THE UNIVERSITY OF ADELAIDE AUSTRALIA

Advanced Lasers and Adaptive Optics

Jesper Munch
for LIGO-Australia and ACIGA

IndIGO-ACIGA meeting
Feb 2011

Contents

Lasers for LIGO-Australia
Adaptive optics
Future Developments
Opportunities for collaboration

Founded in 1990: Chair of Experimental Physics

4 academics: Jesper Munch, Murray Hamilton,
Peter Veitch, David Ottaway

1-2 Post docs: David Hosken,

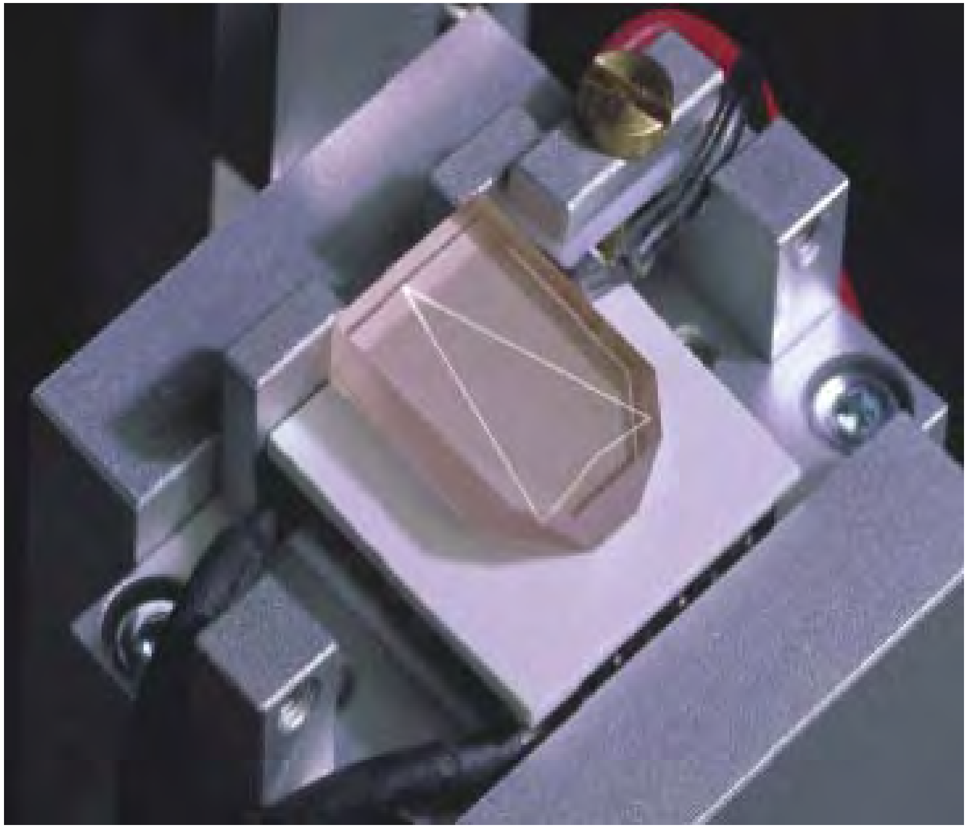
1-2 RAs: Nick Chang, Won Kim

8-12 PhD and MS students: Nick Chang, Alex Dinovitser,
Miftar Ganija, Ori Henderson-Sapir, Ka Wu,
Keiron Boyd, Lachlan Harris, Muddassar Naeem

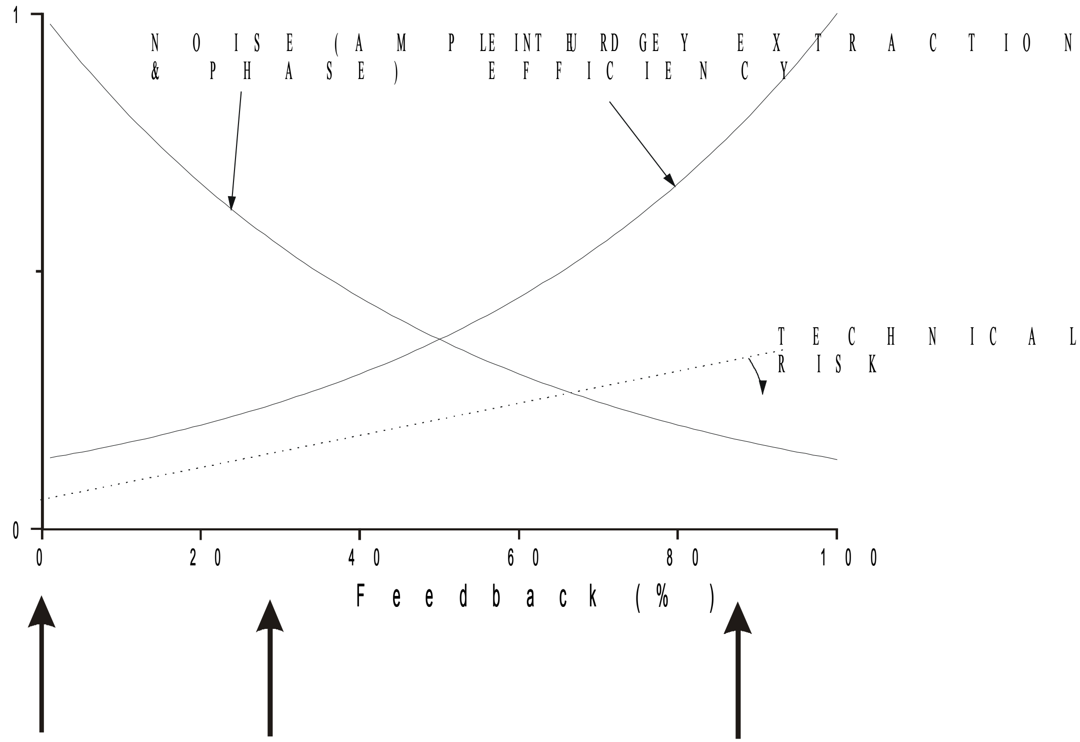
Group is part if University of Adelaide Institute for Photonics And Sensing (IPAS), Prof Tanya Monro, director, 140 members

Laser Applications
Laser Physics
Laser Engineering
Diffractive optics and holography
Nonlinear optics and phase conjugation
Classical optics
Insect vision
Wavefront characterization

Monolithic Ring Laser



AMOPA is an injection l
NO feedback



MOPA

REGENERATIVE OSCILLATOR

INJECTION LOC
OSCILLATOR

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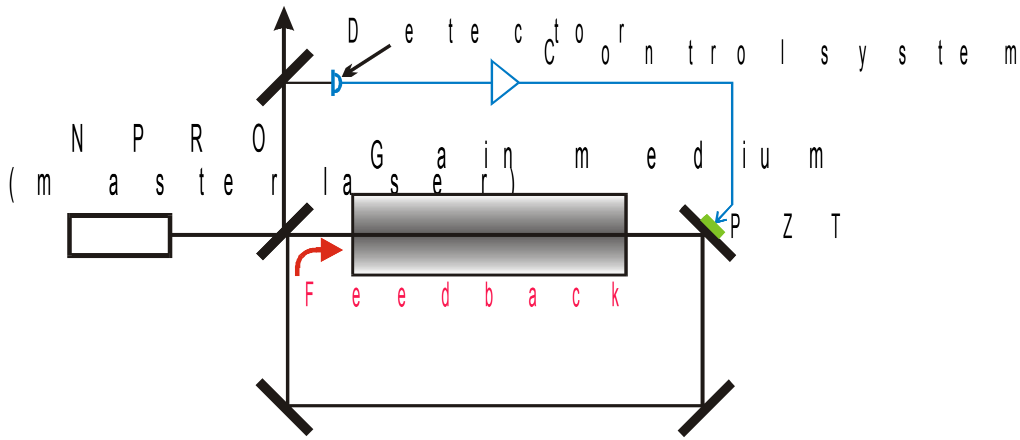
Injection-Locked Osc

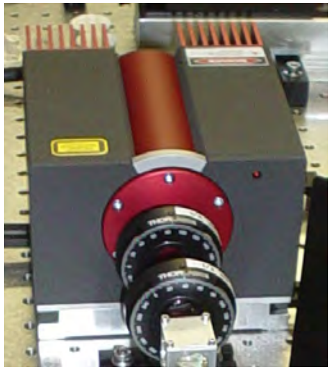


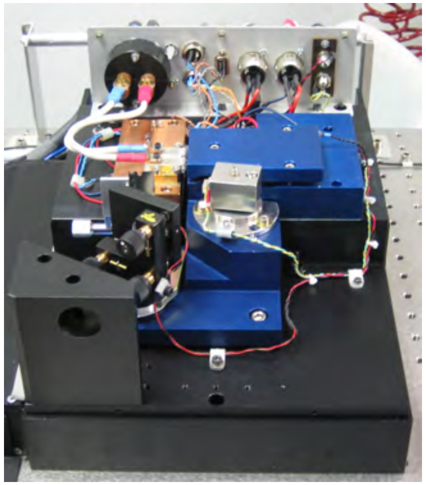
- Inject master oscillator (low frequency) field into slave c
- Amplification of master osc saturates gain
- Free running modes quenc

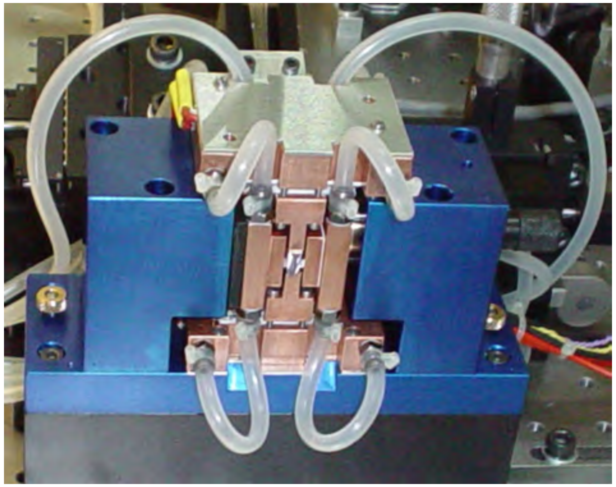
→ Results in low noise amplifi

Adelaide high power laser approach for GWI's

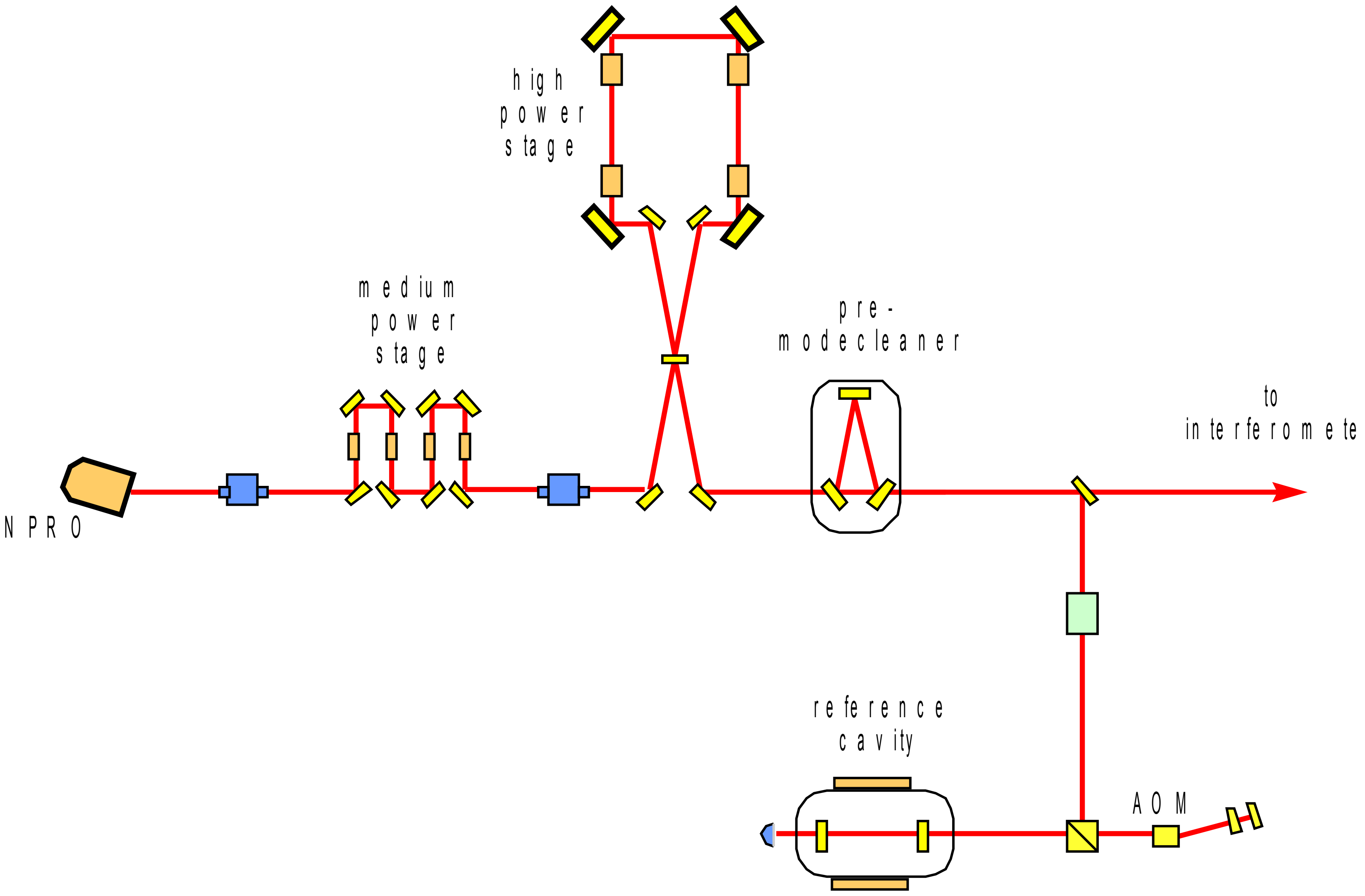
Injection-locked chain of lasers



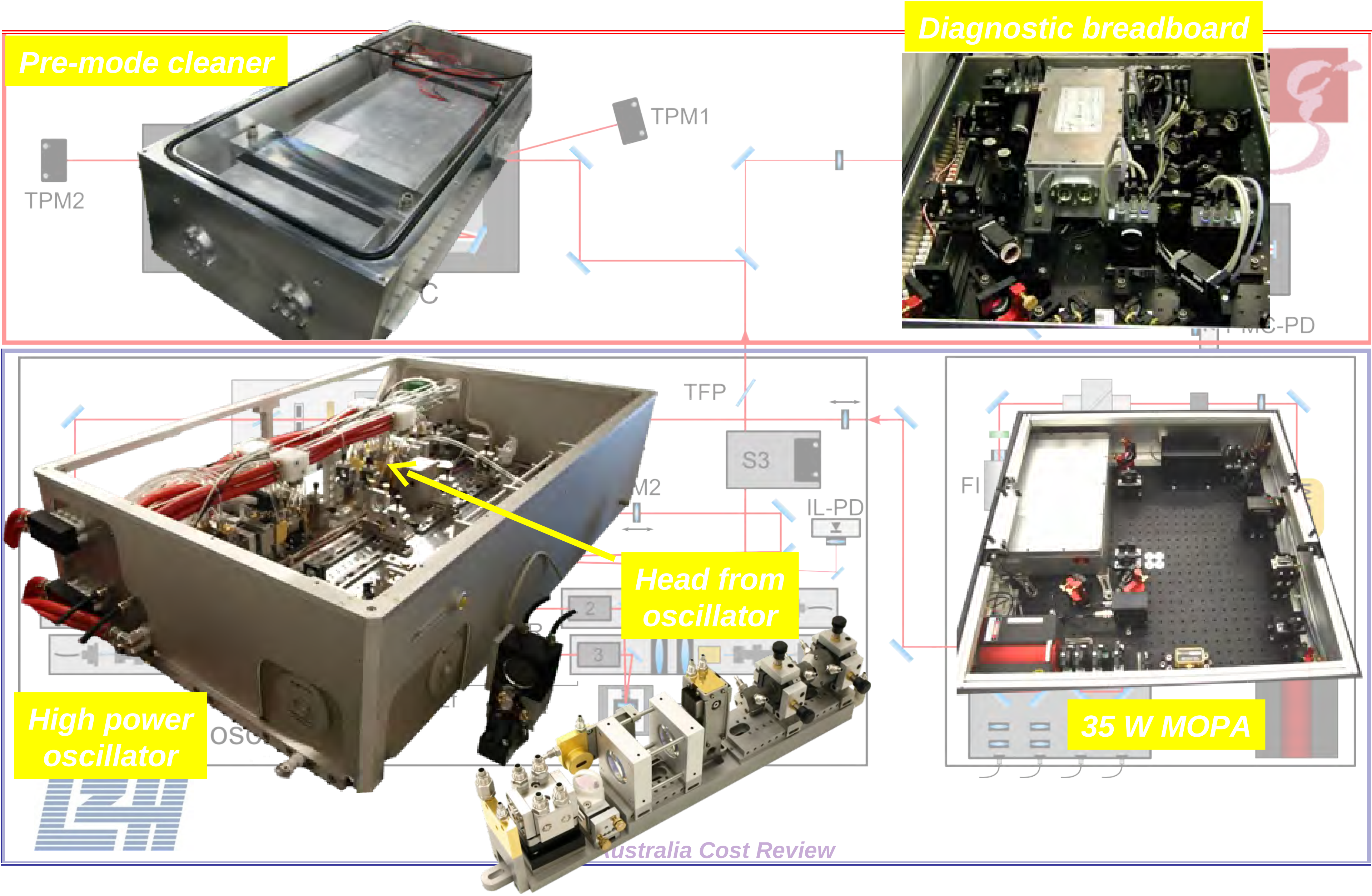




Advanced LIGO prestabilized laser

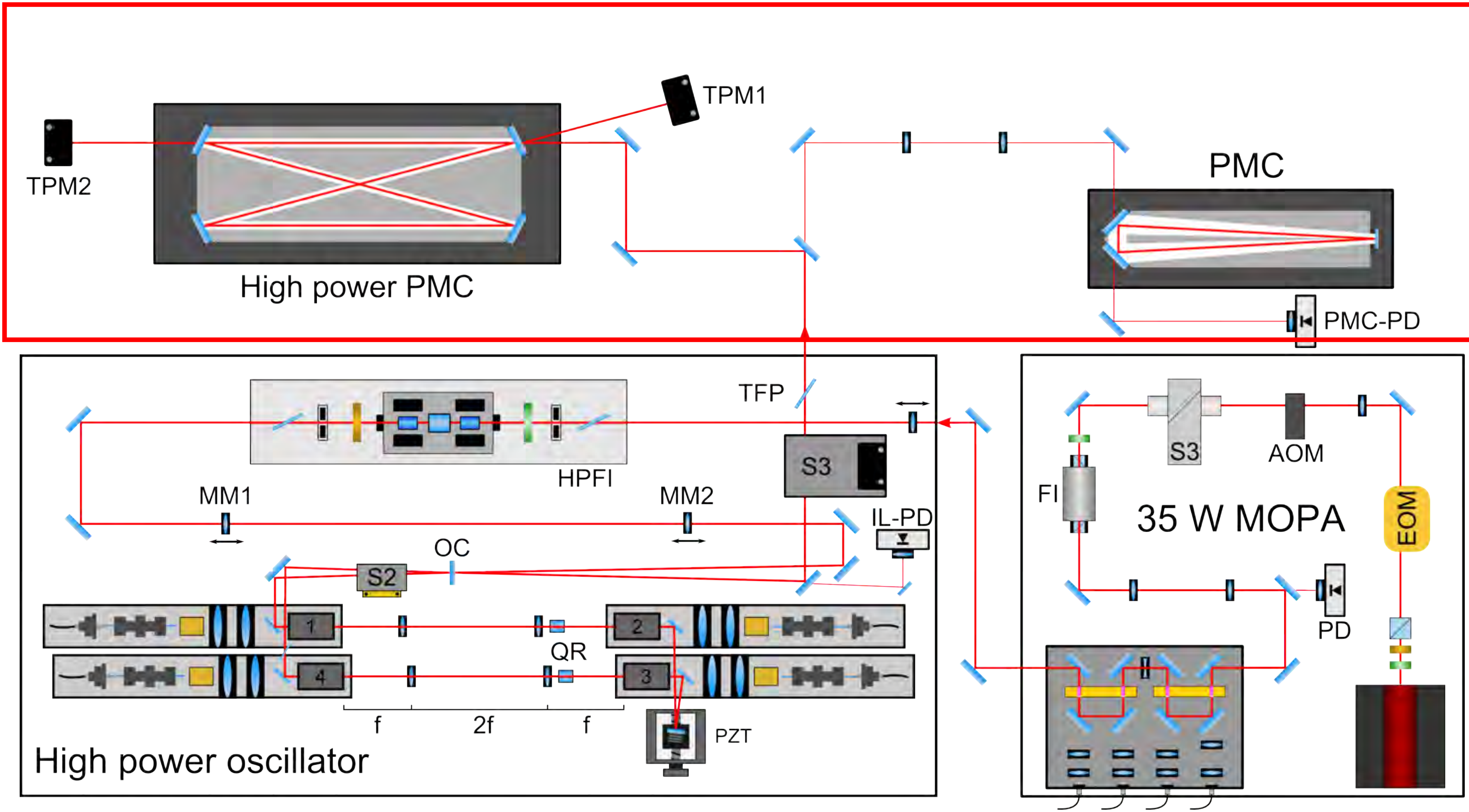


Planck Pre-Stabilized Laser
(Max contribution)



Australia Cost Review

Pre-stabilized Laser
(Max Planck contribution)



The PSL meets all requirements for Advanced LIGO

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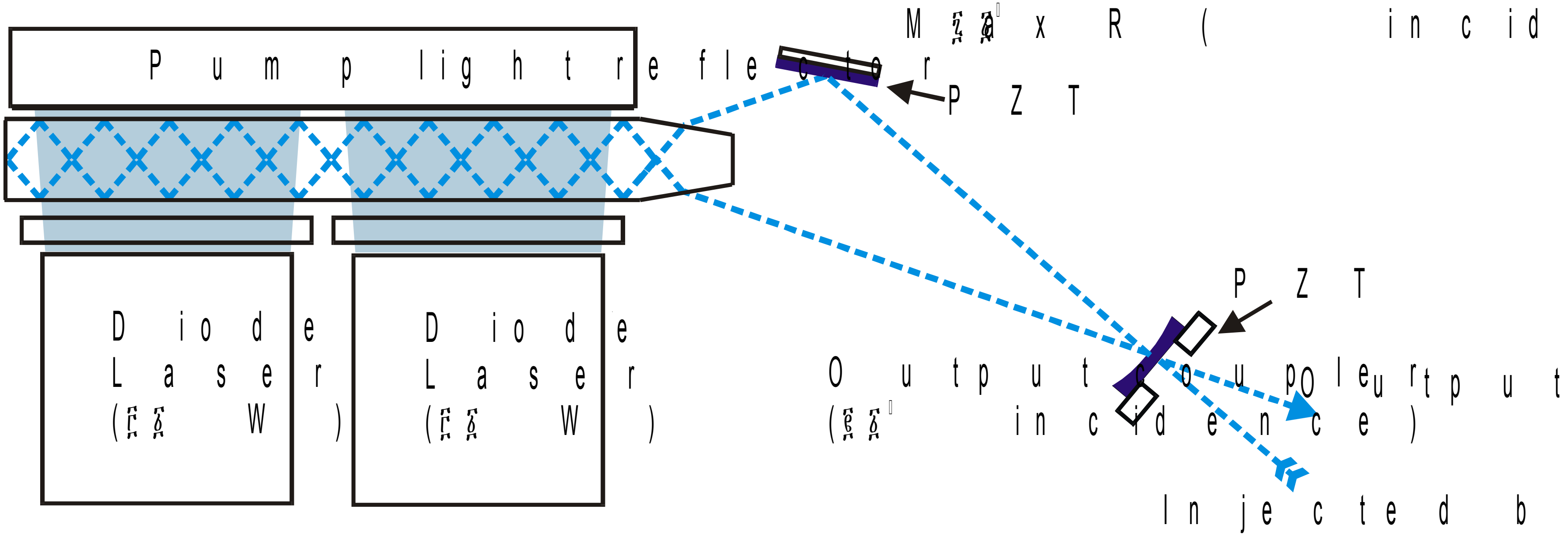
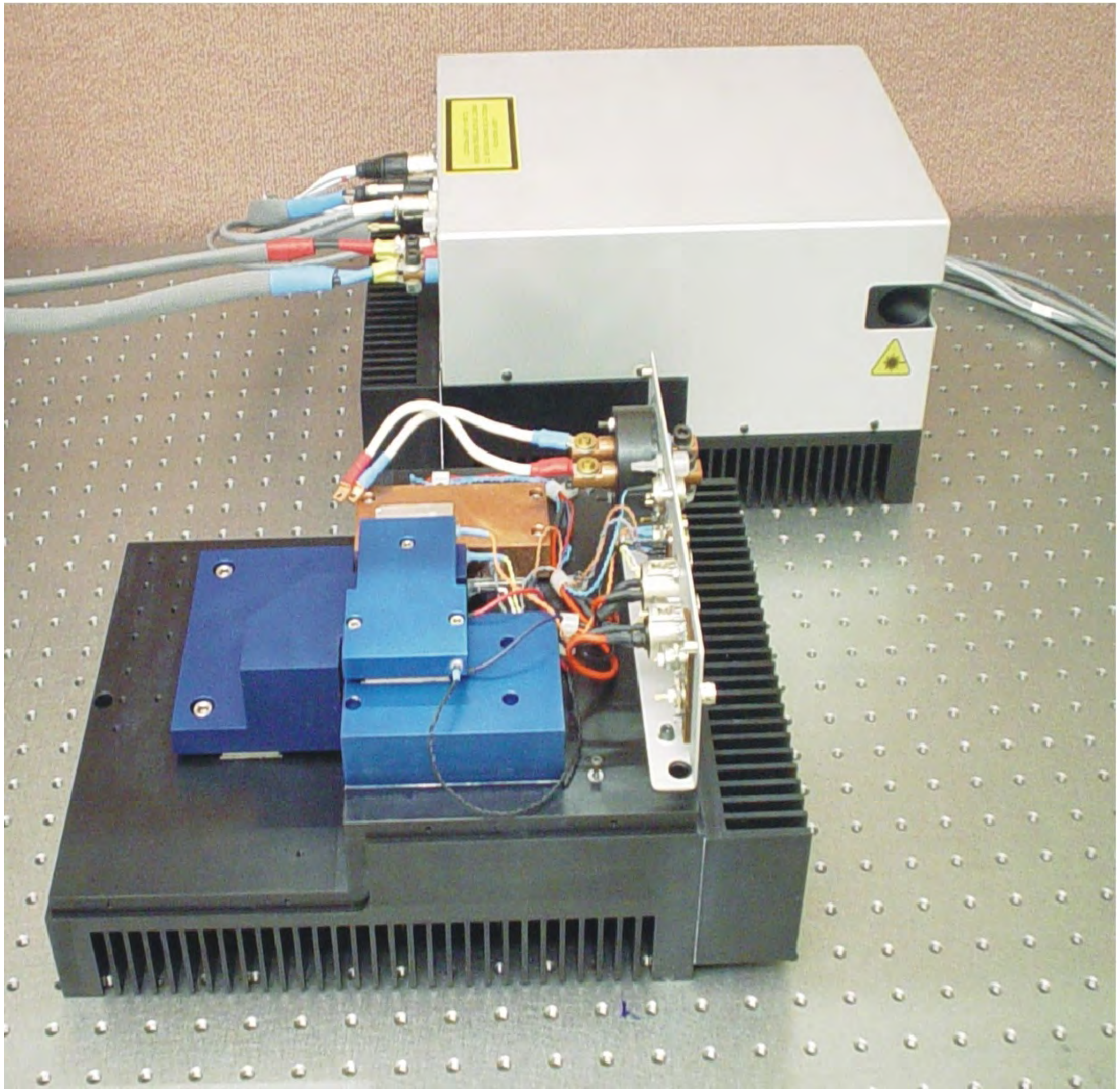
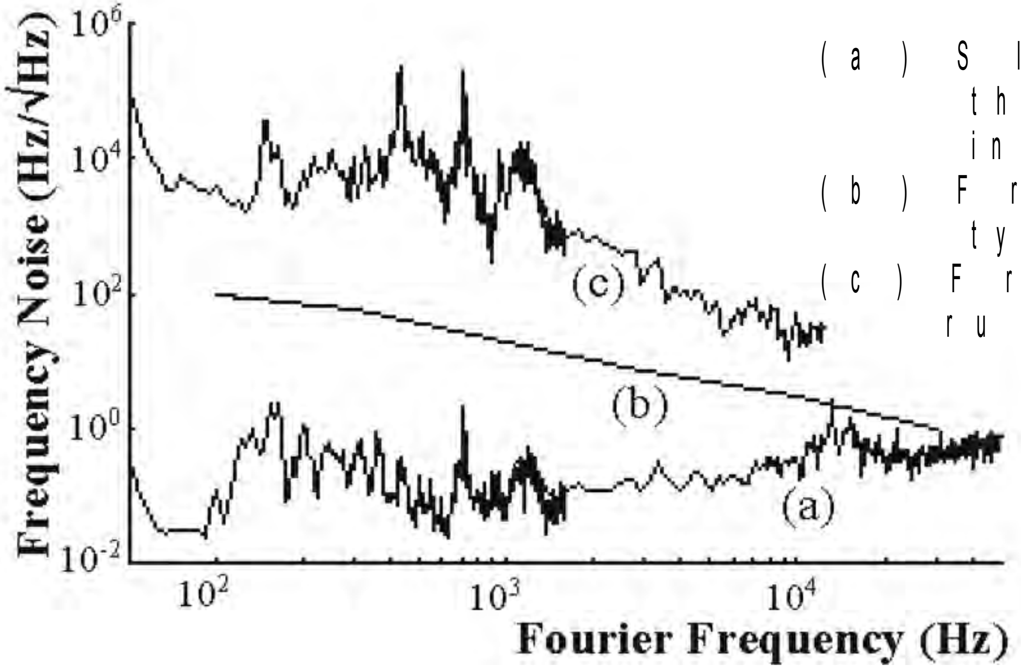
Travelling-Wave Resonator



10W Slave Laser



Frequency Noise o
Locked Laser



(a) Slave laser contri
the frequency no
injection-locked l
(b) Frequency noise
typical free-runni
(c) Frequency noise
running slave lase

- The injection-locked laser is limited
stable master laser

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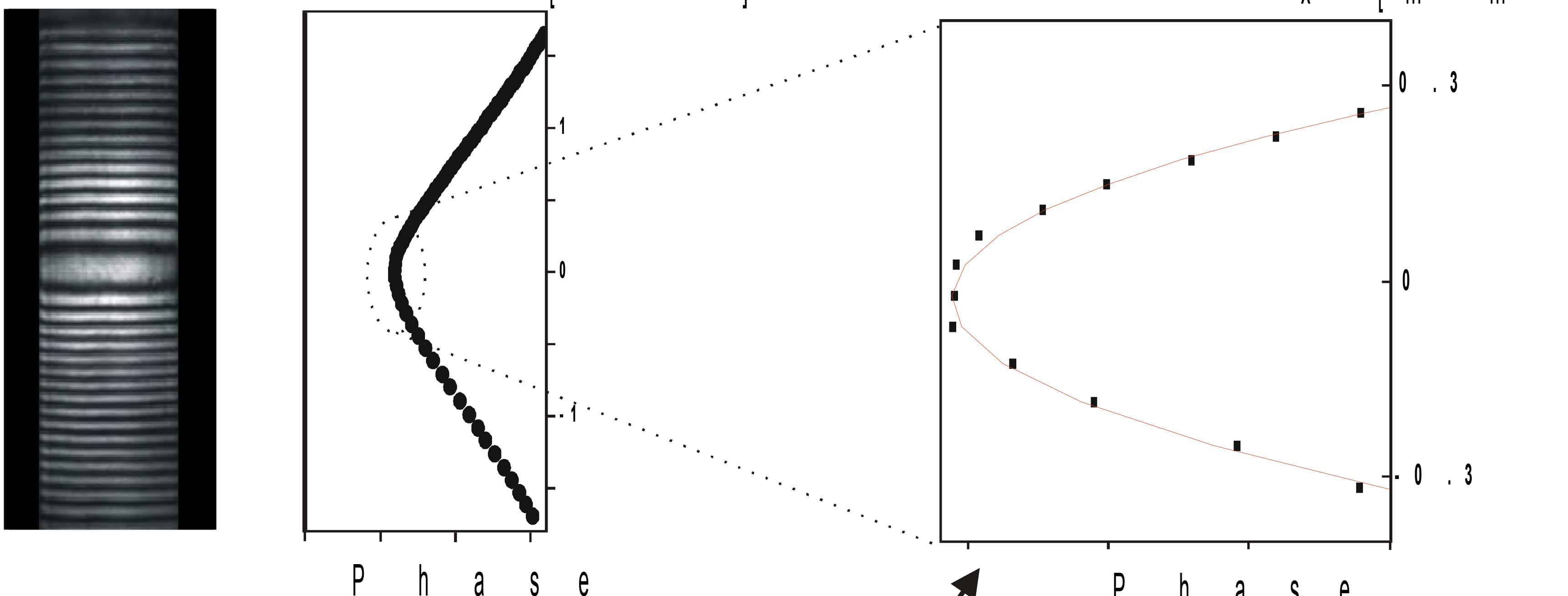
Thermal Lens Meas

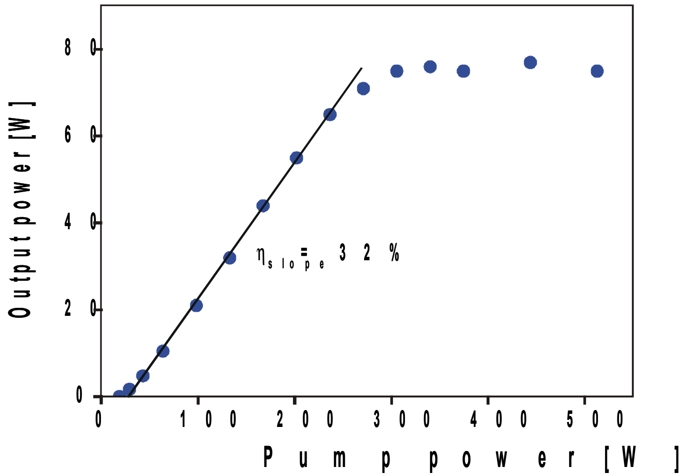


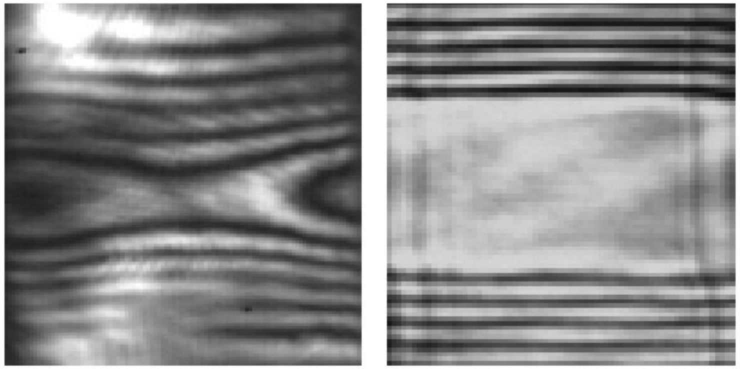
Tilted reference

Lens region

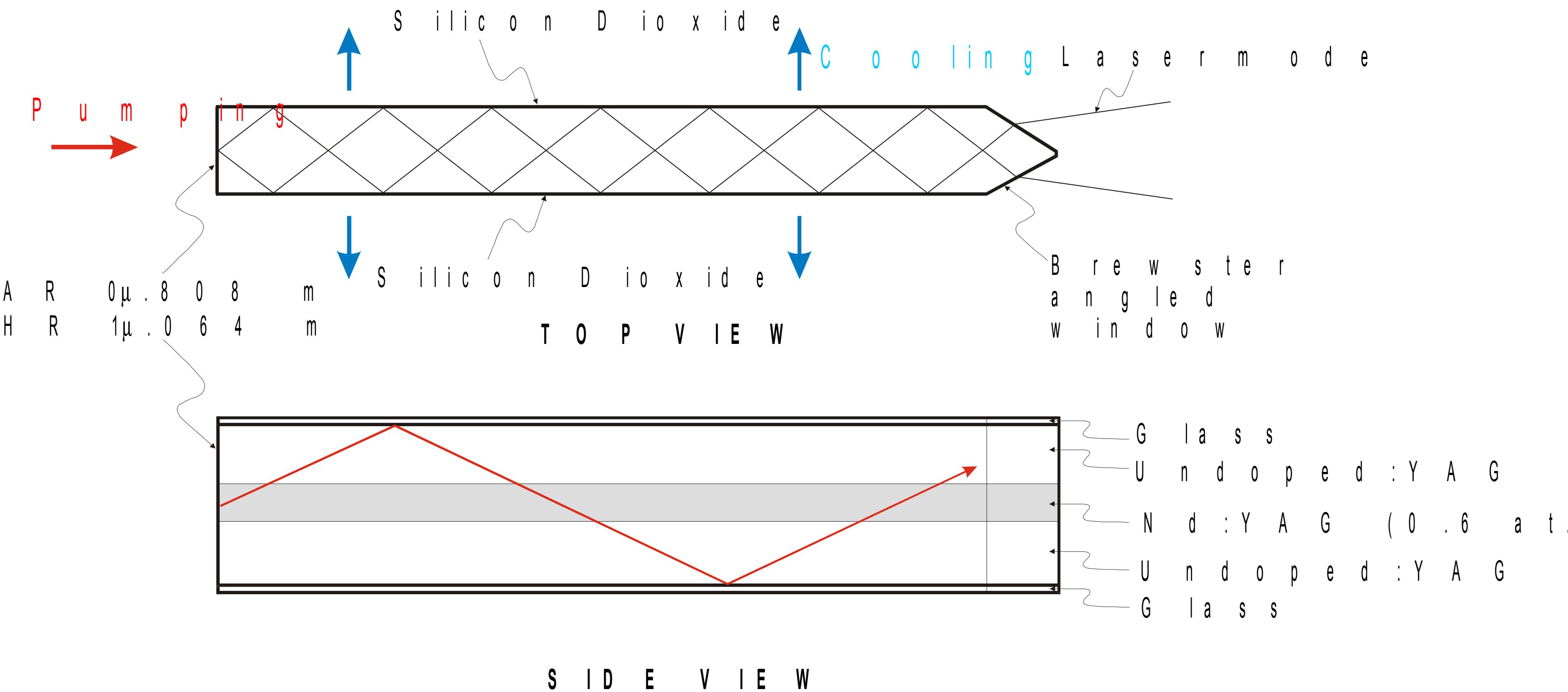
(Fitted focal length

Inhomogeneous pumping leads to output power saturation

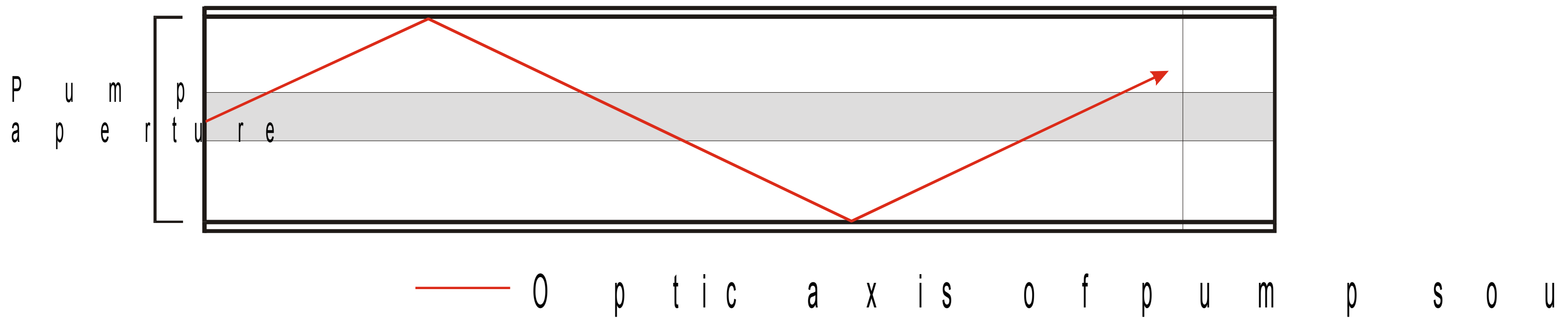




Composite end-pumped, side-cooled folded zigzag slab



Off-axis, zigzag end-pumping



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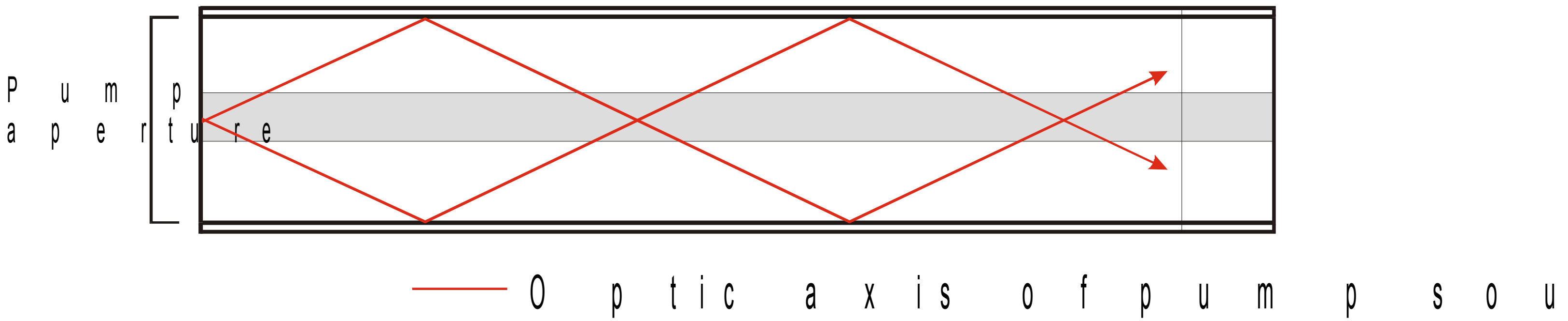
Off-axis, zigzag end-pumping



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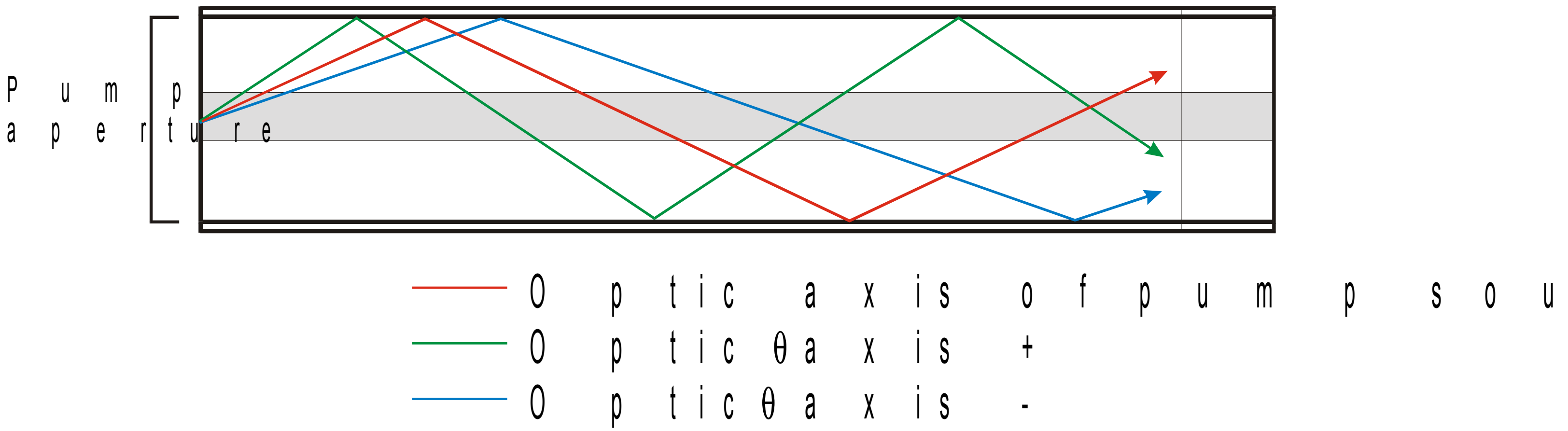
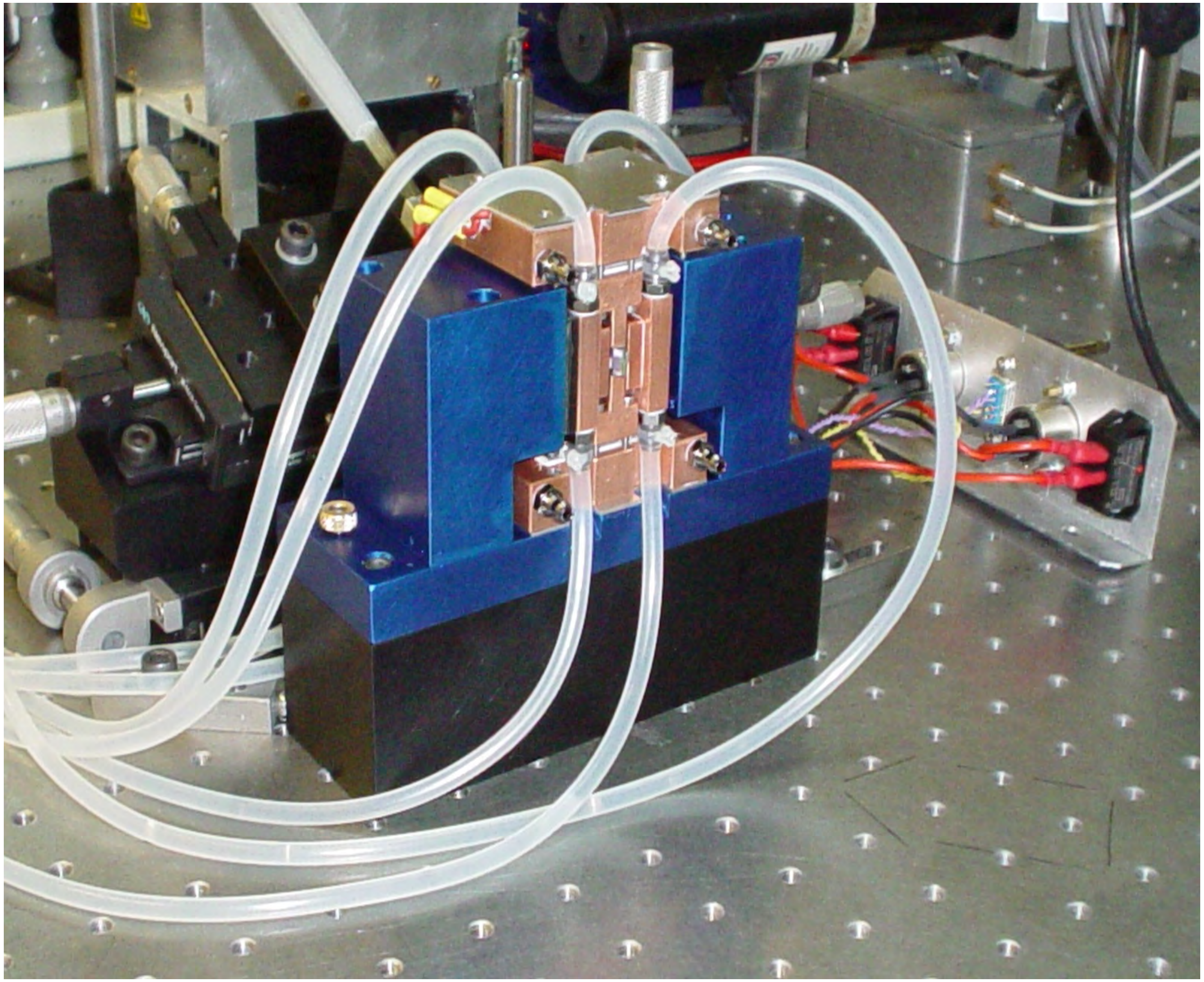
Off-axis, zigzag end-pumping

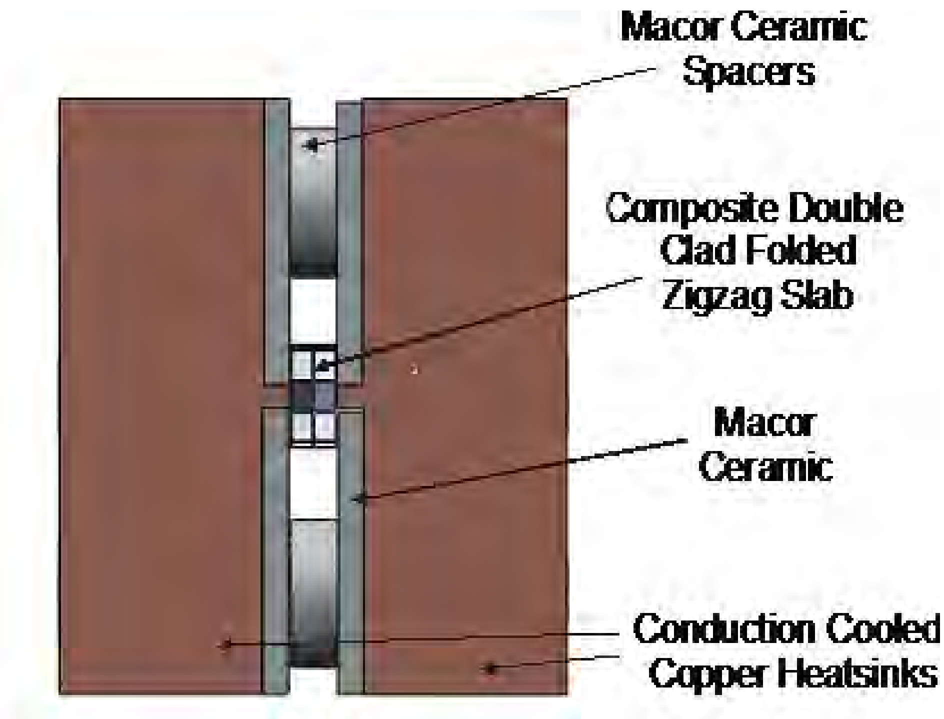


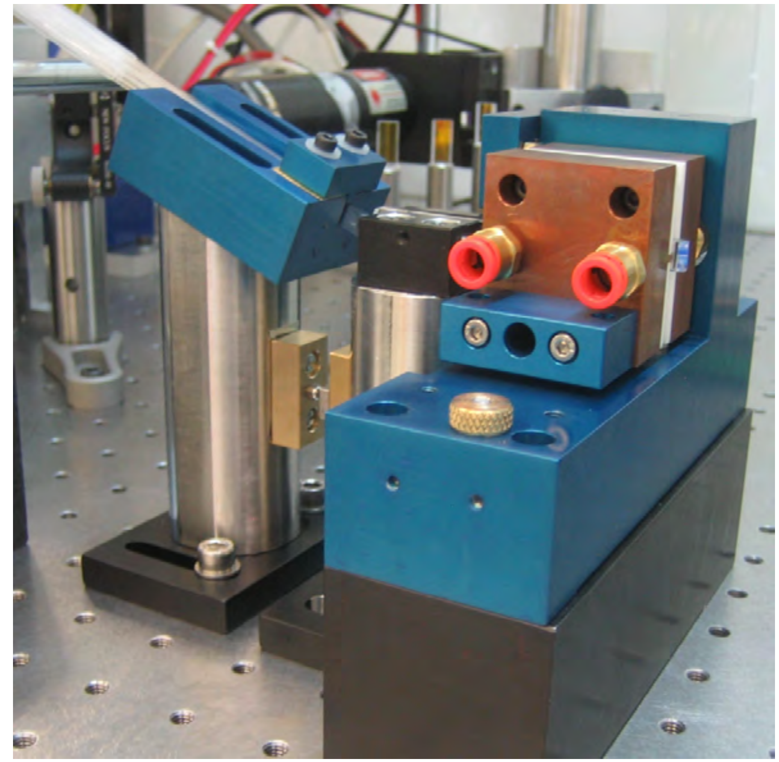


- Injection locked oscillator
- Unstable Resonator
- Zig-Zag slab

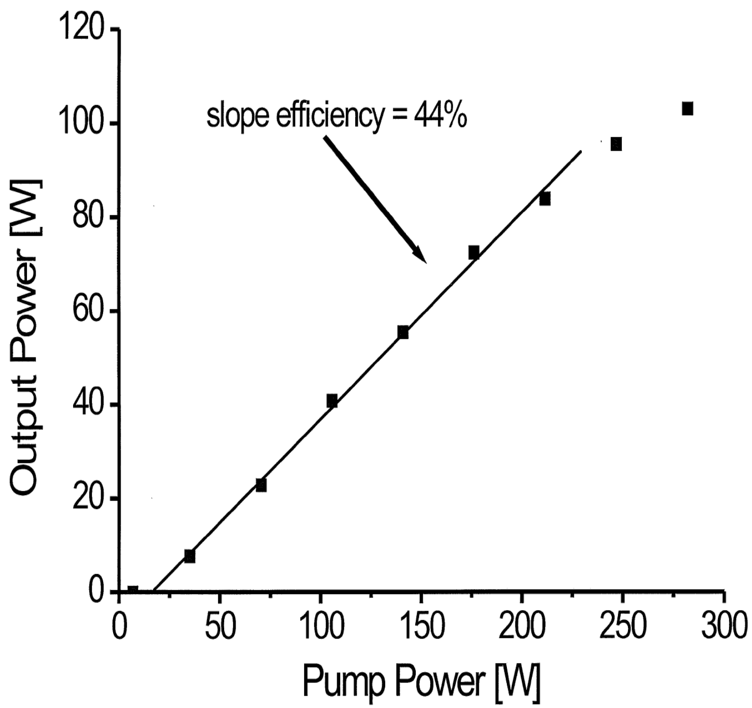
- End pumping
- Birefringence control by defined gain medium
- Improved pump uniformity across wavefront
- Scalable to very high power

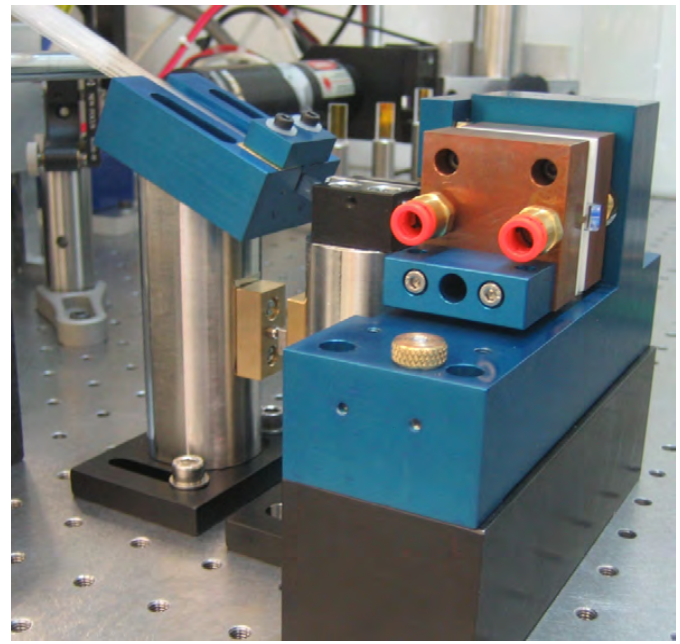
Latest design 100W Laser





50-100W laser for Gingin, 2010





Stable, Single Frequency Er:YAG Lasers at 1.6 μm

Nick Wei-Han Chang, David J. Hosken, Jesper Munch, *Member, IEEE*, David Ottaway, and Peter J. Veitch

***Abstract*—Stable, single frequency lasers in the eye-safe band are essential for coherent remote sensing. We describe an Er:YAG laser that is resonantly pumped using diode lasers, and produces a polarized, single frequency, diffraction limited beam at 1645 nm with a frequency stability suitable for single-shot velocity measurements with a precision $< 0.1\ \mathrm{ms}^{-1}$.**

***Index Terms*—Er:YAG laser, resonant pumping, single frequency, stable.**

I. Introduction

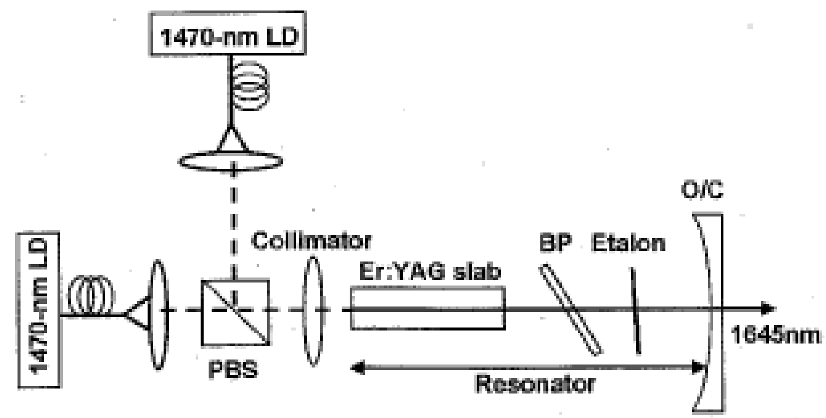
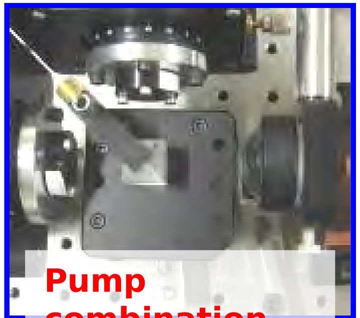
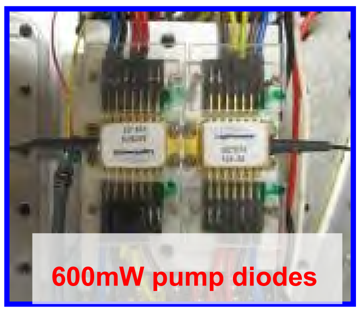
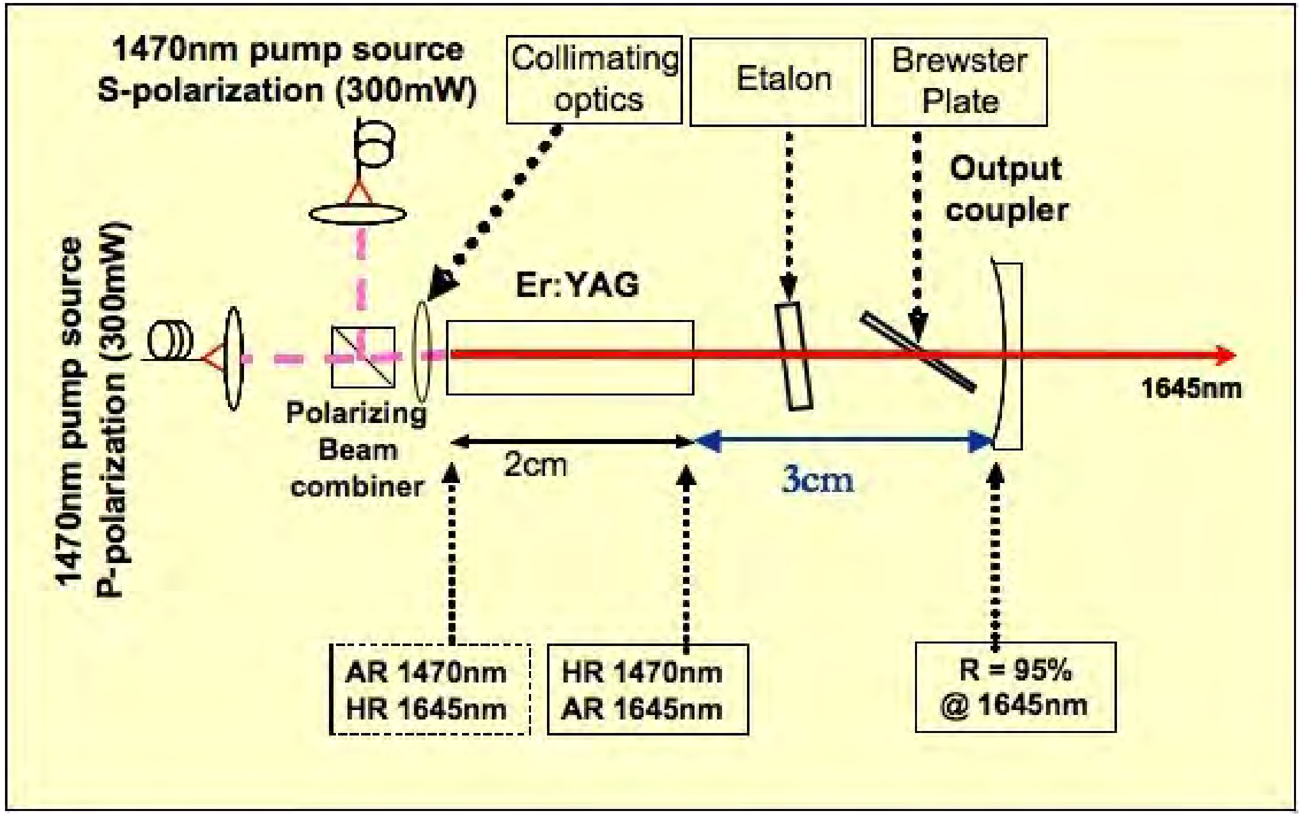


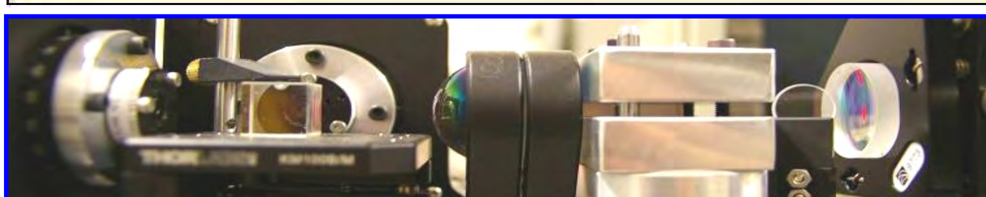
Fig. 1. Schematic of the laser. Abbreviations: LD, laser diode; PBS, polarizing beam splitter; BP, Brewster-angled plate; O/C, out-coupler.

Single frequency Er:YAG master laser

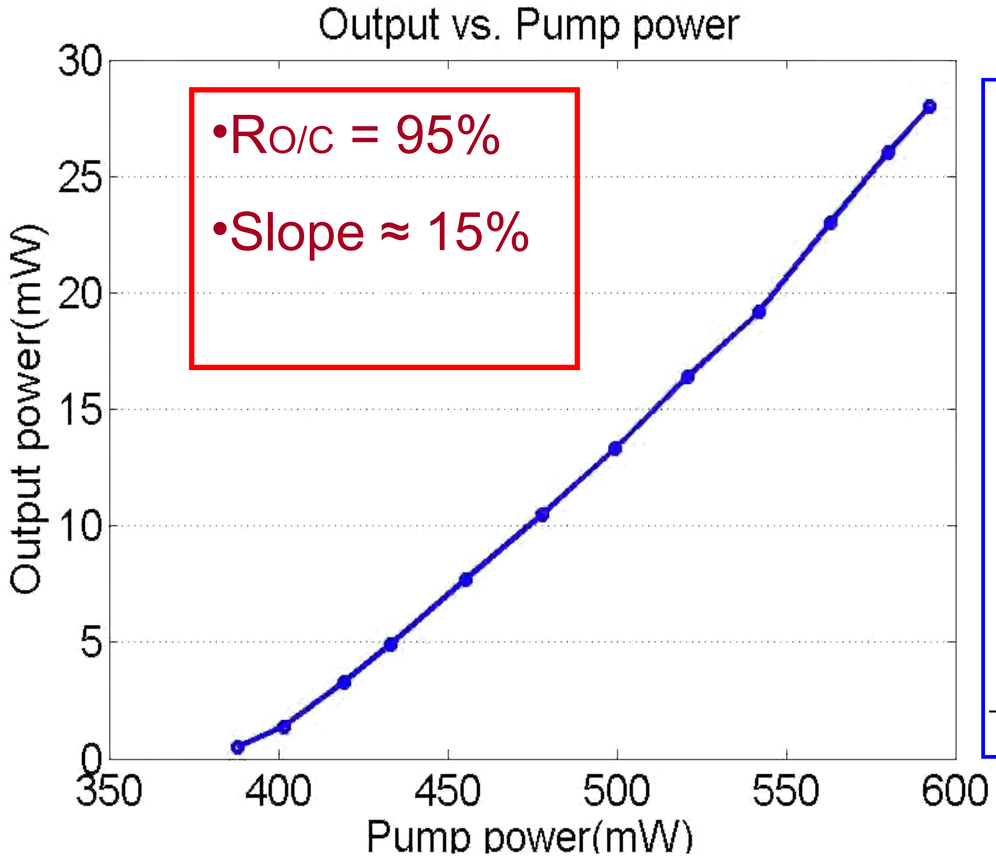




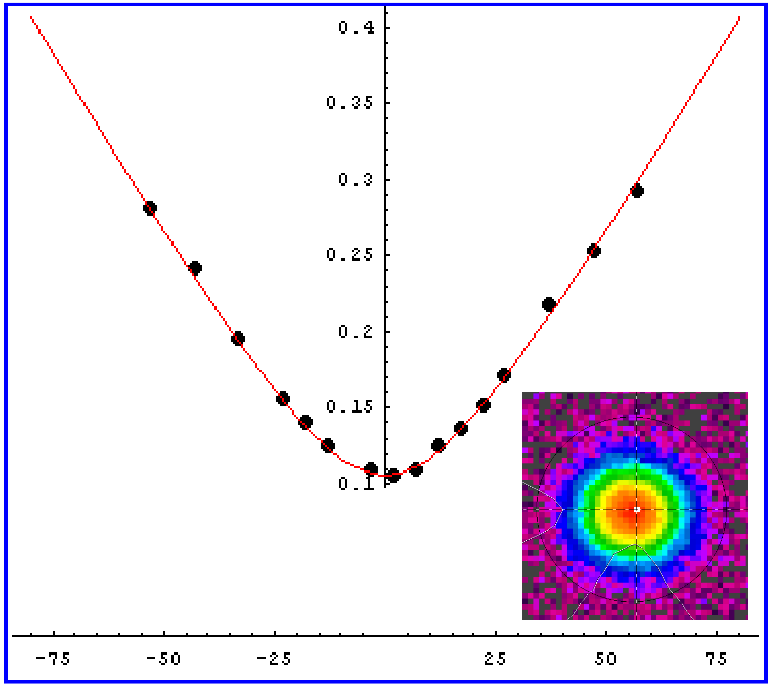




Single-mode output power



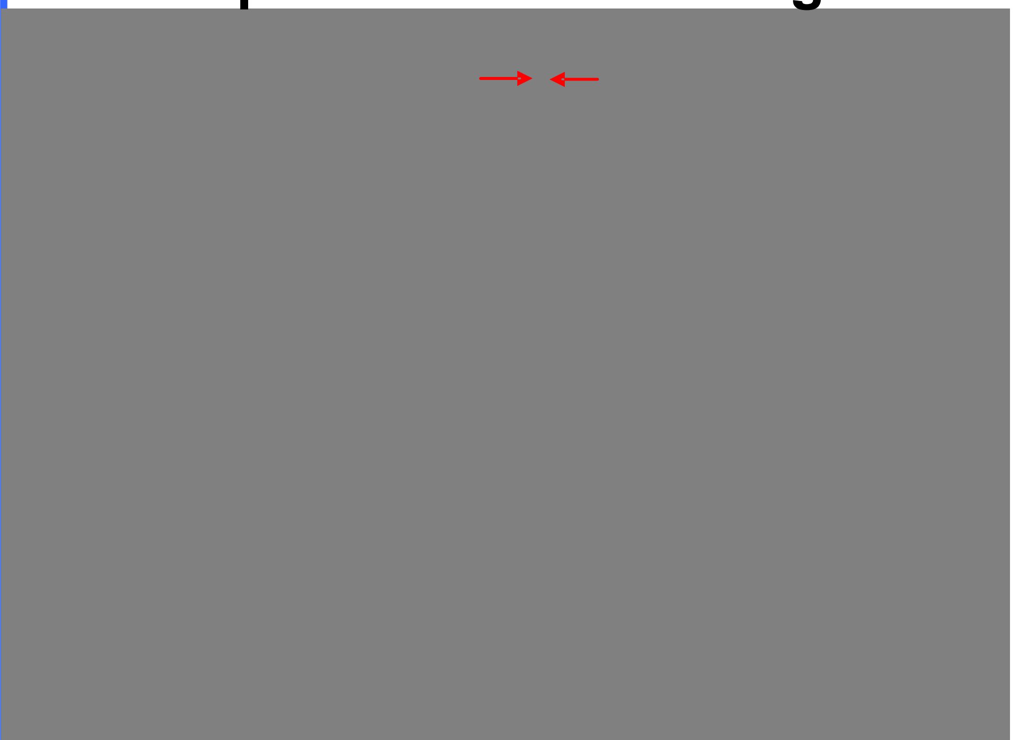
M² measured = 1.02



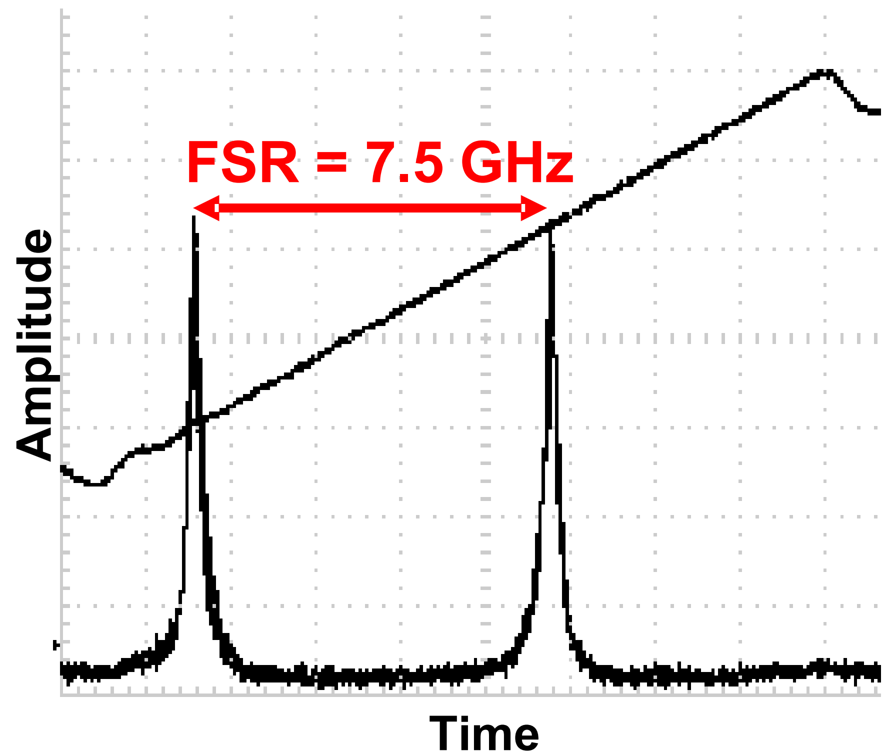
Single-frequency

Grating Spectrometer

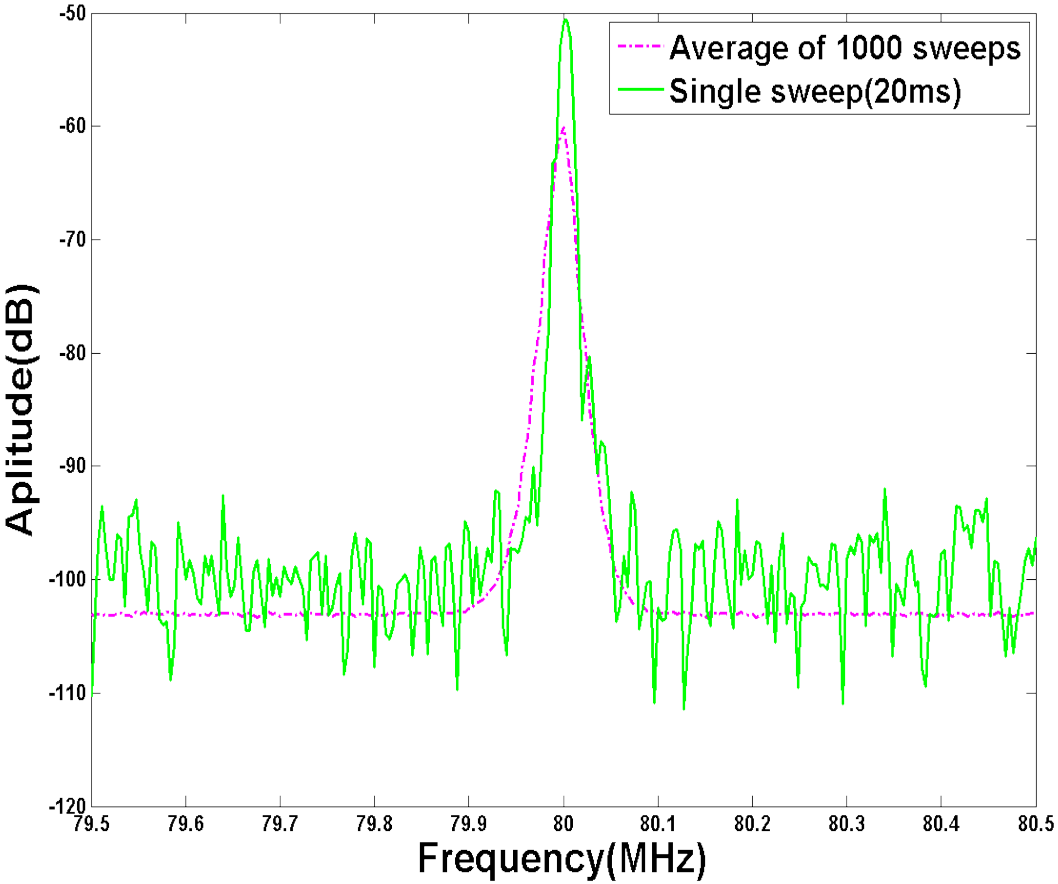
Spectrum from Grating SA



Fabry-Perot OSA



Linewidth Measurement



Self-beating heterodyne detection.

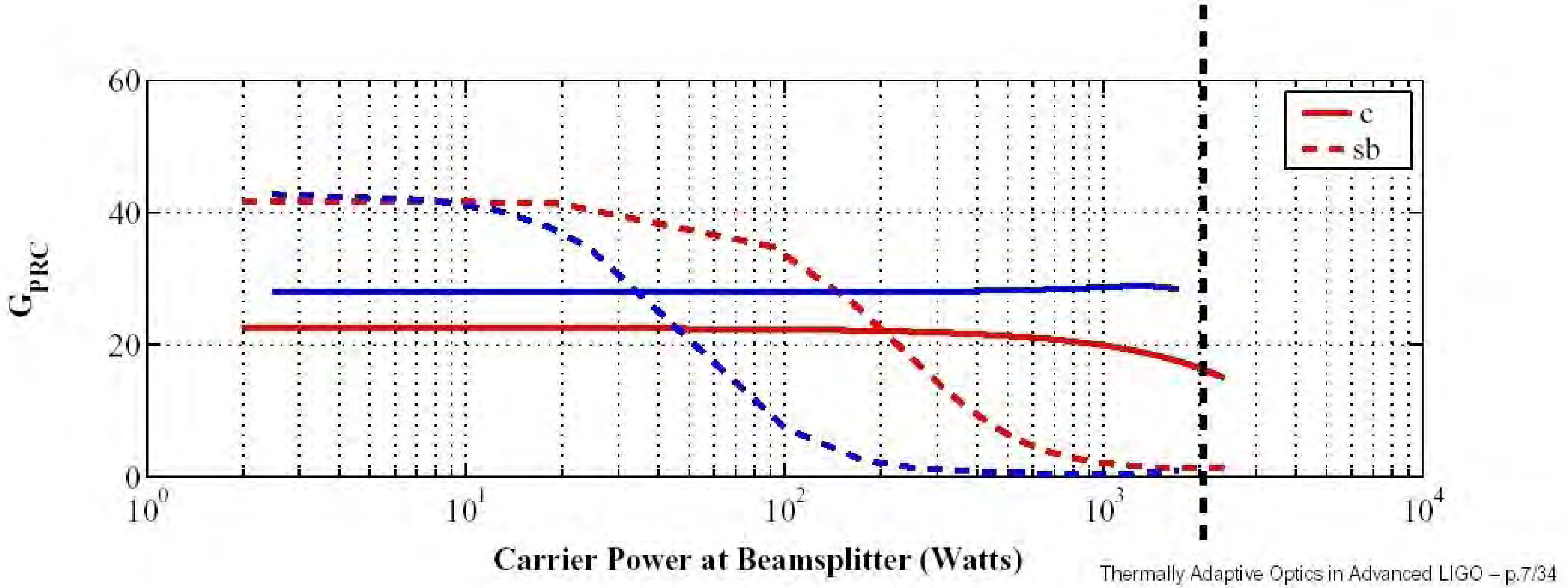
•20km delay from fiber

➔15km CLR range

•Linewidth = 12kHz

➔Velocity resolution ~0.1ms^{-1}

Crux of thermal problem



- Absorbed power causes ‘thermal lensing’
- Prediction of MELODY model of Advanced LIGO
- Sideband power is scattered out of TEM_{00}
- Instrument failure at approximately 2 kW
- Advanced GWI cannot achieve desired sensitivity unaided

How to maintain cavity finesse?

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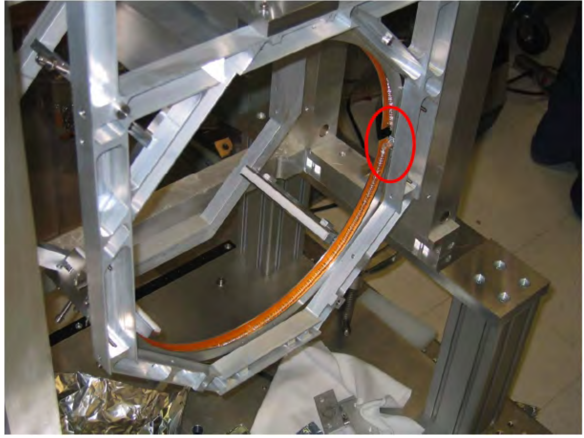
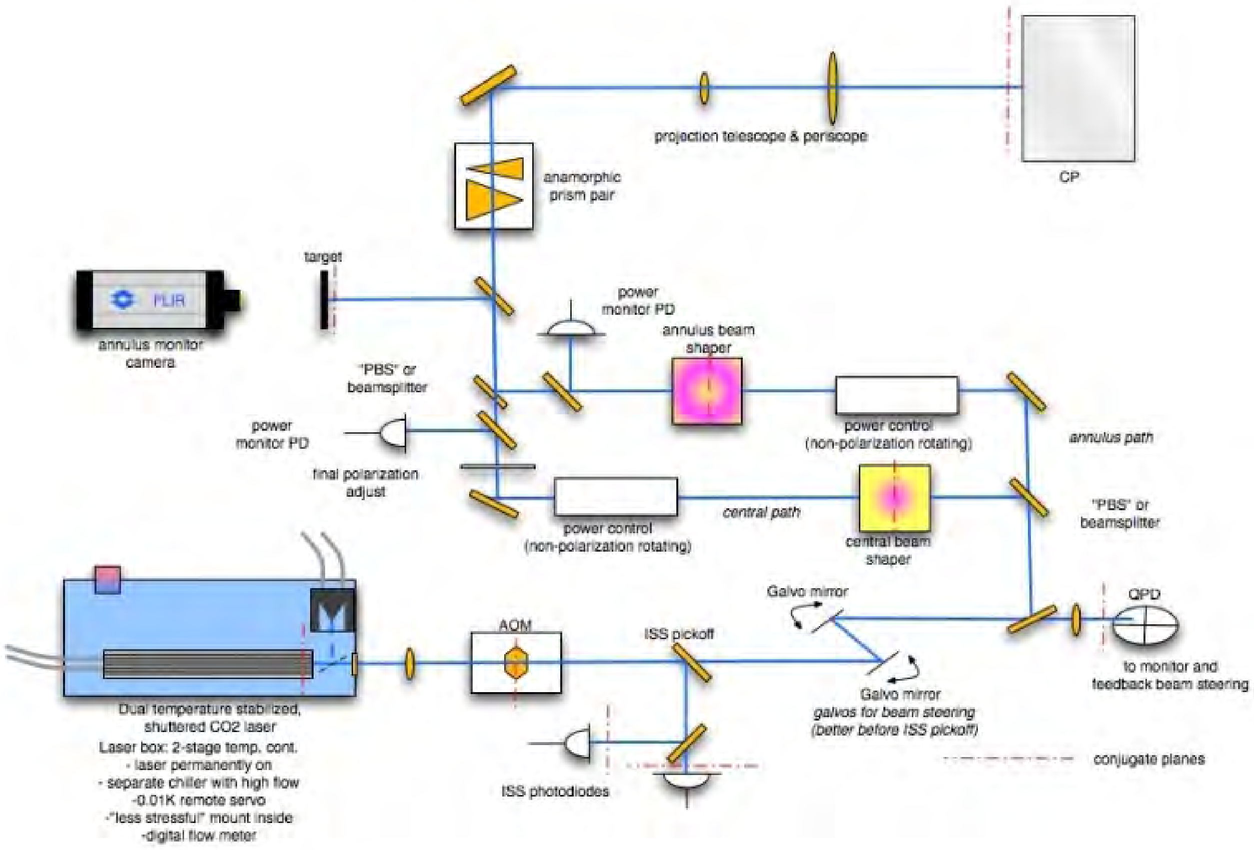
  - sensitivity < λ/600 at 820 nm*
  - suitable for use in active compensation system
  - reliable
  - easy to install in advanced GWI

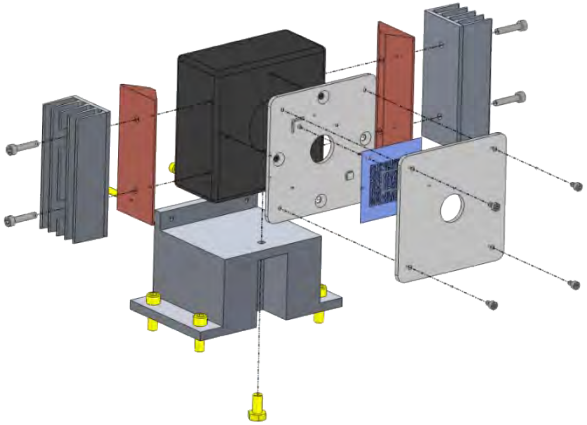
Thermal Compensation System (TCS)



Prototype of Baseline Ring Heater (nichrome wire would around glass former, within reflective shield)

- Ring Heater (4 units)
- CO2 Laser Projector (2 units)
- Hartmann Sensor (2 units)
  - Provided by Australian partners





Why use a Hartmann wavefront sensor?

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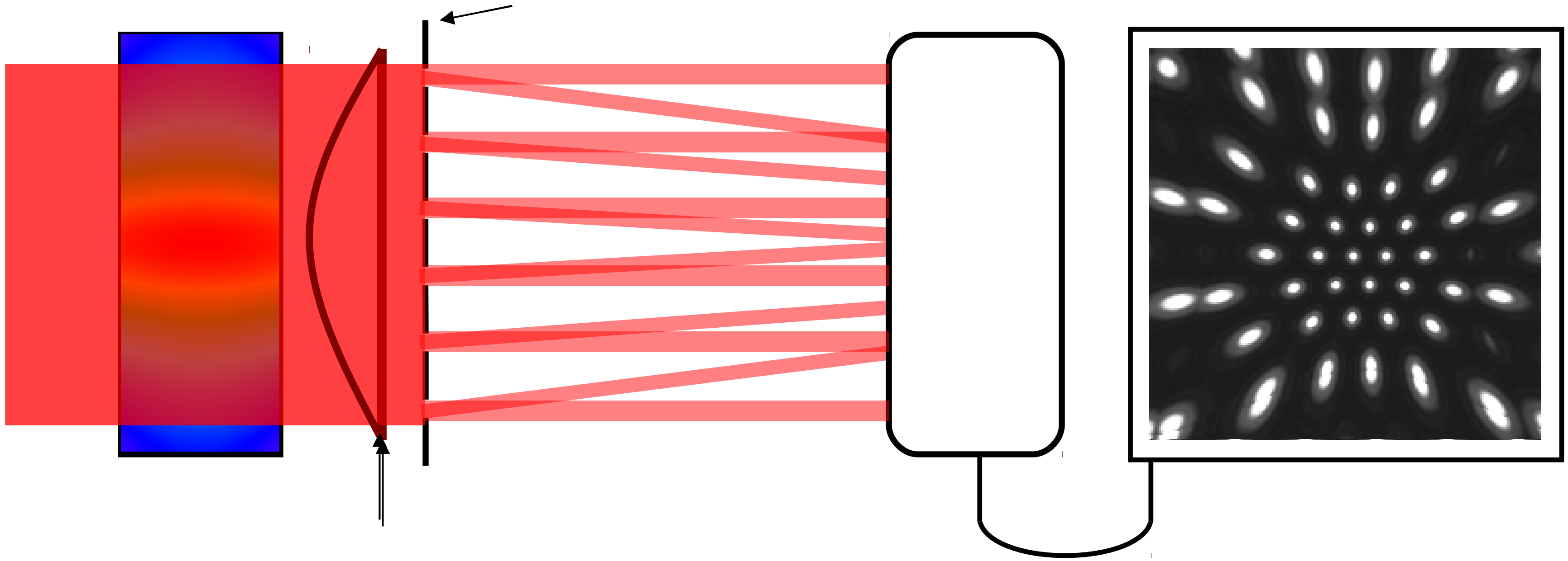
  - easy to align
  - don’t need microlens array
  - ultra-sensitive and accurate

Hartmann Wavefront Sensor: How It Works



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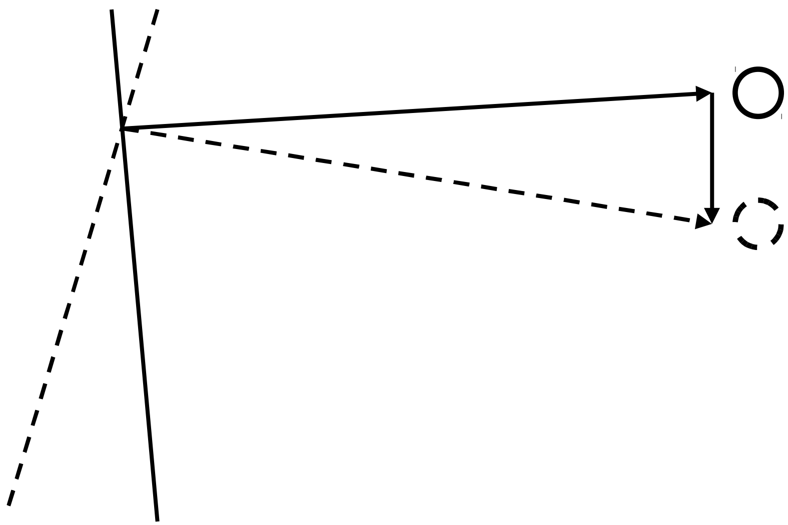
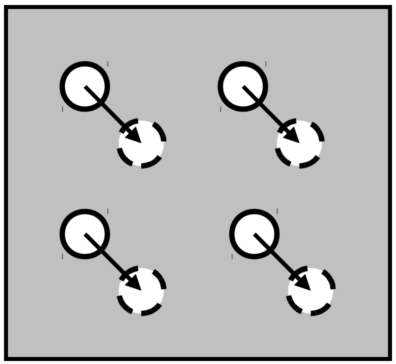
Hartmann WFS measures local wavefront gradient (ϕ)





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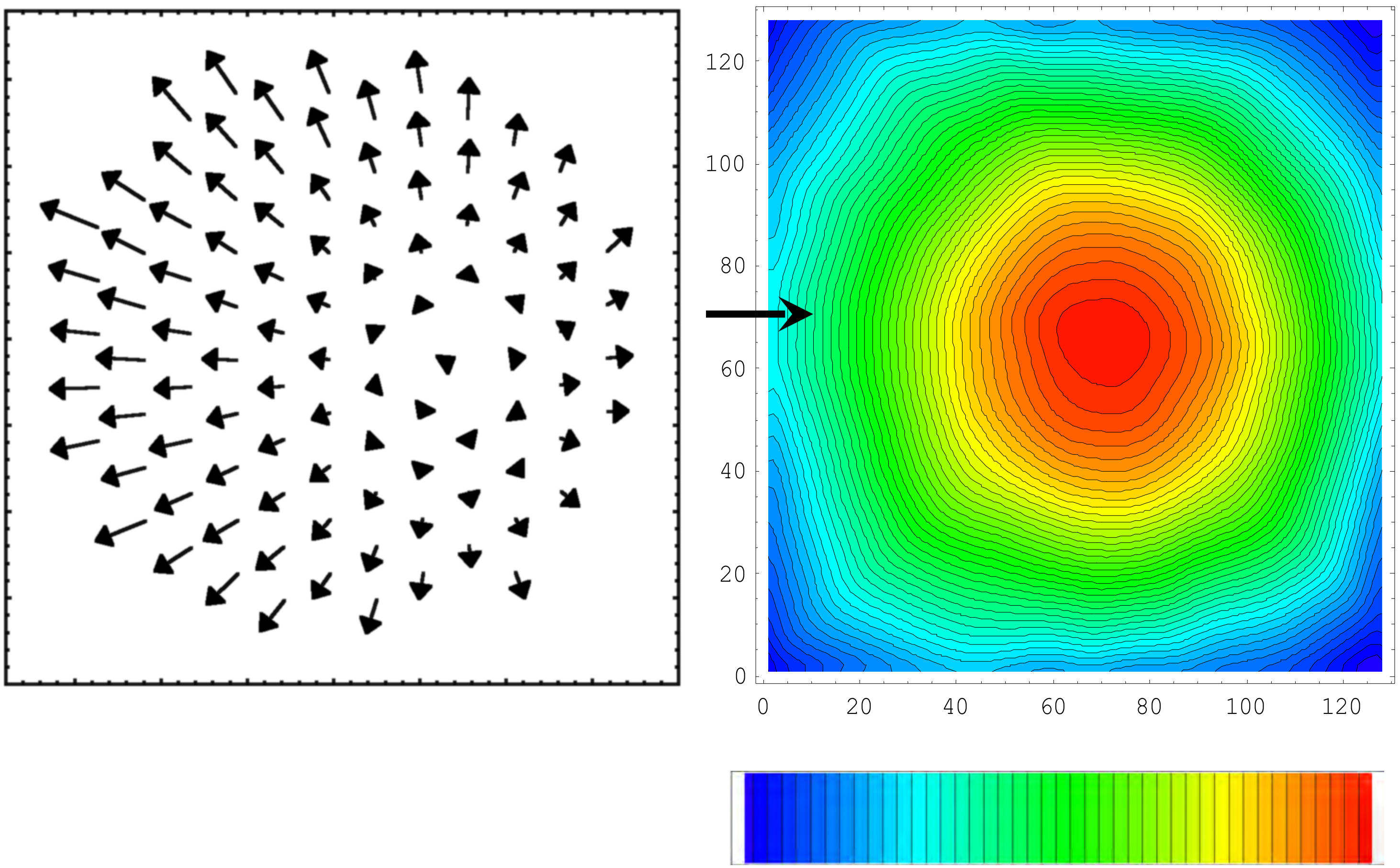
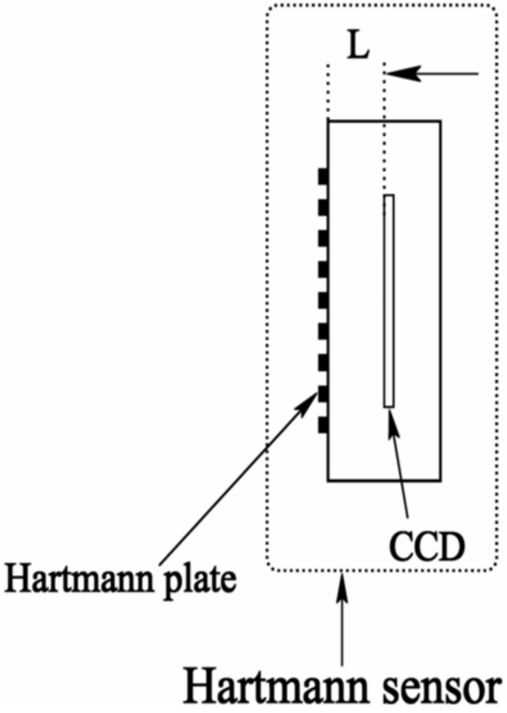
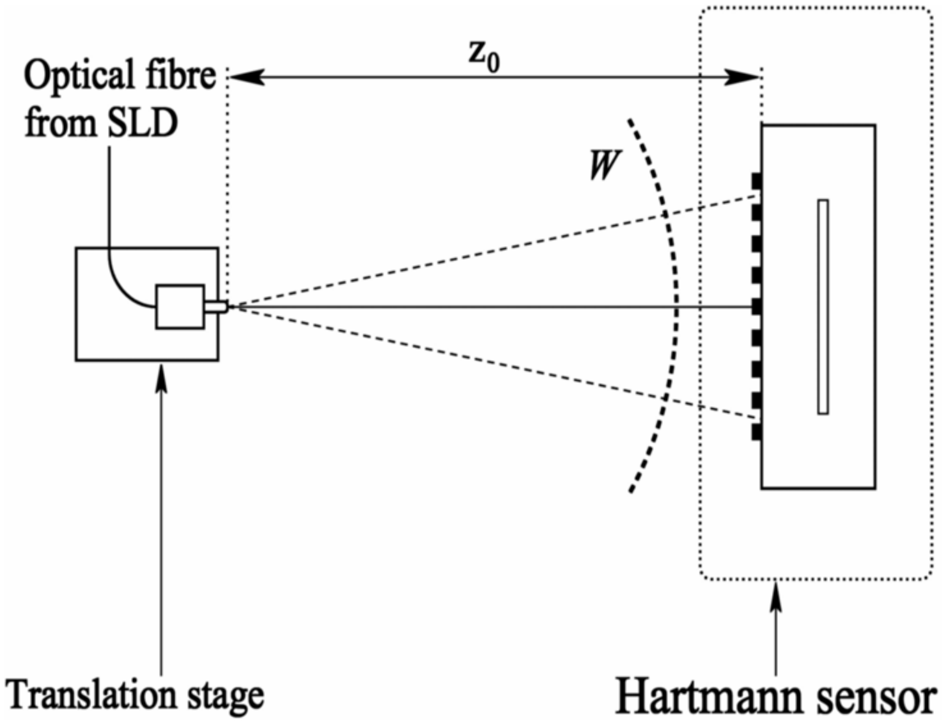
Integrate gradient field → wavefront change



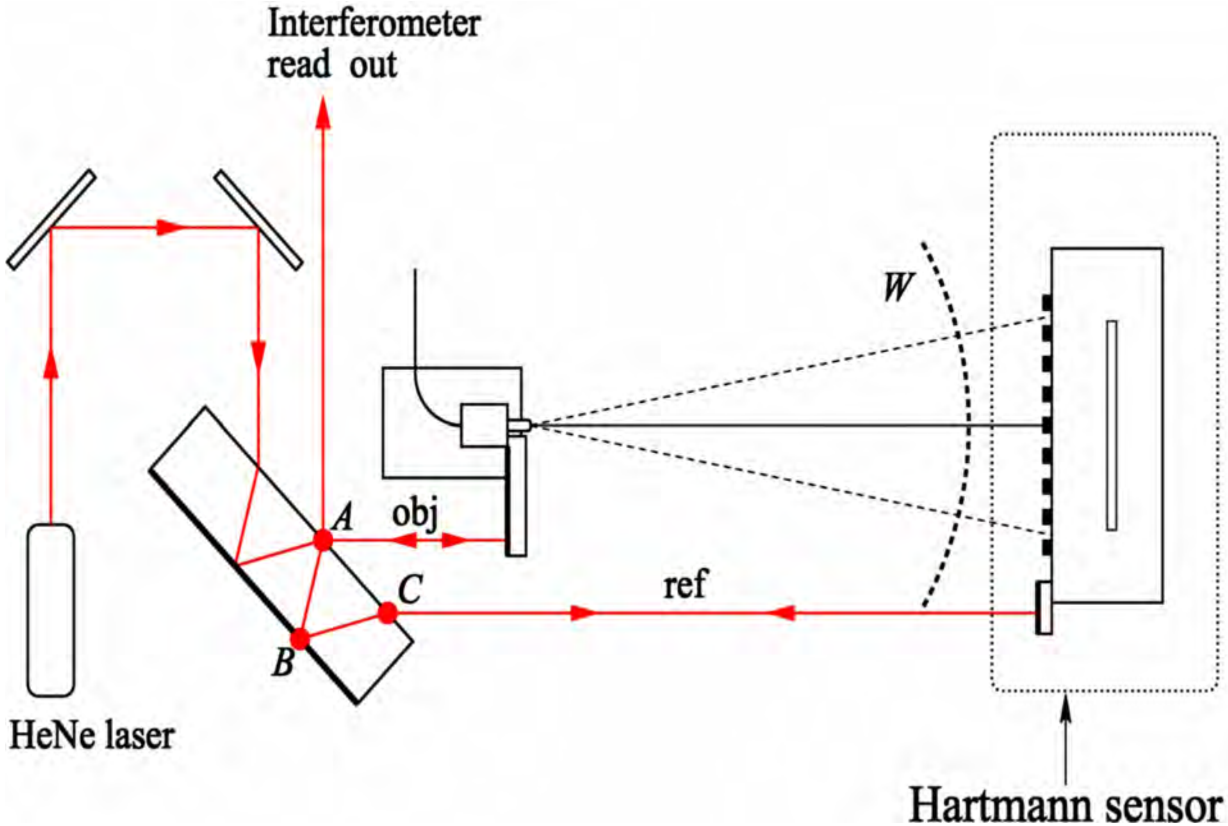
Measurement system for testing HWS



Measurement system for testing HWS



Measurement system for testing HWS



Single-frame wavefront error ≈ λ/1500

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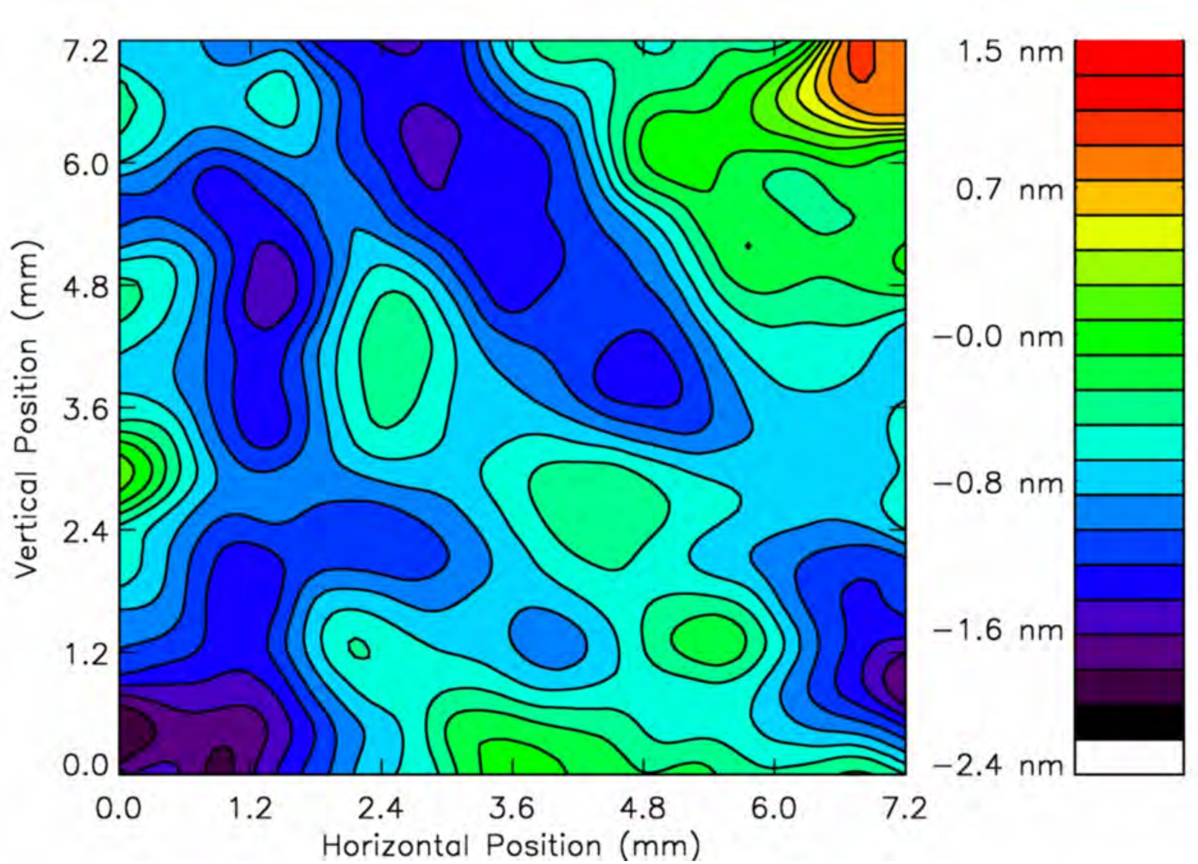
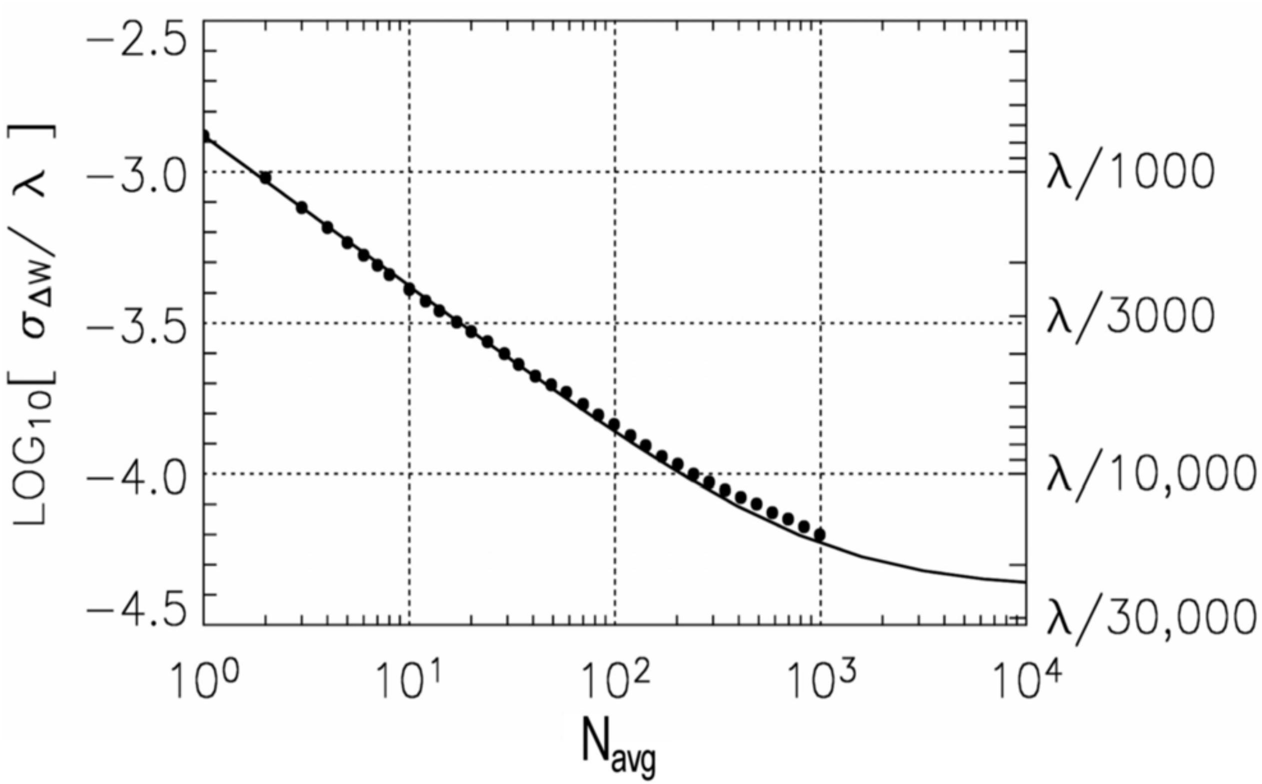
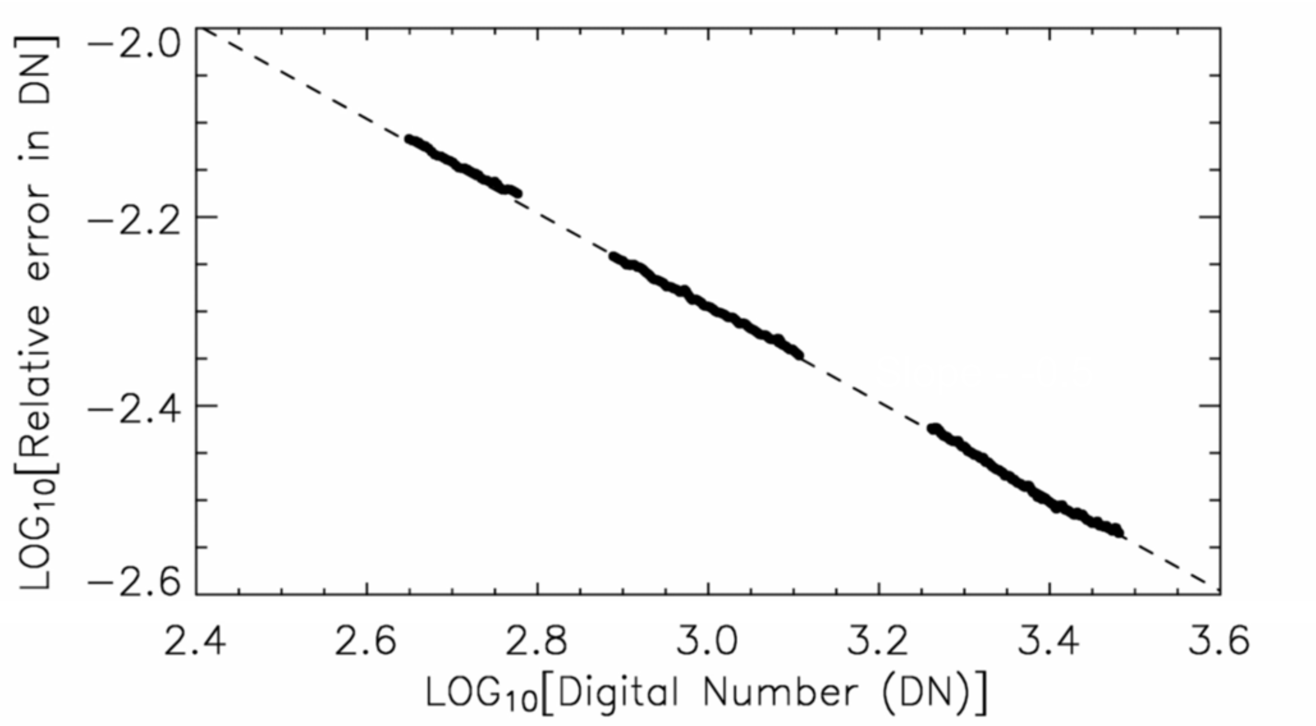
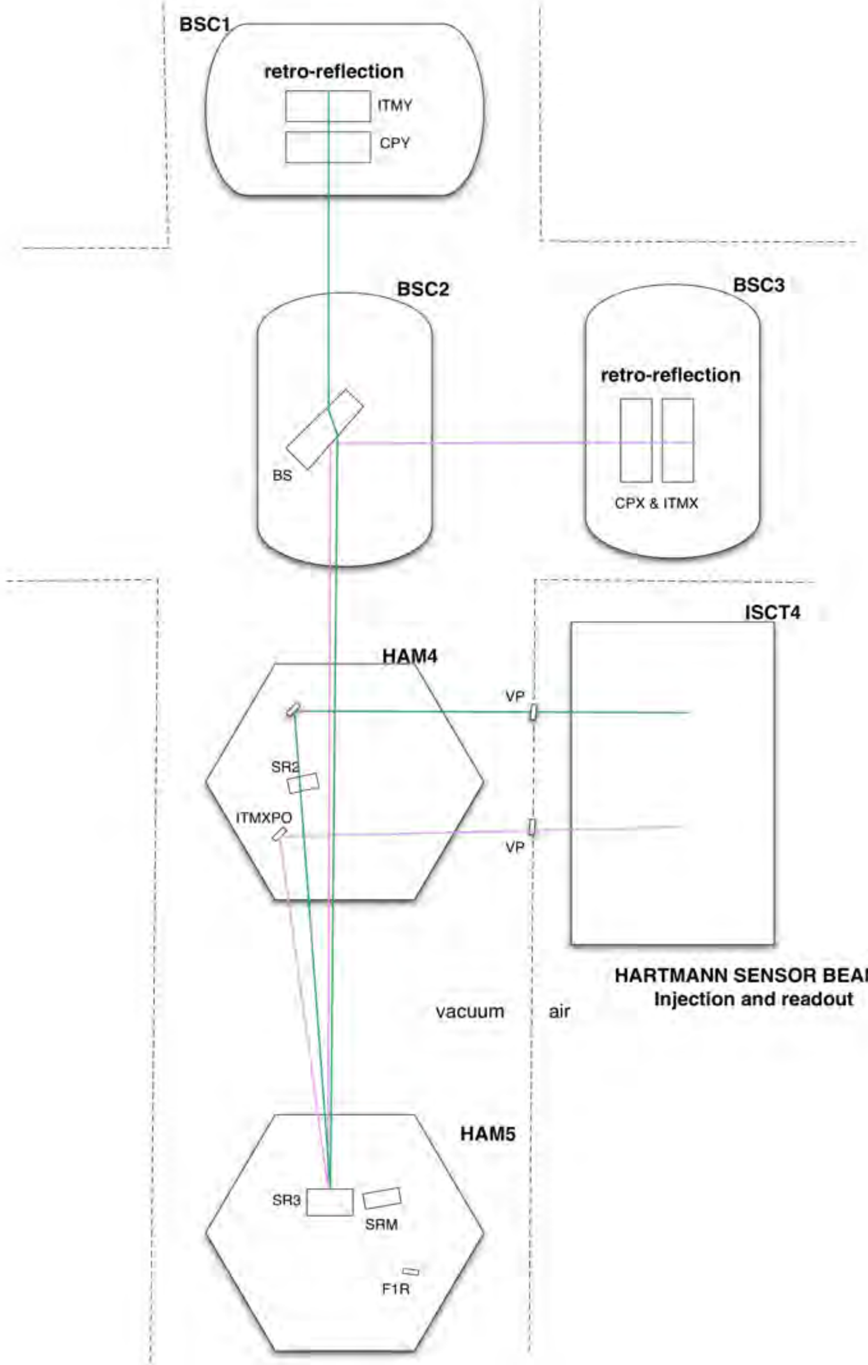


Sensitivity can be improved to λ/15,500 by averaging



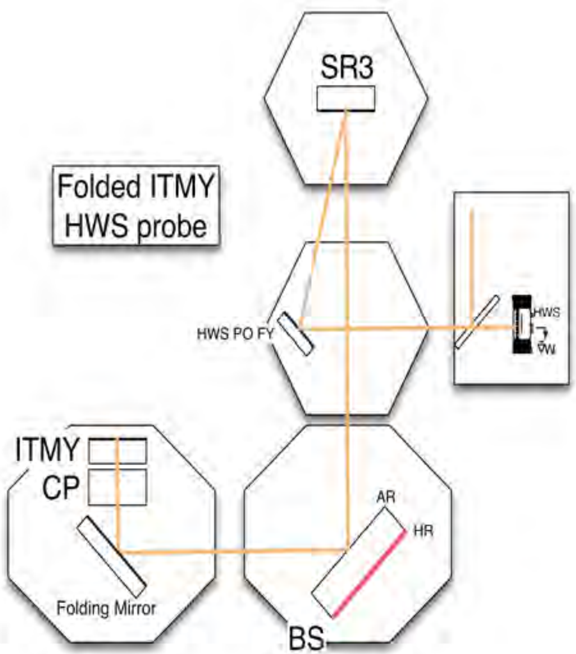
HWS is shot-noise limited

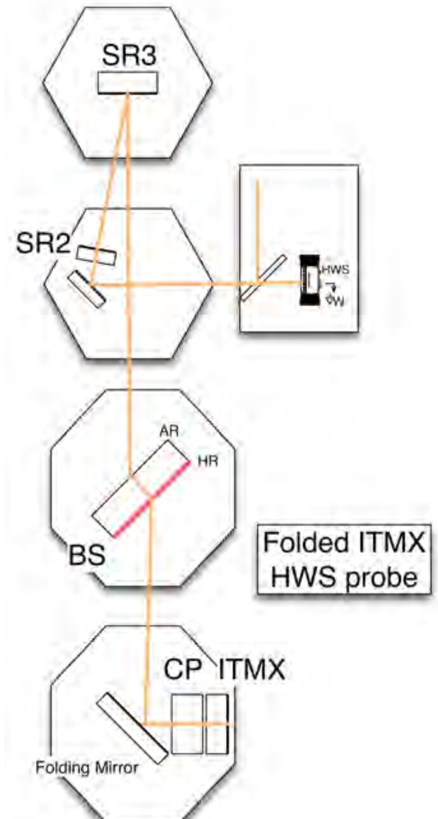




HARTMANN SENSOR BEAMS
Injection and readout

Hartmann sensor configuration folded interferometer





Hartmann Sensor Progress

LIGO-Australia promotes Research and collaboration

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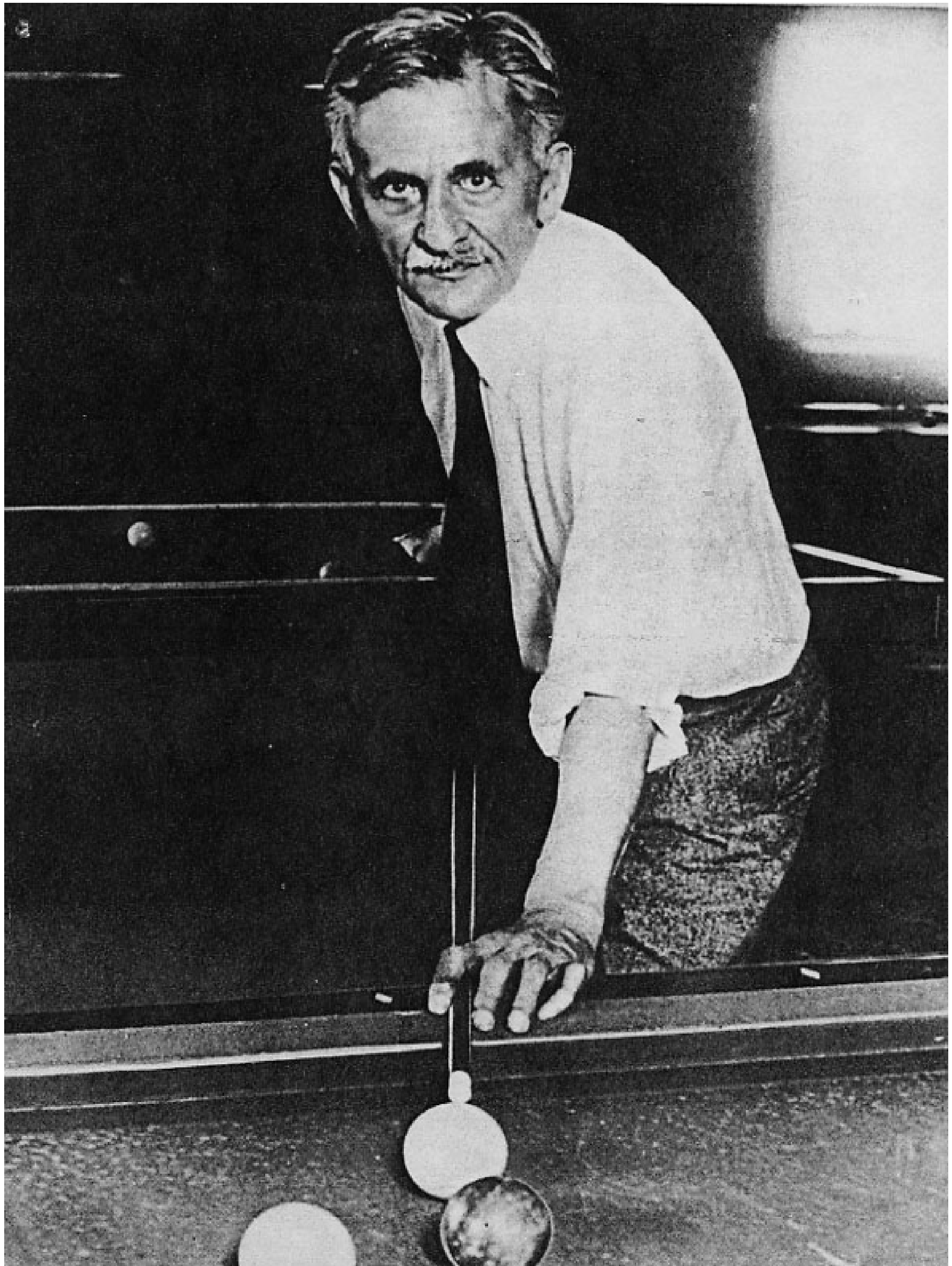
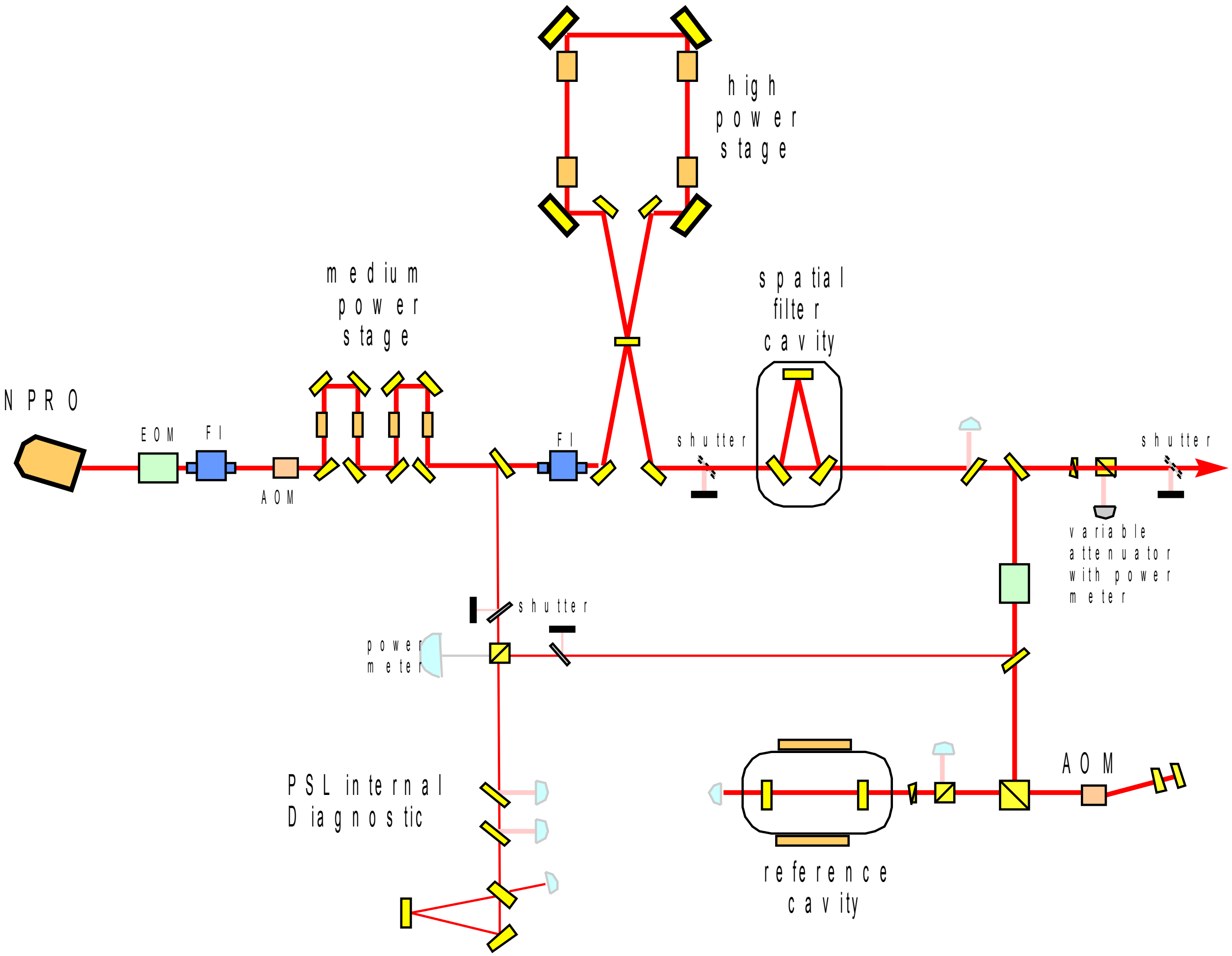
  - Lasers
  - Optics, including NLO
  - Adaptive optics



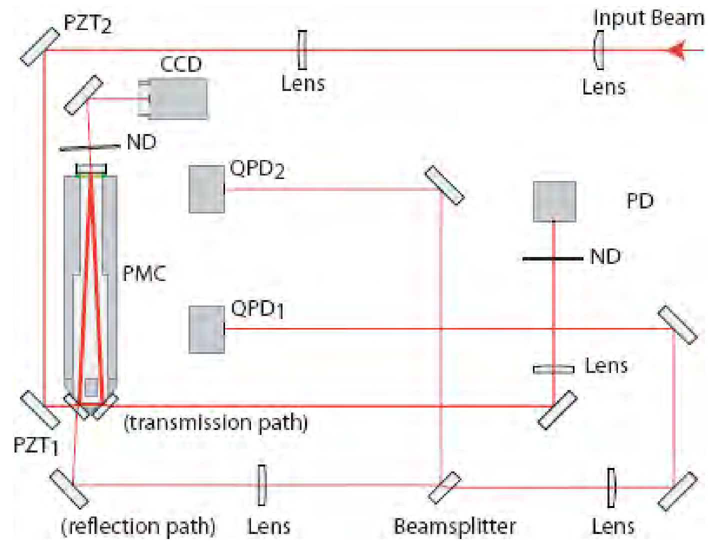
diagnostic bread board

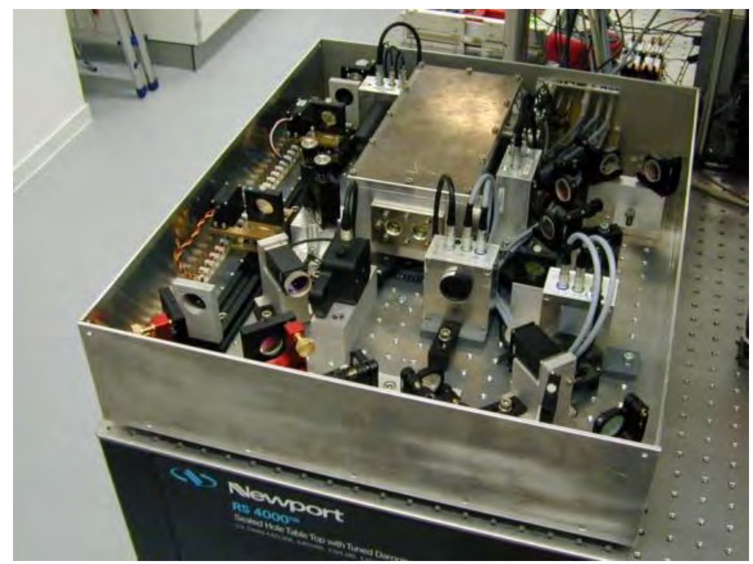


beam diagnostic tool

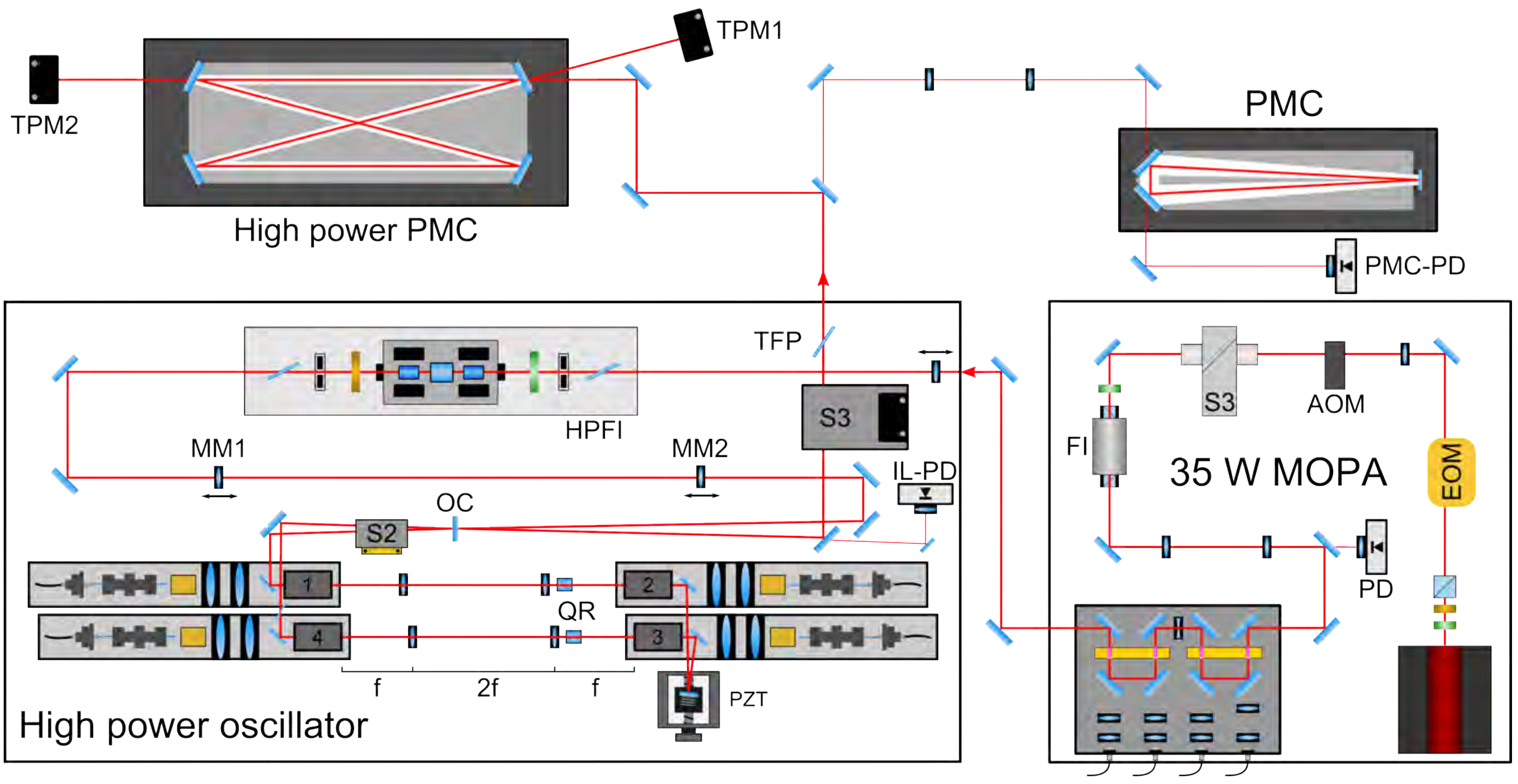
- power noise (low f and rf)
- frequency noise
- higher order mode content
- beam pointing (differential wavefront sensing)

- automatic length and alignment control
- can switch from lock to scan mode
- performs complete beam analysis without human interaction (at night during long term test)
- allows fast turn around between laser optimization and characterization

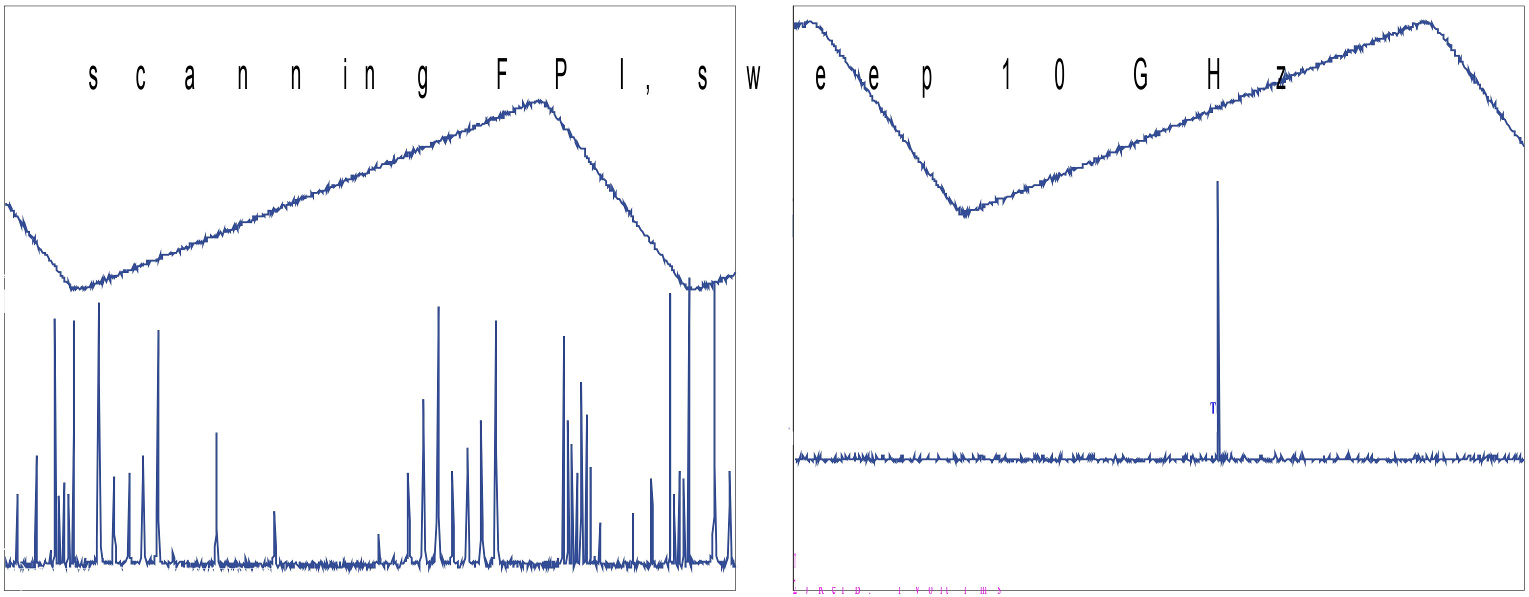




Pre-stabilized Laser
(Max Planck contribution)



Stable-unstable laser



free-running slave laser   master laser

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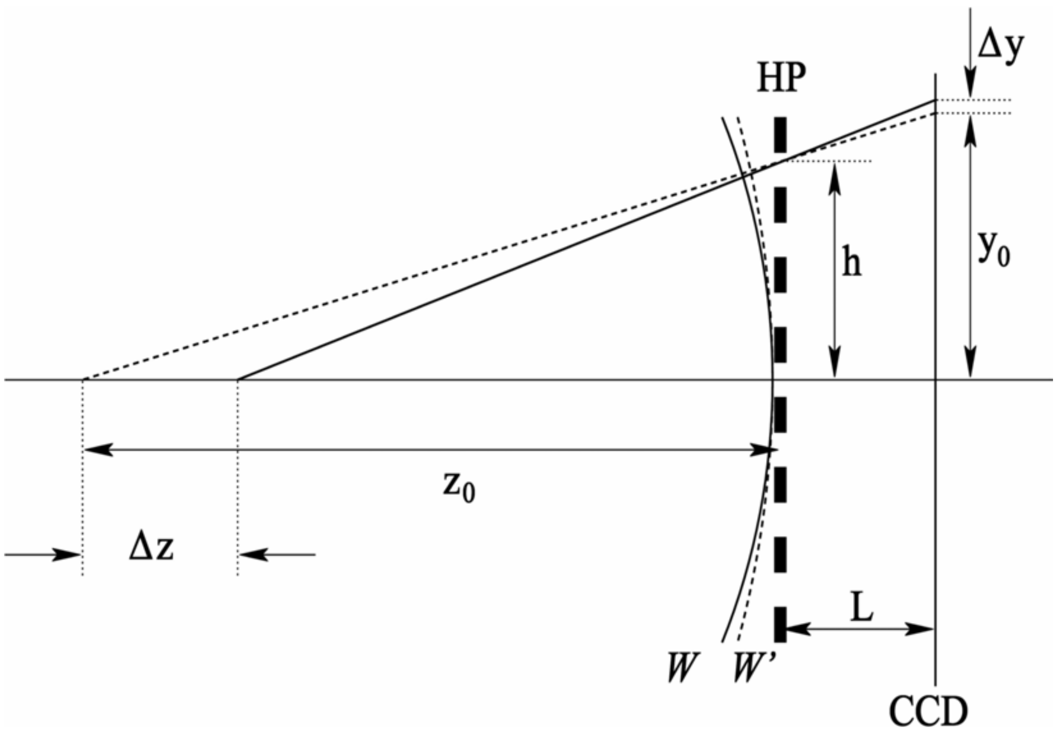
Introduce well-defined wavefront defocus by moving the light source



Expect wavefront gradient: $\Delta y / L \propto y_0$ - slope gives measured defocus

Measured Defocus