Low frequency noise mitigation by inter-platform control

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From 2rd to 3th generation

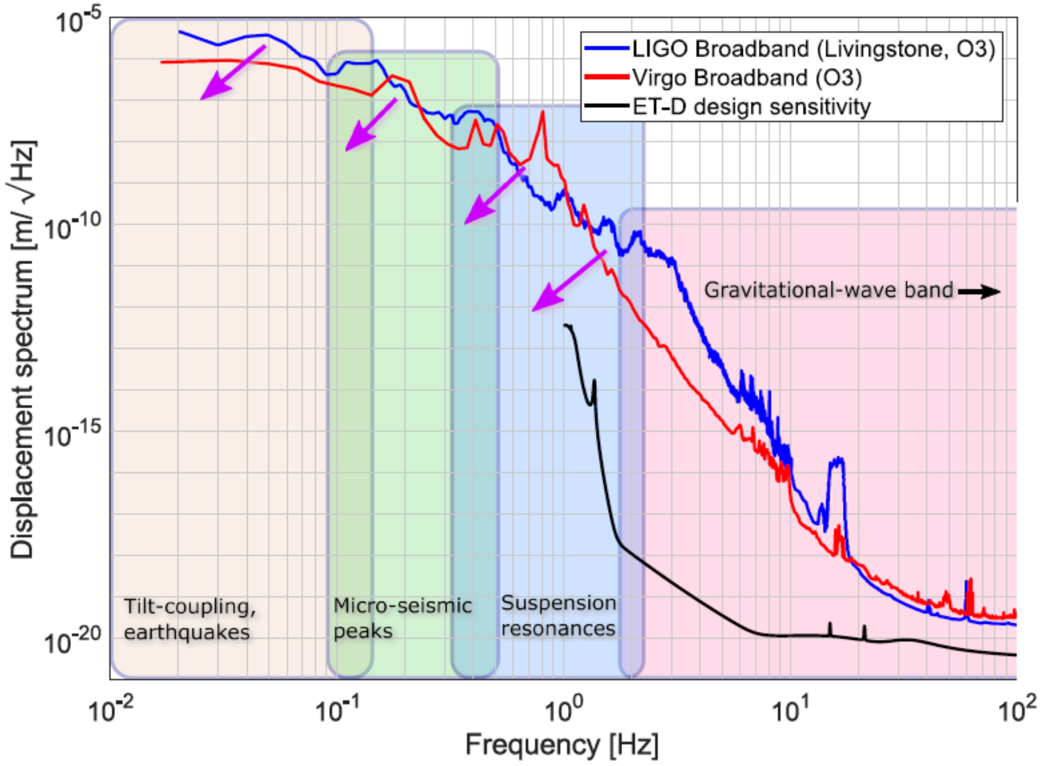


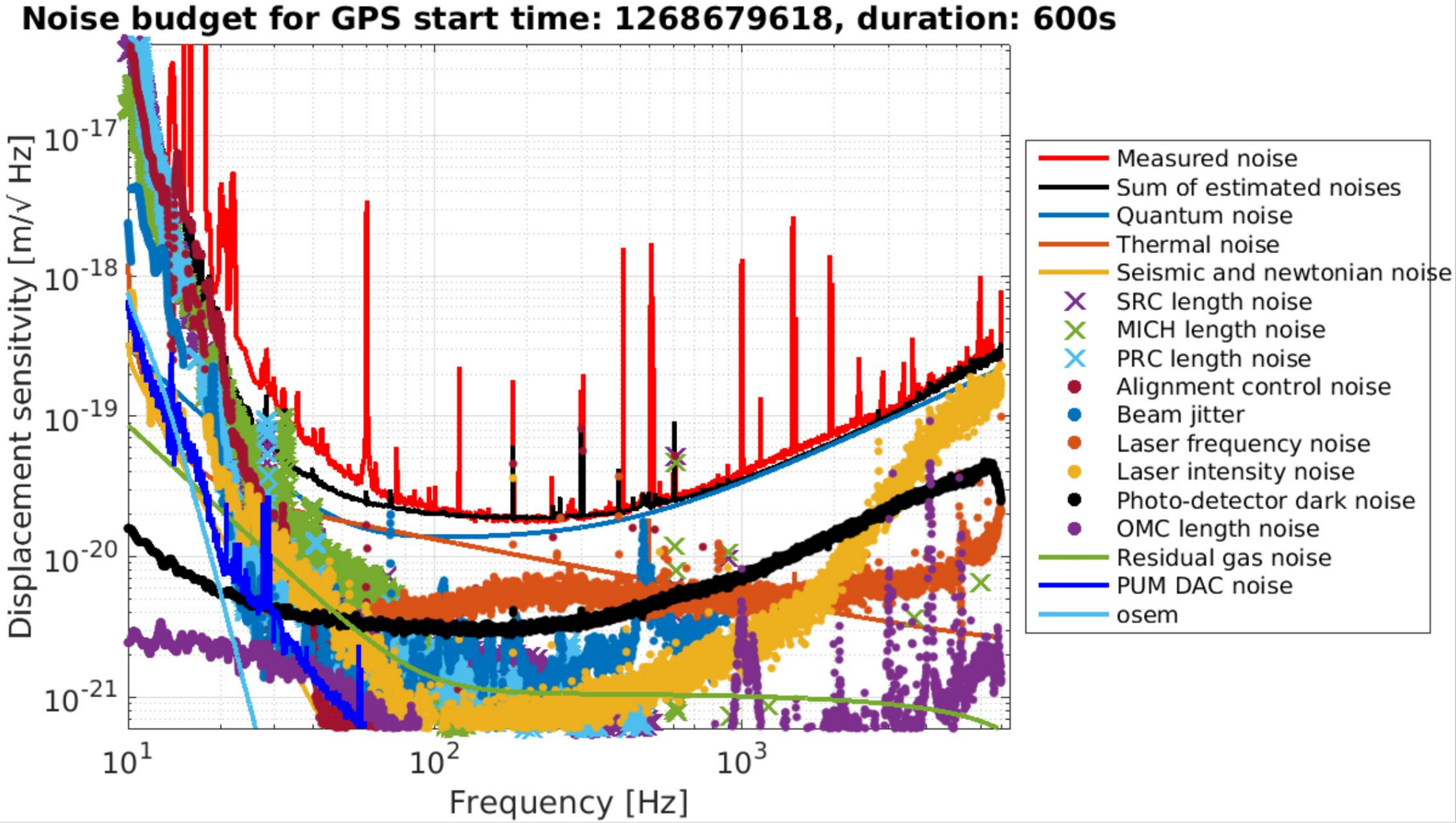
Figure 6.11: A comparison between the performance of the LIGO and Virgo instruments during the 03 observing run and the ET design sensitivity. The coloured windows show the important frequency regions, and the arrows show the regions where ET must have improved performance in order to reduce the corner-frequency of the 'seismic wall'.

- Noise must be lower by ~ six orders of magnitude
- Underground site and passive isolation by modified super-attenuator transmissibility is **theoretically** sufficient for length to length coupling
  - 17 m height
  - 6 magnetic anti-spring filters
  - Equally spaced
- **But:** Control noise of auxiliary control loops and scattered light has been a noise source in the detection band
- Filters cannot roll off arbitrarily steep

Active isolation required below suspension resonances

Control noise dominates the 'known' noise below 50 Hz

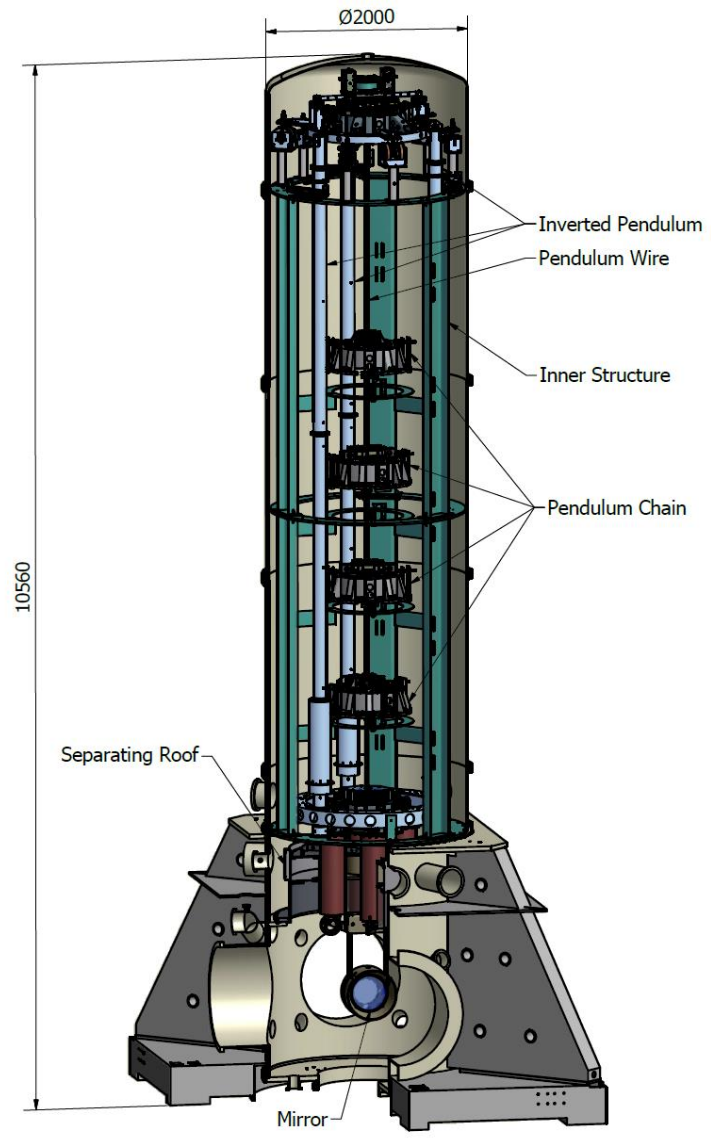
LHO O3 noise budget, S. Dwyer LHO log 55755



Research for aLIGO is ongoing to address noise below 50 Hz

Slide from: Brian Lantz
LVK meeting on Sept 15, 2020
LIGO DCC: G2001539

Active platform for mirror suspension



Pre-isolation platform at “Filter 0”

- Inertial sensors for active isolation
- Actuators for position control

Inertial isolation effective above ~ 100 mHz

- Tilt to horizontal coupling
- Suspension thermal noise

Underground seismic noise is lower, sensor sensitivity needs to scale with it!

Inertial isolation vs. differential control

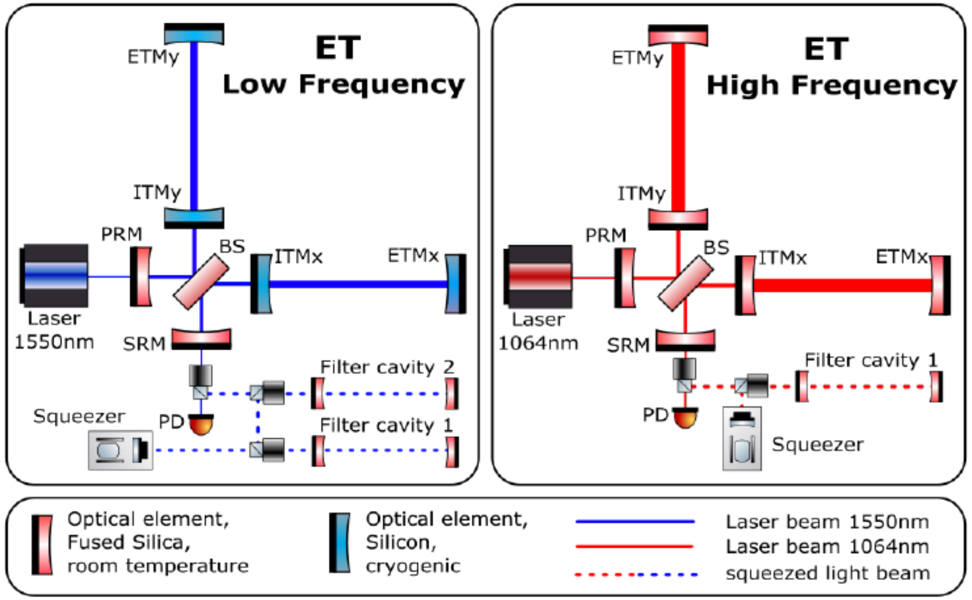


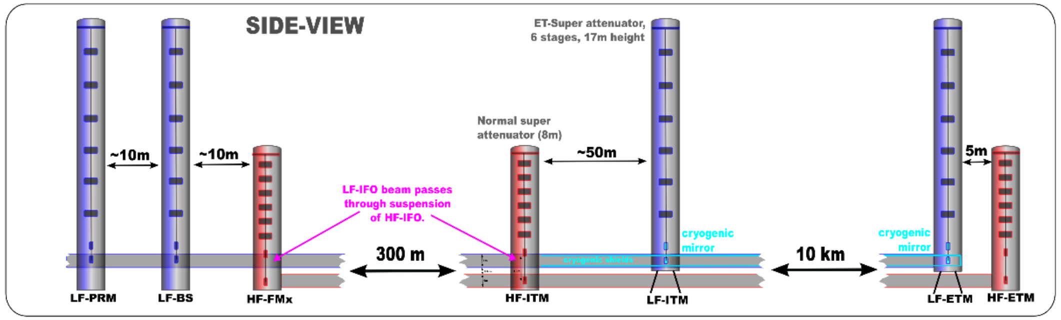
Figure 6.3: Simplified sketch of the ET low and high frequency interferometers of a single ET-detector.

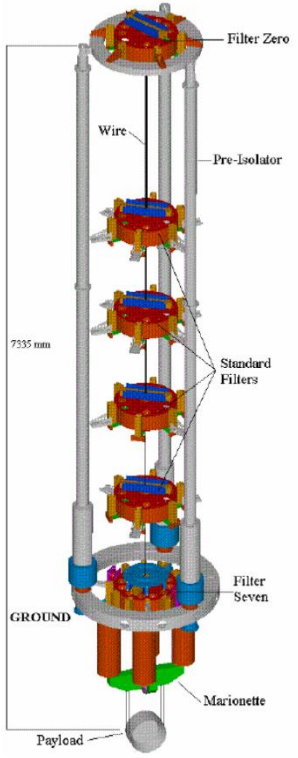
Figure of merit:

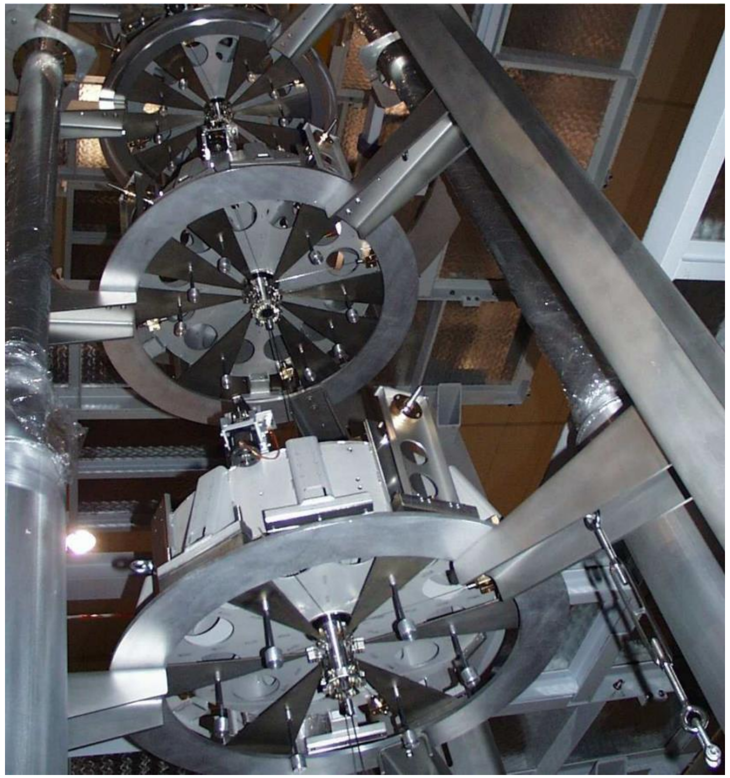
Interferometer displacement below GW band

- Differential length control of main interferometer optics
  - Test masses
  - Beam splitter
  - Recycling cavities
- Can use interferometer signal during operation
- Use additional sensors for differential displacement of suspension points

Suspension point stabilization







Arm cavities:

- No clear line of view
- Need to get near the beam line
- Periscope at inner structure, but:
  - Cryogenic-shield in the way
  - Tilt read-out required

- Angular stabilization to reduce control bandwidth on angular interferometer control loops

Stabilize at a platform supporting the suspension structure

Stabilization in central cavern

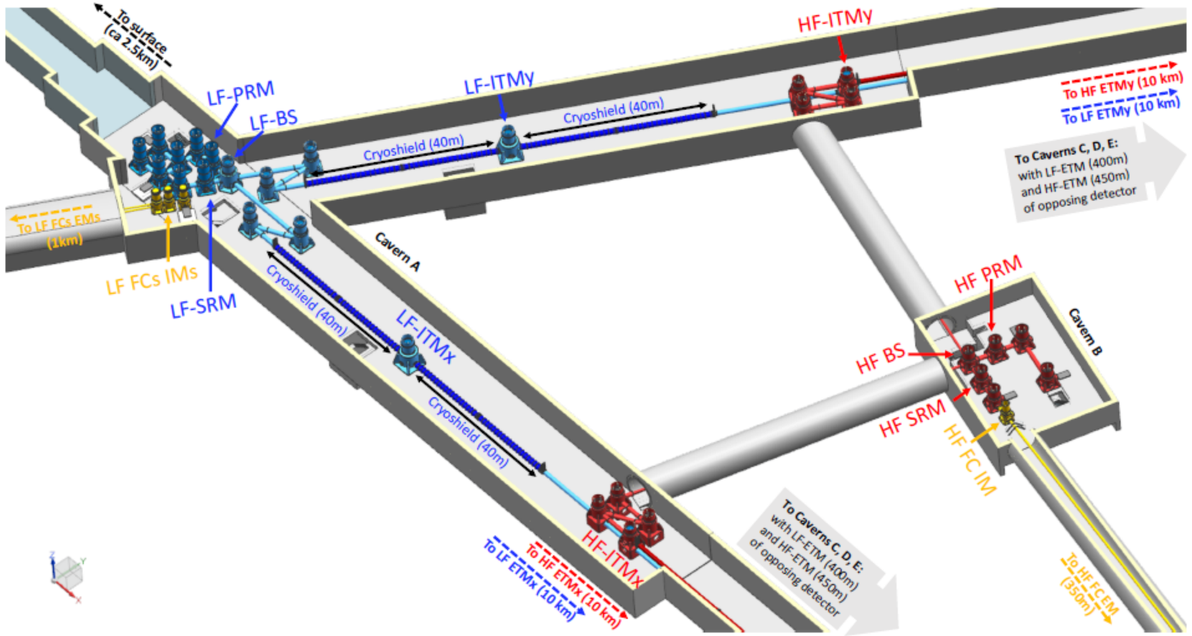


Figure 6.2: Schematic overview of the corner caverns and central interferometers of one of the three ET detectors. (Used acronyms: LF = low frequency; HF = high frequency; ITM = input mirror; ETM = end mirror; BS = beam splitter; PRM = power recyling mirror); SRM = Signal recycling; FC = filter cavity; x/y = x/y-arm).

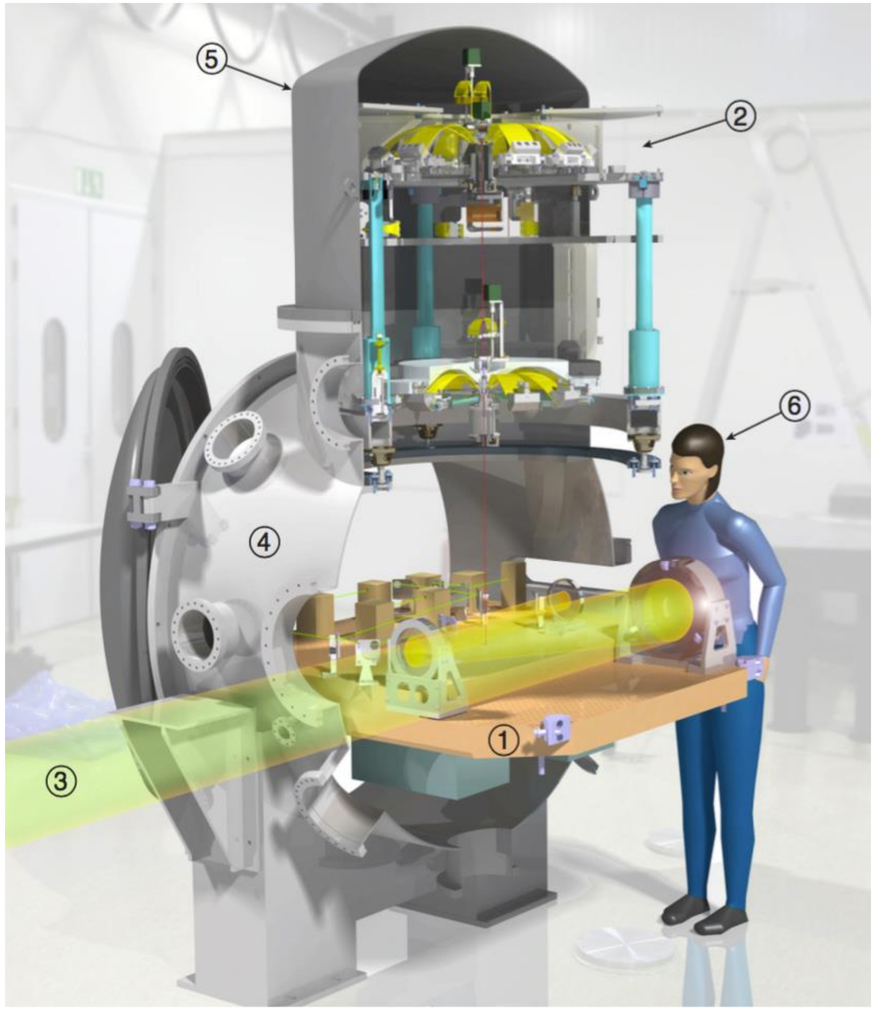
Interferometer between suspension points

- Additional tubes in central cavern are a possible
- Alternative: Platform at beam level

Suspension point control:

- Use Input test masses as virtual reference points
- Consecutively stabilize optics along the input beam line:
  - Folding periscopes
  - Power and signal recycling mirror
- Mode cleaner?
- Filter cavities?

Auxiliary optics



Class. Quantum Grav. **36** (2019) 075007, J V van Heijningen *et al*

Auxiliary control loop can pollute interferometer output

- Unity gain frequency up in the 10th of Hz, to provide sufficient suppression of low frequency motion
- Noise from modulated scattered light

Auxiliary optics on suspended benches:

- Use beamline level to stabilize between platform
- Tilt sensing for pitch and yaw control

Albert-Einstein-Institute (AEI) 10m-Prototype has tested a pre-stabilization scheme

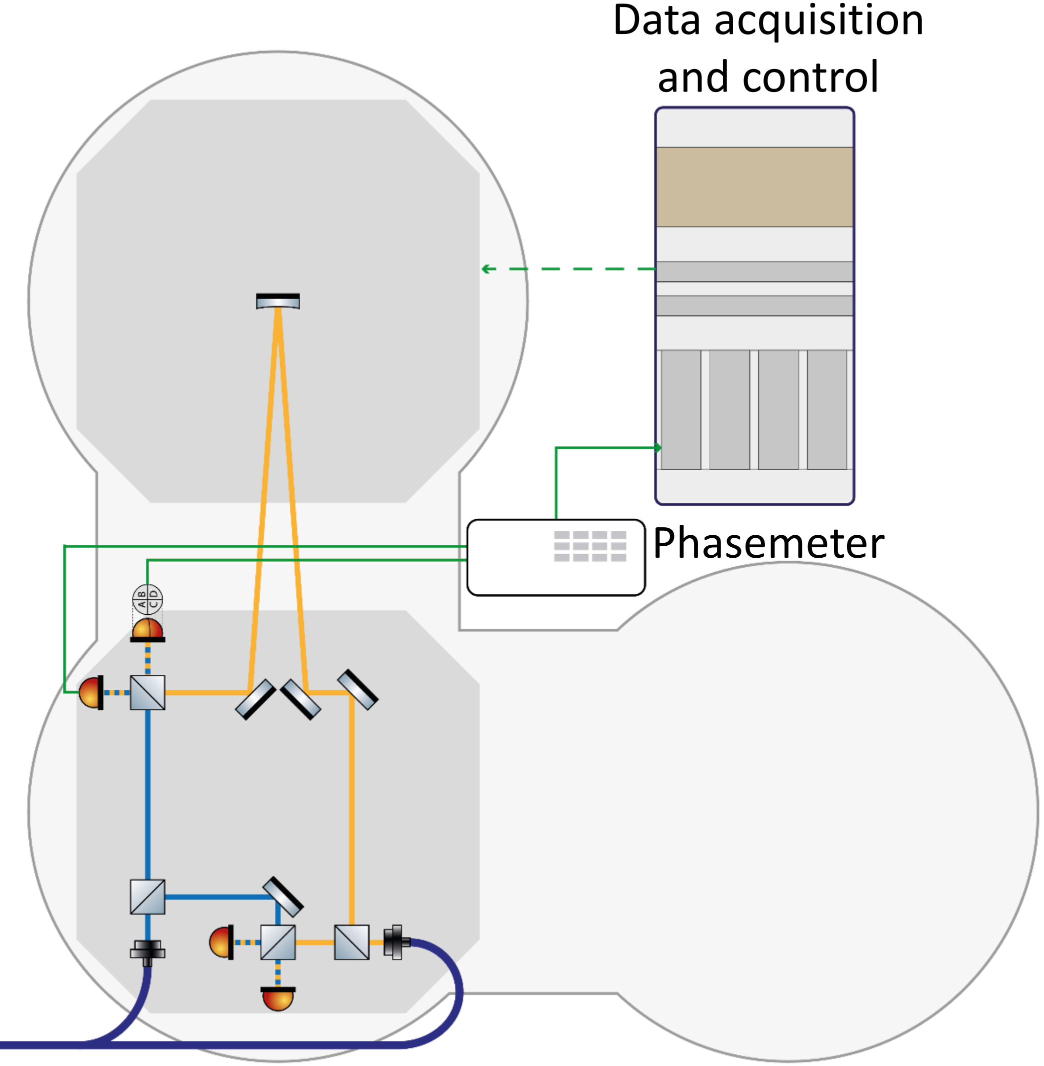
Technology demonstrator AEI 10m-Prototype

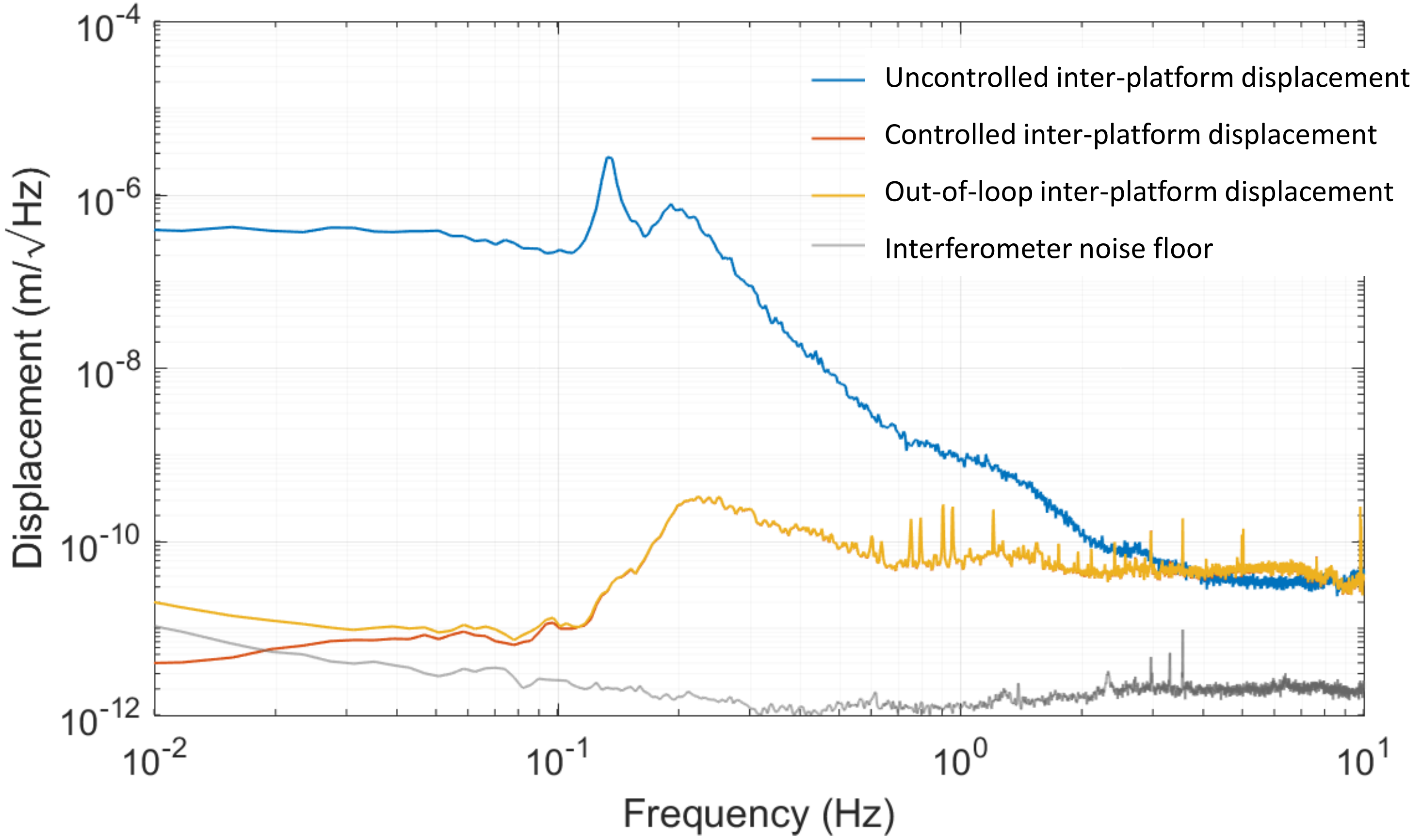
Large facility similar to gravitational wave detector and designed for prototyping

Passive and active seismic pre-isolation by AEI-SAS (similar to Virgo's EIB-SAS)

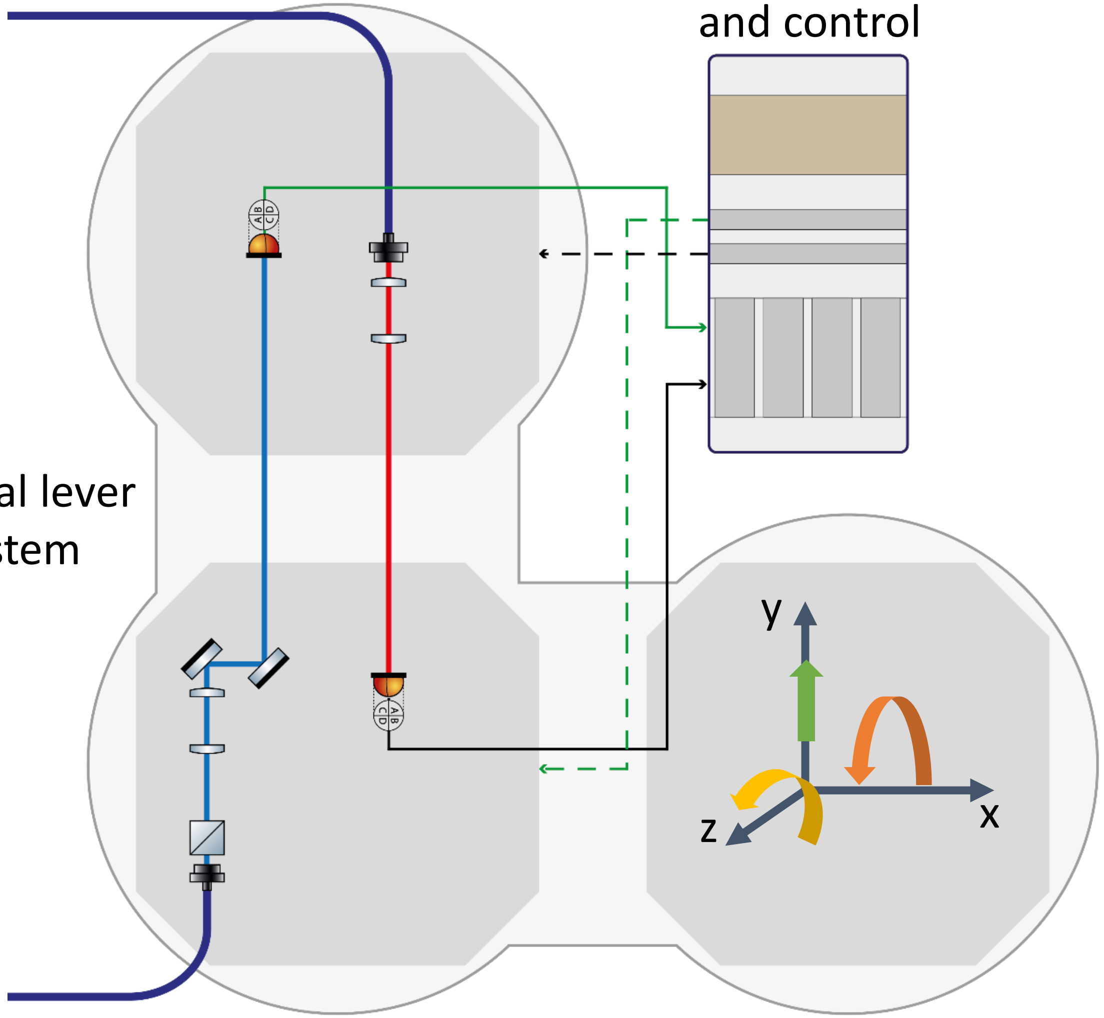
- Passive filtering by Inverted-Pendulum legs and Geometric-Anti-Spring filter
- Active control with inertial sensors: geophones and accelerometers

Interferometer for active differential length control

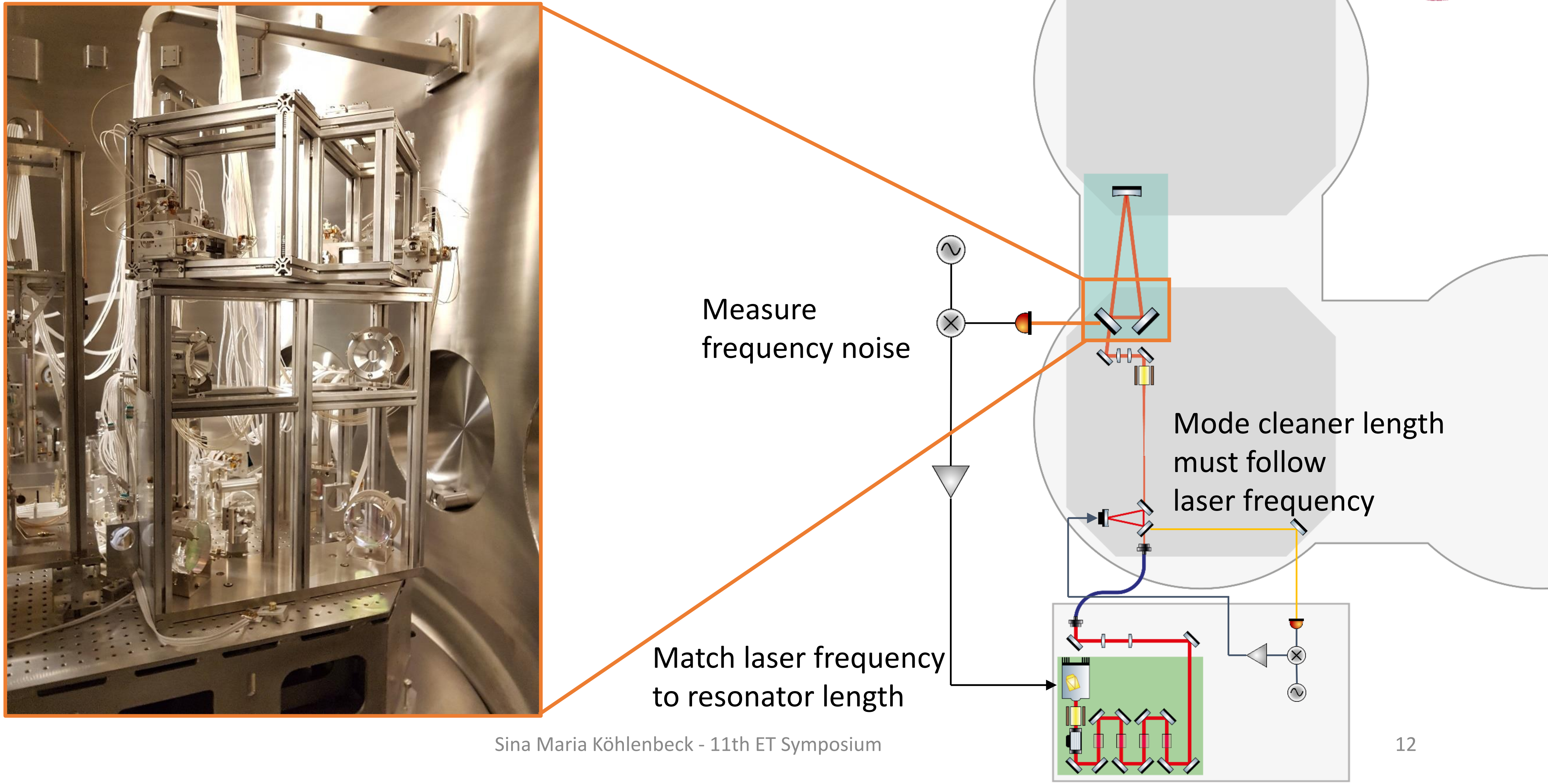




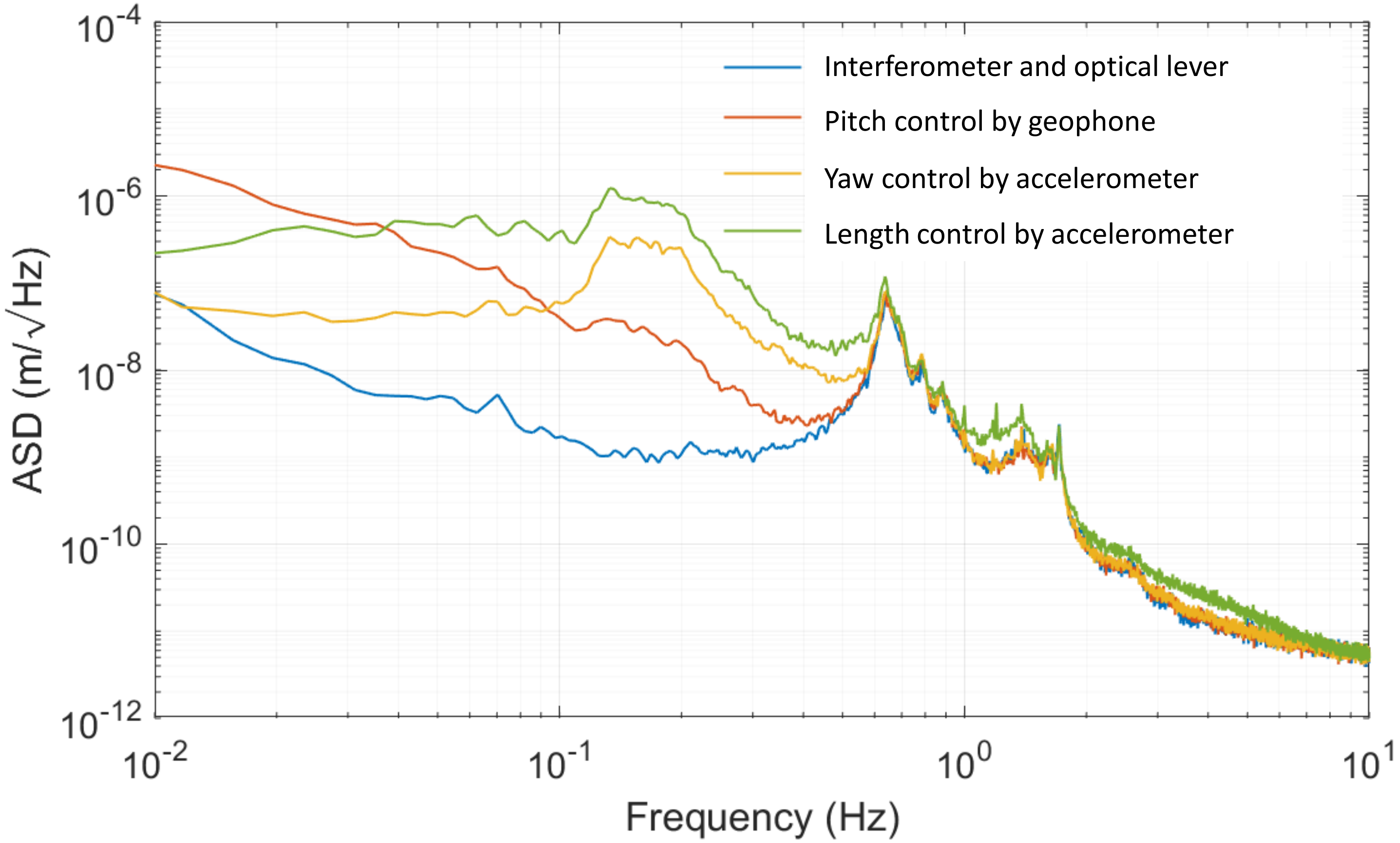
Platform stability ≠ suspension point stability



Suspended cavity as sensor



Demonstration of suspension point stabilization



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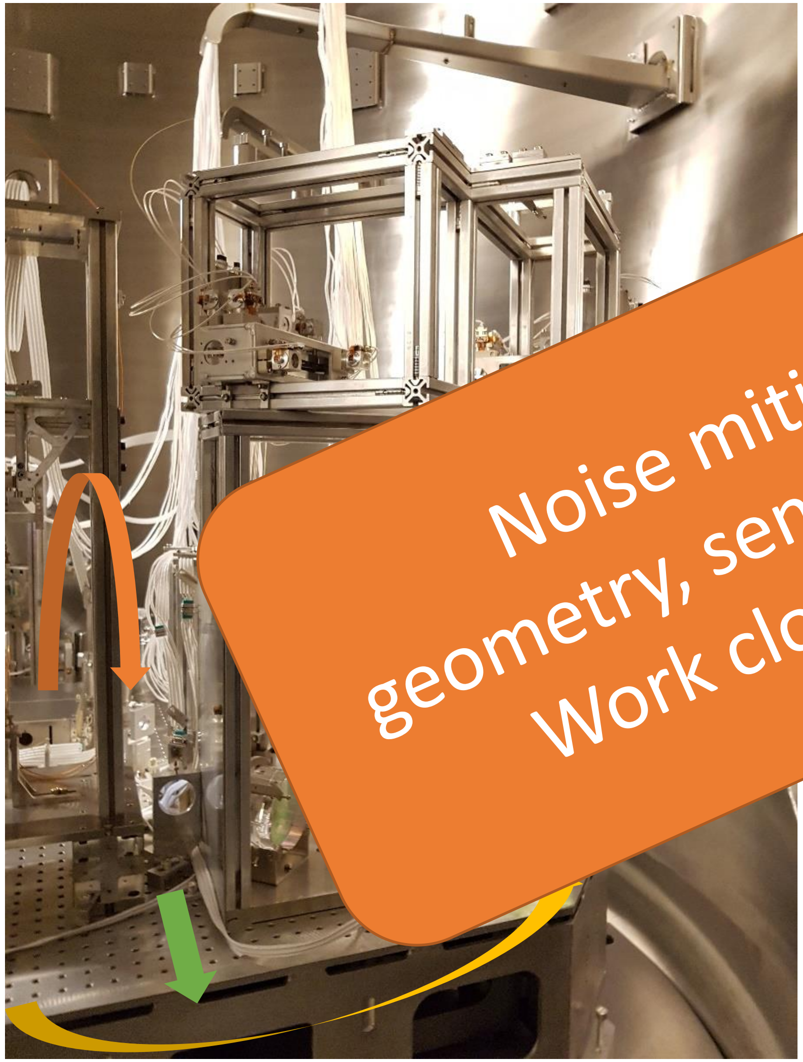
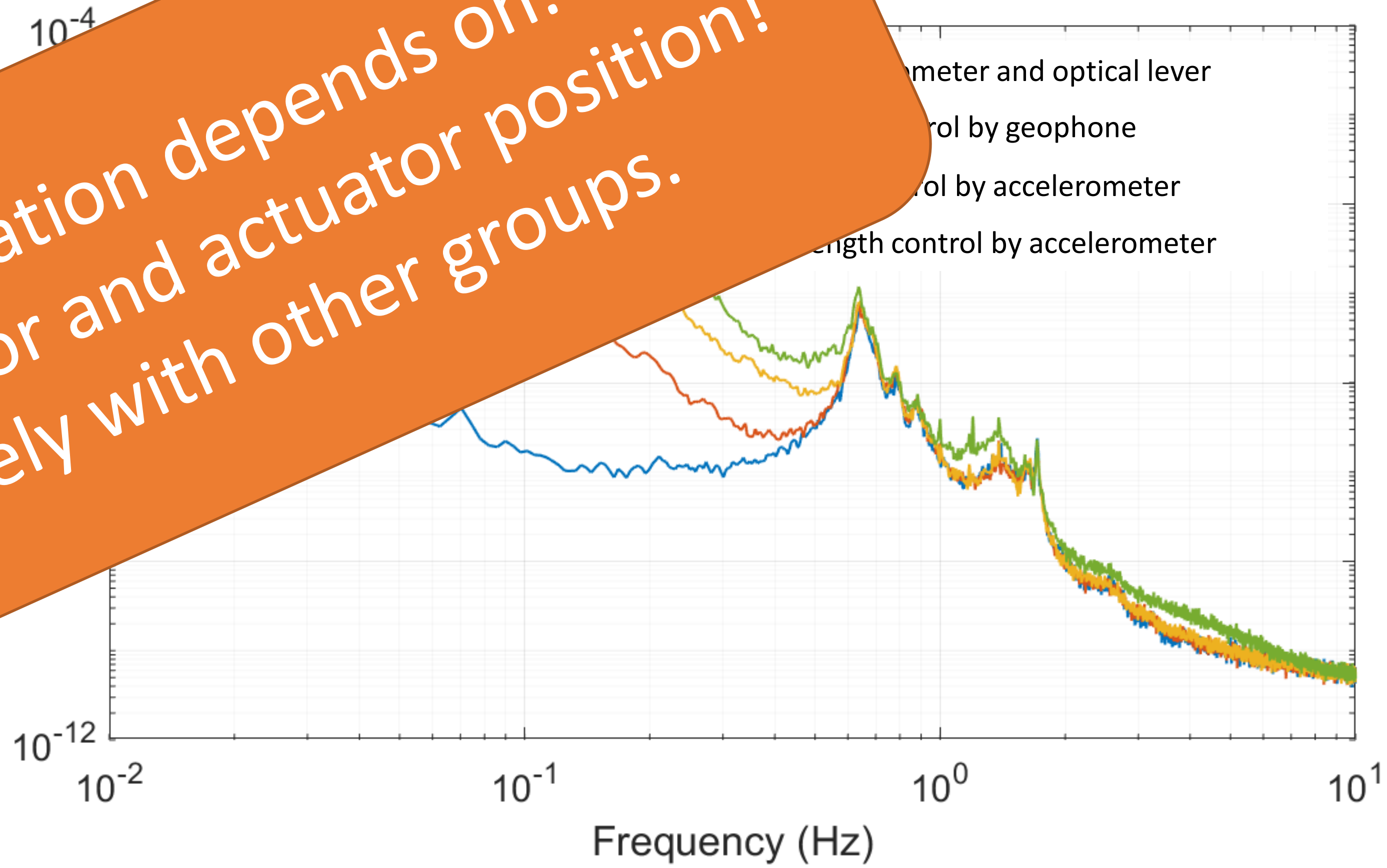


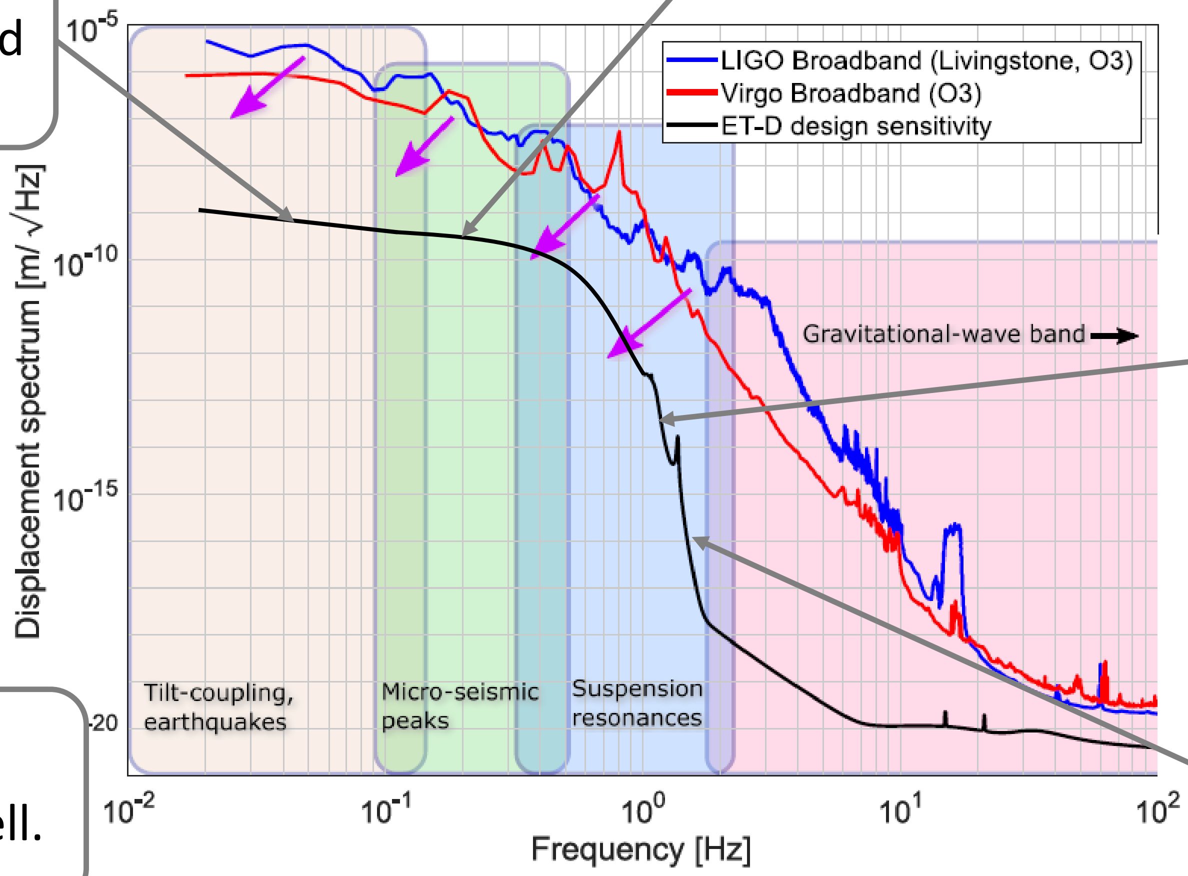


Noise mitigation depends on:
geometry, sensor and actuator position!
Work closely with other groups.

What we want:

Active stabilization to assist lock acquisition and reduce dynamic range.

Low noise due to high signal-to-noise of optical sensor array.



No excess noise from auxiliary control loops and stray light.

Focus on ET-LF but applicable to ET-HF as well.

Angular interferometer control unity gain set by Sidles-Sigg instability.