LIGO

Advanced LIGO Core Optics

- Specifications
- Measurements
  - Fizeau Metrology
  - Reflectivity, Transmission, Scatter and Absorption
- Problems Along the Way
- Simulation and Modeling
- A Path to Production for A+
- Manufacturing and Timetable

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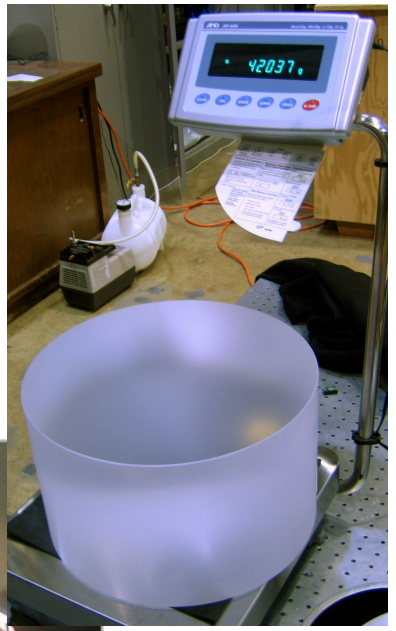
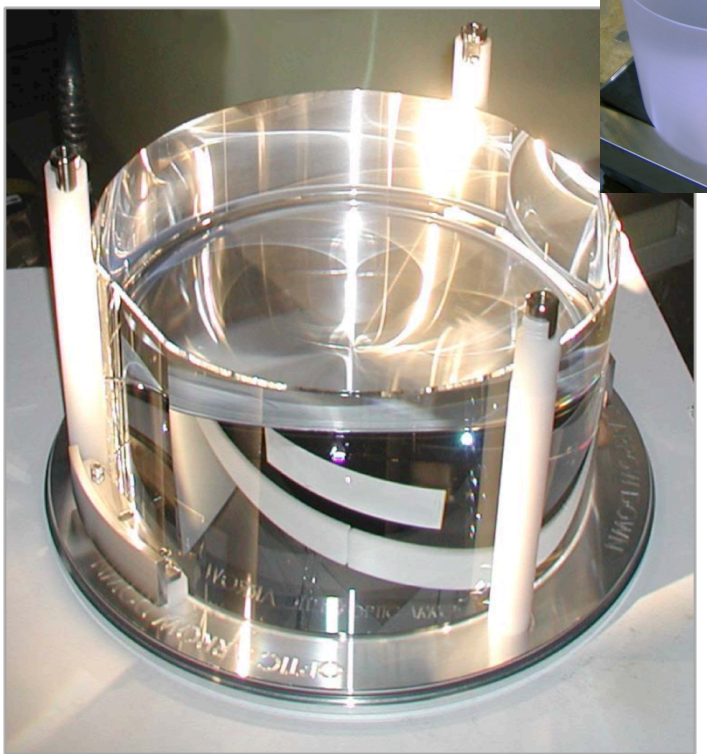
Test Mass Specifications

- Radius of Curvature ~2000 m, match ± 3 m
- RMS figure error
  - » Central 300 mm $\sigma_{rms} < 2.5$ nm
  - » Central 160 mm $\sigma_{rms} < 0.3$ nm
- RMS microroughness
  - » 4 Locations $\sigma_{rms} < 0.16$ nm
- R > 0.999995, T < 5 PPM
- Total Cavity Loss < 75 ppm





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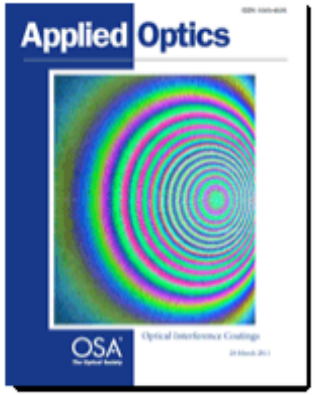
Cavity loss budget

Round Trip Cavity loss 2 surfaces (ppm)	Cavity Budget (ppm)	Actual loss (modeled) based on average of completed pieces in 2013 (ppm)
Microroughness scatter (>1/mm)	8	2.2 Per mirror
Defects (Polish, Coating, Contamination)	26	10 per mirror includes polish and coating
Coating Absorption	1	0.3 per mirror
Surface Figure Error & Diffraction	24	16.2
ETM Transmission	5	4.2
Total (required < 75 ppm)	64	45.4

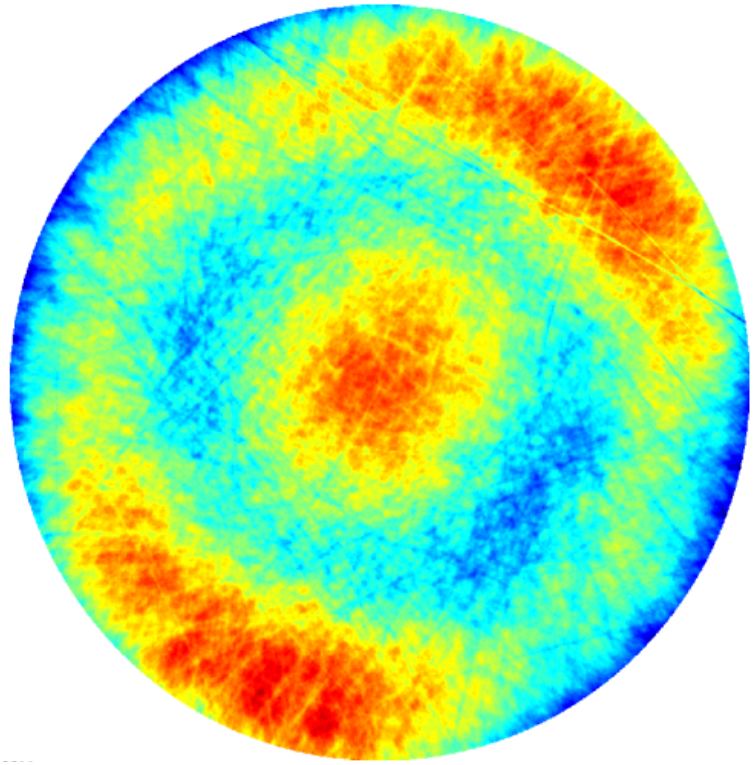
CSIRO

mastered uniformity and AR coating reflectivity but struggled with absorption

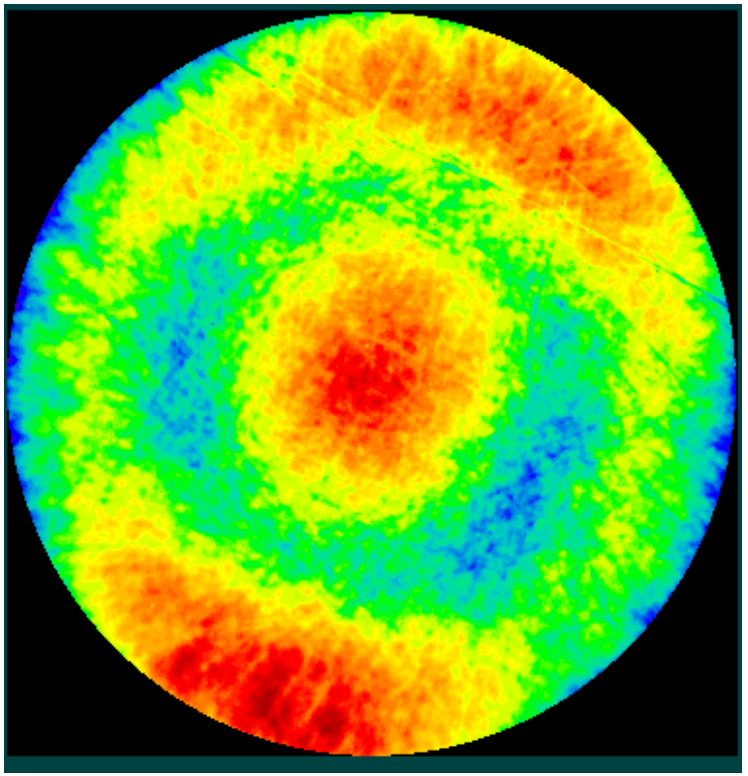


300 mm diameter, same color scale, Power subtracted (Δ 3.5nm)

Uncoated (m-Zygo EPO)
11.4 nm PV 1.7 nm rms



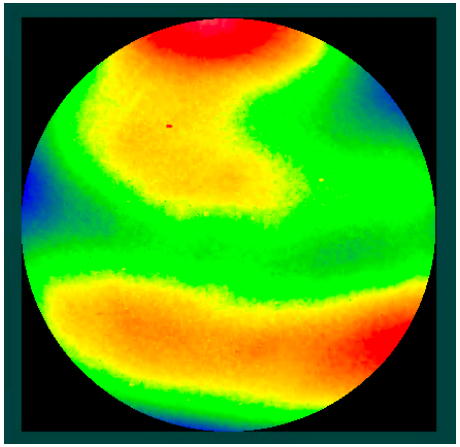
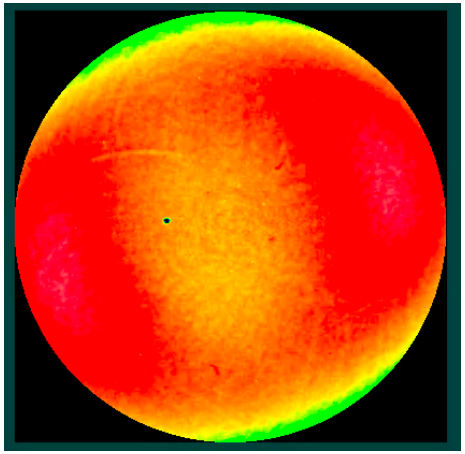
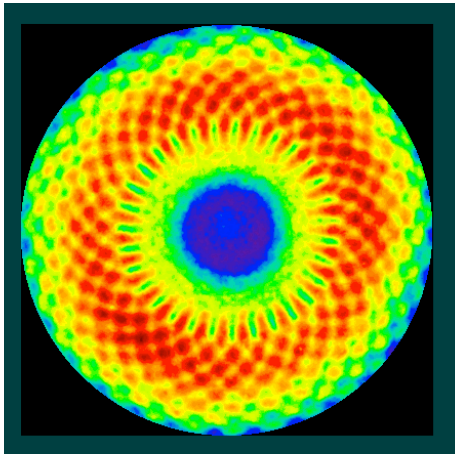
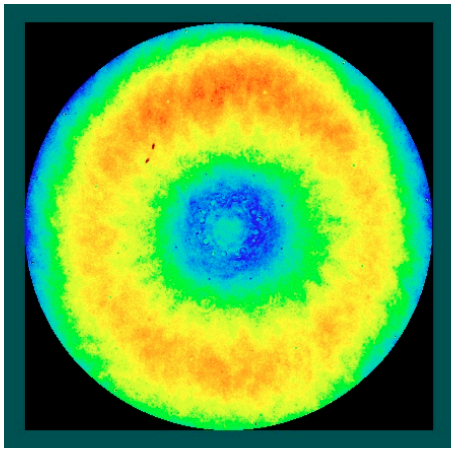
Coated at CSIRO (m-LIGO)
9.8 nm PV 1.6 nm rms



Mark Gross, Svetlana Dligatch, and Anatoli Chtanov, "Optimization of coating uniformity in an ion beam sputtering system using a modified planetary rotation method," Appl. Opt. 50, C316-C320 (2011)

LMA

Mastered absorption and scatter
but struggled with uniformity and AR reflectivity

12 nm PV Feb 2011

11 nm PV

4 nm PV

5 nm PV Mar 2015

160 mm diameter

Specification – no change in Zernike coefficient > 0.5 nm

When is it Good Enough? Ask Hiro

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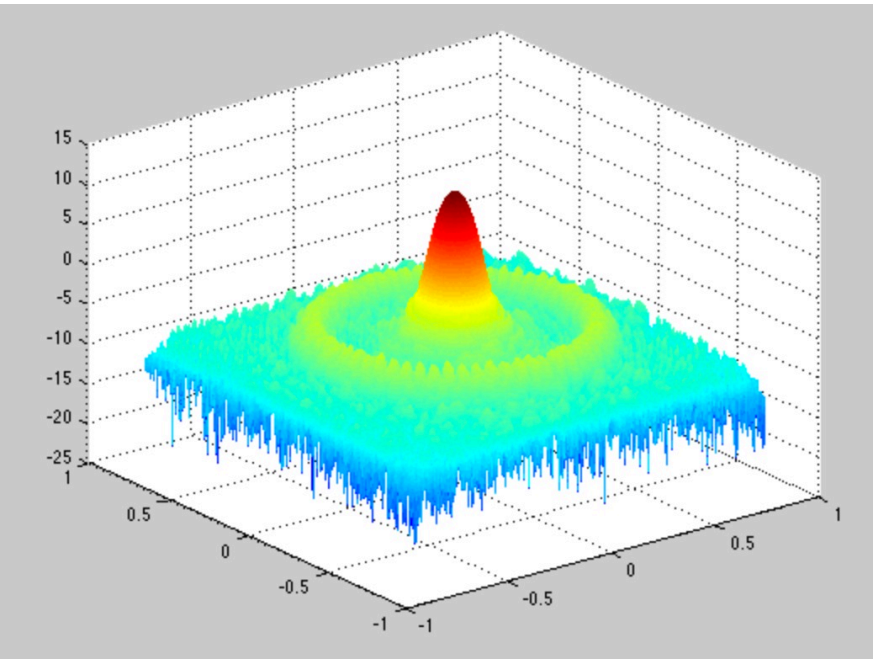
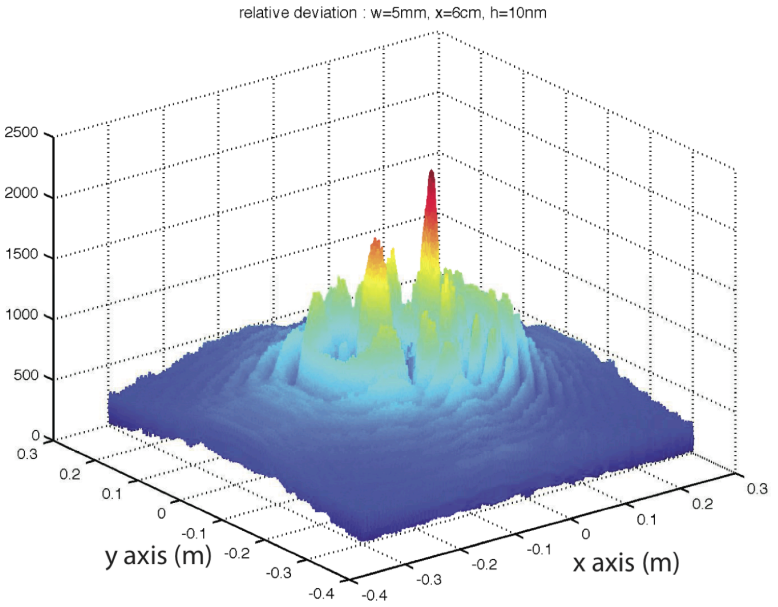
Optical Static Interferometer Simulation (SIS)

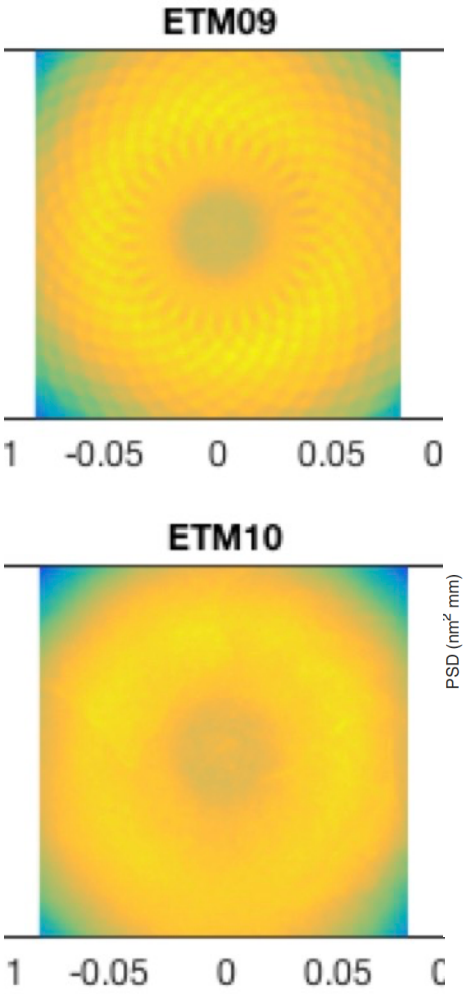


- FFT Propagation
- Coupled optical cavities
- Multiple frequencies
- Edge diffraction and apertures
- Real mirror figure errors



Problems Along the Way

- Spirograph figure error
- AR Reflectivity
- Excess absorption
- Large radius figure error
- 532 Transmission



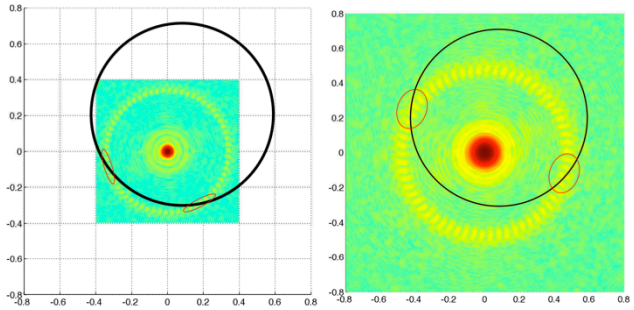
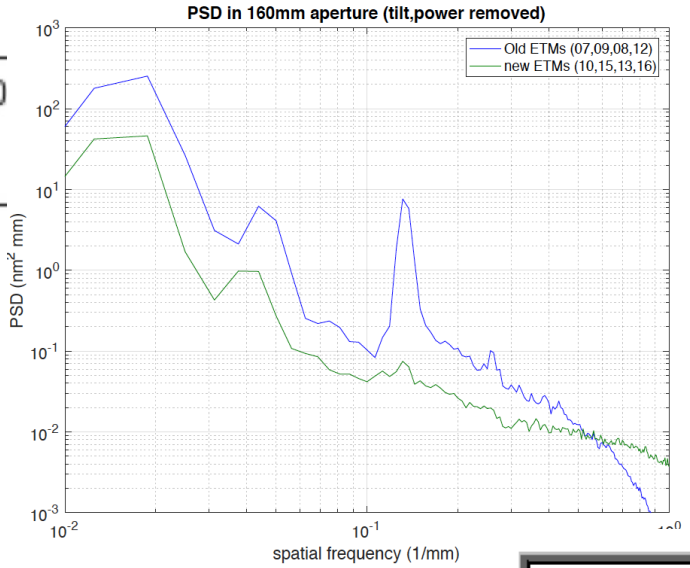
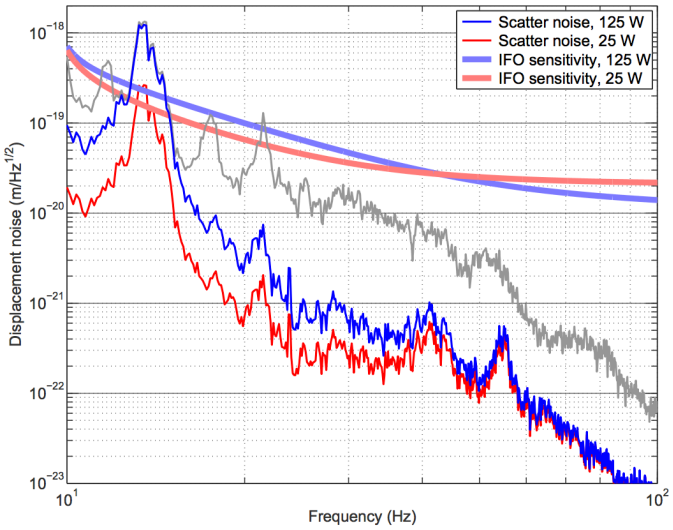


Figure 8. Power distribution in 80cmx80xm plane : left at 2500m, right at 3500m Black circle is the un-shadowed ring on the baffle.





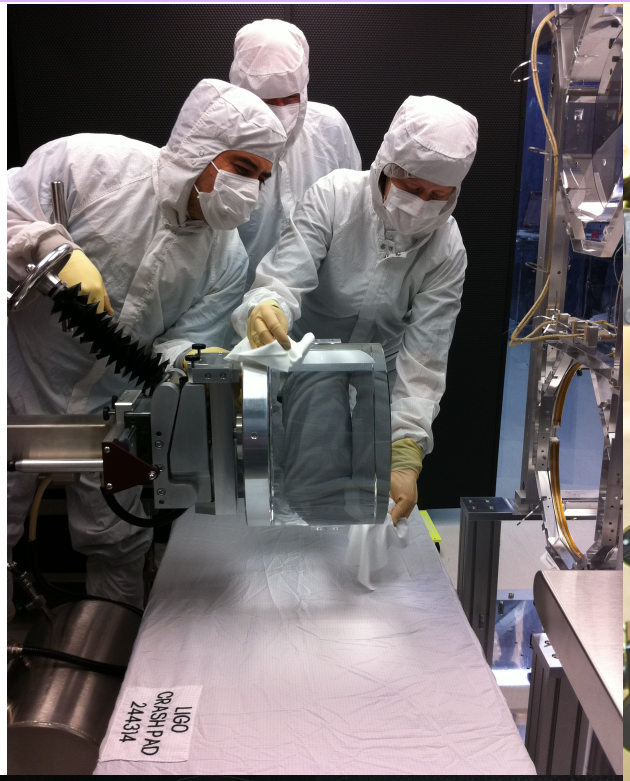
LIGO-T1000090-v5 LIGO April 25, 2012

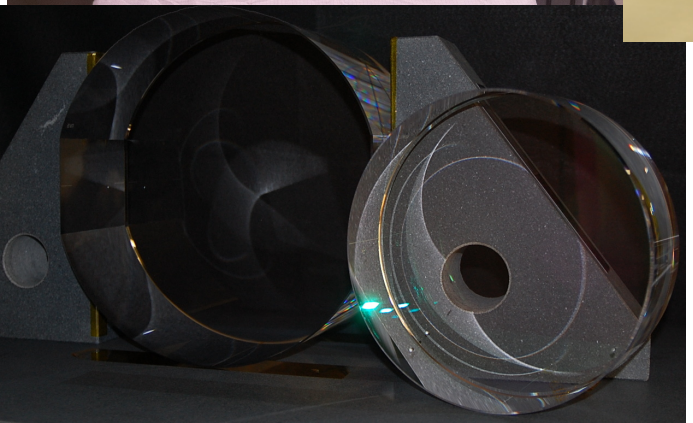
advanced LIGO baffle design using SIS

Hiro Yamamoto

LIGO

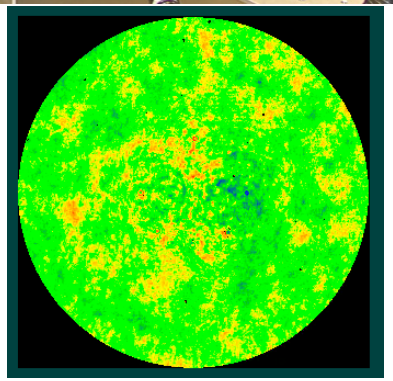
Fizeau Metrology





- 40 cm
- λ/2000
- 1064 nm

0.05 nm rms
30 mm Φ



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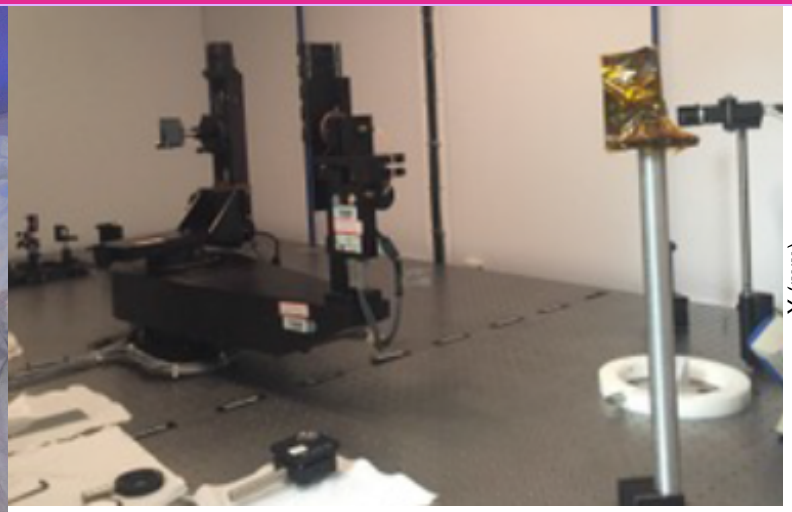
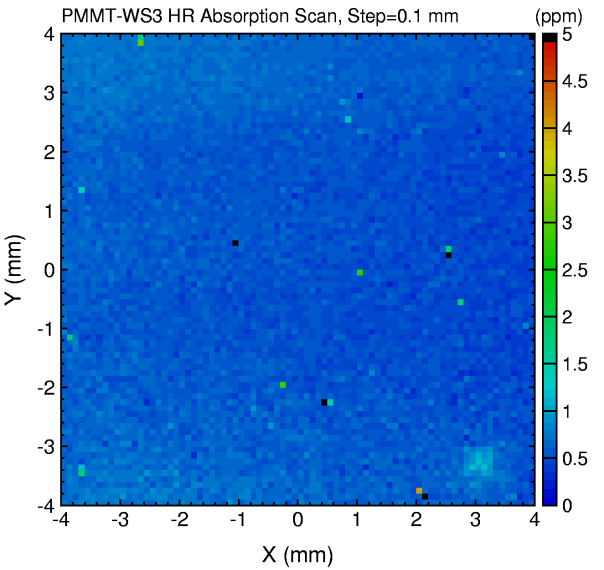
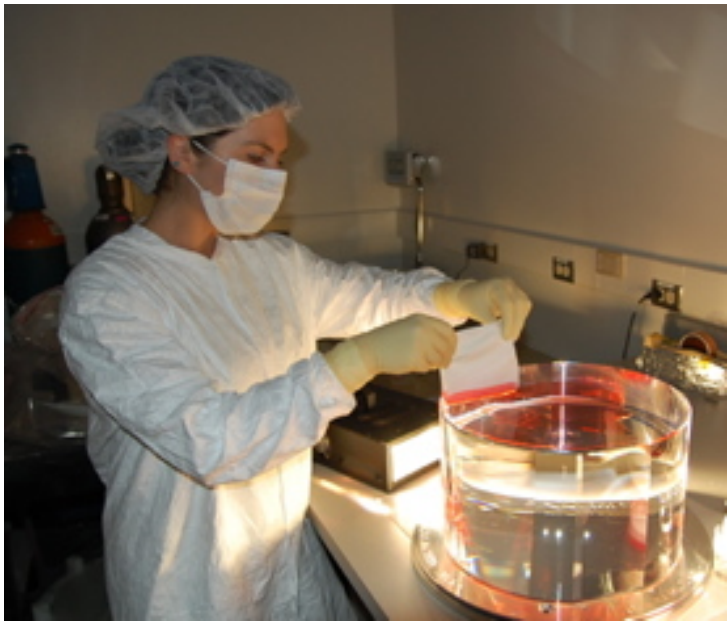
Reflectivity, Transmission, Scattered Light, Absorption



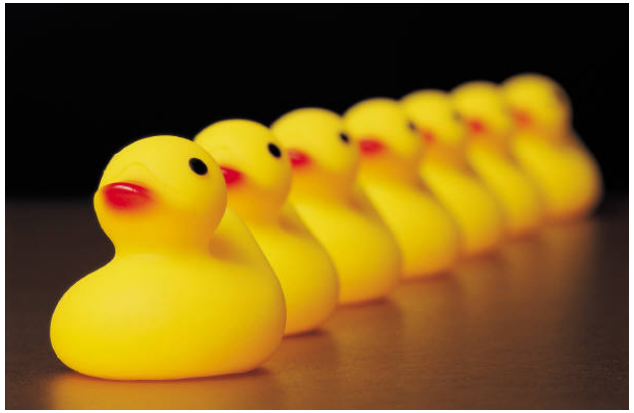


- Reflectivity
- Transmission
- Scattered light
- Absorption



A path to production for A+

- Pathfinder - Competitive demonstration of all specifications on a full size optic by a vendor with full scale coating capacity
  - Competitive bid ~ 3 months
  - Selection and kickoff, review performance specifications ~ 1 month
  - Development
    - Phase 1: Demonstration on small pieces
    - If successful proceed to Phase 2
    - Phase 2: Demonstration on full size optic
  - Review final data at vendor
  - Confirm final measurements at LIGO



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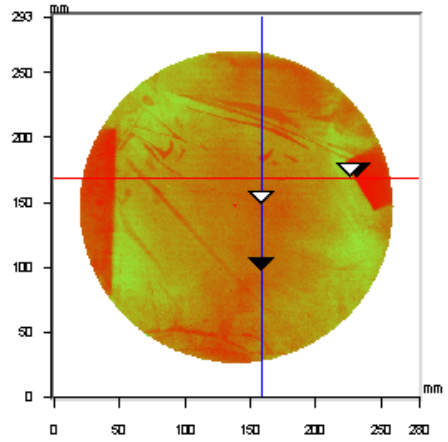
Manufacturing and Timetable

- Advanced LIGO polishing 3 years total
  - 56 total optics, 26 test masses
  - Contract – 2009
  - First delivery 2010
  - Final delivery 2012
  - Throughput rate of 2/month once things got rolling
- Advanced LIGO Test Mass coating 6 years total
  - Contract – 2009
  - First delivery 2011
  - Final delivery 2015
  - Throughput rate of 2/month once things got rolling

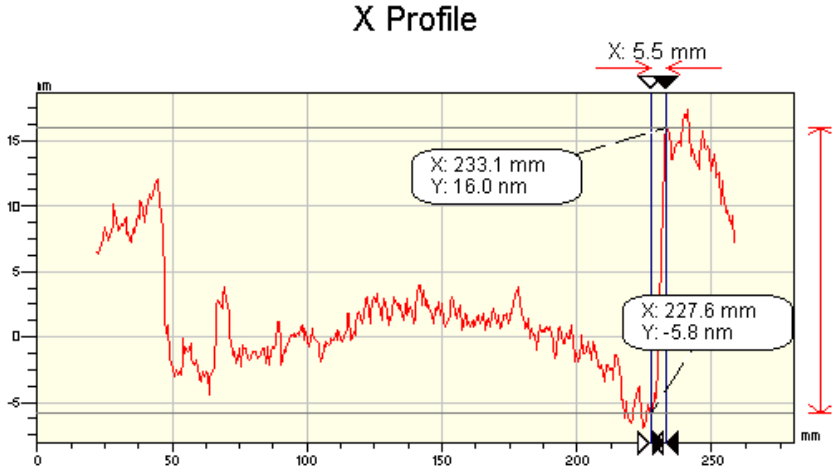
Veeco



X	159.16	-	-	mm
Y	168.57	-	-	mm
Ht	0.81	-	-	nm
Dist			-	mm
Angle			-	°

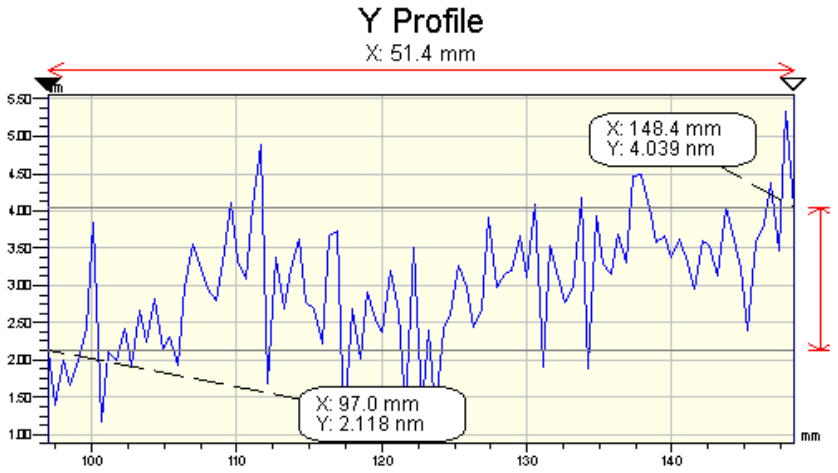
Title: 4ITM01 side 1

Note: -T/P



Rq	8.38 nm
Ra	7.74 nm
Rt	21.82 nm
Rp	15.98 nm
Rv	-5.84 nm

Angle	3.96 urad
Curve	0.62 km
Terms	None
Avg Ht	2.93 nm
Area	16.13 um2

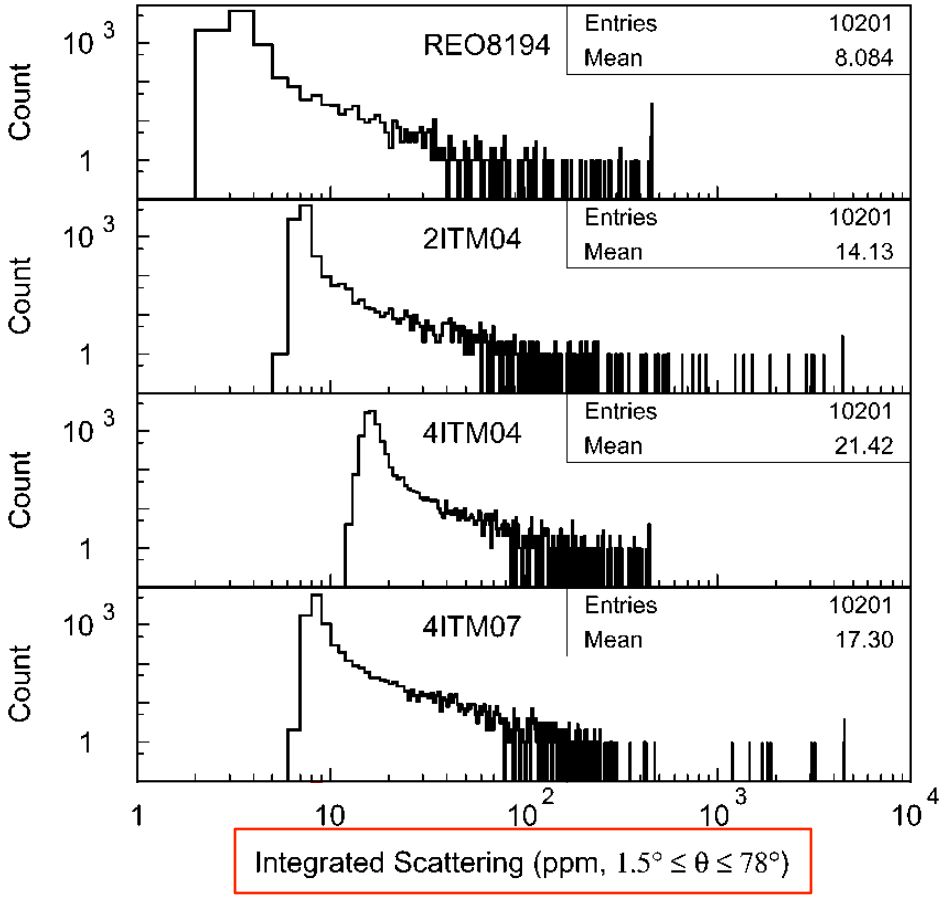


Rq	0.85 nm
Ra	0.69 nm
Rt	4.25 nm
Rp	5.33 nm
Rv	1.08 nm

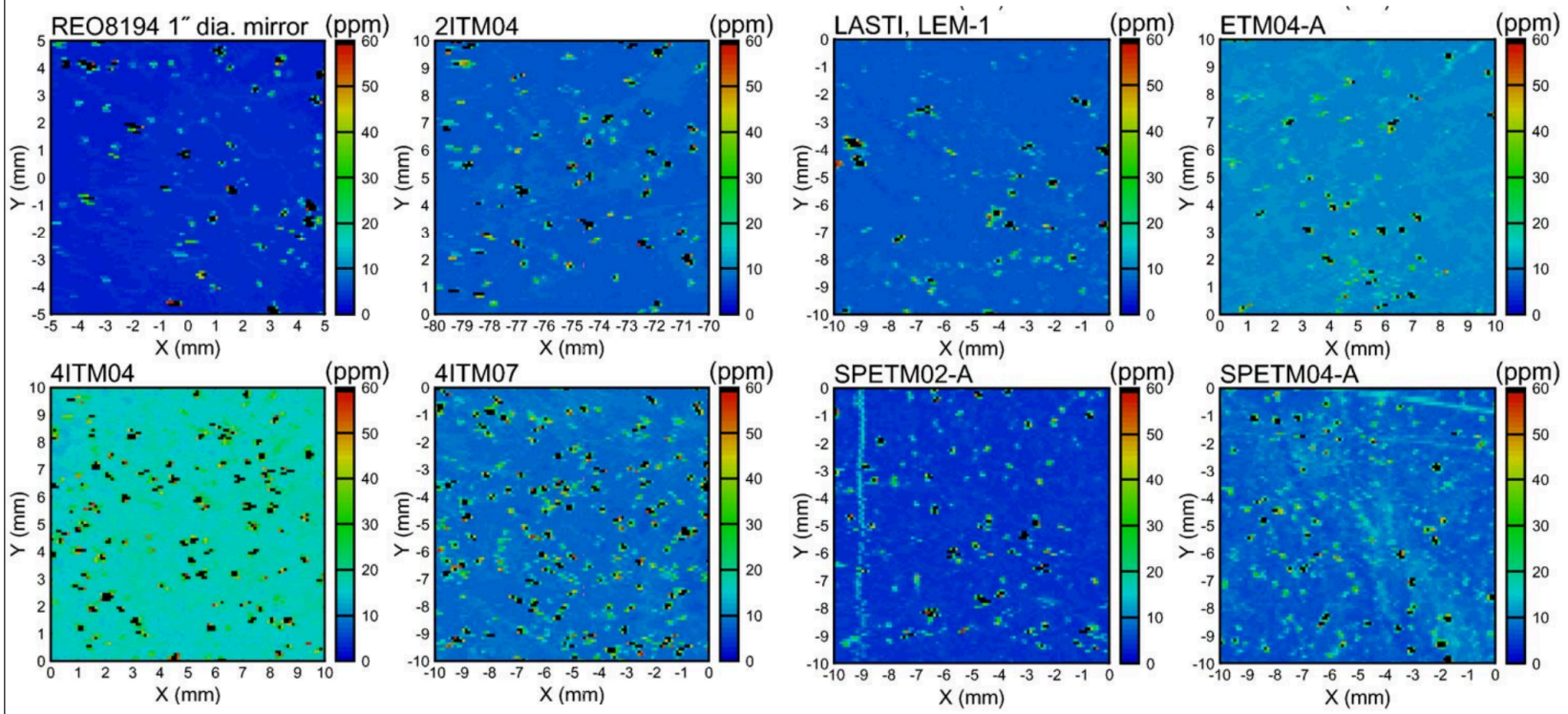
Angle	0.04 urad
Curve	-
Terms	None
Avg Ht	2.98 nm
Area	153.03 um2

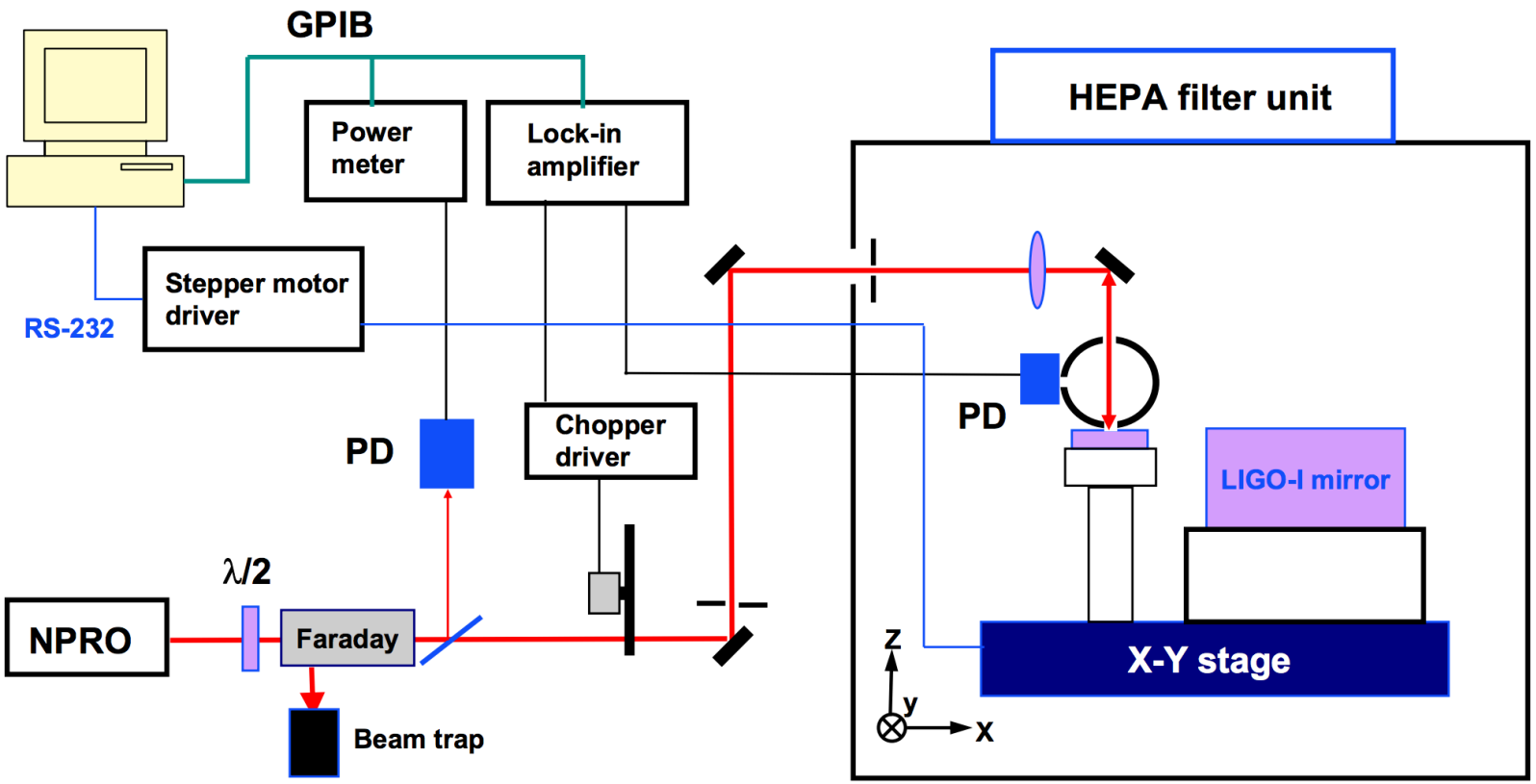
Scatter histograms
An indication of etching

- Lower end represents the base microroughness
- High end represents point defects
- See LIGO-G080162 for details



From Optical Coating Workshop 2008




GPIB
Power meter
Lock-in amplifier
HEPA filter unit
Stepper motor driver
RS-232
PD
Chopper driver
PD
LIGO-I mirror
λ/2
NPRO
Faraday
X-Y stage
Beam trap
z
y
x