Seismic isolation techniques

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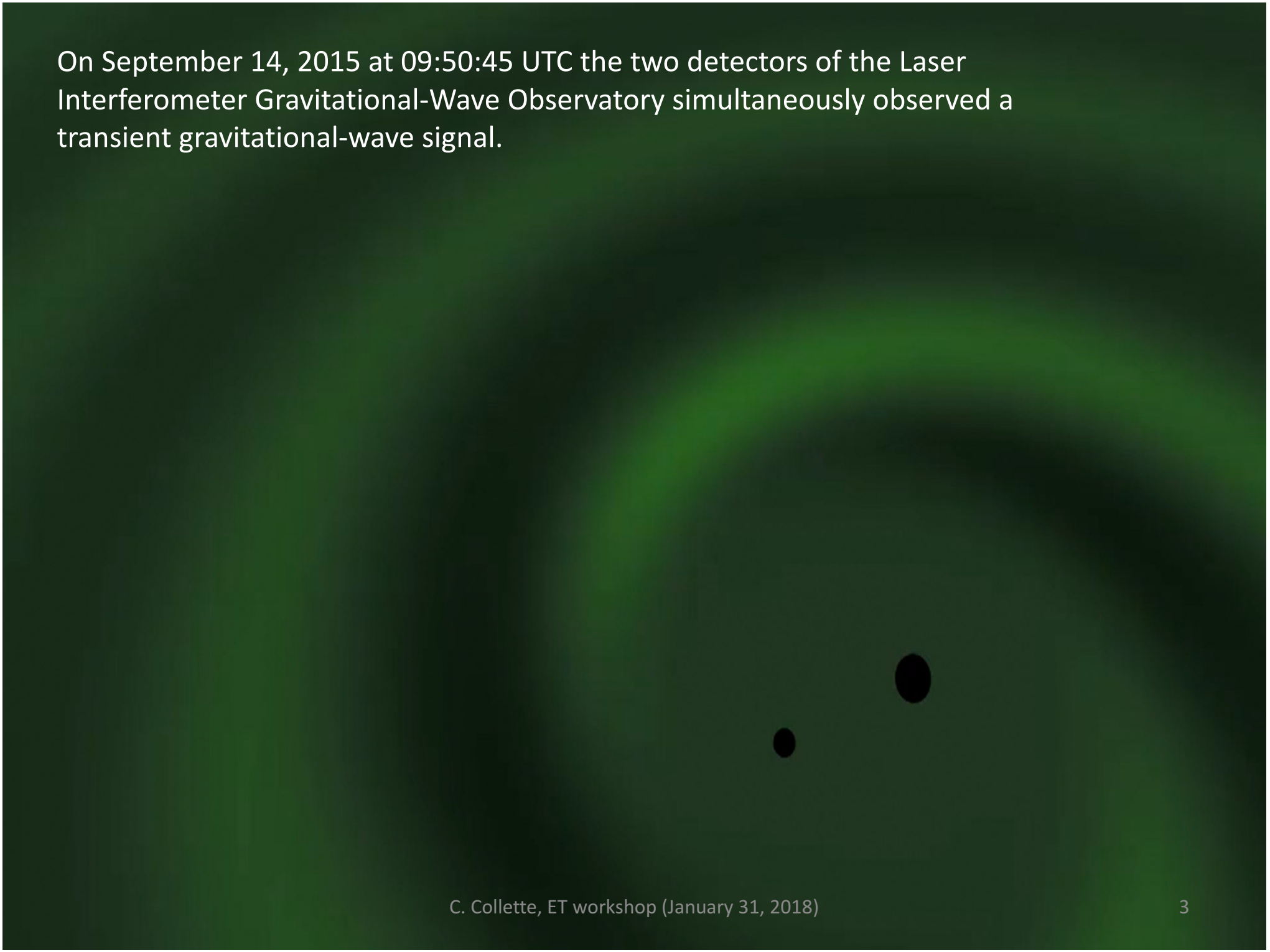
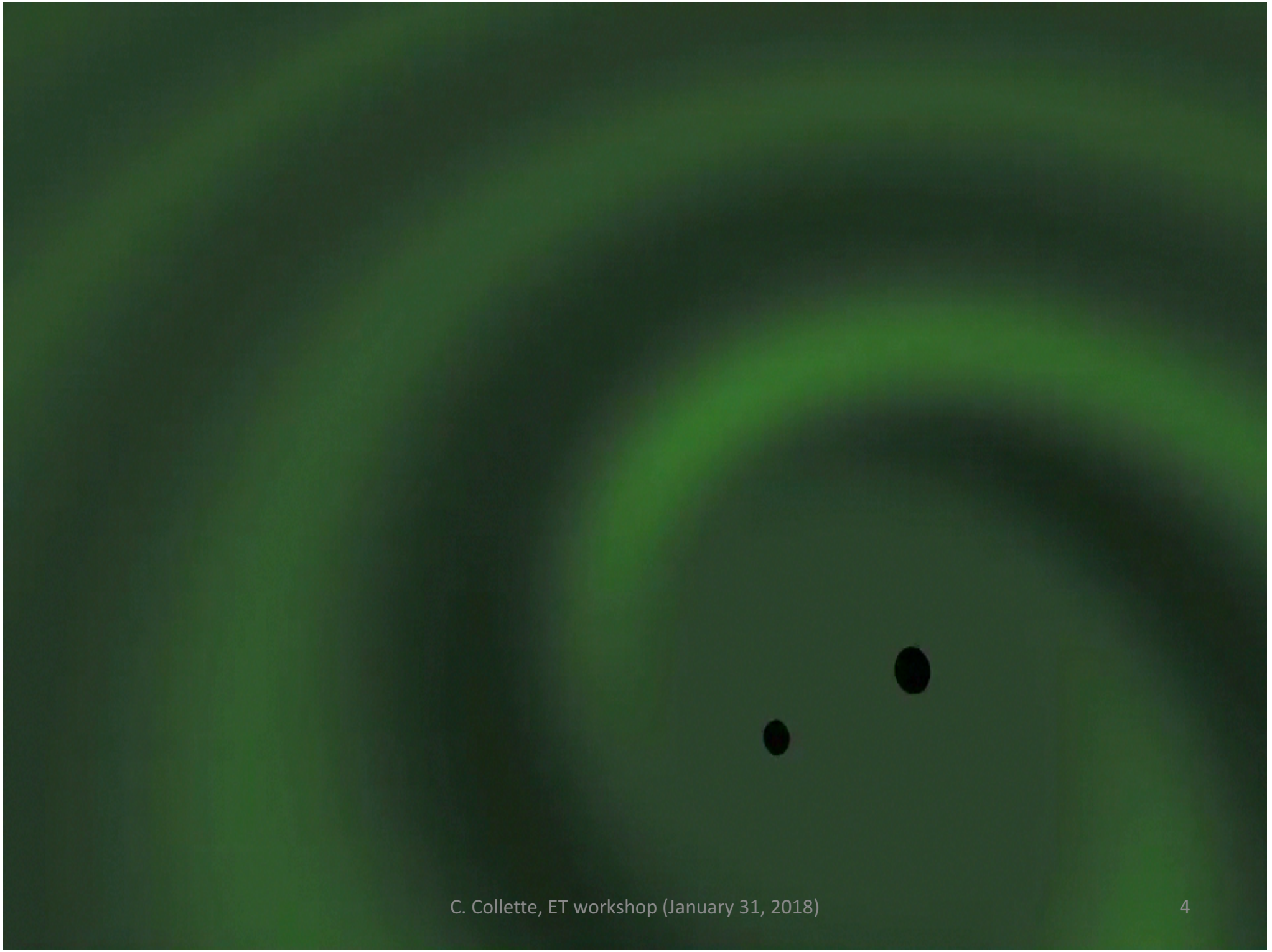
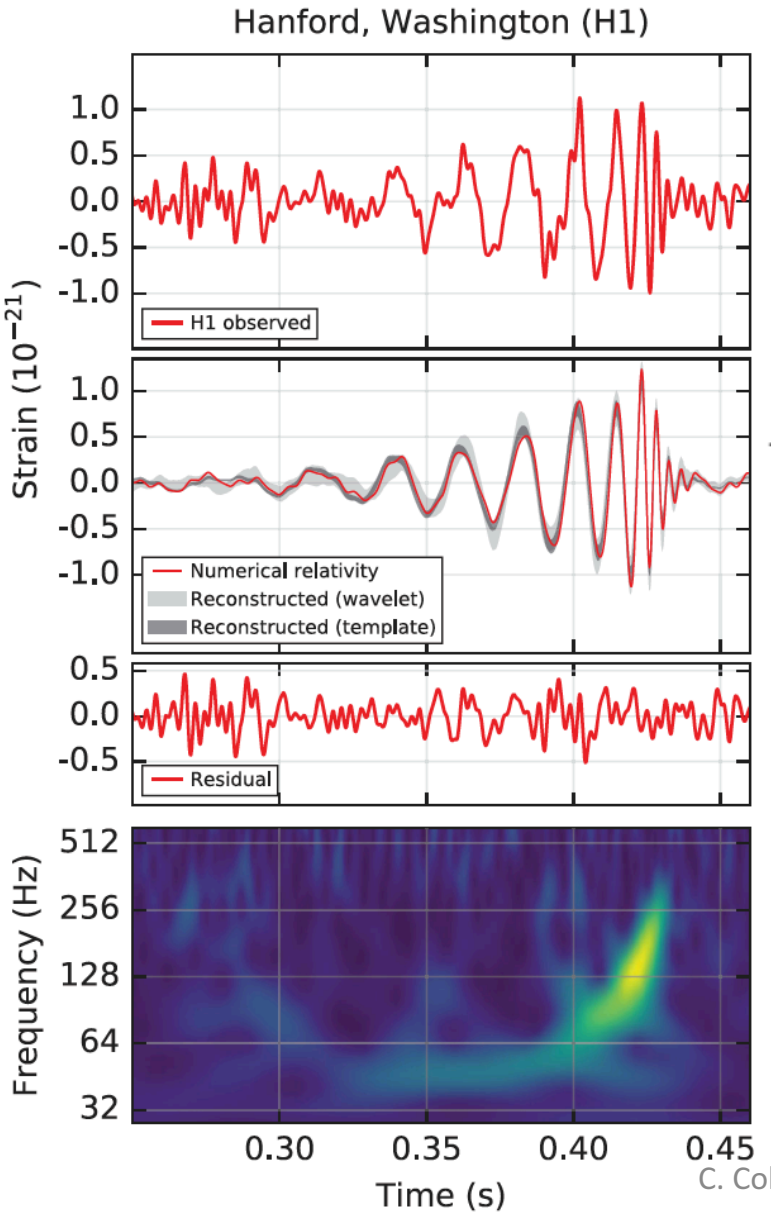
Precision Mechatronics Laboratory

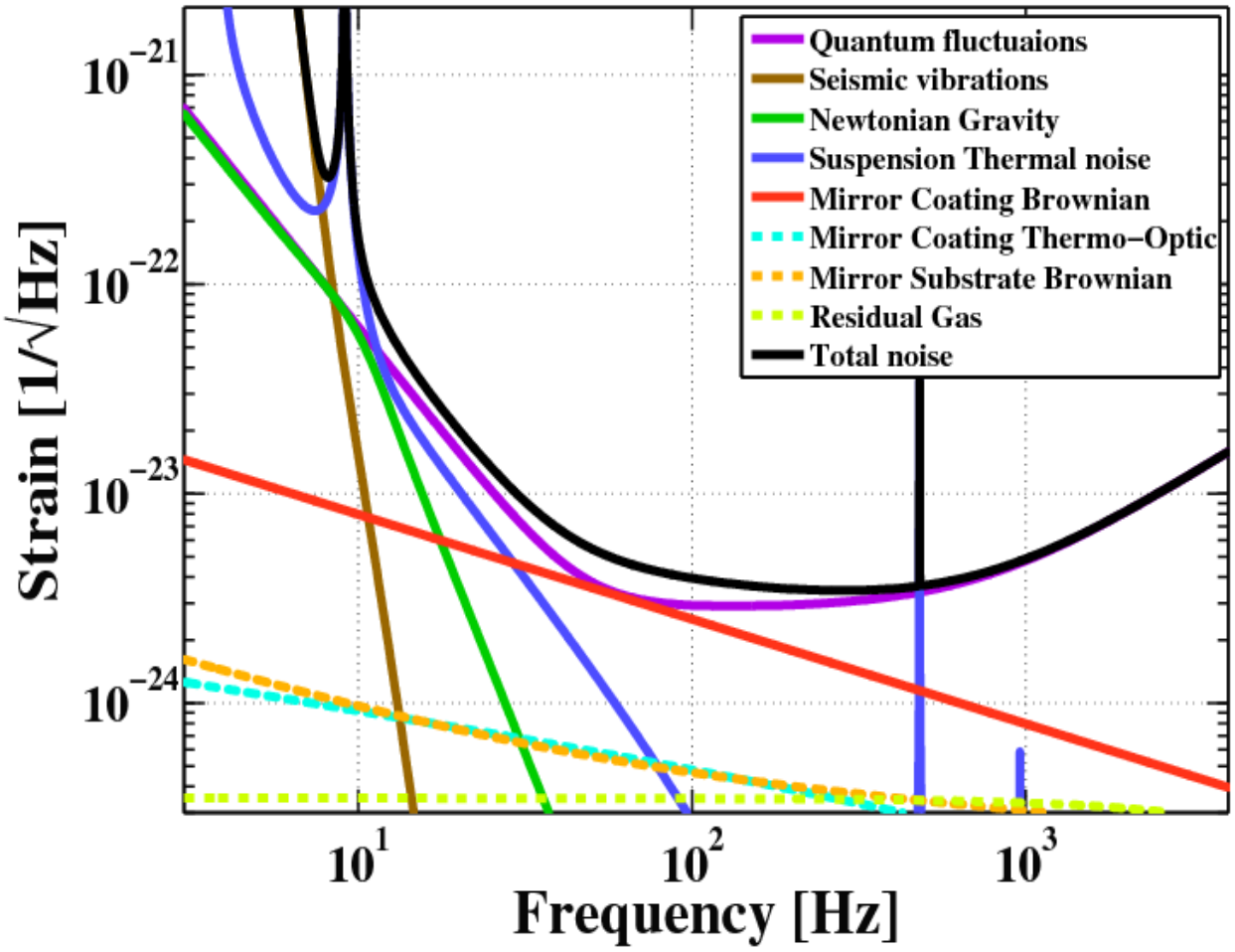
On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal.



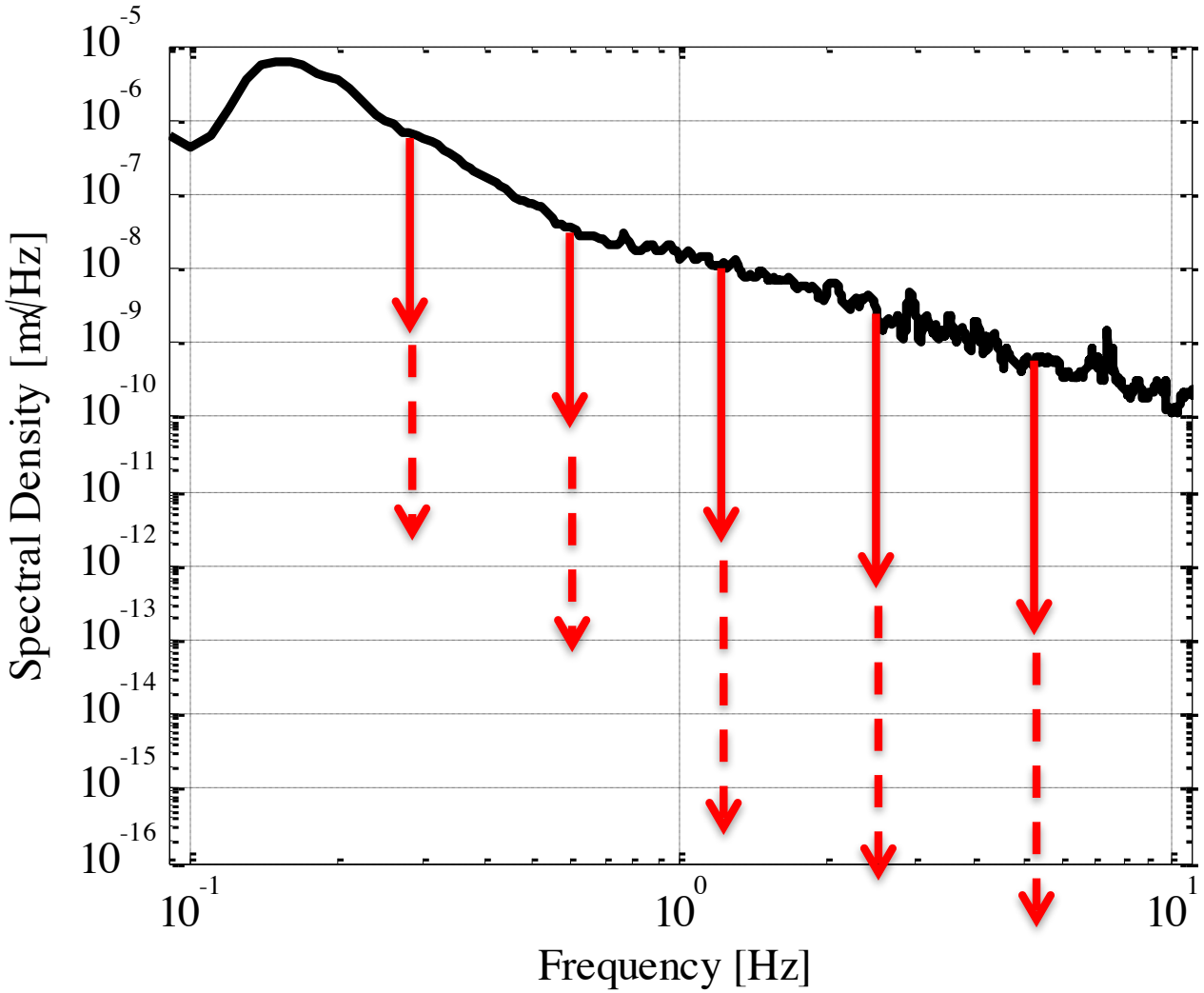


Sensitivity

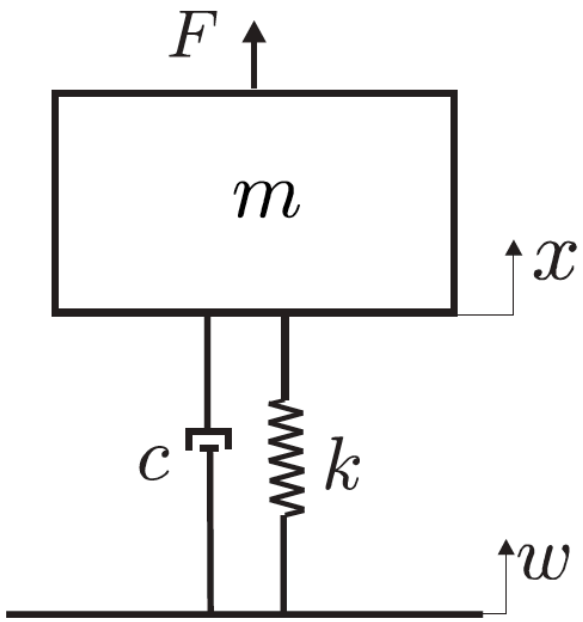


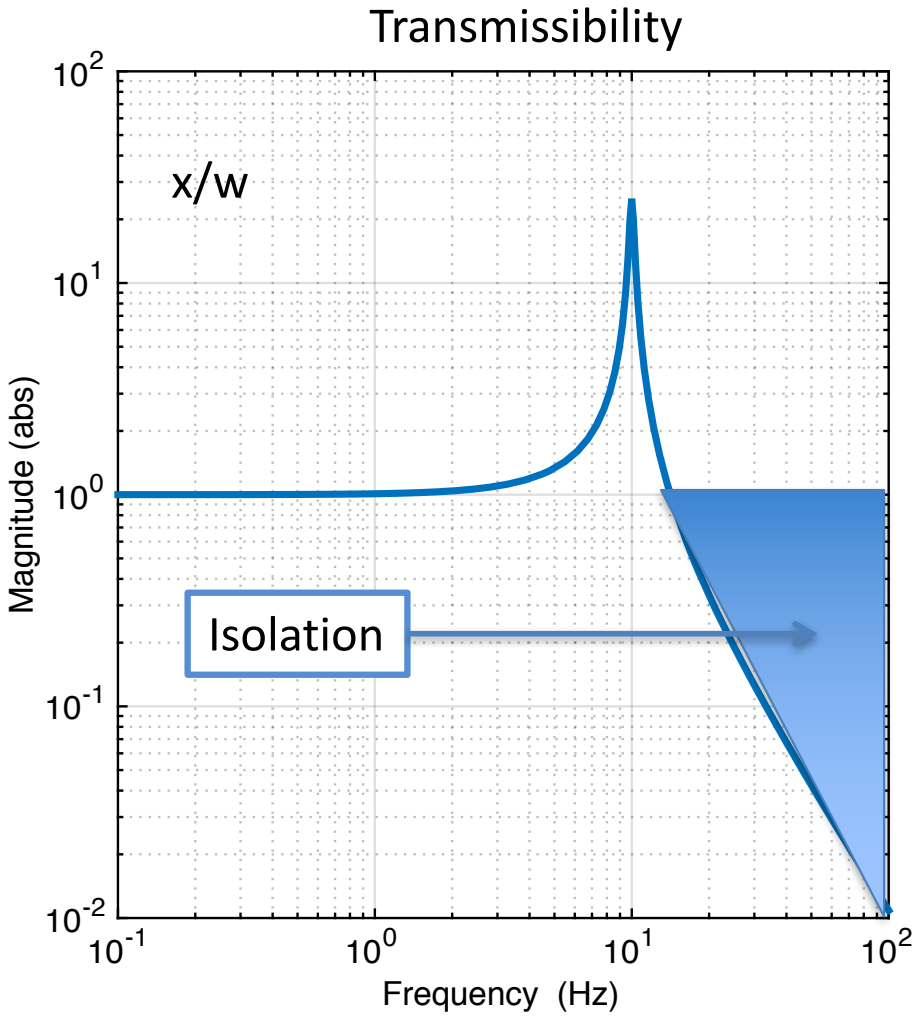


Seismic isolation requirements

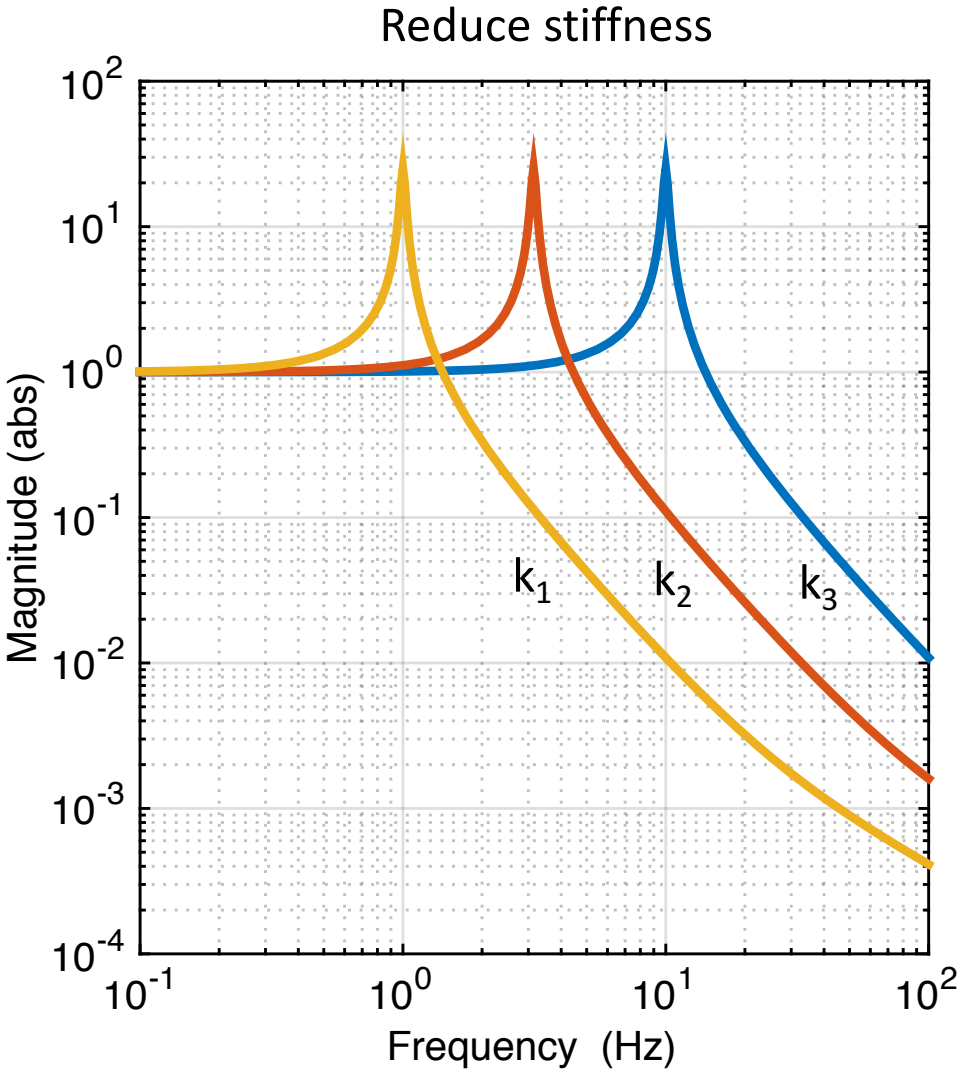


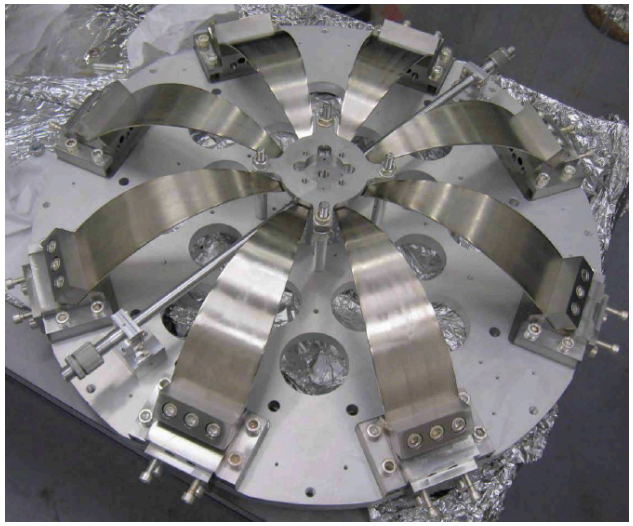
Seismic isolation principle

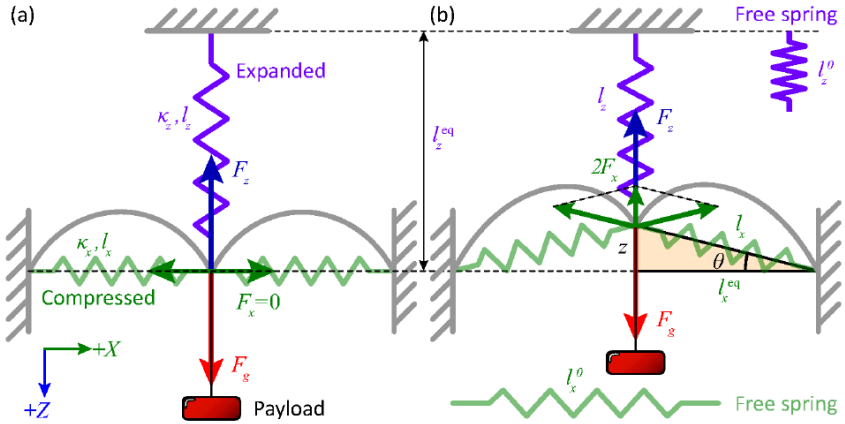




Strategy 1: Passive isolation





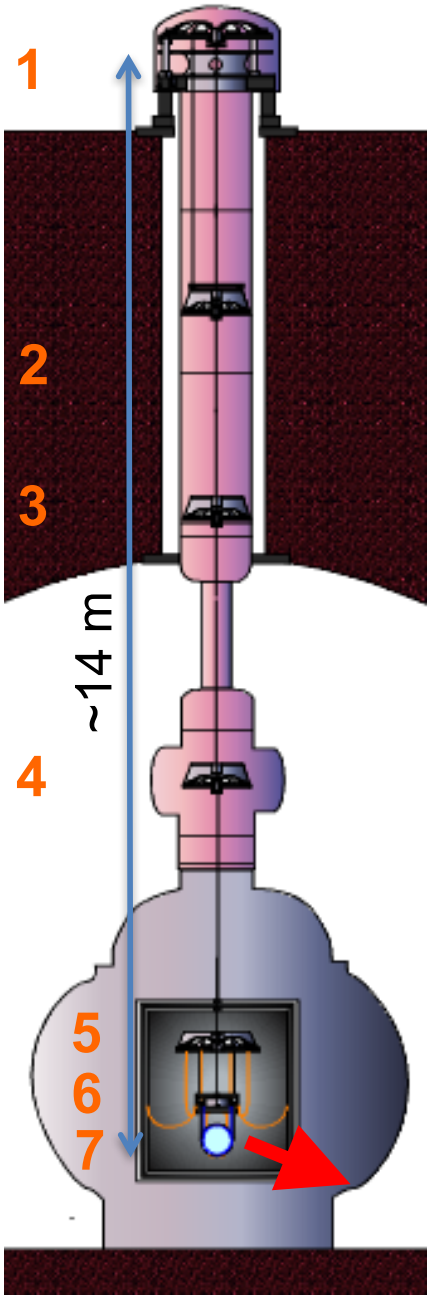


Wanner PhD thesis (2013)

Hybrid Systems

J. Kissel, GWADW, May 17 2012
G1200556-v1

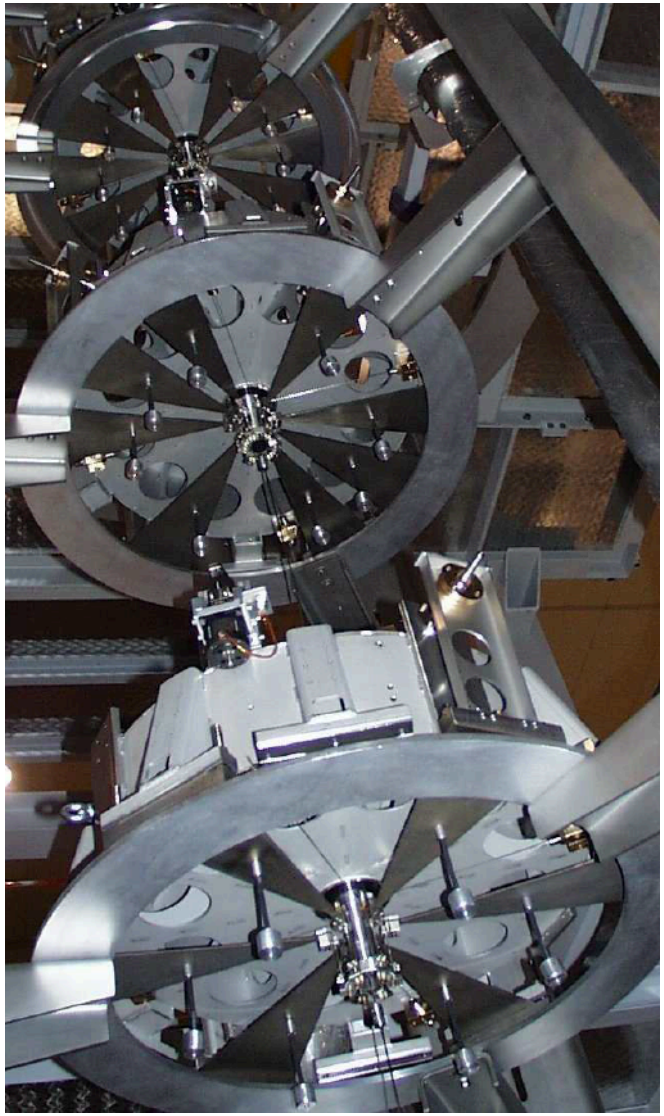
Advanced VIRGO, Kagra, ET – The Design

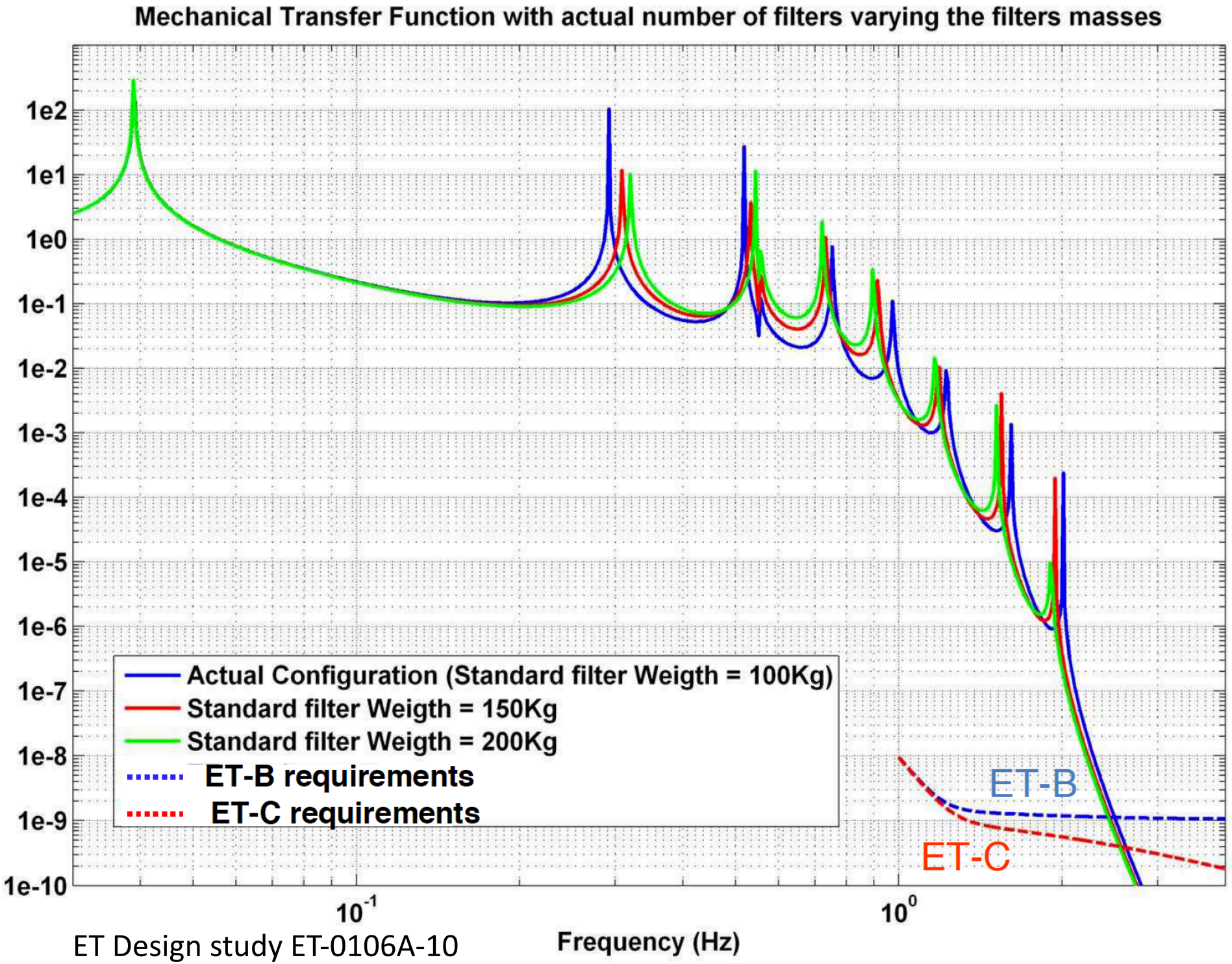


- 7 Stages of Isolation
  - Inverted Pendula Pre-isolation stages (Horz. only)
  - Blade springs and tunable anti-spring vertical pendula (geometric, magnetic)
- Sensors and actuators for 6 DOFs of 6th stage, 4 DOFs (Long., Vert., Pitch, Yaw) at 1st stage
- (4 + 6 + 3) = 13 out of 42 Trans./Rot. resonant modes sensed and controlled

Performance limited by

- **direct transmission of ground motion**
- **Length of the stages**
- **Ultra-soft system: 1N on 1 ton creates a motion of 1cm**

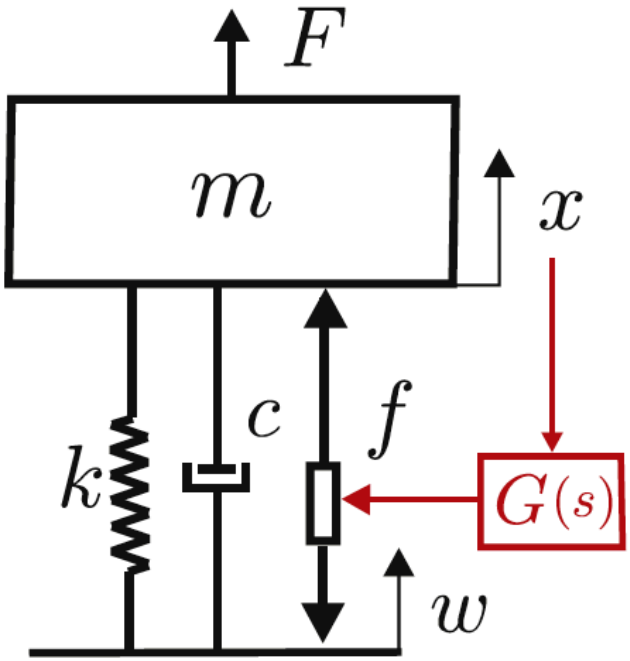


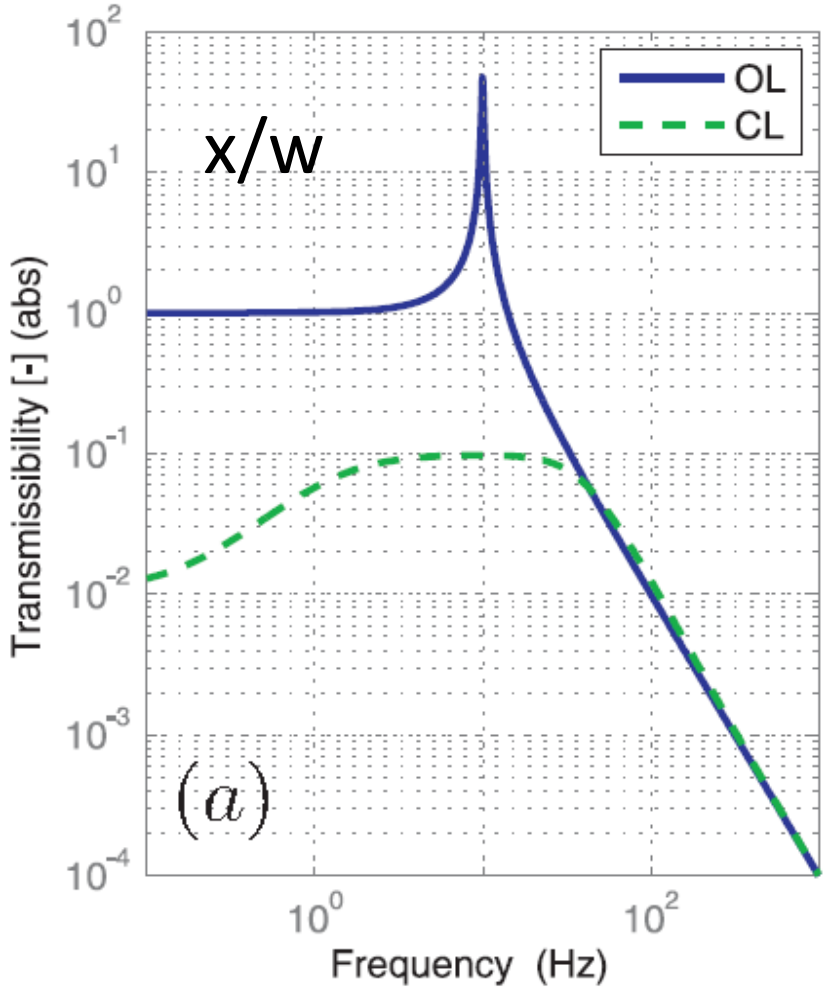


ET Design study ET-0106A-10

Strategy 2: Active isolation

Inertial control

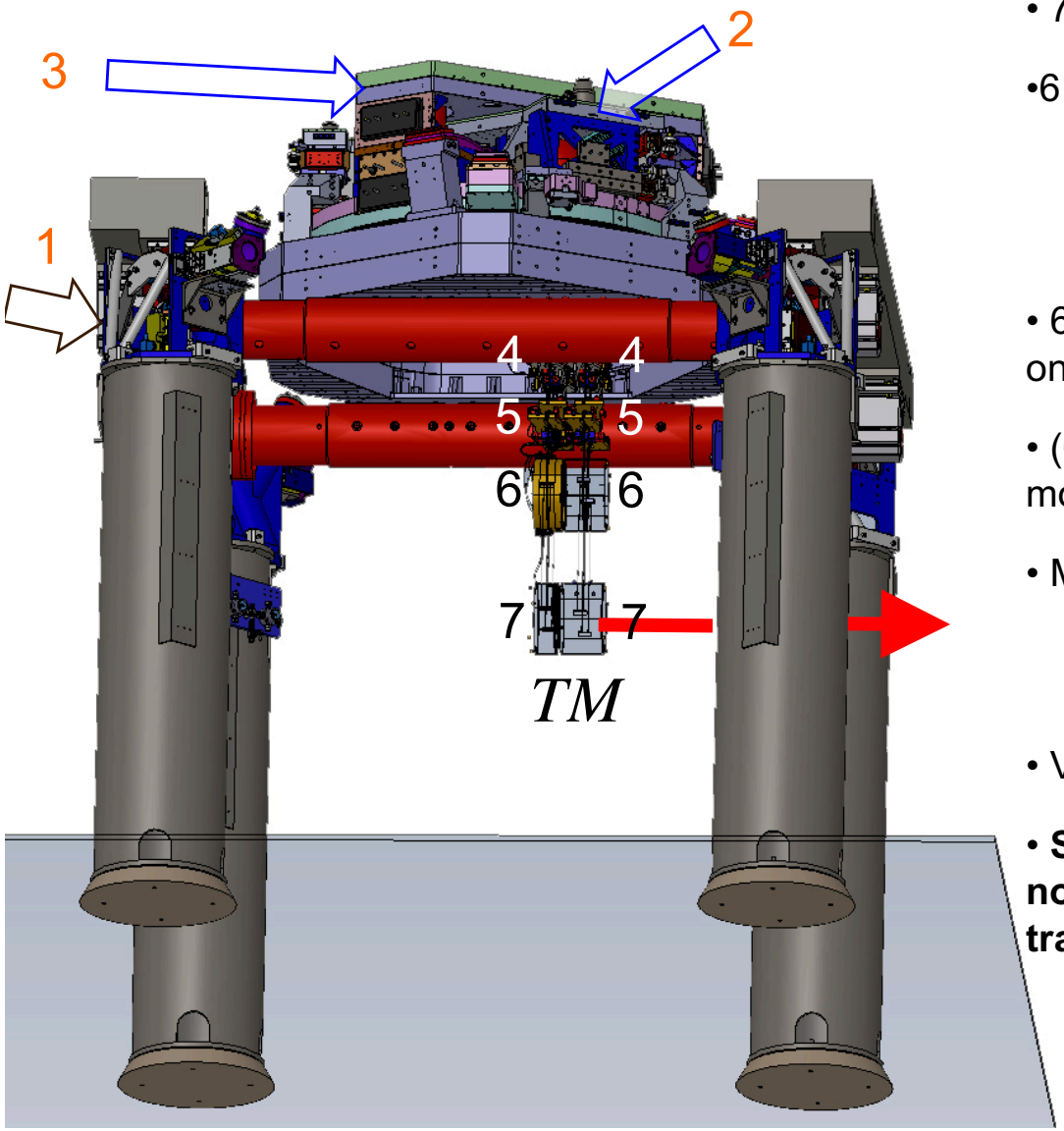




Hybrid Systems

J. Kissel, GWADW, May 17 2012
G1200556-v1

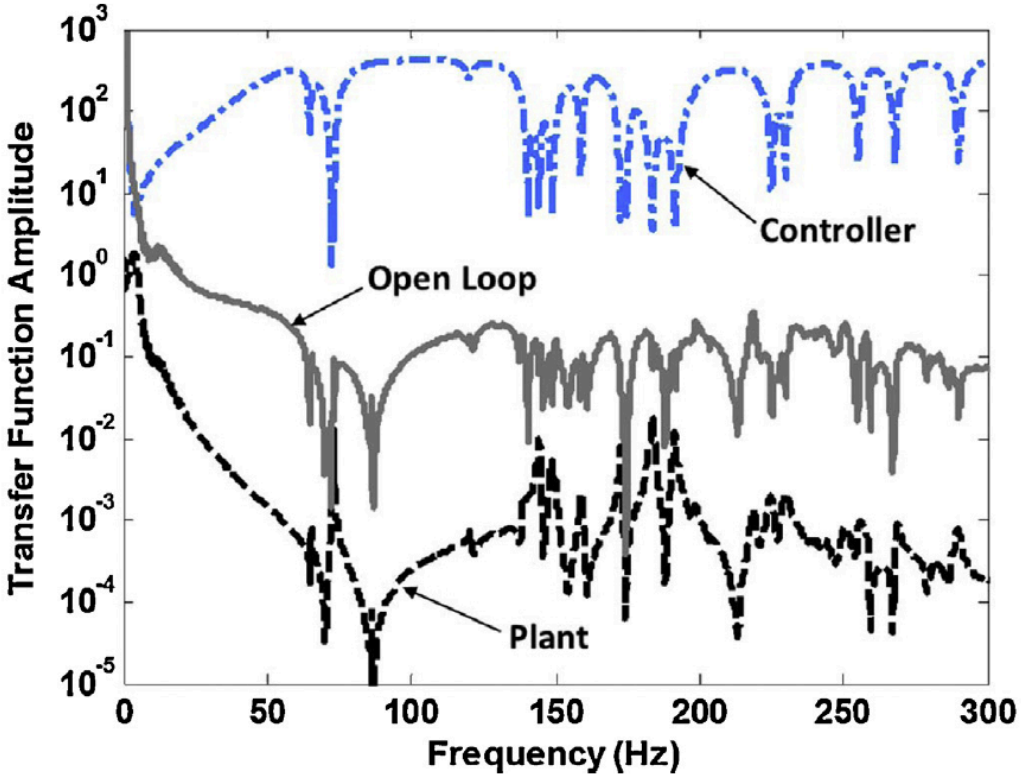
Advanced LIGO - The Design



- 7 Stages of Isolation
- 6 DOF sensing on stages 1 – 4, 3 DOF on 5 – 6
  - Inertial and displacement on stages 1-3
  - Displacement only on stages 4 - 6
- 6 DOF DC - 1kHz actuation on Stages 1 – 4, 3 DOF on 5 - 7
- (6+6+6+[3*6+4]) = 40 out of 42 Trans./Rot. resonant modes sensed and controlled
- Many-control-loop system
  - Sensor blending, Feed back, Feed forward, Sensor Correction, Heirarchical control
- Versatile 800 kg payload
- **Stage 1 – 3 "Performance limited by sensor noise," Stage 4 – 7 "Performance limited by direct transmission of platform motion"**

Limitation 1: Mechanical design

Initial prototype (2008)

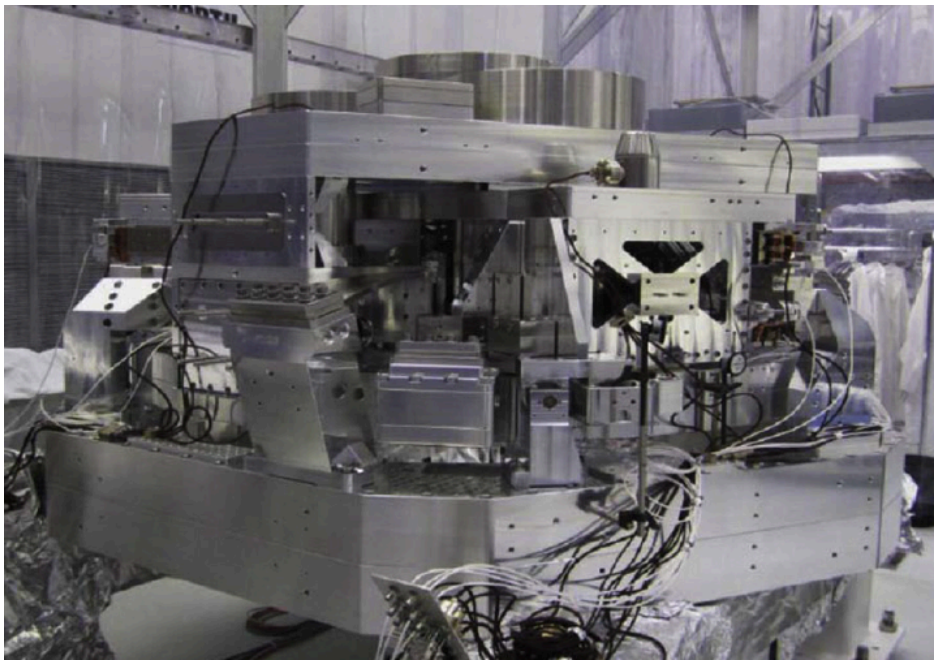


F. Matichard, Precision engineering, 40 (2015), 287-297

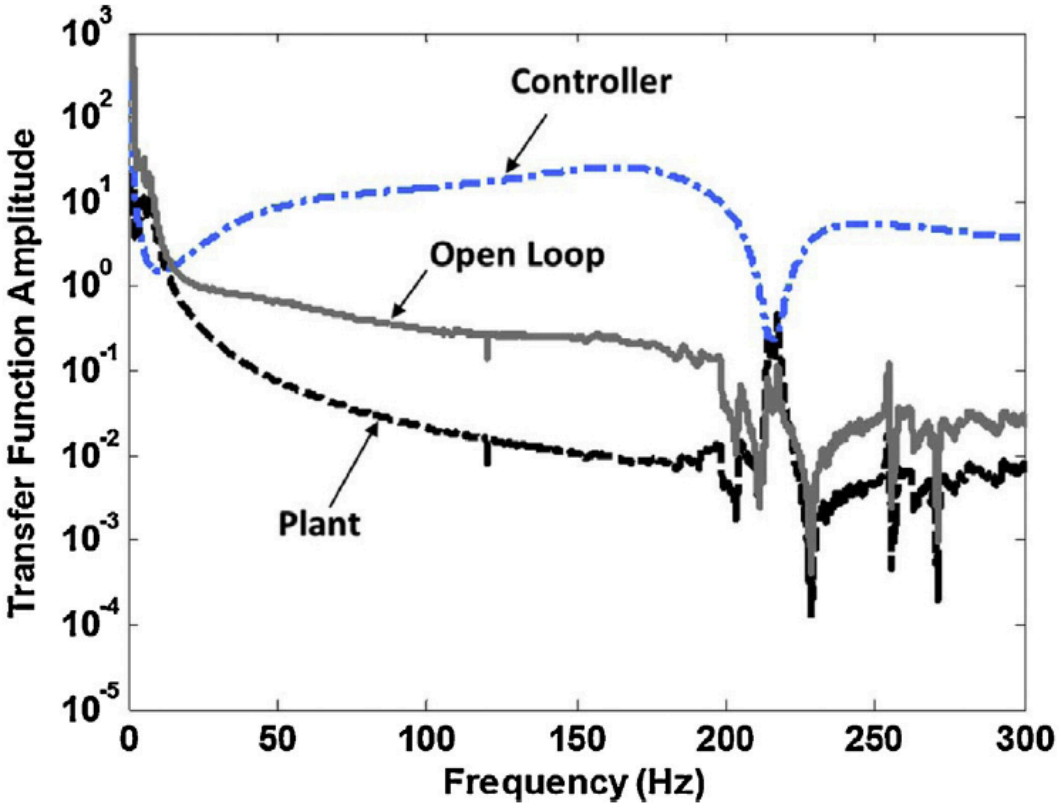
Compensator was made of 104 poles and zeros.

Limitation 1: Mechanical design

Final Design (2011)

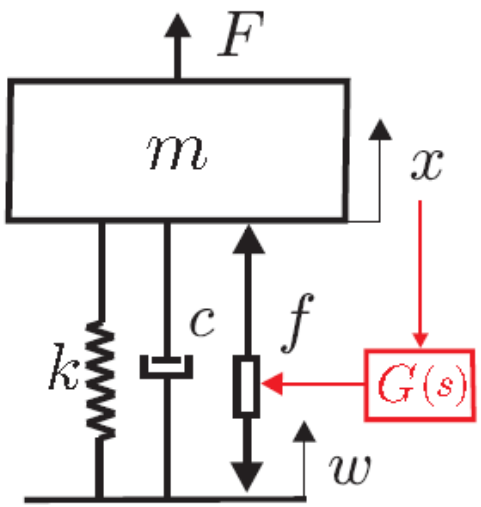


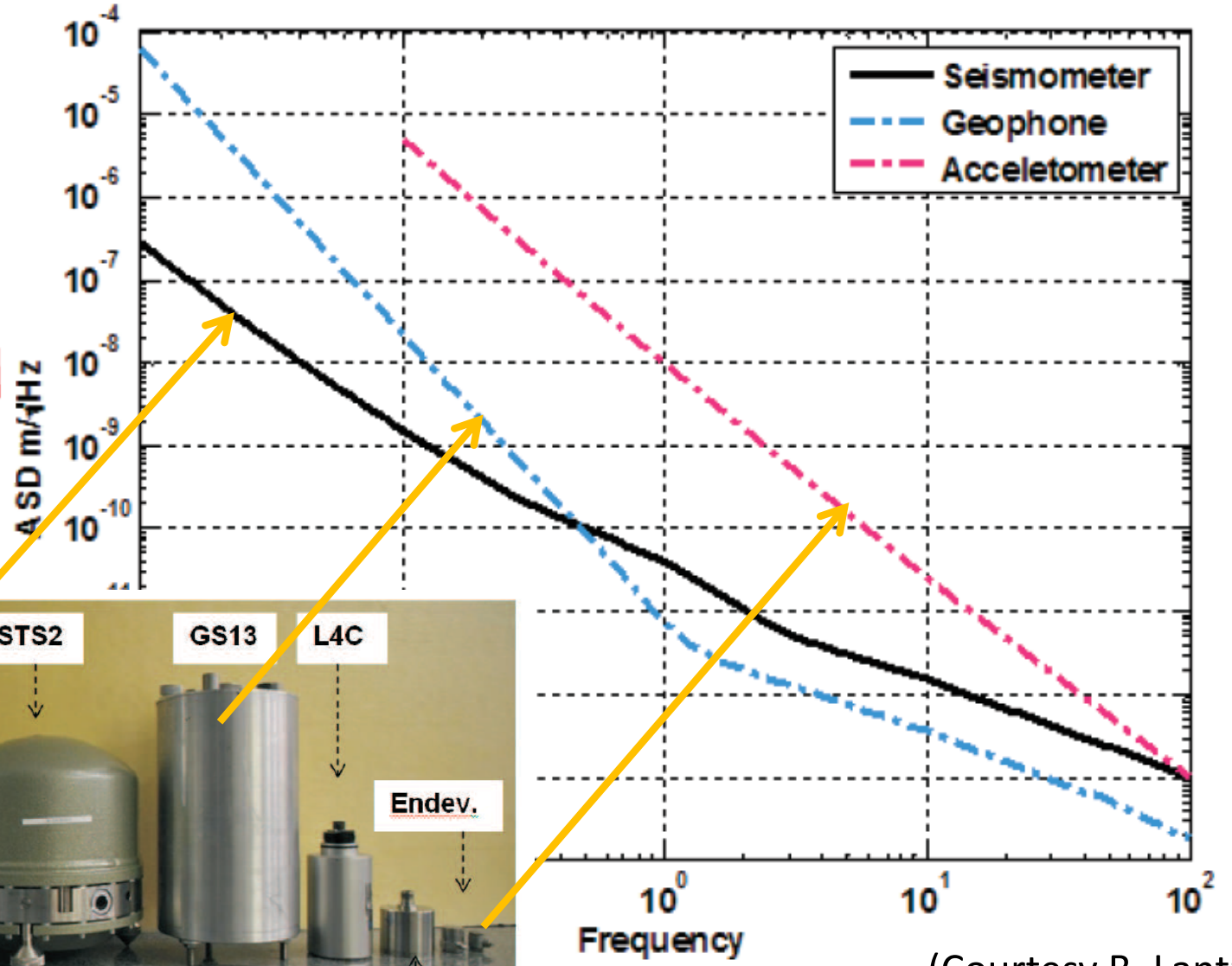
F. Matichard, Precision engineering, 40 (2015), 287-297



22 poles and zeros !

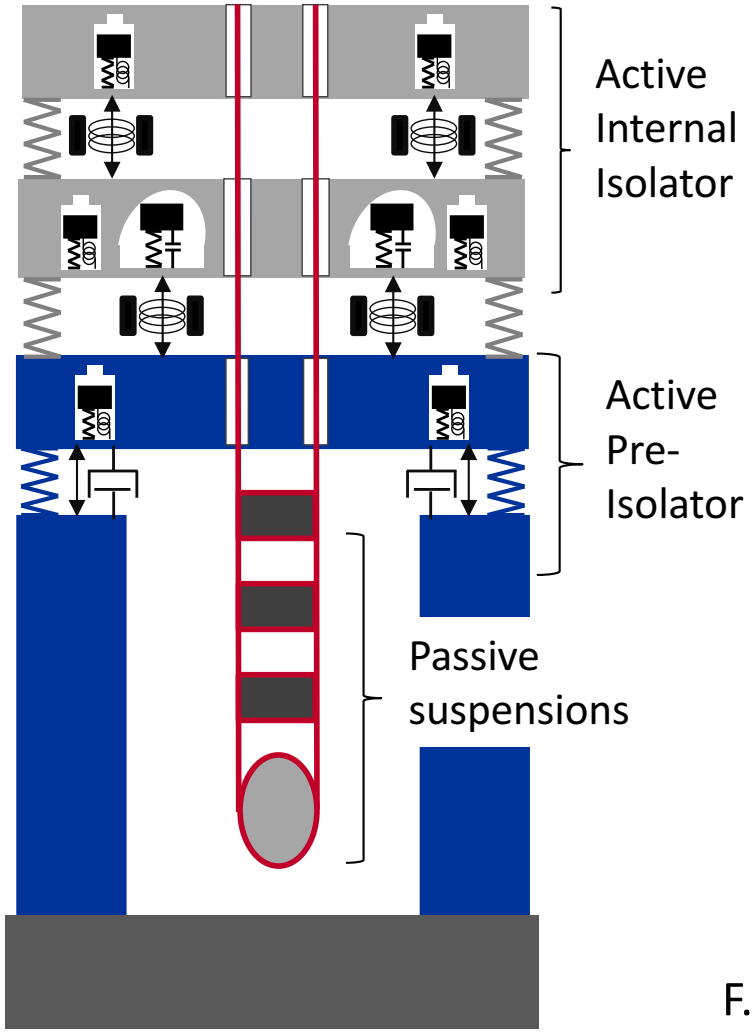
Limitation 2: Sensor noise

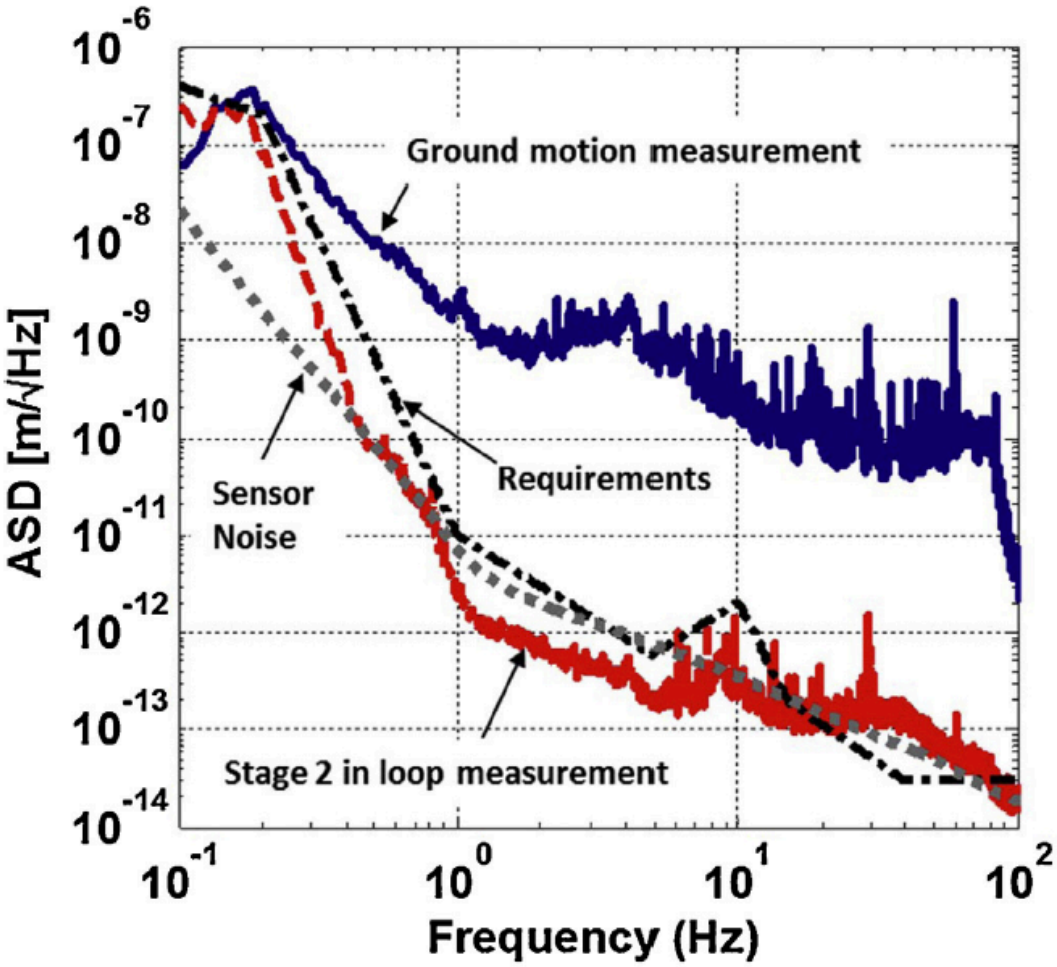




(Courtesy B. Lantz)

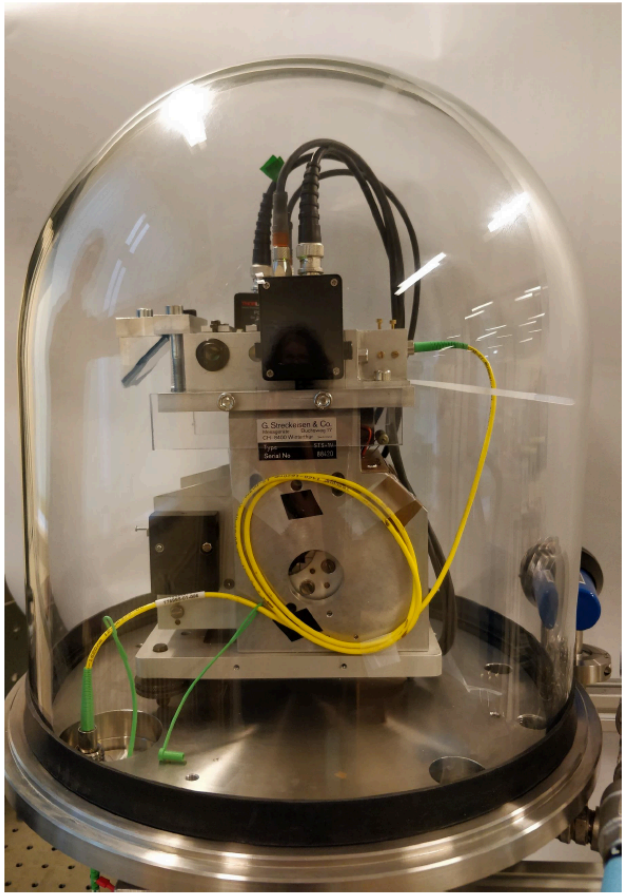
Two-stage active seismic isolation

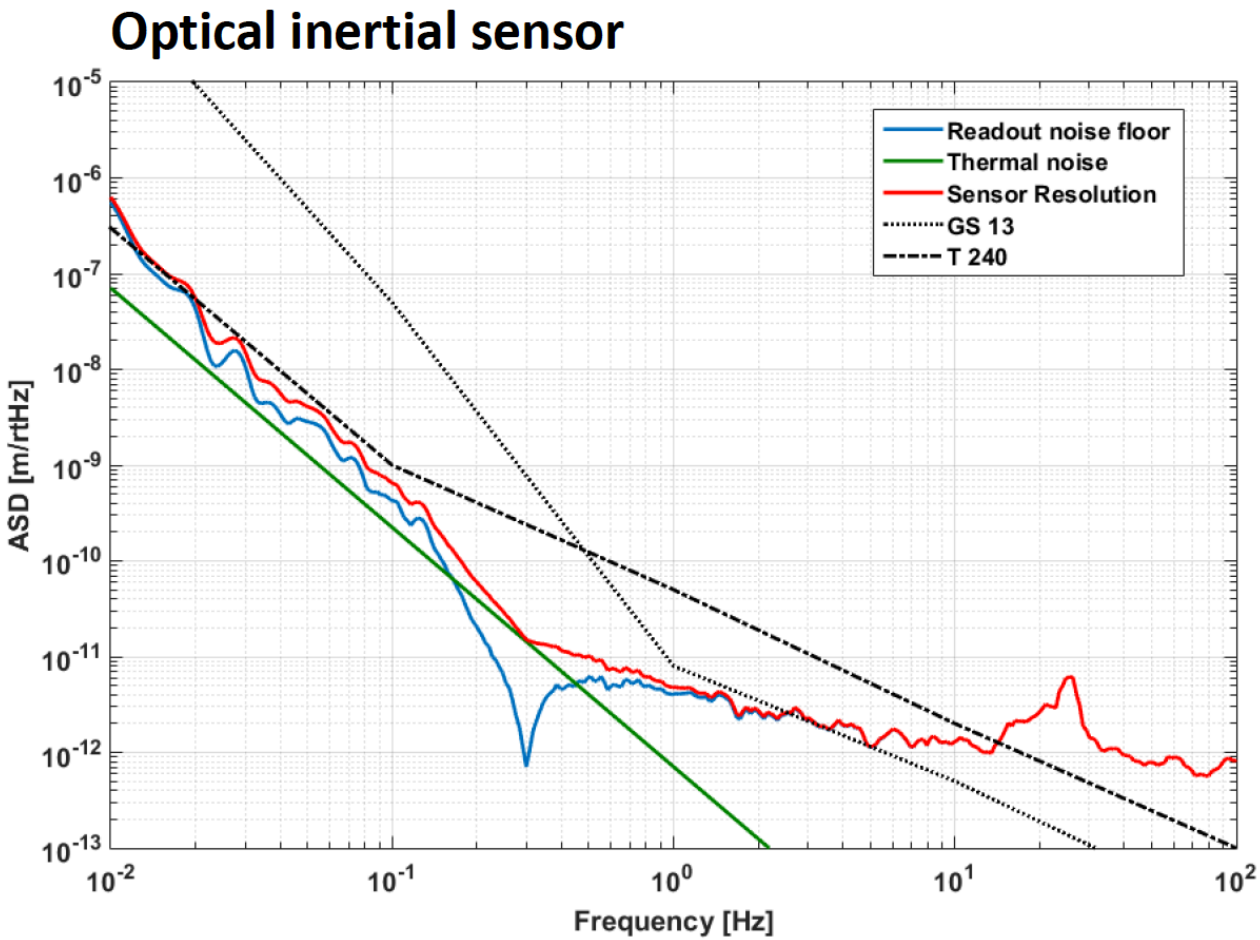




F. Matichard, Precision engineering, 40 (2015), 287-297

Non-magnetic Optical inertial Sensor

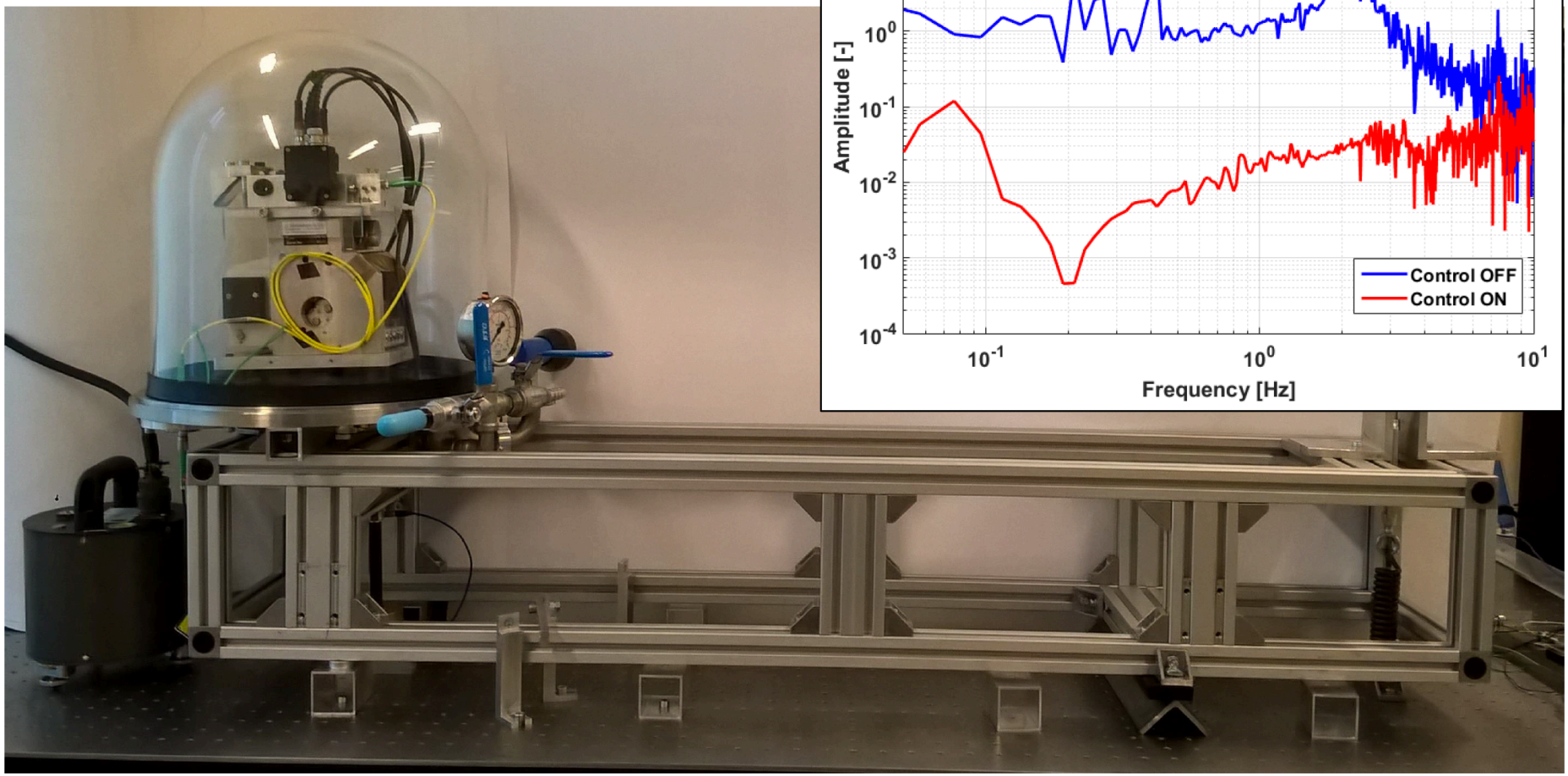




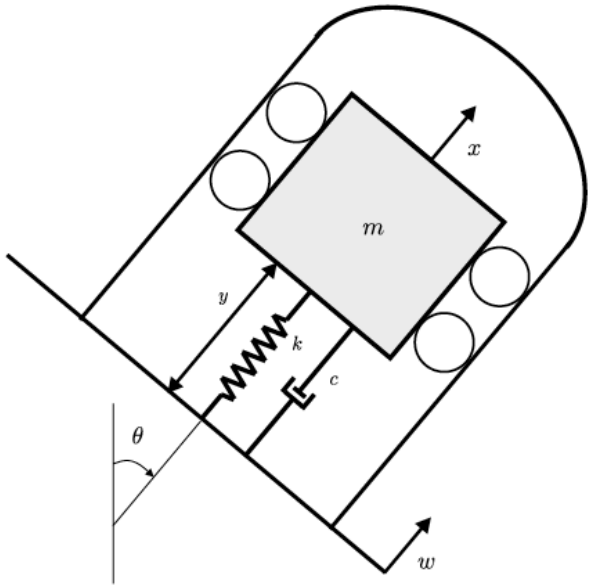
PhD thesis of Binlei Ding

Active vibration isolation system

PhD thesis of Jennifer Watchi

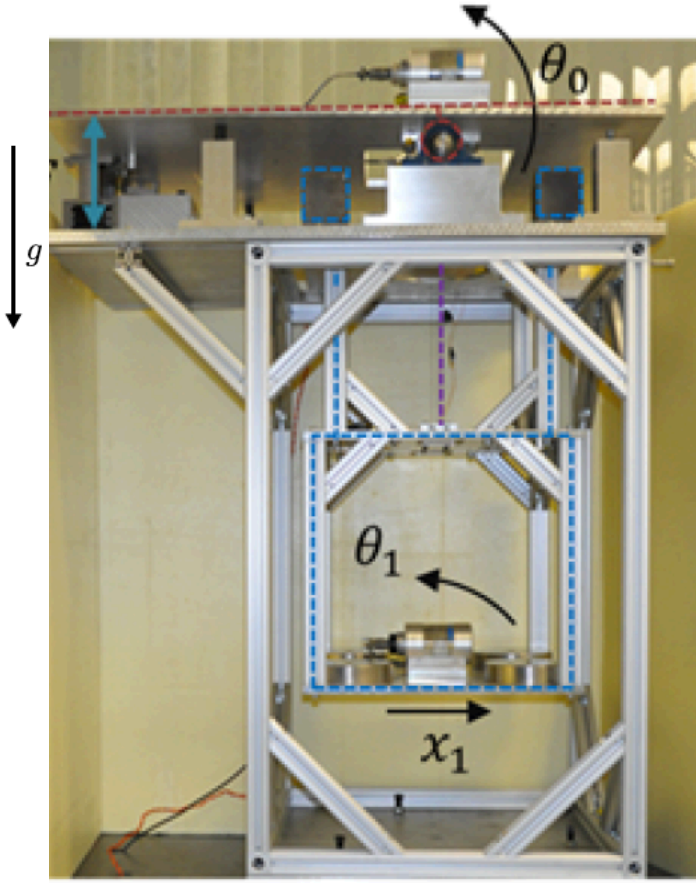


Limitation 3: Tilt-horizontal coupling



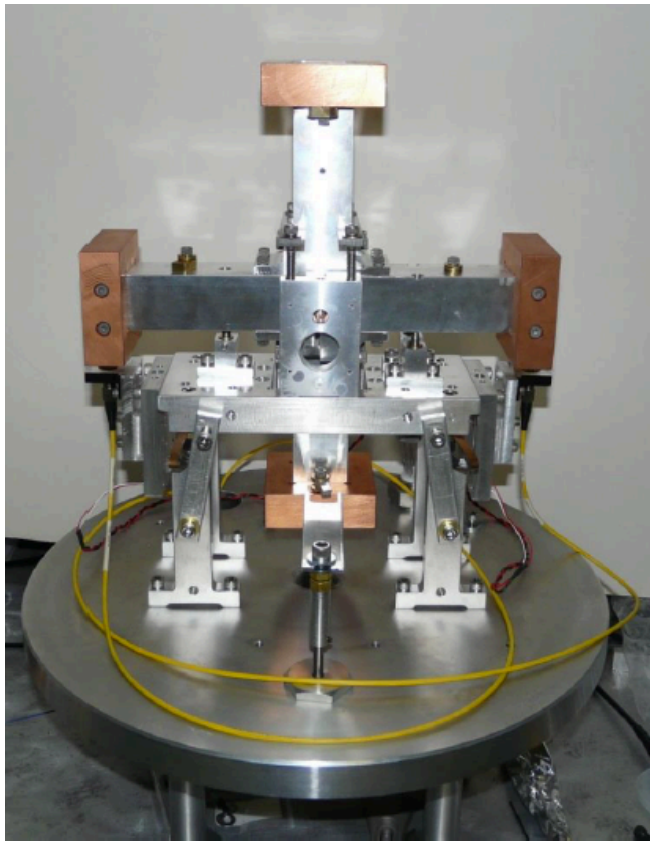
At low frequency, inertial sensor cannot make the difference between support acceleration and rotation

1. Suspended seismometer



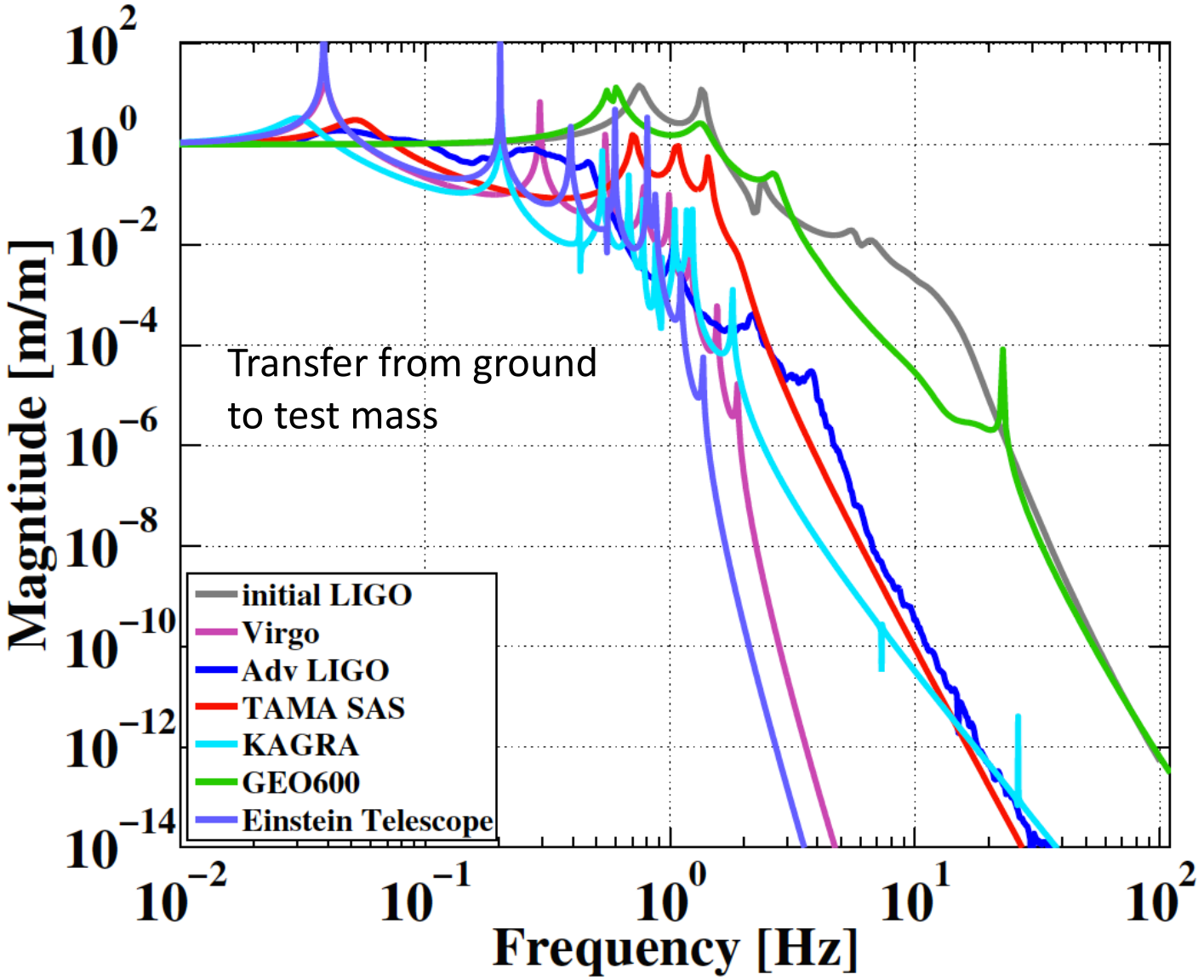
Fabrice Matichard, LIGO P1400061

2. Tilt substraction



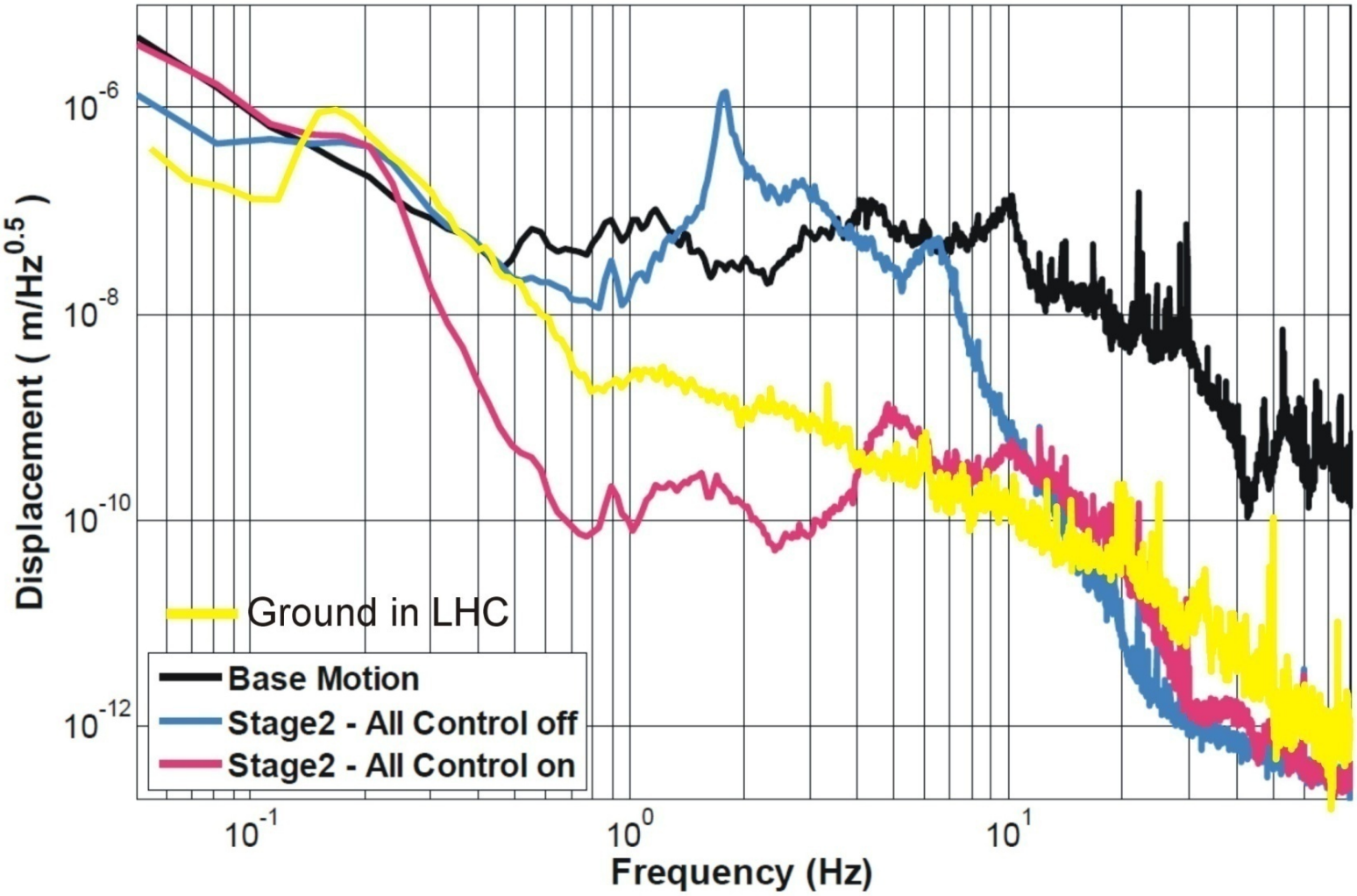
Krishna Venkateswara, BSSA 107(3) 2017

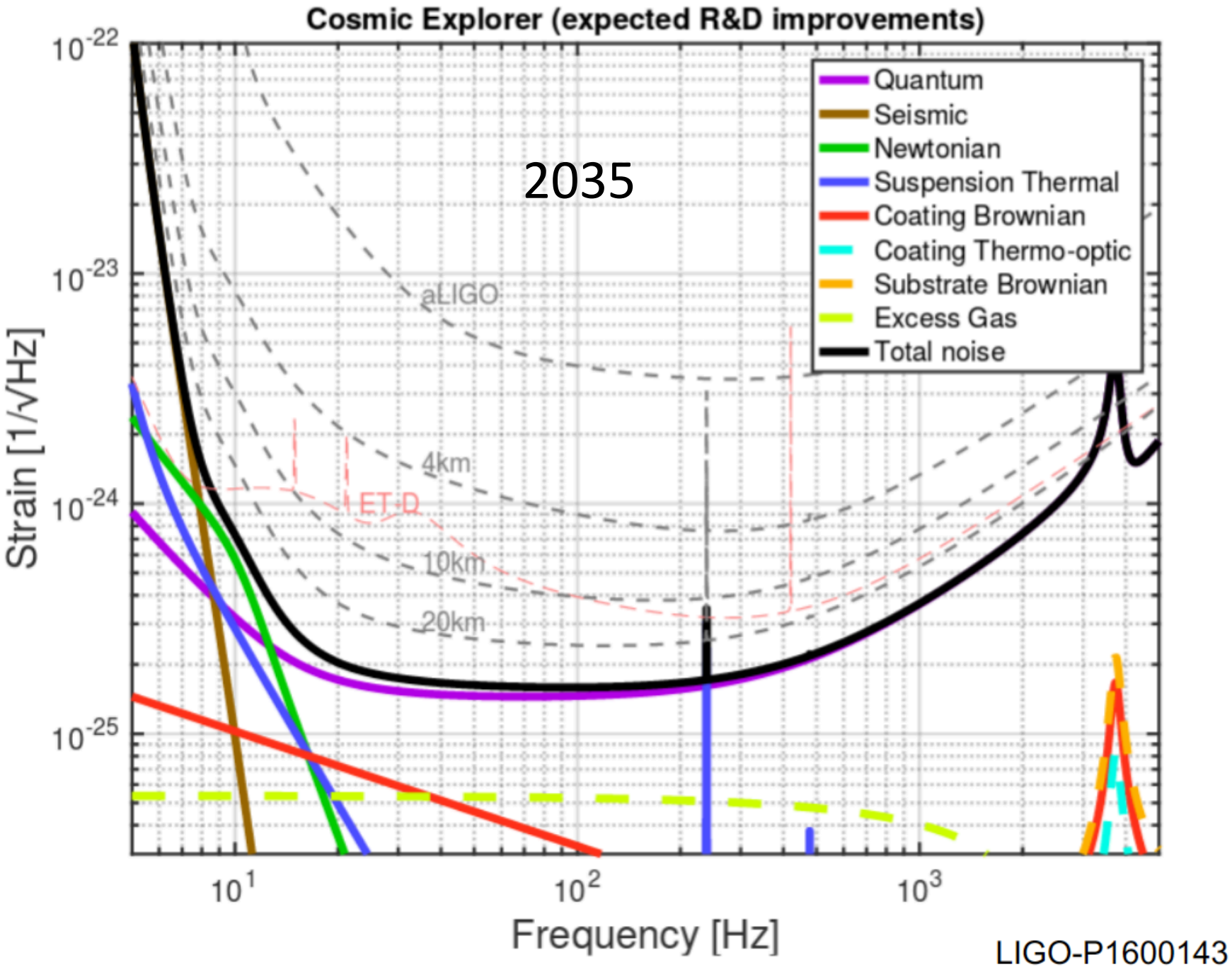
ET transfer function



R. Adhikari, Gravitational Radiation Detection with Laser Interferometry (2014).

LIGO / LHC comparison




Cosmic Explorer (expected R&D improvements)
2035
Quantum
Seismic
Newtonian
Suspension Thermal
Coating Brownian
Coating Thermo-optic
Substrate Brownian
Excess Gas
Total noise
aLIGO
4km
ET-D
10km
20km
Strain [1/√Hz]
Frequency [Hz]
LIGO-P1600143

Conclusions

- Both aVirgo and aLIGO seismic isolation systems are working well
- Both aVirgo and aLIGO seismic isolation systems are upgradable for 3rd generation
- ET seismic isolation OK above 2 Hz
- Several efforts are targeting low frequencies

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