Seismic Isolation for ET

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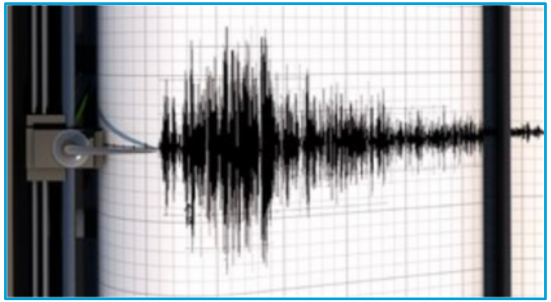
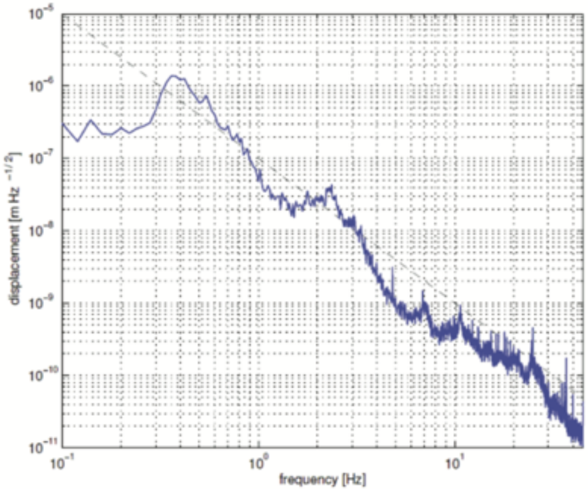
ET EINSTEIN TELESCOPE · Maastricht University · Nikhef

Seismic isolation – Why?

- **Ground all around us moves about a micron all the time.**
- In the frequencies of the detection band we need to reduce displacements of mirrors to about 10^{-20}m/sqrt(Hz).
- At the same time we need to make sure that at **DC** mirror positions / cavity lengths are kept stable, e.g. so that **laser light resonates in the cavities.**

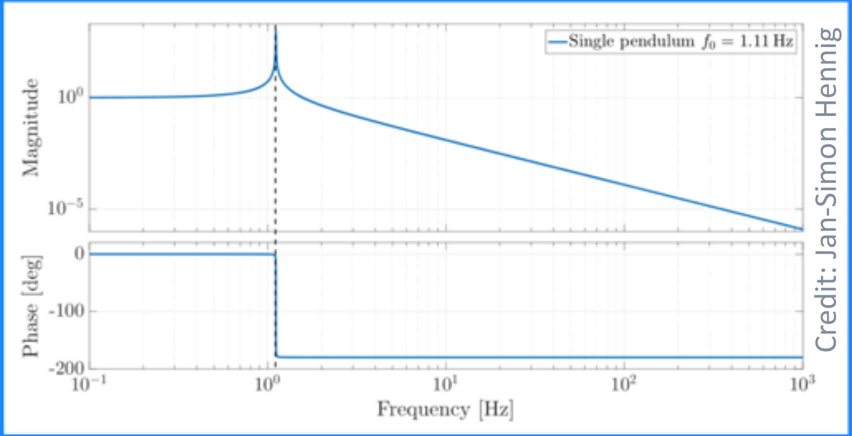




linear spectral density of the horizontal seismic vibration of the ground, measured on the Virgo site; the seismic noise turns out to be roughly isotropic and well approximated by the function $10^{-7} f^{-2} m/\sqrt{Hz}$ (see dashed line)

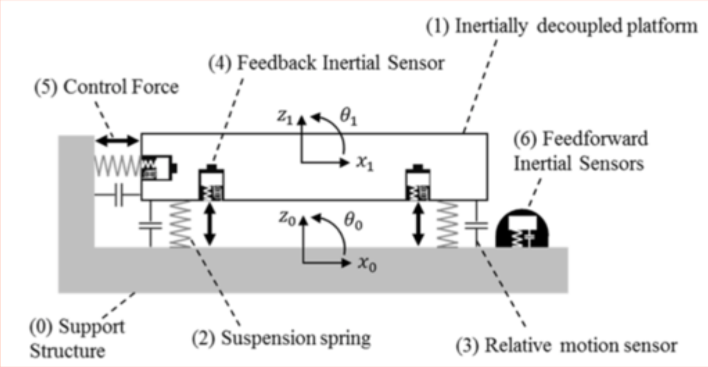
Passive vs Active

Basic Principle: Resonator (pendulum, spring etc) used above resonance



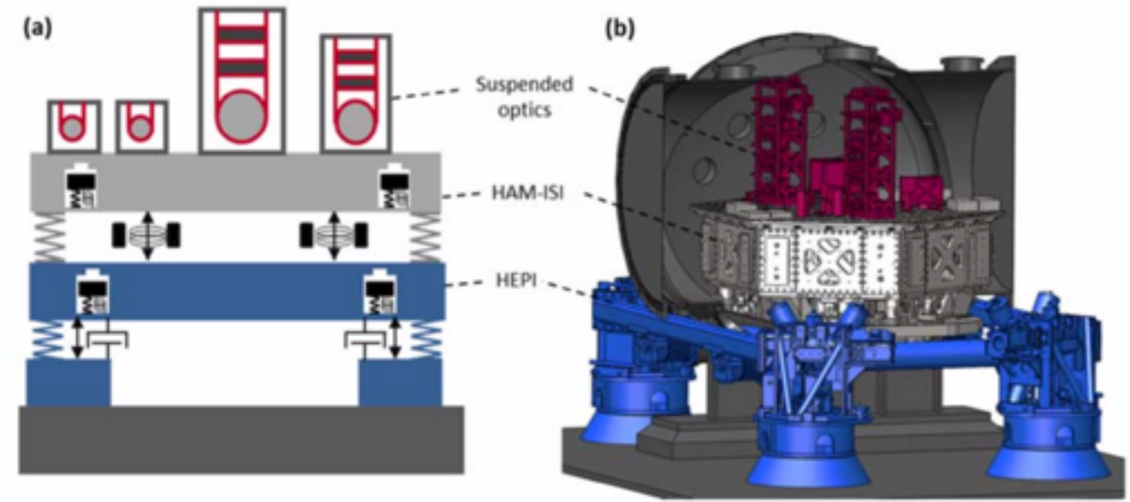
- Simple, effective, only way to get to really low noise.
- In reality very complex. Many modes, crosscouplings etc. Also need to deal with resonances

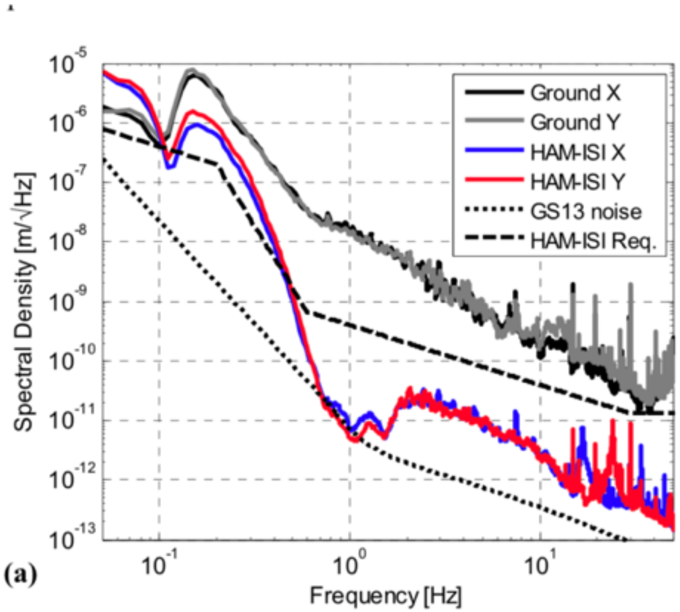
Basic Principle: Measure with inertial sensors and correct



- Broadband, less prominent resonances
- Can only be as good as sensor noise

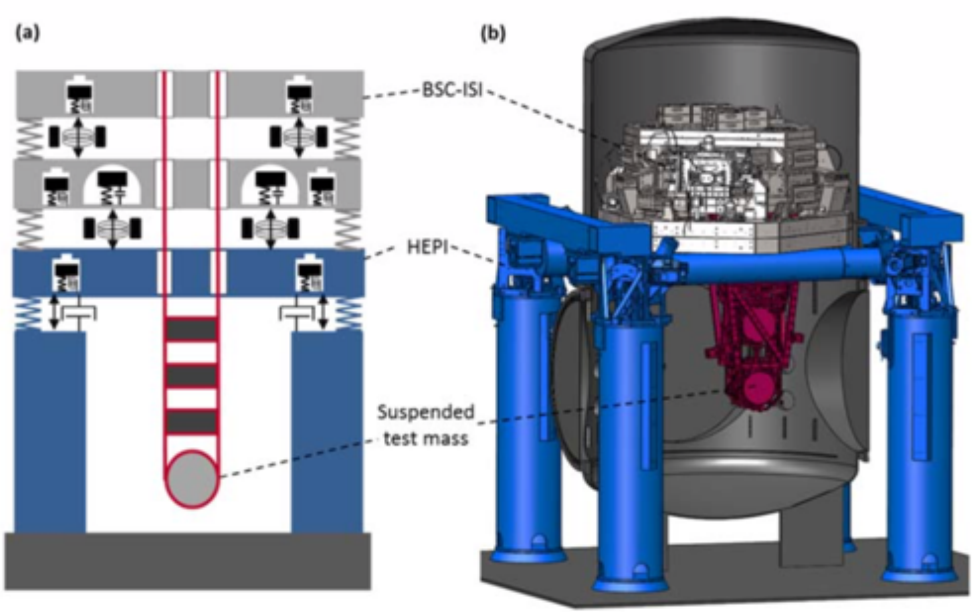
Seismic Isolation in Advanced LIGO: Ham-ISI

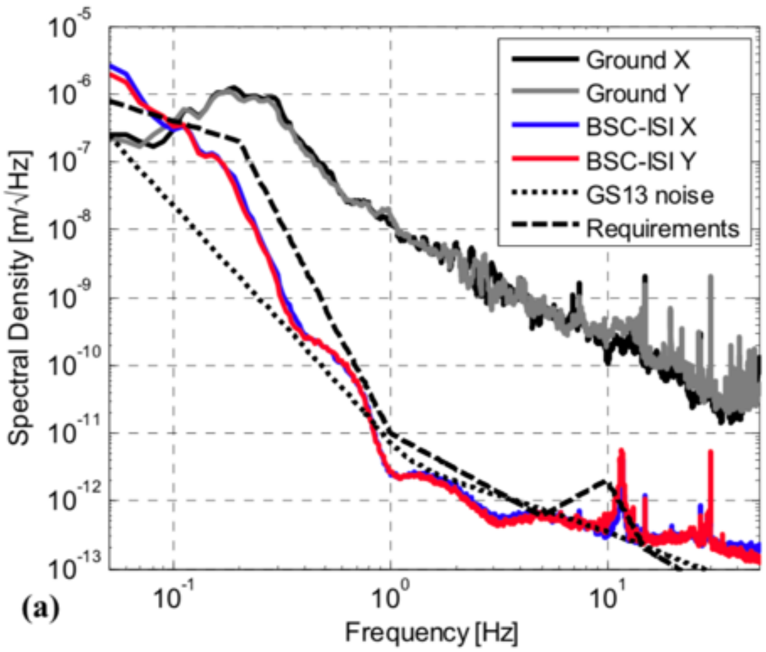




F Matichard *et al* 2015 *Class. Quantum Grav.* **32** 185003

Seismic Isolation in Advanced LIGO: BSC-ISI





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Seismic Isolation in (advanced) Virgo

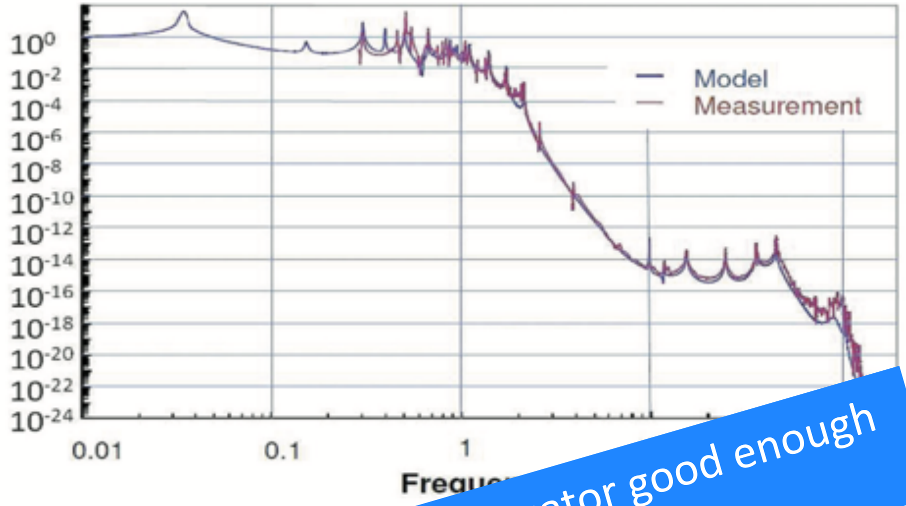
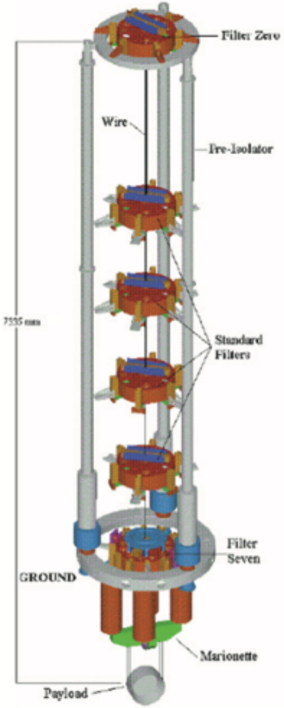
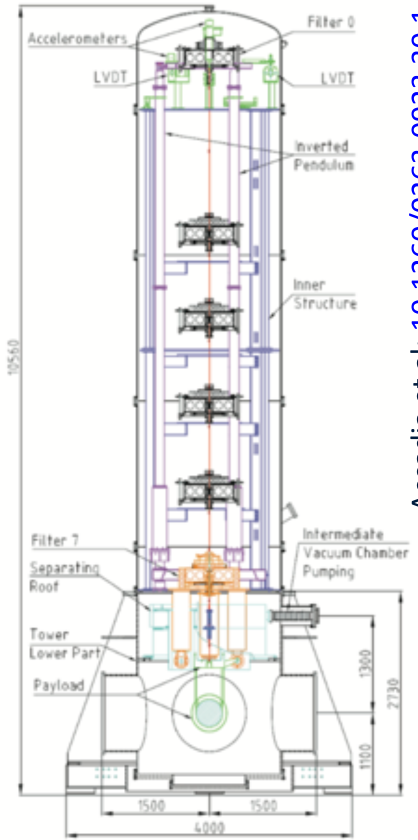


Figure 14. the total Superattenu… …measurements. This qu… …ected at the ground level, assume to be… …placement along the beam.

Virgo Superattenuator good enough for ET-D HF

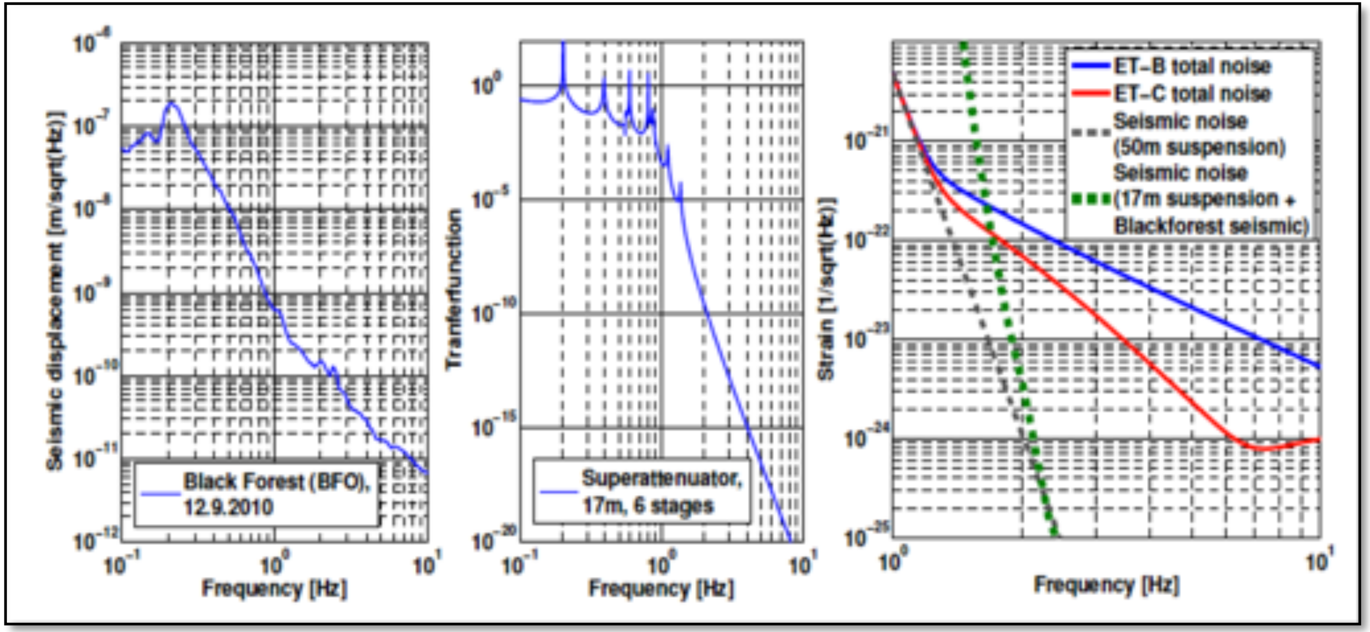


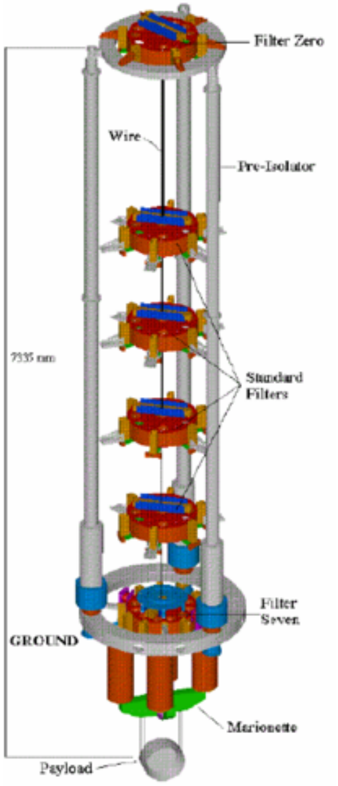


vertical cross-section of a tower, showing inner details and the SA

Accadia et al: 10.1260/0263-0923.30.1.63

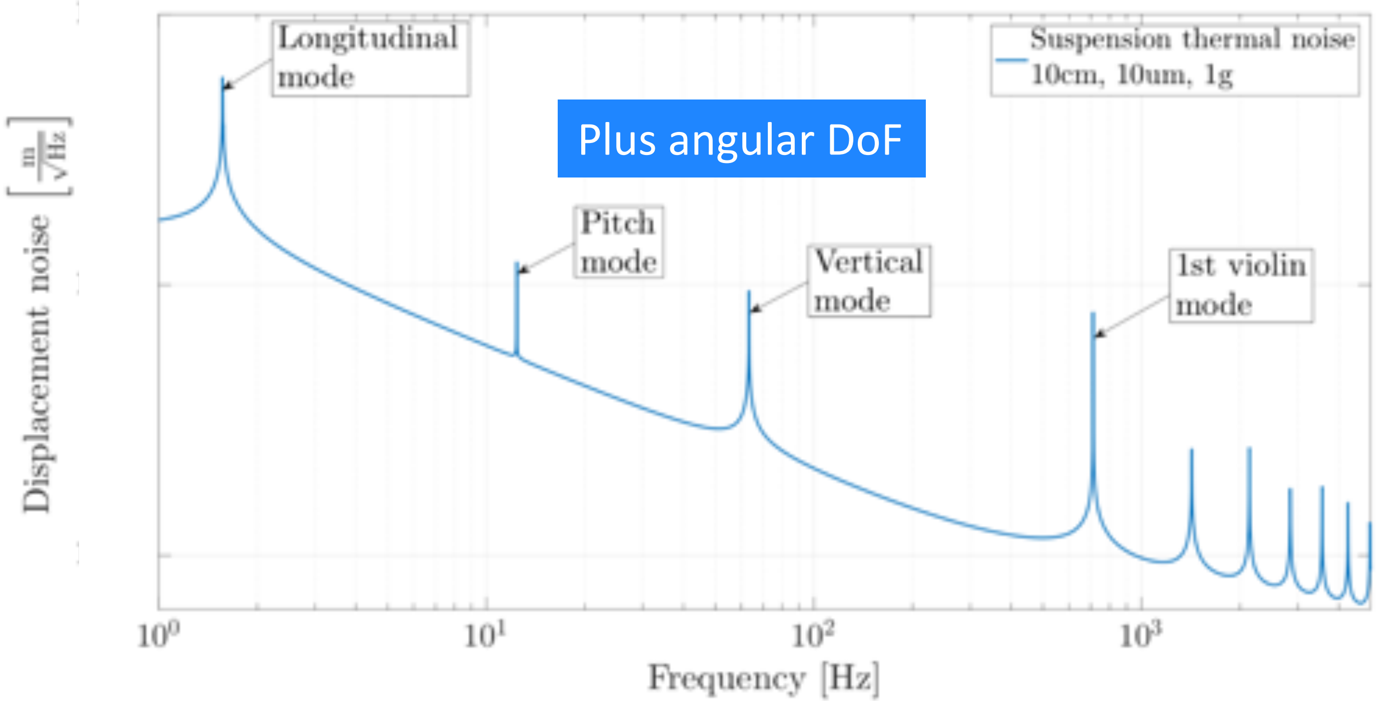
Seismic noise in ET-D LF





Seismic excitation X **17m SA Transfer function** = **Seismic noise contribution**

Many mechanical resonances



Plus angular DoF

Credit: Jan-Simon Hennig

Need high Q for each mode to reduce thermal noise in the wings

Suspension Thermal Noise

Boltzmann constant

Temperature

Loss angle

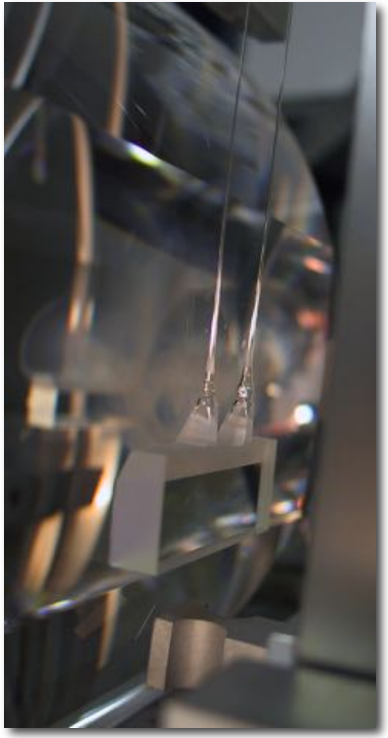
PSD of displacement

$$x^2(\omega) = \frac{4k_{\mathrm{B}}T\omega_0^2\phi(\omega)}{\omega m[(\omega_0^2-\omega^2)^2+\omega_0^4\phi^2(\omega)]}$$

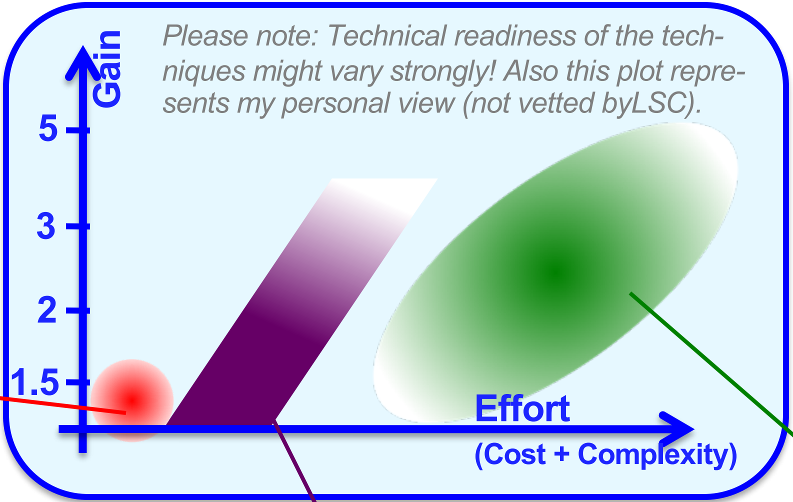
Mirror mass

Resonance frequency

- Mirrors need to be suspended in order to decouple them from seismic.
- Thermal noise in metal wires and glass fibres causes horizontal movement of mirror.
- Relevant loss terms originate from the bulk, surface and thermo-elastic loss of the fibres + bond and weld loss.
- Thermal noise in blade springs causes vertical movement which couples via imperfections of the suspension into horizontal noise.



How to reduce Suspension Thermal Noise?



Improve fibre geometry/ profile
Bending points, energy stored via bending and neck profile can be potentially further optimised.

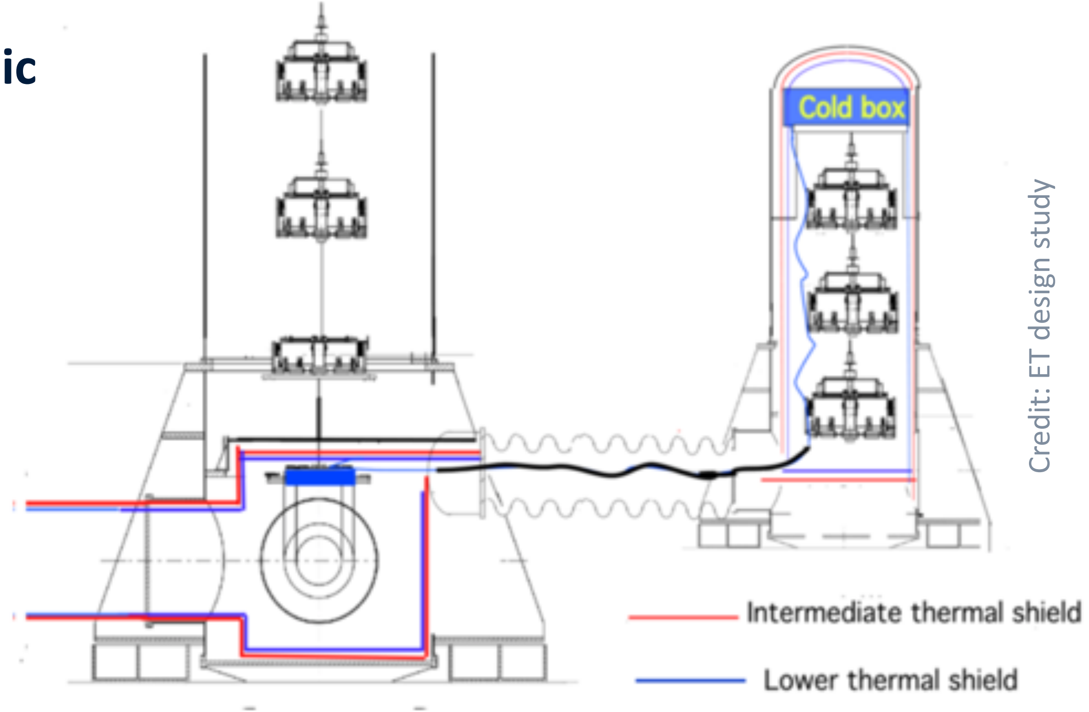
Increase length of final pendulum stage.
Allows the push suspension thermal noise out detection band.

Cooling of the suspension to cryogenic temperatures.
Usually also requires a change of materials.

Cryogenic mirror suspension

- ET-LF will go for cryogenic mirrors and a cryogenic last stage suspension.

- Problem: Noise!

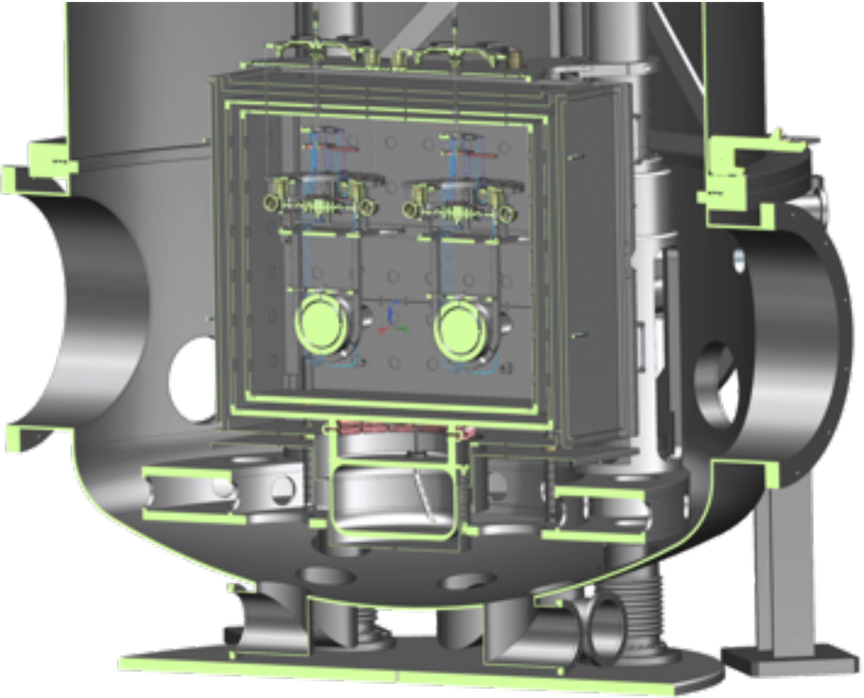


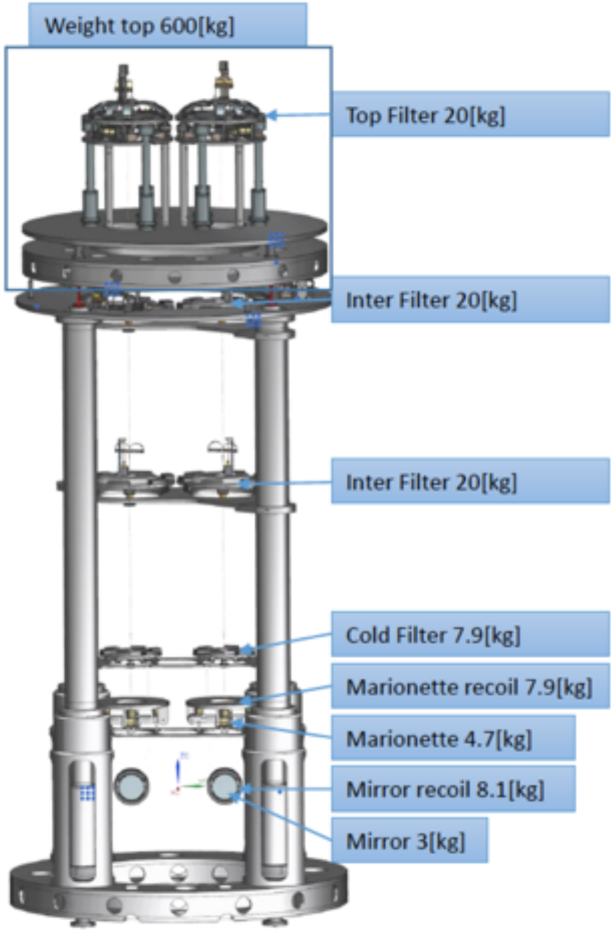
Credit: ET design study

More complete list of requirements for seismic isolation and final stage suspension

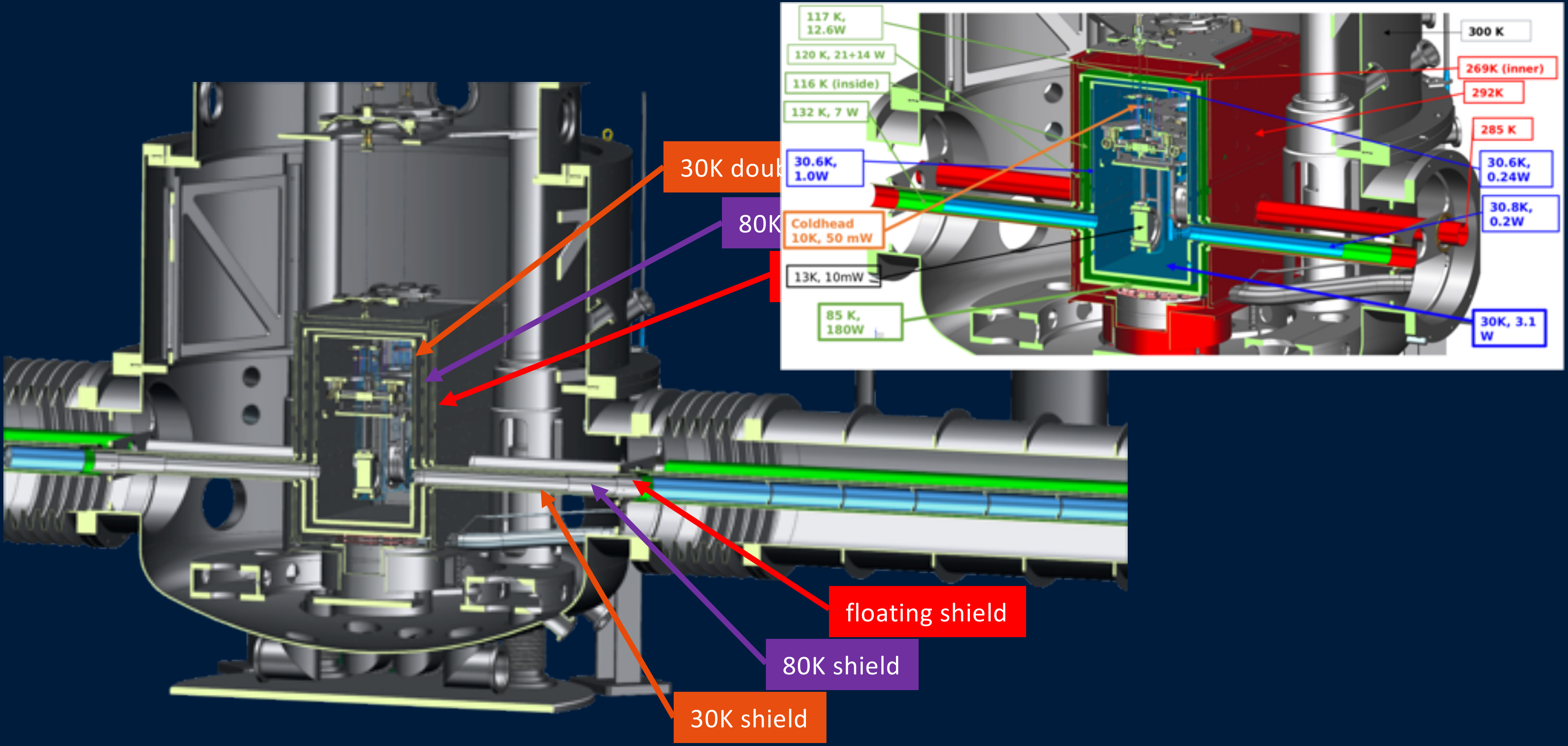
1. Reduce seismic noise to 10^{-20}m/sqrt(Hz) in detection band (f>2Hz)
2. Provide low suspension thermal noise, while at the same time providing enough thermal conductivity to allow to cool mirrors. (Conflicting requirements!)
3. Provide a low-noise cooling systems which does not spoil/short-circuit the pendulum chain of main suspension chain (cryo-fluids, pulse tubes, sorption coolers, superfluid He)
4. Attenuate micro-seismic peak in order to ease locking and control.
5. Provide low noise (suspended reference mass!) actuators to control all degrees of freedom of pendulum chain (not only longitudinal, but also pitch and yaw).

Case Study: Seismic Isolation For ETpathfinder

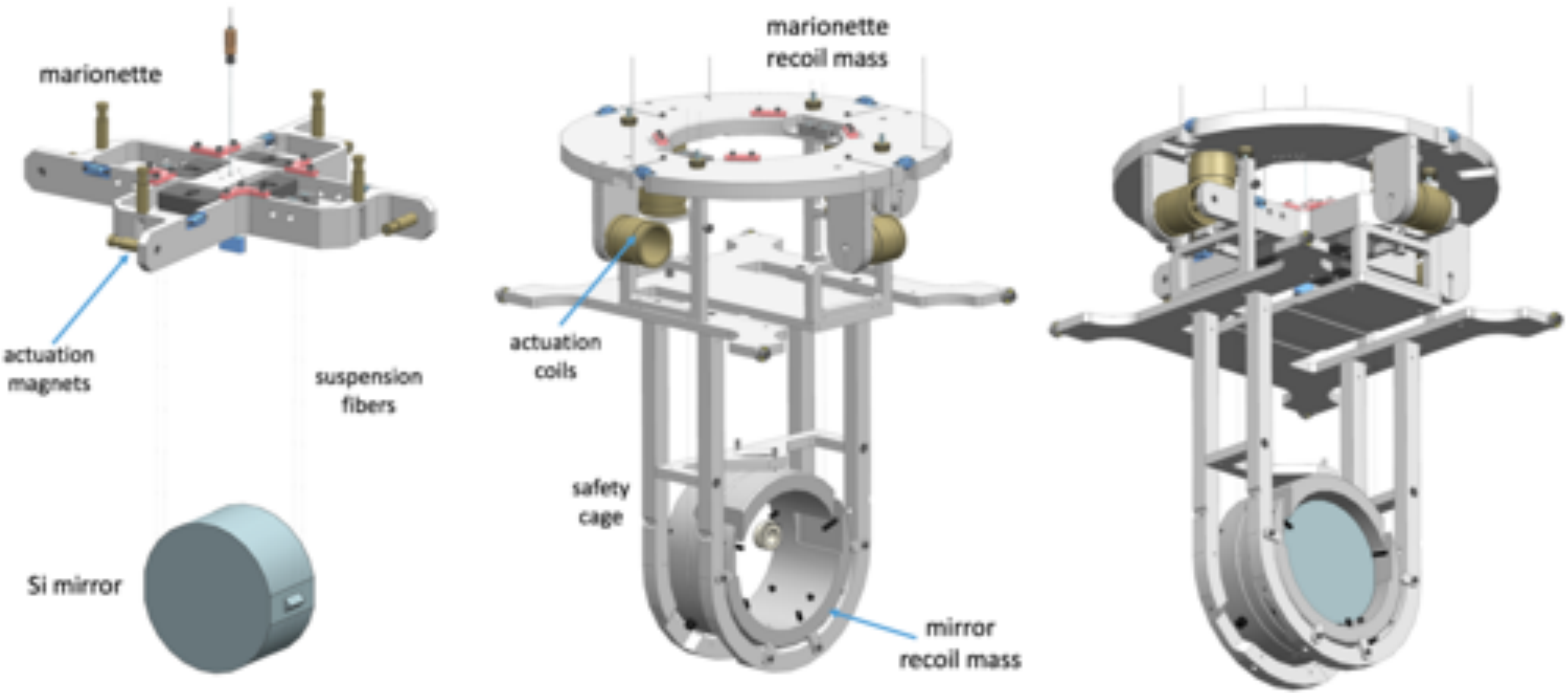




Prototypiong cryogenic silicon mirrors



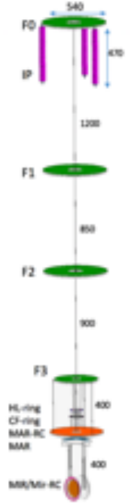
Case Study: Seismic Isolation for ETpathfinder



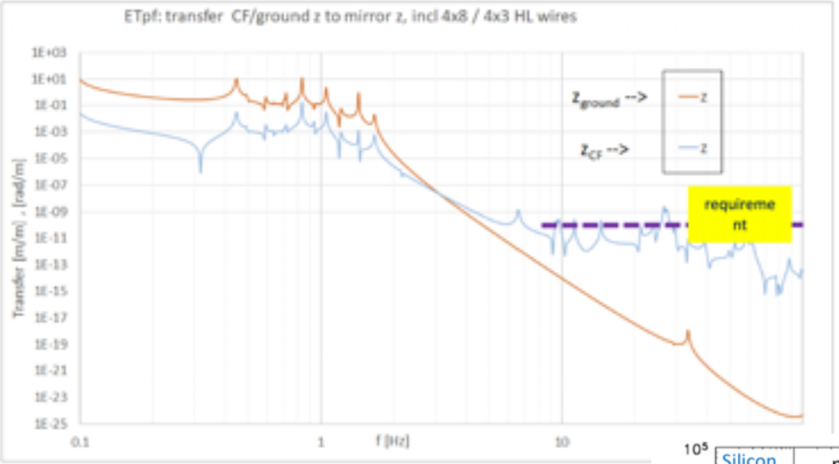
Case Study: Seismic Isolation for ETpathfinder

ET-PF payload

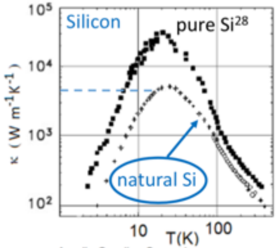
FEM simulated performance



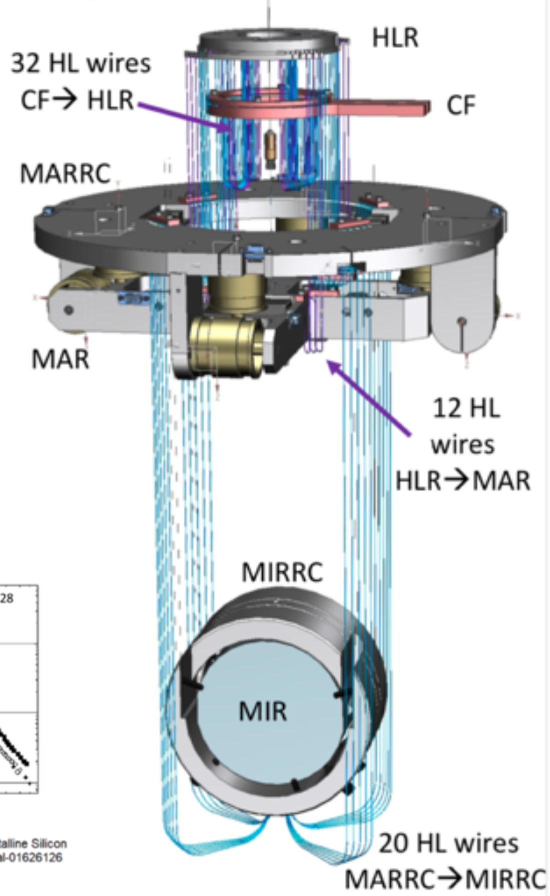
Horizontal response



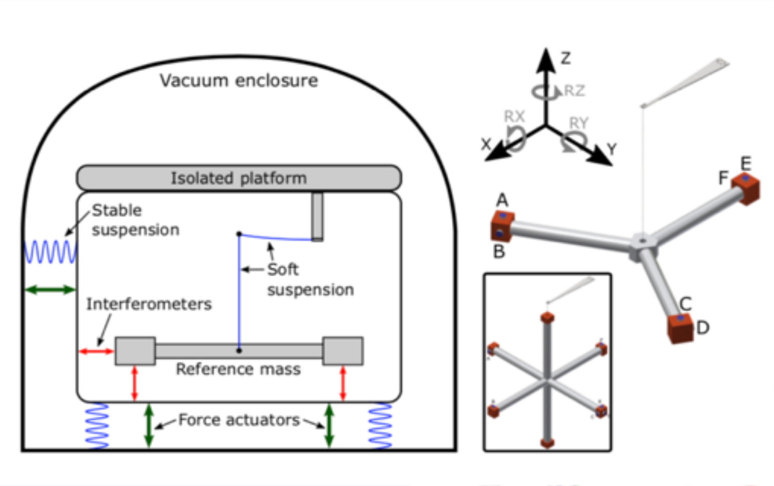
Ground vibration transmission from cold finger is still dominant…



Amelia Carolina Sparavigna.
Thermal Conductivity of the Crystalline Silicon
Philica, Philica, 2017, pp.1143. hal-01626126




Thank you for your attention !
www.etpathfinder.eu



A 6D interferometric inertial isolation system

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(Dated: February 5, 2019)

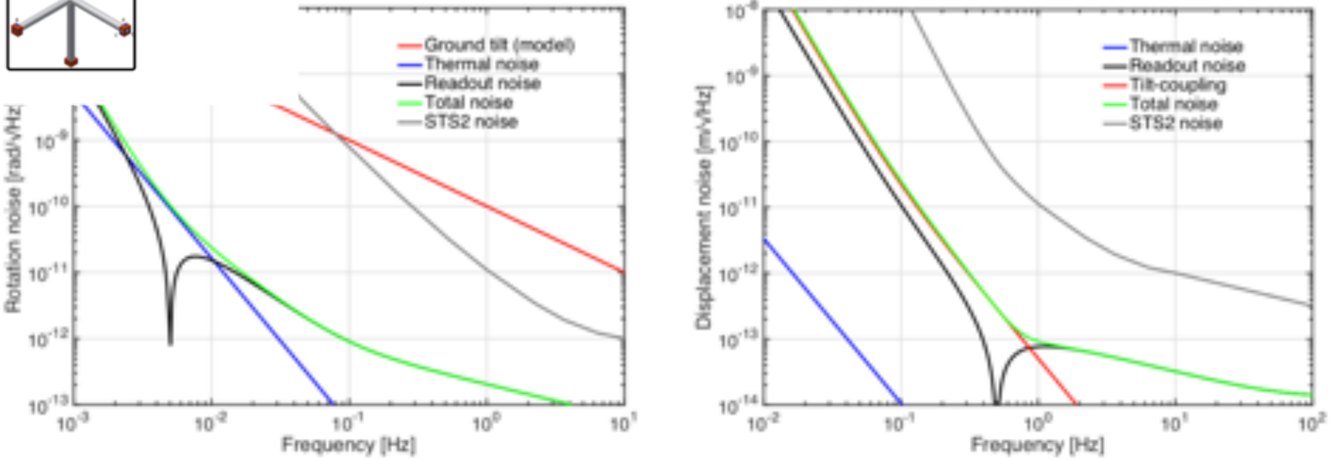
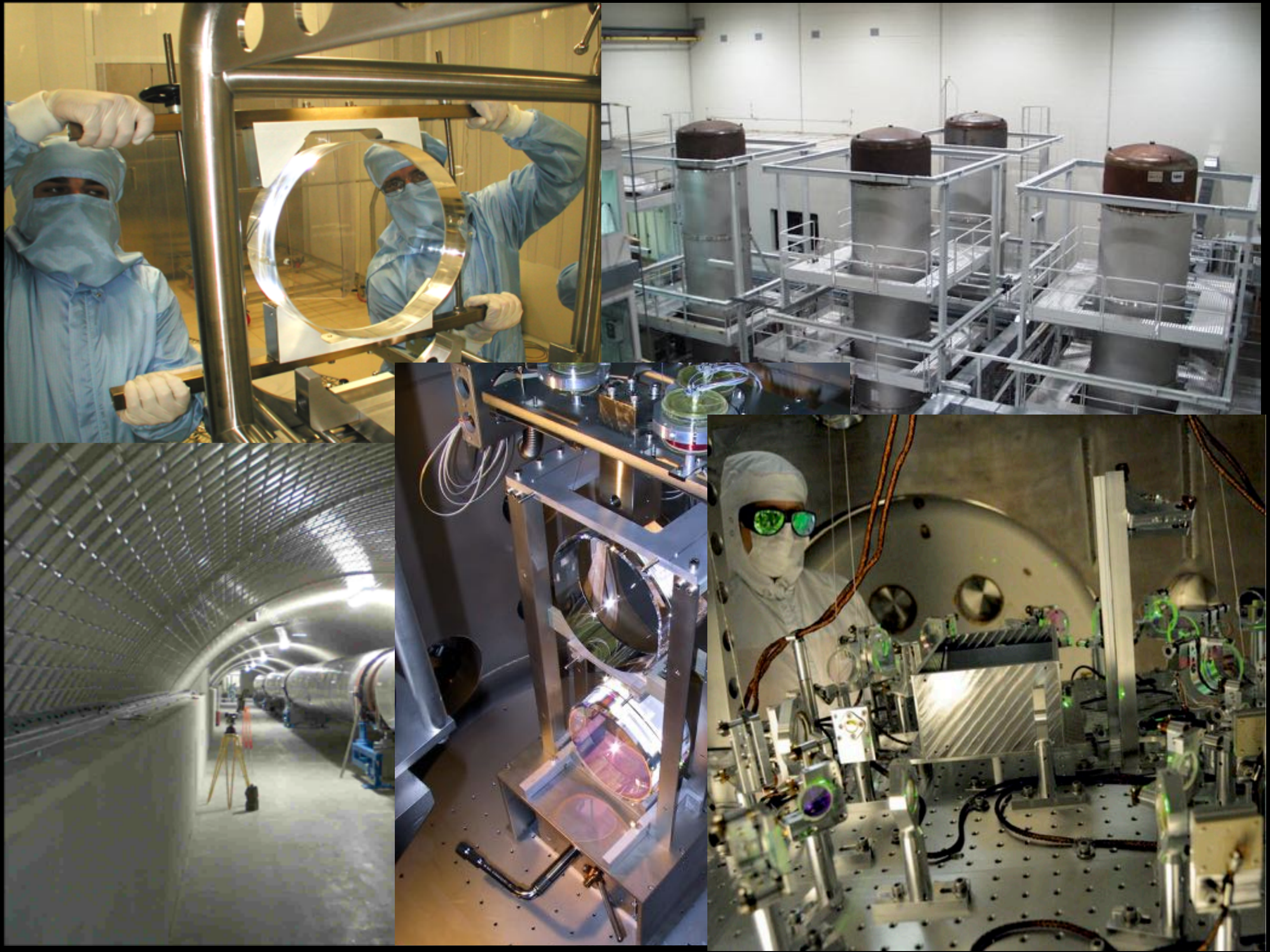


FIG. 2. A noise budget showing (left) the predicted angular self-noise for rotation around the horizontal axes of the 6D isolator and (right) the predicted horizontal displacement self-noise assuming that the angular noise couples with a factor of g/ω^2.

Maastricht University

Pure High Tech!



Pushing the boundaries on all fronts!

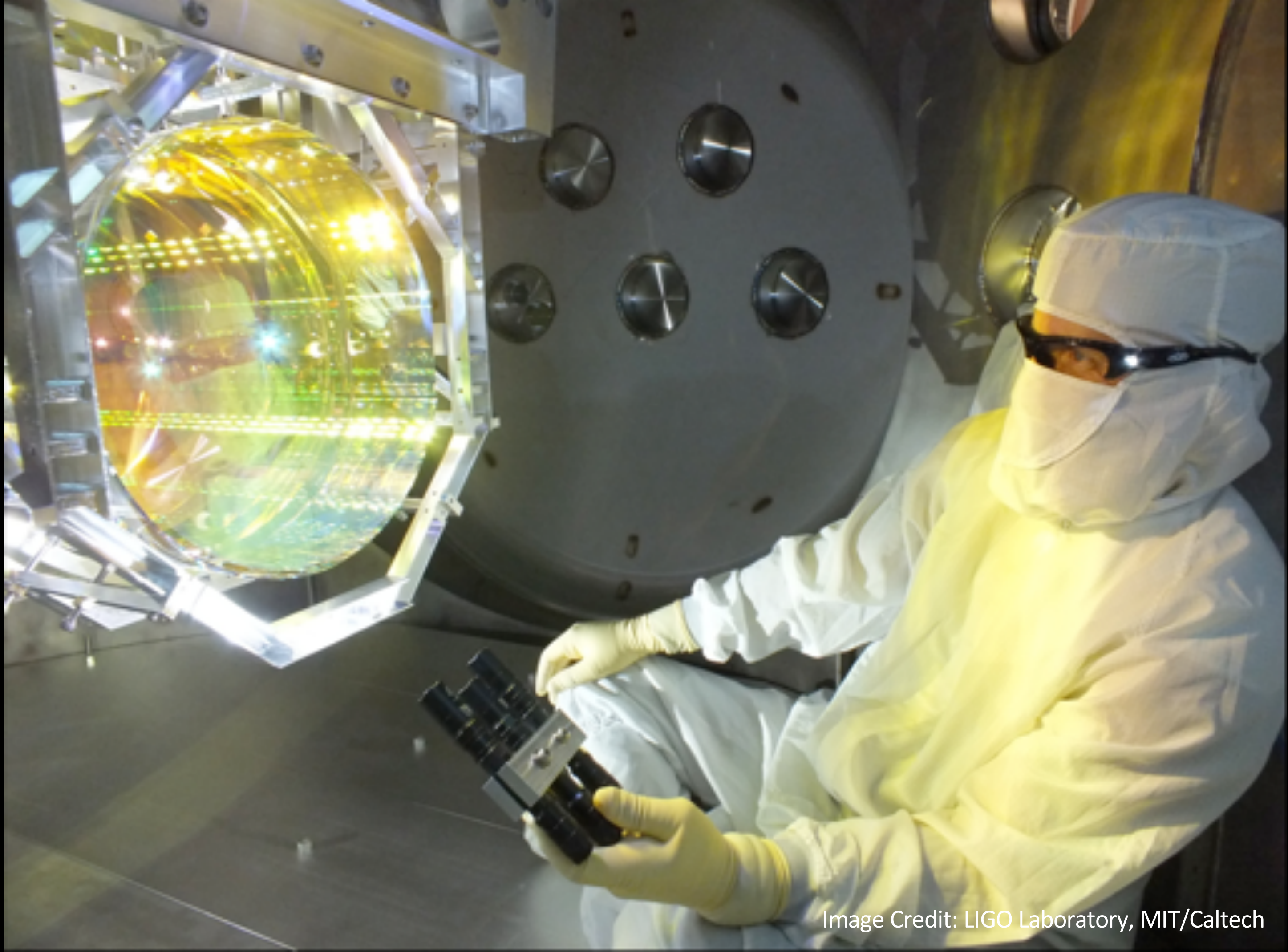
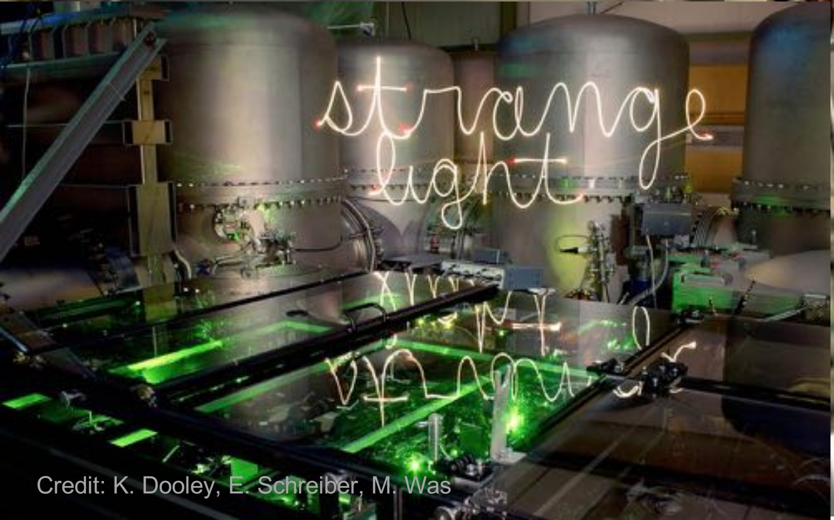


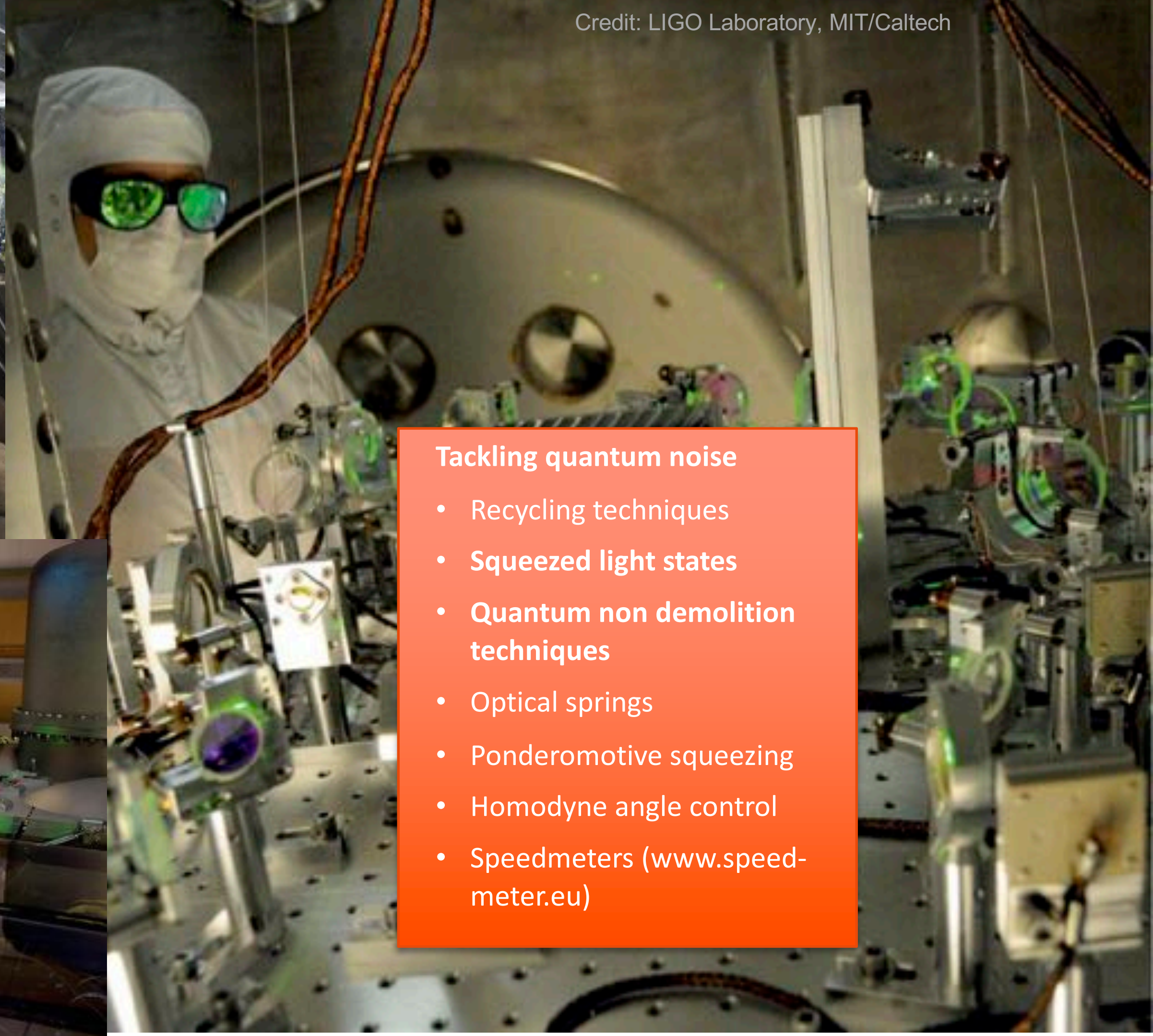
Image Credit: LIGO Laboratory, MIT/Caltech

- Ultra-stable laser (1064nm, 1550nm, Linewidth <1Hz)
- High power optics: ~100kW CW
- Optical resonantors (km length, high finesse)
- **Mirrors polished to sub nm flatness and microroughness**
- **Special low noise coatings**
- **Low absorption (<0.5ppm per coating; <0.25ppm/cm in optics)**
- **Controlling positions of mirrors to pm accuracy**
- Modecleaning and mode healing using optical cavities

Credit: LIGO Laboratory, MIT/Caltech



Credit: K. Dooley, E. Schreiber, M. Was


Credit: LIGO Laboratory, MIT/Caltech

Tackling quantum noise

- Recycling techniques
- **Squeezed light states**
- **Quantum non demolition techniques**
- Optical springs
- Ponderomotive squeezing
- Homodyne angle control
- Speedmeters (www.speed-meter.eu)

Refining construction of Infrastructure