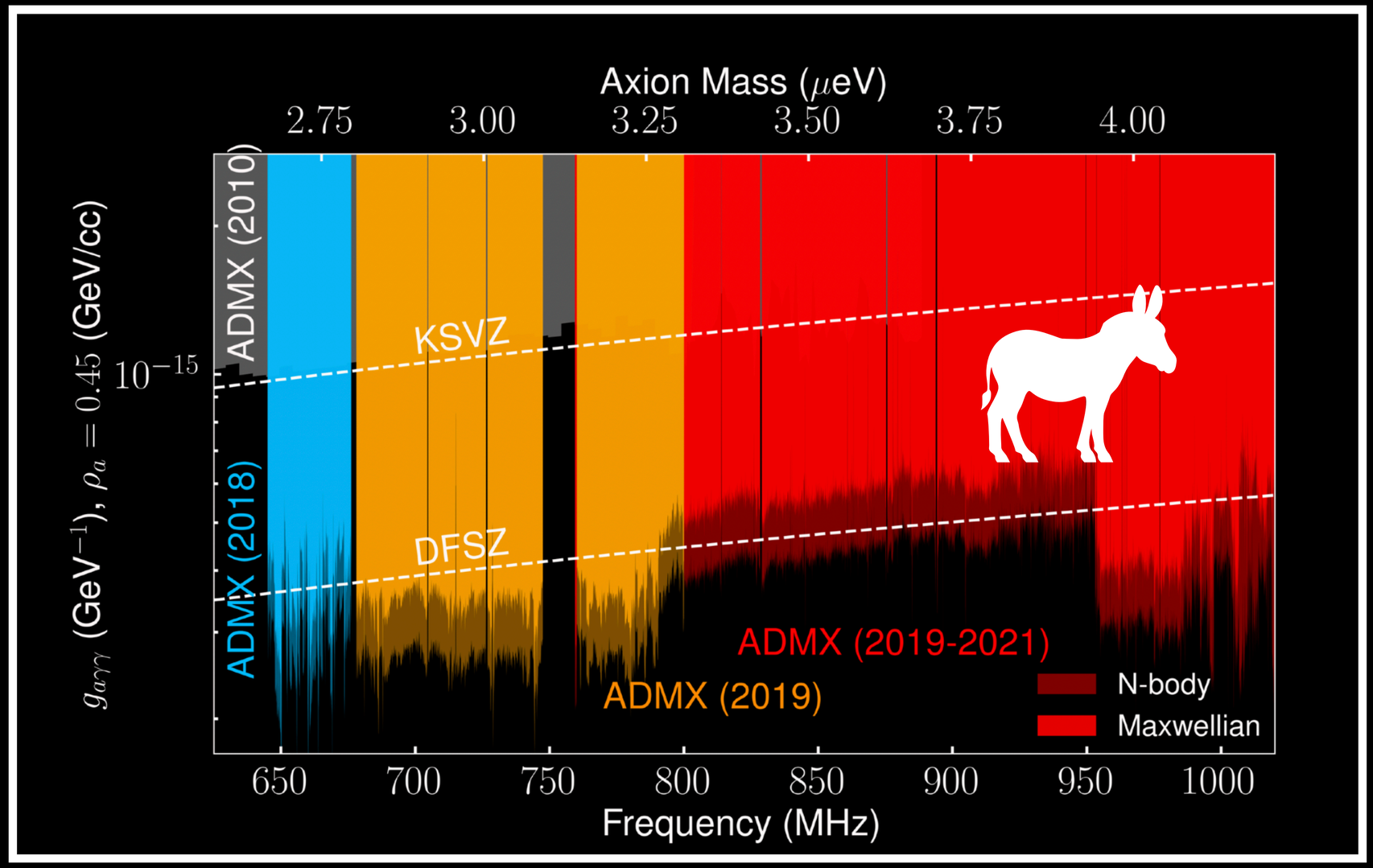
AXIONS AND WAVE-LIKE DARK MATTER

AXION IDENTIFICATION

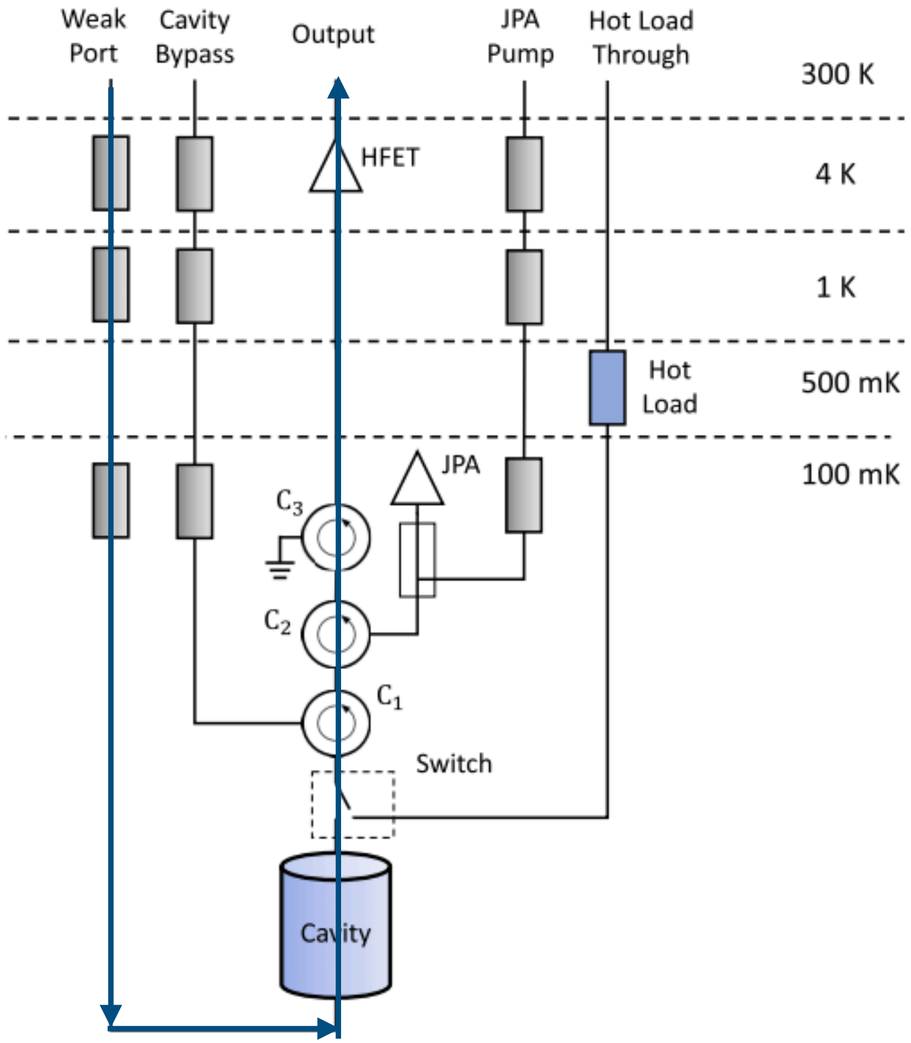
DESY WORKSHOP

CHELSEA BARTRAM 2024

Pin-the-tail-on-the-axion-mass?



ADMX Receiver Chain

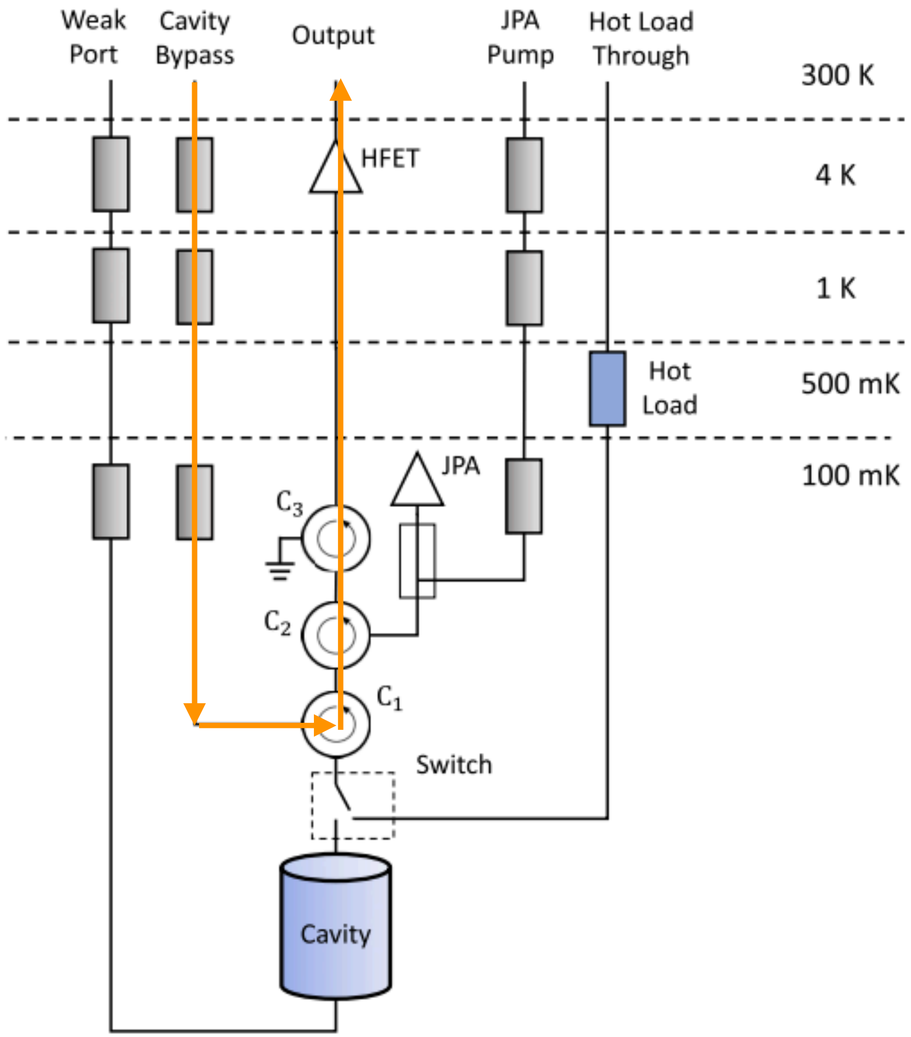


Important characterization measurements

- Transmission Measurements
- Reflection Measurements
- System noise measurements
- Synthetic injections

Followed by digitization

ADMX Receiver Chain



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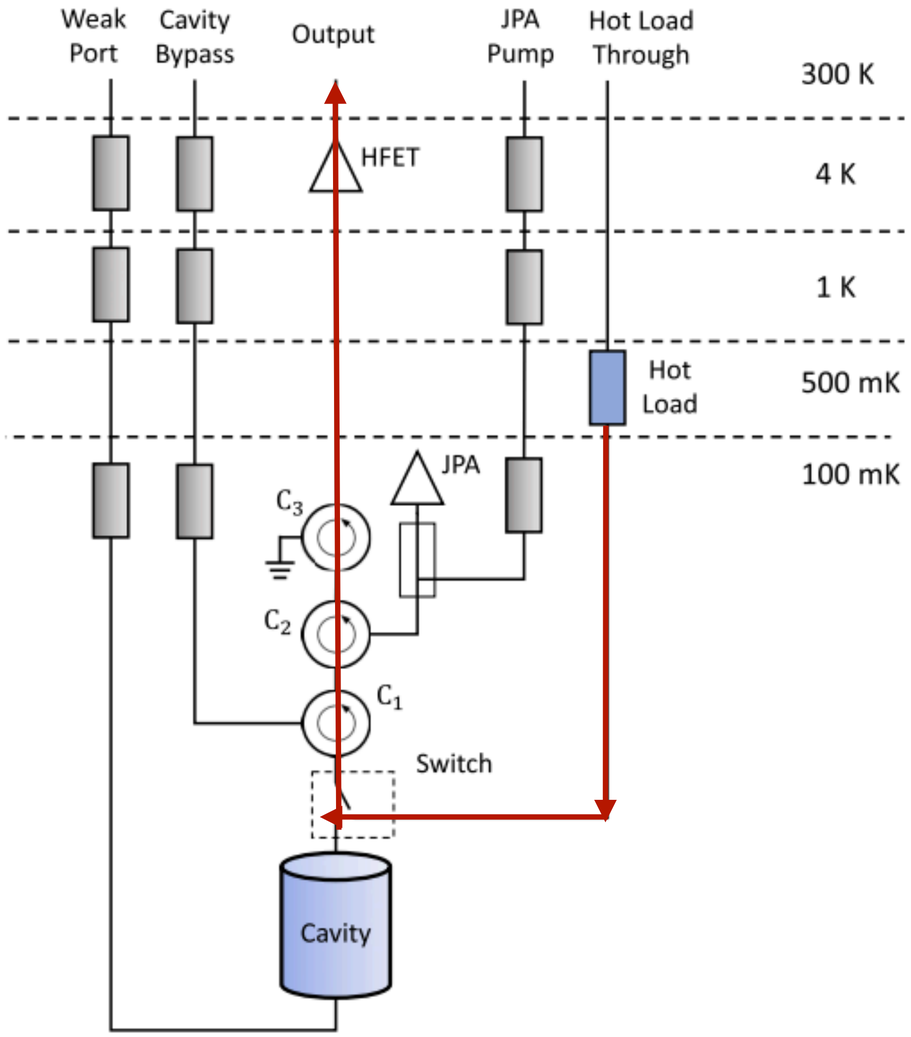

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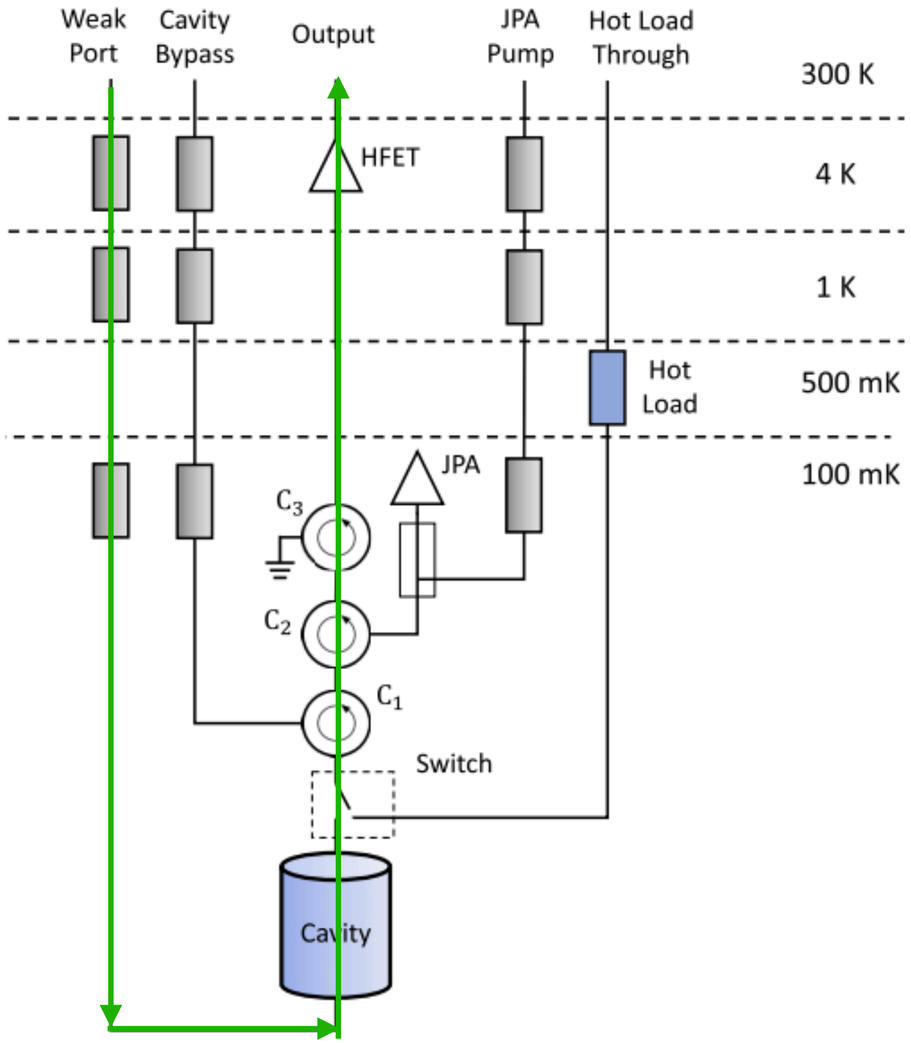

Important characterization measurements

- Transmission Measurements
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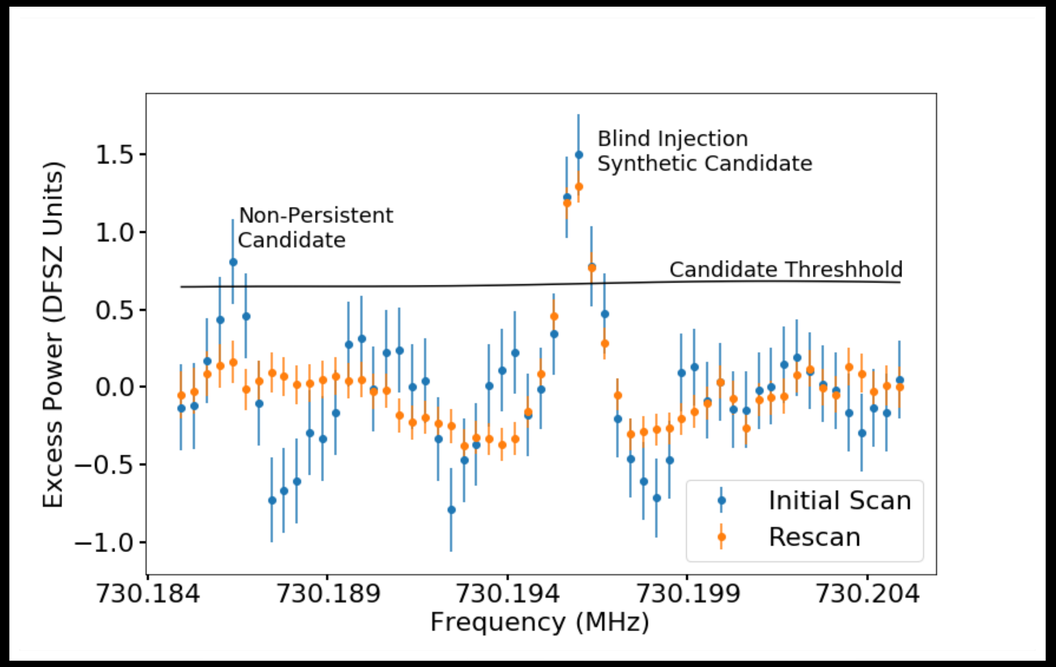
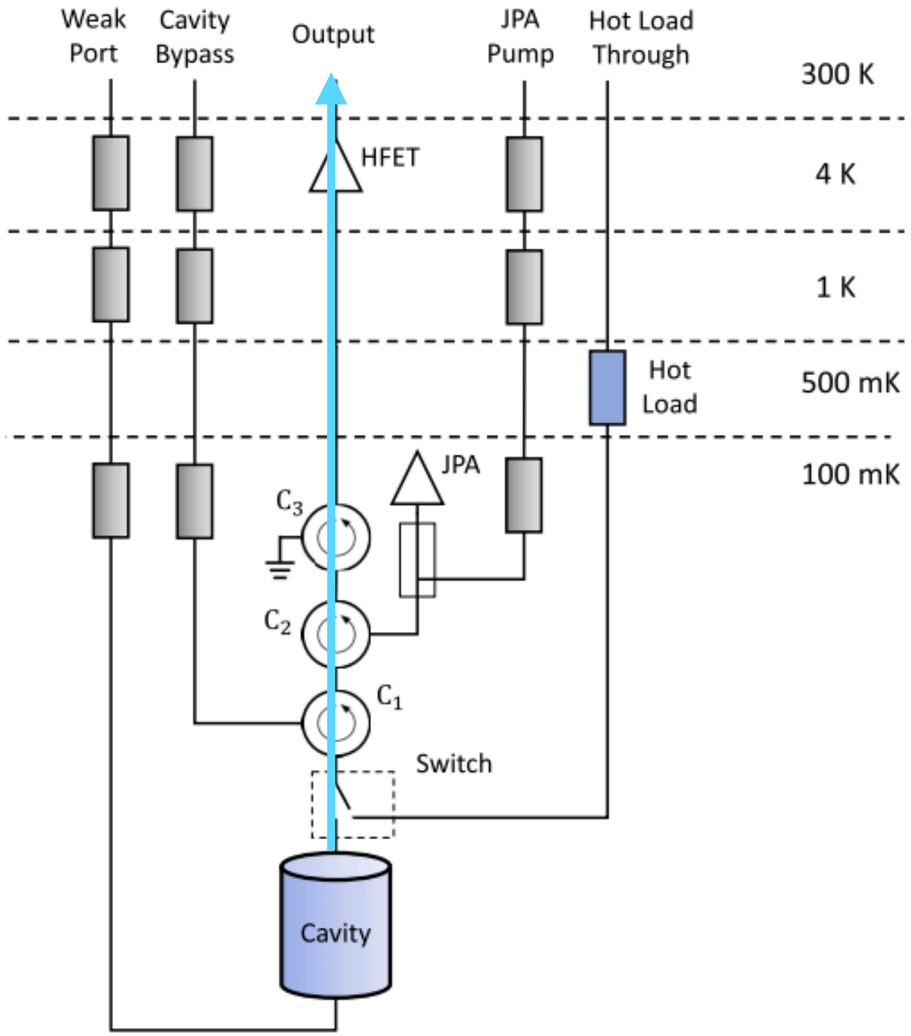
ADMX Receiver Chain

- Arb output at low frequency maxwellian-like signal
- Signal mixed up to axion frequencies
- Grad student placed appropriate attenuation
- SAG signal sent to weak port



Synthetic Axion Generator

ADMX Receiver Chain

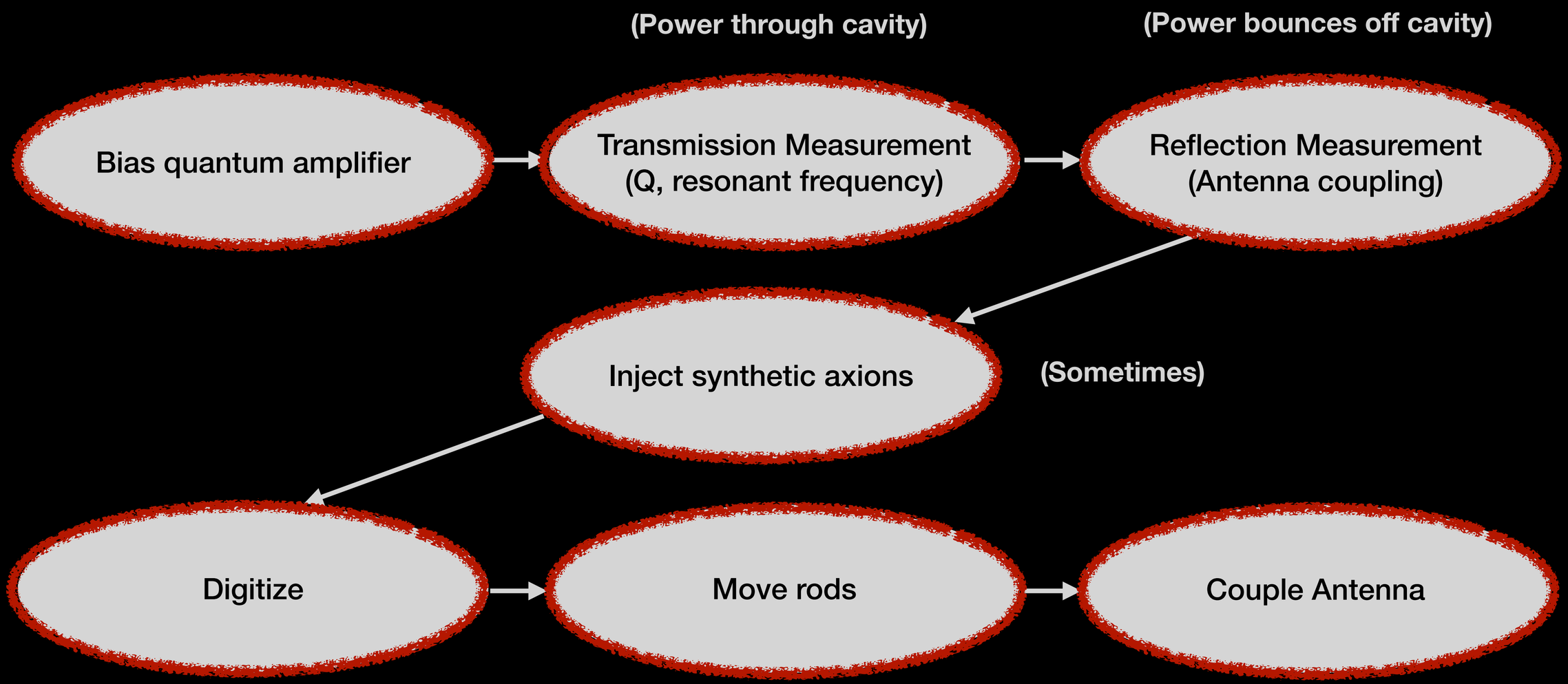


Important characterization measurements

- Transmission Measurements
- Reflection Measurements
- System noise measurements
- Synthetic injections

Followed by digitization

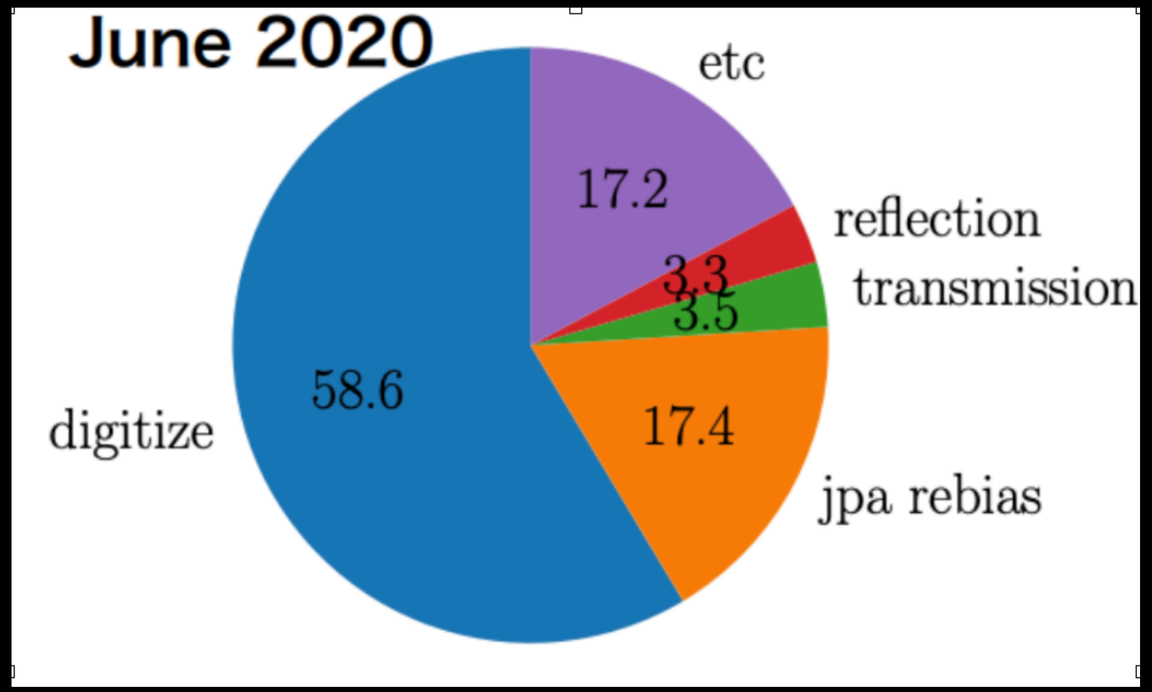
Data-taking operations

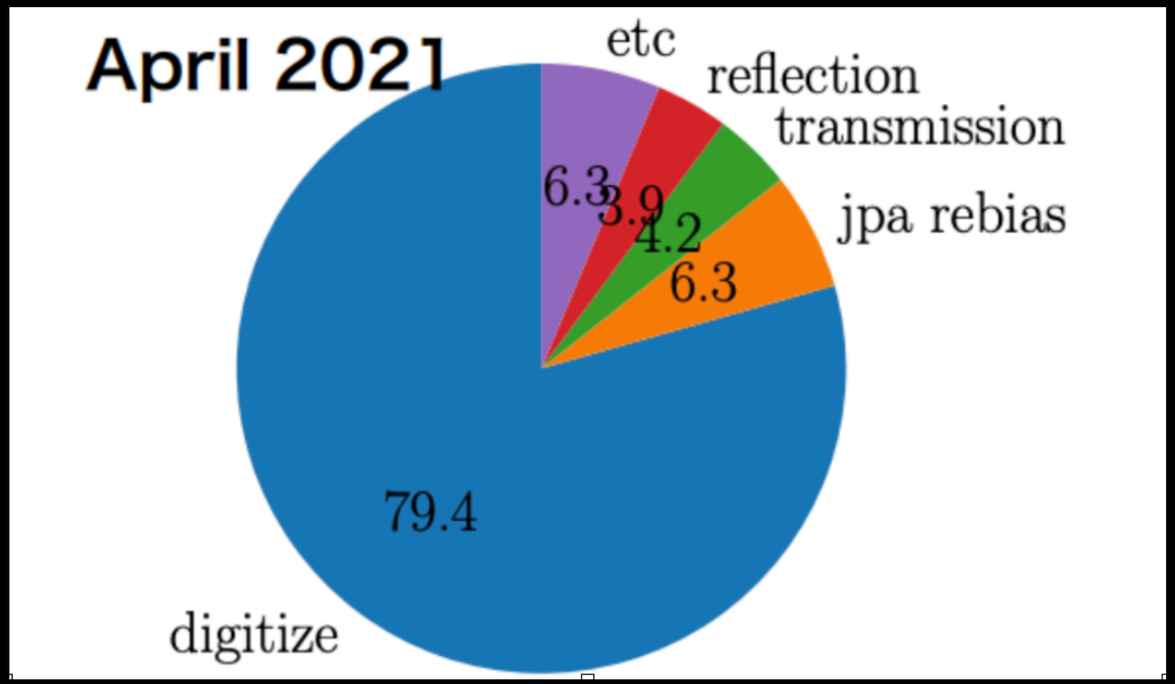


Axion Search Data!

Discussion Questions

- Other characterization and calibration measurements?
  - At what cost?





Sample Data Acquisition System

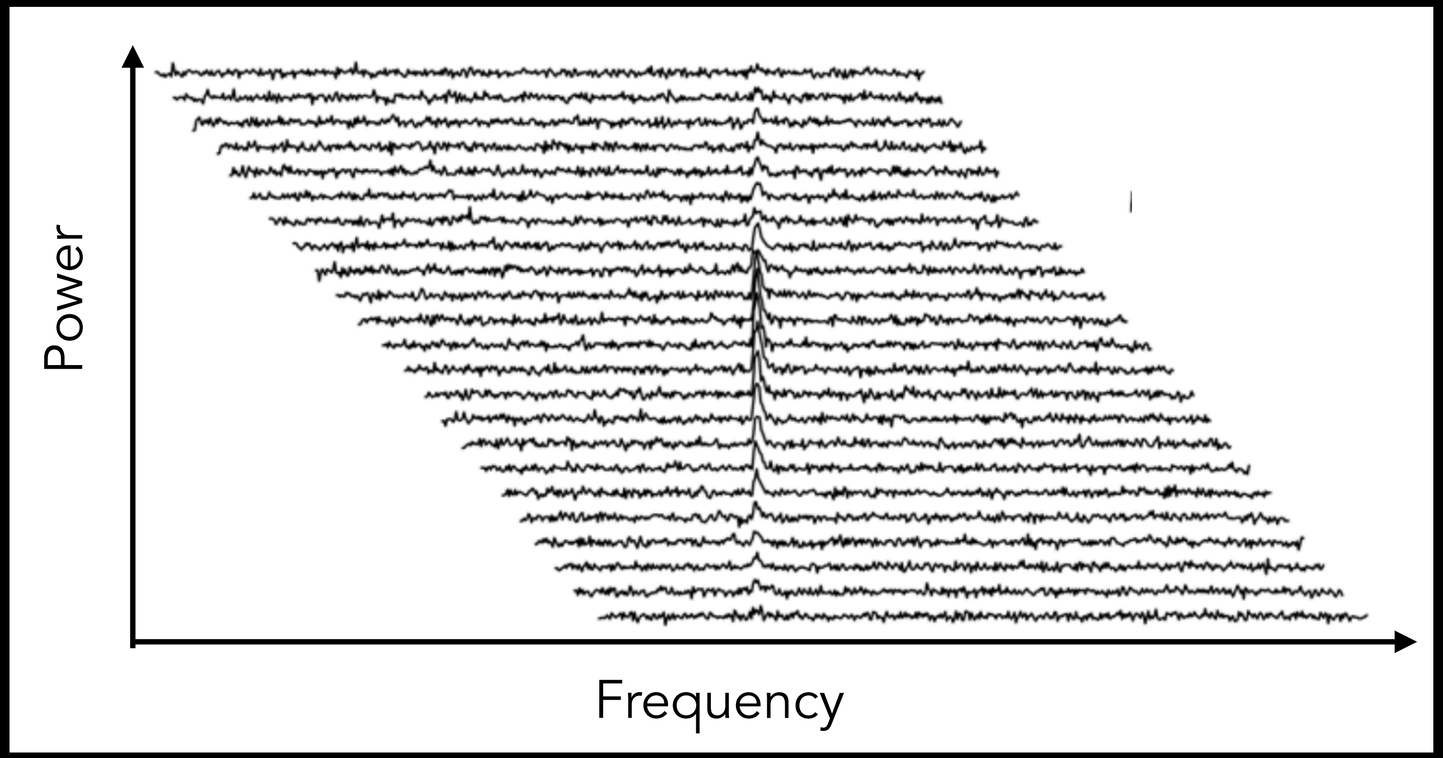
Medium Resolution

- Power spectra
  - Optimized for isothermal halo model
  - Optimized for initial detection
  - 100 Hz bin width
  - 50 kHz PSD (determined by Q)

High Resolution

- Time-series
  - Sensitive to non-virialized axions
  - Sensitive to frequency modulation from orbital and rotational motion
  - 10 mHz native bin width

“Standard” Axion Signal

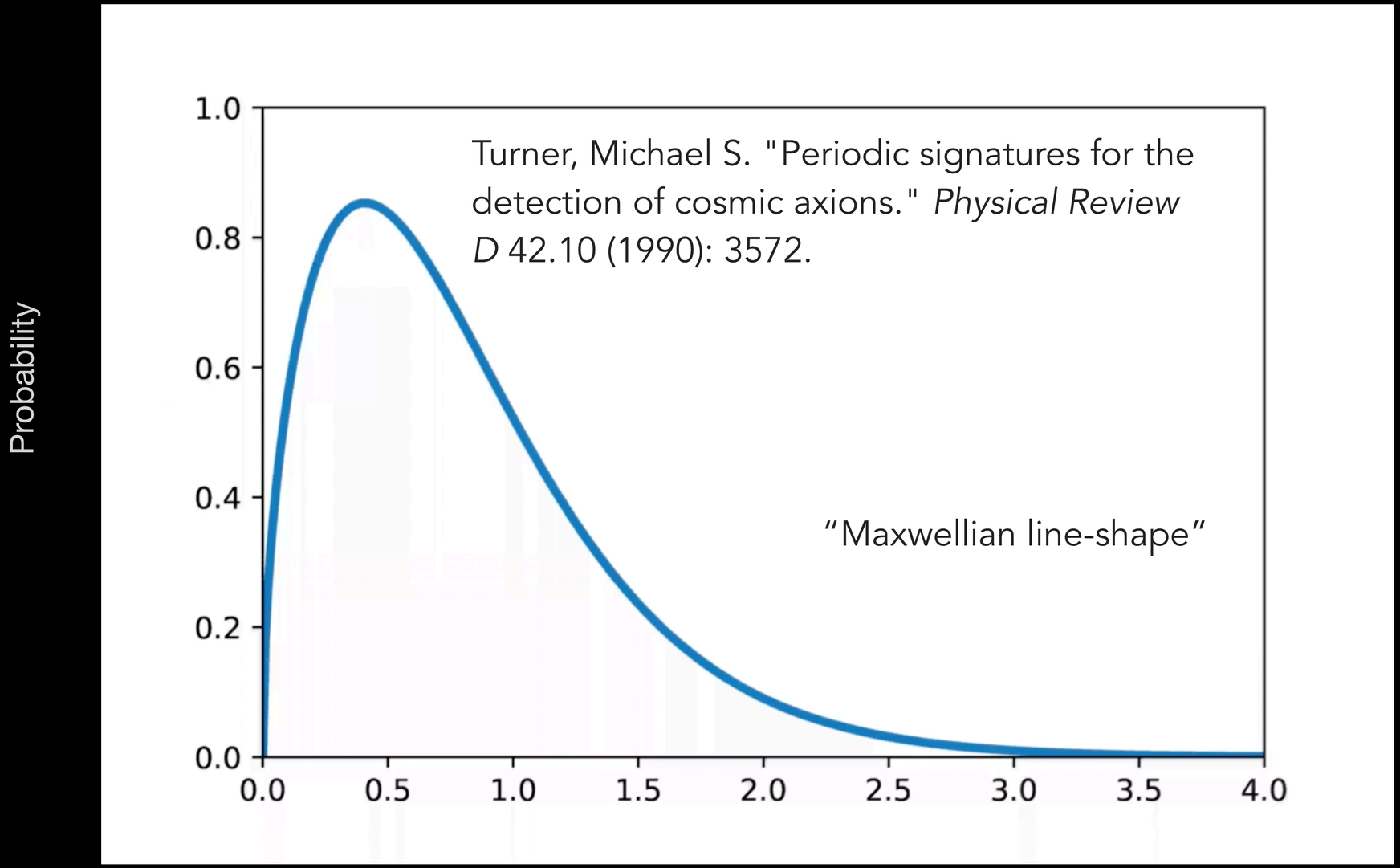


$$P_{a\to\gamma} \propto B^2 V C g_\gamma^2 \rho^2 f Q$$

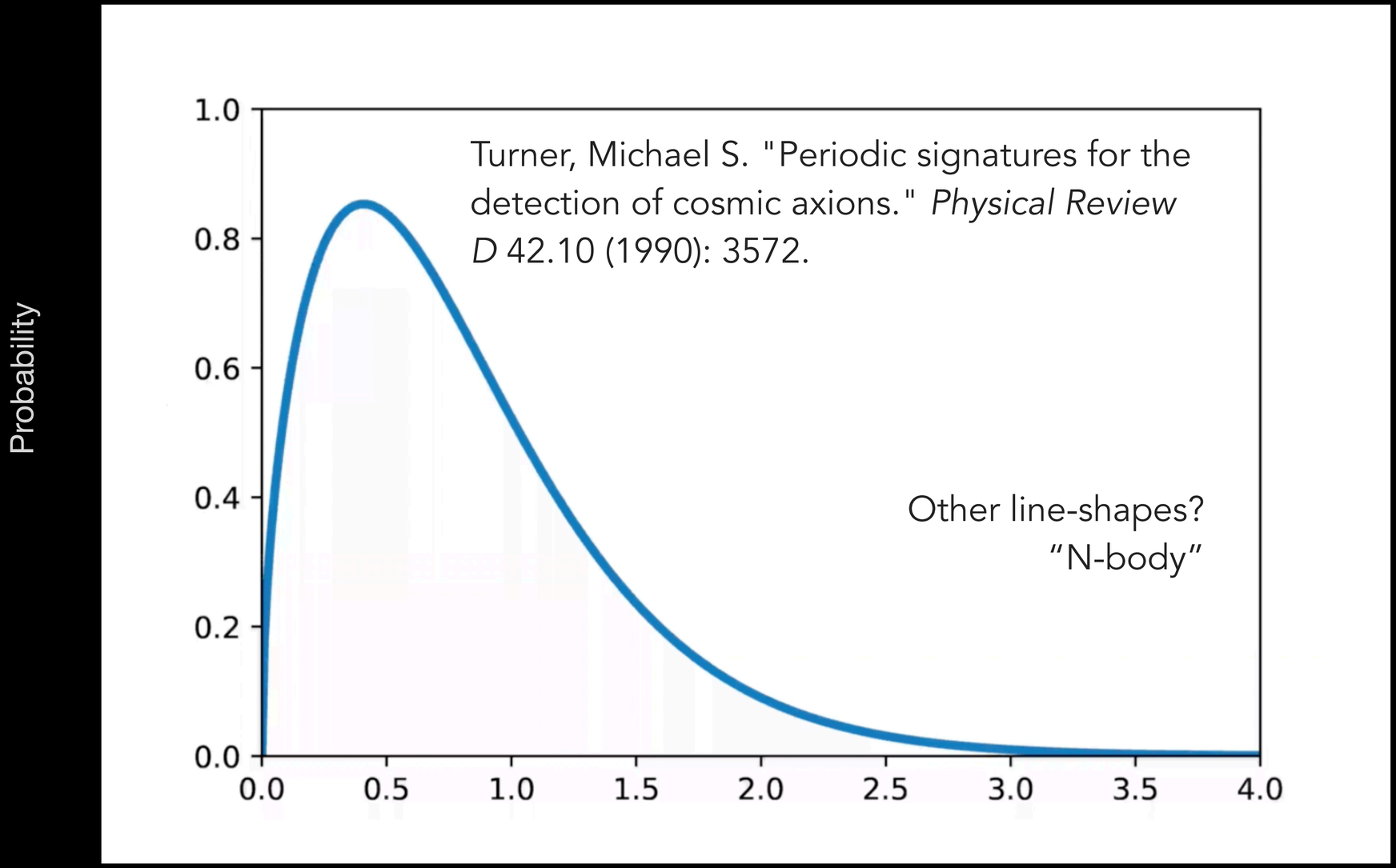
B = magnetic field
V = volume
C = form factor
g_γ = model-dependent term
ρ = dark matter density
F = frequency
Q = quality factor

“Narrowband” peak with a signal strength of ~10^{-23} watts

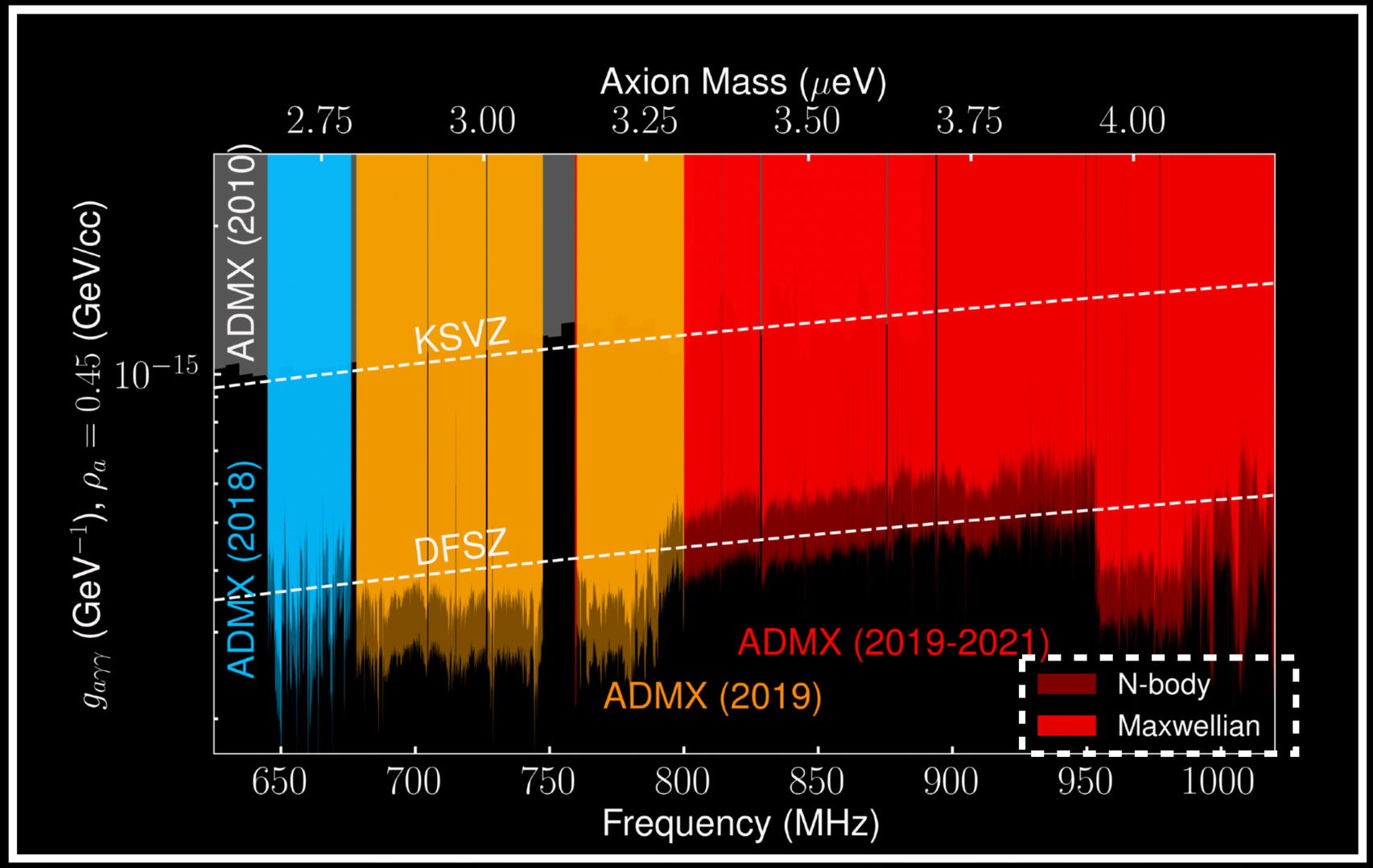
Axion Doppler Shift



Axion Doppler Shift



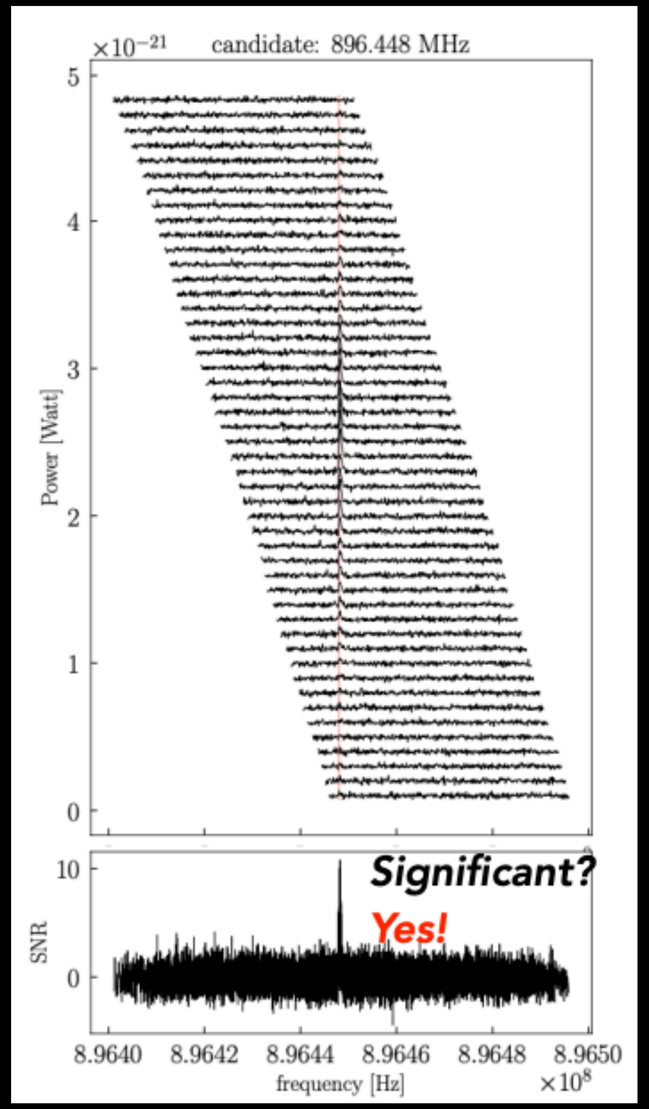
Axion Exclusion Limit



Discussion Questions

- Alternative data formats?
  - Broadband search data?
  - Different bin widths?
  - Alternative line-shapes?
  - Value of time-series data

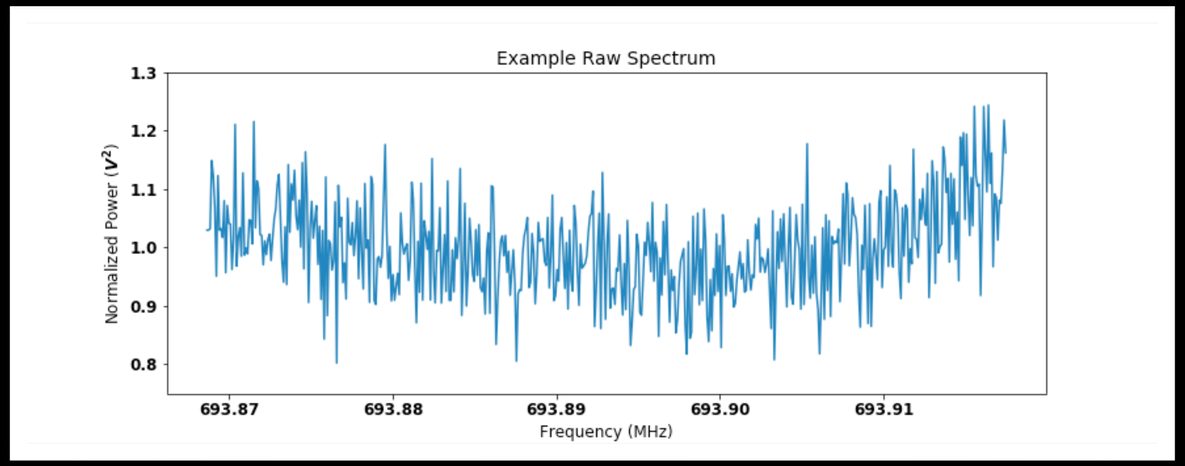
Is it really an axion?

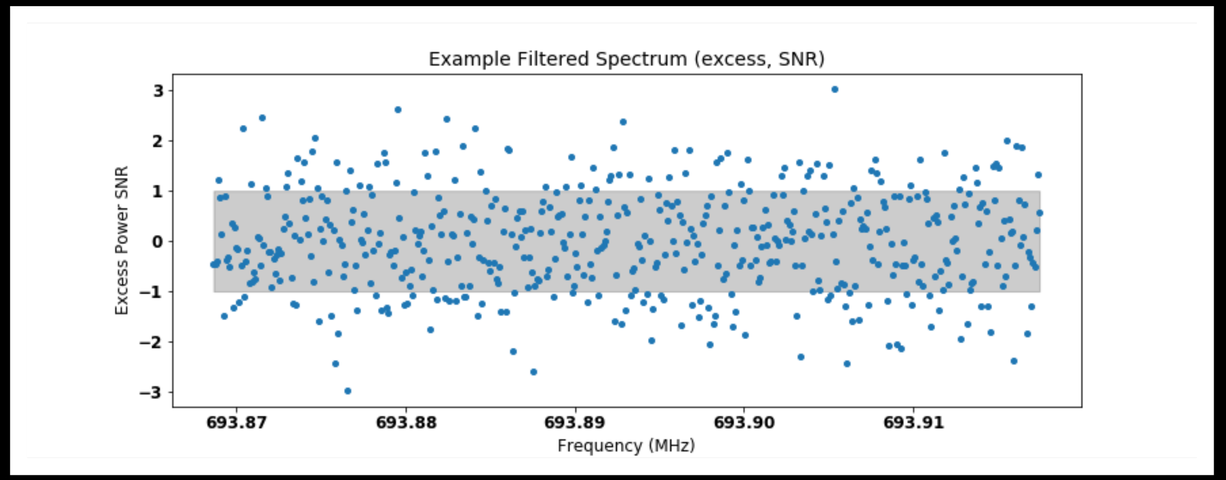


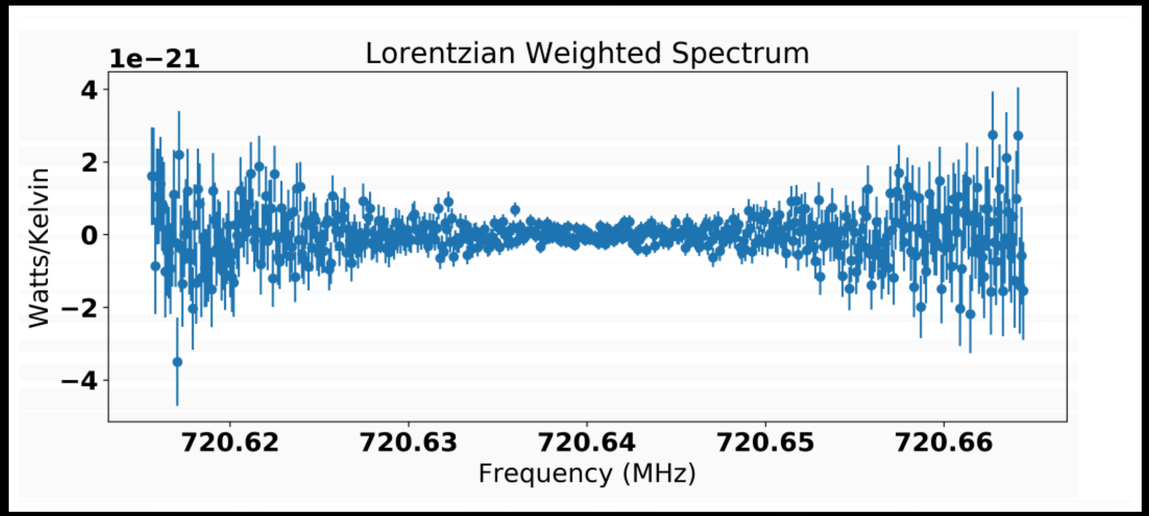
- Must not be a hardware synthetic signal
- Must not be ambient radio frequency interference (RFI) detectable with room temp receiver
- Must appear in every spectrum at that frequency (persistent).
- Must be enhanced on-resonance.
- Must be suppressed in modes that do not couple with the axion.
- Signal power scales as B^2.

← **ADMX hardware synthetic injection mimics an axion signal in the detector**

Data Processing







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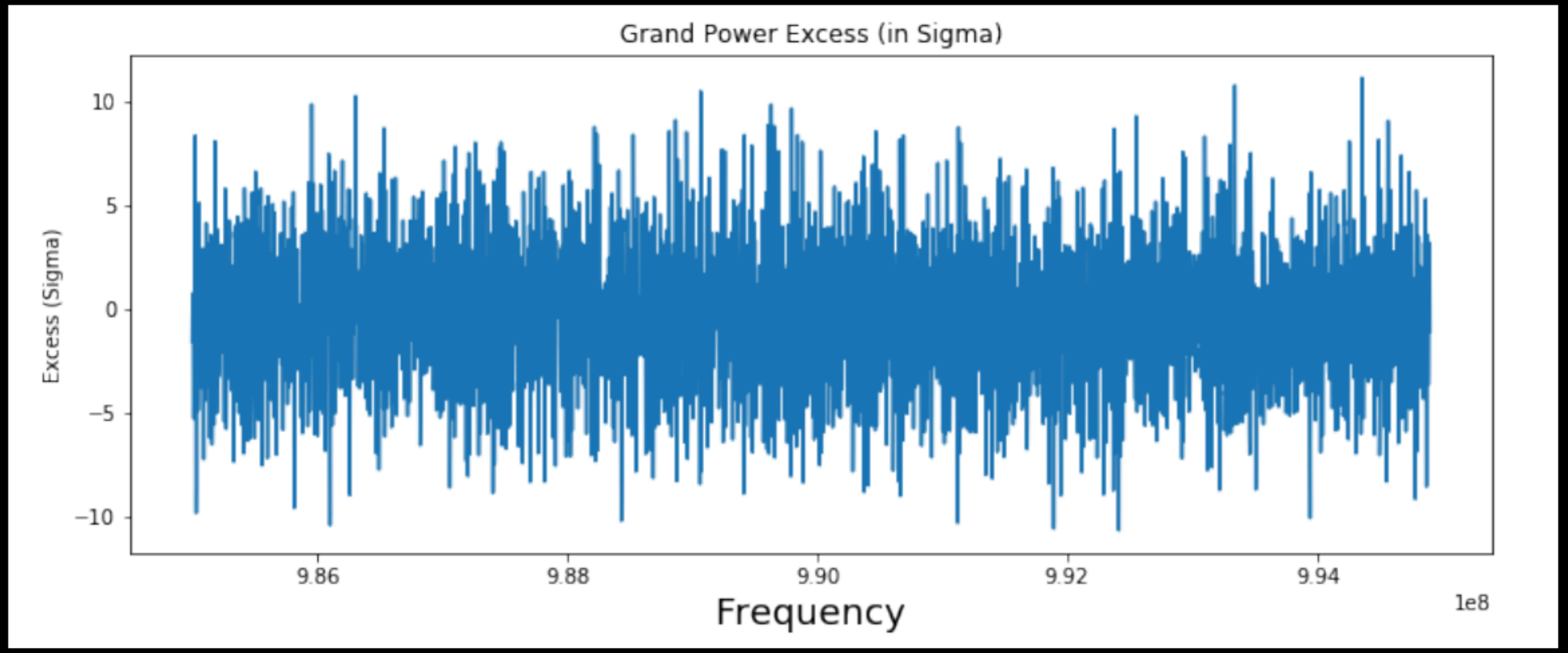
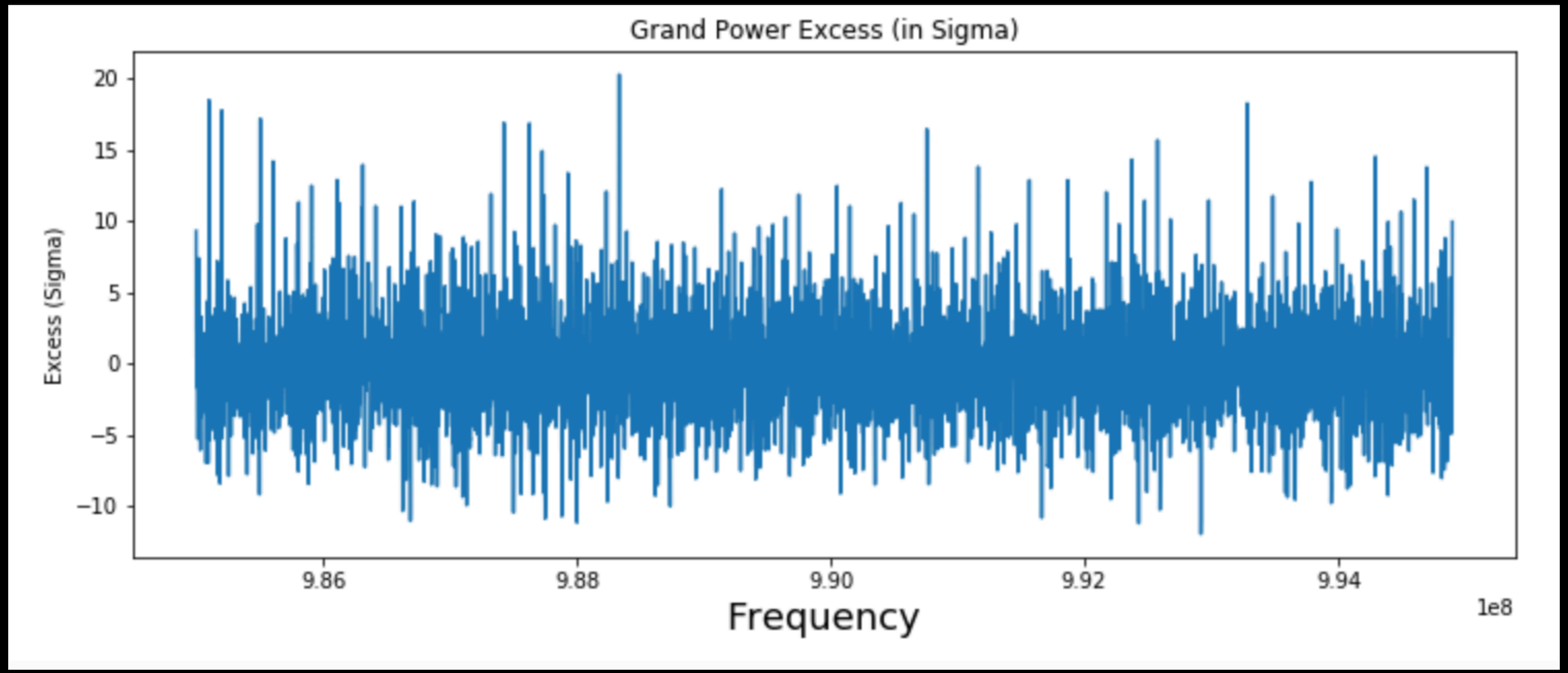


Example Grand Power Spectrum

Data Processing



Software synthetic injections

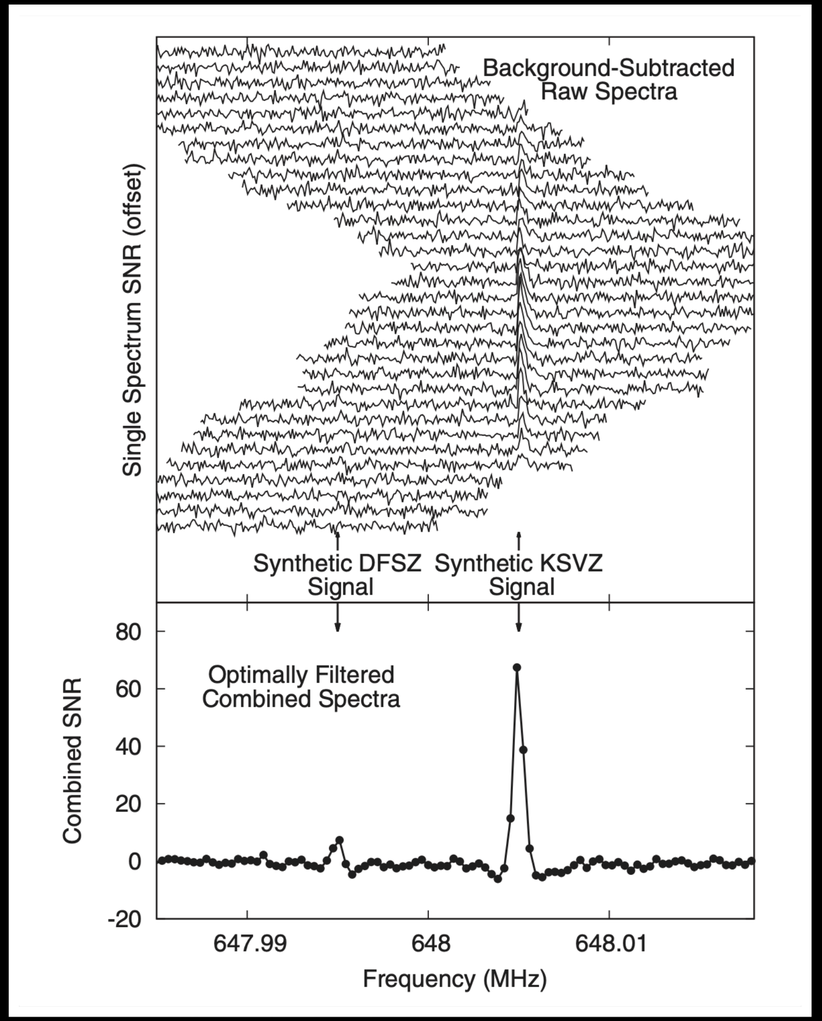
Data Processing

When do you decide to rescan?
3 conditions:

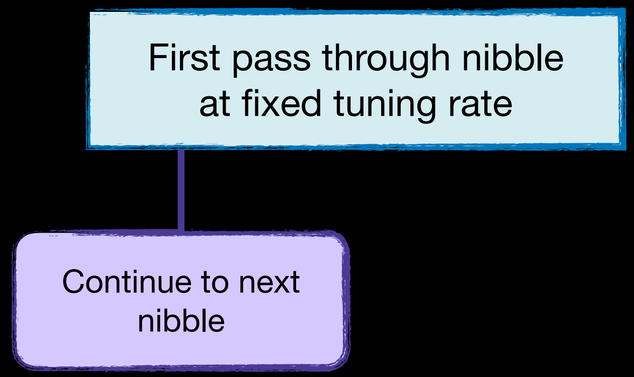
- Not enough data (low SNR): min SNR of 3
- 3.4σ excess
- Excess at DFSZ threshold or above

$$P_{\mathrm{measured}} + 0.85\sigma > P_{\mathrm{DFSZ}}$$

There will always be some of these remaining just due to statistics!

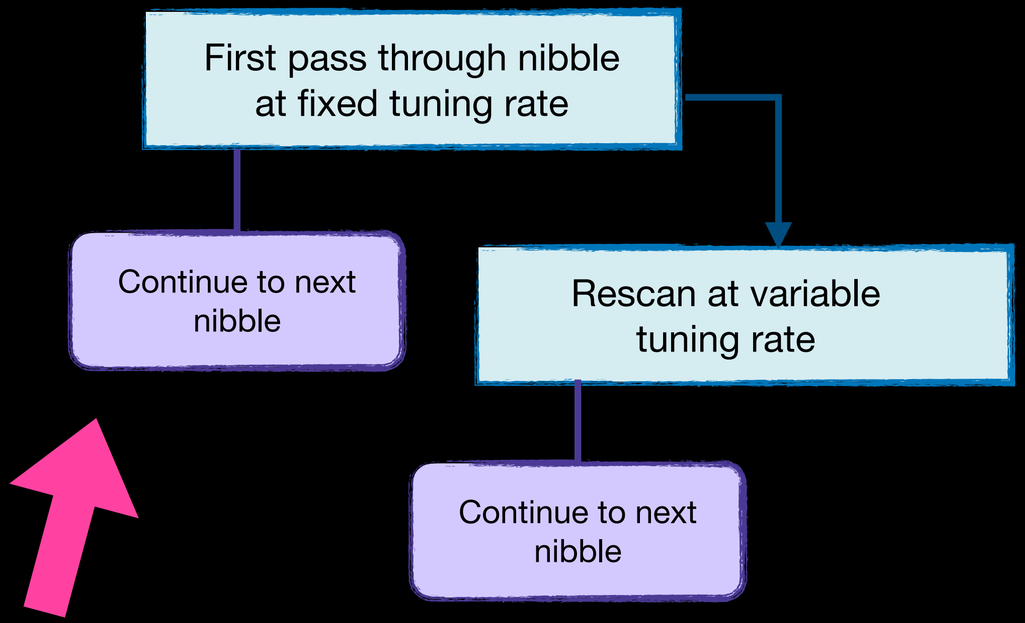


ADMX Candidate Decision Tree



NOTE!
Just due to the statistics involved with our tuning rate this doesn't ever realistically happen!

ADMX Candidate Decision Tree



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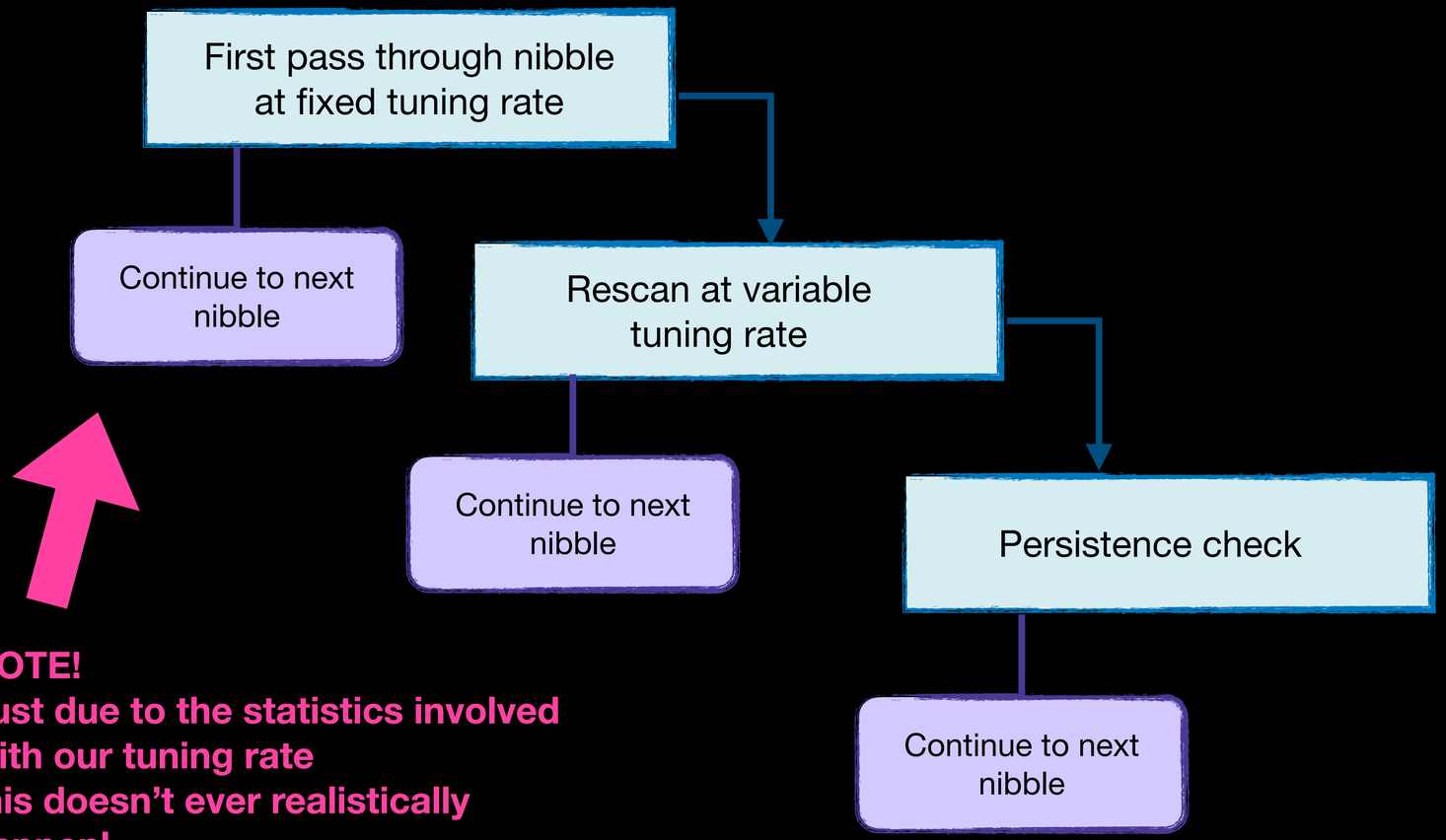

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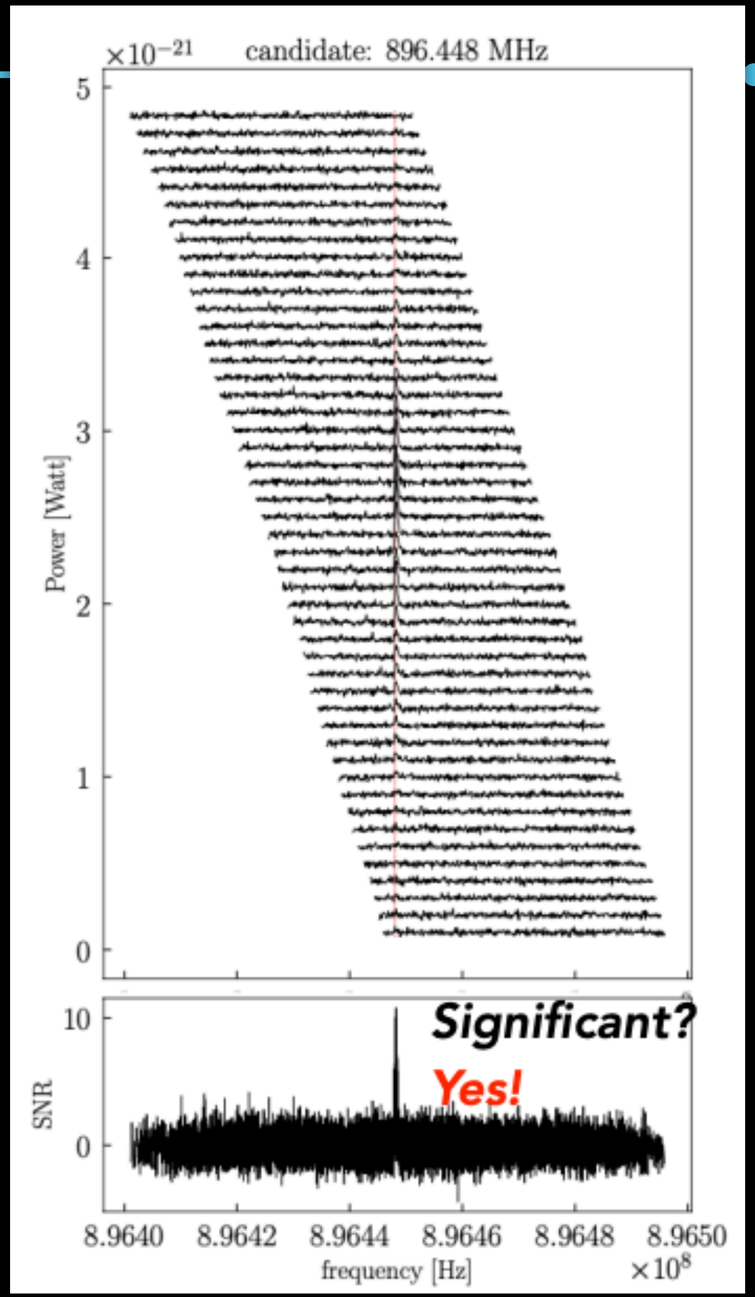

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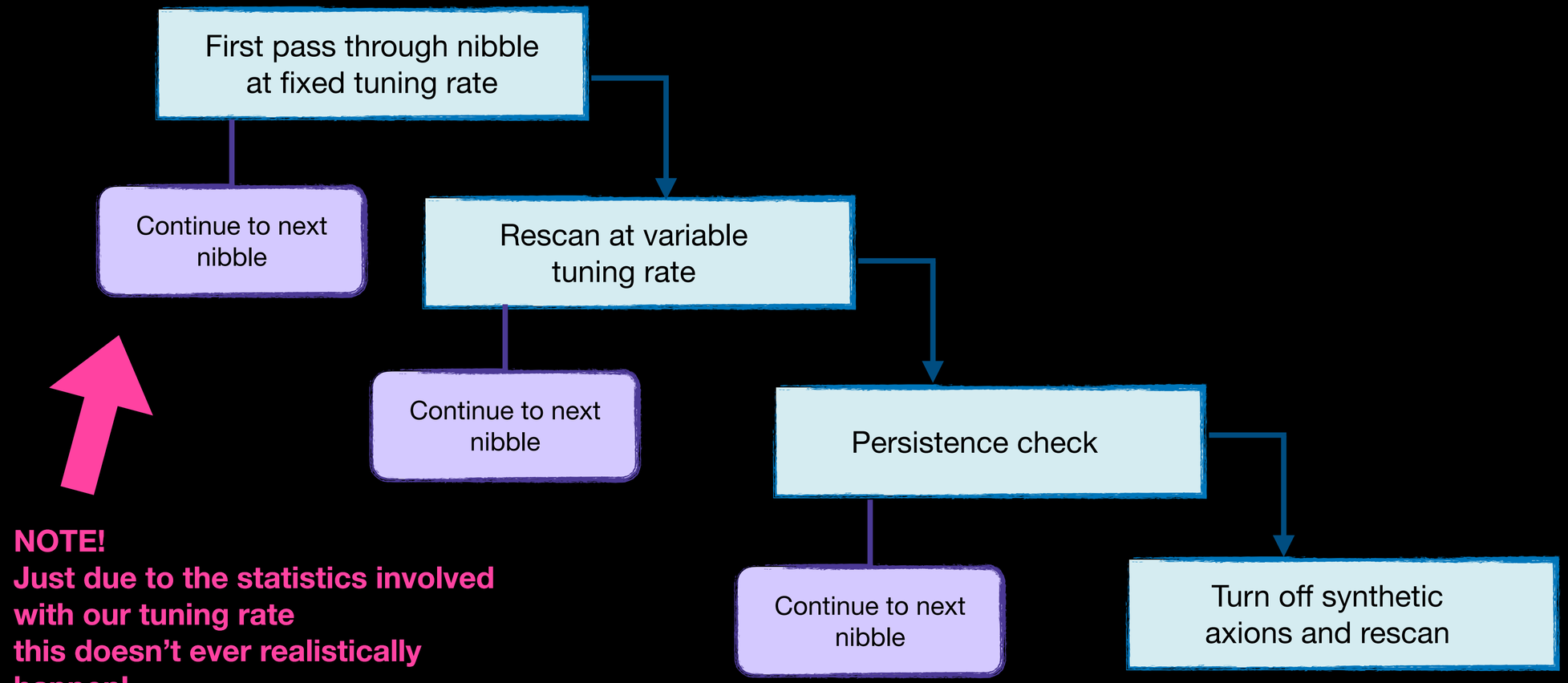

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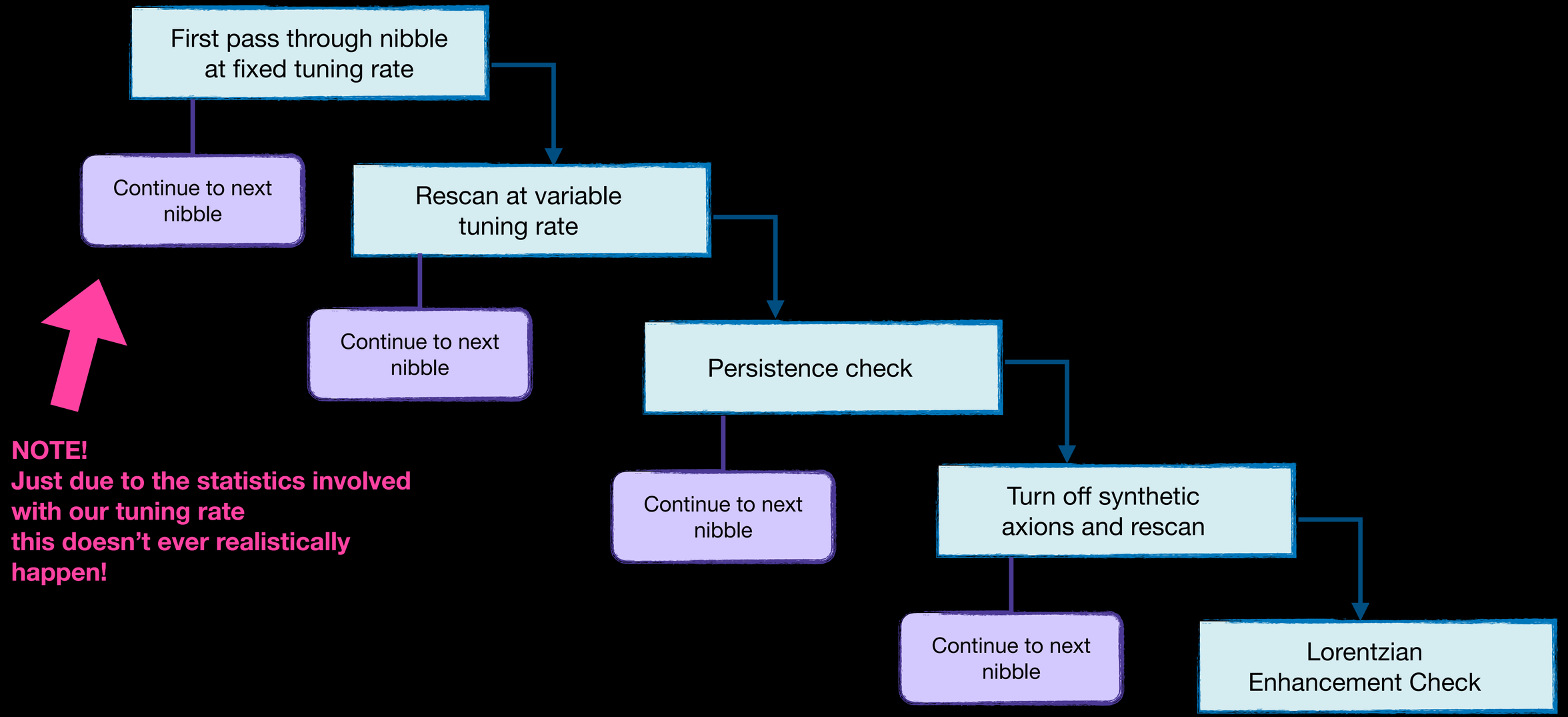

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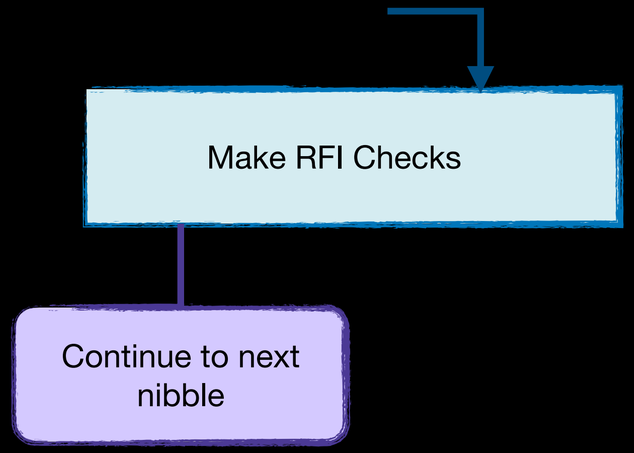

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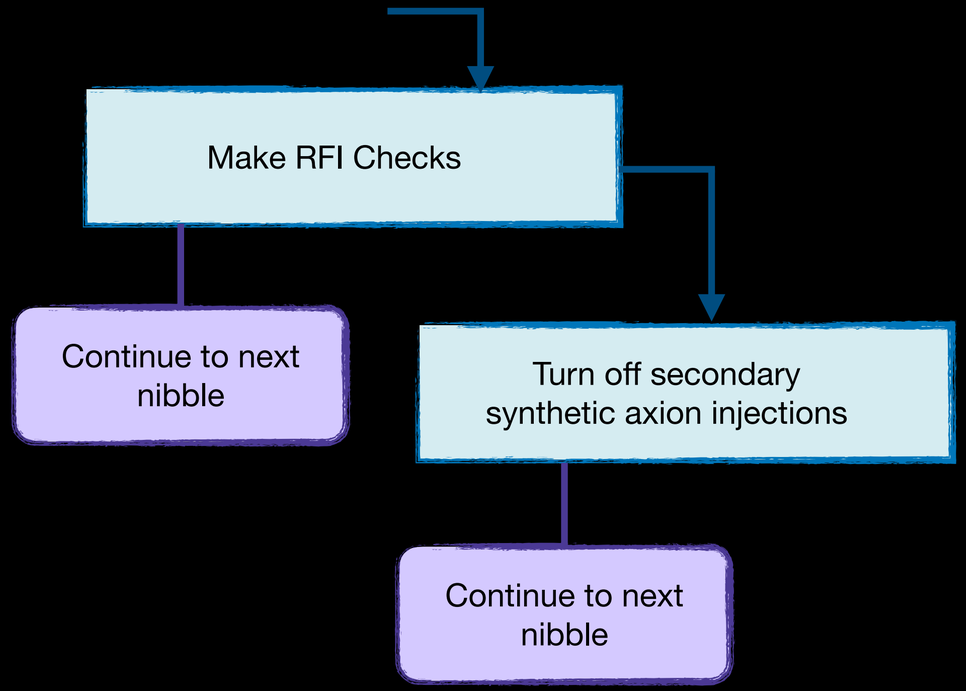

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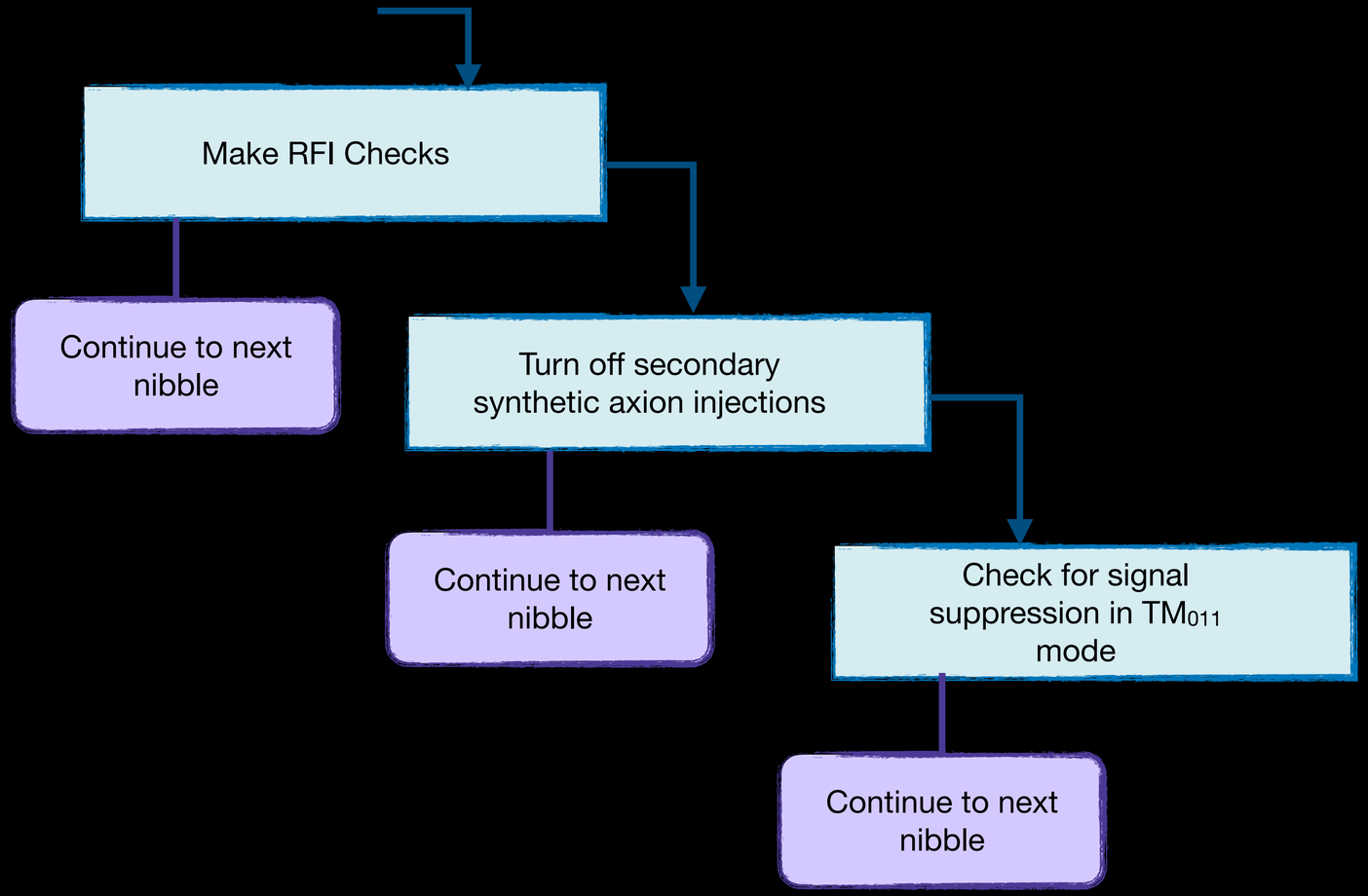

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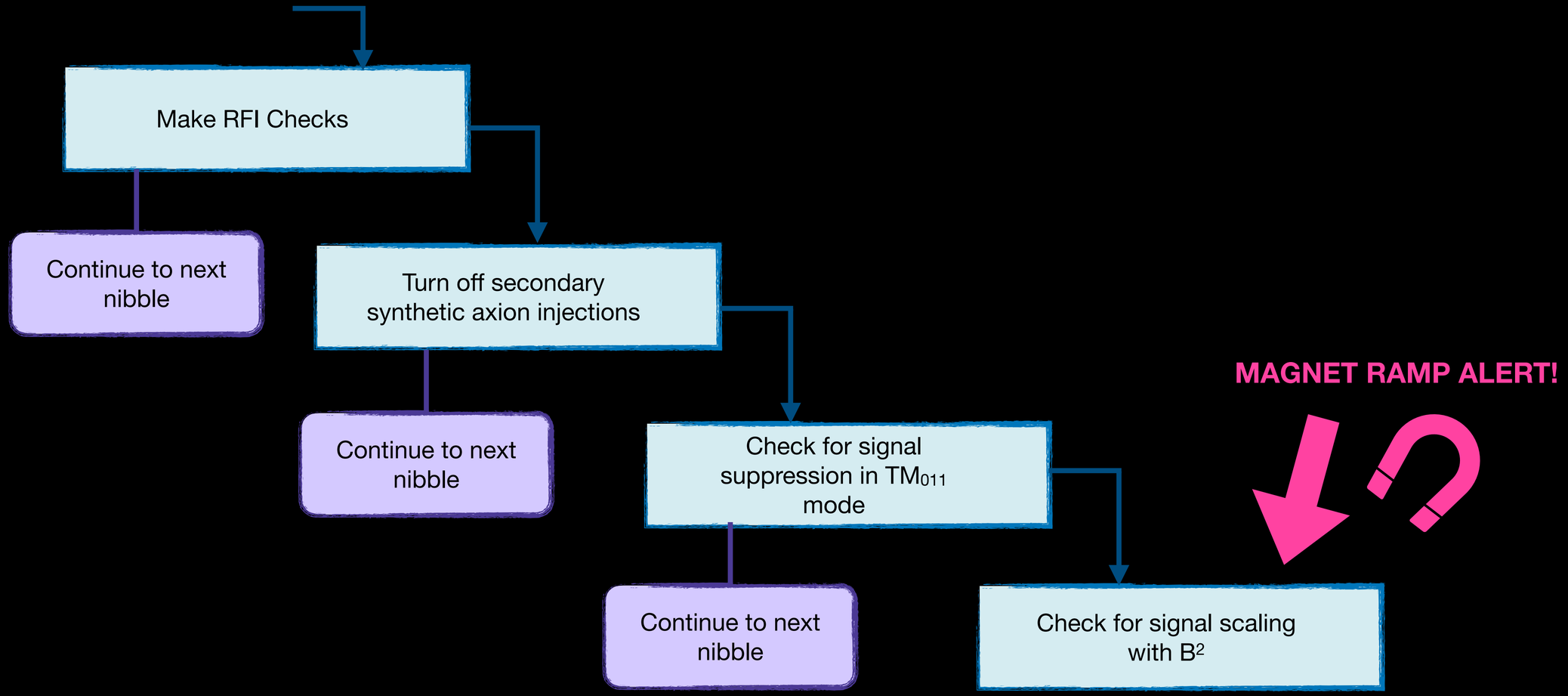

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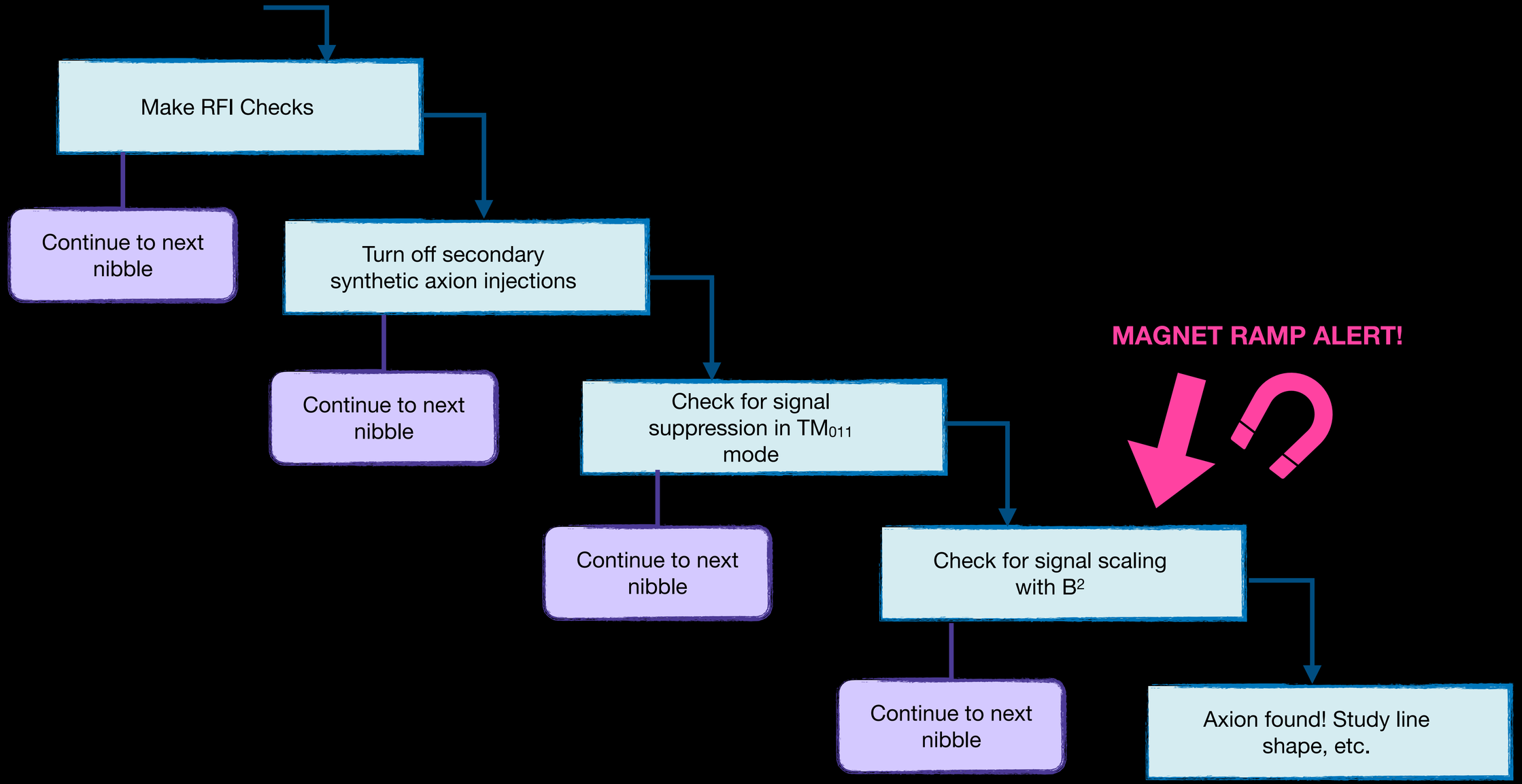


Discussion Questions

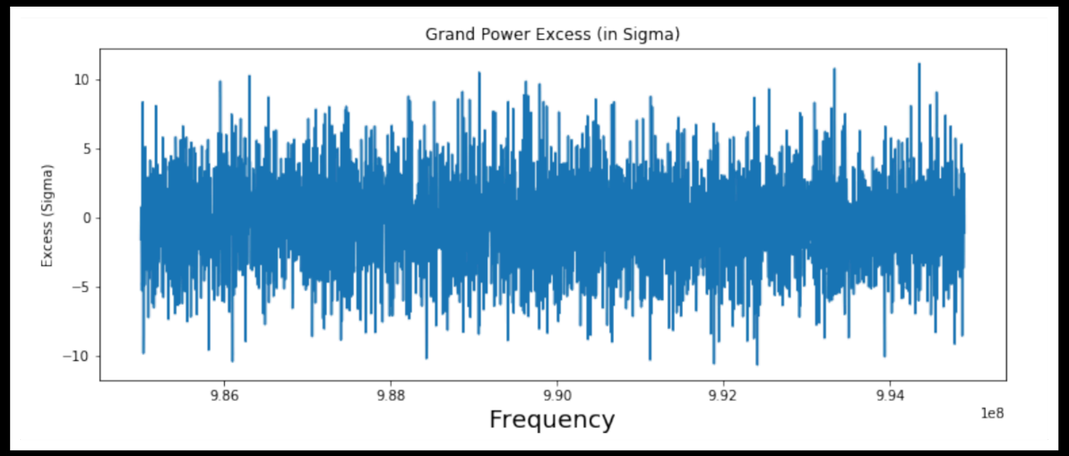
- Does this decision tree preclude interesting models?
  - Improved communication between experiments
  - Improved communication to theorists

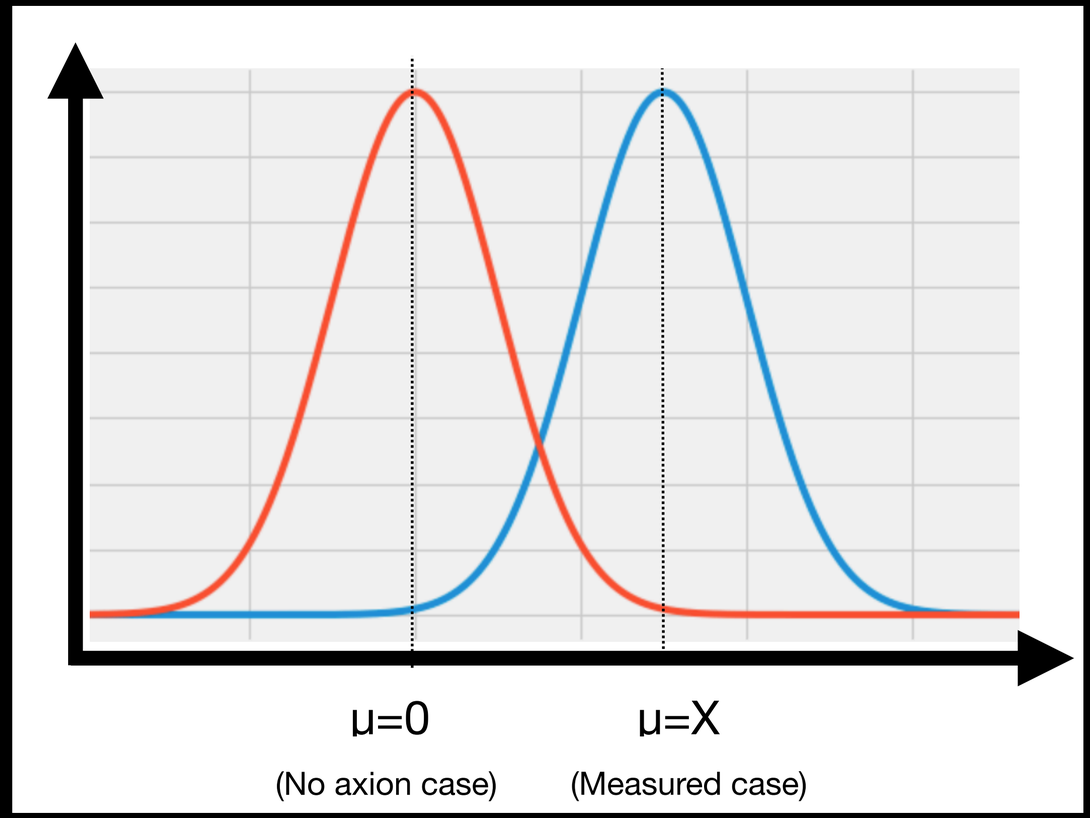
ADMX Exclusion Limit

$$\mu = g_\gamma^2 \eta$$

Measured SNR ratio for an axion

Axion photon coupling





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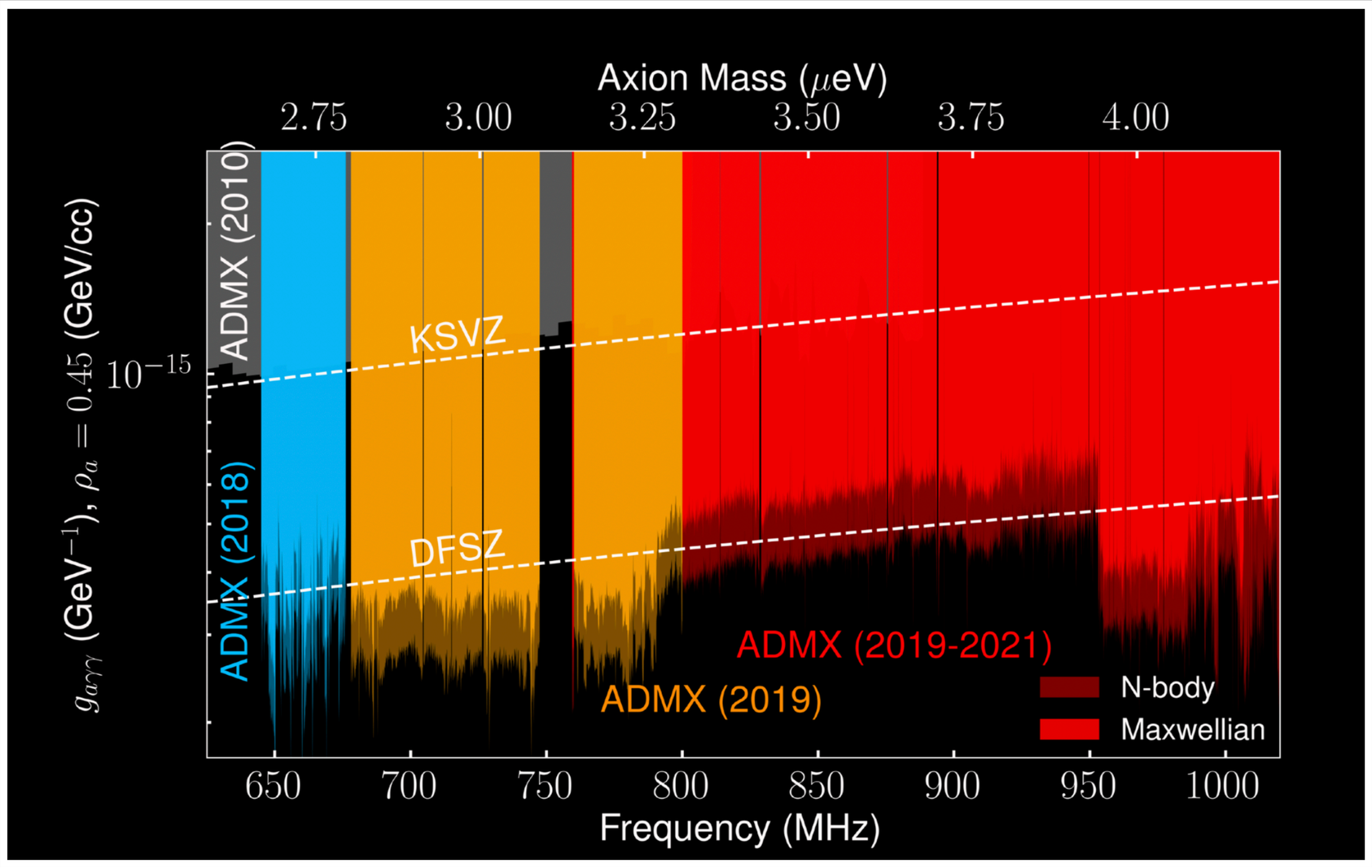
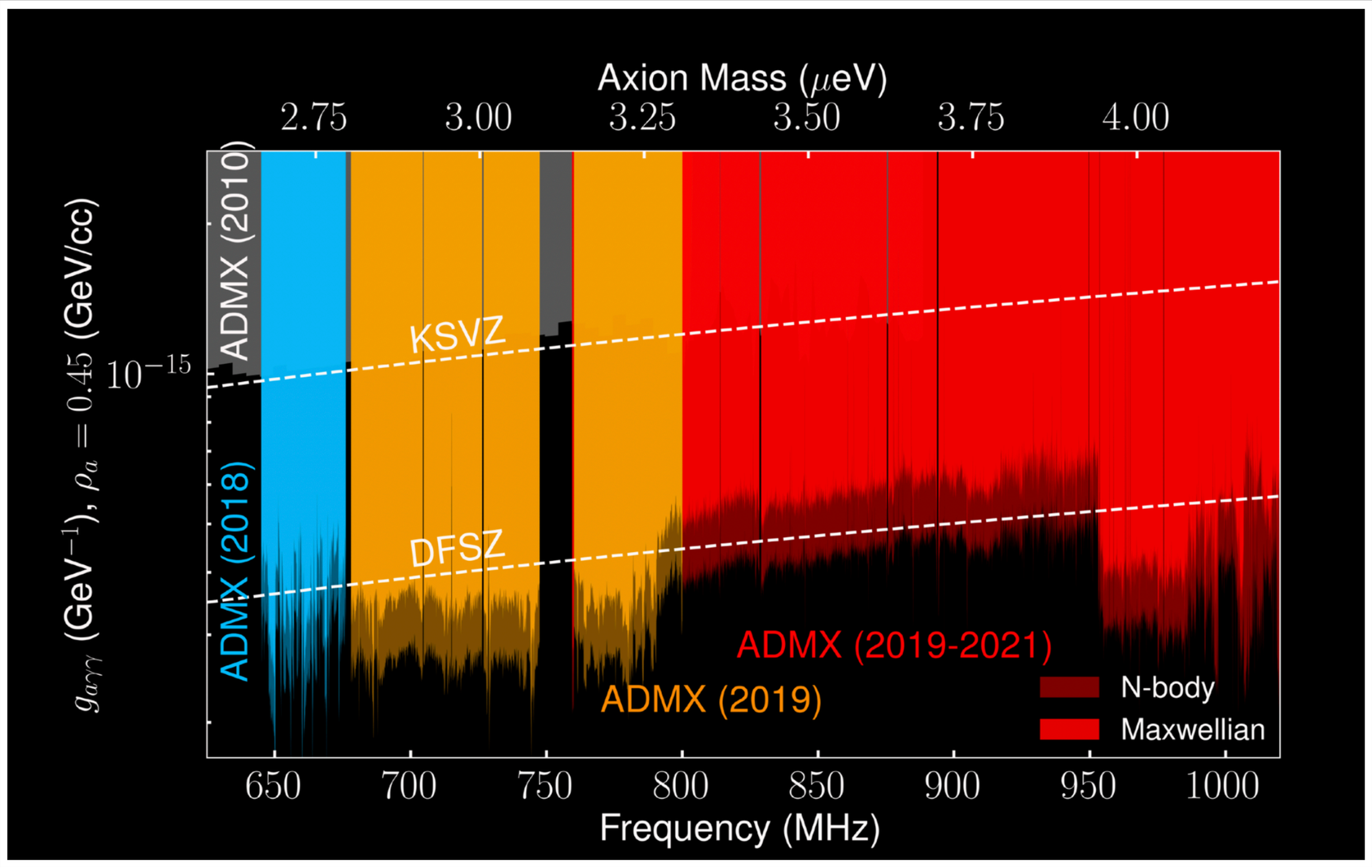


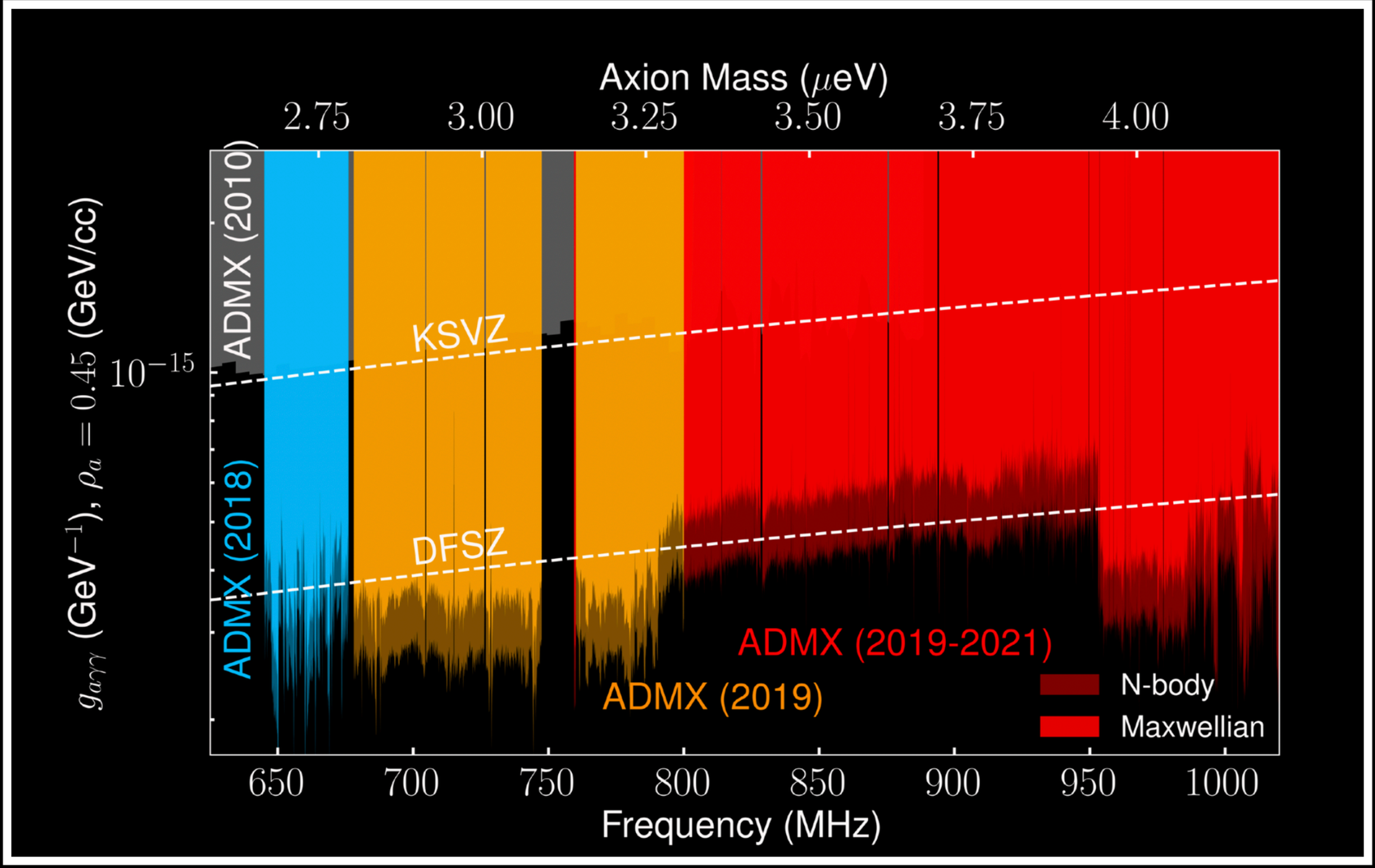
Axion Exclusion Limit



Assumptions

- 0.45 GeV/cc dark matter density
- Isothermal halo model
- Does not resolve features < 300 Hz
- Frequentist interpretation

Axion Exclusion Limit



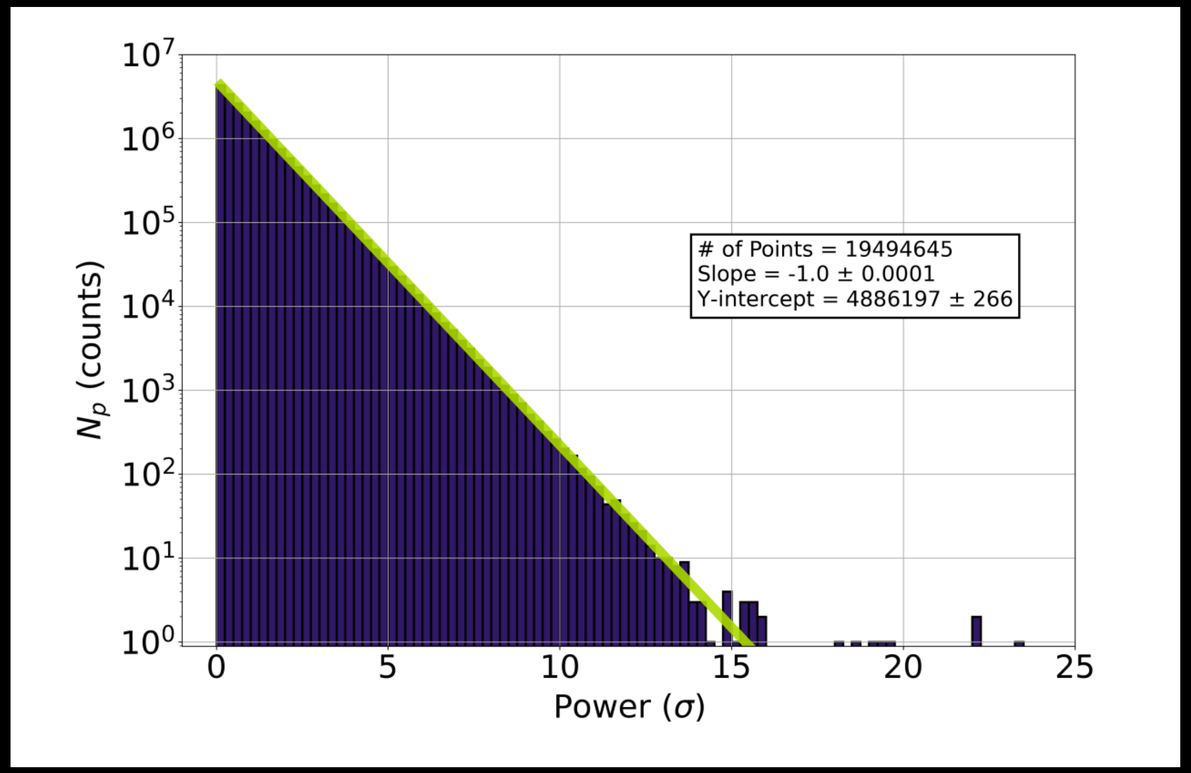
Unique features

- Mode-crossings cause gaps
- Resolution not adequate to see excluded candidates
- Jagged edge due to performance of quantum amplifier

Discussion Questions

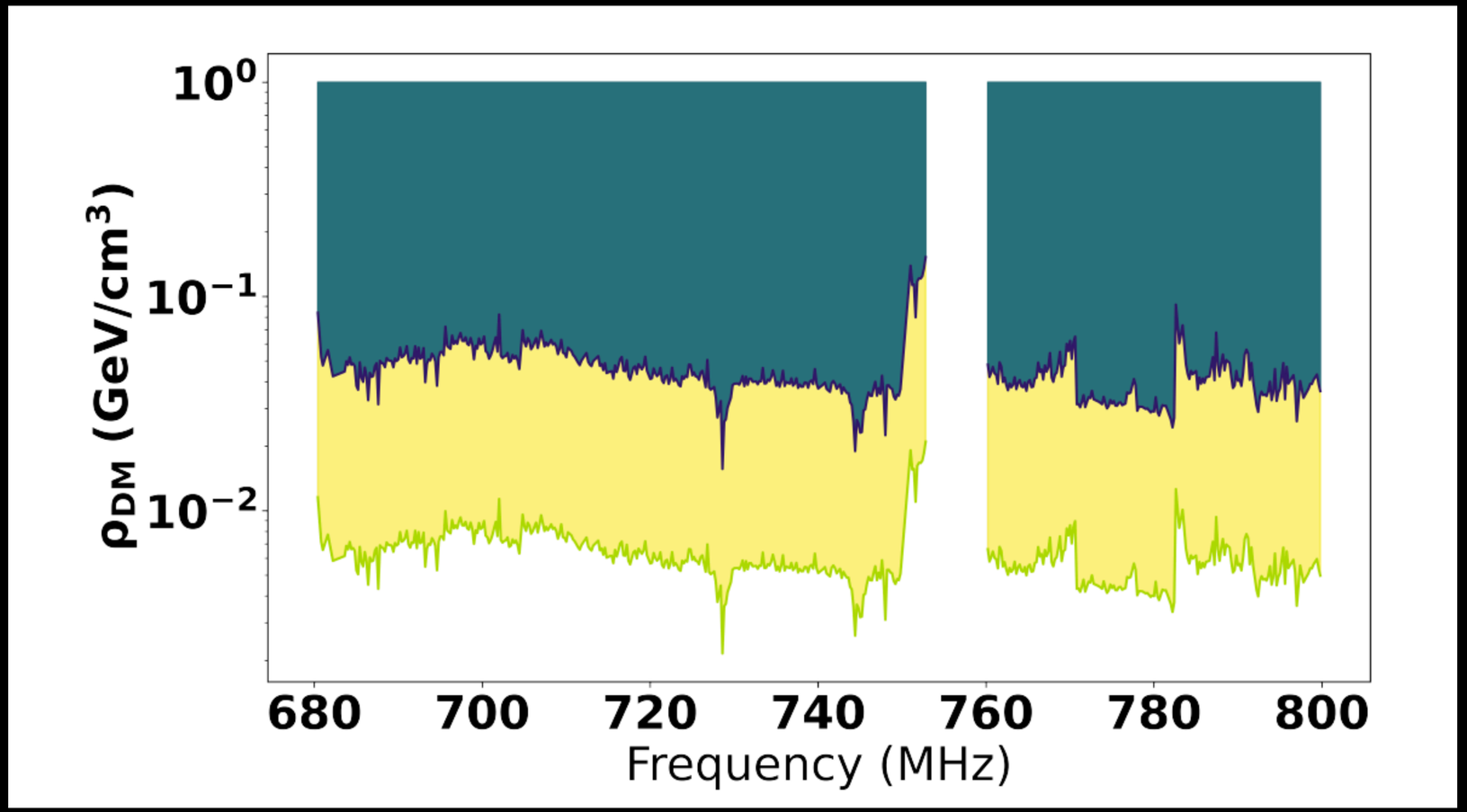
- Exclusion limit plots contain many assumptions
  - Are there ways to improve what is communicated in the plots?
  - Should we eliminate some assumptions?
  - How to have a coherent approach between groups?

High Resolution Search



- Time-series
  - Sensitive to non-virialized axions
  - Sensitive to frequency modulation from orbital and rotational motion
  - 10 mHz native bin width

High Resolution Search



Legend

- Teal: DFSZ assumed
- Yellow: KSVZ assumed

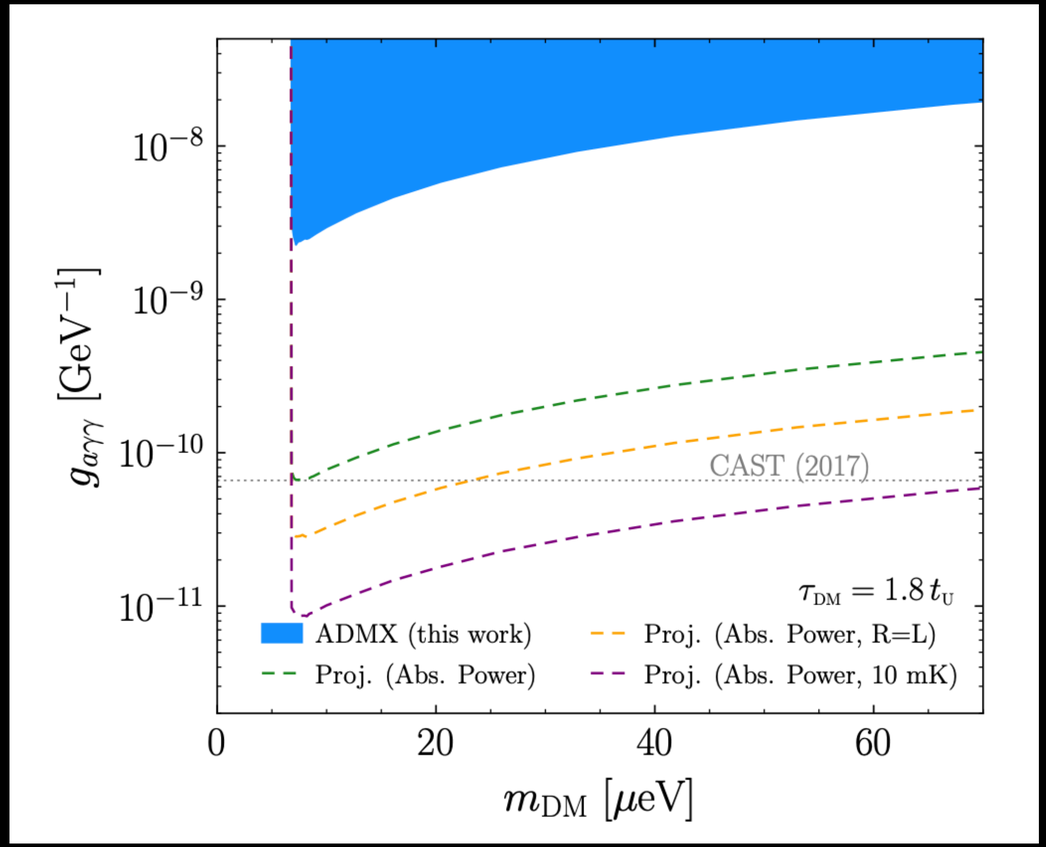
No line-shape implied; monochromatic tone only

Other offline analyses

Cosmic Axion Background

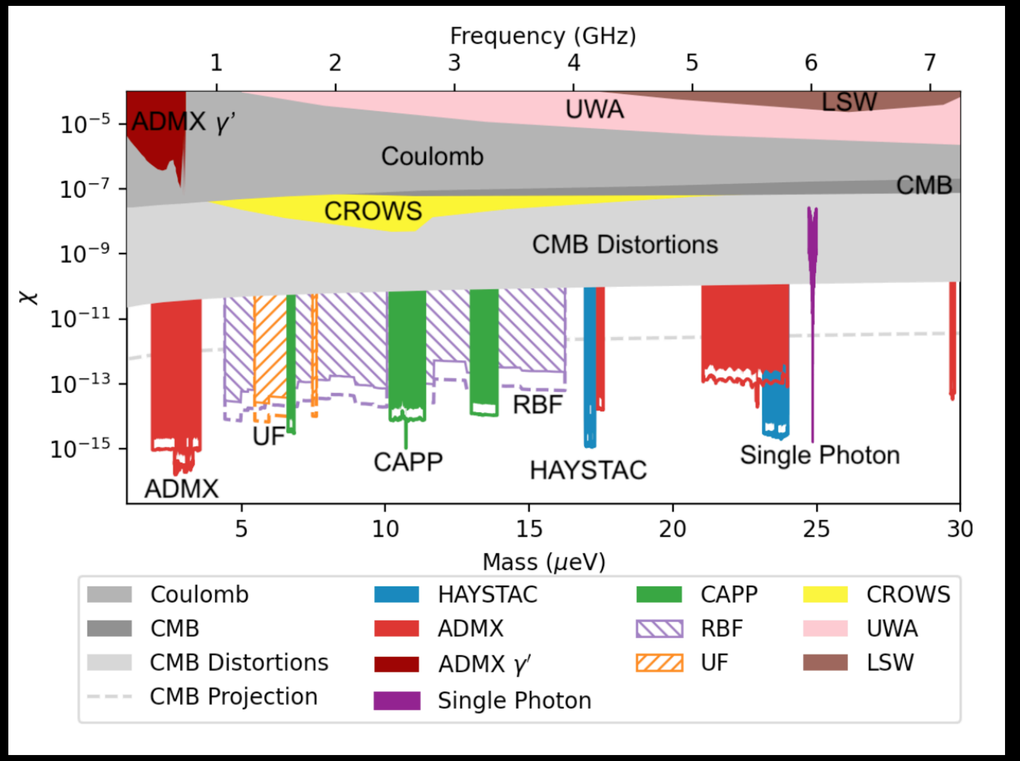
Signal: Broadband amplitude modulation

Nitta, T., et al. "Search for the Cosmic Axion Background with ADMX." *arXiv preprint arXiv:2303.06282* (2023).



Hidden Photon Searches

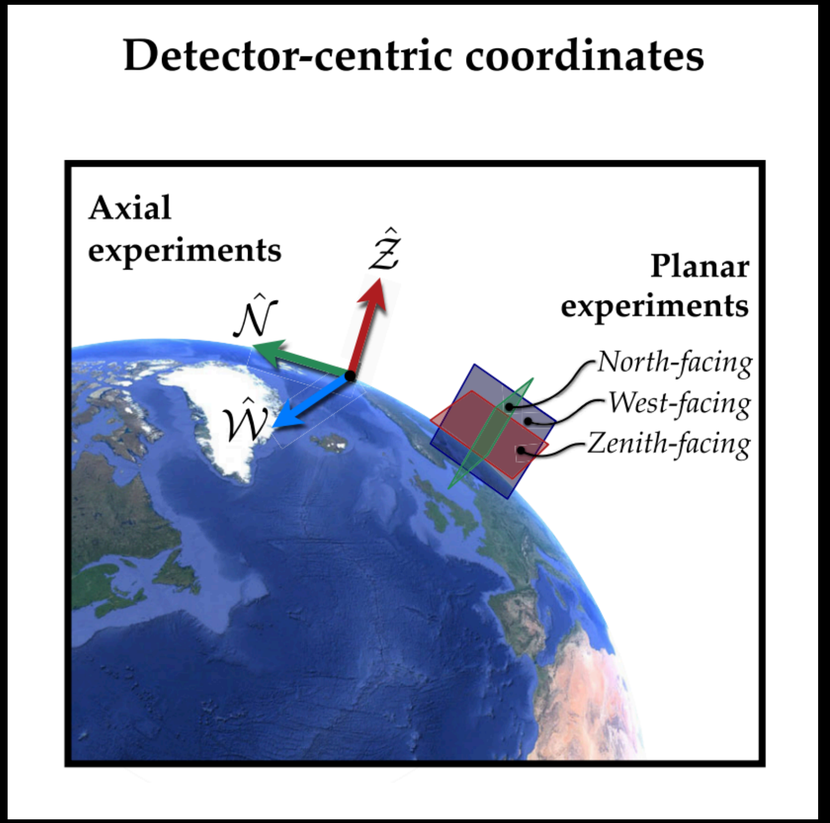
- Hidden photon search does not require a magnetic field
- Simple scaling between axion and hidden photon search



Ghosh, Sumita, et al. "Searching for dark photons with existing haloscope data." *Physical Review D* 104.9 (2021): 092016.

Hidden Photon Searches

- More sophisticated search can account for detector orientation
- Intentional rescanning such that timing can be used to improve detector sensitivity
- Challenging due to rescan process

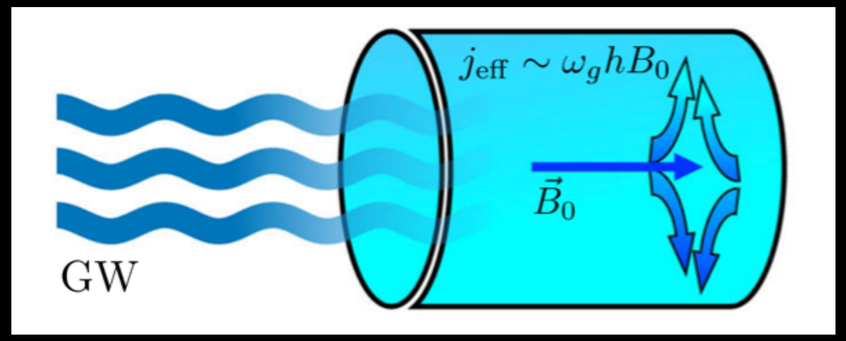


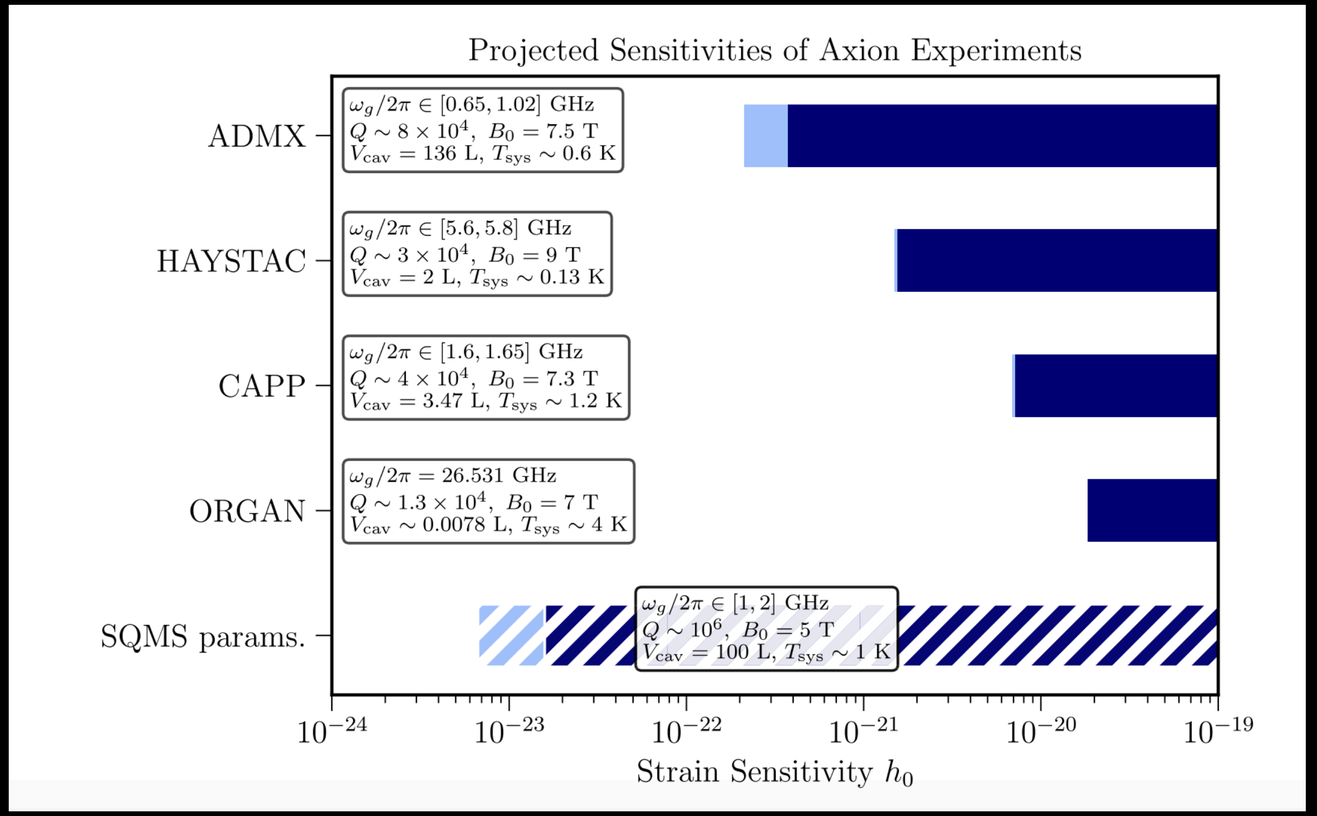
Caputo, Andrea, et al. "Dark photon limits: A handbook." *Physical Review D* 104.9 (2021): 095029.

Other offline analyses

High Frequency Gravitational Wave Searches

Signal: Broadband amplitude modulation





Berlin, Asher, et al. "Detecting high-frequency gravitational waves with microwave cavities." *Physical Review D* 105.11 (2022): 116011.

Discussion Questions

- Operations is driven by the Standard Halo Model.
  - Are there other models we should take into account?
  - At what cost?