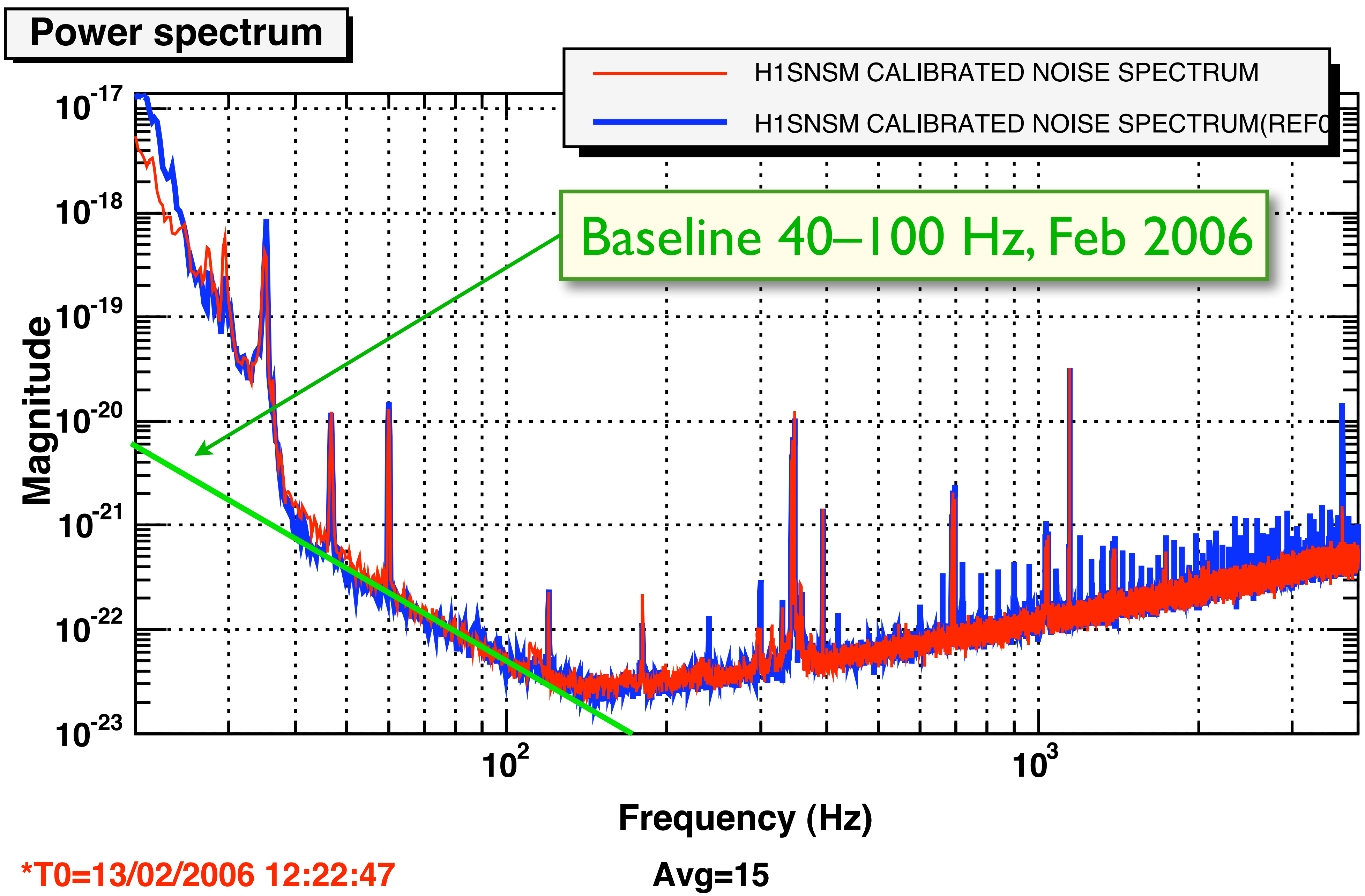
Suspension Thermal Noise in Initial LIGO

Steve Penn, Gregg Harry, Andri Gretarsson

LSC Meeting - LSU - August 2006

LIGO DCC LIGO-G060477-00-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

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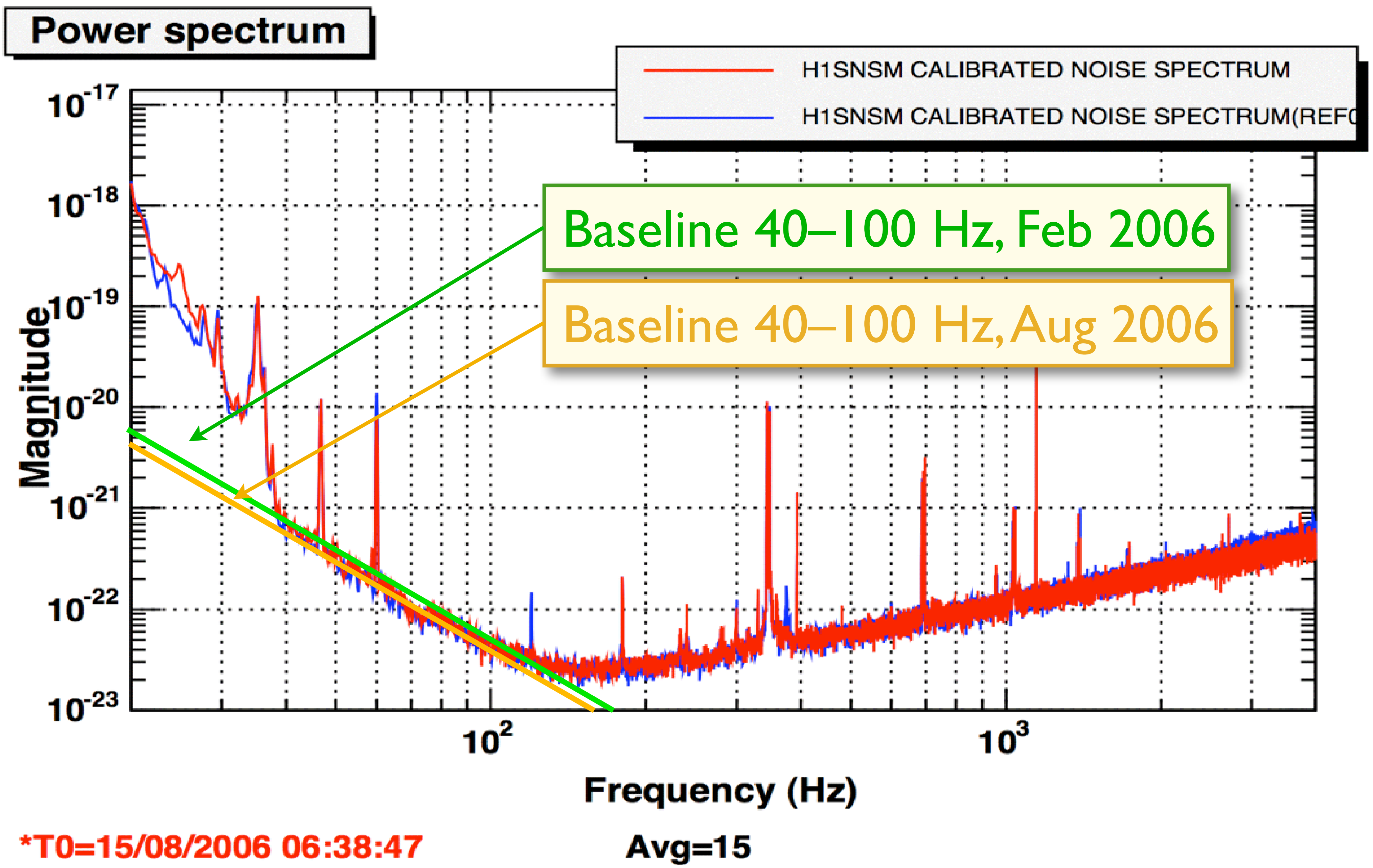

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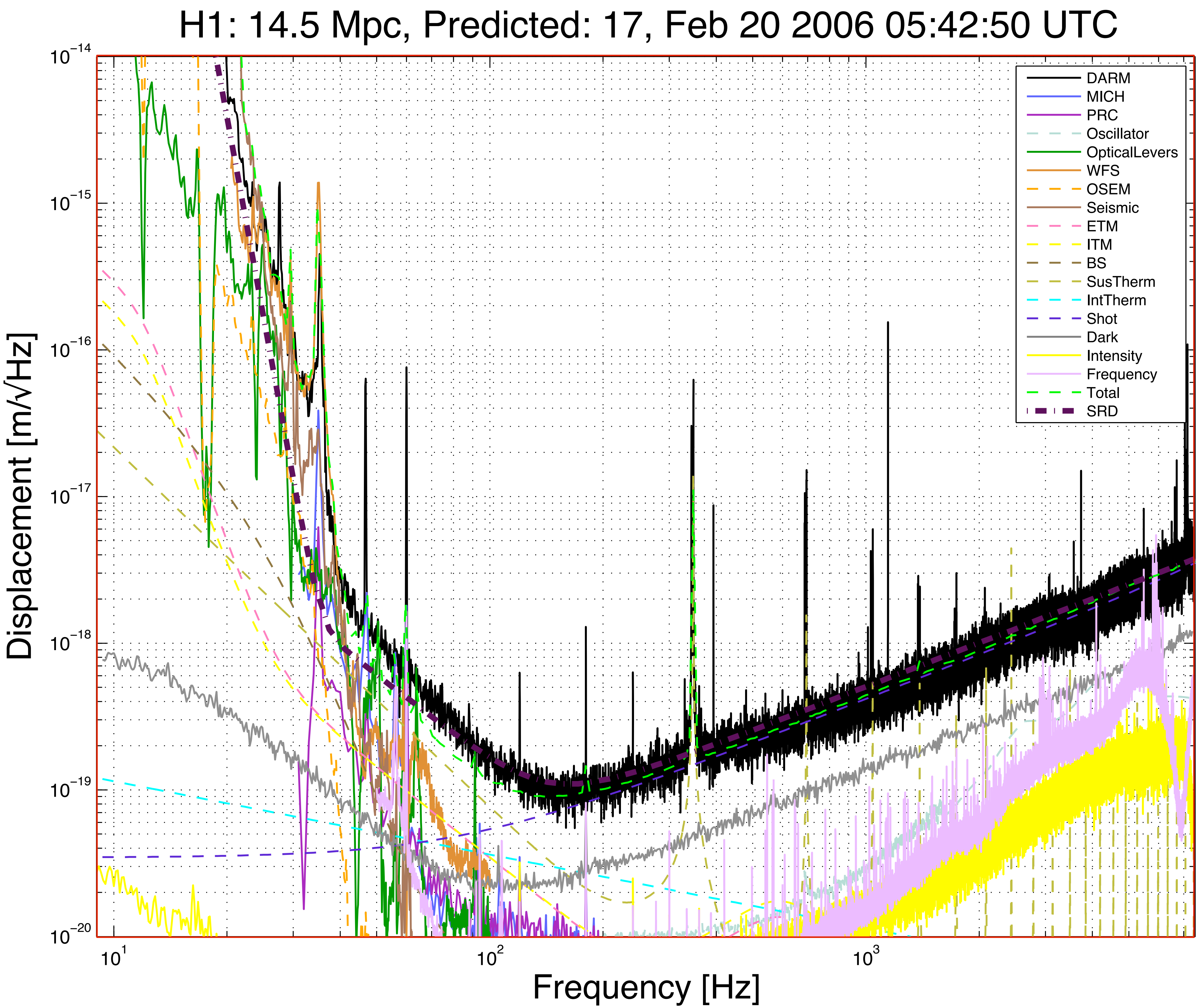
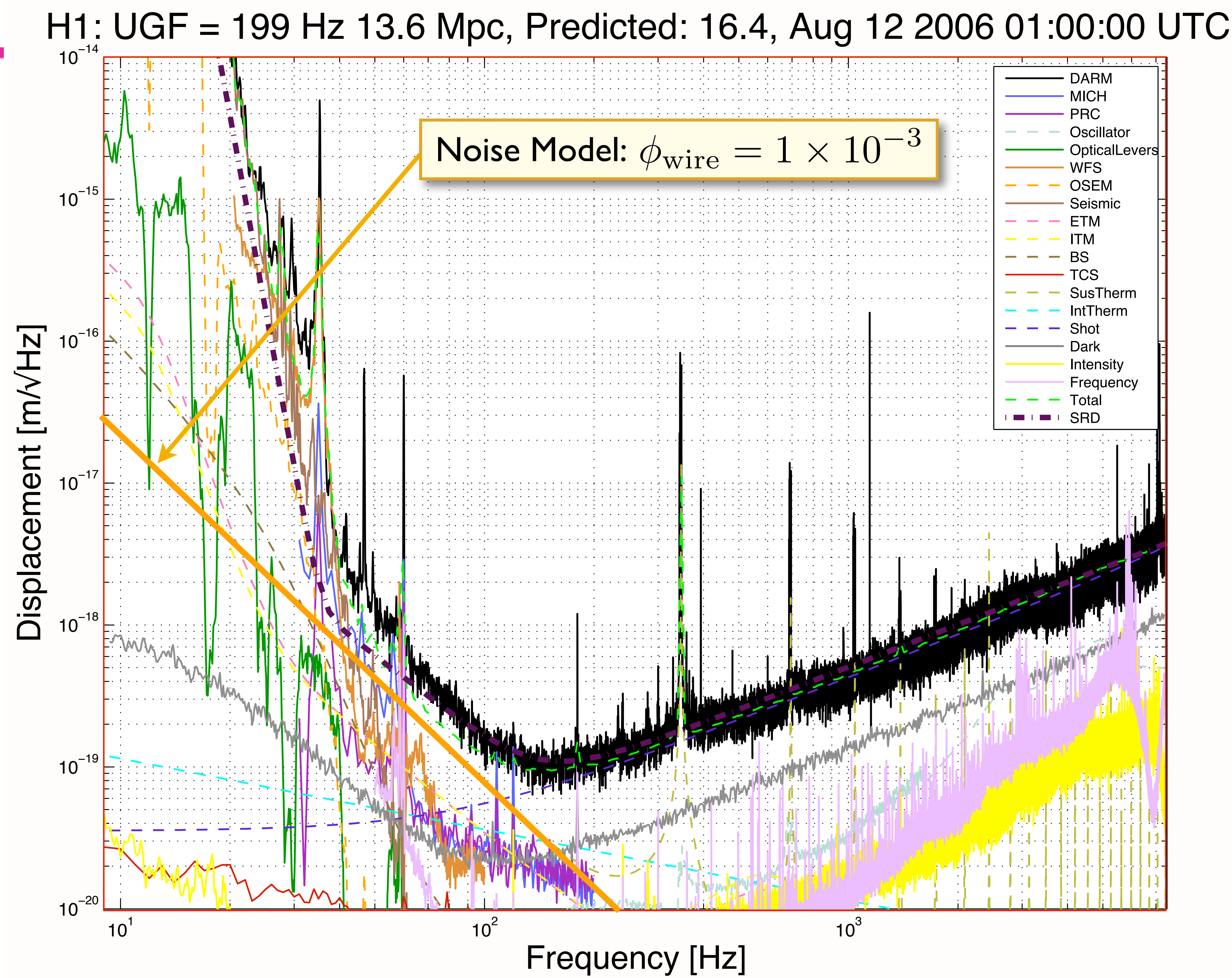


H1: 14.5 Mpc, Predicted: 17, Feb 20 2006 05:42:50 UTC
Displacement [m/√Hz]
Frequency [Hz]
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{1}
10^{2}
10^{3}
DARM
MICH
PRC
Oscillator
OpticalLevers
WFS
OSEM
Seismic
ETM
ITM
BS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD

The Problem



H1: UGF = 199 Hz 13.6 Mpc, Predicted: 16.4, Aug 12 2006 01:00:00 UTC
Noise Model: $\phi_{\rm wire} = 1 \times 10^{-3}$
Displacement [m/√Hz]
Frequency [Hz]
10^{-14}
10^{-15}
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{1}
10^{2}
10^{3}
DARM
MICH
PRC
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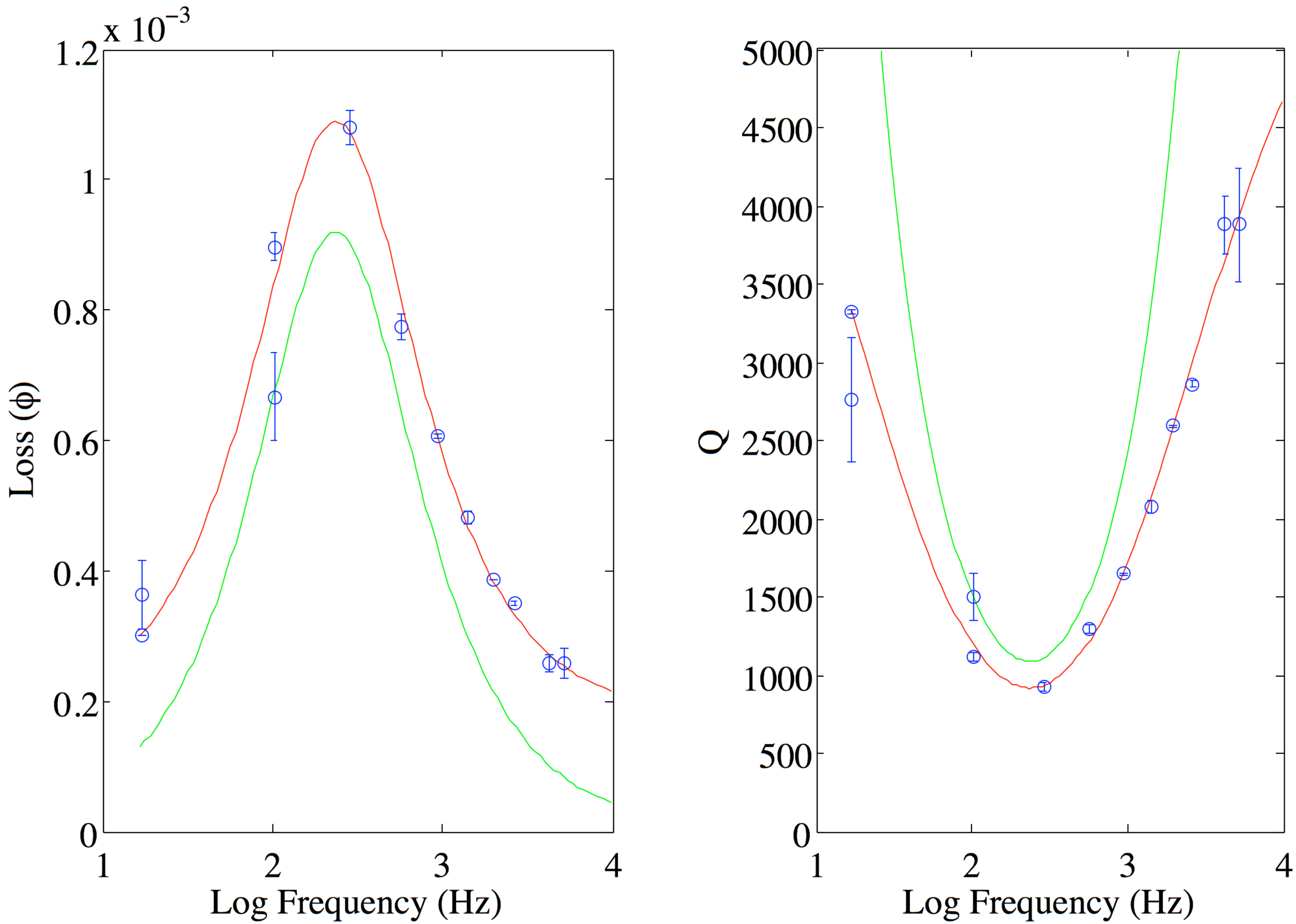
WFS
OSEM
Seismic
ETM
ITM
BS
TCS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD

Mechanical Loss in Wires

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



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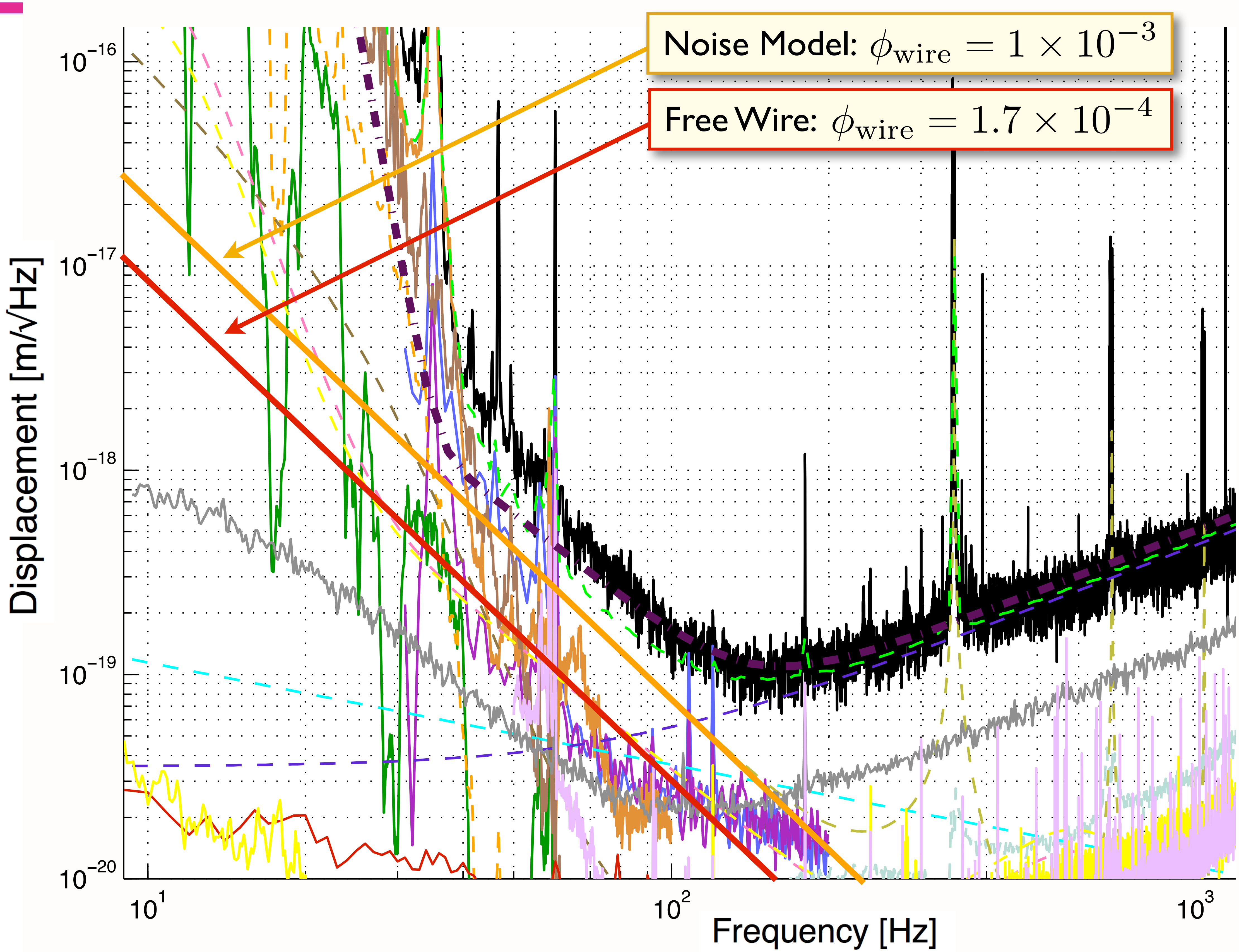
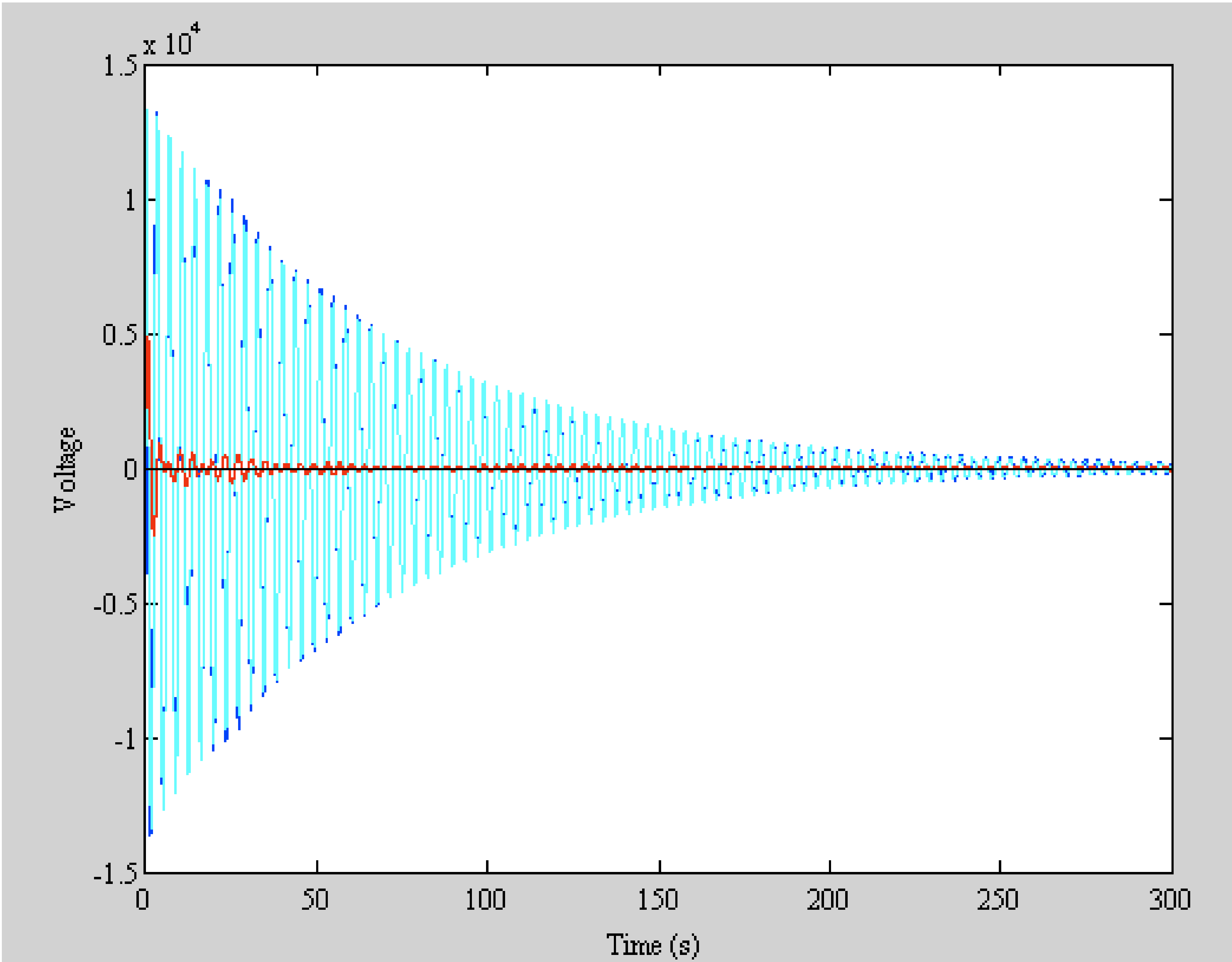


Noise Model: $\phi_{\rm wire} = 1 \times 10^{-3}$
Free Wire: $\phi_{\rm wire} = 1.7 \times 10^{-4}$
Displacement [m/√Hz]
Frequency [Hz]
10^{-16}
10^{-17}
10^{-18}
10^{-19}
10^{-20}
10^{1}
10^{2}
10^{3}

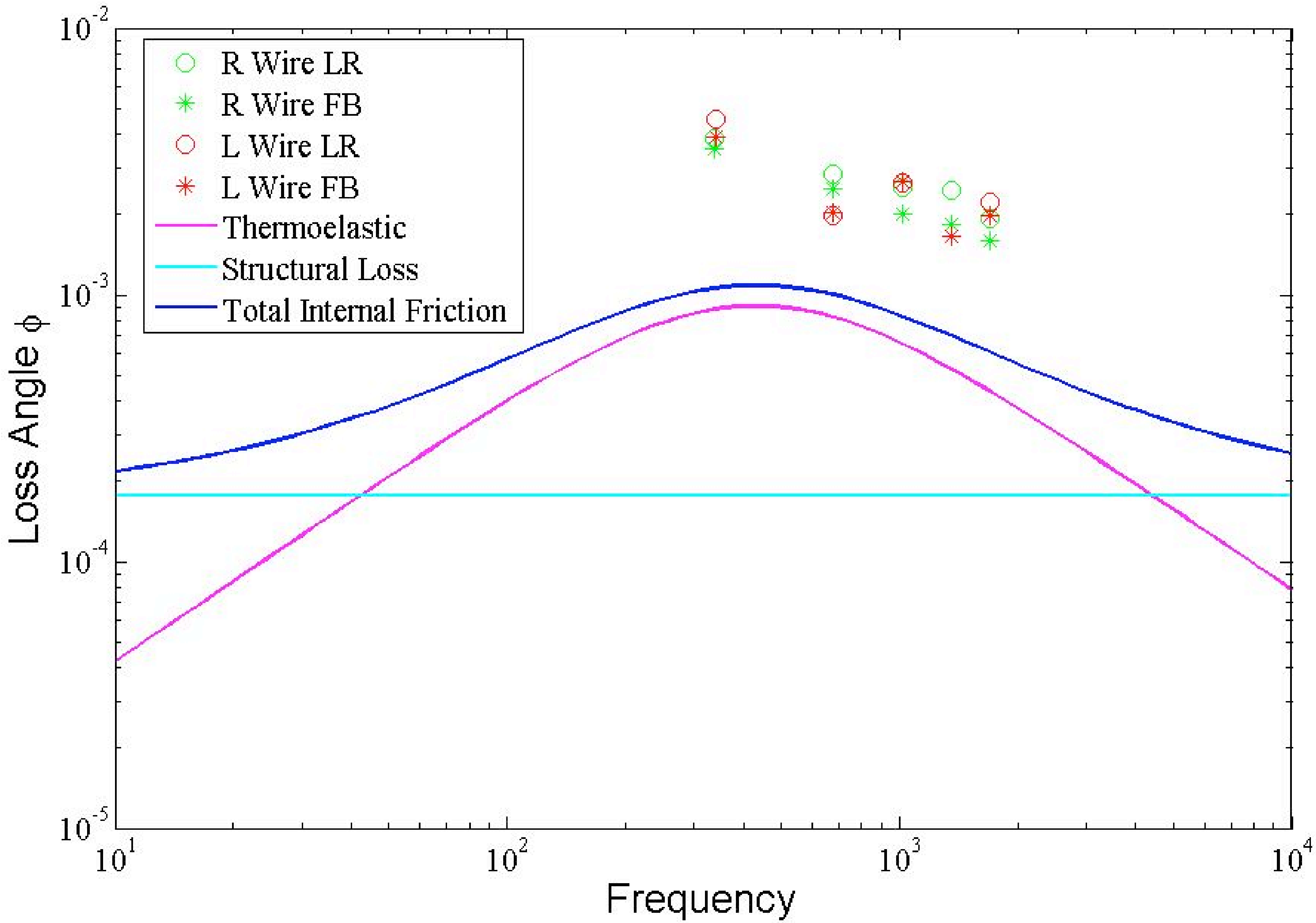
MIT Experiment

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

Typical Violin Mode Loss



Violin Mode: Reused Clamp



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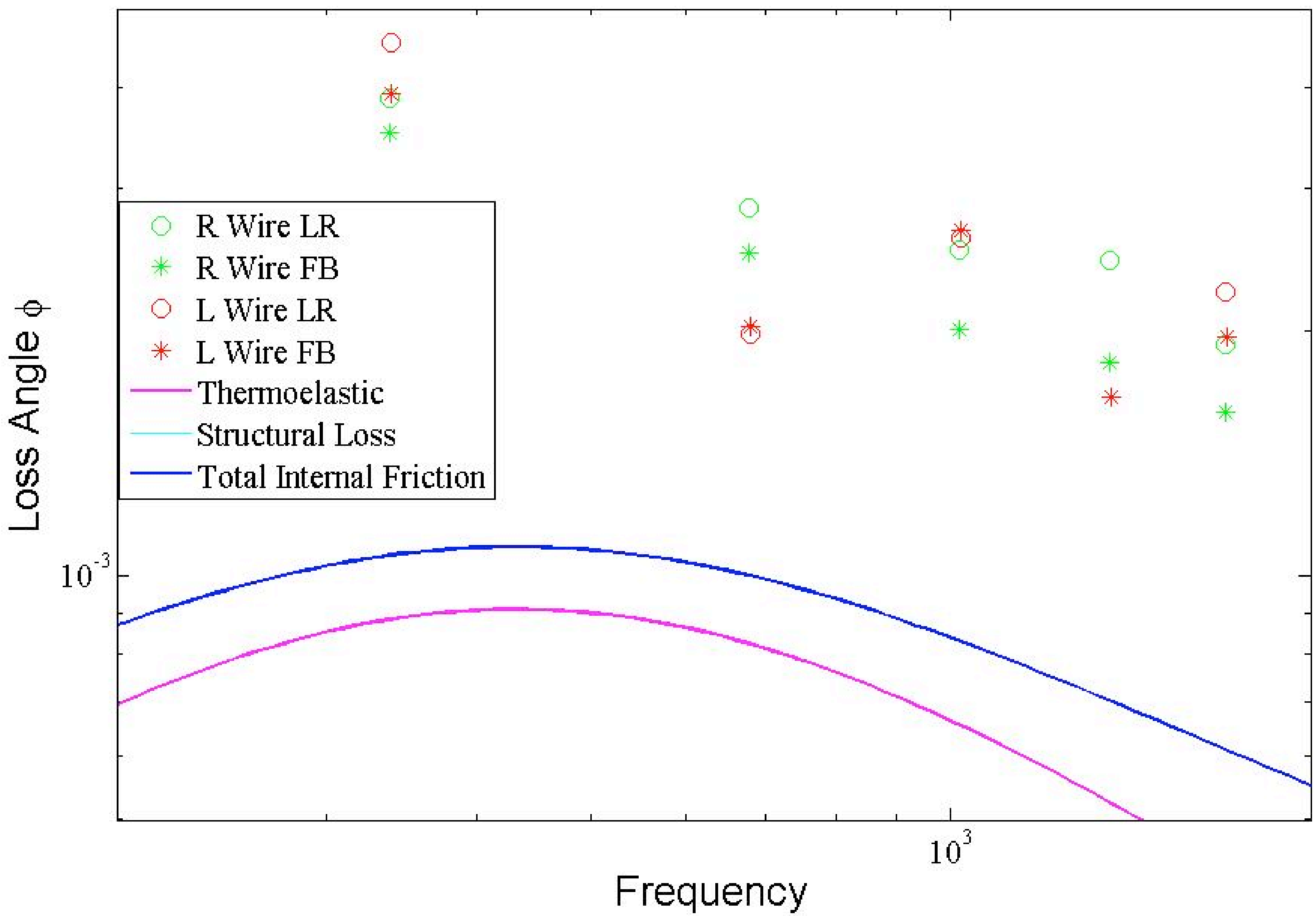

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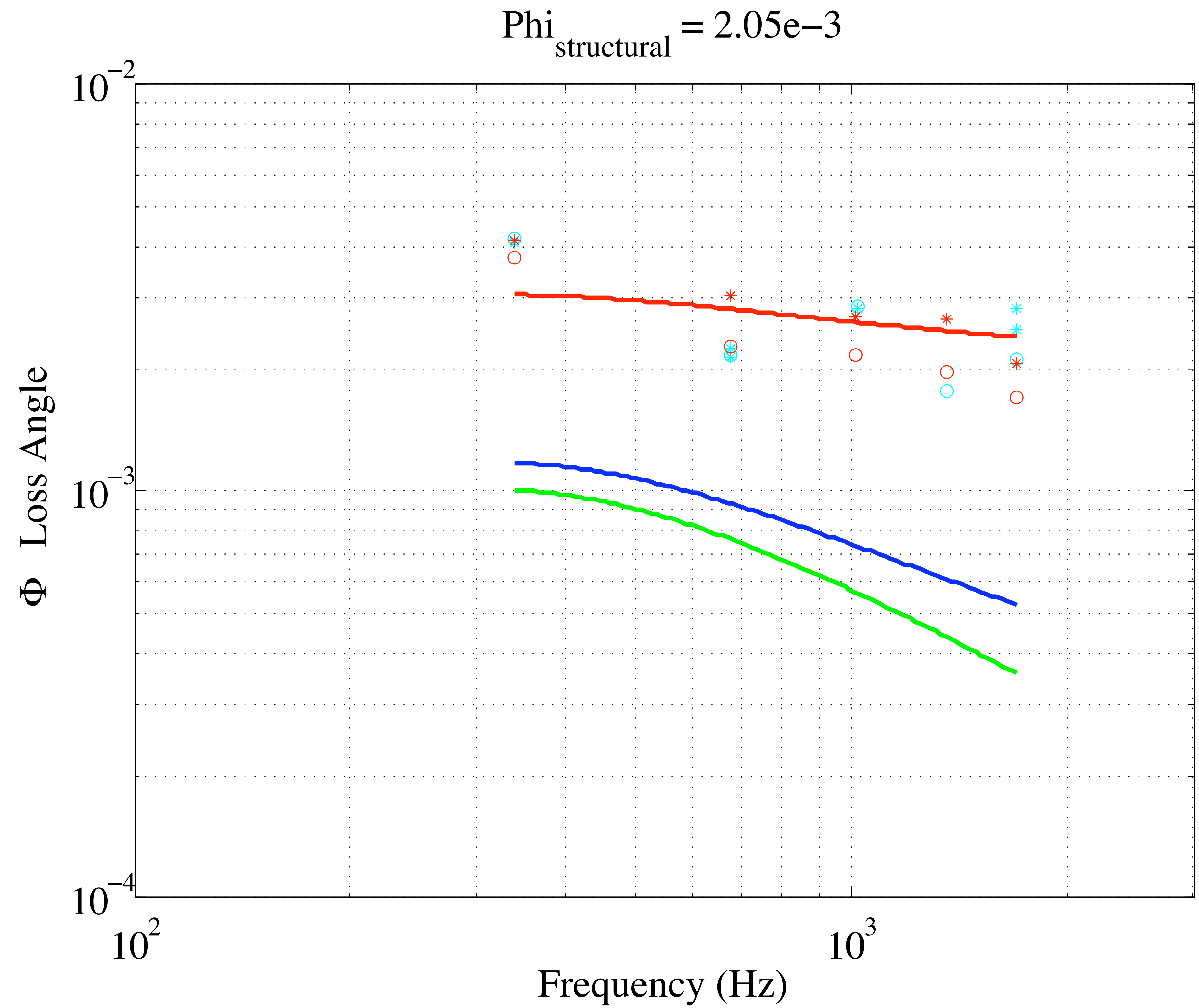
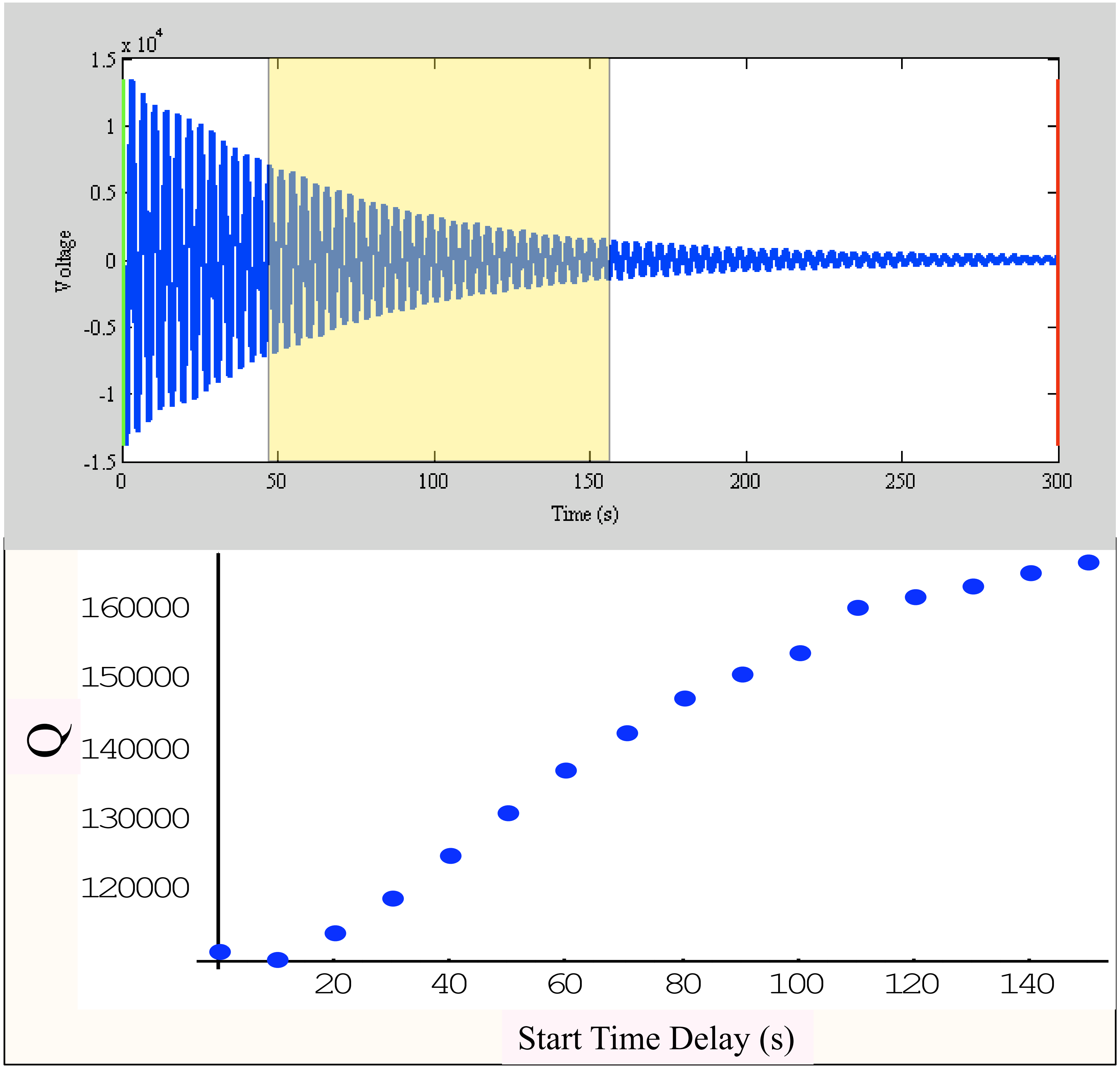


Q vs. Amplitude



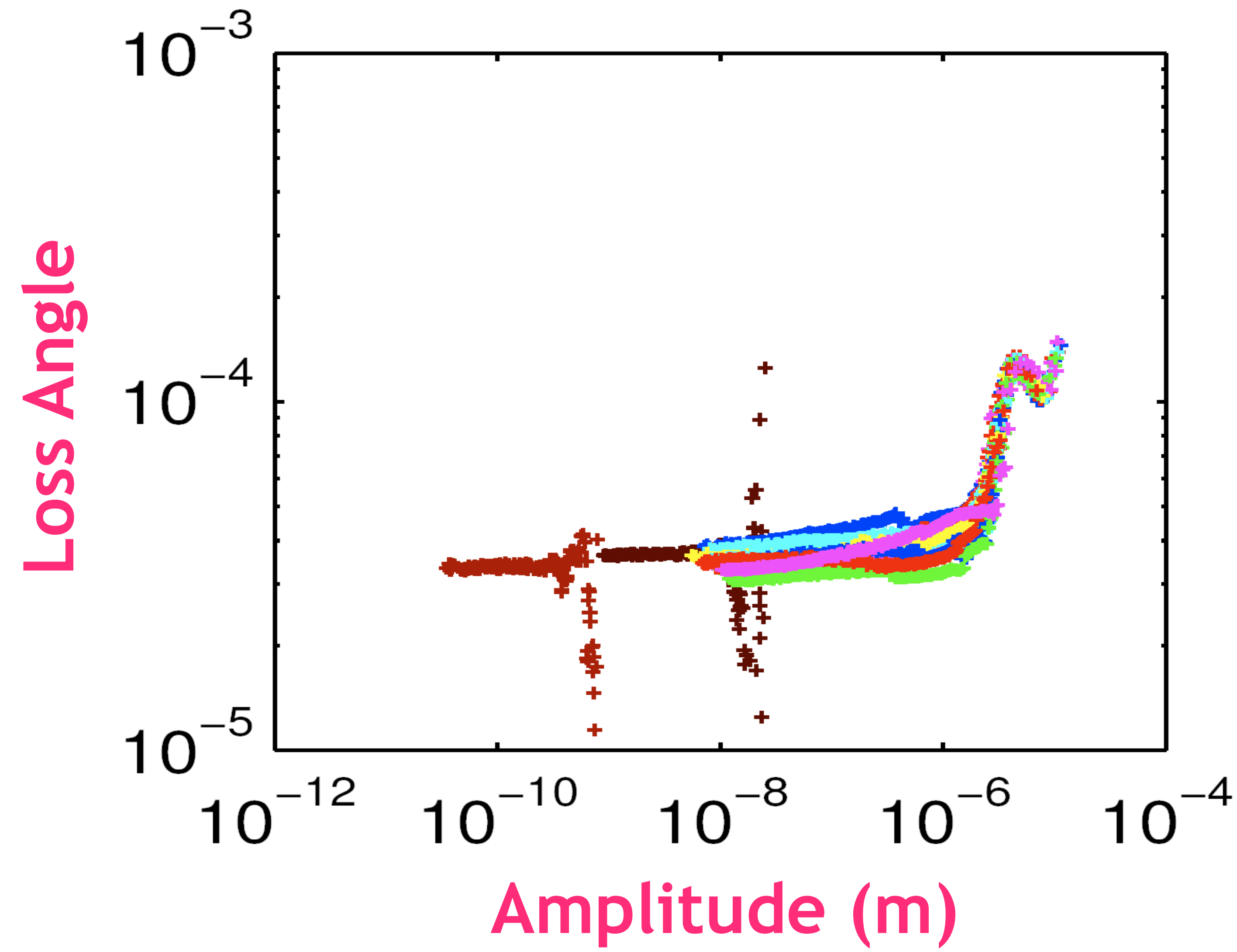
Amplitude Dependence of Loss Angle

Clamp Friction losses

- Rubbing friction at high amplitude
  - Higher loss
  - Amplitude & frequency dependent
- Partial slip (slip-stick) at lower amplitude
  - Nearly frequency independent
  - Degrades with multiple measurements

Proper Clamping

- Clamp should not cause plastic deformation in clamp or fiber
  - Repeatability
  - No time variability
- No Clamp slippage
  - Hardened uniform clamping (collet)
  - Taper fiber ends

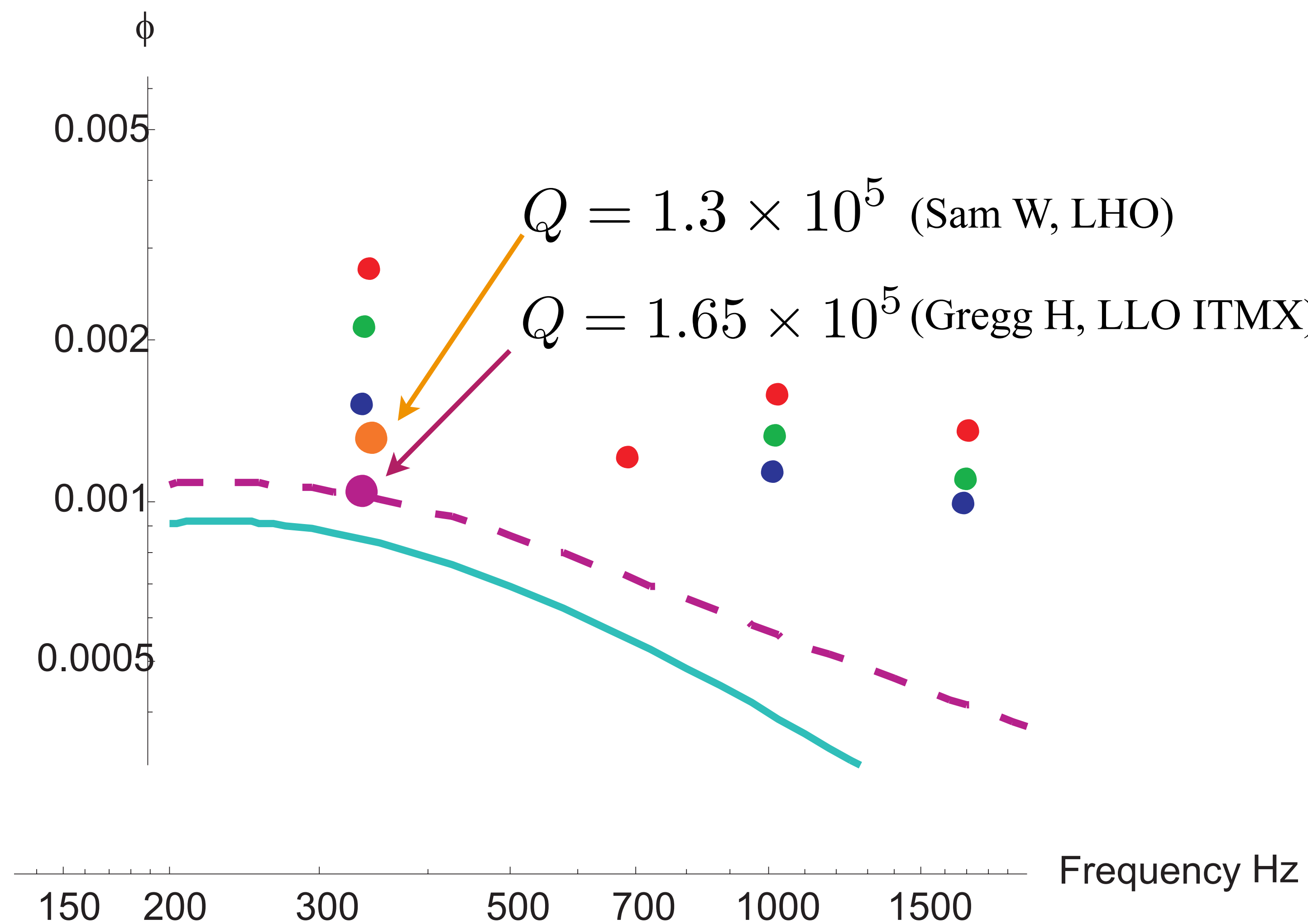


Data from Gretarsson thesis

W wire in Al clamps. Loss is 100 x internal loss.

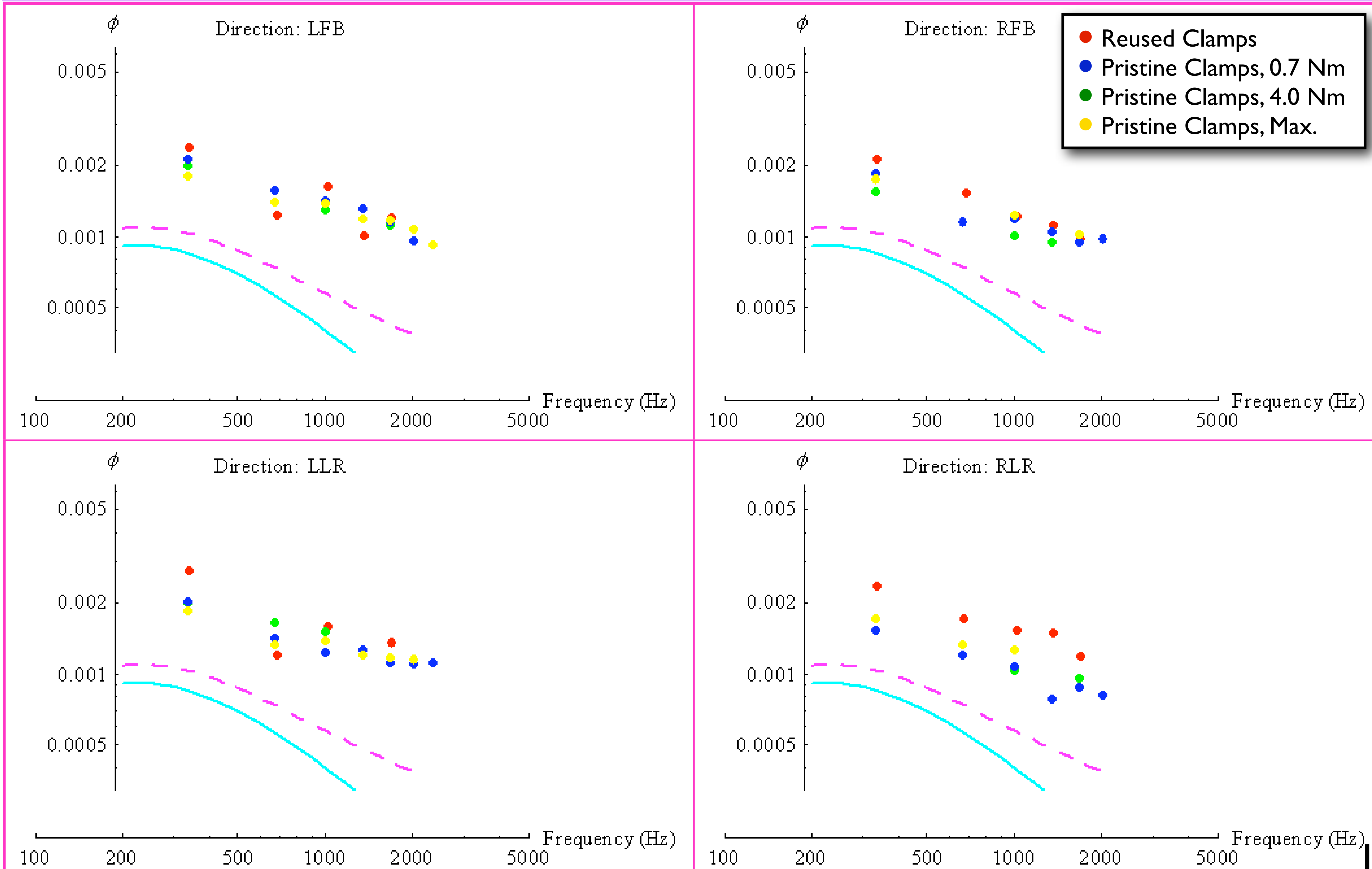
Measurement of Violin Modes at Sites

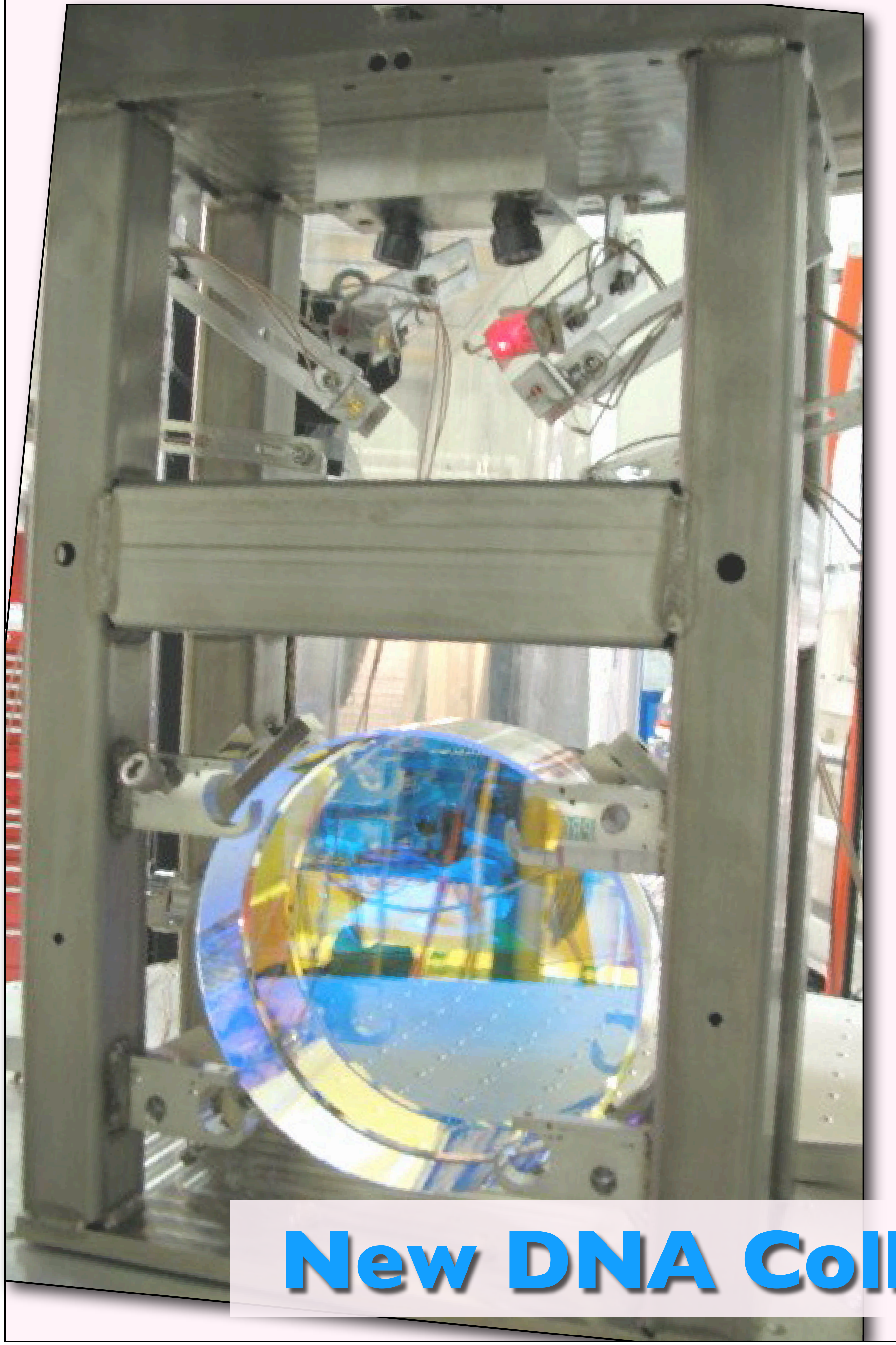
- Measured Q's are typically lower than the value expected if the loss was only due to the intrinsic loss in the wire (thermoelastic damping and structural loss)
- Mysterious changes in Q
    - Consistent within lock stretch
    - Not consistent between optics
    - Feedback effects? No dependence on optical power
    - Recoil Damping?
    - Clamp Losses?

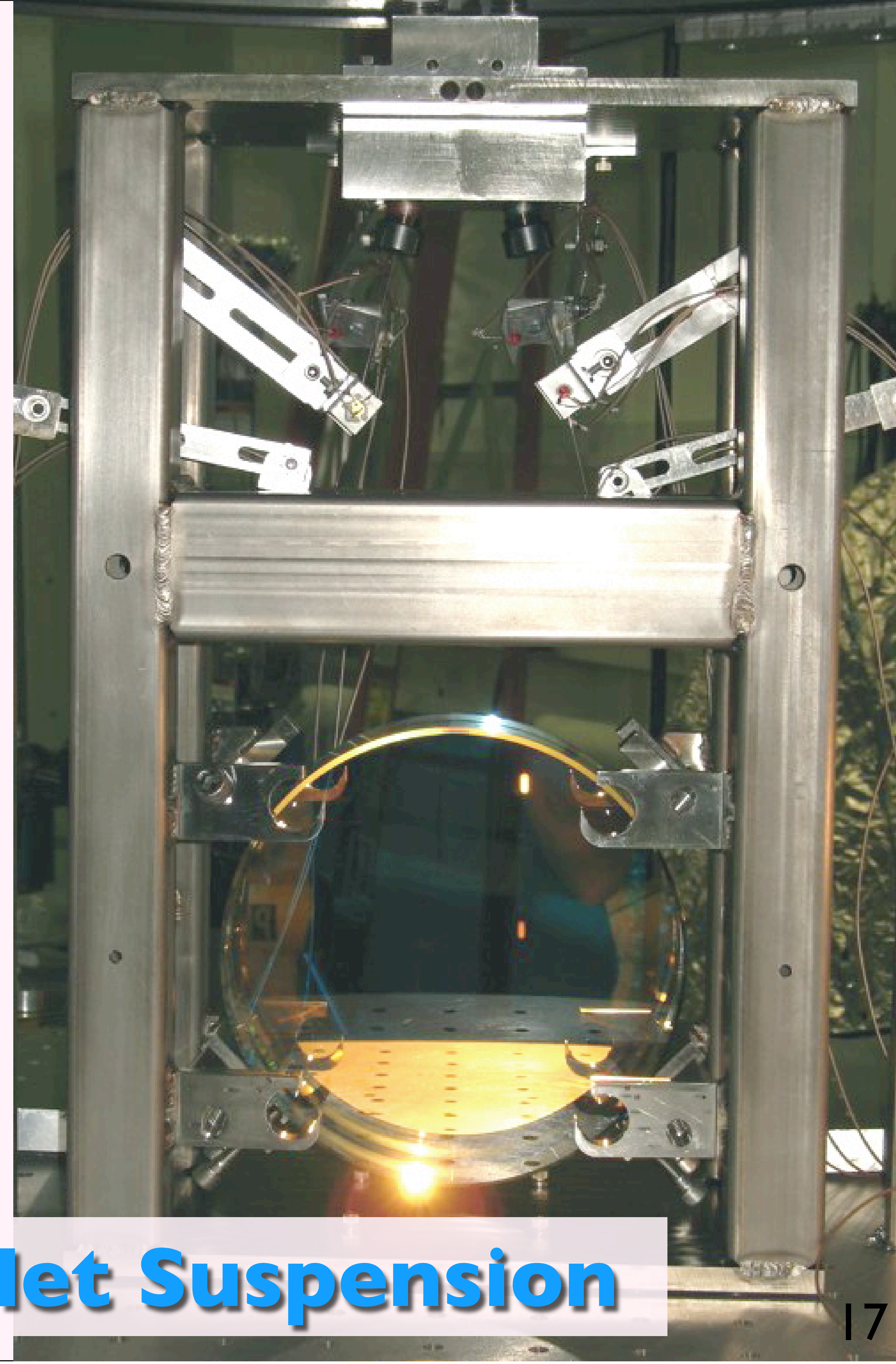


Violin Mode Q's are inconsistent. Best Q consistent with fundamental mechanical loss.

Violin Mode: Pristine Clamp







New DNA Collet Suspension

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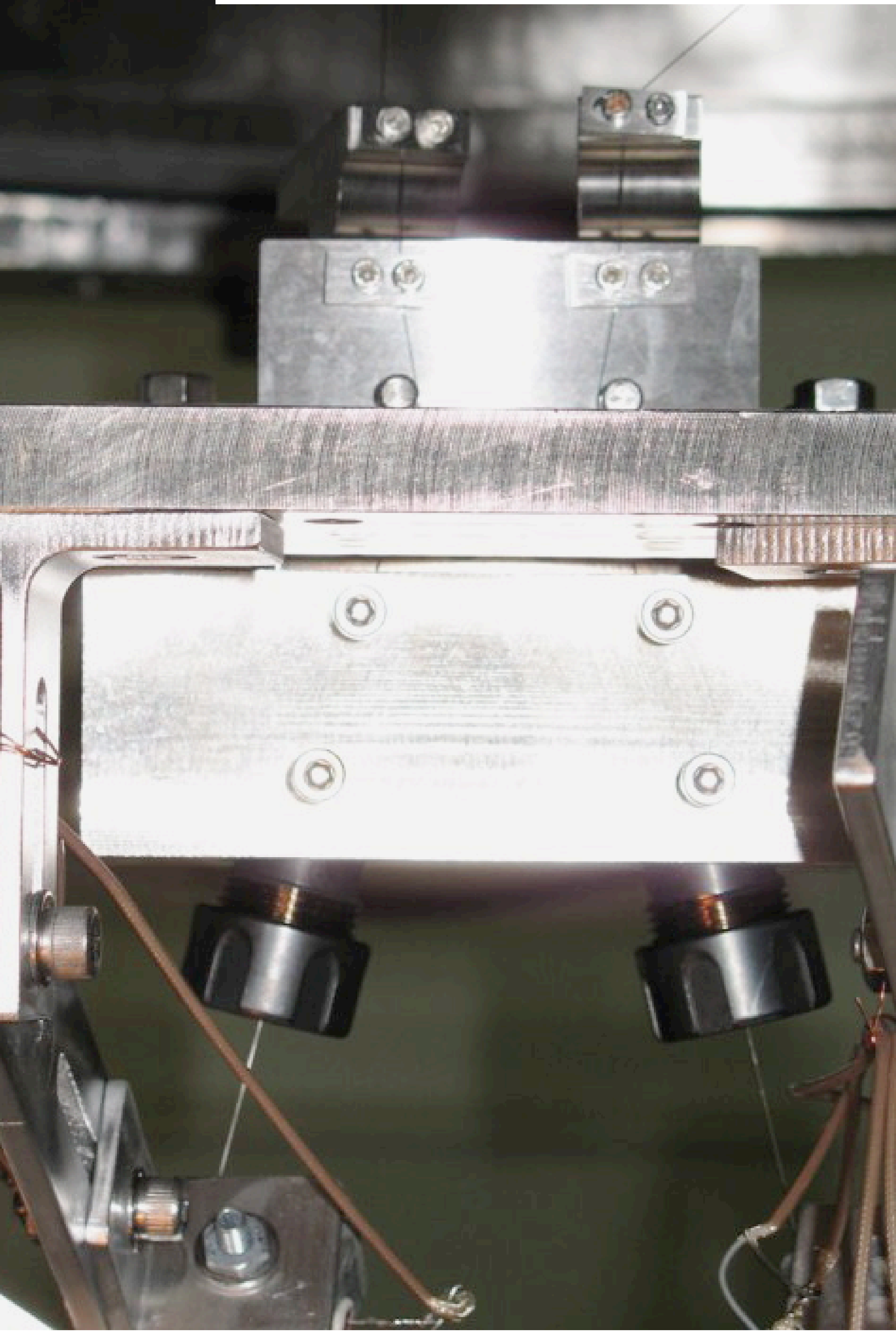
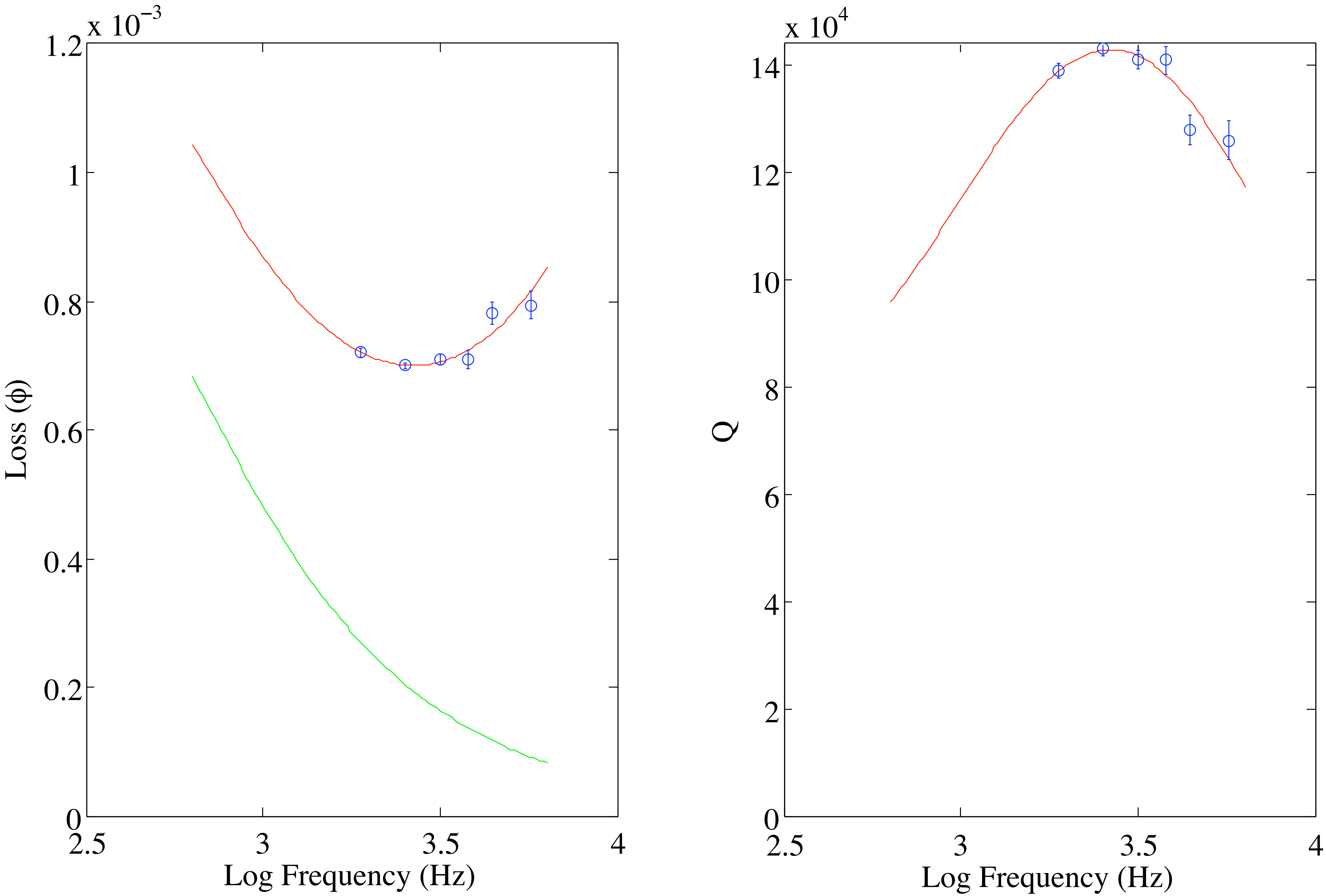
New DNA Collet Suspension

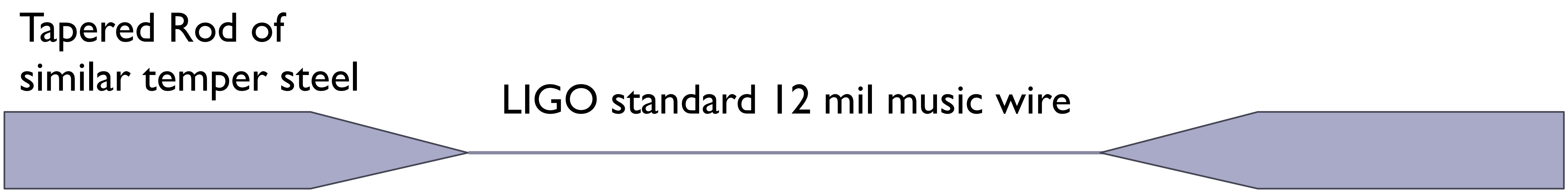


- Spring collets with bore of 0.2–0.3 mm
- Clamping is symmetric
- Hardened Tool Steel has no plastic deformation
- Clamping should be **Repeatable**!

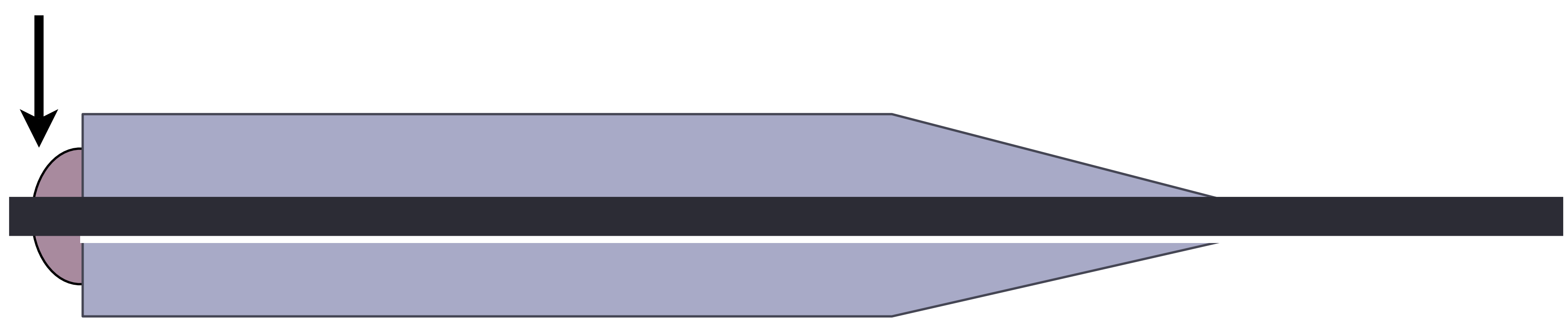
Violin Mode: Collet Clamp



Tapered Wire Suspension



Assembled using shrink fit
with end spot weld



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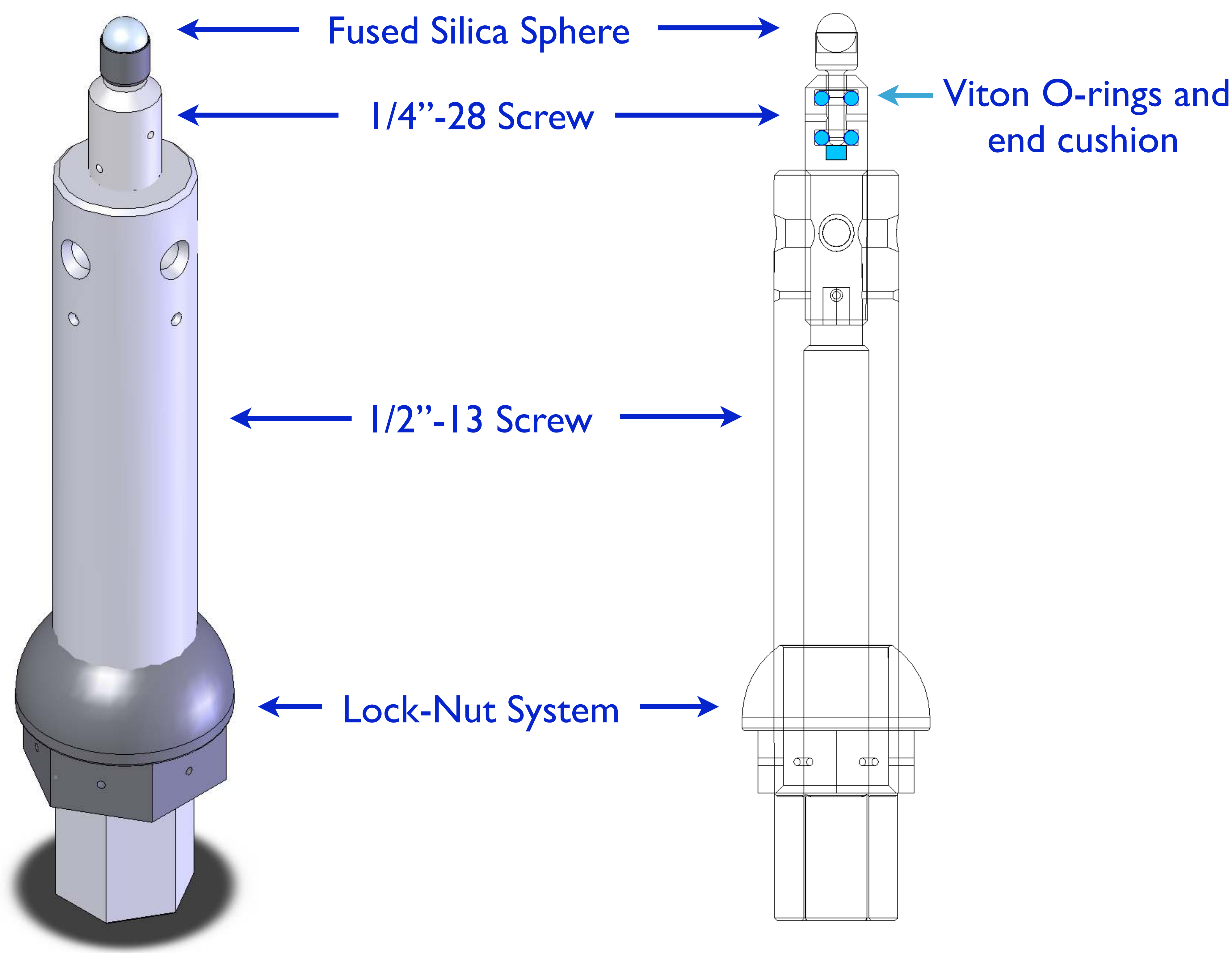
New Directions

- Test wire collets, without galling
- Test tapered wires held in collets

- Test Ribbons
- Test for and correct friction at the standoff (HARD)
- Investigate other materials
- Tests for recoil damping (Easy test. Unlikely source of problem.)

- Use apparatus to test new earthquake stops

New Earthquake Stops



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LIGO-Virgo Thermal Noise Meeting

Saturday, 7 October 2006 at Virgo Observatory

LIGO Speakers

- **Jim Hough** – ***Future research directions***
- **Sheila Rowan** – ***Next generation materials***
- **Gregg Harry** – ***Coating thermal noise***
- **Eric Black** – ***Thermal Noise Interferometer***
- **Stuart Reid** – ***Coating and bonding thermal noise***
- **Andri Gretarsson** – ***Thermorefractive noise***
- **Alastair Heptonstall** – ***Silica suspensions***
- **Vincenzo Galdi** – ***Genetic algorithms***
- **Juir Agresti** – ***Mesa Beams***
- **Steve Penn** – ***Silica substrates***

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The End

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Noise Budget

Estimate for thermal noise assuming the suspension noise for all test mass is the same as our result.

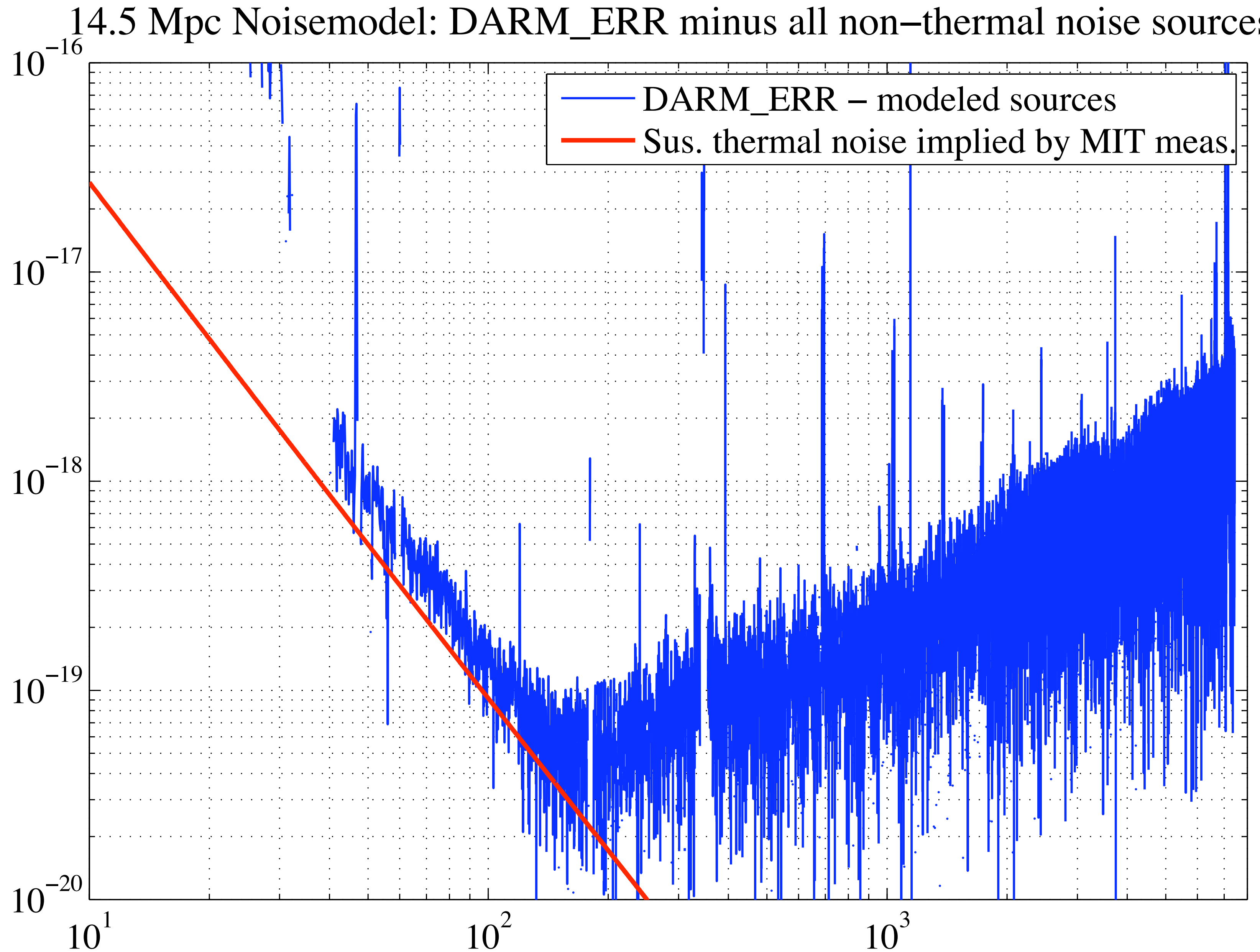
$\phi = 2 \times 10^{-3}$

Worst loss seen from measurements of violin mode at the sites is

$\phi = 1.1 \times 10^{-2}$

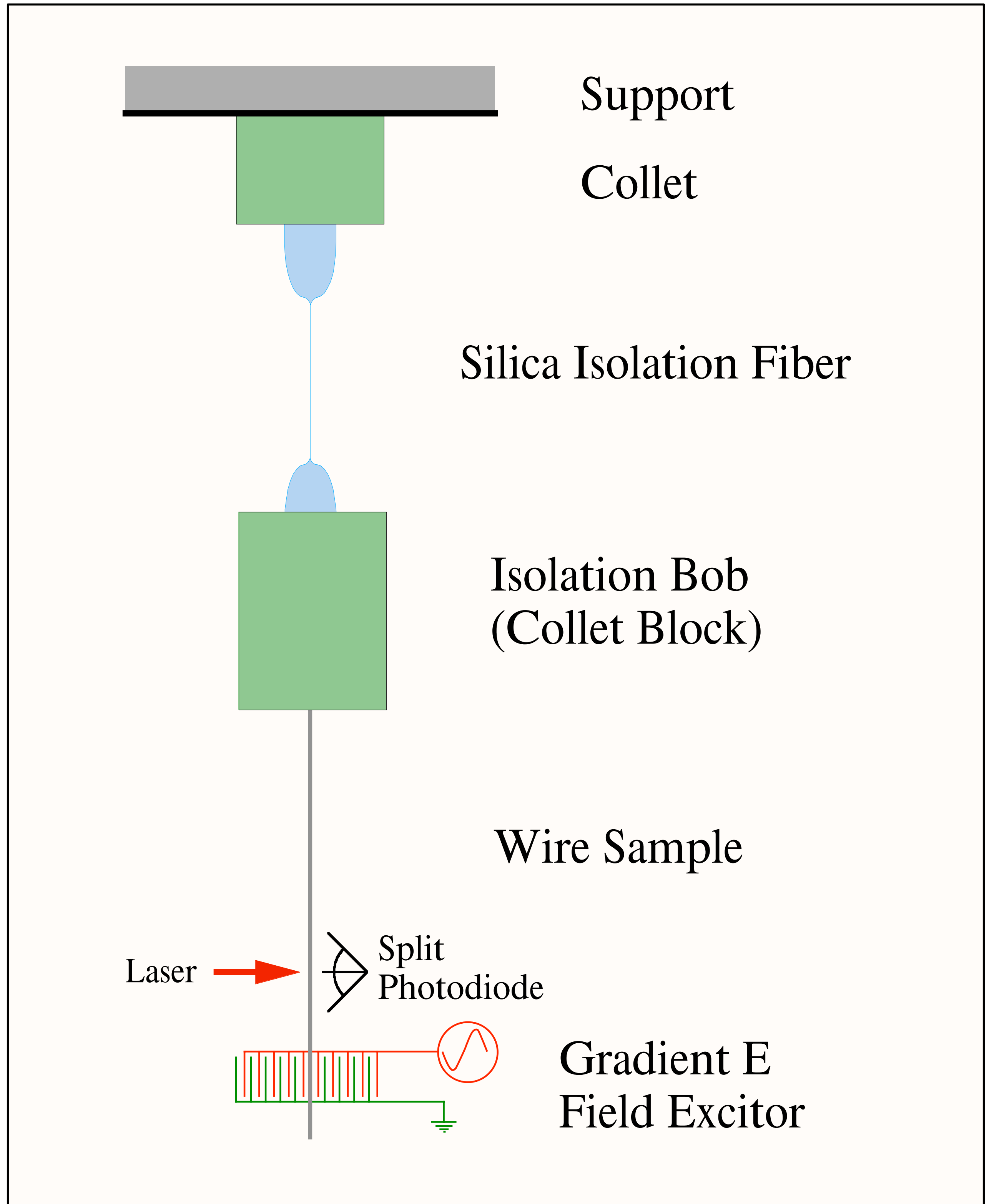
Best fit to observed 40-10 Hz noise is

$\phi \approx 7 \times 10^{-3}$



Strong indications that Suspension thermal noise is a major contributer to the 40–100 Hz excess noise.

Mechanical Loss in Wires



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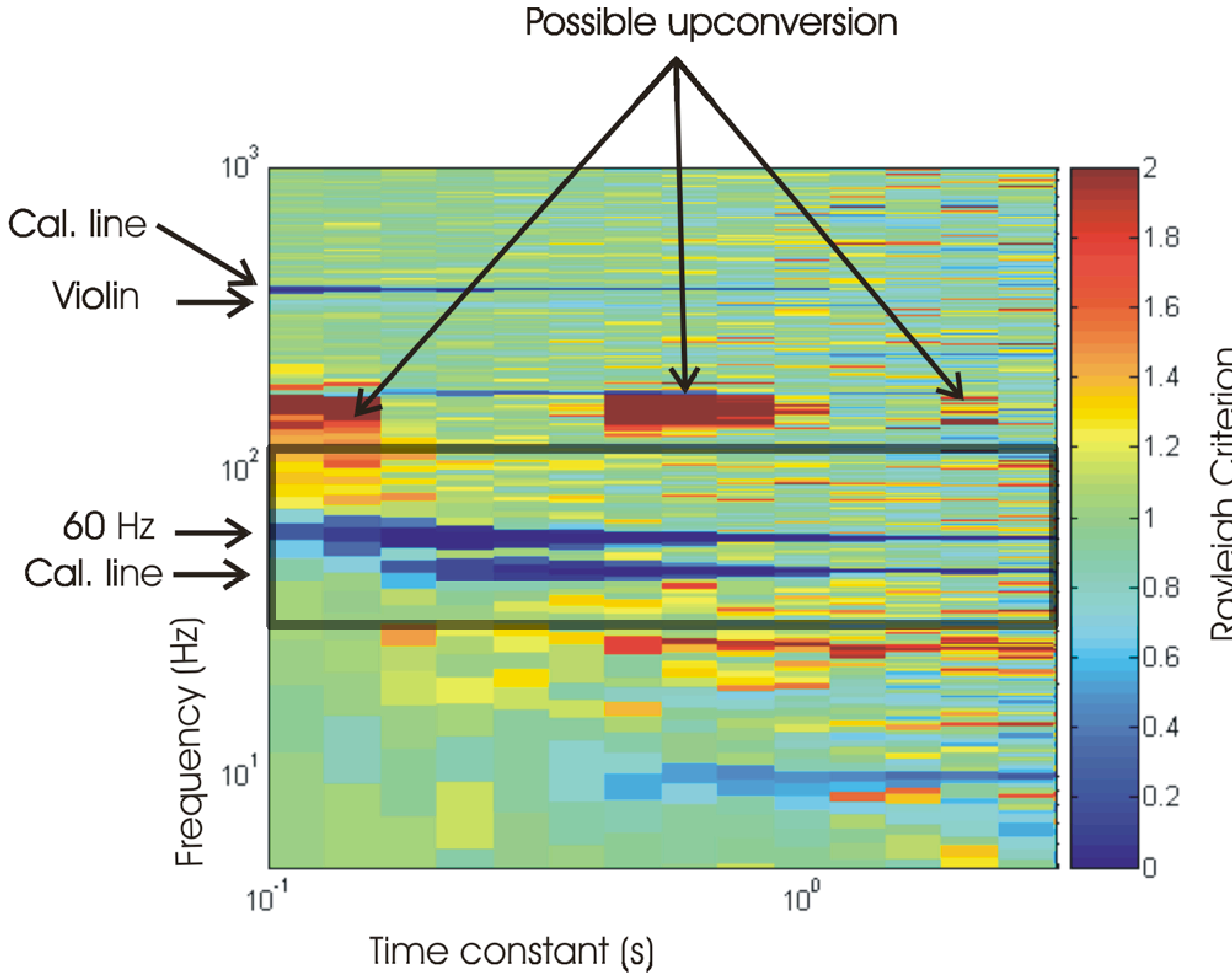
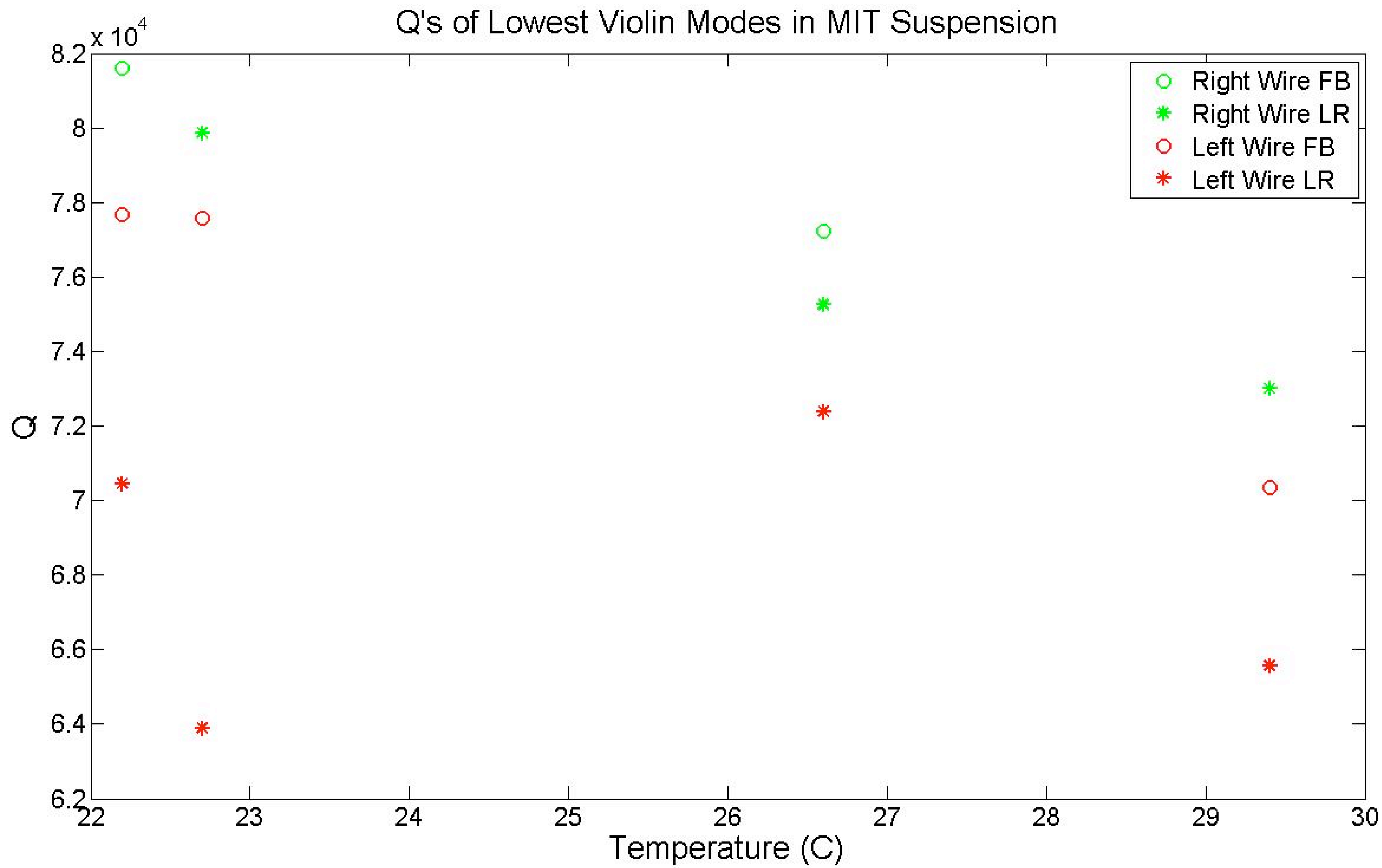
Test for NonGaussian Noise

Rayleigh Monitor indicates no major departure from Gaussian noise in 40–100 Hz region.

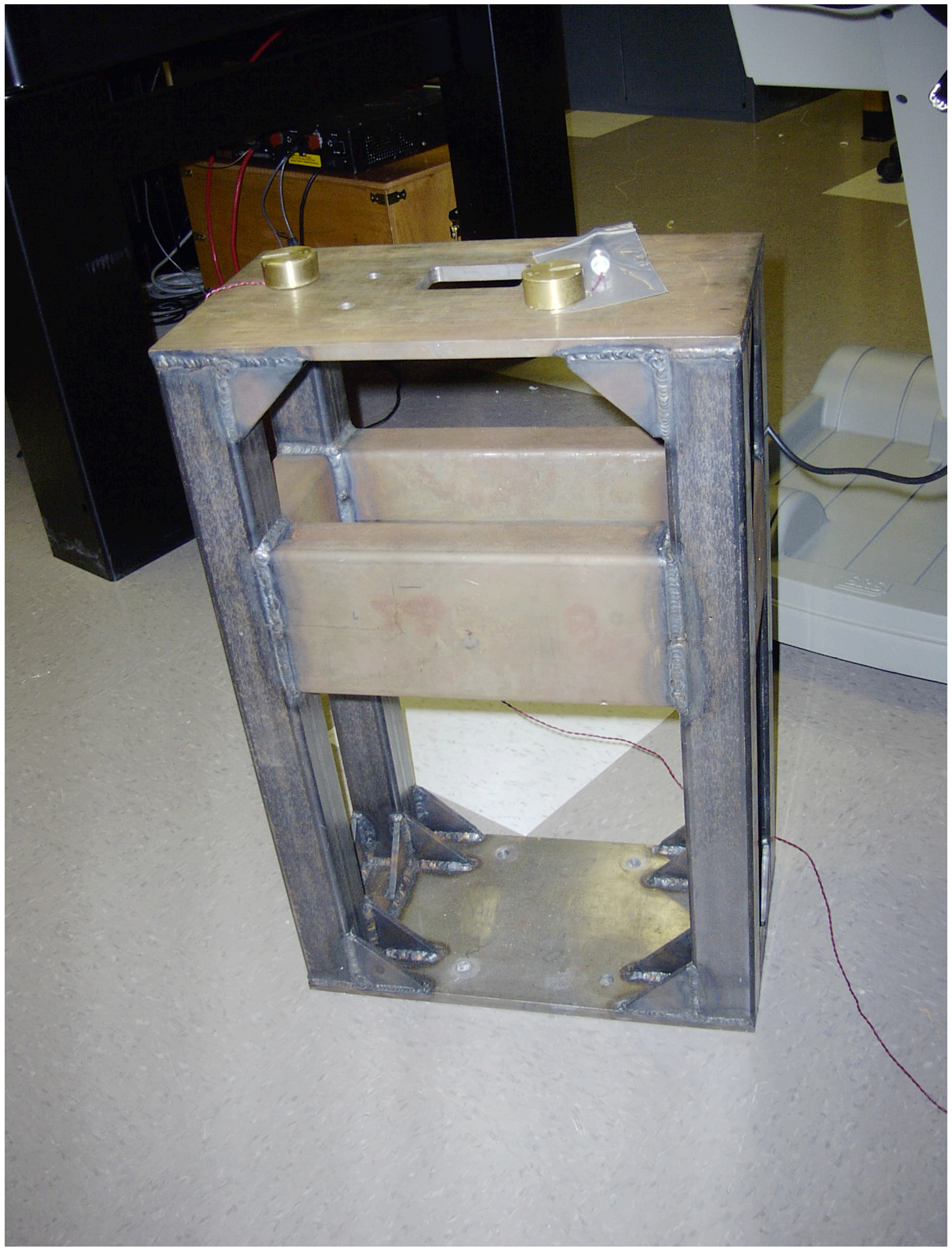


Q vs Temperature



- Does not seem to be a correlation with temperature
- Calls into question recoil damping model to explain Q variation at sites

LIGO Suspension Cage Frequency Measurements



- Measurements on spare cage at ERAU
- Transfer function on top plate
- Compare frequencies with model and measurements at Caltech
- Verify temperature dependance
- Will attempt to modify frequency structure by clamping mass on cage