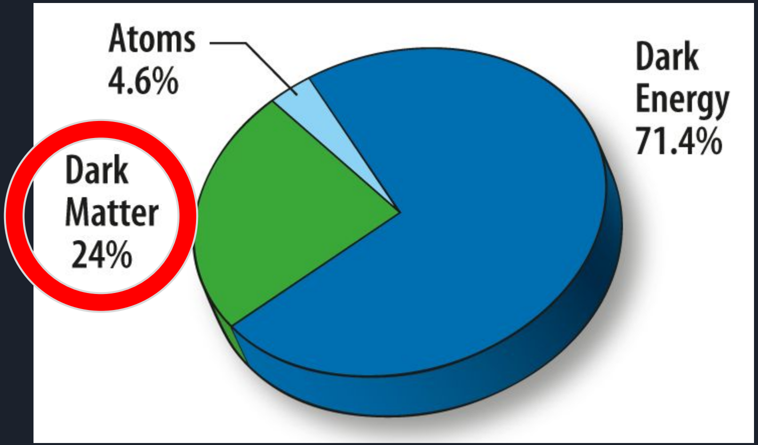
ADMX G2 Cavity Resonance Shift

By Leo Weimer
In association with Dr. Gray Rybka, Dr. Dan Zhang and Taj Dyson

Dark Matter

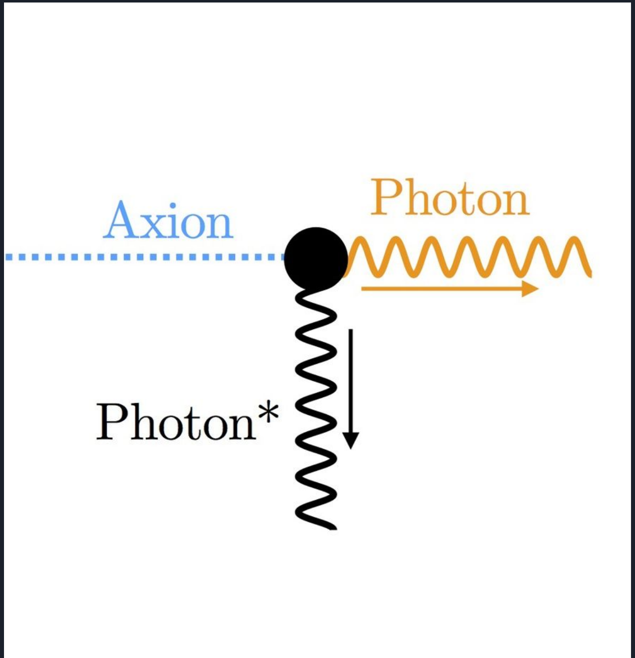
- Dark matter accounts for ~24% of the mass-energy of the universe.
- Understanding dark matter could solve many issues in many areas of physics.
- Axions could account for dark matter and solve the strong CP problem.



Source: WMAP

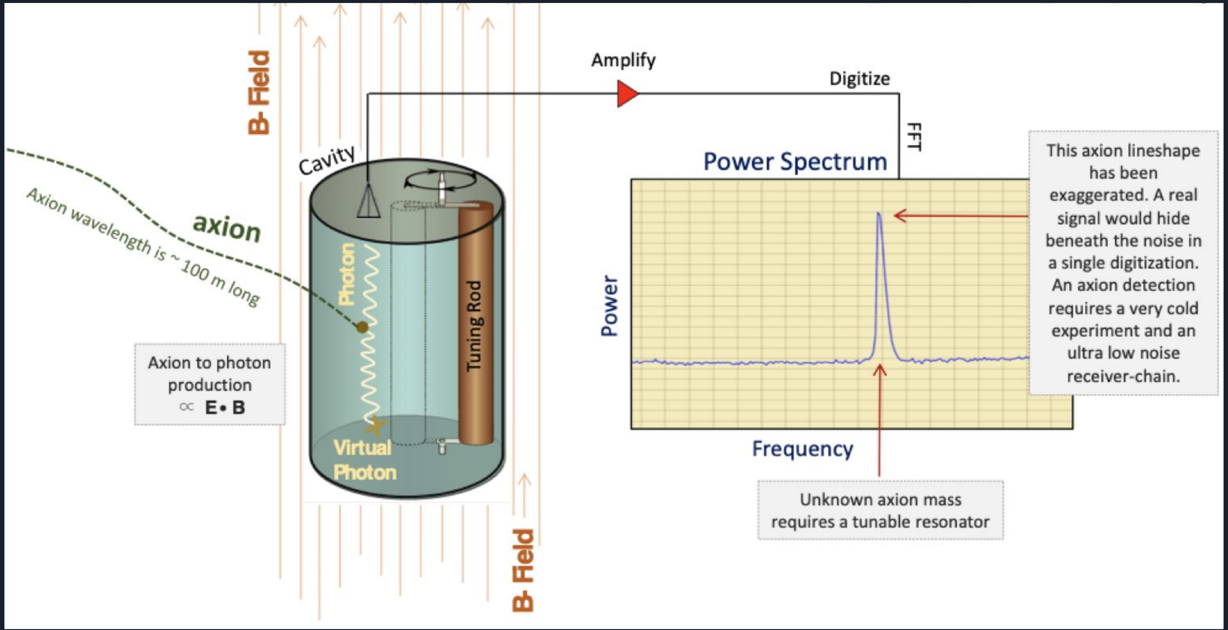
Axions

- Peccei-Quinn theory solves strong CP problem and posits axions.
- Axions could be dark matter due to their mass and rarity of interaction.
- KSVZ and DFSZ are two models for axions. DFSZ axions are more difficult to detect.
- Axions can turn into photons in a strong magnetic field.



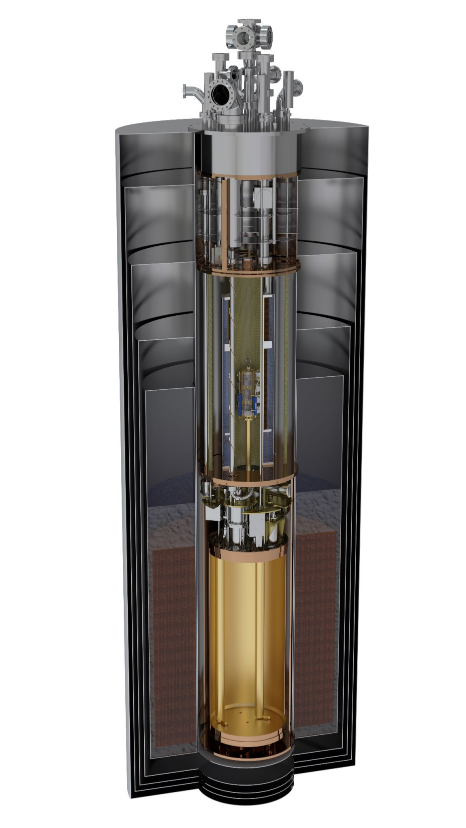
Axion Haloscopes

- Axion Haloscopes detect photons generated by axions in a strong magnetic field.



ADMX

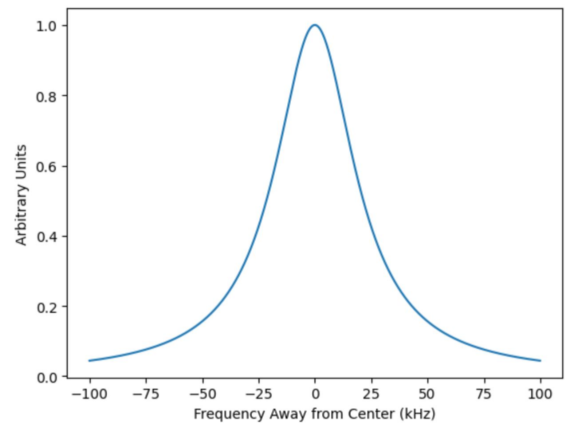
- The Axion Dark Matter Experiment (ADMX) is an axion haloscope.
- Frequency detected is related to axion mass.
- Signal strength is related to coupling.



Source: Fermilab

ADMX, cont'd

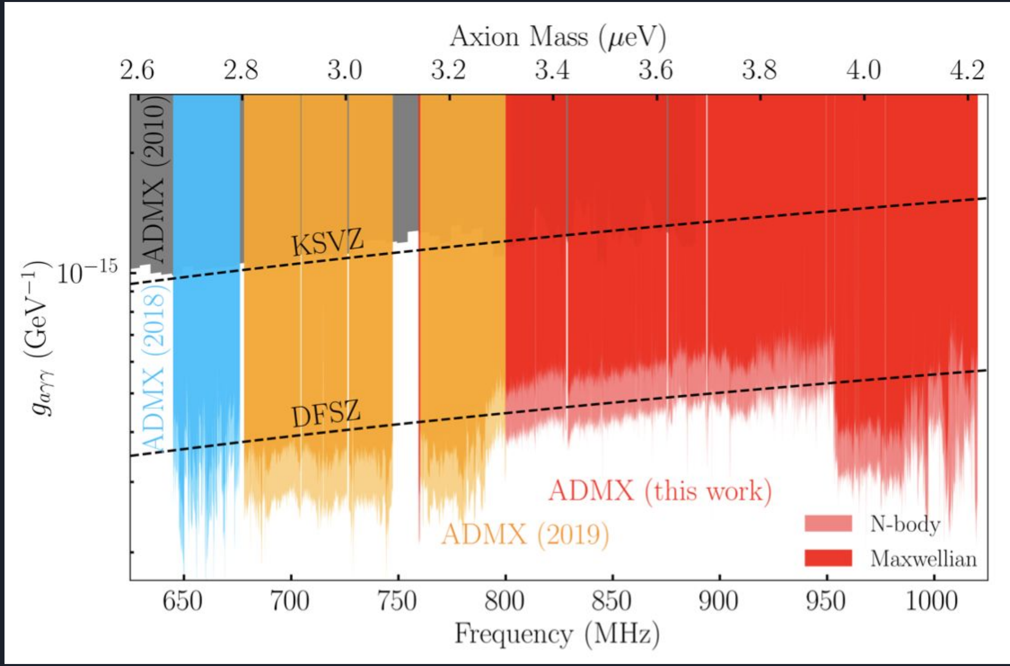
- Cavity resonance tuning determines signal strength.
- Tuning rod adjusts cavity resonance.
- Signal strength vs. frequency makes lorentzian centered at cavity resonance.
- Data is digitized over periods of 100 seconds.



Source: ADMX

Parameter Space Exclusion

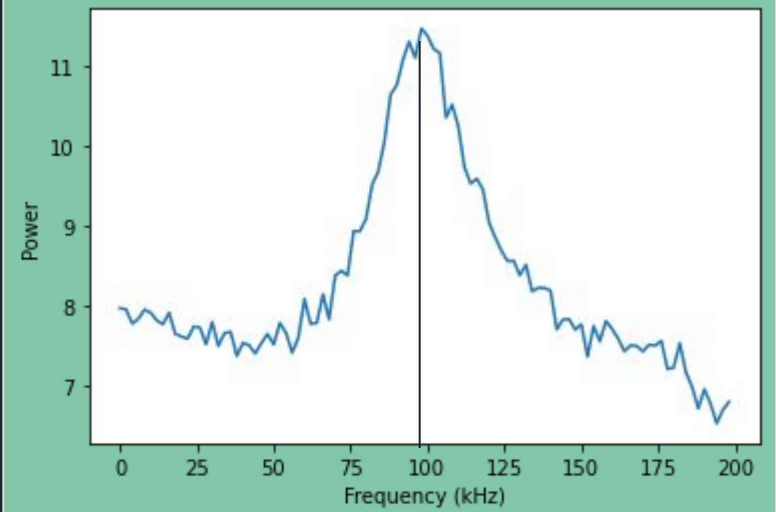
- (right) possible coupling and mass combinations that have been ruled out.

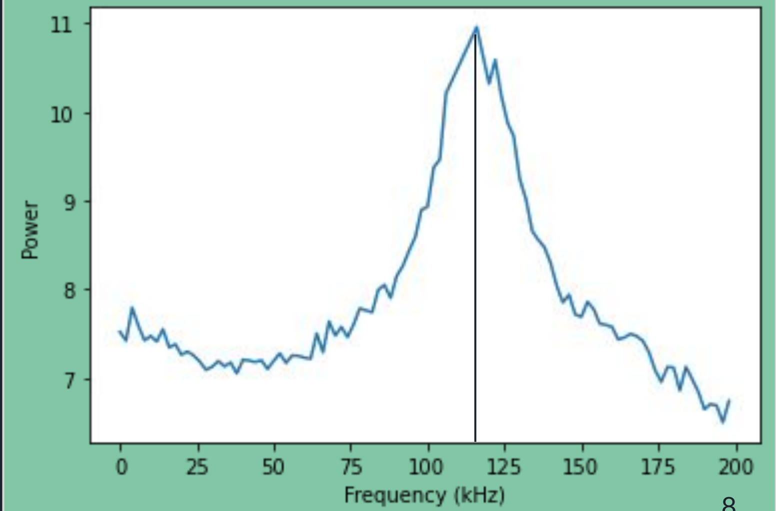


Source: ADMX

Resonance Shifting

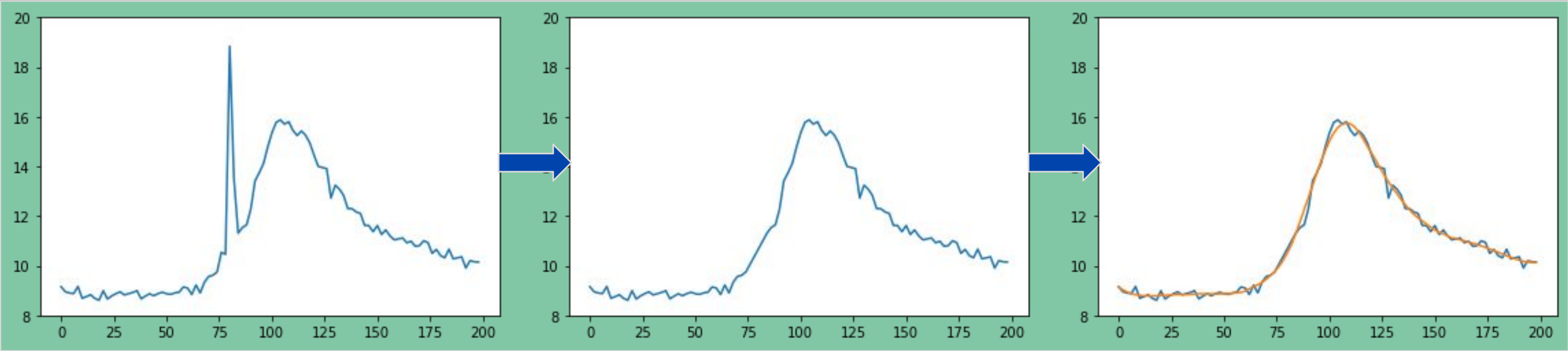
- Cavity resonance is changing during digitizations.
- These shifts result in much of the data being cut.
- The goal of this project is to visualize how the cavity resonance is shifting on a smaller time scale and find a way to reclaim the lost data using this information.





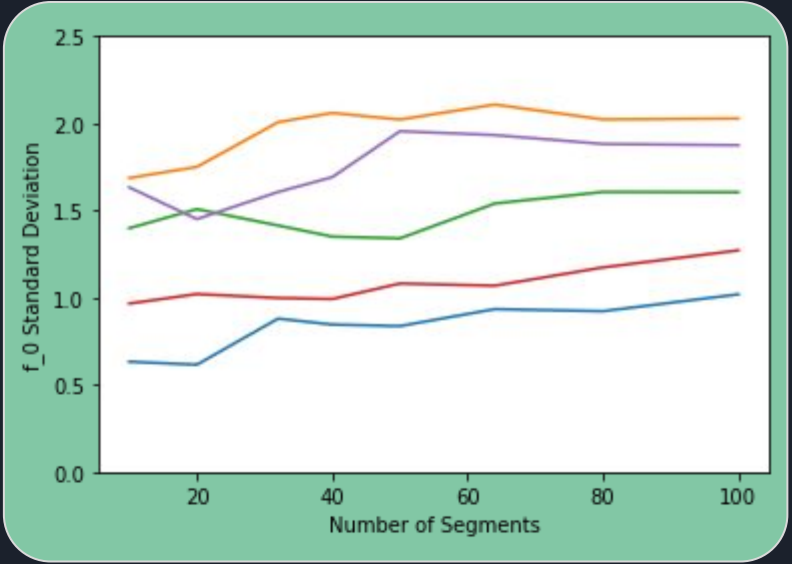
Spectrum Processing

- Mid-run cavity resonance was obtained by doing FFT on smaller segments of time series data.
- Lorentz peak coincides with cavity resonance.
- Power excesses (other peaks) of greater than 3.5 sigma were removed.
- A Savitzky-Golay fit was used to reduce noise.



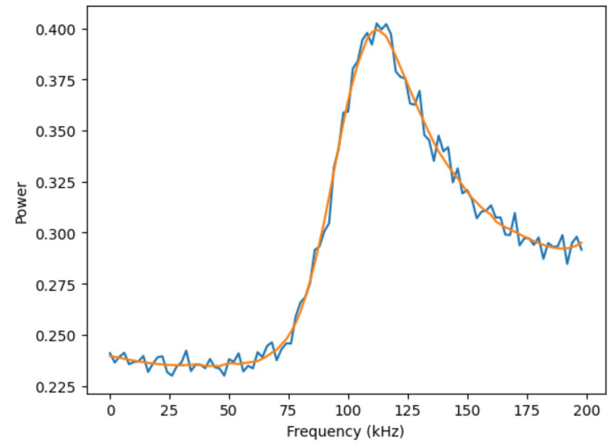
Segment Number Selection

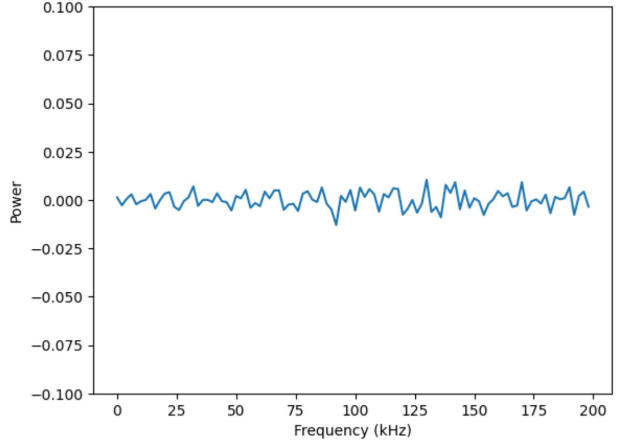
- Many factors contributed to the decision for how many segments to use.
- Error wasn't very correlated with segment number.
- Computation time increased with segment number.
- Only around 50 segments are needed to resolve shifts.



Flatness Check

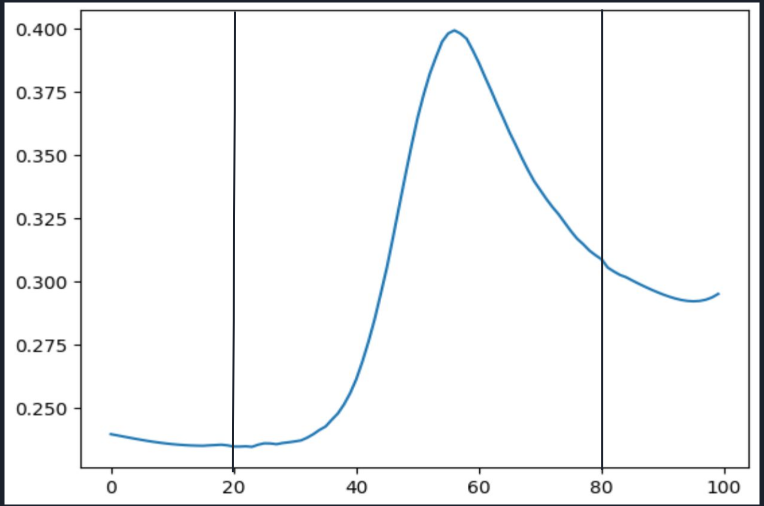
- Resonance peak is only seen when there is a temperature difference.
- If the temperatures are close or the same, then the spectrum is flat, so shifts can’t be tracked.
- Spectra were checked for flatness using SG fit to get baseline noise and comparing standard deviations.

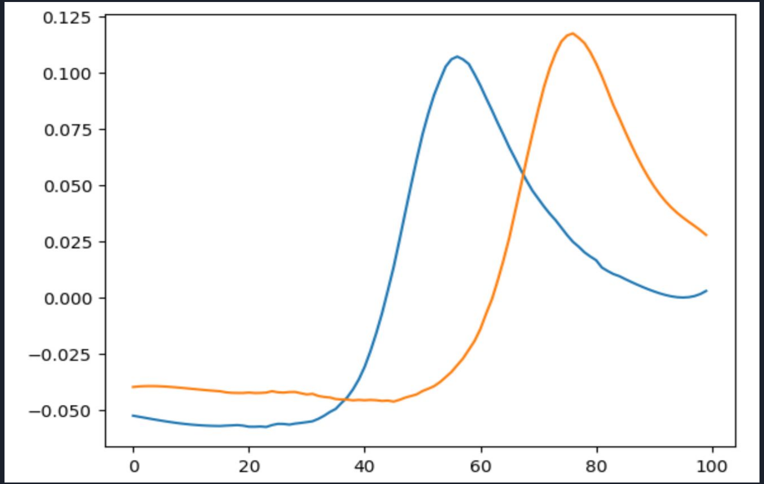




Convolution

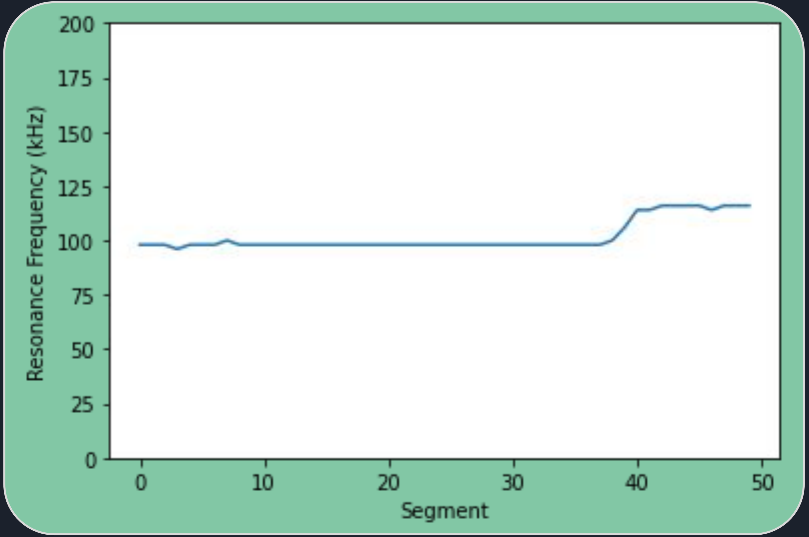
- The position of the cavity resonance peak was tracked using convolution.
- The central part of the spectrum of the first two seconds of a digitization was used as a kernel.
- For all subsequent subspectra (each 2 second timeframe), the position of the kernel was found.
- If this position shifted, a corrected lineshape was used in the analysis.





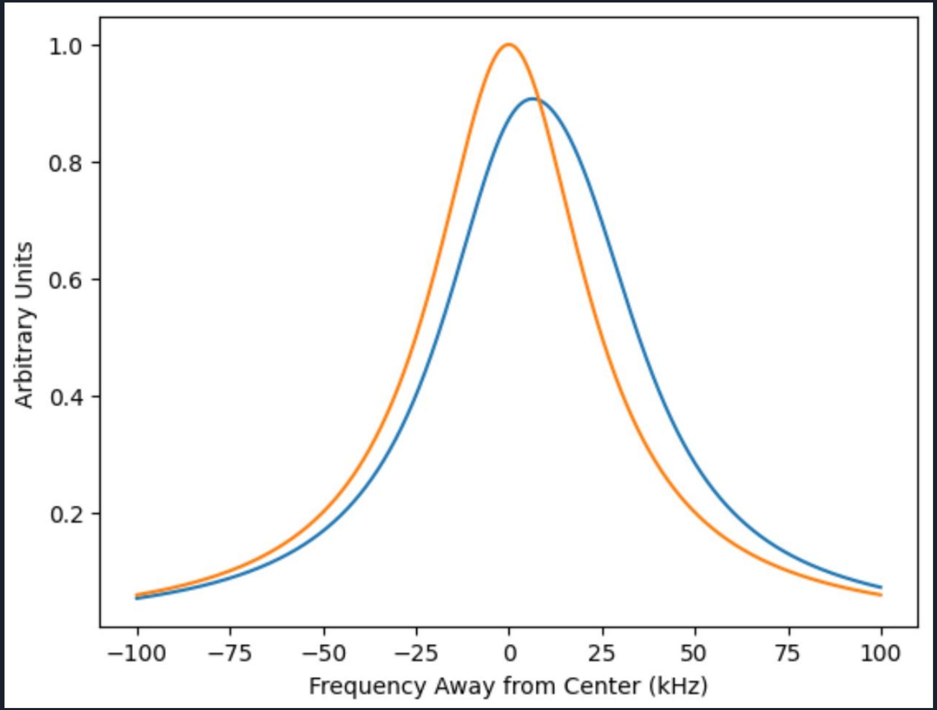
Shifting Tracked

- Using convolution allowed the resonance structure to be tracked for any non-flat spectrum.
- Some digitizations exhibited shifts in the cavity resonance.
- These shifts are likely due to mechanical issues with the tuning rod.



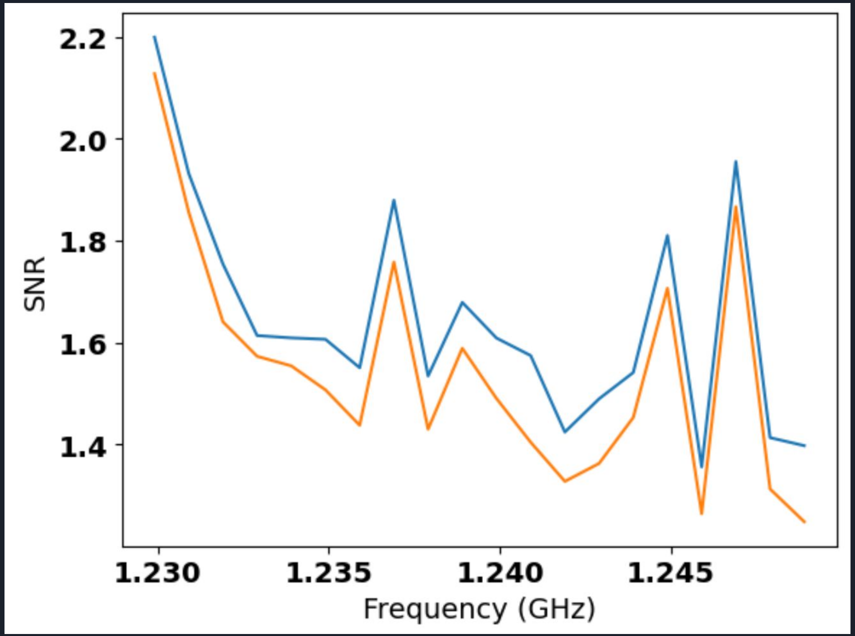
Corrected Lineshape

- Corrected cavity lineshape were made by averaging lineshapes for each 2 seconds.
- The corrected lineshape allows for lost data to be used.



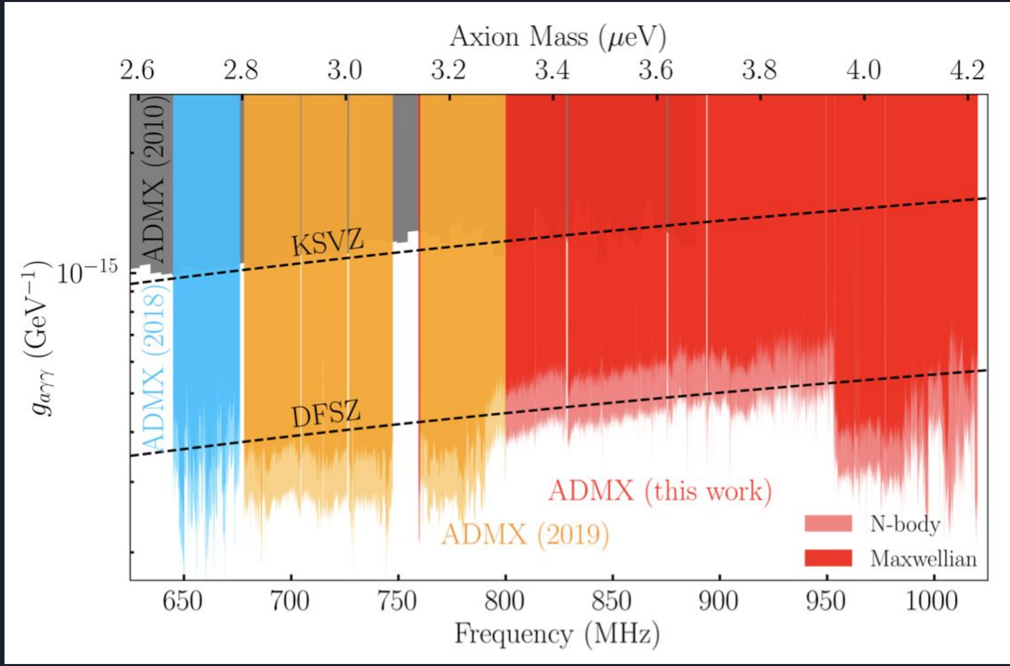
Results

- I have successfully prototyped a technique that recovers previously discarded ADMX data, increasing Signal to Noise Ratio (SNR) by about 6.5% over the whole frequency range, but up to 12% in any given 1 MHz frequency range within that.



Results (cont'd)

- Scan rate is frequency covered per unit time.
- Scan rate increased by ~13% on average.



Source: ADMX

Conclusions

- The cavity resonance is shifting mid run
- Shifting can be accounted for by creating a corrected lineshape.
- Correcting for the shifts increases ADMX’s SNR by 6.5% on average, increasing the scan rate by ~13%.

Next steps:

- Find ways to include more of the flatter spectra.
- Create a more efficient and adaptable implementation of this method to be used in the full analysis.

Acknowledgements

- Dr. Gray Rybka
- Dr. Dan Zhang
- Taj Dyson
- The ADMX collaboration
- The National Science Foundation REU program
- My REU peers and everyone who helped run the program