Quasiparticles for Axion Detection

Alex Millar

M. Lawson et al arXiv:1904.11872
Balafendiev et al arXiv:2203.10083
A. Millar et al arXiv:2210.00017
D. Marsh et al arXiv:2209.12909
Schütte-Engel et al arXiv:2102.05366

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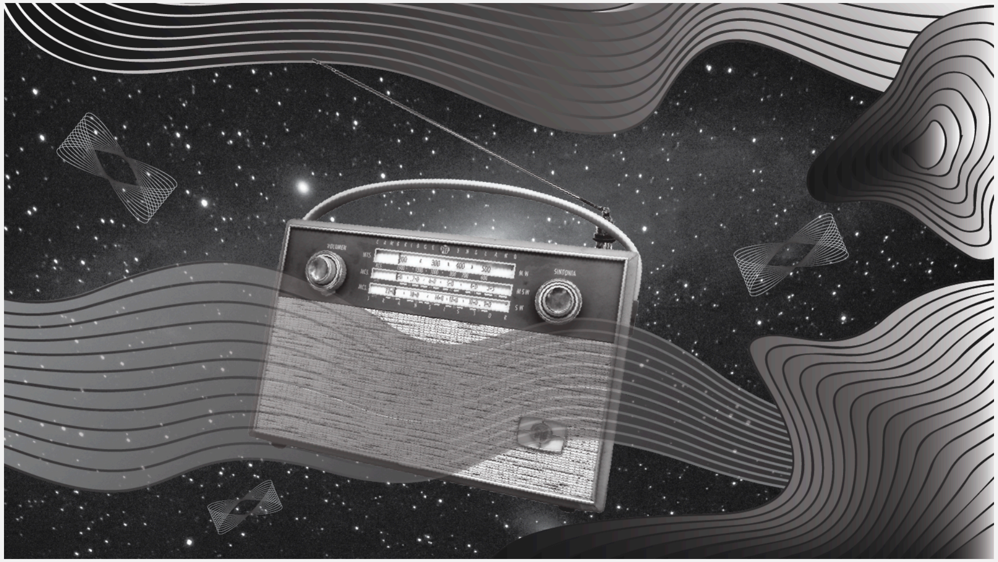
Axion Dark Matter

- Pseudoscalar introduced to explain why the Strong force is CP conserving
- Much lighter than wimps: ~μeV
- Acts like a classical wave!
- Looking for dark matter is like tuning a radio to find the right station (axion mass)
- Lots of new experiment ideas!



Artwork by Sandbox Studio in Symmetry Magazine

Axion-Electrodynamics

- Axions and ALPs interact with photons through an anomaly term

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - J^\mu A_\mu + \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2}m_a^2 a^2 - \frac{g_{a\gamma}}{4}F_{\mu\nu}\widetilde{F}^{\mu\nu}a,$$

- This coupling is tiny, but still important
- The upshot is that in an external B-field the axion sources an E-field

$$\mathbf{E}_a = -\frac{g_{a\gamma}\mathbf{B}_e a_0}{\epsilon} e^{-im_a t} = 1.3 \times 10^{-12}\ \mathrm{V/m}\ \frac{B_\mathrm{e}}{10\ \mathrm{T}}\ \frac{C_{a\gamma} f_{\mathrm{DM}}^{1/2}}{\epsilon}\ .$$

Medium Effects

- Putting in a plasma as a medium

$$\mathbf{E} = -\frac{g_{a\gamma}\mathbf{B}_{\mathrm{e}}a}{\epsilon} = -g_{a\gamma}\mathbf{B}_{\mathrm{e}}a\left(1 - \frac{\omega_p^2}{\omega_a^2 - i\omega_a\Gamma}\right)^{-1}$$

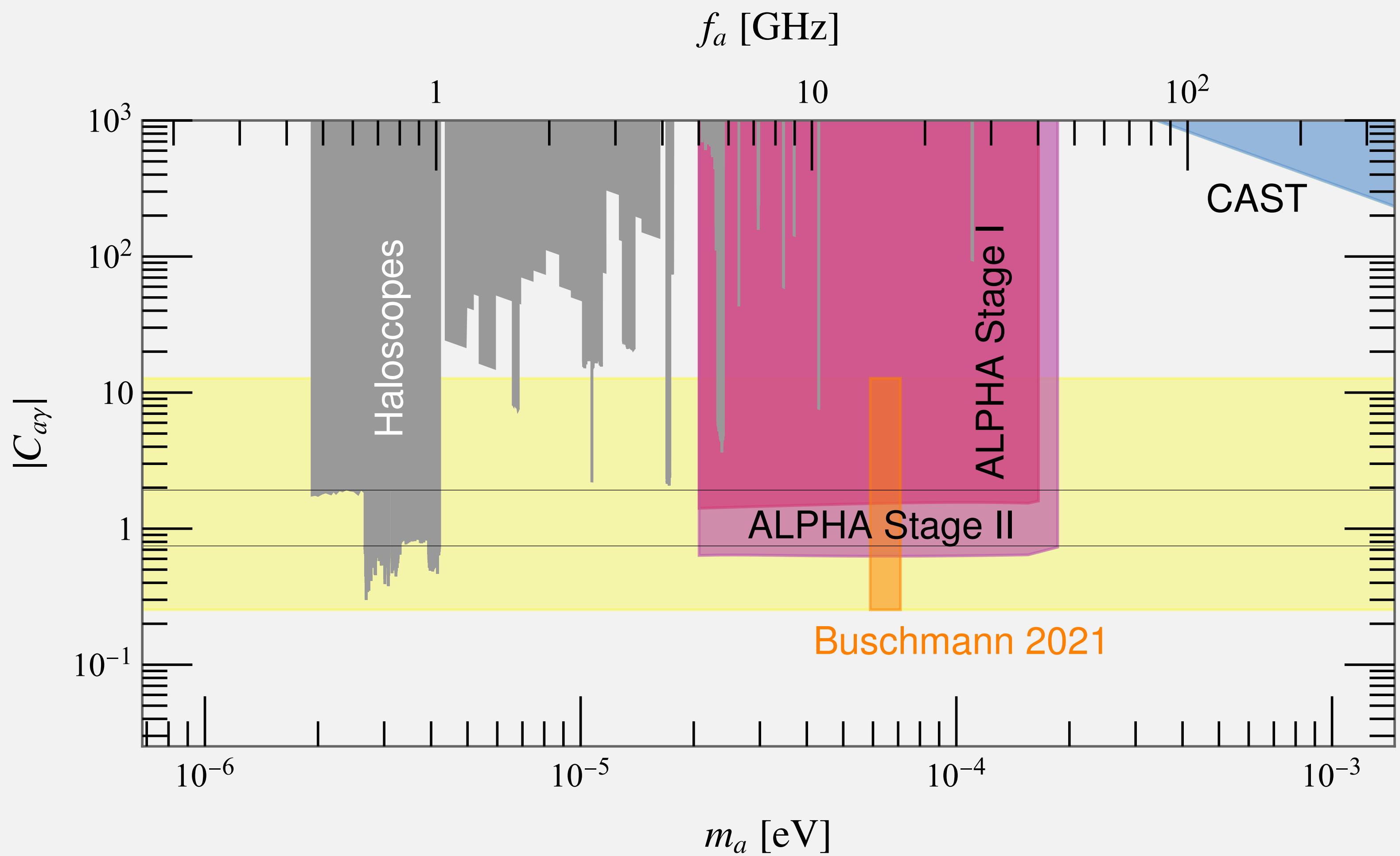
- Resonance when the axion and plasma frequencies match

- Limited by the loss rate of the medium

Wire metamaterials

- One of the first metamaterials
- Plasma frequency determined by two factors: effective electron number density and mass
- Wires mutually induct, changing the plasma frequency
- cm spacing gives ~GHz plasma frequency

Discovery Potential



How else can you make massive photons?

- Plasmons are not the only way to have resonances in the dielectric constant
- Need quasi-particles that can mix with the photon to create new modes
- Inherit a coupling to the axion from the photon

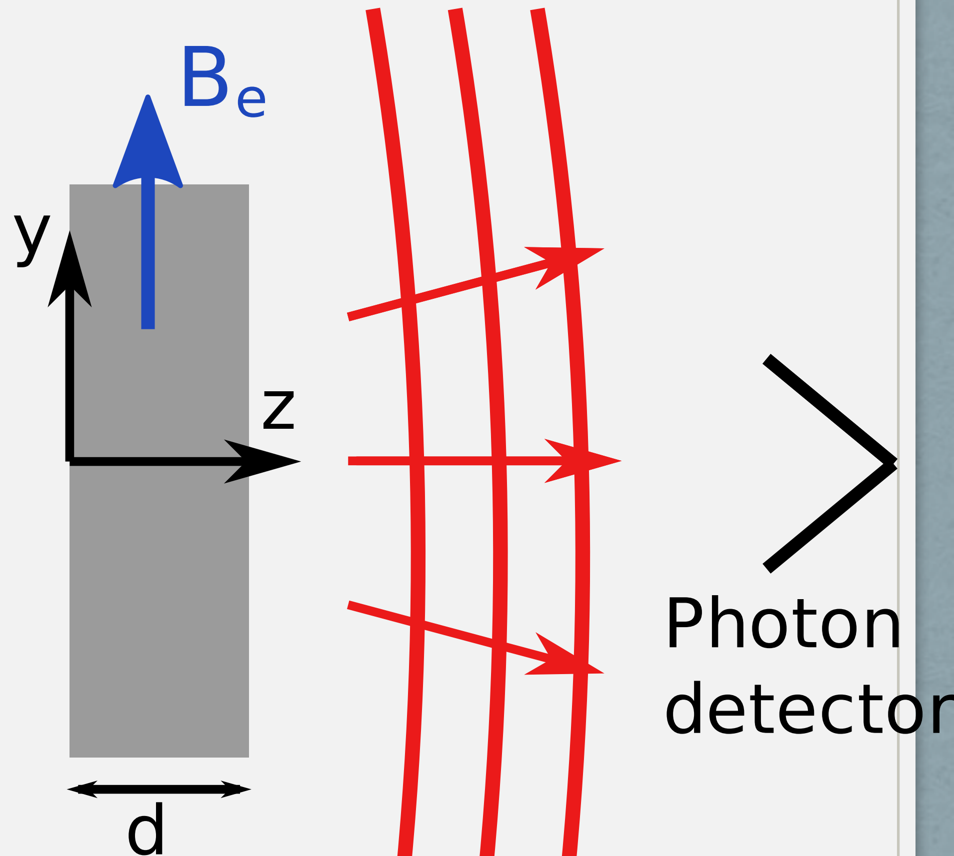
Phonon-Polaritons

- Optical phonons can mix with photons to form polaritons
- Originally proposed in arXiv:2005.10256, using a different formalism and relying on difficult calorimetry
- Easier to think just in terms of the dielectric constant (the axion doesn't care about the electrons)

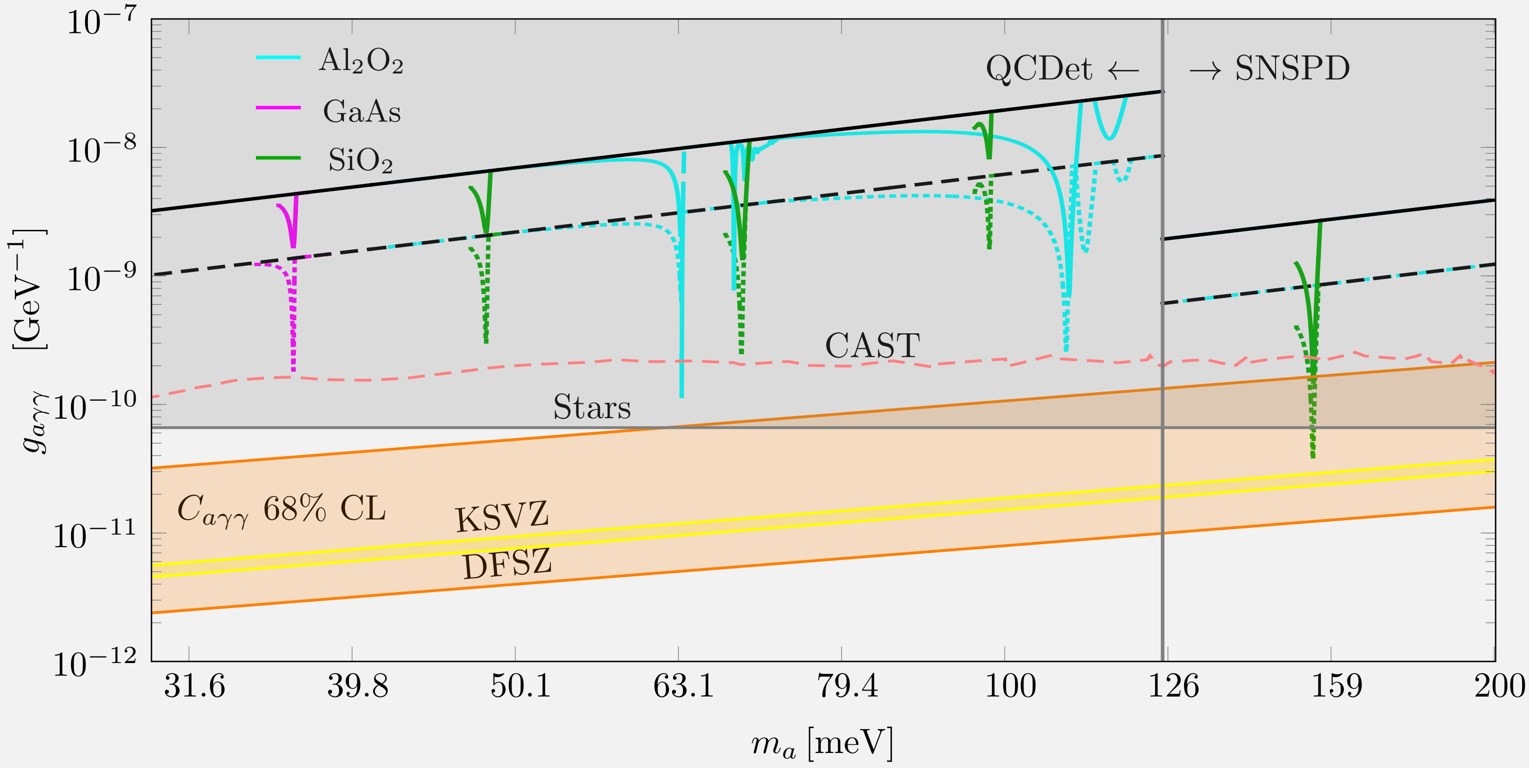
$$\epsilon(\omega) = \frac{(\epsilon_0 - \epsilon_\infty)\,\omega_{\rm TO}^2}{\omega_{\rm TO}^2 - \omega^2 + i\omega\Gamma_{\rm ph}} + \epsilon_\infty .$$

Detecting Phonon-Polaritons

- Changes in dialectic constant create propagating photons
- Near-zero epsilon makes vacuum reflective
- Mini-cavity/dish antenna!



Expected Exclusion



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Axion-Quasiparticles

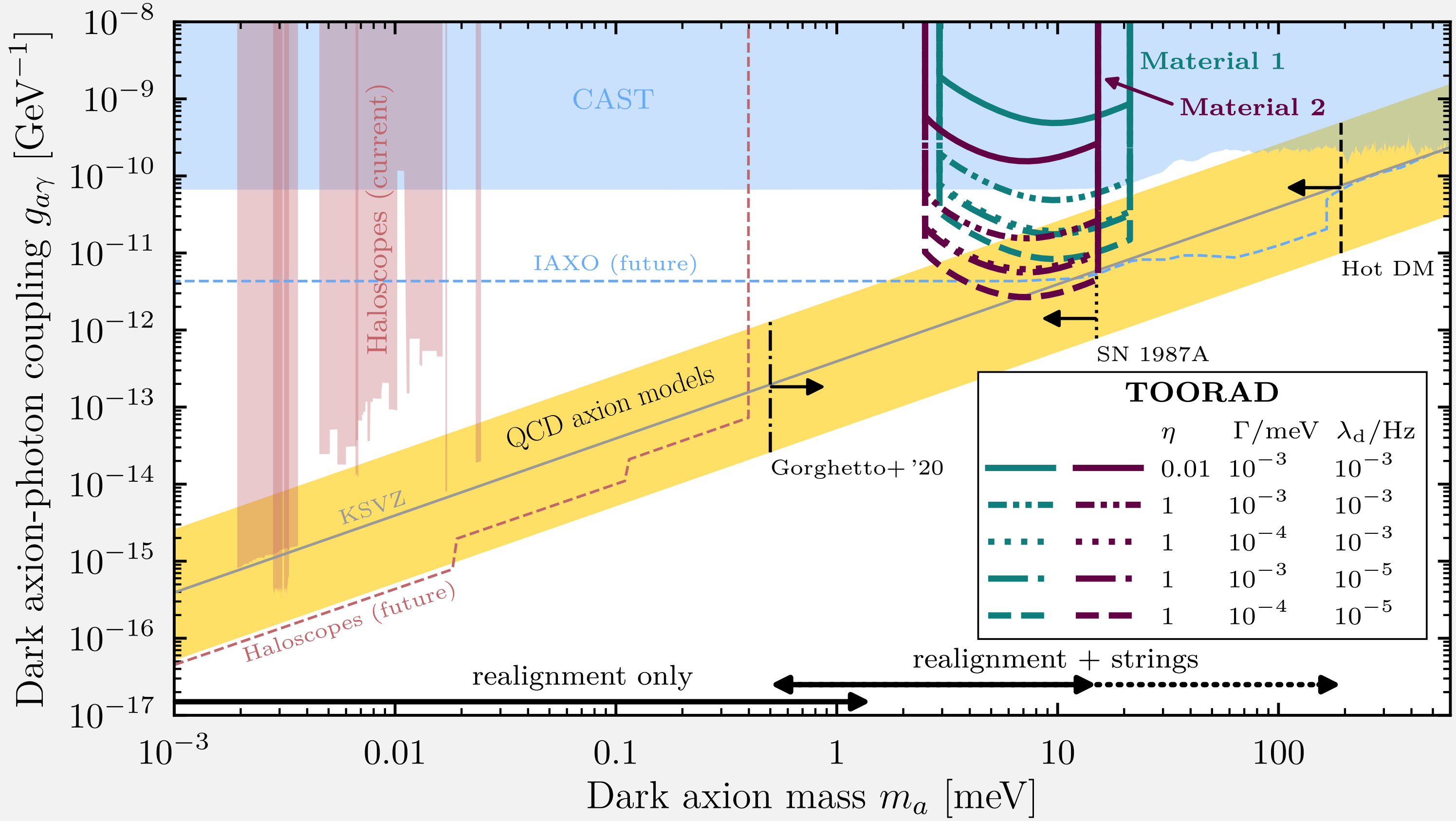
- In principle materials with axion-like quasiparticles exist
- Like “regular” axions they mix with a photon in a B-field, but much more strongly
- Idea in arXiv:1807.08810, theory in arXiv:2102.05366
- Similarly to phonons this can be thought of as an effective refractive index

$$n_\Theta^2 = n^2 \left(1 + \frac{b^2}{m_\Theta^2 - \omega^2 - i\omega\Gamma_m} + i\frac{\Gamma_\rho}{\omega}\right).$$

- Now it depends on the applied magnetic field

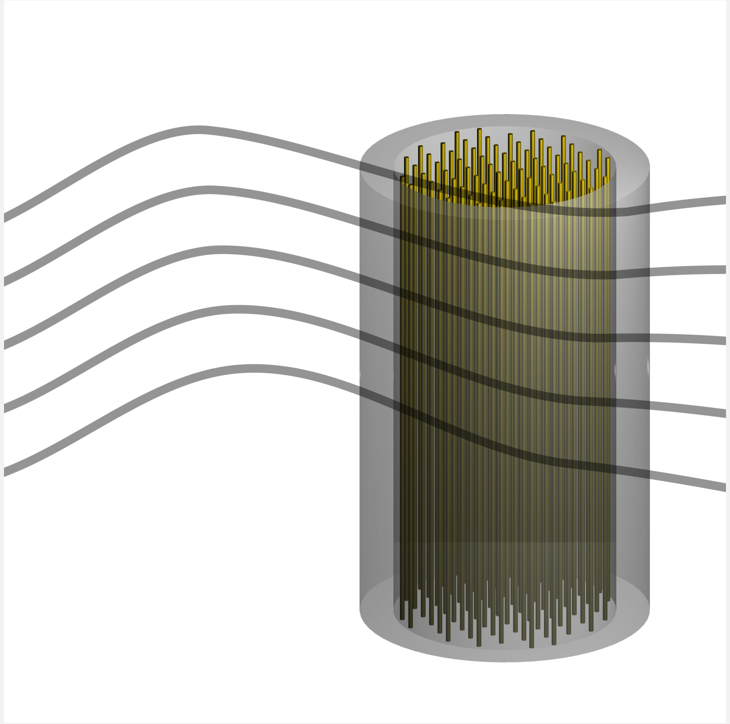
$$b^2 = \frac{\alpha}{\pi}\frac{\Lambda B_e^2}{\epsilon}$$

Expected Exclusion



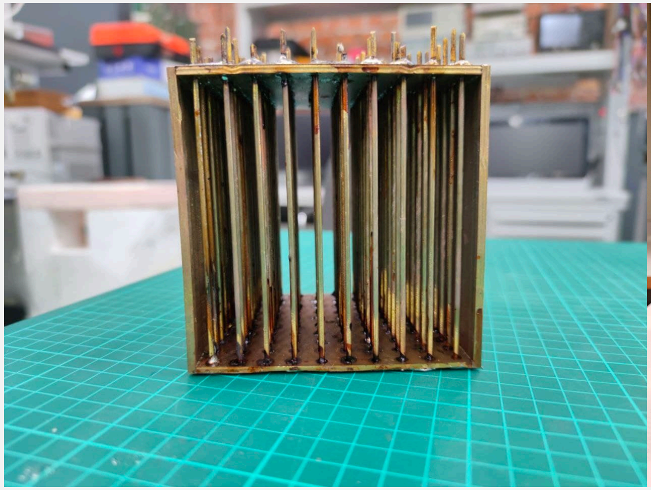
Conclusions

- Playing around with the photon gives many interesting new avenues for detection
- Plasmas so far are the most promising, with significant work being done in ALPHA
- Interested in high quality tunable resonances!

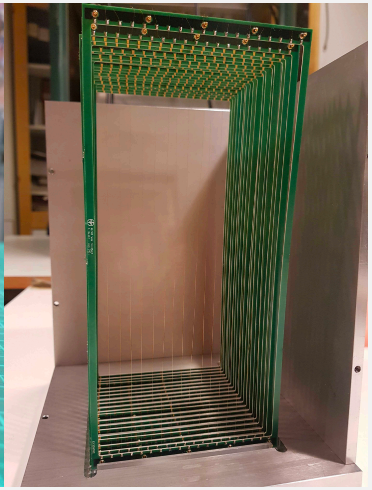


ALPHA

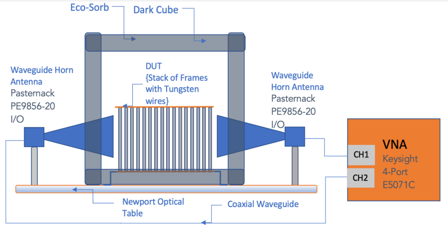
- Experimental consortium coming together to build a plasma haloscope
- Contributions from Stockholm University, UC Berkeley, MIT, ITMO, Cambridge, Yale, the University of Maryland and UC Davis

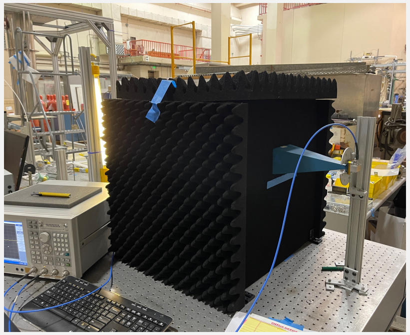


Rustam Balafendiev



Katie Dunne





Saad Kenany

Discovery Potential