LIGO Status Report

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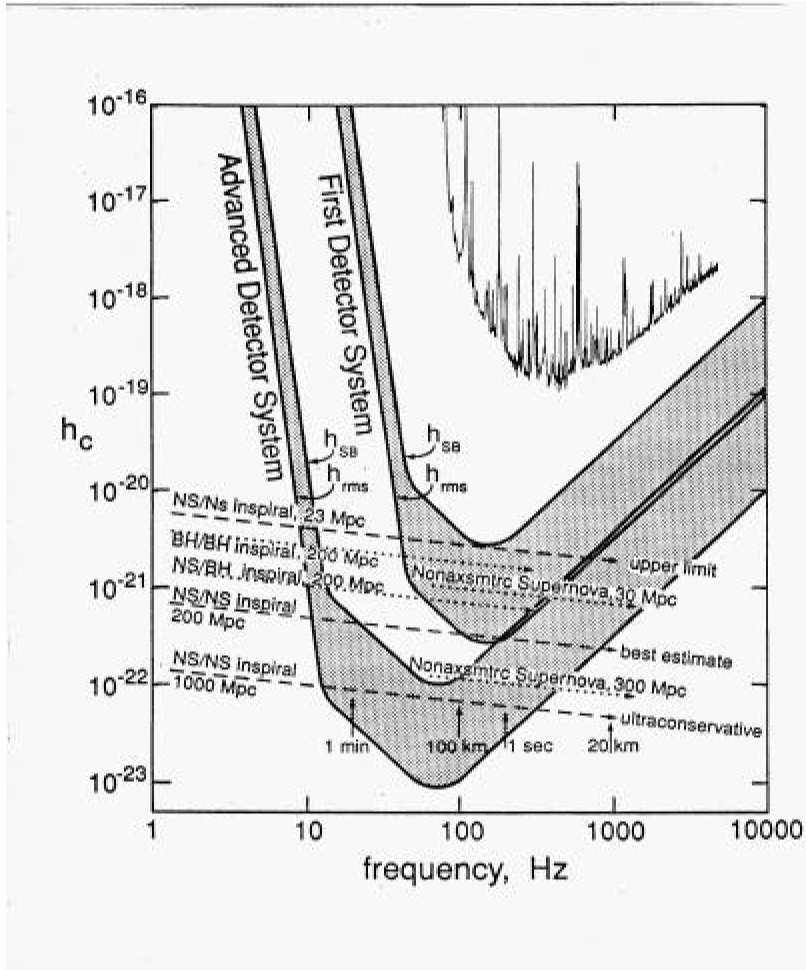
Overview

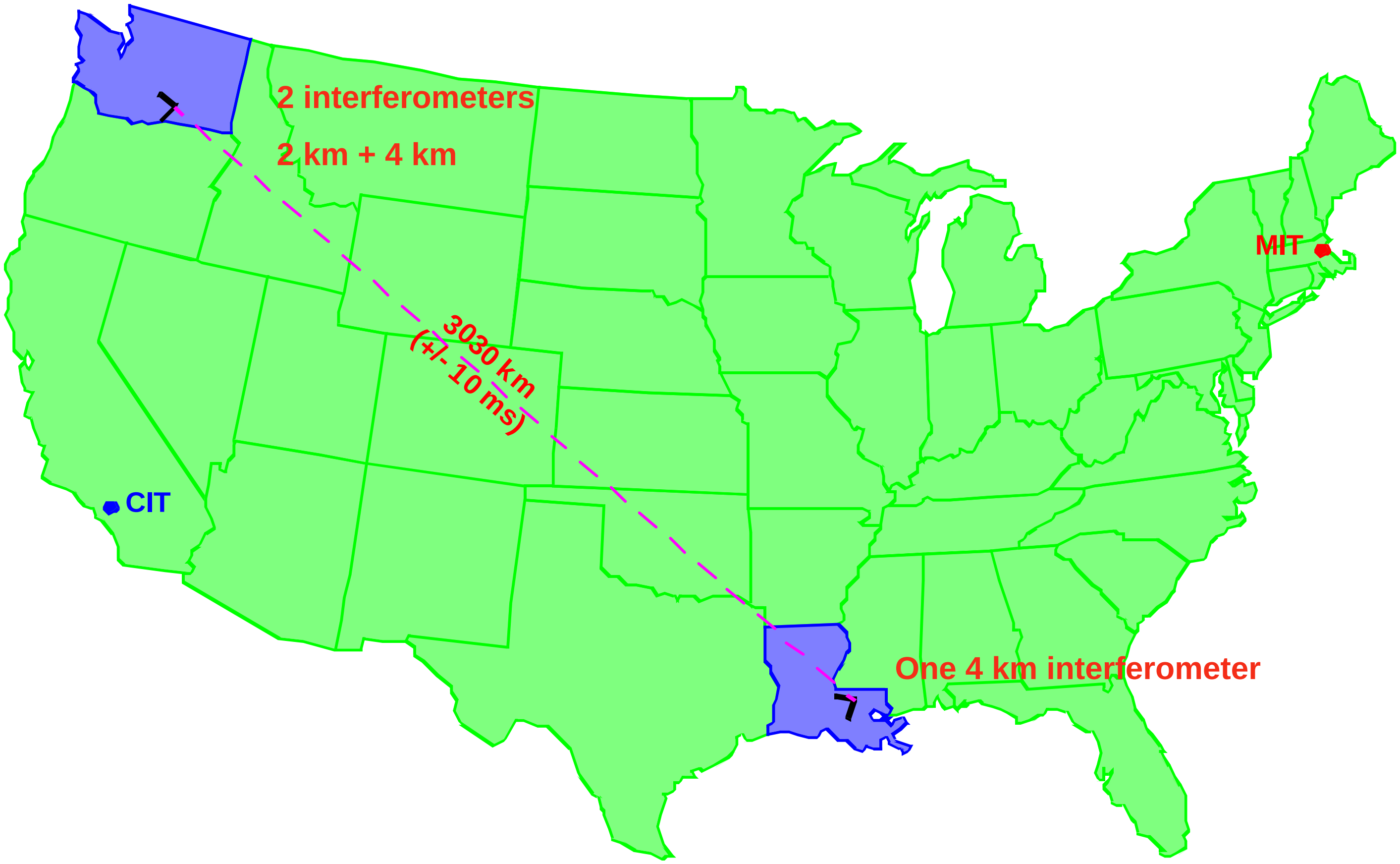
- Description of LIGO
- Design of LIGO Interferometers
- Construction of LIGO Facilities
- Installation of Interferometers and Status
- Plans for Commissioning
- First Science Observation Period
  - » LIGO Scientific Collaboration
- Plans and R&D for Improvements

1989 Astrophysics Goals for LIGO Design Sensitivity

- LIGO planned in phases
- Initial detector planned as 3 interferometers at 2 locations forming an “initial detector”
- Initial detector planned for strain sensitivity of 10^{-21}
- Advanced detectors to improve by 1 and then 2 orders of magnitude with no limits from LIGO facilities

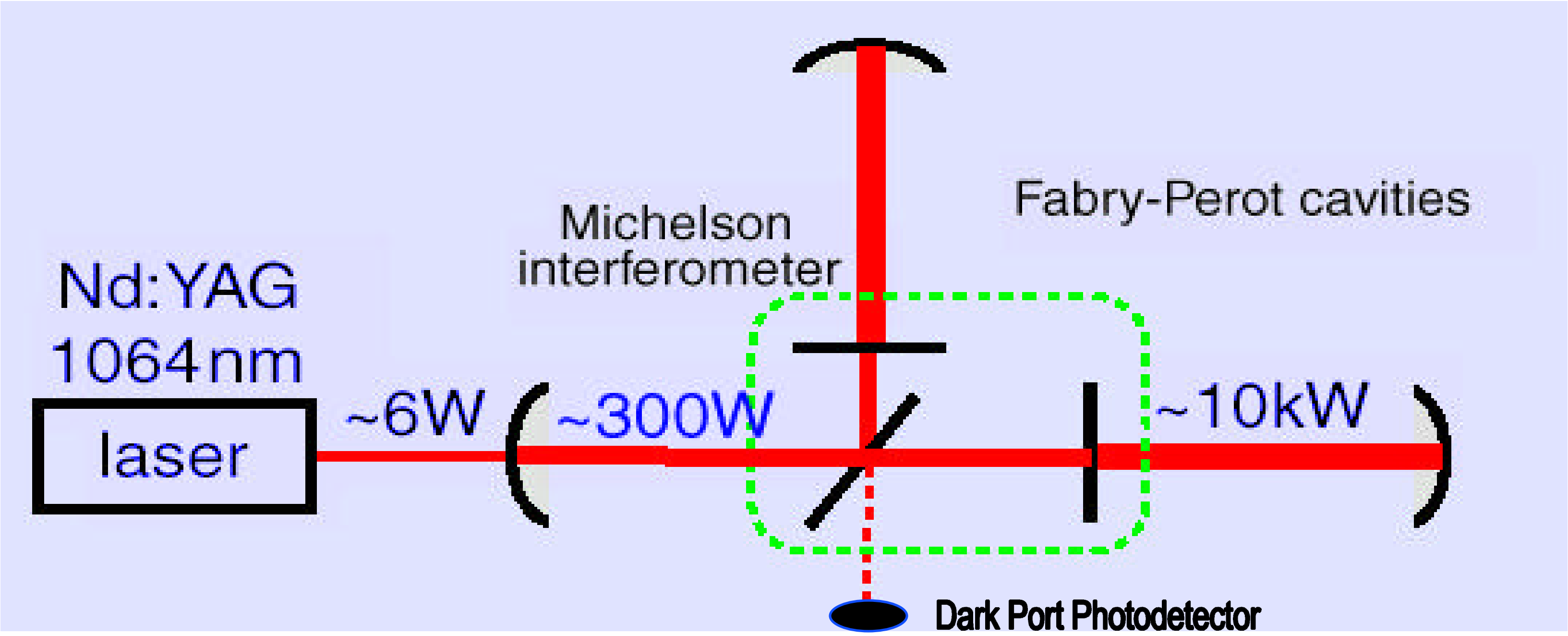


LIGO Interferometers at Two Sites



LIGO

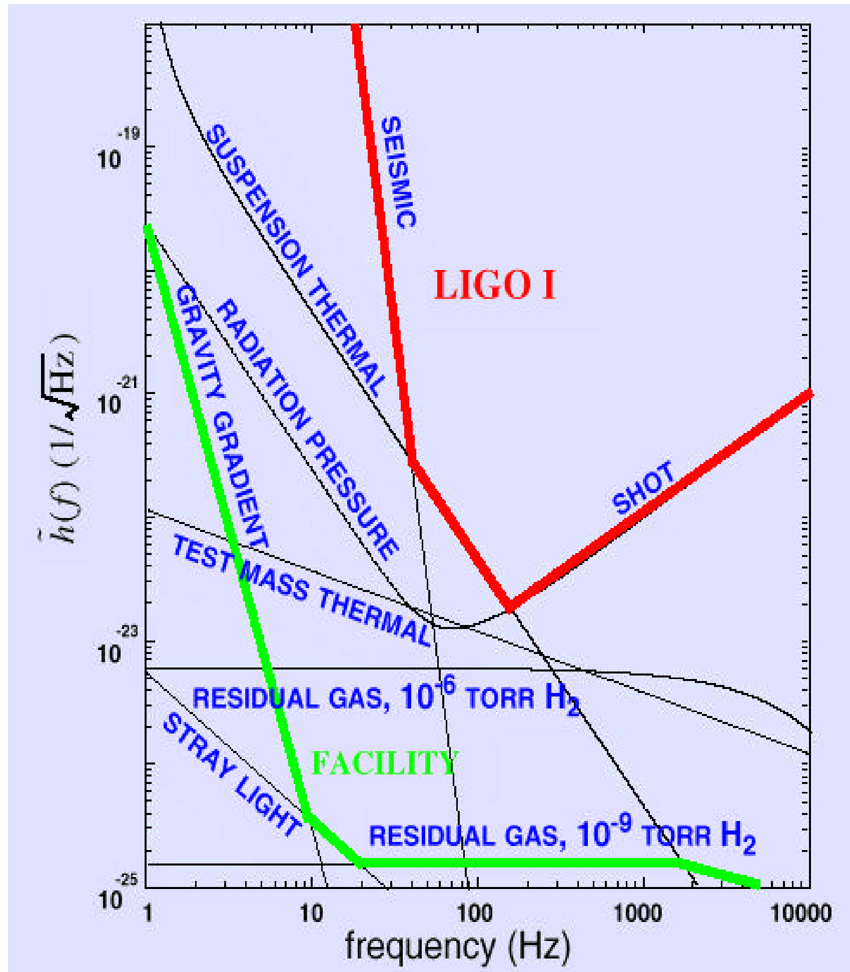
LIGO Interferometer Configuration



- 4 km arm cavities: storage time ~ 100 Hz
- dark fringe operation minimizes shot noise, precision is 10^{-10}
- power recycling gain is ~ 50, recovers light reflected to laser

Initial LIGO Detector Sensitivity (LIGO I)

- LIGO I sensitivity will be achieved for observation run in 2002-2004
- LIGO buildings, location, vacuum system will not limit advanced interferometers
- Improvements depend upon lowering seismic noise, thermal noise and shot noise initially
- Ultimate limits caused by the quantum limit and gravity gradients



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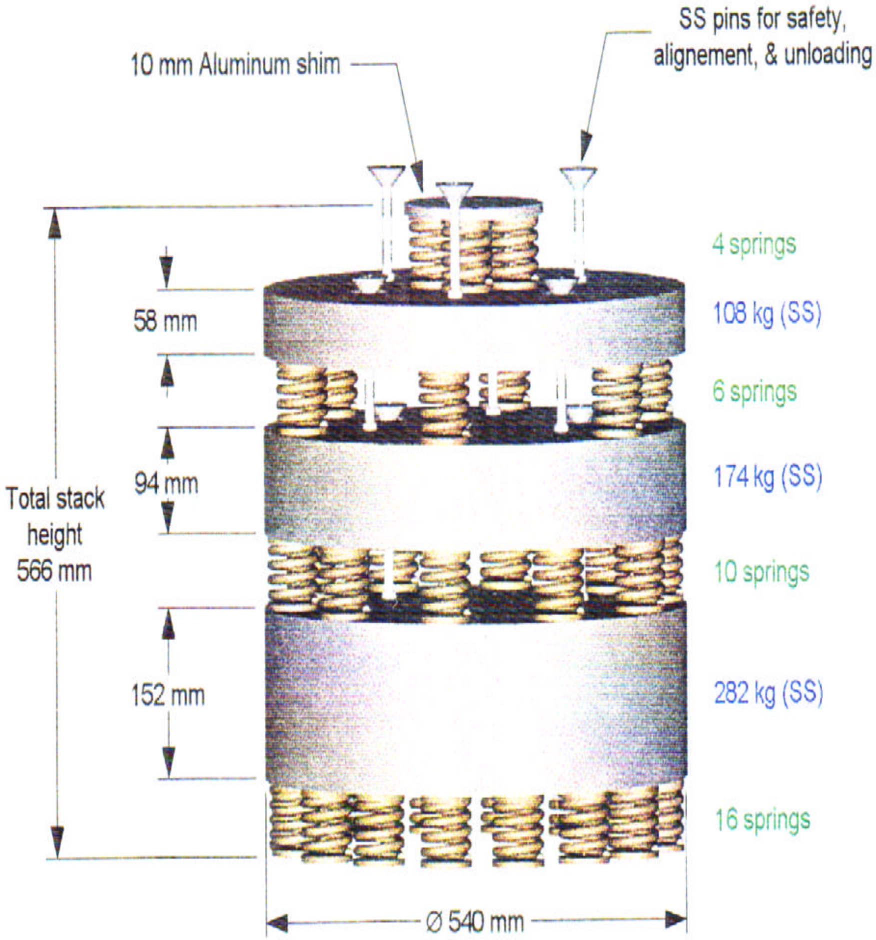
Seismic Isolation in LIGO I

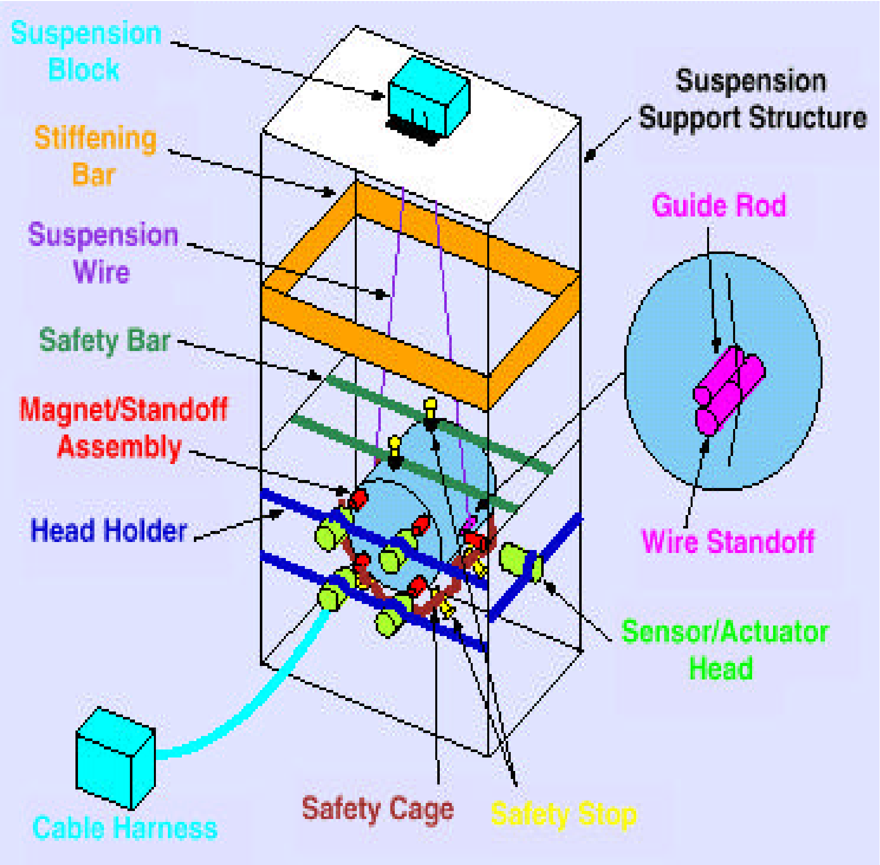
- Passive spring-mass systems ("stacks")
- Stainless steel masses with about 600 kg for each leg assembly
- Coiled helical springs with a lossy viscoelastic damping layer in each spring (Q~40)
- 3 stages with

  $1/f^{6}$ for f > 10 Hz

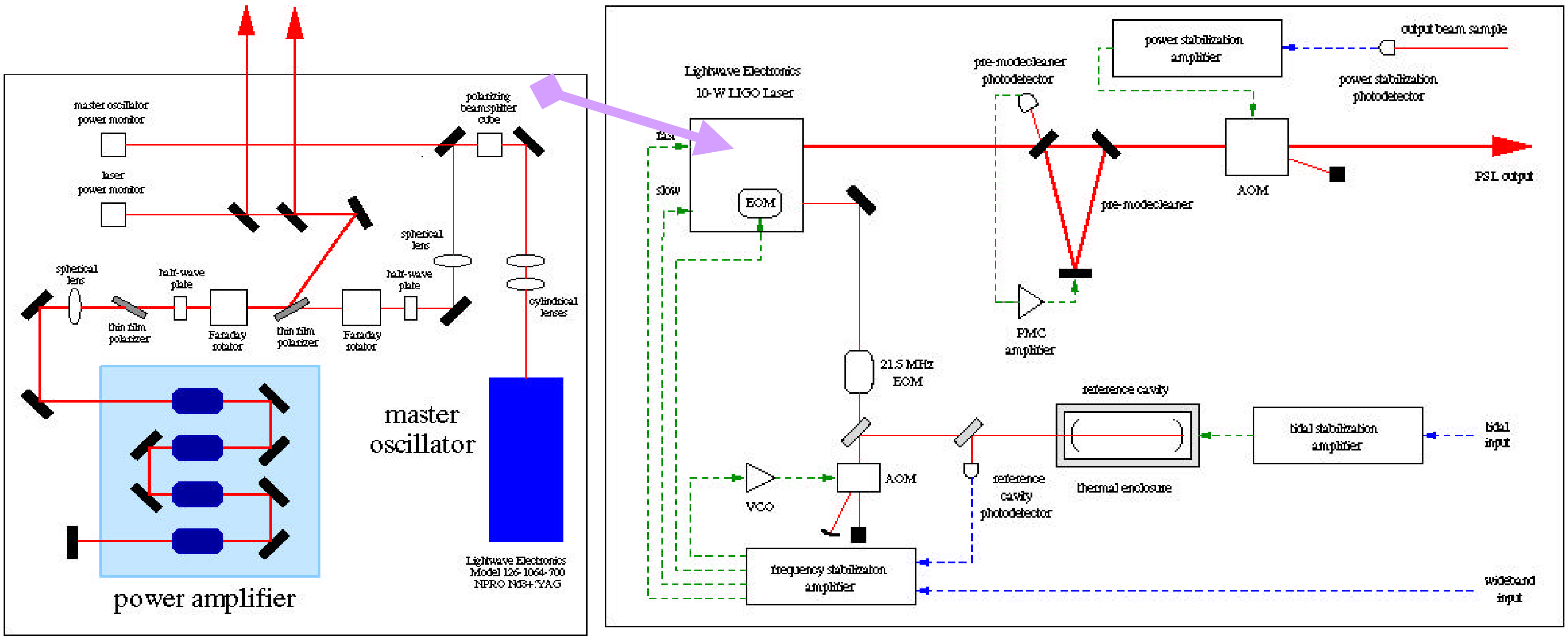


LIGO I Suspensions

- Mirrors hung on single wire pendulum suspension
- Challenge is to minimize losses from mechanical modes
  - » $Q \sim 10^6$ and $1/f^2$ isolation above $f_0 = 1$ Hz
- Control of test mass position done with magnetic actuation
  - » permanent magnets glued on mirrors
  - » electromagnets on support cage



LIGO I Prestabilized Laser

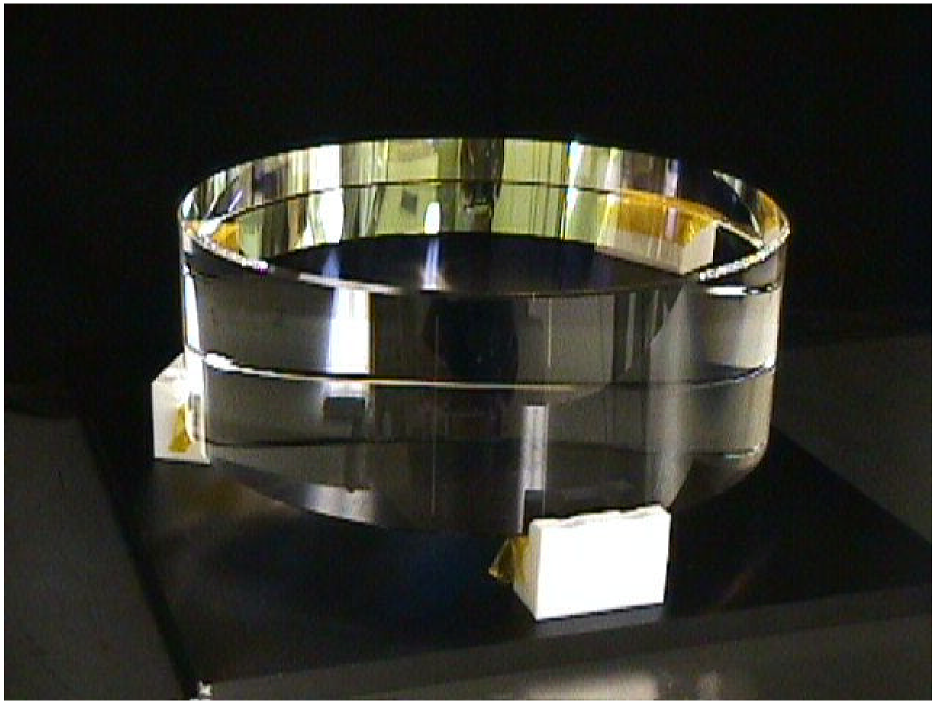


Master Oscillator Power Amplifier (MOPA) 10 W Nd:YAG 1064 nm laser from Lightwave Electronics

LIGO

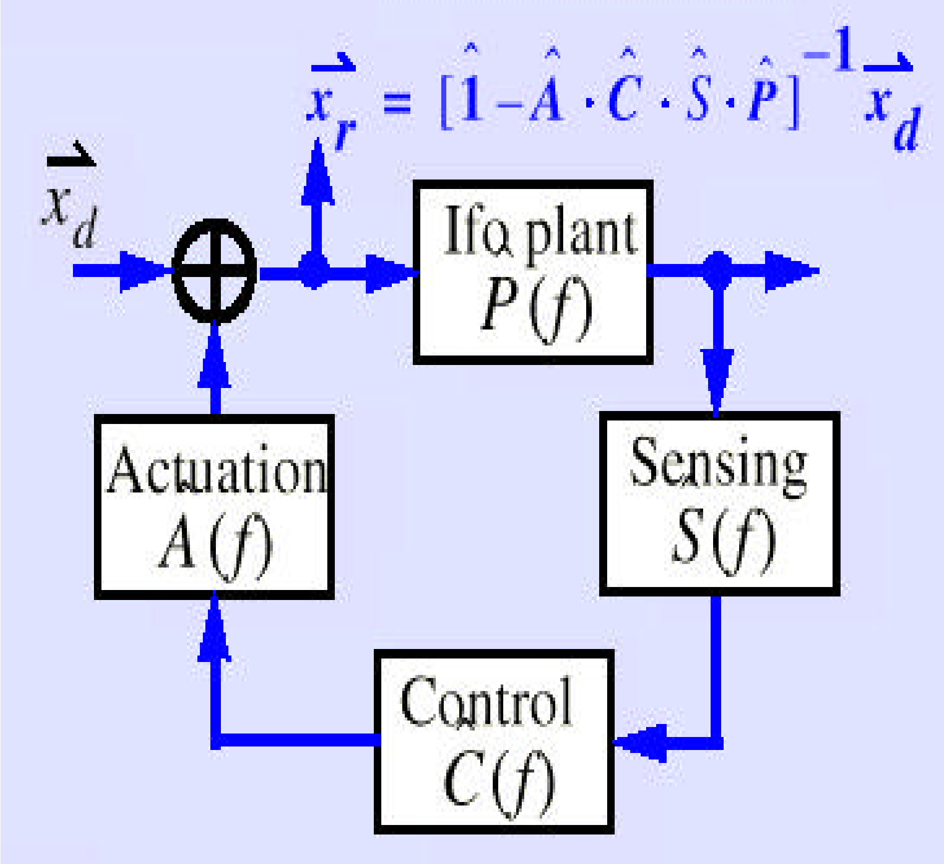
LIGO I Core Optics

- Material is fused silica (SiO_2)
- Polished substrates with very low micro-roughness
- Scattering loss requires very high surface quality of 1 nm on cm scale
- Heating limits require low absorption of < 5 ppm/cm
- Surface coating uniformity requires that a 3.6 Å rms polished surface ► 5.9 Å coated surface



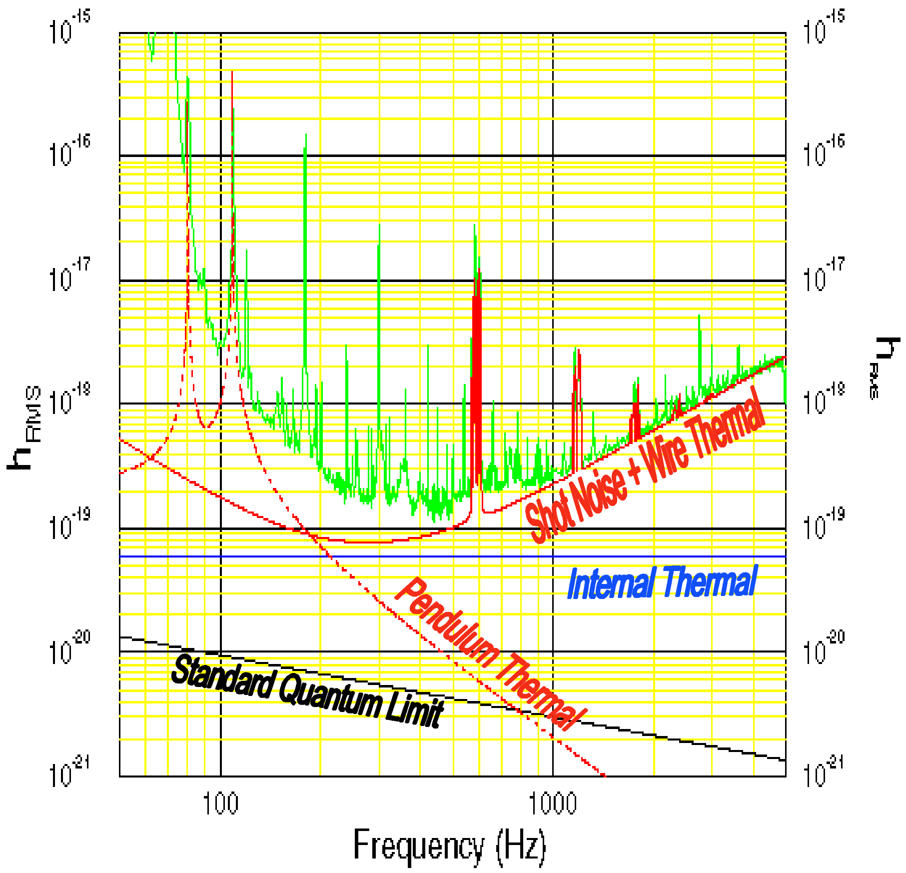
LIGO I Length Sensing and Control

- 4 cavity lengths to be controlled to 10^{-9} m to 10^{-13} m
- 10 alignment degrees of freedom to be controlled within 10^{-8} rad
- Ground noise drives mirrors by 10^{-5} m or 10^{-7} rad !
- Control system uses
  - » phase modulation techniques to extract error signals
  - » digital control
  - » actuators based on magnets on suspensions



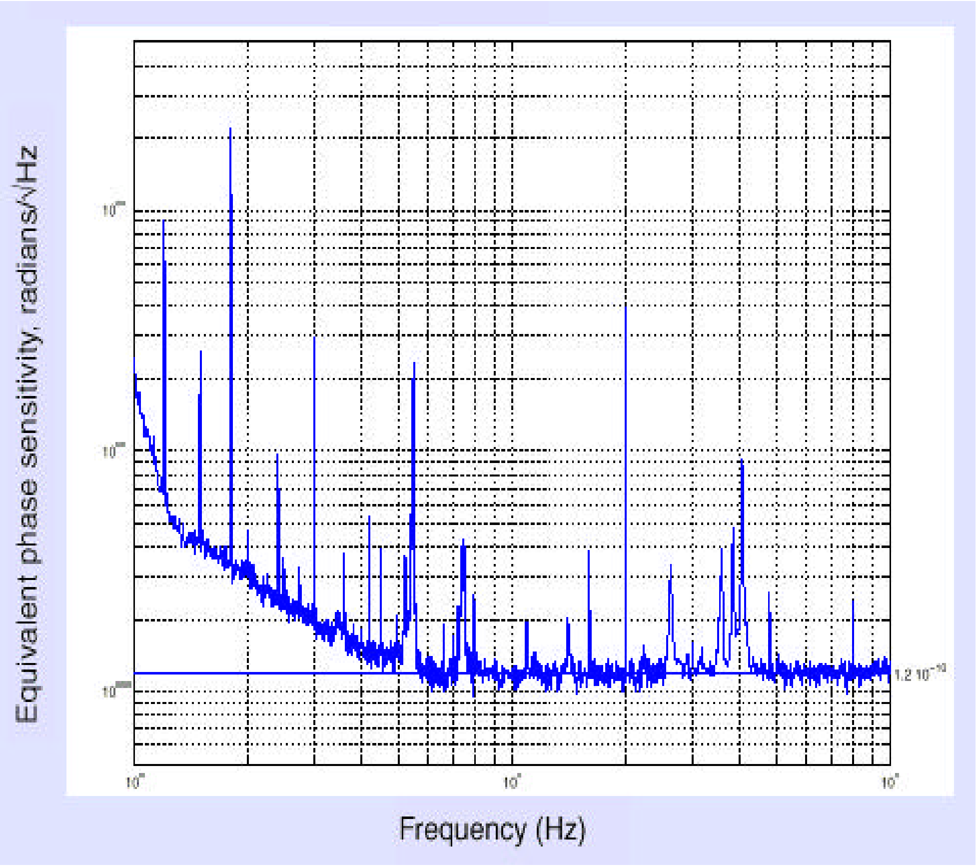
Demonstration of LIGO I Displacement Sensitivity

- 40 Meter Interferometer at Caltech demonstrated required sensitivity in 1994
- Models for noise sources are approximated by data
- Recent demonstration of power recycled system with Fabry-Perot arm cavities has been carried out



Demonstration of LIGO I Phase Sensitivity

- Phase Noise Interferometer at MIT
  - » Power recycled Michelson interferometer
  - » stored 70 W with a recycling factor of 400
- Demonstrated required sensitivity with a measurement of ~1.2×10^{-10} rad/√Hz over the required frequency range



Construction of LIGO: LIGO Schedule at Very Top Level

1996 Construction Underway
» mostly civil construction (buildings, slabs,…)

1997 Facility Construction
» beam pipe and concrete enclosure, vacuum chambers

1998 Construct Detectors
» completion of vacuum systems

1999 Install Detectors
» interferometer systems into vacuum system

2000 Commission Detectors
» first light in arms; subsystem testing

2001 Engineering Tests
» sensitivity: engineering run

2002 LIGO I Run Begins
» $h \sim 10^{-21}$

Satellite View of Livingston Site

Spot 1 satellite - 20 March 1999

LIGO Hanford Observatory

LIGO Livingston Observatory

Vacuum Equipment Installation and Bakeout

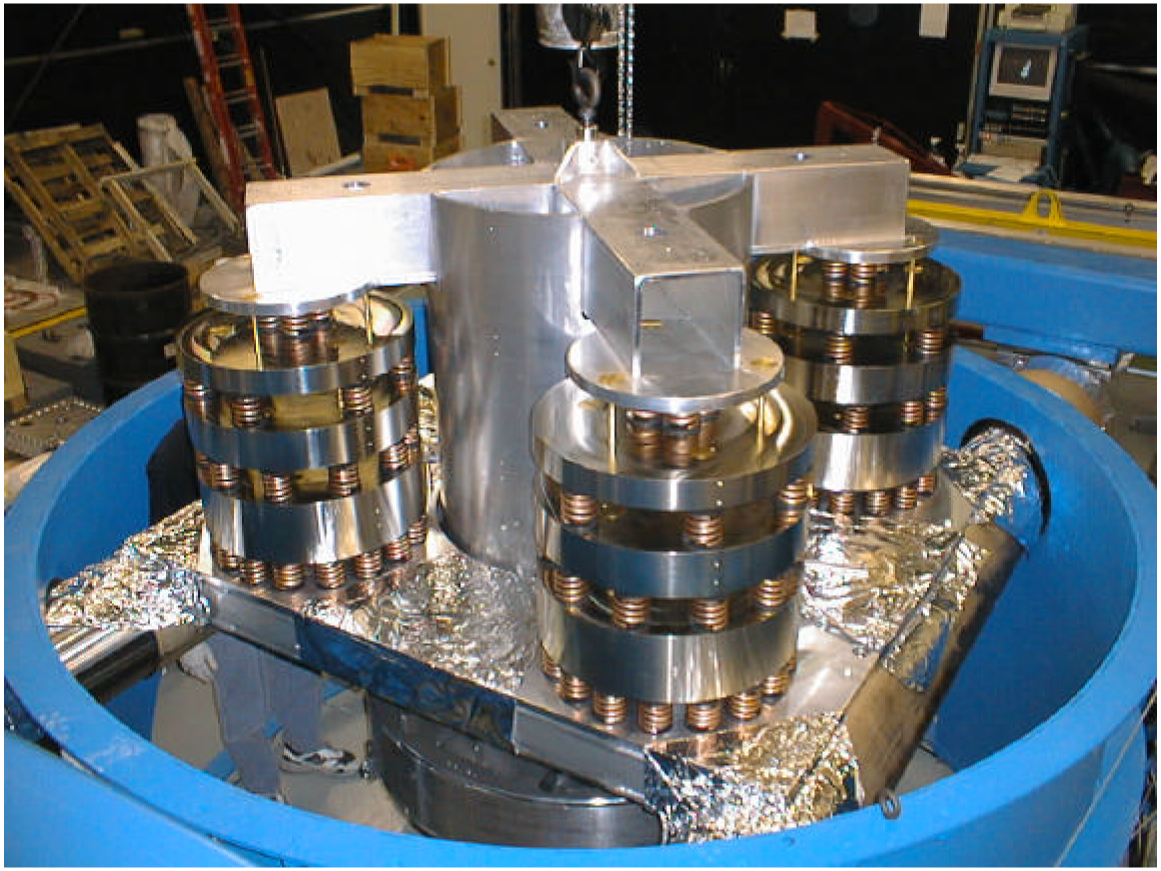
LIGO

Livingston Observatory Vacuum Equipment at Vertex

LIGO

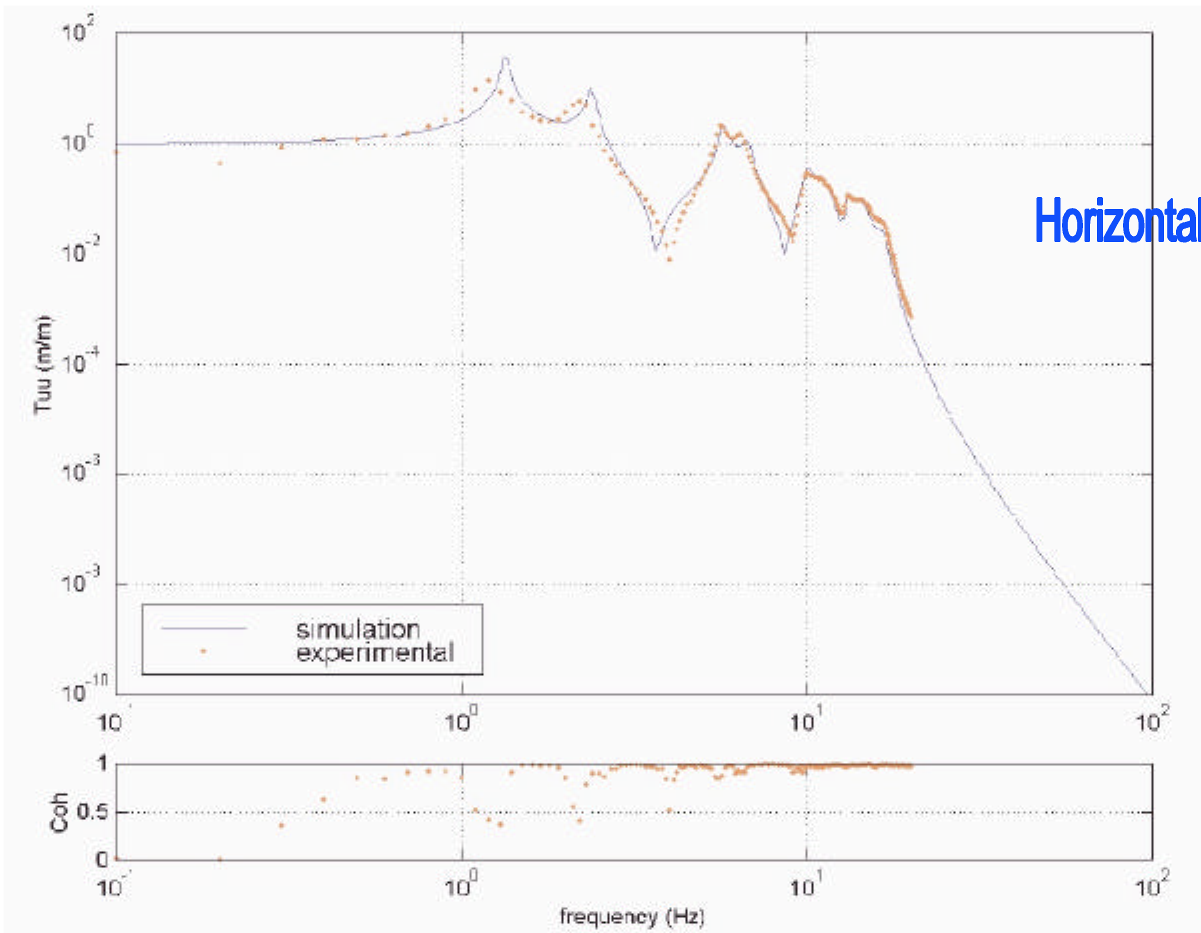
Test of First Article of HAM Chamber Seismic Isolation

Test of First Article BSC Chamber Seismic Isolation



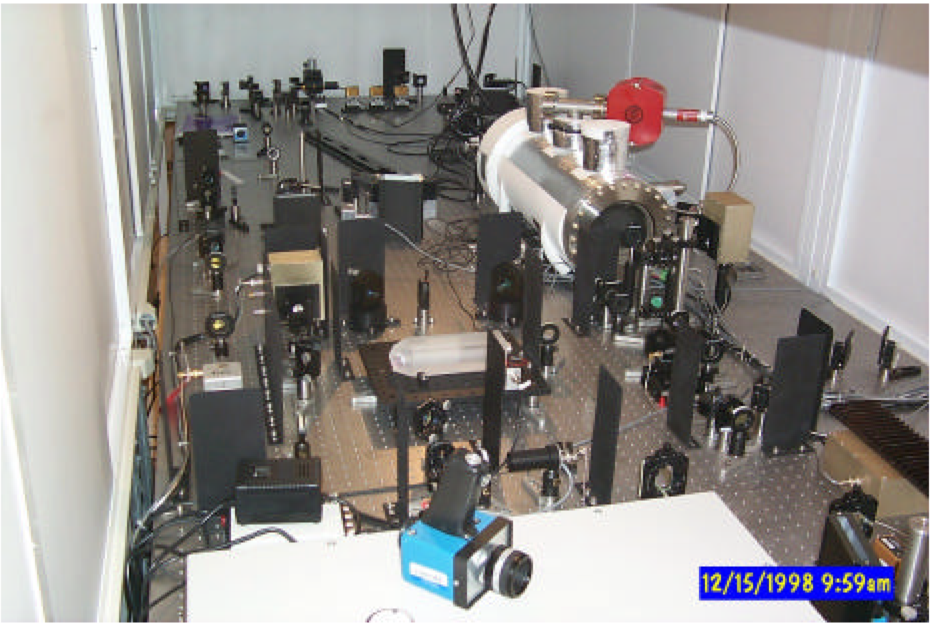
LIGO

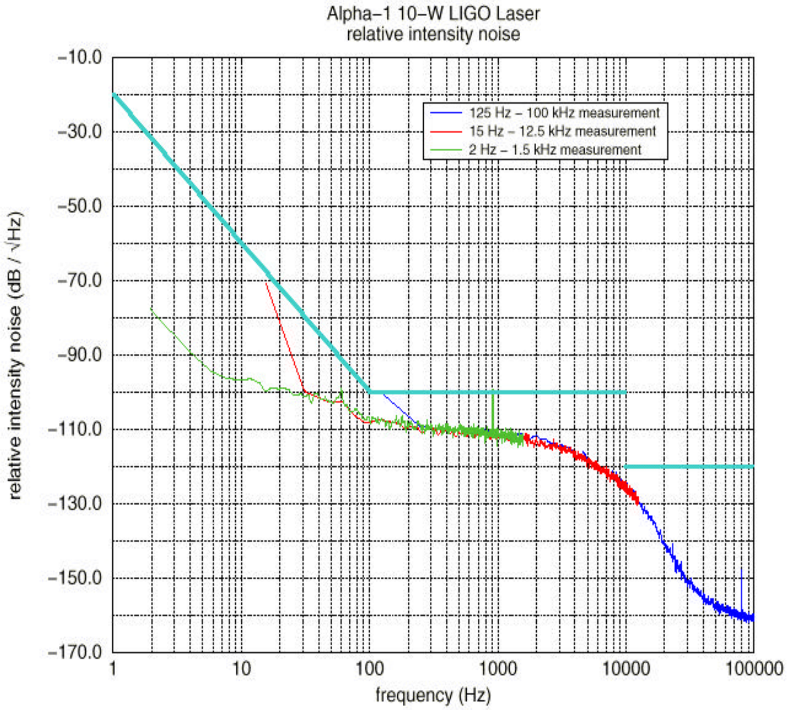
BSC Seismic Isolation Performs as Designed



Horizontal Transfer Function

Prestabilized Laser is Installed at Hanford

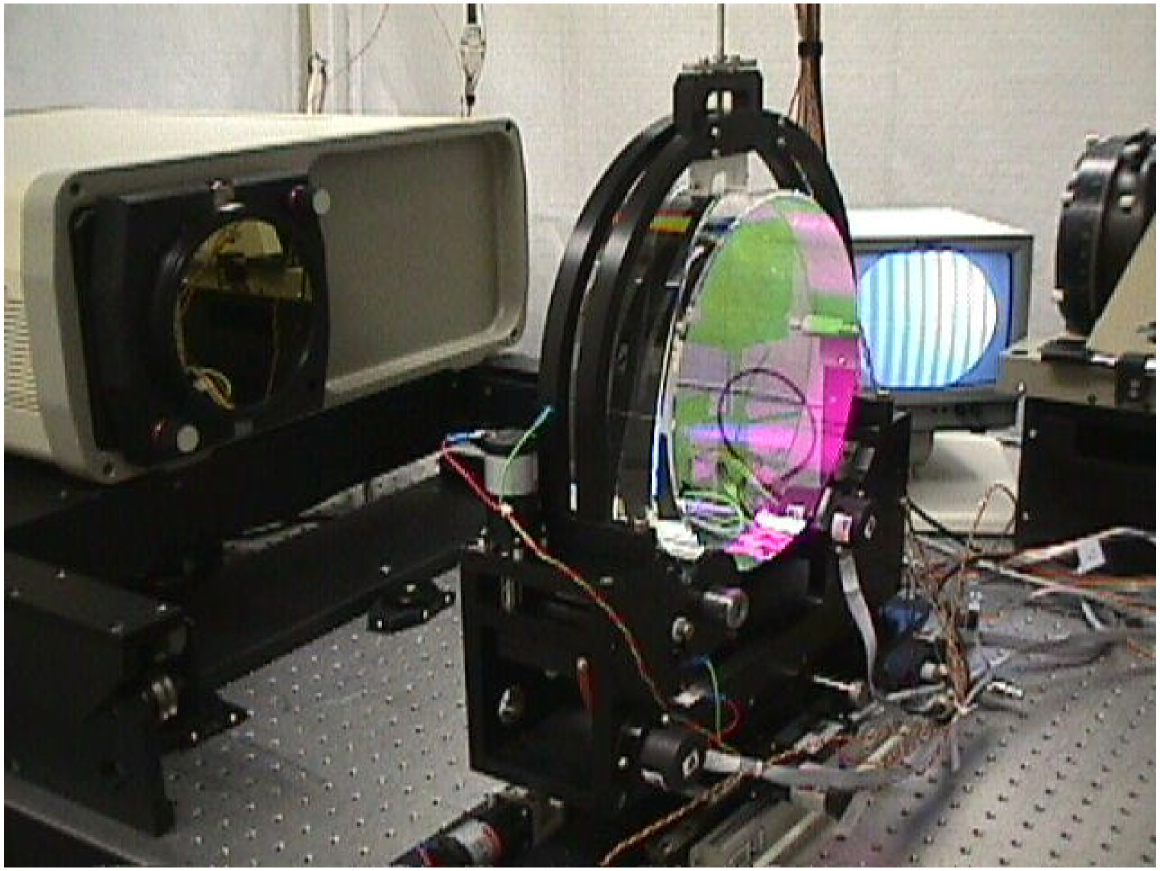




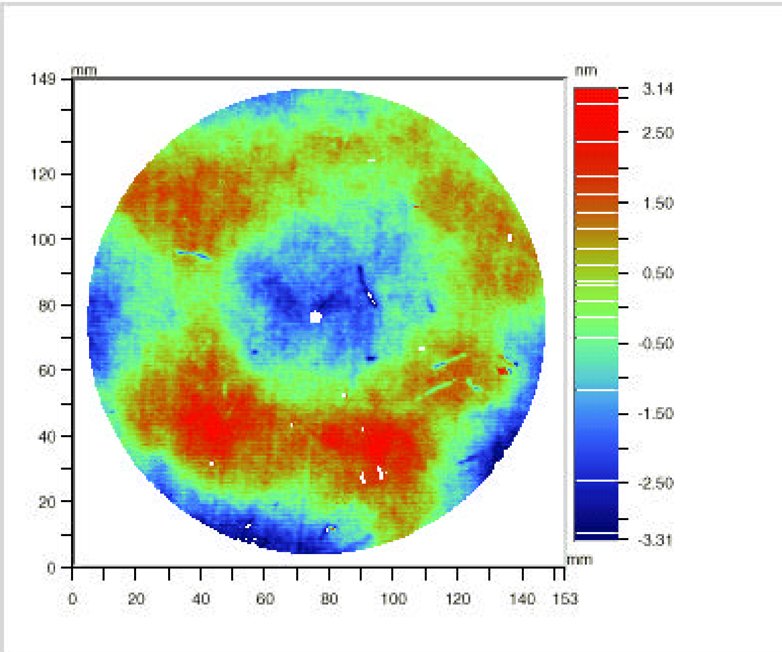
Performance Meets Requirements

LIGO

Infrared Metrology of Core Optics



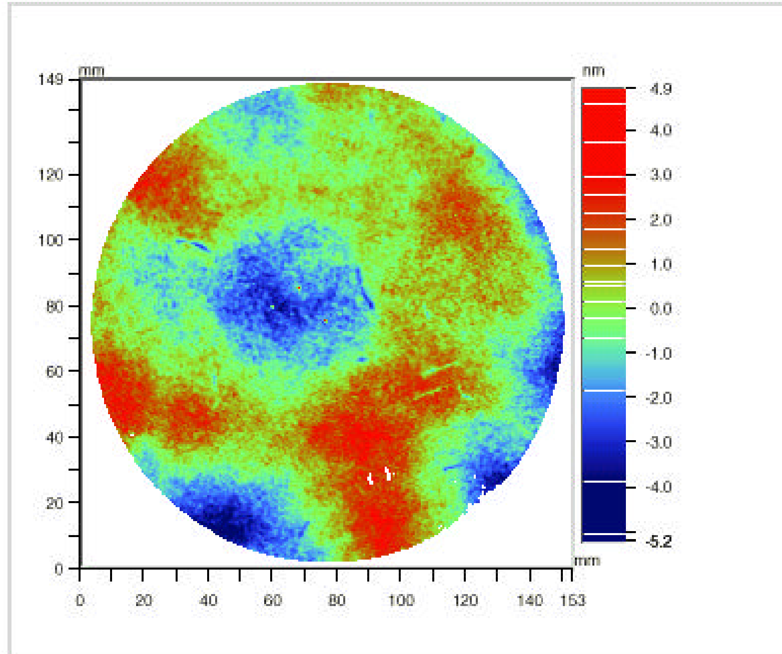
Core Optics Metrology



Date: 11/16/1998
Time: 16:39:59
Wavelength: 1.064 um
Pupil: 100.0 %
PV: 6.4471 nm
RMS: 1.1005 nm
Rad of curv: 570.70 km

X Center: 284.00
Y Center: 240.00
Radius: 267.72 pix
Terms: Tilt Power Astig
Filters: None
Masks: 3.0 Sigma Mask

CSIRO measurement

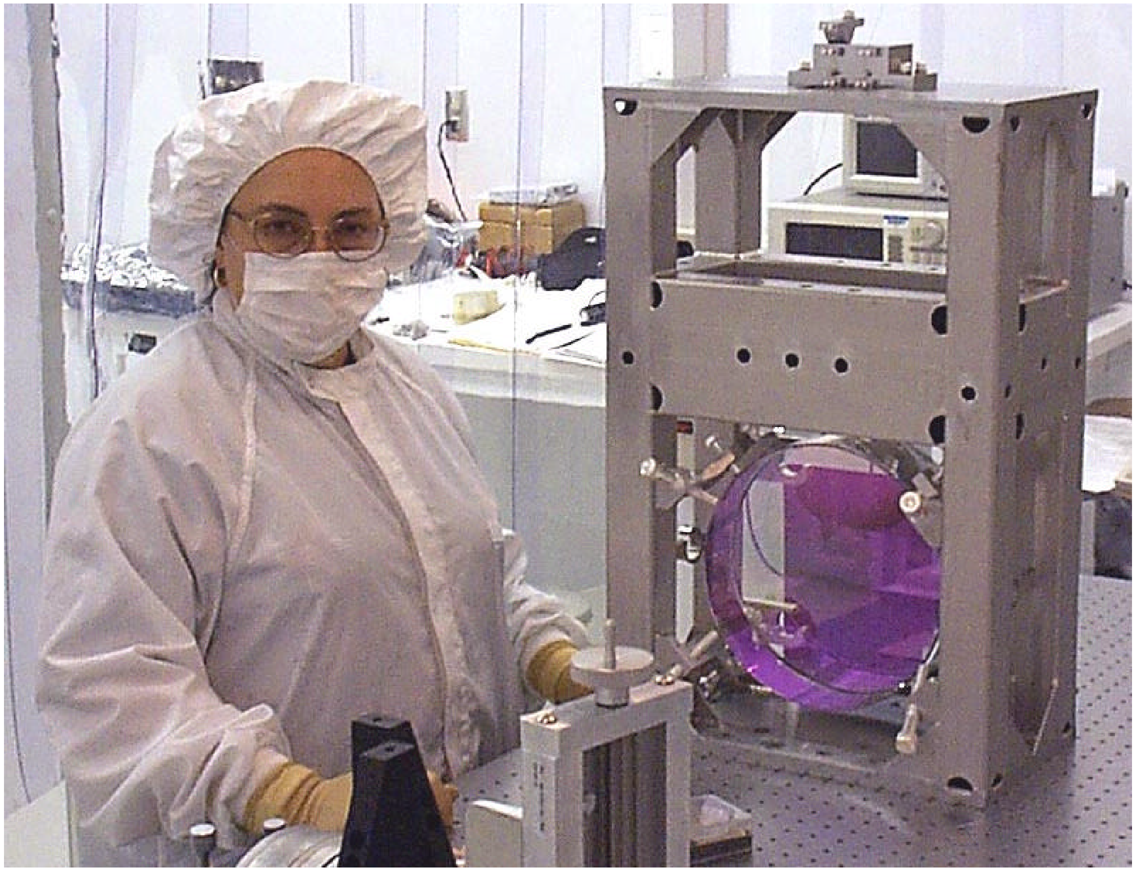


Date: 12/04/1998
Time: 08:56:13
Wavelength: 1.064 um
Pupil: 100.0 %
PV: 10.1607 nm
RMS: 1.2981 nm
Rad of curv: 292.37 km

X Center: 288.00
Y Center: 239.50
Radius: 275.45 pix
Terms: Tilt Power Astig
Filters: None
Masks:

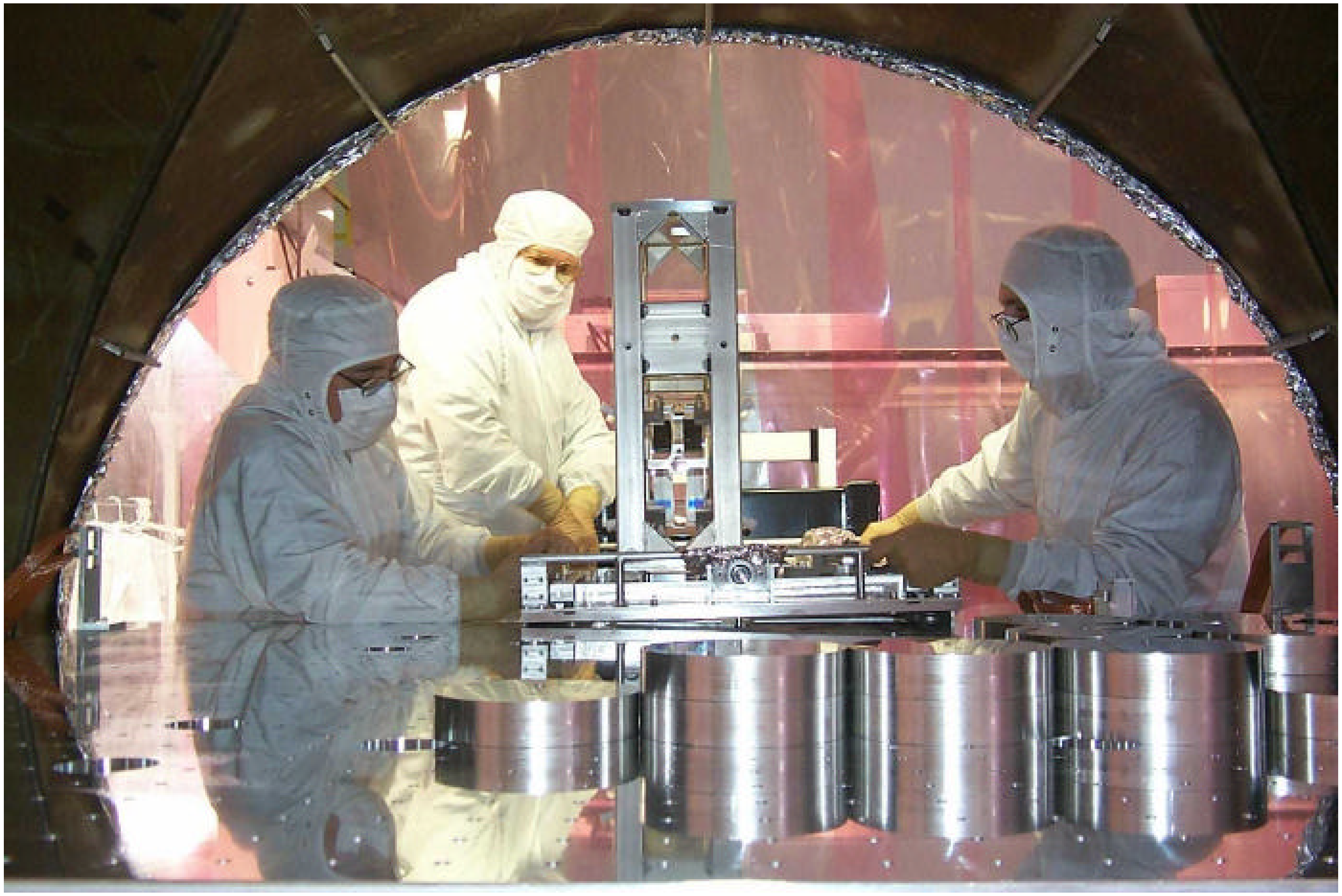
Caltech measurement

First Suspended Large Optic



First Installation of Seismic Isolation in HAM Chamber

First Installation of a Large Mirror



Adjusting Alignment of Installed Recycling Mirror

First Installation of BSC Isolation Downtube

LIGO

First Infrared Laser Light Into Vacuum System

LIGO

Commissioning LIGO I

- Hanford 2 km interferometer to be installed and commissioned first
  - » Prestabilized laser locked and running for ~ 30 days now
  - » Mode cleaner locking in April 1999
  - » Short arm Michelson, with recycling mirror, locked by late summer
  - » add 2 km arms locked in recycled configuration by end of 1999
  - » Currently considering locking one 2 km arm cavity by early summer
- Livingston 4 km interferometer follows same schedule with ~ 6 month lag
- Hanford 4 km interferometer follows this
- $h \sim 10^{-20}$ in 3 interferometers by end 2000
- $h \sim 10^{-21}$ in 3 interferometers by end 2001

LIGO

First Science Observation Period

- Scientific observing begins in January 2002 with a two year run planned at $h \sim 10^{-21}$
- Goal is 75% of the observation period to be covered by 3 interferometers running at design sensitivity
- Analysis of data will be team oriented with teams from LIGO Laboratory and the LIGO Scientific Collaboration analyzing data for different physics goals (bursts, stochastic, periodic,…)
- LIGO Laboratory delivers data product to teams
- We also collaborate in delivering complete end-to-end modeling system to scientific community

LIGO

LIGO Scientific Collaboration

- The scientific program of LIGO is carried out by the **LIGO Scientific Collaboration (LSC)**
- LSC consists of scientists from the:
  - » LIGO Laboratory and
  - » LSC members from external collaborating institutions with Memoranda of Understanding with the LIGO Laboratory
- We view LIGO as open to all scientists who make commitments to contribute to the collaboration
- Currently, more than 200 scientists from more than 25 institutions are members of the LSC
- Our goal is to make LIGO's scientific potential available to the strongest international community

Beyond LIGO I

- LIGO I scientific run in 2002 - 2003
- R&D for LIGO II already in progress
- Installation of LIGO II improvements scheduled for 2004 with baseline design described this year
  - » perhaps in two stages with signal-tuned configuration in 2006
- Beyond another two year observation period, LIGO III upgrade would be implemented
- LIGO III design is not at all specified, but goals are established

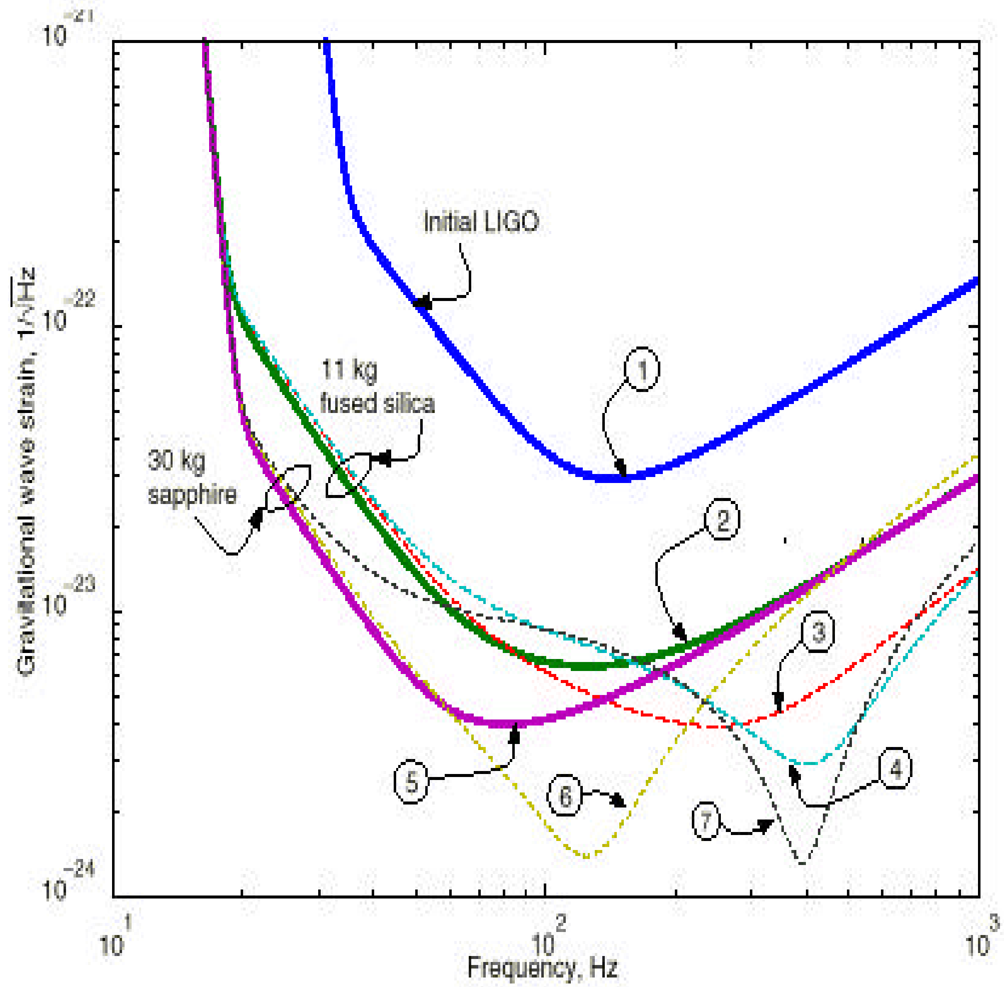
Hopefully physics results will change this plan!

Advanced R&D for LIGO II

LIGO-G990025-00-M

LIGO II Goals

- Improvements:
  - » 40 - 100 W laser
  - » optics quality to reduce thermal effects
  - » heavier test masses
  - » multiple pendulum suspensions
  - » vertical isolation
  - » lower seismic noise
  - » dual recycling/resonant sideband extraction
- Install in 2004
- LIGO III in 2007 ?



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Details of LIGO II Improvements

Parameter	Curve 1	Curve 2	Curve 3, 4	Curve 5, 6, 7
Parameter	Initial LIGO I value	Double suspension, 100 W laser, thermal de-lensing	Signal tuned configuration	Alternative test mass material
Input power to recycling mirror	6W	62W	140W	
Mirror loss (transmission+scatter)	50 ppm	20 ppm		
Effective power recycling	30	93		
Substrate absorption	5ppm/cm	0.4 ppm/cm		17 ppm/ cm
Thermal lensing correction	(none)	factor 10		
Suspension fiber	steel wire, $Q = 1.6\times10^5$	fused silica $Q = 3 \times 10^7$		
Test mass	fused silica, 10.8 kg, $Q = 1\times10^6$	fused silica, 10.8 kg, $Q = 3\times10^7$		sapphire, 30 kg, $Q = 2\times10^8$
Signal recycling mirror transmission	(none)		T=0.6 (curve 3) T=0.15 (curve 4)	Curve 5: none T=0.3 (curve 6) T=0.09 (curve 7)
Tuning phase			0.7 rad (curve 3) 0.45 rad (curve 4)	1.3 rad (curve 6) 0.45 rad (curve 7)

An Exciting Period

- TAMA 300 commissioning the first of the new generation of interferometric detectors
- LIGO installing and beginning commissioning
- VIRGO and GEO installing now as well
- New detectors discussed for the future:
  - » Second European Interferometer
  - » LIGO II with GEO collaboration
  - » LCGT in Japan
  - » Australian plans

Goal: An all-sky gravitational wave map!