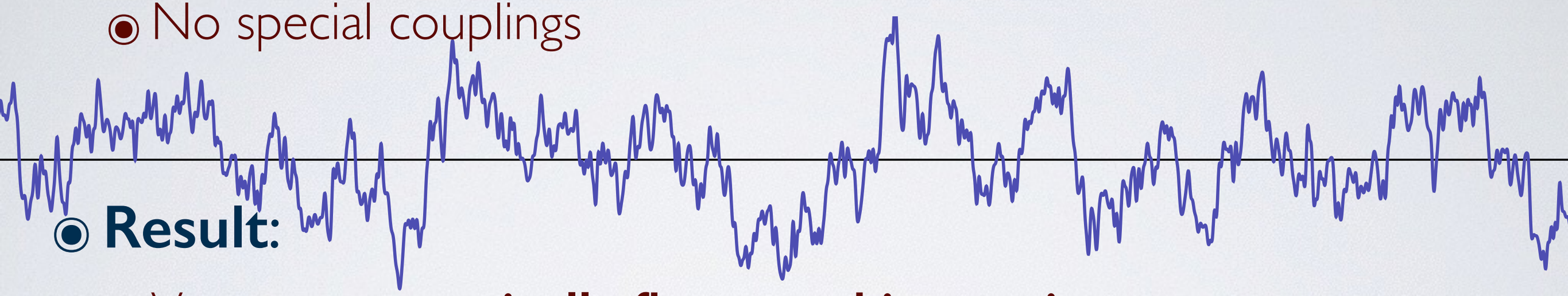
metric fluctuations

primordial gravity waves



INFLATIONARY VECTOR PRODUCTION

- **Requirements:**
  - **Stueckelberg mass** or Higgs scale above H_I
  - No special couplings



- **Result:**
  - Vector **automatically fluctuated into existence**
  - Ends up as **cold matter**

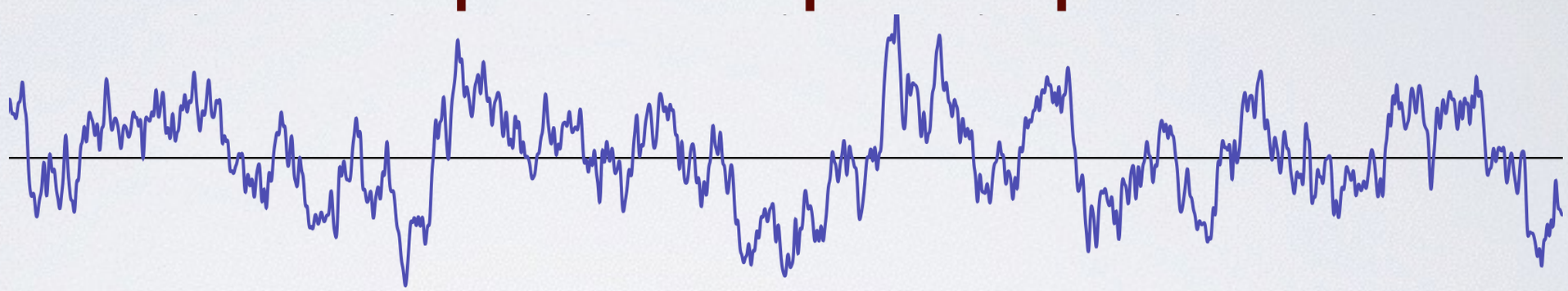
$$\frac{\Omega_A}{\Omega_{\rm cdm}} \approx \sqrt{\frac{m}{6\times 10^{-6}\,{\rm eV}}}\left(\frac{H_I}{10^{14}\,{\rm GeV}}\right)^2$$

  - Spectrum peaked at intermediate wavelengths
    $\longrightarrow$ dangerous **large-scale isocurvature is absent**

New Probe of Inflation

- Map out direction and amplitude as experiment sweeps through space

  — Could we **infer the primordial power spectrum?**

  — This: 

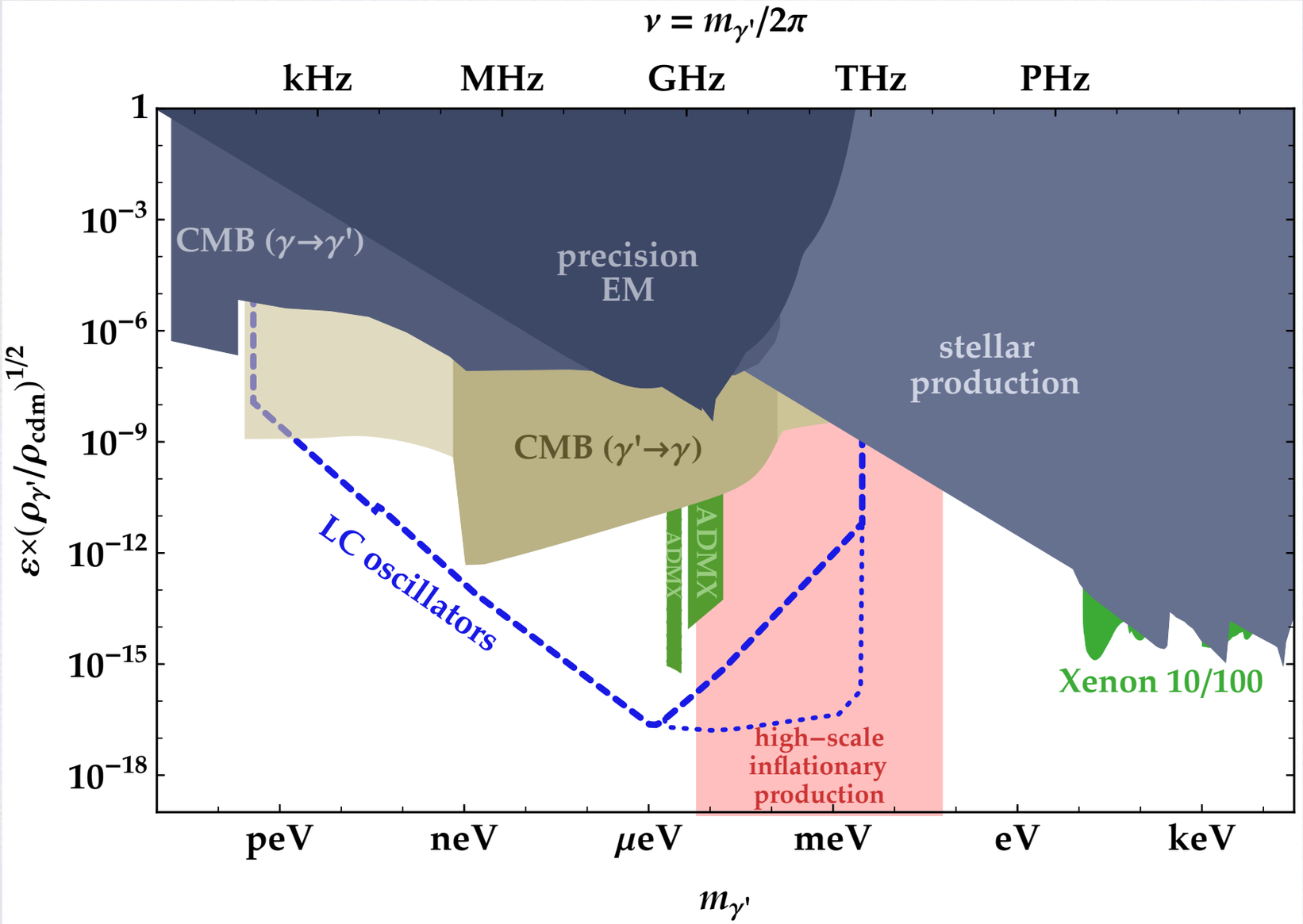
  goes through non-linear structure formation (very complicated)

  — *If* primordial spectrum reconstructed, would give a **new probe of inflation** itself

PRODUCTION SUMMARY

Inflation produced full DM abundance →

← **Inflation produced DM subcomponent**



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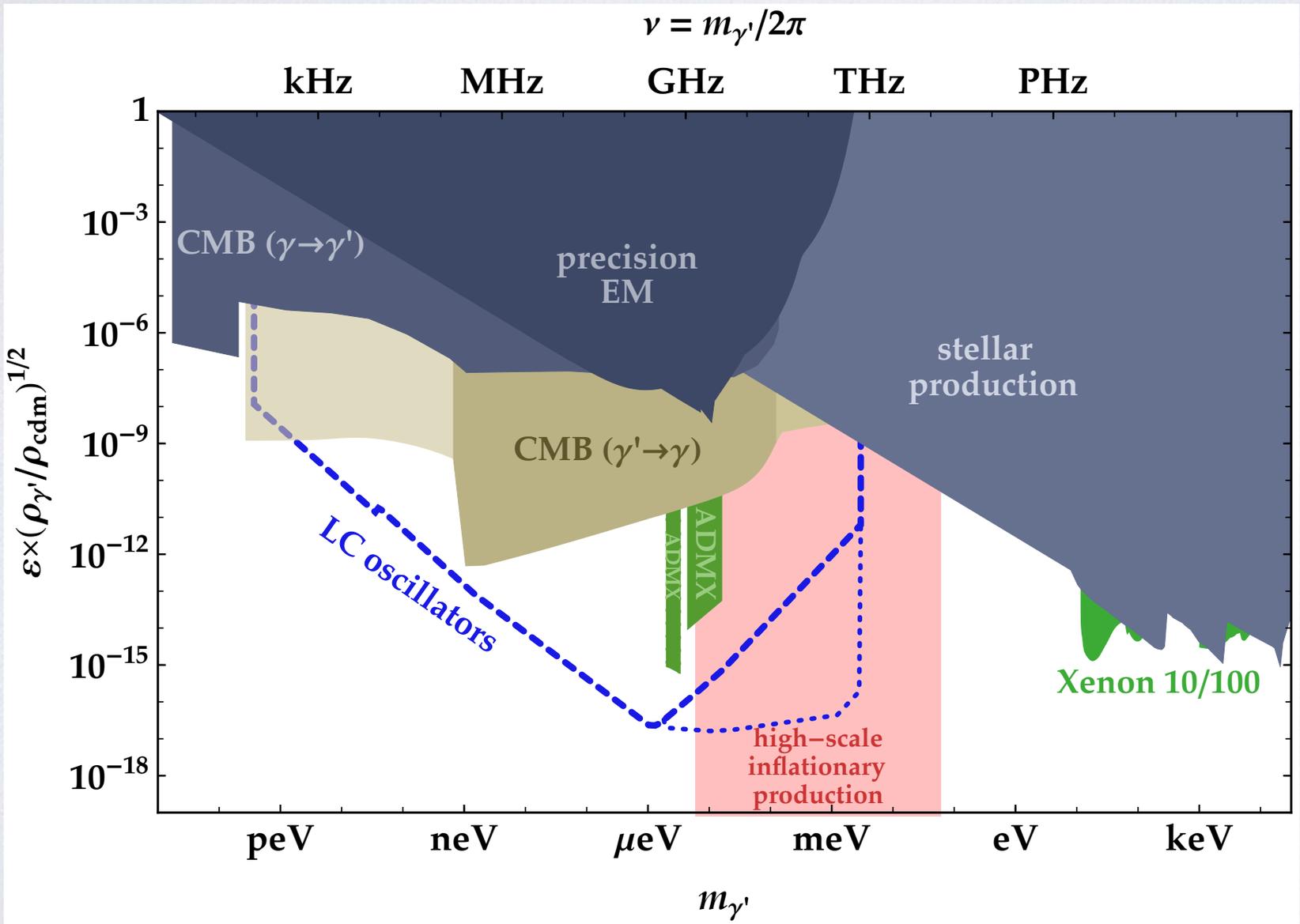


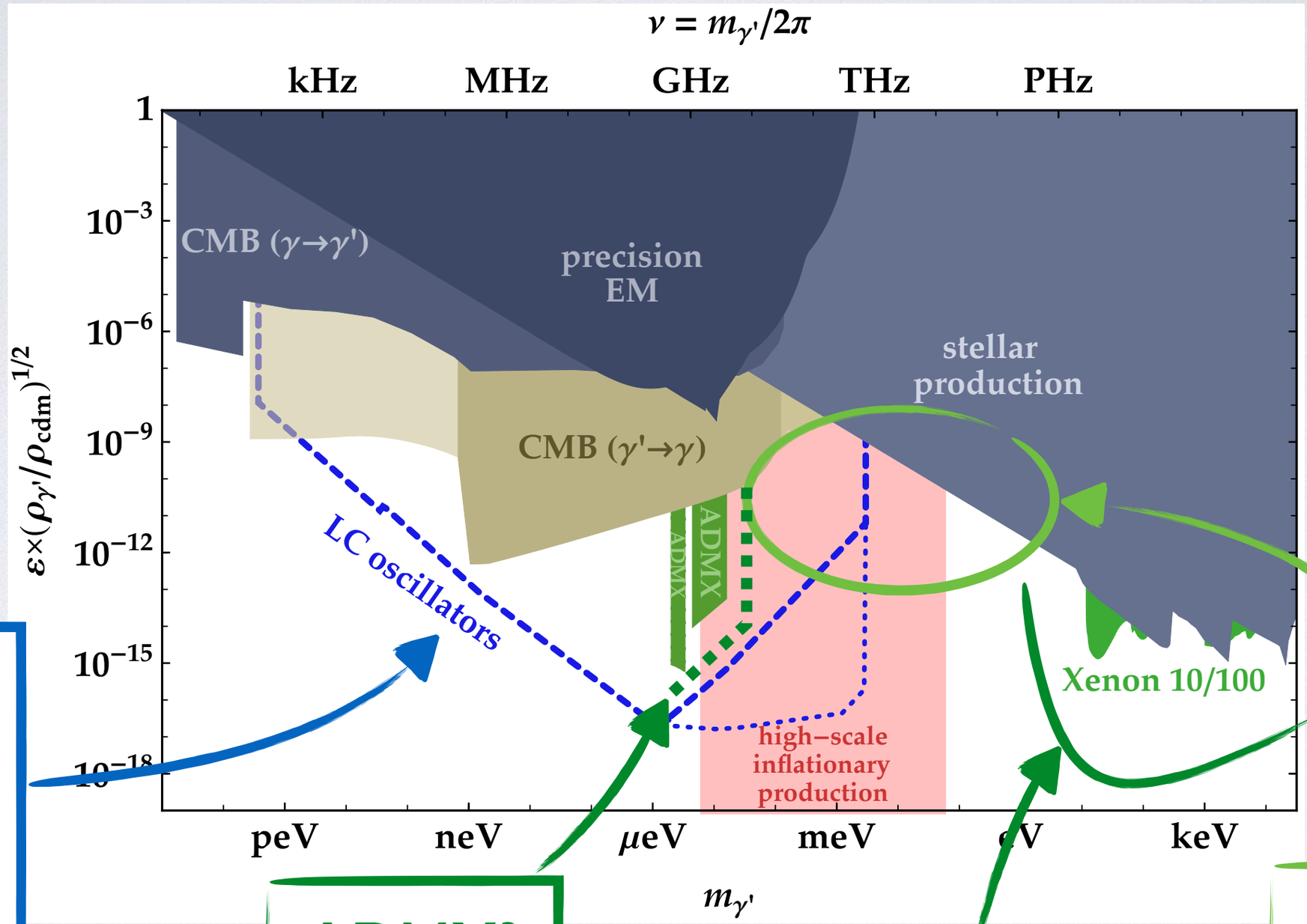
ALSO:

— Misalignment production possible (with special $A_\mu A^\mu \mathcal{R}$ coupling)

Arias et al 1201.5902

— Production not fully explored (work in progress)

Detection Summary



Next few years at SLAC/ Stanford

ADMX?

Direct detection?

?? (dish focussing?)

Stay Tuned