Development of New Diagnostic Techniques for Preliminary and in Situ Characterization of Advanced LIGO Optical Components

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IAP-UF research program has 3 major components:

- Development of *in situ* diagnostic techniques for measuring heating- and contamination-induced distortion of optical components in AdL
    - Investigations of thermal effects simulating AdL conditions

- Investigation of high power, transient effects in Faraday isolators and consequences for AdL

  ⇒ manufacture and certify Faraday isolators for AdL

- Upgrade of 250 mm aperture white light phase modulated interferometer for improved stability/operation

Advanced LIGO

180 W input powers:

- **thermal effects in Core Optics during operation**

⇒ 830 kW stored power in arm cavities (7.3 kW/cm^2)

⇒ up to 1.6 W absorbed power in sapphire test masses

⇒ contamination a concern

- **Needed:**

  ⇒*in situ*, real time techniques for spatially-resolved diagnostics

  ⇒ studies of core optics heating

- **thermal effects in Input Optics**

⇒ Faraday isolators subjected to ~ 150 W

⇒ transient effects during loss of lock --> transient bursts ~ 600 W

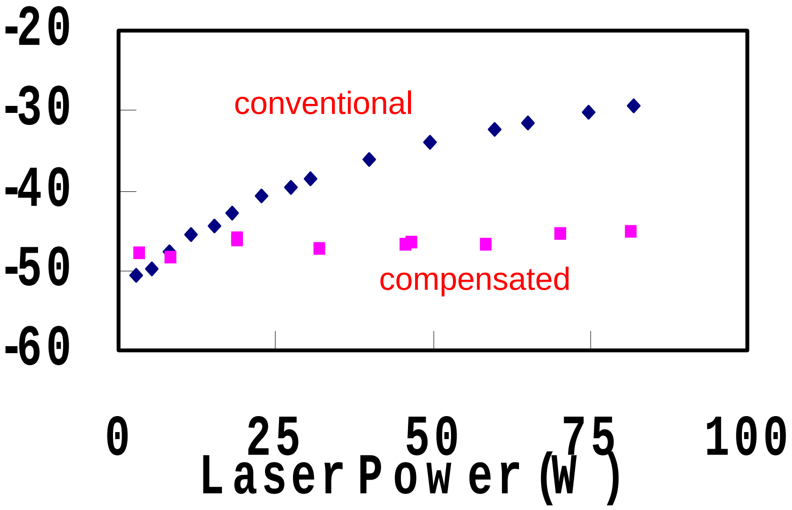
- **Needed:**

  ⇒ FI prototypes at 150 W

  ⇒ studies of transient performance

Prior NSF-sponsored results by IAP-UF collaboration

- development of Faraday rotators capable of improved high power performance
  - ⇒ demonstration of 45 dB isolation at 80 W



- high precision remote wavefront sensing methods based on nonlinear optics
  - ⇒ prototype nonlinear single channel Hartmann sensor capable of λ/3000 resolution

- white light interferometer for large aperture optics wavefront characterization
  - ⇒ RMS λ/1000 accuracy
  - ⇒ 60 x 80 mm area

12 archival journal publications acknowledging NSF support

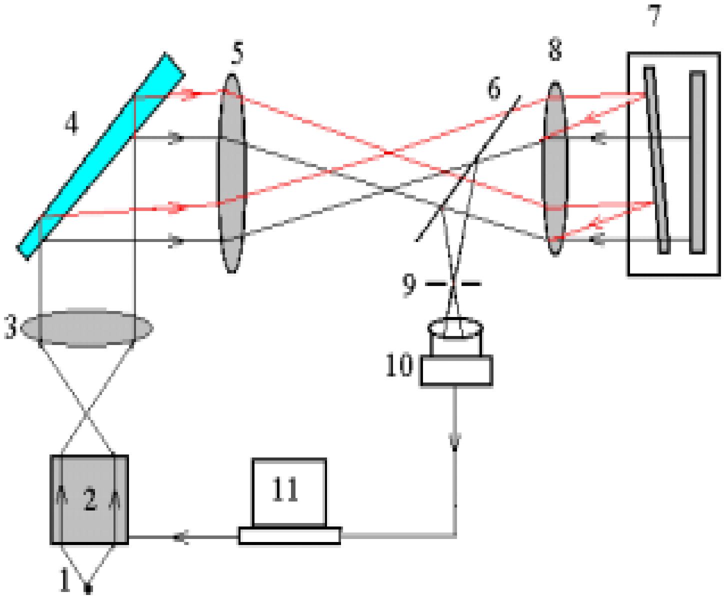
I. In-situ Diagnostics for Advanced LIGO Core Optics

- prototype remote sensing methods for spatially resolving wavefront deformations
  - ⇒ simulations of heating due to coating absorption, bulk absorption, and surface contamination
  - ⇒ complementary suite of techniques for high resolution (λ/1000) techniques

Remote sensing of individual test masses can provide an ‘alarm’ for potential contamination issues

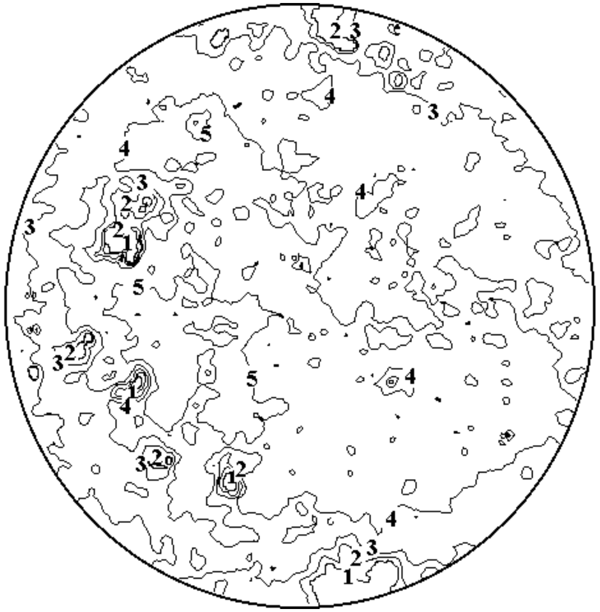
Ia. White light phase-modulated interferometer for *in situ* measurements of optical thickness

- phase modulation provided by external FP interferometer
- λ/200 sensitivity at 2.5 m distance
- deliverables: λ/1000 over 100 mm aperture, remote operation



diameter - 40 mm
thickness - 10 mm

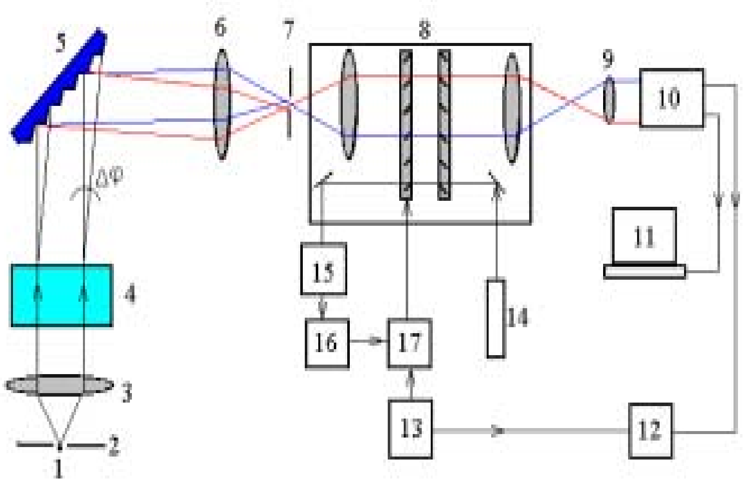
	nm
1	-11.6
2	- 5.0
3	+1.6
4	+ 8.3
5	+15.0
6	+21.6

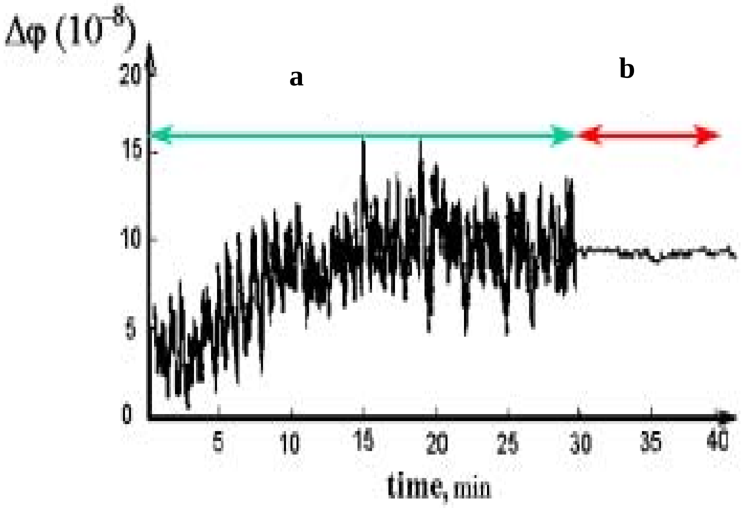


Personnel - IAP: I. Kozhevatov, N. Cheragin, A. Sergeev, technician

Ib. Spectral methods for *in situ* measurements of wavefront distortions

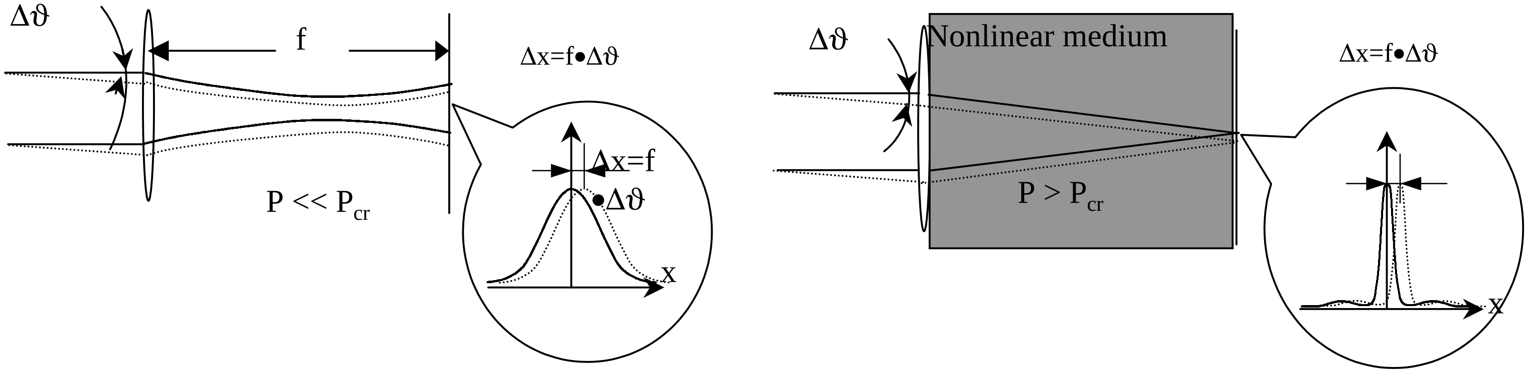
- wave front distortions converted to ‘spectral shifts’ using diffractive element
- wavelength stability of illuminating source essential
- deliverables: λ/1000 over 100 mm aperture, remote operation



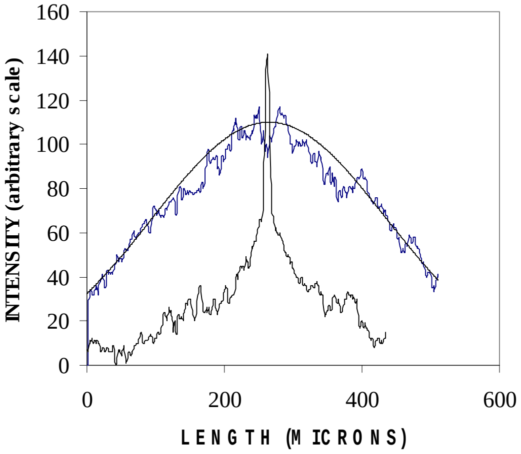


Personnel - IAP: I. Kozhevatov, N. Cheragin, A.Mal’shakov, technician

Ic. Nonlinear Hartmann Sensor



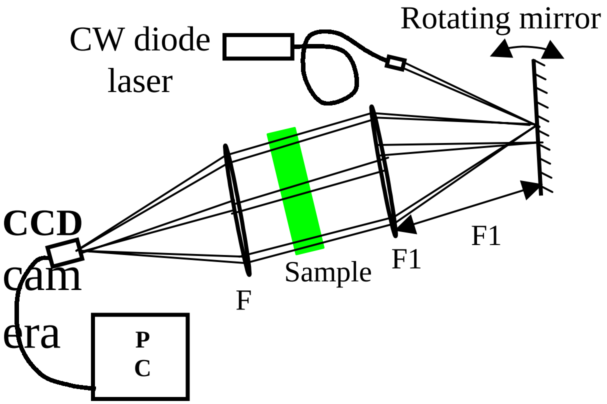
- **beam centroid location improved ~ 50x via nonlinear self-focusing**
- **single channel, λ/3000 sensitivity demonstrated**
- **deliverables: scanning, remote operation, 100 mm aperture**

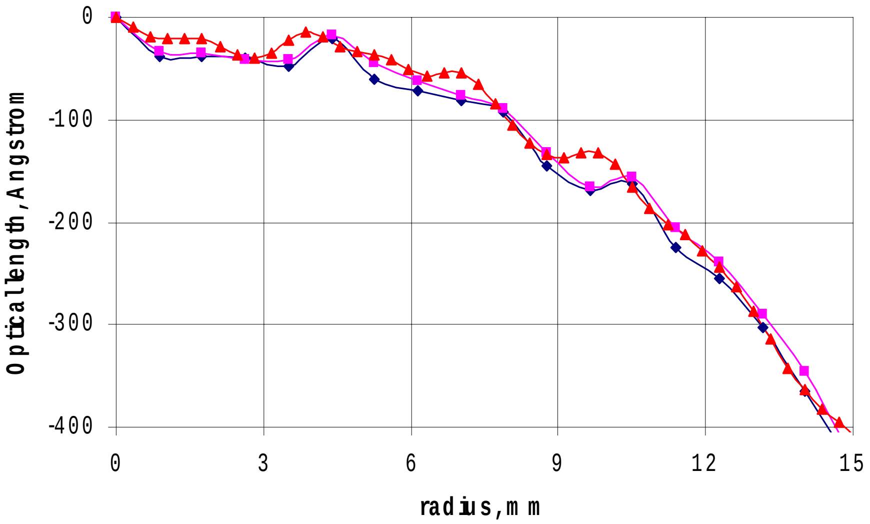


Personnel - IAP: A. Poteomkin, E. Khazanov, A. Mal’shakov
E. Katin, A. Sergeev, technician

Id. Linear Scanning Hartmann Sensor

- novel implementation of Hartmann scanner using Fourier domain techniques
- λ/500 precision demonstrated in lab
- deliverables: λ/1000 over 100 mm aperture

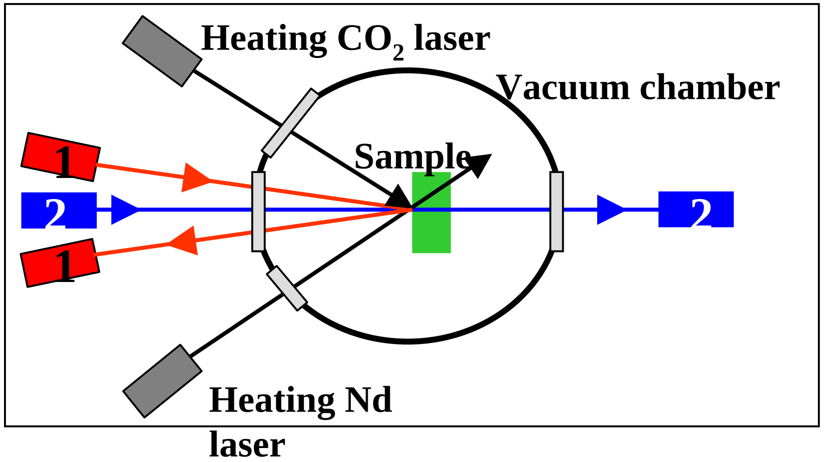




Personnel - IAP: A. Poteomkin, N. Andreev, A. Mal'shakov, E. Katin, technician

Ie. Simulation of Core Optics Heating

- implementation of diagnostics in vacuum environment
- bulk absorption (0.25 - 1.1 W) using 2nd harmonic 50 W Nd:YAG laser + high absorption fused silica
- coating absorption (80 - 500 mW) using CO_2 laser
- surface contamination using local irradiation
- modeling using Hello-Vinet, finite element



Personnel - IAP: all of the above; UF- D. Reitze, M. Rakhmanov

II. High power effect in Faraday isolators

- bulk absorption high compared to other transparent optic elements
- self-induced birefringence superimposed circular birefringence (Faraday effect) changes depolarization
- depolarization leads to beam quality deterioration and reduction in isolation ratio
- polarization modulation --> amplitude modulation

	Forward power, W	backward power, W	total power, W	Time scale
Normal operation. Steady-state locked regime .	125	5	130	∞
Regime A. Power stored in the interferometer emitted into both bright and dark ports.	125	125 - 500	250 - 625	ms
Regime B. Unlocked steady-state regime after power stored in the interferometer has rung down.	125	125	250	s - min
Regime C. Transient regime during lock acquisition.	0 - 125	0 - 125	0 – 250	ms - s

II. High power effect in Faraday isolators

- **Deliverables**
  - ⇒ **simulation of transient states to assess effects on FI performance**
  - ⇒ **quantitative investigations of transient loading of FIs**
  - ⇒ **development of FI performance specifications for AdL**
  - ⇒ **development, characterization of FI for AdL**

Personnel - IAP: Efim Khazanov, O. Palashov, N. Andreev, A. Mal’shakov
technician
UF- D. Reitze, G. Mueller, graduate student

III. Large Aperture White Light Phase-Modulated Interferometer for Core Optics Characterization

- PM has advantages over traditional Fizeau methods
  - ⇒ tuning of illumination
    - ⇒coated and uncoated optics
  - ⇒ no movement of sample or reference
- λ/1000 precision demonstrated in lab
- deliverables: λ/1000 over 250 mm aperture

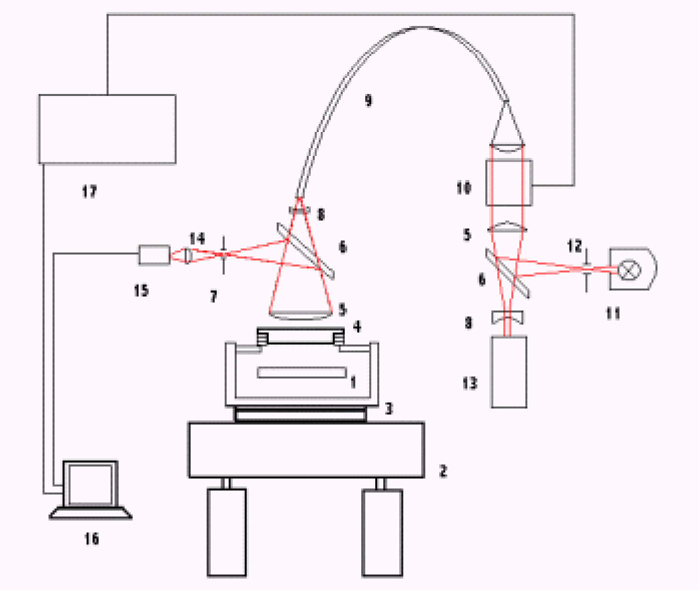


Fig.1. Scheme of interferometer.
Here: 1 - sample; 2 - stabilized optical table; 3 - damping mount; 4 - reference plate; 5 - collimating lens; 6 - beam-splitters; 7 - spatial filter; 8 -lenses; 9 - fiber bundle; 10 - illuminating light spectral modulator; 11 - white light source; 12 - aperture; 13 - frequency stabilized He-Ne laser; 14 -projection lens; 15 - CCD-camera; 16 - computer; 17 - synchronization and control block

Personnel - IAP: O. Kulagin, technician

Collaboration Plan

- **IAP PI: Alexander Sergeev**
- **IAP Technical Liaison: Efim Khazanov**
- **UF Technical Liaison: Dave Reitze**

•MOUs will be signed between UF and IAP for:

- **Task I (in situ diagnostics and simulations) - takes place at IAP;**

⇒ IAP scientists come to UF for preliminary development of SLHS, NLHS

- **Task II (FI research) - takes place at IAP & UF, characterization at UF, LLO**
- **Task III (large aperture WLPMI) - takes place at IAP (possibility of moving to LLO,LHO when completed)**

- **Yearly visits of 2-3 months by 2-4 IAP scientists to UF, LLO for 100 W laser use**

  ⇒ since 1997, 4 visits by IAP scientists to UF for 2-3 months; 1 visit to LLO