



Cryogenic Interferometric Inertial Sensors for next-generation Gravitational-Wave Detectors

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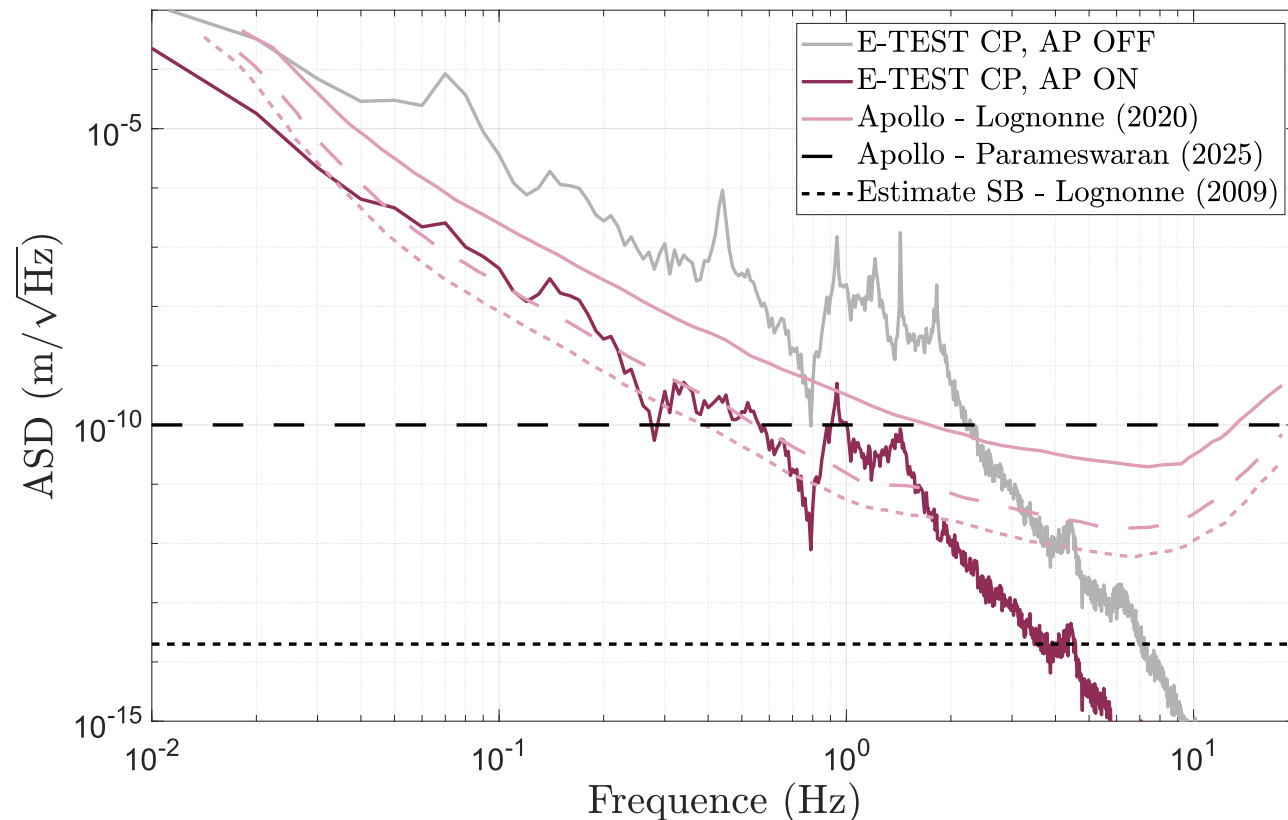


LGWA & E-TEST requirements compatibility

E-TEST is a prototype suspension, combining **passive** and **active isolation techniques**, of a **100 kg silicon mirror** cooled down **radiatively** to **25 K** in a suspended cryostat

Monitor residual motion at the last isolation stage, in the cryostat

Cryogenic compatible inertial sensors with a sensitivity of $2 \times 10^{-14} \text{ m}/\sqrt{\text{Hz}}$ from 3 Hz at **20K**



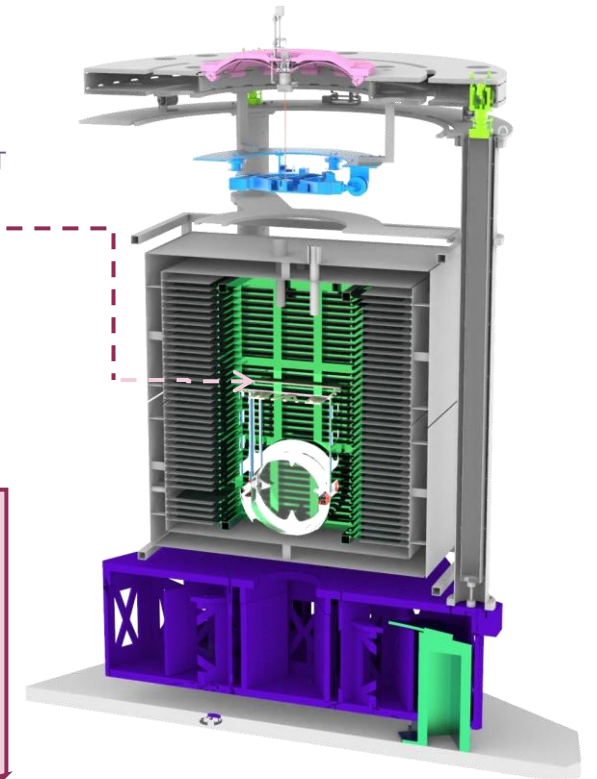
Target residual motion at E-TEST mirror level

Moon vibration estimate



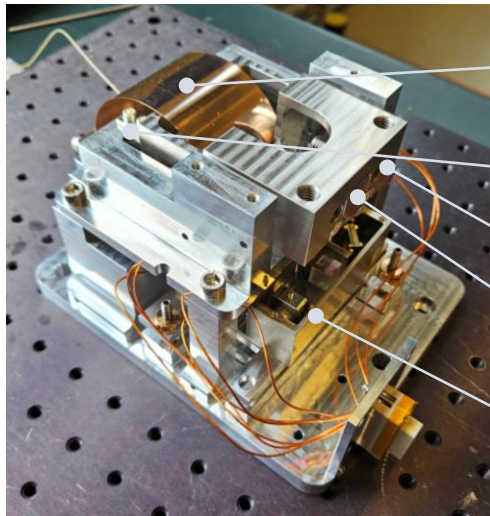
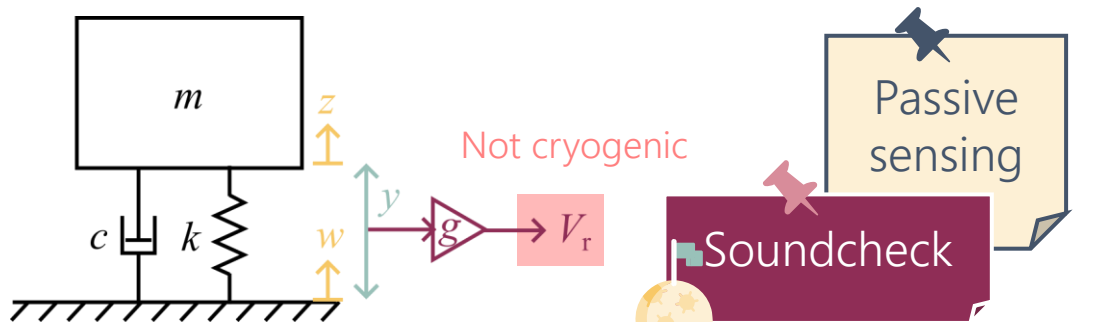
Compatibility

- High-resolution cryogenic sensors
- Vibration level



High-resolution cryogenic inertial sensor suite combining passive and active architectures

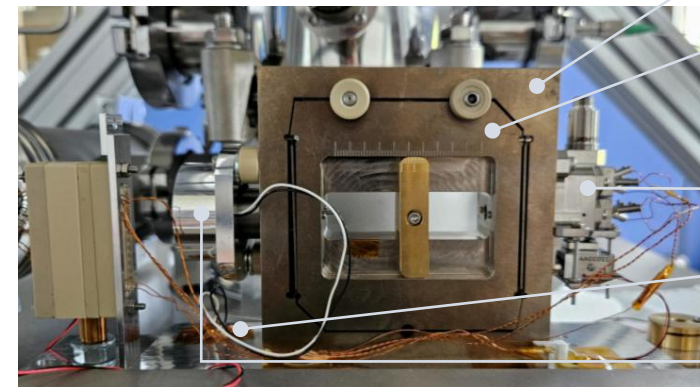
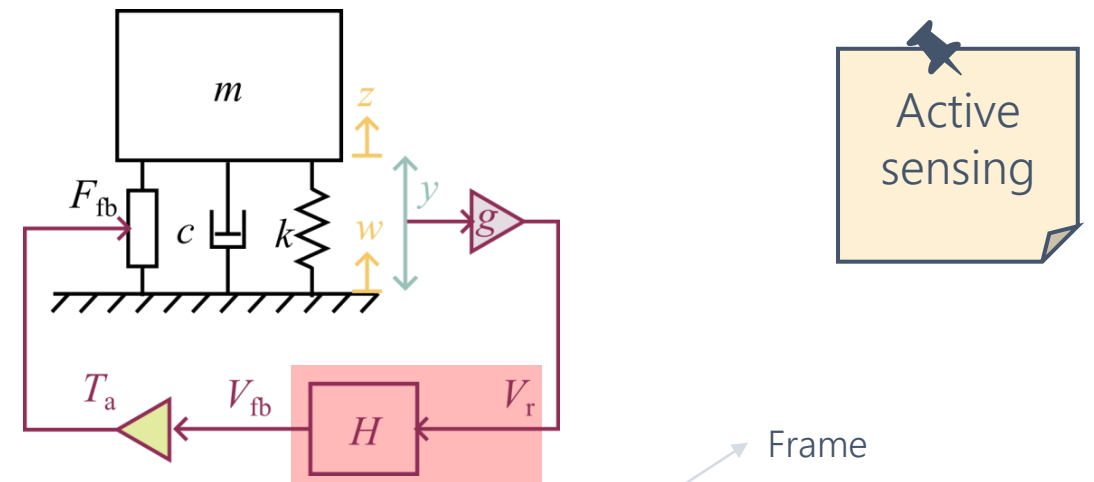
Vertical cryogenic inertial sensor



- Leaf-spring suspension (BeCu)
 - Double-clamped blade hinge (BeCu)
 - Inertial mass
 - Corner cube
 - Homodyne quadrature interferometric readout
- [Amorosi 2025](#)

Cryo-V

Horizontal cryogenic inertial sensor



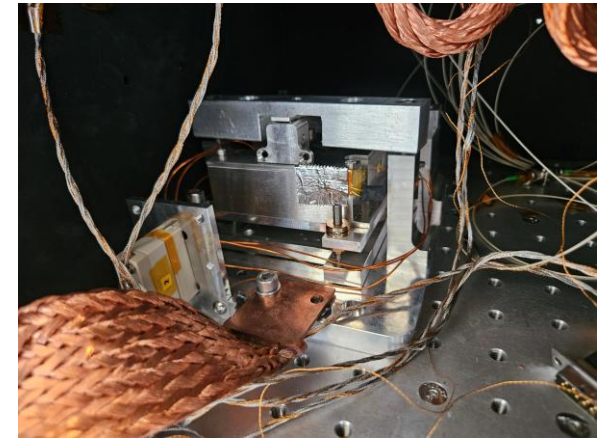
- Frame
- Monolithically suspended $\text{Ti}_6\text{Al}_4\text{V}$ mass
- Interferometric readout
- Current injector
- Voice-coil actuator

Cryo-H

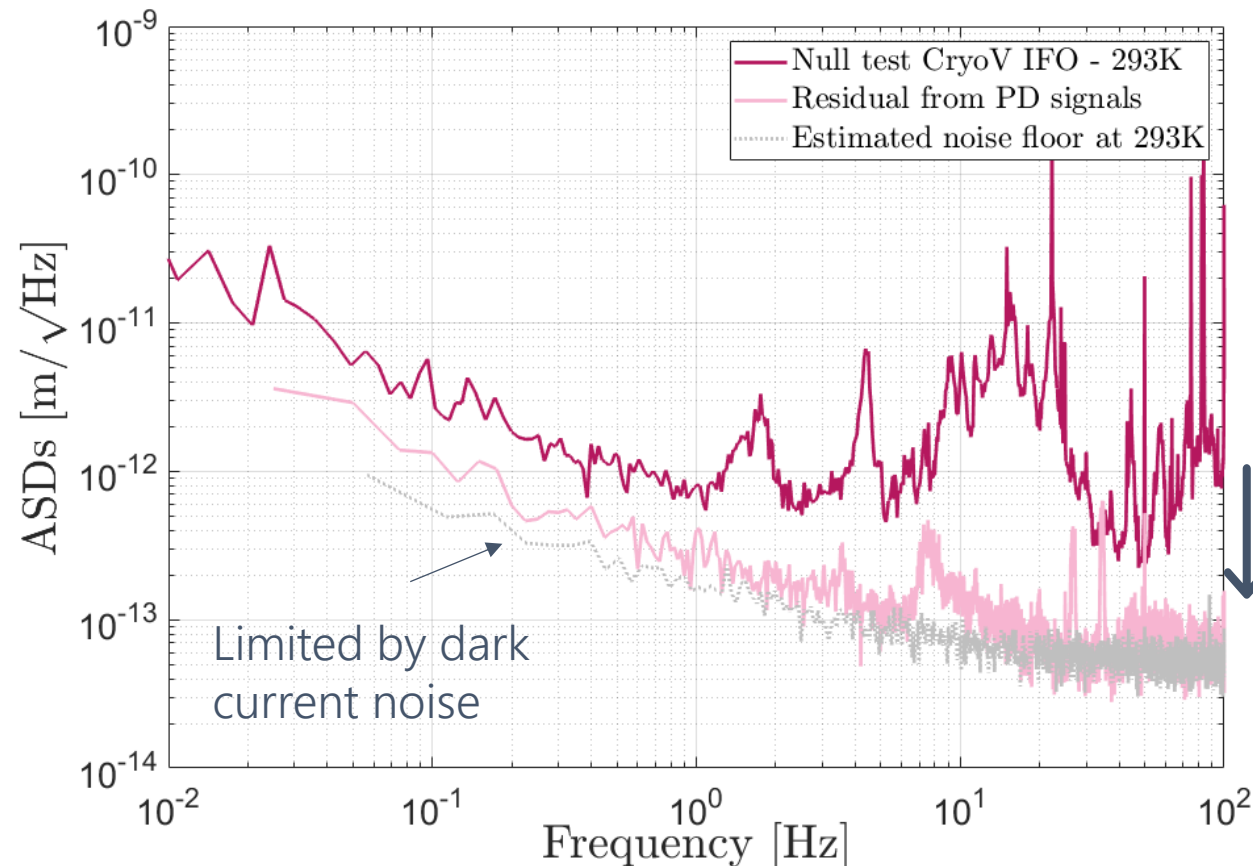
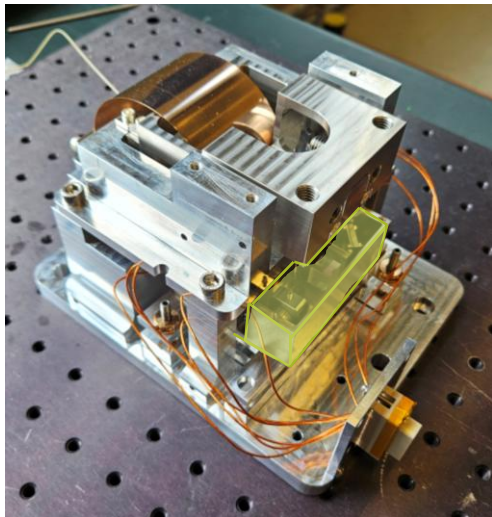


Homodyne quadrature interferometric readout sub pm/ $\sqrt{\text{Hz}}$ resolution from 0.1Hz at 293K

Null measurement: the corner cube is clamped to the interferometer to cancel relative motion between the measuring and reference arm



Homodyne quadrature
interferometer



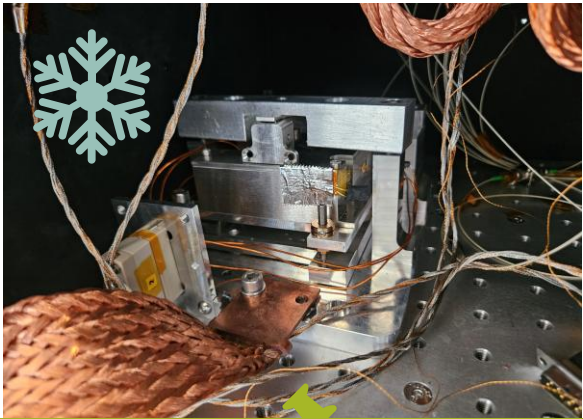
Remove the remaining
vibration by removing the
coherent signals

Shot noise: ~50 fm/ $\sqrt{\text{Hz}}$

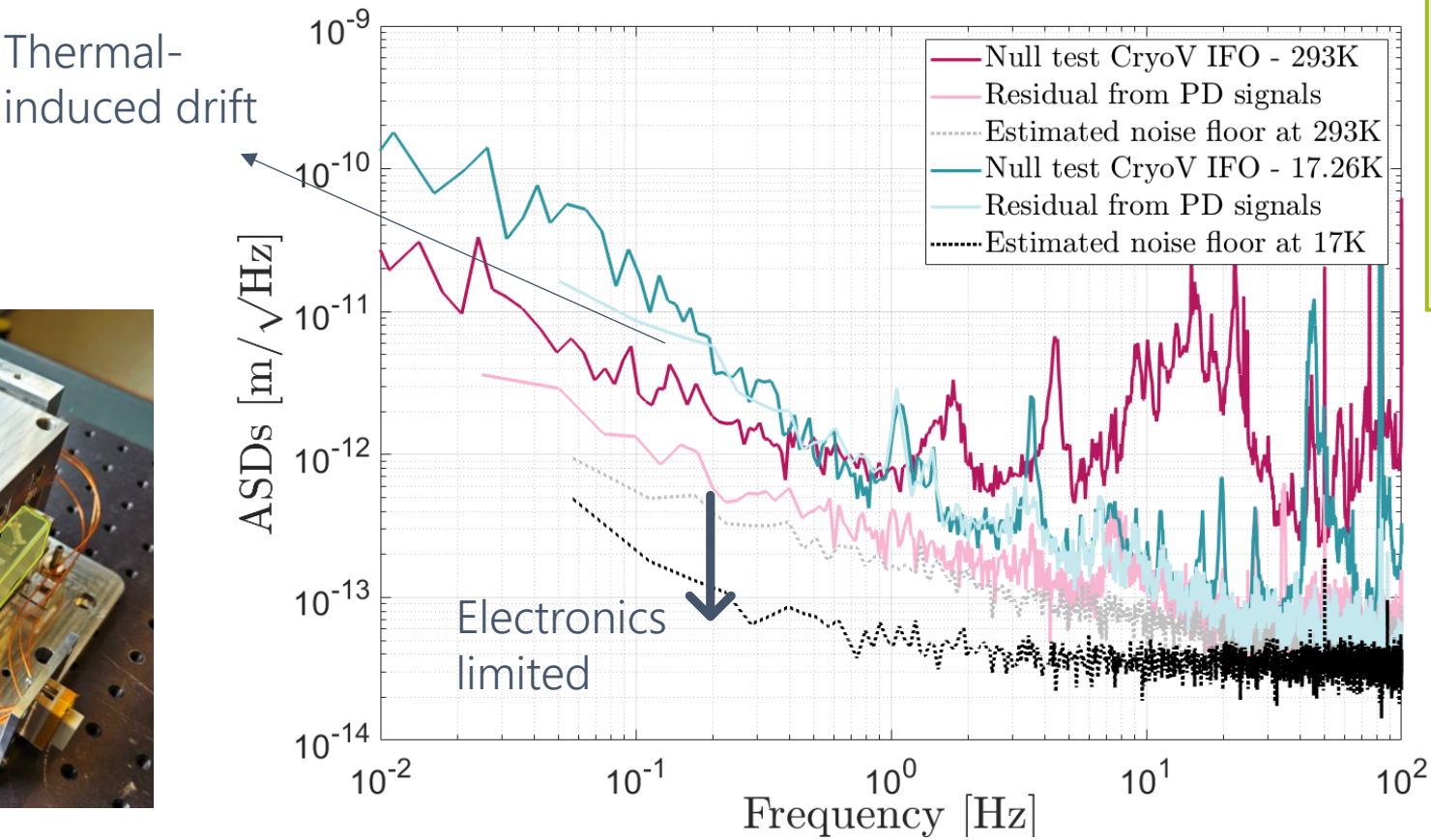
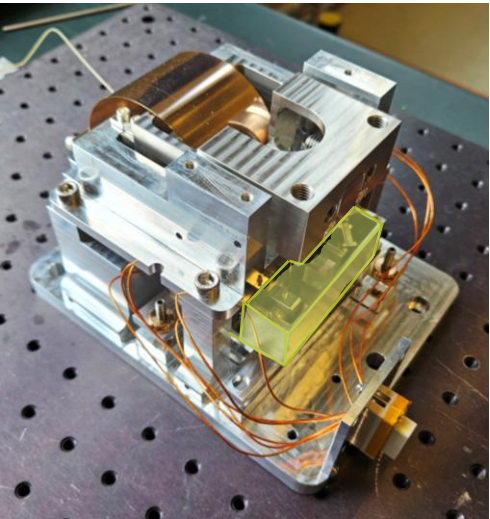


Homodyne quadrature interferometric readout sub pm/ $\sqrt{\text{Hz}}$ resolution from 0.4Hz at 17K

Alignment quality: less than 10% of relative fringe visibility loss from 293K to 17K



Can be used as a standalone cryogenic sub-pm/ $\sqrt{\text{Hz}}$ sensitivity relative displacement sensor

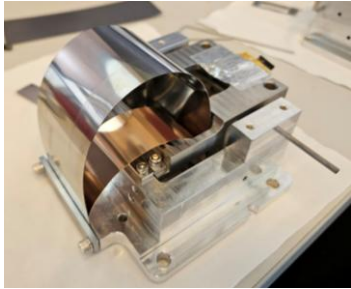
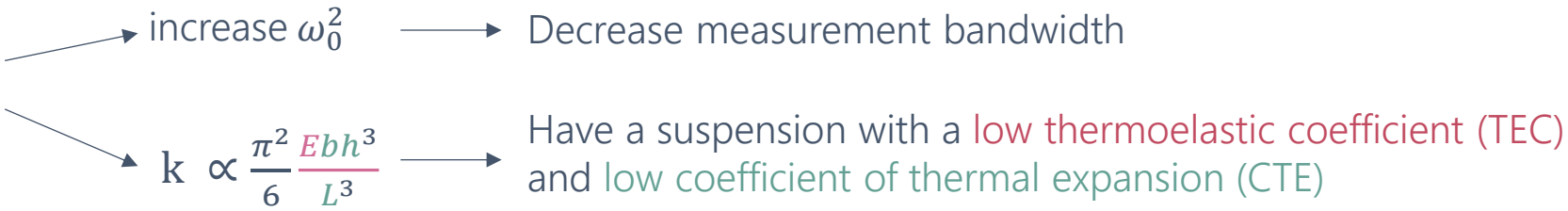


Shot noise: $\sim 50 \text{ fm}/\sqrt{\text{Hz}}$

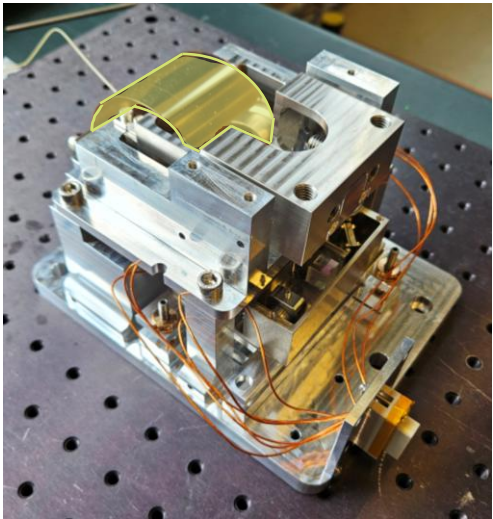


Cryo-V gravity-compensation spring: Elinvar alloys decrease the sensor sensitivity to temperature

Drift(T) $\propto$ 1/ ω_0^2

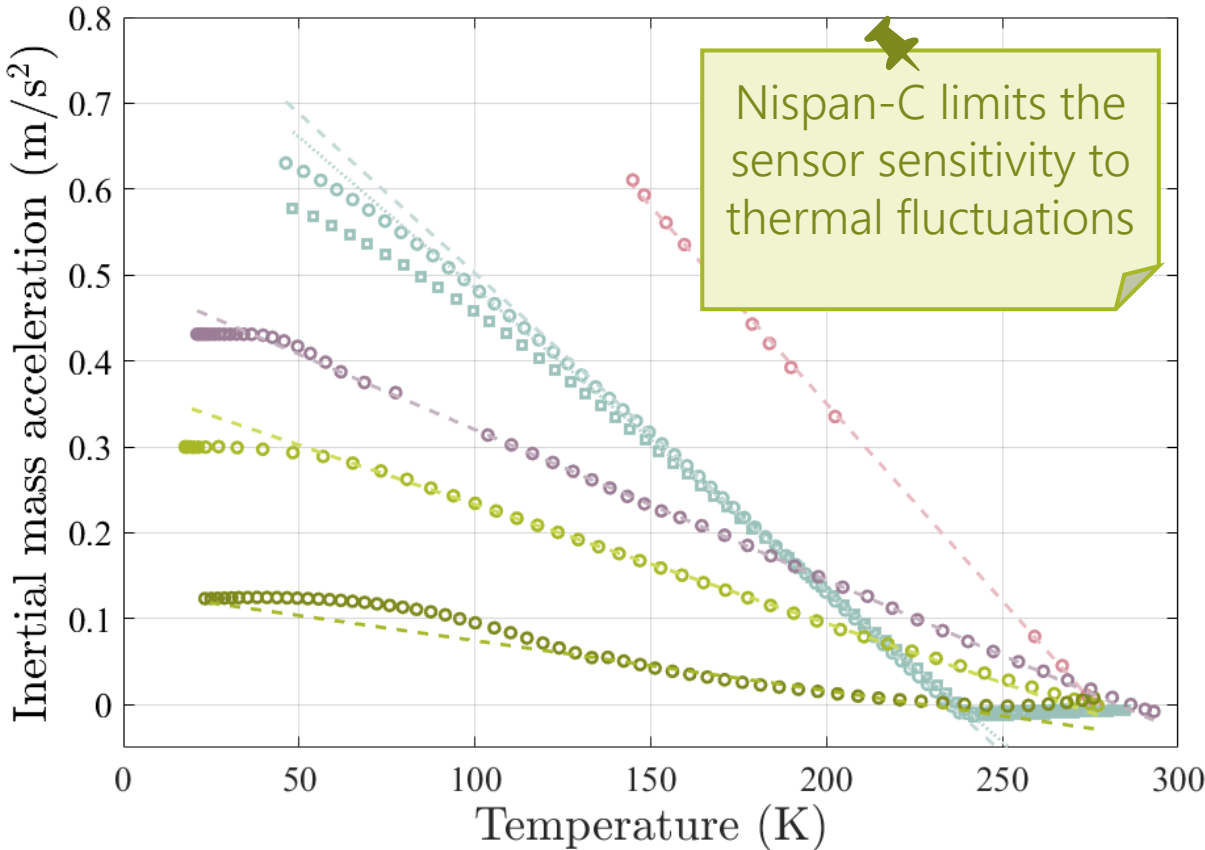


Combine materials with opposite TEC



- BeCu
-4.59 mm/s²/K
- BeCu - compensated
-3.72 mm/s²/K
- BeCu - compensated
-3.52 mm/s²/K
- BeCu + Nispan-C
-1.38 mm/s²/K
- Nispan-C
-0.58 mm/s²/K
- BeCu + Elinvar
-1.75 mm/s²/K

Thermal treatment to get an almost-zero TEC

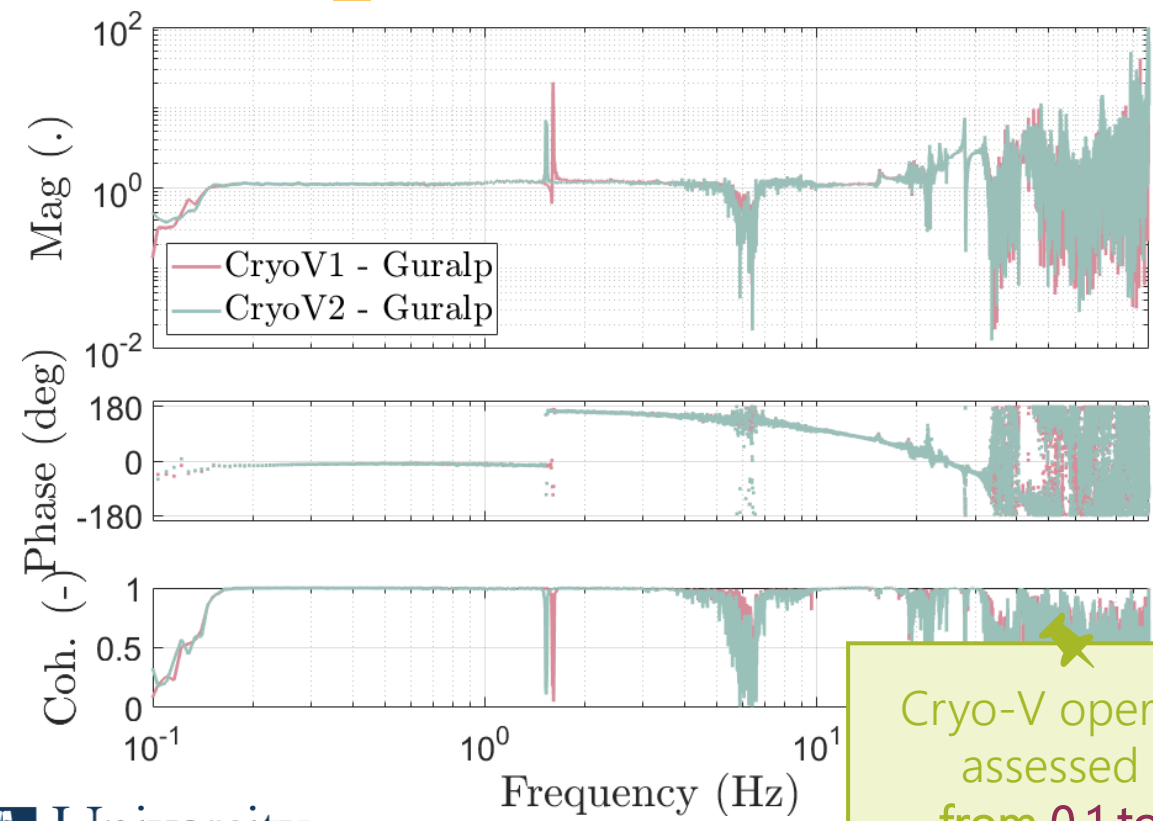
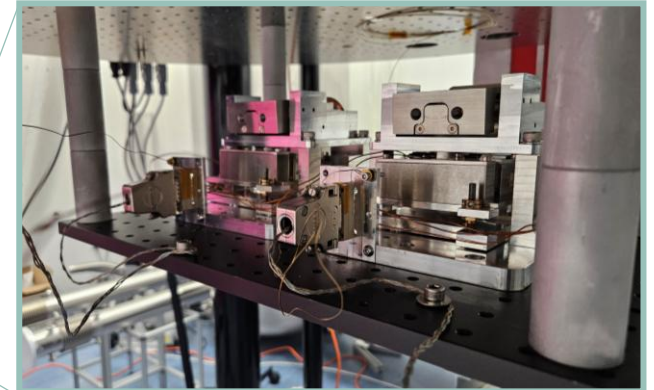




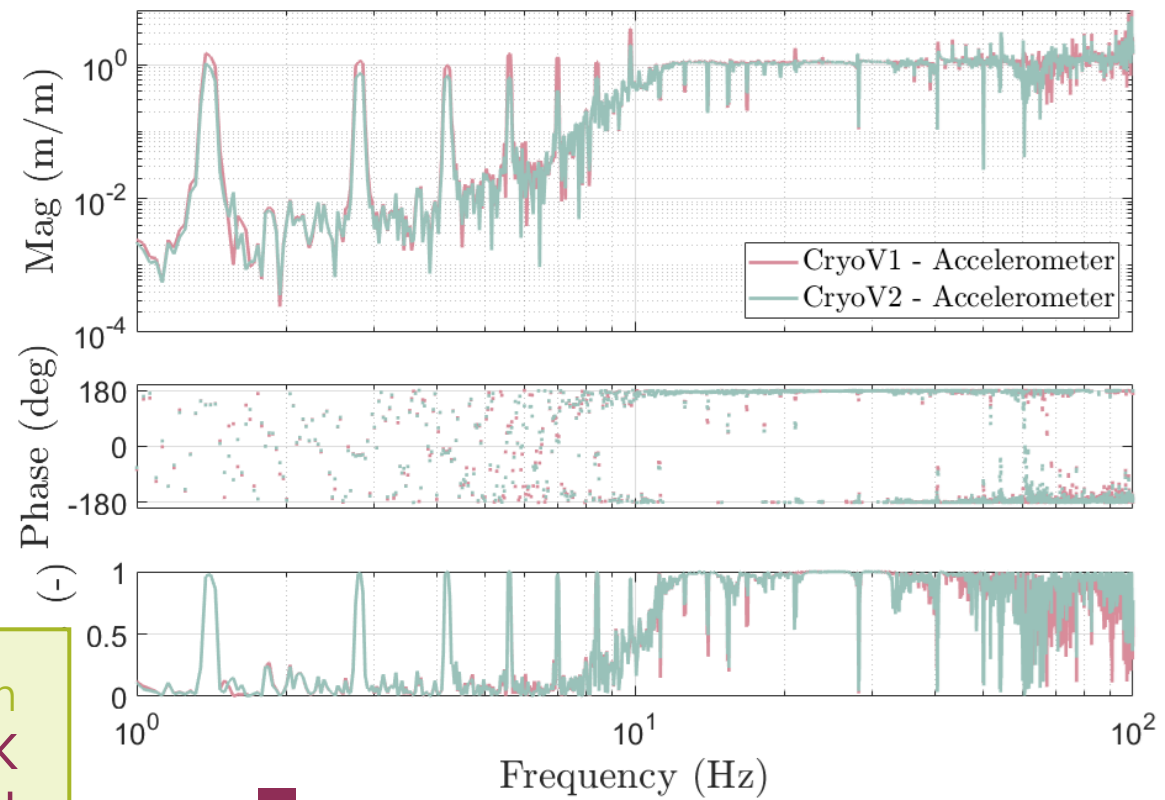
Cryo-V operation at 5.17 K compared to commercial sensors

$T = \frac{\text{Cryo-Vs}}{\text{Guralp Accelerometer}} = \text{Coherent from 0.1 to 30Hz}$

Guralp Accelerometer
Cryo-Vs
4K Cold plate
Vacuum tank

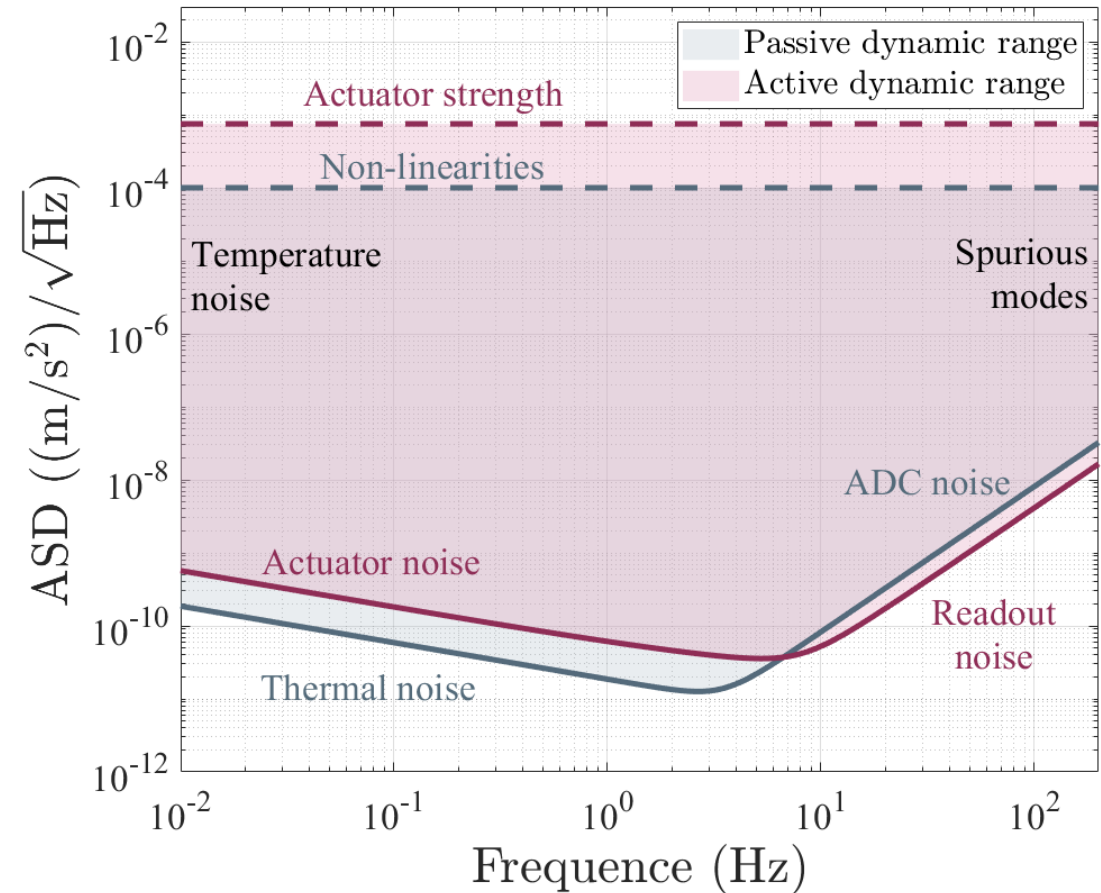
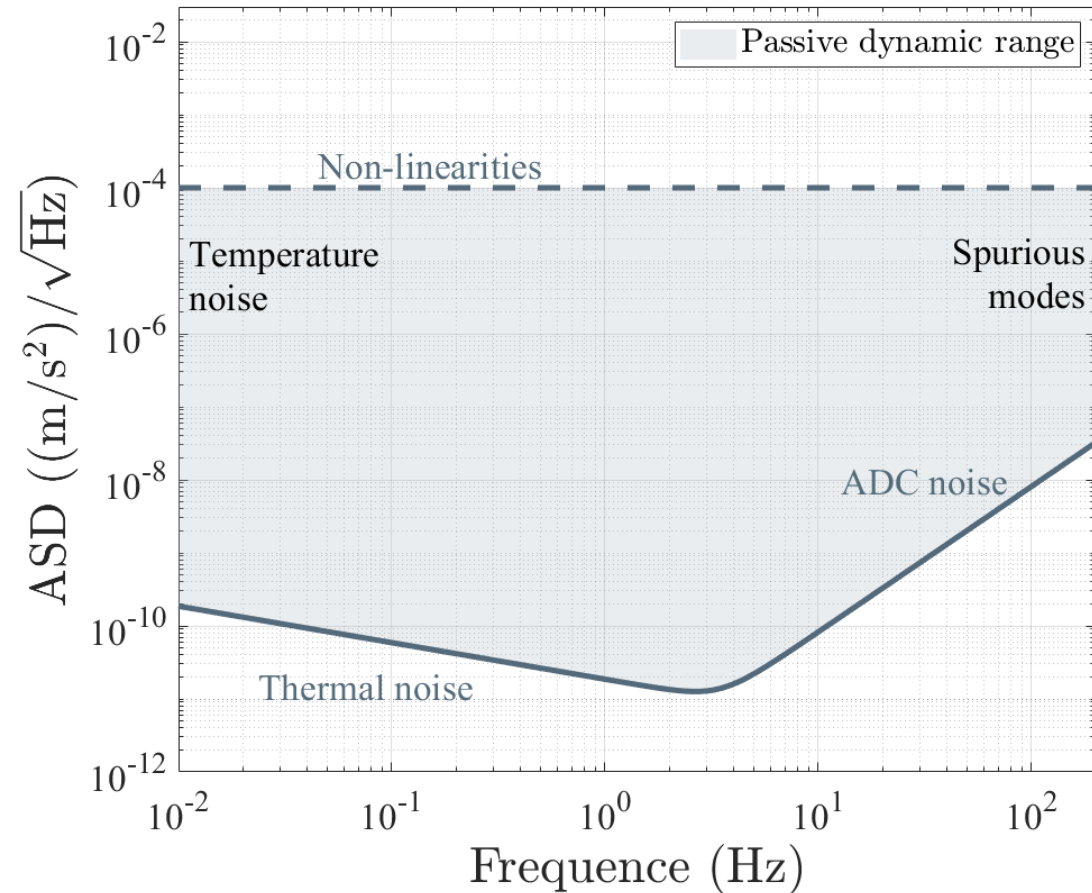


Cryo-V operation assessed at 5K from 0.1 to 50Hz

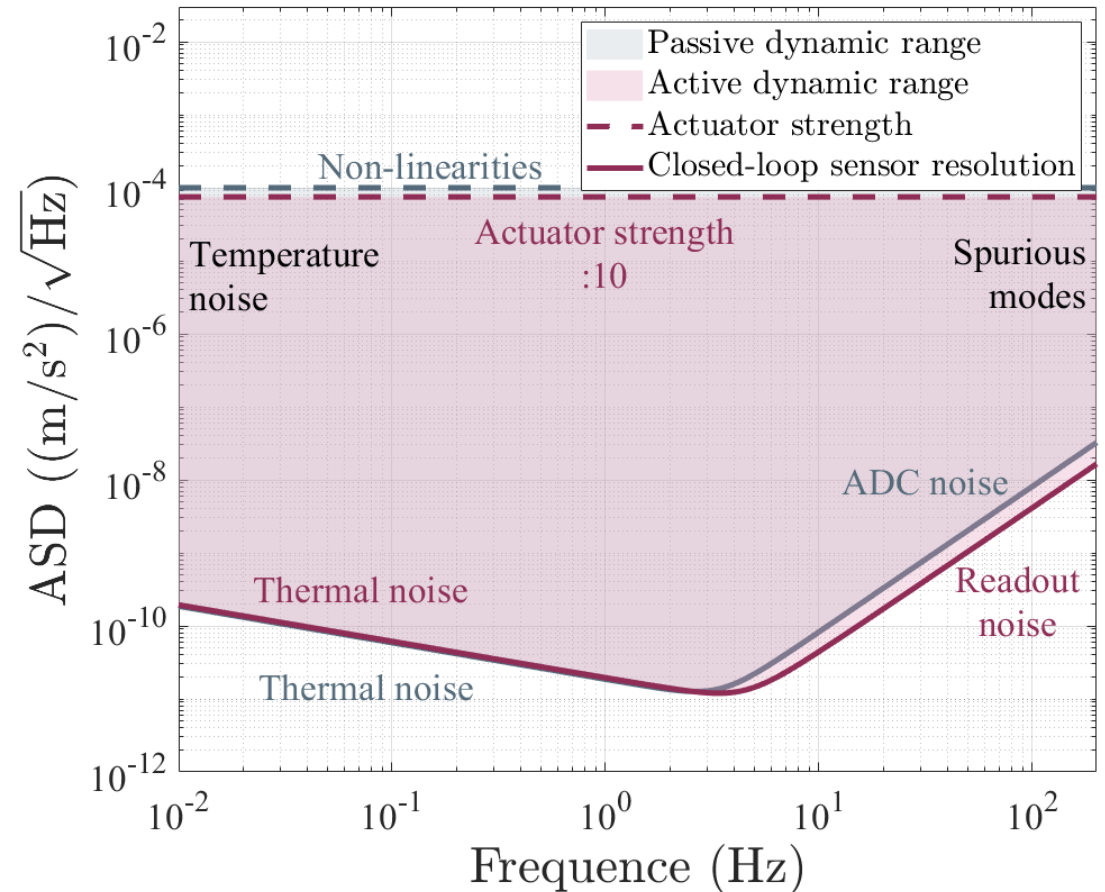
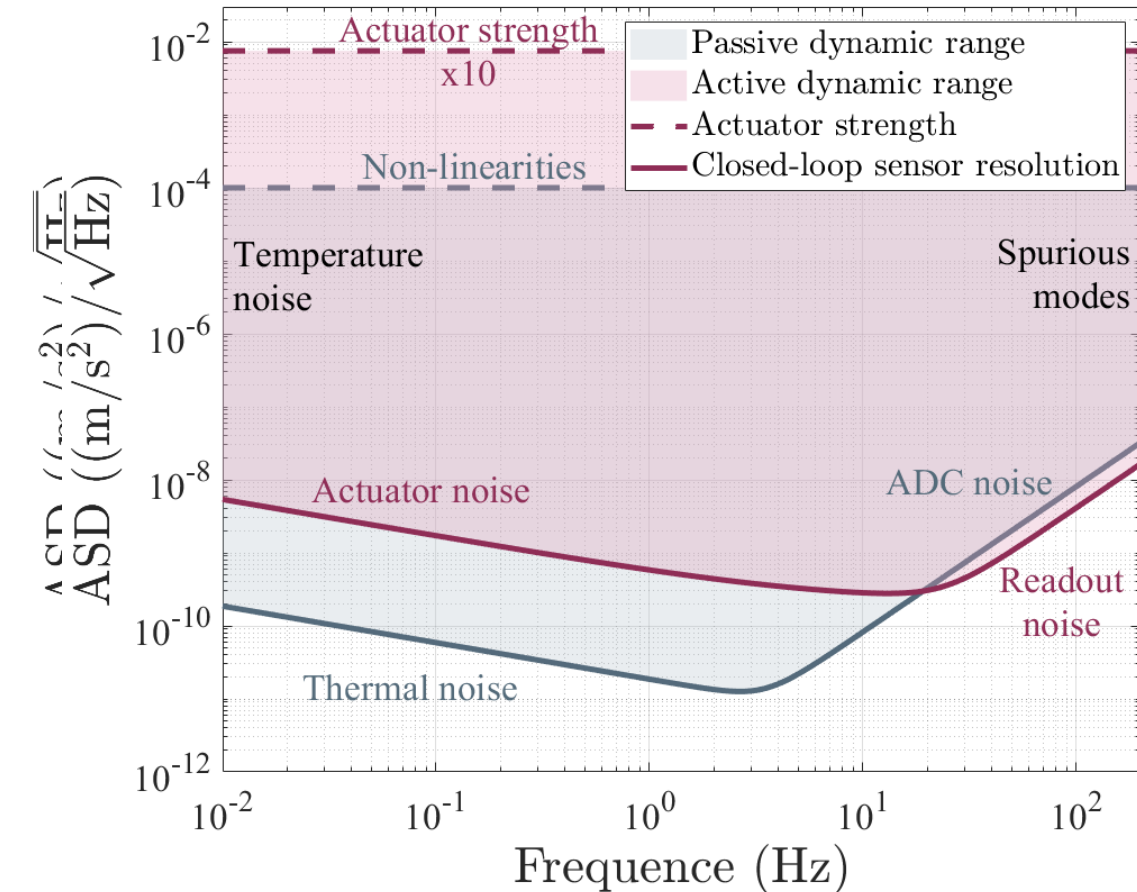


$T = \frac{\text{Cryo-Vs}}{\text{Accelerometer}} = \text{Coherent from 12 to 50Hz}$

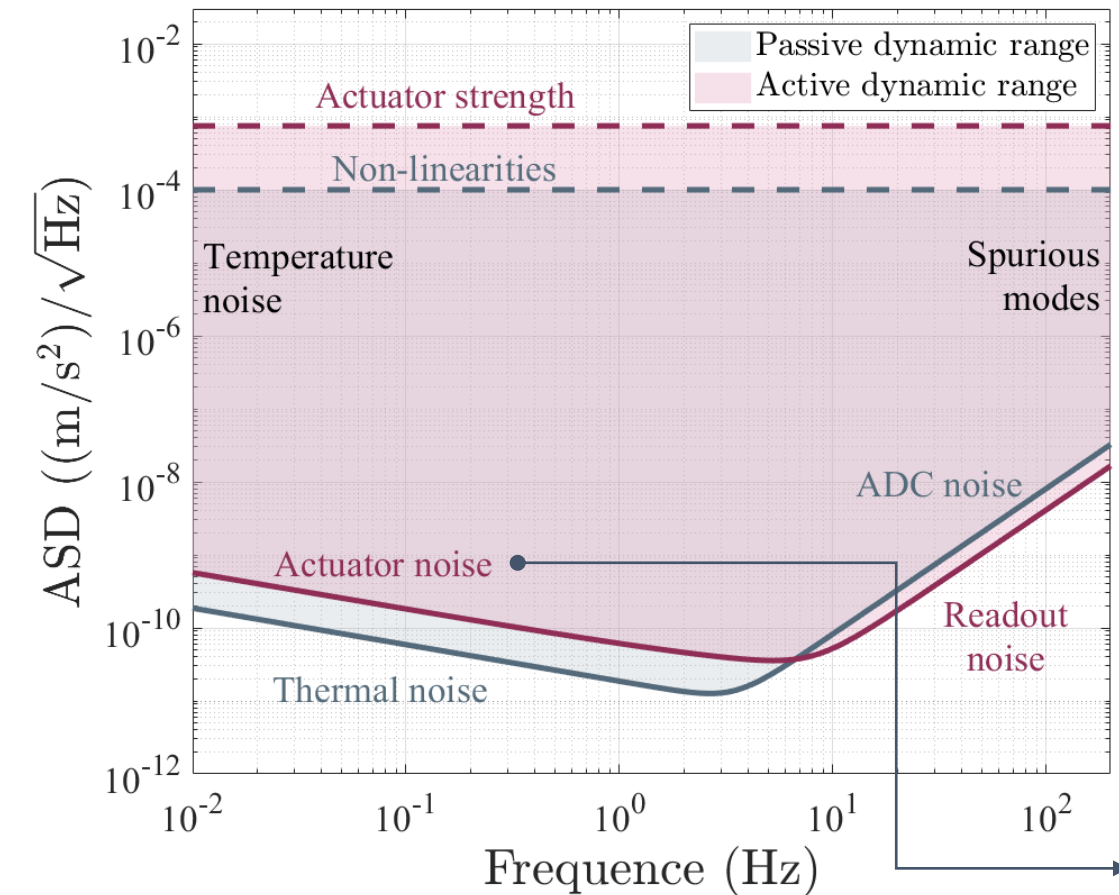
Cryo-H actuation chain adaptation to cryogenic temperature



Cryo-H actuation chain adaptation to cryogenic temperature



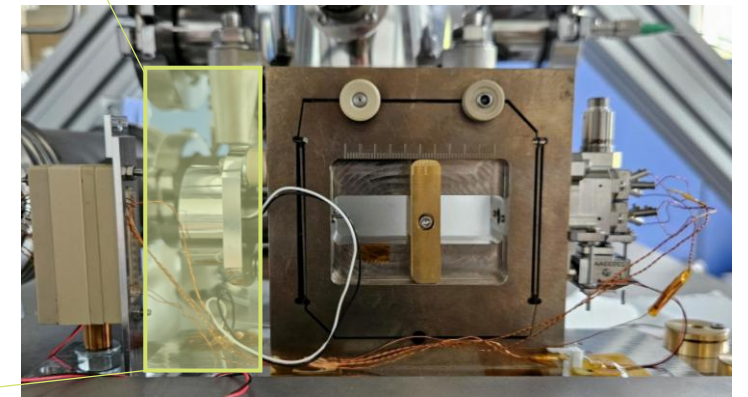
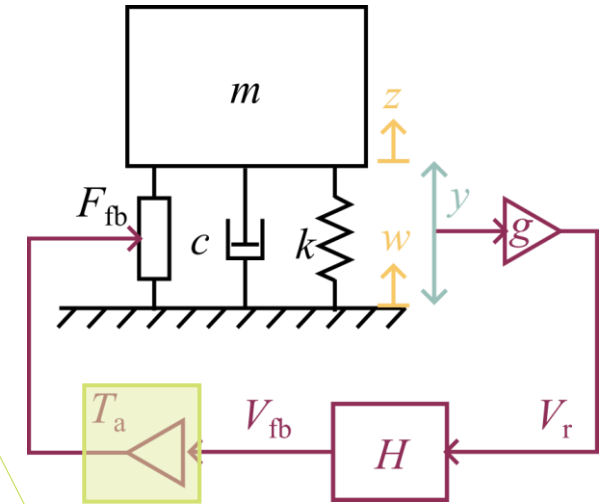
Cryo-H actuation chain adaptation to cryogenic temperature



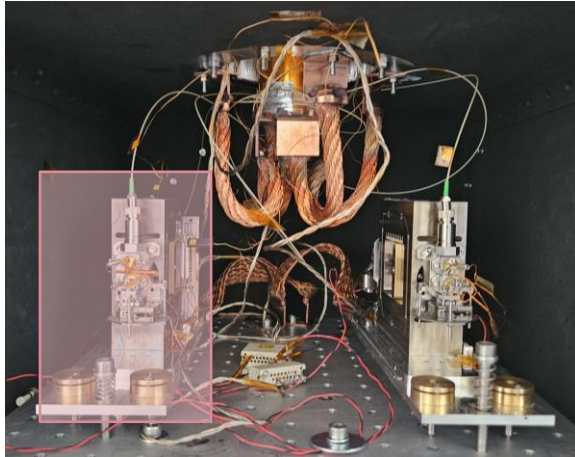
VCA with copper coil and neodymium magnet



Low-noise voltage buffer made with MELF resistors

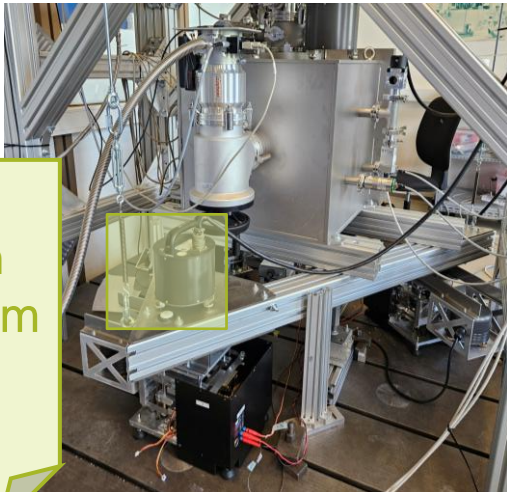


Cryo-H operation at 27.17 K compared to commercial sensors

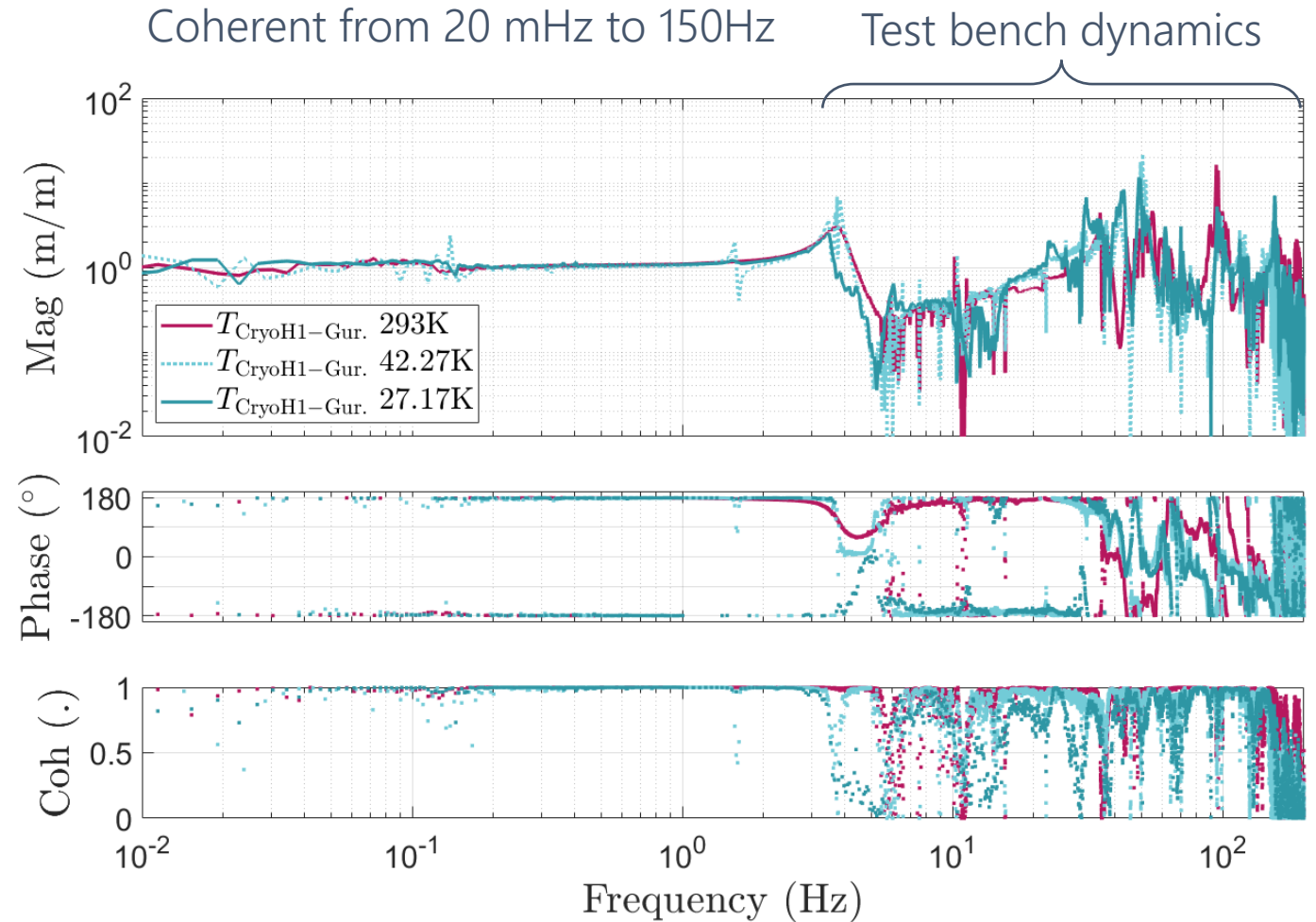


Cryo-H

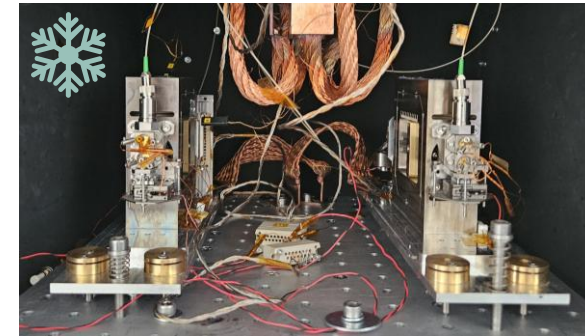
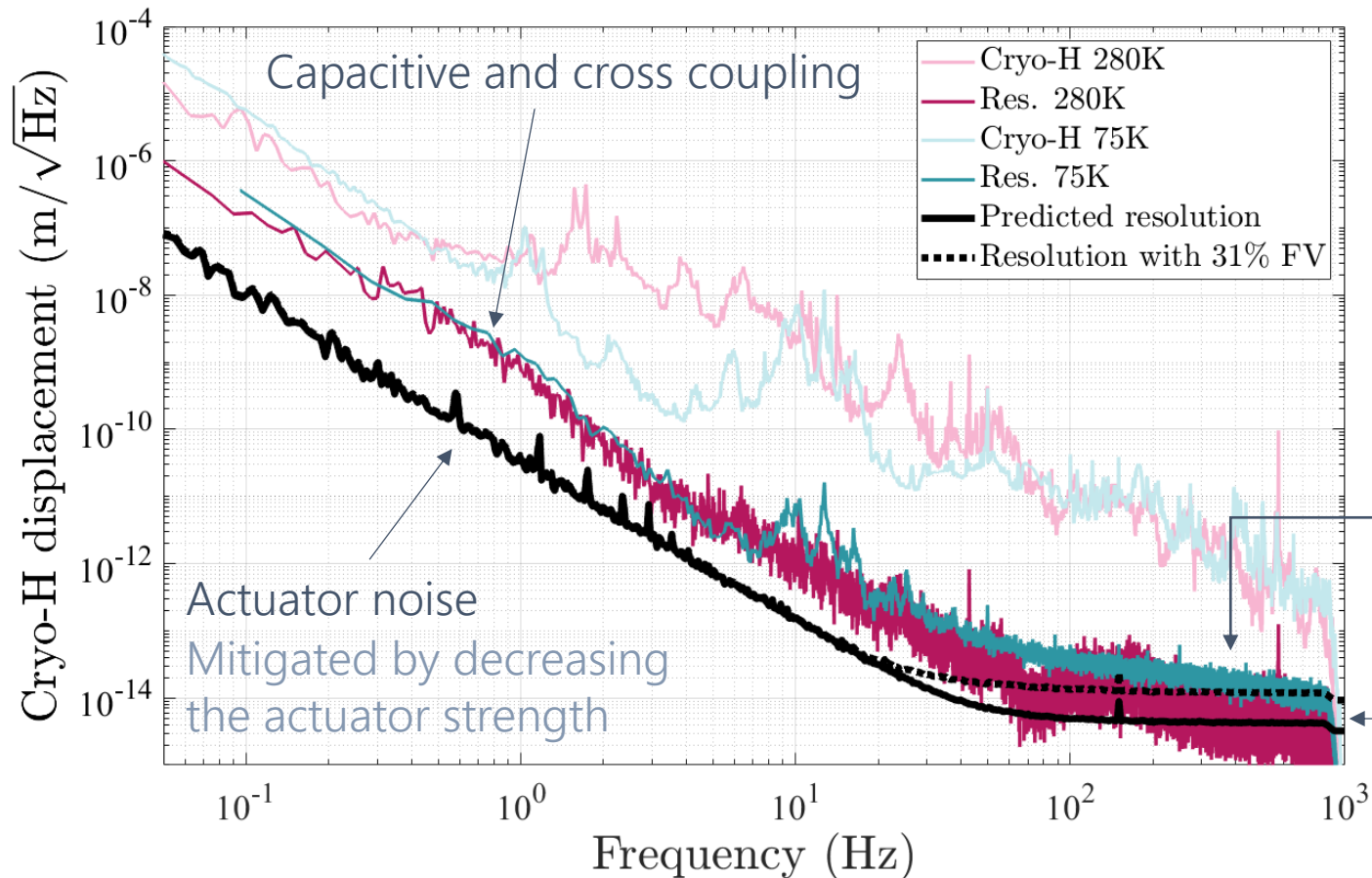
$T =$
Guralp



Cryo-H operation
assessed at 27K from
20mHz to 150Hz



Horizontal cryogenic inertial sensor resolution at 75 K reaches sub-pm level from 5 Hz



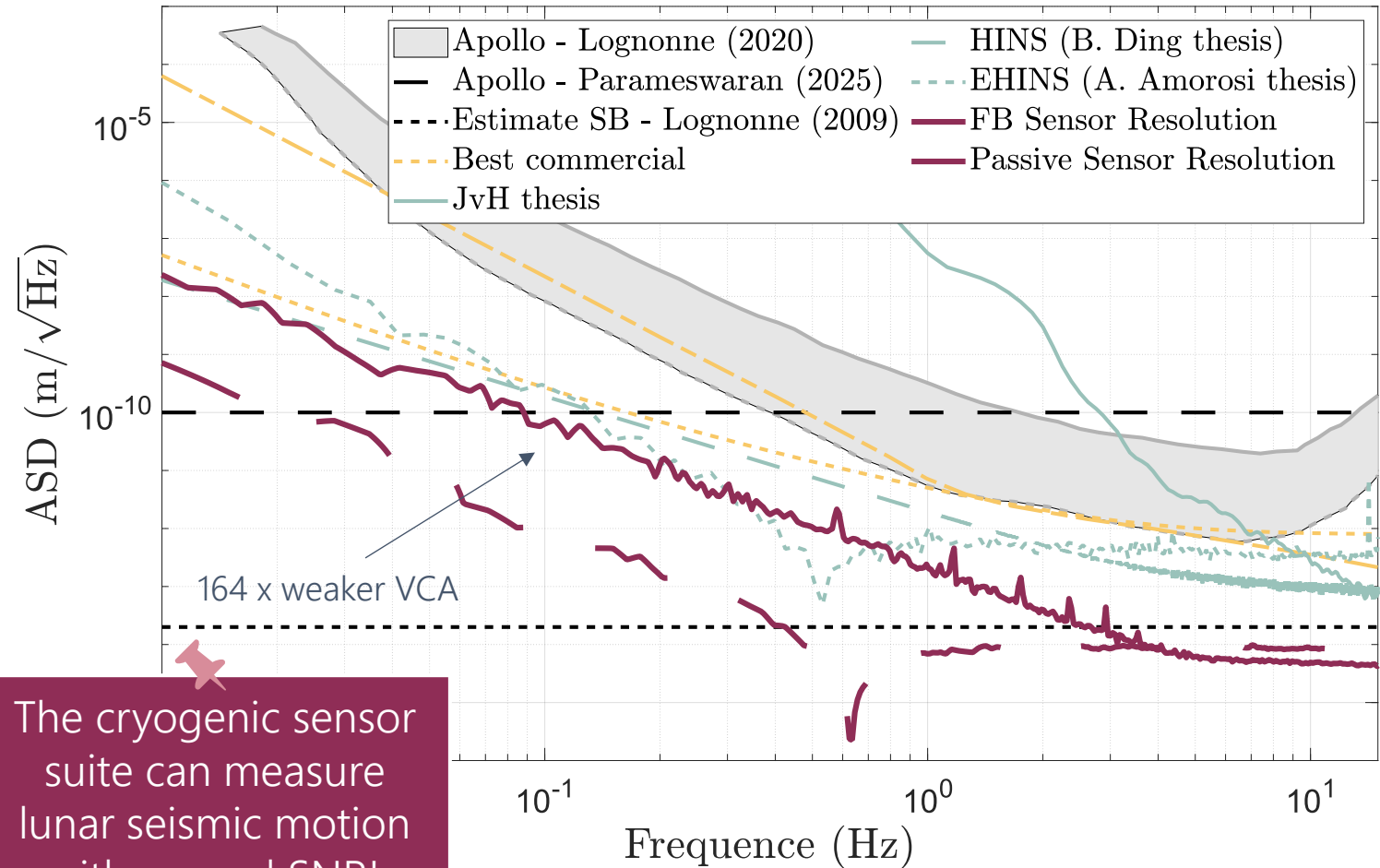
⊖ Huddle test
= coherent subtraction

Shot noise $< 10 \text{ fm}/\sqrt{\text{Hz}}$
(alignment- and input-power-dependent)

Conclusion & Projections for LGWA Soundcheck

We have redesigned and adapted state-of-the-art sensors to cryogenic conditions

- Checked the cryogenic compatibility of **sub-components**
- The homodyne quadrature interferometer can be used as a standalone **cryogenic sub-pm/ $\sqrt{\text{Hz}}$ sensitivity relative displacement sensor**
- The **vertical cryogenic inertial sensor** is operating at 5K from 0.1 to 50Hz
- The **horizontal cryogenic inertial sensor** is operating at 27K from 30 mHz to 150Hz with a sub-pm resolution from 5 Hz



The cryogenic sensor suite can measure lunar seismic motion with a good SNR!