Sapphire Test Masses:

Lowering Thermoelastic noise

Research by

Erika D'Ambrosio, Richard O'Shaughnessy
& Kip Thorne

[Caltech]

Vladimir Braginsky, Sergey Strigin & Sergey Vyatchanin

[MSU]

Presented by GariLynn Billingsley

February 2003

Aspen

Overview

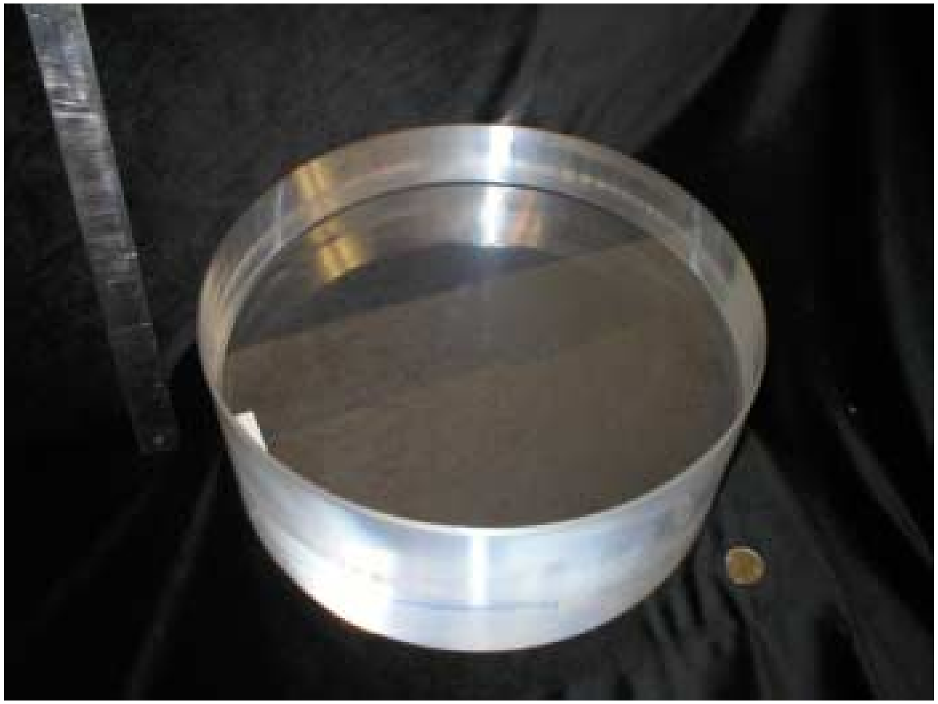
- Sapphire development
- Flat Top Beam profile to reduce thermoelastic noise
  - » Erika D'Ambrosio, Richard O'Shaughnessy, Kip Thorne, Sergey Strigin & Sergey Vyatchanin

Advanced LIGO Test Masses

- Material Selection – May ’03
  - » Sapphire Baseline
  - » Fused Silica Fall-back
- Delivery of first two large sapphire substrates Feb ’03
- Measurement of first two large sapphire substrates
  - » Q, Phil Willems, CIT
  - » Absorption map, SMA Lyon
  - » Scatter map, SMA Lyon or CIT (instrument being built at CIT)
  - » Homogeneity, CIT
- Install LASTI test masses – October ‘04

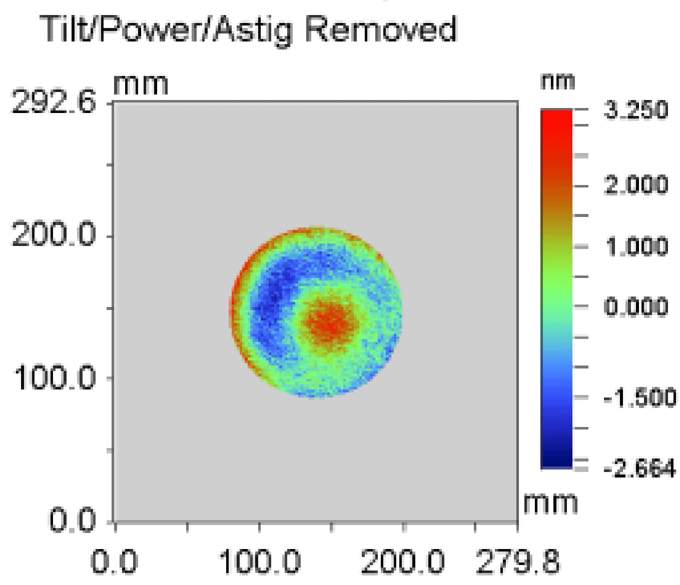
Full size Sapphire substrates

- Five experimental growth runs Crystal Systems
  - » Two of five 15” boules are considered good optical quality
  - » Two of five are not
  - » One “good” one “not” were delivered to Caltech Jan 30, 2003



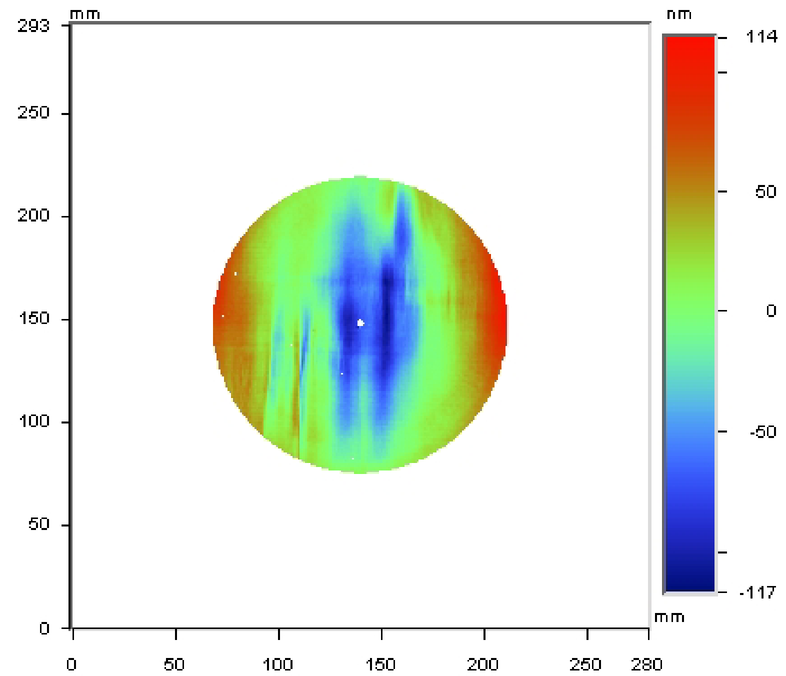
Polishing spherical surfaces

- CSIRO and Wave Precision have good results
  - » Microroughness to ~ 1Å
  - » CSIRO better figure (better metrology)
  - » Rms ~1nm, may be metrology limited



Homogeneity

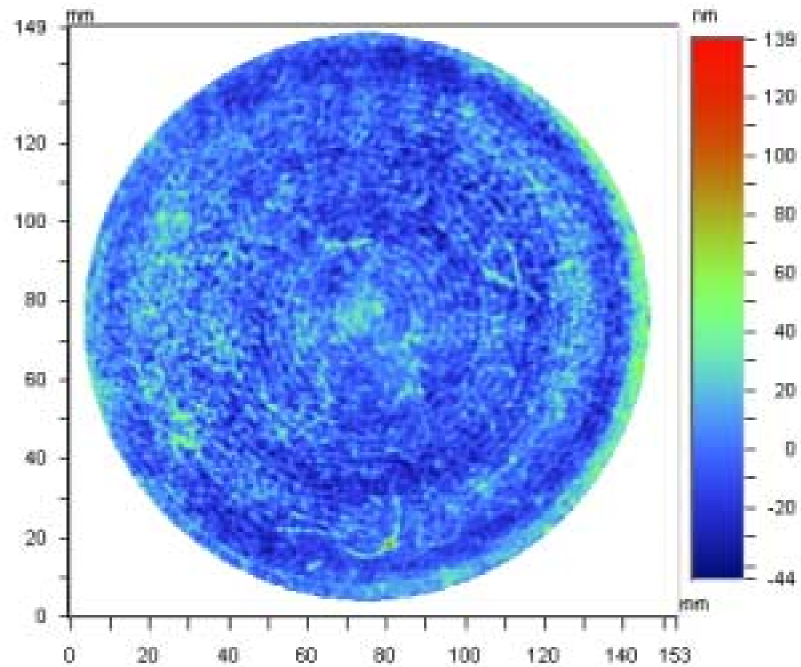
- Can't get c-axis in large sizes 314 mm x 130 mm
- The problem with m- and a-axis sapphire…



Date: 08/11/2000
Time: 14:23:44
Wavelength: 690.700 nm
Pupil: 100.0 %
PV: 231.4251 nm
RMS: 41.4312 nm

X Center: 280.00
Y Center: 280.00
Radius: 143.43 pix
Terms: Tilt
Filters: None
Masks:

Compensating Polish by Goodrich - technology "on hand"



Date: 04/16/2002
Time: 14:37:03
Wavelength: 1.064 um
Pupil: 100.0 %
PV: 183.6397 nm
RMS: 14.6141 nm

X Center: 282.00
Y Center: 243.00
Radius: 269.89 pix
Terms: Tilt
Filters: None
Masks: Detector Mask

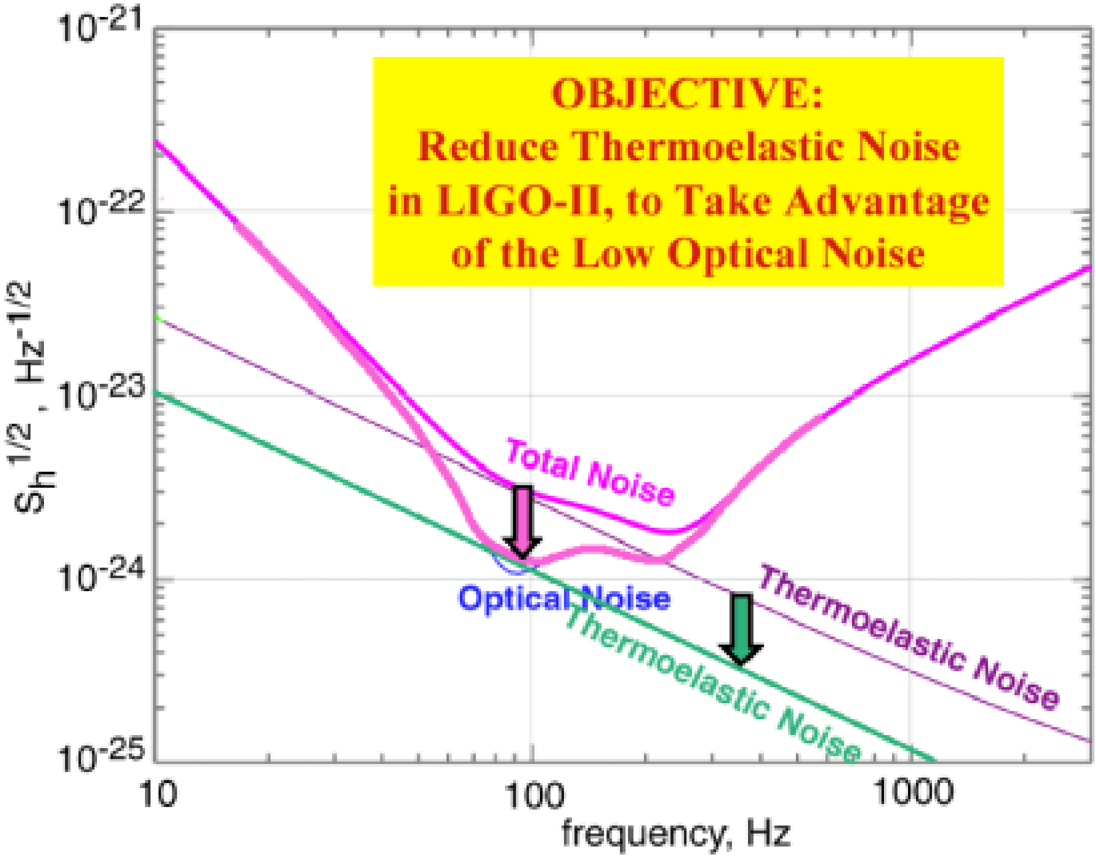
Improve sensitivity of Advanced LIGO

If using Sapphire Test Masses

- Decrease spectral density of Thermoelastic noise by 0.34
- Increase detection rate for CBI by 2.6
  - » LIGO-T030009-00 Erika D’Ambrosio, Richard O’Shaughnessy, Sergey Strigin, Kip Thorne, Sergey Vyatchanin

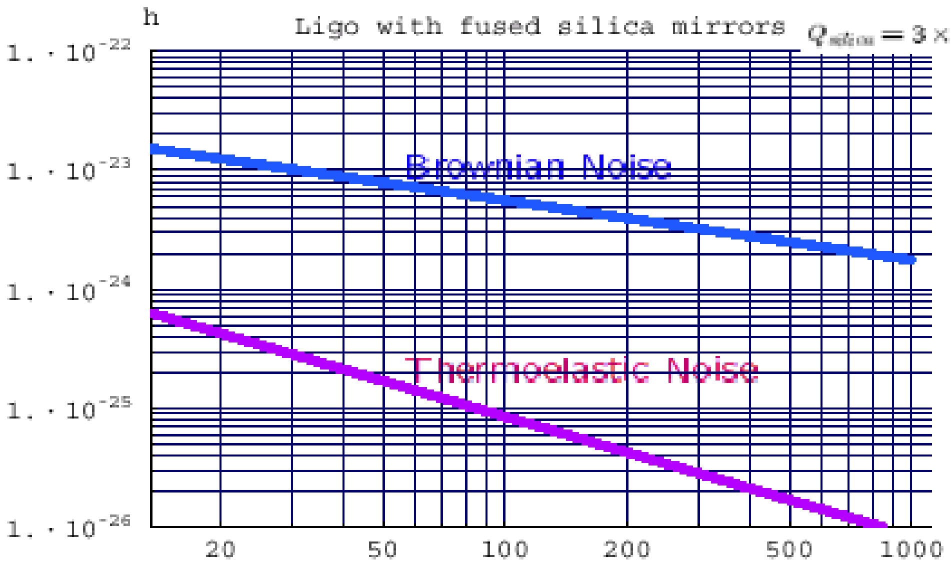
Context

from LIGO-G020543-00, Thorne, D’Ambrosio, O’Shaughnessy



More Context
Noise in Silica vs. Noise in Sapphire

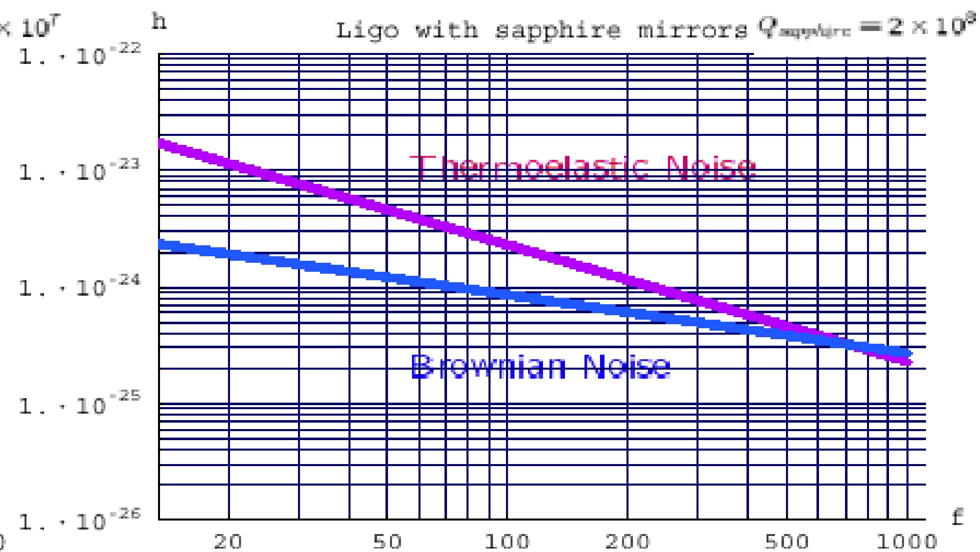
Provided by Erika D'Ambrosio



Lower noise by increasing spot size

$$S_{BN}(f) \sim 1/w$$

$$S_{TE}(f) \sim 1/w^3$$



An alternative could be cooling the mirrors. This gives more advantage for the reduction of thermoelastic noise

$$S_{TE}(f) \sim T^2$$

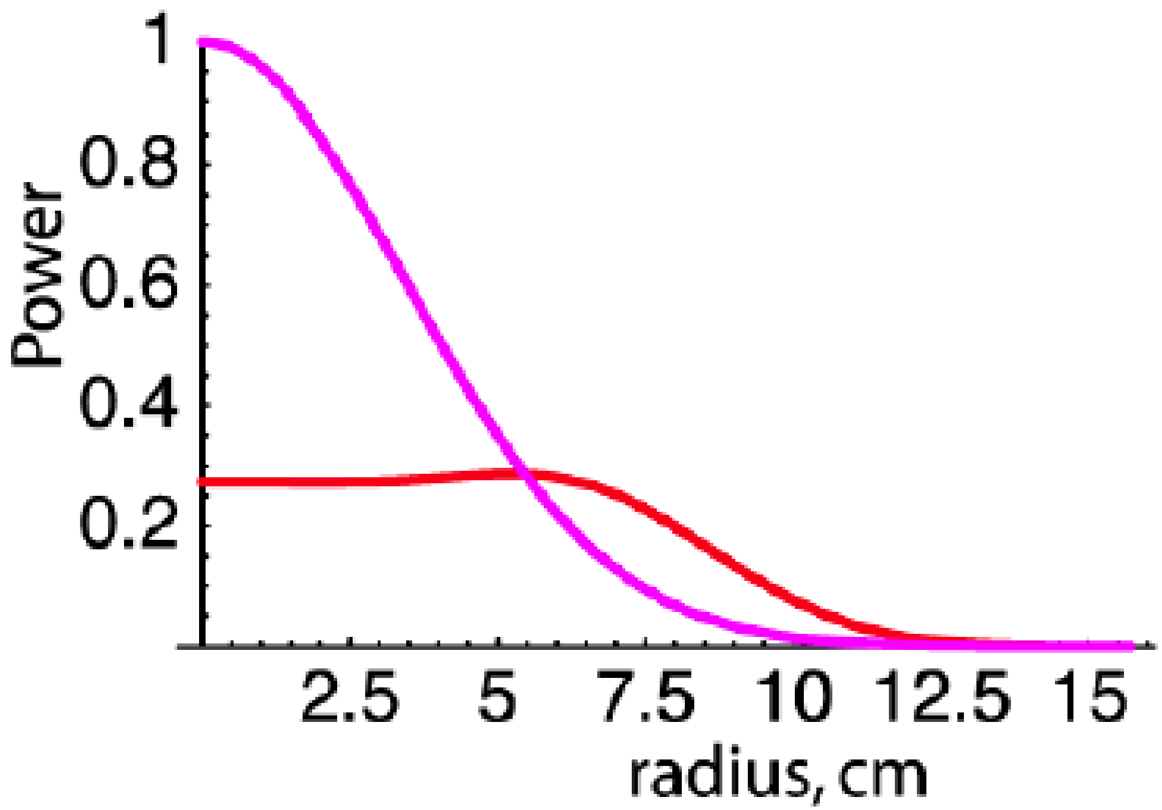
than with Brownian noise

$$S_{BN}(f) \sim T$$

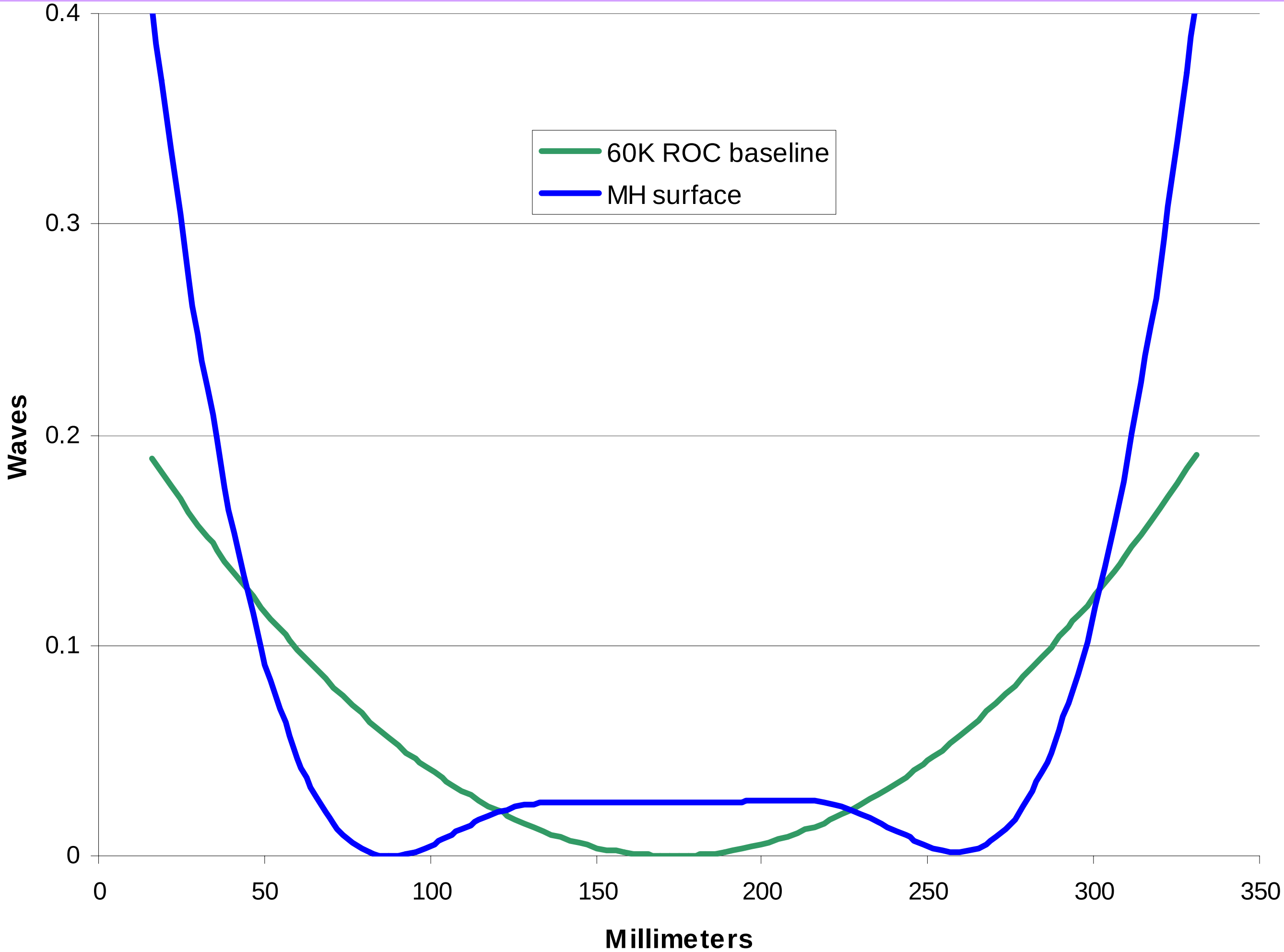
although for very low temperature the dependance of the constants on T must be taken into account.

Distributed power lowers noise

from LIGO-G020543-00, Thorne, D'Ambrosio, O'Shaughnessy



Compute mirror surface which matches phase fronts

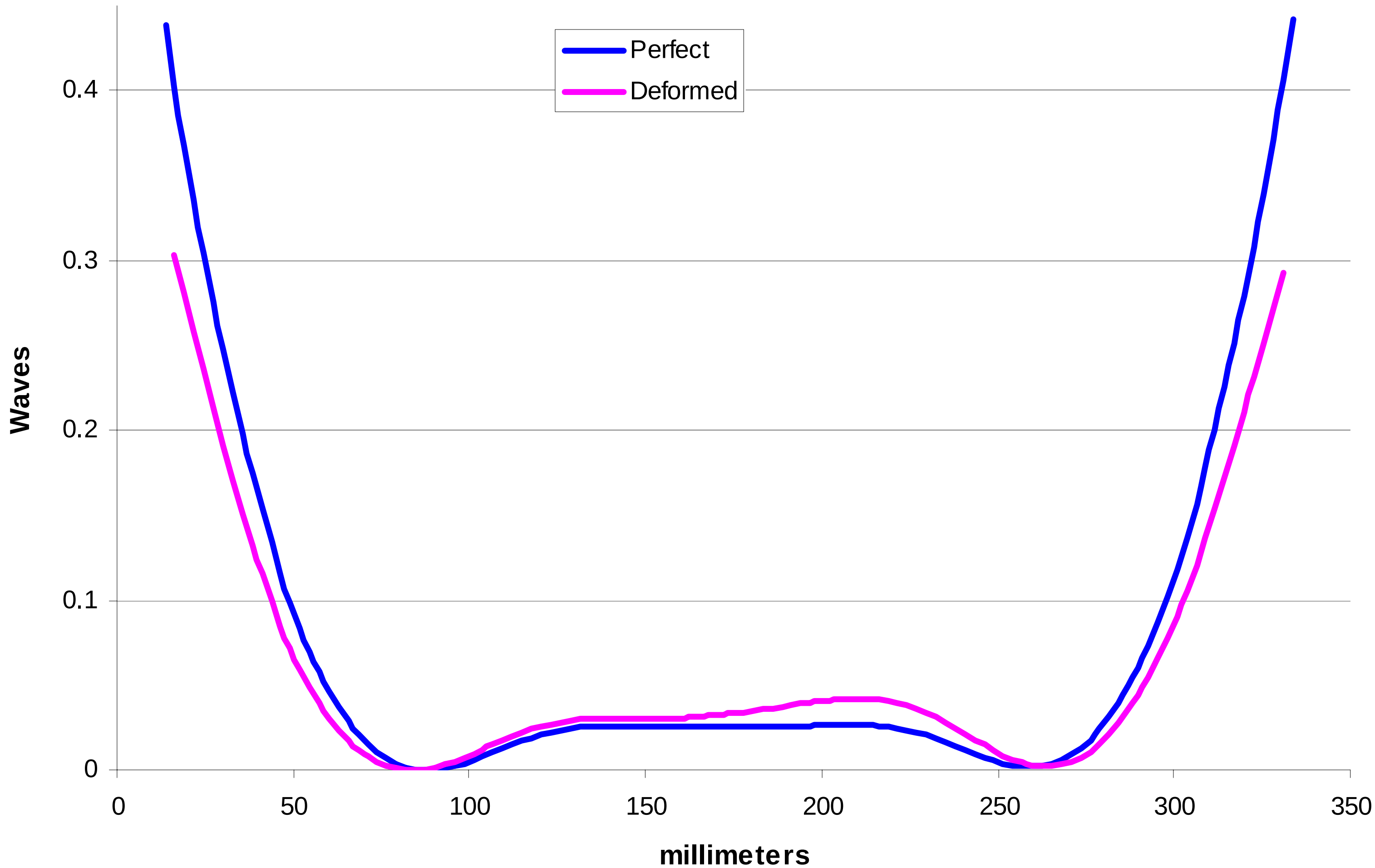


MIT meeting – Fall ‘02

- Can we make surfaces like this?
- How tightly must we control displacement?
- How tightly must we control tilt?

- Answers in the referenced paper T030009-00

How good must the surface be?



Sensitivity to surface deformation

Fraction of Carrier Power ➔	Lost to Parasitic Modes	Lost to Dark Port
Mexican Hat	$.0008(\Delta z\ /6\text{nm})^2$	$.00015(\Delta z\ /6\text{nm})^2$

Δz - PV deviations in inner 100mm radius

2nm ➔ 100ppm loss to modes, 16ppm loss to Dark Port.

Compare Sensitivity to transverse displacement *s*

from LIGO-T030009-00, D'Ambrosio, O'Shaughnessy, Strigin, Thorne, Vyatchanin

Fraction of Carrier ➔	Lost to Parasitic Modes ppm	Lost to Dark Port ppm
Mexican Hat	$100(s/1\text{mm})^2$	$190(s/1\text{mm})^2$
Baseline	$100(s/1.3\text{mm})^2$	$190(s/1.3\text{mm})^2$

Compare Sensitivity to tilt θ

from LIGO-T030009-00, D'Ambrosio, O'Shaughnessy, Strigin, Thorne, Vyatchanin

Fraction of Carrier ➔	Lost to Parasitic Modes	Lost to Dark Port
Mexican Hat	$.001(\theta/0.01\mu rad)^2$	$.002(\theta/0.01\mu rad)^2$
Baseline	$.001(\theta/0.035\mu rad)^2$	$.002(\theta/0.035\mu rad)^2$

Preparing MH surfaces

	Infrastructure	Metrology
Ion Beam figuring		
•ASML	✓	✓
•Kodak	✓	✗
•CSIRO	✗	✓
Corrective coating		
•SMA-Lyon	✓	✓

Summary

- Material selection scheduled for May ’03
- Flat top or Gaussian profile?
- Benchtop demonstration of Flat top is difficult due to small size of optic