Seismic Instrumentation in LIGO

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Seismic Instrumentation Technology Symposium
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Outline

Gravitational wave interferometers and science goals

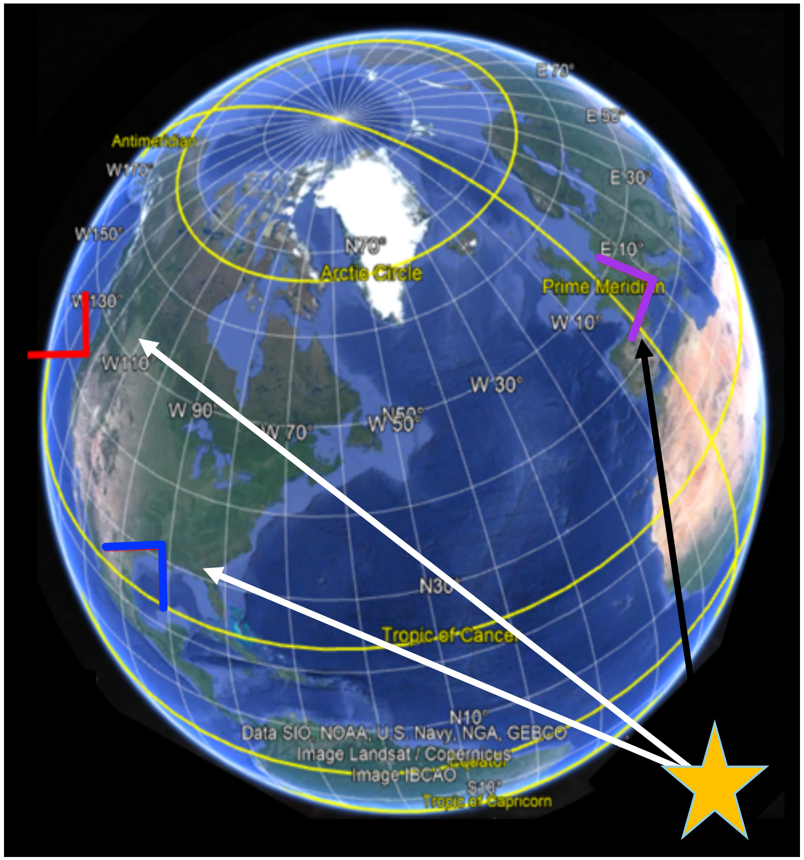
The need for seismic isolation

Seismic isolation in the LIGO interferometers

Developments in seismic instrumentation

LIGO Interferometers Around The World

LIGO, Hanford, WA



Virgo, Cascina, Italy

LIGO, Livingston, LA

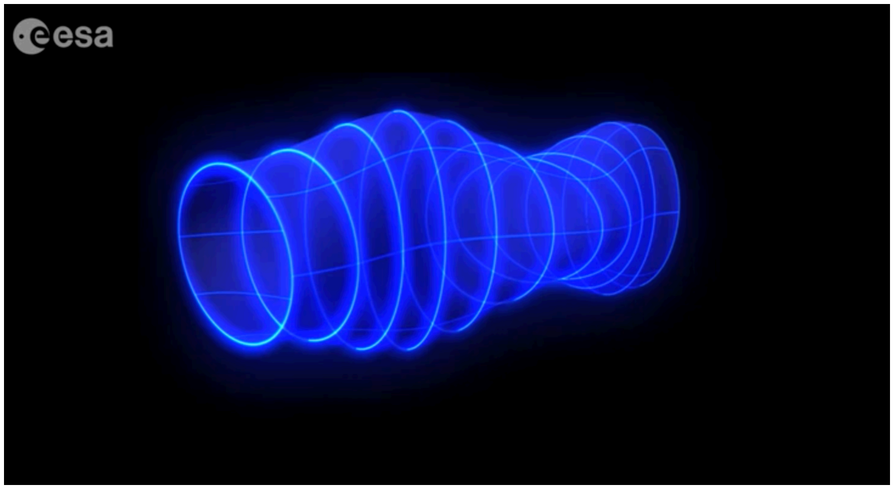
Figure adapted from L. Barsotti

Gravitational Waves Affect Spacetime

Black hole binary inspiralling

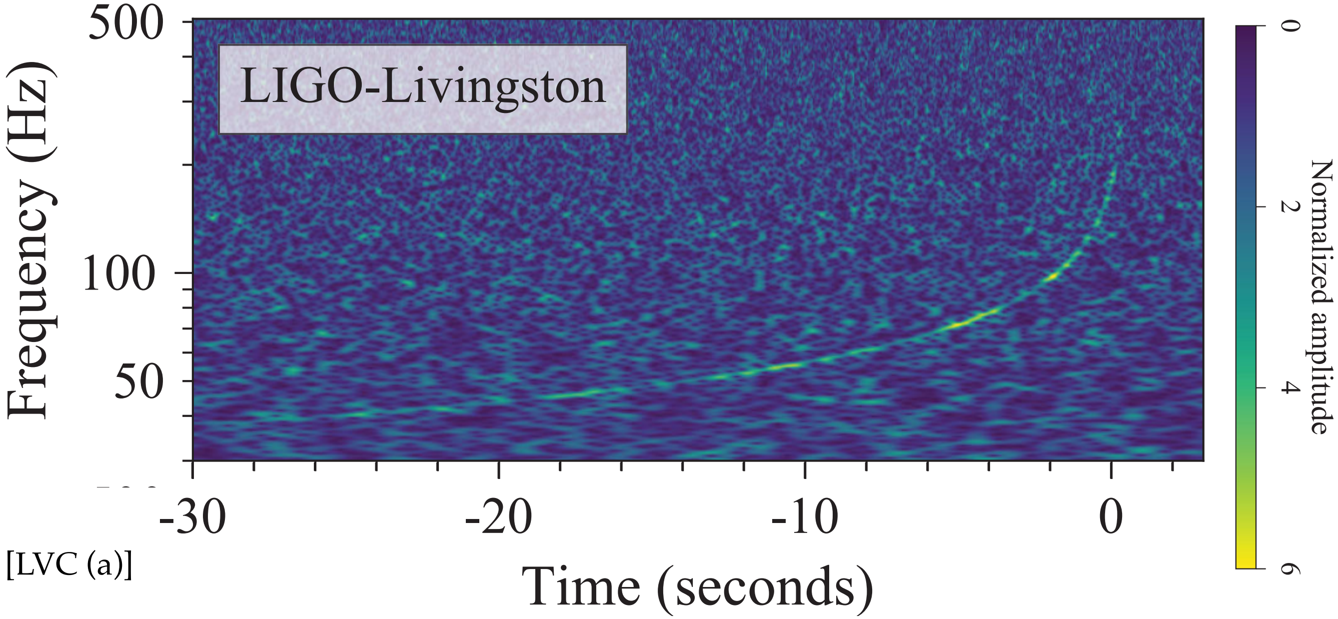
[SXS Collaboration]

Spacetime stretches and squeezes as gravitational waves pass



LIGO measures the distortions of spacetime

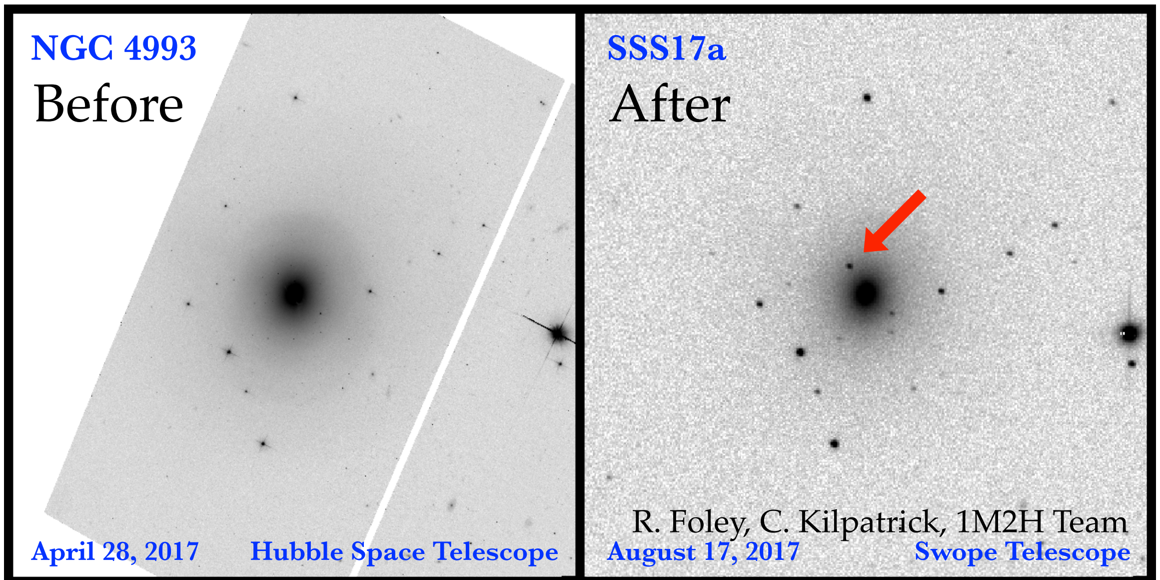
Neutron Star Collision



[LVC (a)]

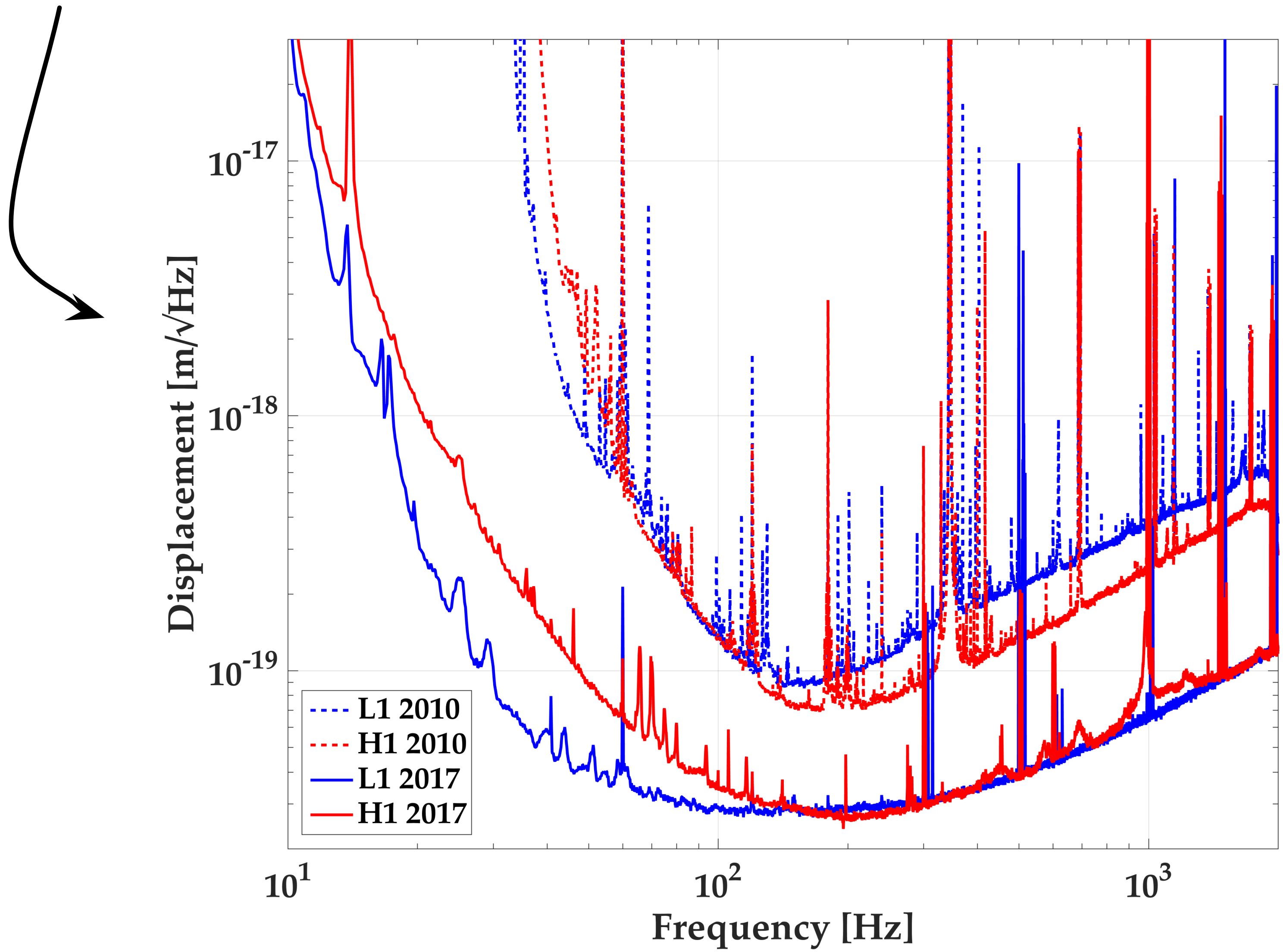
130 million light years away...

A new object in the sky



Interferometer Sensitivities

How much the mirrors move

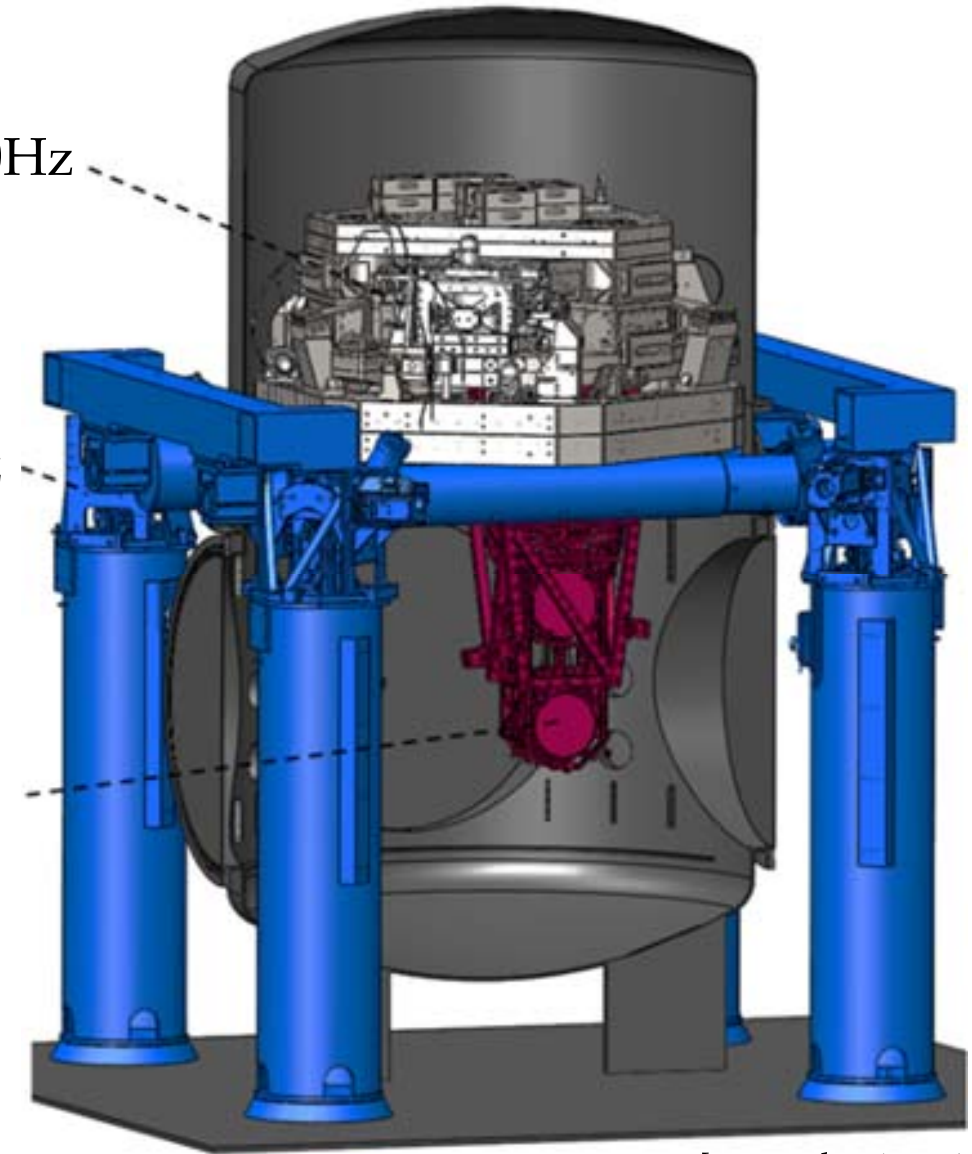


Isolation from Ground Motion

3e-12 m/rtHz at 10Hz

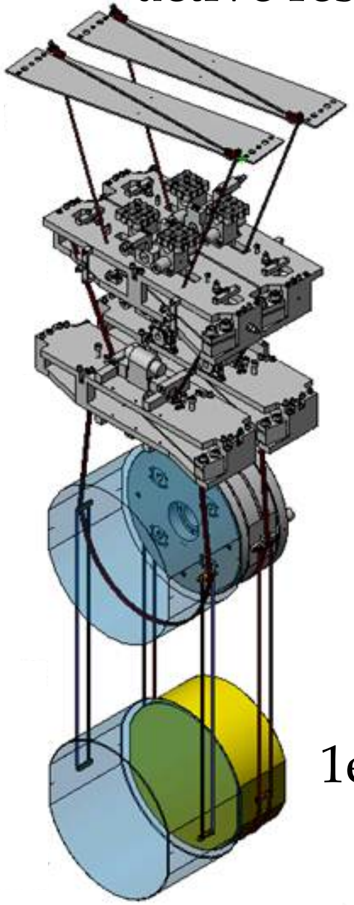
~4e-10 m/rtHZ at 10Hz

Passive and active seismic isolation



[F. Matichard, et al.]

Isolation from Ground Motion

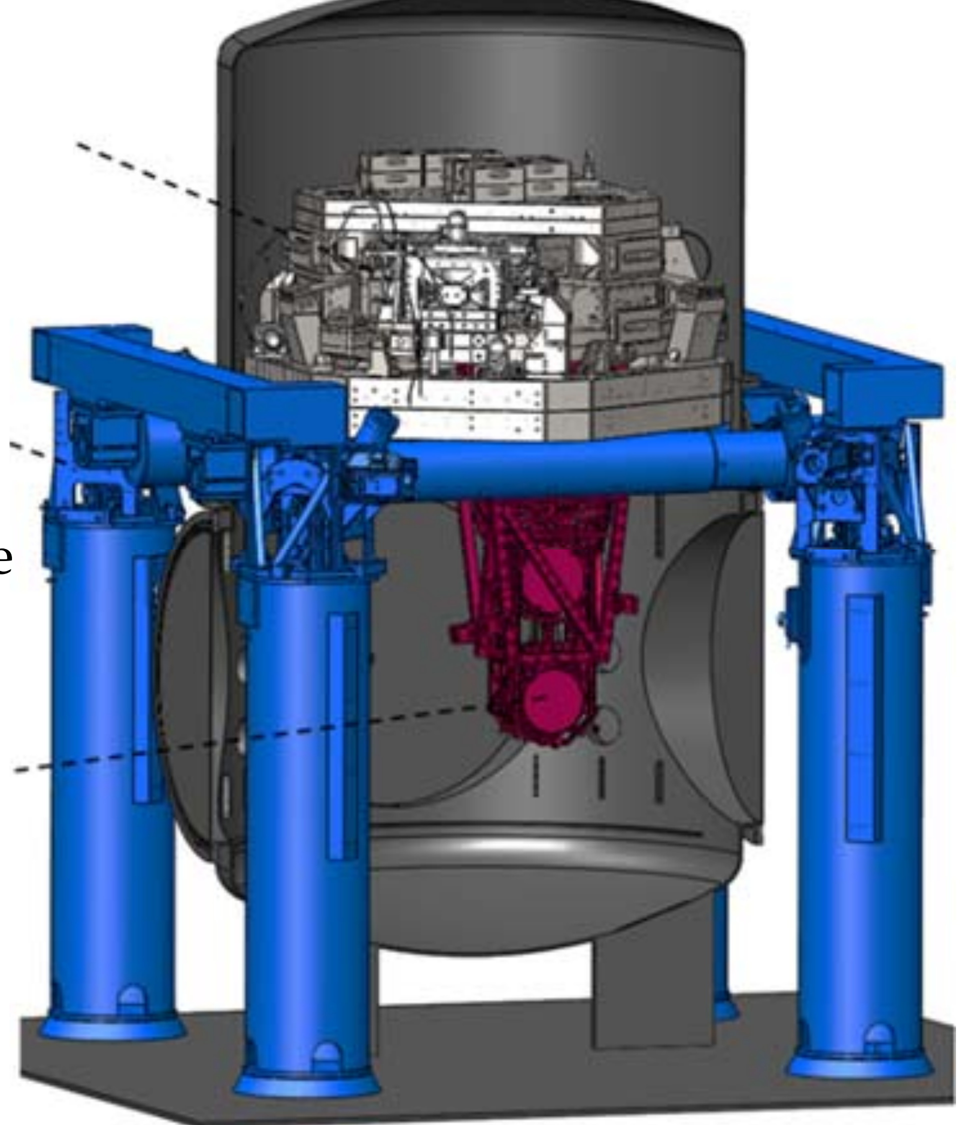


Passive isolation, with active resonance damping

Passive and active seismic isolation

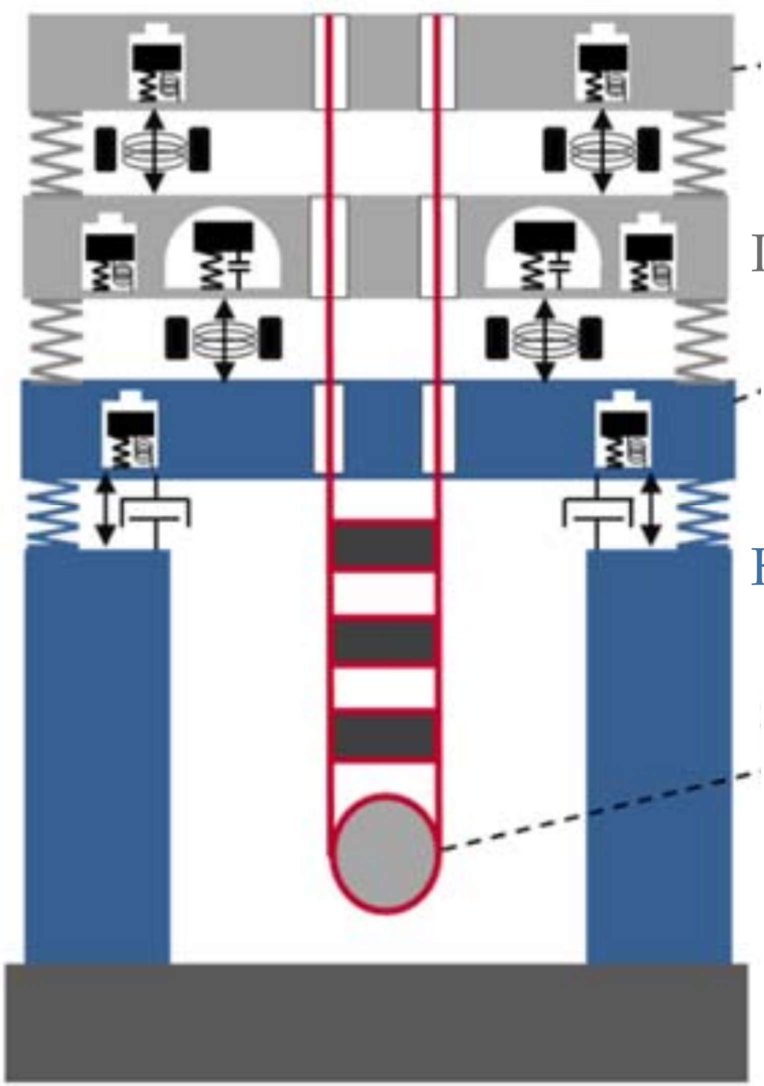
1e-19 m/rtHz near 10Hz

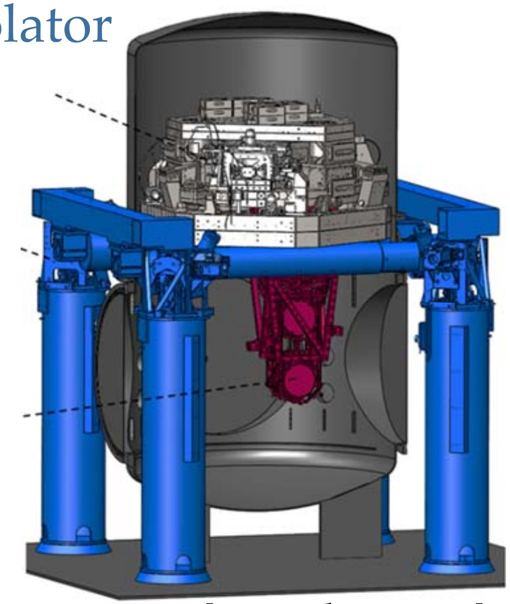
[S. Aston, et al.]



[F. Matichard, et al.]

Isolation from Ground Motion

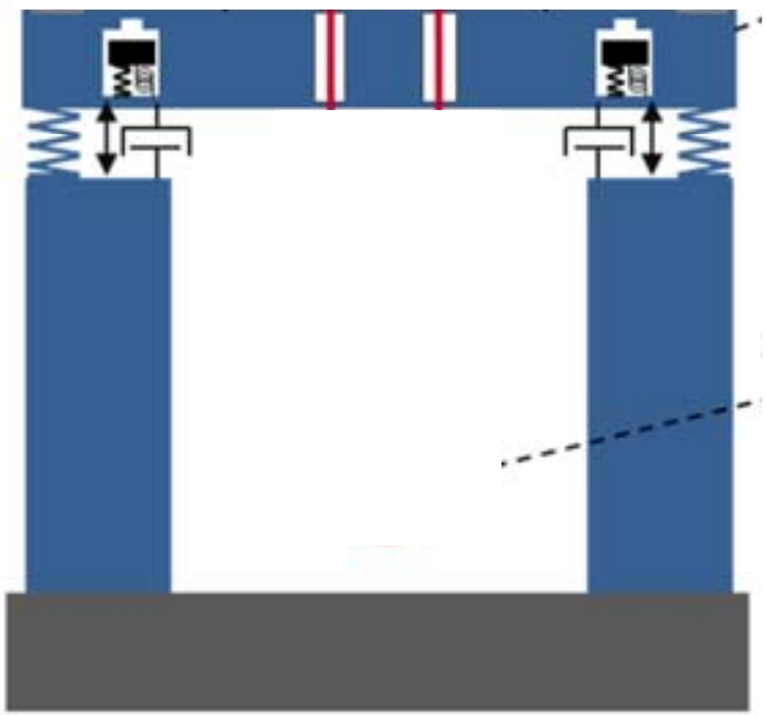


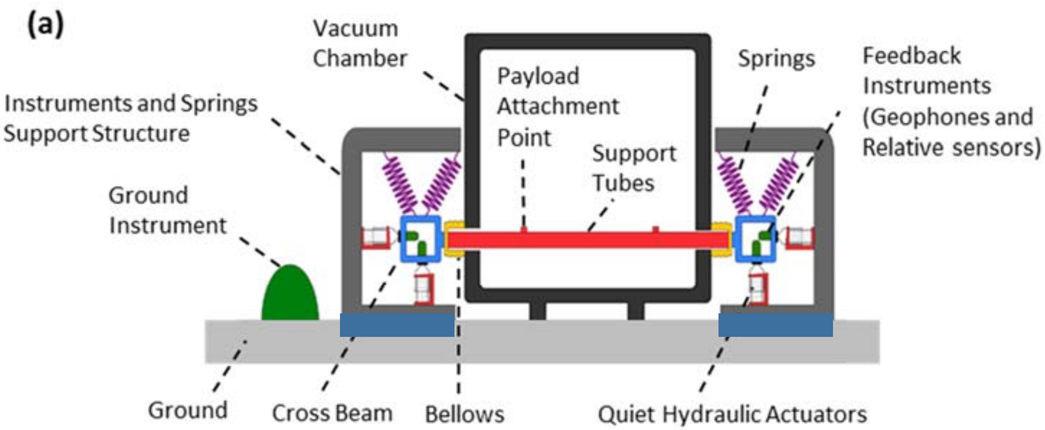


[F. Matichard, et al.]

Isolation from Ground Motion

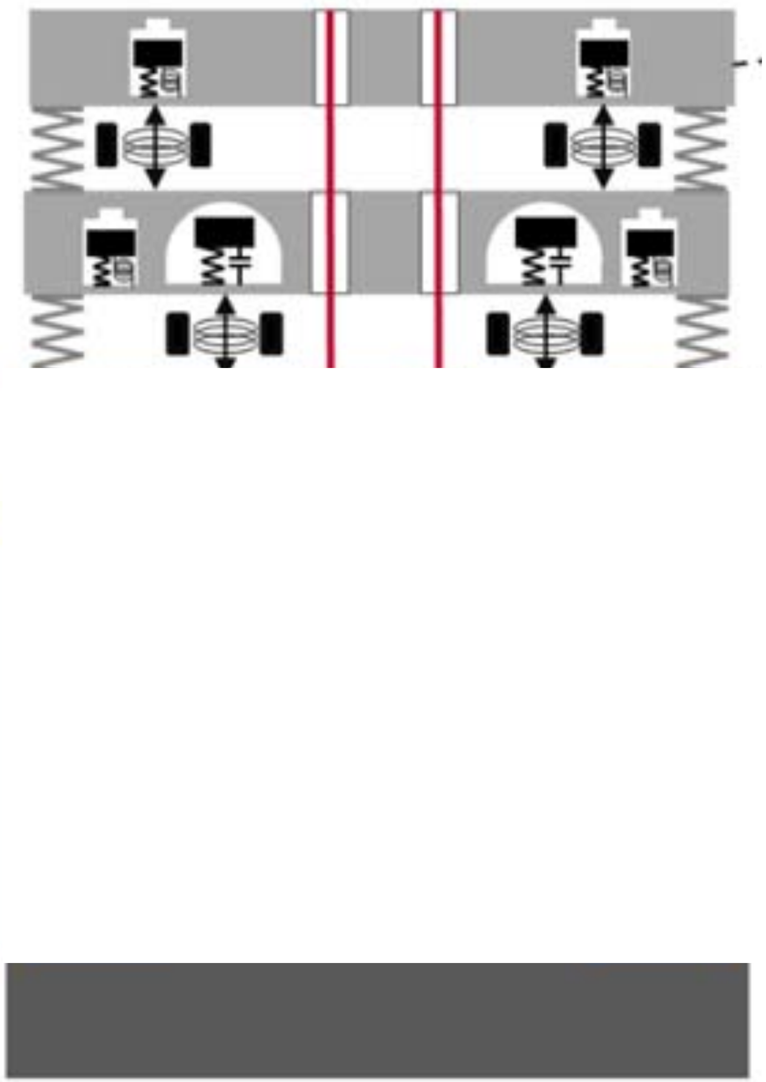
Hydraulic External Pre-Isolator (HEPI)





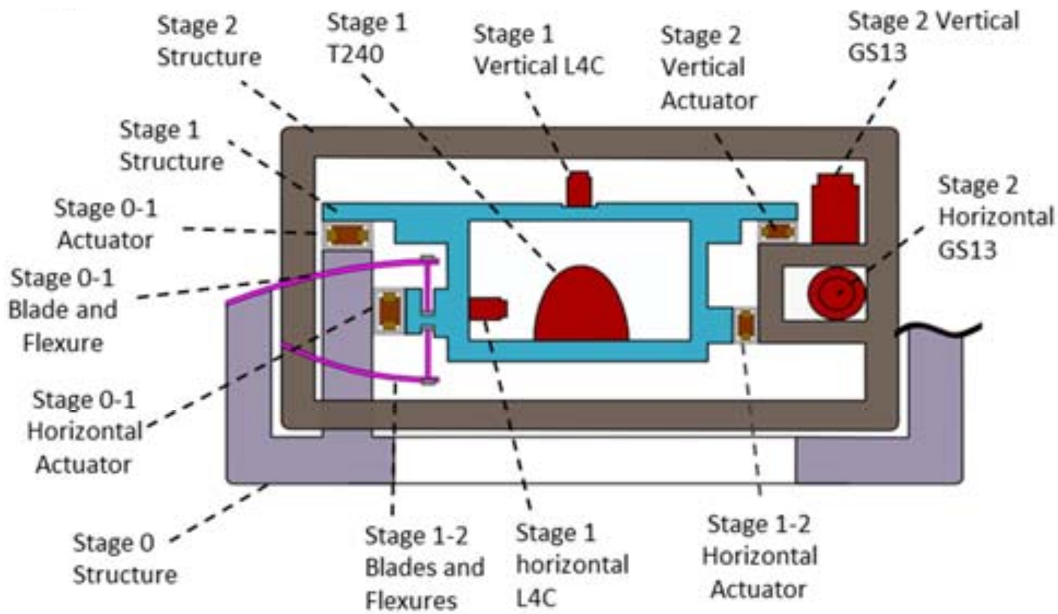
[F. Matichard, et al.]

Isolation from Ground Motion



Internal Seismic Isolation (ISI)
(Stage 1 and Stage 2)

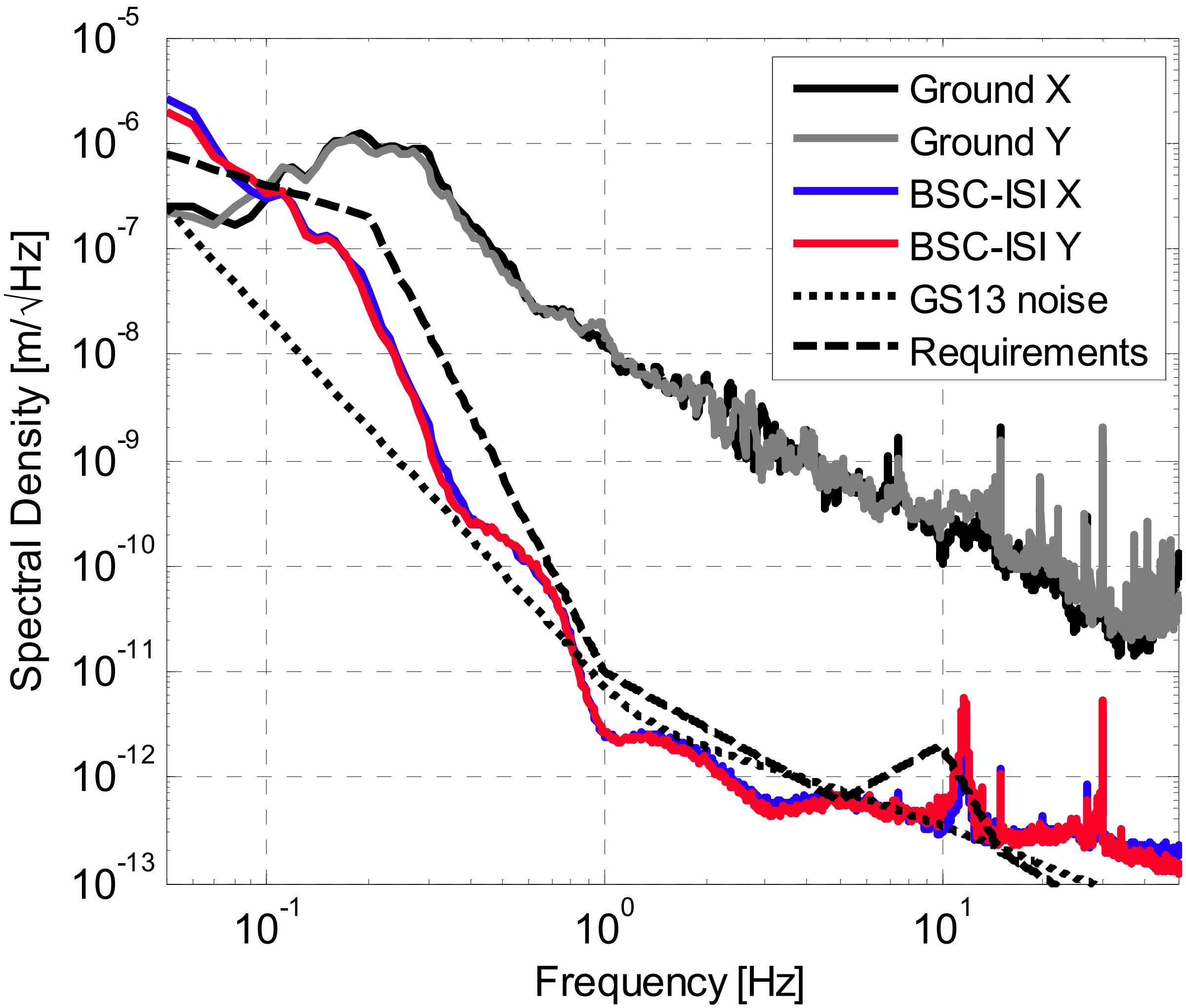
Actuators are voice coils



(Stage 0 = HEPI)

[F. Matichard, et al.]

Performance of Seismic Isolation



More than 2 orders of magnitude isolation at 10 Hz

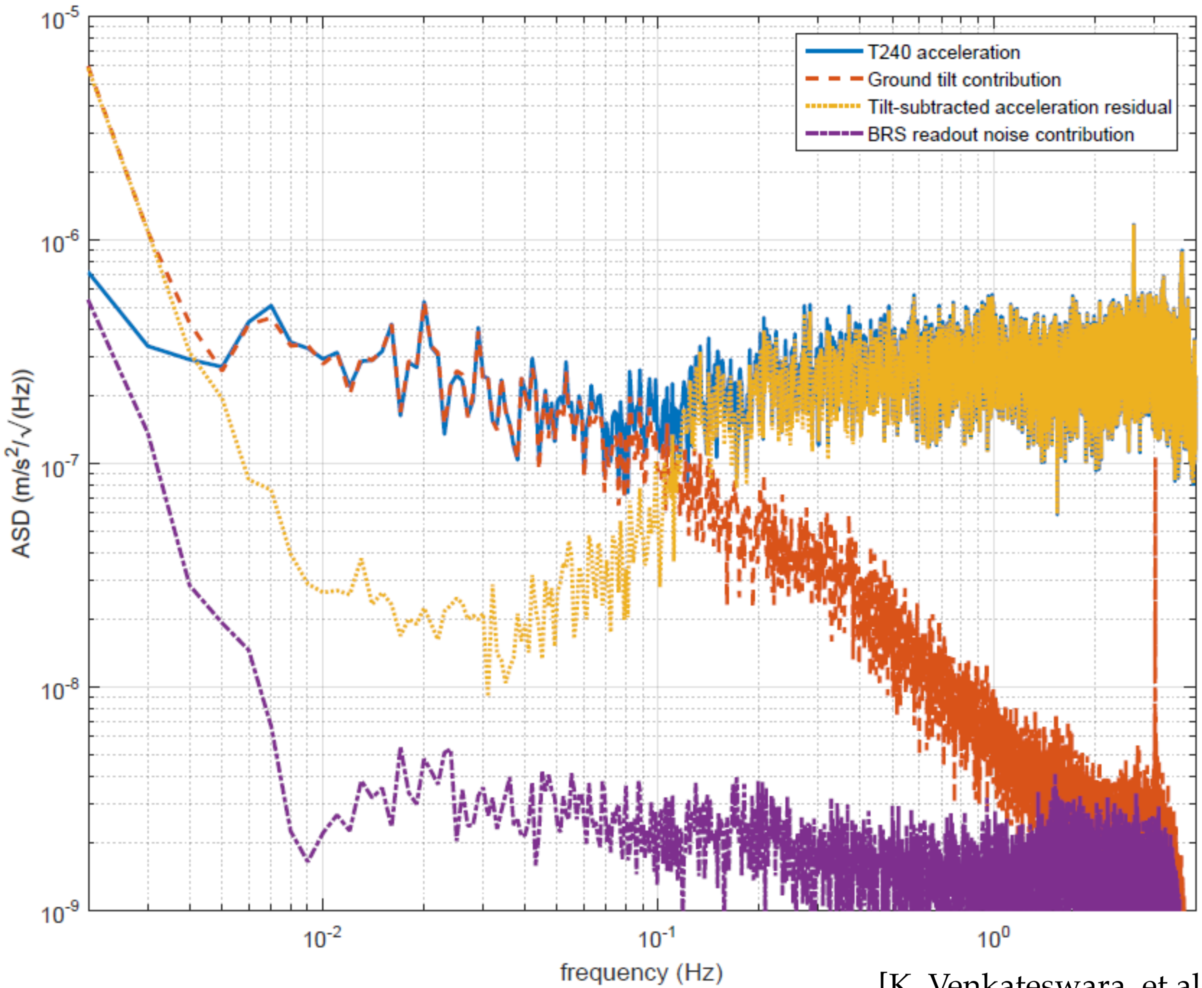
Quadruple pendulum mirrors suspended from these platforms give exquisite total isolation above 10 Hz

[F. Matichard, et al.]

Tilt Coupling Correction

Wind pushes on building walls, pulling up on the instrument floor slab

Ground seismometers used for active isolation pick up resulting tilt noise

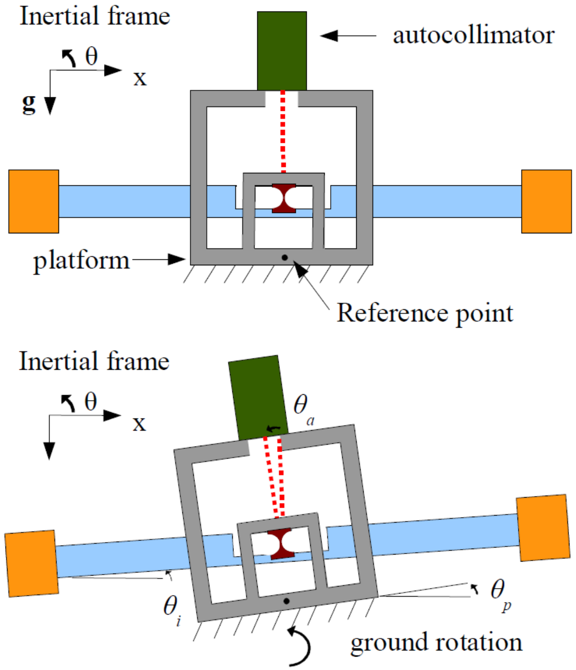


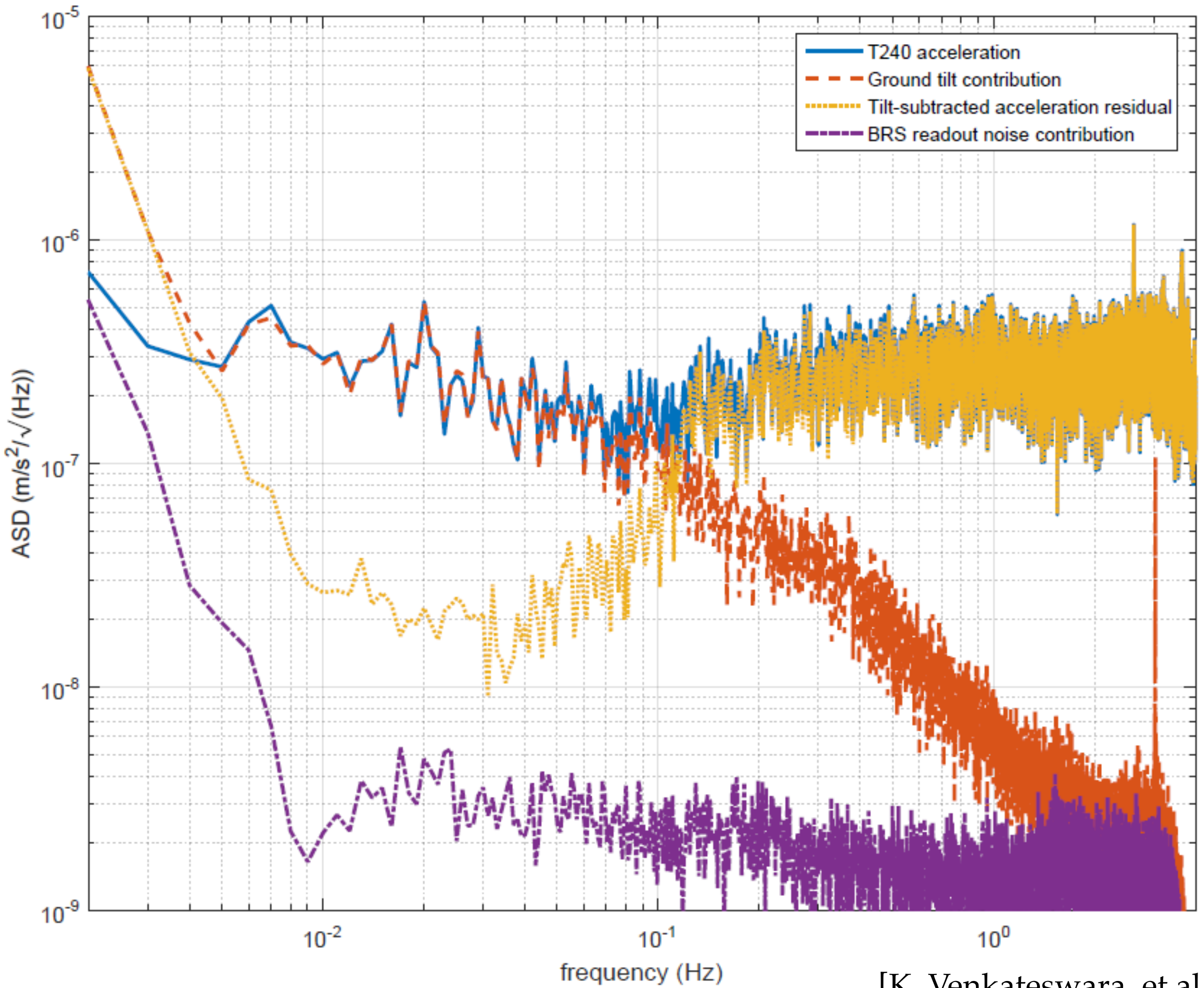
[K. Venkateswara, et al.]

Independently measure the tilt, correct the seismic sensor, then use the super-sensor

Tilt Coupling Correction

Beam rotation sensor

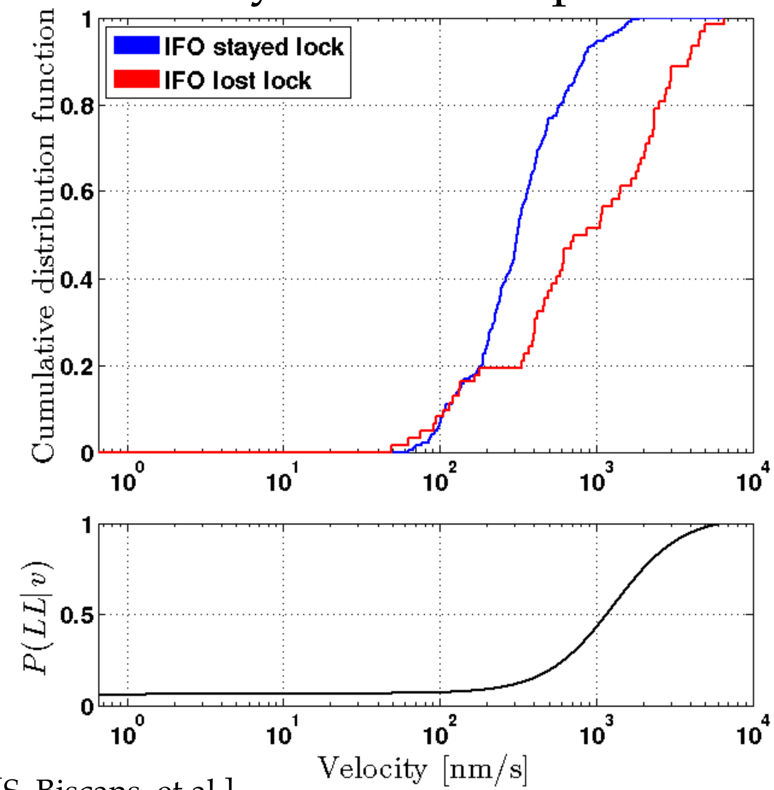




[K. Venkateswara, et al.]

Earthquake Impacts

Velocity of isolated platforms



[S. Biscans, et al.]

Earthquakes around the world can affect LIGO

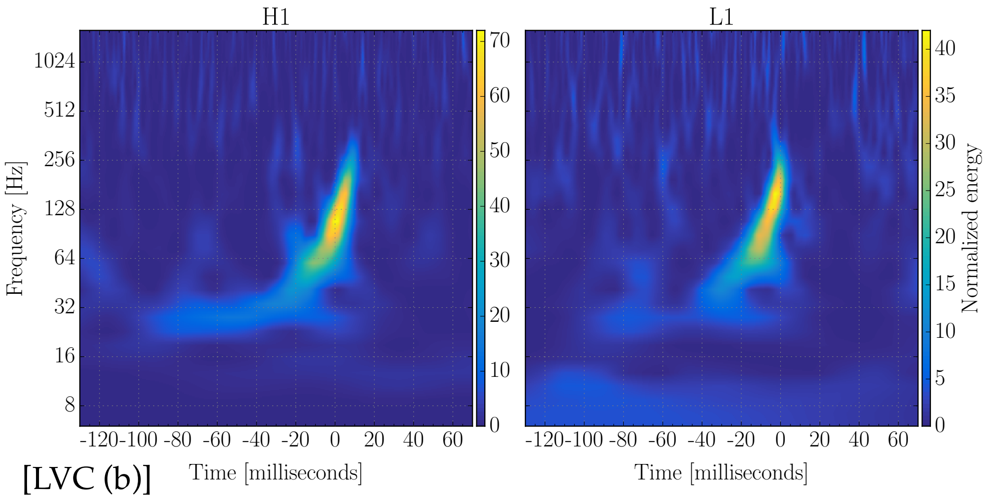
Goal is to predict an earthquake's arrival, transition to a less sensitive but more robust configuration

Preventing "lock loss" allows us to transition back to scientific observation mode much sooner

Pull USGS earthquake alerts, pass location and magnitude information through a machine learning algorithm, then inform control room if lockloss is likely and when to expect S, P, R wave arrivals

Validating GW Events

GW150914, black hole collision



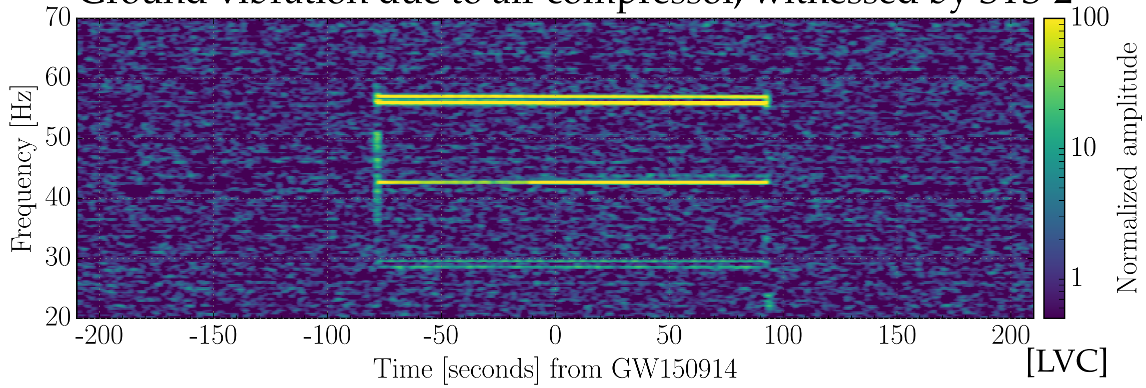
[LVC (b)]

Check that candidate gravitational wave events are not coincident with any auxiliary witness sensors

LIGO records several hundred thousand auxiliary channels to check against

For this event, the closest seismically-related signal was due to an air compressor. The time-frequency plot shows that it is unrelated to the candidate event

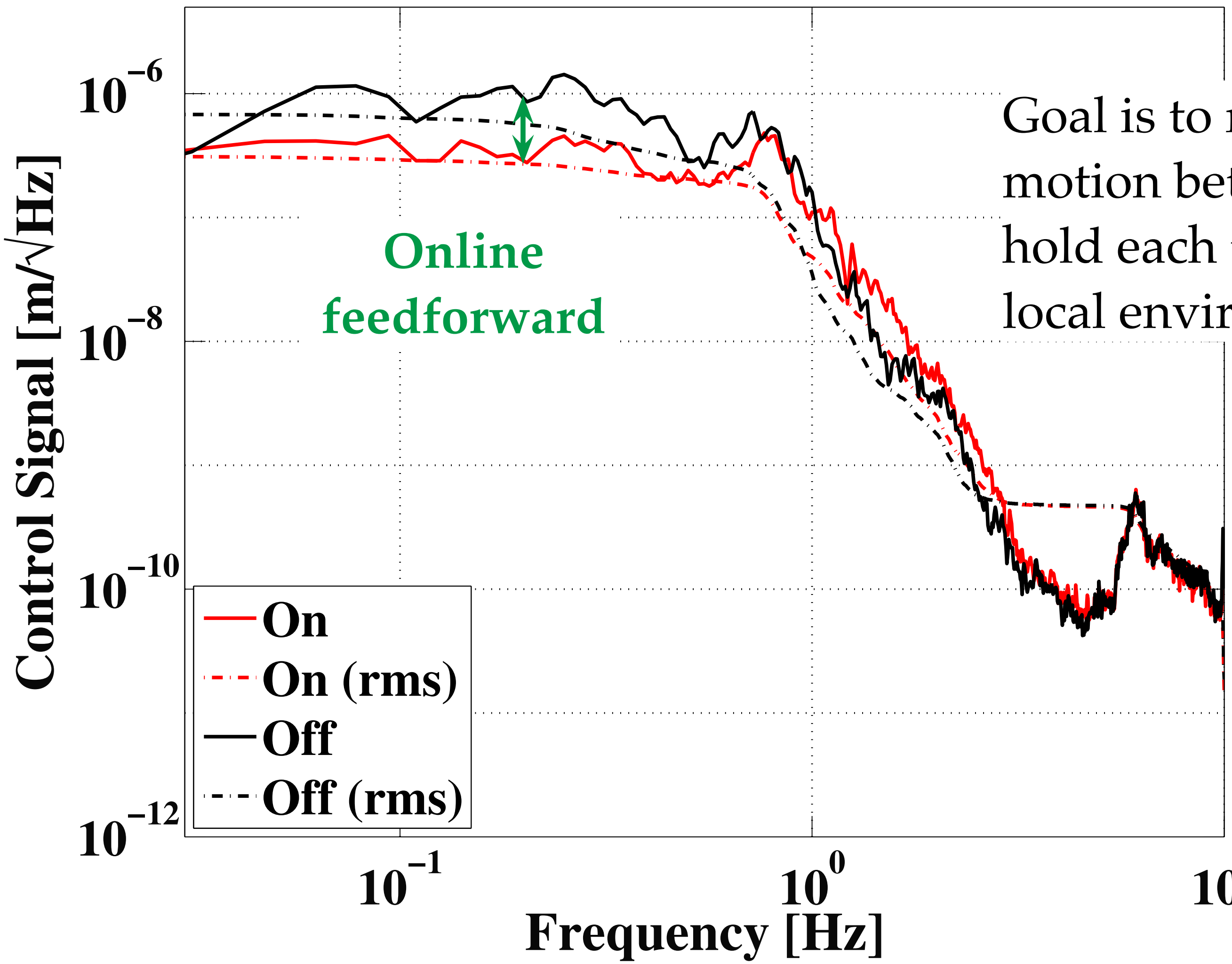
Ground vibration due to air compressor, witnessed by STS-2



[LVC]

Residual Motion Reduction

Livingston Gravitational Wave Readout (2010)



Goal is to reduce the differential motion between tables, rather than hold each table "still" relative to its local environment

Outcomes:

Lower glitch rate

Facilitated S6 (2010) high power

[J. Driggers, et al. (a)]

[R. deRosa, et al.]

Limit of this technique is sensing noise of seismometers

Newtonian Gravitational Noise

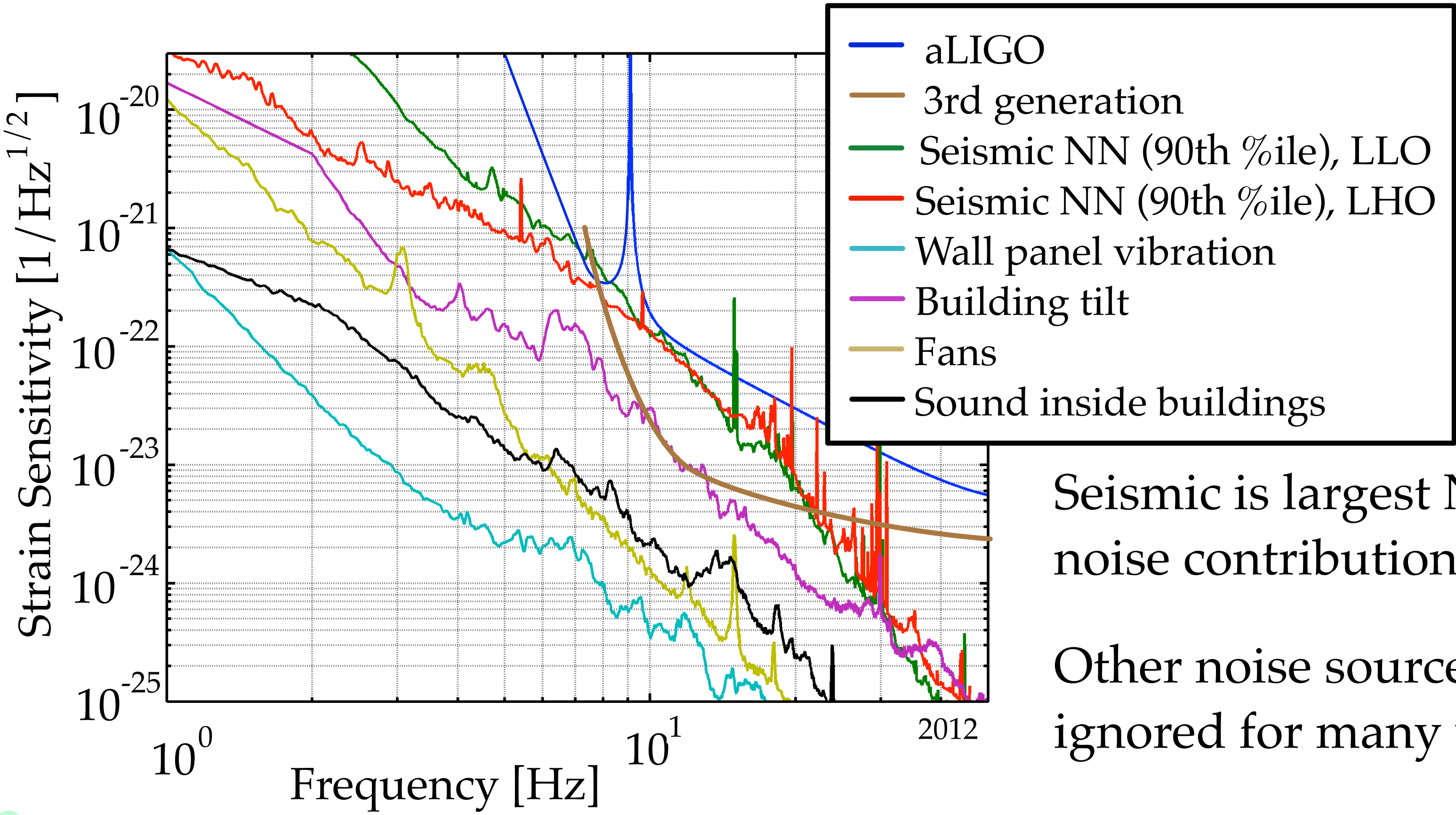
Along arm cavity axis:

$$\delta\vec{a}_{\mathrm{NN}} = \frac{\delta\vec{F}}{m} = G\,\rho_0 \int \mathrm{dS}\ \frac{\xi_{\mathrm{vert}}}{r^2}\hat{r}$$

Newtonian Gravitational Noise

Along arm cavity axis:

$$\delta\vec{a}_{\mathrm{NN}} = \frac{\delta\vec{F}}{m} = G\,\rho_0 \int \mathrm{dS}\ \frac{\xi_{\mathrm{vert}}}{r^2}\hat{r}$$

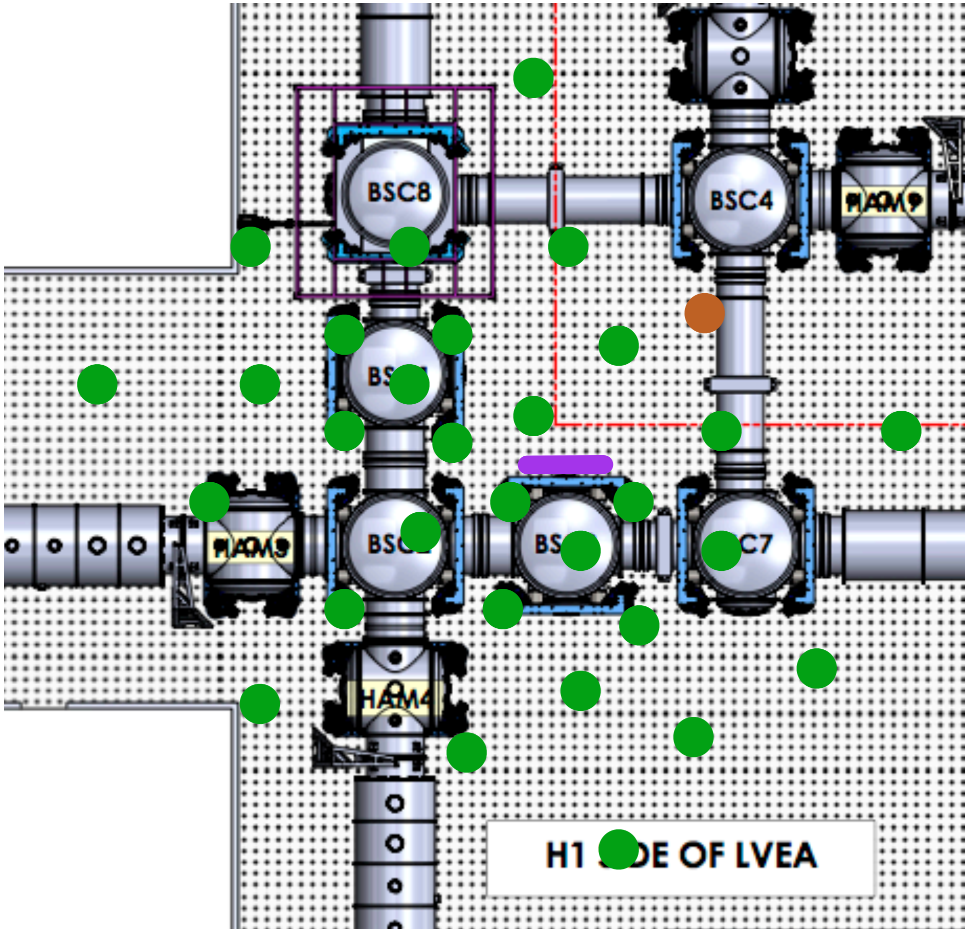


Seismic is largest Newtonian noise contribution

Other noise sources can be ignored for many years

[J. Driggers, et al. (b)]

Newtonian Noise Array



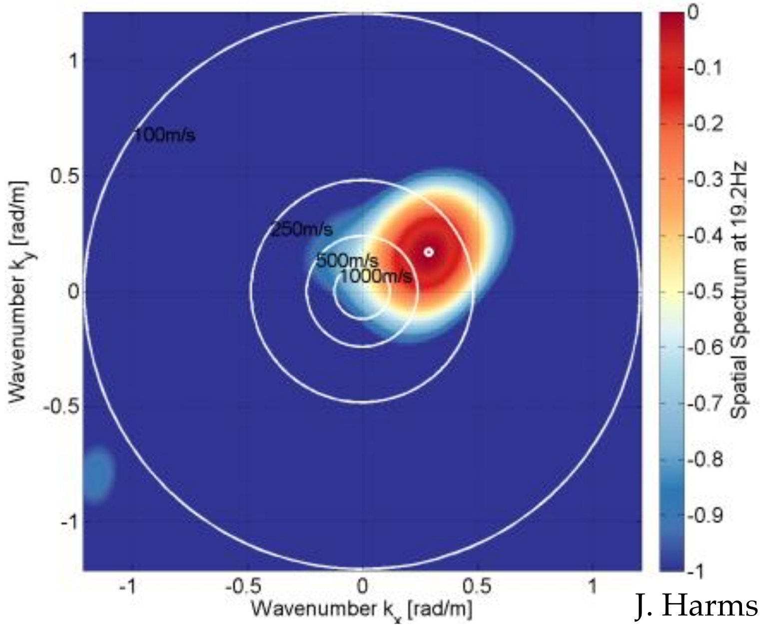
Installed throughout recent observation run

- 30 L4Cs placed on floor in instrument hall
- 1 tilt meter near center of array
- 1 STS-2 (not used in this analysis)

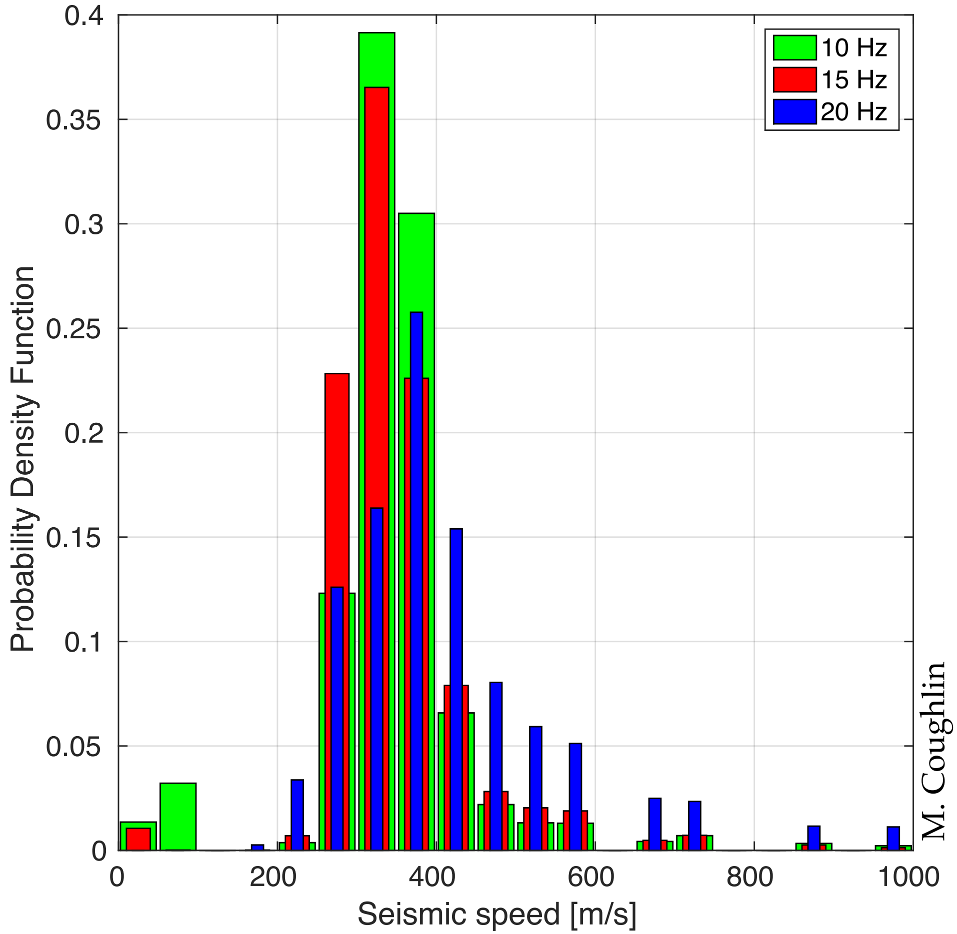
Measure seismic fields present, as a function of time

Determine realistic ability to subtract Newtonian gravitational noise from interferometer

Speed Measurements



Generate Capon maps for several frequencies of interest, for many times



Small amount of dispersion, relatively simple seismic spectrum

Suggests that surface Rayleigh waves dominate

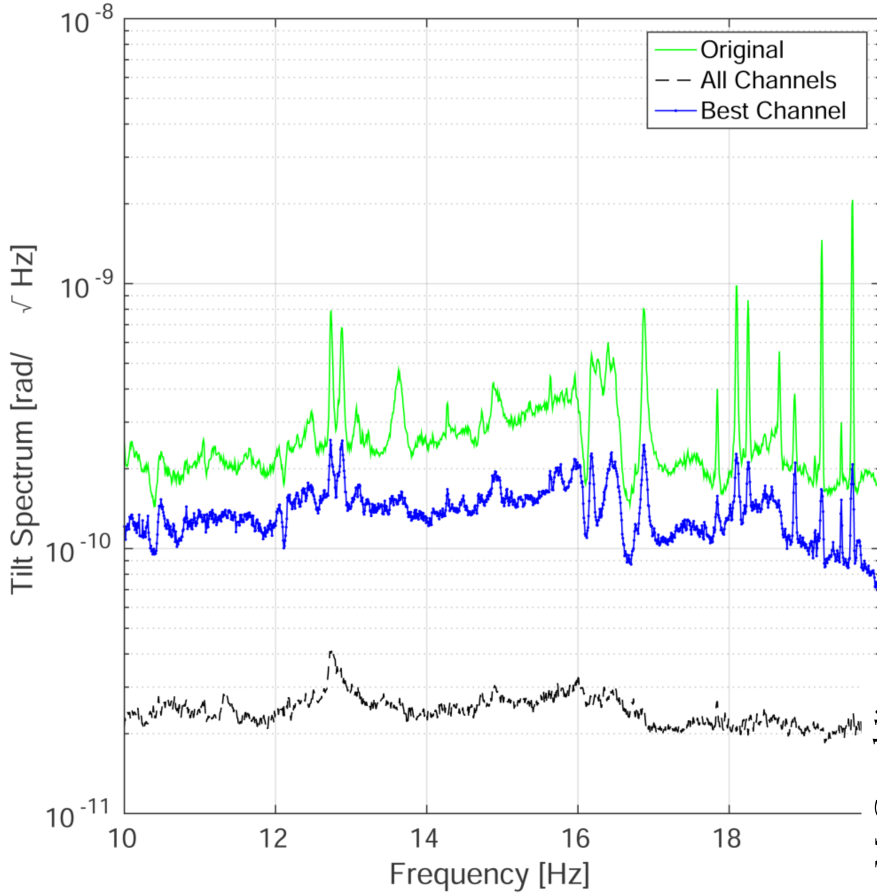
Newtonian Noise Subtraction Test

Use beam rotation sensor as proxy for Newtonian noise

Using Wiener filters, subtract seismometer data from tiltmeter to determine approximately how well we should be able to subtract Newtonian noise

Achieve factors of 10 subtraction; sufficient for Advanced LIGO

Will require factors of 30-100 for future generations of detectors



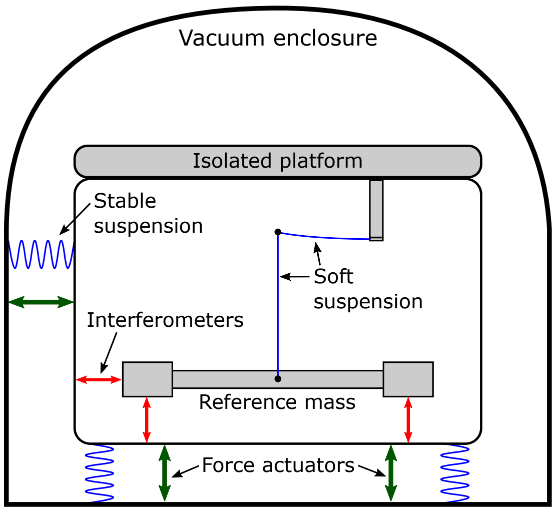
M. Coughlin

[M. W. Coughlin, et al. (a)]
[M. W. Coughlin, et al. (b)]

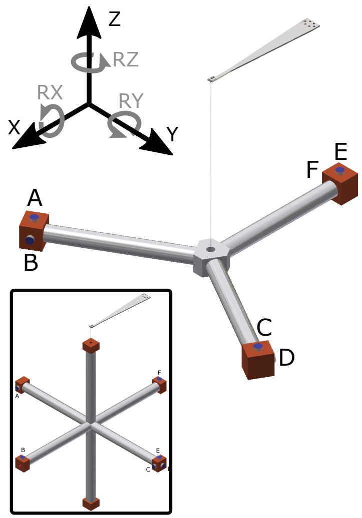
Six Dimensional Inertial Sensor

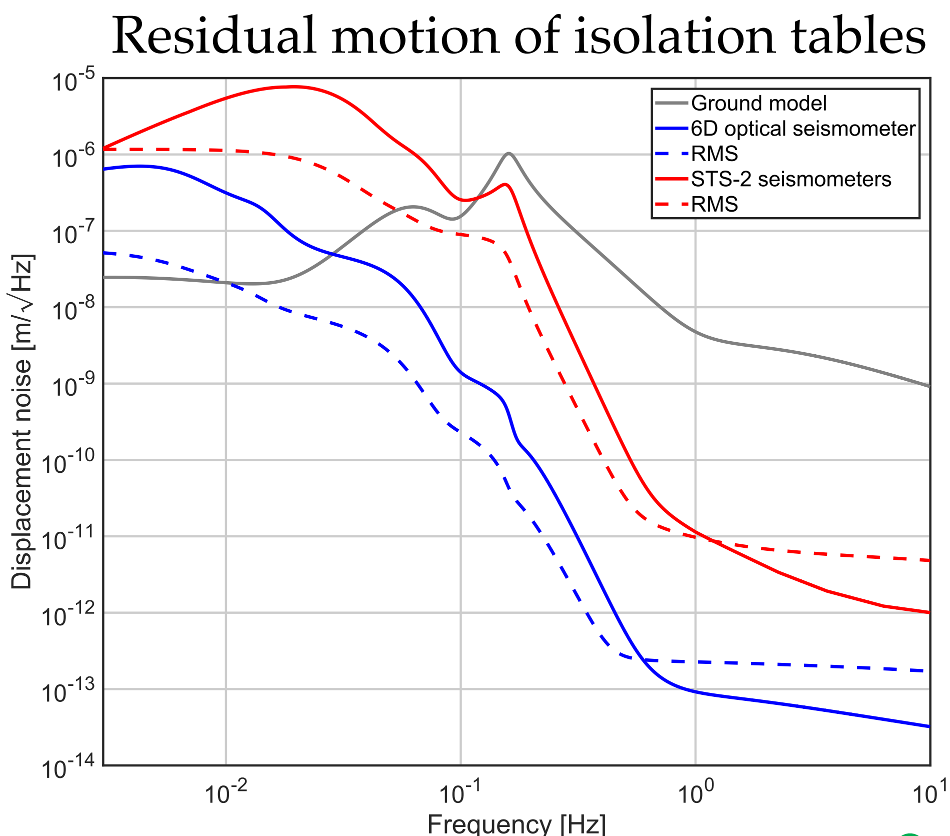
Future ground-based gravitational wave detectors will require more sensitive inertial sensors

A vacuum-compatible six dimensional sensor is under development within the LIGO Scientific Collaboration

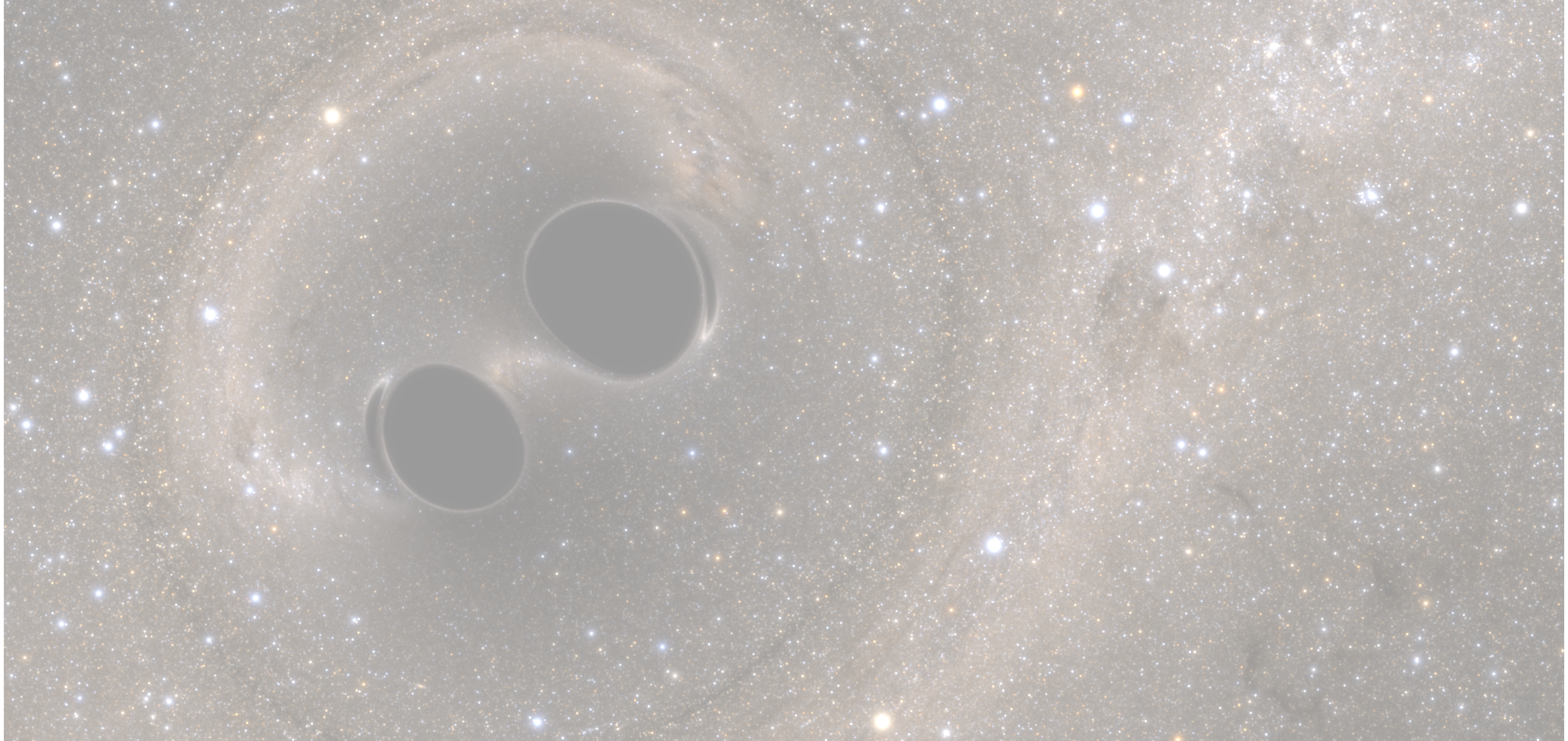


[C. M. Mow-Lowry and D. Martynov]





LIGO has successfully measured gravitational waves resulting from the collisions of compact objects such as black holes and neutron stars



A wide variety of seismic sensors are critical to the operation of the LIGO interferometers

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