LIGO

Laser Interferometer Gravitational-wave Observatory

MEMS AG, October 2008
Daniel Sigg, LIGO Hanford Observatory

G080573-00-D

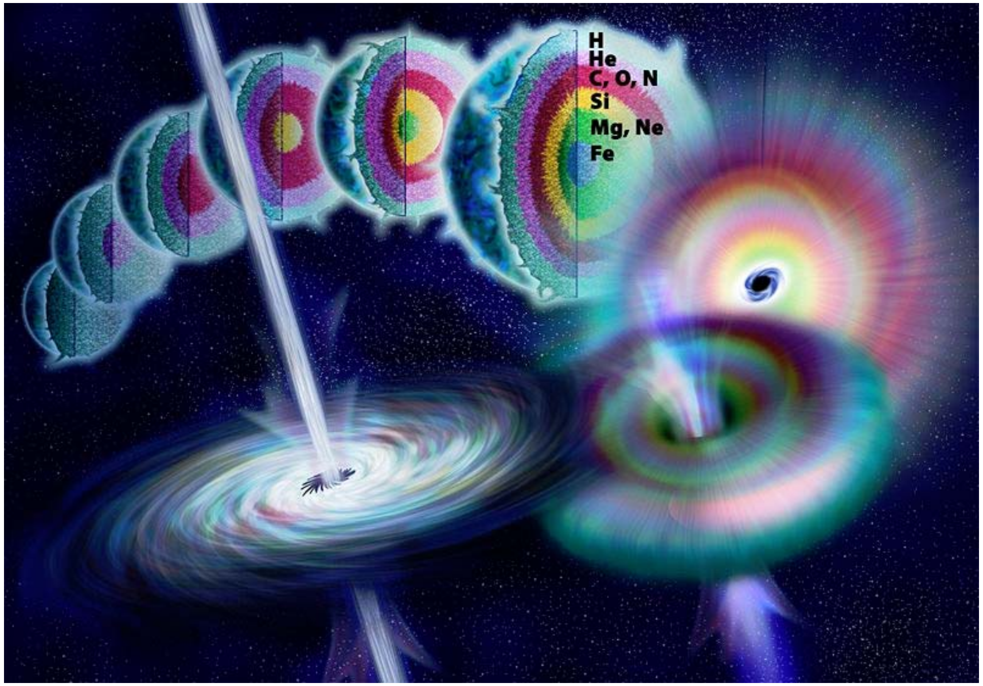
LIGO Scientific Collaboration

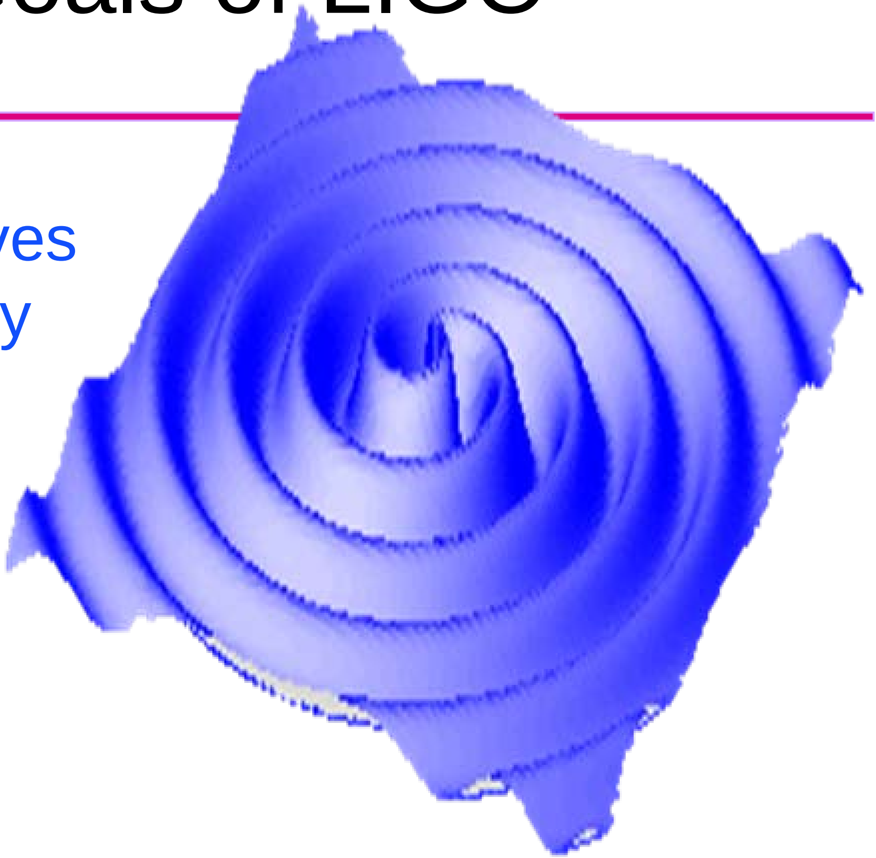
- Australian Consortium for Interferometric Gravitational Astronom
- The Univ. of Adelaide
- Andrews University
- The Australian National Univ.
- The University of Birmingham
- California Inst. of Technology
- Cardiff University
- Carleton College
- Charles Sturt Univ.
- Columbia University
- Embry Riddle Aeronautical Univ.
- Eötvös Loránd University
- University of Florida
- German/British Collaboration for the Detection of Gravitational Waves
- University of Glasgow
- Goddard Space Flight Center
- Leibniz Universität Hannover
- Hobart & William Smith Colleges
- Inst. of Applied Physics of the Russian Academy of Sciences
- Polish Academy of Sciences
- India Inter-University Centre for Astronomy and Astrophysics
- Louisiana State University
- Louisiana Tech University
- Loyola University New Orleans
- University of Maryland
- Max Planck Institute for Gravit

- University of Michigan
- University of Minnesota
- The University of Mississippi
- Massachusetts Inst. of Technology
- Monash University
- Montana State University
- Moscow State University
- National Astronomical Observatory of Japan
- Northwestern University
- University of Oregon
- Pennsylvania State University
- Rochester Inst. of Technology
- Rutherford Appleton Lab
- University of Rochester
- San Jose State University
- Univ. of Sannio at Benevento, and Univ. of Salerno
- University of Sheffield
- University of Southampton
- Southeastern Louisiana Univ.
- Southern Univ. and A&M College
- Stanford University
- University of Strathclyde
- Syracuse University
- Univ. of Texas at Austin
- Univ. of Texas at Brownsville
- Trinity University
- Universitat de les Illes Balears
- Univ. of Massachusetts Amherst
- University of Western Australia
- Univ. of Wisconsin-Milwaukee
- Washington State University
- University of Washingto

Scientific Goals of LIGO

- Discover the gravitational waves predicted by General Relativity





- Use gravitational waves to pioneer a new window on the universe

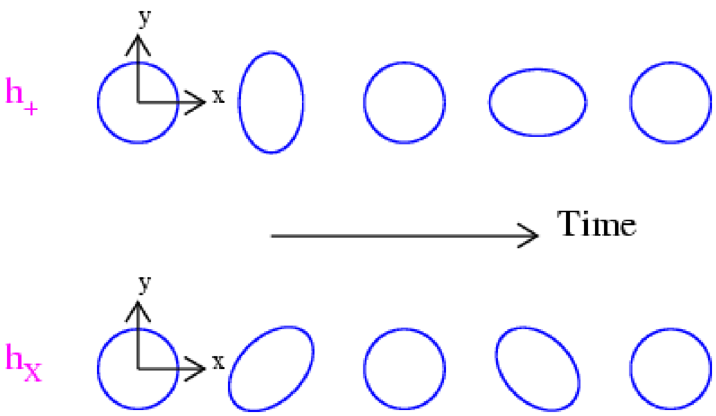
What is the observable effect?

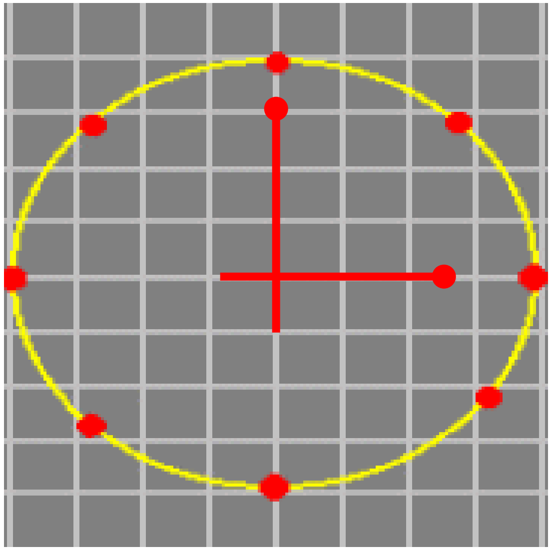
Example:

Ring of test masses

responding to wave

propagating along z





Amplitude parameterized by (tiny) dimensionless strain h:

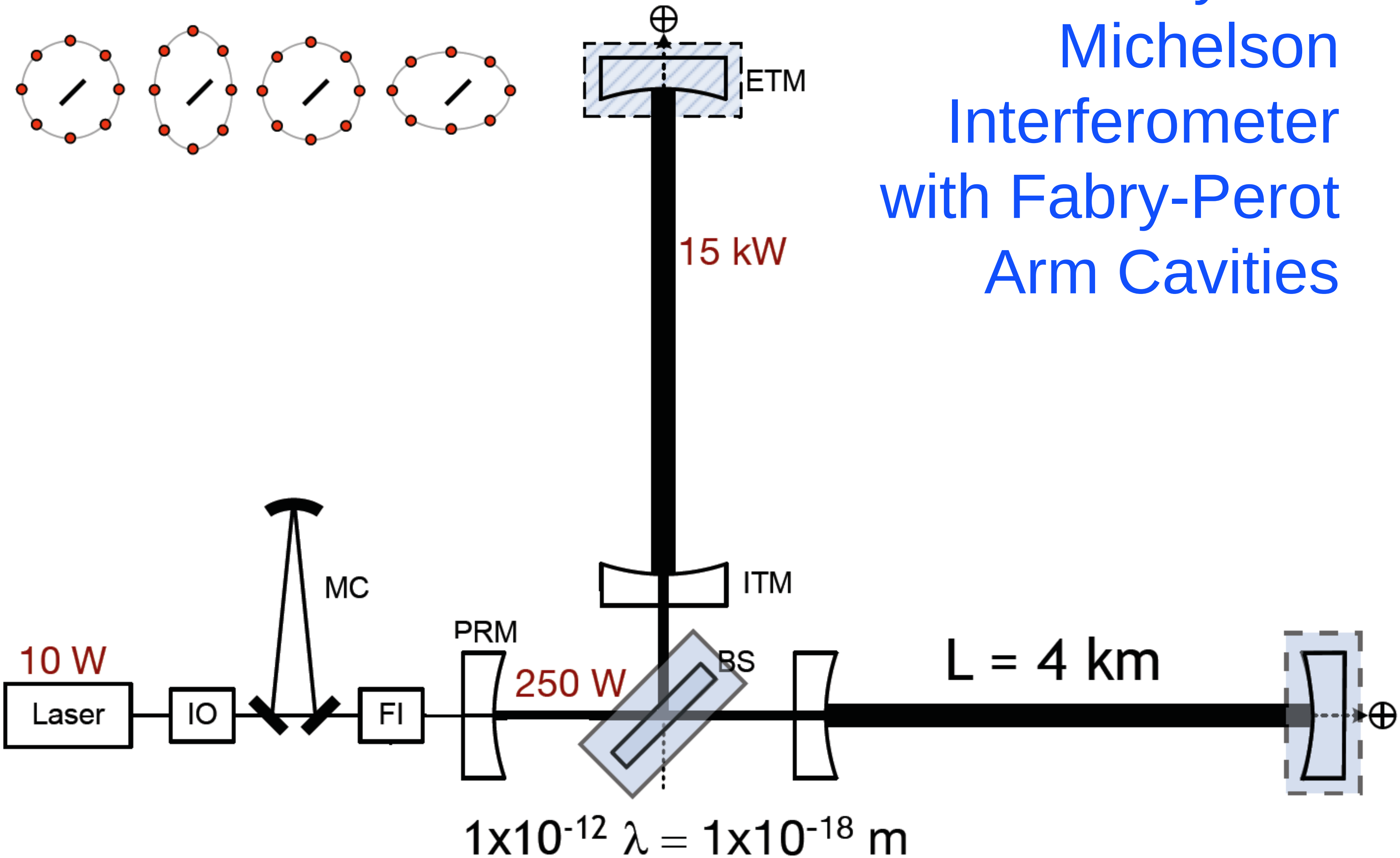
$$h(t) = \frac{\delta L(t)}{L}$$

Arial View of the LIGO Sites

LIGO Hanford Observatory

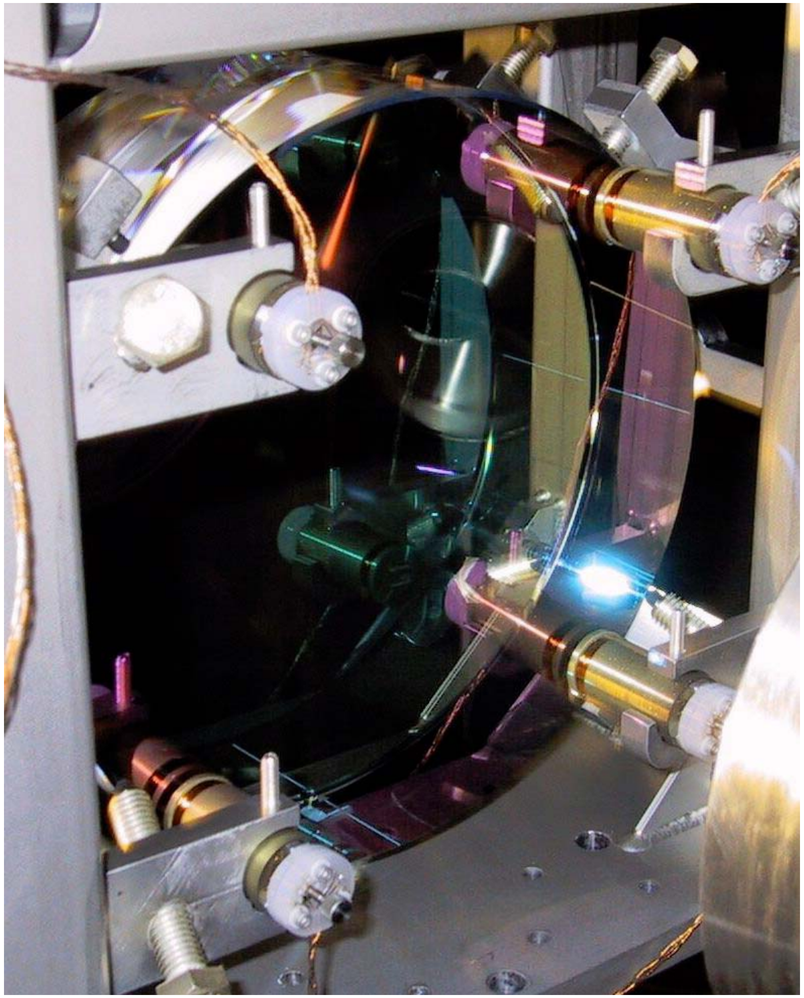
LIGO Livingston Observatory

Power-Recycled Michelson Interferometer with Fabry-Perot Arm Cavities



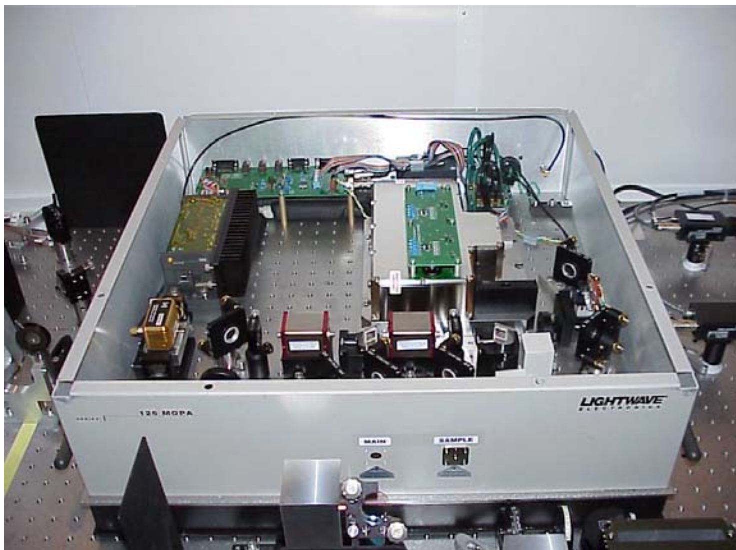
Main Features

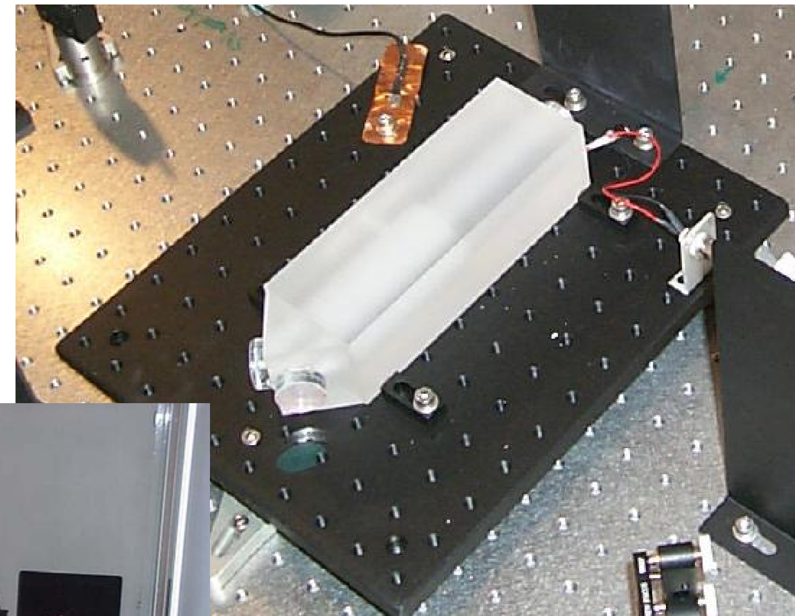
- 4 km vacuum envelope
  10^{-9} torr
- Seismic isolation stack
- Suspended masses
- 10W Nd:YAG laser, 1064 nm
- Suspended mode cleaner
- Feedback controls for length and alignment
- Physical environment monitor



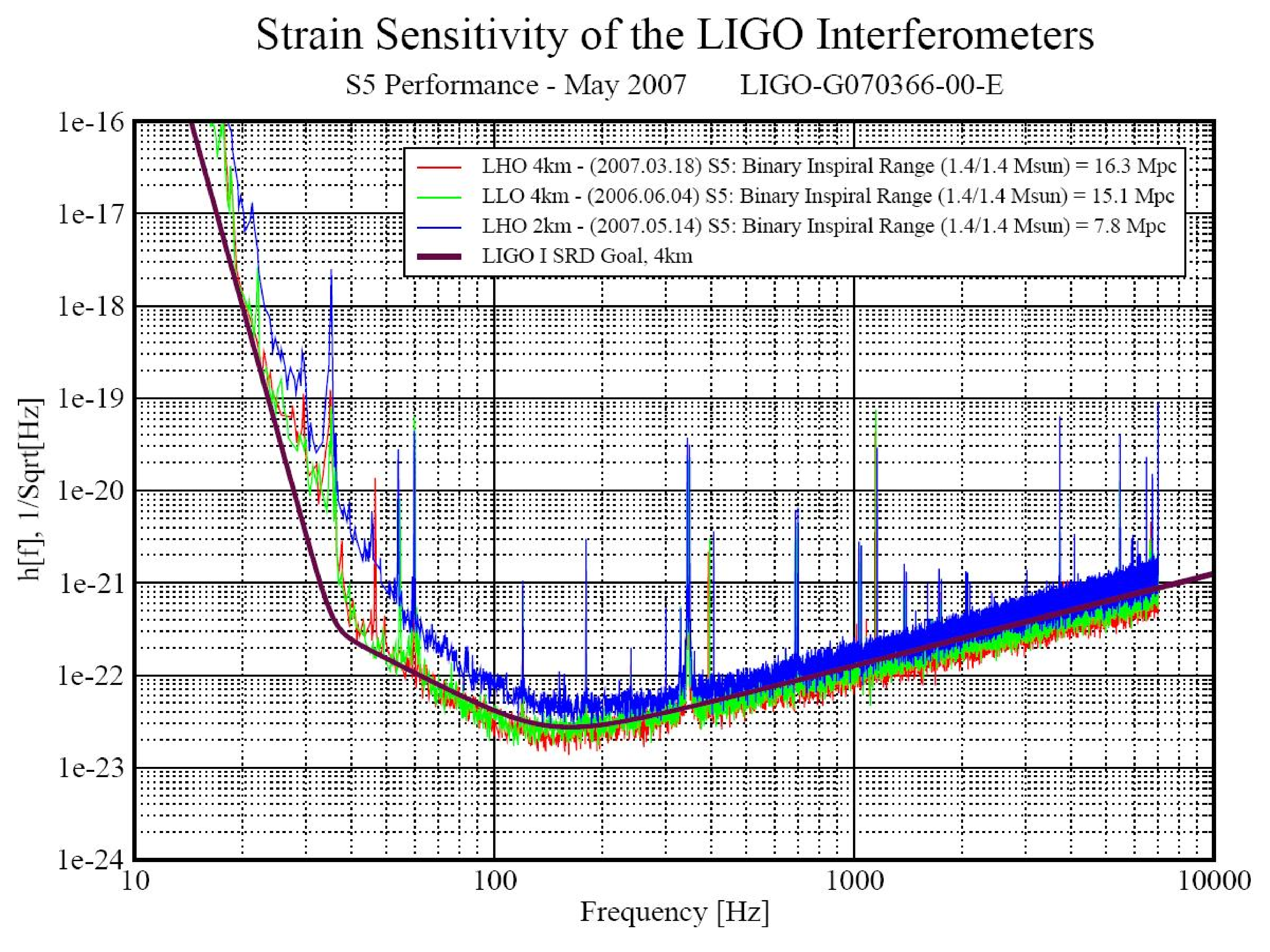
LIGO

Nd:YAG Laser, Reference Cavity and Pre-Mode Cleaner





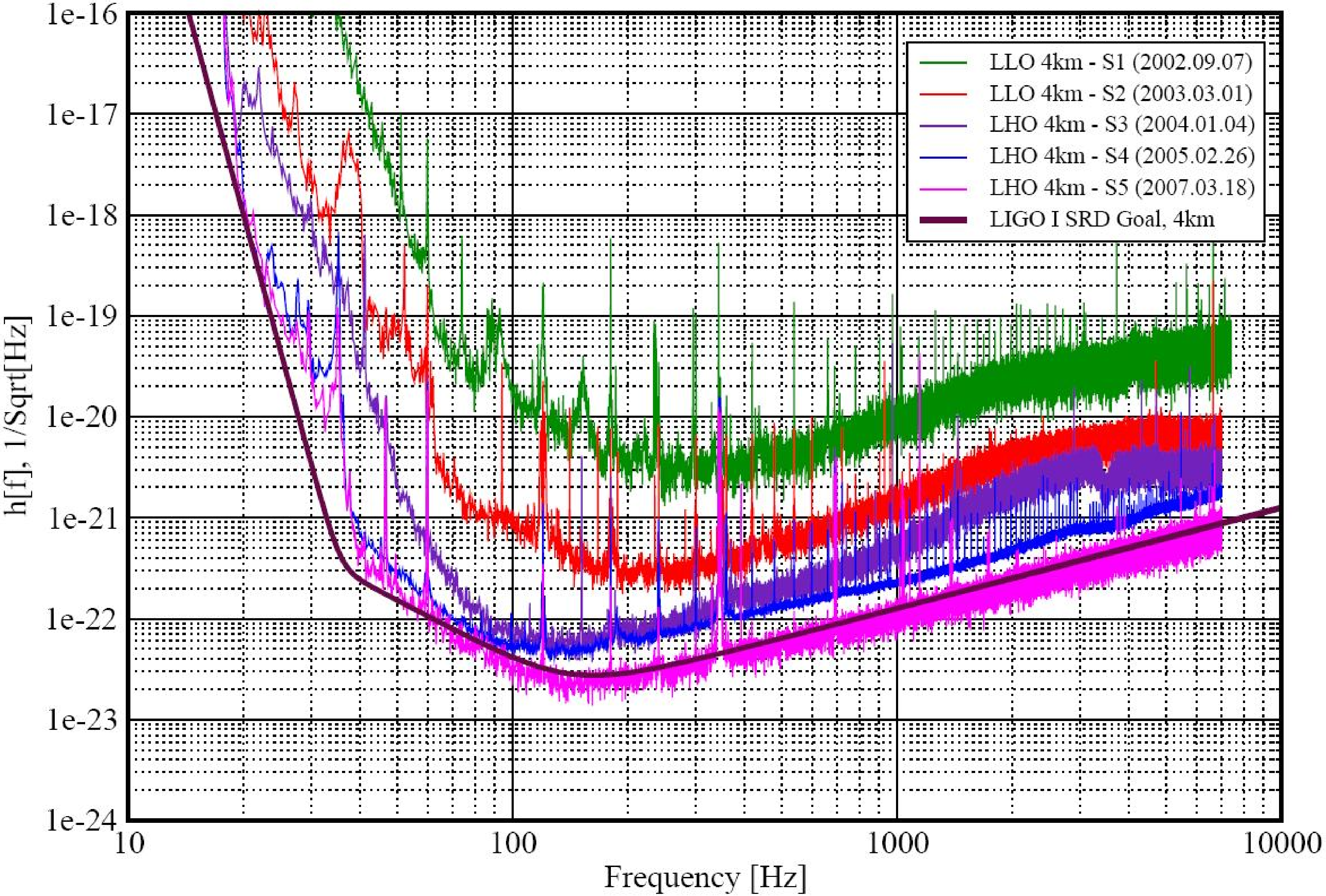
Seismic Isolation Stack

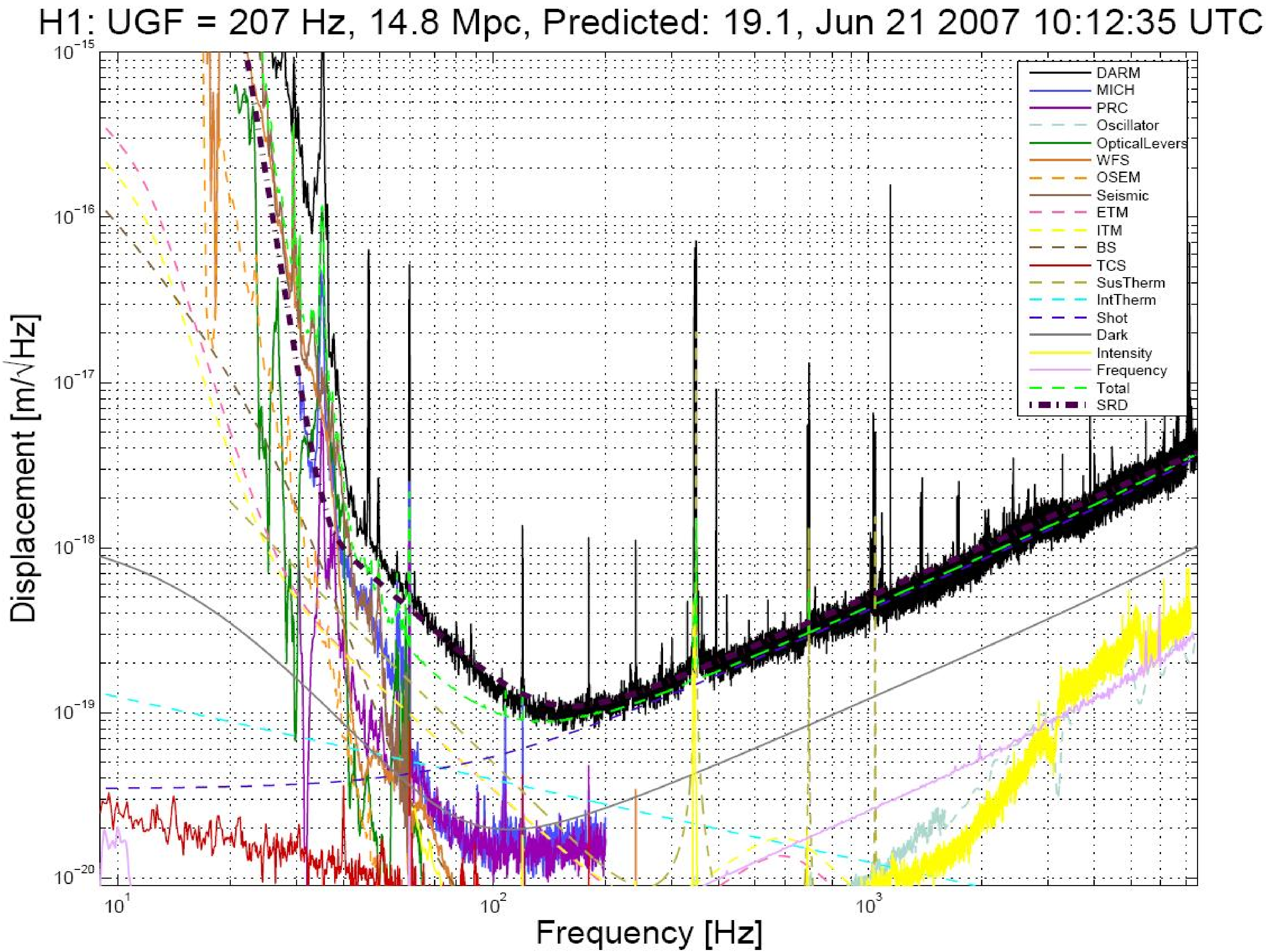


Strain Sensitivity of the LIGO Interferometers
S5 Performance - May 2007 LIGO-G070366-00-E
LHO 4km - (2007.03.18) S5: Binary Inspiral Range (1.4/1.4 Msun) = 16.3 Mpc
LLO 4km - (2006.06.04) S5: Binary Inspiral Range (1.4/1.4 Msun) = 15.1 Mpc
LHO 2km - (2007.05.14) S5: Binary Inspiral Range (1.4/1.4 Msun) = 7.8 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]

Best Strain Sensitivities for the LIGO Interferometers

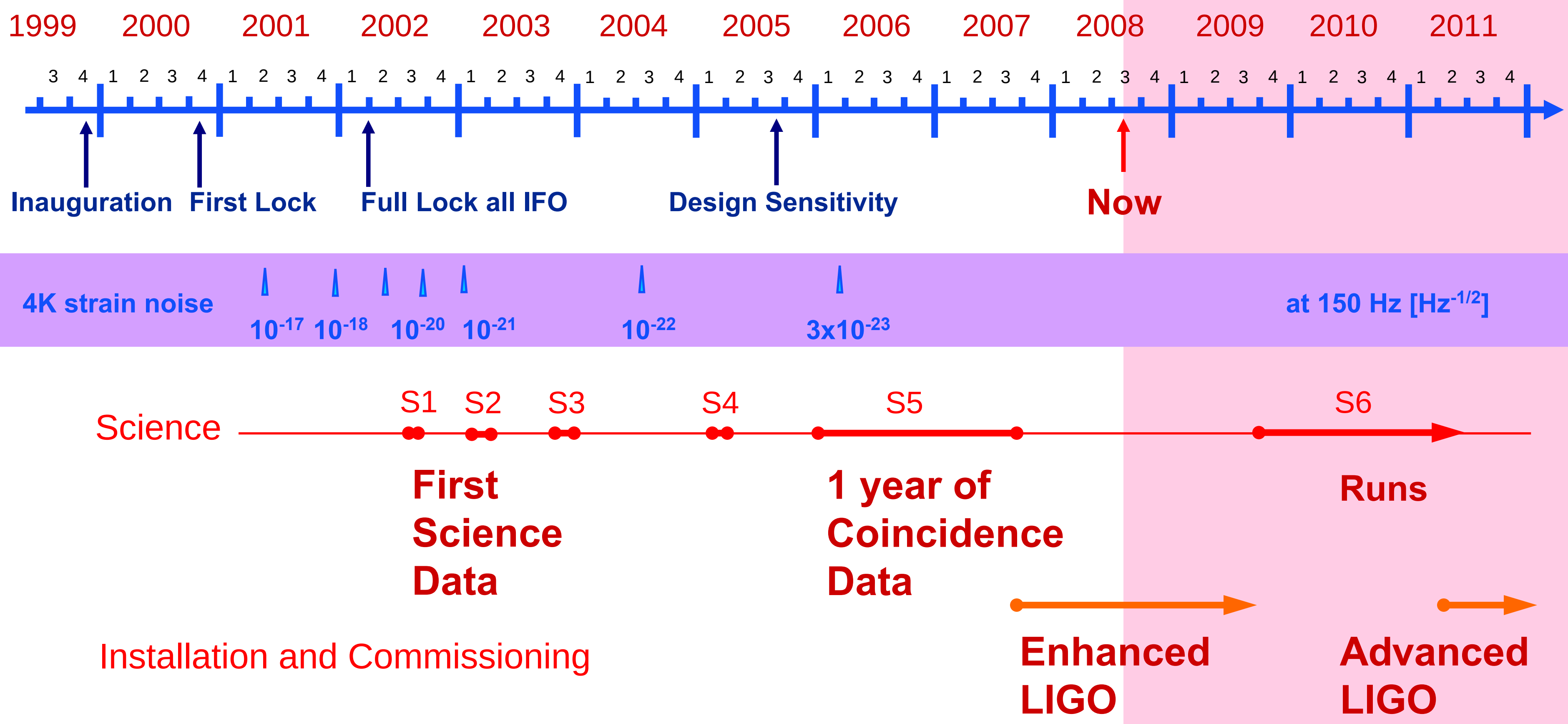
Comparisons among S1 - S5 Runs LIGO-G060009-03-Z





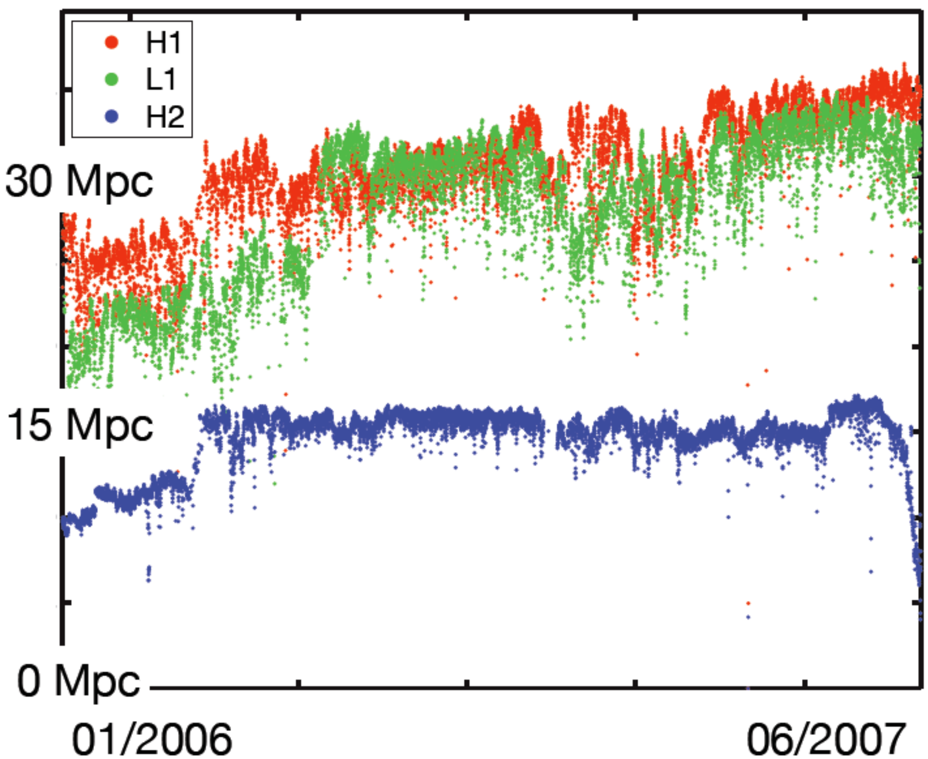
H1: UGF = 207 Hz, 14.8 Mpc, Predicted: 19.1, Jun 21 2007 10:12:35 UTC
Displacement [m/√Hz]
Frequency [Hz]
DARM
MICH
PRC
Oscillator
OpticalLevers
WFS
OSEM
Seismic
ETM
ITM
BS
TCS
SusTherm
IntTherm
Shot
Dark
Intensity
Frequency
Total
SRD

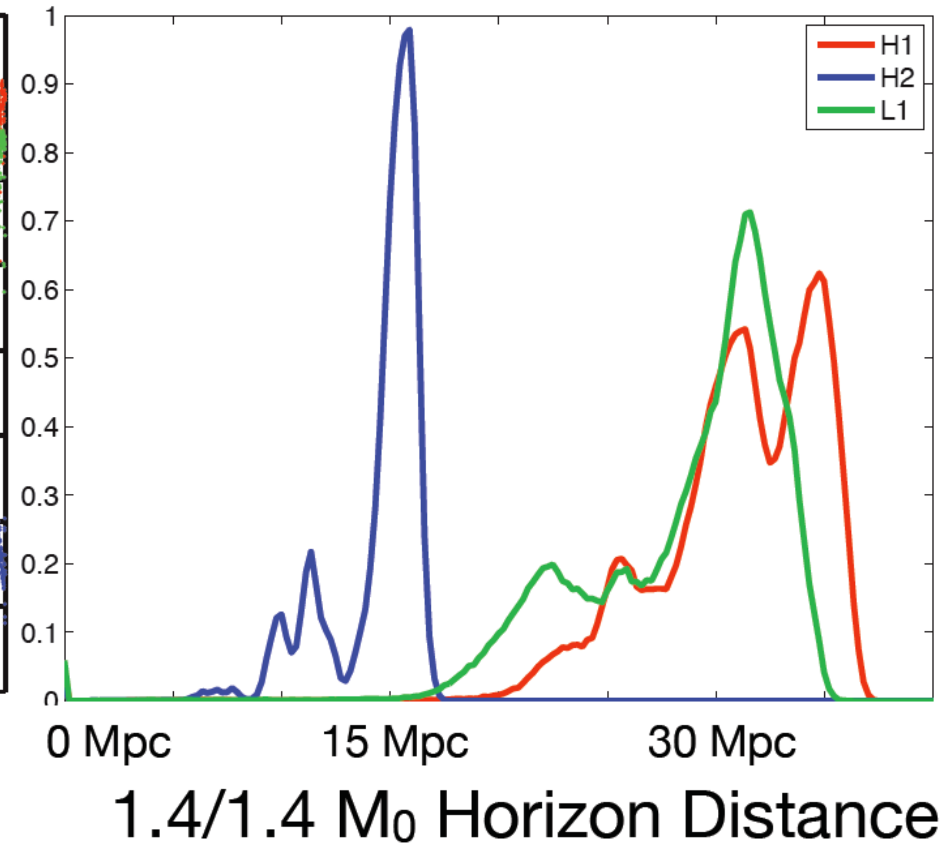
Time Line



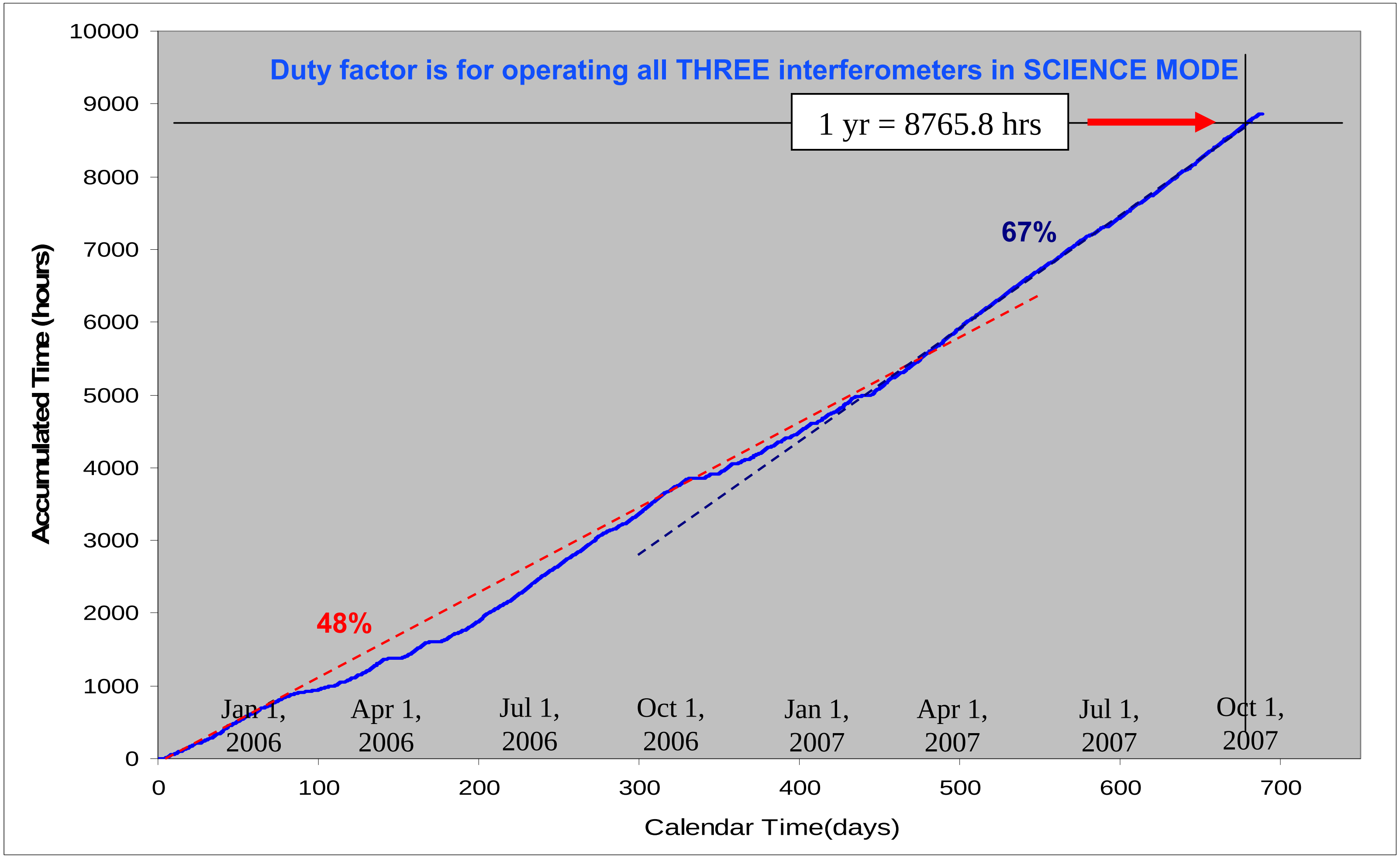
1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
Inauguration
First Lock
Full Lock all IFO
Design Sensitivity
Now
4K strain noise
10-17 10-18 10-20 10-21 10-22 3x10-23
at 150 Hz [Hz-1/2]
Science
S1 S2 S3 S4 S5 S6
First Science Data
1 year of Coincidence Data
Runs
Installation and Commissioning
Enhanced LIGO
Advanced LIGO

The 5th Science Run

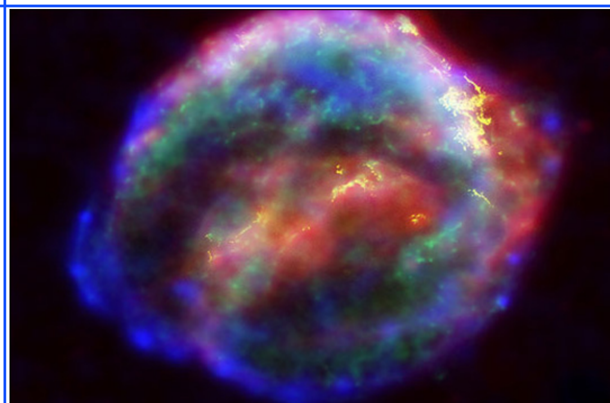
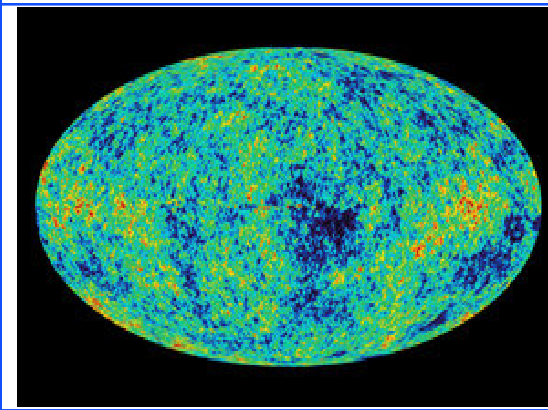
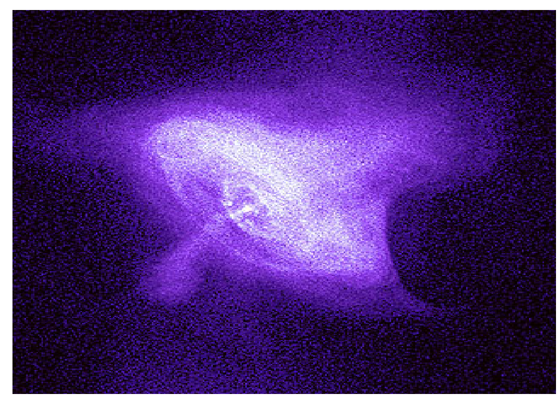




Accumulated triple-coincidence



Signal duration and template

	Short duration	Long duration
un-modeled		
matched filter		

Credit: NASA/CXC/ASU/J. Hester et al.

GRB 070201

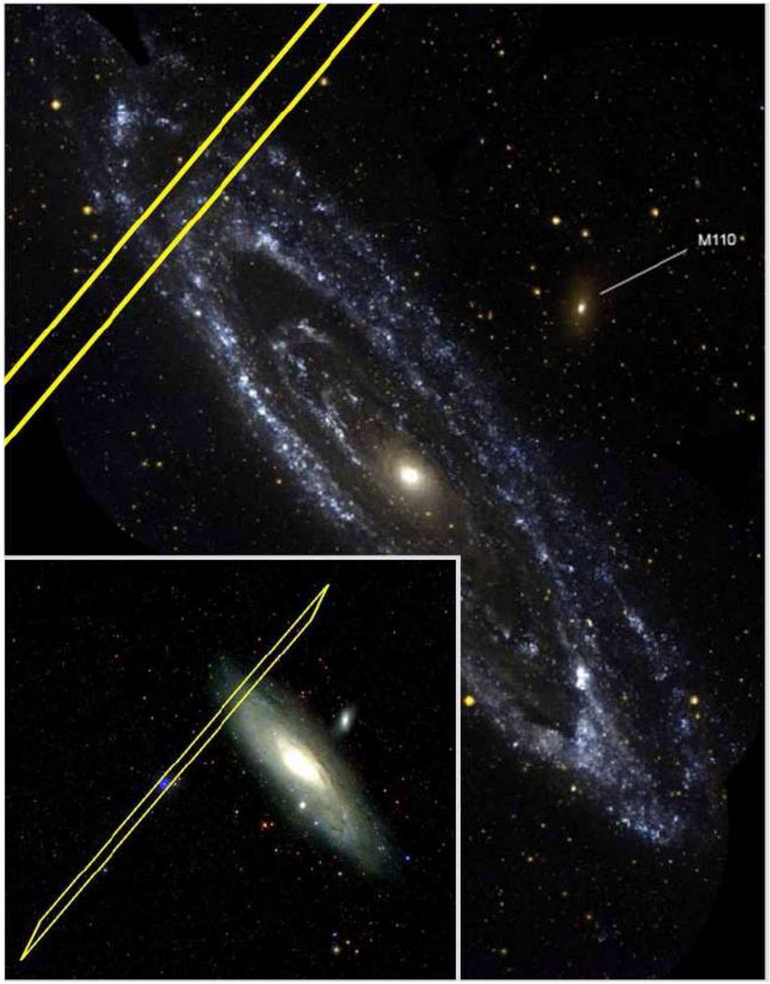


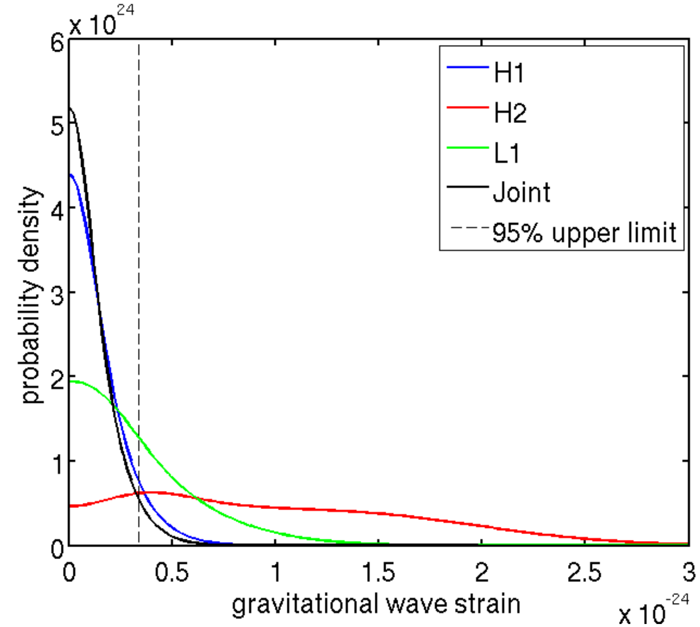
FIG. 1.— The IPN3 (IPN3 2007) (γ-ray) error box overlaps with the spiral arms of the Andromeda galaxy (M31). The inset image shows the full error box superimposed on an SDSS (SDSS 2007) image of M31. The main figure shows the overlap of the error box and the spiral arms of M31 in UV light (Thilker et al. 2005).

- Short, hard gamma-ray burst
  - A leading model for short GRBs: binary merger involving a neutron star
- Position (from IPN) consistent with being in M31 (Andromeda)
- LIGO H1 and H2 were operating
- Result from LIGO data analysis: **No plausible GW signal found; therefore very unlikely to be from a binary merger in M31**

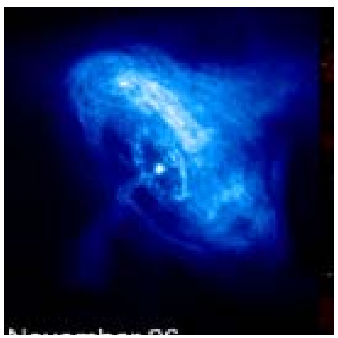
Crab Pulsar

Result from first 9 months of S5:

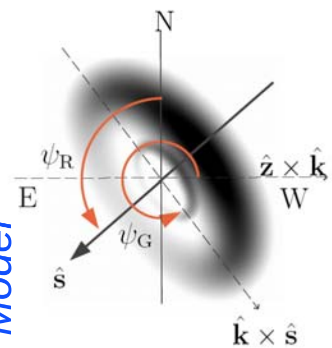
Consistent with Gaussian noise



Chandra image



Model



Upper limits on GW strain amplitude h_0

Single-template, uniform prior: **3.4×10^{-25}**

Single-template, restricted prior: **2.7×10^{-25}**

Multi-template, uniform prior: **1.7×10^{-24}**

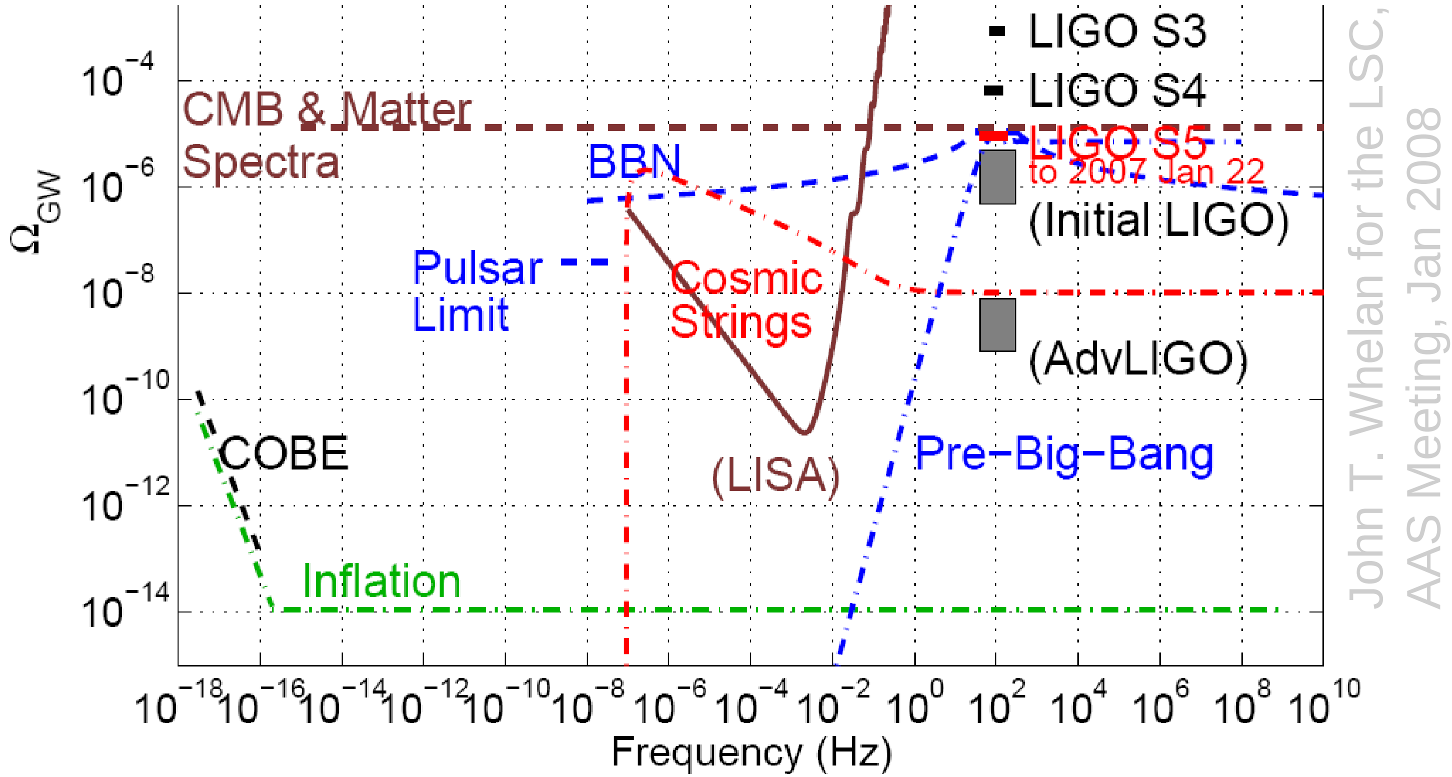
Multi-template, restricted prior: **1.3×10^{-24}**

Implies that GW emission accounts for ≤ 4% of total spin-down power

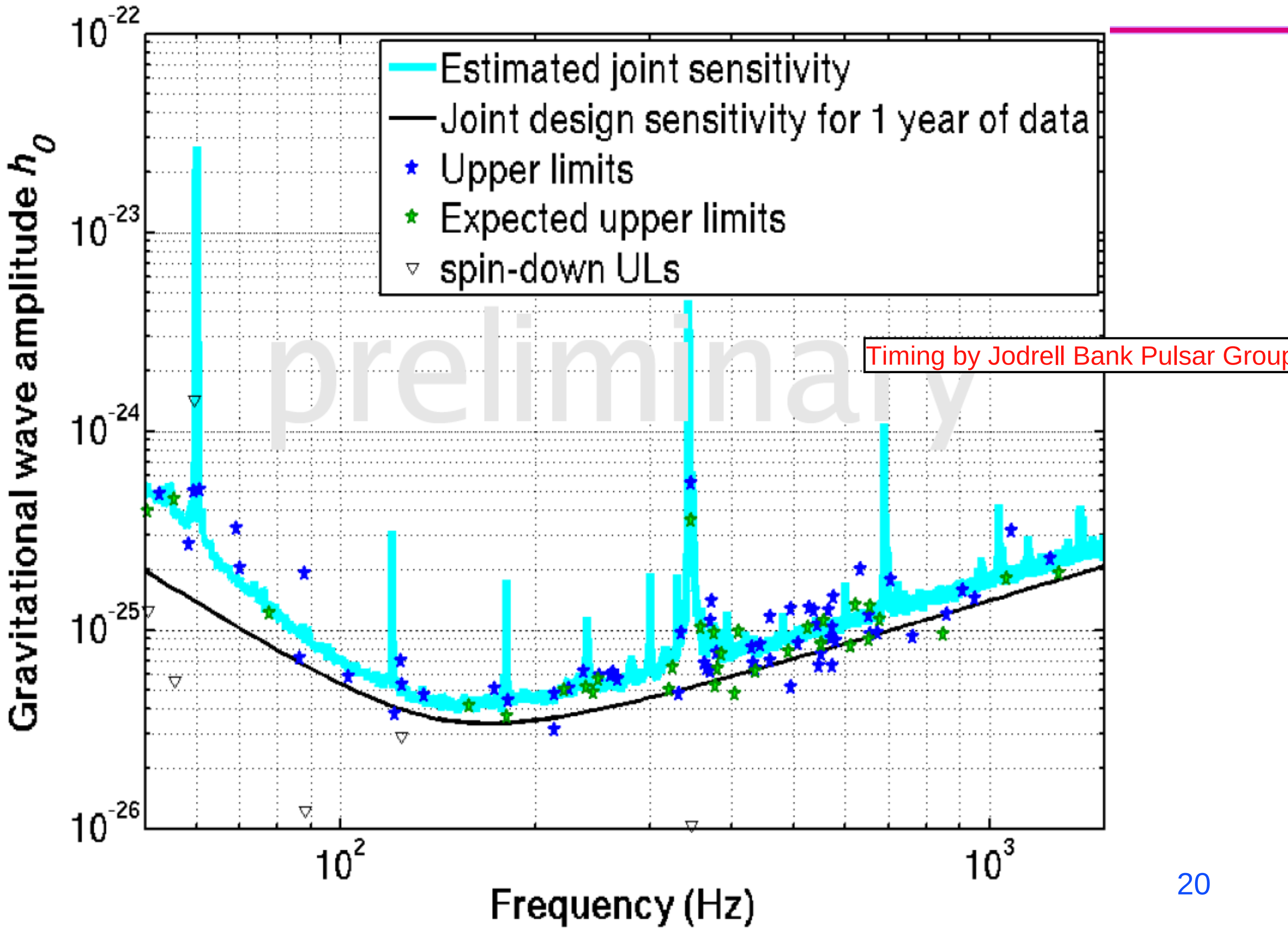
LIGO

Search for a Stochastic GW Background

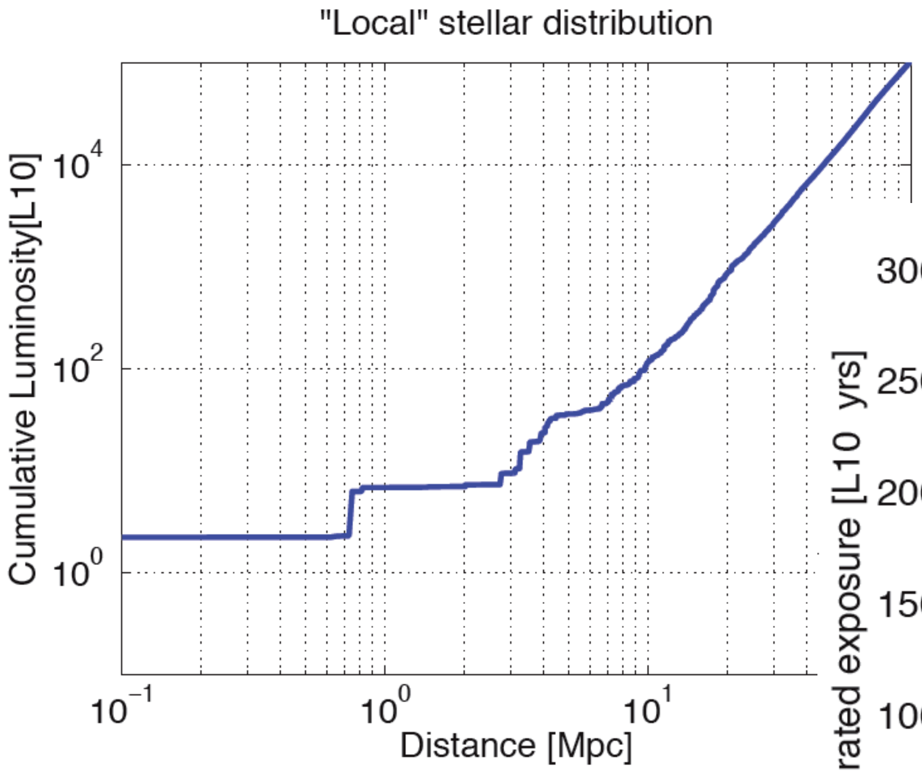
- Cross-correlated LIGO data streams to estimate energy density in isotropic stochastic GW, assuming a power law
- *Partial, preliminary* result from S5 is comparable to constraint from Big Bang nucleosynthesis



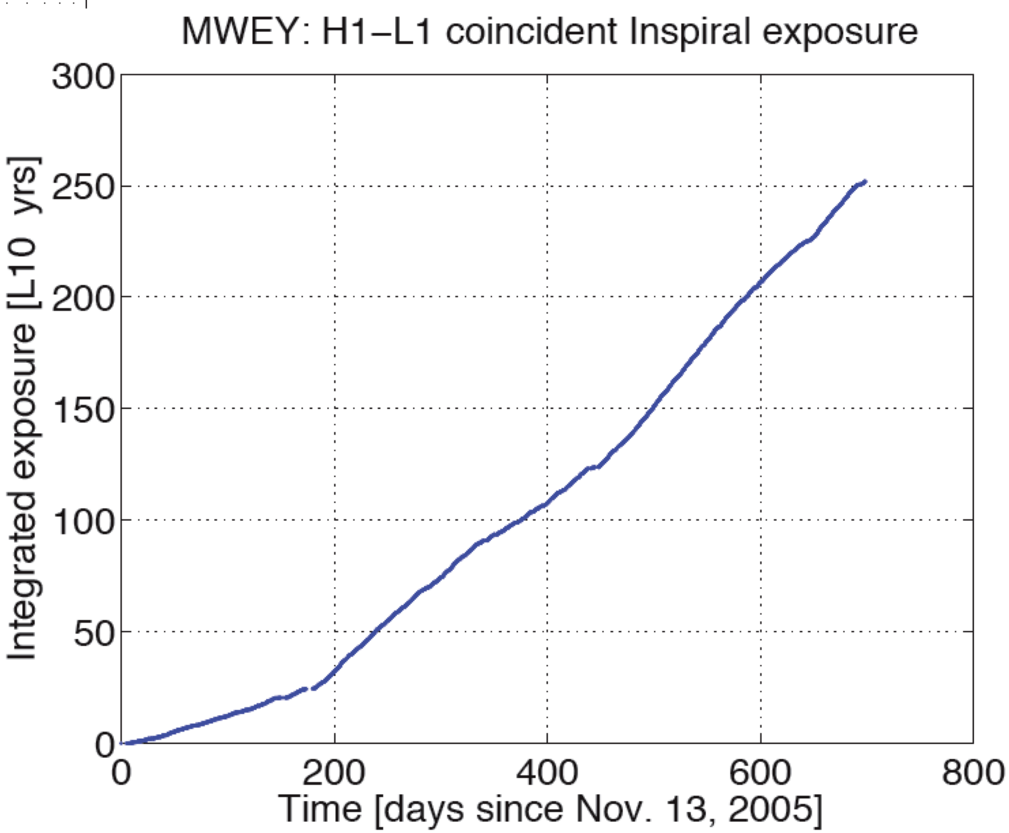
Known pulsars



Binary Neutron Star Sources



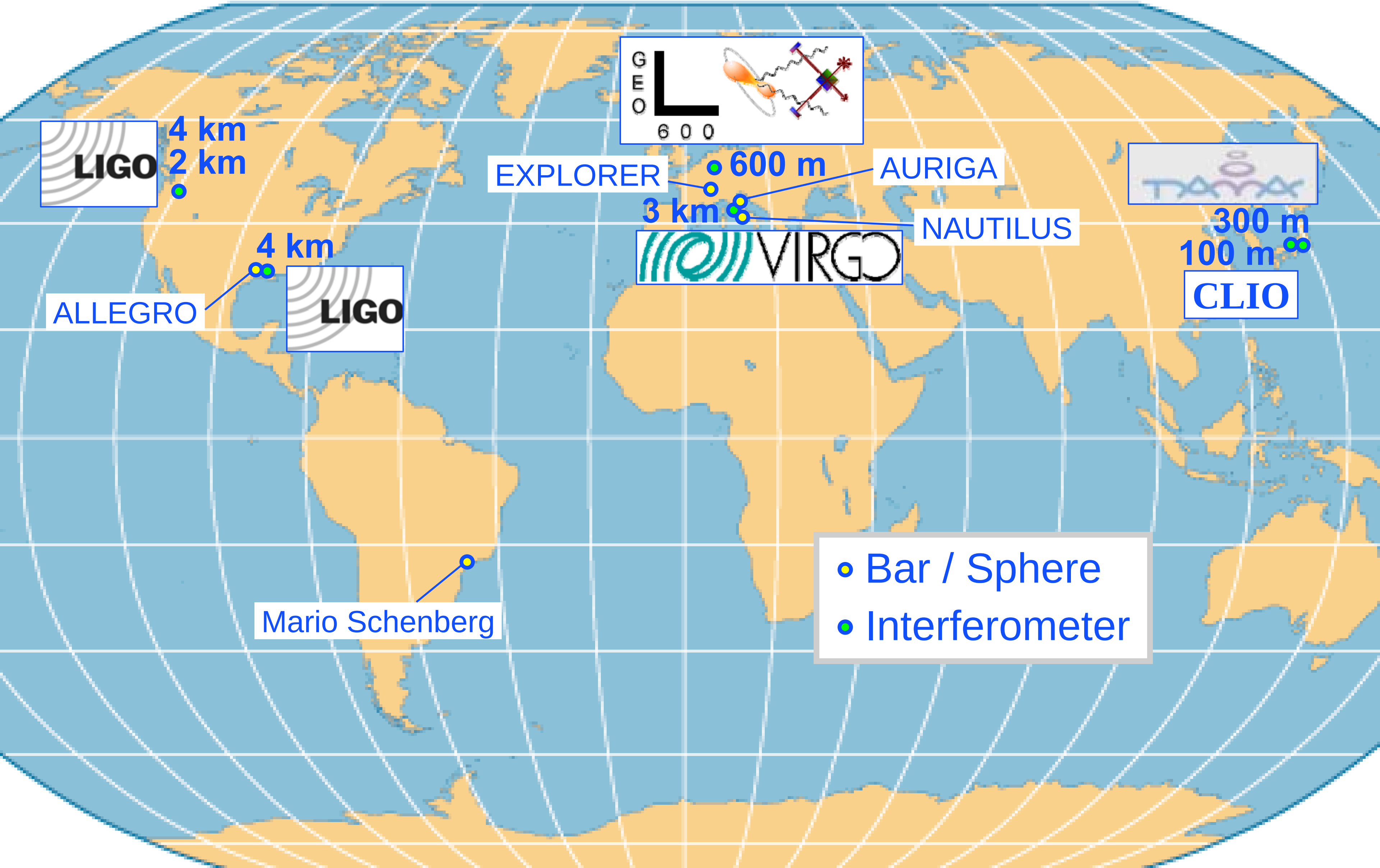
Single detector, SNR=8, averaged
Milky Way ~ 1.6 x L10

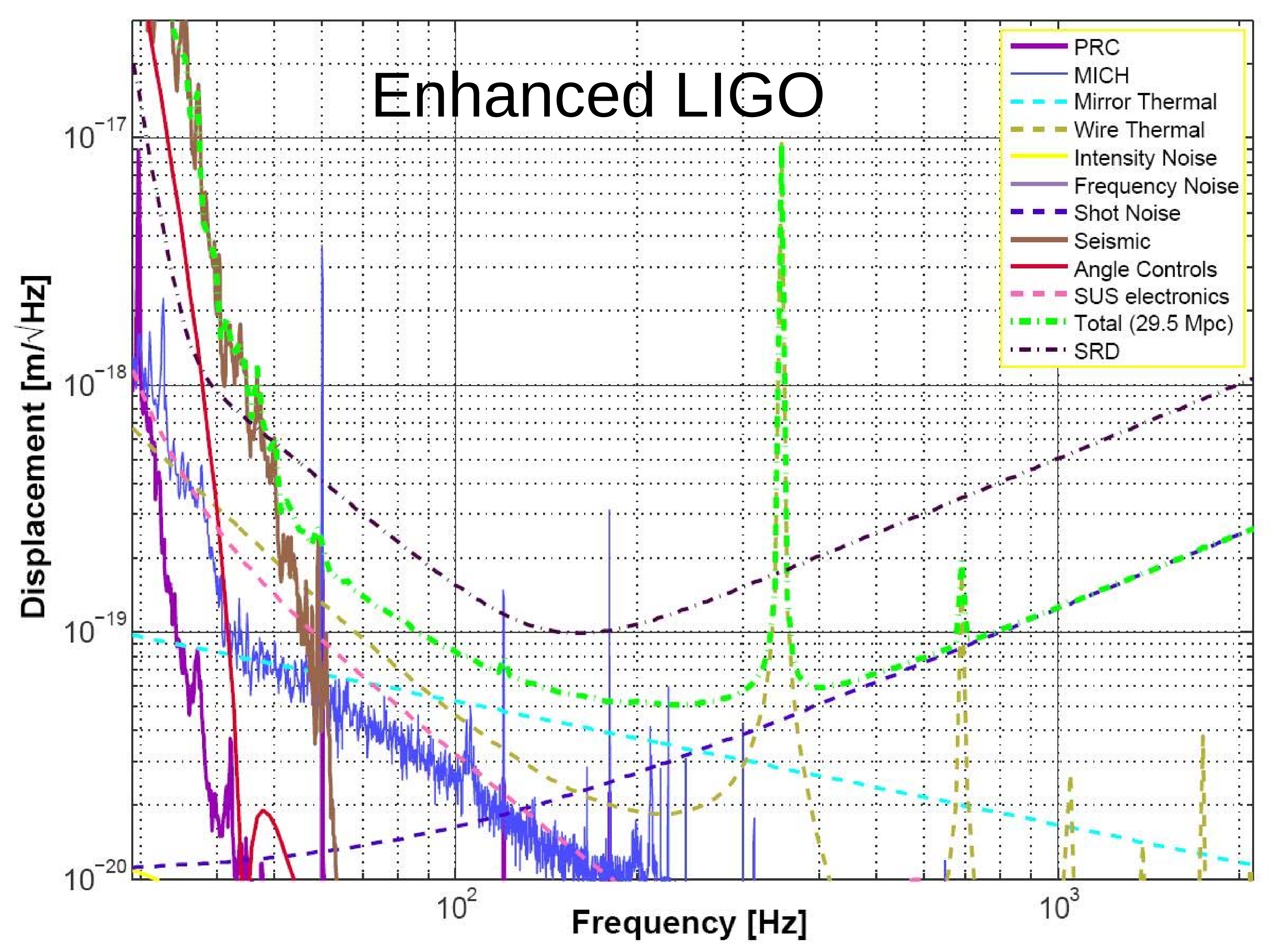


No detection so far

G080573-00-D

Network Analysis



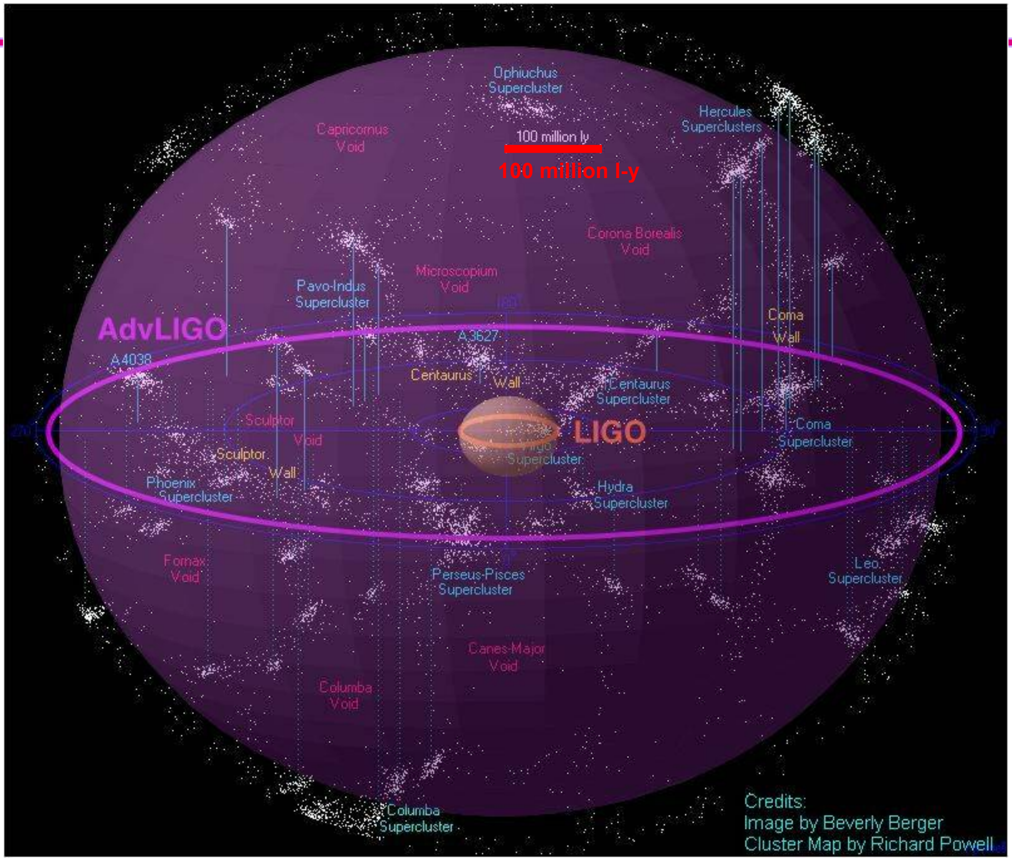

Enhanced LIGO
PRC
MICH
Mirror Thermal
Wire Thermal
Intensity Noise
Frequency Noise
Shot Noise
Seismic
Angle Controls
SUS electronics
Total (29.5 Mpc)
SRD
10^{-17}
10^{-18}
10^{-19}
10^{-20}
Displacement [m/√Hz]
10^{2}
10^{3}
Frequency [Hz]

Key Technologies

- In-vacuum output mode cleaner
  - Currently installed and being commissioned
  - New advanced LIGO seismic isolation
- DC readout scheme
  - Crucial for advanced LIGO
- 30W laser (LZH/Hannover)
  - First stage of advanced LIGO laser
  - Will require bigger thermal compensation system
- Input optics
  - New high power Faraday isolator & Pockels cells
- New earthquake stops (fused silica tipped)

Advanced LIGO

- Funding approved at the beginning of this year!
- An order of magnitude improvement in sensitivity
  - 3 orders of magnitude improvement in rate!



Key Technologies

- Active seismic isolation system
  - Hydraulic pre-isolator
  - 2 stage in-vacuum isolation system
- Multiple suspension stages
- 30 kg test masses
  - Active thermal compensation
- 180 W laser source
  - High power input optics
- Signal recycling added
- In-vacuum detection benches

Summary

- First relevant science results are published! And more to come…
- All LIGO interferometers are at design sensitivity
- For sources like binary neutron star and black hole coalescence we can see well into the Virgo cluster
- The first big science run is done with 1 year of coincidence data
- Enhanced LIGO commissioning is in progress
- Advanced LIGO is funded

We should be detecting gravitational waves regularly within the next 10 years!