ACIGA Status Report

Gingin High Power Test Facility

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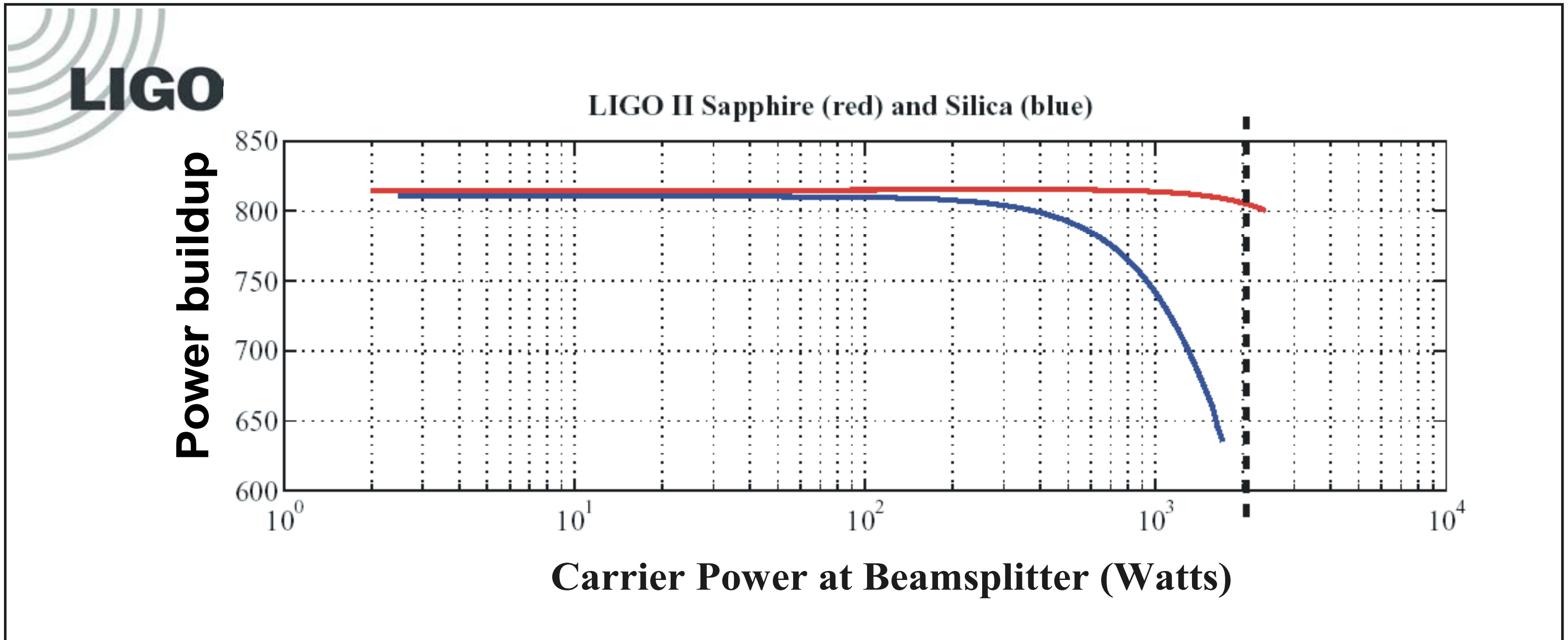
LSC, Livingston, March 2004
LIGO-G040067-00-Z

The problem

- 500 kW stored in arm cavities and ~ 2 kW in power-recycling cavity
- Power absorbed in mirror substrates and coatings
- Thermal gradient in mirror, distorts refractive index of substrate and mirror curvature
- Reduce interferometer sensitivity predicted, (degraded sideband power and buildup in the power-recycling cavity)



Courtesy of Ryan Lawrence and Dave Ottaway, MIT-LIGO

GINGIN HPTF TEST OBJECTIVES

VERIFICATION OF PREDICTED WAVEFRONT DISTORTION

Numerical modeling assumes that the thermo-elastic model** is correct

- no experimental proof
- assumes isotropic test mass rather than sapphire

** P. Hello and J-Y Vinet, J. Phys.France 51 (1990) 1267-1282

DEMONSTRATION OF HIGH POWER LASER TECHNOLOGY

DEVELOPMENT AND DEMONSTRATION OF WAVEFRONT SENSORS:
HARTMANN WAVEFRONT SENSOR

Independent sensor of the wavefront distortion required

- must not interfere with the eigenmode of the optical cavities
- Hartmann sensor may have sufficient sensitivity and is robust.

Contents

- Objectives and design of HPTF tests
- Gingin High Power Test Facility (HPTF)
- Laser development
- Hartmann wavefront sensors

HPTF Test Objectives

- Measure optical distortions in ITM substrate and coatings, validate MELODY

  Test 1: Substrate absorption as in Adv LIGO

  Test 2: High Reflectivity ITM coating absorption

  Test 3: Power recycled FP with unstable recycling cavity at low power as in AdvL

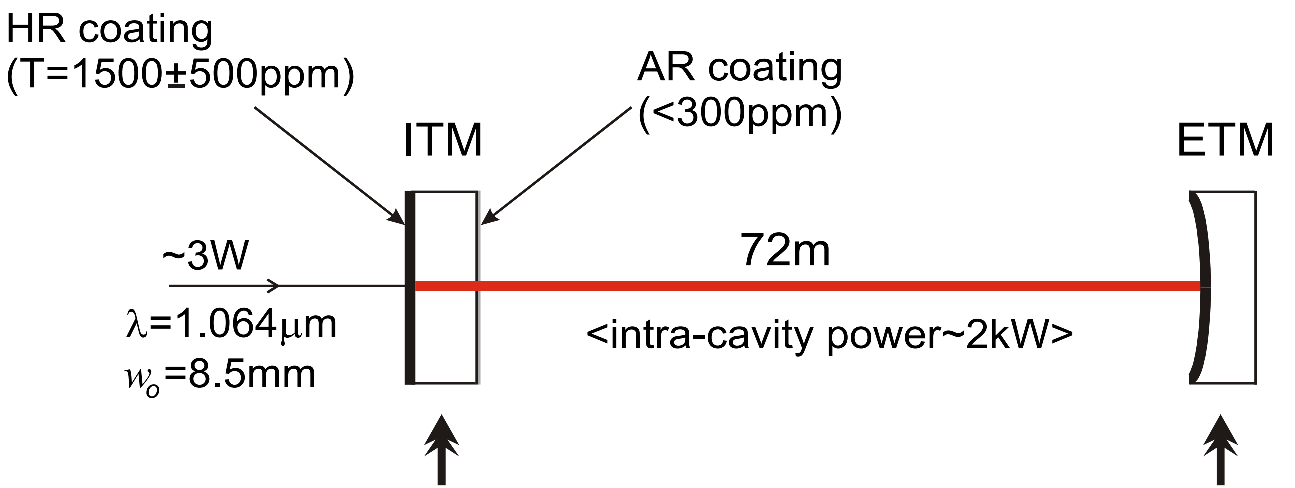
- Test wavefront sensors

- Test actuators for control in cavity

- Investigate control of power recycled FP cavities.

HPTF TEST 1: Measure wavefront distortion due to absorption in **test mass substrate**

- Use rear surface ITM. Measure degradation of finesse with increasing stored power
- Use Hartmann wavefront sensor to characterize distortion.

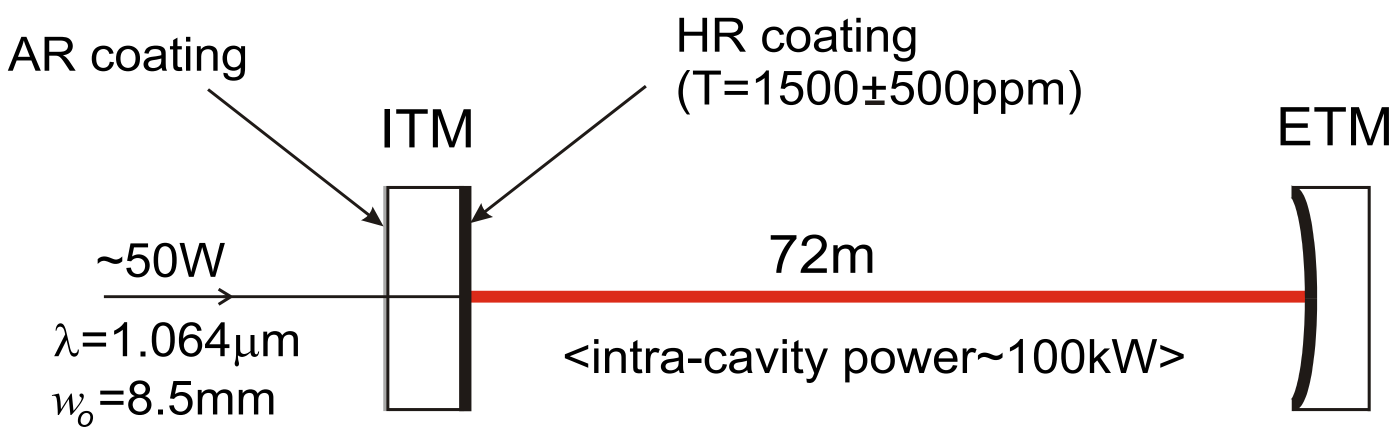


Input Test Mass (ITM)
Diameter: 100mm
Thickness: 50mm
Material: Sapphire (*a*-axis)
flat

End Test Mass (ETM)
Diameter: 150mm
Thickness: 80mm
Material: Sapphire (*m*-axis)
Radius of Curvature: 750±100m
HR coating: T<50ppm

HPTF TEST 2: Measure wavefront distortion due to **absorption in mirror coating**

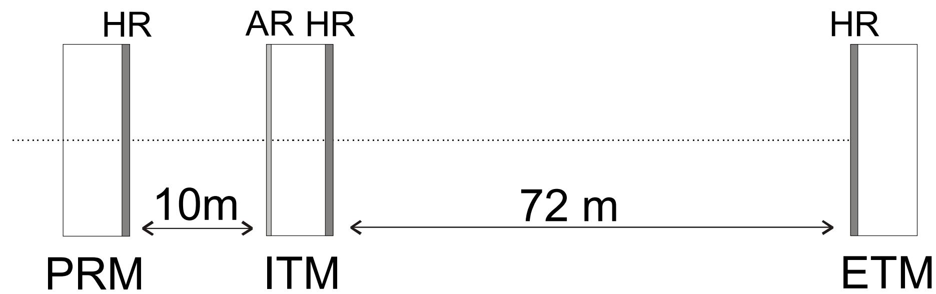
- Reverse ITM
- Measure degradation of finesse with increasing stored power
- Use Hartmann wavefront sensor to characterize distortion.



- Use same optics, reversing ITM.
- Higher input power (~50W).
- Higher intra-cavity power (~100kW).

HPTF test #3

Coupled cavity test:



Recycling cavity unstable at low power as in LIGO 1, and AdL
Radii of curvature: PRM: 5.8 km, ITM: 4.0 km, ETM: 720m

Transmittances: PRM ~ 5%, ITM ~ 8%

Input power = 100 W → recycling cavity power ≈ 4 kW, arm cavity power ≈ 200 kW

At above powers: recycling cavity stable, and same eigenmode as FP

Spot radius similar to test 1, w_0 = 0.9cm

Detailed modeling in progress

HPTF Facility

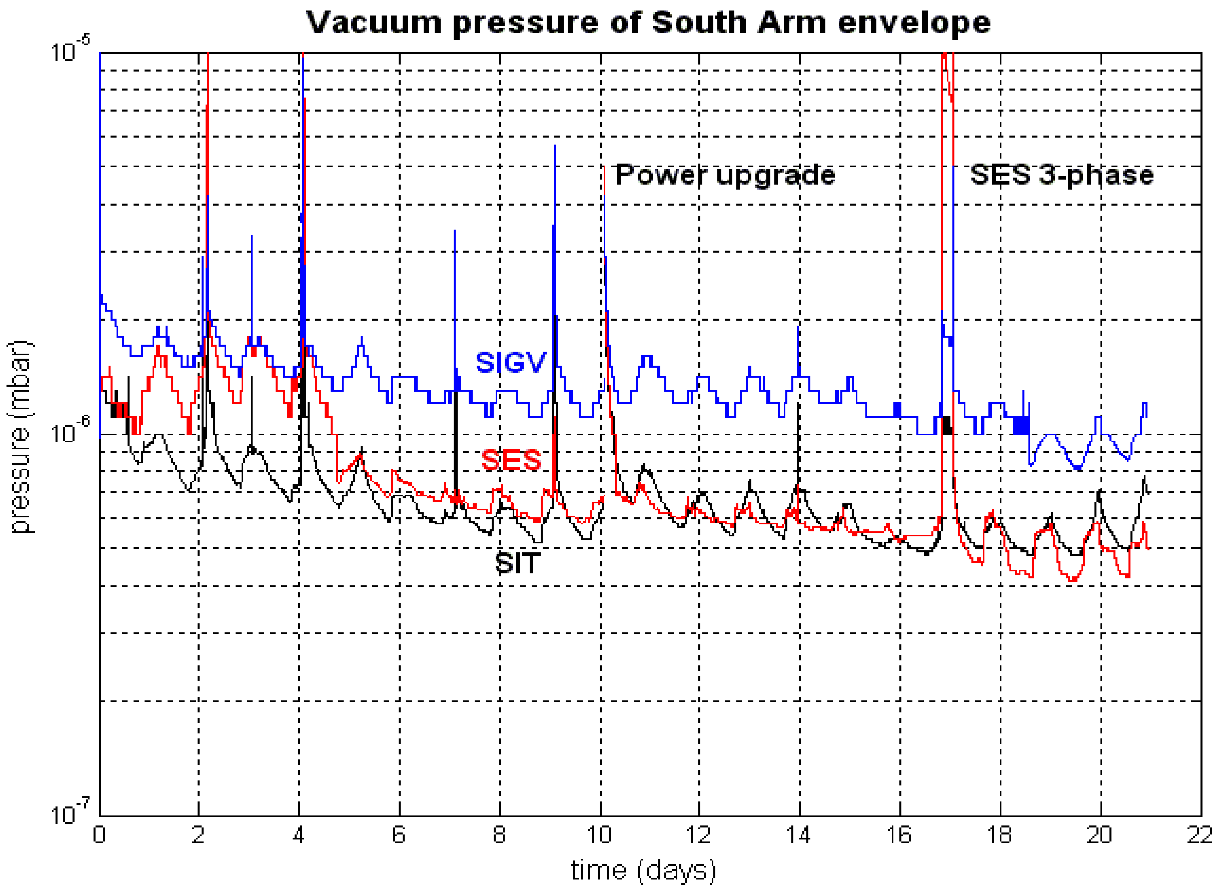
- Vacuum envelope
  - 80 m long vacuum envelope for suspended cavity.
- The Laser Room
  - Class 100 (better than) clean room.
- The Central lab and South-End-Station
  - ~Class 1000 clean room.


BAILEY

Pressure

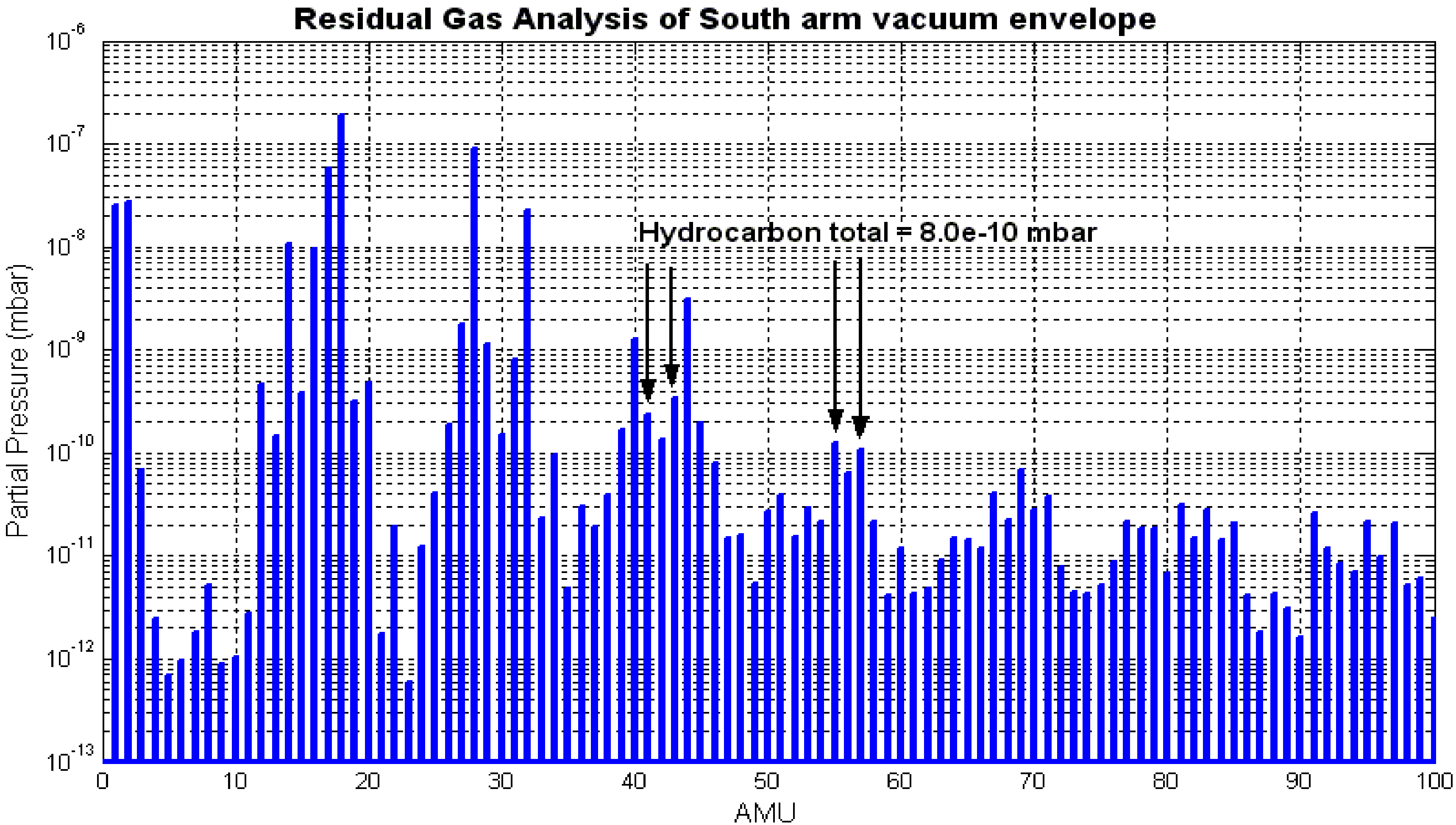
- Vacuum pumps running reliably, 24/7
- Hydrocarbon contamination:

  8e-10 mbar
- Vacuum system not baked



Michael Thomas and Conor Mow-Lowry

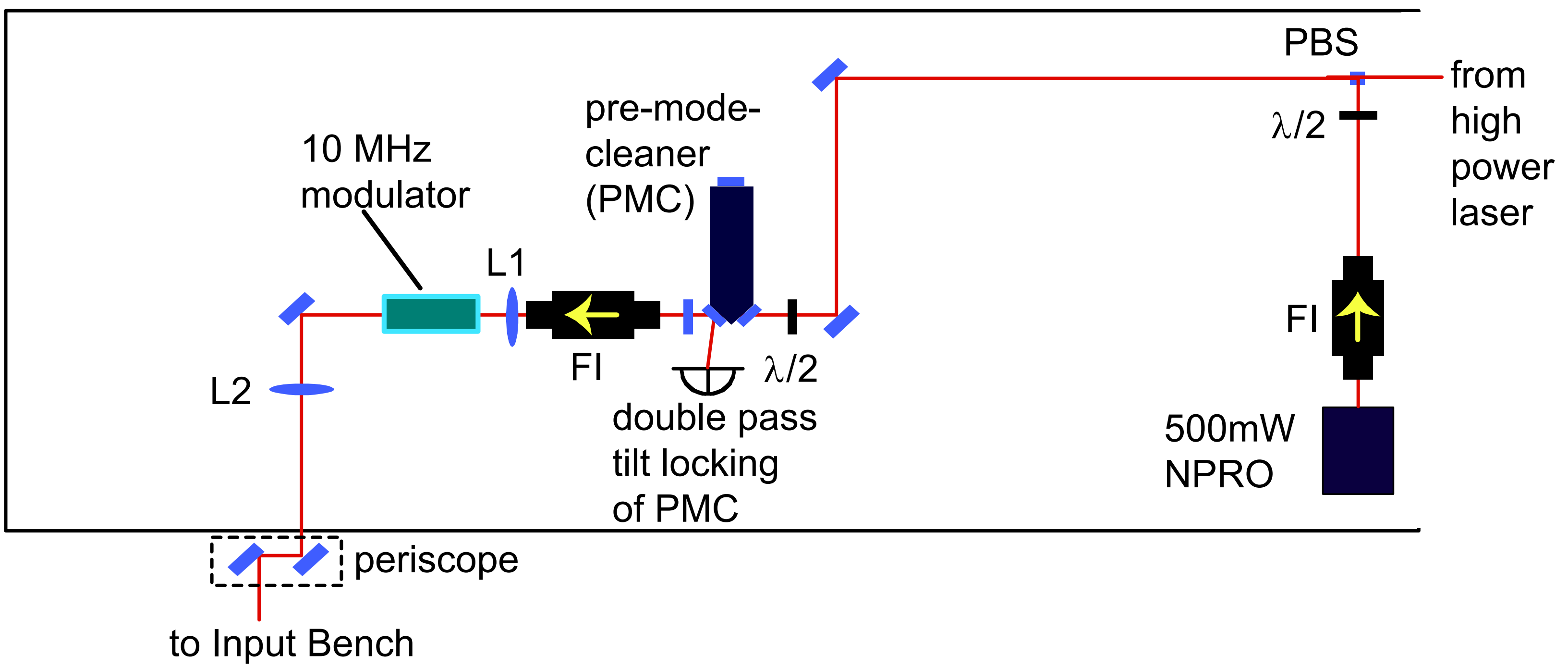
Vacuum RGA



Michael Thomas and Conor Mow-Lowry

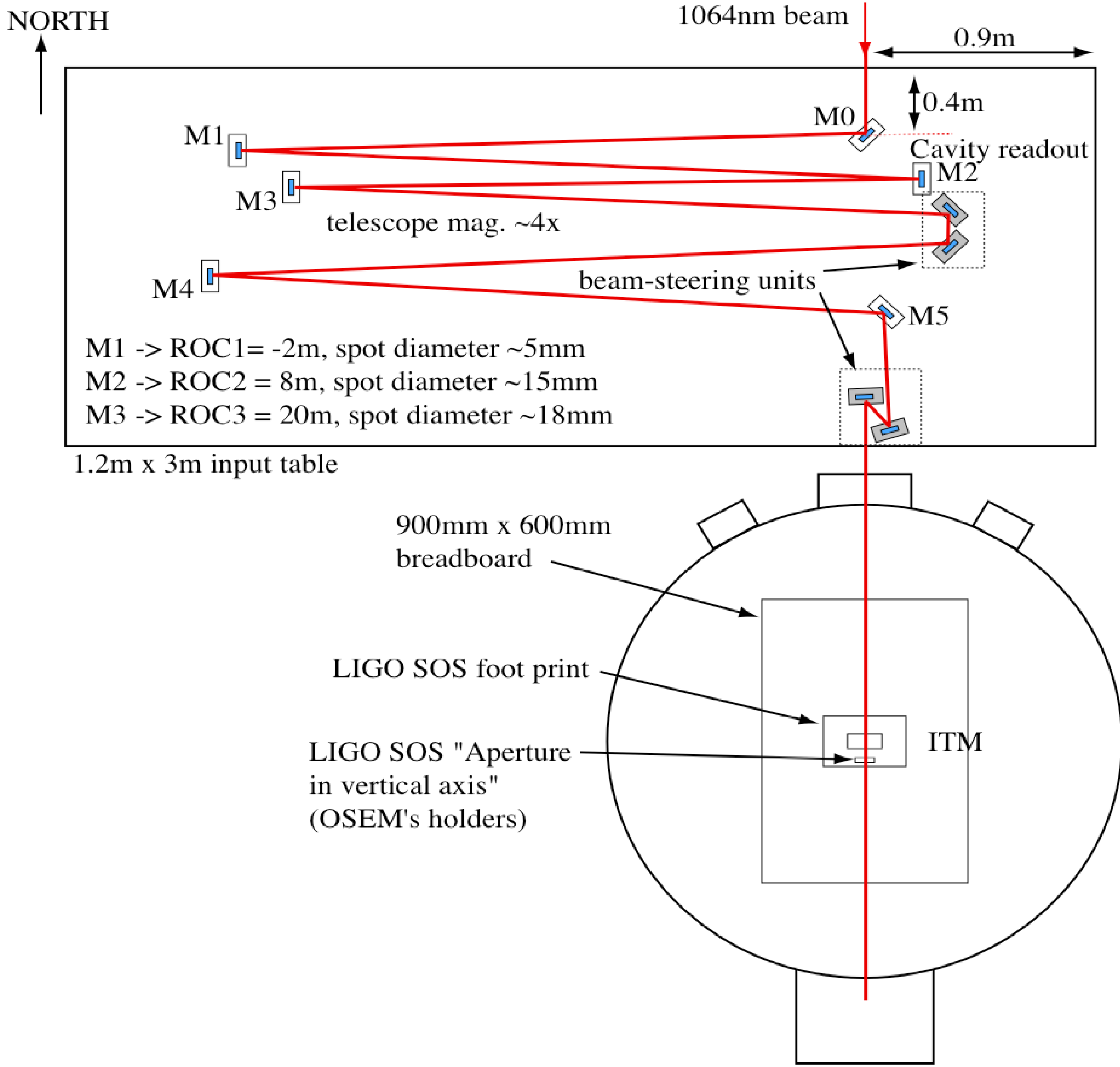
Laser Room

- Preliminary cavity alignment with 500mW NPRO
- PMC transmission (F=200), 85%
- Faraday Isolator(1&2), T=91%



Input Bench

- Mode-matching
- Cavity locking readout, using 10MHz modulation.
- Initially no auto-alignment.



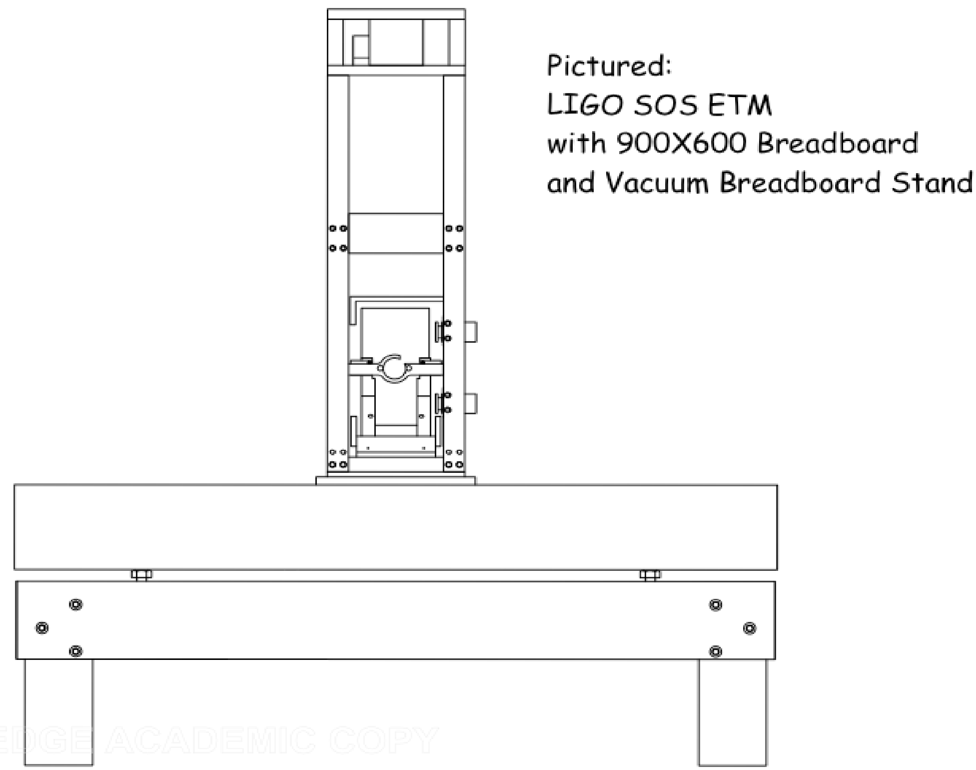
Initial Suspended Cavity

- Using BK7 optics to initial try to
  lock the suspended cavity.

- LIGO SOS, placed on top
  of a 900mm x 600mm breadboa

- Breadboard leveled by 4 bolts,
  with no further isolation

- Replace BK7 optics by the Sapph
  once system is running reliably.



Drawing: Tim Slade

Initial lock

- BK7 Test Masses, R~99.8% (F~500).
- Use of 500mW NPRO, ~250mW incident on arm cavity.
- 10MHz PM sidebands used for locking.
- Laser locked to the arm cavity.
- LIGO SOS damping onto the TM.
- Remote DC control of TM position off-set.

Laser Development for HPTF

10 W laser

Injection-locked 10 W Nd:YAG production laser for HPTF (and TAMA).
Operational
See talk by D. Hosken

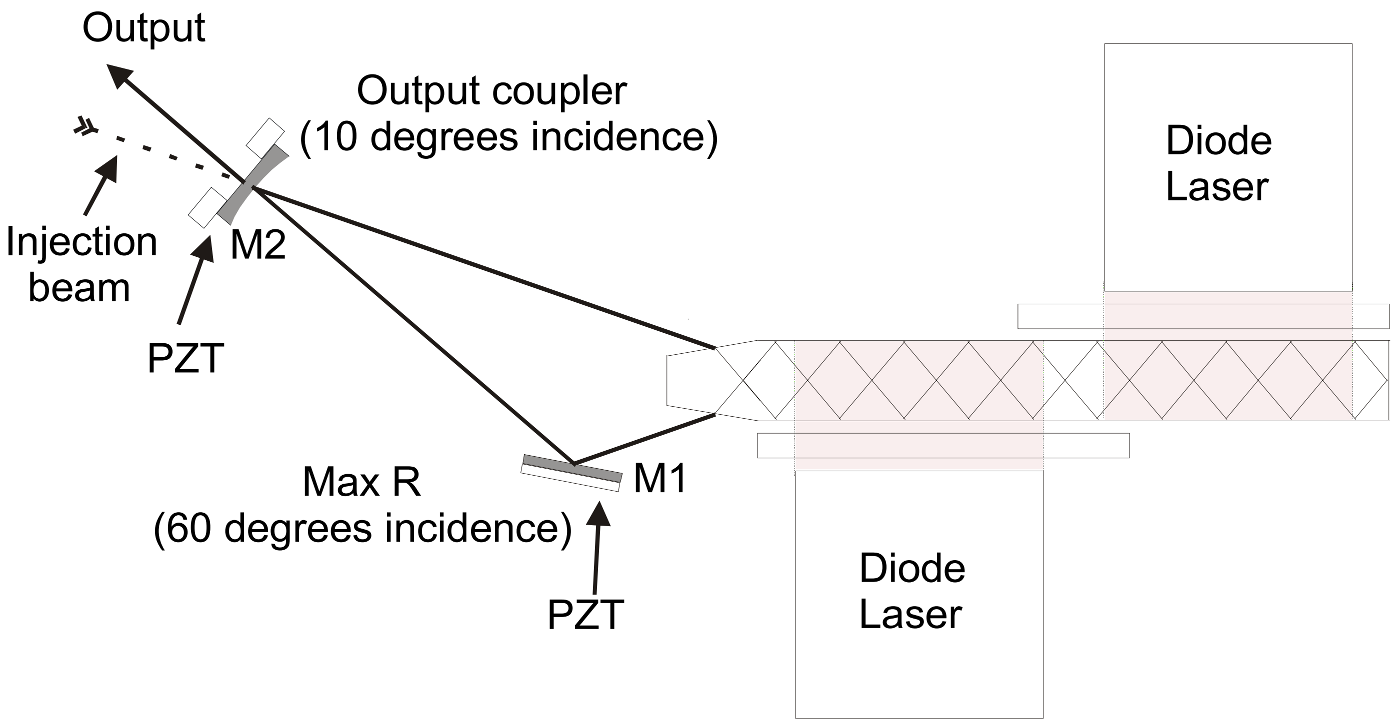
50 W laser

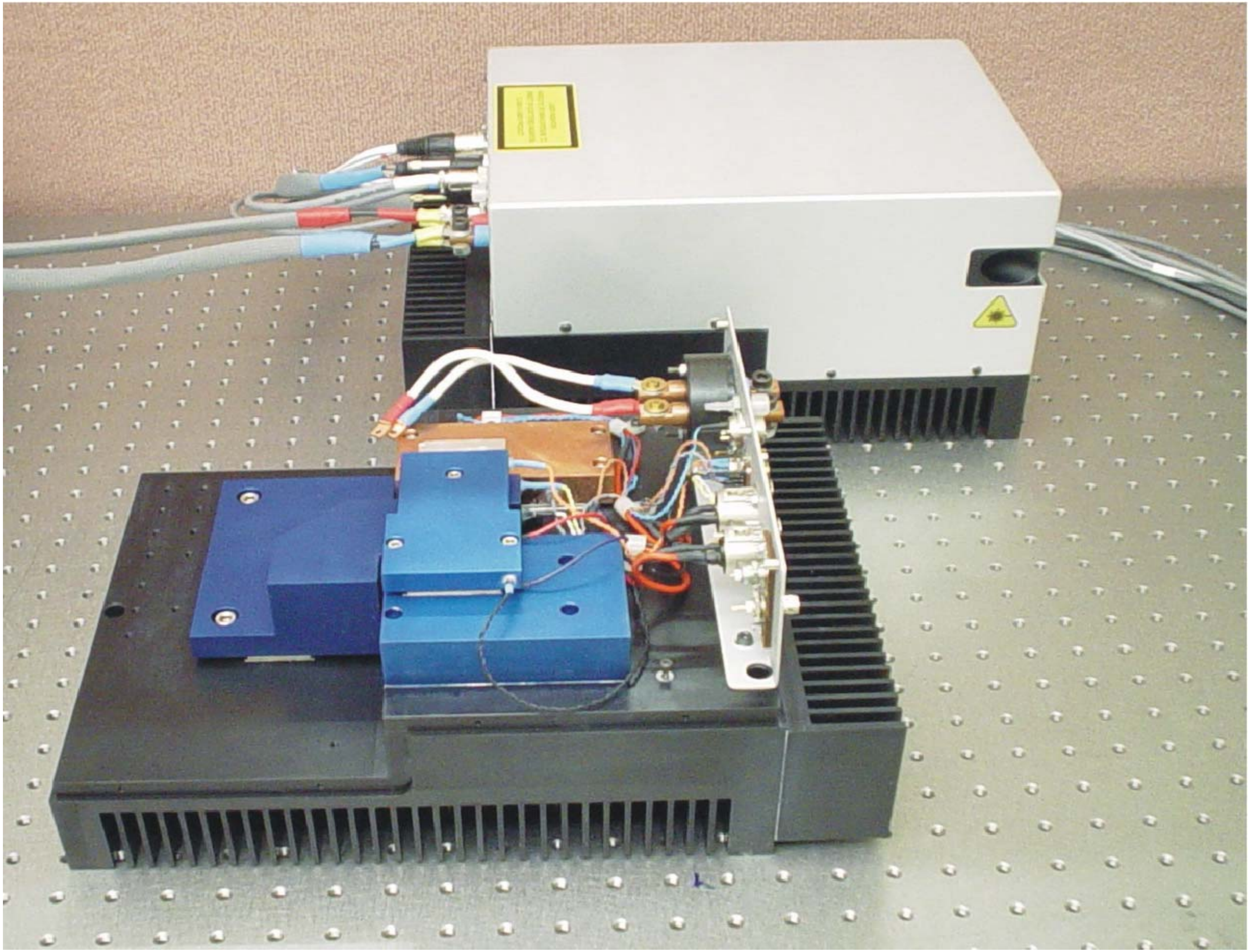
If required as backup, use first generation injection-locked, side-pumped, side-cooled unstable resonator laser.
Would need 2-3 months to deploy.

100 W class laser

New improved laser architecture for laser oscillator to 100W and beyond.
Designed to solve all problems of previous design
See talk by D. Mudge

10W laser resonator





1st Generation High Power Laser

As backup 50W laser for HPTF

NEW 100 W LASER

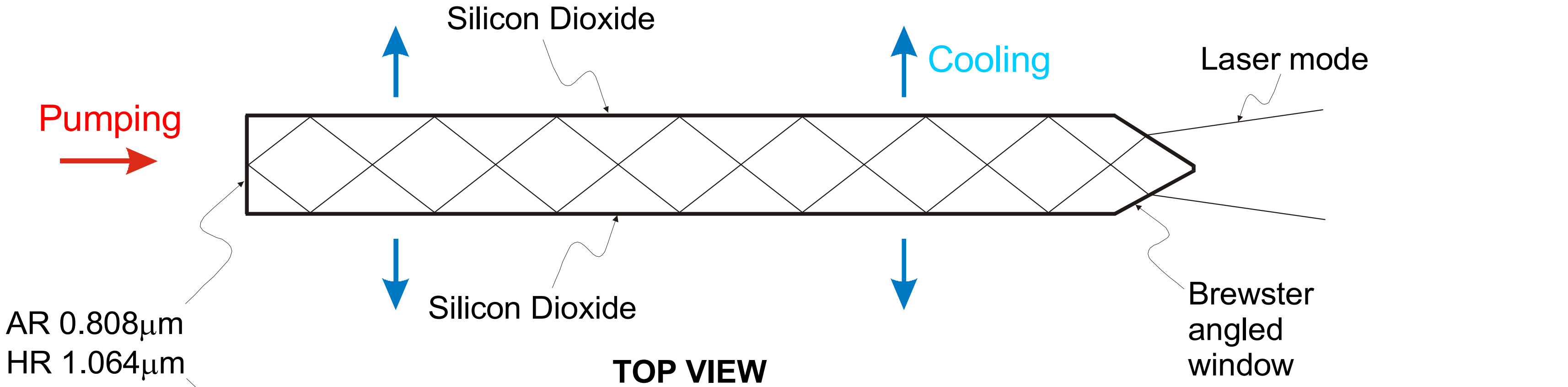
Extension of previous approach:

- Injection locked oscillator
- Unstable Resonator
- Zig-Zag slab

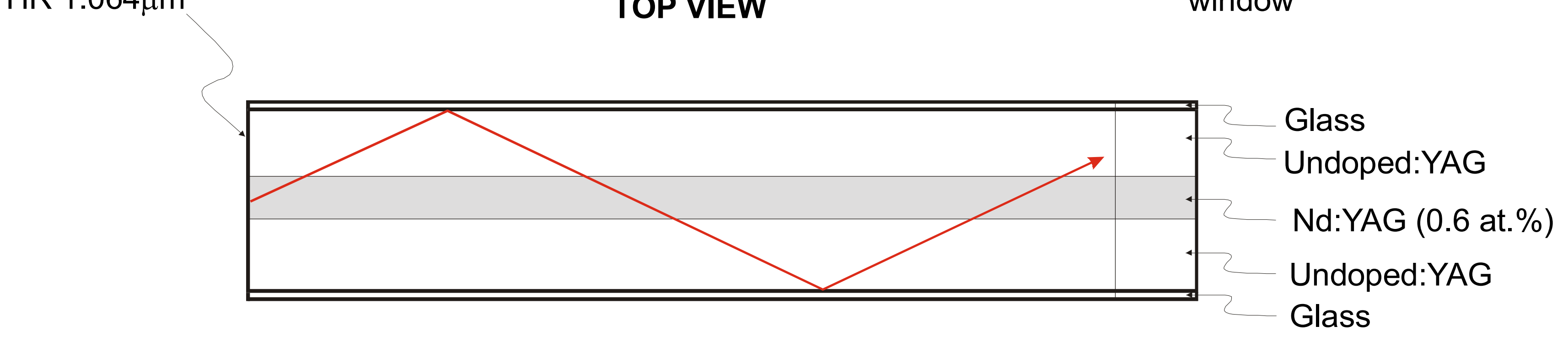
•New Features:

- End pumping
- Birefringence control by defined gain medium
- Improved pump uniformity across wavefront
- Robust
- Scalable to very high power

Composite end-pumped, side-cooled folded zigzag slab

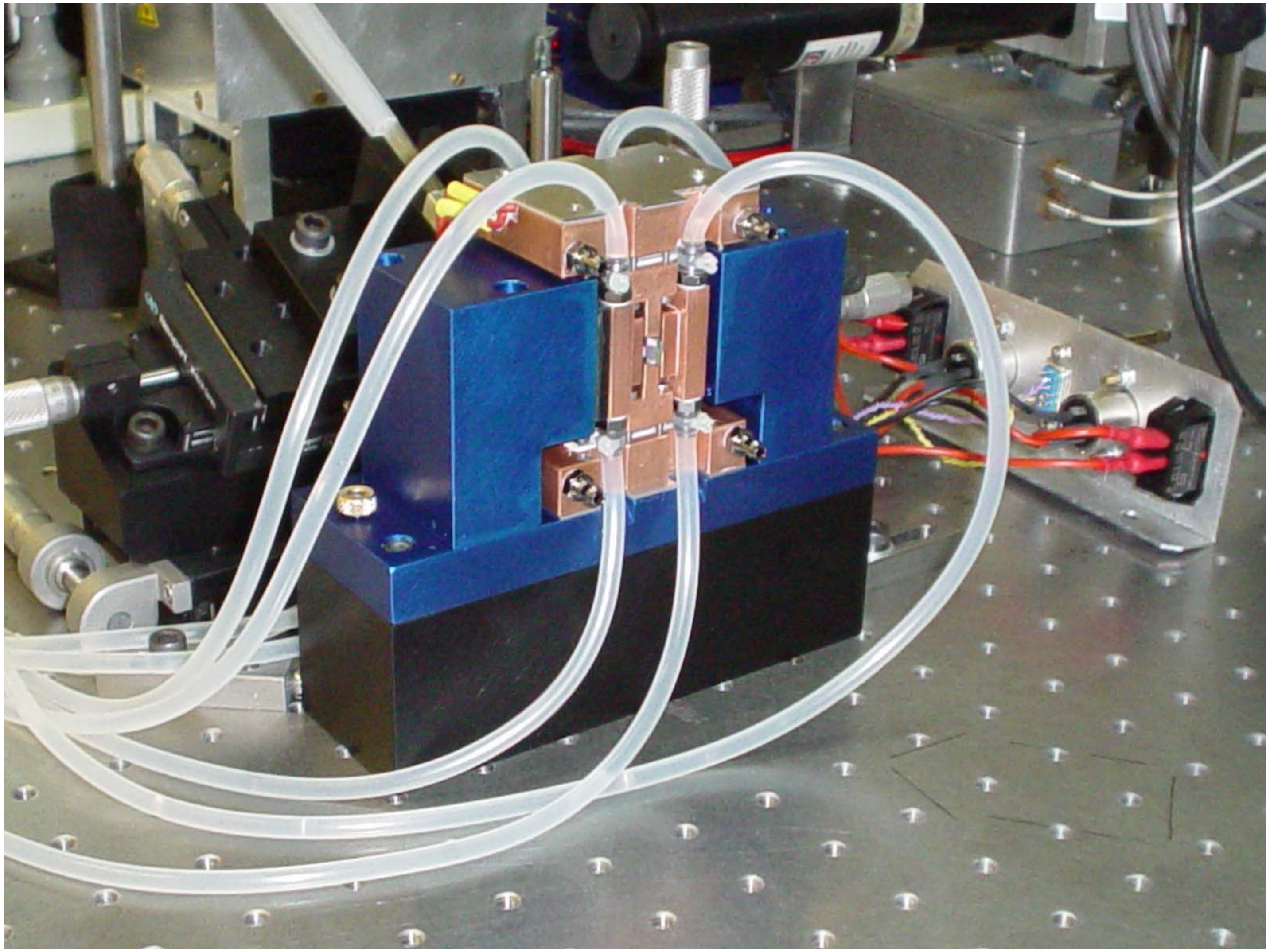


TOP VIEW



SIDE VIEW

New 100W Laser Head



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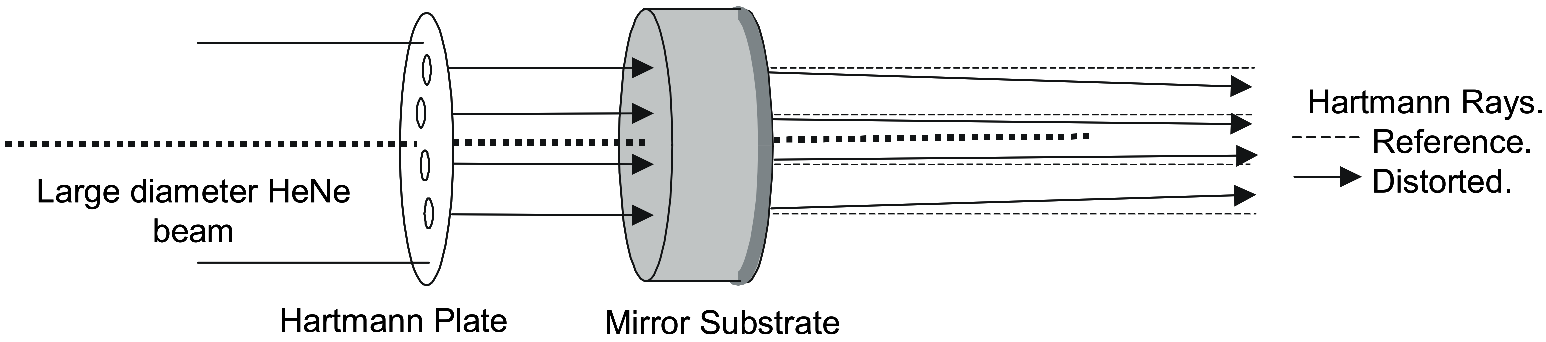
Hartmann wavefront sensor



- Distortion deflects rays from reference positions.
- Determine positions using CCD camera
- Transverse aberration of each ray is used to reconstruct the wavefront distortion.

Advantages

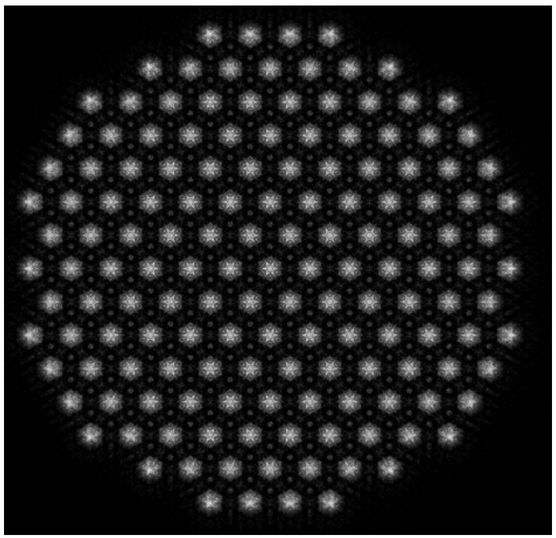
- Alignment much less critical than an interferometer.
- Can be configured as off-axis sensor in working interferometer.
- More sensitive than Shack-Hartmann (more precise centroid location).
- Our implementation gives absolute accuracy.

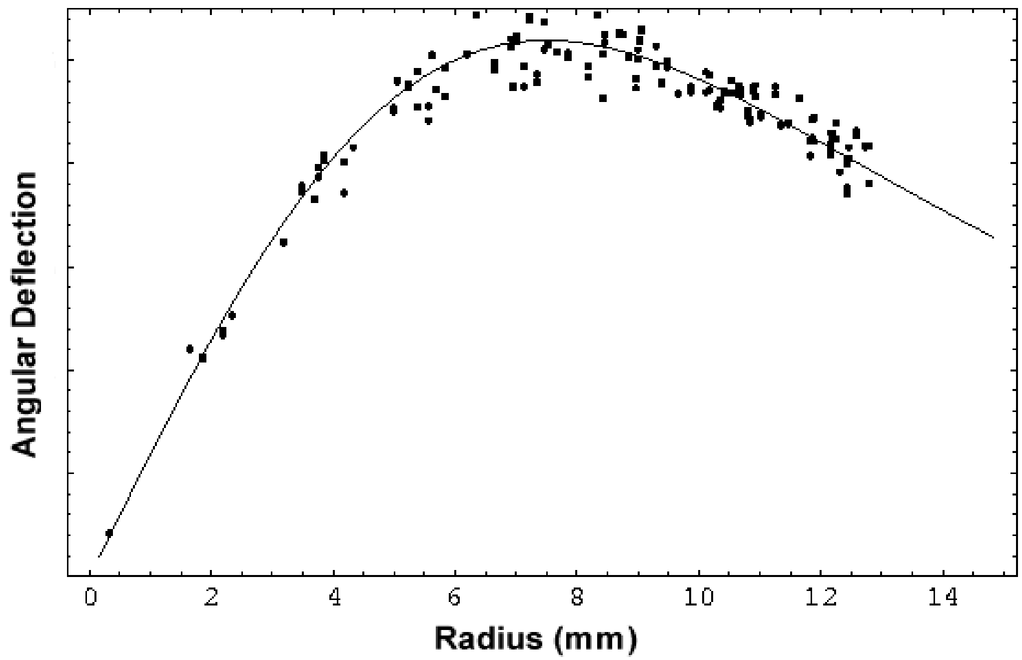
Issue

- Analysis is more complicated when sensor is rotated off the optical axis.

ZEMAX modeling of Hartmann sensor - preliminary

Introduced wavefront distortion predicted by Hello-Vinet into numerical model that used ZEMAX Physical Optics Propagation computer package.





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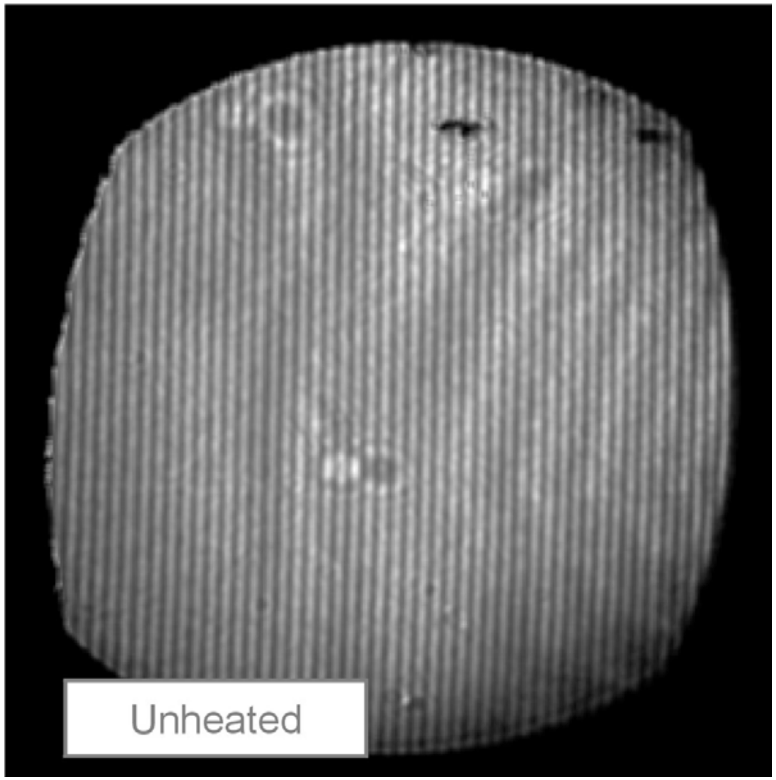
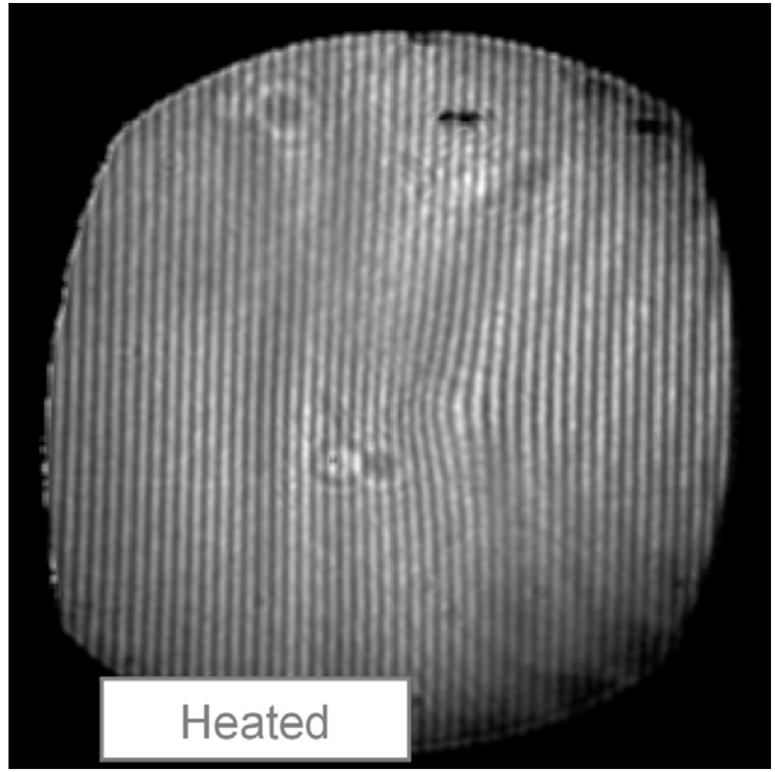
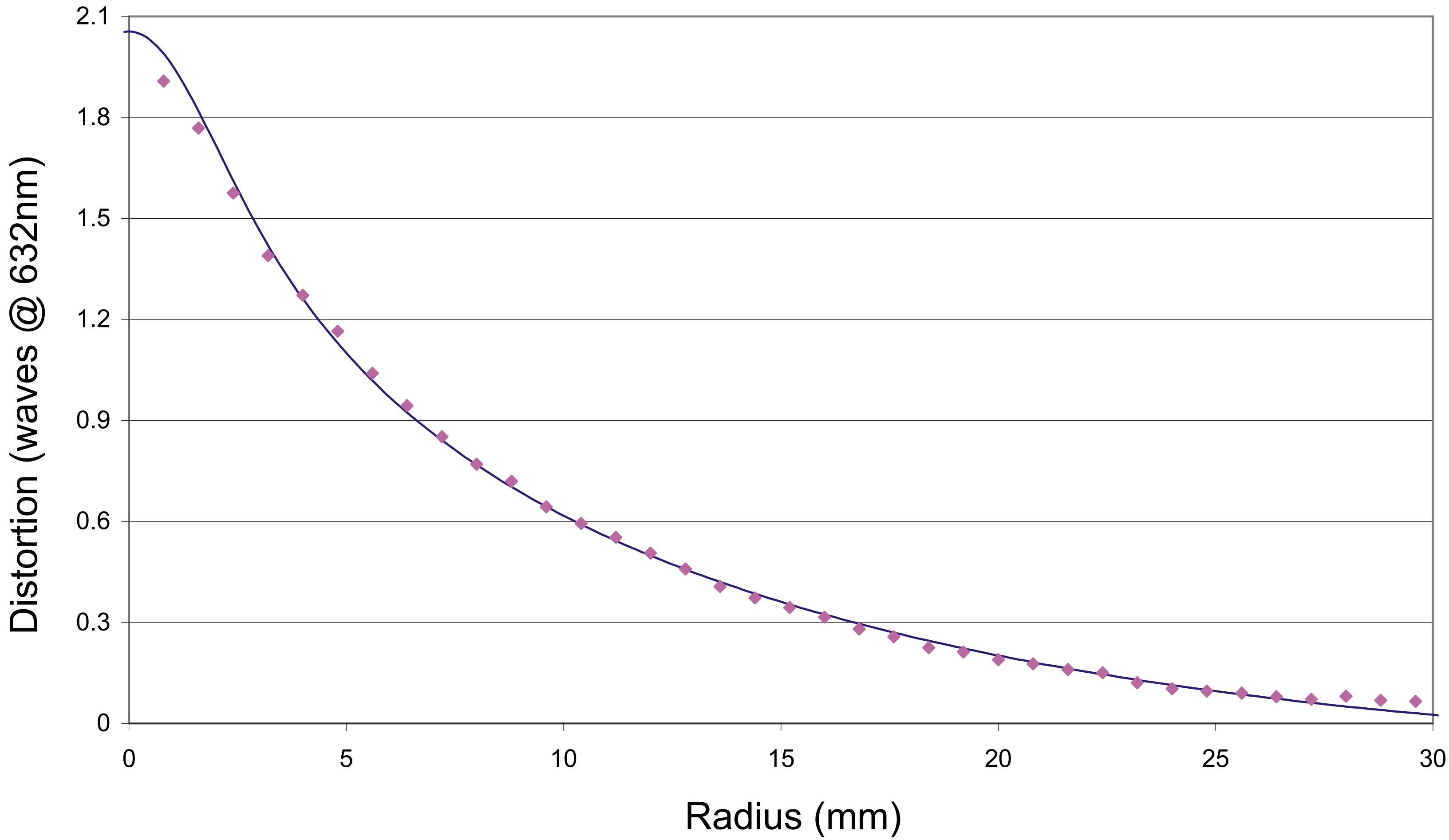
Measured interferogams





Measured wavefront distortion confirms predictions



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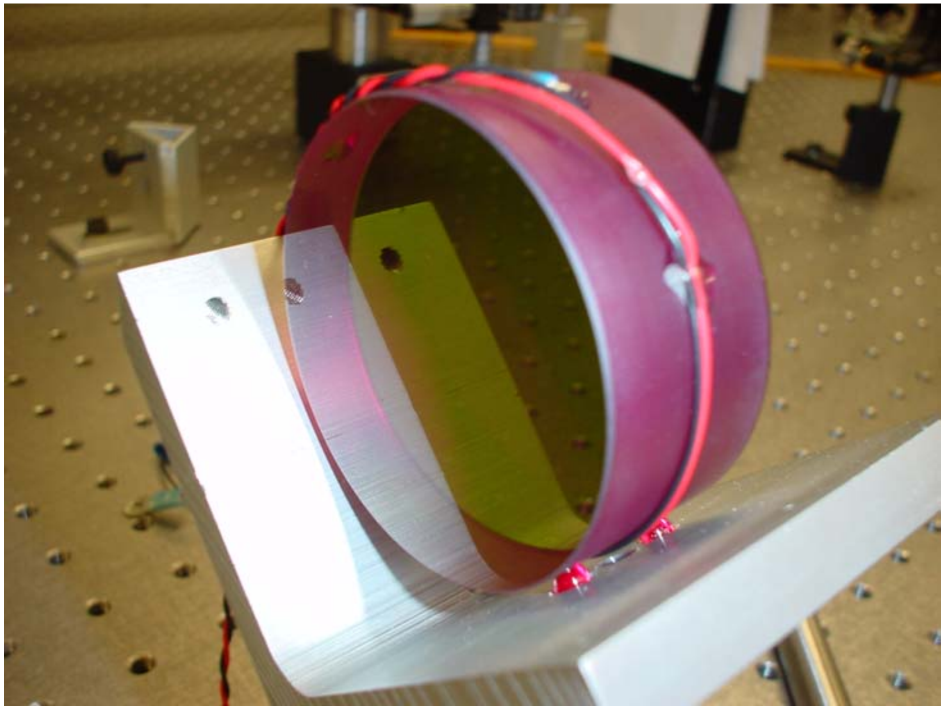
Glass test mass

• BG20 Filter glass from Schott

• Ideal for experiment, absorption (0.36% per mm) not too high (simulates constant flux throughout), not too low (distortion is large enough to be measurable).



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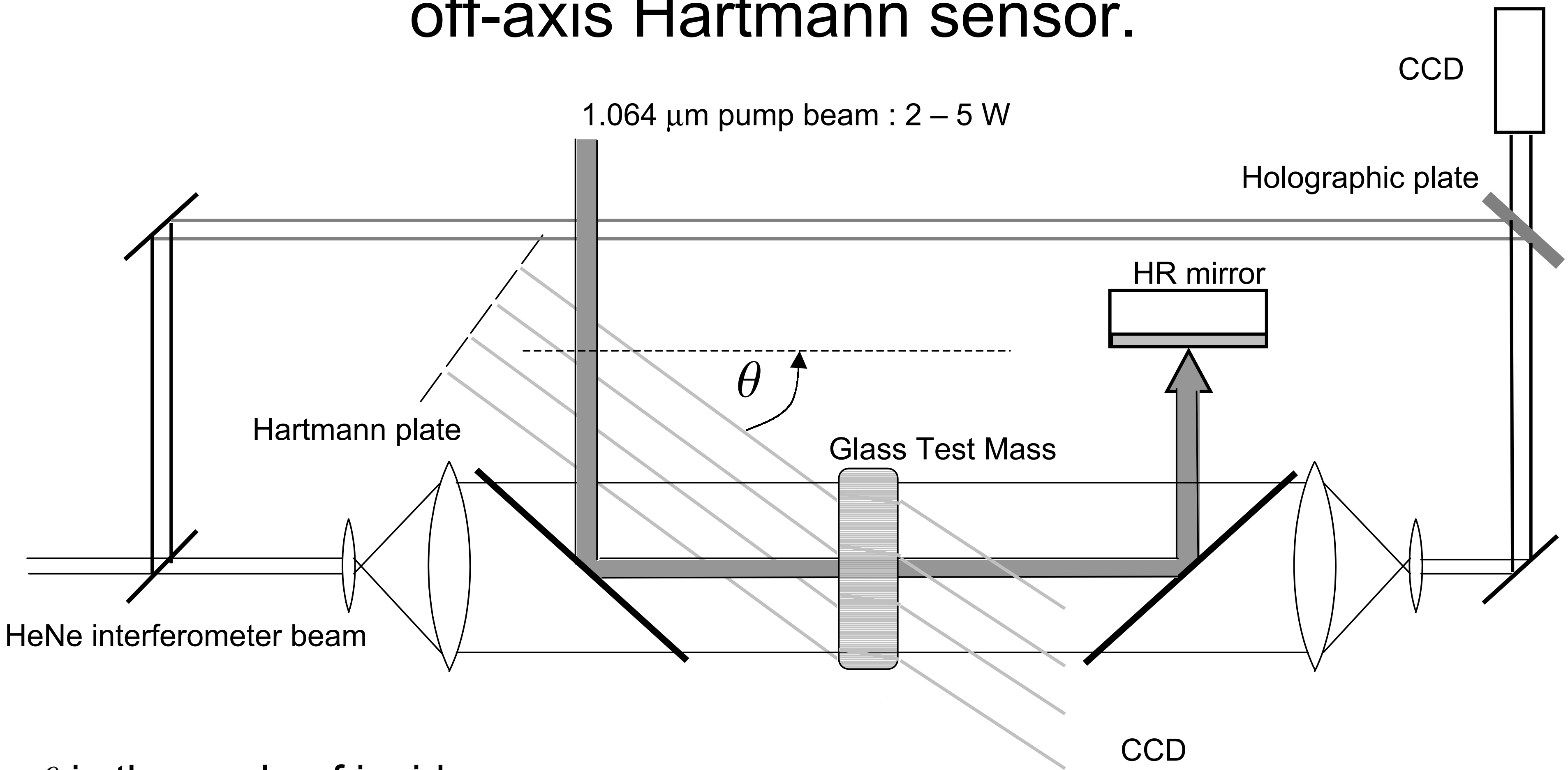
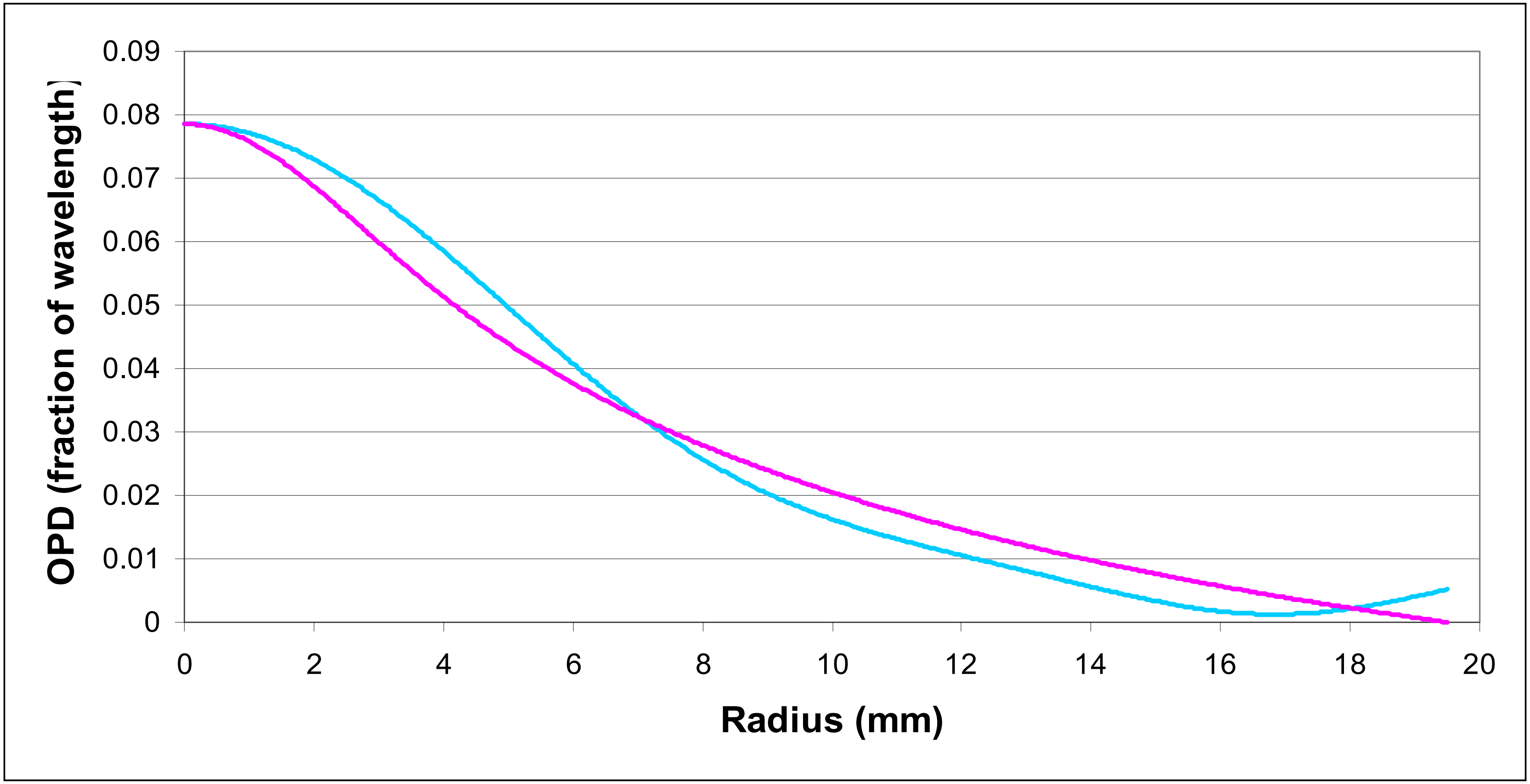
Measuring wavefront distortion using on-axis and off-axis Hartmann sensor.



θ is the angle of incidence.

θ = 0 implies on-axis measurement.

Initial OFF-AXIS Hartmann results



- Theoretical vs Analyzed Data optical path distortion using off-axis Hartmann.
- Off-axis distortion data undergoes complicated rotation and fit to reveal the "measured" distortion on-axis.

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ACIGA/LIGO High Power Test Program: Milestones and deliverable

Milestone	By end of	FROM	TO
Isolation with wiring and local control + clean environment	01/04		
Input Optics system with fixed spacer mode cleaner (MC) to handle 10W	01/04	UWA	GRF
Sapphire test masses (order to be placed 06/02) (fused silica dummies)	*01/04*	*LIGO*	*GRF*
Hartmann sensor + actuation (compensation plate)	04/04	*AU, ANU,LSC*	GRF
Auto alignment system	04/04	ANU	GRF
Locked 80 m cavity with internal ITM substrate, dummy optics, SOS on breadboards, pumped by MISER.	04/04	UWA, ANU, AU, LSC	GRF
10 W power photo-detection	05/04	ANU	GRF
10 W laser	05/04	AU	GRF
Locked 80 m cavity with internal ITM substrate, pumped by MISER, with auto alignment and AOC; SOS on Breadboards	05/04	UWA, ANU, AU, LSC	GRF
Test 1 Completed: Locked 80 m cavity with internal ITM substrate, pumped by 10 W, circulating power 2.1 kW. Results reported.	*08/04*	*GRF*	*LIGO, LSC*
Test 2 installation begins: Locked 80 m cavity with external ITM substrate; 10 W pump.	09/04	ACIGA	GRF
High power optical modulator and isolators delivered	*09/04*	*UF*	*GRF*
Mode cleaner for 100 W down select	10/04	AU	
100 W class laser installed.	10/04	AU	GRF
High power Interferometer optics & detection system installed	10/04	*LSC, ACIGA*	GRF
Test 2 Completed: Locked 80 m cavity with external ITM substrate, pumped by 50 W, circulating power 100 kW. All sensors operational. Results reported.	*02/05*	*GRF*	*LSC*
Test 3 installation begins: power recycled single FP; 100W pump	03/05	ACIGA	
New sapphire ITM + fused silica PRM (ordered 10/04)	*03/05*	*LIGO*	*GRF*
Test 3 Completed: Locked PR FP cavity; 100W input; 8 kW in PRC; 400kW in FP; full sensing and control; cold to hot operation. Diagnosis completed and report compiled.	11/05	ACIGA	LIGO, LSC.

Conclusion

- HPTF nearing completion
- Vacuum system improving, but may need some baking
- First laser lock being set up using ‘dummy’ BK7 optics
- 10W laser to be delivered 04/04
- New high power laser design, demo delayed
- Backup 1st generation laser to be used at Gingin if required to avoid delay
- Wavefront sensor progressing