Coupling mitigation in low frequency active seismic isolation systems based on rotation sensors

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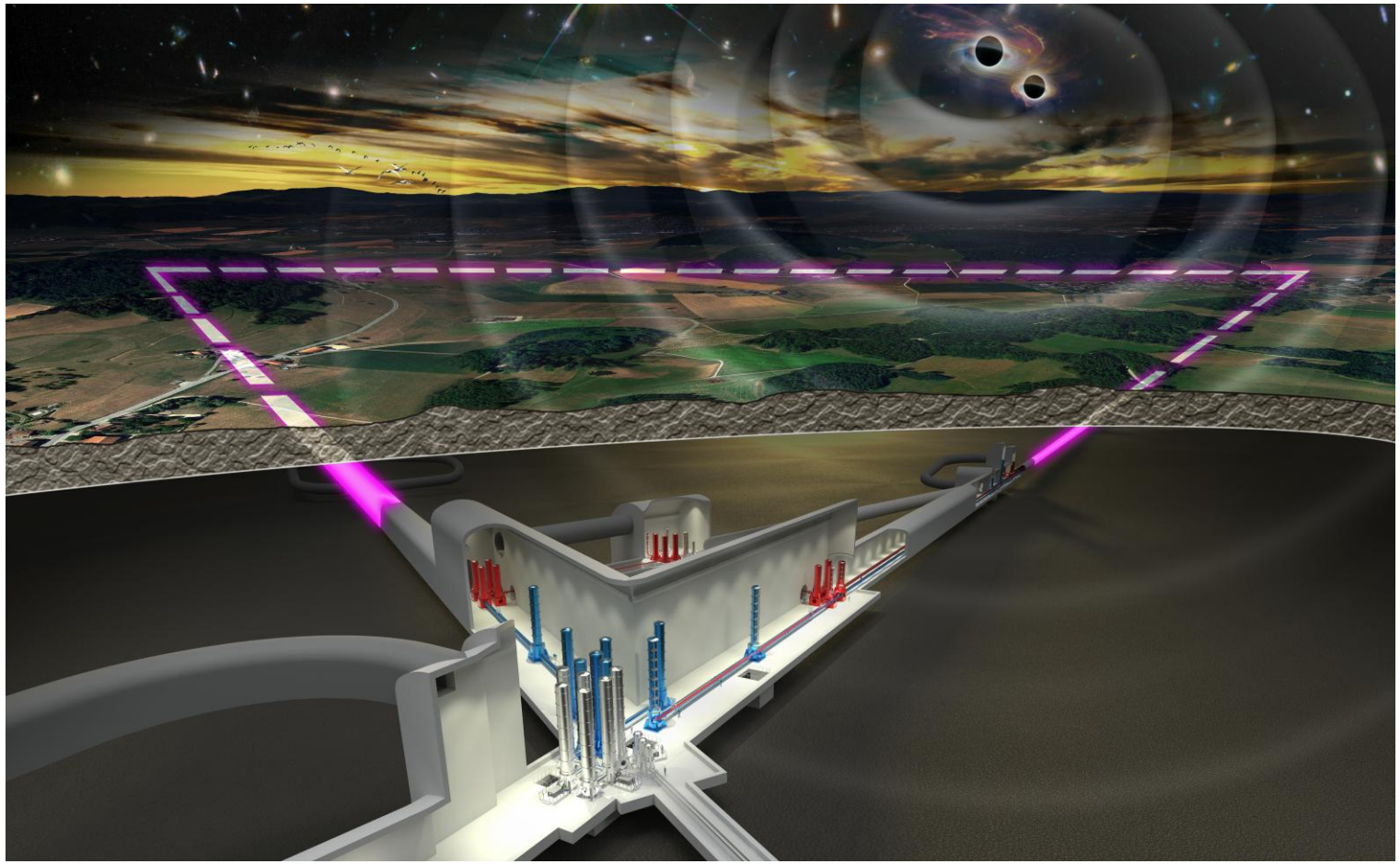
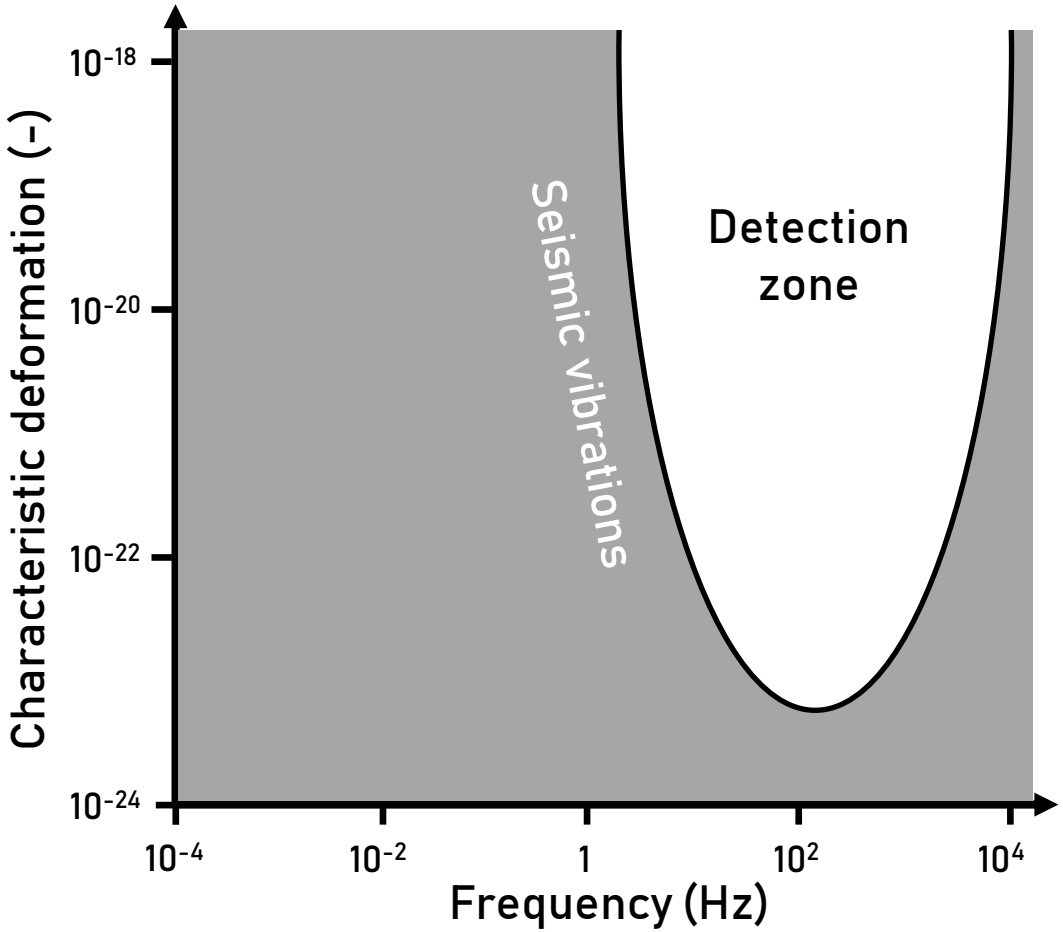
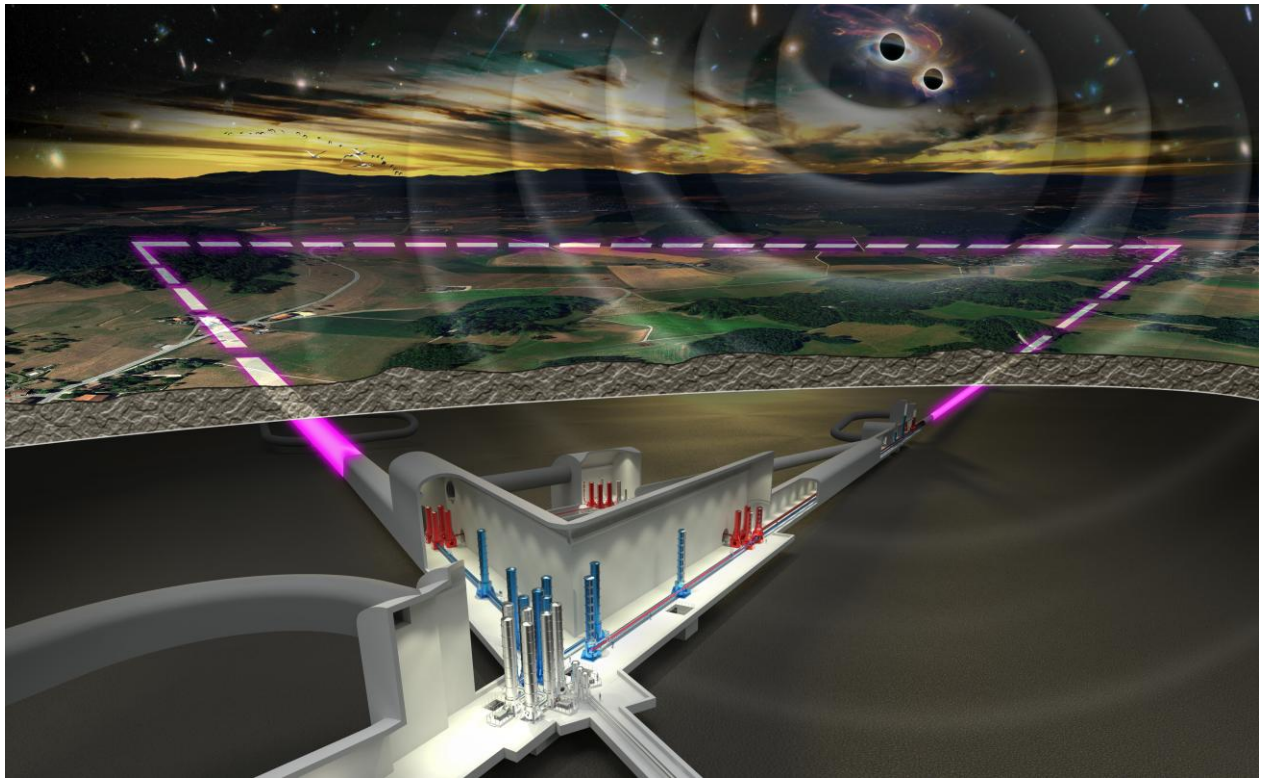
Gravitational wave astronomy

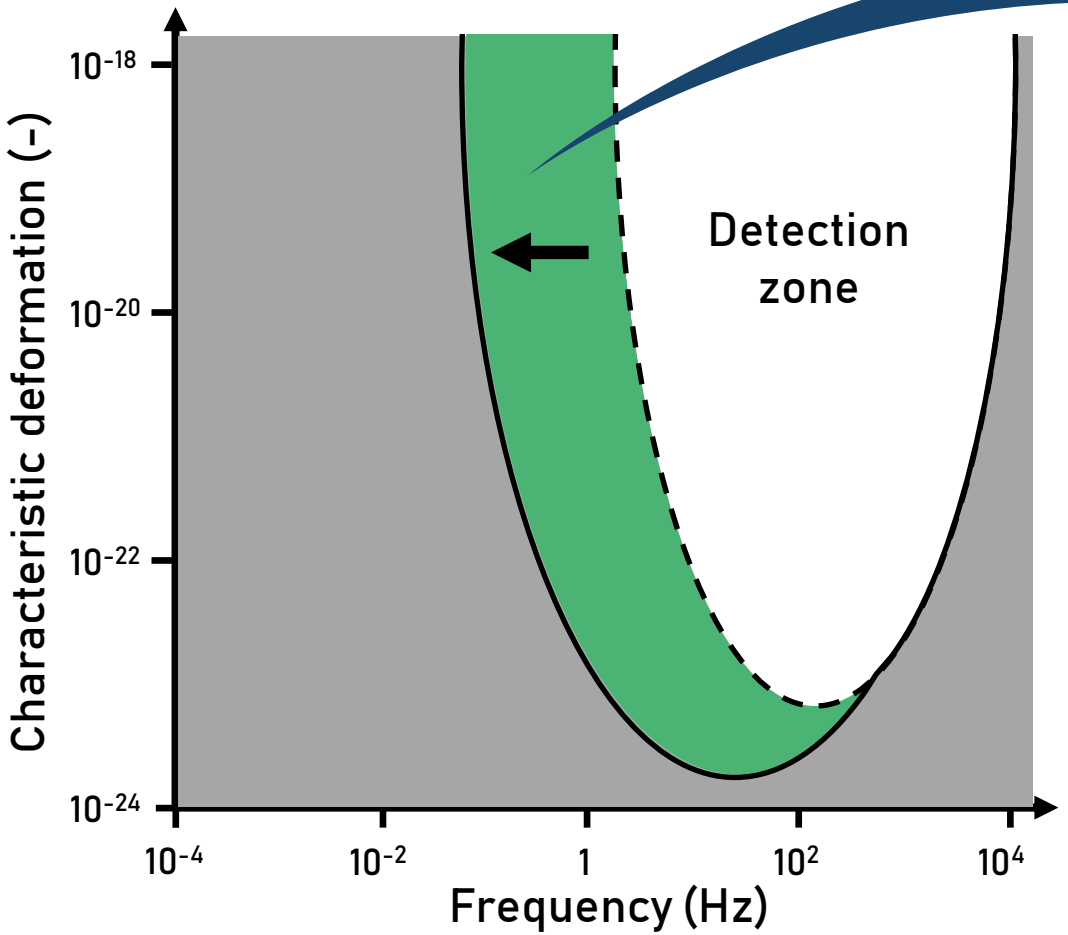


Gravitational wave astronomy



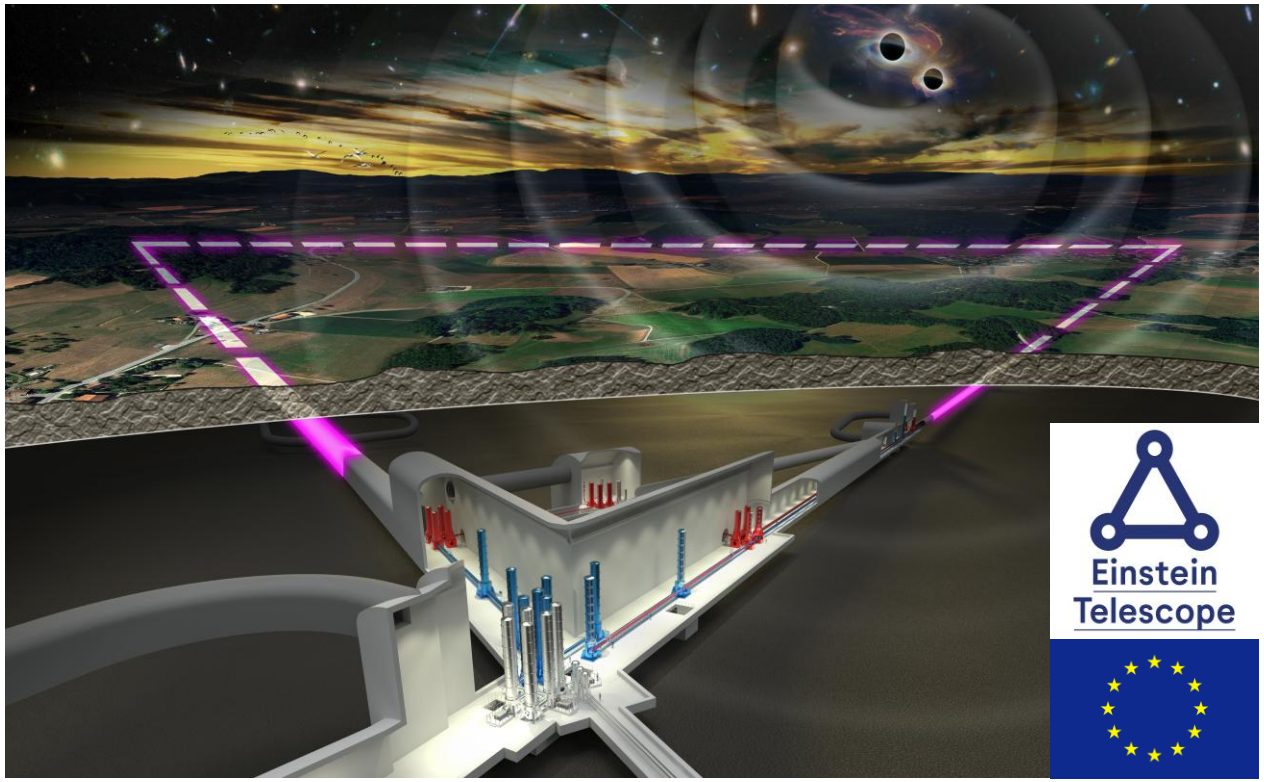


Gravitational wave astronomy



1. Events detection ↗↗
2. Multi-messenger astronomy

Einstein Telescope

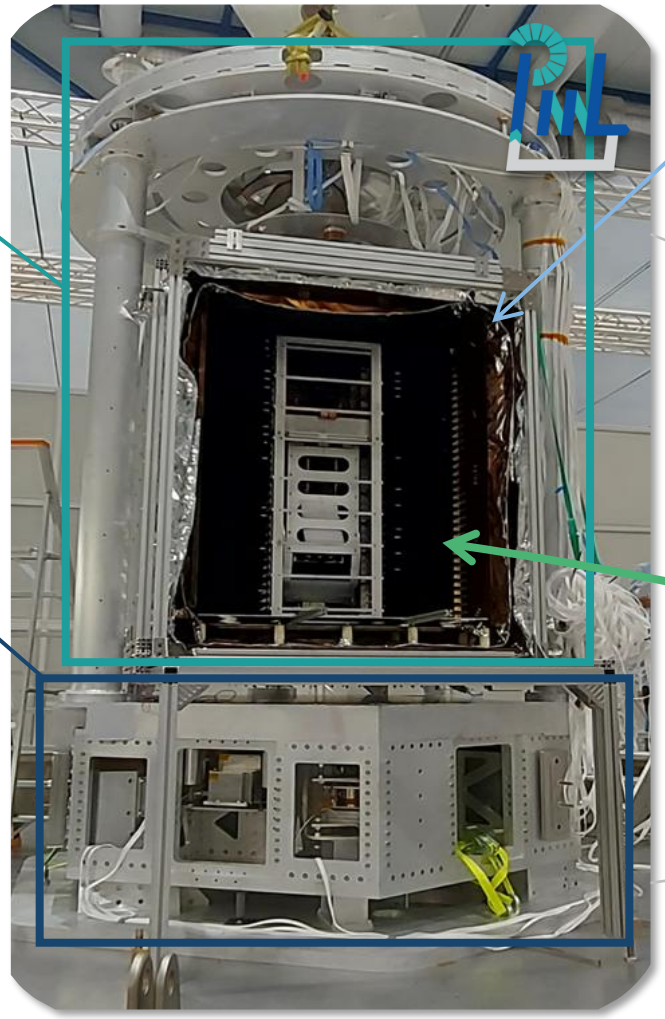


How to extend the detection bandwidth ?

Active seismic isolation

Precision Mechatronics Laboratory

ETEST

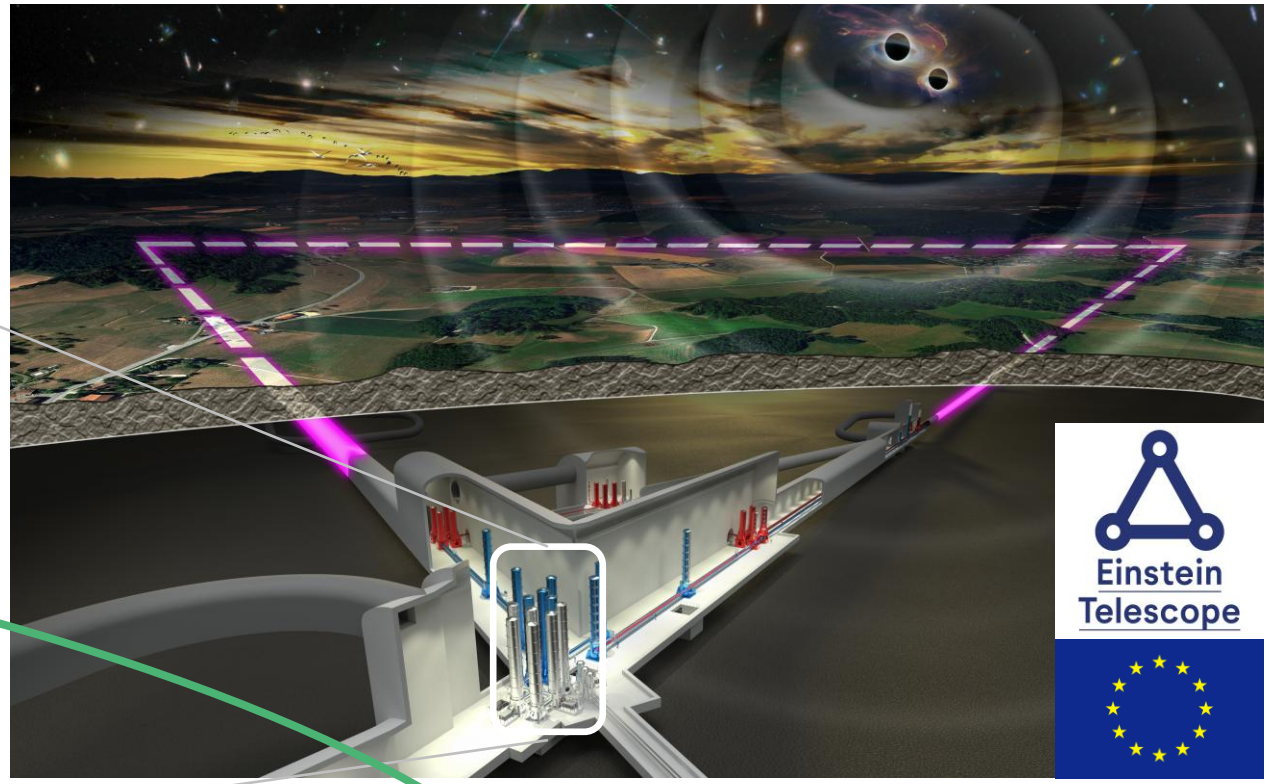


Passive isolation stage

Active isolation stage

Cryostat

Einstein Telescope

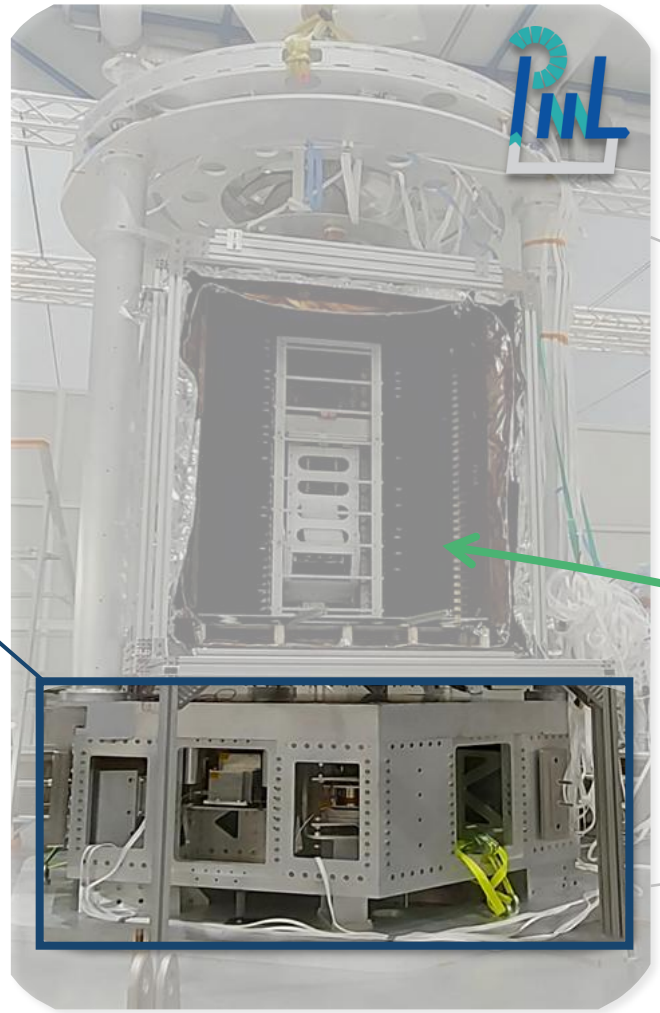


Low noise environment for ET mirros

Active seismic isolation

Precision Mechatronics Laboratory

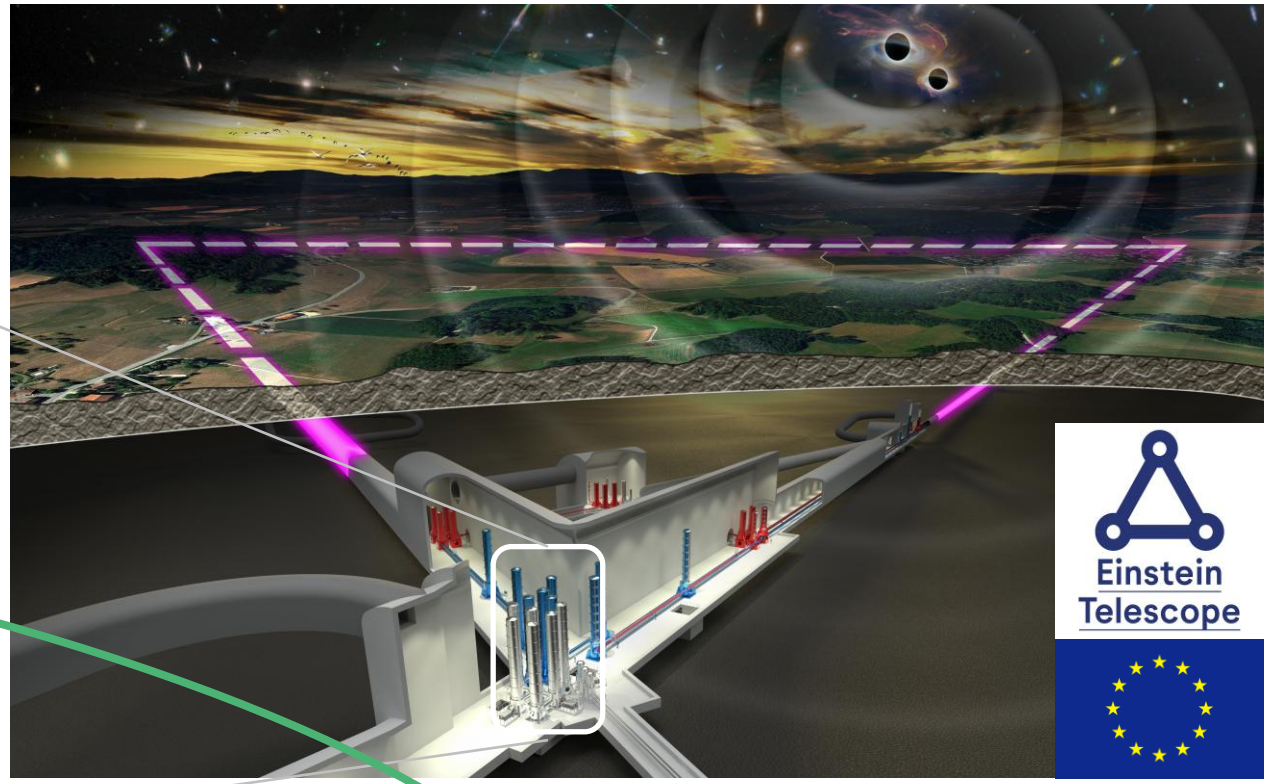
ETEST



Active isolation stage

3 horizontal sensor/actuator pairs
3 vertical sensor/actuator pairs

Einstein Telescope

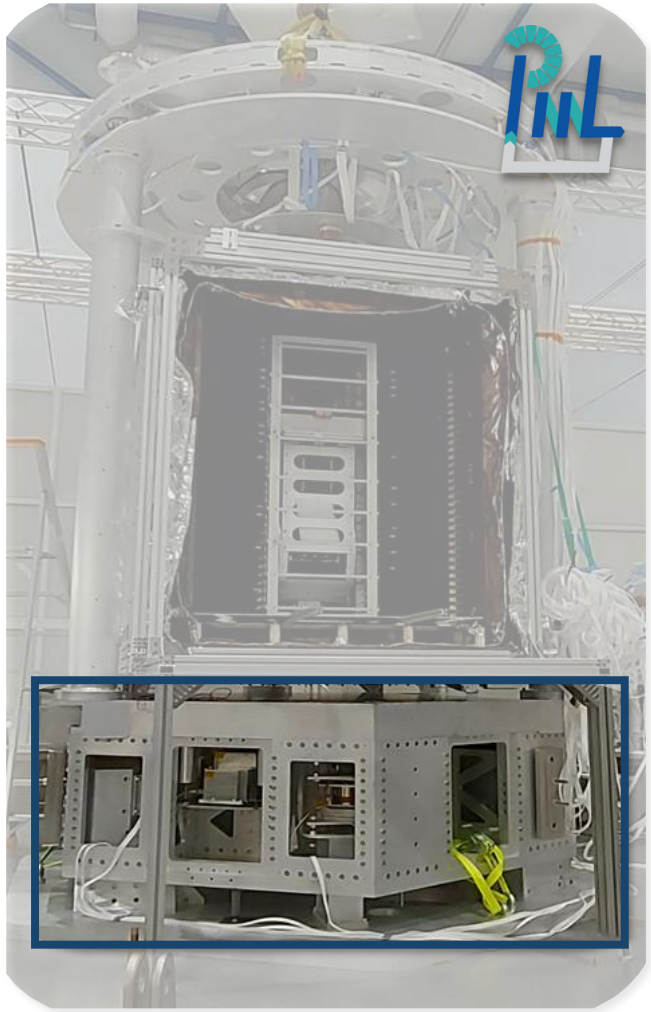


Low noise environment for ET mirros

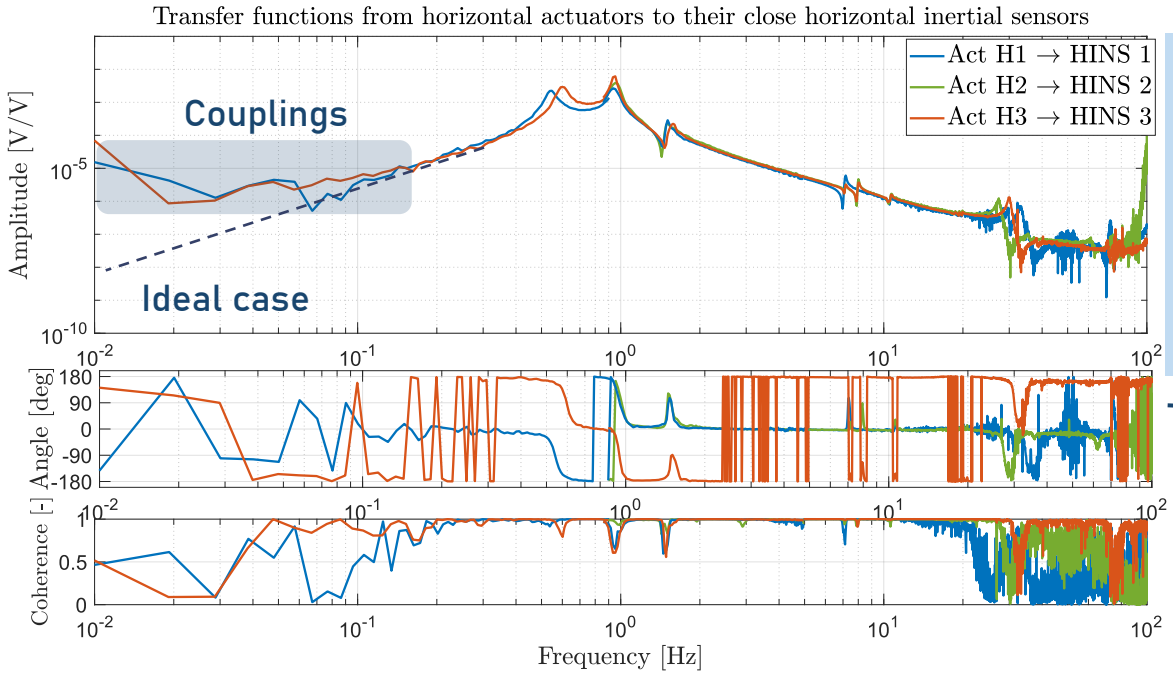
Rotation-translation coupling

Precision Mechatronics Laboratory

ETEST

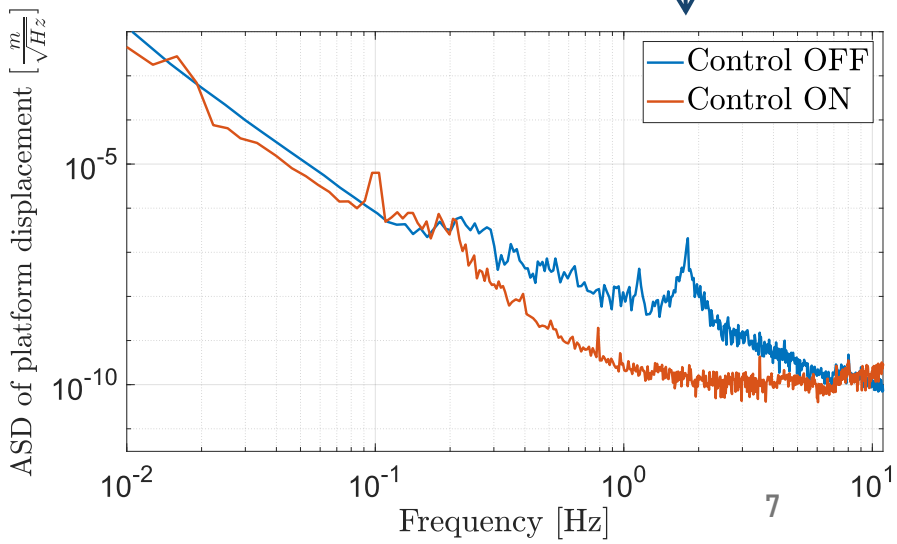


3 horizontal sensor/actuator pairs
3 vertical sensor/actuator pairs



High coupling strongly limits isolation performances at low frequency (< 0.1 Hz)

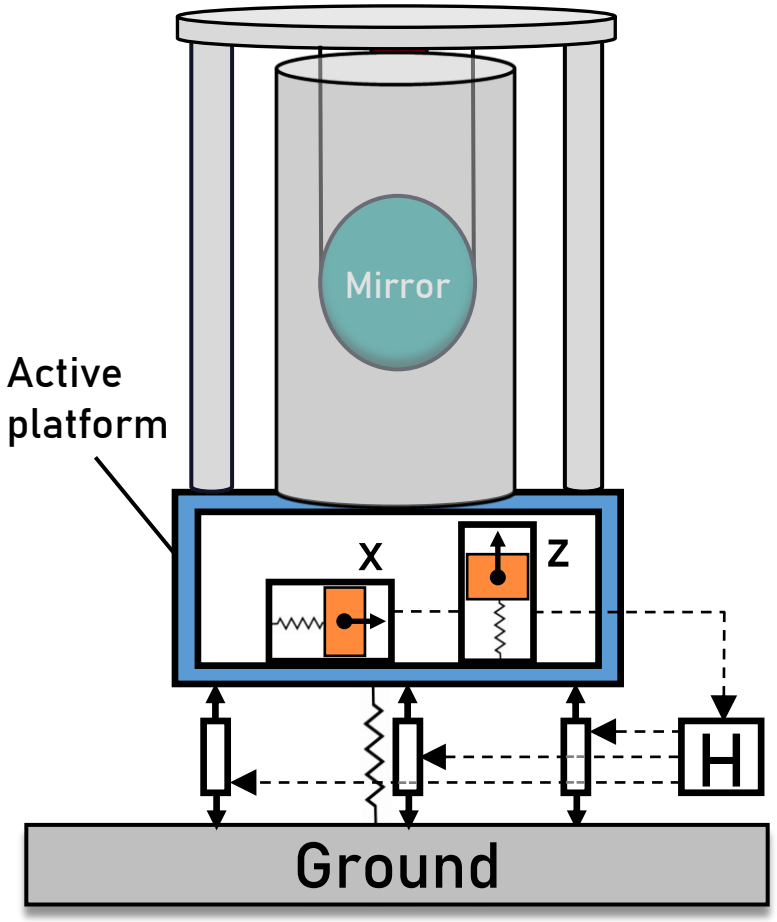
Where does it come from ?



Rotation-translation coupling

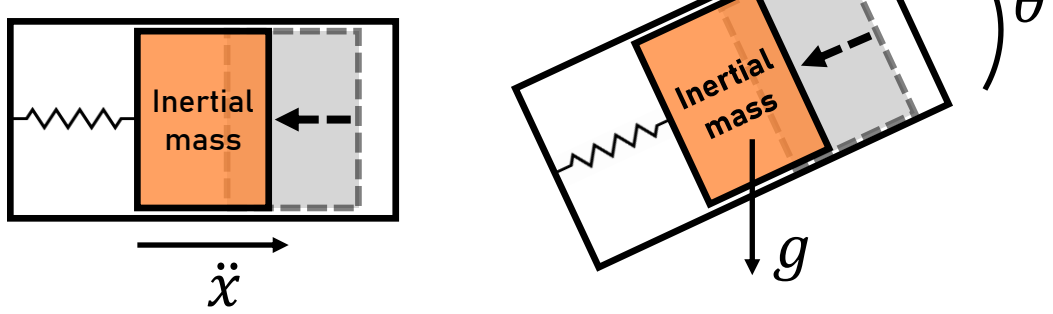
Precision Mechatronics Laboratory

ETEST



3 horizontal sensor/actuator pairs
3 vertical sensor/actuator pairs

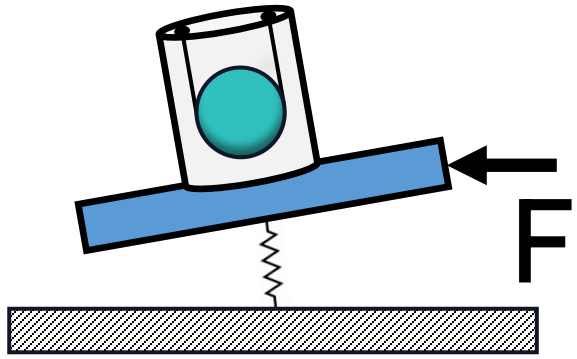
Inertial sensor



➢ No distinction

Impossible to simultaneously control rotation and translation

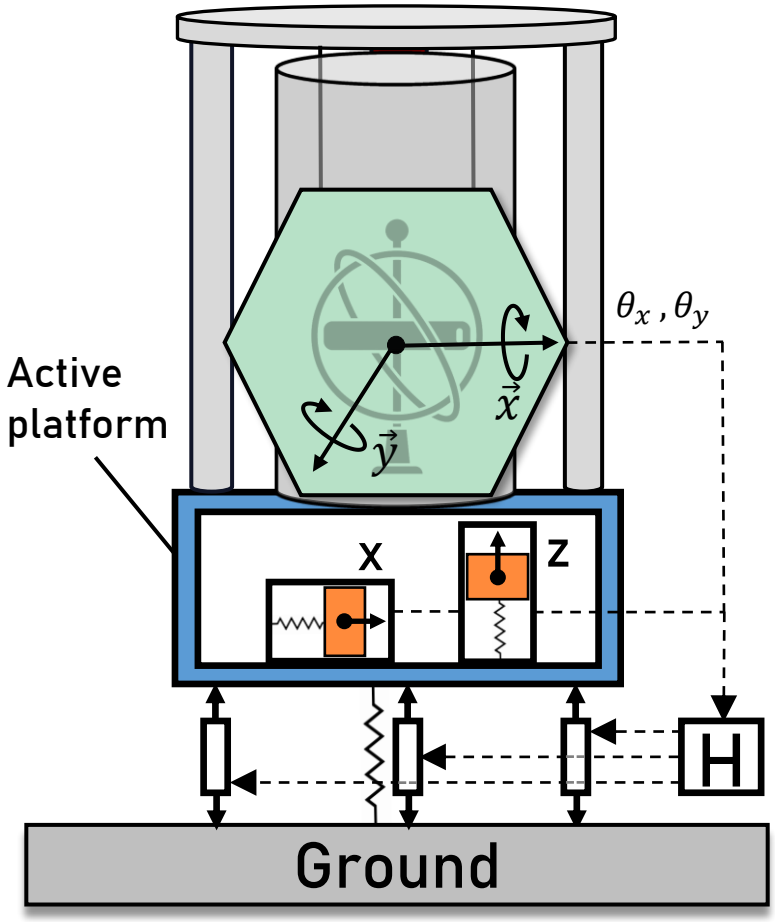
Actuator



➢ Induce rotation

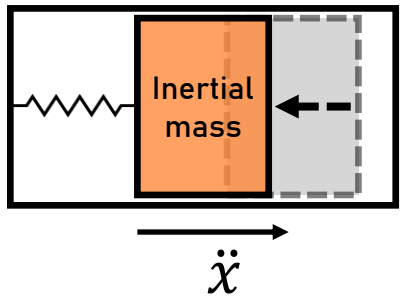
Solution

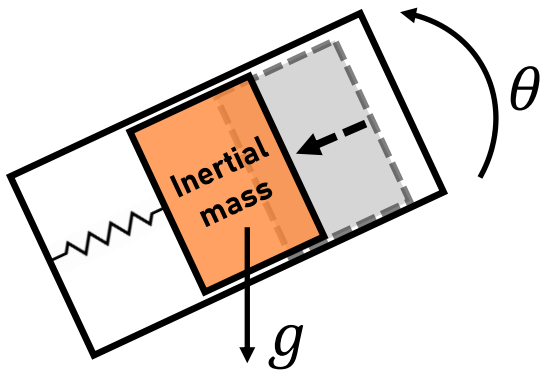
ETEST



3 horizontal sensor/actuator pairs
3 vertical sensor/actuator pairs

Inertial sensor

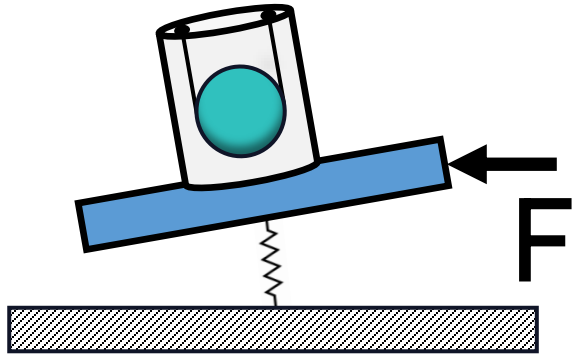




➢ No distinction

Add gyroscope to measure and control rotation

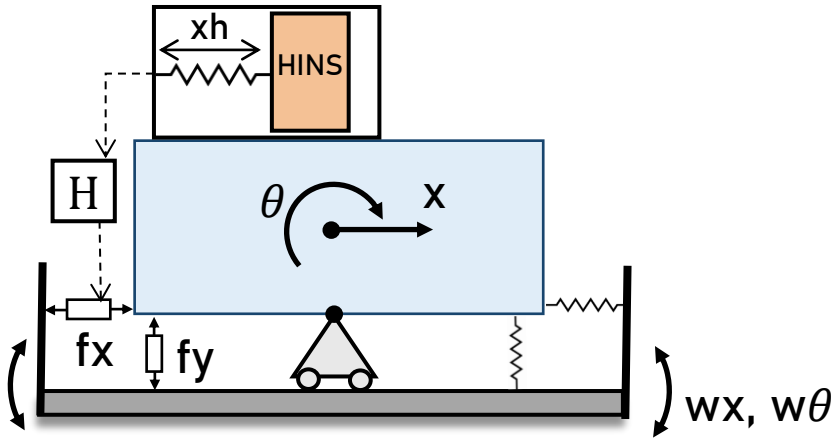
Actuator



➢ Induce rotation

Study on simplified model

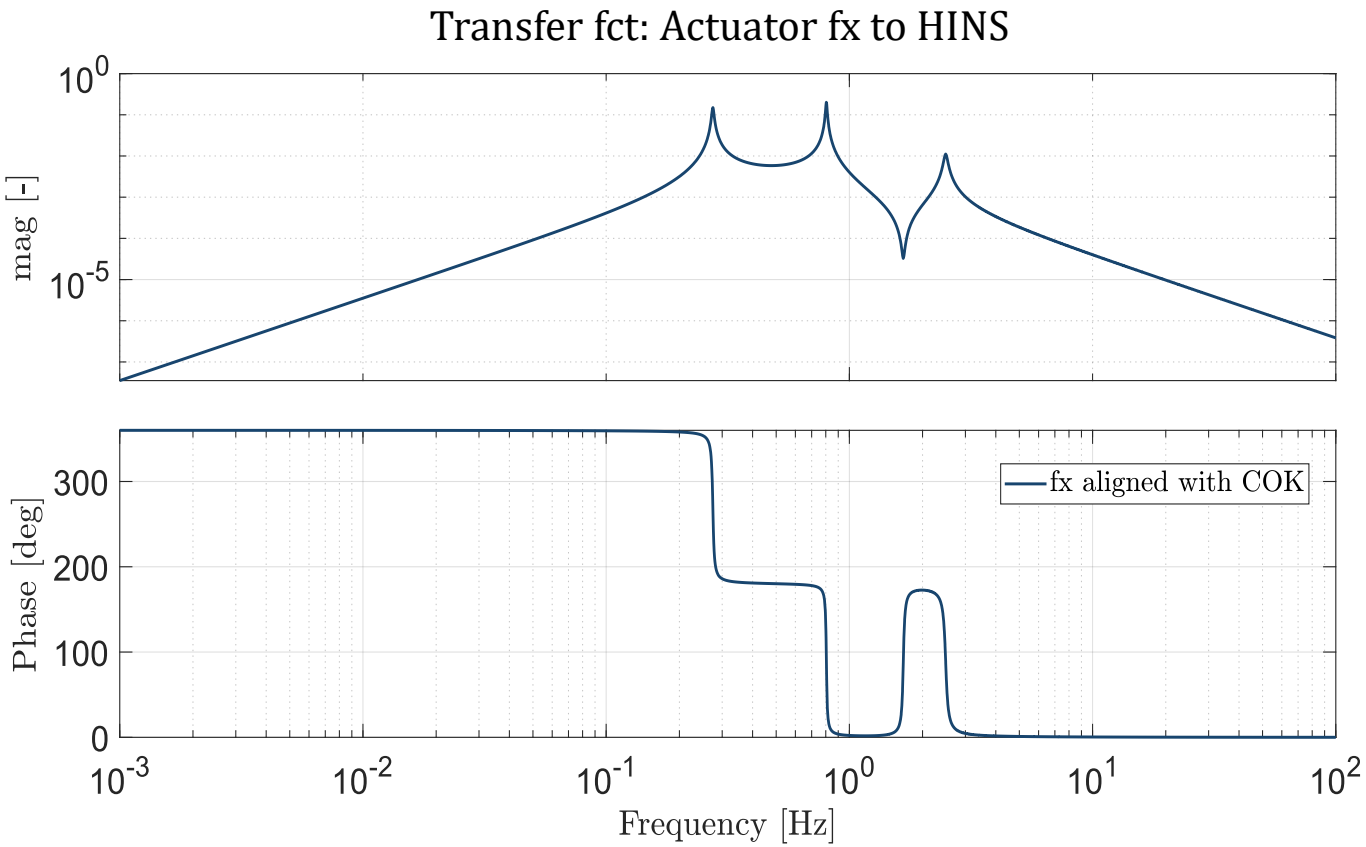
Rotation translation coupling



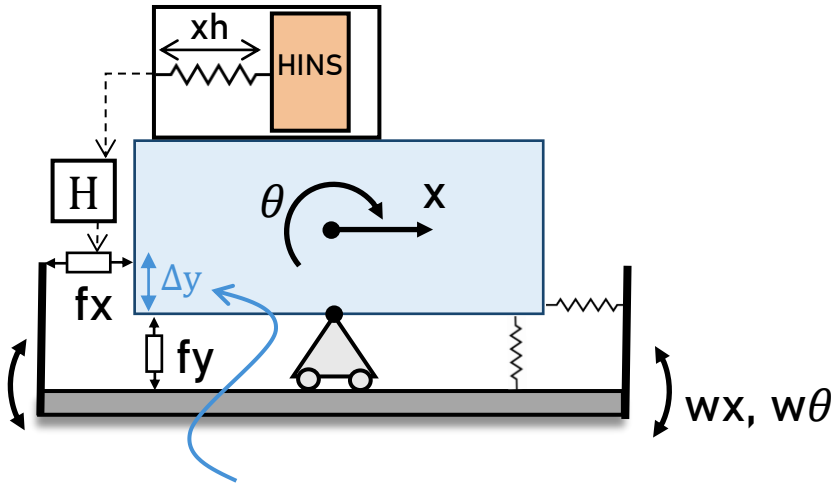
2 dofs :
- Translation x
- Rotation θ

1 sensor :
- HINS measuring xh

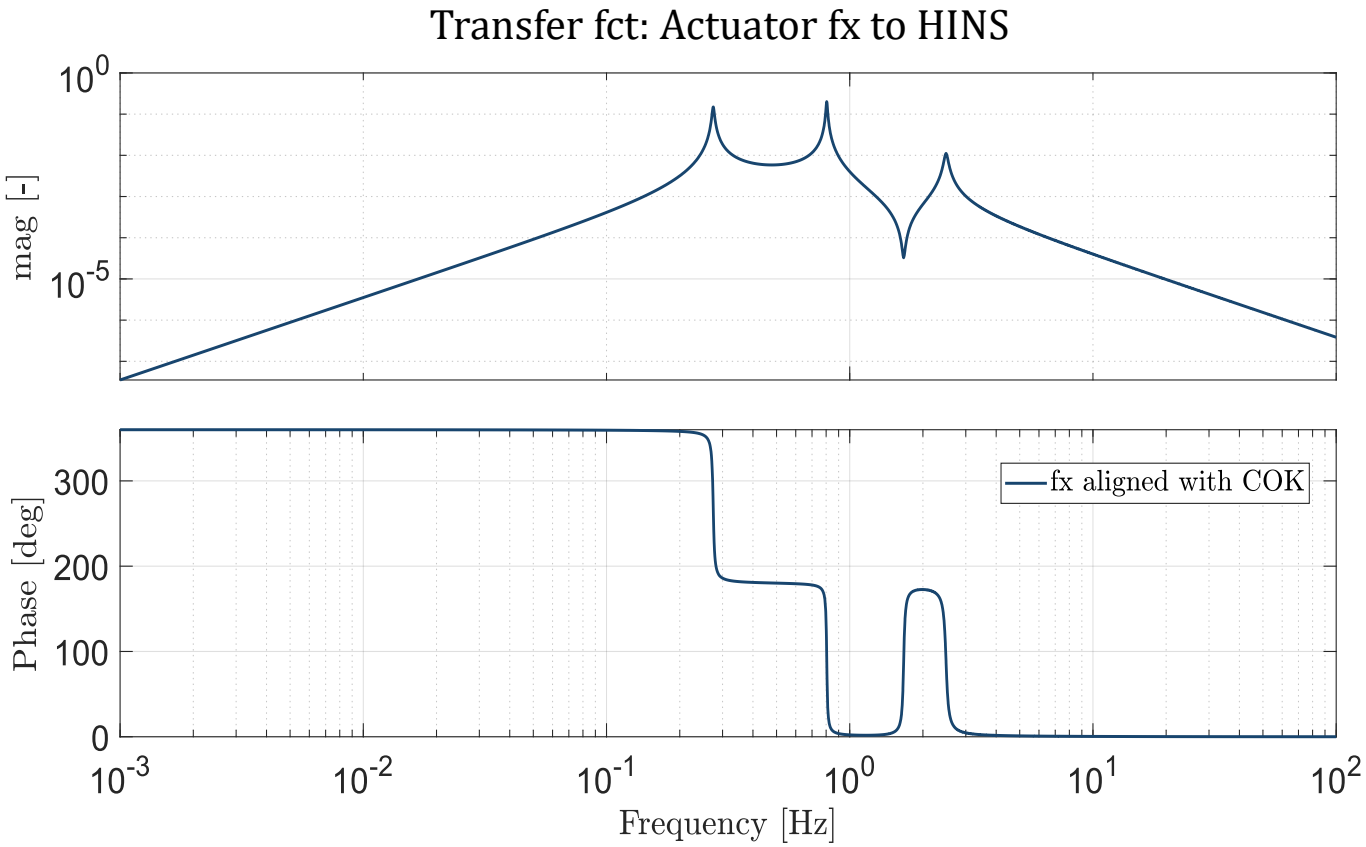
2 actuators :
- fx & fy



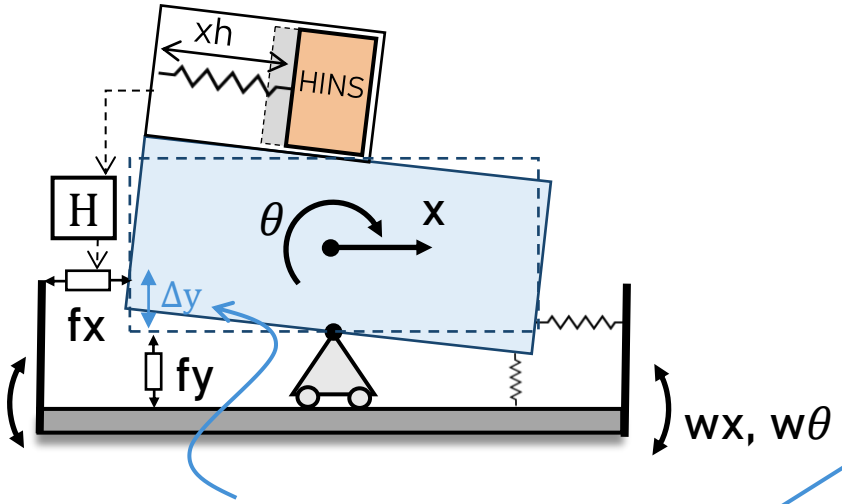
Rotation translation coupling



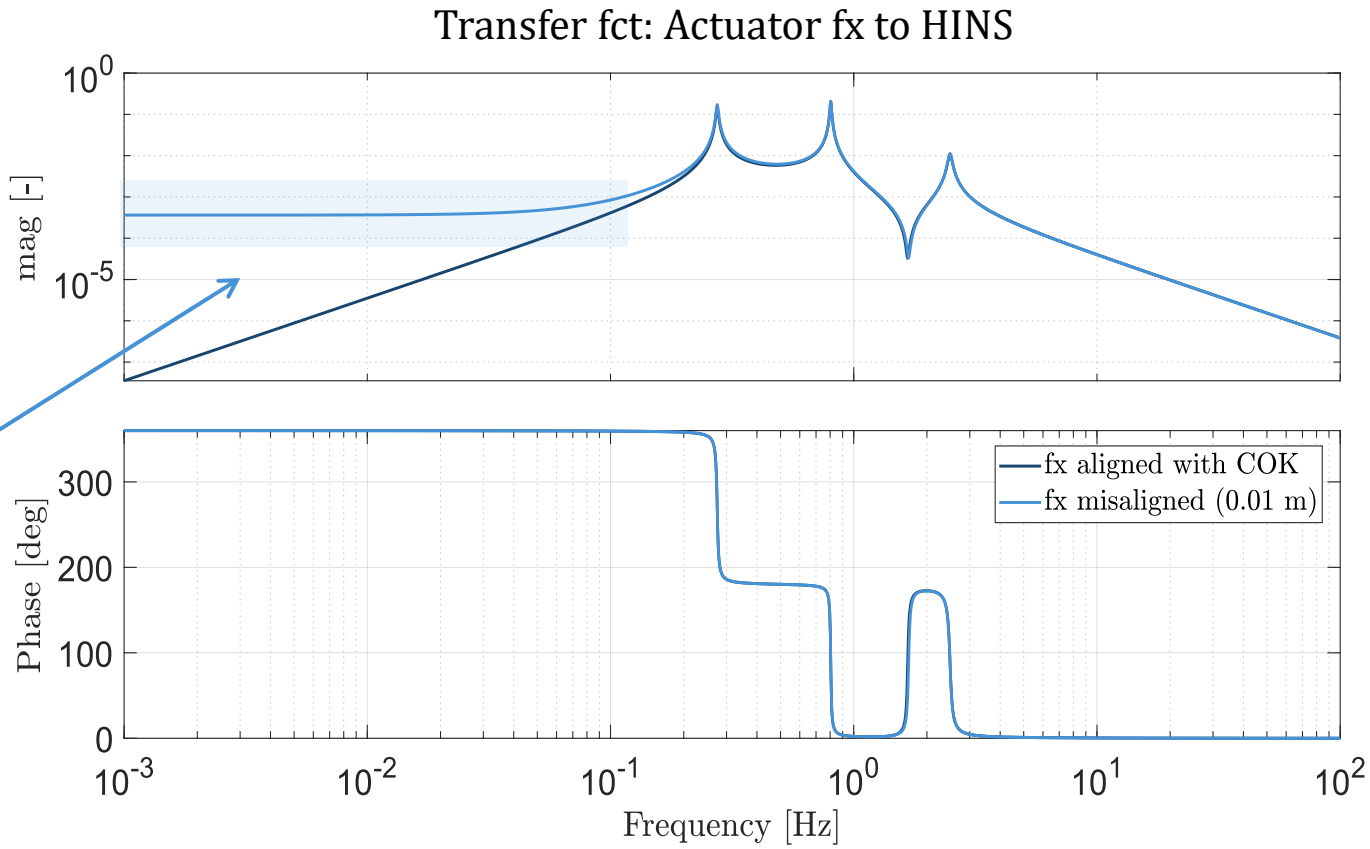
Misalignement of actuator w.r.t Center of Stiffness



Rotation translation coupling

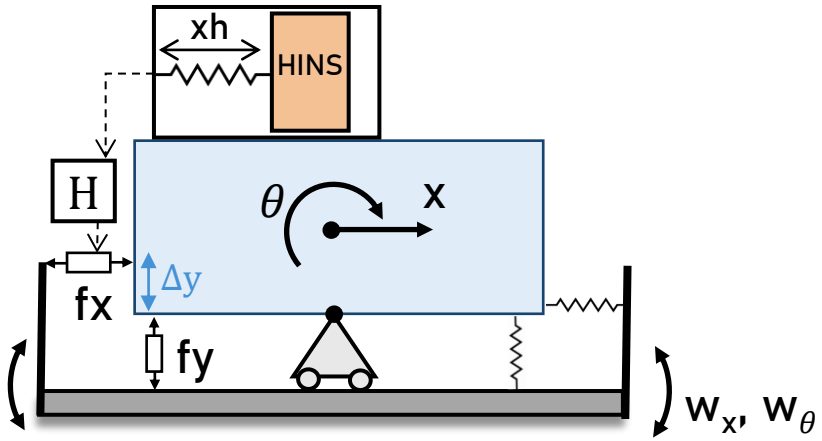


Misalignement of actuator w.r.t Center of Stiffness



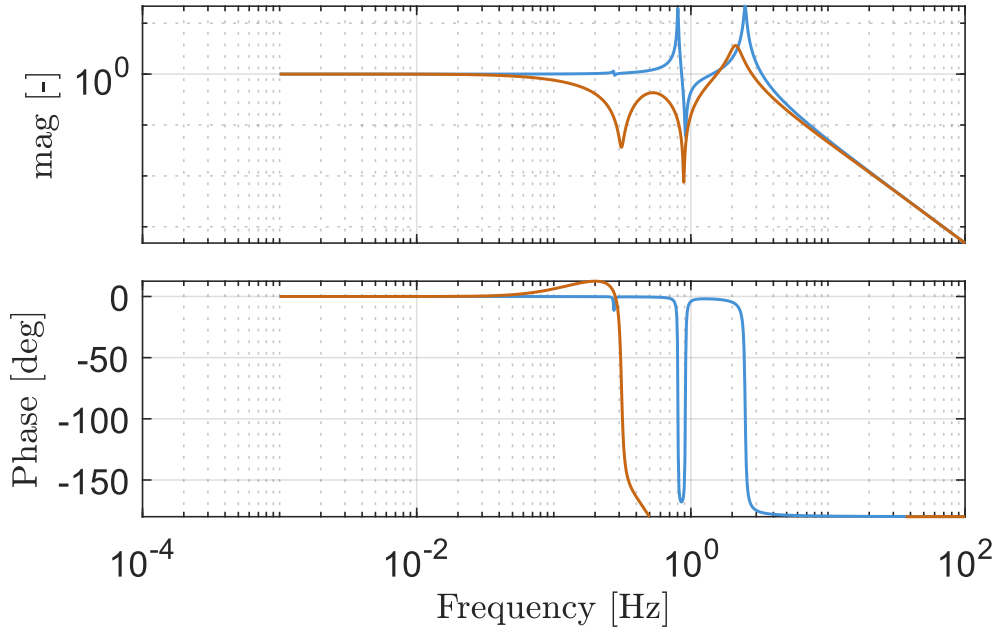
Coupling introduces translation control limitation (BW, gain)

Translation isolation with HINS

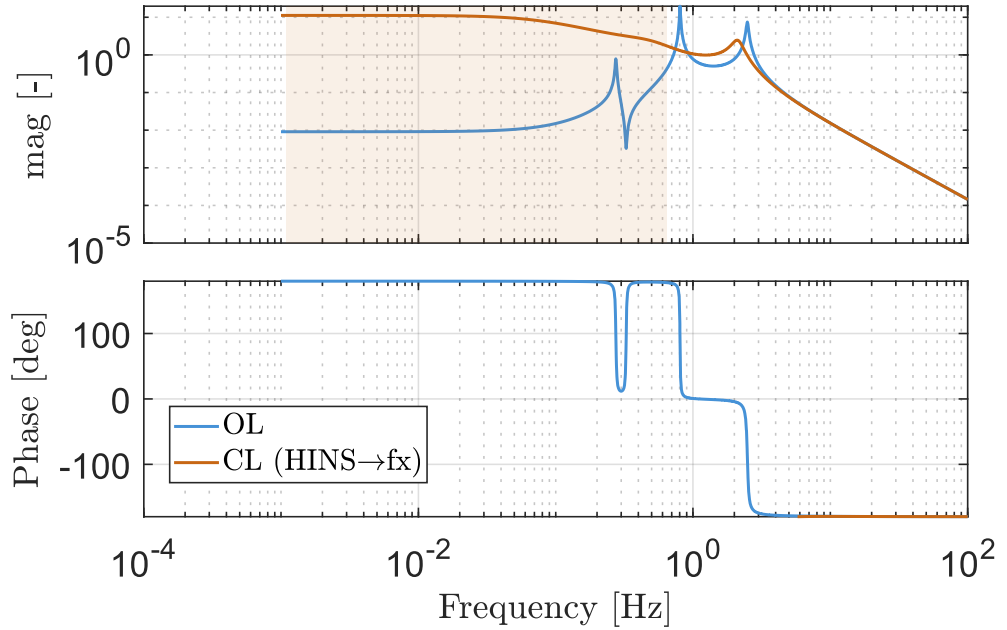


- Very little isolation in translation
- Amplify the effect of ground rotation on payload translation

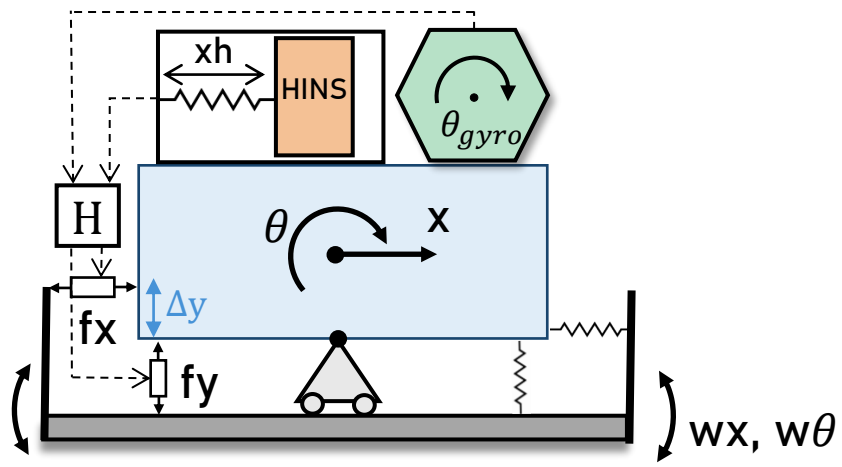
Transmissibility: ground translation to mass displacement



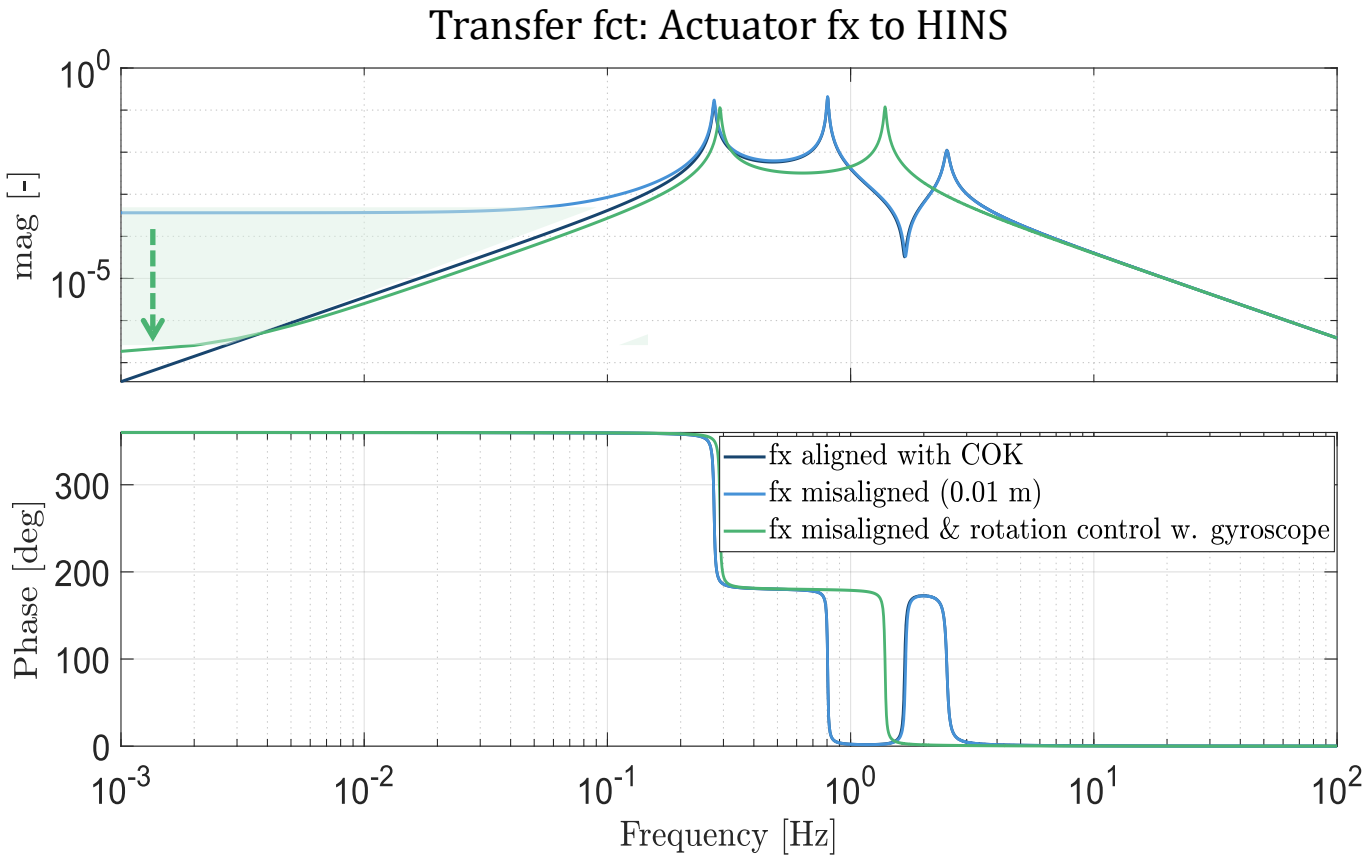
Transmissibility: ground rotation to mass displacement



Effect of rotation control on translation control

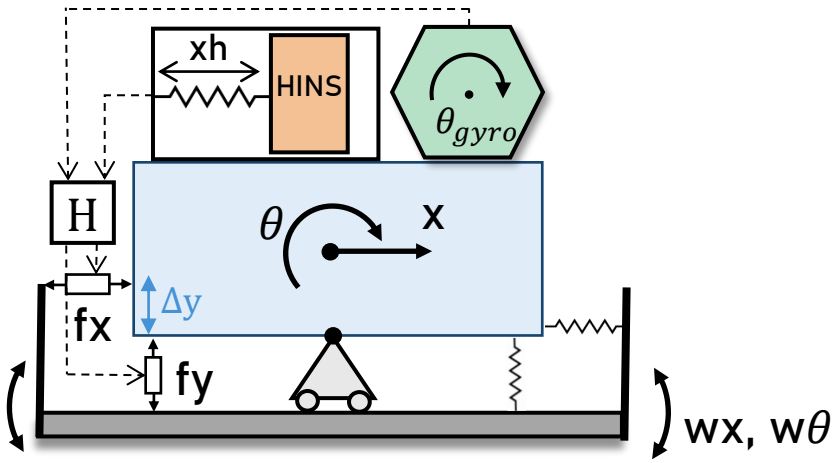


Addition of a gyroscope measuring θ_{gyro}



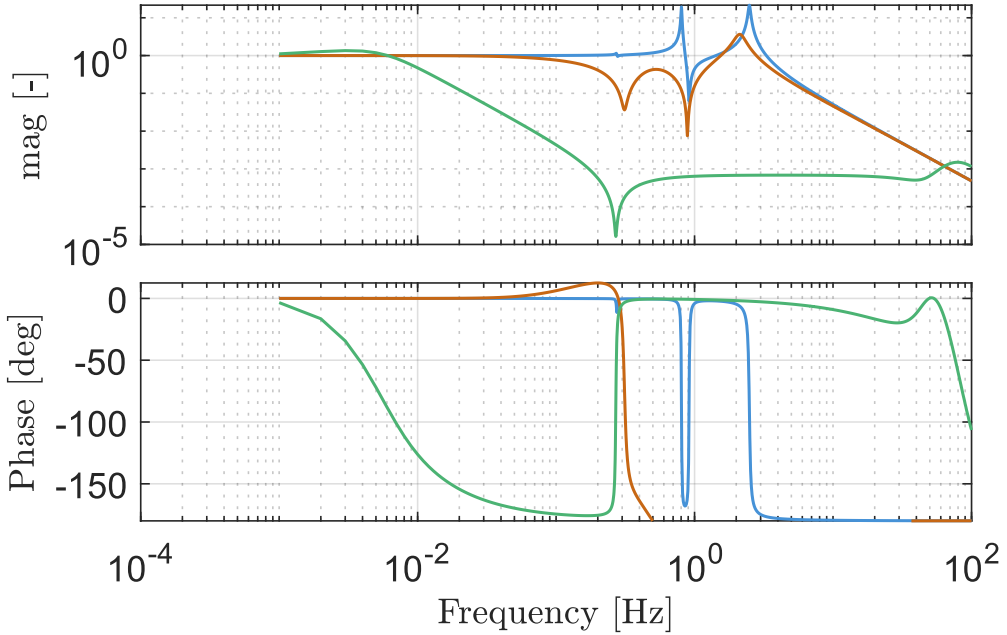
Controlling the rotation decreases coupling effect

Isolation with HINS + GYRO

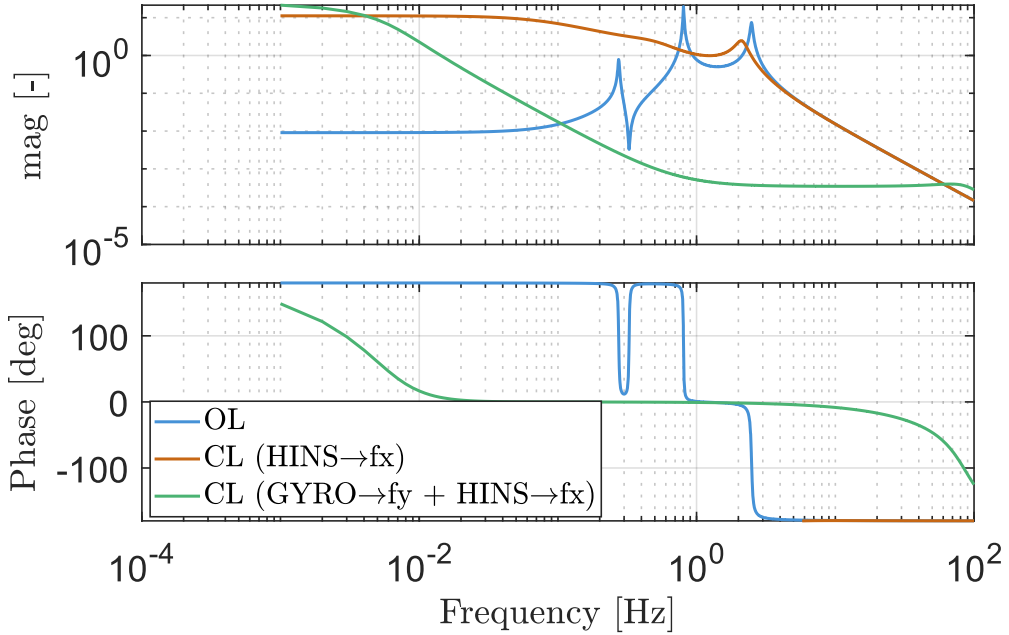


- Much larger isolation in translation
- Greater isolation bandwidth (→ 10 mHz)

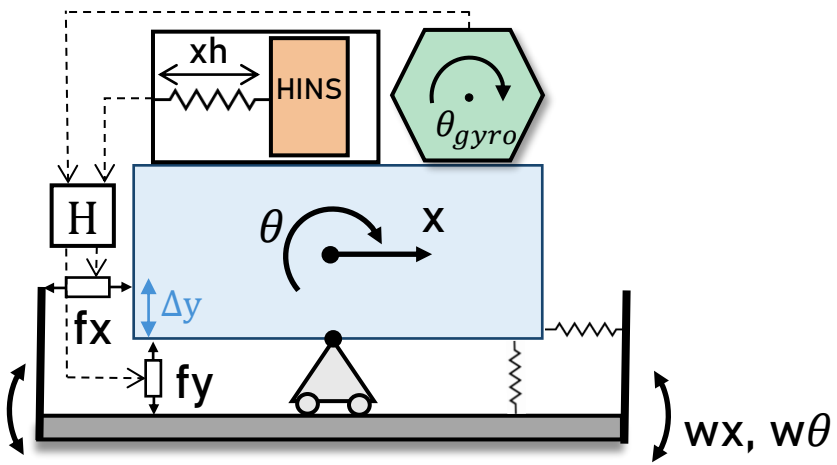
Transmissibility: ground translation to mass displacement

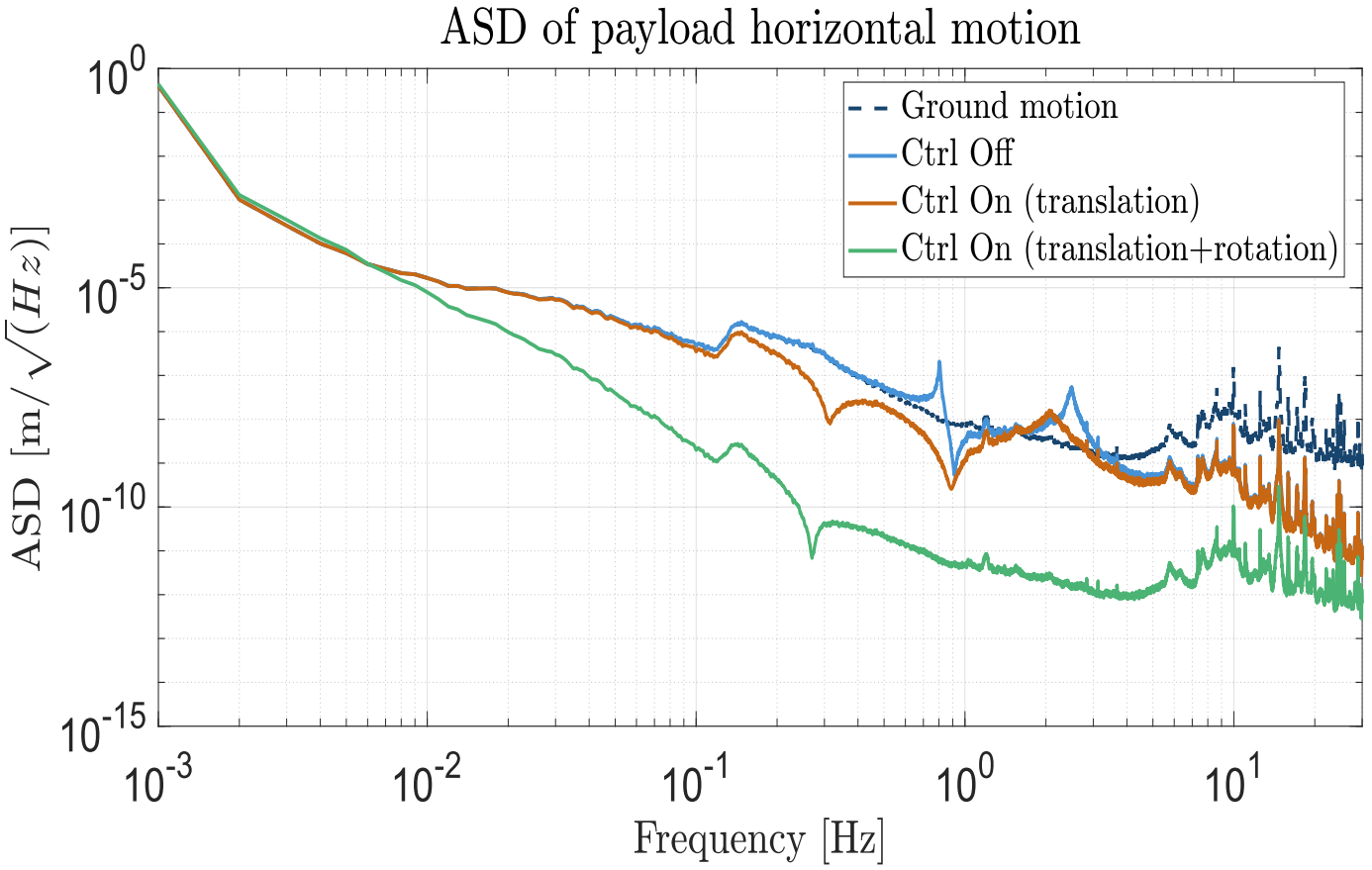


Transmissibility: ground rotation to mass displacement



Amplitude spectral density

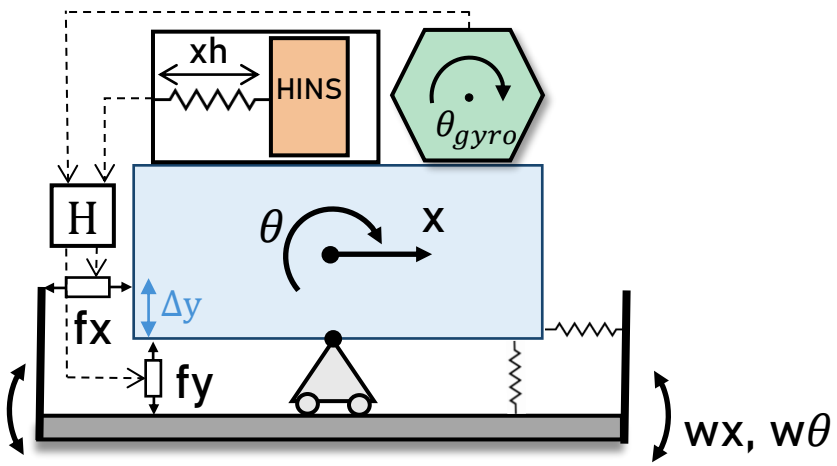


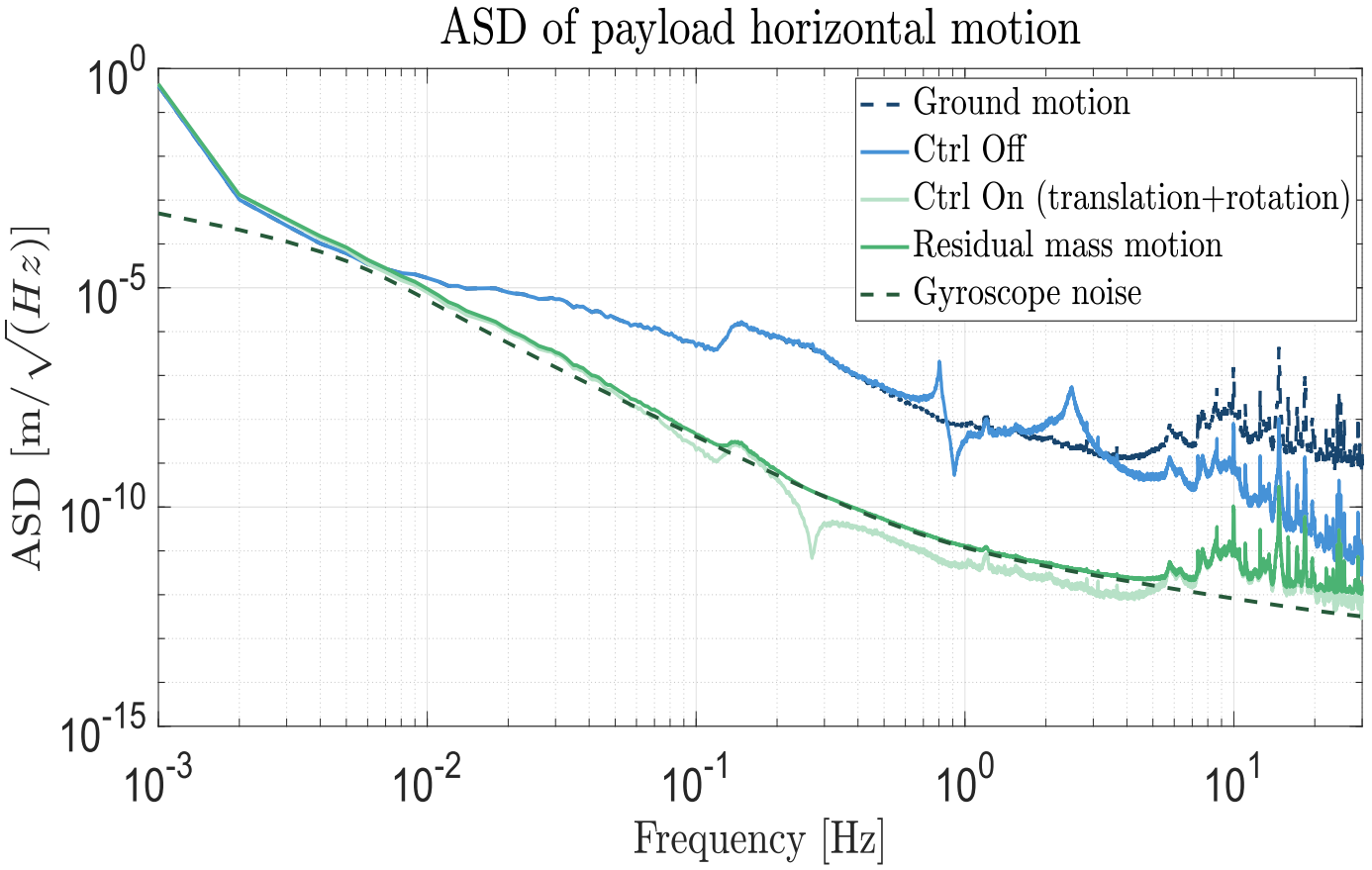


What is the needed resolution ?

- Up to 3 ordres of isolation
- Horizontal isolation down to very low frequencies (→ 10 mHz)

Amplitude spectral density



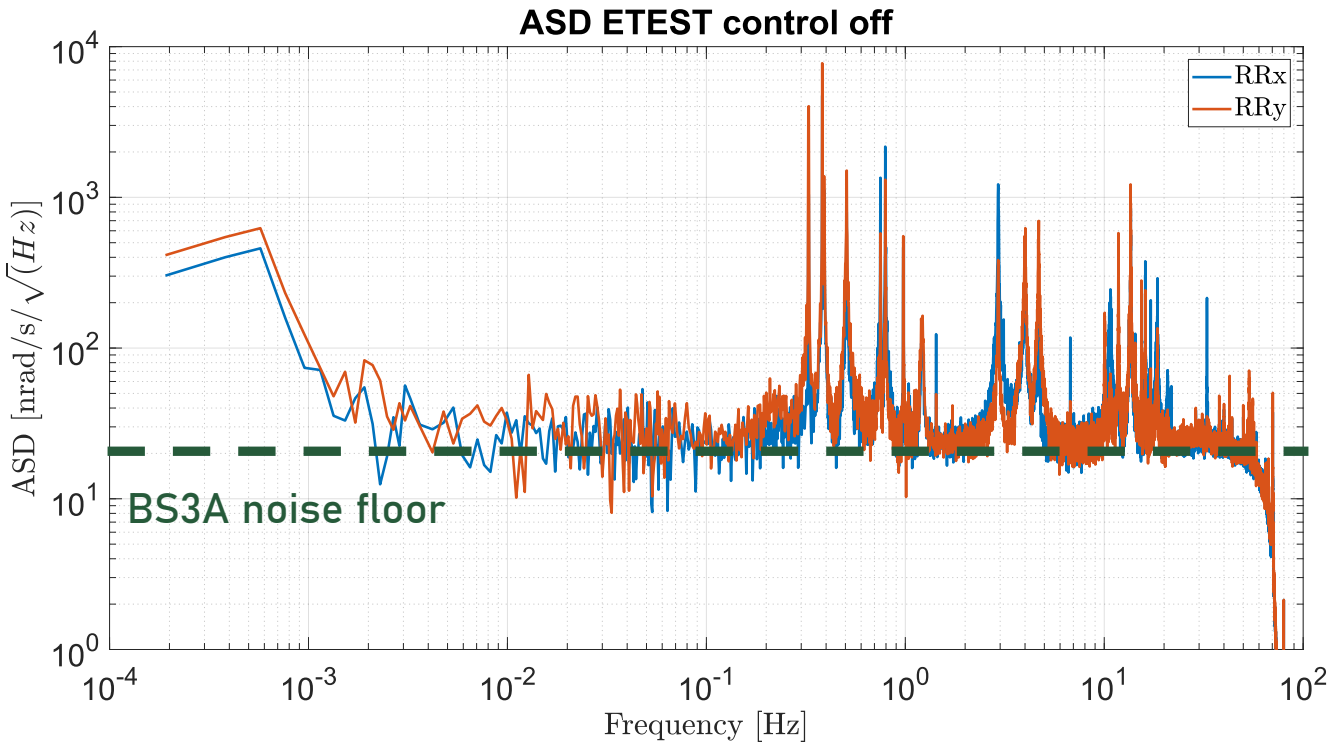


Resolution requirement
0.1 nrad/s/$\sqrt{Hz}$
in BW [10 mHz – 10 Hz]

- Up to 3 ordres of isolation
- Horizontal isolation down to very low frequencies (→ 10 mHz)

Actuator decoupling with BlueSeis3A

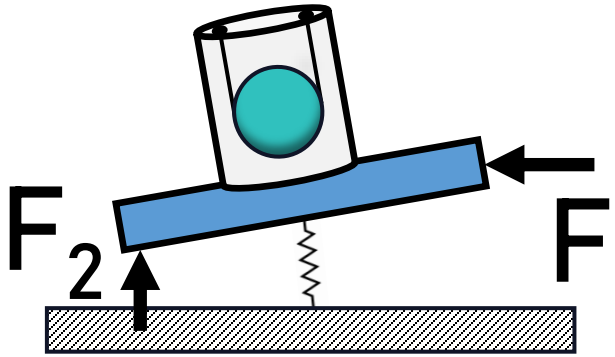
Measurement on AP control-off



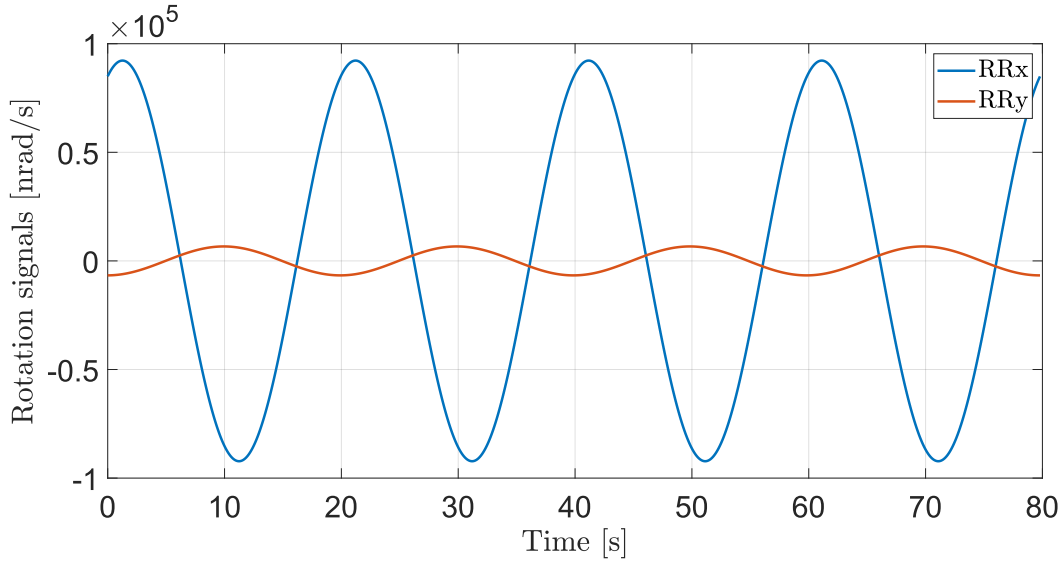
Resonance peaks are seen but too low resolution for active isolation

Actuator decoupling

Knowing the geometry allows to derive decoupling matrices
→ Works to some extent..



Measuring allows to adjust them !

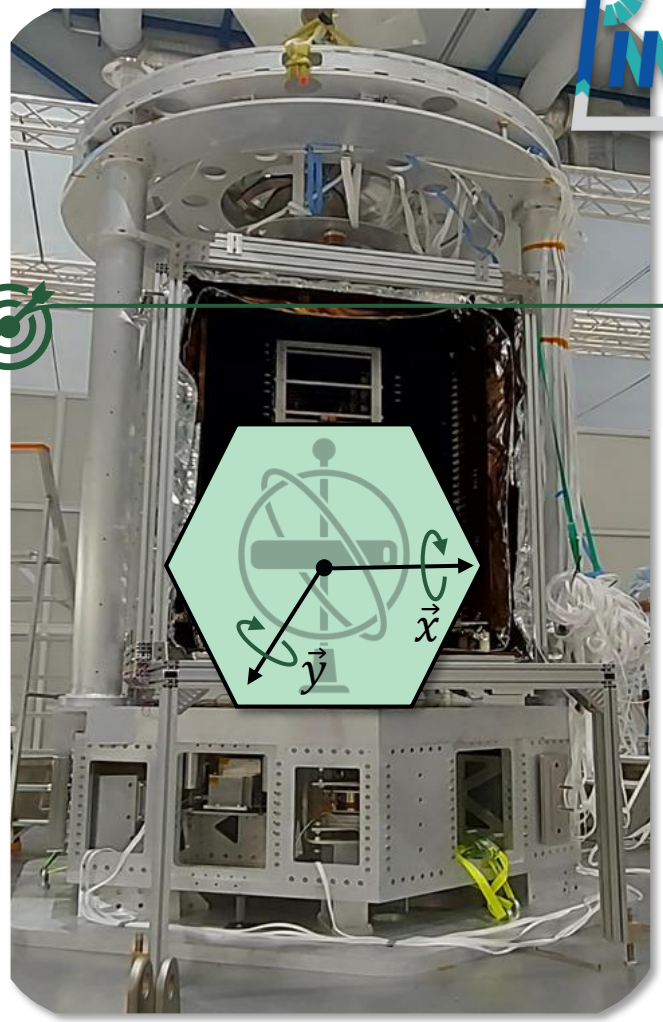


Actuation in rotation around X induce rotation around Y

Very low cross-axis sensitivity

Cross-axis actuation cancellation with BS3A ~1000
(50x better than BOSEM)

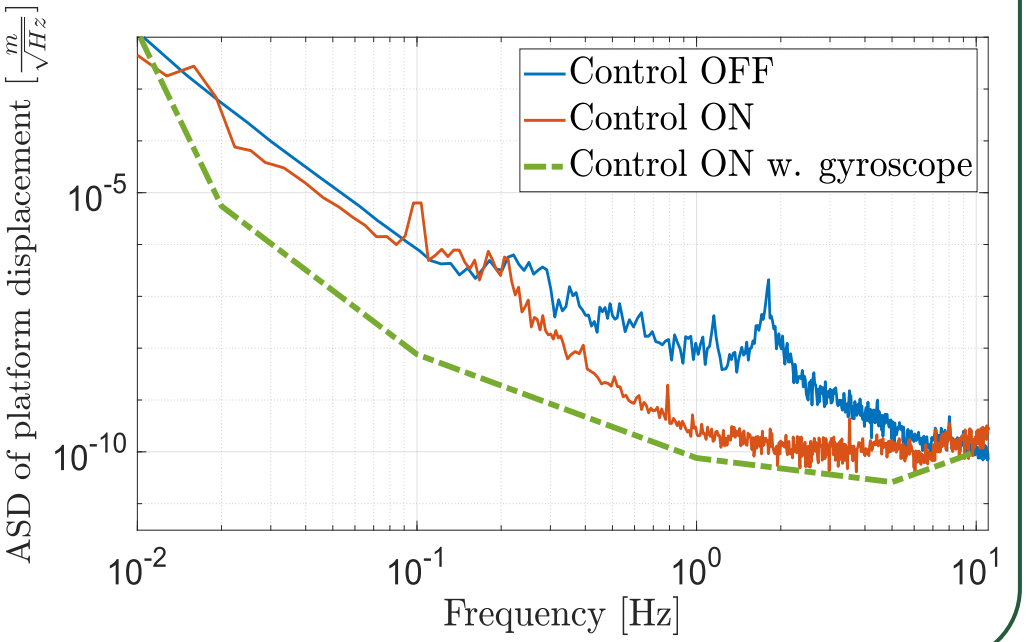
Conclusion



Rotation-translation coupling limits low frequency isolation

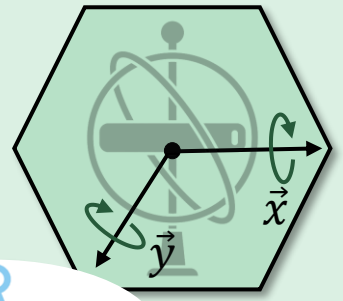
Controlling rotation decreases this detrimental coupling effect

Enhance ETEST isolation performances with high resolution gyroscope



Develop high resolution gyroscope

- 0.1 nrad/s/$\sqrt{Hz}$
- Insensitive to translation
- $S_{cross-axis}$ << 1



MAAGM

Thank you for your attention !

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