Readout and Control of a Power-Recycled Interferometric Gravitational-Wave Antenna

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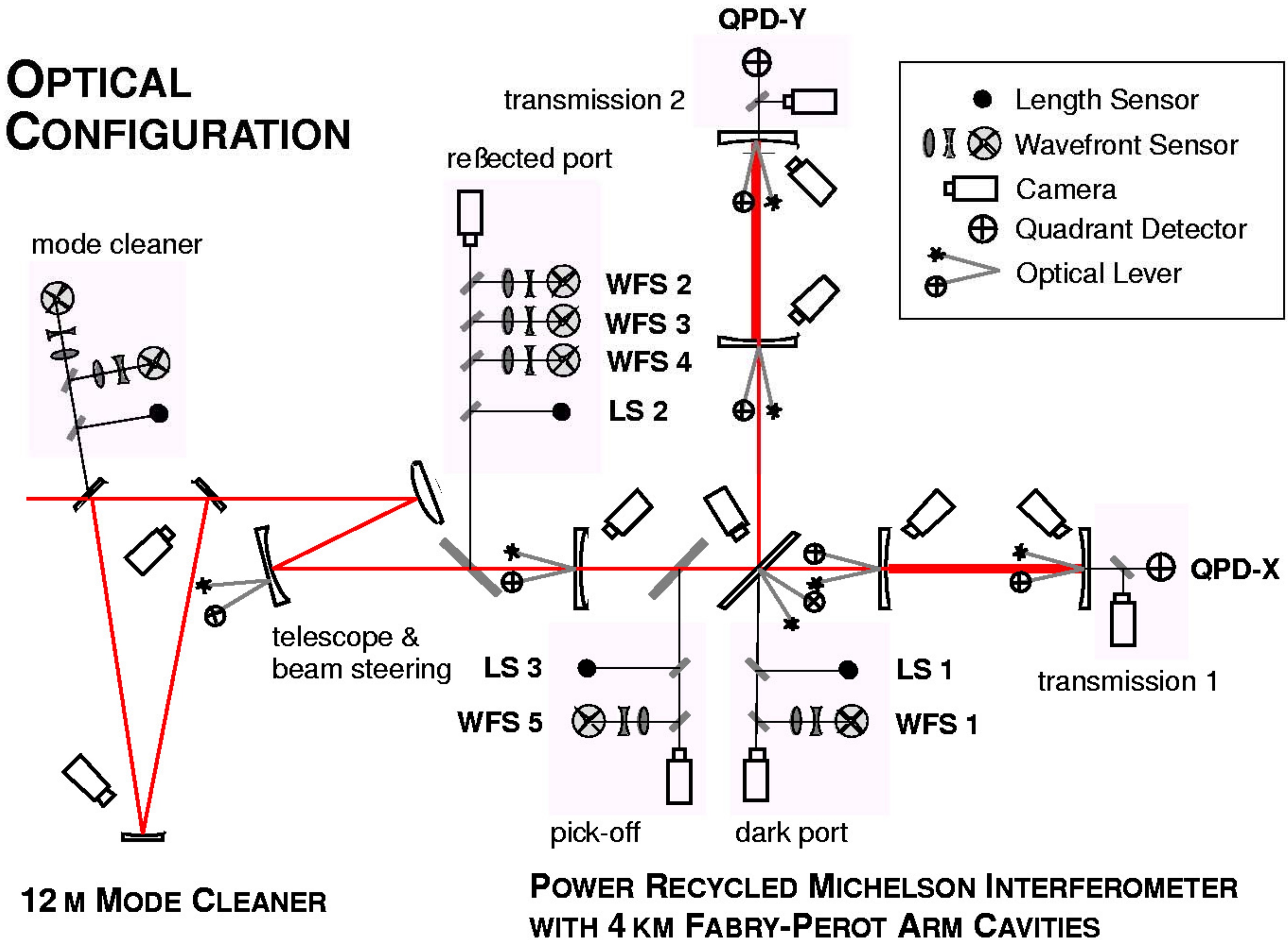
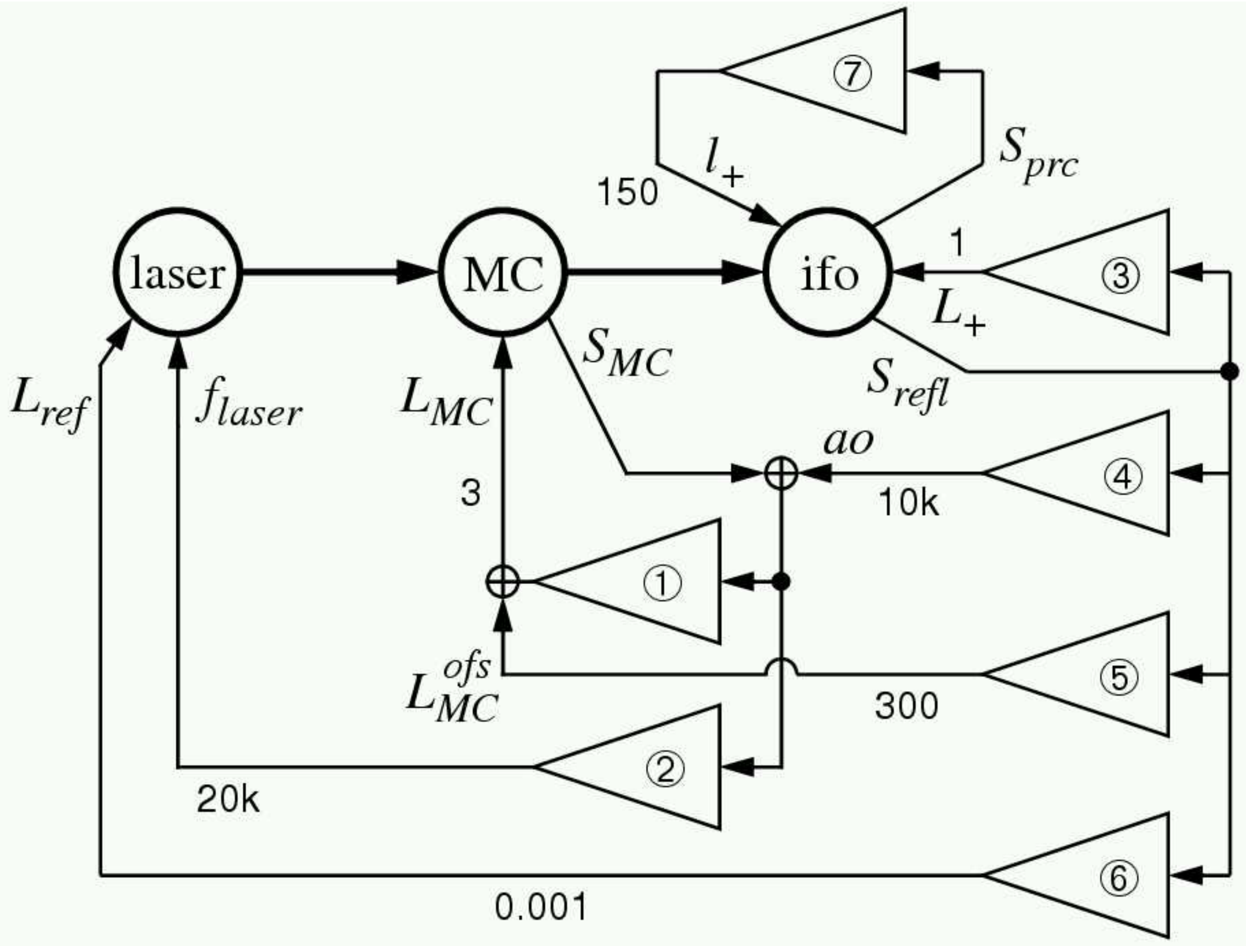
G040458-00-D

Optical Configuration



Length Sensing and Control



- Separate common and differential mode
  - Diff. arm
  - Michelson
  - Common arm
  - PR cavity
- Sensors
  - Anti-symmetric port
  - In reflection
  - PR cavity sample

Some Requirements

- Sensitivity: ~10^{-19} m/$\sqrt{\text{Hz}}$ at 100 Hz
- Controller range: ~100 μm (tides)
- Control of diff. arm length: ≤10^{-13} m rms
- Laser intensity noise: ≤10^{-7} /$\sqrt{\text{Hz}}$
- Frequency noise: ≤3×10^{-7} Hz/$\sqrt{\text{Hz}}$ at 100 Hz

The Auto-Alignment System

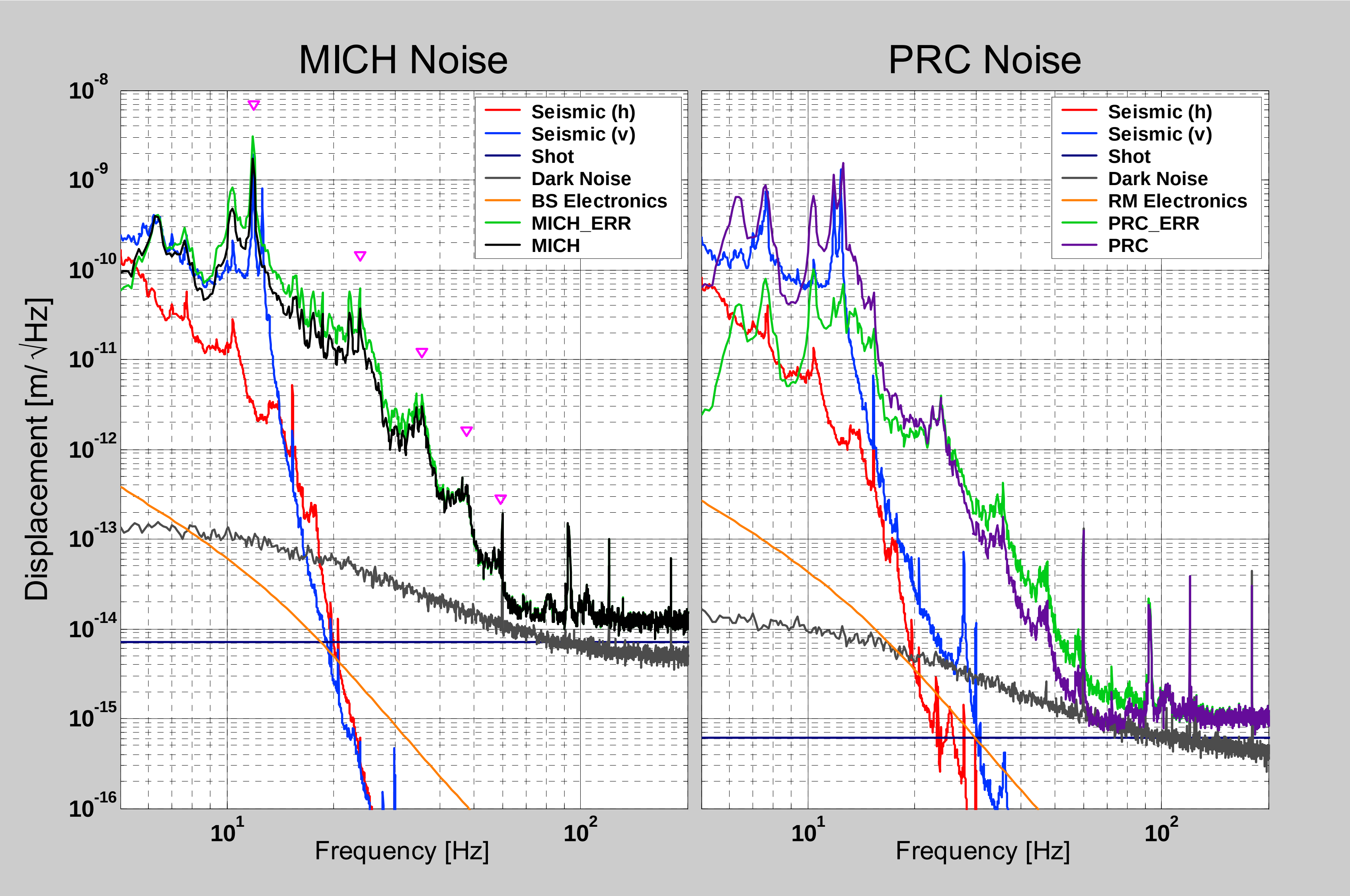
- Optical levers for damping suspension & stack modes
- Wavefront RF sensors for 10 angular dofs
- Quadrant detectors for beam positions on ends
- Video analysis of beam splitter image for input beam position

Going to Run Mode

- Acquire lock requires an adaptive digital servo
  - Adjust for gain changes due to power build-up
  - Change in the feedback topology when cavities are sequenced in
- Auto-alignment system is turned on
- Common mode feedback is switched to laser
- Acquiring lock requires substantial range 1-100Hz
  - Separate photodetectors for locking (low power) and running
  - Whitening filters for sensor inputs
  - Dewhitening filters for controller outputs
- Laser power needs to be increased
  - Thermal compensation

Auxiliary Degrees-of-Freedom

small coupling, but very noisy



High Power Operations

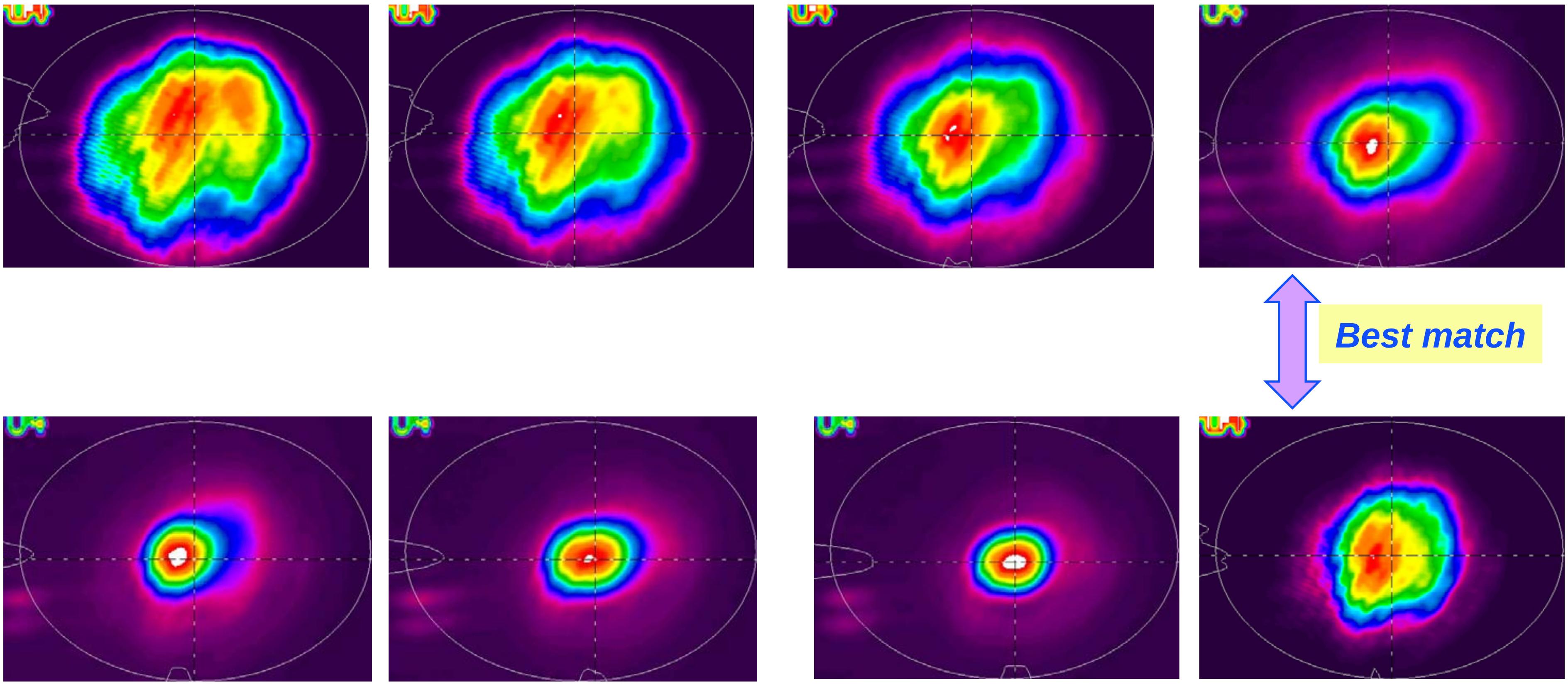
- Power is increased from ~1W to ~8W at mode cleaner input (rotating waveplate & polarizer)
- Multiple photodetectors at anti-symmetric port
- Output mode cleaner would be nice!
  - Carrier contrast defect improves by a factor of 20
    - Makes it possible to reduce modulation depth
  - Removes offset corresponding to 10^{-12} m
    - Reduced AM noise coupling: factor of 60 at 3 kHz
  - Orthogonal phase signal decreases by a factor of 7
  - Would be able to operate with a single PD at AS port!
- Radiation pressure is significant

Thermal Effects

- Cold power recycling cavity is unstable: poor buildup and mode shape for the RF sidebands
  - Carrier basically not effected
- ITM thermal lens power of ~0.00003 diopters needed to achieve a stable, mode-matched cavity
  - intended to be produced by ~25 mW absorbed from 1μm beam
- In reality:
  - Different interferometers have mirrors with different absorption
  - Some mirrors have too much absorption, some too little

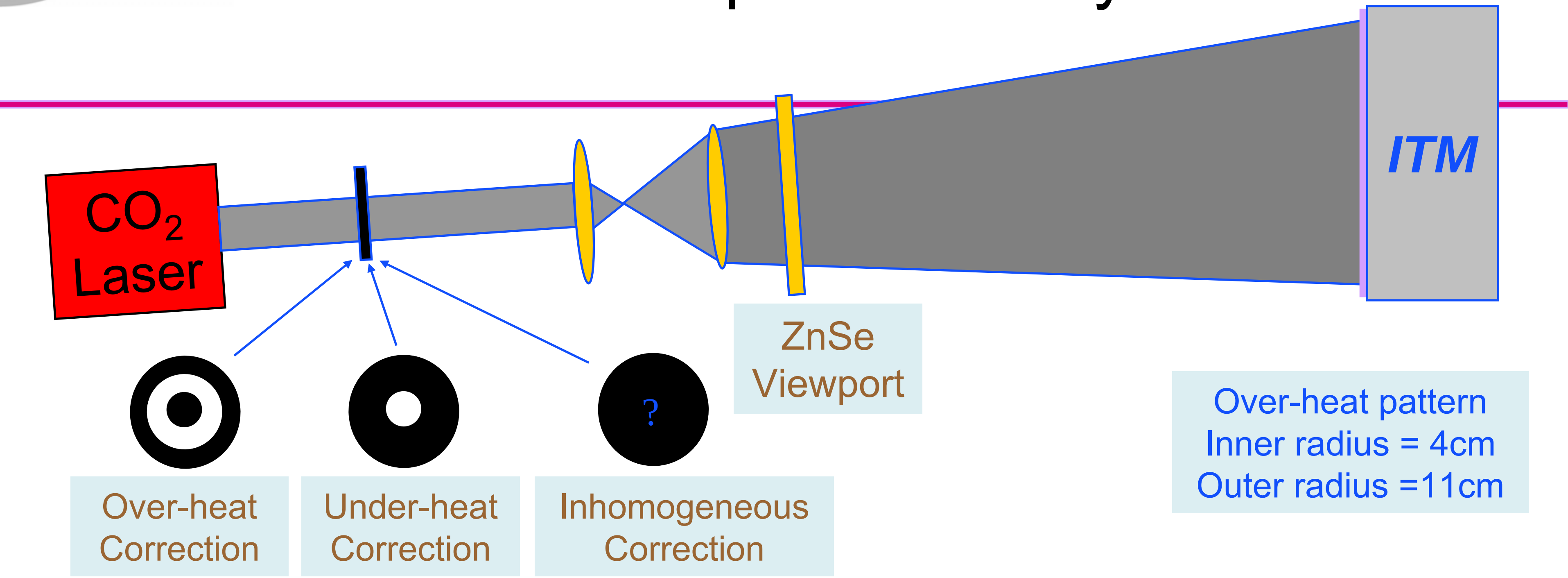
Sideband Images as Function of Thermal Heating

No Heating | 30 mW | 60 mW | 90 mW



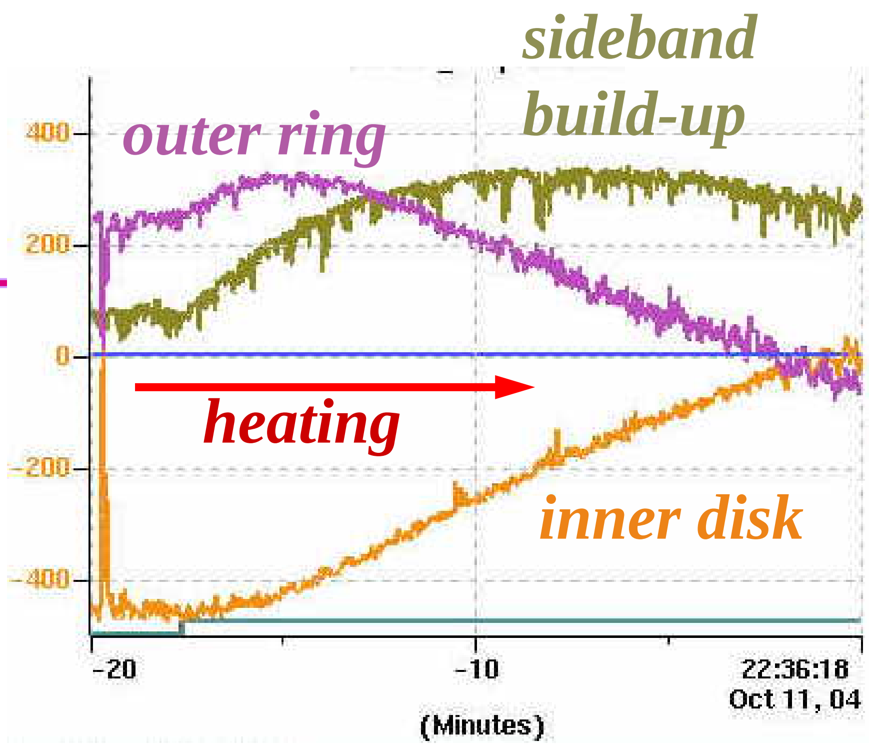
120 mW | 150 mW | 180 mW | Input beam

Thermal Compensation System

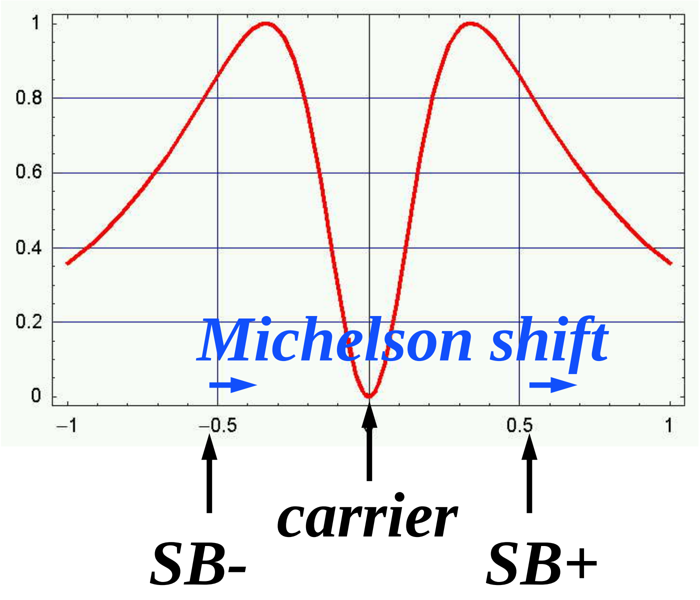


- External CO_2 laser heater
- One system for each input test mass
- Work on feedback system in progress

Thermal Compensation Error Signals

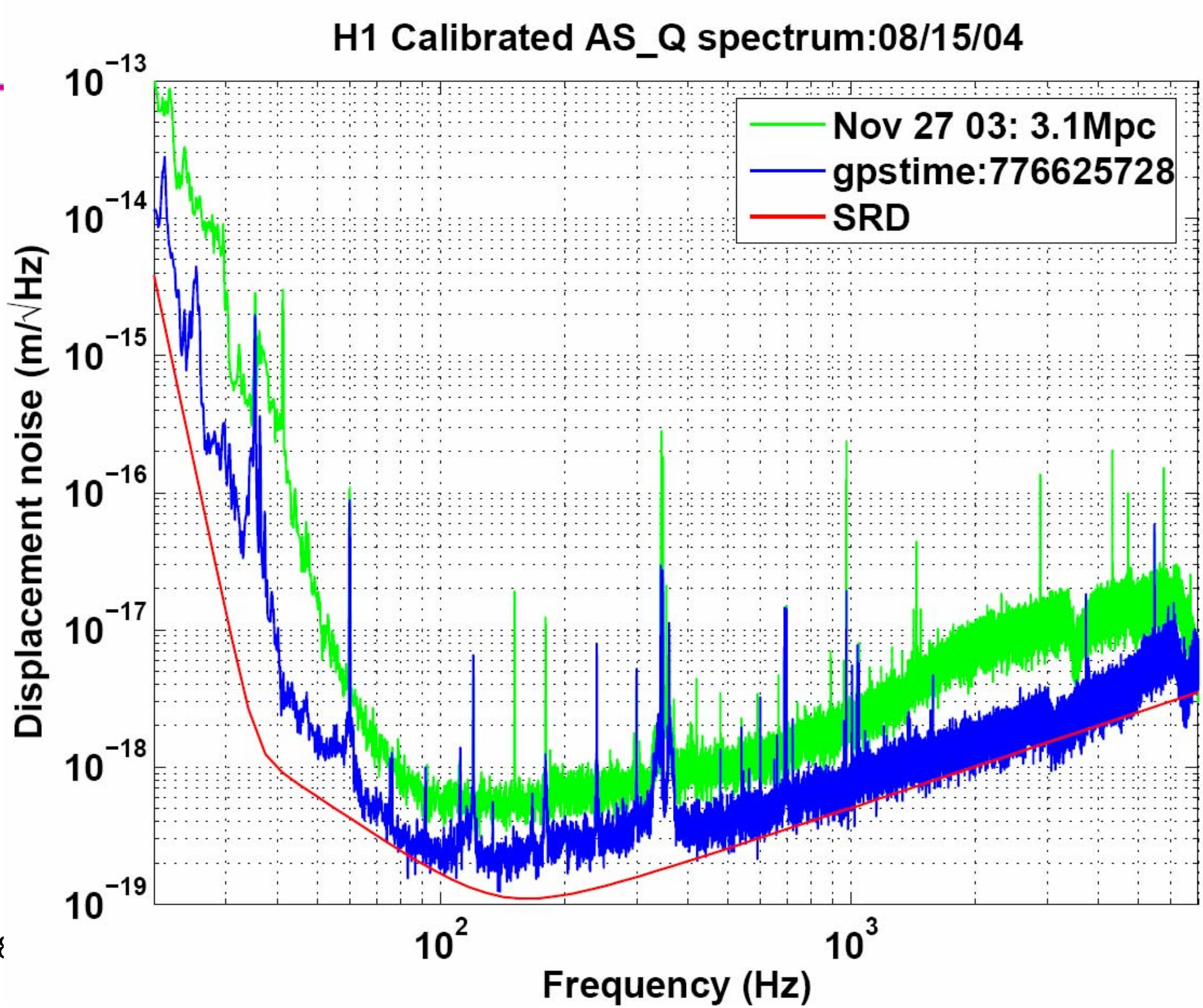


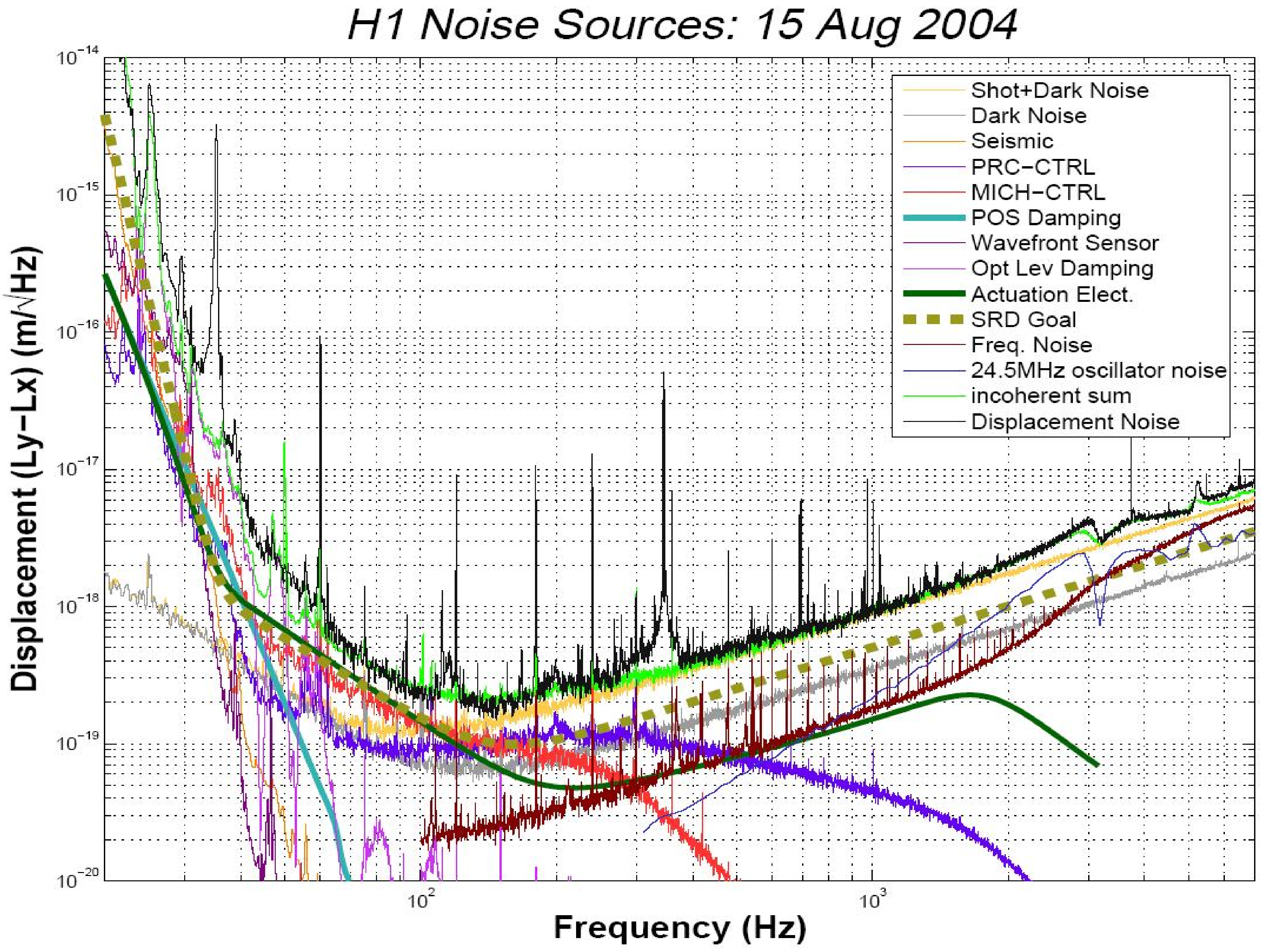
- Size of sideband mode in PR cavity measures cavity geometry
  - Bull's eye detector



- Orthogonal phase signal at anti-symmetric port measures sideband imbalance
  - Sidebands may see a different Michelson length than the carrier
  - This signal can dominate the differential arm cavity error signal

The Latest and Greatest





H1 Noise Sources: 15 Aug 2004
Shot+Dark Noise
Dark Noise
Seismic
PRC−CTRL
MICH−CTRL
POS Damping
Wavefront Sensor
Opt Lev Damping
Actuation Elect.
SRD Goal
Freq. Noise
24.5MHz oscillator noise
incoherent sum
Displacement Noise
Displacement (Ly−Lx) (m/√Hz)
Frequency (Hz)
10^-14
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^2
10^3

Summary

- Sophisticated feedback compensation networks are essential in running a modern gravitational-wave interferometer
- The 4K interferometer at Hanford is within a factor of 2 of design sensitivity over a broad range of frequencies
- For sources like binary neutron star coalescence we can see beyond our own galaxy!