Blackbody Radiation and Cavity Resonance Properties at Low Temperatures

Senna Keesing

Axion Dark Matter eXperiment, University of Washington

ABSTRACT

Blackbody radiation is the name given to the phenomenon that makes warm objects radiate—it explains why a hot stove glows red, or why the sun is so bright. This radiation is well-understood in physics, but some theories of new particles suggest that at low temperatures there will be small deviations to the equations that normally predict the amount of power radiated by these bodies. I am conducting an experiment designed to search for these deviations. This experiment will involve measuring the radiated microwave power from a resonant cavity and a resistor as they are cooled to liquid nitrogen temperatures; standard physics predicts these power values scale linearly with temperature, which is the expected result. However, some expanded standard model theories predict a deficit of power at low temperatures due mixing of photons with new light particles. This research will help refine our understanding of blackbody radiation at low temperatures, including our understanding of the results from the UW Axion Dark Matter eXperiment (ADMX).

THEORY

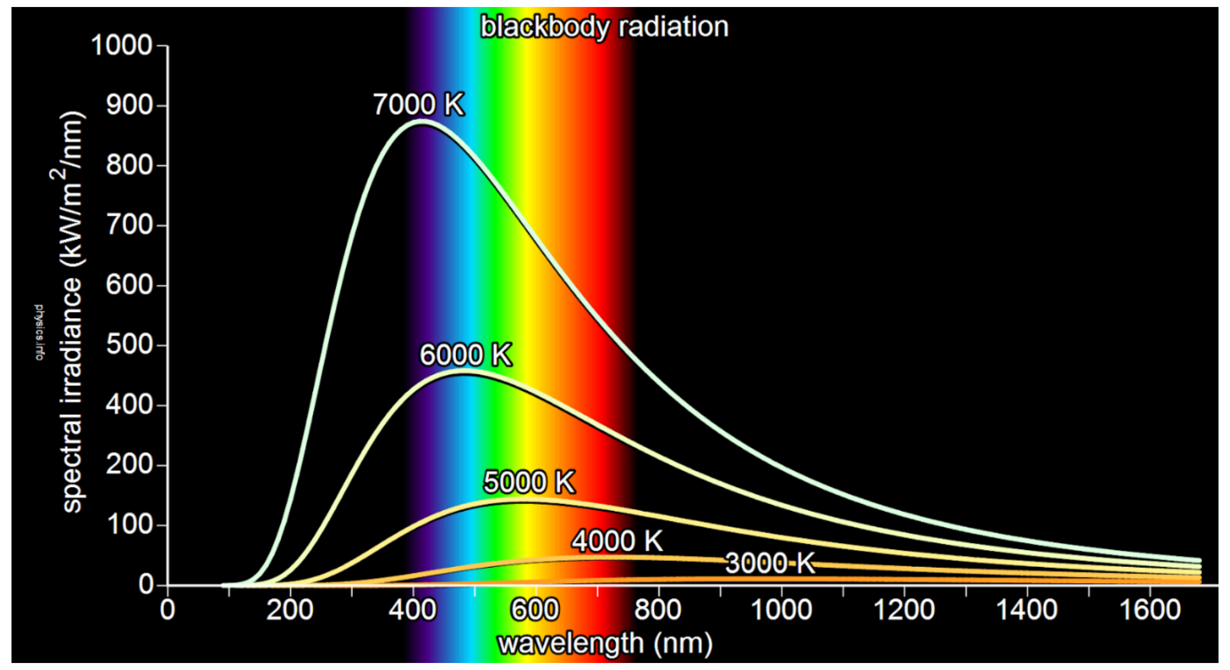

Fig 1. Blackbody radiation spectrum.

Blackbody radiation is a major source of noise for precision physics experiments and quantum computing. Standard electromagnetism predicts a linear relationship between radiated power and temperature at a given frequency, but the evaluation of blackbody radiation, also called thermal noise, from multiple resonant systems can be challenging.

EXPERIMENTAL SETUP

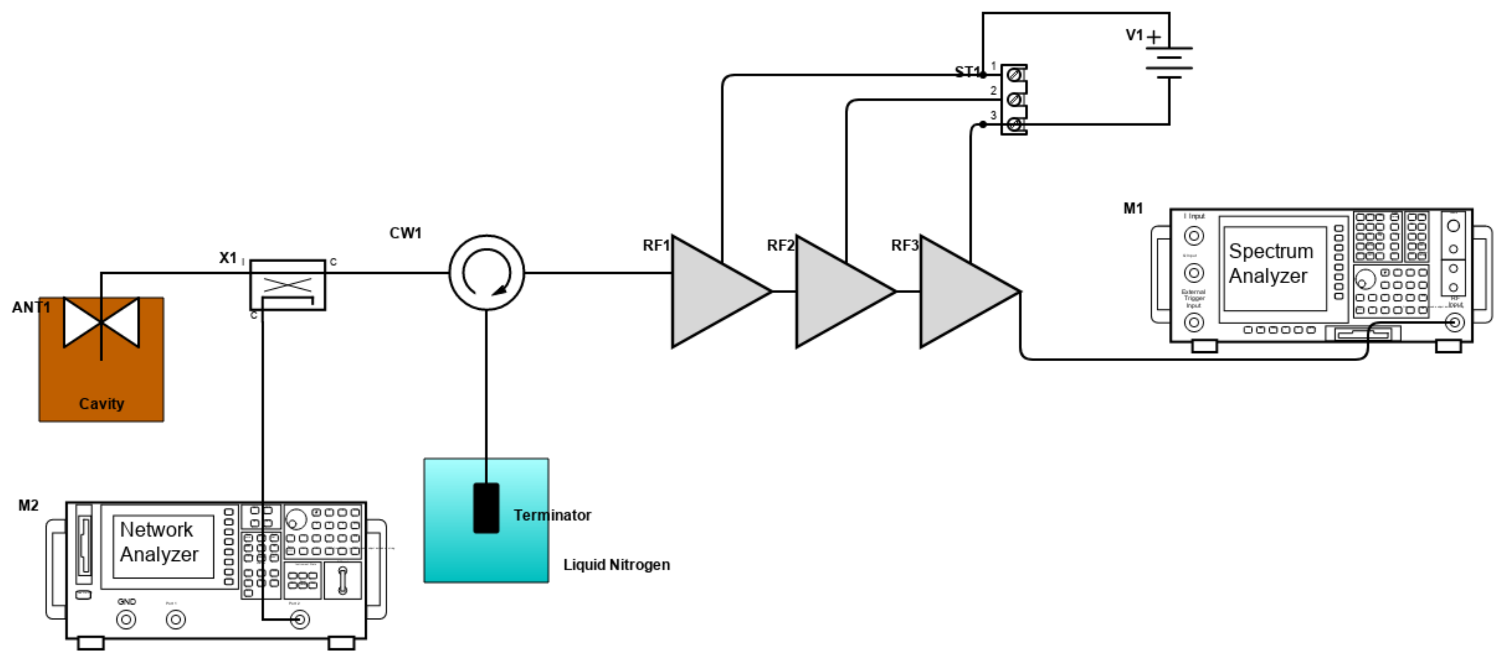

Fig 2. RF diagram of the experimental setup.

Fig 3. A preliminary run of the experiment.

We study an arrangement of a resonator, circulator, and low-noise amplifier common to experiments like ADMX, Project 8, and superconducting quantum computing readout while different components are cooled cryogenically. We measured the noise output of the experimental apparatus in order to gain a baseline for comparison using the equation

$$P = Gbk(T_{amp} + T_{other}),$$

In which:

- P stands for the power output of the experimental apparatus
- G stands for the gain, or how much the signal is increased by the amplifiers
- b represents bandwidth—the range of the frequencies over which the power is measured
- k is the Stefan-Boltzmann constant
- T is the temperature; the subscript "amp" refers to the amplifier, while "other" captures thermal noise

We rearranged this equation for power measurements at both room temperature and liquid nitrogen temperature. This gave us

$$\frac{P_{RT}}{P_{LN}} = \frac{T_{amp}+T_{RT}}{T_{amp}+T_{other}}, \text{ or}$$

$$T_{amp}\left(\frac{P_{RT}}{P_{LN}} - 1\right) = T_{RT} - T_{LN}\left(\frac{P_{RT}}{P_{LN}}\right).$$

The subscript "RT" is for room temperature, while "LN" is for liquid nitrogen.

We measured the power off-resonance to be -114.0 dBm/Hz at 300 K and -117.7 dBm/Hz at 77 K, giving us $T_{amp} = 88.89\ K$.

On-resonance, the radiated power is the same for the terminator at room temperature and at liquid nitrogen temperature. The amplifier noise is roughly within manufacturer specifications, so we can use the frequency-dependent behavior to measure the source of the noise—whether it comes from the cavity or the terminator.

RESULTS

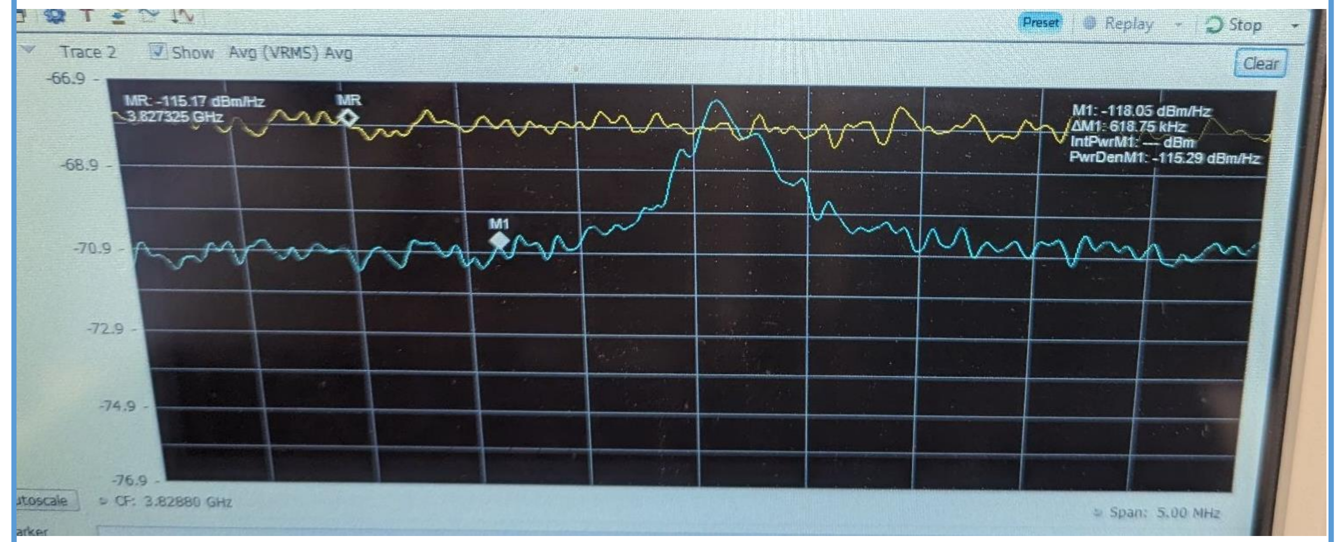

Fig 4. Spectrum analyzer graph of frequency vs. power. The yellow line is with a 300 K terminator, the blue line is with a 77 K terminator.

Here we see that on-resonance, the radiated power is dominated by thermal photons emitted from the cavity. Off-resonance, the thermal photons from the terminator are reflected off the cavity and the primary source of power.

The thermal photons from the cooled terminator do not cool the cavity, which was a source of confusion for some.

FUTURE RESEARCH

Future work includes:

- Accounting for interference effects in multipath systems
- Testing beyond-the-standard-model theories that predict deviations from standard blackbody power at low temperatures
- Comparing measurements to results from setups including quantum amplifier

ACKNOWLEDGEMENTS

Thanks to my mentor Gray Rybka, and the entire ADMX team, including Dan Zhang, Clem Mostyn, Jimmy Sinnis, Charles Hanretty, Cyrus Goodman, Michaela Guzzetti, and many others. Additional thanks to Janning Meinert and Ralf Hofmann for their expanded standard model theory. This work was supported by the US DOE Grant #DE-SC0011665.