LIGO

Commissioning

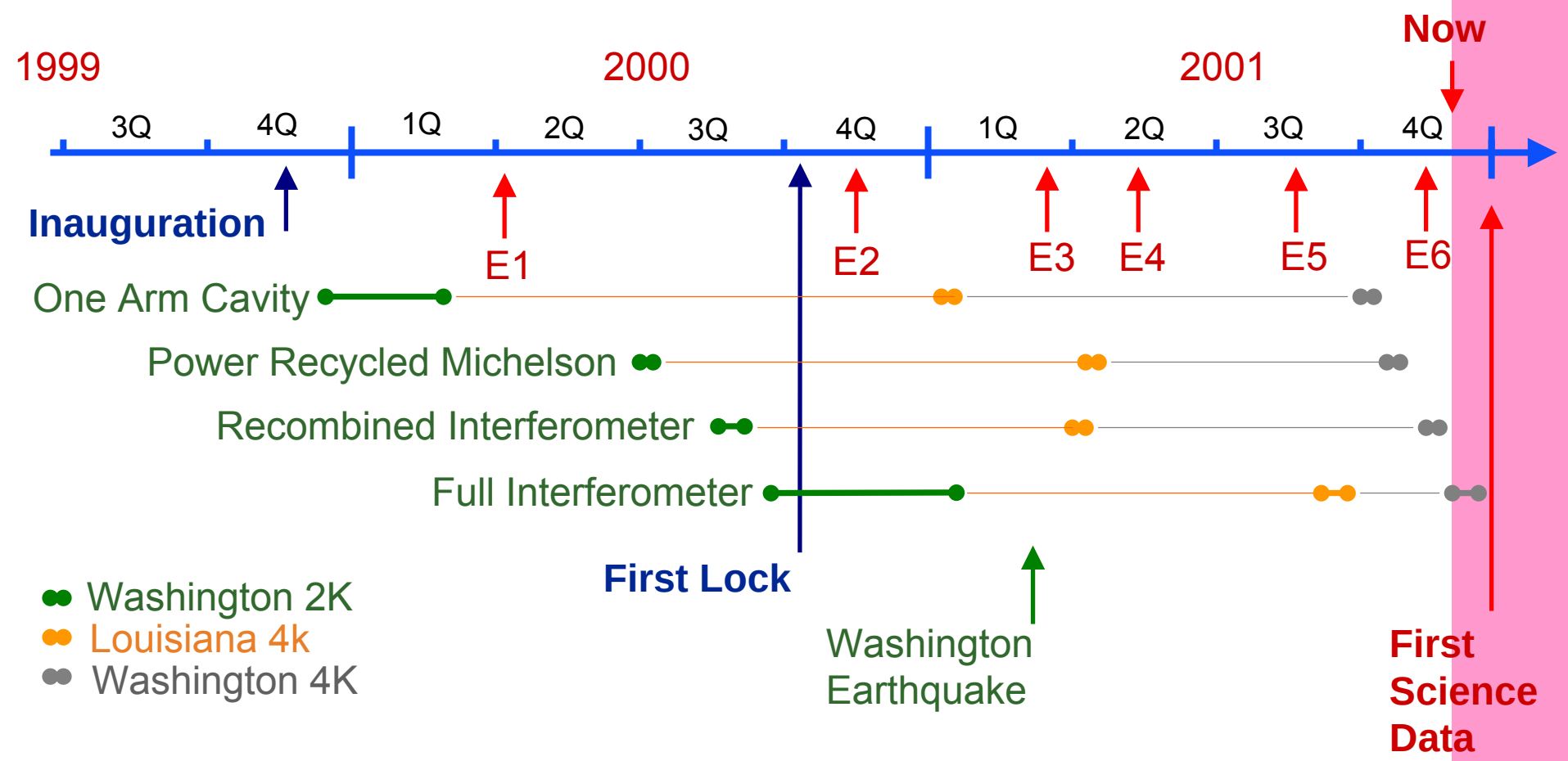
PAC11, 2001

Daniel Sigg, LIGO Hanford Observatory

Installation/Commissioning Philosophy

- Each interferometer has a specific role in commissioning
  - 2 km Interferometer: “Pathfinder”, move quickly, identify problems, move on
  - LLO 4 km Interferometer: Systematic characterization, problem resolution
  - LHO 4 km Interferometer: Scheduled so that all fixes can be implemented prior to installation
    Digital Suspensions
- Stagger the installation and commissioning activities to make optimal use of available staff

Time Line


Now
1999
2000
2001
3Q
4Q
1Q
2Q
3Q
4Q
1Q
2Q
3Q
4Q
Inauguration
E1
E2
E3
E4
E5
E6
One Arm Cavity
Power Recycled Michelson
Recombined Interferometer
Full Interferometer
First Lock
Washington 2K
Louisiana 4k
Washington 4K
Washington Earthquake
First Science Data

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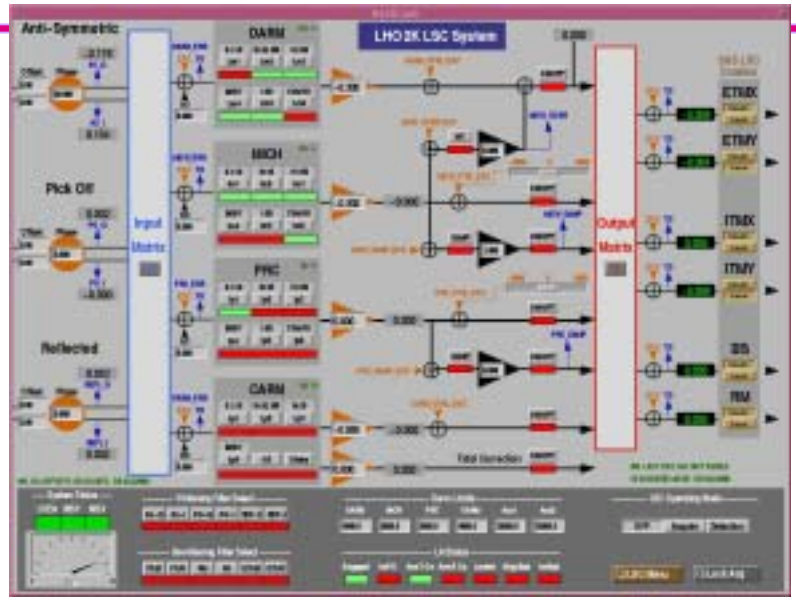
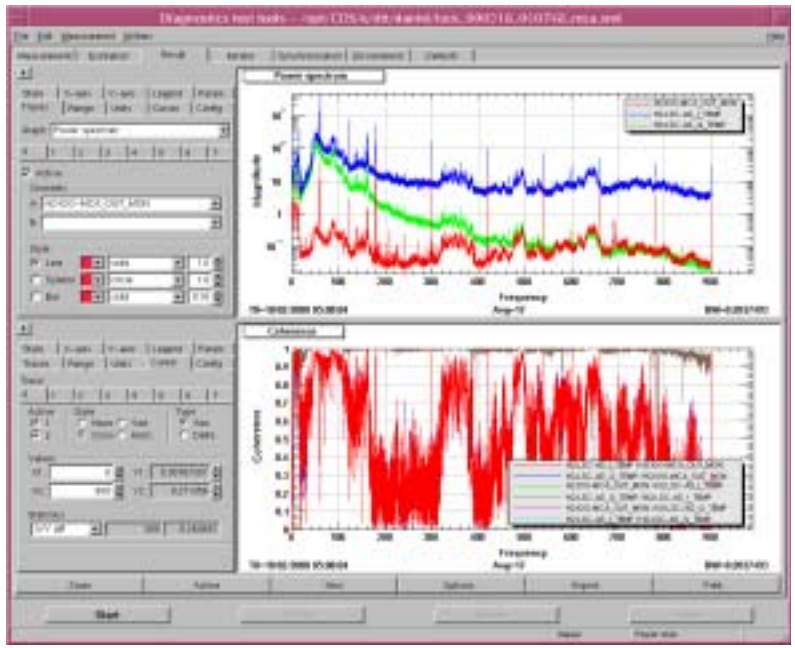
Interferometer Status

- LHO 2K
  - Running in full configuration since a year
- LLO 4K
  - First locked in full configuration this October
- LHO 4K
  - Up to state 3 (PRM & one arm); Poised to get it locked

Data Acquisition, Controls and Diagnostics System



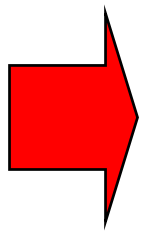
- ~50 real-time processors
- ~20 workstations per site
- ~5000 process variables (switches, sliders, readings, etc) per interferometer
- Fiber optic links between buildings
- Multiplexed video



- Data acquisition rate of 3 MB/s per interferometer, 7d disk storage
- Data Viewer
- Interactive Tools
- Monitor Tools

Status of the Control and Monitoring System

- Recent DAQ Improvements
  - LDAS disk system
  - Long frame files (16s)
  - Faster networking & more memory

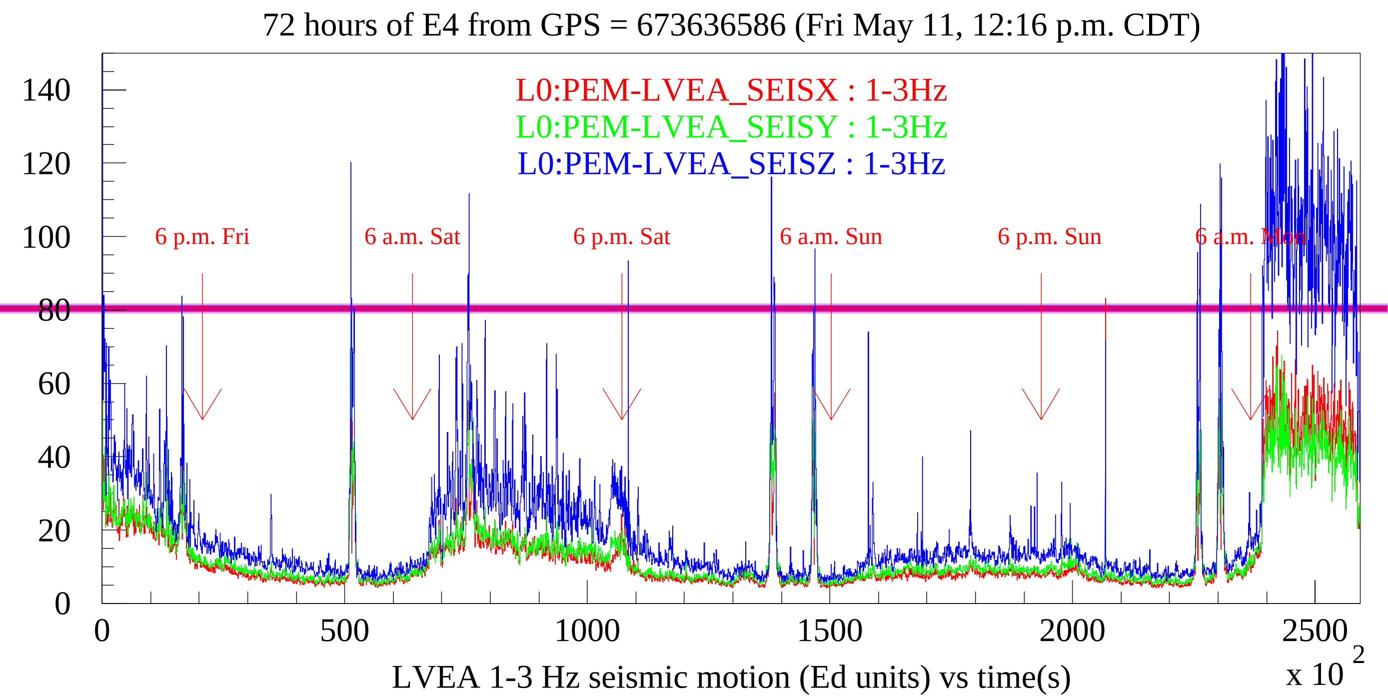


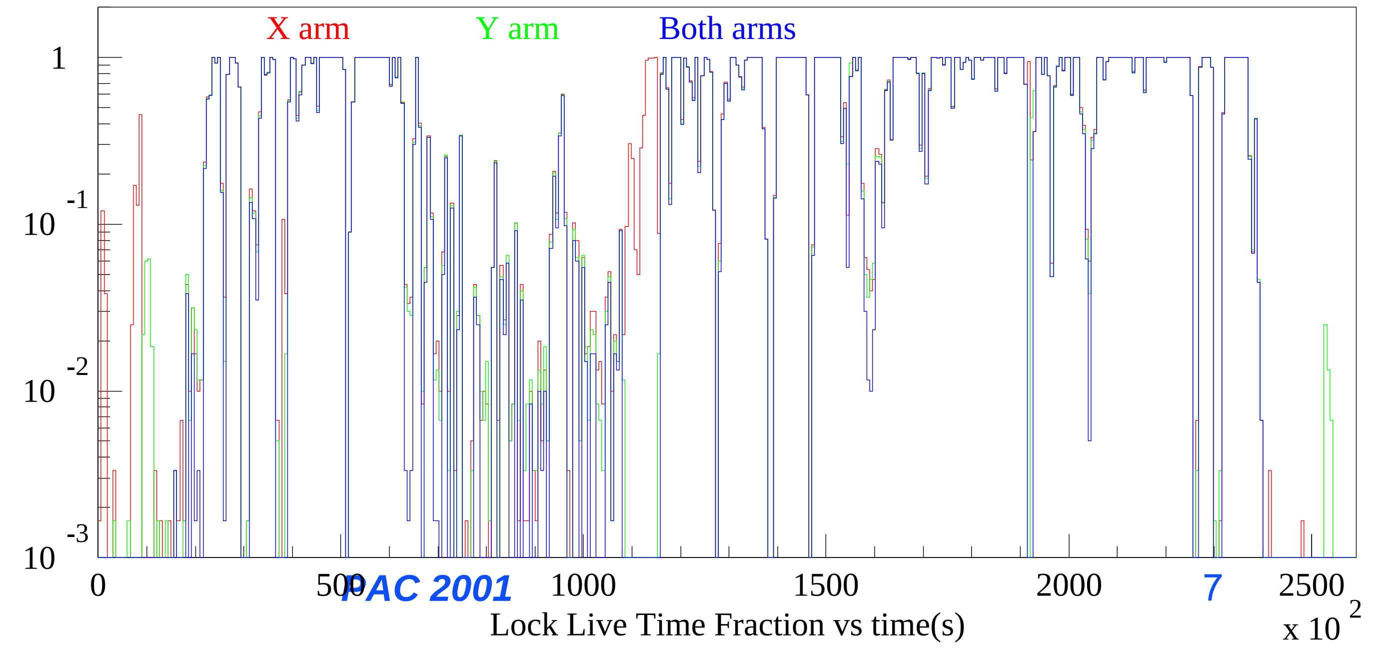
10 times faster

5 MB/s control room

- Integration of digital SUS (LHO 4K)
- 10MB/s distribution to Data Monitor Tool
- Stream Injection Capability
  - E.g., add inspiral signal to DARM control
- Next
  - Better support for slow channels
  - Better support for alarms & summaries
  - Better offline capabilities

Seismic Situation at LLO





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Seismic Situation at LLO (2)

- Spiky seismic noise 1-3 Hz band
  - Related to human activity (trains, highway traffic, lumber industry)
  - Coincident with stack resonances
  - Precludes IFO locking during weekdays
- Most likely growing with time
- Strategy to deal with noise
  - Short term: Coil drivers with extended range
  - Long term: active external compensation system
    - Feed forward
    - Hydraulic/PZT (taken from the LIGO II design)

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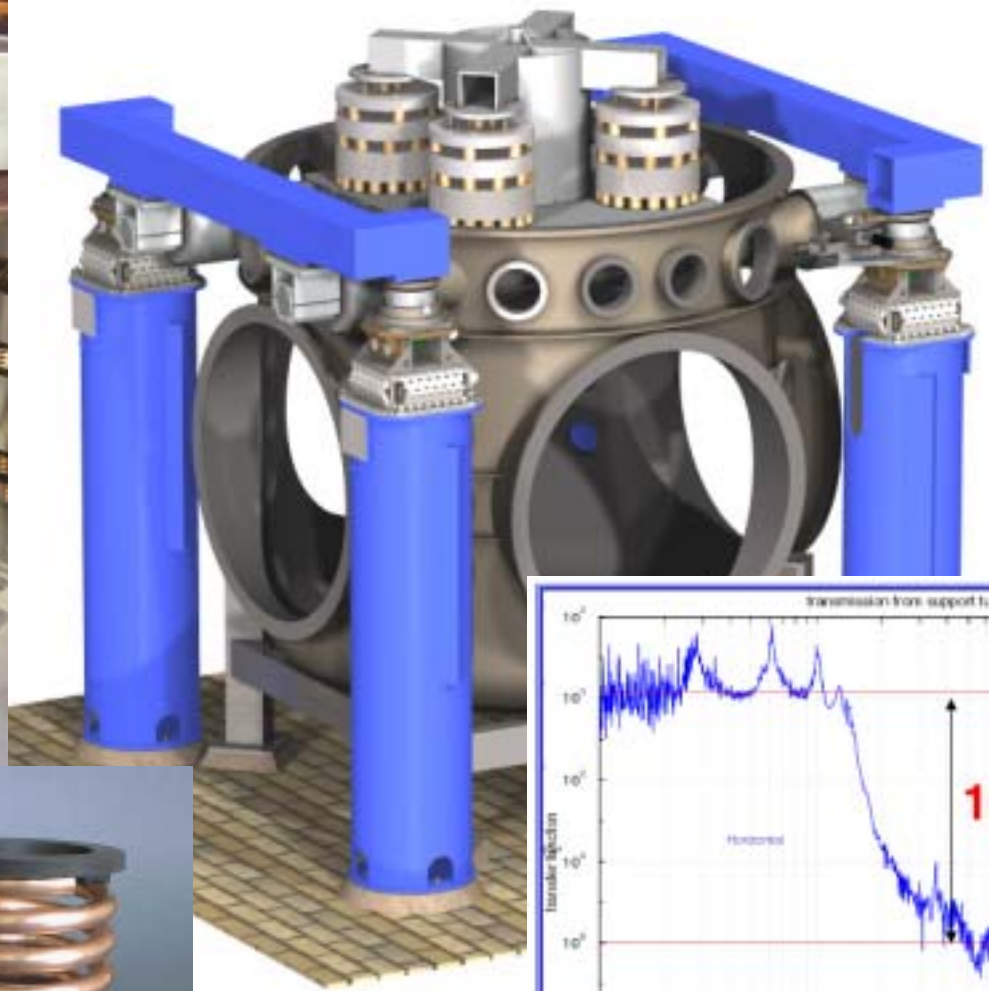
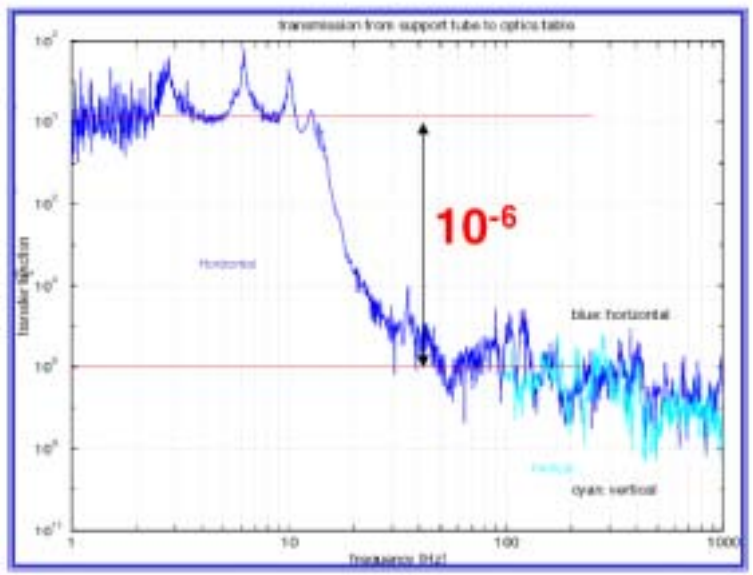
Seismic Performance





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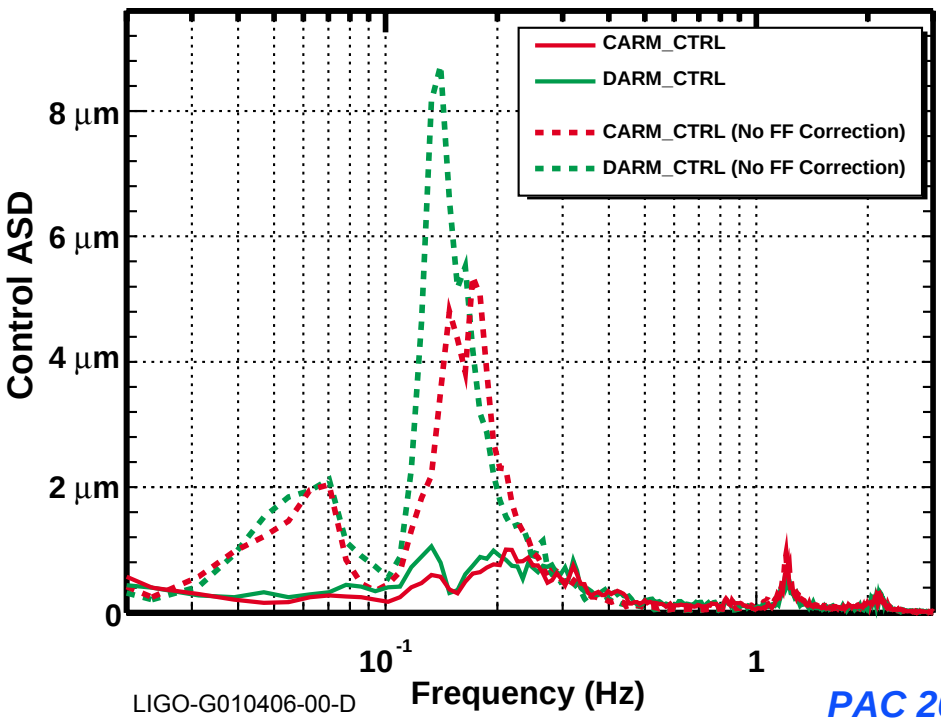
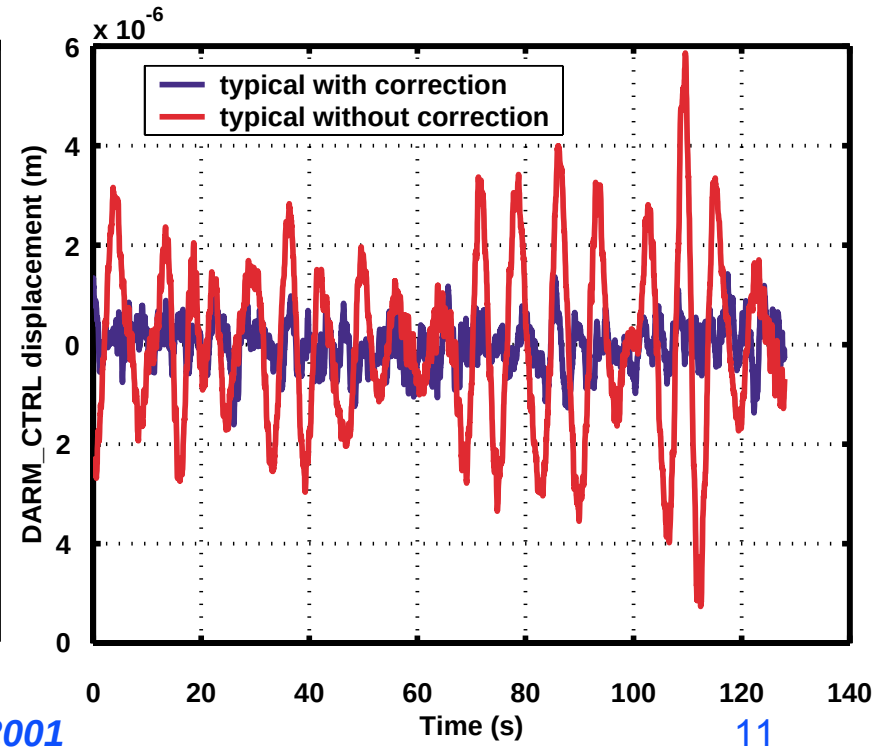
μSeismic Feed-forward System (LLO)

- Standing ocean gravity waves driven by storms can excite double frequency (DF) surface waves that traverse large distances on land, of several μm in amplitude, several km wavelength. This causes motion among LIGO's test masses peaking at 0.15Hz
- Seismic design provides an external fine actuation system (FAS)
  - ±90 μm range for each end (or mid) station BSC payload.
  - Single DOF flexure design allows low-bandwidth correction of arm lengths, for earth tides and the DF microseism.
- Streckeisen STS-2 seismometer signals from each building are filtered to produce differential and common-mode arm length correction signals that are applied to the FAS, largely removing the microseism independently of LSC servos.
- Filters are derived using system-identification tools, and represent a compromise between high performance at the microseism and minimal added noise elsewhere.

Noise Reduction during E6

- E6 was during a period of very high microseism, allowing a good test.
- Test mass RMS (0.03 - 0.5 Hz) reduced by ≈ 85% , so that this spectral band no longer dominates the control signal.





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Extended Range Coil Drivers

- More actuation range needed in 1-3 Hz regime (LLO)
- Increase the maximum current to the coils
- Needs thermal protection!
- Cannot reach ultimate LIGO noise floor

New Suspension Sensors / High Power Operations

- Developed in parallel with low power commissioning activities
  - Develop a robust solution without pressure of critical path
- Use different LED/photodiode combination with interference filter to discriminate against scattered laser light
- Implementation scheduled to minimize impact on commissioning
  - LHO 4 km installation scheduled to make use of new sensors from beginning
  - LHO 2 km retrofit made in combination with earthquake repairs
  - LLO 4 km retrofit in progress
- **LHO 2 km mode cleaner successfully tested to full power**
- **All IFO running with 1W input power**

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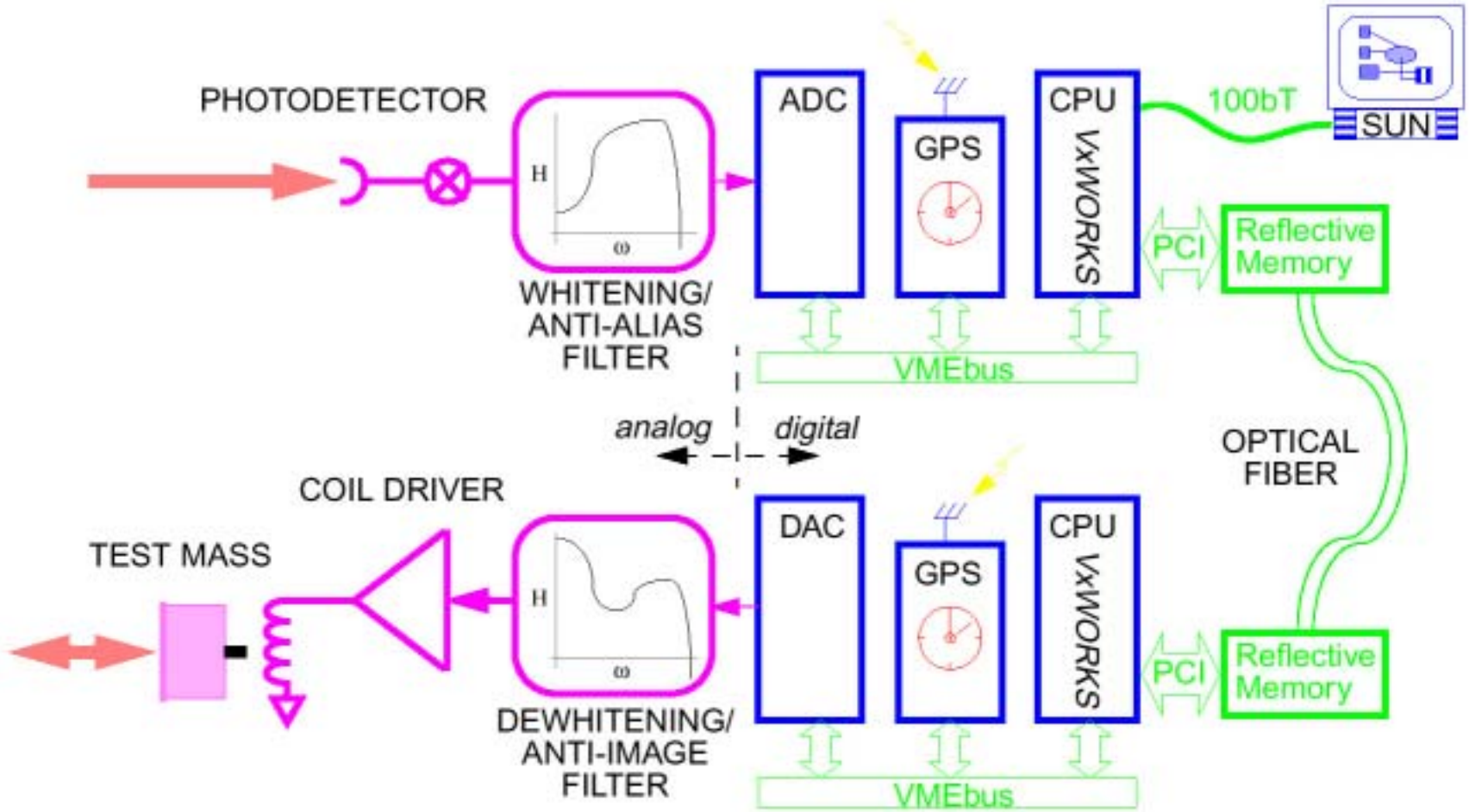
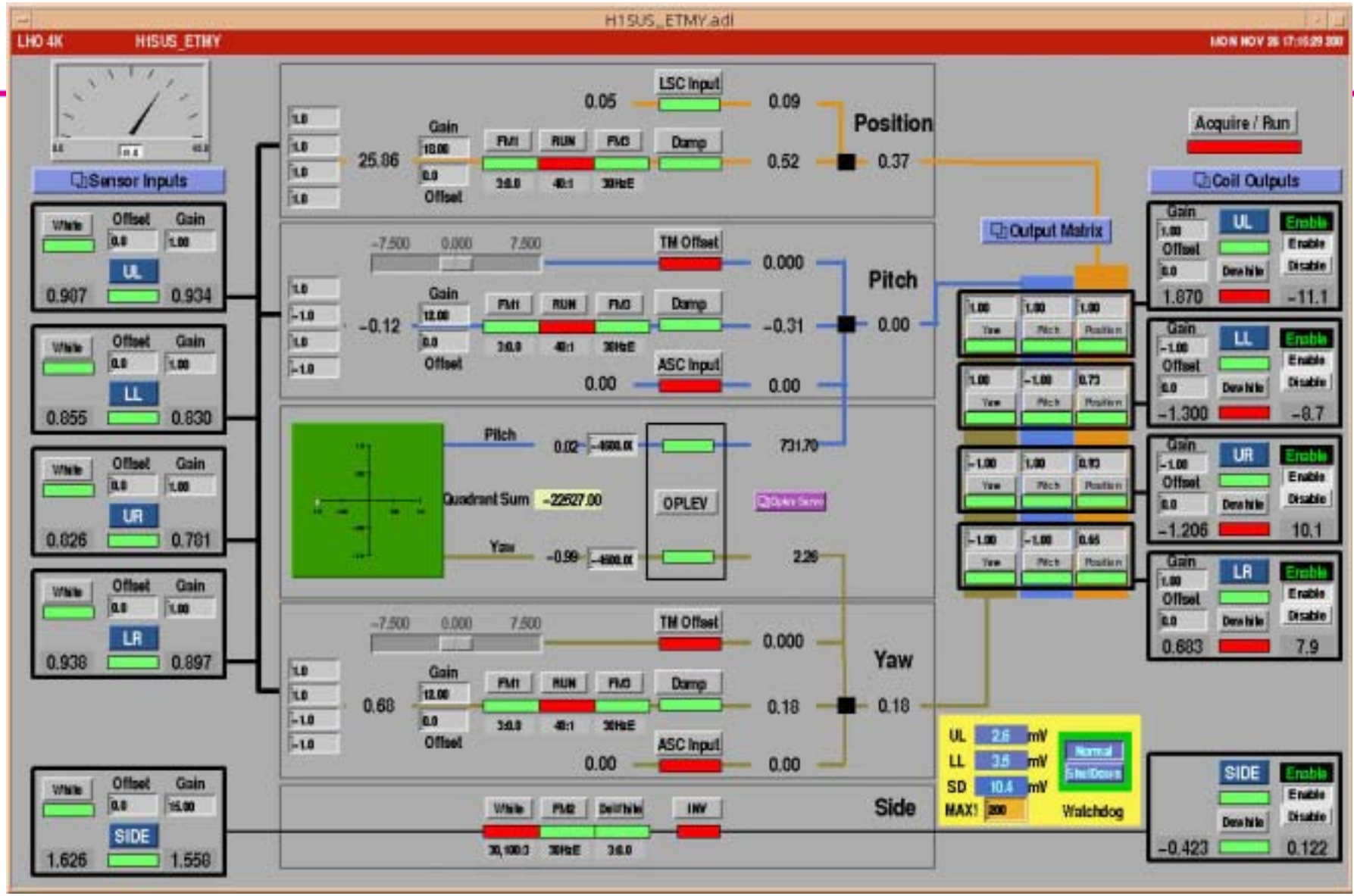
Digital Suspension Controllers

- Why?
  - Flexibility in implementing the MIMO filters
  - low frequency filtering in analog $\Rightarrow$ big capacitors
  - Too much analog electronics; changes are painful
- Implementation
  - Sensor & Coil drivers analog; rest digital
  - Same technology as ASC/LSC
- Status
  - Fully functional @ LHO 4K
  - Mostly built for LLO 4K and LHO 2K; installation after E7(?)

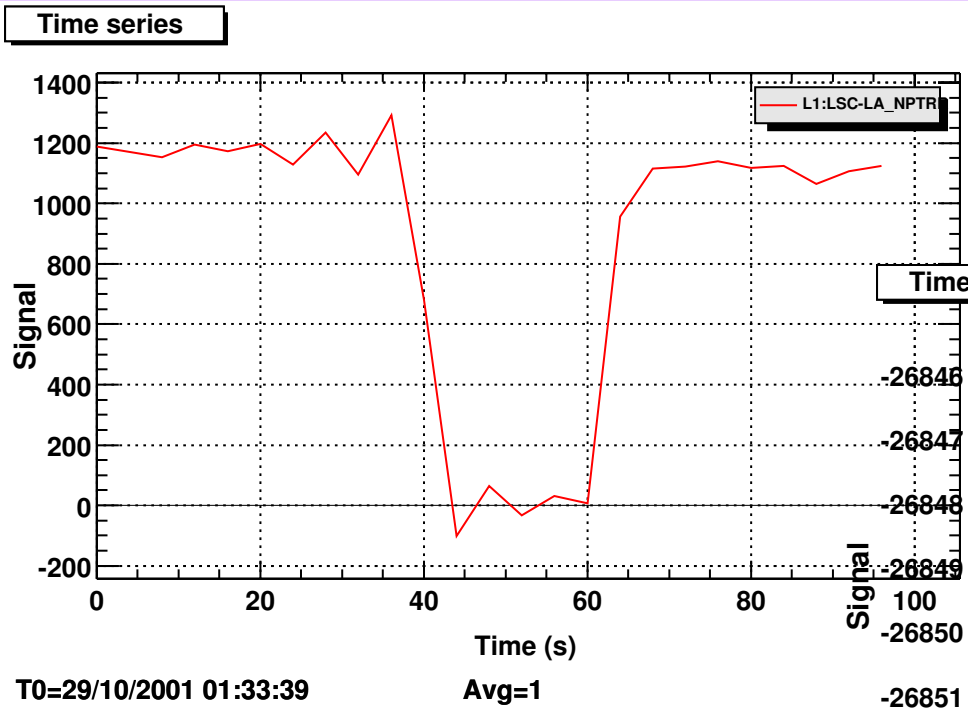
Digital Suspension Controllers (2)



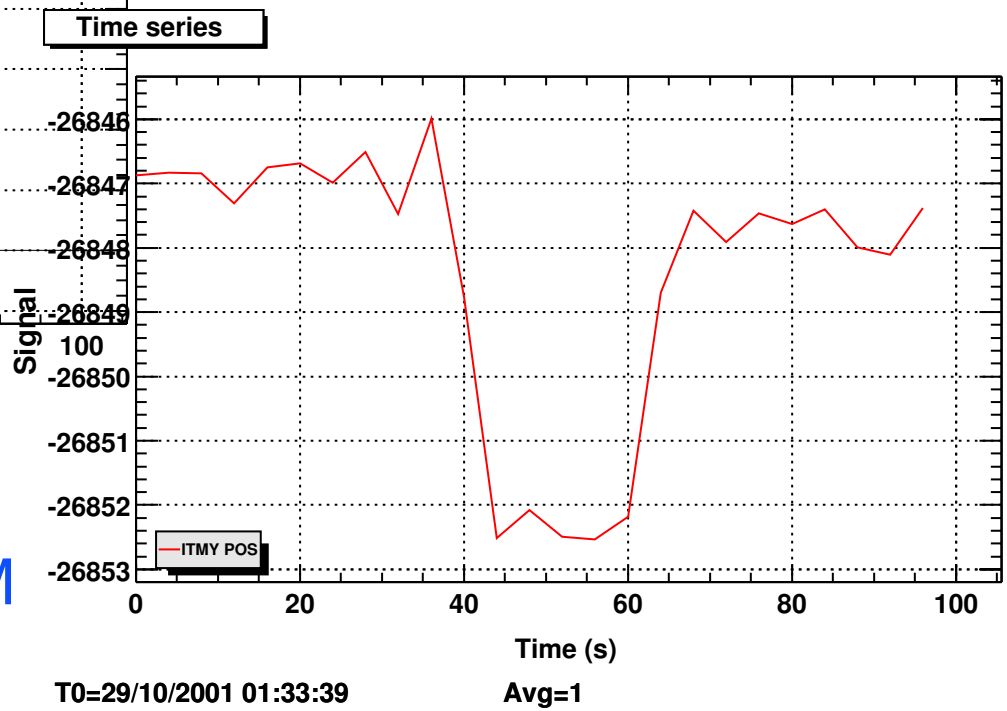
Digital Suspension Controllers (3)



Radiation Pressure

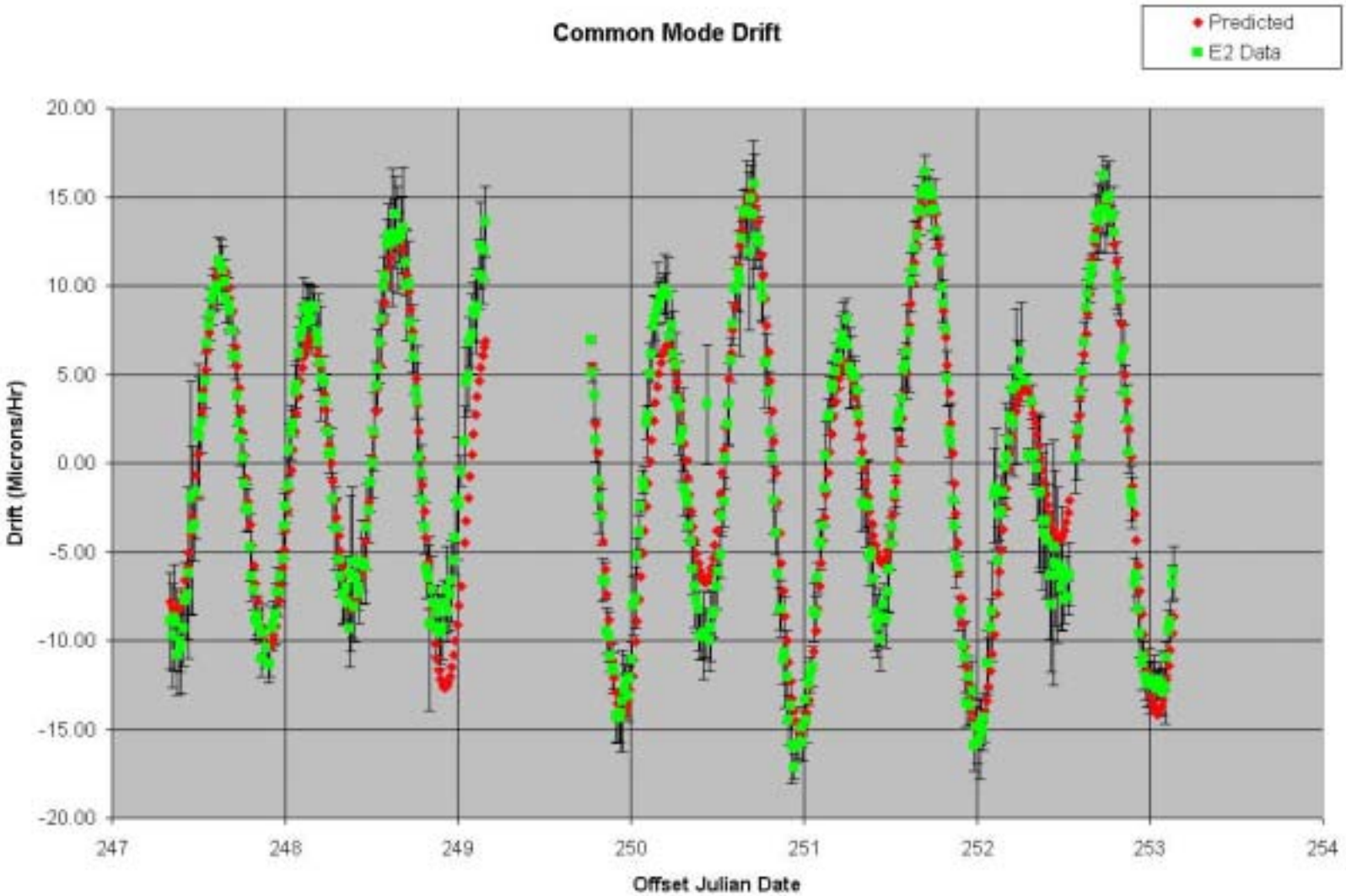


Arm Power



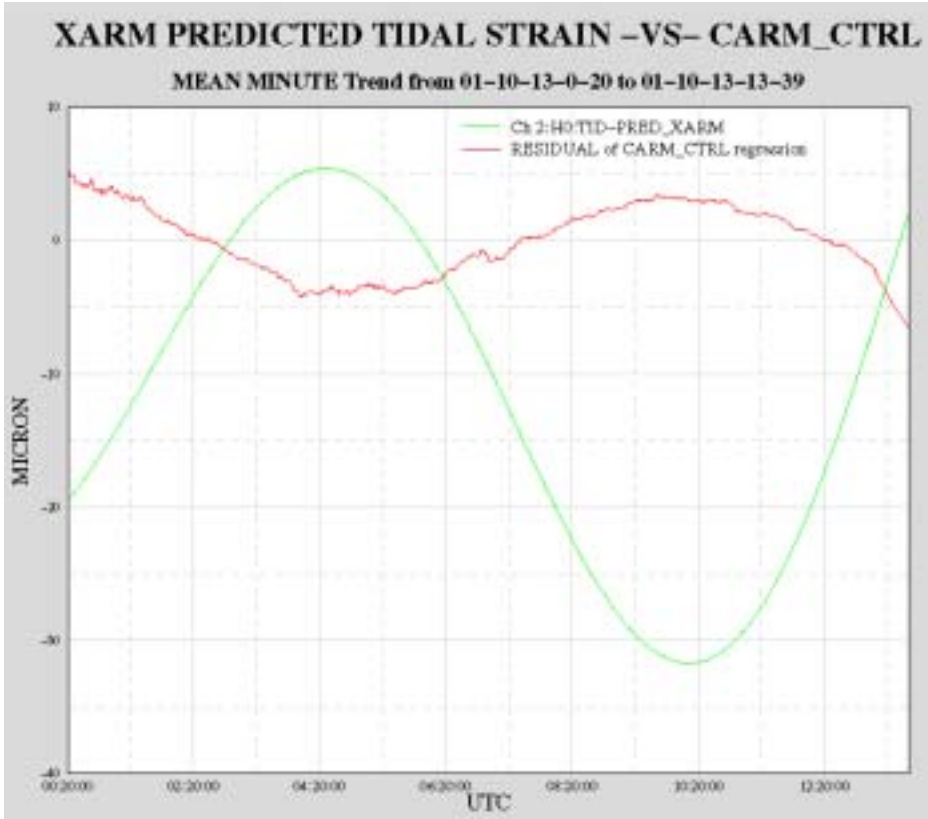
SUS Sensor ITM

Tidal Effects



Tidal Feedforward Compensation Development

- Using fine actuators on single locked arms for investigations at LHO
- Lock extensions provide better data for fitting to unmodeled physics
- Also allow frequency response meas. on PSL reference cavity oven, better drift characterization



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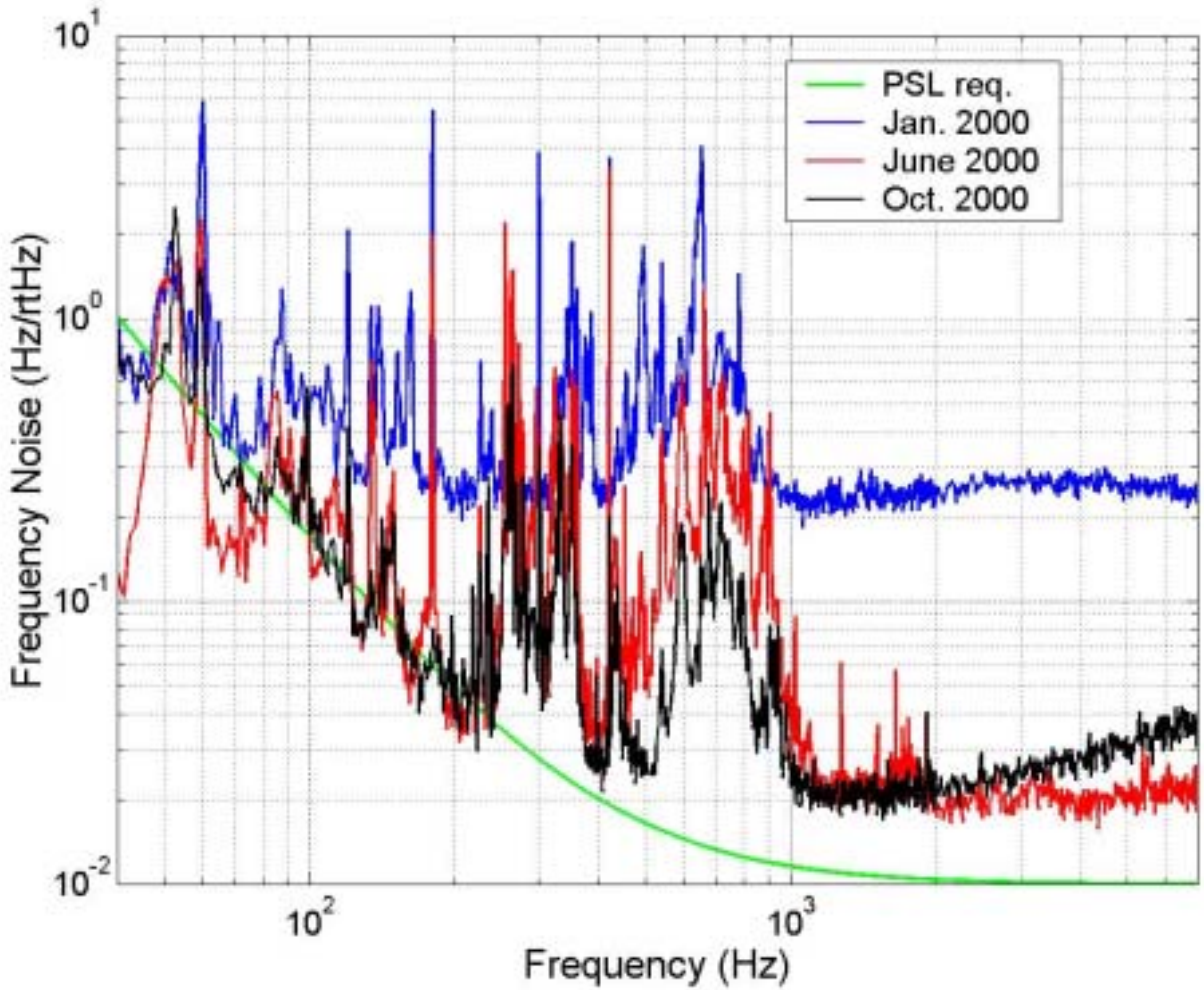
Tidal Feedforward Results to Date

- Approx. 80% removal of tides using simple 1st principles model; 10-14 hr locks
- Presently solving for perturbation phasors to account for unmodeled effects (oceans, local topo.)
- Large non-tidal drifts identified due to temperature changes in reference cavity oven, LVEA
  - Reference cavity stability improved
  - Diurnal temp fluctuations under study
- Plan: solve for perturbed phasors (90-95% removal?), then servo with fine actuators to remove residual

Frequency Noise

Improvement in noise performance

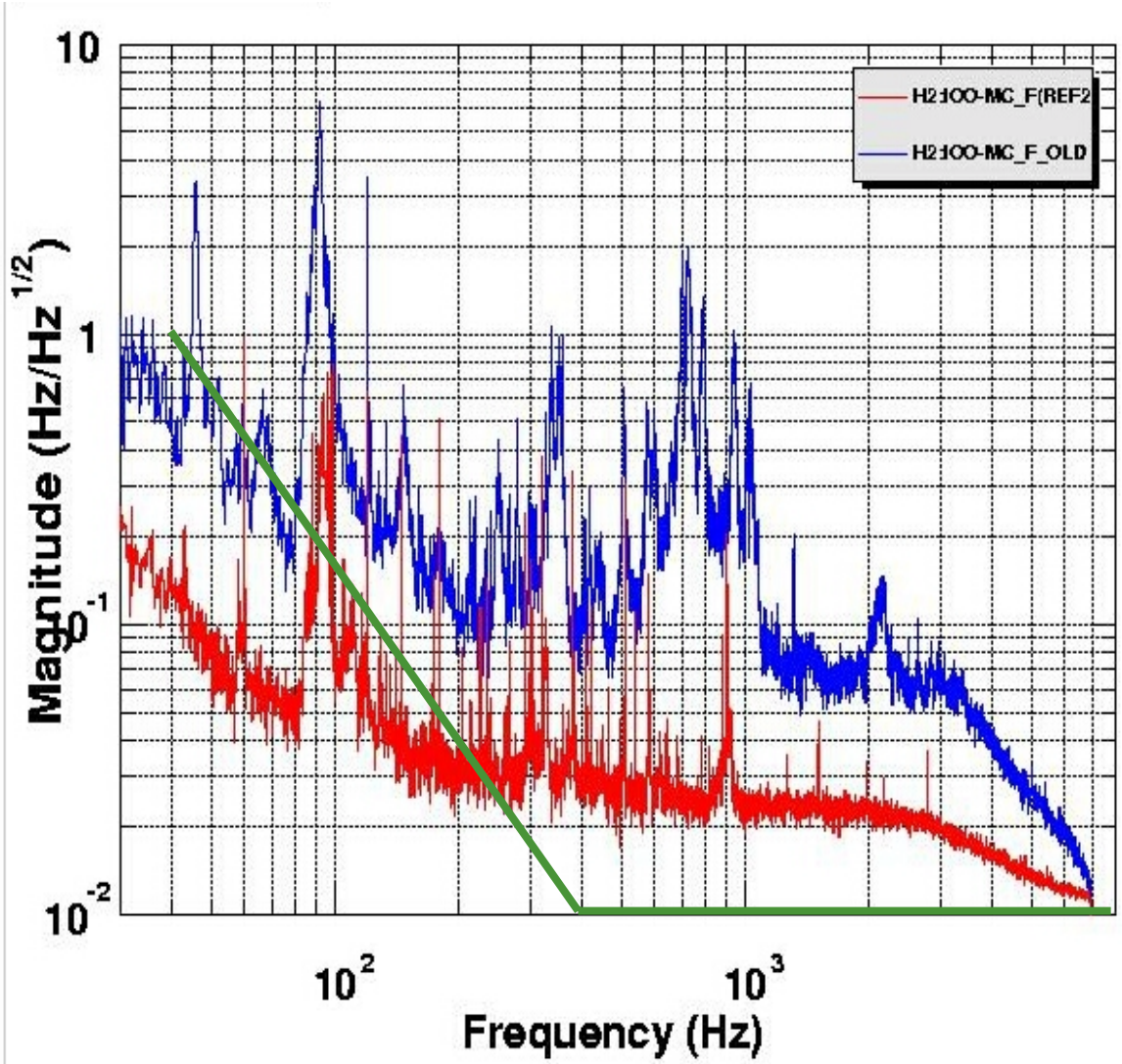
- Electronics
- Acoustics
- Vibrations



Frequency Noise (2)

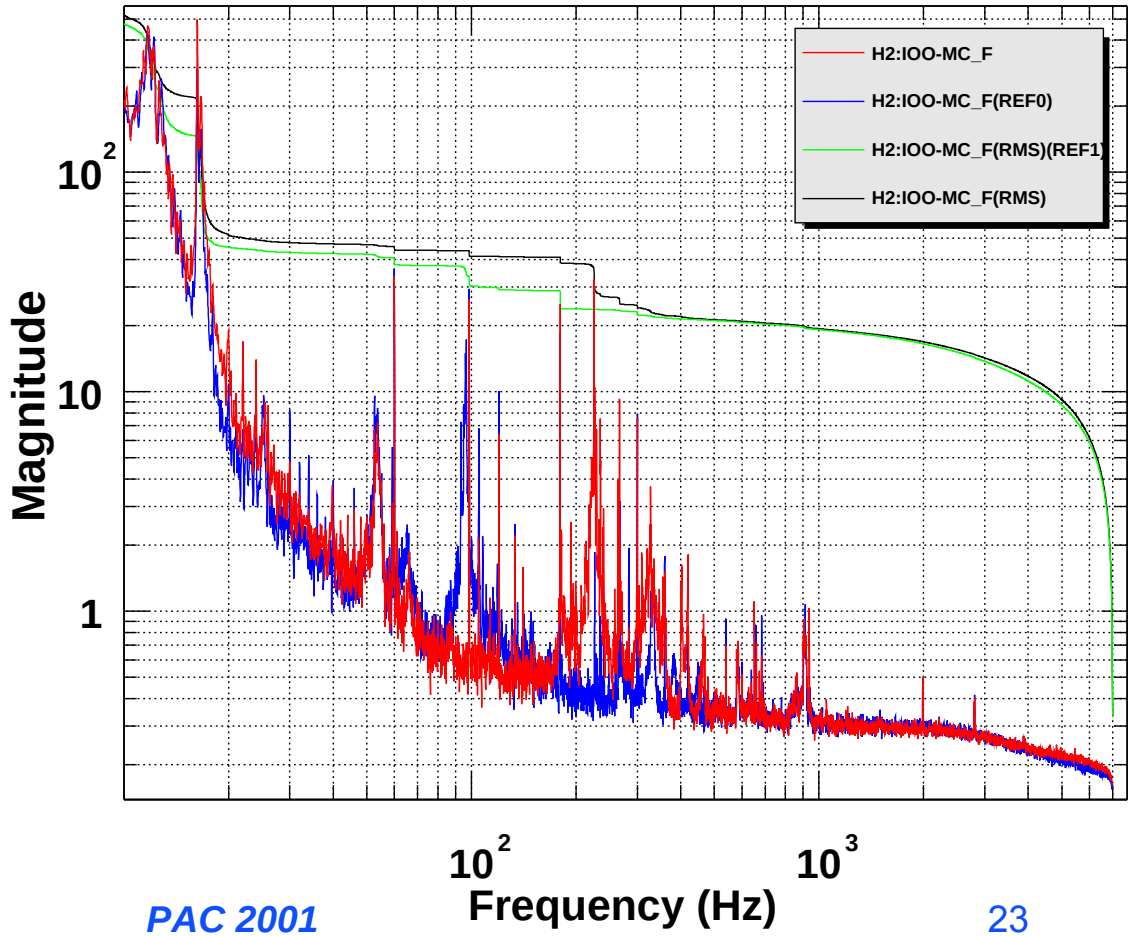
Simplification of beam path external to vacuum system eliminates peaks due to vibrations

Broadband noise better than spec in 40-200 Hz region

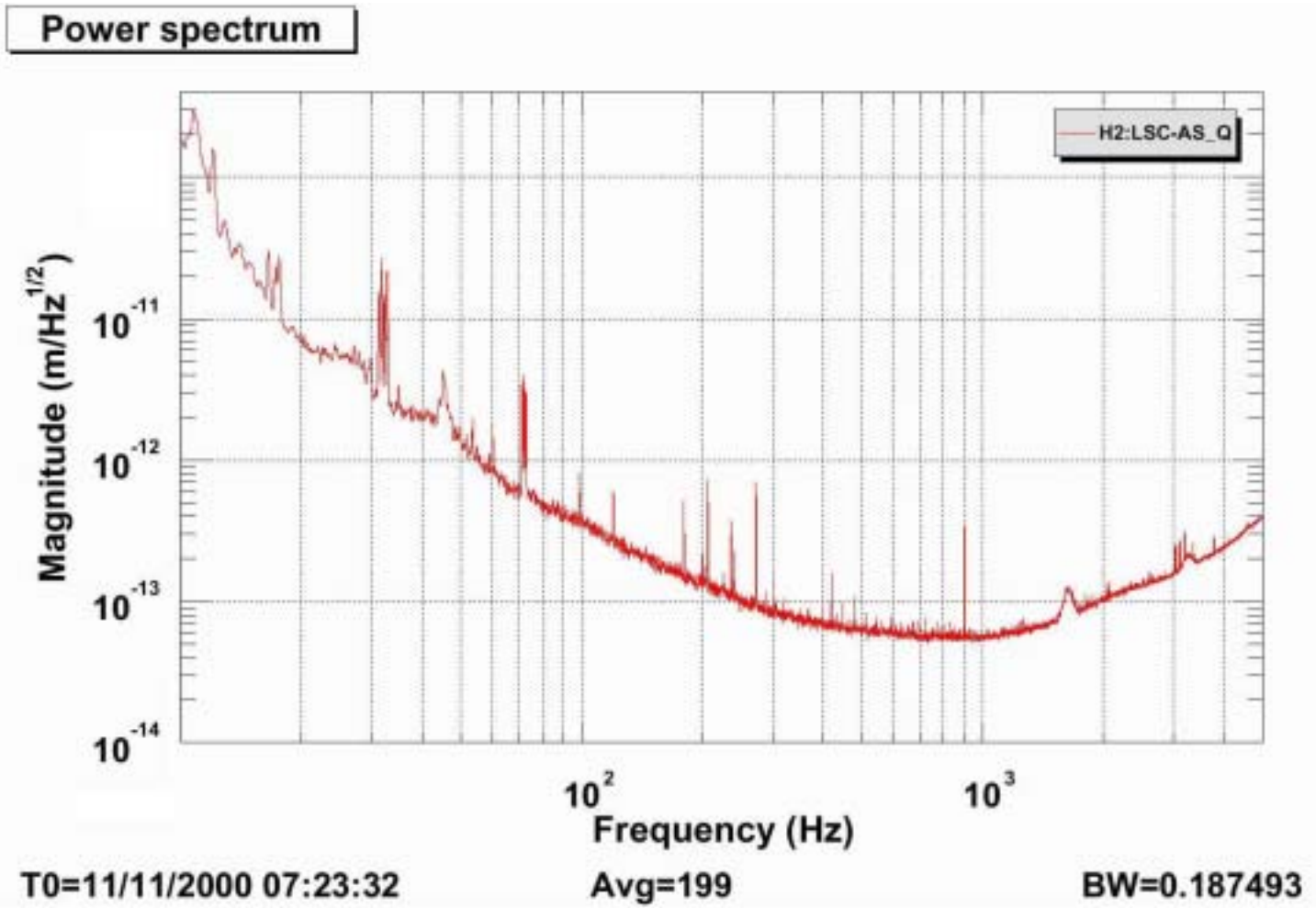


Frequency Noise (3) New Periscope

- 100 Hz ⇒ 22O Hz
- Reasonable agreement with modeling
- The narrow features in the broad periscope peak appear to be narrow acoustic sources coupling more efficiently due to the enhanced susceptibility near the periscope peak

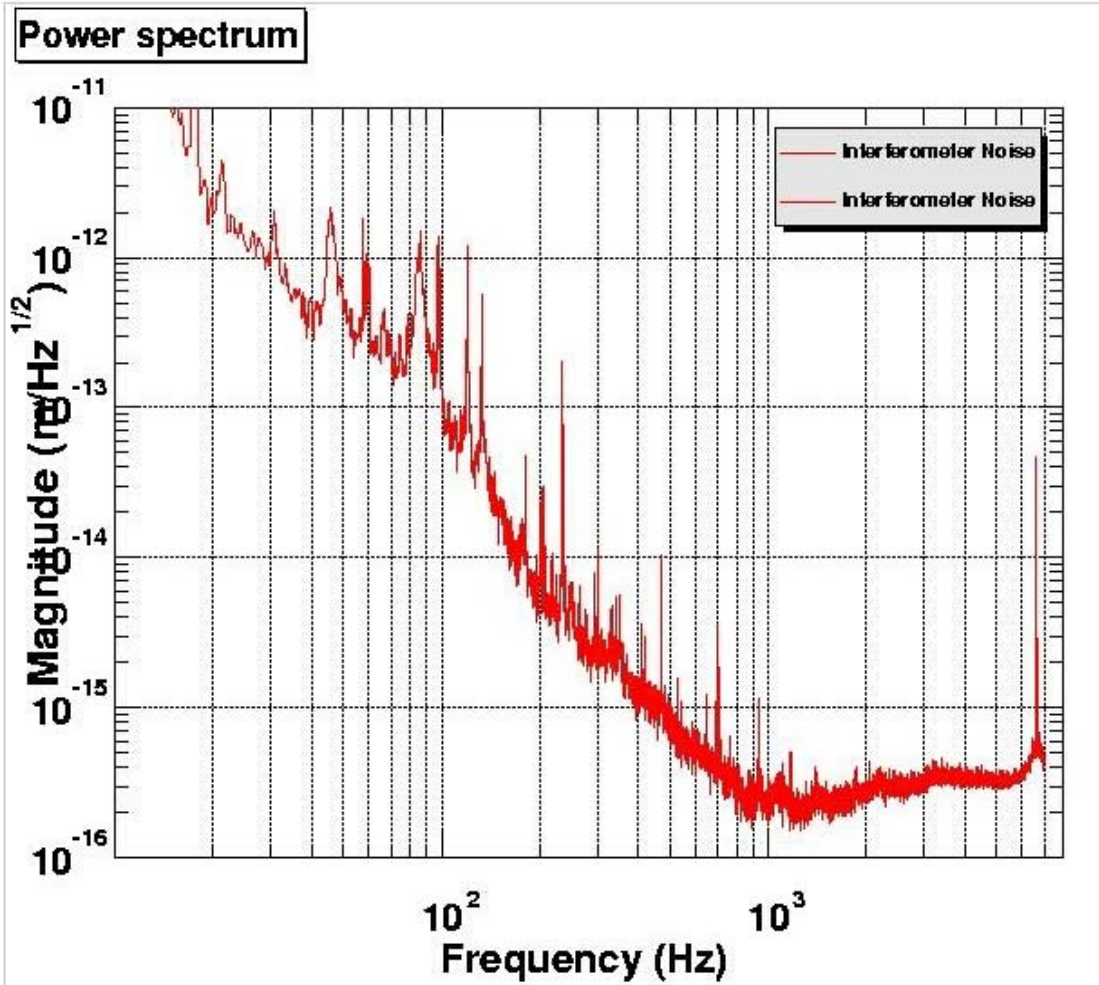


Noise Spectrum: 2K Recombined



E2 Run

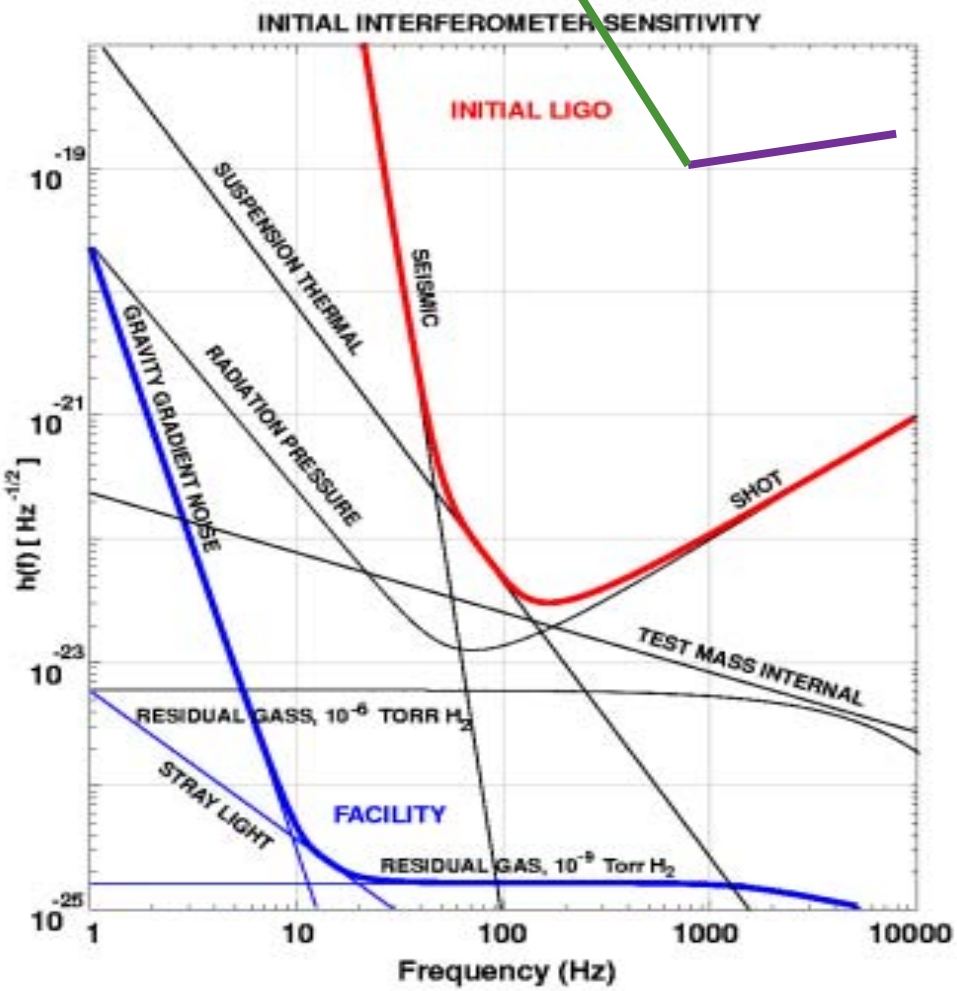
Noise Spectrum: 2K Recycled



Factor of 200 improvement (over E2 spectrum)

- Recycling
- Reduction of electronics noise
- Partial implementation of alignment control

Initial LIGO Sensitivity



- Frequency noise
  - Improve PSL Table layout (done)
  - Tailor MC loop (done)
  - Implement common-mode feedback from arms
- Electronics noise
  - Non-linearities?
  - Filters?
  - Alignment?
  - Others?

LIGO

Summary

- What has been done
  - LLO 4K locked
  - LHO 4K ready
  - Digital SUS
  - Many improvements in electronics/software/training
- Some things that were not
  - No significant improvement in noise since spring
  - Common mode for frequency stabilization
  - Full alignment control
- Seismic situation at LLO needs long-term solution