U.S. DEPARTMENT of ENERGY

UNIVERSITY of WASHINGTON

Dielectric Powder Haloscope SNSPD* Experiment

Madeleine Carhart, CPAD October 22 2026

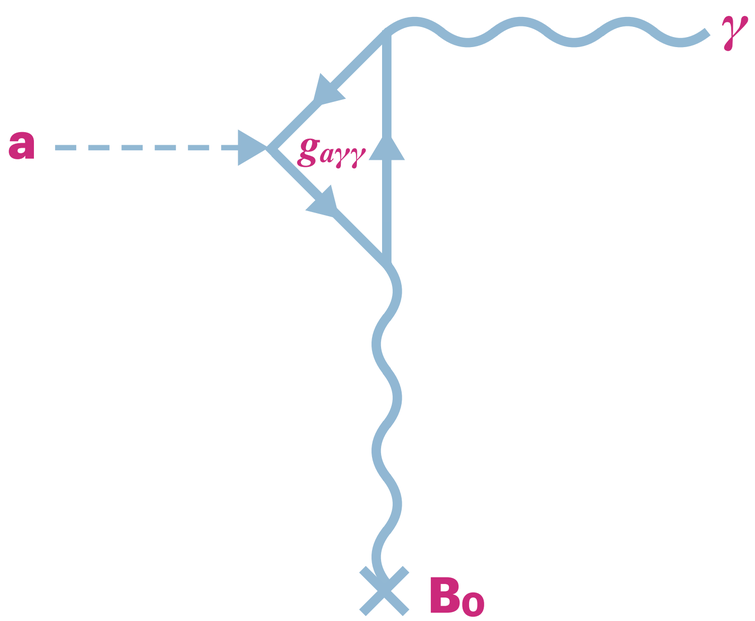
*Superconducting Nanowire Single Photon Detector

Outline

- Axion Motivation
- Haloscopes
- DPHaSE Concept
- Powder Characterization

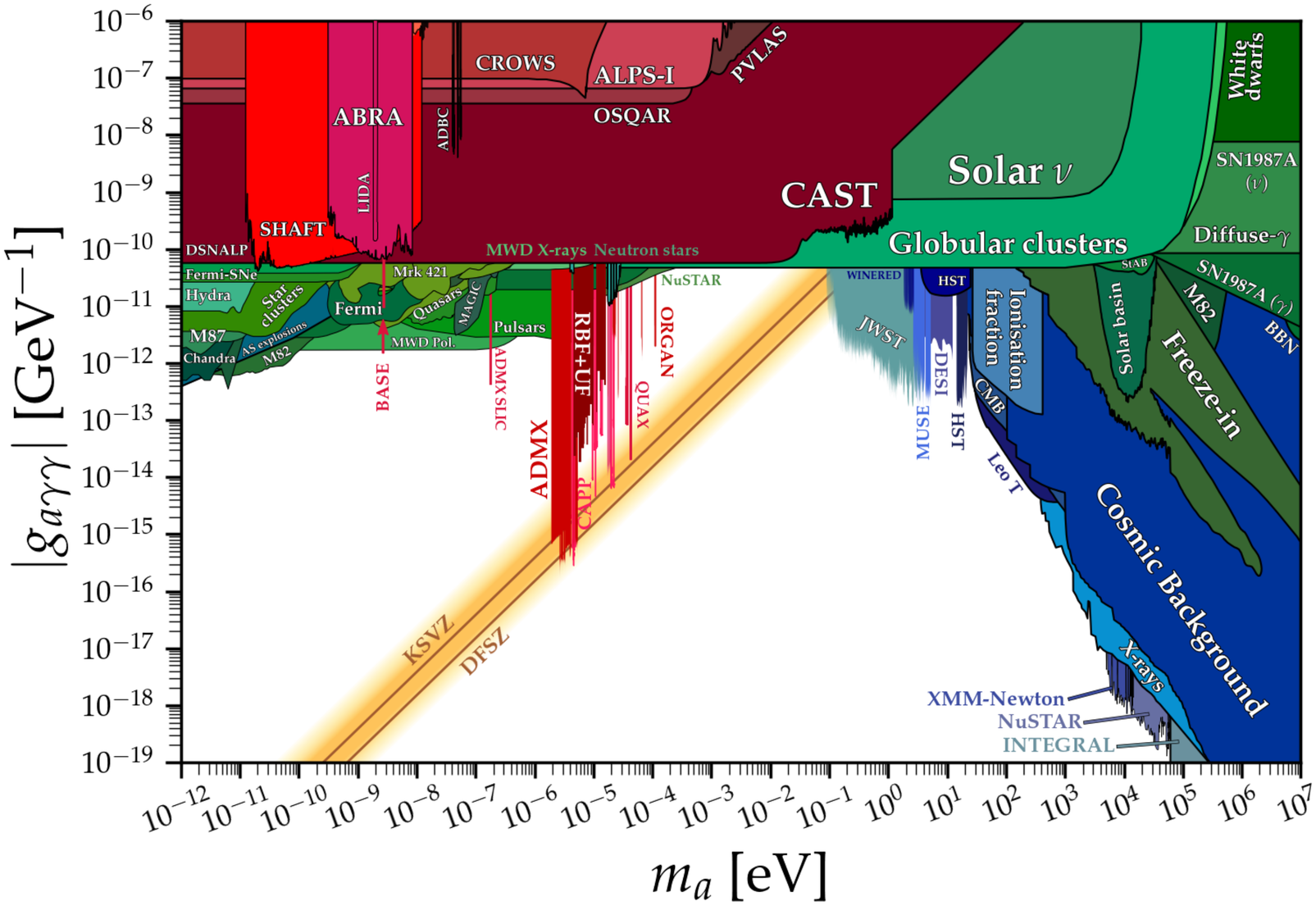
Axion Motivation

- The QCD Axion was proposed as a solution to the strong CP problem
- Axions weakly couple to photons in a strong magnetic field
- Axions are a promising dark matter candidate!



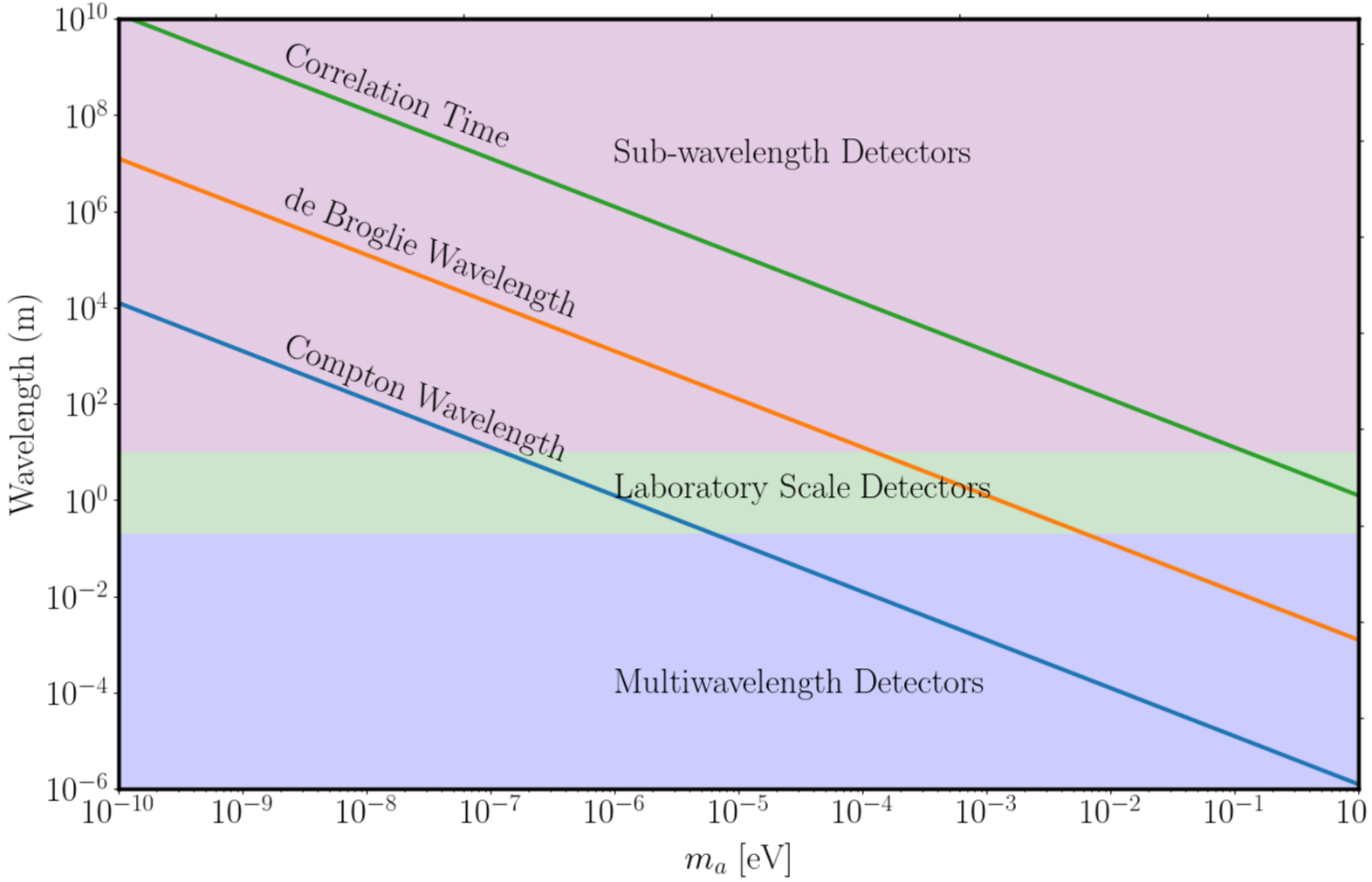
Inverse Primakoff Effect

Current Axion Limits



credit: O'Hare

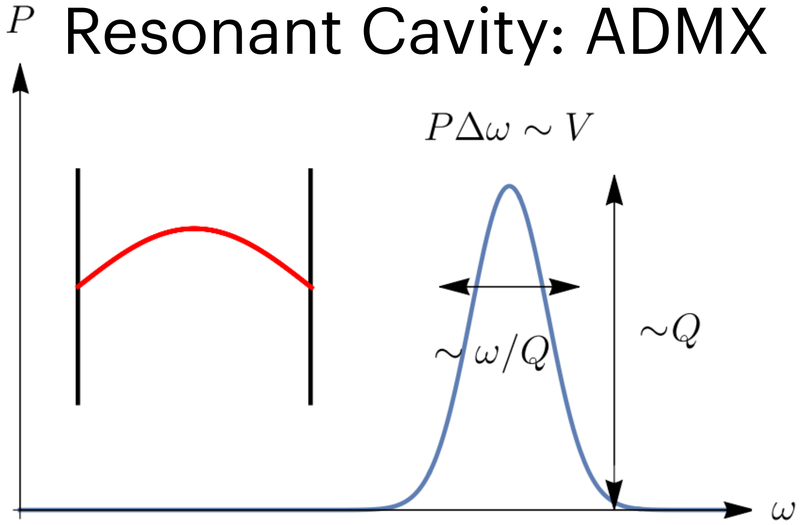
Detector Scale



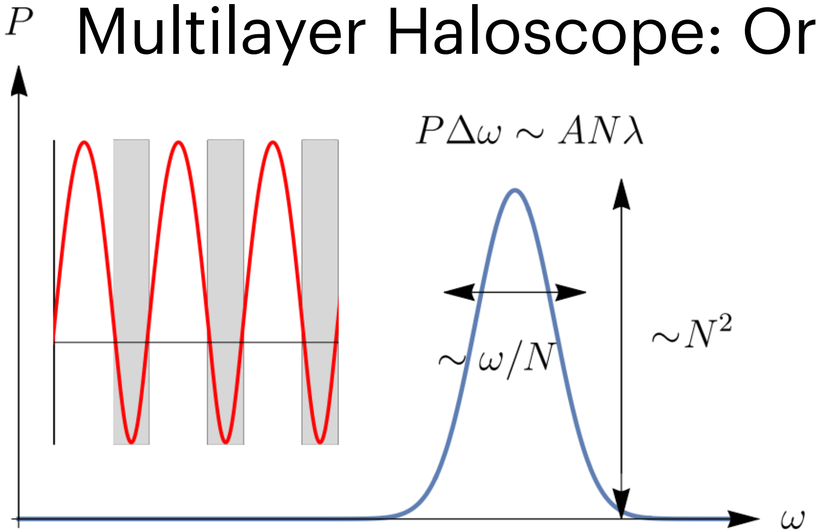
Haloscopes

Haloscope Power

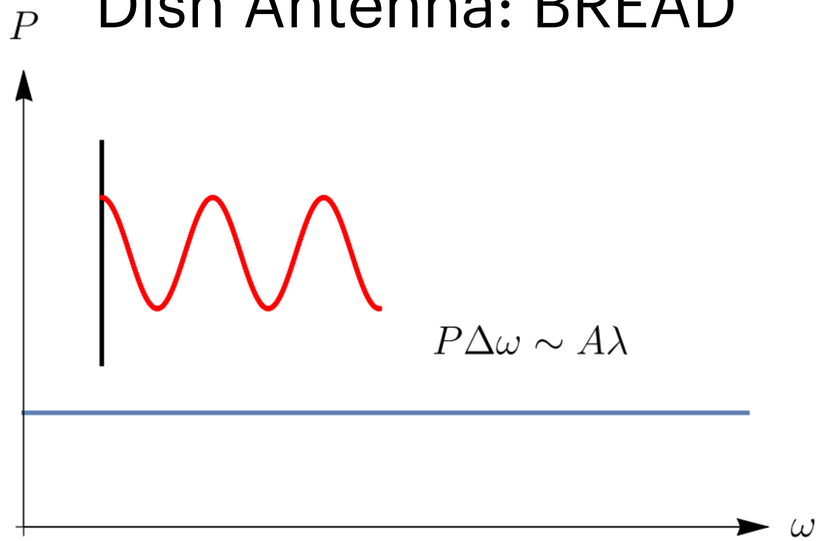
Resonant Cavity: ADMX



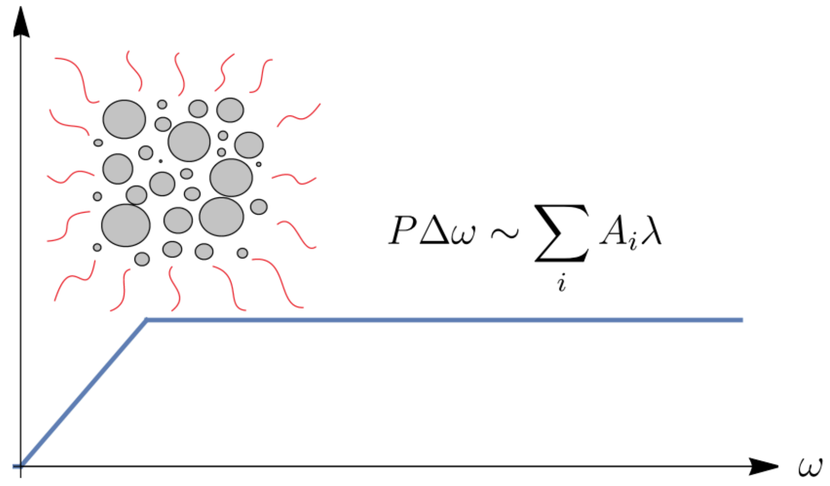
Multilayer Haloscope: Orpheus



Dish Antenna: BREAD



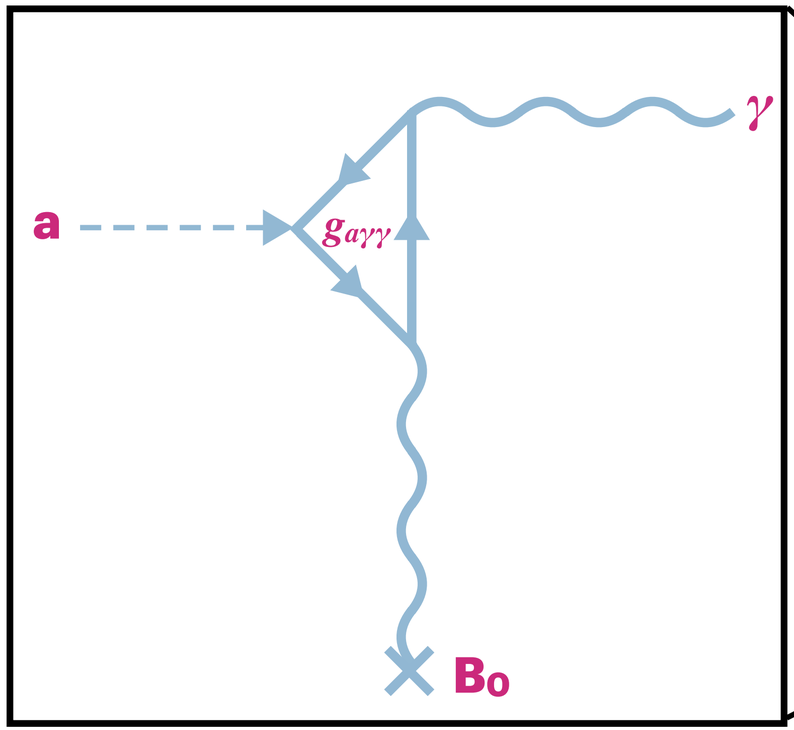
Disordered Dielectric: DPHASE

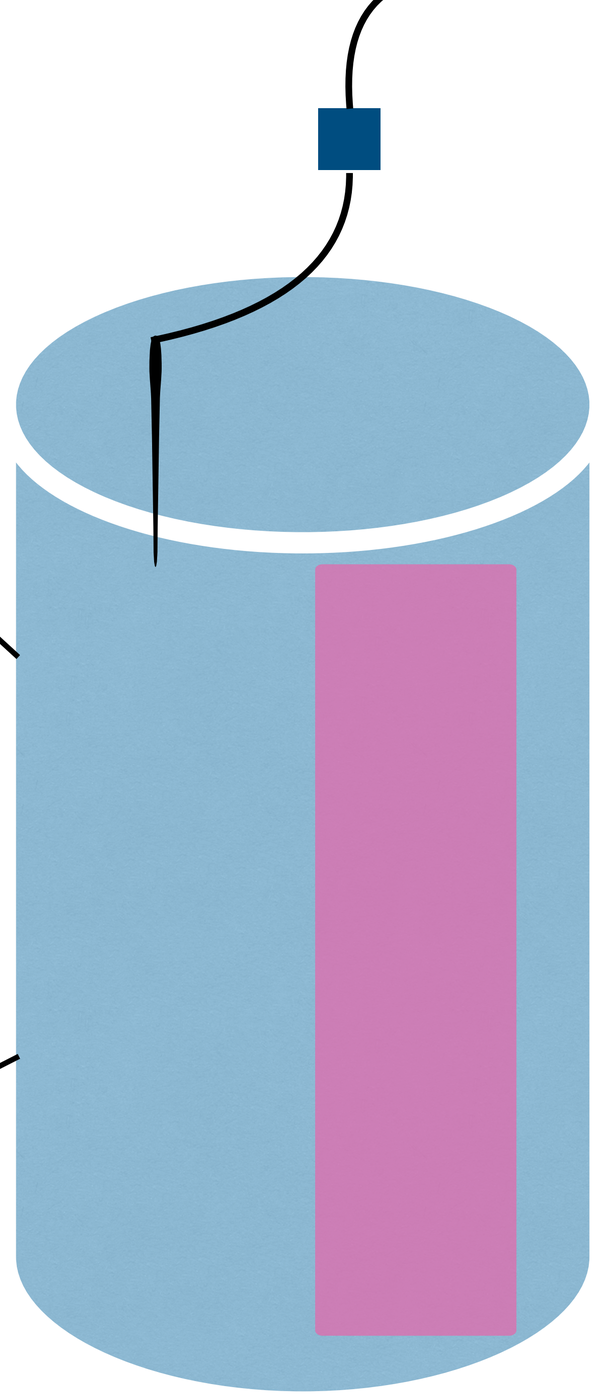


credit: Koppell et al. 10.1103

Resonant Cavity Haloscope

- ★ Cavity
- ★ Rod
- ★ Antenna
- ★ Amplifiers





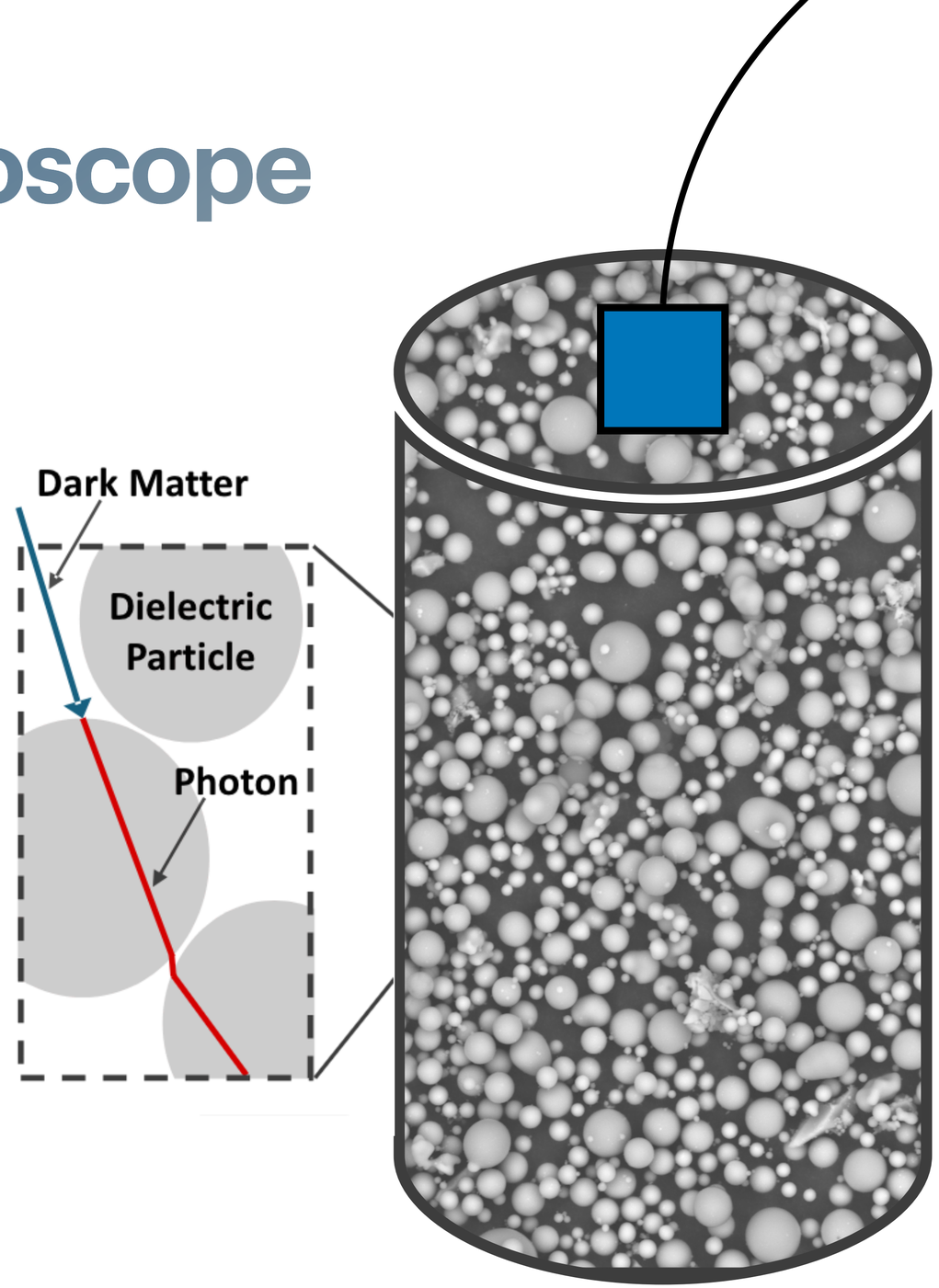
DPHaSE Concept

Disordered Dielectric Haloscope

- ★ Dielectric Powder
- ★ Superconducting Nanowire

  Single Photon Detector

  (SNSPD)

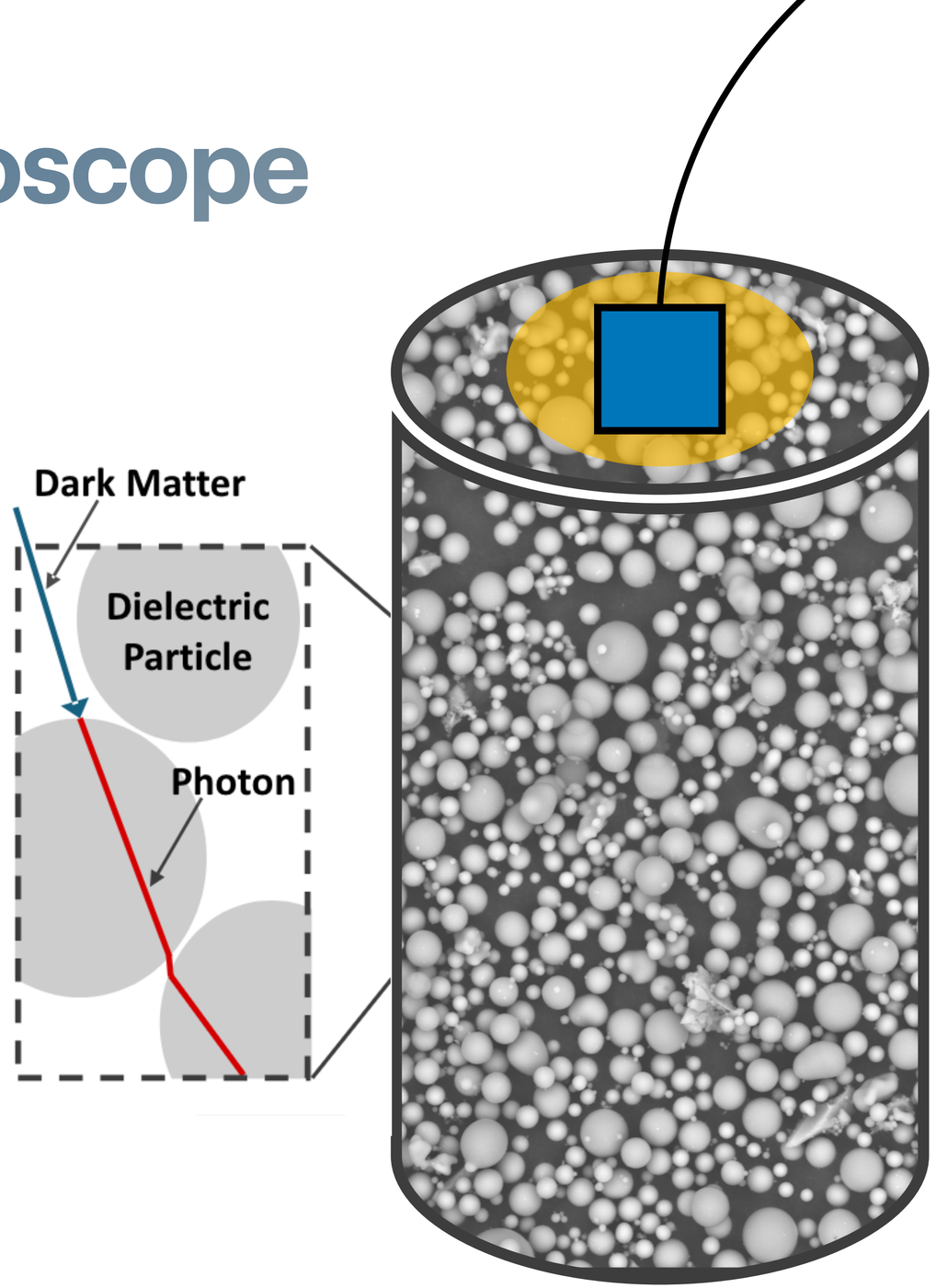


Disordered Dielectric Haloscope

$$P \propto \frac{E_0^2}{2} V_{\text{eff}}$$

$$V_{\text{eff}} \approx \ell_d A_{\text{sensor}}$$

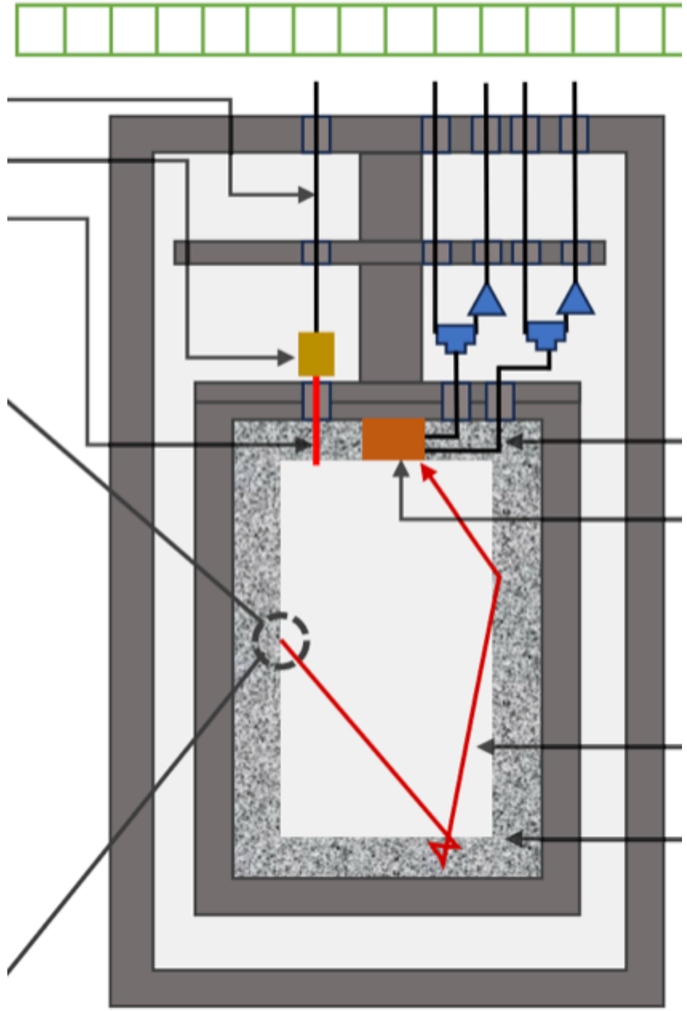
$$\ell_d = (\bar{\ell}_a \ell_s^* / 3)^{1/2}$$



Photon Collection Chamber

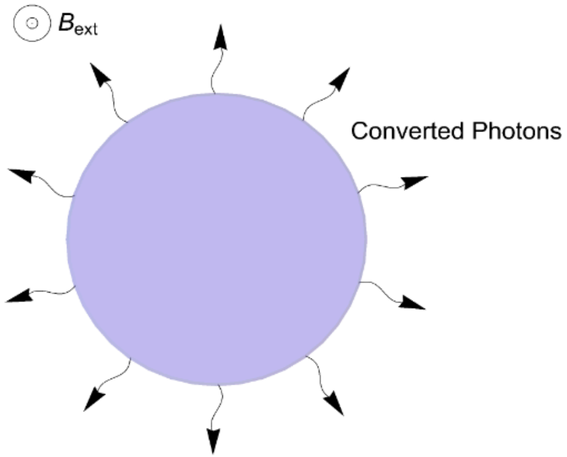
$$P \propto \frac{E_0^2}{2} V_{\text{eff}}$$

$$V_{\text{eff}} \approx \frac{1}{4} \bar{\ell}_a A_{\text{sensor}}$$

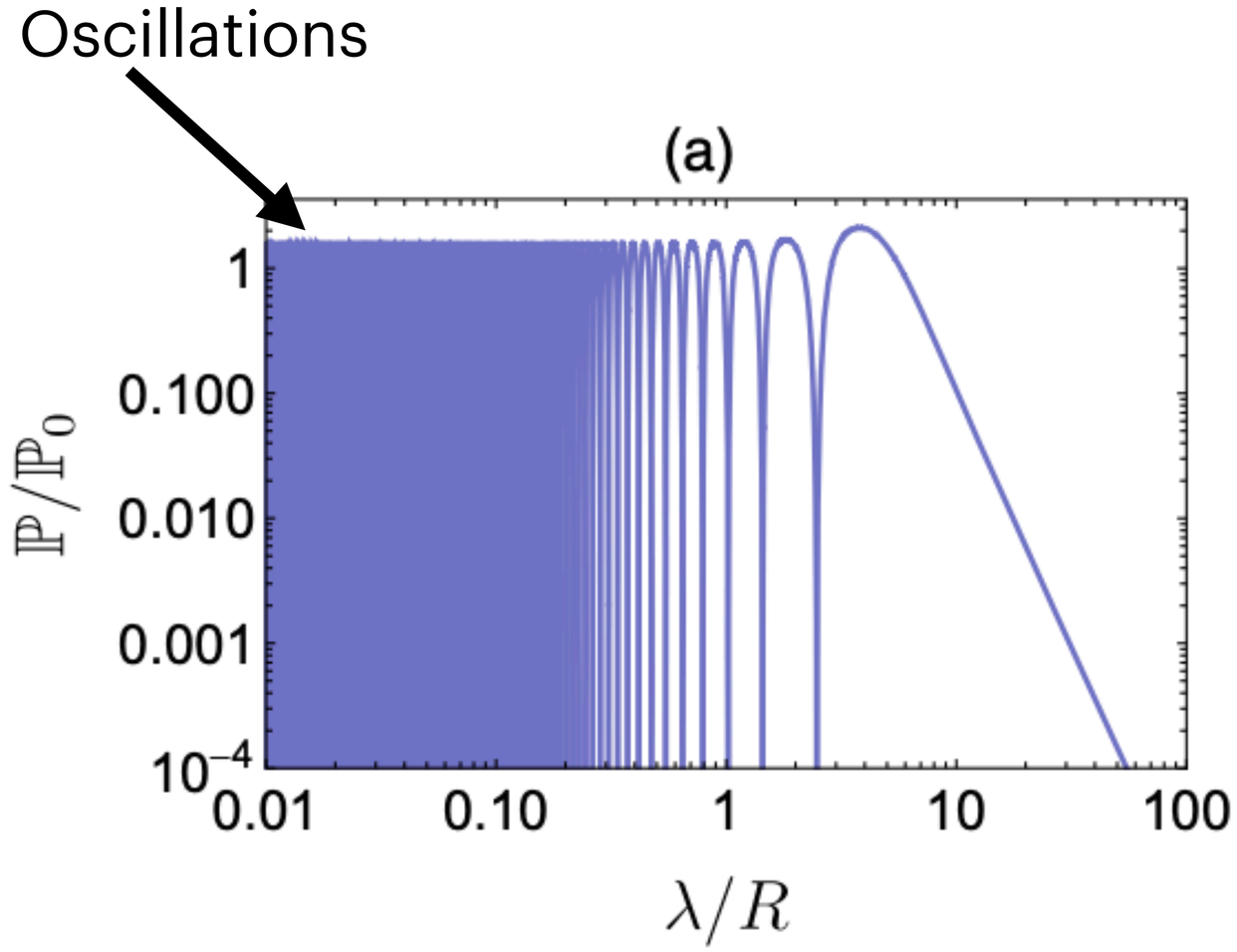


credit: Koppell et al. 10.1103

Single Sphere Conversion

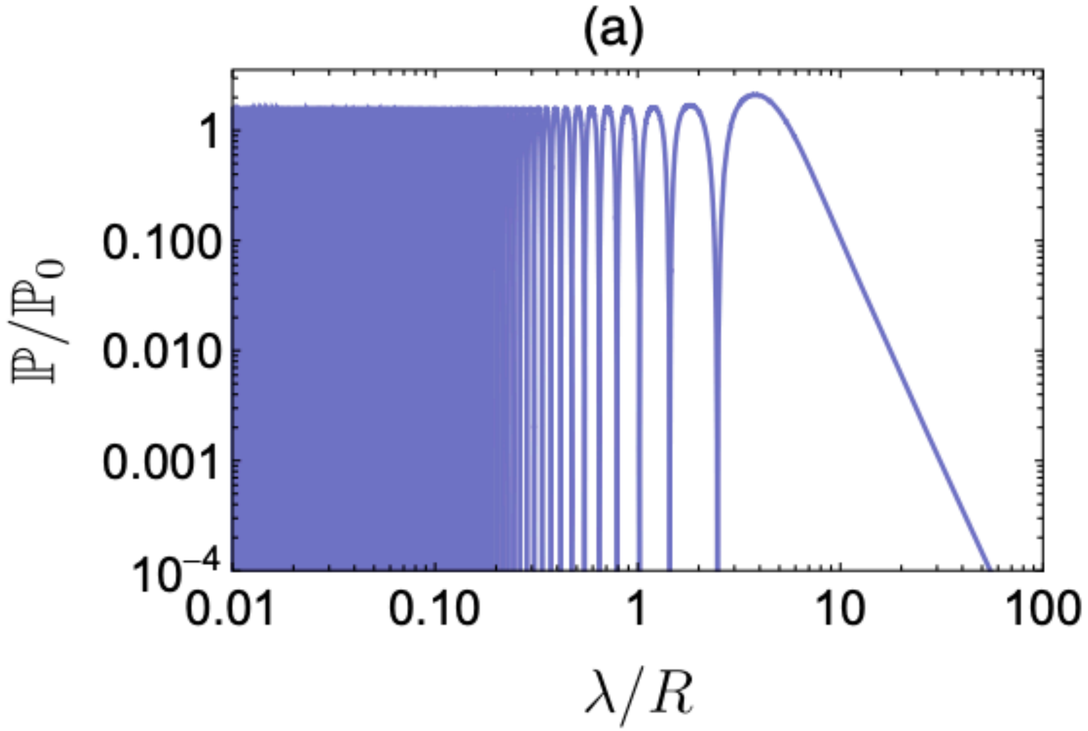


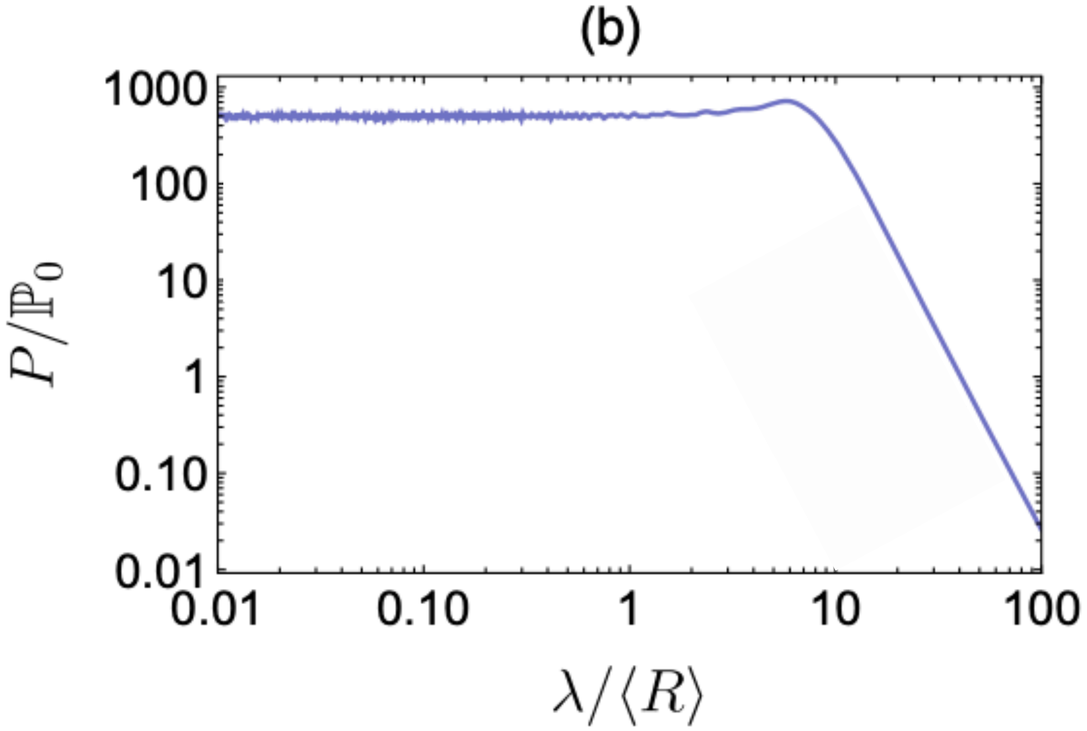
$$P \propto \frac{E_0^2}{2} F(n) A_{\text{sphere}}$$



credit: Koppell et al. 10.1103

Conversion on Many Spheres





$$P \propto \frac{E_0^2}{2} F(n) A_{\text{sphere}}$$

$$P \propto \frac{E_0^2}{2} F(n) \langle A_{\text{sphere}} \rangle$$

credit: Koppell et al. 10.1103

DPHaSE Experimental Projection

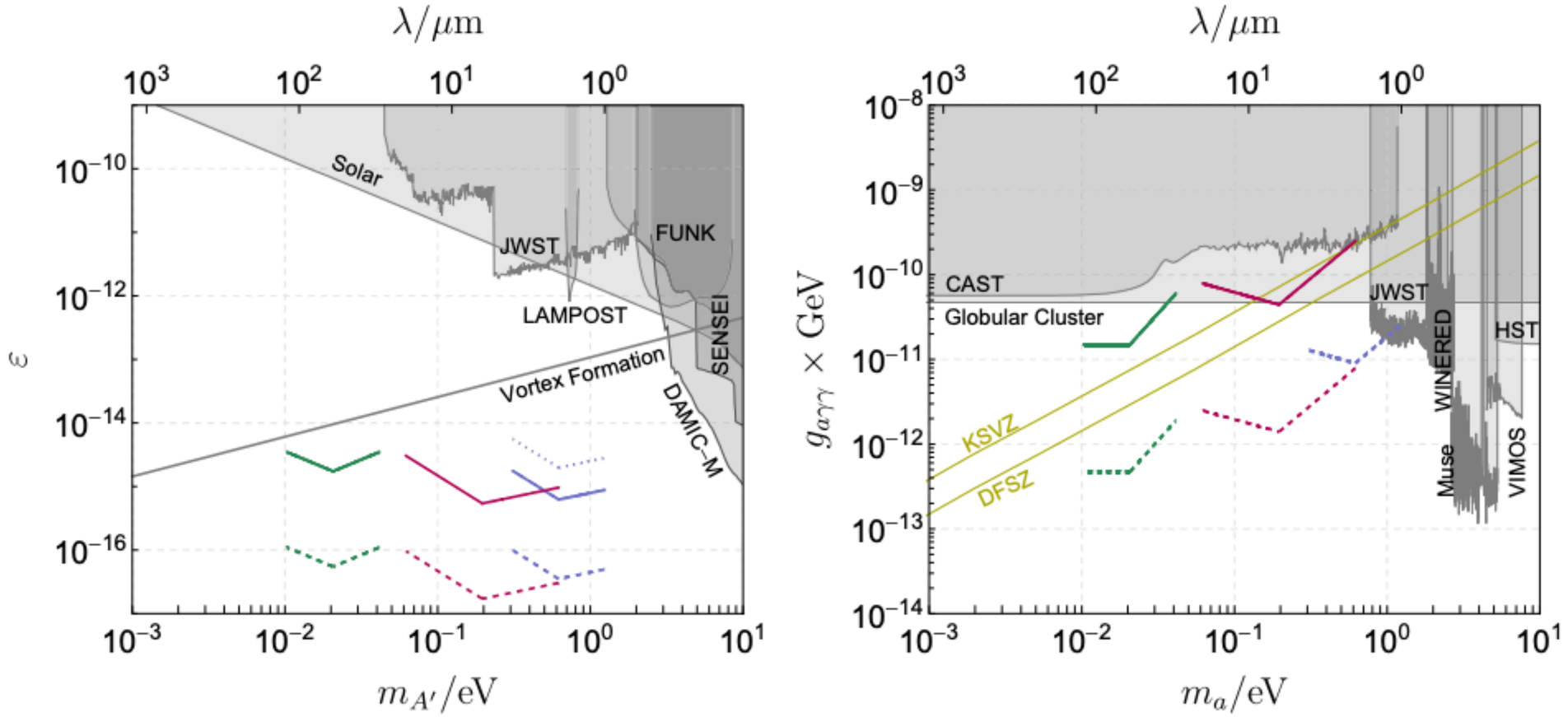
Projected parameters for DPHaSE:

Currently targeting Band A

	Parameter	Band A	Band B	Band C
	Bandwidth	1–4 μm [122]	2–20 μm [123]	30–120 μm [124]
	Material	Alumina	KBr/NaCl	HR-Si
	n	1.7	1.5	3.4
	ℓ_a	10 m [118]	100 m [123]	1.6–6.3 m [124]
	$\langle R \rangle$	0.82 μm	2.11 μm	20.0 μm
Pathfinder	A_{sensor}	1 mm^2		
	V_{eff}	5 cm^3	...	...
	Background rate	10^{-5} Hz		
Phase I	A_{sensor}	1 cm^2	1 cm^2	1 cm^2
	V_{eff}	500 cm^3	5000 cm^3	80–320 cm^3
	Background rate	10^{-3} Hz	10^{-2} Hz	10^{-2} Hz
Phase II	A_{sensor}	10 cm^2	10 cm^2	10 cm^2
	V_{eff}	5000 cm^3	50 000 cm^3	800–3200 cm^3
	Background rate	10^{-6} Hz	10^{-6} Hz	10^{-6} Hz
	Sensor efficiency	85%	50%	50%

credit: Koppell et al. 10.1103

DPHaSE Projected Sensitivity



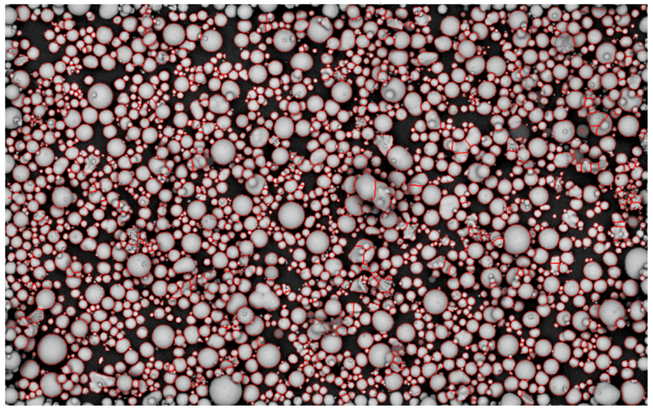
Where dotted line is for pathfinder and solid and dashed lines are for phase I and II respectively. The blue line corresponds with band A with a mean radius of 0.8um, magenta corresponds to band B with mean radius of 2um, and green corresponds to band C with mean radius of 20um.

credit: Koppell et al. 10.1103

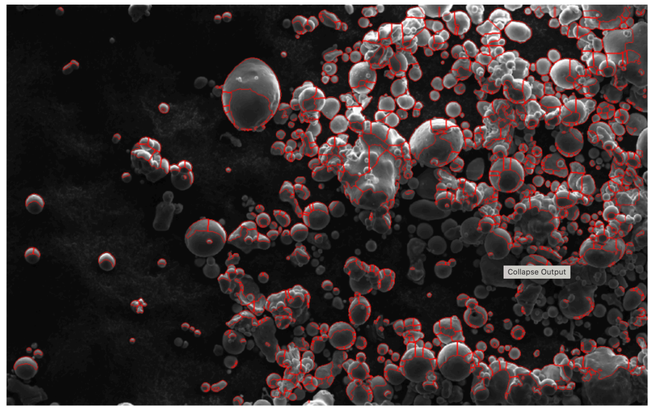
Powder Characterization

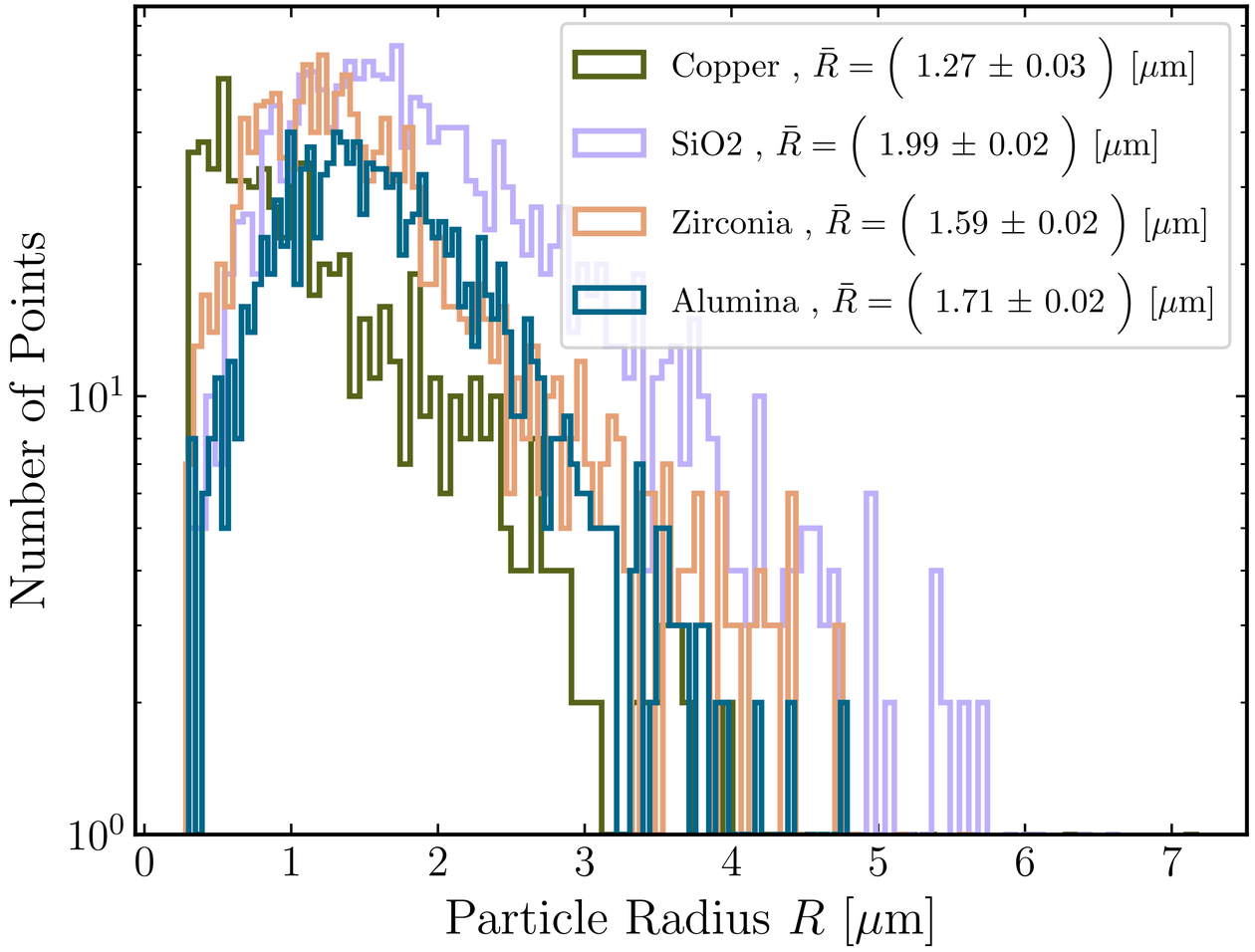
Radius Characterization

Silica



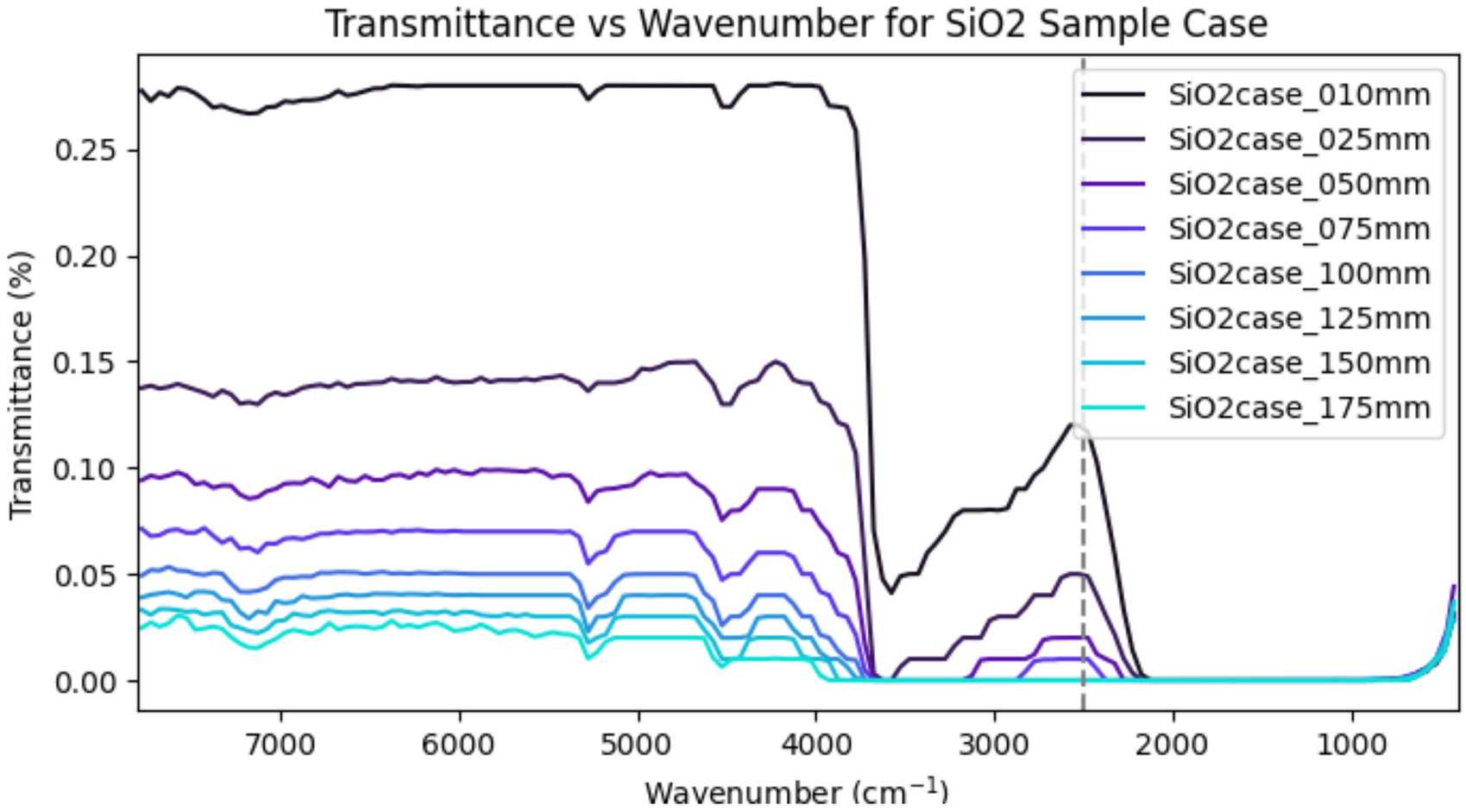
Copper





credit: Creque-Sarbinowski

Characteristic Lengths

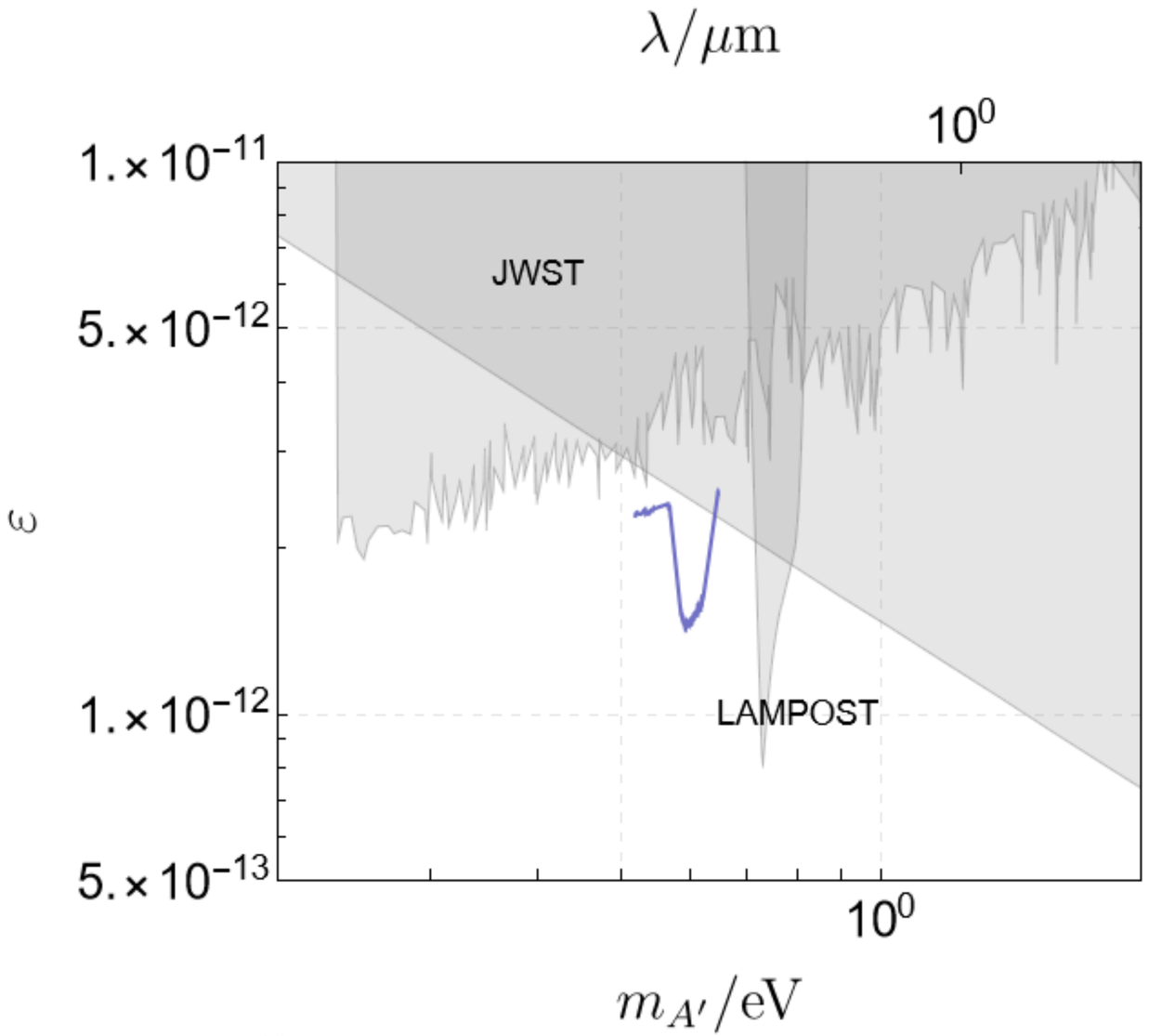


Projected Pathfinder Sensitivity

$$\ell_s^* = 10\mu\mathrm{m}$$

$$\overline{\ell_a} = 10\mathrm{m}$$

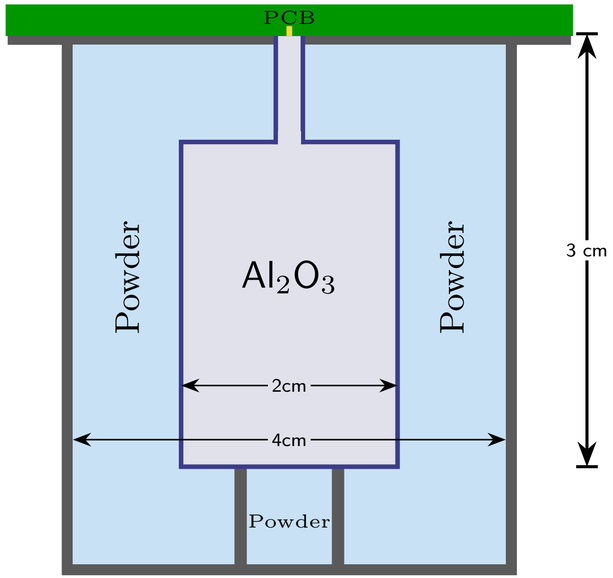
$$V_{\mathrm{eff}} = 2.5\mathrm{cm}^3$$

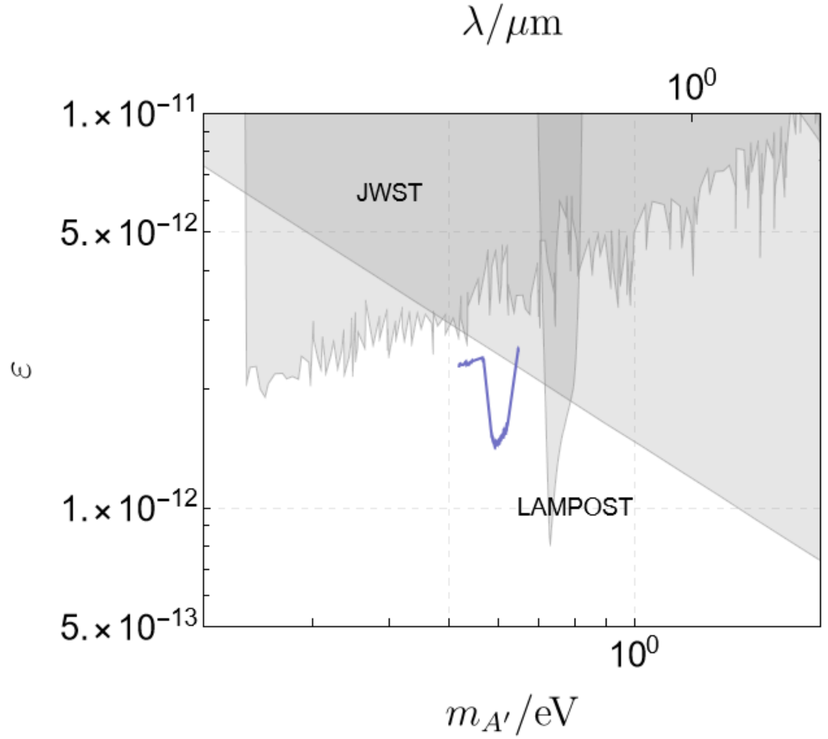


credit: Bittencourt

Status Summary and Next Steps

We’re searching for axions using a new technique with disordered dielectrics.





Next: Build the detector!

DPHaSE Collaborators



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PhD student
MIT



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University of Washington



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Pomona College



Otavio Bittencourt
PhD student
Perimeter Institute



Karl Berggren
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University of Washington



Masha Baryakhtar
Faculty
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Junwu Huang
Faculty
Perimeter Institute



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Max Planck Inst.



Nora Hoch
PhD student
MIT



Samuel Wong
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University of Washington

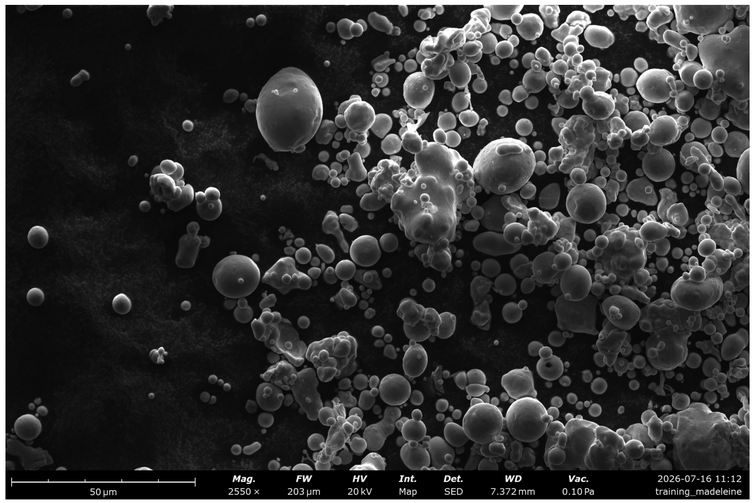


Ella Henry
PhD student
University of Washington

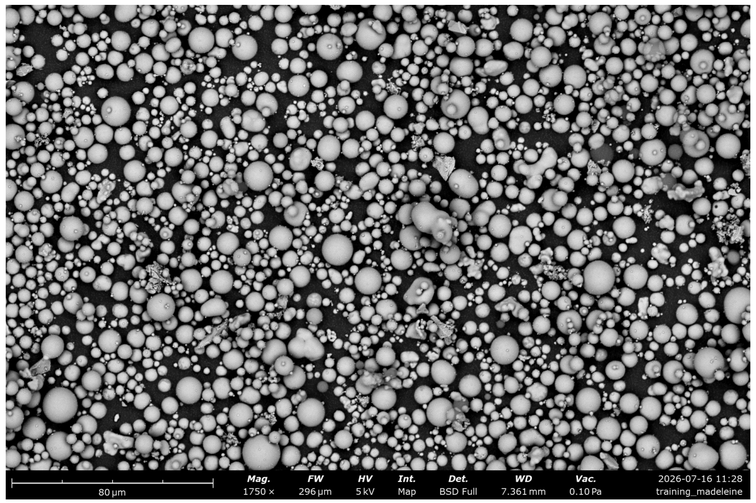
We thank Baskaran Ganapathy and Robin Kaiser for their insights into Anderson localization, Itay Bloch for providing SENSEI constraint data, and Aaron Chou, Giorgio Gratta, Gray Rybka, Dam Thanh Son, Andrew Sonnenschein, and Lindley Winslow for helpful discussions. We also thank Phoebe Ayers of the MIT Libraries for assistance with literature review and David Cyncynates and Ella Henry for comments on the manuscript. The COMSOL simulations in this work were performed using the MTL CAD server at MIT. The MIT coauthors acknowledge support for the initial stages of the work from the DOE under the QuantiSED program, Award No. DE-SC0019129. D. J. P. acknowledges support from the MathWorks Engineering Fellowship. M. B. and J. H. thank the KITP for hospitality during the completion of this work; this research was supported in part by Grant No. NSF PHY-2309135 to the Kavli Institute for Theoretical Physics. M. B. is supported by the U.S. Department of Energy Office of Science under Award No. DE-SC0024375 and the Department of Physics and College of Arts and Science at the University of Washington. M. B. is also grateful for the hospitality of Perimeter Institute, where part of this work was carried out. O. B. and J. H. are supported by the Natural Sciences and Engineering Research Council of Canada through a Discovery Grant. Research at Perimeter Institute is supported in part by the Government of Canada through the Department of Innovation, Science and Economic Development and by the Province of Ontario through the Ministry of Colleges and Universities. This work was also supported by a grant from the Simons Foundation (Grant No. 1034867, Dittrich). This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics, under Award No. DE-SC0026237.

Radius Characterization

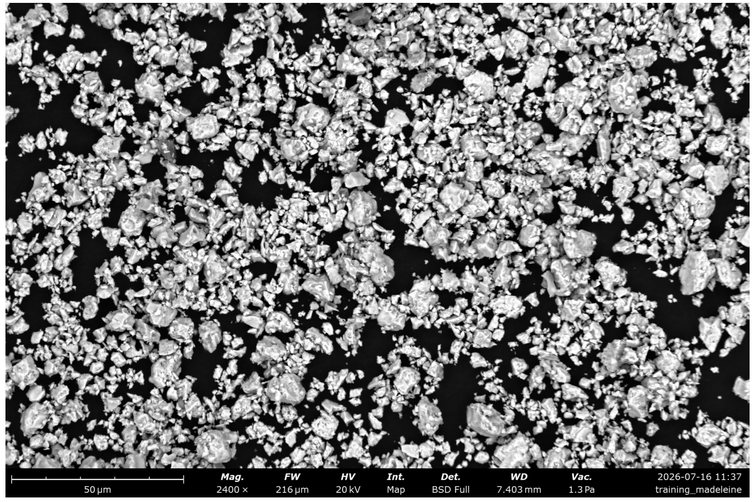
Copper



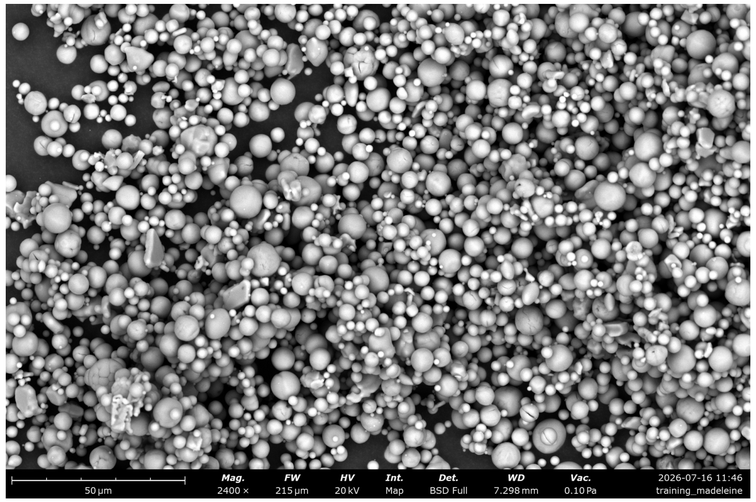
Silica



Zirconia



Alumina



Characteristic Lengths

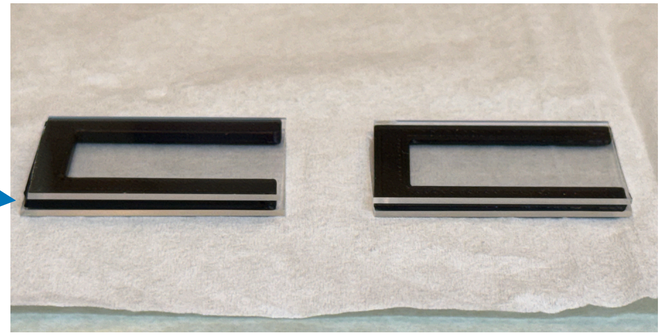
$$\mathbb{T} = e^{-t/\ell_s} + \mathbb{T}_0 \left(\frac{t/\ell_s^*}{2z_0 - t/\ell_s^*} e^{-t/\ell_s} + \frac{1+z_0}{2z_0 - t/\ell_s^*} (1 - e^{-t/\ell_s}) \right)$$

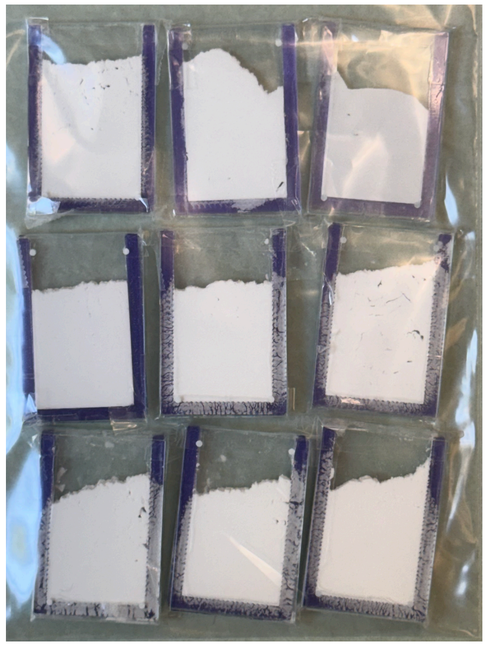
$$\frac{\ell_s^*}{\overline{\ell}_a} = \frac{3(1-\mathbb{R}_\infty)^2}{16\mathbb{R}_\infty^2}$$

credit: Koppell et al. 10.1103

Characteristic Lengths

- Sample case consisting of glass slides with a 3D printed spacer
- Tested eight thicknesses of samples:
  - 0.1, 0.25, 0.5, …, 2mm
- Followed DJ's technique:
  - Powder does not free fall due to gravity
  - Powder moves when strongly shaken

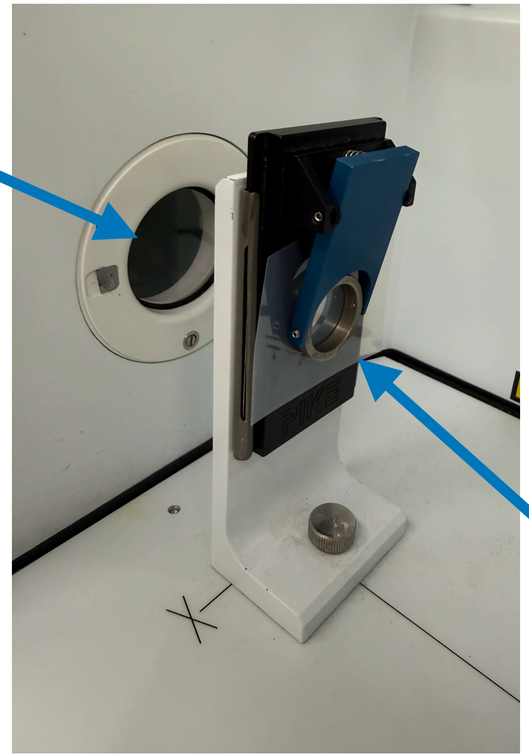




Characteristic Lengths

Fourier Transform Infrared Spectrometer (FTIR)

IR beam enters through window







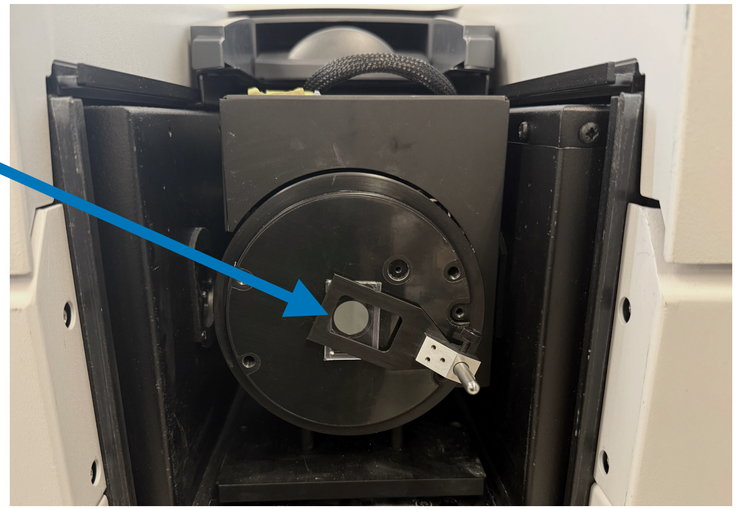
IR beam passes through sample and continues to detector

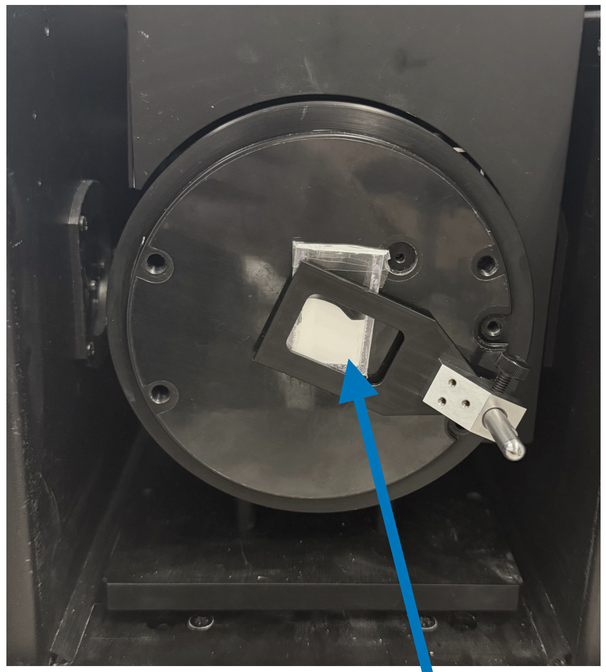
Characteristic Lengths

Diffuse Reflectance Integrating Sphere



IR beam enters through window



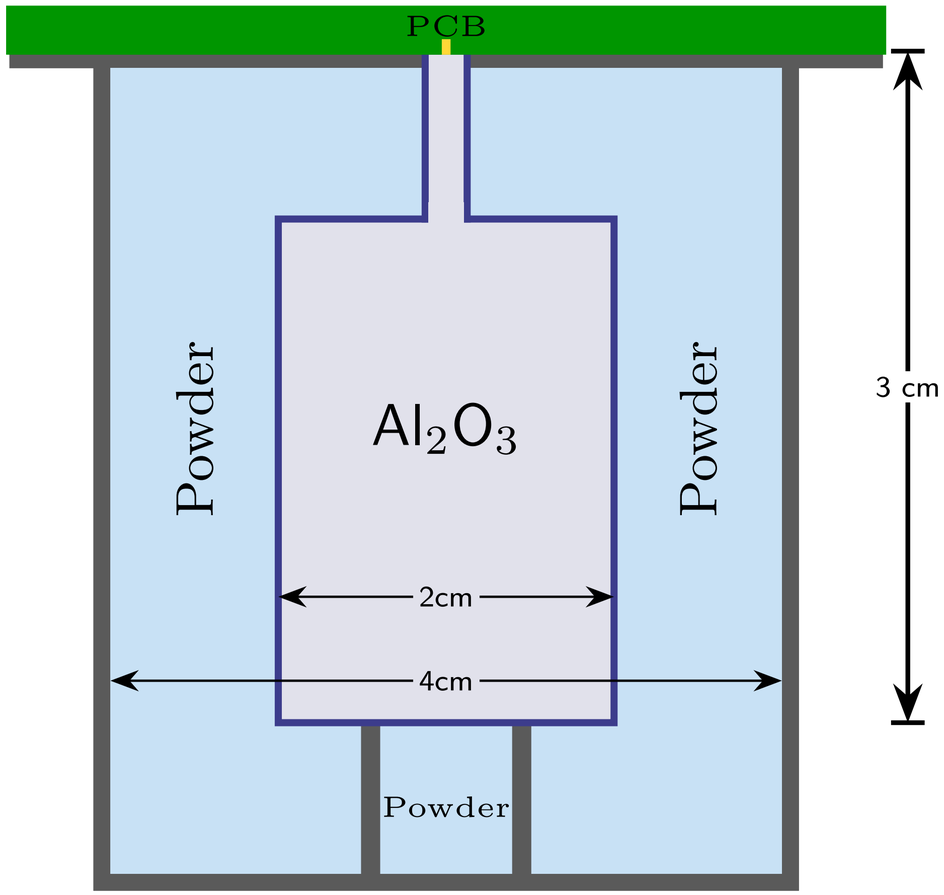


IR beam reflects off powder and continues to integrating sphere

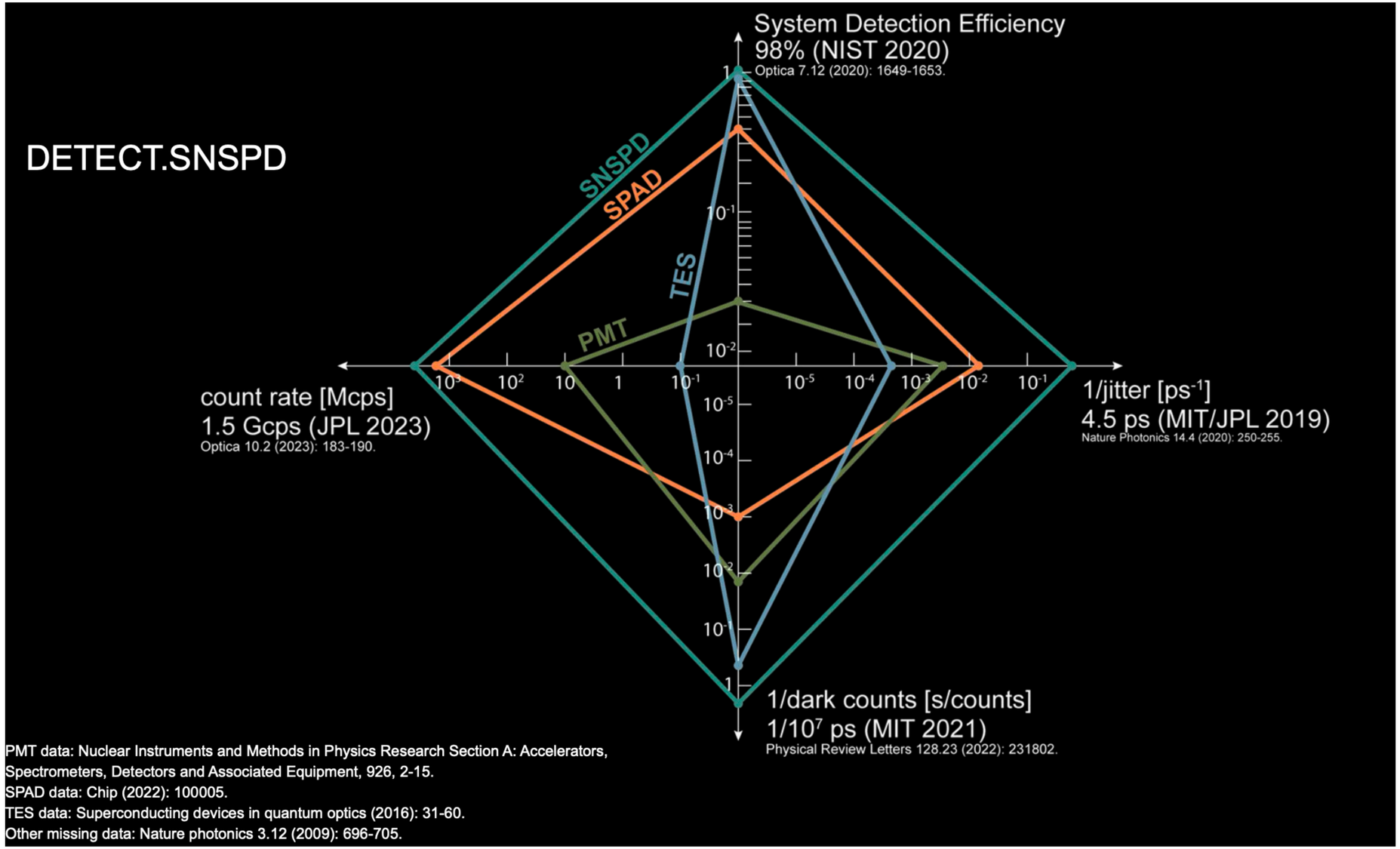
Detector Design

Either:

- ~~Powder suspended in epoxy~~
- Powder Box with Transparent walls
  - ~~Plastic: PTFE, FEP, PEN~~
  - ~~Glass~~ or Sapphire



Single Photon Detectors



credit: Berggren

Grinding Sapphire!

