米国の重力波検出器の現状と将来計画

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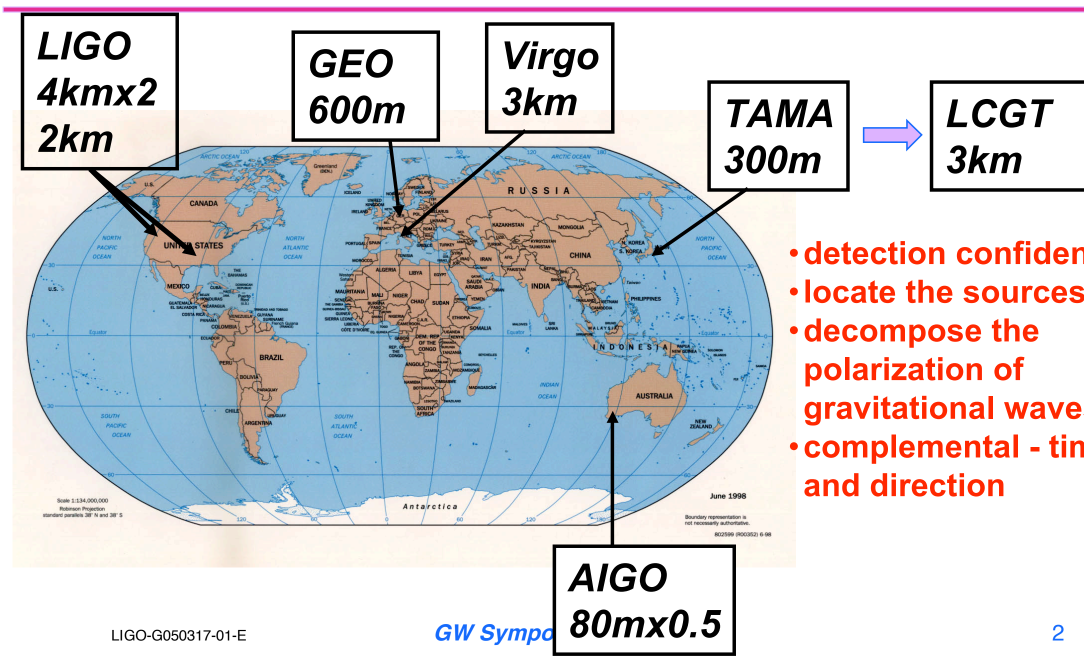
- Laser Interferometer Gravitational Wave Observatory
  レーザー干渉計を使った重力波天文台
  - 絵によるLIGO紹介
- LIGO 20年の歴史
  - 駆け足で見るLIGOの進歩
  - 現在及び将来計画
  - 干渉計及びデーターの共同開発、研究体制
- LIGOの現状
  - 設計感度達成への挑戦
  - 分かっている事、分からない事
- 将来計画　：　Advanced LIGO
  - 新しい技術による更なる挑戦

An International Network of Interferometers



- detection confidence
- locate the sources
- decompose the polarization of gravitational waves
- complemental - time and direction

LIGO

The LIG

Interferometers are alig

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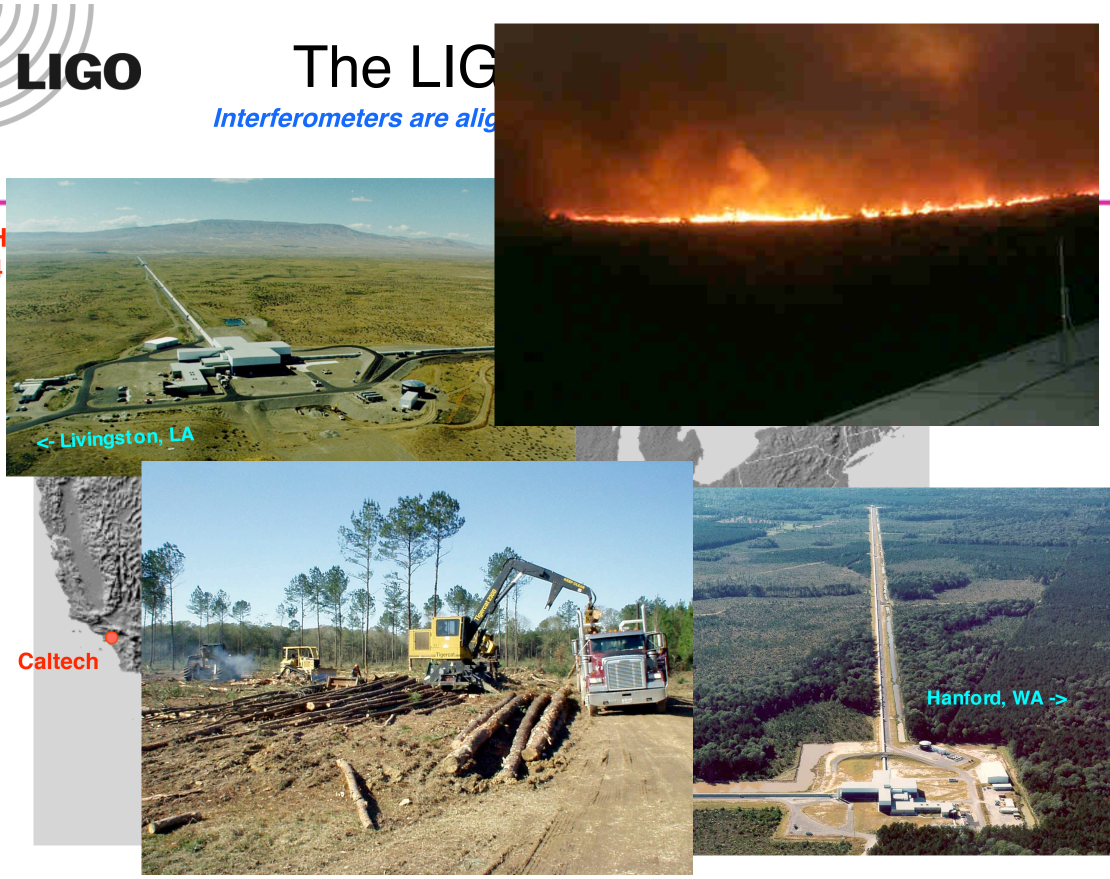


LIGO

LIGO Tour

LIGO Beam Tube

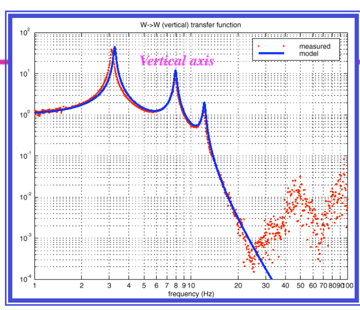
1.2 m diameter - 3mm stainless
50 km of weld

NO LEAKS !!

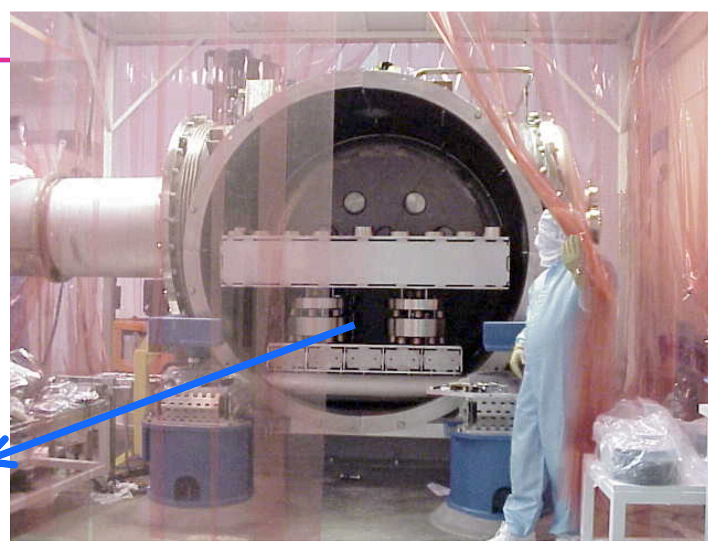
- LIGO beam tube under construction in January 1998
- 65 ft spiral welded sections
- Girth welded in portable clean room
- In situ 160 C bake
- 20,000 m^3 10^{-8} to 10^{-9} torr

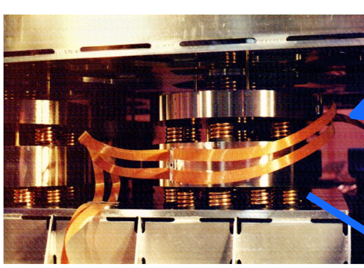
LIGO Vacuum Equipment

Seismic Isolation System



Isolation Performance





Tubular coil springs with internal damping, layered between steel reaction masses

Core Optics

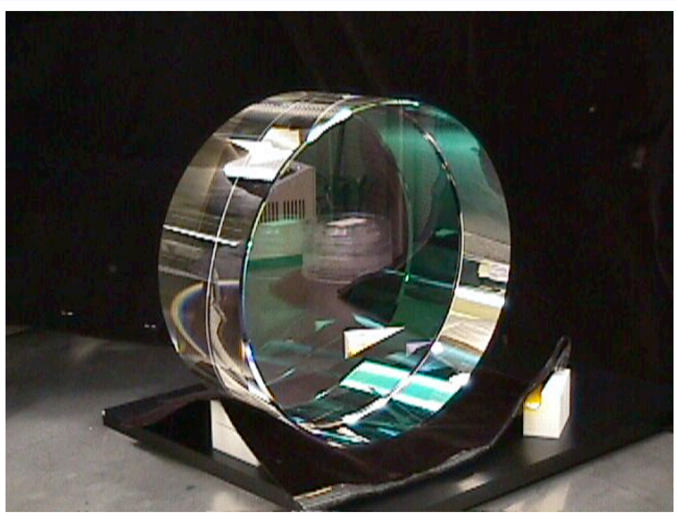
installation and alignment

A LIGO Mirror

Substrates: SiO_2
25 cm Diameter, 10 cm thick
Homogeneity < 5 x 10^{-7}
Internal mode Q's > 2 x 10^{6}

Polishing
Surface uniformity < 1 nm rms
Radii of curvature matched < 3%

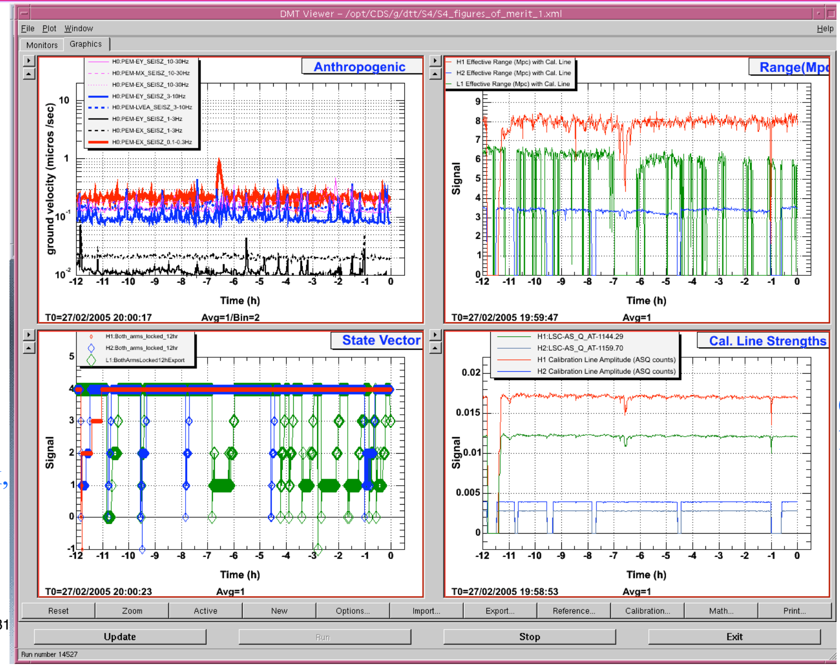
Coating
Scatter < 50 ppm
Absorption < 0.5 ppm
Uniformity <10^{-3}



- ***Best mirrors are λ/6000 over the central 8 cm diameter***

Monitoring interferometer status

Environment monitor (wind,seismic, temperatur,etc)

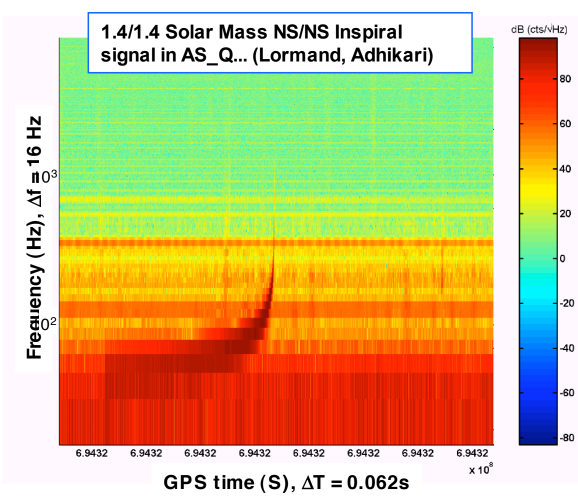


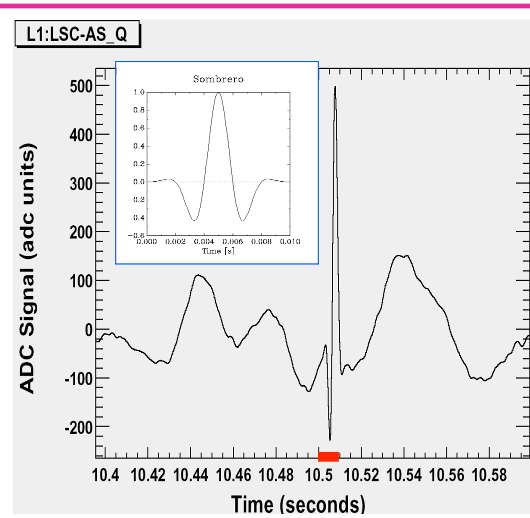
NS-NS range in Mpc

State : unlocked, Michelson lock, full lock, data taking

Calibration line

How does the signal look like

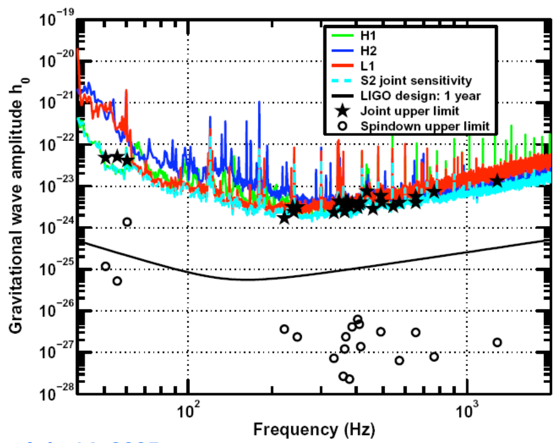




LIGO

Results from the 1st/2nd Science Run

- Binary inspirals (S2):
  - » Neutron star binary coalescence: range up to 1.5 Mpc, rate ≤ 47/y/MW (90% CL)
  - » Black hole coalescence (0.2-1$M_{\odot}$) in Galactic halo: rate ≤ 63/y/MW (90% CL)
- Pulsars (S2):
  - » Limits on 28 pulsars
  - » Upper limits on h as low as 2×10^{-24} (95% CL) and as low as 5×10^{-6} on the eccentricity
- Stochastic background (S1):
  - » Energy limit as fraction of closure density: $h^2_{100}\Omega_0 \leq 23 \pm 4.6$ (90% CL)
  - » **PRELIMINARY** S2: $h^2_{100}\Omega_0 \leq 0.018$ +0.007-0.003 (90% CL)
- Burst (S2):
  - » Sensitivity: $h_{rss} \sim 10^{-20}$ - 10^{-19} /√ Hz, rate ≤ 0.26/day (90% CL)
  - » GRB030329: $h_{rss} \leq 6\times10^{-21}$ /√ Hz



LIGO-GEO directed pulsar search

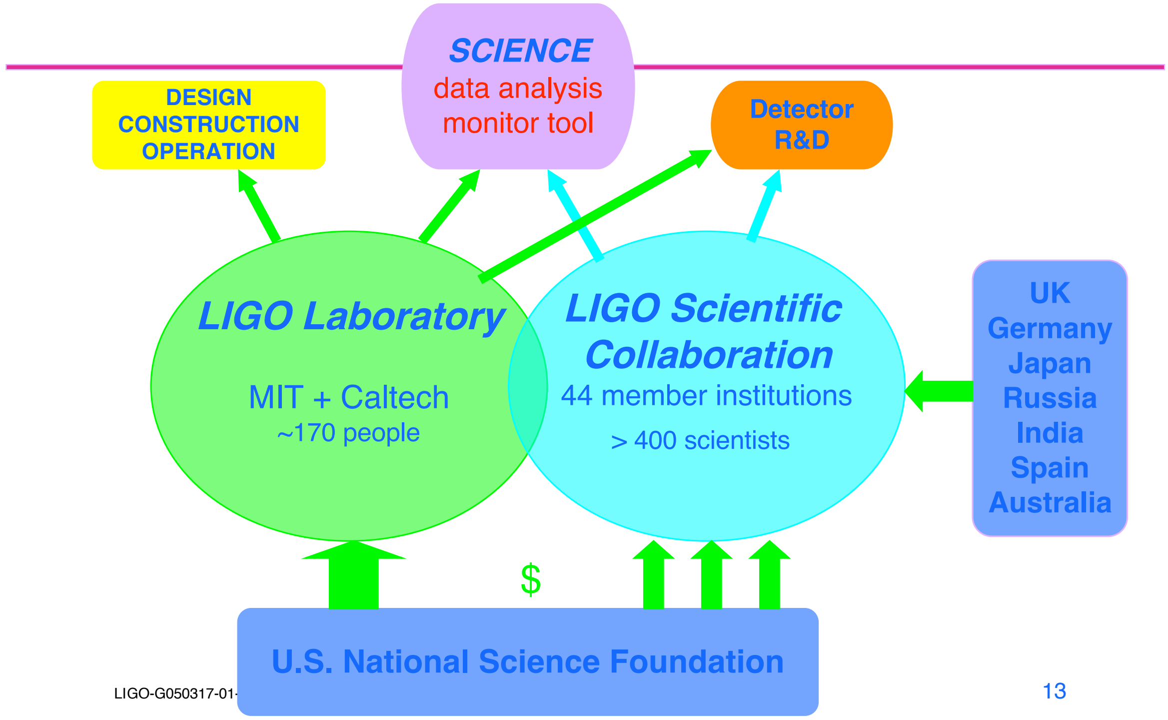
LIGO

20 years history of LIGO

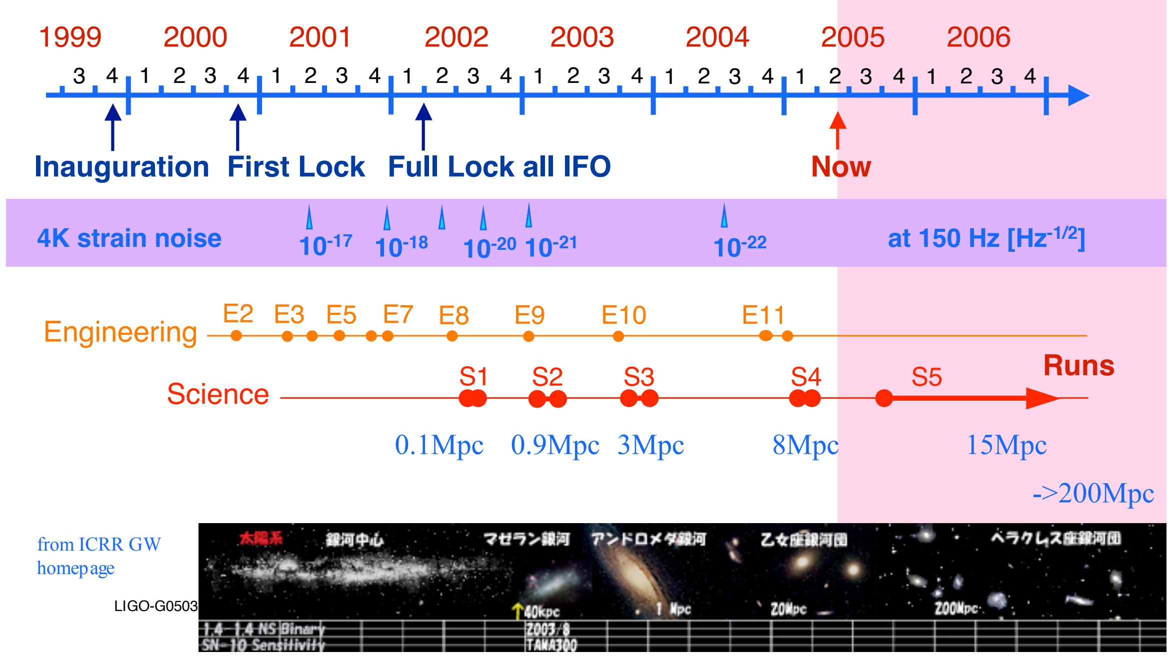
- 1989 - First proposal submitted (210 M$)
- 1994 - NSF approves revised plan (360 M$)
- 1999 - Construction completed
- - commissioning of subsystems and entire interferometers
- - 2002-2006 - LIGO operation extension approved
  - » 33 M$ / year for operation and R&D
- 2002 August - first science data
- 2003 - Advanced LIGO proposal submitted
- 2004 - NSB approved Advanced LIGO proposal
  - » FY2006 request to US Congress : 184 M$ for construction and 195 M$ for operation until FY2014

- 2005 winter - start of a long science run (S5)
  - » 3 interferometers at the design sensitivity to collect 1 year of data
- 2008 - Advanced LIGO funding starts
  - » 195M$ for operation and maintenance between 2008~2014
- - possible mini upgrade discussed
- 2010~2011 - LIGO interferometers stop operation for upgrade
- 2013 - Advanced LIGO operation starts

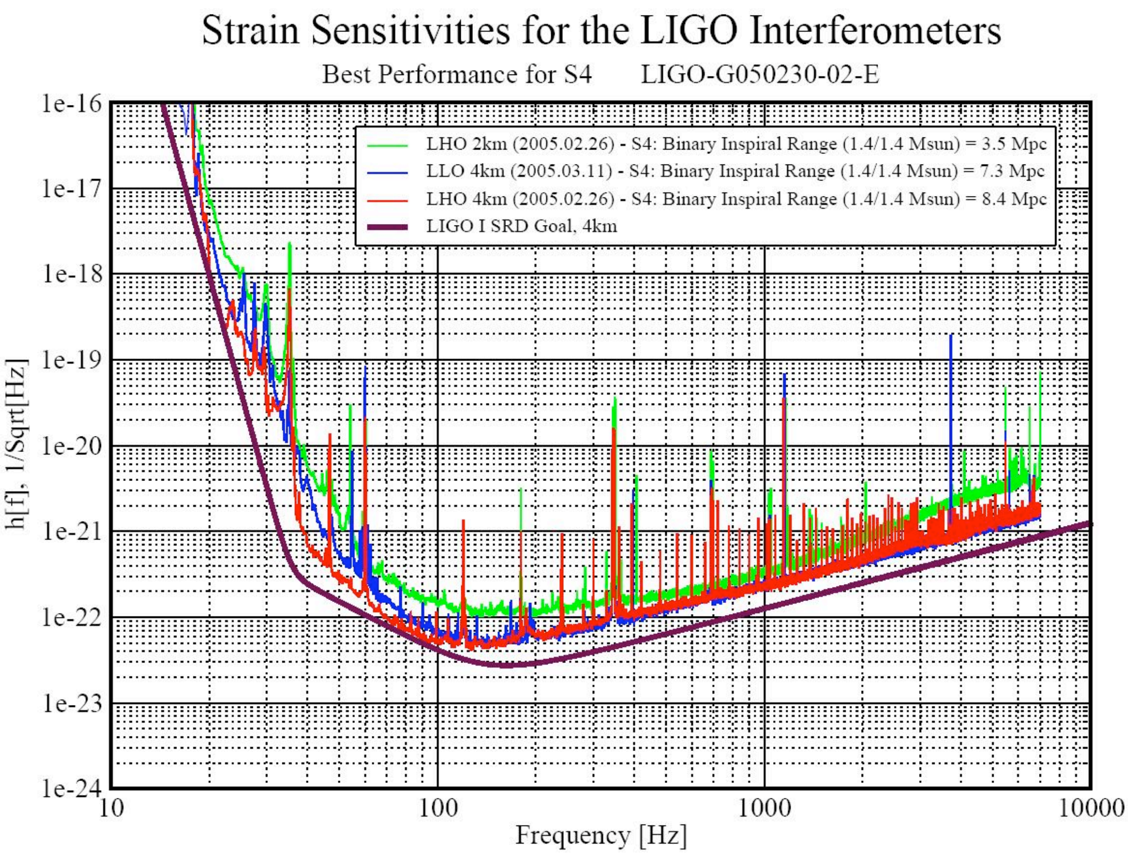
LIGO Organization & Support

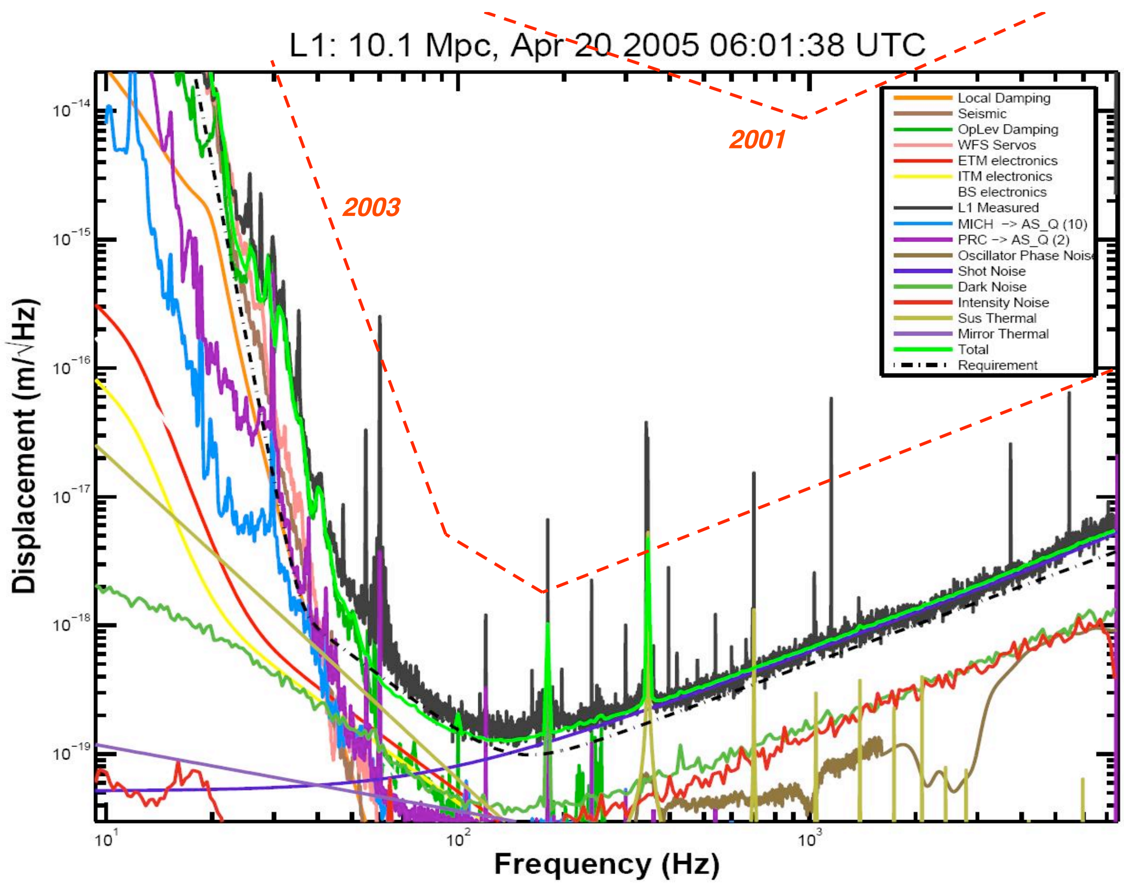


Time Line

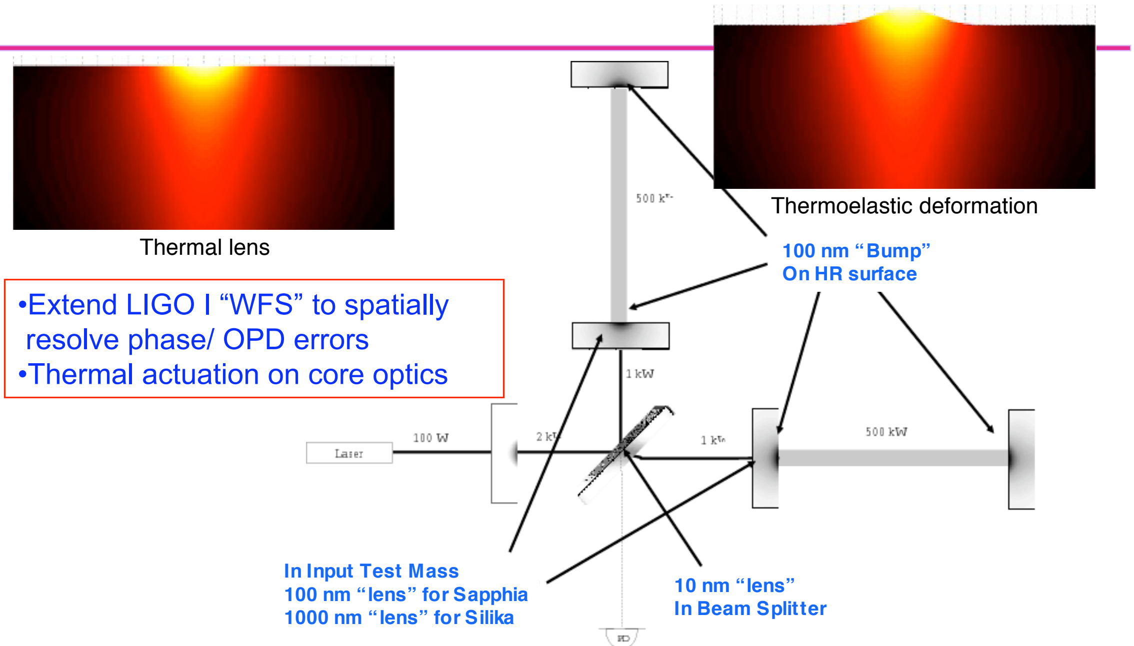


from ICRR GW homepage


Strain Sensitivities for the LIGO Interferometers
Best Performance for S4 LIGO-G050230-02-E
LHO 2km (2005.02.26) - S4: Binary Inspiral Range (1.4/1.4 Msun) = 3.5 Mpc
LLO 4km (2005.03.11) - S4: Binary Inspiral Range (1.4/1.4 Msun) = 7.3 Mpc
LHO 4km (2005.02.26) - S4: Binary Inspiral Range (1.4/1.4 Msun) = 8.4 Mpc
LIGO I SRD Goal, 4km
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]

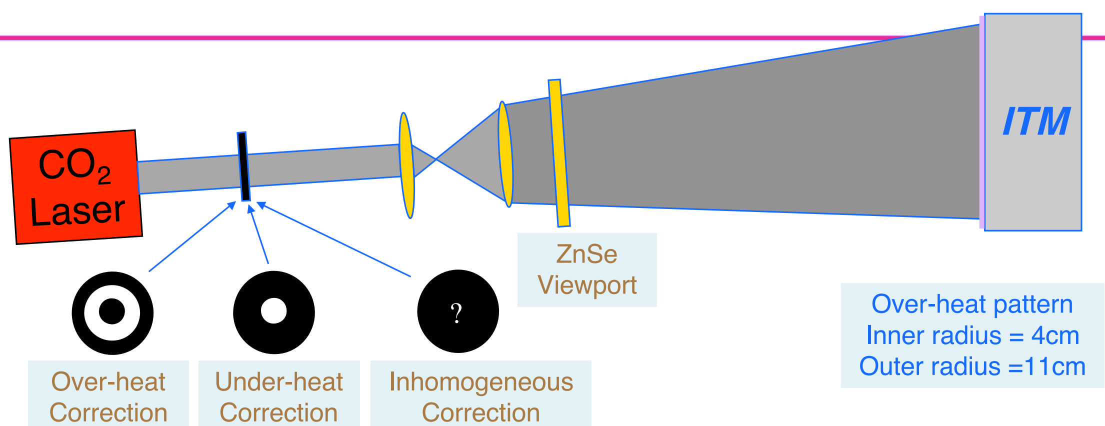

L1: 10.1 Mpc, Apr 20 2005 06:01:38 UTC
2001
2003
Local Damping
Seismic
OpLev Damping
WFS Servos
ETM electronics
ITM electronics
BS electronics
L1 Measured
MICH -> AS_Q (10)
PRC -> AS_Q (2)
Oscillator Phase Noise
Shot Noise
Dark Noise
Intensity Noise
Sus Thermal
Mirror Thermal
Total
Requirement
Displacement (m/√Hz)
Frequency (Hz)

Thermal lensing effect



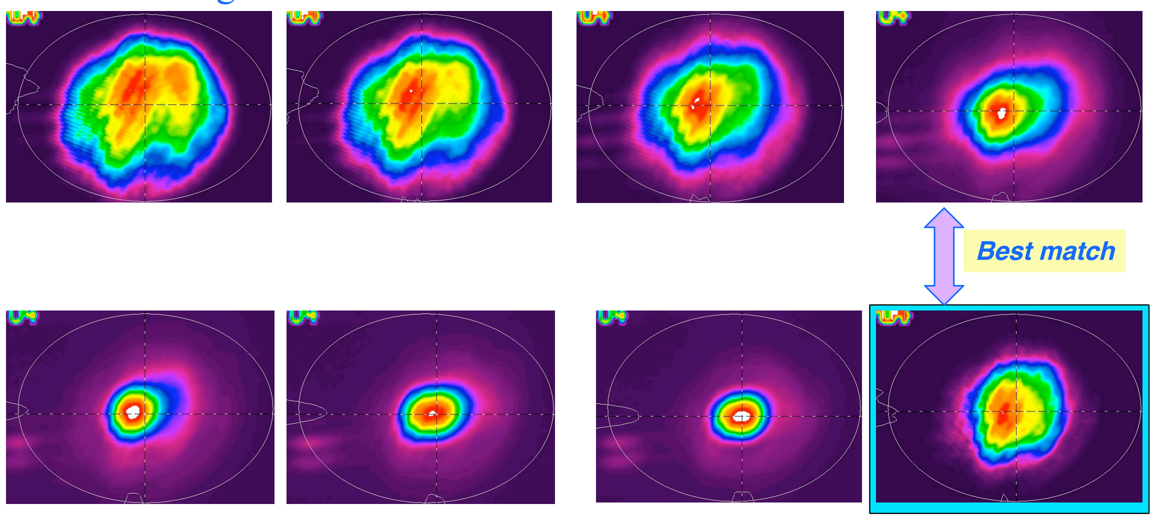
- Extend LIGO I “WFS” to spatially resolve phase/ OPD errors
- Thermal actuation on core optics

Thermal Compensation System

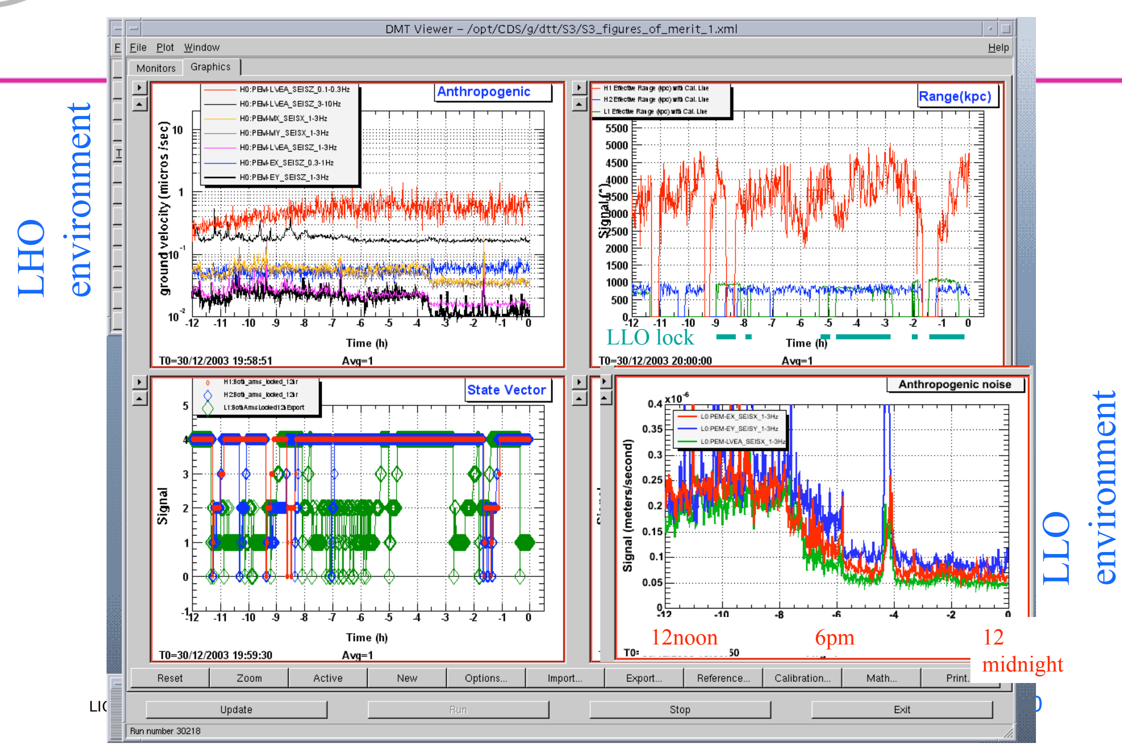


- Cold power recycling cavity is unstable: poor buildup and mode shape for the RF sidebands
- Require 10’s of mW absorbed by 1μm beam

Sideband beam images at the dark port



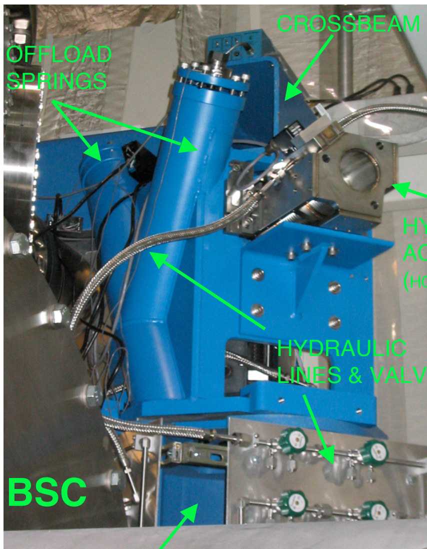
Bad duty cycle of LLO4k

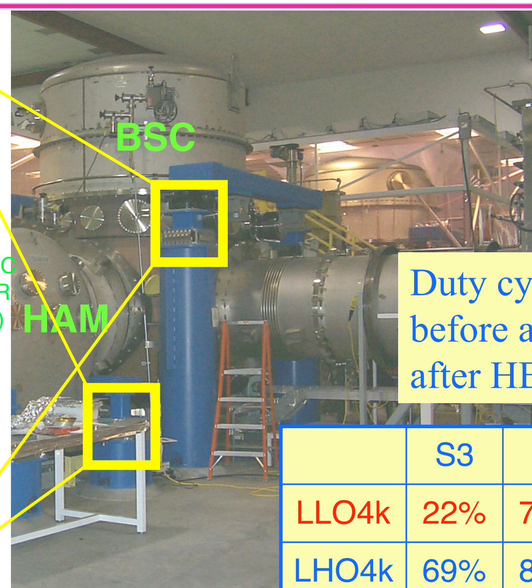


LIGO

Active Seismic Isolation

Hydraulic External Pre-Isolator (HEPI)



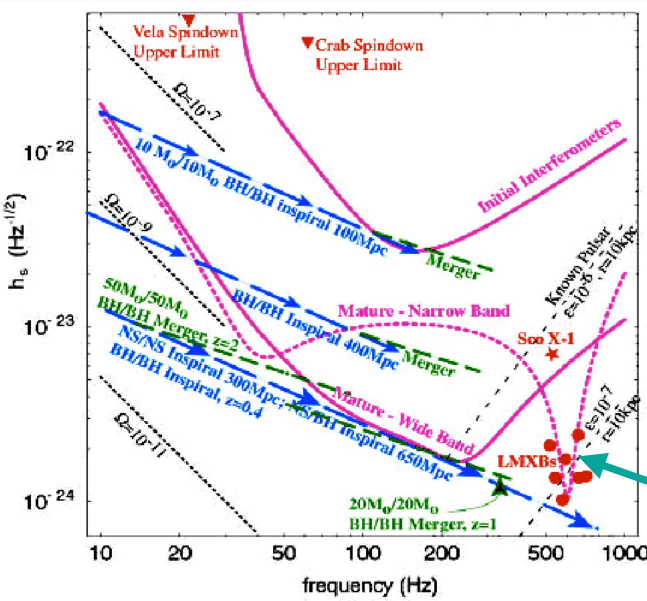


Duty cycle before and after HEPI

	S3	S4
LLO4k	22%	75%
LHO4k	69%	80%
LHO2k	63%	81%

LIGO

Advanced LIGO



Enhanced Systems

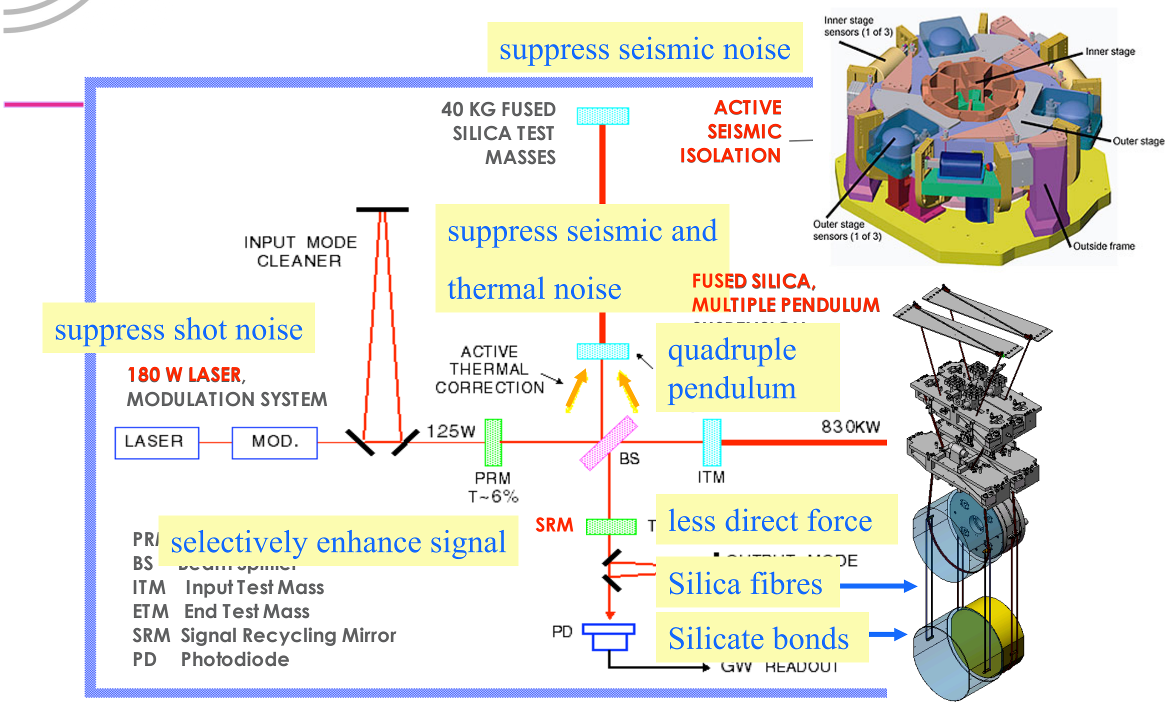
- suspension
- laser
- seismic isolation
- test mass

Rate Improvement ~ 10^4

+

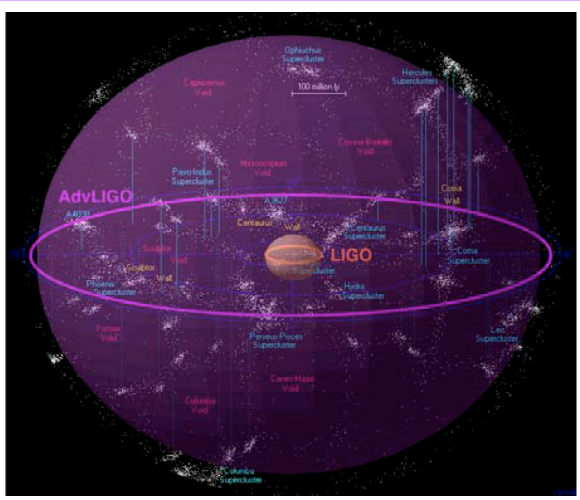
narrow band optical configuration

Advanced LIGO Design Features



Advanced LIGO

10000 times more possibility



Sky map showing locations of superclusters, walls, and voids of galaxies within about 500 million light years. Superimposed circles show the range of LIGO (orange inner circle) and the 10 times larger range of AdvLIGO (purple outer circle). The milky way is at the center in this representation. *Credit: the underlying black and white image with names of clusters and voids is by Richard Powell; the superimposed color circles were added by Beverly Berger, Division of Physics, NSF.*