

Nikhef

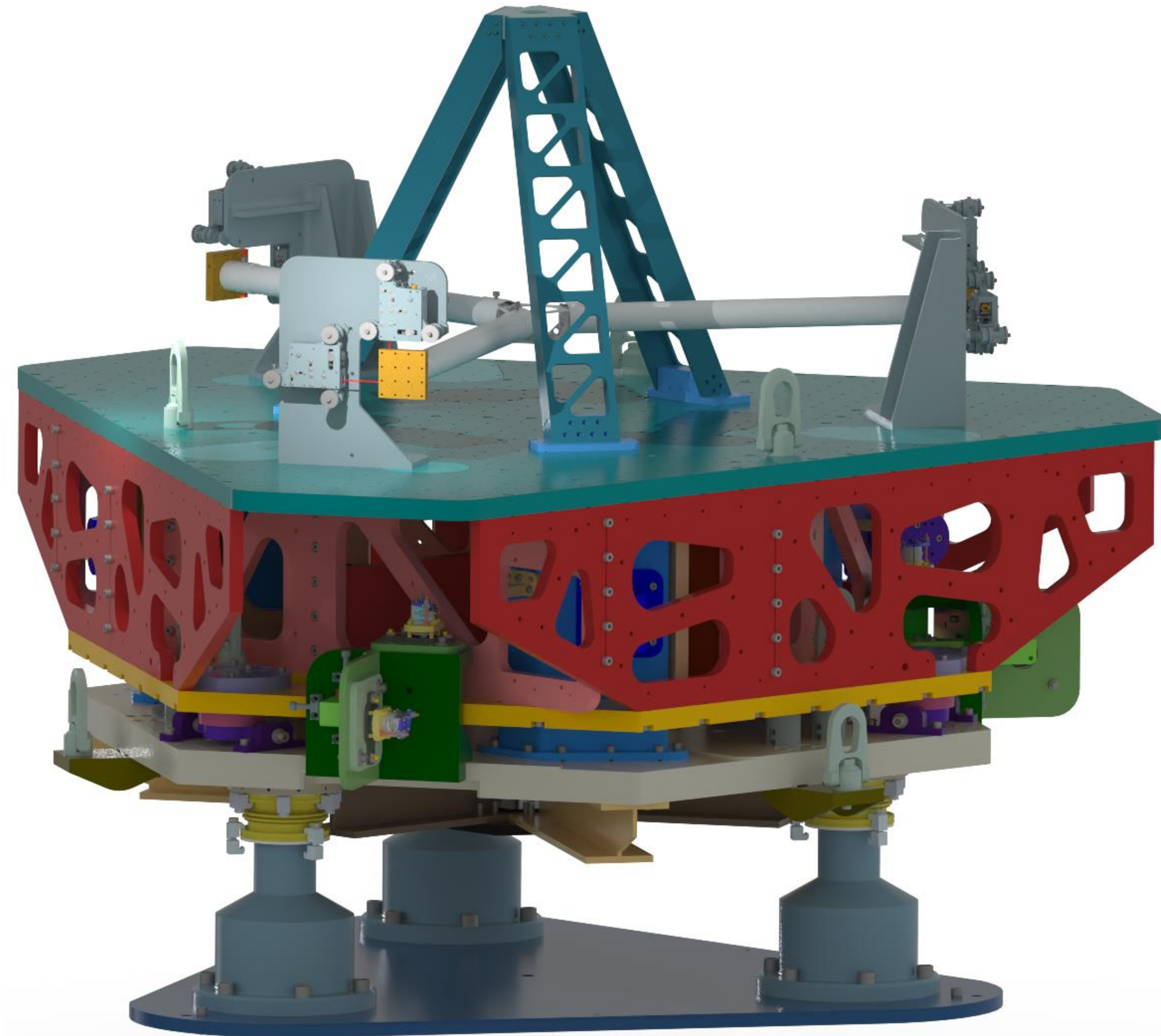


Jesse van Dongen

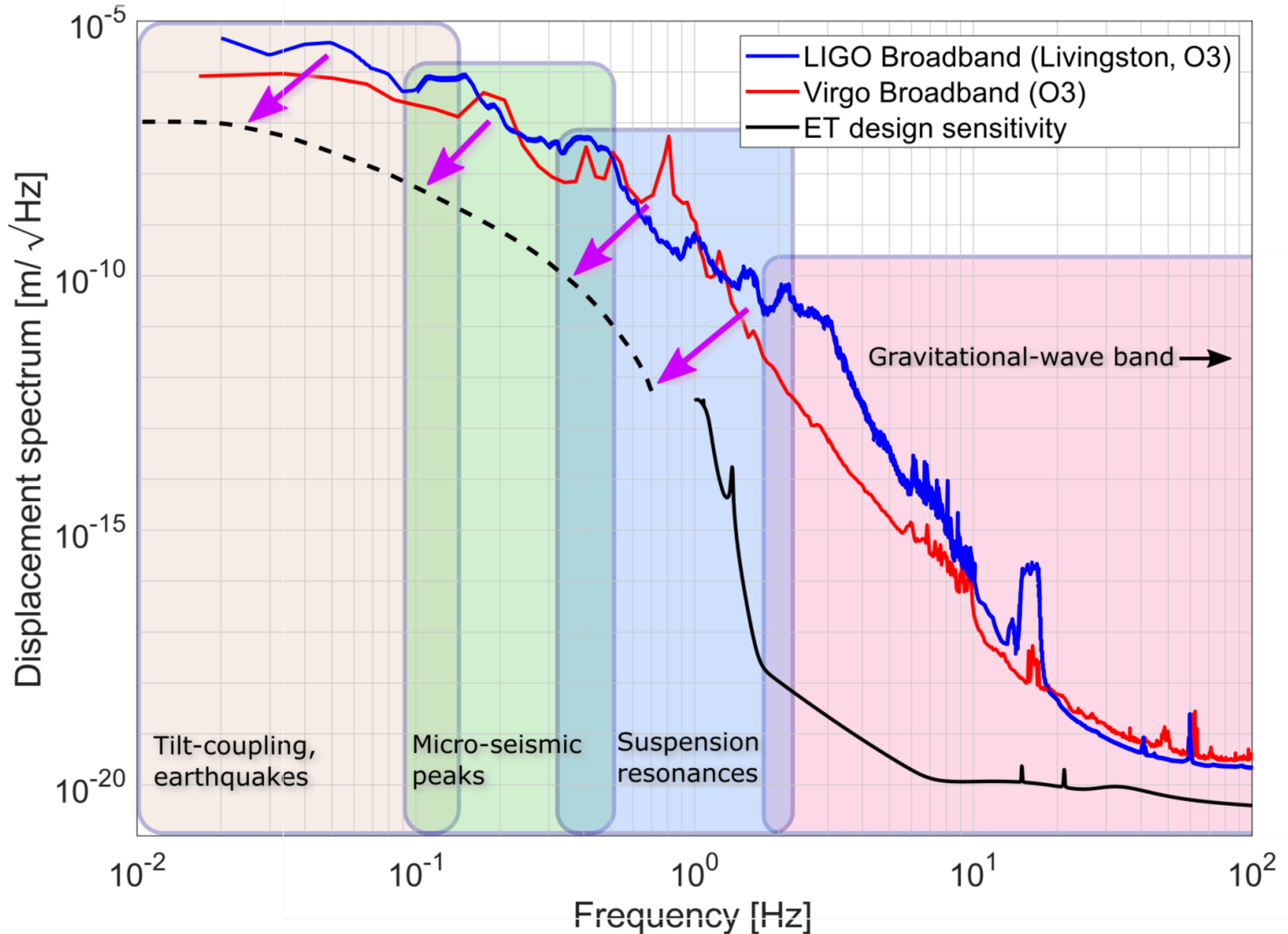
On behalf of:

Nathan A. Holland, Alexandra L. Mitchell,
Armin Numic, Pooya Saffarieh, Michele Valentini,
Conor M. Mow-Lowry and Others

UPDATES FROM THE OMNISENSE PROJECT



ET DESIRE: LOW FREQUENCY SENSITIVITY



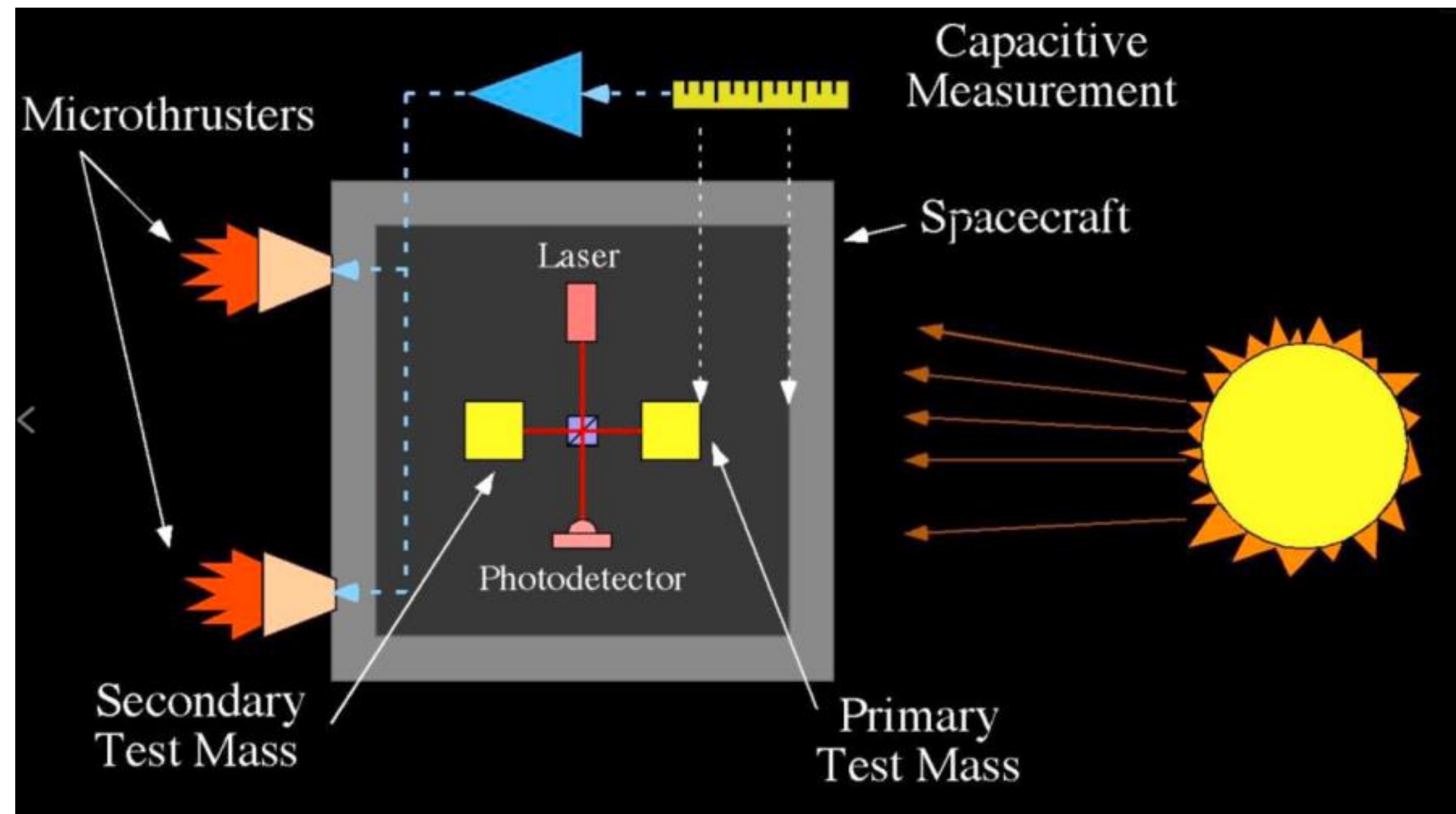
SEISMIC ISOLATION FOR EINSTEIN TELESCOPE

OMNISENS CONCEPT

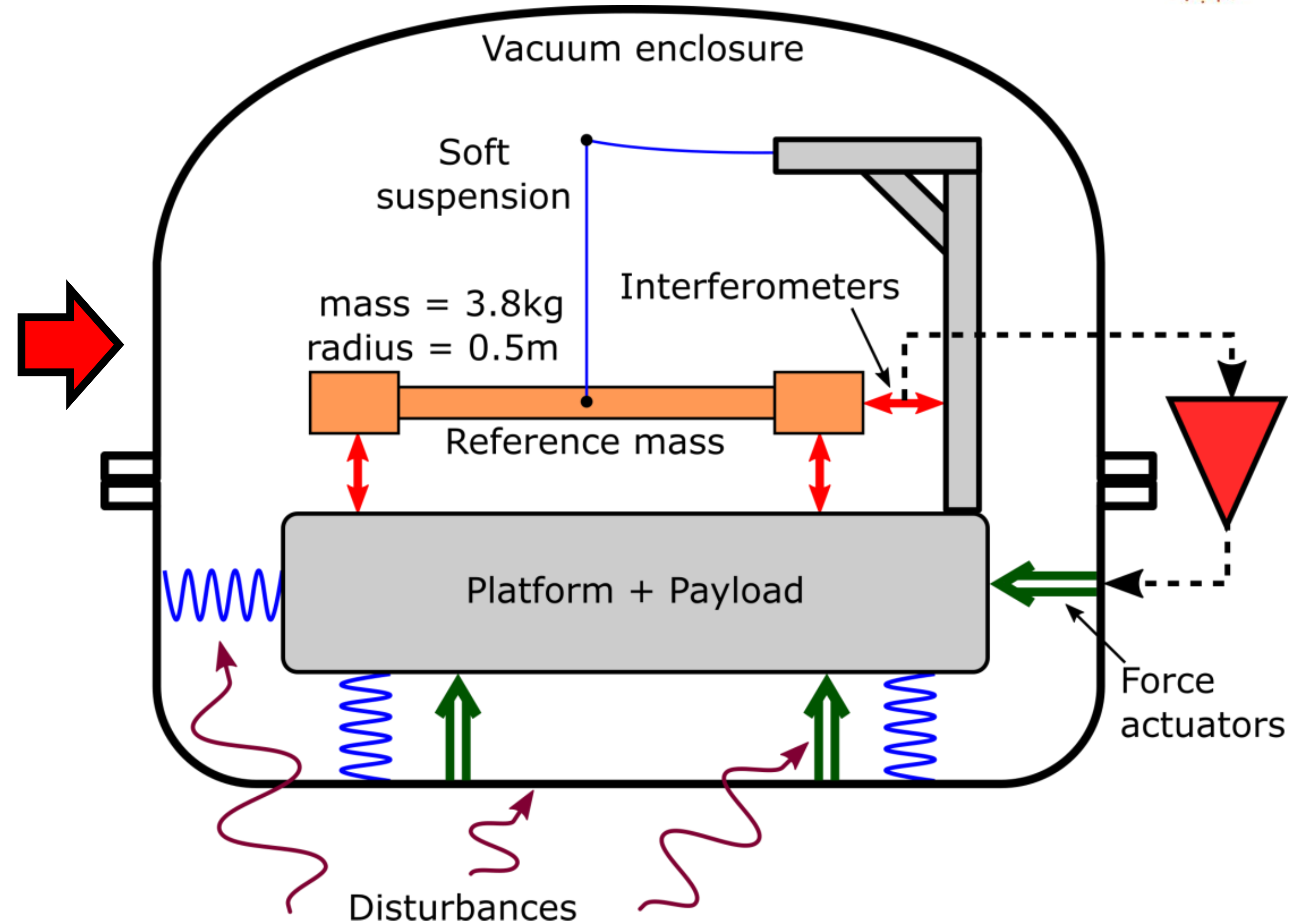
CREDIT: CONOR MOW-LOWRY

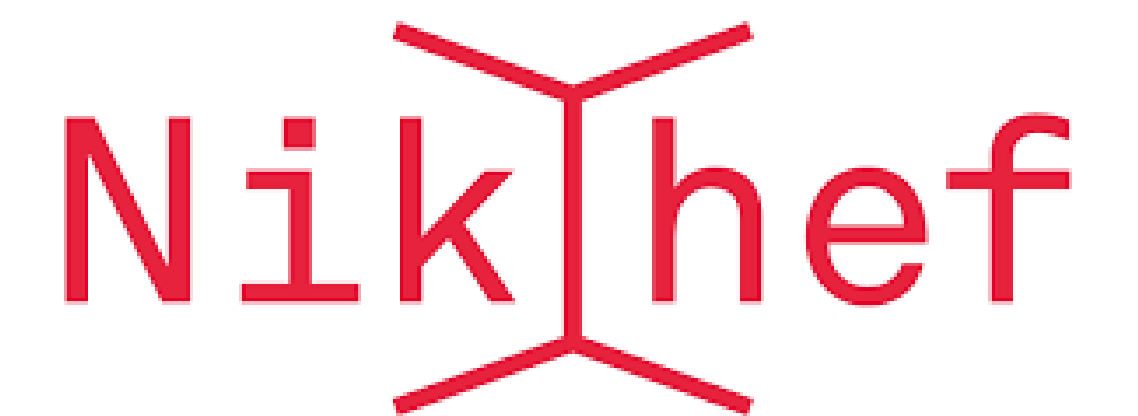
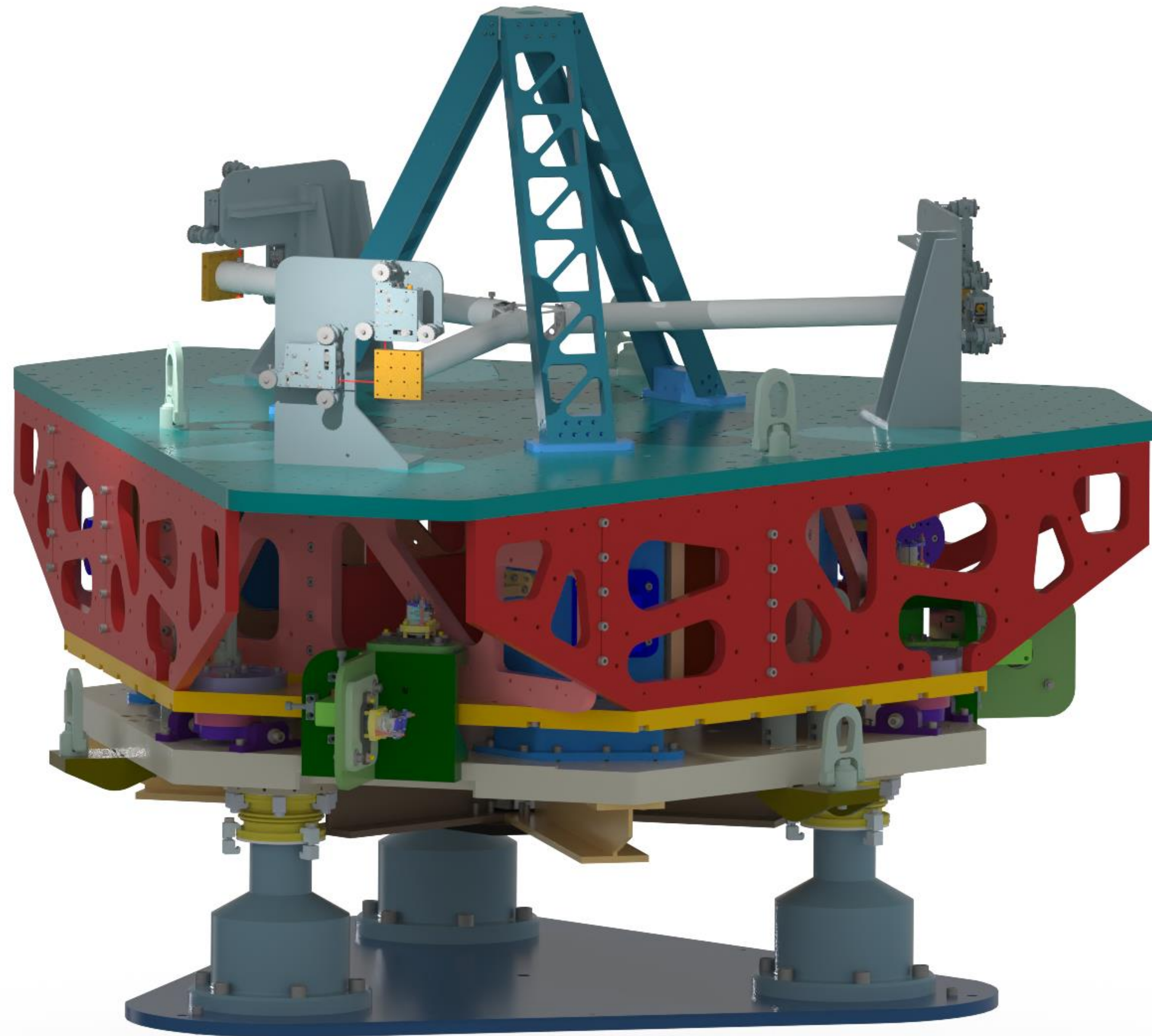


...A SORT OF TERRESTRIAL DRAG-FREE CONTROL



DRS WORKING PRINCIPLE – IMAGE: NASA/JPL

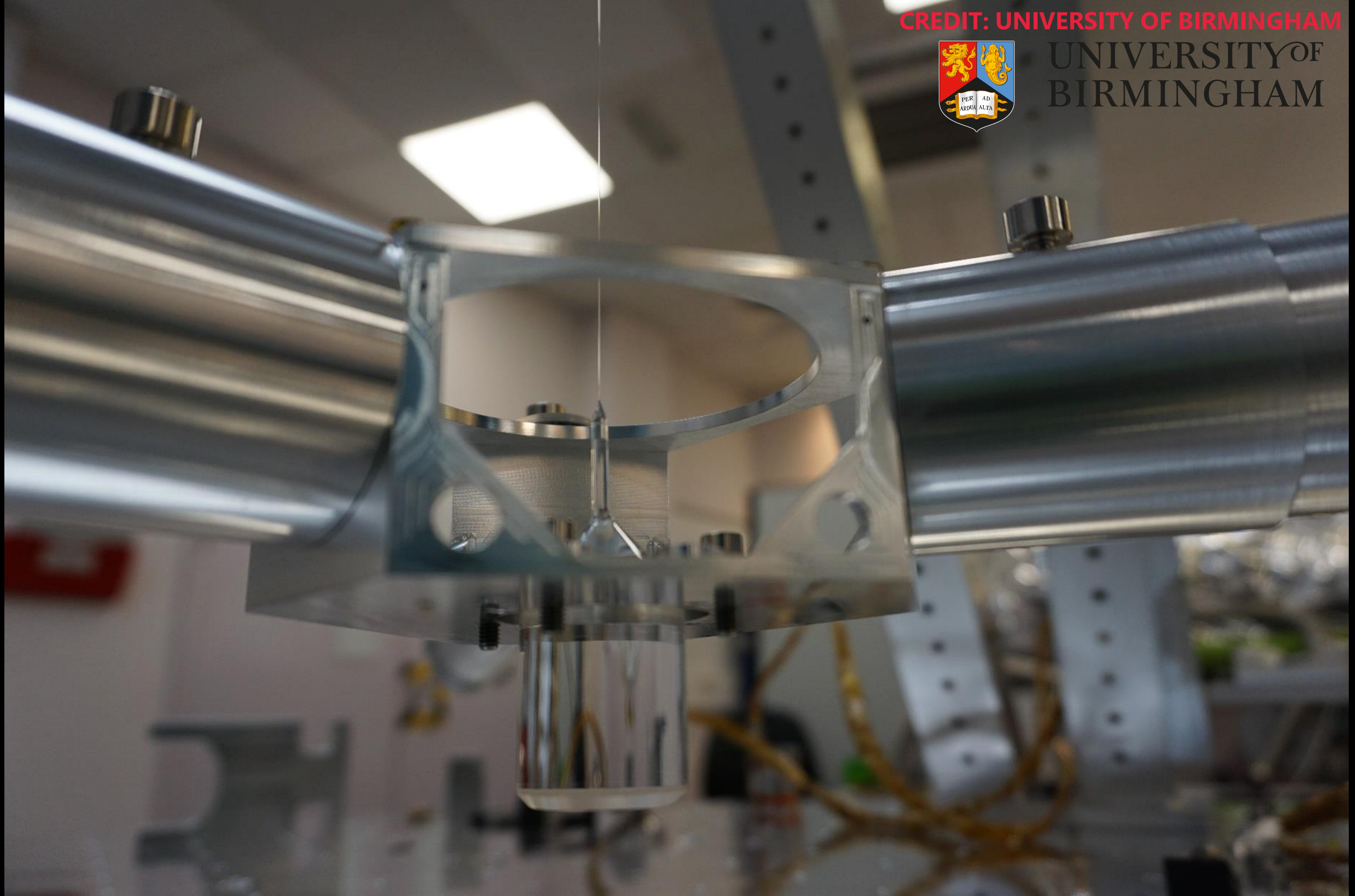




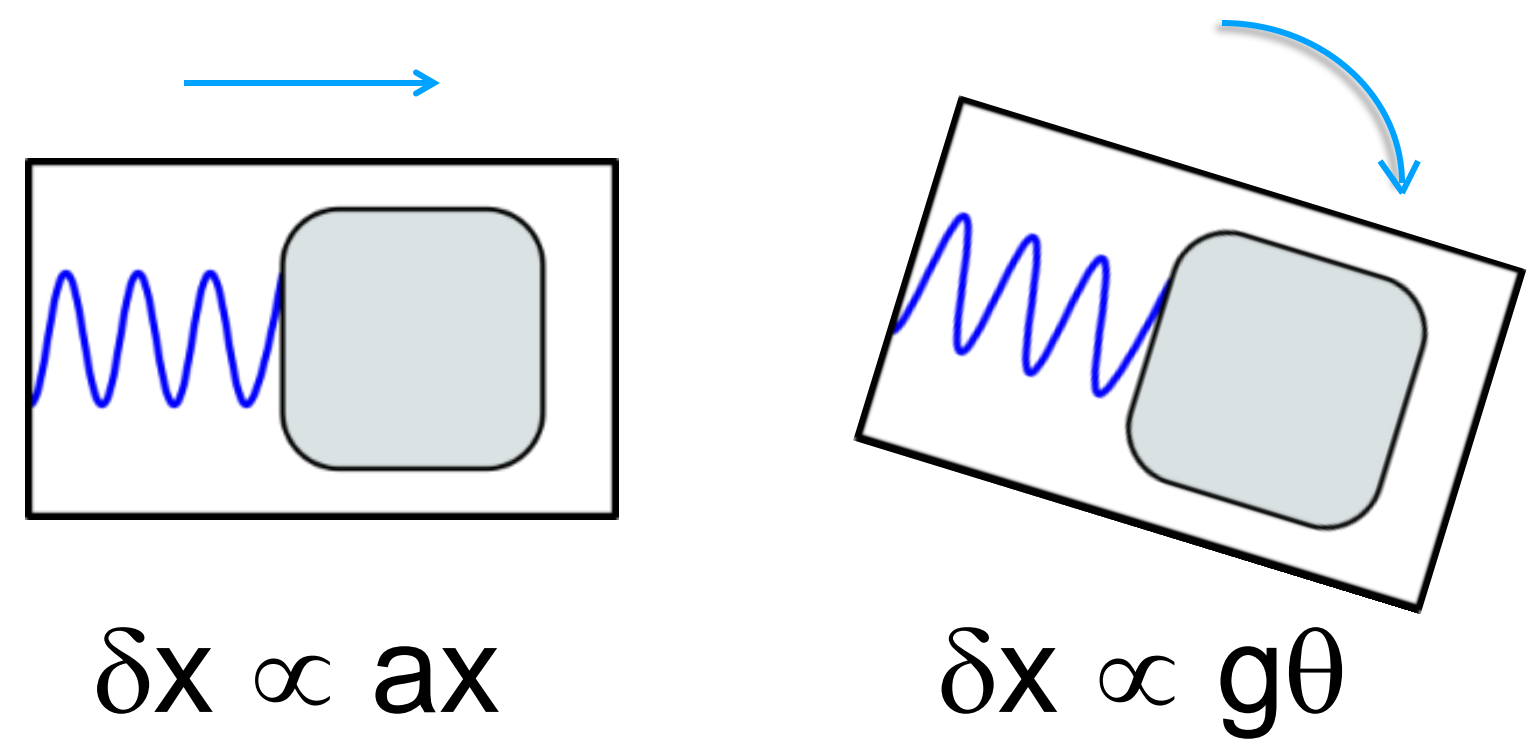
CREDIT: UNIVERSITY OF BIRMINGHAM



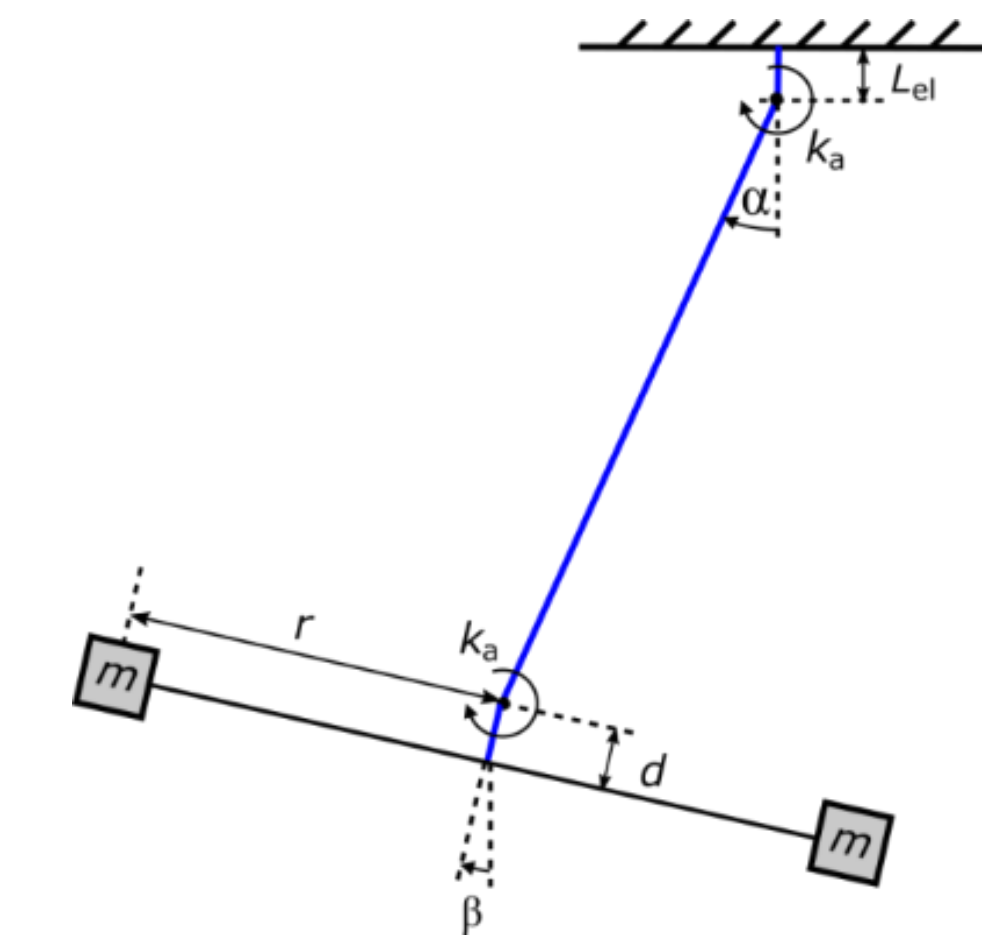
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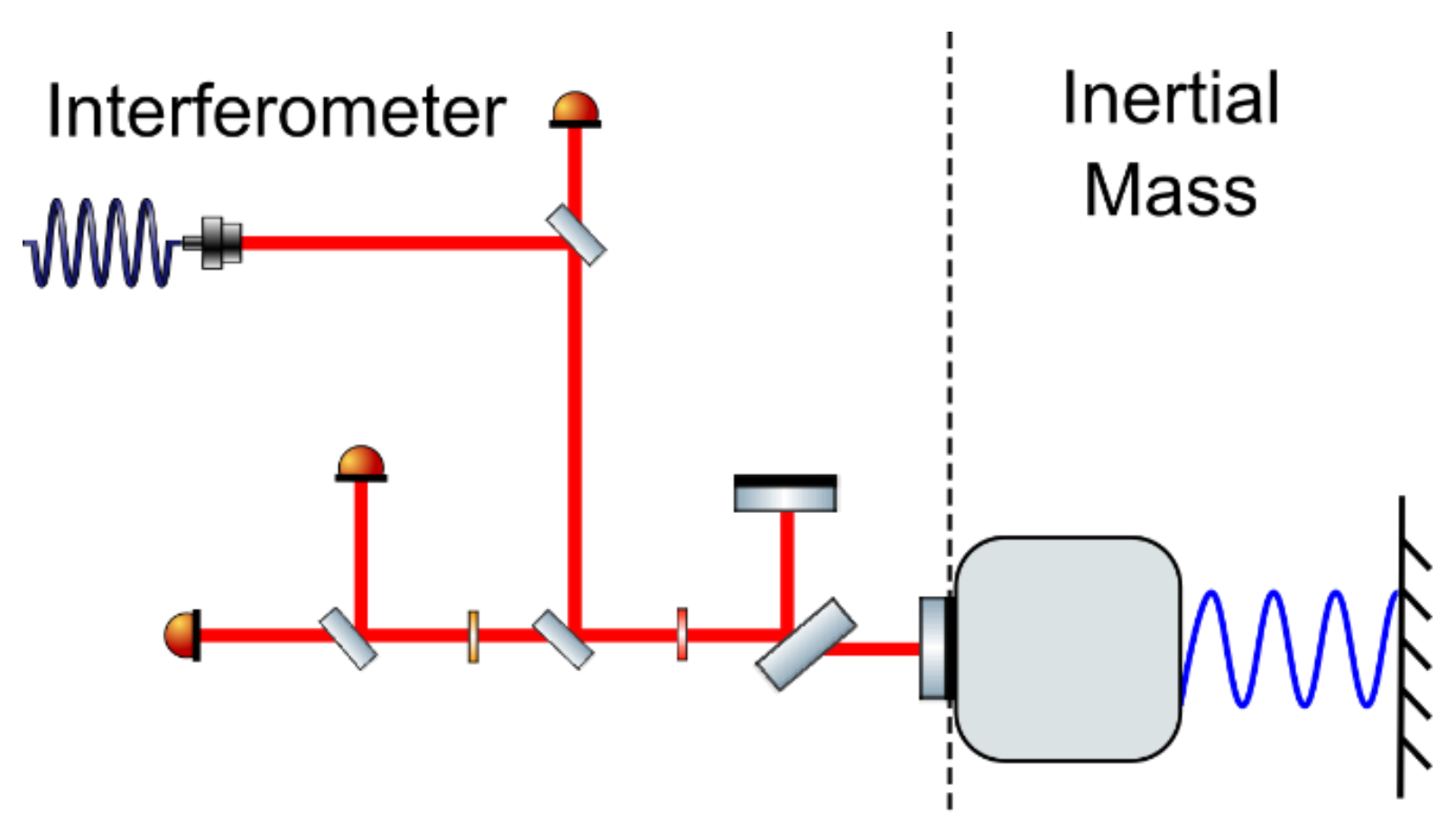
Tilt-to-Horizontal coupling



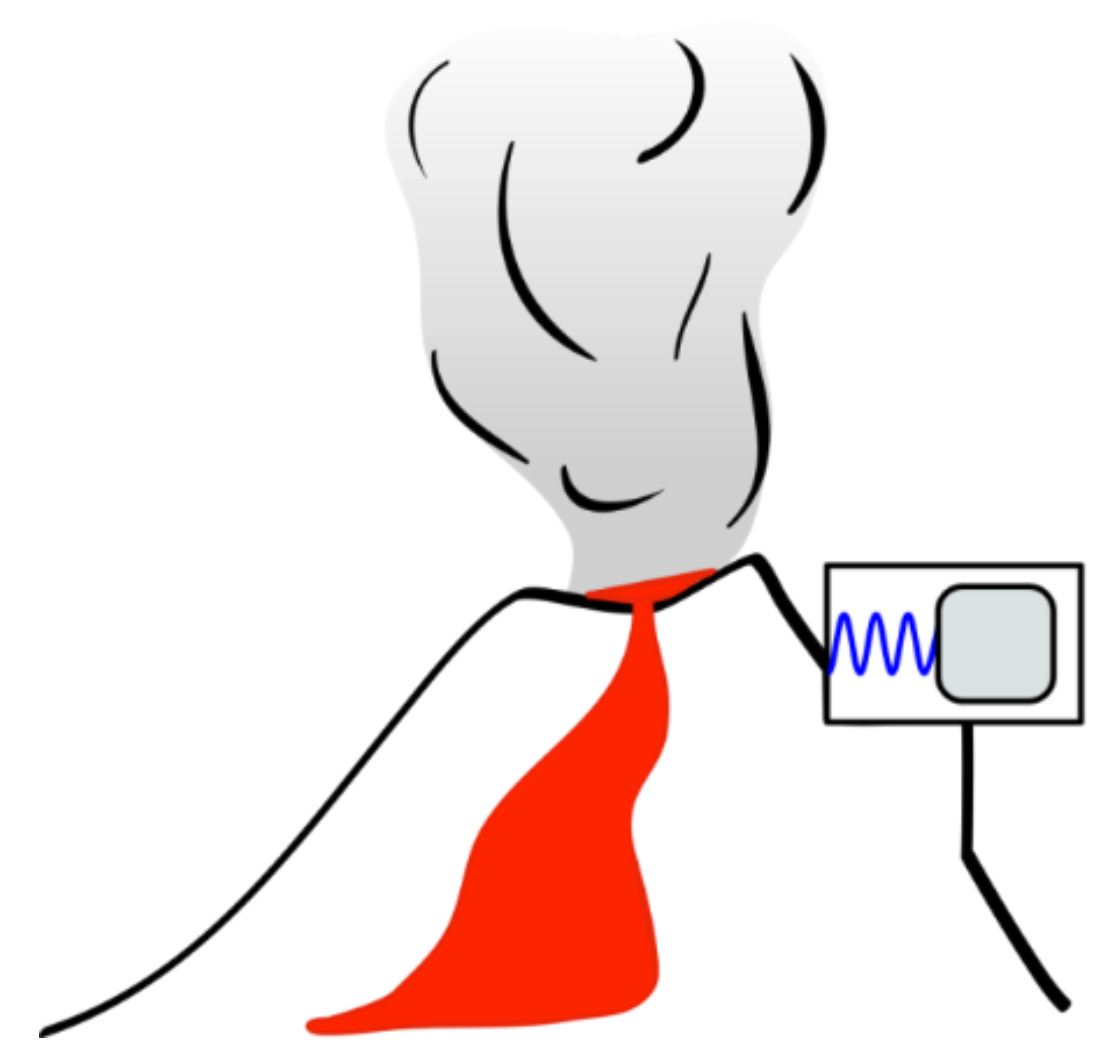
Mechanical cross-coupling



Sensor/actuator noise

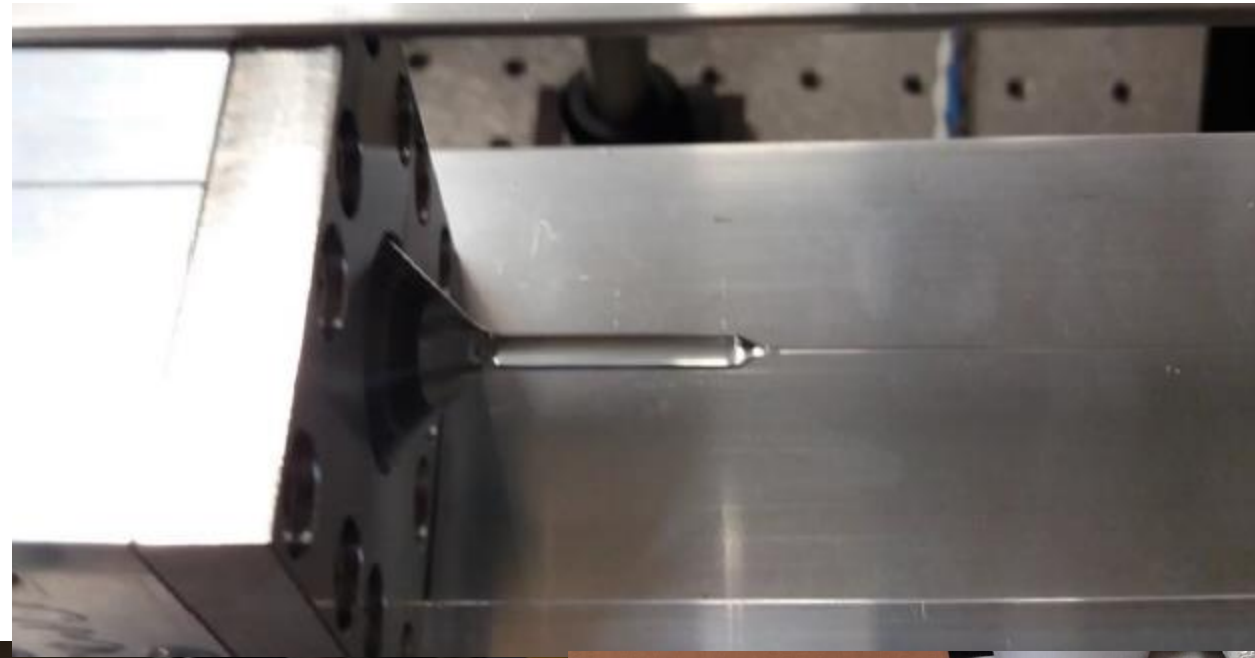


Dynamic range



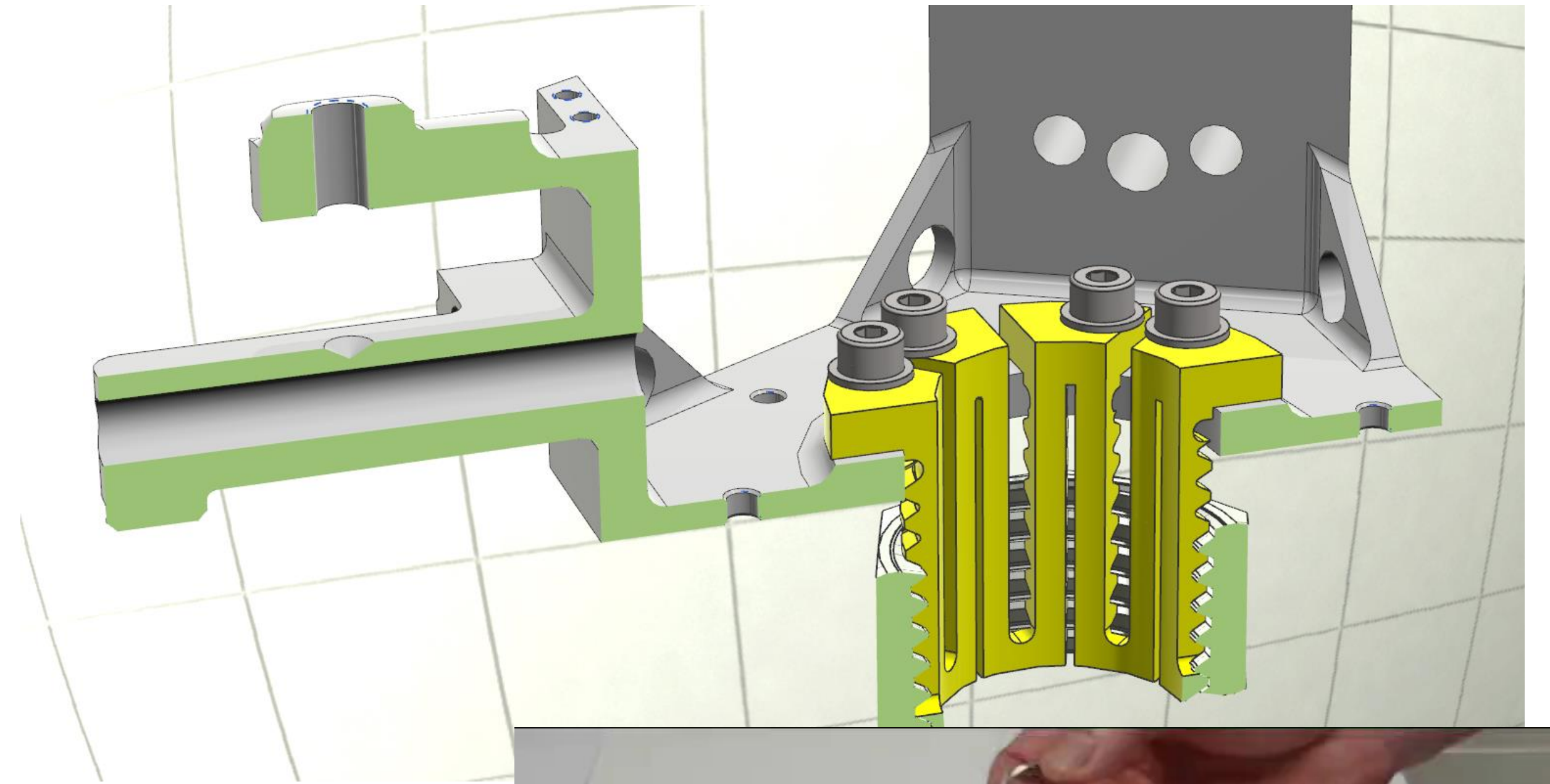
CREDIT: ALAN CUMMING

FIBERS PULLED @ GLASGOW



CREDIT: MARTIN ADAMS

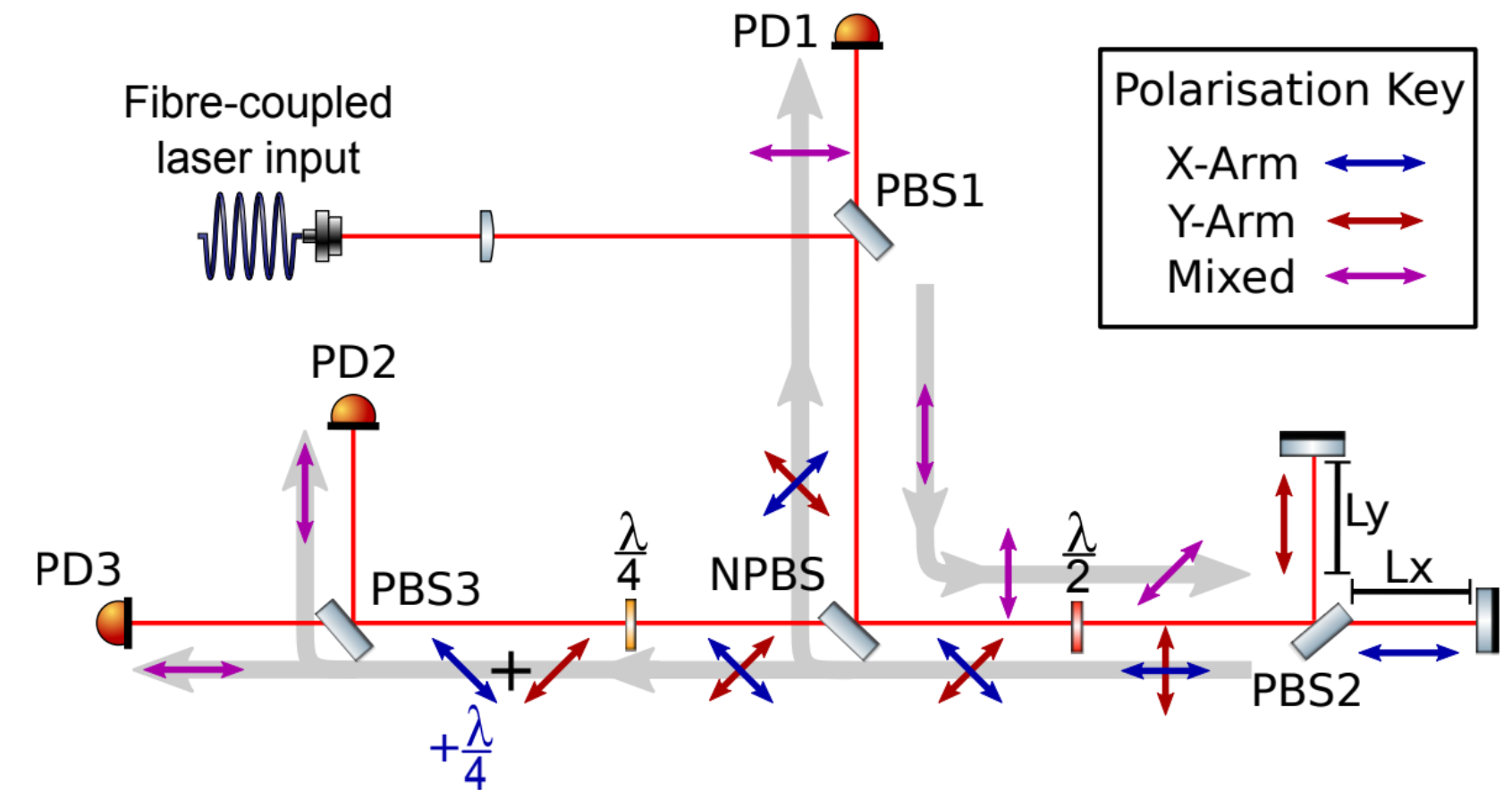
GLASS METAL INTERFACE



HOQI FOR READOUT

Homodyne Quadrature Interferometers

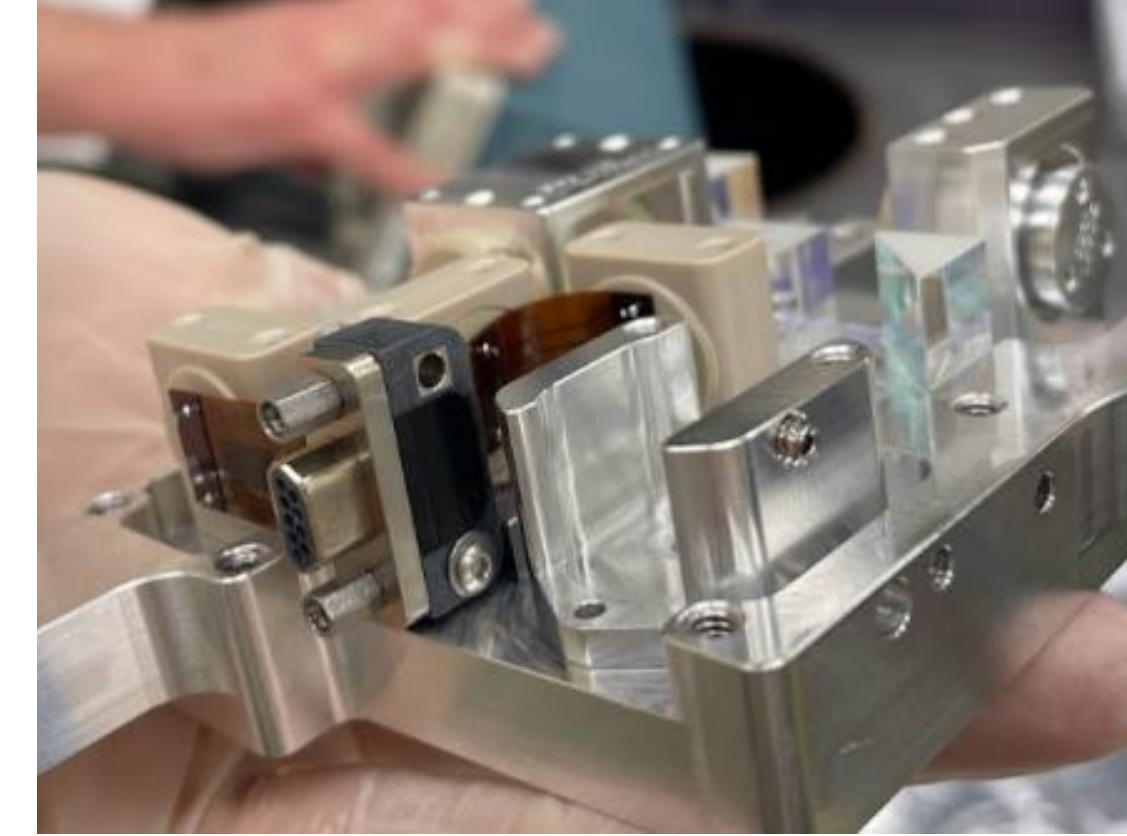
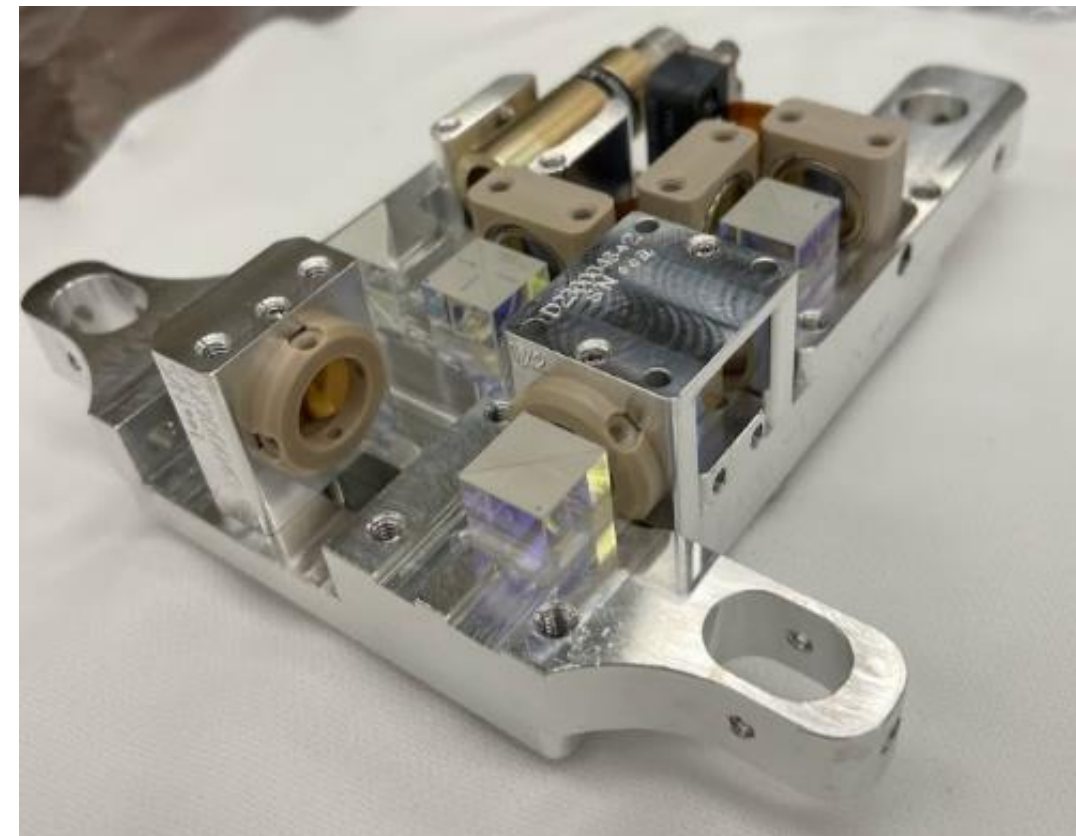
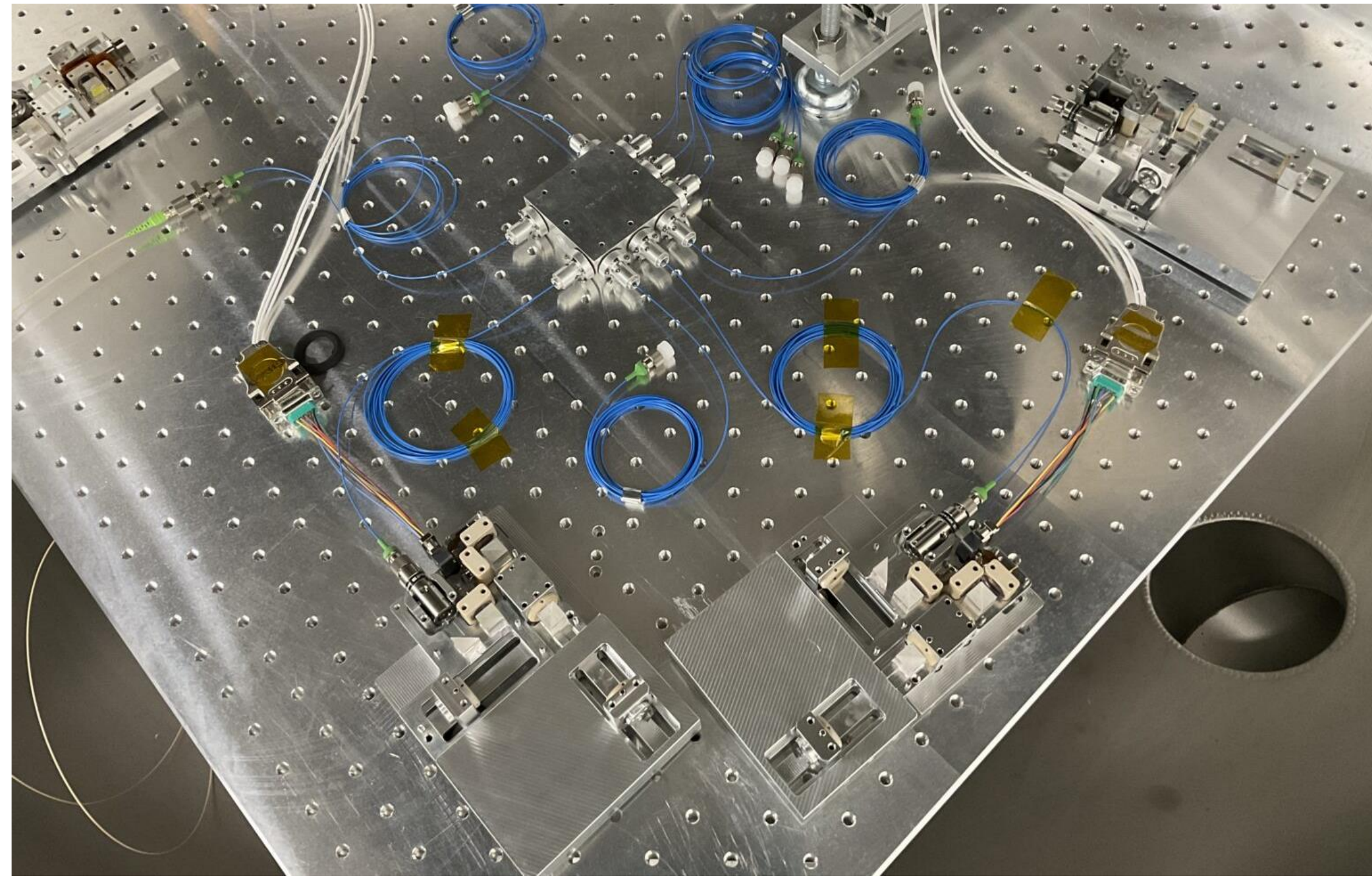
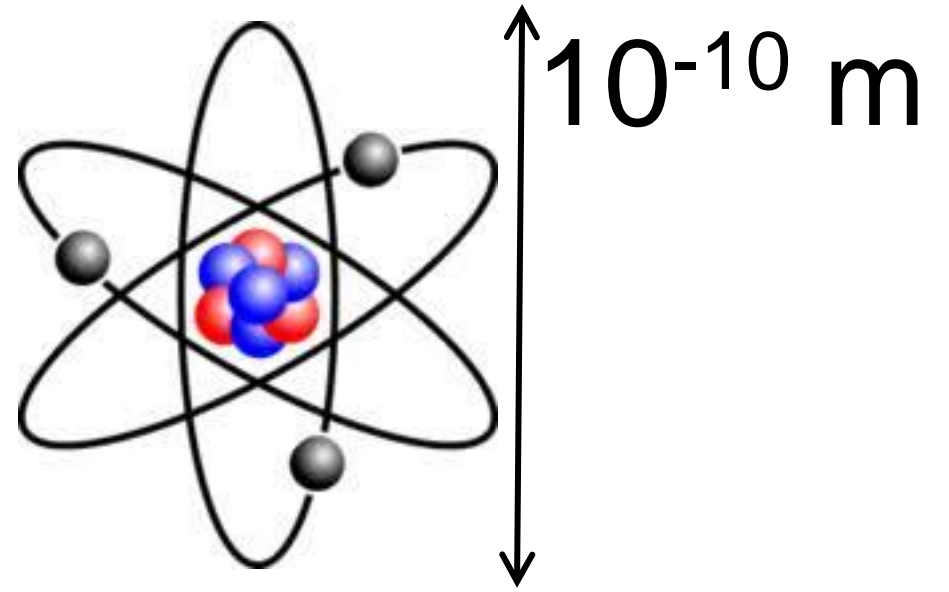
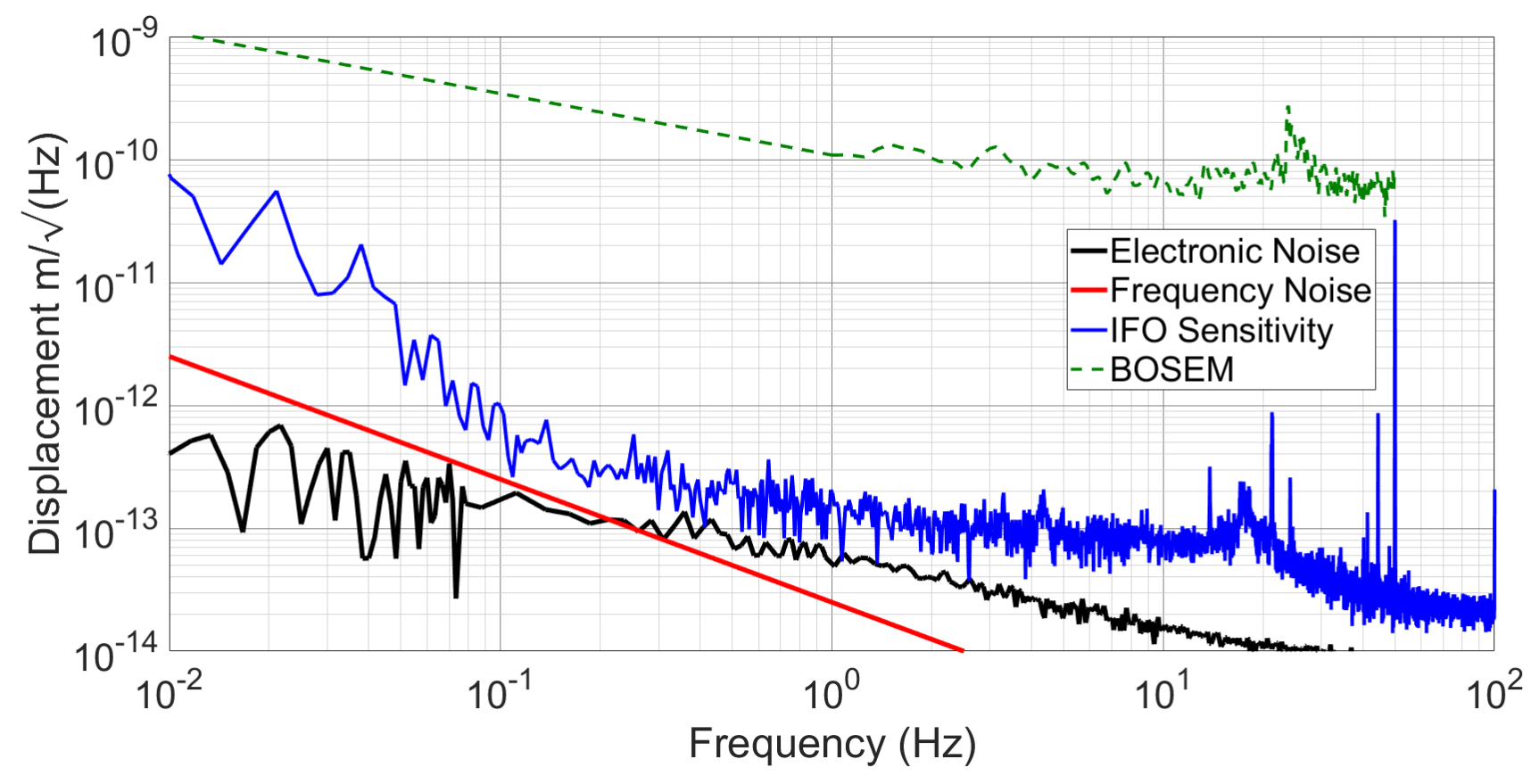
noise hunting / optimizing the performance



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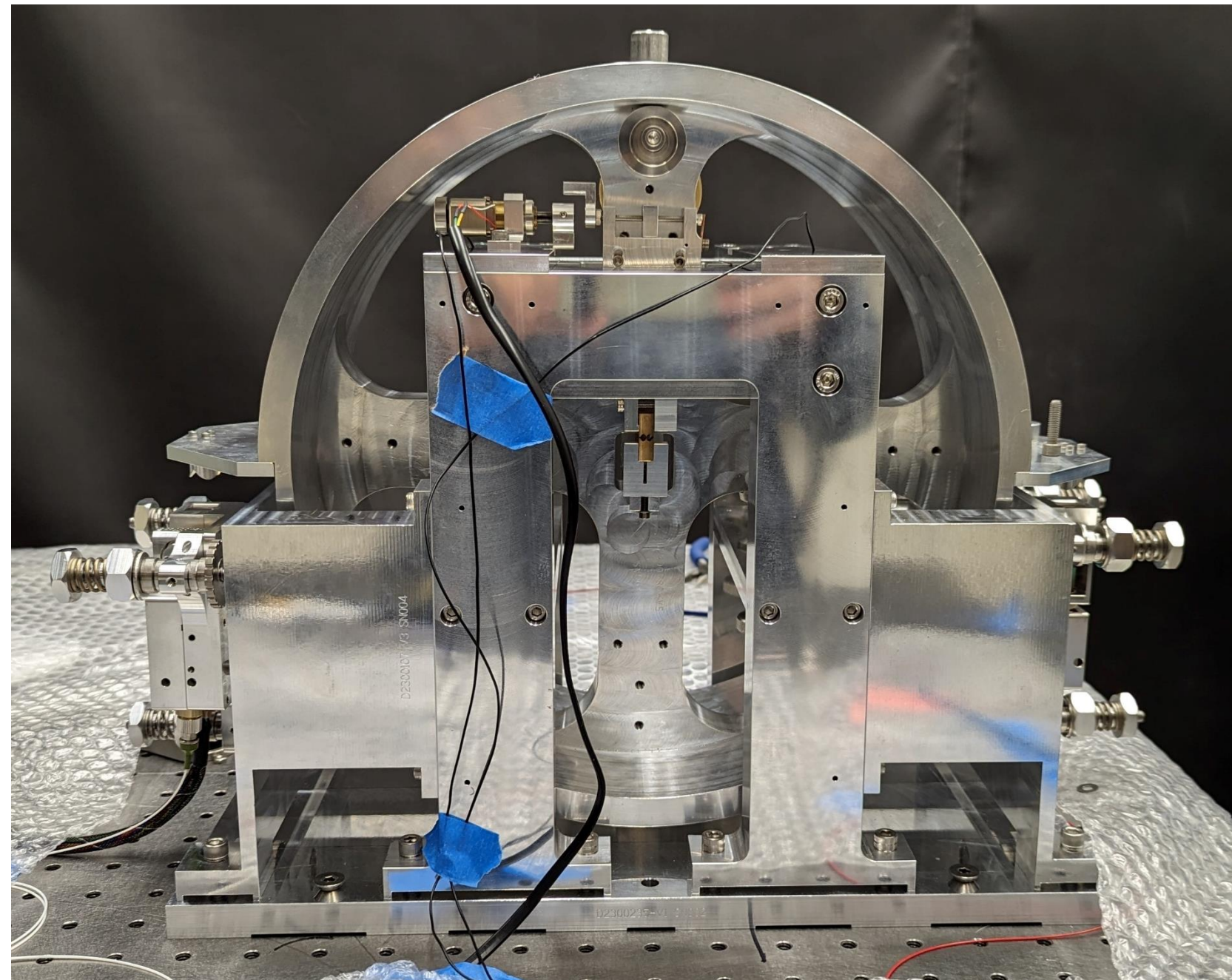
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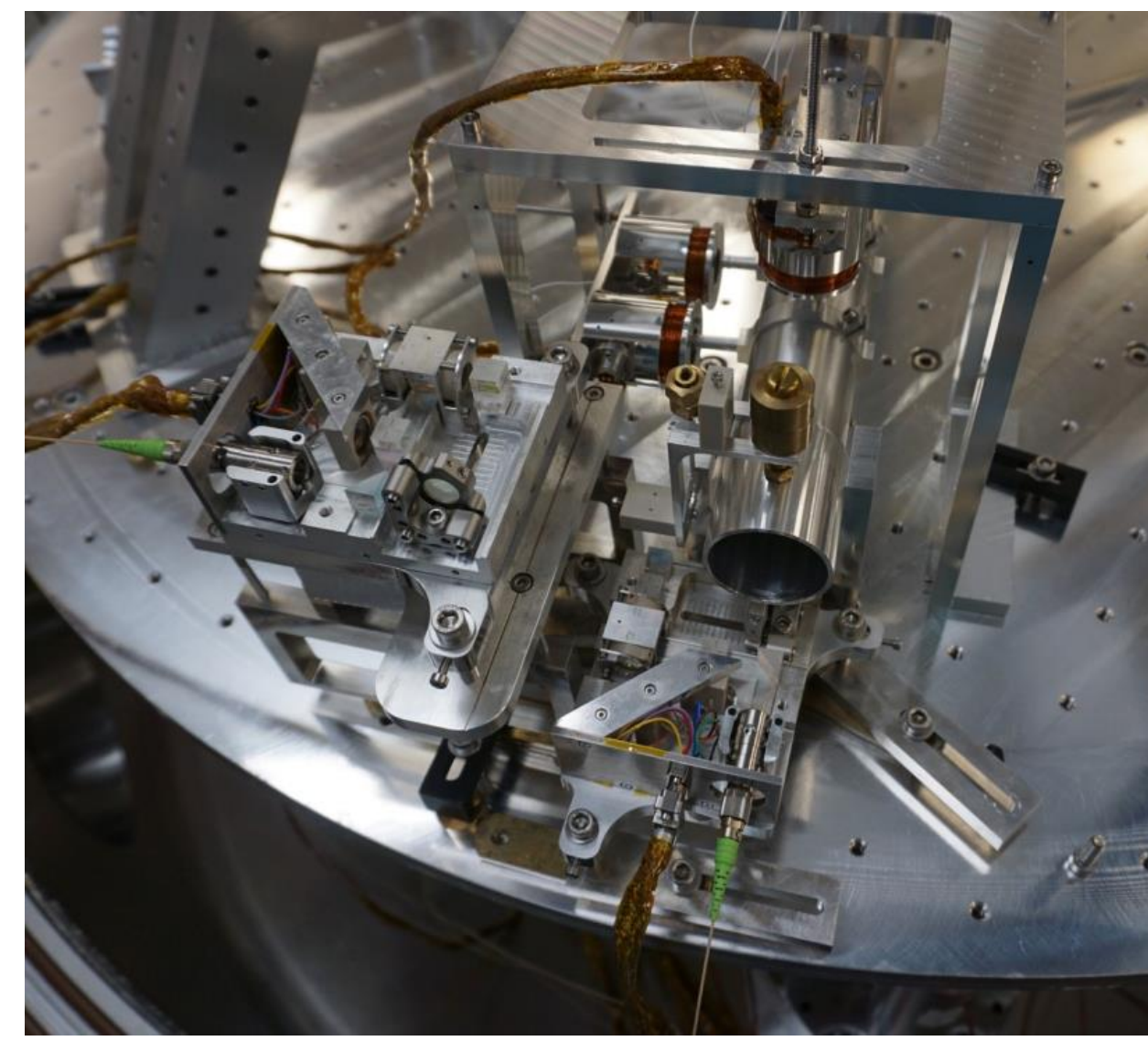


COOPER ET AL., CQG 35 095007 (2018)
[HTTP://IOPSCIENCE.IOP.ORG/ARTICLE/10.1088/1361-6382/AAB2E9/META](http://iopscience.iop.org/article/10.1088/1361-6382/AAB2E9/META)

HoQIs around the world ...

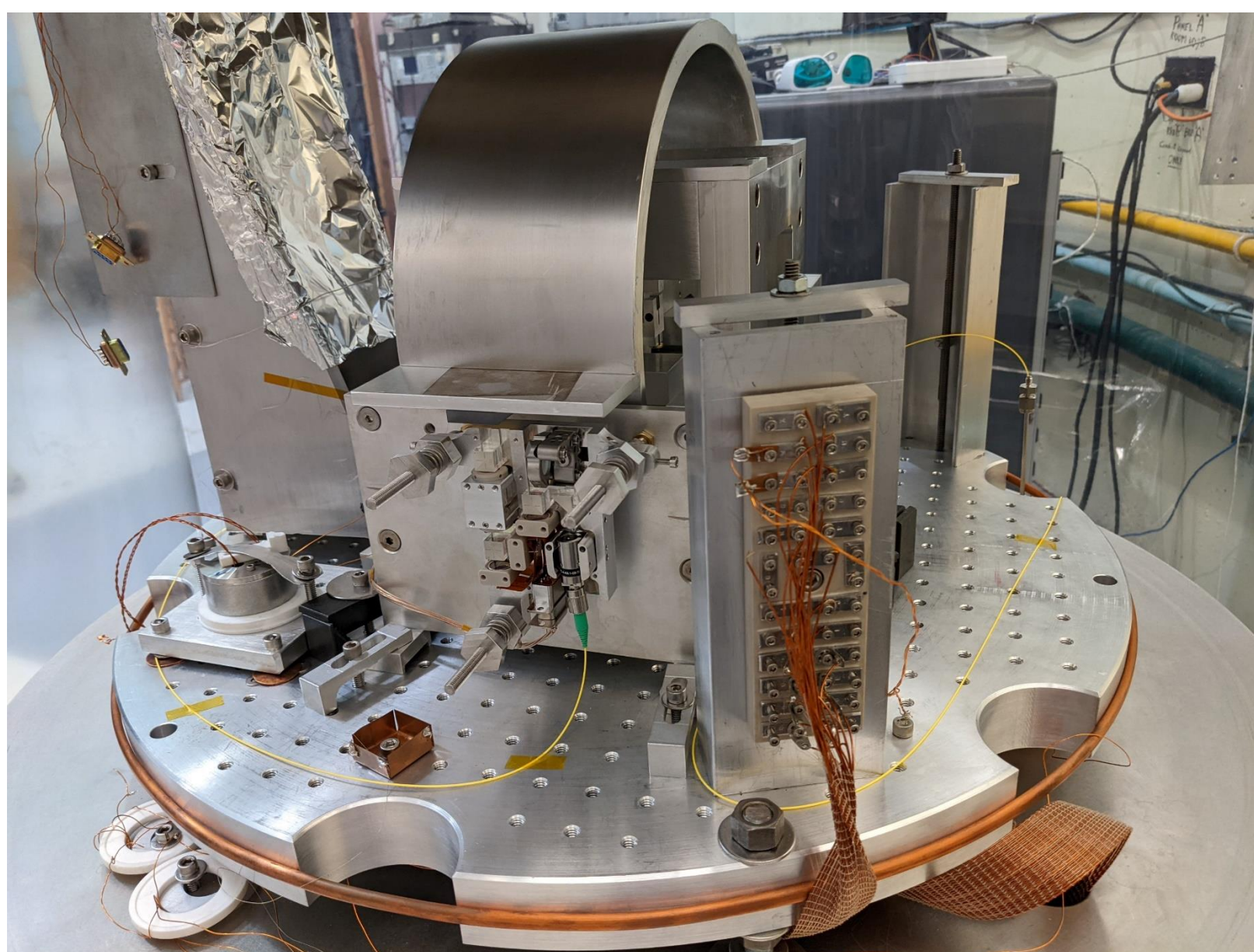


Cylindrical rotation sensor readout at CALtech

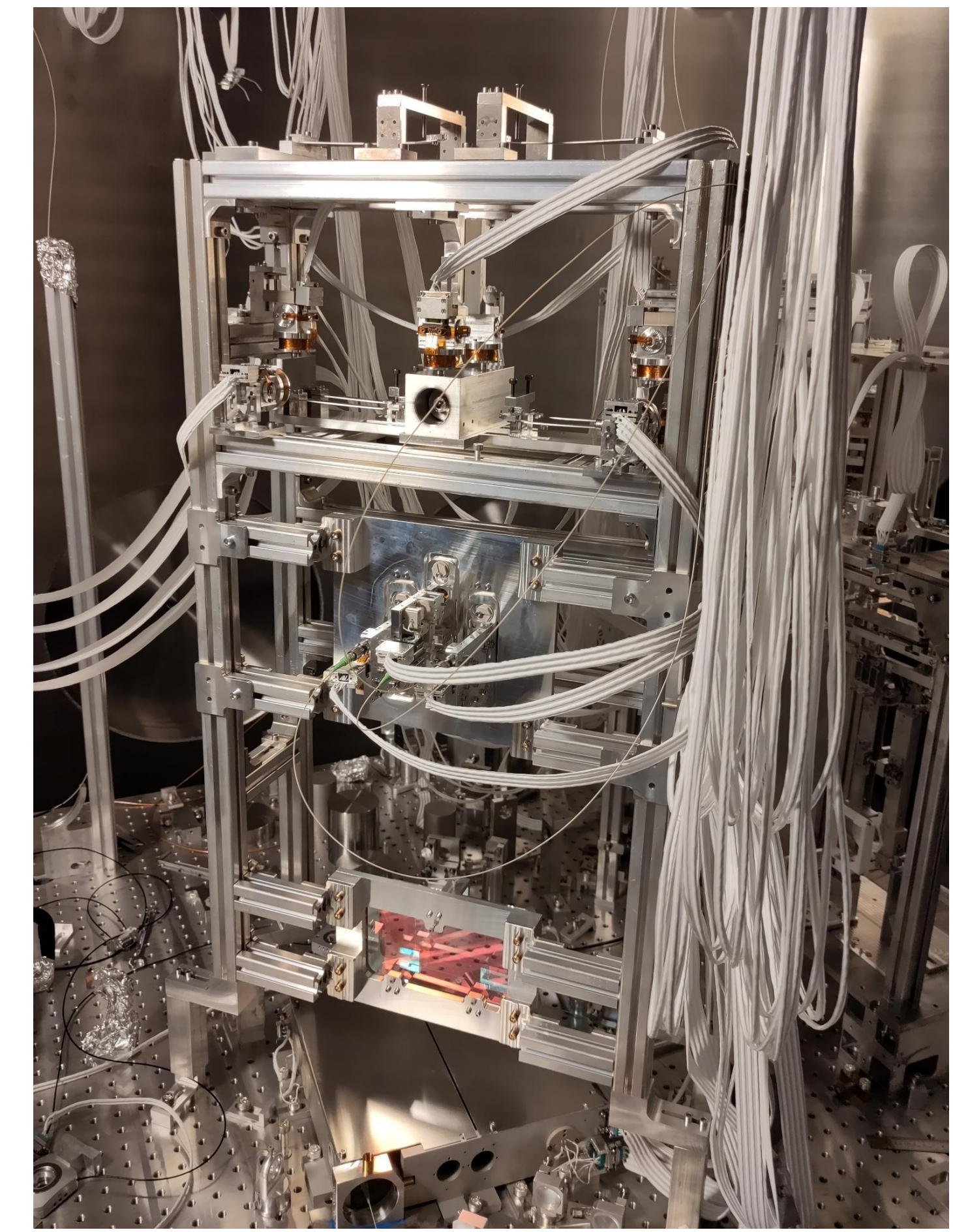


Readout of Birmingham 6D experiment

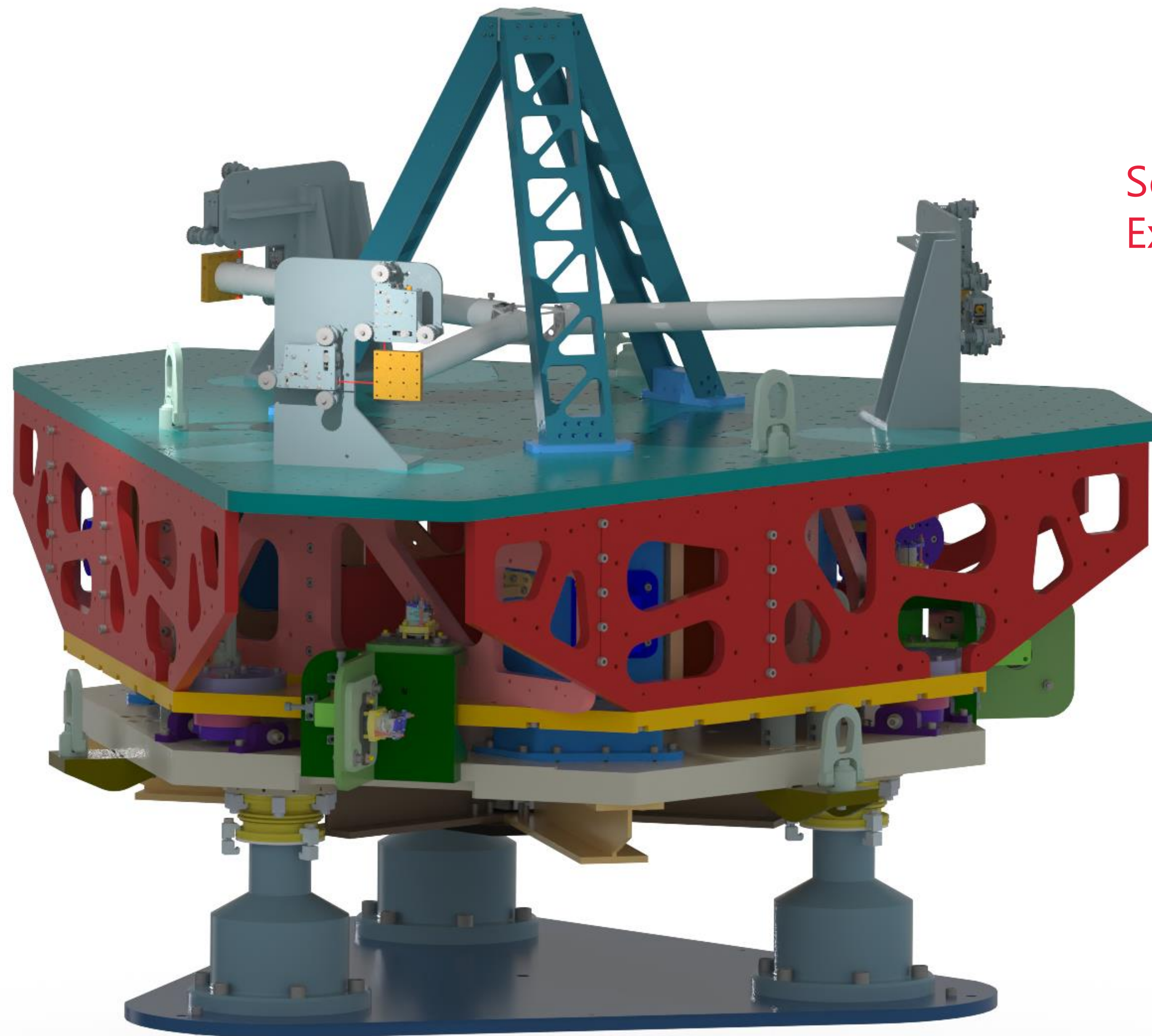
<https://dcc.ligo.org/LIGO-G2300542>



Cylindrical rotation sensor readout at UW



Measuring IM in AEI 10m prototype beamsplitter suspension⁹



Seismic Isolation platform ordered,
Expecting first parts to arrive late January

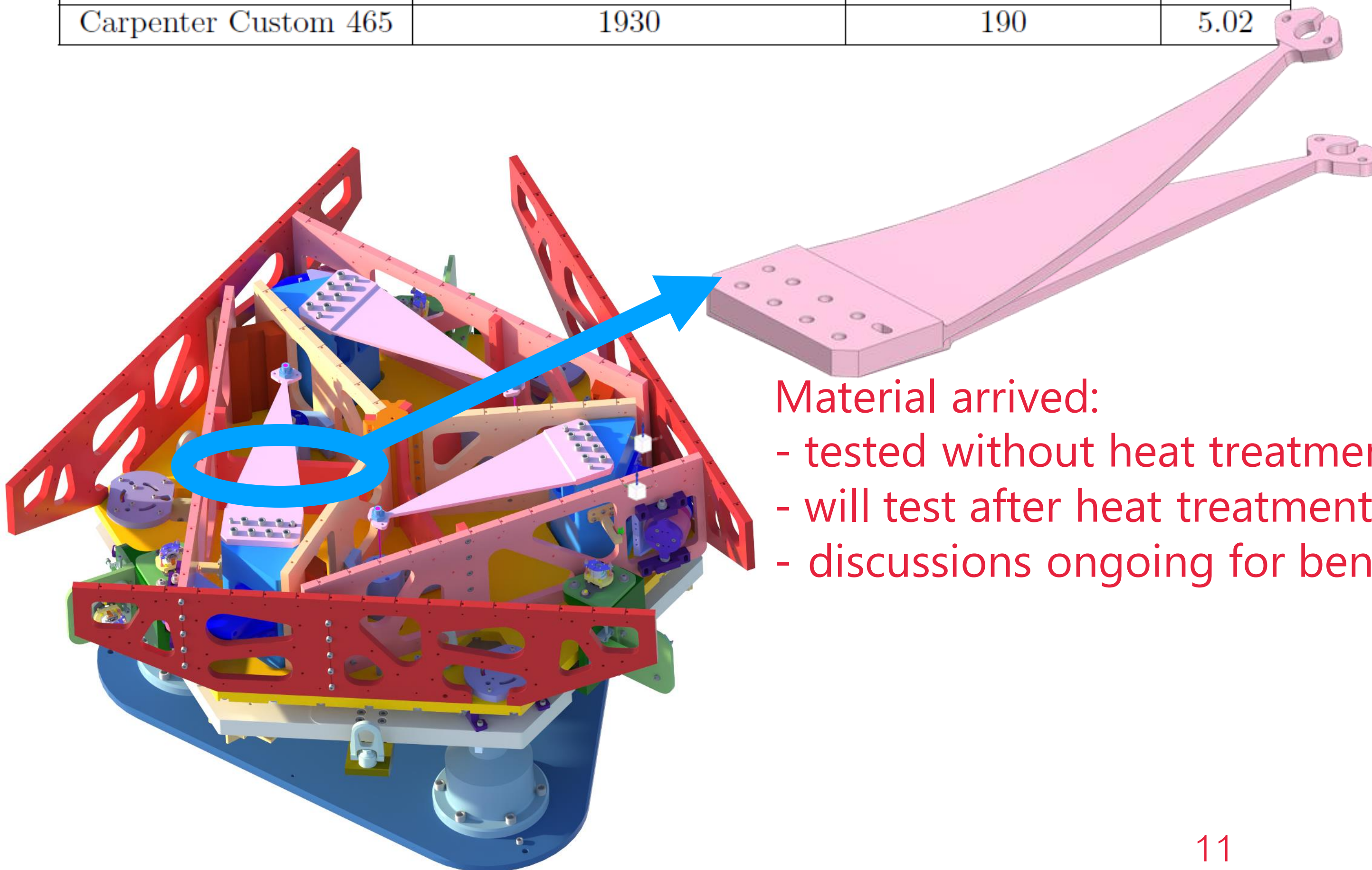


SEISMIC ISOLATION FOR EINSTEIN TELESCOPE

OMNISENS PROTOTYPE

Titanium grade 19 Beta-C

Material	Typical Ultimate Tensile Strength, σ [MPa]	Youngs Modulus, E [GPa]	$E^2/\sigma^3 \times 10^{-6}$
Maraging Steel	1800	190	6.19
Titanium Grade 19	1300	120	6.55
Carpenter Custom 465	1930	190	5.02

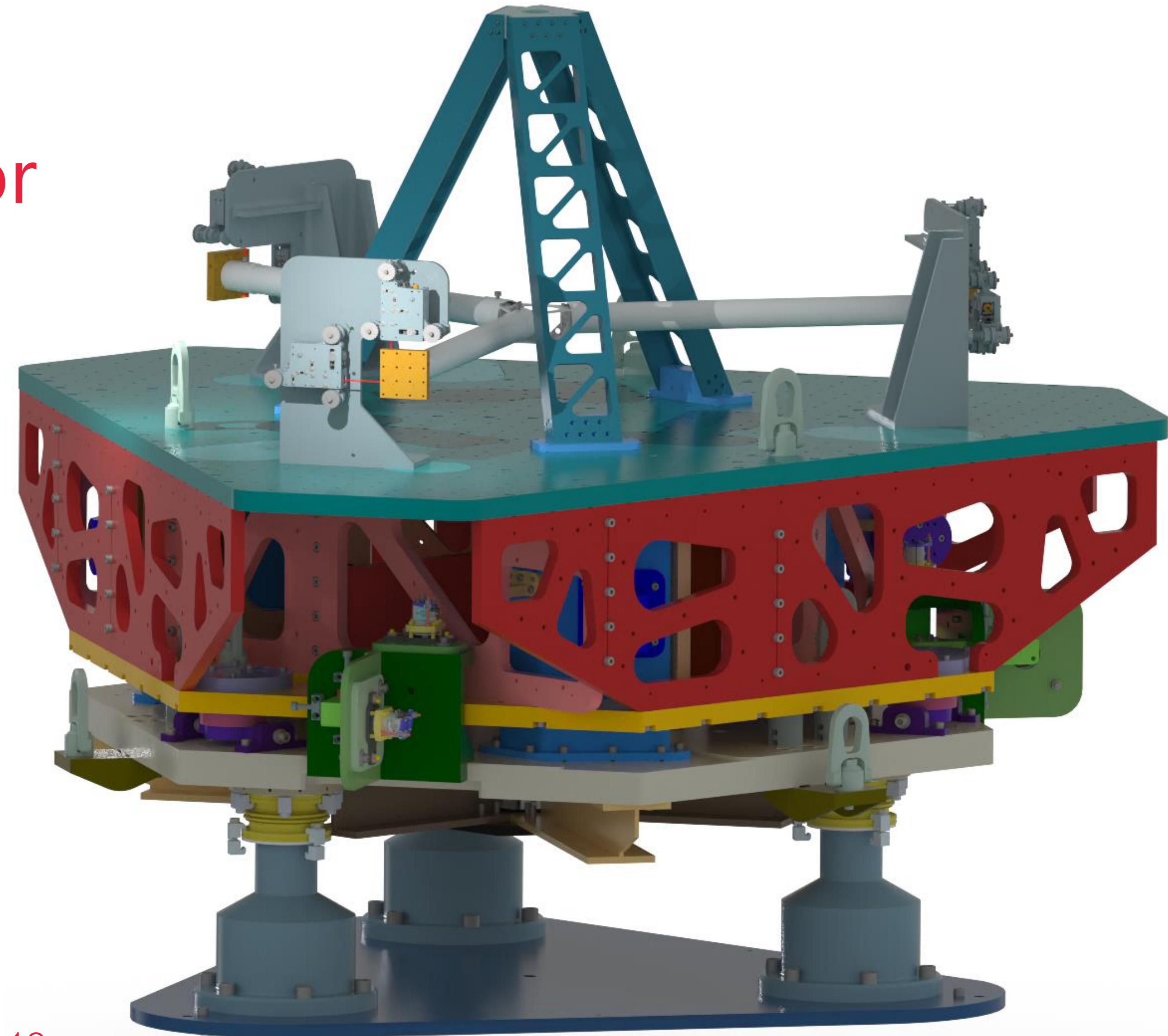


Material arrived:

- tested without heat treatment
- will test after heat treatment
- discussions ongoing for bending

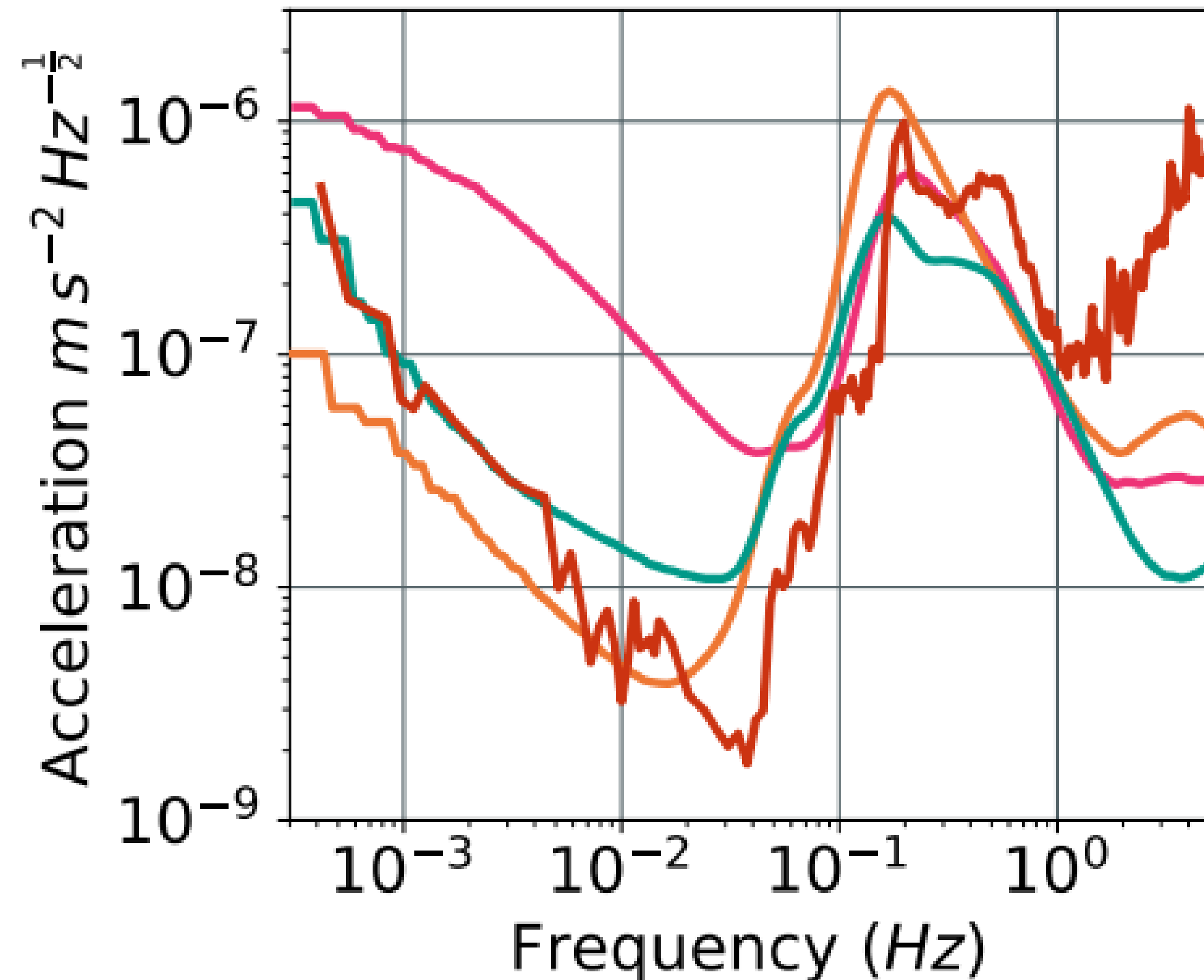


Do we need active isolation for
The Einstein Telescope?



SEISMIC MOTION AT BOREHOLES

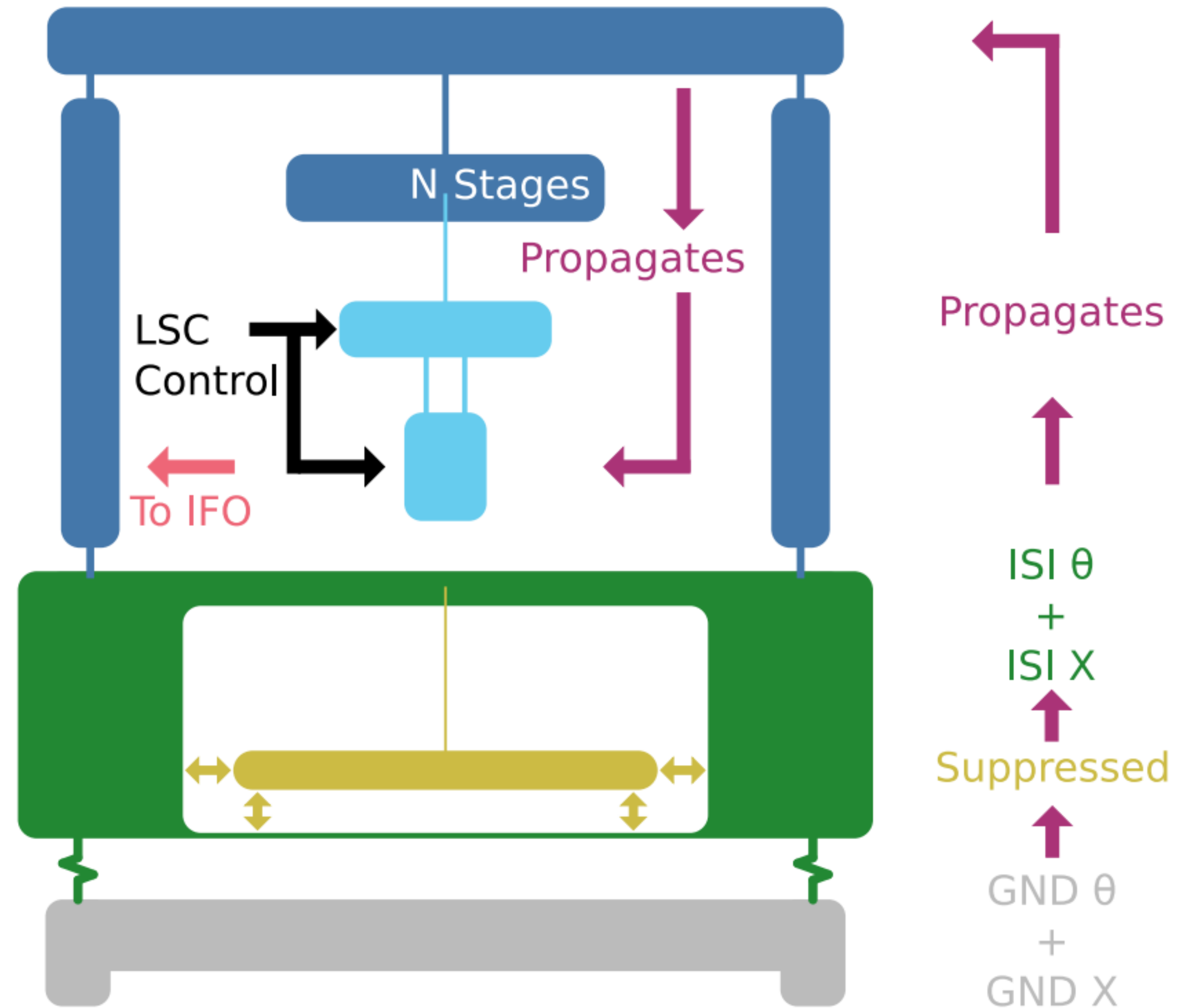
LNGS Terziet Sos Enattos Hanford (no wind)



- Boreholes/seismic vaults are NOT representative of Seismic spectra for large ventilated caverns.
- For analysis worst case LNGS spectrum is used.

MODELLED SYSTEM

- LNGS ground spectra.
- 6D ISI pre-isolation.
- Suspension model used:
 - 9m Virgo.
 - 12m ET.
 - 17m ET-LF.



POSTER ON MODELLING & CONTROL OF OMNISENSE / 6D

By Pooya Saffarieh



OmniSens/6D modelling and control

Pooya Saffarieh (p.saffarieh@nikhef.nl)
Jesse van Dongen, Nathan Holland, Alexandra Mitchell, Michele Valentini, Armin Numic, Conor Mow-Lowry

Introduction:
6D is a seismic isolation system consisting of an actuation bench "ISI", HoQi interferometric sensors, a pendulum-like reference mass, and other components.
Each subsystem has a noise characteristic expressed as linear correlation/power spectral density (PSD).
To gain a complete understanding of the whole system and how noise and signal interplay, we need a mathematical model.
Here you can see the modelling and control scheme.

Modeling:
We use state space which are linear Markovian models. By working out the Lagrangian for each system (A matrix), input couplings (B and D matrix), and sensing geometry (C matrix) we can build a multi-input multi-output (MIMO) state space model.
State Space
 $\dot{x} = Ax + Bu$
 $y = Cx + Du$
Transfer function matrix
 $H(s) = C(sI - A)^{-1}B + D$

General control block:
Here you can see an abstract block diagram representation of whole system. Each block is a MIMO state space model.
Diagram showing ISI, Reference Mass, Control Filter, and Blending filters. Inputs include BOSEM noise, Ground motion, Coil actuation, HoQi noise, and Electrostatic Noise. Outputs include HoQi signal and Coil actuation.
B matrix for reference mass which models how different sources of noise like thermal noise interacts with the dynamics.

Optimal control:
The diagram shown in the left has many "free variables". By changing noise budgets we get a different blending filter variables and control filter variables.
Given a cost function, e.g RMS of platform motion - H2 norm - or H-infinity norm of platform response, we can obtain an optimal set of variables that minimize the cost.
 $\|G(s)\|_{\infty} = \max_{\omega} \sigma(G(j\omega))$
You can see the optimal blending filter using H-inf method contains frequency domain dynamical features of each source of noise.

Noise projections:
Here by employing a hierarchical control scheme we can first stabilize the angular control loop and then use the residual angular motion to stabilize the horizontal loop.
On the left you see the angular noise budget. The total noise on the left is used again by taking into account angular to horizontal coupling to calculate the closed loop horizontal noise budget.

Future work:
Transitioning to a comprehensive 6D full MIMO optimal control system is what we want to explore next. We aim to explore the efficacy of optimal control in system design, particularly when dealing with more intuitive macroscopic cost functions and considering the interconnected subsystem models. In such cases, optimizing filter parameters or providing motivation for hardware design becomes interesting.

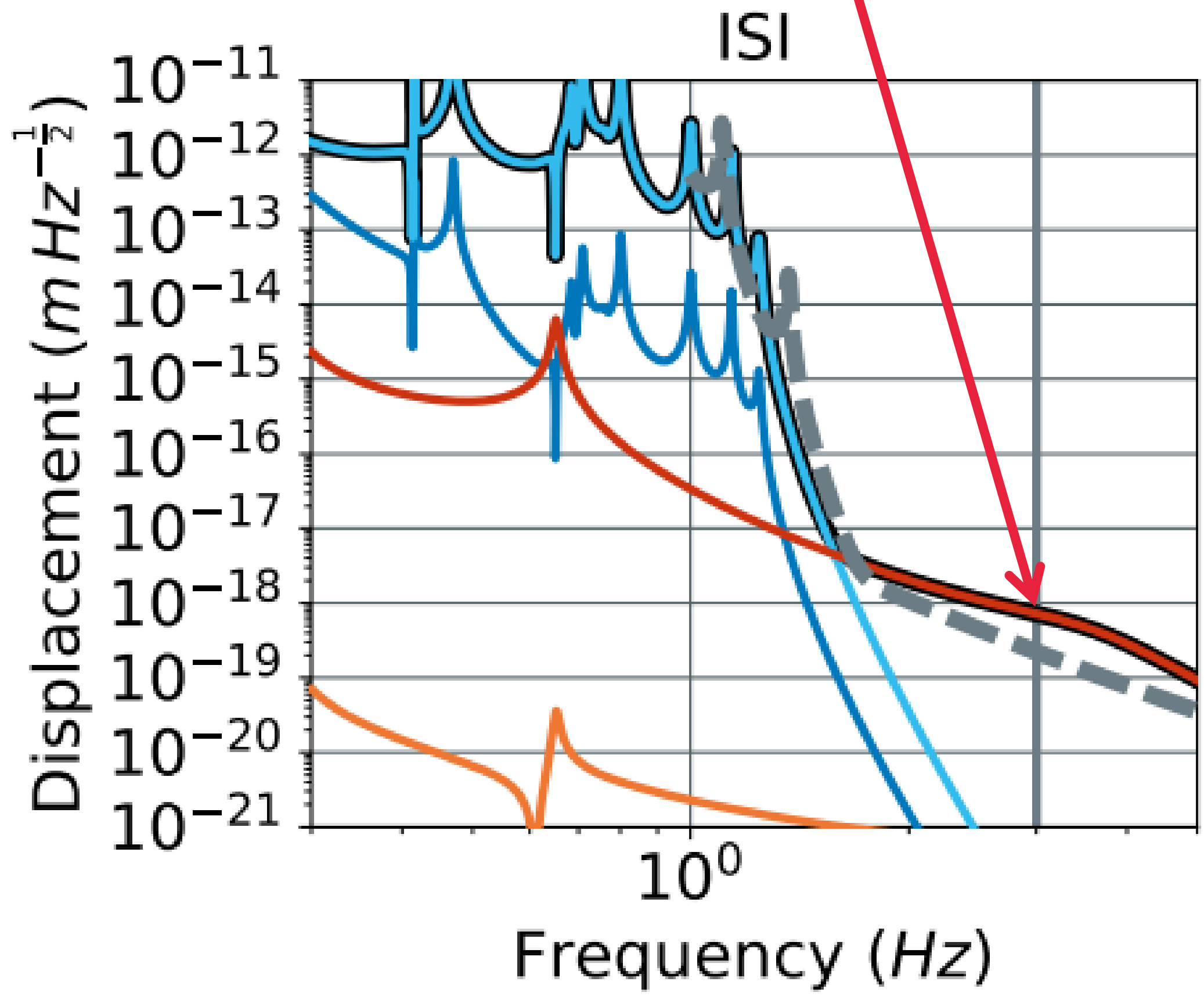
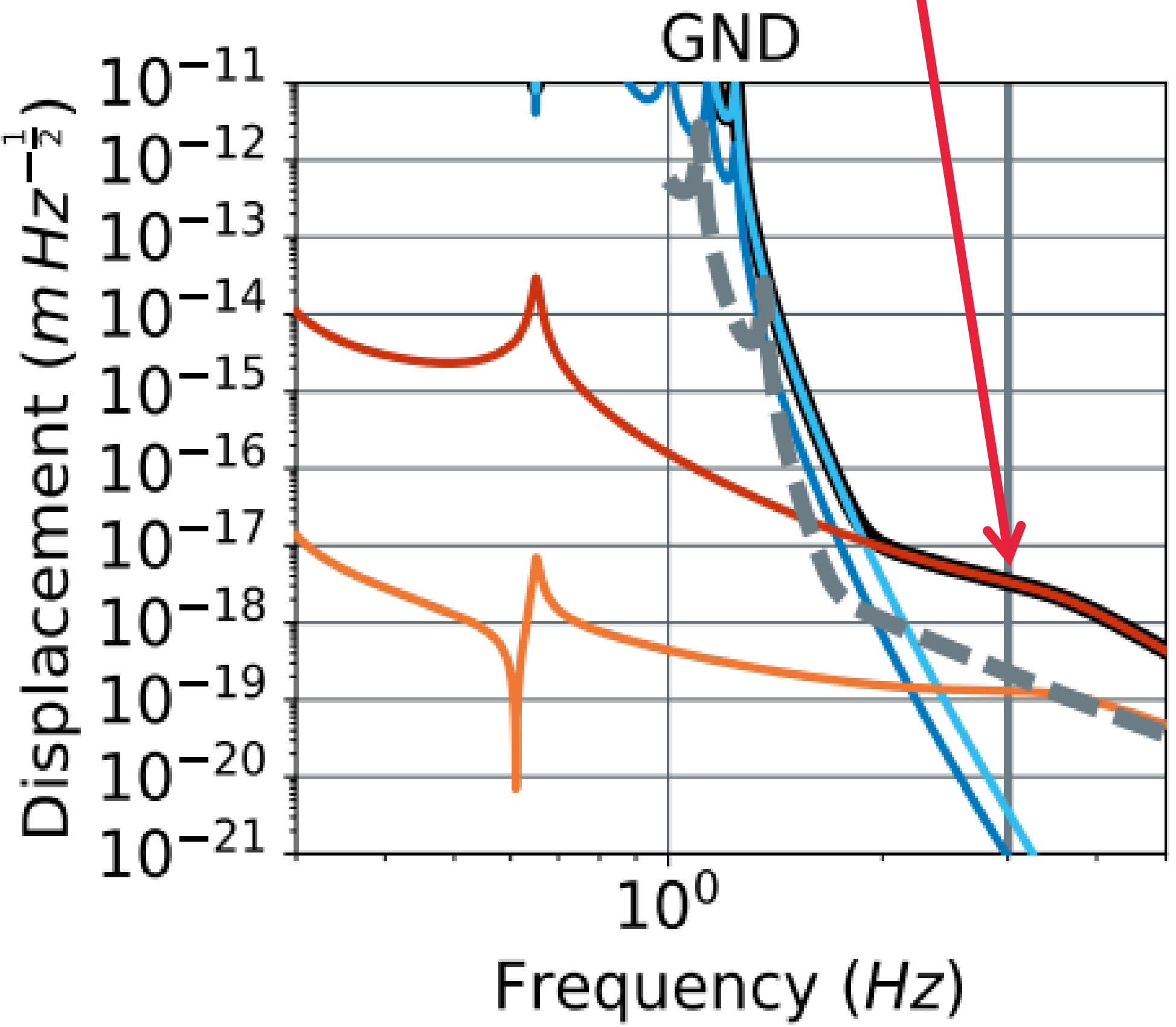
References:
1- A 6D Interferometric inertial isolation system, C M Mow-Lowry and D Martynov 2019 Class. Quantum Grav. 36 245006
2- State-space solutions to standard H2 and H-infinity control problems, John C. Doyle, Keith Glover, Pramod P Khargonekar, and Bruce A. Francis, 1989, IEEE Transactions on Automatic Control 34 (6): 821-42.

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MODELLED RESULTS

No Active Isolation
Noise **35x** too high at **3 HZ**

With Active Isolation
Noise **8x** too high at **3 HZ**



ET-LF
Total
x (SAT)
 θ (SAT)
ACT (STG0)
ACT (STG1)

TAKE HOME MESSAGE

- The 6D experiment at Amsterdam is becoming reality soon.
- Initial extremely optimistic modelling of ET suspensions including actuation noise is not yet good enough.
- An active platform is probably needed for ET

