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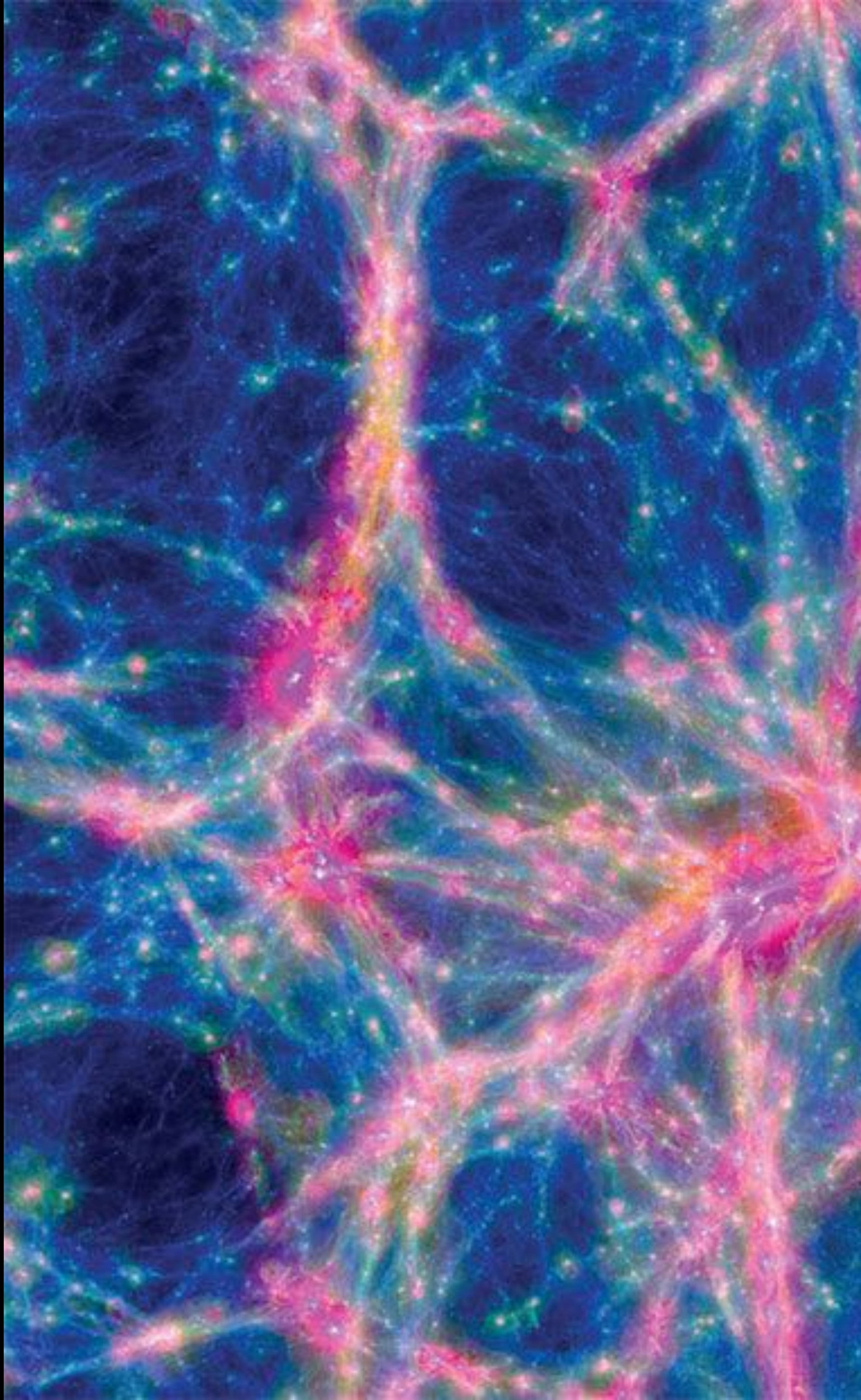
UC SANTA CRUZ

VISUALIZING RESONANT MODES IN ADMX

OUTLINE

- BACKGROUND
- ADMX DESIGN
- OPERATING PROCEDURES
- MY PROJECT
- CONCLUSIONS

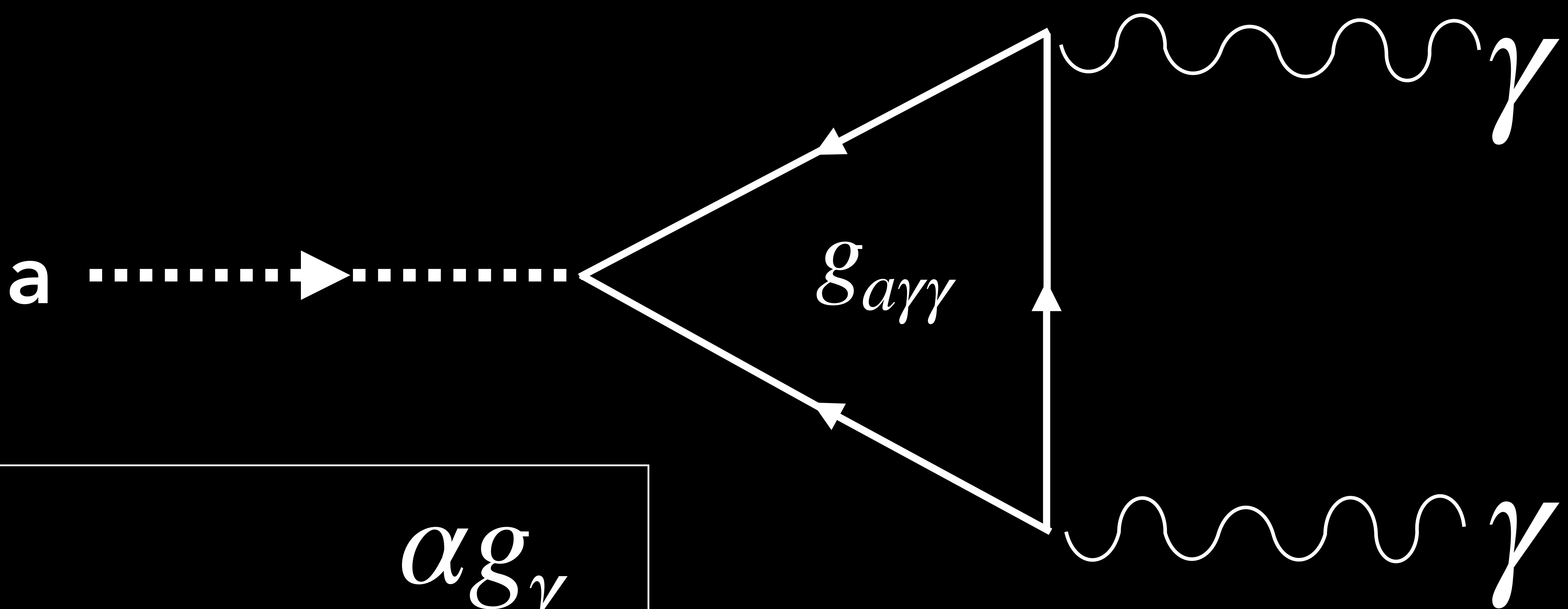


WHY AXIONS?

- No observable CP symmetry violation as expected
- Peccei-Quinn Solution
- Axions appear as pseudo-Goldstone bosons from this symmetry breaking
- Weak coupled and long decay times
- Elusive invisible axions in μeV mass range

COUPLING TO PHOTON

*KSVZ and DFSZ models



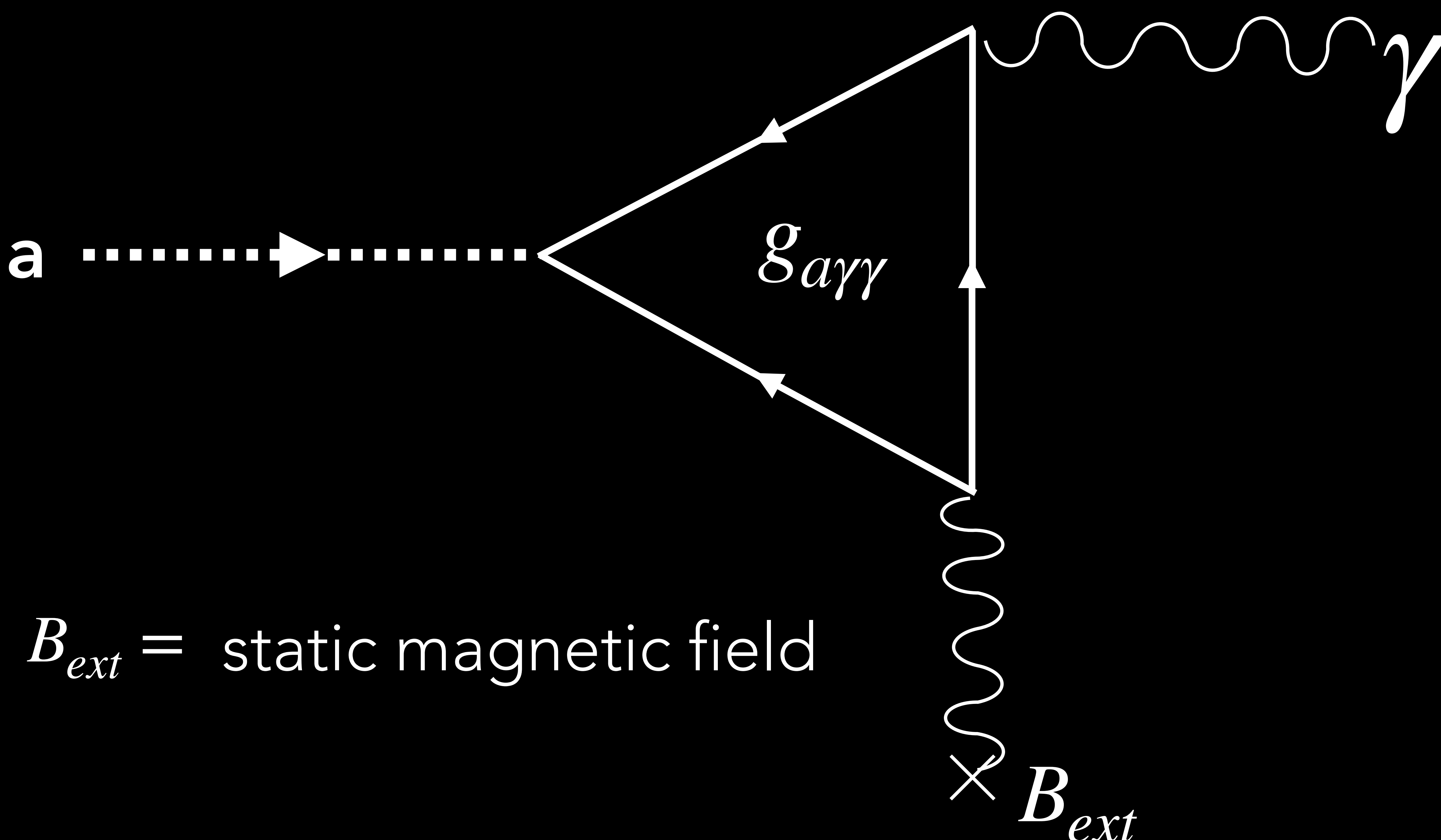
$$g_{a\gamma\gamma} = \frac{\alpha g_\gamma}{2\pi f_a}$$

$\alpha =$ fine structure constant

$g_\gamma =$ model dependent coupling constant

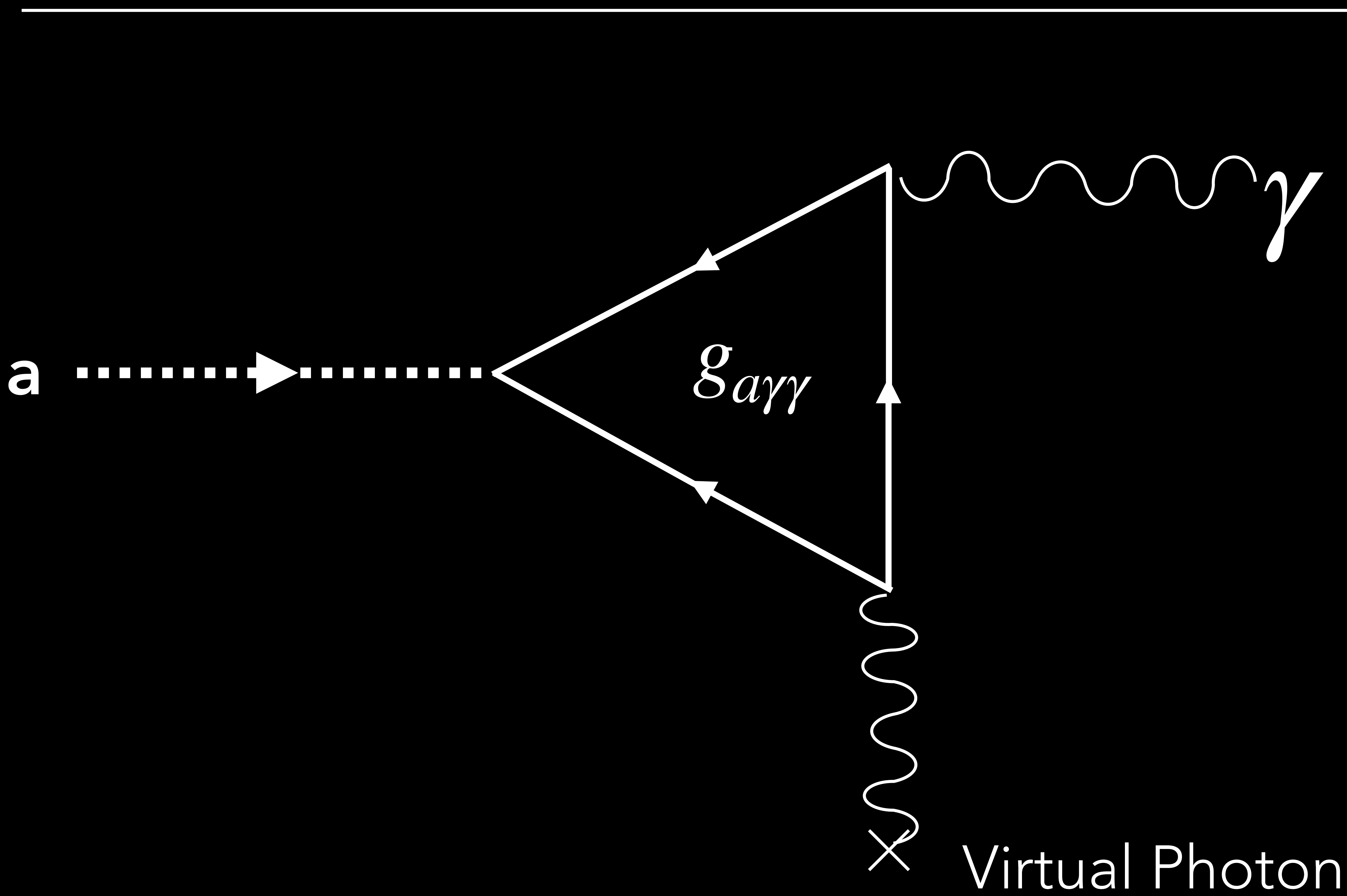
$f_a =$ threshold energy

INVERSE PRIMAKOFF CONVERSION



$B_{ext} =$ static magnetic field

INVERSE PRIMAKOFF CONVERSION



ADMX

AXION DARK MATTER EXPERIMENT

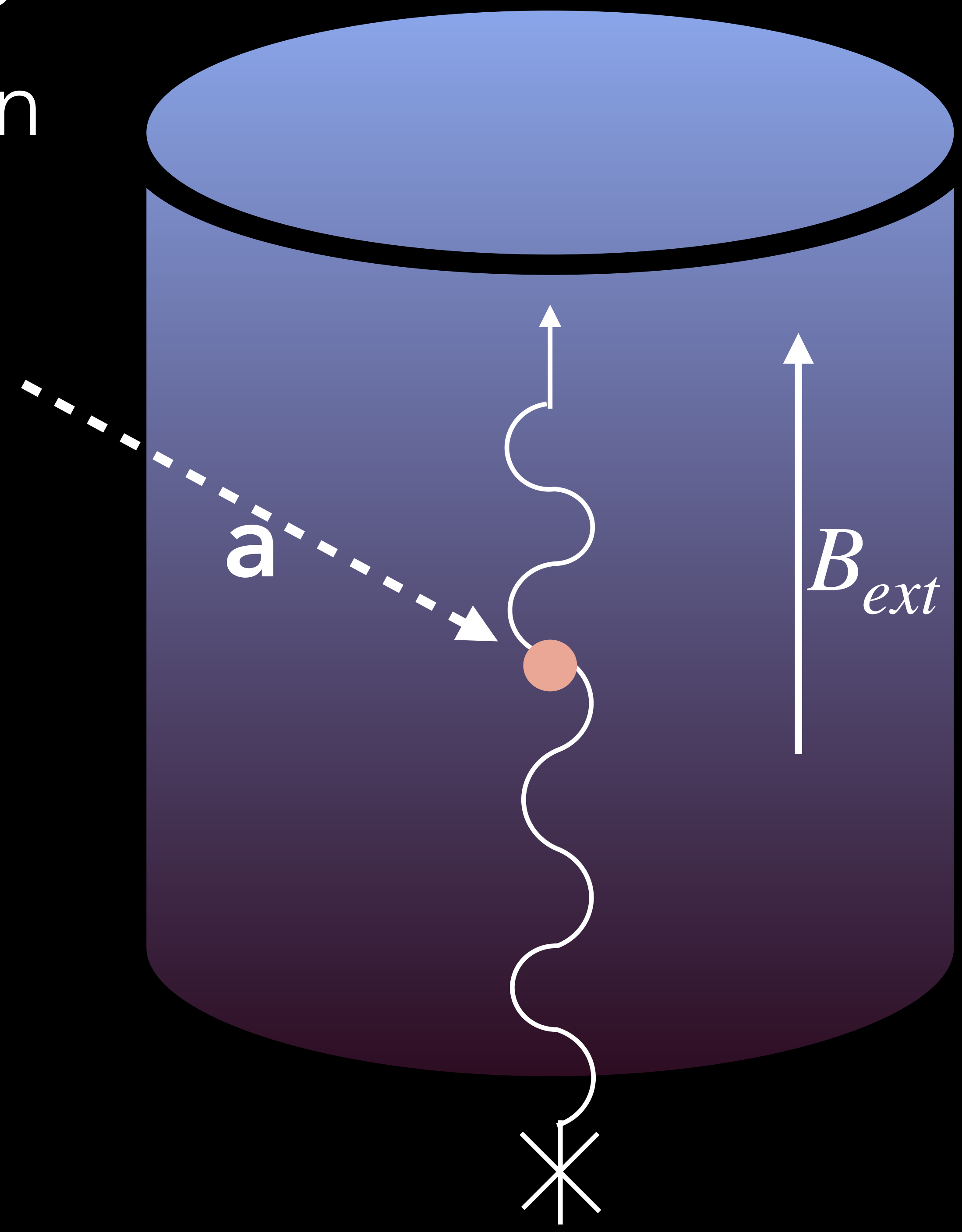
Credits: National Geographic

THE HALOSCOPE METHOD

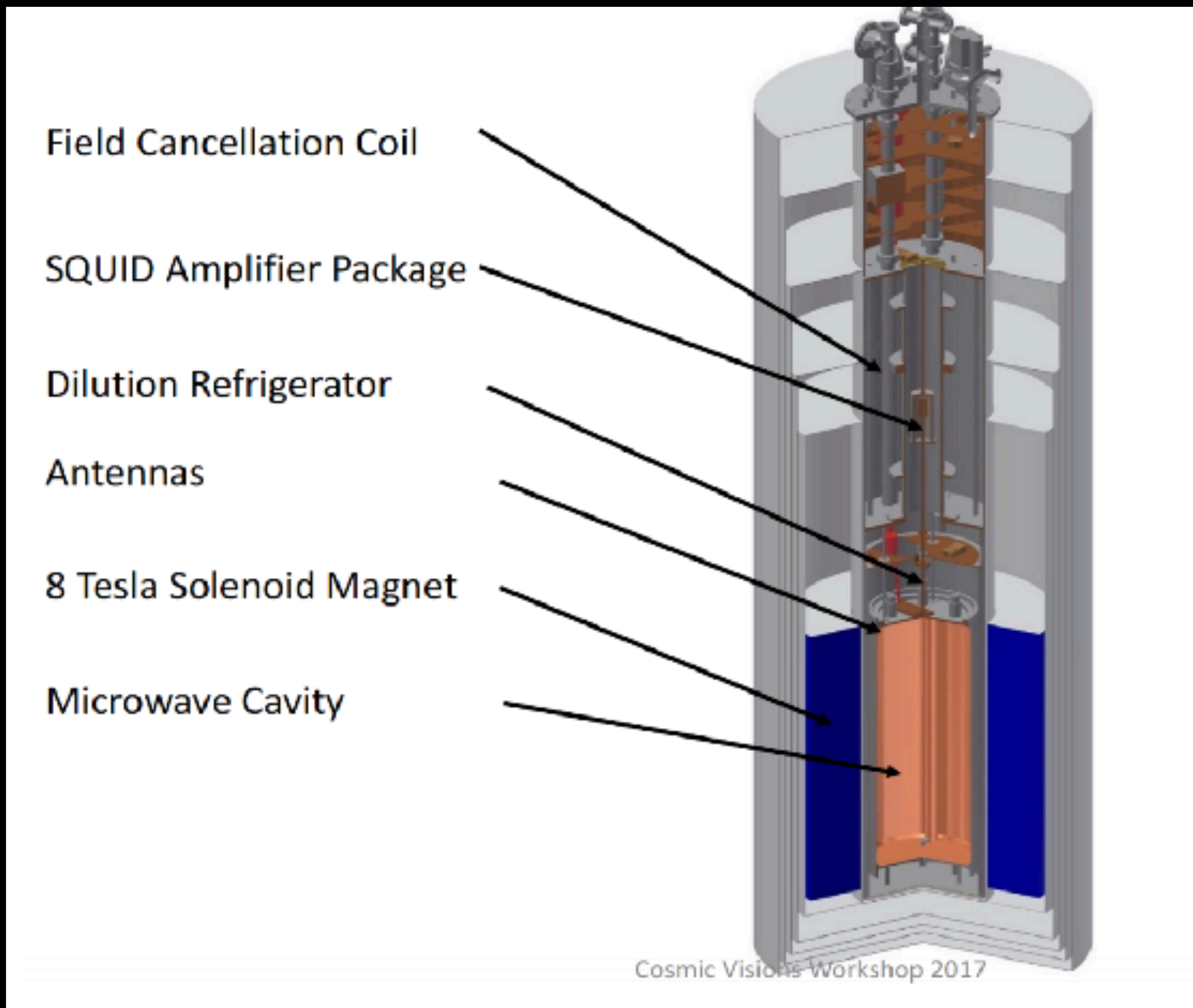
- External magnetic field ~ 7.6 T stimulates axion conversion to microwave photons

- Tunable resonator to sweep frequency space

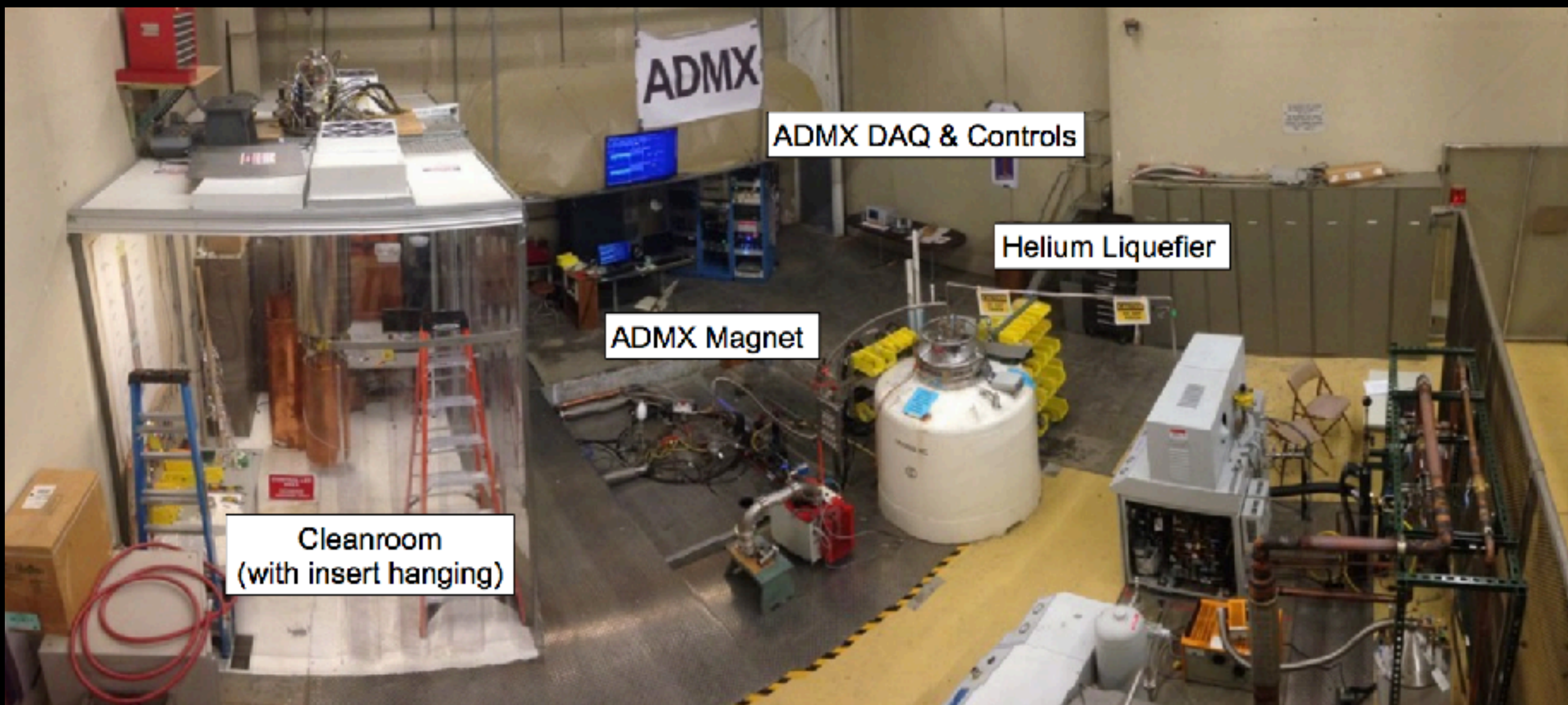
- Increase signal to noise via cooling cavity and JPA amplifiers



THE DETECTOR



ADMX SITE

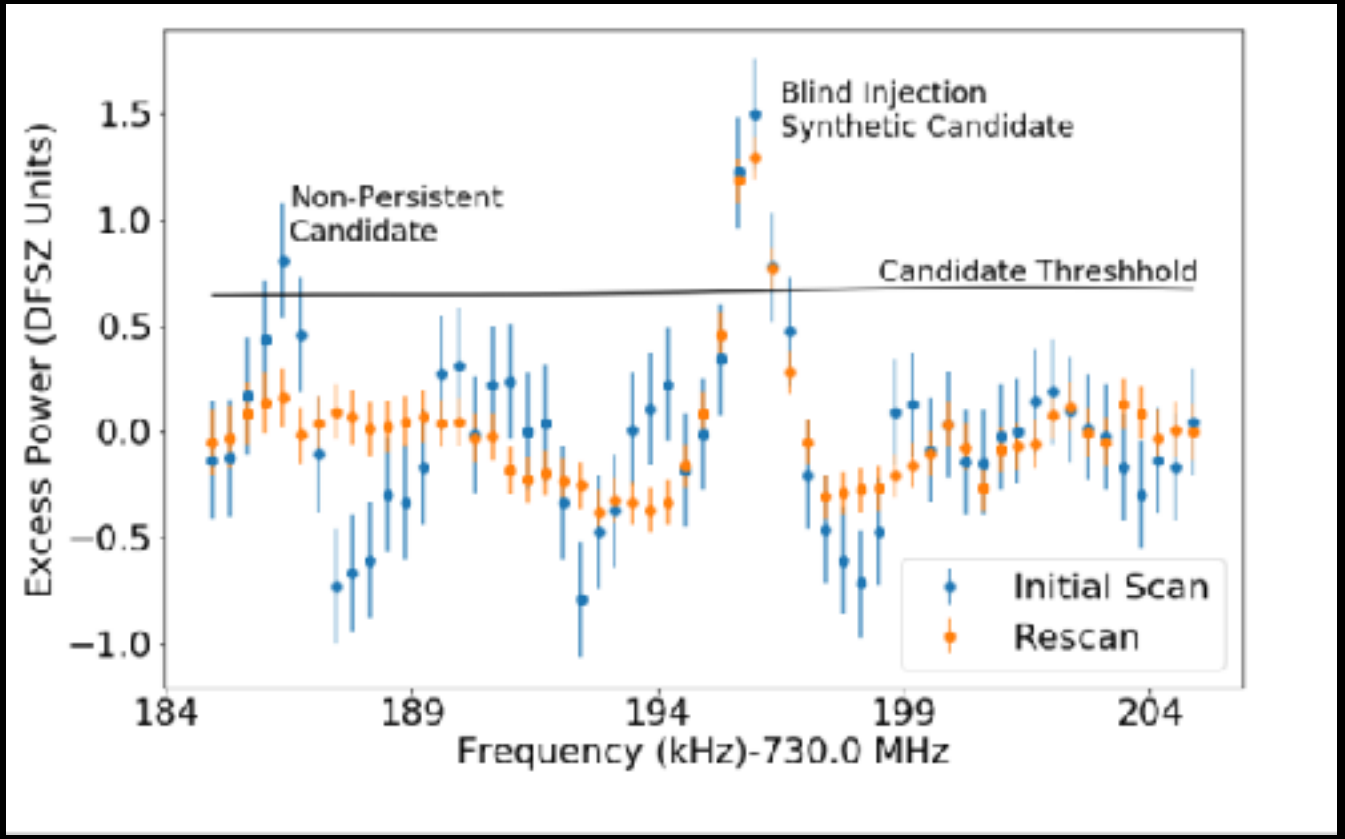

ADMX
ADMX DAQ & Controls
Helium Liquefier
ADMX Magnet
Cleanroom
(with insert hanging)

DATA TAKING CADENCE

- Tune cavity to given frequency
- Adjust JPA
- Listen and Digitize (100s)
- Shift to different frequency, moving tuning rod

SAG (SYNTHETIC AXION GENERATOR)

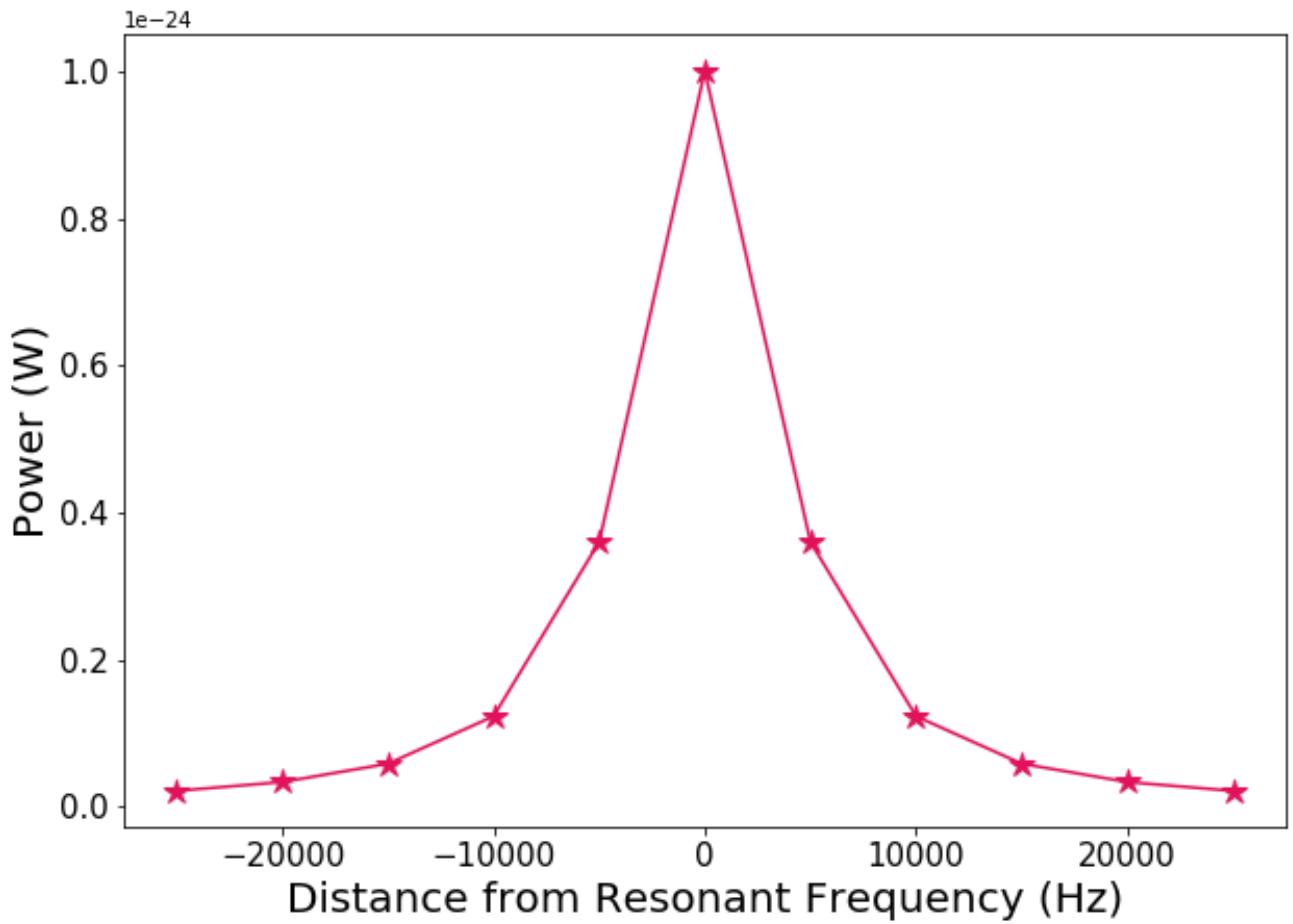
- Create a signal that mimics a real axion signal, inject it into the weak port and use the resulting digitized output power spectrum to:
  - Blind injection serves as a verification of setup of system
  - Help us understand our sensitivity



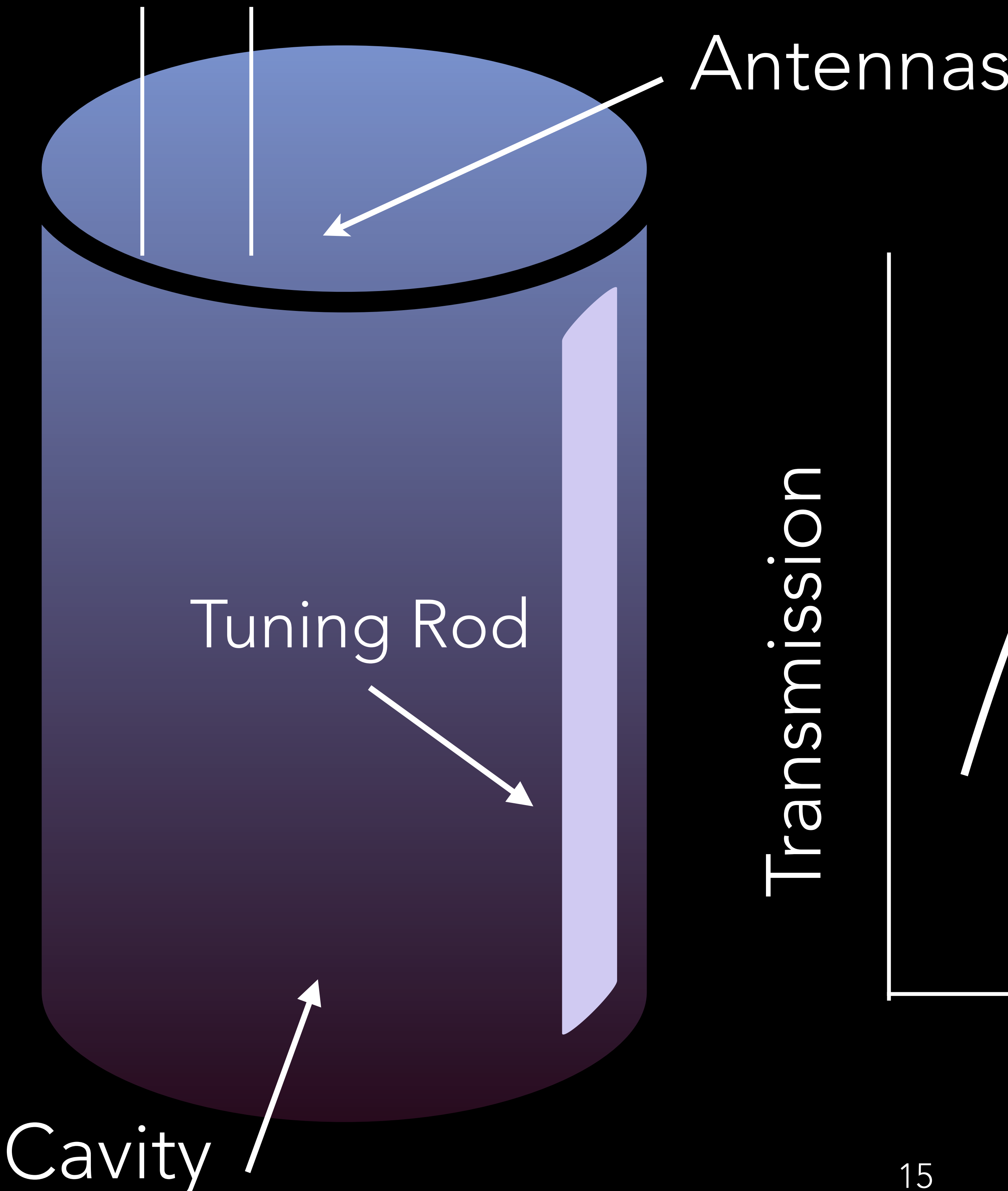
Rybka-GRC 2019

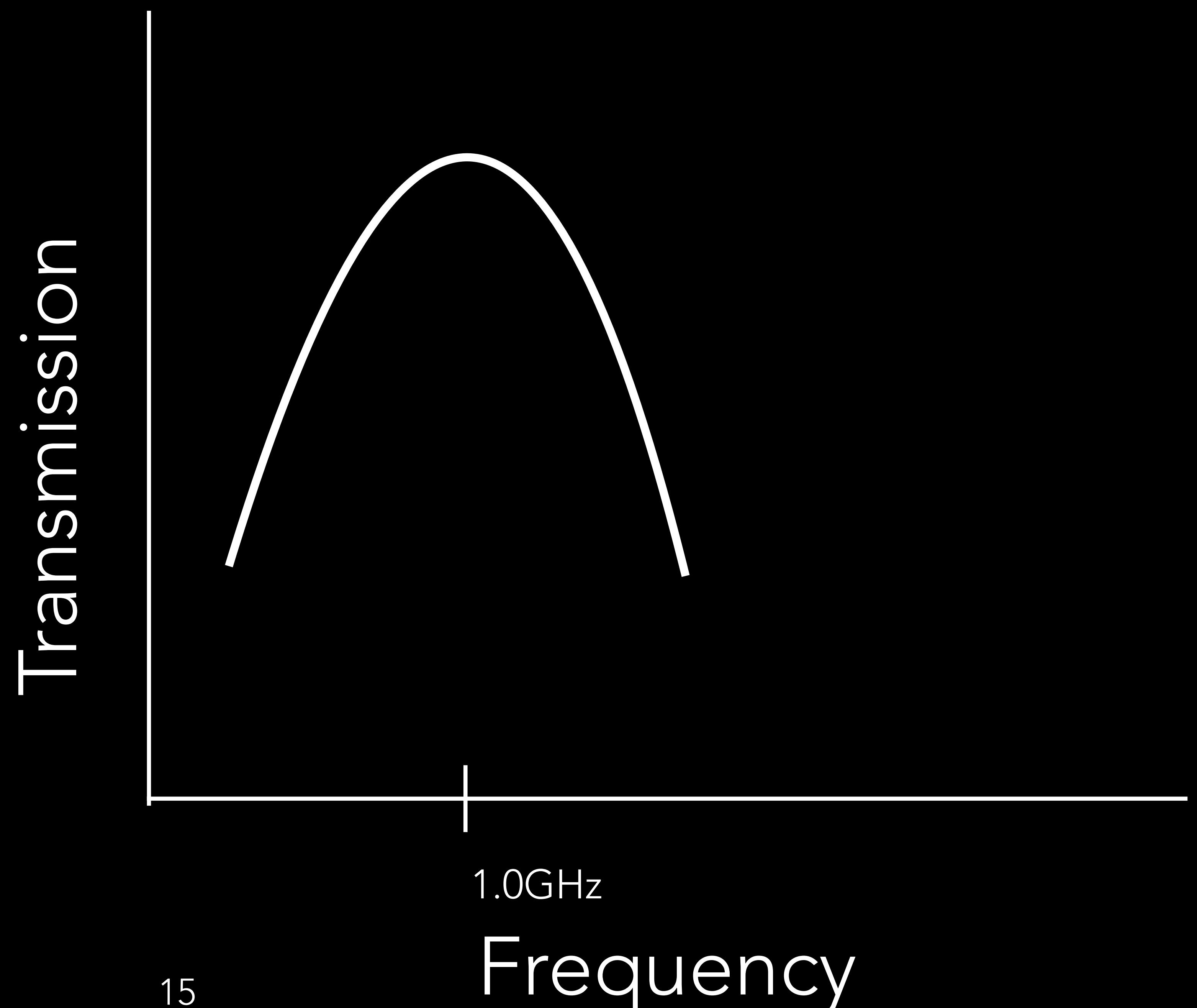
CAVITY RESONANT FREQUENCY

- Power signal is maximized if on cavity's resonant frequency

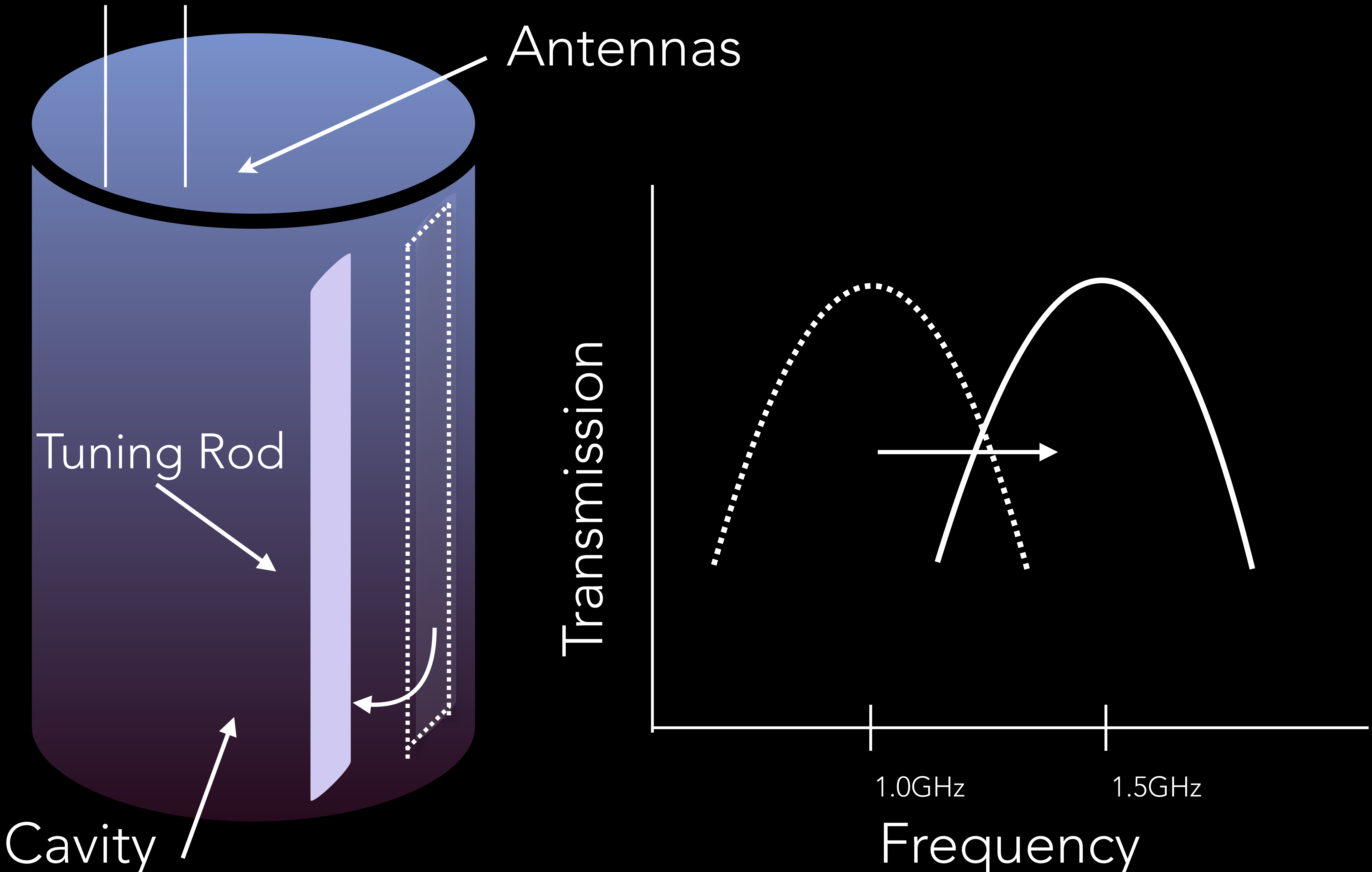


CAVITY TUNING

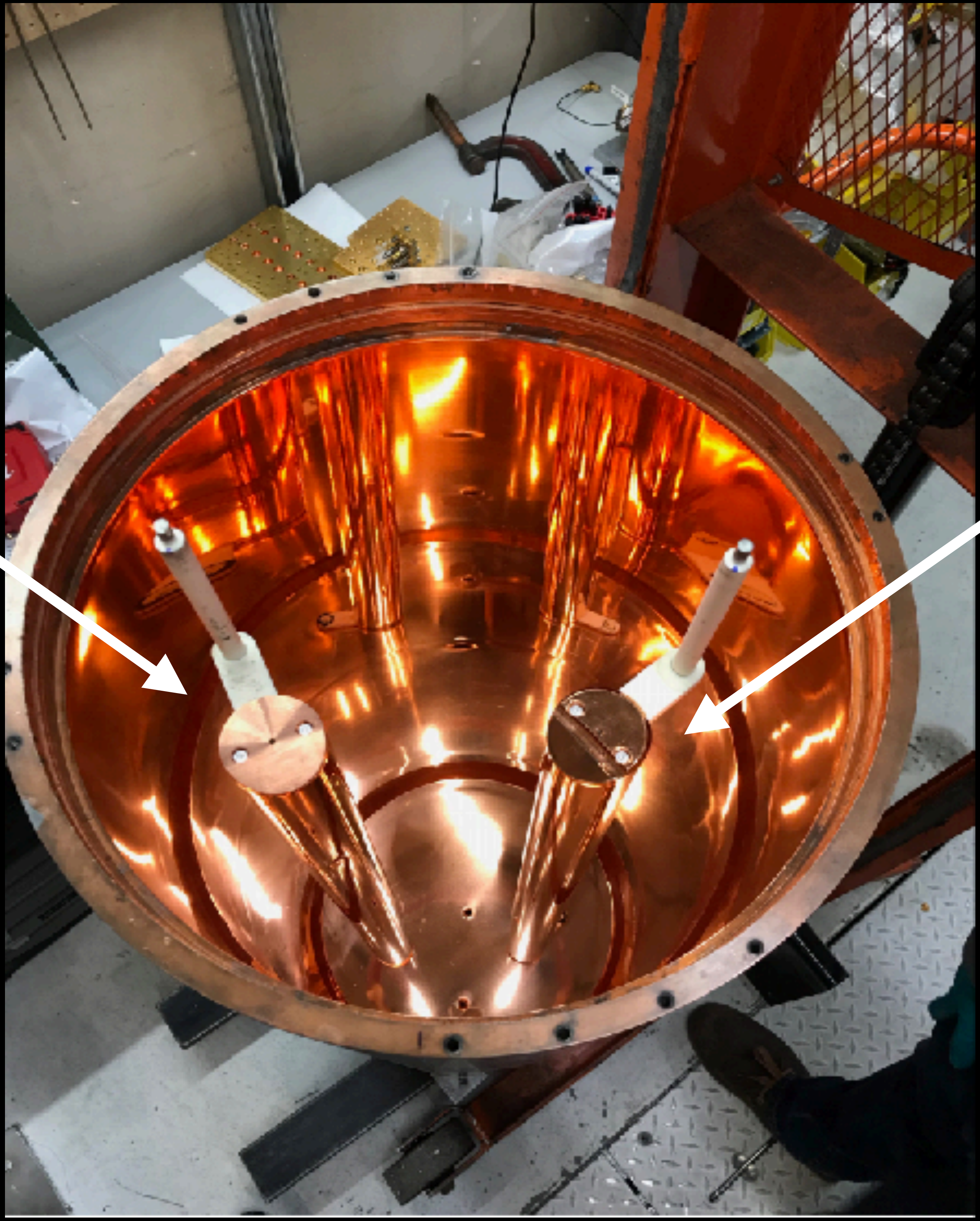




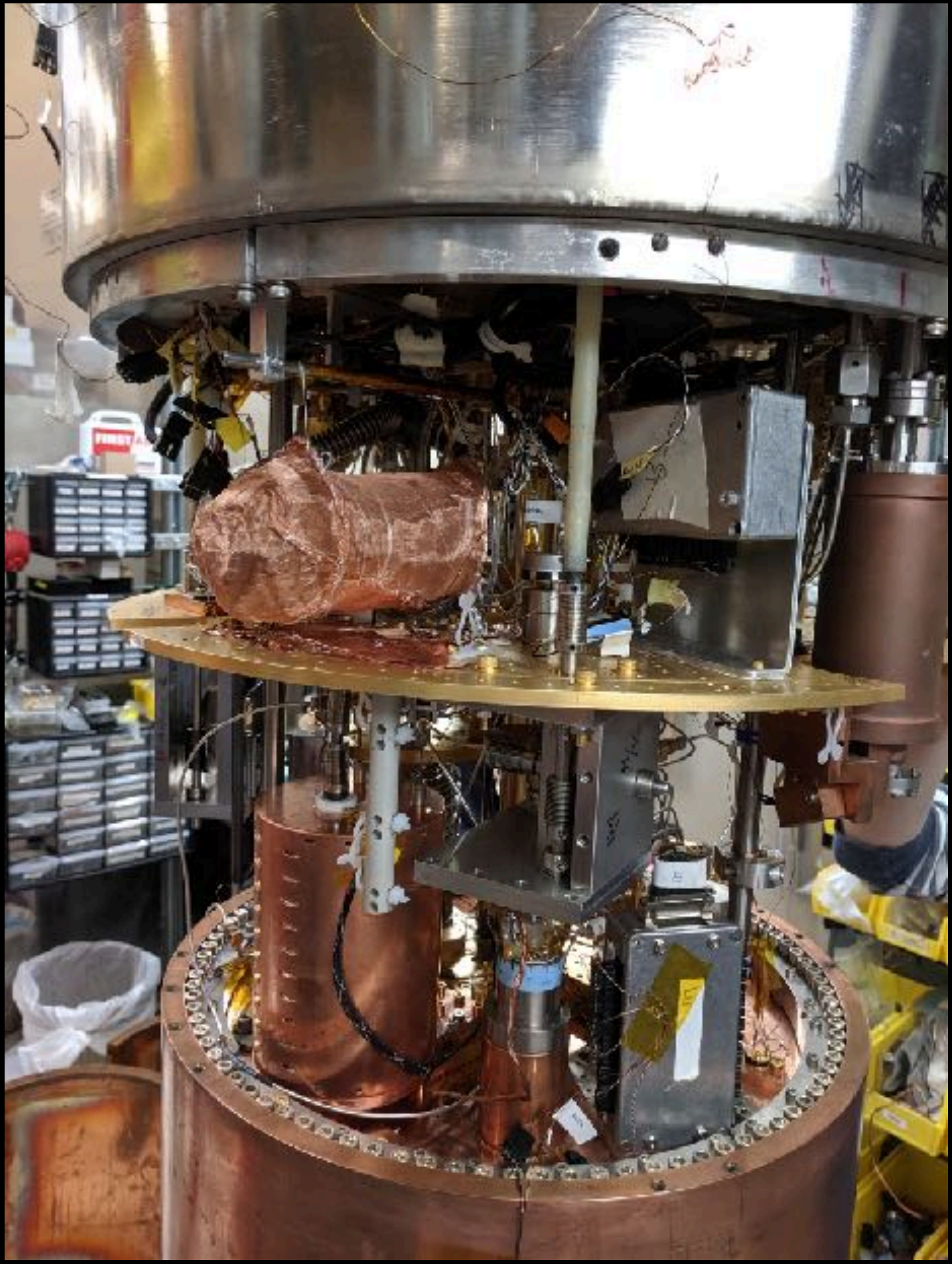
CAVITY TUNING



TUNING RODS



GEAR BOX

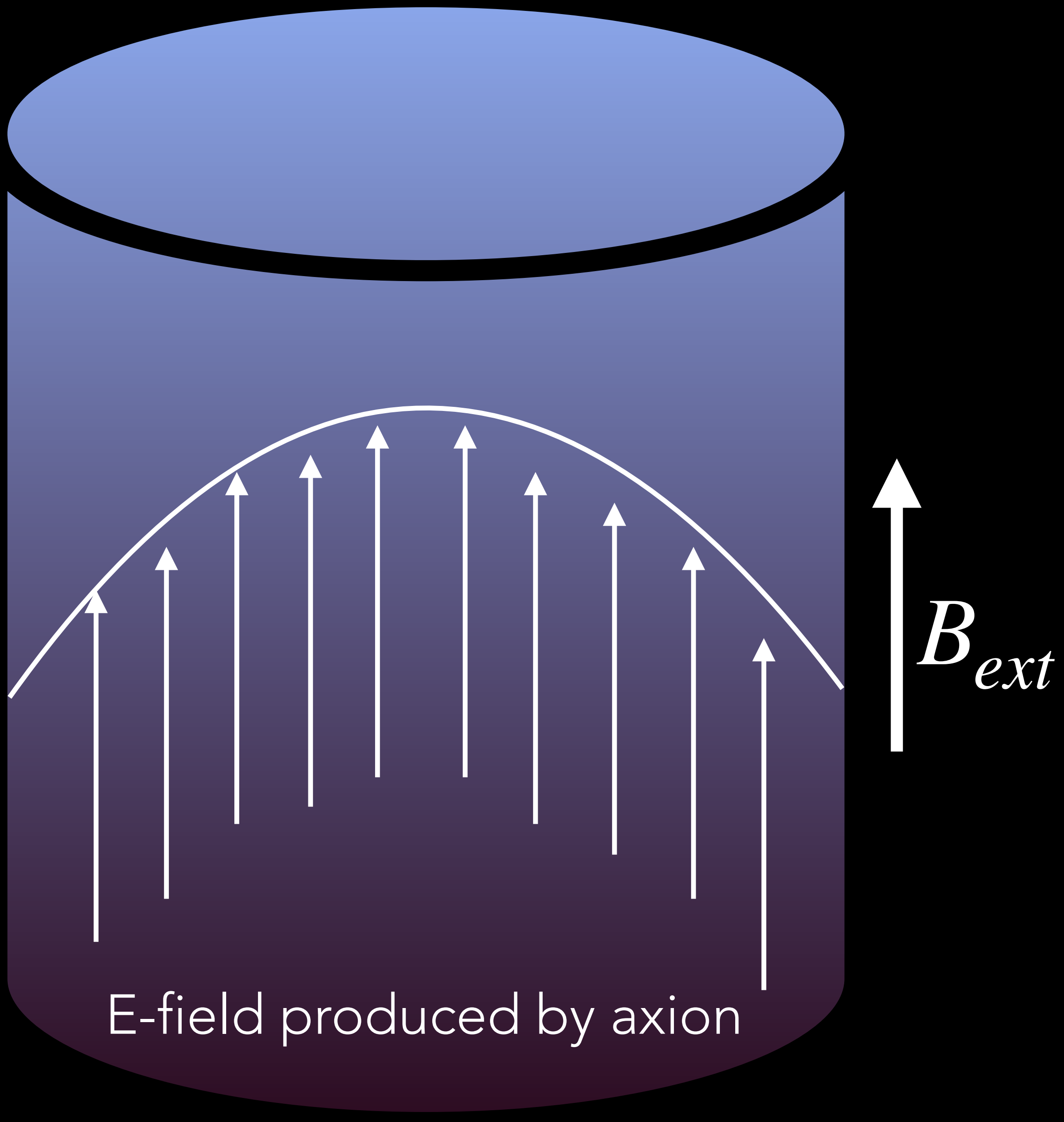


CAVITY MODE

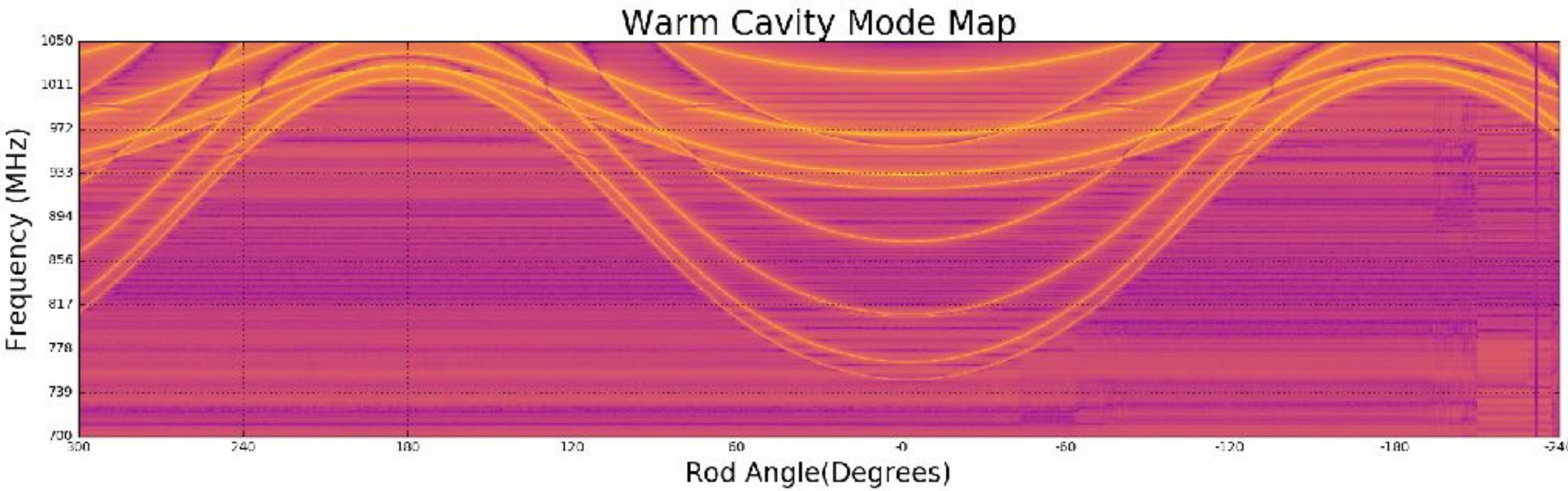
- Maxwell's equations and boundary conditions result in standing waves

- Use mode which maximizes power signal

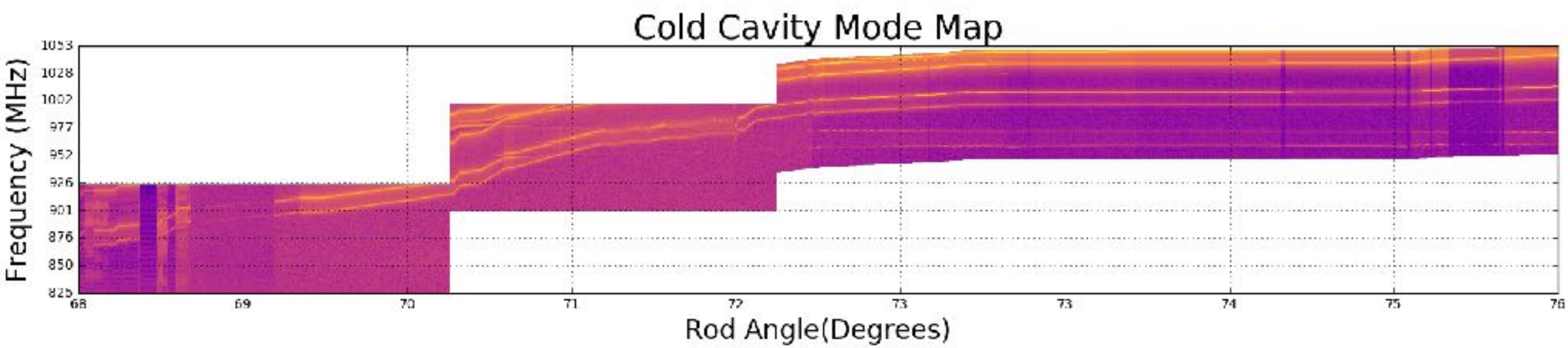
- Couple to TM_{010}, λ is twice length of cavity



TM_{010} mode in cavity


Warm Cavity Mode Map
Frequency (MHz)
Rod Angle(Degrees)

[a]


Cold Cavity Mode Map
Frequency (MHz)
Rod Angle(Degrees)

[b]

MAXIMIZE POWER SIGNAL

Form Factor

$$C_{mnp} = \frac{\left| \int_V dV E_{mnp}(x,t) \cdot B(x)_{ext} \right|^2}{V B_{ext}^2 \int_V dV \epsilon_r E_{mnp}^2}$$

Signal Power

$$P_a \propto B_{ext}^2 Q V C_{mnp}$$

$Q =$ loaded quality factor

$V =$ volume of cavity

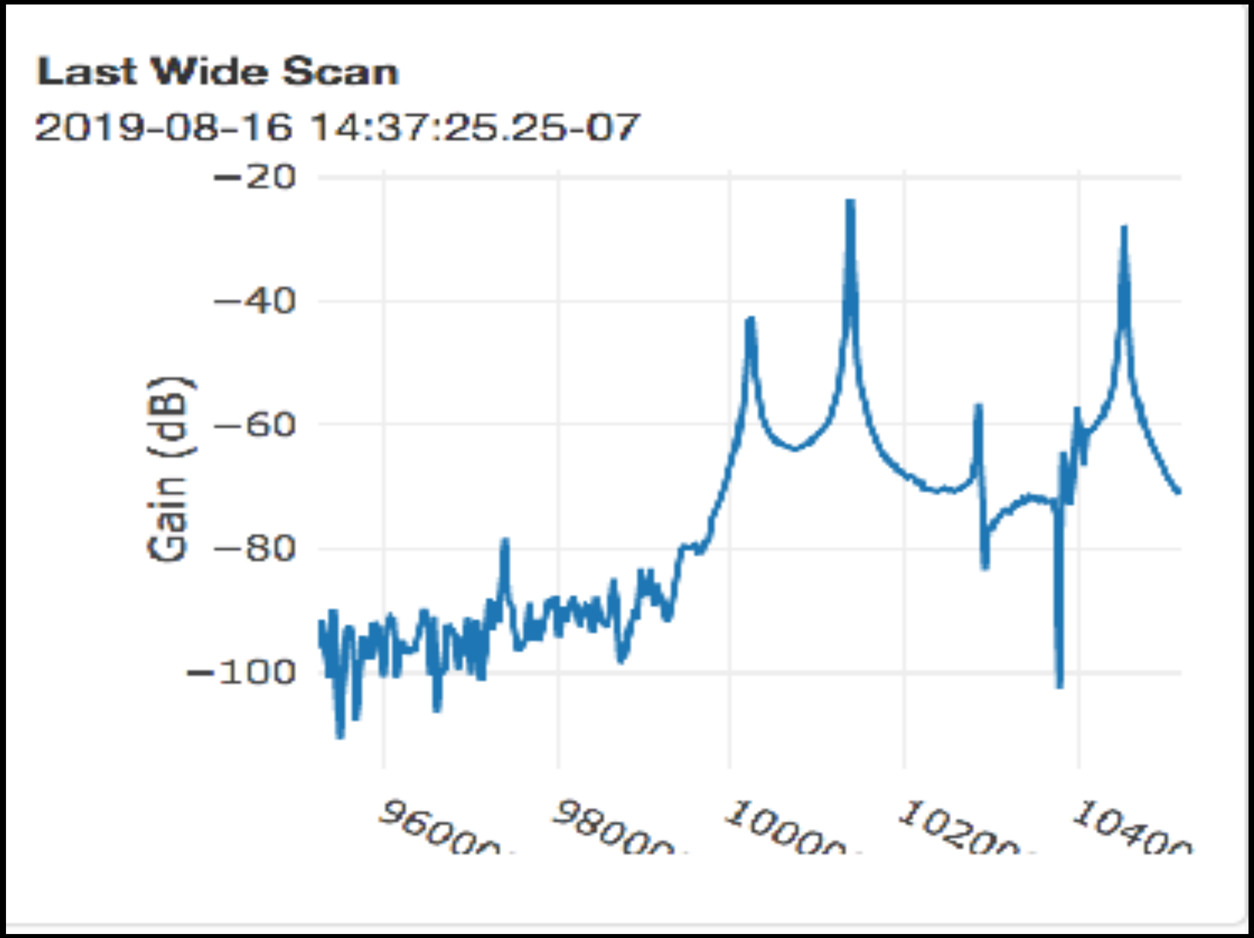
$B(x)_{ext} =$ external B-field

$E_{mnp}(x,t) =$ E-field produced by axion

$\epsilon_r =$ relative permittivity of cavity

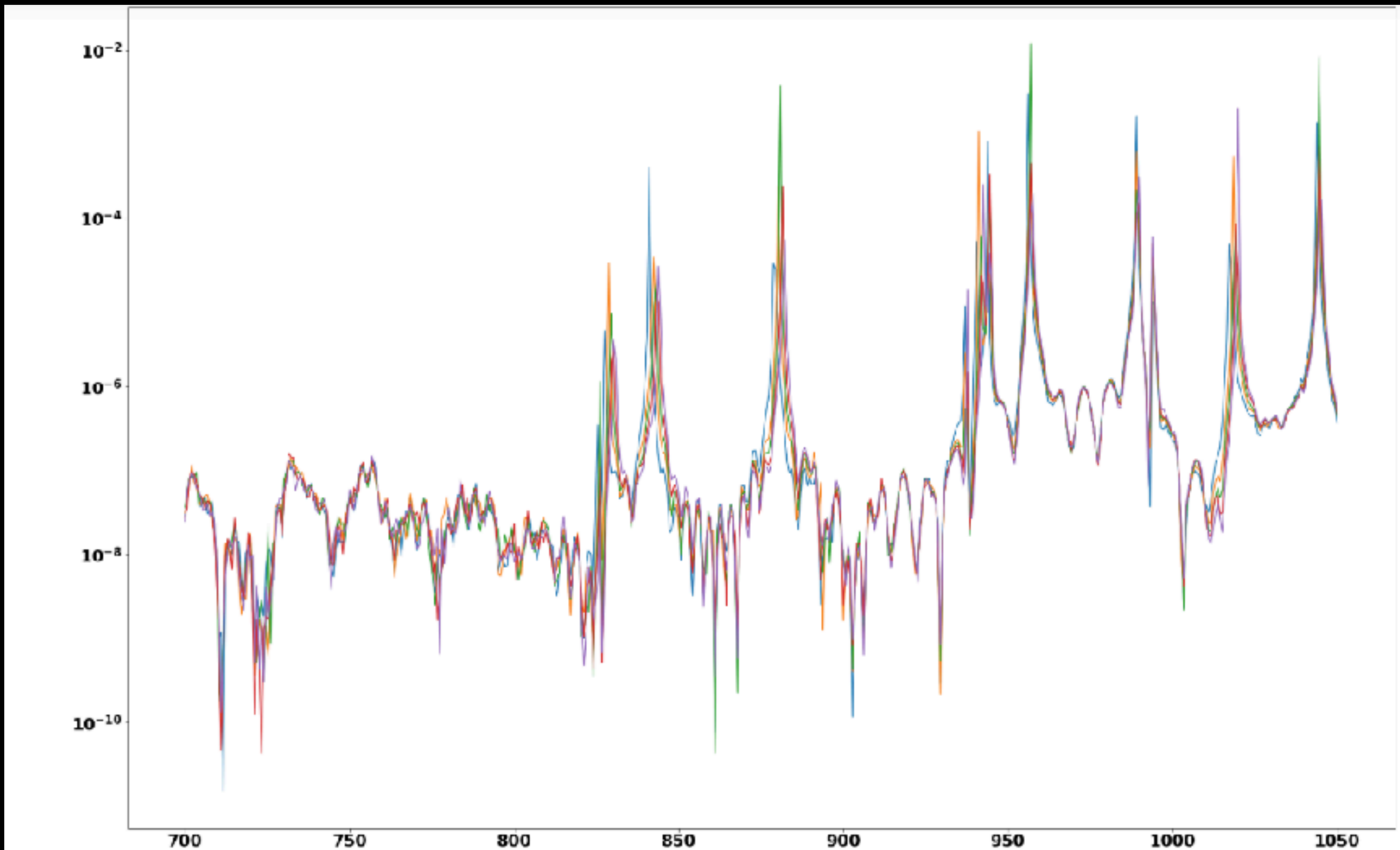
VALIDATING RESONANT MODES

- In ADMX, TM_{010} provides the largest form factor
- Frequency scanned ~700MHz - 1GHz
- Can track this mode using network analyzer transfer measurements
  - Mode map



Frequency (Hz)

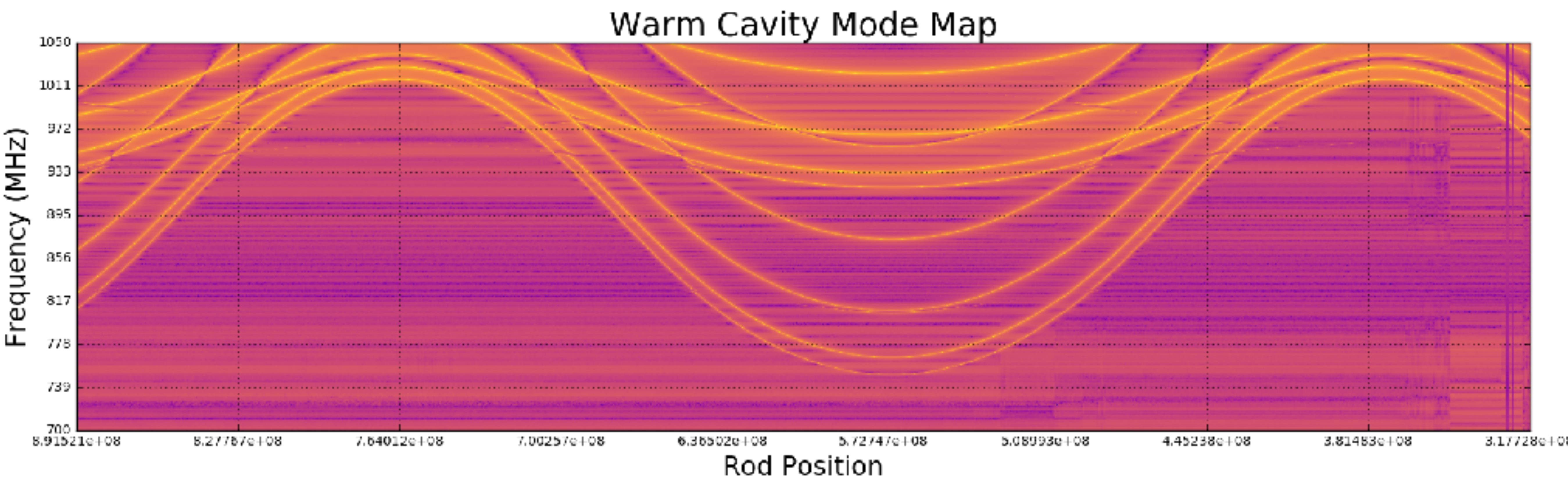
WIDE SCANS

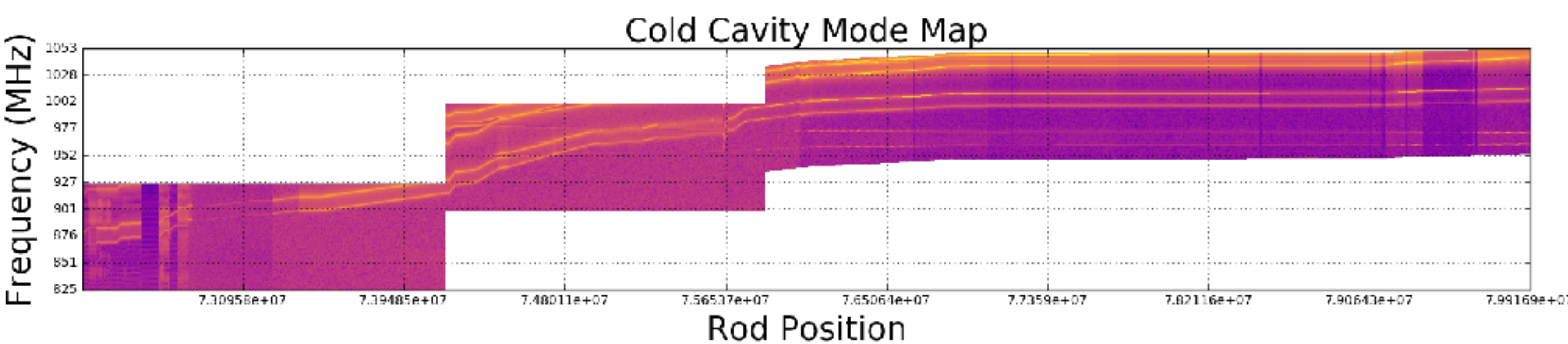


Transmission (dB)

Frequency (MHz)

MODE MAPS


Warm Cavity Mode Map
Frequency (MHz)
1050
1011
972
933
895
856
817
778
739
700
8.91521e+08
8.27767e+08
7.64012e+08
7.00257e+08
6.36502e+08
5.72747e+08
5.08993e+08
4.45238e+08
3.81483e+08
3.17728e+08
Rod Position


Cold Cavity Mode Map
Frequency (MHz)
1053
1028
1002
977
952
927
901
876
851
825
7.30958e+07
7.39485e+07
7.48011e+07
7.56537e+07
7.65064e+07
7.7359e+07
7.82116e+07
7.90643e+07
7.99169e+07
Rod Position

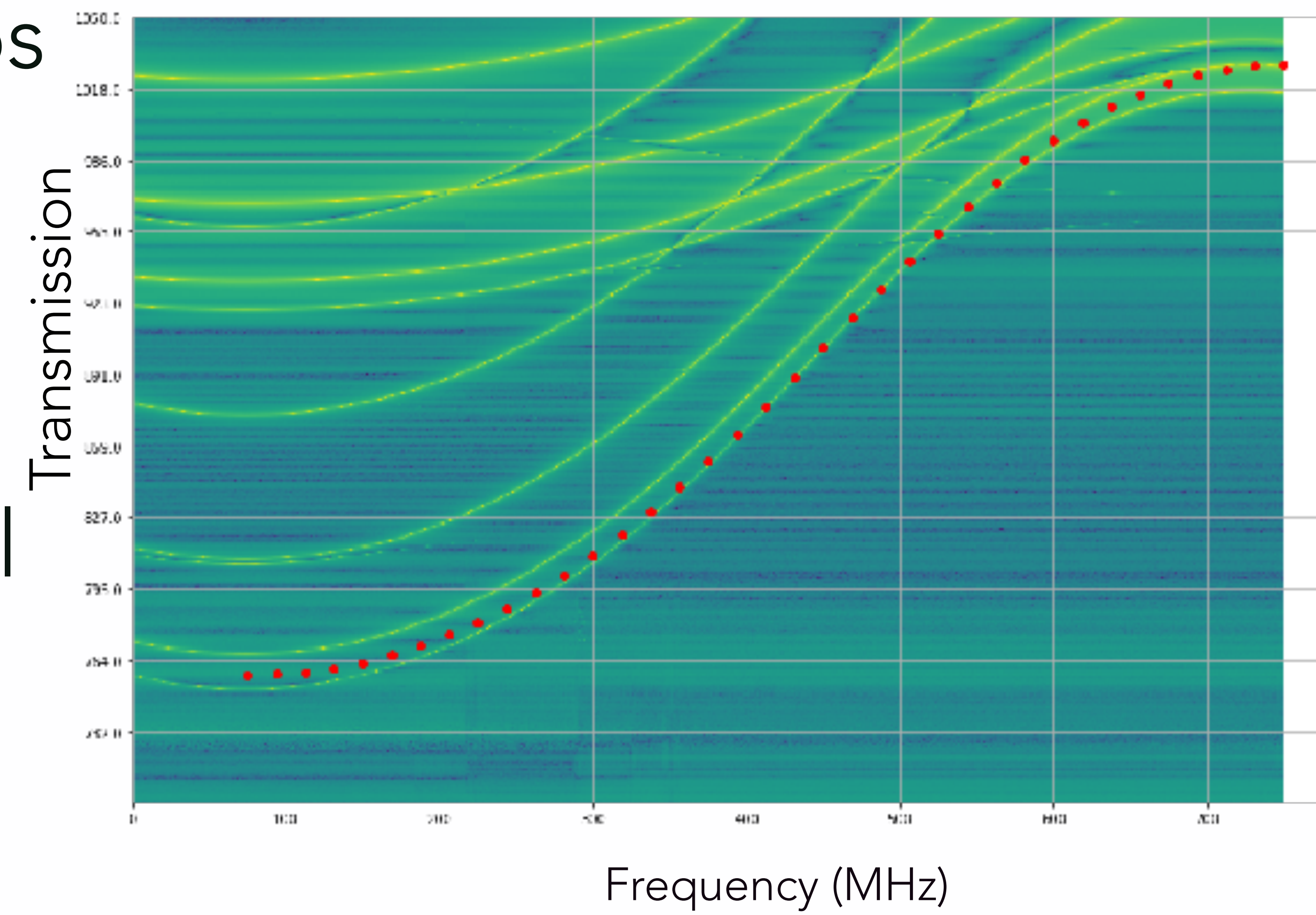
CONCLUSIONS

- We have the reliable means of making mode maps for all future scans

- Can be used for both symmetric and antisymmetric mode maps

FUTURE WORK

- Will be able to compare mode maps to predicted simulations
- Can validate optimal axion-sensitive resonant modes in future ADMX operations



ACKNOWLEDGEMENTS

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CITATIONS

- Brubaker, B.(2018). First results from the HAYSTAC axion search (Ph.D Thesis)

- Du, N. Et al. (ADMX Collaboration), Phys. Rev. Lett. 120, 151301 (2018).