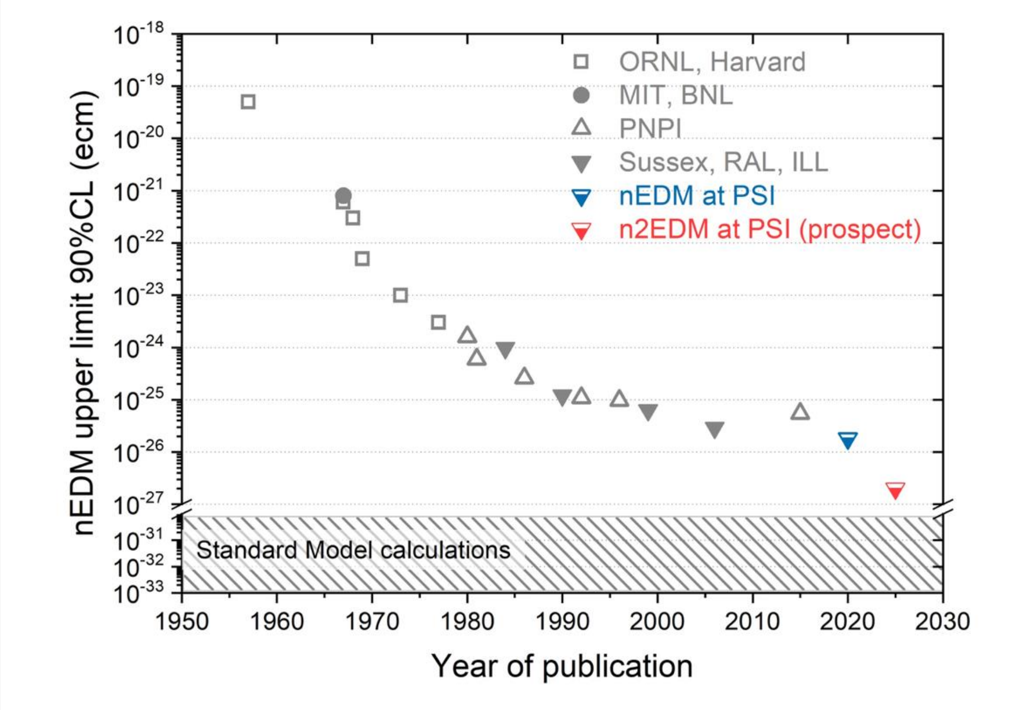
ALPHA STATUS AND RESONATOR DEVELOPMENT AT STOCKHOLM UNIVERSITY

JACOB LINDAHL, STOCKHOLM UNIVERSITY

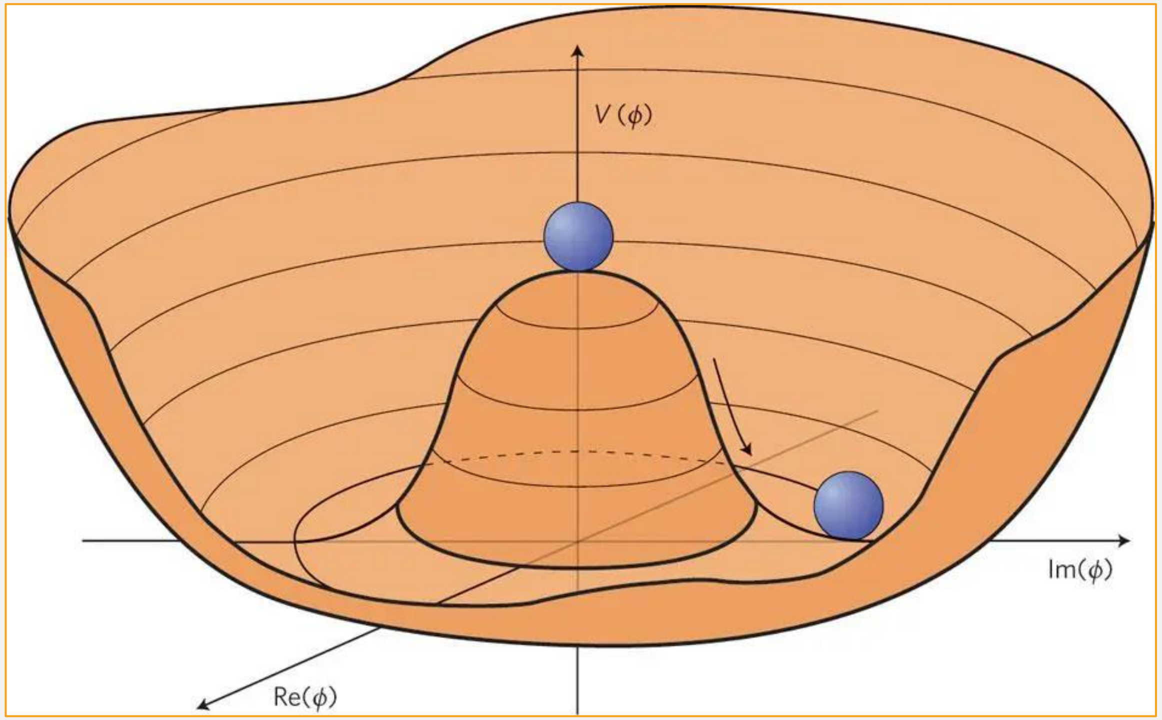
WHY THE AXION?

Strong CP Problem



Credit: nEDM Search Collaboration at PSI

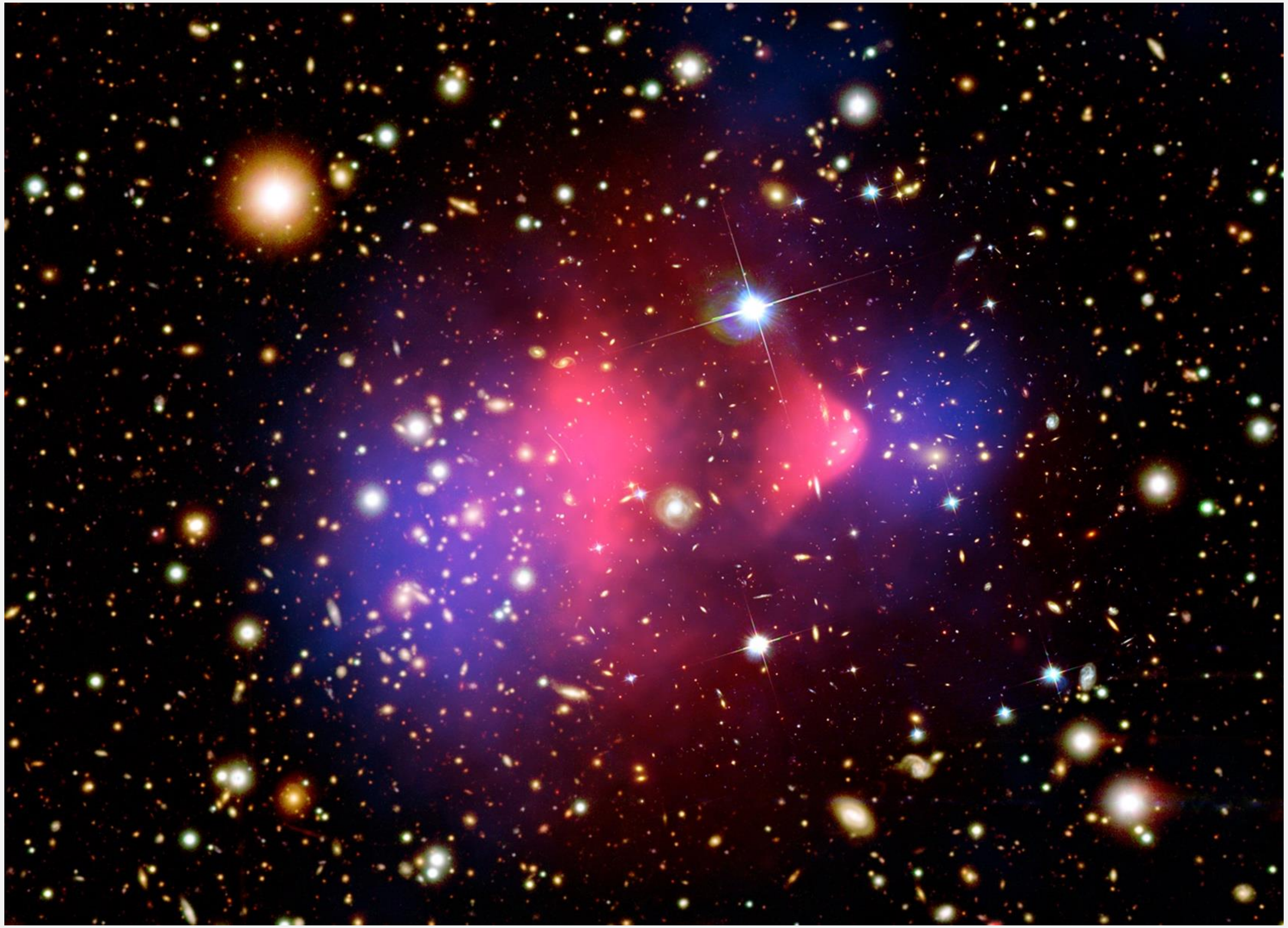
Peccei Quinn Mechanism



Peccei-Quinn Field showing spontaneous symmetry breaking

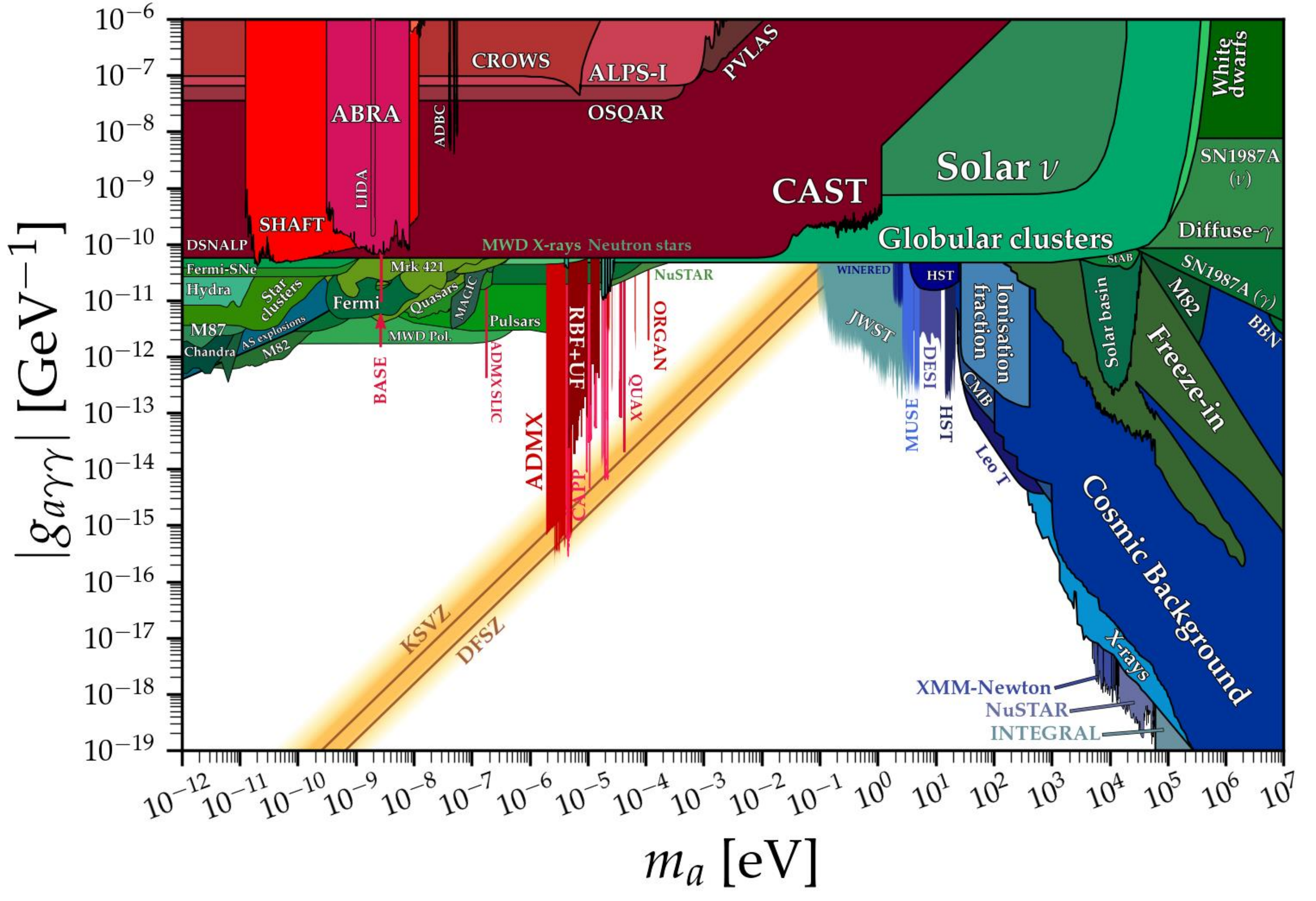
WHY THE AXION?

Cold Dark Matter



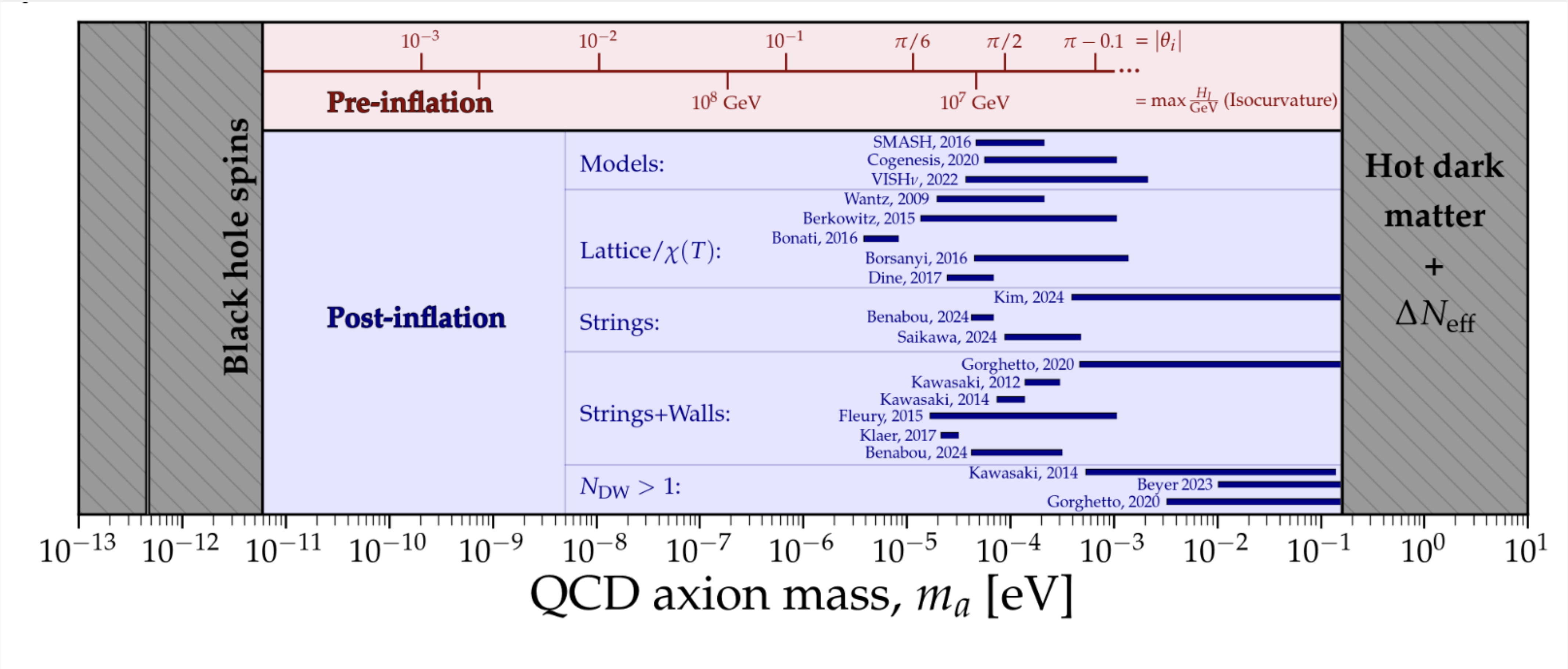
Bullet Cluster with hot intracluster gas marked in pink and dark matter in blue

AXION PARAMETER SPACE



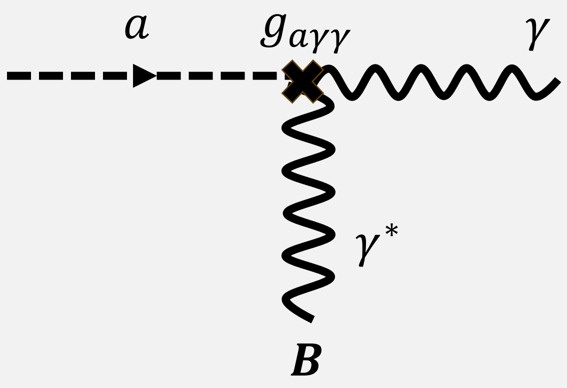
Credit: Ciaran O'Hare. cajohare/axionlimits: Axionlimits. https://cajohare.github.io/AxionLimits/, September 2026

POST-INFLATION AXION

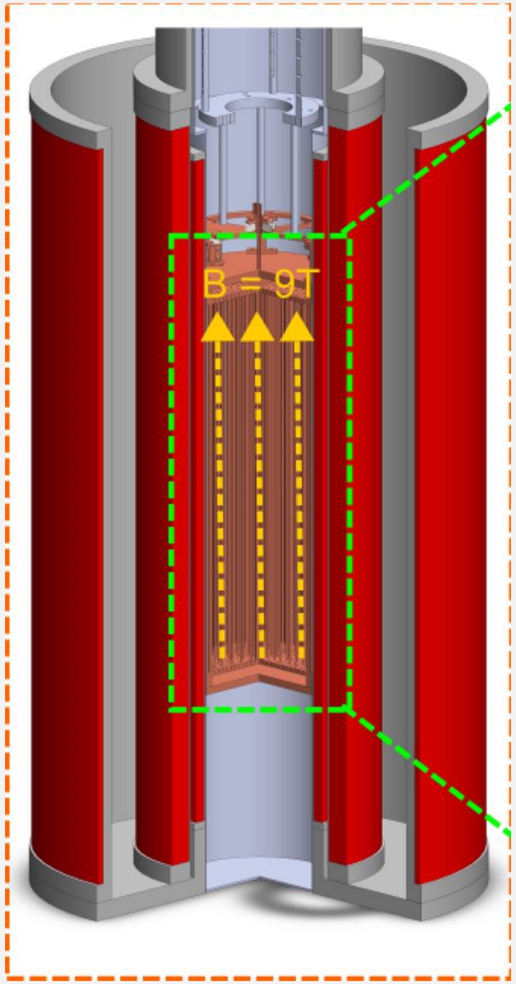


Credit: Ciaran O'Hare. cajohare/axionlimits: Axionlimits. https://cajohare.github.io/AxionLimits/, September 2026

CAVITY HALOSCOPE



Inverse Primakoff Effect

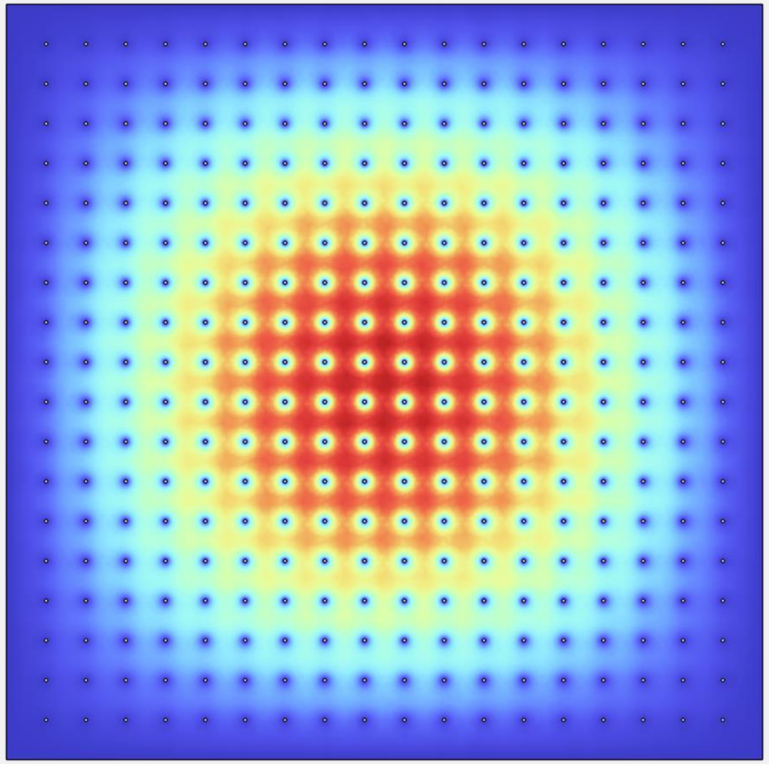


Example Haloscope Inside Magnet Bore

- Signal Power
  - $P \propto VB^2CQ$
- Scanning Rate
  - $\frac{df}{dt} \propto B^4V^2C^2Q$
- Form Factor
  - $C = \frac{\left|\int \mathbf{E} \cdot \boldsymbol{B}_{\text{ext}} dV_c\right|^2}{\int \varepsilon |\mathbf{E}|^2 dV_c \int |\mathbf{B}_{\text{ext}}|^2 dV_c}$

PLASMA HALOSCOPES

- Traditional Haloscope:
  - $f_{cavity} \propto V^{-2}$
- Lawson, Millar, Wilczek et al (2019)
- Wire Metamaterial → Artificial Plasma
- $\omega_p^2 = \dfrac{2\pi}{s^2 \log(s/d)}$
  - *s*: spacing
  - *d*: diameter
- How to reduce mechanical complexity?



Electrical Field of TM010 mode inside a wire metamaterial

ALPHA: AXION LONGITUDINAL PLASMA HALOSCOPE

alpha

Collaborating Institutes:

- Yale University (Host University)
- Arizona State University
- University of California, Berkley
- Cambridge University
- Colorado University
- University of Iceland
- John Hopkins University
- Massachusetts Institute of Technology
- Oak Ridge National Laboratory
- Stockholm University
- Wellesley College

> 50 collaborators

Supported by:

JOHN TEMPLETON FOUNDATION
Inspiring Awe & Wonder

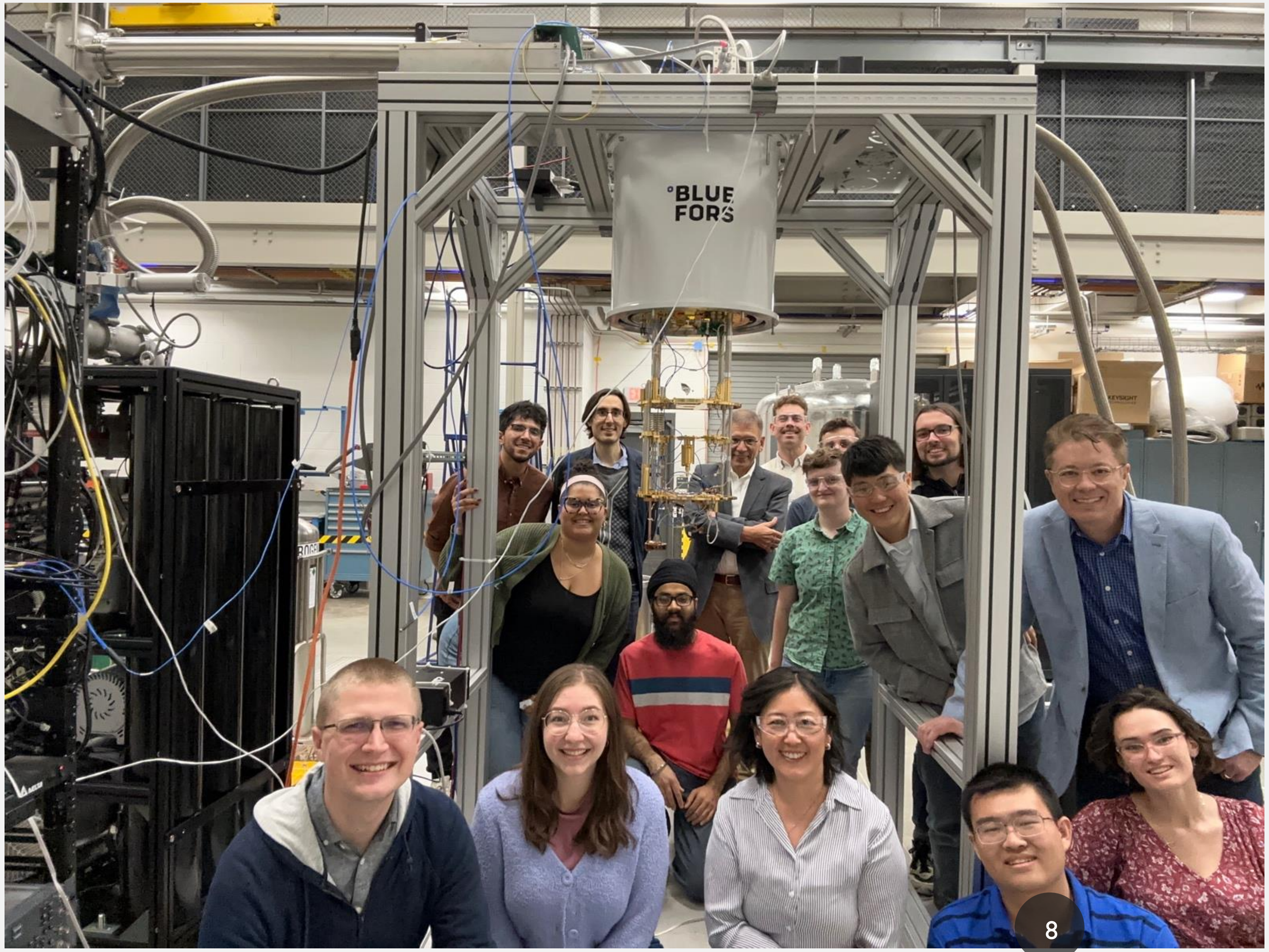
SIMONS FOUNDATION

Yale

Knut and Alice Wallenberg Foundation

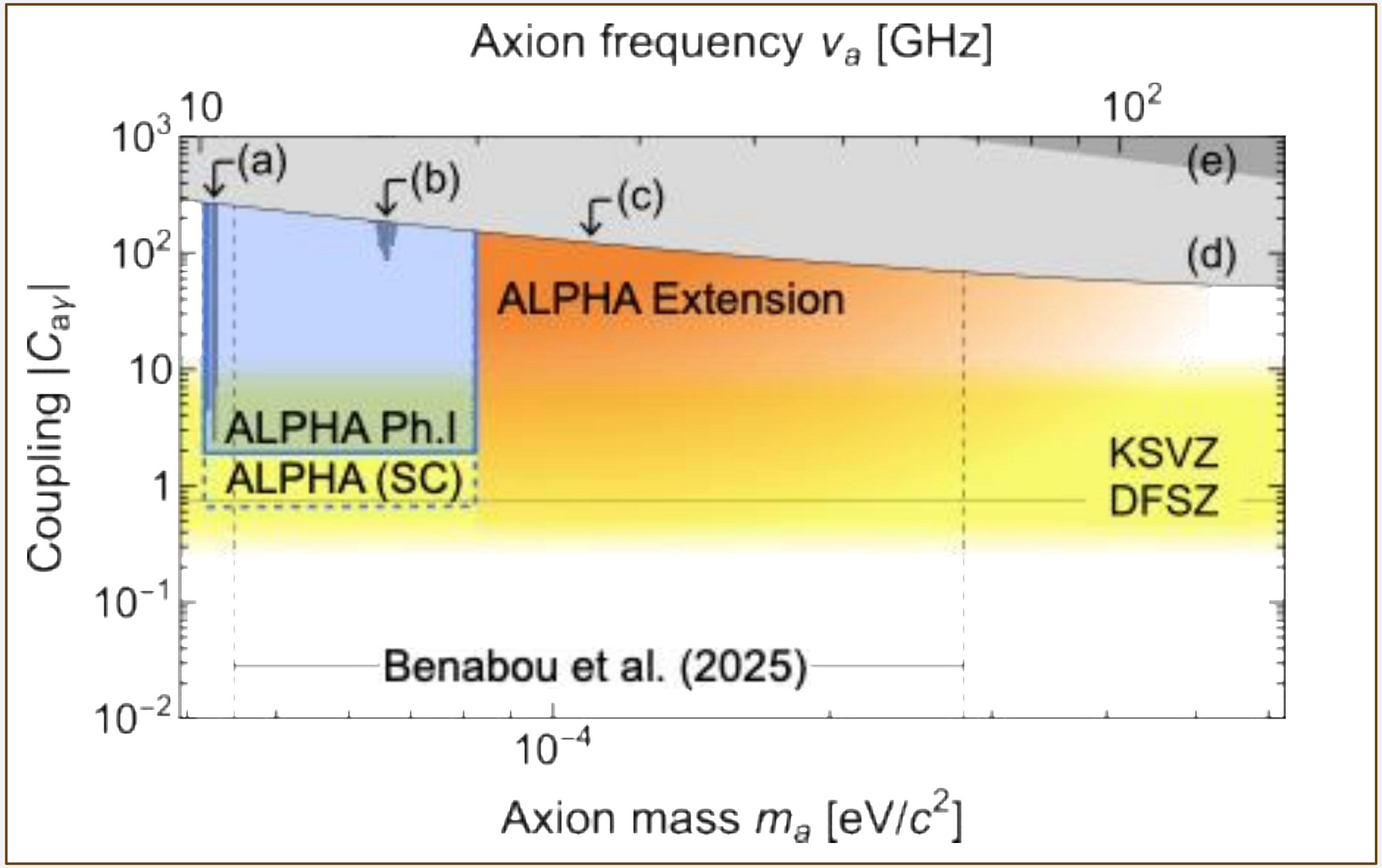
Swedish Research Council

OLLE ENGKVISTS STIFTELSE



ALPHA: PHASE 1

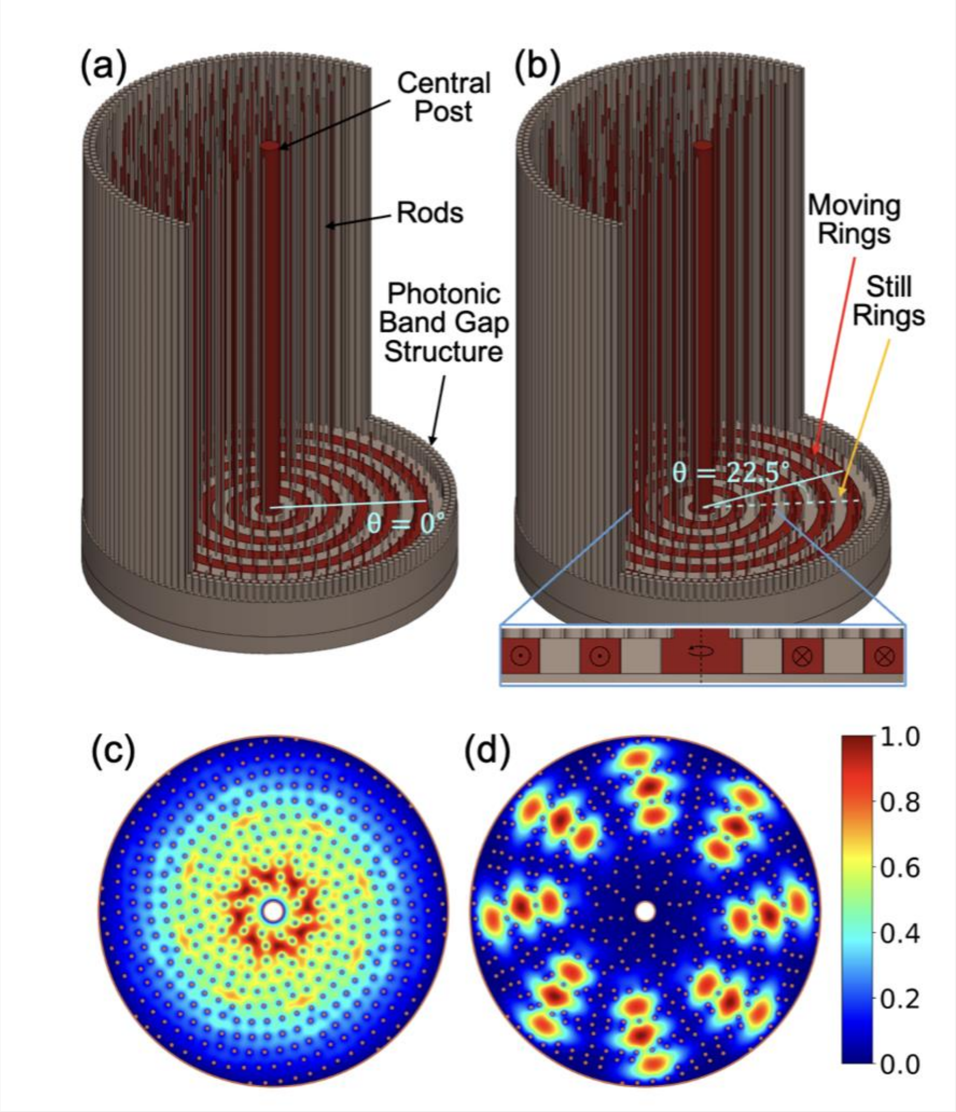
- Hosted at Yale Wright Lab
- Frequency Range:
  - 10 - 20GHz (40-80 ueV)
- Readout:
  - Quantum limited readout
  - KSVZ sensitivity
- Magnet:
  - 9T / Φ202.4x1000 mm



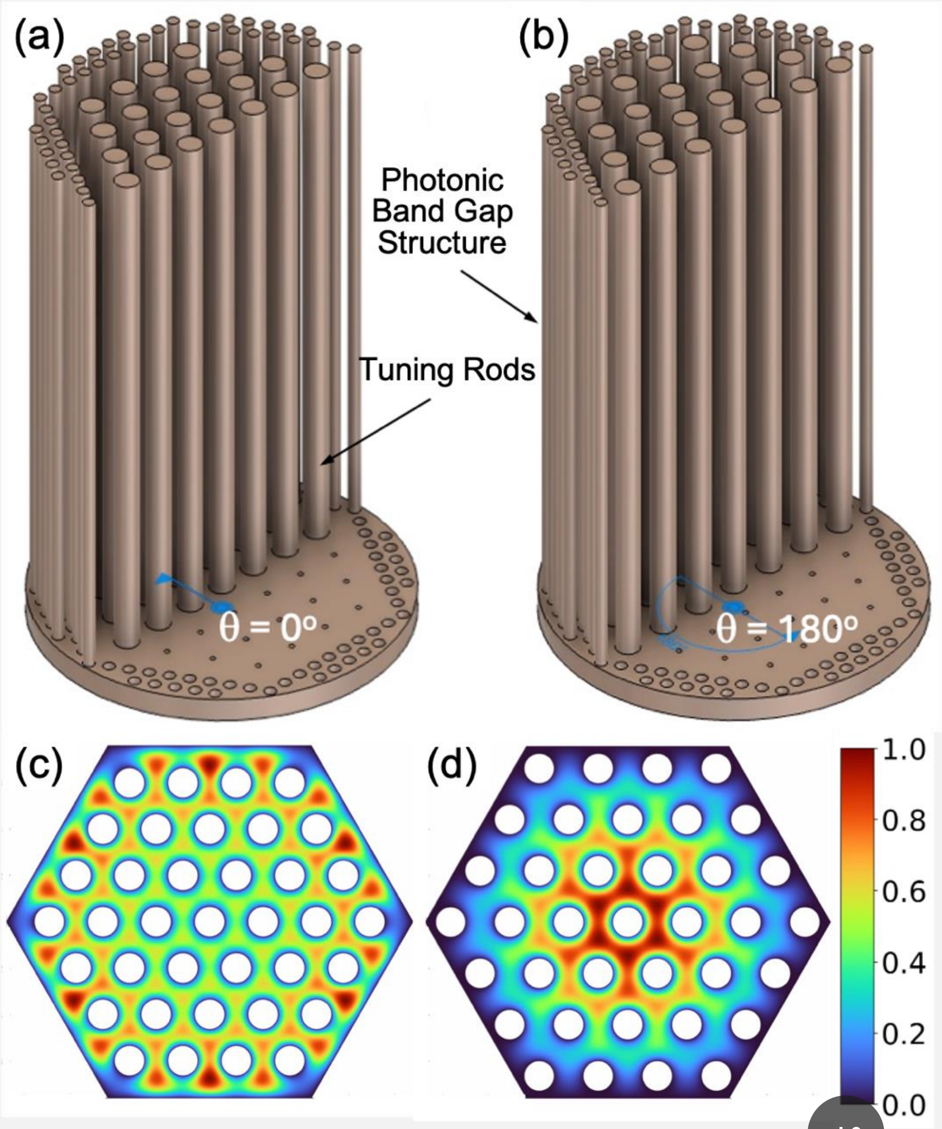
ALPHA Phase 1 sensitivity projection from 10-20GHz

<u>Phase 1 Design Paper: arXiv:2608.10292</u>

ALPHA: PHASE I RESONATOR

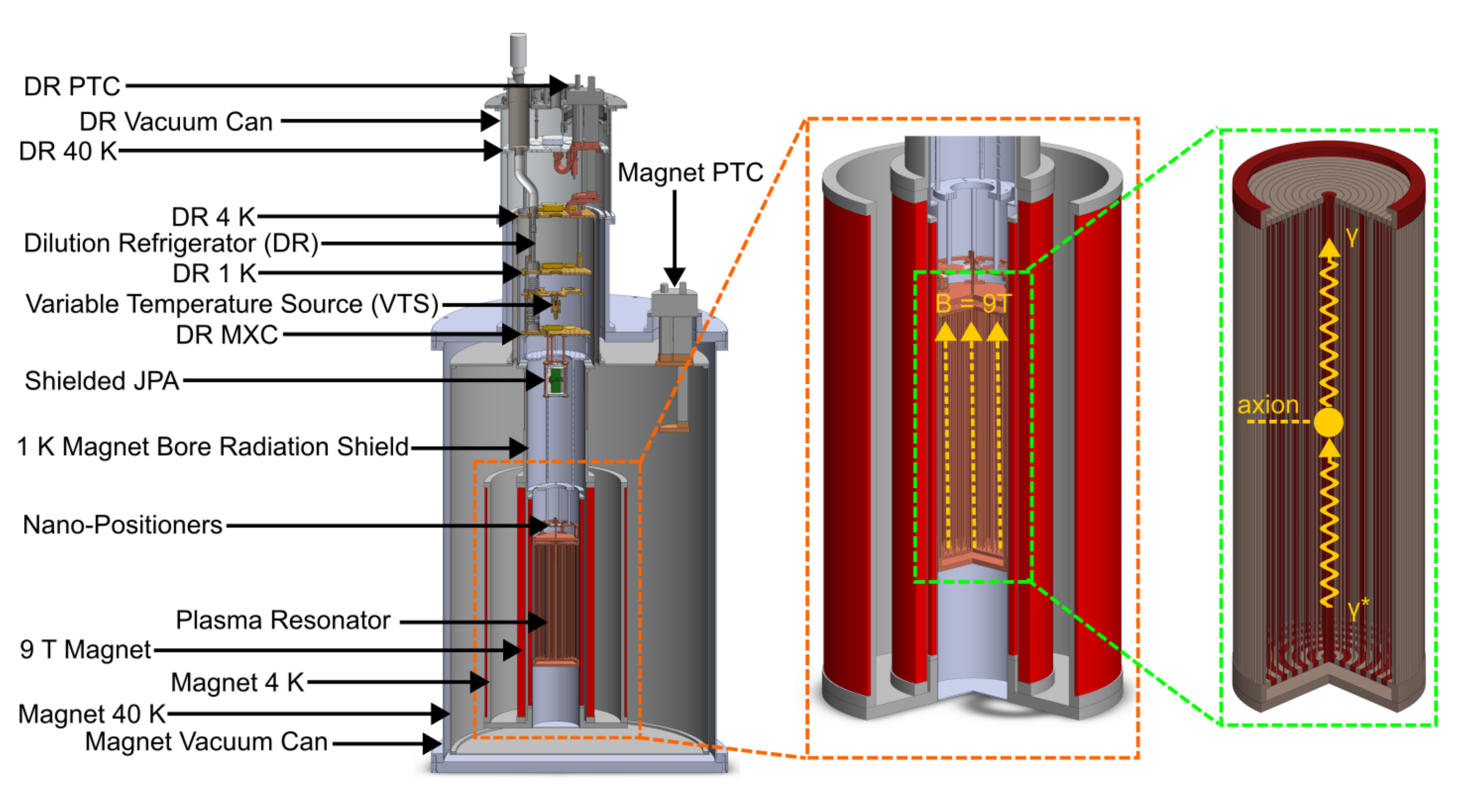


Rinnegan Design (Stockholm University Group)



Symmetric Lattice Design (Berkley University Group)

ALPHA: PHASE I EXPERIMENT SETUP



Experimental setup for ALPHA Phase I

MAJOR UPCOMING MILESTONES

Spiral Dark Photon Run: 2026

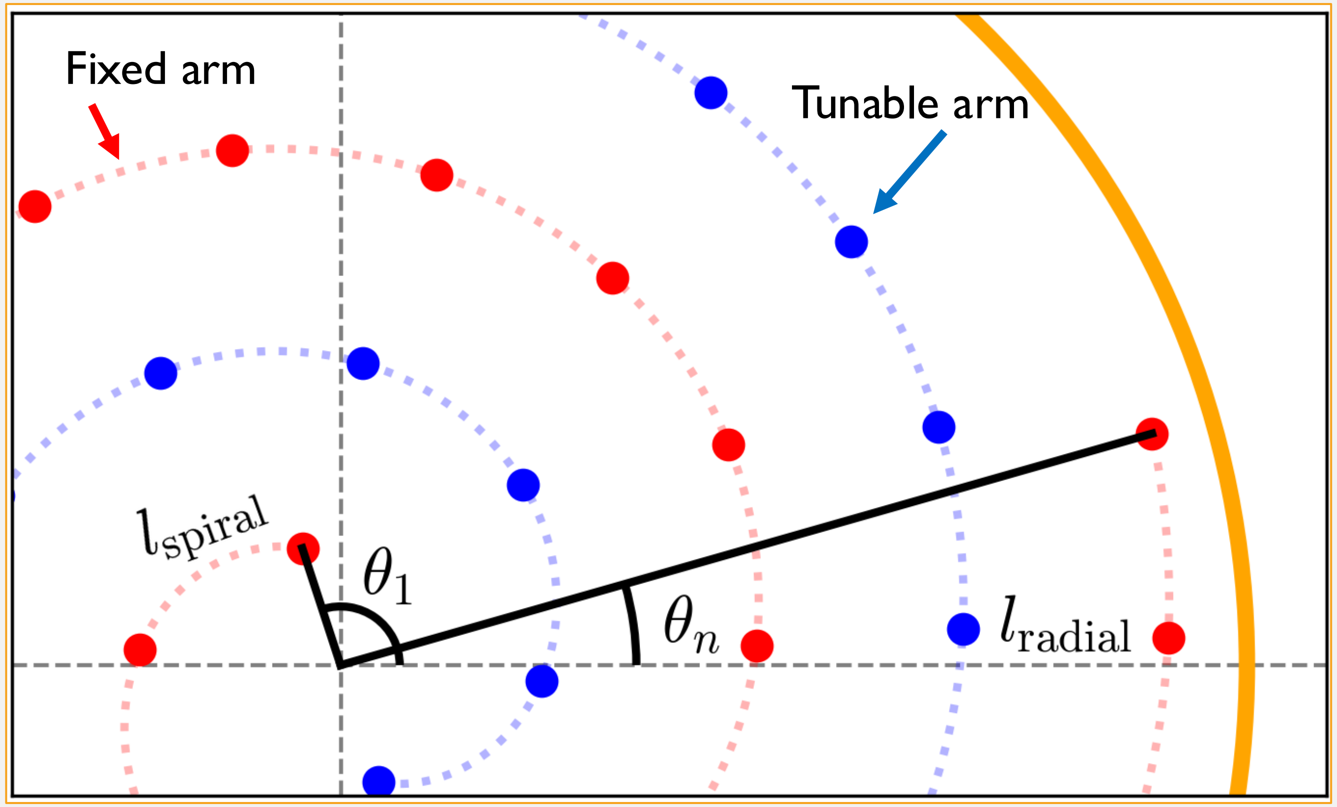
Magnet Delivery: 2027

First Axion Science Run: 2028-

ALPHA: STOCKHOLM UNIVERSITY

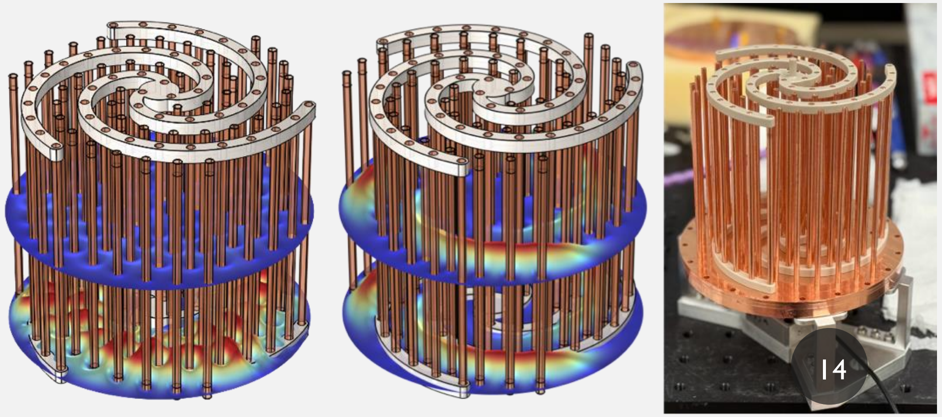
- Resonator:
  - Junu Jeong (Resonator co-lead)
  - Jon E. Gudmundsson [former spokesperson] (U of Iceland)
  - Rustam Balafendiev (U of Iceland)
  - Gagandeep Kaur
  - Jianyang Qi
  - Jacob Lindahl
- Analysis:
  - Jan Conrad (Deputy Spokesperson)
  - Andrea Gallo Rosso (Analysis co-lead)
  - Andy Meyer (See his talk for analysis overview!)

SPIRAL TUNING METHOD

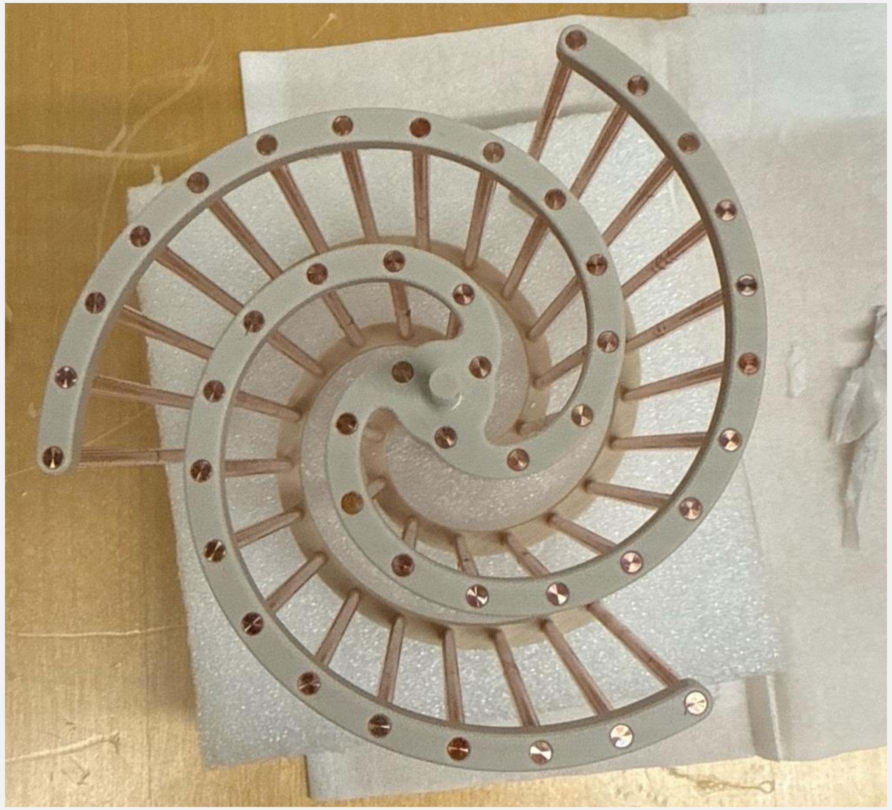


Spiral bundle geometry for wire positioning. Red and blue dots are locations of wires corresponding to one spiral.

- One central rotation
- $l_{\text{spiral}} \sim l_{\text{radial}}$
- $f \propto \sqrt{\dfrac{N_s \times n}{\text{Cross-sectional Area}}}$
- arxiv.2508.18145



DARK PHOTON CAVITY

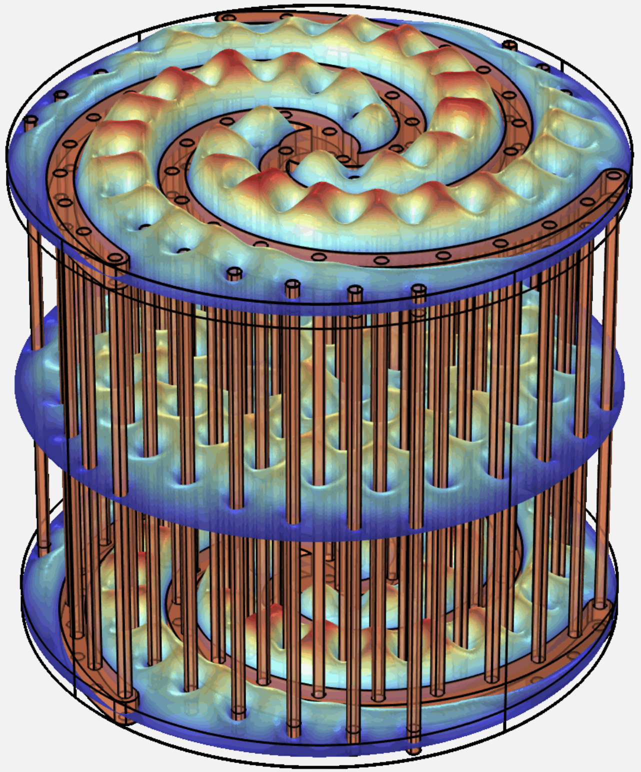


PEEK Support Spiral

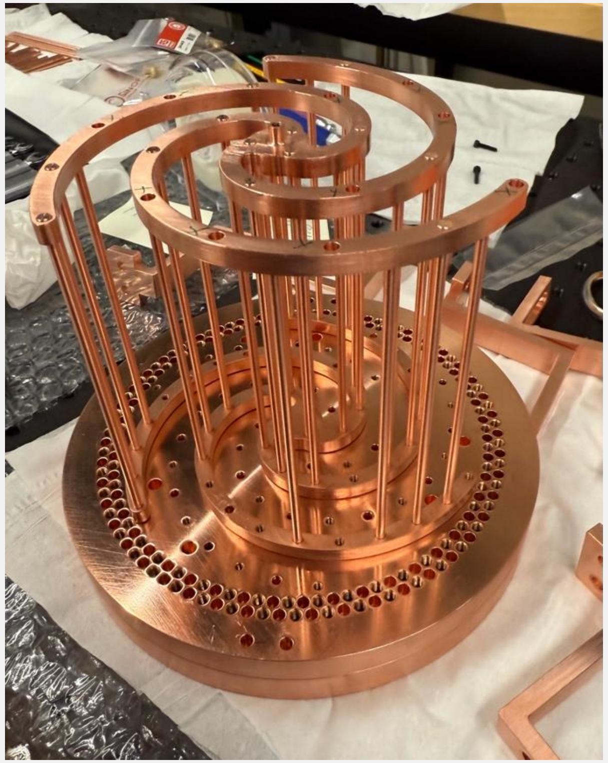
Copper Support Spiral

Wire Diameter changed from 3.175mm to 2.5mm and focused on 10.5-11GHz

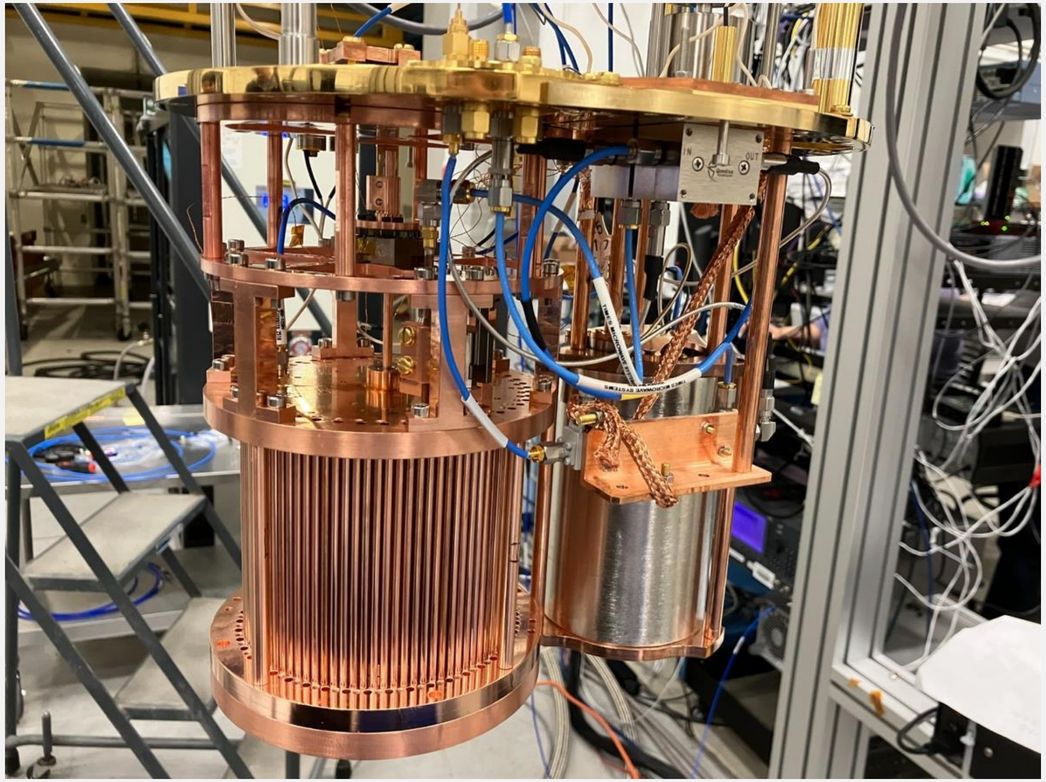
DARK PHOTON CAVITY



Electrical field profile under rotation

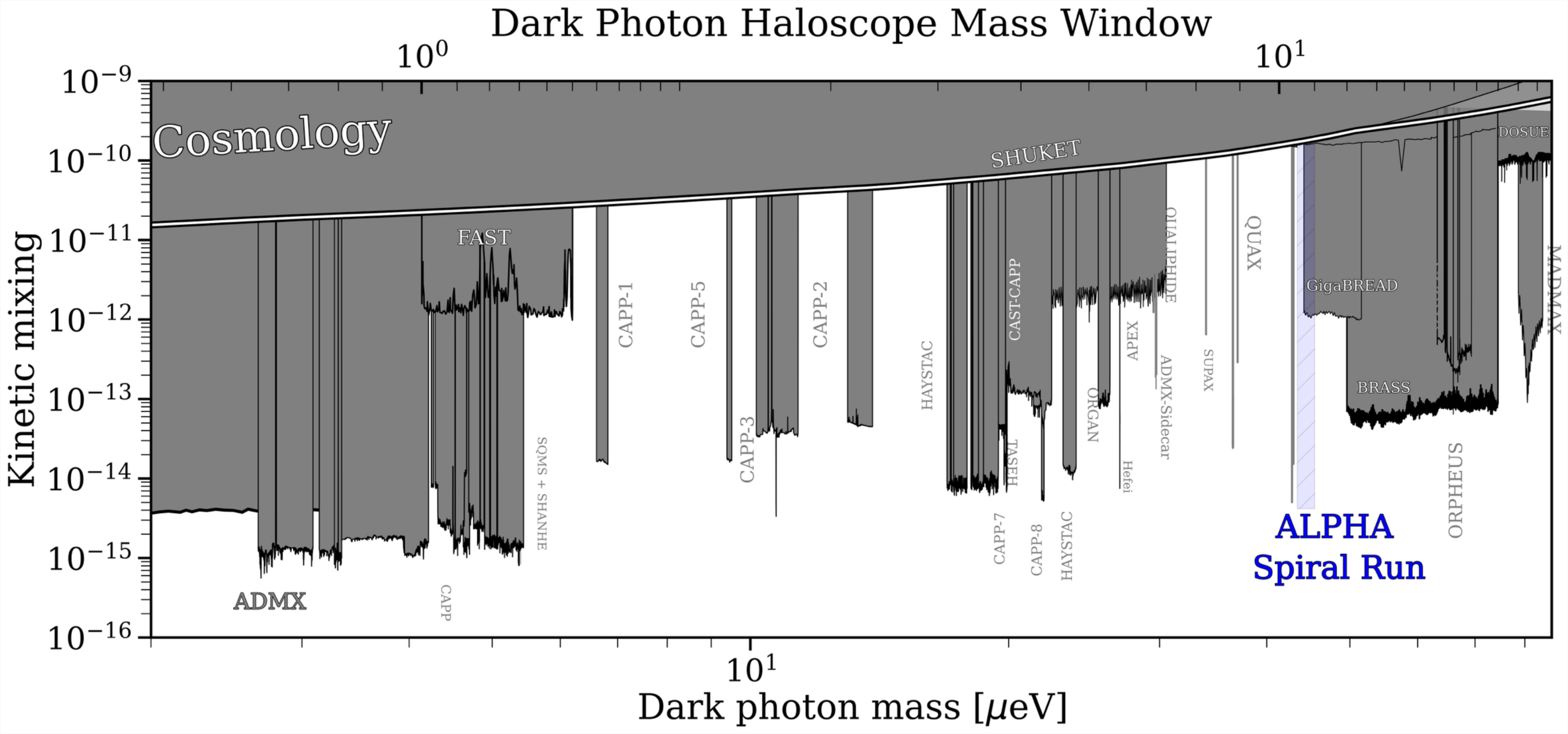


Half-assembled cavity



Cavity mounted inside ALPHA fridge

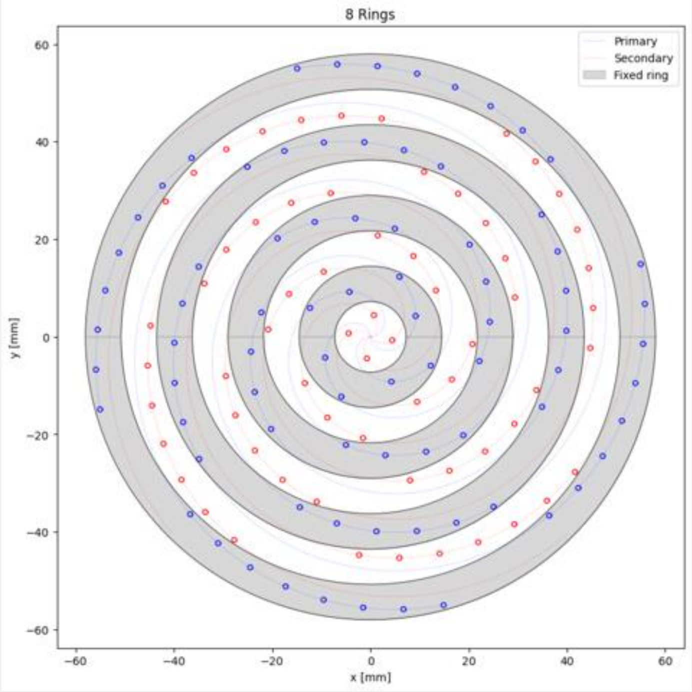
ALPHA DP RUN PROJECTION



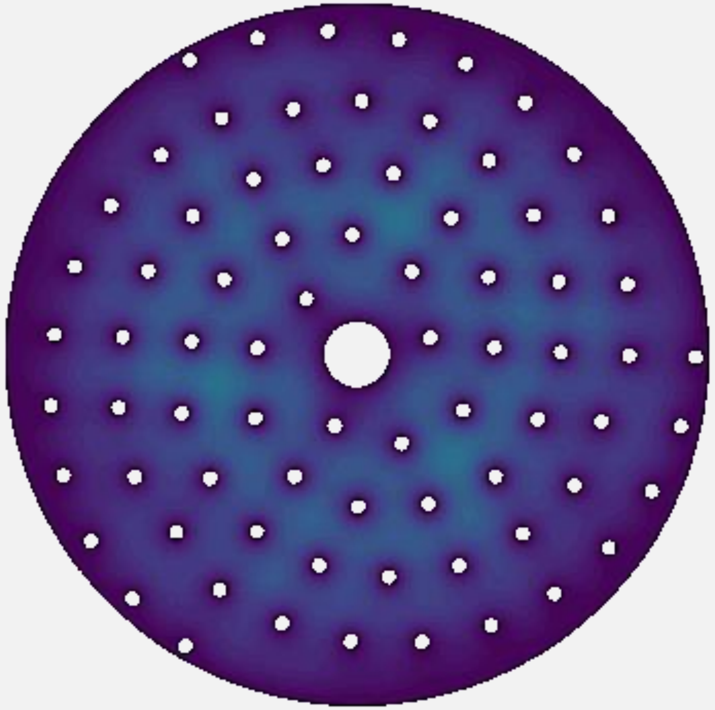
ALPHA Spiral Run projected sensitivity of 10.5-11GHz for 40 days integration time compared with other limits with data collection starting this year!

RING NESTED GROUP ROTATION (RINNEGAN)

- One central rotation
- Spiral distributed across series of concentric rings
- Flush surface
  - No longitudinal symmetry breaking



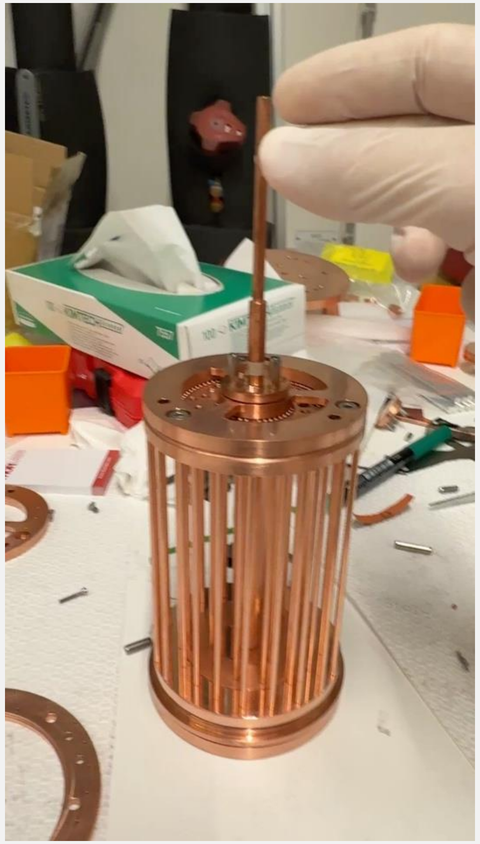
Wires spread across 8 rings



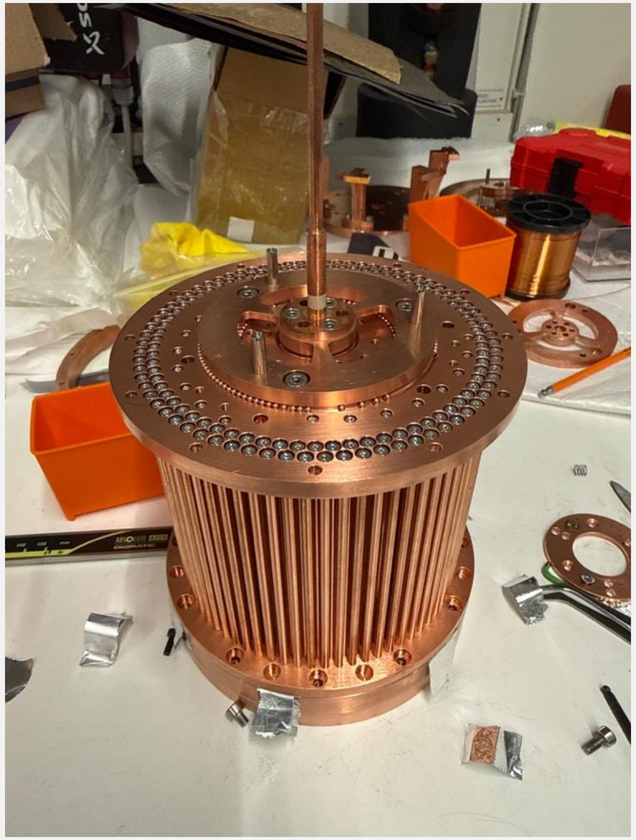
2D simulation of tuning

RINNEGAN PROTOTYPE

- Confirmed rotation of rings in cryogenics
- Prototype Measurements happening now!
- Will be used for simultaneous Dark Photon search at Stockholm University!



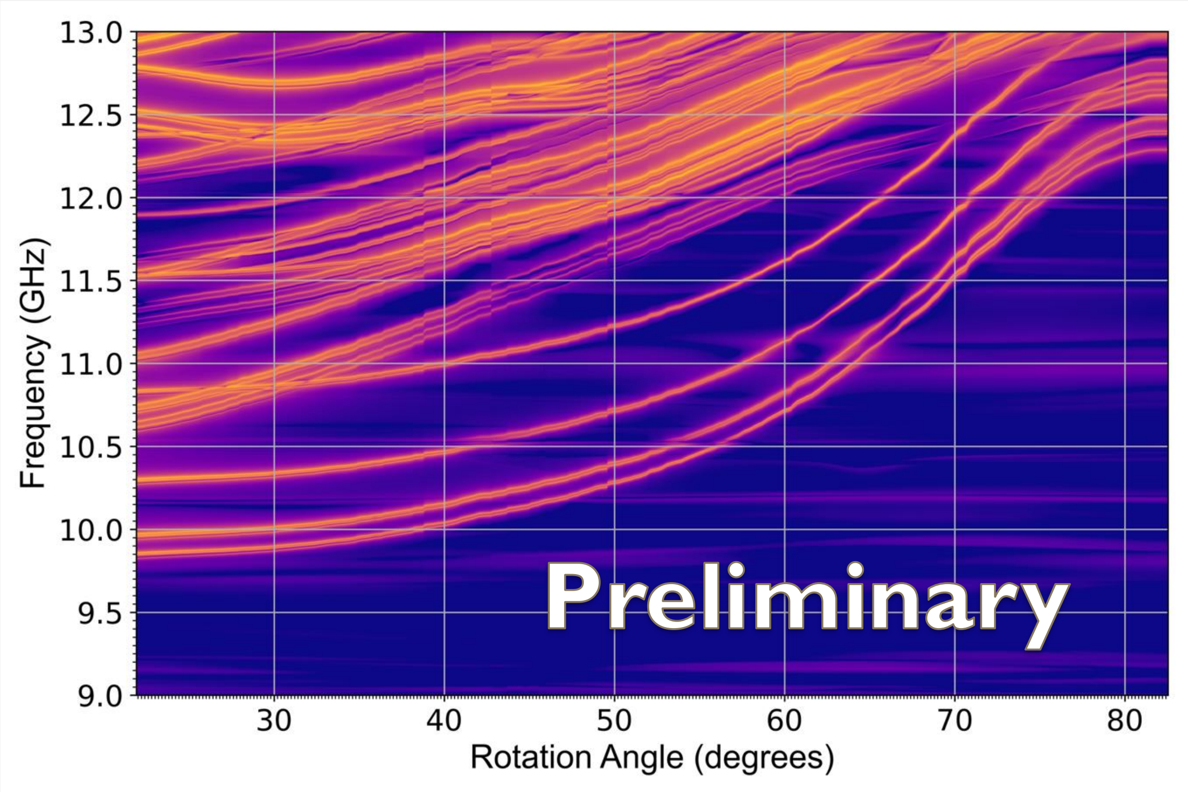
Rotation test of protype rings



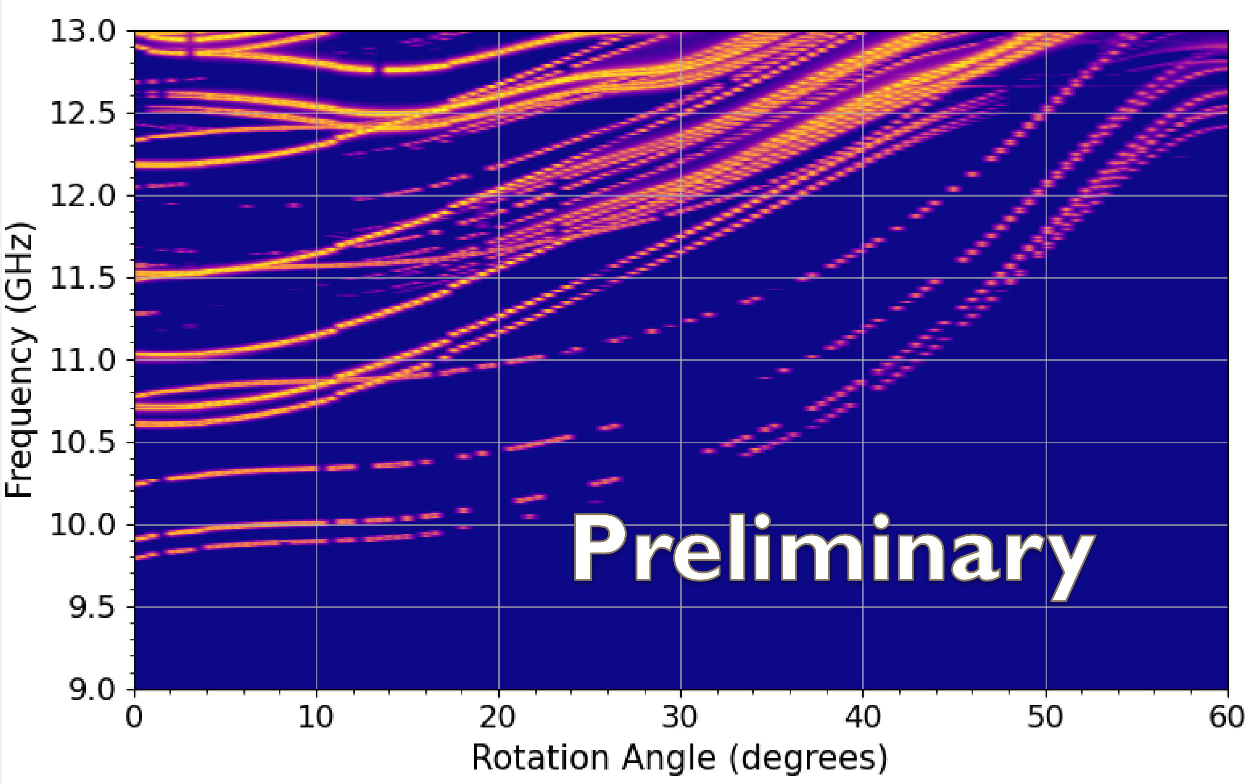
Assembled Rinnegan Prototype

RINNEGAN MODEMAP

Measured Modemap

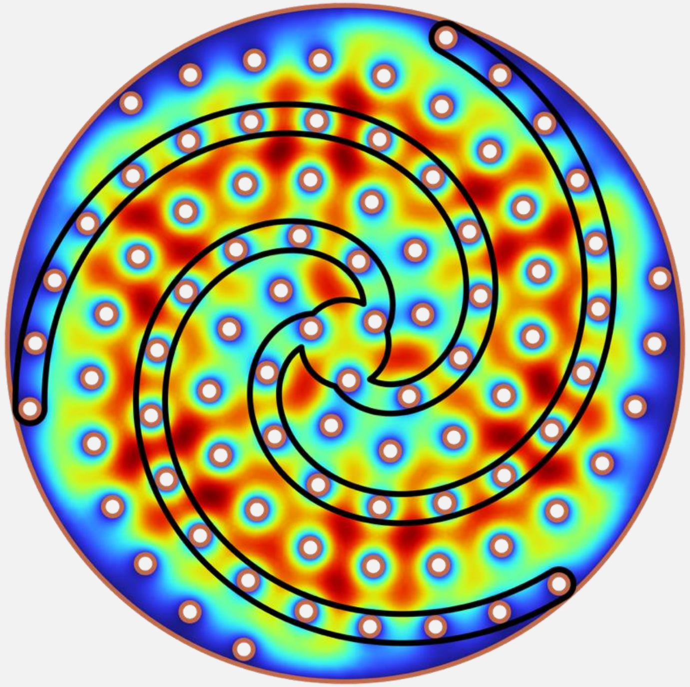


3D Simulated Modemap



CONCLUSIONS

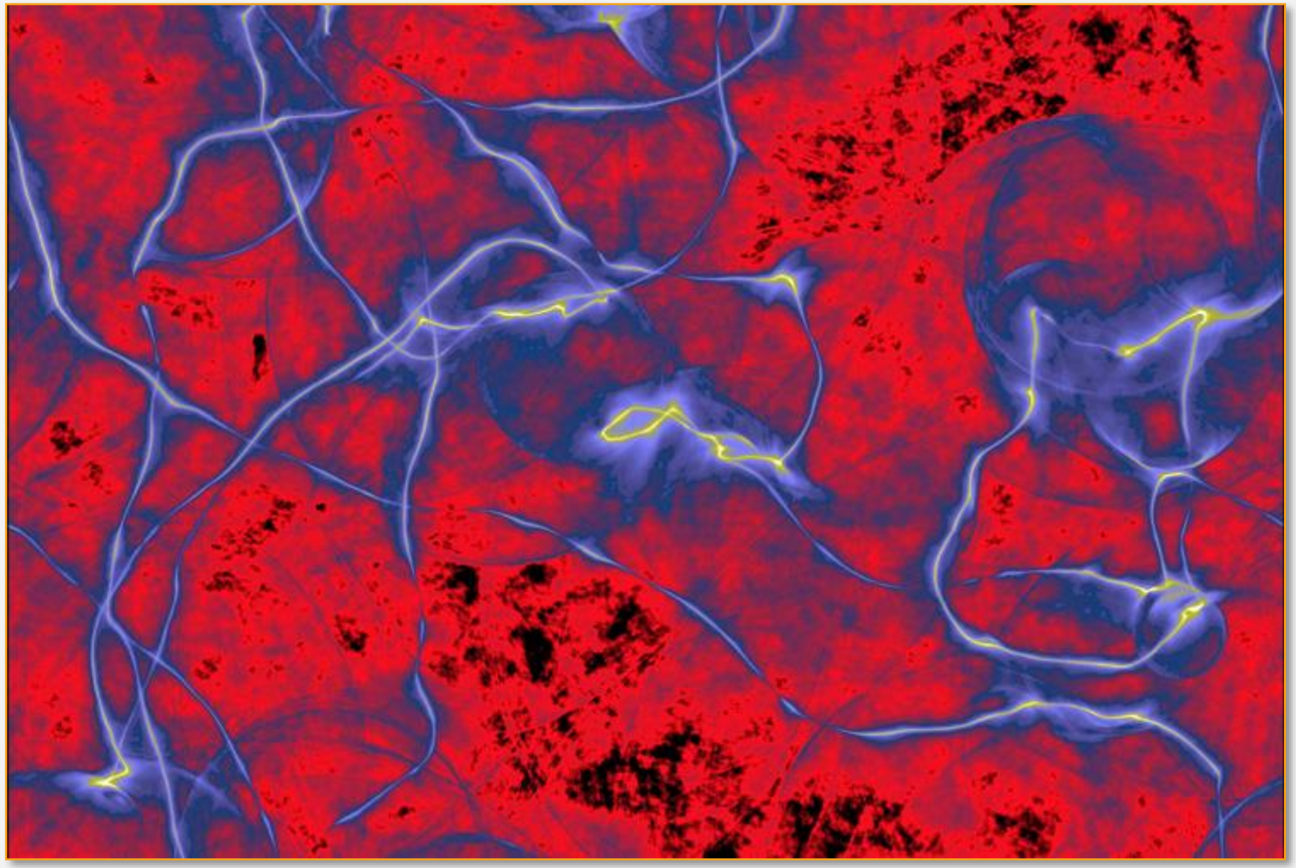
- ALPHA Phase I will scan 10-20 GHz at KSVZ sensitivity
- First dark photon science run in 2026
- Spiral design will be used for the 10.5 - 11 GHz dark photon run
- Rinnegan prototype is being tested
- Simultaneous Dark Photon search 10.5-11 GHz at SU



2D 6-arm simulated Electrical field

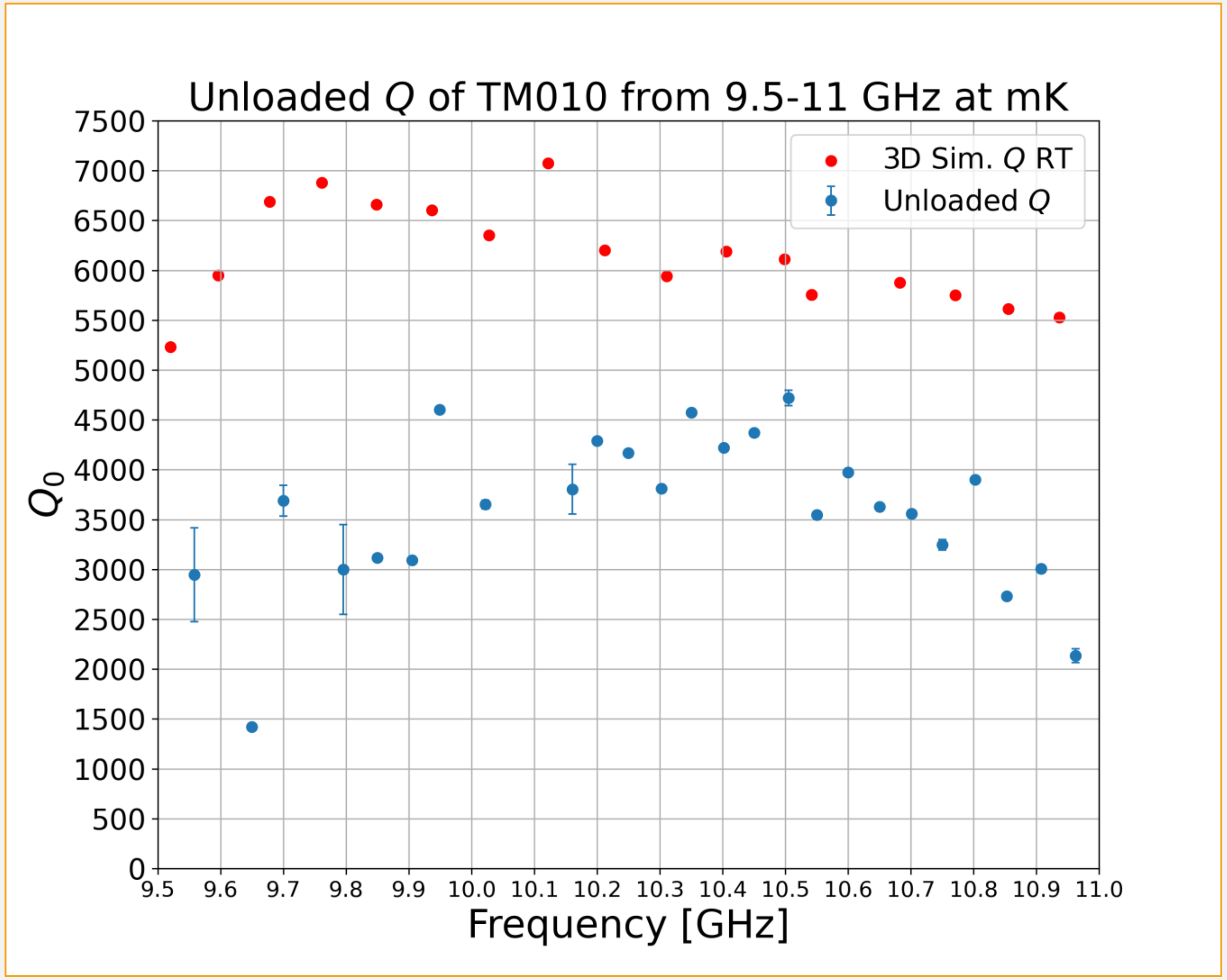
BACKUP SLIDES

POST-INFLATION AXION



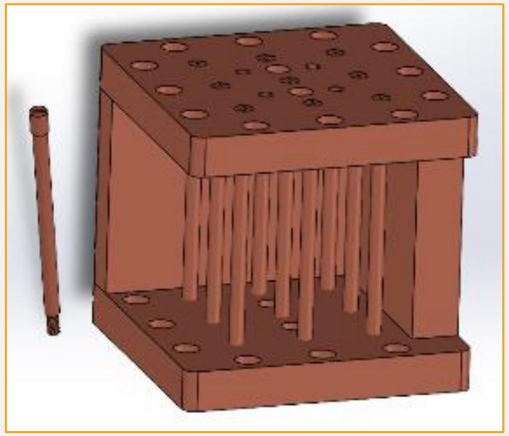
Simulation of early universe axion energy density
Credit: Malte Buschmann, Princeton University

DP CAVITY QUALITY FACTOR



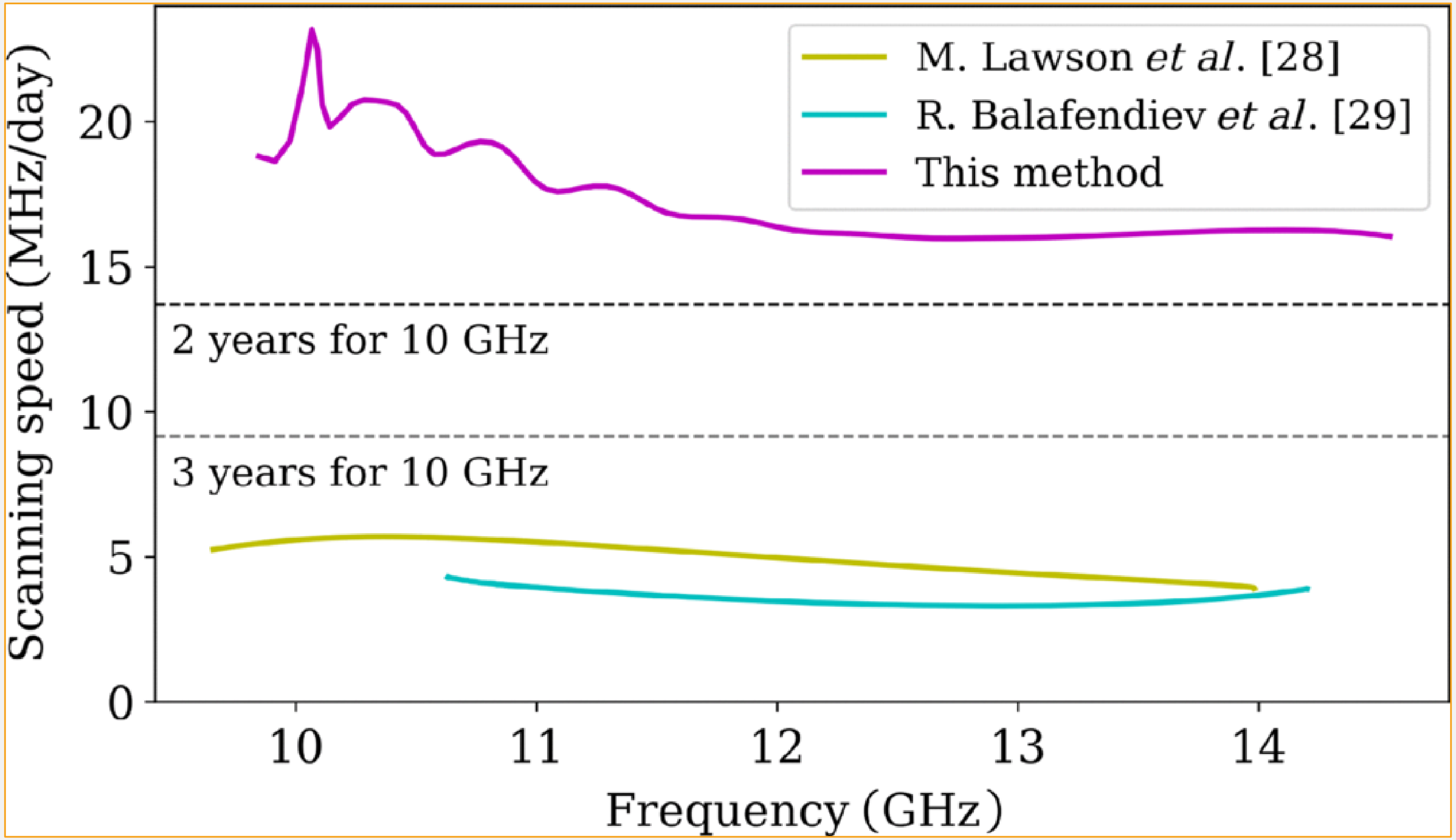
Measured and 3D simulated quality factor at 100 mK

- Factors Affecting the Q
  - Contact Resistance
  - Surface Roughness



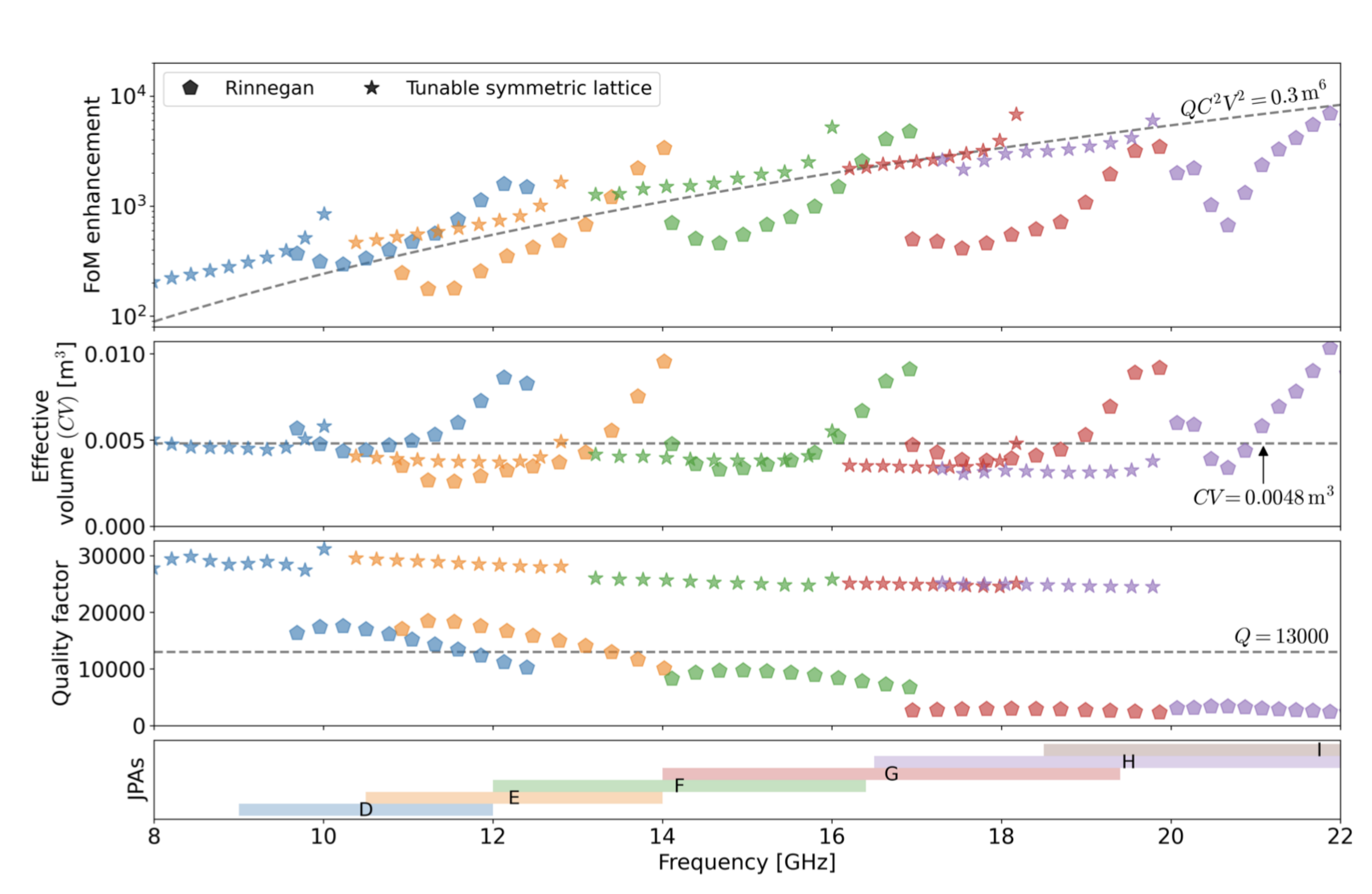
Contact Resistance Test Cavity

SCANNING RATE COMPARISON



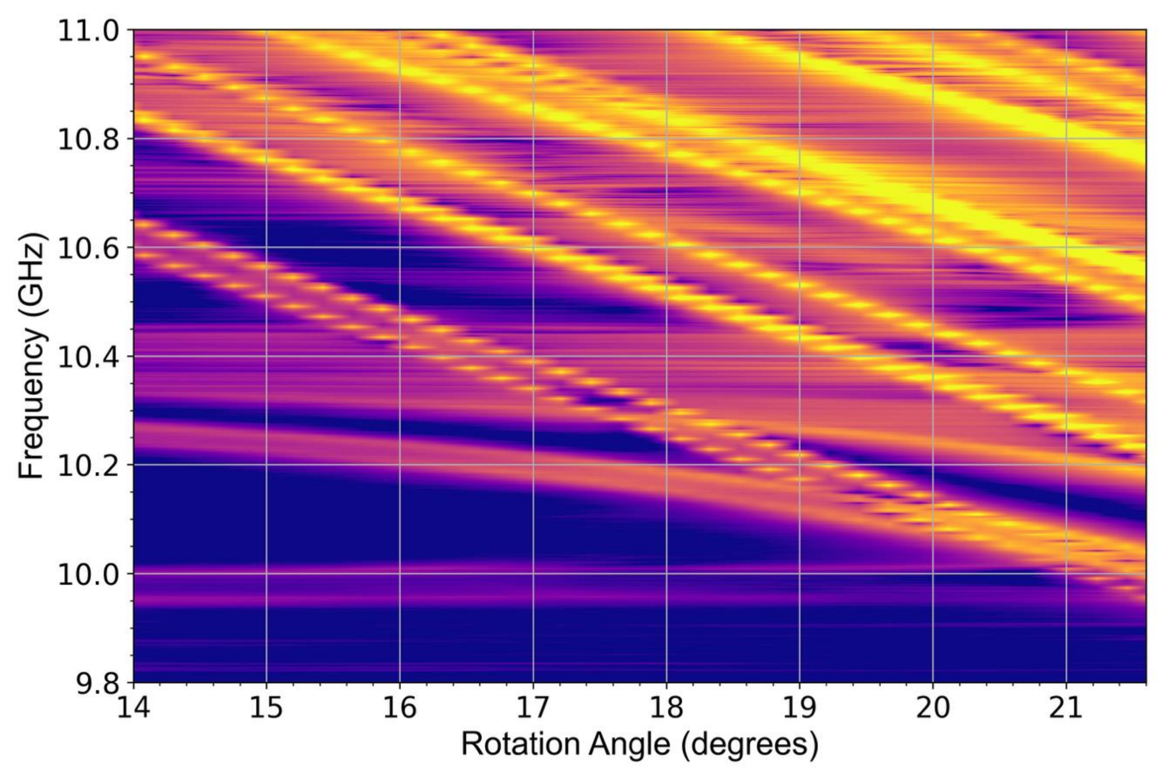
Scanning rate comparison for an 8-arm spiral cavity with dominant contribution from spiral packing

RESONATOR SCANNING RATE COMPARISON



DARK PHOTON CAVITY MODEMAP

Measured Modemap



3D Simulated Modemap