Status of the LIGO Project

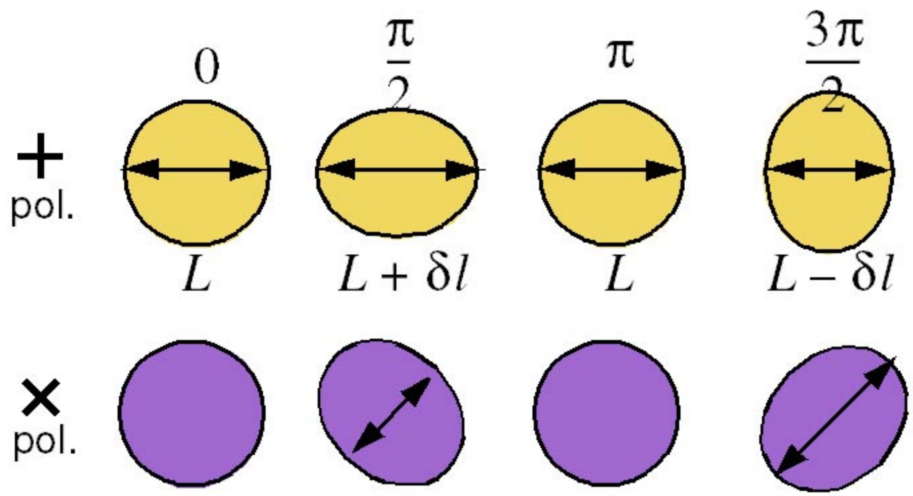
SLAC, August 1, 2000

Daniel Sigg, LIGO Hanford Observatory

LIGO-G000178-00-D

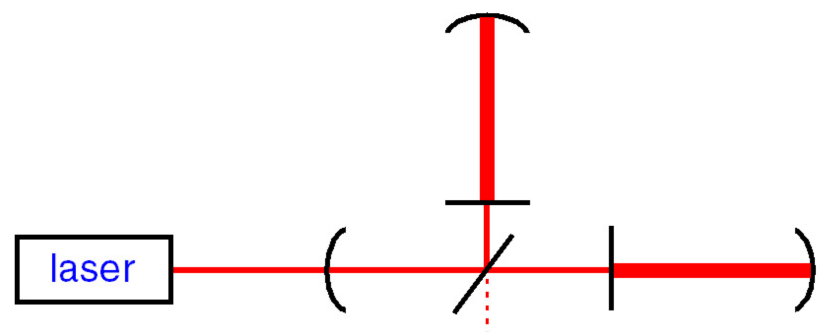
Basic Idea

General Relativity (Einstein 1916) predicts freely propagating transverse space-time distortions



Michelson Interferometer

Pirani '56, Gerstenshtein and Pustovoit, Weber, Weiss '72



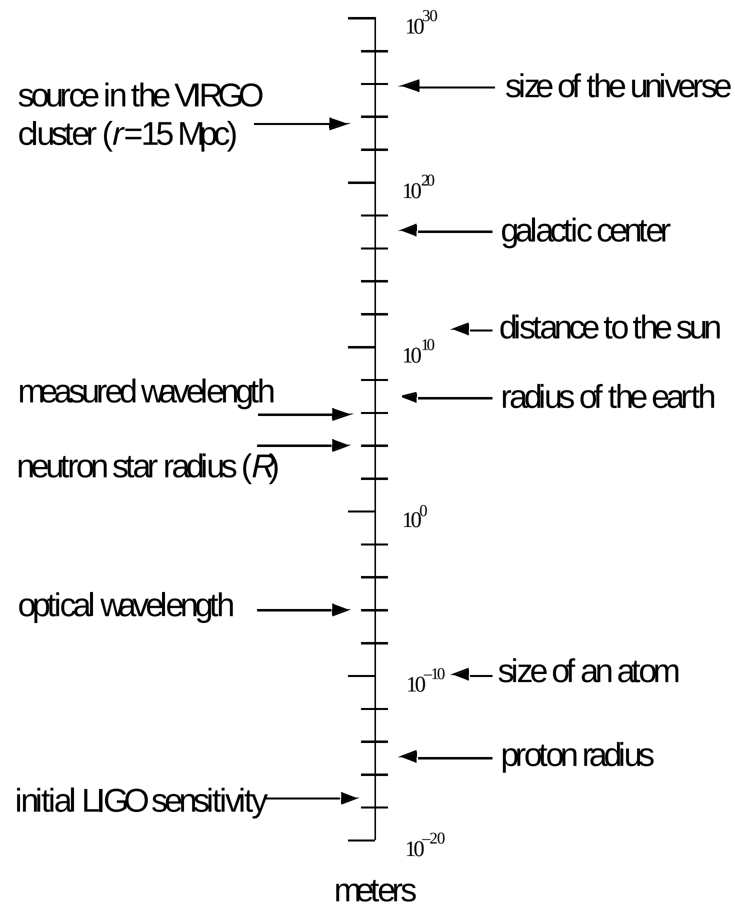
Detection of Gravitational Waves

Strength:

$$\frac{\delta L}{L} \approx 10^{-20} \times \left(\frac{E^{\text{kinetic}}_{\text{non-spherical}}}{M_{\odot} \times c^2} \right) \times \left(\frac{15\ \text{Mpc}}{r} \right)$$

Rough estimate of binary neutron star merger rate:

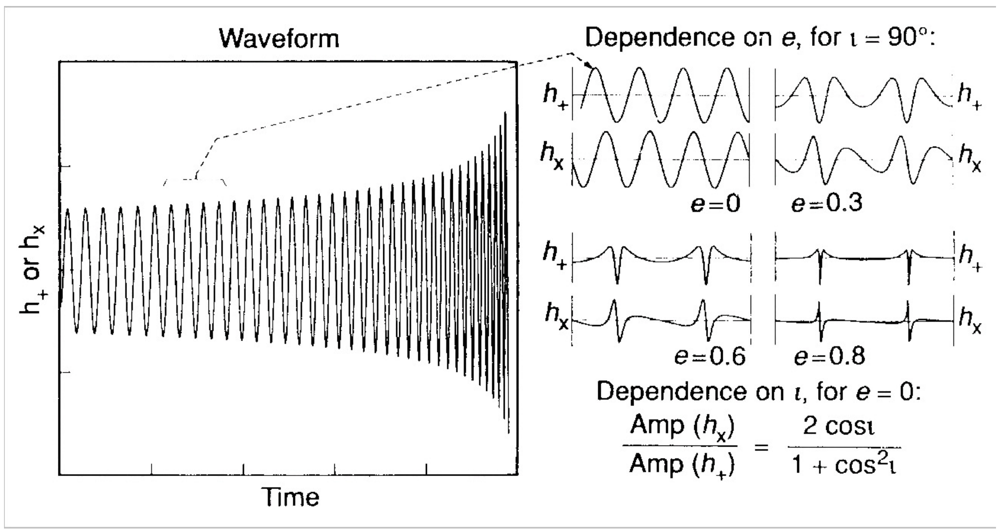
3 events/year within 200 Mpc $\Rightarrow \frac{\delta L}{L} \approx 10^{-22}$



LIGO

List of Possible Sources

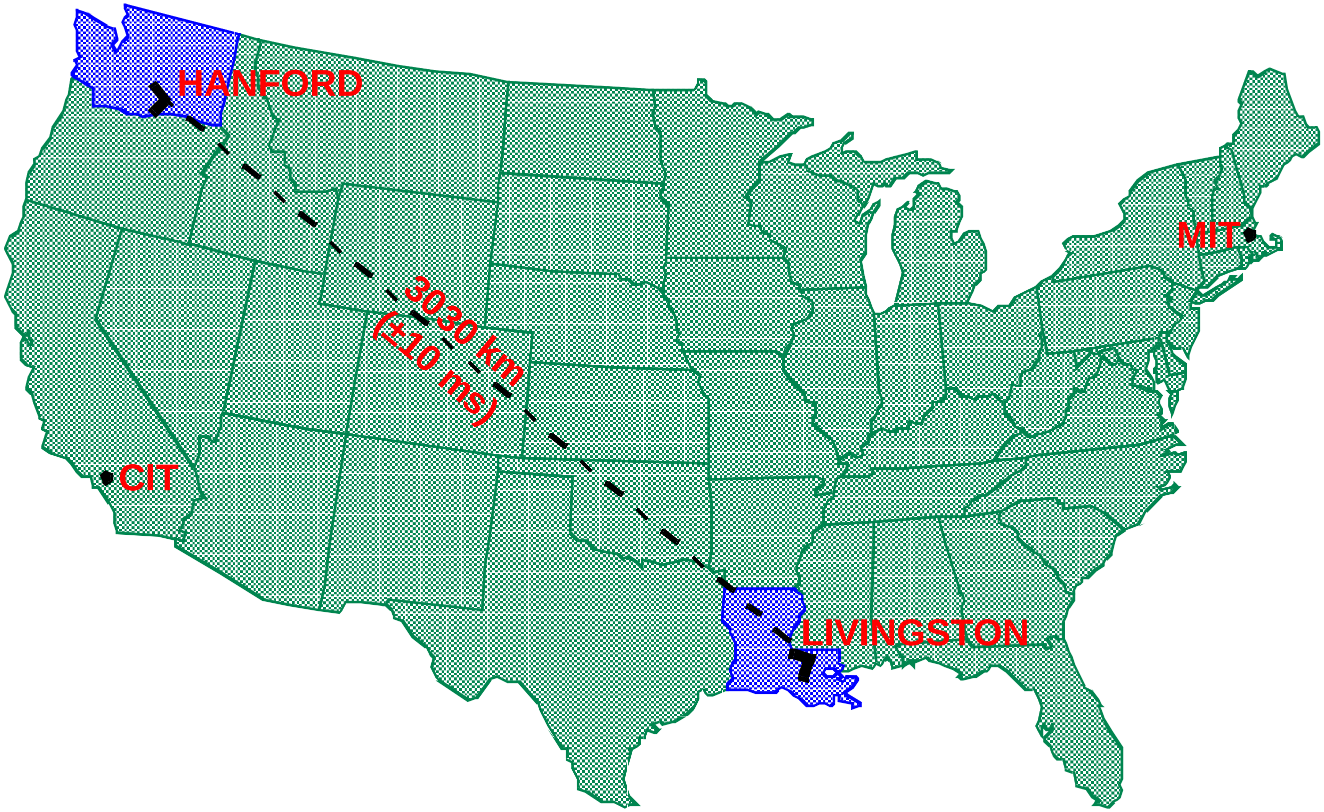
- Coalescing Compact Binaries
  - Neutron stars: large scale nuclear matter
  - Black holes: strong field general relativity



- Burst Events
  - Supernova: asymmetric collapses
  - Gamma-ray burst events(?)
- Periodic Sources
  - Spinning neutron stars: rotational instabilities, r-modes, numerical hard
- Stochastic Background
  - Primordial big-bang background
  - Cosmic strings
  - Confusion limit
- The Unexpected

LIGO

LIGO Sites

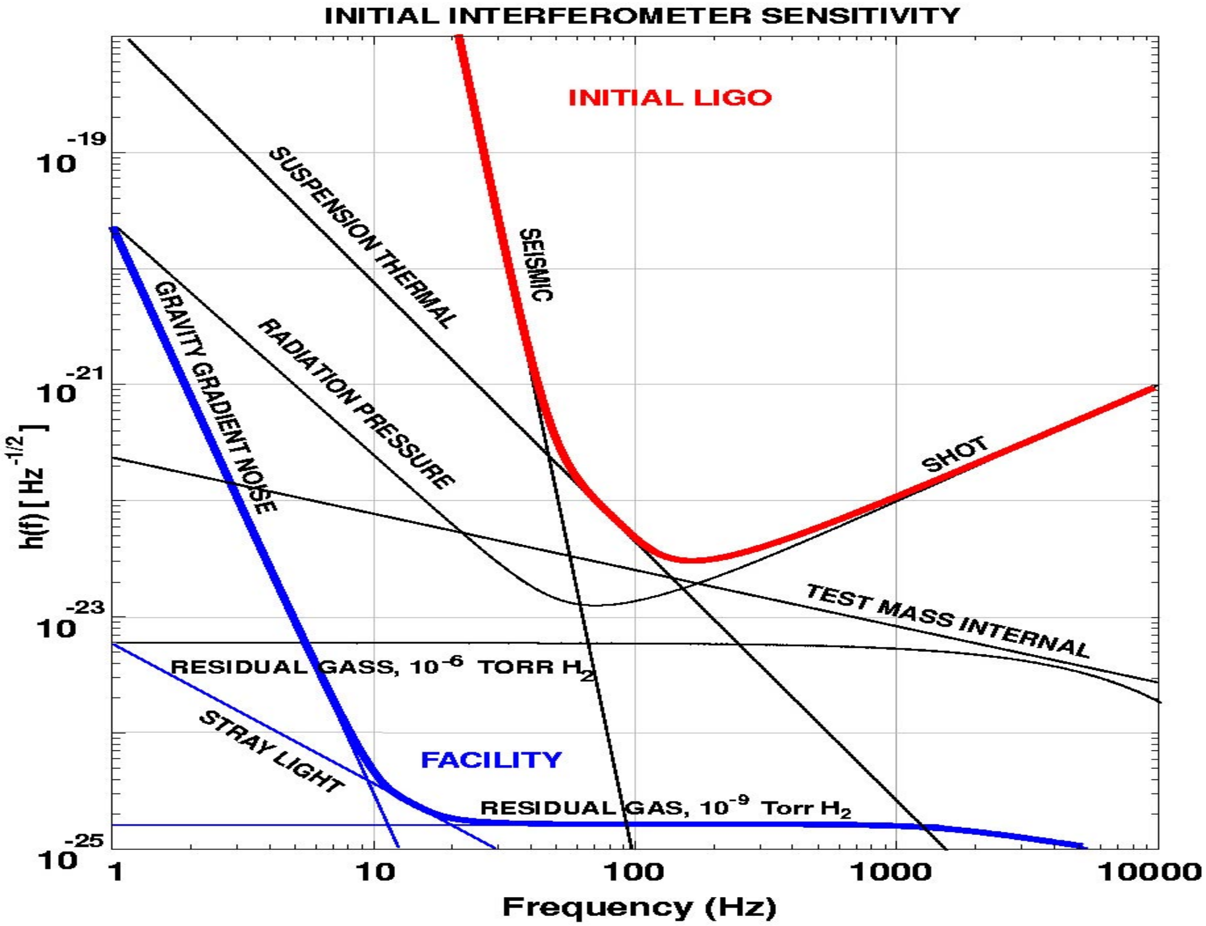


Arial View of the LIGO Sites

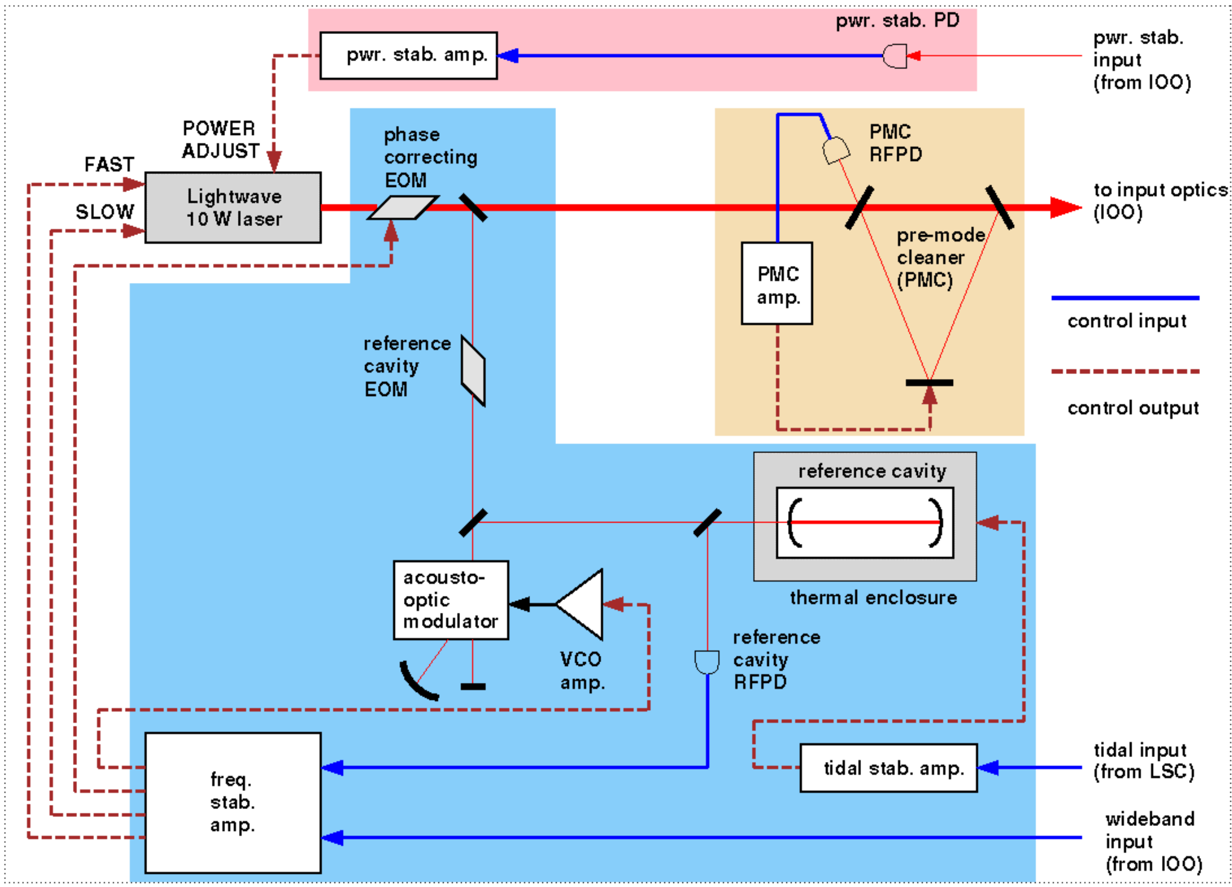
LIGO Hanford Observatory

LIGO Livingston Observatory

Noise and Sensitivity

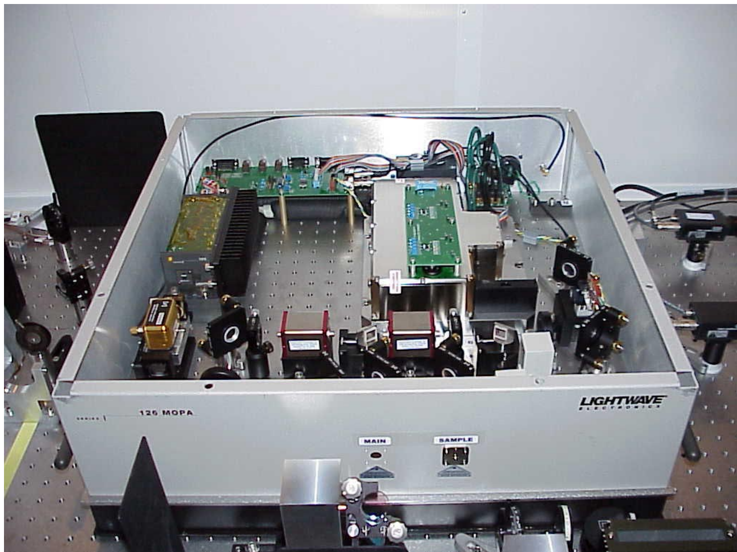


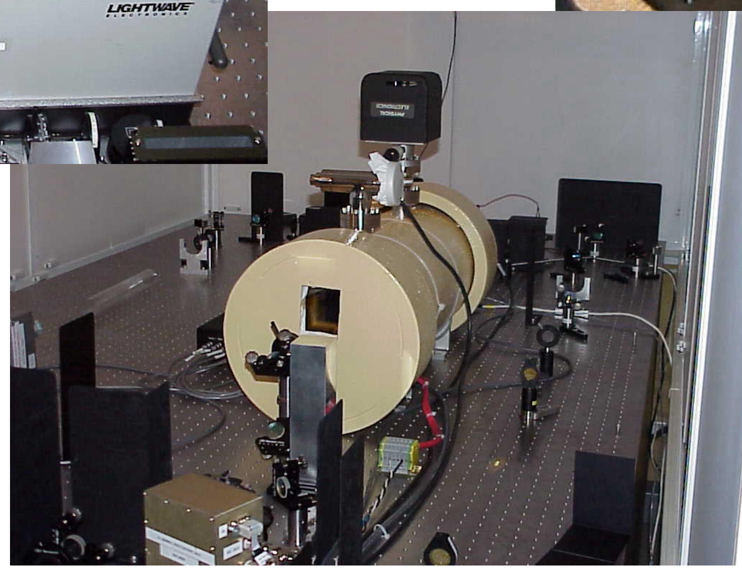
Stabilized Laser Source

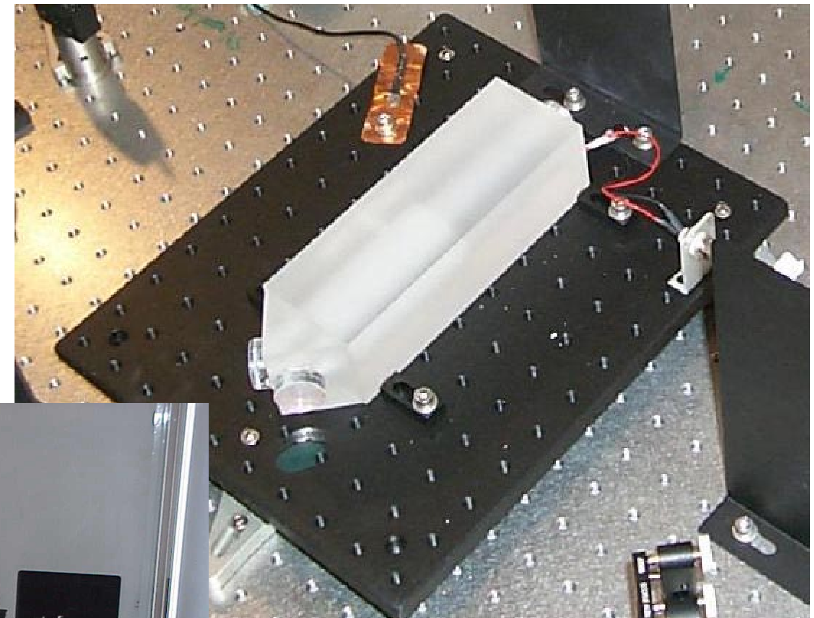


- Master Oscillator Power Amplifier configuration
- Lightwave Model 126 non-planar ring oscillator
- Double-pass, four-stage amplifier
- All solid state: amplifier utilizes 160 watts of laser diode pump power

Washington 2k Laser, Reference Cavity and Pre-Mode Cleaner

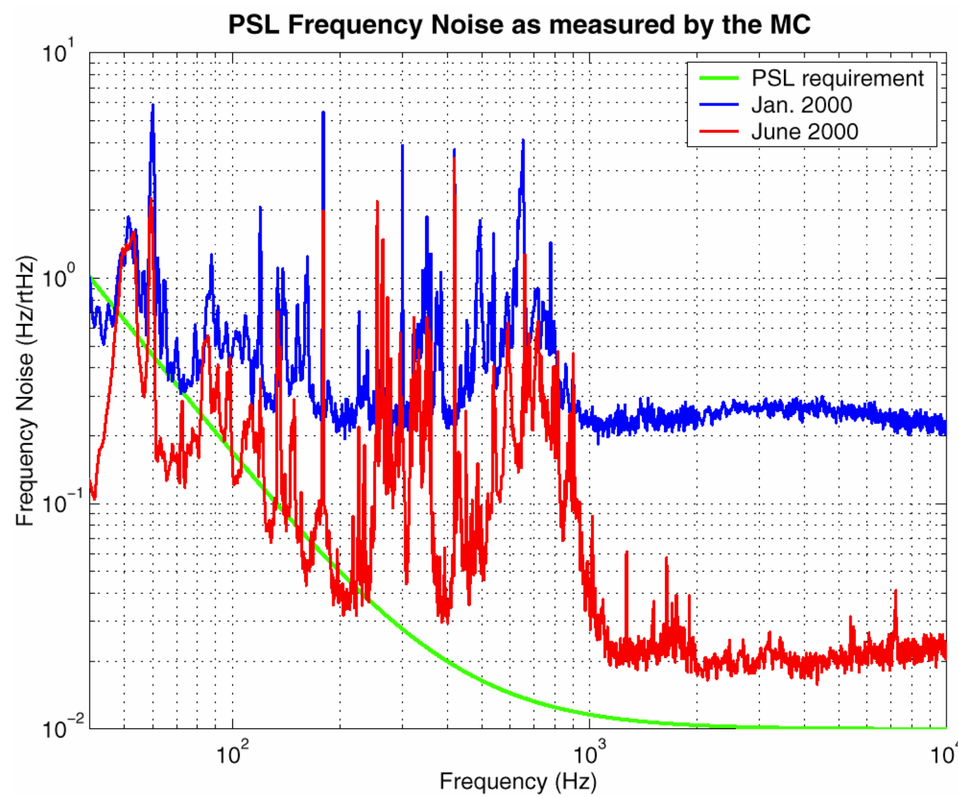




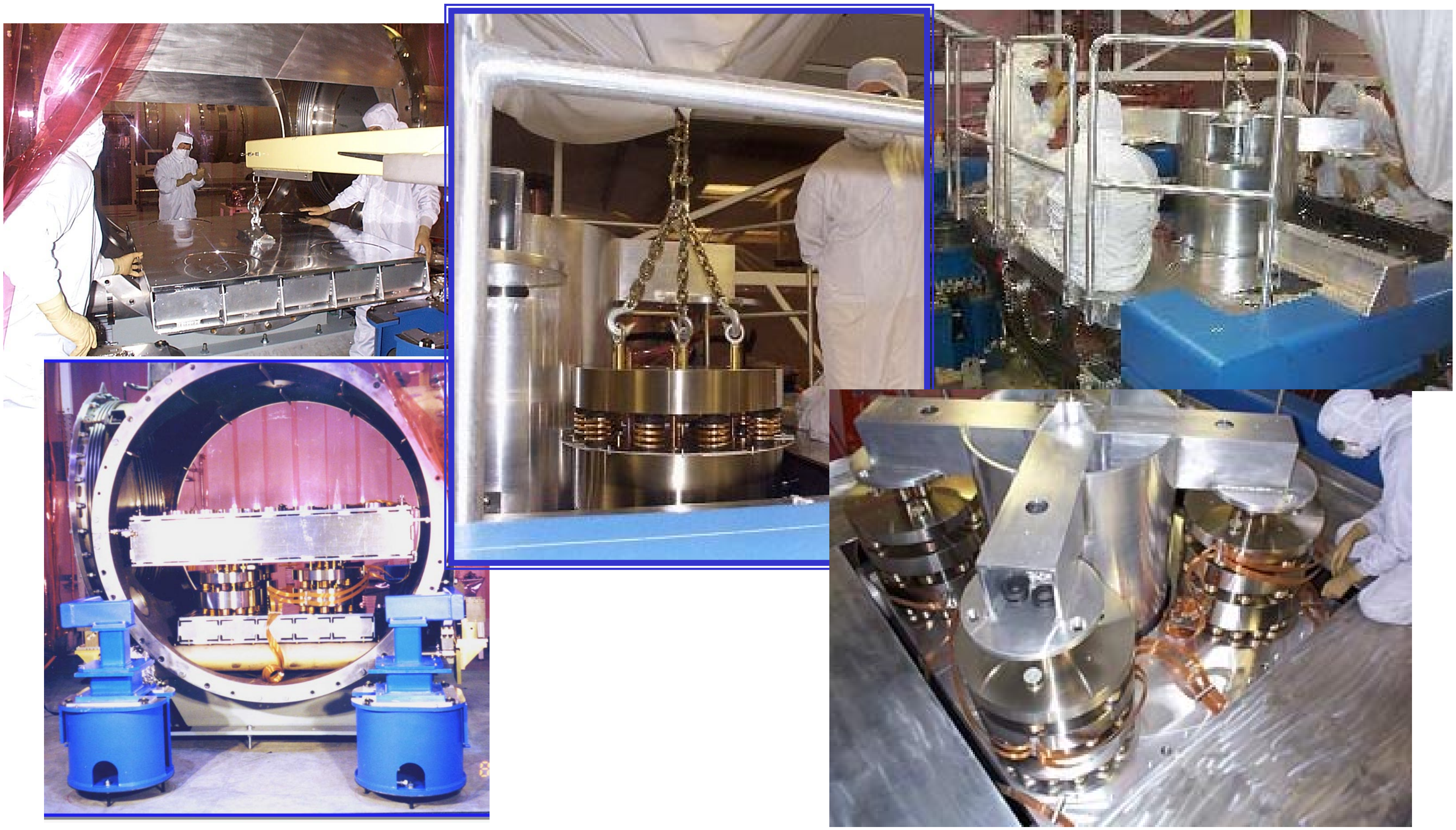


Laser Specifications and Performance

- WA-2k PSL > 15,000 hours continuous operation
  - Two power supply failures
- Frequency and PMC lock very robust
- TEM_{00} power > 8 Watts
- Non-TEM_{00} power < 10%
- Free-running frequency noise ~100 Hz/√Hz at 100 Hz. Falling as 1 / f
- Six units delivered to LIGO to date.

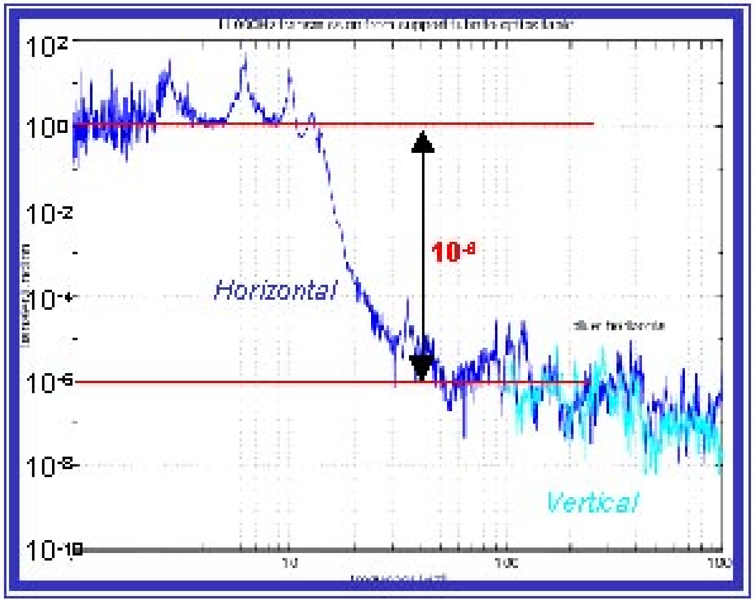


Seismic Isolation Installation Completed



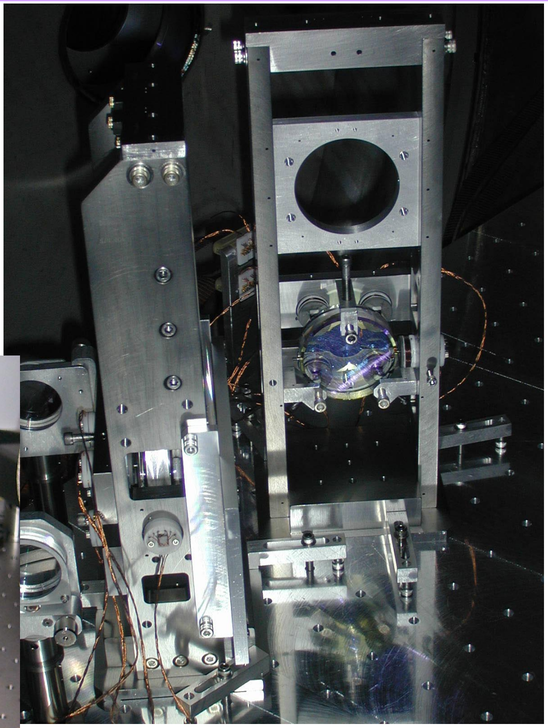
Seismic Isolation: Commissioning

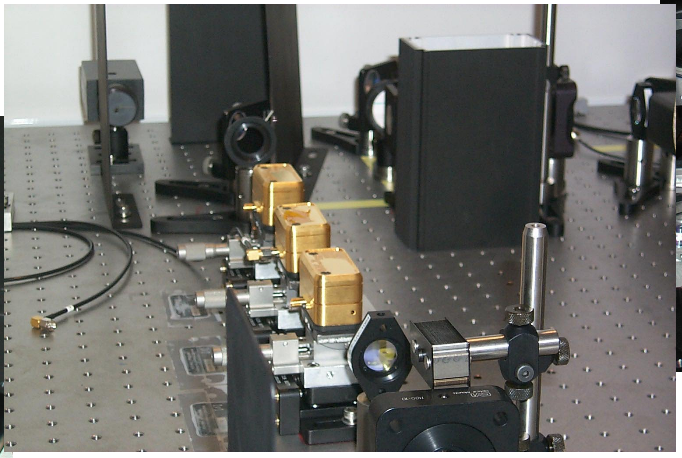
- First-article tests and in-air transfer functions
- In-vacuum transfer functions begun at Livingston, ongoing at Hanford, using in-vacuum accelerometers
- Fine actuator transfer functions measured using 2-km Fabry-Perot

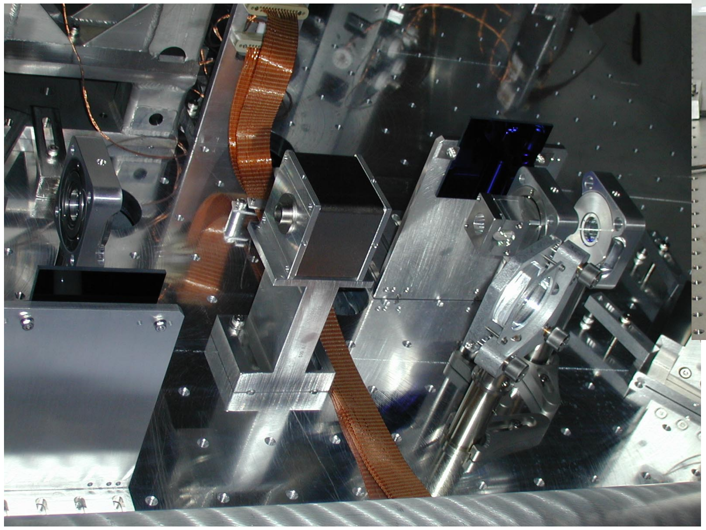


Input Optics: RF Modulators, Mode Cleaner & Faraday Isolator

- Impose phase-modulated RF sidebands
- Filter non-TEM_{00} components of its input light
- Serve as a reference for frequency stabilization
- Suppression of amplitude noise and beam jitter
- Purify polarization







- Optical Isolation
- Provide sensing signal for IFO alignment control

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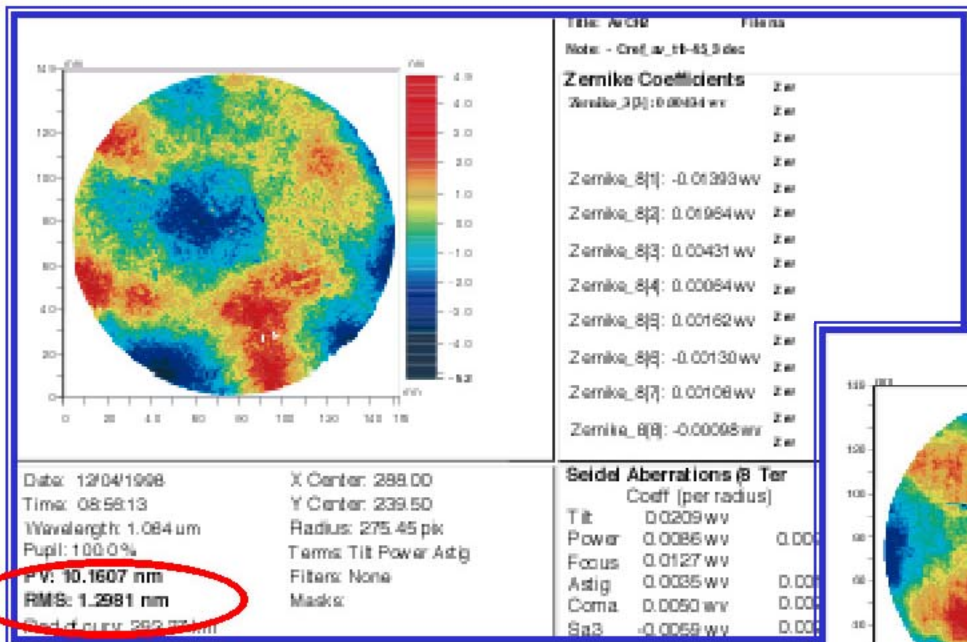
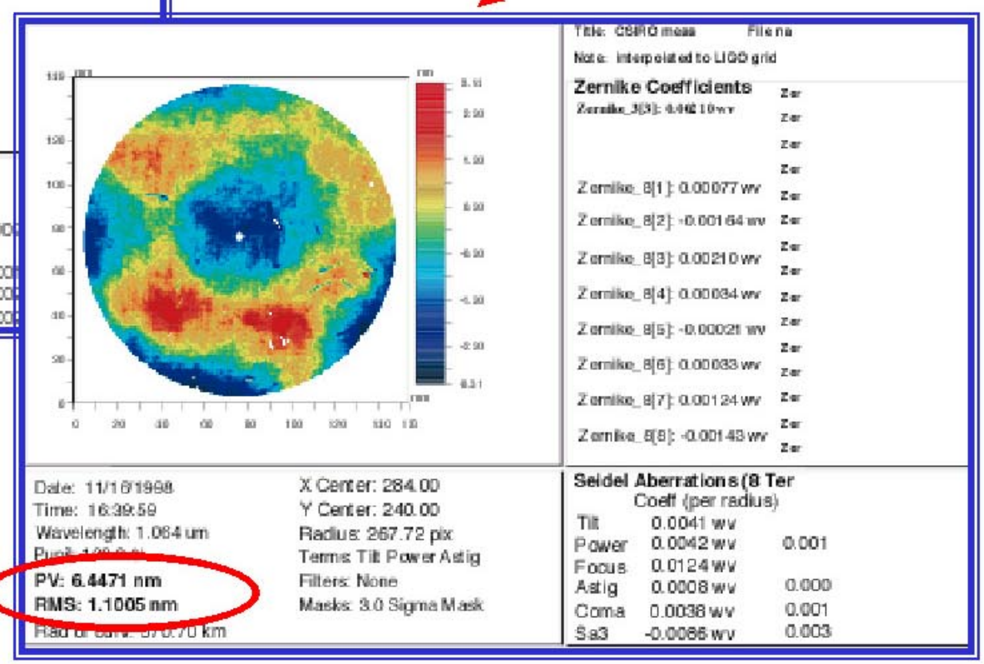
Large Optics: Metrology



Caltech Data

CSIRO Data



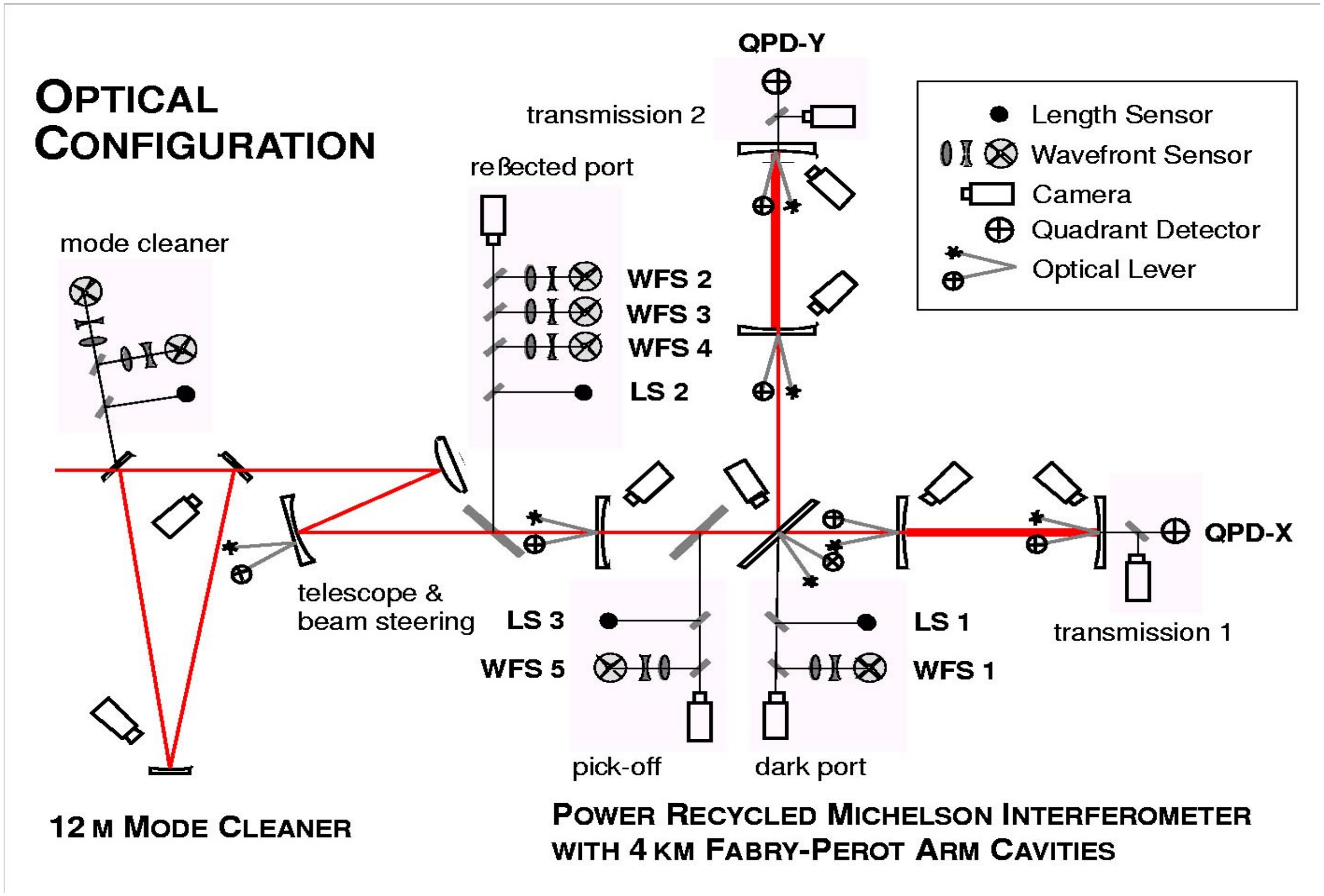
Surface uniformity:

- 3.6 Å rms (polished)
- 5.9 Å rms (coated)

Suspensions Suspension Installation & Commissioning

- Solved conflicts between bonding and cleaning procedures
- Developed reliable fixturing and alignment procedures on the job
- Installation is now smooth
- Mechanical Q's measured for mirror and pendulum modes look on target, but some instances of low Qs need follow-up
- Developed tuning procedures to minimize "cross-coupling" in shadow sensors/drivers

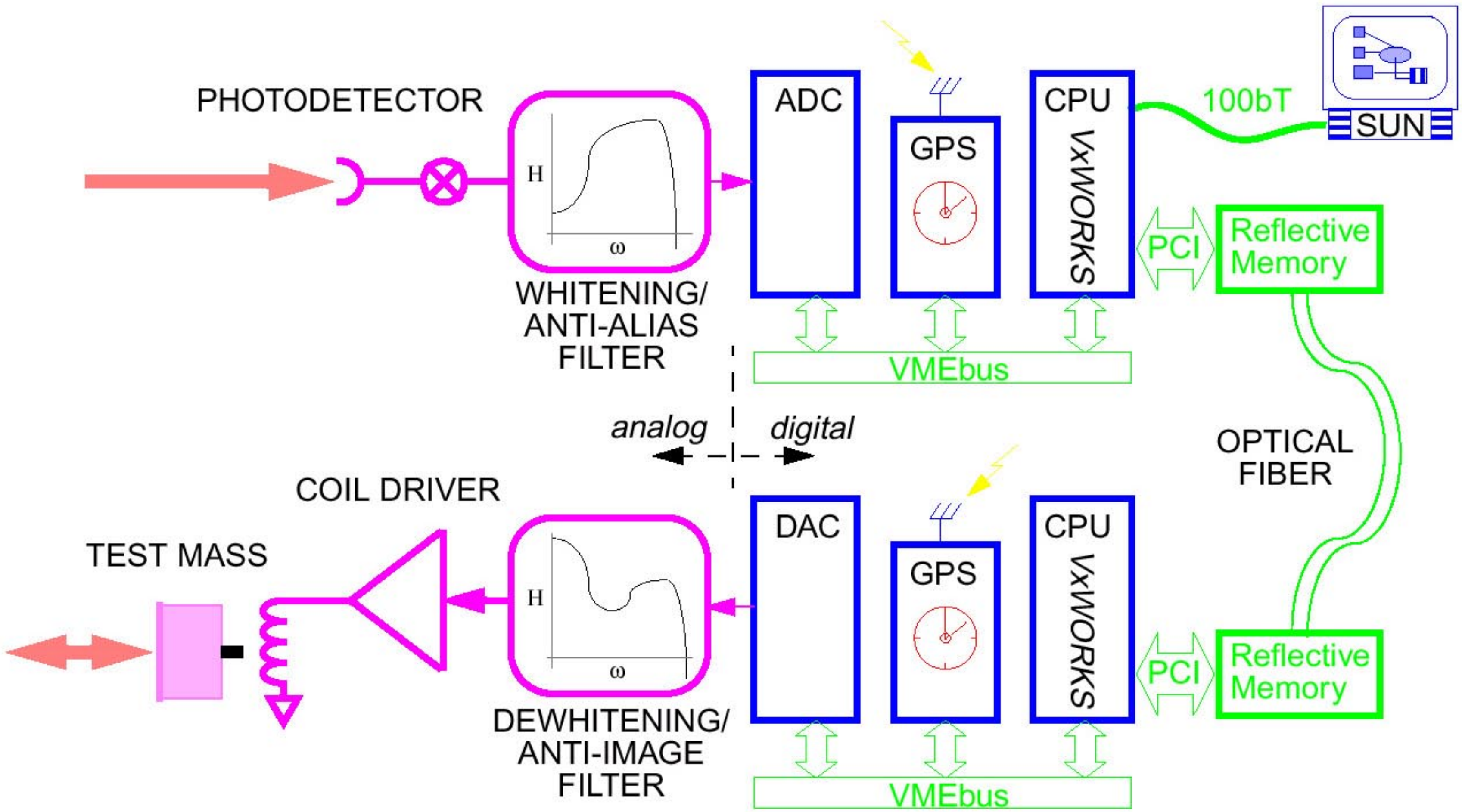
Interferometer Layout



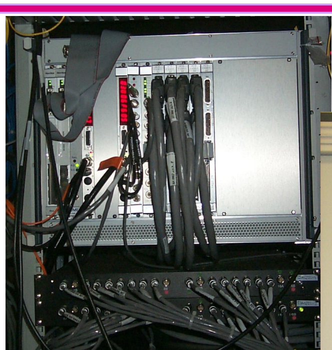
Interferometer Sensing and Control

- Length sensing and control
  - Monolithic photodetectors (Pound-Drever-Hall signal)
  - Control 4 longitudinal degrees-of-freedom & laser frequency
  - Requirements:
    - differential arm length $<10^{-13}$ m rms
    - 3×10^{-7} Hz/$\sqrt{\text{Hz}}$ frequency noise @ 100 Hz
    - controller noise for differential arm length $< 10^{-20}$ m/ $\sqrt{\text{Hz}}$ @ 150 Hz
    - and many more
- Alignment sensing and control
  - Wavefront Sensors (split photodetectors)
  - Digital control of 12 mirror angles & the input beam direction
  - Requirement: angular fluctuations $<10^{-8}$ rad rms

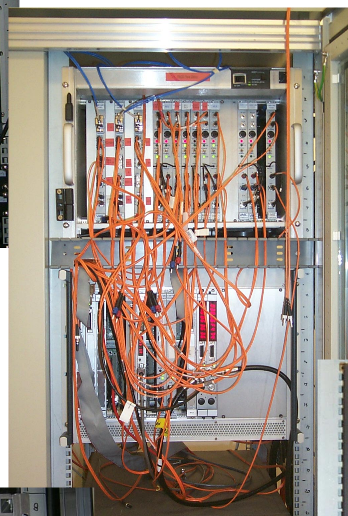
Sensing and Control System



Data Acquisition and Diagnostics

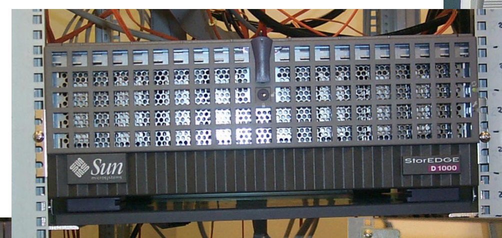


Switch

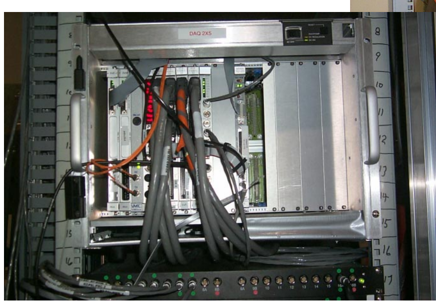


Control room

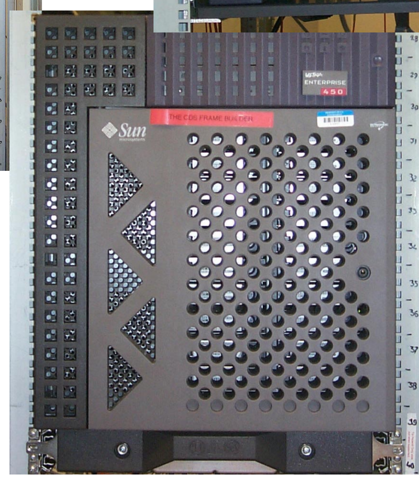
Disk farm



Data Collection

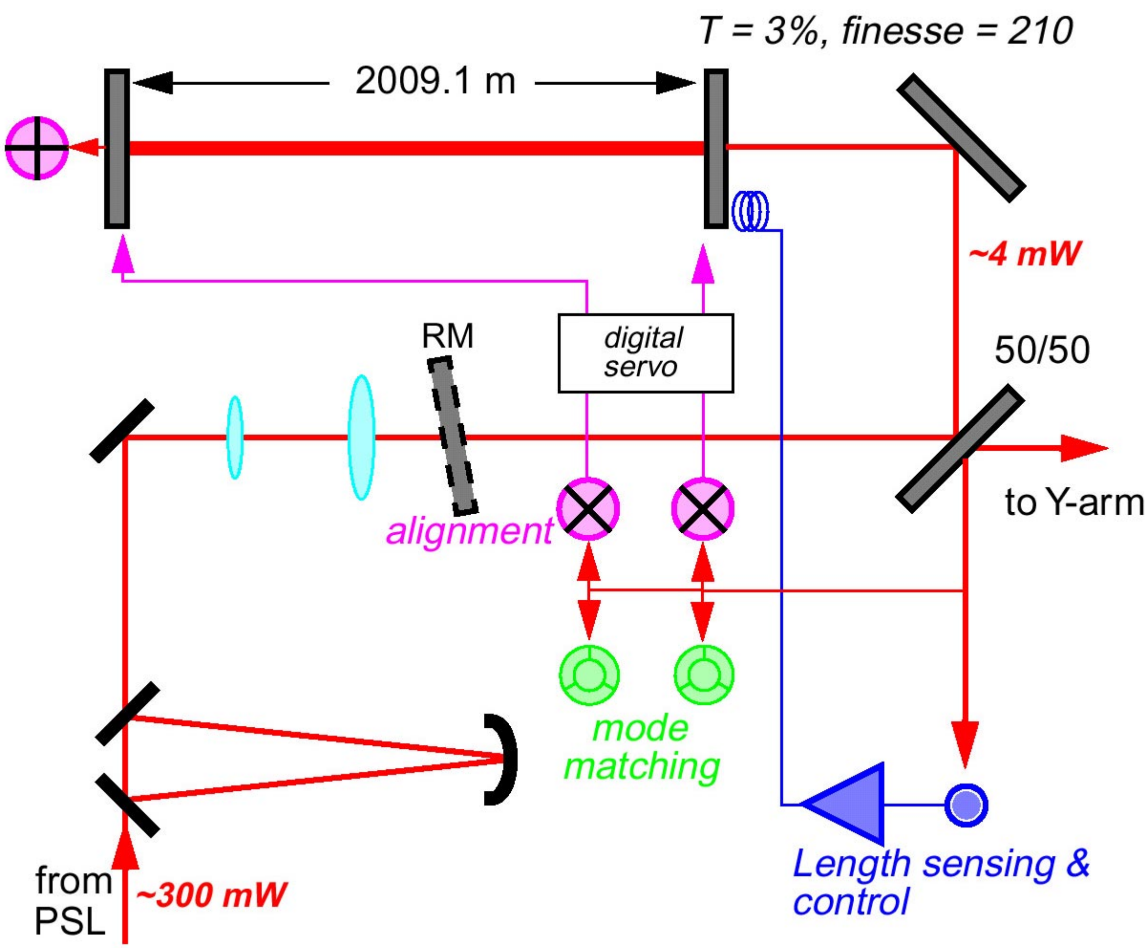


Server



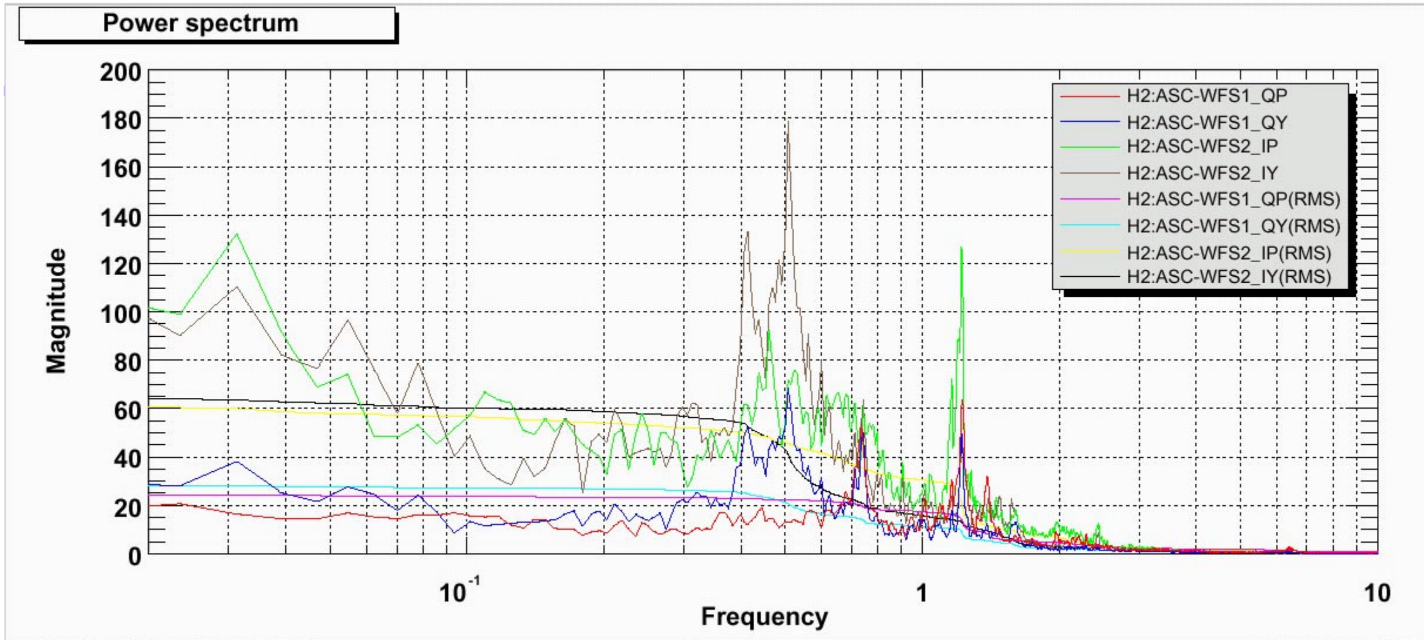
Diagnostics Monitoring

2-km Single Arm Test

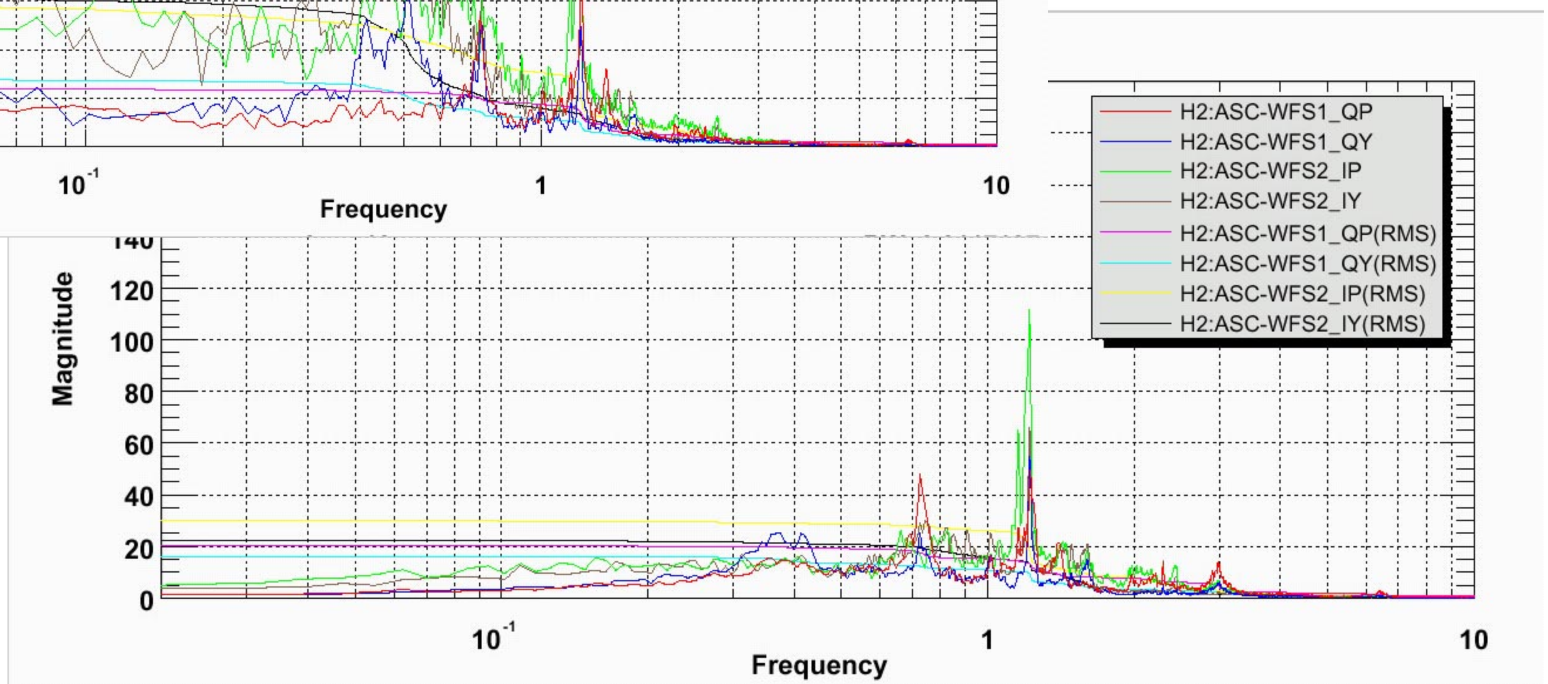


- Tested: Half of alignment sensing
- Digital Controls, networks and software all worked flawlessly
- Exercised fast analog laser frequency control
- Verified core optics meet specs(!)

Alignment Fluctuations

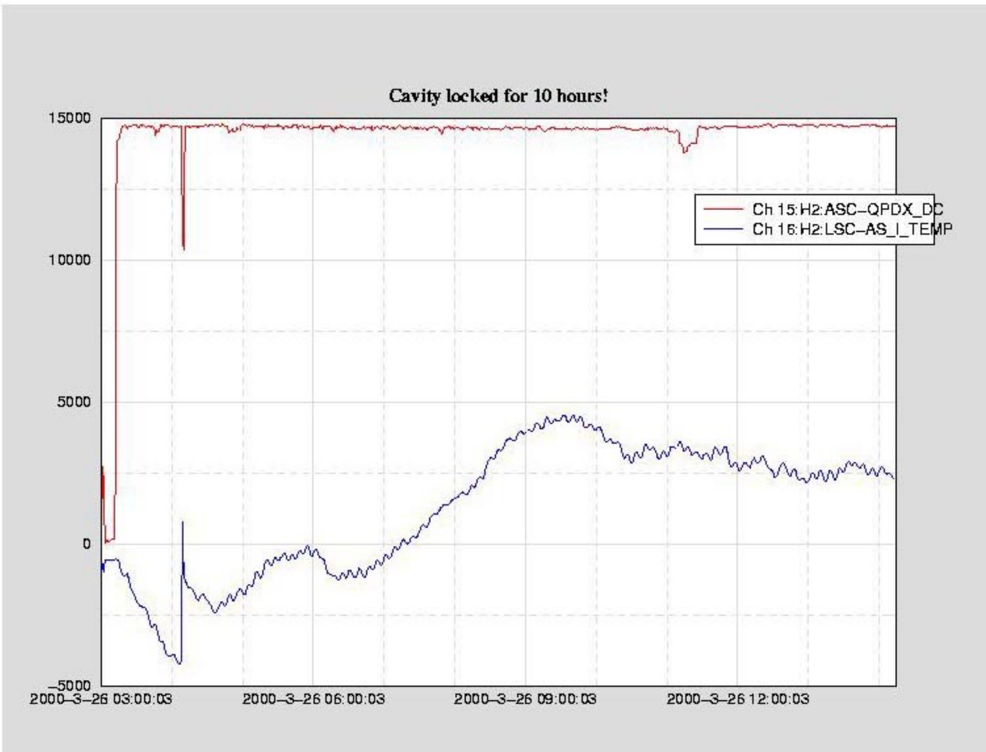


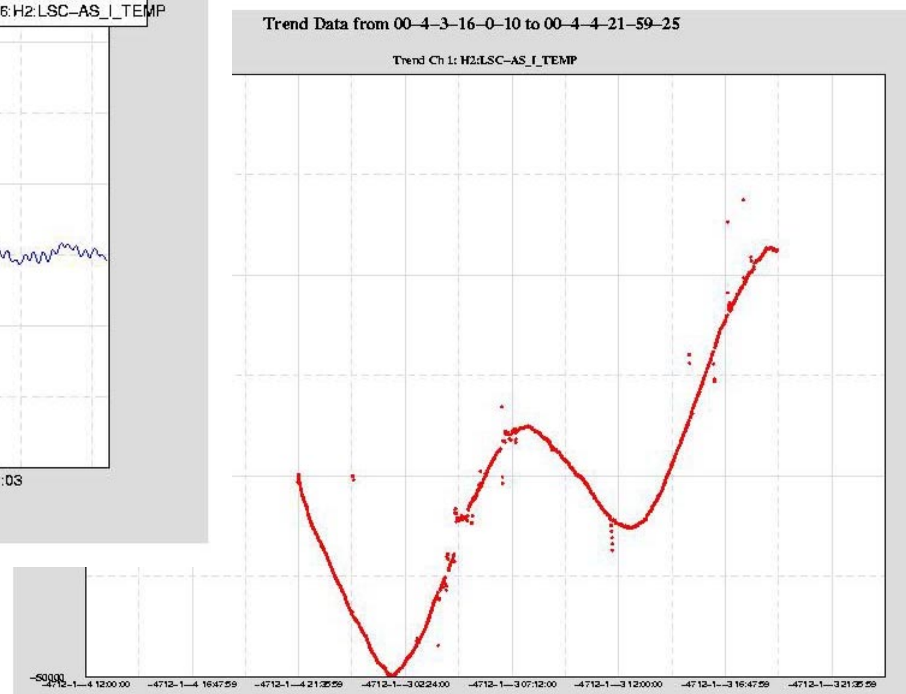
before



after

Data From Locked Stretch on Hanford 2-km Y Arm





Initial Results from Single Arm Tests

- It works!
- Optical parameters consistent with lab metrology
- Refined methodologies for aligning, tuning, mode-matching
- RMS motions dominated by microseism as expected
- Drifts consistent with earth tides in magnitude
- Auto alignment system improved fringe alignment

Shadow sensor redesign to improve scattering sens.

PSL/IO mount redesign to improve microphonics

Alignment & mode matching redone on input optics

Needed strong frequency noise suppression to deal with 350 Hz arm line width

Electronics saturates easily

“Butterfly” mode of mirror required “notching”

Current Status

- Laser and mode cleaner controls fully operational
- All hardware for Hanford 2-km interferometer installed
- Data acquisition and diagnostics systems fully operational
- Data analysis system installation started
- Livingston 4-km interferometer not far behind
- Locking of power-recycled (short) Michelson achieved
- Just started trying to add an arm cavity

LIGO, Built to Last