LASER INTERFEROMETRIC GRAVITATIONAL-WAVE OBSERVATORY

Recent Progress

February, 2000

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LIGO-G000017-00-D

LIGO

OVERVIEW

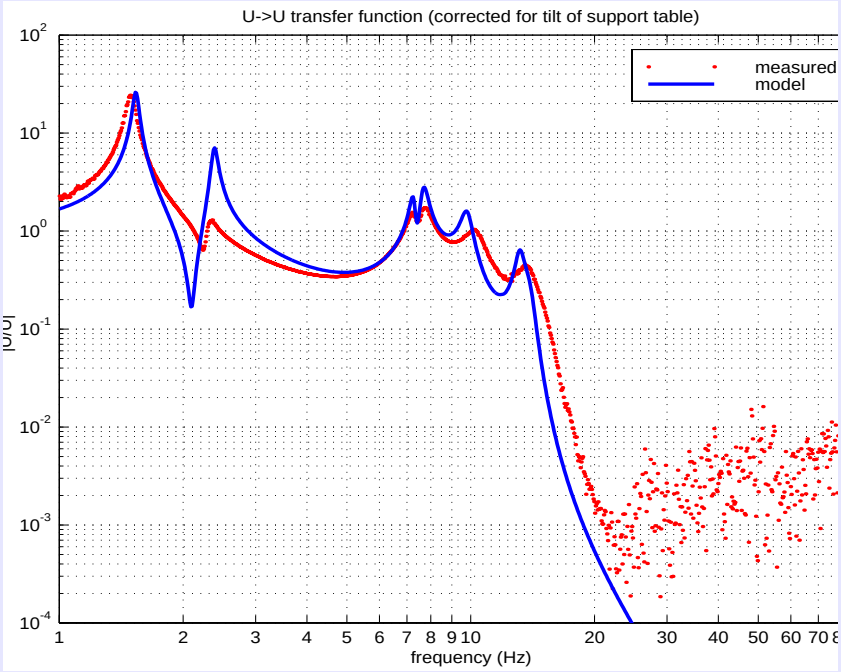
- **Facilities and construction complete**
- **Vacuum system complete**
- **Beam tube bakeout**
  - LIGO Hanford Observatory: completed
  - LIGO Livingston Observatory: X-arm completed; Y-arm underway
  - **Seismic isolation stacks**
  - LHO 2k and LLO complete
  - LHO 4k underway
- **All core optics polished and coated**
  - Metrology shows good results
- **Suspensions**
  - LHO 2k complete
  - LLO ~ 50%

FACILITIES AND CONSTRUCTION

- **All buildings and civil construction complete**
- **All vacuum equipment installed**
- **All beam tubes ready**
- **Beam tube bakeout**
  - LHO: completed
  - LLO: X-arm completed; Y-arm underway
  - H_2O partial pressures ➡ < 10^{-9} torr
- **Vacuum status**
  - Maintaining < 3 x 10^{-8} torr even with chambers loaded
  - Partial pressure of H_2O carefully monitored/budgeted to avoid contamination of beam tube

SEISMIC ISOLATION SYSTEM

- **Seismic isolation stacks**
  - Stainless steel masses ➡ ~ 600 kg each stage
  - Helicoil springs with lossy viscoelastic layer ➡ $Q \sim 40$
  - 3 stages ➡ $1/f^6$ for $f > 10$ Hz
- **Stack installation**
  - LHO 2k and LLO complete
  - LHO 4k underway
- **First-article testing of HAM stack**



- **Water outgassing from viton seats**

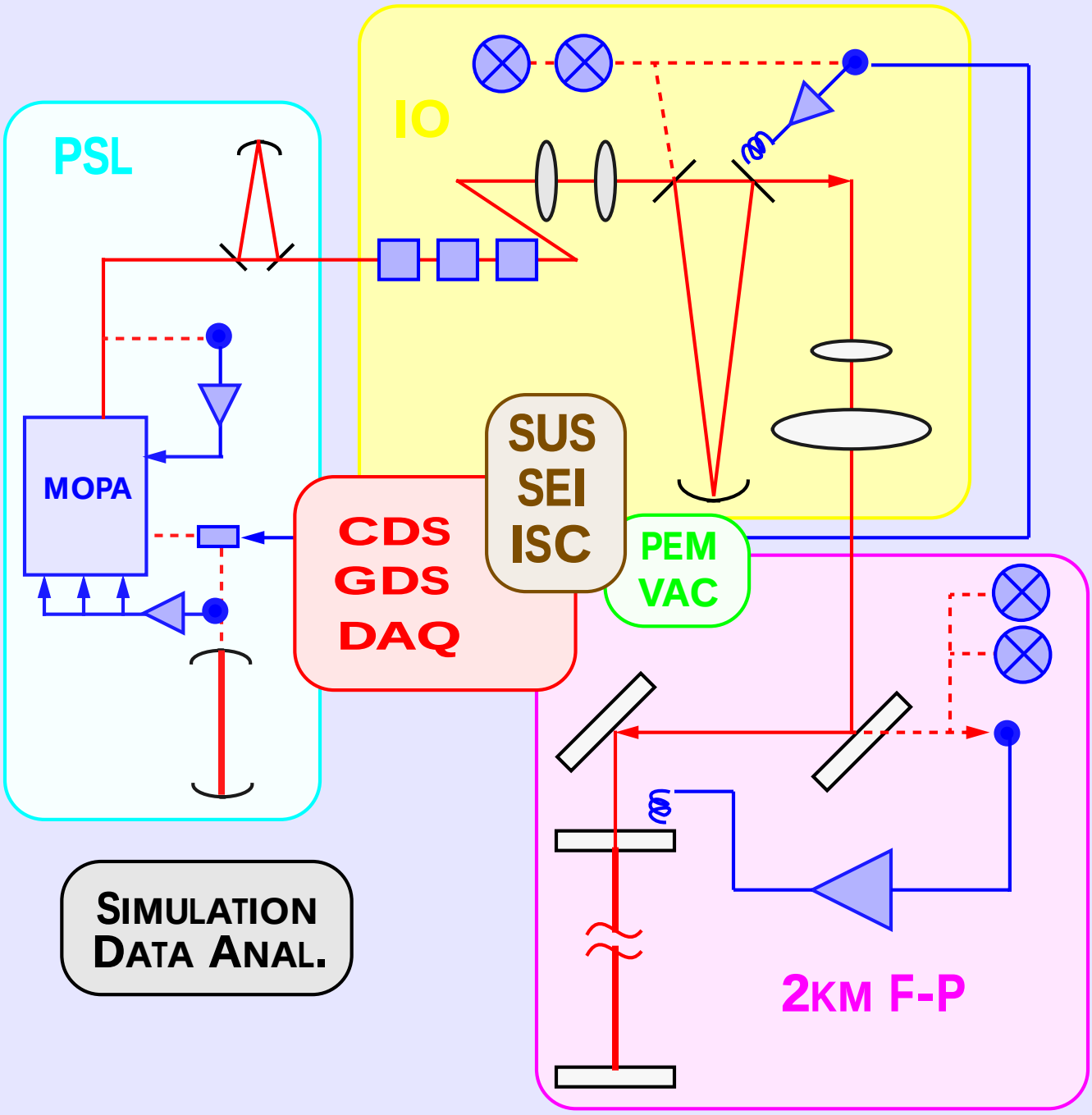
CORE OPTICS

- **All 40 optics polished and coated**
- **Polished substrates**
  - μ-roughness: < 10 ppm scatter
  - Radius of curvature: δR/R < 5%
    (hand selected pairs ➡ δR/R < 3%
- **Coated optics**
  - Point defects: < 2 ppm
  - Coating absorption: < 1ppm
  - Surface uniformity
    3.6 Å rms (polished) ⇨ 5.9 Å rms (coated)
- **Metrology**
  - CSIRO and NIST (633 nm)
  - 1.064 mm Veeco (Wyko) interferometer
    - compares Core Optic and reference flat
    - 1 nm_{rms} surface variation accuracy
    - 3% radius of curvature accuracy
- **Internal resonance Q factors**

SUSPENSIONS

- **Single wire-loop suspensions**
- **Four electromagnetic actuators**
- **Four ‘shadow’ sensors for local position sensing**
- **Installation**
  - LHO 2k complete
  - LLO ~ 50%
- **Testing**
  - PD-LED package used for shadow sensors sensitive to 1.06 mm laser light
  - Cross-coupling between principle degrees of freedom in sensors

COMMISSIONING ACTIVITIES AT LHO

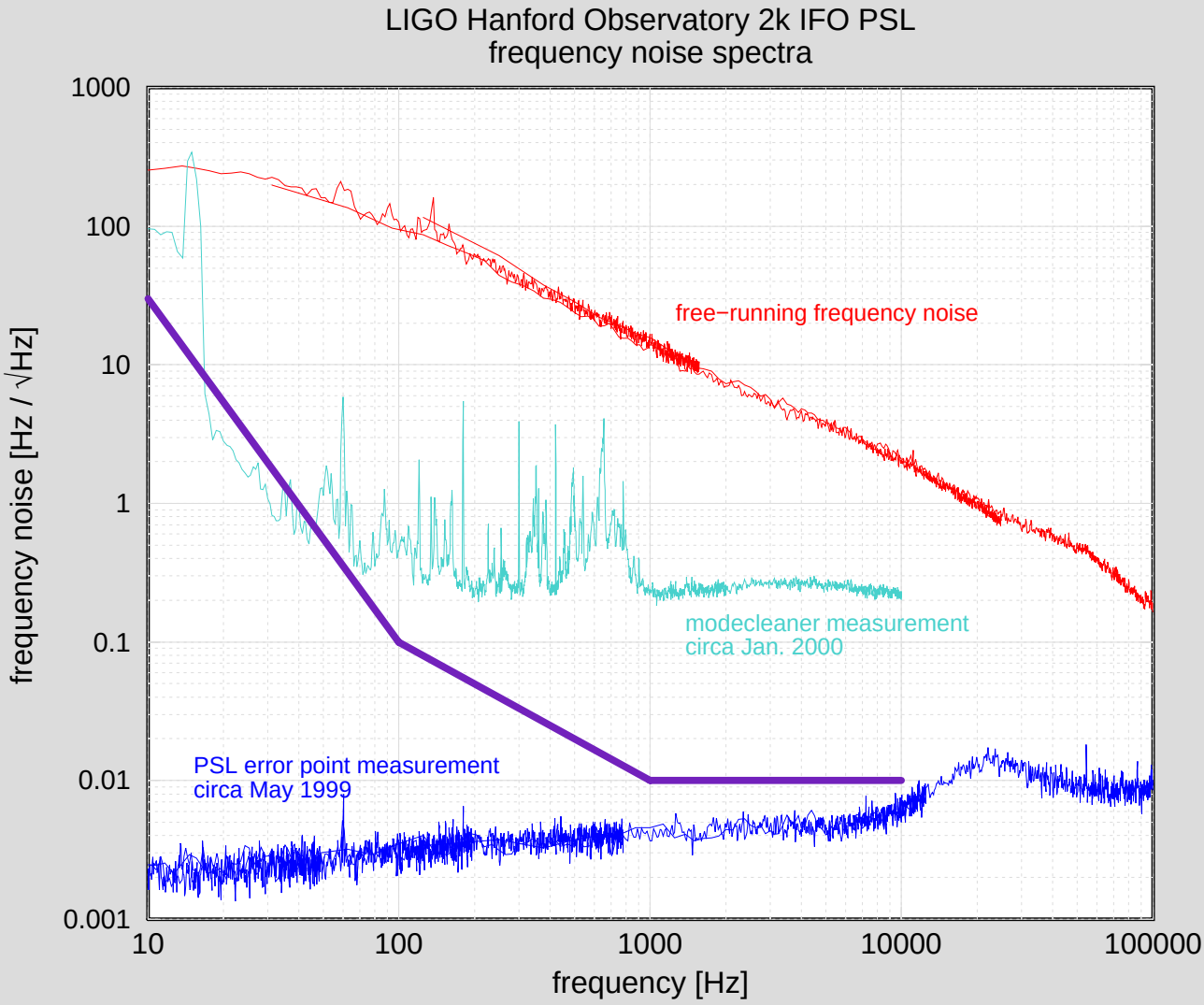


PRE-STABILIZED LASER

- **Laser**
  - Master Oscillator Power Amplifier
  - 10 W in TEM_{00} mode
- **PSL functions**
  - Frequency stabilization
  - Intensity stabilization
  - Pre-modecleaner
- **Nested loop strategy**
  - fixed-spacer reference cavity $\Rightarrow$ 0.1 Hz/$\sqrt{\text{Hz}}$
  - 12 m suspended mode cleaner cavity $\Rightarrow$ 10^{-4} Hz/$\sqrt{\text{Hz}}$
  - 4 km arm cavities $\Rightarrow$ 10^{-7} Hz/$\sqrt{\text{Hz}}$

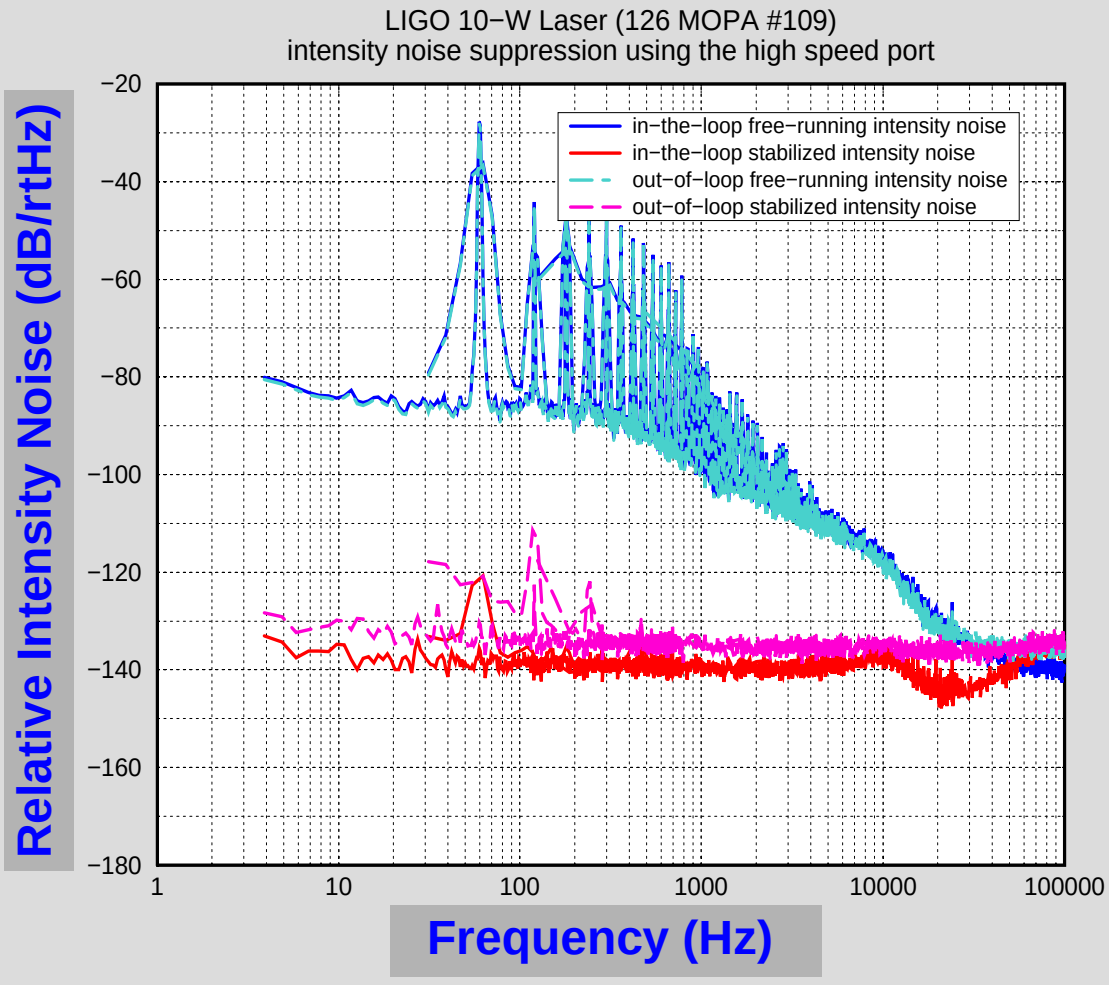
PSL CHARACTERIZATION

❑ Frequency stabilization



PSL CHARACTERIZATION (2)

❑ Intensity stabilization



Input Optics: Mode Cleaner

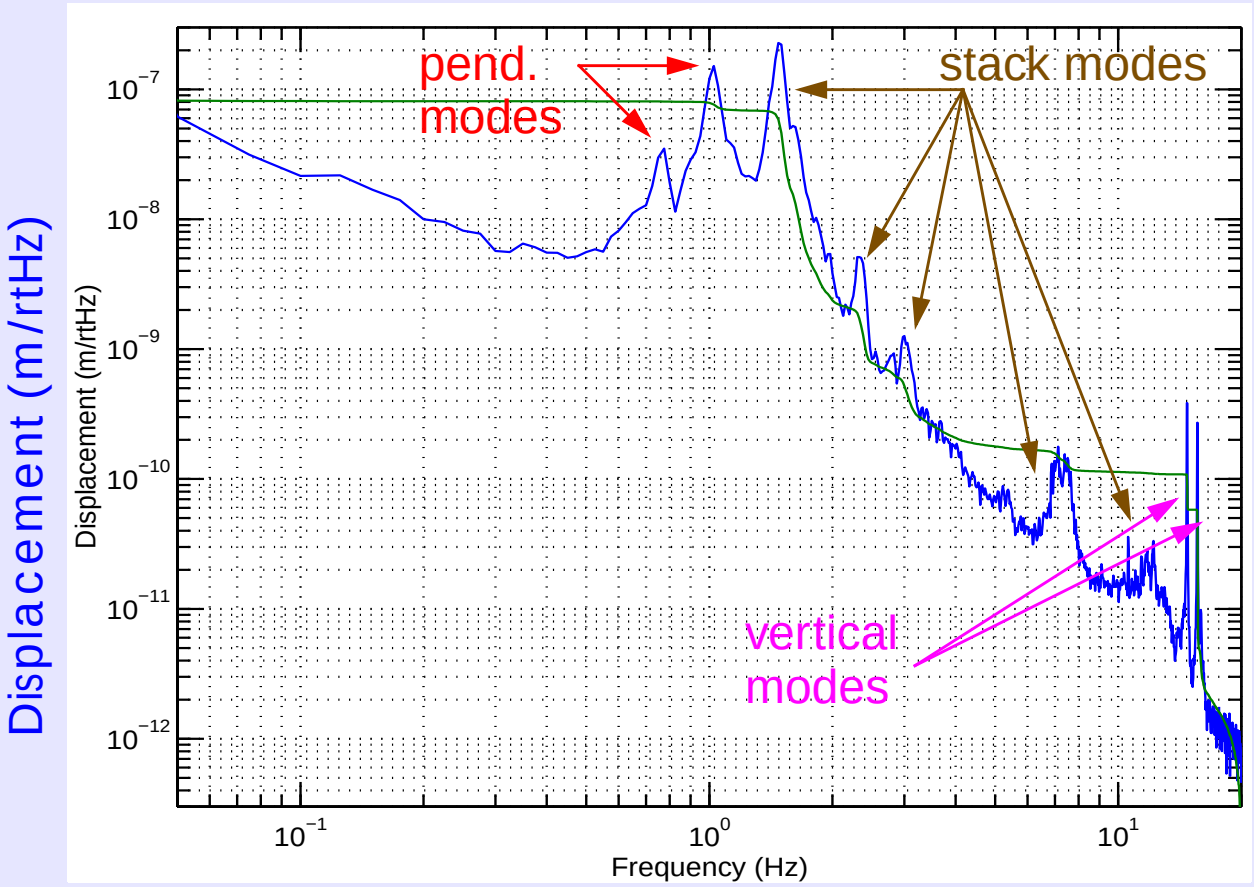
- **EO Modulation**
- **Mode-matching telescope**
- **Suspended mode cleaner**
  - ‘Small’ optics: 7.5 cm diameter
  - Triangular cavity
  - Finesse designed to be 1550
- **Locks easily and stably for >24 hrs**
- **Length/frequency servo BW ~ 30 kHz**
- **Output beam angular stability**
  - Long term drift ~ 4 μrad/hr
  - Fluctuations ~ 3 μrad rms

Mode Cleaner Characterization (2)

❑ Length stability

- ❍ Long term drift ~ 1 μm/hr
- ❍ Fluctuations ~ 0.1 μm rms
  (mostly at pendulum and stack eigenmodes)

Mode Cleaner Length Fluctuations



Displacement (m/rtHz)

Frequency (Hz)

Mode Cleaner Characterization (3)

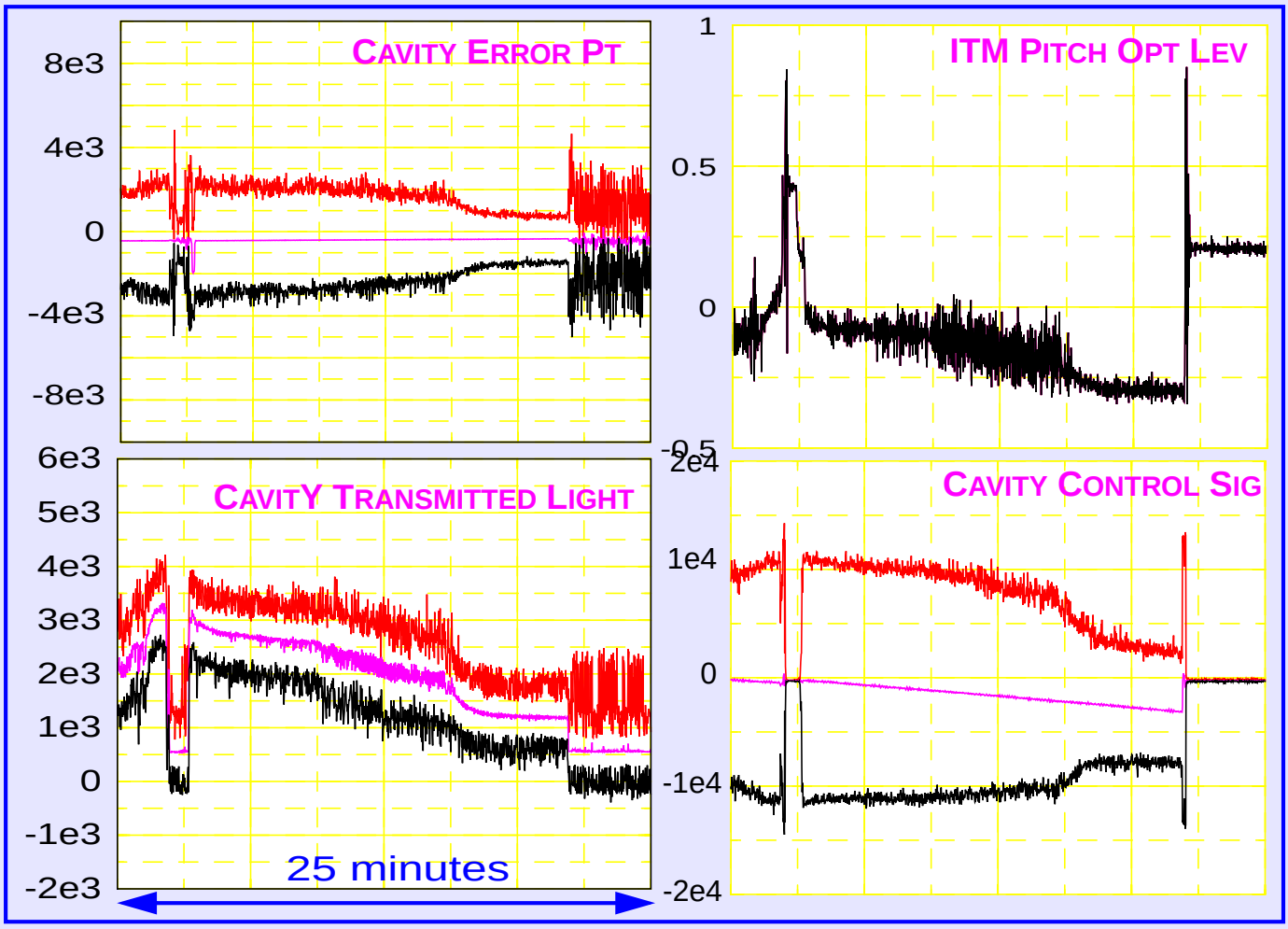
- **Length measured by resonant RF sideband tuning: L = 15.239595 m ± 50 μm**
- **Cavity linewidth measured**
  - ringdown/up and AM transfer function ➡ Δf = 7.31 kHz ⇒ finesse, $\mathcal{F}$ = 1346
  - T_{in} = T_{out} = 2255 ppm, T_{curve} = 10 ppm, $\mathcal{F}$ = 1346 ⇒ **total loss = 49 ppm/mirror**
- **Total transmission measured: 0.98 ± 4.7%**
- **Internal resonances of optics measured**
  - Q = **0.75 million** to **1.29 million** for f_0 = 28.233 kHz mode
- **Ongoing work:**
  - Operation at full power
  - Increase servo bandwidth
  - Implement intensity stabilization after MC

2 km Fabry-Perot Cavity Test: Why?

- Exercise lock acquisition controls
- Measure frequency noise from IO mode cleaner
- Test nested loop frequency control
- Early look at optical properties (losses, radii of curvature) of core optics
- Mode matching
- Degree of excitation of suspension eigenmodes and test mass internal resonances
- Measure enviromental fluctuations

2 km F-P Test: Locking

- Gate valves between corner and mid stations first opened Dec ‘99
- Laser beam on suspension cage
- Cavity locks for ~15 minute stretches

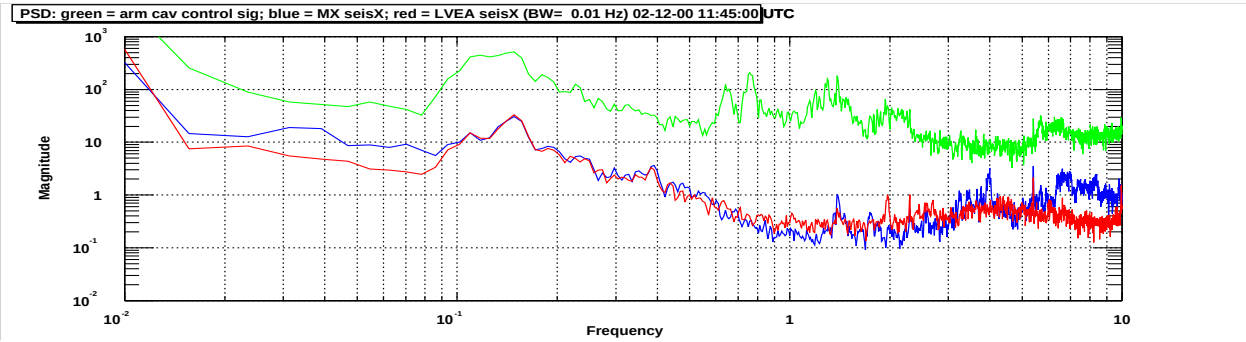


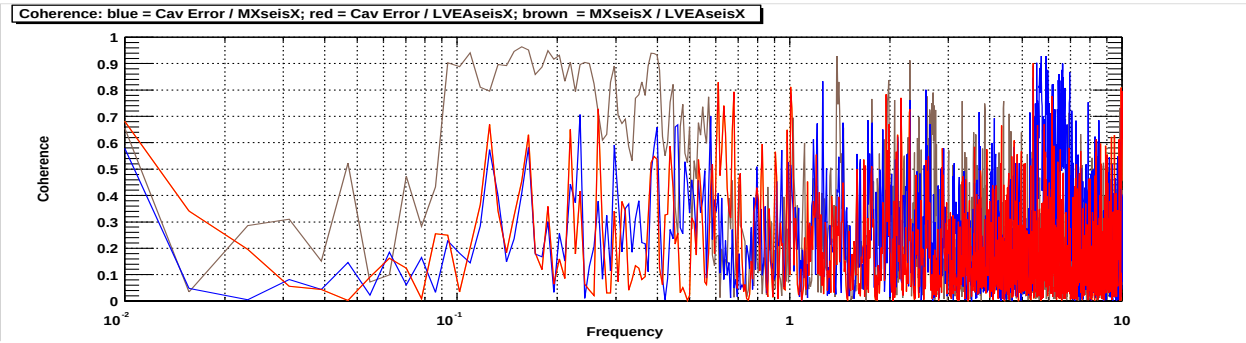
2 km Cavity Locking

- **Observe ~ 0.5 μm/min drift during 15 minute stretches**
  - Arm cavity length drift consistent in magnitude and sign with drift in laser frequency due to reference cavity drift
  - Thermal control being implemented on ref cav
- **Length-alignment coupling as length drifts**
  - More coupling than can be accounted for by observed cross-coupling in actuators at DC
  - Possible saturations in coil drivers under investigation
  - Wavefront-sensing based alignment control next
- **Excitation of 6.75 kHz 'butterfly' mode of TM**
  - Sensitive to centering of laser beam on mirror
- **Other internal resonances also excitable, e.g. 31.25 kHz !!**
- **Internal mode Q's for several core optics measured 200,000 to 10 million**

2 km F-P Test: First Look

- **Correlation studies: μ-seismic peak**
  - Common-mode displacement of optics 2 km apart is ~ 2x smaller than each optic





- **Cavity length: L = 2009.1096 ± 0.01 m (surveying ➡ 2009.119 m)**
- **Cavity storage time ≈ 460 μsec ⇒ $F \approx 216$**
- **Sensitivity dominated by frequency noise**

Outlook for the Near Future

- **LHO 2km commissioning**
  - Single arm test ⇒ Summer 2000
  - Power-recycled Michelson ⇒ Winter 2000
  - PRM with FP arm cavities ⇒ Summer 2001
- **LLO**
  - Similar commissioning path
  - ~3 months behind LHO schedule
- **LHO 4km**
  - Early 2002
- **Noise reduction and performance enhancement phase**
- **Science run begins 2002**