Precise absolute gravimeter for inertial control

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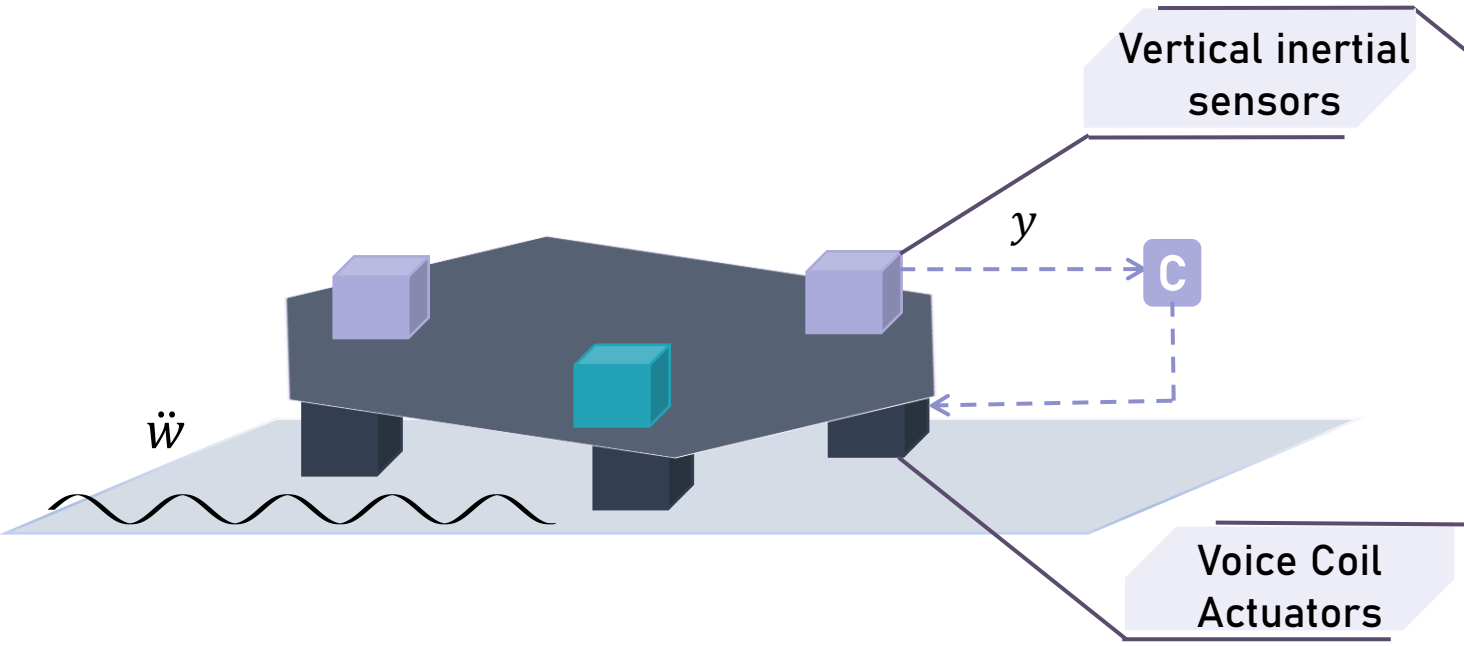
3rd year of PhD in Université Libre de Bruxelles

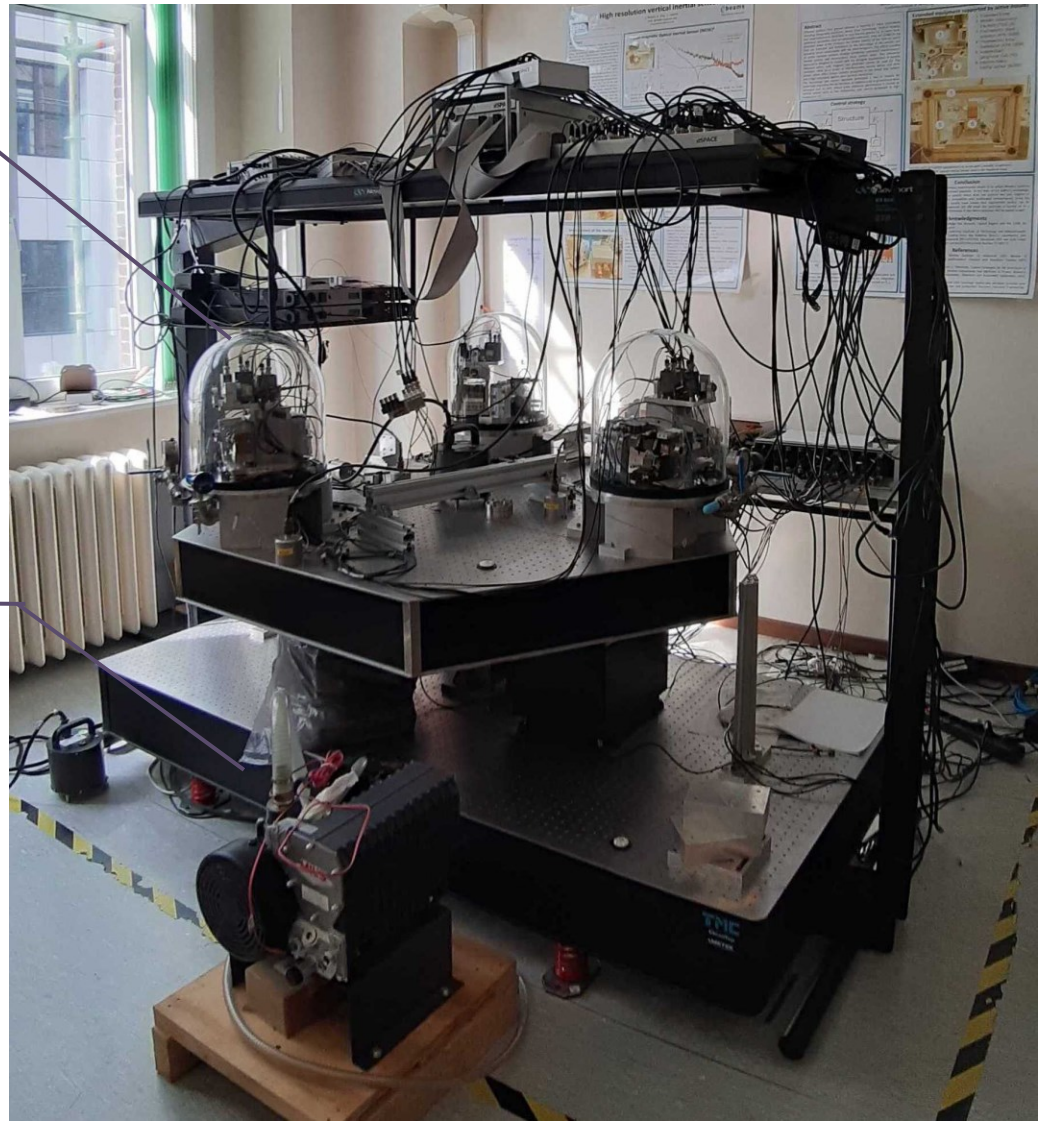
Supervisor: Pr. Christophe Collette

Ligo-Virgo-Kagra Collaboration meeting - Barcelona

23 - 26 September 2024

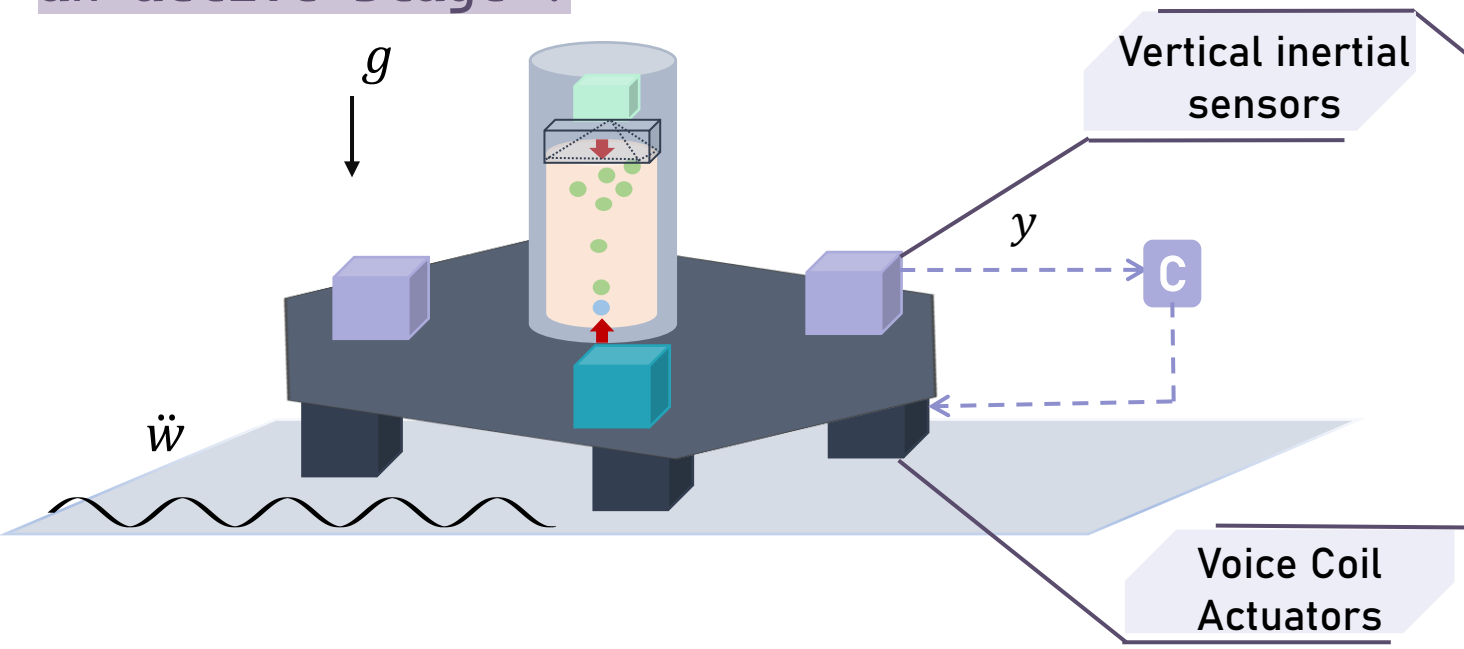
Context

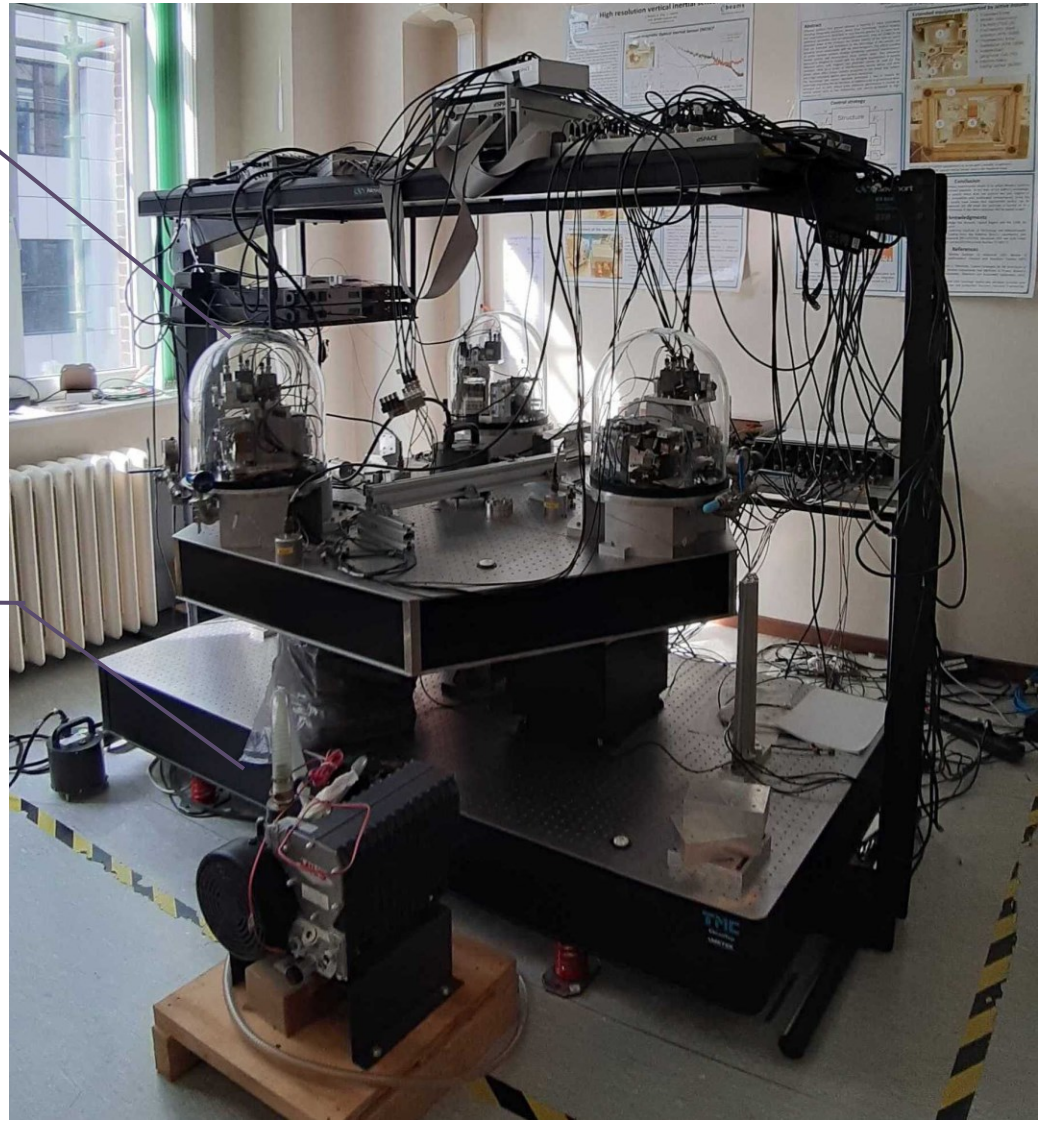




Context

How is gravity impacting an active stage ?



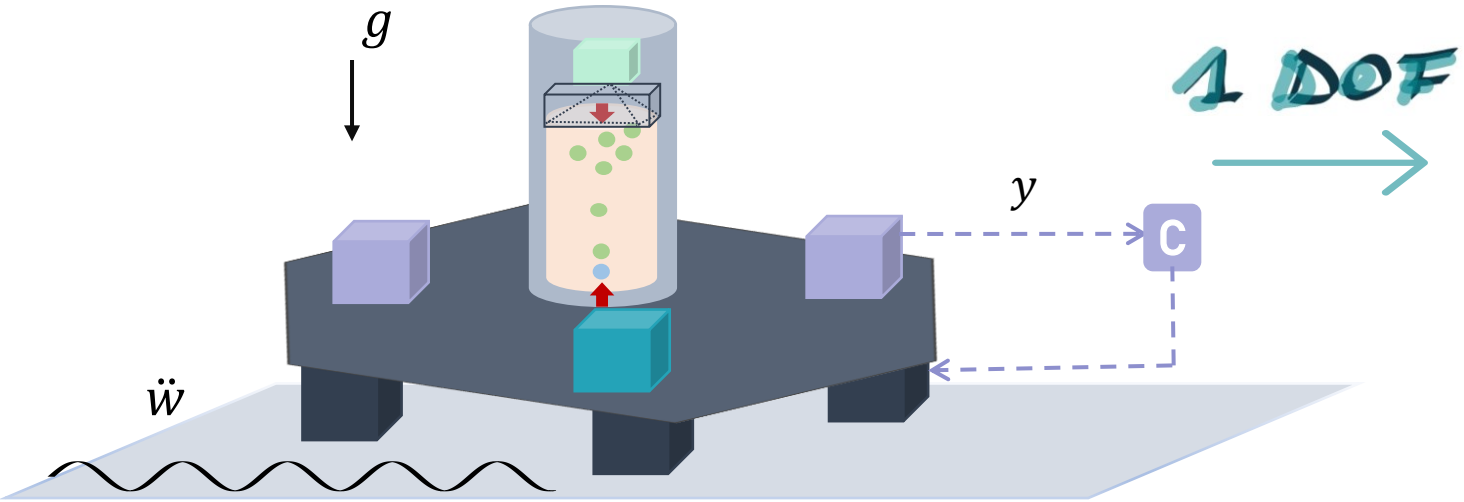


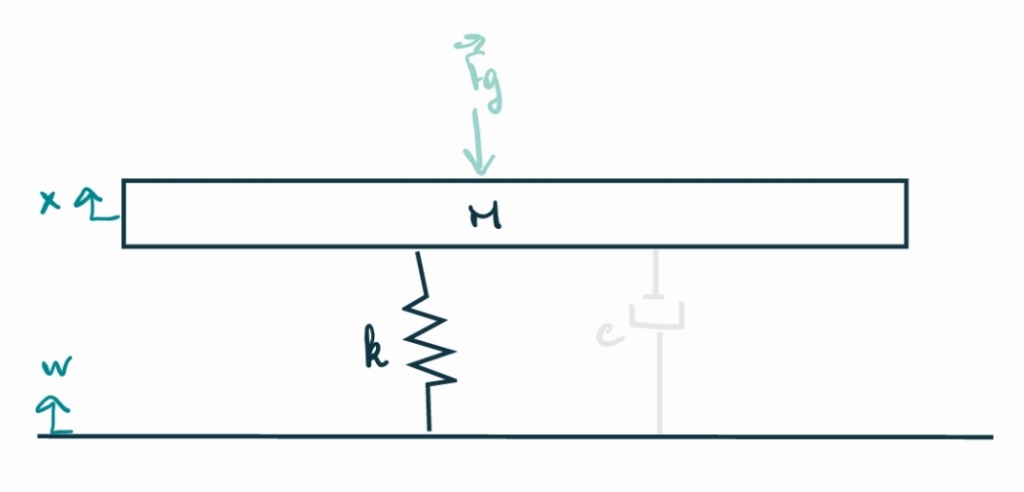
1. Effect of gravity on an active isolation stage ?
2. Test-bench for experimental validation
3. Control the gravity ?

1. Gravity in active isolation

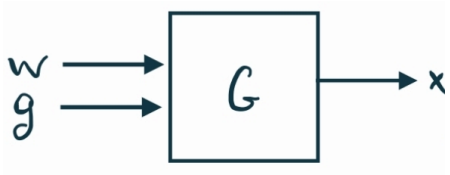
Effect of gravity on passive stage

1





1. Gravity in active isolation

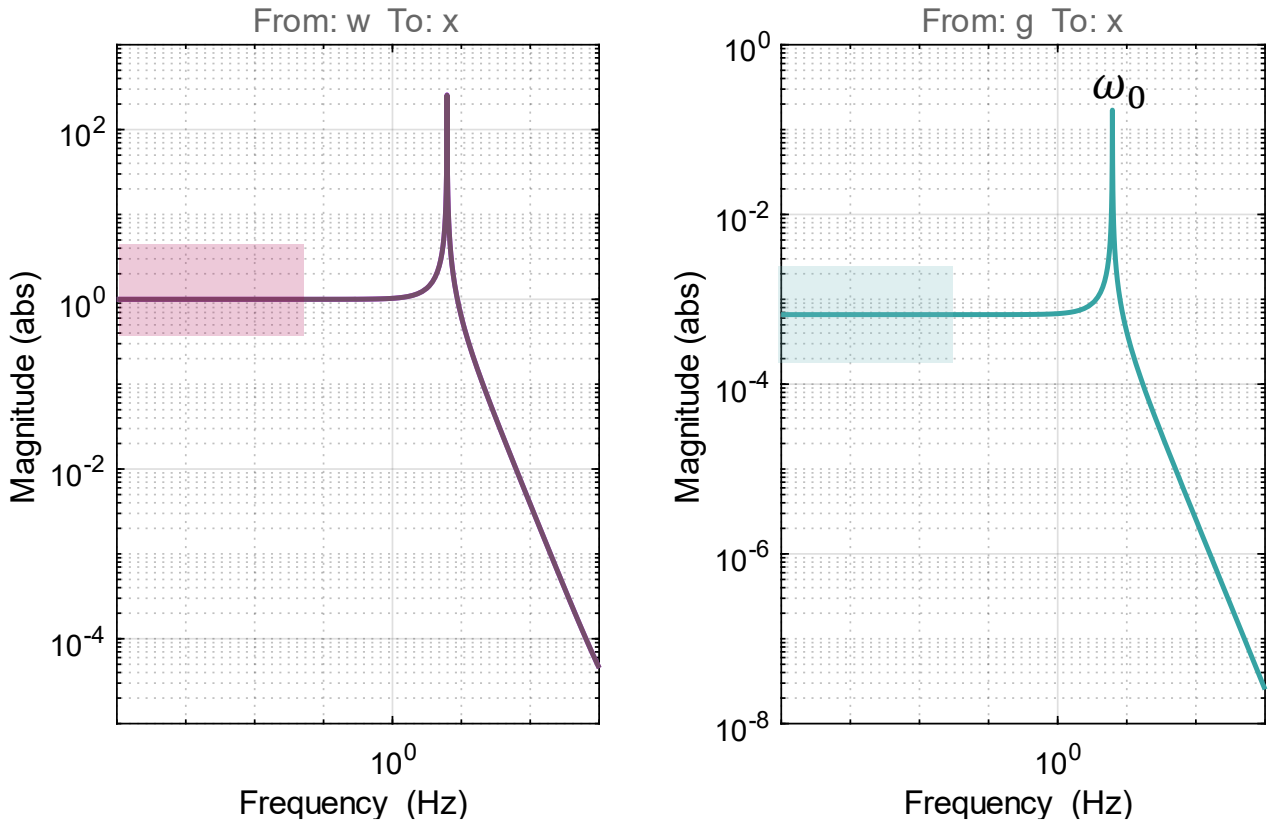


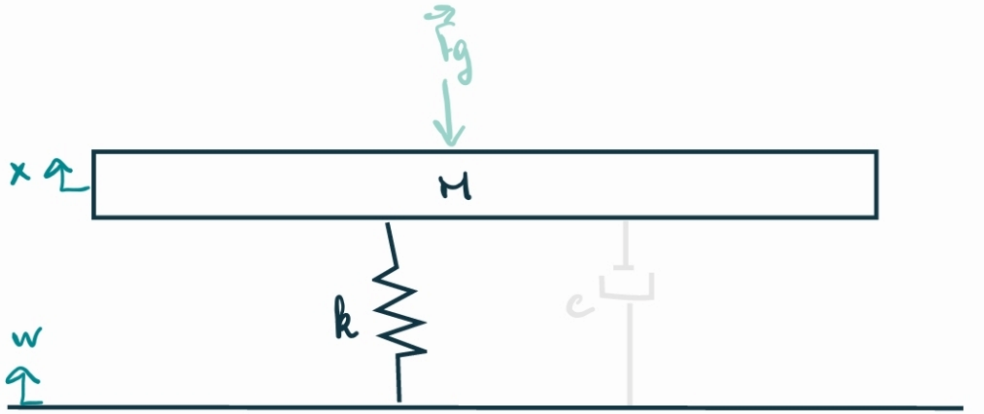
$$M\,\ddot{x} + k(x - w) = -Mg$$

$$\rightarrow X = \frac{\omega_0^2}{s^2 + \omega_0^2} w - \frac{1}{s^2 + \omega_0^2} g$$

Effect of gravity on passive stage

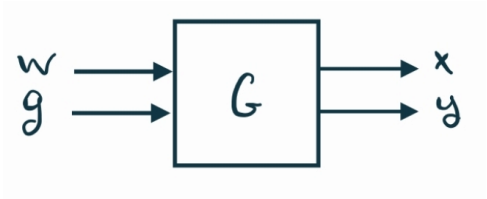
1





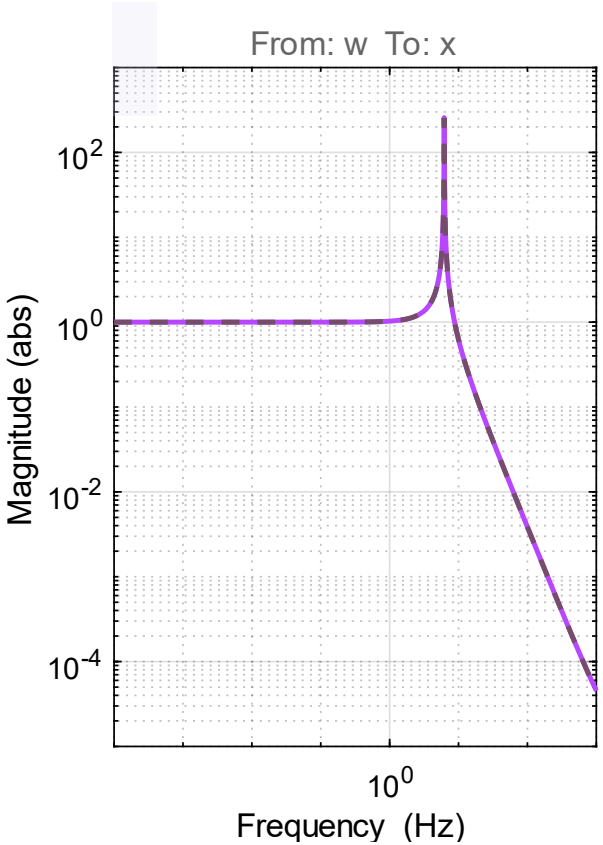
The platform sensitivity to gravity is dependent on its resonance ω_0

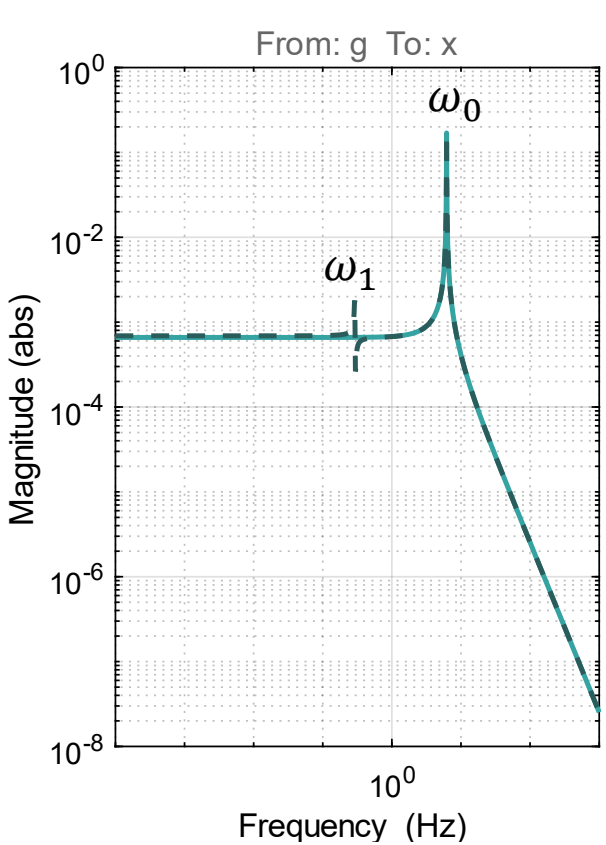
1. Gravity in active isolation



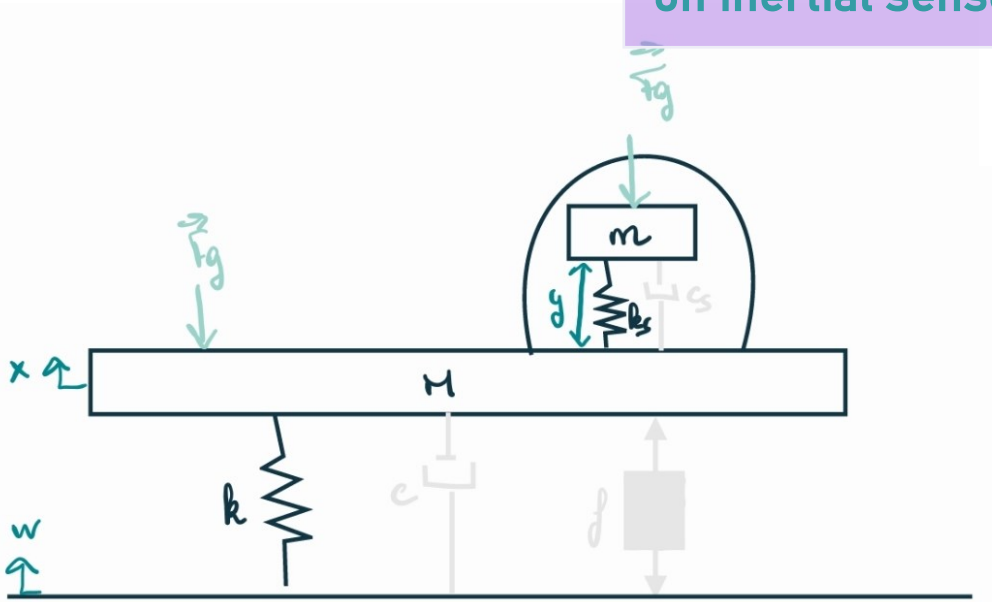
$$(1):\ M\ddot{x} + k(x - w) - k_s y = -Mg$$
$$(2):\ m(\ddot{y} + \ddot{x}) + k_s y = -mg$$

$$\rightarrow X = \frac{\omega_0^2}{s^2 + \omega_0^2} w - \frac{1}{s^2 + \omega_0^2} g$$



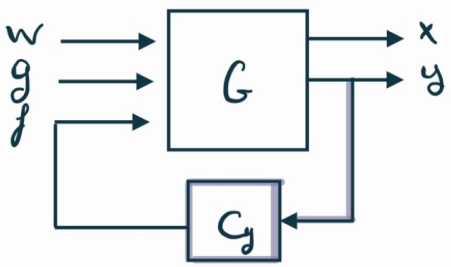


2 Effect of gravity on inertial sensor



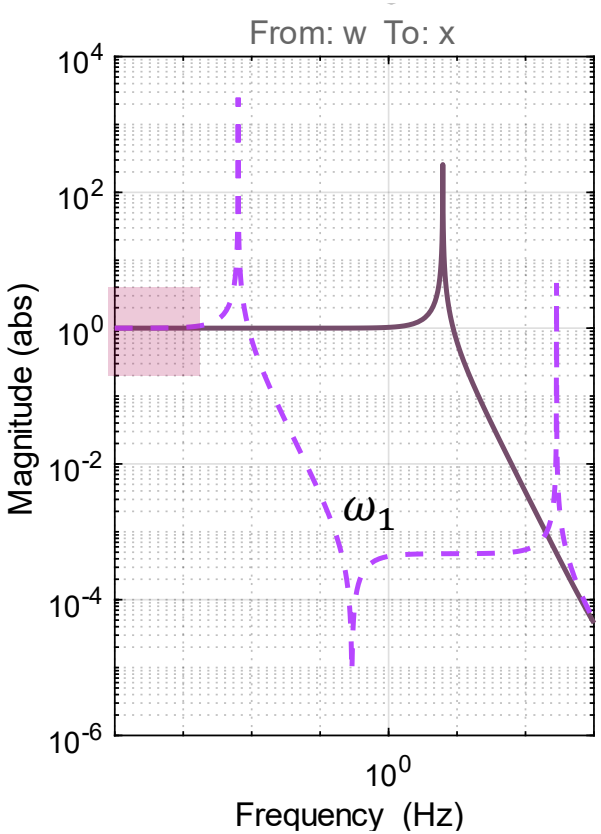
The platform sensitivity to gravity is dependent on its resonance ω_0

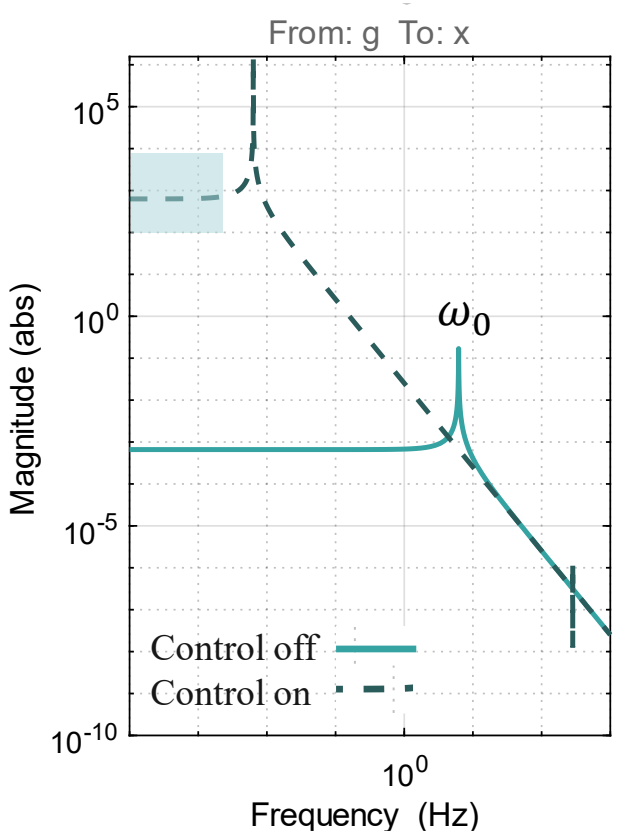
1. Gravity in active isolation



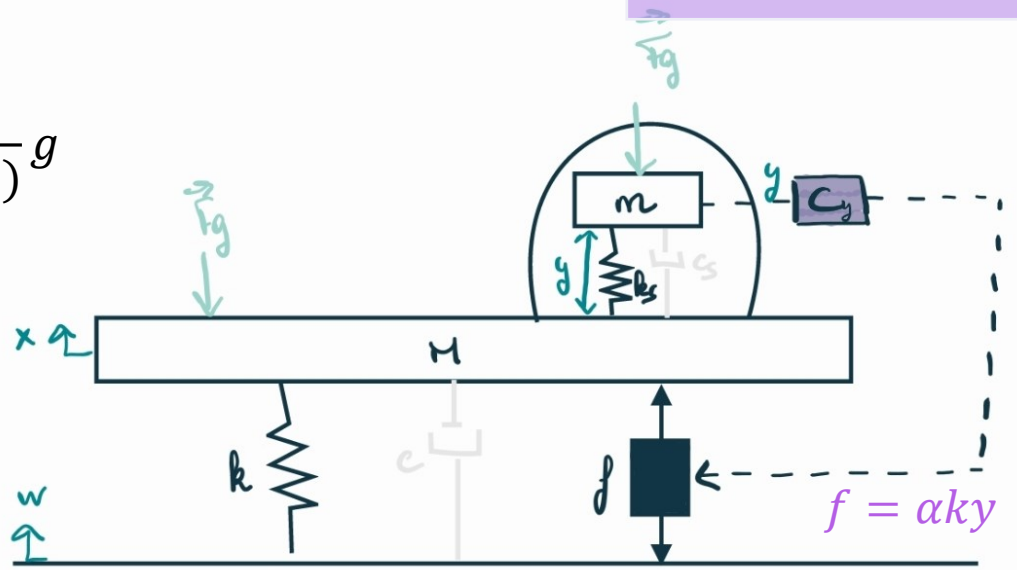
$$(1):\ M\ddot{x} + k(x - w) - k_s y = -Mg + f$$
$$(2):\ m(\ddot{y} + \ddot{x}) + k_s y = -mg$$

$$\rightarrow X = \frac{s^2 + \boldsymbol{\omega_1^2}}{s^2(1+\alpha) + \boldsymbol{\omega_1^2}} w - \frac{s^2 + \omega_1^2 + \boldsymbol{\alpha}\omega_0^2}{\omega_0^2(s^2(1+\alpha) + \boldsymbol{\omega_1^2})} g$$

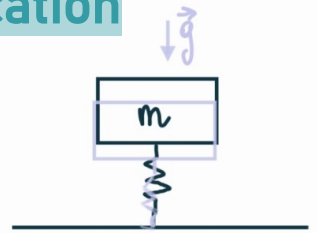




3 Effect of gravity in active control

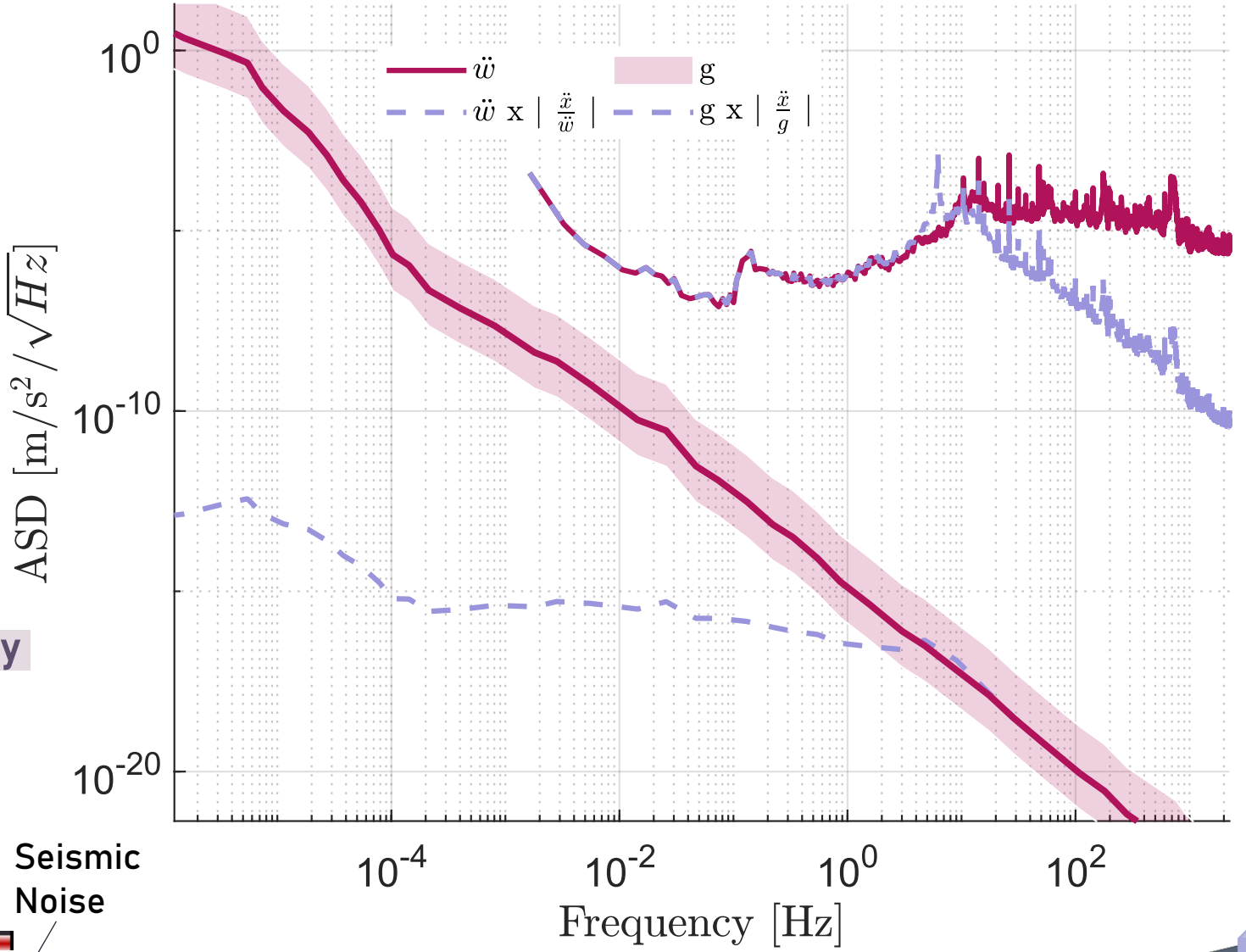


→ Low frequency magnification



Seismic isolation using inertial sensor magnifies the payload sensitivity to gravity

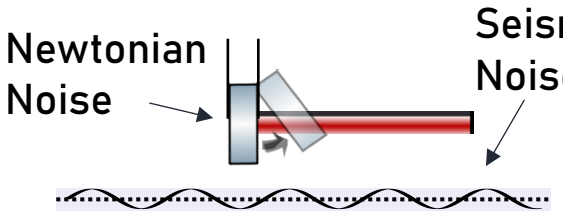
1. Gravity in active isolation

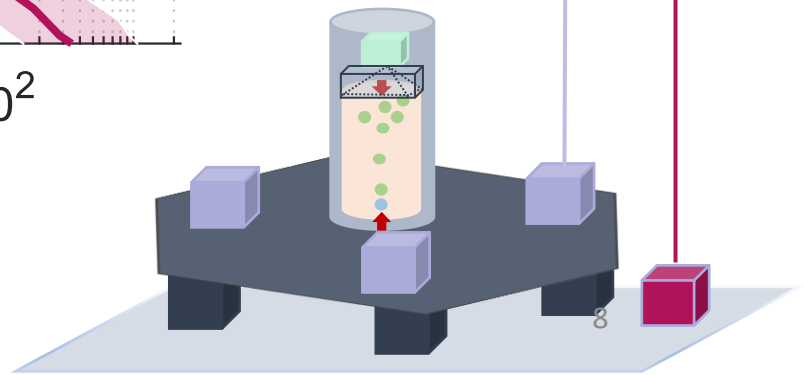


No isolation

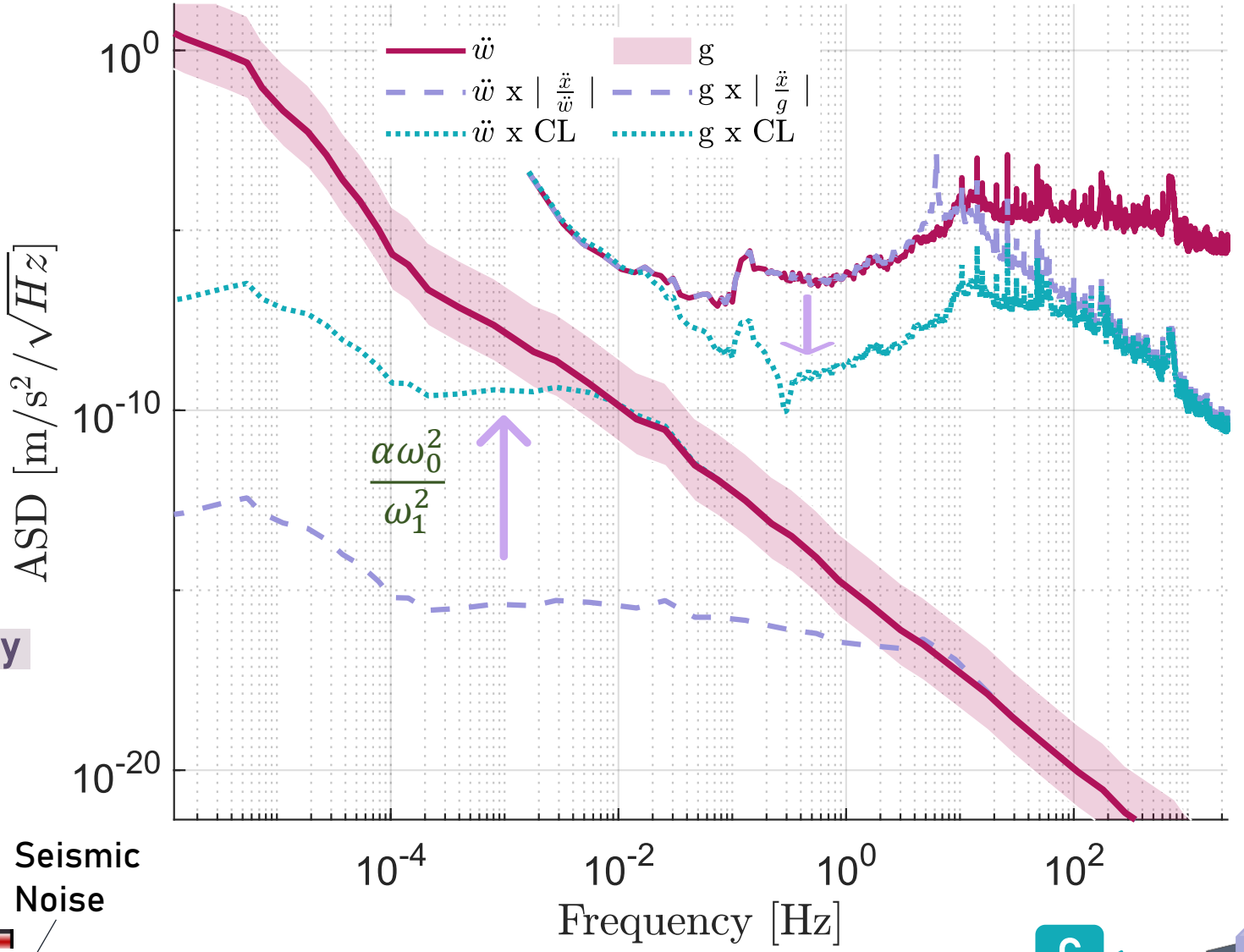
Passif isolation

→ **Theoretical gravity spectrum ~ Newtonian Noise**





1. Gravity in active isolation

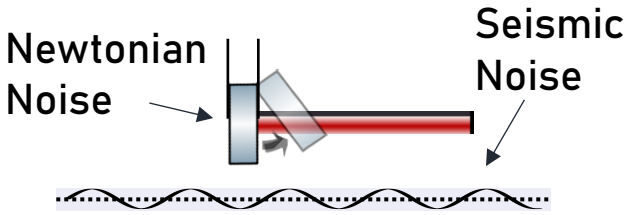


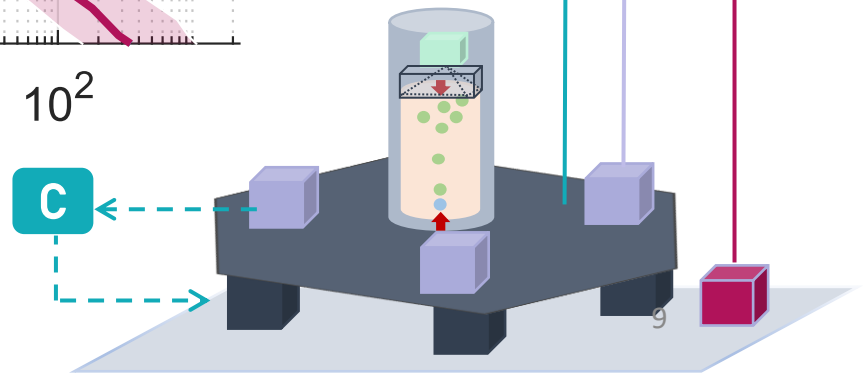
No isolation

Passif isolation

Actif isolation

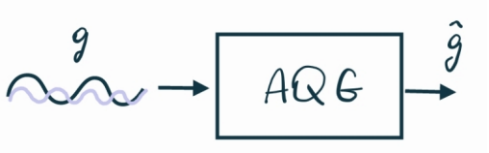
→ **Theoretical gravity spectrum ~ Newtonian Noise**

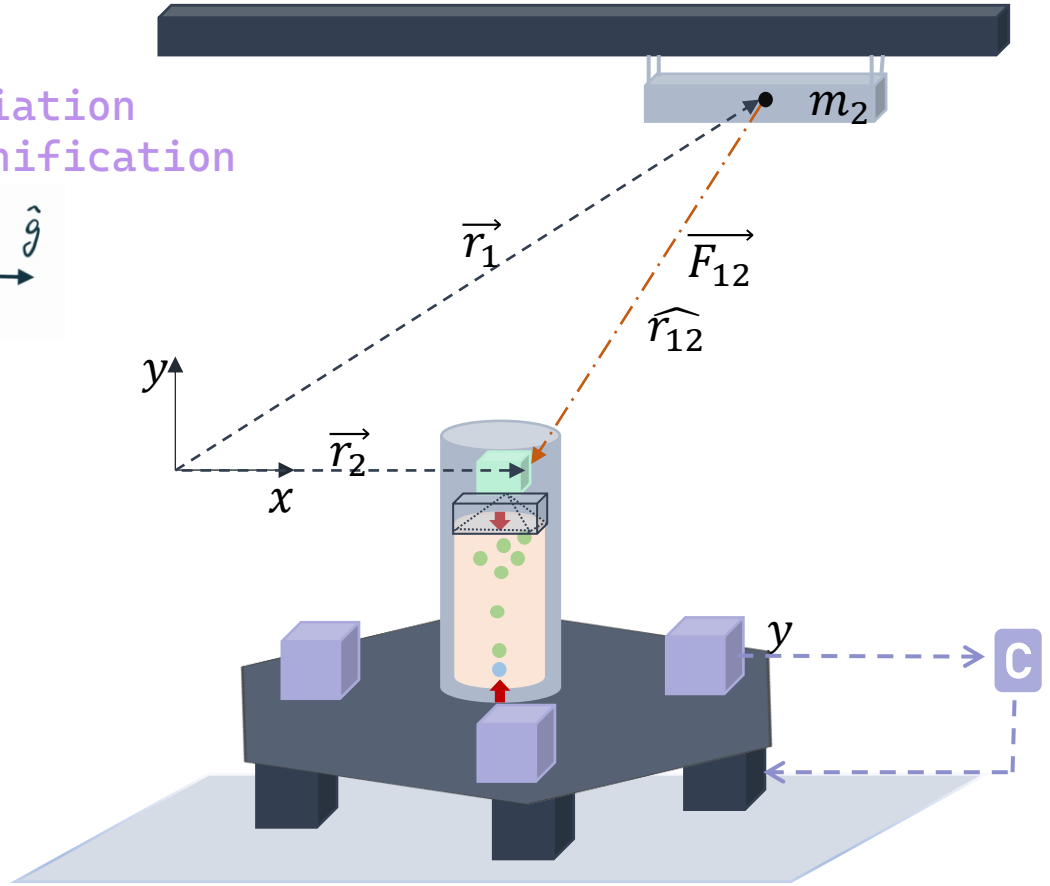




2. Experimental set-up

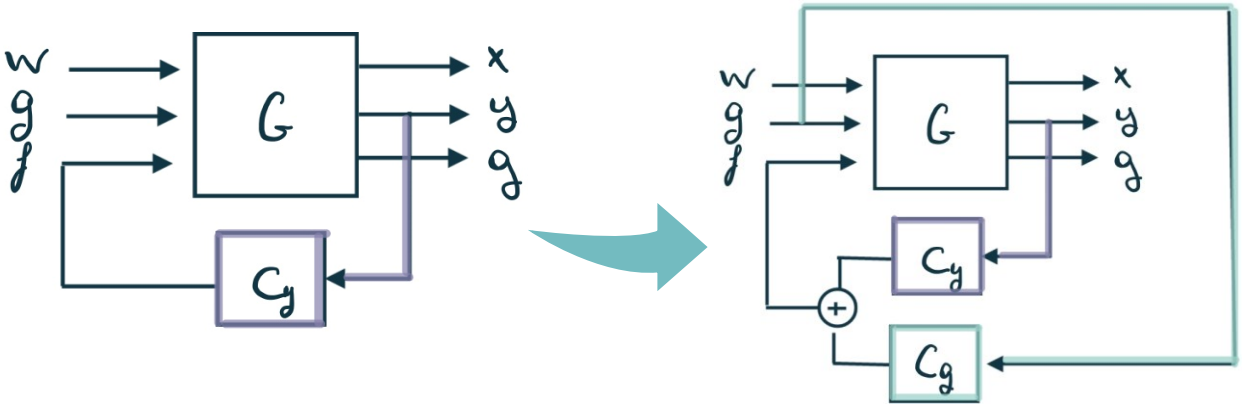
Induce known gravity variation
Verify low-frequency magnification



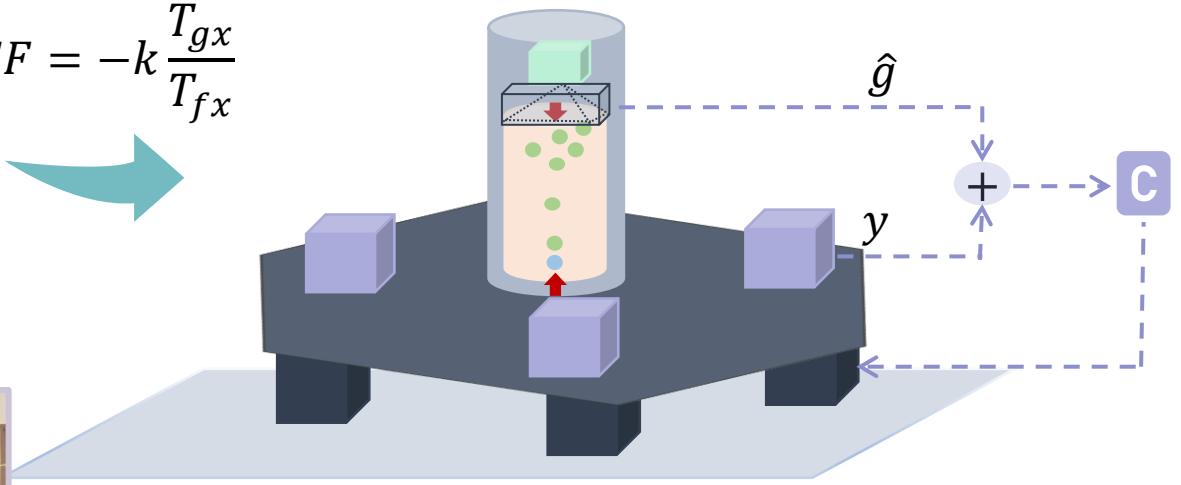


$$\overrightarrow{F_{12}} = -\frac{Gm_1m_2}{|\overrightarrow{r_{12}}|^2}\widehat{r_{12}}$$

3. Gravity Feed-Forward



$$FF = -k\frac{T_{gx}}{T_{fx}}$$



2 Post-Doc positions

Seismic Newtonian Noise estimation
based on sensor arrays
In the scope of the Etest prototype

Fully funded for 18 months

more information:
http://www.pmlab.be/team
https://www.etest-emr.eu/prototype-2/

christophe.collette@uliege.be

Precision Mechatronics Laboratory

CSL CENTRE SPATIAL DE LIÈGE

Thank you for the attention

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Christophe Collette: christophe.collette@uliege.be

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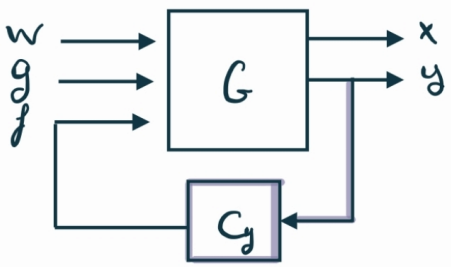
3 Effect of gravity in active control



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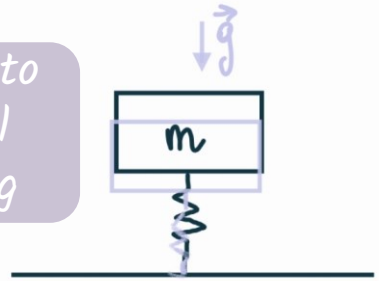
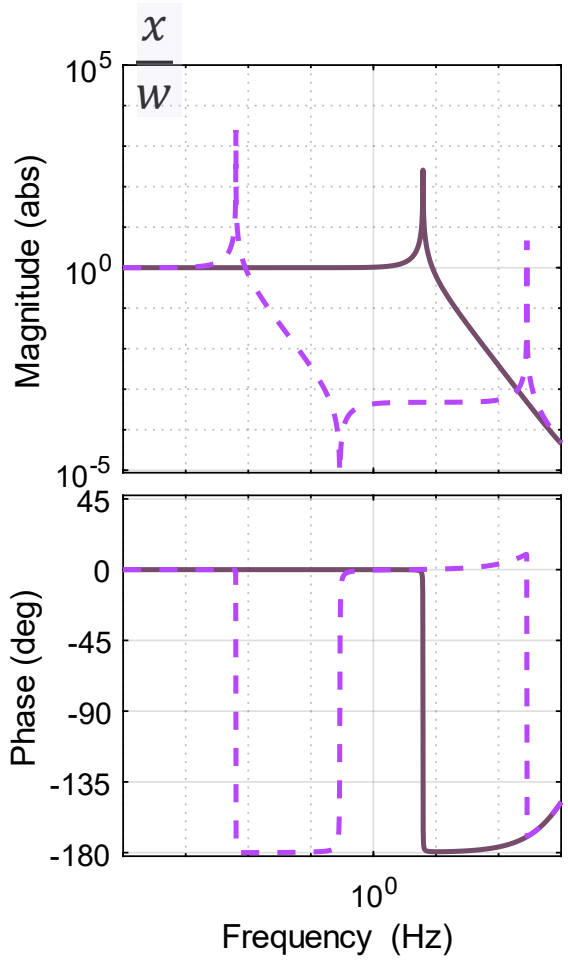
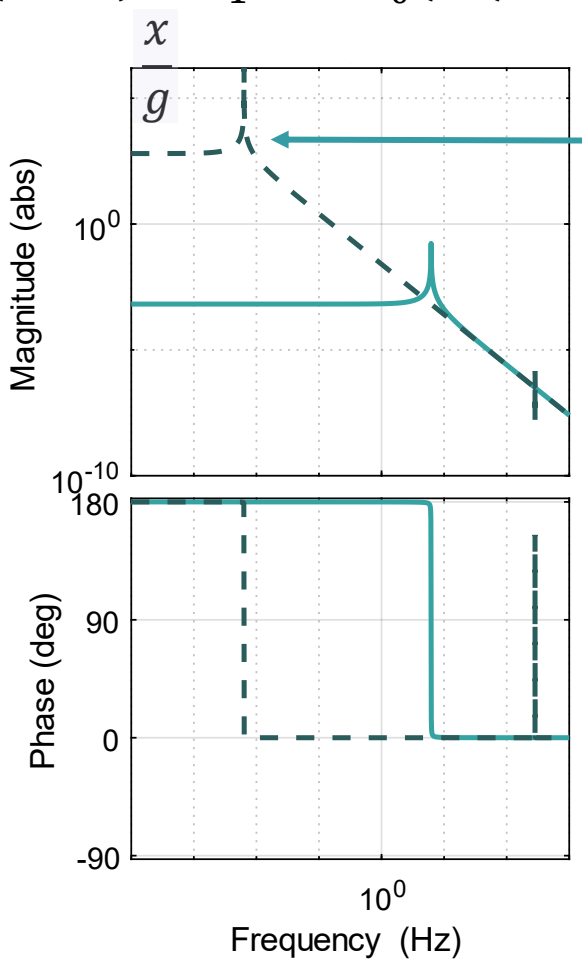
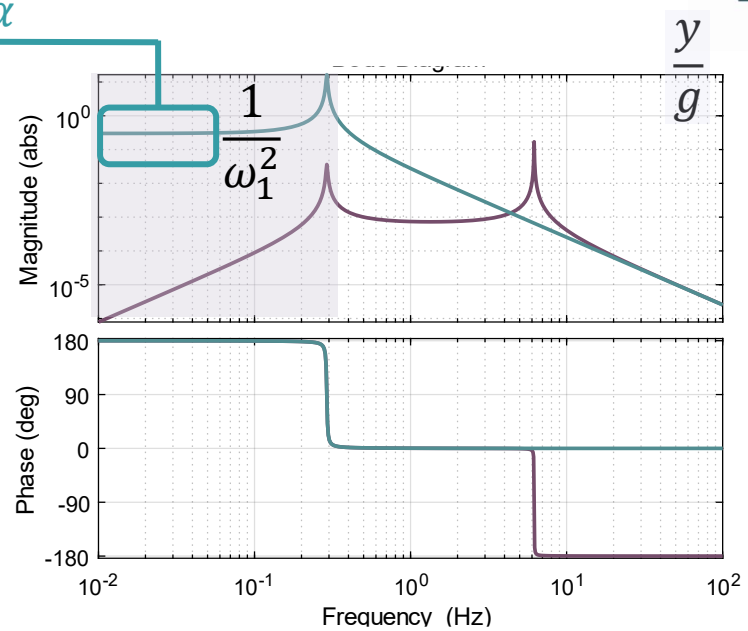
Gravity-to vertical coupling







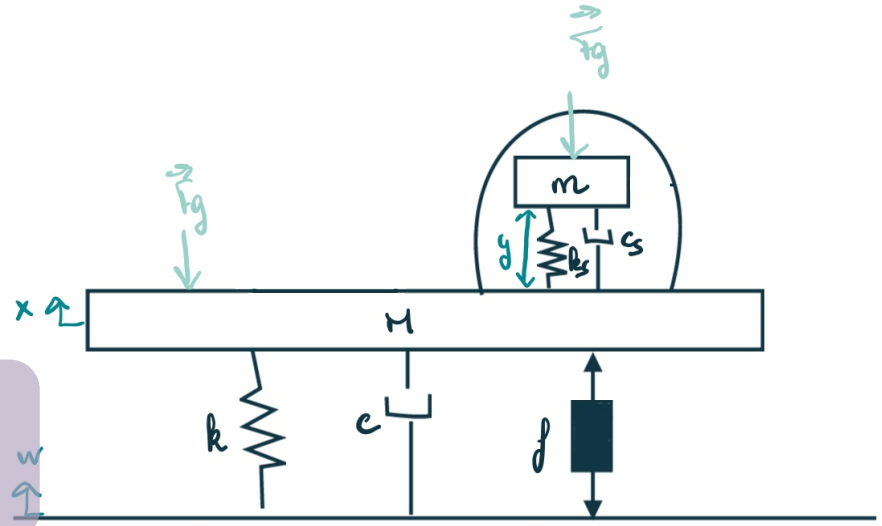


Additional Slides

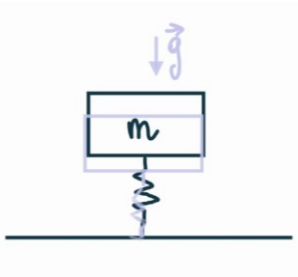
Effect of gravity in active control

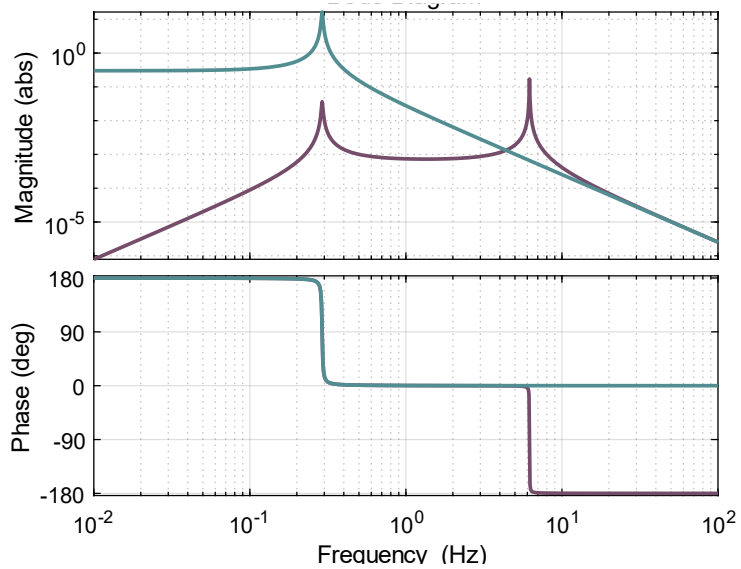
2

Gravity-to vertical coupling

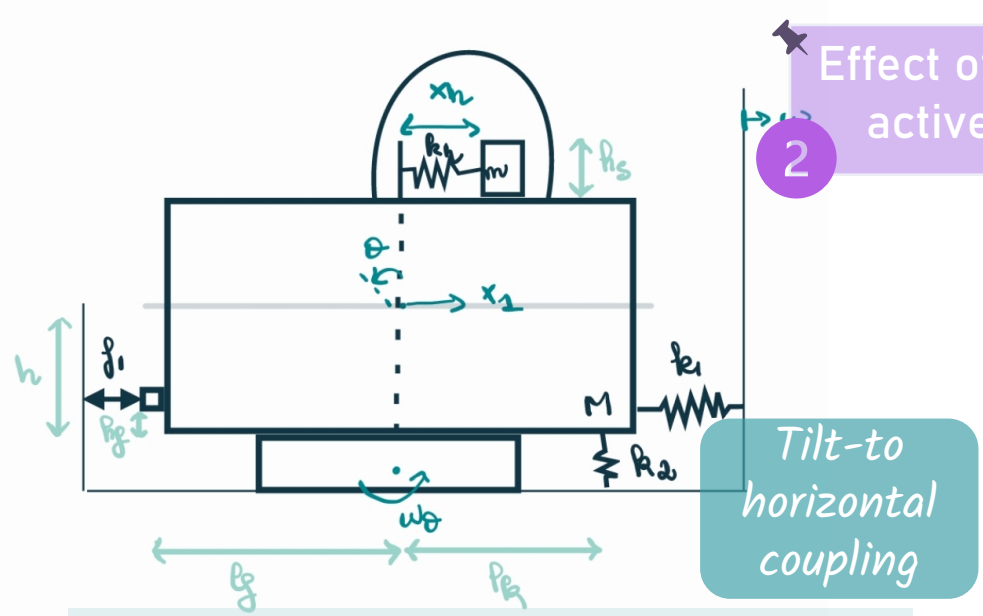


$$y = \frac{-s^2}{s^2+\omega_1^2}x - \frac{1}{s^2+\omega_1^2}g$$

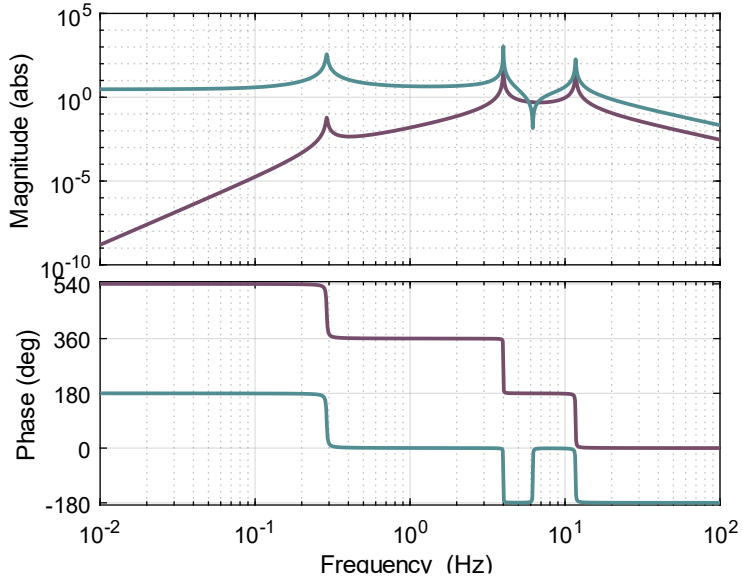


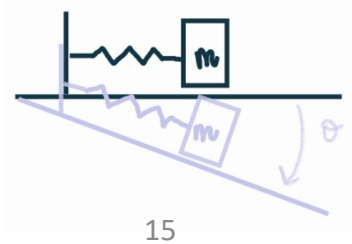


Tilt-to horizontal coupling



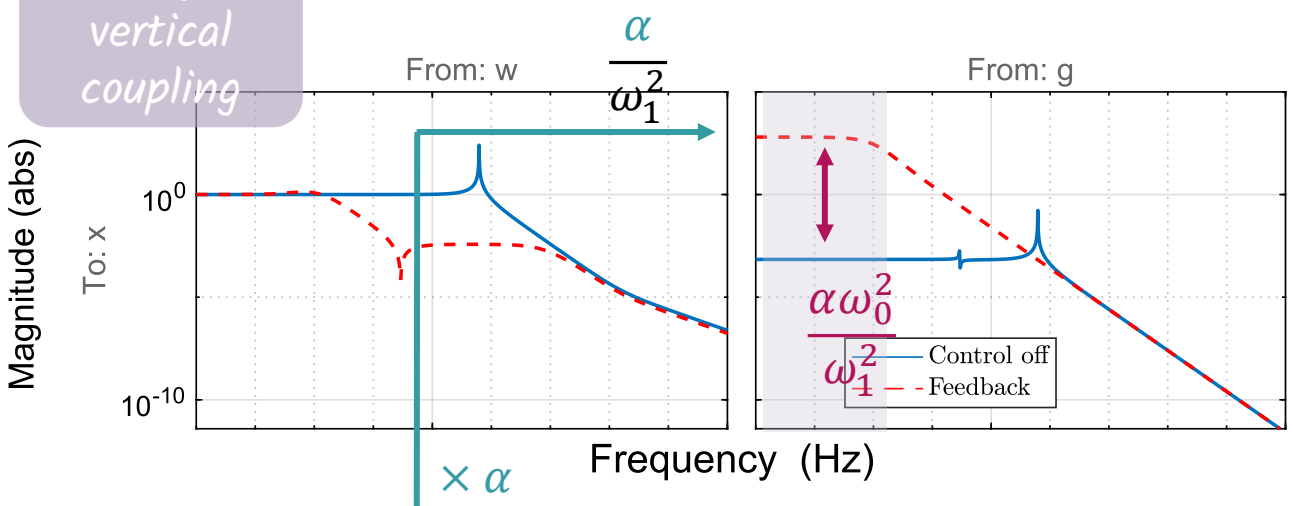
$$x_h = -\frac{s^2}{s^2+\omega_1^2}x_1 + \frac{s^2(2h+h_s)-g}{s^2+\omega_1^2}\theta$$





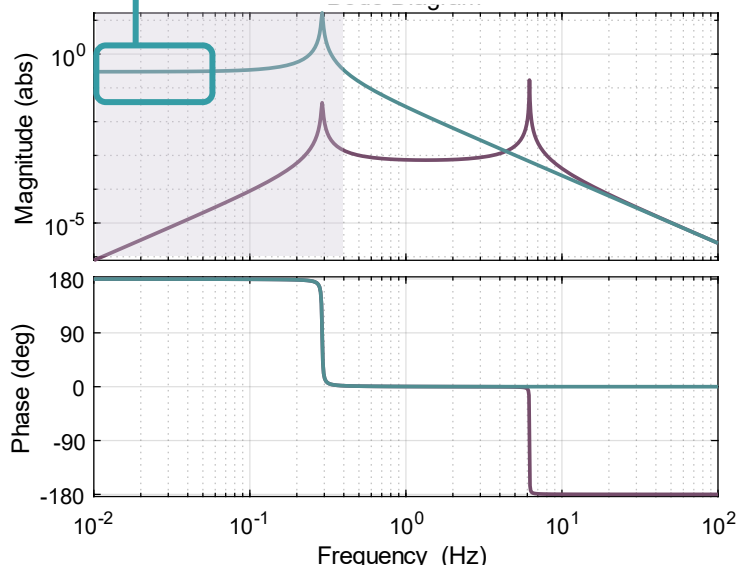
Additional Slides

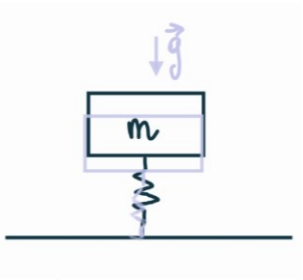
Gravity-to vertical coupling



$\times\,\alpha$

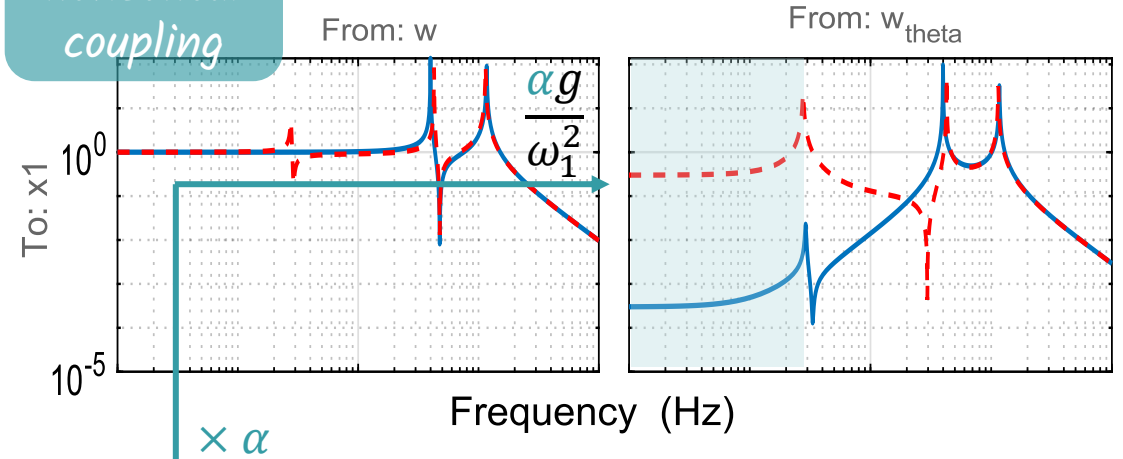
$\frac{1}{\omega_1^2}$





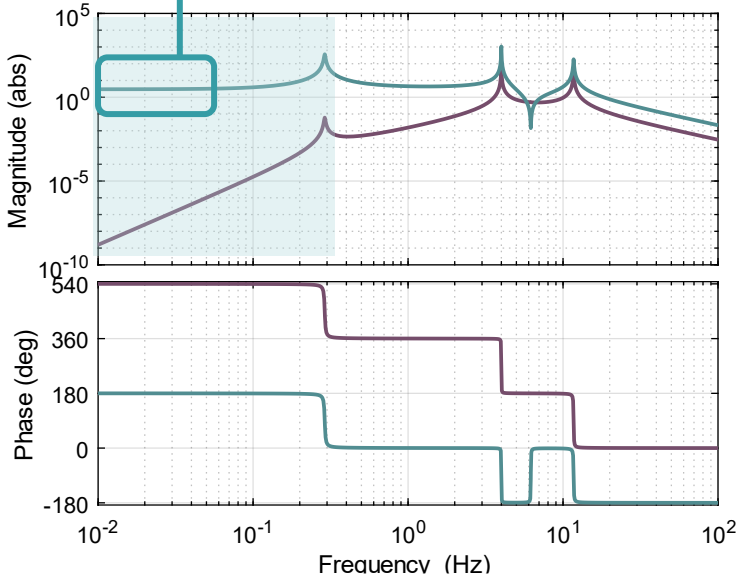
$C = \alpha y$

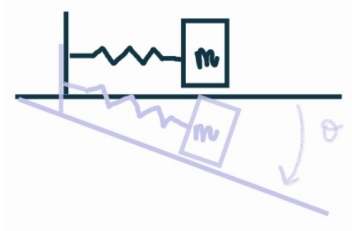
Tilt-to horizontal coupling



$\times\,\alpha$

$\frac{g}{\omega_1^2}$



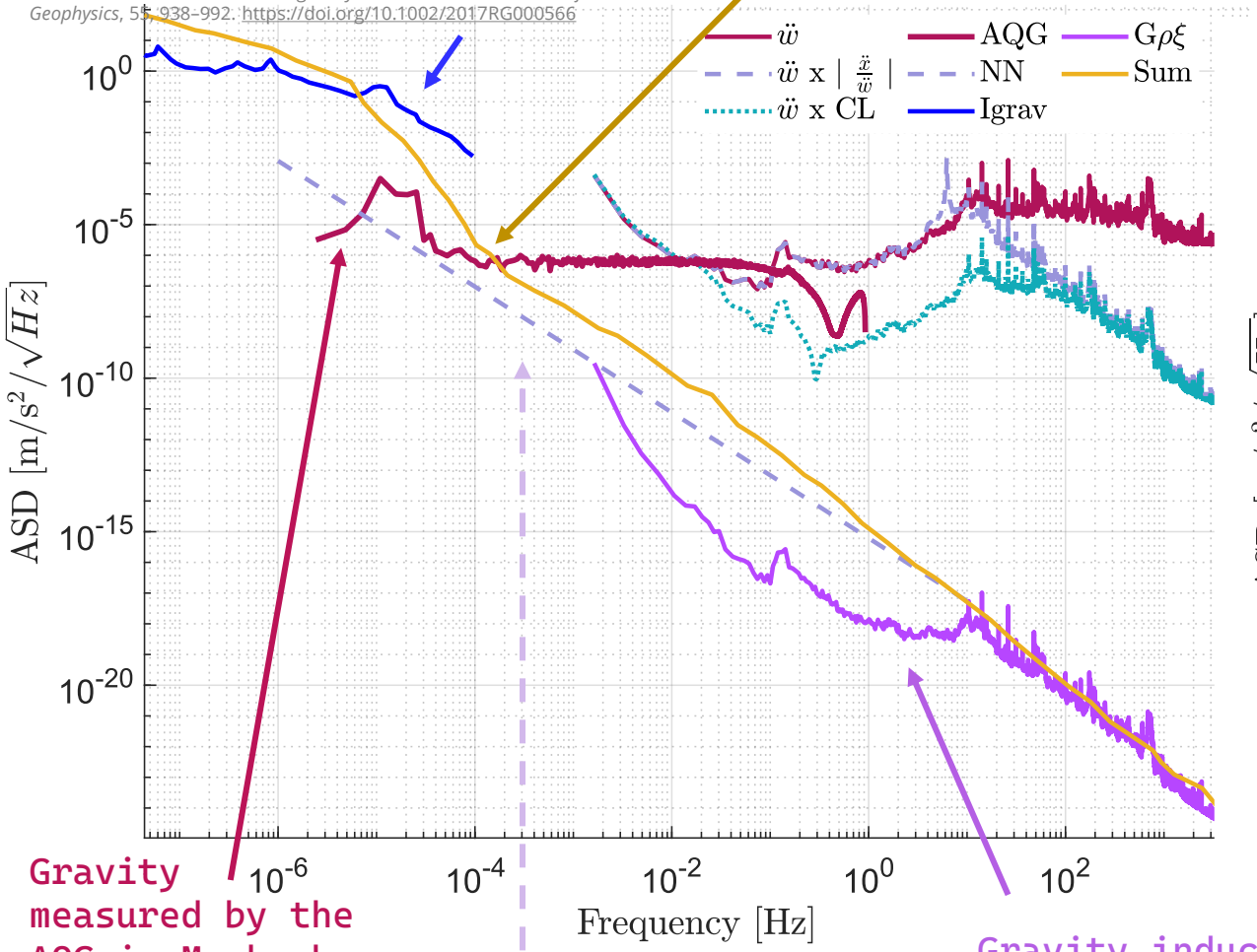


Additional Slides

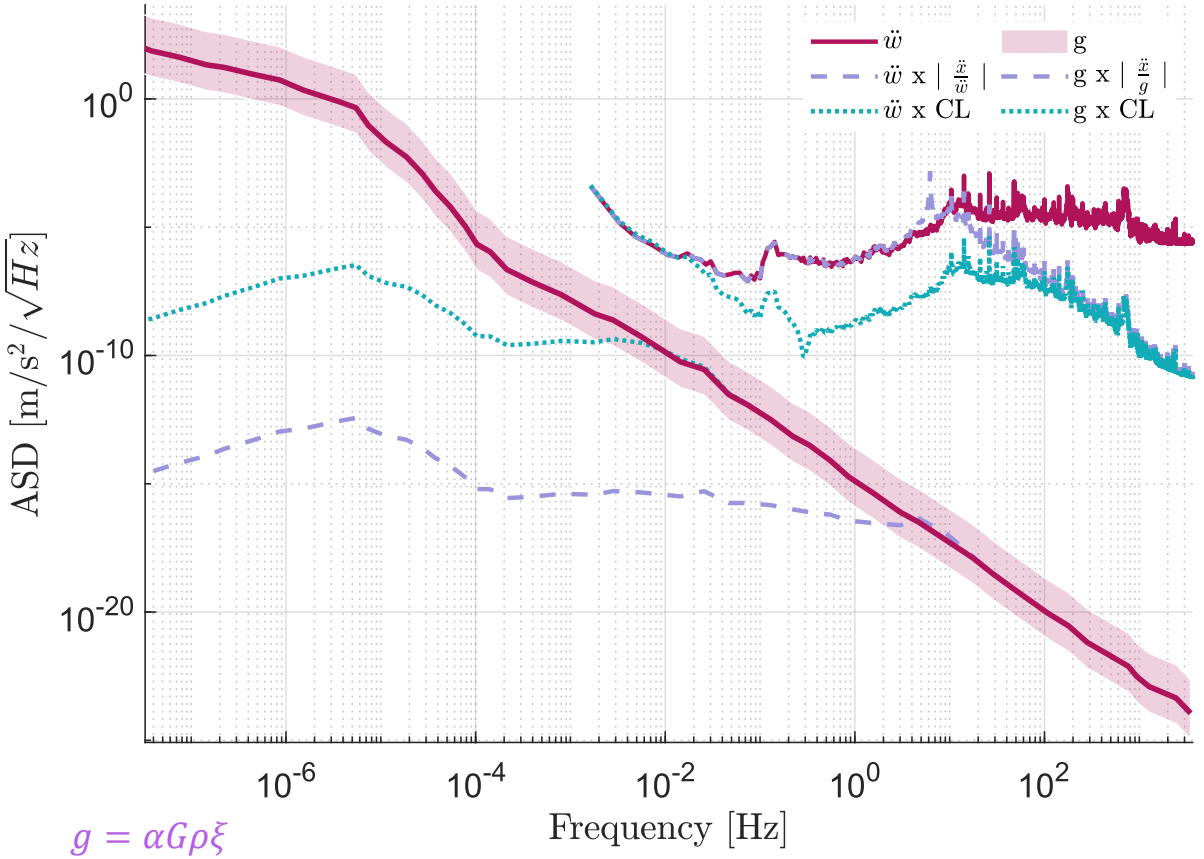
Data from superconducting gravimeter in Membach 1996–2016

Van Camp, M., de Viron, O., Watlet, A., Meurers, B., Francis, O. & Caudron, C. (2017). Geophysics from terrestrial time-variable gravity measurements. *Reviews of Geophysics*, 55, 938–992. https://doi.org/10.1002/2017RG000566

Approximation ~ sum of all gravity signals



Gravity measured by the AQG in Membach



$g = \alpha G \rho \xi$

Gravity induced by ground displacement

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

Newtonian Noise from ET sensitivity curve

Newtonian Noise in the low frequency limit. Markus Bachlechner, David Bertram, Achim Stahl,Aaroodd Ujjayini Ramachandran 3. Physikalisches Institut RWTH Aachen University, June 9, 2023