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IAP/UF/LIGO Research Collaboration: Status and Prospectives

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Topics of IAP/UF/LIGO Research

1. **Methods and instruments for remote *in situ* monitoring of weak distortions in LIGO Core Optics**

2. **Instrument for high accuracy preliminary core optics characterization using white light phase-modulated interferometry**

3. **Study of high power effect in Faraday isolators**

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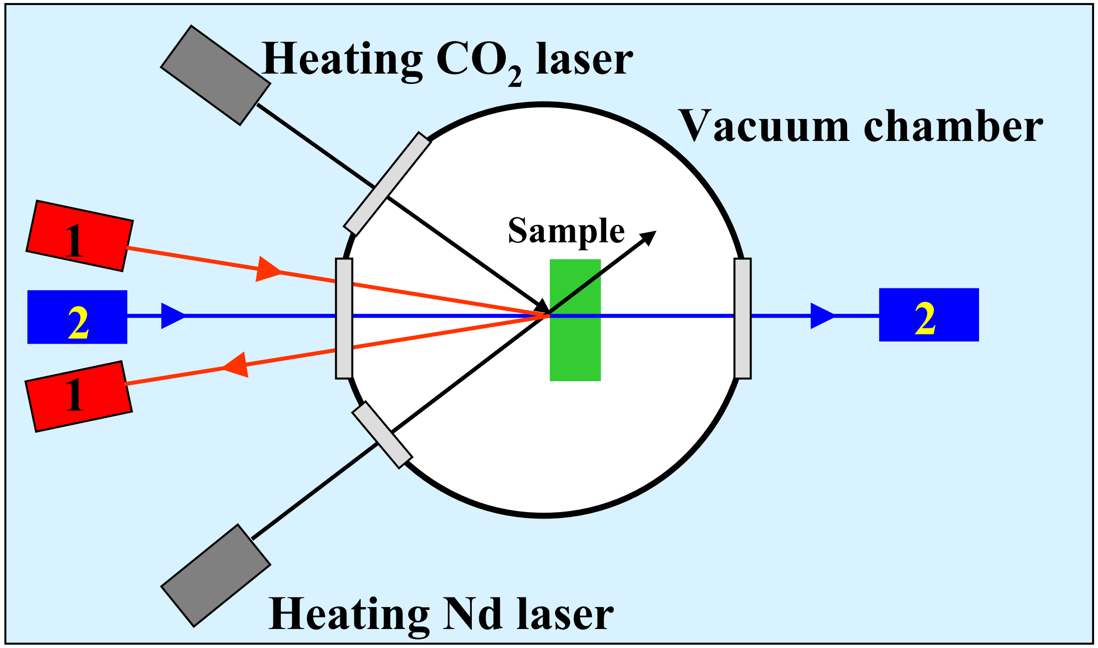
Methods and instruments for remote *in situ* monitoring of weak distortions in LIGO Core Optics

1. ***Scanning Nonlinear Hartmann Sensor***
2. ***Scanning Linear Hartmann Sensor***
3. ***White-Light Phase-Modulated Interferometer***

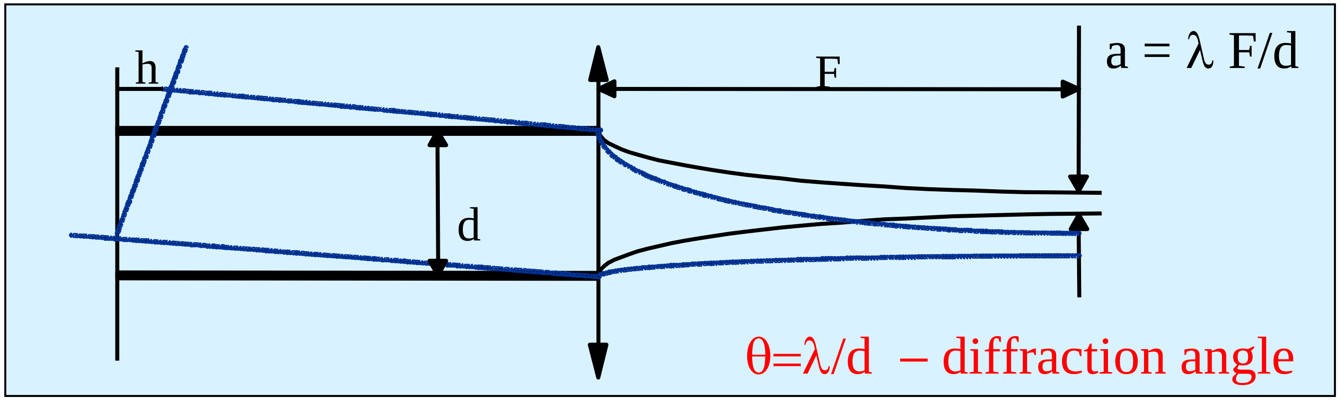
Remote *in situ* monitoring of weak distortions emerging under auxiliary laser heating. Setup.



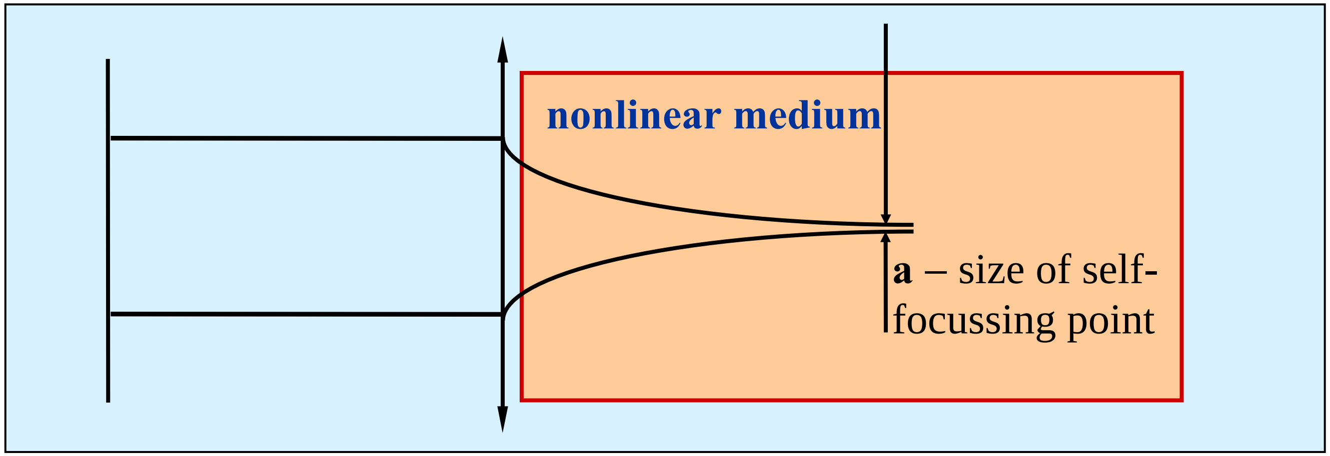
1 - WLPMI
2 - NHS and PIT

- Optical sample bulk heating by the fundamental or second harmonic of Nd:YAG laser at a power of 10-20 W
- Surface heating with the use of a CO_2 laser at power of several Watts
- Inducing contamination of a small region (characteristic size of 20-100 micron) on the optical element's surface and focusing of low-power laser radiation (<100 mW) on it

NHS: Idea

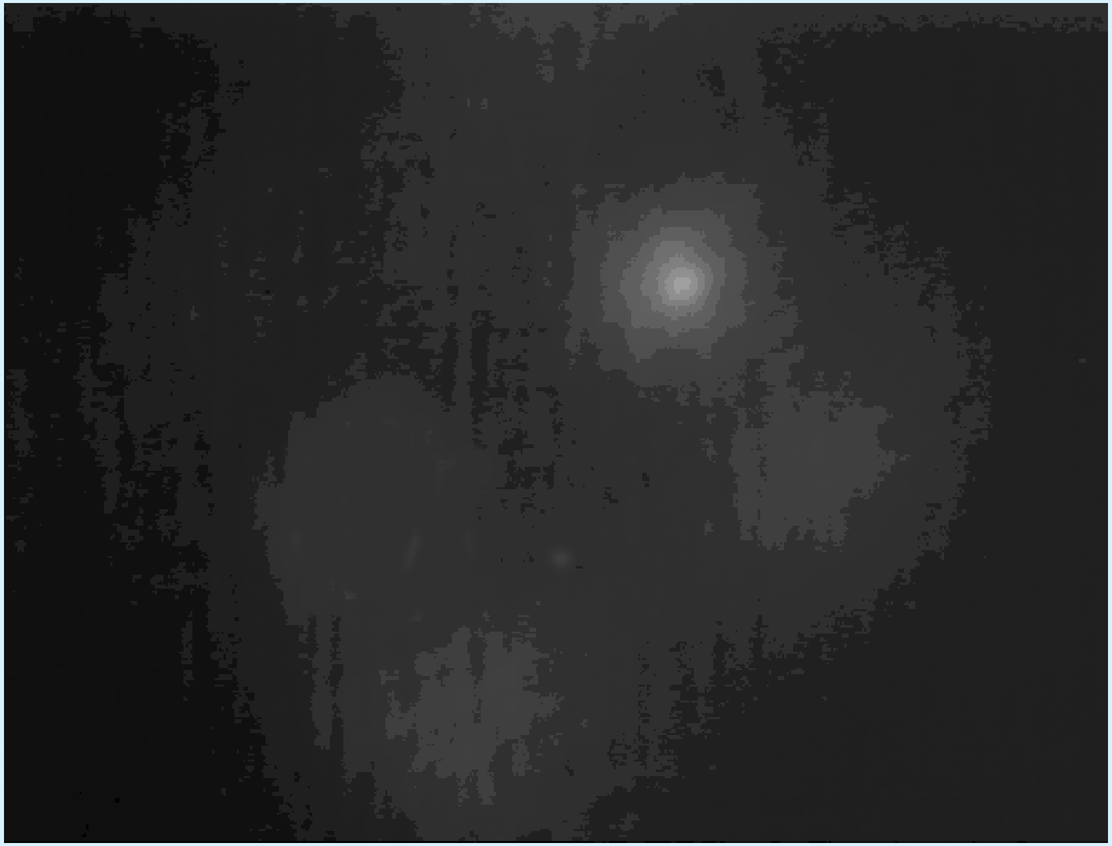


In linear electrodynamics the major limitation to measure wave front deviations angles comes from a finite size of the focal spot . $h=\lambda/100$ is achieved by an accurate measurement of the transverse beam distribution



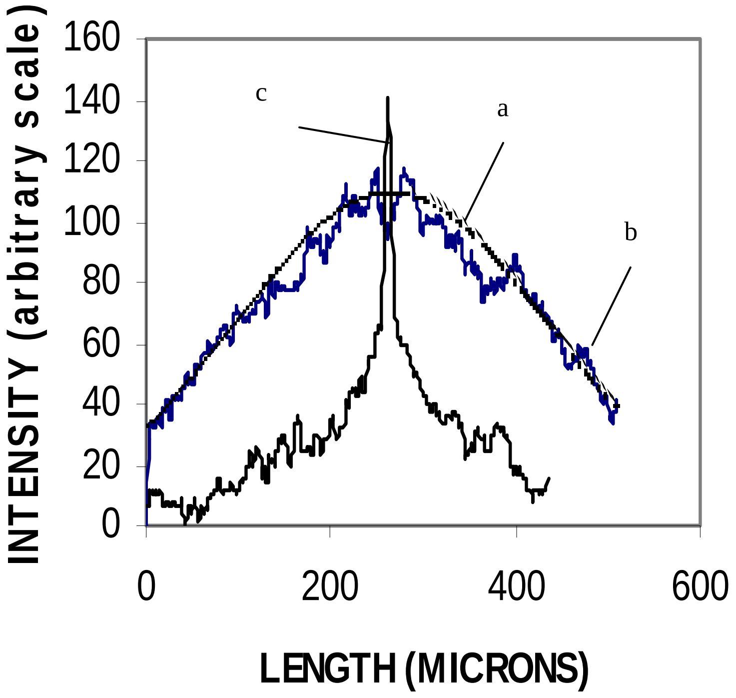
How to get $\lambda/1000$? Use self-focusing to decrease the size of the focal spot.
At $P=P_{critical}$ $a \to 0$ and is determined by nonlinear medium properties

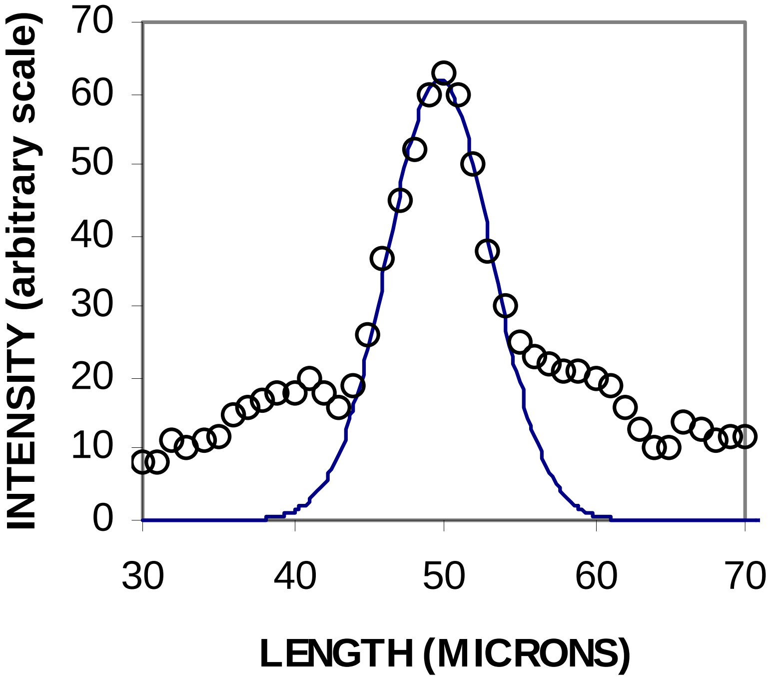
NHS: Self-Focusing Points



difraction limited diameter

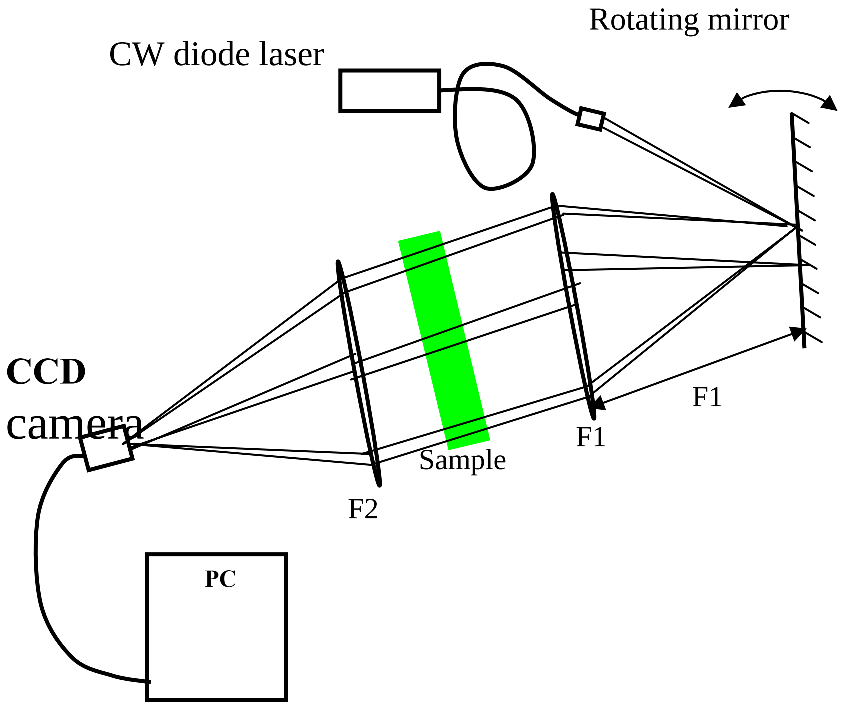
NHS: Results with Moving Sample

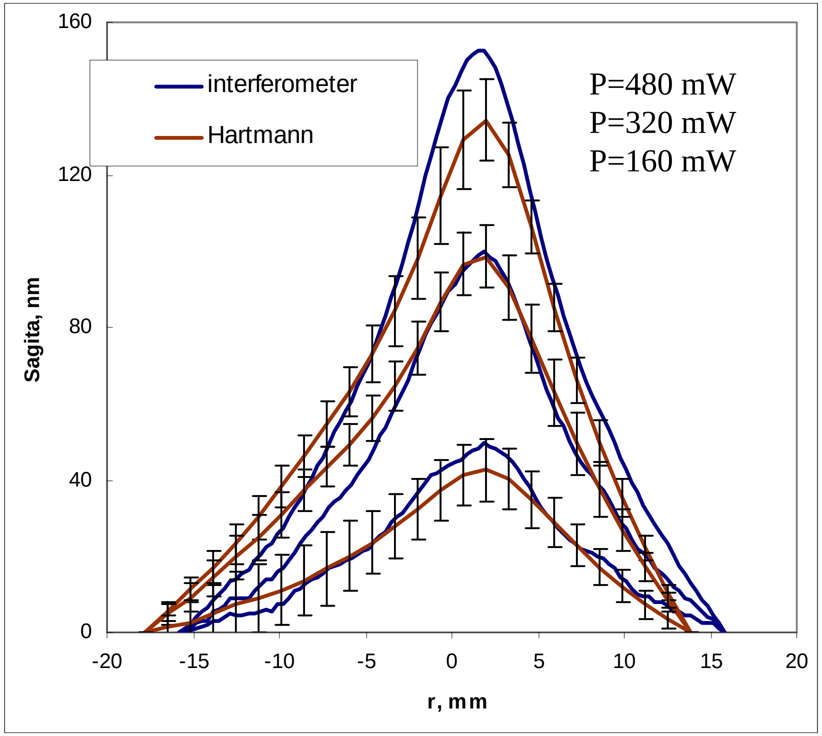




Of all the tested substances, the minimum size of a self-focusing point is in benzene, i.e. 5 μm at the length of a nonlinear cell of 60 cm, which results in the precision of wave front inclination measurements λ/3000.

Scanning Linear Hartmann Sensor





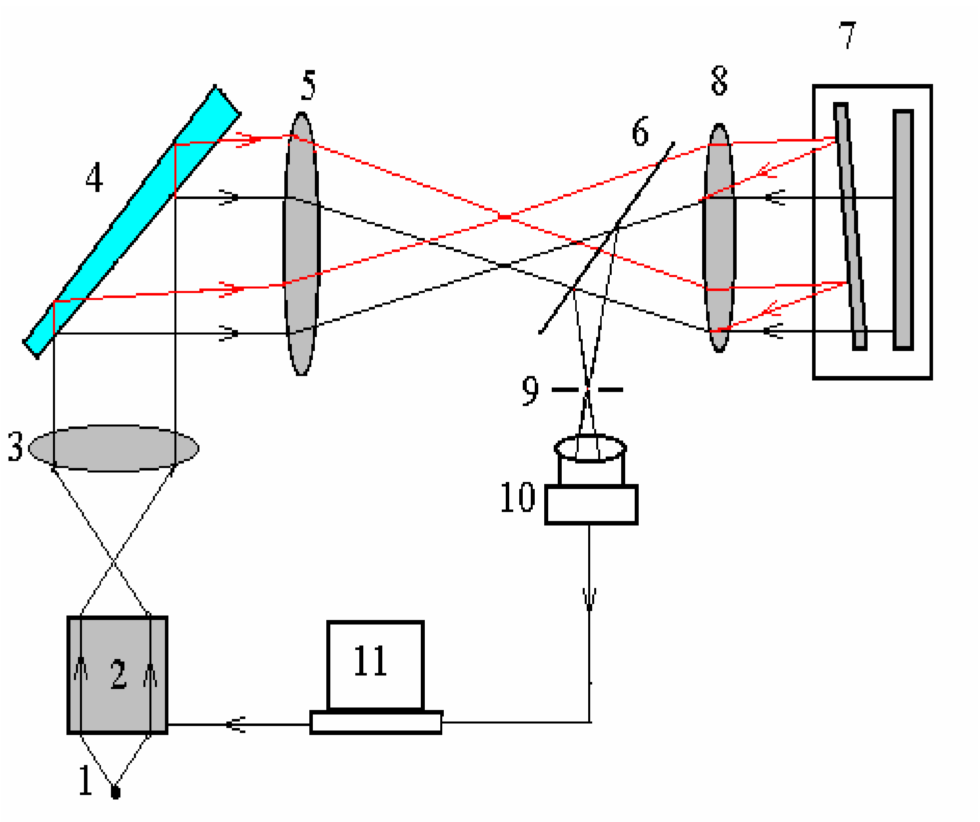
Scheme of Linear Scanning Hartmann Sensor

Wavefront distribution when a sample made of BK7 glass was heated by a CO_2 laser beam with different power

“White Light” *In Situ* Measurement Interferometer (WLISMI)

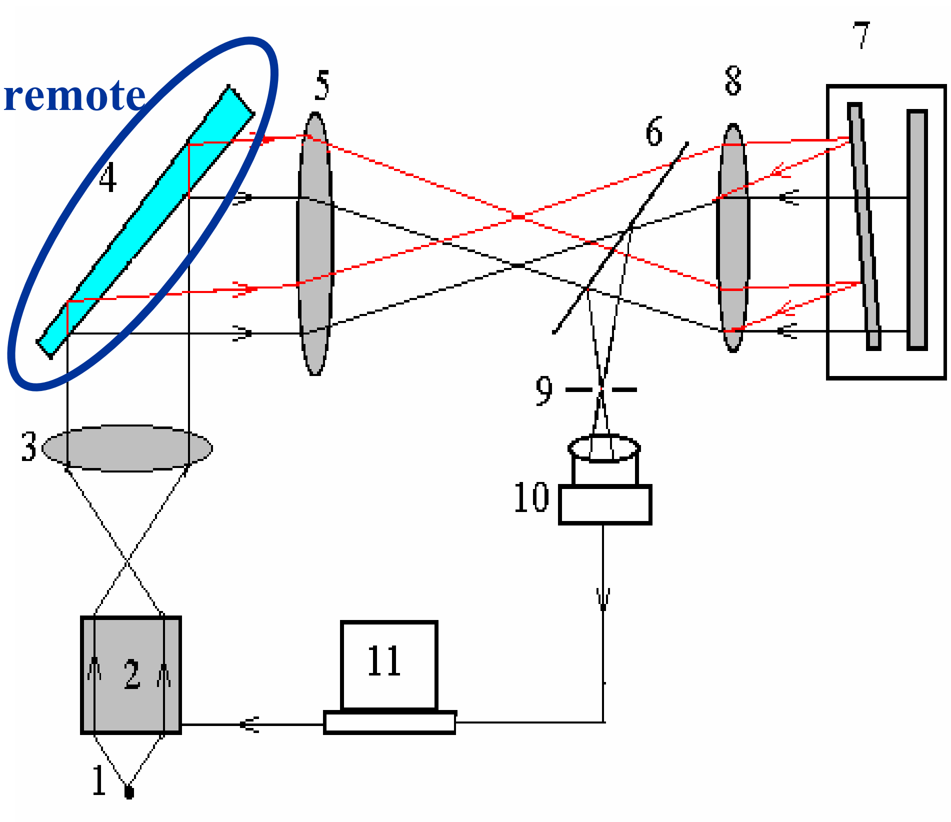
Standard interferometers	Newly developed interferometers
Measurement of optical length of air spacing between two surfaces. In profilometers one of them is a sample surface, and the other is a reference surface. The problem of precise measurement of phase in the interferogram is solved by phase modulation according to a known time law.	The proposed method relies on measurements of the phase of interferogram of radiation reflected **from two surfaces of one sample** under study. The precise phase measurements are ensured by the **modulation** of the probing radiation **spectrum**. The method provides a two-dimensional pattern of a sample's **optical thickness distribution** simultaneously over the whole aperture. The method is applicable to **remote testing** of optical elements with flat, spherical and cylindrical surfaces, and also with a wedge between them.

“White Light” *In Situ* Measurement Interferometer. Experimental setup



1 – broad band light source;
2 – spectrum modulator;
3, 5, 8 - lenses
4 - sample;
6 – semitransparent mirror
7 – wave front shaper;
9 – spatial filter
10 - CCD camera;
11 - PC

“White Light” *In Situ* Measurement Interferometer. Experimental setup



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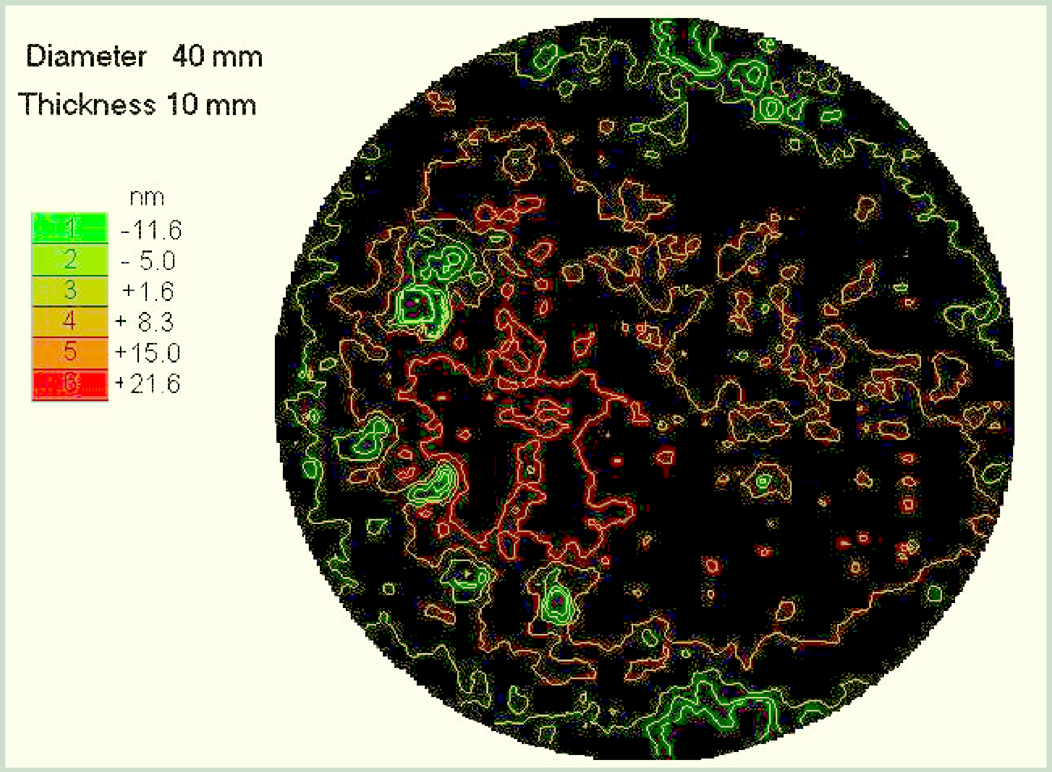
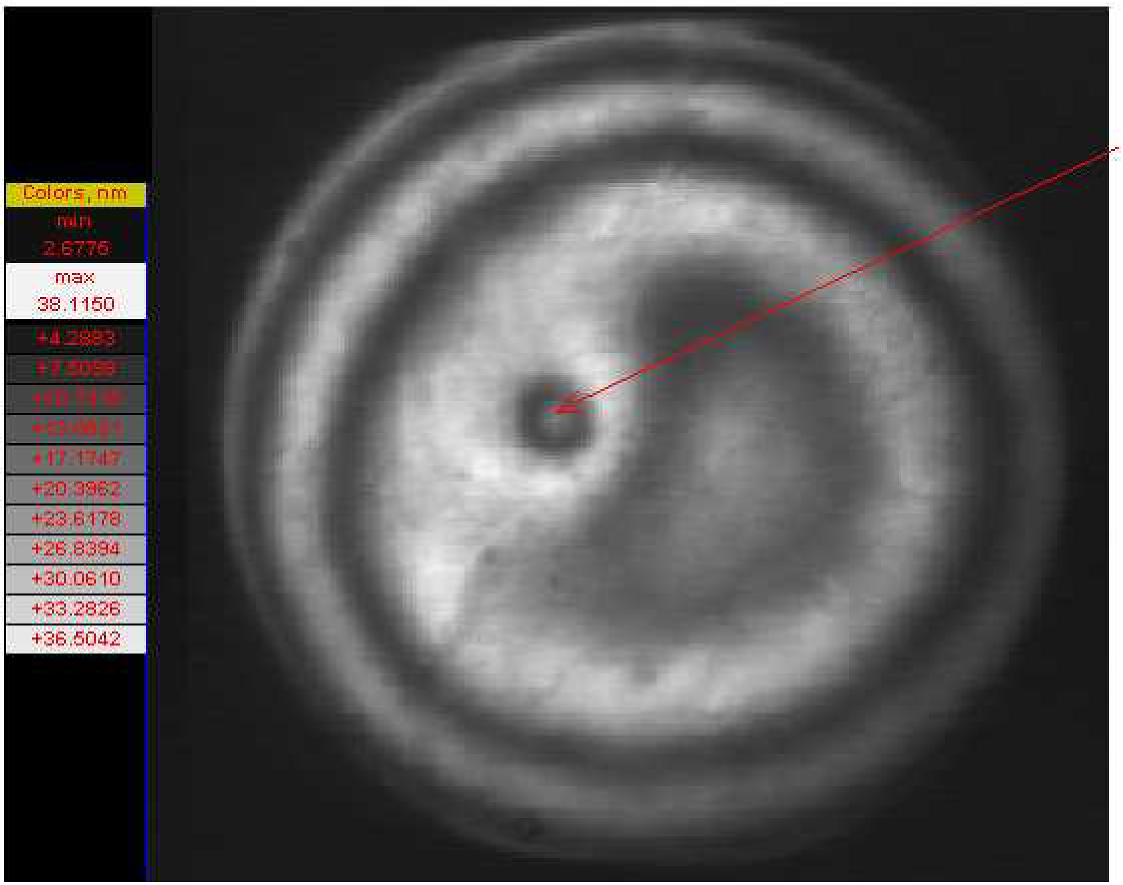
White Light *In Situ* Measurement Interferometer Phase Map



- Sensitivity:	**better $\lambda/1000$**
- Diameter of the sample under study:	**up to 100 mm**
- Number of points measured simultaneously:	**250 x 340**
- Measurement time:	**no more than 4 s**
- Time of data processing:	**no more than 5 s**
- Output data:	**24-bit graphic file**

CCD camera image of optical sample heated by CO_2 laser

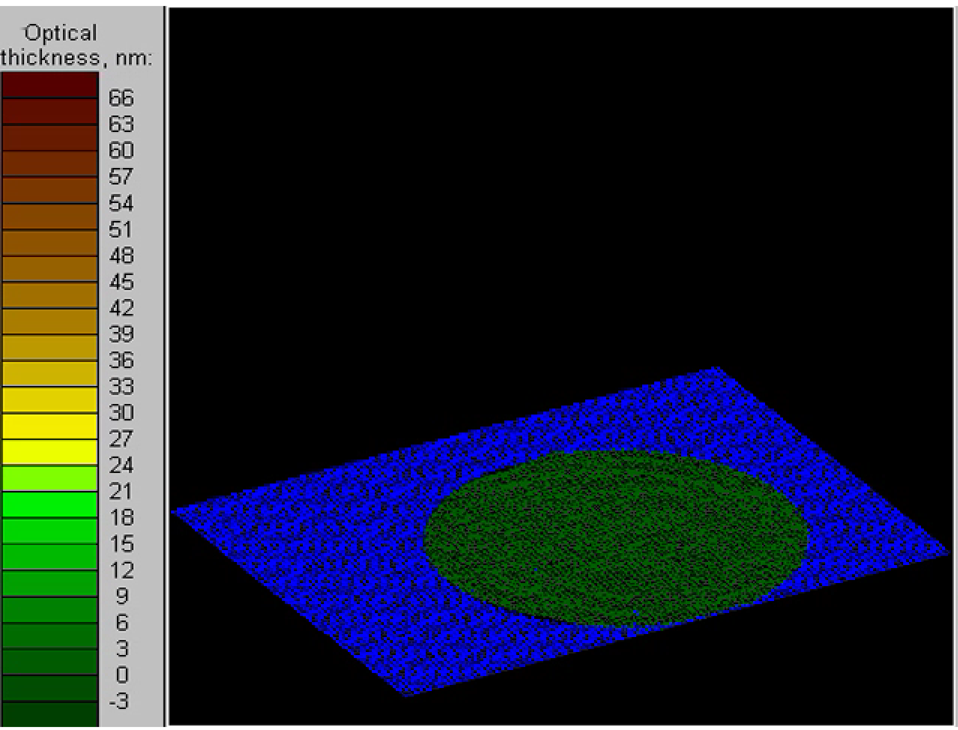


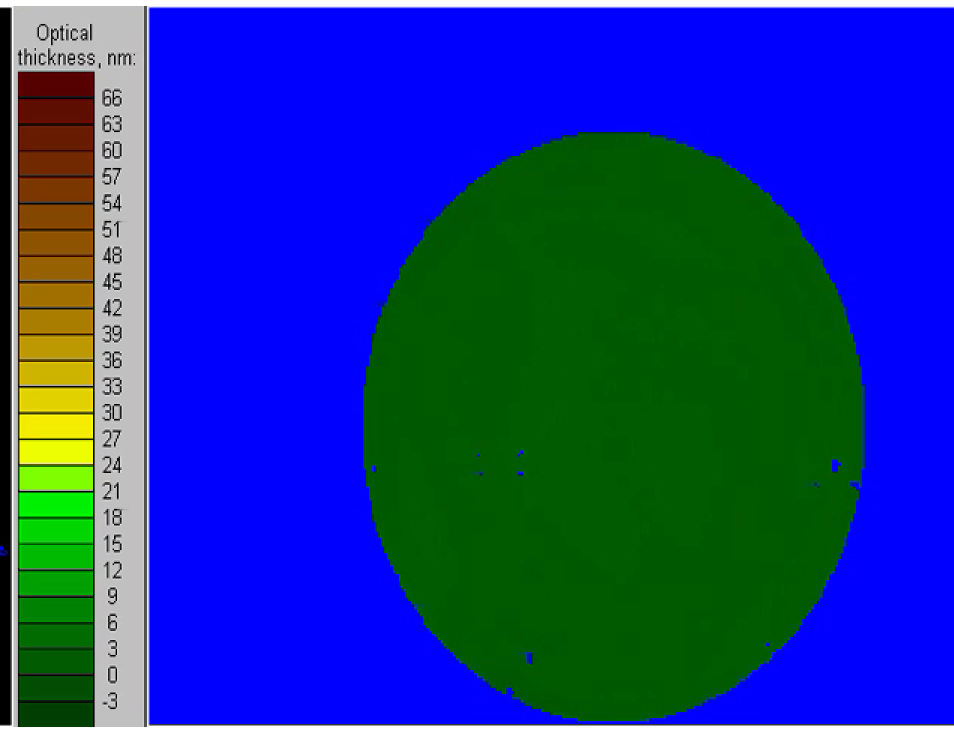
Place of heating beam

Thickness - 15 mm
Diameter - 85 mm

Dynamical monitoring of BK7 glass sample heating – “cross writing”

CO_2 laser power=300 mW	CO_2 laser beam diameter =1mm
Heating duration = 3 min	Sample: length 20 mm, aperture 35mm





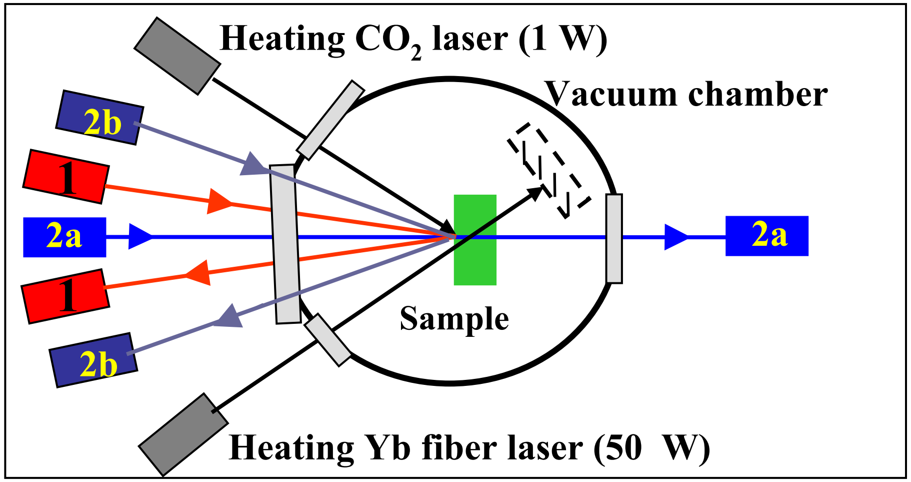
Next steps to do:

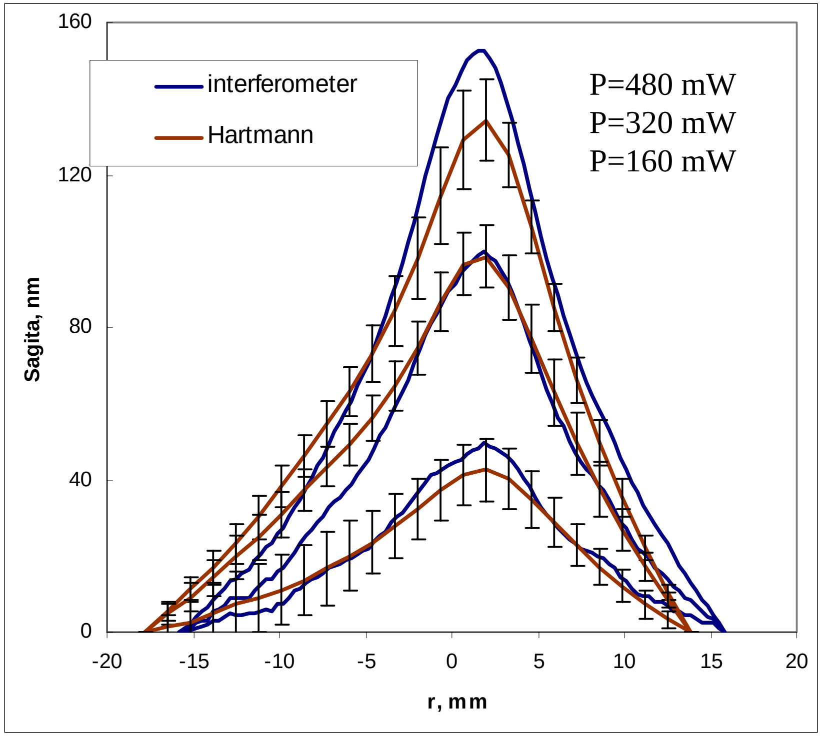
• to confirm experimentally the feasibility of remote (*in situ*) high sensitivity monitoring of thermal distortions in core optics components using several complementary techniques:
- white-light phase-modulated interferometry
- scanning linear Hartmann sensing in through-passing geometry
- scanning linear Hartmann sensing in reflective geometry

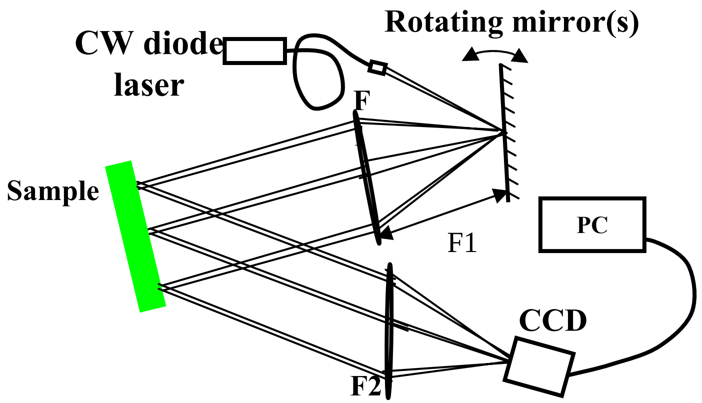
• to separate volume and surface distortions by simultaneous measurements using several techniques

• to install the instruments at a LLO end station

Next Steps

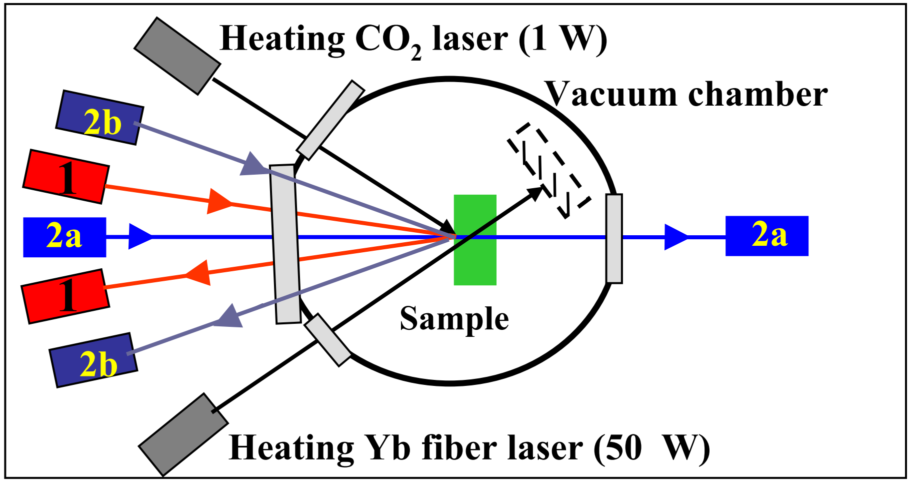






Wavefront distribution when a sample made of BK7 glass was heated by a CO_2 laser beam with different power

Separation of volume and surface distortions by simultaneous measurements using several techniques



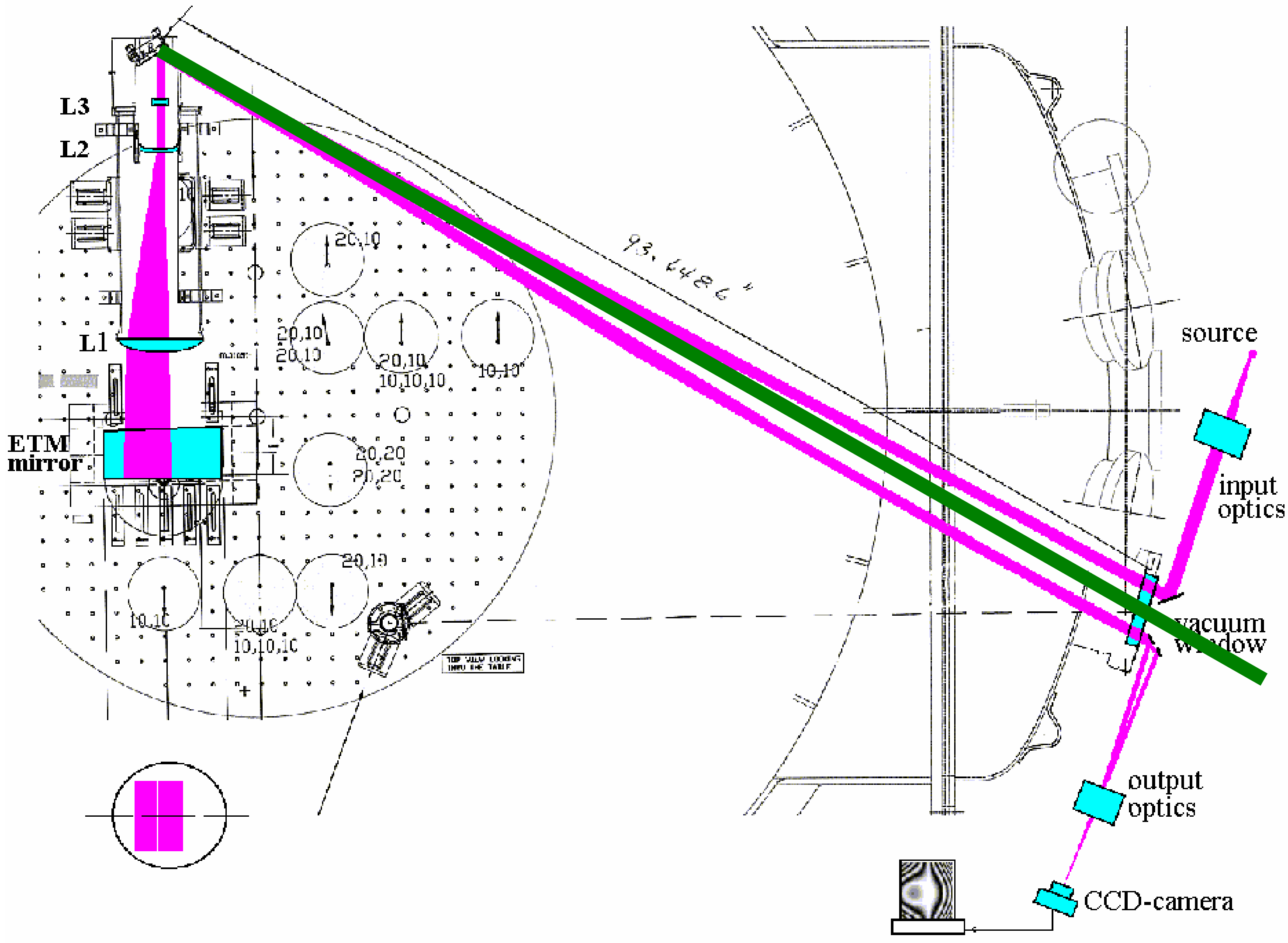
2a Hartmann sensor measures

$$\left(\frac{dn}{dT}+(n-1)\left(\frac{dL}{dT}\frac{1}{L}\right)\right)L\cdot\Delta T$$

1 Interferometer measures

$$\left(\frac{dn}{dT}+n\left(\frac{dL}{dT}\frac{1}{L}\right)\right)L\cdot\Delta T$$

How to install WLISMI in LIGO-I interferometer?



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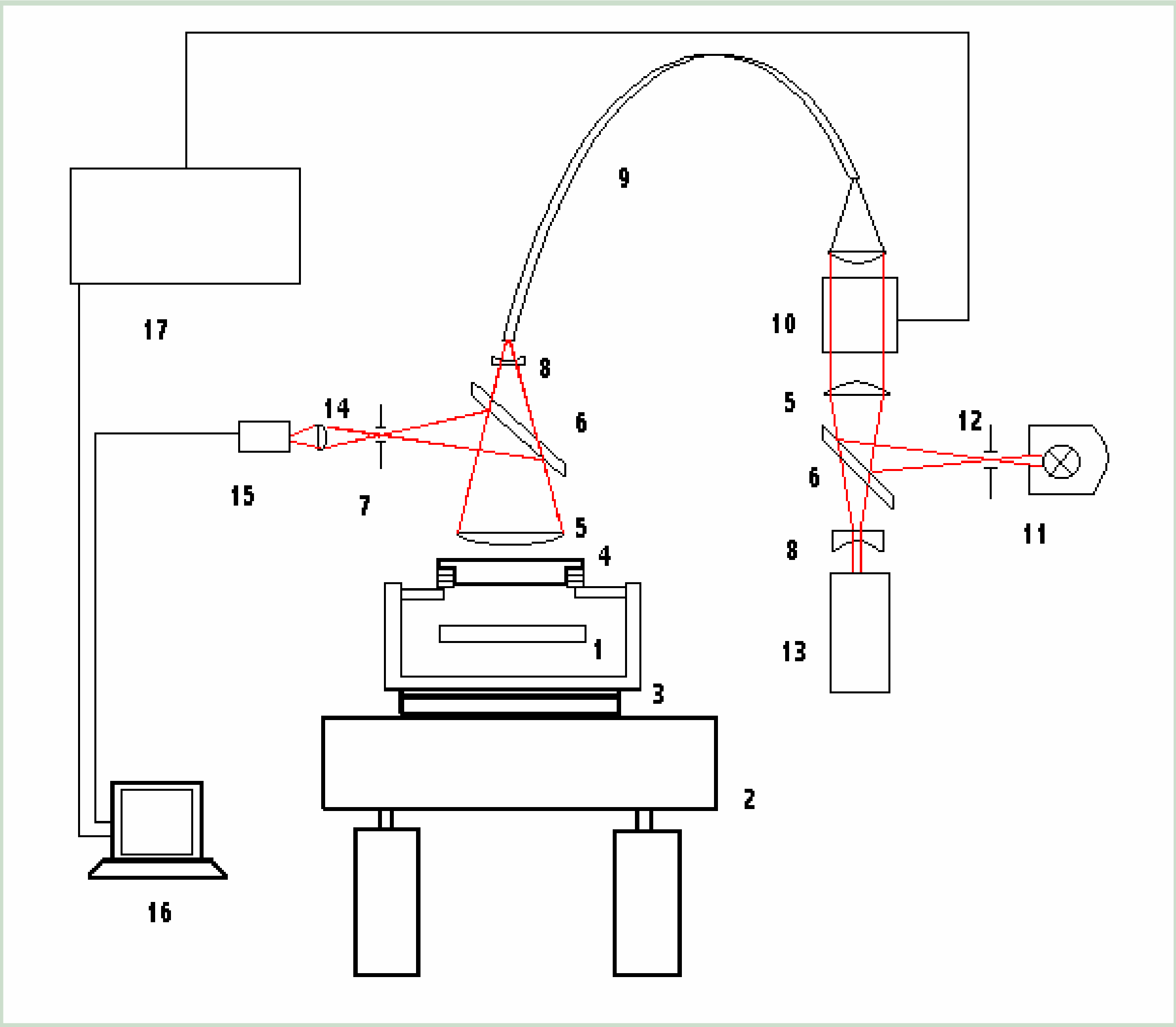
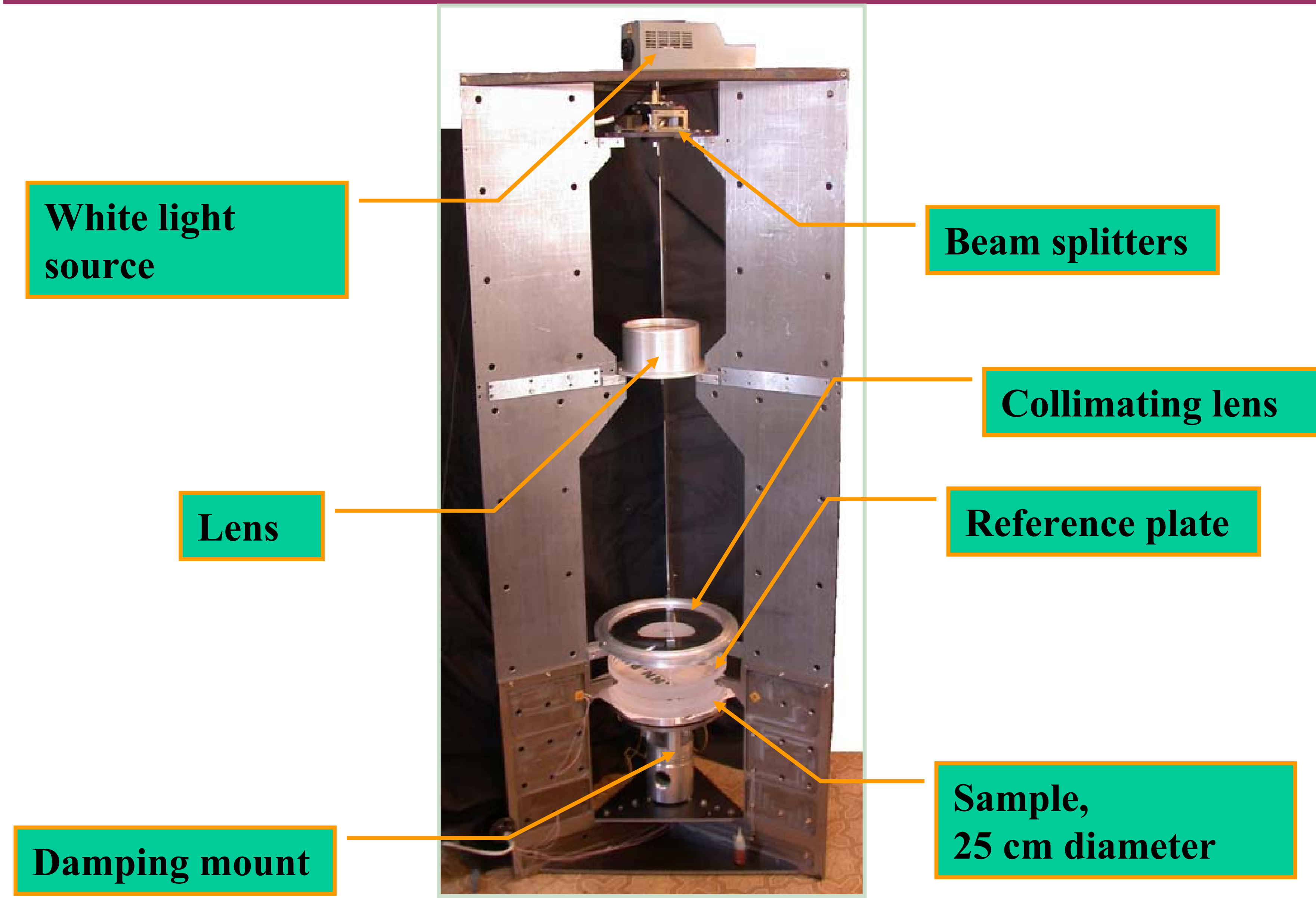
Large aperture white-light phase-modulated interferometer (WLPMI) for preliminary control of LIGO Core Optics

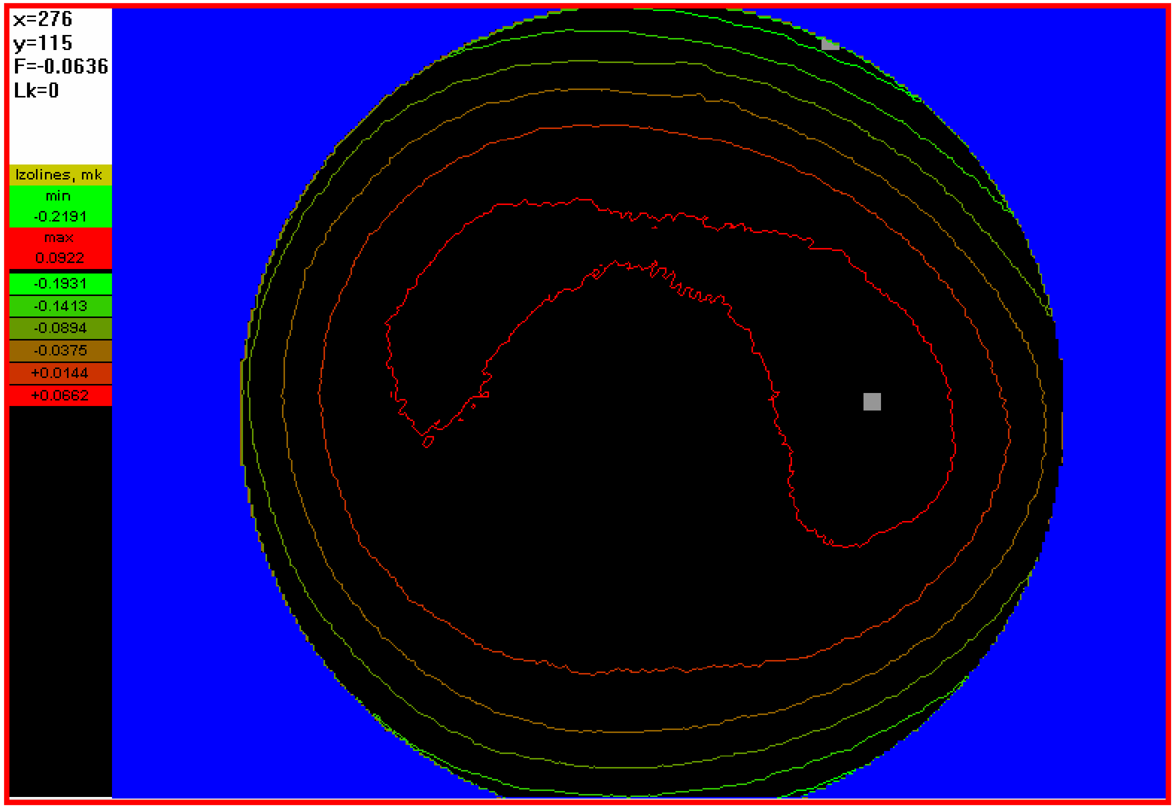


1 – sample
2 – optical table
3 – damping mount
4 – reference plate
5 – collimating lens
6 – beam splitters
7 – spatial filter
8 – lenses
9 – fiber bundle
10 – spectral modulator
11 – white light source
12 – aperture
13 – He-Ne laser
14 – projection lens
15 – CCD-camera
16 – computer
17 – control unit

Large aperture white-light phase-modulated interferometer (WLPMI) for preliminary control of LIGO Core Optics



White Light Measurement Interferometer for preliminary Core Optics control



Root-mean-square accuracy	**λ/2000 (λ/6000 over 100mm !)**
Spatial frequency resolution	**1 cm^{-1} to 1000 cm^{-1}**
Maximum processing area	**270 mm diameter**
Measuring and processing time for a 240 x 320 pixel pattern	**< 10 min**

Next steps to do:

- By optimizing performance (hardware and software based noise removal) we will achieve $\lambda/2000$ over 270 mm aperture

- Implementation of spherical surface measurement mode (new wave front shaper and absolute calibration strategy)

- Ready to install at LIGO sites

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Next steps to do:

- • Search for solid-state material suitable for adaptive thermal lens compensation in high-power FI unit
- • Manufacturing and experimental testing of FI with both depolarization compensation and adaptive thermal lens compensation
- • Experimental demonstration of total loss in the fundamental transverse mode corresponding to specification at Adv.LIGO power level
- Investigation of FI designs subjected to transient states and assessment of their performance with respect to design specifications
- • Experimental testing of adaptive thermal lens compensation in non stationary regimes