Reducing Suspension Thermal Noise for Enhanced LIGO

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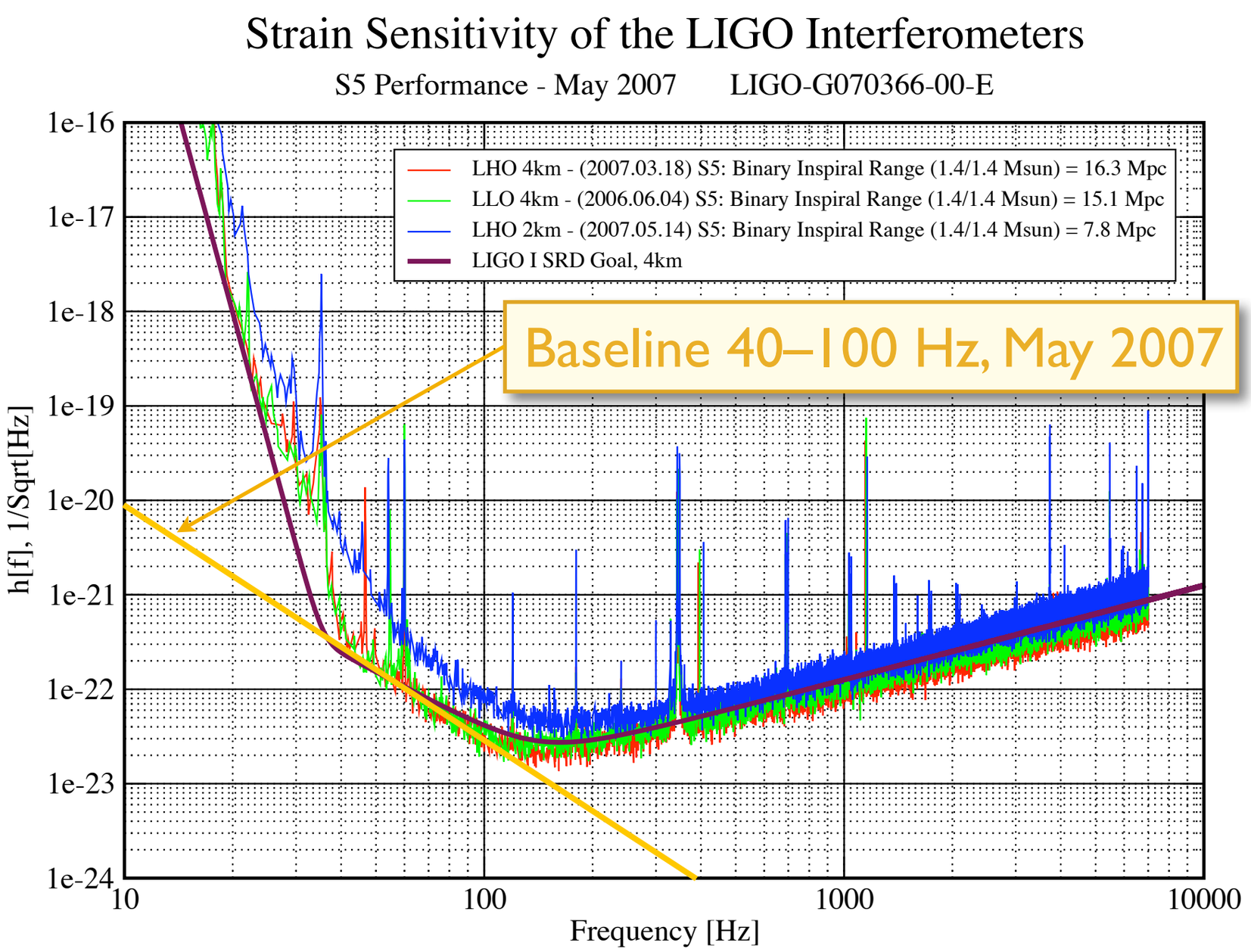
DCC: LIGO-G070553-00-Z

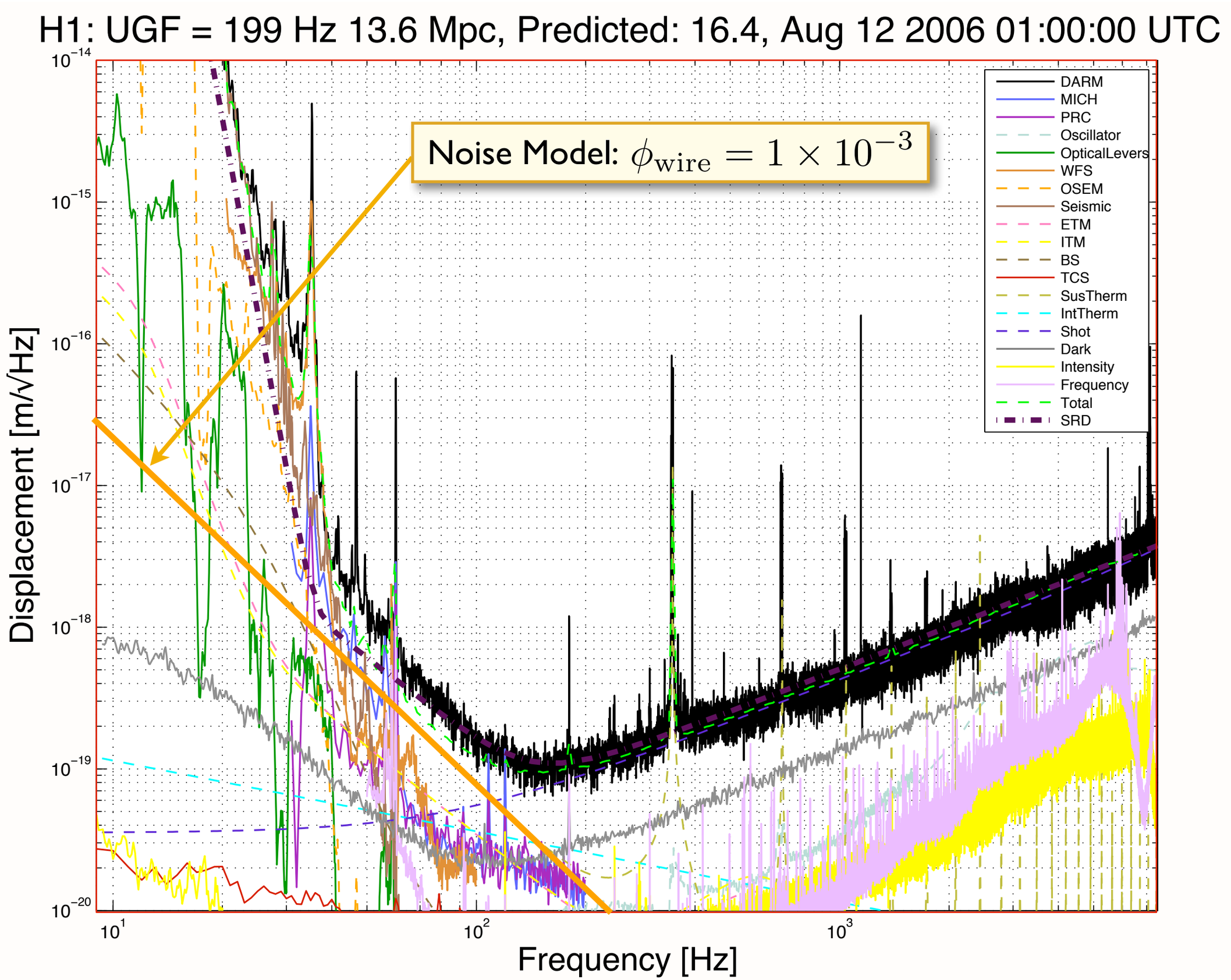
The Problem



- Noise between 40 Hz and 150 Hz has slope near 5/2
- Level is high, but not impossibly high, to be suspension thermal noise
- Very similar level in all three interferometers

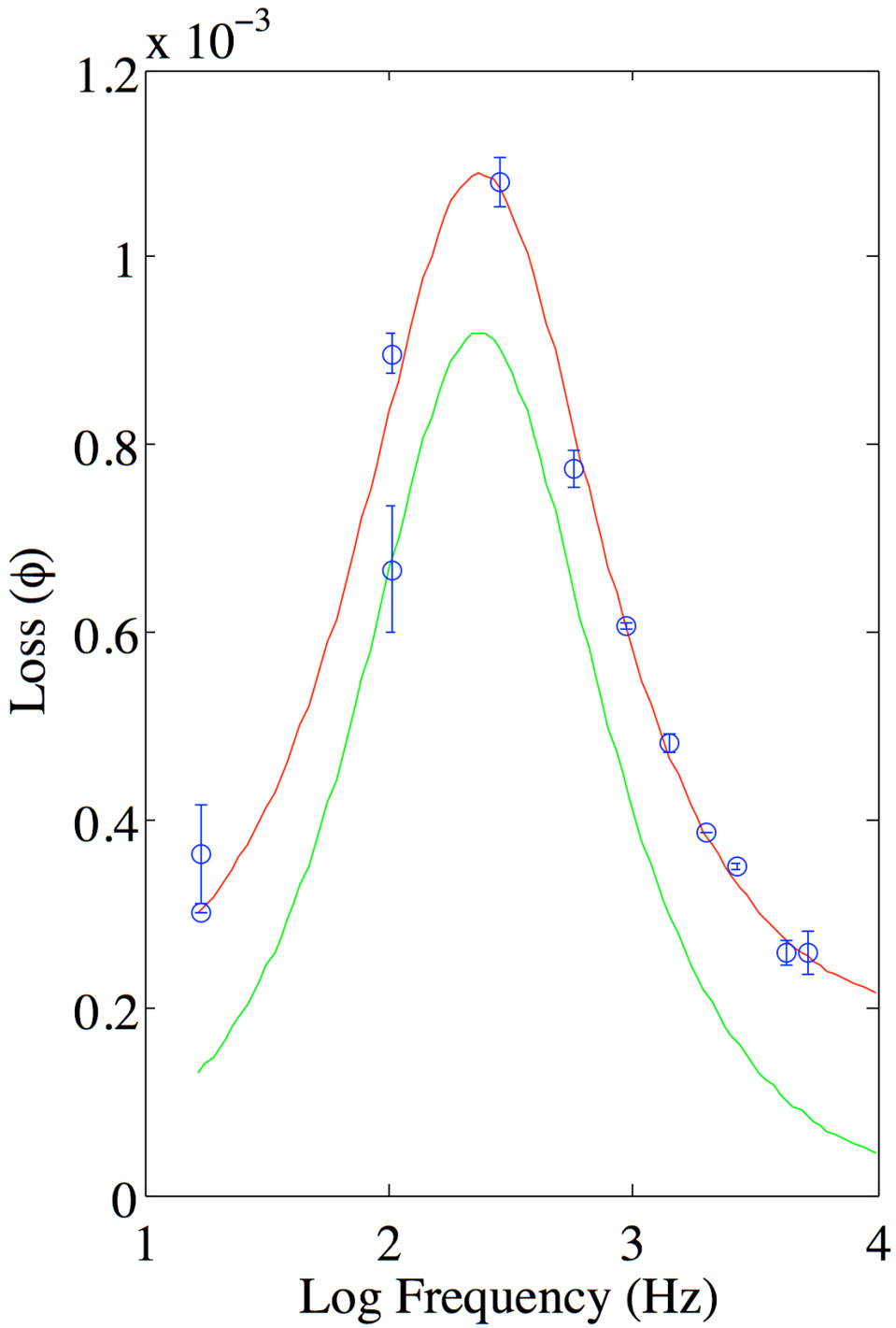
LIGO

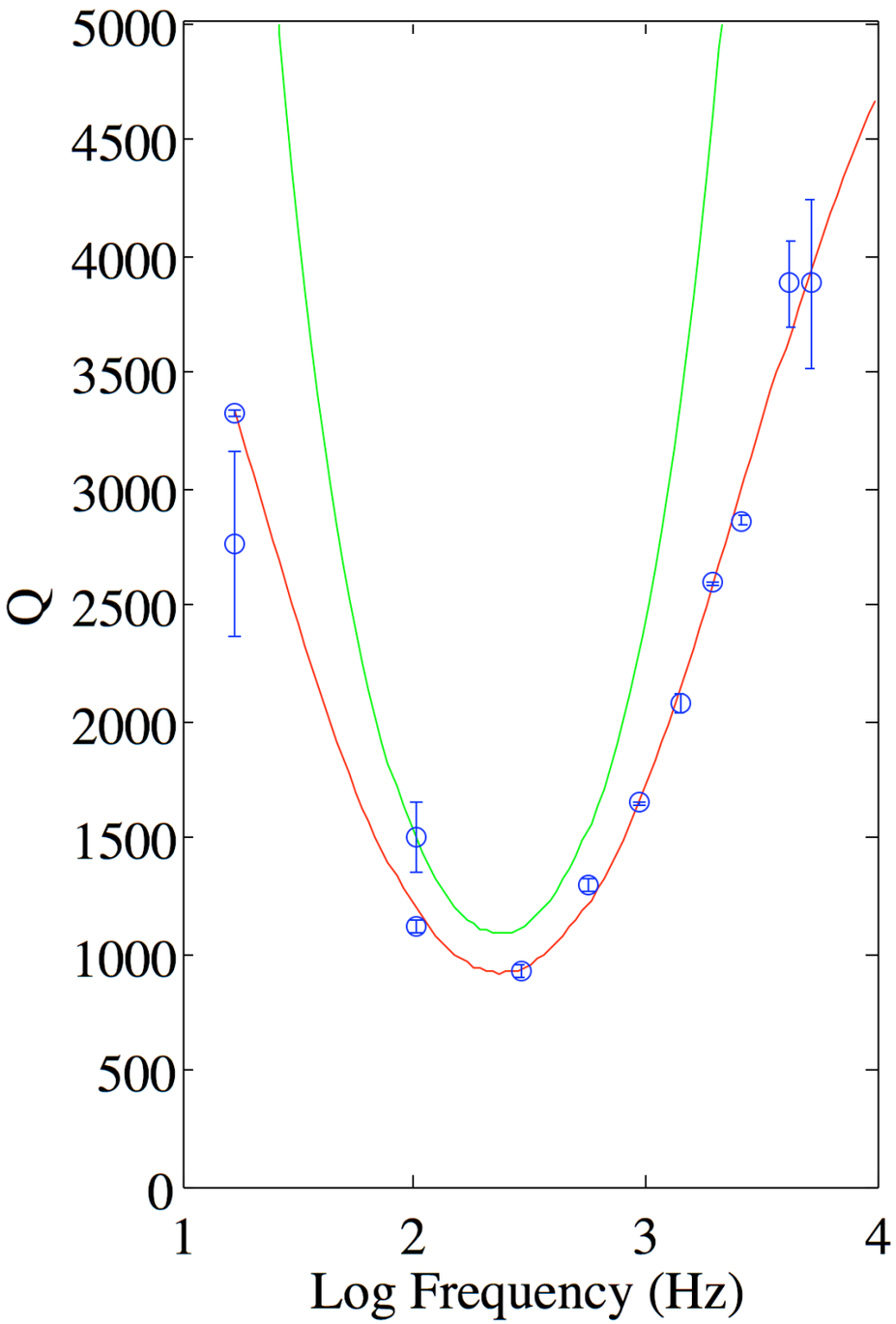
The Problem



Mechanical Loss
Music Wire clamped in Pin Vise

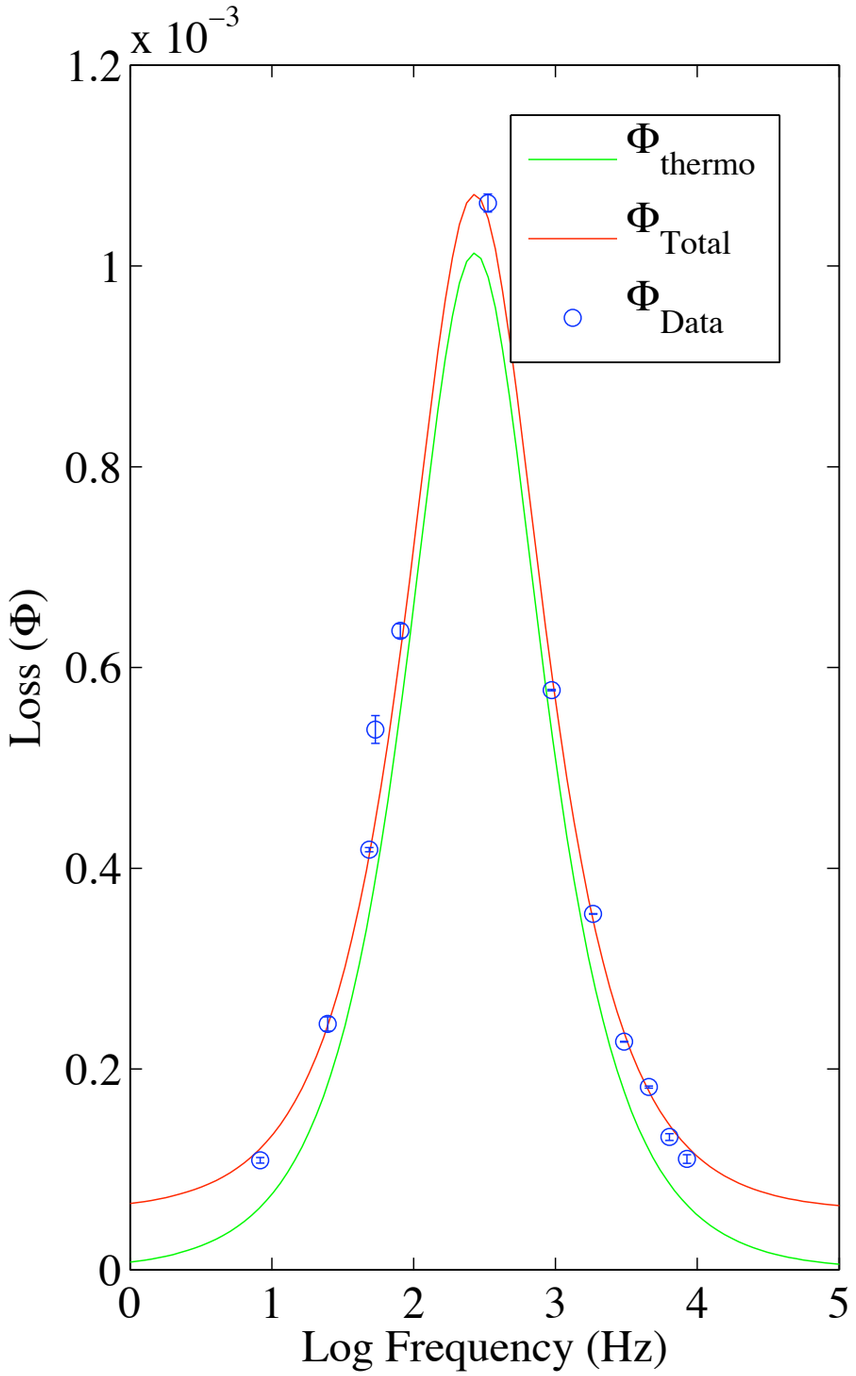
$\phi_{\rm str} = 1.70 \times 10^{-4}$ *Structural loss ≈ half of assumed design value.*

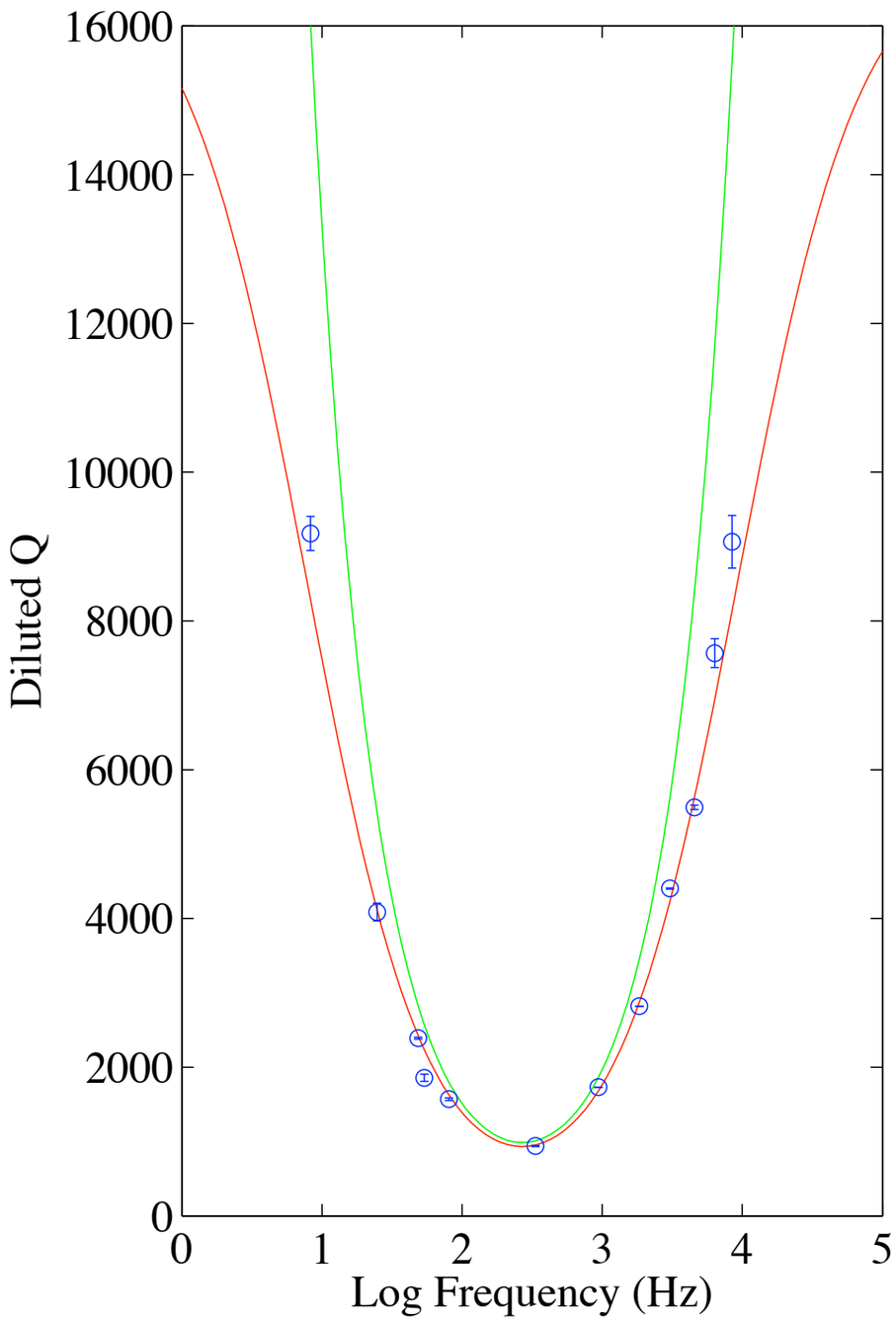




Mechanical Loss
Music Wire in Virgo Clamps

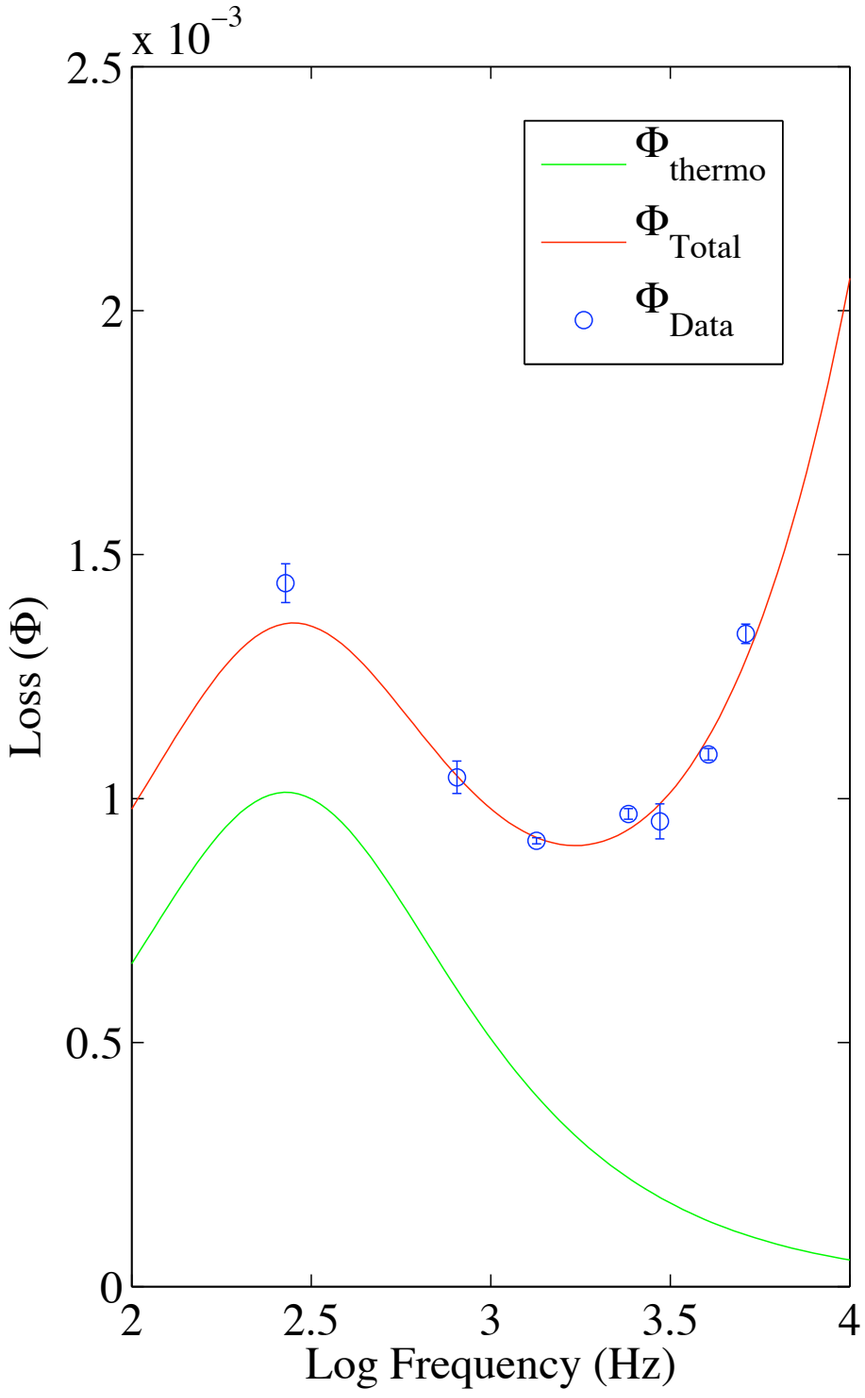
$\phi_{\mathrm{str}} = 5.9 \times 10^{-5}$ *Structural loss << Assumed design value.*



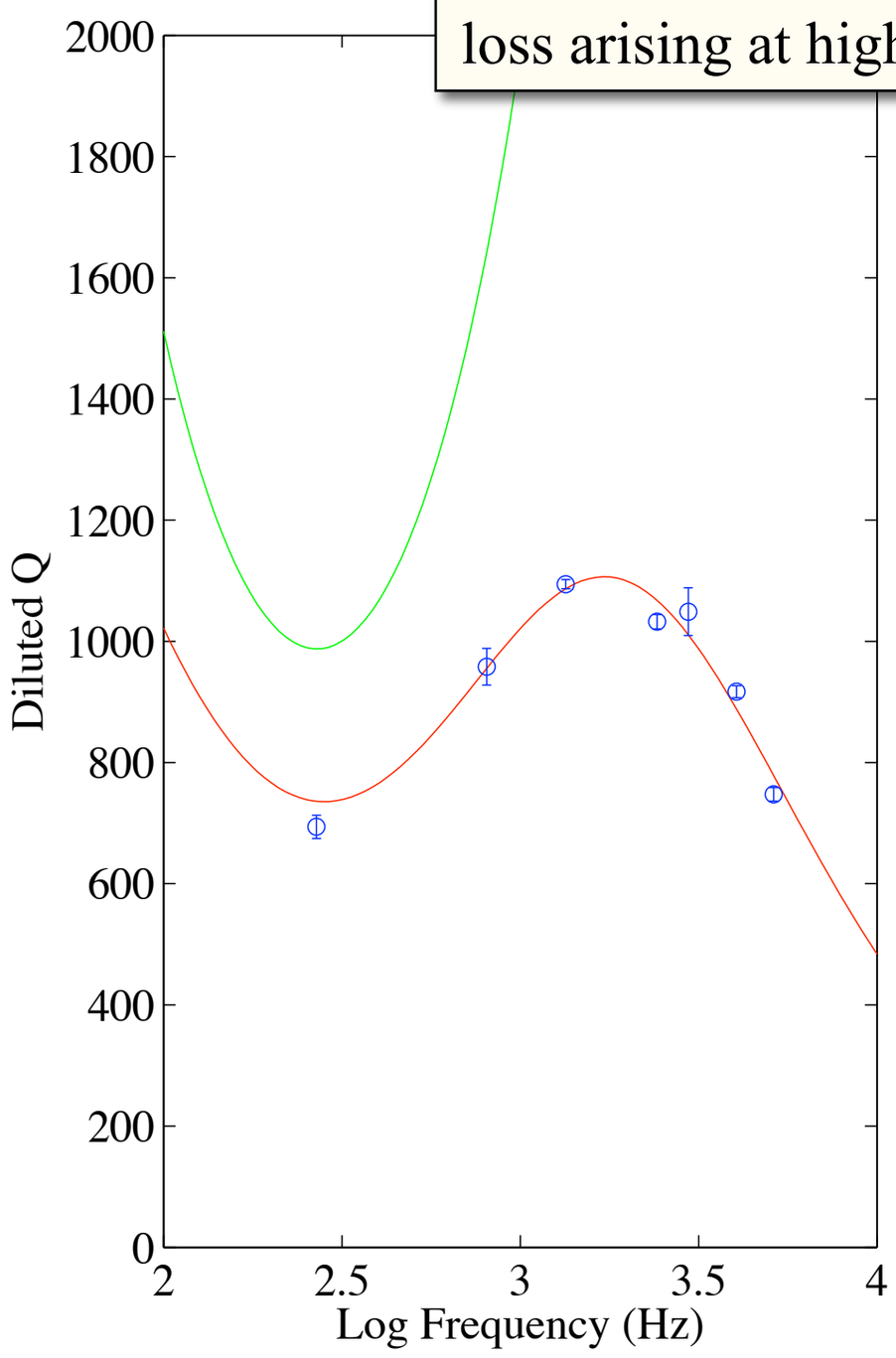


Mechanical Loss
Tensioned Music Wire in Virgo Clamps

Steel Wire: Thermoelastic fixed, Φ_0 = 3.00e–04, Φ_1 = 1.71e–07



Tensioned Wire has viscous loss arising at high frequency.



LIGO Loss in Violin Modes at Observatory

- Loss Measured in time by exciting the violin modes and observing the ringdown
  - » Measurements were sometimes in agreement with wire loss, but usually higher and not stable in time.
  - » Concerns raised that high amplitude of oscillation may cause excess loss (rubbing friction)

- Loss measured in frequency by analyzing the power spectrum of long lock stretches.
  - » David Malling's summary page:

    http://physics.syr.edu/research/relativity/ligo/susqs/
  - » Malling fit the set of violin modes that are nominally thermally excited
  - » Loss still varies in time, not stable

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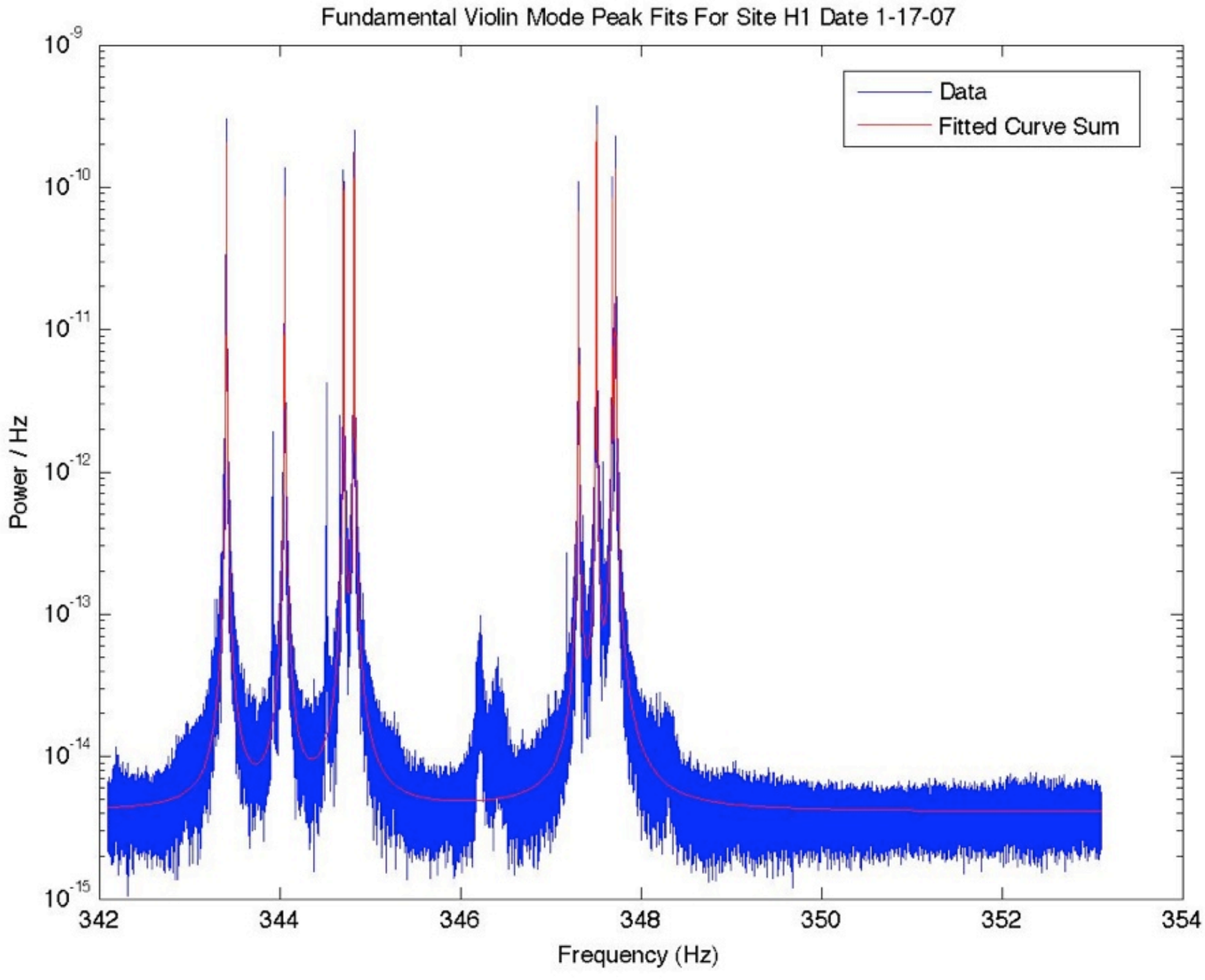
Fit of Loss in Violin Modes



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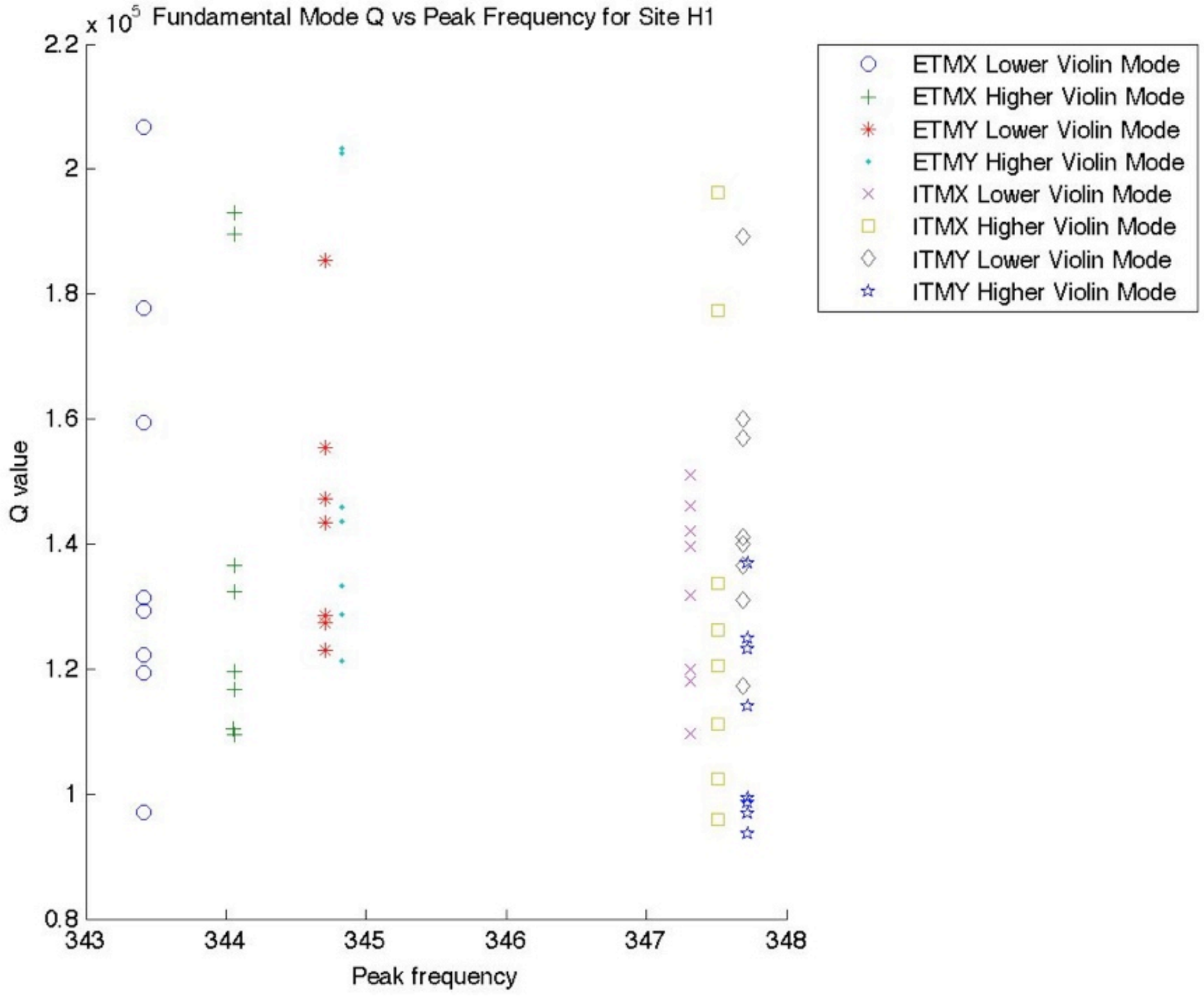
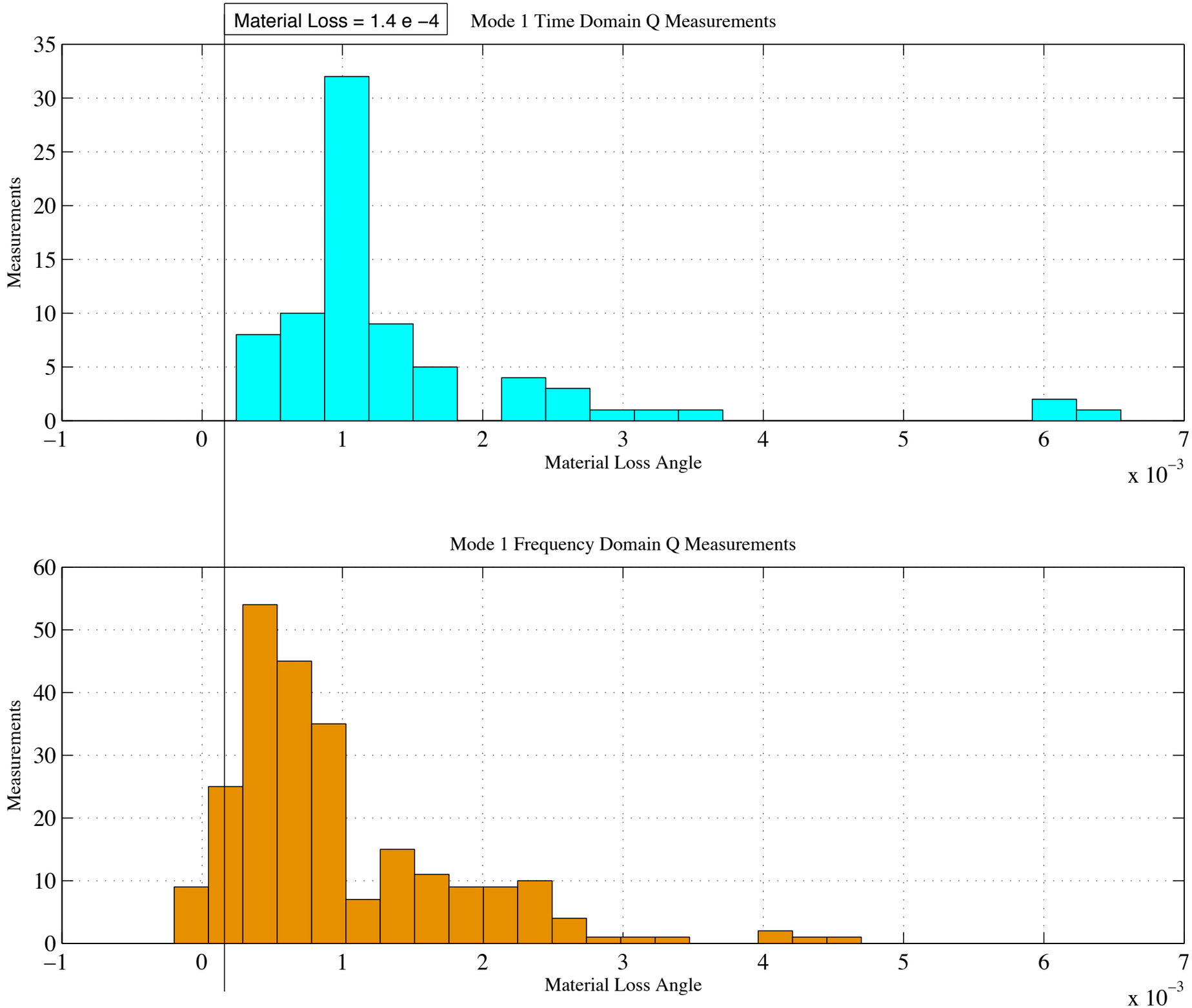
Variation of Loss in Violin Modes



Distribution of Loss in Violin Modes



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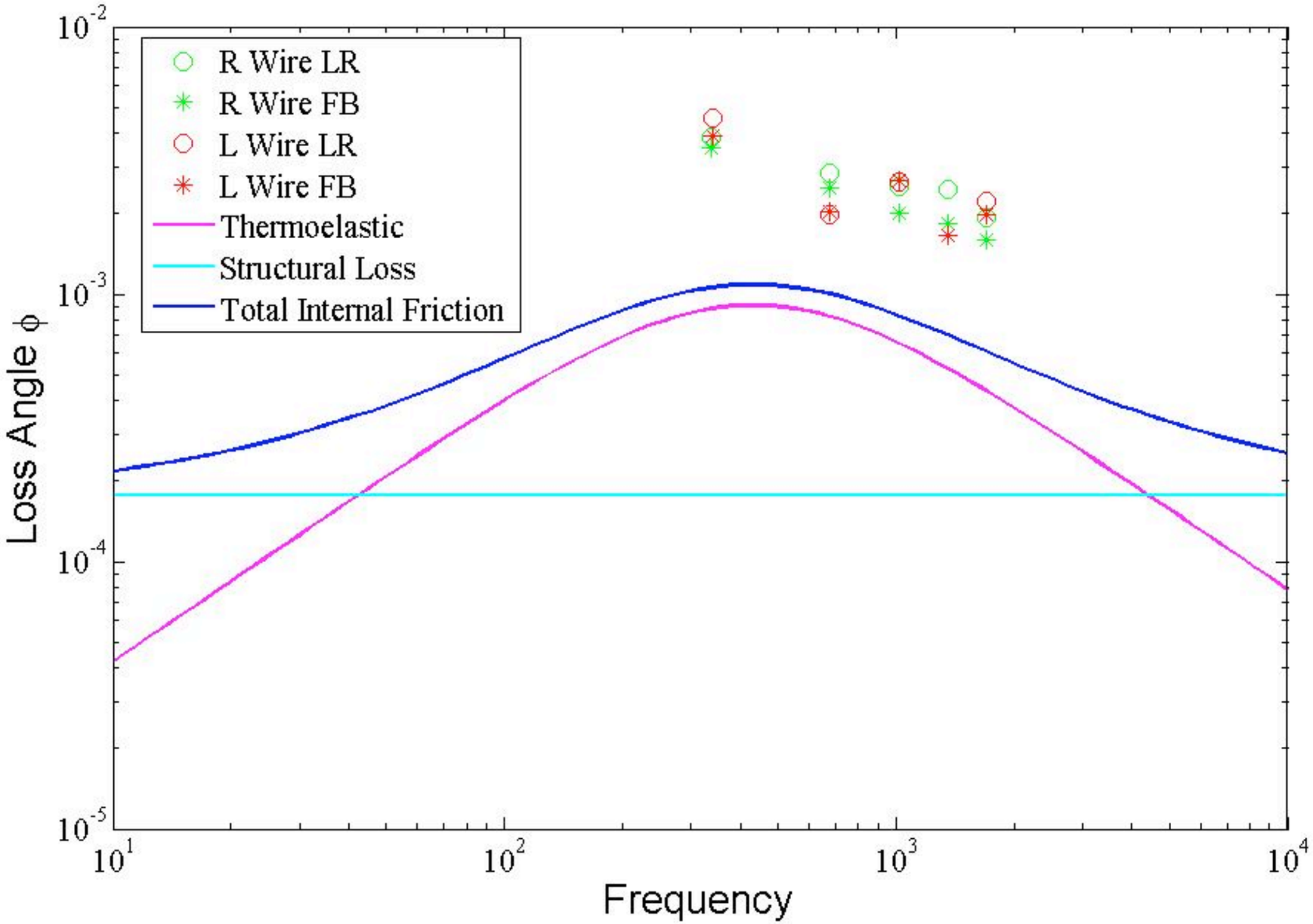
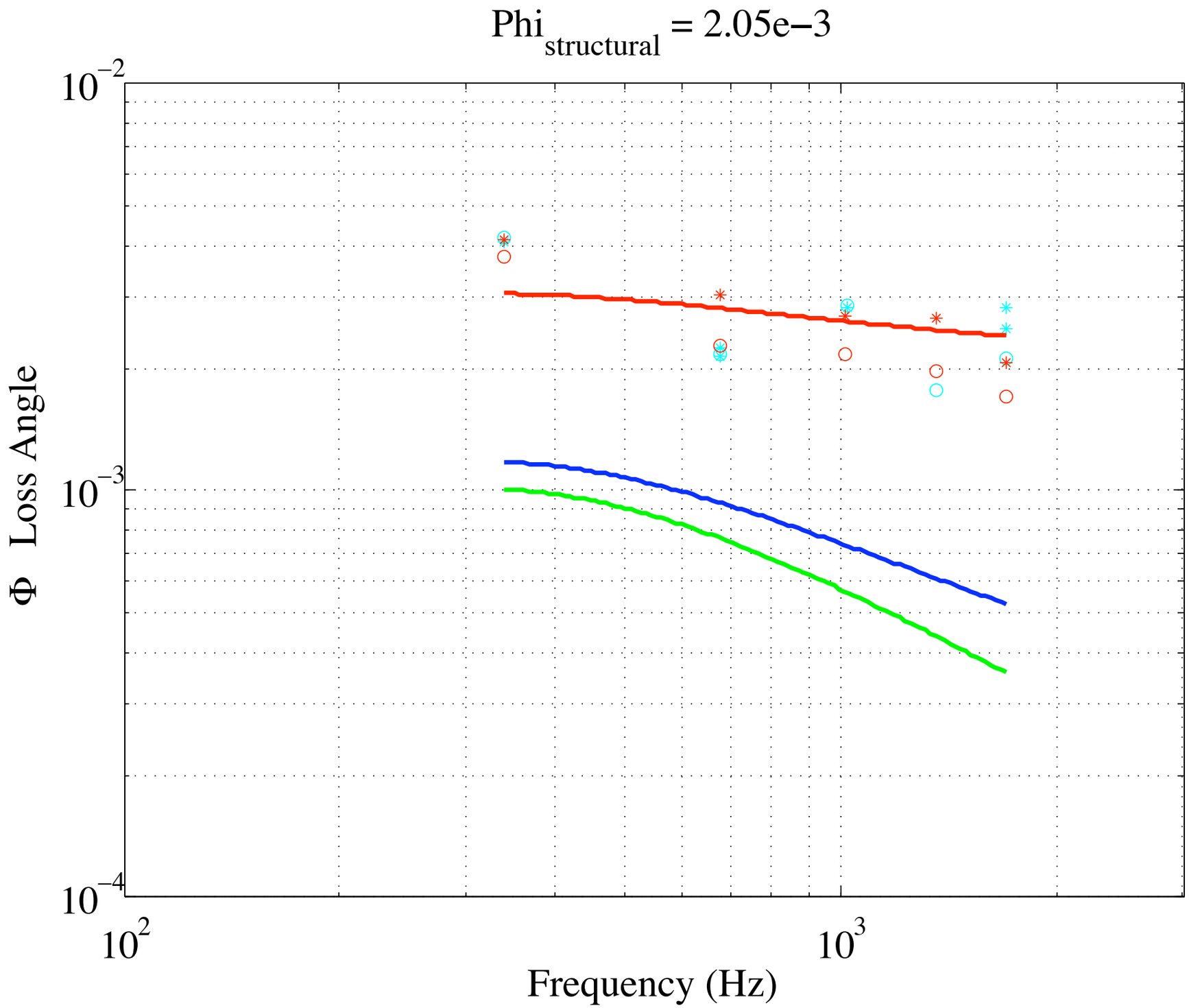
MIT Experiment

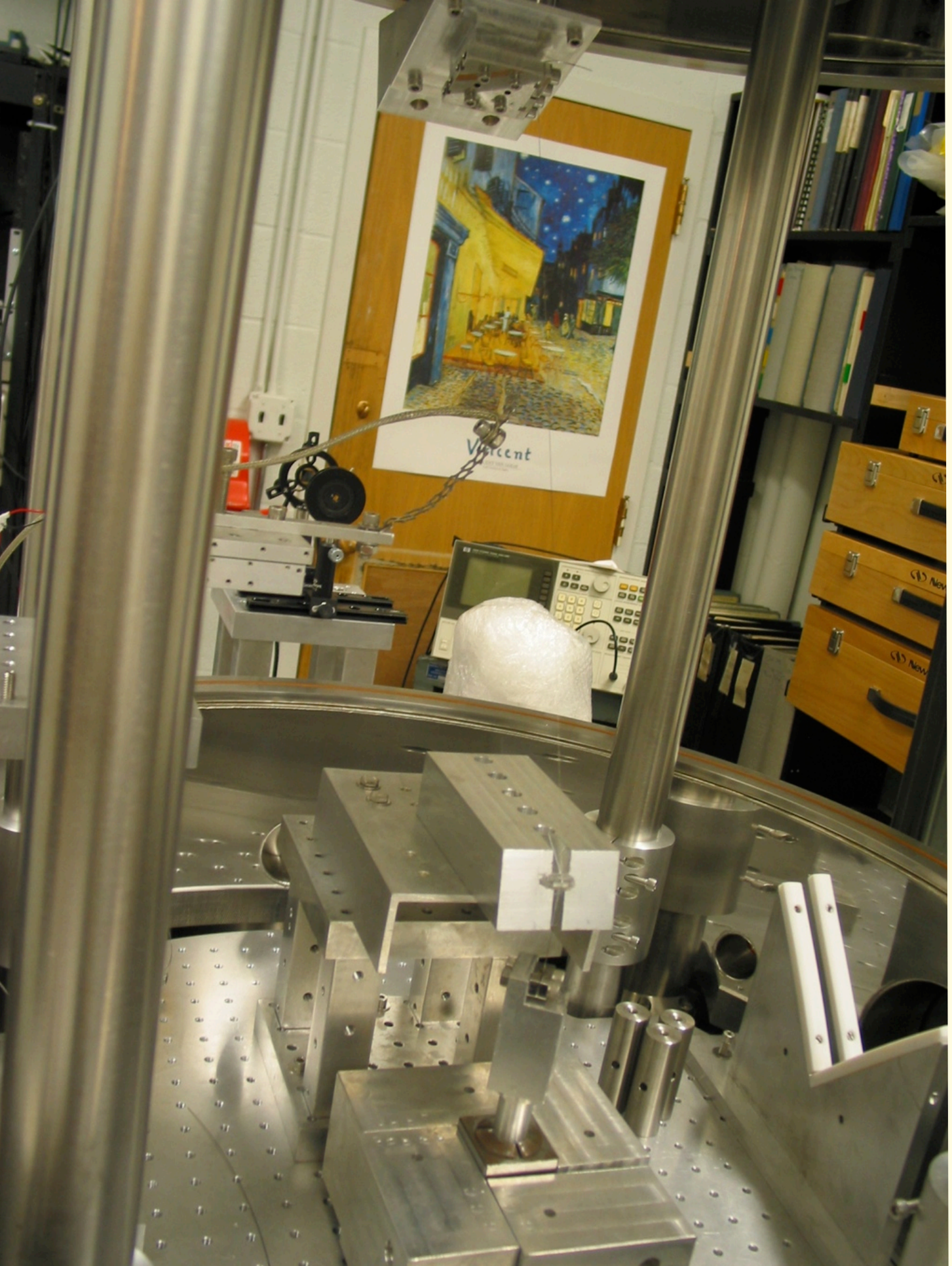
Pathfinder Optic hung in spare frame with wire from the sites. Each wire monitored by eight shadow sensors.

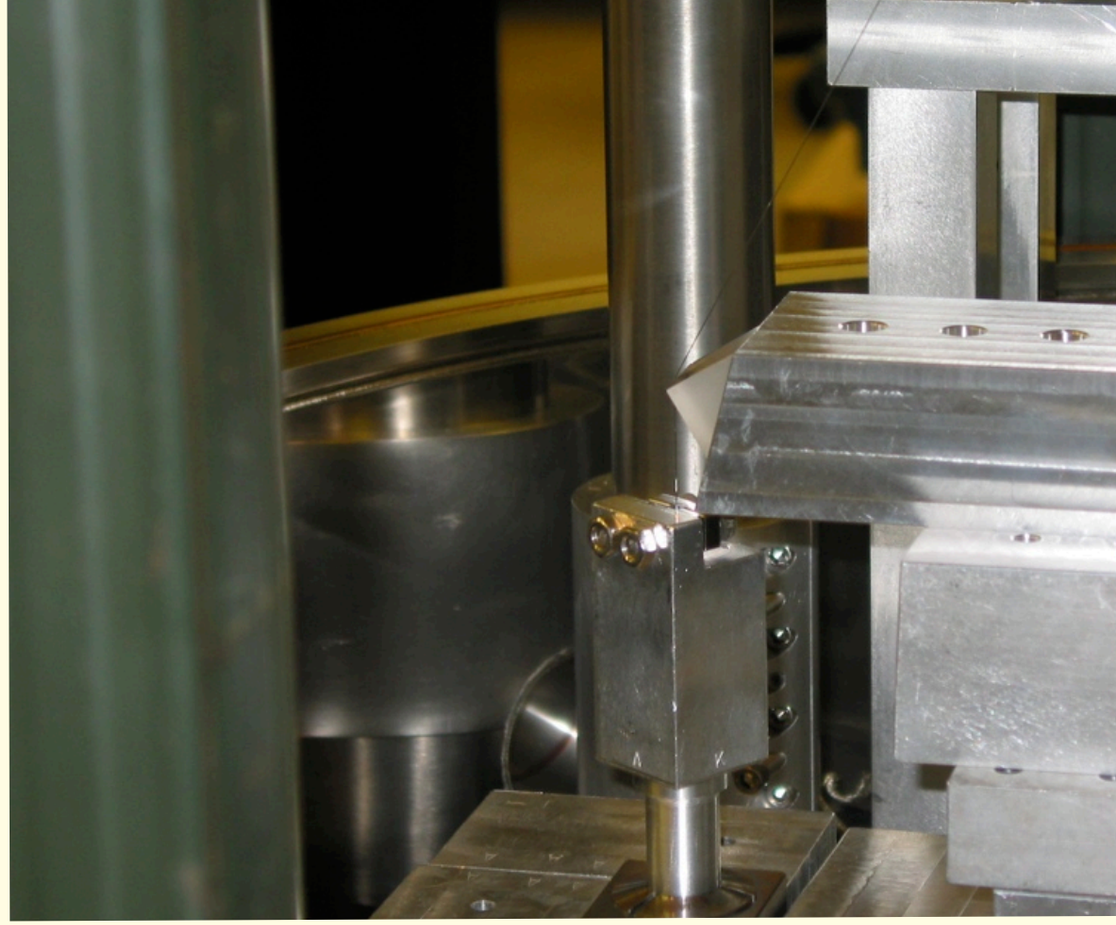
Loss in Violin Modes of Pathfinder

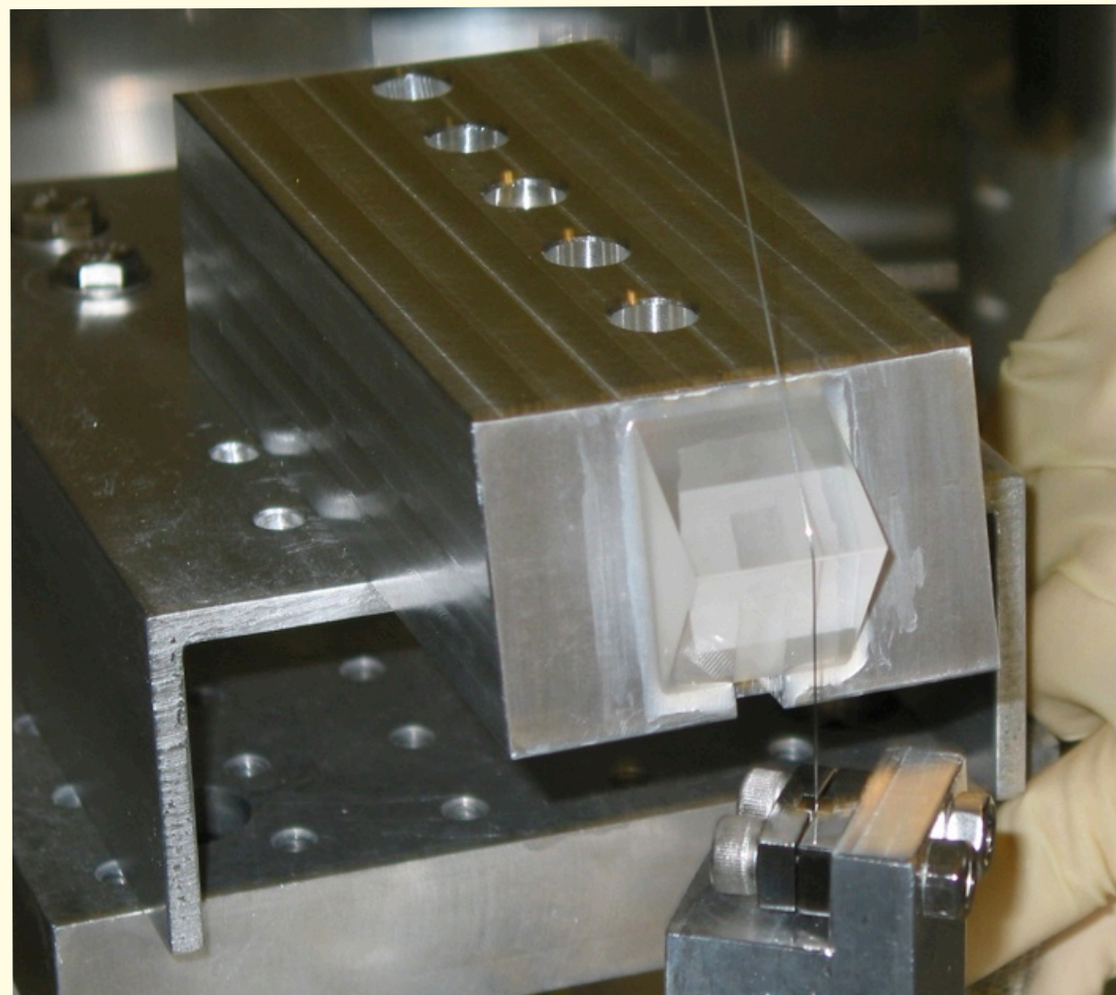


Violin Mode: Reused Clamp



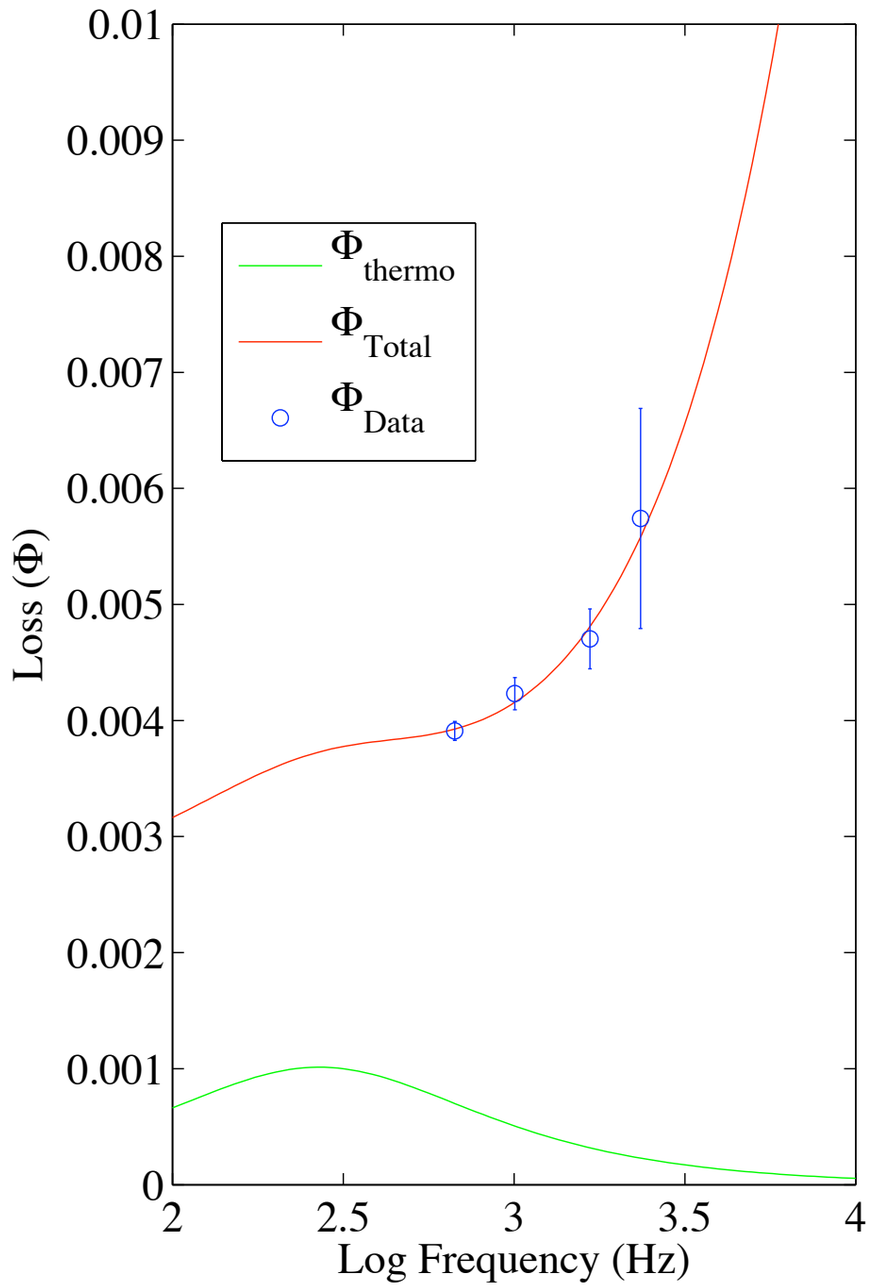

Vincent



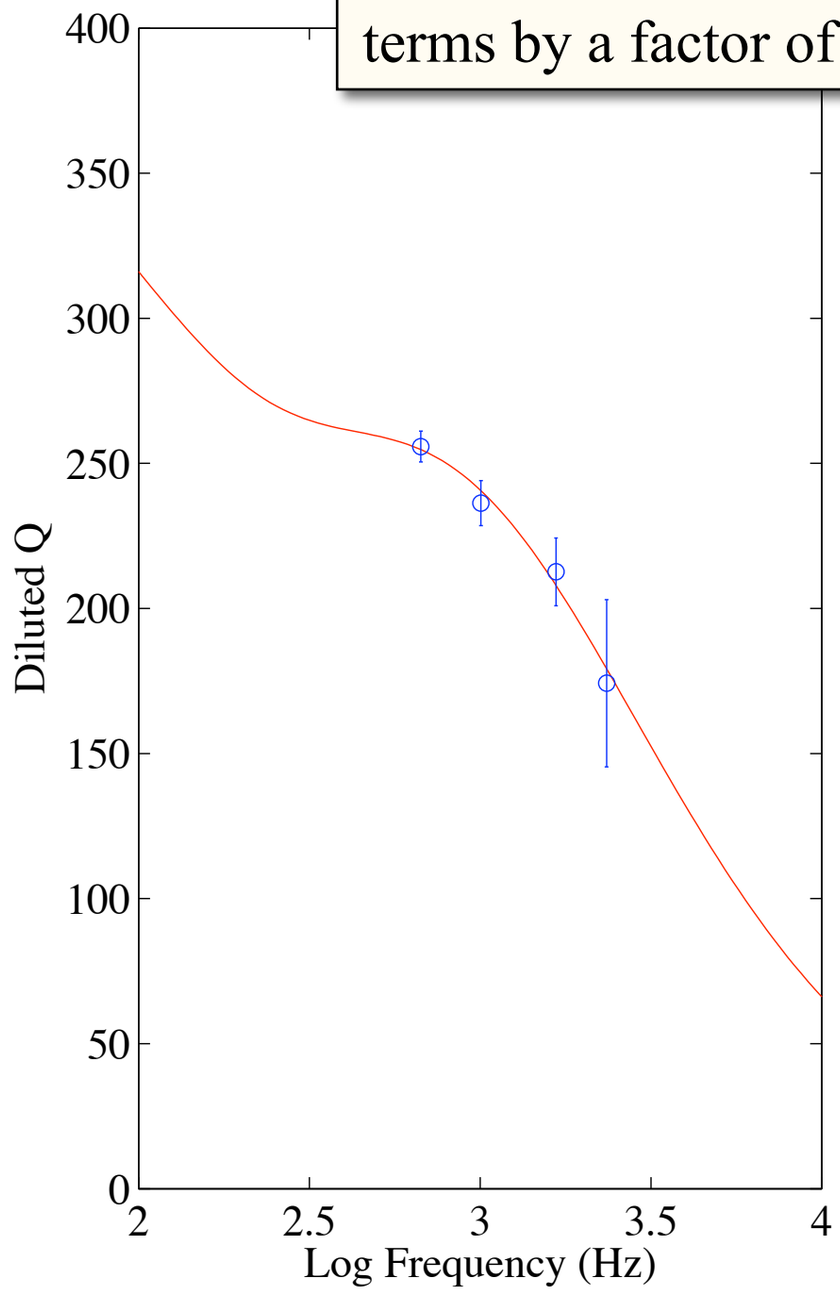


Loss from the Silica Standoff

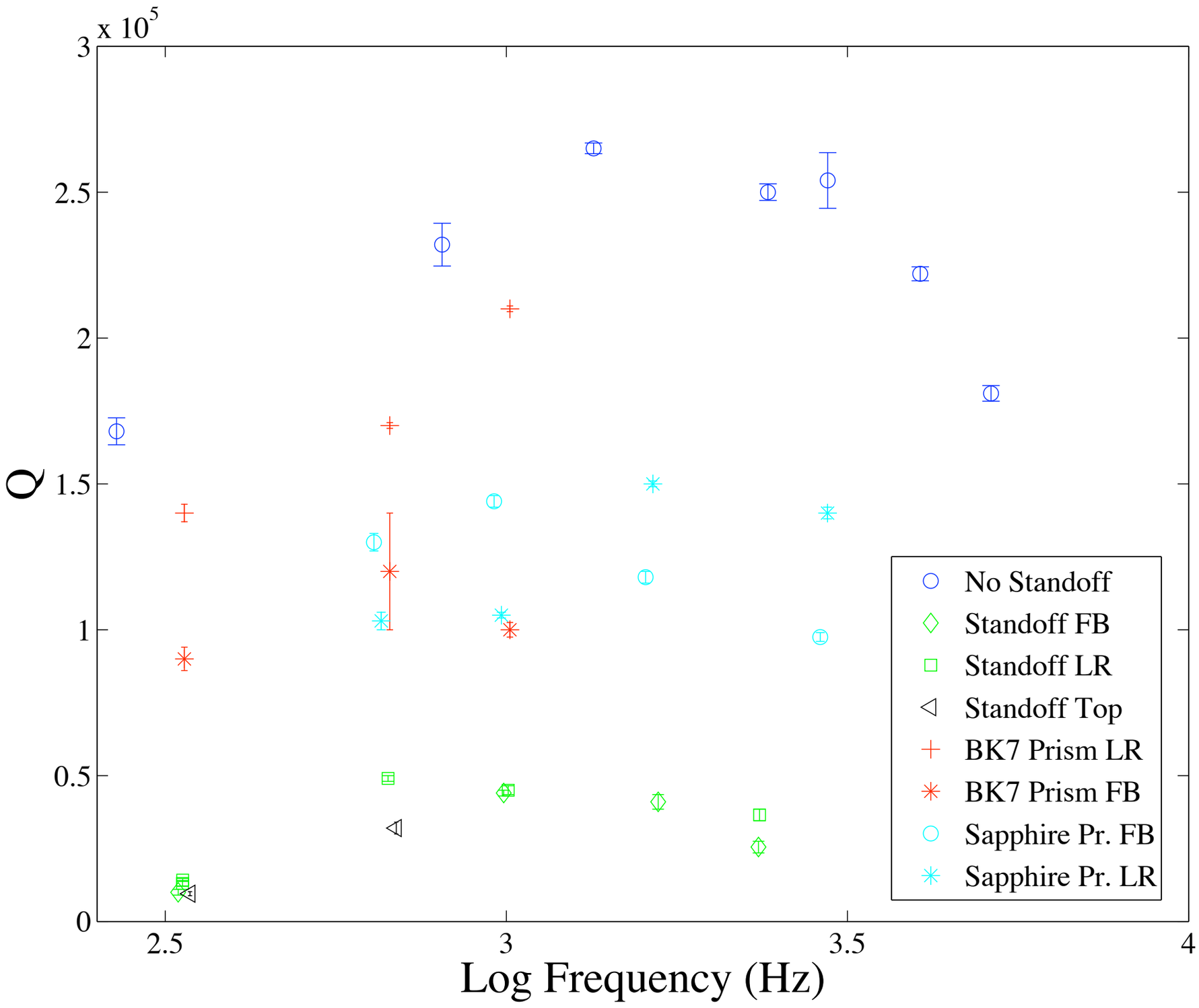
Steel Wire: Thermoelastic fixed, Φ_0 = 2.37e–03, Φ_1 = 1.27e–06



Standoff increases the wire loss terms by a factor of several

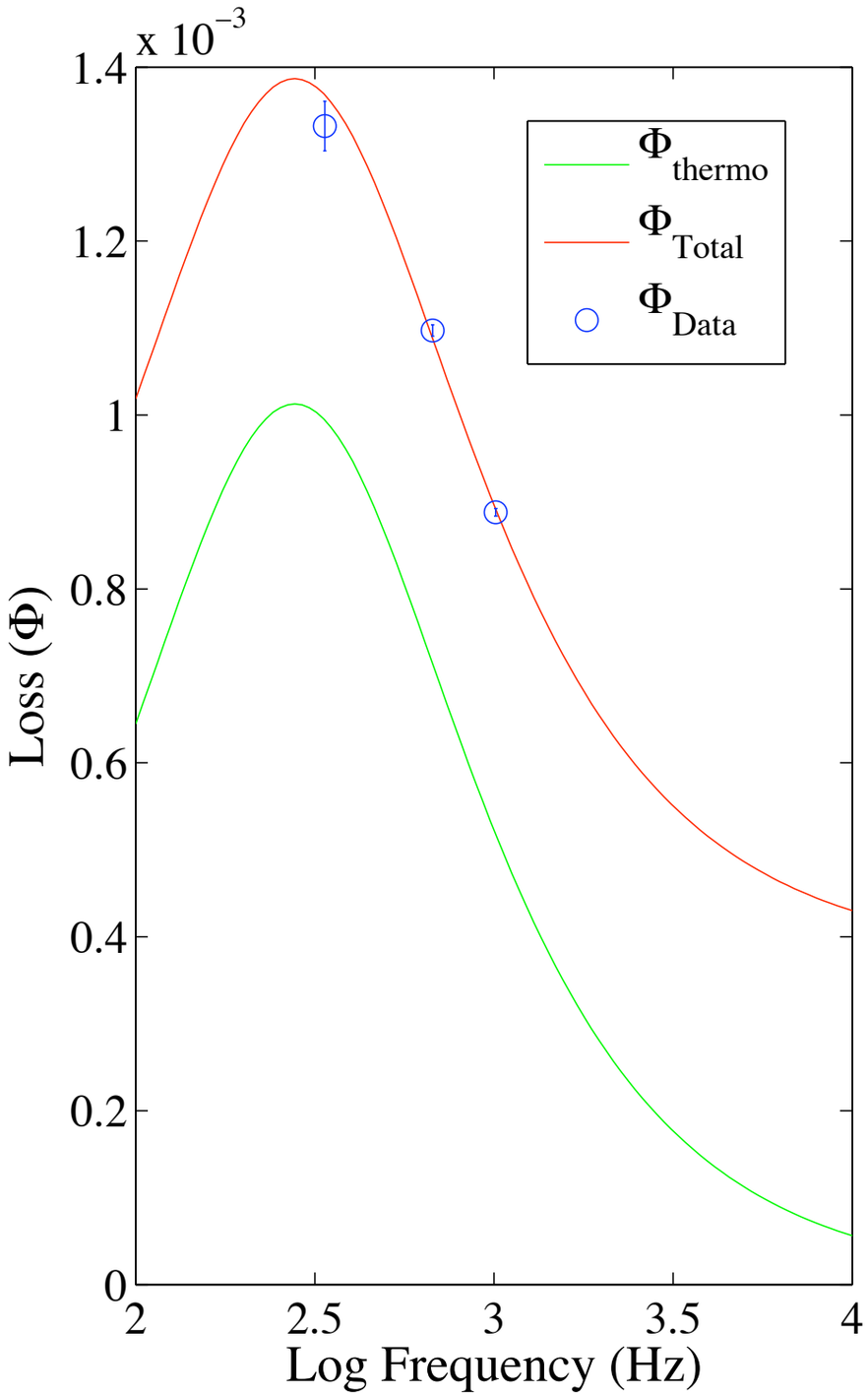


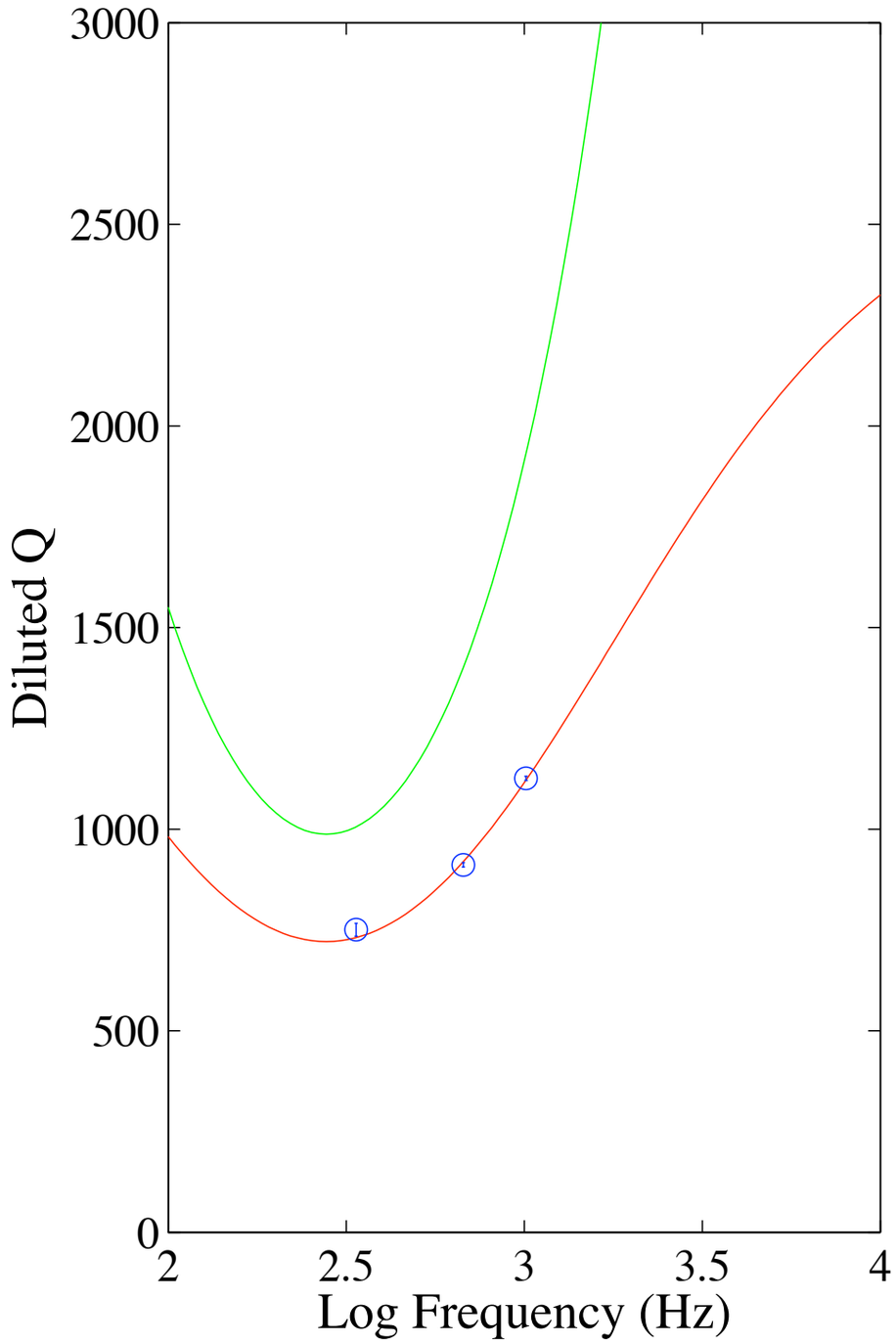
Q's of Various Standoffs



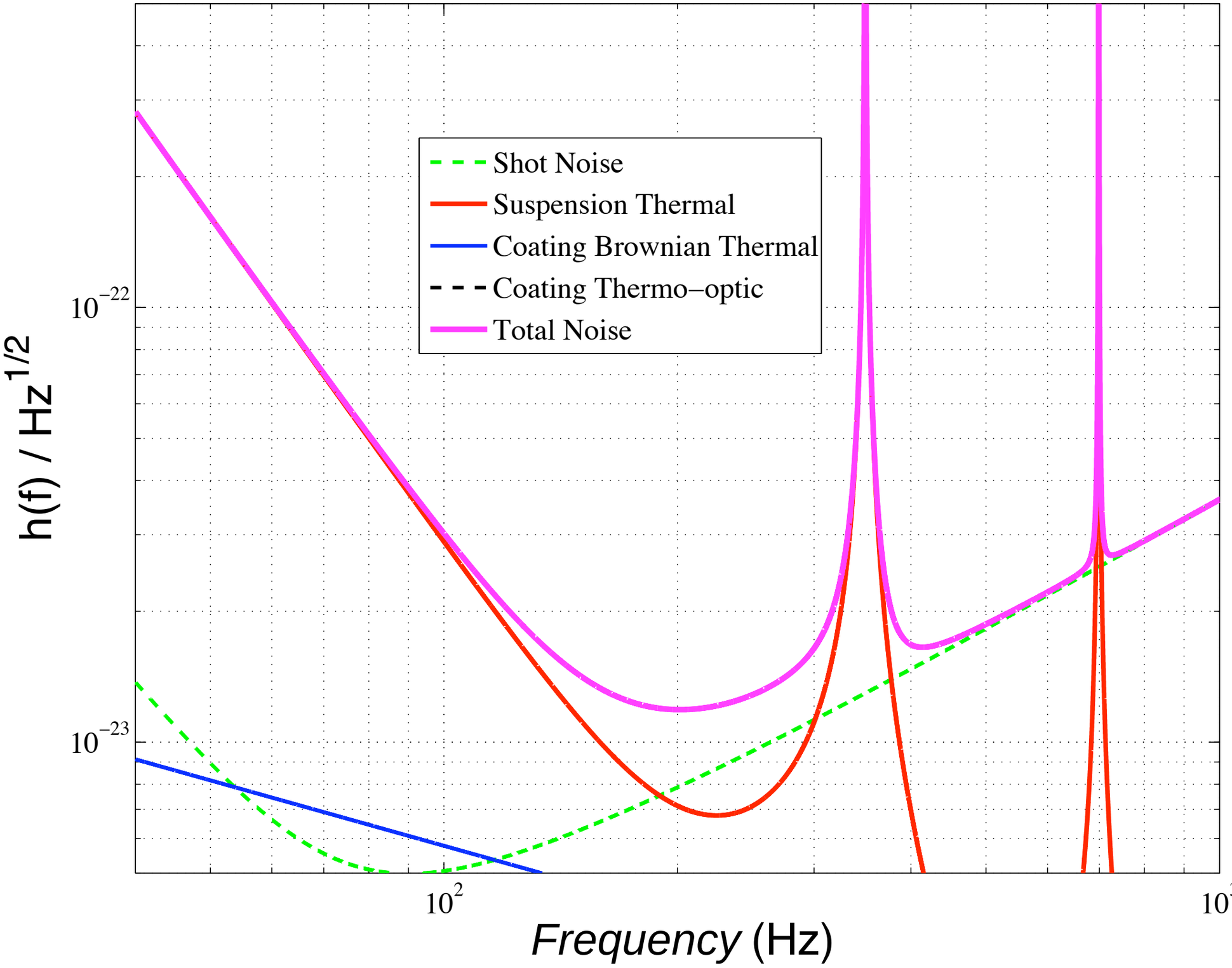
Loss in BK7 Standoff with Pathfinder

Steel Wire & BK7 Prism Standoffs: Thermoelastic fixed, Φ_0 = 3.74e–04

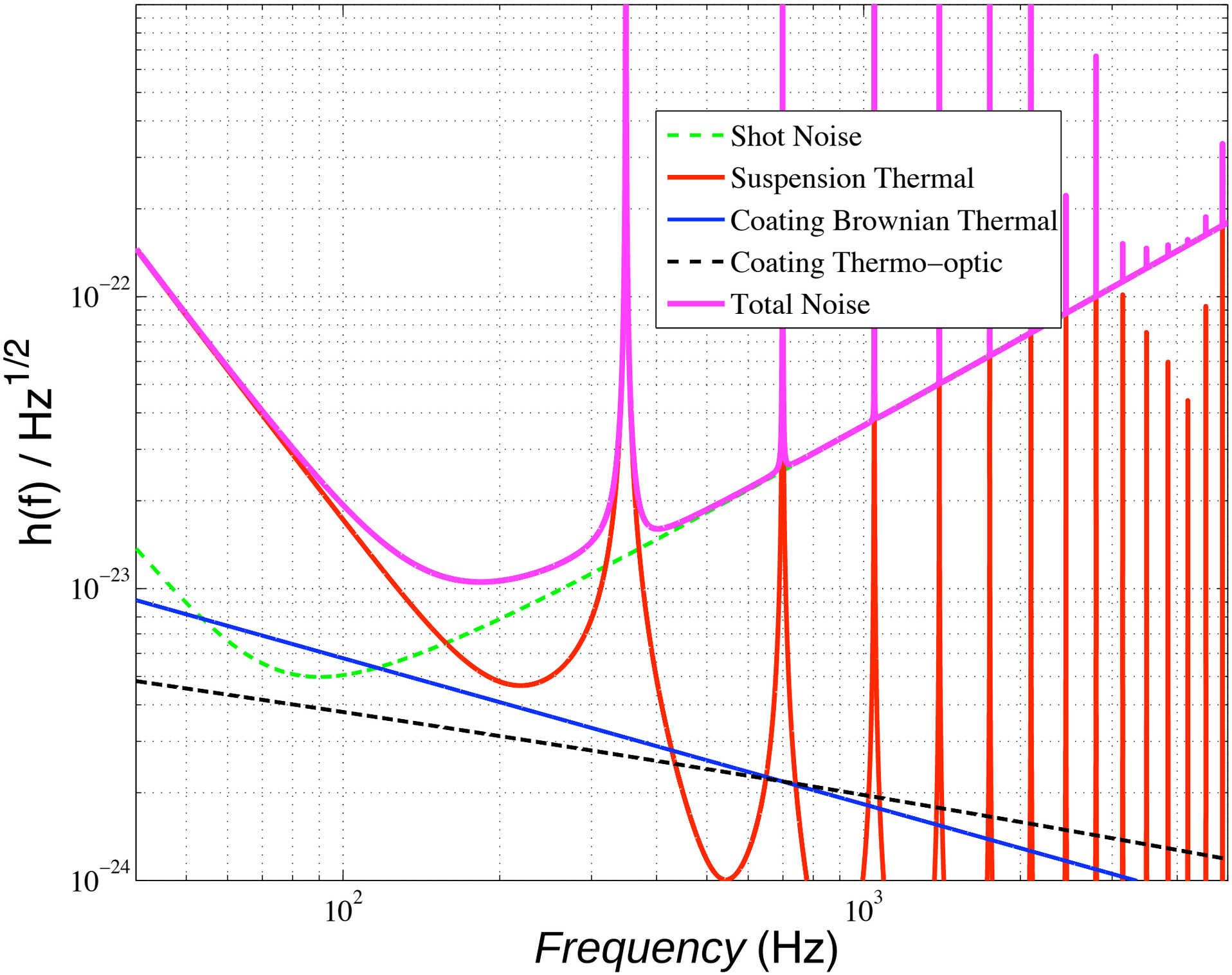




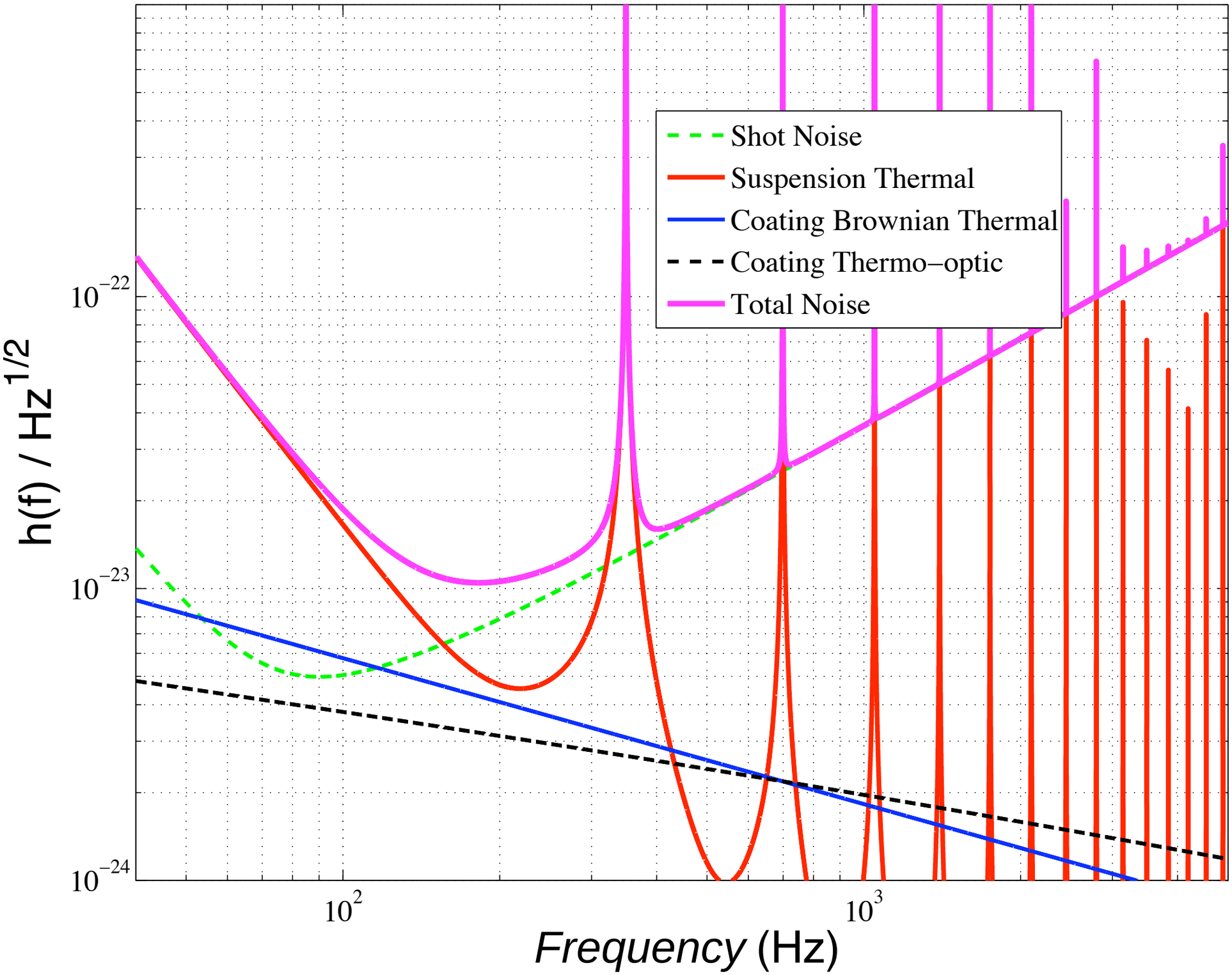
eLIGO Sensitivity with Silica Standoff



eLIGO Sensitivity with BK7 Prism Standoff



eLIGO Sensitivity with No Standoff



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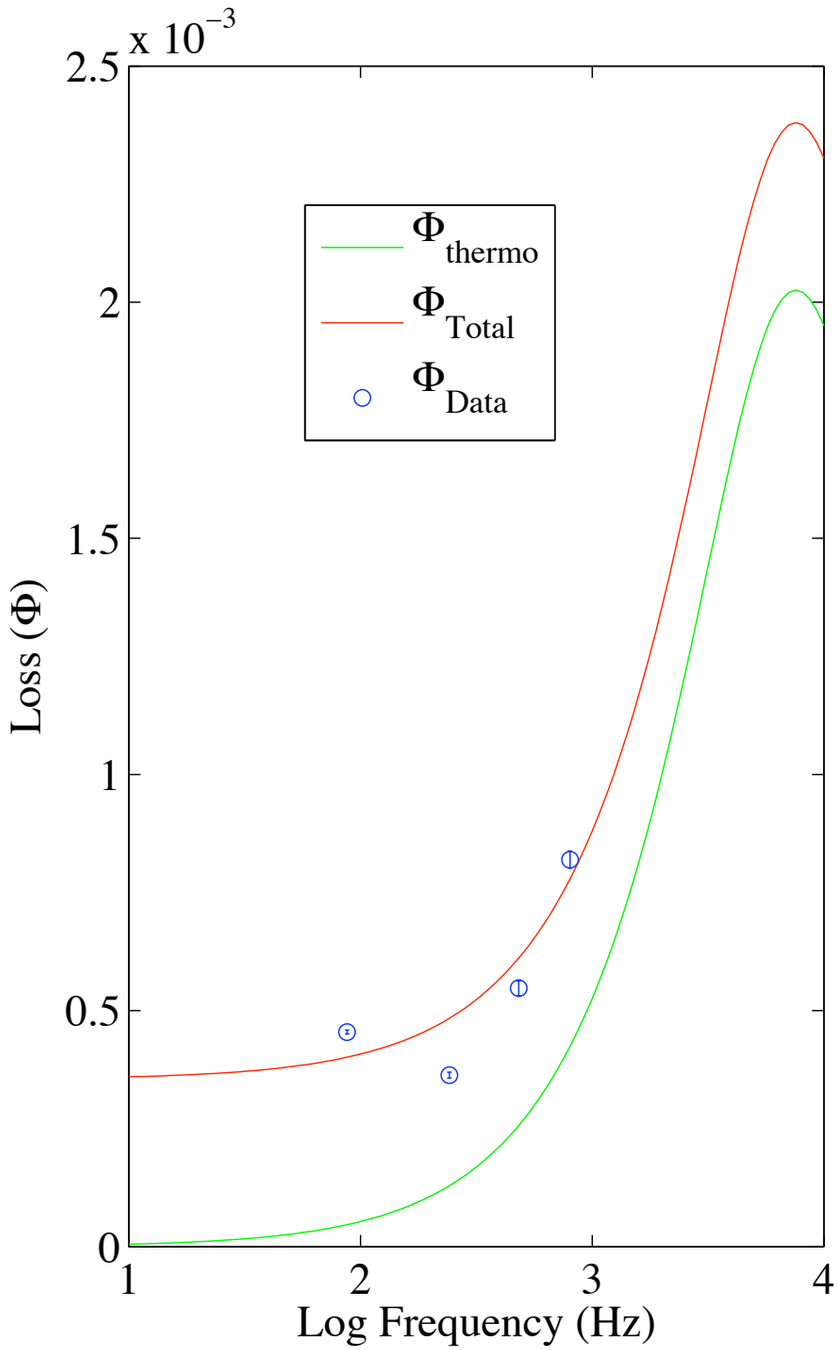
Modified Ribbons

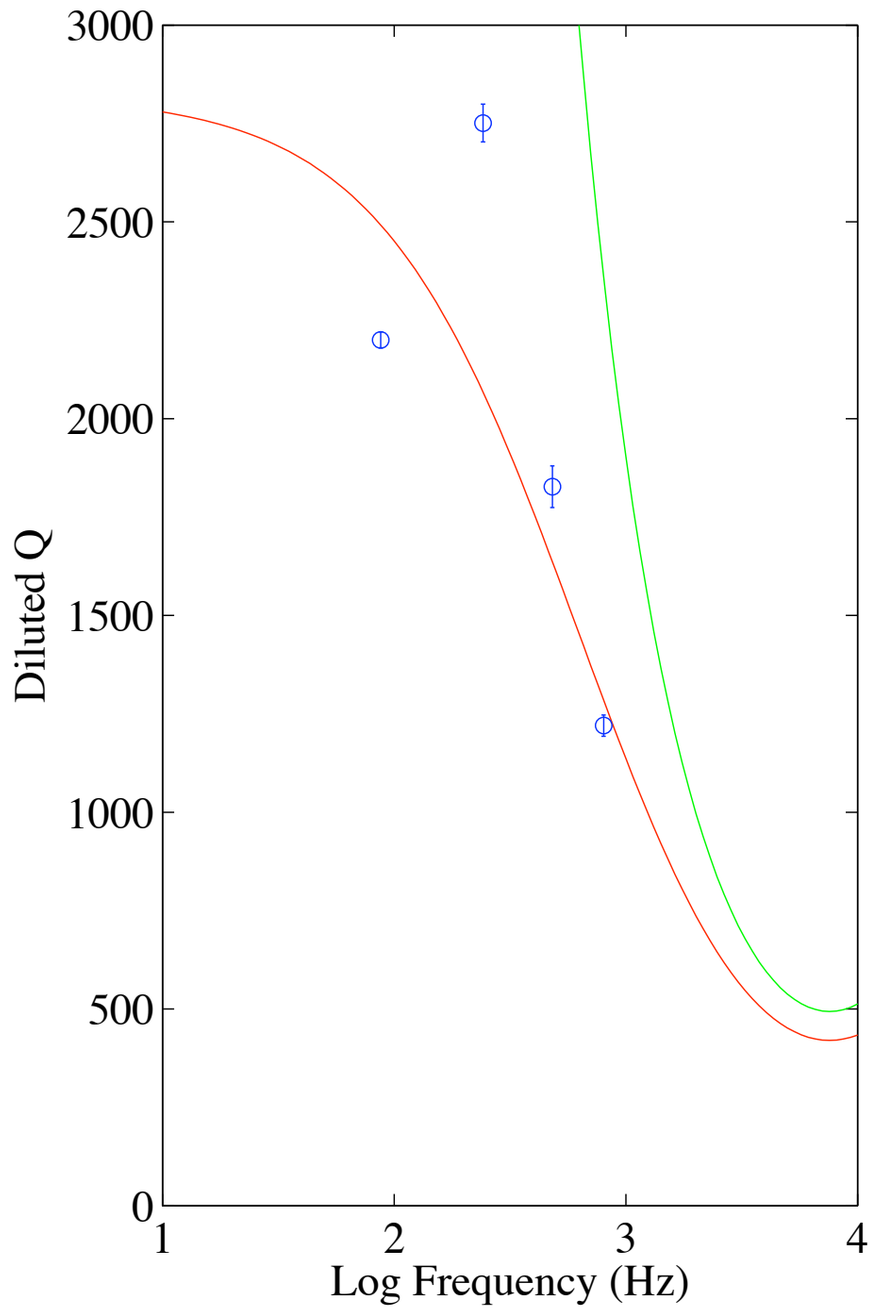
- Ribbons formed from Music wire by flattening in Rolling mill
  - Flattened everywhere except at standoffs where it is wire
  - Orientation around optic is configured to wrap around optic
  - Orientation in suspension is face forward
  - Ribbon is gimpy in forward direction. Lower areal moment favorably increased the dissipation dilution, thus lowers thermal noise.
  - ThermoElastic peak shifted to high frequency, 4–5 kHz
  - Maybe no requirement to change Standoffs

Loss in Free Steel Ribbon

Thermoelastic x2

Steel Ribbon: Thermoelastic fixed, Φ_0 = 3.54e–04

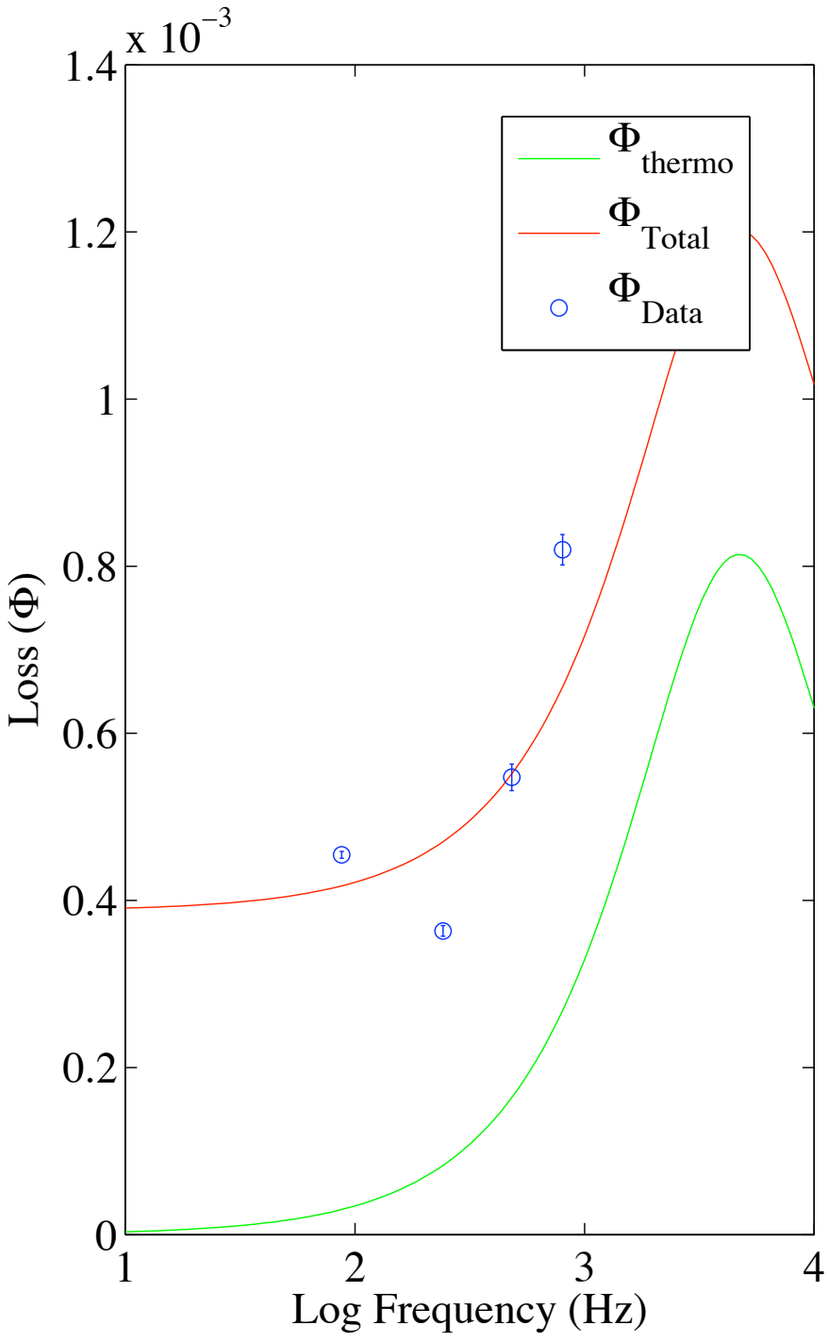


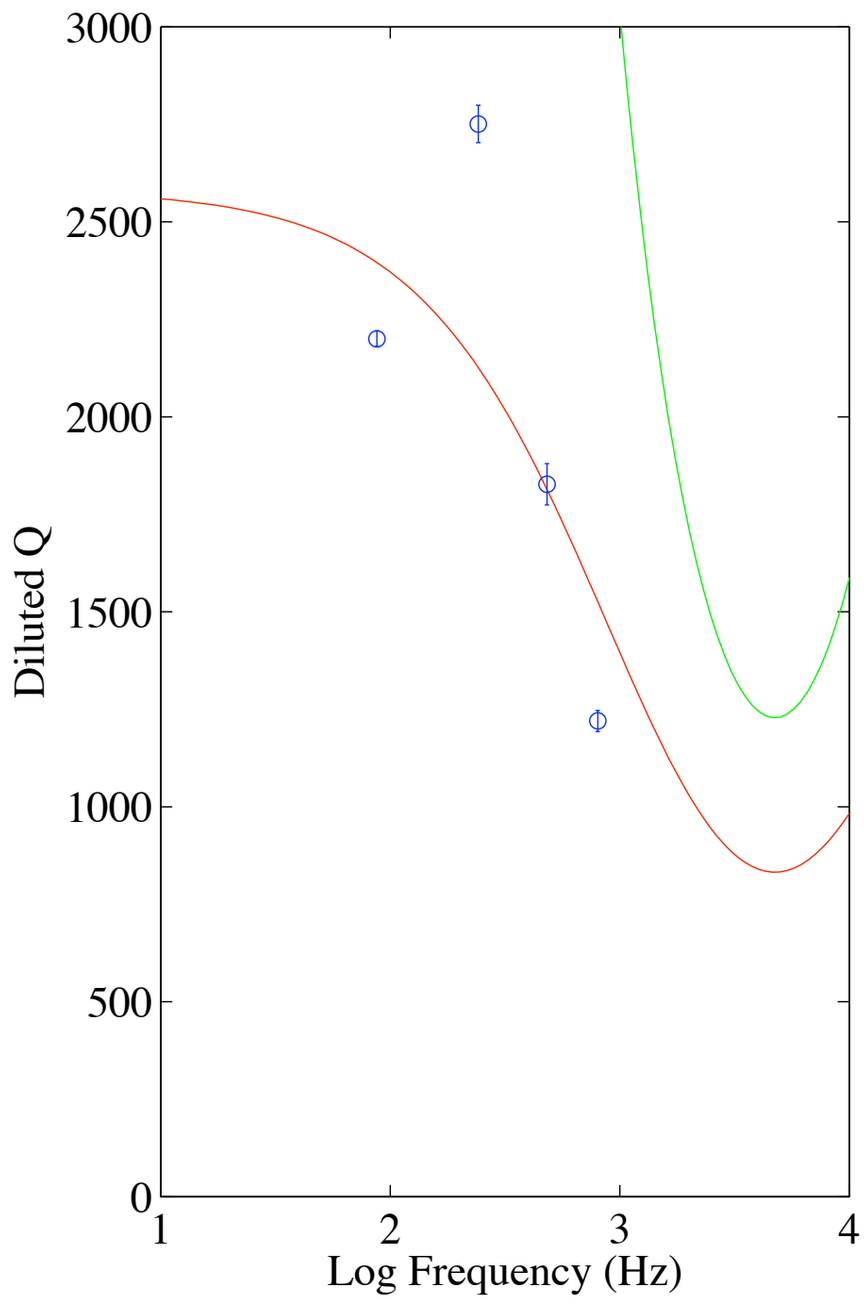


Loss in Free Steel Ribbon

Thermoelastic Fit

Steel Ribbon: Thermo. scale = 0.80, Φ_0 = 3.87e–04

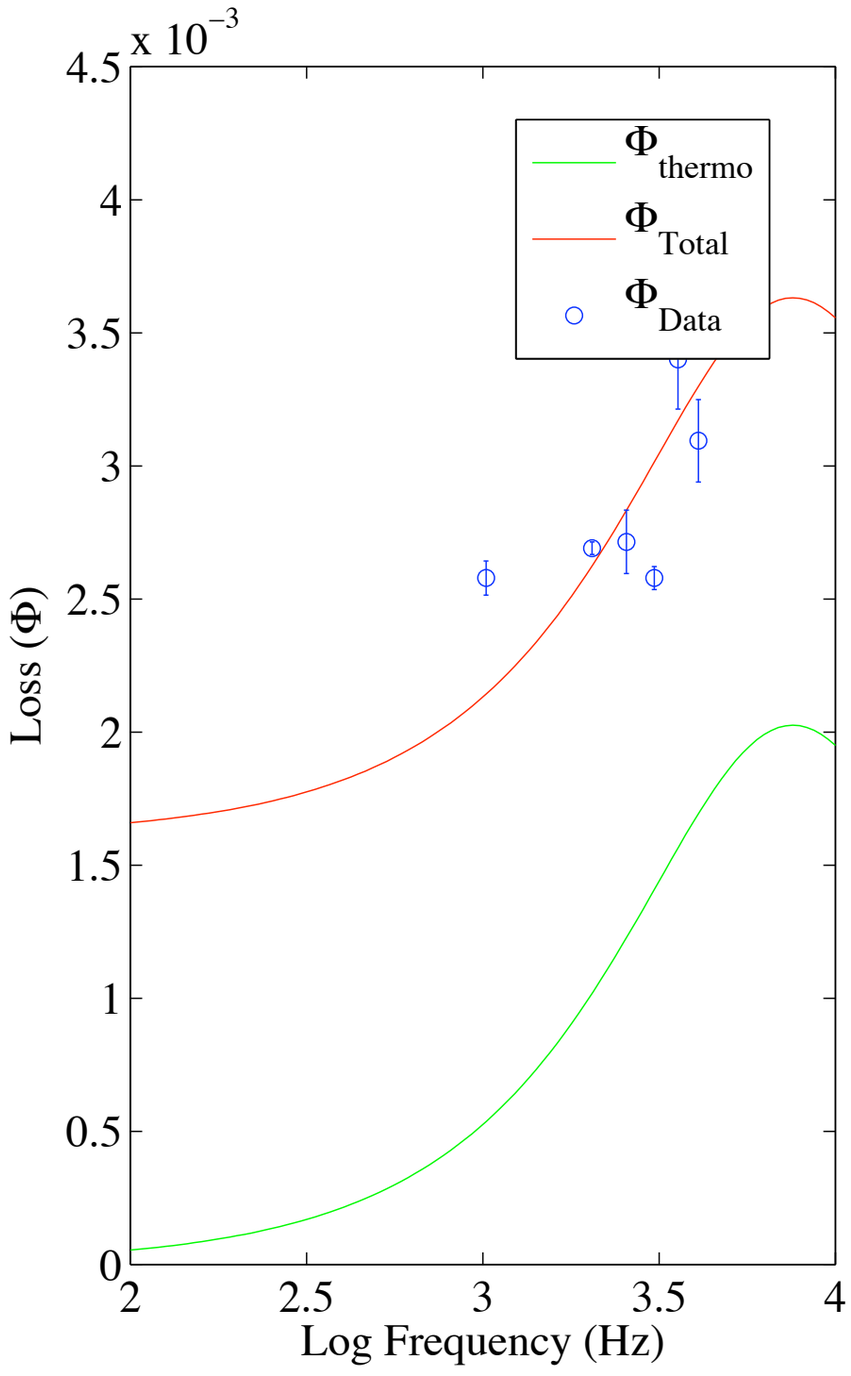


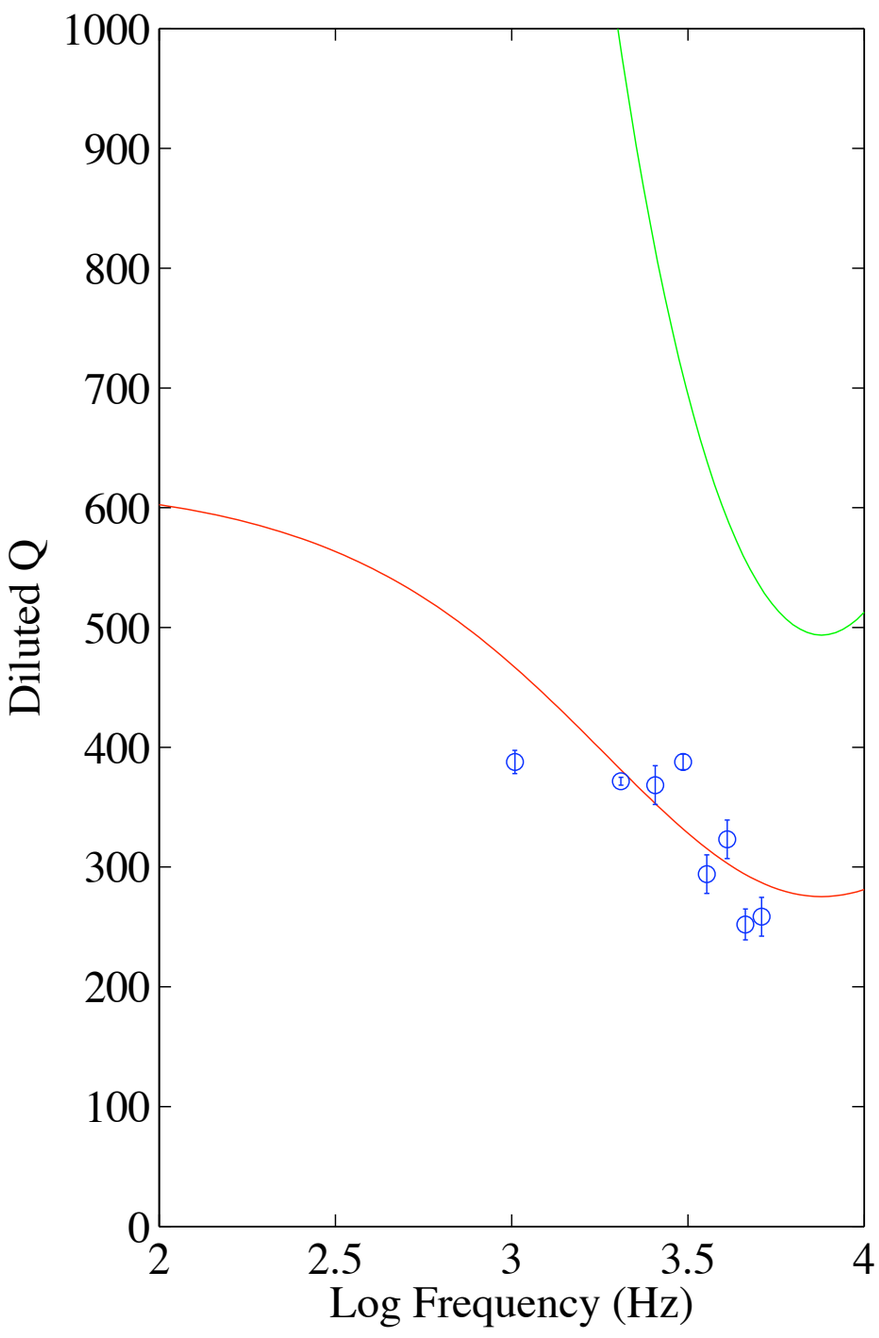


Loss in Tensioned Steel Ribbon

Thermoelastic x2

Steel Ribbon: Thermoelastic fixed, Φ_0 = 1.61e–03

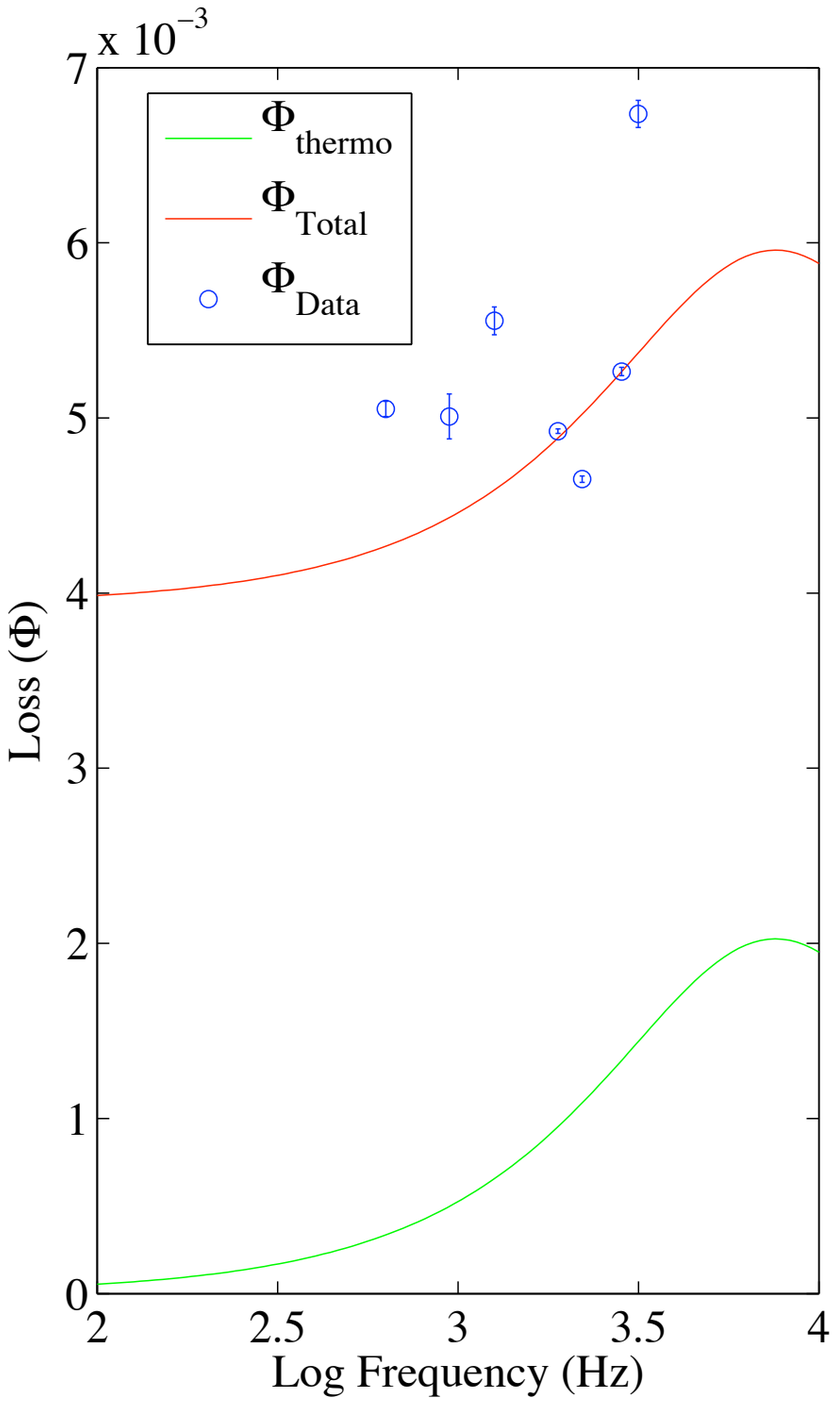


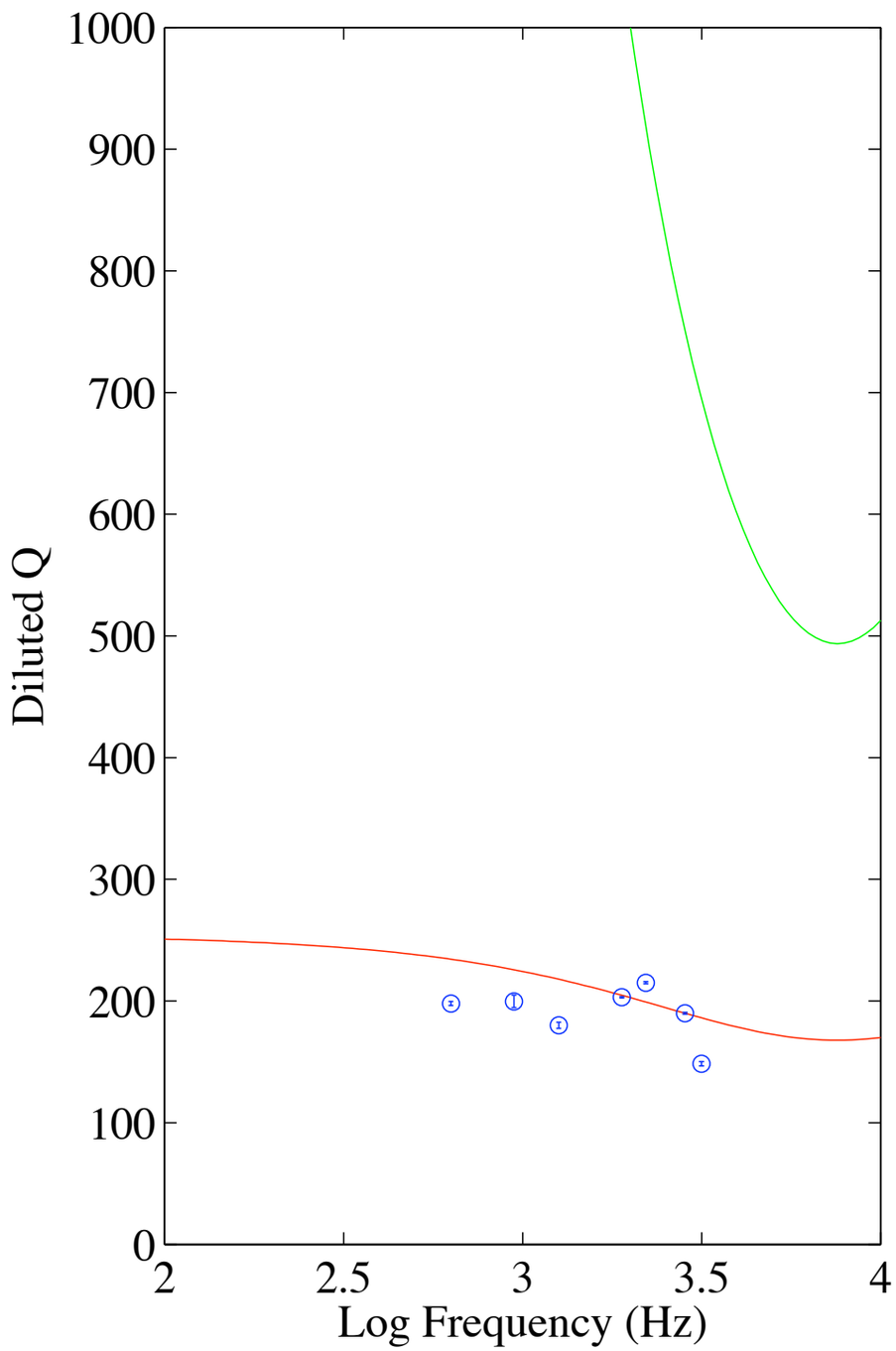


Tensioned Steel Ribbon with Standoff

Thermoelastic x2

Steel Ribbon: Thermoelastic fixed, Φ_0 = 3.93e–03





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New Directions

- Sapphire Clamps.
  - Similar to Virgo clamps. Binding material is sapphire.
  - Cylindrical grooves formed by laser ablation.
    - Accurate to 10^{-5} inches.

- Test Prism standoffs to improve loss.
  - Silica and/or sapphire prisms with well defined wire notch

- Test Full Modified Ribbon Suspension
  - Define Thermoelastic better
  - Better manufacturing of these ribbons
  - Use with prism standoffs

The End