# BREAD: Broadband Reflector Experiment for Axion Detection

**Snowmass CF2 Wavelike Dark Matter Meeting**

10 min review talks | 8 October 2021

**Jesse Liu** *for BREAD*
University of Chicago → University of Cambridge

BREAD COLLABORATION

THE UNIVERSITY OF CHICAGO

UNIVERSITY OF CAMBRIDGE

# BREAD science team

**Science goal: broadband m $\gtrsim 10^{-4}$ eV axion & dark photon DM search**

R&D supported by DOE HEP-QIS QuantISED, FNAL LDRD

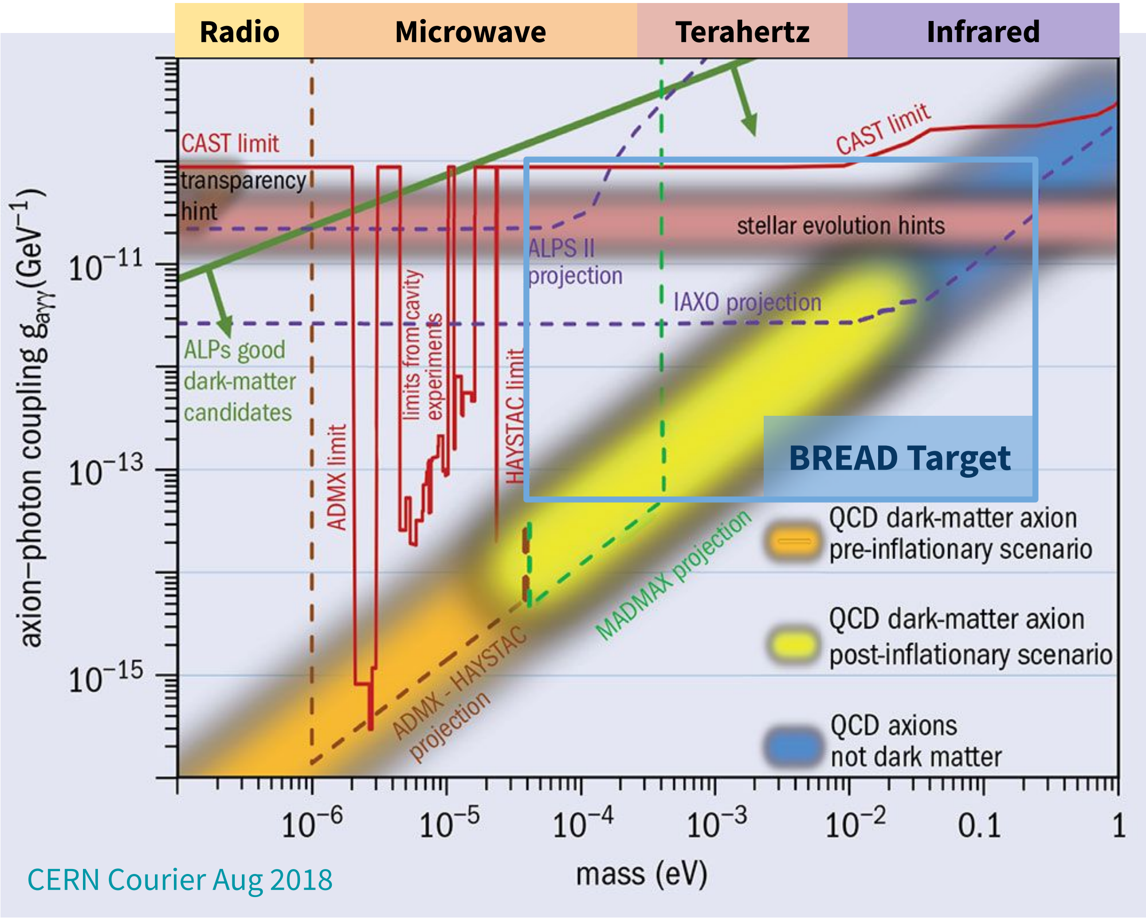
Pete Barry,[1,2] Daniel Bowring,[3] Gianpaolo Carosi,[4] Clarence Chang,[1,2] Aaron Chou,[3] Kristin Dona,[5,*] Mohamed Hassan,[3] Gabe Hoshino,[3,5] Rakshya Khatiwada,[3,6] Stefan Knirck,[3,†] Noah Kurinsky,[7,3,2,‡] Samantha Lewis,[3] Jules Li,[1] Jesse Liu,[5,§] Matthew Malaker,[3] David Miller,[5,8,¶] Sae Woo Nam,[9] Omid Noroozian,[10] Andrew Sonnenschein,[3,**] and Tony X. Zhou[11,††]

(BREAD Collaboration)

[1] *Argonne National Laboratory, Lemont, IL 60439, USA*
[2] *Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL 60637, USA*
[3] *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[4] *Lawrence Livermore National Laboratory, Livermore, CA 94551, USA*
[5] *Department of Physics, University of Chicago, Chicago, IL 60637, USA*
[6] *Department of Physics, Illinois Institute of Technology, Chicago, IL 60616, USA*
[7] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*
[8] *Enrico Fermi Institute, University of Chicago, Chicago, IL 60637, USA*
[9] *National Institute of Standards and Technology, Boulder, CO 80305, USA*
[10] *NASA Goddard Space Flight Center, Grenbelt, MD 20771, USA*
[11] *Massachusetts Institute of Technology, Cambridge, MA 02139, USA*

See also UW Beyond Gen2 [Jan 2021], CPAD [Feb 2021] (Andrew Sonnenschein), Patras [Jun 2021] (Stefan Knirck) and Snowmass LoI CF2 No. 179

# The broadband & high-mass search problem




**1) Desire broadband** but existing cavity haloscopes are narrowband $\Delta m/m \ll 1$

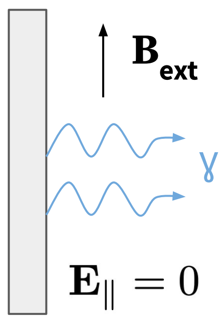
**2) Desire high mass** but canonical search rate* $R \sim f^{-14/3}$ impractical for m > 50 μeV

BREAD COLLABORATION **: R&D program to overcome both longstanding obstructions**

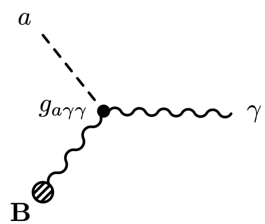
*See e.g. Backes et al [2008.01853] for how to overcome this scaling in HAYSTAC

# Step 1: convert DM to photons

## Induce axion–photon conversion via conducting surface in B-field




Axion dark matter augments Ampère–Maxwell equation




$$\nabla \times \mathbf{B} - \partial_t \mathbf{E} = \mathbf{J}_{\text{DM}}$$

Boundary conditions imply ⊥ SM photon emission

$$\frac{P_a}{10^{-21}\ \text{W}} = 3.1 \cdot \frac{\rho_{\text{CDM}}}{0.3\ \text{GeV cm}^{-3}} \frac{A}{10\ \text{m}^2} \left(\frac{B}{10\ \text{T}}\right)^2 \times \left(\frac{g_{a\gamma\gamma}}{10^{-11}\ \text{GeV}^{-1}} \frac{1\ \text{meV}}{m_a}\right)^2 .$$

**Dish eschews tuning to unknown DM mass**
**Inherently broadband ⇒ ideal for searches**

Concept proposed in Horns et al [1212.2970]

## Cylindrical barrel driven by standard solenoid & fridge geometries

9.4 T human MRI @ UIC
https://meml.lab.uic.edu

10.5 Tesla/88 cm bore
Passively Sheilded

Resources

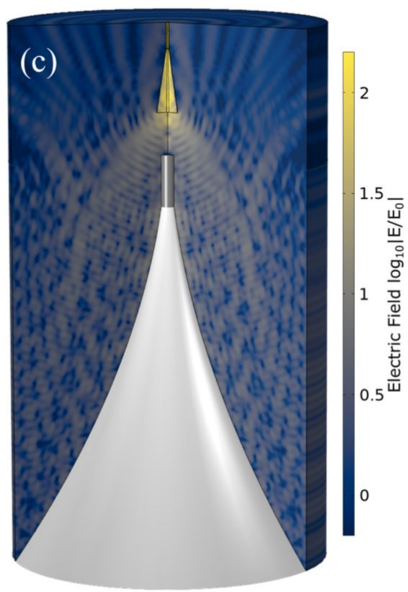

U Minnesota Radiology

Fridge for ADMX science at FNAL (photo: Kristin Dona)

See also "Ultra-High Field Solenoids and Axion Detection" Mark Bird (2020)

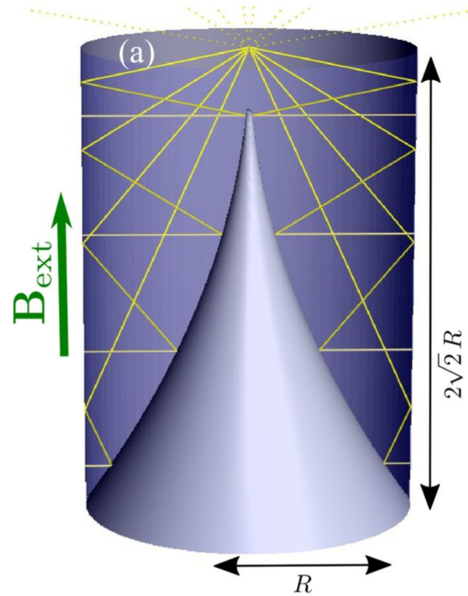
# Step 2: collect photons

**Low frequency ~ 20 GHz numerical Maxwell eqn**




*COMSOL simulation*

**High frequency ~ IR ray limit $\lambda \ll \ell_{sens}$**

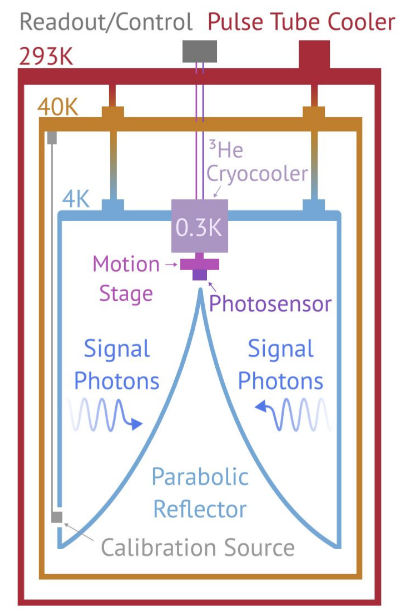



*Ray tracing simulation*

**Small 3D-printed test model @ FNAL**

Gabe Hoshino led in situ tests

**Proposed dark photon pilot schematic**

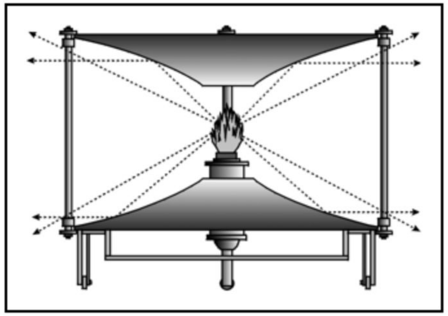



Kate Azar, Matthew Malaker, Gabe Hoshino (summer students) led many detailed simulation studies

↑ **Parabolic reflector geometry for BREAD**

→ **Inverse of classical lighthouse** (Bordier-Marcet 1811)

Cylindrically symmetric parallel rays from/to a point



uslhs.org/reflectors

Currently iterating with engineers to manufacture reflector for pilots

## Step 3: detect photons

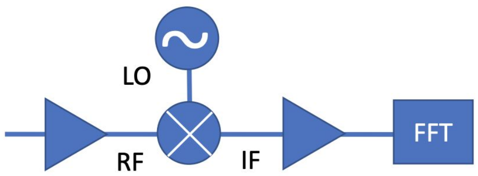
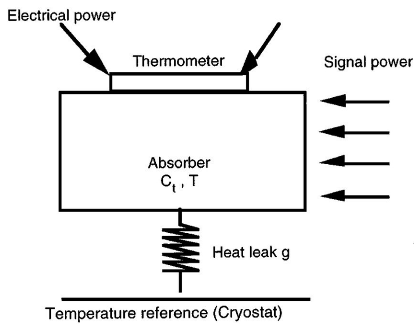
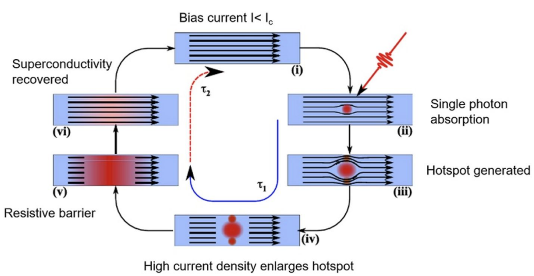



Fig from Stefan Knirck's talk




Yvon and Sushkov (2000)




singlequantum.com

### CANDIDATE PHOTOSENSOR CLASSES

### Heterodyne [microwave]

Down-convert frequencies with local oscillator
High resolution for narrow spectral features
Noise limited by standard quantum limit $k_B T = h\nu$
Promising for QCD axions around O(10) GHz regimes

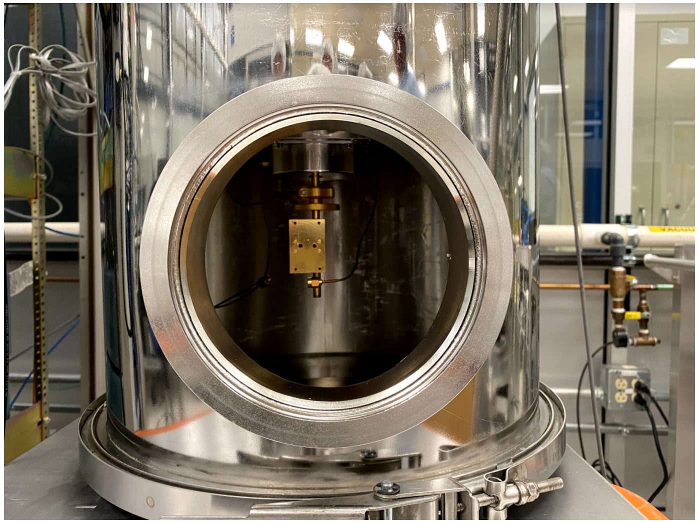
### Bolometers [microwave to optical]

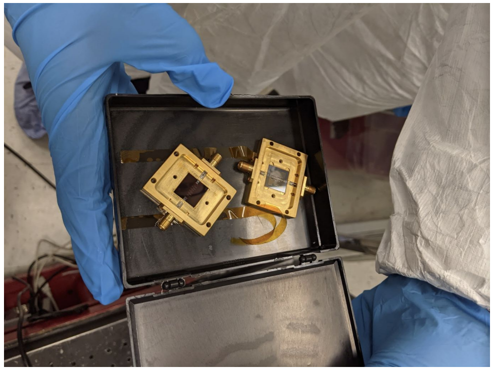
Very broadband $\Delta m/m \gg 1$, noise limited for QCD axions
Transition Edge Sensors, Kinetic Inductance Detectors
Well-established sensors reach ~ $10^{-19}$ W/√Hz (TES, KID)
Recently Quantum Capacitance Detectors ~ $10^{-20}$ W/√Hz

### Photocounters [near-IR]

Superconducting nanowires (SNSPD) e.g. by Caltech/MIT/NIST
Low noise but present $E_{threshold}$ around near-IR for counting
Hochberg et al 1903.05101 $10^{-4}$ Hz dark count for DM search
Verma et al 2012.09979 extended up to 9.9 µm (0.12 eV)

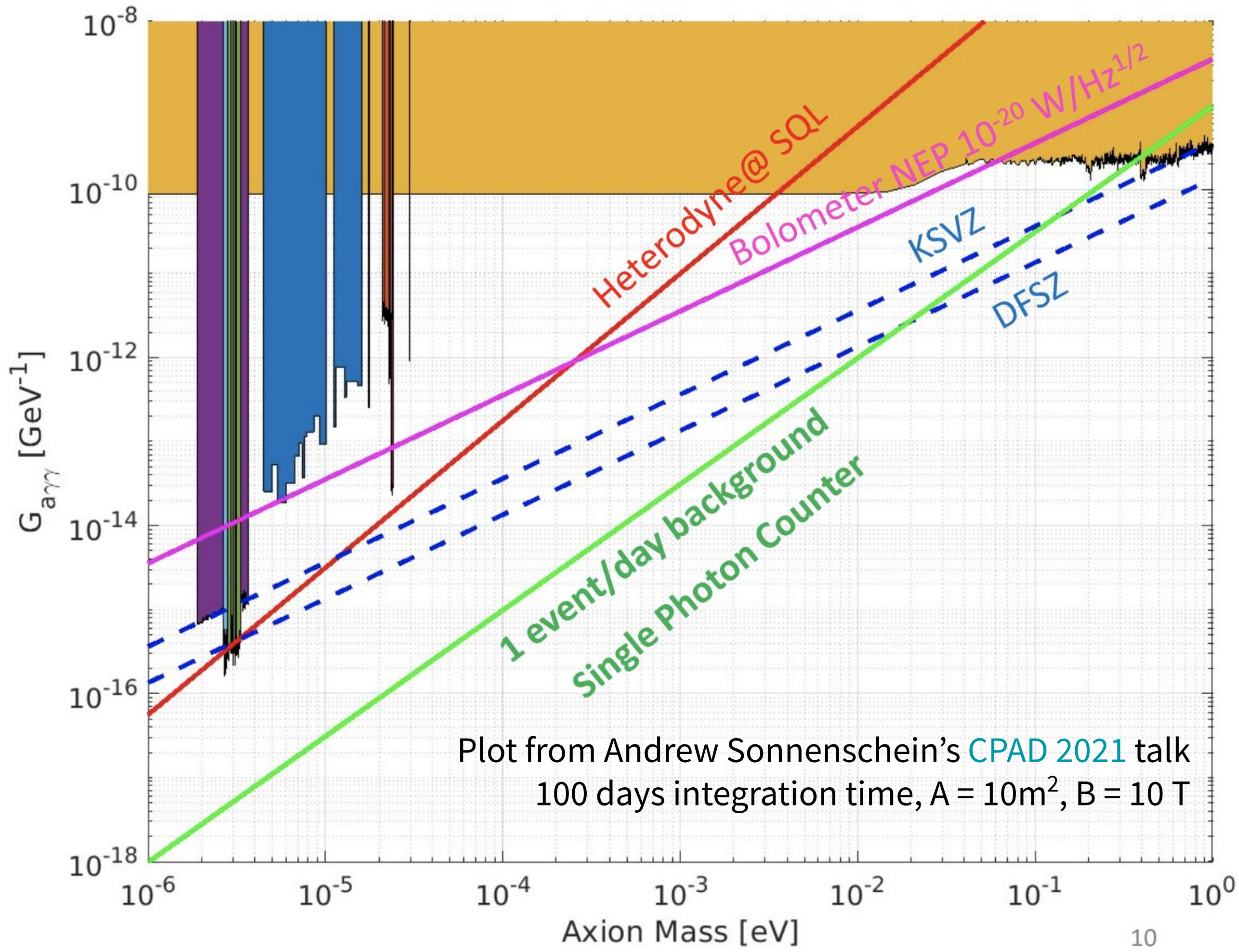
# Preparing sensor testing @ Fermilab towards pilot

Kristin Dona, Stefan Knirck, JL, Andrew Sonnenschein pictured; thanks to Israel Hernandez, David Miller, Tony Zhou et al

# Projected sensitivity




**Bottom line**: next generation photosensors could decisively search QCD axion benchmarks over several mass decades motivating sensor R&D

# Snowmass synergies

**Particle physics**
Principal goal to discover axion and/or dark photon dark matter in next decade

**Astronomy**
Decadal survey, sub-mm/IR science, Photosensors for future observatories

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**Quantum technology**
Information science, sensing, telecommunications

**Cosmic Frontier**
CF2 wavelike dark matter

**Accelerators**
AF7 R&D
High field magnets

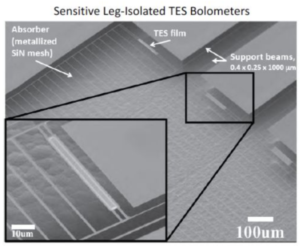
**Instrumentation**
IF1 quantum sensing
IF2 photon detectors

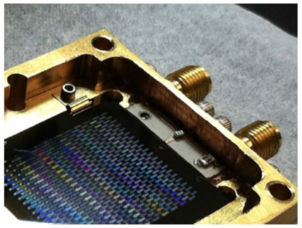
**Underground**
UF2 Facilities
for cosmic frontier

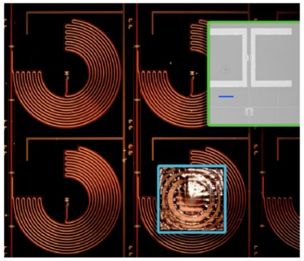
BREAD naturally fits in high-mass CF2 whitepaper with inevitable IF1/2 synergy

# E.g. synergy: different science driving similar sensor R&D

## Origins space telescope demands ~ $10^{-20}$ W/√Hz sensors across mid-/far-IR



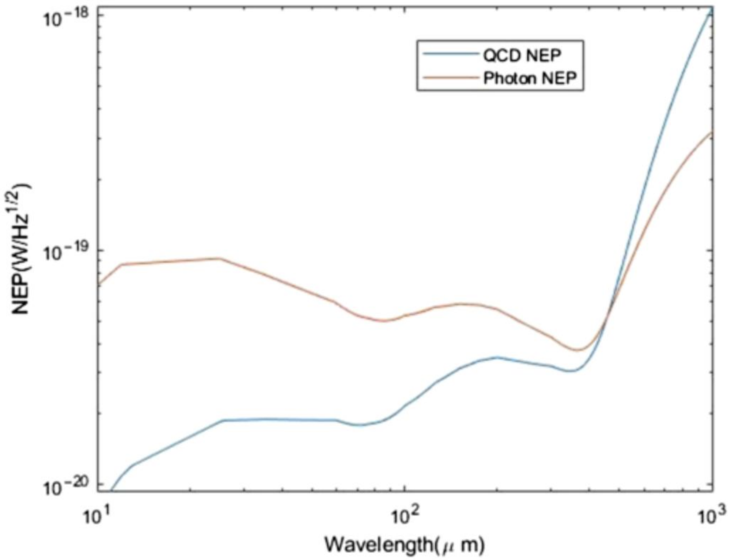


← origins.ipac.caltech.edu technology & science
↓ J. Astron. Telesc. Instrum. Syst 7(1), 011004 (2021)

6 January 2021
**Large array of low-frequency readout quantum capacitance detectors**
Pierre M. Echternach, Andrew D. Beyer, Charles M. Bradford



Simulation of QCD NEP (blue) versus wavelength for the optical loading predicted for the OST compared with the required NEP (orange).




Example TES, KID, SNSPD discussion for OST science

SUMMARY

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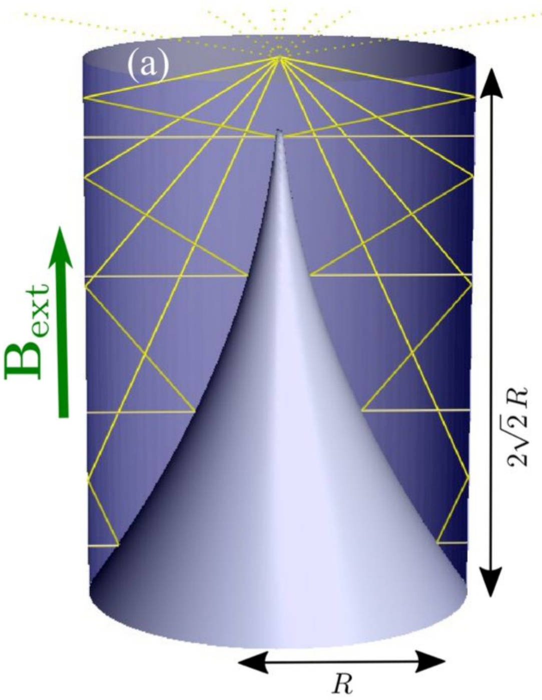
# Broadband Reflector Experiment for Axion Detection




**Multidecade discovery reach** of axion/dark photon DM overcoming broadband & high-mass search problem

**Unique geometry** practical for standard solenoids & fridges with science demands driving next-gen photosensor R&D

**Preparing sensor testing** at FNAL for nearer term pilot
Longer term 5-10 year R&D parallelling Snowmass scope

**Interesting synergies** crossing traditionally non-HEP communities from astronomy to quantum technology

**Welcoming friendly** multidisciplinary group at early stages with much room for individual creativity 😊

# EXTRAS