Update on Mechanical Loss Studies in Fused Silica

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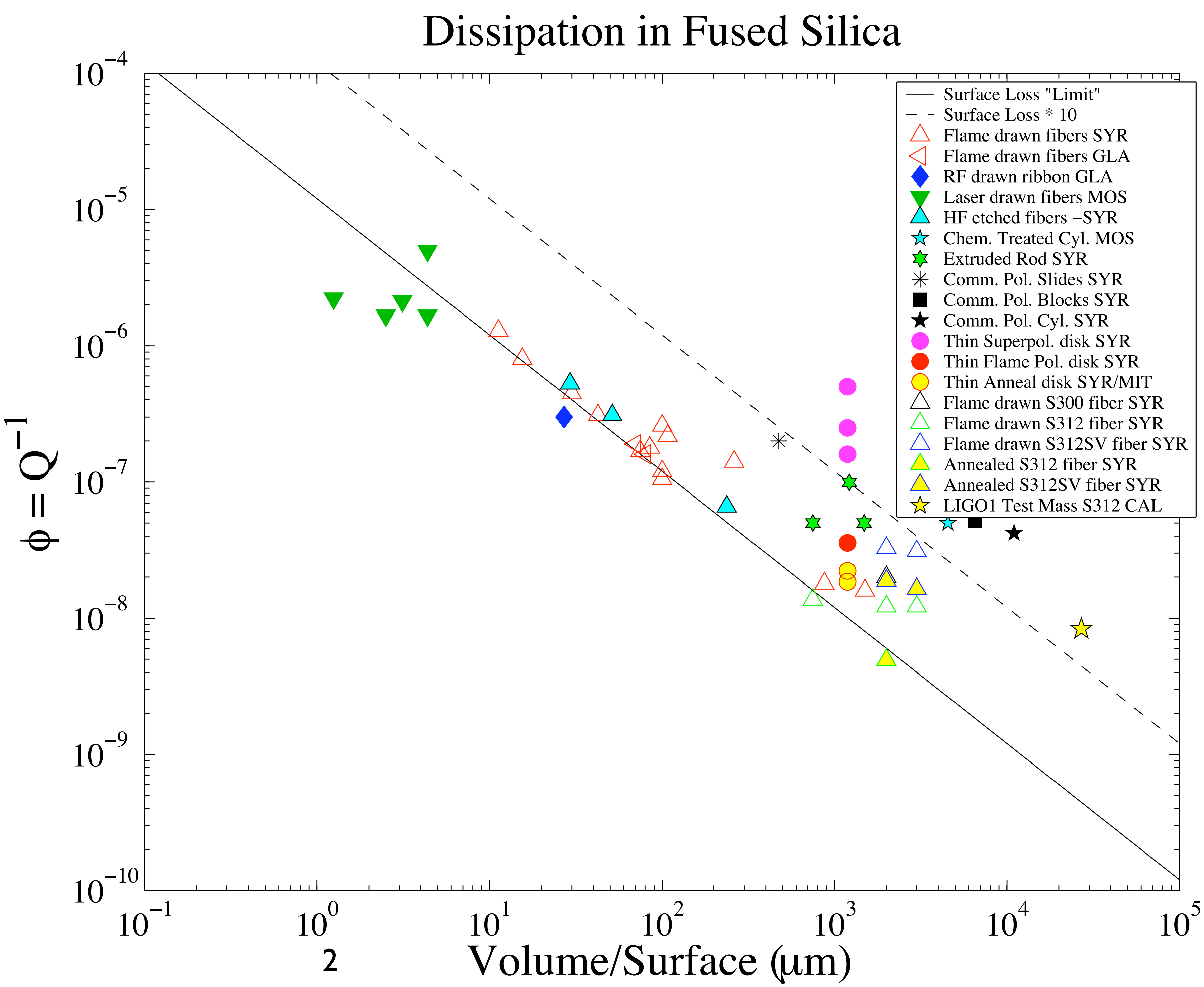
LIGO DCC LIGO-G060140-00-Z

Surface Loss Dependence

- Loss dependent on V/S ratio
- Loss dependent of surface condition
- Pristine surface condition dependent on initial preparation and annealing to reduce internal stress

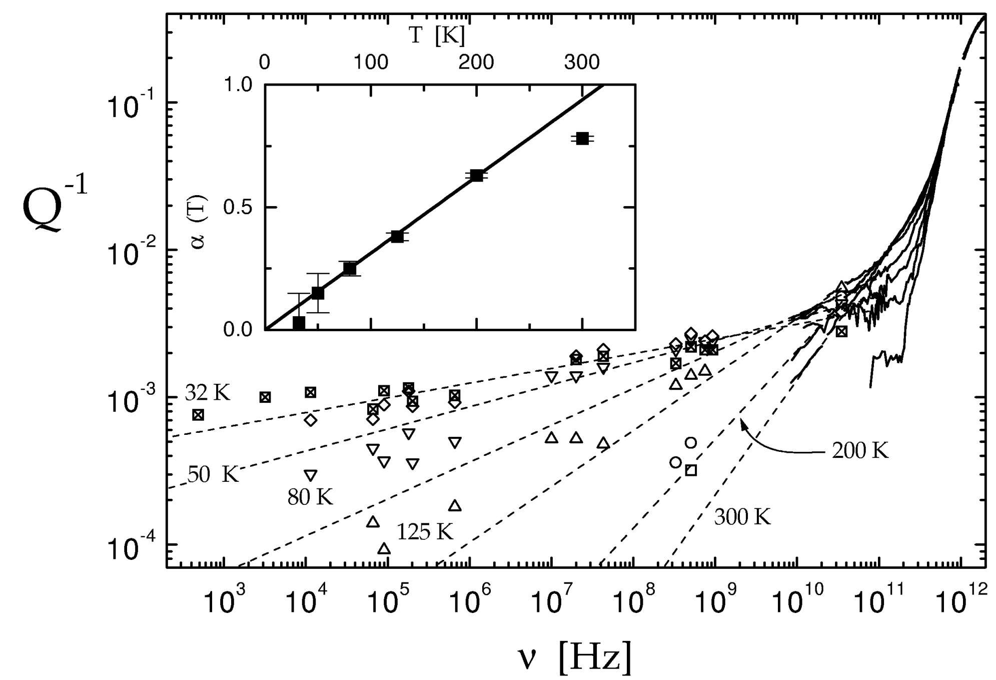


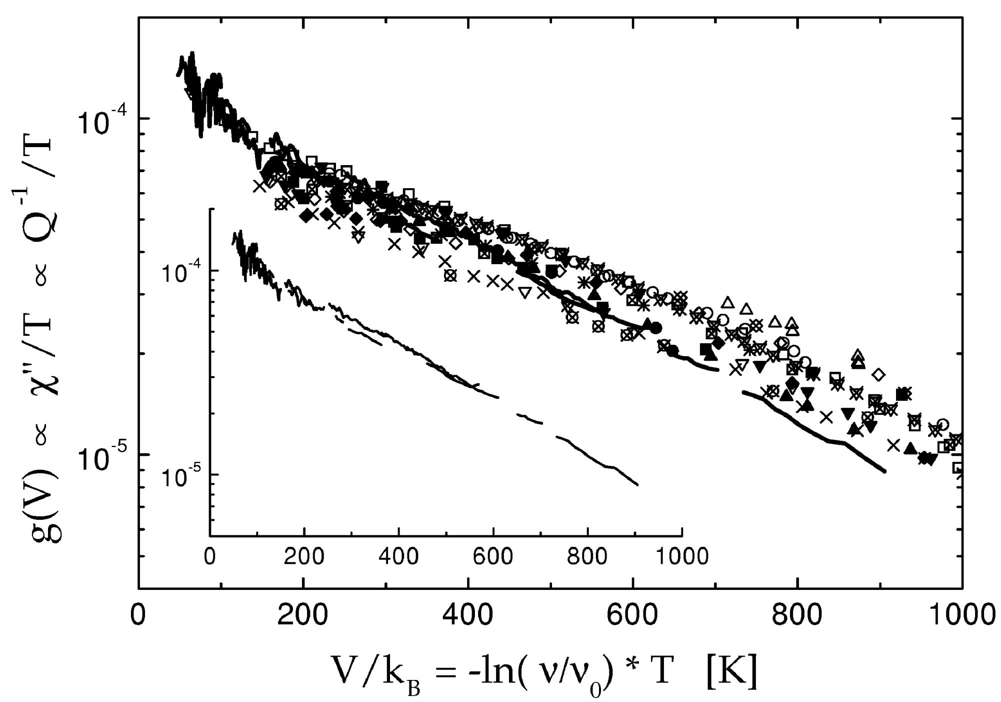
Frequency Dependence

- Loss has frequency power law dependence
- Broad distribution of relaxation times arising from thermally activated asymmetric double-well potentials

$$\phi \propto f^{\alpha}, \quad \alpha = T/319$$

- Frequency range (500 Hz — 500 GHz)
- Temperature range (32 — 300 K)





Wiedersich, Adichtchev, and Roessler, PRL 84, pp2718-2721, March 2000

Mechanical Loss Model

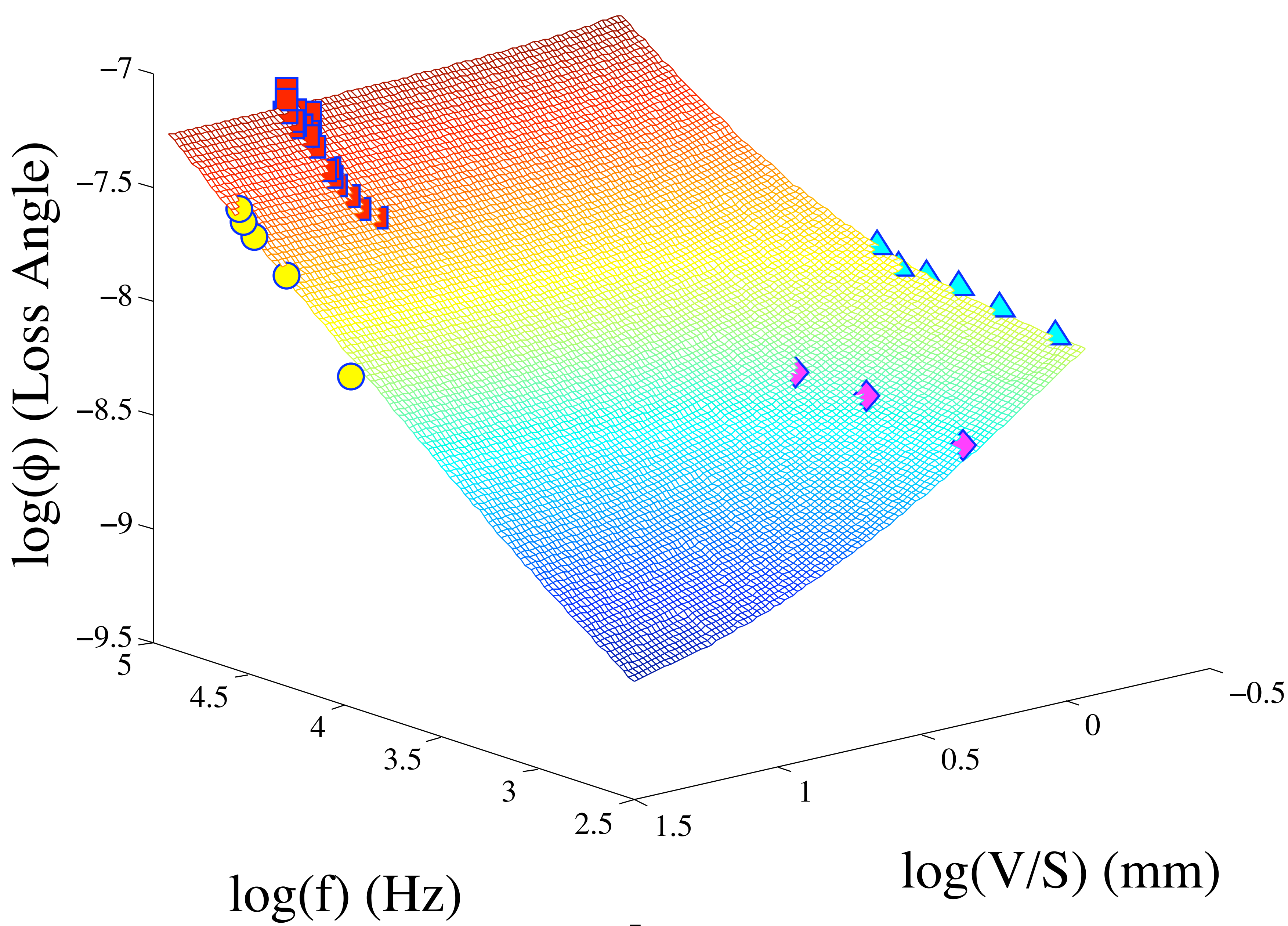
$$\phi\left(f, \tfrac{V}{S}\right) = \left(C_1 / \tfrac{V}{S}\right) f^{C_2} + C_3 f^{C_4} + C_5 \phi_{\mathrm{Th}}$$

- **Surface Loss Term** — strained Si-O-Si bonds with larger angle distribution near surface — C2 < 0.1

- Bulk Frequency Loss Term — asymmetric double-well potential from strained Si-O-Si bonds — C4 ≈ 0.77
- Surface Loss Term — strained Si-O-Si bonds with larger angle distribution near surface — C2 < 0.1
- Thermoelastic Term — compression/expansion creates thermal gradient. Loss from heat flow.

Suprasil 312

$$\phi = (6.82e{-}09\ S/V\ f^{0} + 7.31e{-}12\ f^{0.773})$$



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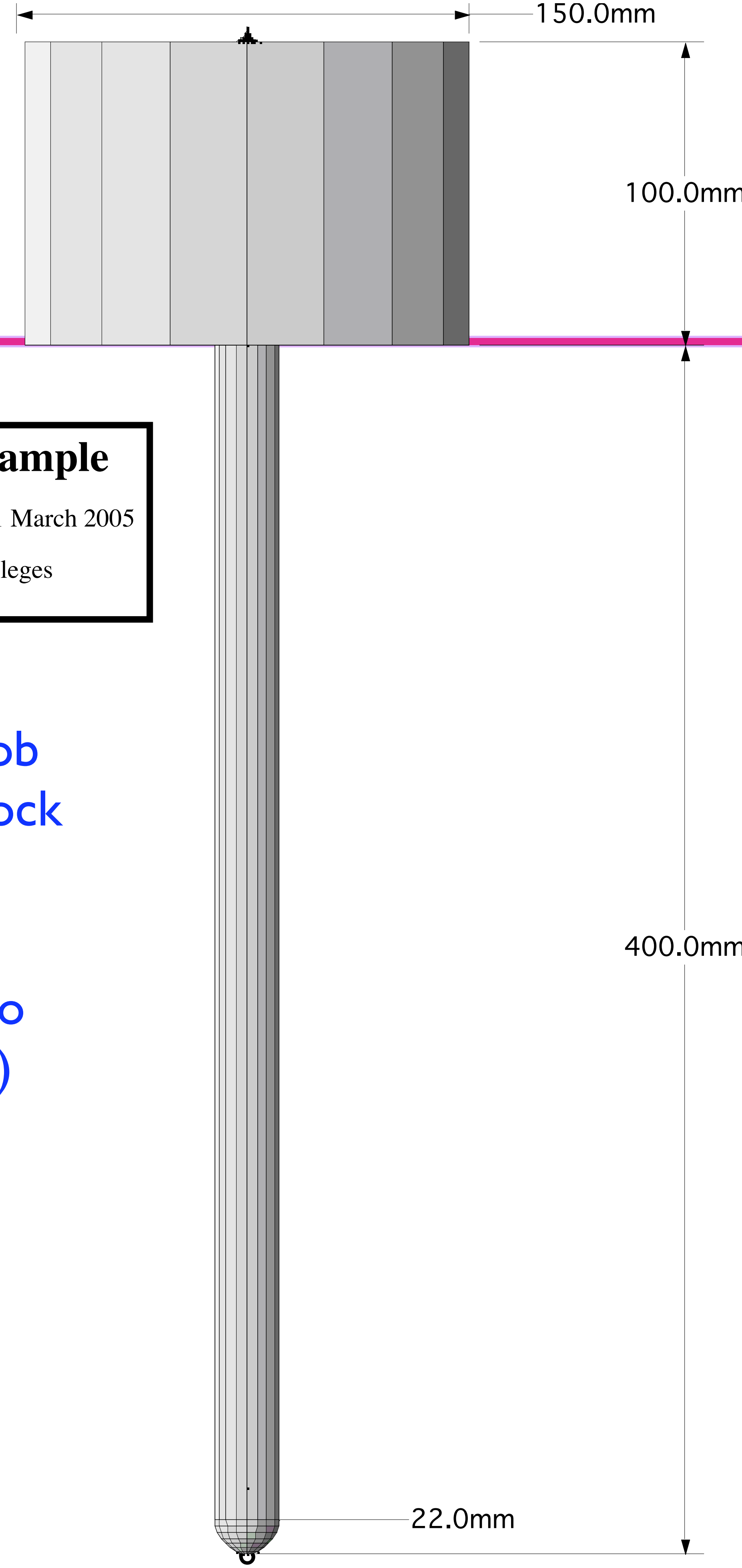
Large Cantilever Sample

LIGO

HWS LIGO



Cantilever Rod Sample

1 Required • Suprasil 312 • 11 March 2005
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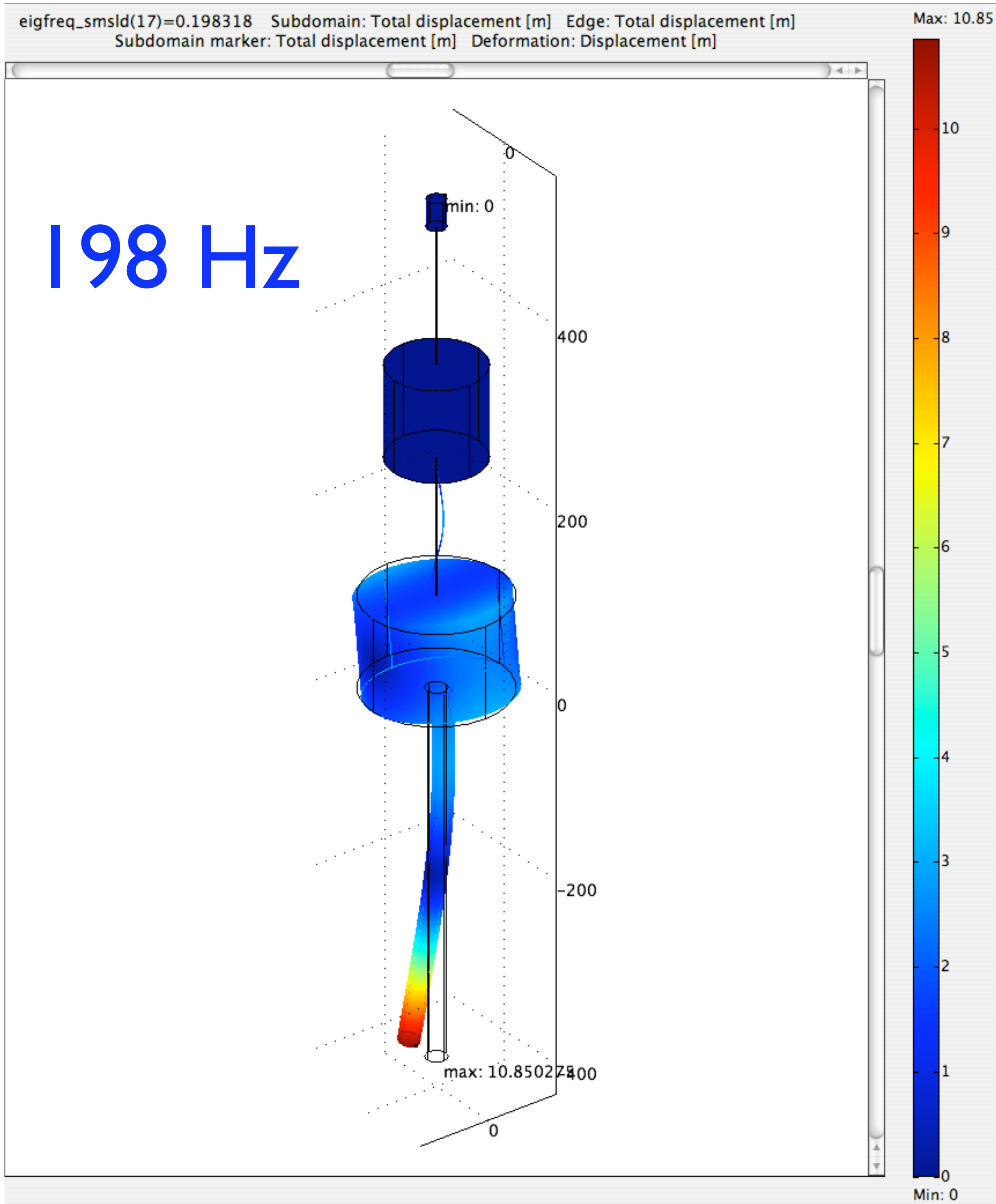
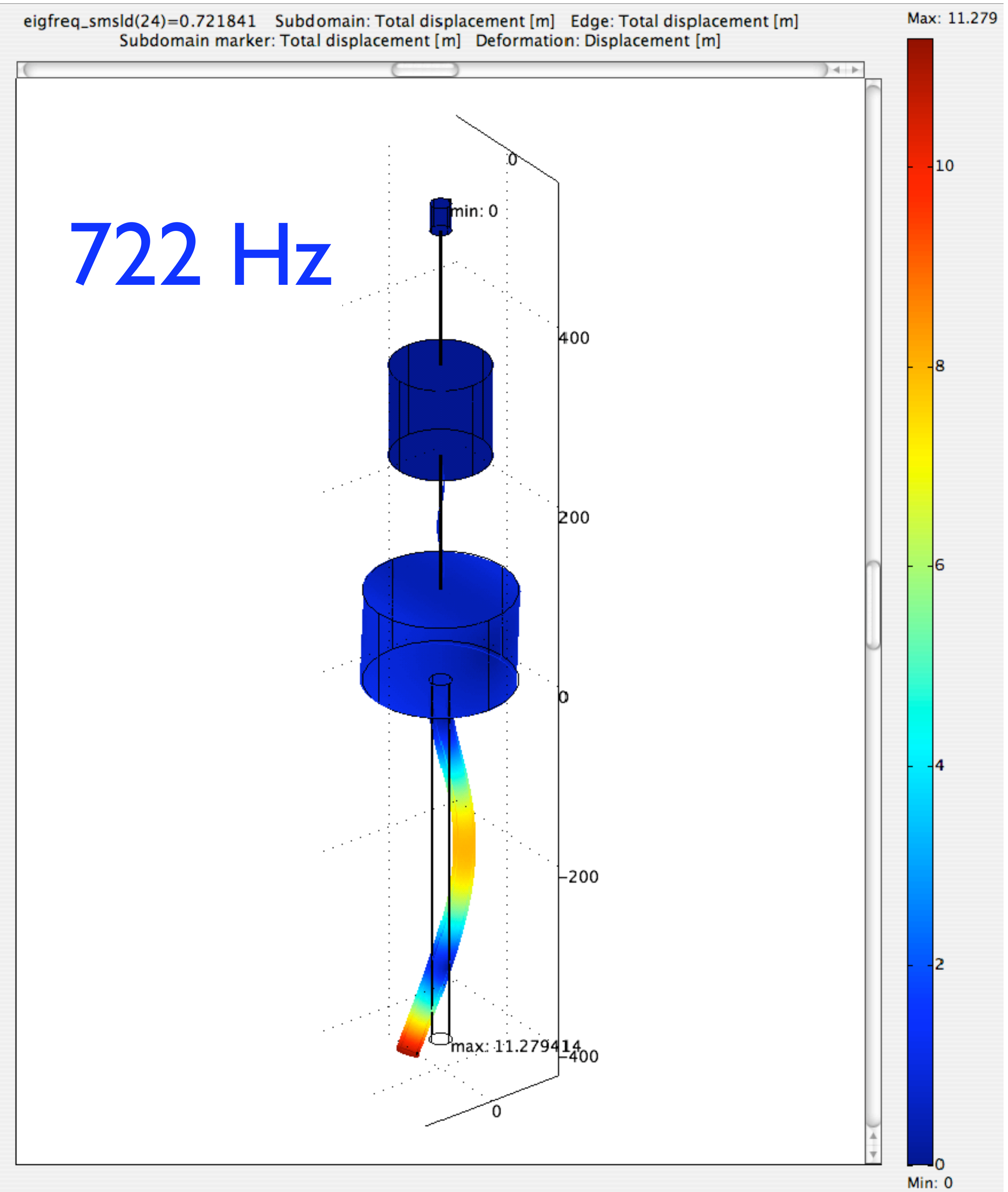
LIGO Science Collaboration

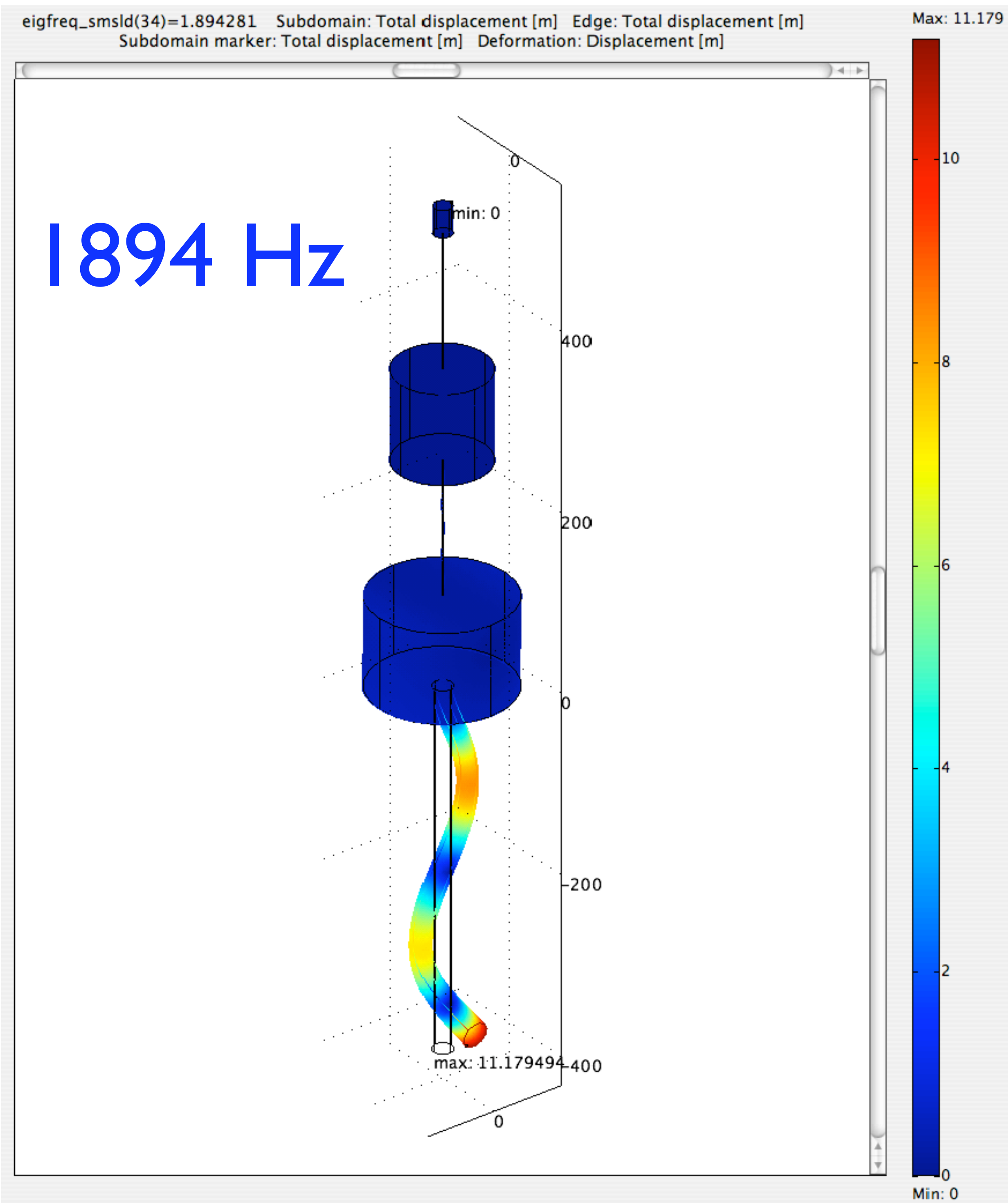
- Suprasil 312 rod with attached bob made from Suprasil 311-3 raw stock
- Slow Anneal:
  - 1°C/hr from anneal point to stress point (1150–1030 C)
  - 2°C/hr down to 900 C
- V/S = 5.5 mm
- f_0 = 198, 722, 1894, 3610 Hz
- ORDERED MARCH 2005

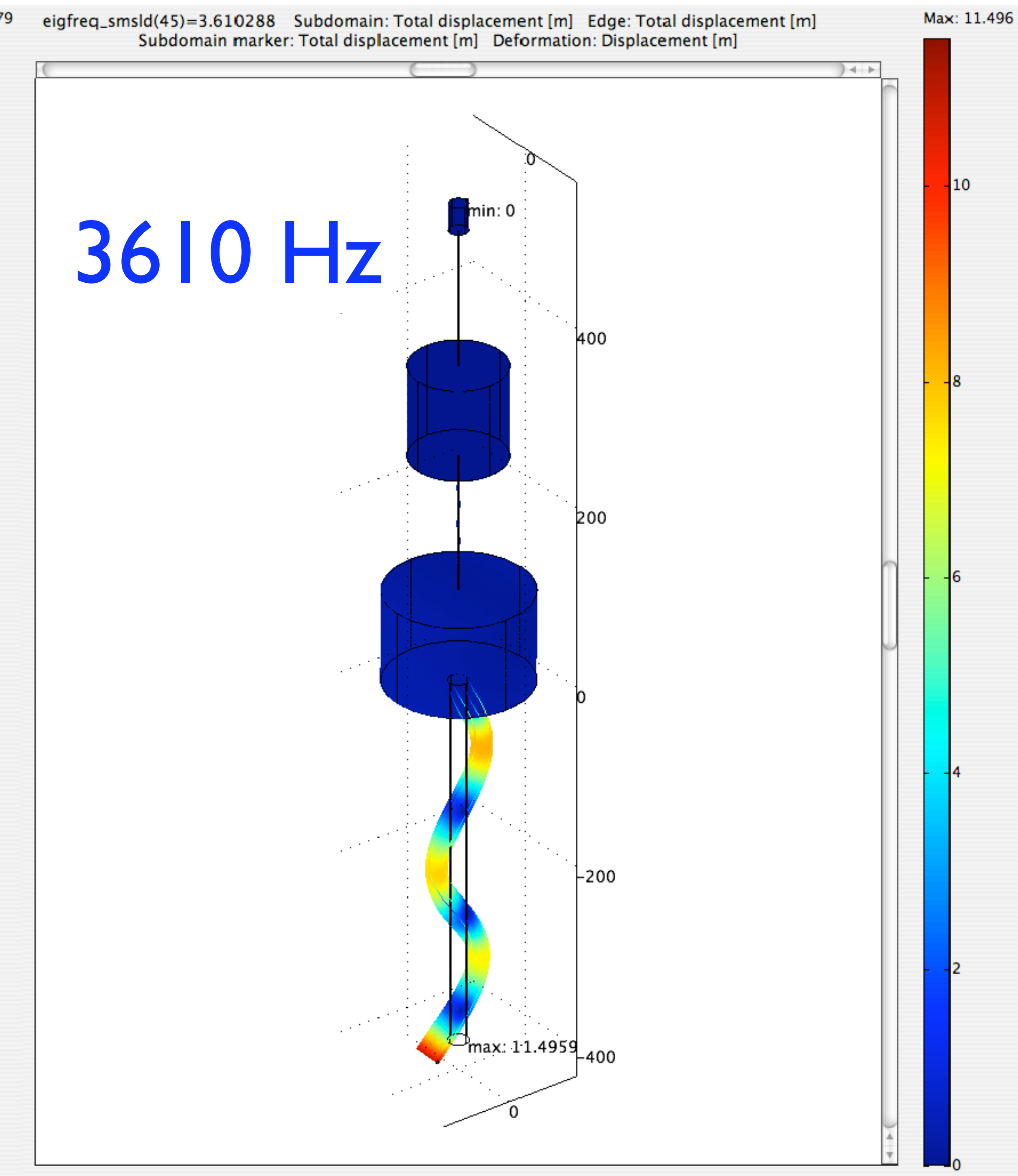
Large Cantilever Modes





Large Cantilever Modes



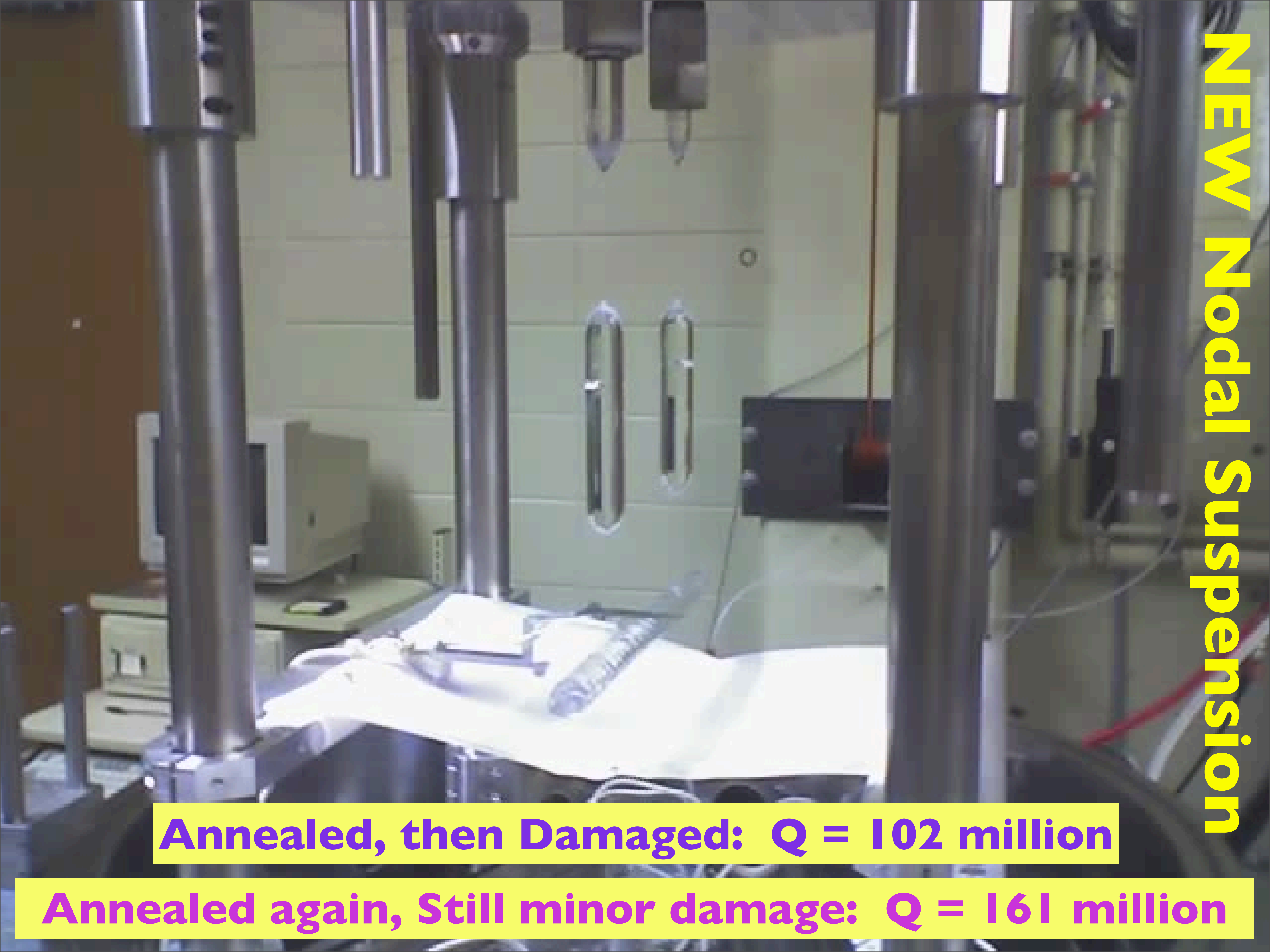


… and then we wait …

Phil Willems suggests an alternate low-loss suspension.
"Just suspend the sample rod at the nodal points."

Nodal Suspension

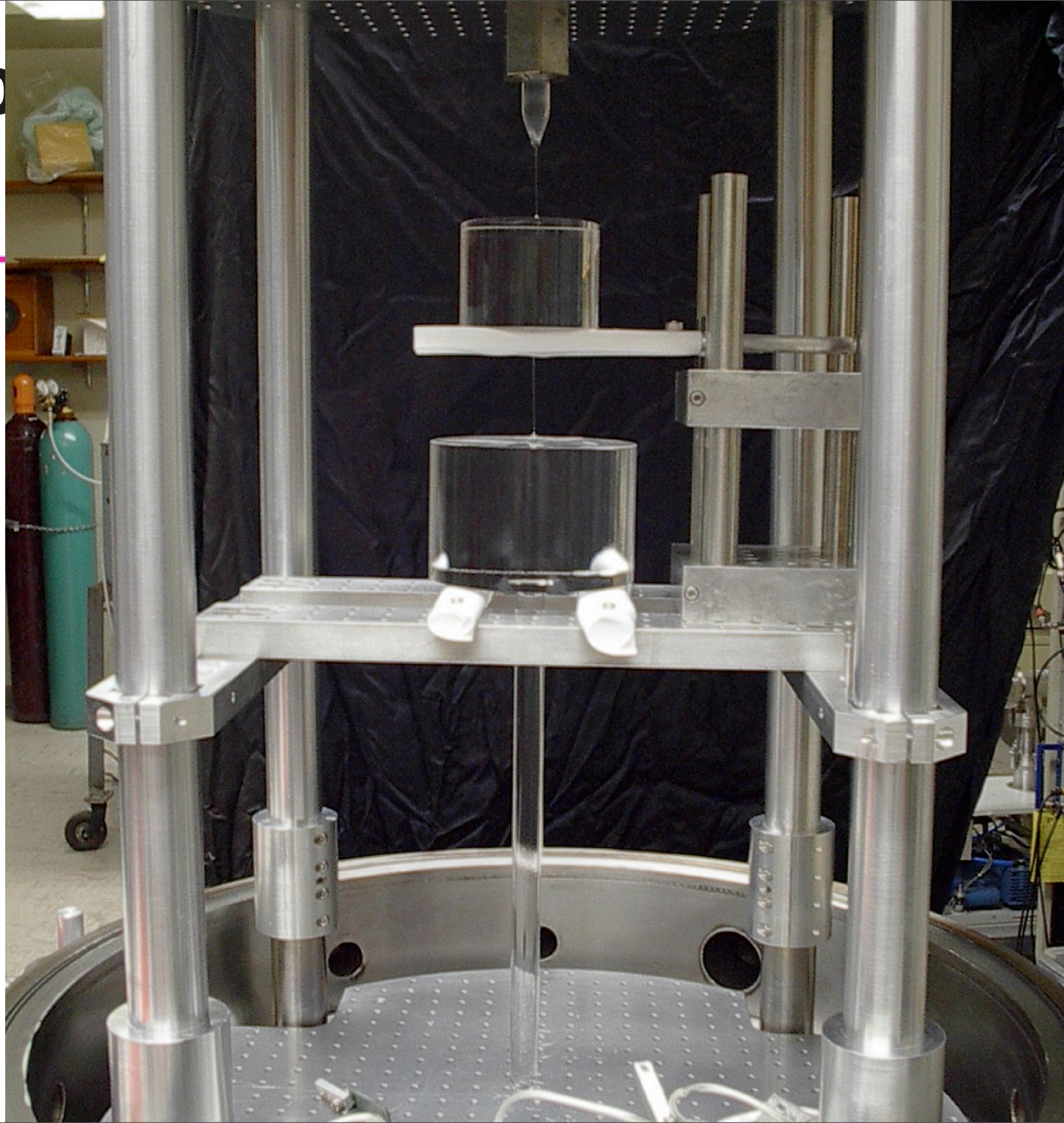
Q = 86 million


NEW Nodal Suspension
Annealed, then Damaged: Q = 102 million
Annealed again, Still minor damage: Q = 161 million

Nodal Suspension Results

Measurement	Q
Before Annealing	86 million
Annealed, Badly damaged	102 million
Annealed again, Still some damage	161 million

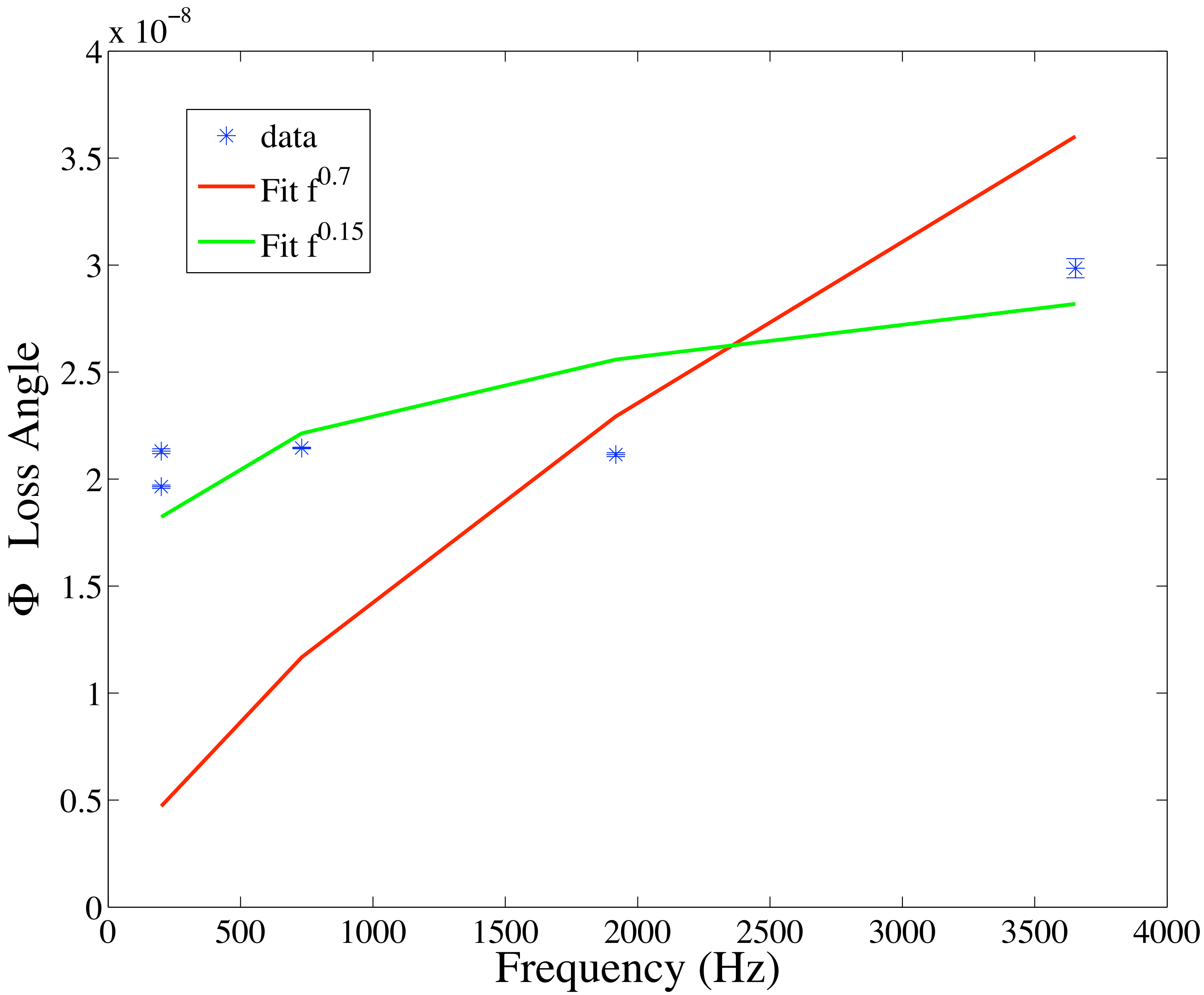
Large Cantilever Sample




Large Cantilever Sample


DAMAGE
Pits in surface
Large Cantilever Sample

Large Cantilever - First results



- High loss with low frequency dependence indicative of suspension loss.
- Suspension has high torsional mode and thin (100 micron) fibers. Possible source of loss.
- Moving to thicker suspension fibers (1-2 mm) and model the loss.
- Need to work with Heraeus to correct surface defects.

Conclusions

- Our model for the mechanical loss in fused silica explains the existing low loss data, but we need to finish measurements in regime of low frequency and high V/S.
- Hai-Ping Cheng of UFlorida does atomic level modeling of FS. She is trying to develop a predictive model for loss in FS that describes our data and hopefully agrees with our model. If that works, then hopefully she can expand that model to the various coating materials.
- Gari has ordered the fused silica cylinders for studies of optimal annealing cycle vs sample size.