Microwave Resonant Cavities

in the Search for Dark Matter Axions

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REU FINAL REPORT

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Outline

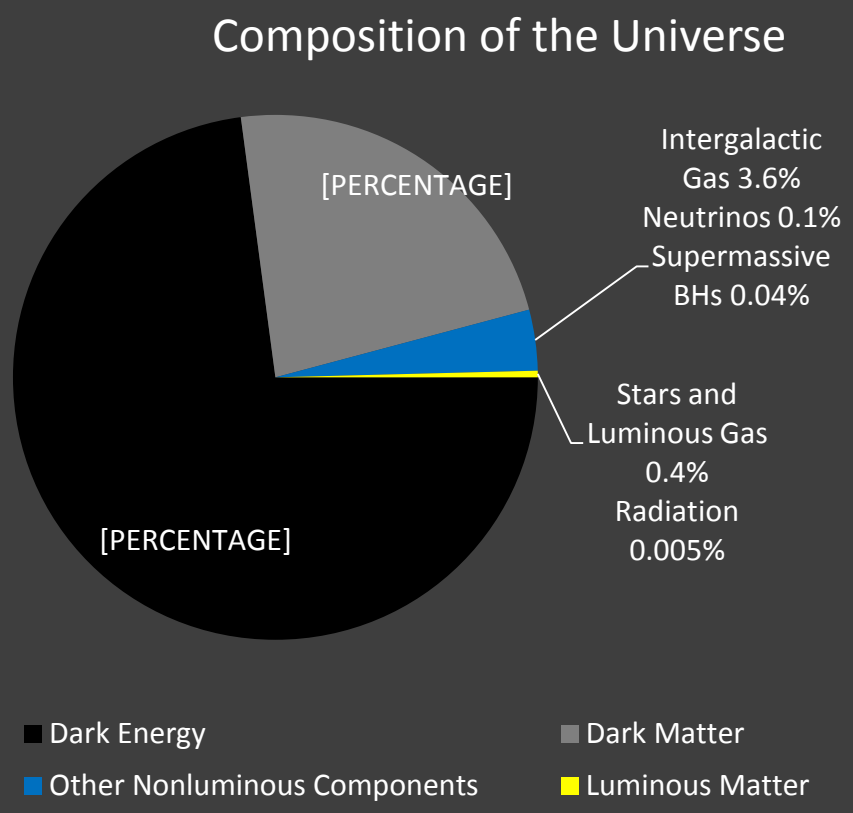
- Background
  - Problems: Dark Matter and the Strong CP Problem
  - Solution: Axions
- Searching for Axions
  - Resonant Cavities
  - ADMX
- What I Did All Summer
  - Cavity Design and Construction
  - Testing
  - Results
- Conclusion
- Acknowledgements

Dark Matter

WHAT IS DARK MATTER?

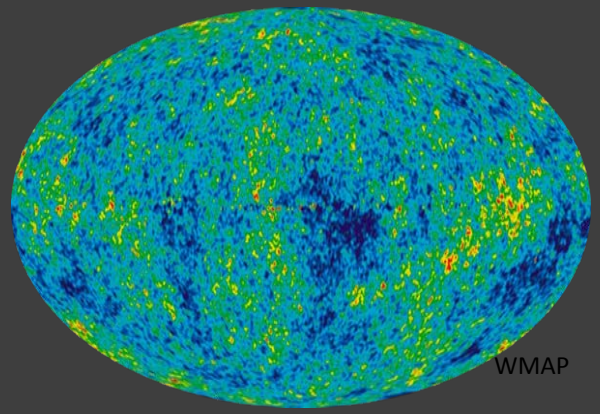
We Have No Idea

We (maybe) understand ~4% of our universe



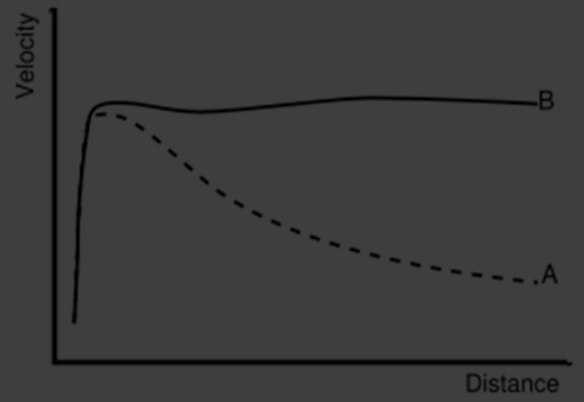
Evidence for Dark Matter

- CMB Data
- Bullet Cluster
- Galactic Rotation Curves



WMAP

Composite: NASA, Markevitch et al., Clowe et al.



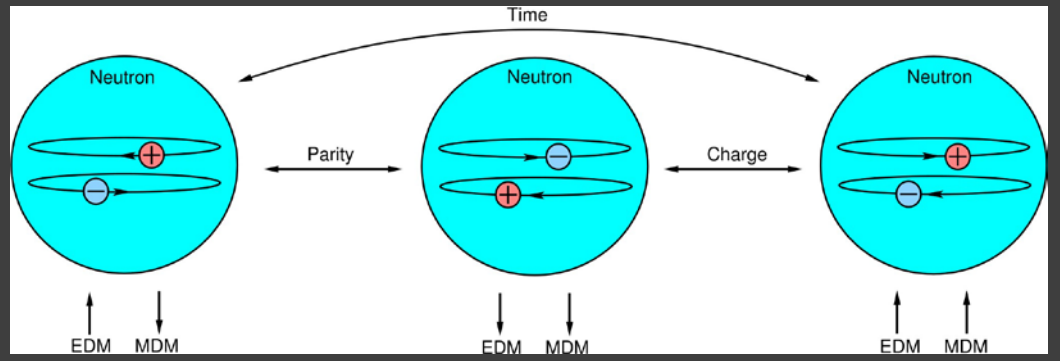
Strong CP Problem

WHY IS IT A PROBLEM?

CP Violation

- QCD is expected to violate CP by the Standard Model

- Lack of neutron electric dipole moment
  - Strong force is CP invariant → Strong CP Problem



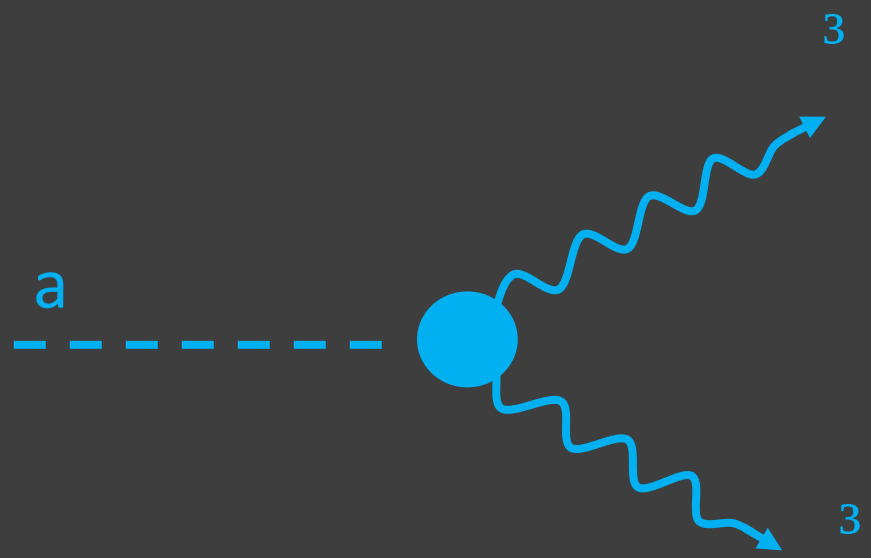
Axions

TO THE RESCUE

What are Axions?

- A solution to the Strong CP Problem purposed by Peccei and Quinn (1977)
  - Posit a hidden broken symmetry
  - New particle (Weinberg, Wilczek)

- Decays into two photons
  - Has a lifetime of 10^{50} seconds



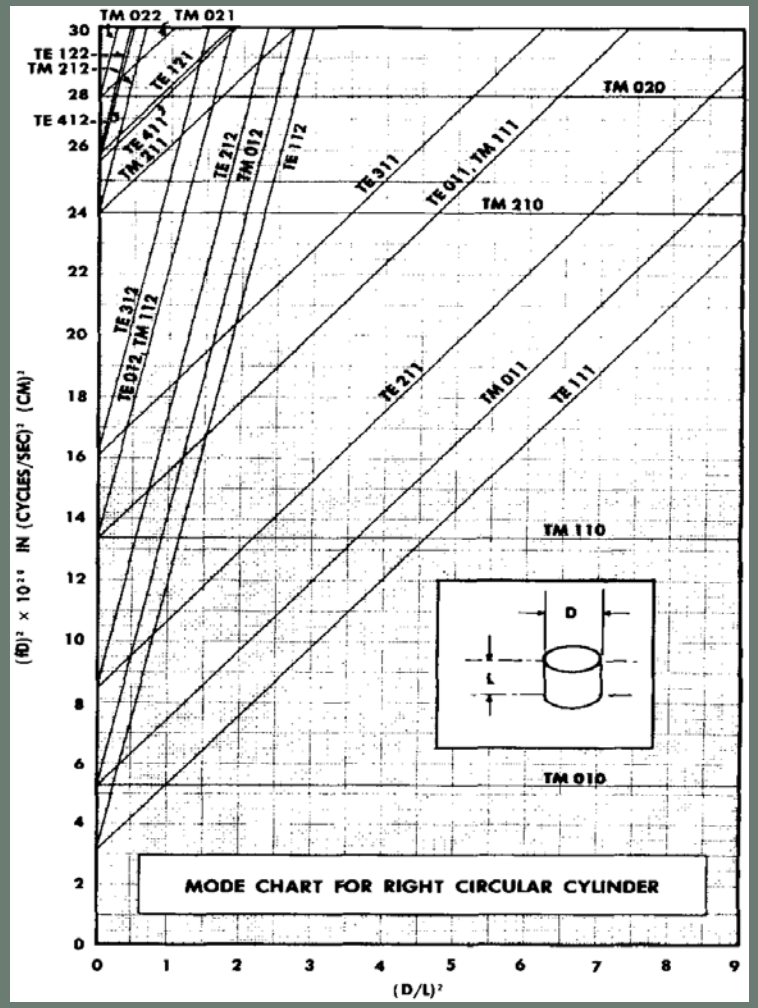
Axions as Dark Matter

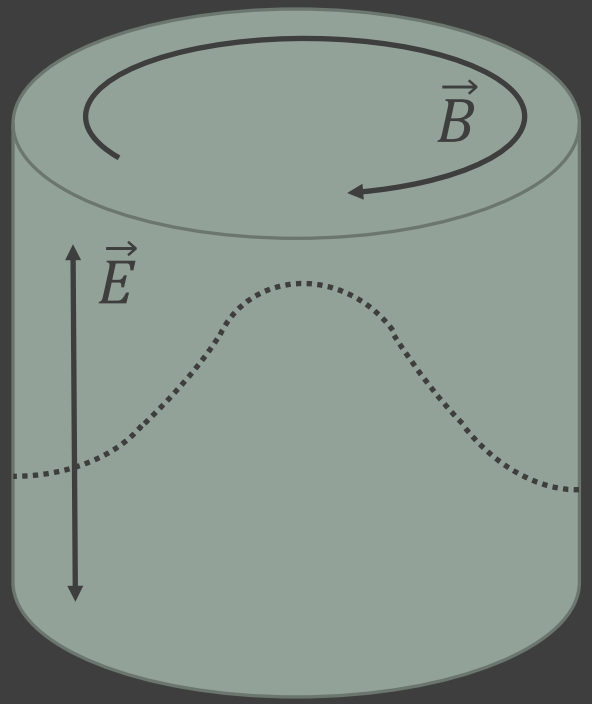
- At light masses, axions are excellent candidates for dark matter
- $\sim 1\mu eV < m_a < \sim 100\mu eV$
  - Abundant particle
    - Found everywhere – in our solar system, this room, under your bed
    - $\sim 10^{15}$/cc
- Very weak coupling to ordinary matter

Searching for Axions

WITH RF CAVITIES

Resonant Cavities





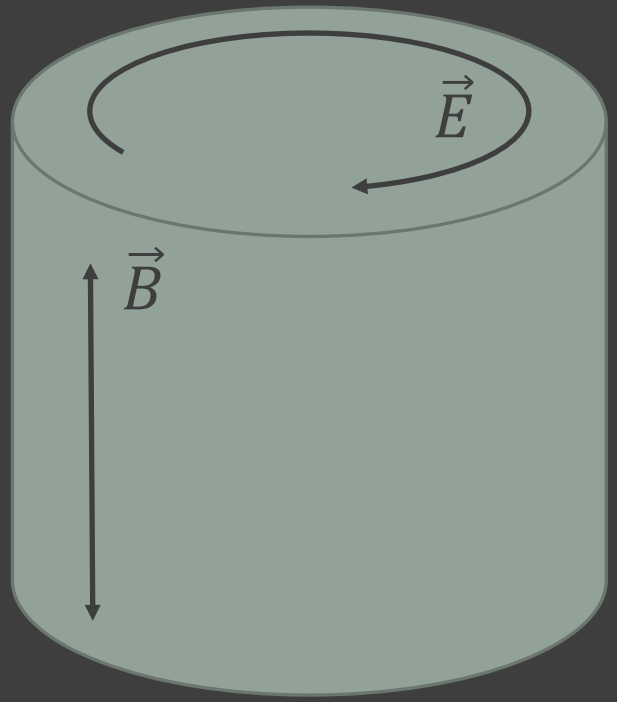
← TM Modes

TM_{010}

Main mode for axion conversion

$f_{TM_{010}} \sim \frac{1}{D}$

TE Modes →



The Hunt

- Dark Matter axions convert to photons in a magnetic field
  - Strong magnetic field greatly reduces lifetime
    (Inverse Primakoff Effect)
  - Better measurement if photon frequency corresponds to cavity's resonant frequency

- **What you want:**
  - Large Cavity Volume
  - Large Quality Factor
  - Large Magnetic Field

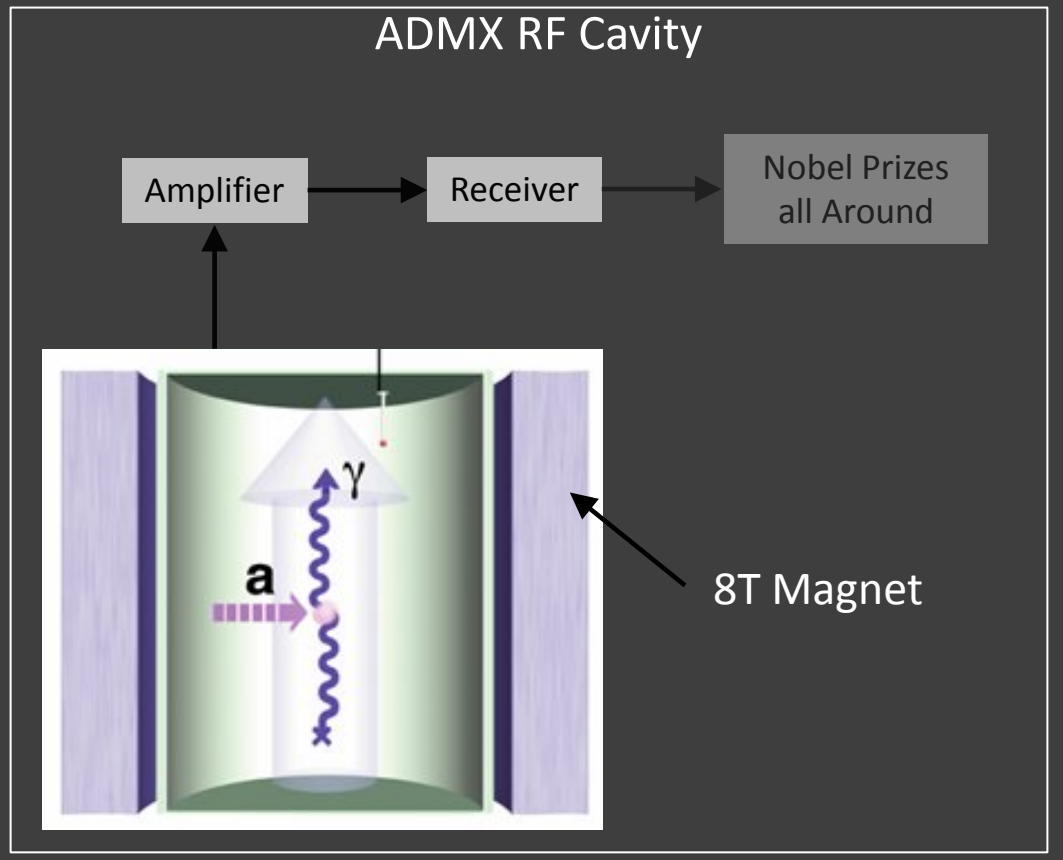
What You Don't Want:

- Large Noise
  - Thermal
  - Amplifier

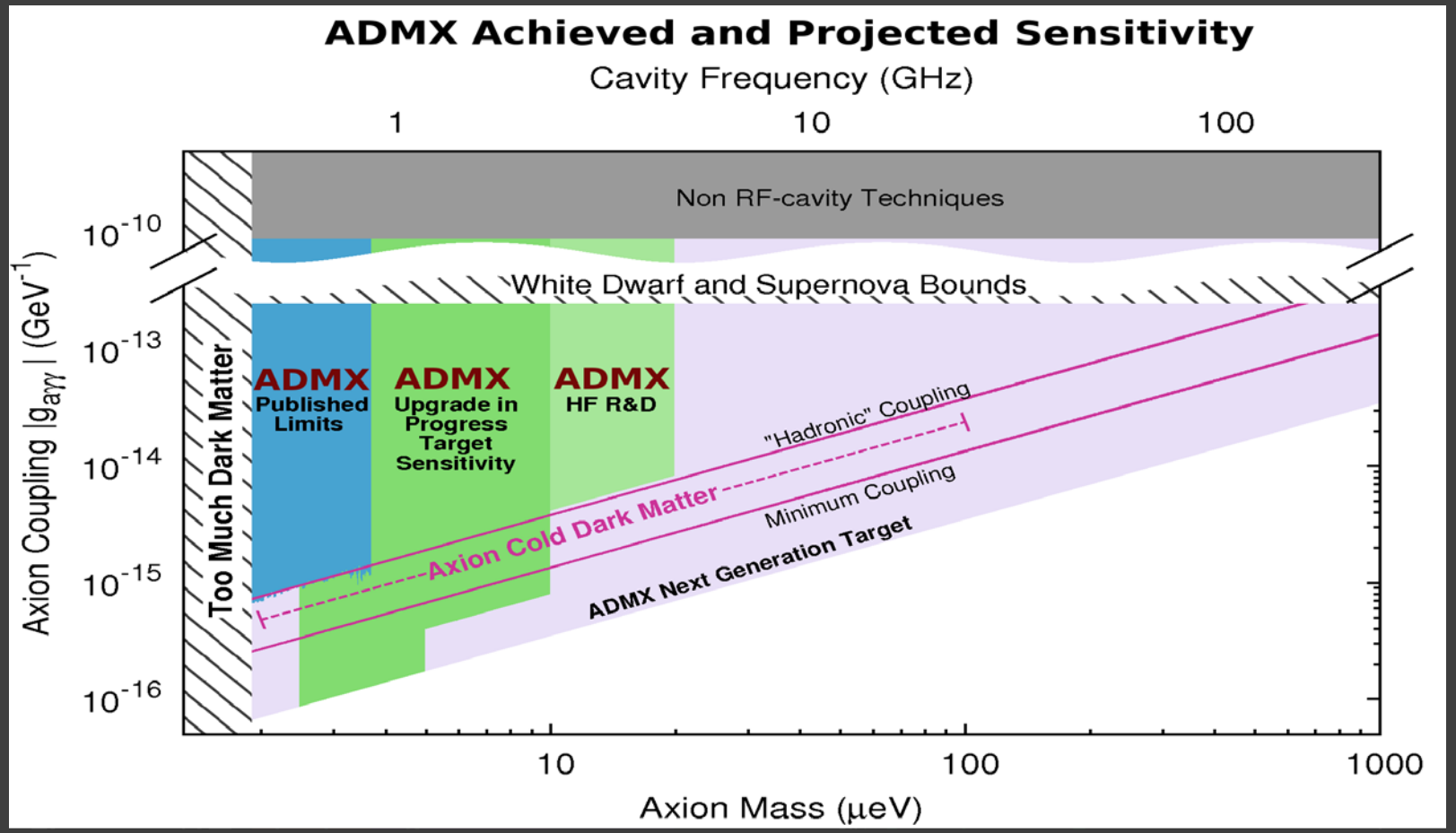
- **Also want**: ability to search over many frequencies

ADMX Axion Dark Matter eXperiment

- Approximately 1m length × 0.5m diameter
- Large – 8 Tesla – magnet
- Cryogenic temperatures – 100mK
- SQUID amplifiers
- Tuning rods to change cavity frequency



ADMX Search Range



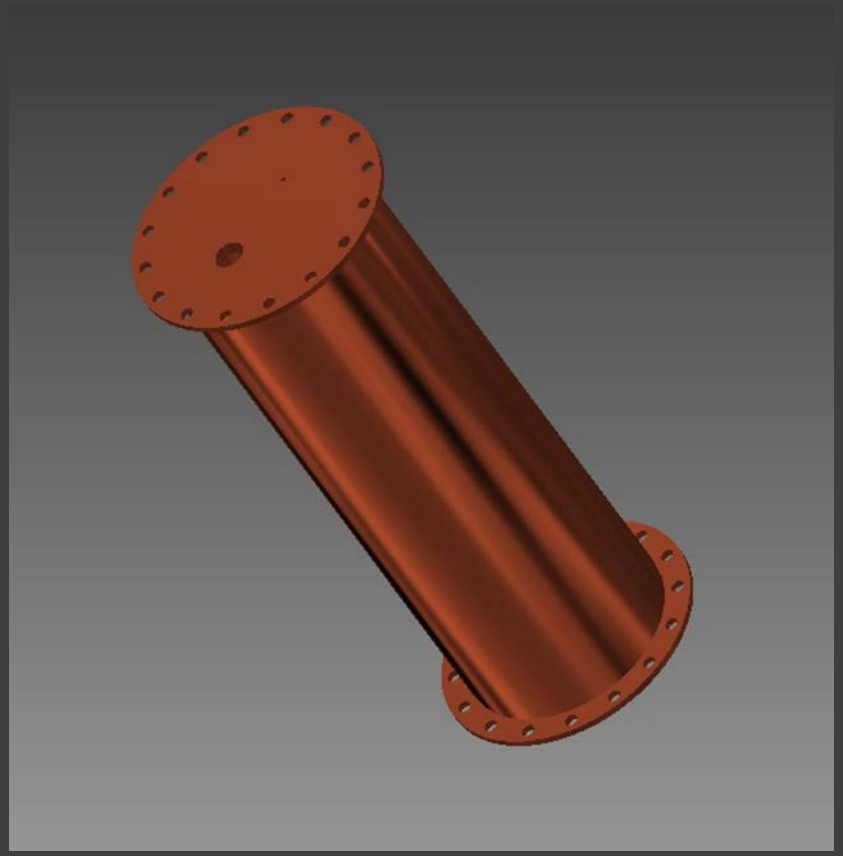
Resonant Cavities

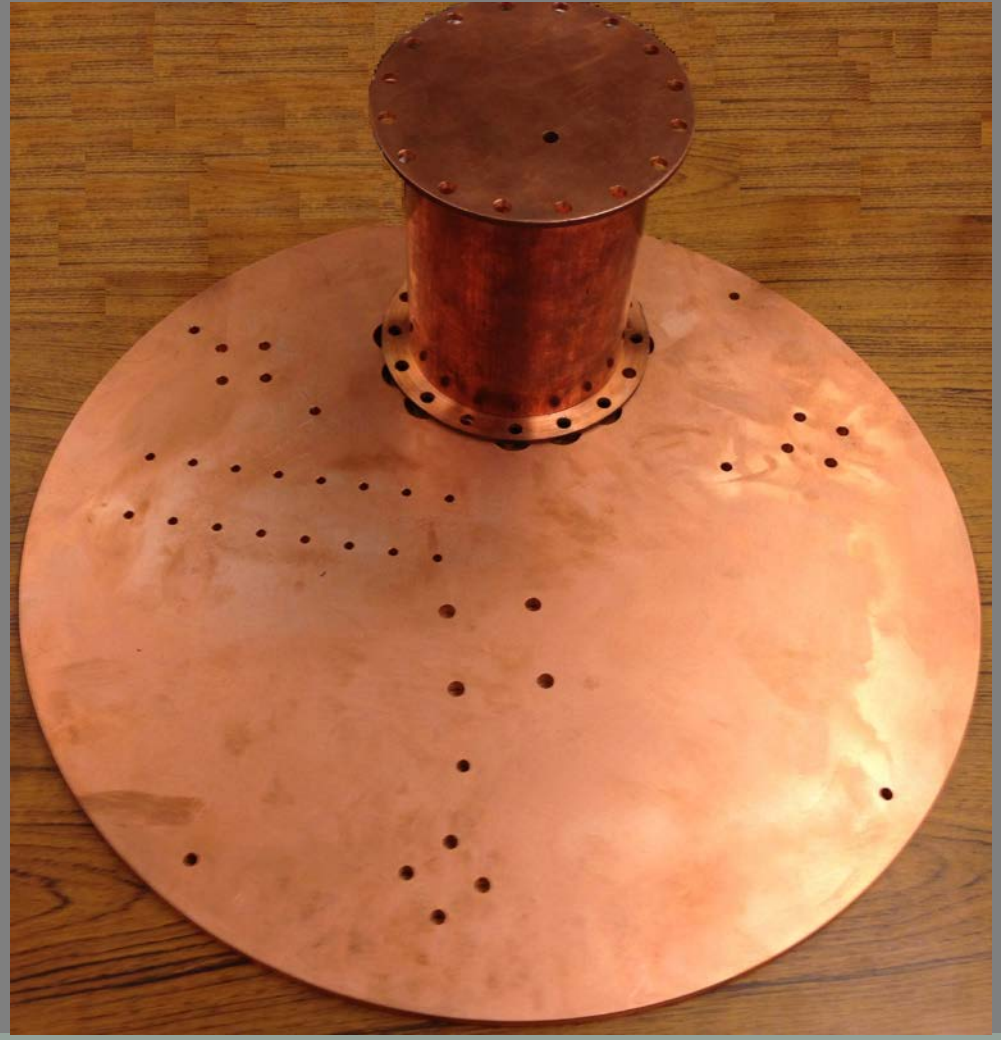
AND ME

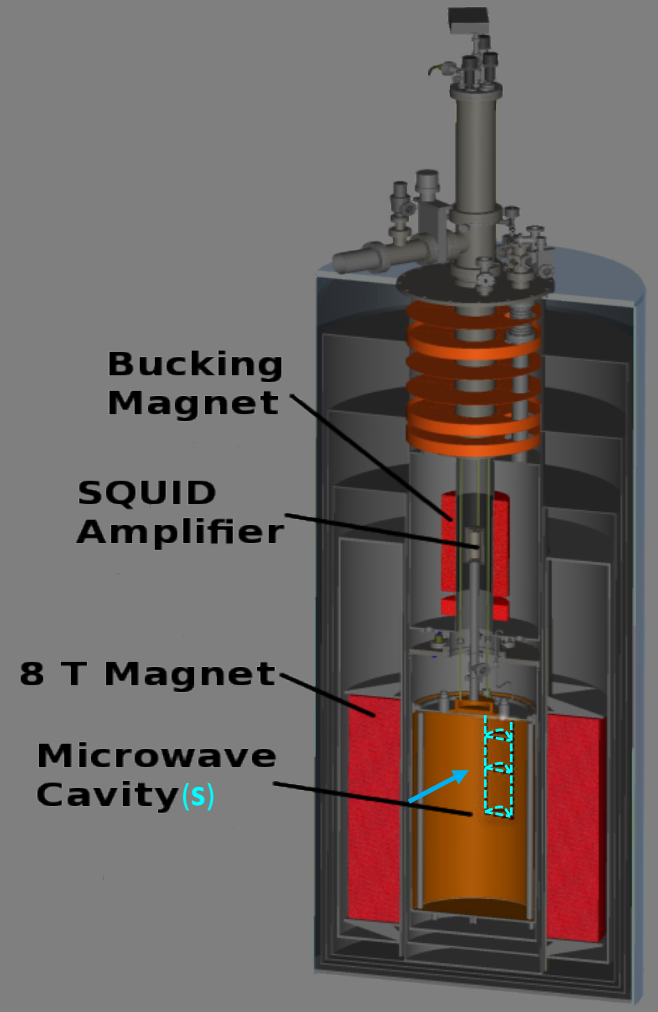
Parameters for Design

- Higher Frequencies
  - $f_{TM_{010}} \sim \frac{1}{D}$ means small diameter
  - Intend range: roughly 2 – 5 GHz → 3.5” diameter
- High Electrical Conductivity
  - Copper
- Study Various Mode Structures
  - Multiple cavities of different lengths

Design and Construction





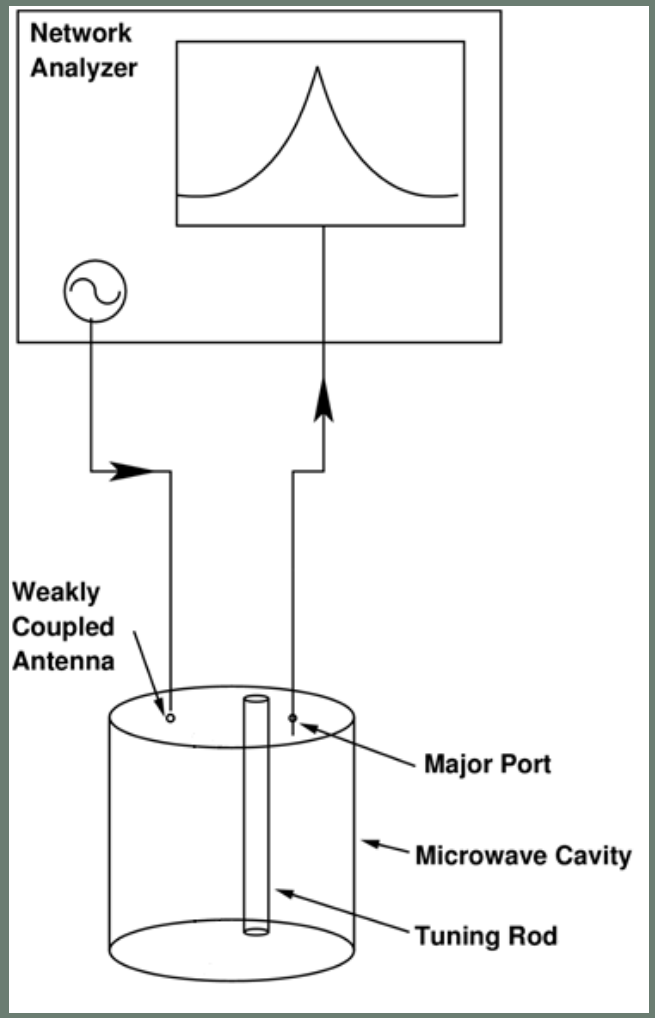


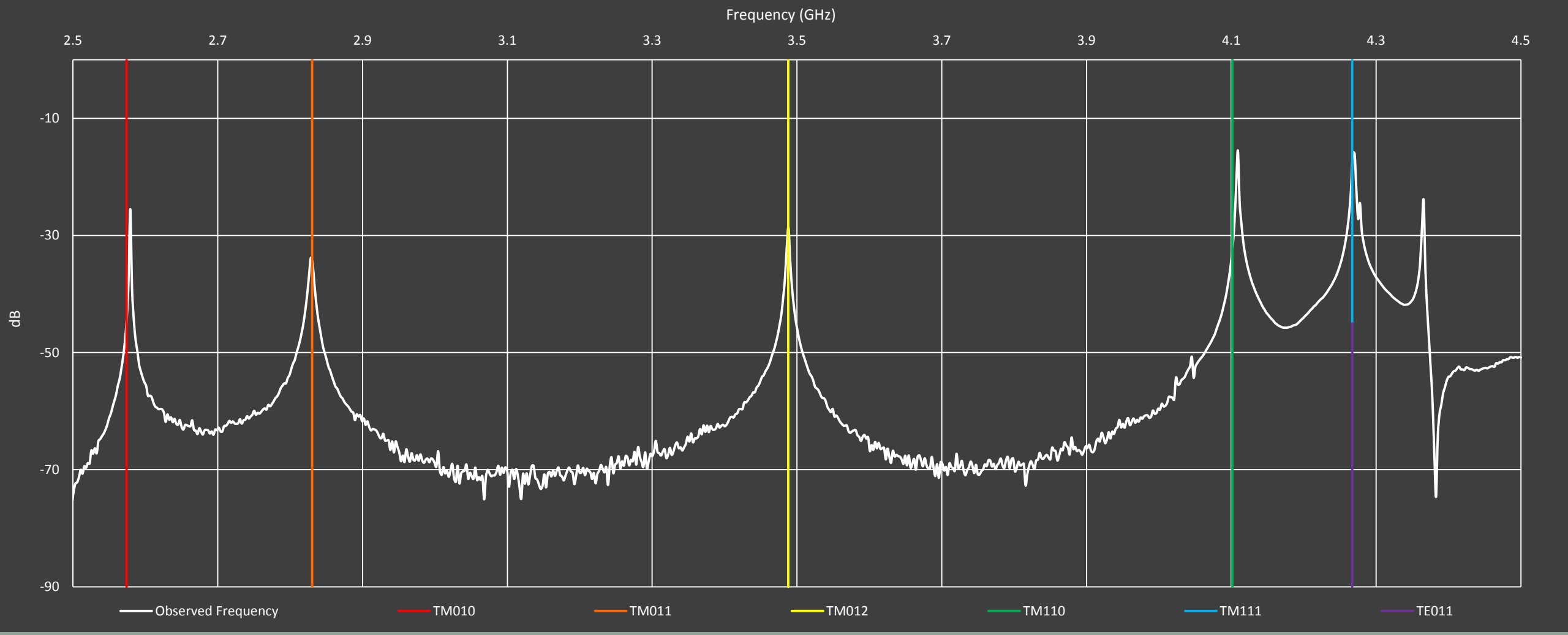
Fitting In

With ADMX

Testing

- Two antenna probes
  - Measure Log |transmission|
  - Weakly coupled
- Variable frequency source
  - Sweep across a range of frequencies
- Three different lengths
  - Study different mode structures



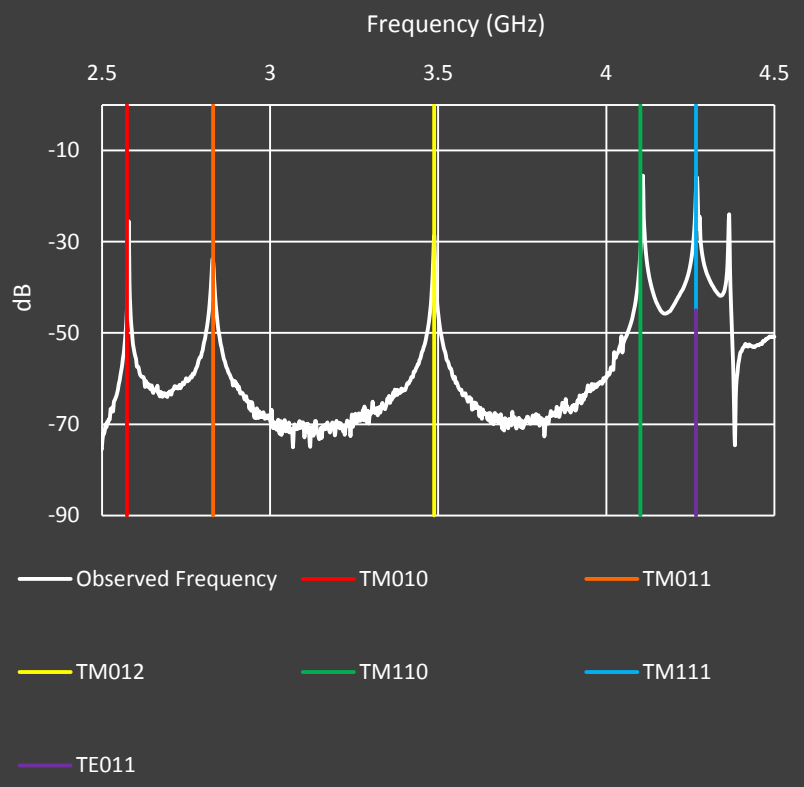


Small Cavity Frequency Measurements

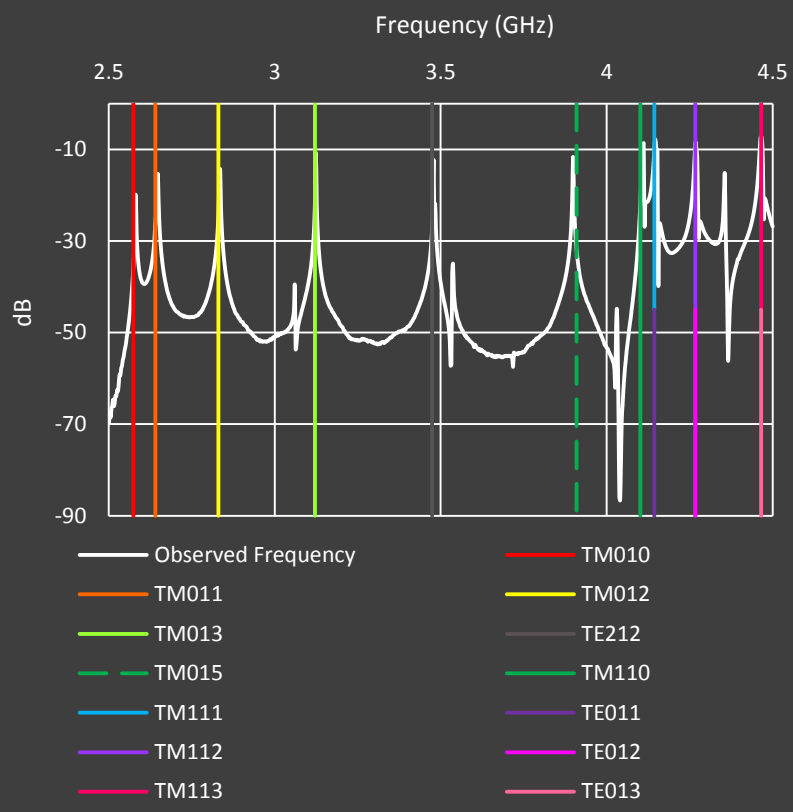
Frequency of the small, empty cavity as observed compared with the expected frequencies of various modes

Empty Cavity Measurements

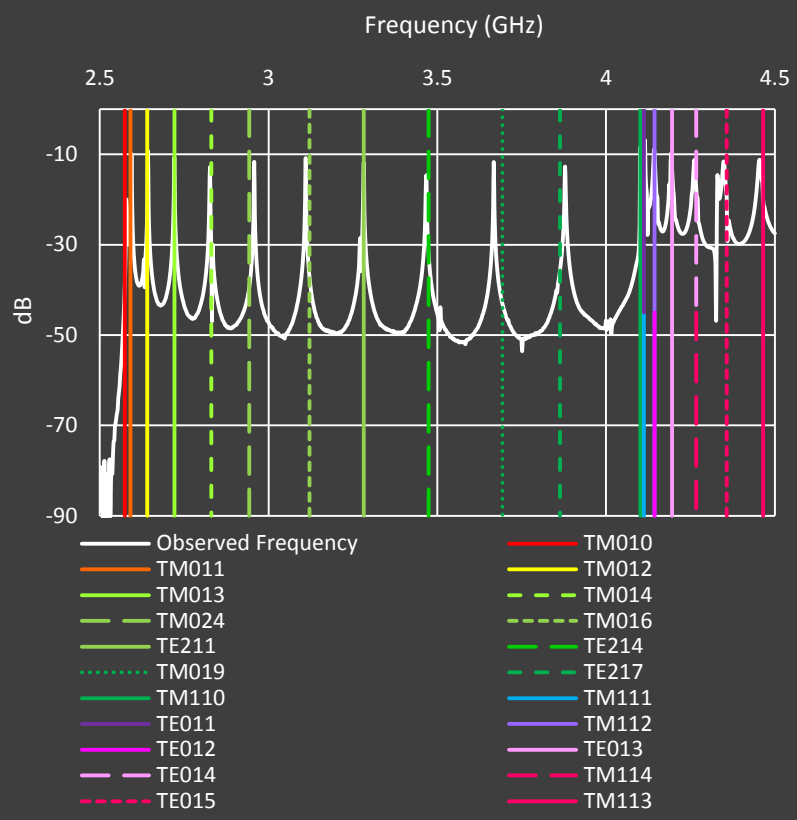
SMALL



MEDIUM

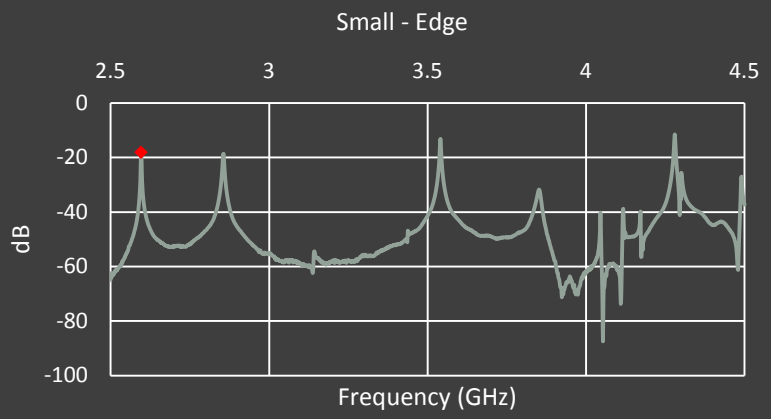


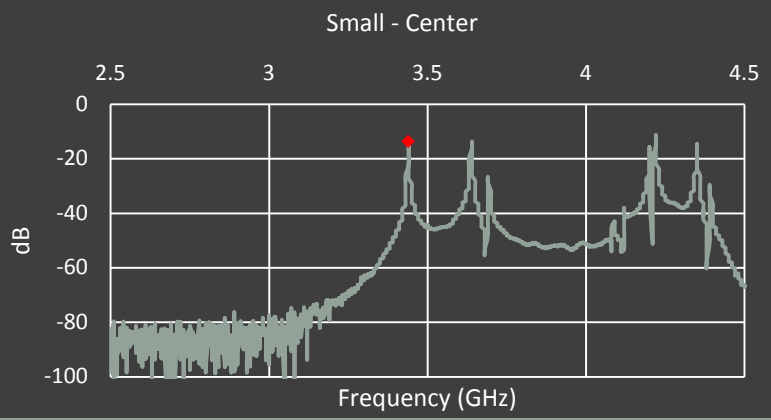
LARGE



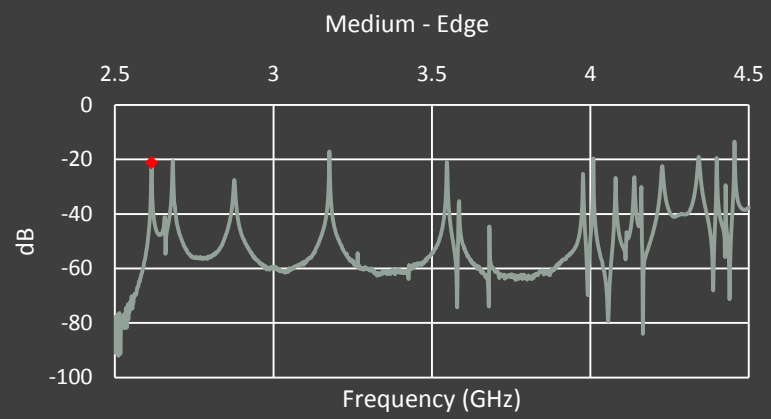
Measurements with Rod

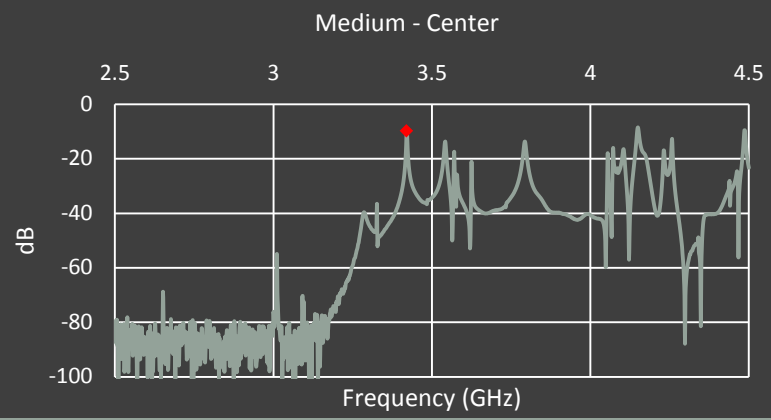
SMALL





MEDIUM





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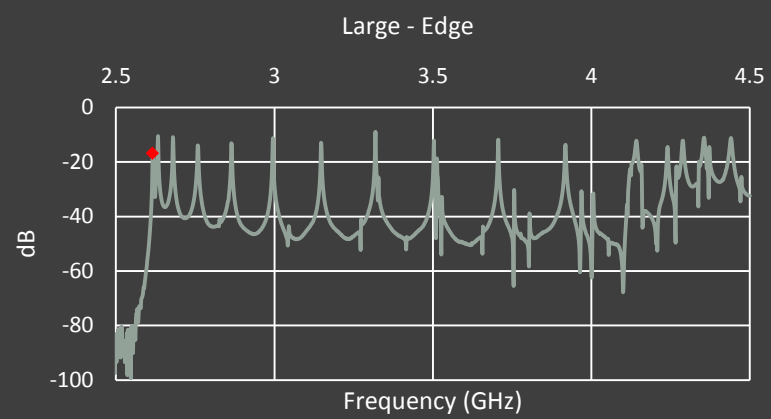
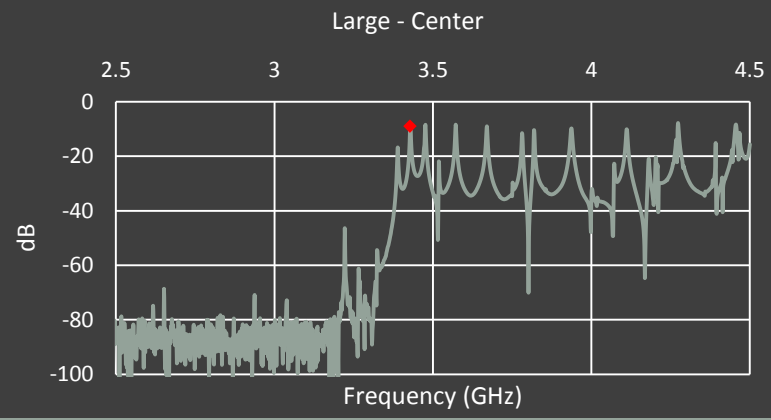
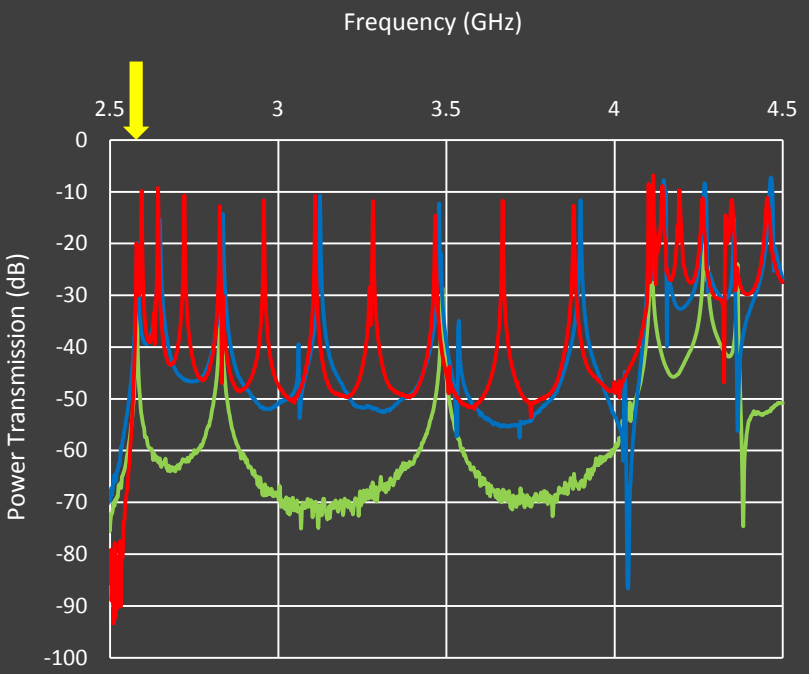




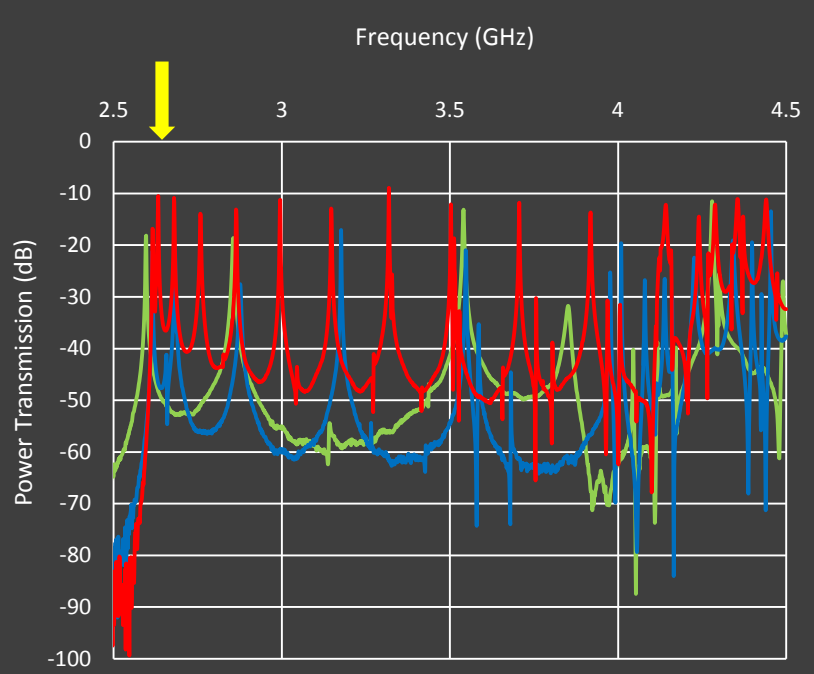
Comparisons

of frequencies of each cavity length at different rod positions

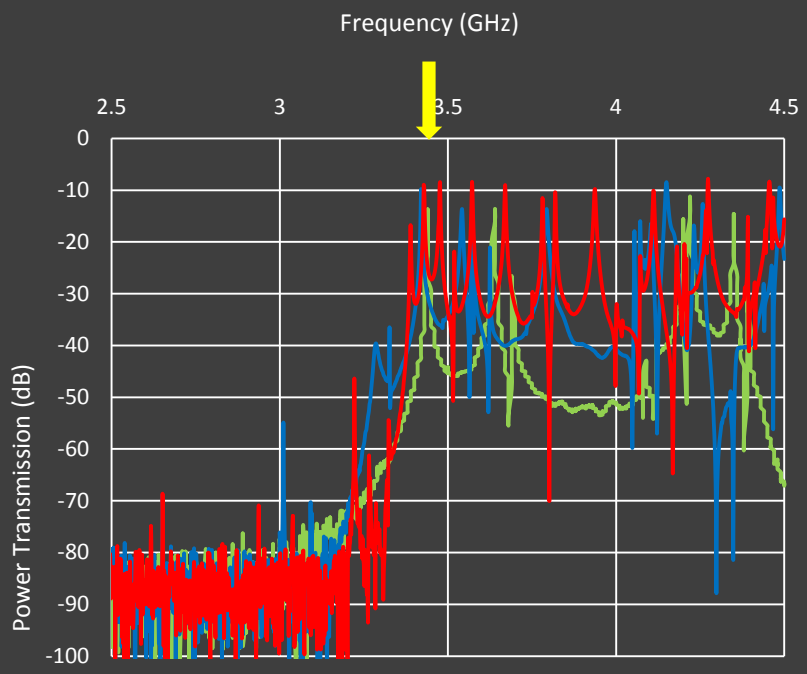
EMPTY



EDGE



CENTER

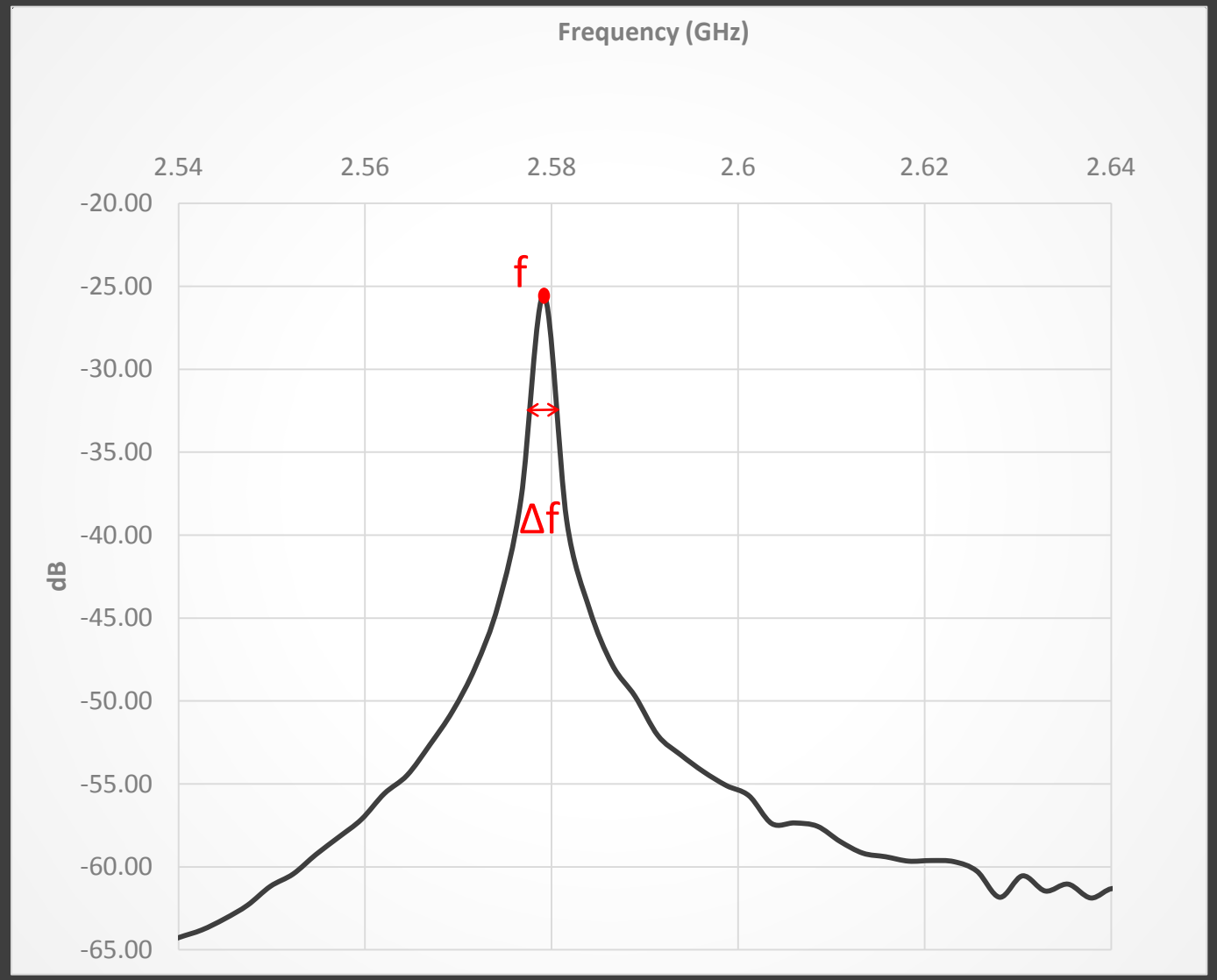


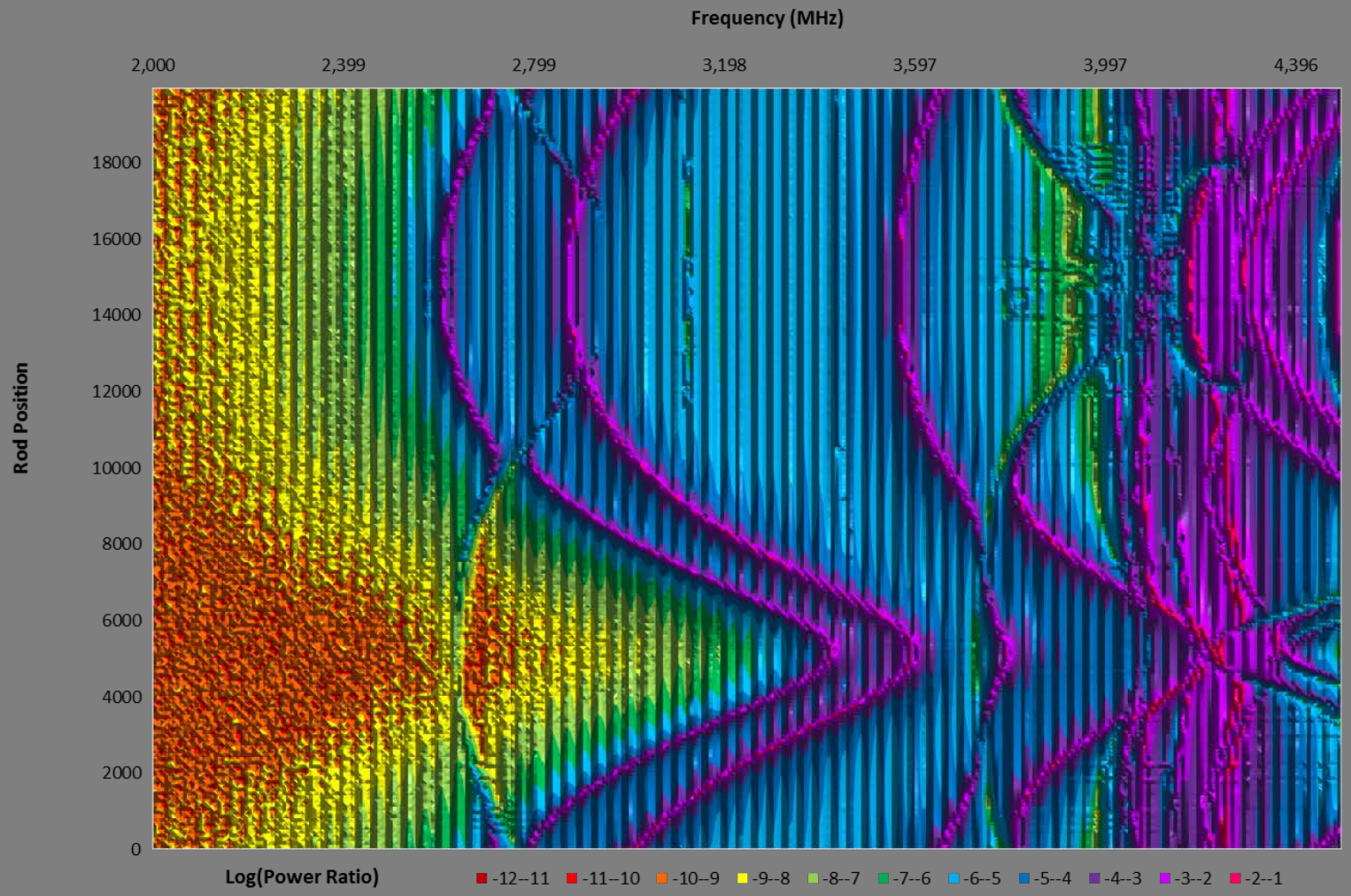
Small Medium Large

TM010

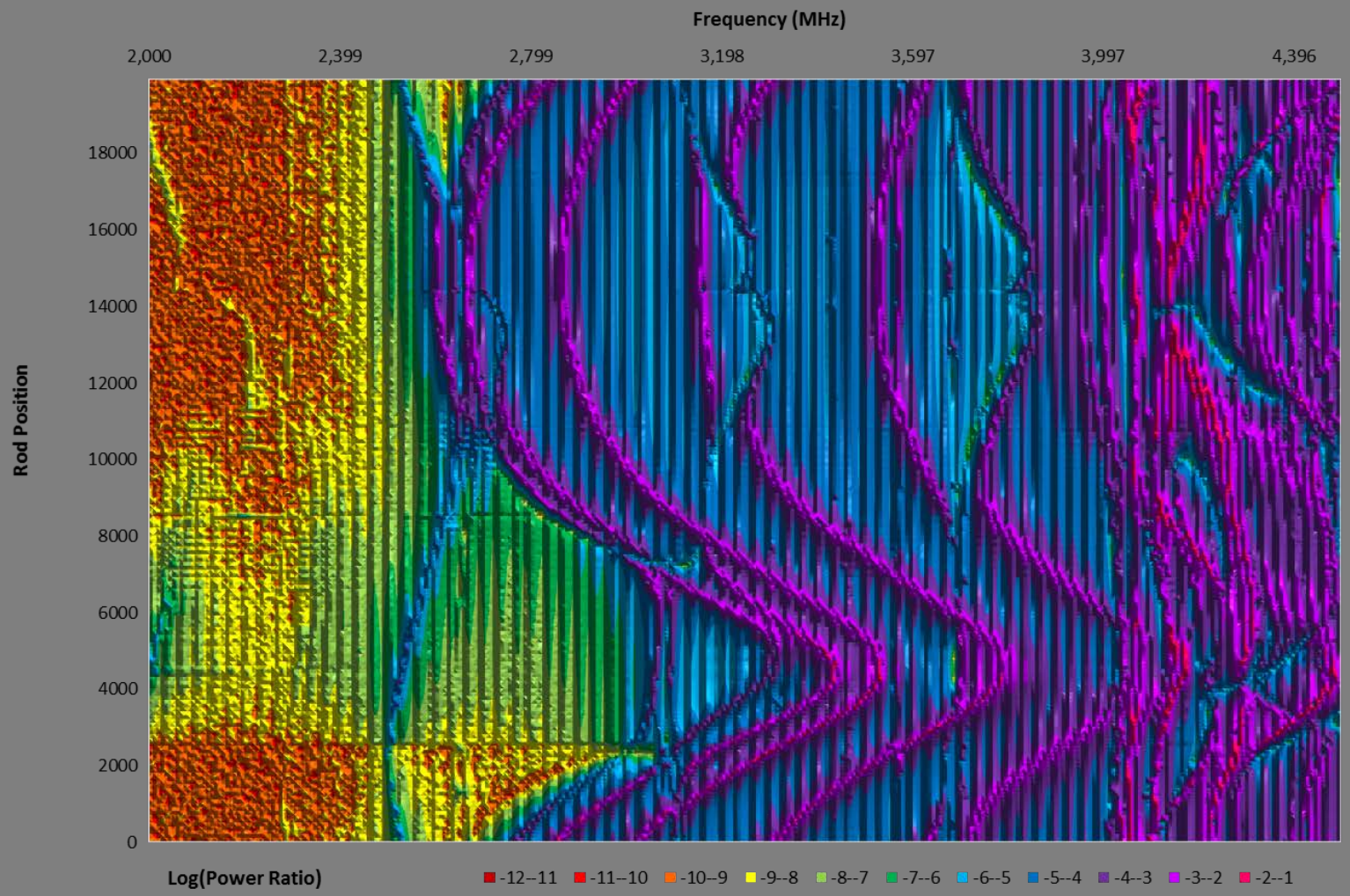
Quality Factor

- $Q = \frac{f}{\Delta f}$
- Q ≈ 2000
- Less than expected
  - low data resolution
  - room temperature

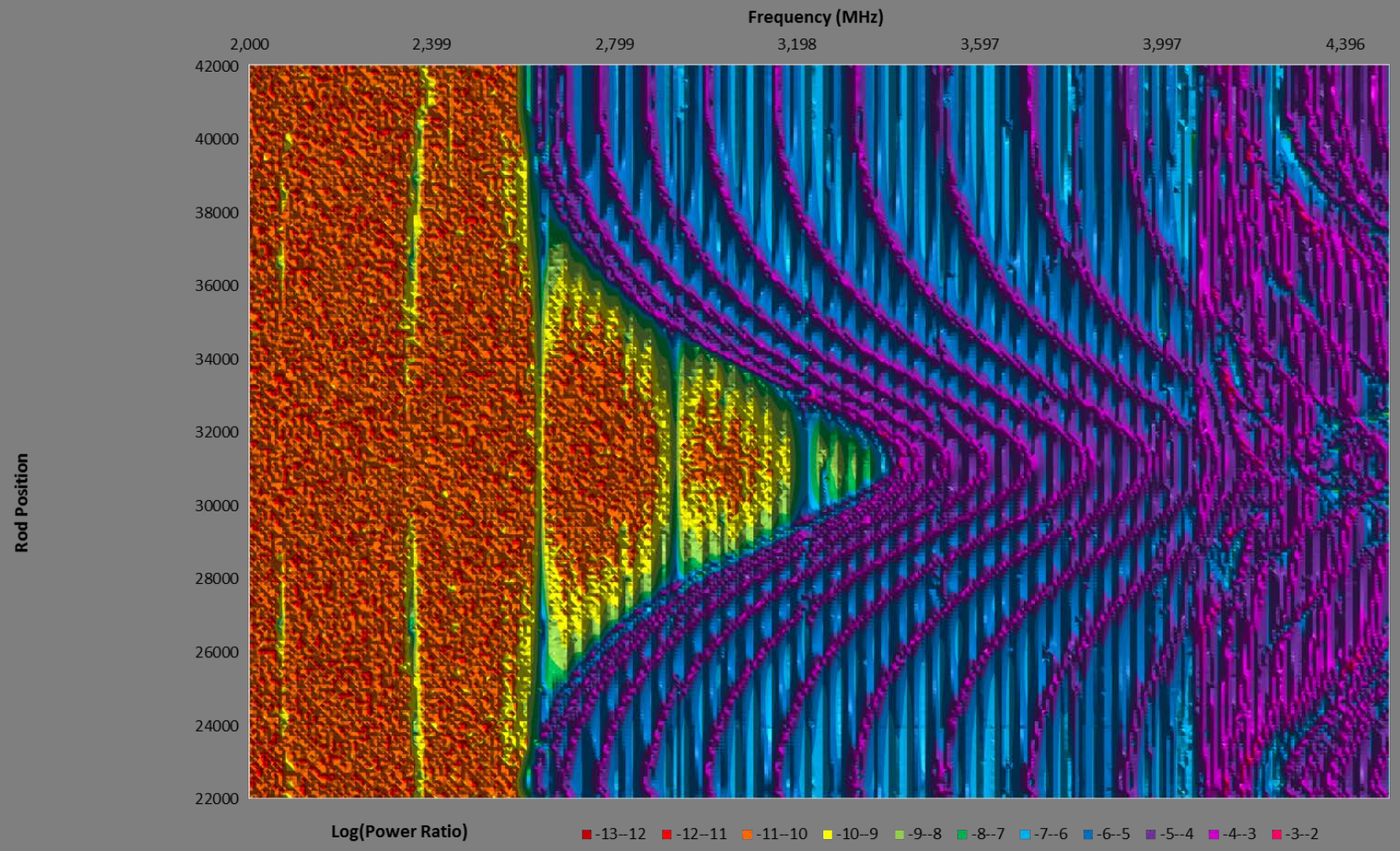




Small Cavity Mode Map



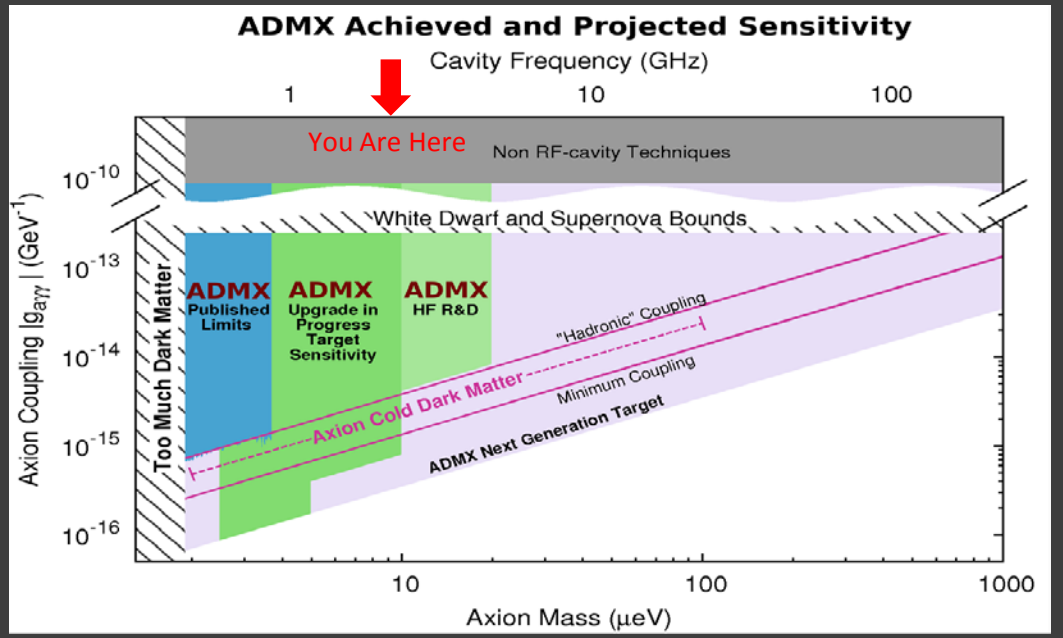
Medium Cavity Mode Map



Large Cavity Mode Map

Conclusion

- Axions are highly motivated dark matter candidates
- ADMX is searching for axions in a wide mass range using RF cavities
- My cavities:
  - Designed to fit within current ADMX hardware
  - Extend current ADMX search range into higher frequencies
  - Could be installed and tested at cryogenic temperatures by 2014



Acknowledgements

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People that Kept Us Organized

Subhadeep Gupta

Alejandro Garcia

Janine Nemerever

Linda Vilett

And Also

NSF

Questions?

COMMENTS?

CONCERNS?