Mechanical Loss in Silica and Silica/Alumina Coatings

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The Experiment

- Silica is the LIGO low-index coating material.
  - Excellent optical properties.
  - Low Mechanical Loss that this well understood for *bulk* samples.

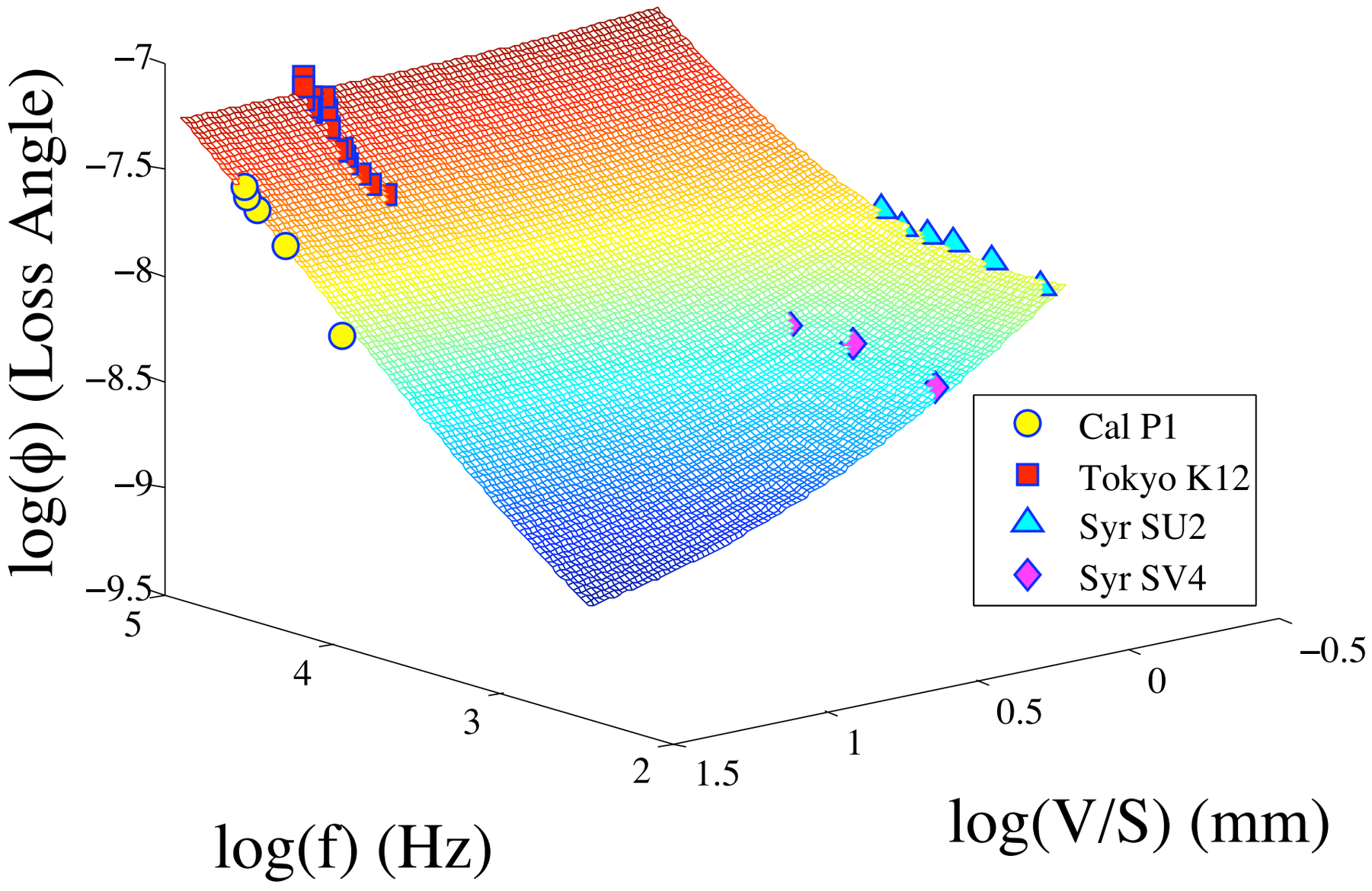
- Determining the loss in silica coatings allows:
  - Separation of mechanical losses of the materials in a composite coating
  - Optimization of the silica/tantala (doped) coatings
  - Test if the loss model for the *bulk* applies to thin films

- Measured a 1 micron silica coating
  - Annealed at 600 C by the coater (CSIRO)
  - Annealed by HWS at 800 C, 1025 C (Suprasil stress temp) , and 1150 C (Suprasil anneal temp).
  - Checked vs silica loss model and other results

- Measured a Silica/Alumina coating
  - Used the silica loss to extract the alumina loss.
  - Measured coating change with annealing temperature.

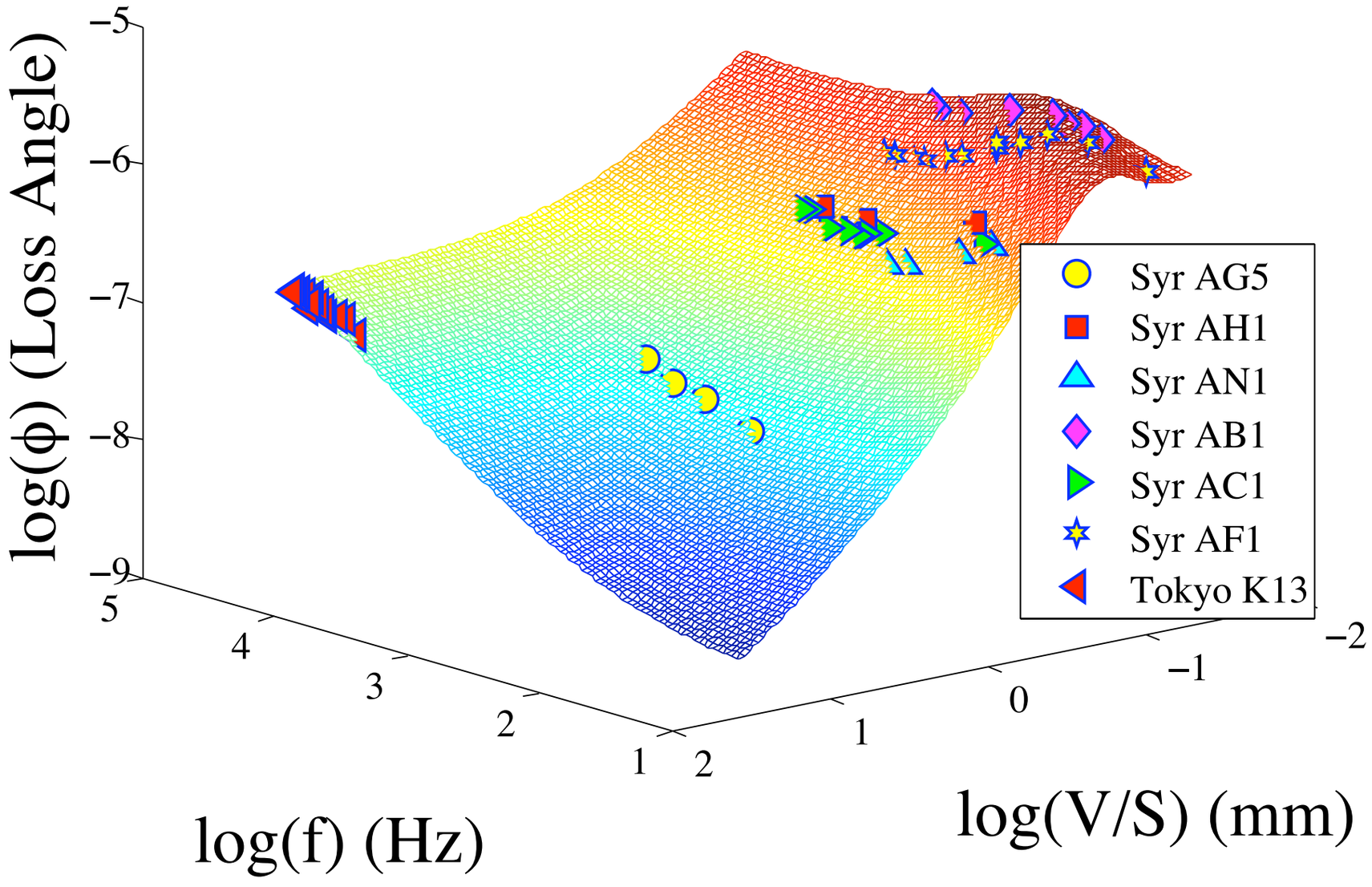
Fused Silica Loss Model

$$\phi = (6.52e{-}09\ S/V\ f^{0} + 7.64e{-}12\ f^{0.77} + 1\ \phi_{th})$$



Fused Silica Loss Model

$$\phi = (1.21\text{e}{-08}\ \text{S/V}\ f^{0} + 1.18\text{e}{-11}\ f^{0.77} + 0.614\ \phi_{th})$$



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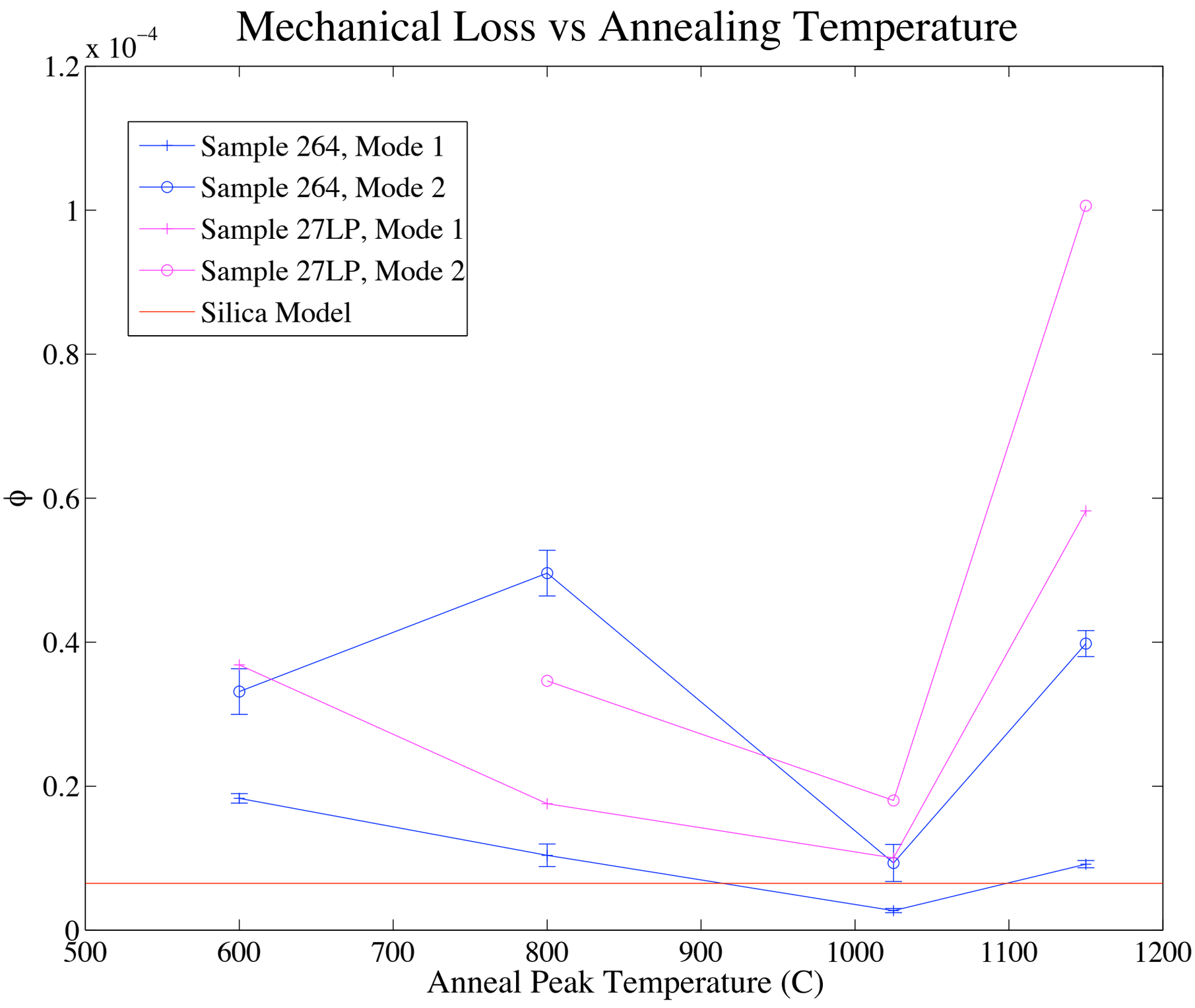
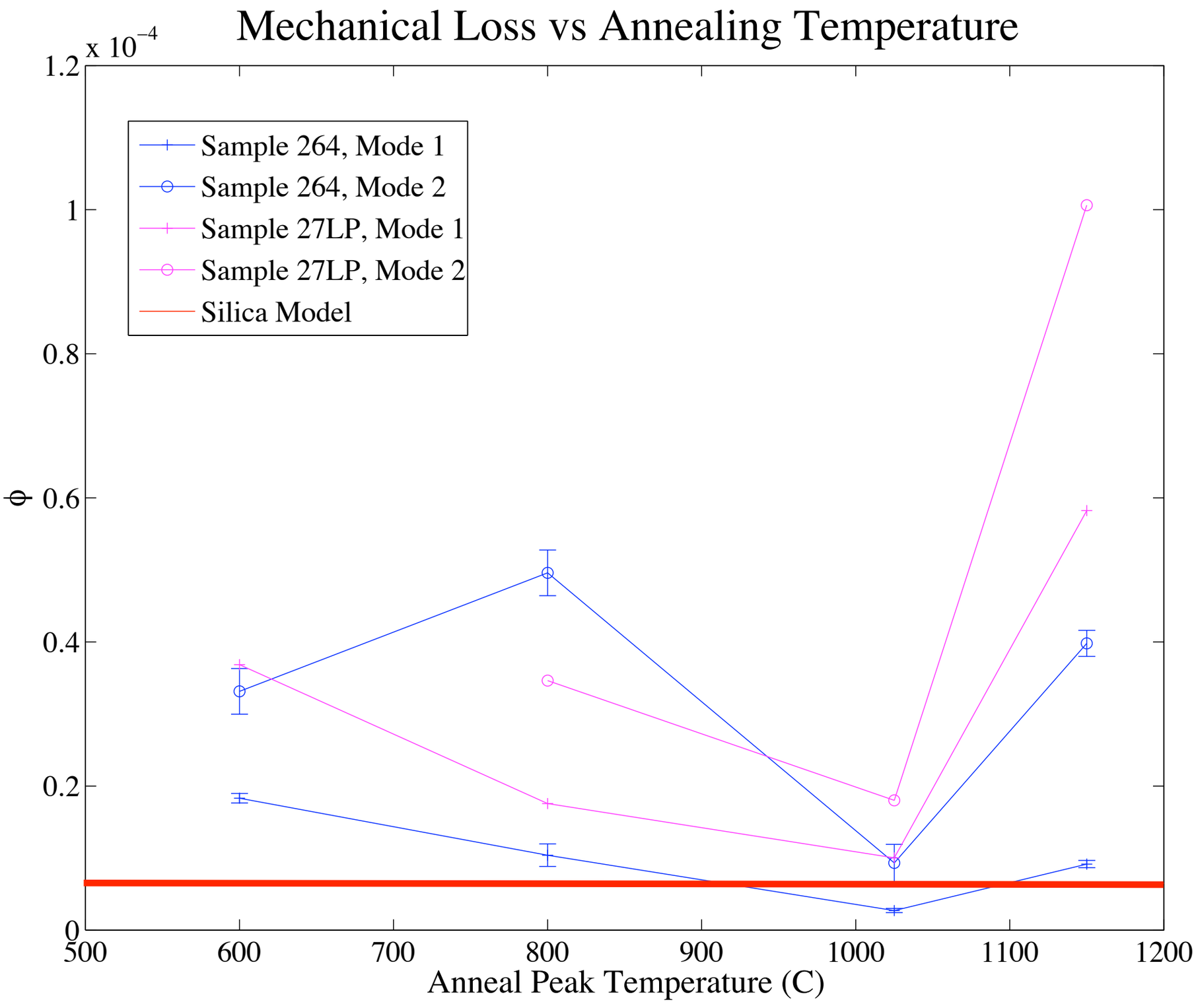
Fused Silica Coating Loss



Fused Silica Coating Loss



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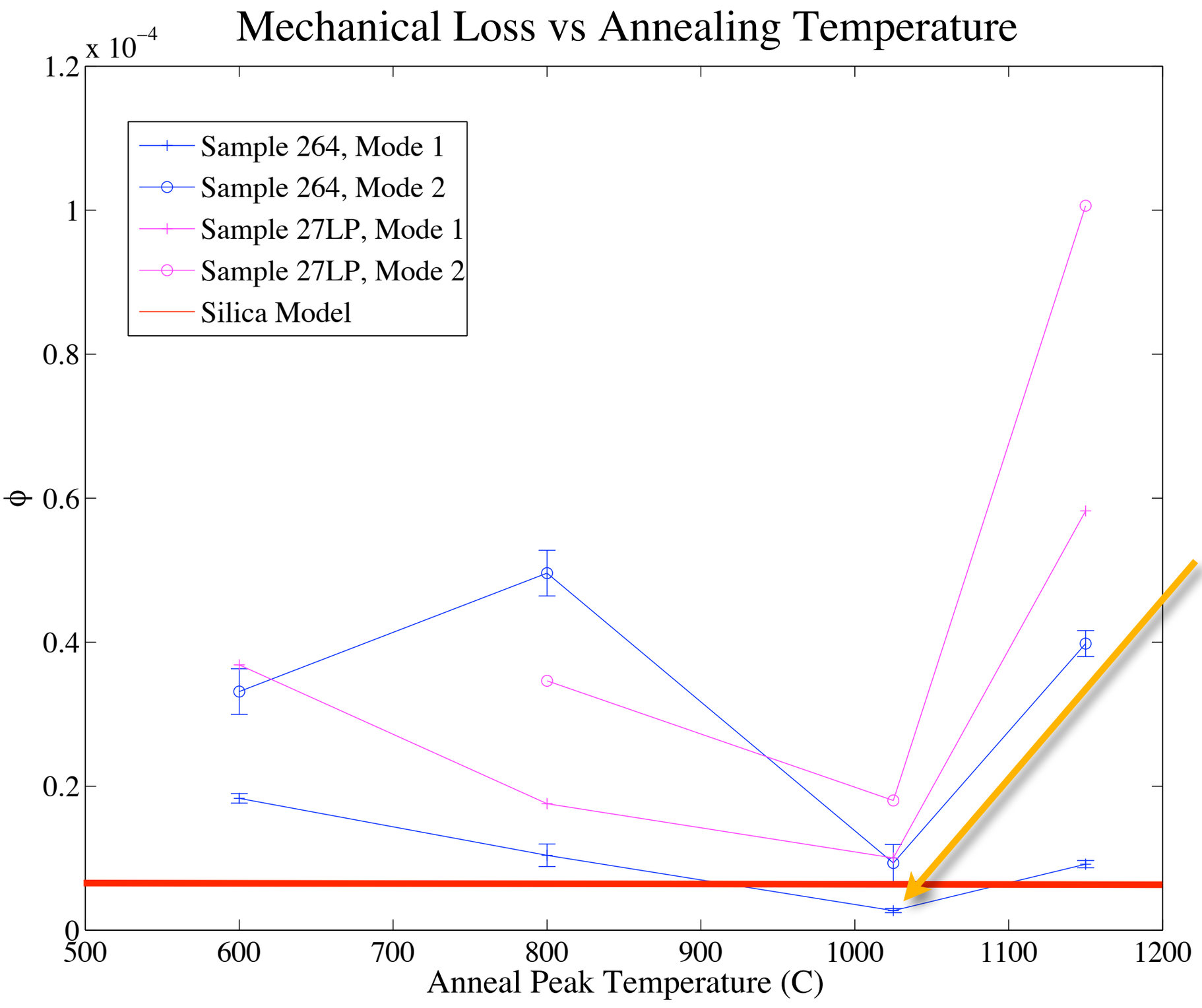
Fused Silica Coating Loss



$\phi = 2.7 \times 10^{-6}$

Does this sample violate the silica model?

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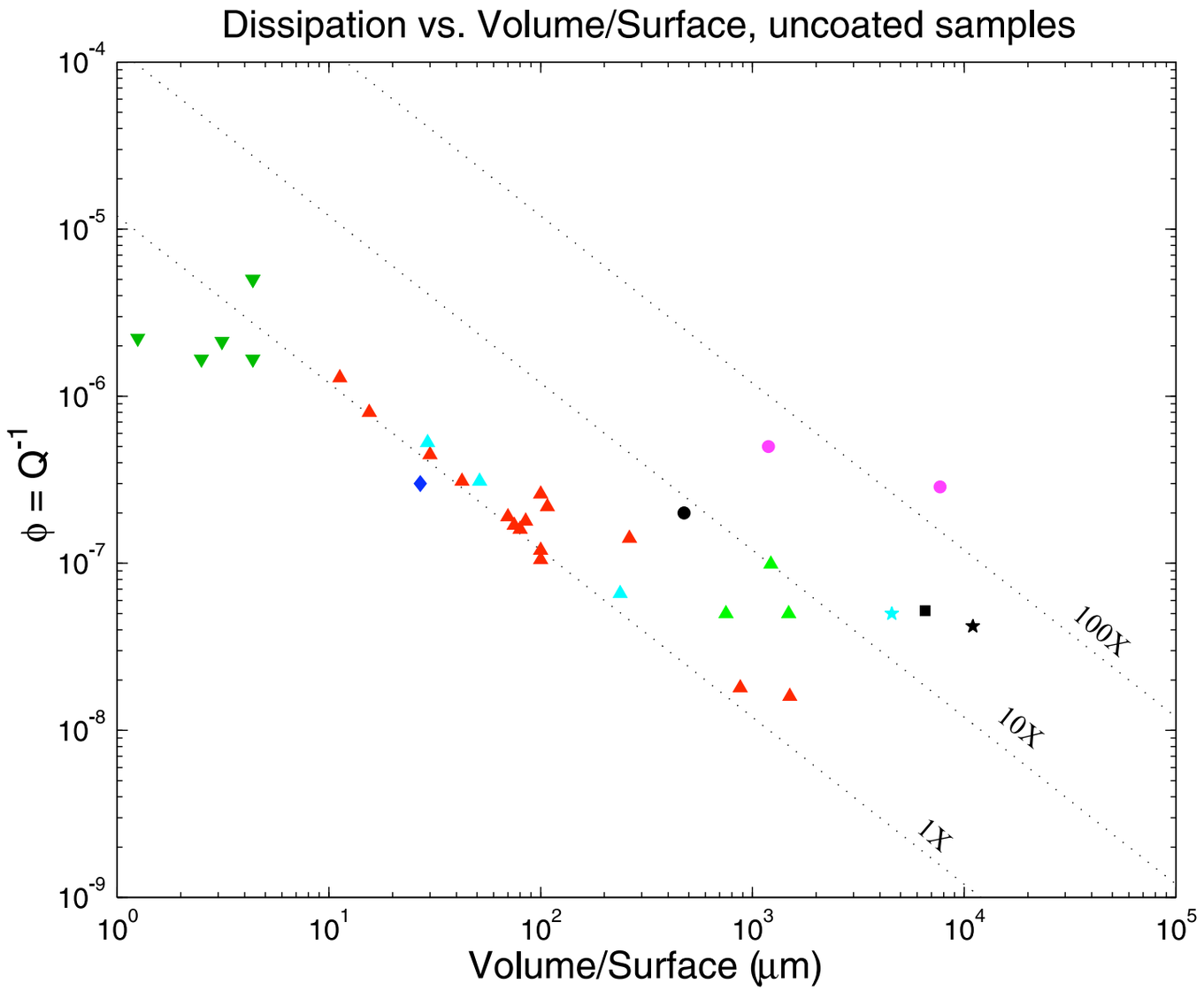
Fused Silica Surface Loss



- ▲ flame-drawn fibers -- (Cagnoli, Gretarsson, Harry, Penn, Schiller)
- ▲ extruded fibers -- (Gretarsson, Harry, Penn)
- ▲ HF-etched fibers -- (Gretarsson, Shiller)
- ★ chemically treated cylinder -- (Lunin)
- ● Microscope slide, commercial polish -- (Harry)
- ■ block, commercial polish -- (Startin)
- ★ cylinder, commercial polish -- (Cagnoli)
- ● disk, superpolished -- (Harry)
- ◆ RF oven-drawn fiber -- (Rowan)
- ▼ CO_2 laser drawn cantilever beam -- (Gorodetski)

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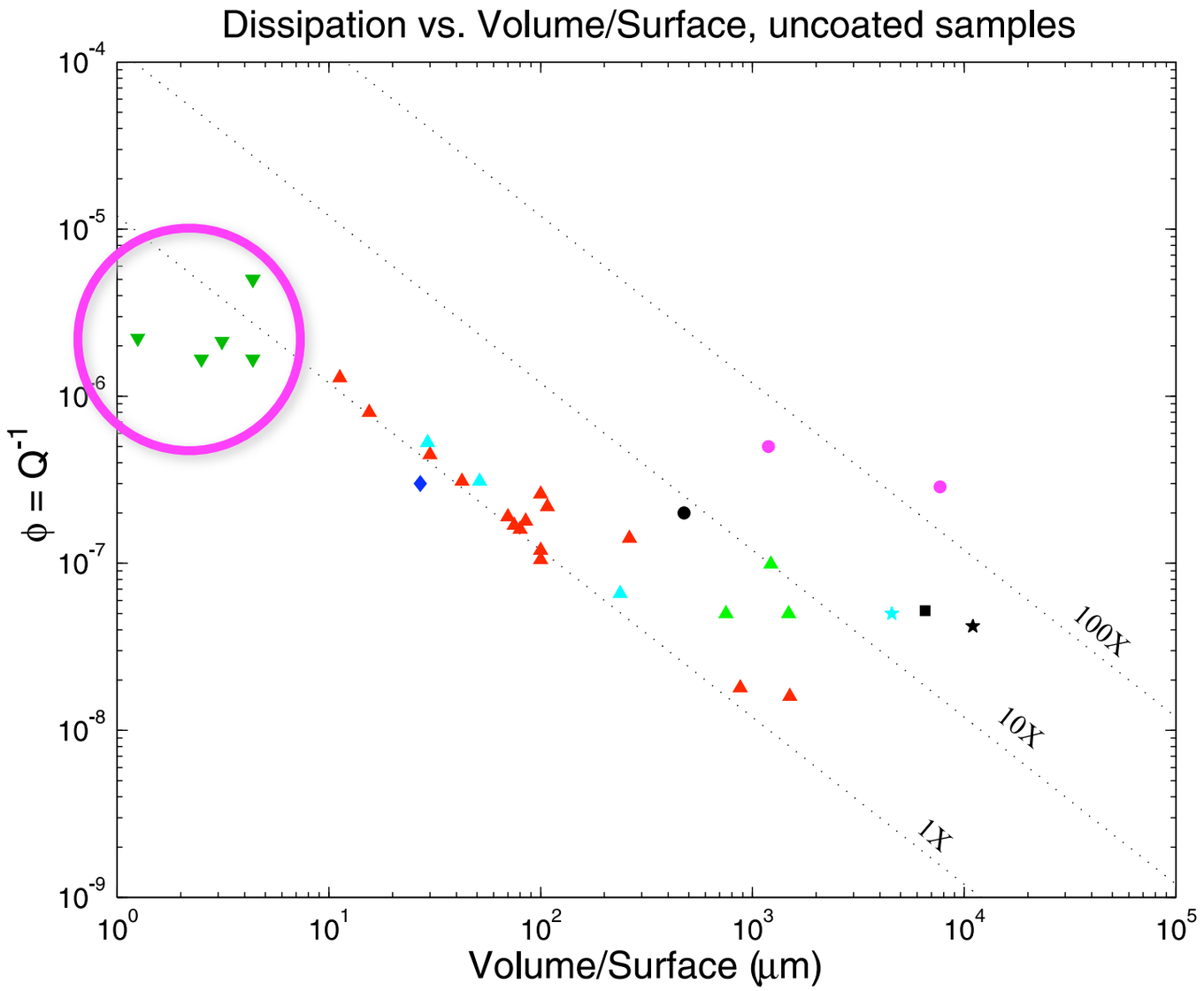
Fused Silica Surface Loss



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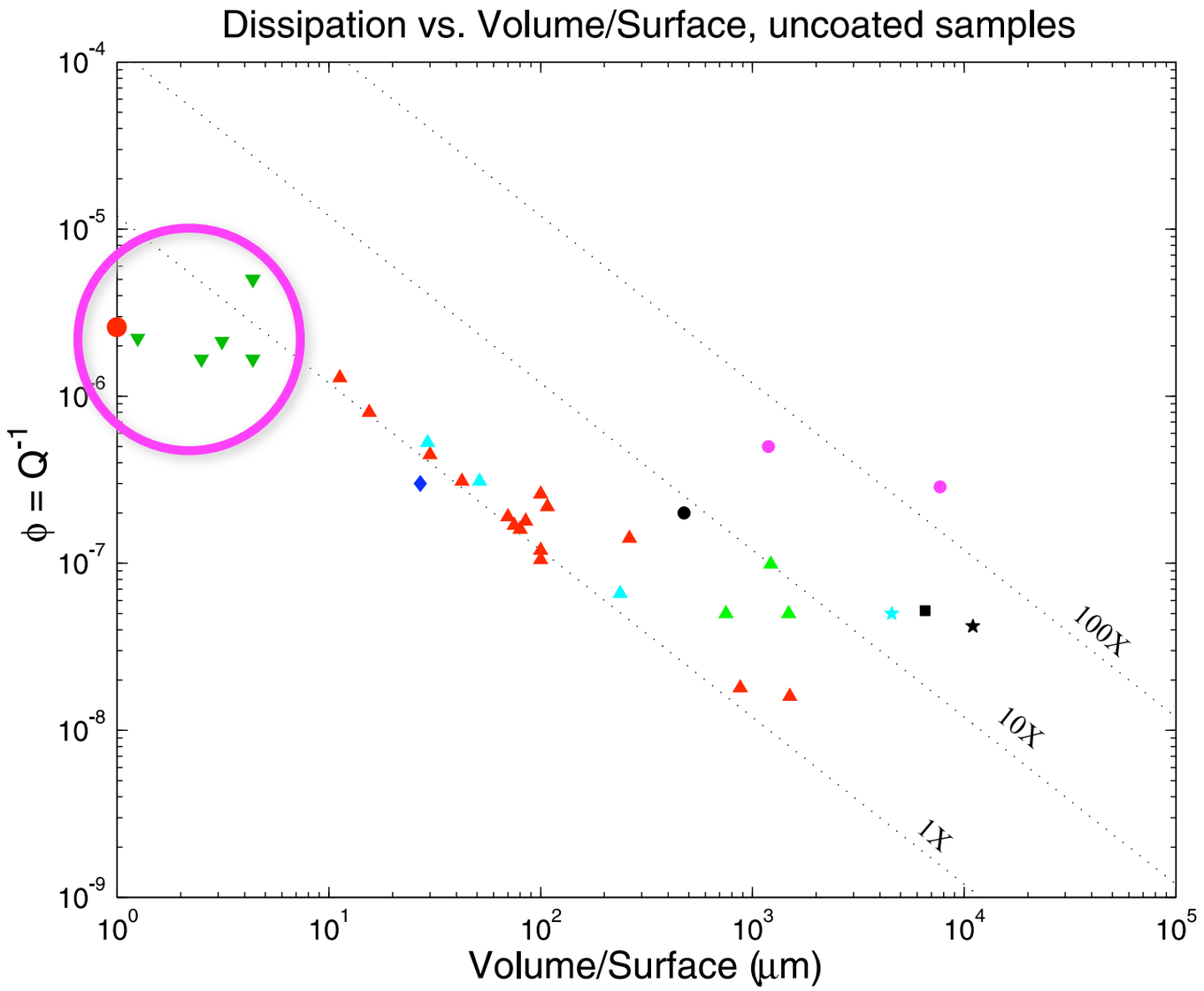
Fused Silica Surface Loss



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Silica/Alumina Coating

- Silica/Alumina Coating:
  - Choice of two low-index, low-mechanical loss materials
  - Additional ≈3x layers required for high reflectivity coating
  - Total loss could be lower if material losses sufficiently low
  - Both Materials may be annealed at high temperature.
  - Difference in CTE causes coating breakdown when annealing above 600 C.

- Loss Measurements
  - From vendor: $\phi = 6 \times 10^{-4}$
  - Annealed at 400 C: $\phi_{400^\circ\mathrm{C}} = 2.7 \times 10^{-4}$
  - Annealed at 600 C: $\phi_{600^\circ\mathrm{C}} = 1.7 \times 10^{-4}$
  - Silica coating after 600 C anneal: $\phi_{\mathrm{Silica}} = 1.7 \times 10^{-5}$

$$(Y\,s)_{\mathrm{total}}\phi_{\mathrm{total}} = (Y\,s)_{\mathrm{silica}}\phi_{\mathrm{silica}} + (Y\,s)_{\mathrm{alumina}}\phi_{\mathrm{alumina}}$$

  - Calculated Alumina Loss $\phi_{\mathrm{Alumina}} = 2.0 \times 10^{-4}$

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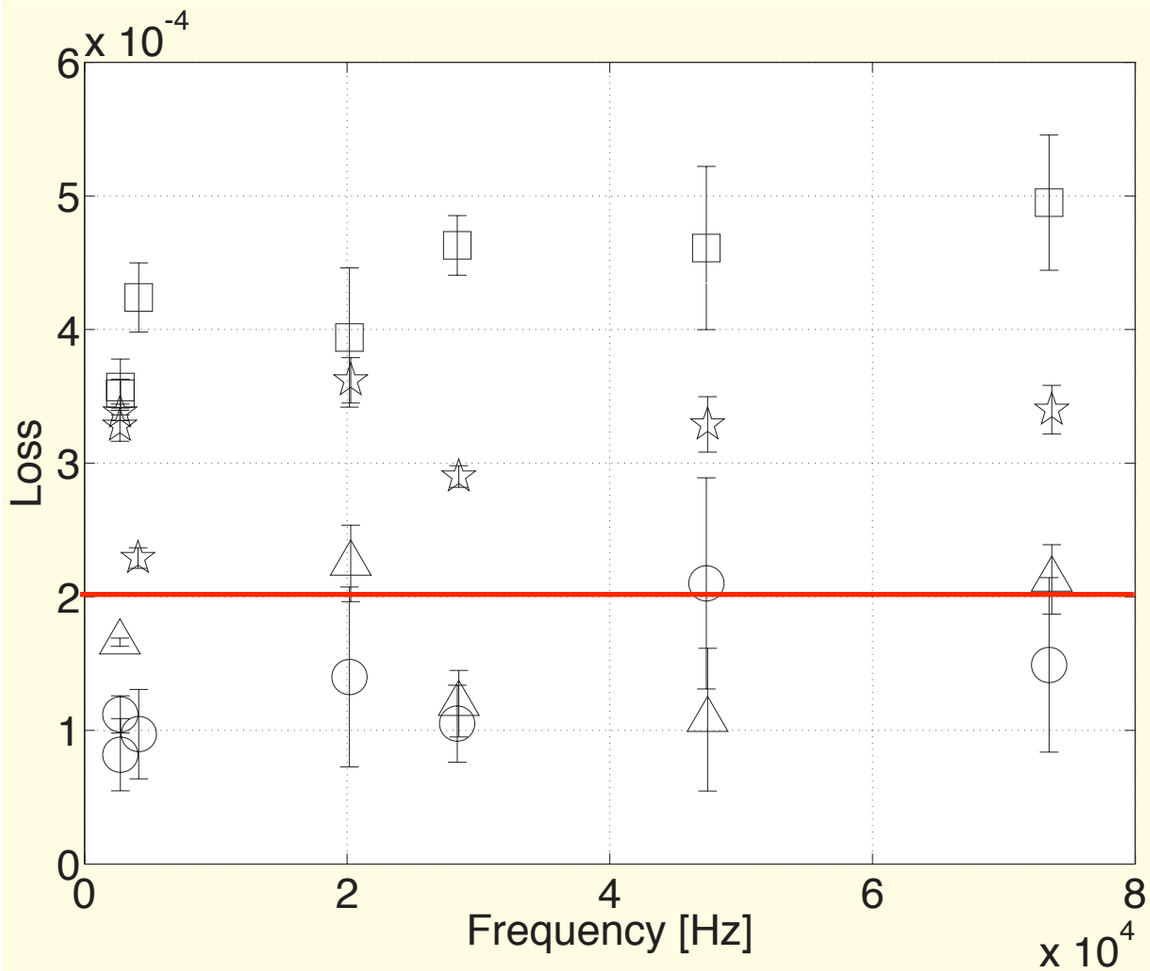
Silica/Alumina Coating



D.R.M. Crooks, et al.,
Class. Quantum Grav. 23 (2006)
4953-4965

Figure 4. Residual losses for SiO_2 (ϕ_{SiO_2}), Ta_2O_5 ($\phi_{Ta_2O_5}$) and Al_2O_3 ($\phi_{Al_2O_3}$) as a function of frequency. Note that for the Al_2O_3, losses are quoted for both the sample obtained from MLD and that obtained from Wave Precision.

- Calculated Alumina Loss $\phi_{\mathrm{Alumina}} = 2.0 \times 10^{-4}$

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New Directions

- Additional tests of silica with coating thickness
- Explore doping of small atoms (boron) into Alumina to lower CTE. Preserve coating at higher anneal T.