BREAD COLLABORATION

Dielectric Enhancement: Concept

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&

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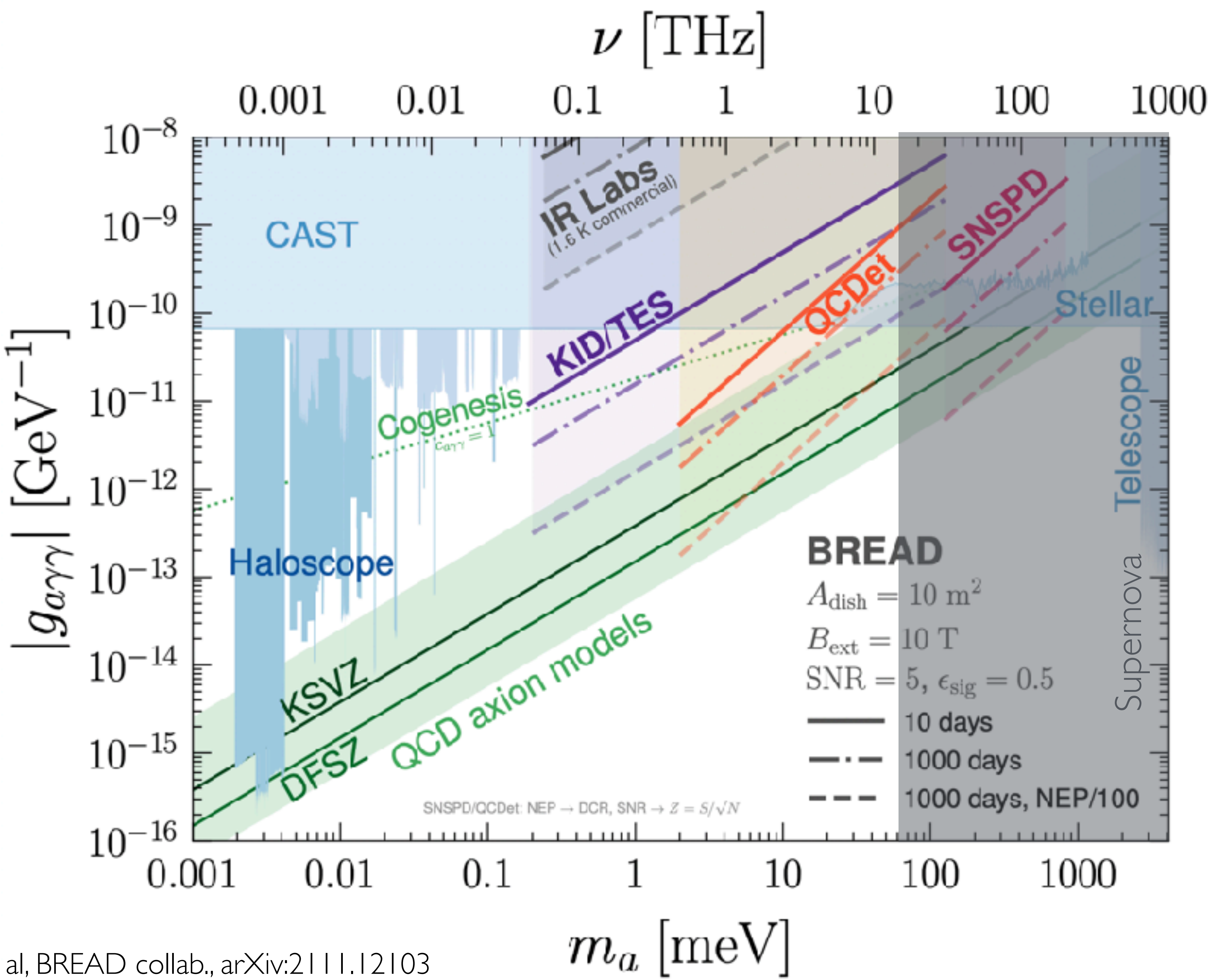
October 5, 2023

Motivation: Reaching the *QCD* Axion



Liu et al, BREAD collab., arXiv:2111.12103

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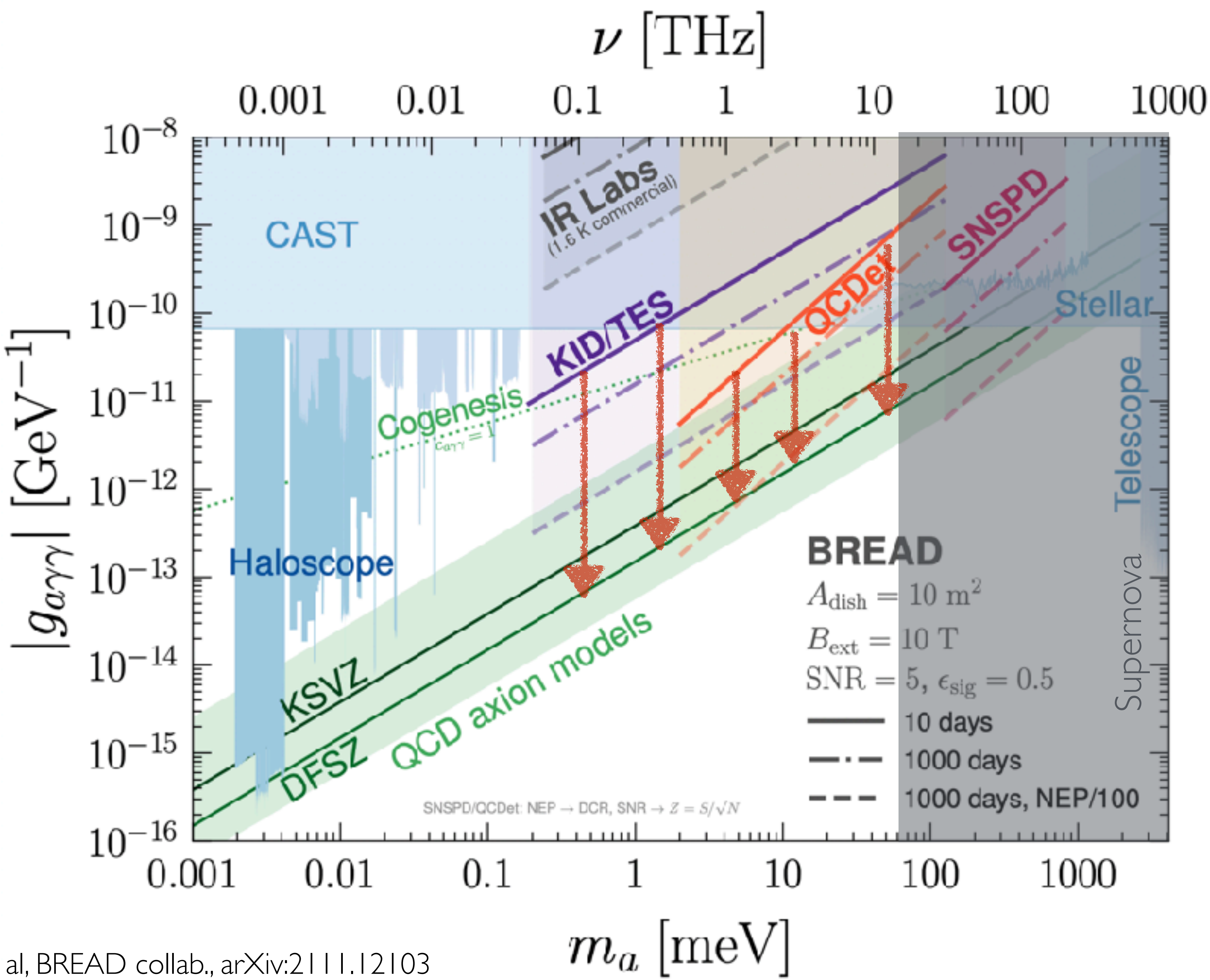
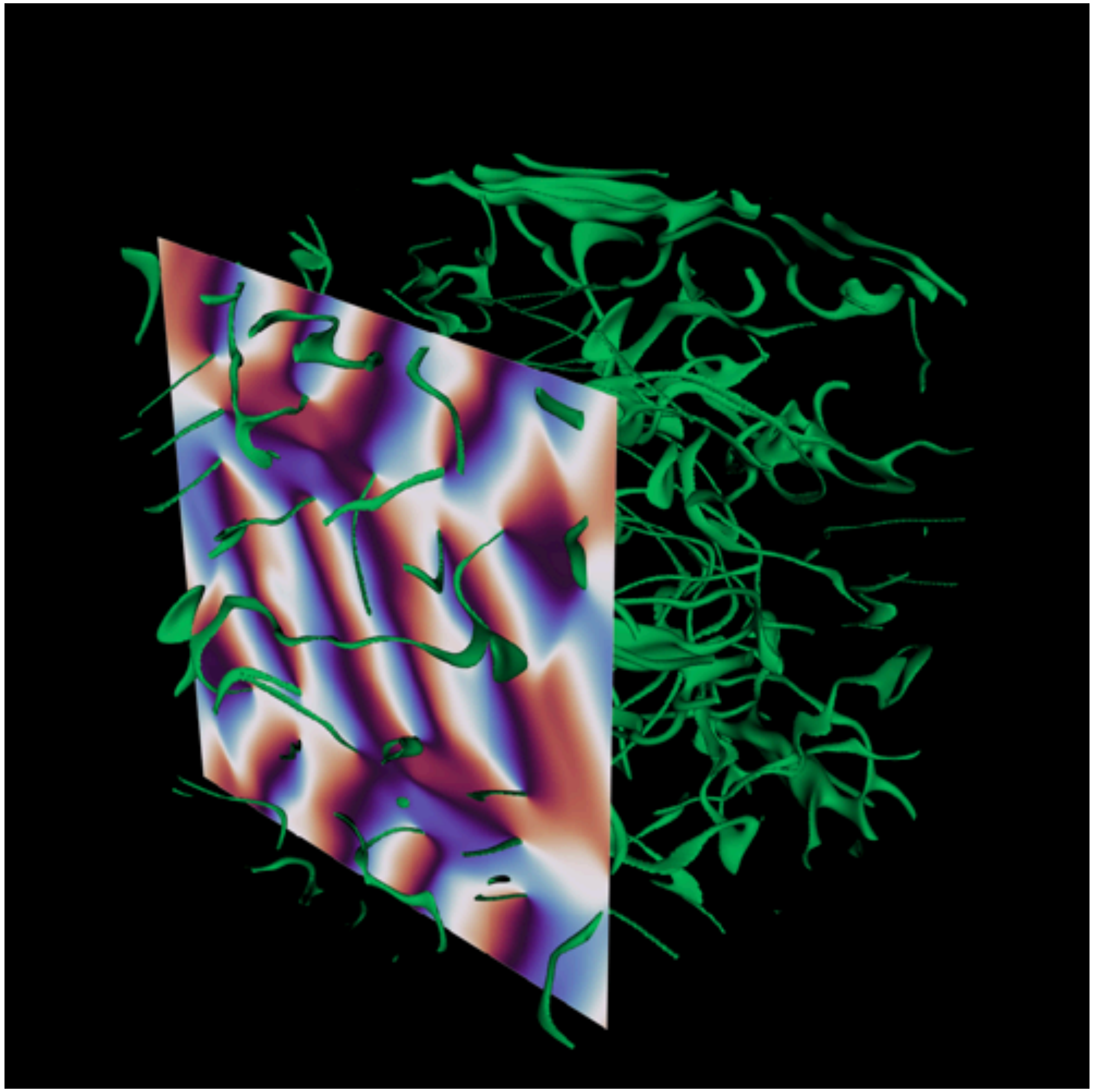


Liu et al, BREAD collab., arXiv:2111.12103

Extra Motivation: Difficulties with Dark Photon Dark Matter

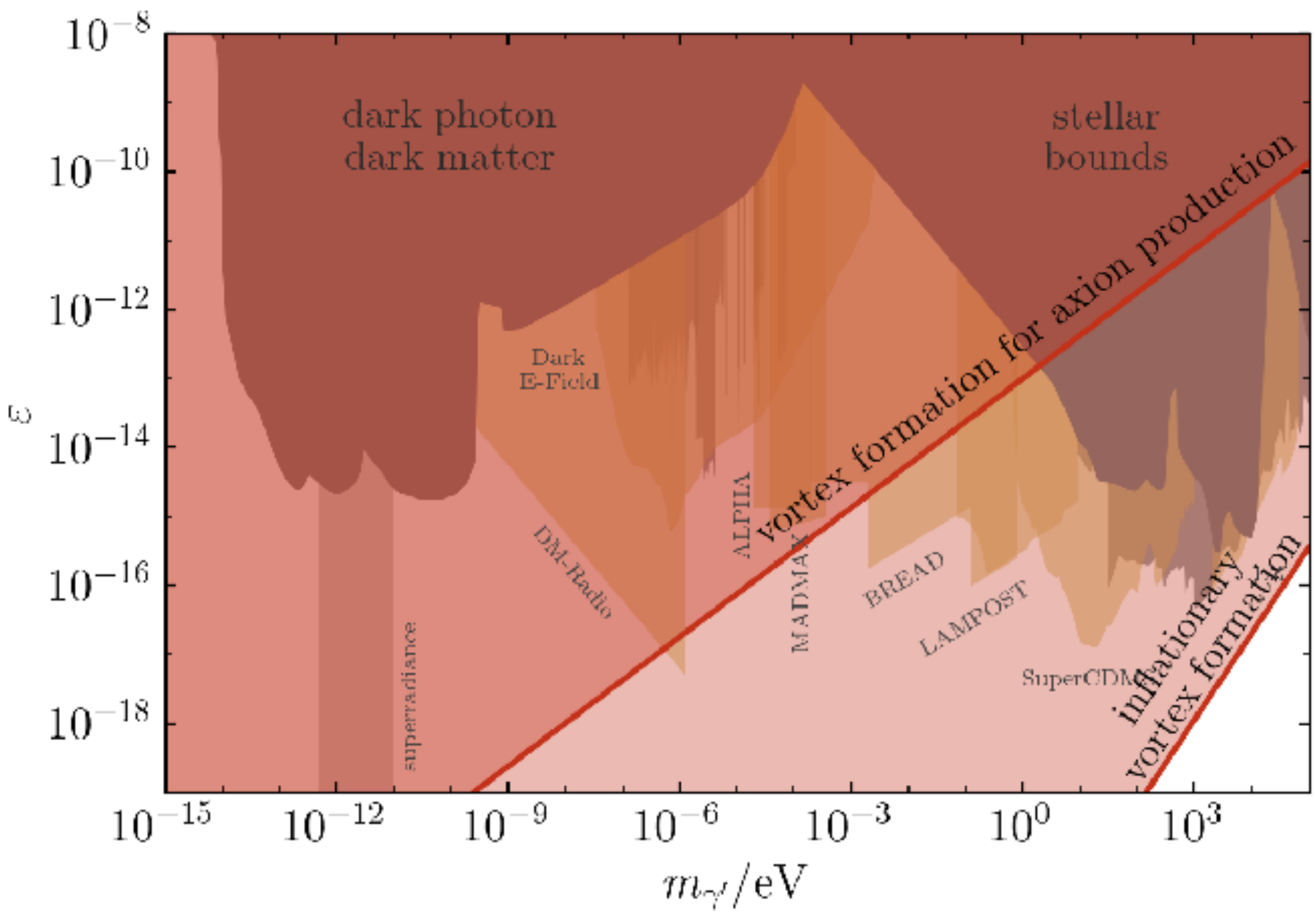
- Dark photon dark matter production can lead to the formation of vortices.
- At high density, energy stored in dark photon dark matter is converted into a large number of vortex strings, destroying the coherent dark photon dark matter field.
- Similar dynamics to type II superconductors
- Can only be avoided with very weak couplings (undetectable)



Will East & Junwu Huang **arXiv:2206.12432**

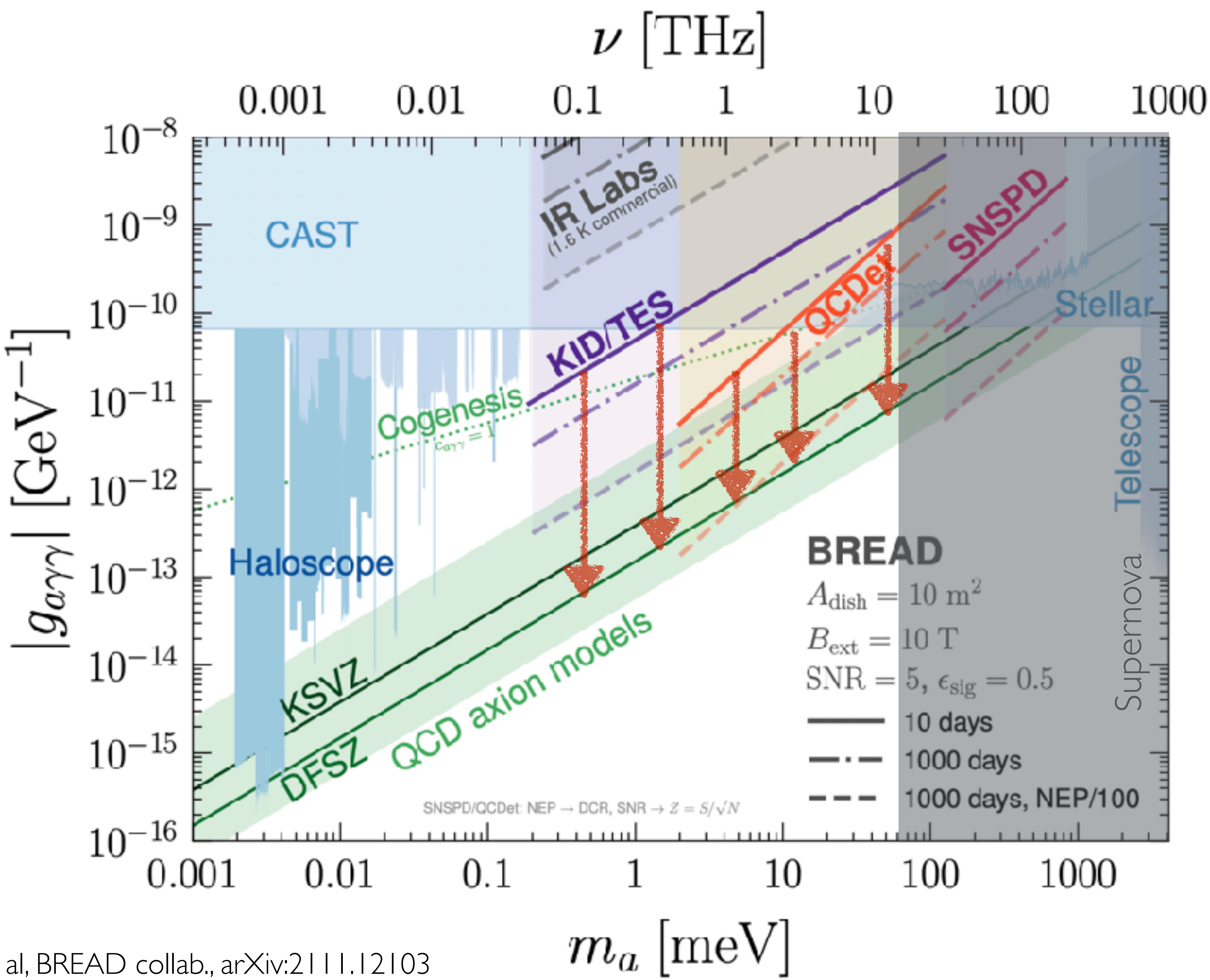
Extra Motivation: Difficulties with Dark Photon Dark Matter

- `Standard' mechanisms do not produce dark photon dark matter that can be reached by experiment
- Assuming dark matter exists in the early universe, energy density is large enough to produce vortices and destroy dark matter for a large range of parameters, even with new production models



David Cyncynates and Zachary Weiner, **arXiv:23xx.xxxxx**

Goal: Increase Signal for Fixed Magnet Volume



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Dielectric Enhancement

Dielectric Haloscope Proposal (Phys. Rev. Lett. 118, 091801 (2017))

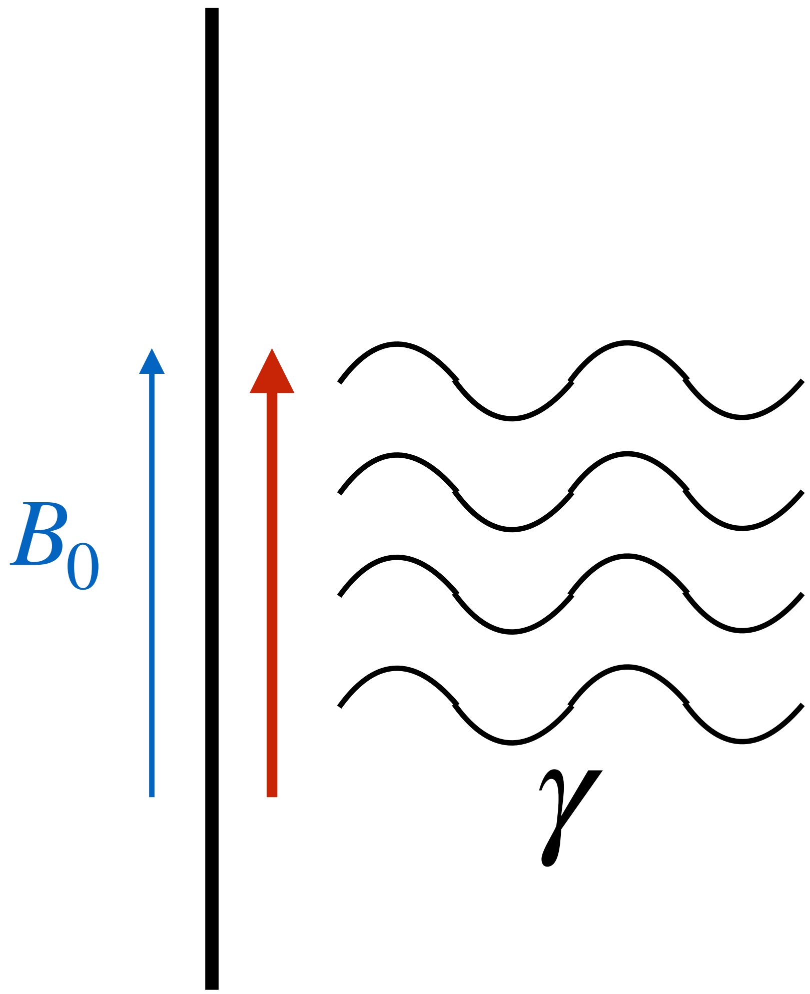
MADMAX Collaboration White Paper (Eur. Phys. J. C (2019) 79: 186)

MB, J. Huang, R. Lasenby, PRD 2018

Cervantes, Kimes, Mohapatra, Ottens, Rybka 2019

Conducting surface

Dish Antenna idea



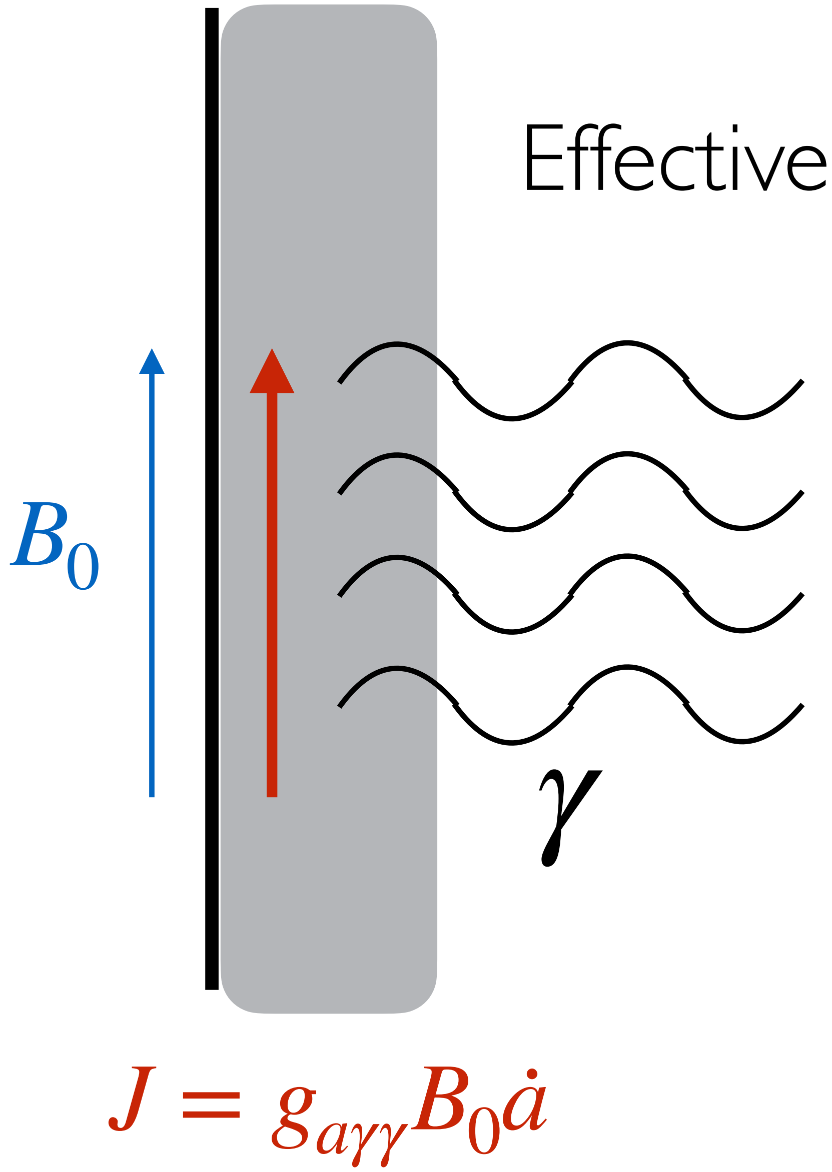
$$J = g_{a\gamma\gamma} B_0 \dot{a}$$

Horns et al JCAP 04 (2013) 016

Conducting surface

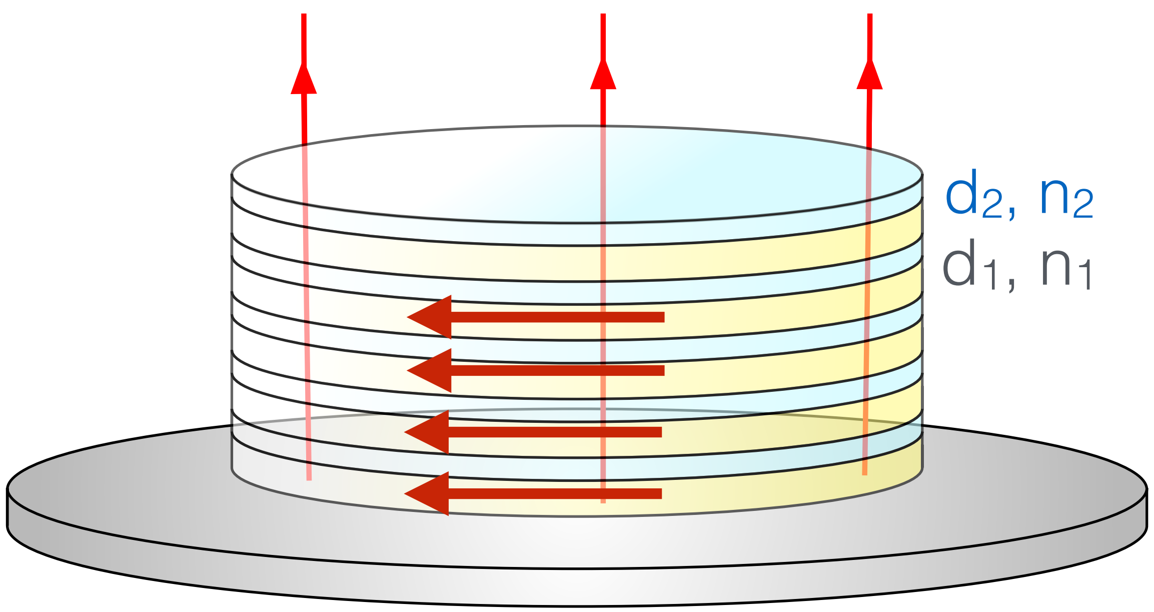
Dish Antenna idea

Effective volume: $V = \lambda \cdot \text{Area}$

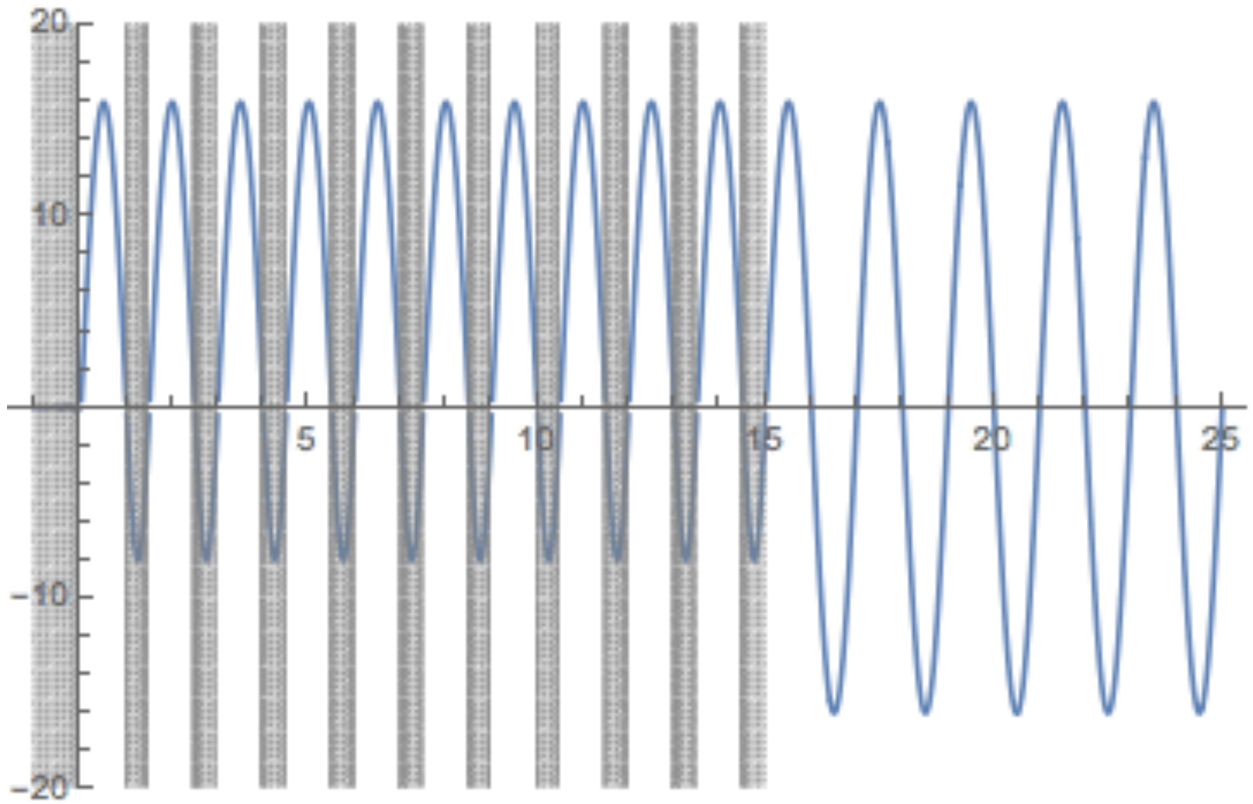


Horns et al JCAP 04 (2013) 016

Coherent enhancement

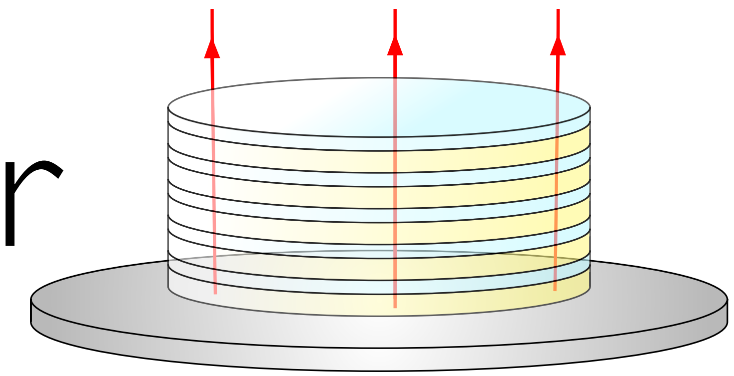


$$\omega = \frac{\pi}{n_1 d_1} = \frac{\pi}{n_2 d_2}$$



MB, J. Huang, R. Lasenby, PRD 2018

Converted power

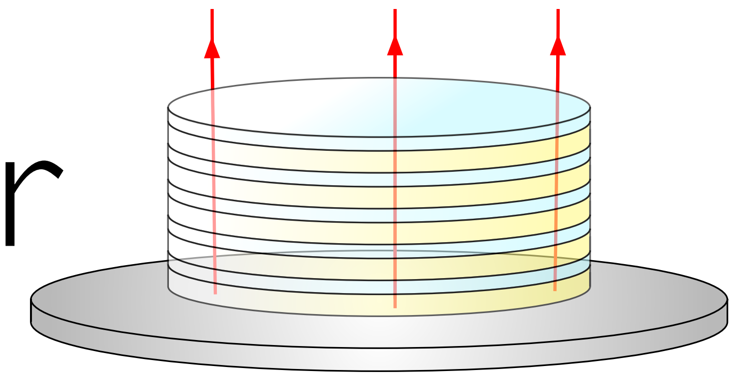


- For stack of N periods, with area A , converted power from DM at half-wave frequency is

$$\langle P_{\rm abs}\rangle \simeq g^2 B_0^2 \frac{\rho_{\rm DM}}{m^2} Q A N \left(\frac{1}{n_1}+\frac{1}{n_2}\right)\left(\frac{1}{n_2}-\frac{1}{n_1}\right)^2$$

MB, J. Huang, R. Lasenby, PRD 2018

Converted power



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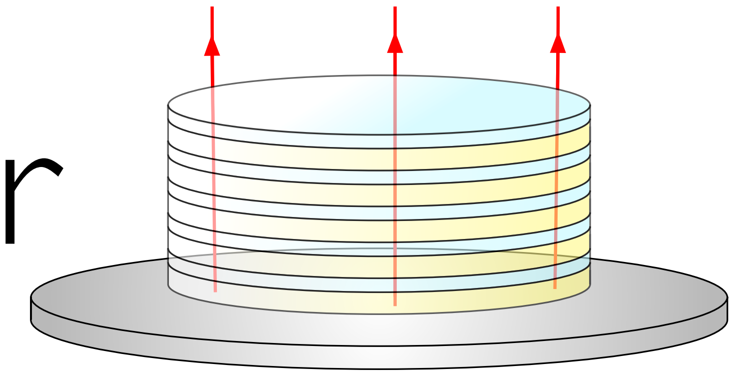
Increasing effective volume

Converted power



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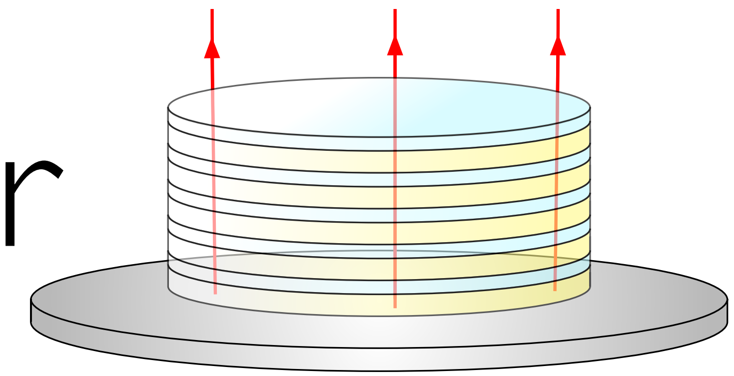
- For "open cavity", $Q \propto N$

Helps beat down noise

MB, J. Huang, R. Lasenby, PRD 2018

Converted power



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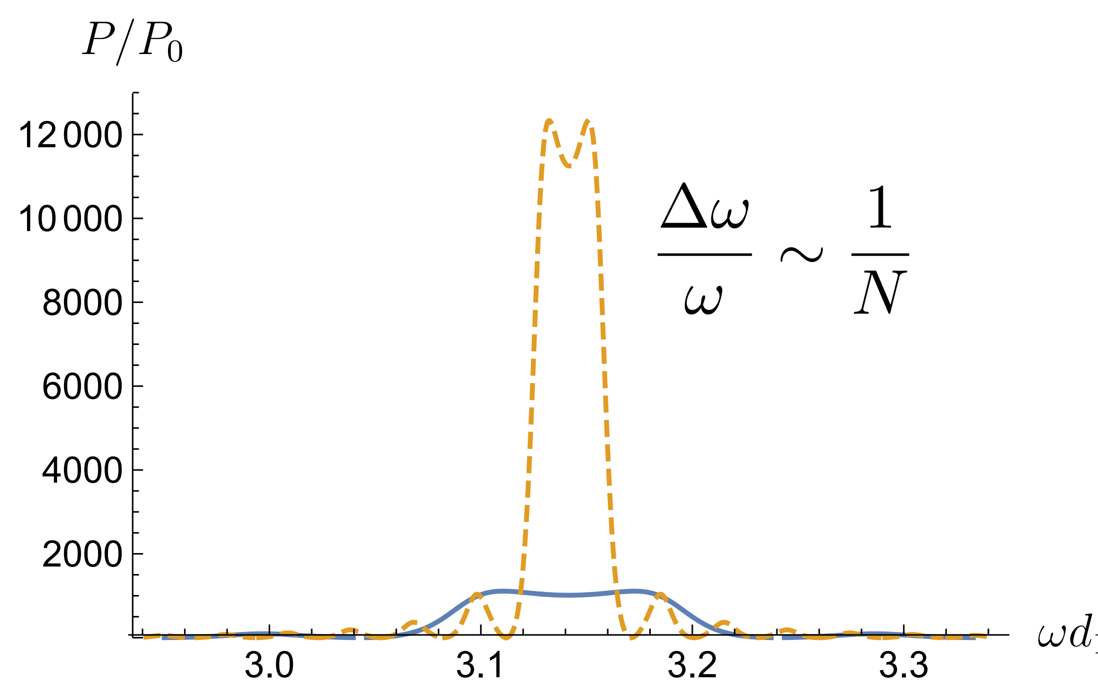
- For "open cavity", $Q \propto N$
- Frequency coverage:



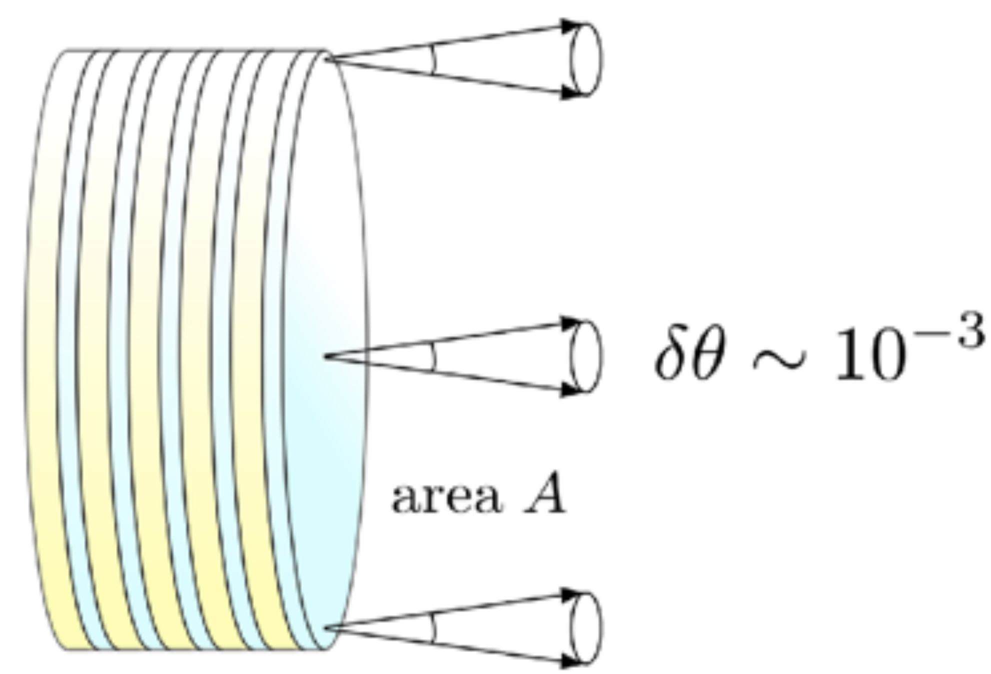
- Higher peak power compensated for by reduced bandwidth: frequency-averaged conversion power $\propto N$: gain with volume

MB, J. Huang, R. Lasenby, PRD 2018

Focusing

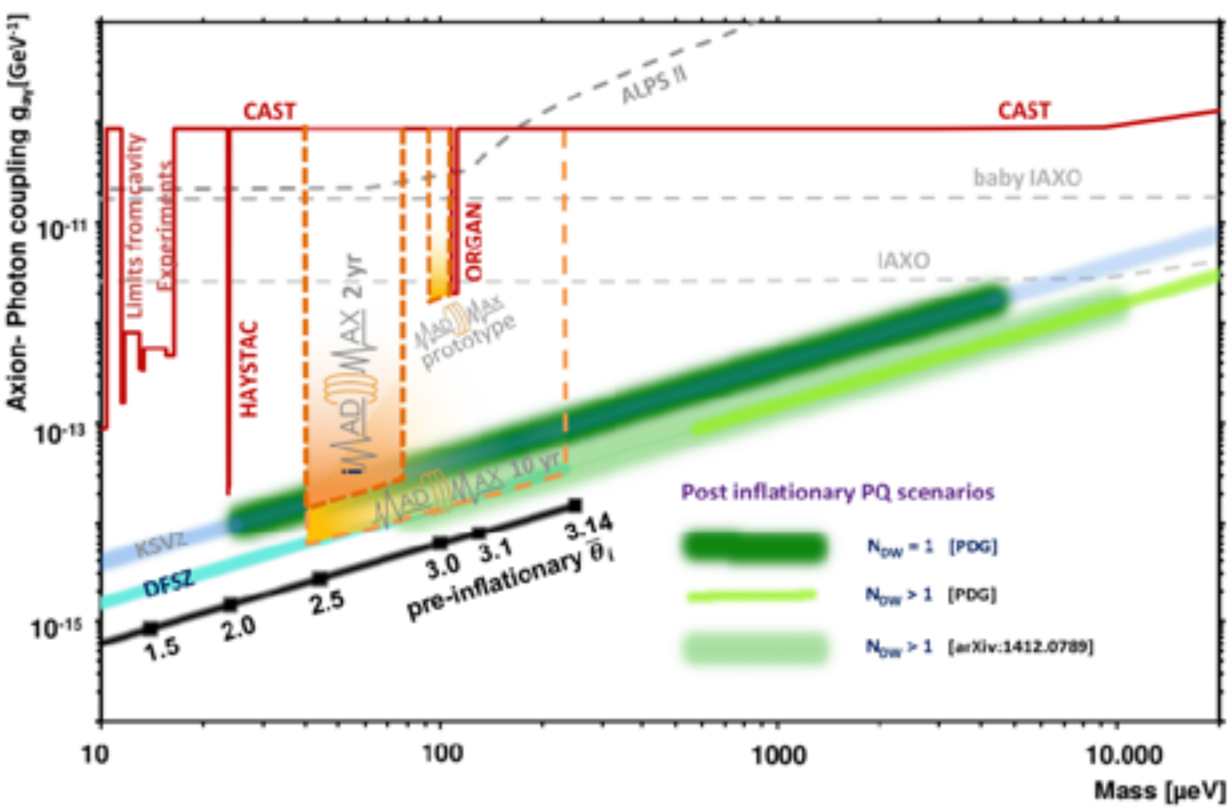
- Photons are emitted collimated to the surface

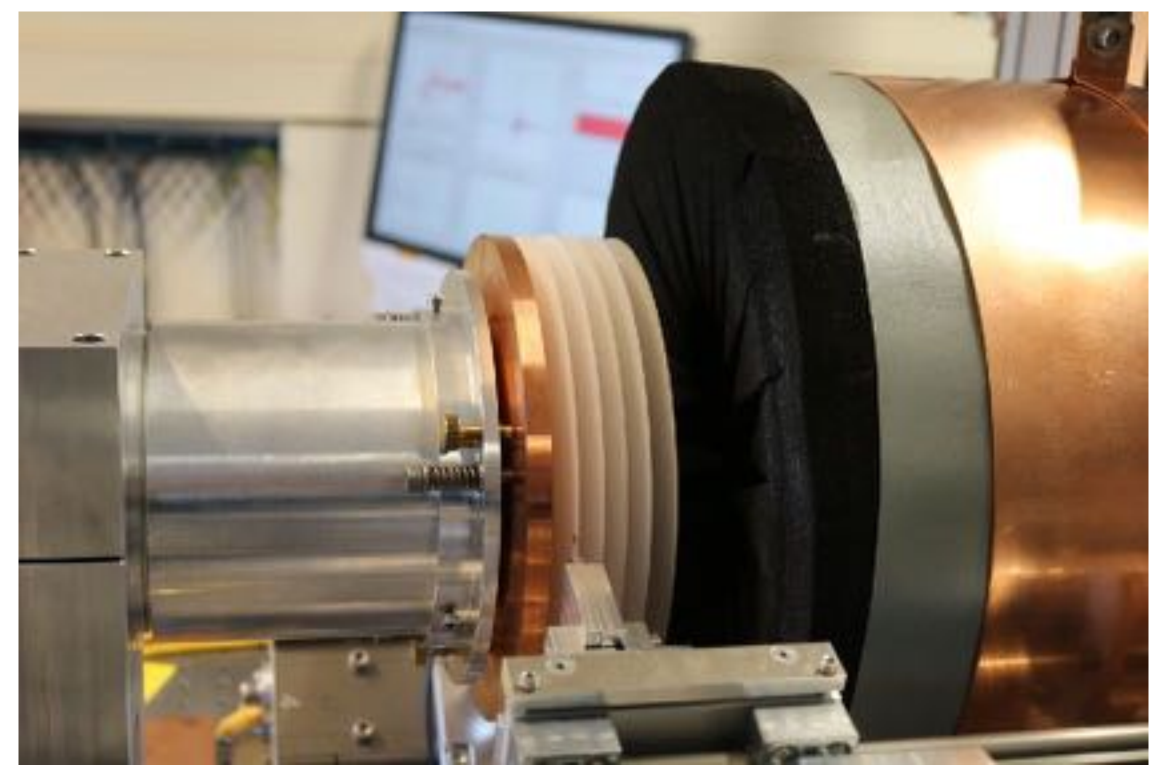
- Photons can be focused down to area $\sim 10^{-6} A$ (due to DM phase space same as for dish)



Dielectric Enhancement Demonstrated in Several Prototypes

MADMAX





See talk by Jacob Mathias Egge

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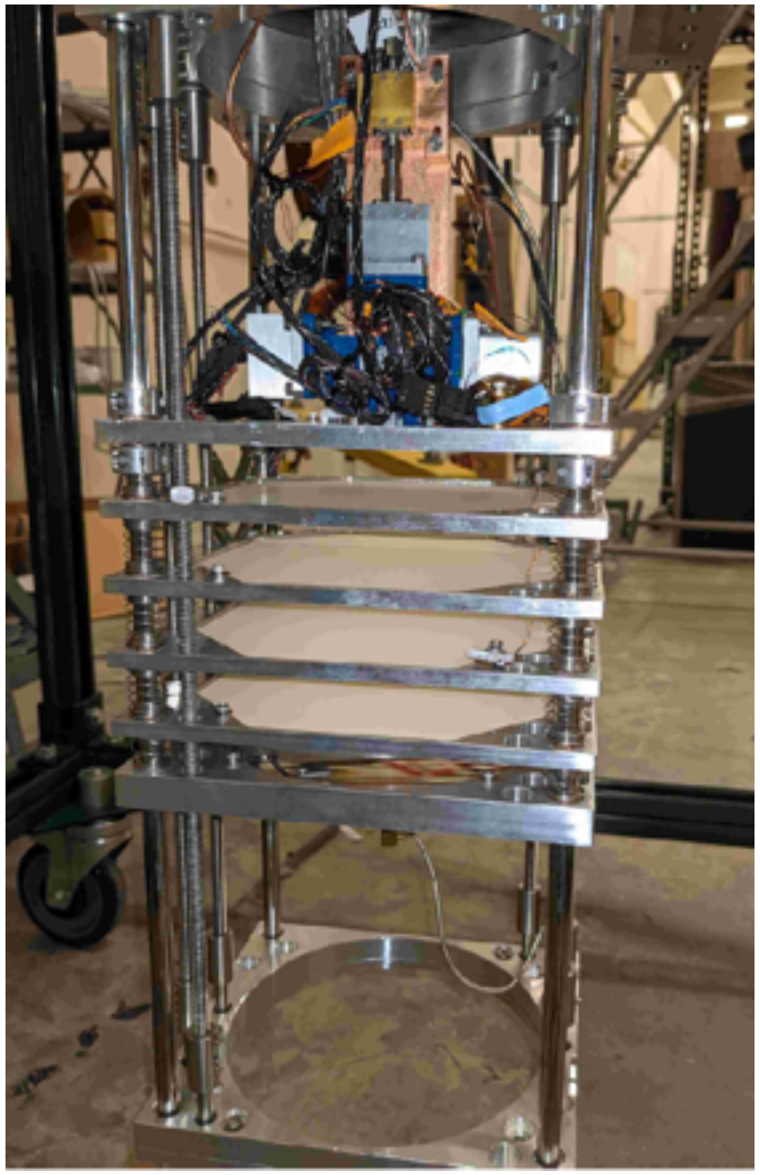
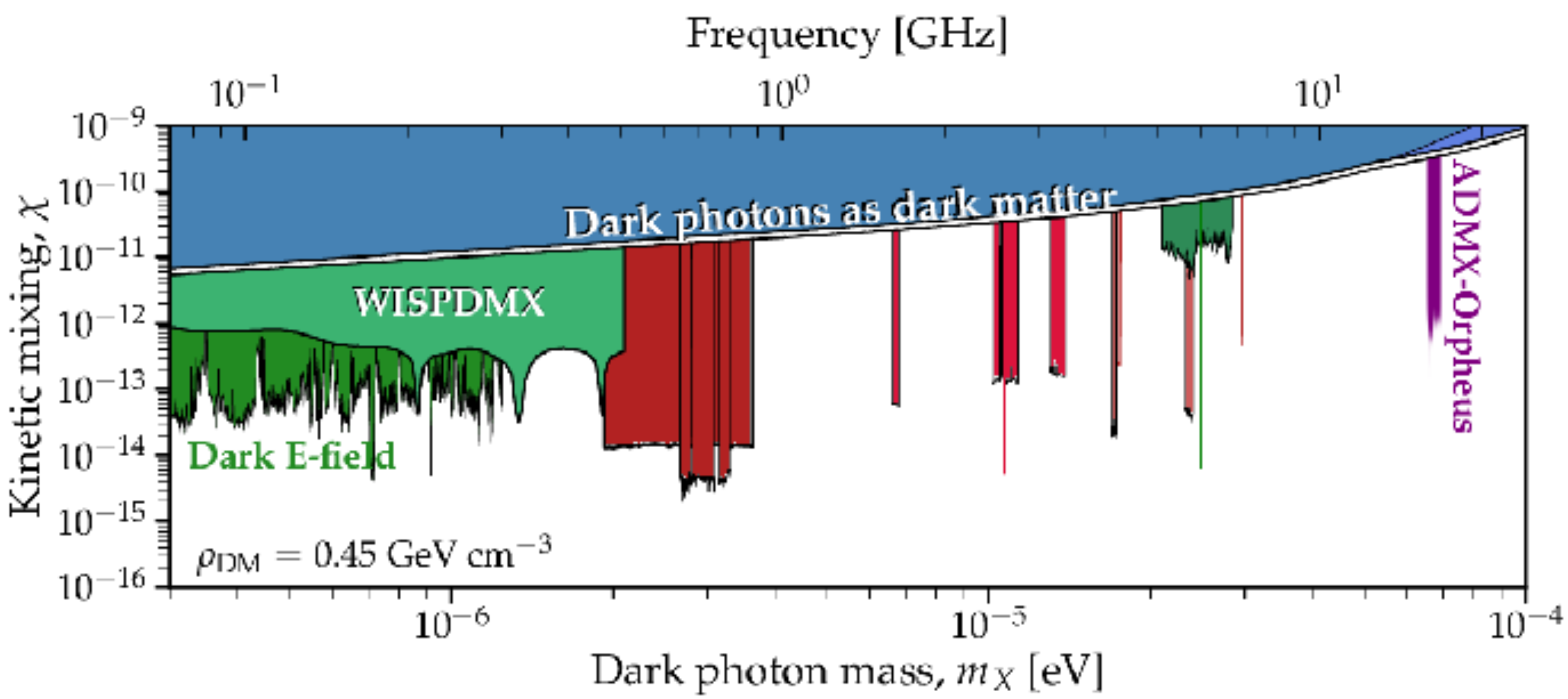
ADMX-Orpheus

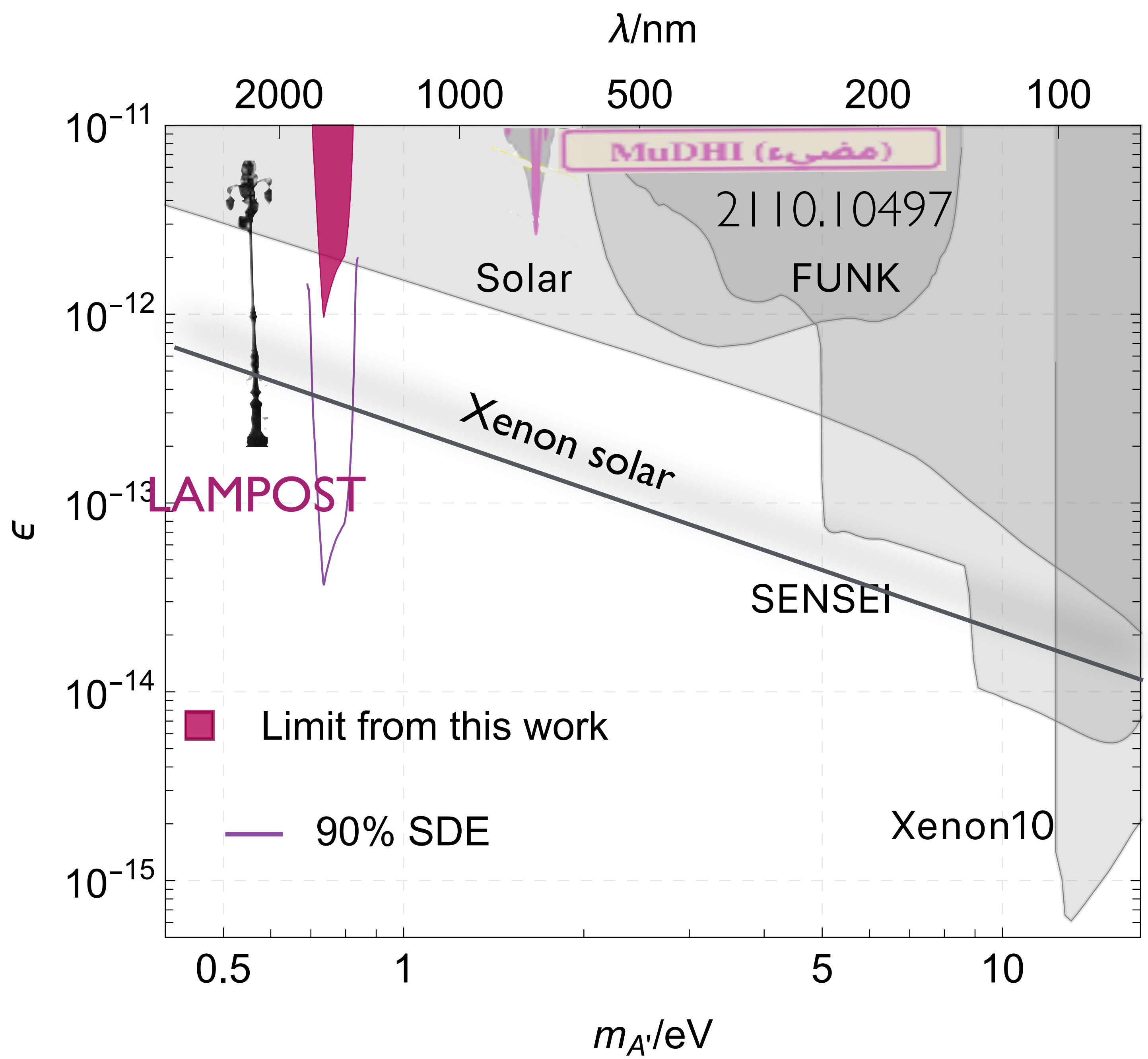


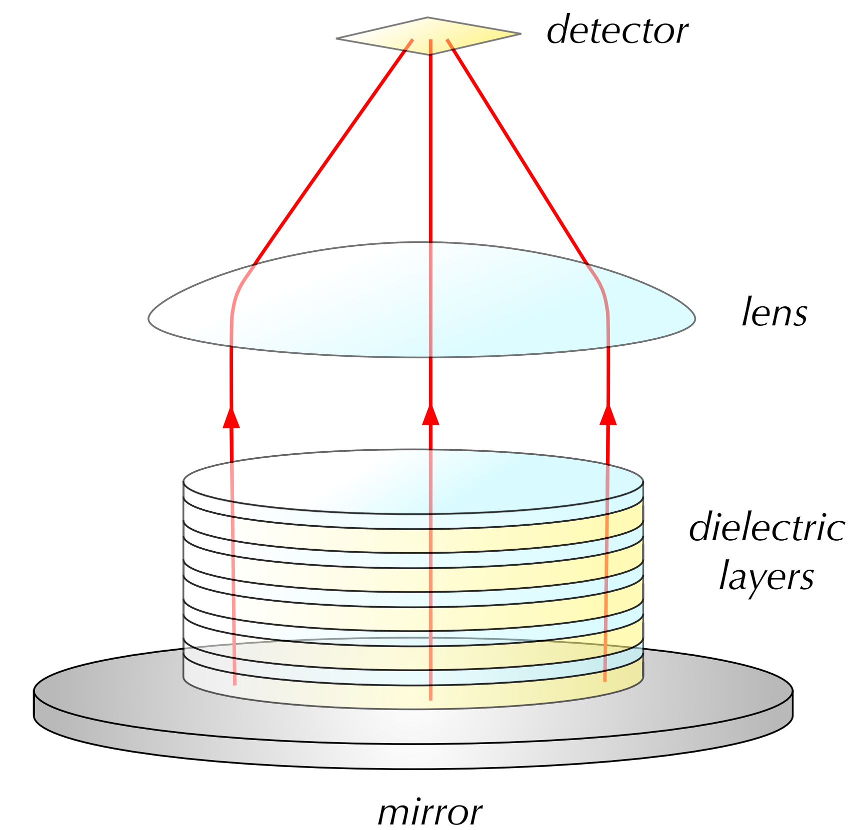


Raphael Cervantes **arXiv:2112.04542**

Carosi, Cervantes, Kimes, Mohapatra, Ottens, Rybka 2019

LAMPOST





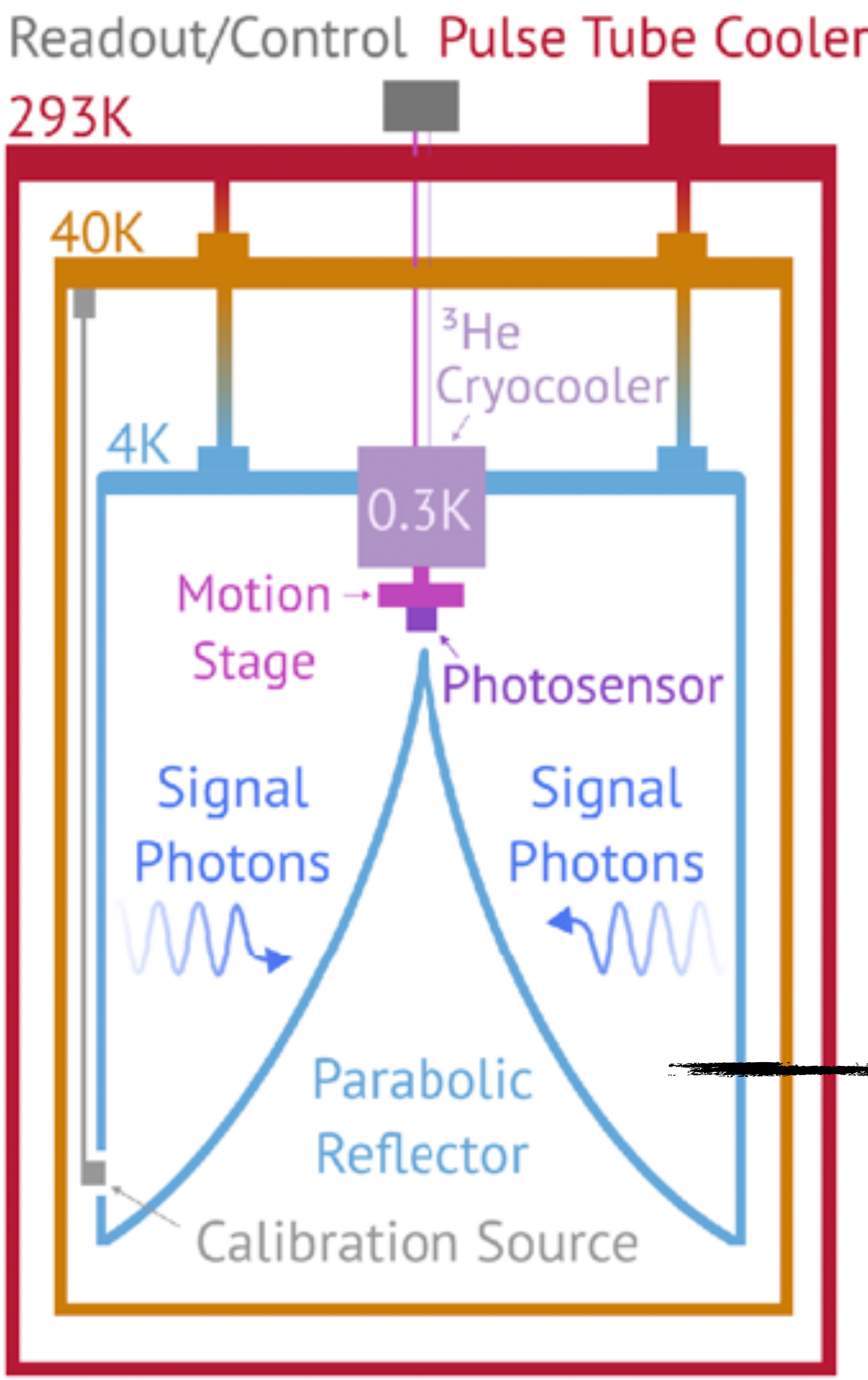
- Prototype cuts into new parameter space with 5 days run
- 2 inch diameter, 5 period stack. Poor efficiency due to alignment control, 100-fold improvement possible

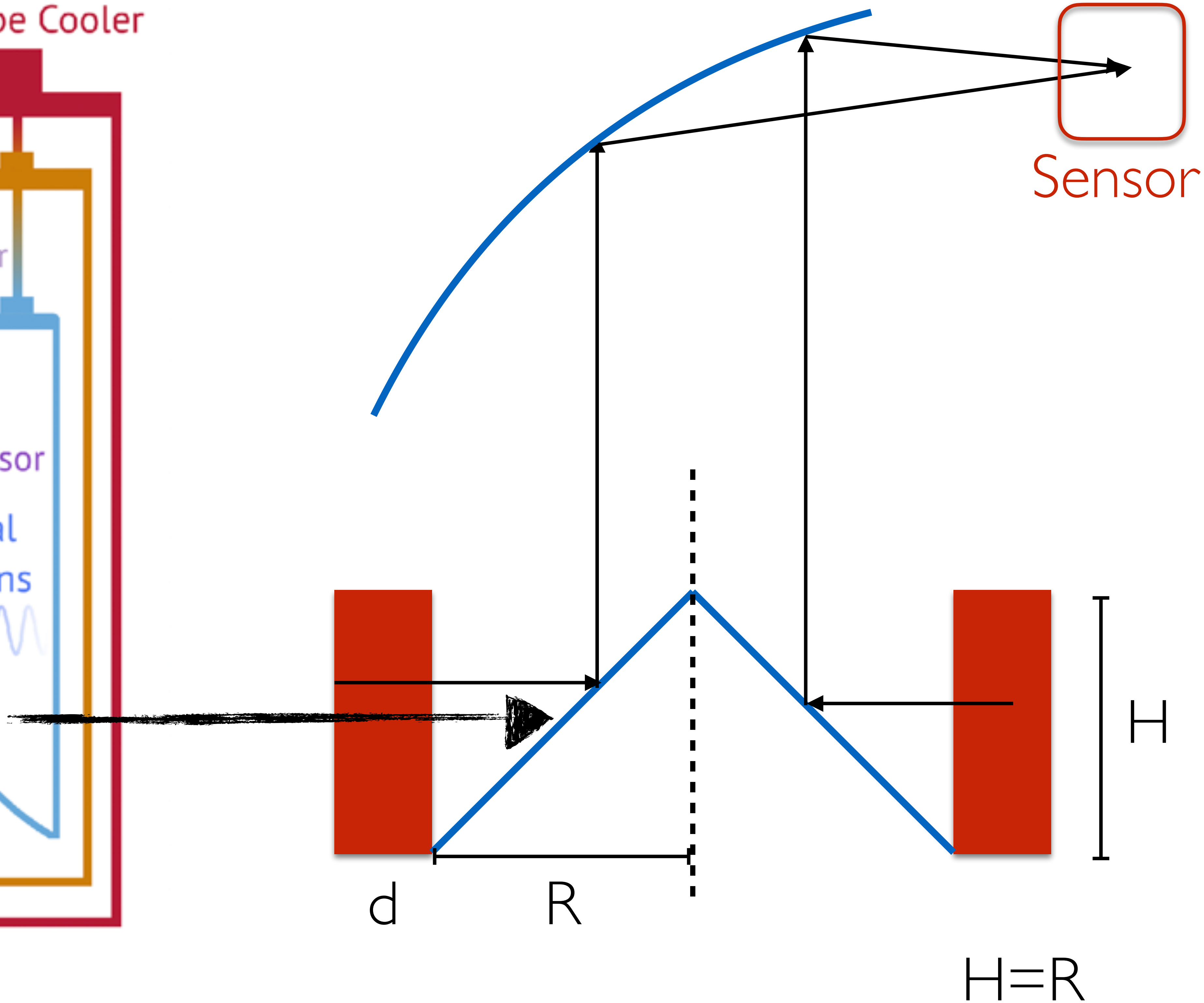
MB, J. Huang, R. Lasenby, PRD 2018

Chiles, Charaev, Lasenby, **MB**, Huang, Roshko, Burton, Colangelo, Van Tilburg, Arvanitaki, Nam, Berggren arXiv:2110.01582, PRL 2022

Potential Setups

Integrate Dielectric Stack

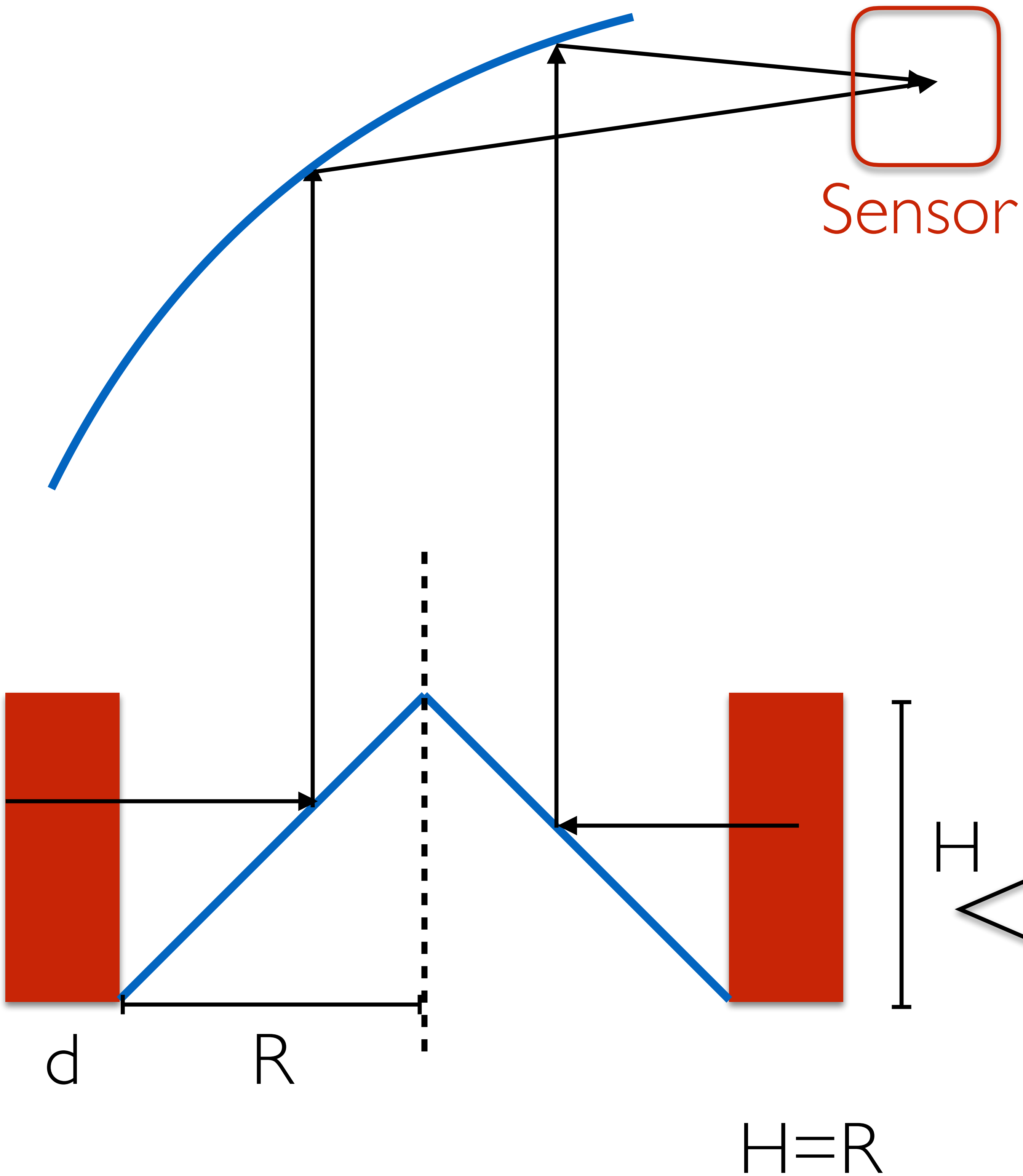


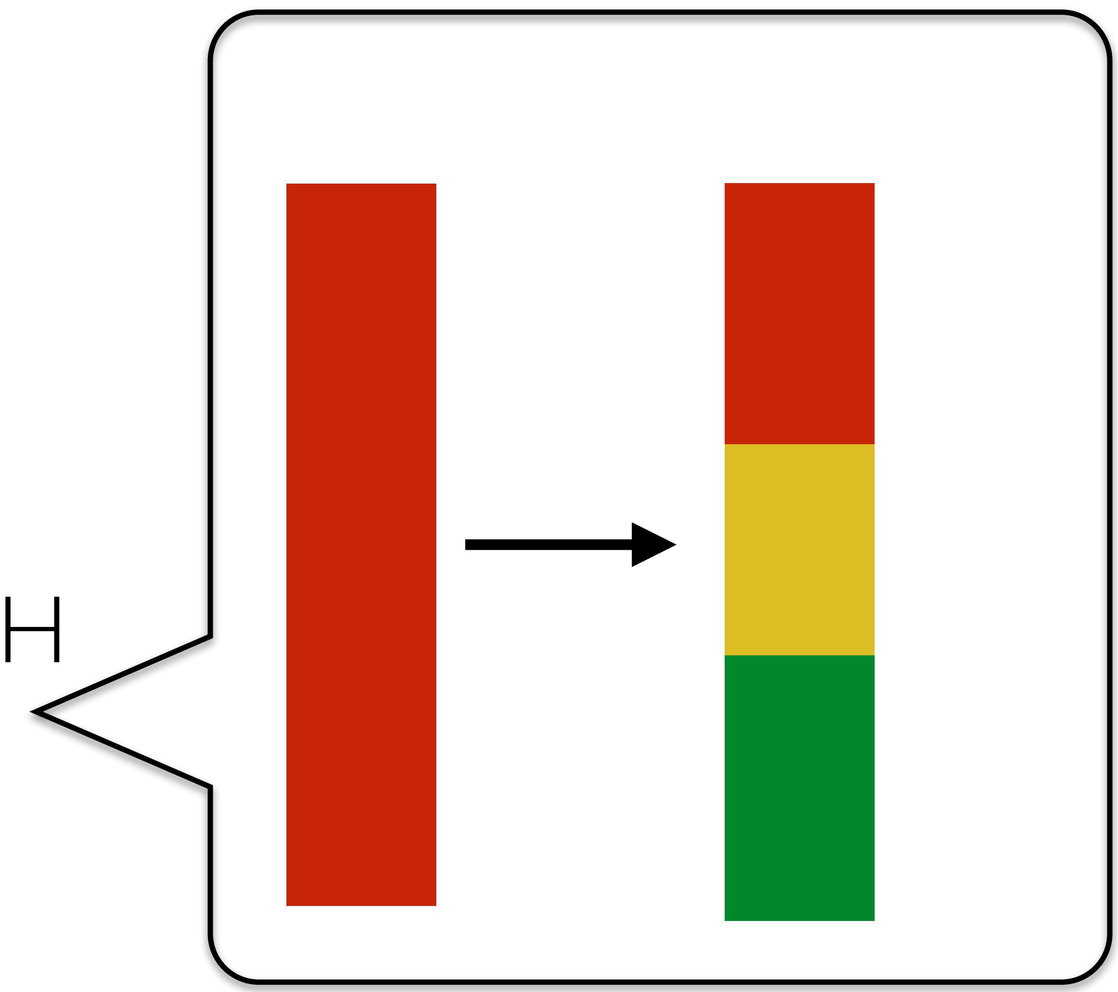


- Mirror geometry has to change

Scanning

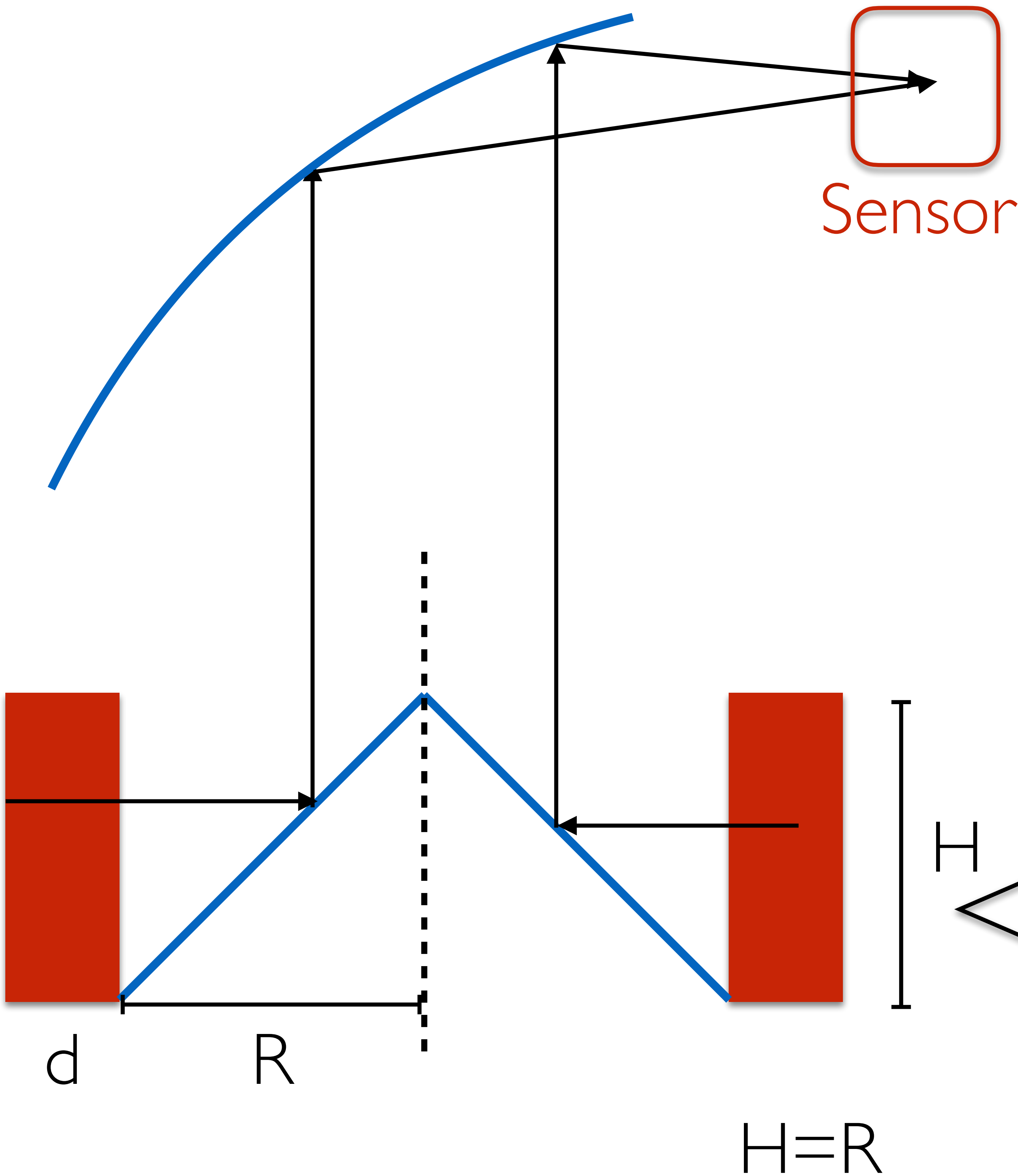
- Possibilities:
  - Parallel stacks of different periodicity

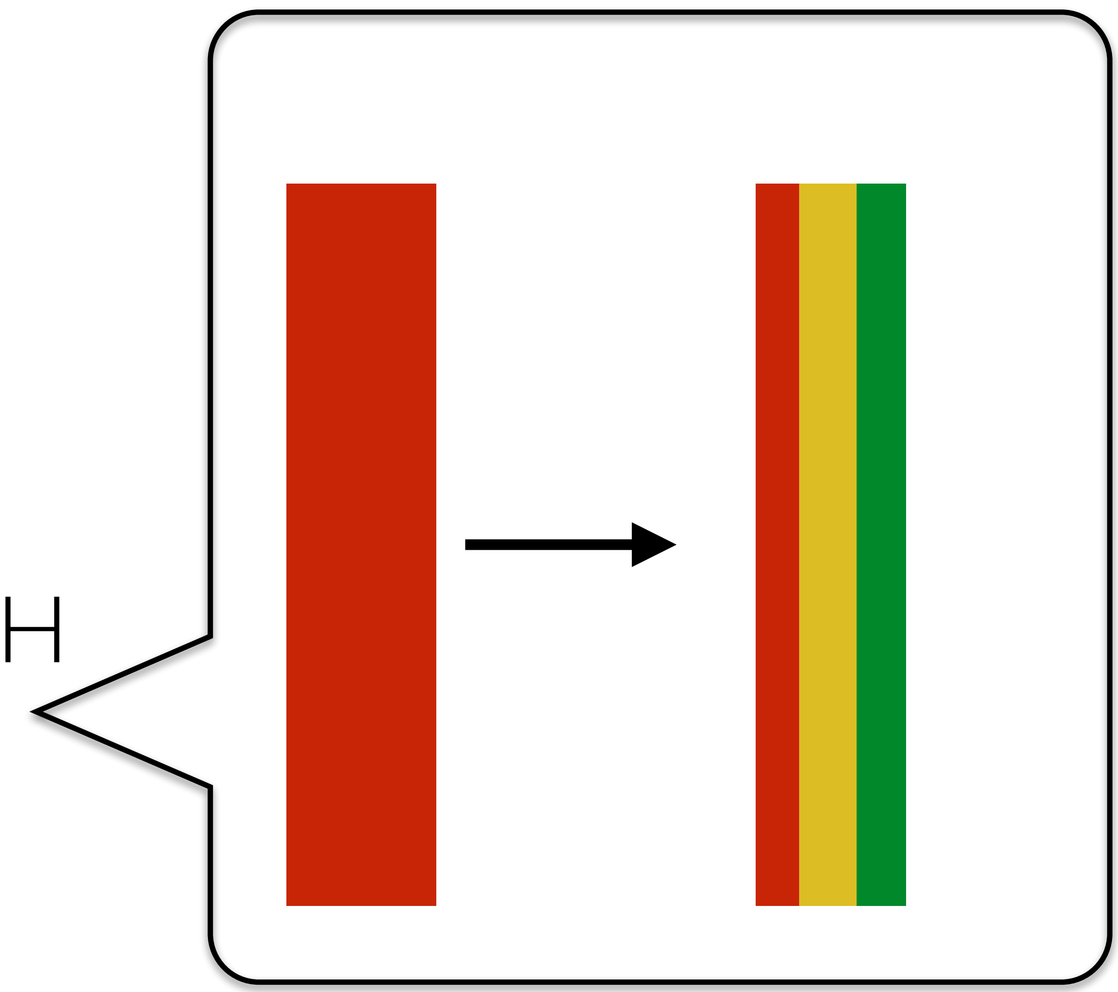




Scanning

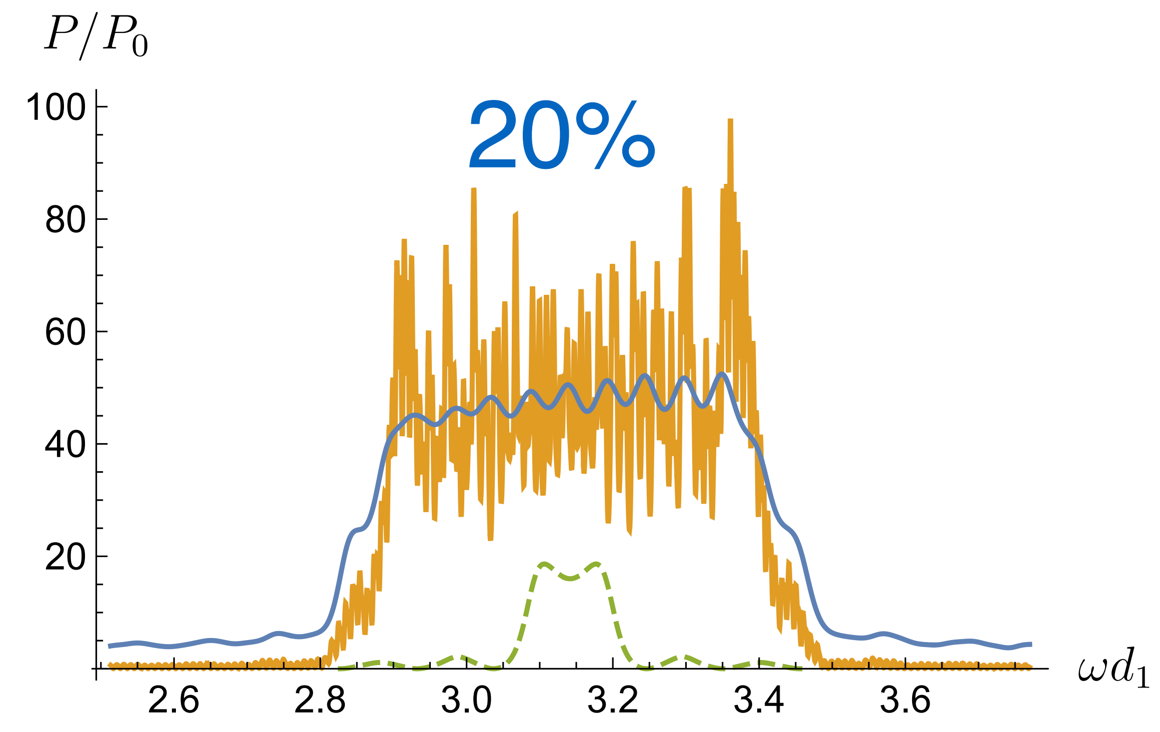
- Possibilities:
  - Chirped Stack

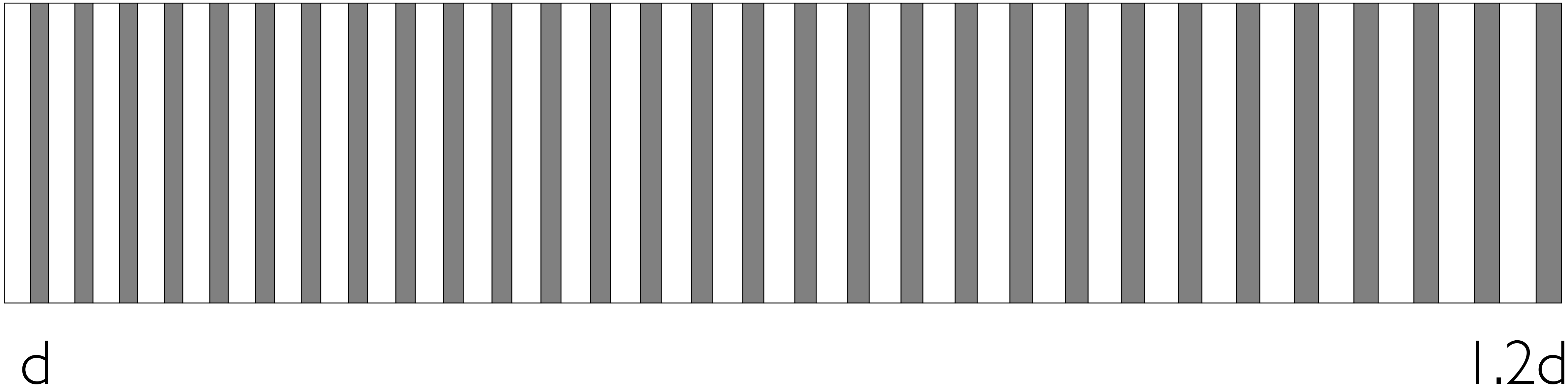




Chirped stack

- Gradually increase thickness of layers
- Cover larger volume and frequency range together
- Maximum ~30% range of frequencies and need to be careful with reflections to avoid destructive interference

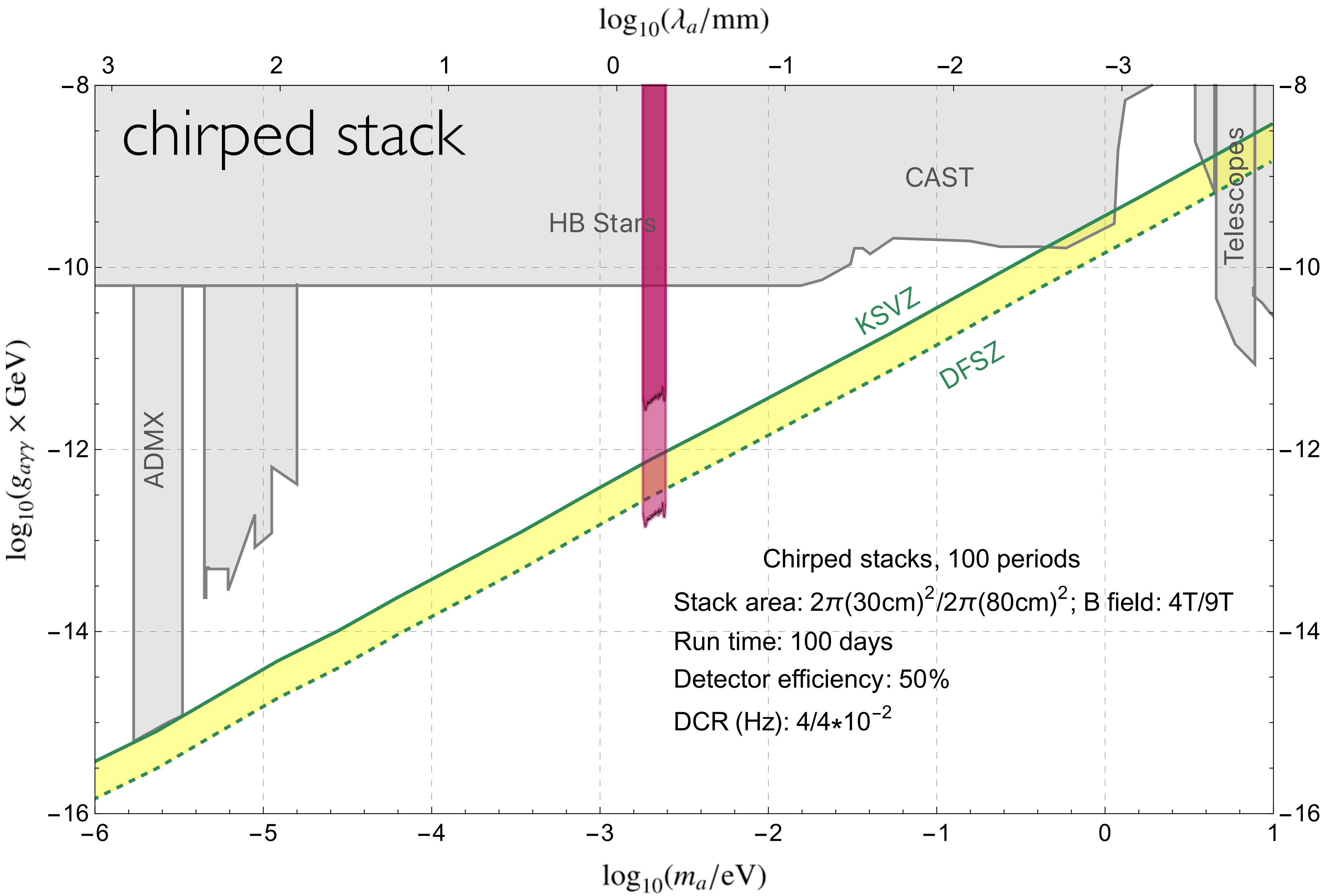




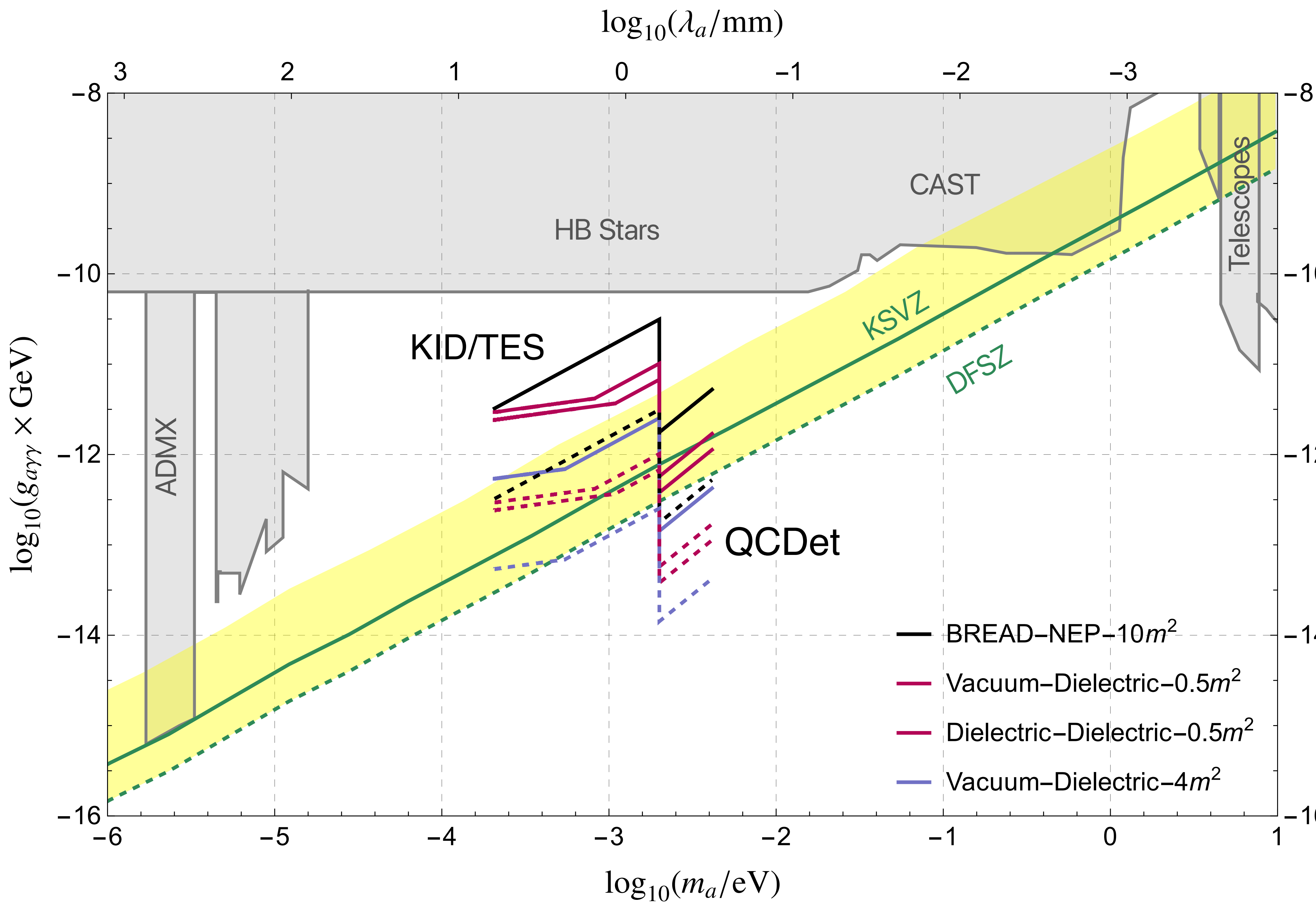
MB, J. Huang, R. Lasenby, PRD 2018

Projections

The case for SANDWICH



The case for SANDWICH

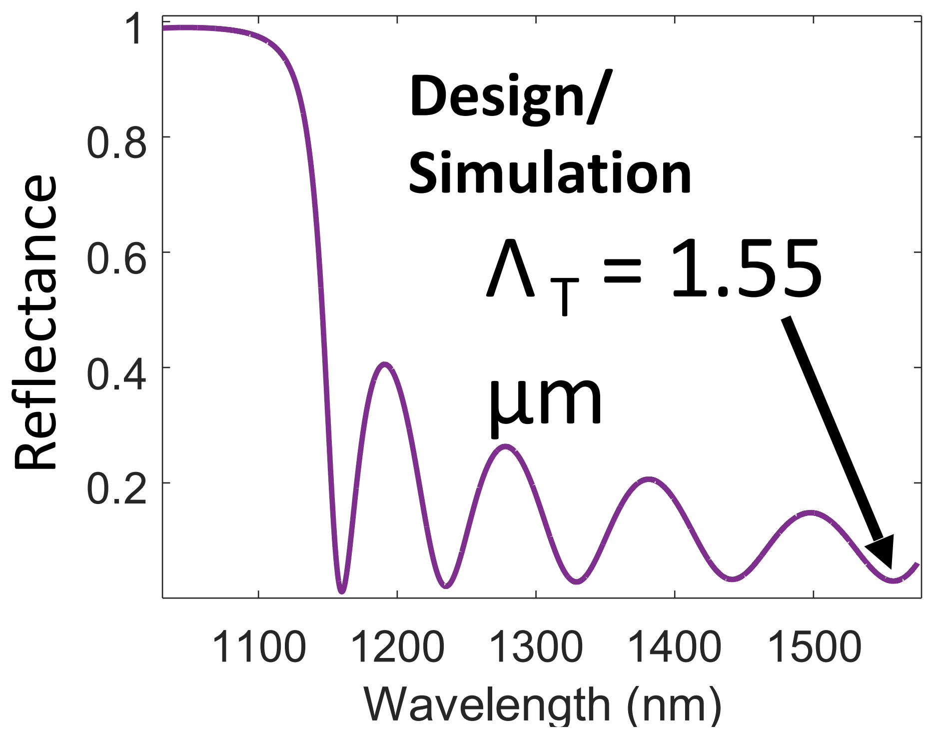


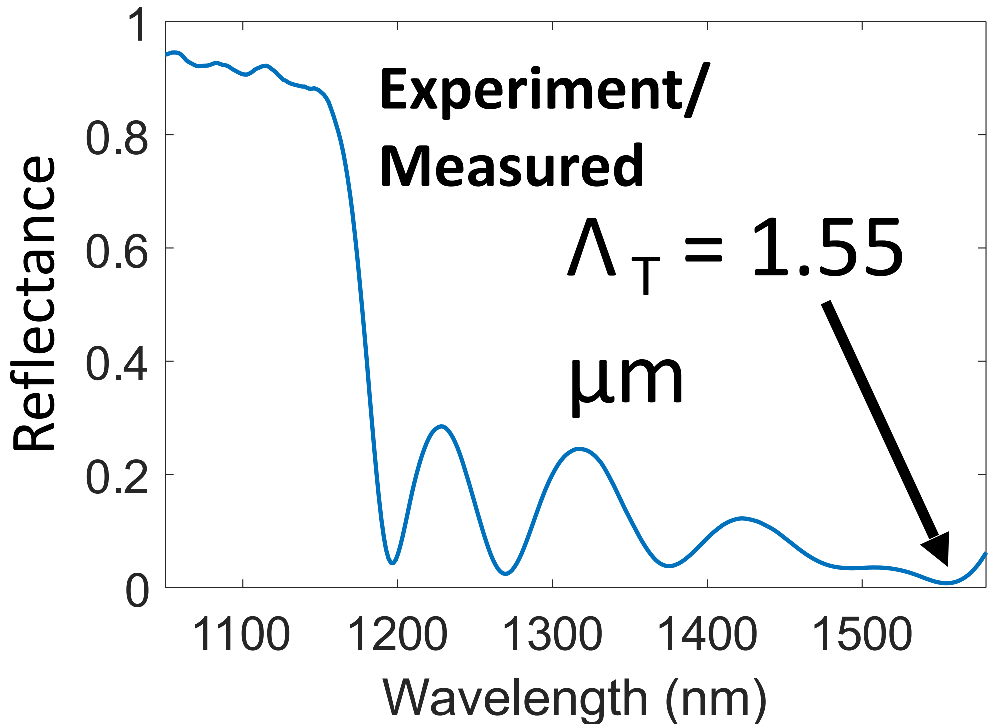
The case for SANDWICH: conclusions and next steps

- Periodic dielectric materials can increase the volume where axion to photon conversion is efficient
- Flat layer geometry successfully demonstrated in prototypes in multiple frequency bands; possible to reach very small couplings with larger setups
- Future directions:
  - Optimize light collection geometry with dielectric-in-cylinder setup
  - Study different dielectrics including absorption, thermal properties

Multilayer target characterization

- White light interferometry
  - Fifth reflectance null after photonic bandgap indicates emission wavelength Λ_T





About 1 dB power loss in optical transmission through the target