Coating Program Update

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on behalf of the Coating Working Group

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LSC Meeting – LHO

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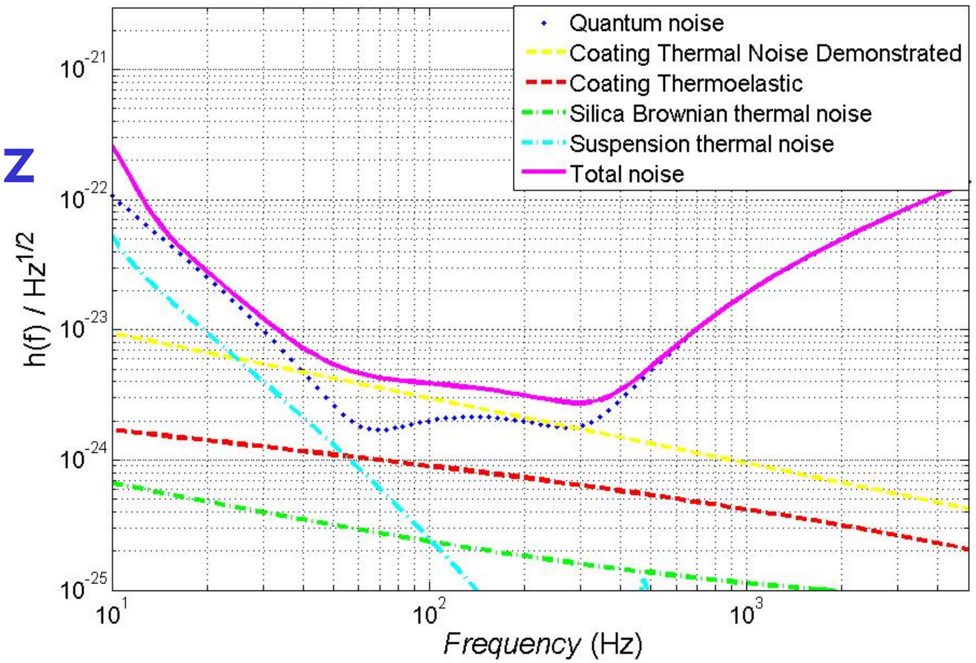
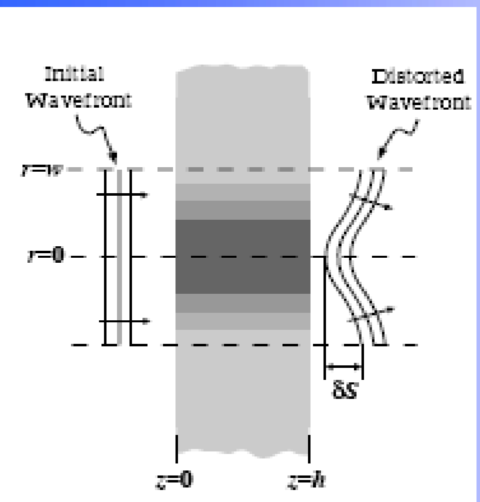
Coating Issues

Coating Thermal Noise

- Limiting noise source 50-3000 Hz
  - Most sensitive region
  - Astrophysical reach a strong function of thermal noise level
  - Limit for narrowbanding at high frequency
- Limits gains from reduction of other noise sources

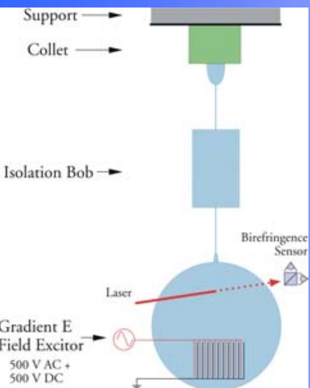




Optical Performance

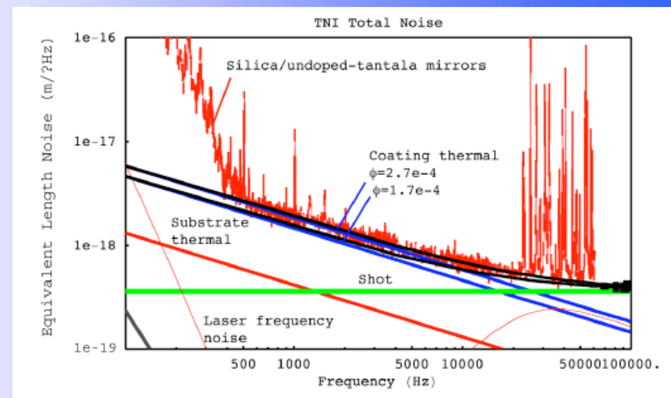
- Detailed plans for thermal compensation are counting on very low absorption coatings
- Uniformity of absorption could complicate thermal compensation
- Need to maintain low scatter, high reflectivity, thickness uniformity, etc.

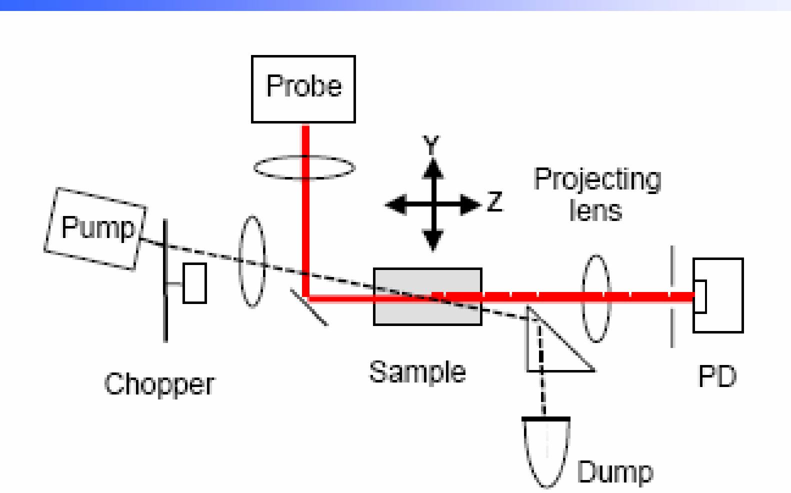
Experimental Methods



Coating Thermal Noise

- Q measuring on coated disks
  - Can test many candidate coatings
- Direct thermal noise measurements at the TNI
  - Verification of Q results
  - Seen improvement from TiO_2 doping of Ta_2O_5



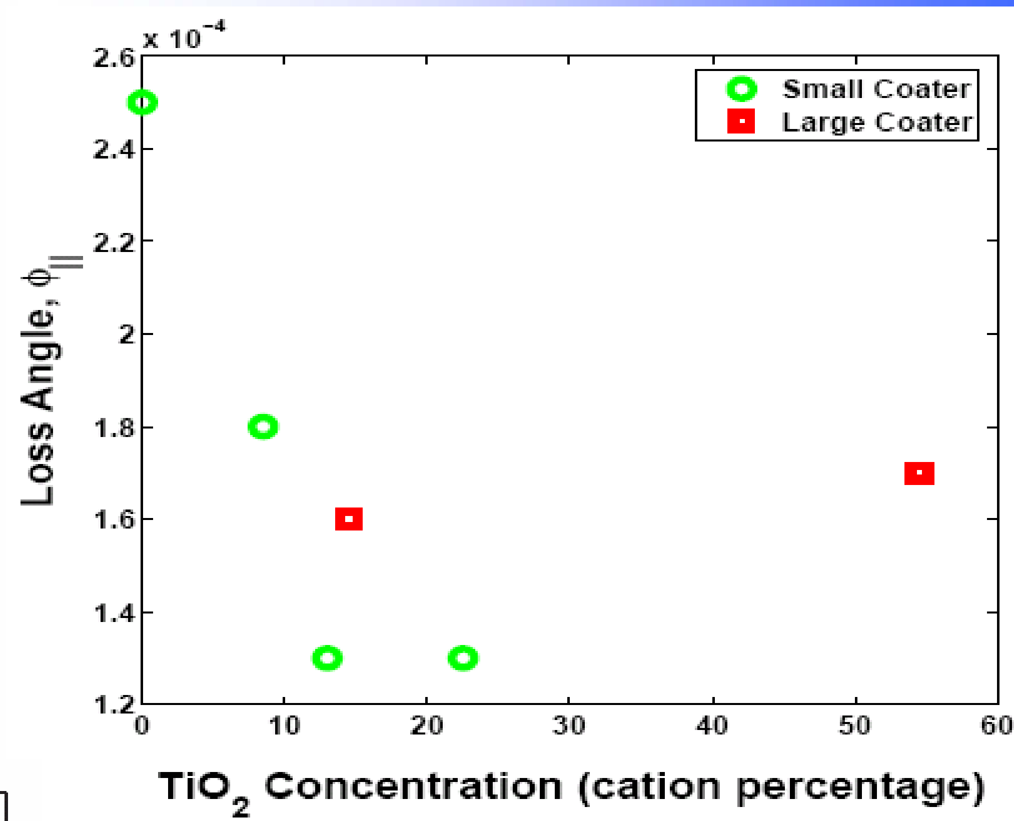


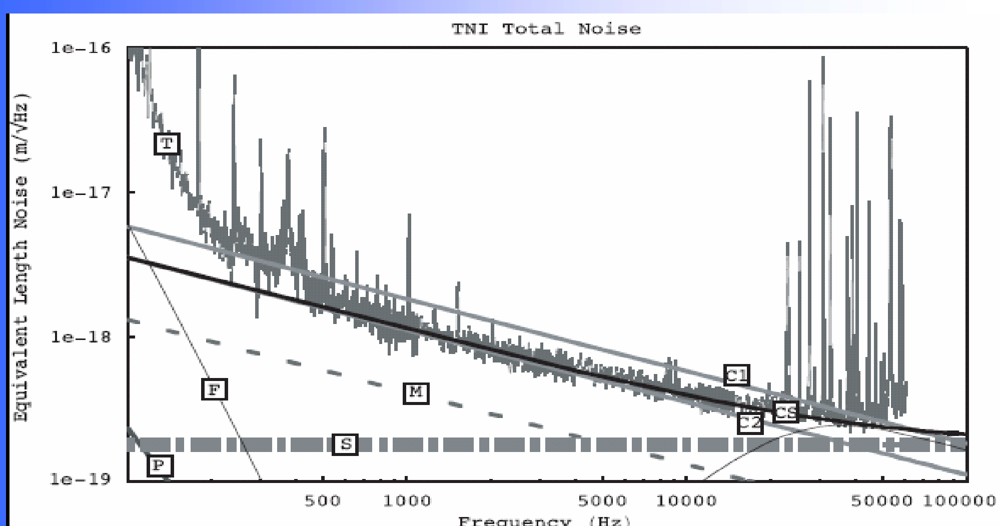
Optical Performance

- Absorption measurements using photothermal common path interferometry (Stanford, LMA)
- Developments with initial LIGO optics
  - Scatter

TiO_2-doped Ta_2O_5

- Full analysis done of all data
- Two methods to calculate layer thickness and TiO_2 concentration
- $\phi \approx 1.5\ 10^{-4}$
- Young's modulus and index of refraction nearly unchanged
- TNI directly sees reduction in thermal noise



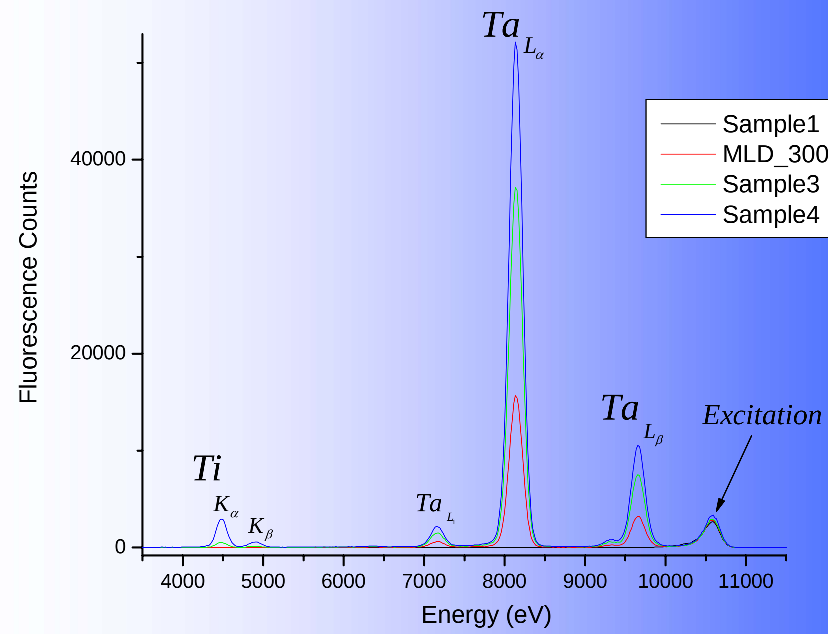


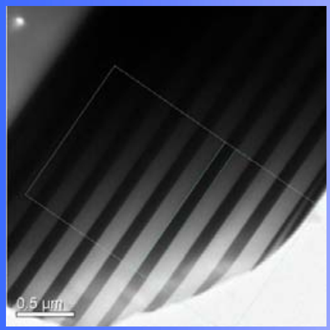
- Optical absorption 0.9-1.1 ppm
  - 55 % TiO_2 anomalously high at 2.5 ppm
  - Single layer 4.5 ppm

Coating Constituents Measurements

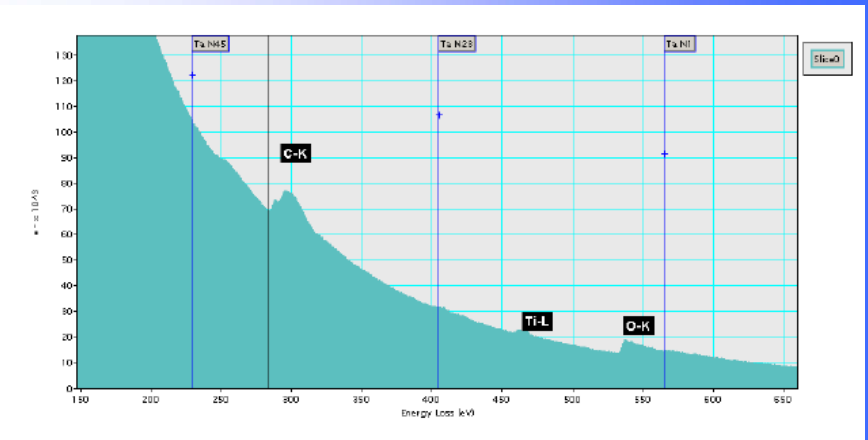
- Electron Energy Loss Spectroscopy used at Glasgow to measure Ti concentration of TiO_2 doped Ta_2O_5/SiO_2 coatings
- X-ray florescence and X-ray Absorption Near Edge Structure measurements at Southern
  - Beam time is secured for further measurements
  - Additional samples, beyond TiO_2 doped Ta_2O_5 to be explored

X-Ray Florescence Results from Southern Univ/CAMD





Electron Energy Loss Spectroscopy results from Glasgow



SiO_2-doped TiO_2

Thin Sample Results

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	$5.1\ 10^5$	$3.2\ 10^{-4}$

Caveats: Bubble in coating, assuming 87 GPa for Young's modulus, d=4.3 μm

Low Young's modulus (but higher index) makes figure of merit about 15% worse than TiO_2-doped Ta_2O_5

Thin Sample Results

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 0 Hz:

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

Absorption about 1.5 ppm with a few peaks around 3 ppm

XPS analysis at CSIRO shows about 50% SiO_2, 50% TiO_2, with 0.1% Ta from support wire. Also find index to be 2.53

Pure Tantala

Thin Sample Results CSIRO 1.8 μm thick

	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 thick

	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	$9.9\ 10^{-4}$

From LMA/Virgo, between $\lambda/8$ and $3\lambda/8$ thick

$\phi_{Ta2O5} = (3.8 +/- 0.2)\ 10^{-4} + f\ (1.8 +/-0.5)\ 10^{-9}$

$\phi_{SiO2} = (1.0 +/- 0.2)\ 10^{-4} + f\ (1.1 +/-0.5)\ 10^{-9}$

Using the above ϕ_{SiO2}, for CSIRO $\lambda/4$ thick

$\phi_{Ta2O5} = 4.6\ 10^{-4}$

Other Coatings

Lutetium doped Ta_2O_5/SiO_2

Thin Sample Results

f_{mode} (Hz)	Q	ϕ
2810	$4.0\ 10^5$	$3.6\ 10^{-4}$
2814	$4.3\ 10^5$	$3.3\ 10^{-4}$
4245	$3.2\ 10^5$	$4.2\ 10^{-4}$

Caveats: Assuming Young's modulus and index unchanged from pure Ta_2O_5

Full frequency analysis of thick samples gives:

$\phi = 3.8 +/- 0.5\ 10^{-4}$

Optical Absorption ≈10-12 ppm

Poor Stoichiometry Ta_2O_5/SiO_2

Results from unannealed original sample poor, $\phi \approx 6\ 10^{-4}$

Sample was annealed in inert (N_2) atmosphere at Stanford

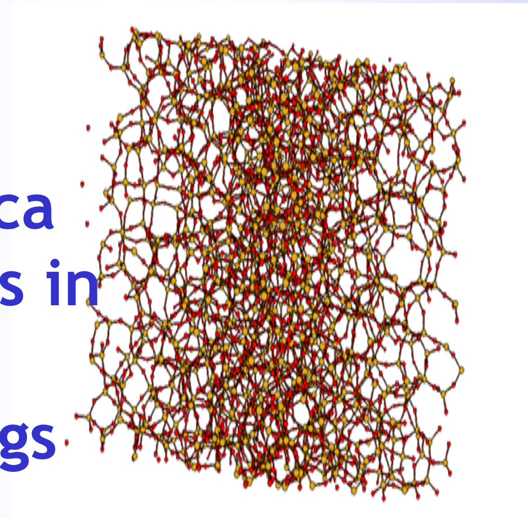
New Q measuring is beginning

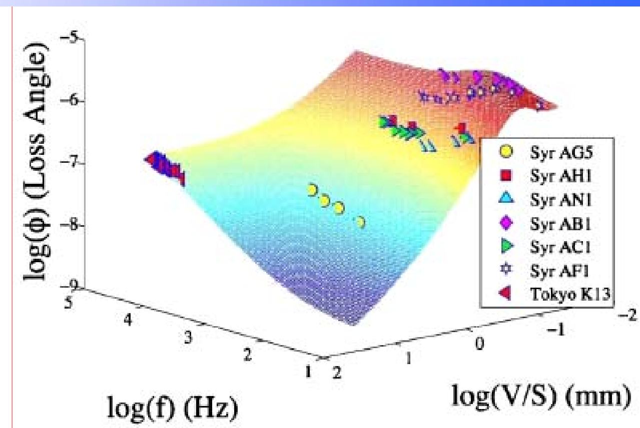
No annealing of substrate causes technical problems

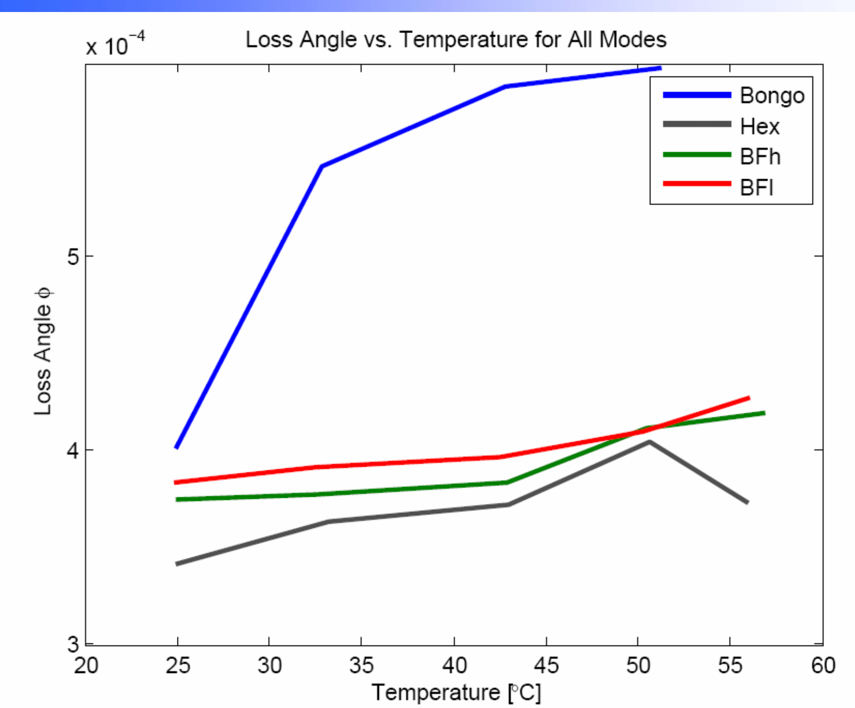
Mechanical Loss Mechanisms

Modeling

- Hai-Ping Cheng at U Florida
- Atomic level modeling of silica
- From known loss mechanisms in silica, expand to similar amorphous oxides for coatings
- In progress







Q Measuring

Measure modal Q's versus temperature

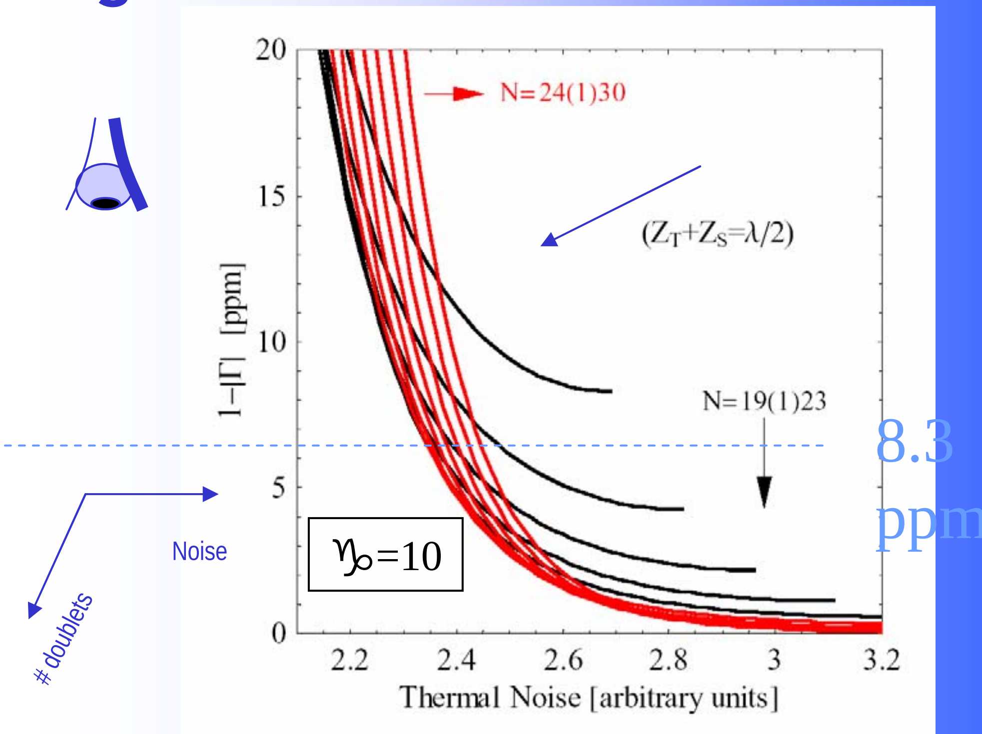
Clear increase in mechanical loss

- TCS to make advLIGO mirrors about 30 C above room temperature
- minimal effect on coating thermal noise and astrophysical reach

Optimization of Coating Thicknesses

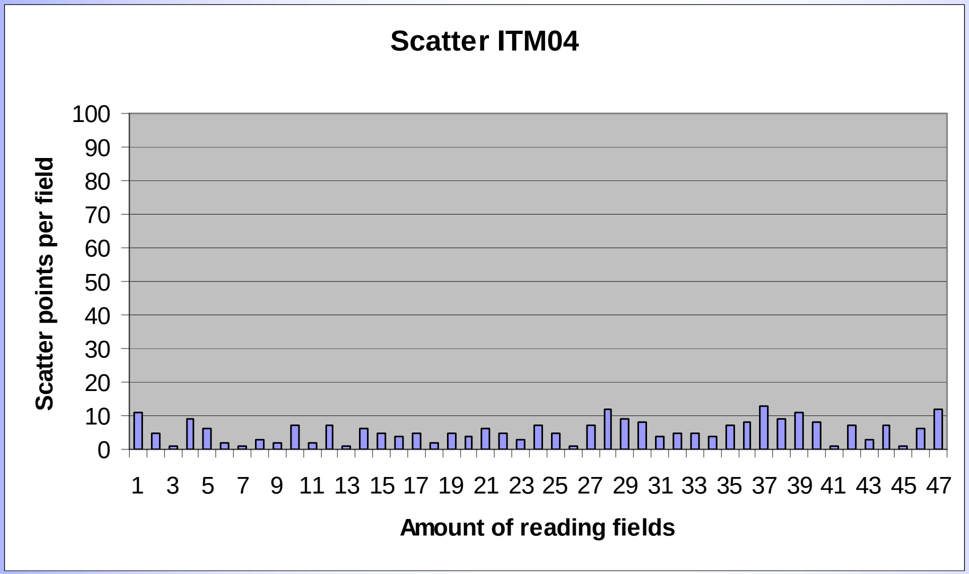
- More precise knowledge of SiO_2 or other low index material is important for optimization
- Young's modulus and Poisson ratio important as well as mechanical loss for defining γ, the ratio of importance to thermal noise of high index to low index material
  - Be good to get more and better information on all mechanical properties of coating materials

- Knowledge of source of uncertainties in error bars useful
  - Poisson statistics if they are measurement uncertainties
  - Gaussian if they are variations in coating process



Initial LIGO scatter

- 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
- It will be very informative to see absorption and scatter results from Virgo mirrors
- Advanced LIGO scatter must be below 2 ppm



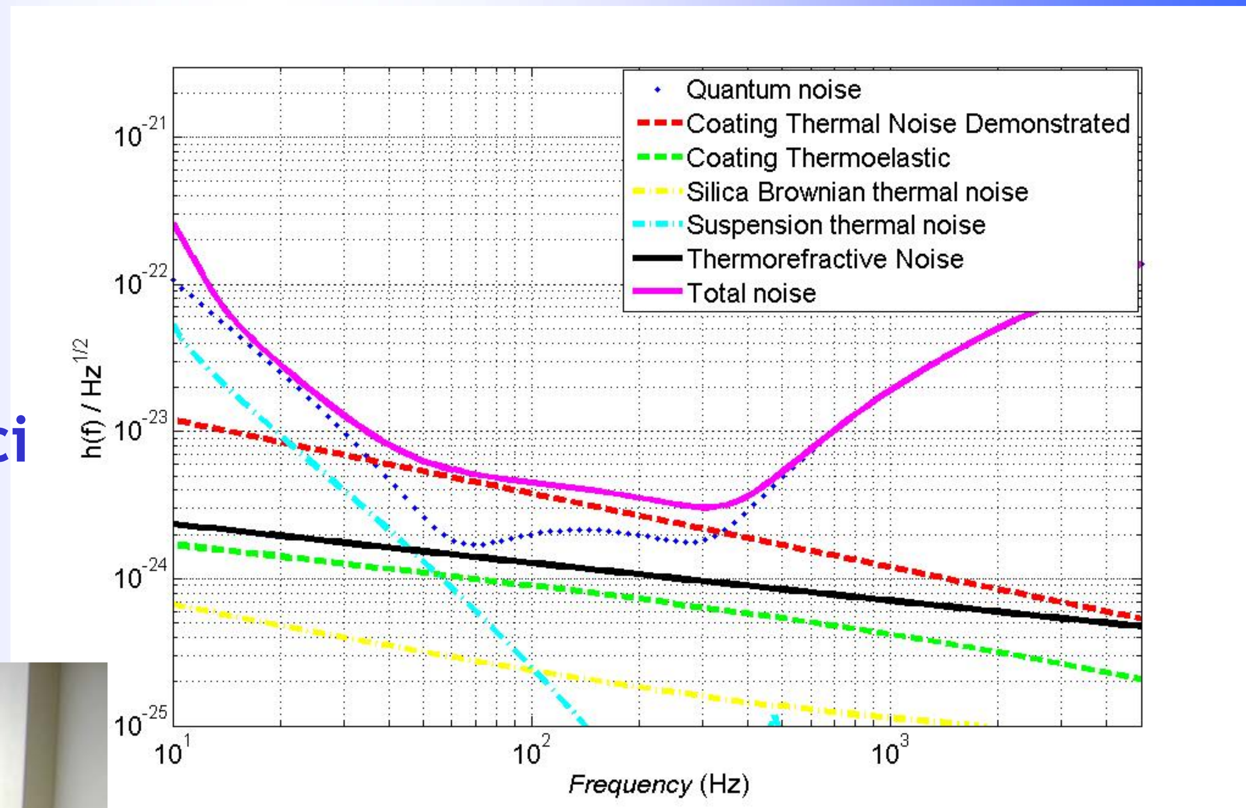
Thermorefractive Noise

Thermorefractive Noise

- From dn/dT of coating
- Curve assumes dn/dT
  - SiO_2 1.5 10^{-5}
  - Ta_2O_5 1.2 10^{-4}
- Ta_2O_5 value from M N Inci

Suggested it is too high

- Need a solid number



Measurement of dn/dT

- Difficult to separate dn/dT from dL/dT
- Experiment starting at ERAU
  - In addition to coating Q work

Future Plans

- Reduce optical absorption in TiO_2-Ta_2O_5
- Single layers of SiO_2, other materials
- Need reliable Young's modulus and other elastic (and thermal) property measurements
  - Some work with nanoindenters
  - Stanford acoustic measurements
- Further materials and dopants
  - Hafnia target now available at CSIRO
  - Trinary allow with TiO_2 and Ta_2O_5
- Need more theoretical work
  - Finite mirror formula