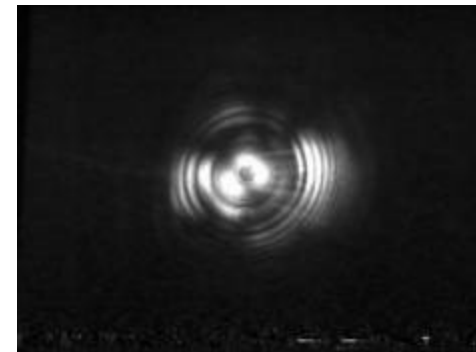# LIGO Sensing System Performance

Michael Landry – LIGO Hanford Observatory

Outline

- Two complex interferometric sensing systems, length and alignment
- Length sensing strategy, implementation, challenges, result
- Alignment sensing strategy, implementation, result
- Noise curve

Amaldi4

Why length and alignment sensing and controls?

❏ **Deviation from perfect destructive interference** $\Rightarrow$ coupling of noise to GW signal

   ○ e.g. laser intensity noise

$$\frac{S(\delta P/P = 10^{-7})}{S(\delta L_D)} \leq 0.1 \Rightarrow \delta L_D \leq 10^{-13} \text{ m}$$

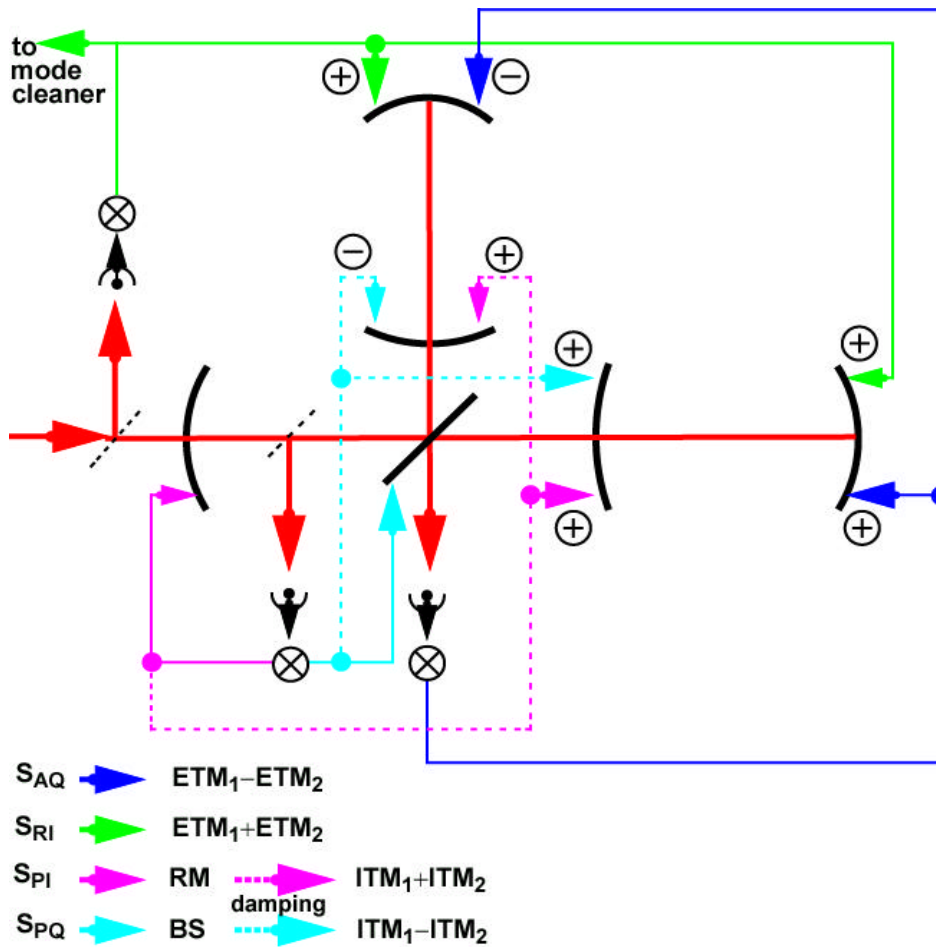❏ **Deviation from perfect resonance** $\Rightarrow$ less power build-up in ifo $\Rightarrow$ less GW signal

   ○ e.g. $\left.\dfrac{P(\delta L_C)}{P_{max}}\right|_{arm} \geq 0.99 \Rightarrow \delta L_C \leq 10^{-12} \text{ m}$

❏ **Ground noise excitation ~ 10^{-5} m (typical μ-seismic motion of earth)**

❏ **Degradation of GW sensitivity**

$$\frac{(S/N)_{GW}(\delta\theta_i)}{(S/N)_{GW}(\delta\theta_i = 0)} \leq 0.995 \Rightarrow \delta\theta_i \leq 10^{-8} \text{ rad}$$
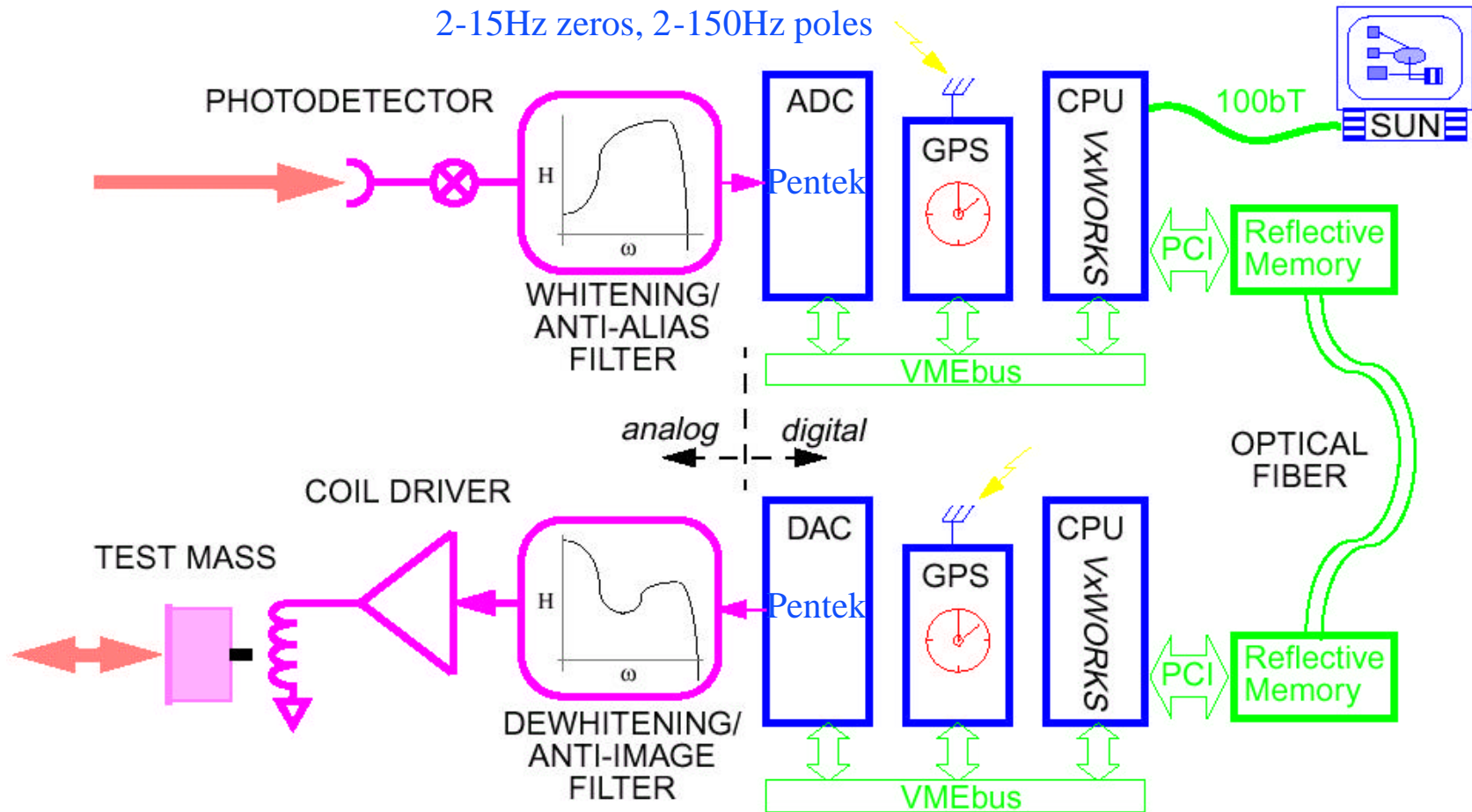
Interferometer control system

- Multiple Input / Multiple Output

- Three tightly coupled cavities

- off-diagonal plant matrix

- L+ dominates pick off and reflected ports; implement gain hierarchy

S_{AQ} → ETM$_1$–ETM$_2$

S_{RI} → ETM$_1$+ETM$_2$

S_{PI} → RM ---> ITM$_1$+ITM$_2$

S_{PQ} → BS damping ---> ITM$_1$–ITM$_2$

# Digital interferometer sensing & control system

Challenges in commissioning

- Noise: Pentek ADC noise and Pentek DAC noise (several microV/rtHz each)
- Saturations: RF photodiode during lock acquisitions transients
- Delays in digital system: 16384/s, 60 microseconds for all I/O and computations
- High power operations burns photodetectors

Effect of whitening filters

•Error signal at AS port
•With (red and without (blue) whitening
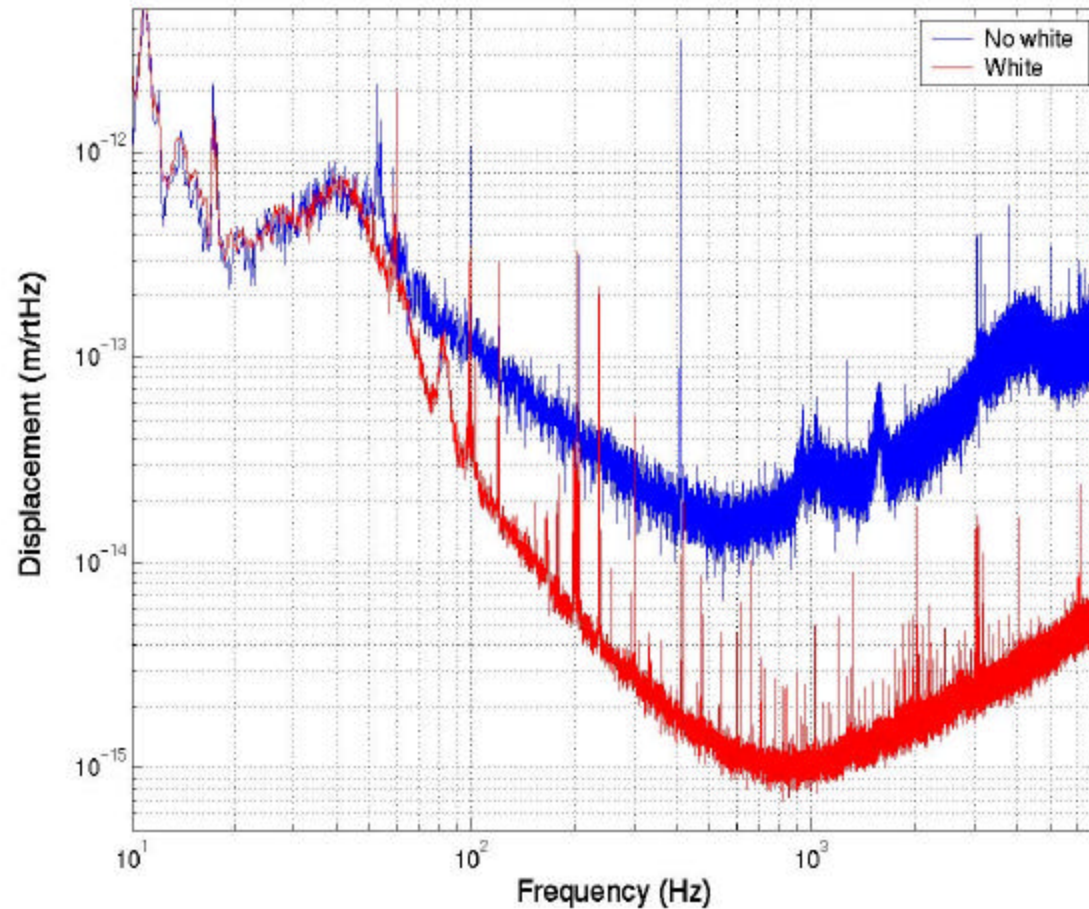
Wavefront sensing strategy

Angular misalignments excite higher-order transverse modes

- TEM$_{10}$ amplitude proportional to misalignment angle
- Wavefront sensor measures TEM$_{10}$ amplitude
  - » Length of sensor signal:
    beating of carrier TEM$_{00}$ field against sideband TEM$_{00}$ field
  - » Wavefront sensor signal:
    -beating of carrier TEM$_{00}$ field against sideband TEM$_{10}$ field
    -spatial map of this TEM$_{10}$ mode at modulation frequency
    -segmented photodetector
  - » Distinguish mirrors of the interferometer by Gouy phase shift
    (near field/far field)
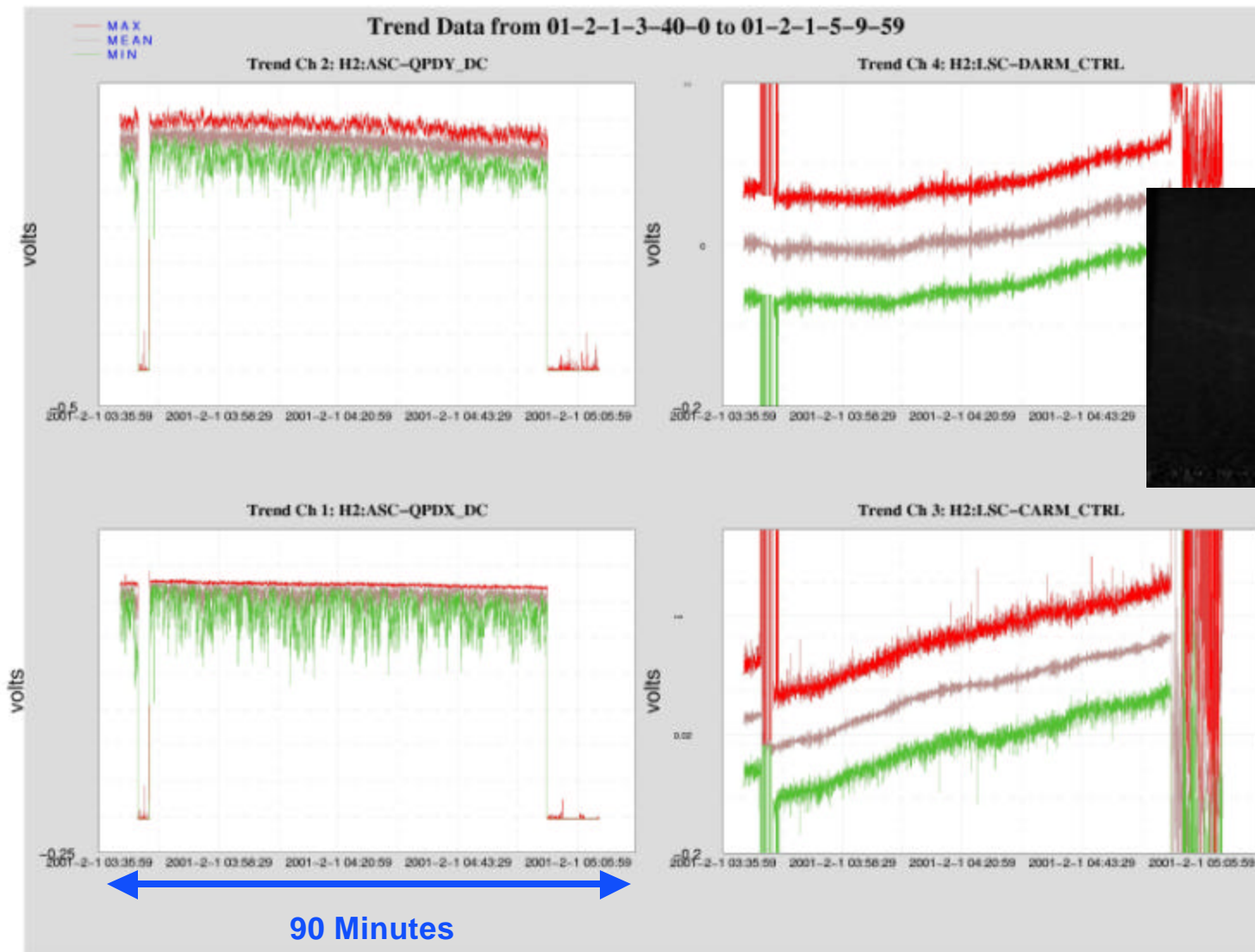
TEM$_{00}$

TEM$_{01}$

segmented photodiode

-

+

WFS signal
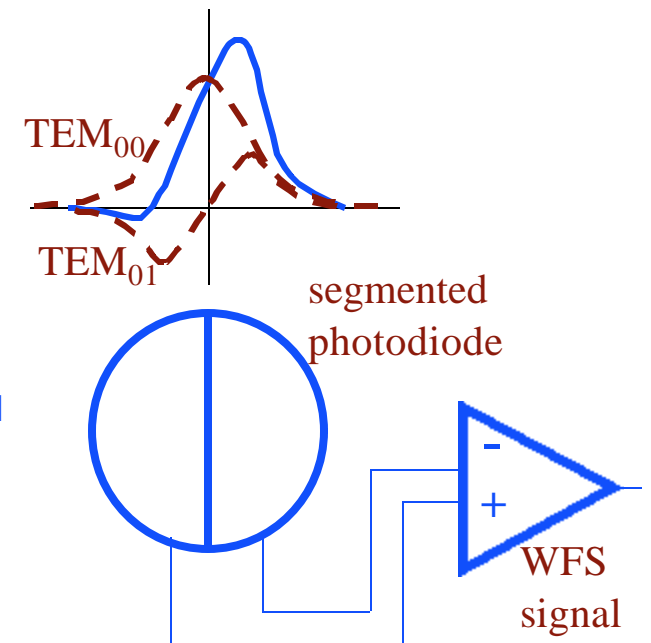
Wavefront sensing stabilization

- One-arm test
- 90 min lock stretch
- WFS engaged at end
- Lock broken manually

transmitted light, x-arm

control signal
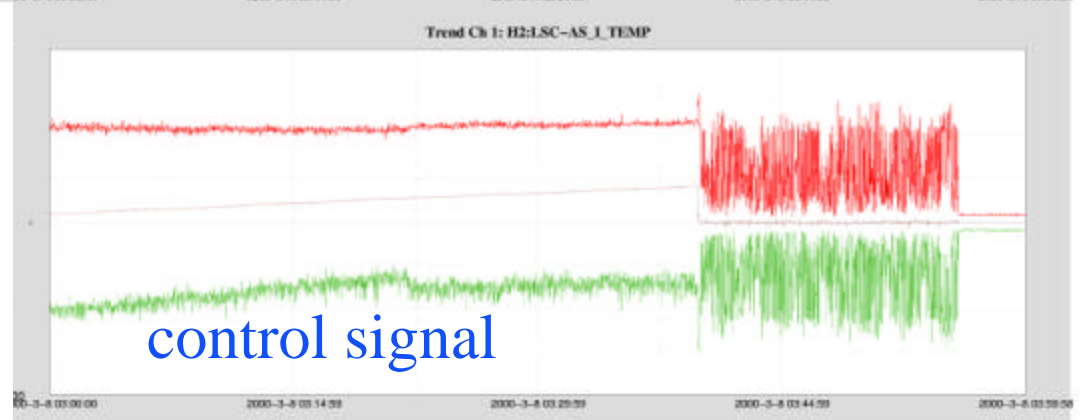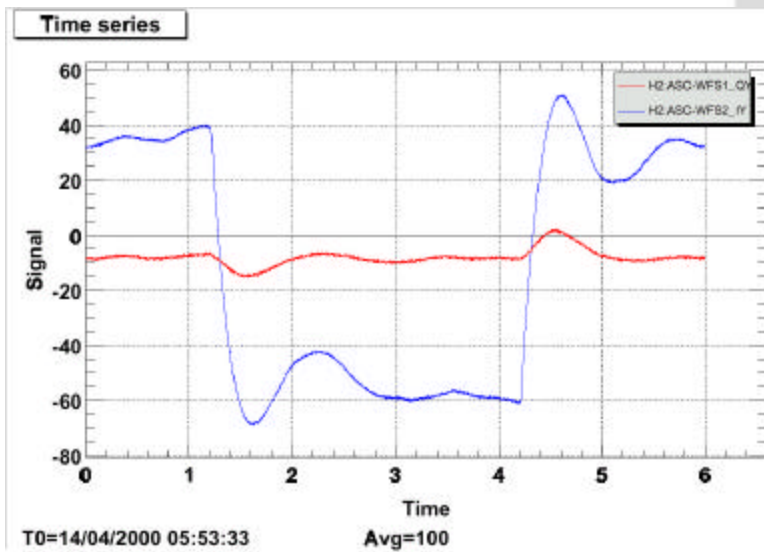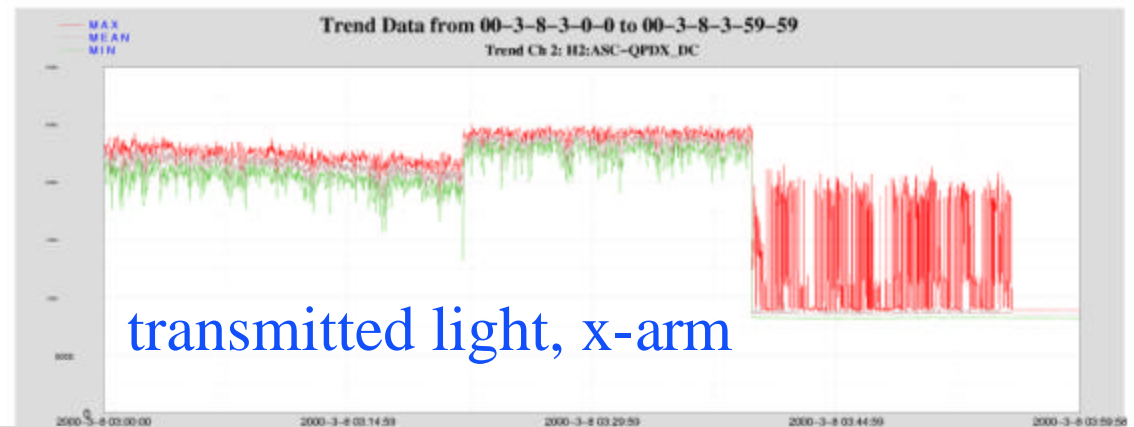
WFS: fully recycled IFO

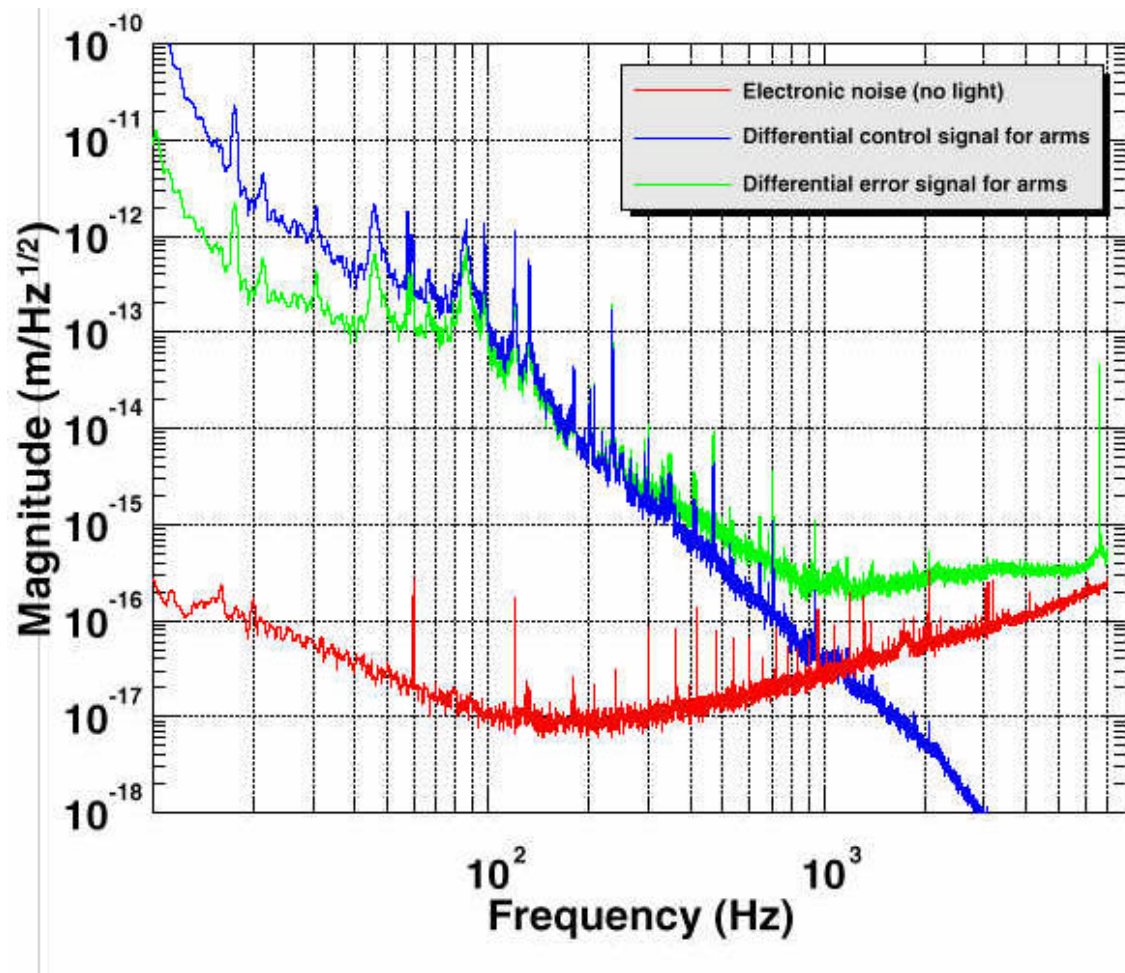# Sensitivity curve for fully-recycled LHO 2km IFO

Bandwidths of loops (design):

L- : 300Hz
L+ : 3Hz (arms)
    : 10kHz (modecleaner)
l- : 50Hz
l+ : 50Hz

Outlook

- Stabilize the laser to common arm

- Implement Michelson off-diagonal compensation

- Add tidal mode

- Add remaining wavefront sensors

- Go to high power operation