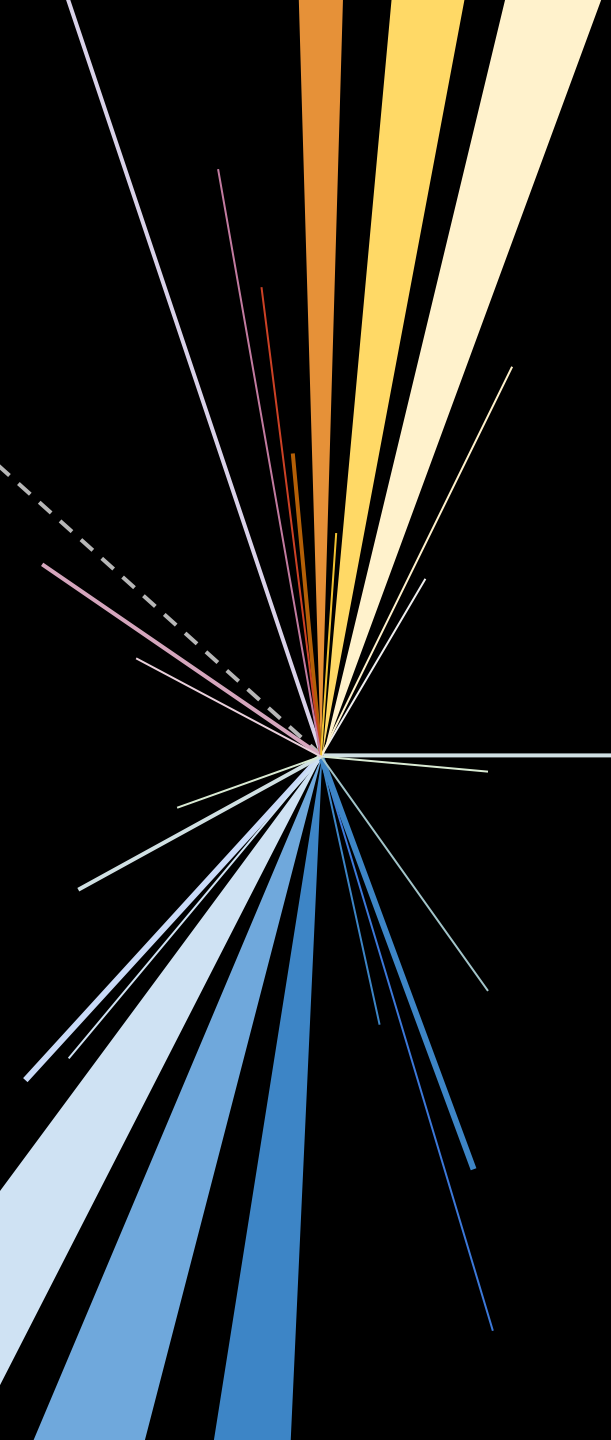


BREAD: Broadband Reflector Experiment for Axion Detection

International Conference on High Energy Physics
Bologna, Italy
8 July 2022

Jesse Liu *for the BREAD Collaboration*
University of Cambridge

BREAD COLLABORATION

TRINITY COLLEGE CAMBRIDGE

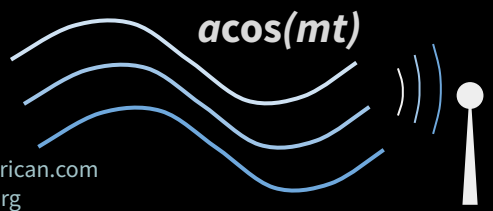
UNIVERSITY OF CAMBRIDGE

TWO DARK MATTER LAMPPOSTS

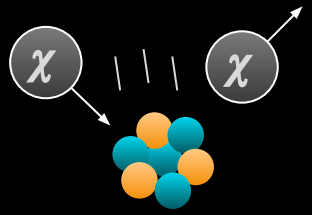
Axion
Wave-like
e.g. ADMX
Non-thermal

WIMP
Particle-like
e.g. LZ, LHC
Thermal relic

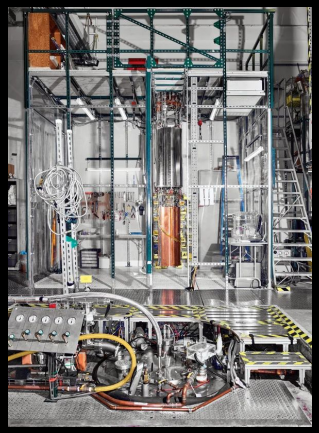
peV neV μeV meV eV keV MeV GeV TeV PeV EeV

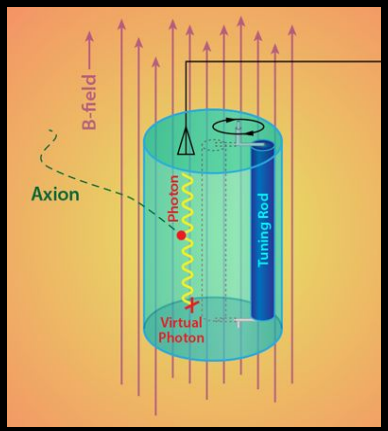


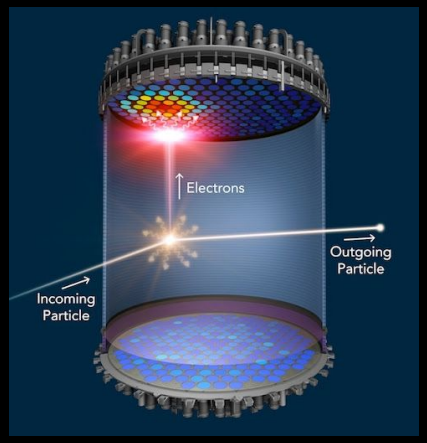
scientificamerican.com
physics.aps.org

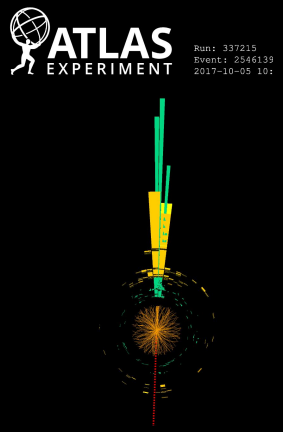


lz.ac.uk
2102.10874

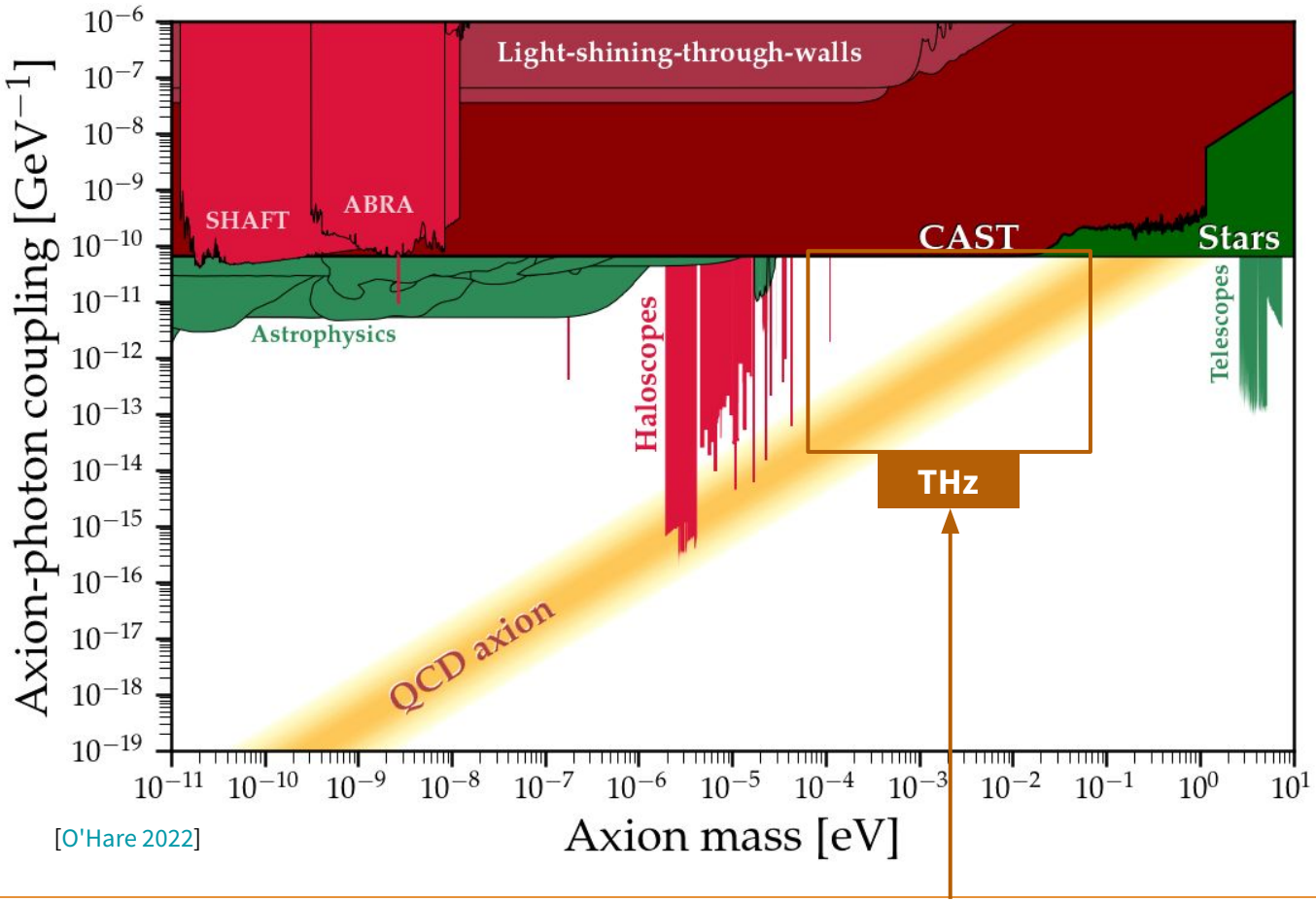








The milli-eV/terahertz axion search problem



[O'Hare 2022]

Problem 1: Desire broadband but cavity haloscopes narrowband $\Delta m/m \ll 1$

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

NEED CREATIVITY TO OVERCOME BOTH LONGSTANDING OBSTACLES

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

Broadband Reflector Experiment for Axion Detection

🥳 Proposal paper on the cover of PRL & Editors' Suggestion 🎉

BREAD COLLABORATION

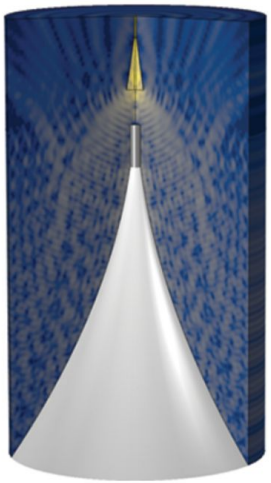
SLAC NIST Lawrence Livermore National Laboratory THE UNIVERSITY OF CHICAGO UNIVERSITY OF CAMBRIDGE

Argonne NATIONAL LABORATORY Fermilab MIT NASA Goddard SPACE FLIGHT CENTER ILLINOIS TECH

PHYSICAL REVIEW LETTERS

JL, Dona et al [2111.12103]

Highlights Recent Accepted Collections Authors Referees Search Press



ON THE COVER

Broadband Solenoidal Haloscope for Terahertz Axion Detection

March 28, 2022

Simulation of the full electric field inside the conceptual design of the Broadband Reflector Experiment for Axion Detection (BREAD). Selected for an Editors' Suggestion.

Jesse Liu *et al.*

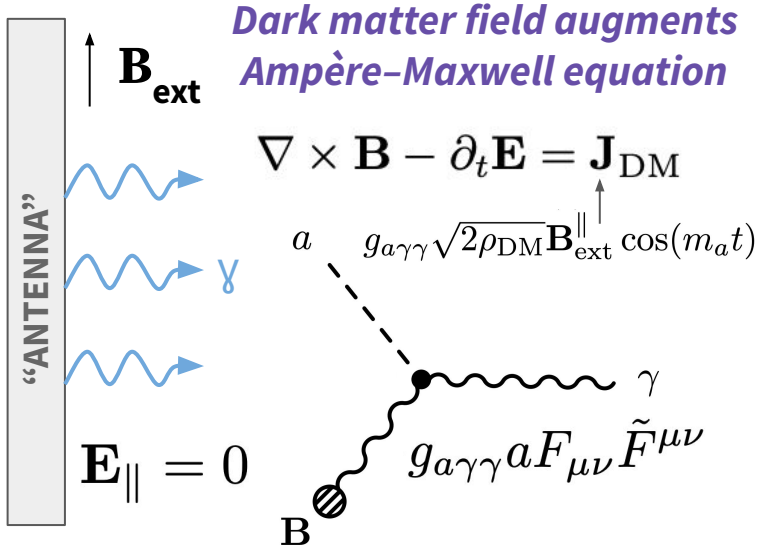
Phys. Rev. Lett. **128**, 131801 (2022)

Issue 13 Table of Contents | More Covers

Jesse Liu, Kristin Dona, Gabe Hoshino, Stefan Knirck, Noah Kurinsky, Matthew Malaker, David W. Miller, Andrew Sonnenschein, Mohamed H. Awida, Peter S. Barry, Karl K. Berggren, Daniel Bowring, Gianpaolo Carosi, Clarence Chang, Aaron Chou, Rakshya Khatiwada, Samantha Lewis, Juliang Li, Sae Woo Nam, Omid Noroozian, and Tony X. Zhou (BREAD Collaboration)

Step 1: convert DM to photons

a) Oscillating axion field makes conductor emit photons



Dark matter field augments Ampère–Maxwell equation

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

$$\mathbf{J}_{\text{DM}} \propto g_{a\gamma\gamma}\sqrt{2\rho_{\text{DM}}}\mathbf{B}^{\parallel}_{\text{ext}}\cos(m_a t)$$

$$g_{a\gamma\gamma} a F_{\mu\nu}\tilde{F}^{\mu\nu}$$

INHERENTLY BROADBAND

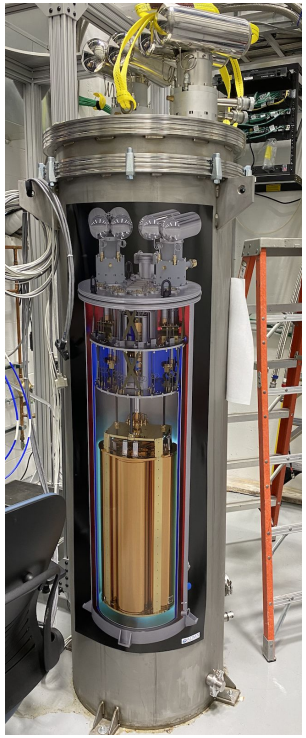
No tuning to unknown DM mass

Concept proposed in Horns et al [1212.2970]

b) Make cylindrical to embed in standard solenoids & cryostats

→ Fridge for ADMX science at FNAL
(Photo by Kristin Dona)

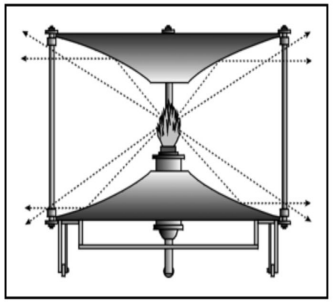
↓ Solenoids for Magnetic Resonance Imaging
hopkinsmedicine.org



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

Step 2: collect photons

Historical inspiration → **Novel parabolic reflector design focuses photons** → **3D-printed prototype @ FNAL** → **Proposed dark photon pilot design**

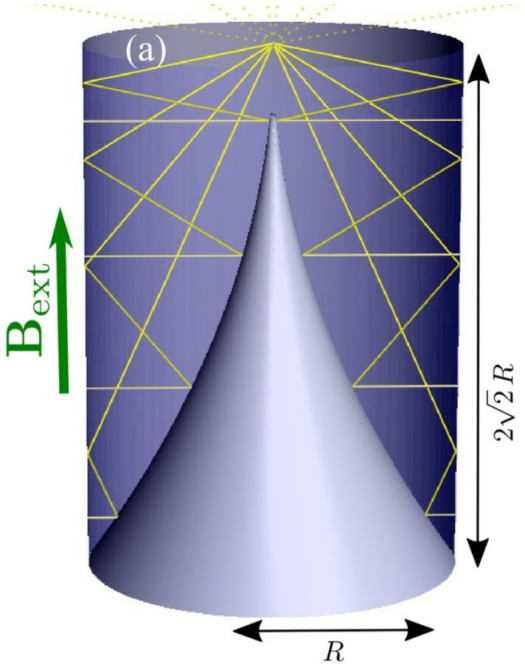


Inverse of 19th century lighthouse

Bordier-Marcet 1811

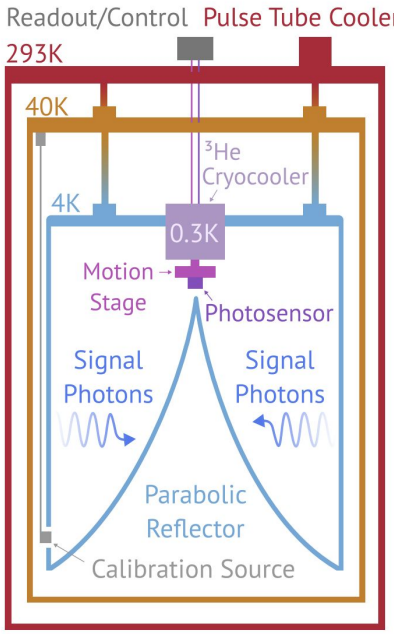
Cylindrically symmetric co-parallel rays from point source

uslhs.org



Ray tracing simulation

Gabe Hoshino led in situ measurements with antenna



Status: iterating reflector design with engineers

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

JL, Dona et al [2111.12103]

BREAD COLLABORATION

Step 3: detect photons

gentec-eo.com

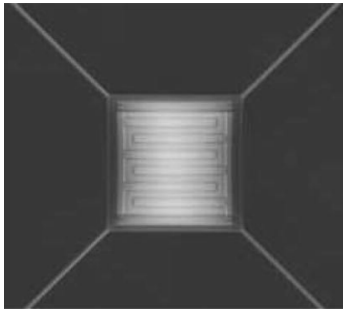
irlabs.com

Commercial bolometers

Lower noise is better ↓

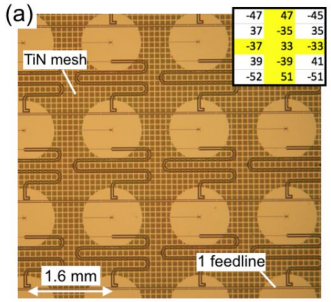
Photosensor	E / meV	T_{op} / K	NEP / $W/\sqrt{Hz}$	A_{sens} / mm^2
GENTEC [97]	[0.4, 120]	293	$1 \cdot 10^{-8}$	$\pi 2.5^2$
IR LABS [98]	[0.24, 248]	1.6	$5 \cdot 10^{-14}$	1.5^2
KID/TES [99, 100]	[0.2, 125]	0.3	$2 \cdot 10^{-19}$	0.2^2
QCDet [101, 102]	[2, 125]	0.015	$\frac{DCR}{Hz} = 4$	0.06^2
SNSPD [103, 104]	[124, 830]	0.3	$\frac{DCR}{Hz} = 10^{-4}$	0.4^2

JL, Dona et al [2111.12103]



Transition Edge Sensor

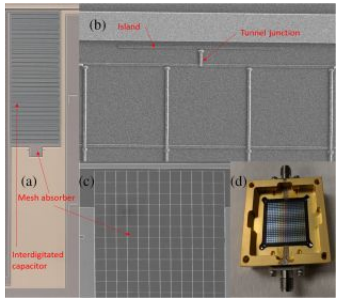
Goldie et al [JLTP 2016]



Kinetic Inductance Detector

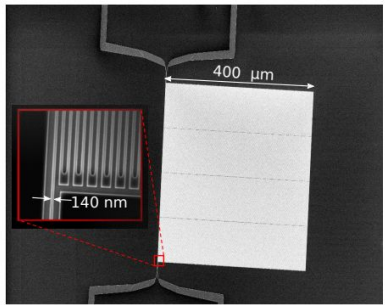
Baselmans et al [A&A 2017]

Established technology for astronomy/CMB



Quantum Capacitance Detector

Echternach et al [JATIS 2021]



Superconducting Nanowire Single Photon Detector

Hochberg et al [1903.05101]

Emerging technology for infrared photon counting

BREAD roadmap to flagship next-gen axion experiment

BREAD	Pilot	Stage 1	Stage 2a	Stage 2b
Axion a	—	✓	✓	✓
Dark photon A'	✓	✓	✓	✓
Experimental parameters				
$A_{\rm dish}$ [m^2]	0.7	10	10	10
$B_{\rm ext}$ [T]	—	10	10	10
ϵ_s	0.5	0.5	0.5	0.5
Δt [days]	10	10	1000	1000
NEP [W Hz$^{-1/2}$]	10^{-14}	10^{-18}	10^{-20}	10^{-22}
Coupling sensitivity (SNR = 5)				
$\left\lvert g_{a\gamma\gamma}/g_{a\gamma\gamma}^{\rm KSVZ}\right\rvert$	—	280	9.0	0.90
$\left\lvert g_{a\gamma\gamma}/g_{a\gamma\gamma}^{\rm DFSZ}\right\rvert$	—	740	23	2.3
$\kappa/10^{-14}$	8400	22	0.7	0.07

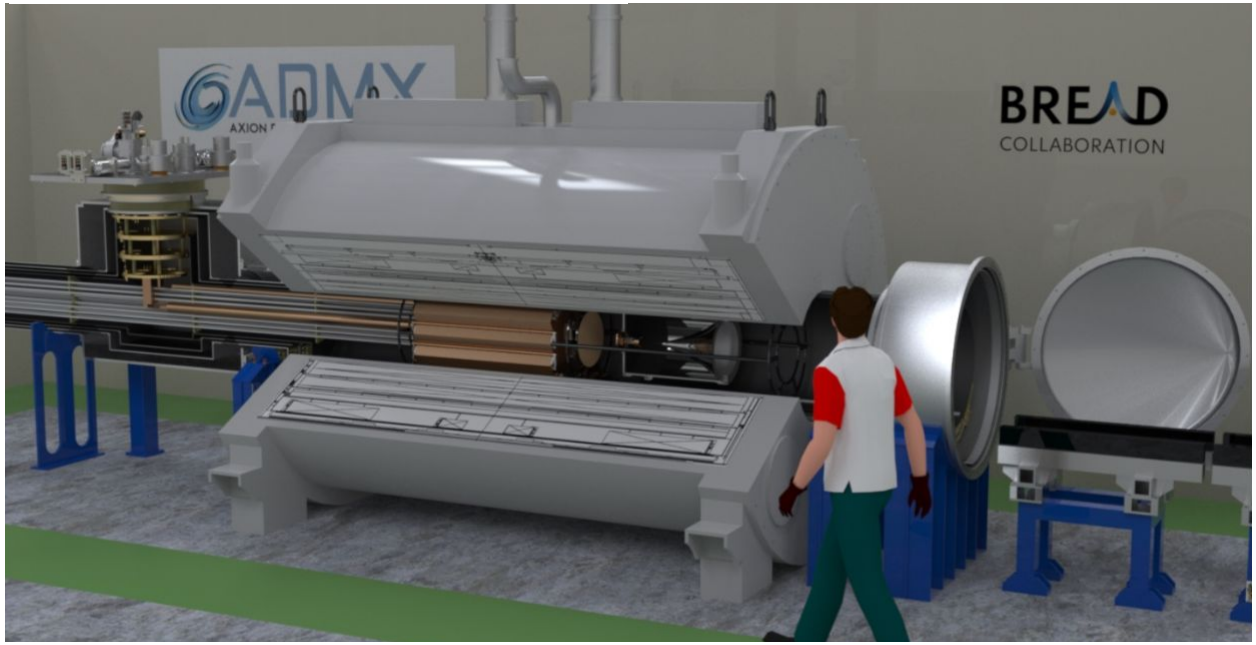
Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

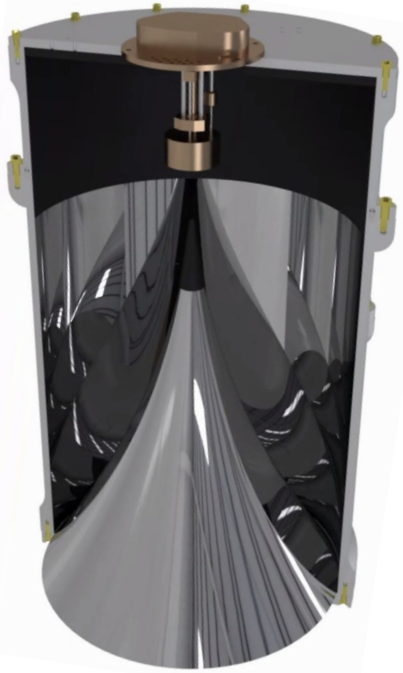
2203.14923 (JL contributing author)

Snowmass 2021 White Paper Axion Dark Matter

J. Jaeckel[1], G. Rybka[2], L. Winslow[3], and the Wave-like Dark Matter Community [4]

[1]Institut fuer theoretische Physik, Universitaet Heidelberg, Heidelberg, Germany
[2]University of Washington, Seattle, WA, USA
[3]Laboratory of Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA, USA
[4]Updated Author List Under Construction





Figs: Don Mitchell

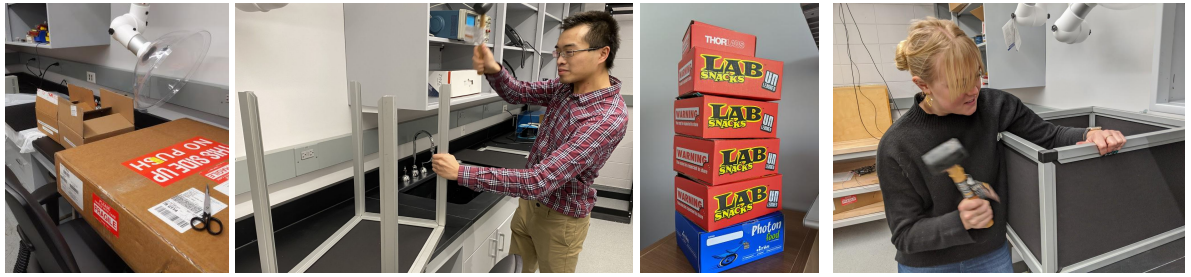
Hands on 1: build spectrometer to characterize optics

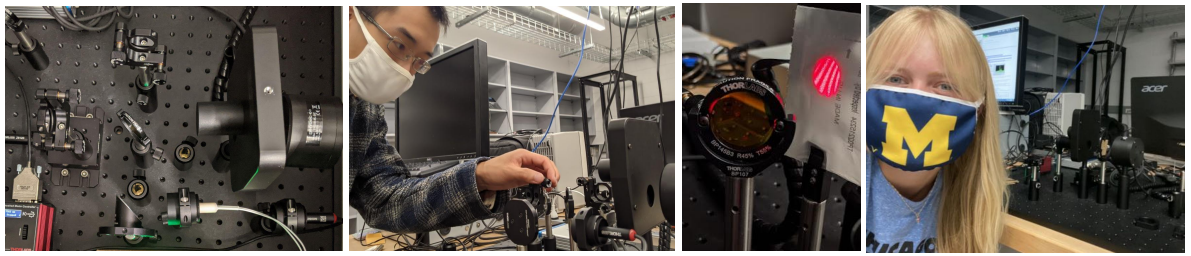
JANUARY 2020
Hardware arrival & assembly

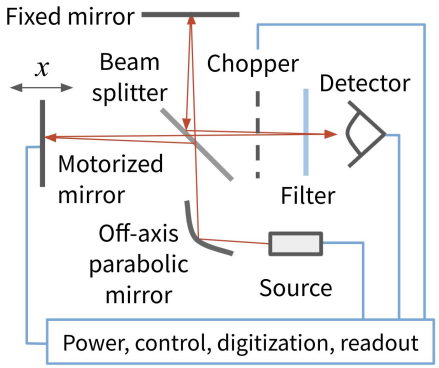
AUGUST
Laser alignment

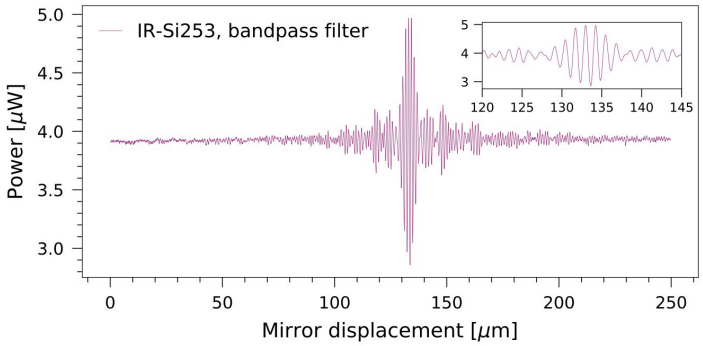
OCTOBER
Begin measurements

APRIL 2021
Dona, JL et al
2104.07157 (JINST)









PAPER

Design and performance of a terahertz Fourier transform spectrometer for axion dark matter experiments

K. Dona[1], J. Liu[1], N. Kurinsky[2,3], D. Miller[1], P. Barry[2,4], C. Chang[2,4] and A. Sonnenschein[3]

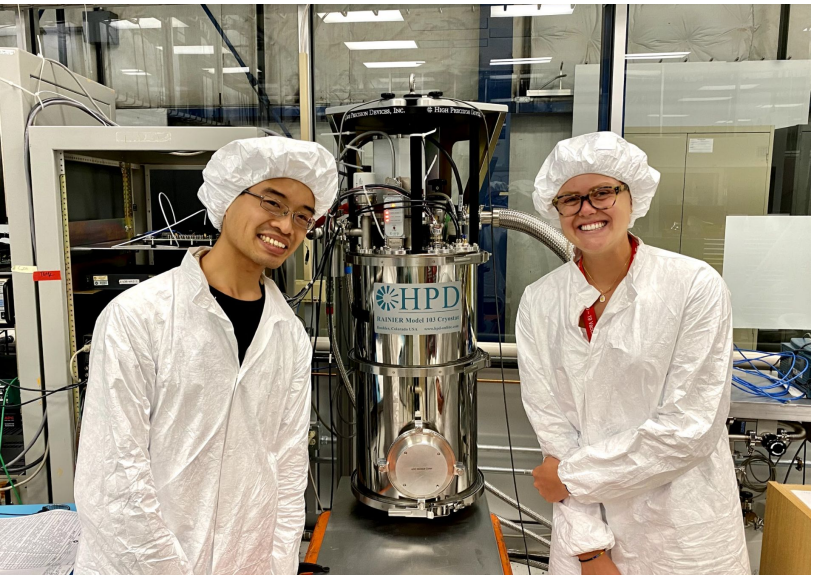
Published 13 June 2022 • © 2022 IOP Publishing Ltd and Sissa Medialab

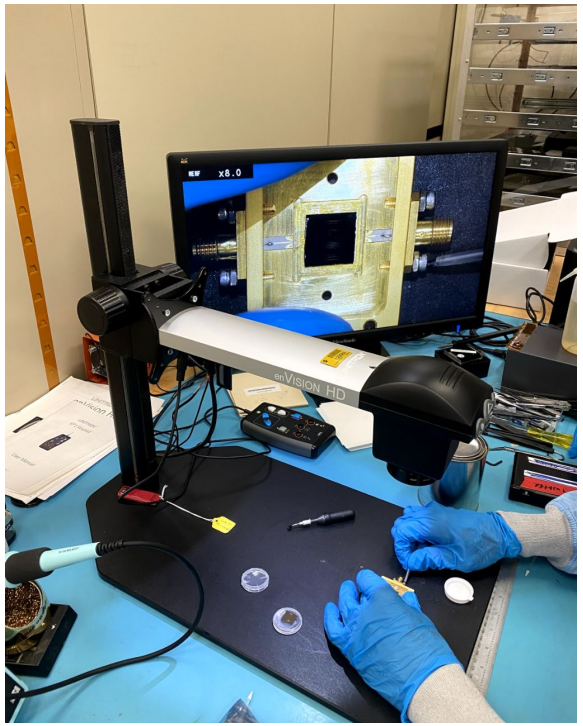
Journal of Instrumentation, Volume 17, June 2022

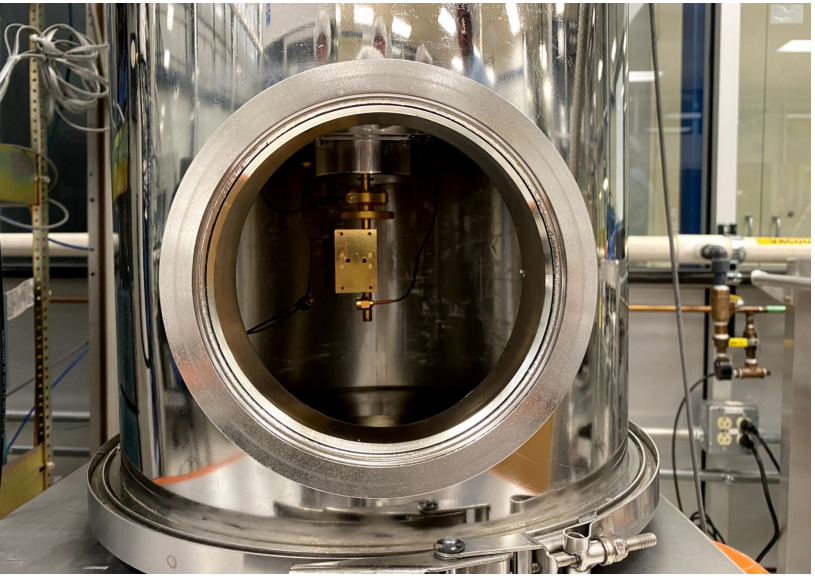
Citation K. Dona *et al* 2022 *JINST* **17** P06014

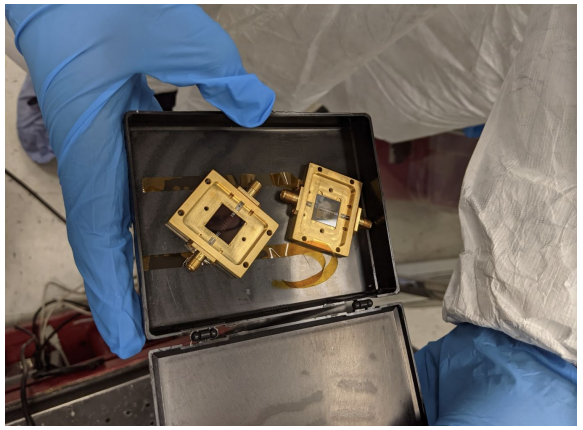
Funded by DOE HEP-QIS QuantISED grant with FNAL and Argonne collaborators

Hands on 2: quantum photosensor testing @ Fermilab





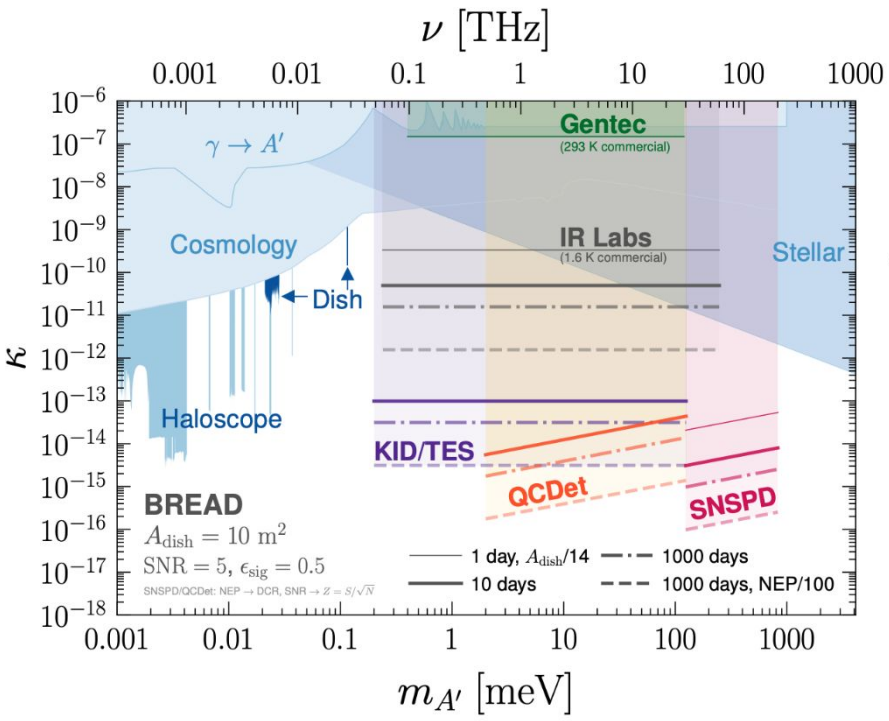


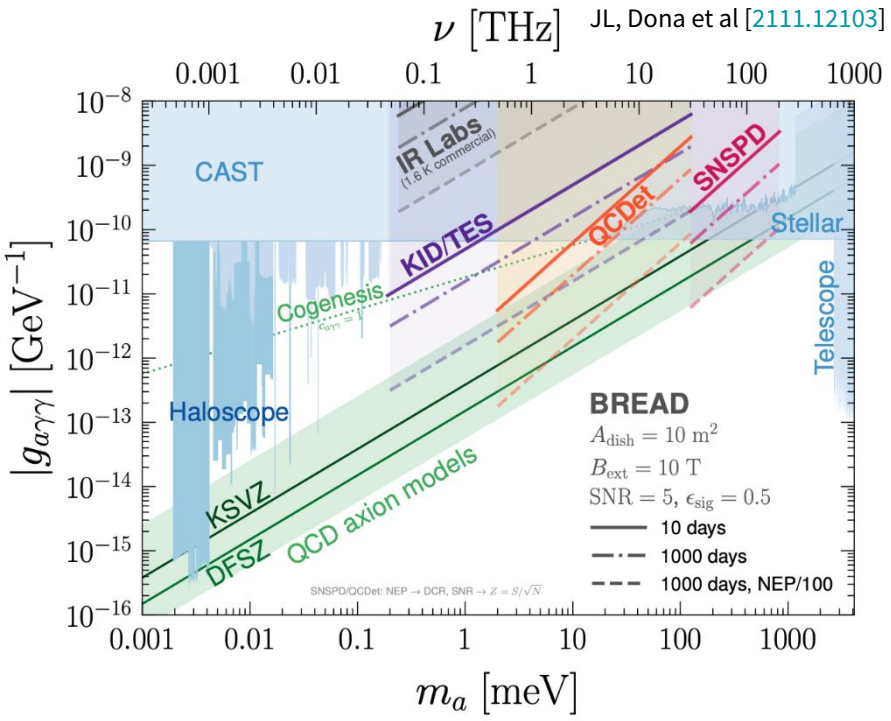


🤩 **See Kristin Dona's poster!** 👩‍🔬

With Kristin Dona, Stefan Knirck, Andrew Sonnenschein
Thanks to Israel Hernandez, David Miller, Tony Zhou et al

Sensitivity: concept → pilot → full science program





JL, Dona et al [2111.12103]

DARK PHOTON (VECTOR)
Preparing "sourdough starter" pilot
Near term ~3 years proof of principle

AXION (PSEUDOSCALAR)
Need high-field magnet & sensor R&D
Longer term ~5-10 year timescale

BREAD COLLABORATION

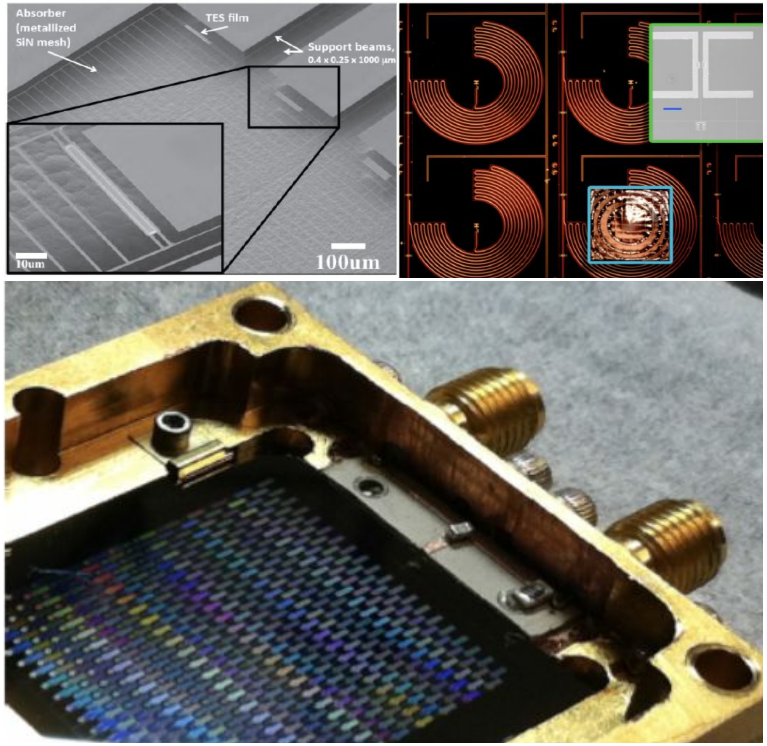
$$\left\{\left(\frac{g_{a\gamma\gamma}}{10^{-12}}\right)^2\right\} = \left\{\begin{array}{c}\frac{3.0}{\mathrm{GeV}^2}\left(\frac{m_a}{\mathrm{meV}}\right)^3\left(\frac{10\,\mathrm{T}}{B_{\rm ext}}\right)^2 \\ 11.9\frac{2/3}{\alpha_{\rm pol}^2}\frac{m_{A'}}{\mathrm{meV}}\end{array}\right\}\left(\frac{\mathrm{hour}}{\Delta t}\right)^{1/2}\frac{10\,\mathrm{m}^2}{A_{\rm dish}}\frac{Z}{5}\frac{0.5}{\epsilon_s}\left(\frac{\mathrm{DCR}}{10^{-2}\,\mathrm{Hz}}\right)^{1/2}\frac{0.45\,\mathrm{GeV/cm}^3}{\rho_{\rm DM}}$$

Innovation at interdisciplinary interfaces

ASTRONOMY
Origins of habitability & life

BREAD COLLABORATION

QUANTUM TECHNOLOGY
Information & sensing



"Think *Inside*, Think *Outside* the box. Make connections to other fields"
NSF Program Director at Snowmass Oct 2020

"Synergies between particle and astroparticle physics should be strengthened"
European Strategy Update Jun 2020

Images: origins.ipac.caltech.edu
Space-based far-IR mission recommended in US Astro 2020 Decadal Survey

SUMMARY

BREAD COLLABORATION

Broadband Reflector Experiment for Axion Detection

Multidecade discovery reach

Target meV–eV axion & dark photon dark matter

Unique geometry

Practical for standard solenoids & fridges

Preparing sensor testing

At Fermilab for near-term pilot – see Kristin Dona's poster

Interdisciplinary synergies

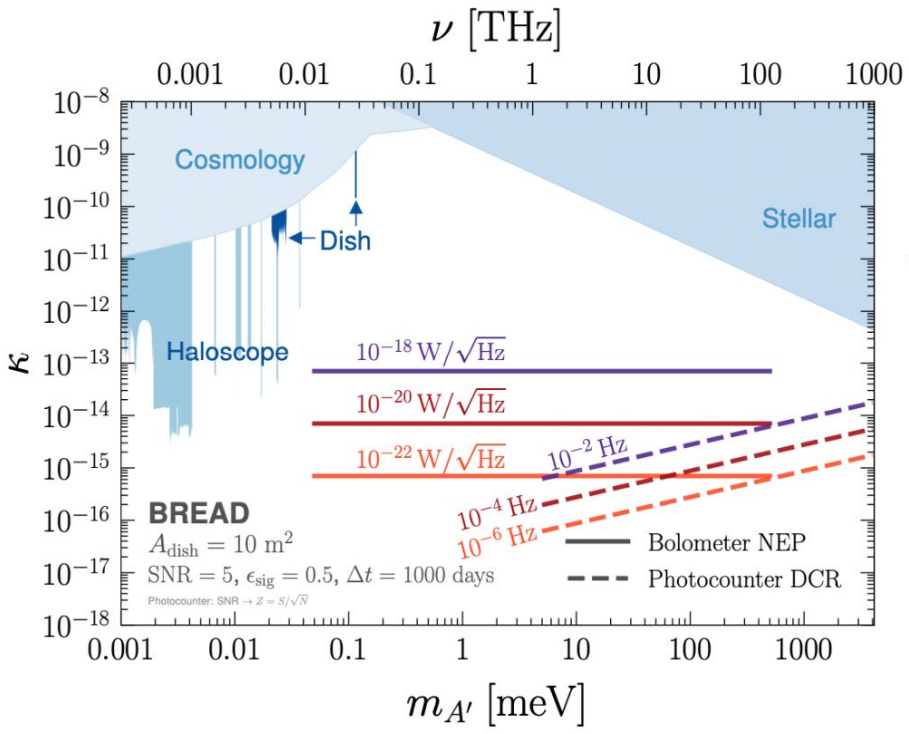
Across HEP, astronomy & quantum technology

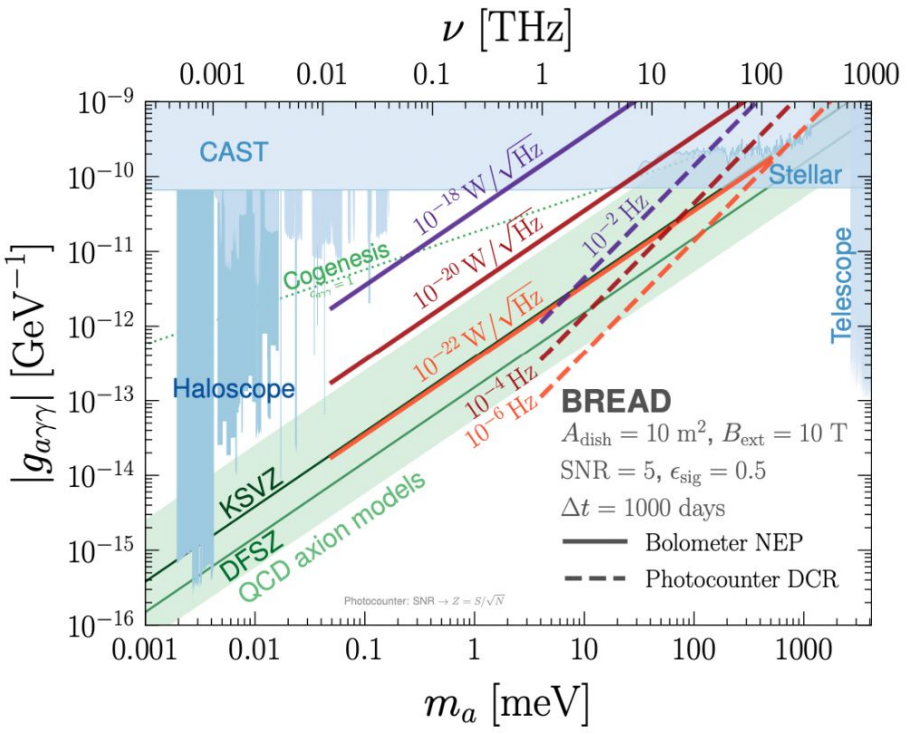
Welcoming friendly community 😊

Early stages with much room for individual creativity

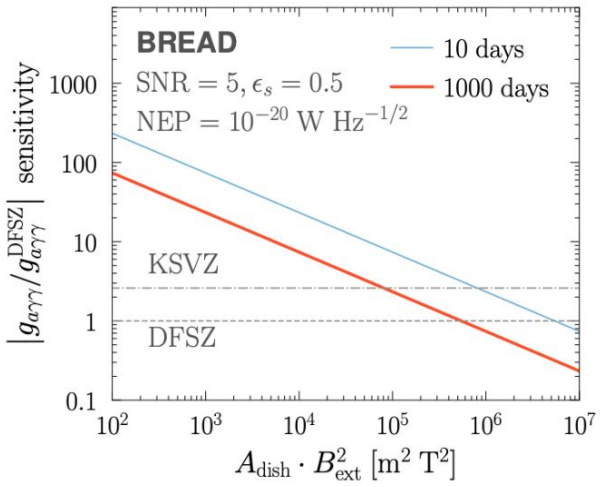
EXTRAS

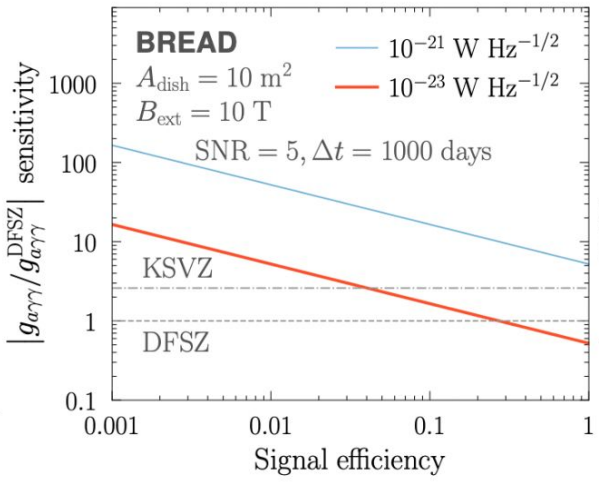
BREAD generic sensitivity

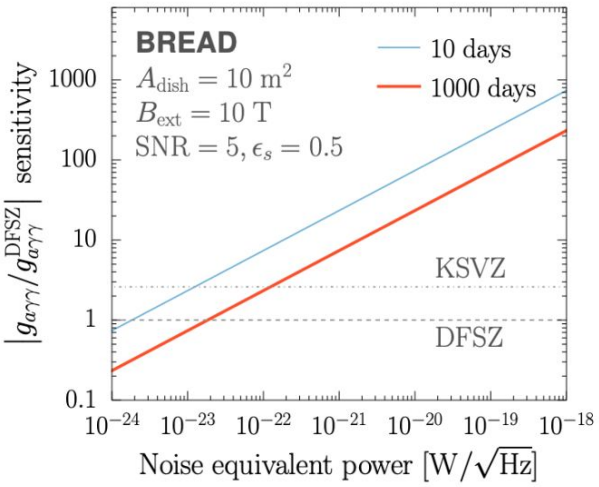


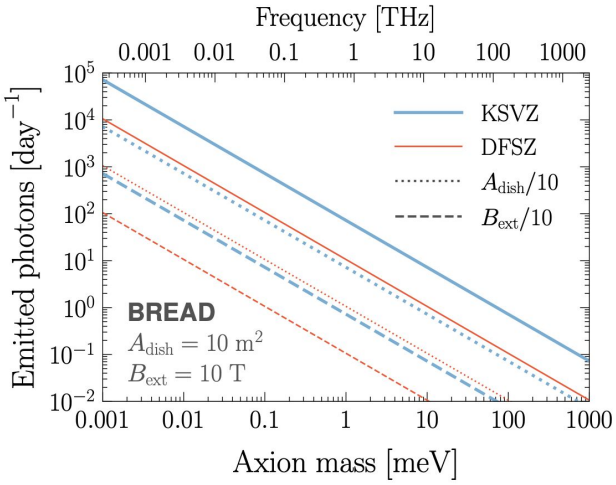


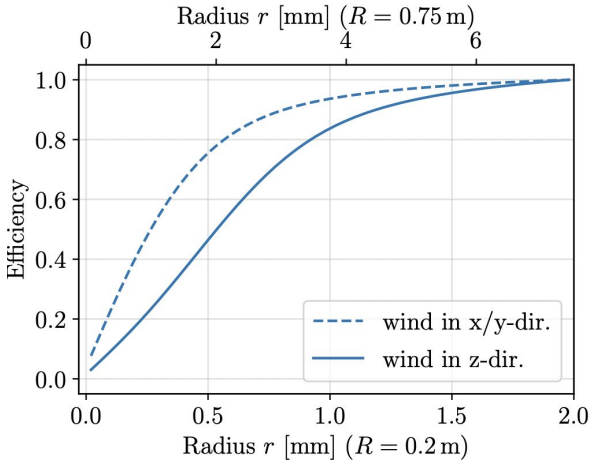
BREAD experimental considerations











BREAD	Pilot	Stage 1	Stage 2a	Stage 2b
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Dark photon A'	✓	✓	✓	✓
Experimental parameters				
$A_{\rm dish}$ [m^2]	0.7	10	10	10
$B_{\rm ext}$ [T]	—	10	10	10
ϵ_s	0.5	0.5	0.5	0.5
Δt [days]	10	10	1000	1000
NEP [W Hz$^{-1/2}$]	10^{-14}	10^{-18}	10^{-20}	10^{-22}
Coupling sensitivity (SNR = 5)				
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