High Optical Power Cavity with an Internal Sapphire Substrate

—Thermal lensing, thermal compensation & three modes interactions

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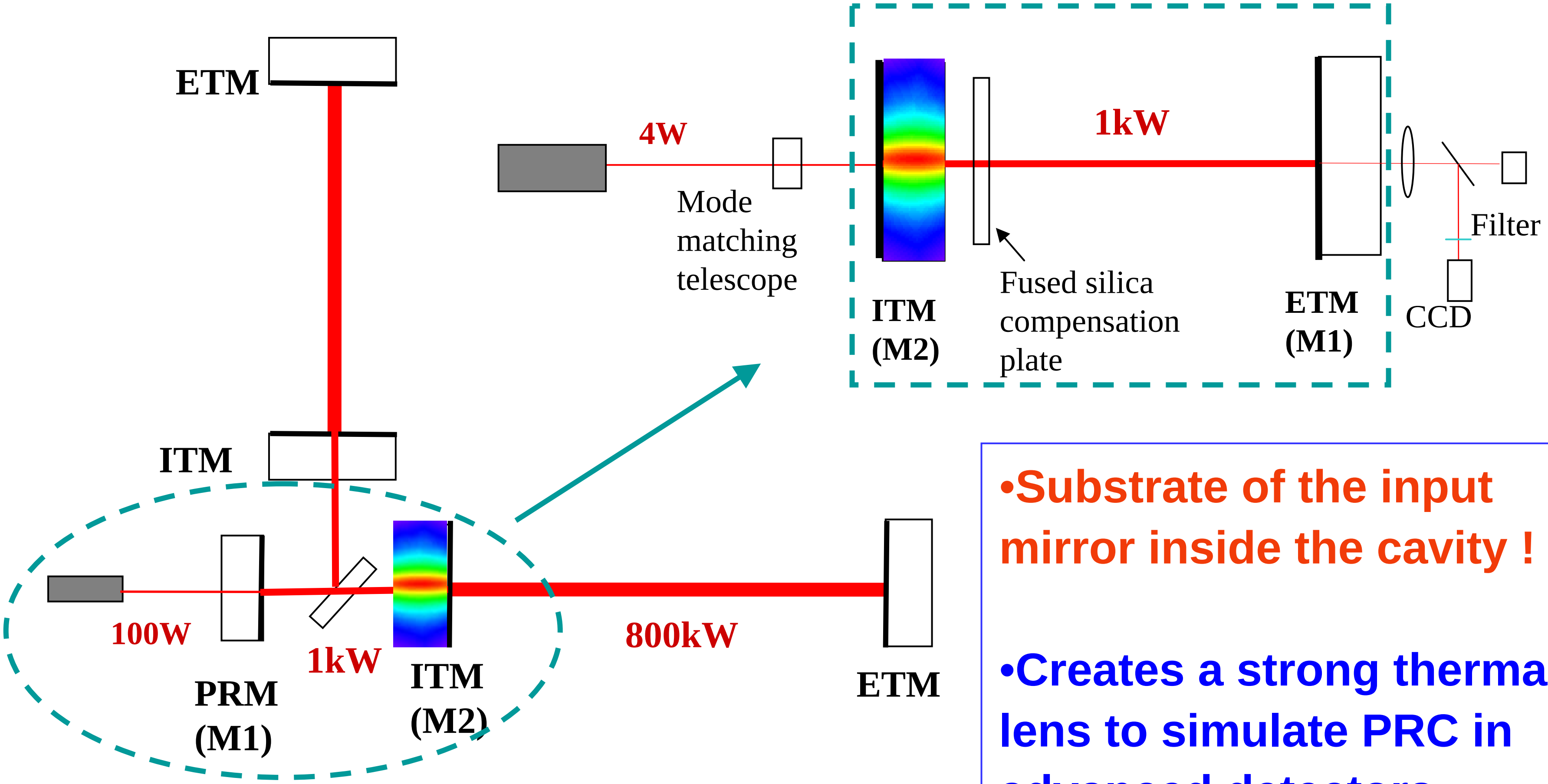
for

ACIGA

Contents

- Strong thermal lensing observation
- Closed loop thermal lensing control
- Observation of beam astigmatism in high power cavity
- Opto-acoustic parametric interactions

Gingin High Power Facility cavity setup

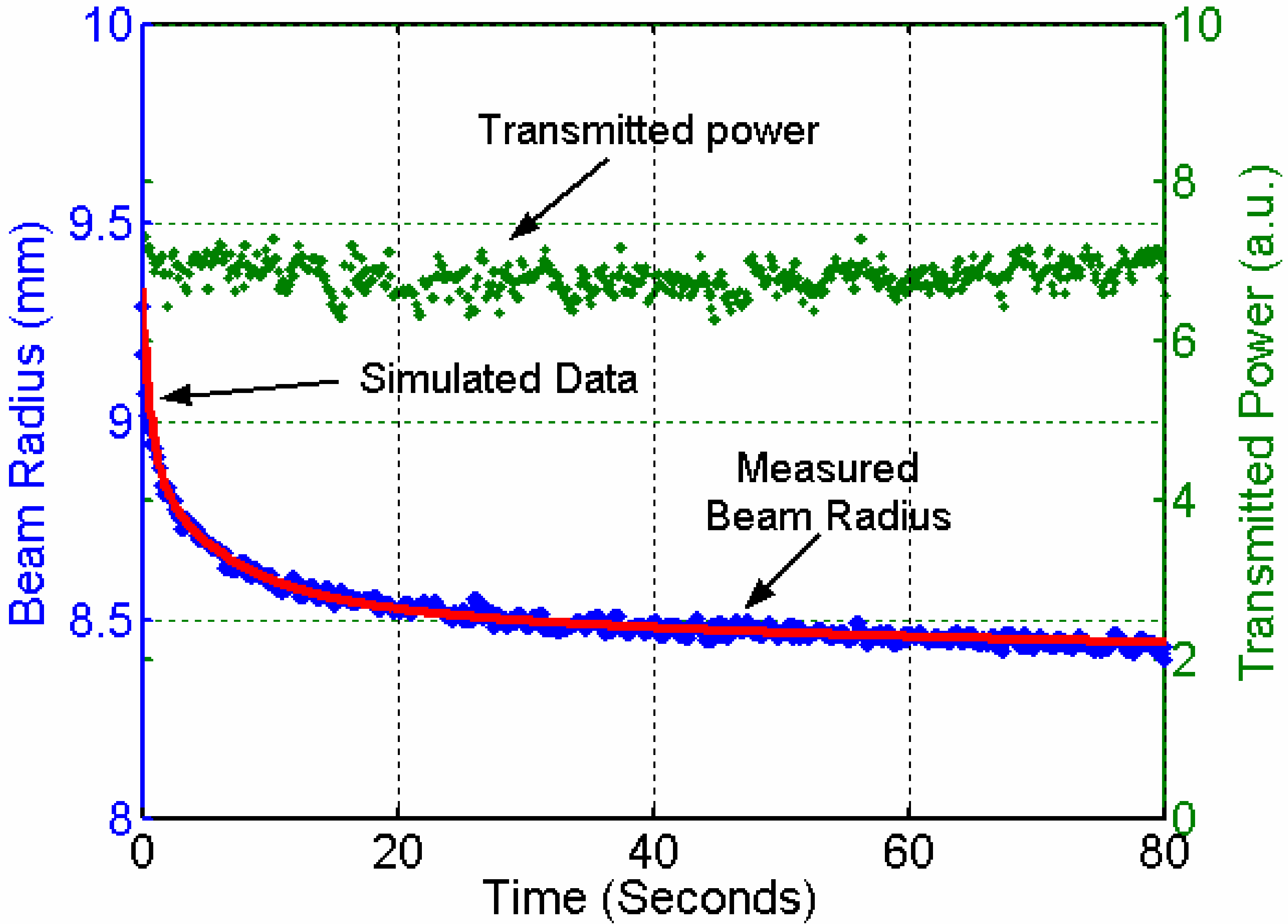


- Substrate of the input mirror inside the cavity !

- Creates a strong thermal lens to simulate PRC in advanced detectors

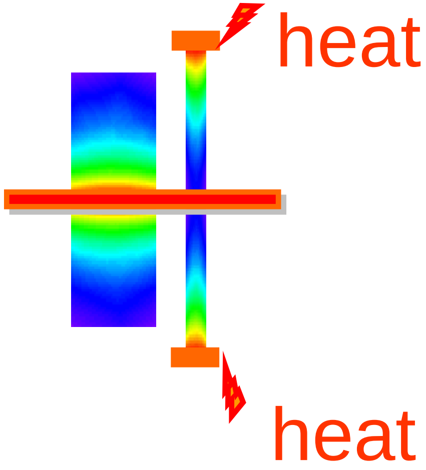
Strong Thermal Lensing

Observation and compensation (PRL 16 June 2006)

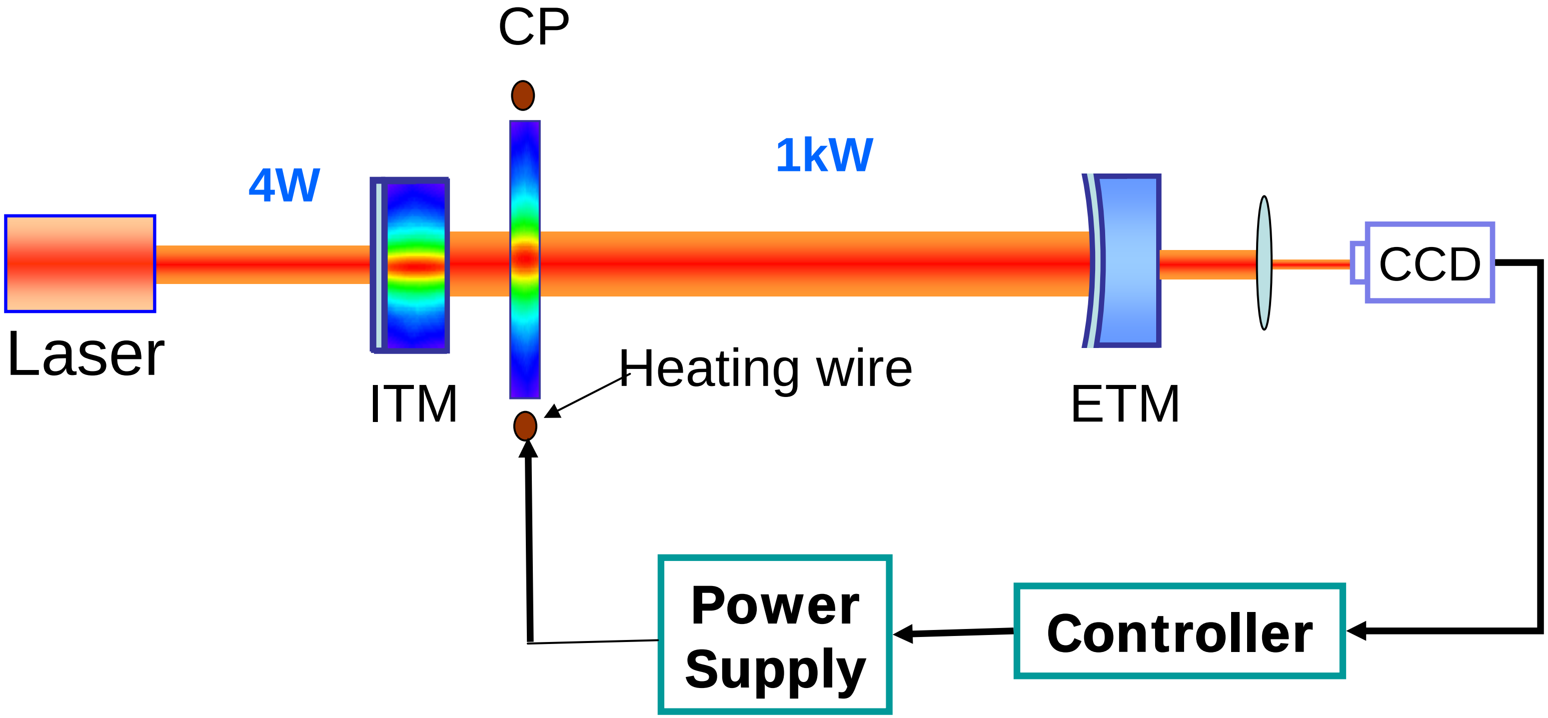


Thermal Lensing and Thermal Compensation

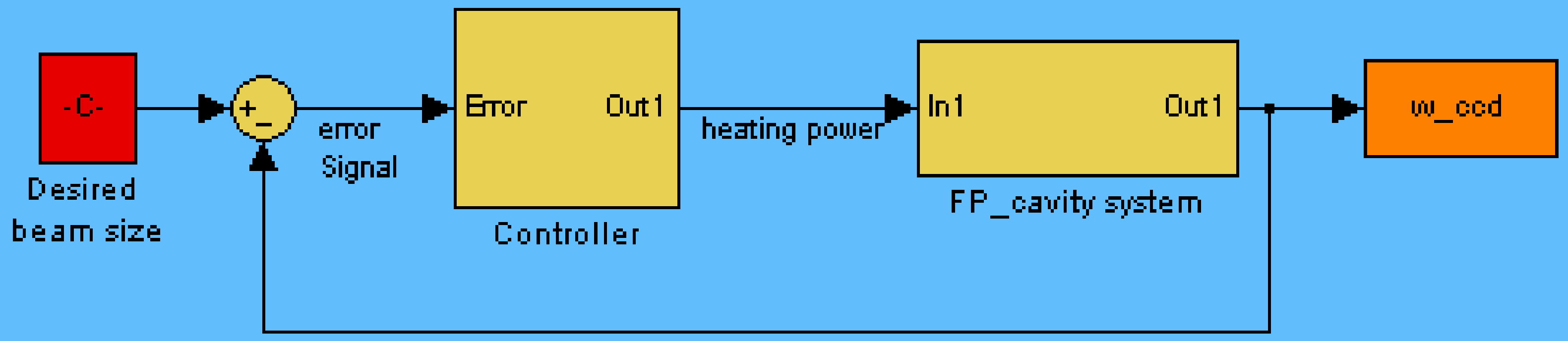
Compensation Plate + Heating ring



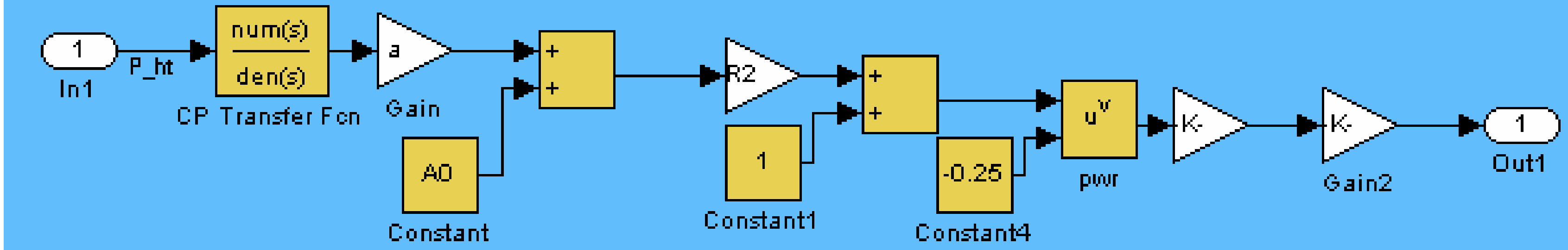
Closed Loop Thermal Lensing Control



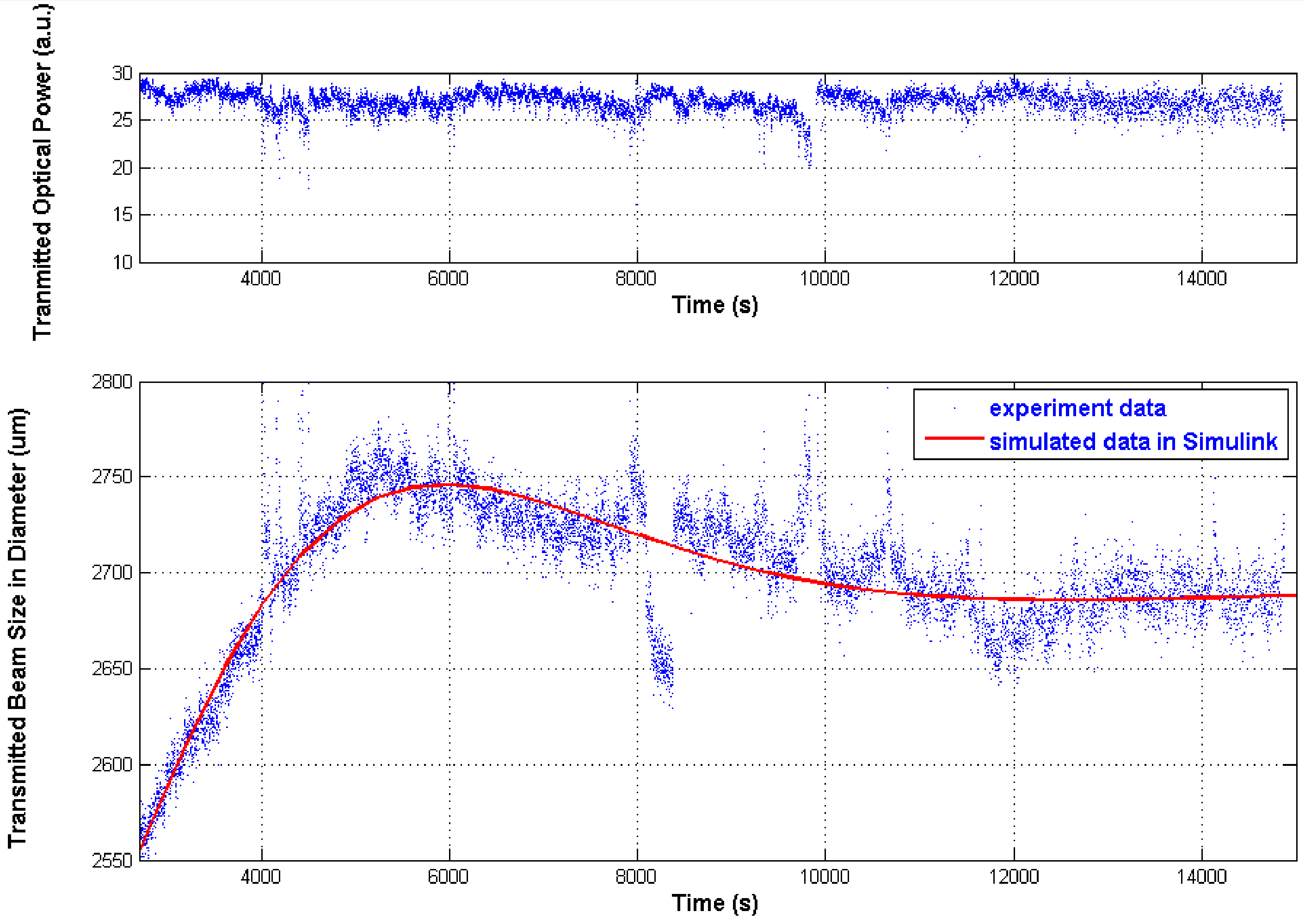
Feedback control of thermal lensing compensation



F-P Cavity System



Thermal lensing control Demonstrated



The beam distortion due to thermal lensing

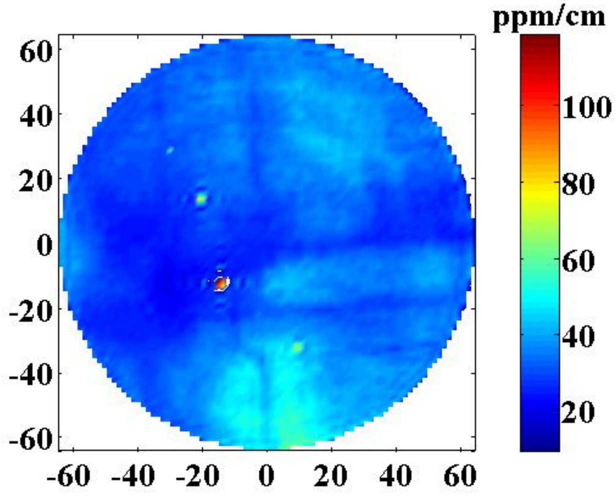
- non-quadratic thermal lensing
- thermal stress birefringence
- inhomogeneous absorption in the test mass

- Sapphire is known to have high inhomogeneity
- Gingin test mass
  - No detailed absorption map
  - At centre ~50ppm/cm (Measured in Caltech, agrees with average thermal lensing measured in Gingin)

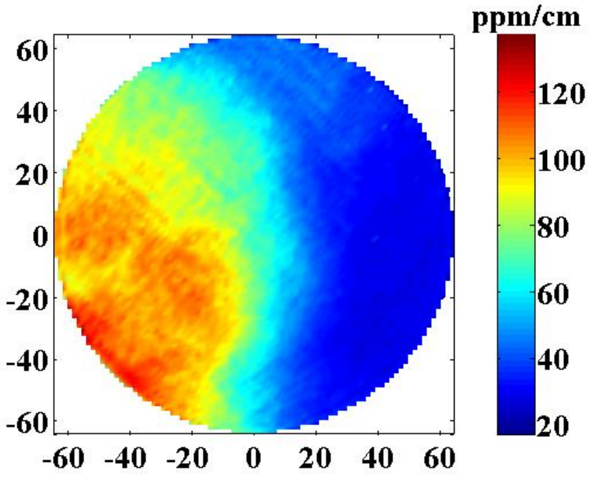
- Analysis of several other samples to get “typical absorption” in sapphire samples

Average absorption across sapphire samples

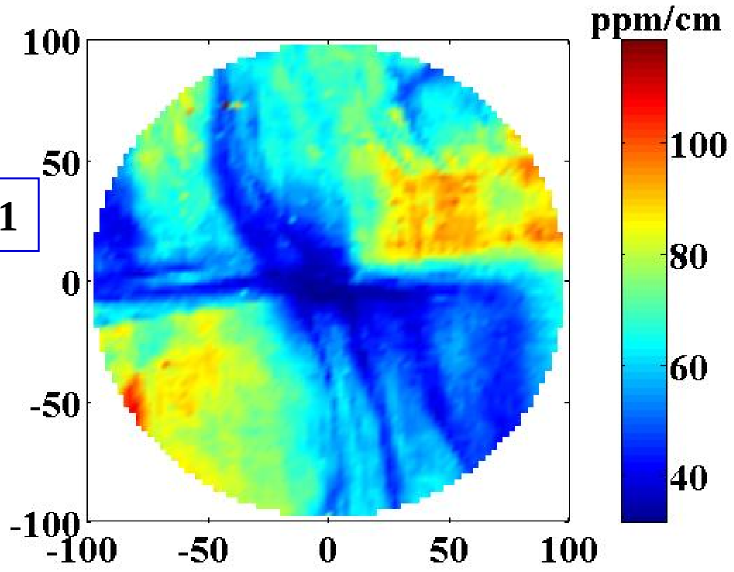
UWA 1



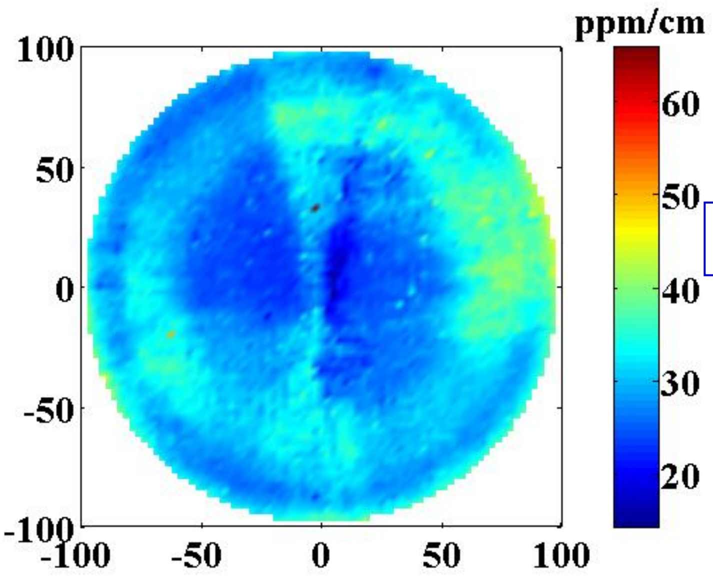
UWA 2



Caltech 1

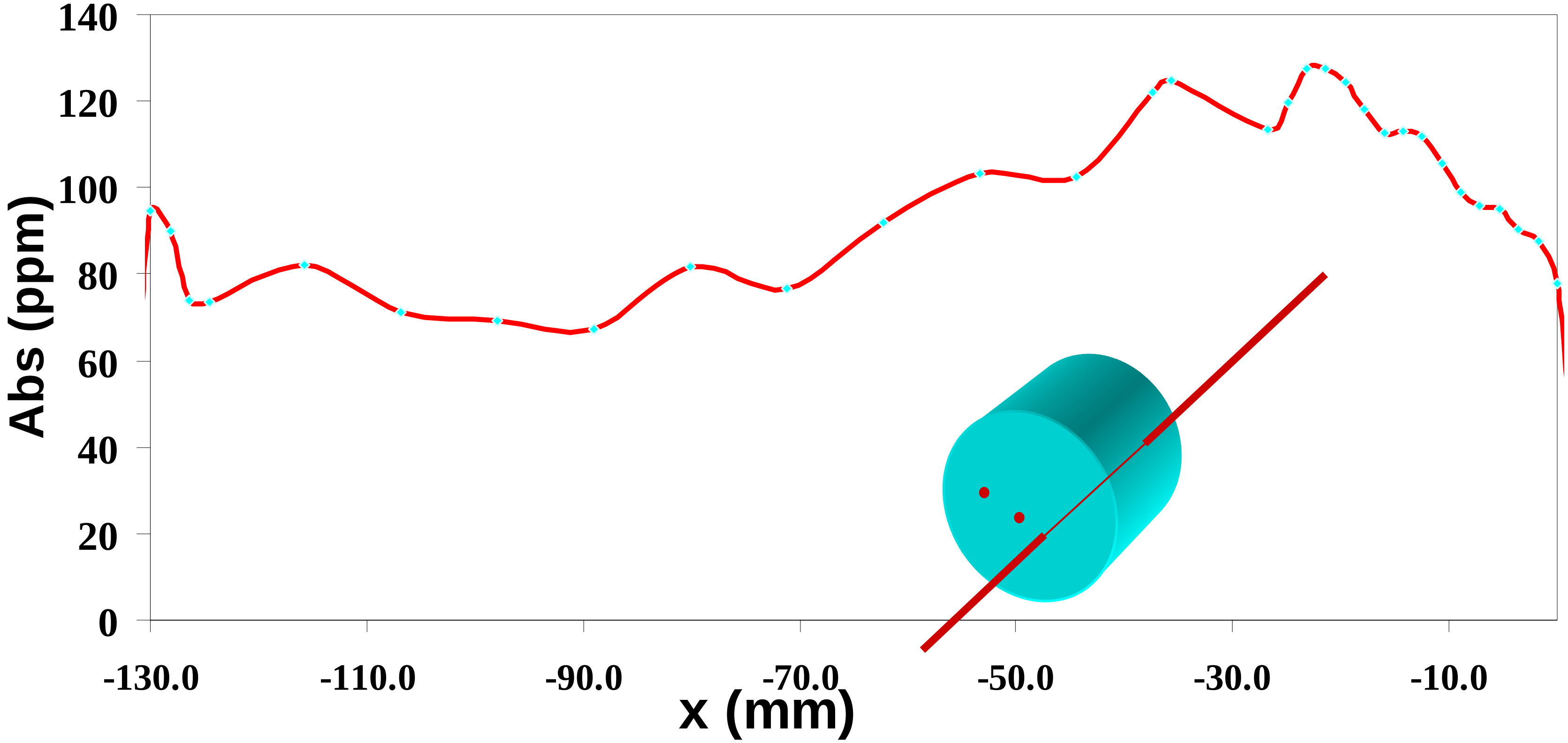


Caltech 2

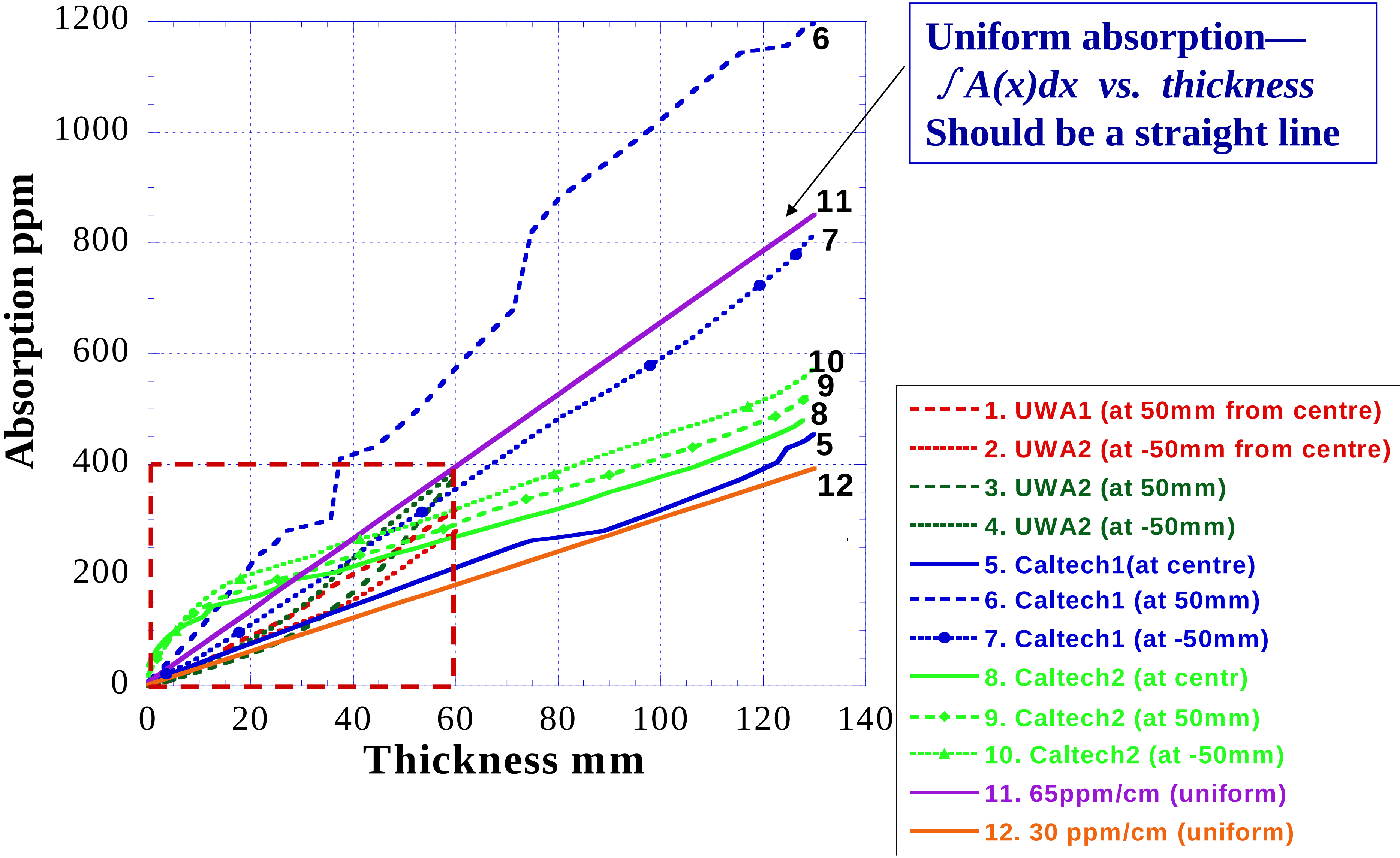


Absorption measured at at Laboratoire des Matériaux Avancés (LMA)

Example of absorption along the thickness of a sample (Caltech 1)

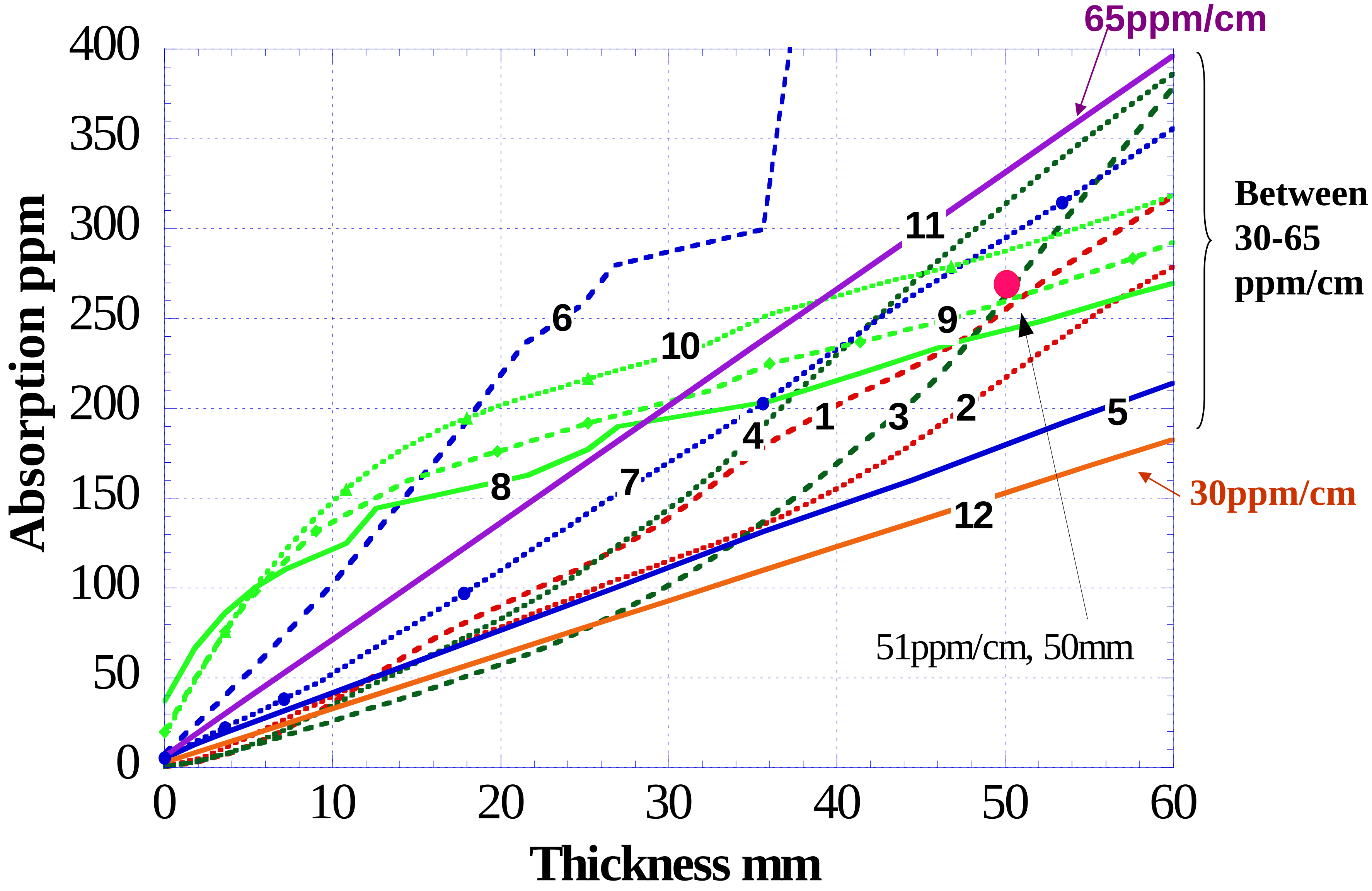


Integrated absorption along the thickness of test masses

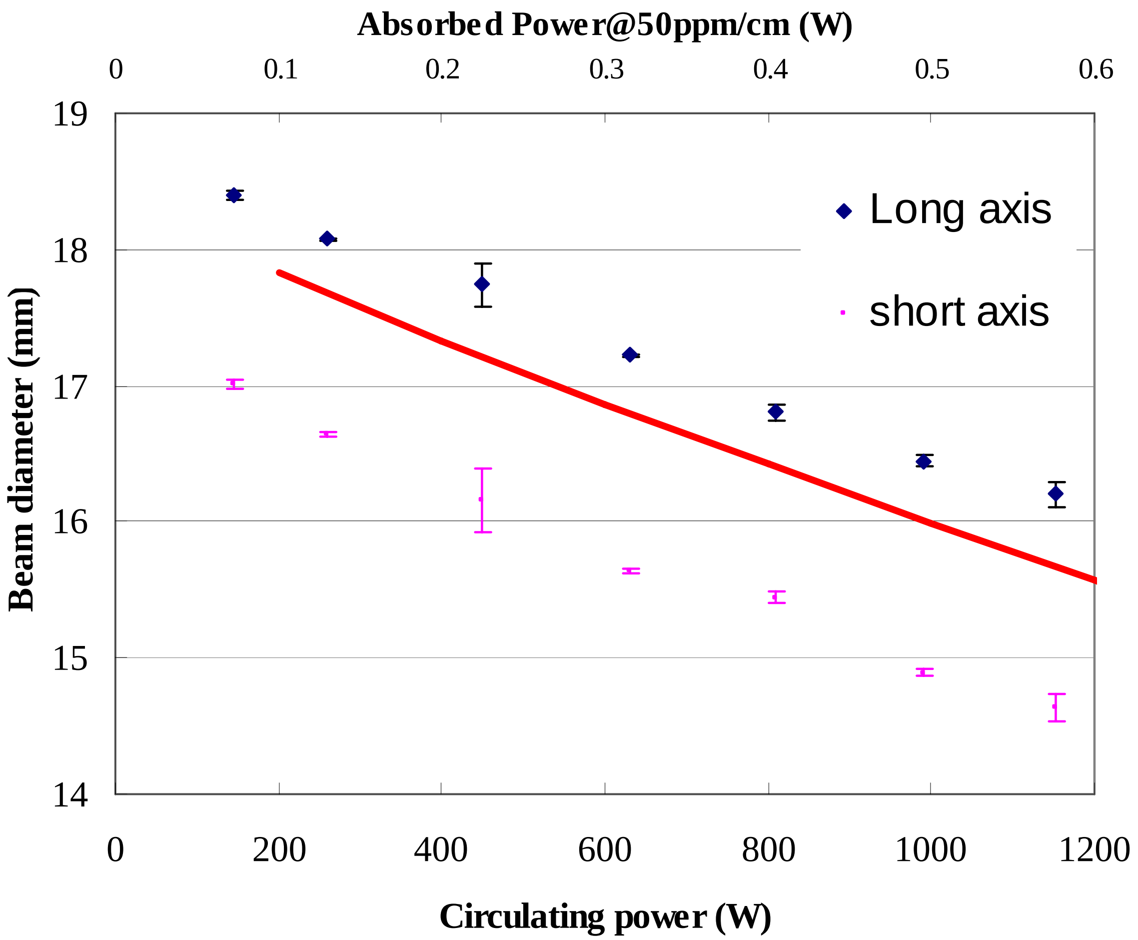


Uniform absorption—
∫A(x)dx vs. thickness
Should be a straight line

Integrated absorption along the thickness of test masses (enlarged)



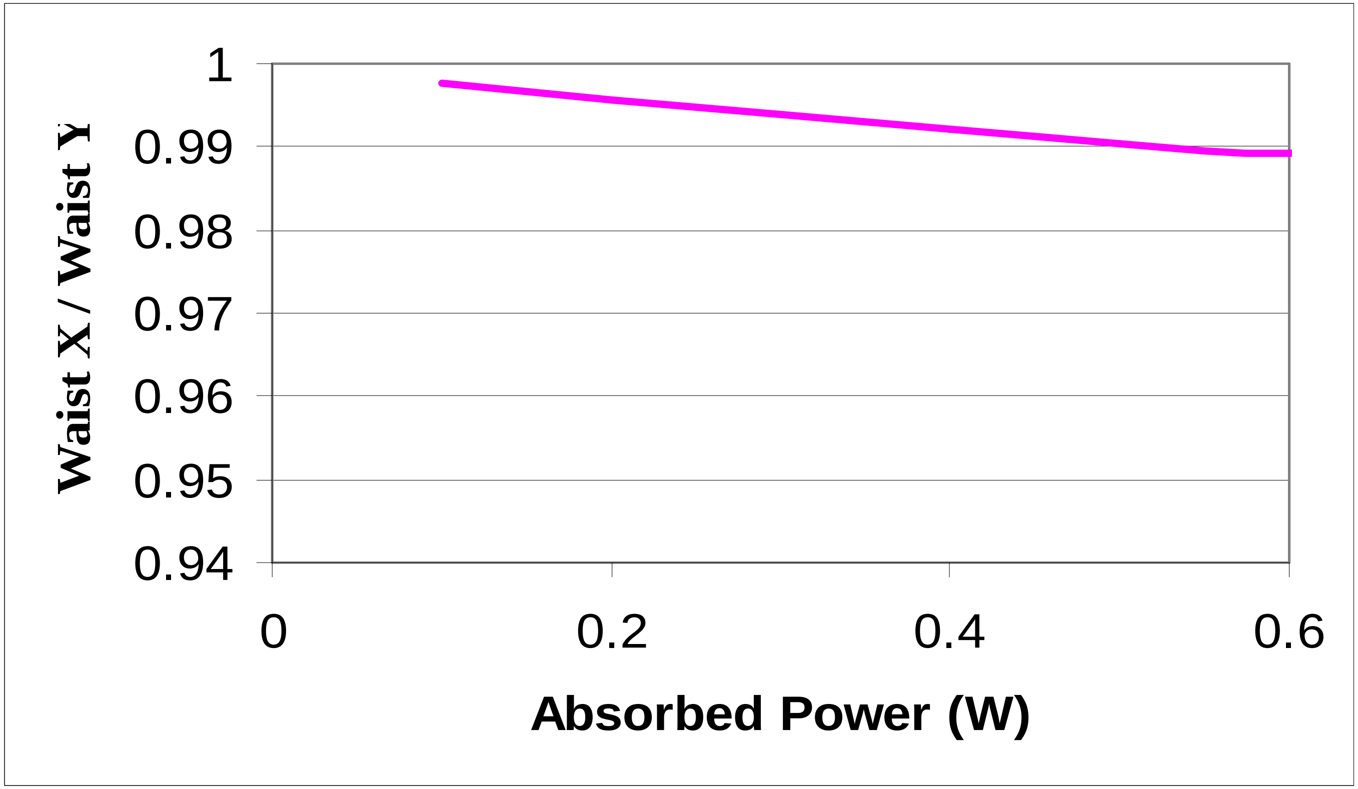
Beam size vs circulating power at Gingin HOPF



Simulated @50ppm/cm

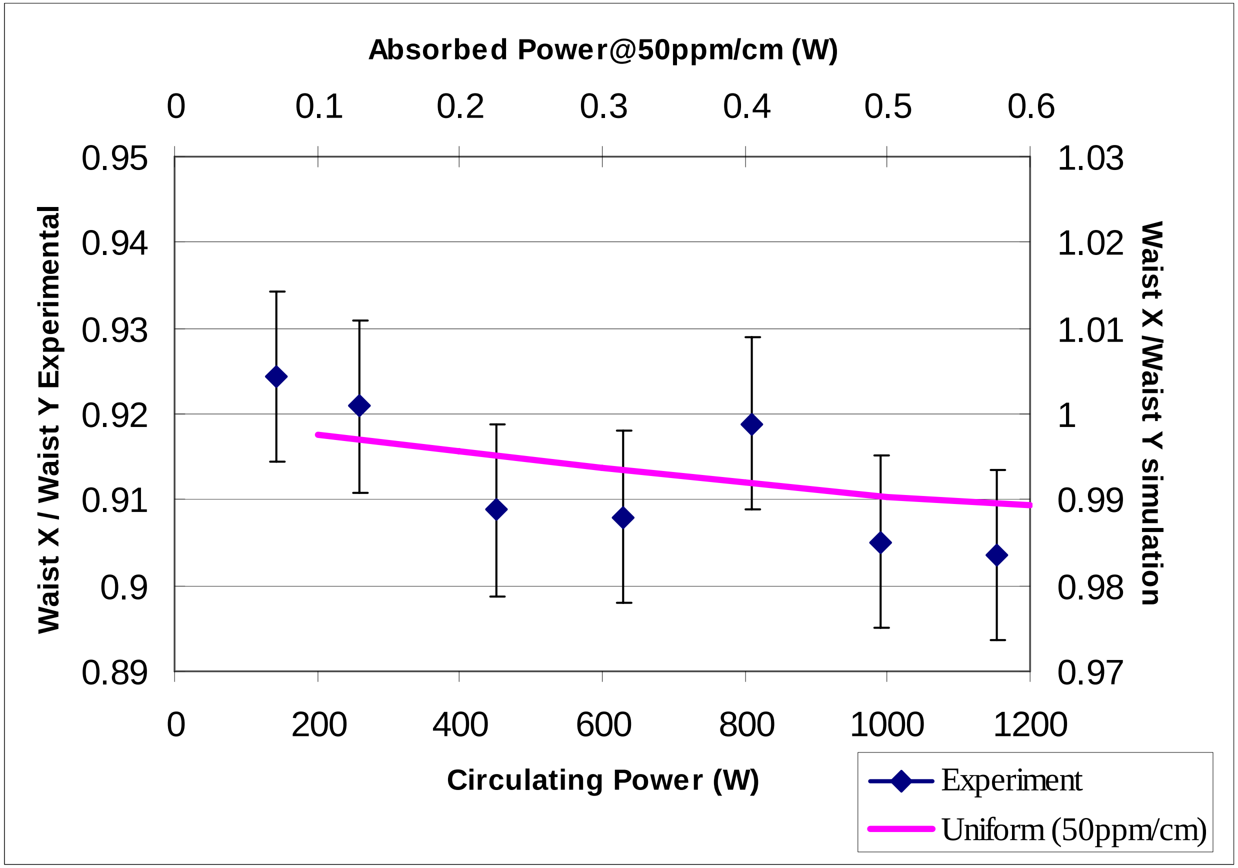
Astigmatism due to birefringence

(simulated sapphire with **uniform** absorption)



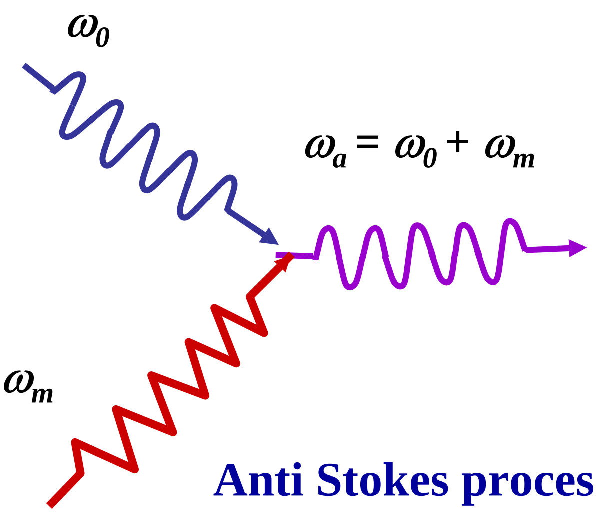
Uniform absorption will still result in power dependent astigmatism due to stress birefringence

Astigmatism vs Circulating Power

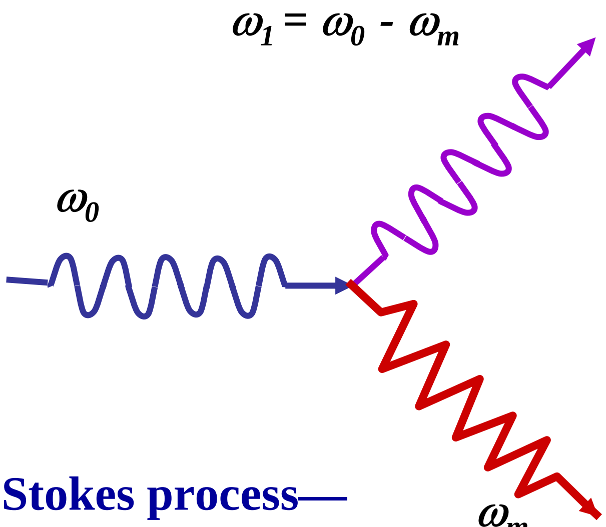


- There is an initial systematic astigmatism
- The power dependent astigmatism did not differ much from that due to uniform absorption

Opto-Acoustic Parametric Oscillation



Anti Stokes process—absorption of phonons



Stokes process—emission of phonons

- Some test mass ultrasonic acoustic modes heated(amplified)
- OAPO gain must be kept below acoustic oscillation threshold
- Significant number of modes likely to be excited above threshold in Advanced interferometers.
- OAPO interaction observed at Gingin.

Instability Condition

Parametric gain[1]

$$R \sim \frac{2PQ_m}{McL\omega_m^2}\left(\frac{Q_1\Lambda_1}{1+\Delta\omega_1^2/\delta_1^2}\right) > 1$$

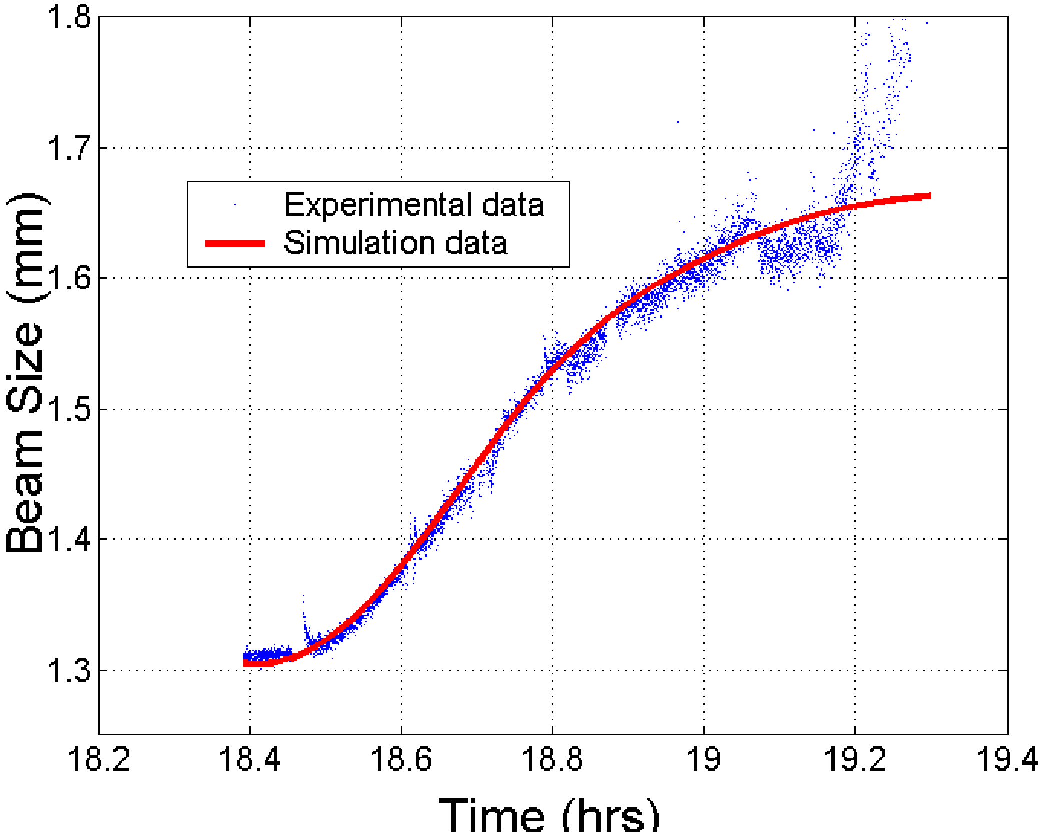
$$\Delta\omega_1 = \left|\omega_0-\omega_1\right| - \omega_m$$

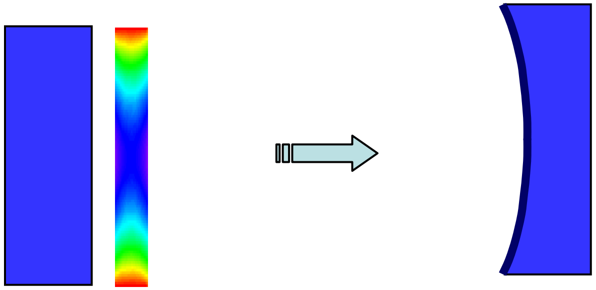
$$\omega_0-\omega_1 = \frac{\pi c}{L}\left(k_1 - \frac{m+p\times n}{\pi}\arccos\sqrt{\left(1-\frac{L}{R_1}\right)\left(1-\frac{L}{R_2}\right)}\right)$$

Changing mirror radius of curvature will change the cavity mode gap

[1] V. B. Braginsky, S.E. Strigin, S.P. Vyatchanin, *Phys. Lett. A*, 305, 111, (2002)

Demonstration of thermal tuning of high order optical frequencies



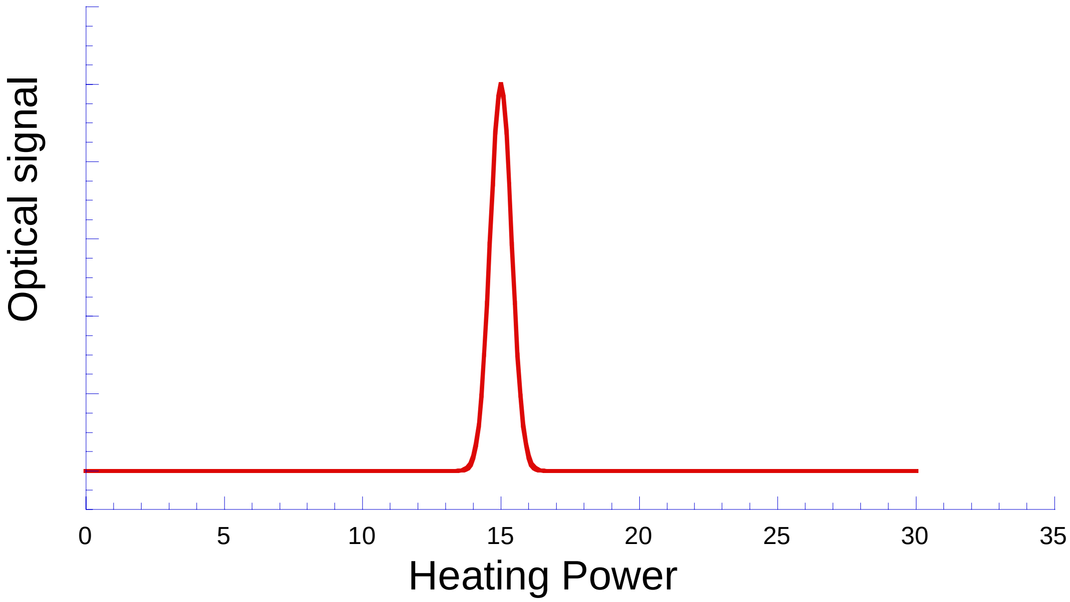


- •Heat the compensation plate
- •Change the equivalent RoC
- •Change the cavity mode spacing

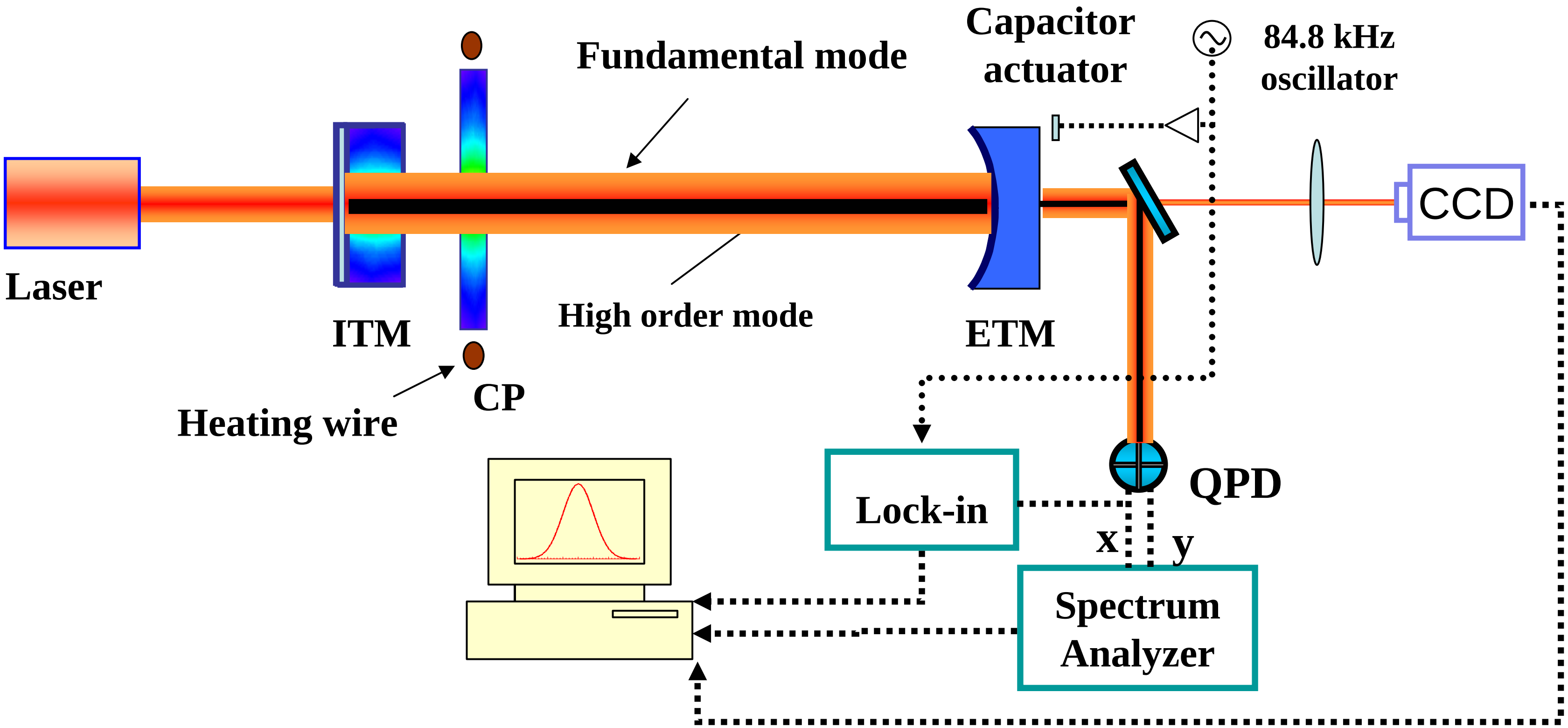
Transmitted beam size ⇨ Mode spacing between TEM00 and LG01

Three mode interaction at low power level

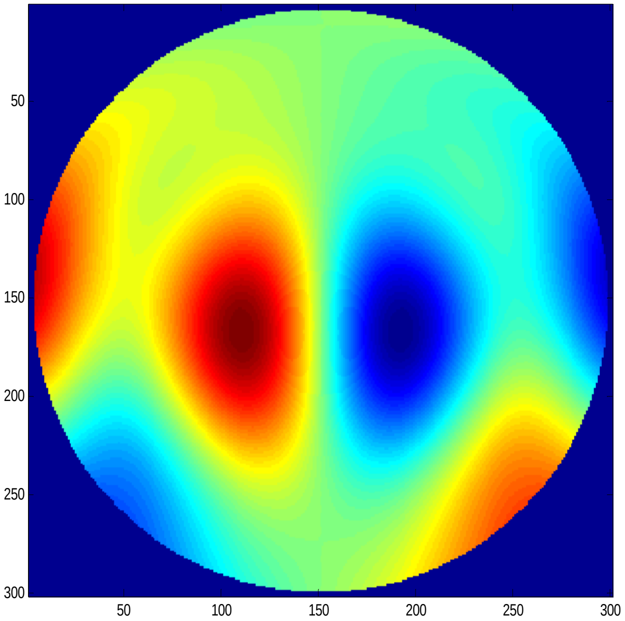
- Excite the target acoustic mode electrostatically
- Observe the high order mode resonance as the HOM resonance frequency is thermally tuned



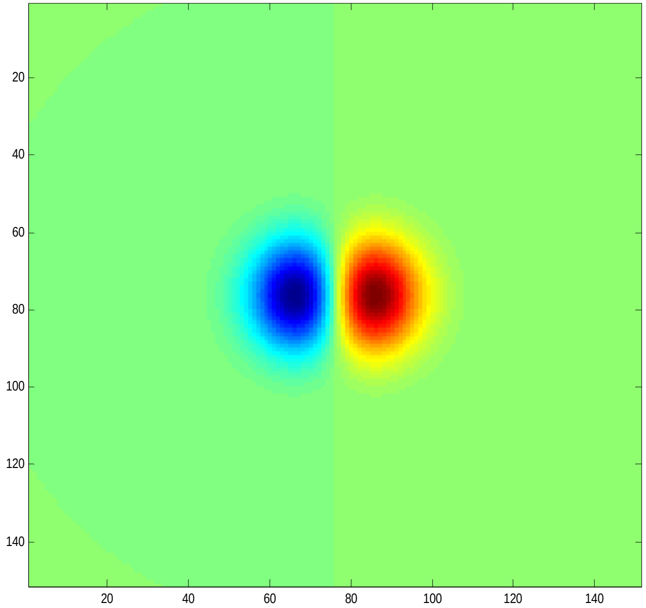
Experimental Setup



Mechanical mode and optical mode overlap

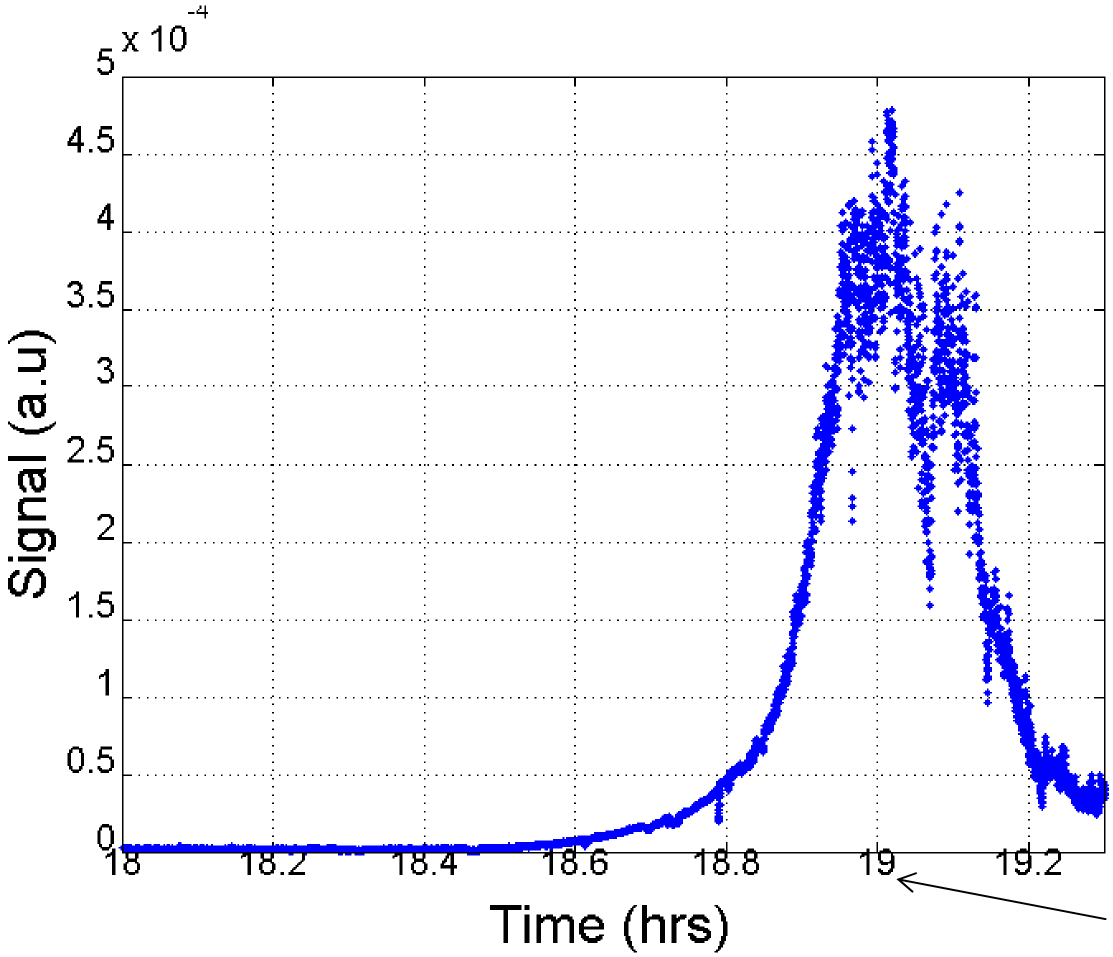


Mechanical mode
84.8kHz



Optical mode

Three modes interaction observation at Gingin HOPF



Amplitude of optical modes beating signal at 84.8kHz vs. time of heating (RoC change)

g factor ~ 0.98

Conclusions

- Feedback control of thermal lensing demonstrated
- Sapphire test mass inhomogeneity effect marginally detectable
- First demonstration of opto-acoustic parametric interactions between the cavity fundamental mode, the cavity high order mode and the test mass acoustic mode (basic physics of parametric instability).

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