



# The LIGO Gravitational Wave Detectors

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- Introduction: The LIGO observatory
  - » Detector overview
  - » Sensitivity goal
- Talk Focus: the Length Sensing and Control System (LSC)
  - » Pre-Stabilized Laser (PSL)
  - » Input Optics (IO)
  - » LSC configuration (E1 – E7)
  - » LSC current configuration : Common Mode Servo
- Current Sensitivity

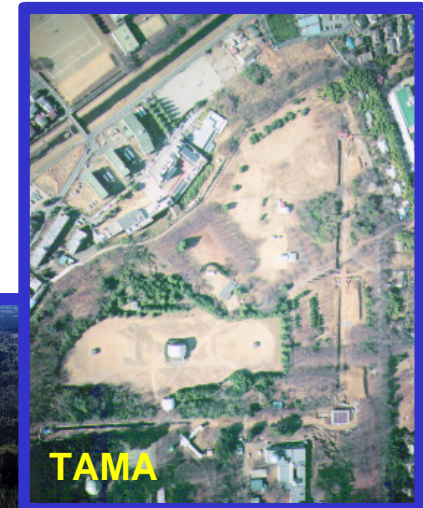




# International Network of Interferometric Detectors

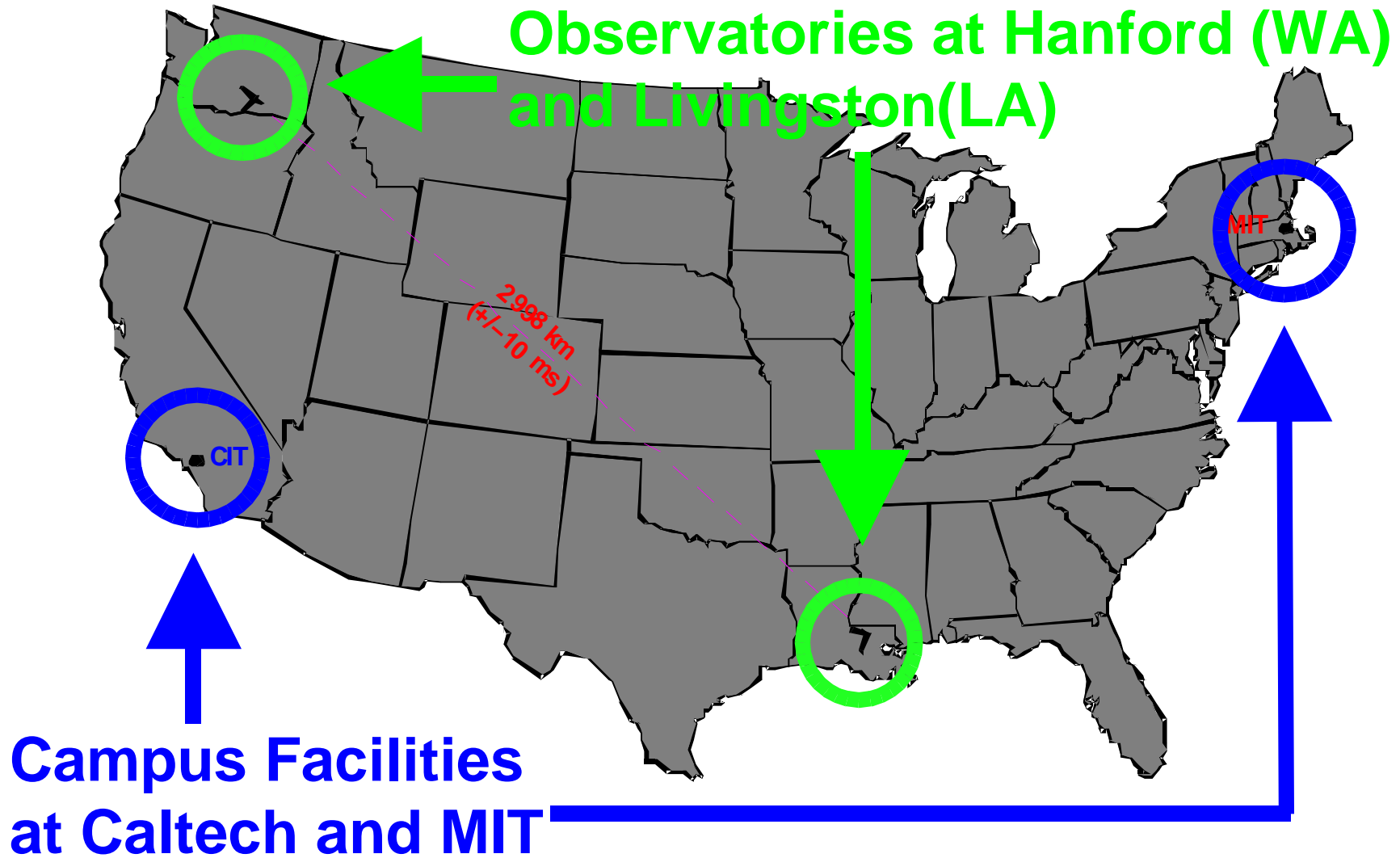
- LIGO, VIRGO, GEO, TAMA

- » 4000m, 3000m, 2000m, 600m, 300m interferometers built to detect gravitational waves





# The LIGO Laboratory







# Aerial Views of the Observatories: LIGO Hanford(WA)

Located on DOE Hanford Nuclear Reservation, north of Richland (WA)







# Aerial Views of the Observatories: *LIGO Livingston(LA)*

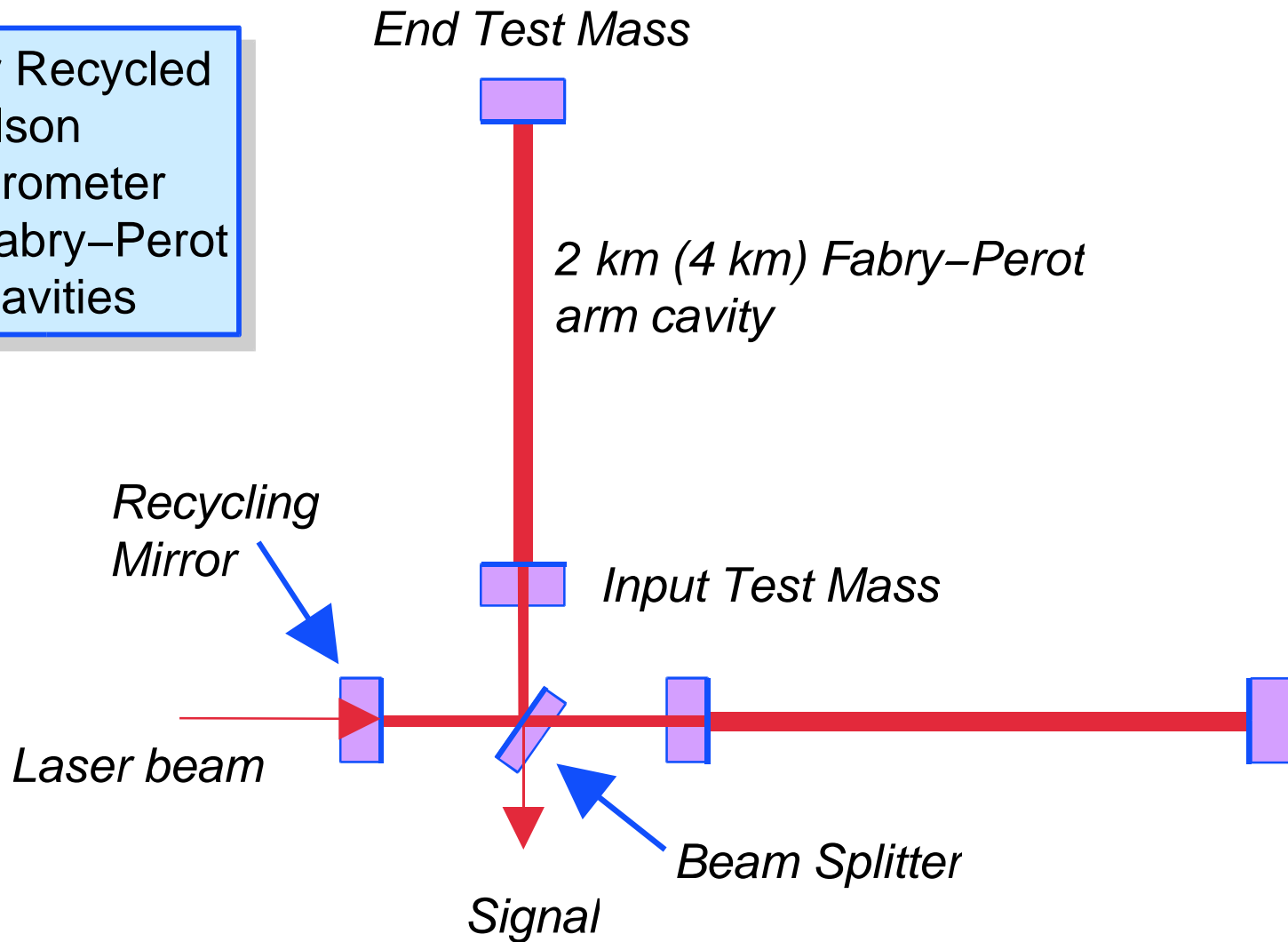
Located in a rural area of Livingston Parish east of Baton Rouge(LA) 4 km



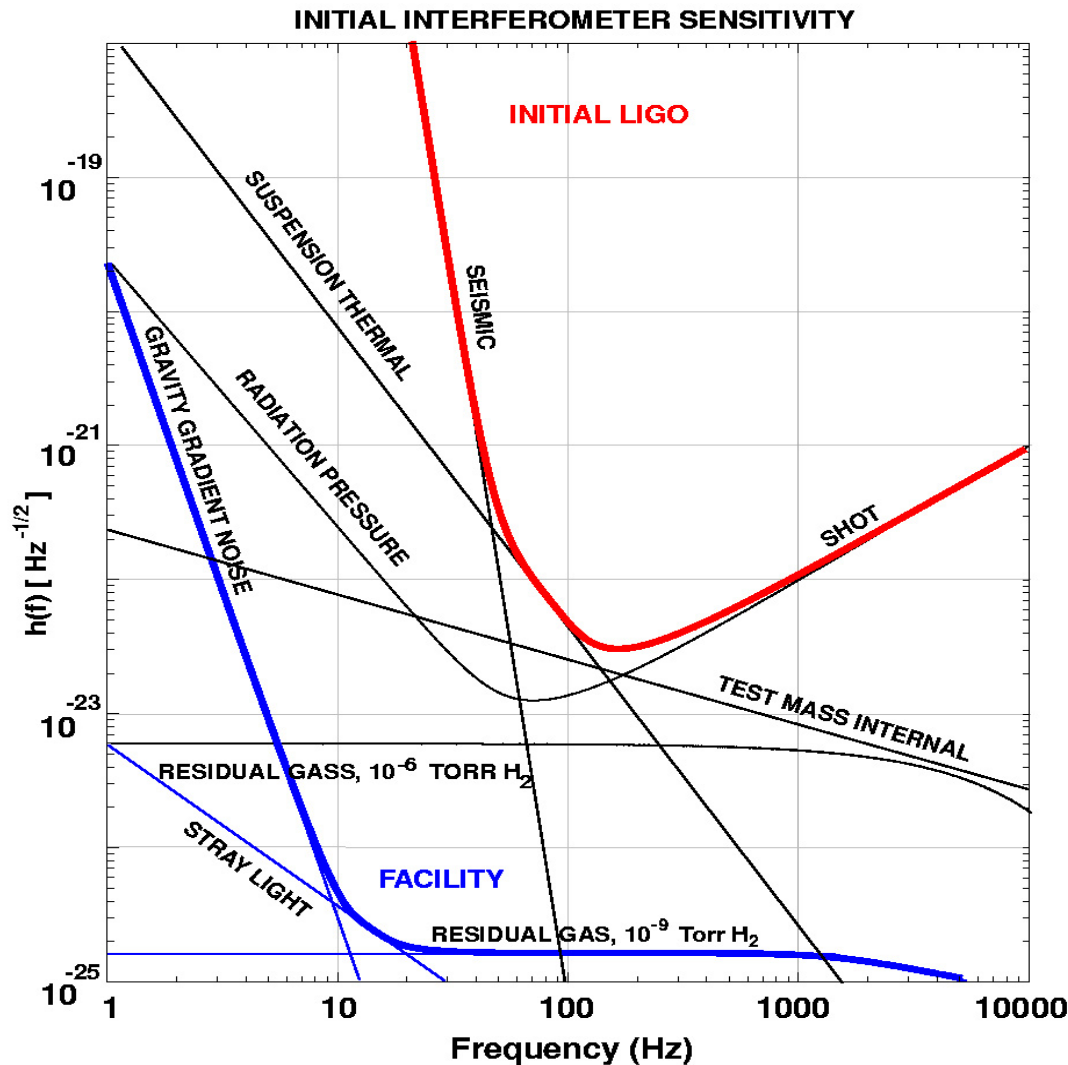


# LIGO Detector Overview: Optical Configuration

Power Recycled  
Michelson  
Interferometer  
with Fabry-Perot  
Arm Cavities



# Aimed Strain Sensitivity



- Strain sensitivity

»  $\sim 10^{-23} / \text{Hz}^{1/2}$  @ 150 Hz

- Sensing Noise

Photon Shot  
Residual Gas

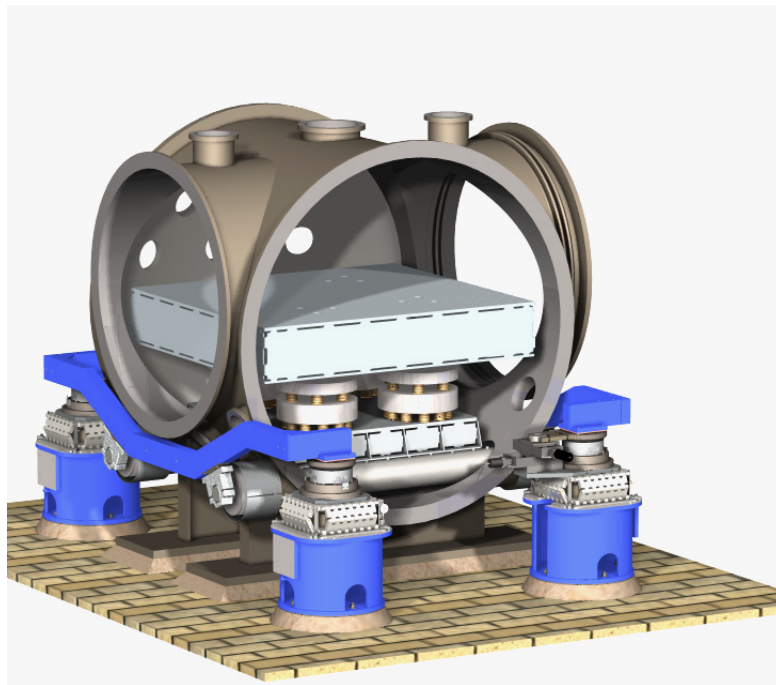
- Displacement Noise

Seismic  
Thermal  
Radiation Pressure

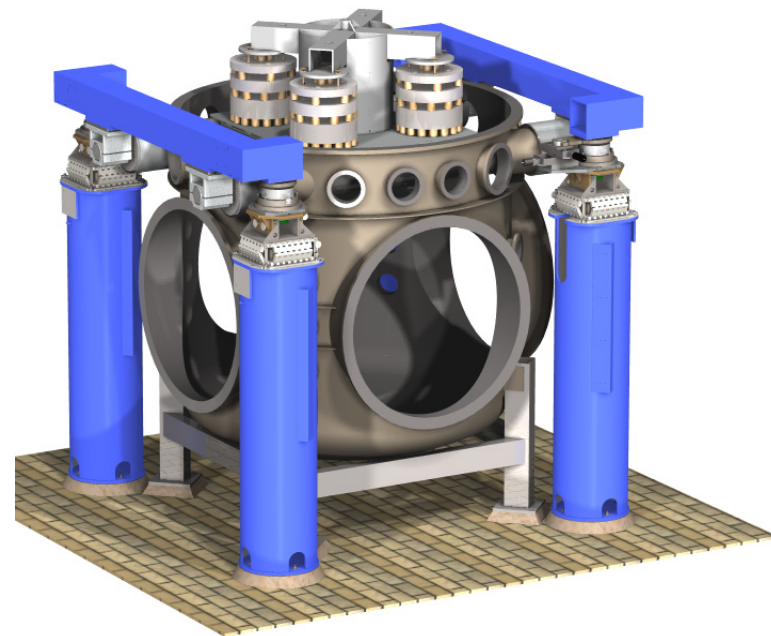


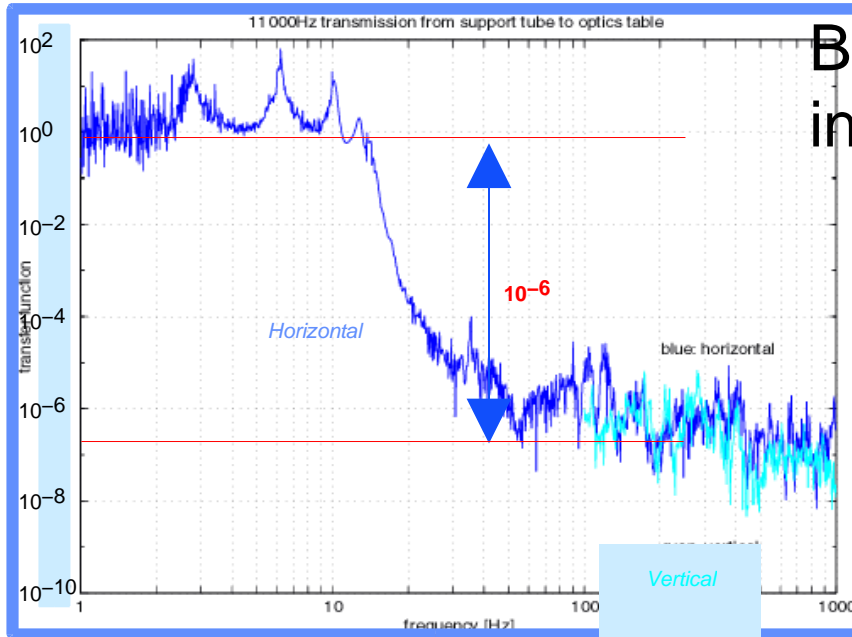
- Reduce seismic motion by 4–6 orders of magnitude
- Earth tides and Micro–seismic correction

HAM Chamber

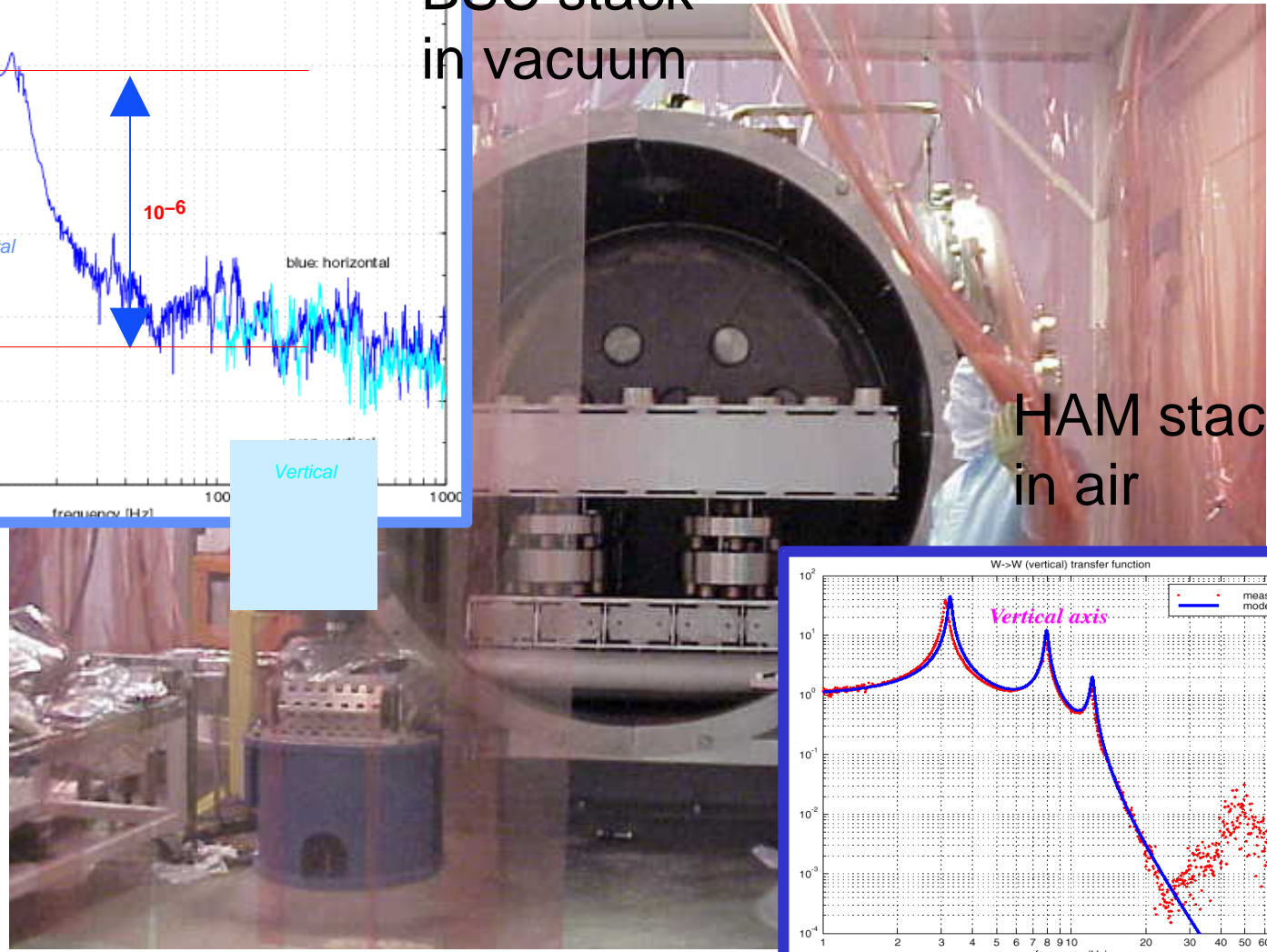


BSC Chamber

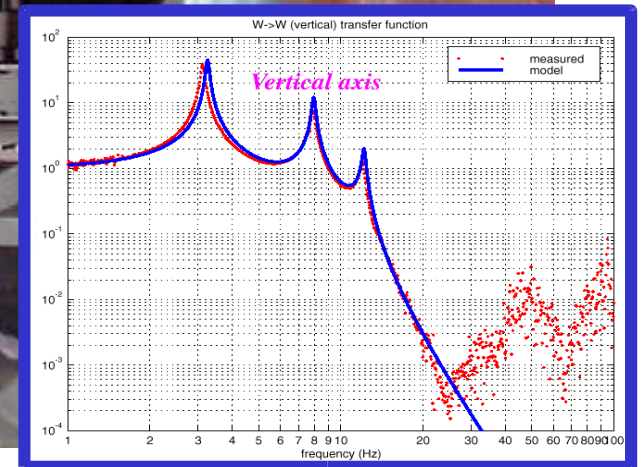




BSC stack  
in vacuum



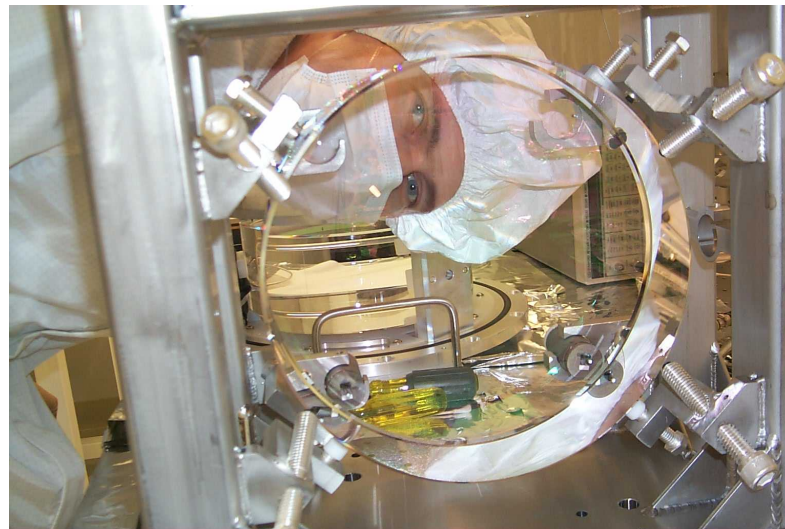
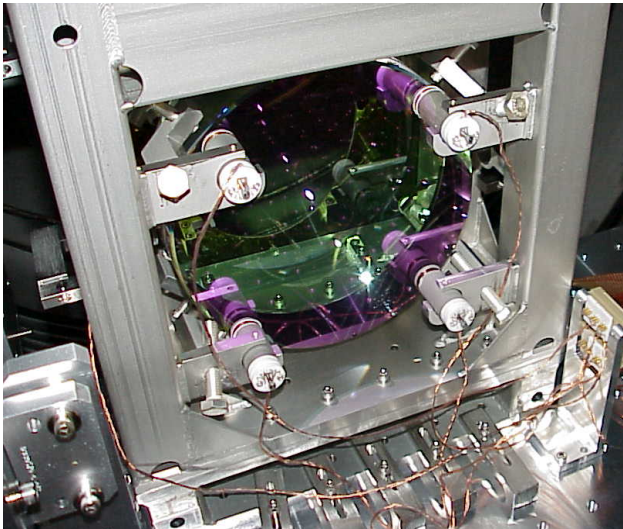
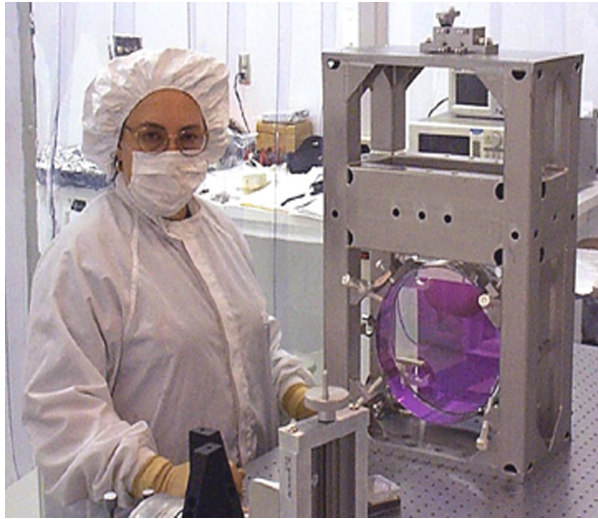
HAM stack  
in air





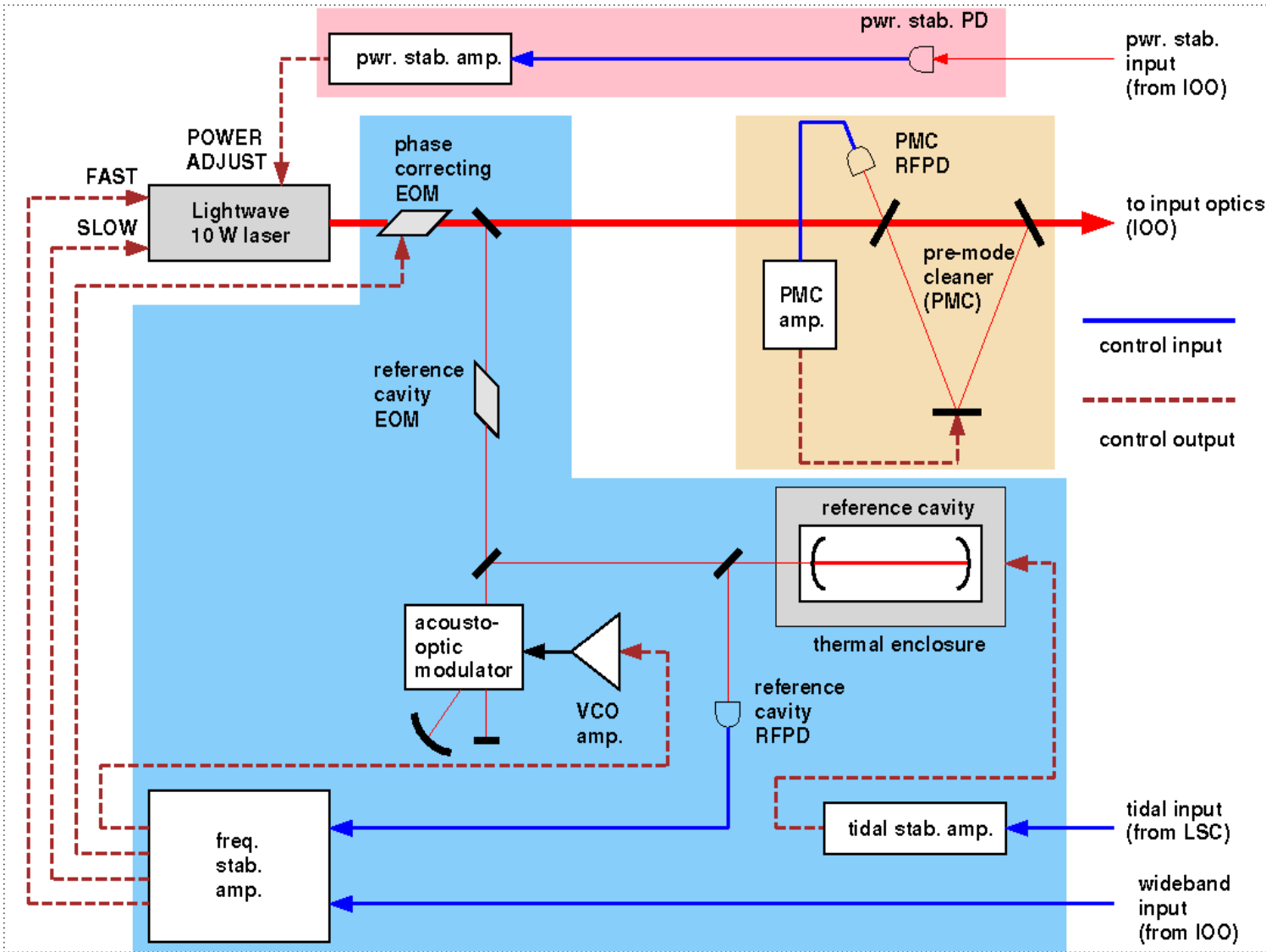


# LIGO Core Optics Suspension and Local Controls



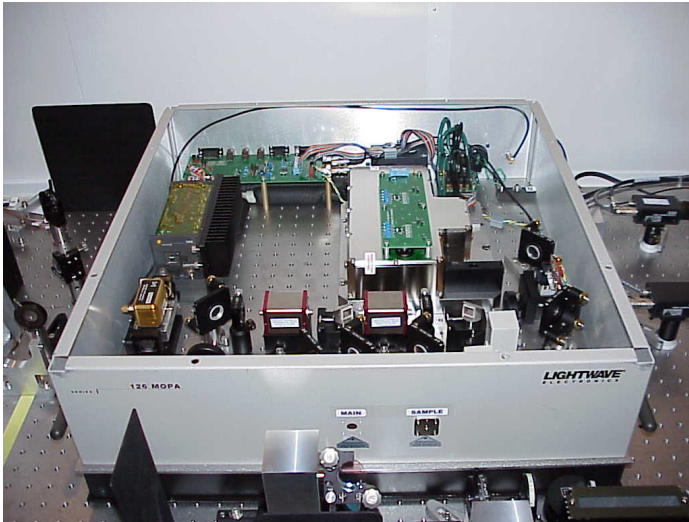


# LIGO Pre-Stabilized Laser (PSL): Block Diagram

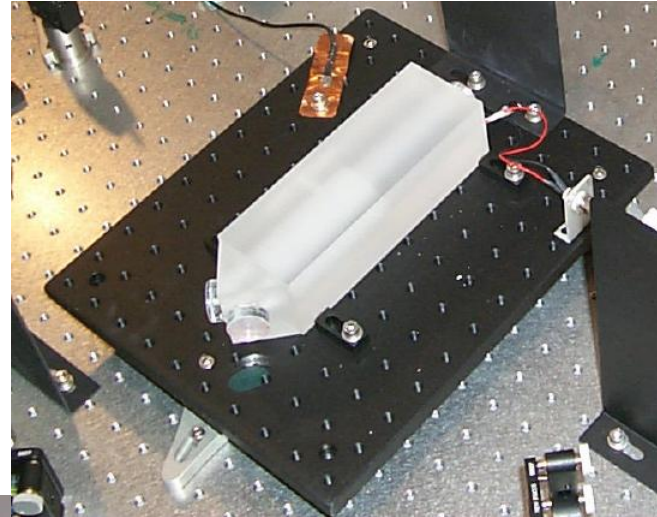




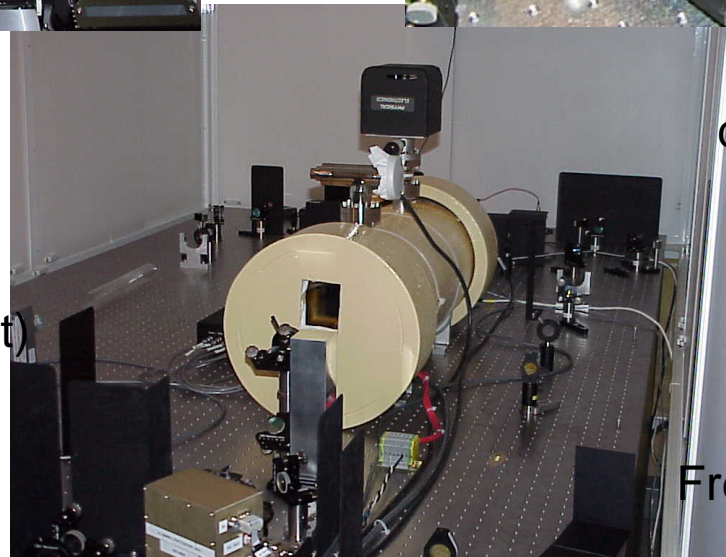
# LIGO Pre-Stabilized Laser (PSL): Hardware



Custom-built  
10 W Nd:YAG Laser,  
joint development with  
Lightwave Electronics  
(now commercial product)

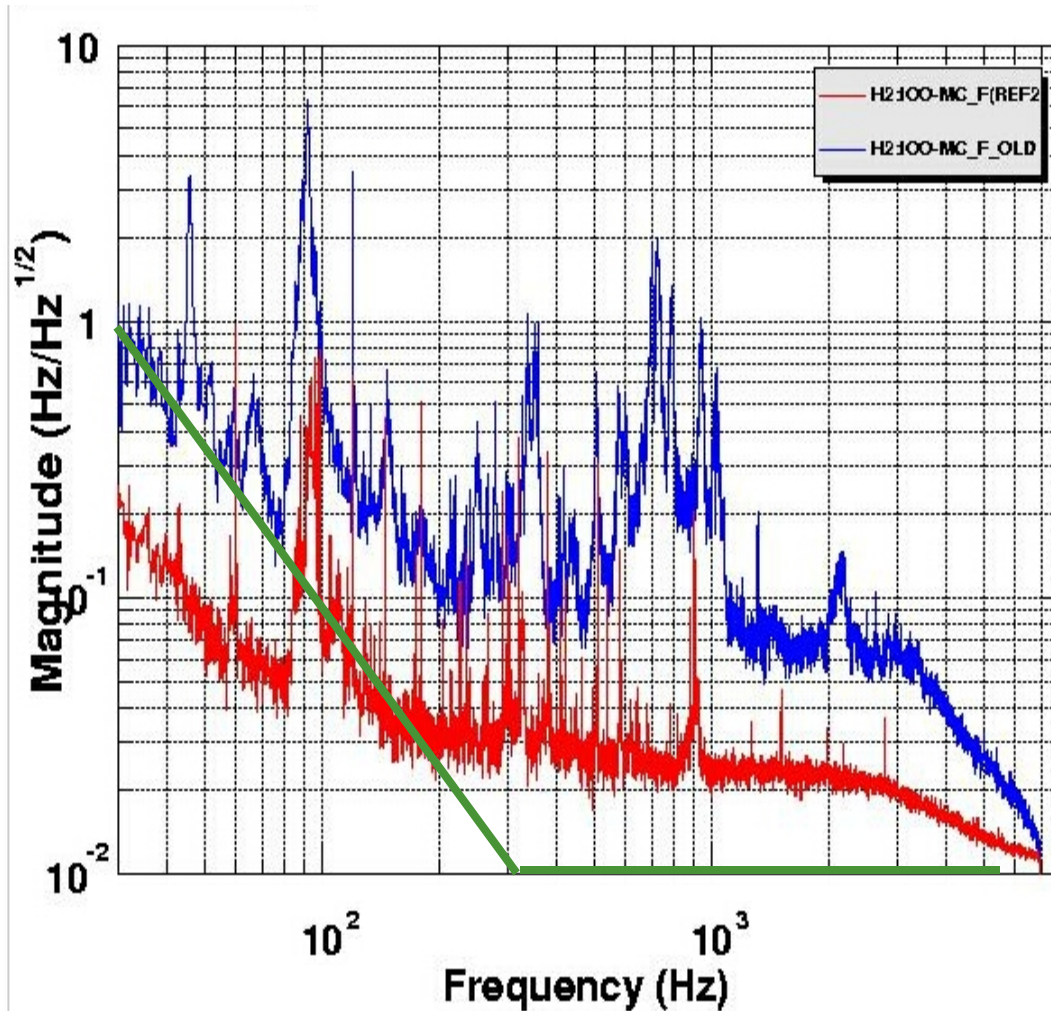


Cavity for  
defining beam geometry,  
joint development with  
Stanford

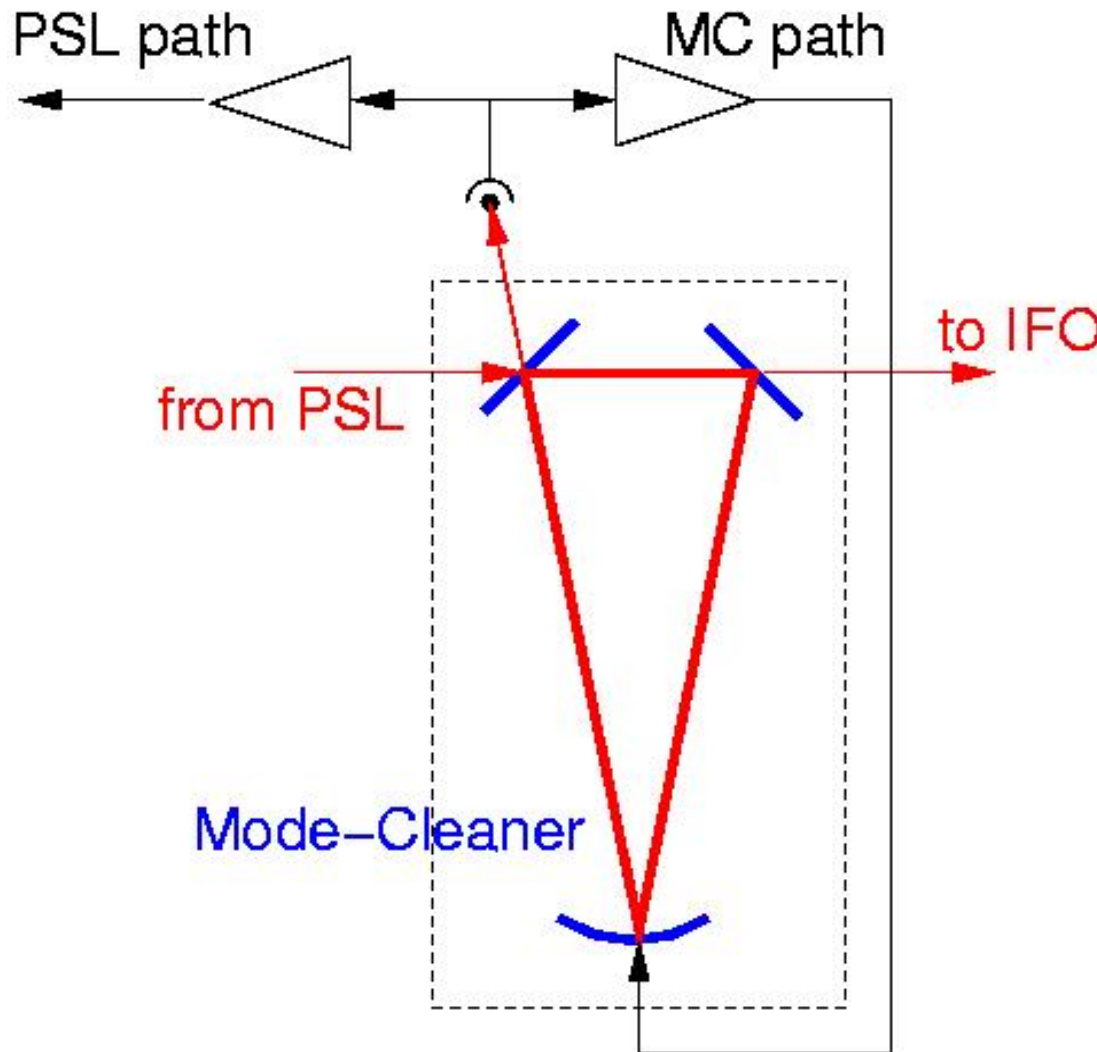


Frequency stabilization  
cavity<sup>1</sup>





- Simplification of beam path external to vacuum system eliminated peaks due to vibrations
- Broadband noise better than spec up to 200 Hz, still work to do above 200 Hz
- $10^{-1}$  Hz/rHz @ 100Hz



- 2 paths: MC and PSL
- Objective: PSL to follow MC (frequency reference)
- $10^{-4}$  Hz/rHz @ 100Hz



# LIGO Laser/Vacuum Equipment Area (LVEA)

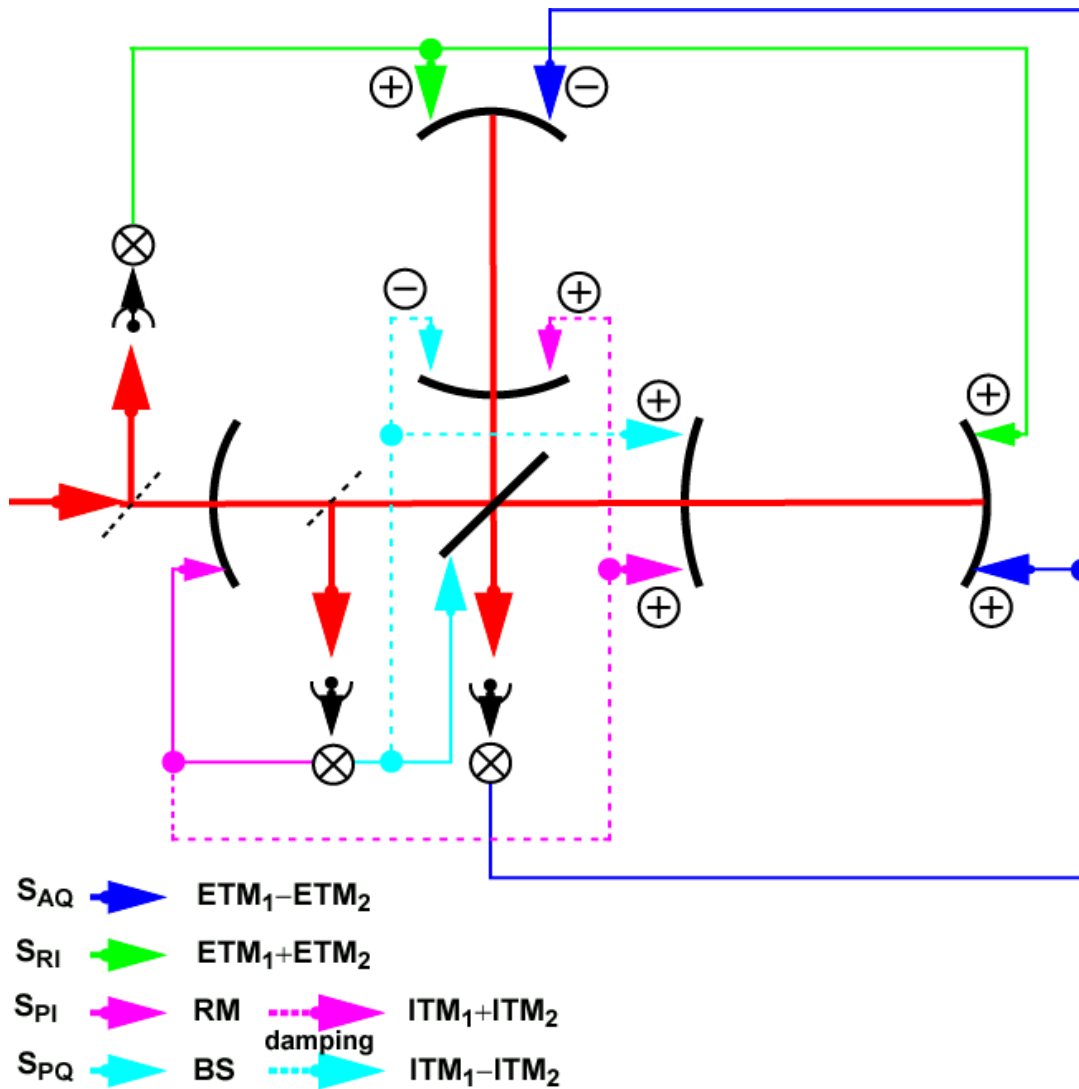


View inside Corner Station



Standing at vertex beam splitter

# LSC (E1-E7): Signal Extraction and Control Scheme



- IFO follows laser, differential handled by mirrors

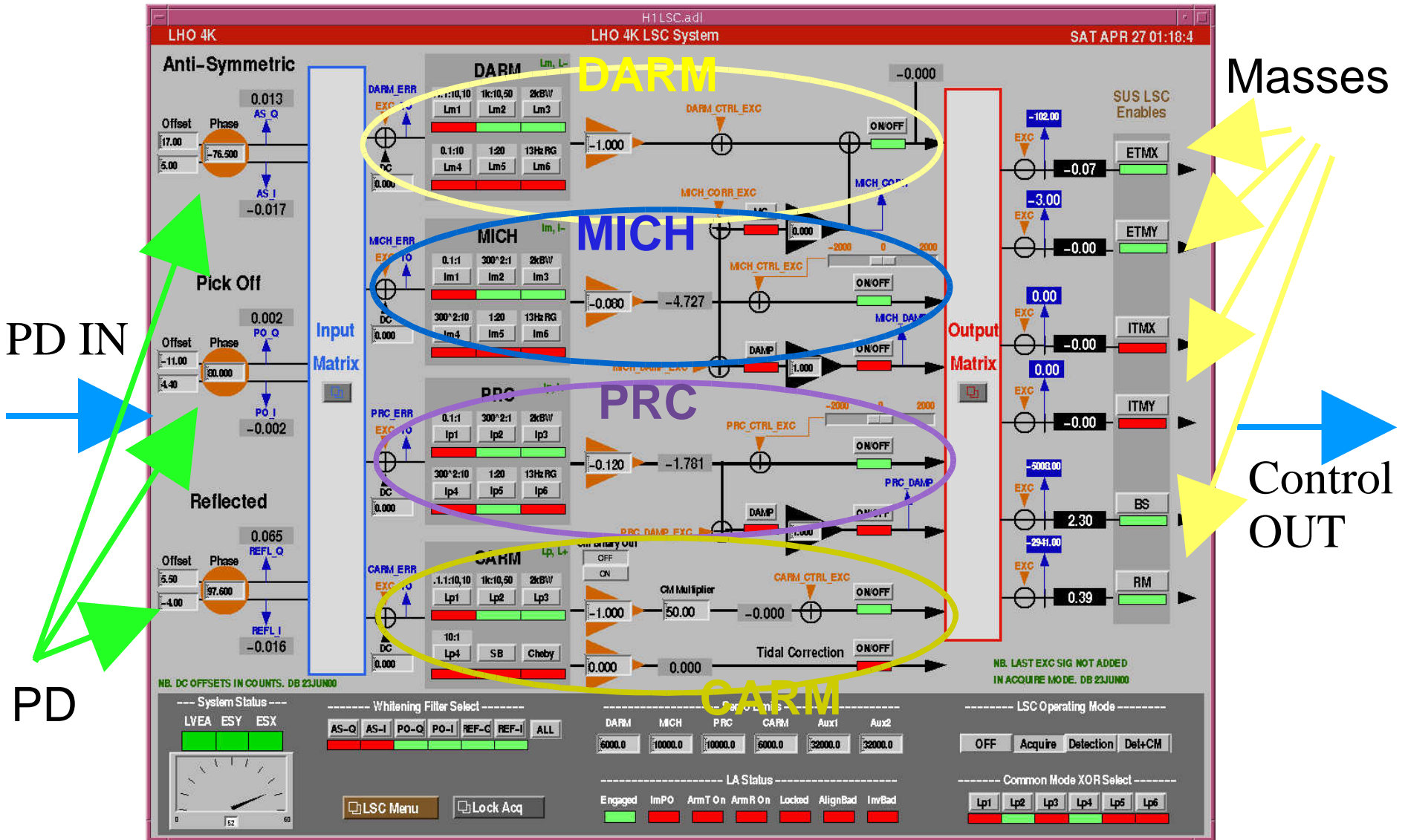
- Detection Matrix

- »  $S_{AQ} \rightarrow L_-$
- »  $S_{RI} \rightarrow L_+$
- »  $S_{PI} \rightarrow I_+$
- »  $S_{PQ} \rightarrow I_-$





# The LSC Control Screen







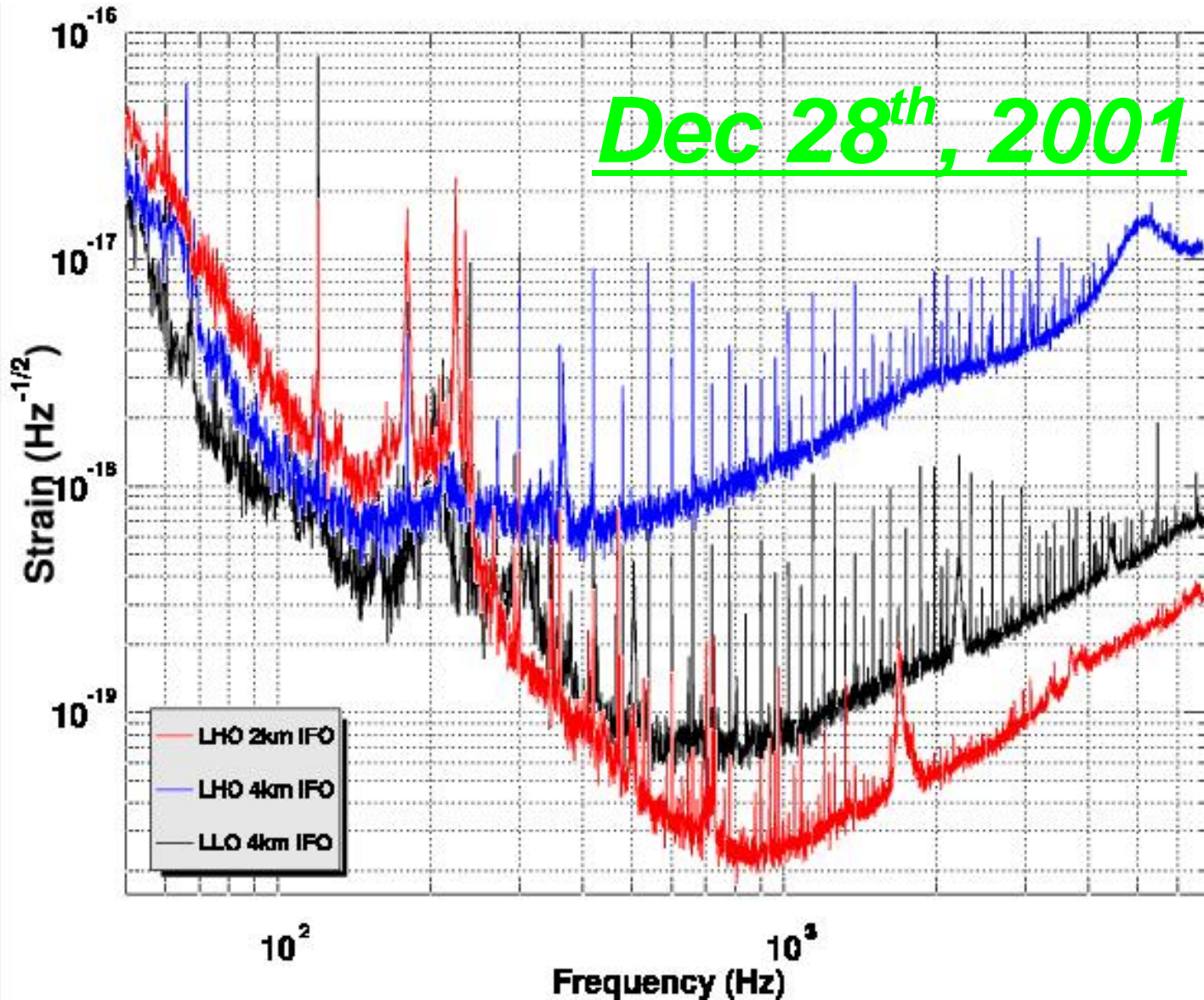
## *E7 (Dec 28<sup>th</sup>, 2001 – Jan 14<sup>th</sup>, 2002) Interferometer Configurations*

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- H1: 4–km interferometer at Hanford; recombined configuration; digital suspension controllers; tidal compensation; 1–W laser power
- H2: 2–km interferometer at Hanford; full power–recycling configuration; differential–mode wave–front control; analog suspension controllers; tidal compensation ; 1–W laser power
- L1: 4–km interferometer at Livingston; recombined configuration; analog suspension controllers; micro–seismic compensation ; 1–W laser power

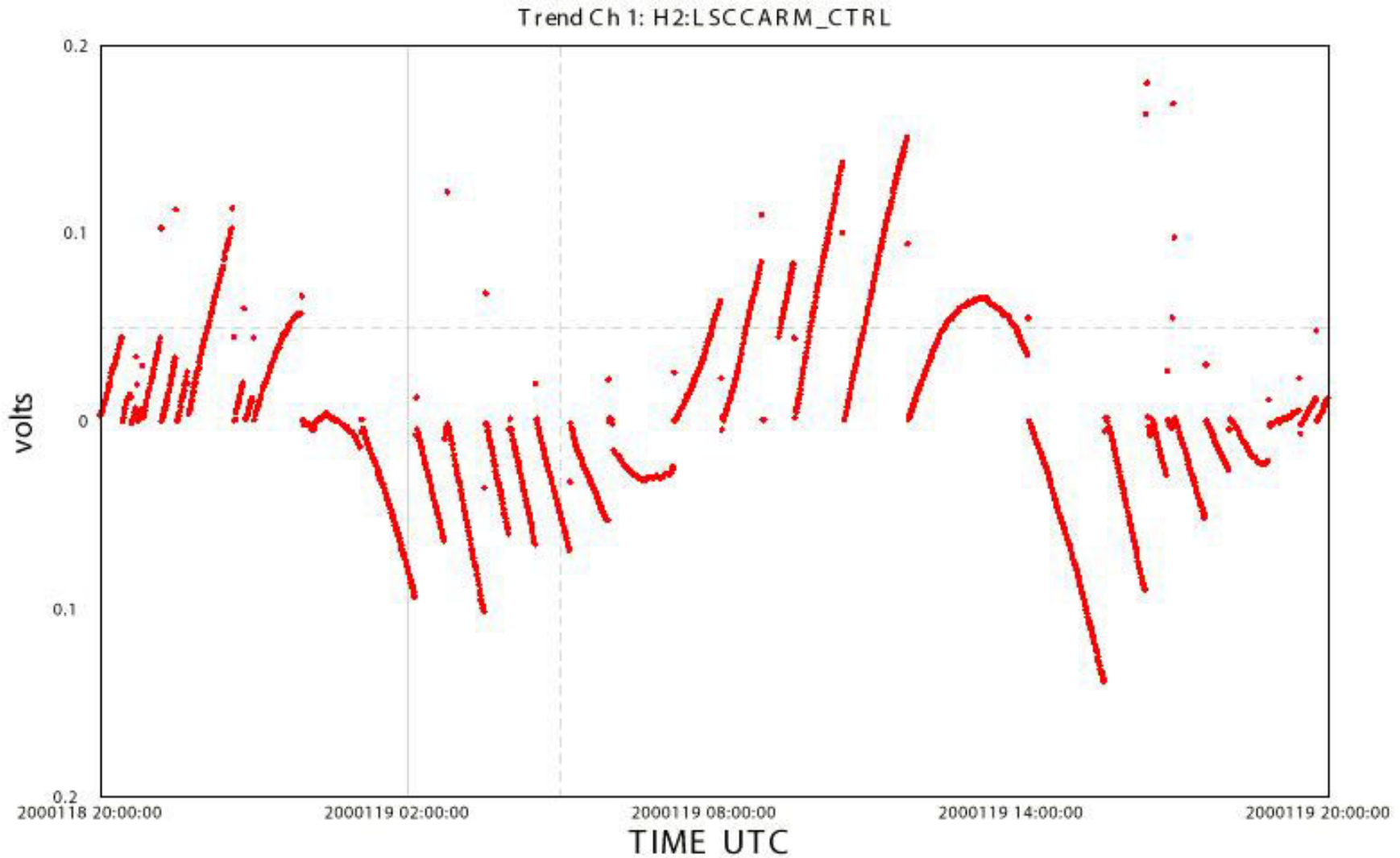


# E7 (Dec 28<sup>th</sup>, 2001 – Jan 14<sup>th</sup>, 2002)

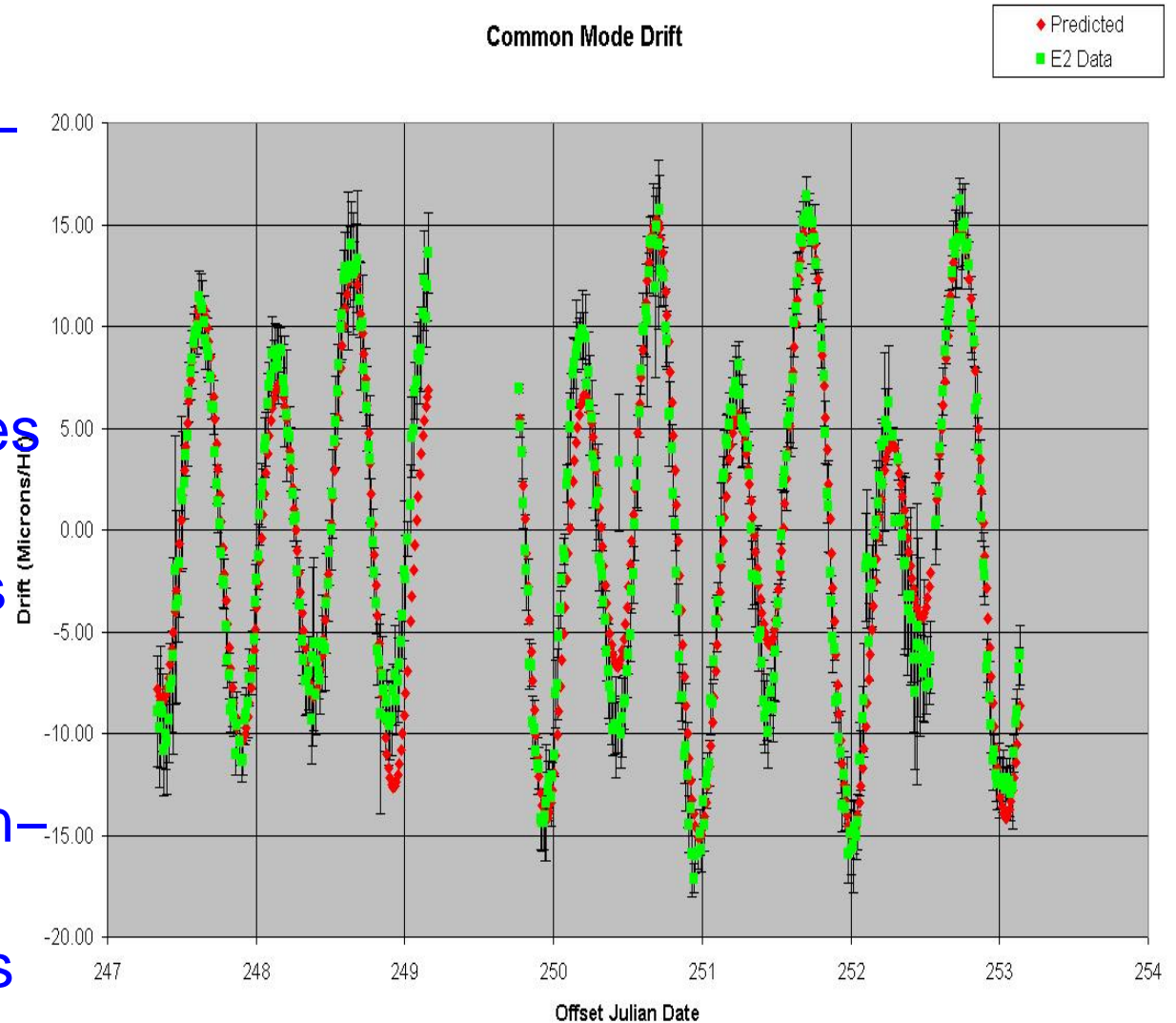




# LIGO *Effect of Earth Tides on Control Signals*



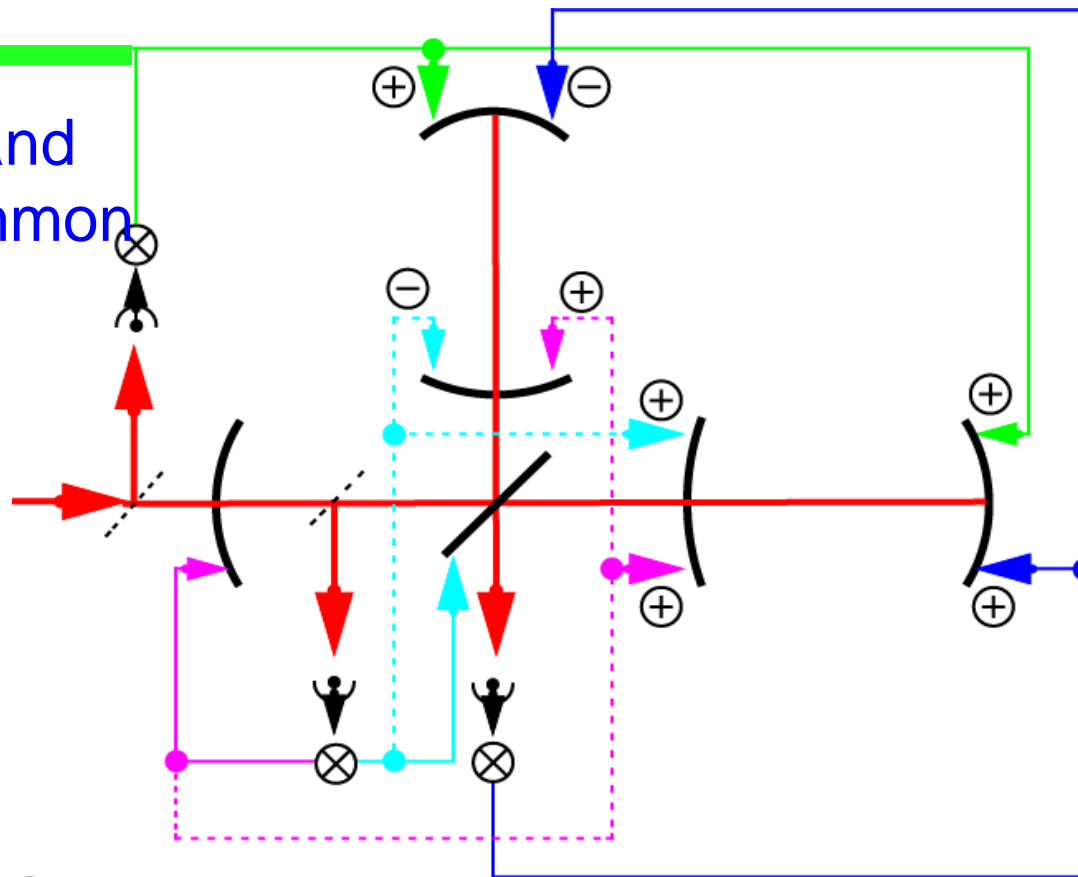
- Actuation End/Mid-Stations and on reference cavity
- Simple model in feedforward removes ~80%
- Feedback removes ~20%
- Analysis of feedback gives non-modeled tidal and temperature effects









- Common-mode feedback from arms to laser frequency is now engaged on Hanford 2-km interferometer
  - » Improved control of laser frequency noise
  - » Establishes gain hierarchy to get better-conditioned control system
- Power-recycling works on Hanford 4-km interferometer
  - » Important validation of digital suspension controllers
- Laser power increased to 6 W for Hanford 2-km interferometer; tuning up under new operating conditions

# Common Mode Servo

To PSL and MC (Common Mode)



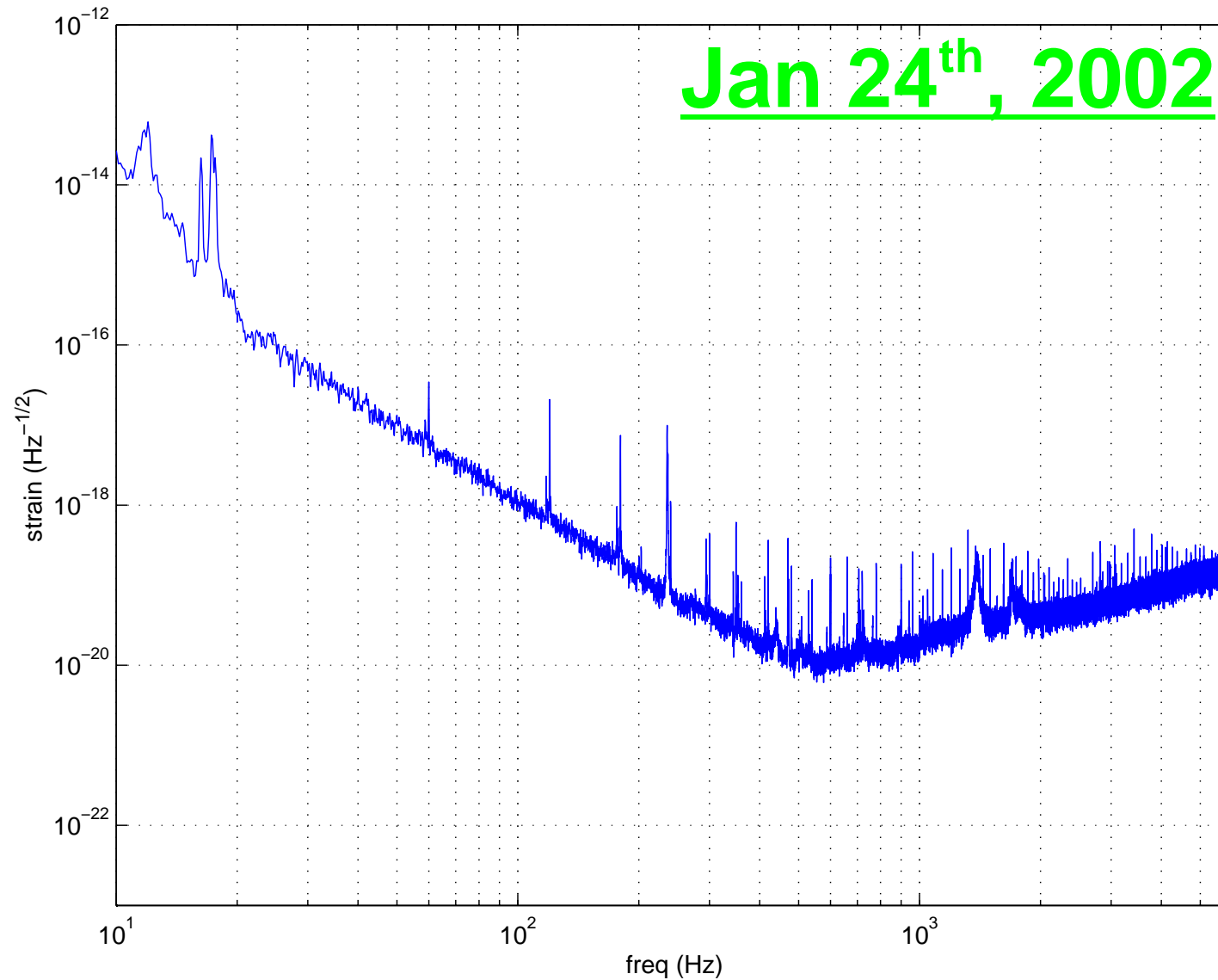
IFO is now the frequency reference

- $S_{AQ}$    $ETM_1-ETM_2$
- $S_{RI}$    $ETM_1+ETM_2$
- $S_{PI}$   RM   $ITM_1+ITM_2$
- $S_{PQ}$   BS   $ITM_1-ITM_2$



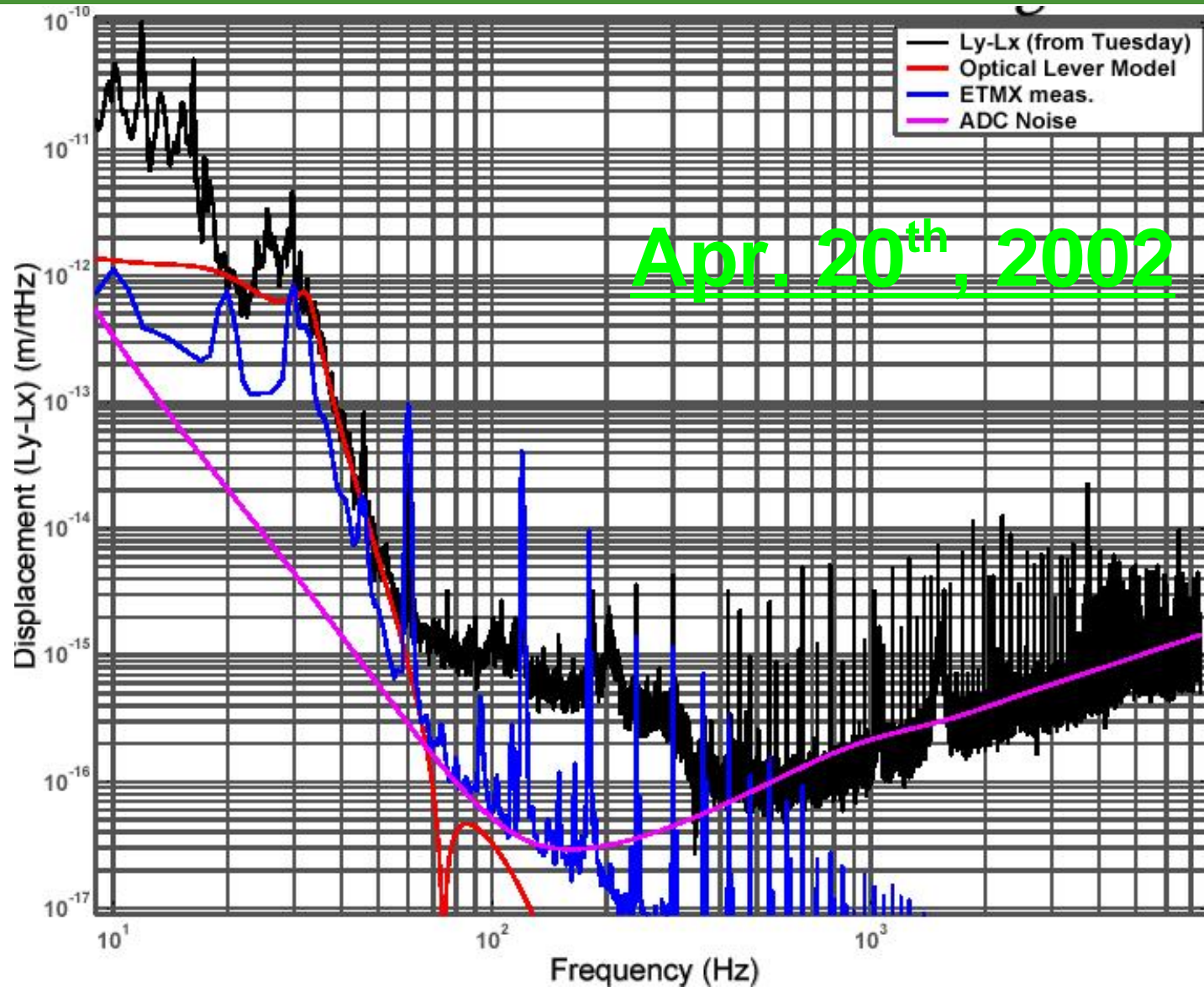


# LHO 2km: Strain Sensitivity with CM





# LIGOLLO 4k: Displacement Sensitivity with CM







# LIGO: Built to Last

