Optical Metrology Applications at TAS-I in support of Gravity and Fundamental Physics

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Workshop “GG/GGG: state of the art and new possibilities”

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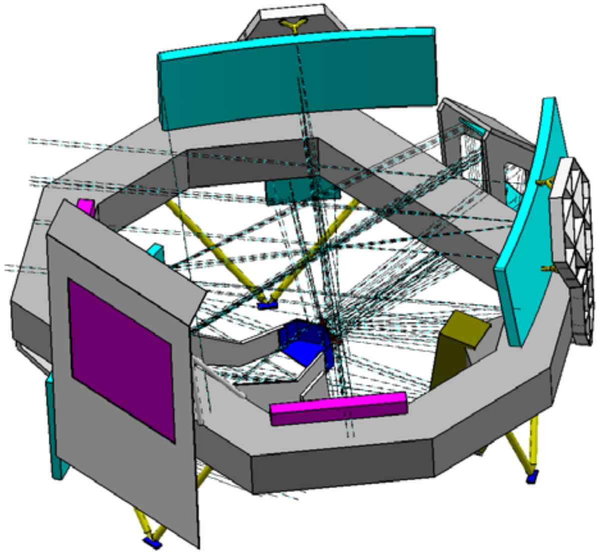
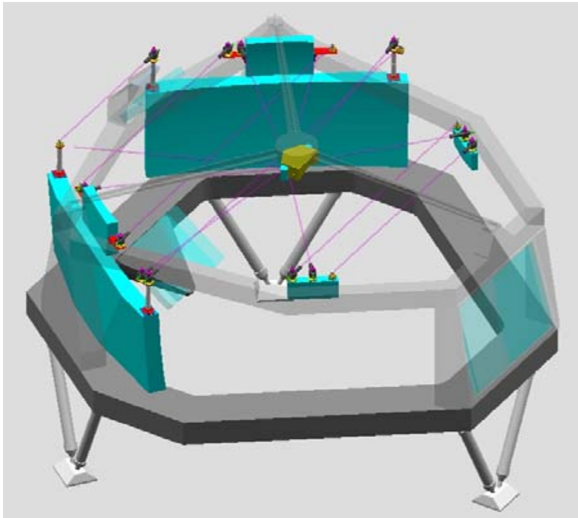
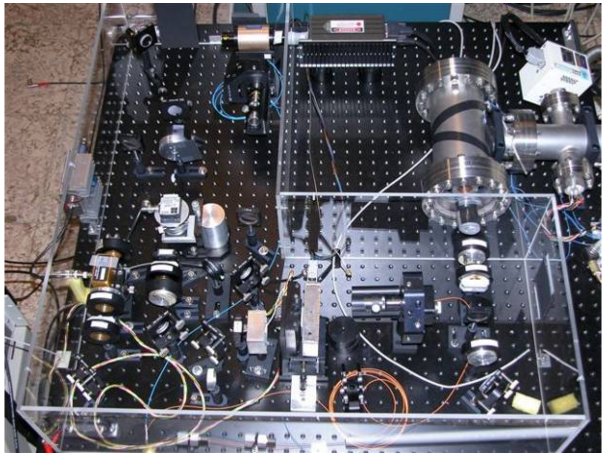
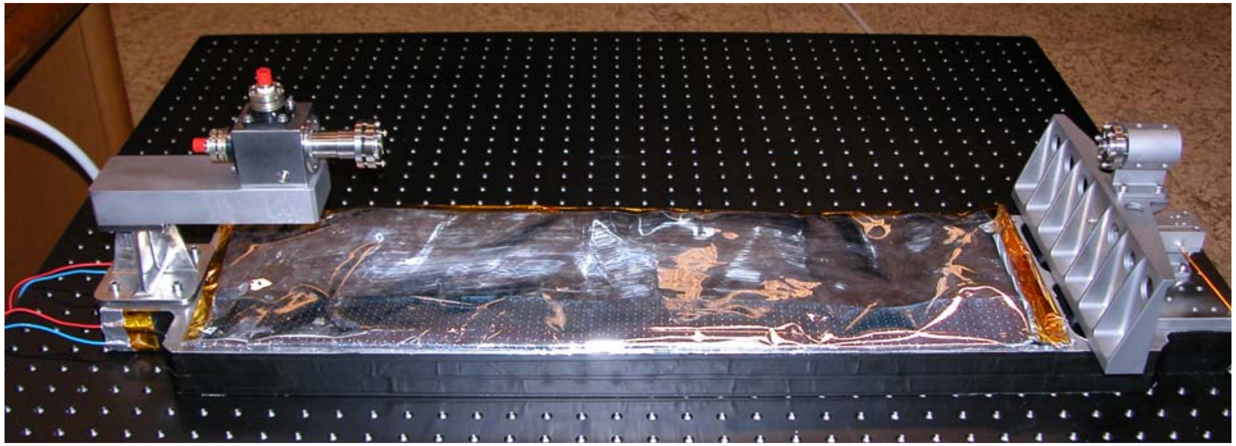
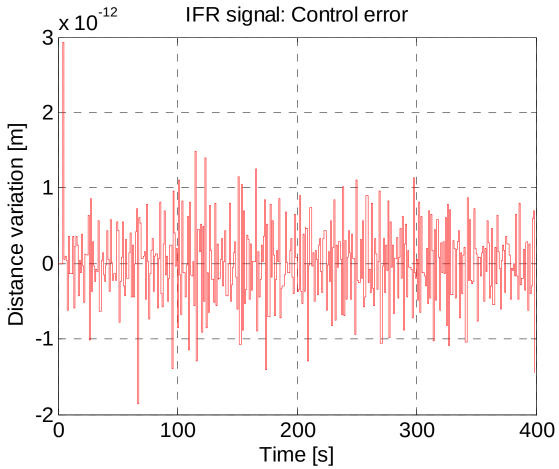
Main research projects and applications of optical metrology at TAS-I:

- Monitoring of the GAIA astrometric instrument stability (1997 – 2003).
- Co-phasing of optical interferometers (2002 – 2006).
- Satellite-to-satellite laser tracking for Next Generation Gravity Missions (2004 – present).
- Nanobalance facility for characterization of micro-Newton thrusters (2001 – present).

Collaborations:

- Istituto Nazionale di Ricerca Metrologica
- Politecnico di Torino
- INAF – Osservatorio Astronomico di Torino

Metrology for GAIA astrometric instrument

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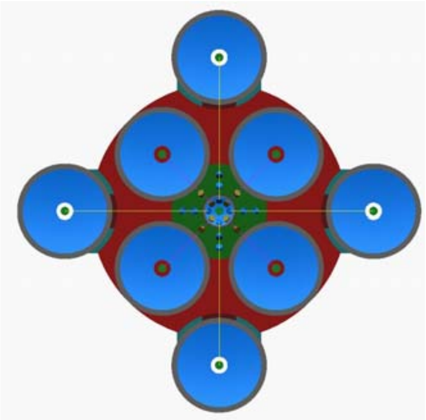
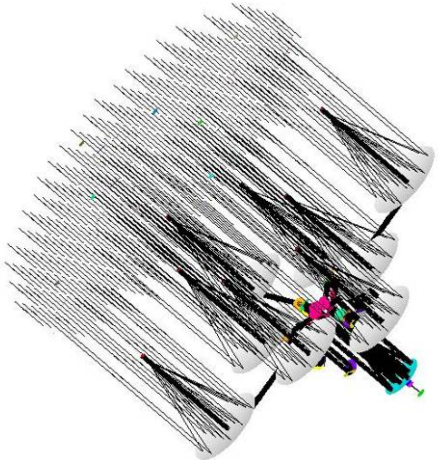
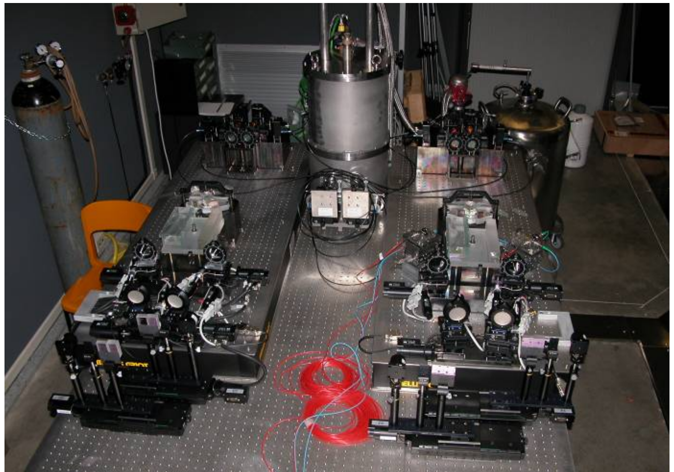
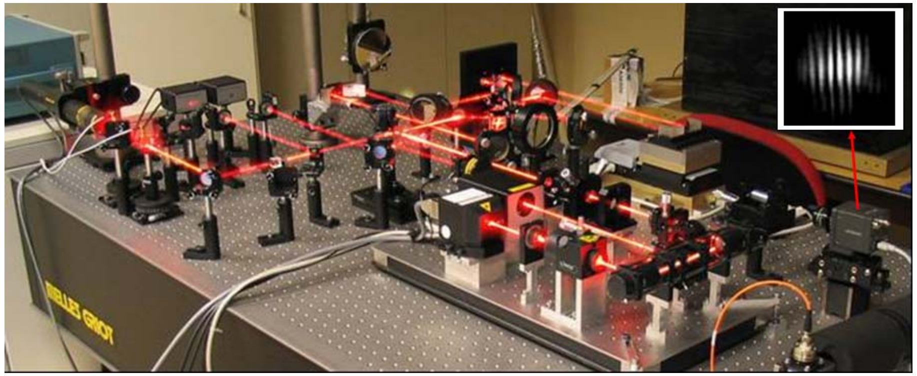
Co-phasing of optical interferometers

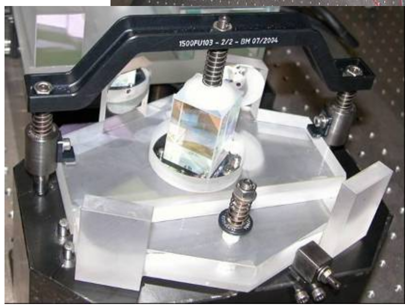


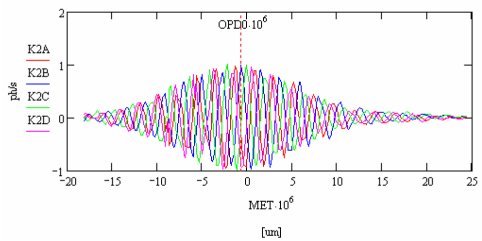






Breadboard of a two-aperture optical interferometer with its co-phasing system, for the development project of a synthetic-aperture optical telescope.





Fringe Sensor Unit realized for the co-phasing of the VLTI (ESO). Operative at Cerro Paranal, Chile.

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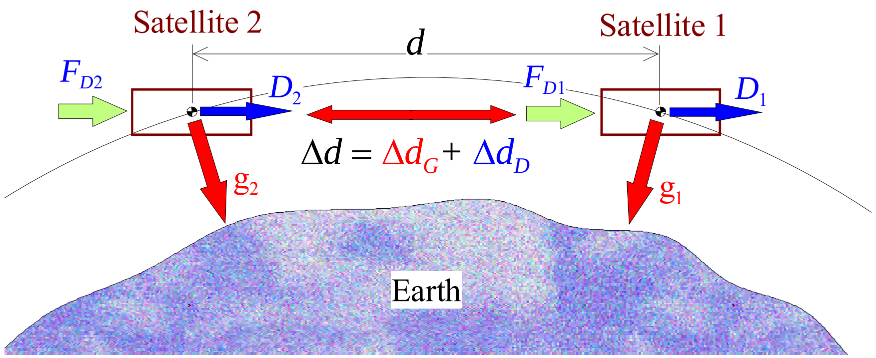
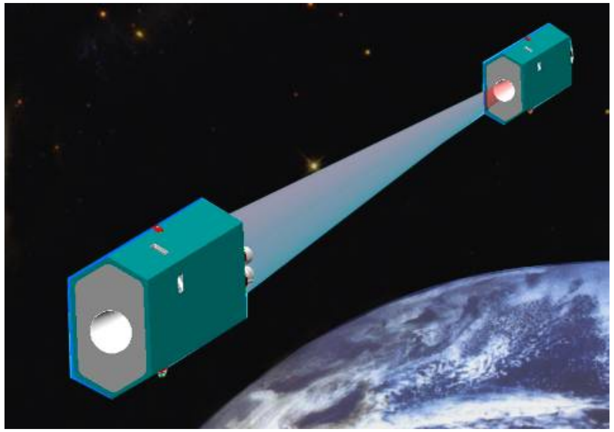
Gravimetry by satellite-to-satellite tracking

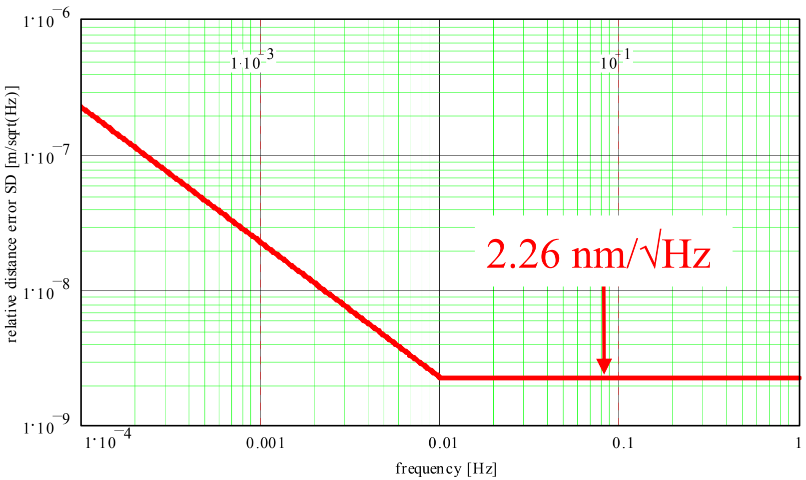


The distance variation between two satellites (Δd) is measured by a laser metrology system.

The distance variation between the satellites produced only by drag forces (Δd_D) is measured by accelerometers.

Subtracting (Δd_D) from (Δd) the distance variation produced by the gravity acceleration is obtained: $\Delta d_G = \Delta d - \Delta d_D$





Requirement for the laser interferometer measurement noise (relative distance = 10 km)

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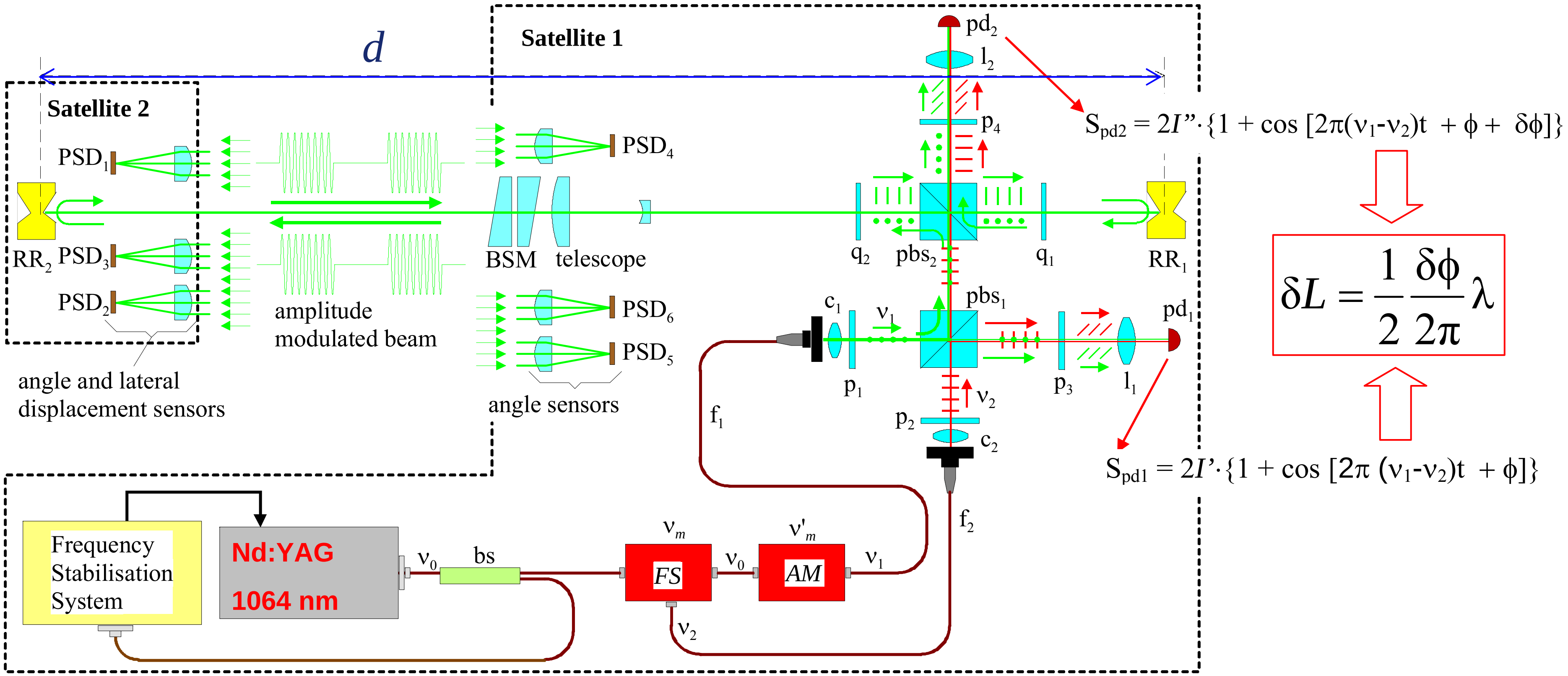
Satellite-to-satellite laser tracking for NGGM

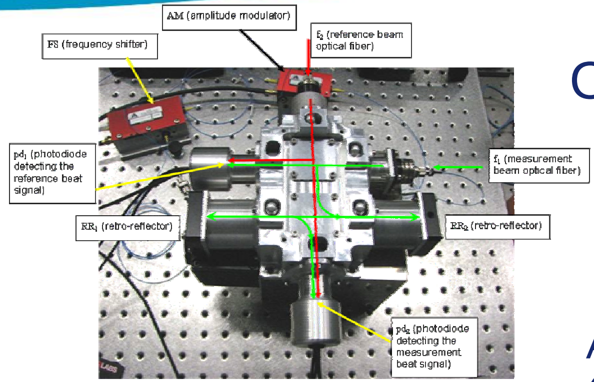
Optical metrology concept for the NGGM



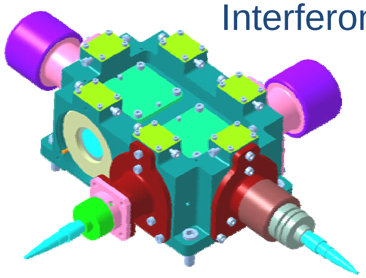
- Michelson-type heterodyne laser interferometer based on polarized beams, with chopped measurement beam to avoid spurious signals and non-linearity caused by the unbalance between the strong local beam and the weak return beam.
- Passive retro-reflection of the laser beam on S2: simple solution, suitable for *d* up to 100 km.

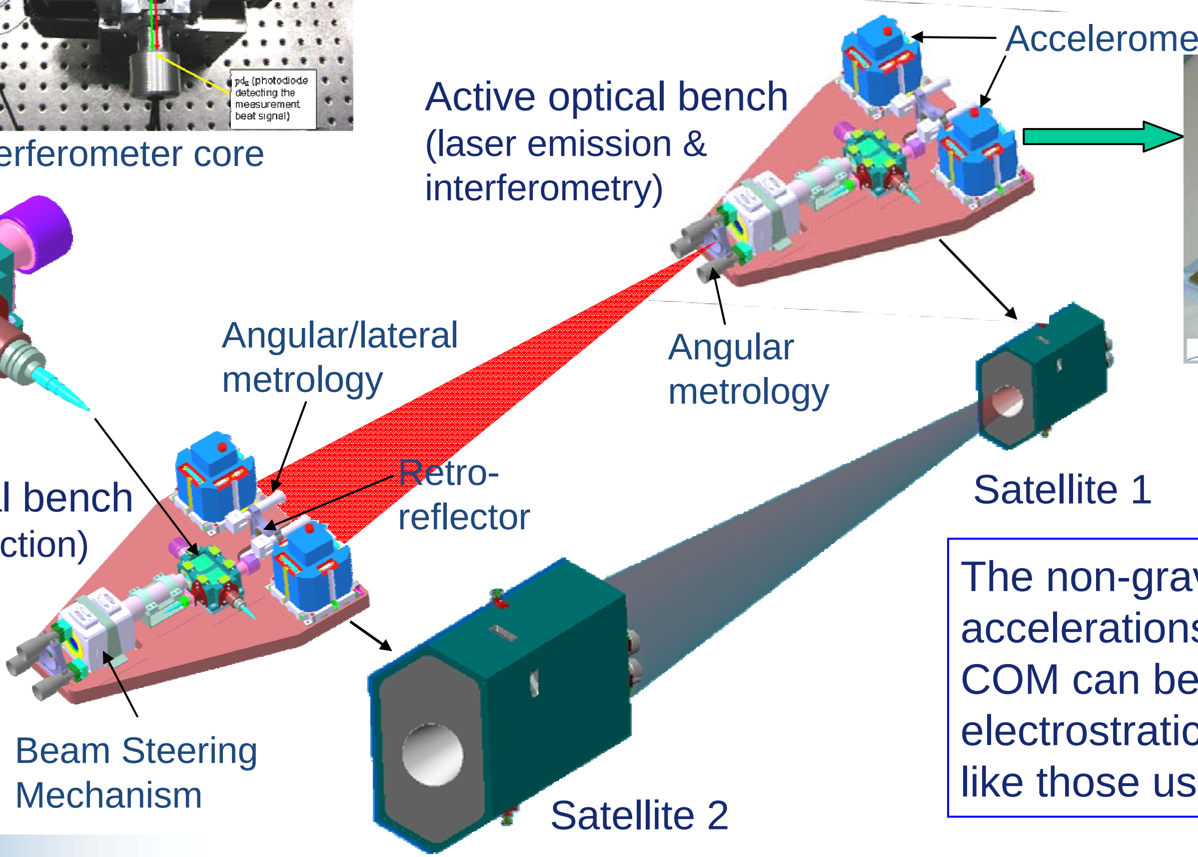
Satellite-to-satellite laser tracking for NGGM

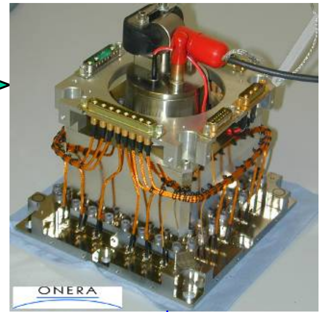
Optical metrology arrangement on the satellites



Interferometer core







The non-gravitational accelerations of the satellite COM can be measured by electrostratic accelerometers like those used on GOCE.

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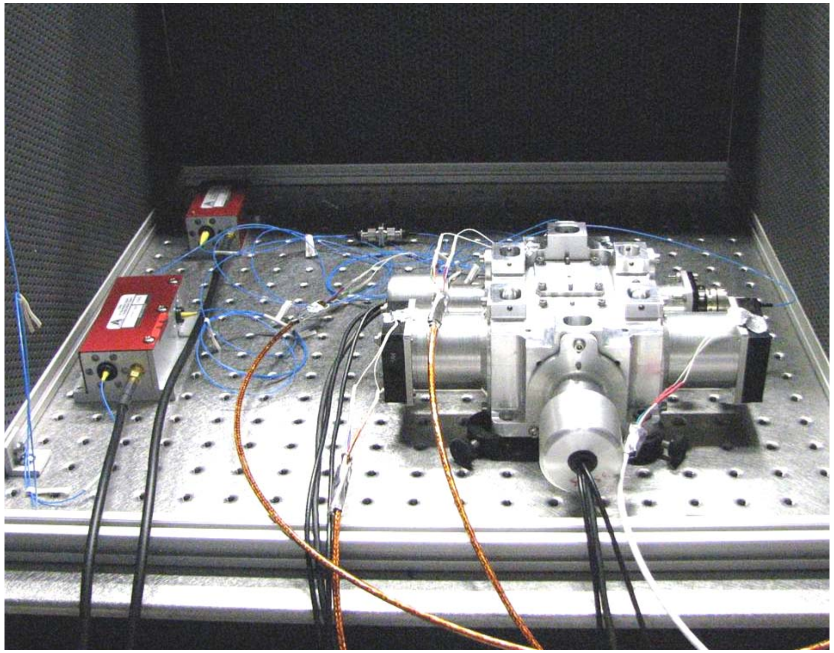
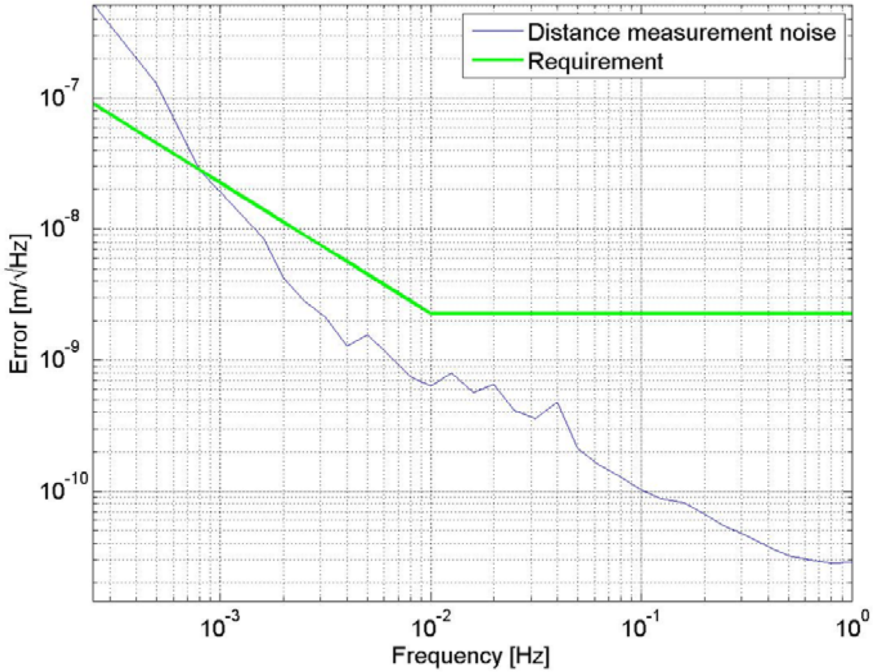
Interferometer BB test



Laser interferometer breadboard prepared for the intrinsic noise test (measurement of a constant distance).



Spectral density of the distance variation measurement error obtained during the tests and compared to the requirement.

In order to achieve the specified measurement performance over a distance of 10 km, the laser frequency shall have a relative stability $\delta\nu/\nu \leq 1.4 \cdot 10^{-13}$ Hz$^{-1/2}$.

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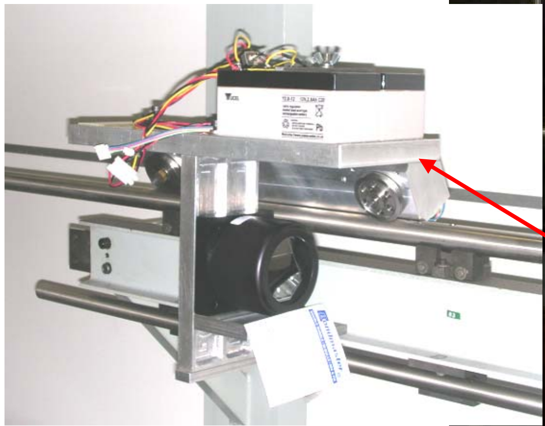
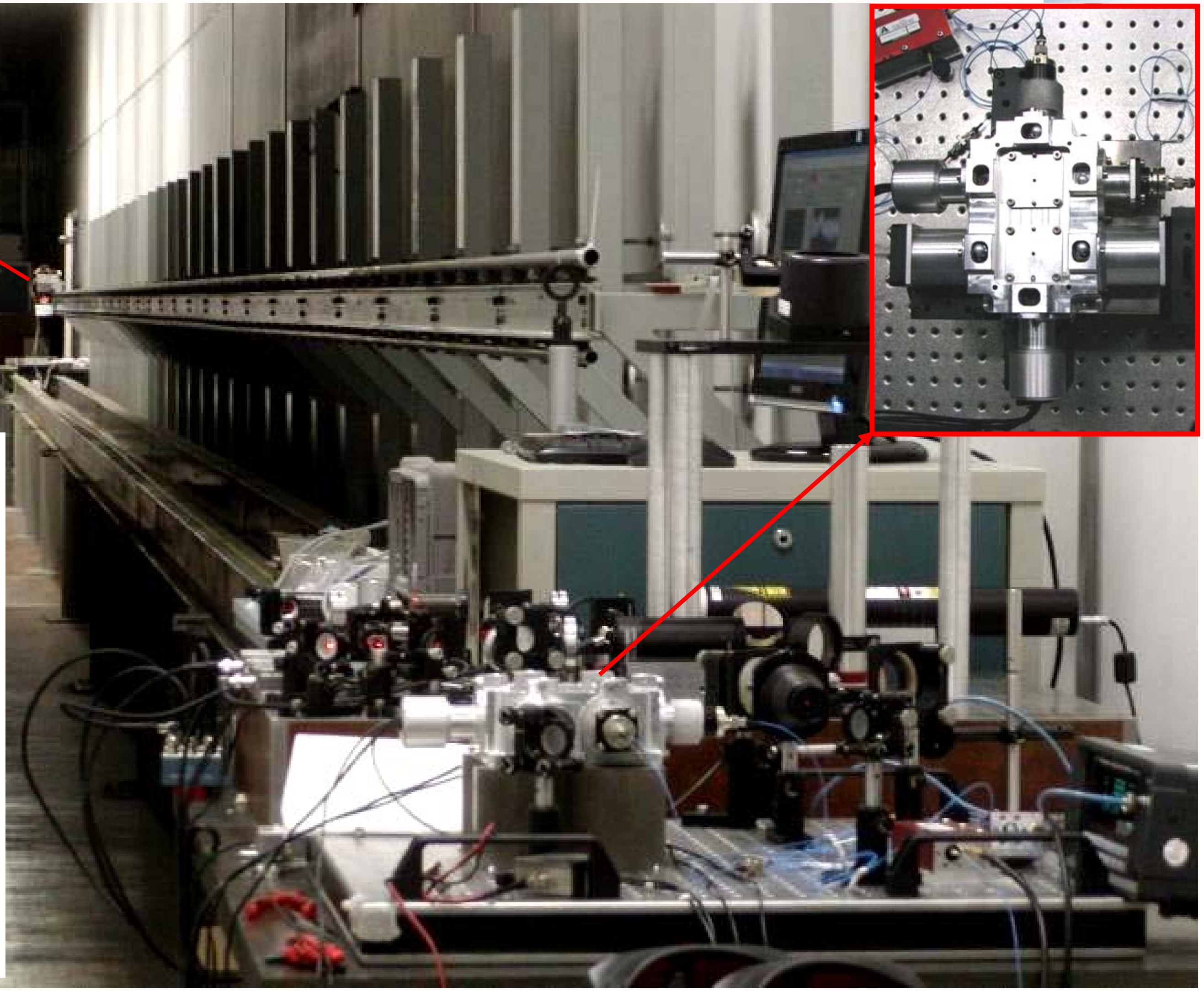
Satellite-to-satellite laser tracking for NGGM

Interferometer BB test



Laser interferometer breadboard under the functional test over a long distance (~90 m) with a moving target. The effectiveness of the measurement beam chopping scheme was successfully verified in this test.



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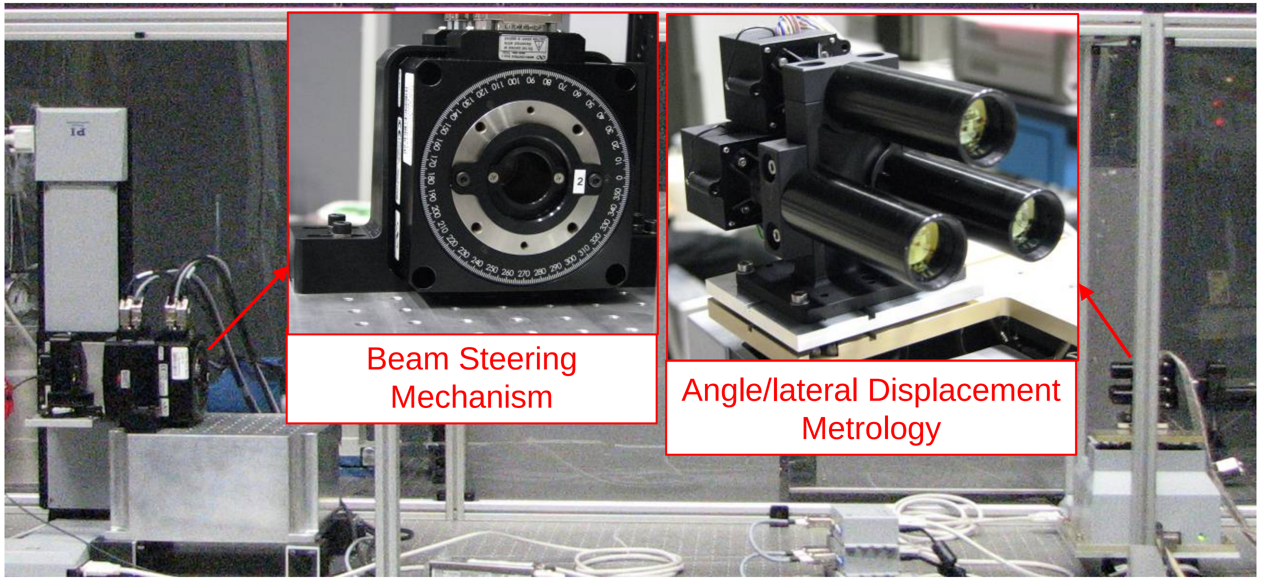
Test of the laser beam pointing control system BB.

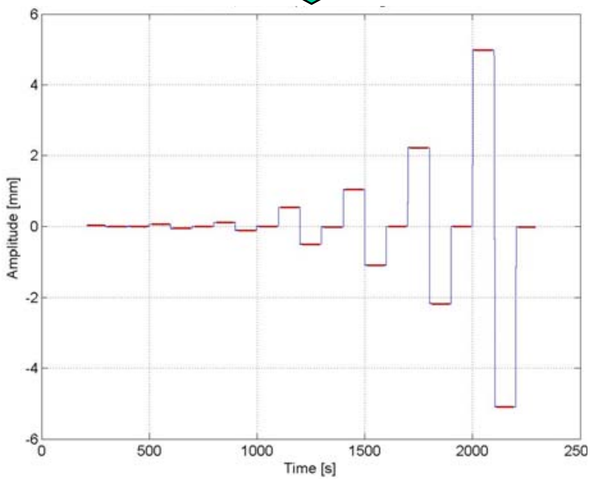


Open-loop test of the Lateral Displacement Metrology.

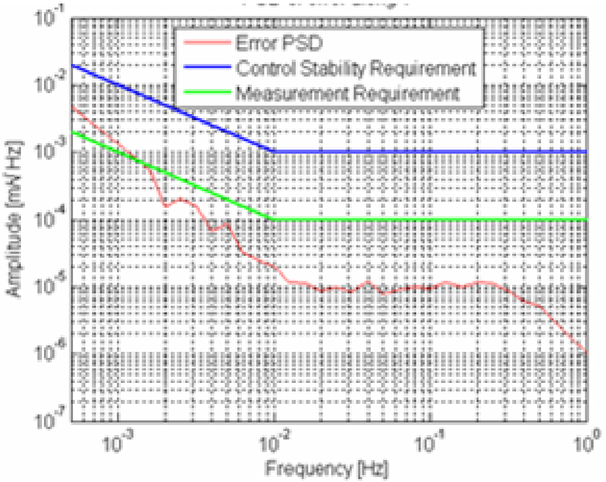
Lateral displacement steps (from ±50 μm to ±5 mm) measured by the optical metrology at 10 Hz.

Max. measurement error: 0.25 mm (over the largest steps)

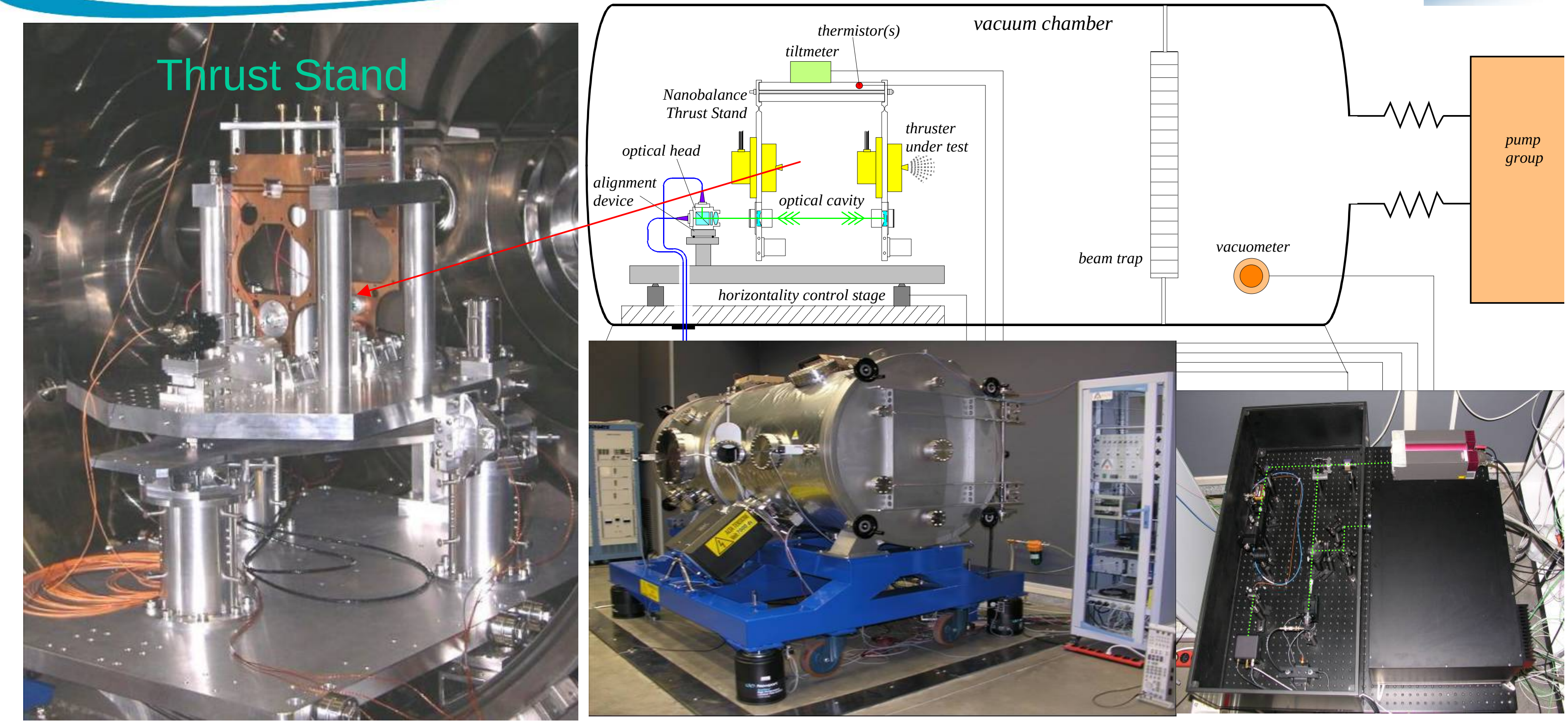
Max. measurement noise: 14 μm 1σ.



Closed-loop test of the laser beam pointing control system (BSM driven by the Lateral Displacement Metrology measurements). Laser beam pointing stability results.

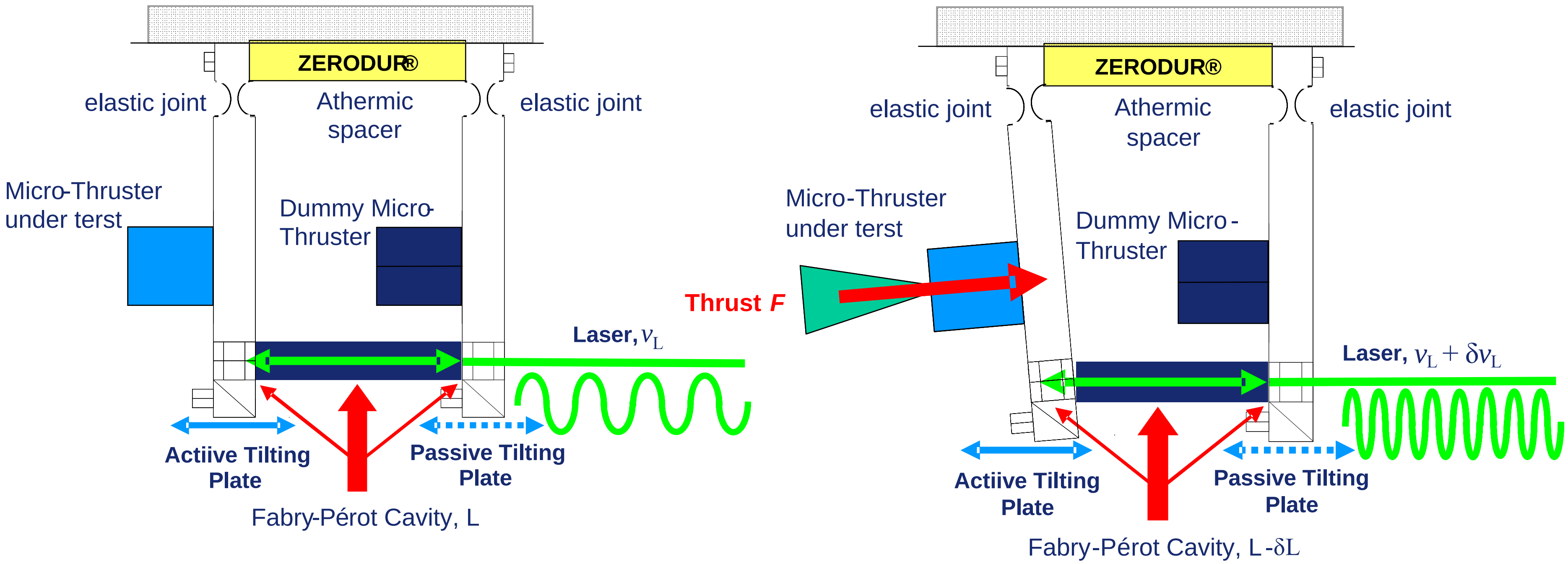


Nanobalance



The Nanobalance is a complete test facility for the direct measurement of the force provided by a micro-thruster along its thrust axis, developed by TAS-I for ESA.

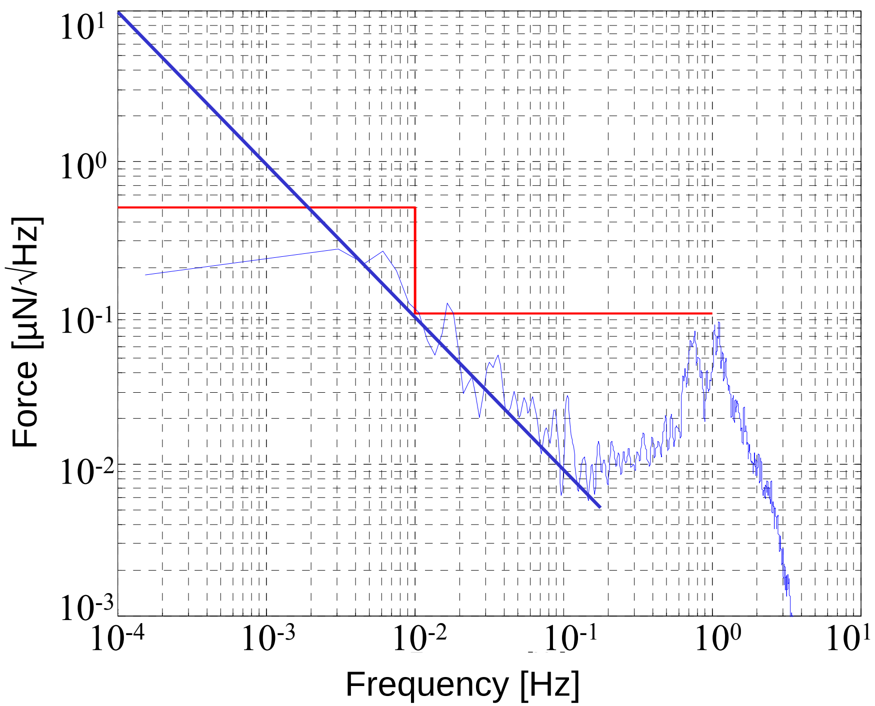
Nanobalance



A micro-thruster force F = 0.1 μN induces a distance variation between the tilting plates δL ≅ 14 pm, corresponding to frequency variation of the laser locked to the Fabry-Perot cavity $\delta\nu_L \cong$ 40 kHz.

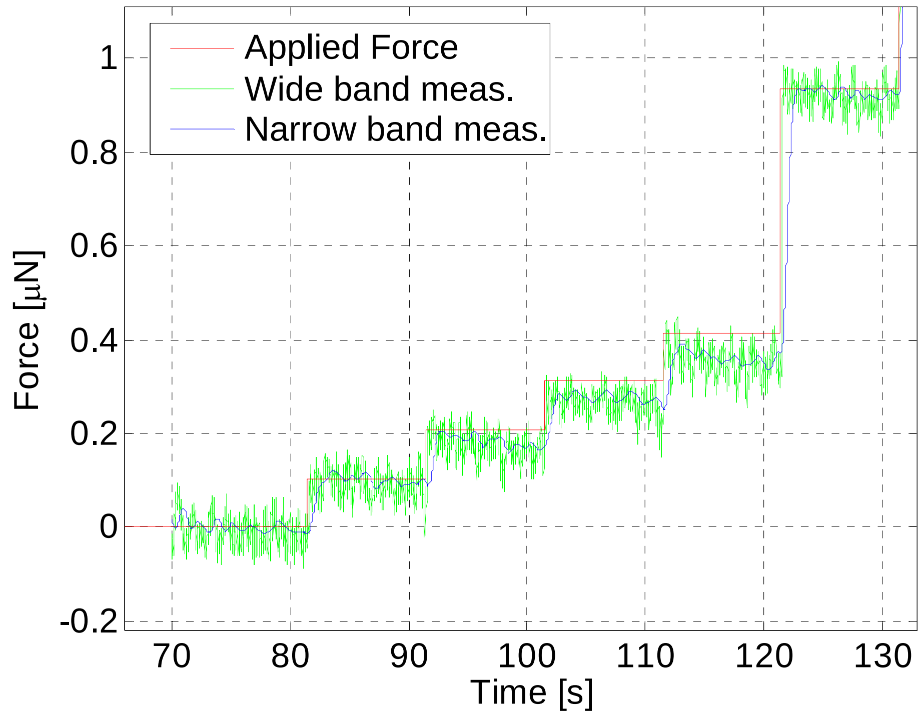
Nanobalance

NB background noise - PSD



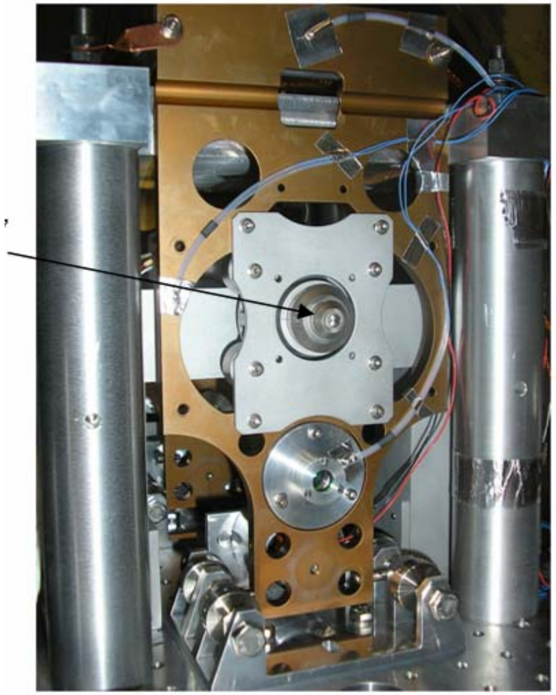
Power Spectral density of the measurement force noise after post-processing for removing the low-frequency drift effect.

NB Resolution

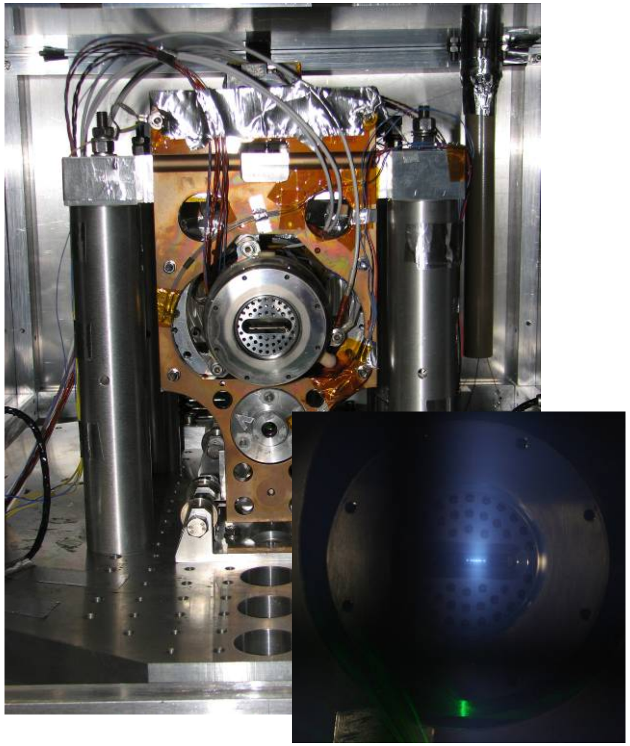


Measured thrust corresponding to the smallest applied force steps with a voice coil actuator.

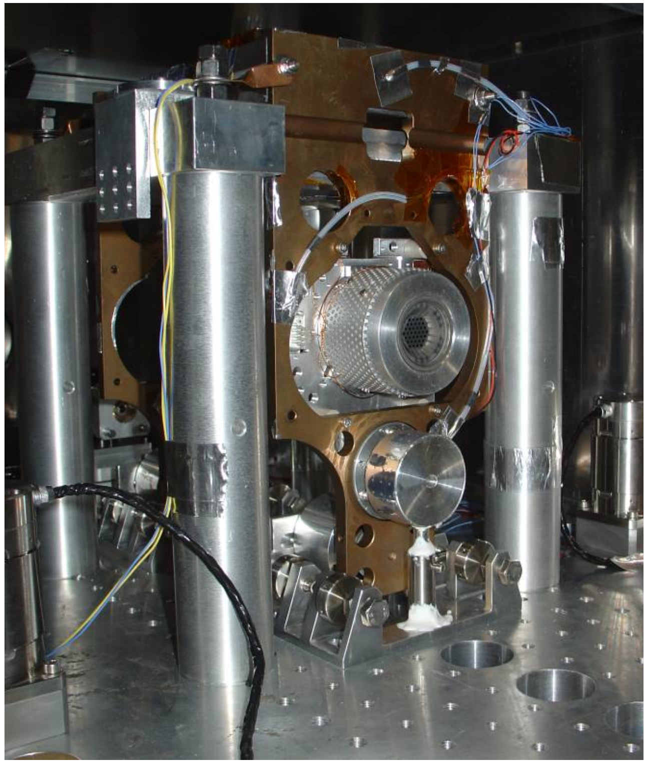
Nanobalance



Test of a cold-gas thruster

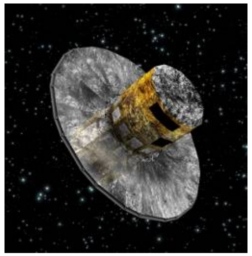


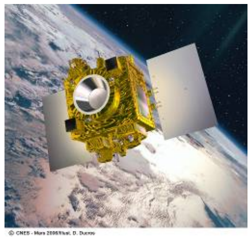
Test of a FEEP thruster



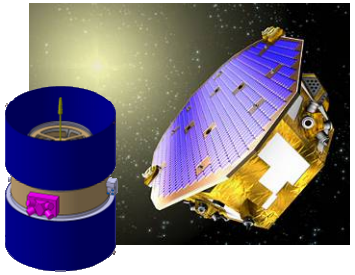
Test of a mini-RIT

Applications: GAIA, Microscope (backup)

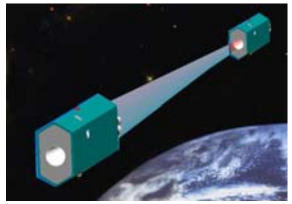




Applications: LISA PF, Microscope, GG



Applications: NGGM, GG (backup)



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