Fused Silica Research for Advanced LIGO

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Sapphire vs. Fused Silica

- High *Q*, ≈ 200 million (Willems, MSU, Glasgow)
- Higher Young's Modulus
- Higher Density
- Higher Thermal Conductivity

- Higher Optical Absorption
- High Thermoelastic Loss
- Less History as an Optical Material
- Expensive

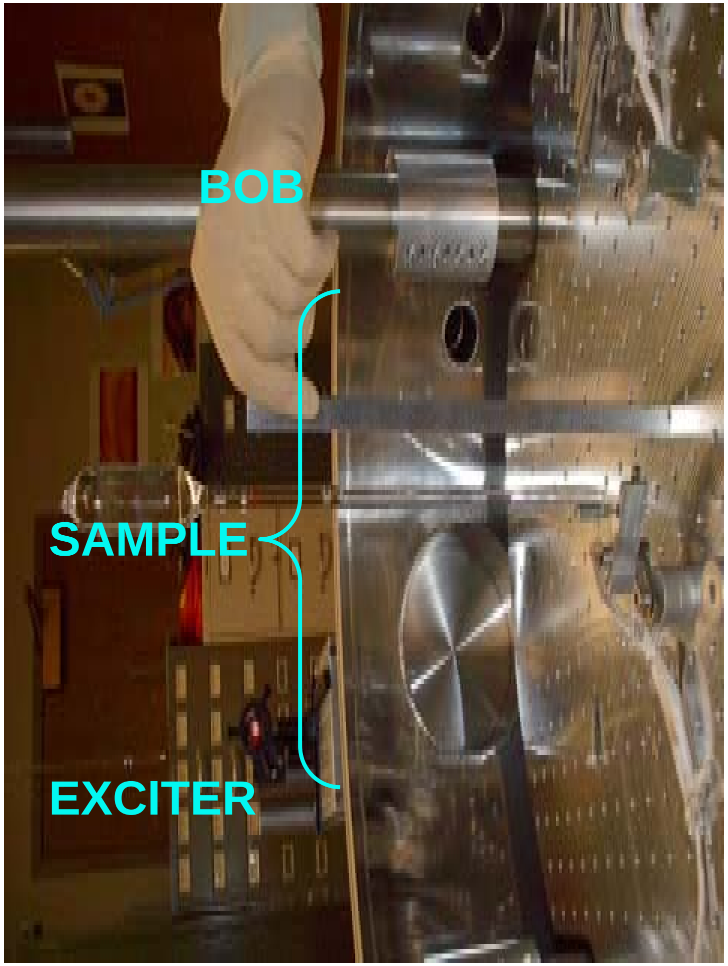
- High *Q* (but not consistantly)
  - 200 million Ageev/Penn - rods
  - 120 million, Willems - LIGO I optic
- Lower Young's Modulus
- Lower Density
- Lower Thermal Conductivity

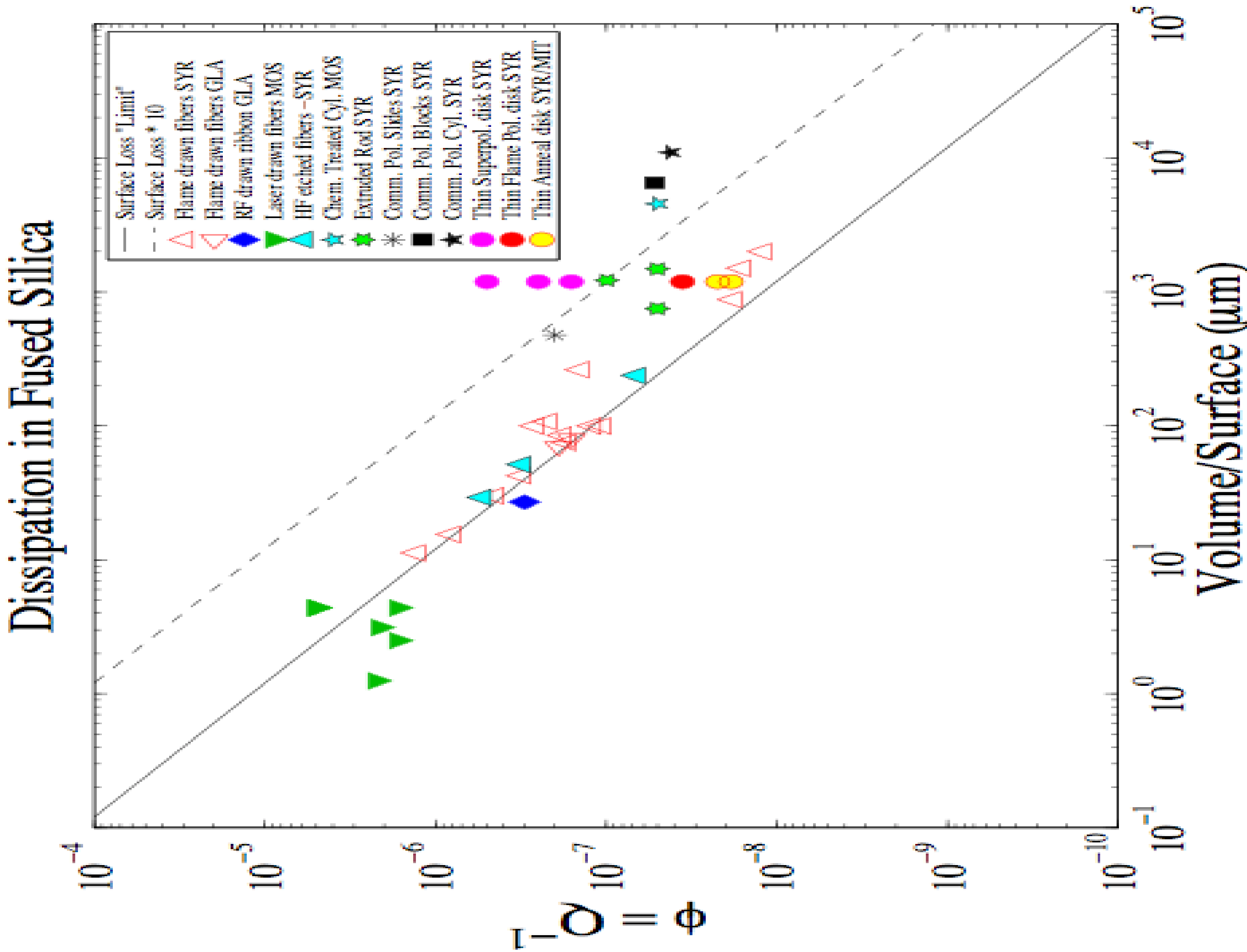
- Lower Optical Absorption
- Negligible Thermoelastic Loss
- Extensive History as an Optical Material
- Expensive

I am ignoring the elephant in our laboratory — **Coating Loss.**

Brief History of Silica Research

- Research has been conducted over the past several years to understand the fundamental loss mechanism in fused silica and produce extremely low loss FS optics suitable for Advanced LIGO. (Syracuse, Glasgow, Caltech, MSU, HWS)
- Experiments have been performed on fiber/rod samples over wide range of sizes reveal a clear surface loss dependence. Loss appears to be entirely in the surface.
- For each sample, loss also increases with frequency.
- Slowly “annealing” samples can lower loss, but not below the surface loss limit.

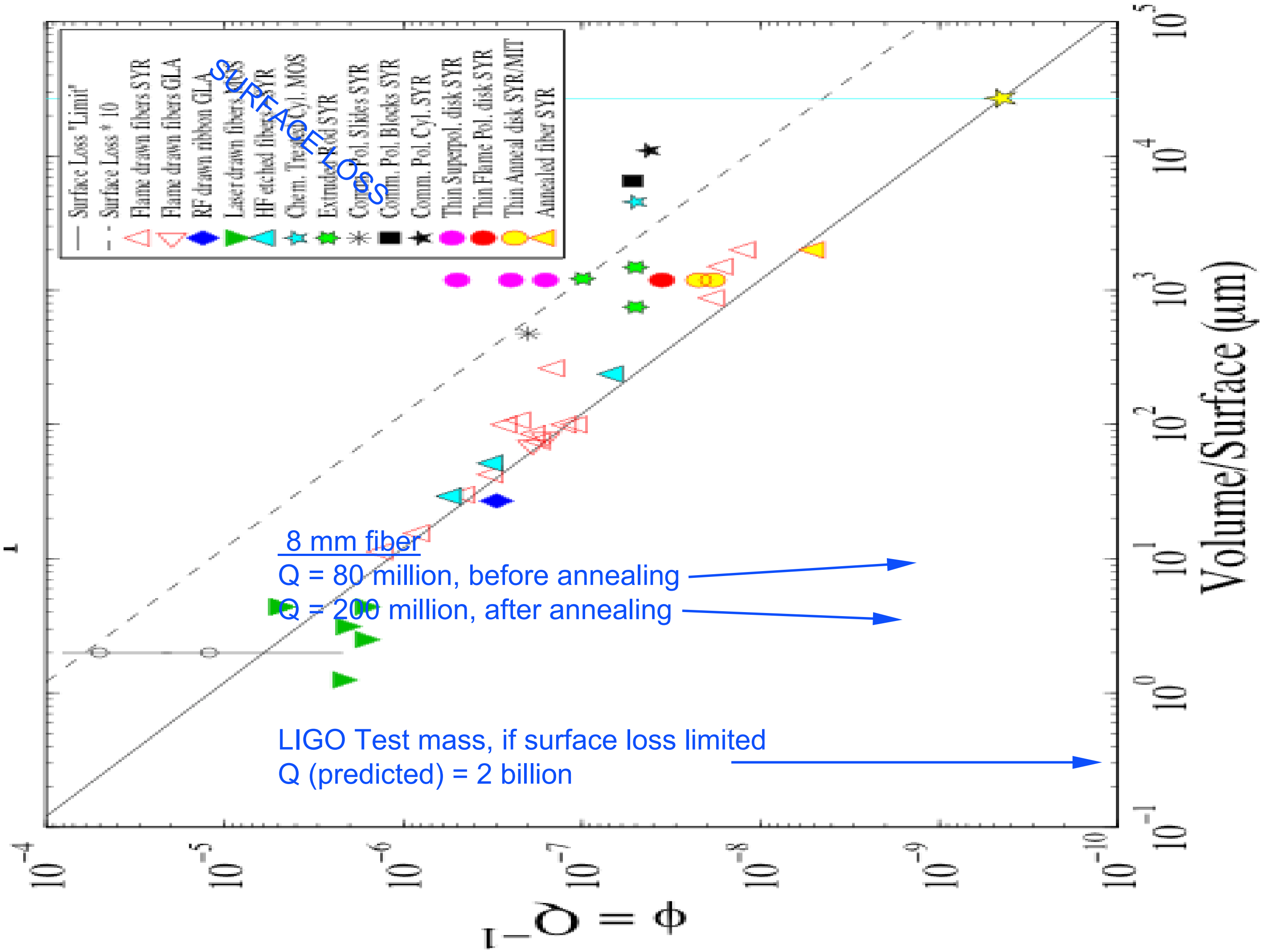



Dissipation in Fused Silica
Surface Loss "Limit"
Surface Loss * 10
Flame drawn fibers SYR
Flame drawn fibers GLA
RF drawn ribbon GLA
Laser drawn fibers MOS
HF etched fibers –SYR
Chem. Treated Cyl. MOS
Extruded Rod SYR
Comm. Pol. Slides SYR
Comm. Pol. Blocks SYR
Comm. Pol. Cyl. SYR
Thin Superpol. disk SYR
Thin Flame Pol. disk SYR
Thin Anneal disk SYR/MIT
$\phi = Q^{-1}$
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
Volume/Surface (μm)
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
10^{5}

Research Plan: August 2002

- Use newly refurbished fiber annealing oven to test for improvement in loss via annealing.
- Explore variations in *Q* with variety of fused silica.
- Measure *Q* of samples with increasing V/S ratio in order to determine the bulk loss.
- Break our highest Q sample.

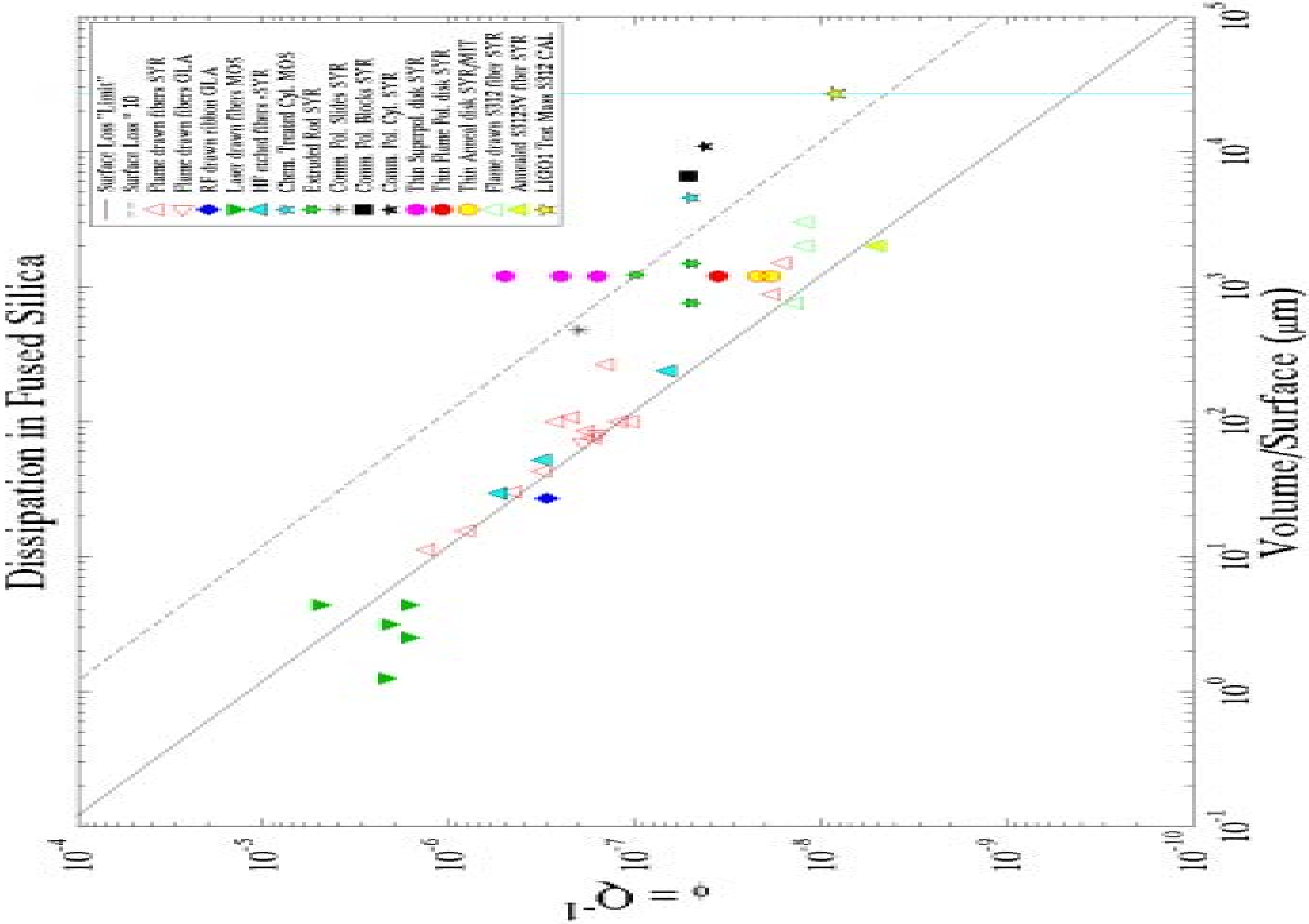
Surface Loss & the Effect of Annealing



Annealing: Benefits & Challenges

- Annealing can greatly lower the mechanical loss for samples above the surface loss limit, including superpolished samples.
- The loss after annealing will depend on the maximum temperature and the cool down rate of the annealing cycle. This parameter space is being explored, but high Q's make it time consuming.
- Low temperature anneals (600° C) yield large decrease in loss (≈ 10) for superpolished samples. (Standard Anneal temp. ≈ 11,000° C)
- Annealing could change surface figure, optical absorption, or silicate bonding to support structure.
- Cool down rate is geometry dependent and could be prohibitively long for Advanced LIGO masses.

What is the initial Q of LIGO masses?



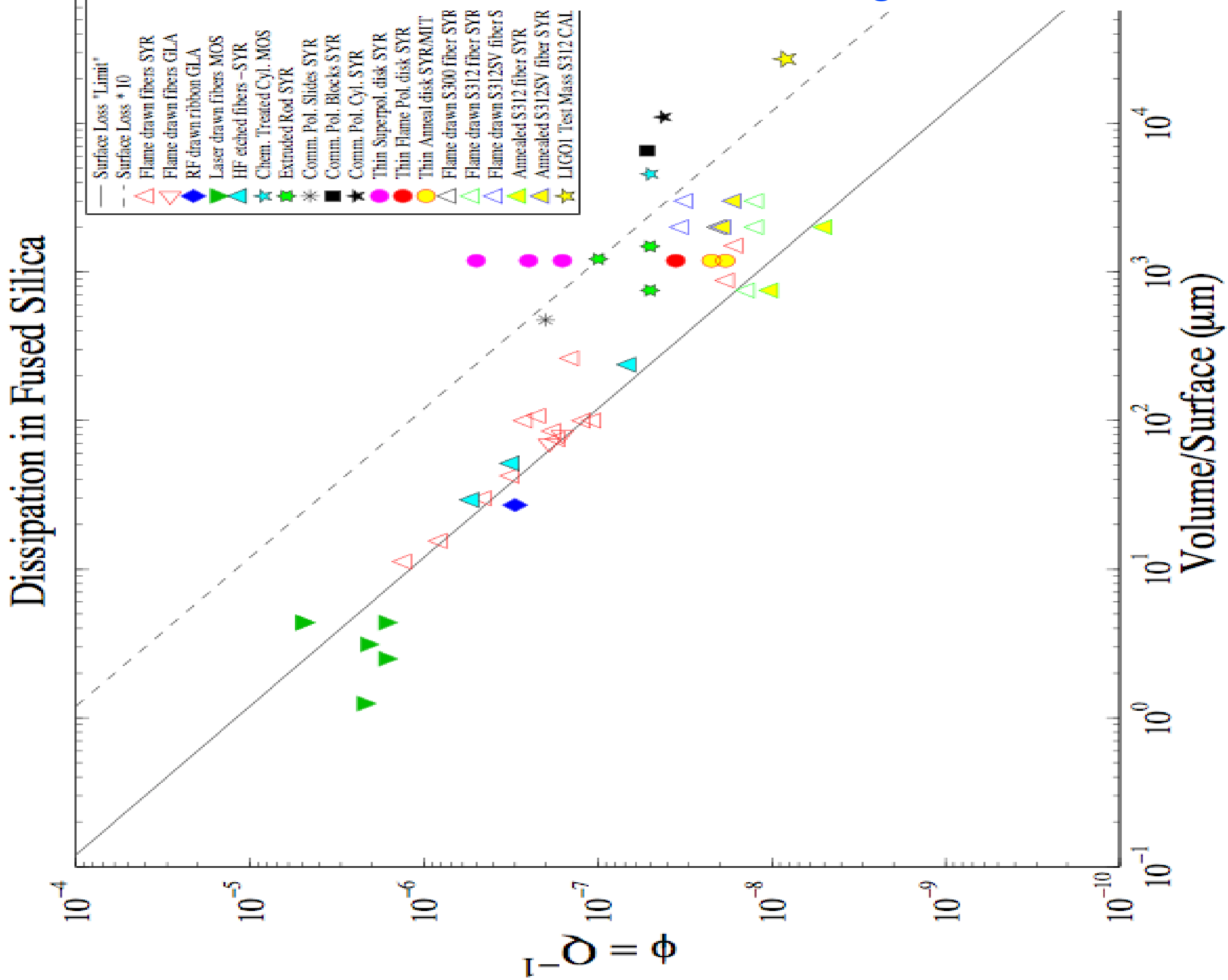
Silica Research Plan

(May 2003, LIGO-T030102-00-R)

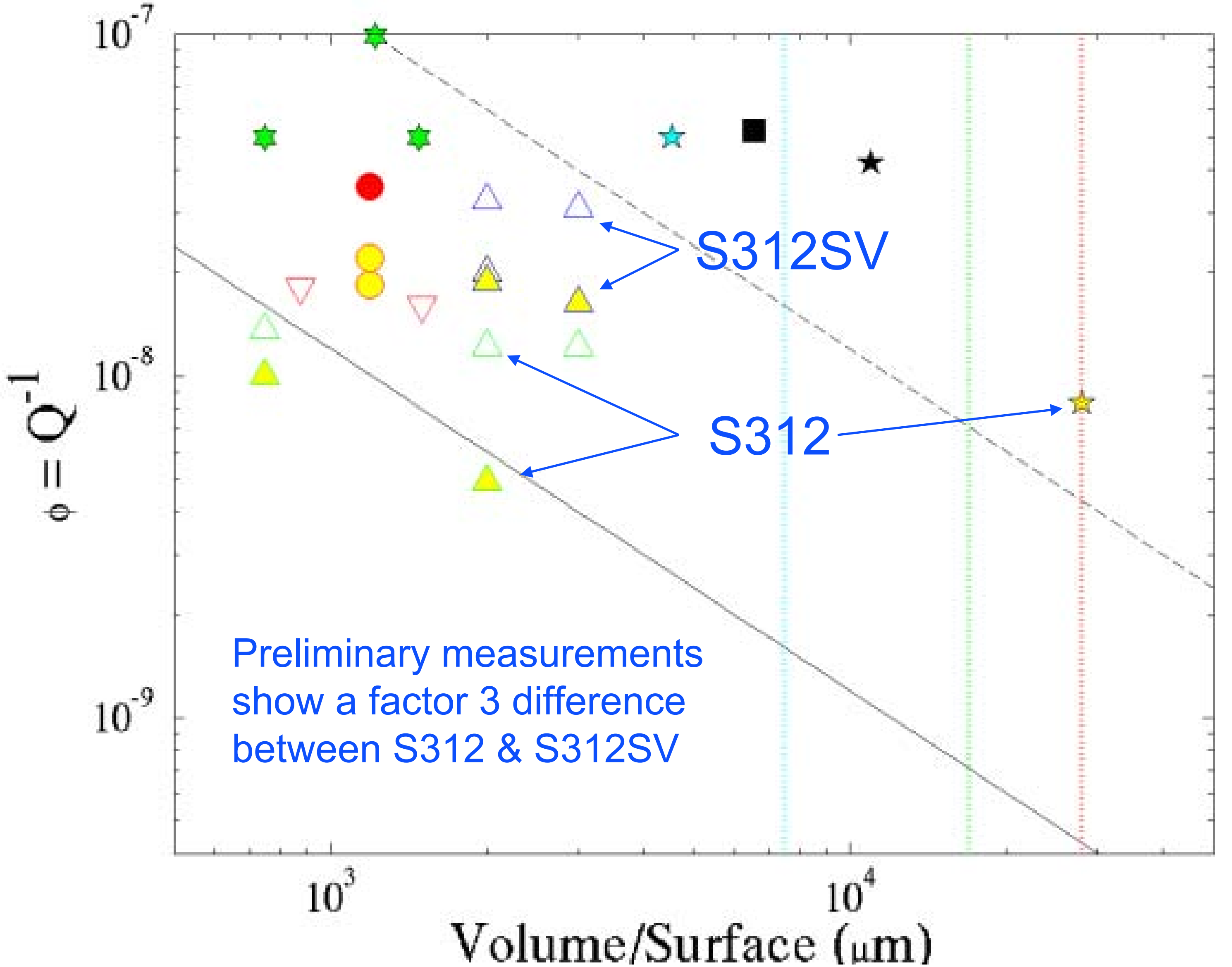
- Explore optimal annealing curve for flame-drawn rod samples and small superpolished disk samples as a function peak temperature and annealing atmosphere. Choose samples for 3 logarithmic steps up in V/S from current rod samples to LIGO I optics.
- Test dependence of mechanical loss on fused silica type. Thus far Heraeus Suprasil 312 has the lowest measured loss for each sample size and surface condition. Is this preliminary result is a real function of the material?
- Test annealed superpolished disks for changes in surface figure, contamination, and optical absorption. If repolishing is required, measure the effect on the mechanical loss. (Garilynn is investigating.)
- Test impact of annealing on the silicate bonds connecting the “ears” to the test mass.
- Test optimize annealing procedure on LIGO-sized uncoated optics.

LIGO

Measurements as of 14 August 2003



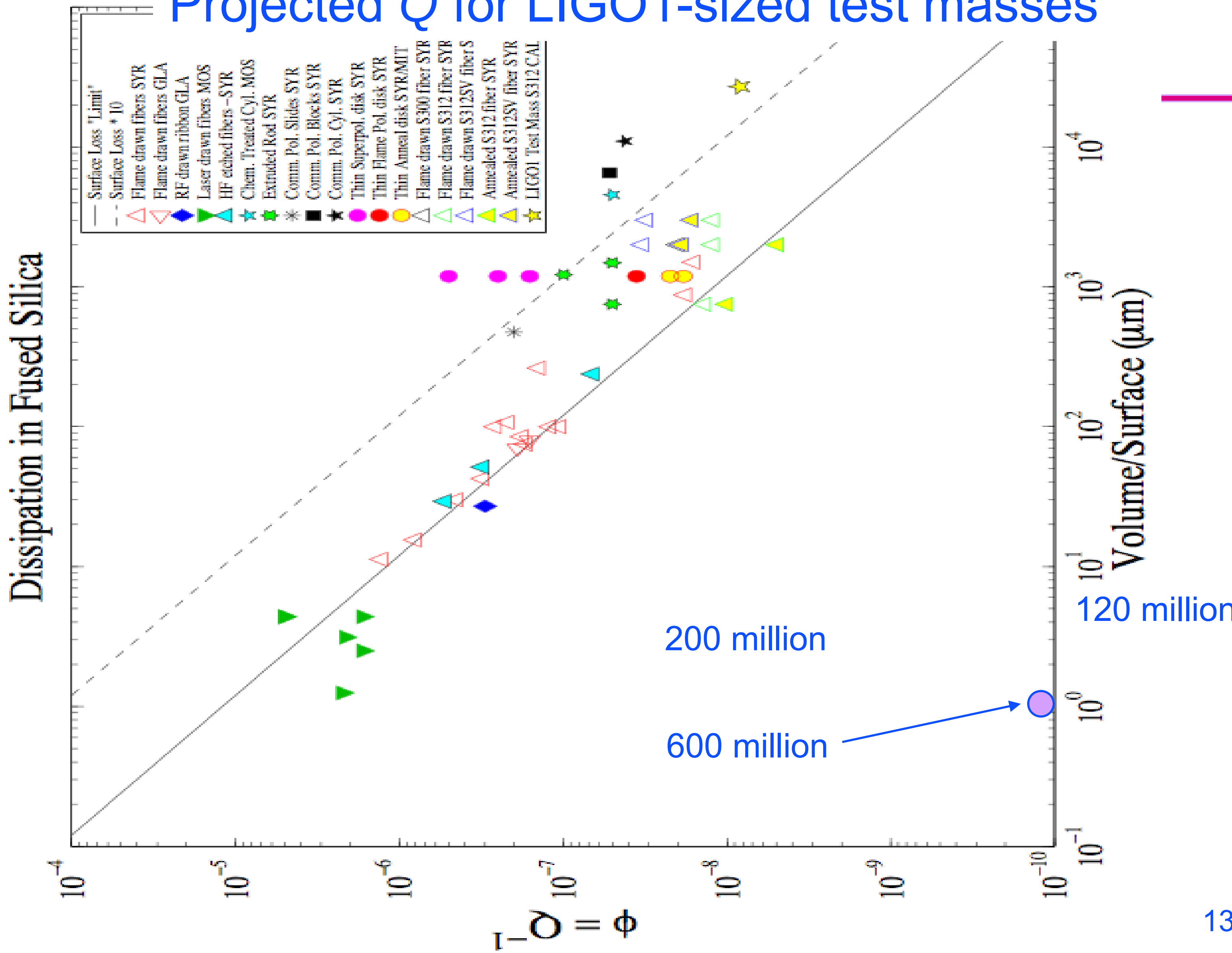
Q Dependence on Silica Type?



Differences between S312 & S312SV

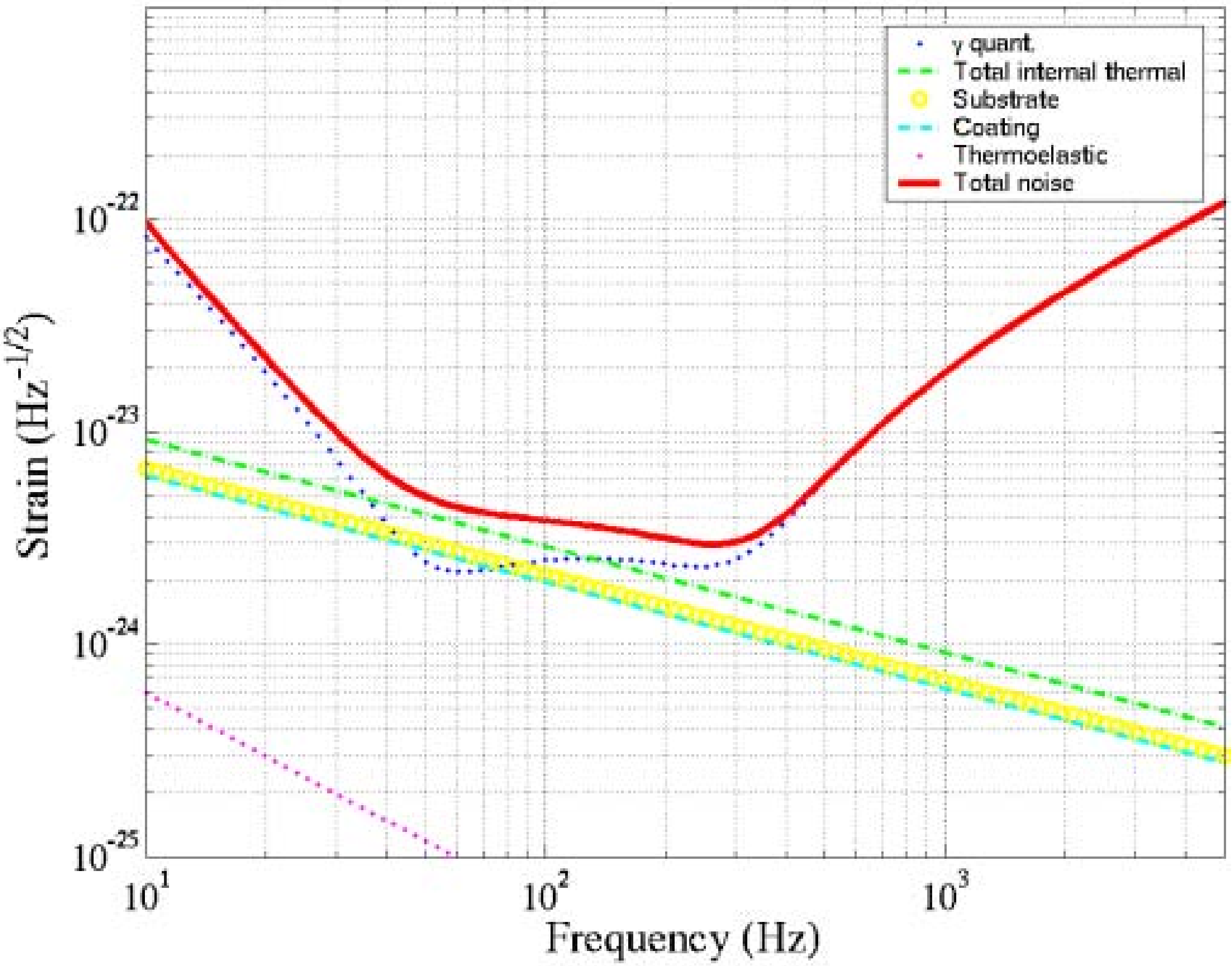
- Heraeus has provided limited insight into the differences between the Suprasil families: (S1, S2, S3), (S311, S312, S313), (S311SV, S312SV, S313SV).
  - » Manufacturing processes differ for each family (no details).
  - » No significant composition difference except for OH content.
  - » OH level affects the fictive temperature of the glass such that lowering OH raises the fictive temperature.
  - » Annealing temperature scales with fictive temperature. Heraeus suggests that a change in annealing temperature from 950 C upto 1050 C could be significant for S312SV.

Projected *Q* for LIGO1-sized test masses

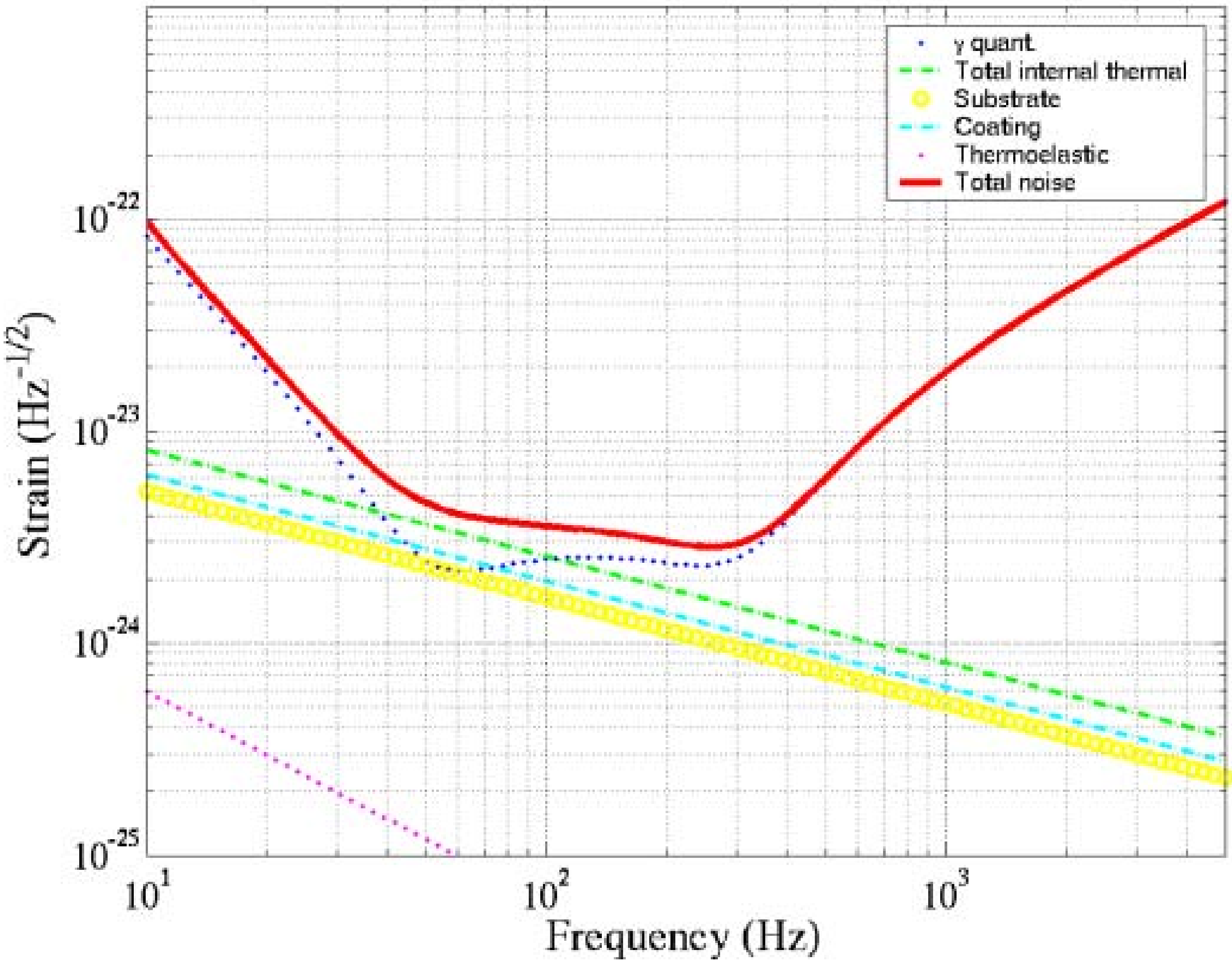


LIGO

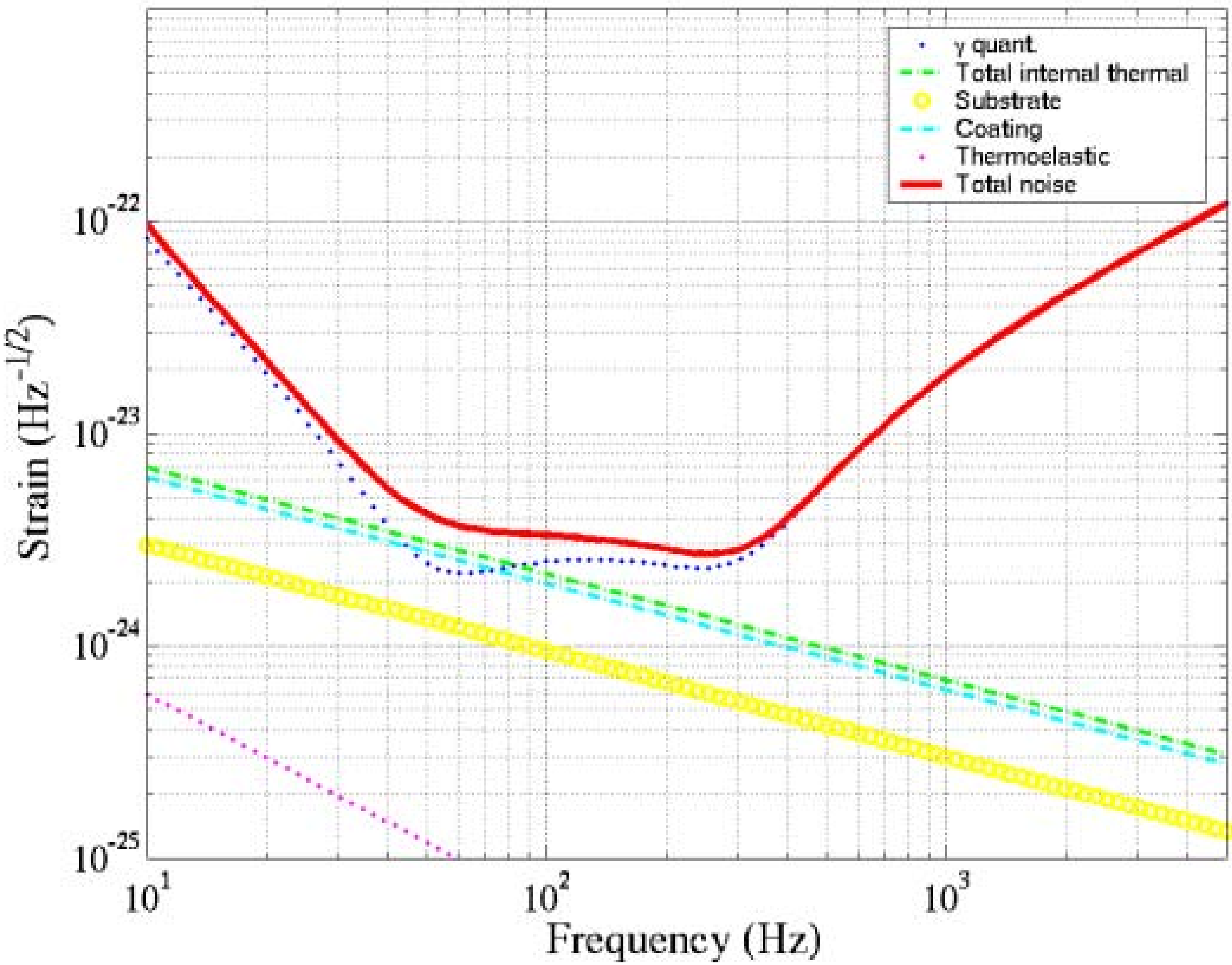
Q = 120 million, NSB Range = 185 Mpc



Q = 200 million, NSB Range = 196 Mpc



Q = 600 million,   NSB Range = 210 Mpc



Silica Research Plan

(Current Status)

- The differences between S312 and S312SV will be explored by changing the annealing cycle (peak temp) and additional samples.
- Samples are in limited supply for our tight timescale. We need to leapfrog using the few existing extra samples.
- Changes in surface figure must be known before we can anneal larger optics that we do not wish to damage.
- A *Q* during annealing experiment is being considered once the new large bell jar is online. Hopefully it will inform us on how best to optimize the annealing cycle.
- Test optimize annealing procedure on large (LIGO-sized?) uncoated optics.
- Coating Experiment

LIGO

Current Resources

- Large (1 m^3) Bell Jar in operation (SU)
- Large (1 m^3) Bell Jar being commissioned (HWS)
- Medium (0.3 m^3) Bell Jar in operation (HWS) for Coating and Silica work
- Fiber oven (inert gas)
- Box oven (air — pictured)
- Vacuum Annealing oven at RAL for hire
- Vacuum Annealing oven being purchased

The New Vacuum Annealing Furnace

(Special thanks to Beverly Berger & the NSF)