Interferometric Detectors on the Earth

5th Amaldi Conference

Rainer Weiss

LIGO MIT

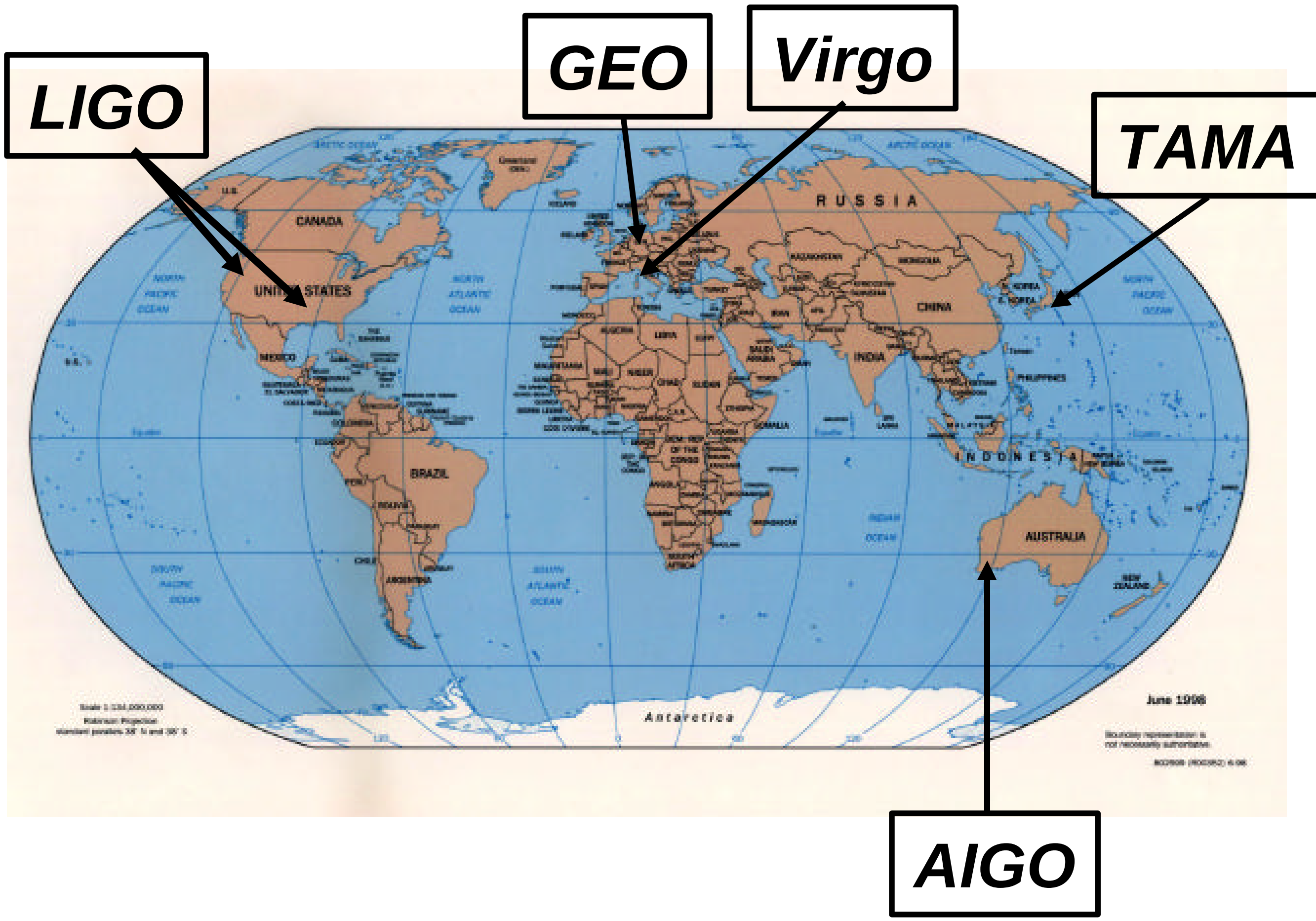
July 7, 2003

Pisa, Italy

LIGO-G030369-00-D

Interferometers
international network

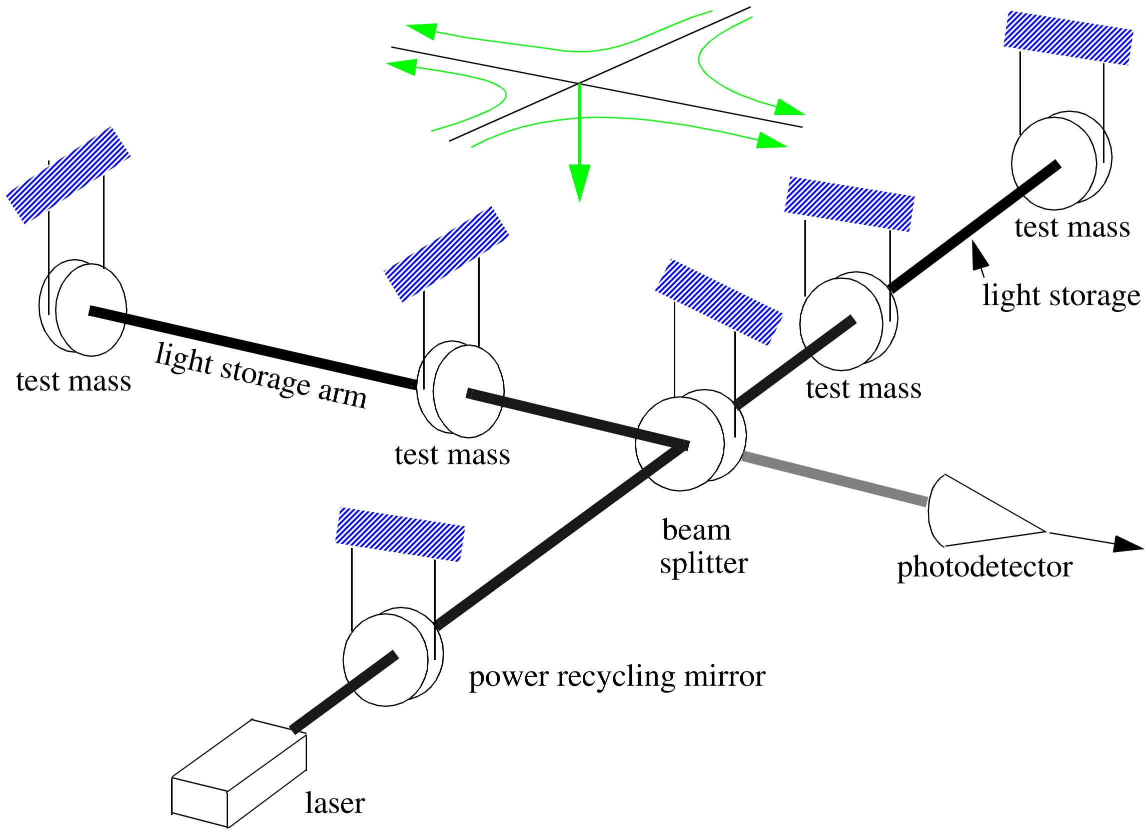
Simultaneously detect signal (within msec)



detection confidence

locate the sources

decompose the polarization of gravitational waves


test mass
light storage arm
test mass
test mass
light storage arm
test mass
beam
splitter
photodetector
power recycling mirror
laser

FRINGE SENSING

wavelength 1×10^{-6} m

$$h = \frac{x}{L} \sim \frac{\lambda}{L b \sqrt{\dot{N} \tau}}$$

arm length = 4000 m

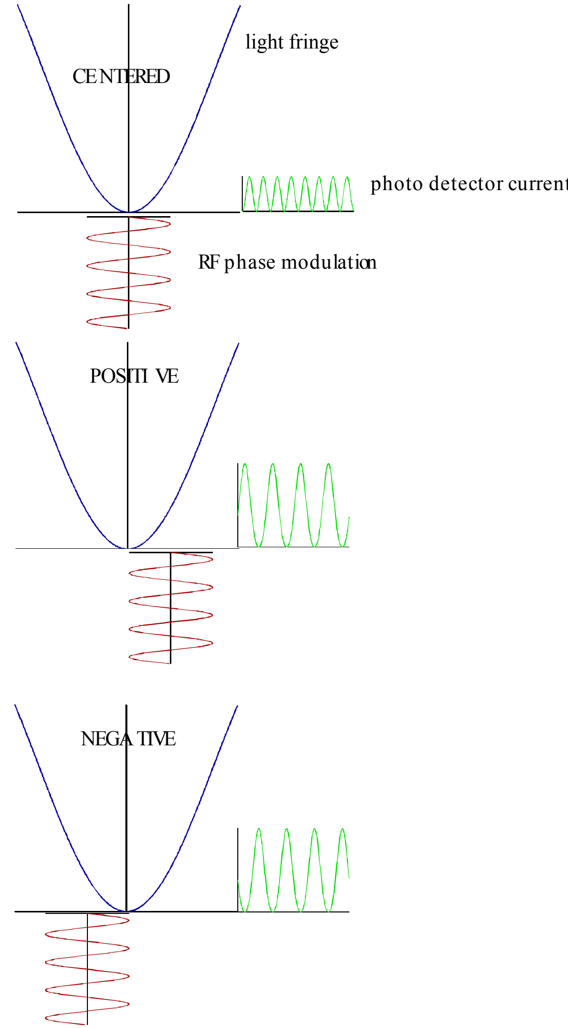
equivalent # of passes = 100

integration time

number of quanta/second at the beam splitter

300 watts at beam splitter = 10^{21} identical photons/sec

$h = 6 \times 10^{-22}$ integration time 10^{-2} sec



PENDULUM THERMAL NOISE

Pendulum Brownian motion

Dissipation leads to fluctuations

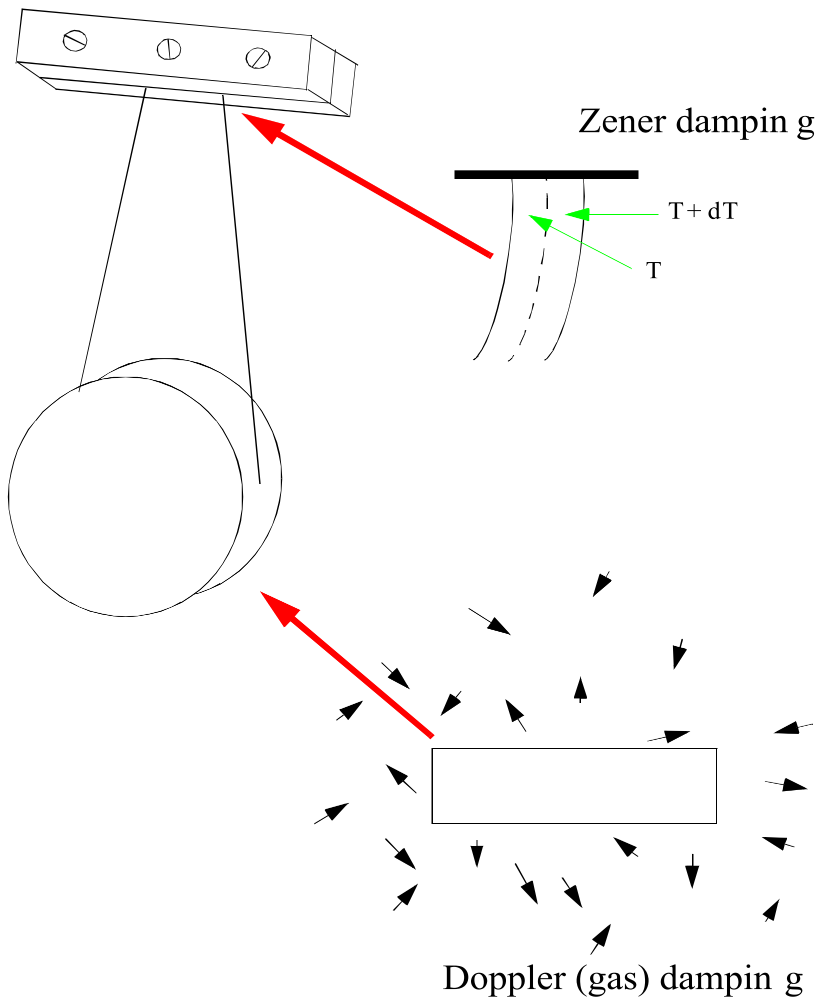
Tc = coherence or damping time

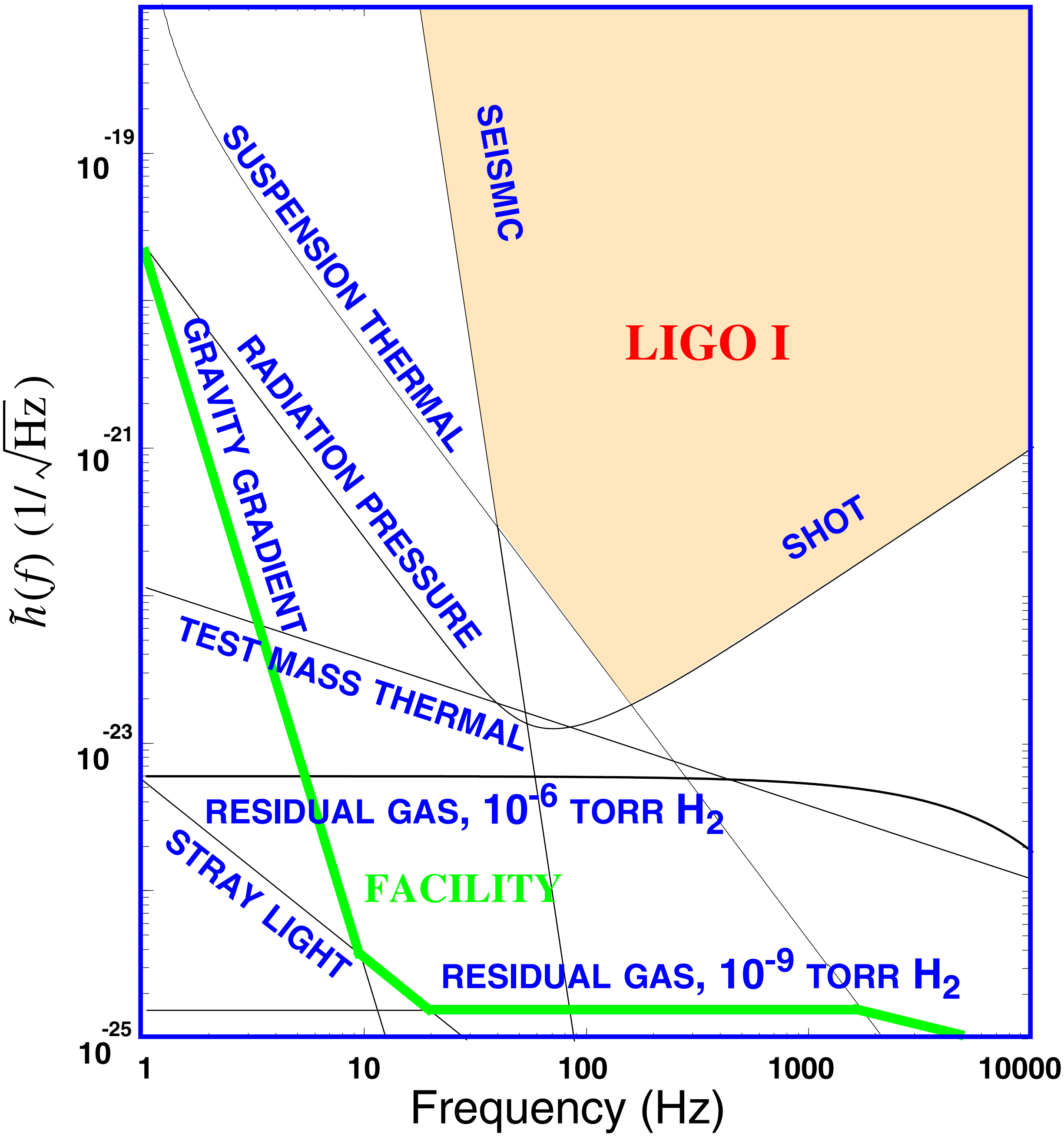
= Q x period of oscillator

Exchange with surroundings:

$$E(\text{thermal}) = \frac{kT\ t}{Tc}$$

Large Tc => smaller fluctuations





SUSPENSION THERMAL
SEISMIC
LIGO I
GRAVITY GRADIENT
RADIATION PRESSURE
SHOT
TEST MASS THERMAL
RESIDUAL GAS, 10^{-6} TORR H_2
STRAY LIGHT
FACILITY
RESIDUAL GAS, 10^{-9} TORR H_2
10^{-19}
10^{-21}
10^{-23}
10^{-25}
1
10
100
1000
10000
Frequency (Hz)
$\tilde{h}(f)$ $(1/\sqrt{\mathrm{Hz}})$

Current State of Interferometers

7/7 F. Frasconi *Status of Virgo*

7/7 R. Takahashi *Status of TAMA 300*

7/7 D. Sigg *Commisioning of LIGO Detectors*

7/7 B. Willke *Status of the GEO 600 detector*

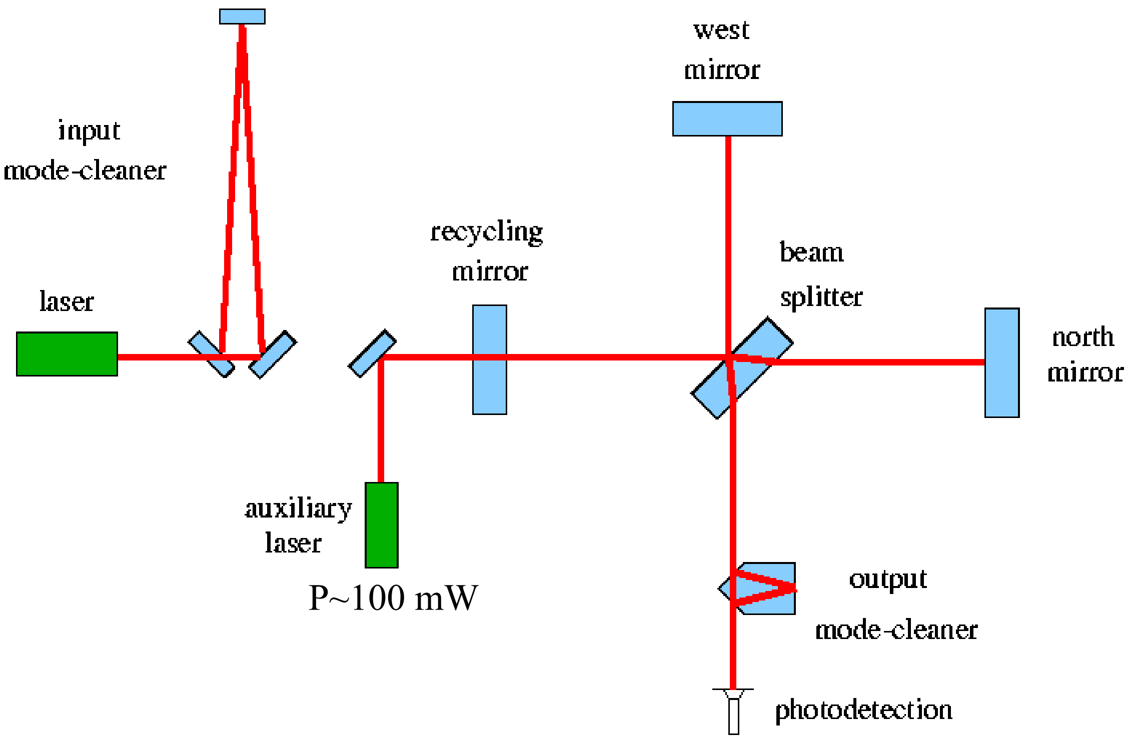
CONGRATULATIONS

VIRGO INAUGURATION
July 23, 2003

- Completion of the vacuum system
- Hanging of all the test masses

CITF main steps

- Vacuum chamber installation in 1999
- Interferometer installation in 1999 and 2000
- Suspensions pre-commissioning in 2000
- Injection system pre-commissioning longer than originally thought
- CITF Commissioning started with small auxiliary laser in February 2001

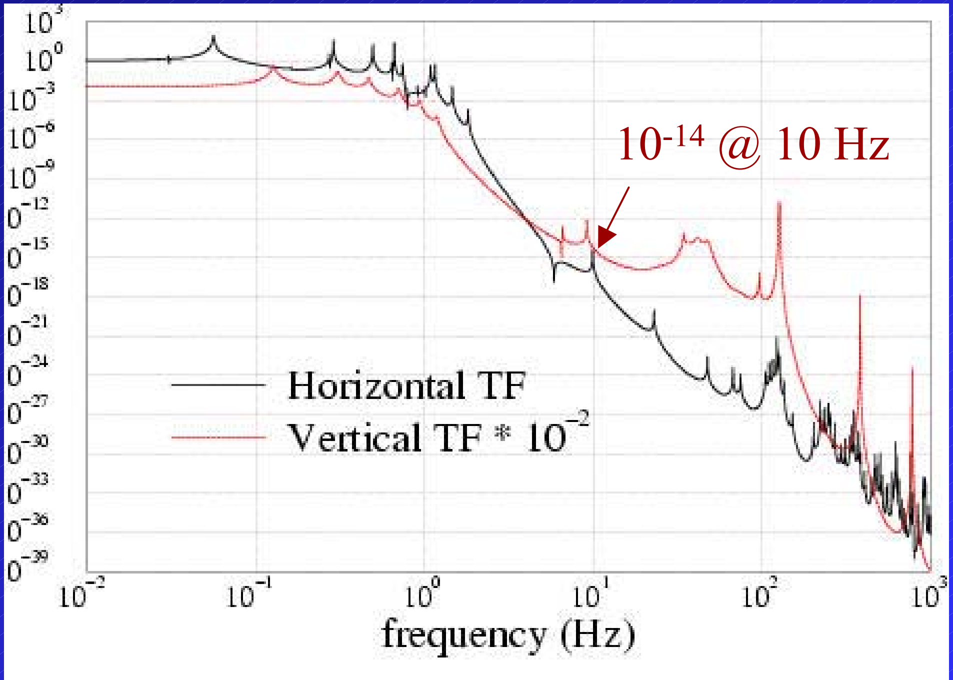


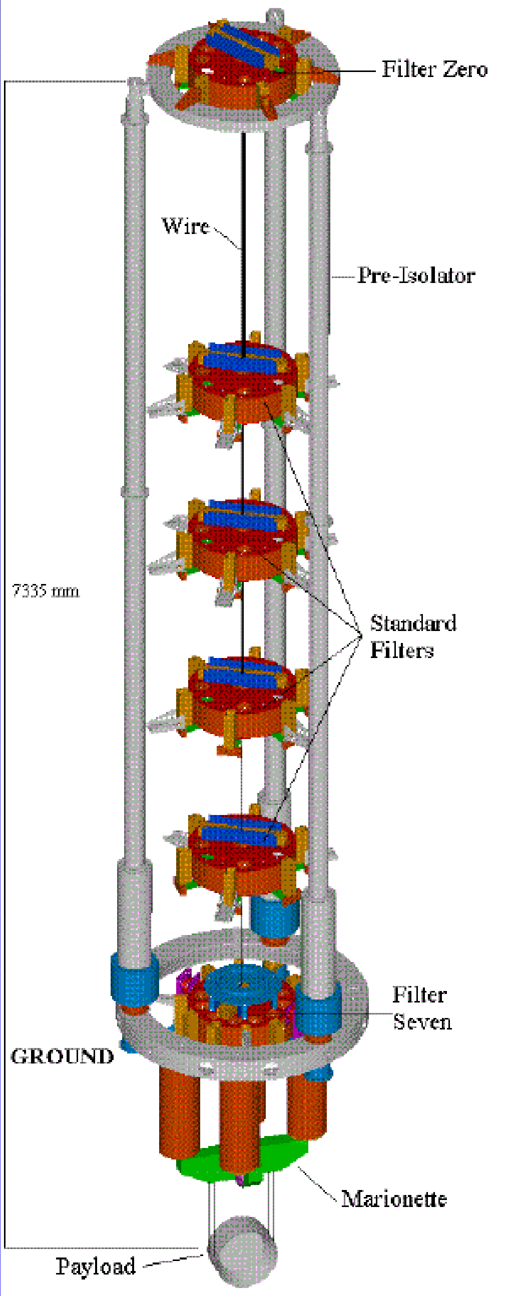
Main CITF commissioning steps

- Interferometer first alignment
- Simple Michelson
- Recycled Michelson
- Recycled Michelson with Injection

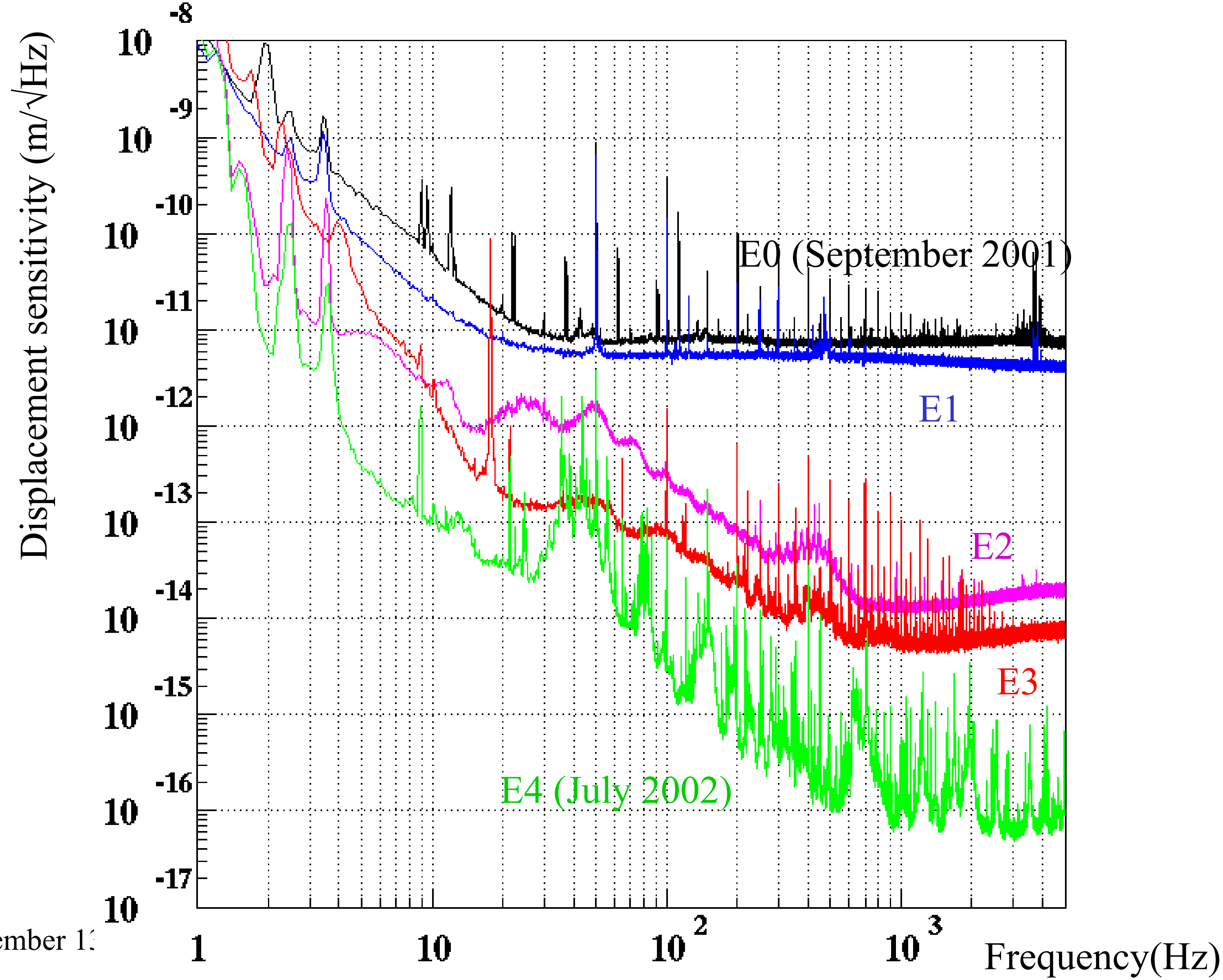
- The SA filters off the seismic noise above 4 Hz
- Below 4 Hz the mirror moves at the SA resonances of tens of microns
- ITF locking requires resonance damping

Zeroth law of vibration isolators: remove as much energy as you can





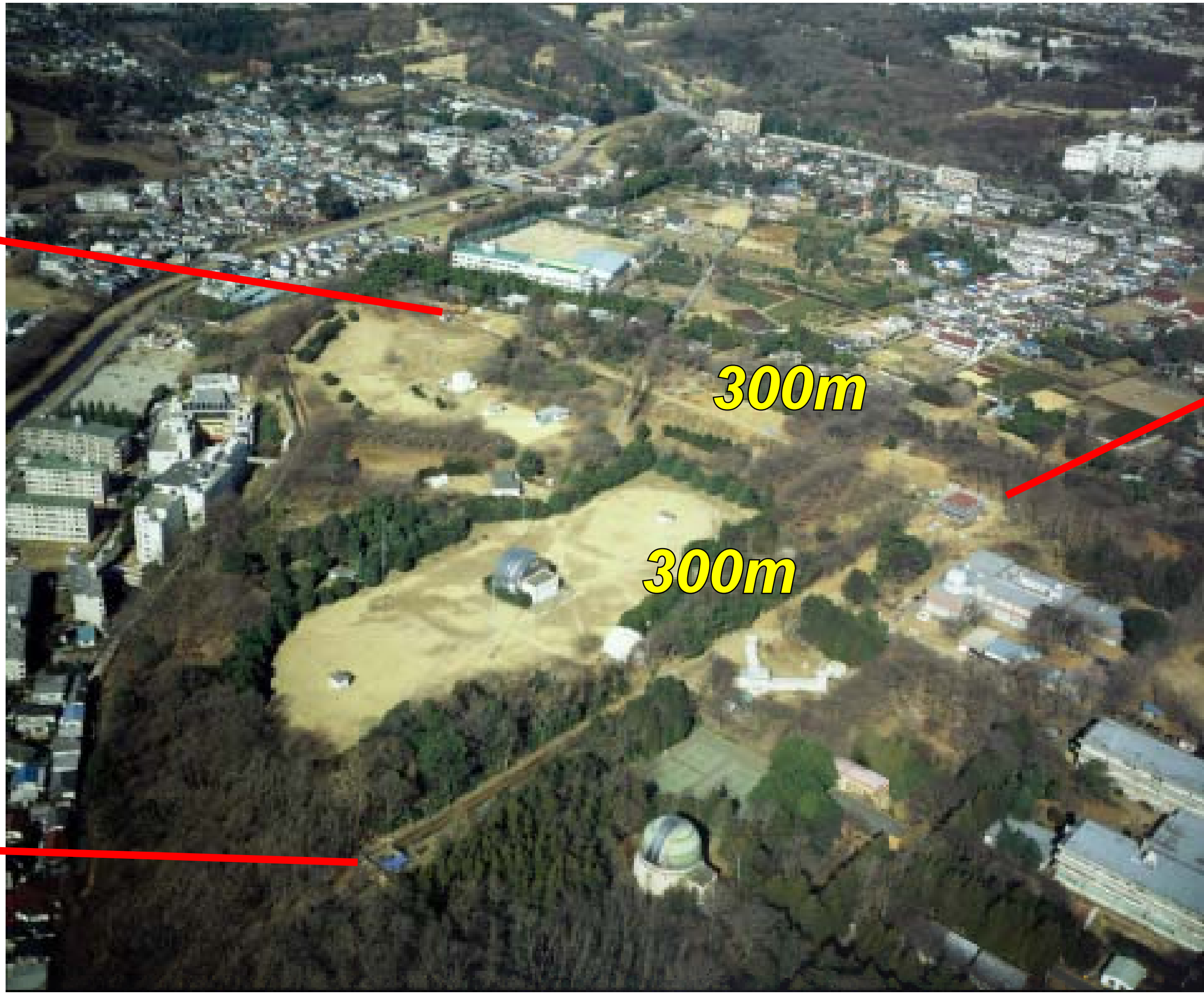
Summary of CITF sensitivity



TAMA (Japanese) L=300m

- サイト: 国立天文台三鷹キャンパス(東京)

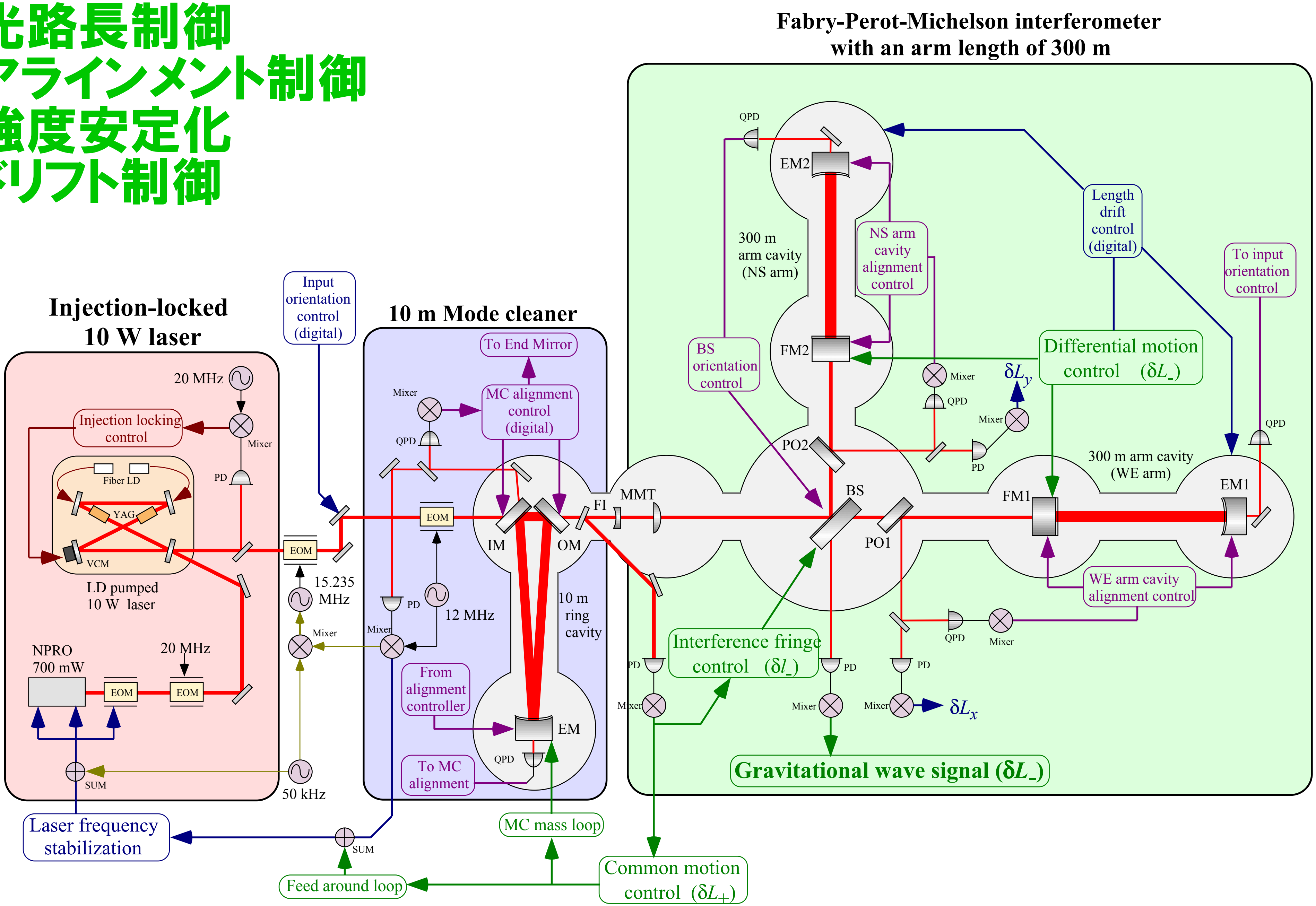
(E139.32.21 N35.40.25)



市街地の真っ只中に位置・交通量多し

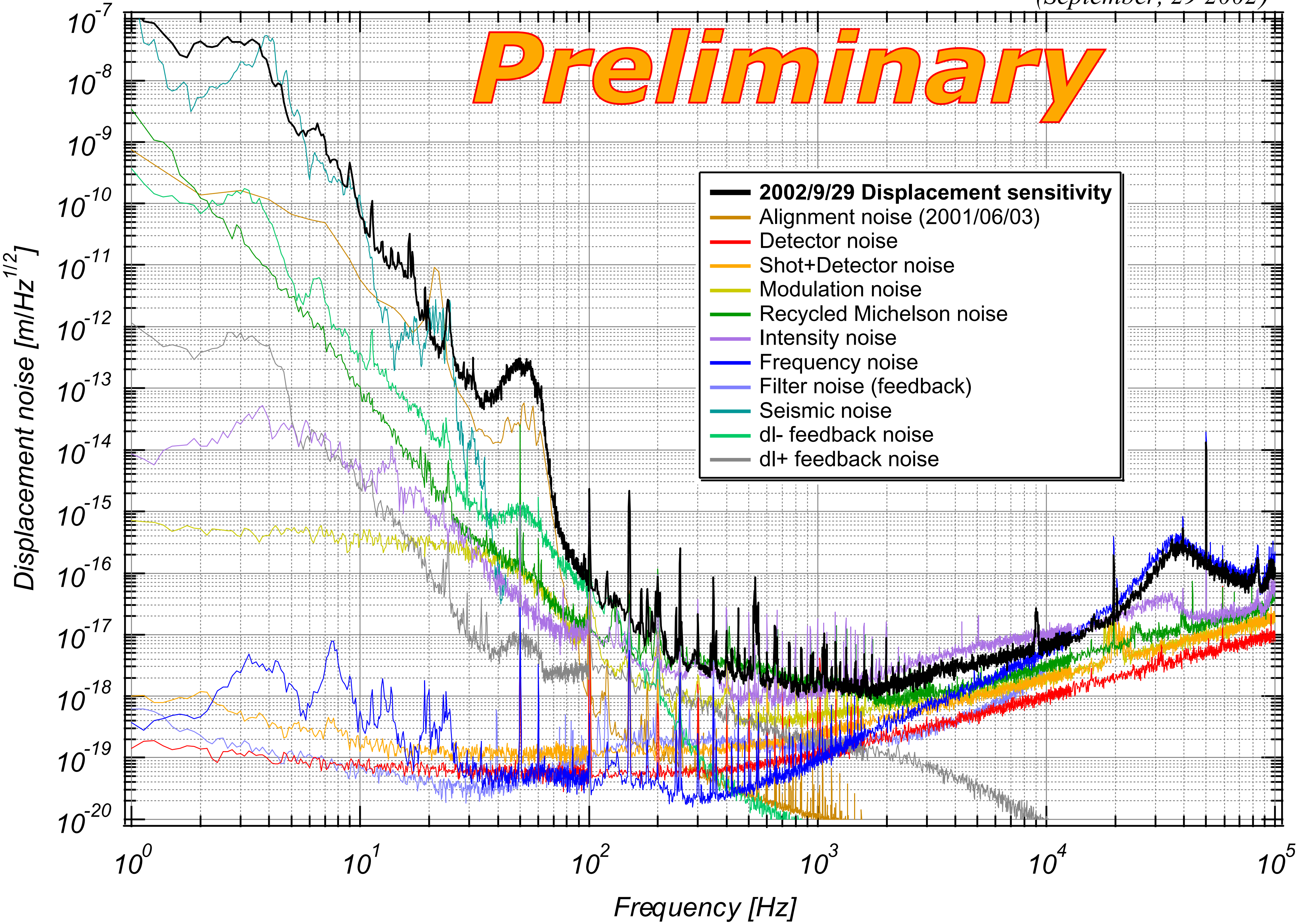
制御系

光路長制御
アラインメント制御
強度安定化
ドリフト制御

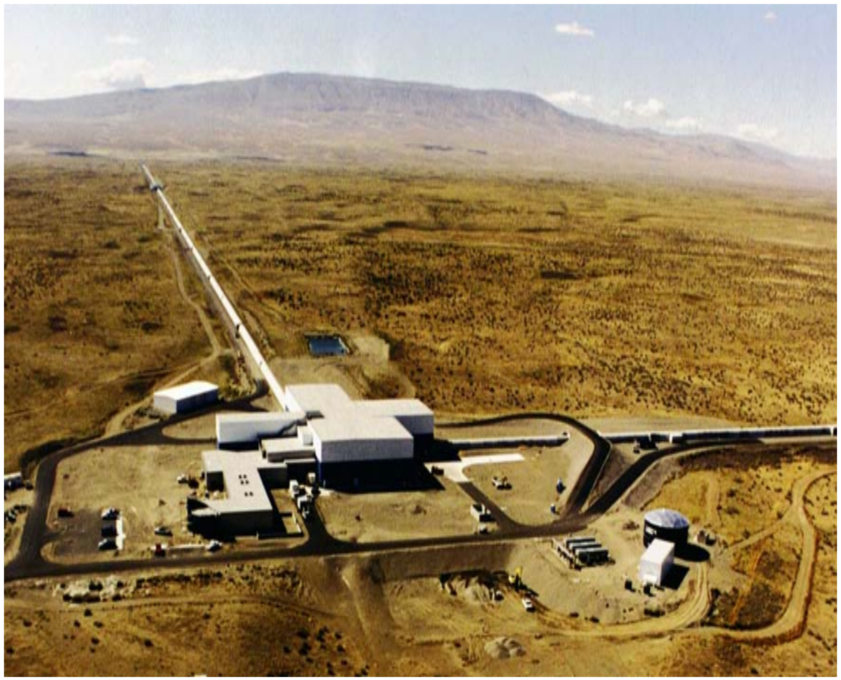


Displacement noise level of TAMA300

(September, 29 2002)



LIGO Observatory Facilities



LIGO Hanford Observatory [LHO]

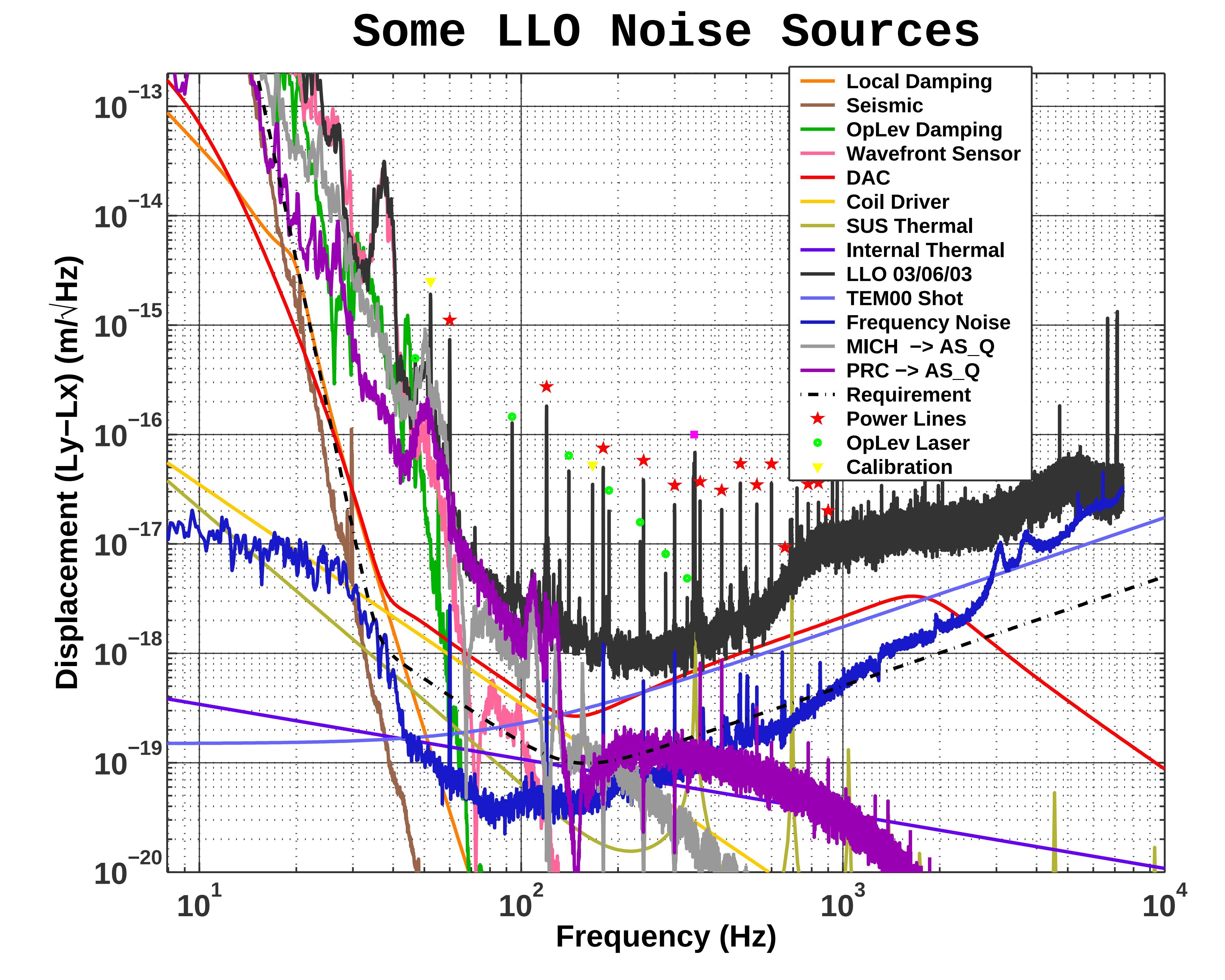
26 km north of Richland, WA

2 km + 4 km interferometers in same vacuum envelope

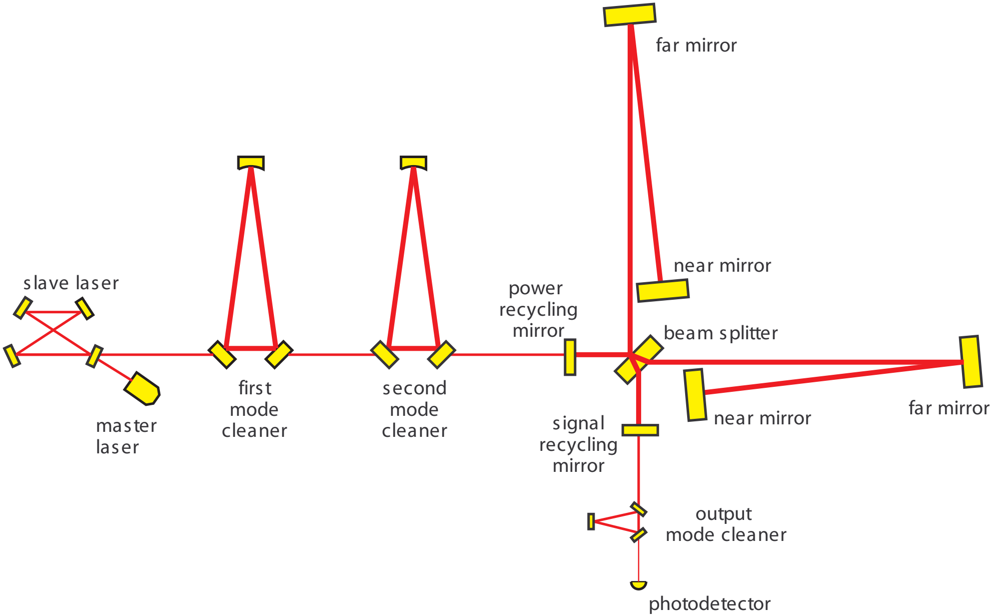
LIGO Livingston Observatory [LLO]

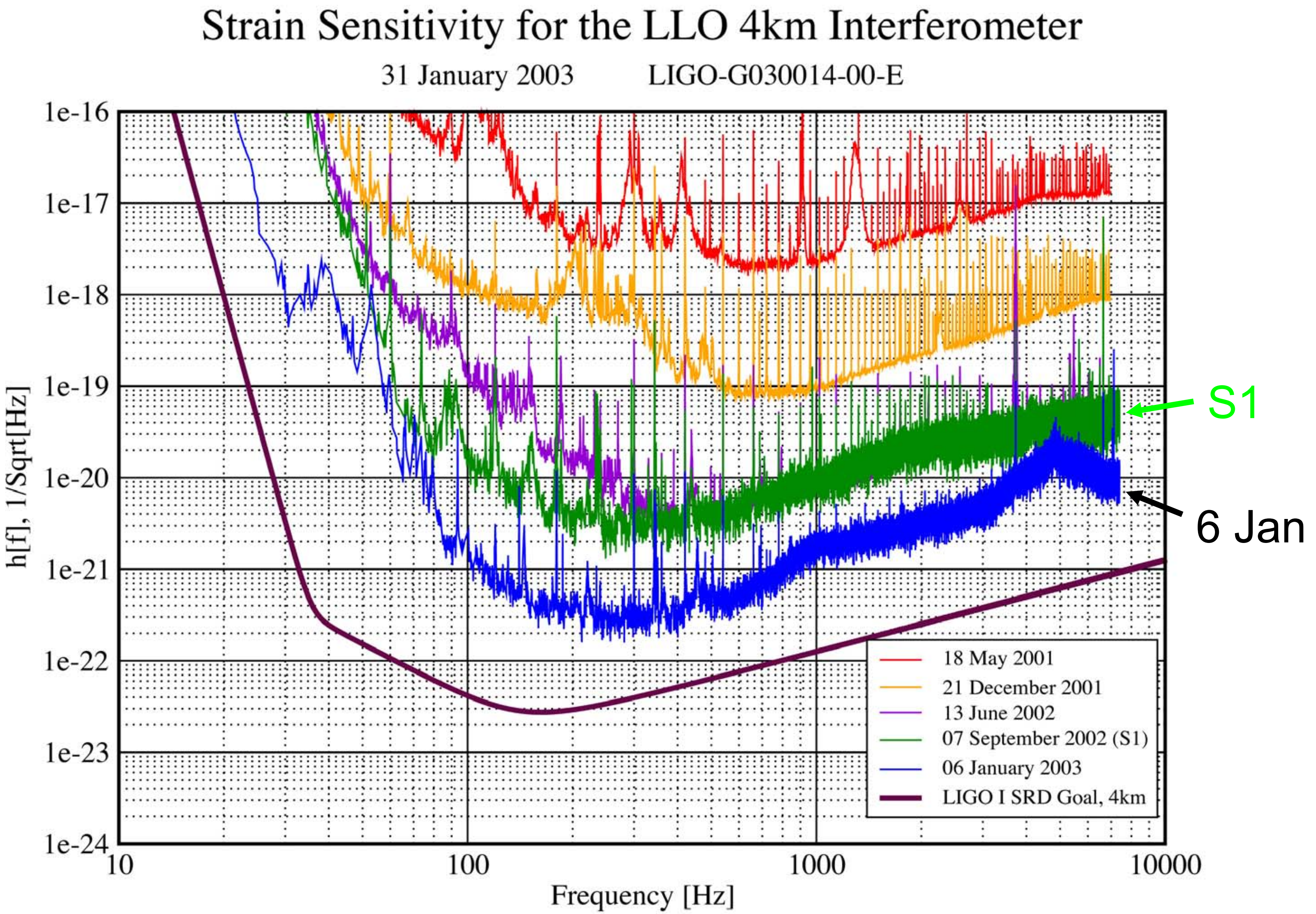
42 km east of Baton Rouge, LA

Single 4 km interferometer



Some LLO Noise Sources
Local Damping
Seismic
OpLev Damping
Wavefront Sensor
DAC
Coil Driver
SUS Thermal
Internal Thermal
LLO 03/06/03
TEM00 Shot
Frequency Noise
MICH −> AS_Q
PRC −> AS_Q
Requirement
Power Lines
OpLev Laser
Calibration
Displacement (Ly−Lx) (m/√Hz)
Frequency (Hz)


far mirror
near mirror
slave laser
power
recycling
mirror
beam splitter
far mirror
near mirror
first
mode
cleaner
second
mode
cleaner
master
laser
signal
recycling
mirror
output
mode cleaner
photodetector


Strain Sensitivity for the LLO 4km Interferometer
31 January 2003
LIGO-G030014-00-E
h[f], 1/Sqrt[Hz]
1e-16
1e-17
1e-18
1e-19
1e-20
1e-21
1e-22
1e-23
1e-24
10
100
1000
10000
Frequency [Hz]
18 May 2001
21 December 2001
13 June 2002
07 September 2002 (S1)
06 January 2003
LIGO I SRD Goal, 4km
S1
6 Jan

LIGO Scientific Collaboration Member Institutions

University of Adelaide ACIGA
Australian National University ACIGA
Balearic Islands University
California State Dominquez Hills
Caltech CACR
Caltech LIGO
Caltech Experimental Gravitation CEGG
Caltech Theory CART
University of Cardiff GEO
Carleton College
Cornell University
Fermi National Laboratory
University of Florida @ Gainesville
Glasgow University GEO
NASA-Goddard Spaceflight Center
University of Hannover GEO
Hobart – Williams University
India-IUCAA
IAP Nizhny Novgorod
Iowa State University
Joint Institute of Laboratory Astrophysics
Salish Kootenai College

LIGO Livingston LIGOLA
LIGO Hanford LIGOWA
Loyola New Orleans
Louisiana State University
Louisiana Tech University
MIT LIGO
Max Planck (Garching) GEO
Max Planck (Potsdam) GEO
University of Michigan
Moscow State University
NAOJ - TAMA
Northwestern University
University of Oregon
Pennsylvania State University
Southeastern Louisiana University
Southern University
Stanford University
Syracuse University
University of Texas@Brownsville
Washington State University@ Pullman
University of Western Australia ACIGA
University of Wisconsin@Milwaukee

Data Analysis for Sources

7/7 B. Allen *Analysis of data from LIGO and GEO*

7/9 A. Weinstein, M.Ando,P.Sutton, L.Cadonati *....Burst limits*

7/9 J. Whelan *....Stochastic limits*

7/9 G. Gonzalez, H. Takahashi, L. Bosi *....Inspiral limits*

7/9 G. Woan,B.Allen,M.Yvert,A.Vechio *....Periodic source limits*

7/9 Y. Tsunesada *.. Black Hole ringdown limits*

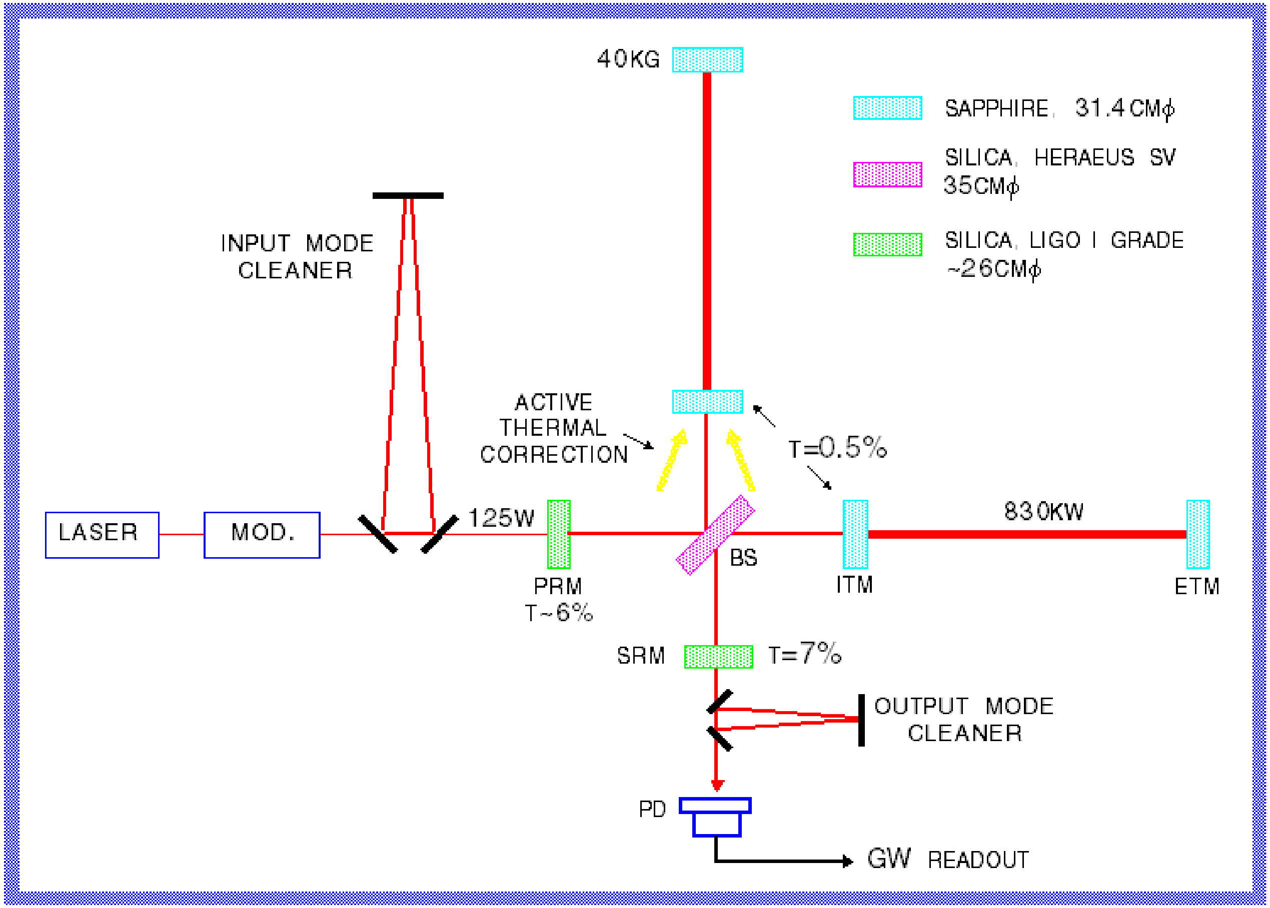
7/9 S. Mohanty *GRB and GW*

Nearer term improvements

7/11 D. Shoemaker *Advanced LIGO*

7/11 T. Uchiyama *Present Status of LCGT*

Advanced Interferometer Concept



» Signal recycling

» 180-watt laser

» 40 kg Sapphire test masses

» Larger beam size

» Quadruple suspensions

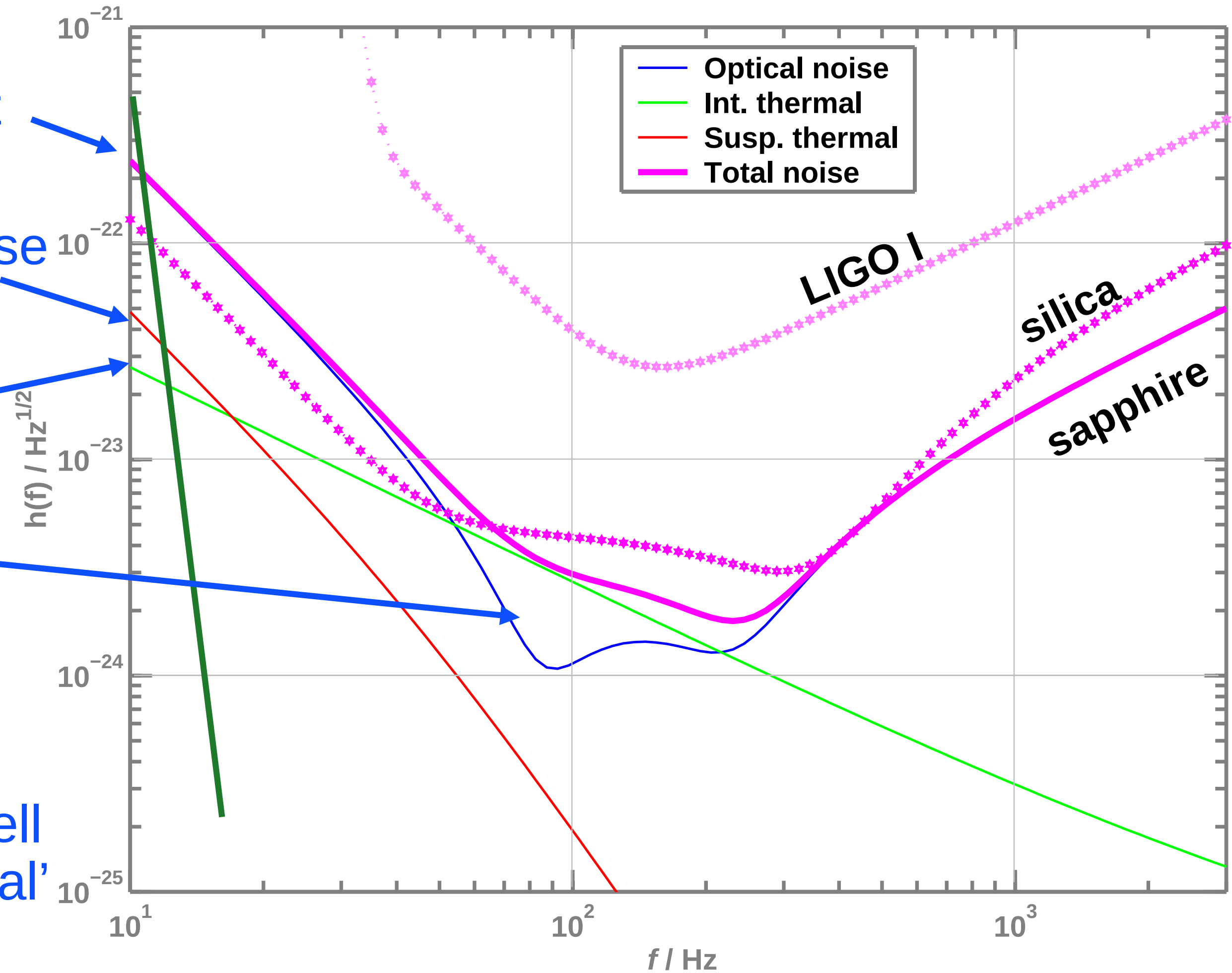
» Active seismic isolation

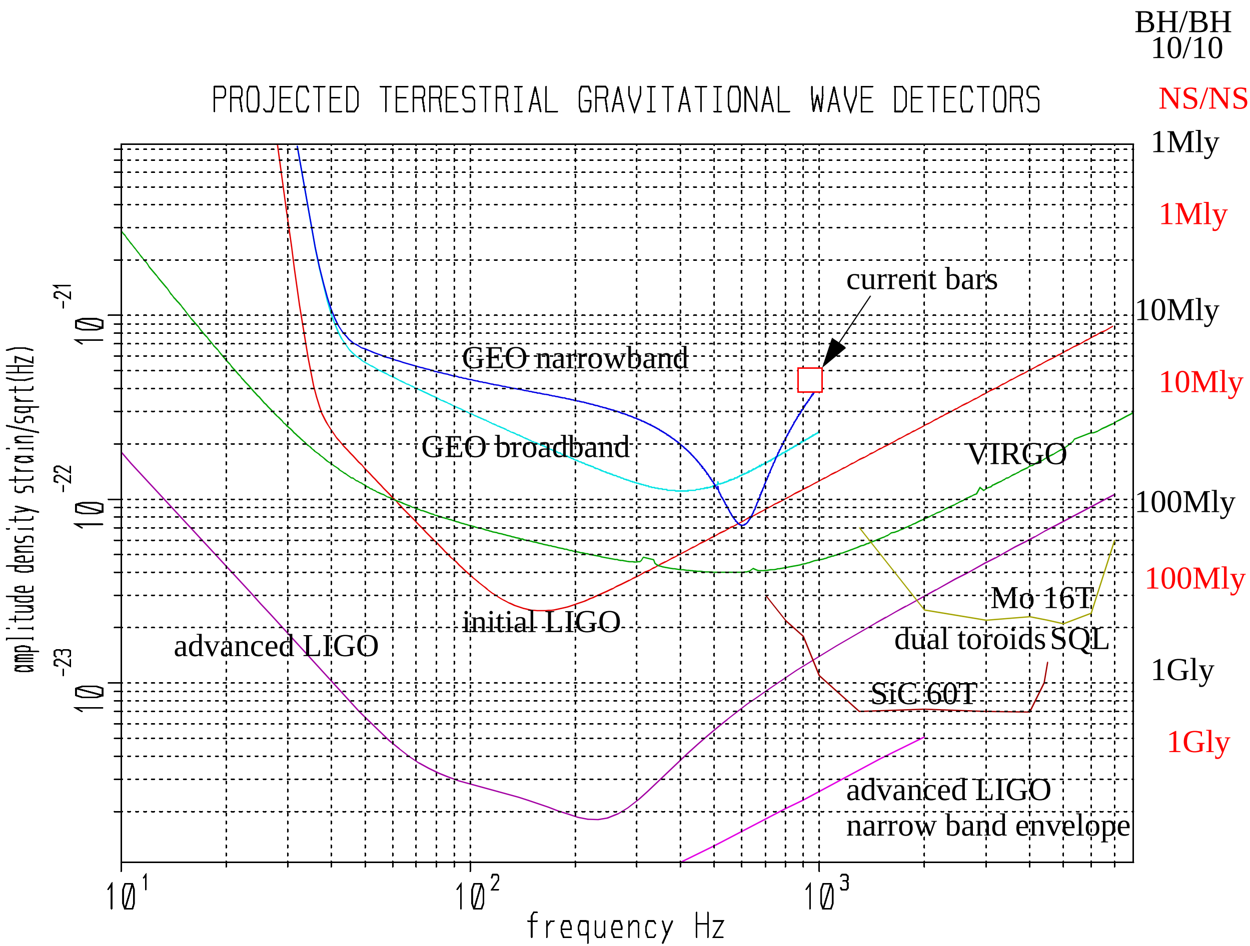
» Active thermal correction

» Output mode cleaner

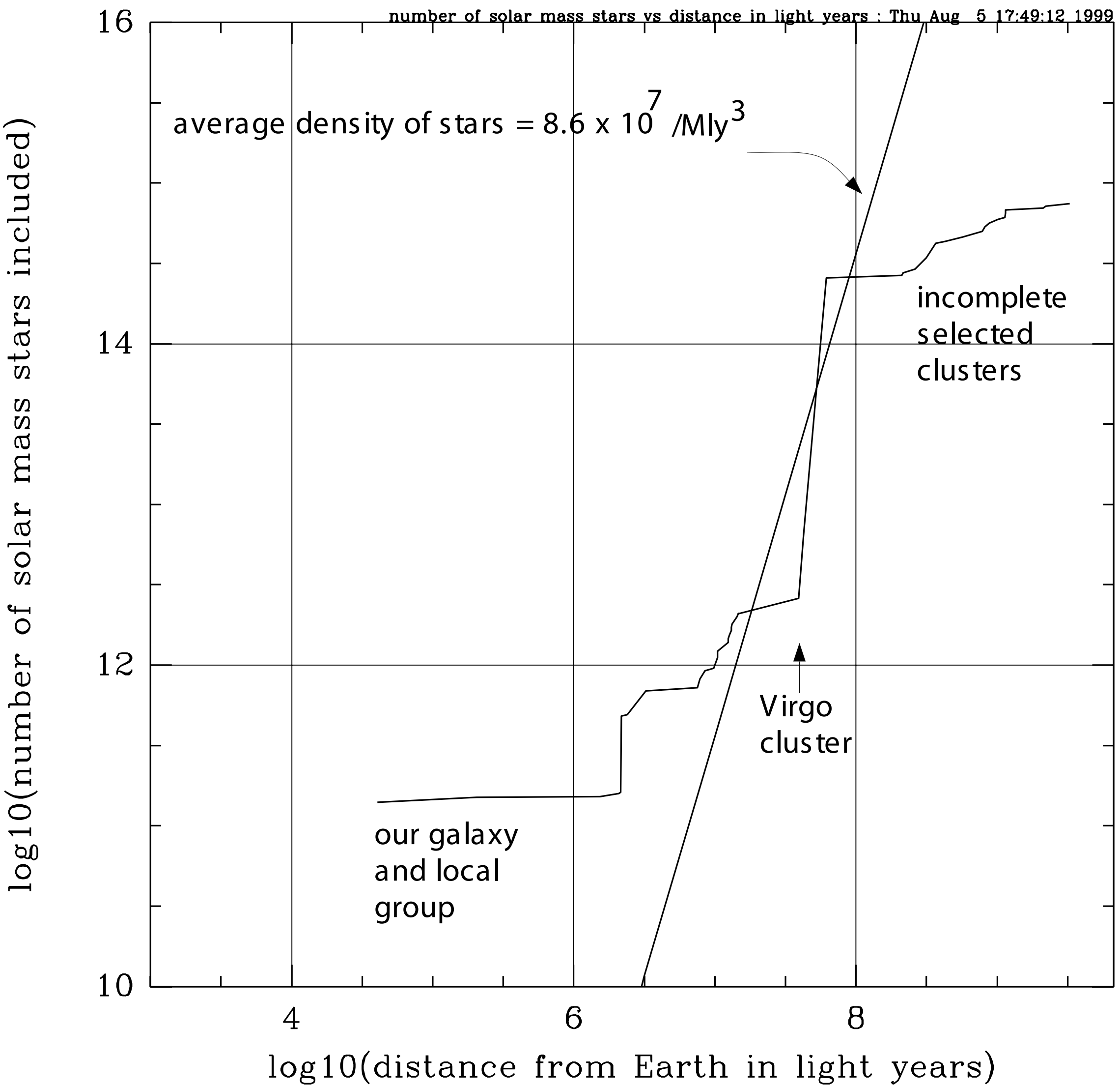
Projected Performance

- Seismic ‘cutoff’ at 10 Hz
- Suspension thermal noise
- Internal thermal noise
- Unified quantum noise dominates at most frequencies
- ‘technical’ noise (e.g., laser frequency) levels held in general well below these ‘fundamental’ noises





PROJECTED TERRESTRIAL GRAVITATIONAL WAVE DETECTORS
BH/BH
10/10
NS/NS
1Mly
1Mly
10Mly
10Mly
100Mly
100Mly
1Gly
1Gly
current bars
GEO narrowband
GEO broadband
VIRGO
initial LIGO
advanced LIGO
Mo 16T
dual toroids SQL
SiC 60T
advanced LIGO
narrow band envelope
amplitude density strain/sqrt(Hz)
10^{-21}
10^{-22}
10^{-23}
10^{1}
10^{2}
10^{3}
frequency Hz



DATA: Cosmology of the Local Group G.Lake
Astrophysical Quantities C.W. Allen

Longer term improvements

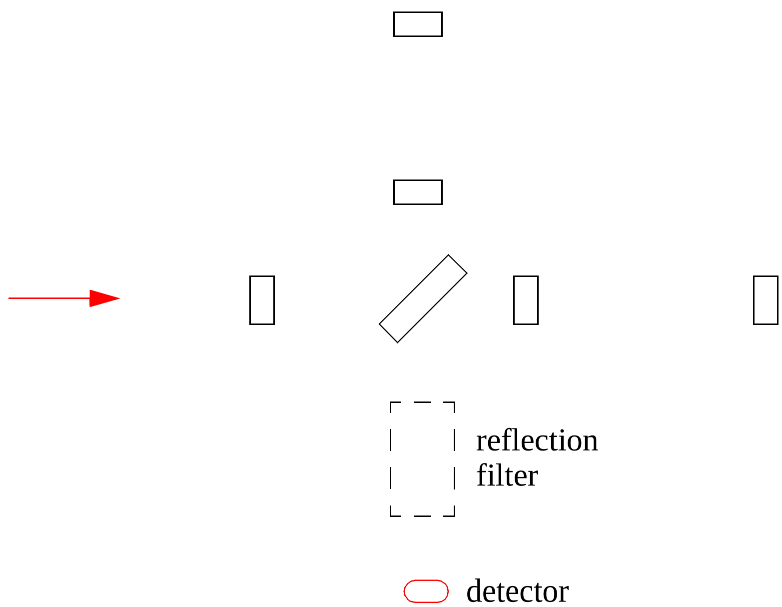
- *7/11* S. Miyoki *CLIO Cryogenic Laser Interferometer*
- *7/11* A. Giazotto *Cryogenic Interferometers*
- *7/11* K. McKenzie *Squeezing in GW detector*

THINGS TO THINK ABOUT

DETECTORS:

Matched detection filters

- Time domain optimization: NS/NS binaries - vary amplitude recycling mirror position to follow spectrum
- Frequency domain optimization with multiple cavities and/or time delay at antisymmetric port



Detector output
S(f) = N(f) + M(f)

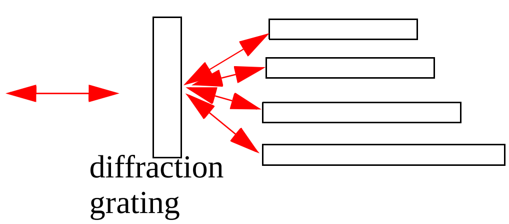
Detector filter function
T(f)

Source model
M(f)

Least square minimization of difference detector output - model

T(f) = M(f)/(N(f) + M(f))

example reflection filter: diffraction grating with multiple cavities



DATA ANALYSIS

- Work on the gravitational waveform inverse problem

determine the dynamics at the source from the waveform