Sapphire Test Masses:

Lowering Thermoelastic noise

Research by

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Presented by GariLynn Billingsley
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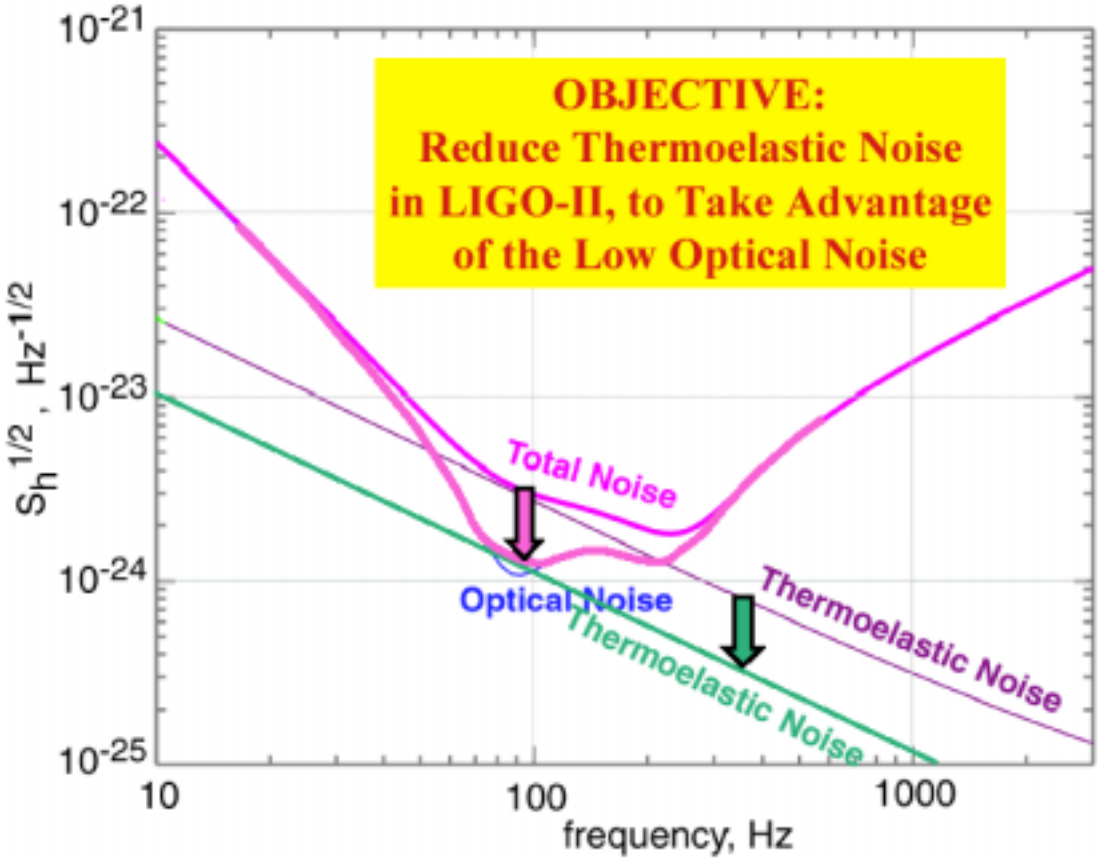
Aspen

Improve sensitivity of Advanced LIGO

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

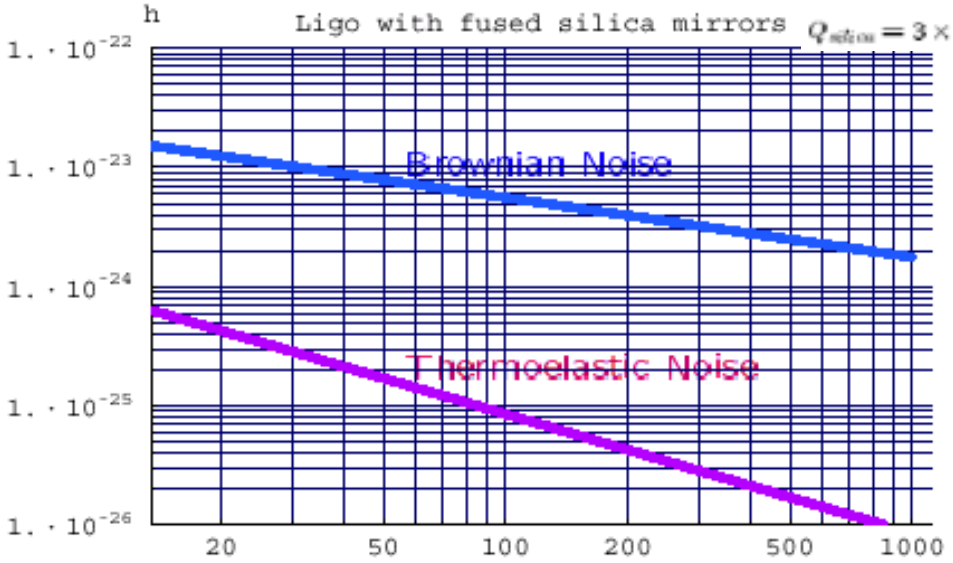
Context

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



More Context
Noise in Silica vs. Noise in Sapphire

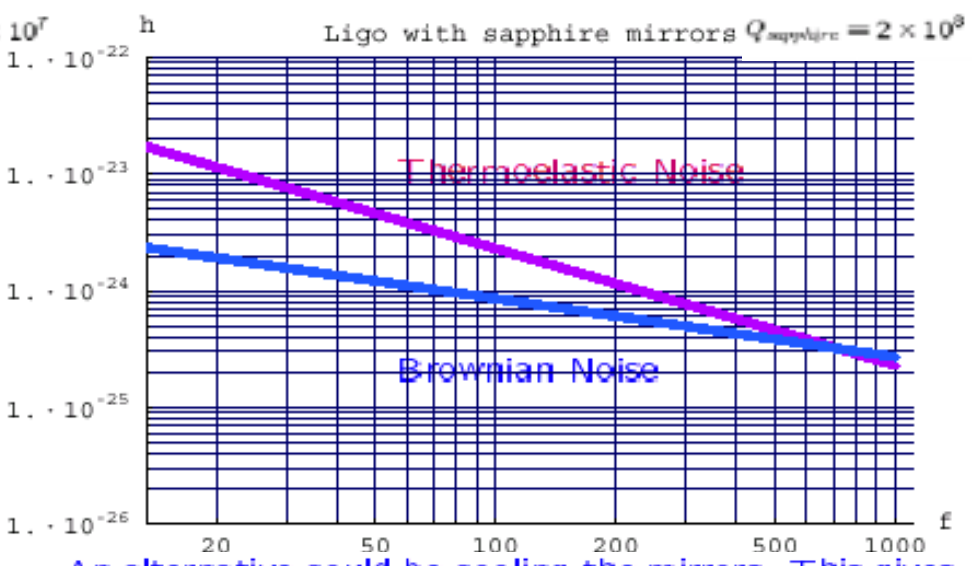
Provided by Erika D'Ambrosio



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

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

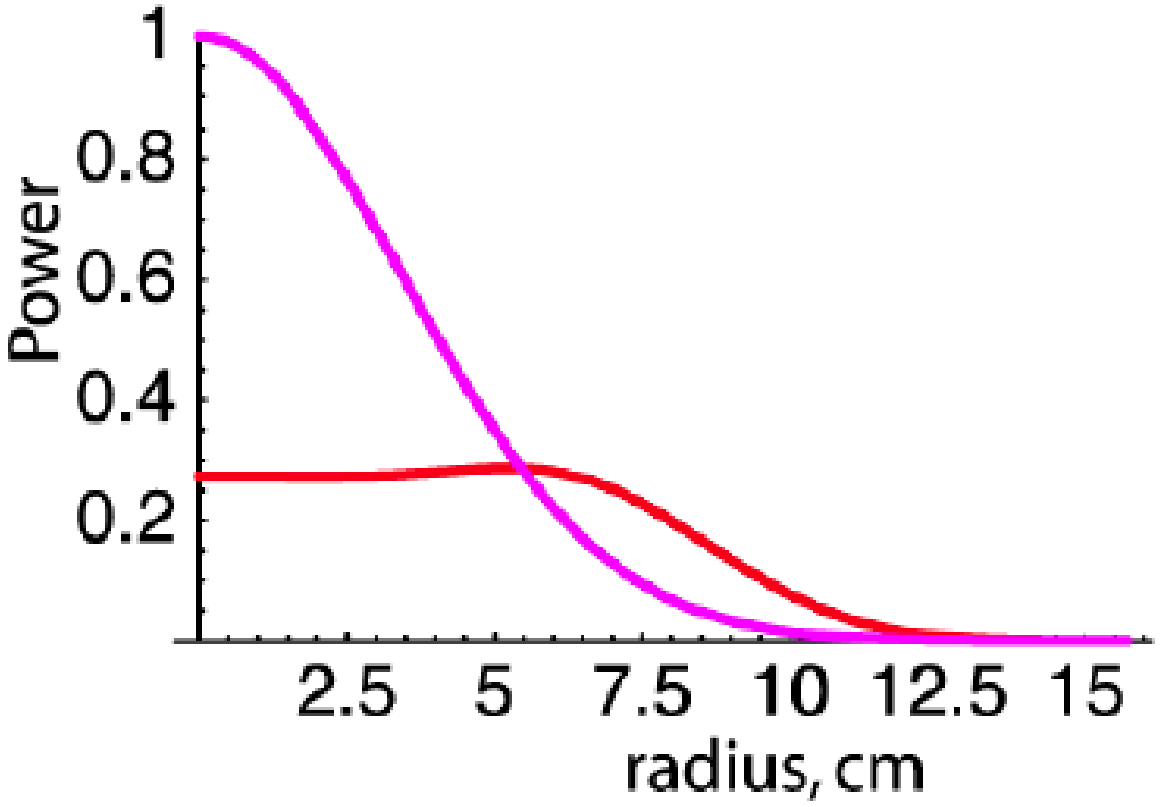
than with Brownian noise

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

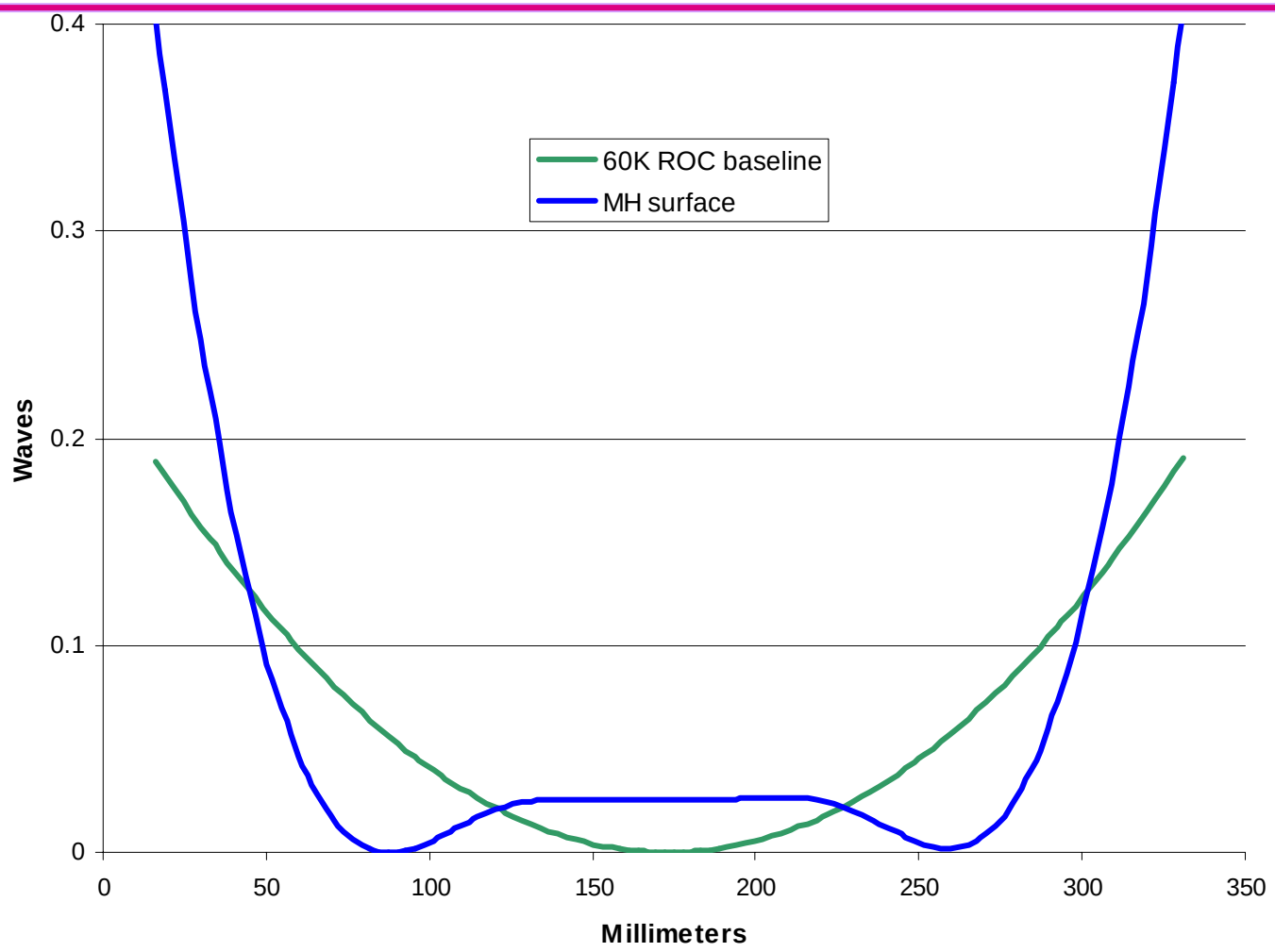
although for very low temperature the dependance of the constants on T must be taken into account.

Distributed power lowers noise

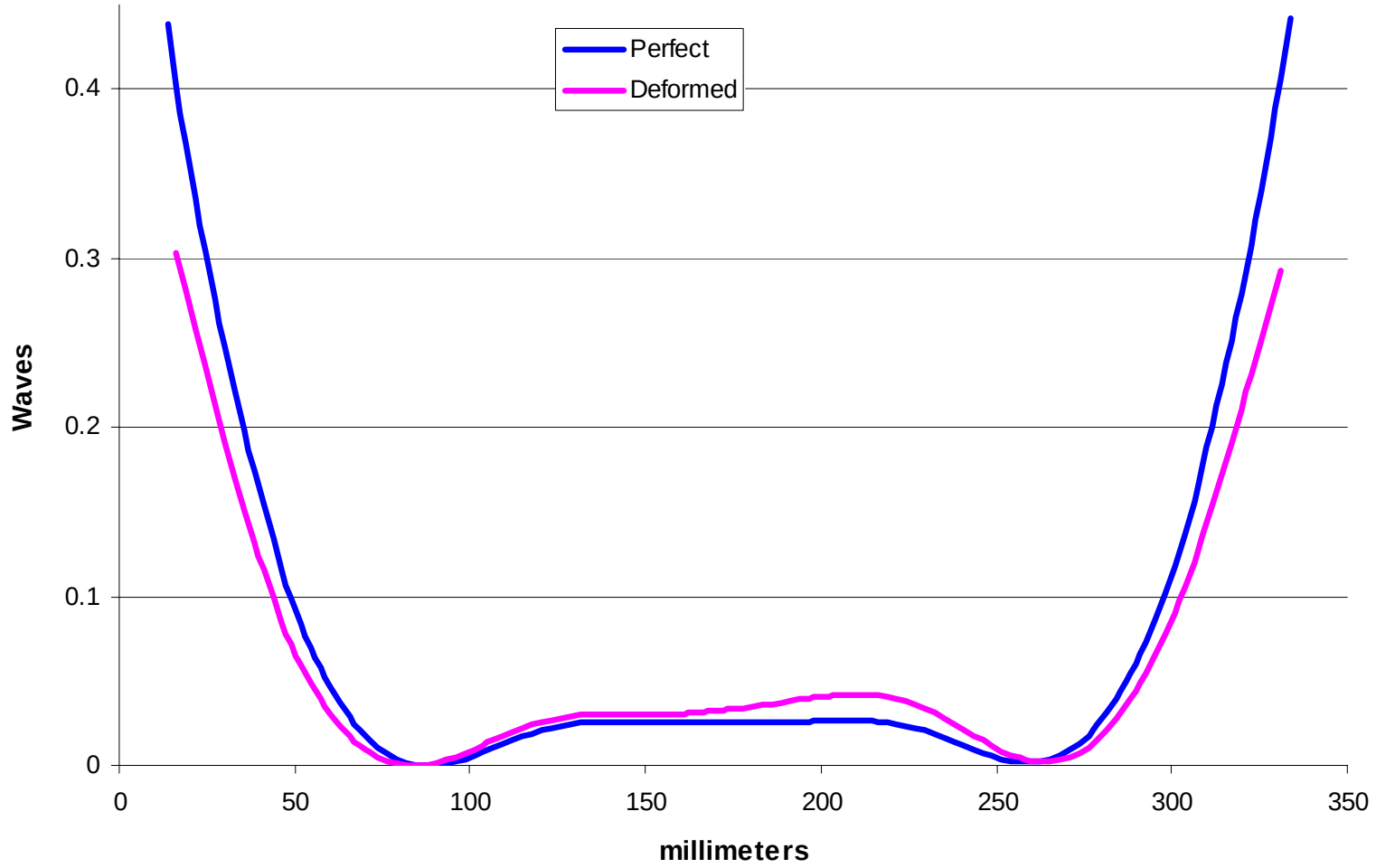
from LIGO-G020543-00, Thorne, D'Ambrosio, O'Shaughnessy



Compute mirror surface which matches phase fronts



How bad can it be… and still work?



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, 160ppm 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	$100(s/1.3\text{mm})^2$	$190(s/1.3\text{mm})^2$

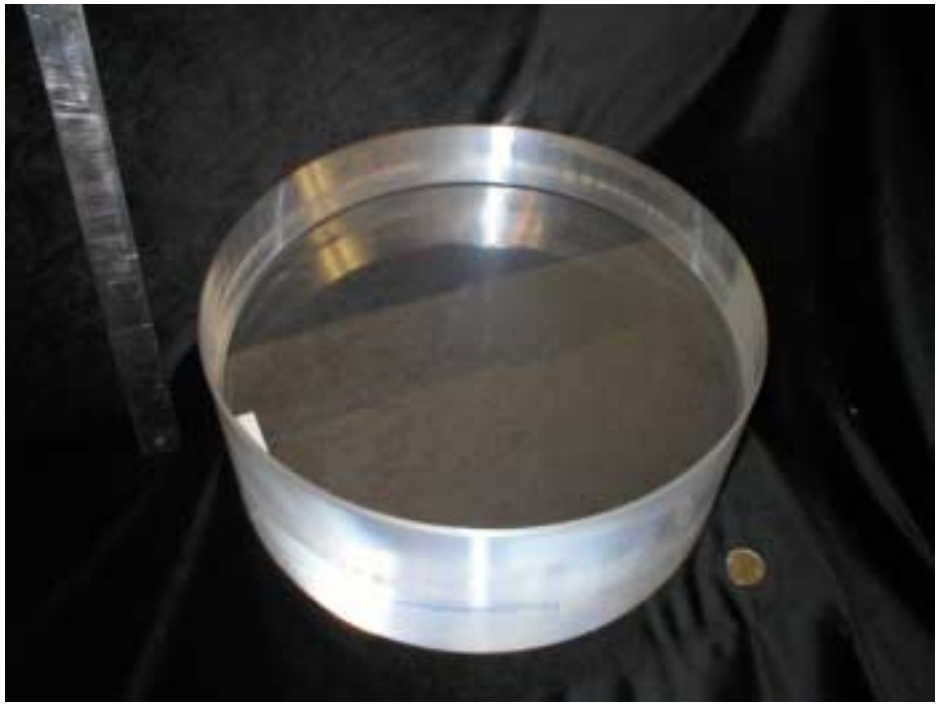
Compare Sensitivity to tilt θ

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	$.001(\theta/0.035\mu rad)^2$	$.002(\theta/0.035\mu rad)^2$

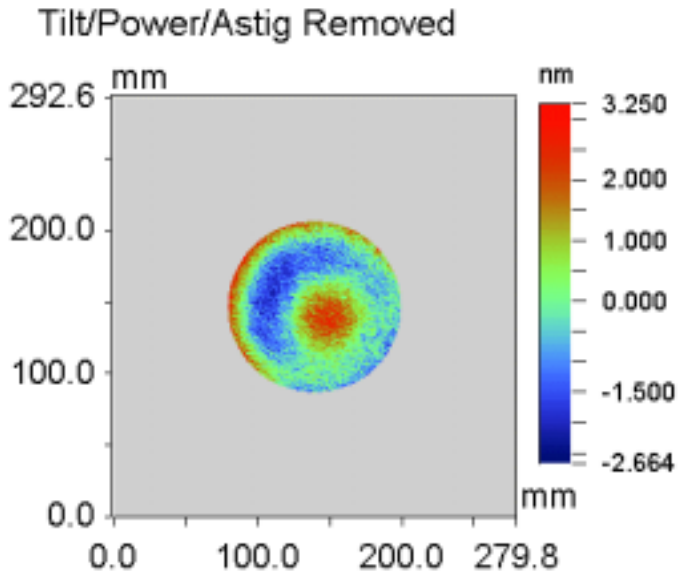
Can we get sapphire that big?

- 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

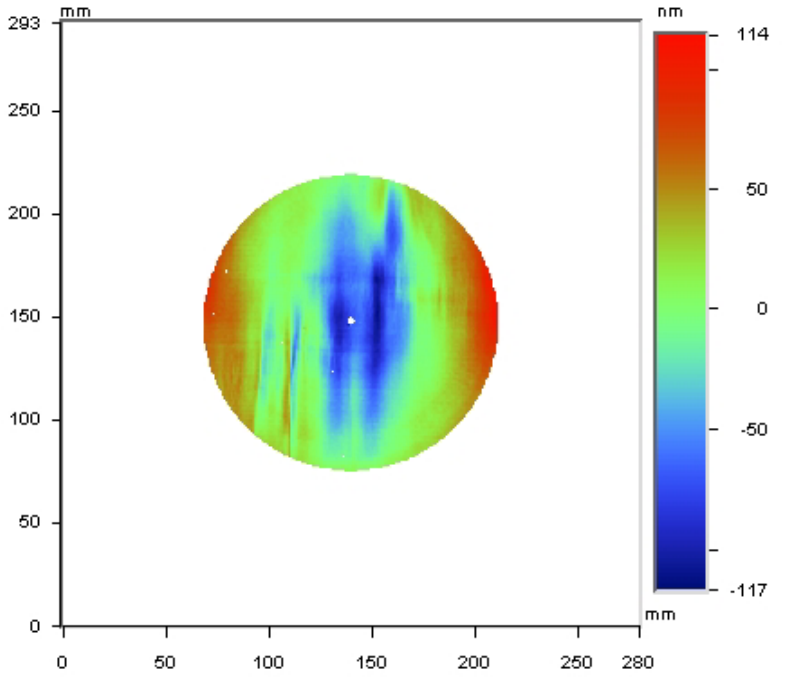


Preparing MH surfaces

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

Homogeneity

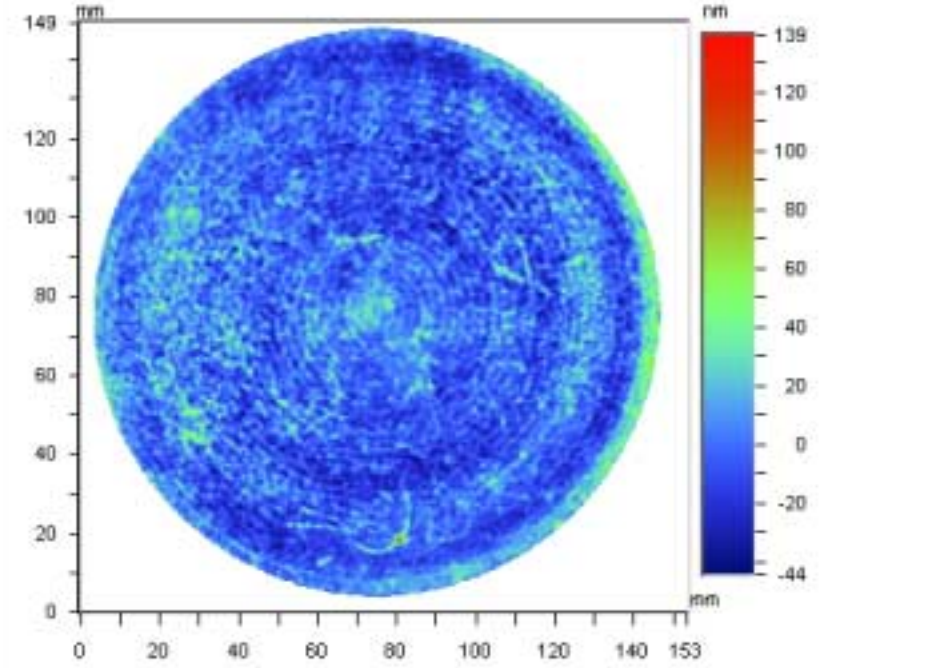
- Can't get c-axis in large sizes 314 mm x 130 mm
- The problem with m- and a-axis sapphire…



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

Schedule Milestones

- 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
- Material Down-select – May ’03
- Install LASTI test masses – October ‘04