

Underground Site Characterization & Control of the GEMINI Platforms

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Experimental Framework:
GEMINI



The Seismic Wall

Below 10 Hz,
gravitational wave
detectors are limited
by ground motion

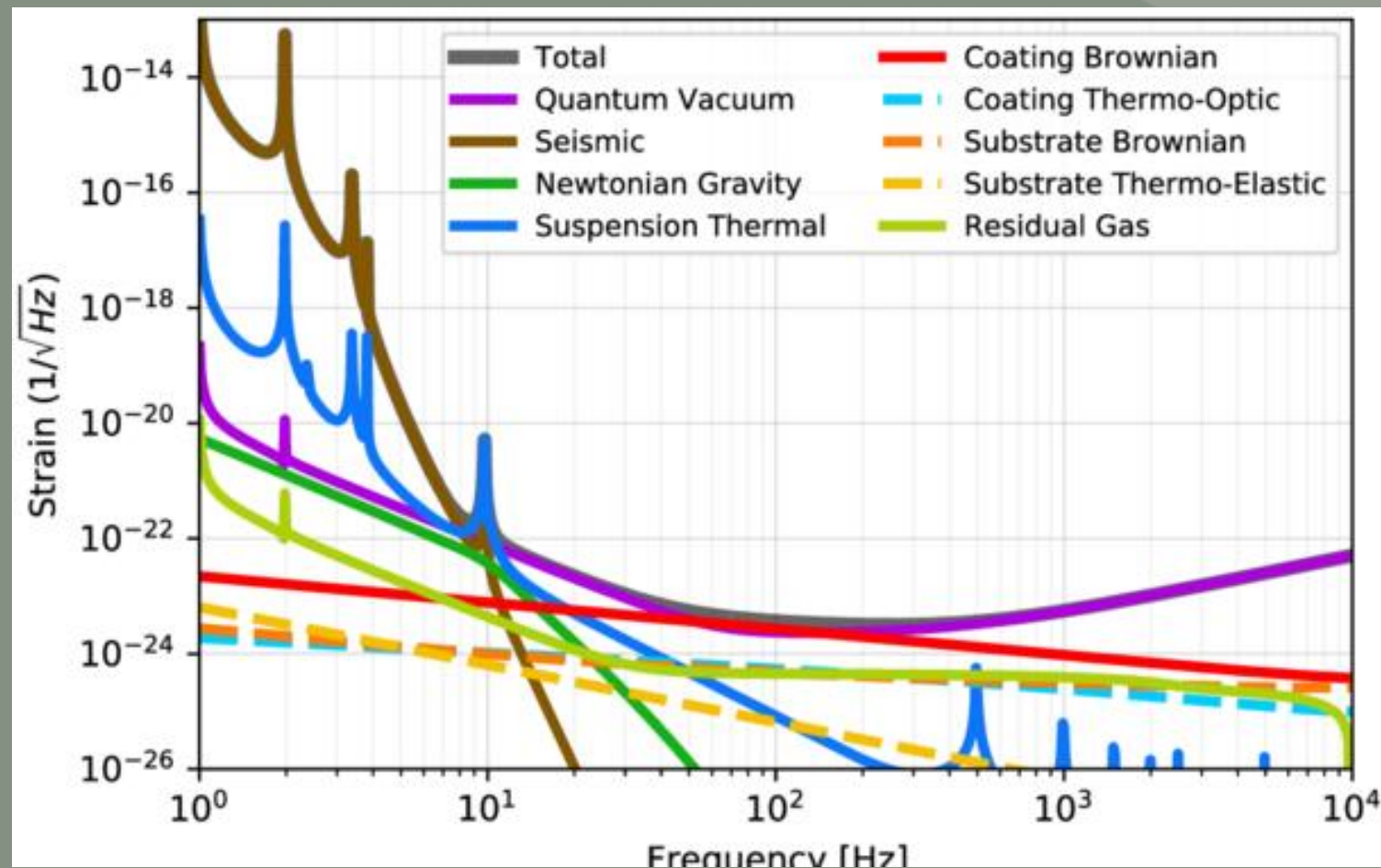
Even the most
advanced isolation
systems cannot fully
reject seismic noise

Ground displacement
follows approximately:

$$S_x(f) = \alpha / f^2, \text{ with } \alpha \approx 10^{-7} \text{ m} \cdot \text{Hz}^{3/2}$$

At 10 Hz: ground strain $\approx 10^{-12} / \sqrt{\text{Hz}}$, but required
detector sensitivity is
 $10^{-21} / \sqrt{\text{Hz}}$

Seismic vibrations must be
suppressed by 10^9 !



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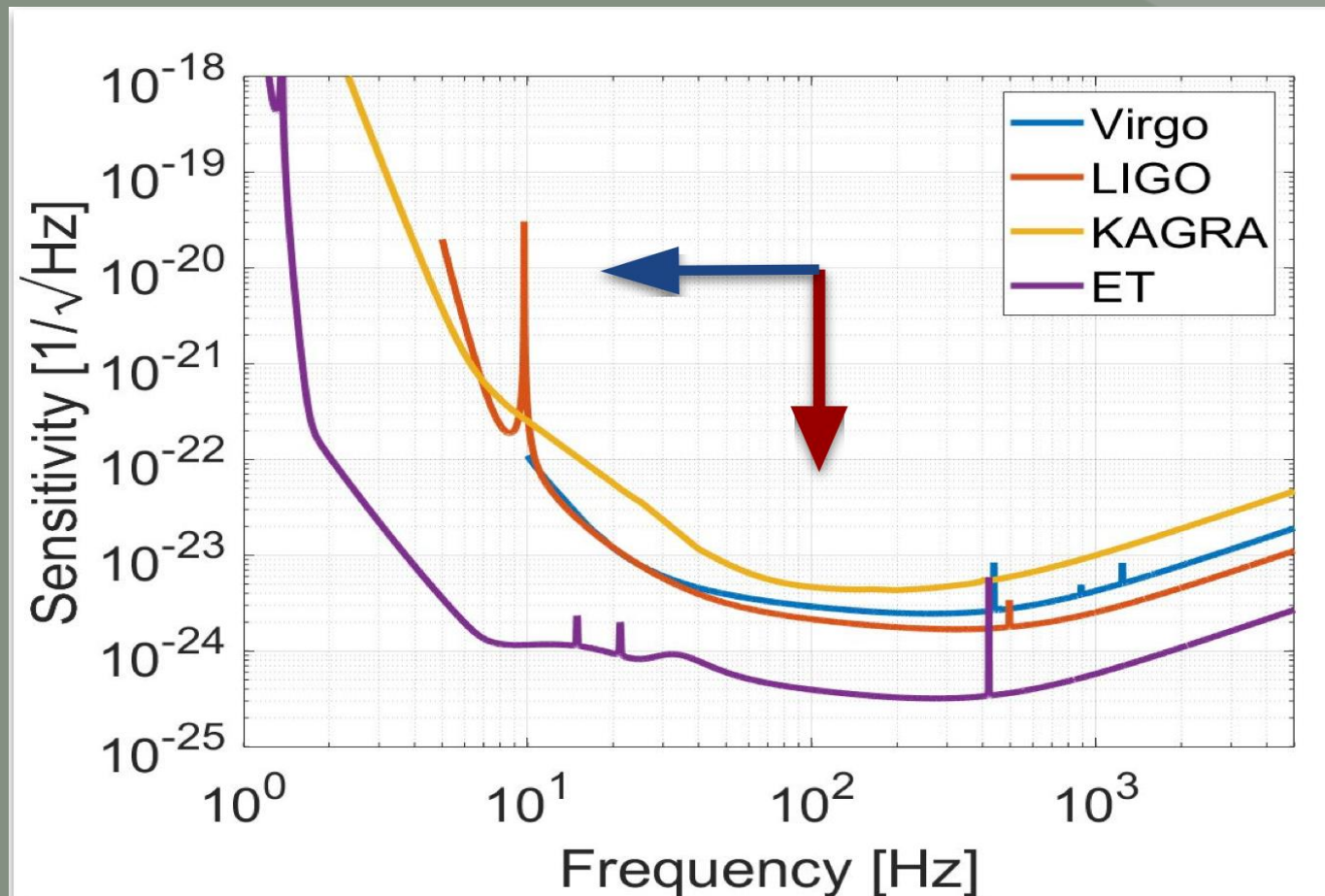
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GEMINI



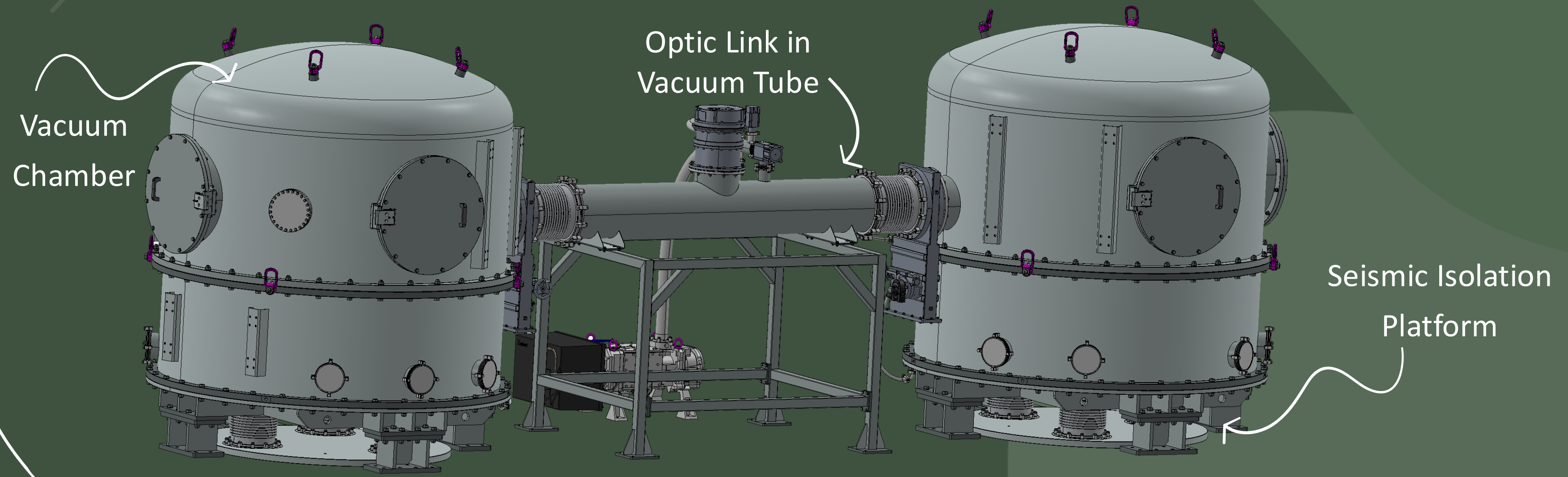
Testbed for validating new **low frequency seismic isolation technologies**.



Combines passive isolation (spring blades, flexure rods) with active isolation (sensors, actuators).



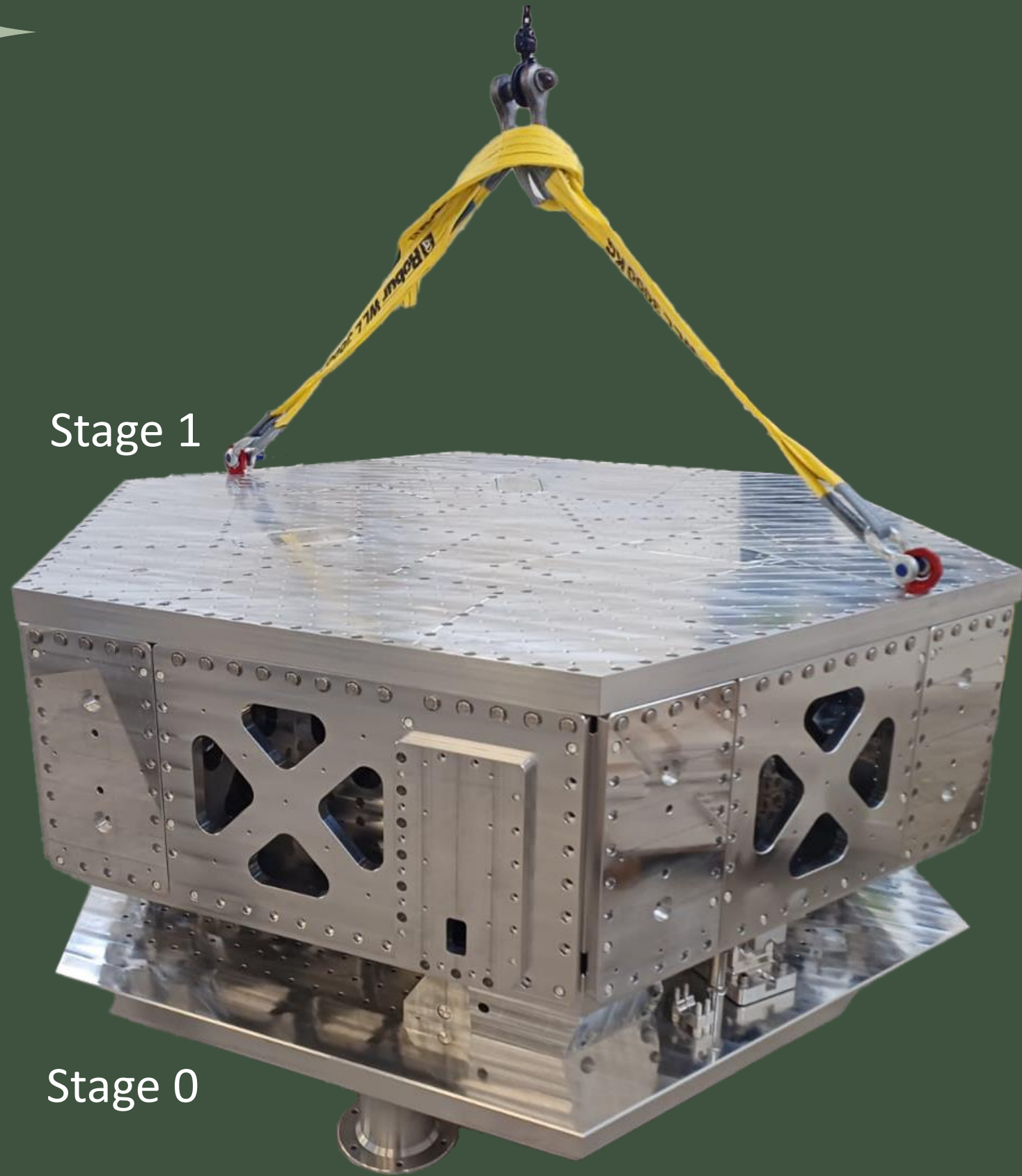
Technology can then be scaled up and implemented in future GW facilities such as the Einstein Telescope and the Lunar GW Antenna.



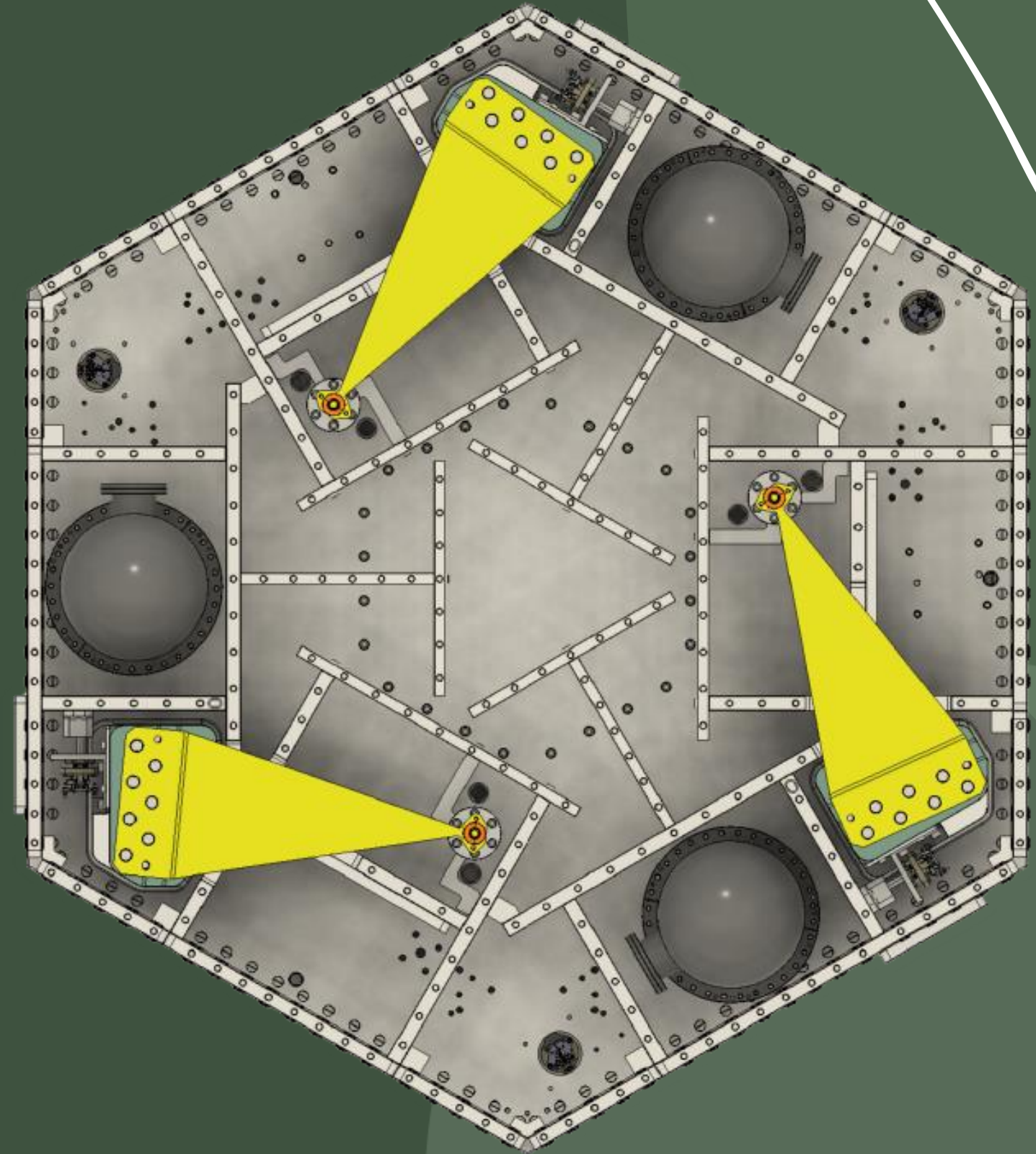
GEMINI II



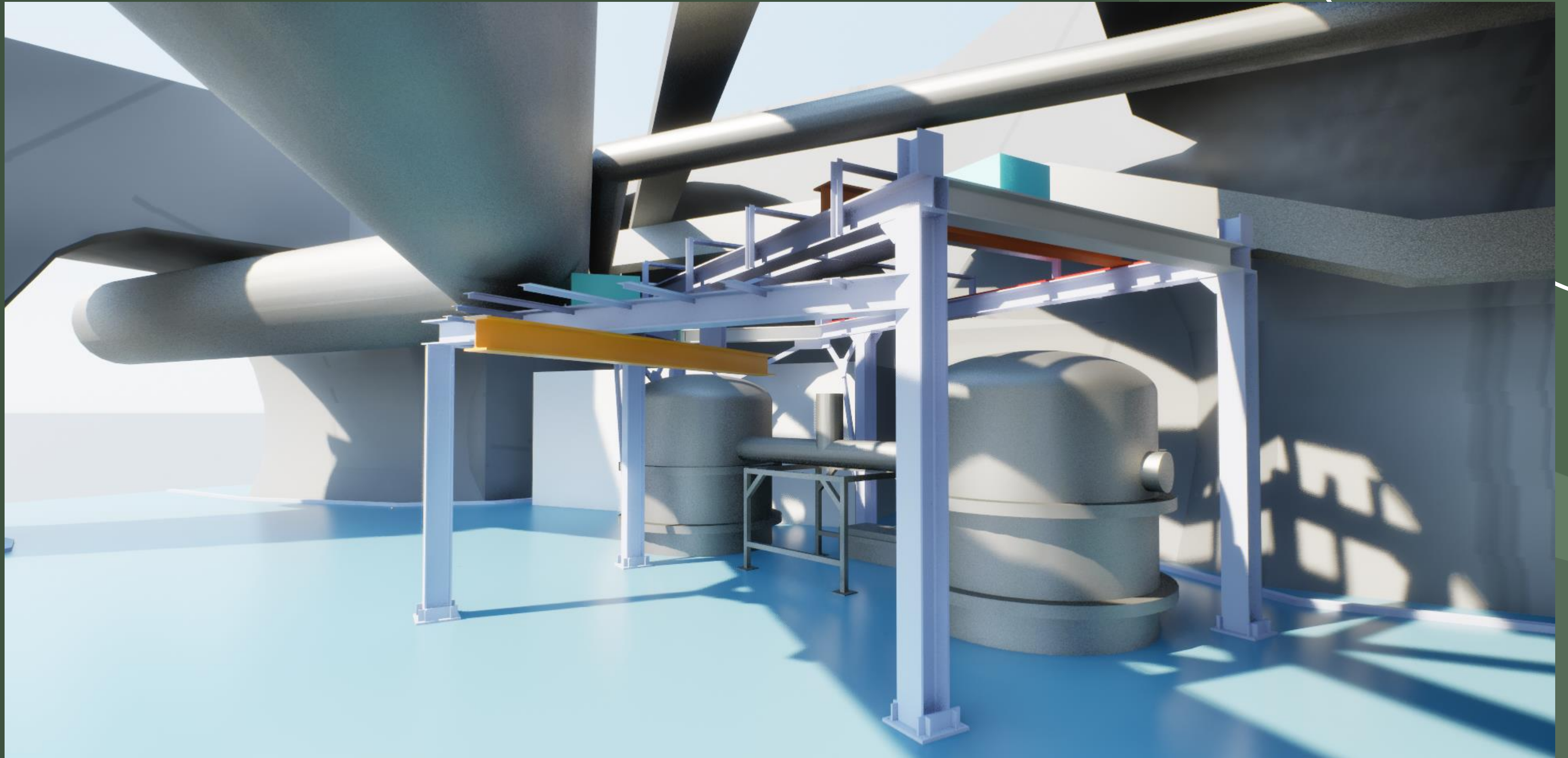
Stage 1



Stage 0



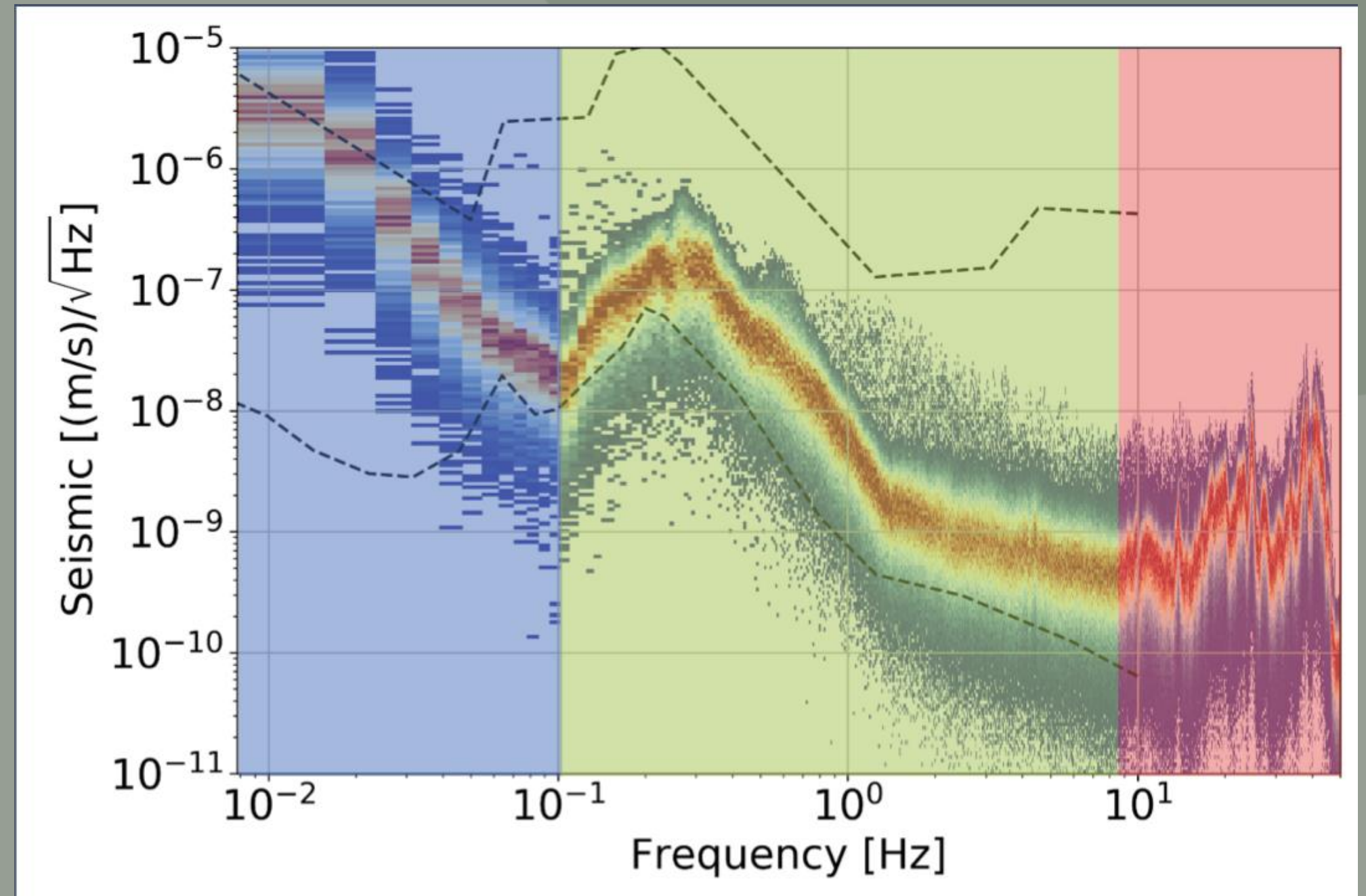
GEMINI ♊



Seismometer Isolation

Motivation: previous measurements of two seismometers placed a few cm apart showed uncorrelated noise below 0.1 Hz.

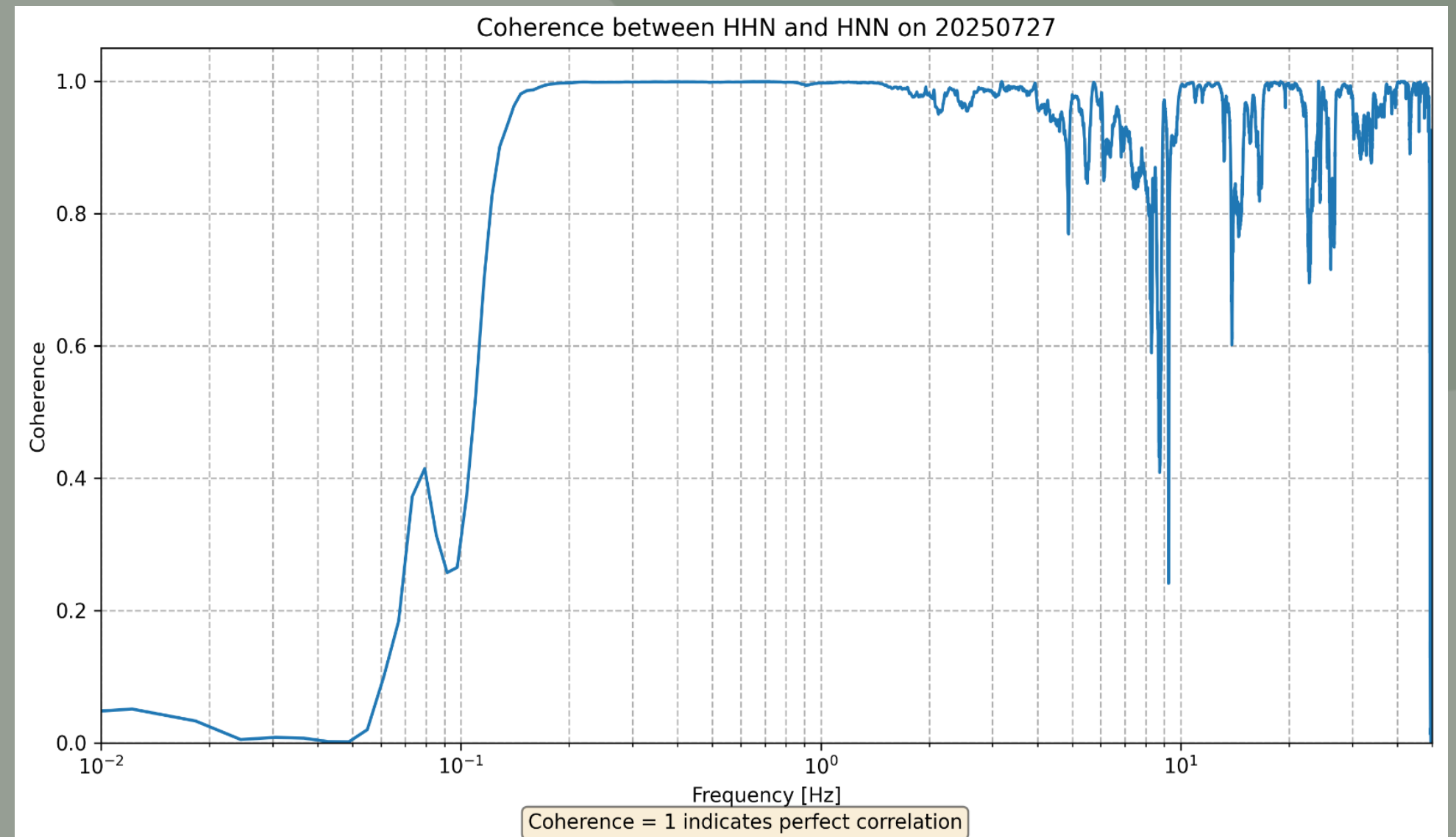
Raised question: Is the absence of correlation due to the instruments themselves, or due to local temperature/air fluctuations?



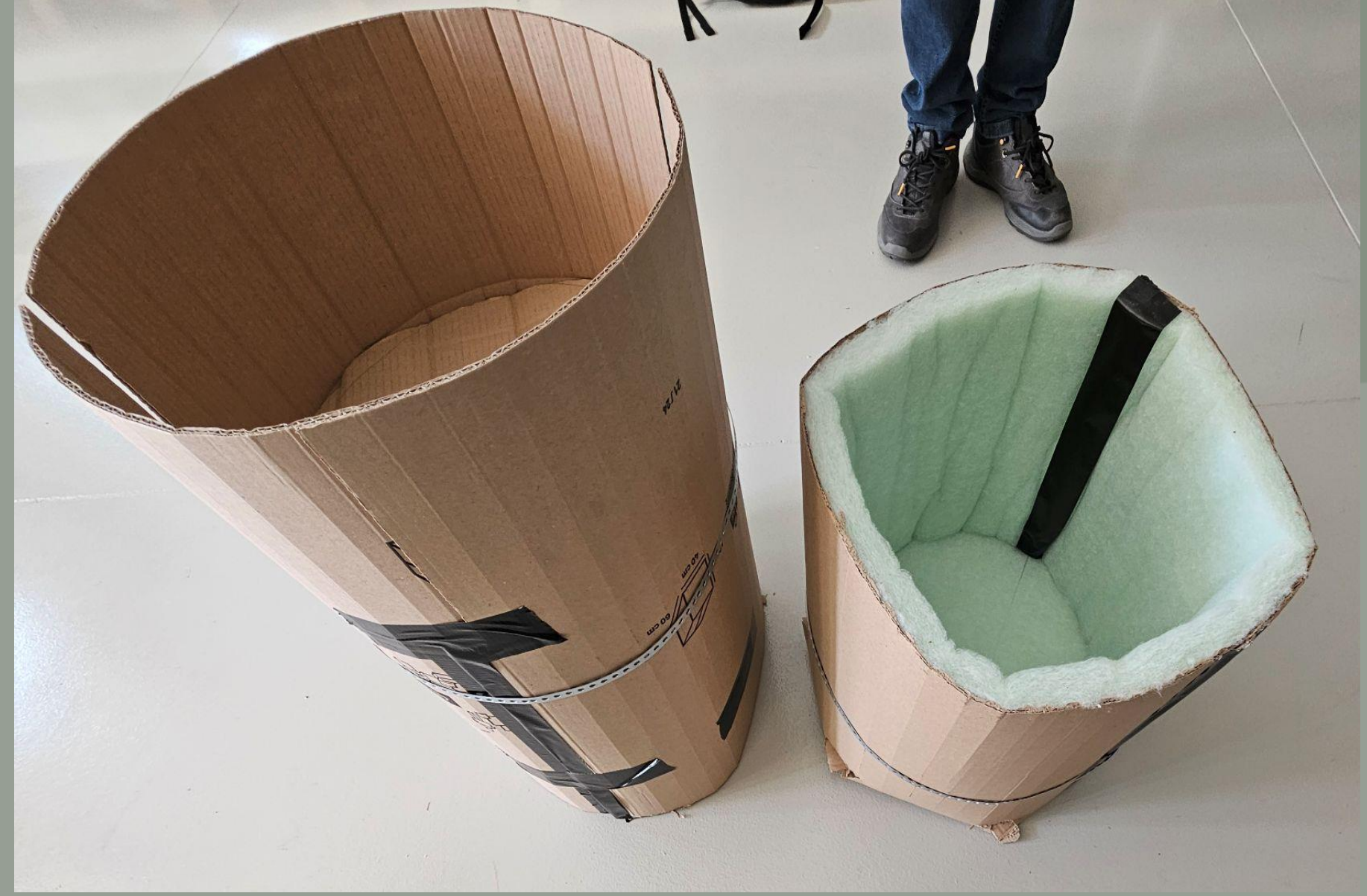
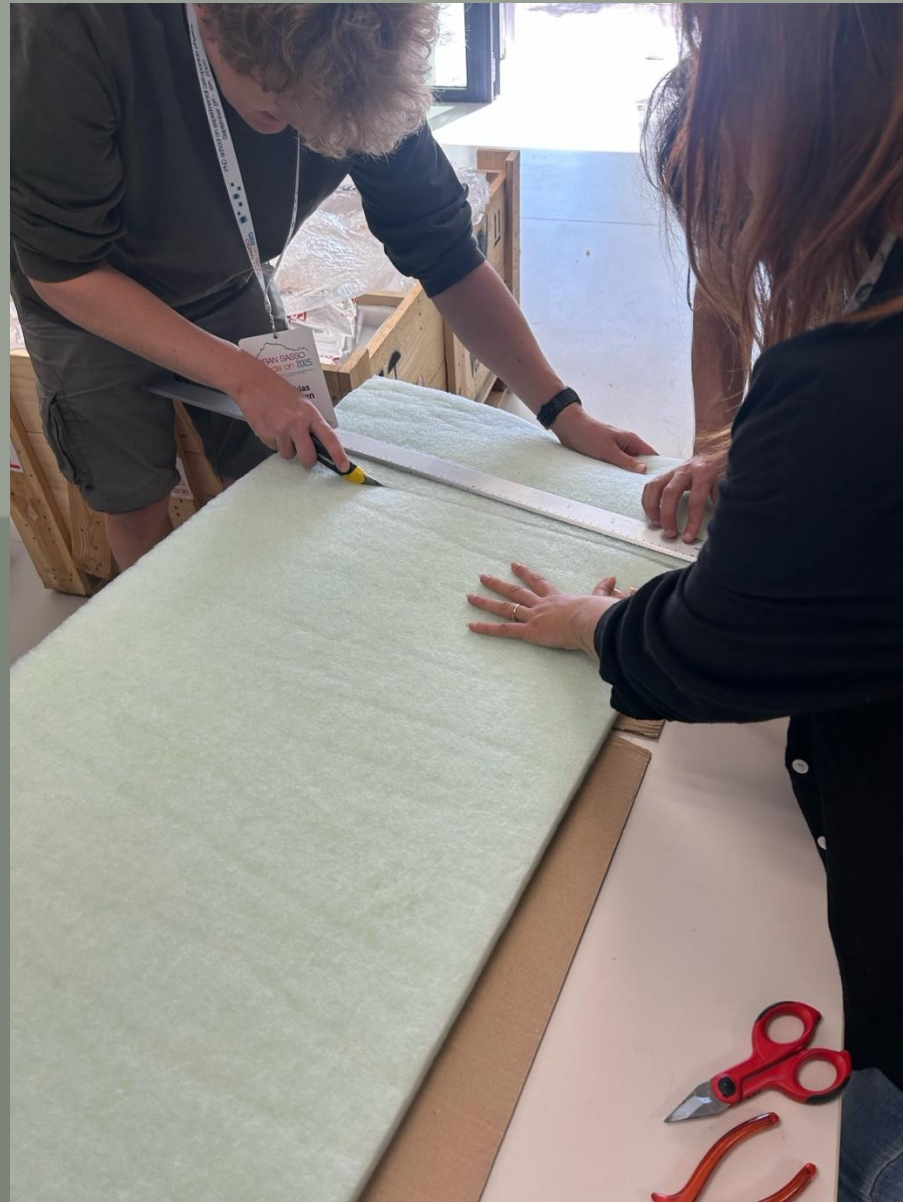
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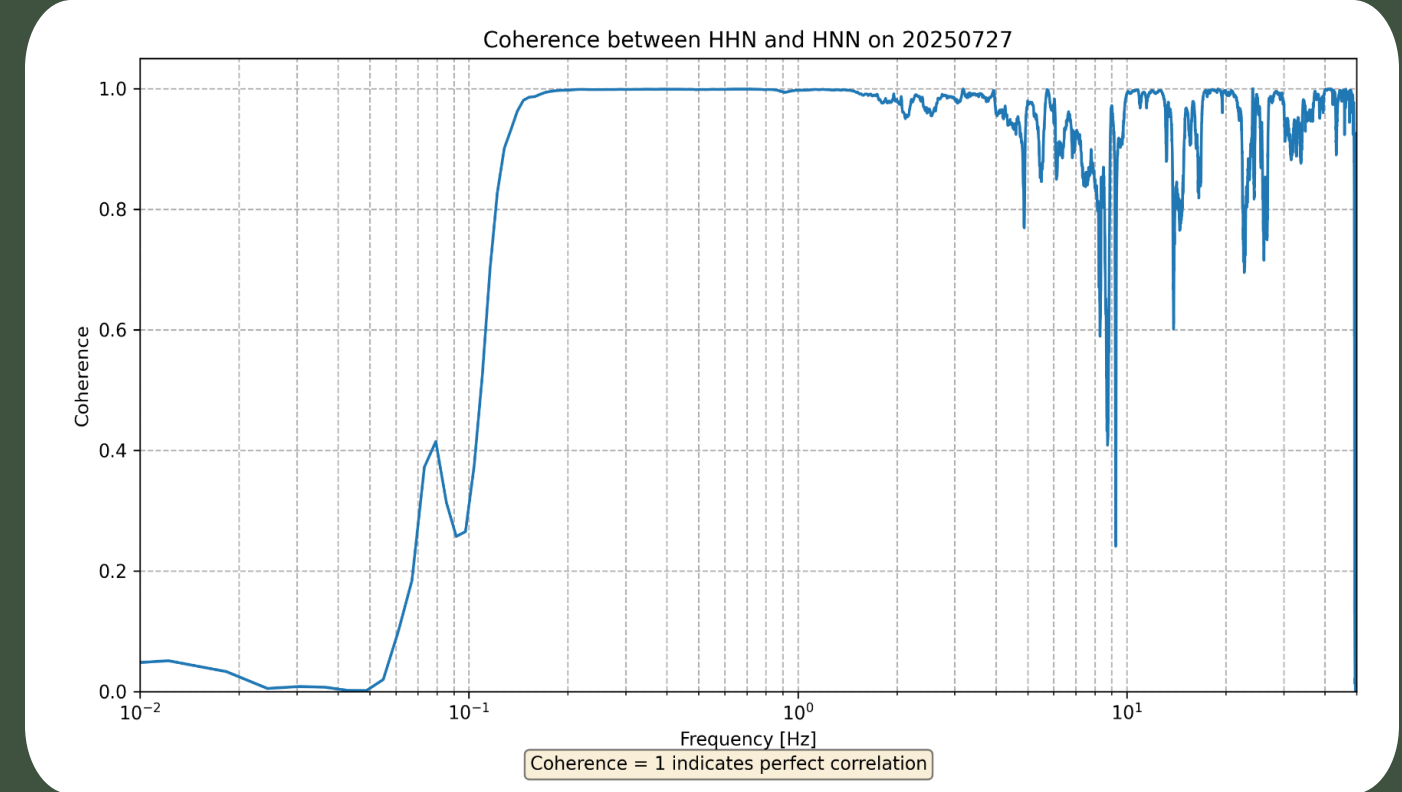
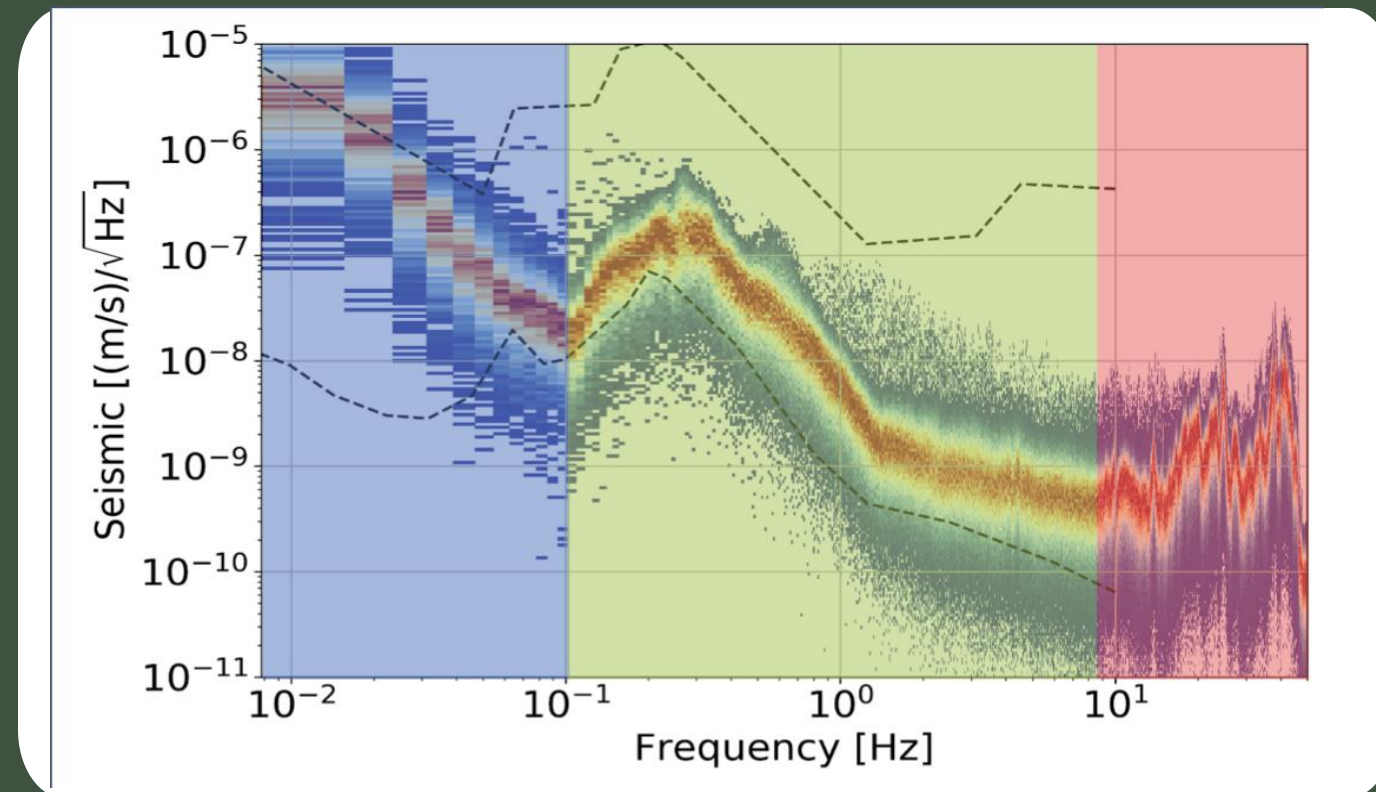


Seismometer Isolation

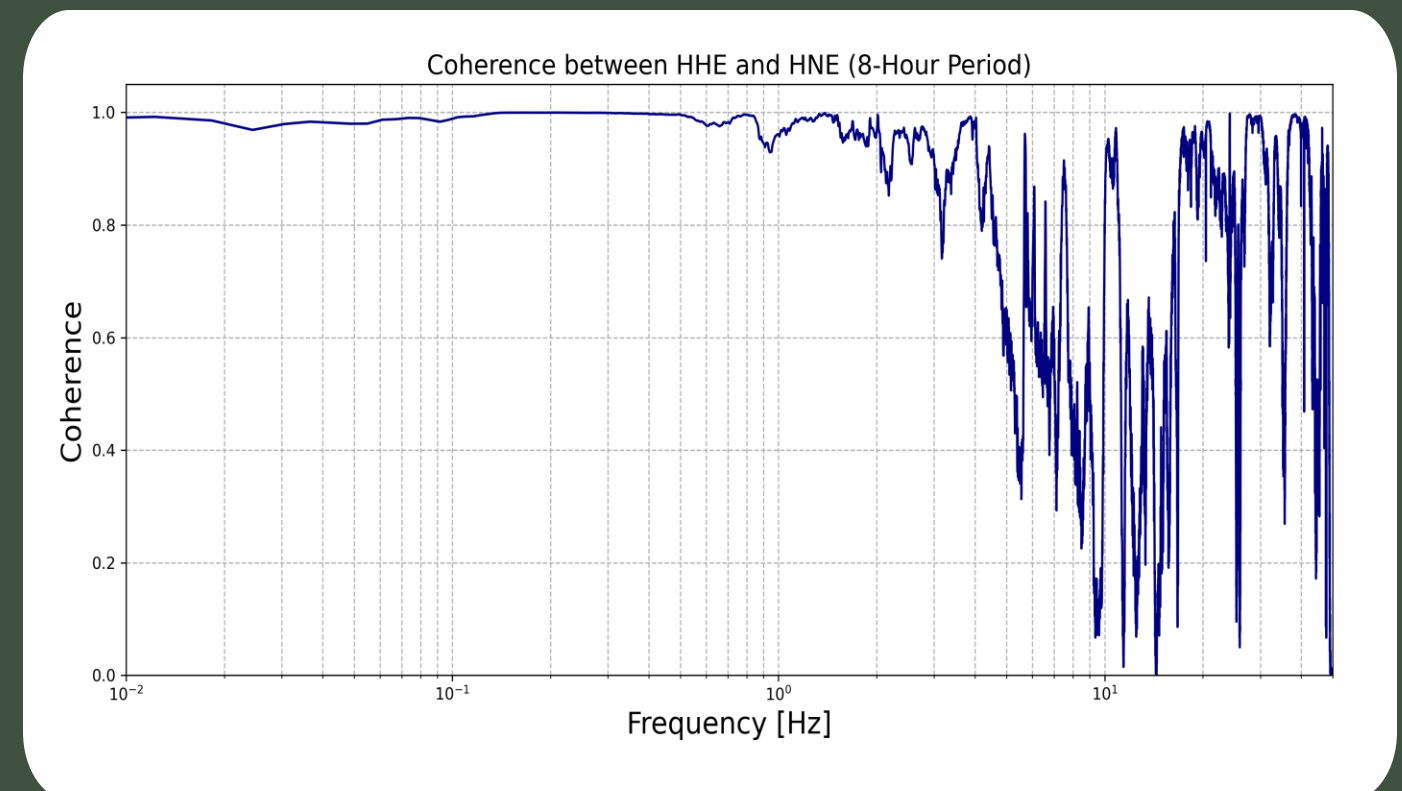
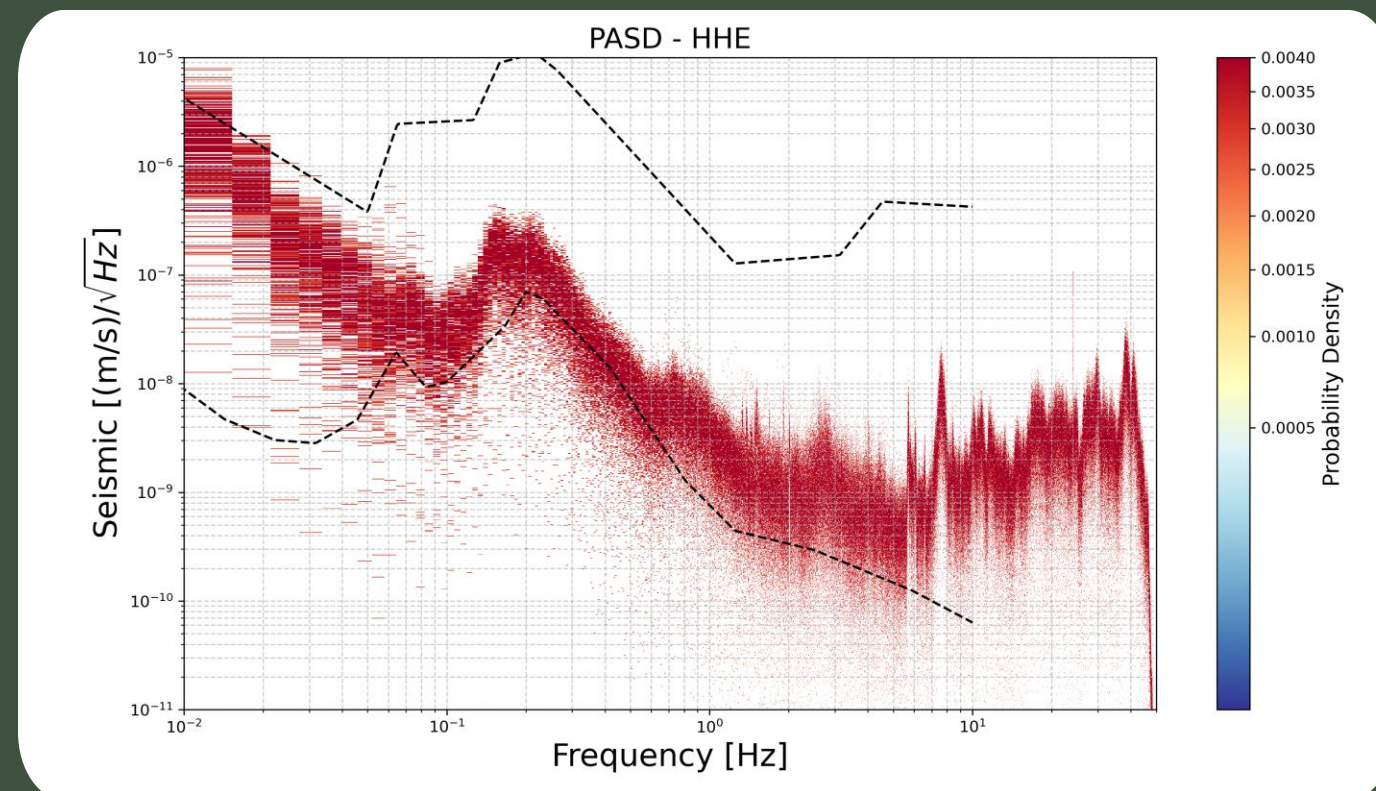


Data Analysis

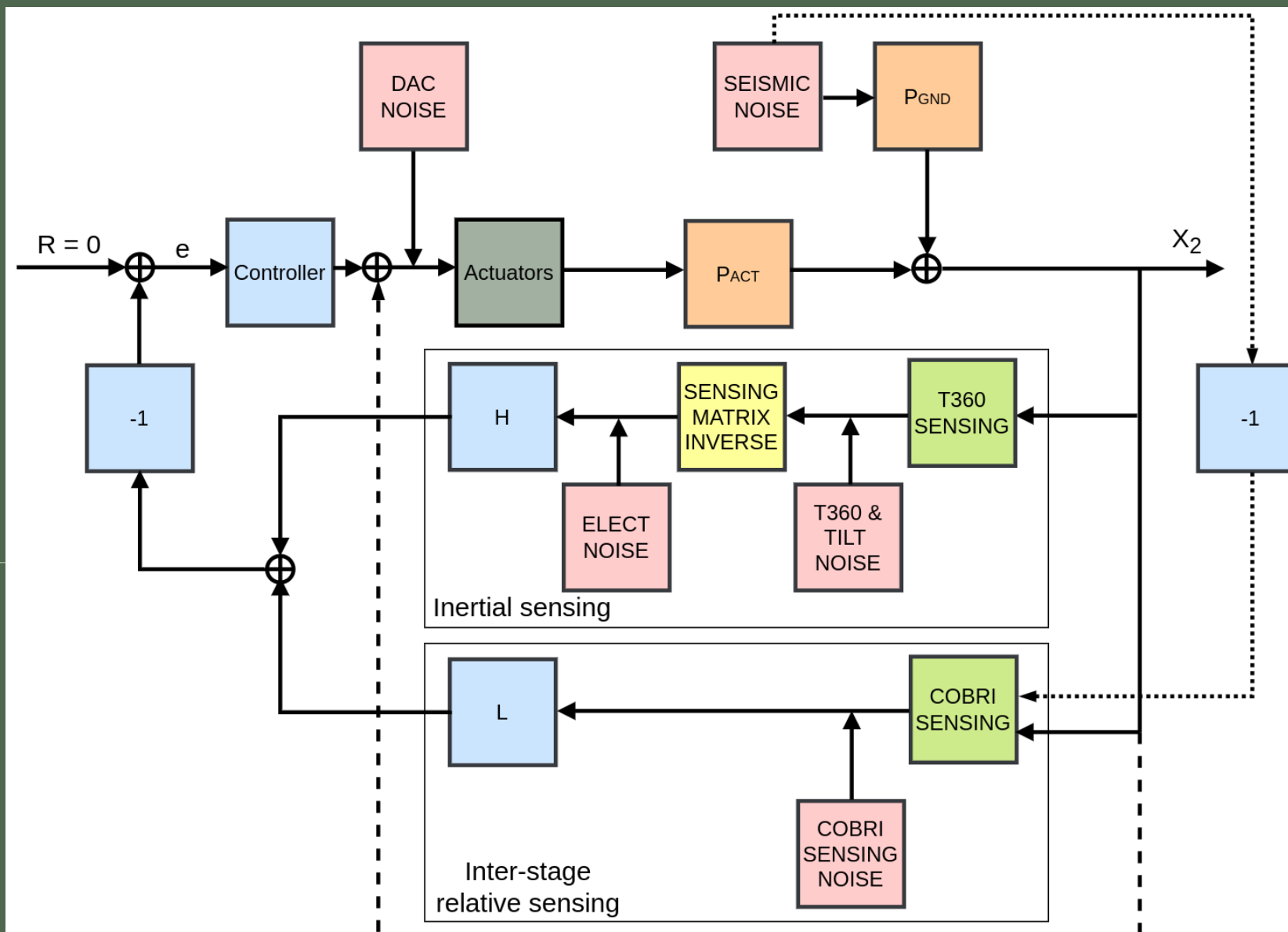
Original



Latest



Time Domain Simulations



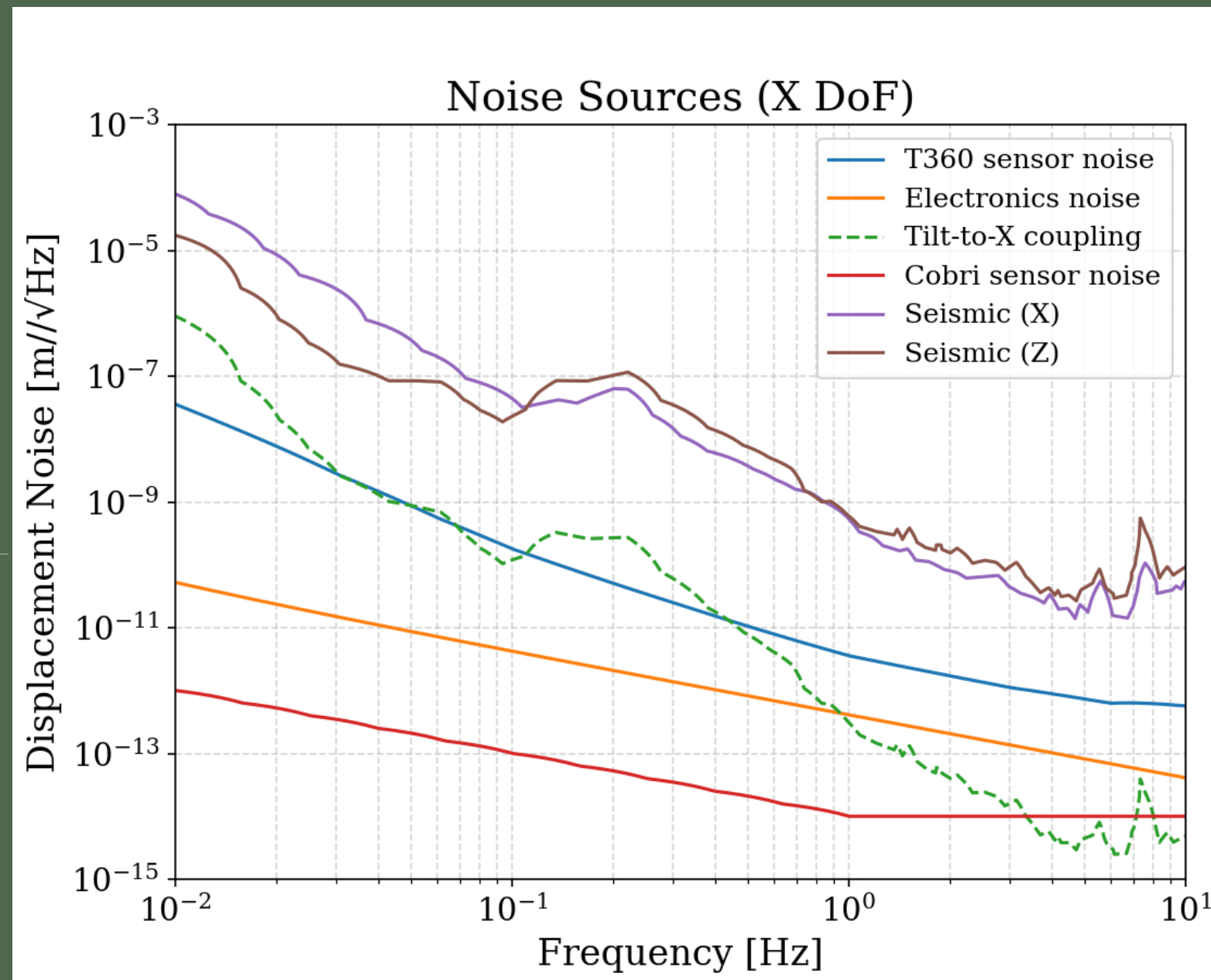
Simulated GEMENI platform with displacement sensors

Feedback control for residual noise minimization and maximum stability

Controller for motion correction

Actuators for motion counteraction via applied force

Time Domain Simulations



Implementation of noise into code simulation for more realistic model

Seismic noise

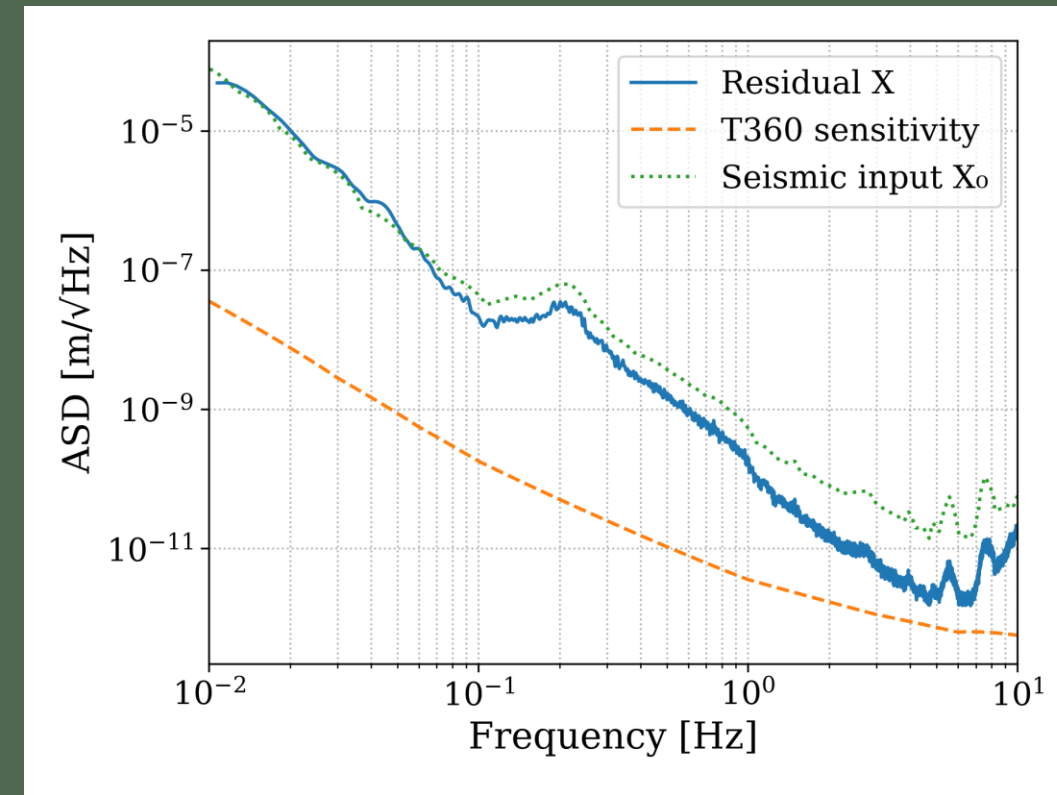
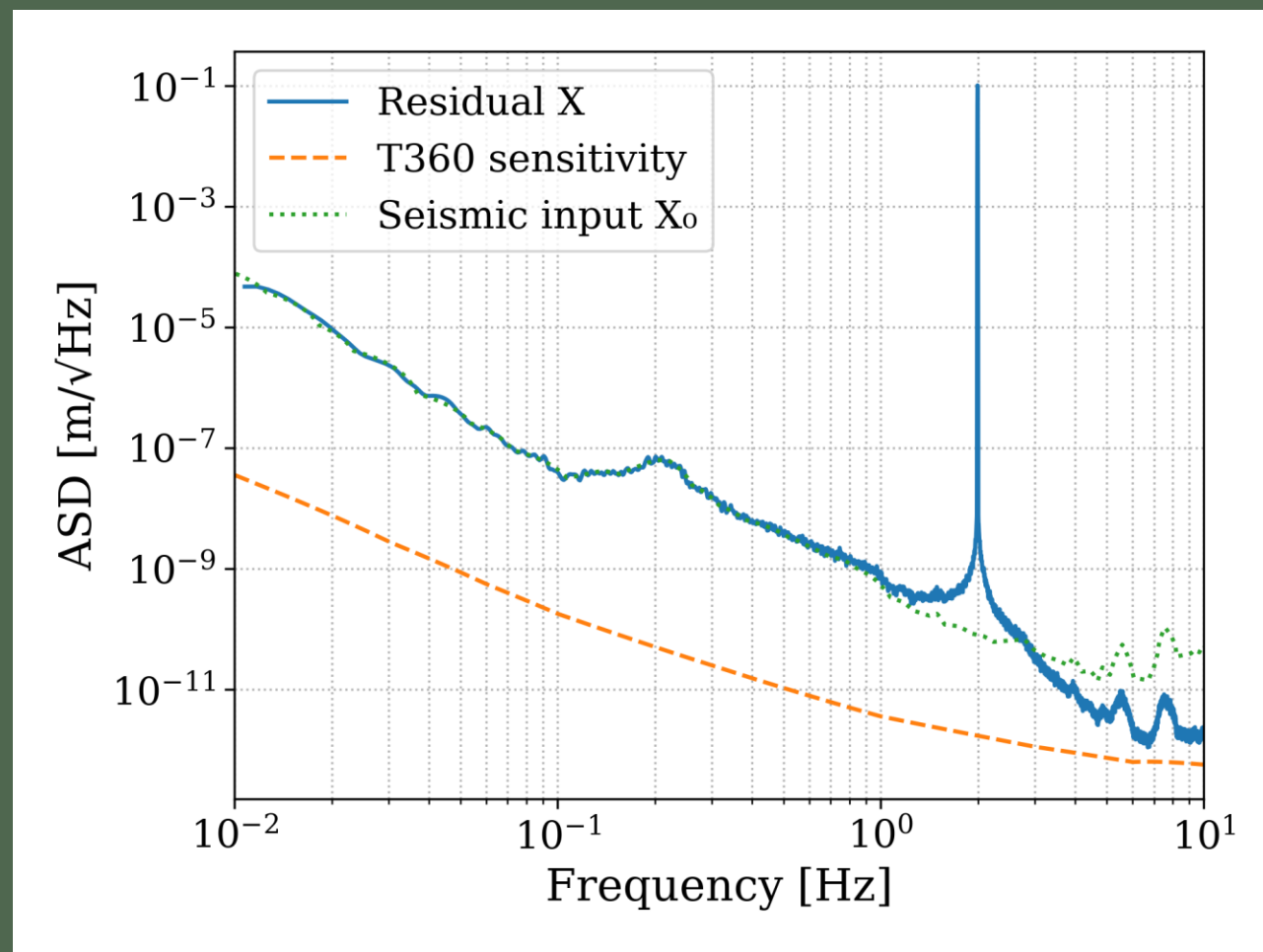
Electronic noise

Tilt-to-length coupling

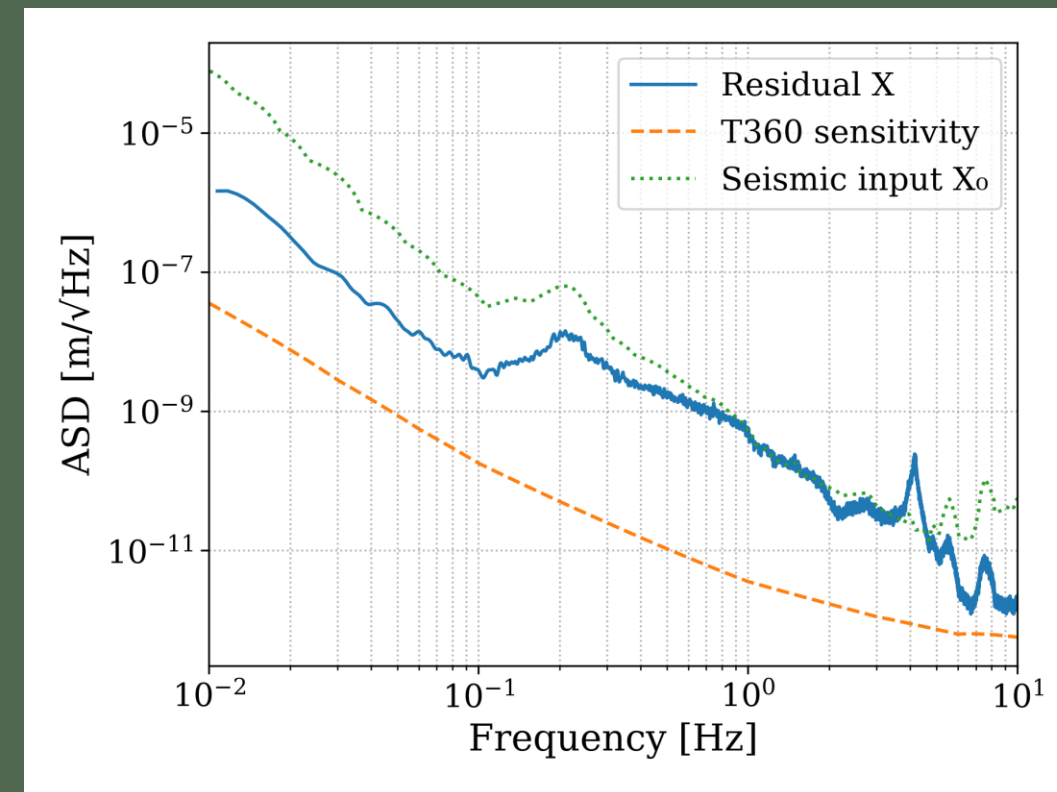
Sensing noises

Controller Implementation

Without Control



PID Controller



ZPK Controller

Bibliography

Trozzo, L., & Badaracco, F. (2022). Seismic and Newtonian Noise in the GW Detectors. *Galaxies*, 10, 20.

<https://doi.org/10.3390/galaxies10010020>

<https://doi.org/10.48550/arXiv.2509.04730> GEMINI: The First Underground Testbed for Seismic Isolation and Interplatform Control in Next-Generation Gravitational-Wave Detectors

Harms, J. Terrestrial gravity fluctuations. *Living Rev Relativ* 22, 6 (2019). <https://doi.org/10.1007/s41114-019-0022-2>

Thank you for your attention!



Summary

Seismic Wall:

Gravitational wave detectors limited by ground motion below 10 Hz

Seismic vibrations must be suppressed by many orders of magnitude

GEMINI:

Testbed for new **low frequency seismic isolation technologies**

Combines **passive isolation** (platform) with **active isolation** (sensors)

Methods:

Build enclosure for seismometer isolation to suppress environment effects

GEMINI simulation based on a feedback loop, so the platform continuously corrects itself to remain stable

Results:

Seismometer isolation led to **higher coherence** of the data

Controller design implemented but **optimal tuning** requires more time