LIGO
Laser Interferometer Gravitational Wave Observatory

Status of LIGO and what the future holds

Toward joint EM/GW observations

Transient Universe 2006

Kavli Institute for Theoretical Physics
Santa Barbara, CA, March 14, 2006

For the LIGO Scientific Collaboration

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G060045-00-I

Effect of Gravitational Waves

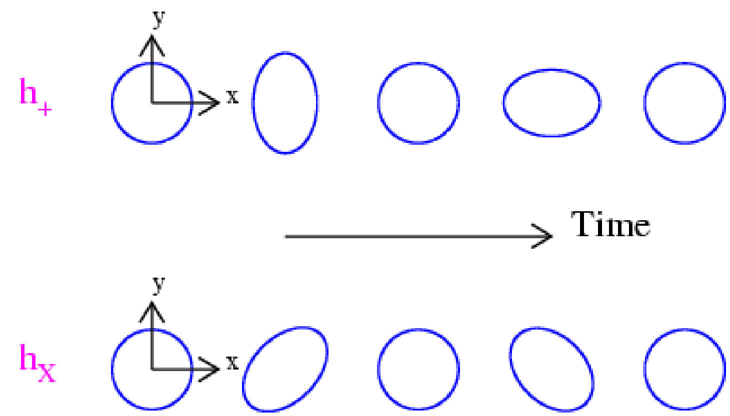
- Two transverse polarizations - quadrupolar: + and x

Example:

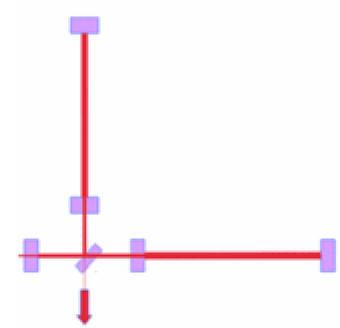
Ring of test masses

responding to wave

propagating along z



Amplitude parameterized by dimensionless strain h: DL = h(t) / 2 x L



The LIGO Observatories

Interferometers are aligned along the great circle connecting the sites

GEODETIC DATA (WGS84)

h: -6.574 m — *X arm: S72.2836°W*

f: N30°33'46.419531" — *Y arm: S17.7164°E*

l: W90°46'27.265294"

Livingston Observatory
Louisiana
One interferometer (4km)

Hanford Observatory
Washington
Two interferometers
(4 km and 2 km arms)

GEODETIC DATA (WGS84)

h: 142.555 m — *X arm: N35.9993°W*

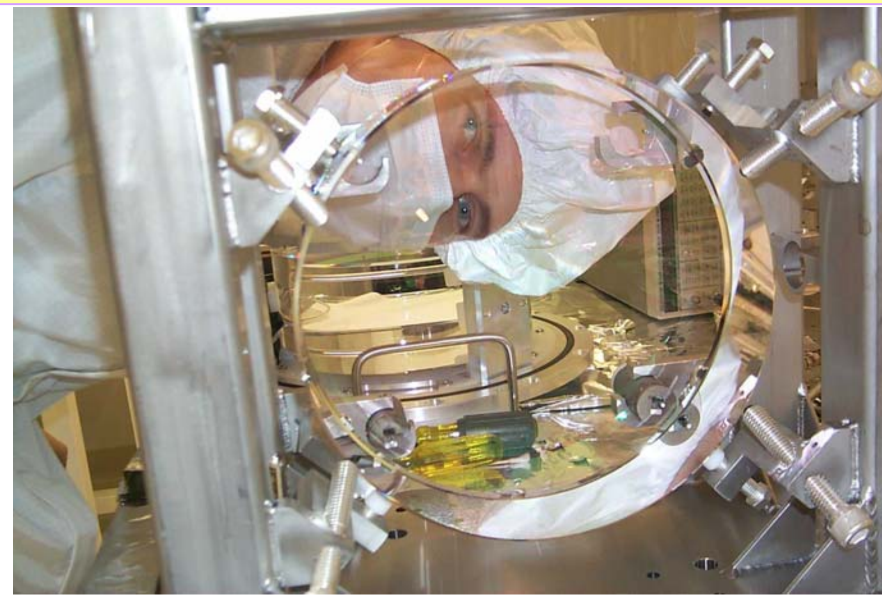
f: N46°27'18.527841" — *Y arm: S54.0007°W*

l: W119°24'27.565681"

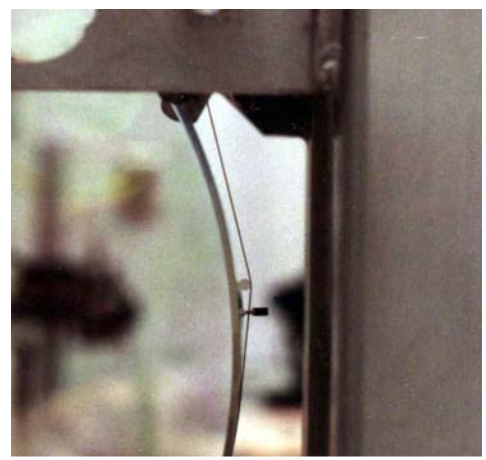
Adapted from "The Blue Marble: Land Surface, Ocean Colo…
NASA Goddard Space Flight Center Image by Reto Stöckli…
Simmon (ocean color, compositing, 3D globes, animation). Da…
Support Team; MODIS Atmosphere Group; MODIS Ocean Gr…
Terrestrial Remote Sensing Flagstaff Field Center (Antarctica); Defense Meteorological Satellite Program (city lights).

Vacuum "Envelope"

Optic Suspension



- Magnets and coils control position and angle of mirrors
- Suspension provides $1/f^2$ attenuation above the pendulum resonance ~0.75 Hz.
- Suspension is critical to controlling thermal noise.



LIGO Optics

Substrates: SiO_2

25 cm Diameter, 10 cm thick

Homogeneity < 5 x 10^{-7}

Internal mode Q's > 2 x 10^{6}

Polishing

Accuracy < 1 nm

Micro-roughness < 0.1 nm

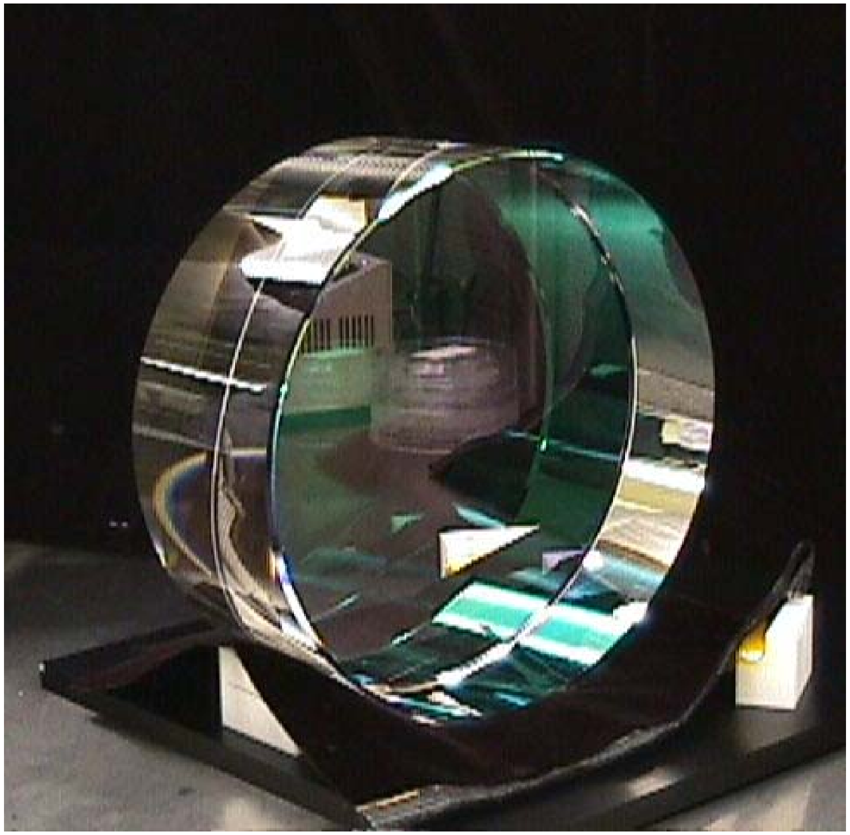
Radii of curvature matched < 3%

Coating

Scatter < 50 ppm

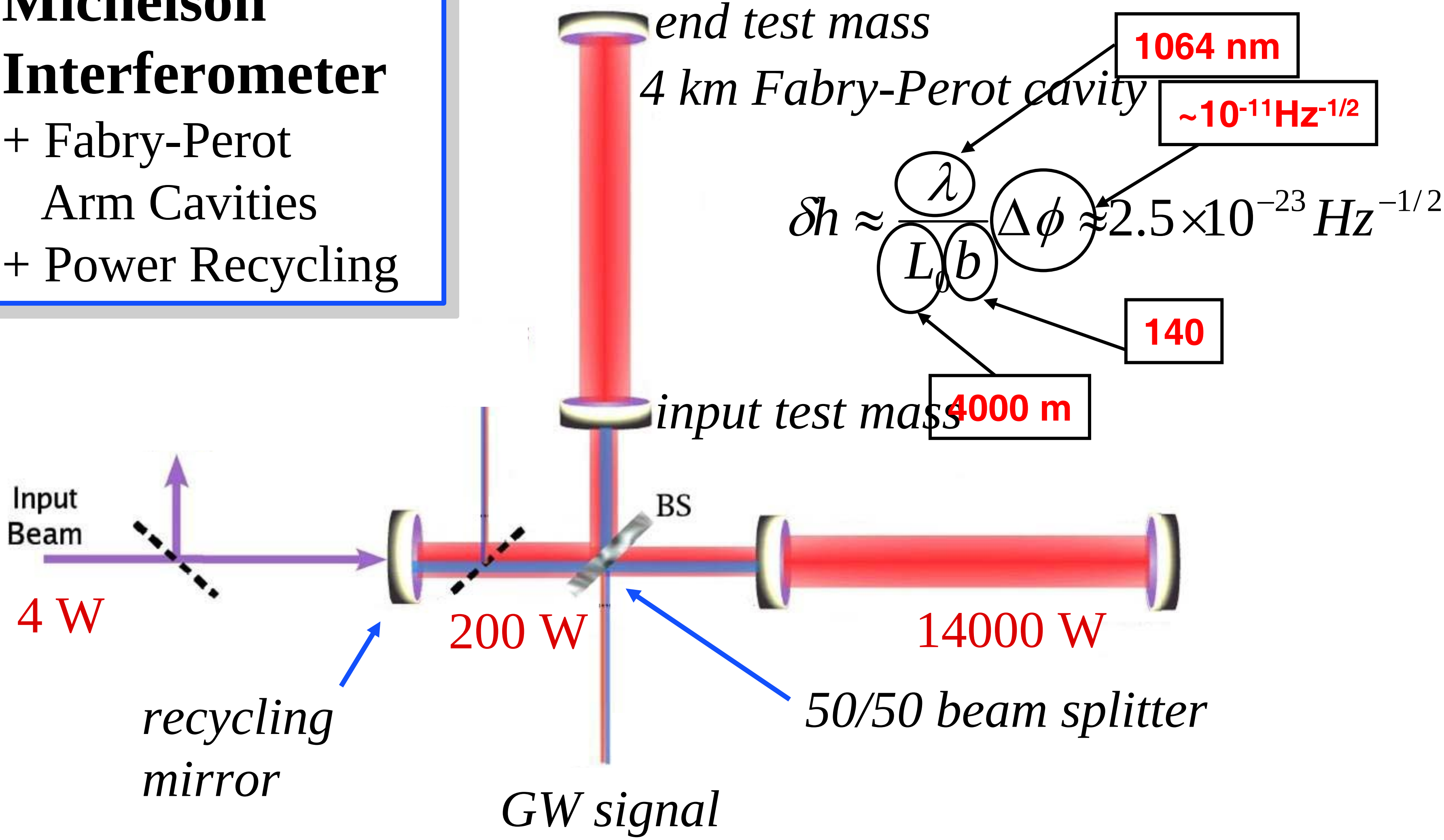
Absorption < 0.5 ppm

Uniformity <10^{-3} (~1 atom/layer)



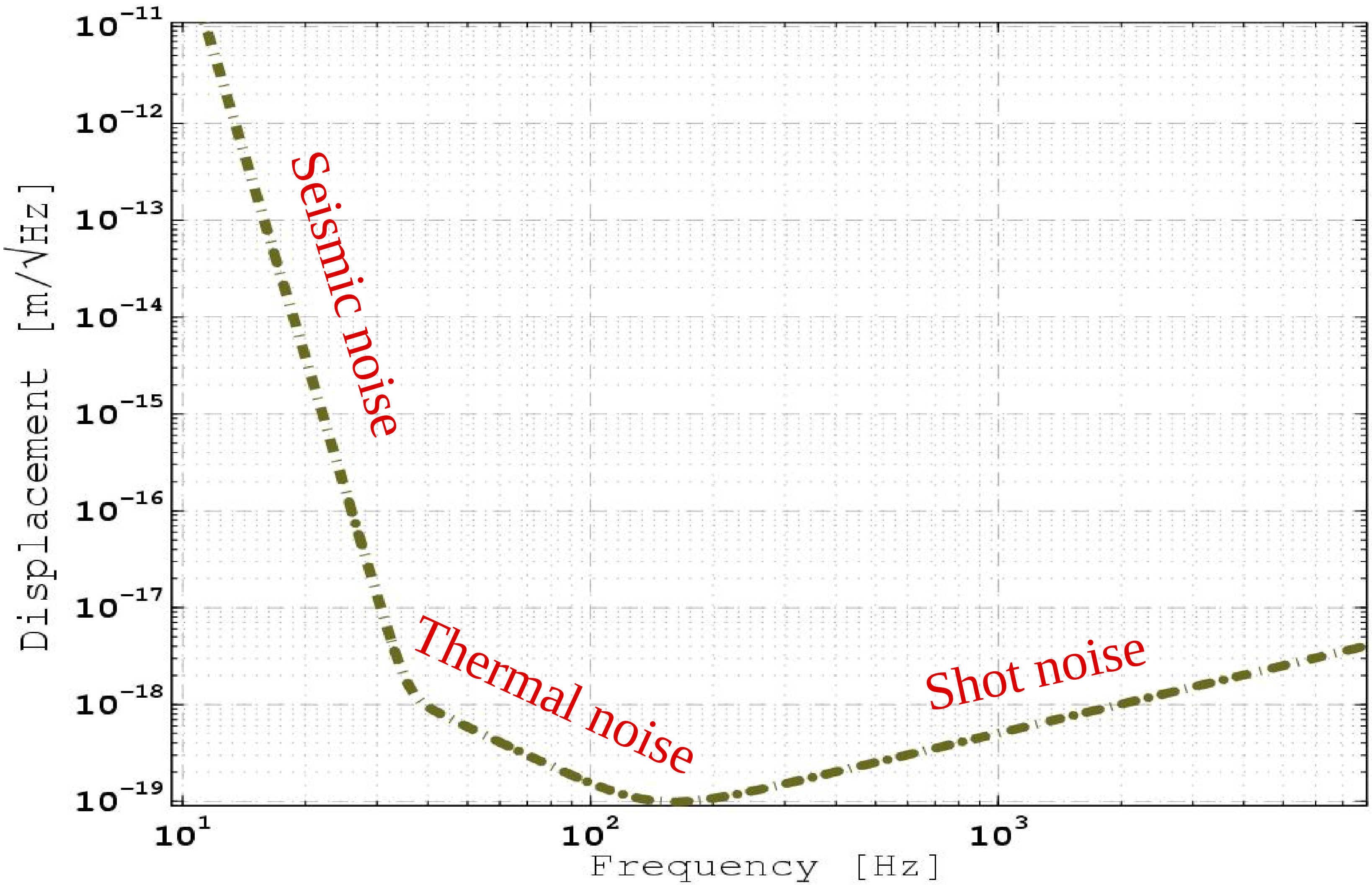
LIGO Interferometers

Michelson Interferometer
+ Fabry-Perot Arm Cavities
+ Power Recycling

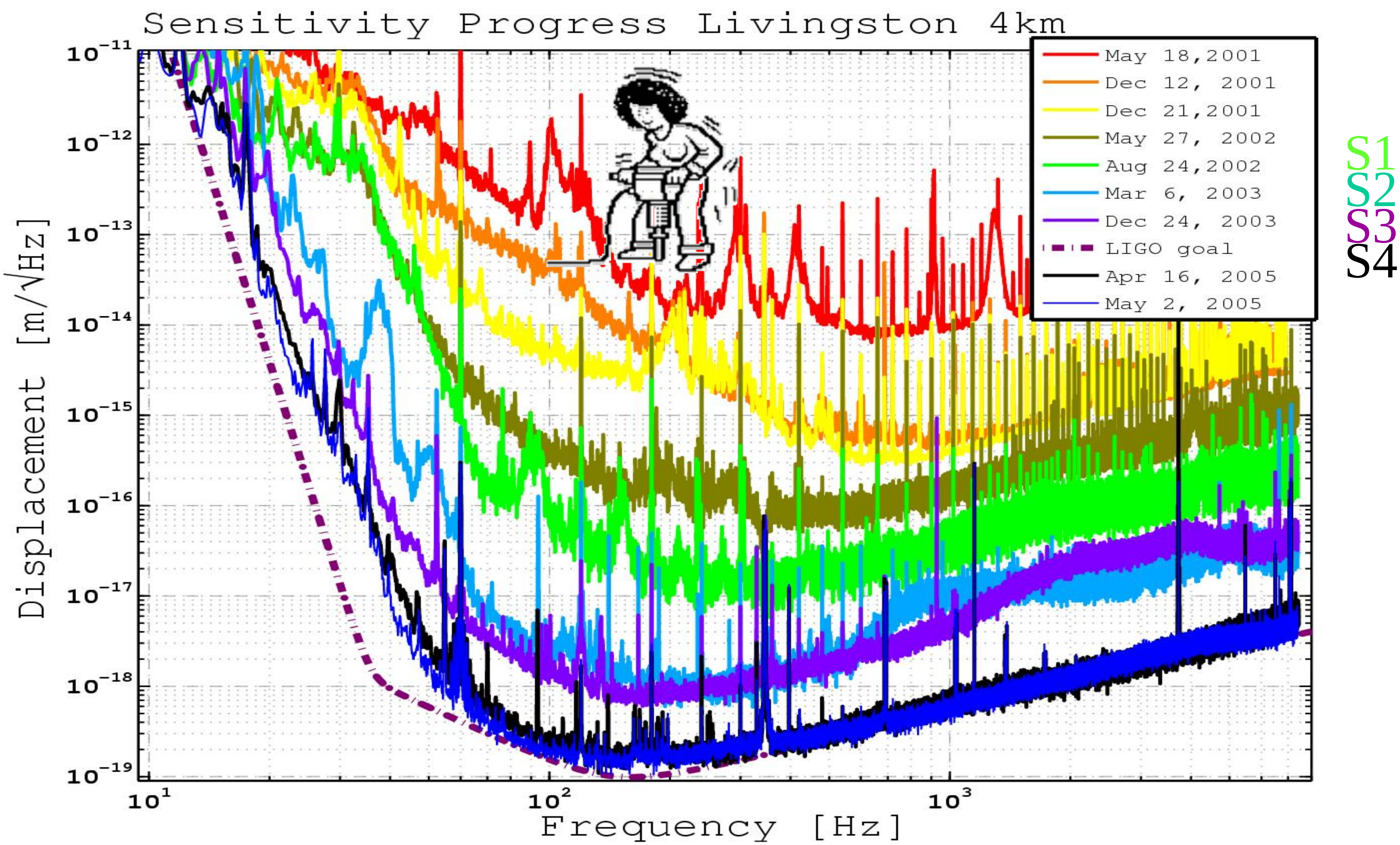


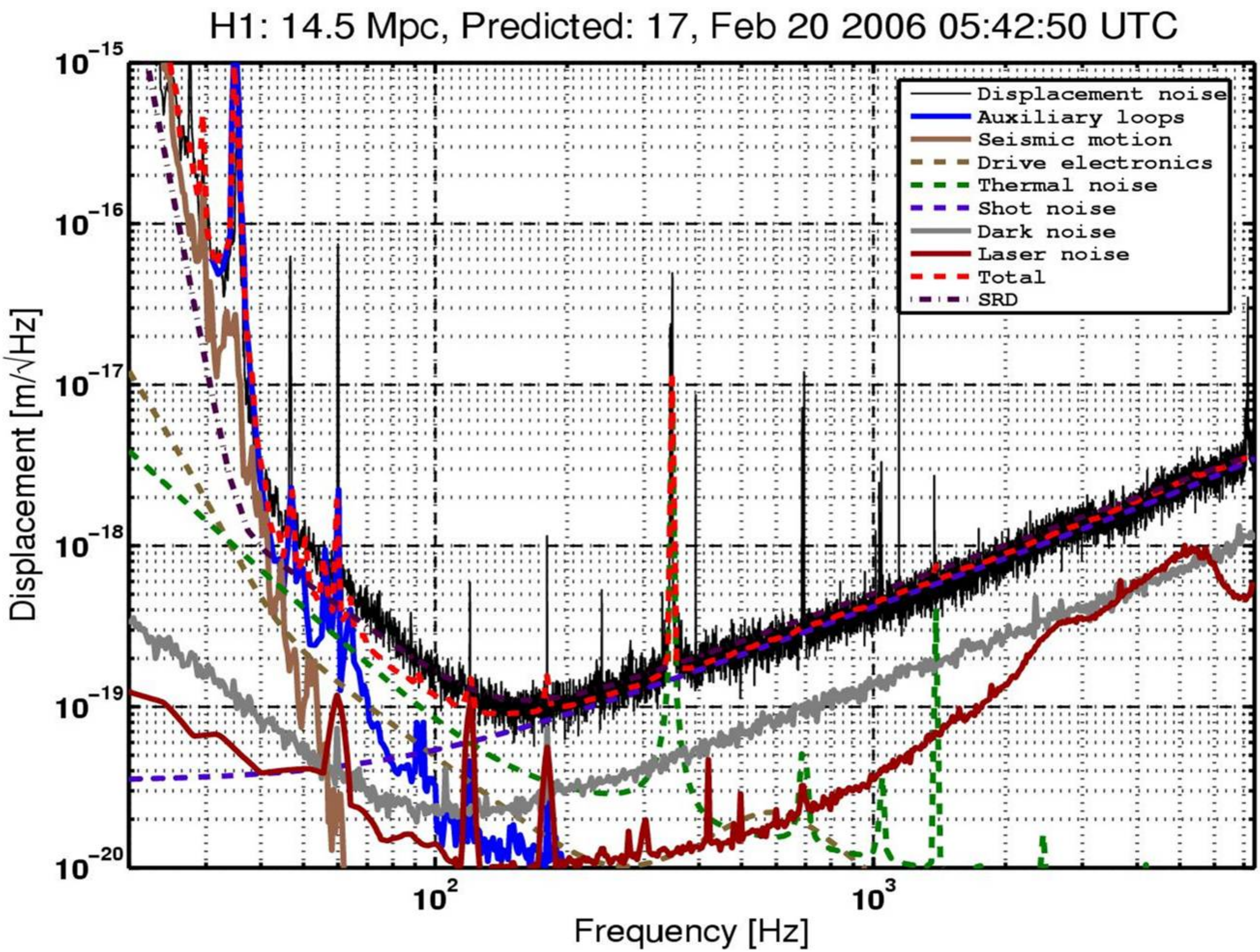
$$\delta h \approx \frac{\lambda}{L_0 b} \Delta\phi \approx 2.5\times 10^{-23}\, Hz^{-1/2}$$

Design sensitivity



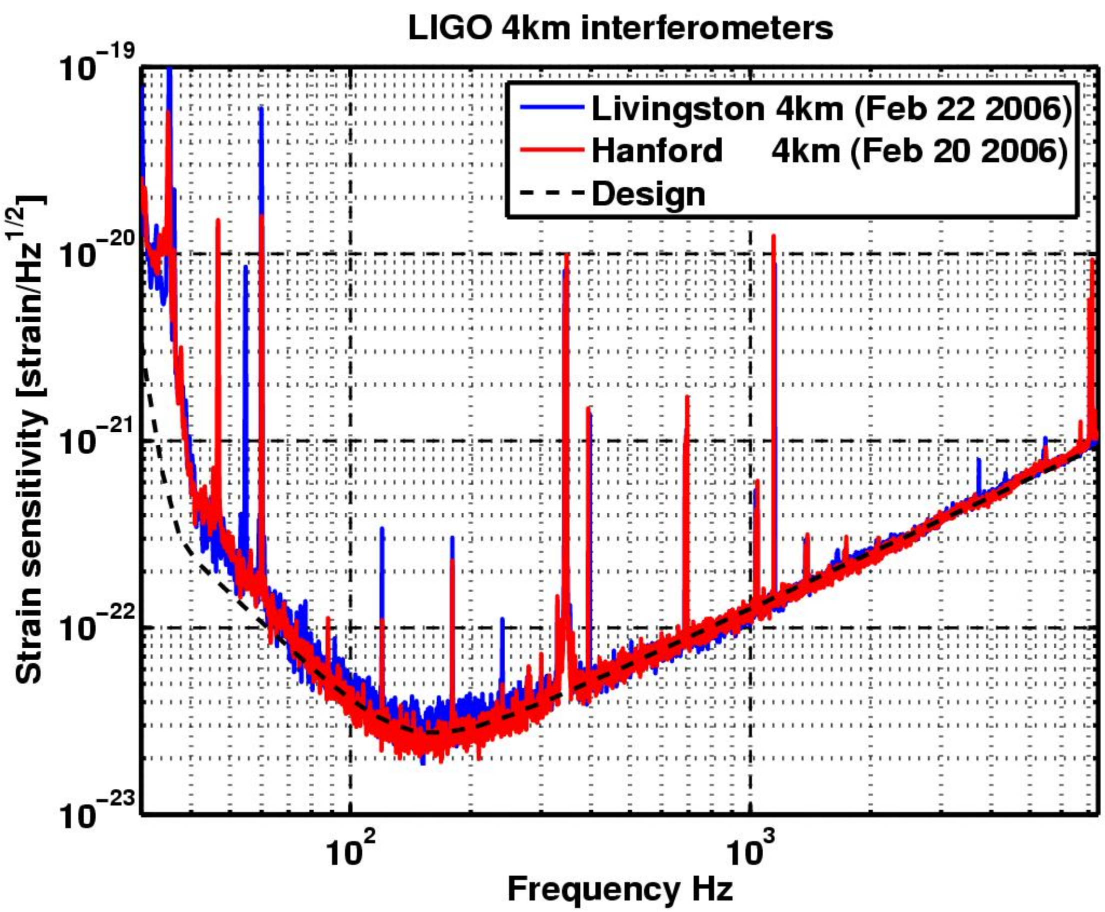
Noise Progression Livingston 4km



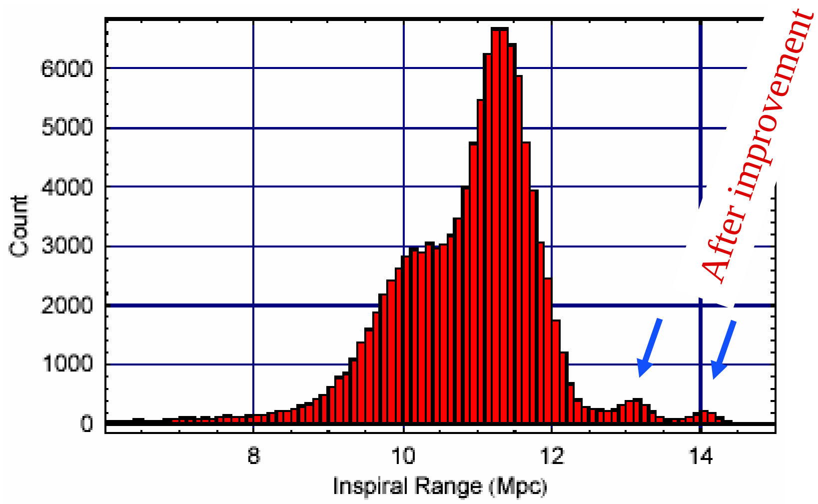

H1: 14.5 Mpc, Predicted: 17, Feb 20 2006 05:42:50 UTC
Displacement [m/√Hz]
Frequency [Hz]
10^-15
10^-16
10^-17
10^-18
10^-19
10^-20
10^2
10^3
Displacement noise
Auxiliary loops
Seismic motion
Drive electronics
Thermal noise
Shot noise
Dark noise
Laser noise
Total
SRD

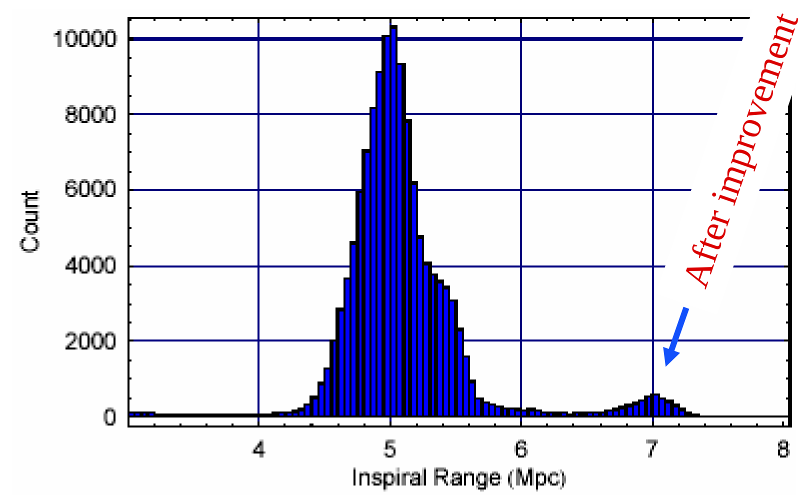
Current performance (S5) Sensitivity

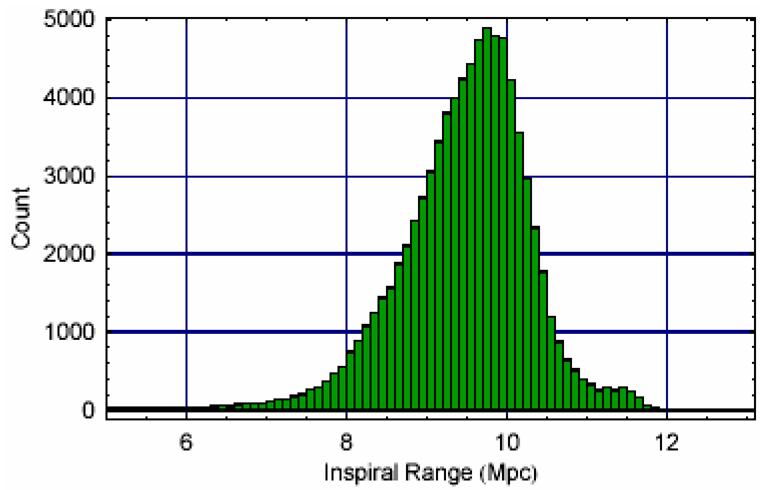
- All 3 interferometers at design sensitivity
- Benchmark number: Binary Inspiral Range
  - Sky-averaged distance to which a NS/NS ($1.4M_{sun}$) binary insprial can be seen with SNR>=8
  - Up to 14.5 Mpc reached
- In S5 science run since Nov 2005

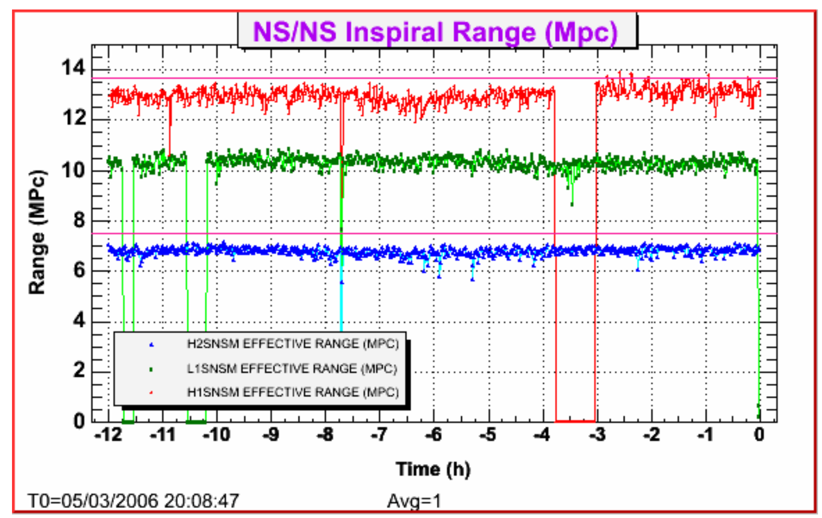


Current performance (S5) Range Histograms







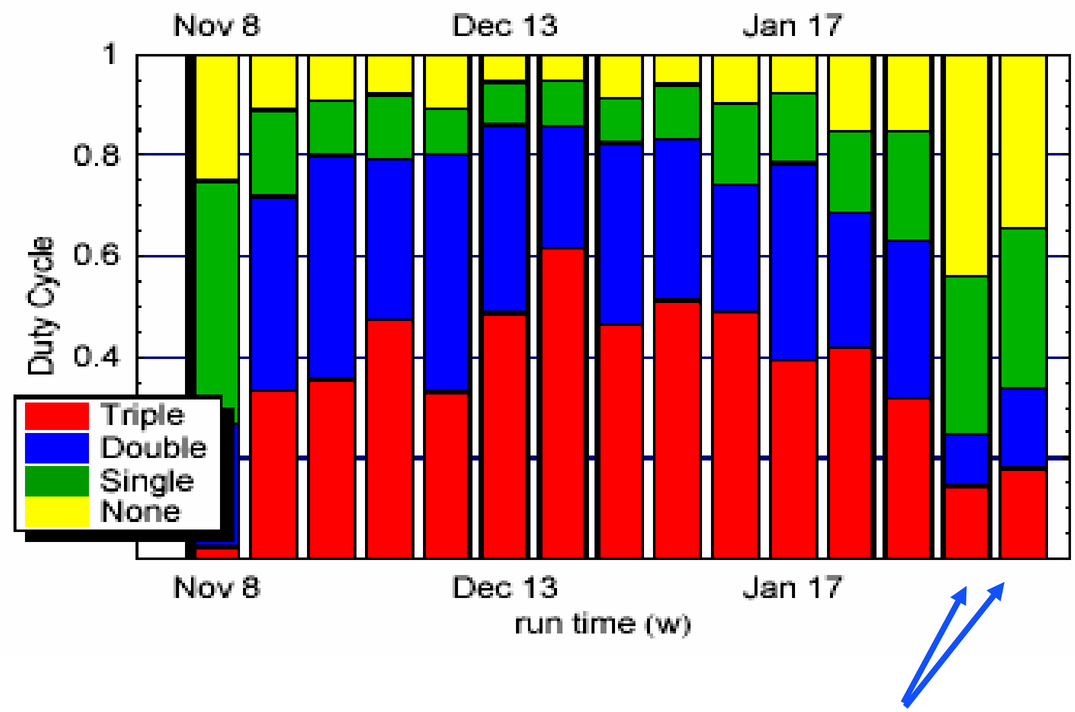


Current performance (S5) Duty cycle

- 62% Hanford 4km
- 72% Hanford 2km
- 55% Livingston 4km

- Include 2 week commissioning break

- Currently the biggest problem !
- Was better during last science run (S4)…



2 week commissioning break at Hanford

The near term future

- S5 science run ongoing
  - Goal: 1 year of data at design sensitivity
  - Short commissioning breaks may be scheduled
    - Duty cycle and moderate sensitivity improvements expected
- Current interferometers can do better
  - Design sensitivity is not a fundamental limit
  - Increase circulating power
    → doubling sensitivity possible (x8 in event rate)
    - Requires: new Laser, in-vacuum output mode cleaner
    - Tentative plans to do this after S5
- Advanced LIGO installation scheduled after 2010

Advanced vs Initial LIGO

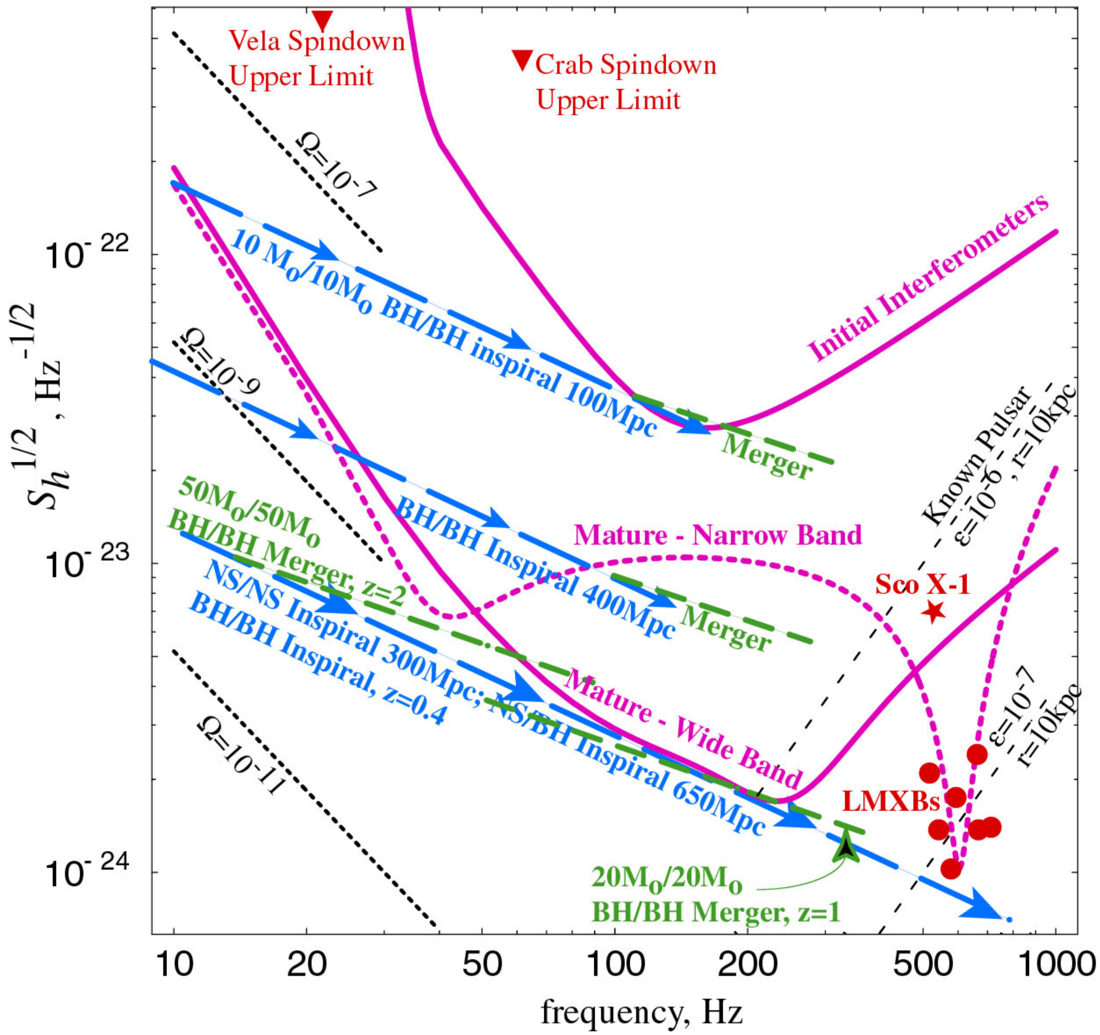
x10 better amplitude sensitivity

x1000 rate=(reach)^3

x4 lower frequency bound from 40Hz to 10Hz

x100 better narrow-band at high frequencies

- **NS-NS Binaries:**
  ~20 Mpc → ~350 Mpc
- **BH-BH Binaries:**
  10 M_o, 100 Mpc → 50 M_o, z=2
- **Known Pulsars:**
  e = 3×10^{-6} → e = 2×10^{-8}
- **Stochastic background:**
  $\Omega \sim 3 \times 10^{-6}$ → $\Omega \sim 3 \times 10^{-9}$



Why should you care about LIGO?

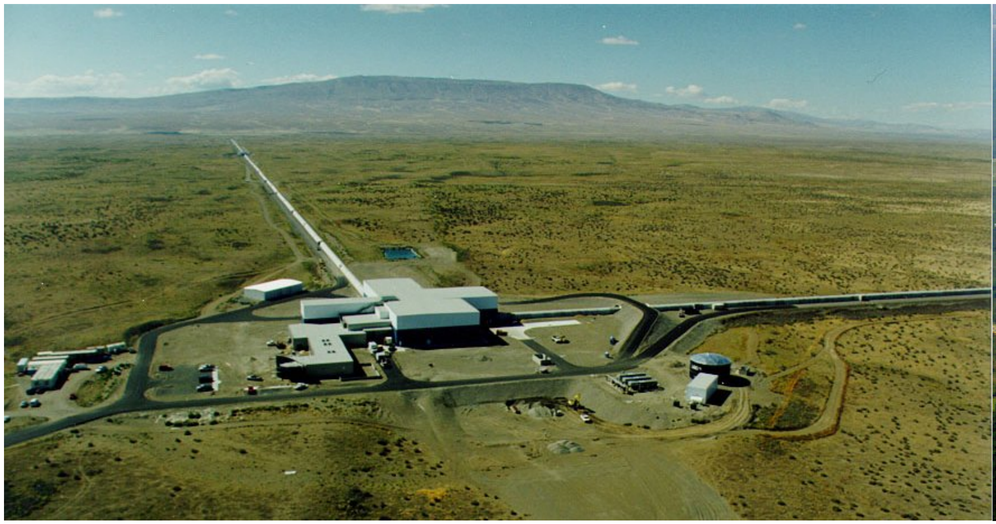
- GW so far have not been directly measured
  - But chances are significant in the current science run

    "Brits bet on gravity wave discovery before 2010 !"
    Betting firm had to shorten the odds…

  - Most likely sources are binary NS inspirals
  - Recent SWIFT and HETE suggest that these are also related to short GRBs
    ➔ Were chasing the same objects!

- EM / GW coincidence is scientifically interesting
  - GW probe directly the engine of the explosion but no good source localization
  - EM / GW coincidence will increase confidence in first detection

The End?



The Beginning...