Innovative Technologies for the Gravitational-Wave Detectors LIGO and Virgo

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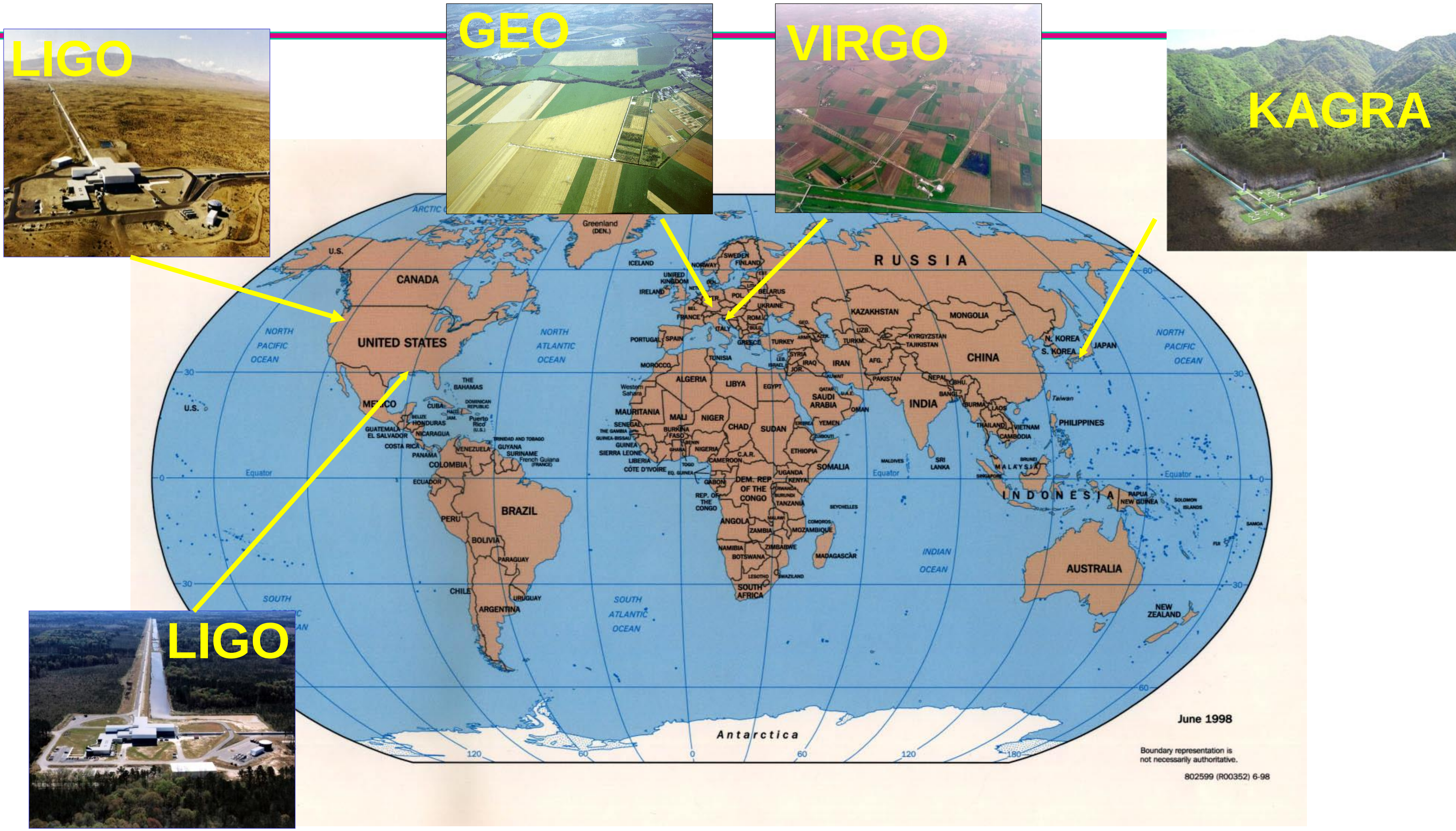
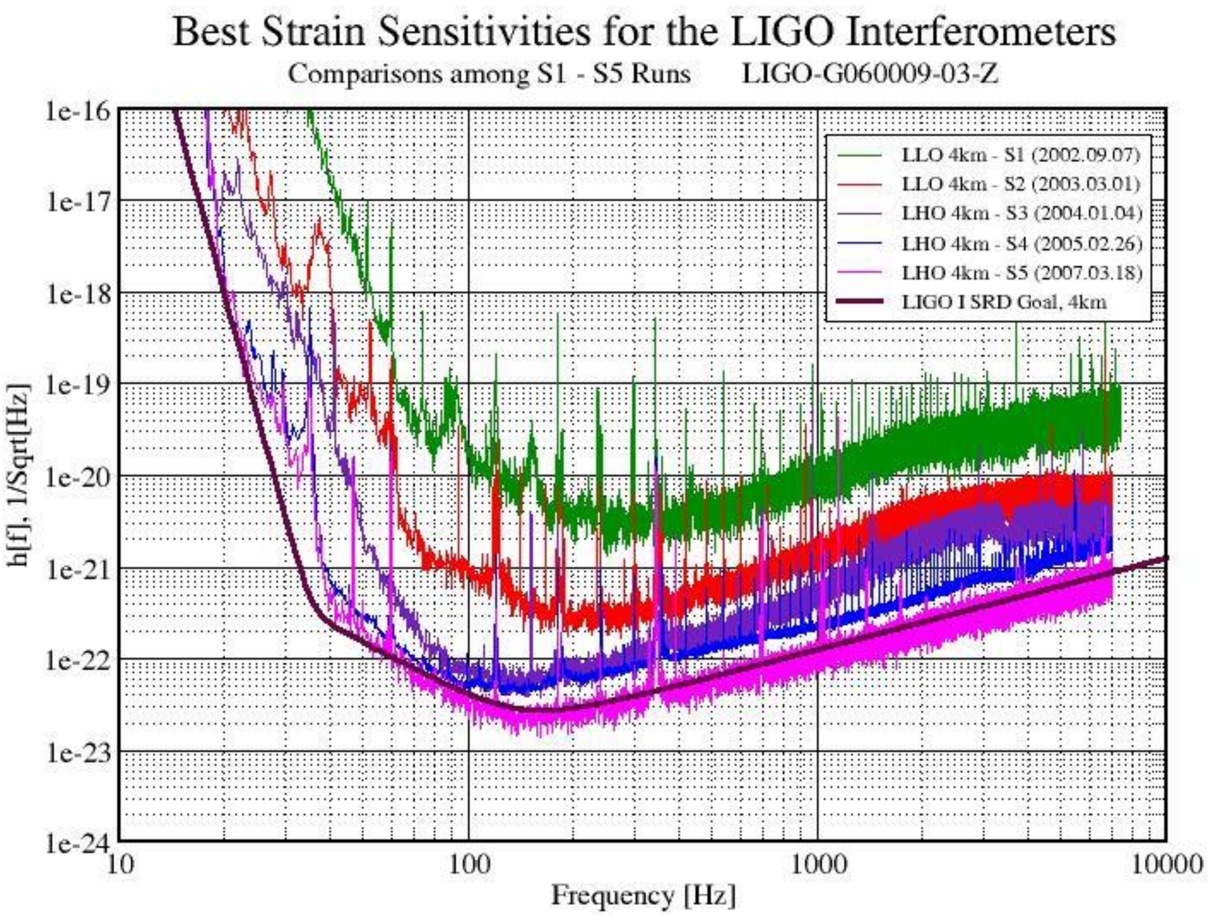
INFN, Sezione di Firenze

On behalf of LIGO and Virgo

Global Network of Detectors



Commissioning of the LIGO Detector



NS/NS Inspiral range

S1 ~ 100 kpc

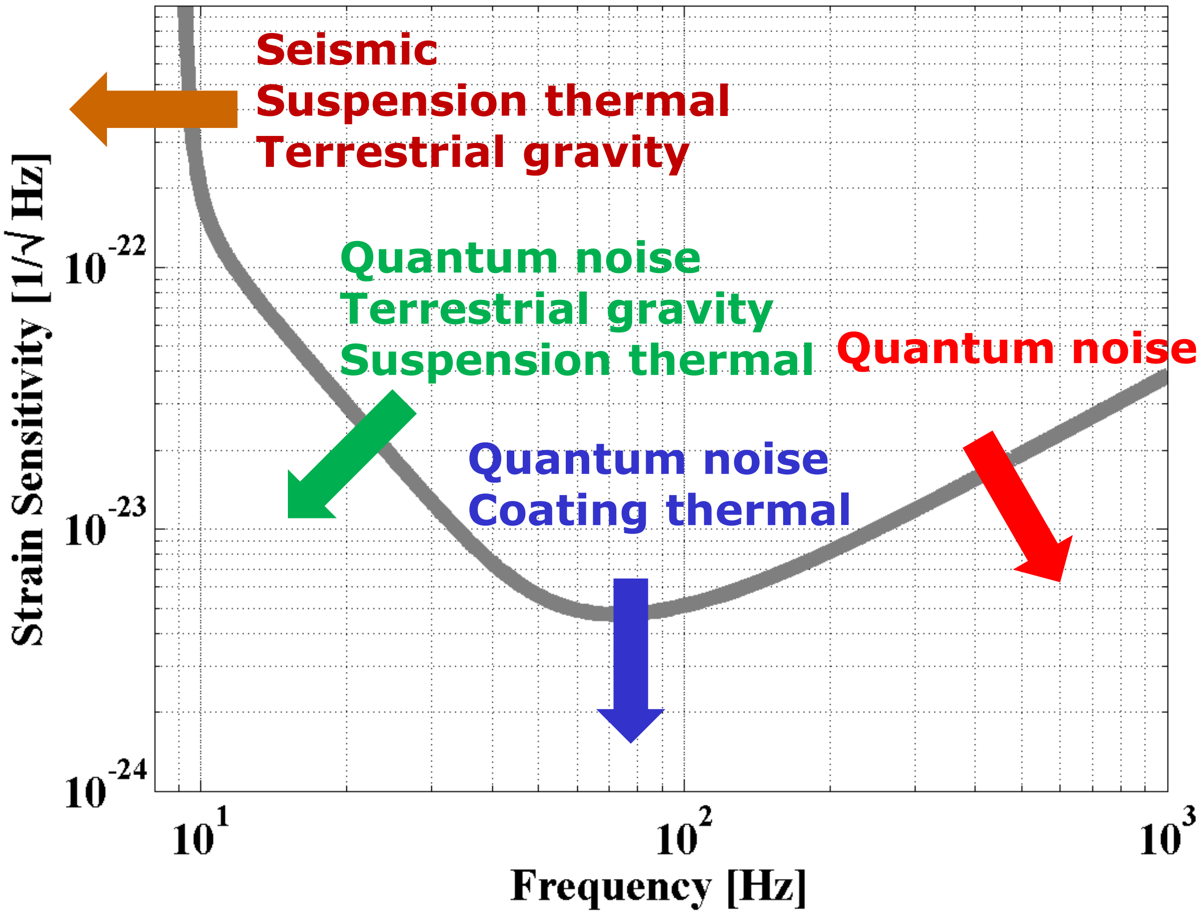
S2 ~ 0.9Mpc

S3 ~ 3 Mpc

S4 ~ 8 Mpc

S5 ~ 15 Mpc

Instrumental Noise



New Technology for the Advanced Detectors

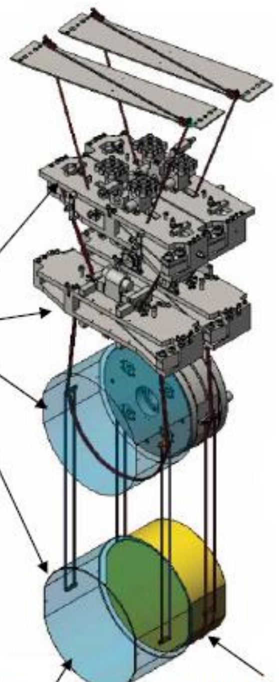
Seismic Isolation for Advanced LIGO

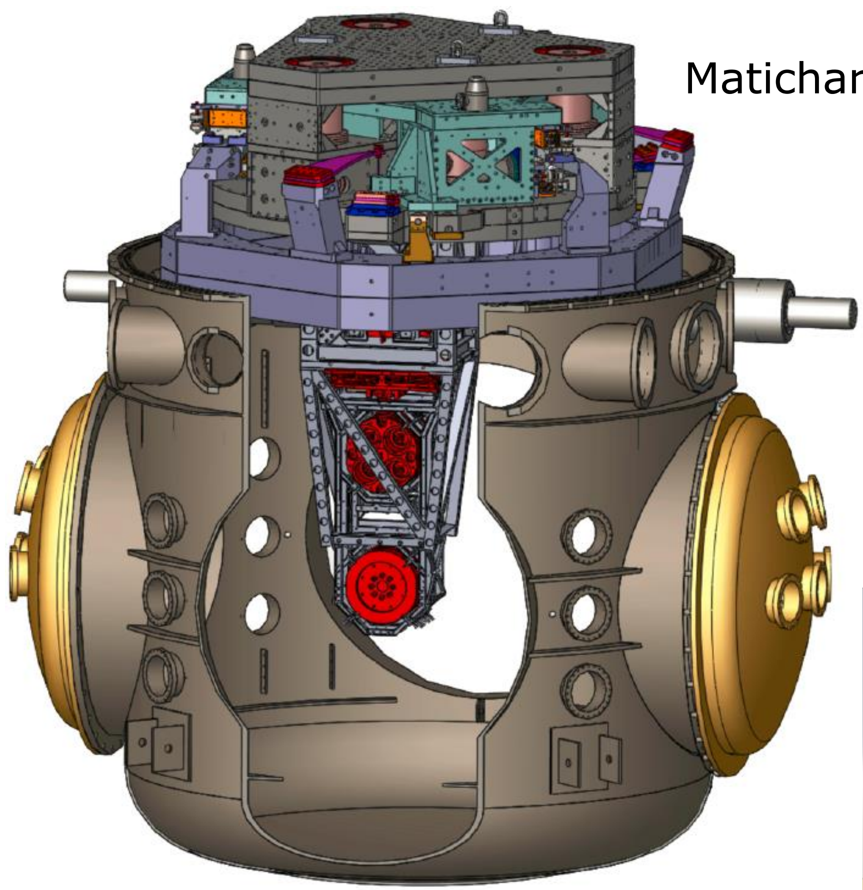
Suspension system

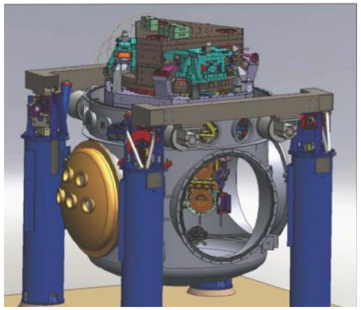
Internal seismic isolation

Matichard et al., MIT

4 stages

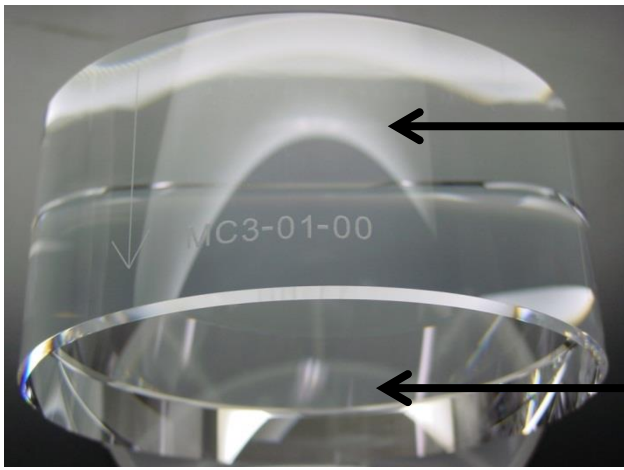


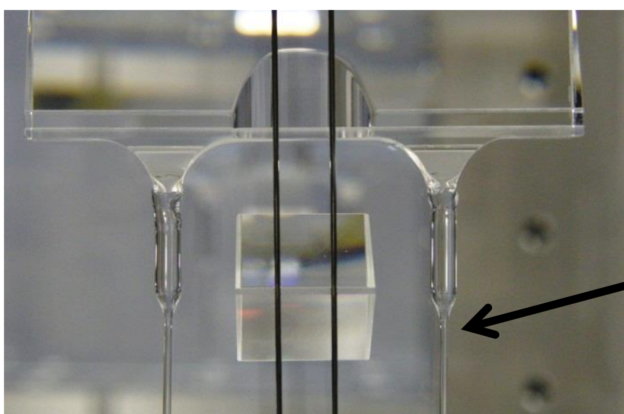




Rowan et al., Glasgow
Robertson et al., Caltech

Optics and Suspension Improvements (aVirgo and aLIGO)





Substrates (SiO_2)

- Main goal: minimize light scattering
- Polishing quality: about 0.1nm rms
- RoC errors around 0.1%

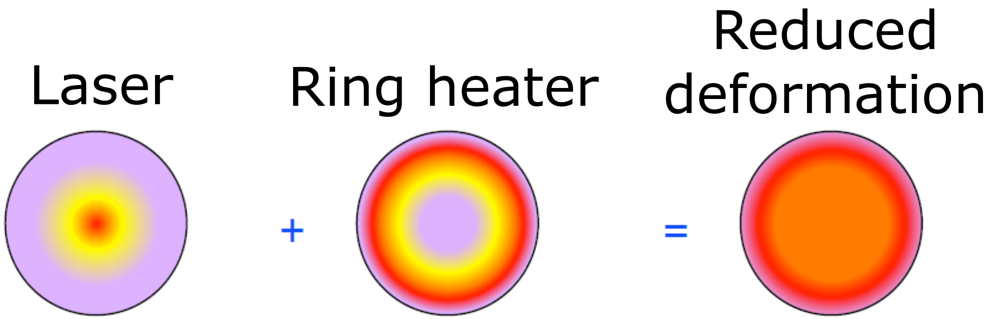
Coatings (SiO_2,Ta_2O_5)

- Main goals: minimize scattering and thermal noise
- Can be produced without significantly deteriorating mirror profile
- High purity, few point defects

Suspensions (SiO_2)

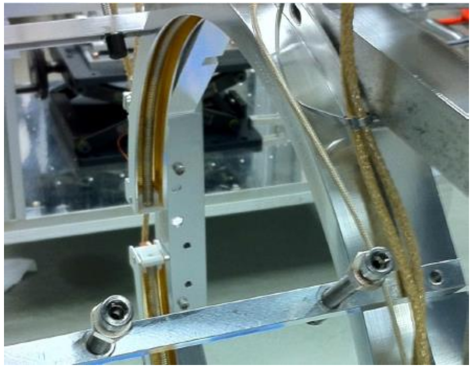
- Main goal: minimize thermal noise
- Monolithic implementation
- Diameter: 0.4mm

Thermal Compensation



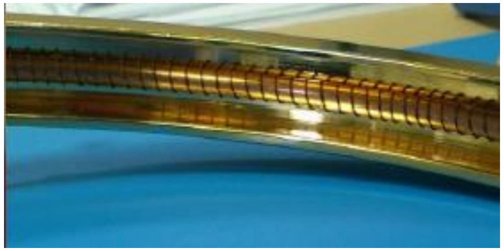
Ring heaters

aLIGO

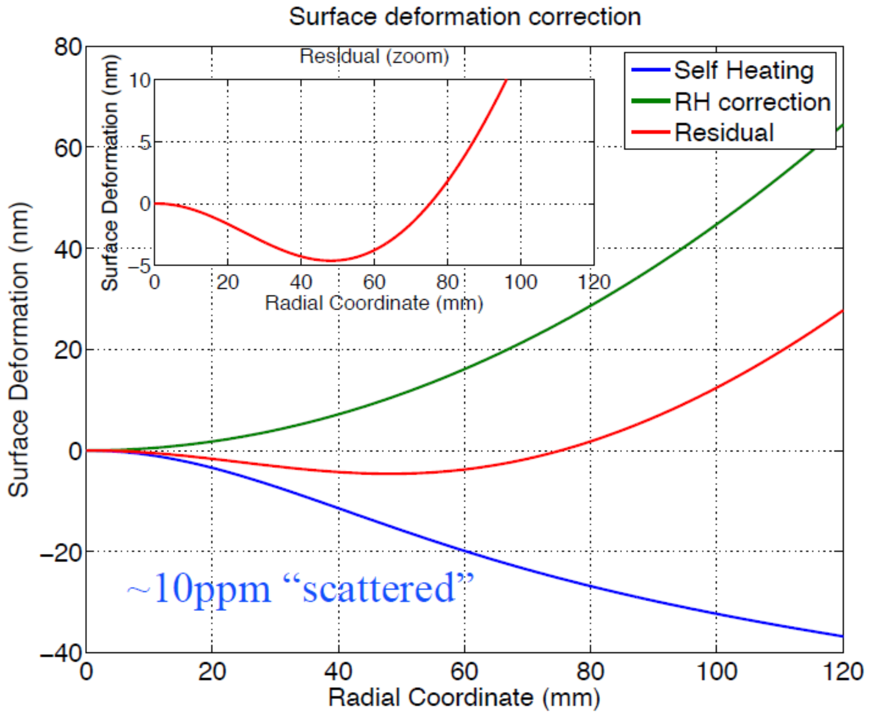


A.Brooks, Caltech

aVirgo

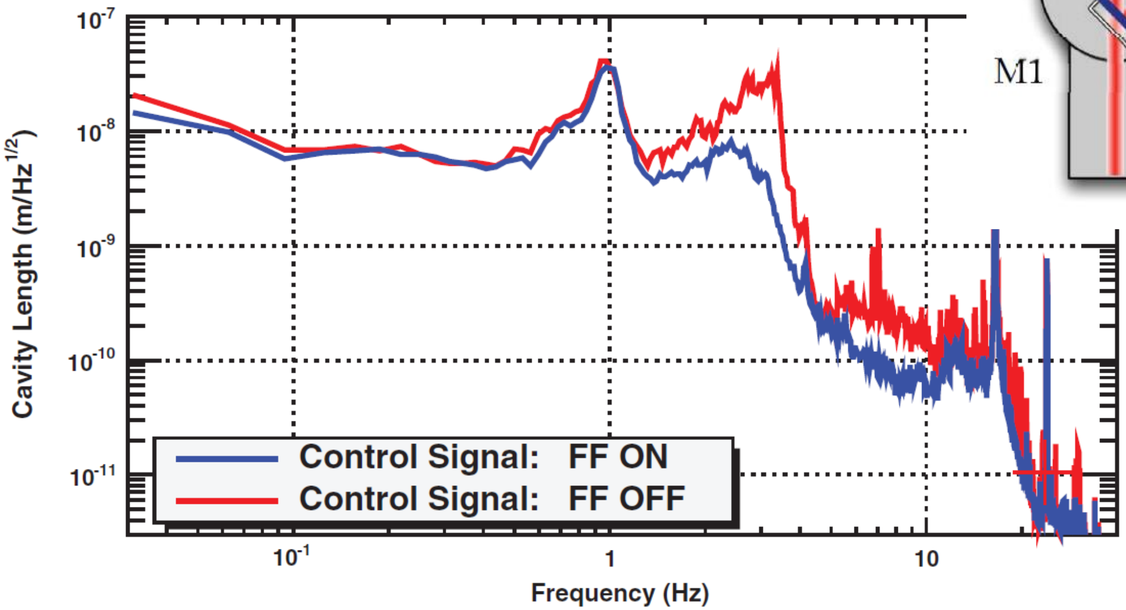


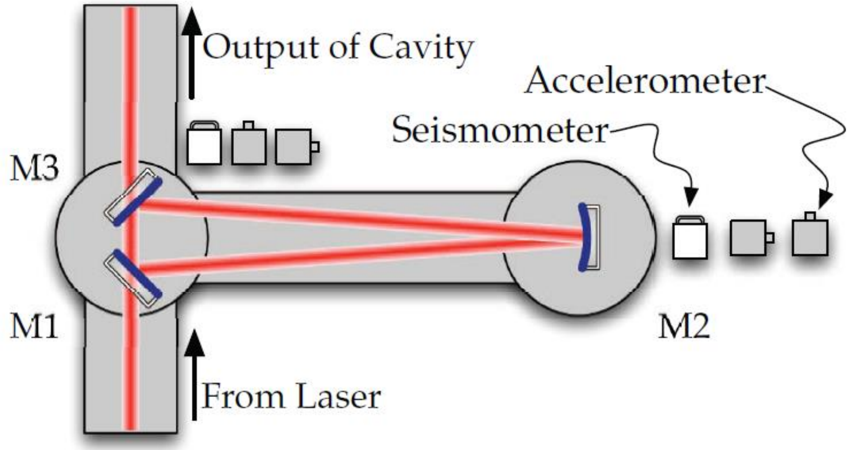
V.Malvezzi, Rome



Feed-Forward Noise Cancellation

Ground motion shakes mirrors, and therefore cavity length changes.





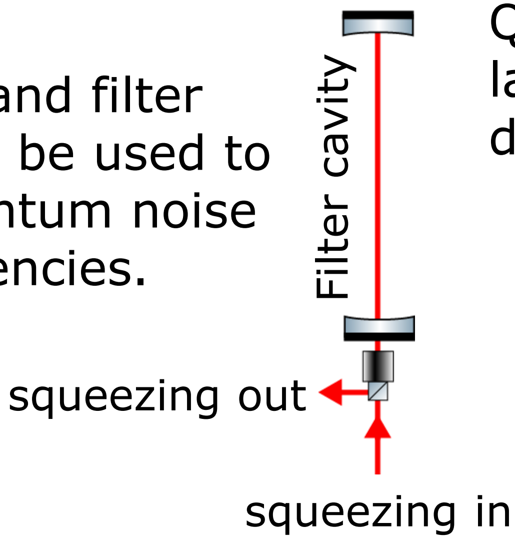
No improvement below some frequency since sensor SNR is insufficient to resolve small differential ground motion.

Rev.Sci.Instr. 83, 024501, 2012

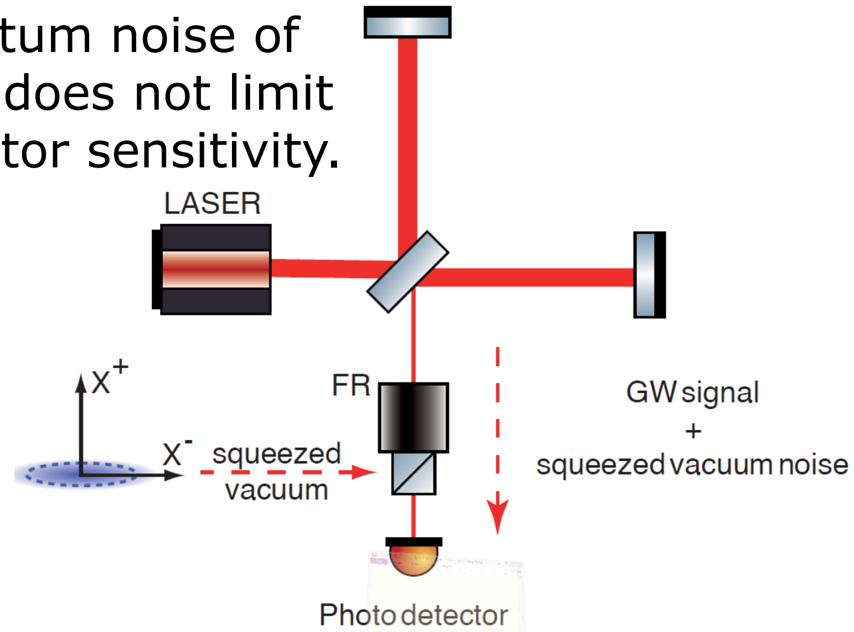
Beyond Advanced:
Quantum Noise Reduction

Quantum Noise

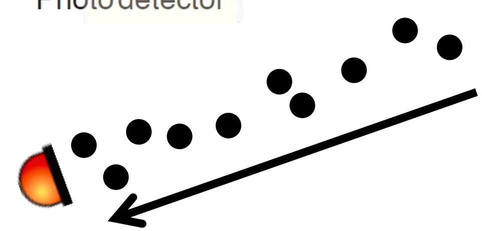
Squeezing and filter cavities can be used to reduce quantum noise at all frequencies.



Quantum noise of laser does not limit detector sensitivity.



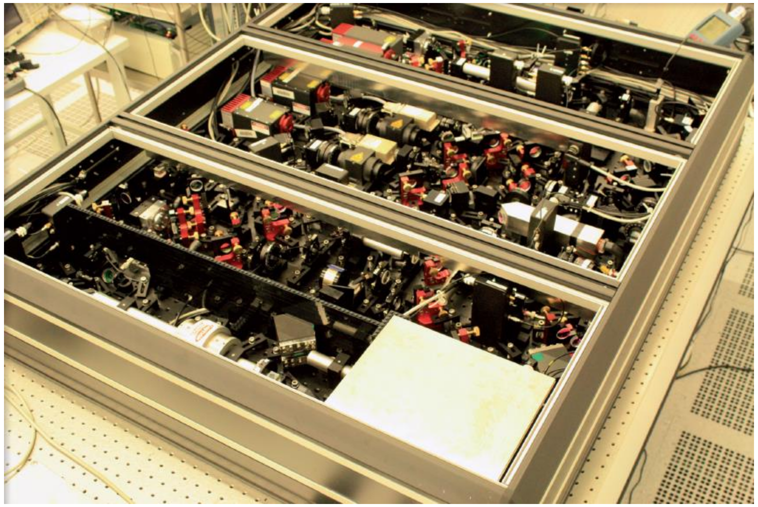
Photon statistics at output port are mainly determined by vacuum fields incident at output port.



Counting photons

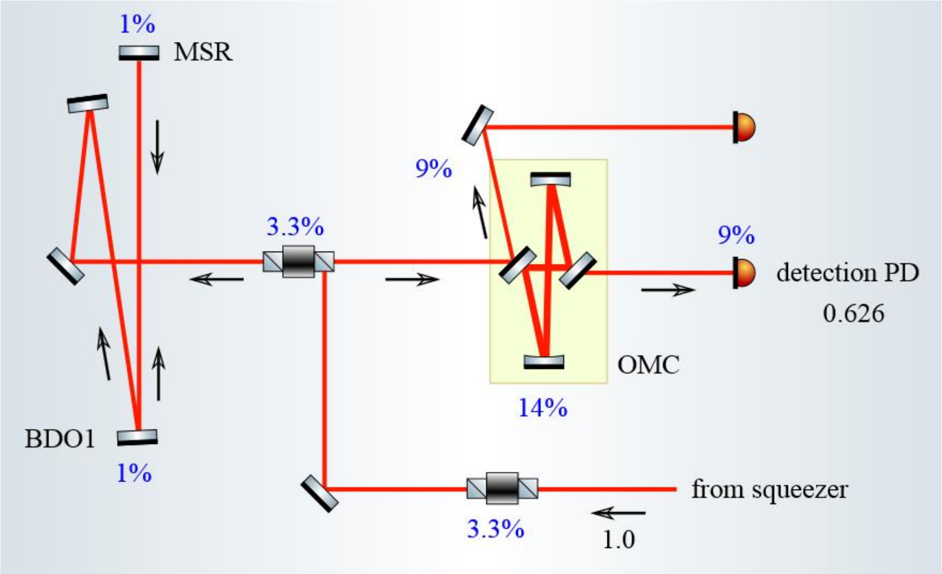
Improving Quantum-Noise Reduction

Quantum-noise reduction by squeezing has been first demonstrated in large-scale detectors at GEO600.



A. Khalaidovski, GEO600

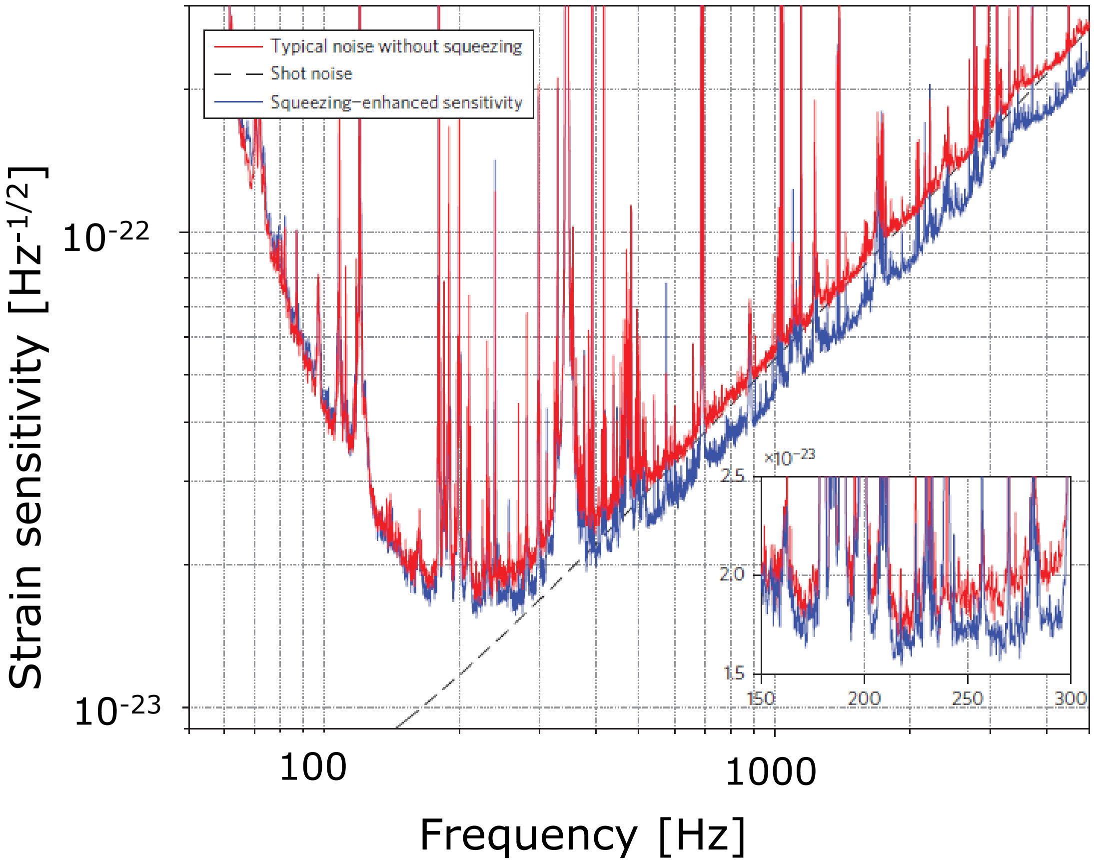
Since then, scientists at GEO600 have been trying to improve the performance by characterizing and minimizing optical loss.



K. Dooley, GEO600 (2012)

Squeezing at LIGO Hanford

Nature Photonics, 177 (2013)



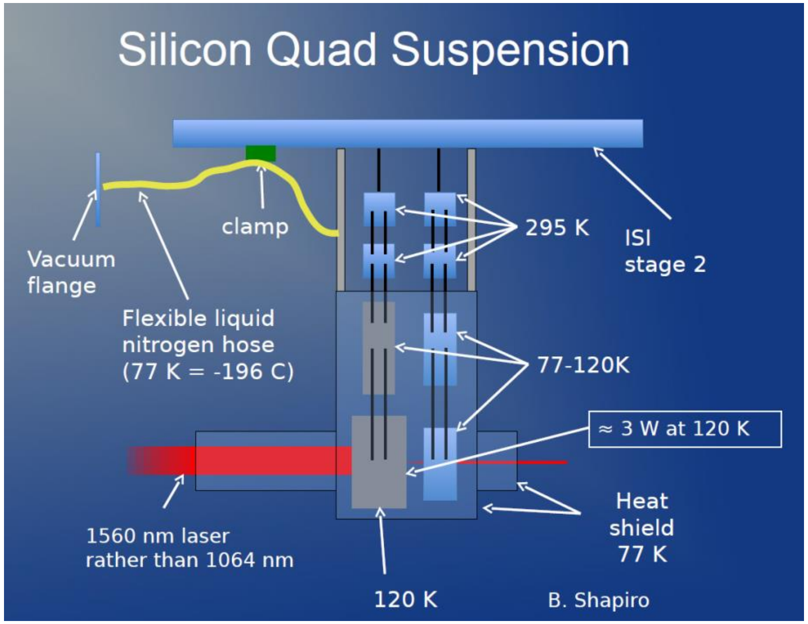
Squeezing applied to LIGO interferometer led to best sensitivity for a gravitational-wave detector to date!

Beyond Advanced: Cryogenics

How to Make GW Detectors Cryogenic?

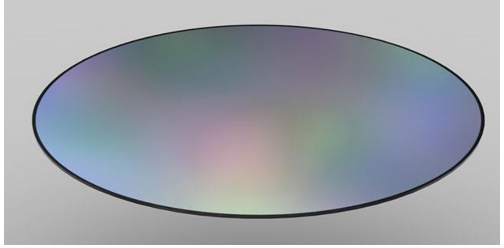
New Laser wavelength:1560nm

Adjusted suspension design



Shapiro, Stanford

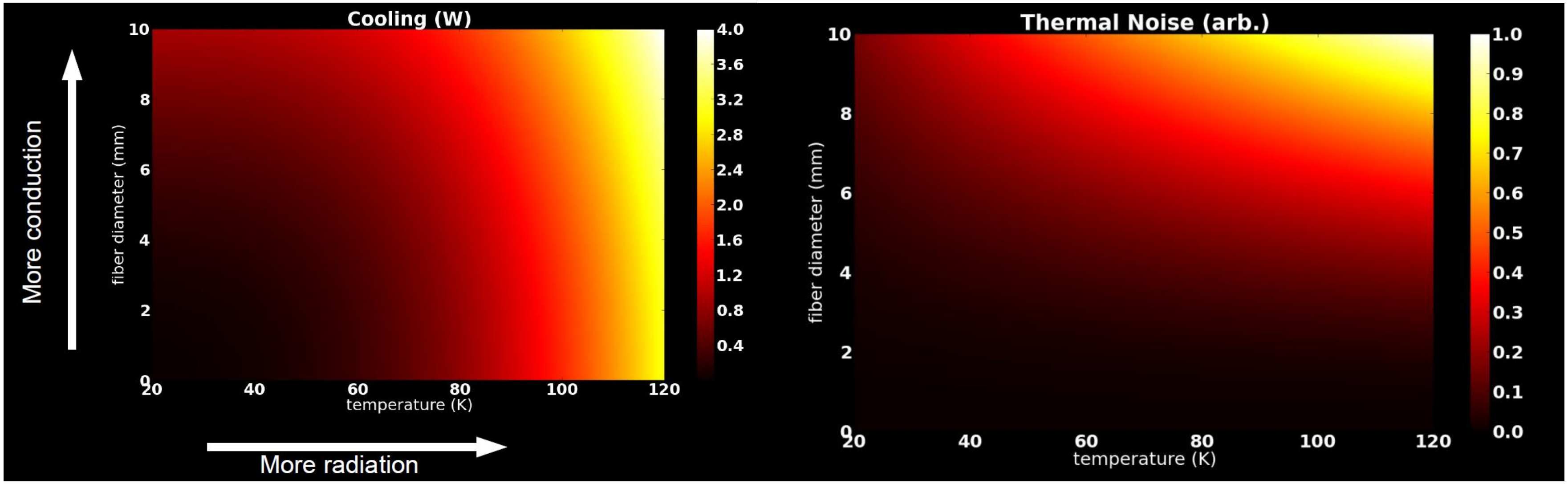
New material for optics and suspensions: Si



Cryogenic infrastructure

Decreasing Thermal Noise

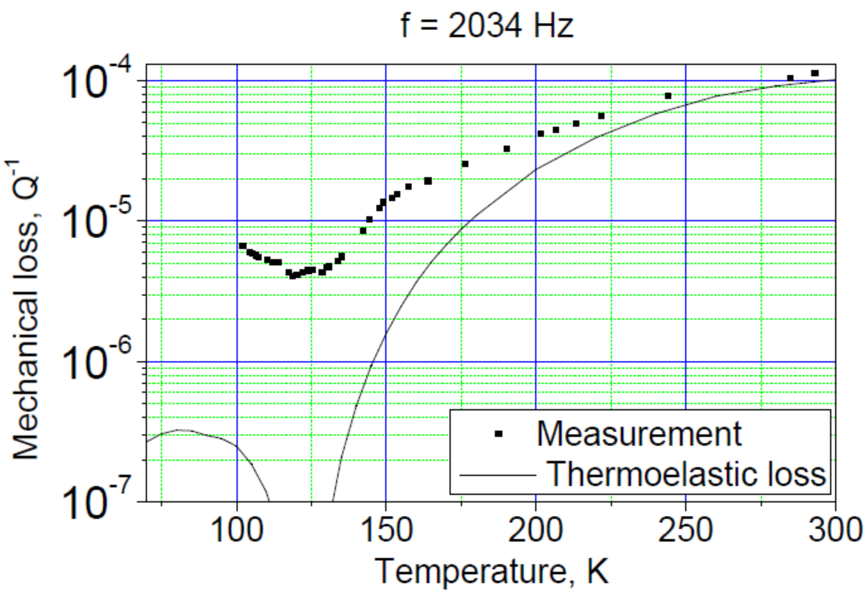
Decreasing thermal noise efficiently is an optimization problem that includes the cooling process.



Smith, Caltech, 2013

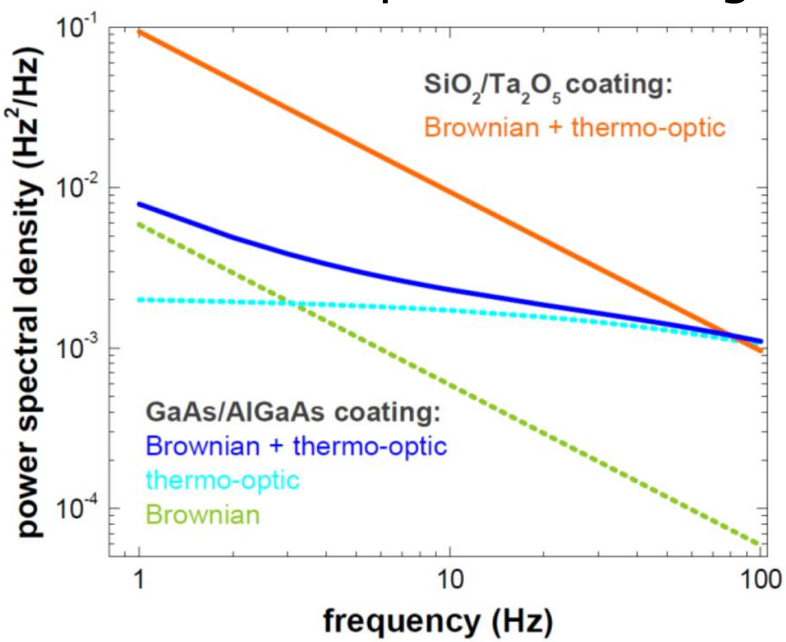
Materials at Cryogenic Temperatures

Mechanical loss measurements on silicon wafers



Prohorov and Mitrofanov, MSU, 2013

Mechanical loss of crystalline coatings is significantly better than in amorphous coatings



Cole et al, Vienna, 2013

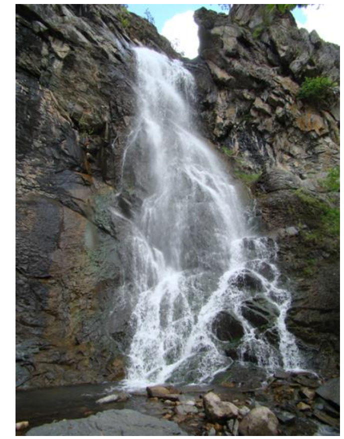
Beyond Advanced:
Terrestrial Gravity Noise

Terrestrial Gravity Noise

Anthropogenic noise

Ocean waves

Rivers

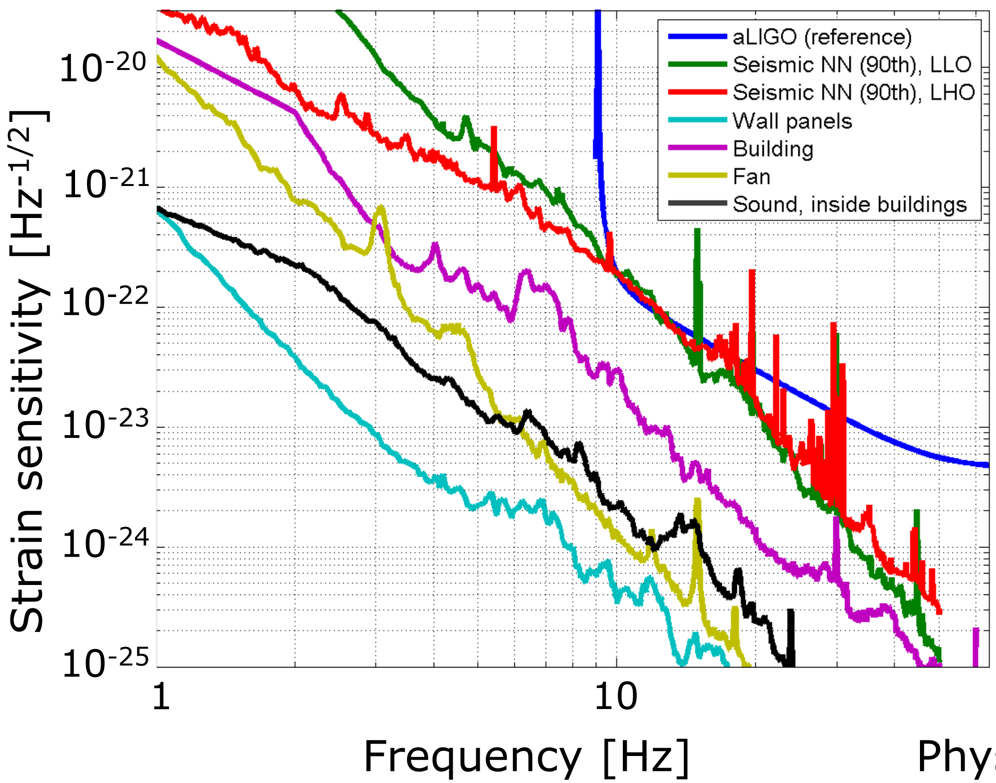


Wind and atmosphere

To understand Newtonian noise, you need to understand the sources and propagation effects.

Newtonian Noise at LIGO

Estimated NN Budget



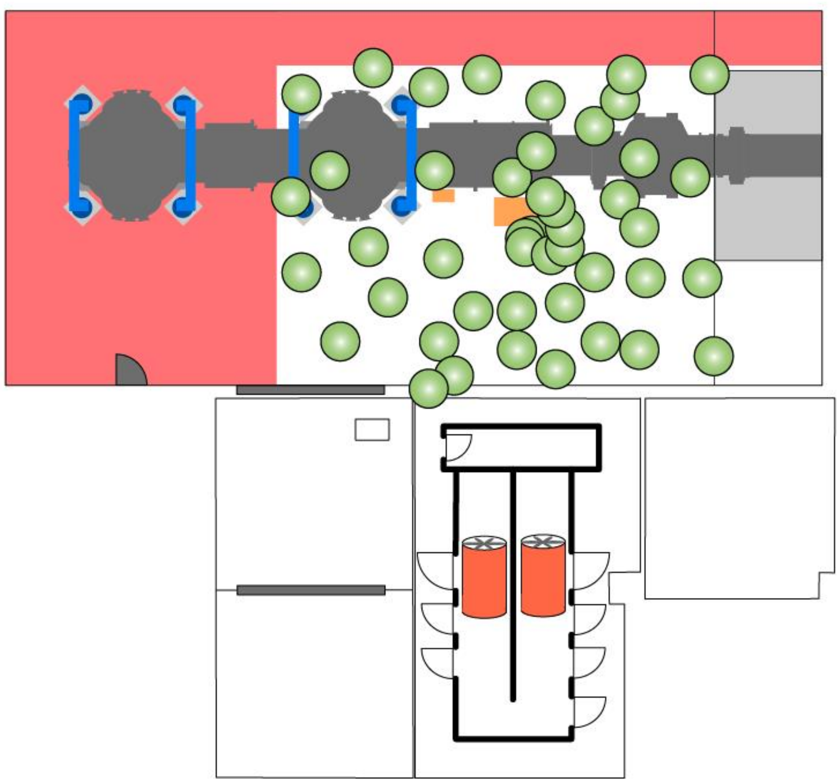
- Seismic surface waves

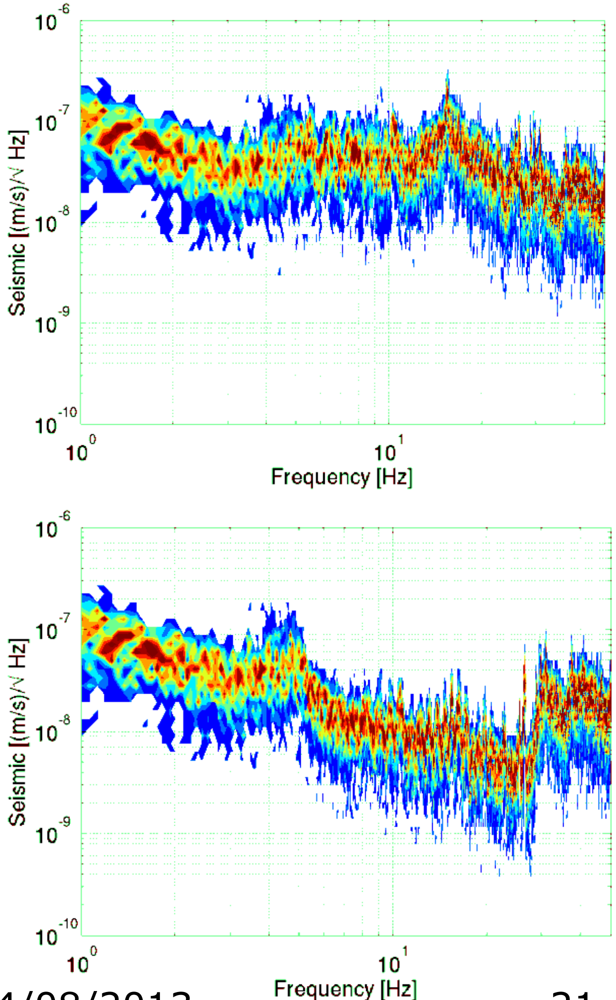
- Vibrations of buildings
- Vibrations of water pipes
- Vibrating vacuum chambers
- Exhaust fans

- Sound inside and outside buildings

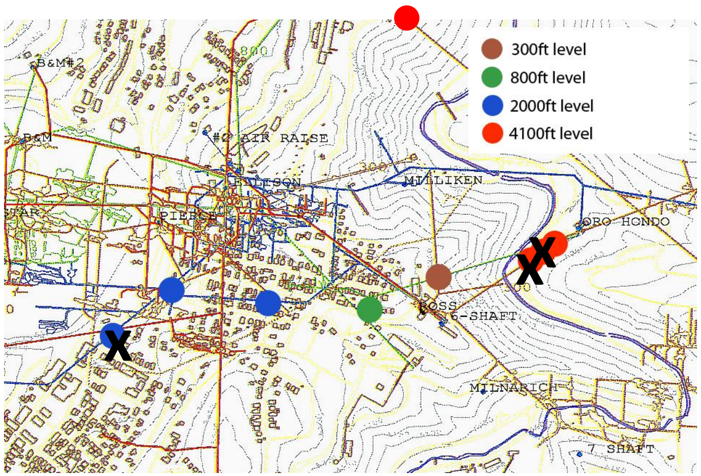
Phys. Rev. D 86, 102001 (2012)

Gravity Noise Cancellation

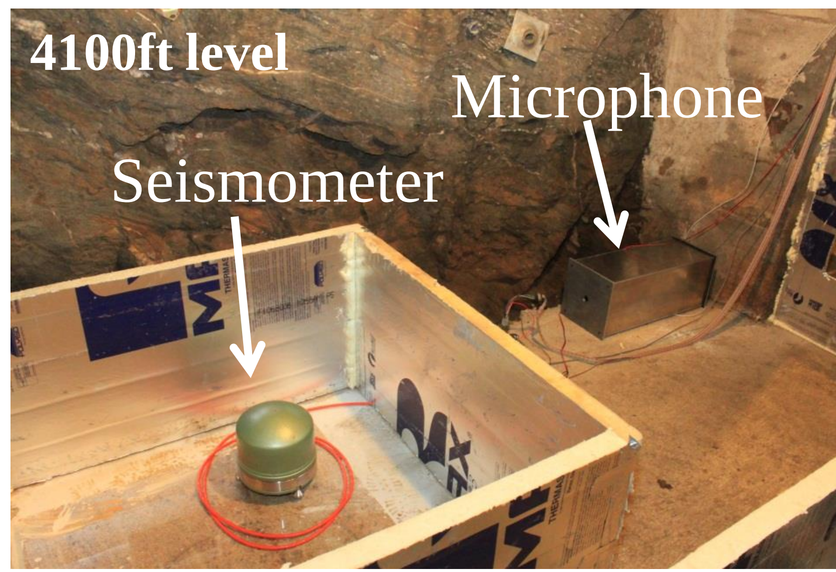




Seismic Underground Array



- Stations equipped with broadband seismometers (T240, STS-2)
- Infrasound microphones installed at almost all stations.
- Stations at depths between 90m and 1250m



Closing the Circle

Davis chamber, 2009

Inside

Outside