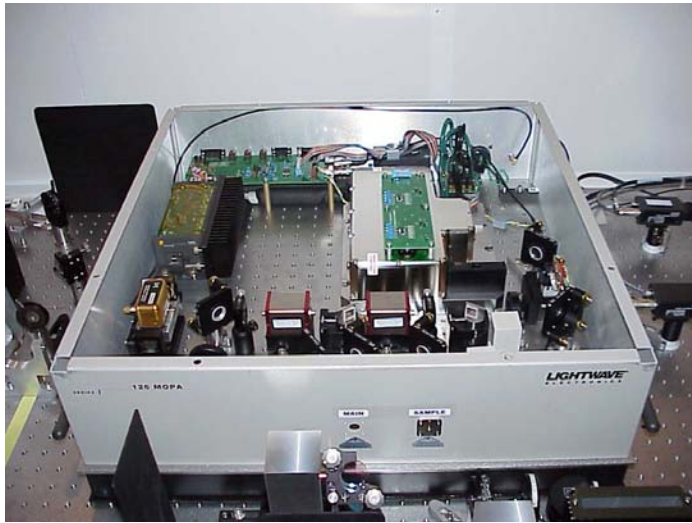


## The LIGO Instruments



*Stan Whitcomb*

NSB Meeting

LIGO Livingston Observatory

4 February 2004

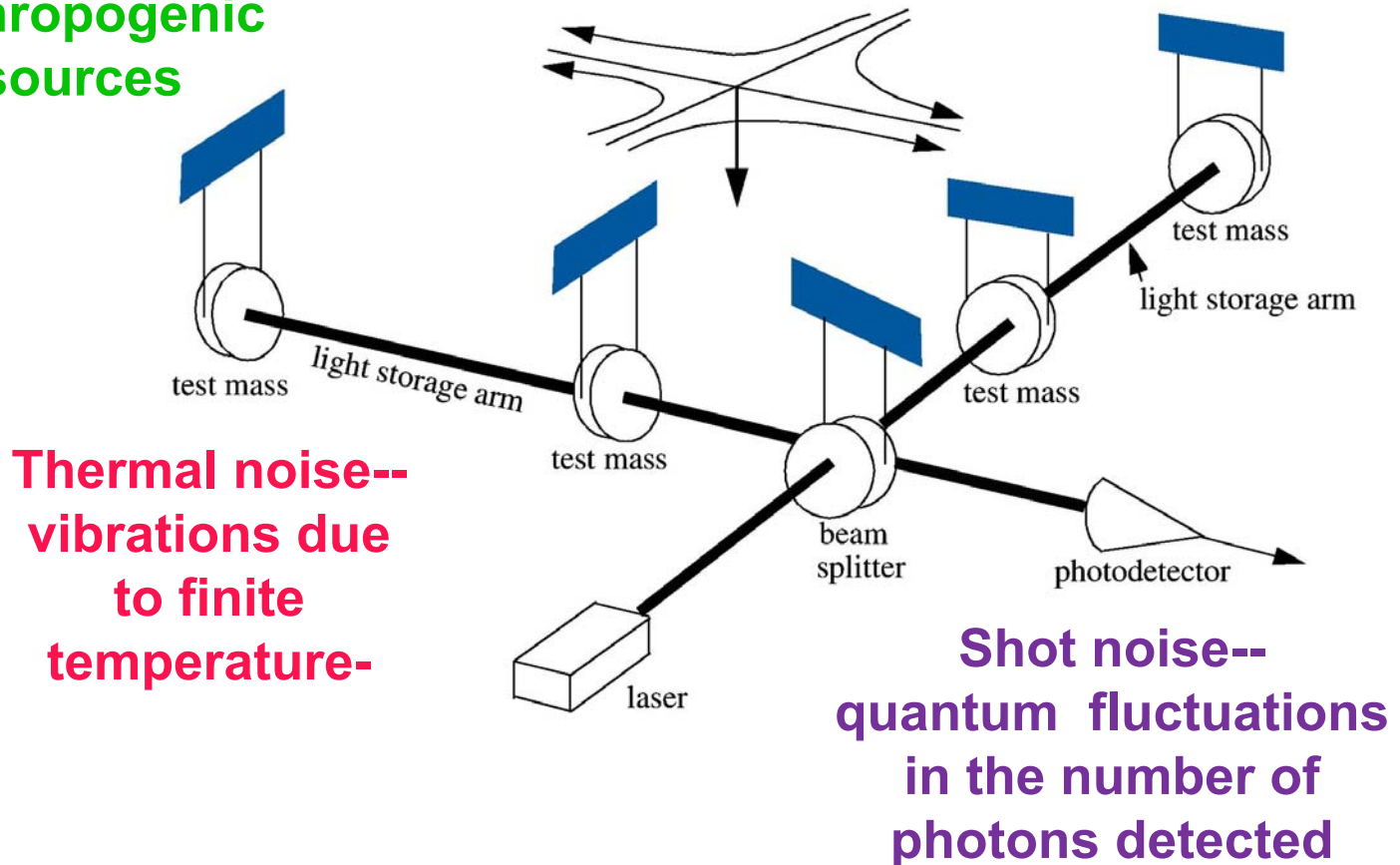
**Seismic motion--  
ground motion due to  
natural and  
anthropogenic  
sources**

$L \sim 4 \text{ km}$

For  $h \sim 10^{-21}$

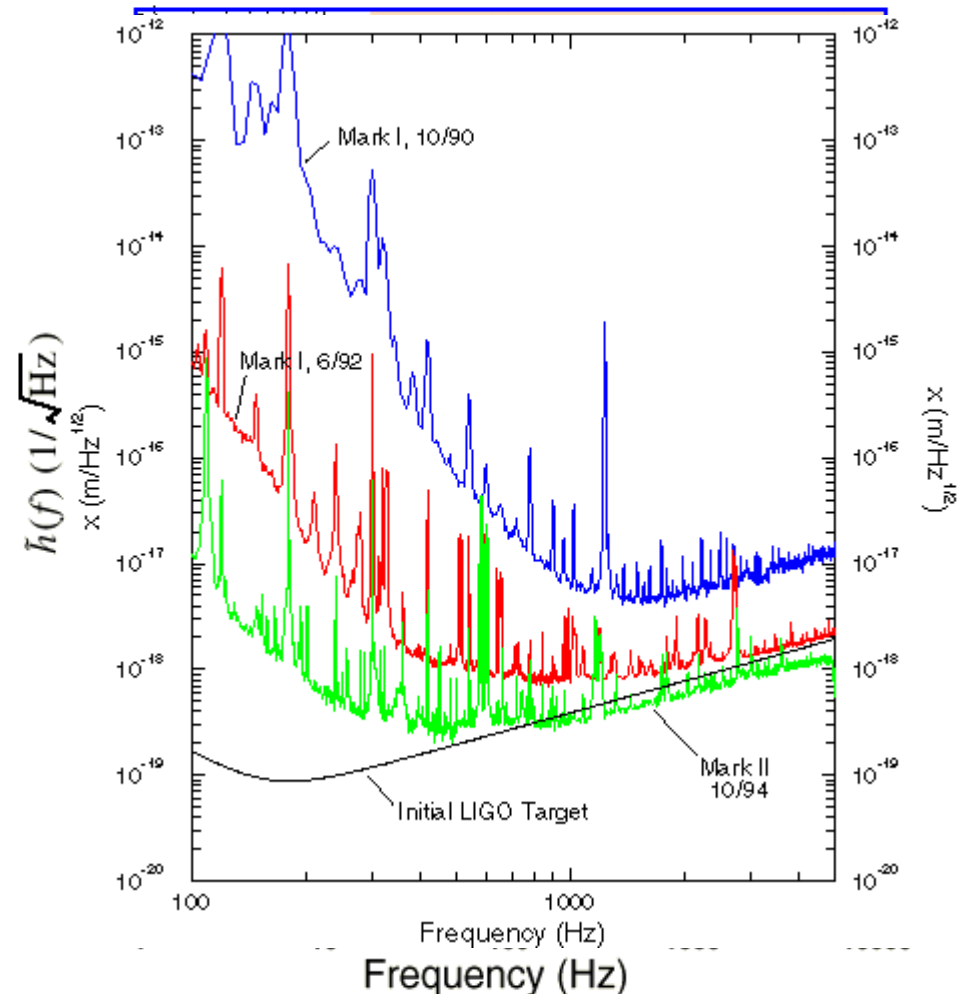
$\Delta L \sim 10^{-18} \text{ m}$

$$h = \Delta L / L$$

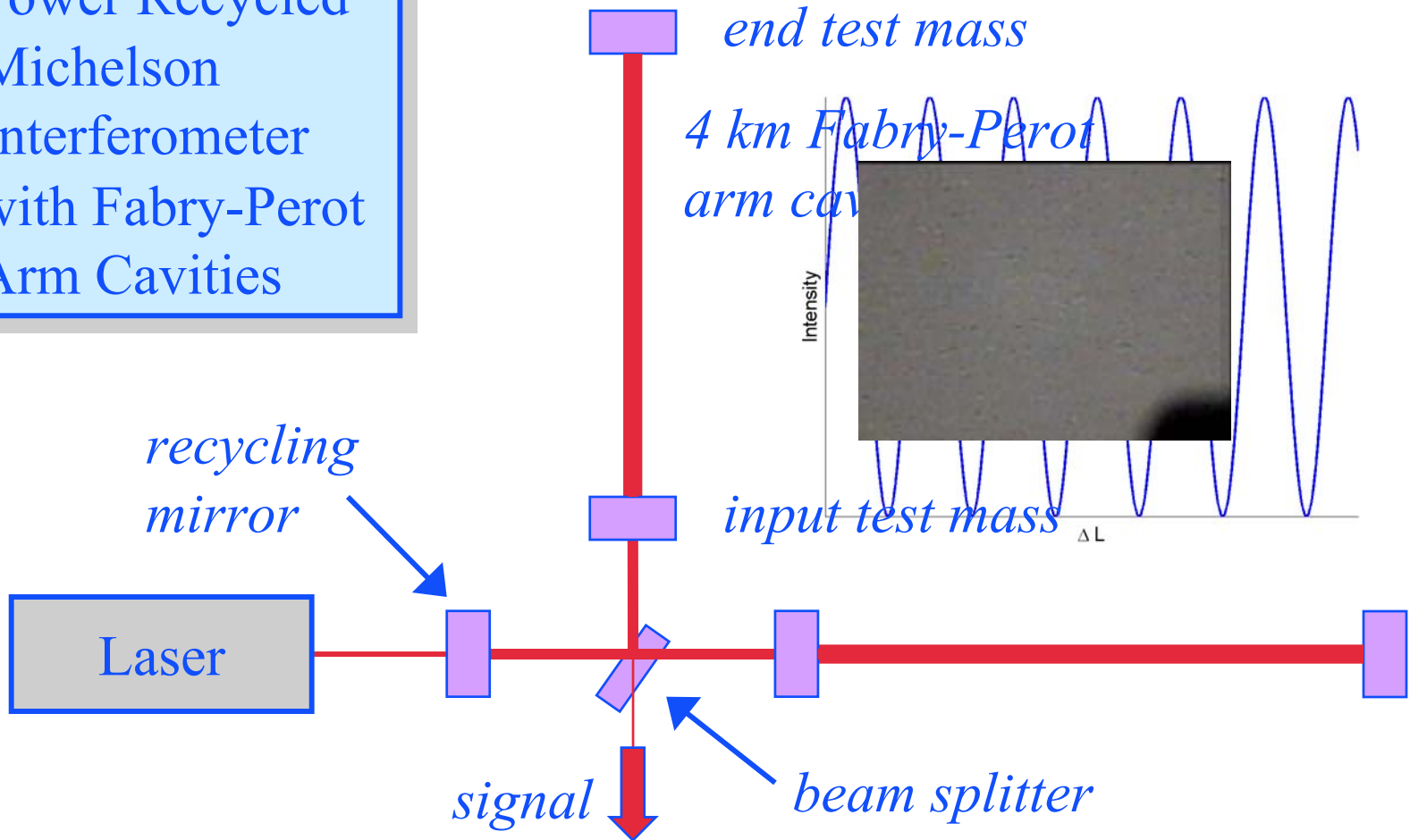


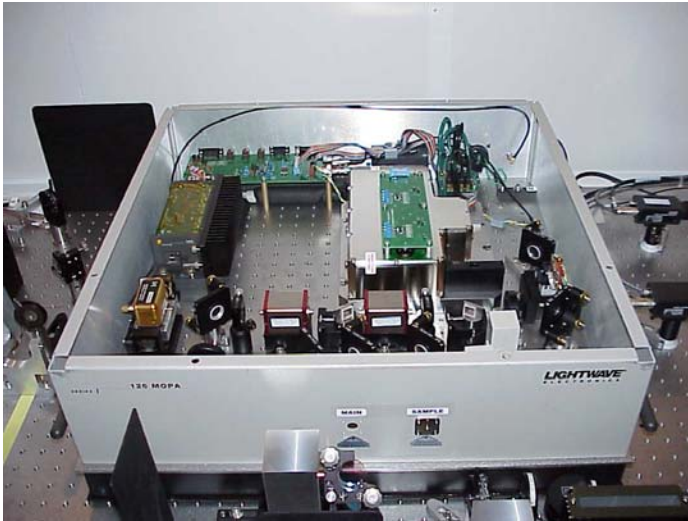
# Initial Interferometer Design Noise Budget

- Understanding of noise sources developed with 40 m prototype
- Limiting noise (with available technology)
  - » **Seismic** at low frequencies
  - » **Thermal** at mid frequencies
  - » **Shot noise** at high frequencies
- Facility limits much lower to allow improved detectors as technology matures

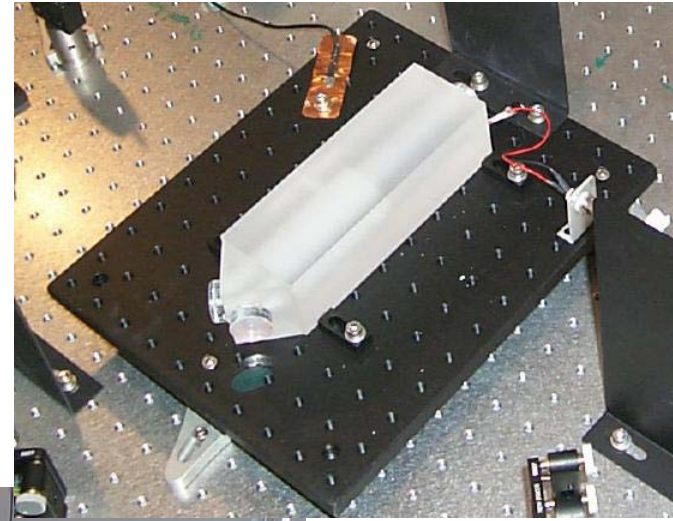


Power Recycled  
Michelson  
Interferometer  
with Fabry-Perot  
Arm Cavities



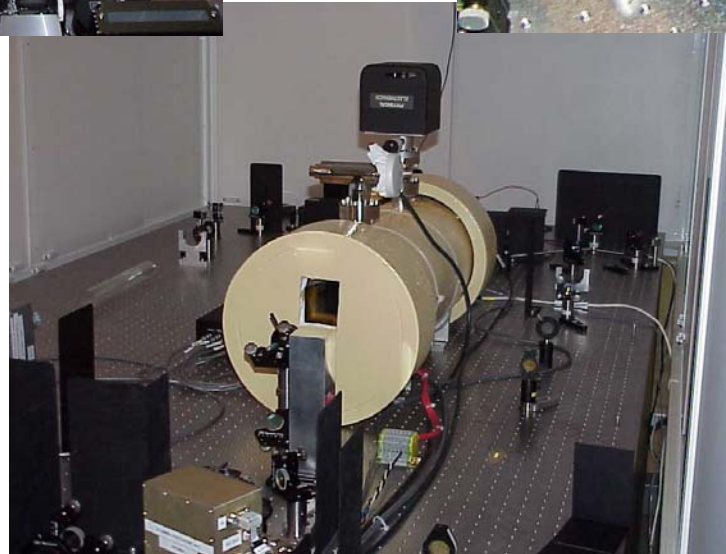


Custom-built  
10 W Nd:YAG  
laser—  
Now a commercial  
product



Stabilization cavities  
for laser beam—  
Widely used for  
precision optical  
applications

$$\frac{\delta f}{f} \approx 10^{-21}$$





## **Substrates: SiO<sub>2</sub>**

High purity, low absorption

## **Polishing**

Accuracy < 1 nm (~10 atomic diameters)

Micro-roughness < 0.1 nm (1 atom)

## **Coating**

Scatter < 50 ppm

Absorption < 0.5 ppm

Uniformity < 10<sup>-3</sup> (~1 atom/layer)

## **Worked with industry to develop required technologies**

2 manufacturers of fused silica

4 polishers

5 metrology companies/labs

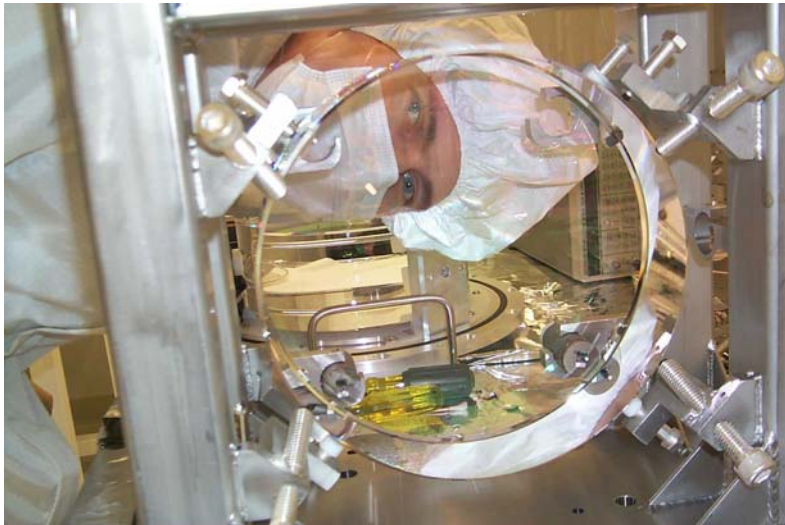
1 optical coating company



# Optics Suspension and Control



- Suspension is the key to controlling thermal noise
- Magnets and coils to control position and angle of mirrors





- Cleanliness of paramount importance

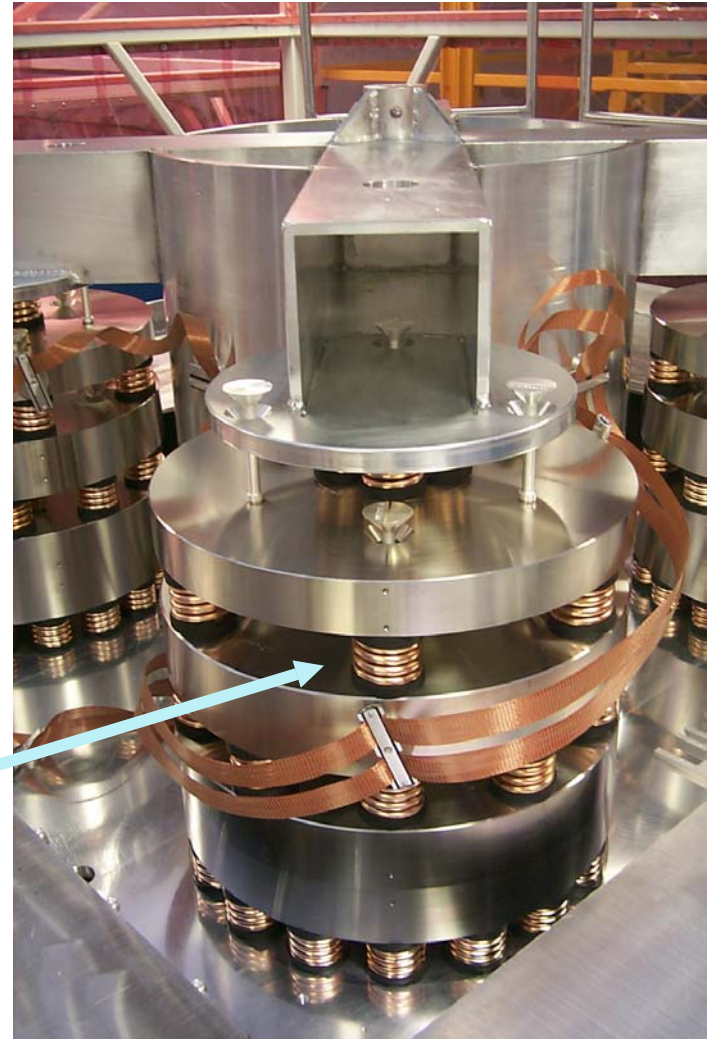


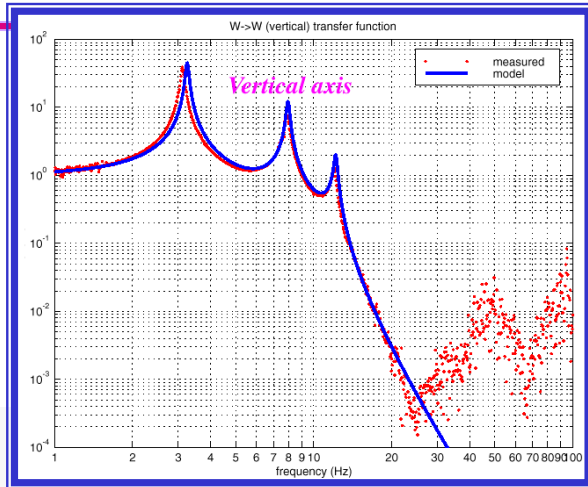


- Cascaded stages of masses on springs (same principle as car suspension)

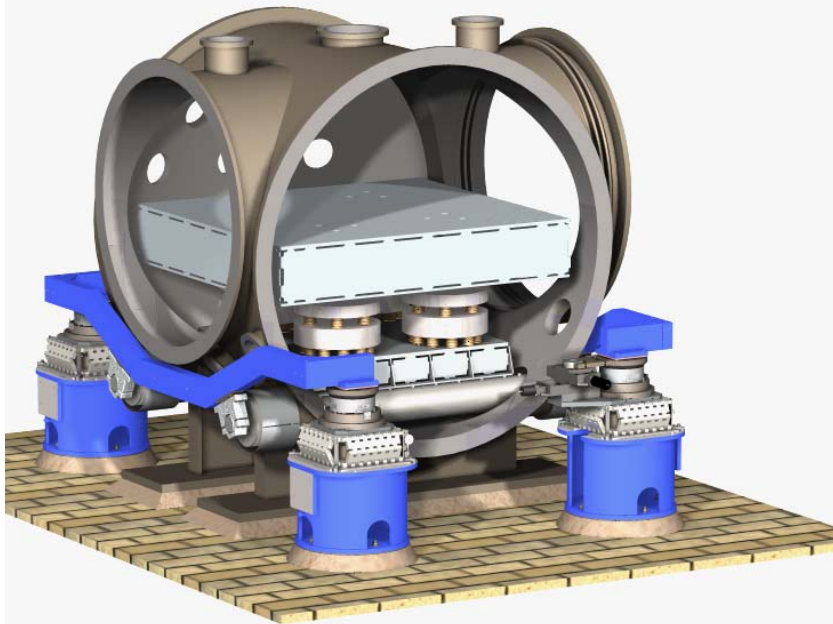


damped spring  
cross section

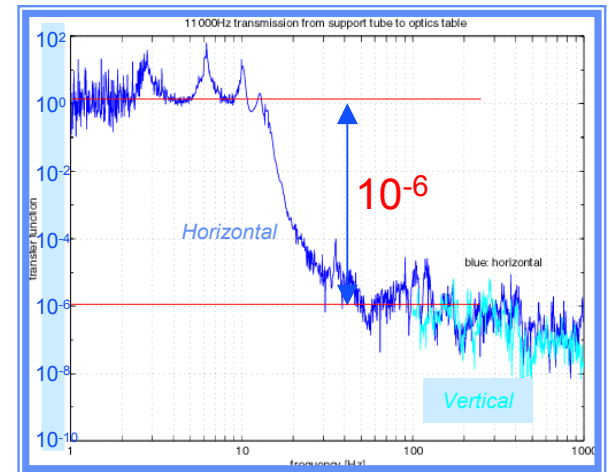




In air



In vacuum

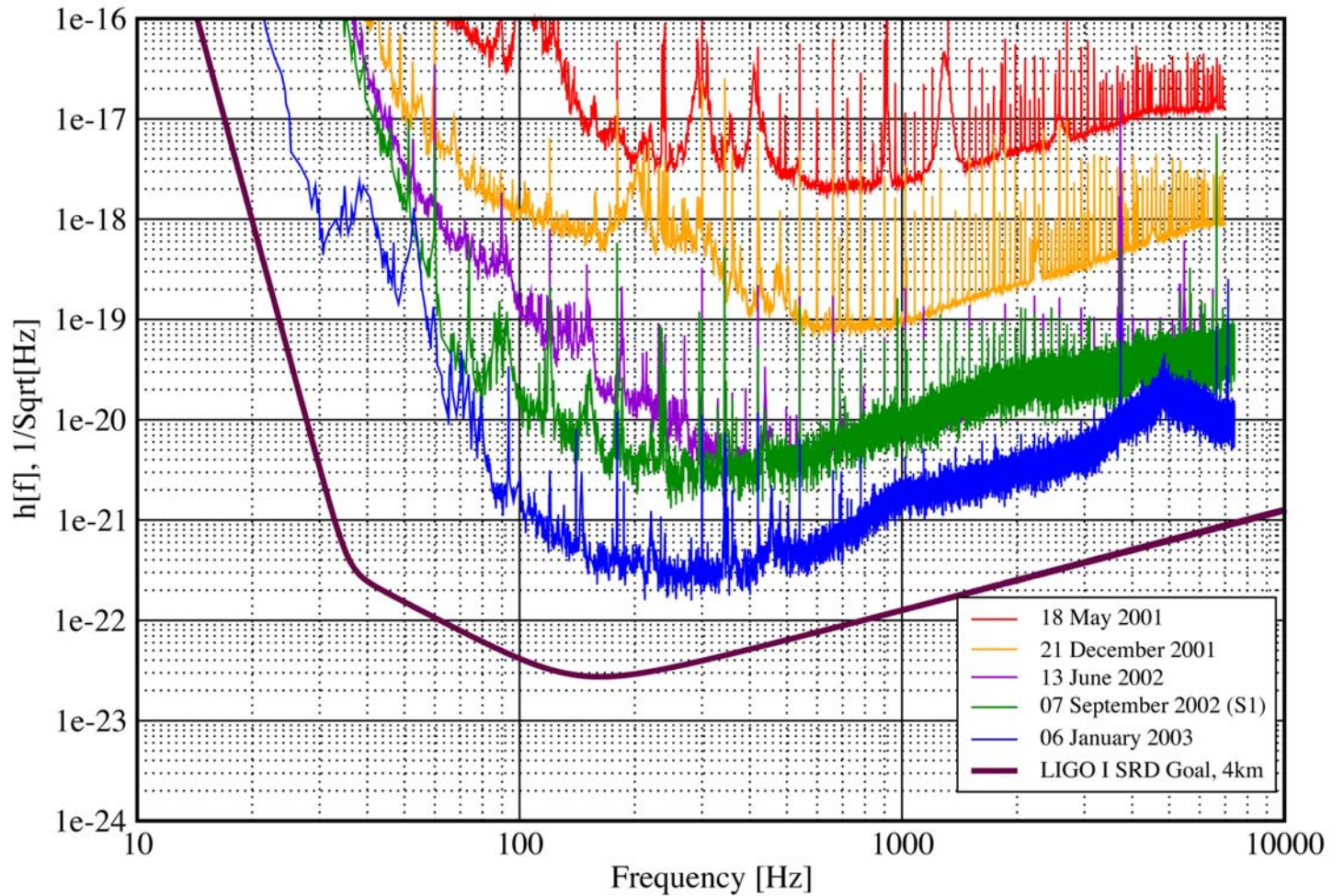


# Commissioning Progress

## Strain Sensitivity for the LLO 4km Interferometer

31 January 2003

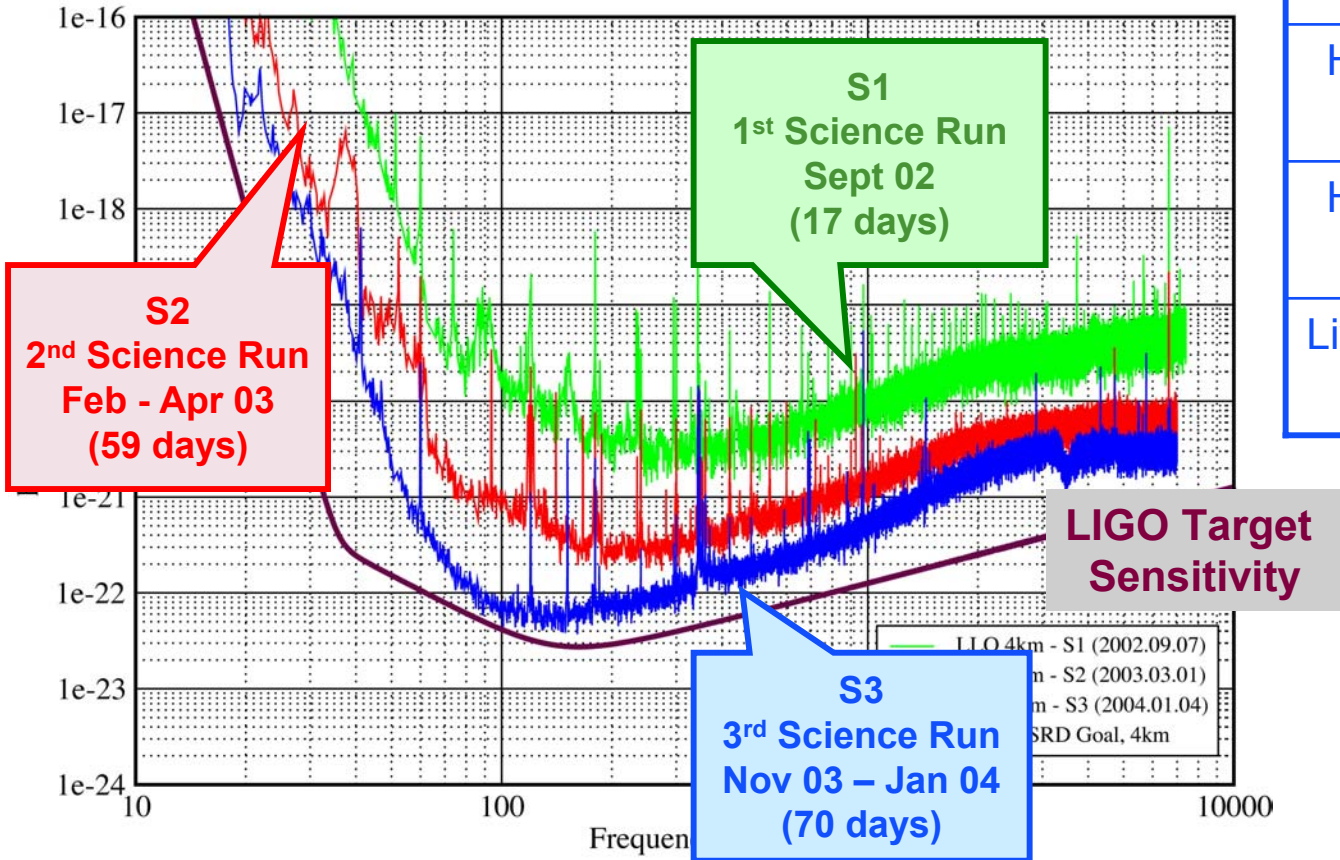
LIGO-G030014-00-E





# Science Runs as Sensitivity Improves

Best Strain Sensivities for the LIGO Interferometers  
 Comparisons among S1, S2, S3 LIGO-G030548-02-E

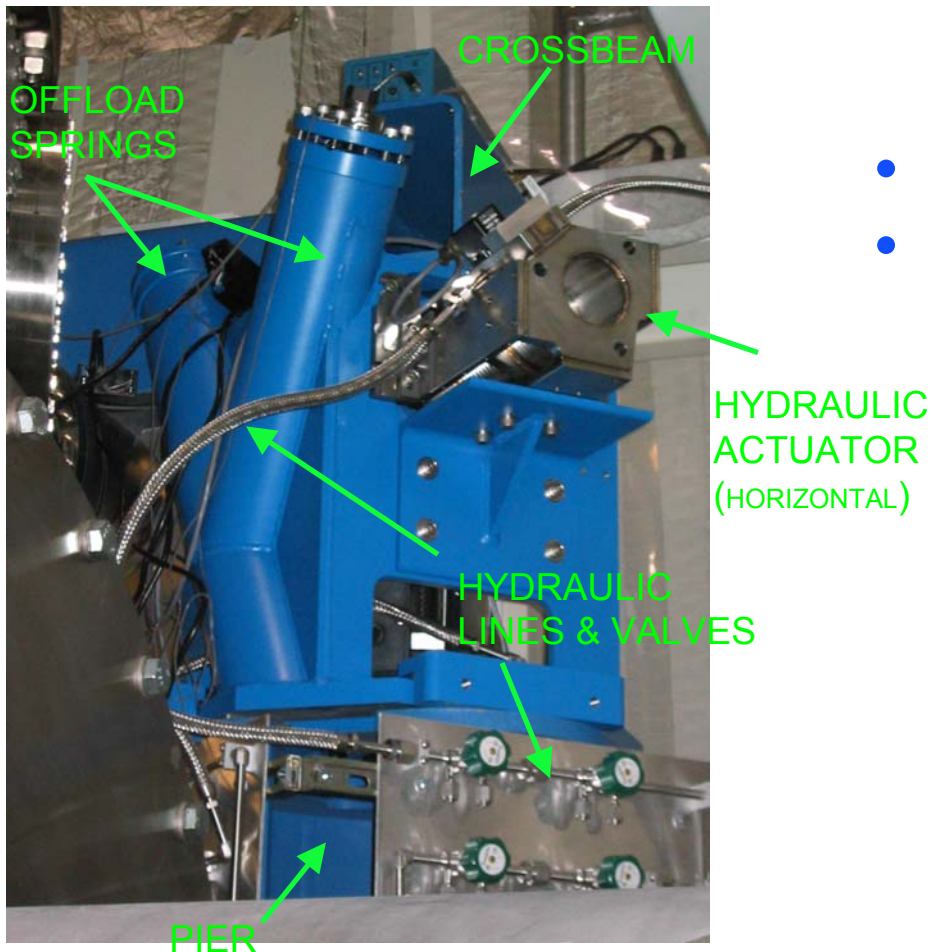


Hanford 4km	69%
Hanford 2km	63%
Livingston 4 km	22%*

\* Limited by high ground noise



## Test at MIT



- Anthropogenic ground vibrations
  - » Related to human activity – mostly logging
- Microseism due to ocean waves
- Strategy for recovering full-time duty at LLO
  - » Use Hydraulic External Pre-Isolator (HEPI) system developed for AdvLIGO
  - » Prototype tested at Stanford and MIT
  - » Fabrication nearly complete, installation just beginning

- Jump from laboratory-scale to kilometer-scale interferometers has been successful
- Commissioning on track
  - » Sensitivity nearing design level
  - » Reliability and duty cycle as expected for this stage
  - » Active seismic isolation development addresses excess seismic noise at LLO, as well as Advanced LIGO requirements
- Interleaving of Science Runs with commissioning
  - » Science begins
  - » Analysis community prepares for full operation
    - Development of analysis algorithms, grid computing, ...