Coating Project Update

Gregory Harry
Massachusetts Institute of Technology
- On Behalf of the Coating Working Group -

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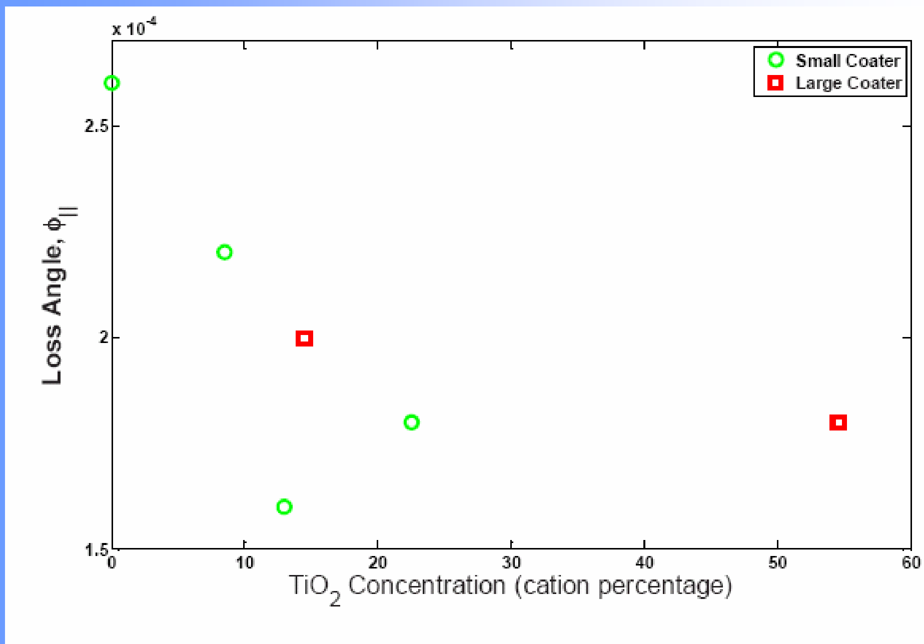
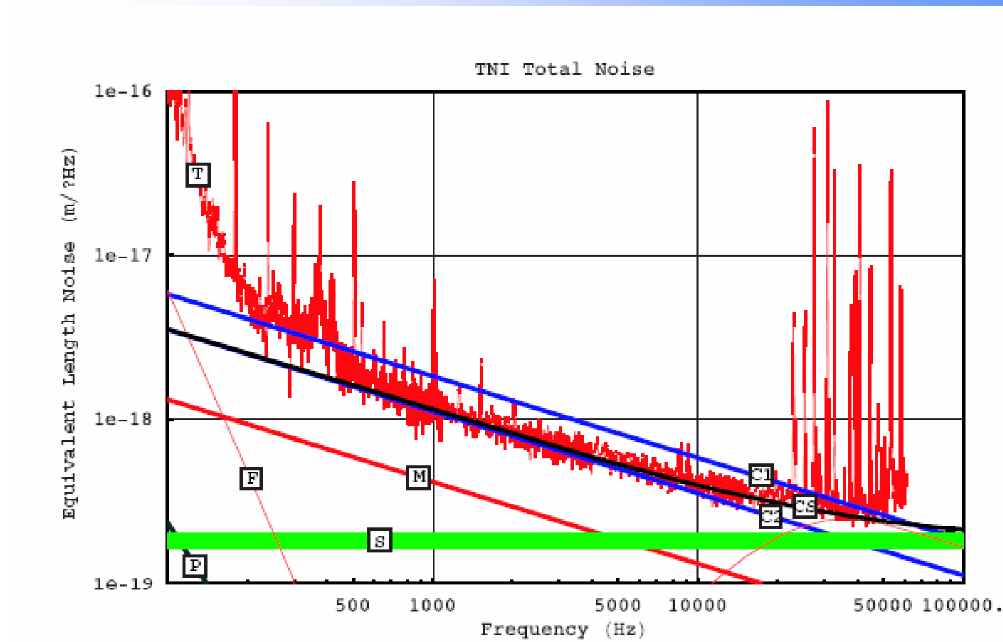
LSC Meeting – Baton Rouge
LIGO-G060384-00-R

Titania doped Tantala/Silica





Q Measurement

$\phi_{coat||} = 1.6\ 10^{-4}$

BNS Range 190 +/- 10 Mpc
BBH Range 1040 +/- 50 Mpc
Stochastic 1.1 +/- 0.1 10^{-9}

TNI Measurement

$\phi_{coat||} = 8.5\ 10^{-5}$

BNS Range 205 +/- 10 Mpc
BBH Range 1110 +/- 50 Mpc
Stochastic 1.1 +/- 0.1 10^{-9}

Silica doped Titania/Silica

Thin Sample – Run 1

Bubble, 50/50, 4.3 μm, 87 GPa

f_{mode}	Q	ϕ
2808	$5.7\ 10^5$	$3.1\ 10^{-4}$
2811	$4.3\ 10^5$	$4.1\ 10^{-4}$
4250	$5.2\ 10^5$	$3.2\ 10^{-4}$
6393	$5.8\ 10^5$	$3.0\ 10^{-4}$
6395	$5.9\ 10^5$	$3.0\ 10^{-4}$
9835	$5.1\ 10^5$	$3.2\ 10^{-4}$

Thin Sample – Run 2

65/35, 4.8 μm, 73 GPa

f_{mode}	Q	ϕ
2809	$9.2\ 10^5$	$1.8\ 10^{-4}$
4239	$7.8\ 10^5$	$2.2\ 10^{-4}$
6391	$8.6\ 10^5$	$2.1\ 10^{-4}$
6394	$9.5\ 10^5$	$1.9\ 10^{-4}$
9808	$8.4\ 10^5$	$2.1\ 10^{-4}$

Thick Sample – Run 1

f_{mode}	Q
20225	$5.01 +/- 0.0976\ 10^6$
28475	$4.30 +/- 0.114\ 10^6$
47448	$7.30 +/- 0.357\ 10^6$
73558	$4.56 +/- 0.146\ 10^6$

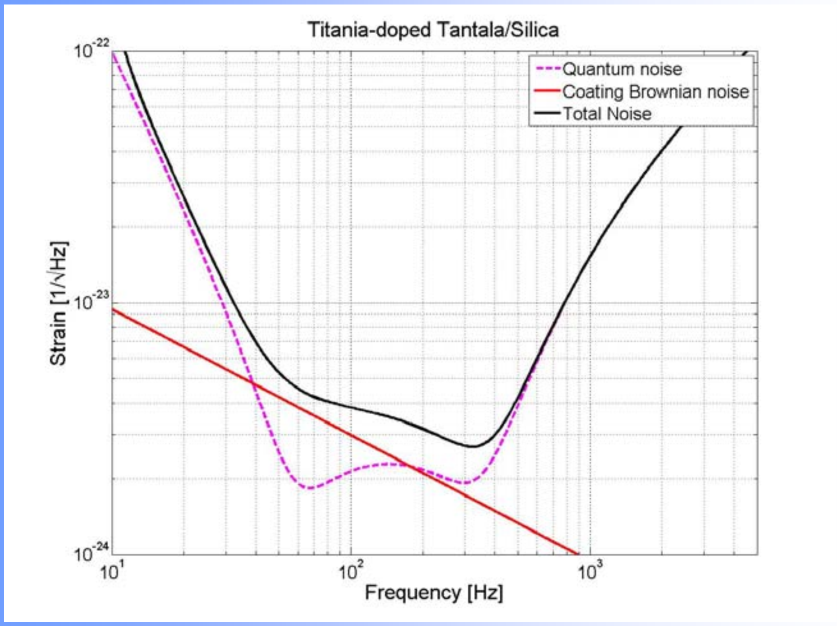
Full frequency analysis of thick samples gives at 100 Hz:

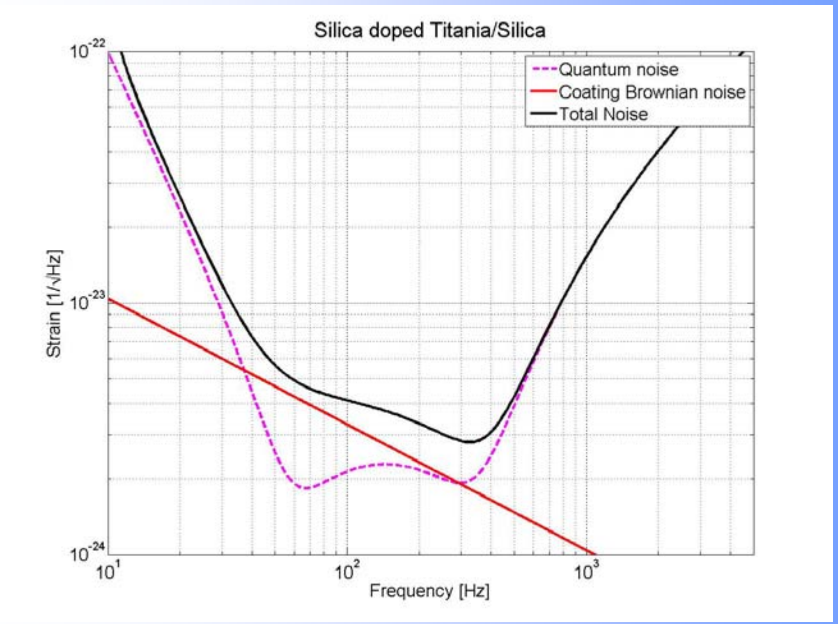
$\phi = 2.4 +/- 0.9\ 10^{-4}$

	Absorption	Index
Run 1	1.5 ppm	2.15
Run 2	0.5 ppm	1.85

XPS analysis at CSIRO shows about 50% SiO_2, 50% TiO_2, with 0.1% Ta from support wire for Run 1.

Coating Comparison





Titania doped Tantala/Silica

Young's modulus higher than silica
High index -> Less layers
Working on bringing absorption < 1 ppm

BNS Range 190 +/- 10 Mpc
BBH Range 1040 +/- 50 Mpc
Stochastic 1.1 +/- 0.1 10^{-9}

Silica doped Titania/Silica

Young's modulus close to silica
Low index -> More layers
Demonstrated absorption 0.5 ppm
Need information on scatter

BNS Range 165 +/- 10 Mpc
BBH Range 910 +/- 50 Mpc
Stochastic 1.3 +/- 0.1 10^{-9}
Reach very sensitive to index and Y

Pure Tantala

Thin Sample Results
CSIRO 1.8 μm

	f (Hz)	ϕ
Mode 7	2674	$5.8\ 10^{-4}$
Mode 8	2674	$5.5\ 10^{-4}$
Mode 9	4032	$6.2\ 10^{-4}$
Mode 10	6094	$6.1\ 10^{-4}$
Mode 12	9340	$6.2\ 10^{-4}$

Thin Sample Results
CSIRO 4.65 μm, -220 MPa Stress

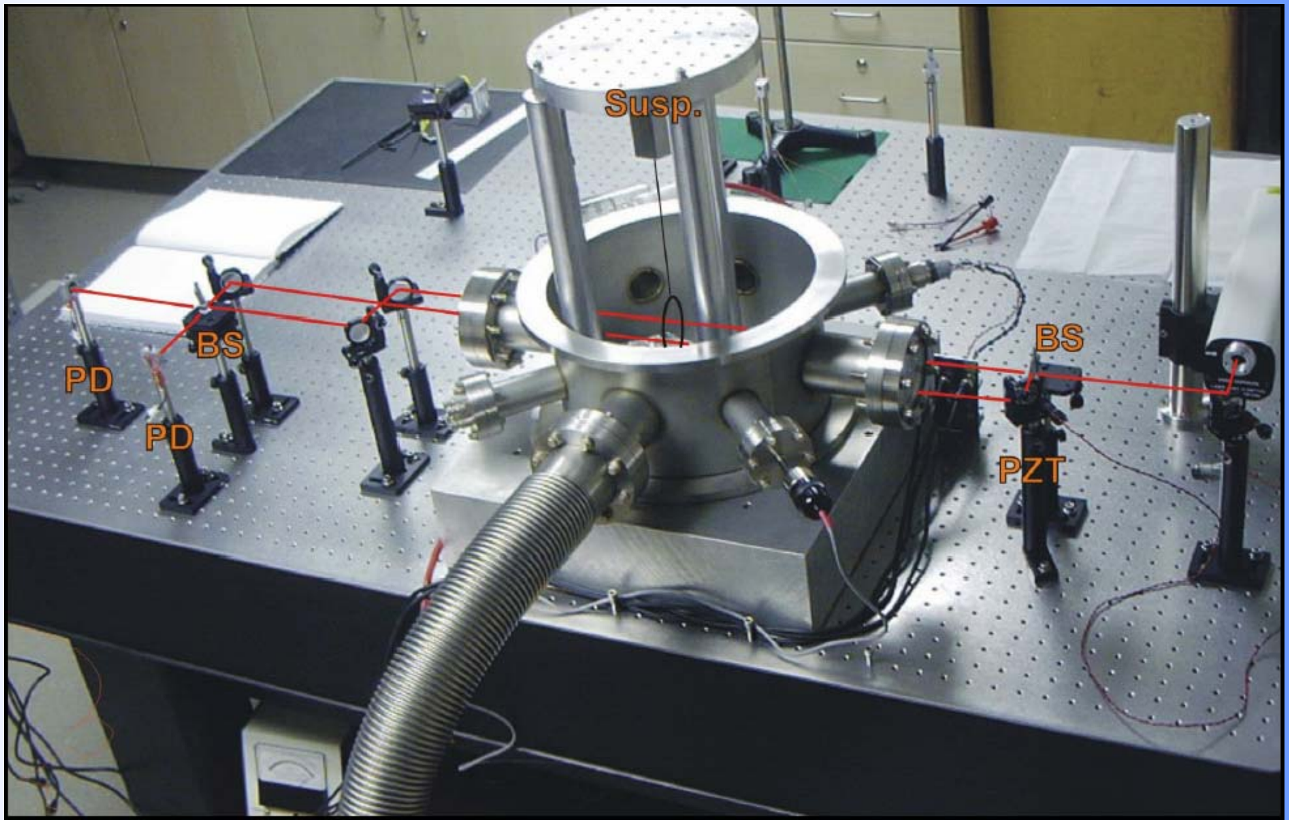
	f (Hz)	ϕ
Mode 7	2707	$1.3\ 10^{-3}$
Mode 8	2709	$9.3\ 10^{-4}$
Mode 9	4088	$8.7\ 10^{-4}$
Mode 10	6168	$8.5\ 10^{-4}$
Mode 12	9423	$9.9\ 10^{-4}$

Thin Sample Results
CSIRO 4.65 μm, unannealed

	f (Hz)	ϕ
Mode 7	2719	$1.5\ 10^{-3}$
Mode 8	2720	$1.6\ 10^{-3}$

ERAU Coating Q Setup

- Mach-Zender interferometer readout
  - Cancels low frequency modes
  - More sensitive than birefringence
- Thin sample, monolithic welded silica suspension
- Making measurements this week



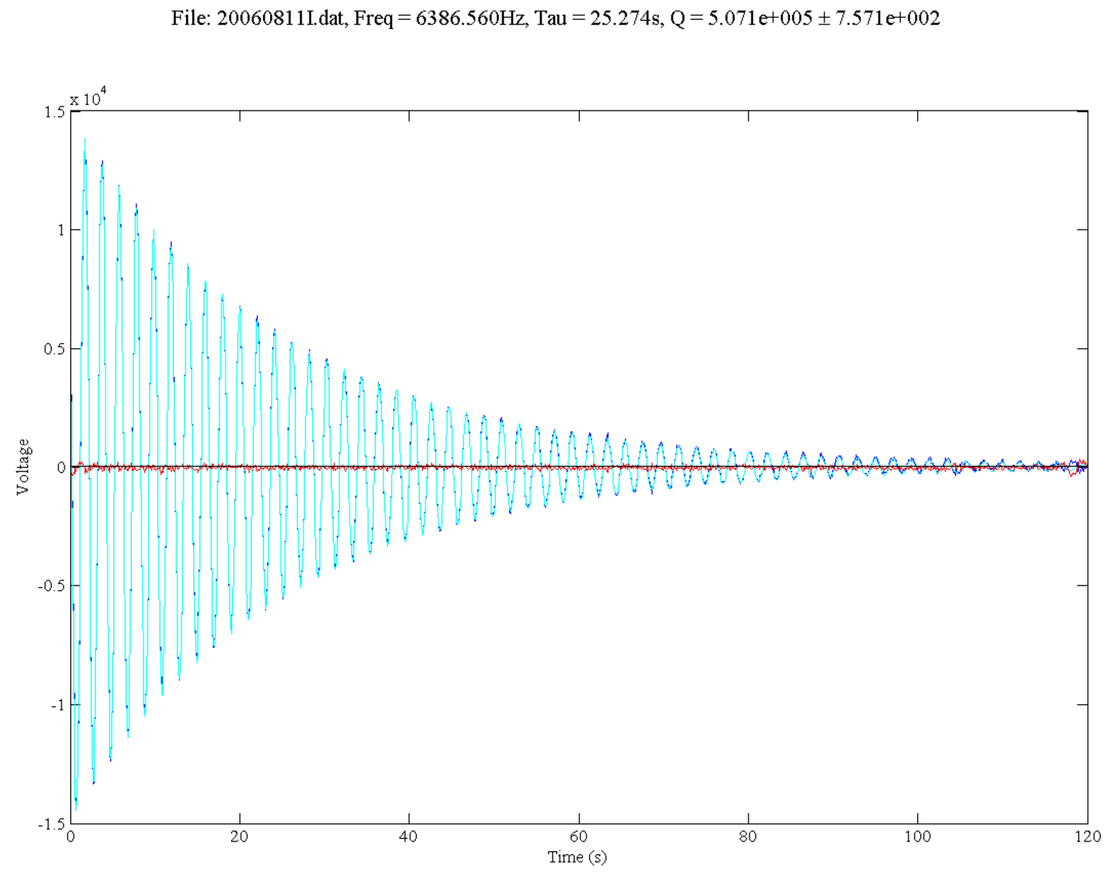
Silica doped Tantala / Silica

Thin Sample Results
35/65 Si/Ta - CSIRO

f (Hz)	Q	ϕ
2806	$5.2\ 10^{5}$	$3.3\ 10^{-4}$
2812	$5.0\ 10^{5}$	$3.5\ 10^{-4}$
4241	$4.7\ 10^{5}$	$3.5\ 10^{-4}$
6387	$5.0\ 10^{5}$	$3.5\ 10^{-4}$
6397	$4.9\ 10^{5}$	$3.5\ 10^{-4}$
9817	$4.7\ 10^{5}$	$3.5\ 10^{-4}$

n = 1.9
Y = 76 GPa
Annealed 24 h at 600 C

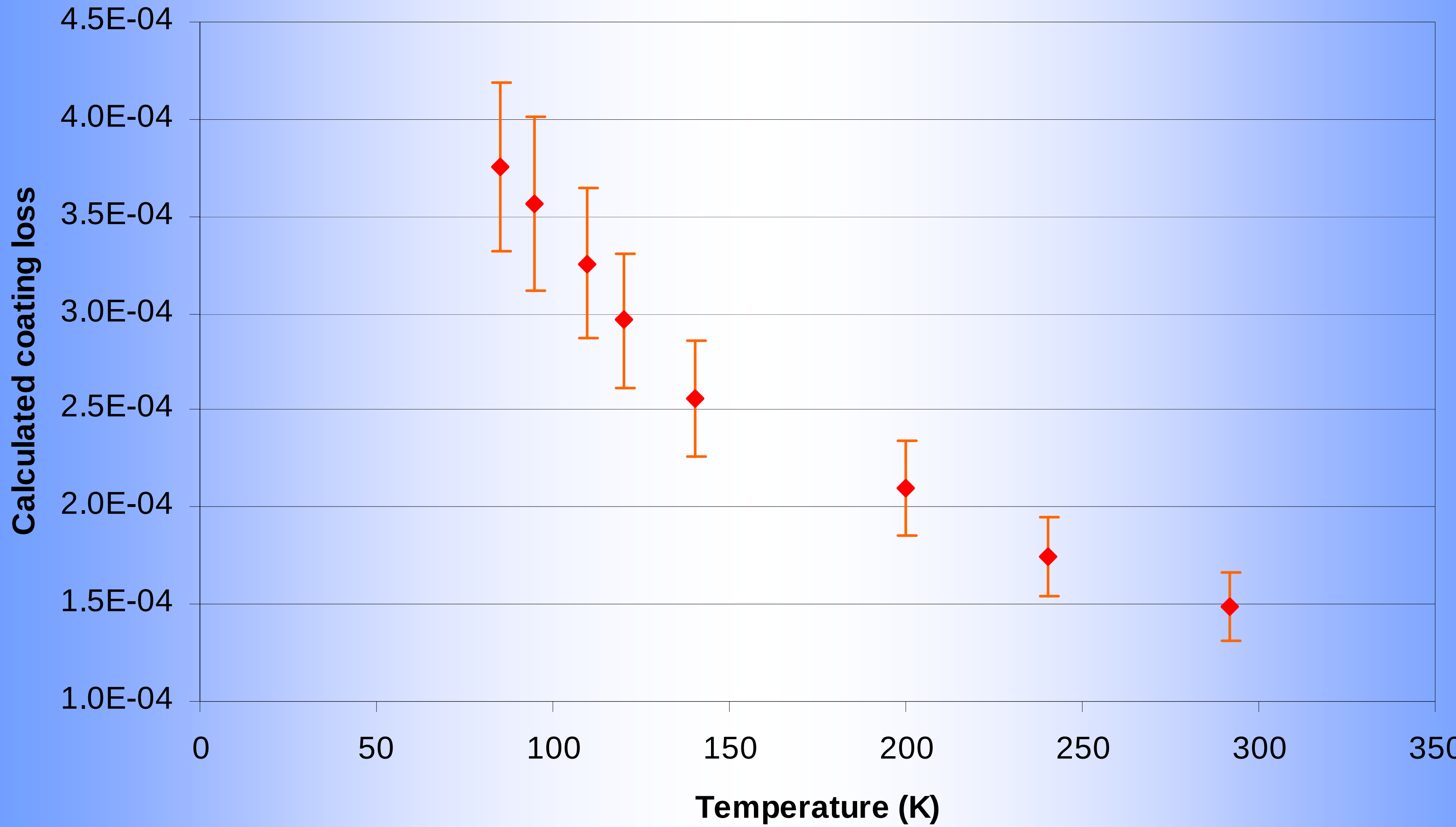
BNS Range 150 Mpc



Q Measurements in Progress

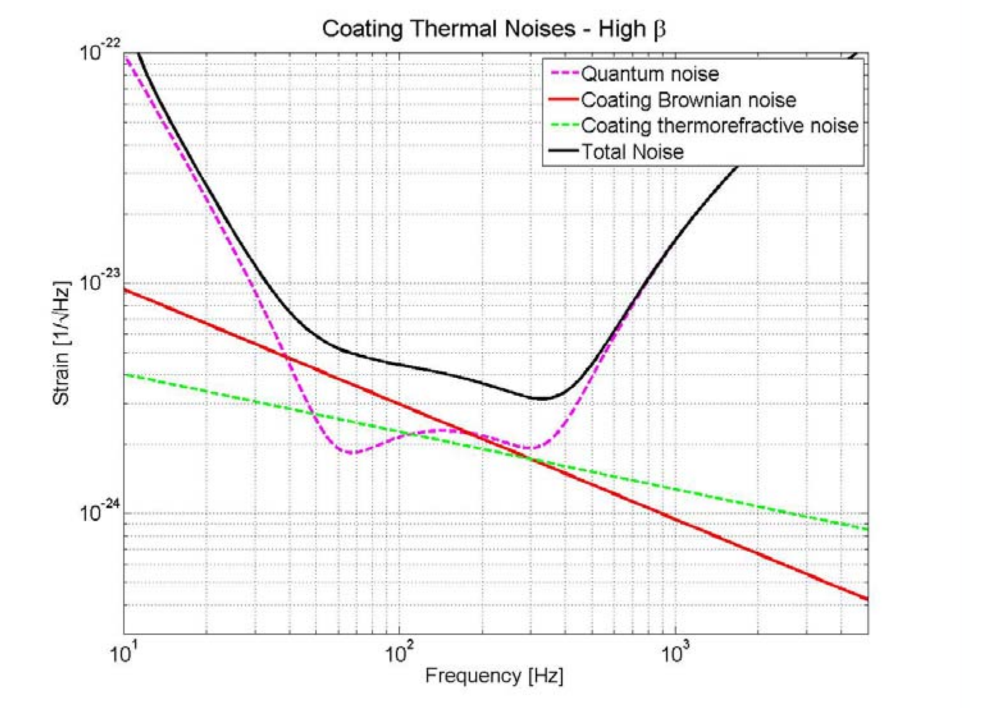
- Nitrogen atmosphere annealed poor stoichiometry sample
  - Determine effect of poor stoichiometry independantly of annealing state
  - Poor stoichiometry annealed in air gave worse mechanical loss than standard stoichiometry
  - Hobart and William Smith Colleges/ERAU
- Finish thick pure tantala from CSIRO, unannealled
  - Higher frequency modes
  - Mechanical loss versus temperature
  - Have Q vs Temperature results on silica/tantala sample
  - MIT

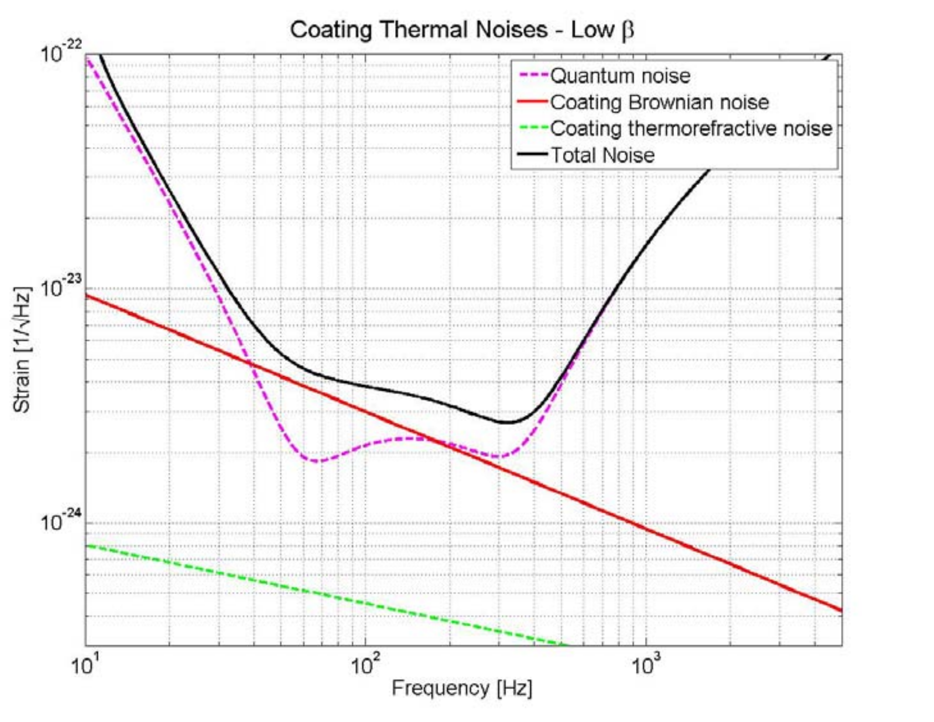
Temperature Dependence of Titania doped Tantala



See talk by Stuart Reid

Thermorefractive Noise





β = dn/dT = 1.2 10^{-4}

Value from M N Inci, cited by Braginsky

Factor of 10 higher than other amorphous oxides

α = dL/dT = - 4.4 10^{-5}

others have found + 3.6 10^{-6}, + 5.0 10^{-6}

Qualitatively, TNI data limits this. Needs to be looked at quantitatively

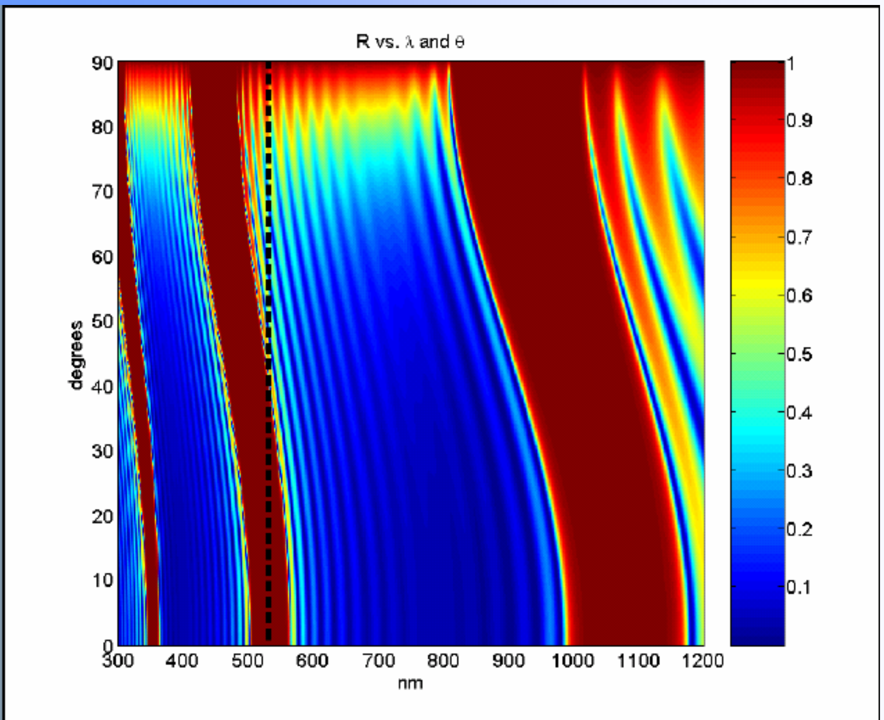
Assuming Inci is wrong

β = dn/dT = 1.2 10^{-5}

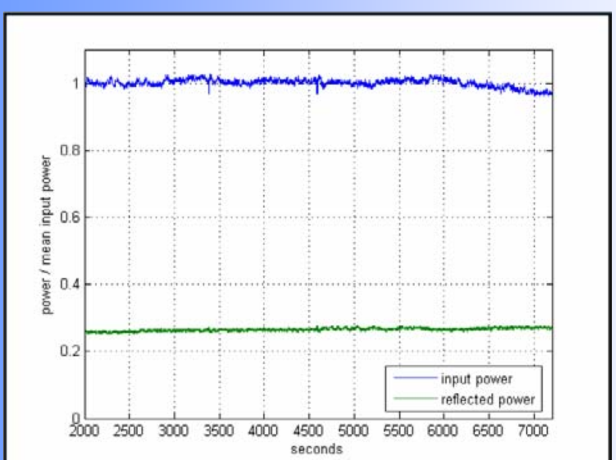
Coating thermorefractive thermoelastic noises are correlated; add in phase

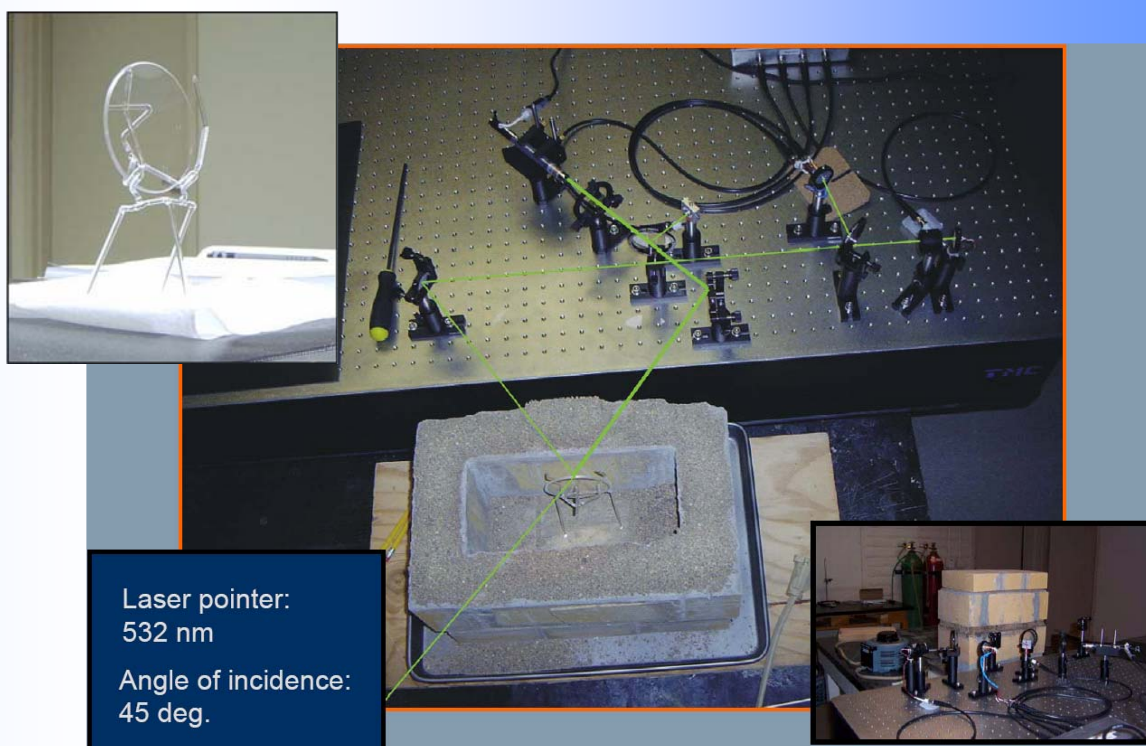
Need calculation of these noises with optimized thicknesses

ERAU dn/dT Experiment



- Measure change in reflectivity versus temperature
- Use green He-Ne laser at 45 degrees
- 100 C change in temperature enough to verify/rule out Inci result for tantala
- Can measure dn/dT in titania doped tantala, silica doped tantala, etc.



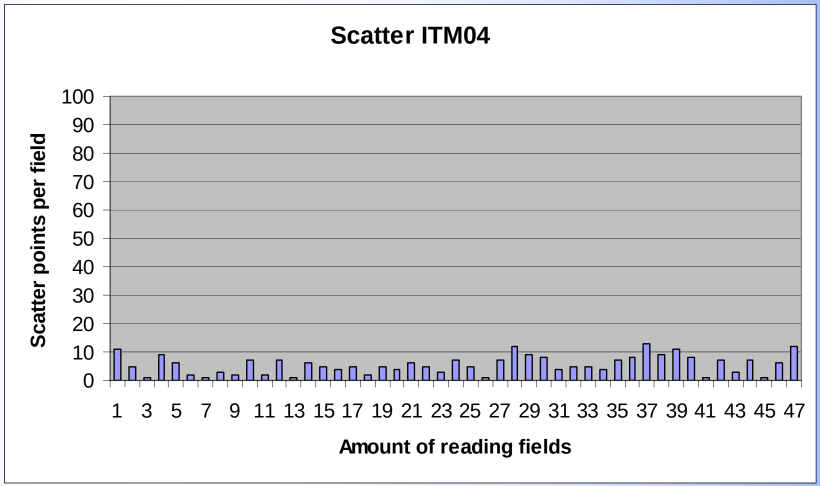


Ideas for Future Coating Runs

- Bring down optical absorption in titania doped tantala
- Investigate both promising coatings (TiO_2 doped Ta_2O_5 and SiO_2 doped TiO_2) from other vendors than developer
- Single layers of silica, tantala, titania doped tantala, and silica doped titania from CSIRO
- Get TNI mirrors with silica doped titania coating
- Three way alloys, based on silica - titania and titania - tantala
  - Silica-titania-tantala a good first thought: matching Y to substrate with mechanical loss like titania-tantala would be ideal coating
  - Alumina, niobia, hafnia possible
- Alumina as a dopant into tantala and titania (and possibly silica?)
- Silica, titania, alumina dopants into niobia and/or hafnia
- Further investigations of cobalt doped tantala
  - Change oxidation state of cobalt
  - Trinary alloys
- Nitrides

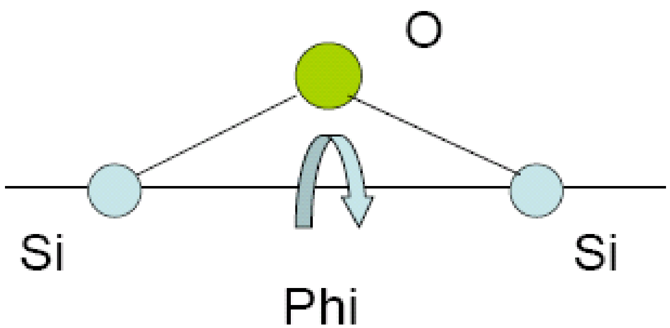
Scatter in Advanced LIGO Optics

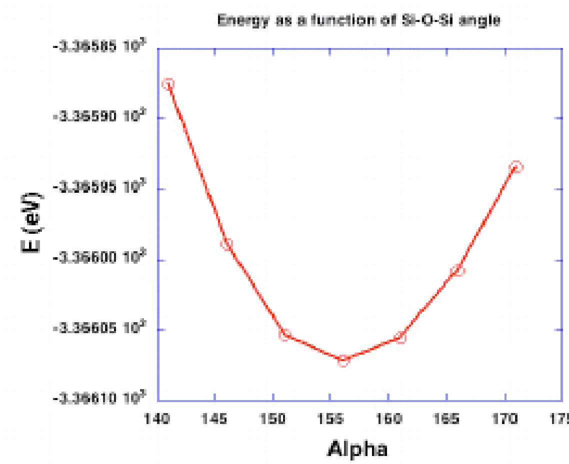
- Scatter in initial LIGO optics high, often > 50 ppm
- Does not go down when optics are drag wiped
  - Absorption of LHO 4K ITMy, did go down
- Scatter is either in coating or on substrate
  - Suggestion from LMA/Virgo of small bubbles in coating
- Round trip loss at Virgo very high, ~ 500 ppm
  - Hard to determine cause; clipping, scatter?
- Advanced LIGO scatter must be below 2 ppm
- Titania known to have scatter problems (microcrystals)
- Southern University to use Atomic Force Microscope to study scatter points



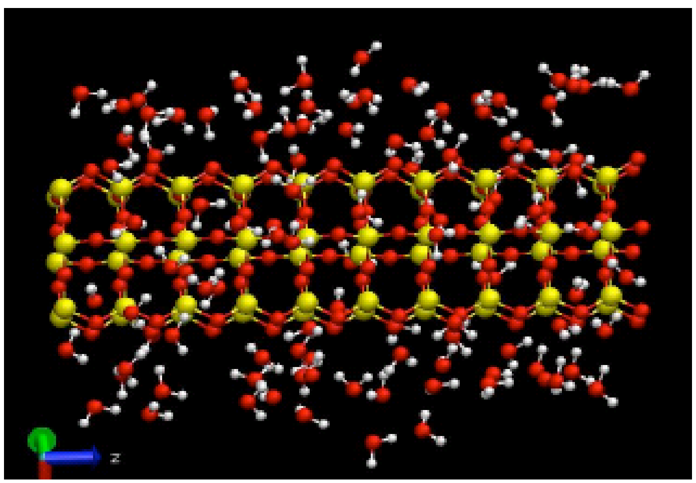
Modelling of Amorphous Materials

Quantum calculations of silica

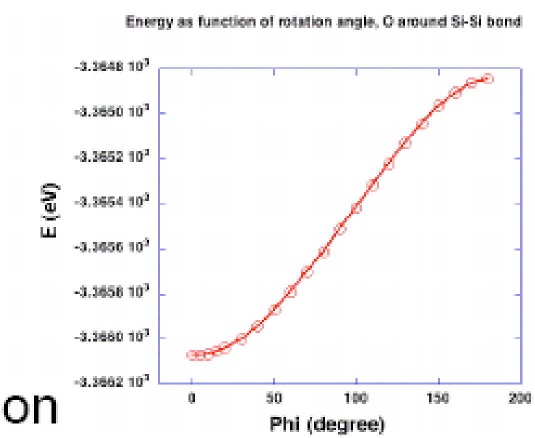




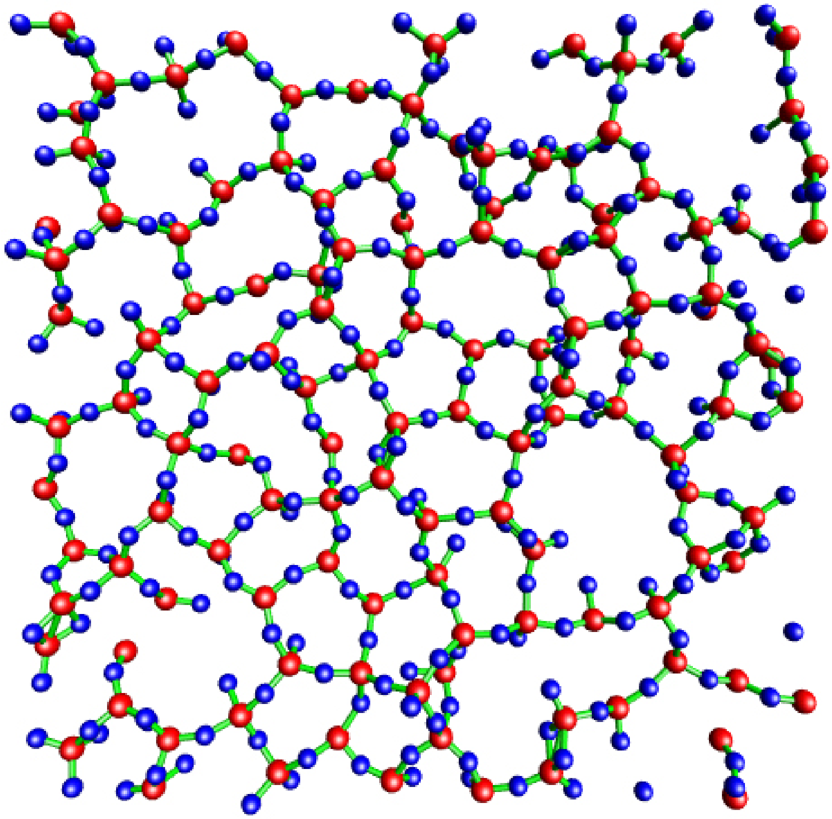
Alpha=angle(Si-O-Si)



A snapshot of SiO_2rod-water interaction



Properties of Amorphous Silica Surfaces



Water destroys TMR, heating above 500 ºC restores the TMR, surface dehydroxylation

- In the absence of strain, the Si-O bonds are inert to H_2O and NH_3, etc.
- Strained Si-O bonds greatly increase the reactivity by creating acidic and basic adsorption sites on silicon and oxygen.
- Reactive sites (surface defects) play crucial roles in the surface corrosion
- Two-membered-ring (TMR) is a surface defect with high abundance

Bunker et al, Surf. Sci. **222**, 95 (1989); Bunker et al, Surf. Sci. **210**, 406 (1989).

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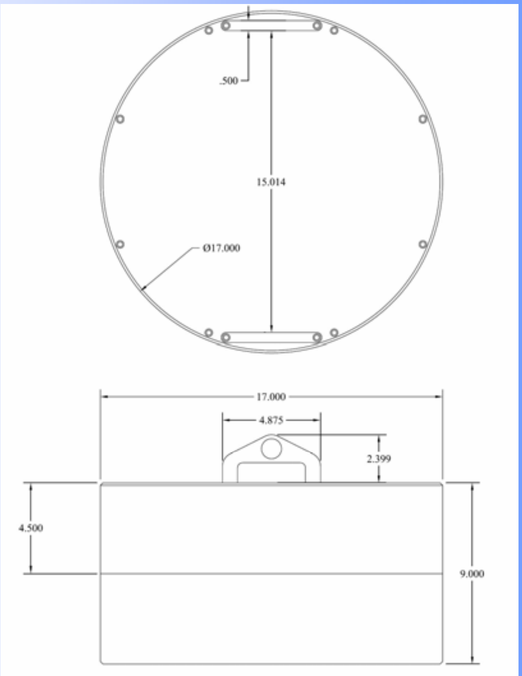
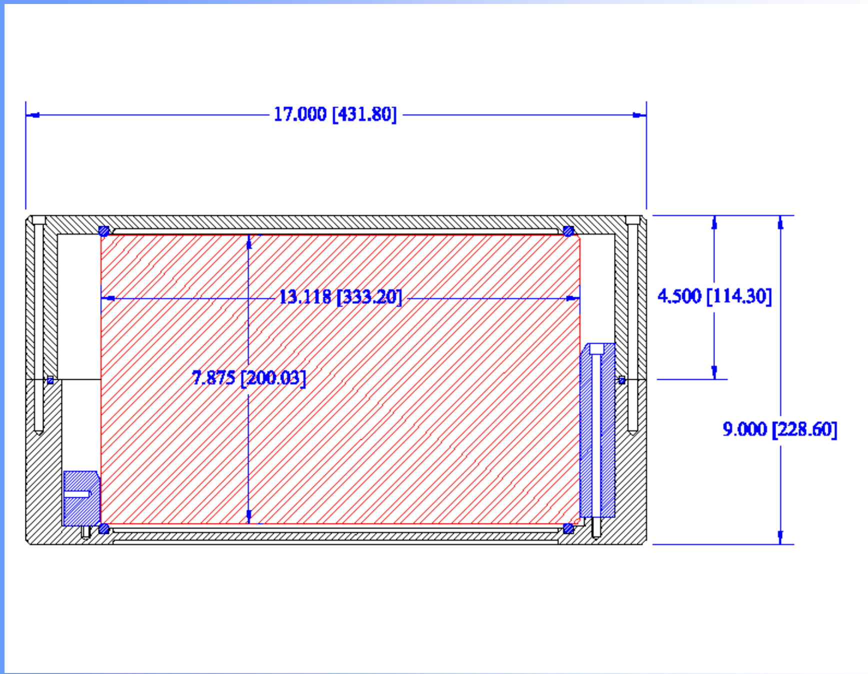
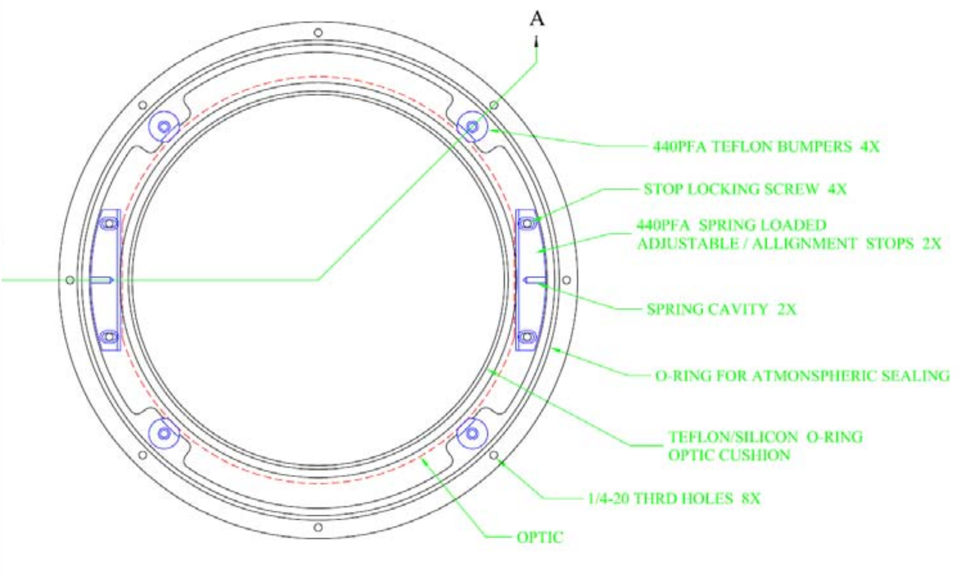
Advanced LIGO Mirror Storage Case

- Material: Aluminum
- Designed to handle bonded ears
- Allows for safe insertion and removal of the mirror
- The Teflon spring loaded adjustable stops lock the mirror and prevents rotation
- When the top half of the case is lowered down, two ¼” rods are screwed into the bottom box and the top is slid down over the screws preventing the mirror from being able to contact the top lid.







Advanced LIGO Mirror Shipping Case

- Material: Polyethylene resin (molded)
- Sealed, waterproof/dust proof case
- Purge valve
- Roller system
- Custom interior foam
- Anti-static protection
- Removable lid