ADMX
AXION DARK MATTER EXPERIMENT

Noise Calibration in the ADMX Receiver Chain

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Berkeley University of California
UF University of Florida
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University of Washington 1861
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Lawrence Livermore National Laboratory
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Figure from KIPAC

Outline

Motivation/
Background

↓

Noise Temperature
Measurement

↓

Results

↓

Conclusion

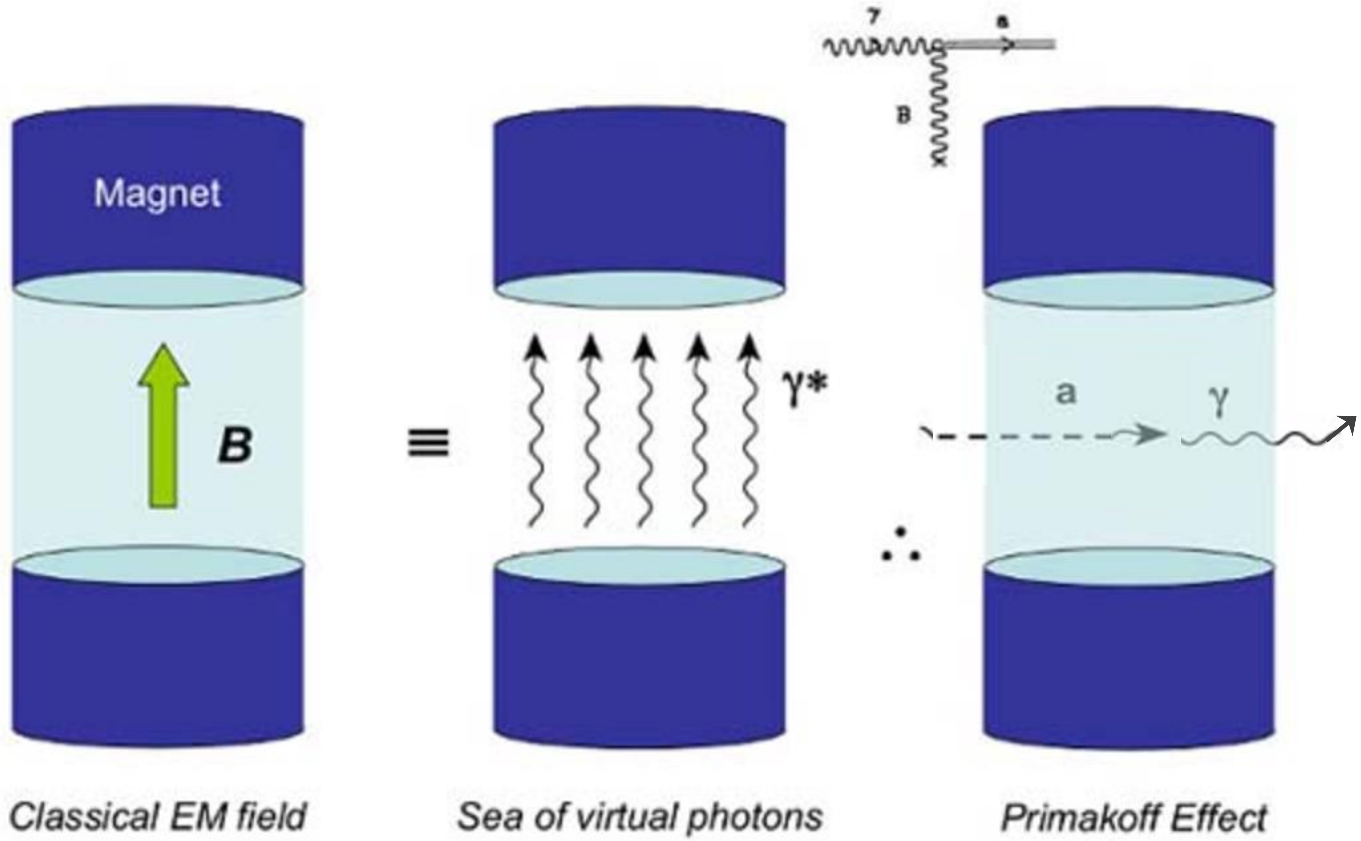
The Axion

An elegant solution to two problems

Nuclear Physics Problem

Dark Matter Problem

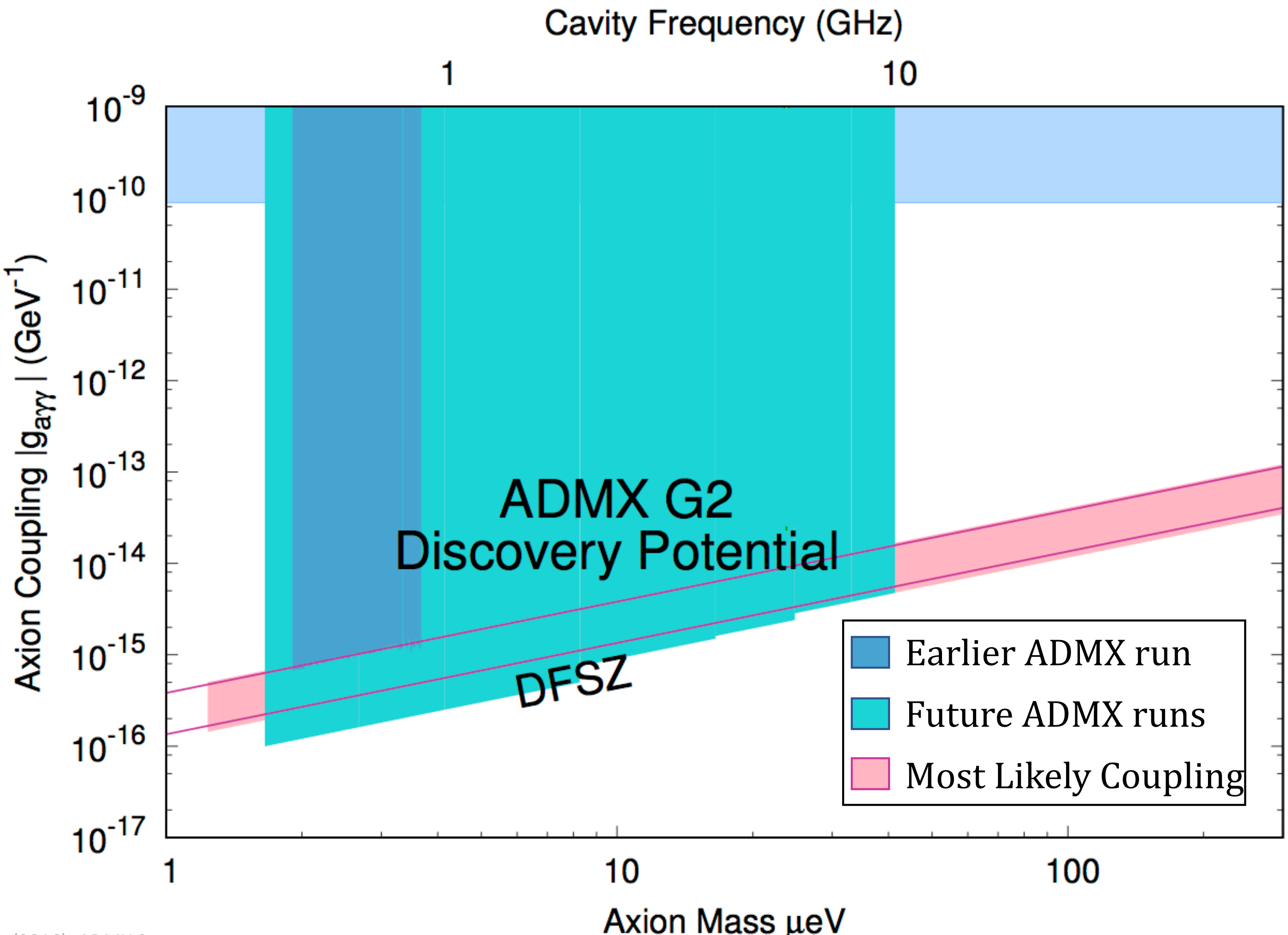
Axion
"Haloscope"
Detection
Scheme



ADMX Public Website

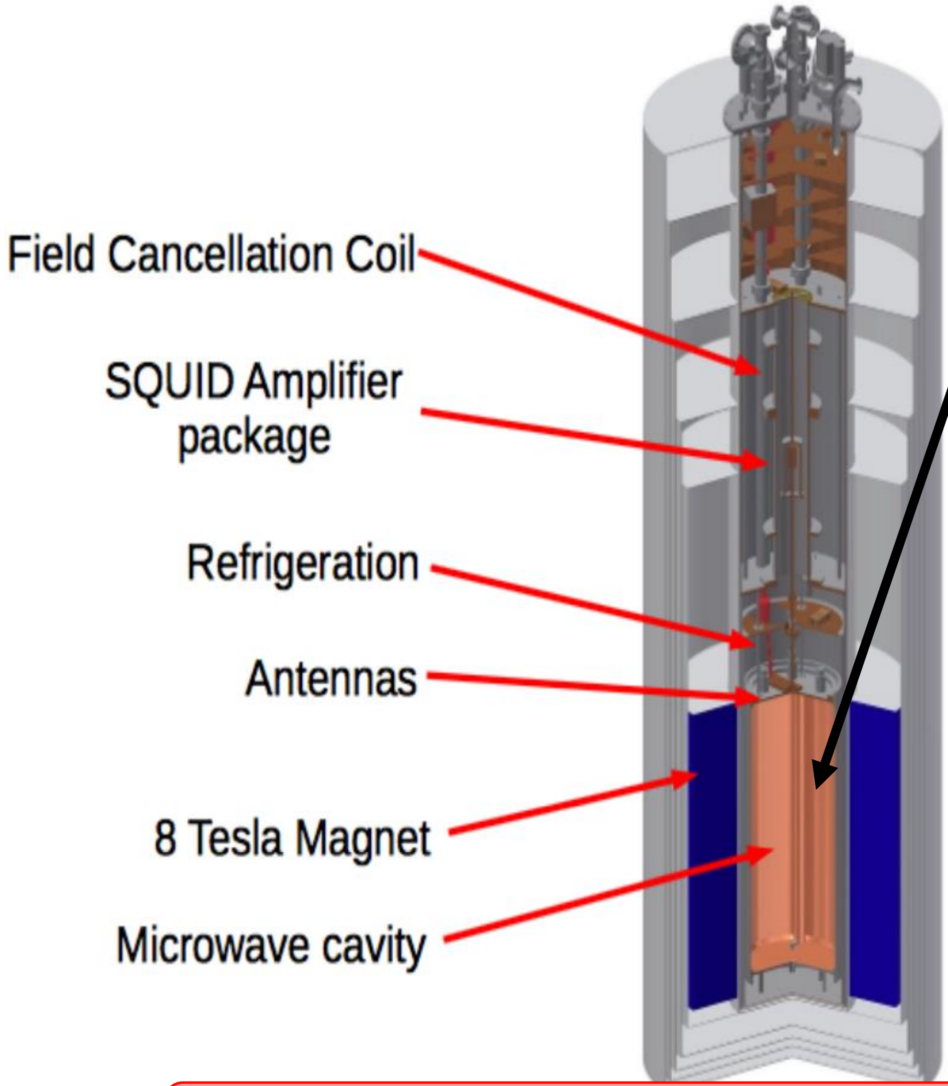
ADMX

The Biggest and the Best



Stern, I. (2016). ADMX Status

ADMX



Power of axion signal in cavity:

$\approx 10^{-24}$ Watts

Dicke Radiometer Equation:

$$SNR = \frac{P_a}{P_N}\sqrt{Bt}$$

Scan Time with Fixed SNR

$$\text{scan rate} \propto (B_0^2 V)^2 \boxed{\frac{1}{T_s^2}}$$

Sensitivity with fixed scan rate

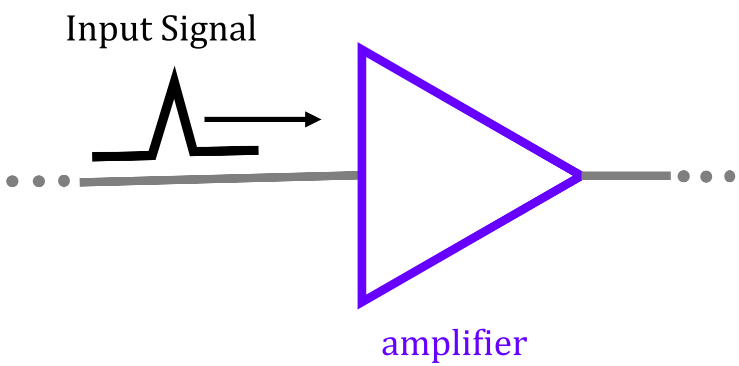
$$g_{\alpha\gamma\gamma} \propto \frac{\boxed{T_s}}{B_0^2 V}$$

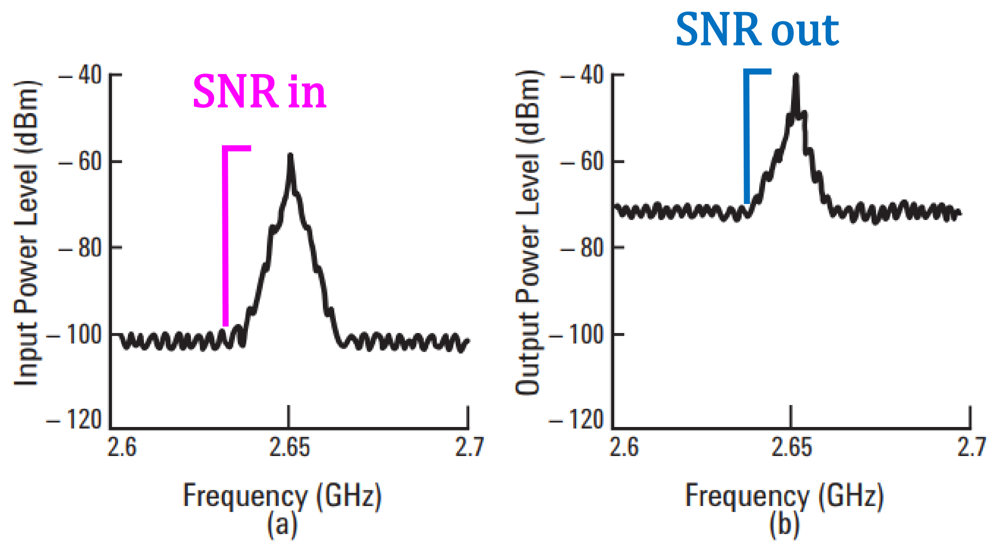
System Temperature (Ts) is a critical system parameter

Khatiwada 2017

ADMX Collaboration: S.J. Asztalos et al. *Phys. Rev. Lett.* 104:041301, 2010

Noise Temperature





Convenient to treat device noise sources as if they were all thermal noise

$$P = k_B T B$$

Noise Power

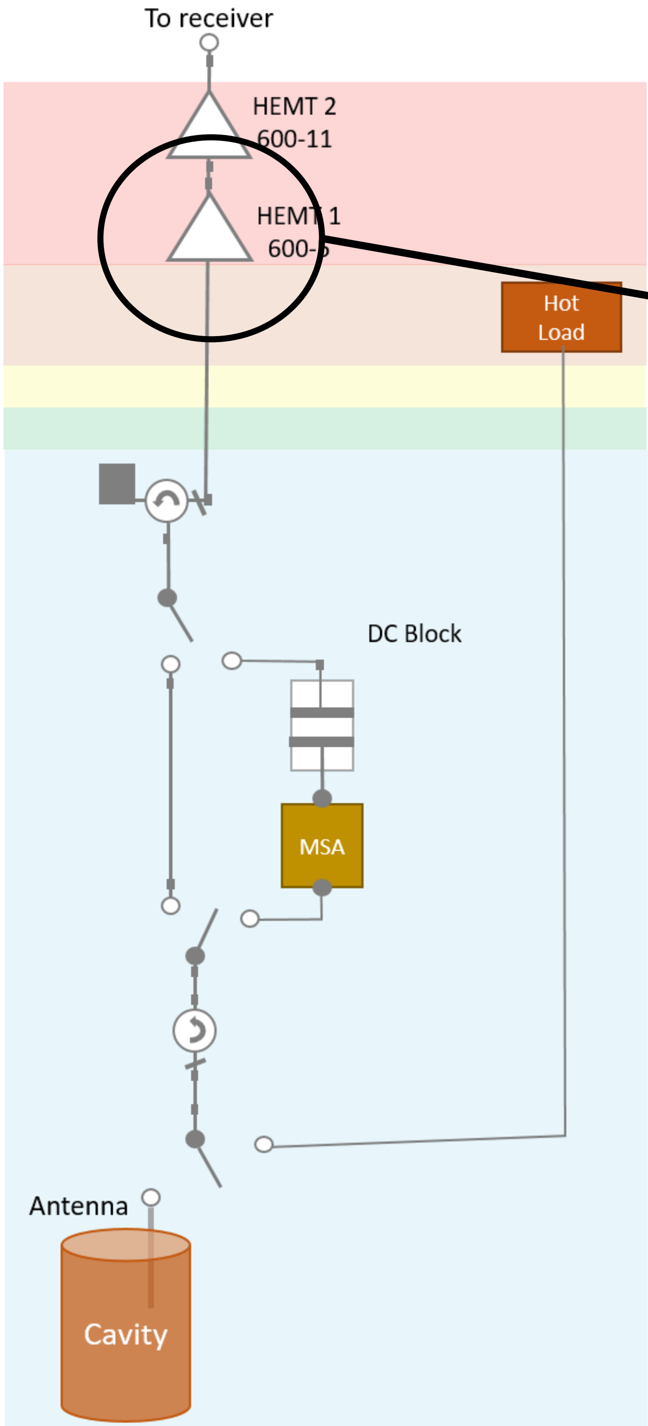
Boltzmann Constant

Noise Temperature

Bandwidth

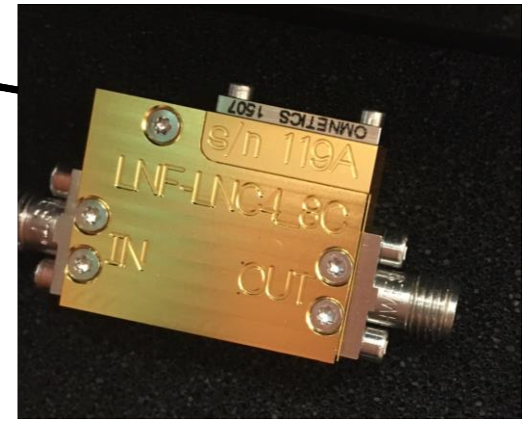
http://admxdatastore.npl.washington.edu/img_auth.php/b/bc/5952-8255E.pdf

ADMX Receiver Chain

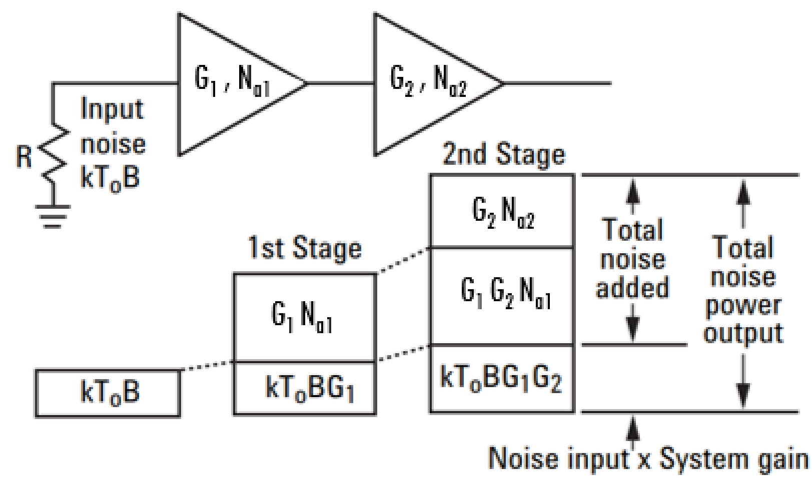


Physical Temperature Key

- 4-10 K
- 4 K
- 1 K
- 500 mK
- 100 mK

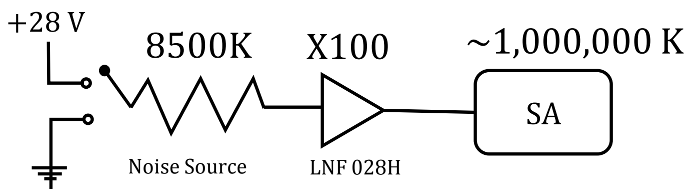


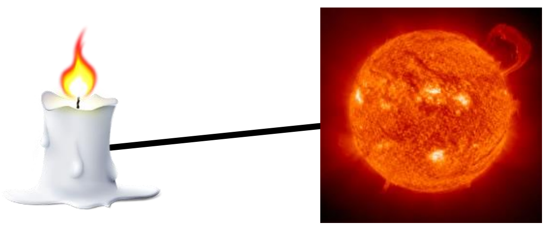
Low Noise Factory (LNF) High Electron Mobility Field Effect Transistor (HFET)

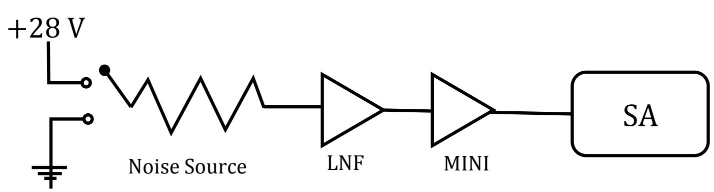


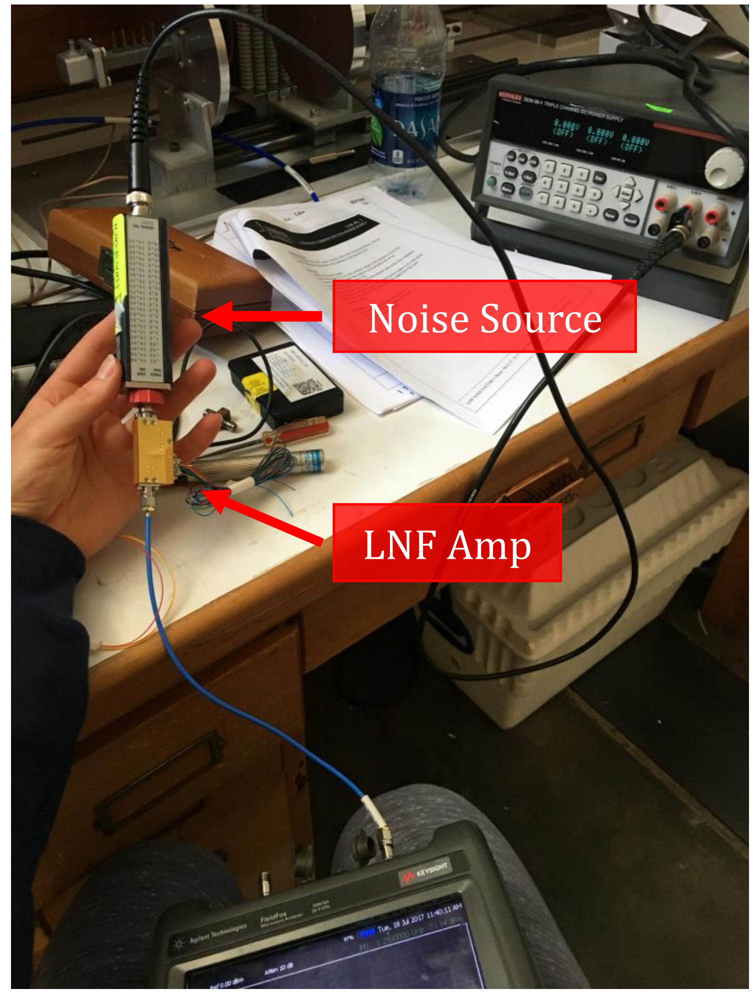
Simplified Model of Cascaded Amplifiers

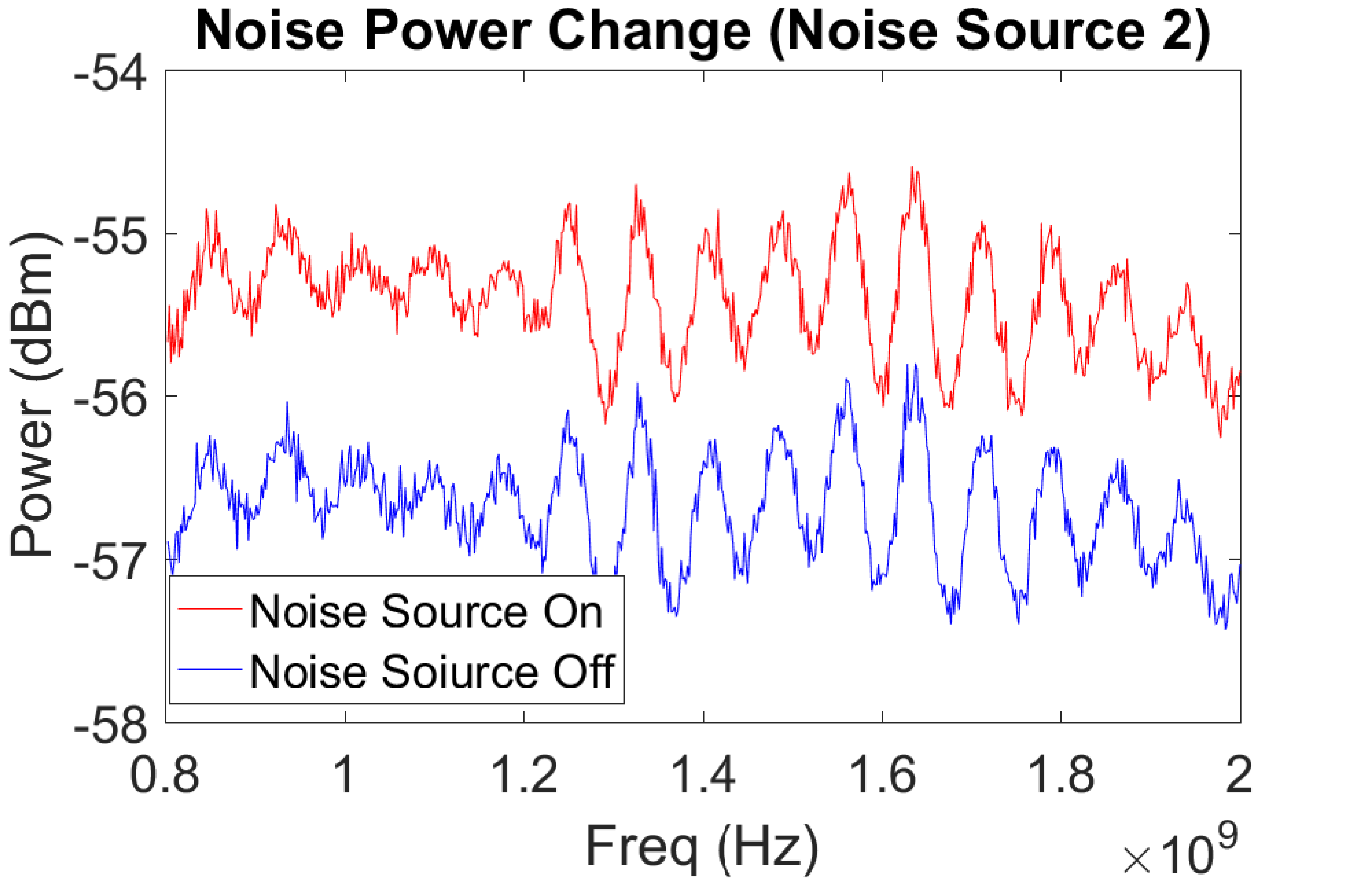
Room Temperature Measurement





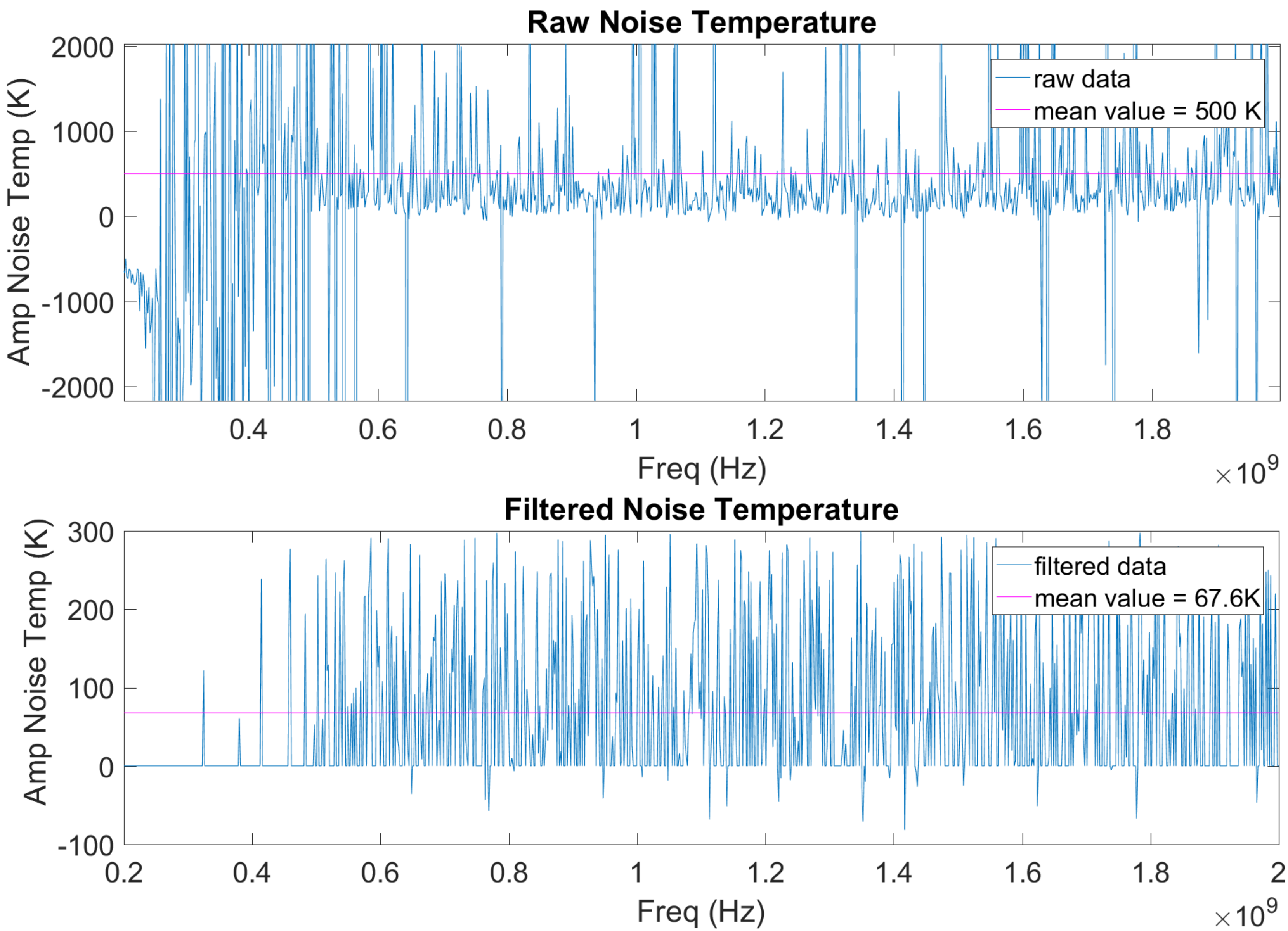






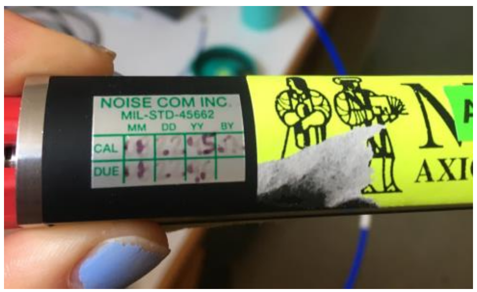
Noise Power Change (Noise Source 2)
Power (dBm)
-54
-55
-56
-57
-58
0.8
1
1.2
1.4
1.6
1.8
2
Freq (Hz)
$\times 10^9$
Noise Source On
Noise Soiurce Off

LNF Noise Temp, Physical Temp 300K

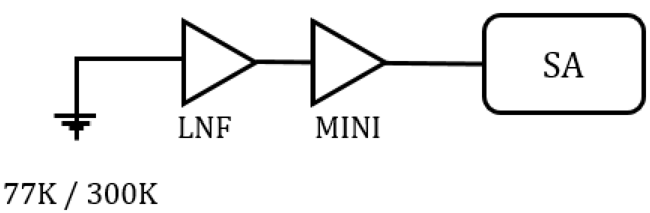


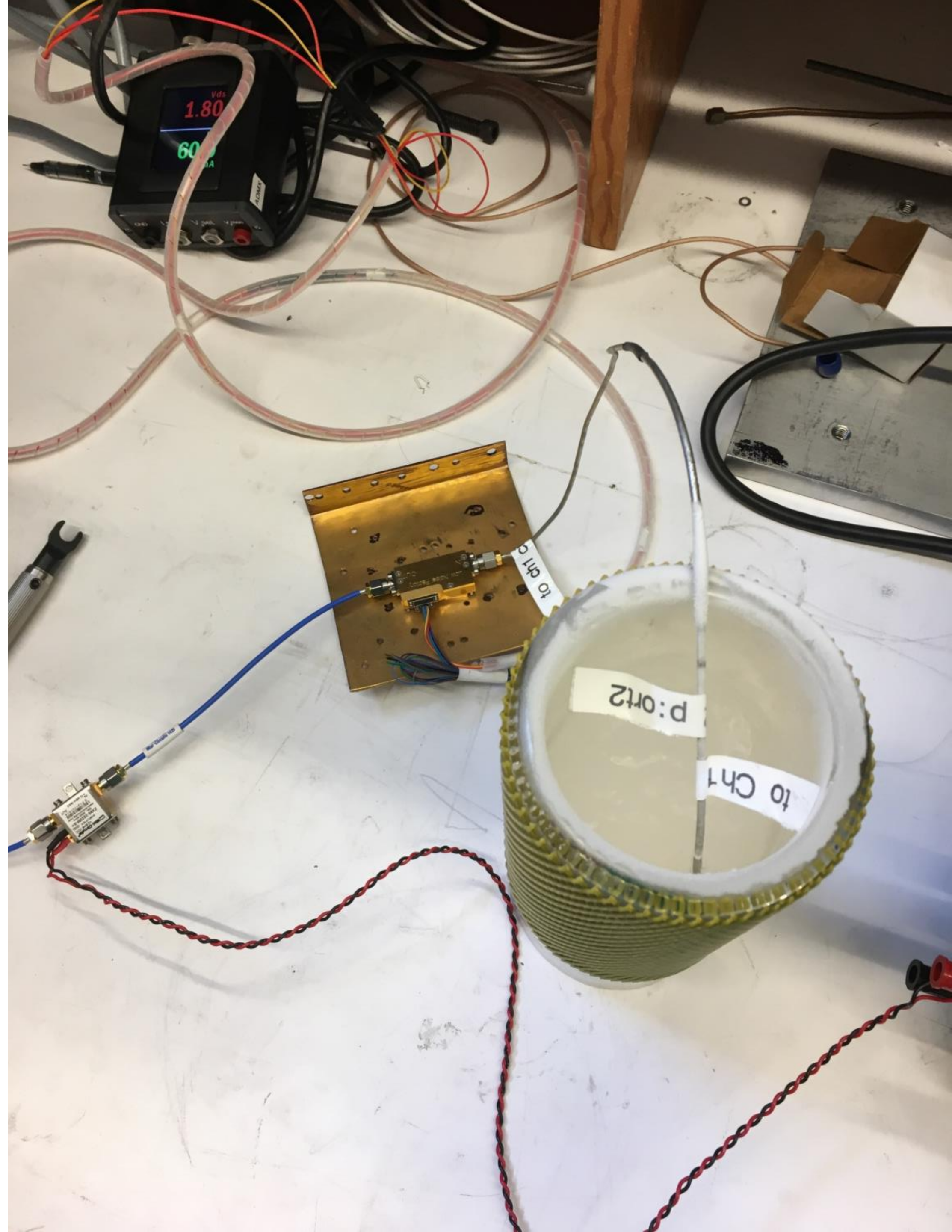
Manufacturer Data RT Noise Temp: ~60K

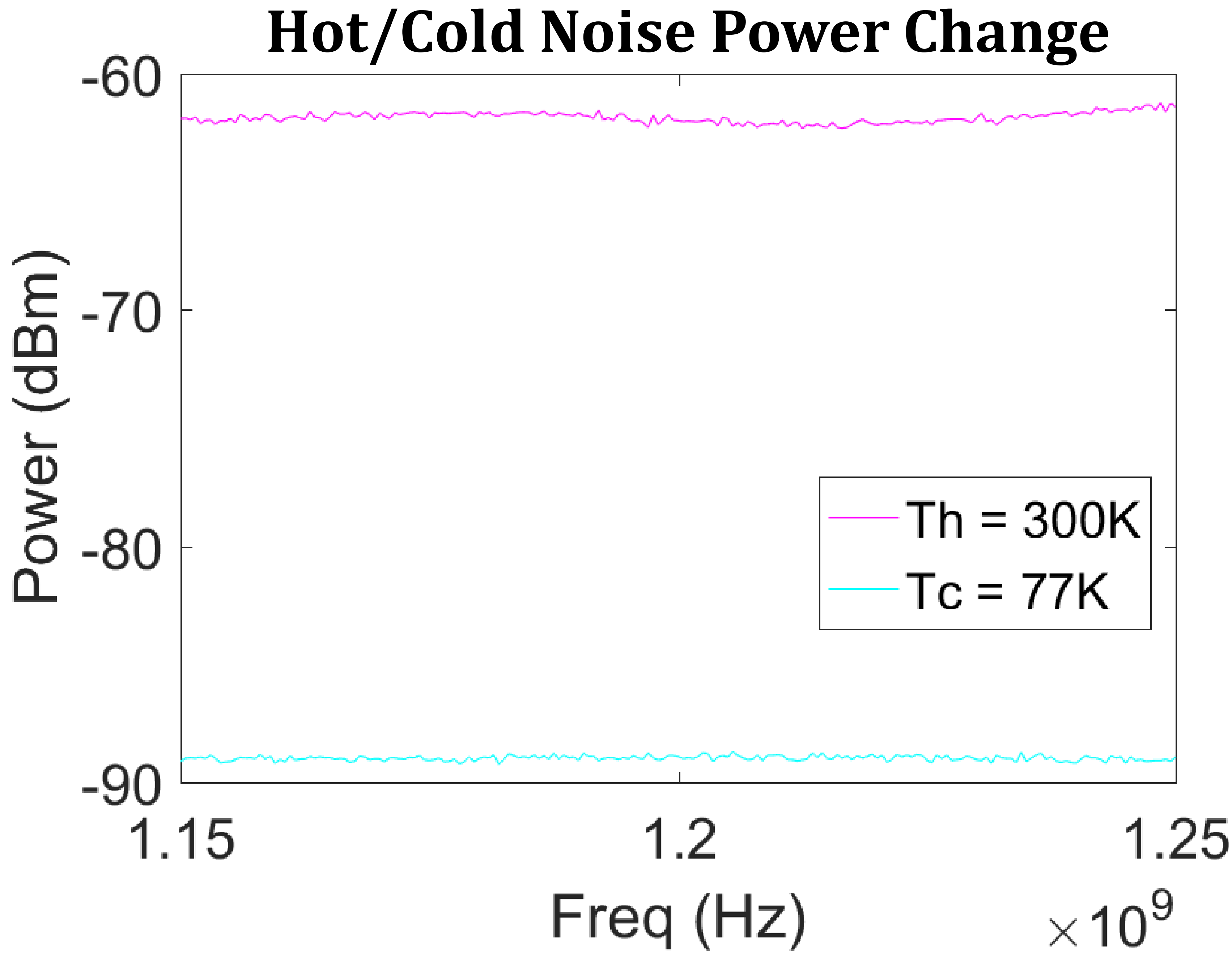
Liquid Nitrogen Test



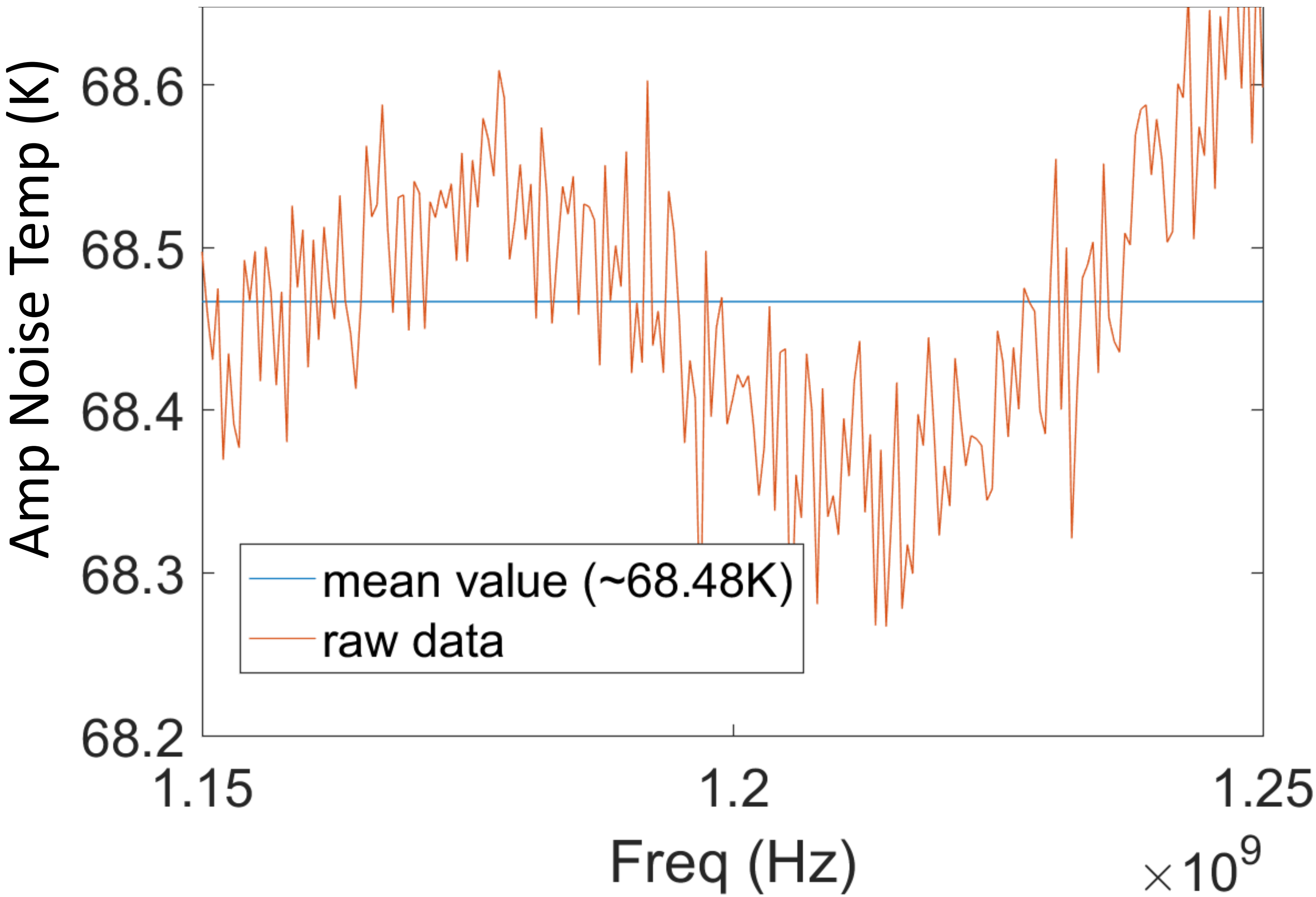
“Due to be calibrated in 1996”



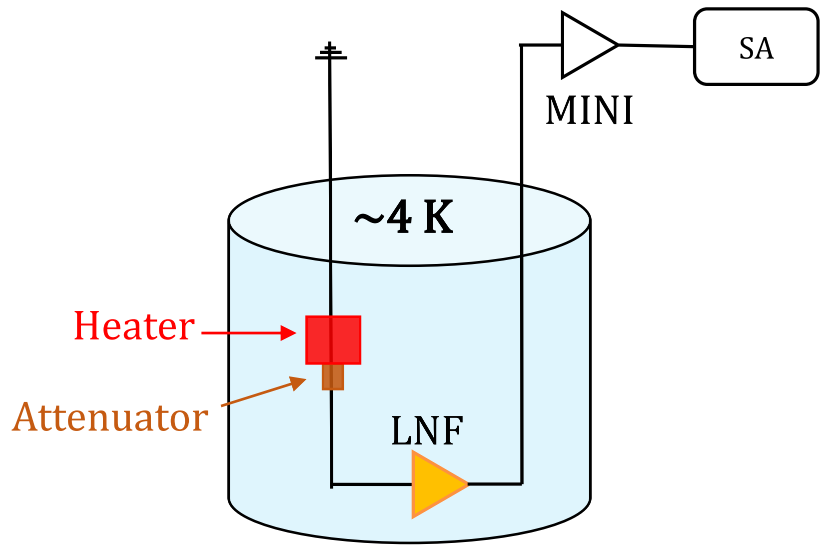


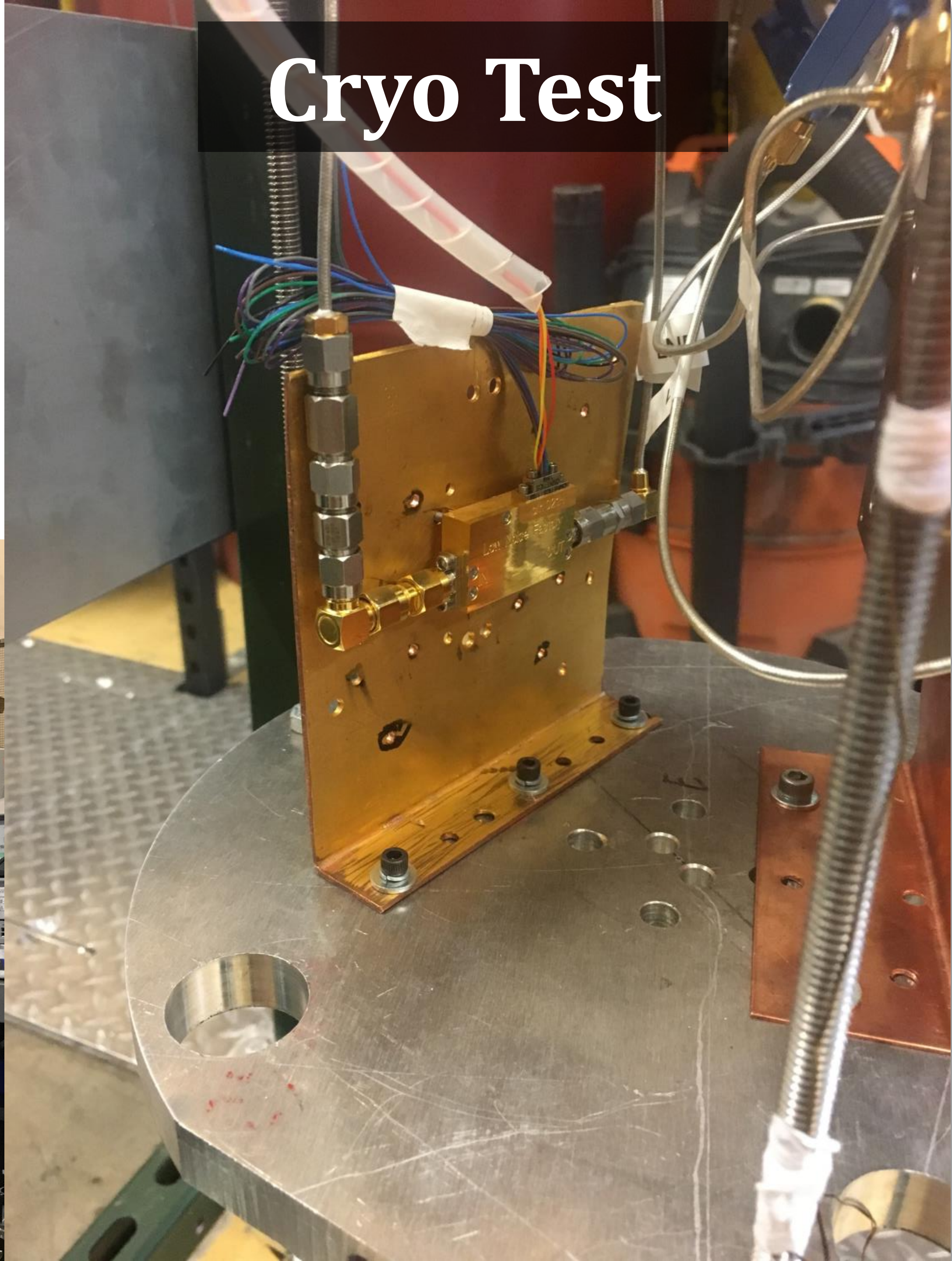

Hot/Cold Noise Power Change
-60
-70
-80
-90
Power (dBm)
Th = 300K
Tc = 77K
1.15
1.2
1.25
Freq (Hz)
×10^9

LNF Noise Temp, Physical Temp 300K

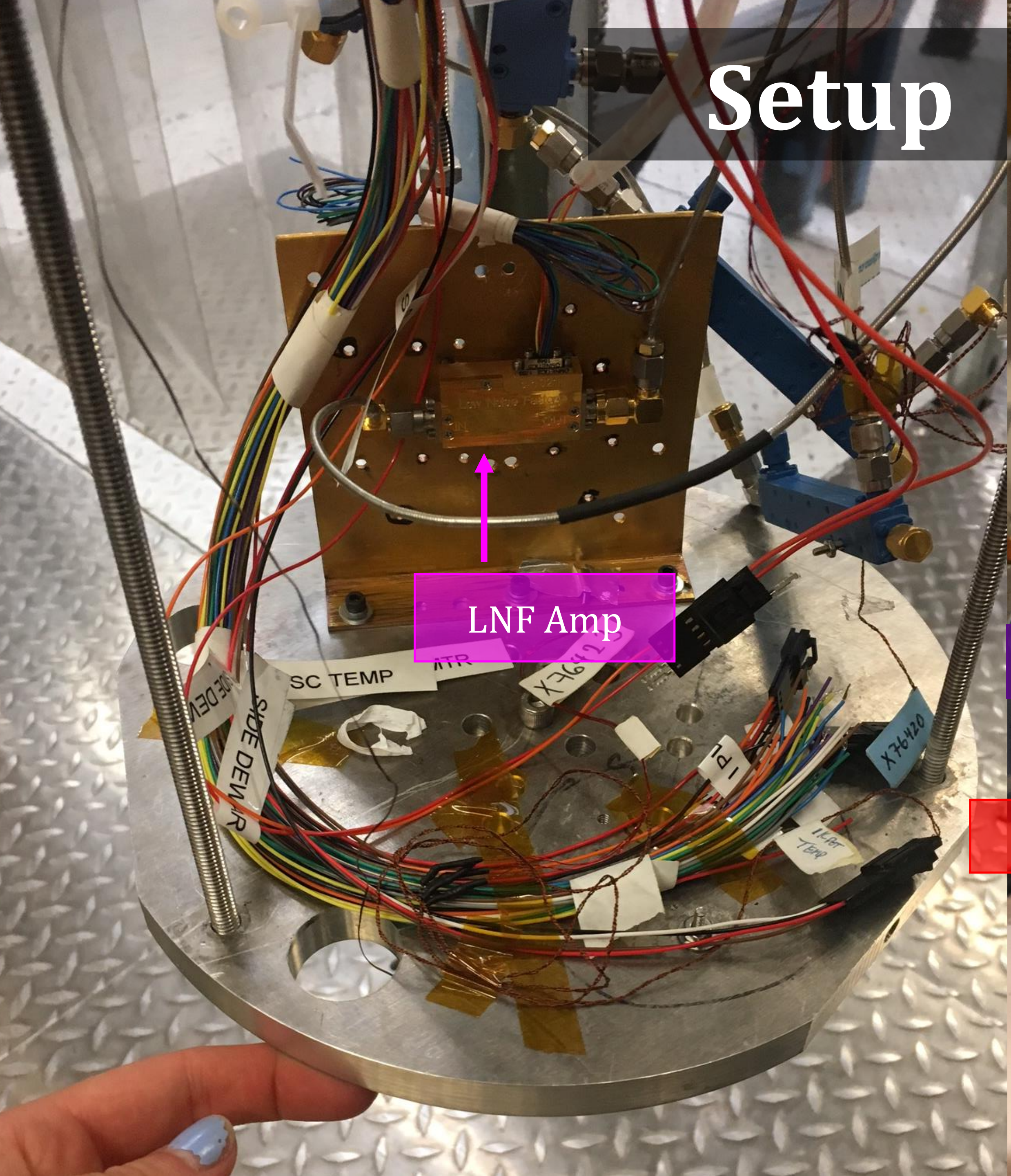


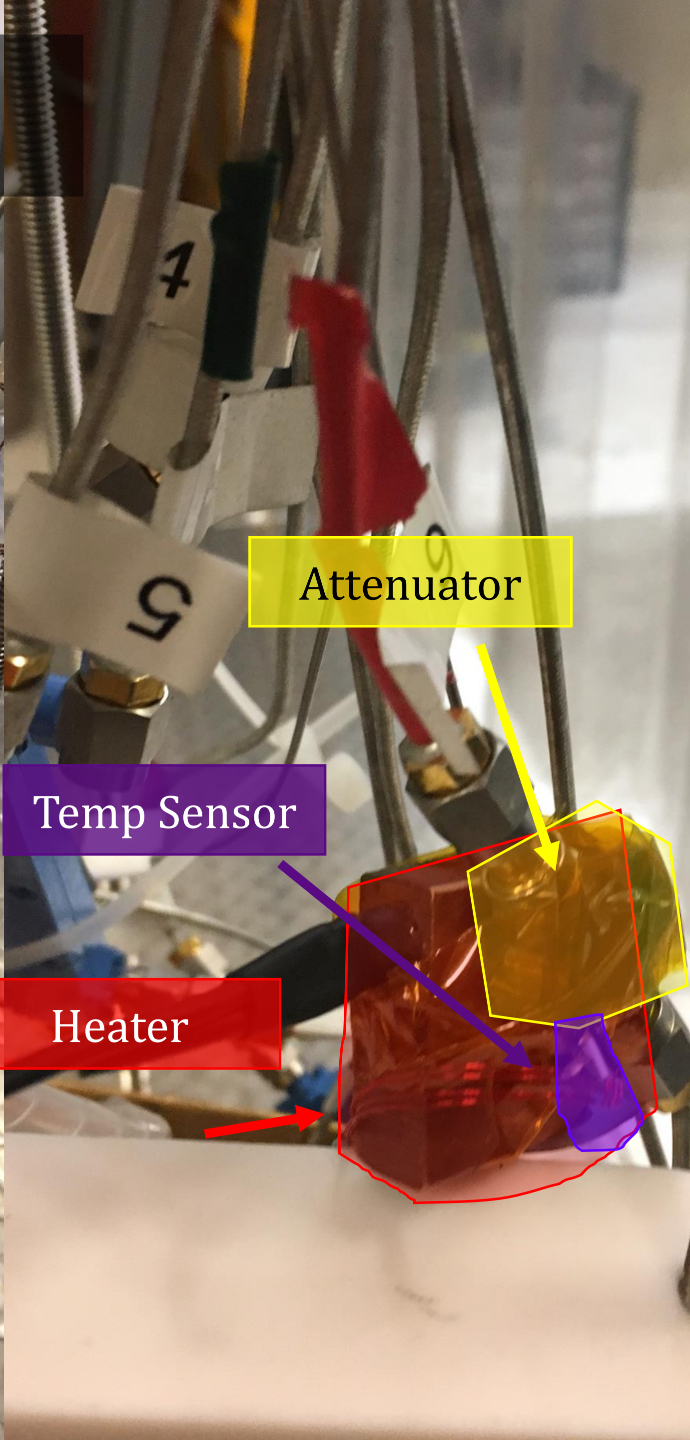
Cryo Test



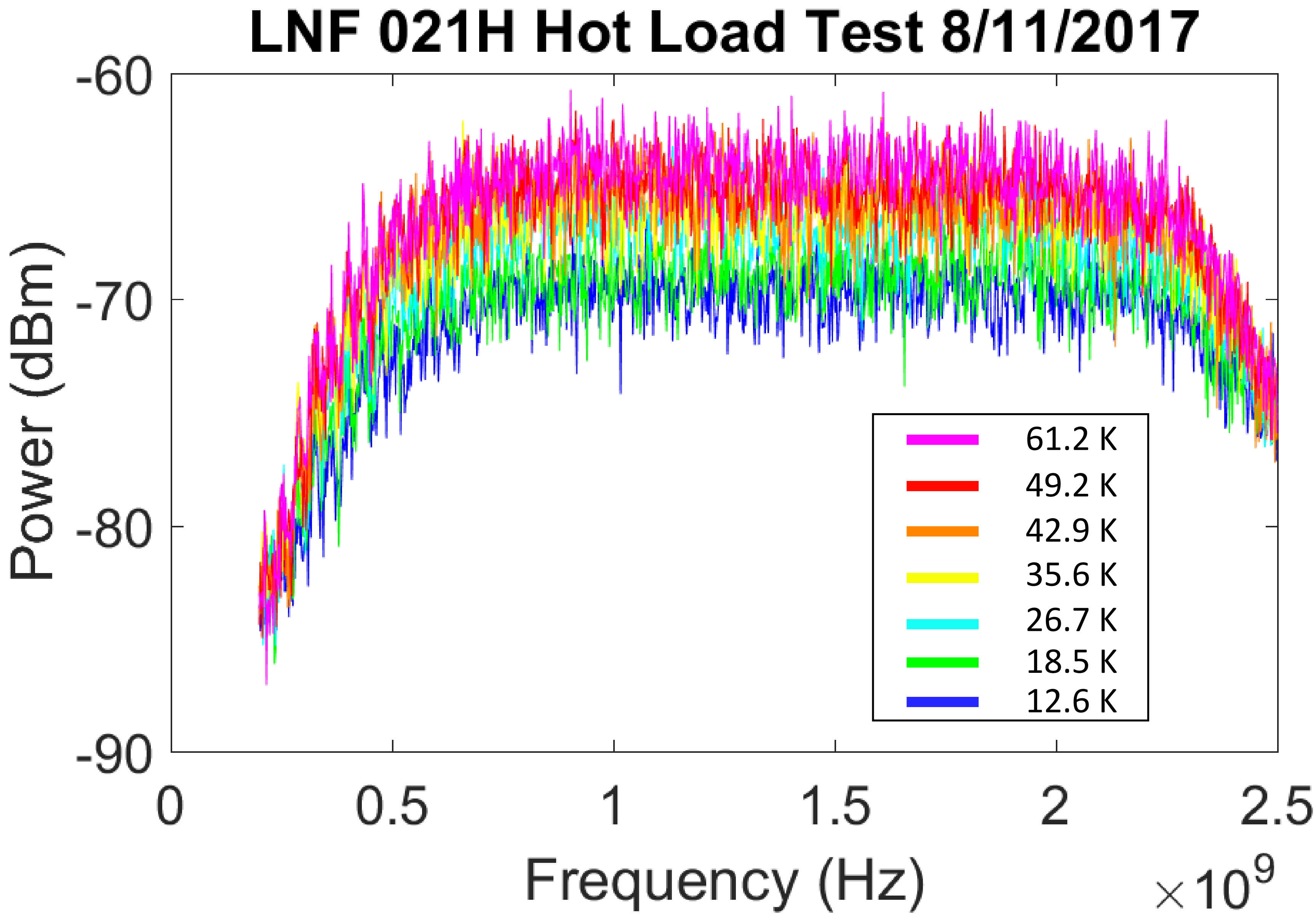


Setup


LNF Amp
SC TEMP
SIDE DEWAR
X76420

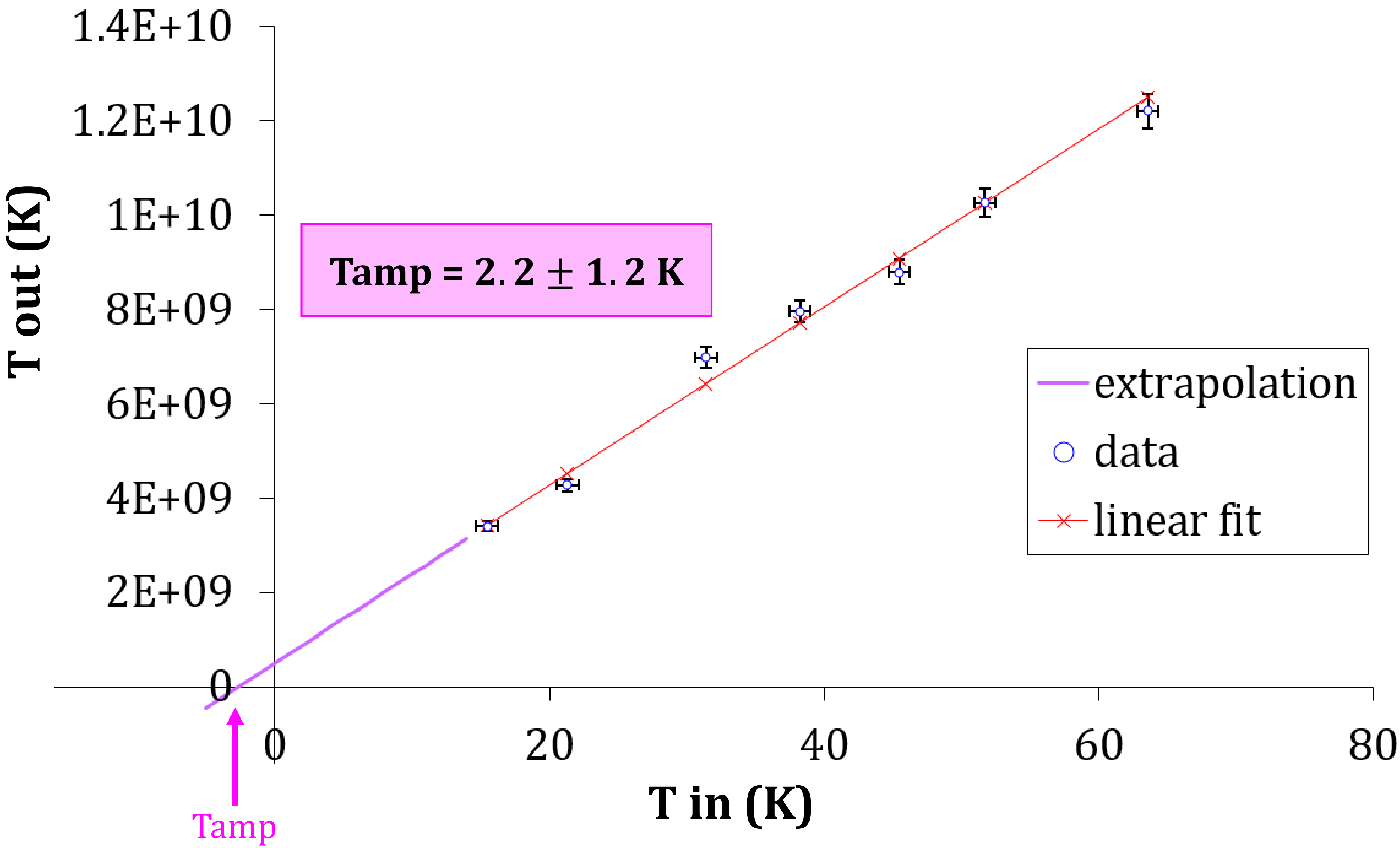

Attenuator
Temp Sensor
Heater
5

Results



LNF 021H Hot Load Test 8/11/2017
Power (dBm)
-60
-70
-80
-90
0
0.5
1
1.5
2
2.5
Frequency (Hz)
×10^9
61.2 K
49.2 K
42.9 K
35.6 K
26.7 K
18.5 K
12.6 K

Amp Noise Temp, Physical Temp ~10K



Manufacturer Data 5K Temp: ~2K !

Conclusion

Ts is a critical parameter in determining ADMX sensitivity and scan rate

Do not trust things that are out of calibration.
Do trust liquid nitrogen.

Noise temperature measurements are hard

LNF 021 H looks like a promising amplifier to add to the ADMX receiver chain!

Thank you to the ADMX team!

HEISING-SIMONS FOUNDATION

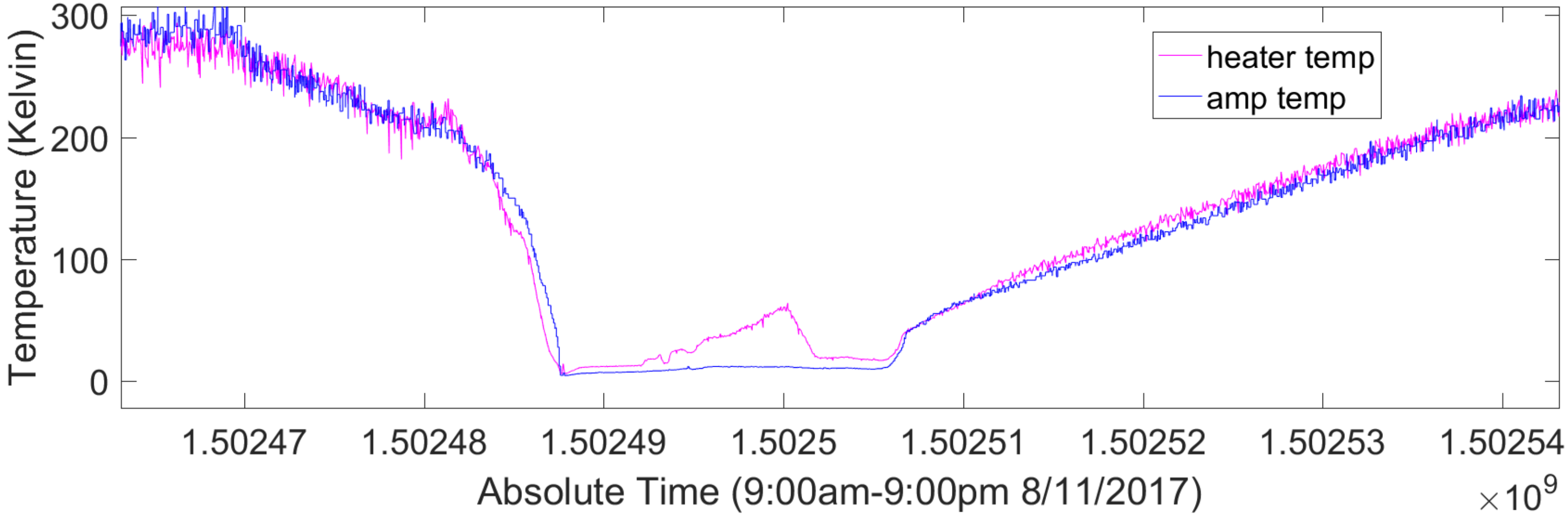
NSF

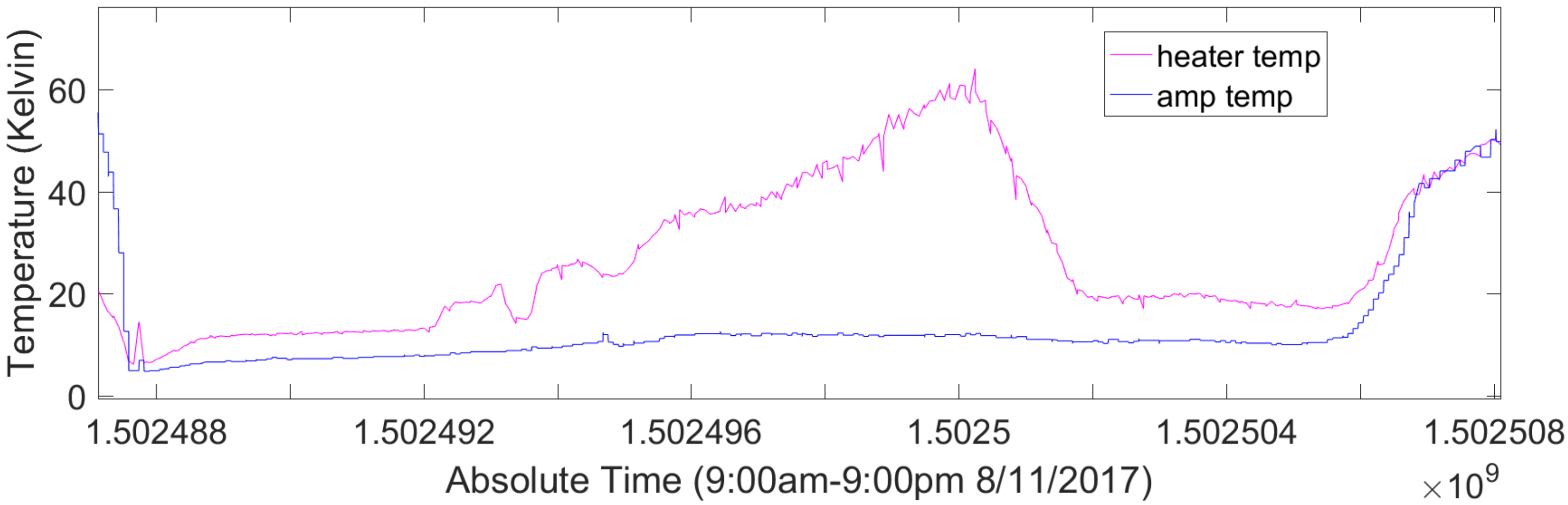
UNIVERSITY of WASHINGTON

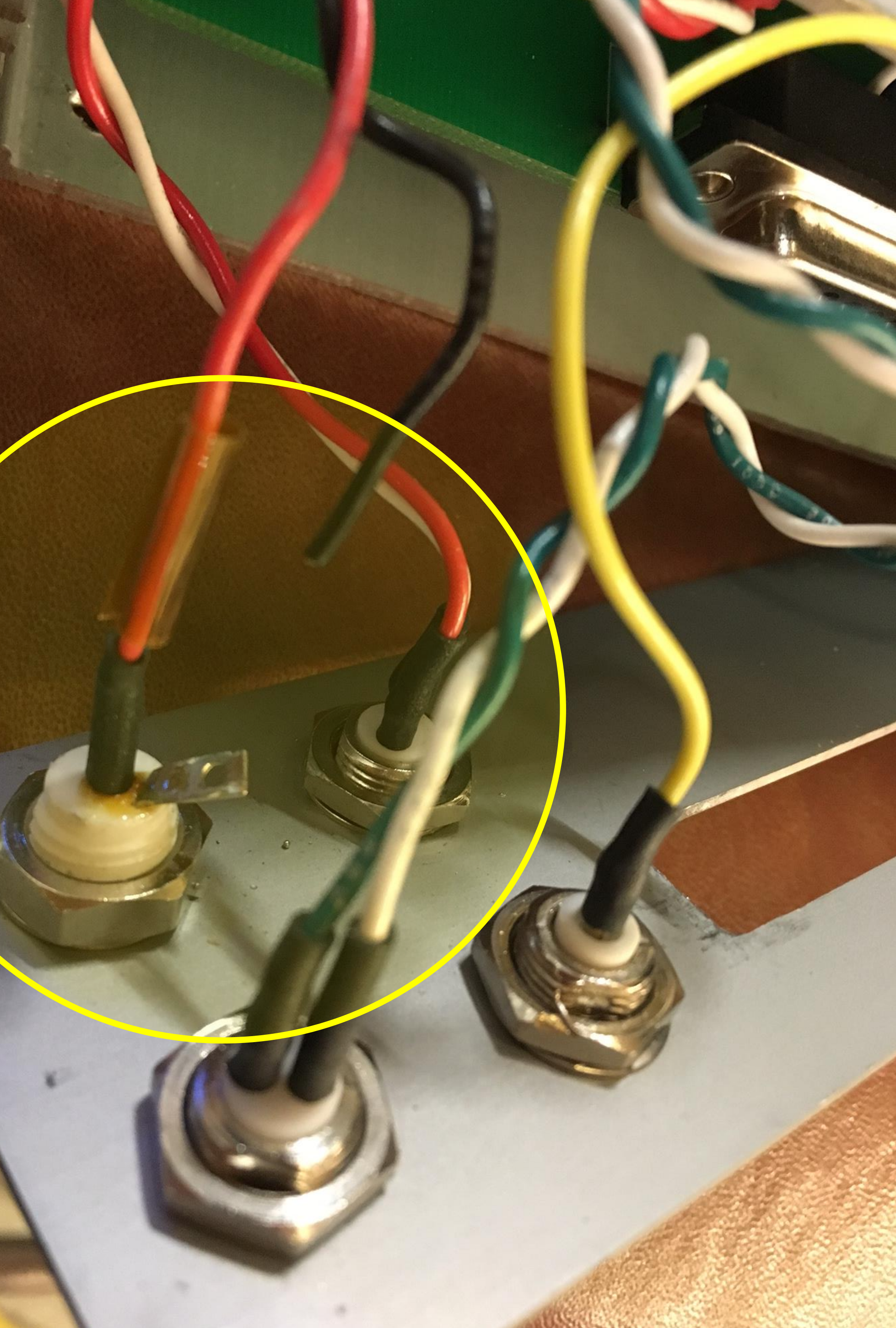
U.S. DEPARTMENT OF ENERGY

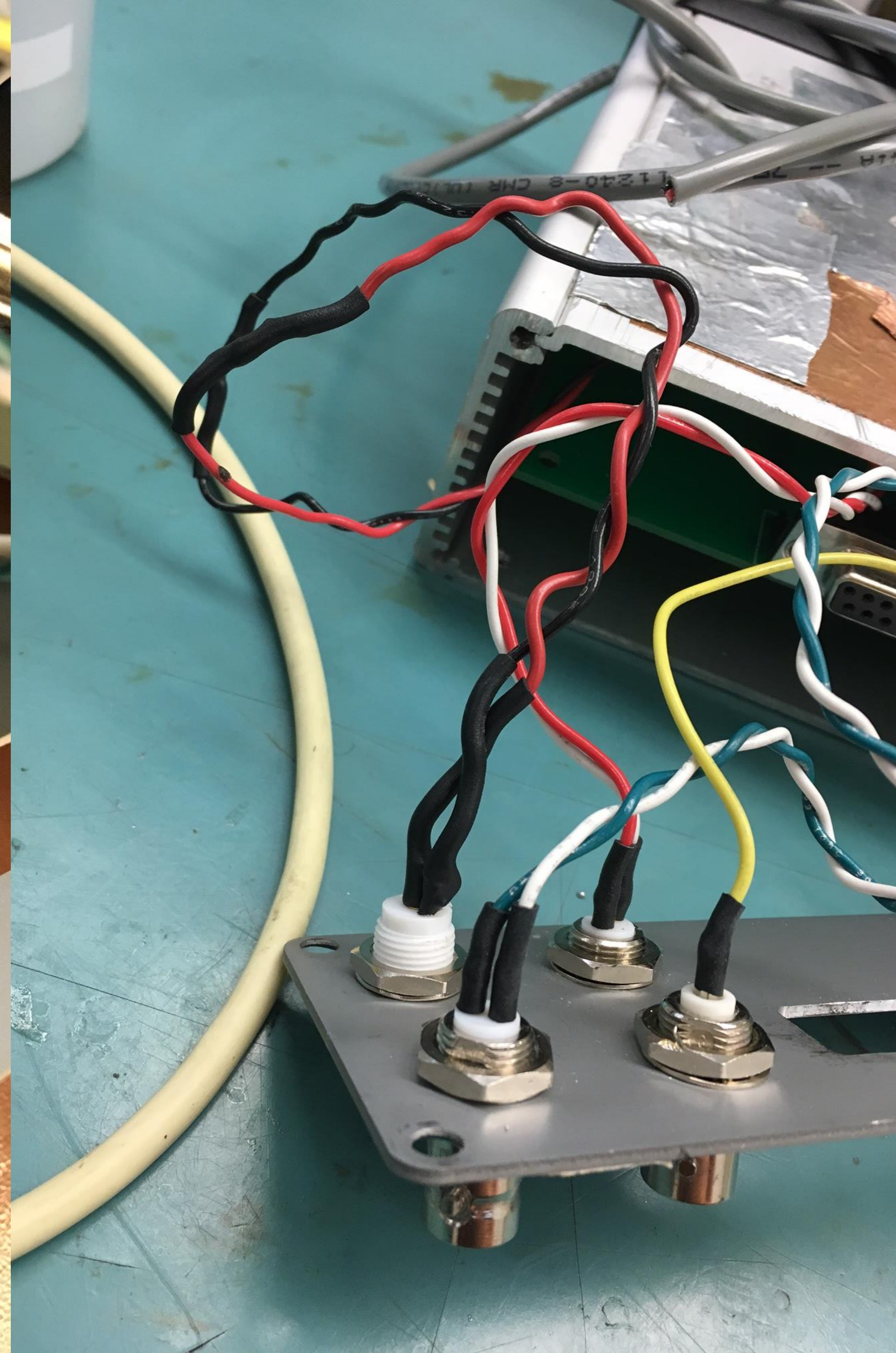

Questions?
HARDHATS
REQUIRED!

Thermometry Data









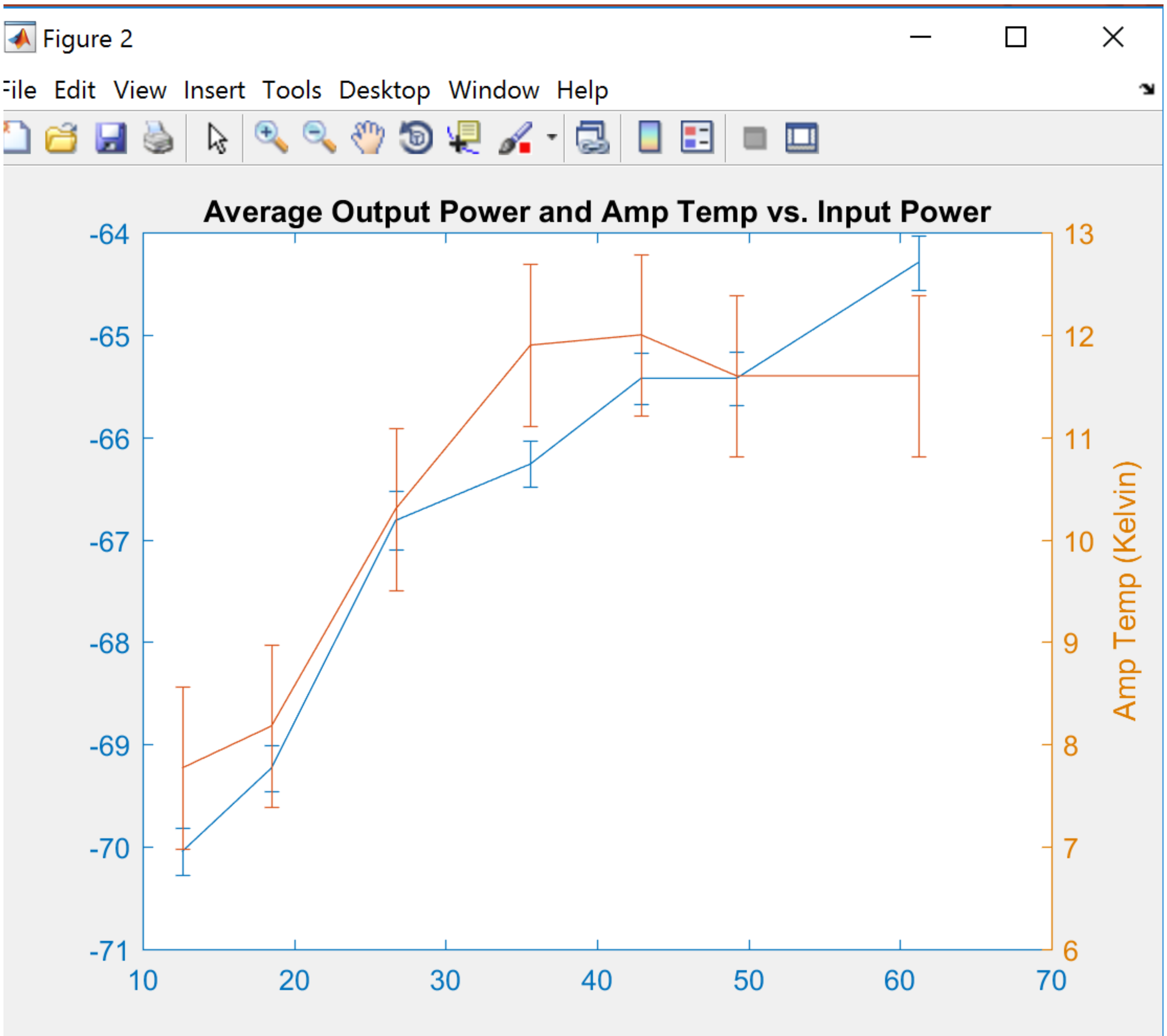
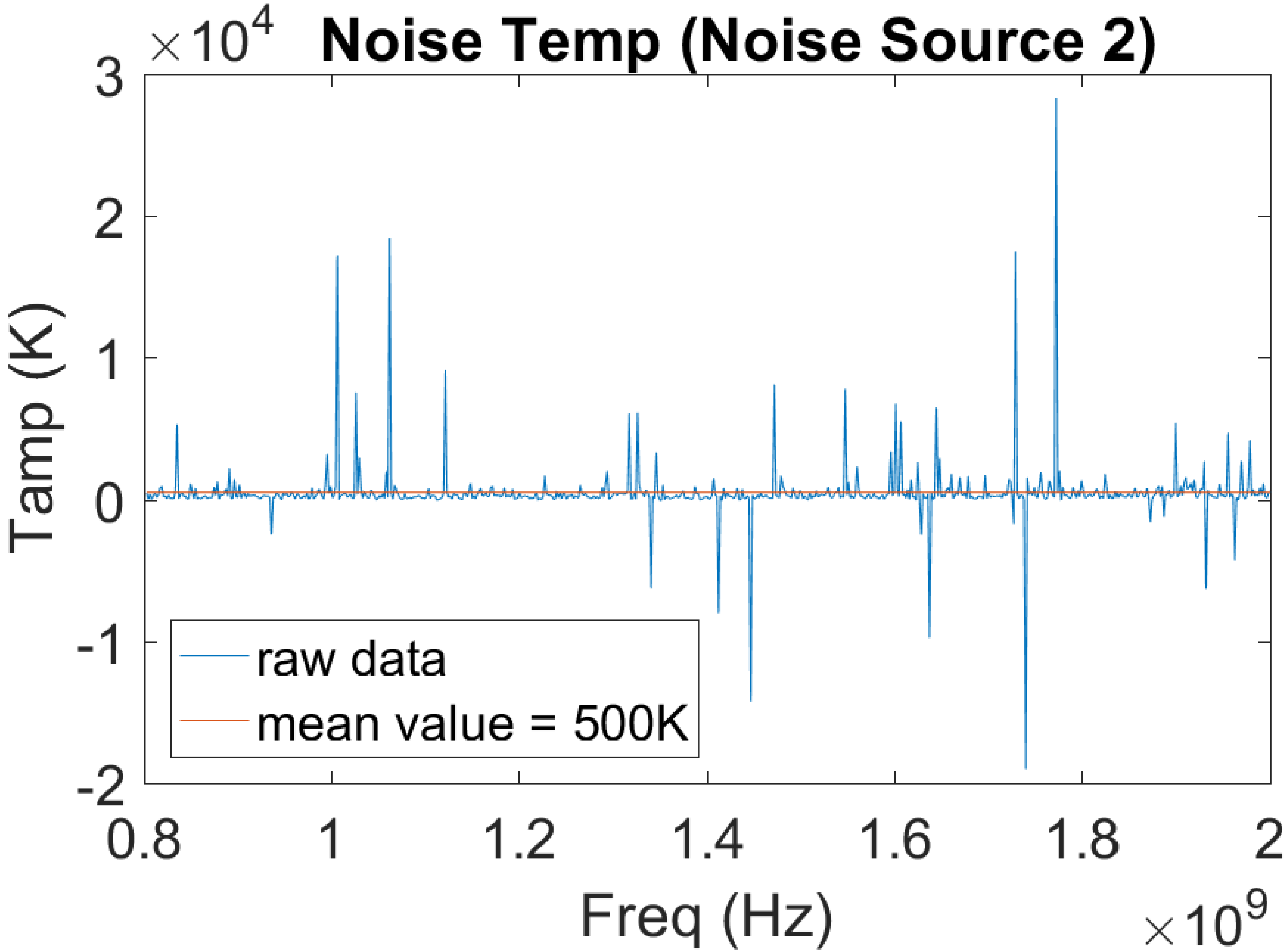


Figure 2
File Edit View Insert Tools Desktop Window Help
Average Output Power and Amp Temp vs. Input Power
-64
-65
-66
-67
-68
-69
-70
-71
10
20
30
40
50
60
70
13
12
11
10
9
8
7
6
Amp Temp (Kelvin)



Manufacturer Data RT Noise Temp: ~60K

The Axion

An elegant answer to two problems

Originally postulated by Pecci-Quinn theory in 1977 to solve problem in QCD:

QCD Lagrangian term $\propto F\tilde{F}\bar{\theta} - ?$

These terms must cancel to 1 part in 10^-10

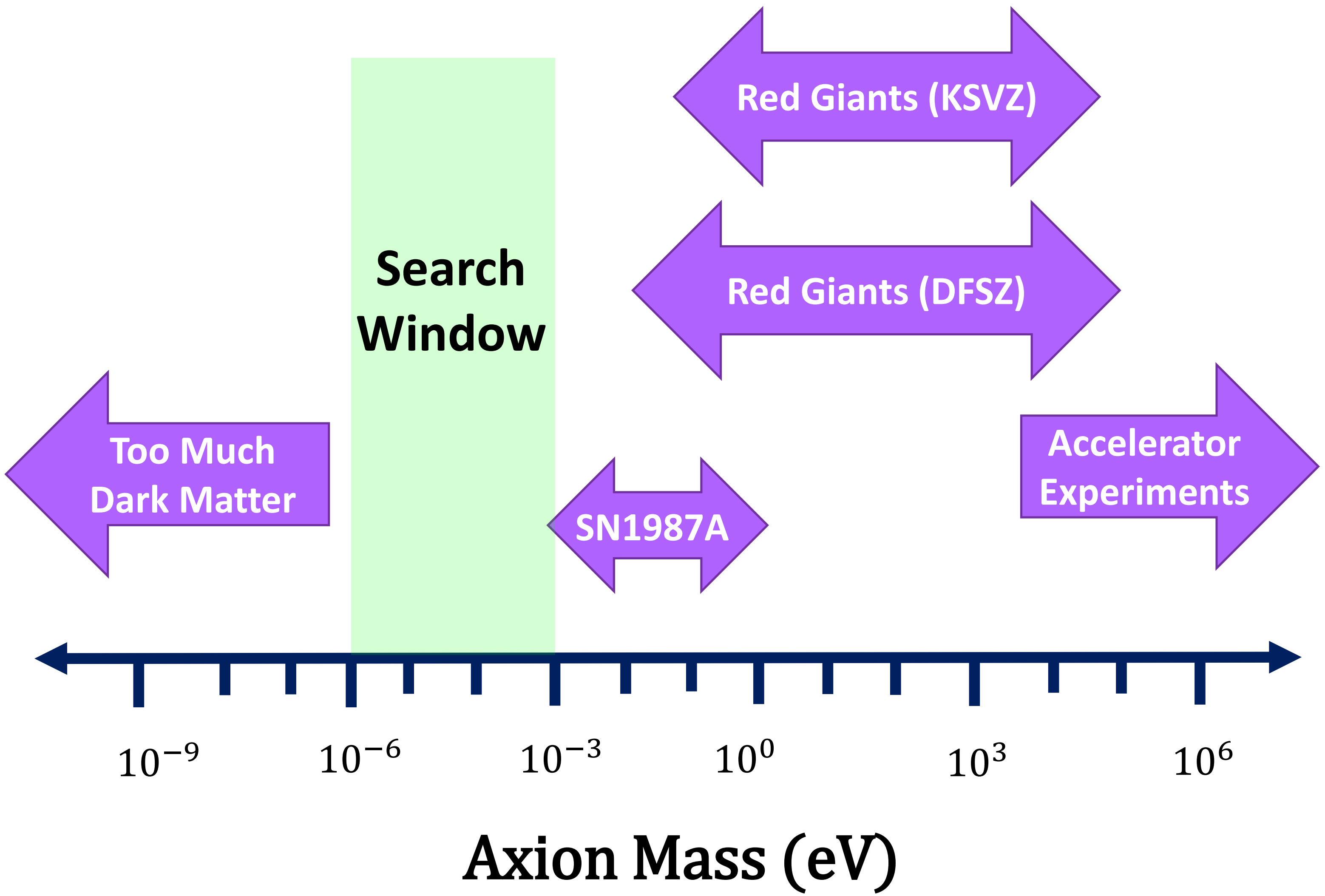
Axion field could explain this hidden symmetry

Axion Mass:

$$m_a = \frac{(m_u m_d)^{1/2}}{m_u + m_d} \frac{f_\pi}{f_{PQ}/N} m_\pi$$

Axion Density: 10^{14} axions/cm^3 in the local galaxy

Axion Mass Constraints



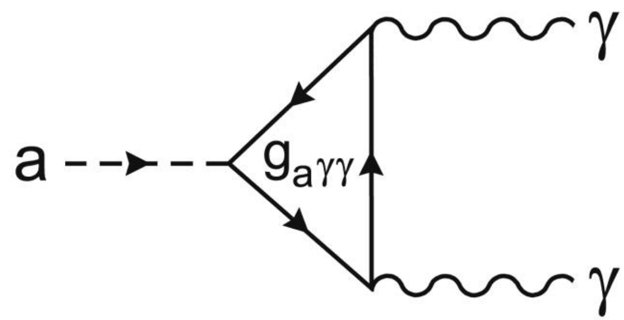
Detection Theory

Resonant conversions of axions to photons:

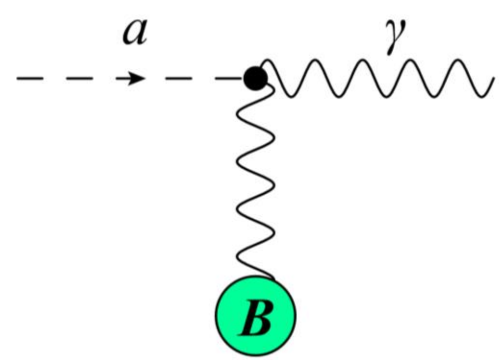
$$\mathcal{L}_{a\gamma\gamma} = g_{\gamma} \frac{\alpha}{\pi} \frac{a(x)}{f_a} \mathbf{E} \cdot \mathbf{B},$$

Axion coupling constant

Kim-Shifman-Vainshtein-Zakharov **(KSVZ)** model, $g_\gamma = -0.97$
DineFischler-Srednicki-Zhitnitsky **(DFSZ)** model $g_\gamma = 0.36$



Primakoff Effect



Haloscope Detection Scheme

https://inspirehep.net/record/1391618/plots
https://ned.ipac.caltech.edu/level5/March06/Overduin/Figures/figure24.jpg

The Axion

An elegant answer to two problems

Nuclear Physics Problem

Dark Matter Problem

Why do two seemingly unrelated terms in QCD Lagrangian cancel to 1 part in 10^{10}?

What is this "missing mass" that makes up ~30% of our universe?

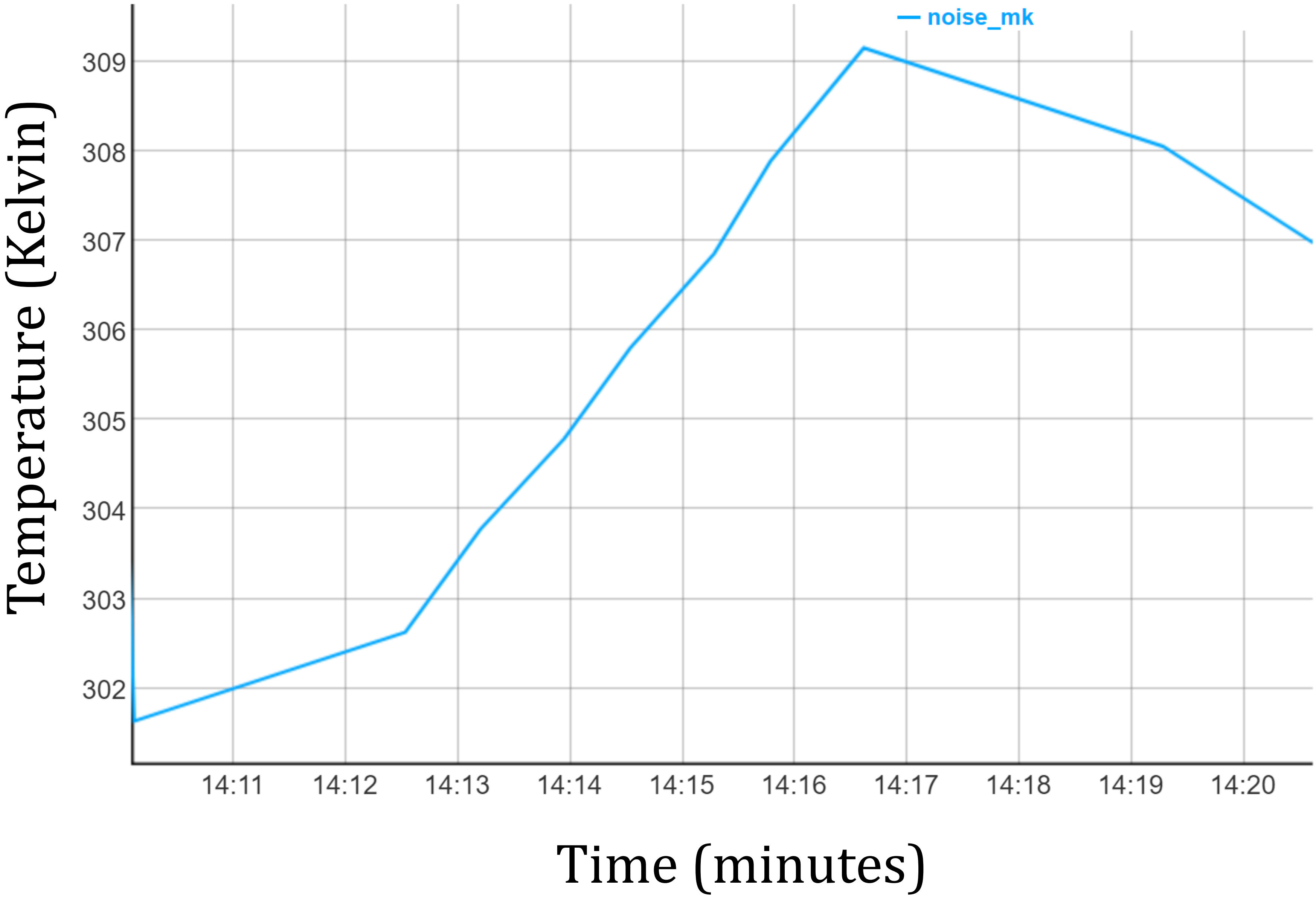
Axion Mass: $m_a = \frac{(m_u m_d)^{1/2}}{m_u + m_d} \frac{f_\pi}{f_{PQ}/N} m_\pi$

Axion field could explain this hidden symmetry

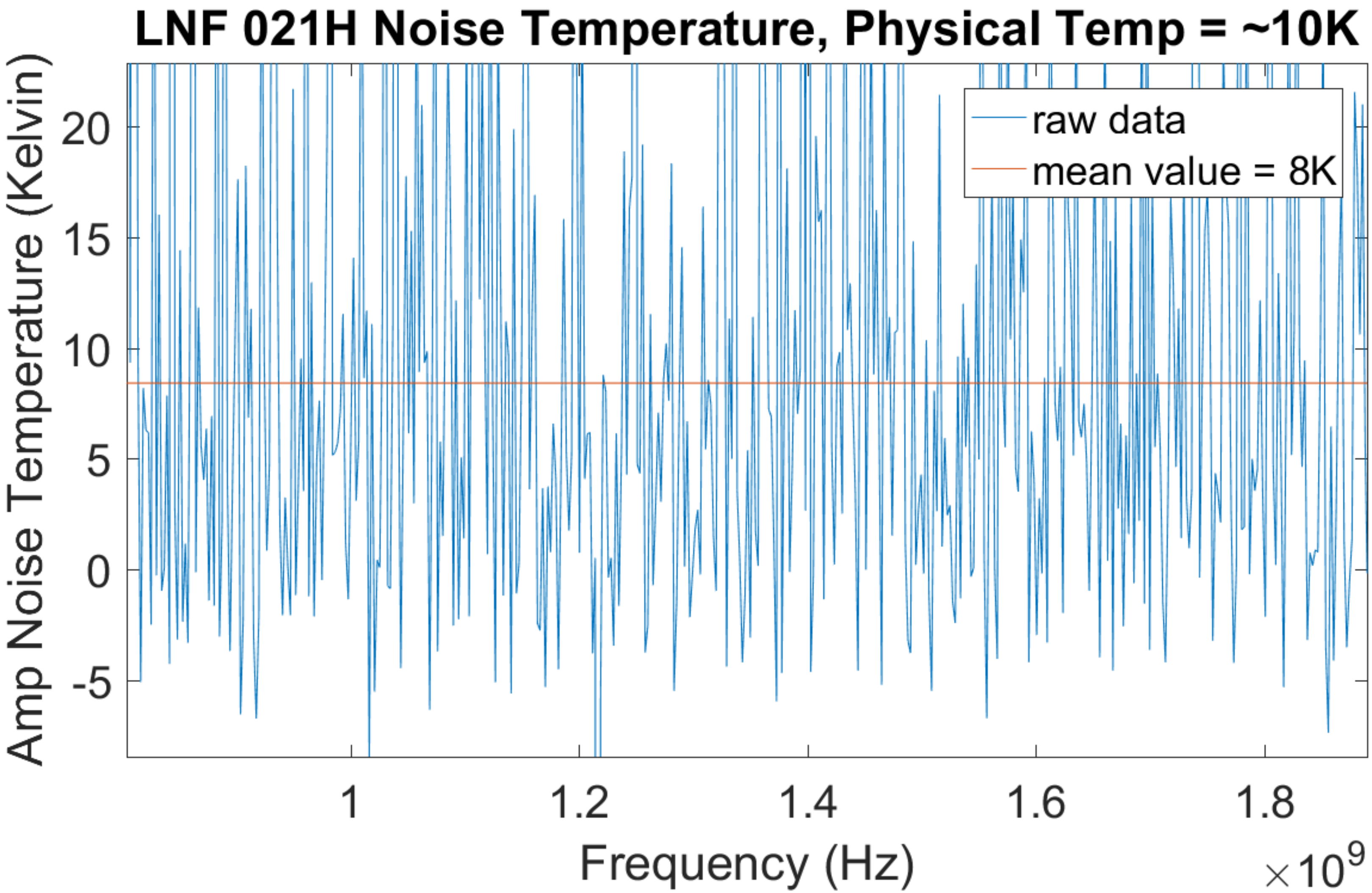
A^0

Axion Density: 10^{14} axions/cm^3 in the local galaxy

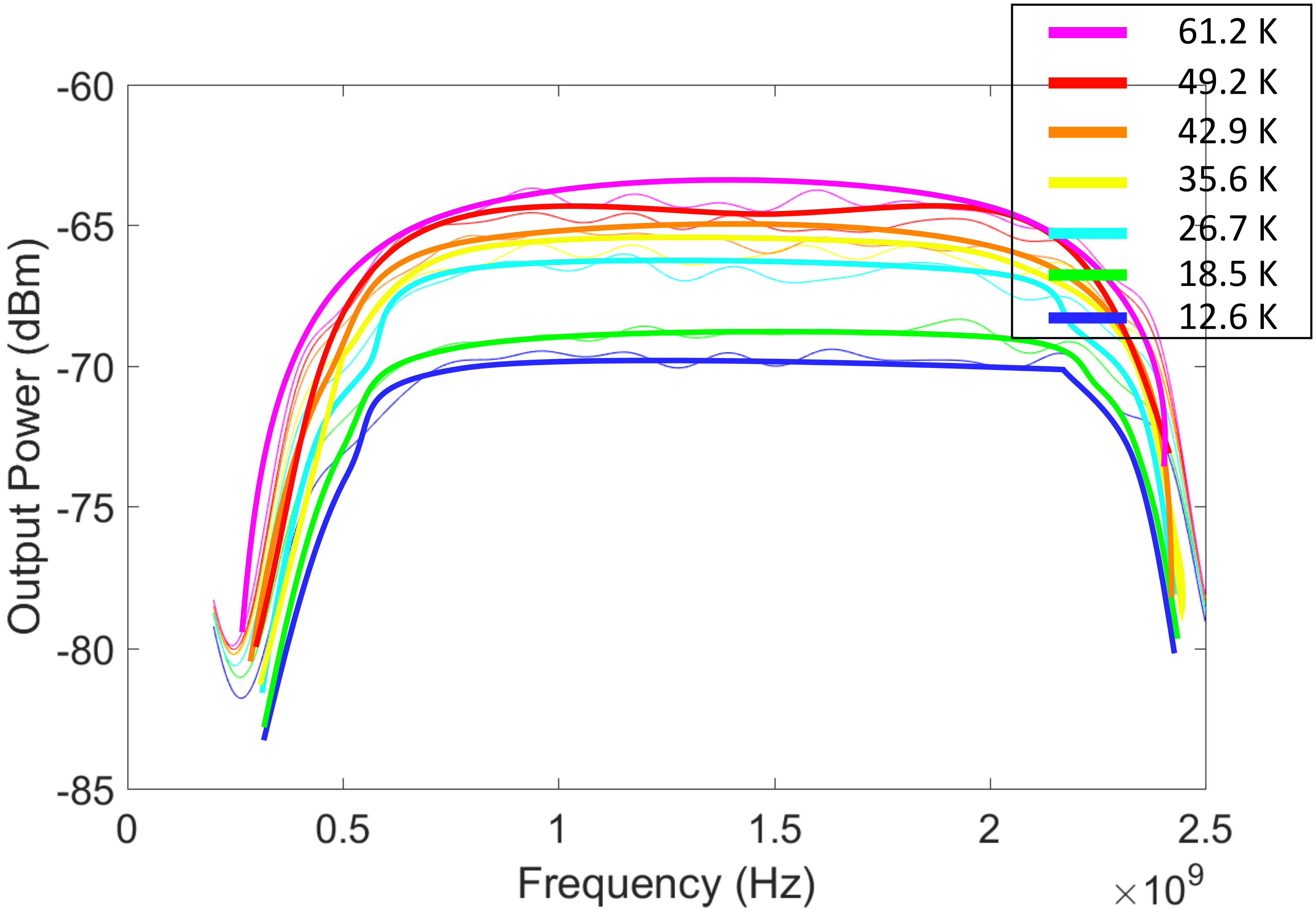
Yes, Heater Works



Results



LNF 021H Noise Temperature, Physical Temp = ~10K
raw data
mean value = 8K
Amp Noise Temperature (Kelvin)
20
15
10
5
0
-5
1
1.2
1.4
1.6
1.8
Frequency (Hz)
×10^9



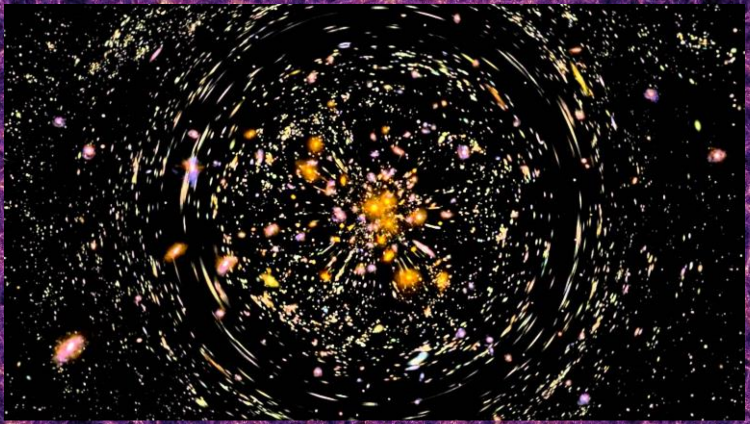
61.2 K
49.2 K
42.9 K
35.6 K
26.7 K
18.5 K
12.6 K
-60
-65
-70
-75
-80
-85
Output Power (dBm)
0
0.5
1
1.5
2
2.5
Frequency (Hz)
$\times 10^9$

Dark Matter: The Evidence

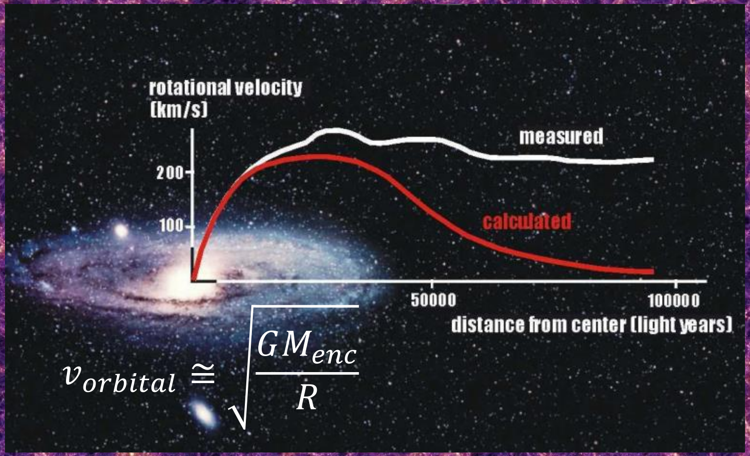
Bullet Cluster (Colliding Galaxies)

X-ray: NASA/CXC/M.Markevitch et al. Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al. Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

Gravitational Lensing



Galactic Rotation Curve



SuperCDMS (Queens University)

Max Planck Society Millennium Simulation Project
Springel et al. (2005)