Methods and Instruments for Characterization of Large-Aperture LIGO Optical Components with Subnanometer Precision

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Caltech, January 2005

LIGO-G050079-00-Z

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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**

Outline

1. Instrument for laboratory (input) control of large aperture (~25 cm) optical components with subnanometer precision

2. Methods and instruments for remote (in situ) characterization of optical surface and sample thickness with subnanometer precision

3. Prospects of instrument installation at LLO end station

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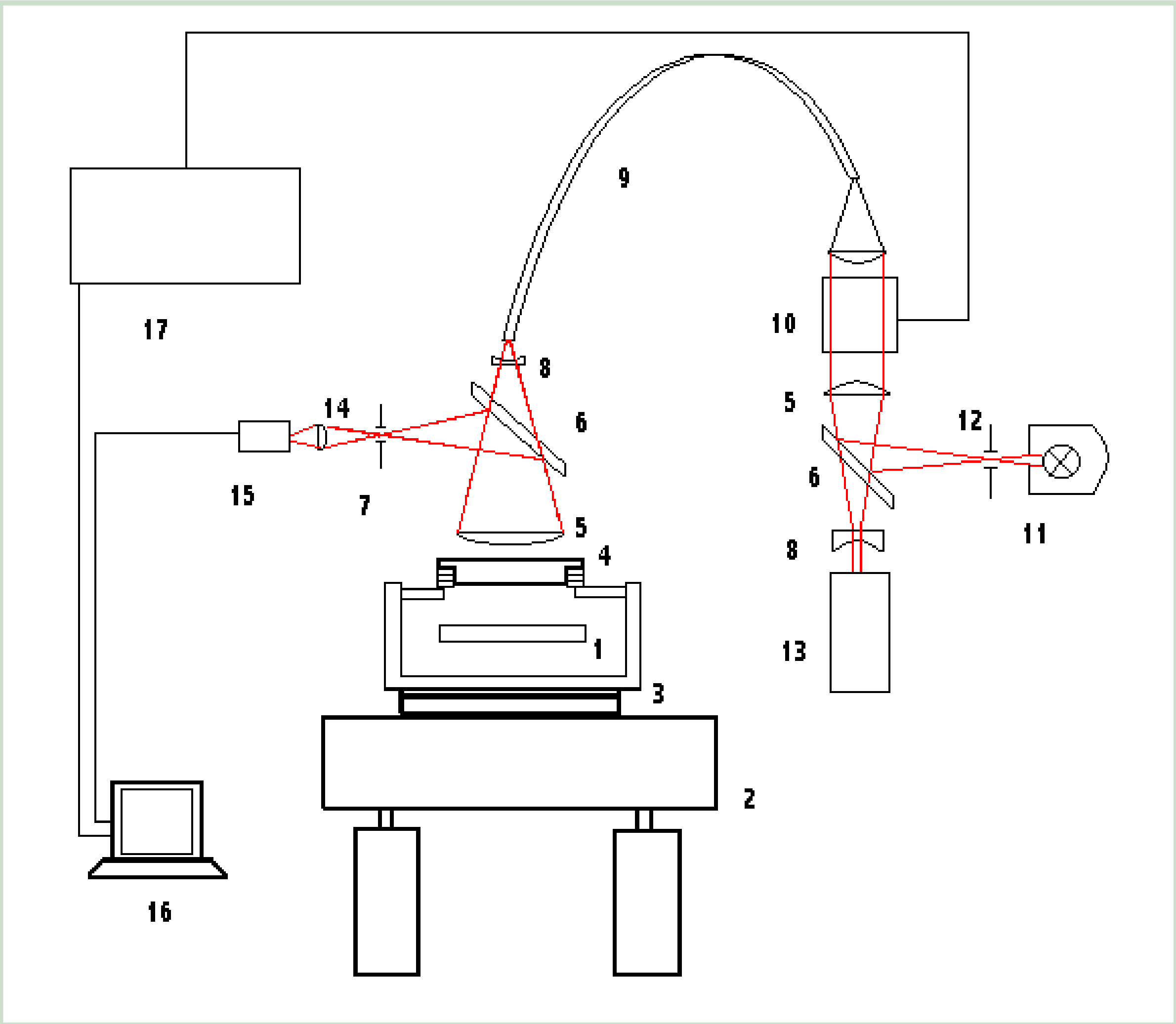
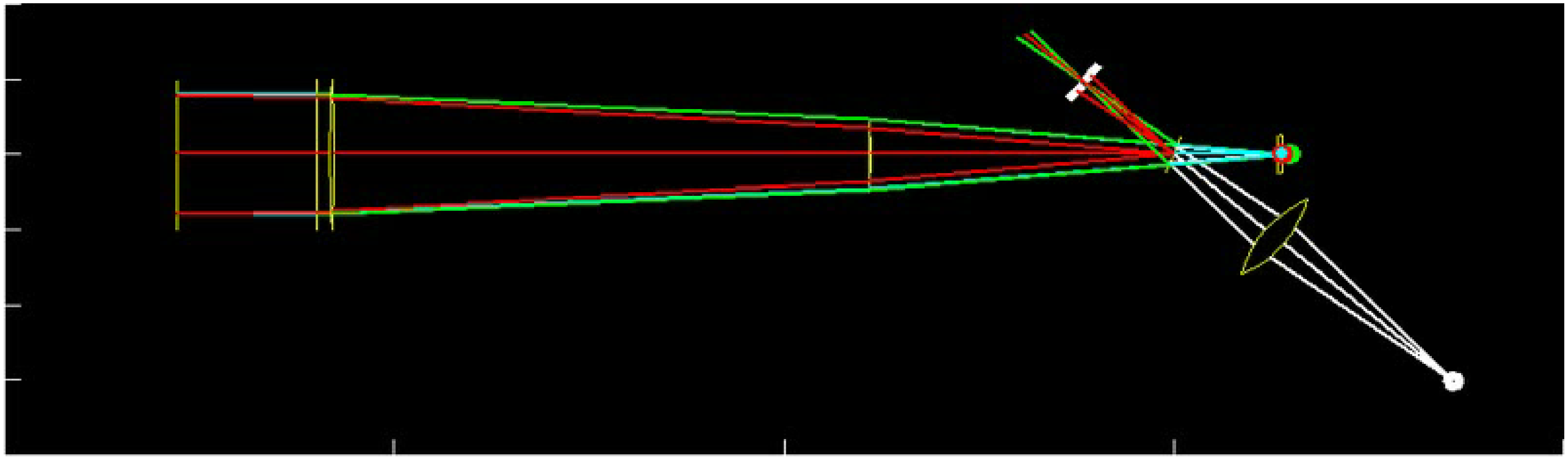
White-light phase-modulated interferometer (WLPMI) for preliminary control of large aperture optical components



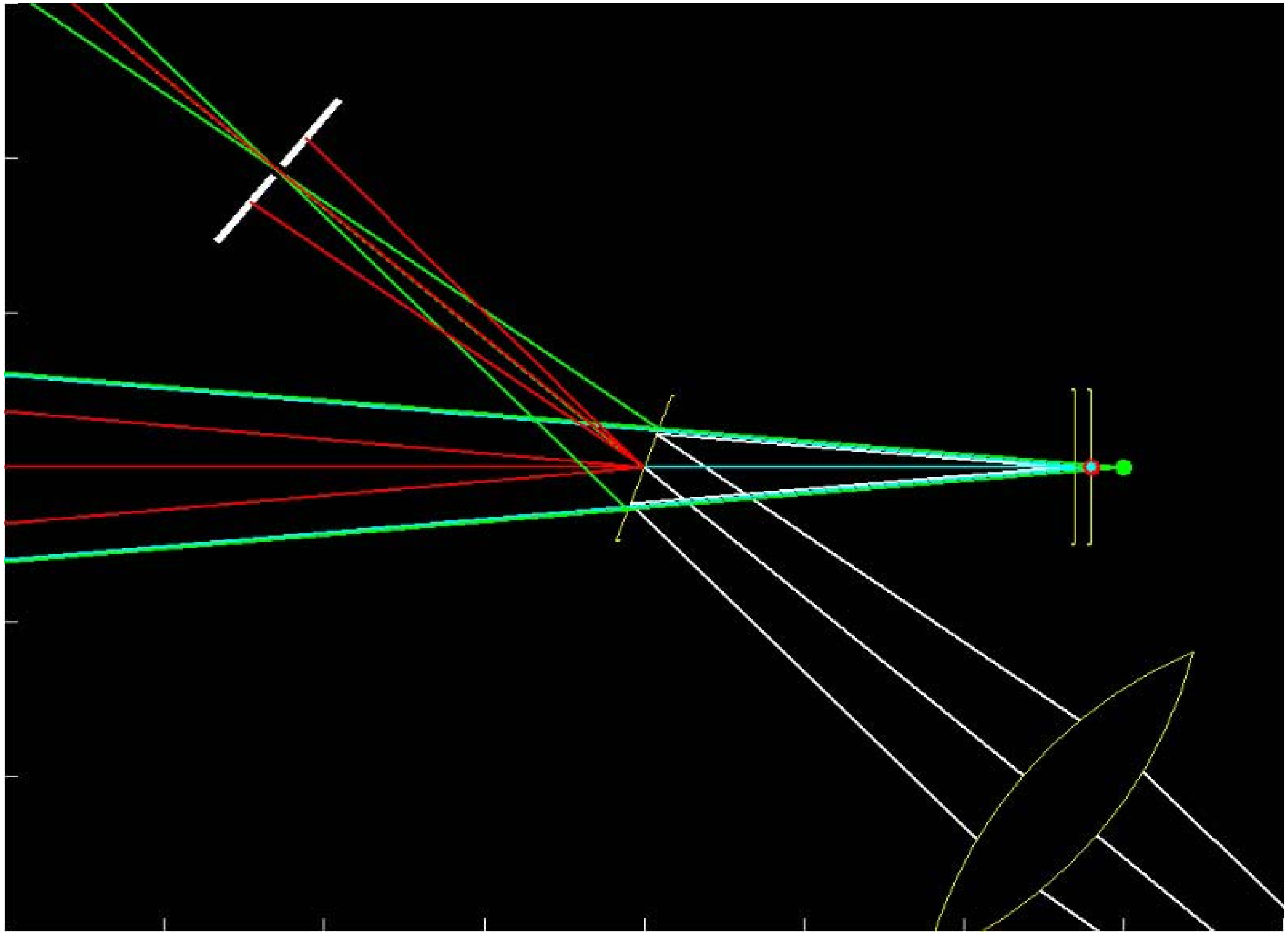
1 – sample
2 – optical table
3 – damping mount
4 – reference plate
5 – collimating lens
6 – beam splitters
7 – spatial filter
8 – lenses
9 – fiber bundle
10 – spectral modulator
11 – white light source
12 – aperture
13 – He-Ne laser
14 – projection lens
15 – CCD-camera
16 – computer
17 – control unit

Scheme of interferometry

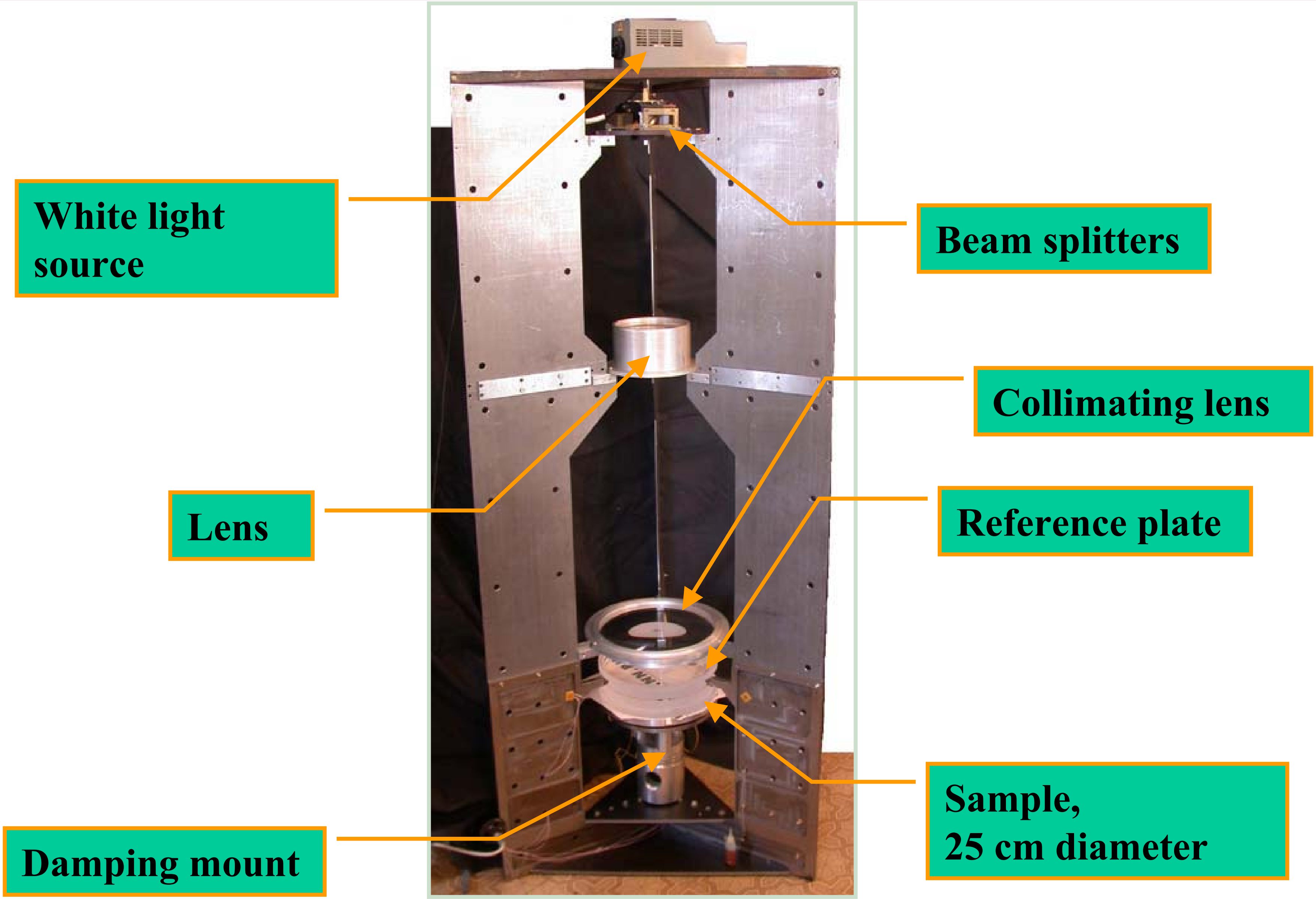
Two secondary imaginary sources are created by a real white-light source and two mirrors. The interference pattern is produced by beams created by the secondary sources upon reflection from two measured surfaces (similar optical paths). Wave fronts of radiation produced by the secondary sources coincide with measured surfaces (plane, sphere, wedge).



Preparation of probing beams



White-light phase-modulated interferometer (WLPMI) for preliminary control of large aperture optical components



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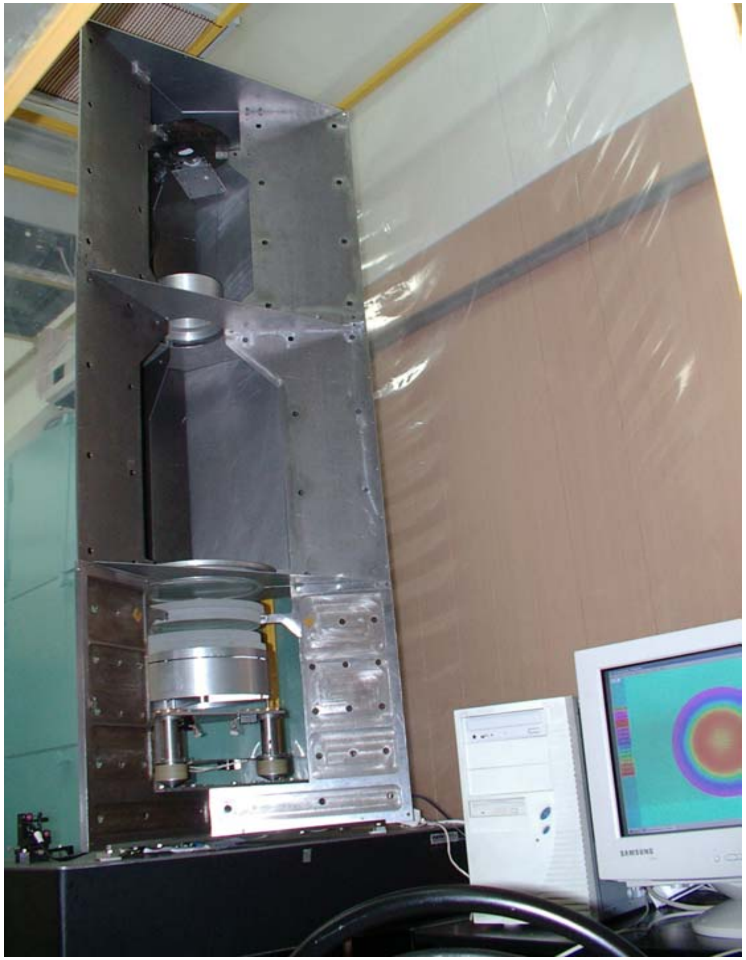

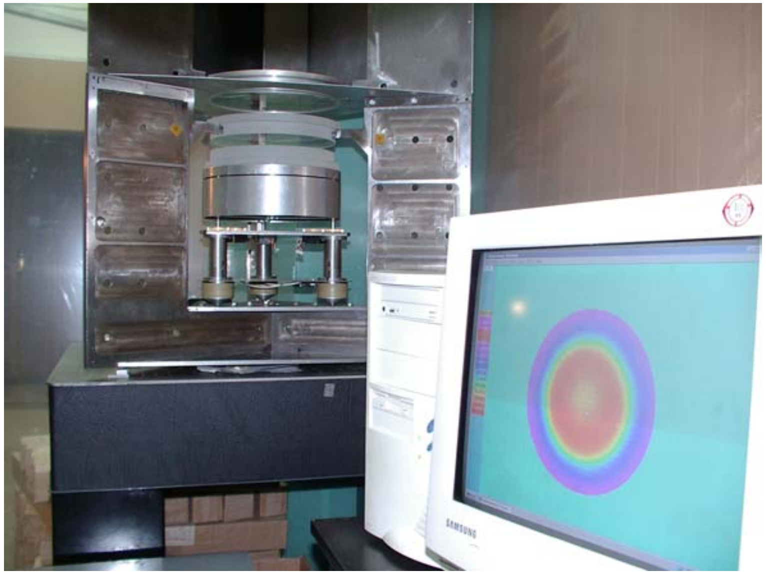

White-light phase-modulated interferometer (WLPMI) for preliminary control of large aperture optical components

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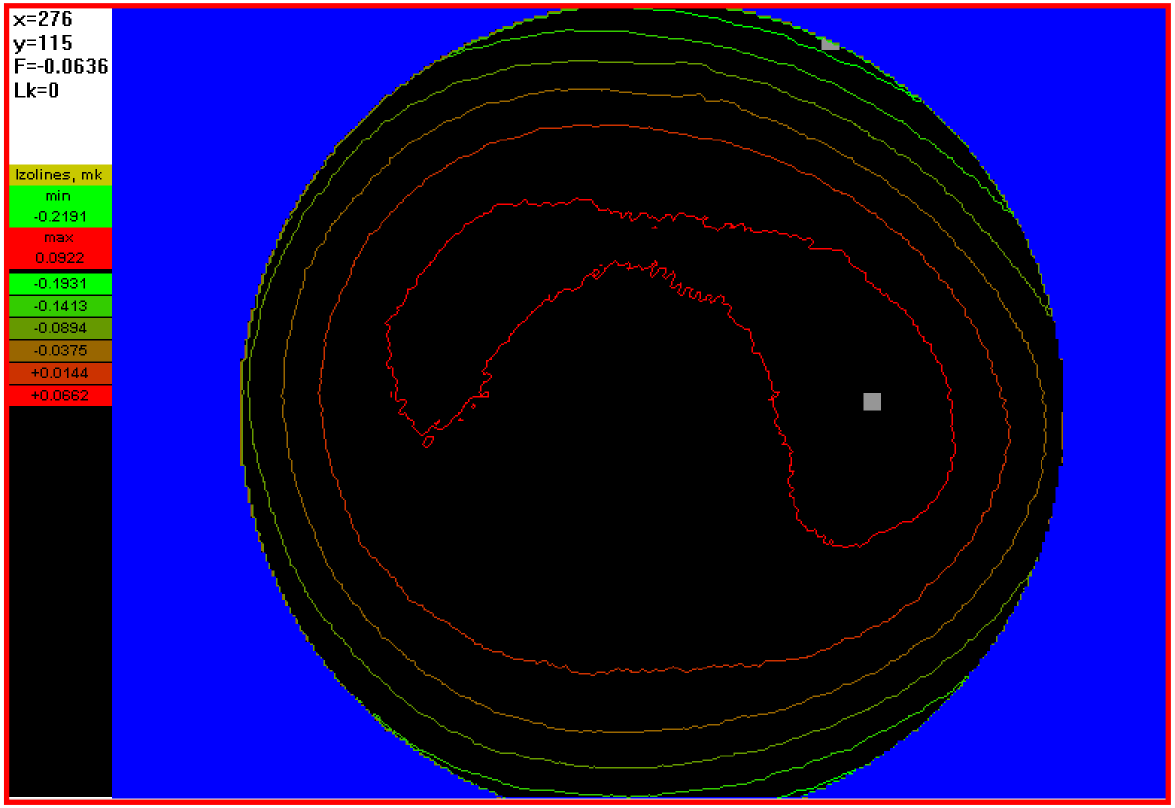

Root-mean-square accuracy	**λ/2000 (λ/6000 over 100mm !)**
Spatial frequency resolution	**1 cm^{-1} to 1000 cm^{-1}**
Maximum processing area	**270 mm diameter**
Measuring and processing time for a 240 x 320 pixel pattern	**< 10 min**

Next steps to do:

- By optimizing performance (hardware and software based noise removal) we will achieve λ/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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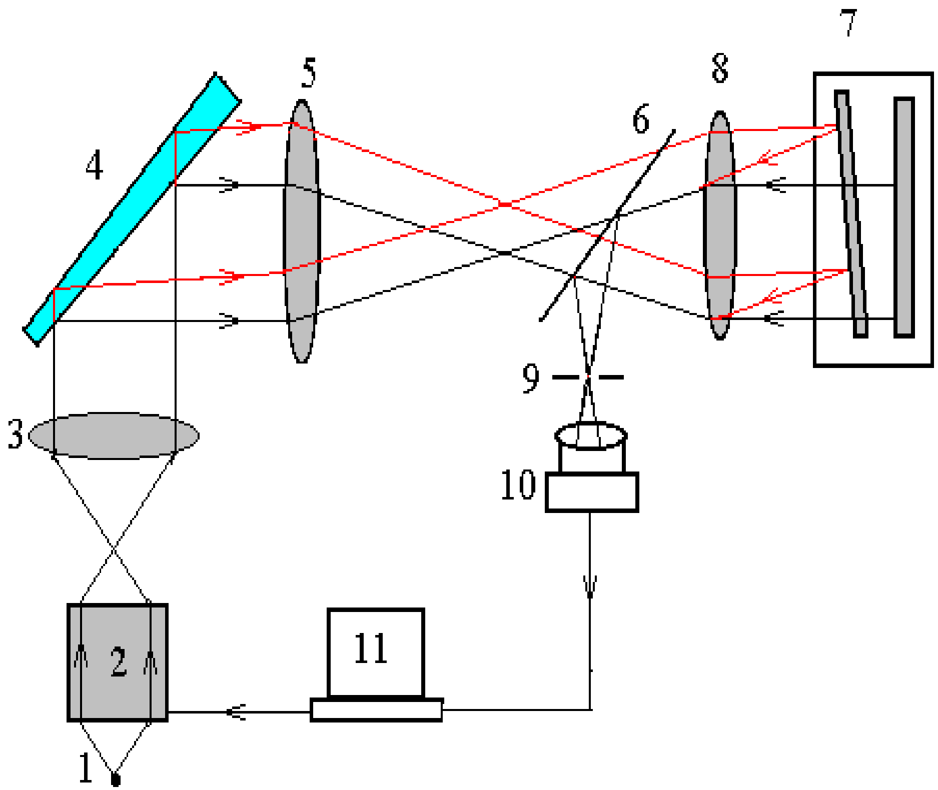
“White Light” *In Situ* Measurement Interferometer (WLISMI)

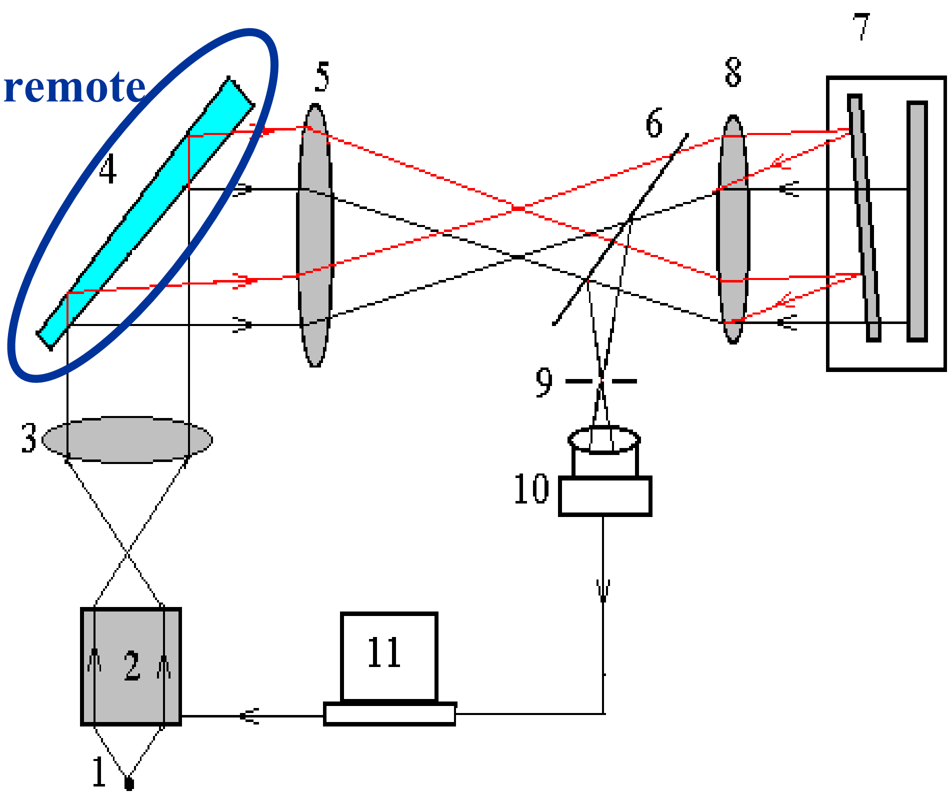
Standard interferometers	Newly developed interferometers
Measurement of optical length of air spacing between two surfaces. In profilometers one of them is a sample surface, and the other is a reference surface. The problem of precise measurement of phase in the interferogram is solved by phase modulation 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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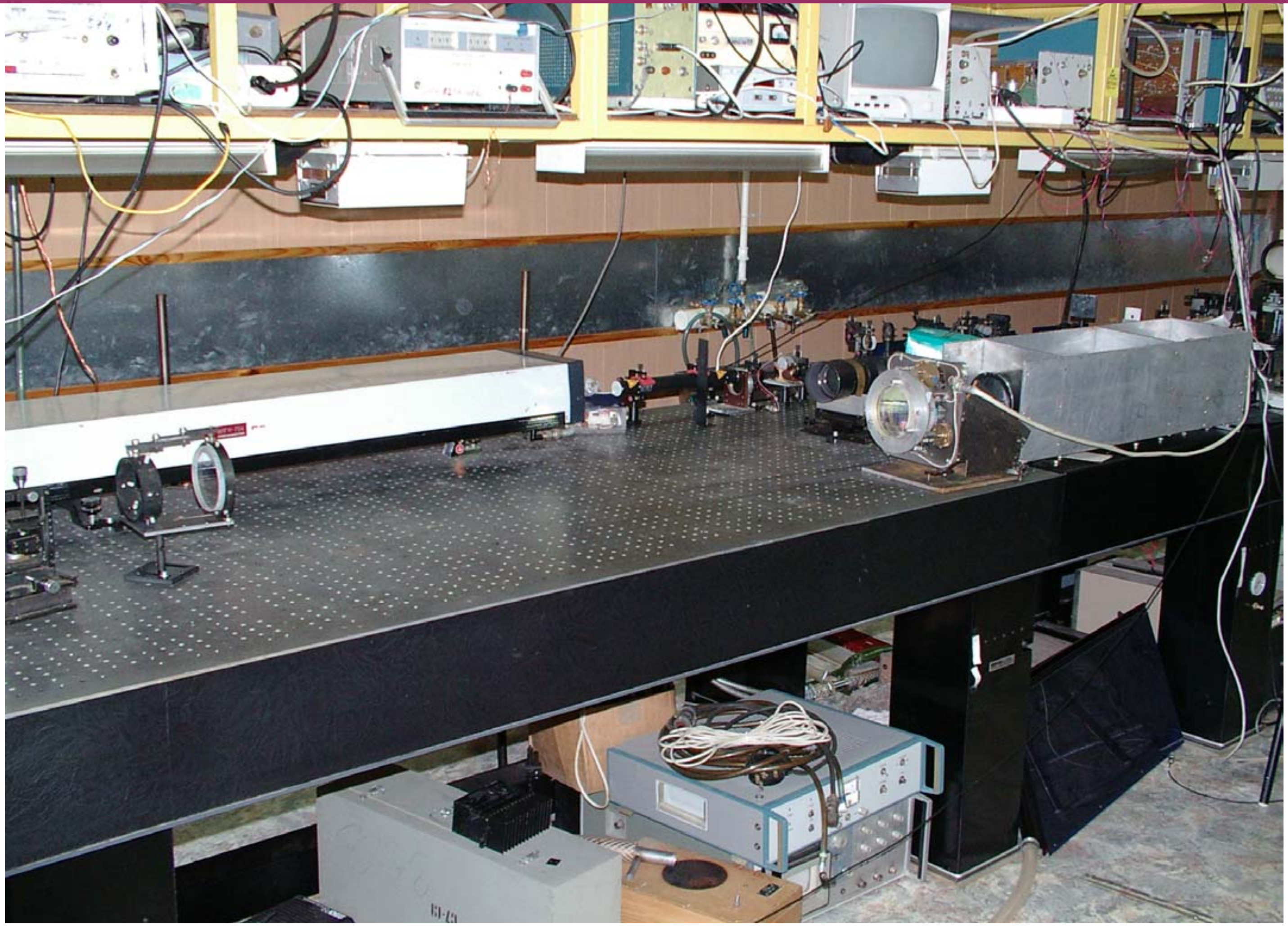
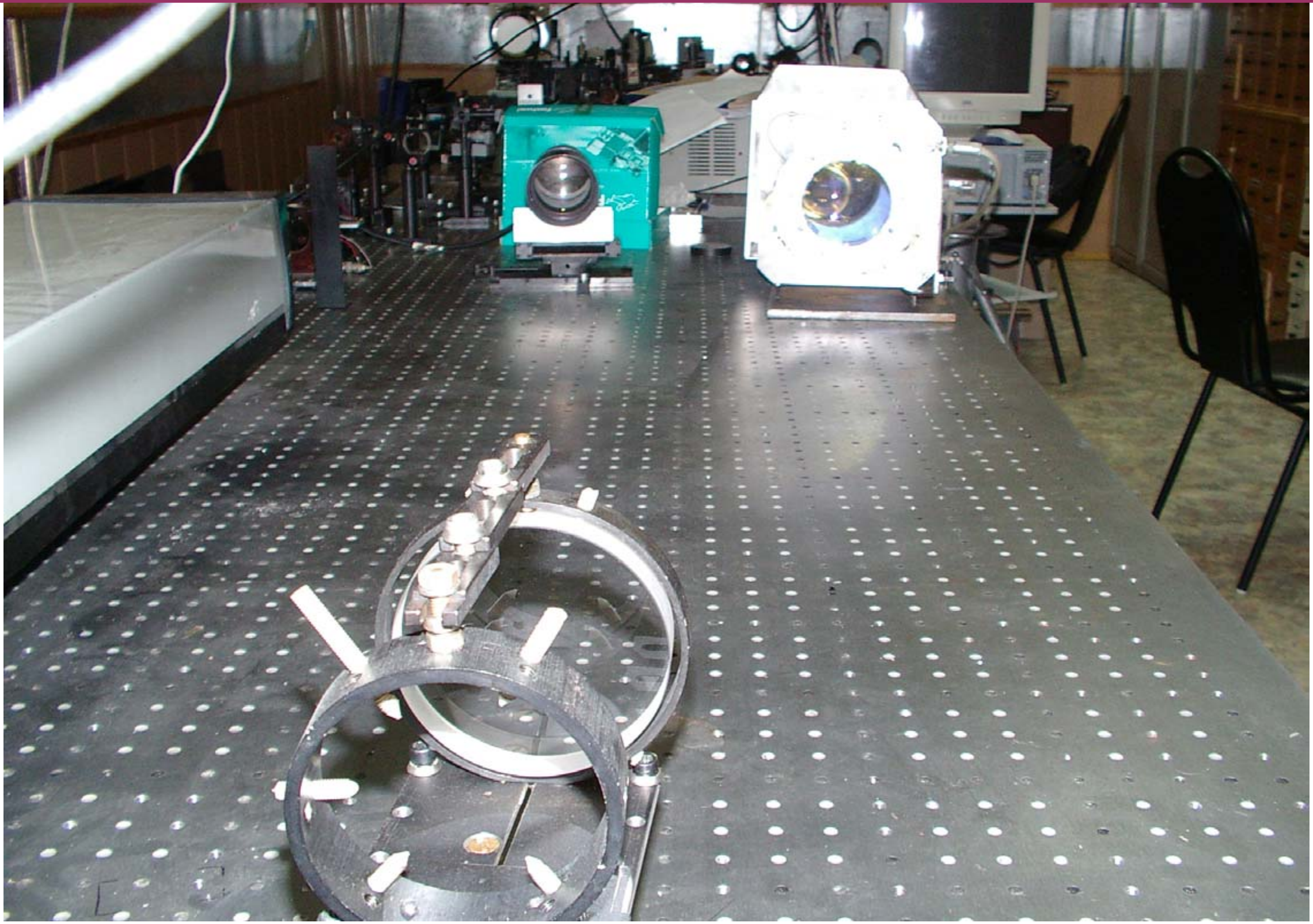
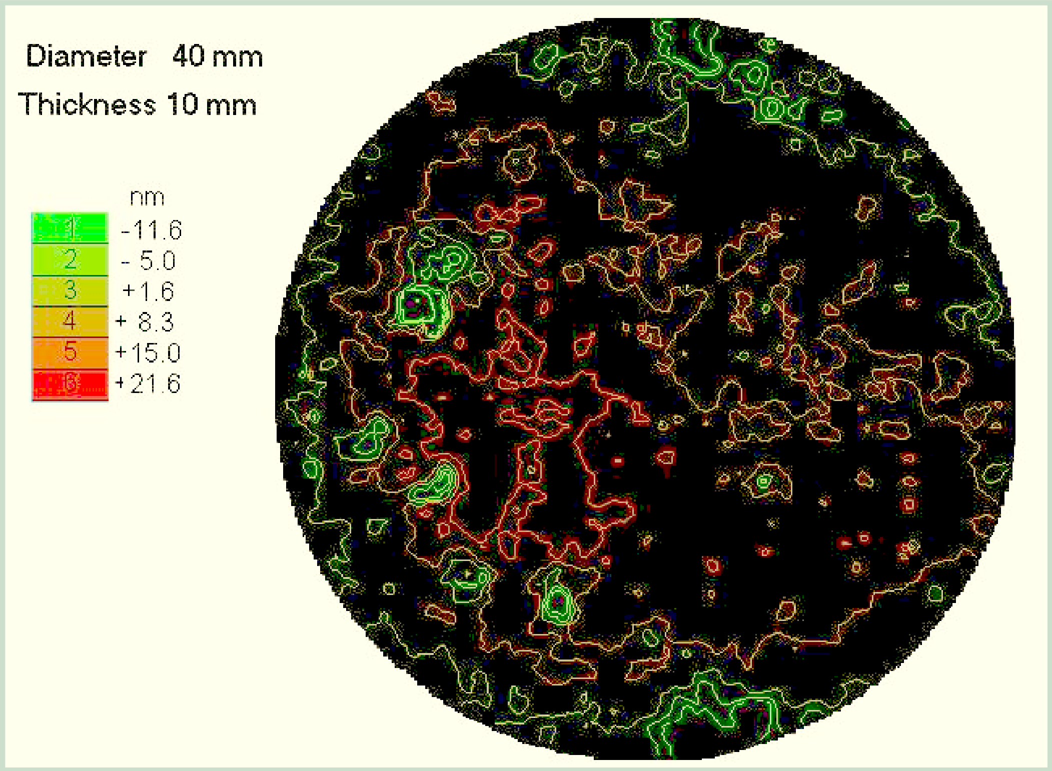
“White Light” *In Situ* Measurement Interferometer.
Experimental setup



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

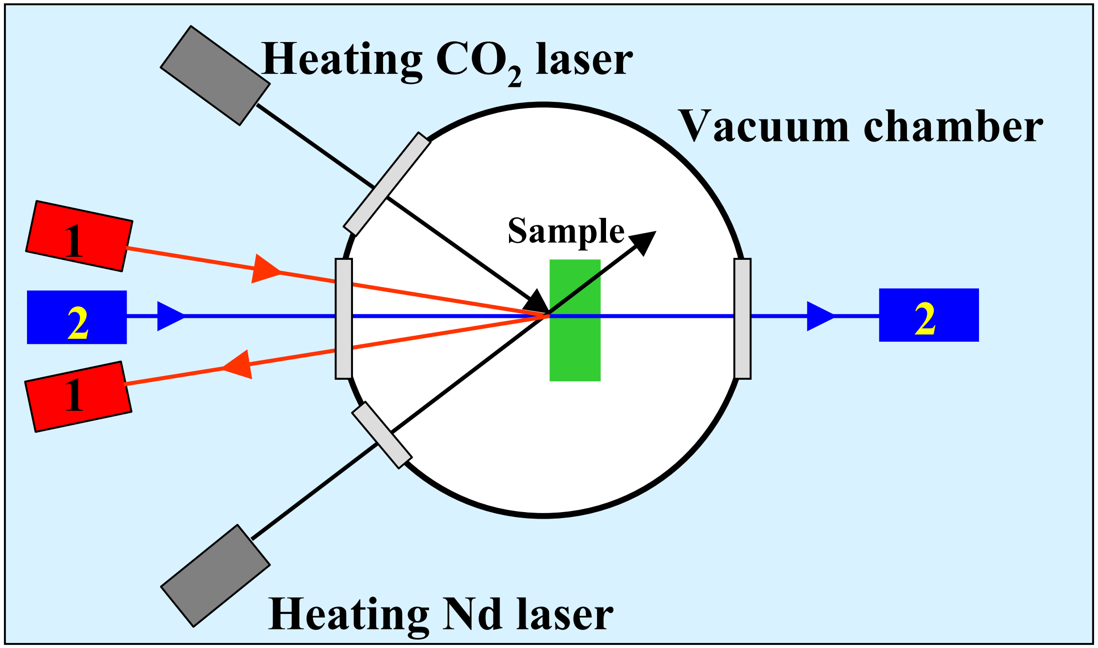


White Light *In Situ* Measurement Interferometer Phase Map

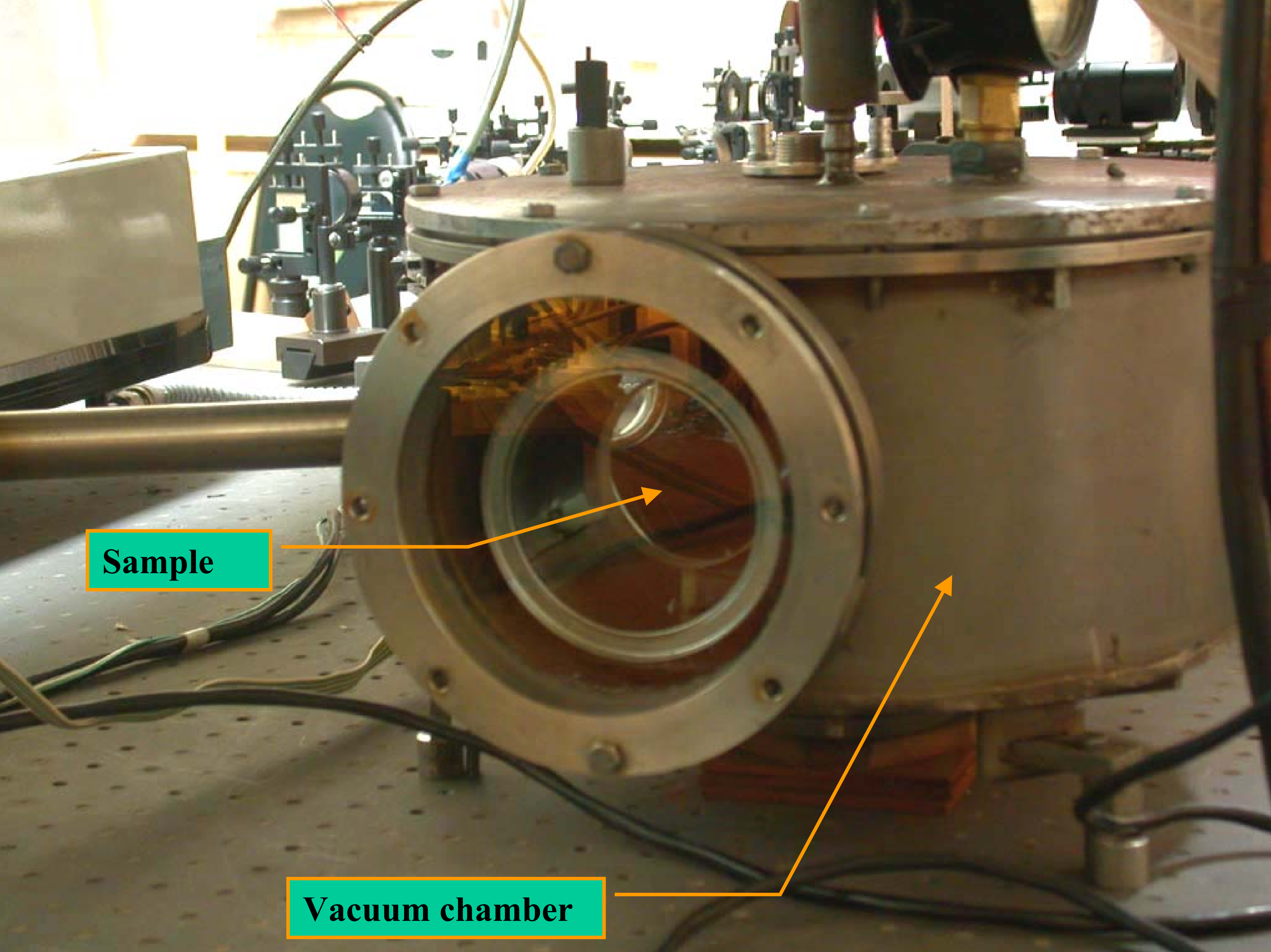


- Sensitivity:	**better λ/1000**
- Diameter of the sample under study:	**up to 100 mm**
- Number of points measured simultaneously:	**250 x 340**
- Measurement time:	**no more than 4 s**
- Time of data processing:	**no more than 5 s**
- Output data:	**24-bit graphic file**

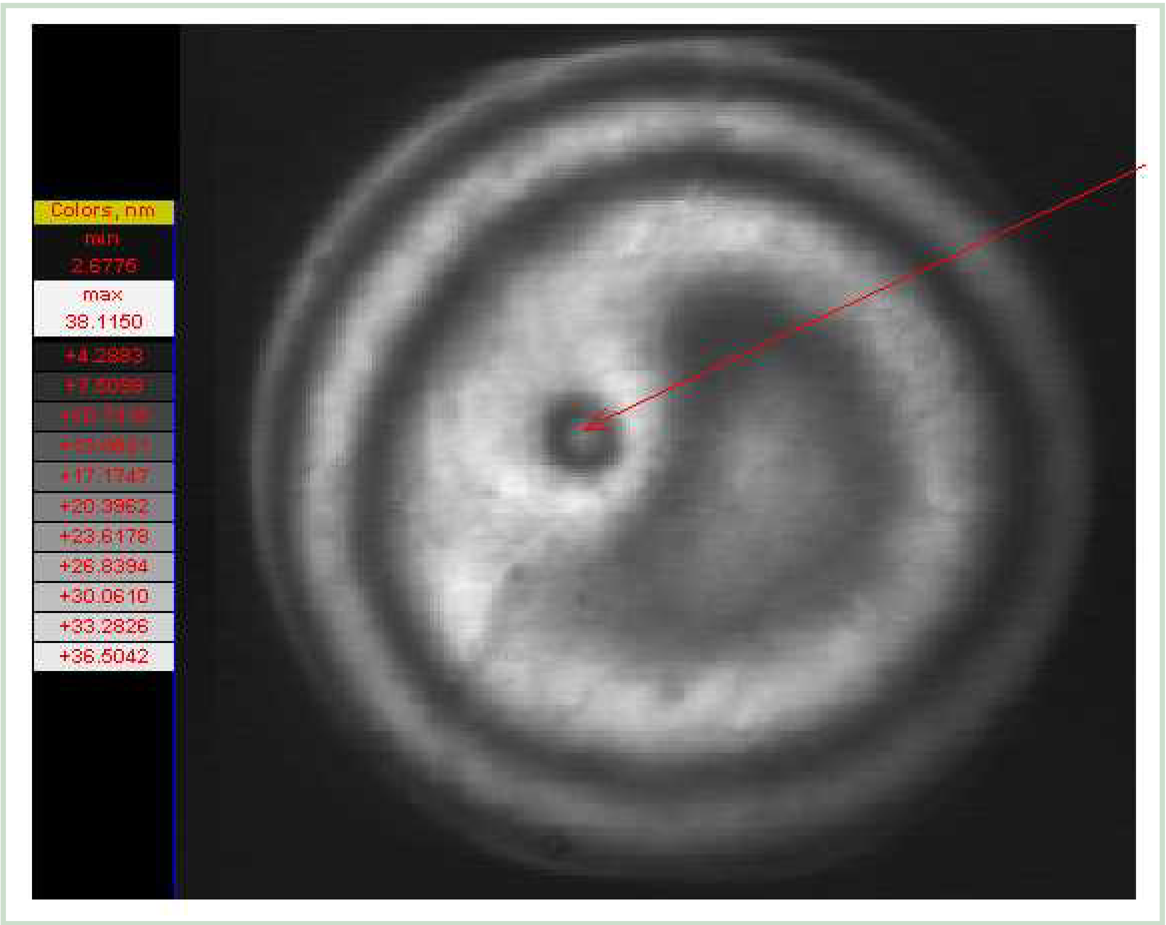
Remote *in situ* monitoring of weak distortions emerging under auxiliary laser heating



LIGO-IAP Laboratory


Sample
Vacuum chamber

CCD camera image of optical sample heated by CO_2 laser

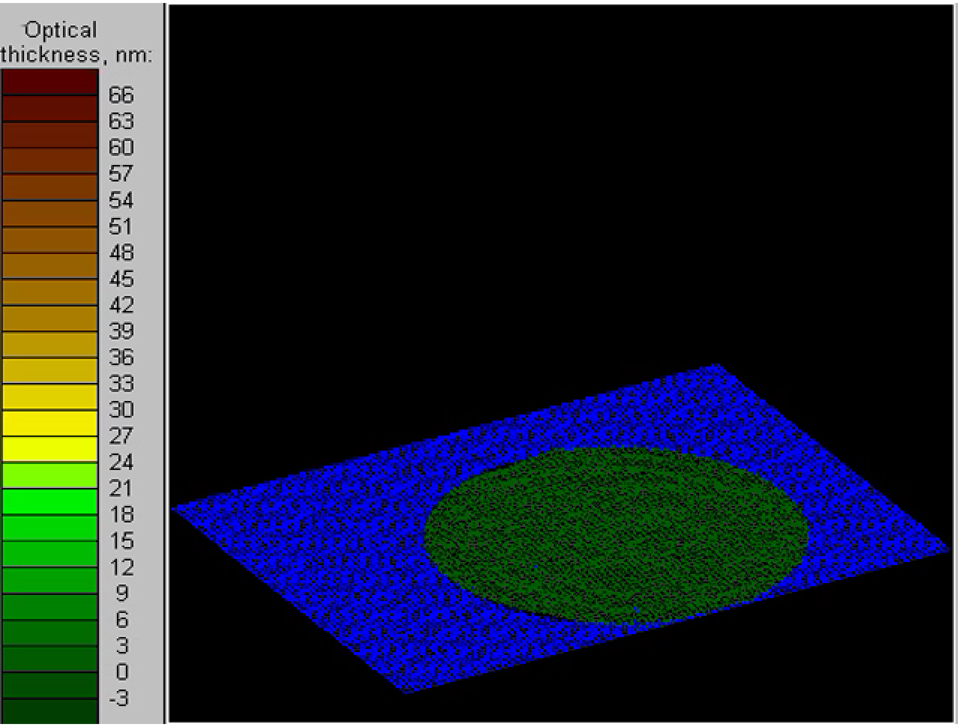


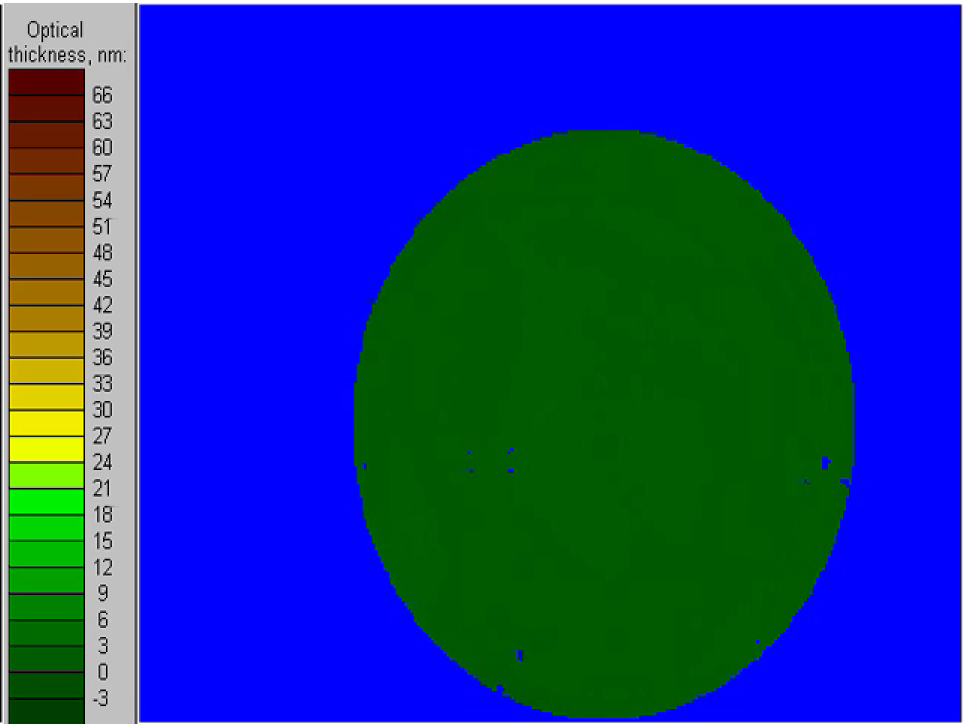
Place of heating beam

Thickness - 15 mm
Diameter - 85 mm

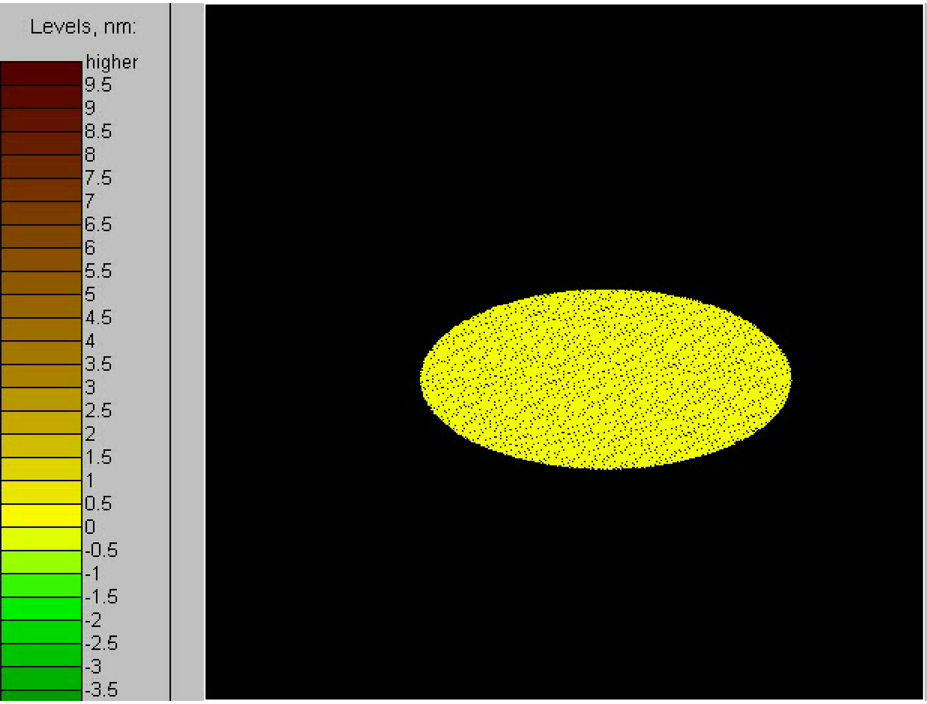
Dynamical monitoring of BK7 glass sample heating – "cross writing"

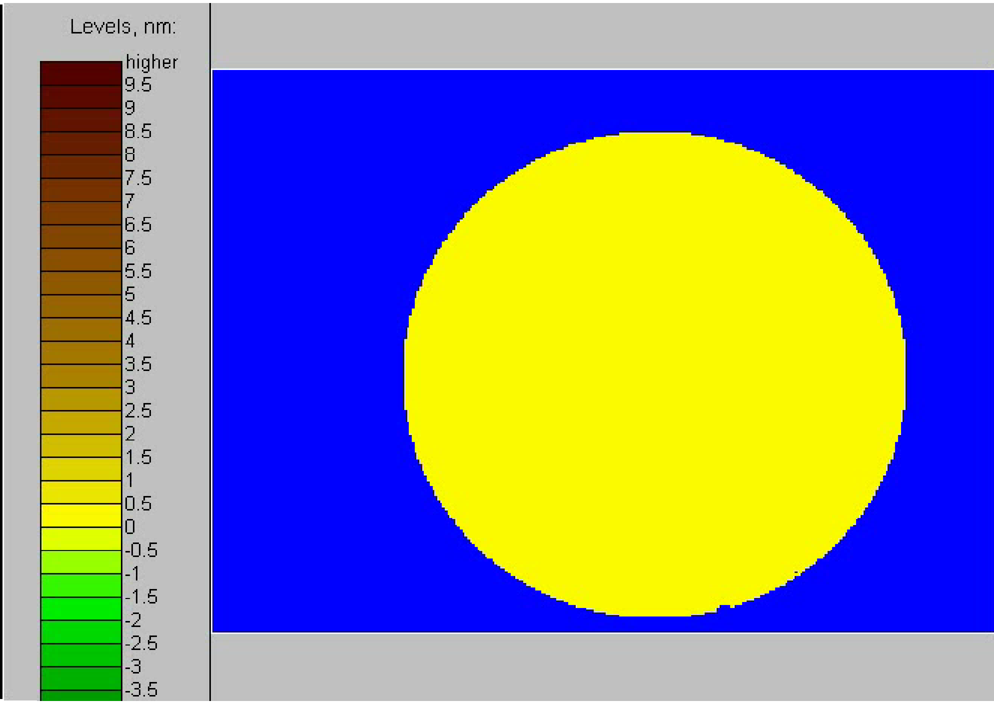
CO_2 laser power=300 mW	**CO_2 laser beam diameter =1mm**
Heating duration = 3 min	**Sample: length 20 mm, aperture 35mm**





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





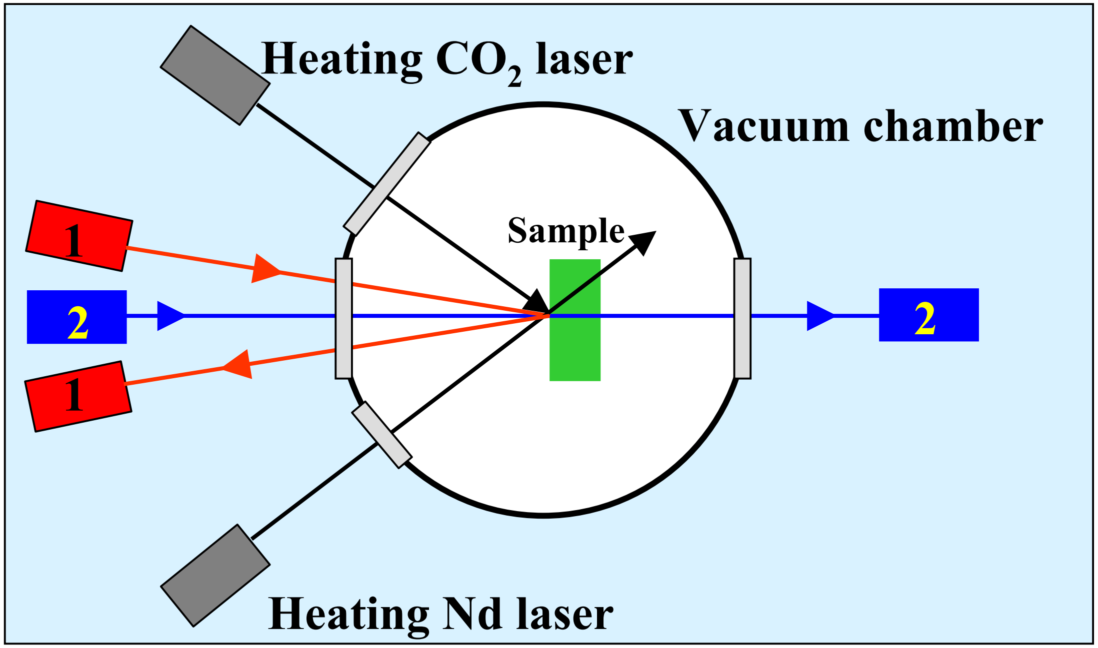
Next steps to do:

• 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

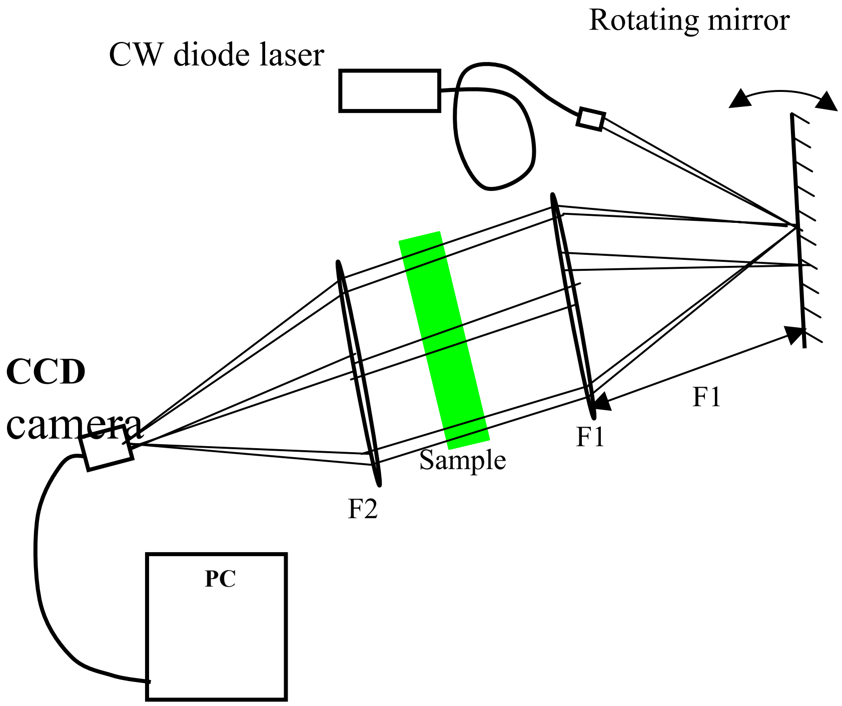
Remote *in situ* monitoring of weak distortions emerging under auxiliary laser heating. Setup.



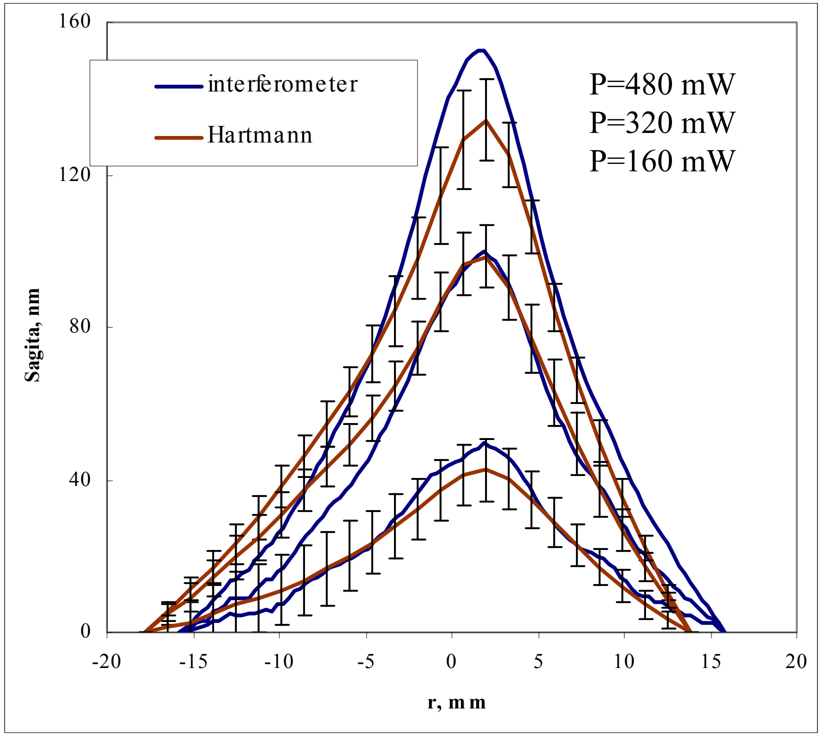
1 - WLPMI
2 - NHS and PIT

- 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

Scanning Linear Hartmann Sensor

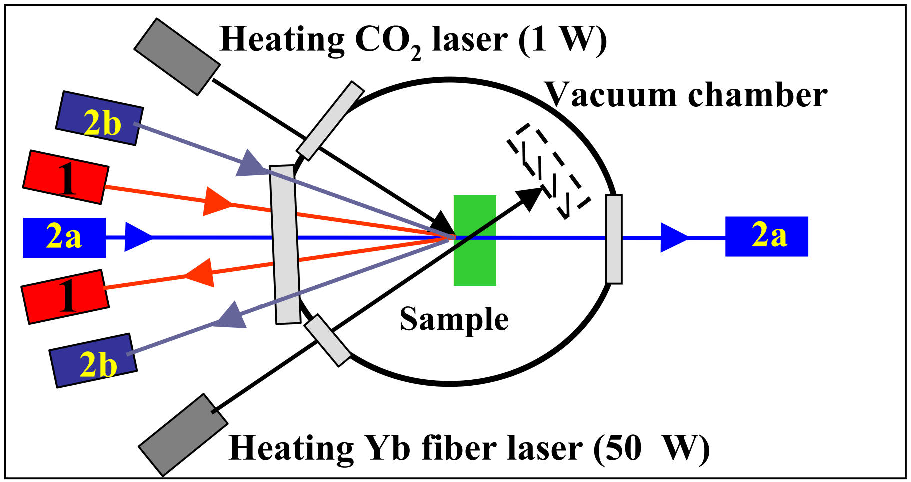


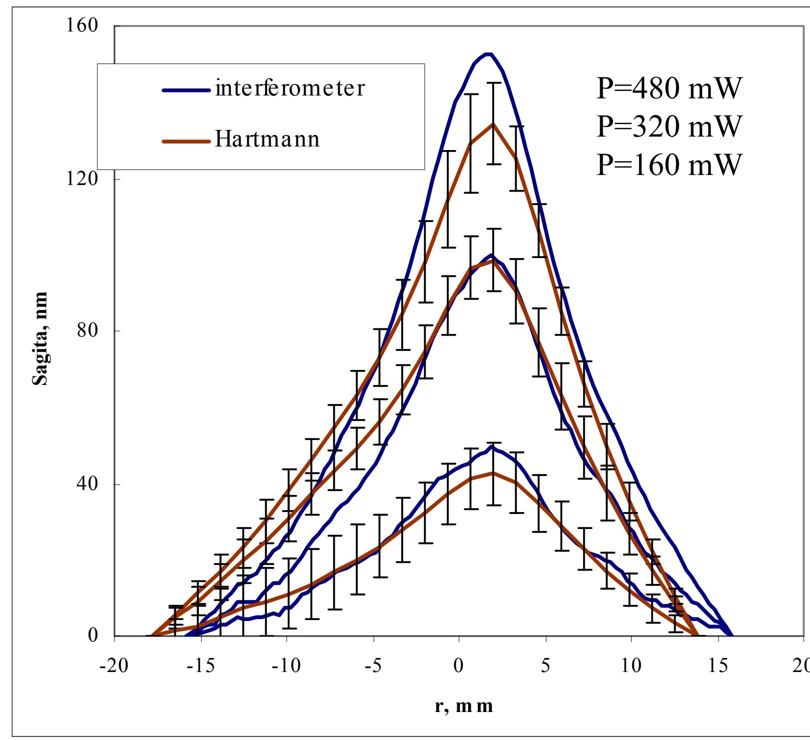
Scheme of Linear Scanning Hartmann Sensor

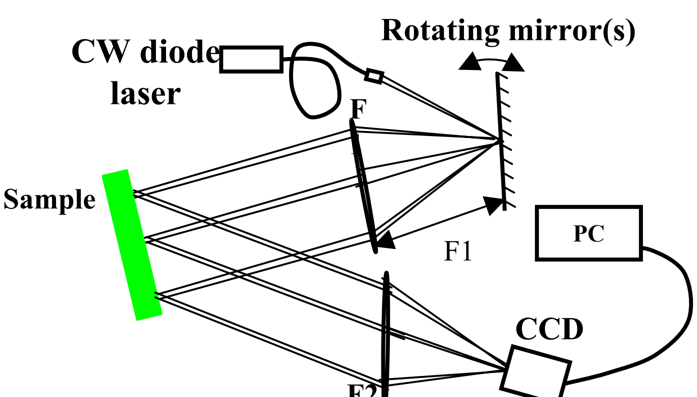


Wavefront distribution when a sample made of BK7 glass was heated by a CO_2 laser beam with different power

Next Steps







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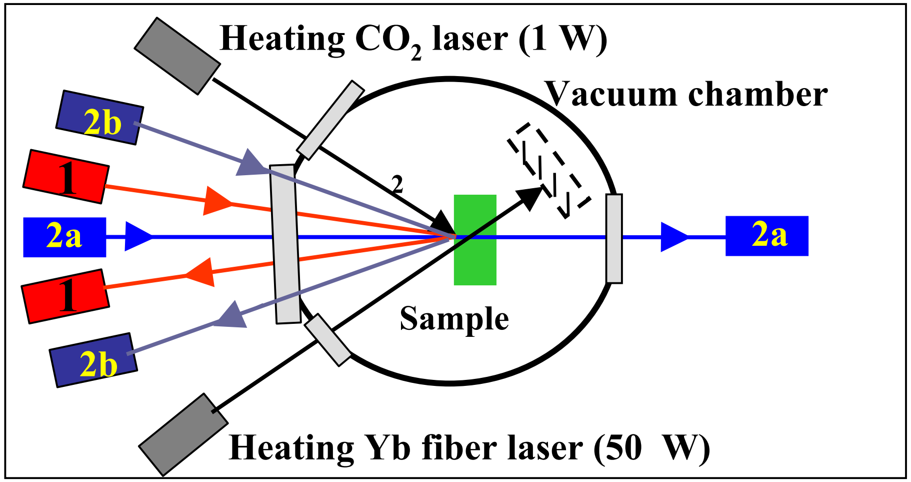
Separation of volume and surface distortions by simultaneous measurements using several techniques



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

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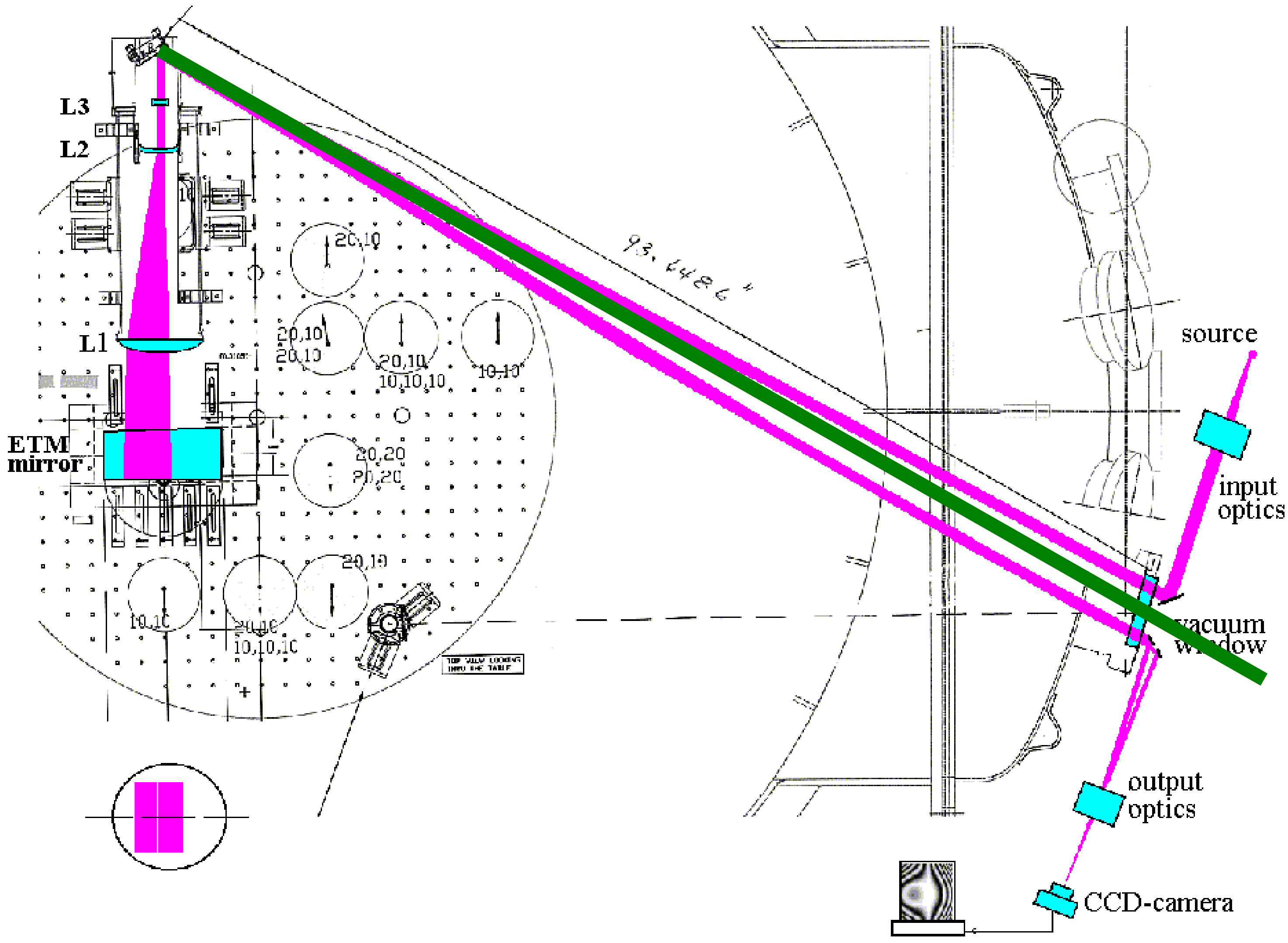
How to install WLISMI in LIGO-I interferometer?



Future installation place

Conclusion

- **White-light phase-modulated interferometer (WLPMI) for preliminary control of large aperture optical components was designed, implemented and used in a variety of measurements**

- **"White light" *in situ* measurement interferometer (WLISMI) for remote control of optical components was created and tested in several experiments**

- **Combination of several techniques to separate volume and surface distortions of large aperture optical components was proposed for *in situ* measurement**

- **Version of WLISMI was developed for in situ characterization of LIGO ETM. Instrument is ready to install at LLO**