Bosonic dark matter detection at IR-optical frequencies
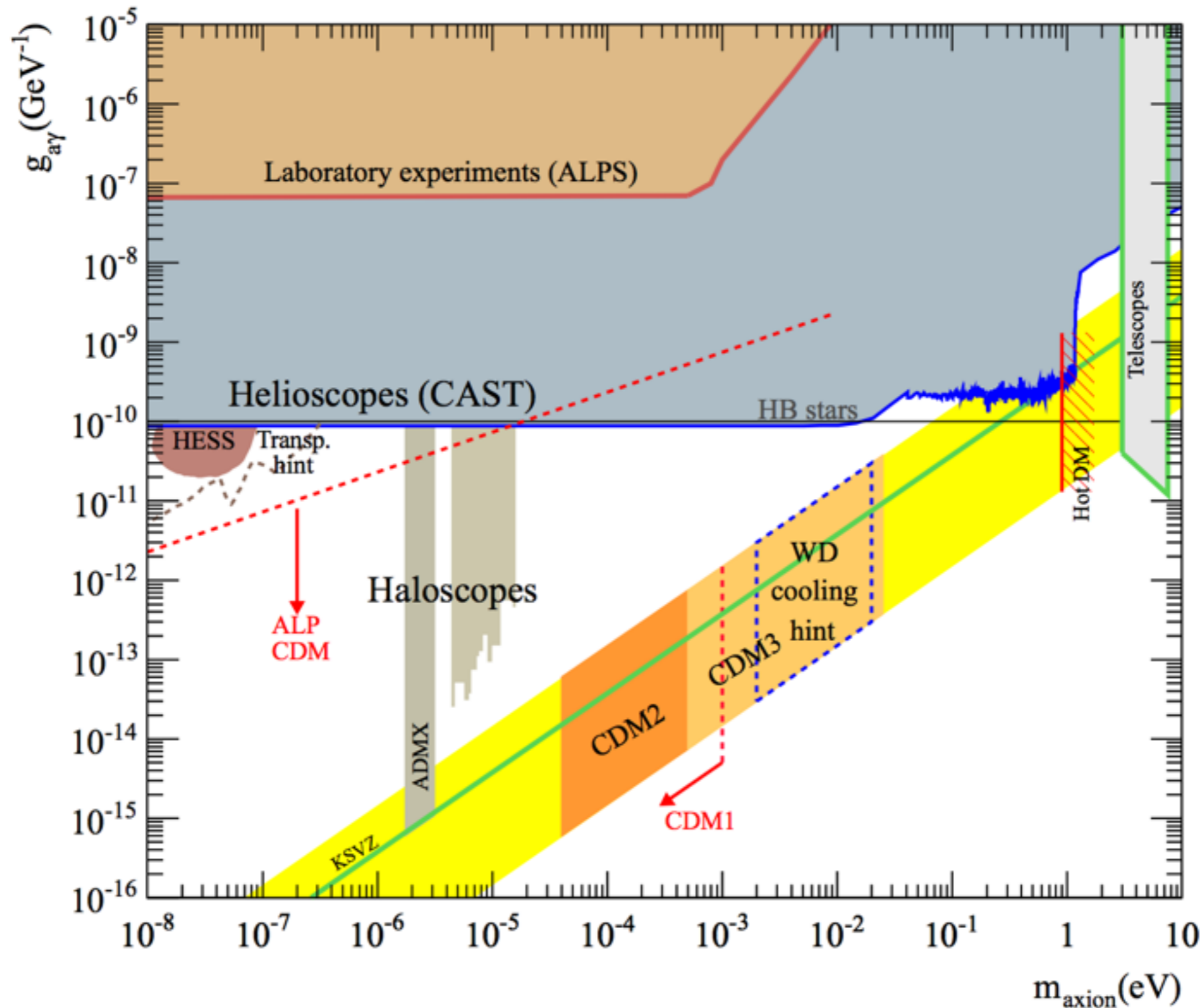
Robert Lasenby, Stanford University

Aspen, April 5, 2018
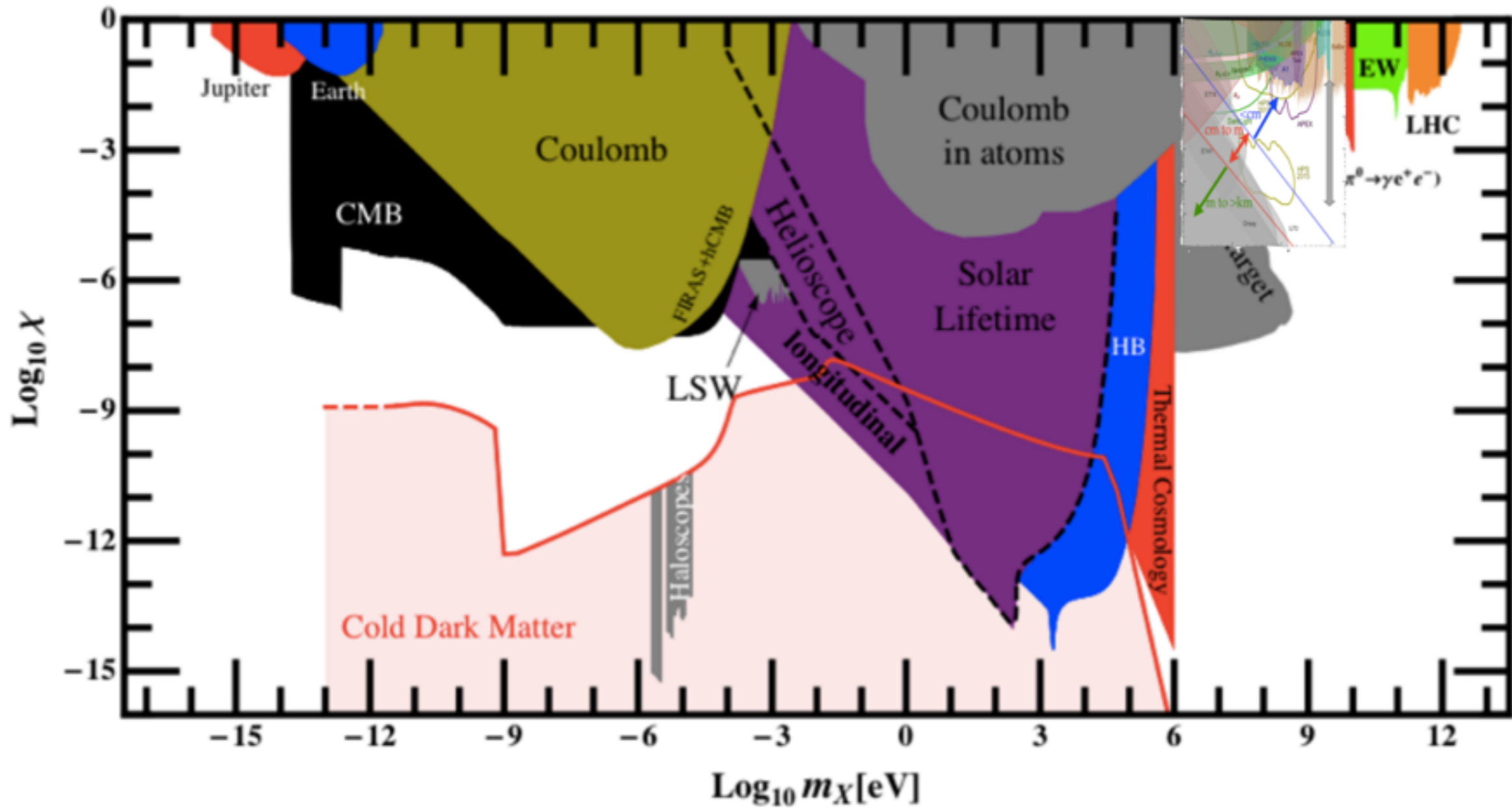
Axion dark matter

(IAXO)

Dark photon dark matter

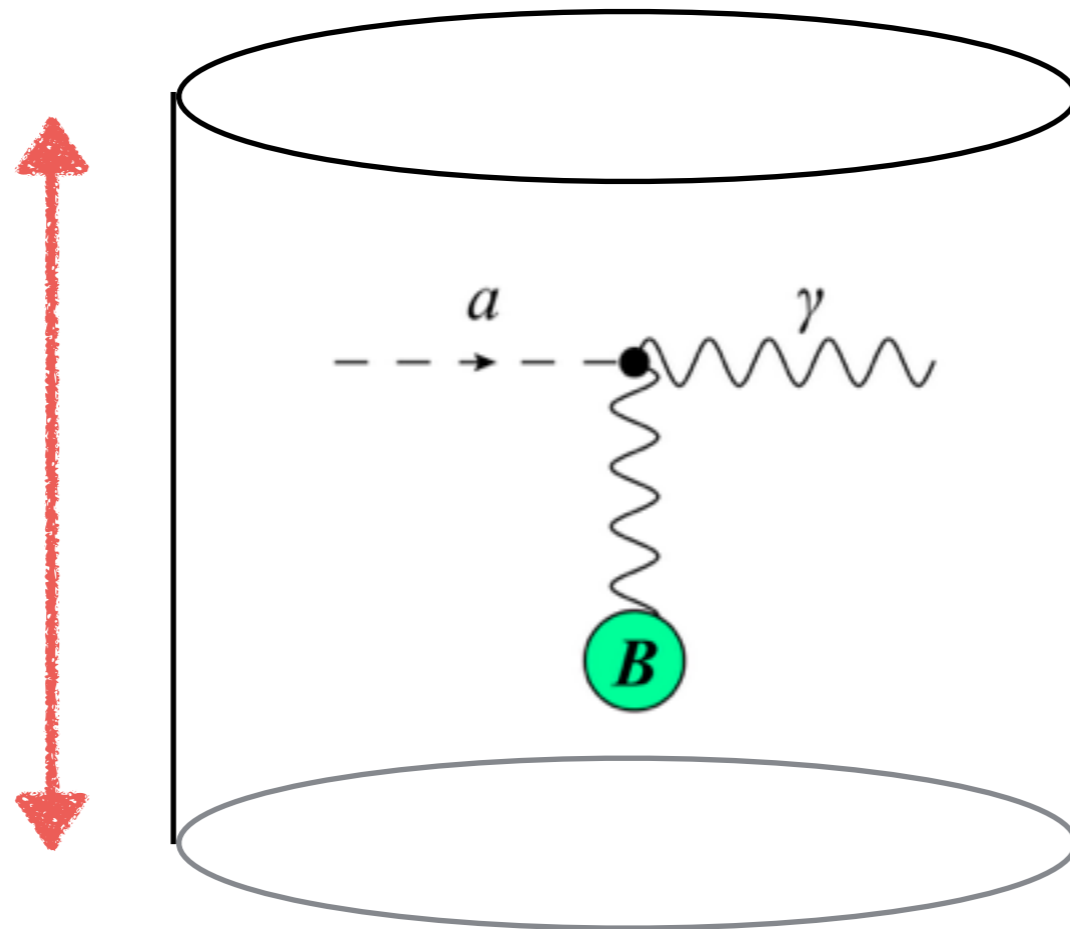
(Jaeckel 2013)

DM ➡ photon conversion
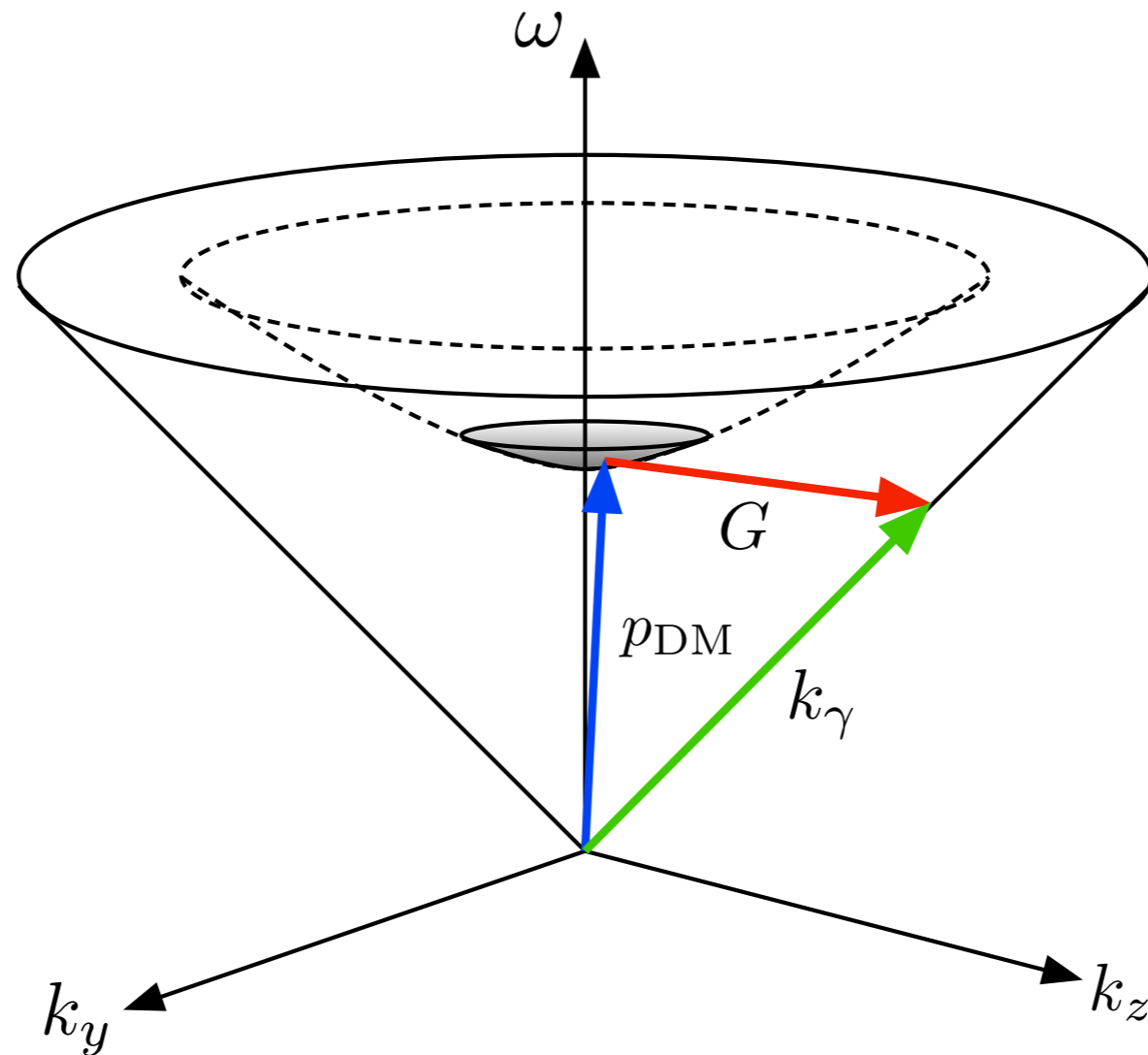
- Natural channel for axion-photon coupling, dark photon, …

ADMX etc:

$$L \sim m_a^{-1}$$

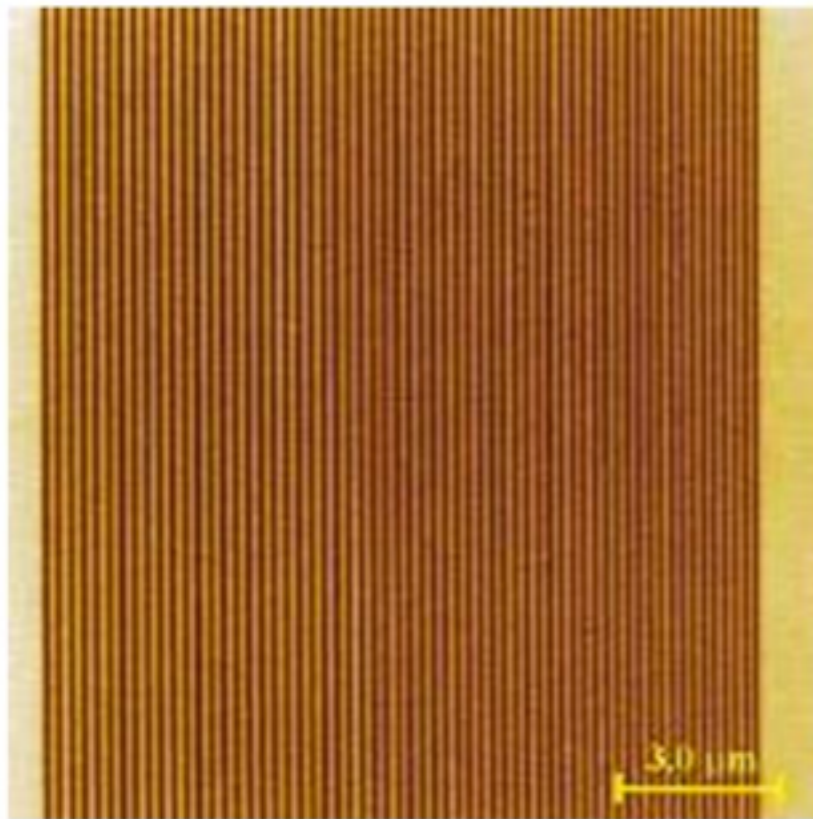# DM ➞ photon conversion

- Natural channel for axion-photon coupling, dark photon, …

- In large target, photons are relativistic - momentum mismatch with DM:
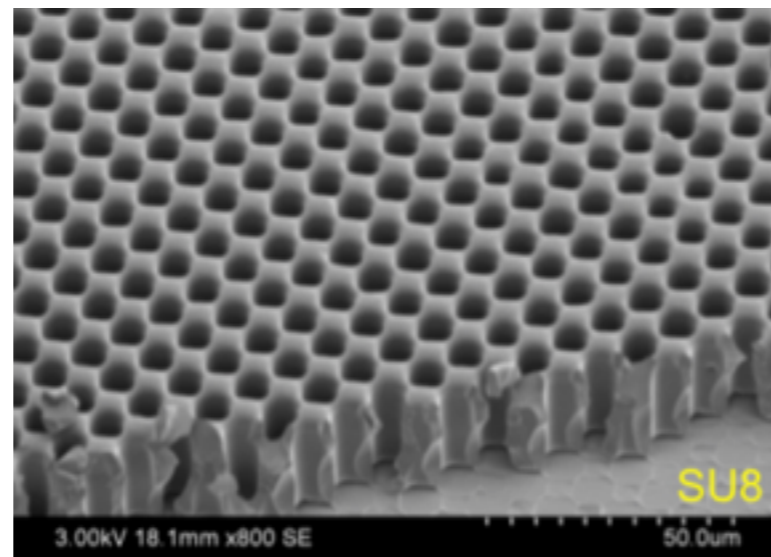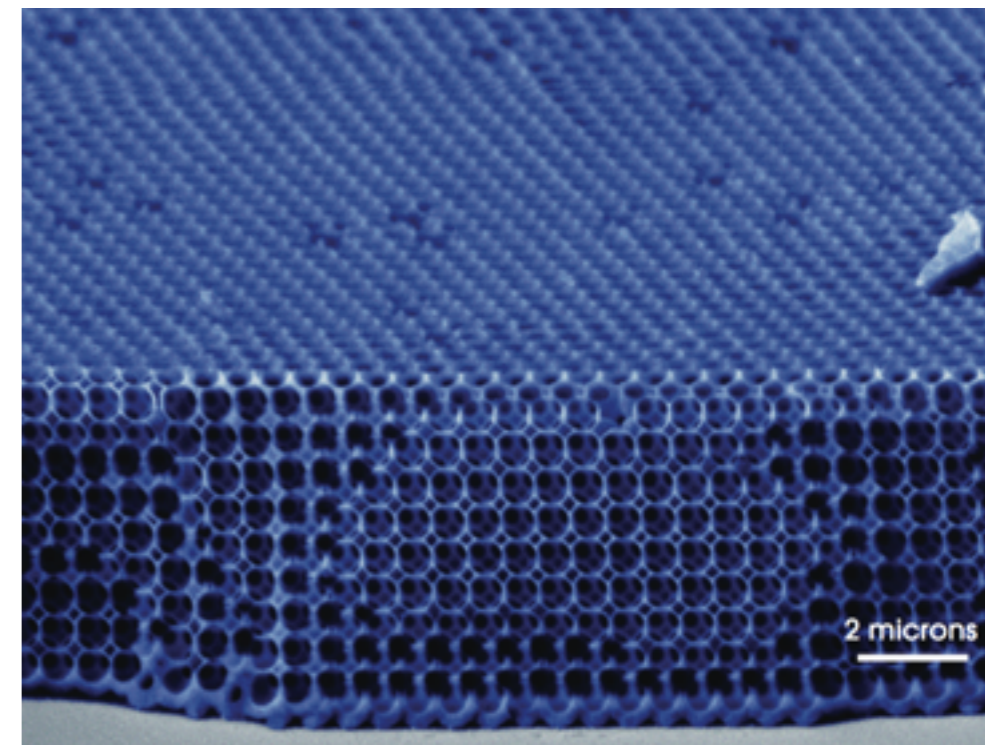
Photonic materials

- Materials with periodic optical properties

1D

2D

3D

Dielectric haloscopes
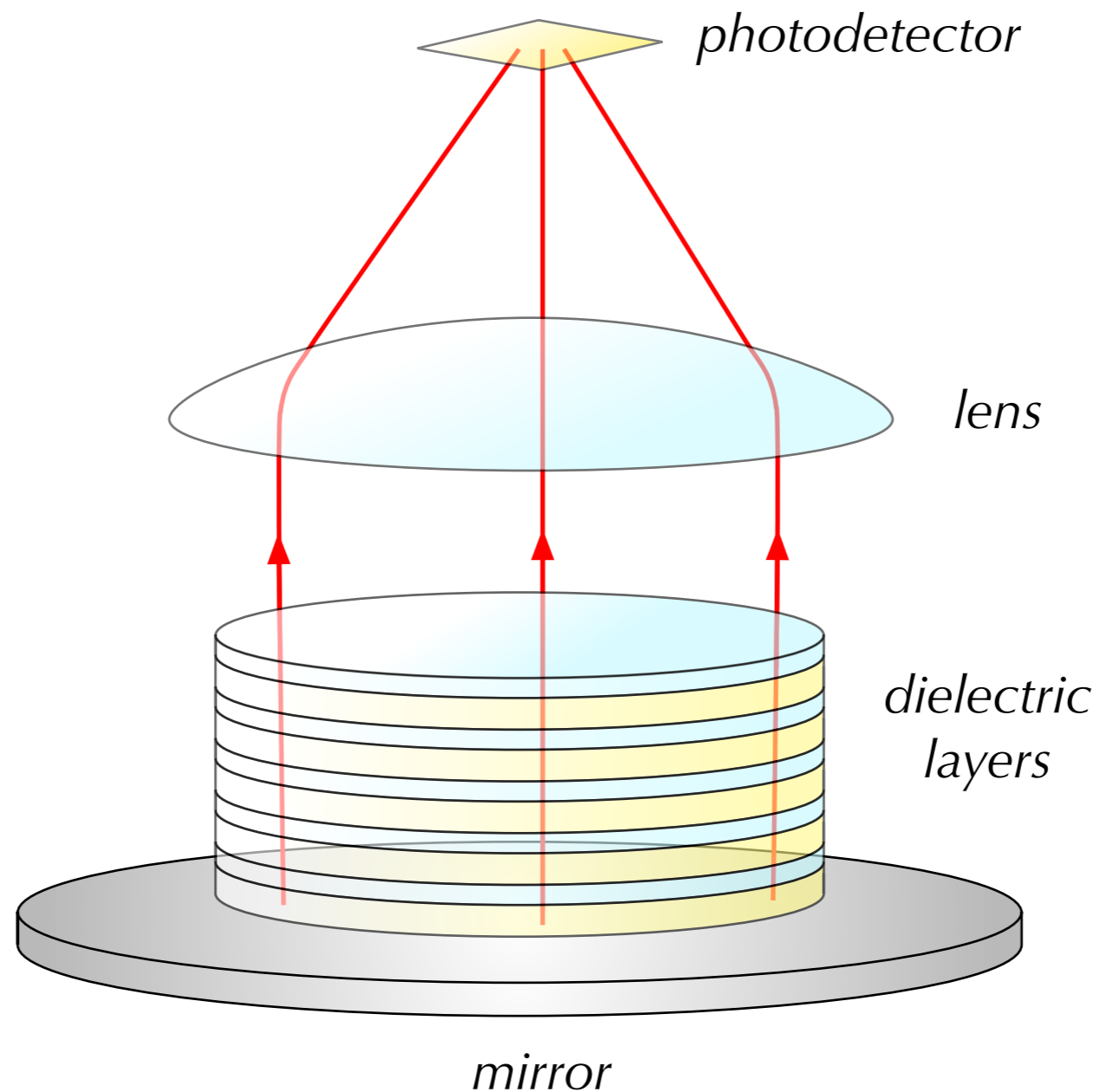
- DM can Bragg-convert in medium, producing photons:

photodetector

lens

dielectric layers

mirror

Dielectric haloscopes

- DM can Bragg-convert in medium, producing photons:

photodetector

lens

B_0

dielectric layers

mirror

Dielectric haloscopes

- DM can Bragg-convert in medium, producing photons:

photodetector

lens

$\delta\theta \sim 10^{-3}$

dielectric layers

mirror
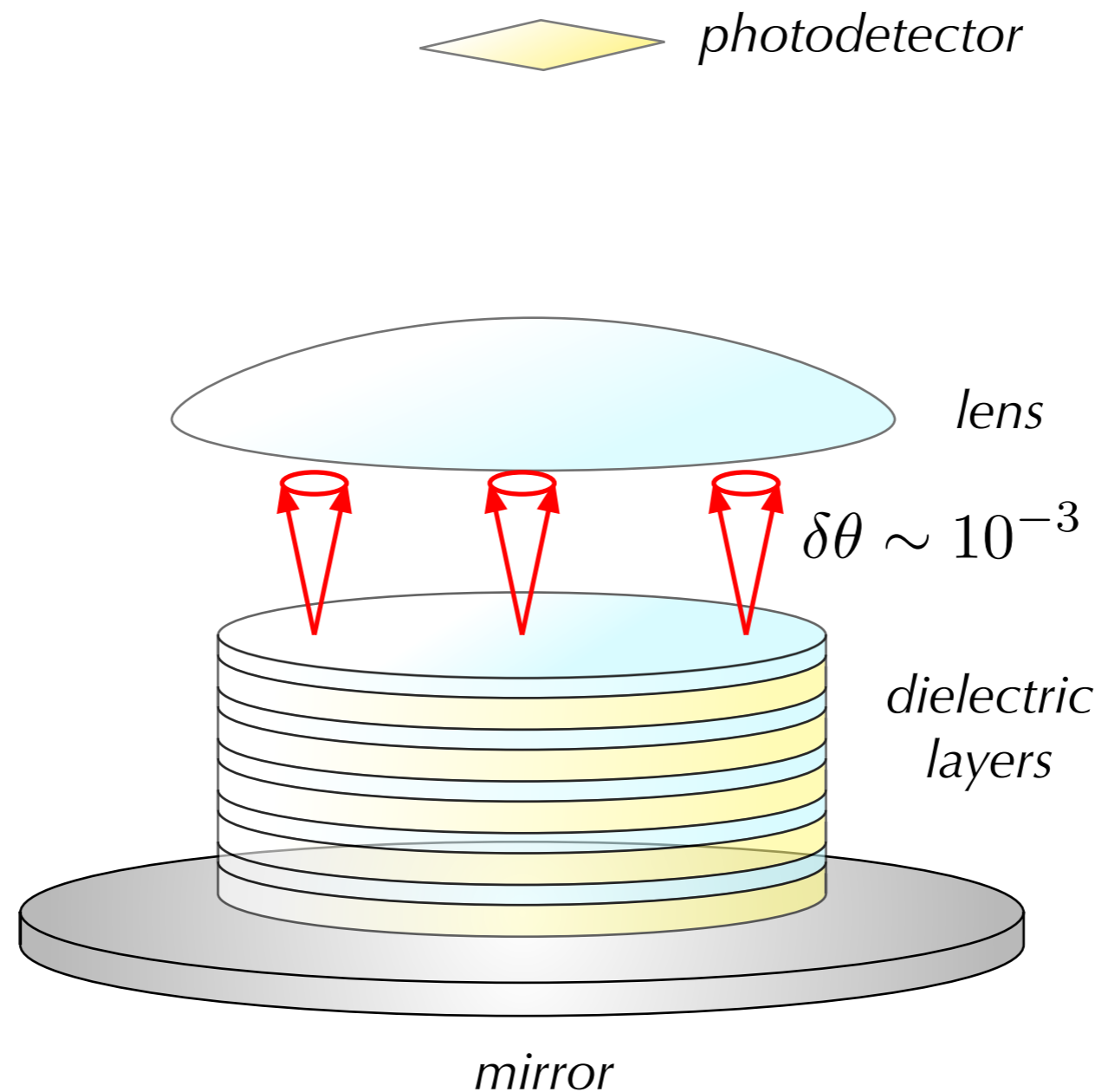
Dielectric haloscopes

- Concepts at different frequencies:

  - "Electric Tiger" $\quad\quad$ $4 - 7\,\mathrm{GHz}$

  - MADMAX $\quad\quad$ $10 - 100\,\mathrm{GHz}$

  - Photonic Haloscopes $\quad$ IR - optical

Dielectric haloscopes

- Concepts at different frequencies:

  - **"Electric Tiger"** $4 - 7\,\text{GHz}$

  - MADMAX $10 - 100\,\text{GHz}$

  - Photonic Haloscopes   IR - optical
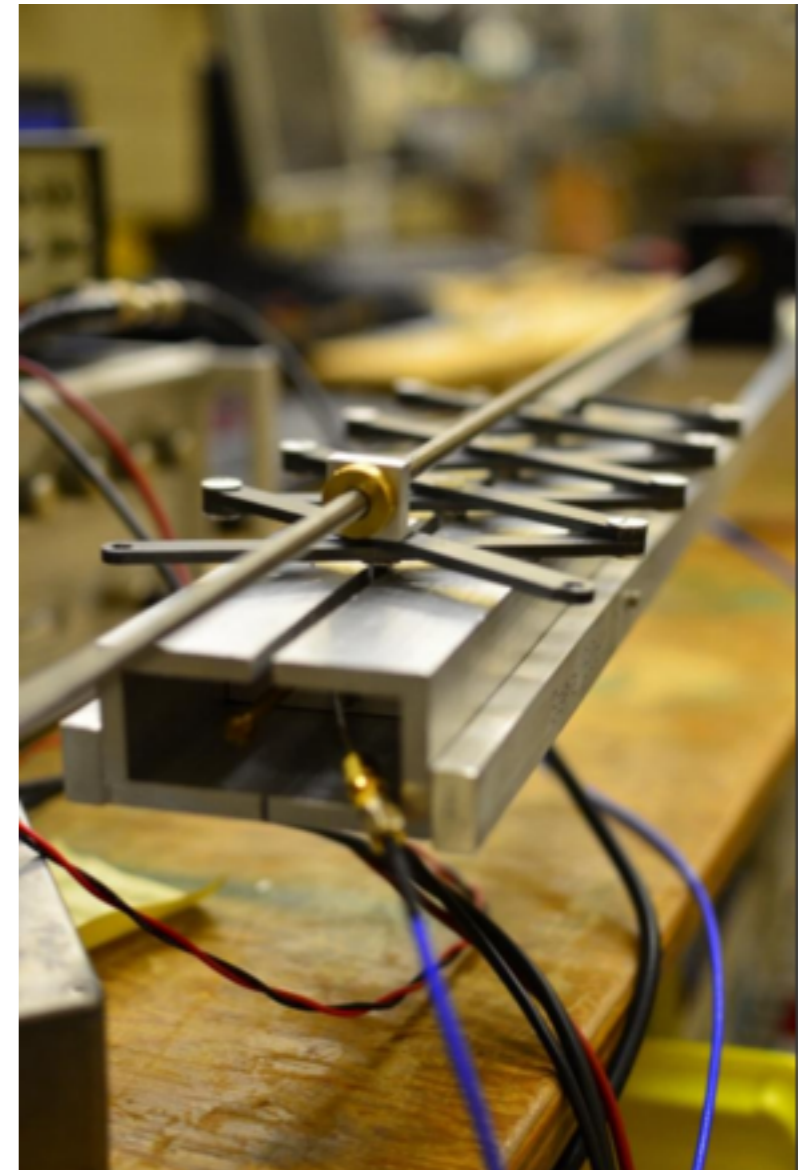
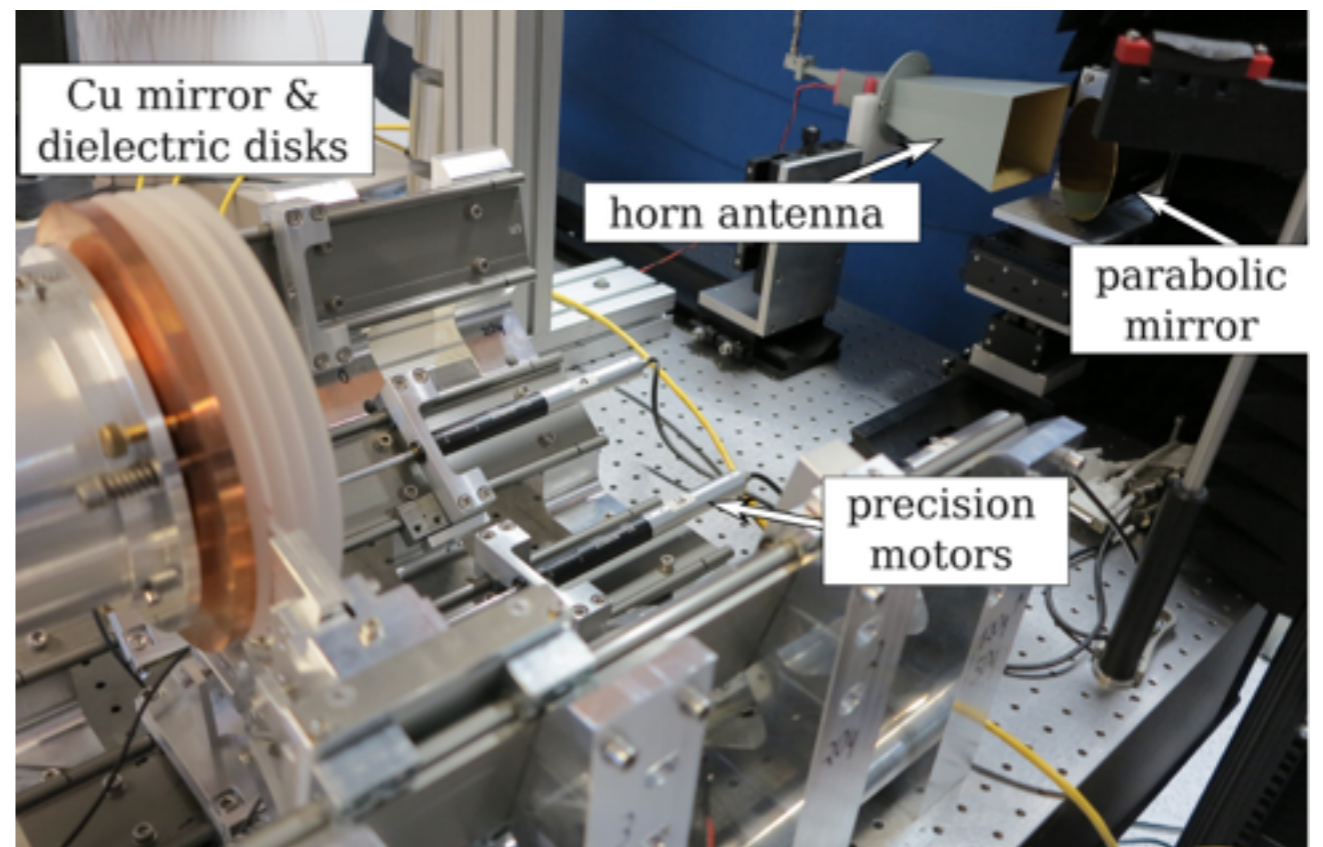# Dielectric haloscopes

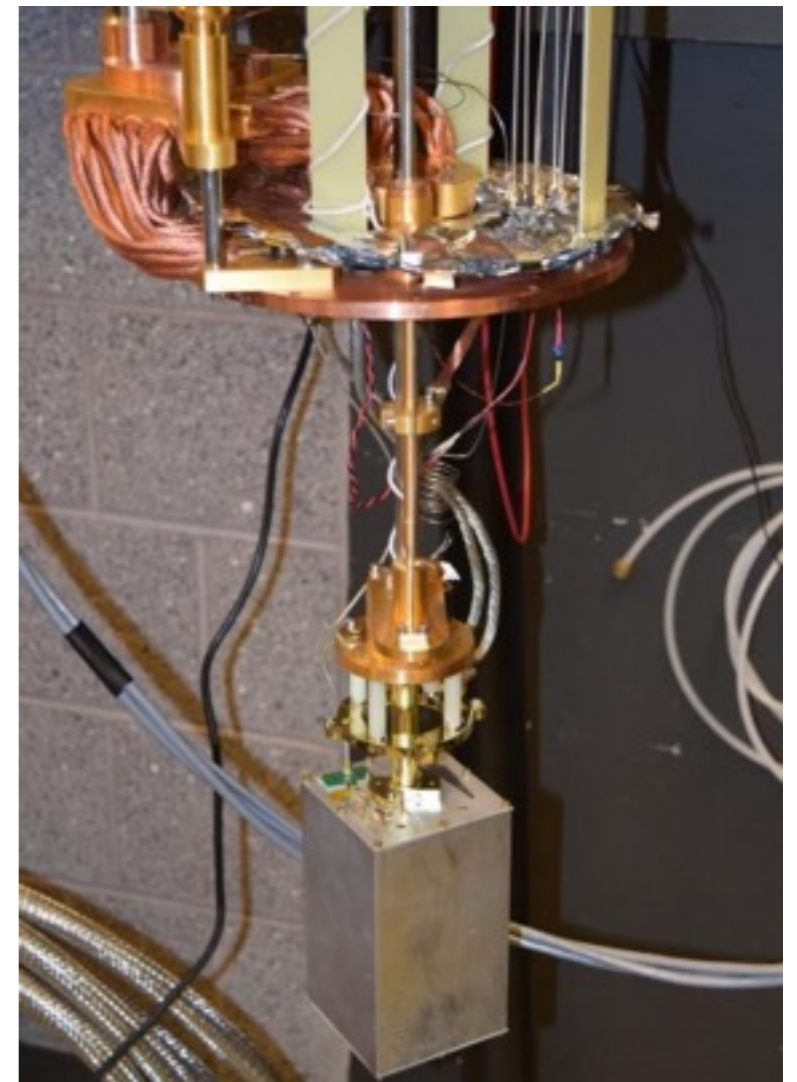- Concepts at different frequencies:

  - "Electric Tiger"

 - **MADMAX**

  - Photonic Haloscopes

Dielectric haloscopes

- Concepts at different frequencies:

  - "Electric Tiger" $4 - 7\,\mathrm{GHz}$

  - MADMAX $10 - 100\,\mathrm{GHz}$

  - **Photonic Haloscopes**   IR - optical
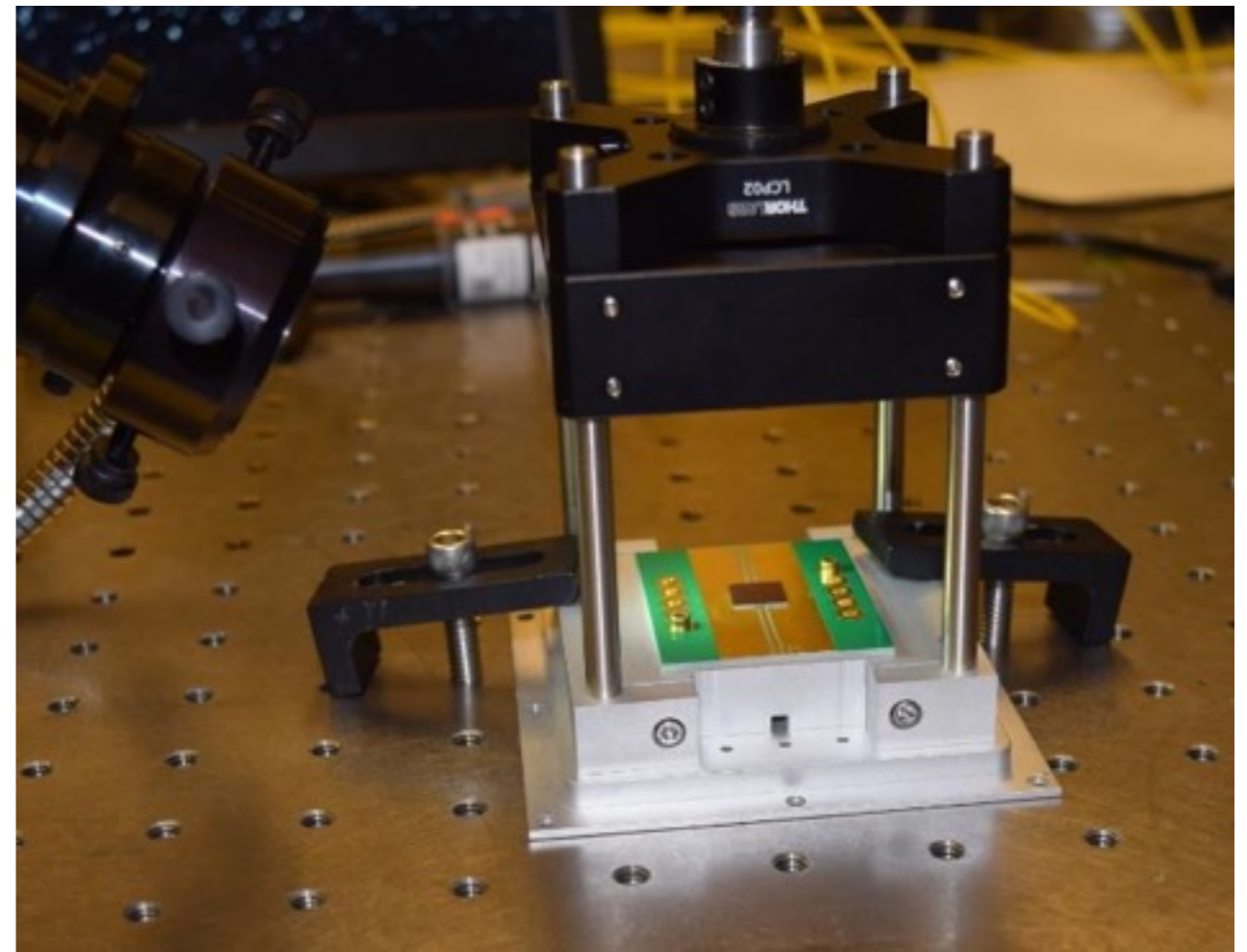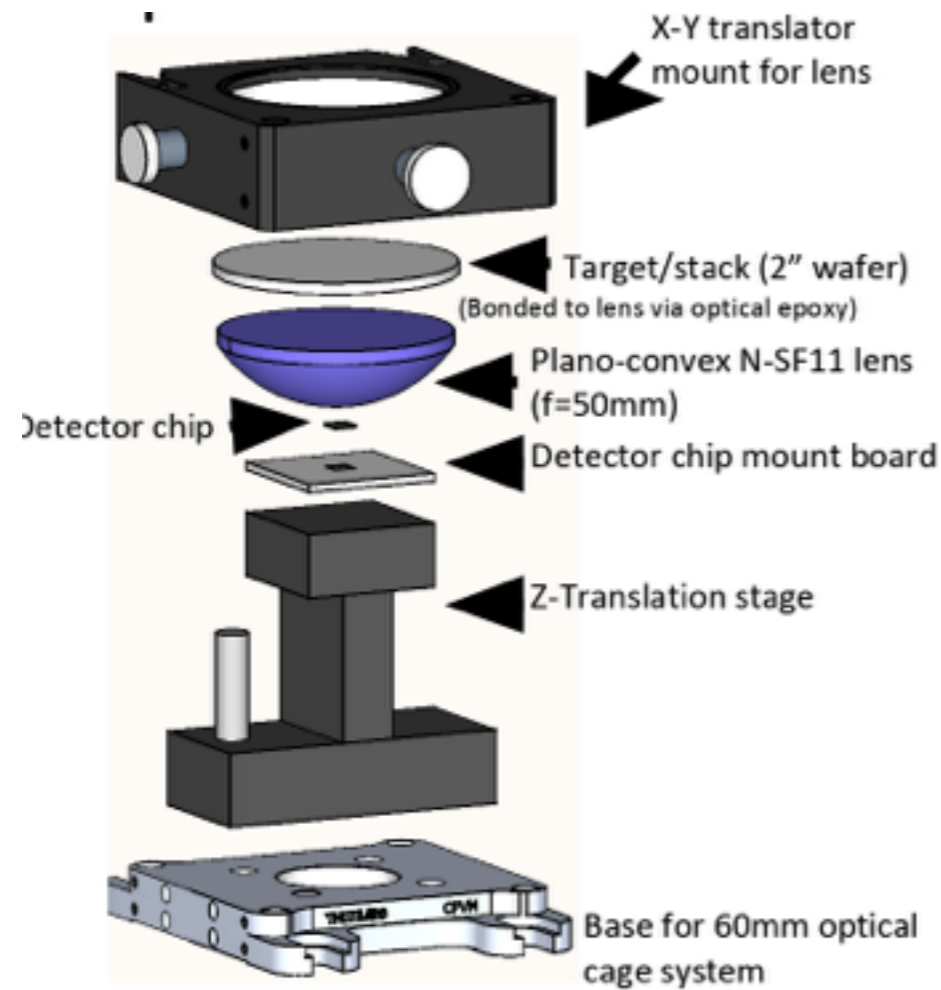
Photon detection

- Collimated emission means that emitted photons can be focused down to area of layers' area $\sim 10^{-6}$

  - e.g. $(100\,\mu\text{m})^2$ detector for $(10\,\text{cm})^2$ layers

- Enables use of small, low-noise detectors

  - e.g. Superconducting Nanowire Single-Photon Detectors (SNSPDs), $\text{DCR} < 10^{-5}\,\text{Hz}$

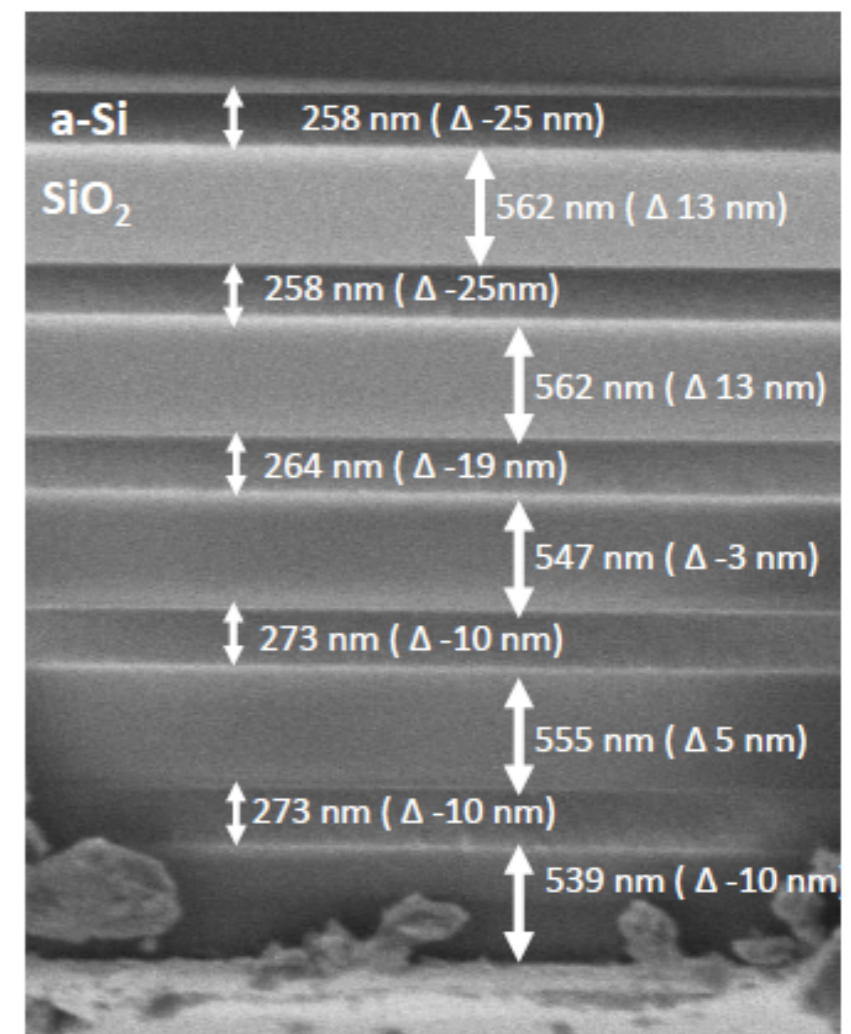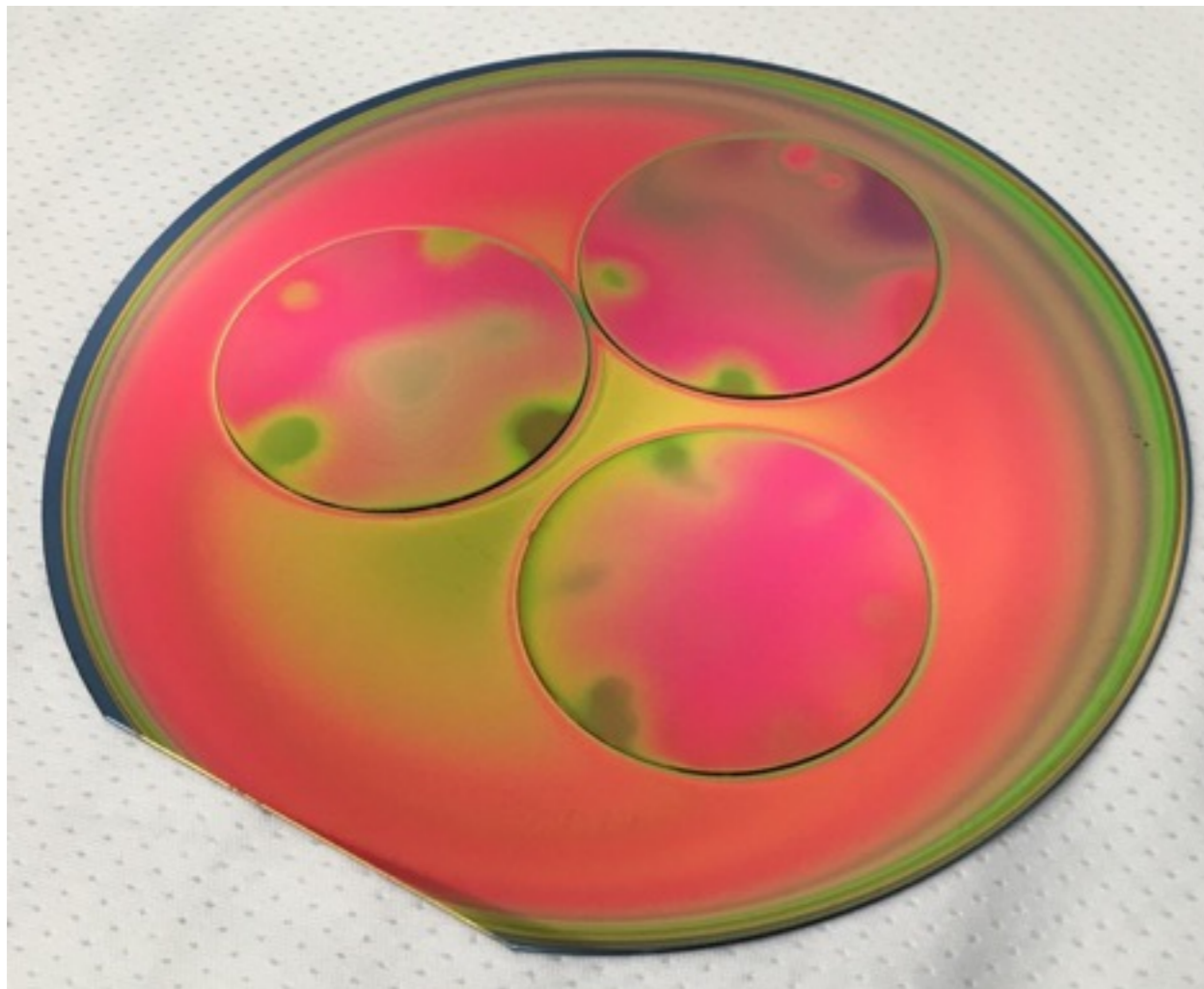$400 \times 400\,\mu\text{m}^2$
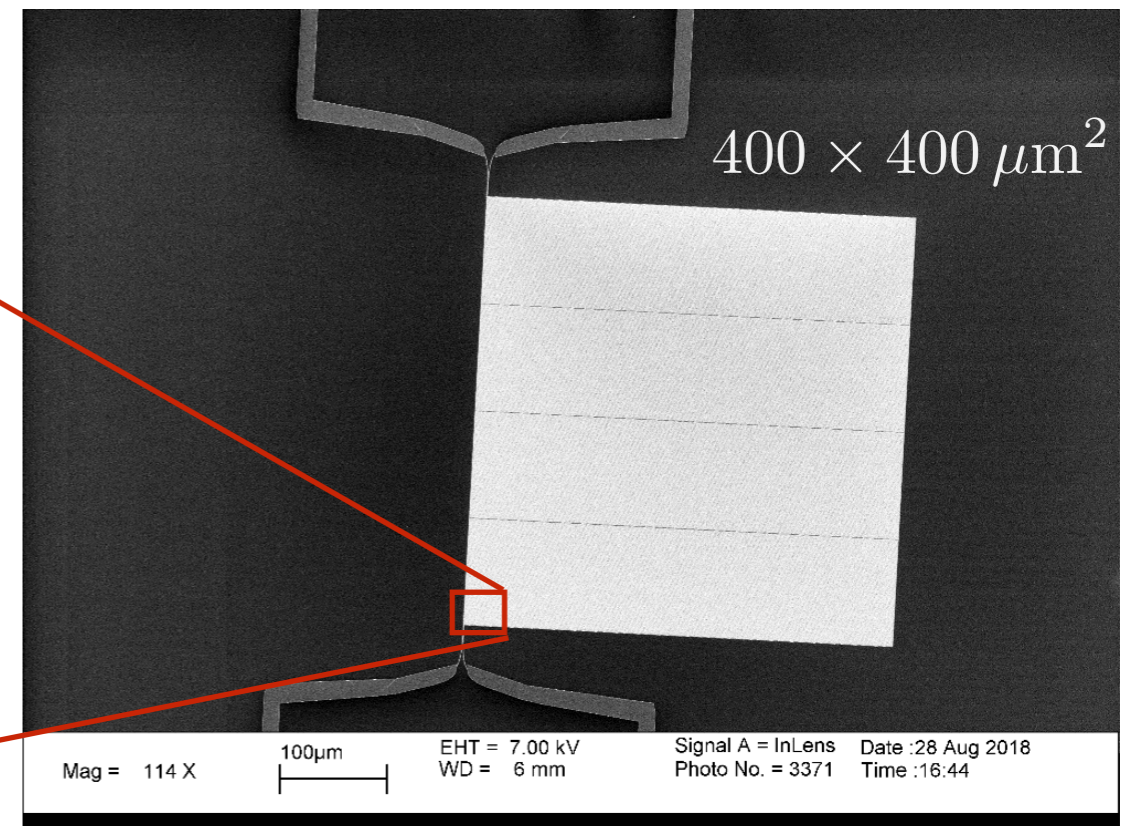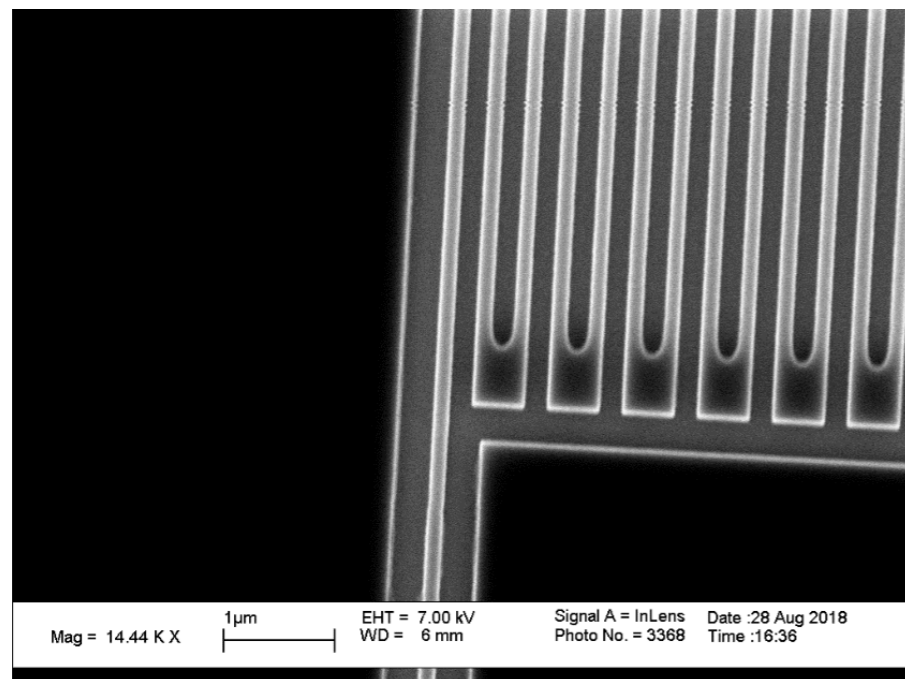
Prototype detector

- Collaboration with:

  - NIST: Sae-Woo Nam, Jeff Chiles

  - MIT: Karl Berggren, Ilya Charaev

  - Stanford: RL

  - Perimeter Institute: Asimina Arvanitaki, Junwu Huang

  - NYU: Masha Baryakhtar, Ken Van Tilberg (/IAS)

- Funded by DoE QUANTIZED program
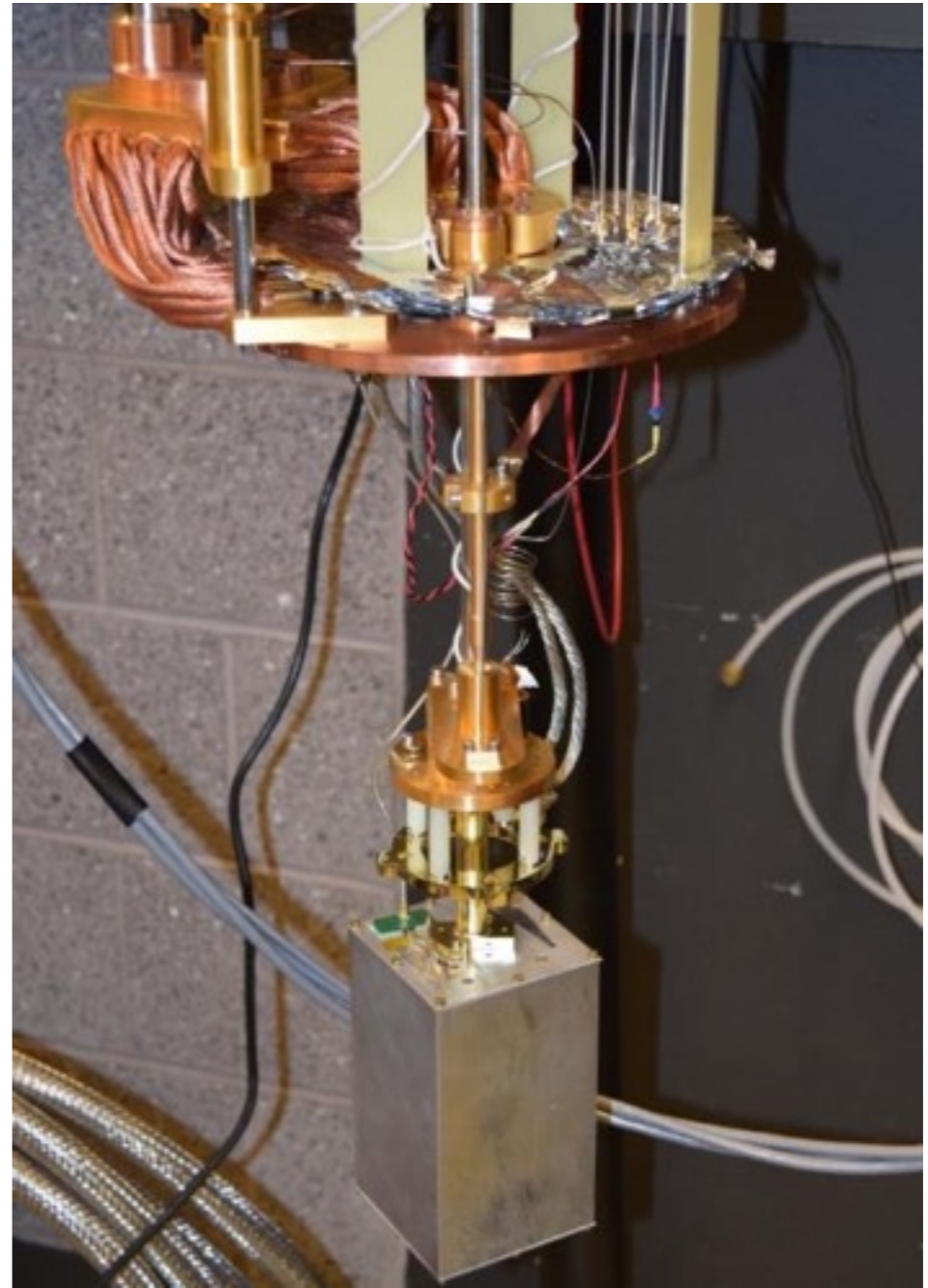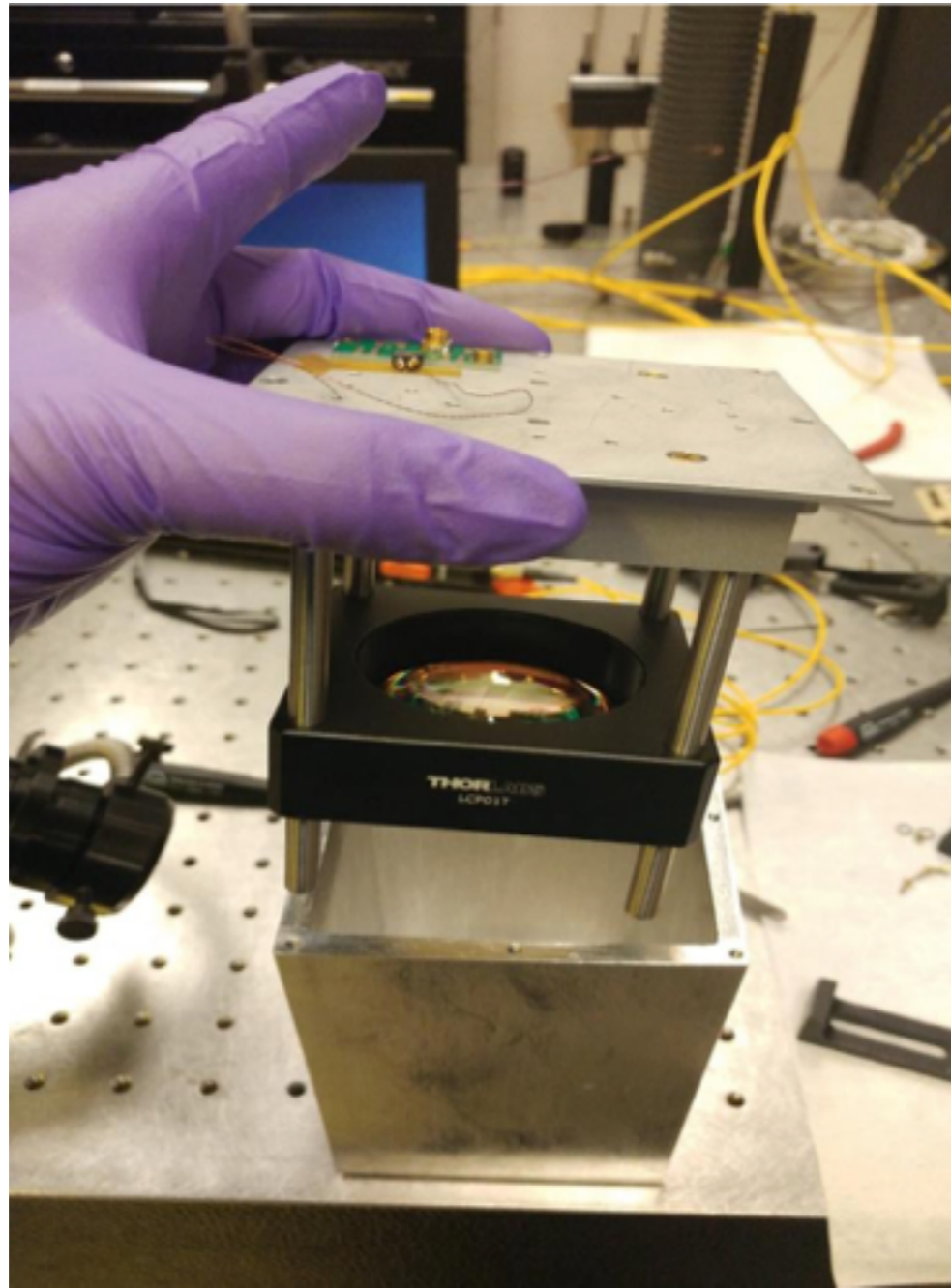
Prototype detector

X-Y translator mount for lens

Target/stack (2" wafer)
(Bonded to lens via optical epoxy)

Plano-convex N-SF11 lens
(f=50mm)

Detector chip

Detector chip mount board

Z-Translation stage

Base for 60mm optical cage system

Prototype detector

a-Si — 258 nm (Δ -25 nm)
SiO$_2$ — 562 nm (Δ 13 nm)
258 nm (Δ -25nm)
562 nm (Δ 13 nm)
264 nm (Δ -19 nm)
547 nm (Δ -3 nm)
273 nm (Δ -10 nm)
555 nm (Δ 5 nm)
273 nm (Δ -10 nm)
539 nm (Δ -10 nm)

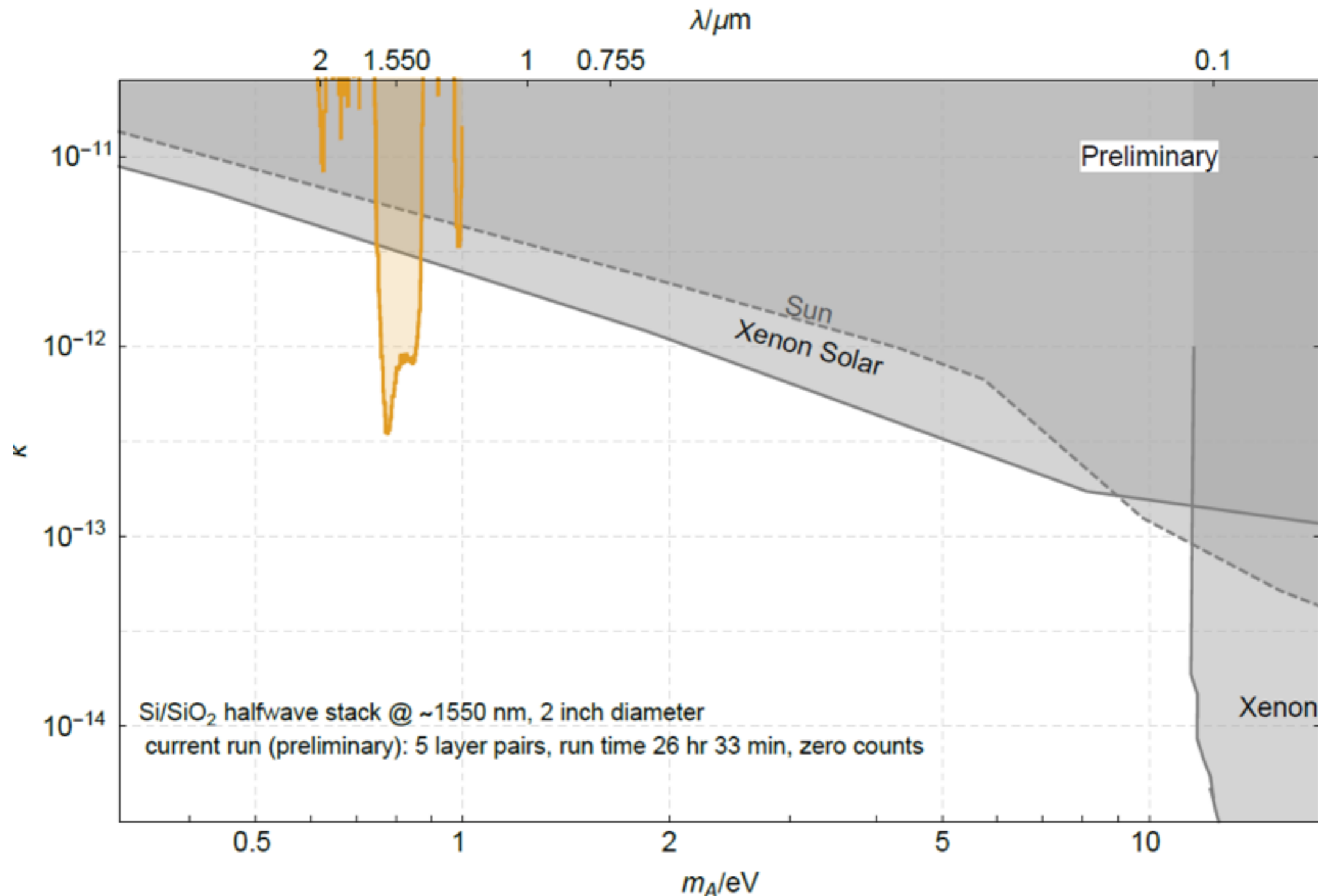# Prototype detector

Results!
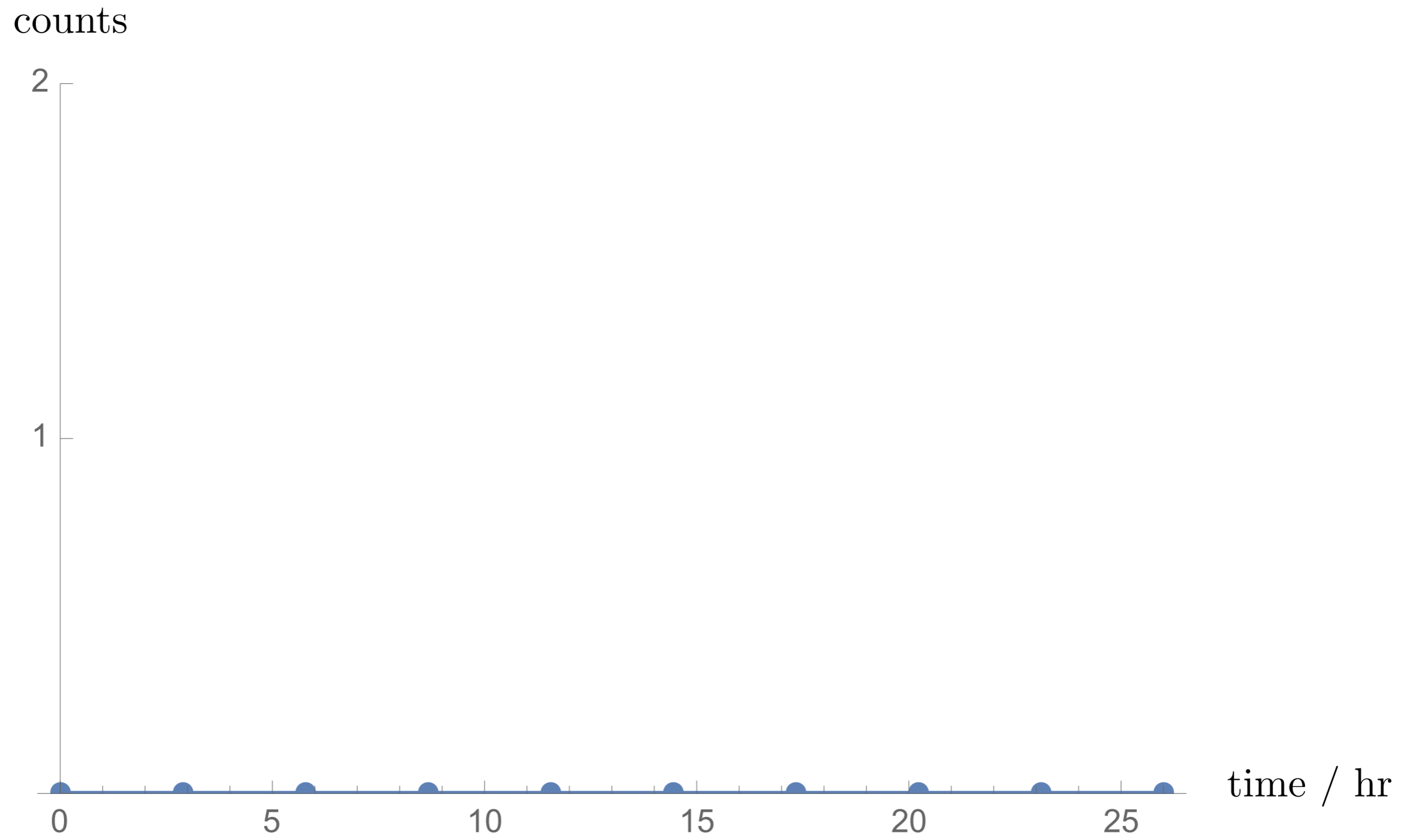
Projected sensitivity

Future sensitivity
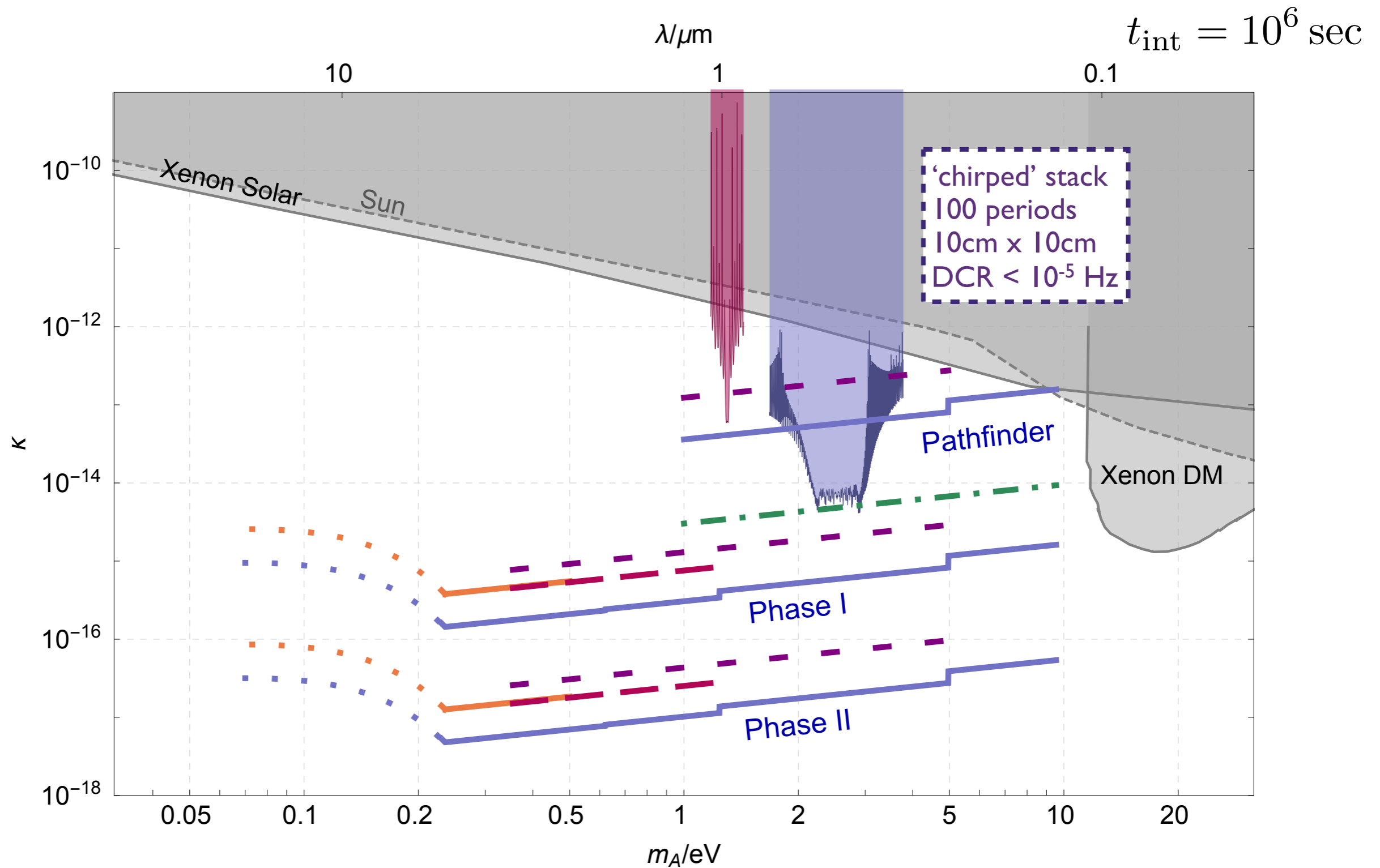
$t_{\rm int} = 10^6$ sec

λ/μm

'chirped' stack
100 periods
10cm x 10cm
DCR < 10^{-5} Hz

Xenon Solar   Sun

Pathfinder

Xenon DM

Phase I

Phase II

κ

m_A/eV

Future sensitivity

$t_{\rm int} = 10^6 \, {\rm sec}$

$\lambda/\mu{\rm m}$

100 periods, $(10\,{\rm cm})^2$
$\rm DCR = 10^{-5}\,Hz$
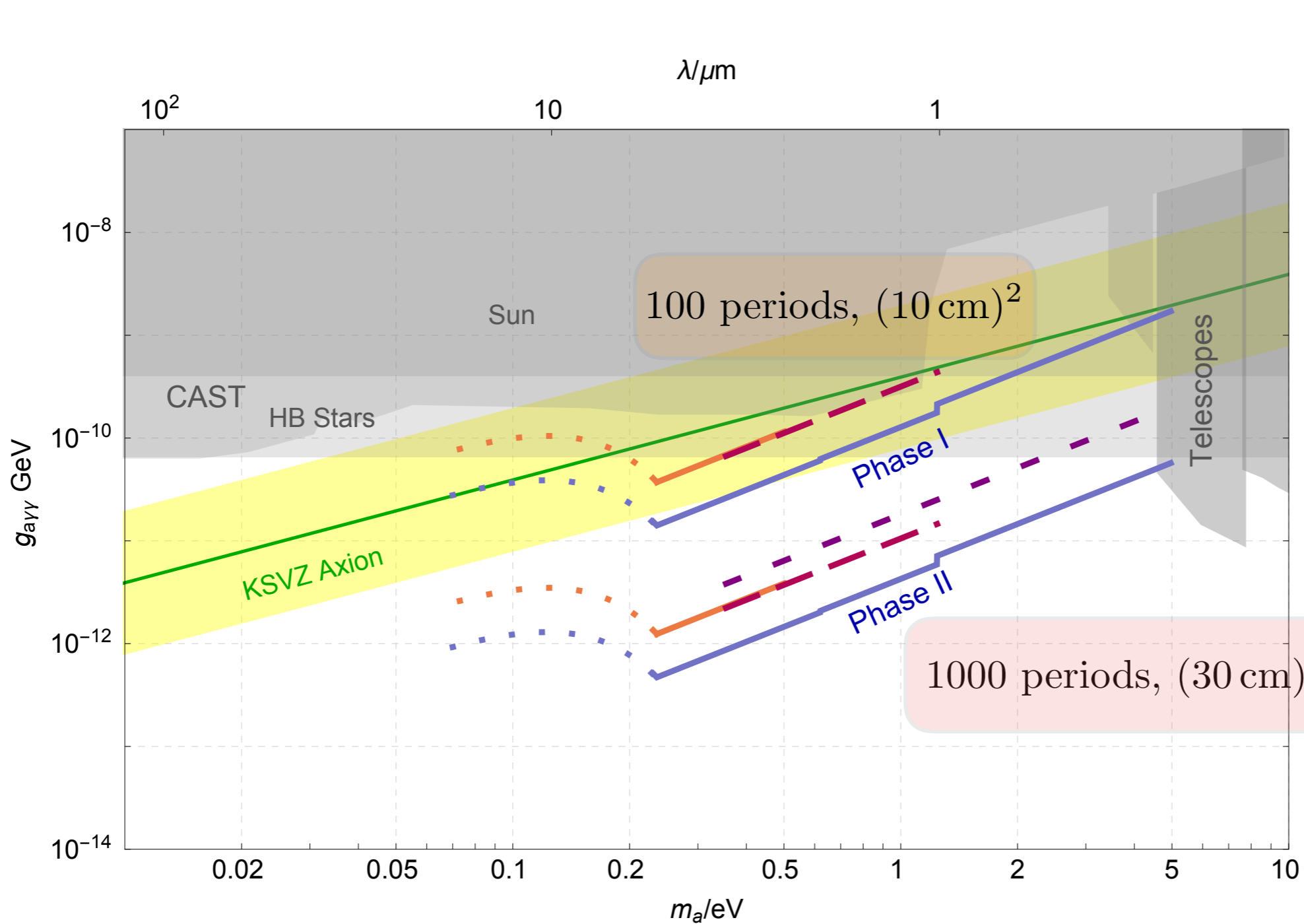$\eta_{\rm det} = 0.9$

Xenon Solar   Sun

Pathfinder

Xenon DM

Phase I

Phase II

1000 periods, $(30\,{\rm cm})^2$

κ

$m_A/{\rm eV}$
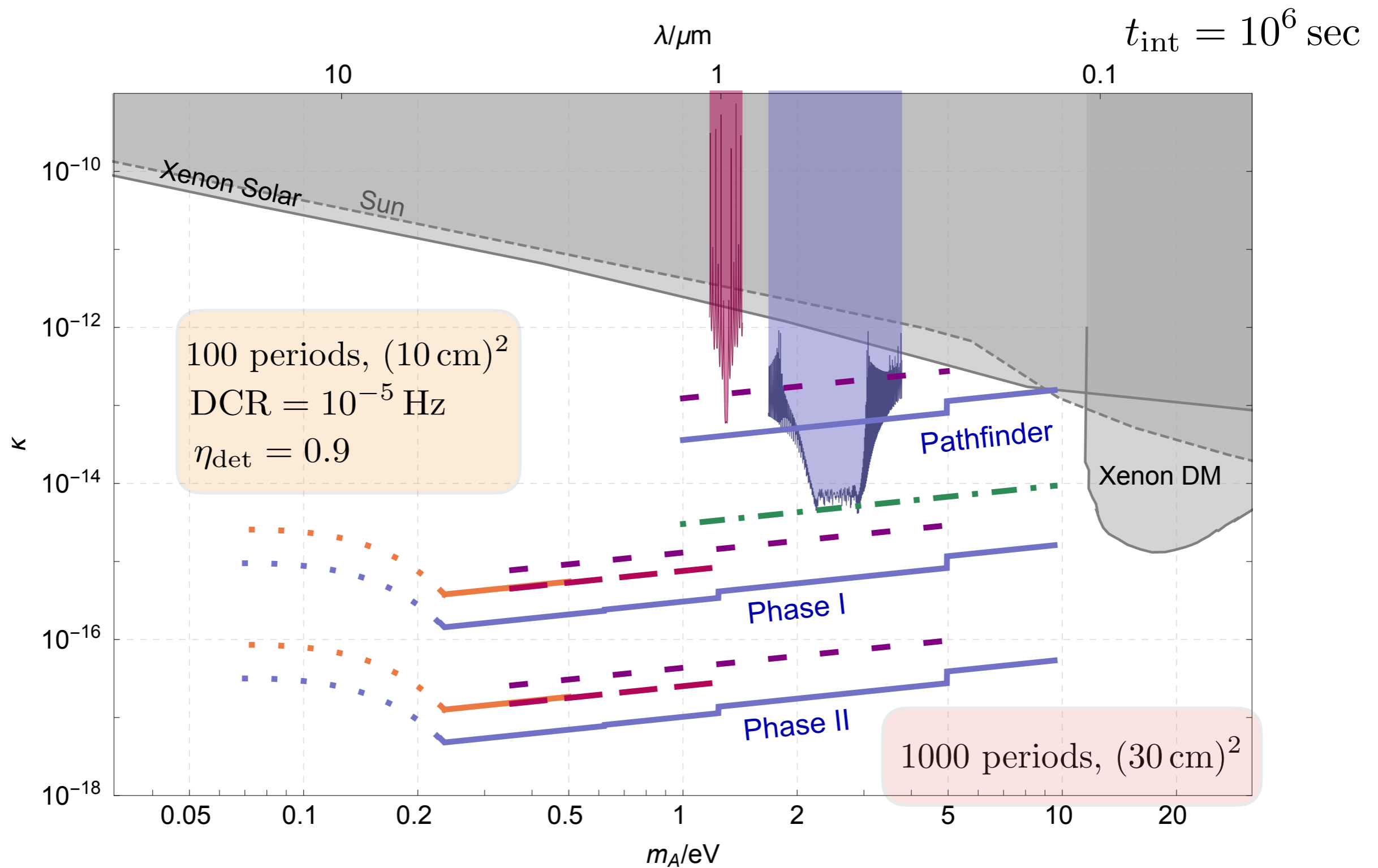
Axion sensitivity

Future directions

- Larger targets:

  - 2D / 3D photonic structures?

- Other DM candidates:

  - Magnetic field for axion-photon coupling

  - Directional materials for spin-0 DM

- Lower frequencies:

  - Detector development