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Demonstrator for the TTL Coupling Measurement in the LISA Experiment

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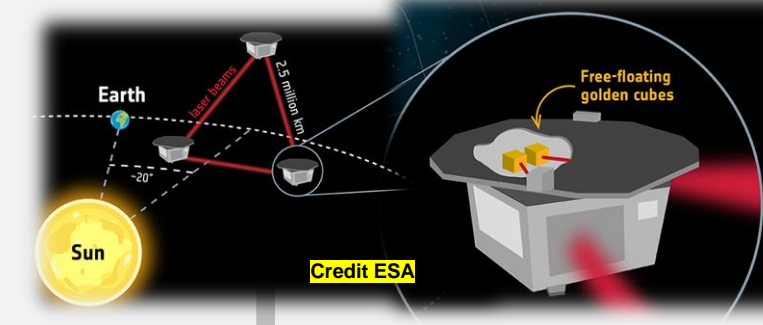
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OVERVIEW We present some of the key functions of a setup aimed at measuring the Tilt-To-Length (TTL) coupling on the LISA optical benches. It integrates off-the-shelf components, a metallic breadboard, servo-loops and position memories for beam alignments and obtained straightforward alignments with submicrometric accuracy. The setup demonstrates an optomechanical stability better than a few microns (130 hours), compliant with the specifications for LISA.

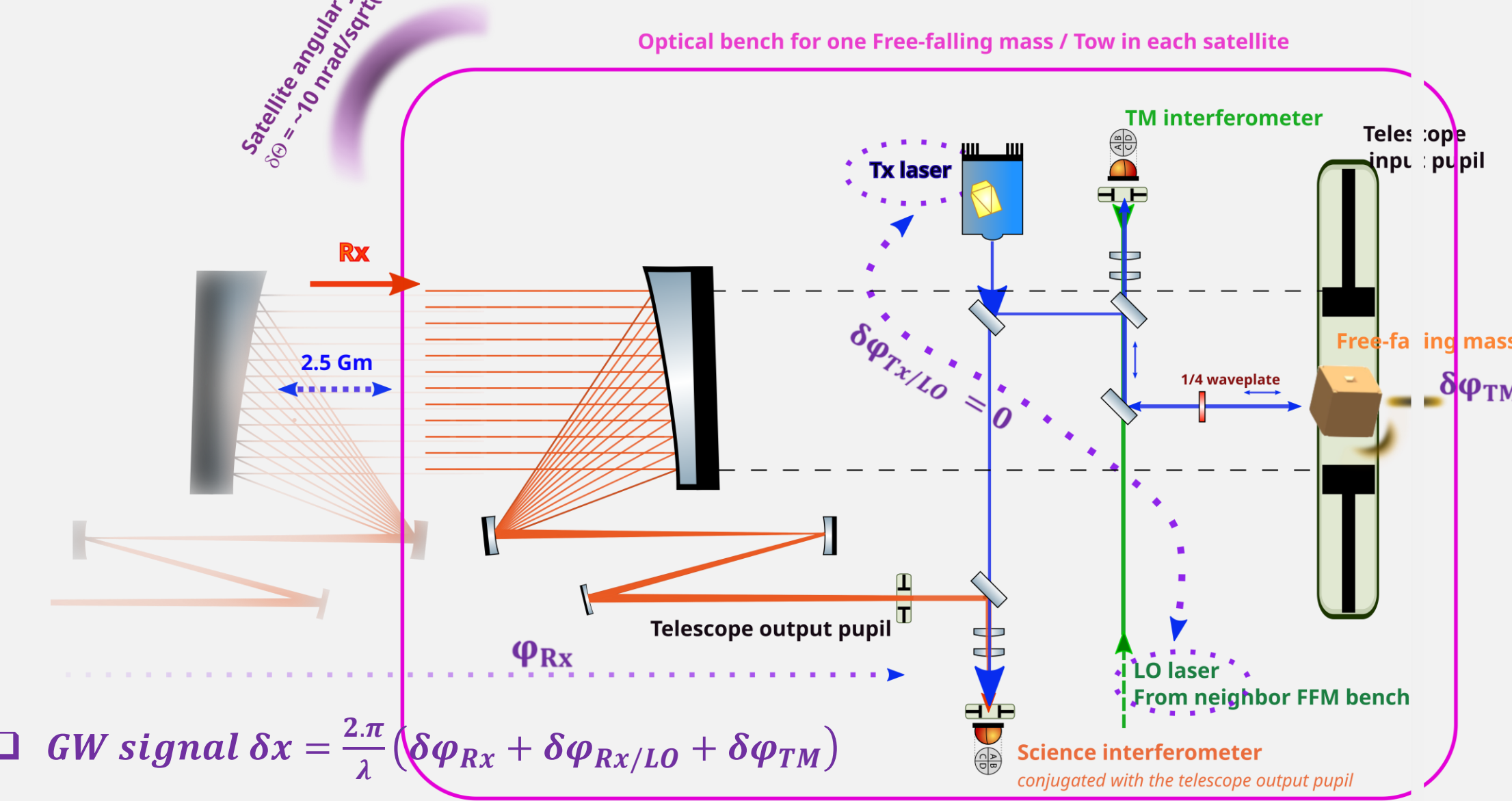
I - LISA mission for Gravitational Waves (GW) detection and TTL coupling

Laser ranging between Free-Falling Masses in space (FFM), 2.5 Mkm length optical link, it targets ~ few picometer/ $\sqrt{\text{Hz}}$. Heterodyne detection of the optical phase between the incoming & local beams attached to the far / local FFM's.



II - LISA optical bench

Aimed at detecting the Opt. Path Length "Input pupil"-to-FFM ("δφ" in rad)

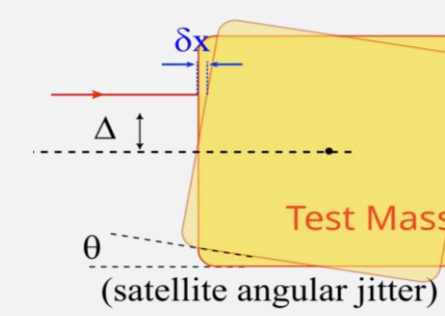


III - TTL coupling : One of the major noise source in LISA

Pupil's-to-Test Mass conjugation → OPL FFM-to-detectors unaffected by the bench/satellite angular jitter

!! Residual pupil misalignments → deleterious « Tilt-To-Length » coupling $TTL = \frac{\partial \delta x}{\partial \theta} = \Delta, \text{ in } \frac{\text{m}}{\text{rad}}$

→ FOGOB optical bench demonstrator for TTL measurement

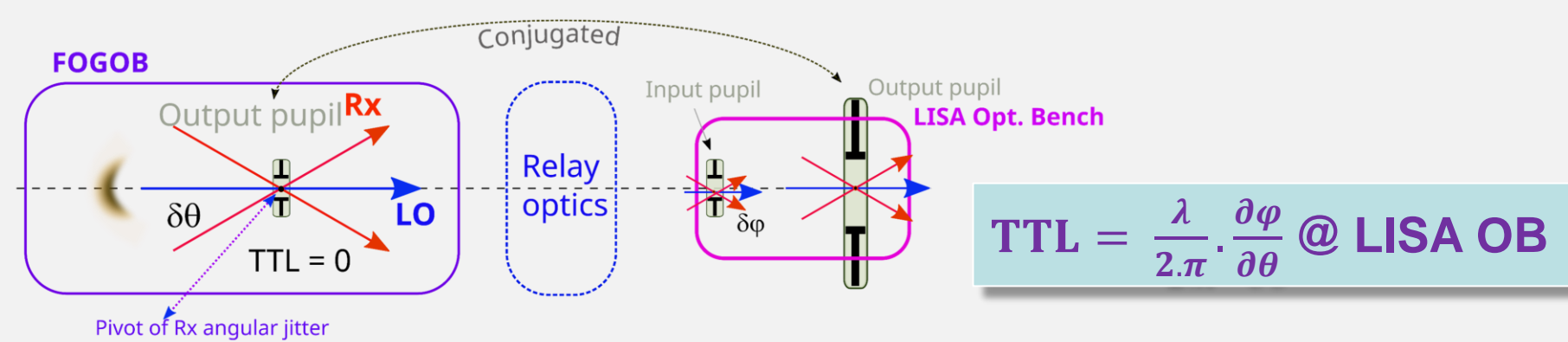


IV - FOGOB - Measurement principle

Provides Rx & LO beams, $\lambda = 1064 \text{ nm}$, ~ 10 mW

Rx is tilted ($\theta_0 \times \sin(2\pi \cdot f_0 \cdot t)$) at the output pupil center

We conjugate the FOGOB pupil with the LISA OB pupil

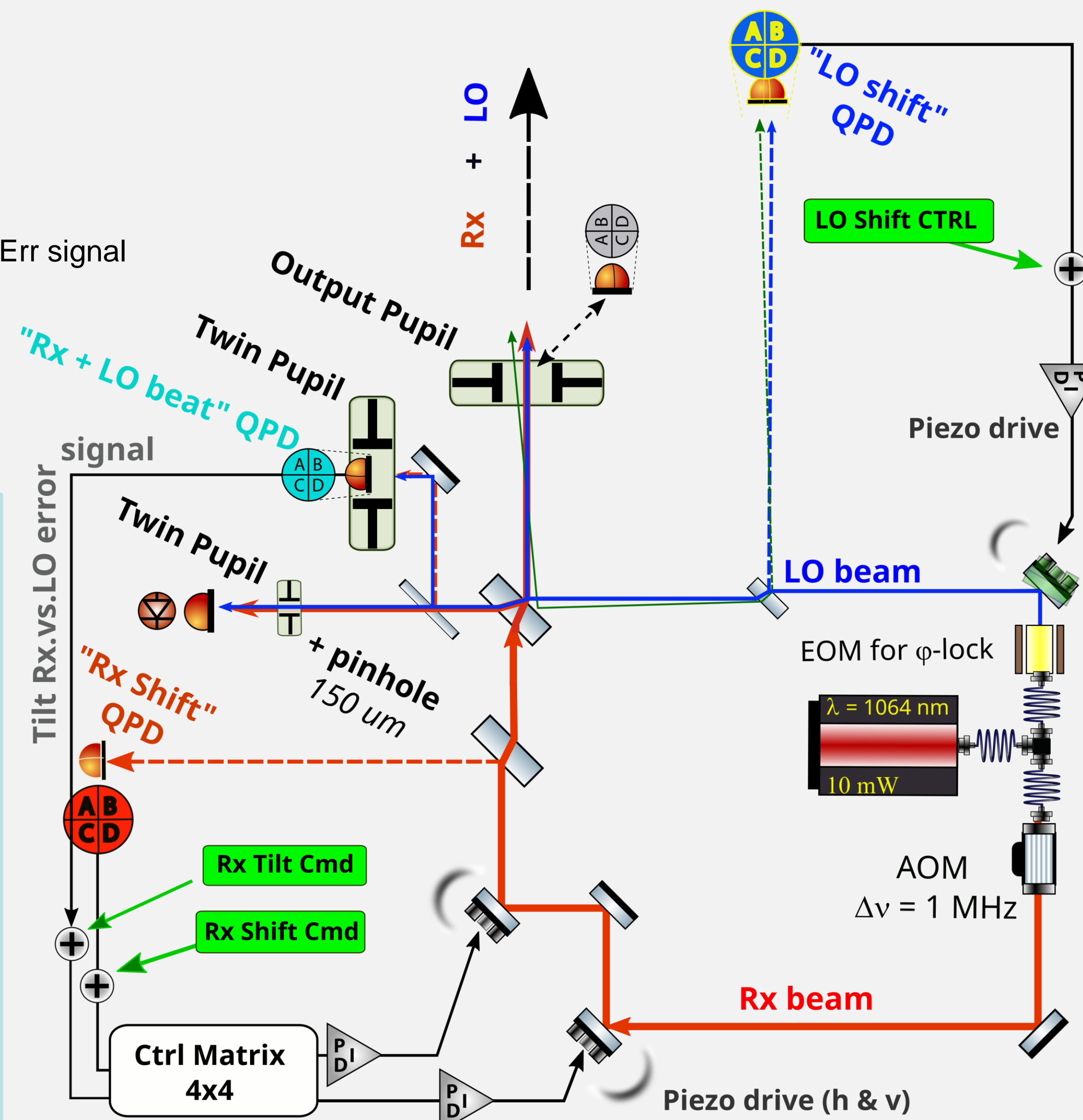


Specification: $Rx = (\theta_0 \sim 150 \mu\text{rad}) \times \sin(2\pi \cdot \text{few Hz} \cdot t)$, Pivot point centring accuracy < 15 μm, TTL @ FOGOB pupil accuracy < 10 μm/rad, over days. Std(TTL) < 10⁻⁷ m/rad for few minutes trends. Rx flattop intensity profile

V - FOGOB demonstrator - Detection scheme

Heterodyne detection scheme, data of interest: $\phi = \text{Rx-to-LO } 1 \text{ MHz beat phase}$

- Detection @ Output pupil, with a Quadrant Photo-Detector (QPD) delivers: residual « piston » = $\sum_{i=1..4} \phi_i$
 - Detection @ Twin output pupil, with a QPD delivers: Tilt Rx-wrt-LO, $\theta = \sum_{i=1..4} \pm \phi_i$
 - Detection @ Twin output pupil, with a pinhole Single Element PhotoDiode (SEPD), centered @ pupil, delivers: Rx-vs-LO phase lock Err signal
- TTL = piston @ $f_0 / \theta @ f_0$ meter/radian

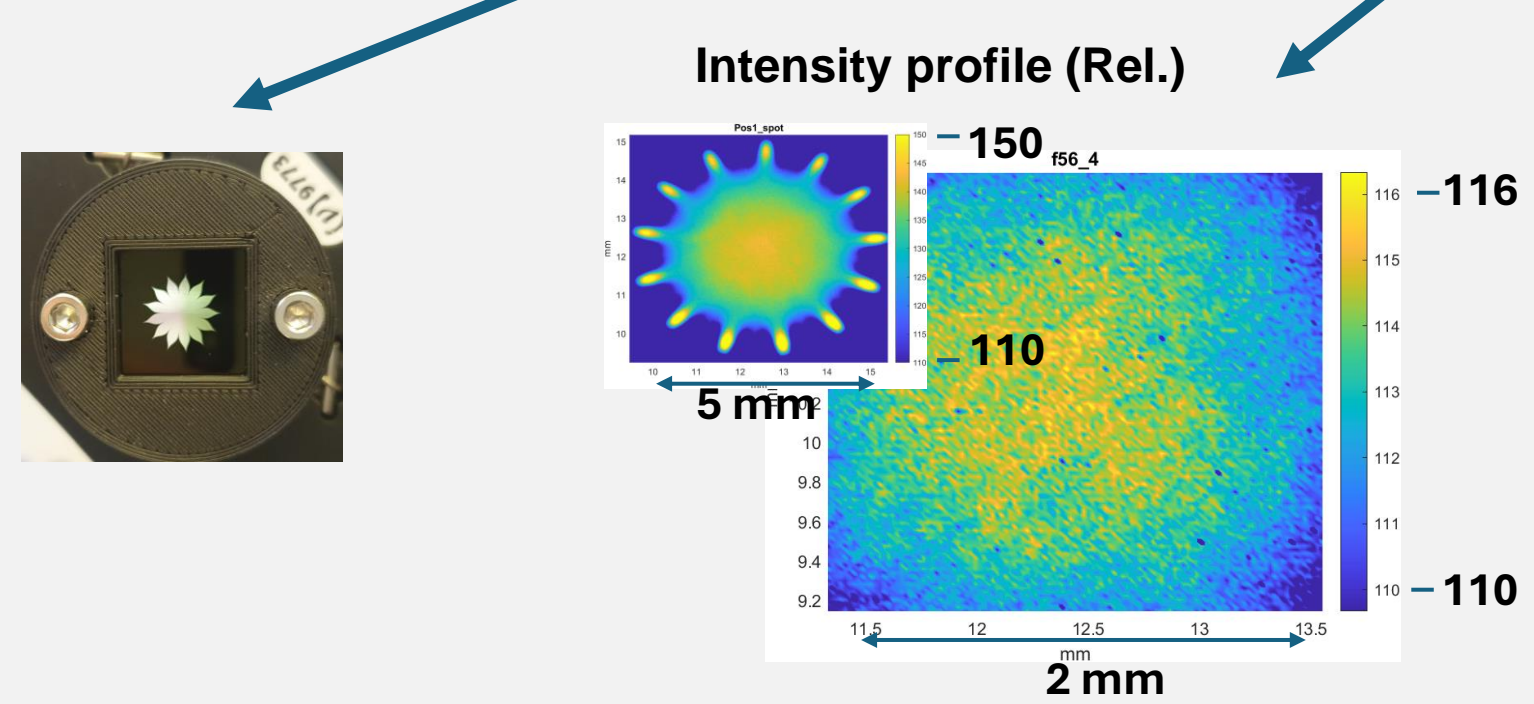


VI - FOGOB demonstrator - Flattop generation / Beam alignment Ctrl / Mechanical Stability

Flat Top intensity profile (Rx beam)

Goal: mimic a plane wave over a 2.5 mm diam. pupil. The pupil is located ~ 80 cm away from the source

Setup: SM fiber collimated using a 30 cm lens & apodization for diffraction mitigation (transmissive mask), detection @ 0.8 m

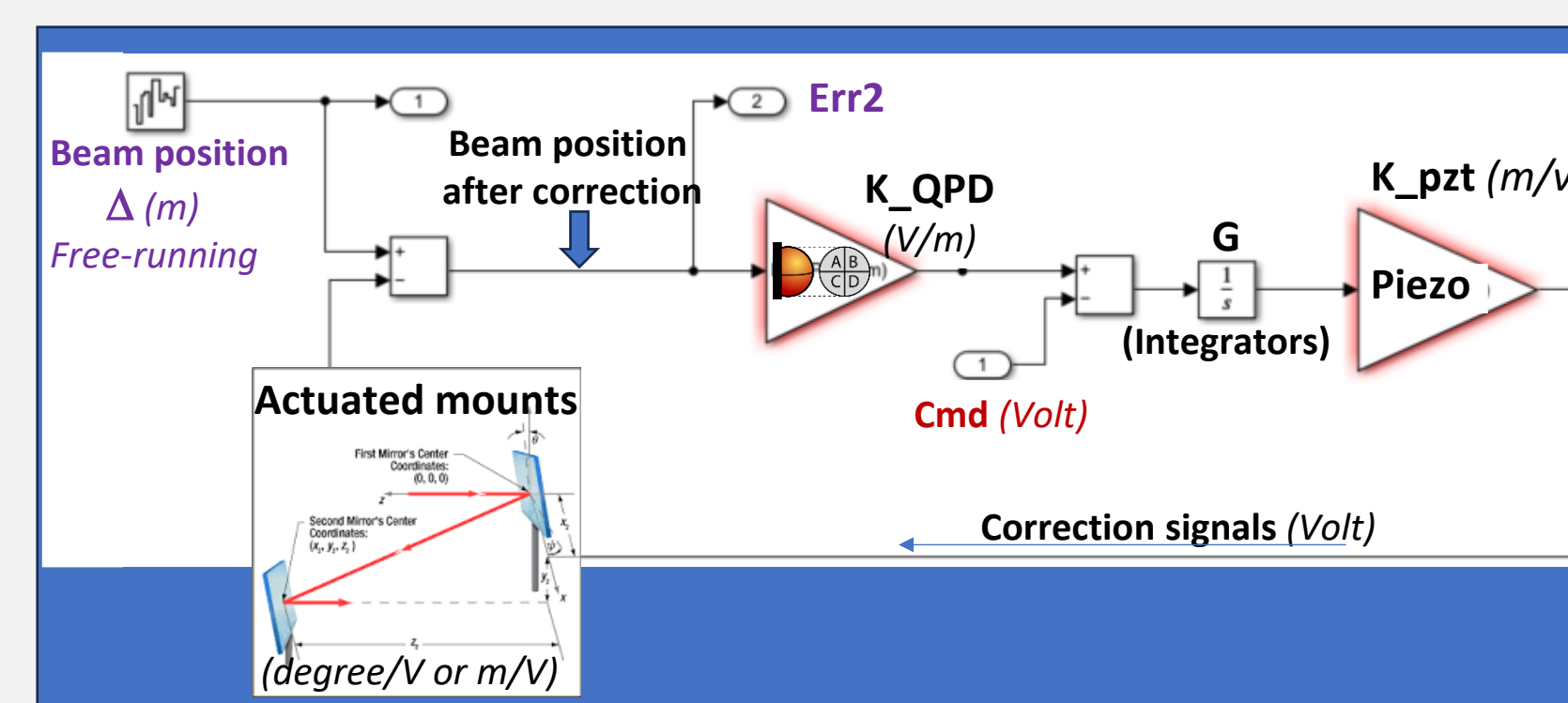


Results

- Intensity variations < 3 % P.V. over 3 mm
- rms. intensity variations < 1% rms
- Wavefront error < λ/100 rms (1064 nm)

→ Associated TTL < 0.1 μm/rad

Beam position Ctrl



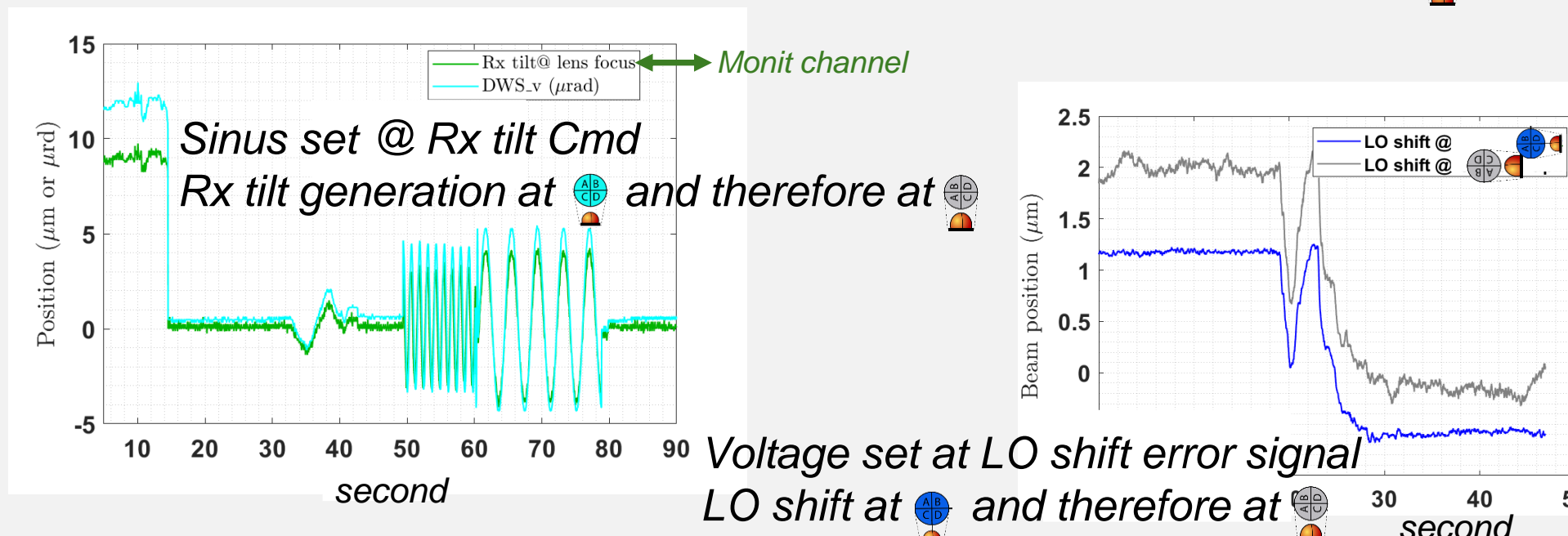
$$Err2 = \Delta / OLTf + Cmd / K_QPD \approx Cmd / K_QPD \text{ with } OLTf \gg 1$$

- « Err2 »: in-loop error signal
- OLTF = $G \cdot K_pzt \cdot K_QPD$, Open Loop Transfer Function
- OLTF ∝ 150/f, f: the Fourier frequency
- $K_QPD \propto P/w$, w: beam waist, P: Laser power
- « Cmd »: Electronic setting

Results

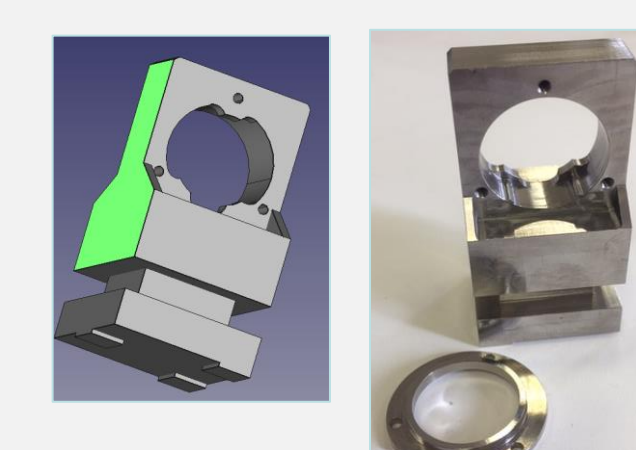
- Beams position (shift & Tilt) locked at (all 3 conjugated)
- Beams tilt & shift: fine Cmd added to the servo loop error signals

→ Submicrometric & fast alignments (< 60 sec) at

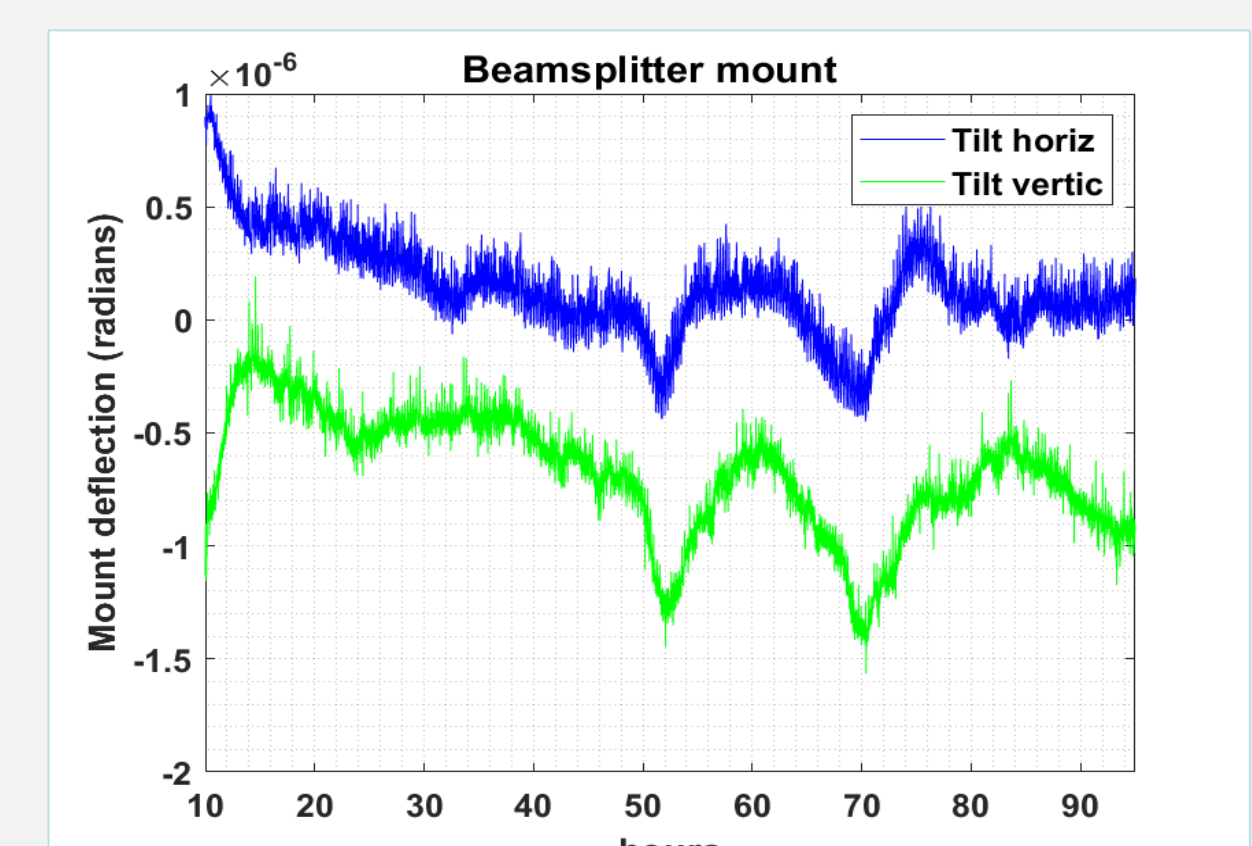


Opto-mechanical mounts stability *

Invar-based design



* Measured with SIOS triple laser interferometer



ie 1 μm beam drift @ pupil (assuming ≈ 0.25 m lever arms)

VII - Conclusion

- TTL_{Meas.}⁵ accuracy < 5 μm/rad
- TTL_{Meas.}⁵ drifts < 1 μm/rad, 130 h run
- Std(TTL_{Meas.}⁵, 60 s. data trends) < 10⁻⁷ m/rad, 130 h run

→ Compliant with the FOGOB specifications

- Sub-micrometric and straightforward beam alignments
- Operated with off-the-shelf components, in a « standard » Laboratory environment

- Missing
 - Flattop integration
 - TTL meas. @ output pupil

⁽⁵⁾ measured at the "Rx-to-LO" QPD, rather than at the output pupil

