A Novel Method of Thermal Detection Using a Torsional Pendulum

Alex Kelser Liam Stewart

Motivation

- Recent study demonstrated fabrication of thermally active “torsional muscle” from twisted nylon fiber*

- To determine if a thermally active torsional pendulum can be created using a small mass attached to the bottom of a twisted nylon fiber.

- To demonstrate that such a pendulum can be driven by a pulsed IR source to stably oscillate at a constant frequency.

- To characterize the infrared transmittance of materials using this torsional pendulum as a thermal detector.

*Carter Haines et al., Science 343 p868 2014

Procedure

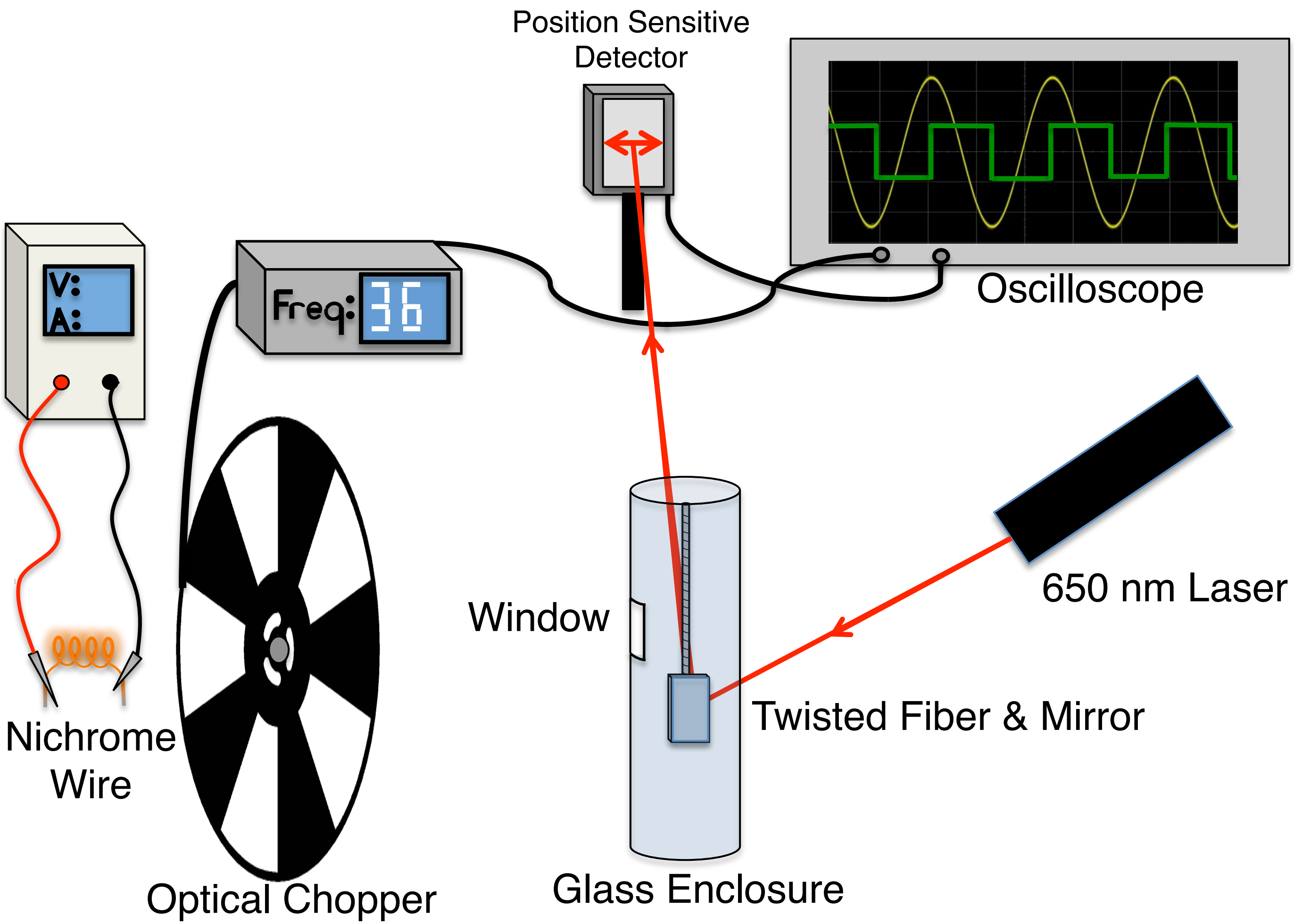
- A current was passed through a Nichrome wire, exciting blackbody radiation.
- The radiation was passed through an optical chopper rotating at the natural torsional frequency of a freely-suspended twisted nylon fiber.
- The chopped blackbody radiation incident upon the fiber then forced it into torsional resonance.

Procedure Cont.

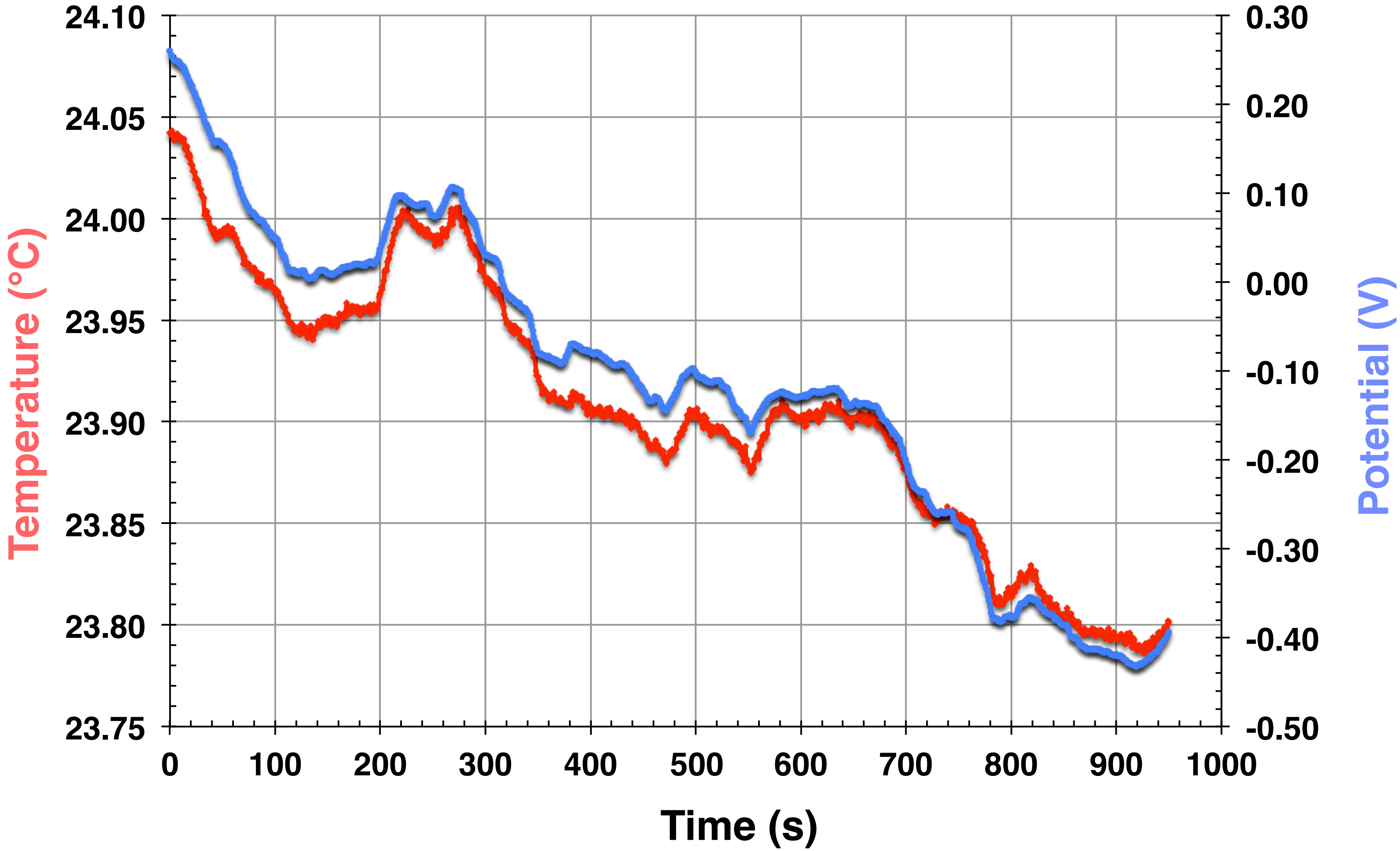
- A small mirror was glued onto the bottom of the hanging fiber, and a laser was directed off of the mirror into a Position Sensitive Detector (PSD).

- The signal from the PSD was AC-coupled into an oscilloscope which was externally triggered by the chopper which was adjusted to the resonant torsional frequency.

Experimental Setup



Preliminary Experiment Without Resonant Excitation: PSD Signal and Temperature Correlation Showing ca. 0.01 °C Sensitivity



Analysis of Torsional Pendulum

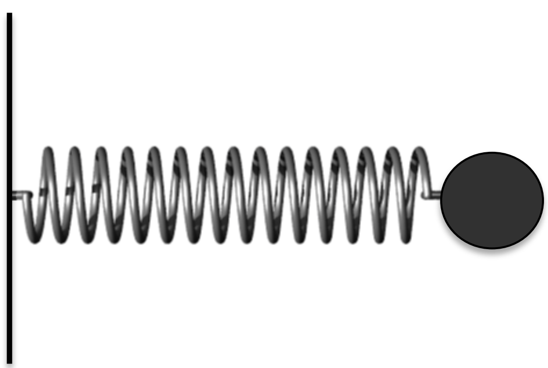
Simple Harmonic Oscillator Analogous to Mass on Spring System

Mass on Spring System

$T = 2\pi \text{ sqrt}(M/K)$

M = Mass (kg)

K = Spring constant (N/m)

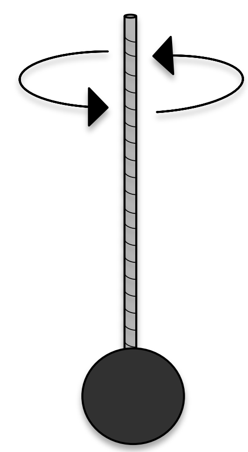


Torsional Pendulum

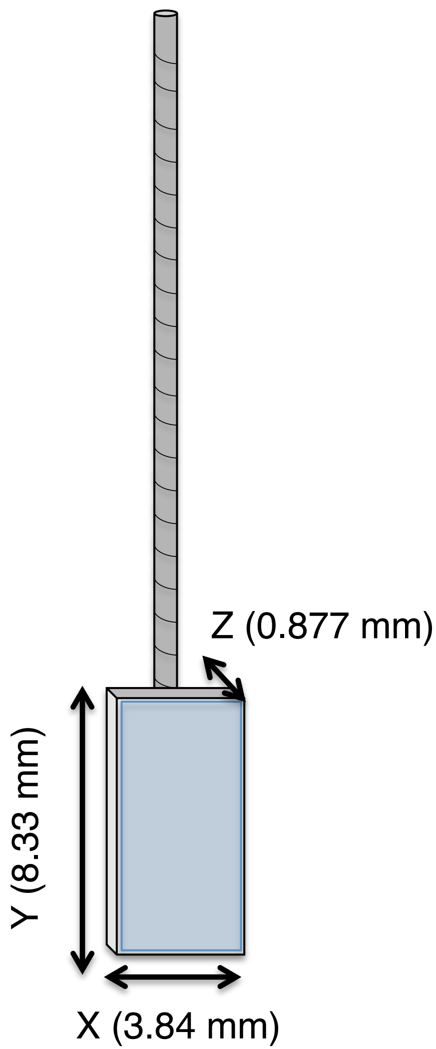
$T = 2\pi \text{ sqrt}(I / \kappa)$

I = Moment of Inertia ($kg \cdot m^2$)

κ = Torsion Constant ($N \cdot m$ / rad)



Calculating the Moment of Inertia and Torsion Constant



$I_y = (1/12)\ M\ (x^2 + z^2)$

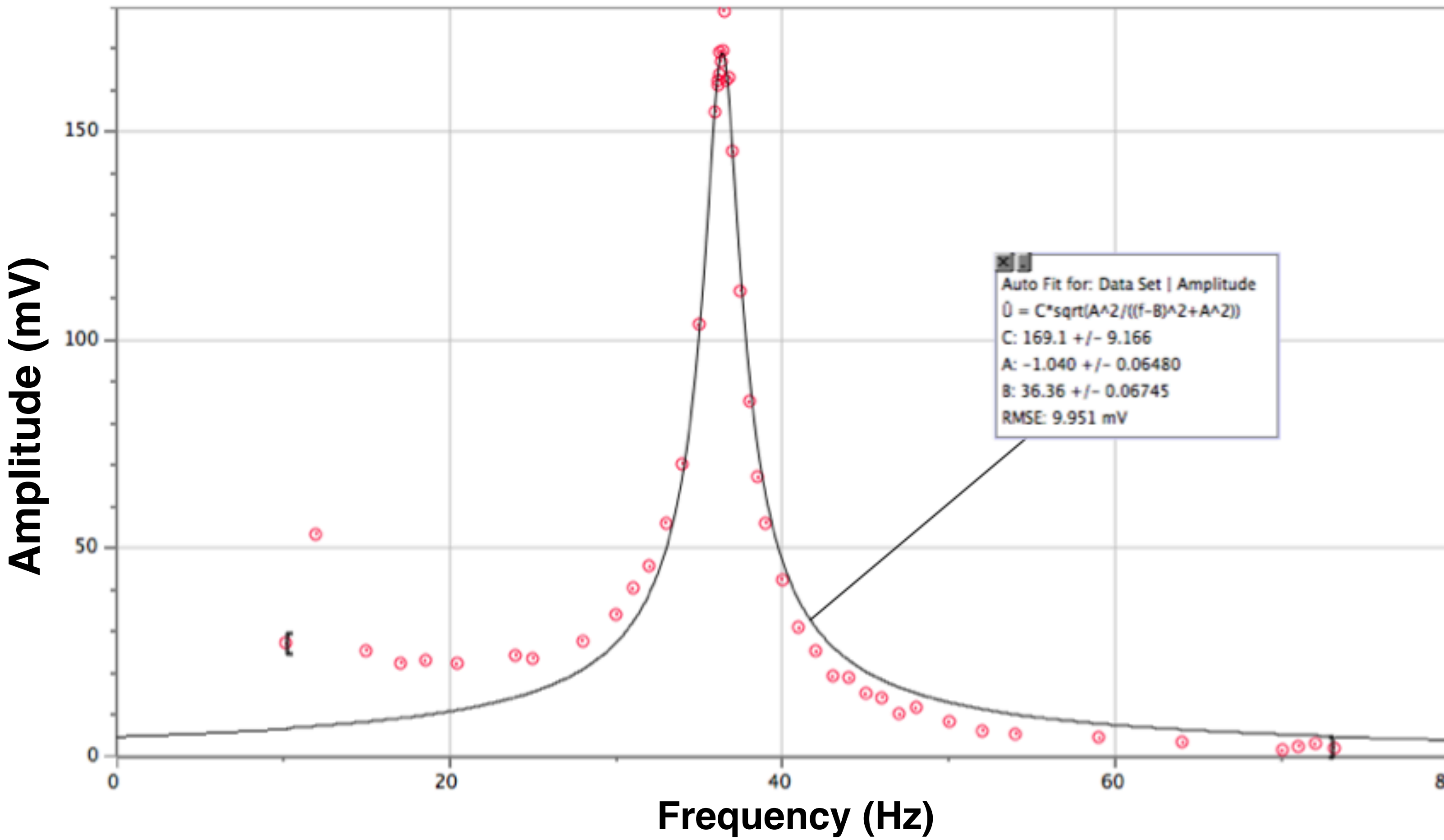
$I_y = (1/12)\ (5.5*10^{-5}\ kg)\ ((3.84*10^{-3}\ m)^2 + (0.877*10^{-3})^2)$

$\mathbf{I_y = 7.11 * 10^{-11}\ kg \bullet m^2}$

$T = 2\pi\ sqrt(I\ /\ \kappa)$

κ (Calculated) = $3.71 * 10^{-6}$ Nm/rad

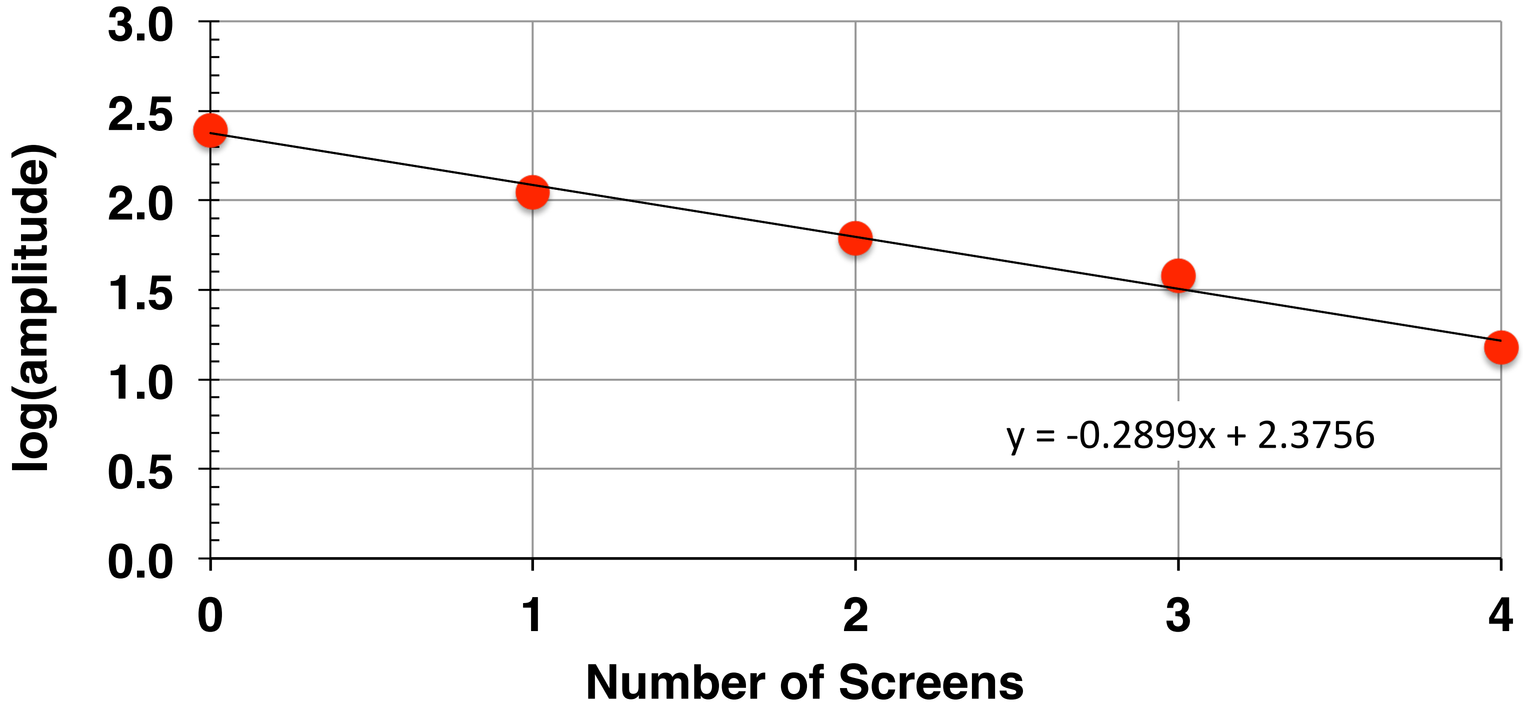
Torsional Resonance (36.36 Hz)



Q-Factor: Parameter describing damping of system.

$$Q = (f_{peak})/(\Delta f_{halfpower}) = (36.36/3.61) = 10.08$$

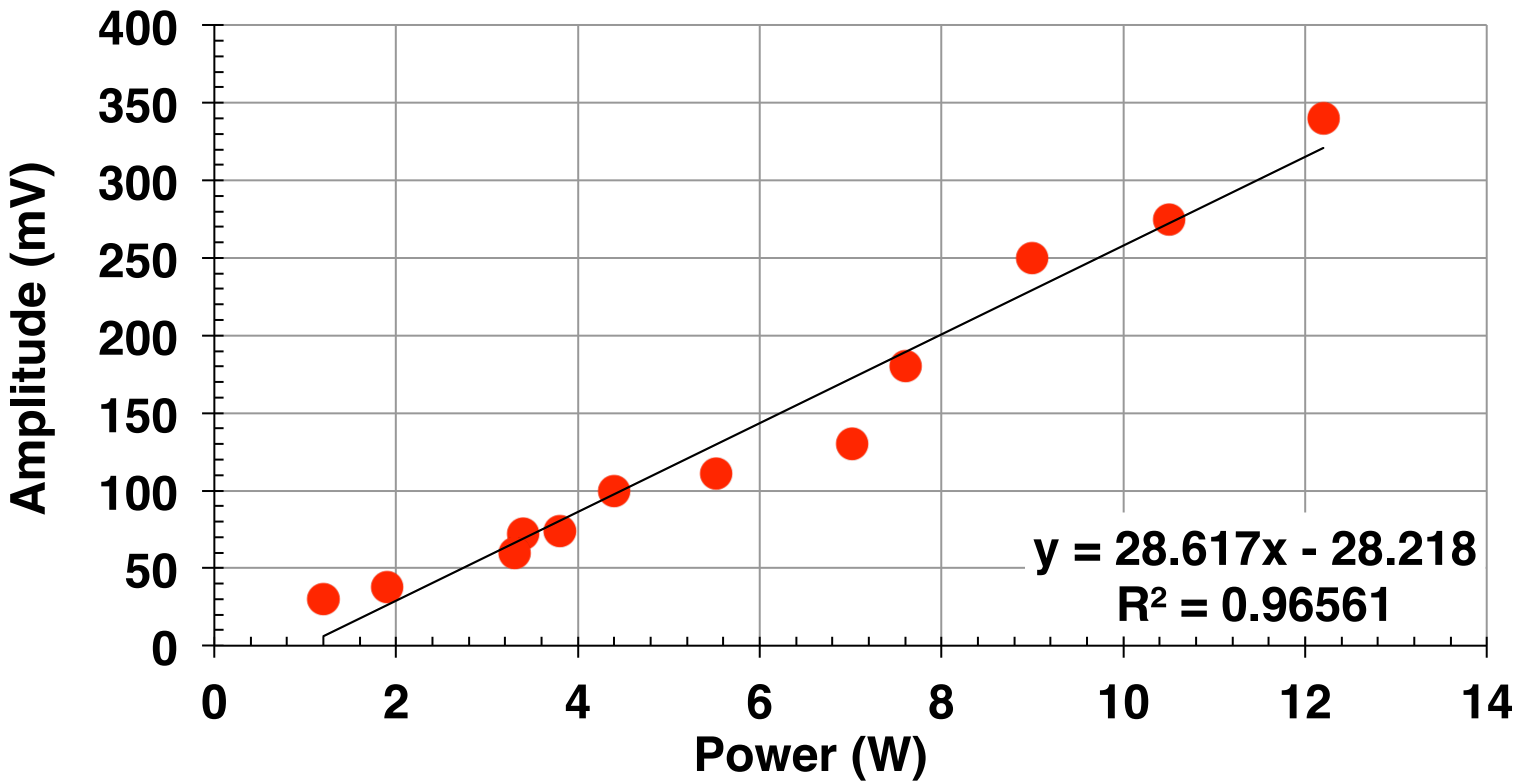
Demonstration of Detector Linearity Using Wire Mesh Screens



Percent decrease in transmission per screen = $10^{-0.2899} \approx 51.3\%$

(In separate measurements using visible light and a photodiode, change for each screen averaged 47.5%.)

Further Demonstration of Signal (mV) Linearity vs. Coil Power (W)



Determining Detectability Limit

- Power radiated at the coil (Ohm's Law):

  $P = I \cdot V = 3.8\ A \cdot 3.9\ V = 15\ W$

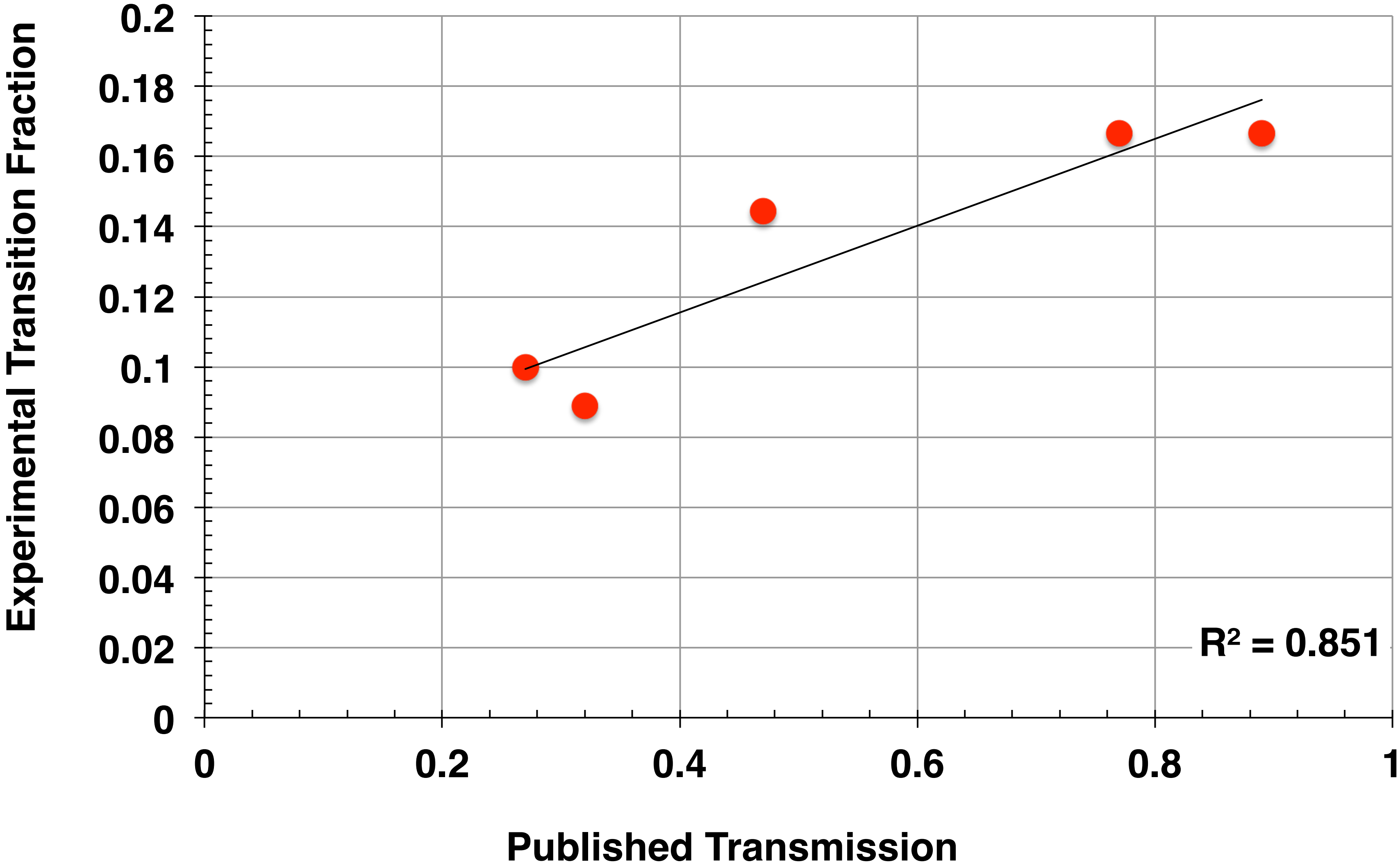
- Intensity at the fiber (located 6.5 cm from coil):

  $I = {}^{Power}/_{Area} = {}^{15\ W}/_{4\pi r^2} = 28\ {}^{mW}/_{cm^2}$

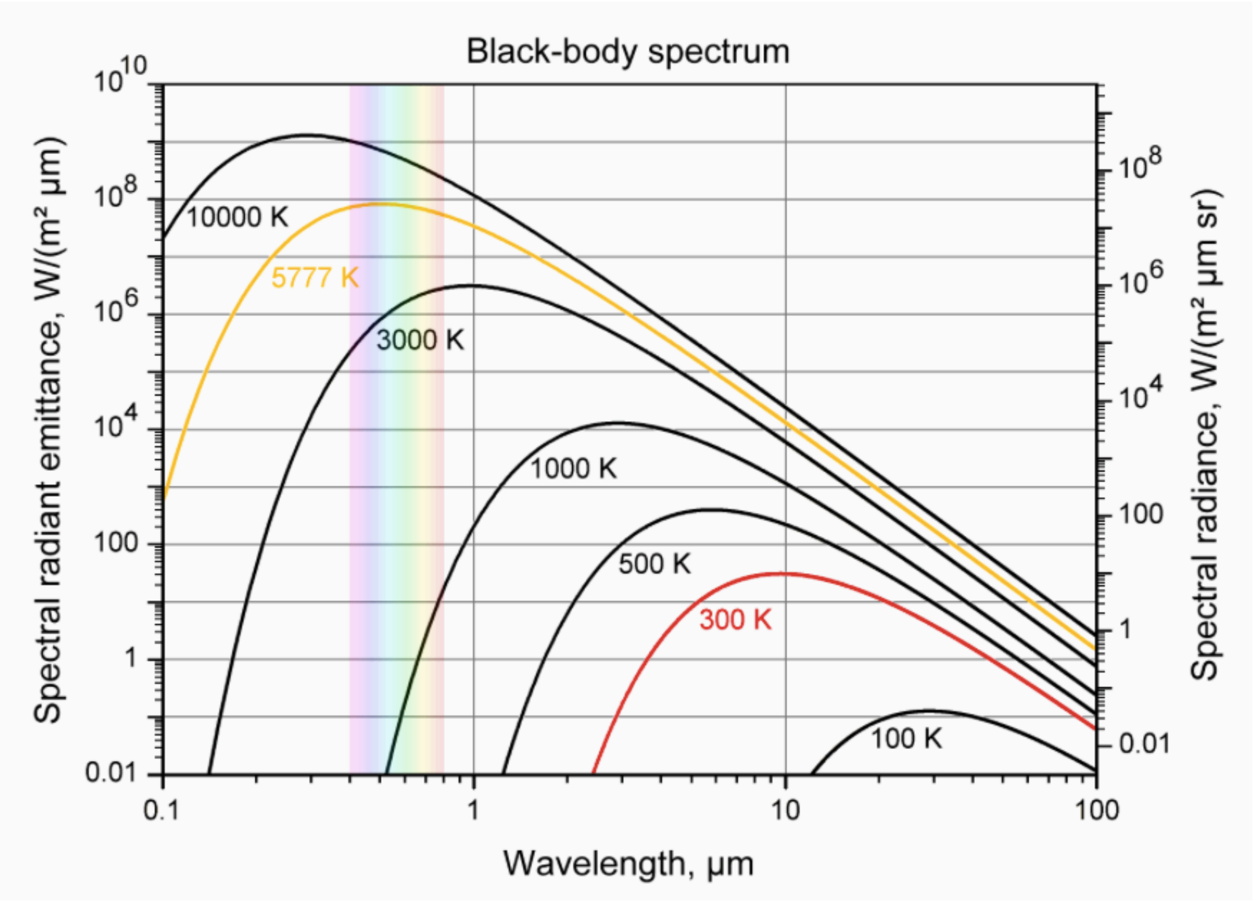
- This resulted in a 200 mV signal from the PSD, which was 100x the observed noise limit.

- This yields a detectability limit of 0.28 ${}^{mW}/_{cm^2}$

Glass Transmission: Published vs. Observed



Overlap of Blackbody Emission Spectrum and Nylon Absorption Spectrum is Largely Unknown



Conclusions and Future Directions

Acknowledgements

- Summit Educational Foundation
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Experimental Transition vs. Published Total Energy Transmission