# HiRes Analysis of the ADMX Run 1c Data

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For the ADMX Collaboration*

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# Motivation for HiRes Analysis

- Theory predicts there are cold, nonvirialized axion flows in the galactic halo[1]
- The velocity dispersion of these flows is small, resulting in a narrow signal
- A high frequency resolution is needed to detect these

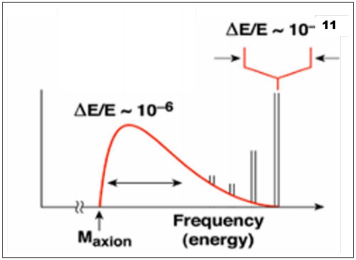


Figure: Cartoon Axion Signal. Diagram provided by Leanne Duffy.

[1] L.D. Duffy and P. Sikivie. The Caustic Ring Model of the Milky Way Halo. *Phys. Rev. D*, 78:063508, 2008.

# Overview of Analysis

- The HiRes data is produced by the ADMX DAQ system, which Fourier transforms the data, filters it, then inverse Fourier transforms it back into a complex 100-second time series
- The Fourier Transform is computed, producing a frequency series spanning 0 kHz to 50 kHz
- Next, the power spectrum is computed
- The power spectrum is fitted with and divided by an 8th degree polynomial to produce a normalized power spectrum

# 100 Second Scan

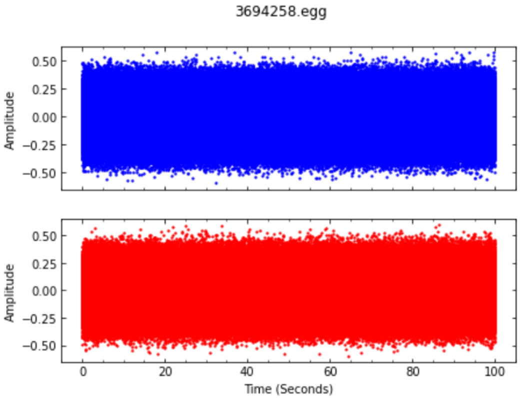


Figure: Top: real part of the data; Bottom: imaginary part of the data, for a 100 second scan.

# Power Spectrum

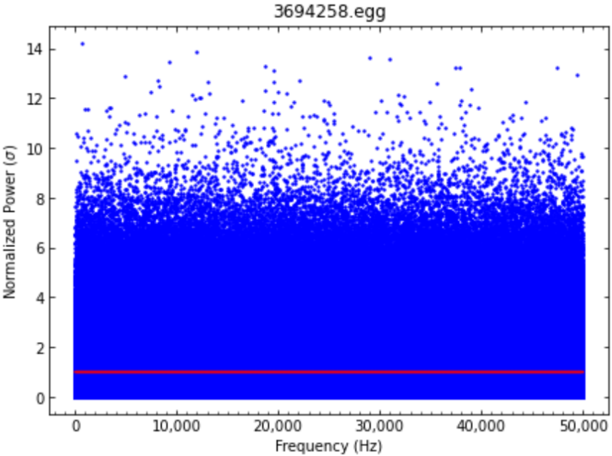


Figure: Power spectrum from the cavity.

# Histogram of Power Spectrum

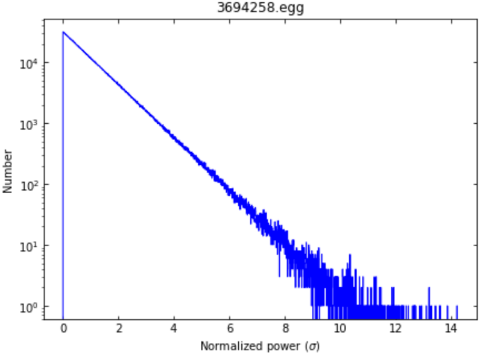


Figure: Histogram of power spectrum.

# Power Spectrum with Synthetic Axion Injection

- Injected signals have a width of approximately 1 kHz
- They are composed of about 30 separate frequencies, spaced 50 Hz apart
- Intended to simulate the Maxwellian kintetic energy spectrum for a virialized axion spectrum

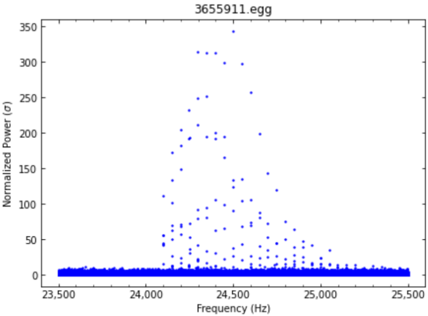


Figure: Close up of an injected signal.

# Singe Component of Injected Peak

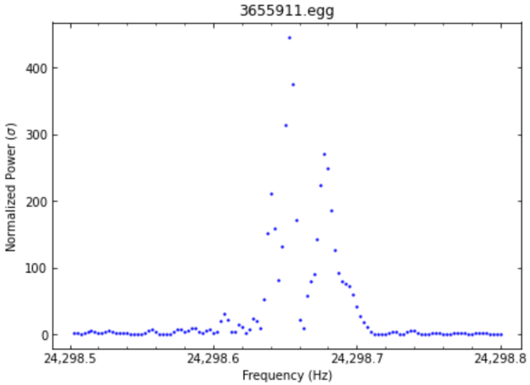


Figure: Single component of the peak for an injected signal.

# Identifying Candidates

- For run 1c, there are roughly 100,000 100-second scans
- First we produce a list of triggers, which are points with a power of $\sim 14\sigma$ or higher, and convert their fourier frequencies to candidate frequencies
- Next, we make various cuts to the list
- One cut in particular considers the frequency modulation of a signal and its persistence
- The triggers which remain after all cuts compose the list of candidates

# Frequency Modulation

- There are frequency modulations due to diurnal and annual effects
- Diurnal effects result in a maximum shift of about 1 Hz and annual effects of 100 Hz

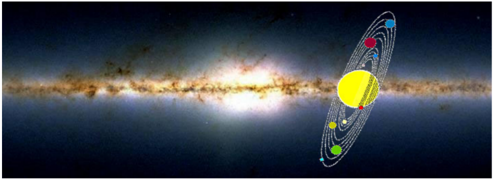

Figure: Cartoon of our solar system in the Milky Way.

- The relevant quantities are $v_\odot = 220$ km/s, $v_e = 30$ km/s, $v_U = 0.30$ km/s, and $v_a$

# Calculation of Frequency Modulation

- The frequency we would detect for an axion is given by

$$hf = m_a c^2 + \frac{1}{2} m_a \vec{v} \cdot \vec{v}$$

where $\vec{v} = \vec{v}_a - \vec{v}_{det}$ and $\vec{v}_{det} = \vec{v}_\odot + \vec{v}_e + \vec{v}_U$

- Substituting these expressions in yields

$$hf = m_a c^2 \left[ 1 + \frac{v_a^2 + v_\odot^2 - 2\vec{v}_a \cdot \vec{v}_\odot}{2c^2} + \frac{(\vec{v}_a - \vec{v}_\odot) \cdot (\vec{v}_e + \vec{v}_U)}{c^2} \right]$$

- Taking the derivative of this expression allows us to calculate doppler shifts

$$\frac{df}{dt} = f_0 \left[ \frac{(\vec{v}_a - \vec{v}_\odot)}{c^2} \cdot \left( \frac{d\vec{v}_e}{dt} + \frac{d\vec{v}_U}{dt} \right) \right]$$

- To anticipate how the analysis for run 1c will be done, we will now go through the process used for run 1b

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- Next, next we remove all injections and identified environmental noise, of which there are 56,571, leaving 356,686 triggers left

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- Next, we remove all triggers which are farther than the Doppler estimate away from any other trigger, removing 148,655 and leaving 7,777
- Lastly, a persistence cut requires triggers to show up in at least 30% of the scans containing its frequency, removing 7,058 and leaving us with 719 candidates, all at either 686.3 MHz or 792.6 MHz
- Results will be discussed by Shriram Jois on Thursday

# Future Plans

- Continue work on developing a model to calculate accurately the frequency modulation of a signal
  - Work based on the caustic ring model, developed by Pierre Sikivie and his students [2]
- Begin a multi-resolution search in collaboration with the HiRes team
  - The HiRes team is made up of graduate students, post docs, and scientists from UW, UF, UWA, FNAL, and LANL

[2] Sankha S. Chakrabarty, Yaqi Han, Anthony Gonzalez, and Pierre Sikivie. Implications of triangular features in the Gaia skymap for the Caustic Ring Model of the Milky Way halo. arXiv:2007.10509

# Conclusion

- The HiRes analysis channel has potential to be the discovery channel for the axion
- Its ability to detect small frequency modulations of a signal could provide strong evidence for axions making up the dark matter in our galaxy
- The information provided by a detection in the HiRes channel could lead to axions becoming a 4th source in mulit-messenger astronomy