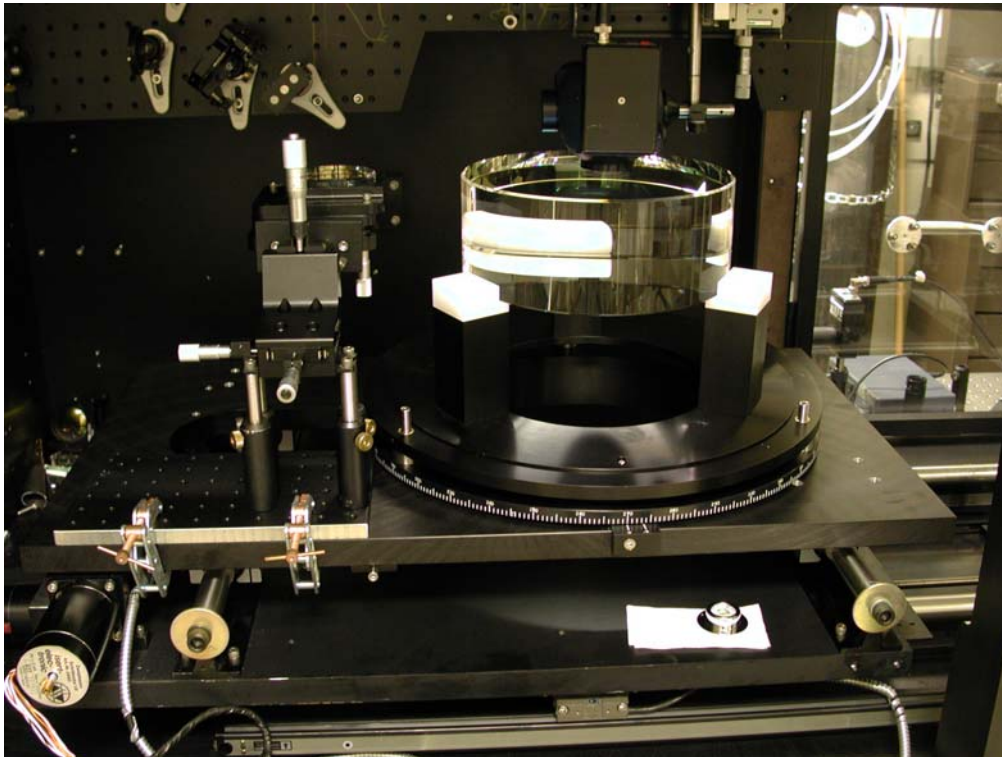


The Coating Scattering and Absorption Measurements of LIGO I mirrors at Caltech

Liyuan Zhang, Bill Kells, Lee Cardenas, Helena Armandula, GariLynn Billingsley

California Institute of Technology

RTS system, an optical characterization bench



It was established at Caltech OTF lab in 1997 :

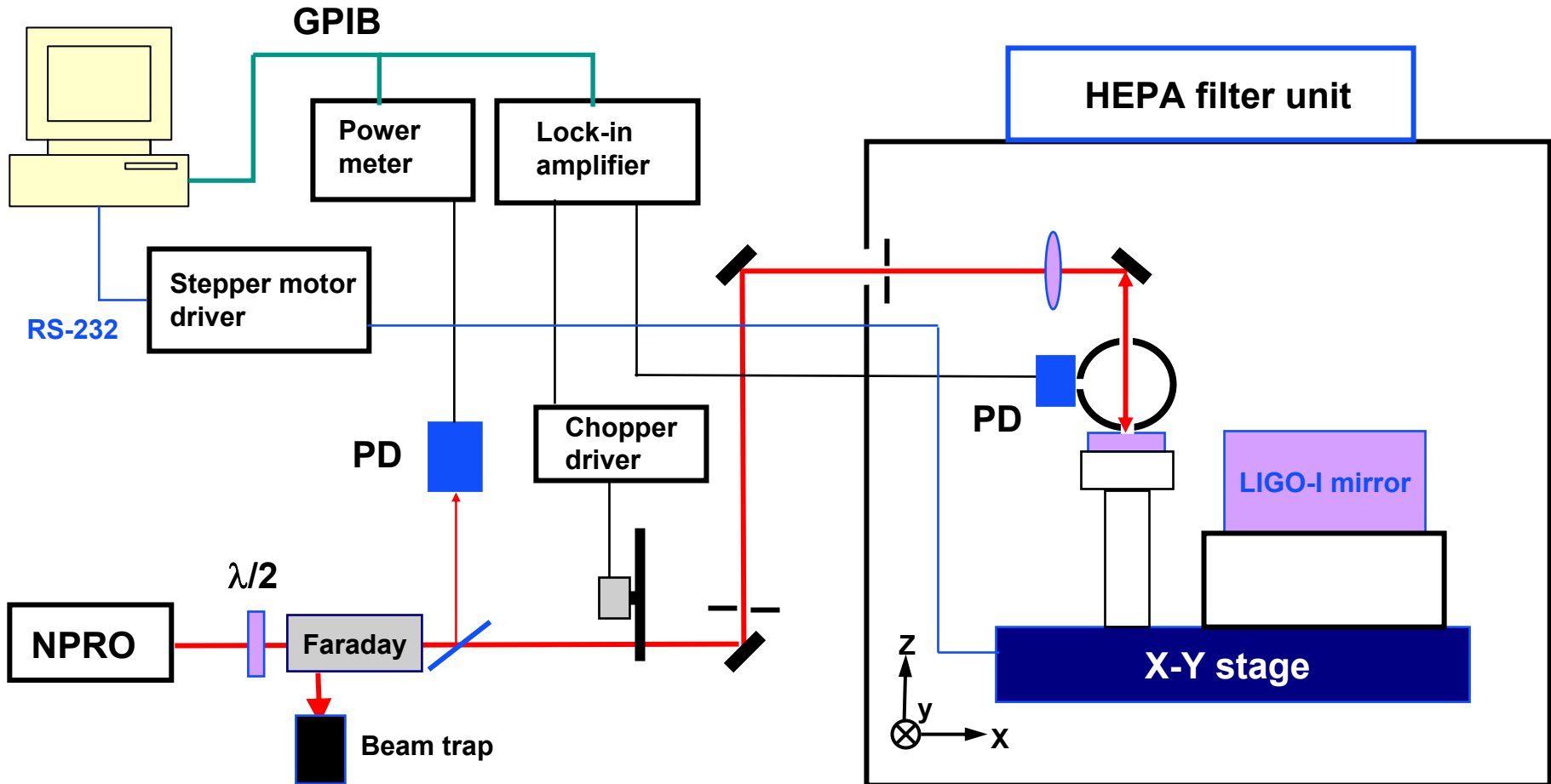
(Jordan Camp, Bill Kells et. al.)

- AR Reflection,
- HR Transmission,
- HR Scattering at 45° .

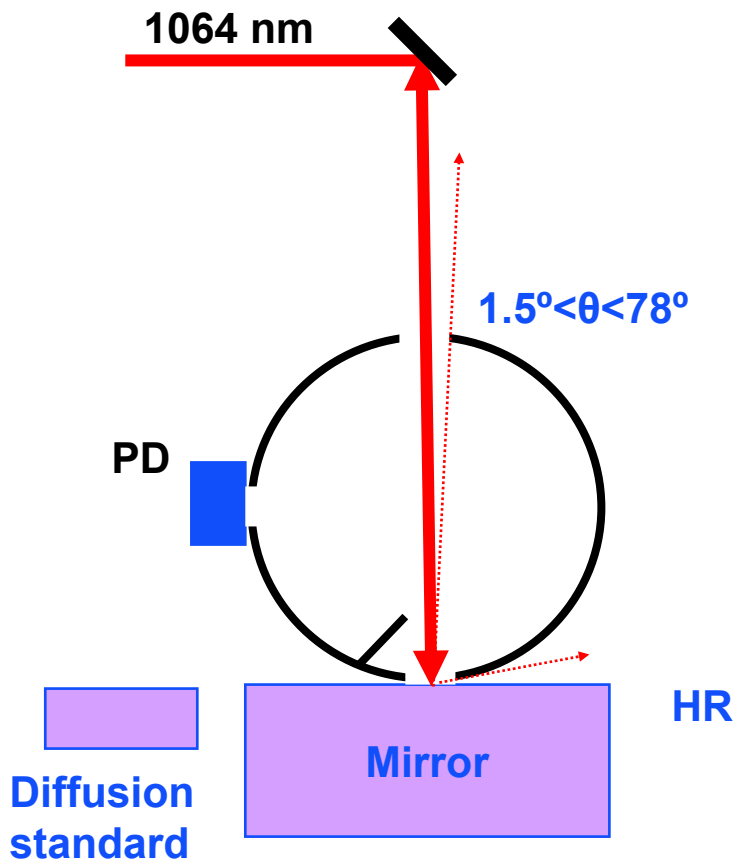
Since 2001 :

- Substrate birefringence homogeneity,
- HR 'Total Integrated Scattering' ($1.5^\circ < \theta < 78^\circ$),
- Substrate bulk absorption,
- HR Coating absorption.

Schematic of the 'TIS' measurement



Calibration and bandwidth of the 'TIS' measurement



$$\text{TIS} = \frac{\text{Diffuse reflection}}{\text{Specular + Diffuse reflection}}$$

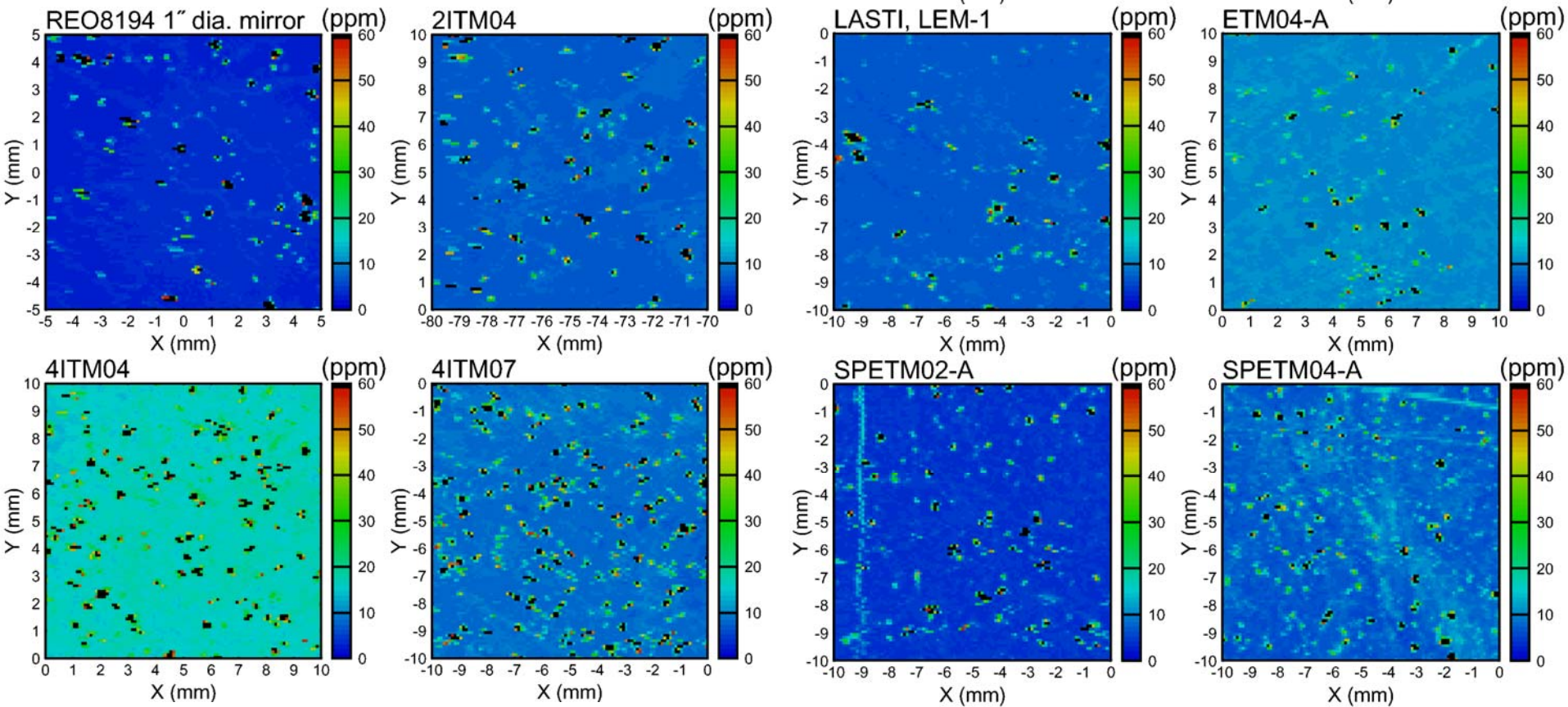
$$\sim \frac{I_{\text{PD}} \text{ with mirror}}{I_{\text{PD}} \text{ with standard} \times \text{attenuation}}$$

For the micro roughness component:

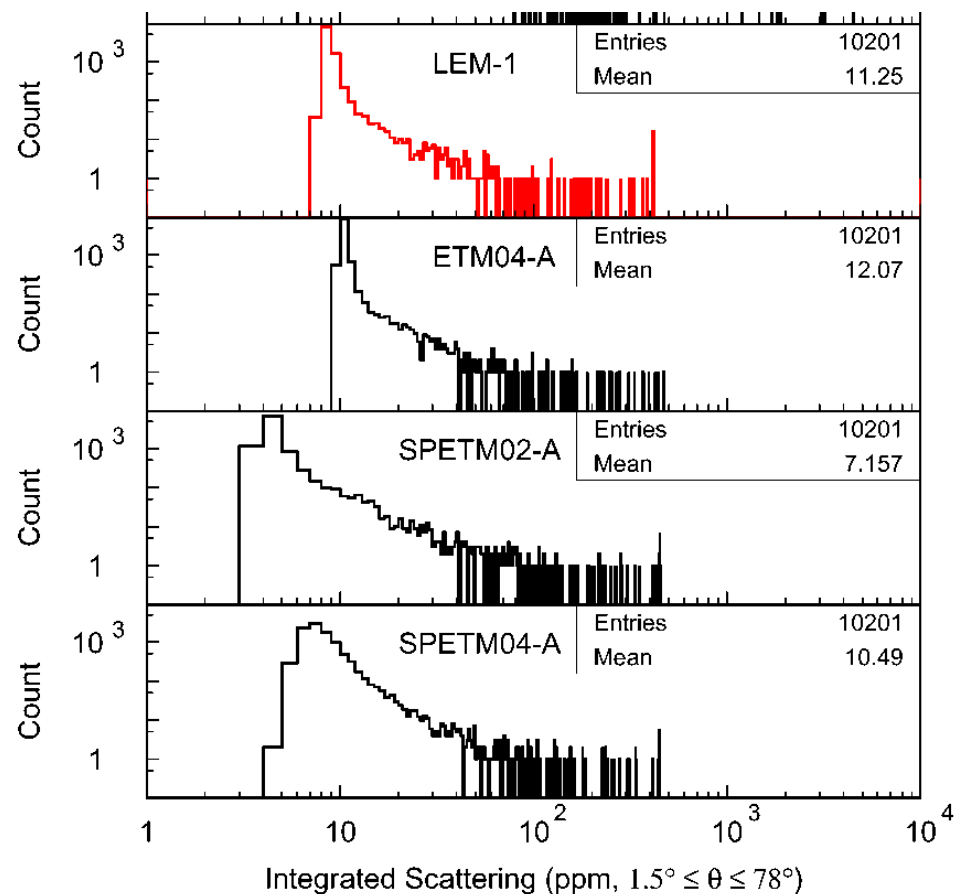
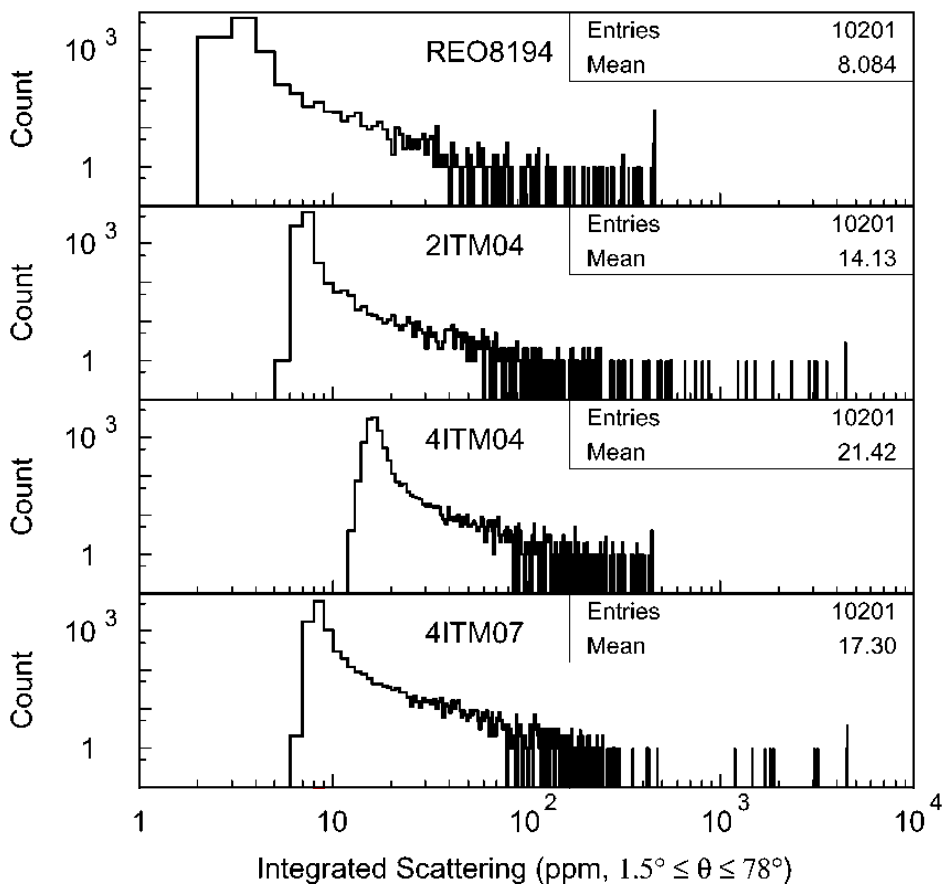
$$1.5^\circ < \theta < 78^\circ \longleftrightarrow 250 - 9100 \text{ cm}^{-1}$$

$$\lambda_s^{-1} = \sin(\theta)/1064 \text{ nm}$$

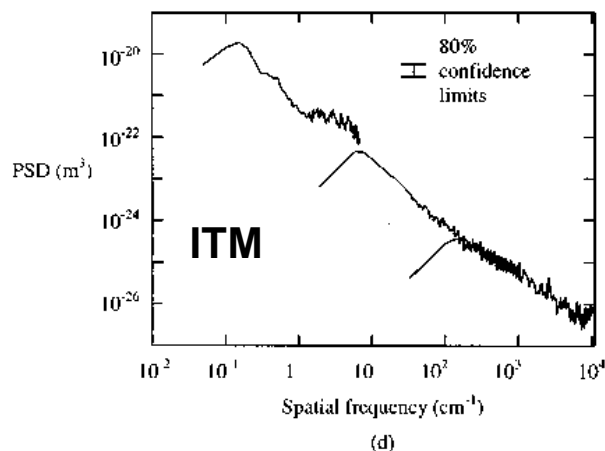
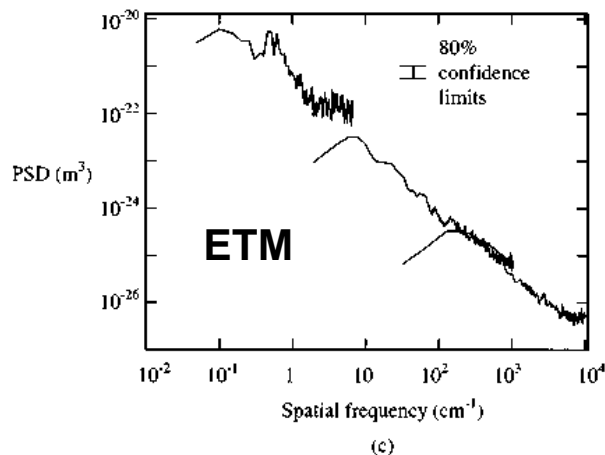
TIS results of the LIGO I mirrors



Histograms of the TIS results



The measured micro roughness of the LIGO I substrates



Power spectral density analysis of optical substrate for gravitational-wave interferometry

Christopher J. Walsh et.al., Applied Optics, Vol. 38, p4790, 1999

$$\text{PSD}(\nu) = \frac{A}{\nu^n}$$

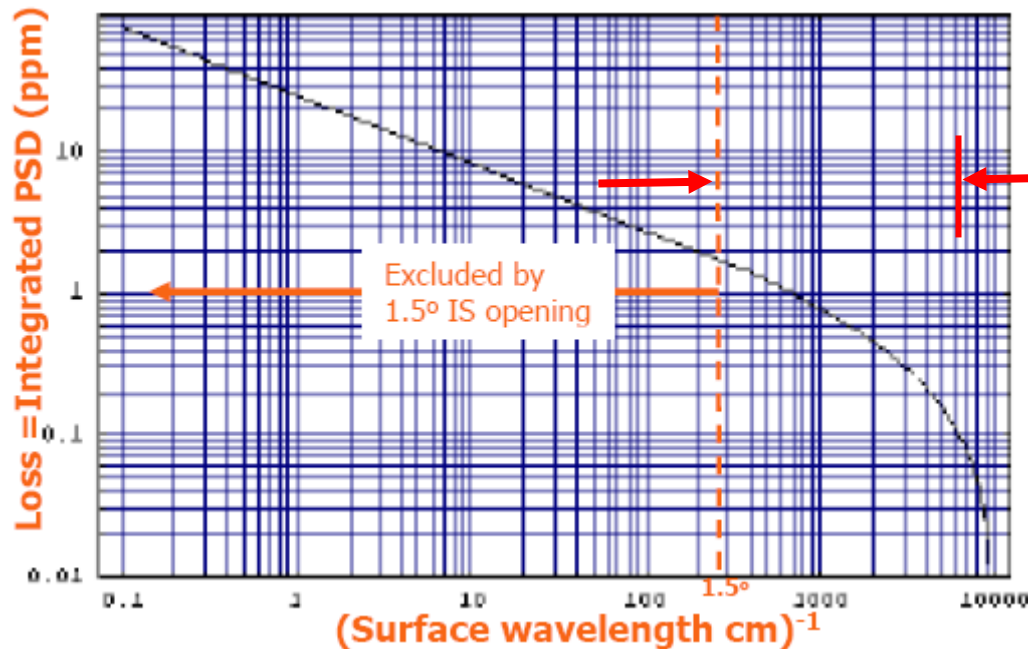
Table 1. Values of the Exponent n in Eq. (12) Obtained by Fitting of an Analytic Curve to the PSD Curves from the LIGO and the TOPO 2.5× and 40× Data^a

Substrate Surface	Radius of Curvature R	n	Number of Surfaces
RM			
Side 1	15 km	1.43–1.47	3
Side 2	Plane	1.43–1.45	4
ETM side 1	7.4 km	1.41–1.51	4
FM side 1	Plane	1.22–1.39	3
ITM side 1	14.18 km	1.45–1.55	3

^aThe values of n represent the range of values found for the number of surfaces given. R indicates the specified radius of curvature of the surface.

Interpretation of the measured micro roughness scatter

William P. Kells, LIGO-T080010



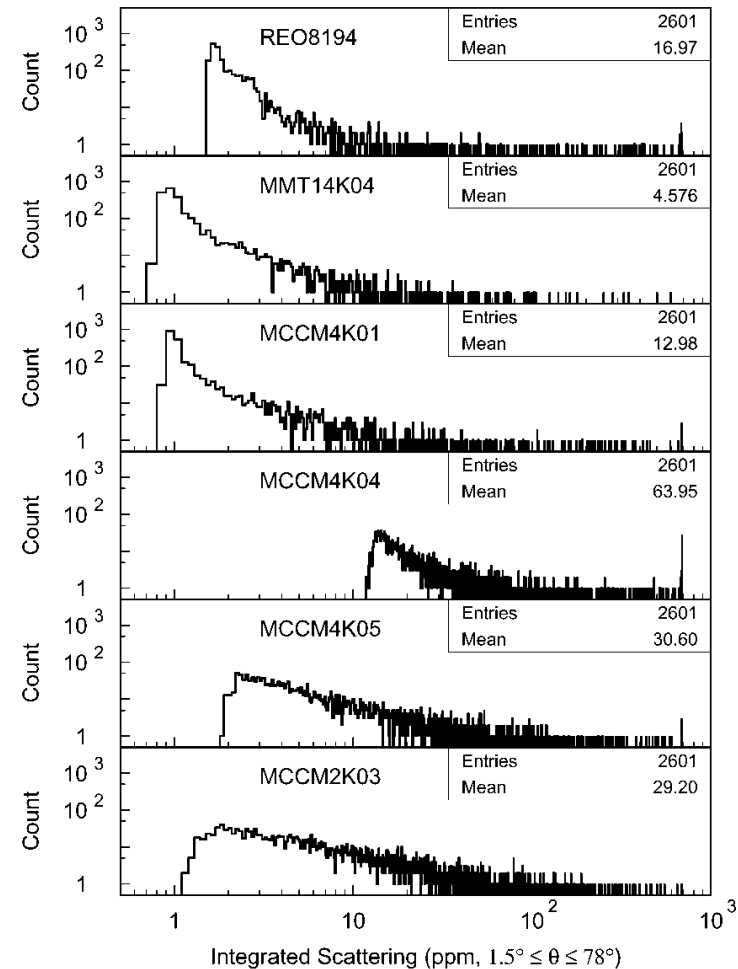
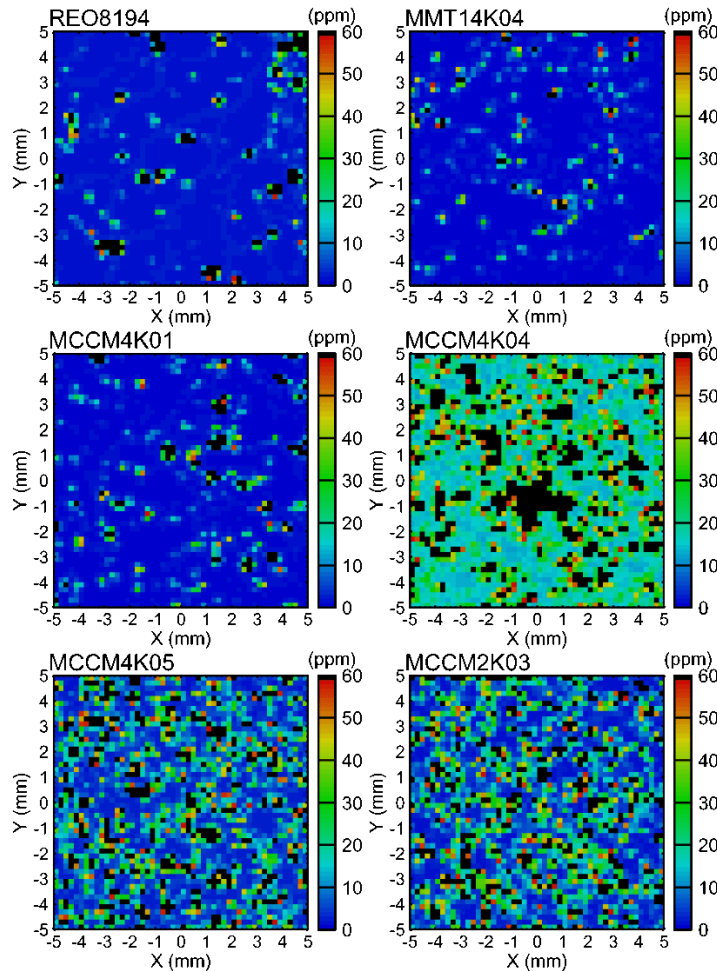
$$\text{TIS} \sim (4\pi\sigma/\lambda)^2$$

σ : integrated PSD from v to infinite.

Bandwidth of the integrating sphere

Only ~5% the micro roughness scatter of the LIGO I mirror (test mass) in the interferometer is captured.

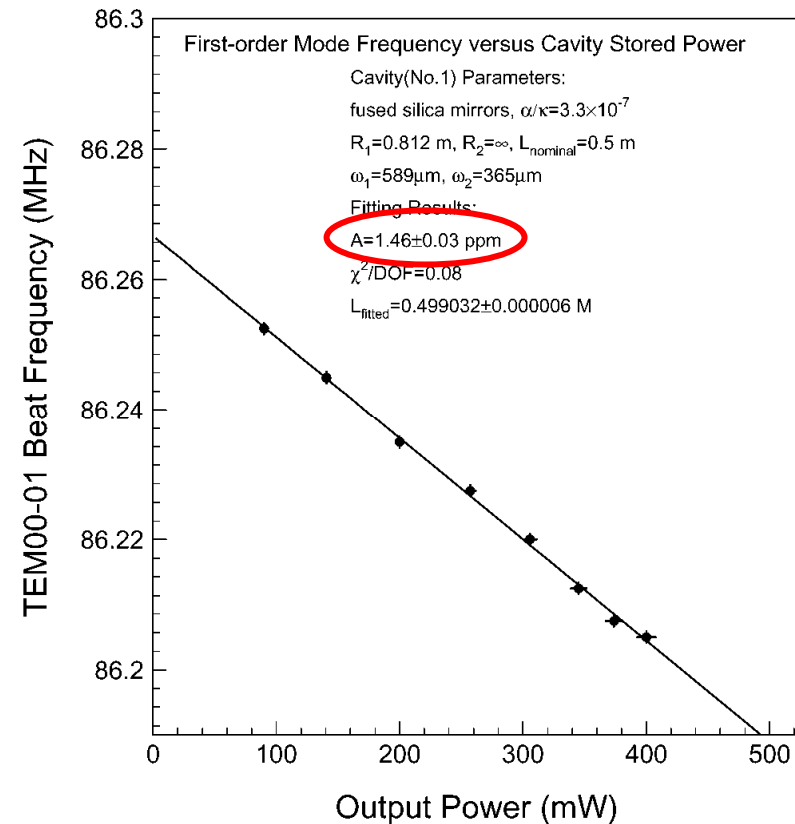
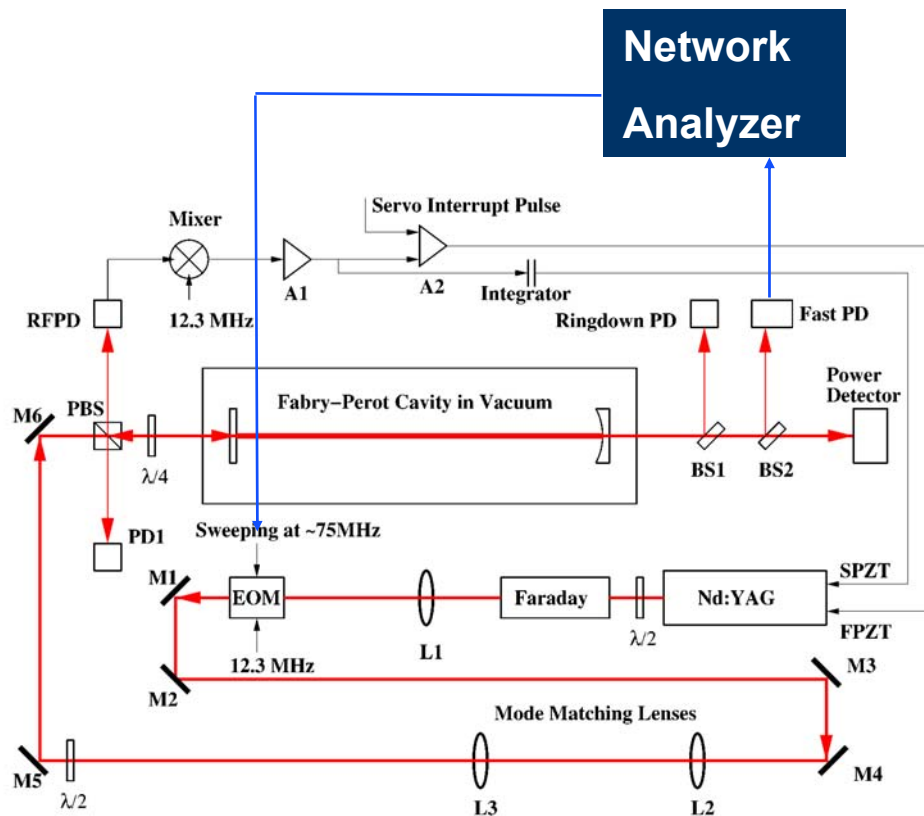
Results of the 5 Mode Cleaner spare mirrors



Absorption measurement

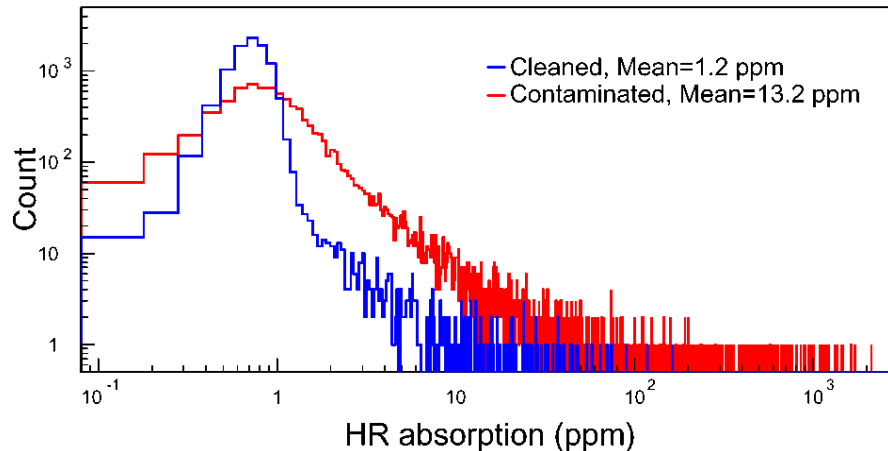
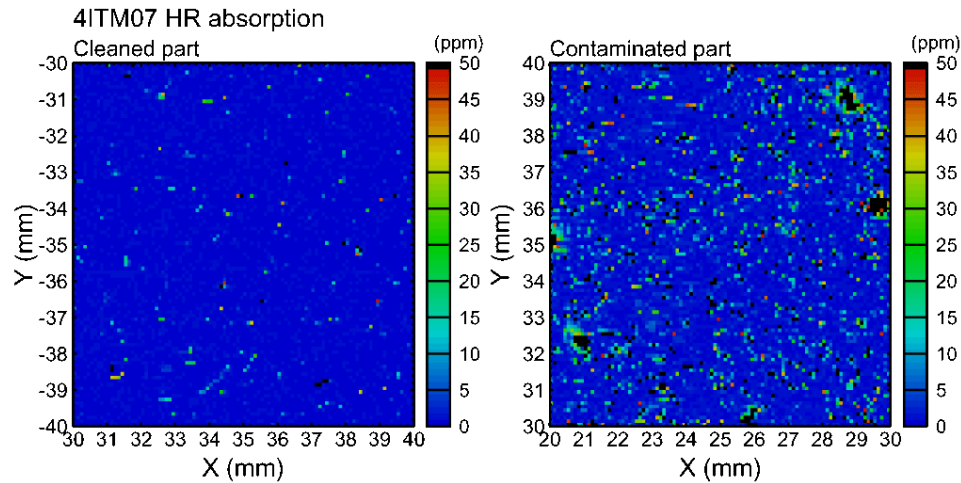
- Thanks to a visit to Ginzton Laboratory, Stanford University, we implemented the photothermal common-path interferometer (PCI, see A. Marksoyan's talk) in our RTS bench, using a 30W cw Nd:YAG and 5mW He-Ne.
- The calibration is based on the 1" (dia.) reference mirror which is measured in the contamination cavity, and cross checked with the mirror measured at Ginzton Laboratory.

HR absorption measurement in the contamination cavity



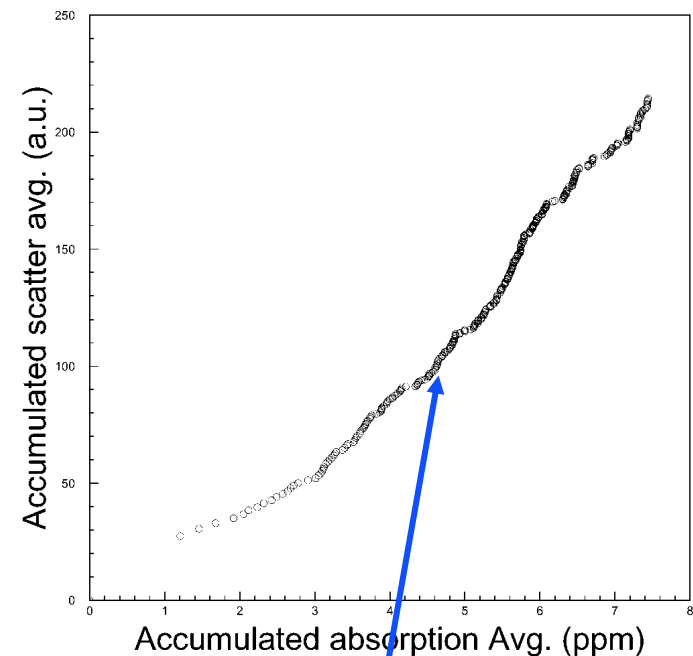
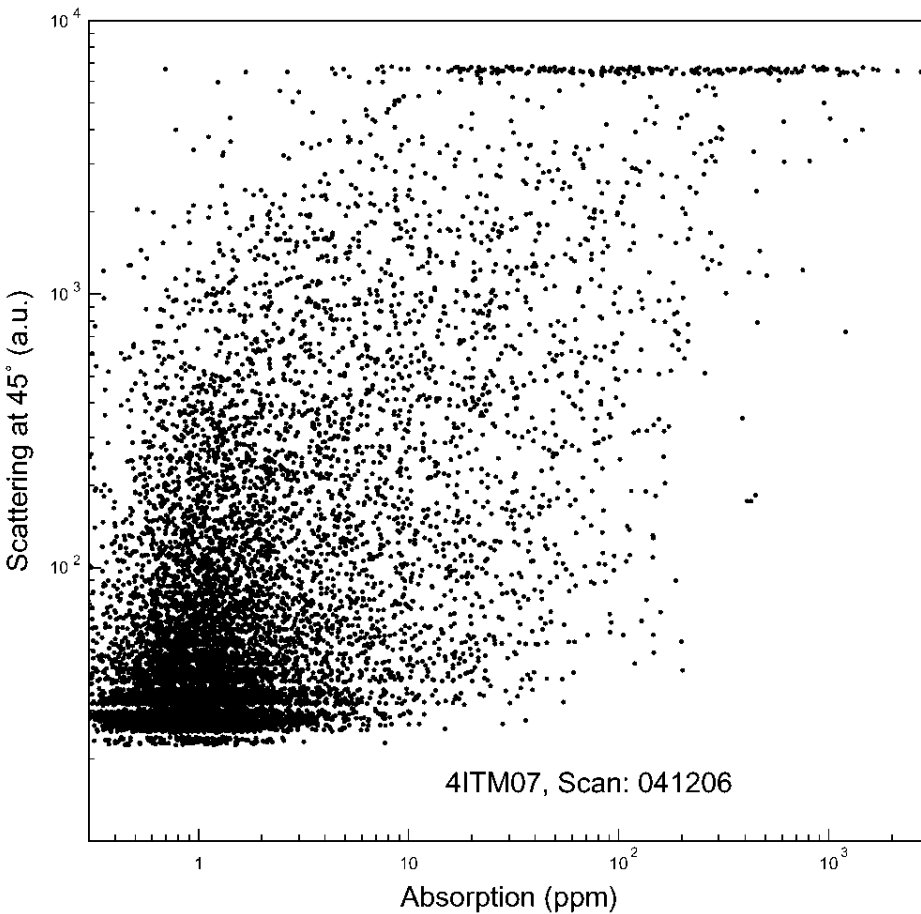
Daqun Li, Dennis Coyne, and Jordan Camp, Applied Optics, Vol.38, p5378, 1999

HR absorption of 4ITM07, *which was swapped out from LHO in 2005*



- No uniform contamination layer is observed.
- Contamination are some high absorption points.
- The point contamination can easily be cleaned by drag wiping.

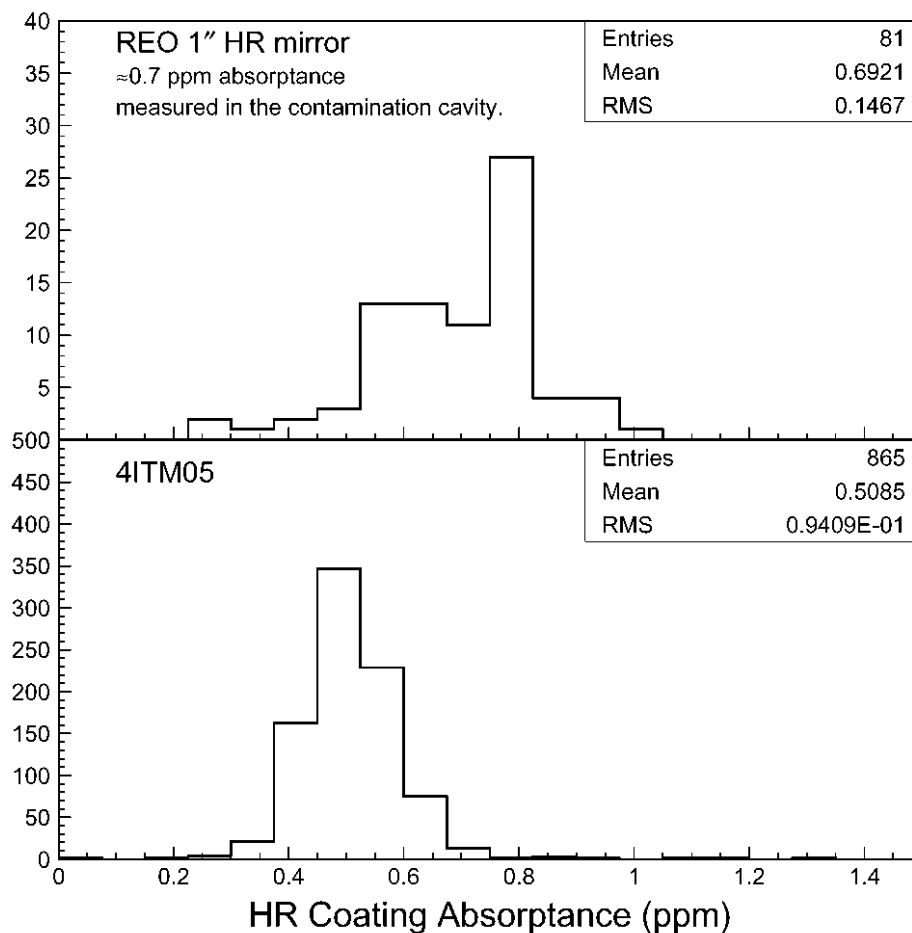
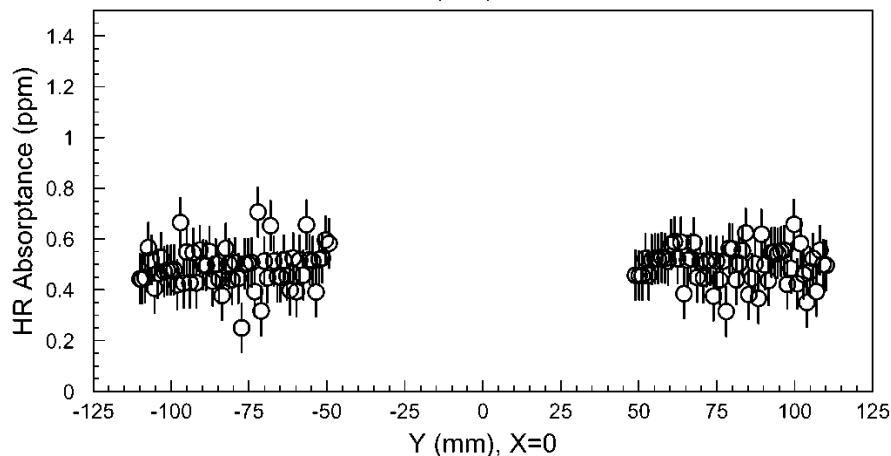
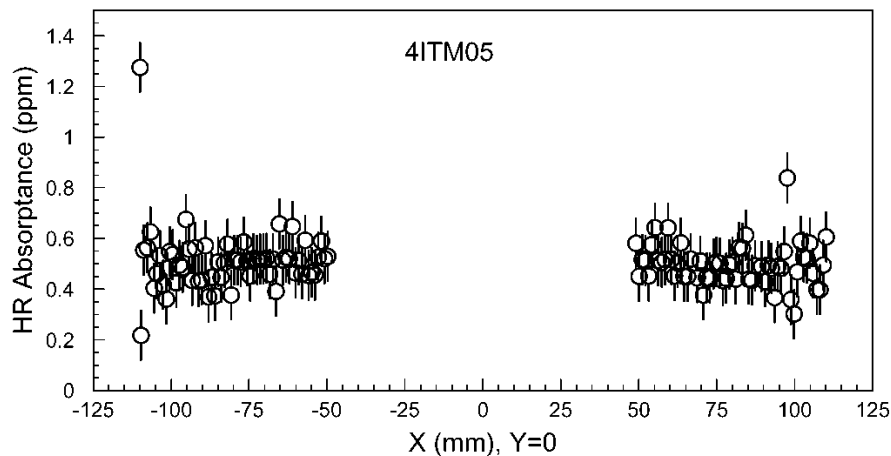
HR scatter vs. absorption of 4ITM07



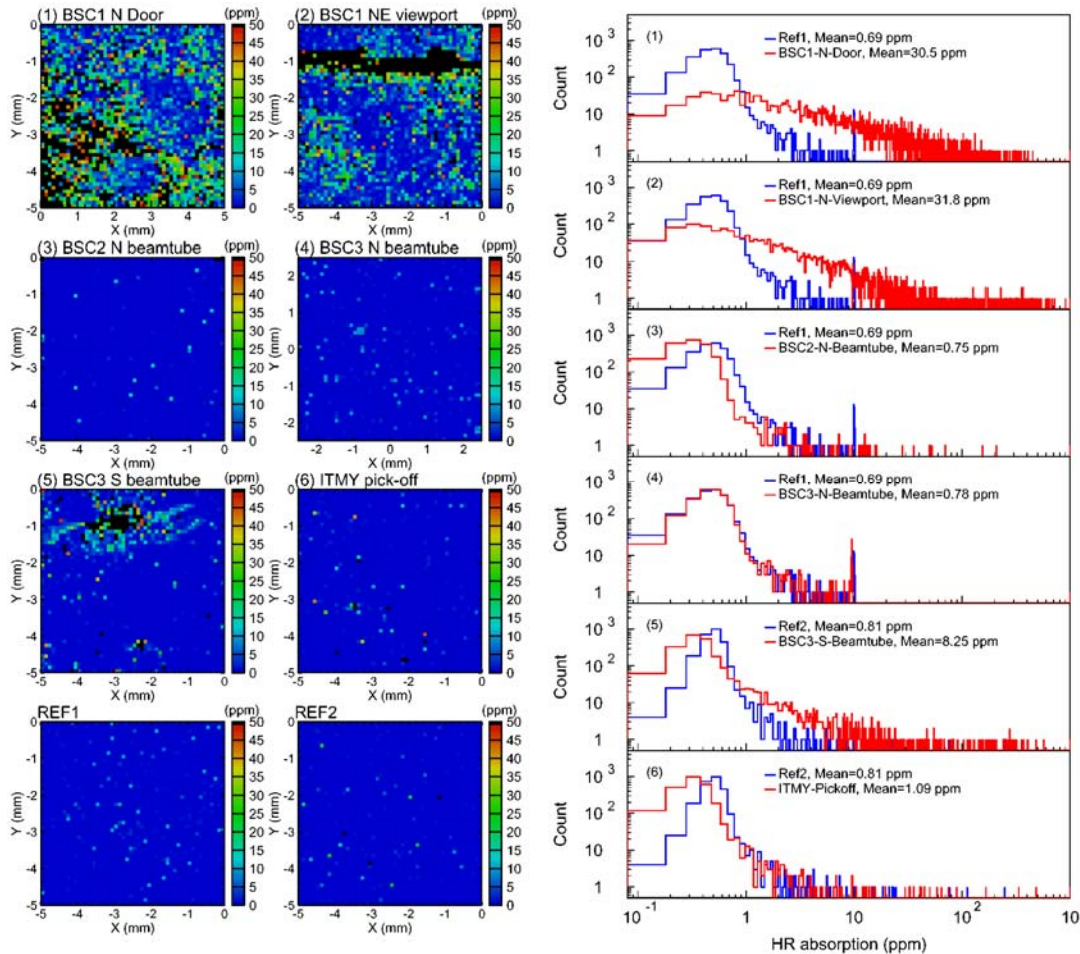
The correlation indicates that it may use a PD to monitor this kind of contamination

HR absorption of 4ITM05,

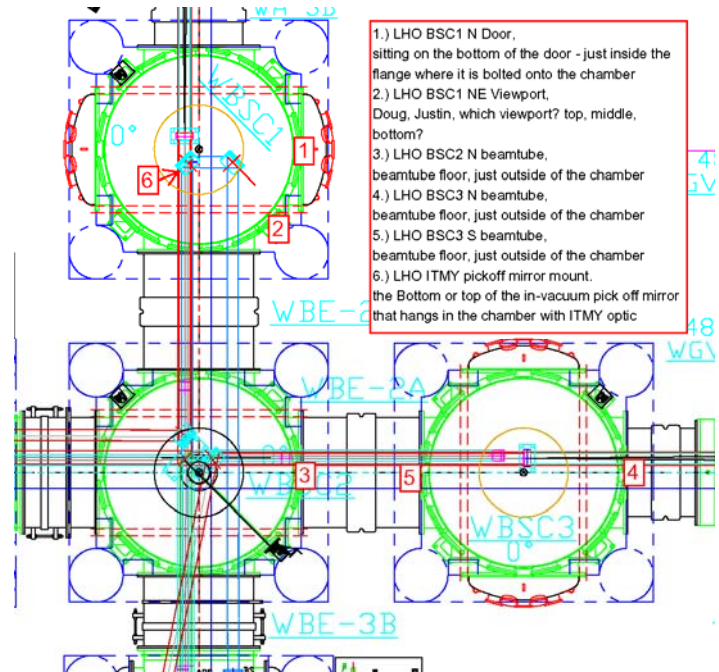
which replaced 4ITM07 at LHO in 2005



HR absorption of the witness mirrors at LHO

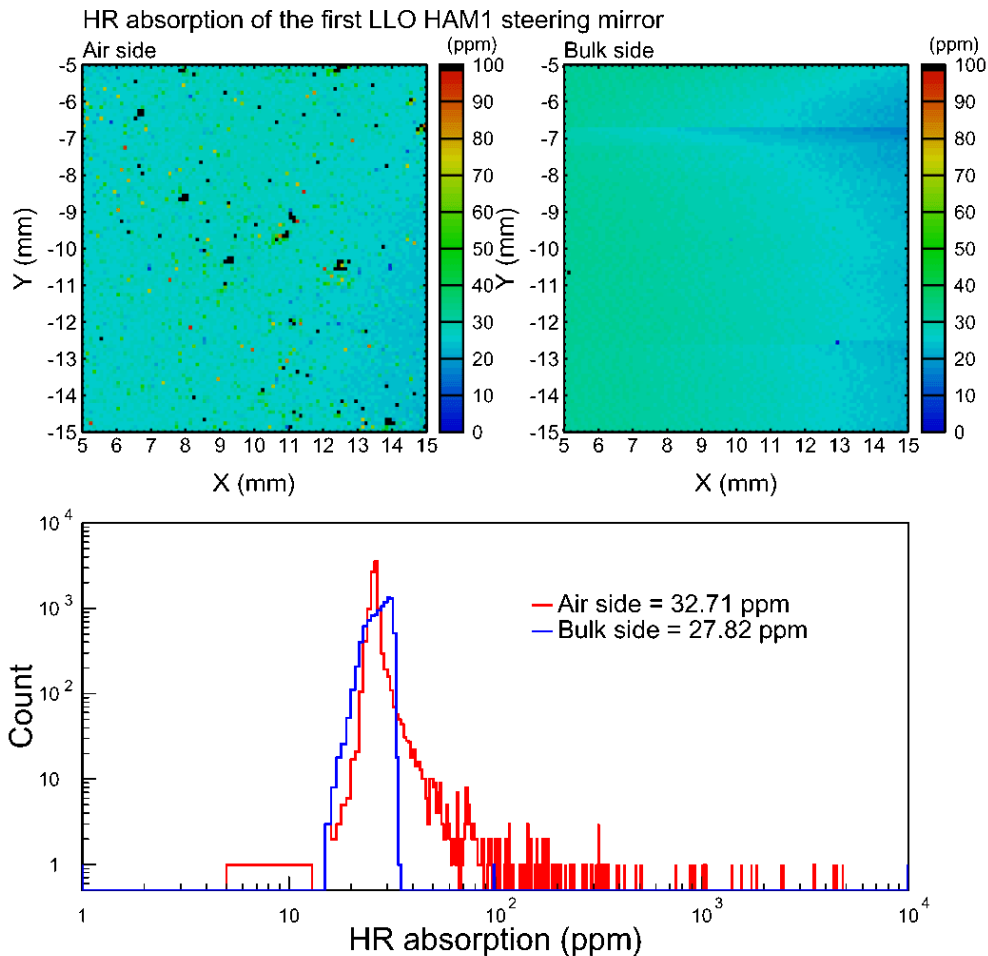


G. Billingsley, LIGO-T080072



The contamination are also of points, and can be easily removed by wiping.

HR absorption of a steering mirror from LLO HAM1 chamber



- In addition to some high absorption points, there is a high uniform absorption (~25 ppm).
- This uniform absorption can not be changed by regular cleaning process.
- The bulk side is also measured, which shows a consistent uniform absorption.
- There is almost no high absorption point at bulk side.

Summary

- By using an integrating sphere ($1.5^\circ < \theta < 78^\circ$, or $250 - 9100 \text{ cm}^{-1}$), the TIS measurement was carried out with six LIGO-I mirrors. Substantial difference of the micro-roughness cut-off edge is observed between the measured mirrors, in which the two super polished ETMs show the best result.
- More work is needed to understand the discrepancy between the measured micro roughness cut-off and the estimation calculated by the substrate micro roughness measurement.
- The HR absorption of the 4ITM07 swapped out from LHO was measured to be about 13ppm, which is caused by some removable high absorption particle-like contamination. This result is consistent with that of the following witness samples.
- The HR coating of a steering mirror from LLO HAM1 chamber was found to have an unusual more or less uniform absorption of about 30 ppm. Further investigation is underway.