Noise Calibration in the ADMX Receiver Chain

Jenny Smith
Harvey Mudd College
Advisors: Leslie Rosenberg and Gray Rybka
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The Axion

An elegant solution to two problems

Nuclear Physics Problem

Dark Matter Problem

Axion “Haloscope” Detection Scheme

Classical EM field

Sea of virtual photons

Primakoff Effect

ADMX Public Website
**ADMX**

The Biggest and the Best

Cavity Frequency (GHz)

| Axion Coupling $|g_{aY}|$ (GeV$^{-1}$) |
|-----------------|
| $10^{-10}$      |
| $10^{-11}$      |
| $10^{-12}$      |
| $10^{-13}$      |
| $10^{-14}$      |
| $10^{-15}$      |
| $10^{-16}$      |
| $10^{-17}$      |

- Earlier ADMX run
- Future ADMX runs
- Most Likely Coupling

**ADMX G2 Discovery Potential**

**DFSZ**

Power of axion signal in cavity:

\[ \approx 10^{-24} \text{ Watts} \]

Dicke Radiometer Equation:

\[ SNR = \frac{P_a}{P_N} \sqrt{Bt} \]

Scan Time with Fixed SNR

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

Sensitivity with fixed scan rate

\[ g_{\alpha \gamma \gamma} \propto \frac{T_s}{B_0^2 V} \]

System Temperature (Ts) is a critical system parameter
Convenient to treat device noise sources as if they were all thermal noise.

\[ P = k_B T B \]

- **Input Signal**
- **amplifier**
- **SNR in**
- **SNR out**
- **Noise Power**
- **Boltzmann Constant**
- **Noise Temperature**
- **Bandwidth**

Noise Temperature

SNR in

SNR out
ADMX Receiver Chain

Simplified Model of Cascaded Amplifiers

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

Physical Temperature Key
- 4-10 K
- 4 K
- 1 K
- 500 mK
- 100 mK

To receiver

HEMT 2
600-11

HEMT 1
600-

Hot Load

DC Block

MSA

Antenna

Cavity

Room Temperature Measurement

+28 V

Noise Source

LNF 028H

SA

8500K

X100

~1,000,000 K

8500K

X100

~1,000,000 K

Noise Source

LNF 028H

SA

LNF Amp

Noise Source
Noise Power Change (Noise Source 2)

Power (dBm)

Freq (Hz) \times 10^9

-54

-55

-56

-57

-58

0.8

1

1.2

1.4

1.6

1.8

2

- Noise Source On
- Noise Source Off
LNF Noise Temp, Physical Temp 300K

Raw Noise Temperature

Filtered Noise Temperature

Manufacturer Data RT Noise Temp: ~60K
Liquid Nitrogen Test

“Due to be calibrated in 1996”

77K / 300K
Hot/Cold Noise Power Change

Power (dBm)

Freq (Hz) \times 10^9

Th = 300K
Tc = 77K
Cryo Test

- Heater
- Attenuator
- LNF
- MINI
- SA

Diagram showing a cryogenic system with a heater and an attenuator connected to a \(~4\,\text{K}\) cryostat.
Results

LNF 021H Hot Load Test 8/11/2017

Power (dBm)

-90
-80
-70
-60

Frequency (Hz) ×10^9

0 0.5 1 1.5 2 2.5

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 \( \sim 10K \)

\[
T_{\text{amp}} = 2.2 \pm 1.2 \text{ K}
\]

Manufacturer Data 5K Temp: \( \sim 2 \text{ K} \)!
Conclusion

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

Noise temperature measurements are hard.

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

LNF 021 H looks like a promising amplifier to add to the ADMX receiver chain!
Thank you to the ADMX team!
Thermometry Data
Figure 2

Average Output Power and Amp Temp vs. Input Power
Noise Temp (Noise Source 2)

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 \( \propto F \tilde{F} \tilde{\theta} - \)?

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

Too Much Dark Matter

Search Window

Red Giants (KSVZ)

Red Giants (DFSZ)

SN1987A

Accelerator Experiments

Axion Mass (eV)

$10^{-9}$  $10^{-6}$  $10^{-3}$  $10^{0}$  $10^{3}$  $10^{6}$
Detection Theory

Resonant conversions of axions to photons:

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

Axion coupling constant

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

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Nuclear Physics Problem

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

Axion field could explain this hidden symmetry

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

Dark Matter Problem

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

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

![Graph showing temperature (Kelvin) over time (minutes). The temperature increases significantly, indicating that the heater works effectively.]
Results

LNF 021H Noise Temperature, Physical Temp = ~10K

Amp Noise Temperature (Kelvin) vs Frequency (Hz)
The graph shows the output power (dBm) as a function of frequency (Hz). Different temperatures are represented by colored lines, with the following temperatures and colors:

- 61.2 K: Pink
- 49.2 K: Red
- 42.9 K: Orange
- 35.6 K: Yellow
- 26.7 K: Cyan
- 18.5 K: Green
- 12.6 K: Blue

The x-axis represents frequency in Hz, ranging from 0 to 2.5 × 10^9 Hz. The y-axis represents output power in dBm, ranging from -85 to -60 dBm.
Dark Matter: The Evidence

Bullet Cluster (Colliding Galaxies)

Gravitational Lensing

Galactic Rotation Curve

\[
\frac{v_{\text{orbital}}}{v_{\text{enc}}} \approx \frac{G M_{\text{enc}}}{R}
\]

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

SuperCDMS (Queens University)