

# Searches for Daily Modulations with the CAST-CAPP Detector

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on behalf of the CAST Collaboration

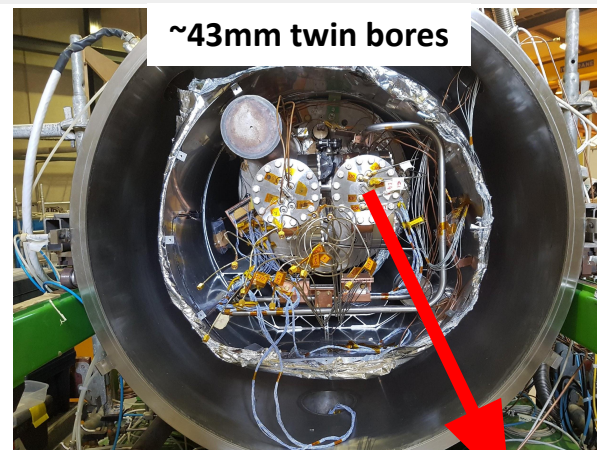
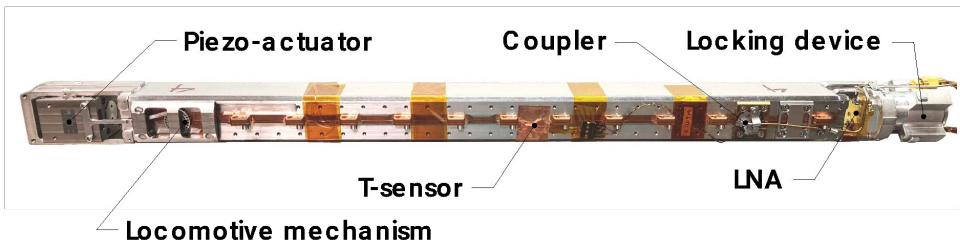
03/07/2023

18TH PATRAS WORKSHOP ON AXIONS, WIMPS AND WISPS

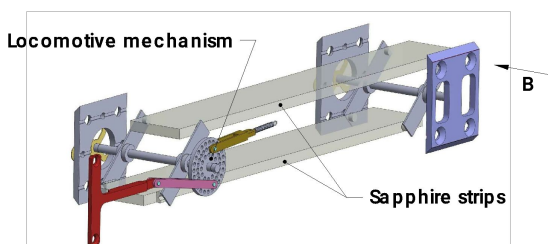
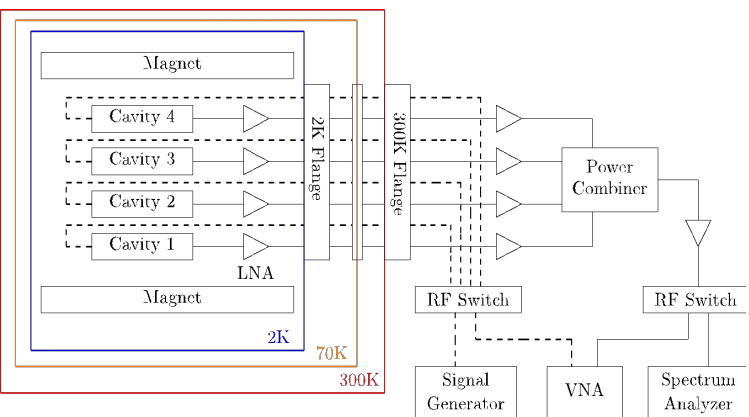


# CAST-CAPP Operation

**Four** identical stainless steel **tunable** cavities electroplated with  $\sim 30\mu\text{m}$  of copper installed in one of the two twin bores of CAST magnet with the split plane parallel to the magnetic field.



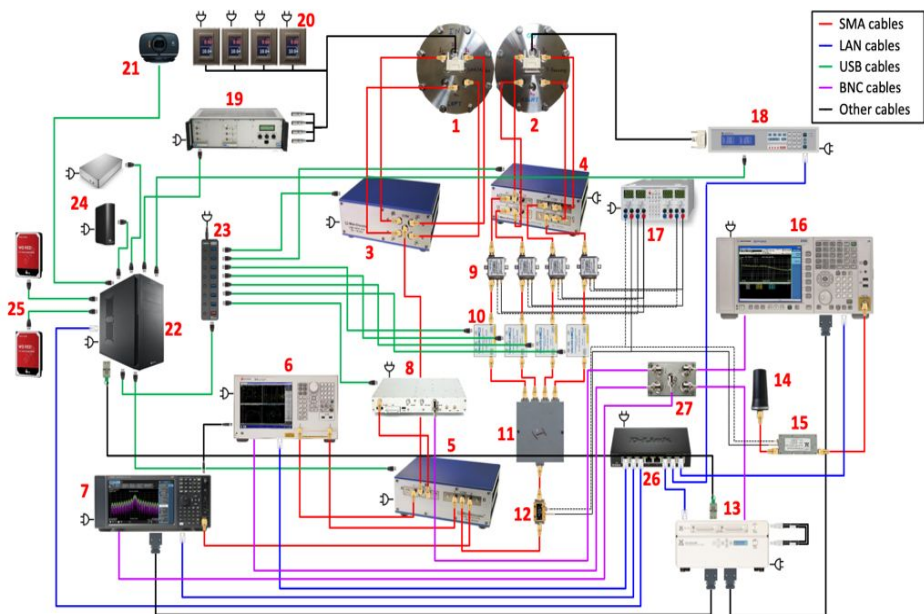
**CAST-CAPP**



Tuning mechanism: 2 dielectric sapphire bars symmetrically placed parallel to the longitudinal sides, moving simultaneously towards the center and activated by a piezoelectric motor.

# CAST-CAPP Data Acquisition

- 1-min measurements
- Bandwidth = 5 MHz
- Tuning step size = 200 kHz
- Size =  $\sim 3$  GB / file !!



## QUALITY CHECKS:

Main source  $\rightarrow$  Vibrations

Nr.	Parameters	Criteria
1	Frequency stability	$\Delta\nu_0 < 100$ kHz
2	Amplitude variation	$\Delta A_0 < 3$ dB
3	Quality factor	$10^3 < Q_L < 4 \times 10^4$
4	Quality factor shift	$\Delta Q_L < 7 \times 10^3$
5	Temperature variation	$\Delta T_{\text{cav}} < 3$ K
6	Temperature	$1 \text{ K} < T_{\text{cav}} < 273 \text{ K}$
7	Magnetic field variation	$\Delta \vec{B} < 0.1 \text{ T}$
8	Frequency mismatch	$< 20$ kHz (before) & $< 80$ kHz (after)
9	Amplitude mismatch	$< 1$ dB
10	Temperature mismatch	$< 3$ K

## RESULTS:

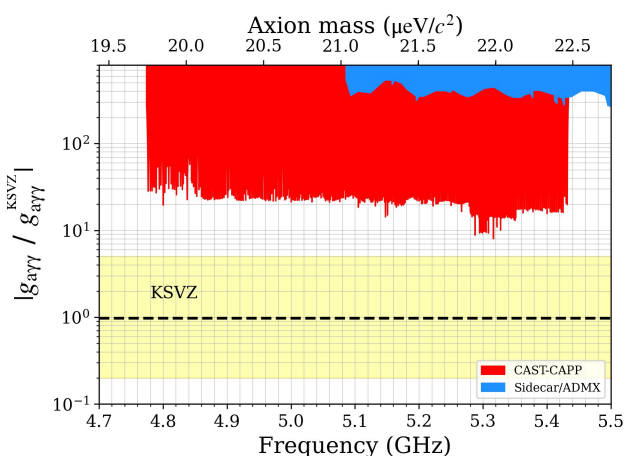
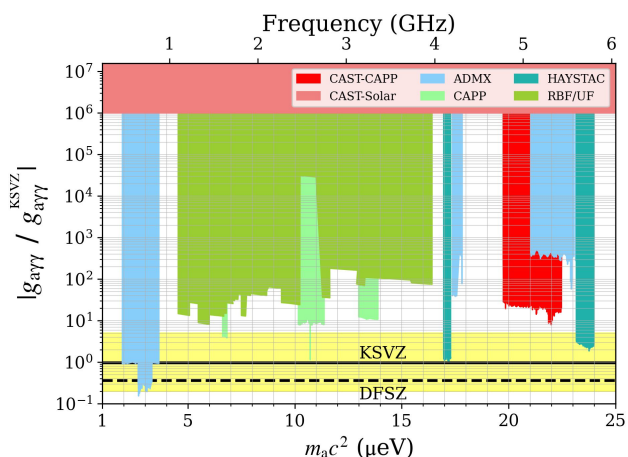
- Data-taking time: 4124 h (172 d)
- Frequency range: 660.15 MHz
- Axion Masses: 4.77 - 5.43 GHz
- Data size:  $\sim 650$  TB !!

# CAST-CAPP Results → Alternative analyses

- Total data-taking time: 4124 h (172 d)
- Data size: ~ 650 TB
- Frequency range: 660.15 MHz
- Axion masses: 19.74  $\mu\text{eV}$  - 22.47  $\mu\text{eV}$
- Present sensitivity:
- Confidence level: 90 %
- Total uncertainty: 7.4%

## New analysis options:

1. Dark photons
2. Transient events  
(high resolution time series measurements)
3. **AQN daily modulations** (24h, Low Q, fixed frequency measurements, temperature isolation of complete datataking chain.)



CAST-CAPP was not designed for daily modulation analysis. We present an analysis model on retrospective data that will pave the way for future experiments.

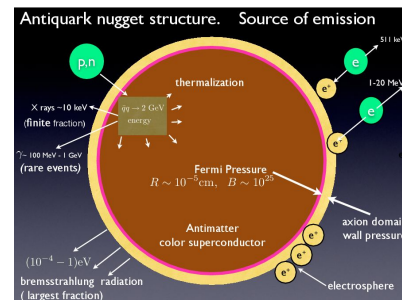
# Motivation for a New Analysis

- ❖ No Dark Matter detection so far by direct experimental searches.
  - ❖ Haloscopes focus on narrow resonant searches while trying to maximize the SNR.
  - ❖ A broadband approach might be the key to the discovery of the axion.
  - ❖ Daily modulations of the axion power are also expected from various models.
- 
- CAST-CAPP has 172d of data stored also in the time-domain (650TB).
  - Broadband electronics and wide frequency range.
  - 5 MHz Bandwidth  $\gg$  200 kHz Resonance width.
  - Post-data-acquisition analysis possible.

# Axion Quark Nuggets (AQNs)

- Originally proposed by A. Zhitnitsky (2003) to explain  $\Omega_{\text{DM}} \sim \Omega_{\text{visible}}$ .
- Also explain other mysteries (core-cusp, solar corona etc).
- Composite particles with axion domain walls.
- Relativistic axions with  $\langle \mathbf{u}_a \rangle \sim 0.6\mathbf{c}$  are emitted from AQNs as they propagate towards the Earth and also occasionally penetrate the Earth.
- Production mechanism would cause:
  - Daily modulation ( $\sim 10\text{-}20\%$ ).**
  - Seasonal phase shift.**

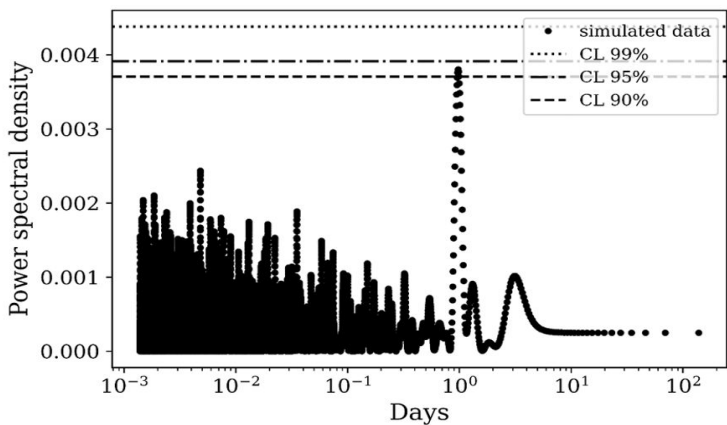
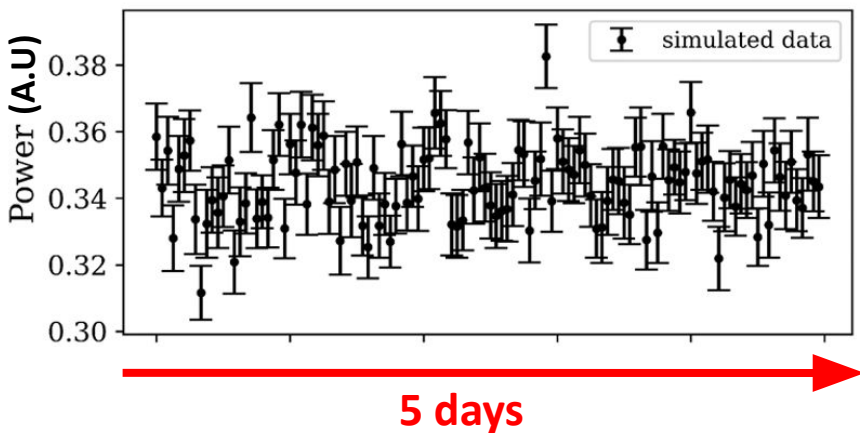
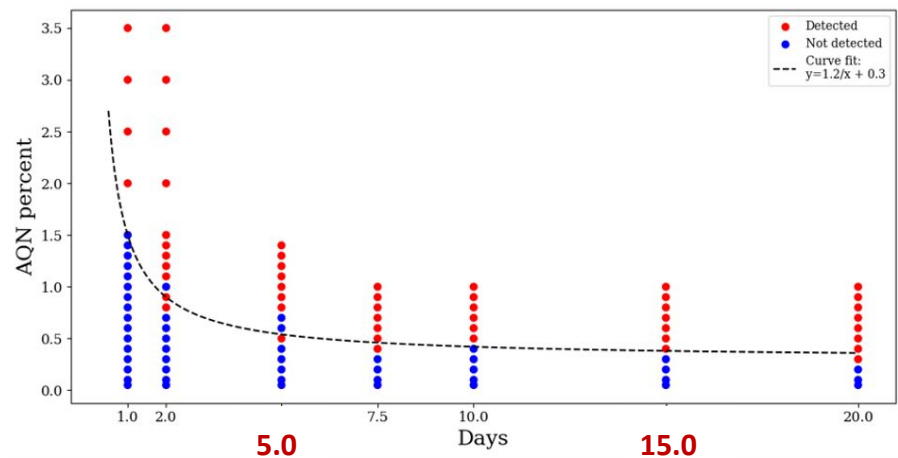
**See talk by A. Zhitnitsky in this workshop**



<https://doi.org/10.1103/PhysRevD.98.043013>

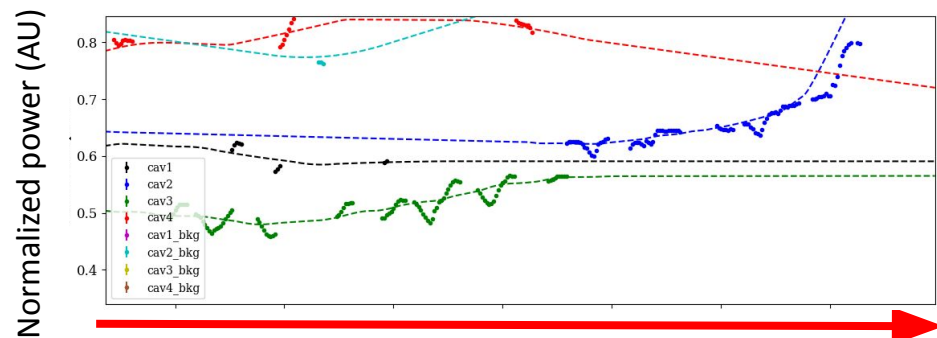
# Simulations

- AQN power= 0.7% of the mean spectrum power
- 1-min spectra created by real background + random noise + AQN power
- 5 days / 1 min = 7200 simulated spectra
- Create a periodogram using Lomb Scargle method
- ML algorithm to find the best decision threshold

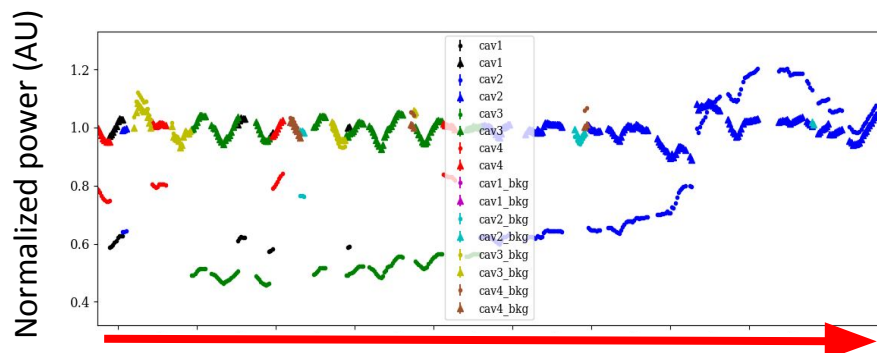


# Data Treatment

- Phase-matched data can not be used (attenuation added).
- Fast-tuning data can not be used.
- ❖ Single cavity data in fixed-frequency measurements.
- ❖ Use of high-quality data (clean from mechanical vibrations).
- ❖ Use of both B=ON & B=OFF (bkg) data.
- ❖ All data are detrended before analysis



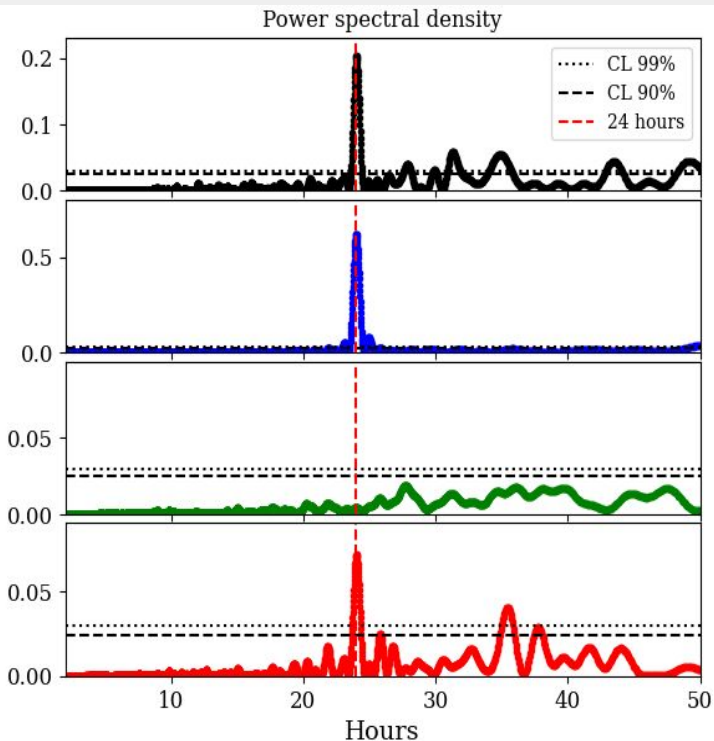
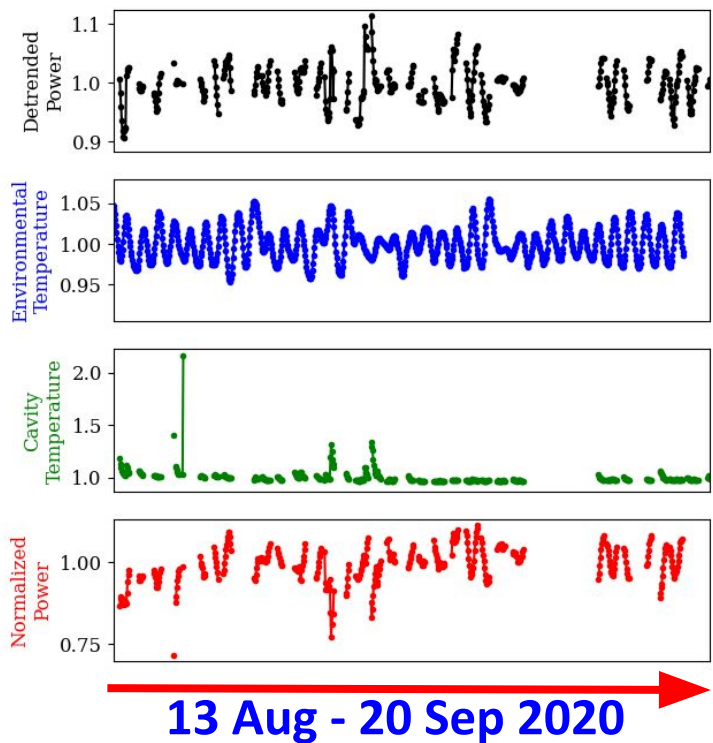
13 - 25 Sep 2020



11 - 29 Sep 2020

# Data Analysis - B=ON

Arbitrary Units



Cavity 3:  
B=ON data shows  
daily periodicity.

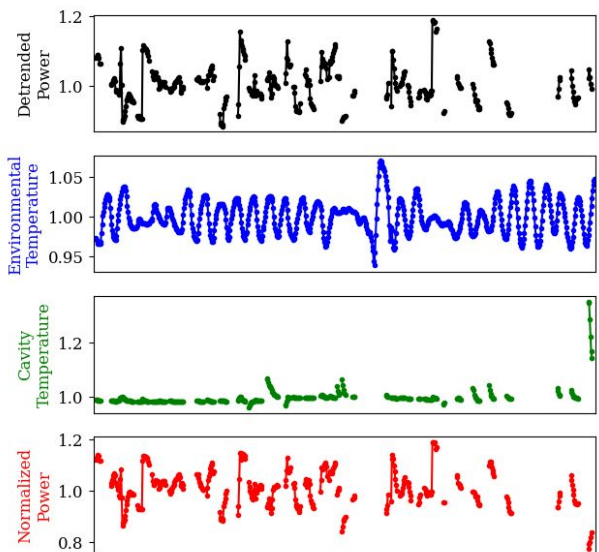
CAST hall  
temperature shows  
strong daily  
modulations.

No periodicity for  
cavity temperature.

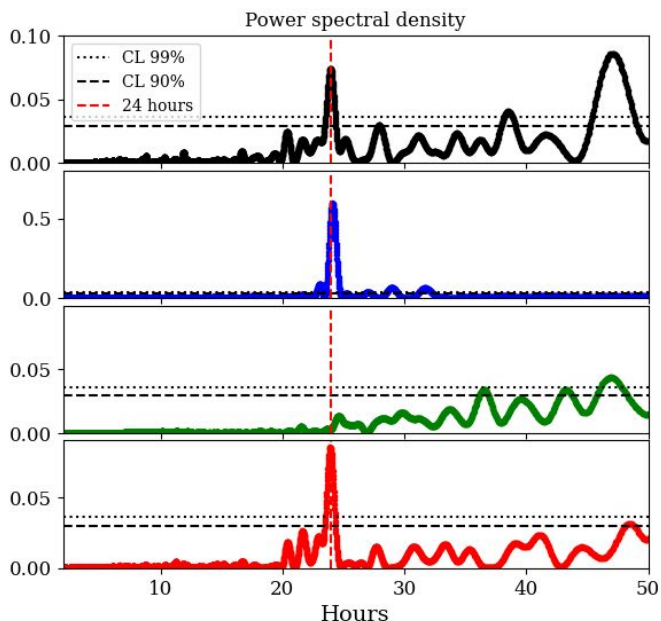
$$\text{Normalized power} = \text{Detrended power} / T_{\text{environmental}} / T_{\text{cavity}}$$

# Data Analysis - B=OFF

Arbitrary Units



13 July - 13 Aug 2020



## Cavity 2:

Prelim data → Both B=ON and B=OFF show daily variations.

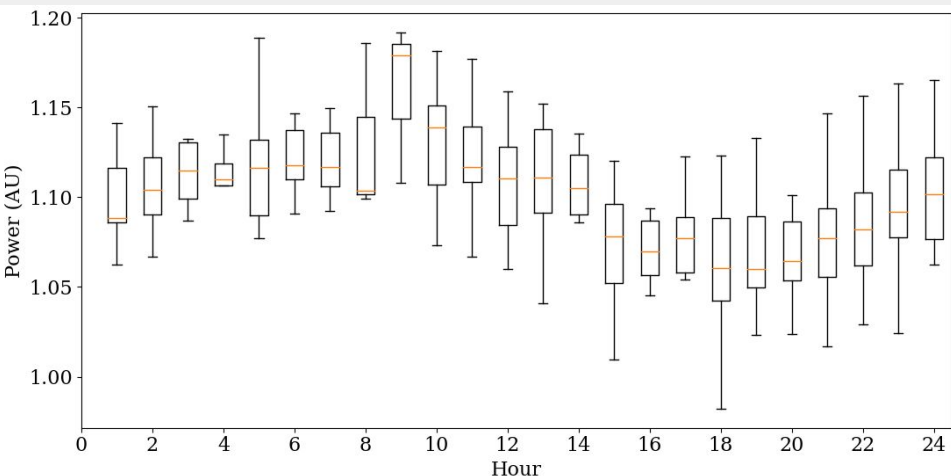
Origin may not be due to temperature OR temperature dependency might be more complex than anticipated

Other parameters are being scrutinized. **Further investigation required.**

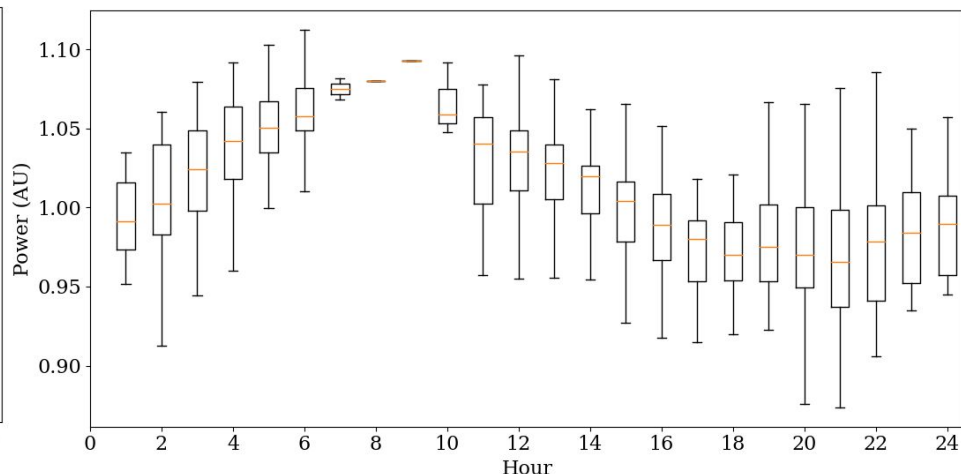
We cannot verify the AQN induced daily modulations without first understanding the daily variations included in B=OFF data.

$$\text{Normalized power} = \text{Detrended power} / T_{\text{environmental}} / T_{\text{cavity}}$$

# Data Analysis - Seasonal Phase Shift



**18 Nov - 2 Dec 2020, CAV 4**



**13 Aug - 20 Sep 2020 CAV 3**

- Box plots for normalized power.
- Selected intervals are ~3 months apart.
- Theory suggests 6 hours of shift in daily AQN power peak.
- We do not observe it in our data.

# Discussion / Conclusions

Status report of CAST-CAPP searching for signatures (daily modulation) as expected from the AQN model:

- Daily modulation observed in both B=ON and B=OFF data.
- Temperature dependency of the gain of 2<sup>nd</sup> stage (room temp) LNAs is the most probable scenario.
- Voltage drifts less probable due to the existence of a line-interactive UPS.
- Other parameters need to be checked.

- ◆ **Proof of principle → Done**
- ◆ **No conclusive result so far.**
- ◆ **Data need to be scrutinized further.**



*Stay tuned...*

