Extending our reach:
the next decade of GW detectors

Sam Waldman
LIGO Caltech
April APS Meeting
St. Louis 2008

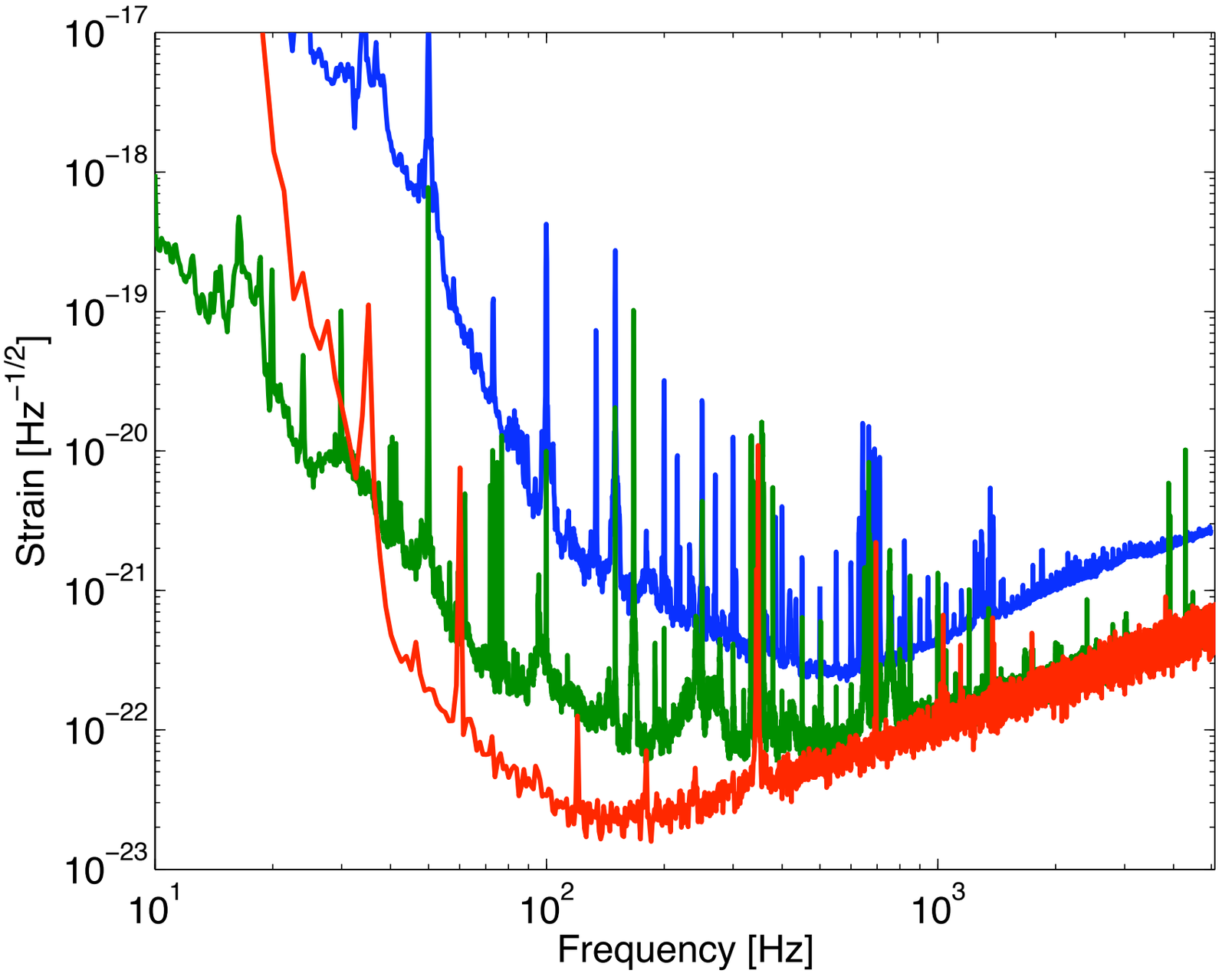
Outline

Waldman
April APS '08

GW detectors

GEO, VIRGO, LIGO

Future upgrades



Strain and Gauge

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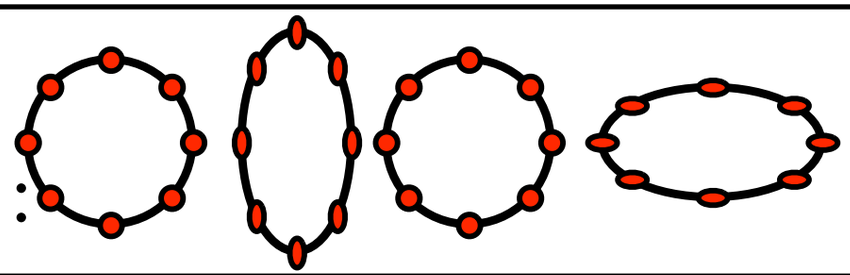
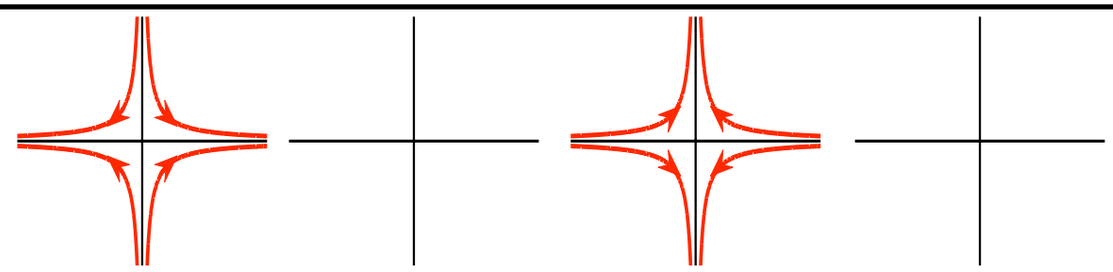
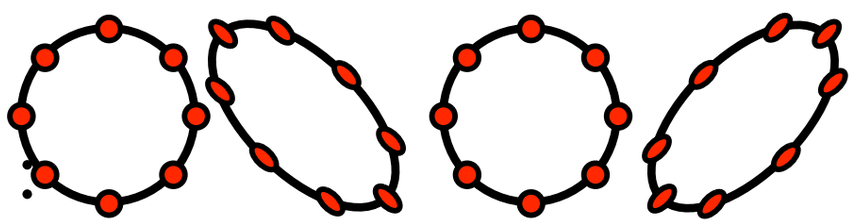
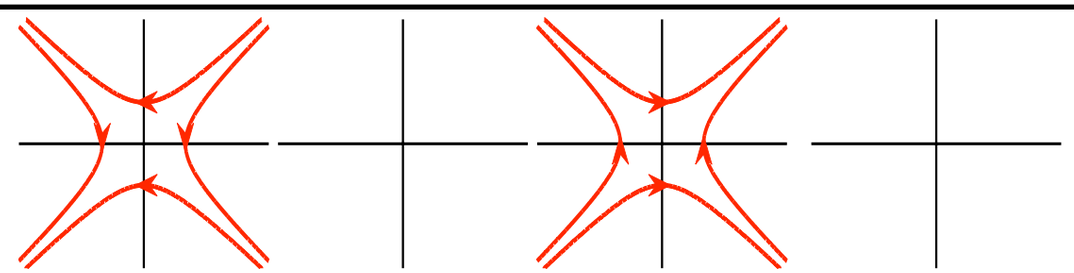
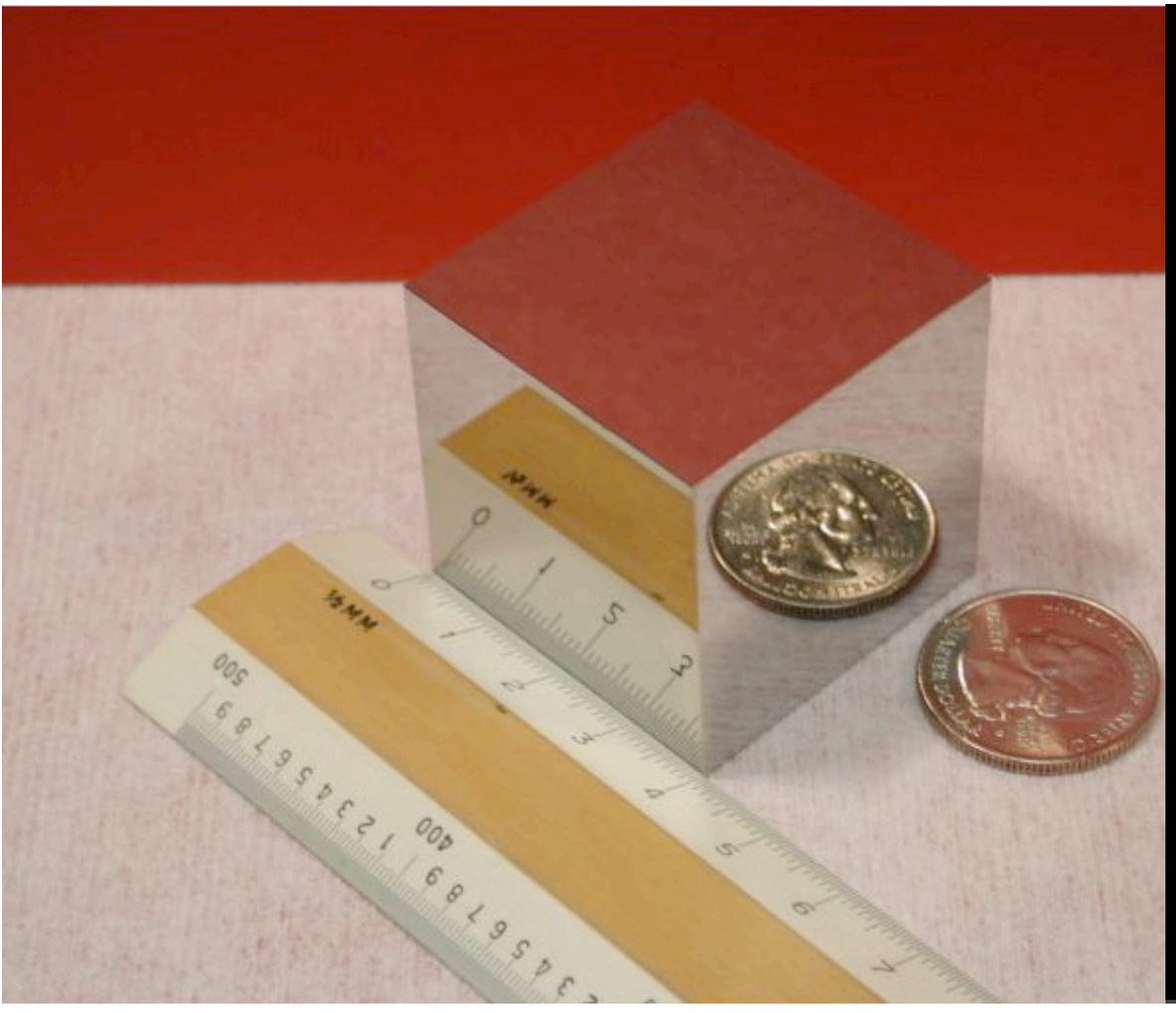
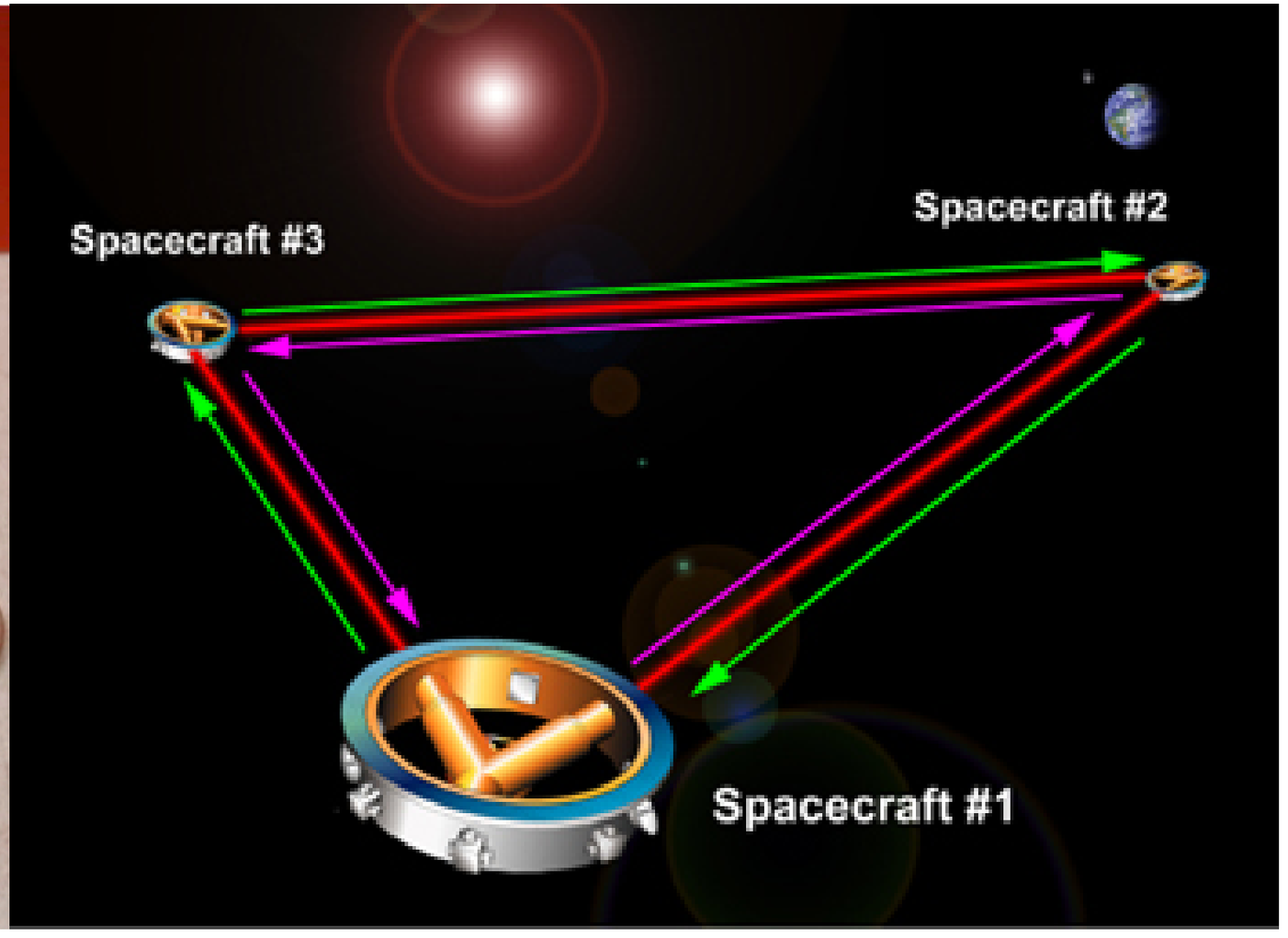
Transverse Traceless	**Locally Lorentz**
Induced strain	Induced acceleration
$h = \frac{\delta l}{l}$	$\frac{d^2x}{dt^2} = \frac{1}{2}\left(\ddot{A}_+ x\,\hat{x} + \ddot{A}_\times y\,\hat{y}\right)$
A_+ 	
$A_\times$ 	

Virgo Cluster inspiral: $h \sim 10^{-21}$

GW in Space





"LISA promises to open a completely new window into the heart of the most energetic processes in the universe, with consequences fundamental to both physics and astronomy." -National Academy

GW Detector 0.01

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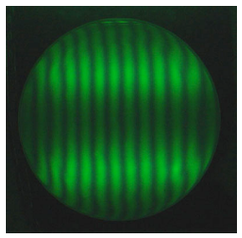
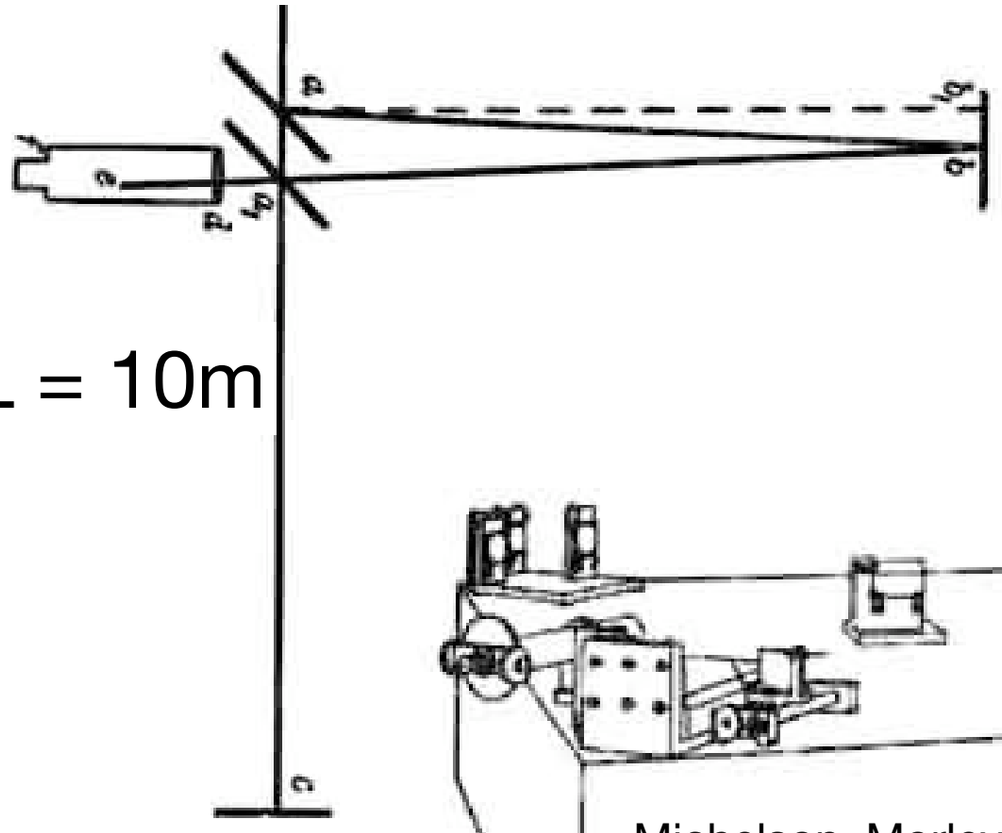
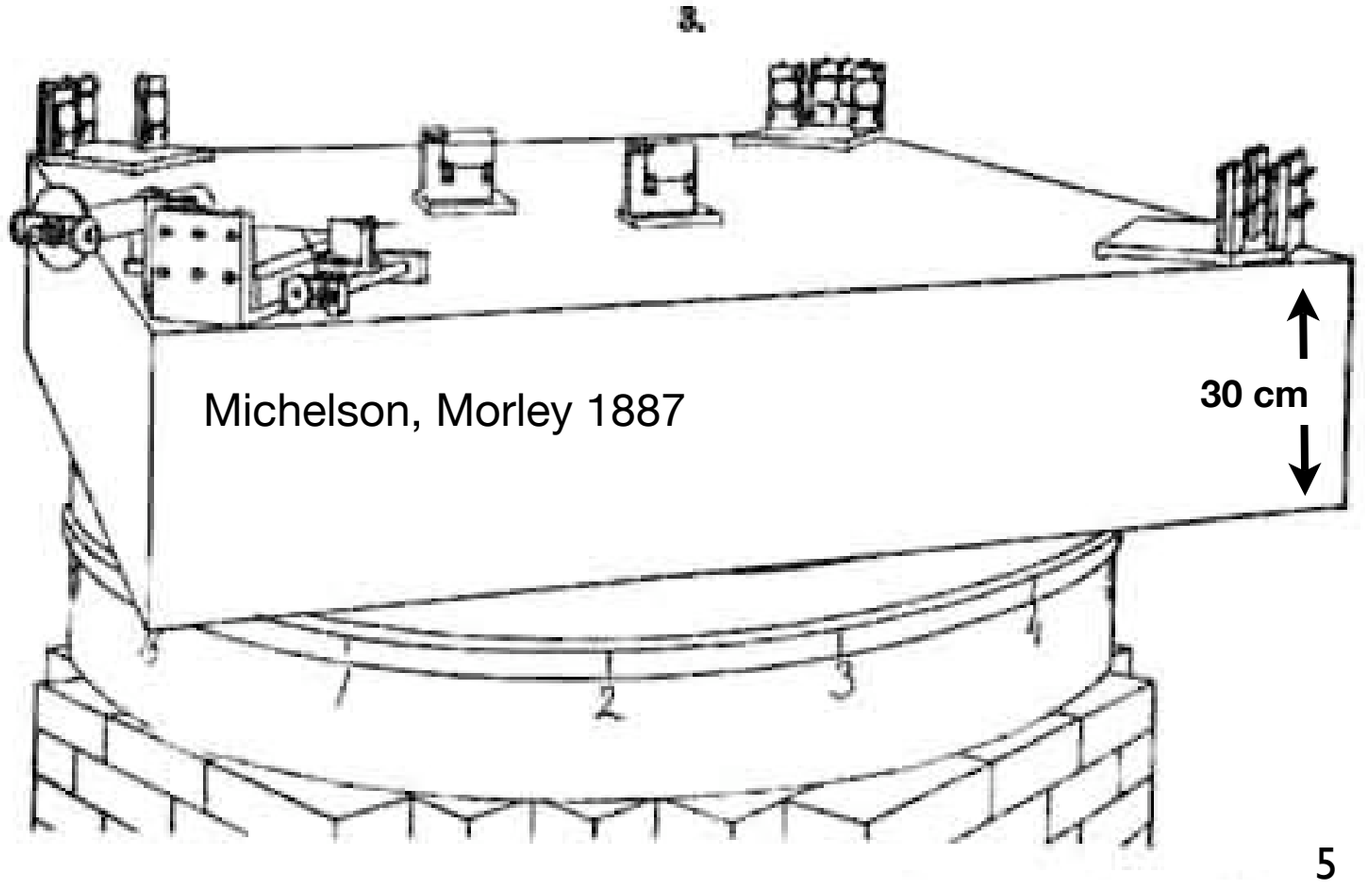
First GW detector
$dx/x \sim 5 \times 10^{-10}$

Albert A. Michelson



~ 1 mW



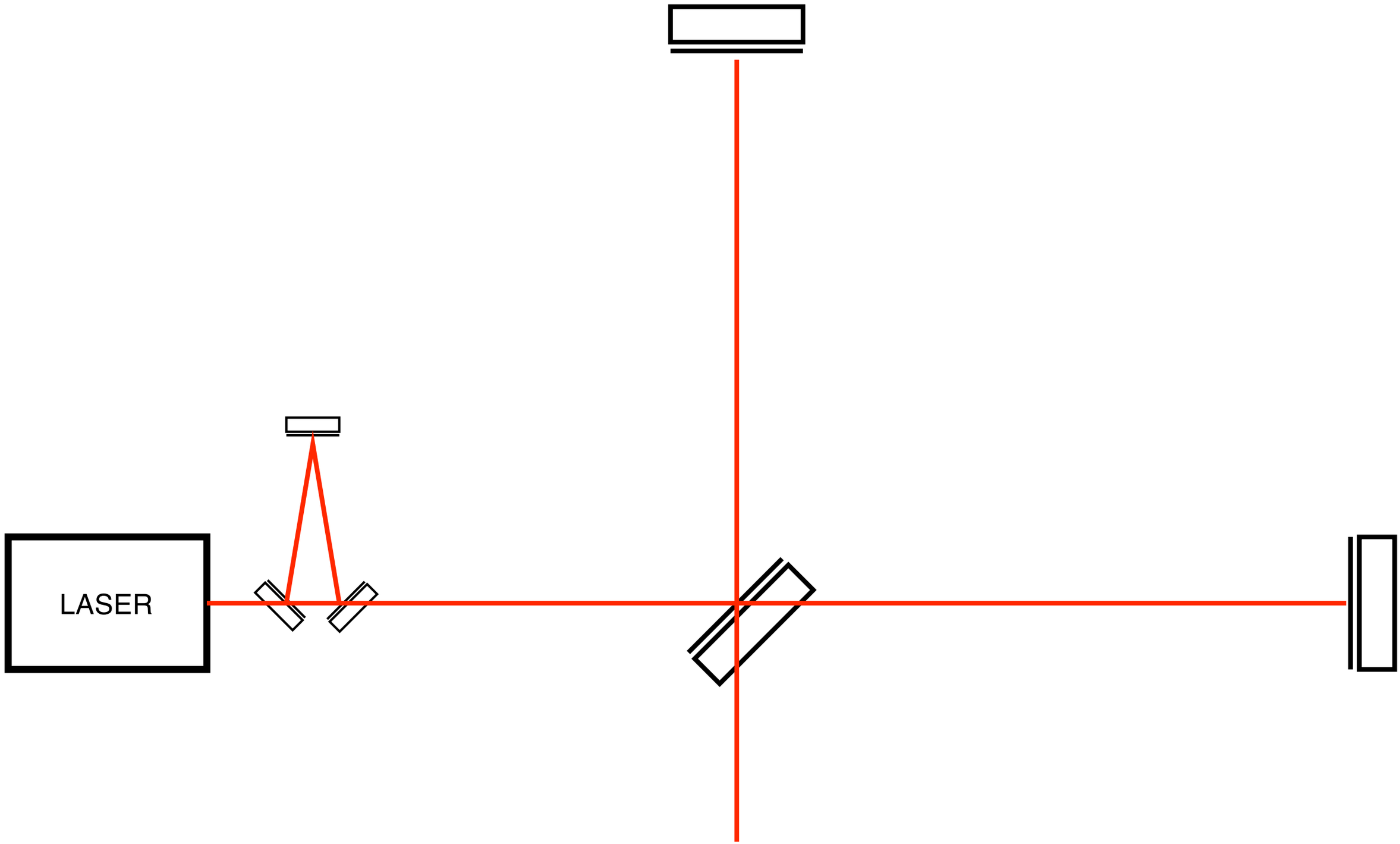


Michelson, Morley 1887

Modern IFOs

Michelson

$$SNR(\omega) \propto (P_0)^{-1/2}$$



Modern IFOs

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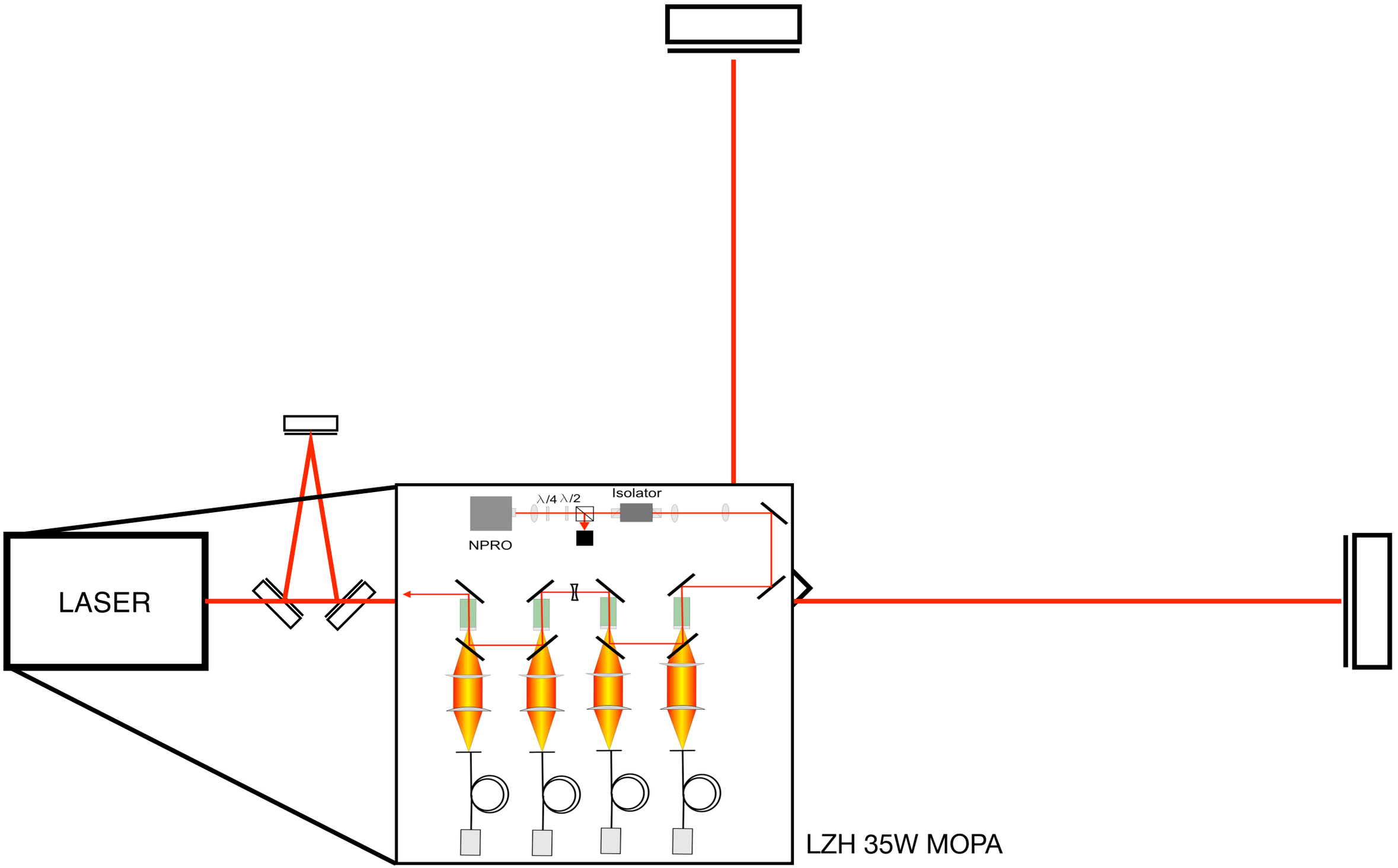

LZH 35W MOPA

Modern IFOs

Michelson

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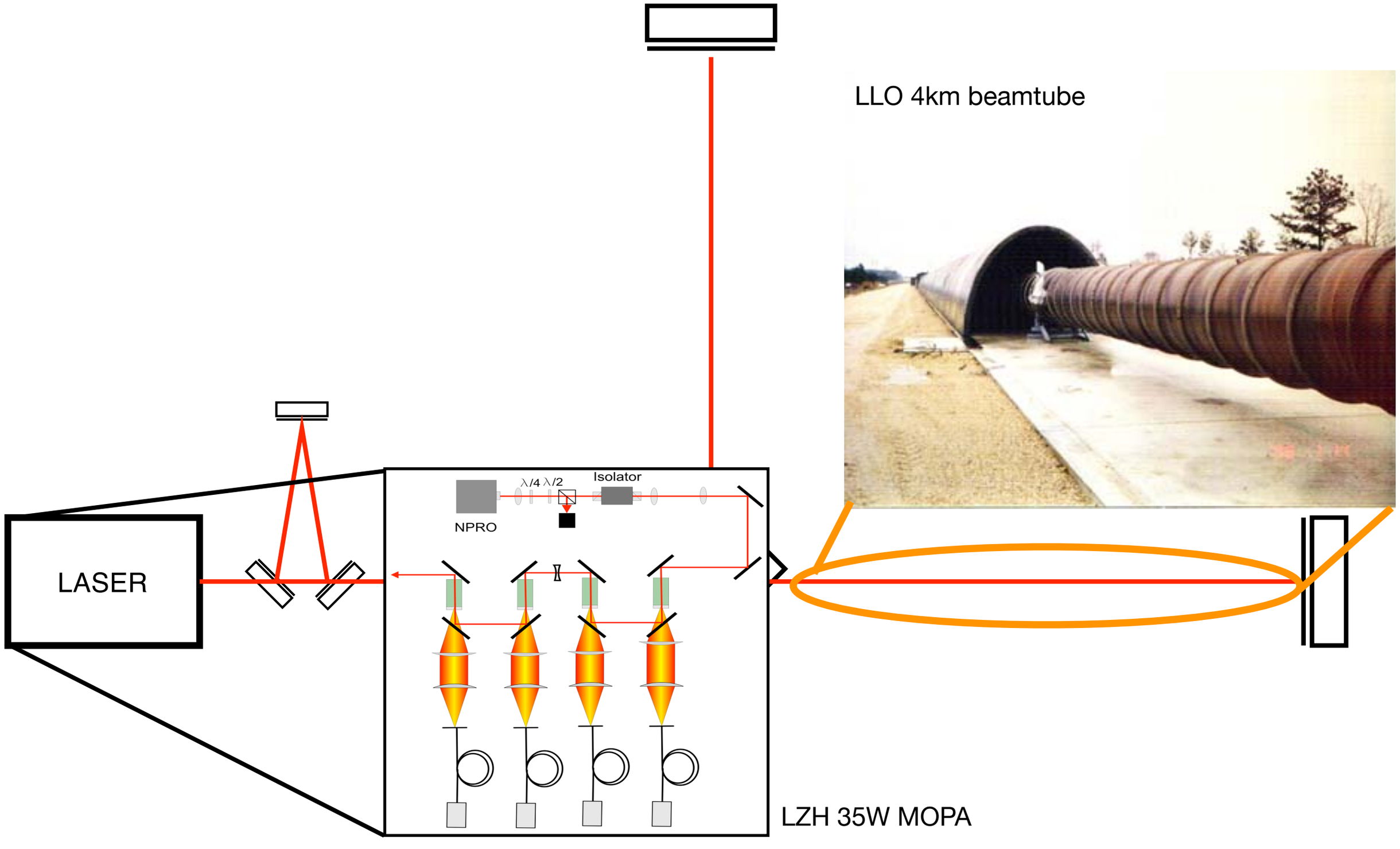

Modern IFOs

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Michelson

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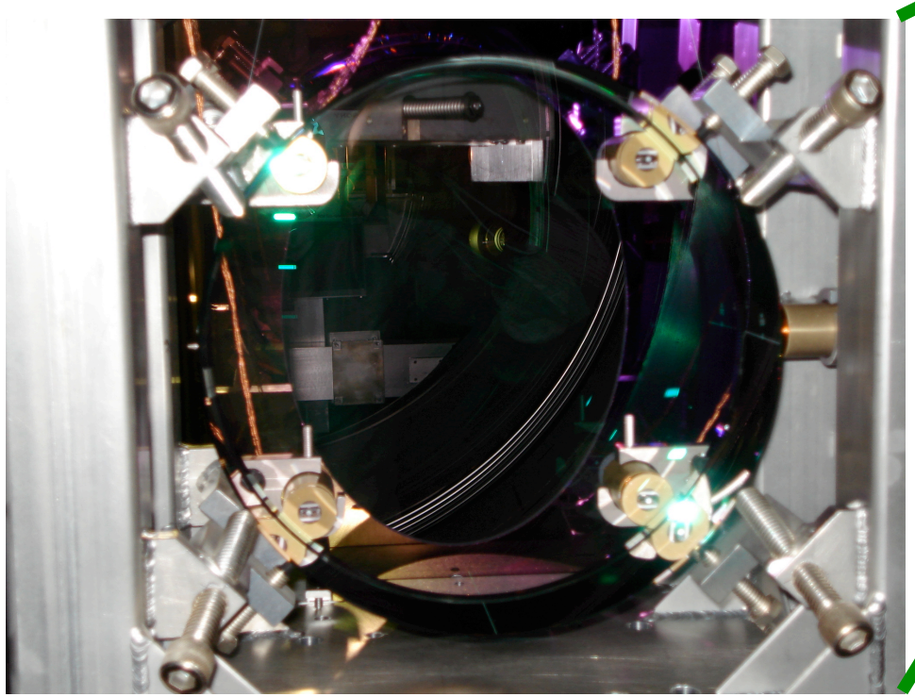


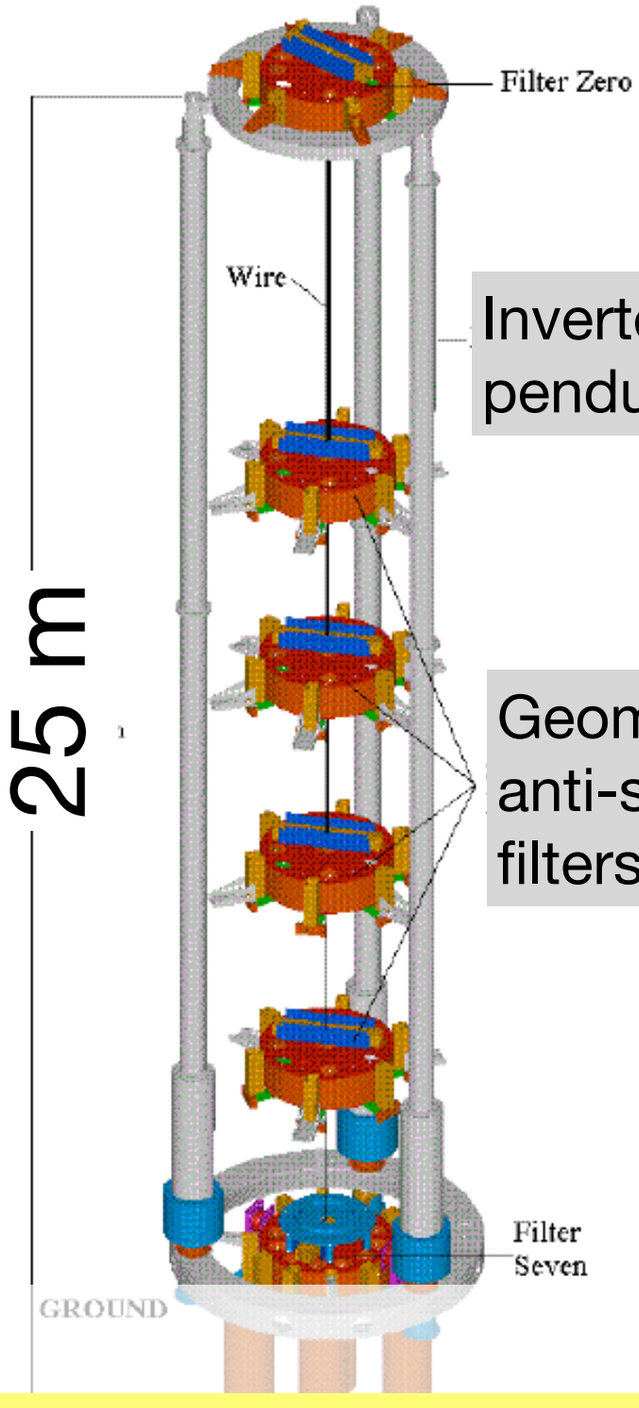
LHO Test Mass

LLO 4km beamtube

LZH 35W MOPA

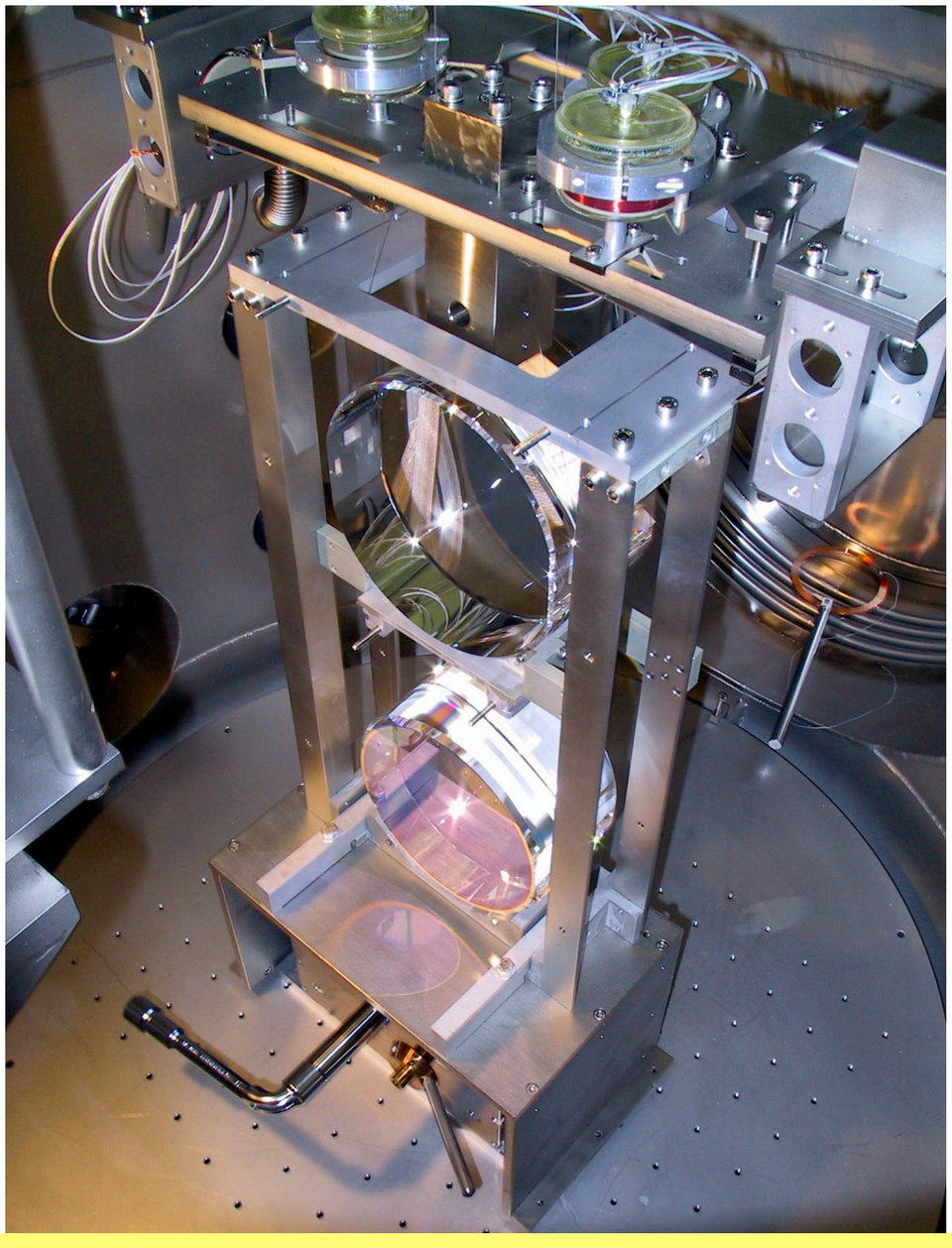
Seismic isolation

Virgo:



Super Attenuator System

GEO:



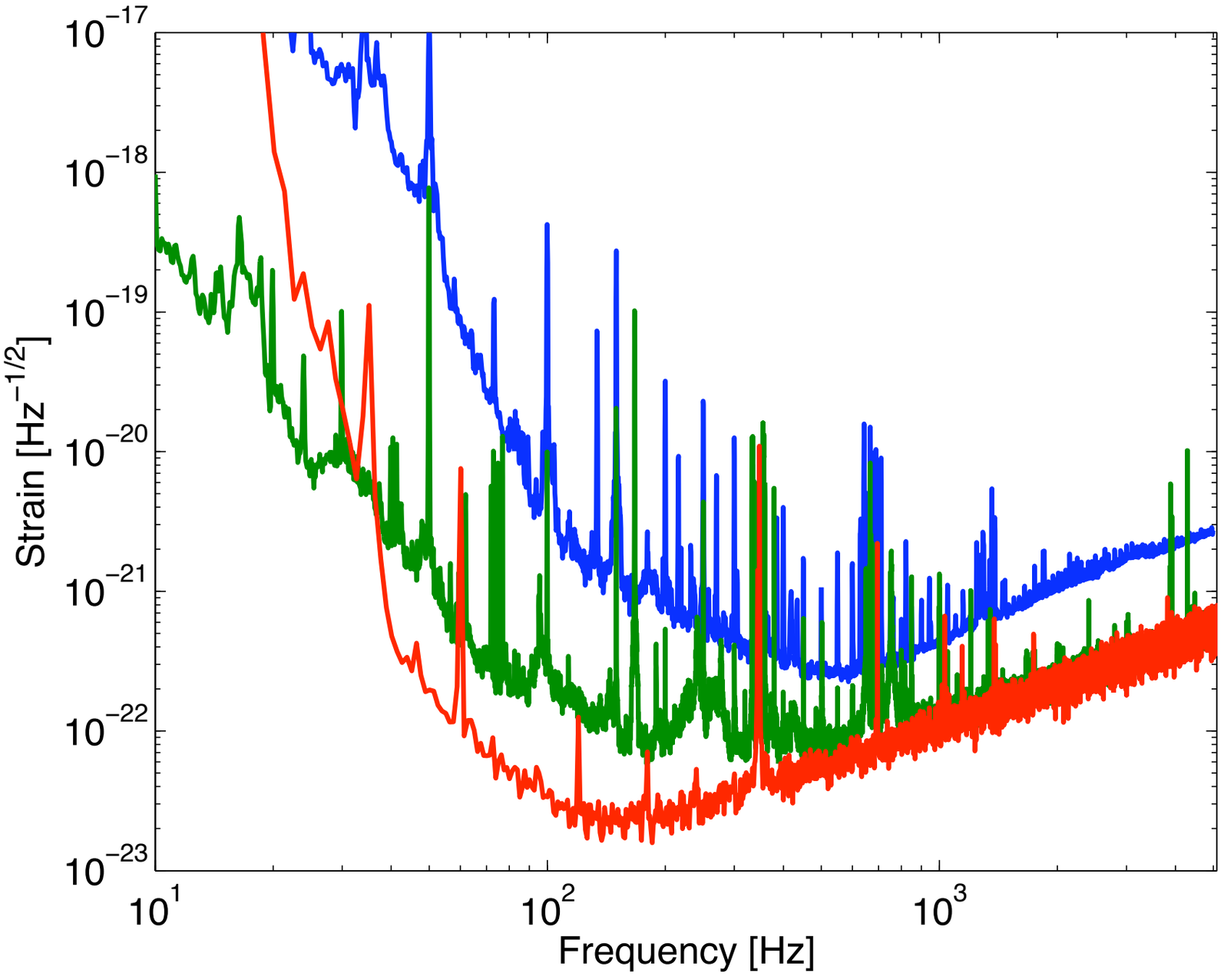
Triple Pendulum Suspension

Outline

GW detectors

GEO, VIRGO, LIGO

Future upgrades



Worldwide network

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LHO

GEO

CLIO
TAMA
LCGT

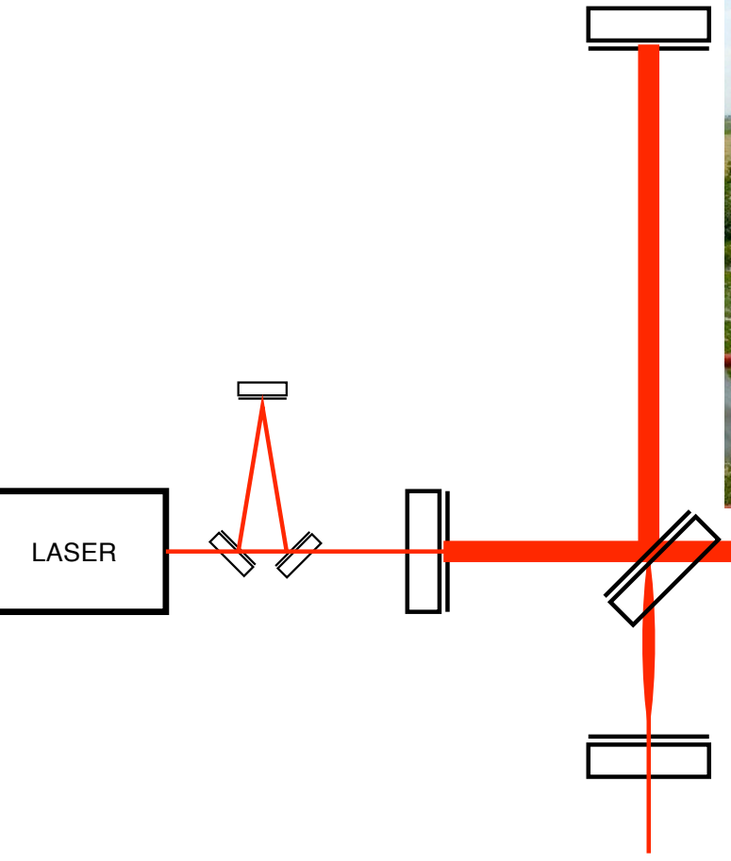
LLO

Virgo

Earth at Night
More information available at:
http://antwrp.gsfc.nasa.gov/apod/ap020811.html

Astronomy Picture of the Day
2002 August 11
http://antwrp.gsfc.nasa.gov/apod/astropix.html

GEO 600

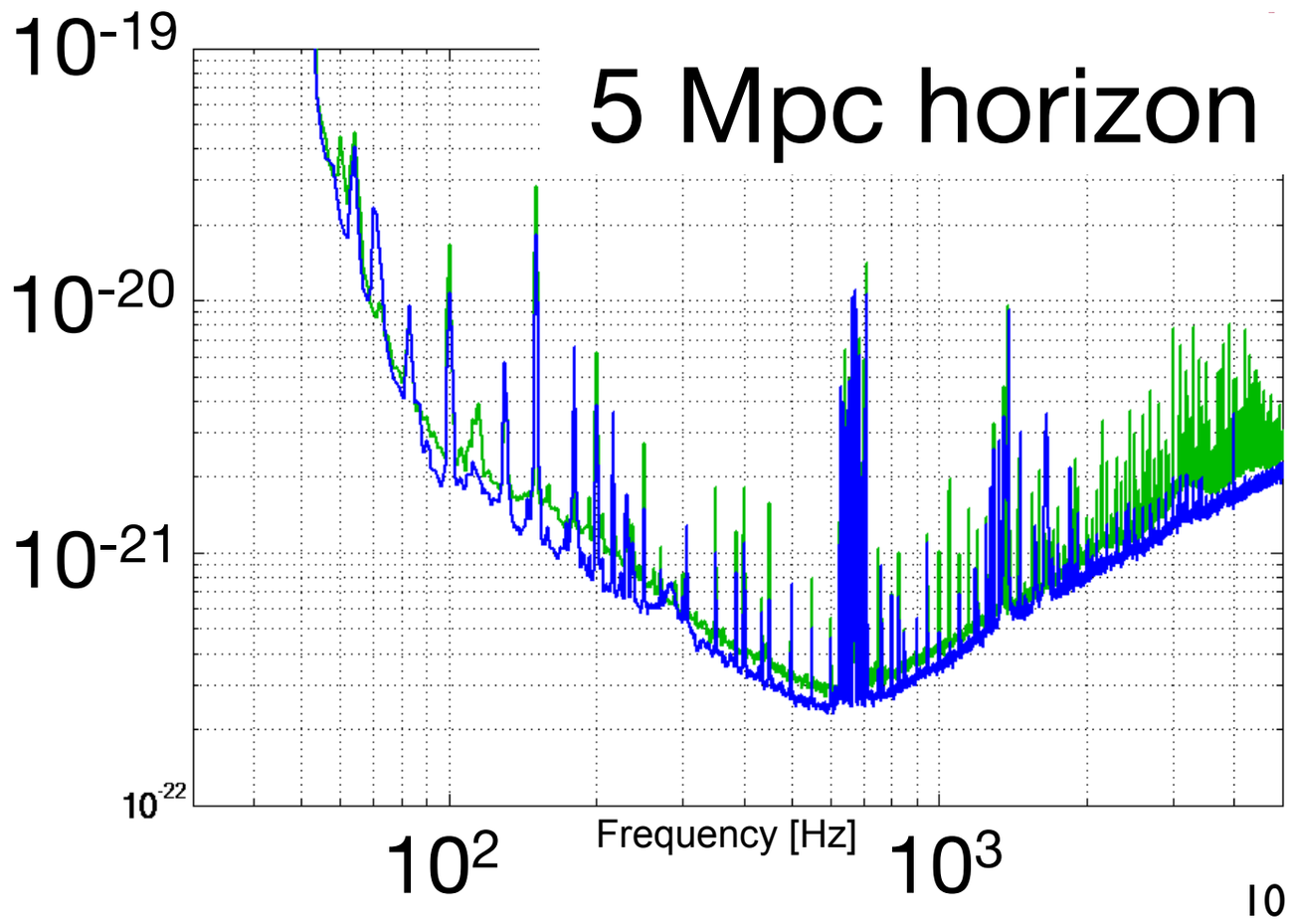


Near Hannover, Germany

600 m folded arms

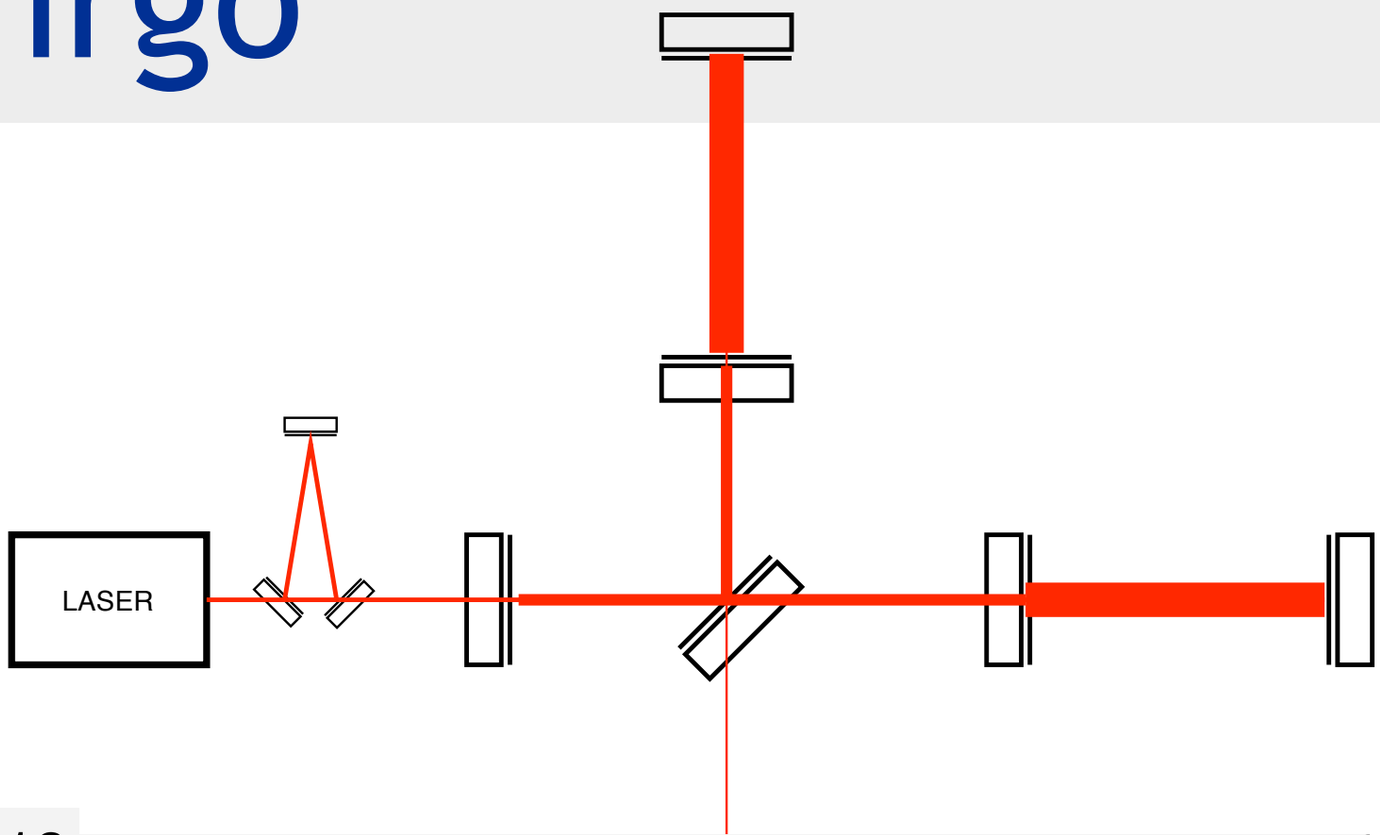
Dual recycled Michelson

Triple pendulum suspensions



LIGO

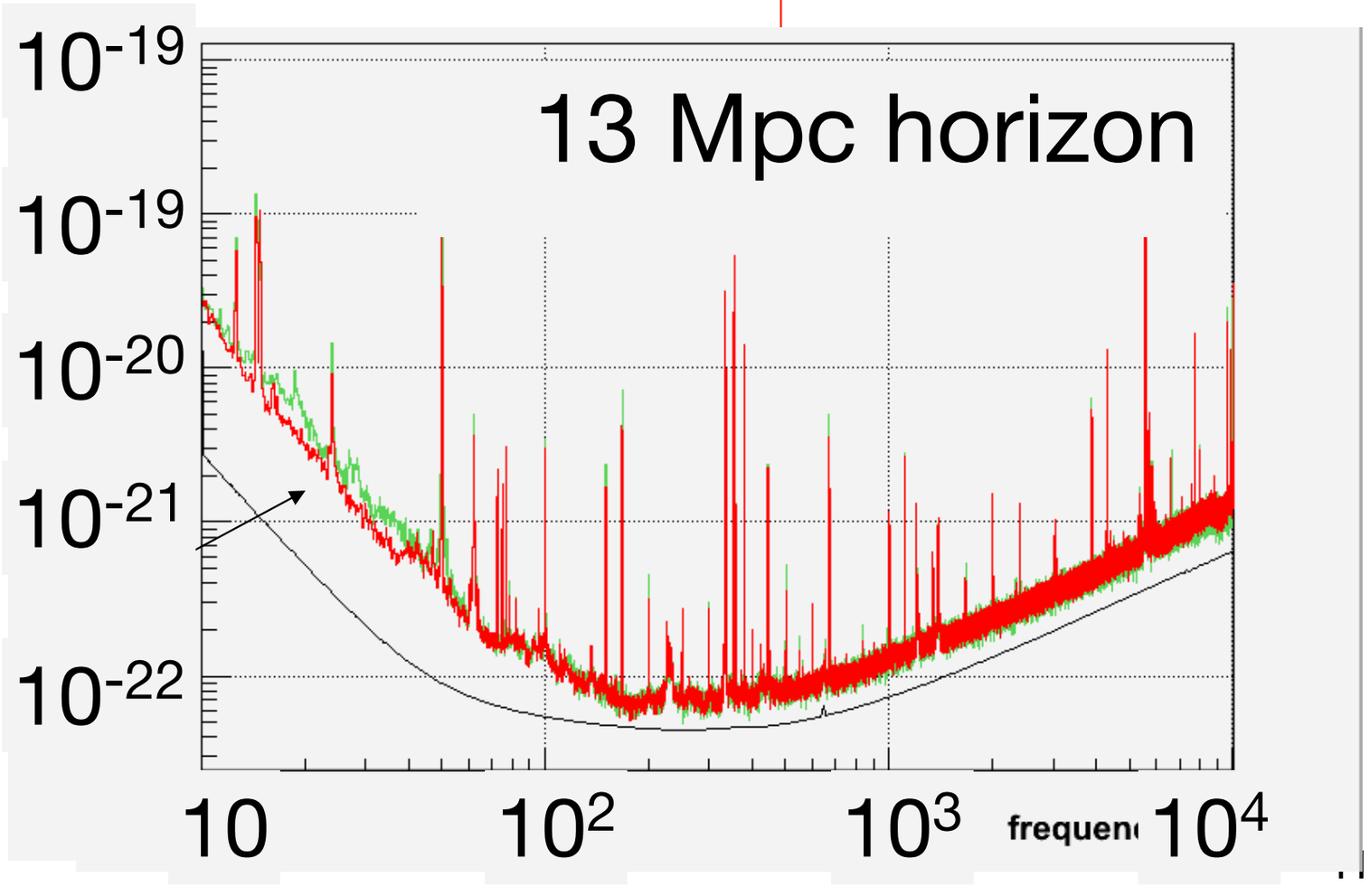
Virgo



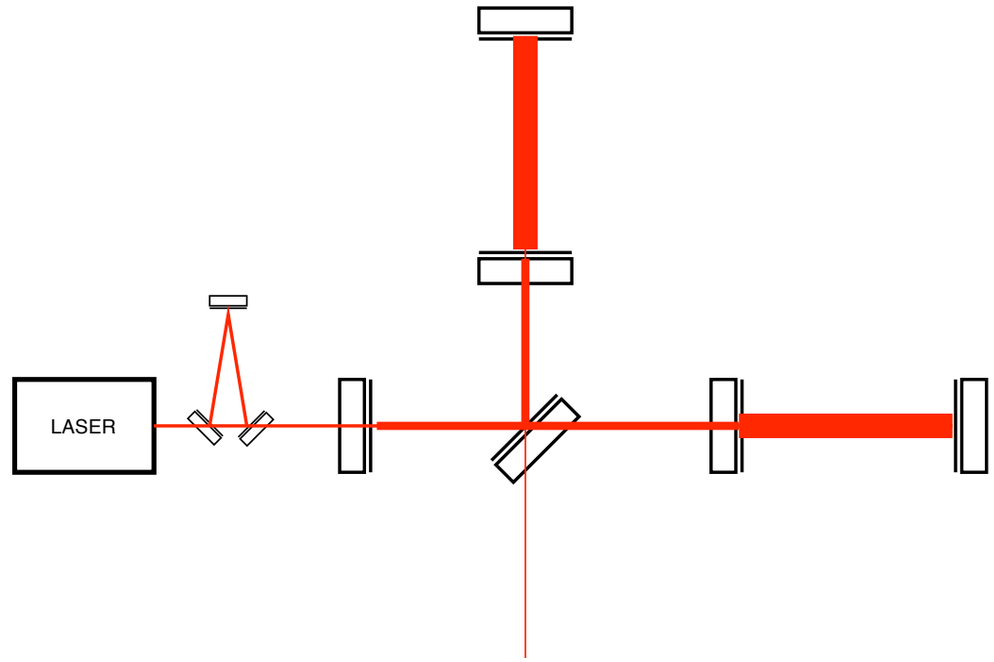
Near Pisa, Italy

3 km power recycled Fabry-Perot Michelson

Super-attenuator seismic isolation



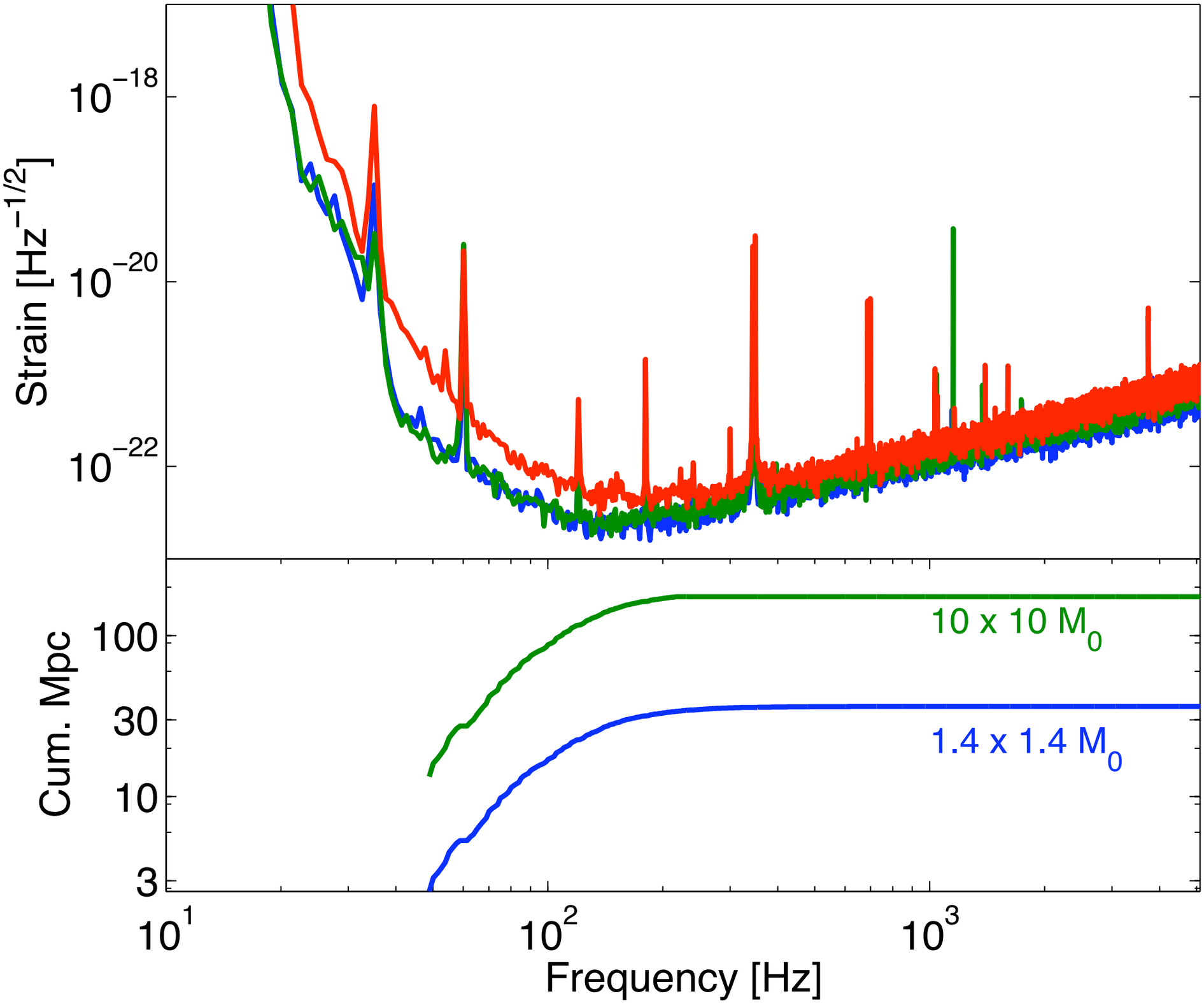
LIGO



3 IFOs at 2 sites in Hanford, WA & Livingston, LA

Power recycled Fabry-Perot Michelson

LIGO performance



NS/NS horizon

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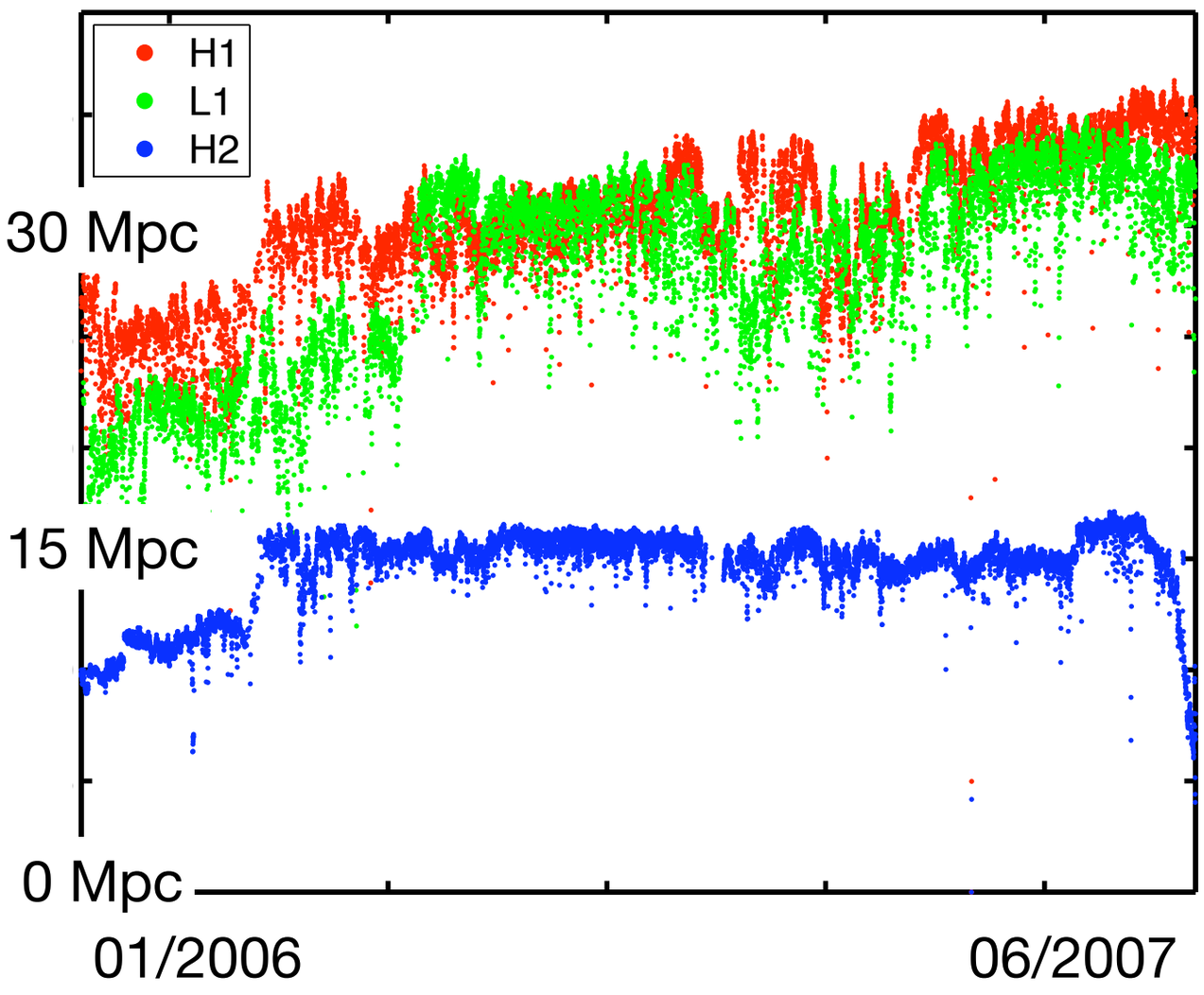
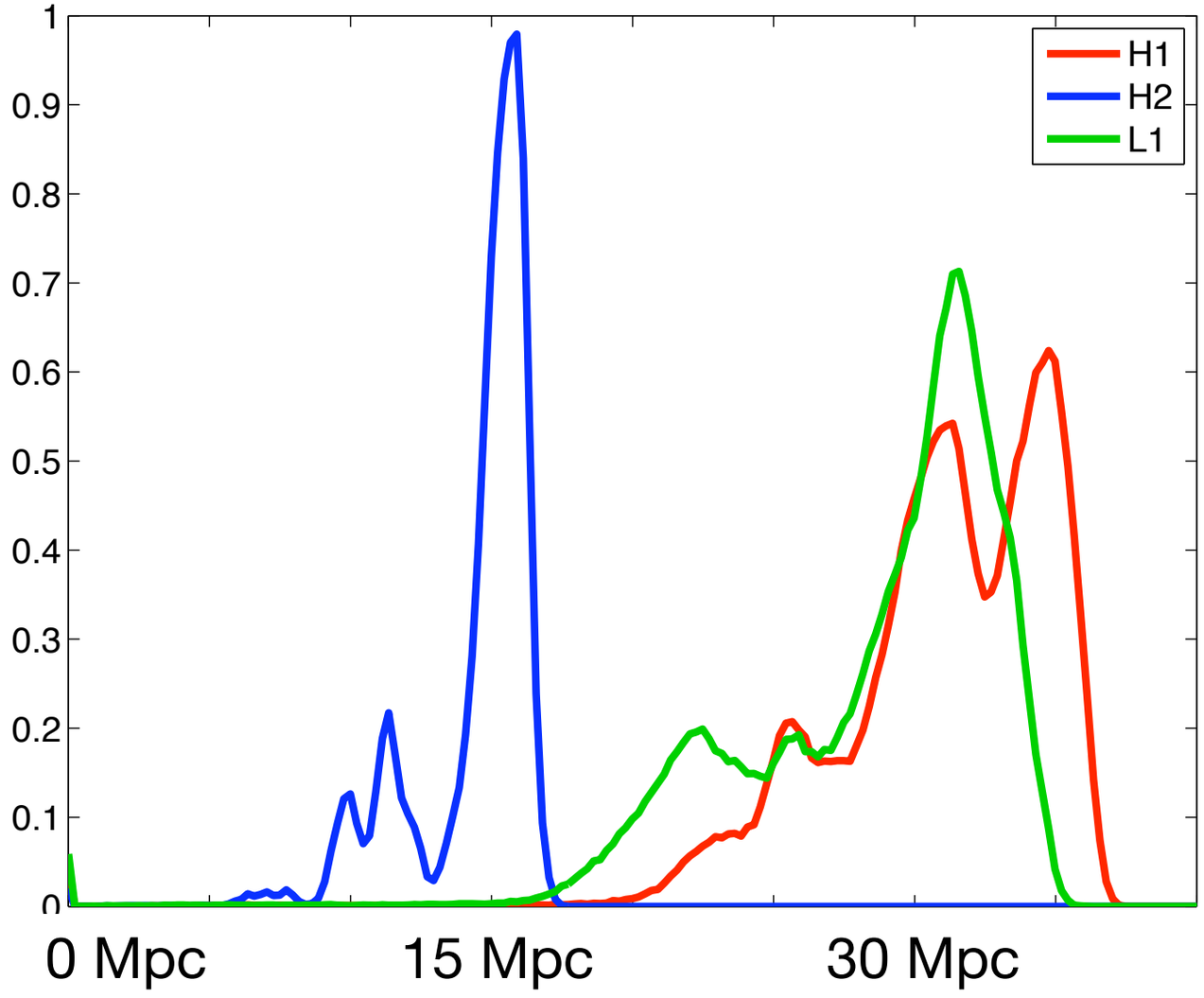
S5 Science run

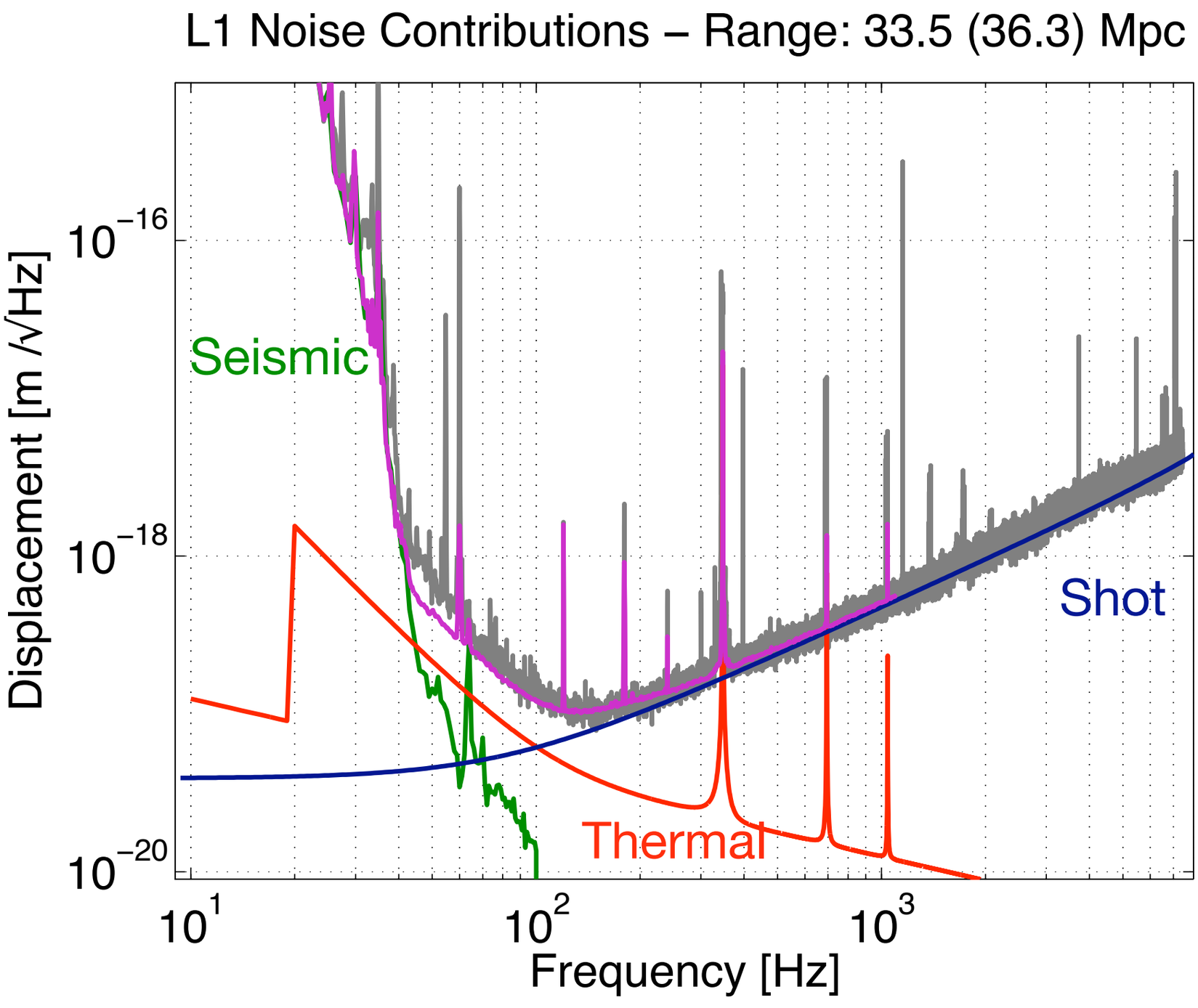




~70% duty factor

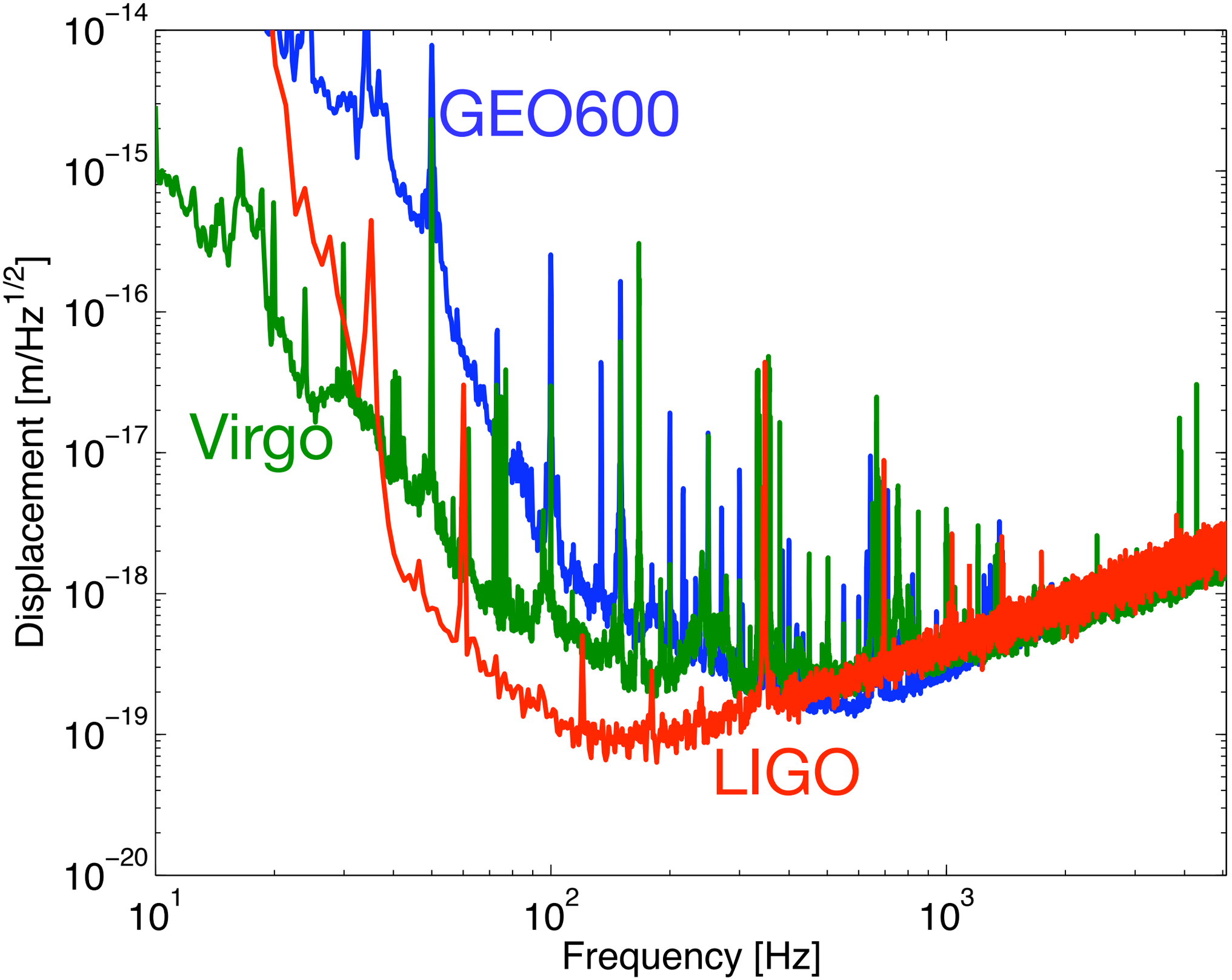
1.4/1.4 M_0 Horizon Distance

Noise Budget (2)



injection/response measurements of noise couplings to test mass displacement

Displacement



Outline

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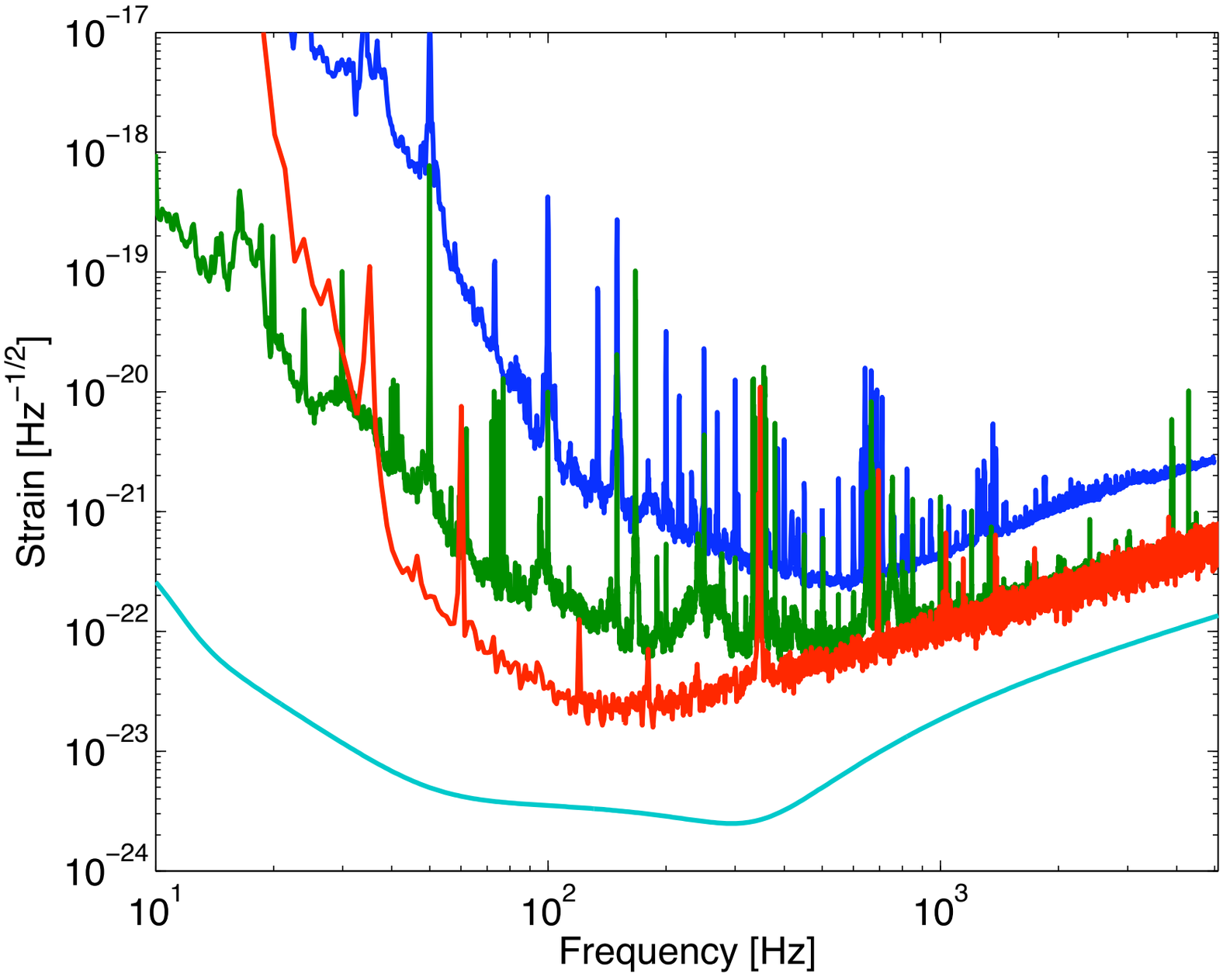
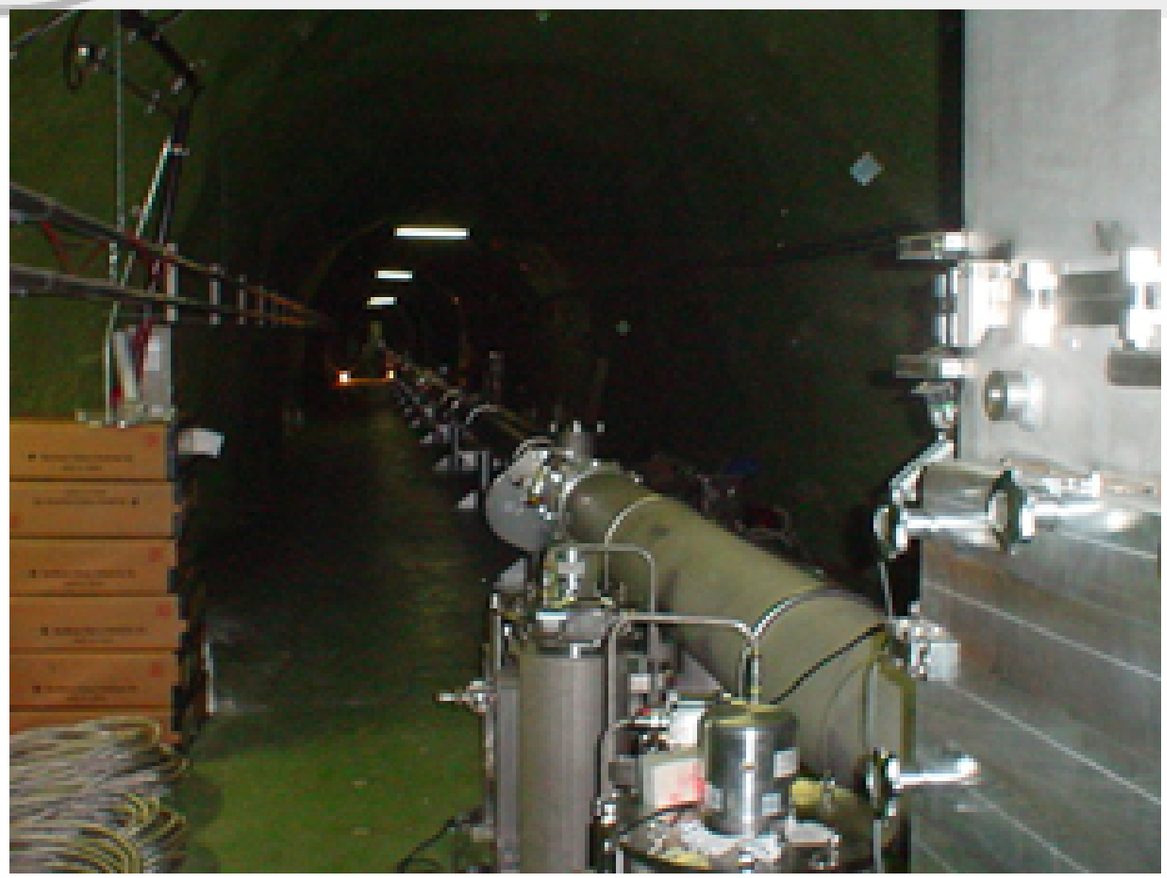
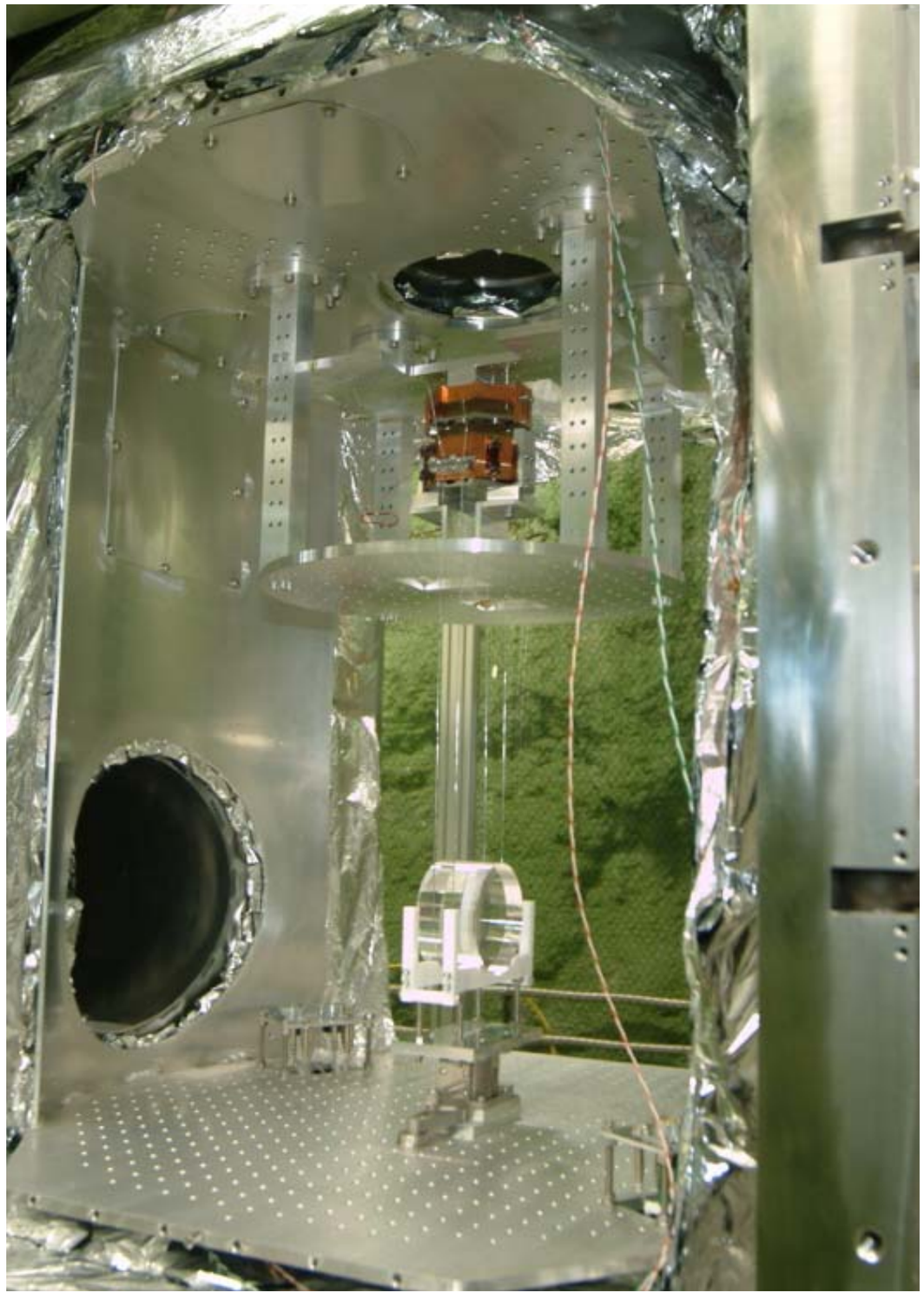


CLIO



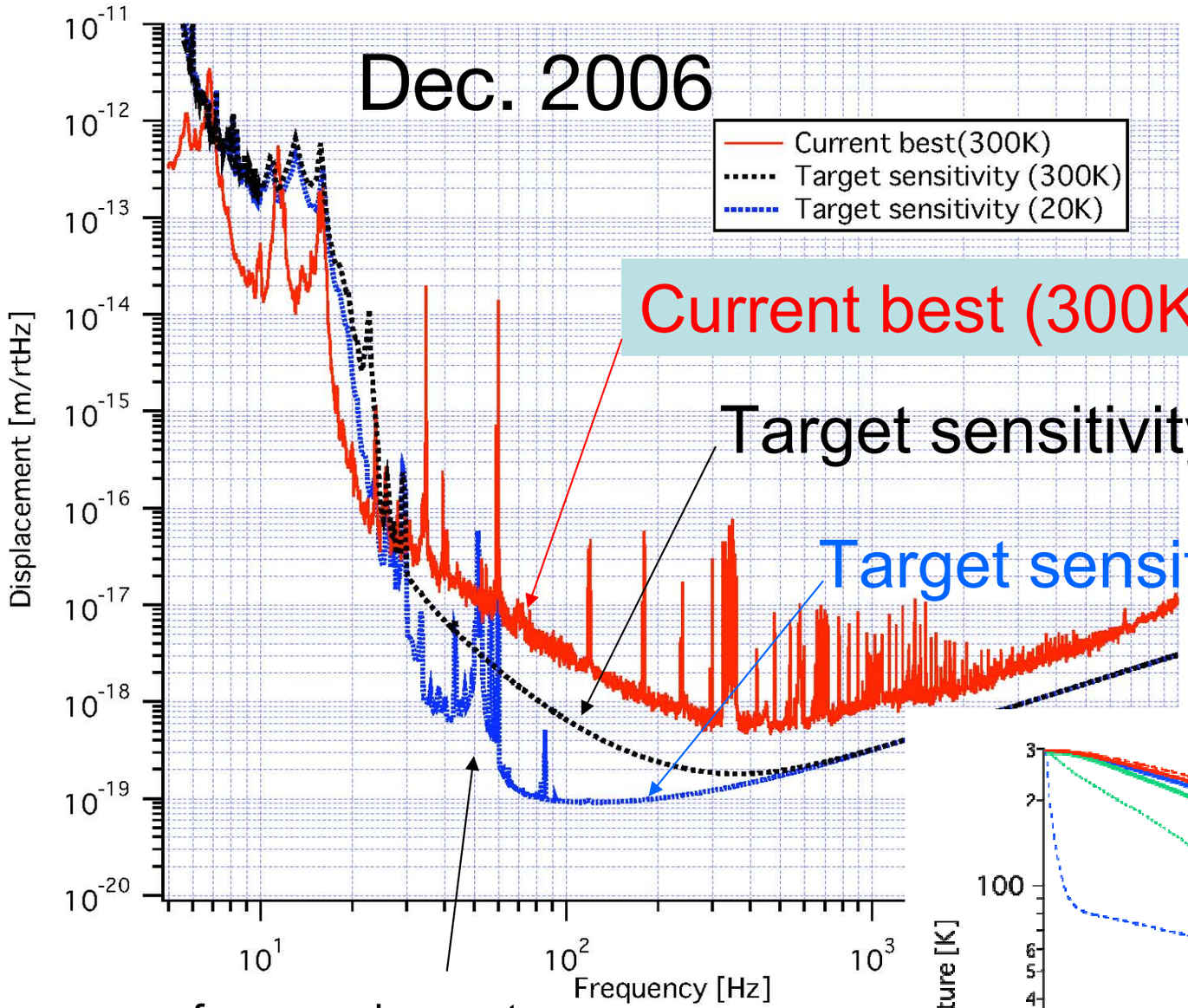


Cryogenic Laser Interferometer Observatory

100m FP Michelson in Kamioka

20 K mirrors, SAS system

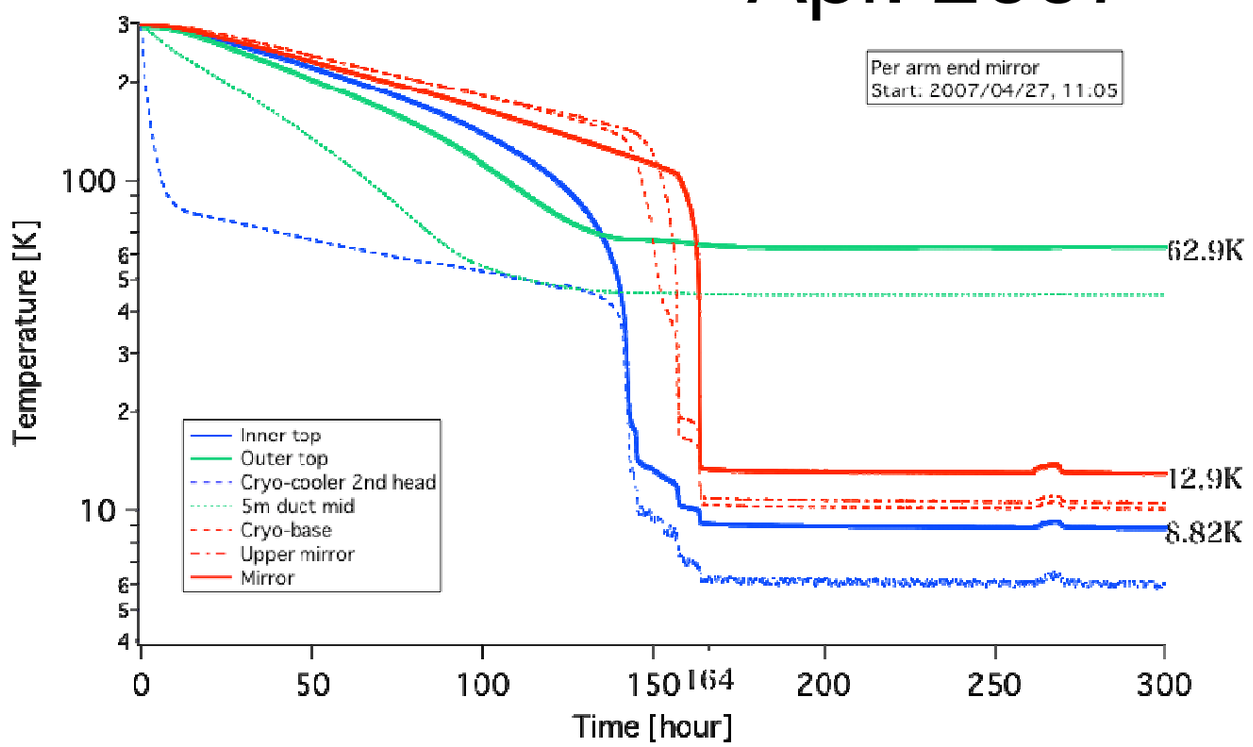
LIGO CLIO 300K performance



Resonance of suspension system

2 kG sapphire test masses

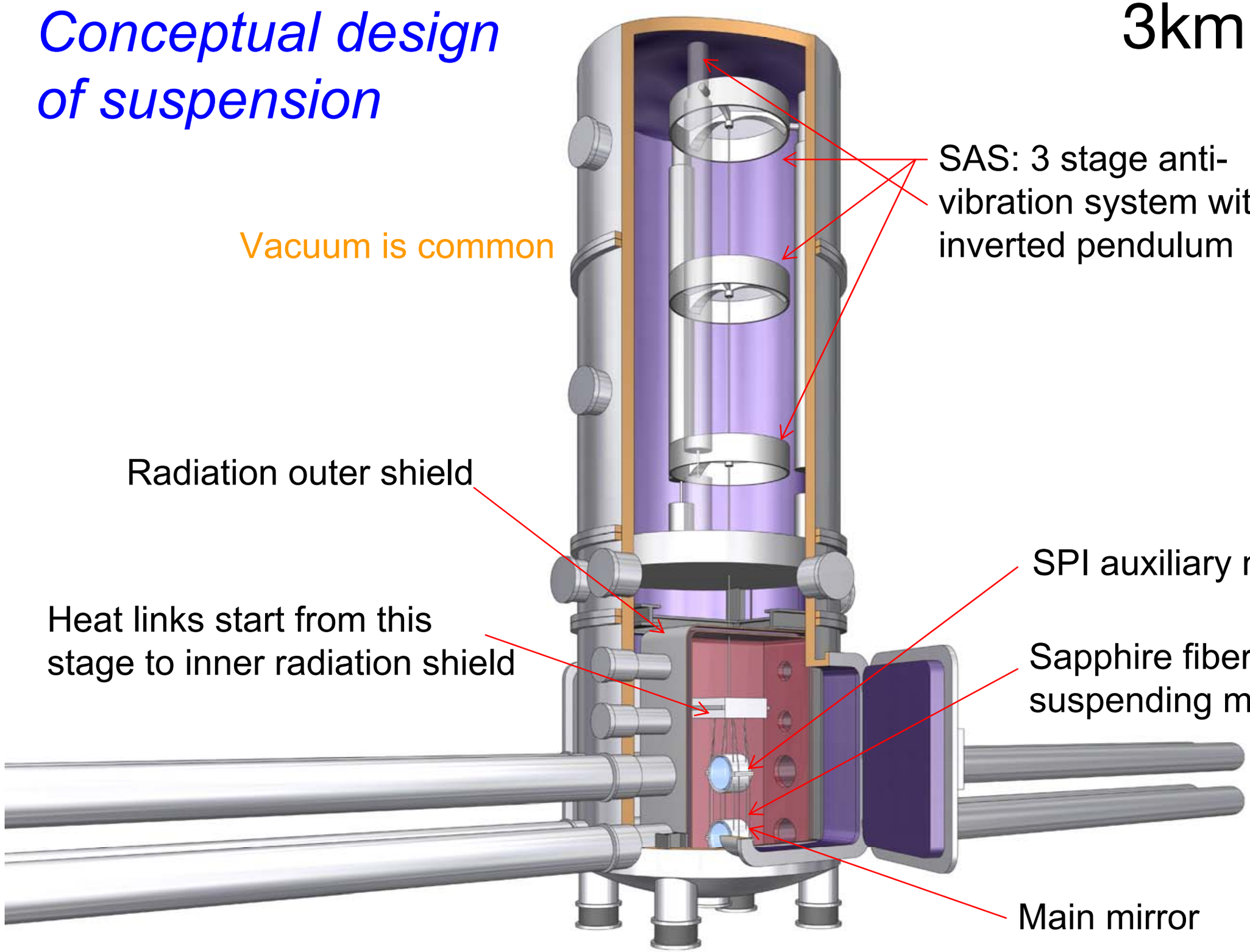
Apr. 2007



from K. Kuroda 03/2008

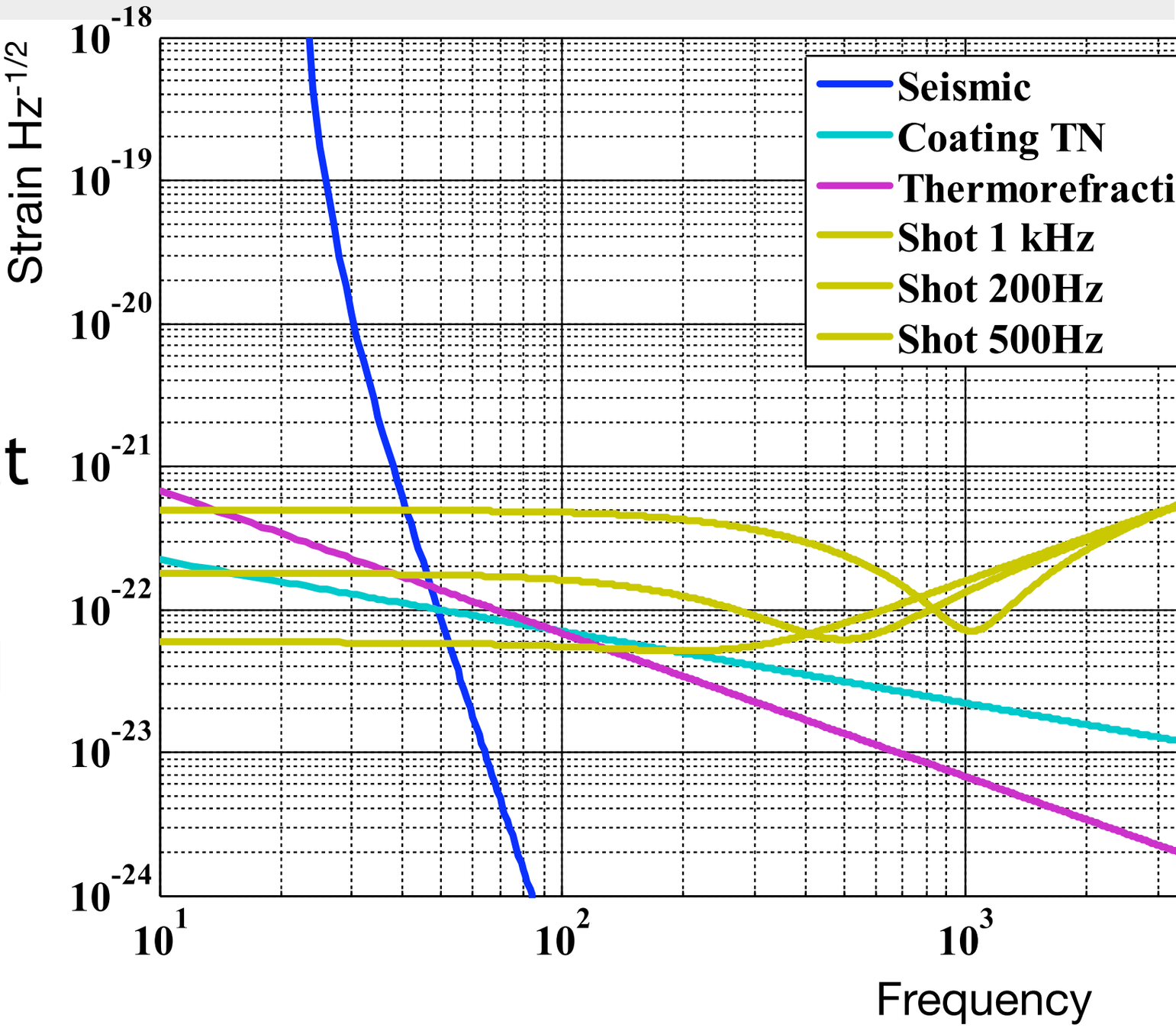
Conceptual design of suspension

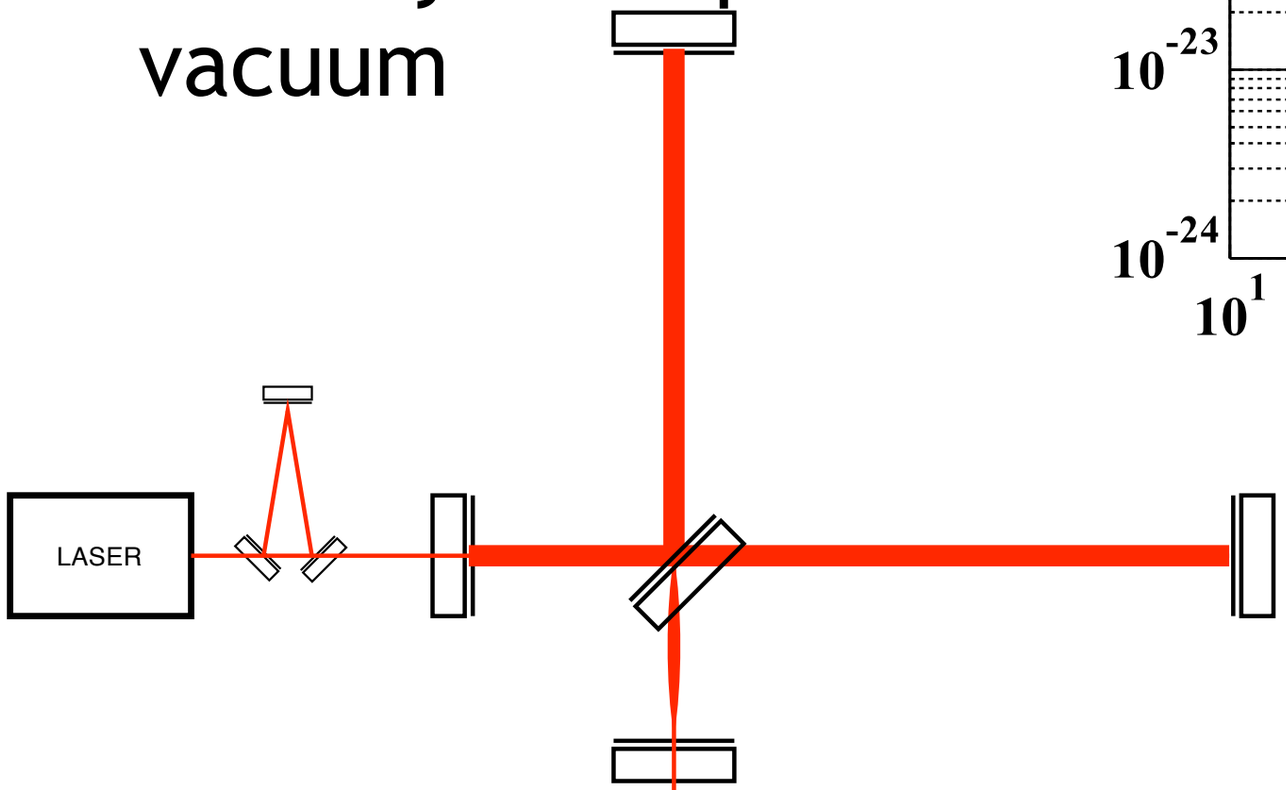
3km



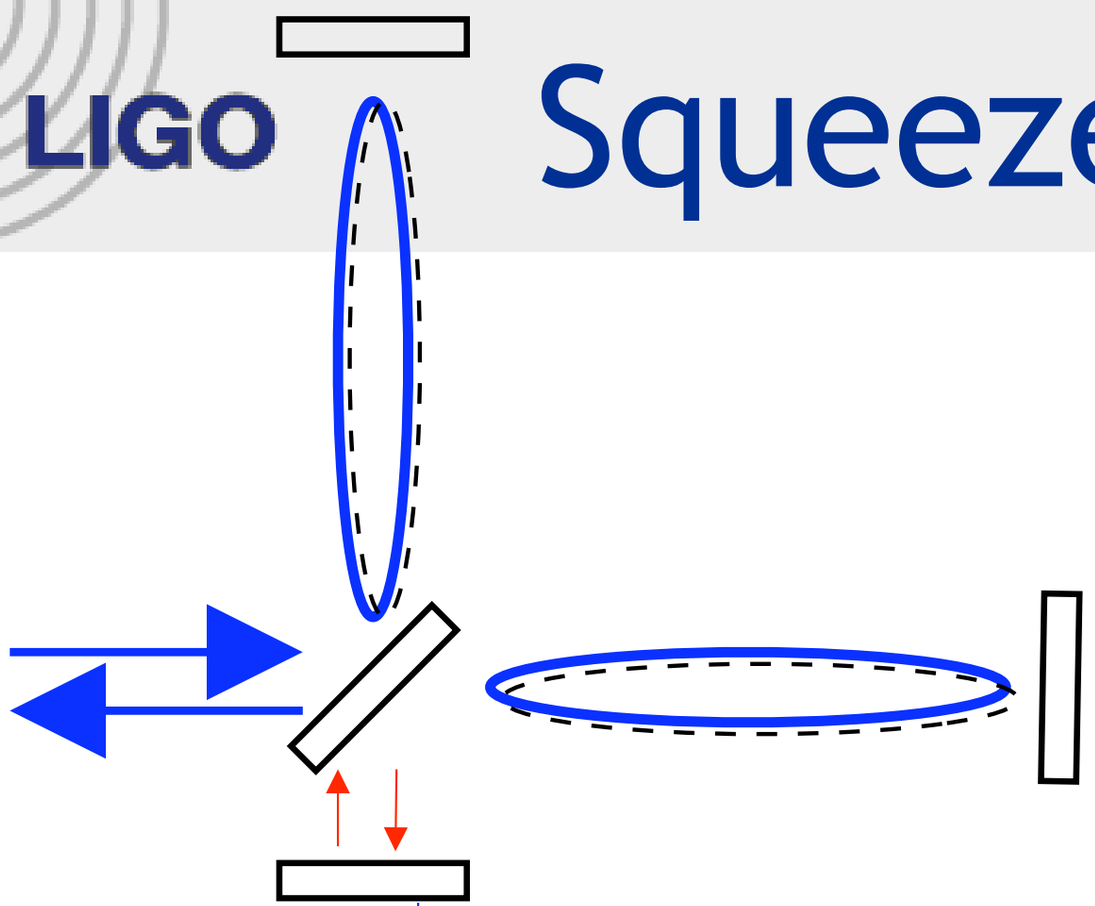
GEO-HF

- High frequency complements long detectors
- Increased power to reach thermal noise at 1 kHz
- Possibly use squeezed vacuum



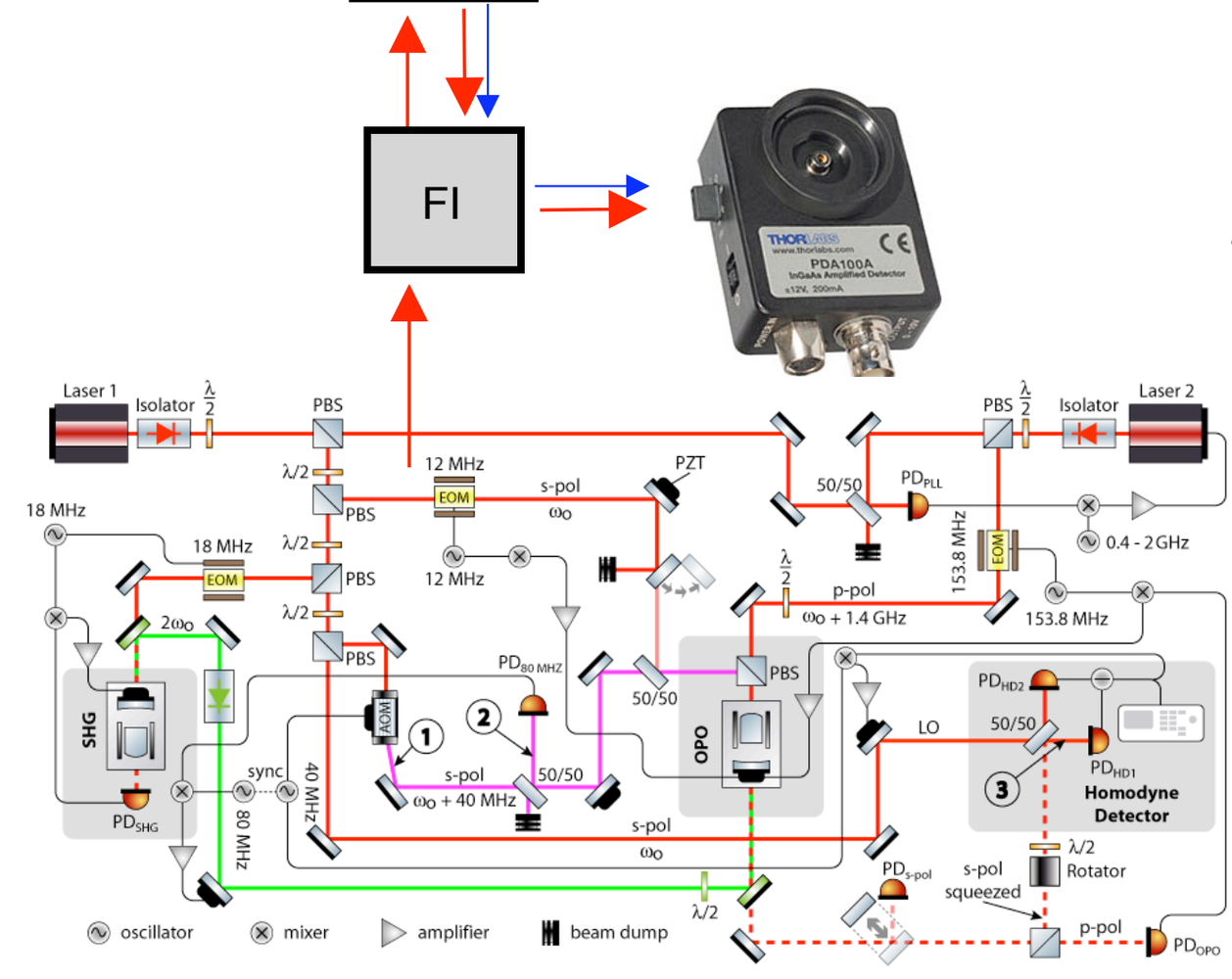


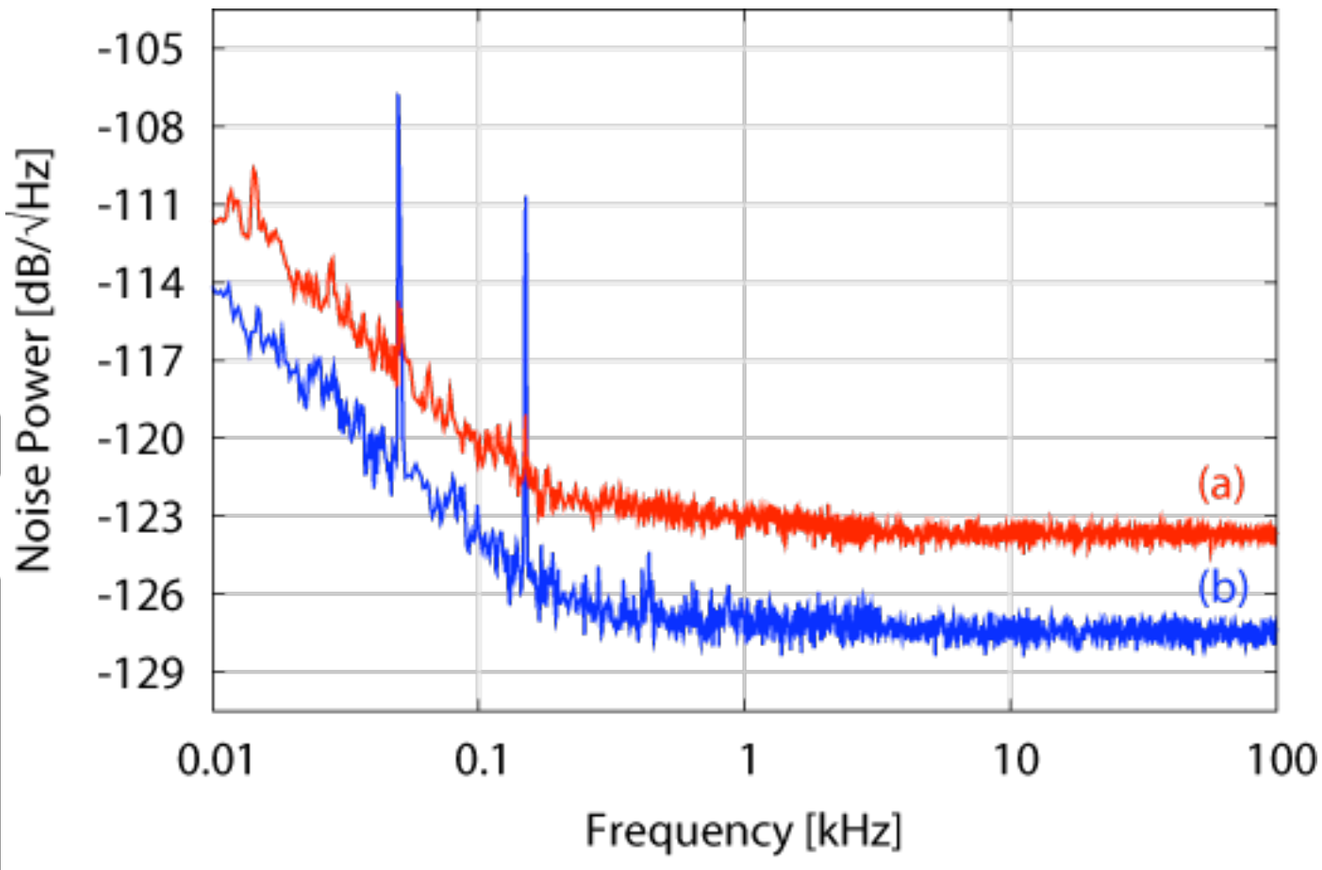
Squeezed vacuum



Inject squeezed vacuum to reduce shot noise by ~4dB

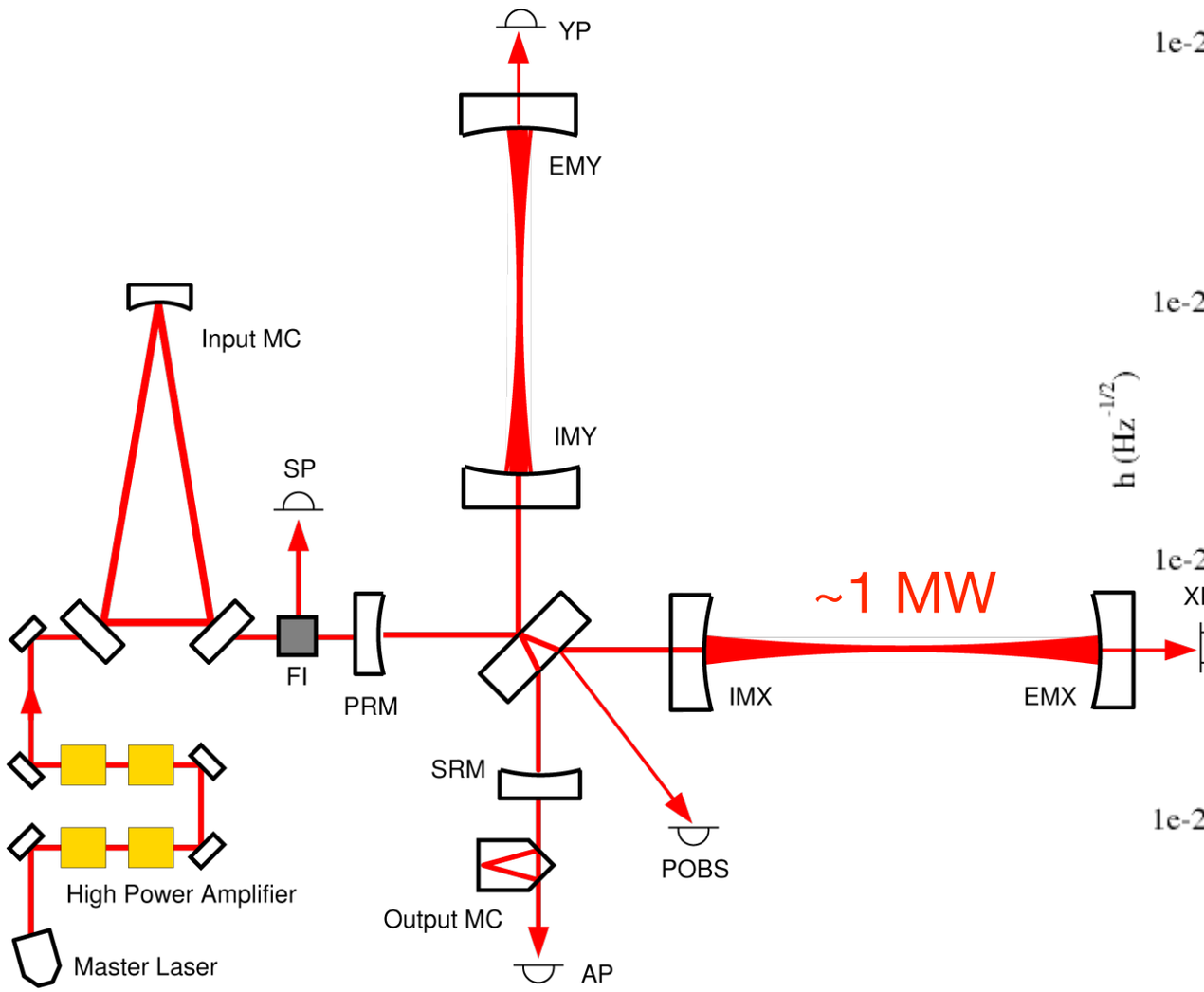
Planning for deployment at GEO Spring 2009

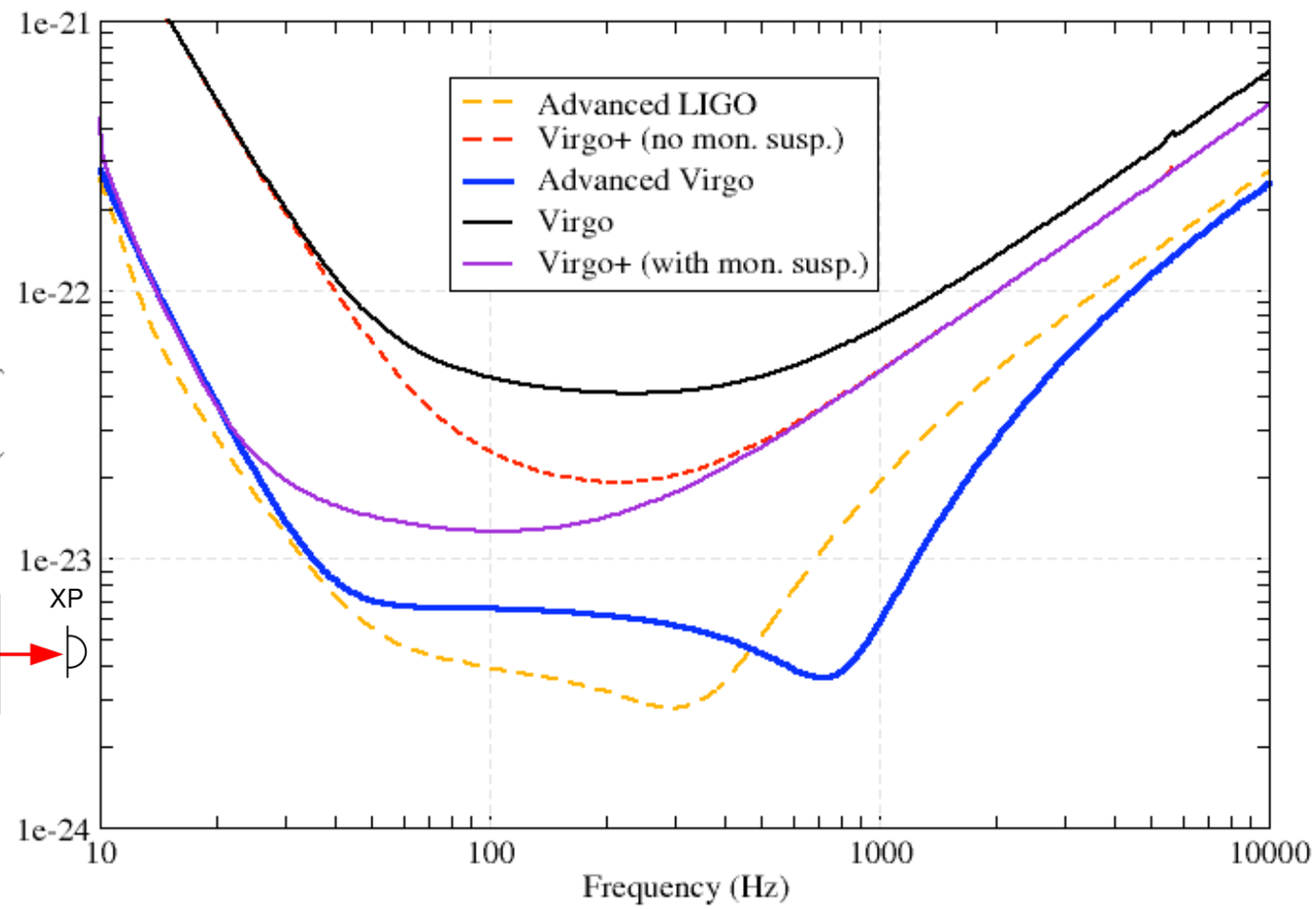




Chelkowski et al: PRA 75, 043814

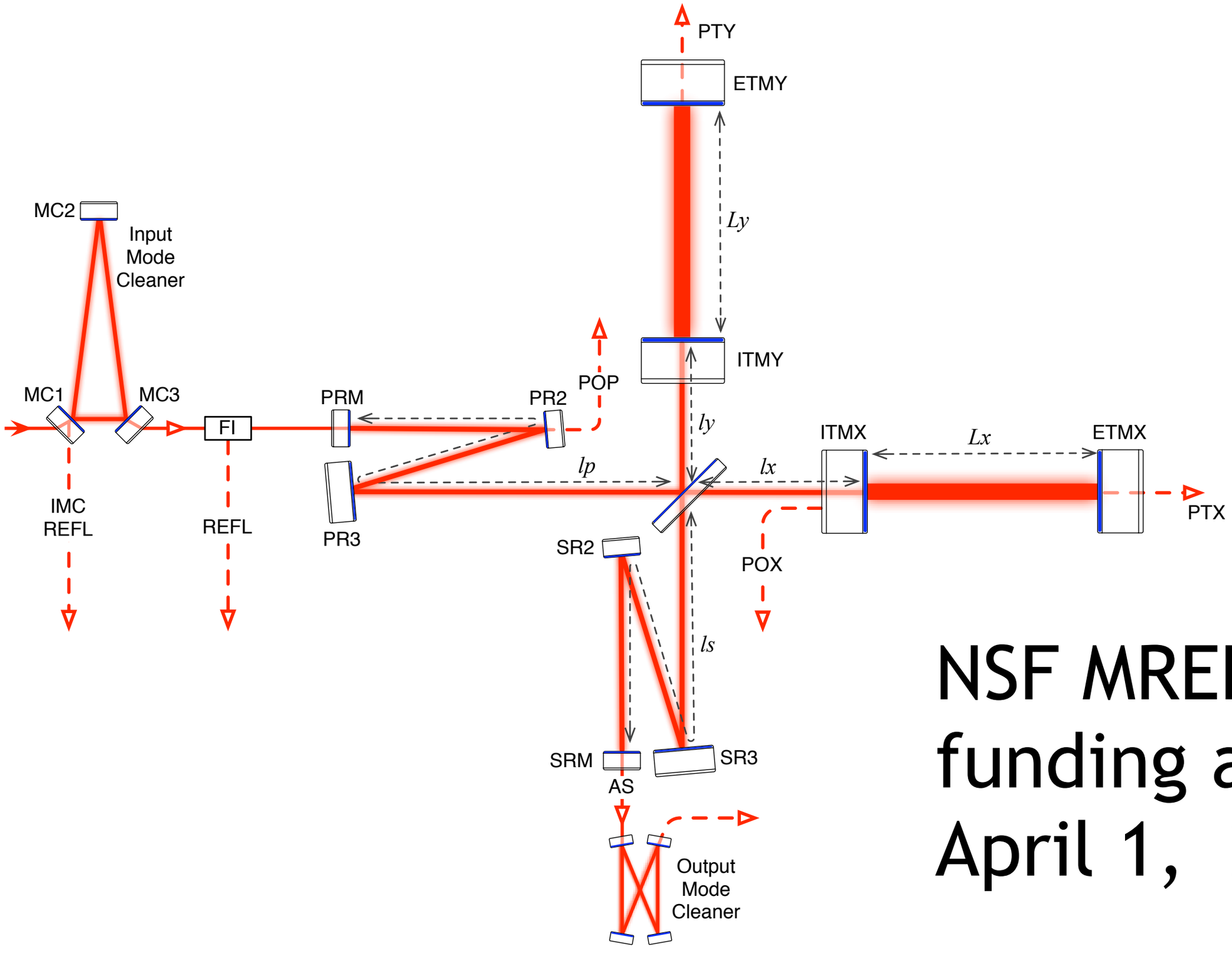
Advanced Virgo





- Improved Super-attenuator mechanics, 6 DOF payload control, Monolithic suspensions
- Signal recycling, increased laser power, adaptive thermal compensation
- Heavier mirrors, low thermal noise coatings

Advanced LIGO



NSF MREFC funding approved April 1, 2008 !

aLIGO vs LIGO

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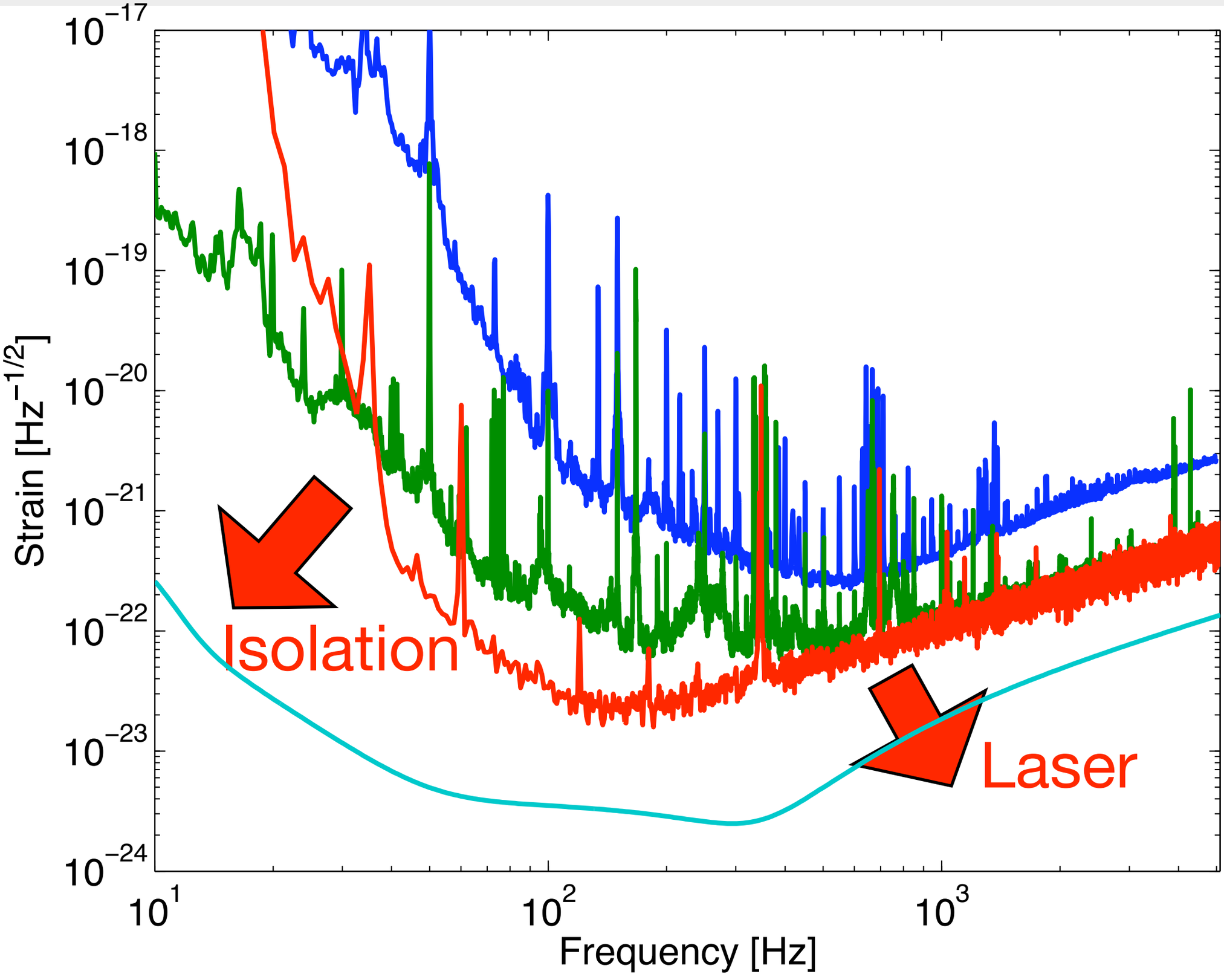
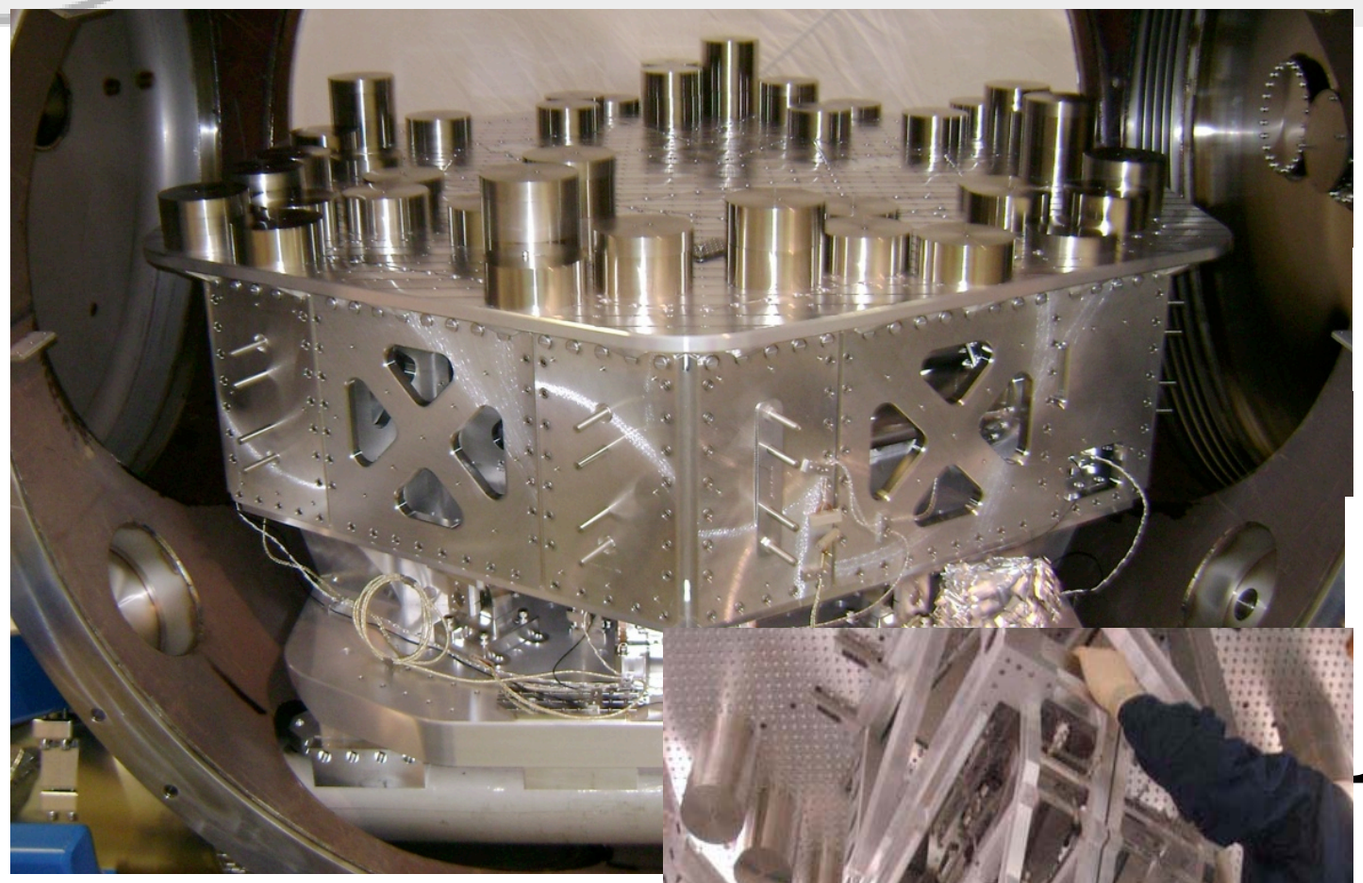
April APS '08

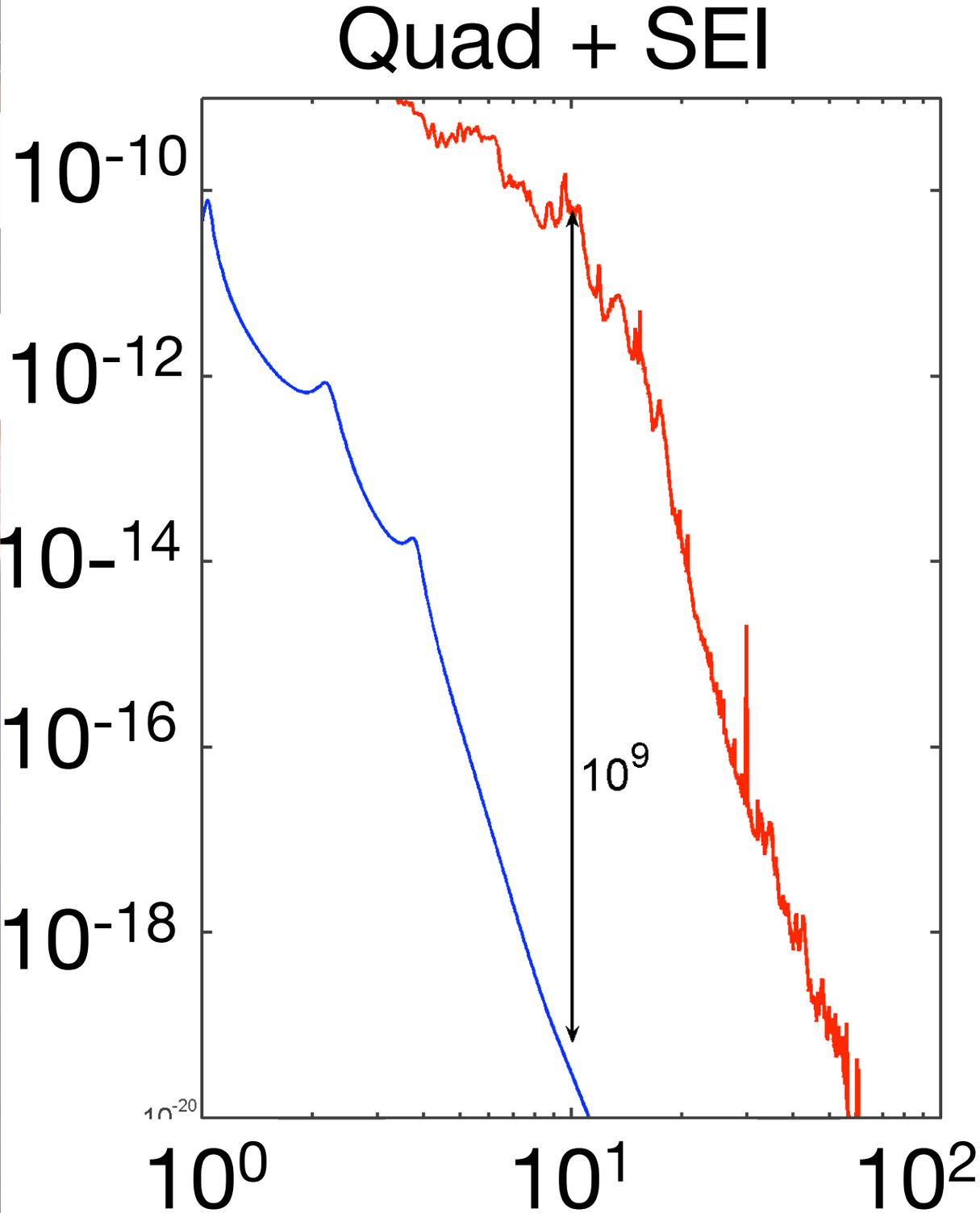


Active isolation



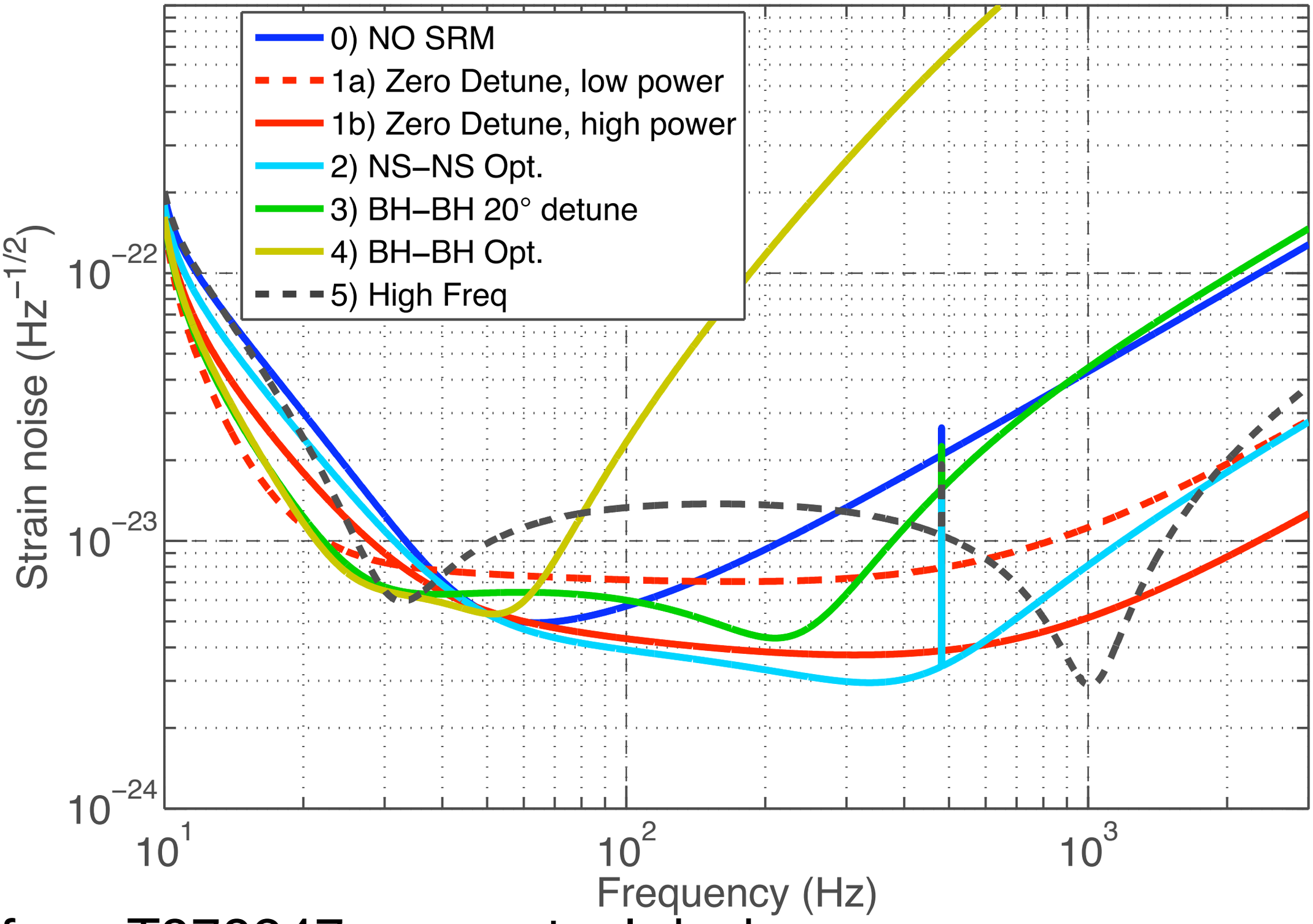
HAM ISI at Livingston
Feb. 20, 2008
DeBra et al. Stanford

Noise prototype at
LASTI, MIT 2008
UK GEO group



aLIGO sensitivity

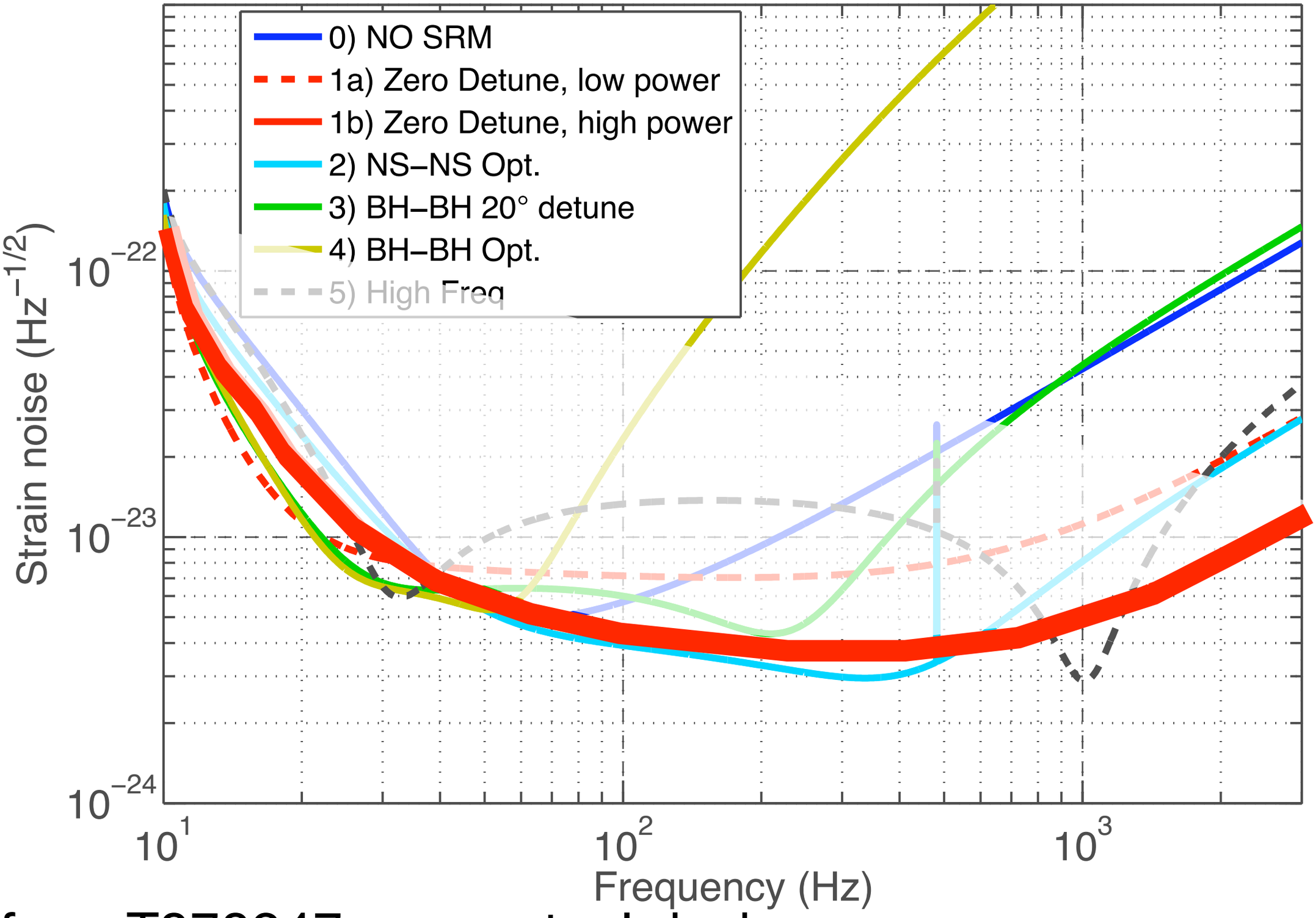
Waldman
April APS '08



from T070247 conceptual design

aLIGO sensitivity

Waldman
April APS '08



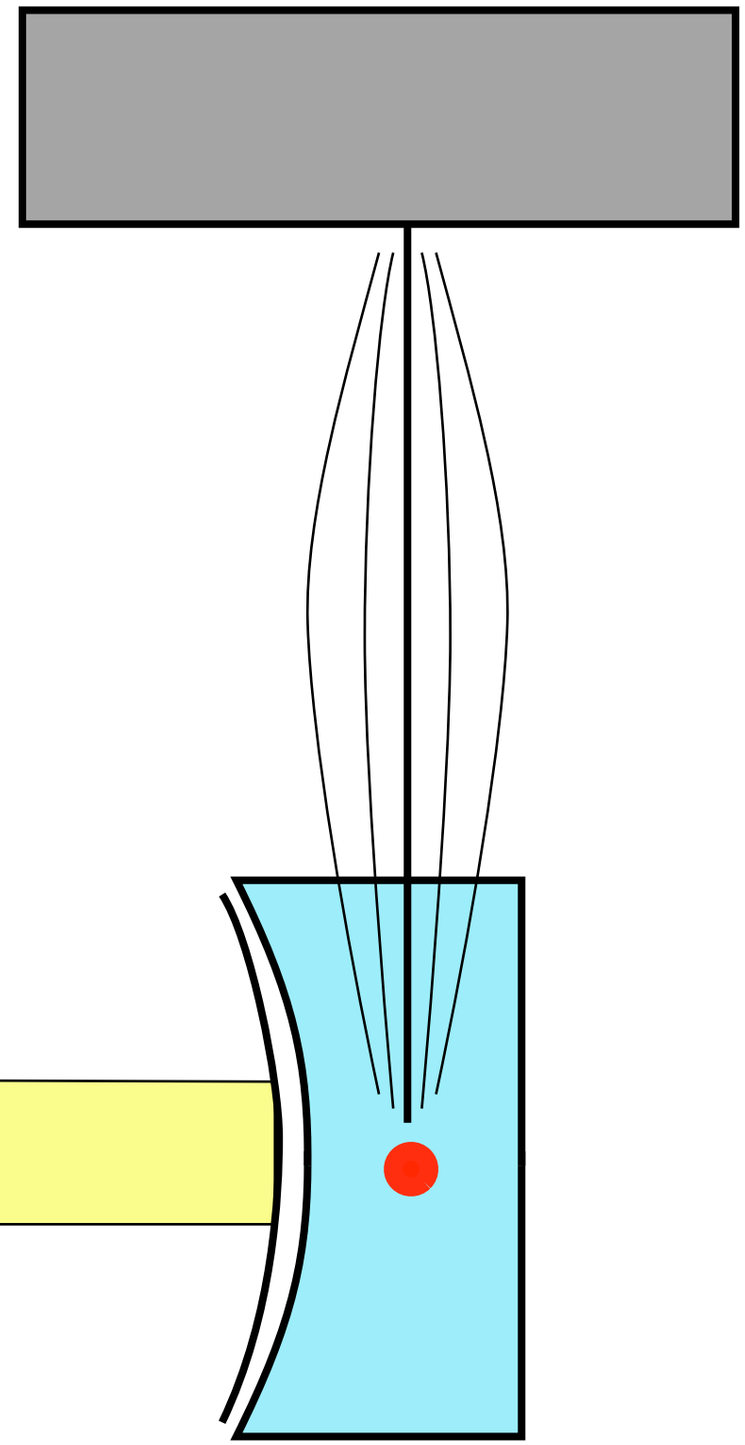
from T070247 conceptual design

Heisenberg microscope

Waldman
April APS '08

"Light enforced quantum uncertainty"

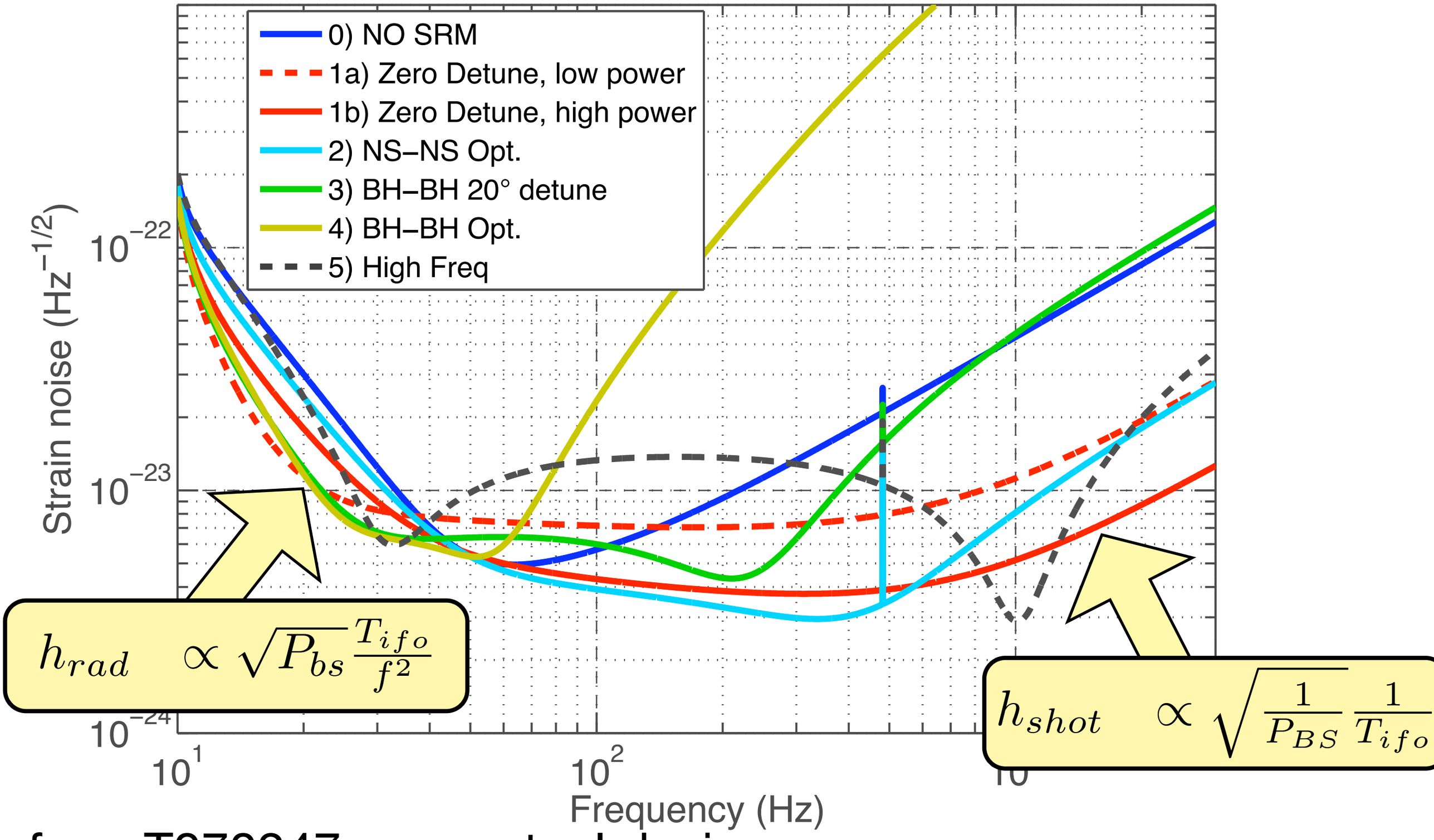
$$\delta x \geq \sqrt{\frac{\hbar}{2M\omega}}$$



Laser readout of the test mass position changes the test mass position

Quantum noise

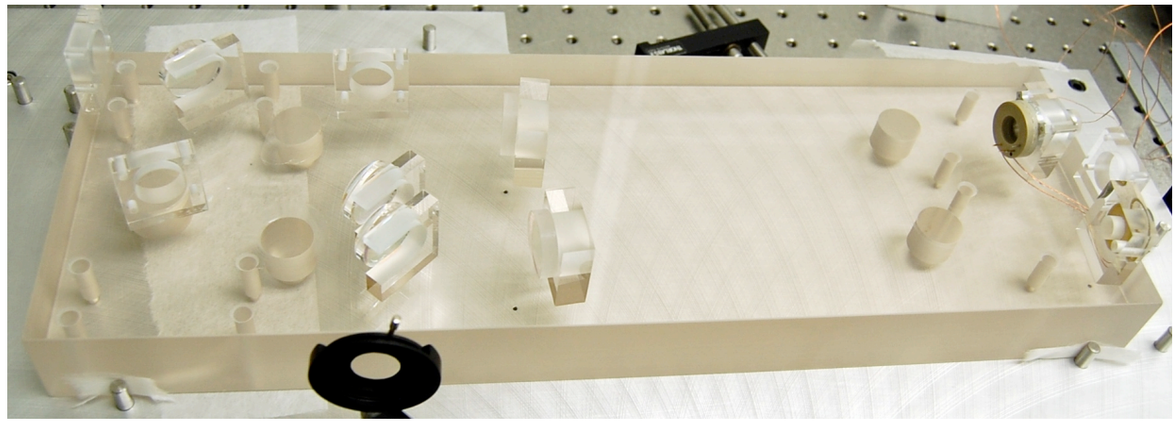
Waldman
April APS '08

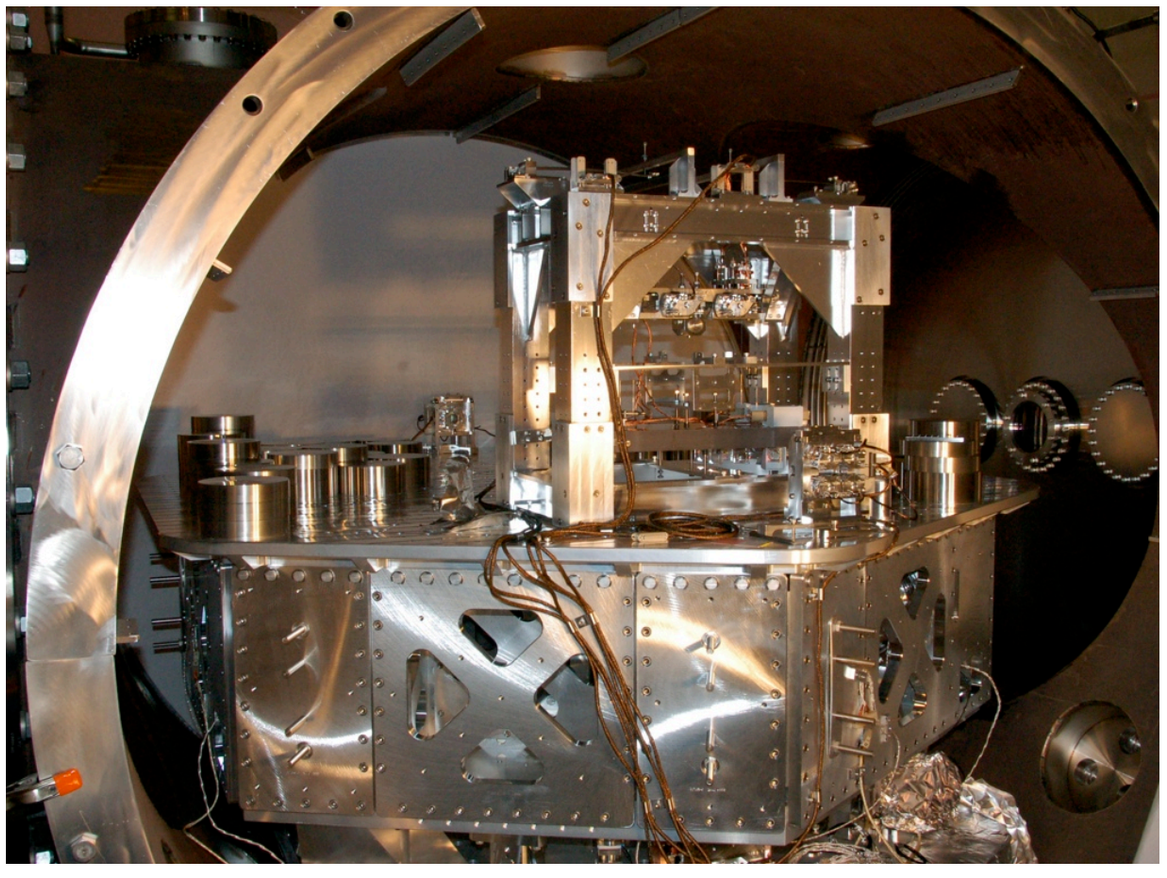


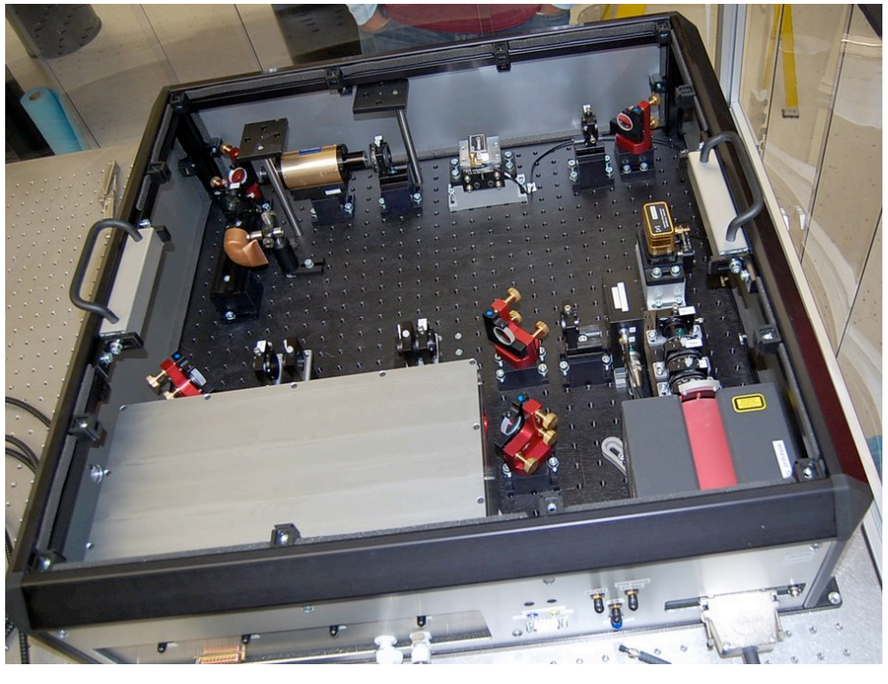
from T070247 conceptual design

Enhanced LIGO

- ~1 year science run at 2x S5 sensitivity starting 2009
- Prototype aLIGO technologies
  - DC readout
  - Active seismic isolation
  - High(er) power
  - Low frequency noise
- ~10x increase in detection rate!







Conclusions

- h = 3 x 10^{-22} in a 100 Hz band, dx ~1.4 x 10^{-18} m
- Noise sources well understood for LIGO, Virgo, GEO
- 1 year data at design sensitivity, 70% single IFO duty factor
- Next generation technologies installed at the observatories 2008-2010
- Enhanced IFOs with ~2x range, ~10x rate in 2009
- CLIO, LCGT, GEO-HF, Advanced Virgo in development
- Advanced LIGO underway, first IFO 2012

GW Astronomy

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April APS '08

1.4 x 1.4 M_{sun} NS/NS inspiral

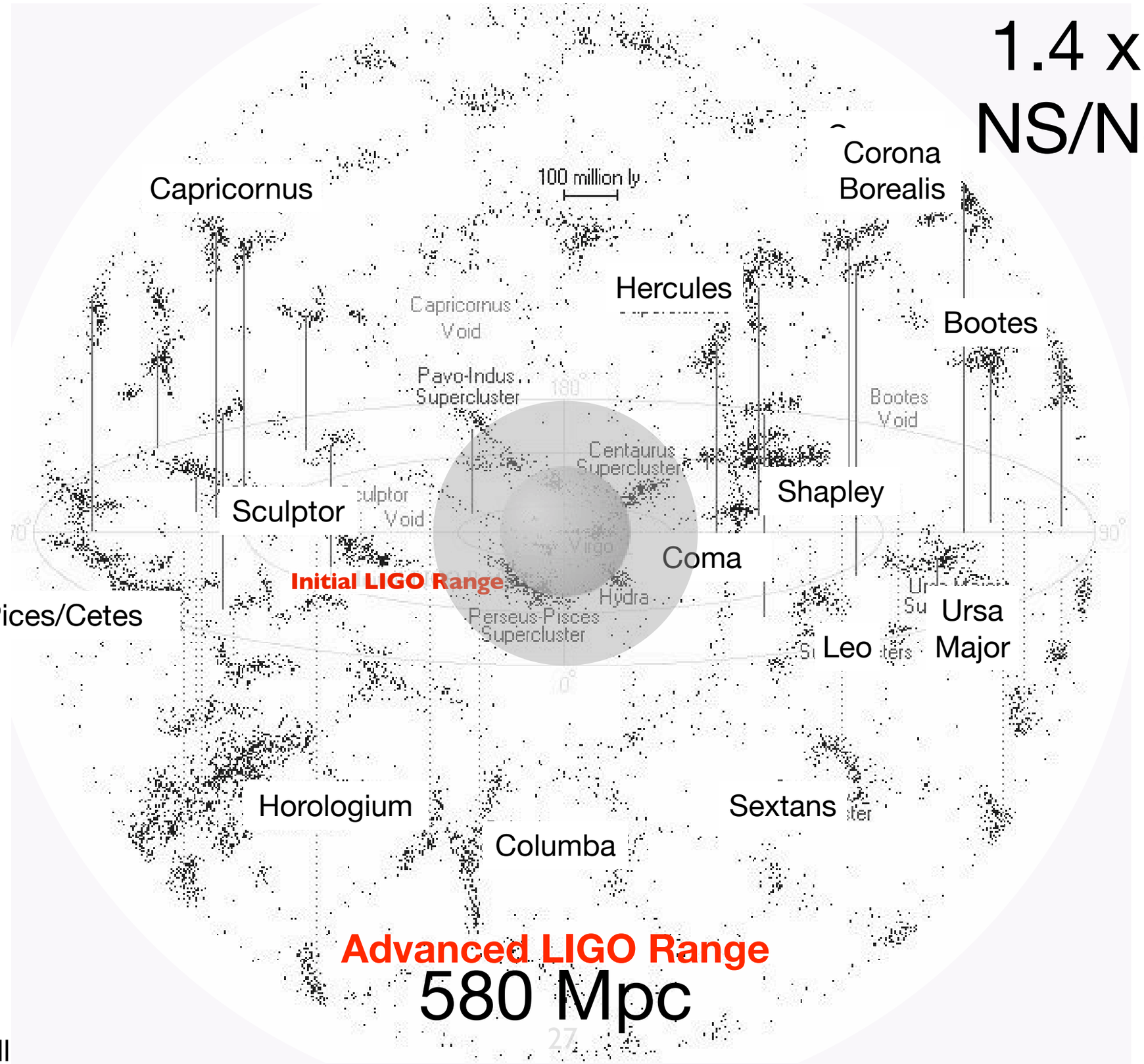

Image: R Powell