

Torsion Pendulum Ground Testing Results for LISA Gravitational Reference Sensors

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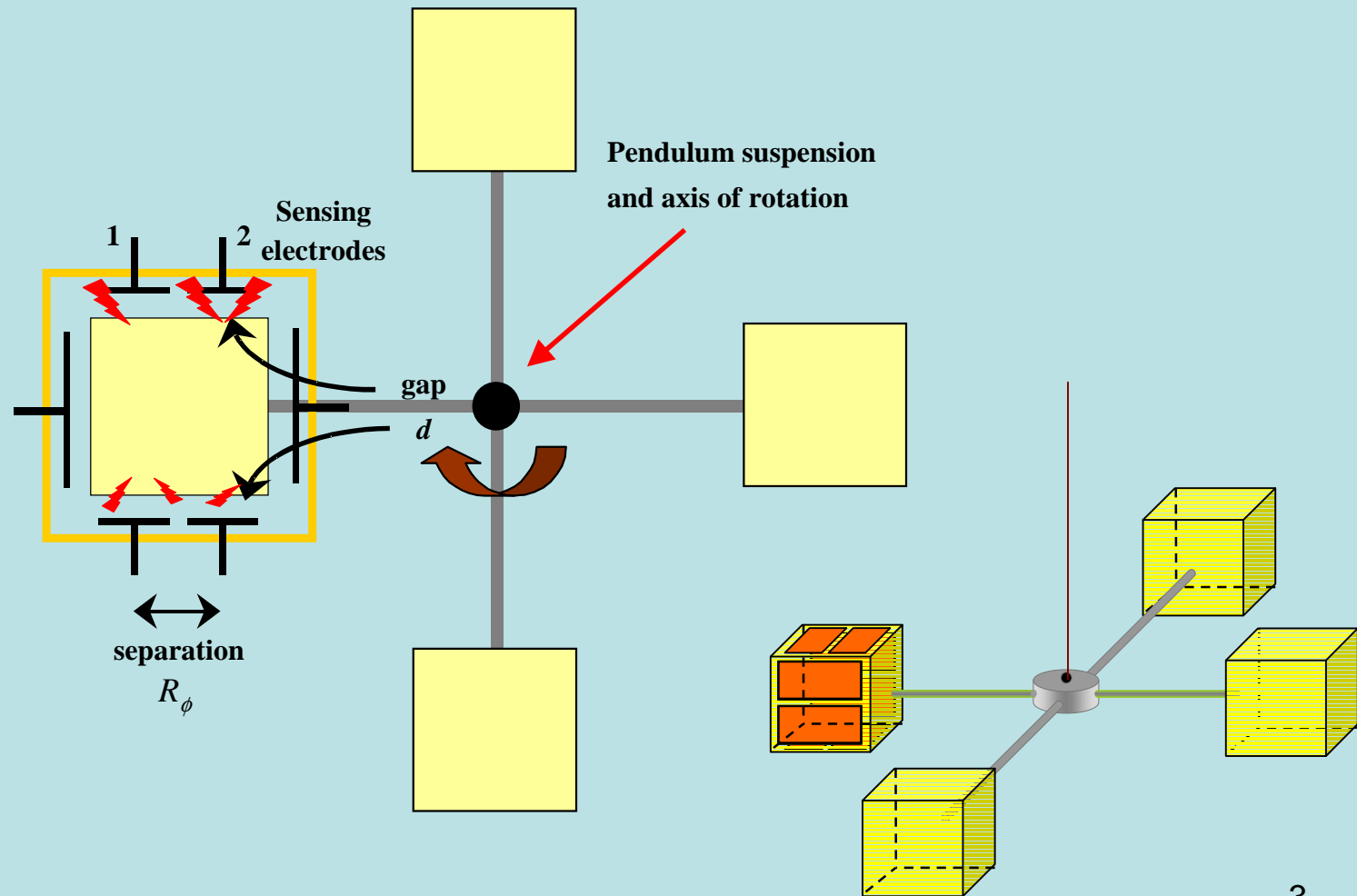
LIGO-G030472-00-Z

Talk summary

- n Scheme of the experiment
- n Random force noise measurements
- n Sensor disturbances characterization:
 - stray DC bias measurements and compensation
 - electric charge measurements
 - electrostatic coupling (stiffness)
- n Status and future of the facility

Testing LISA gravitational sensors with torsion pendulum

- Light weight test mass suspended as part of the inertial member of a low frequency torsion pendulum, surrounded by representative LISA sensor housing

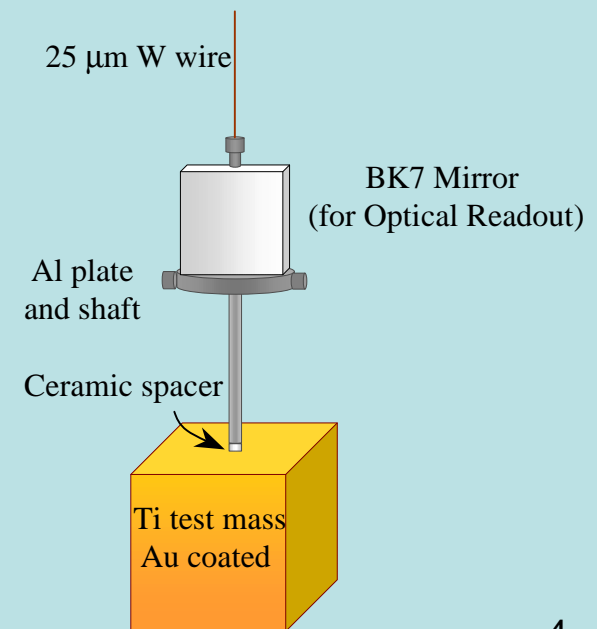
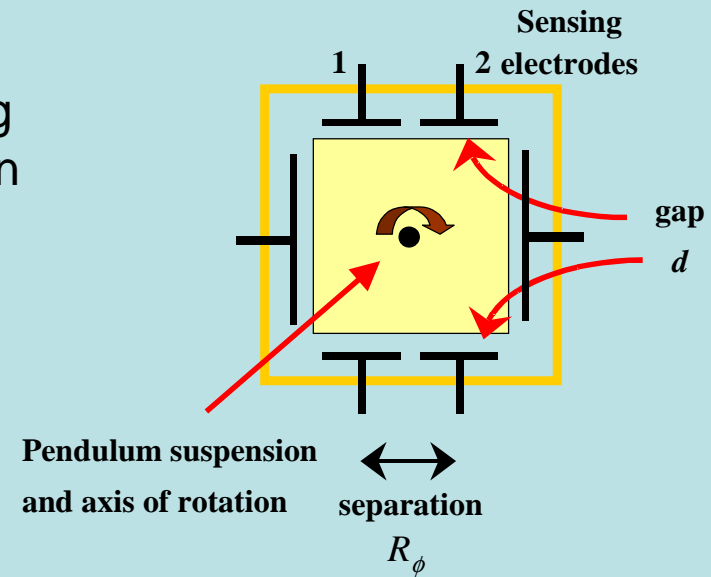


- Measure **surface stray forces** and coupling to sensor as deflections of pendulum rotation

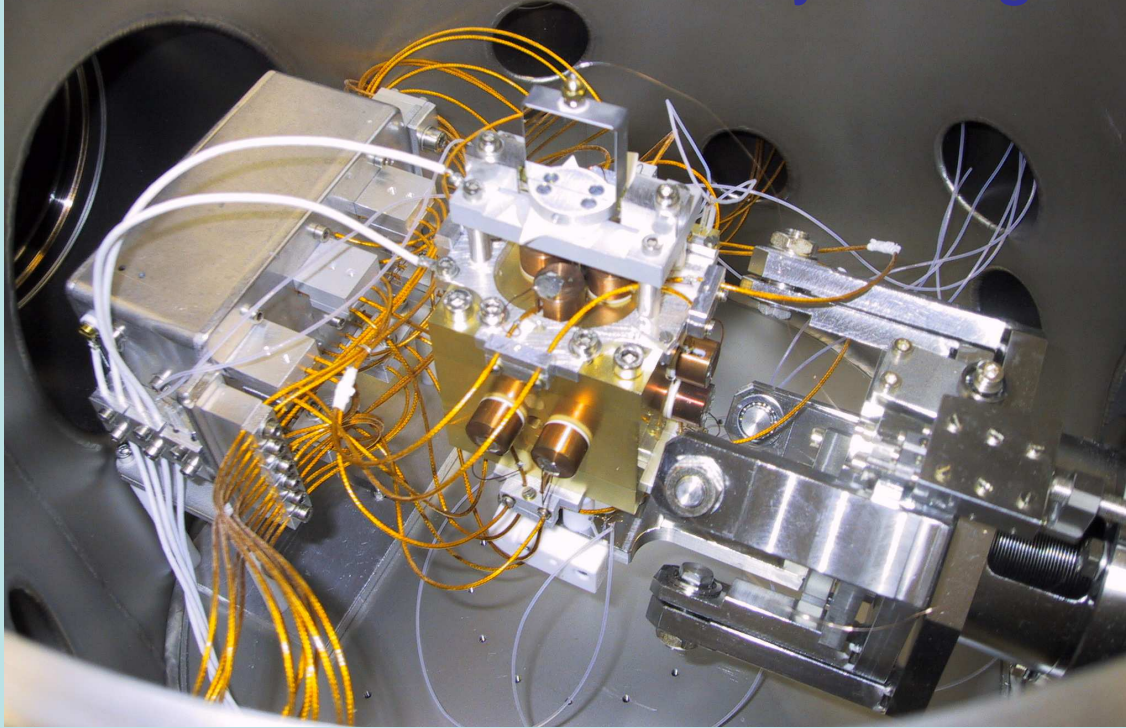
- Upper limit to **differential force noise** along 1 rotational dof

- Precise measurements of **residual coupling** to sensor (electrostatic, gravitational)

- **Disturbance sources** study: stray DC voltages (charge, patch fields)

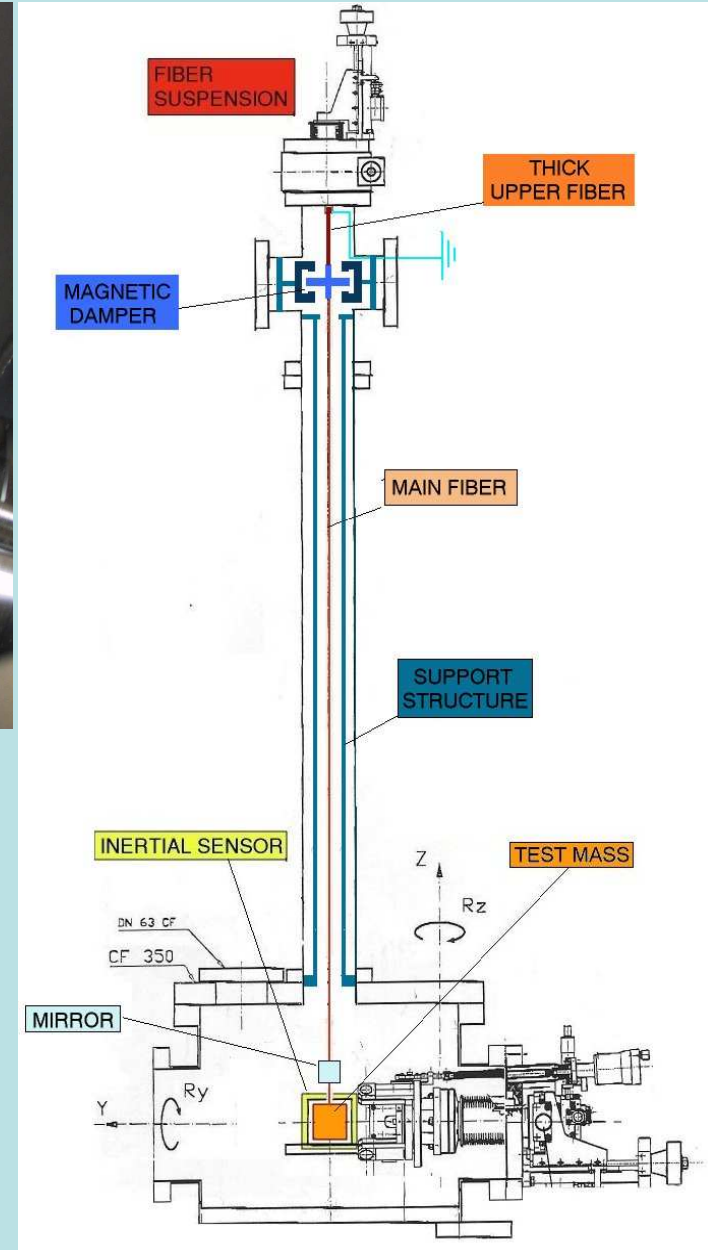
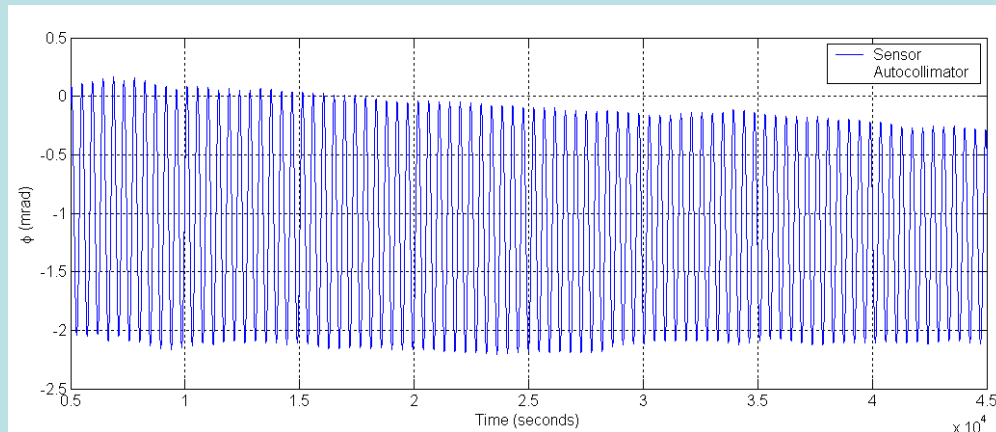


The facility at a glance

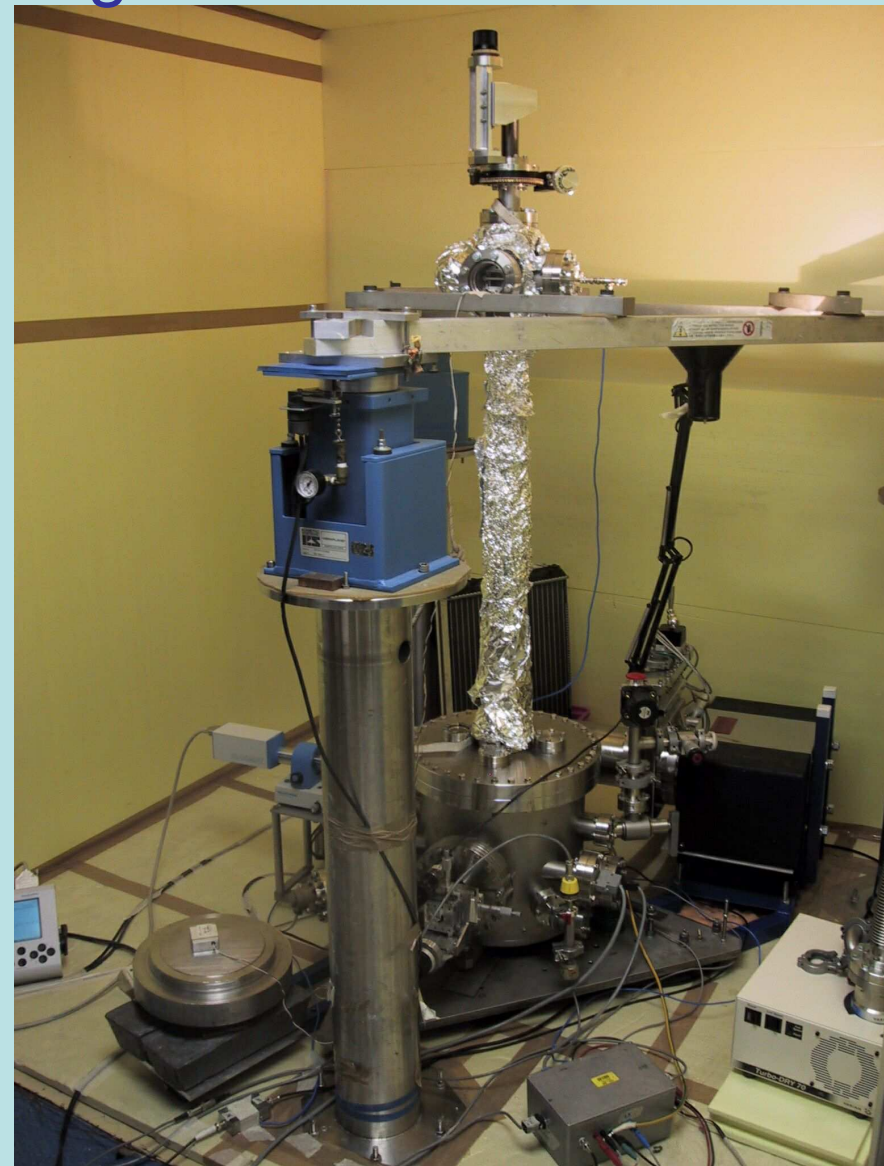
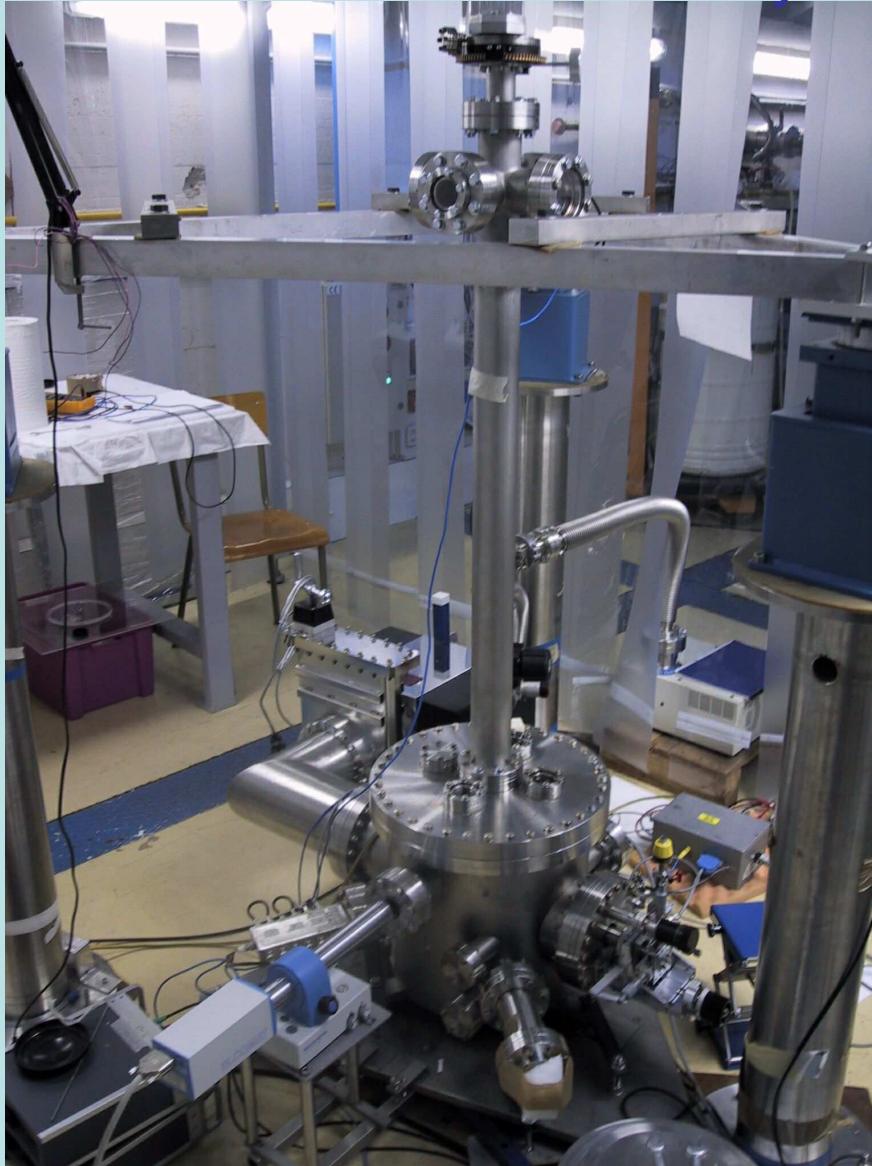


25 μm
1m W fiber

$T_0 = 513 \text{ s}$
 $Q = 1750$

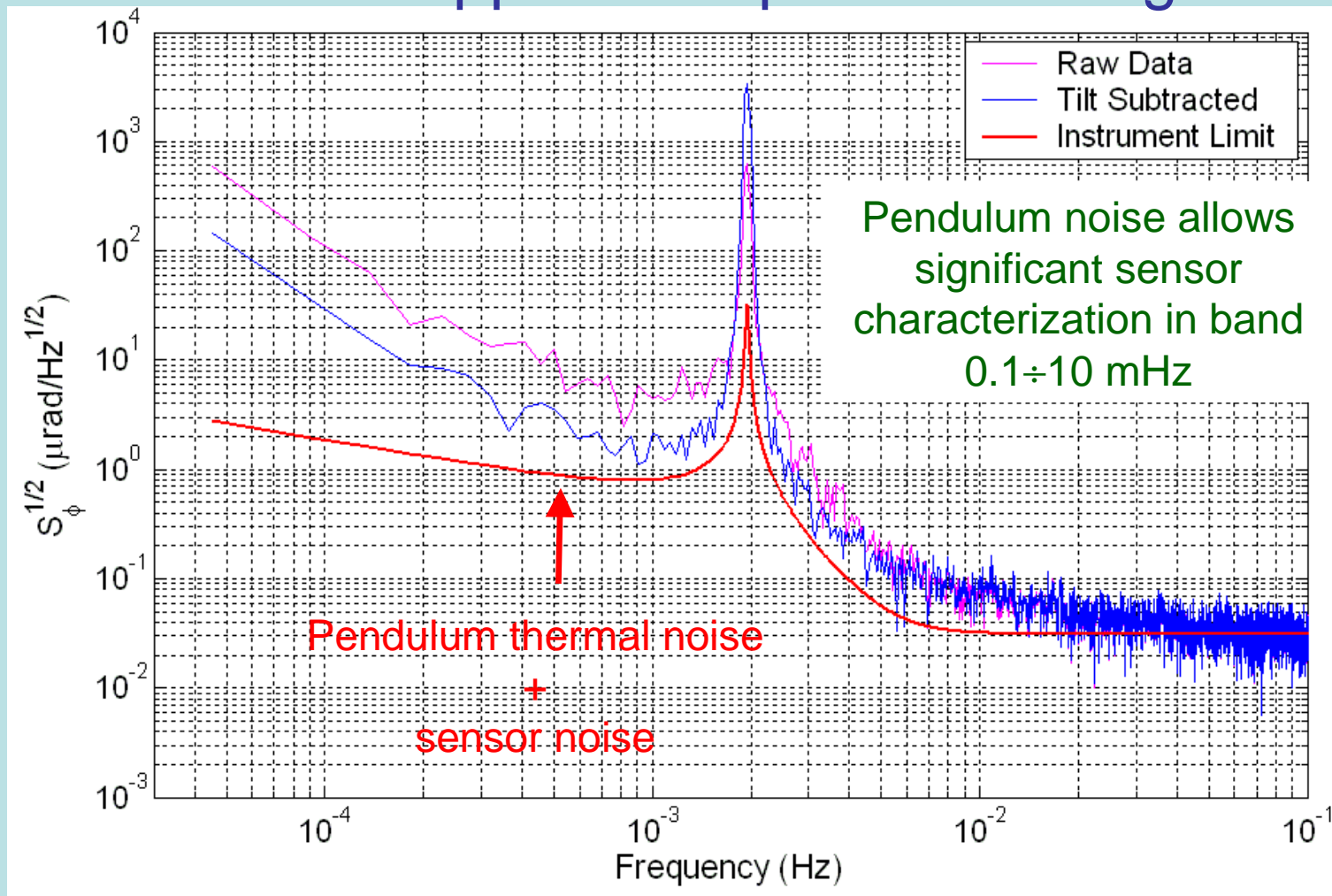


The facility at a glance



**Many more details in poster by
L.Carbone *et al***

Random forces upper limit: pendulum angular noise



- Angular noise of roughly 6 times the thermal limit at 1 mHz
- Tilt-subtracted data by measured coupling coefficients: roughly 2-3 times the thermal limit

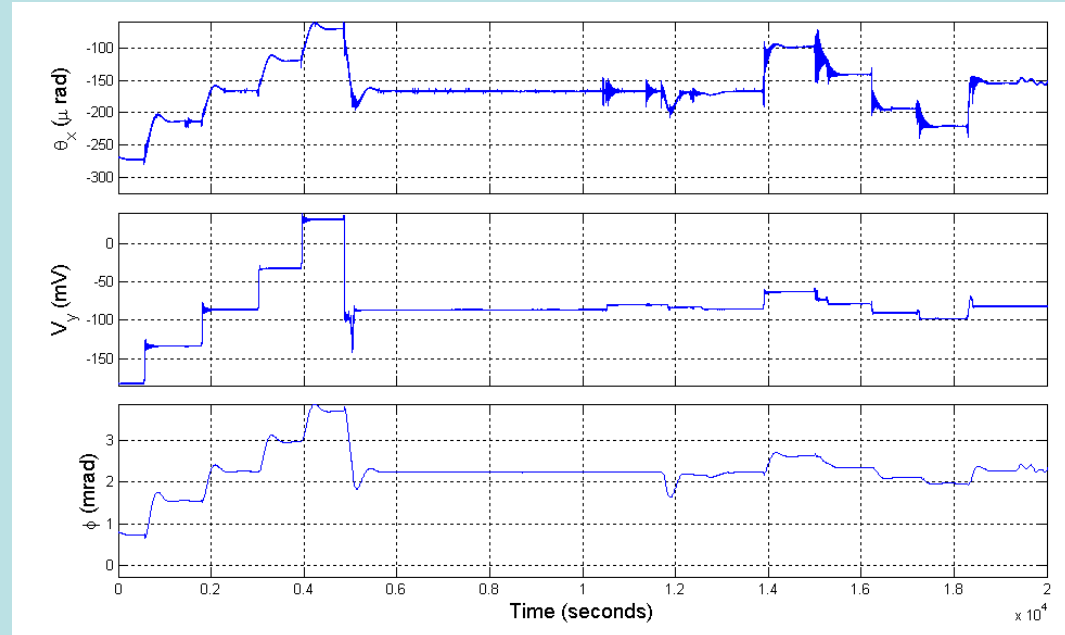
Pendulum tilt noise

- “Tilt-twist” feedthrough couples tilt into torsional mode
- Measured: $\sim 300 \text{ nrad/Hz}^{1/2}$ at 1 mHz

Pendulum x tilt

Pendulum y tilt
(uncalibrated sensor,
 $2000 \text{ mV} \sim 1 \text{ mrad}$)

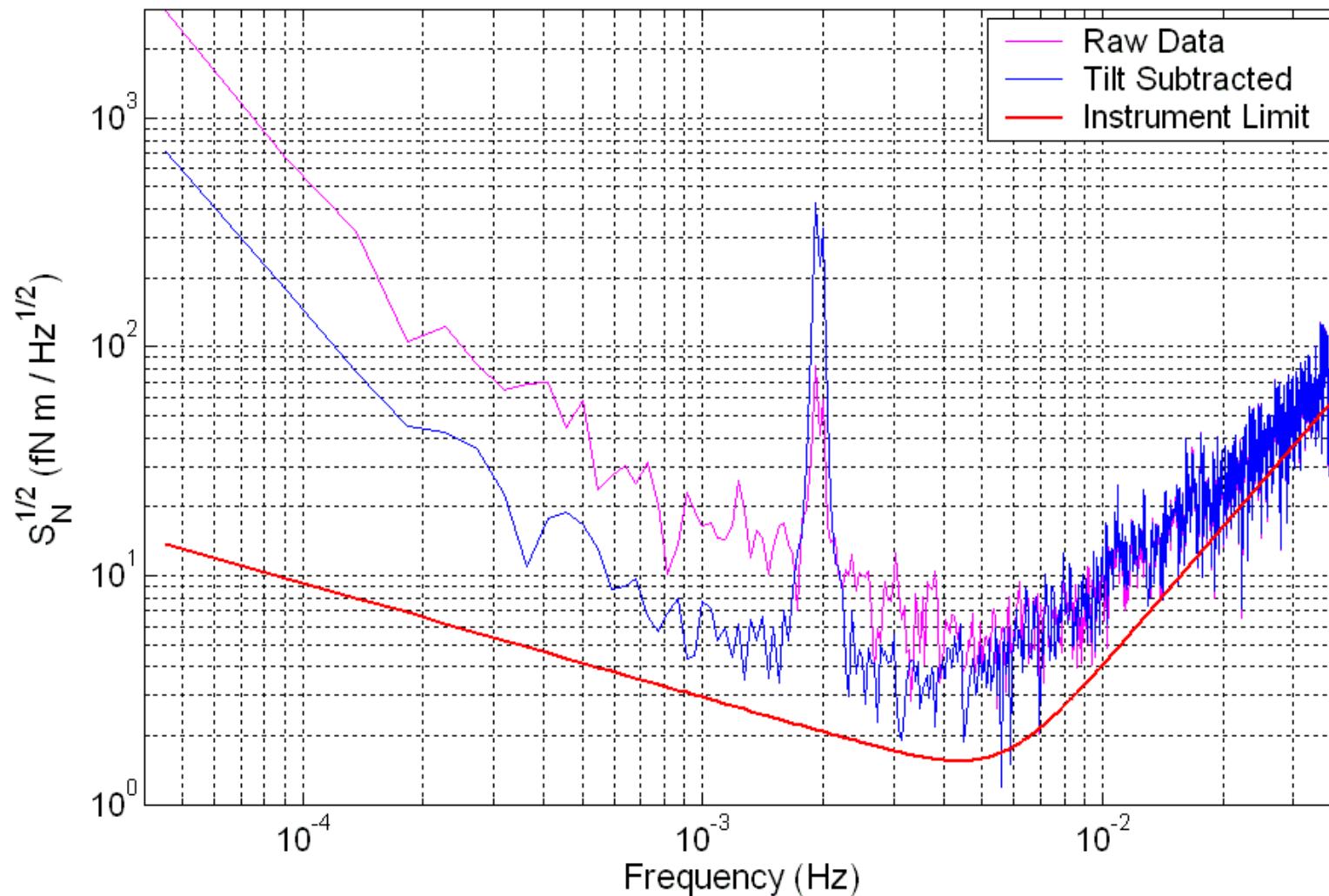
Pendulum twist



- Tilt pendulum platform, measure tilt and resulting pendulum rotation
- Time series subtraction of effect of floor tilt, with sensor θ_x, θ_y data and measured coefficients

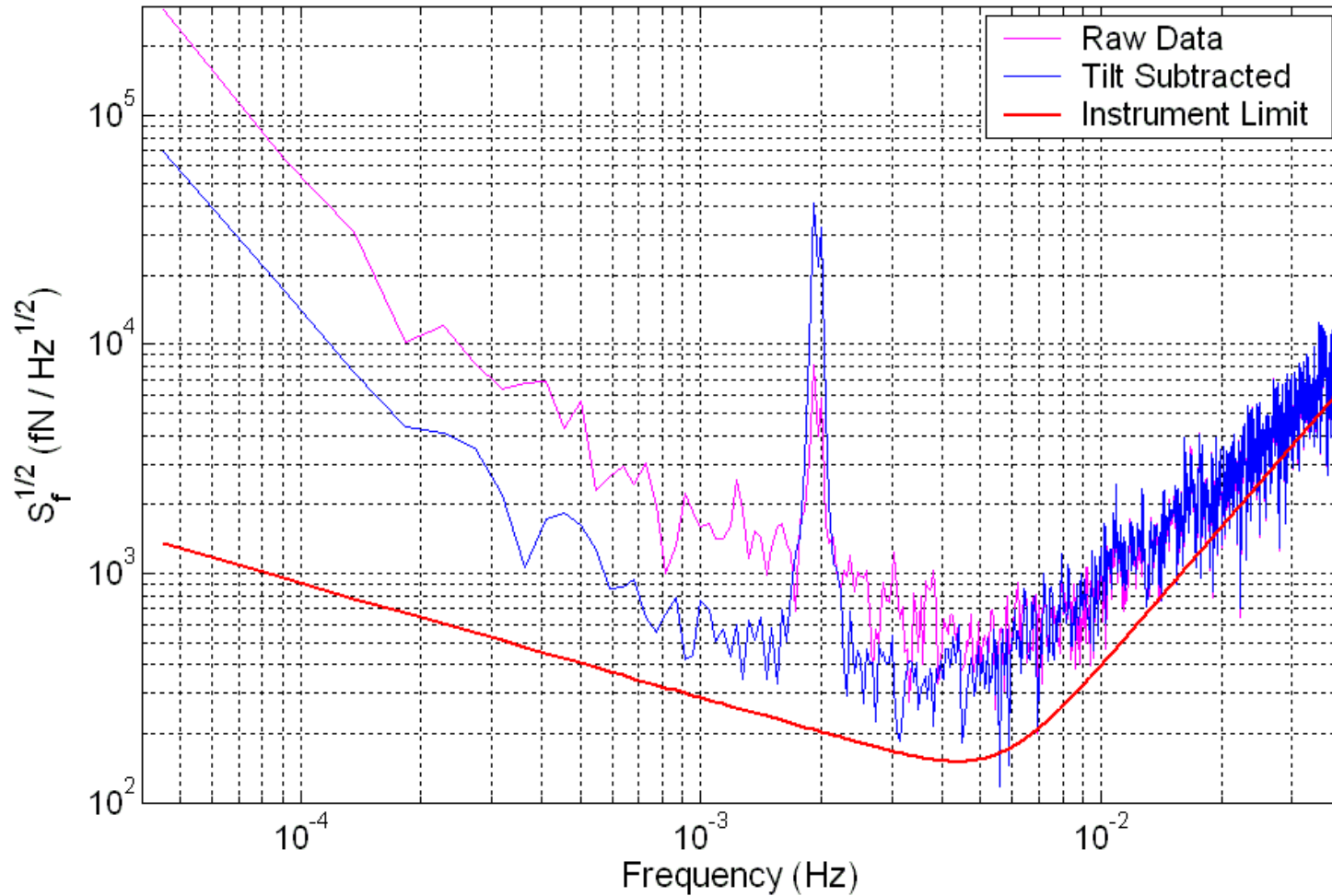
$$\Delta\phi(t) = T_{\theta_x} \Delta\theta_x(t) + T_{\theta_y} \Delta V_Y(t)$$
$$\phi(t) = \phi_{raw}(t) - \Delta\phi(t)$$

Random forces upper limit: torque noise



- Torque noise $< 10 \text{ fN m} / \text{Hz}^{1/2}$ between 0.6 and 10 mHz

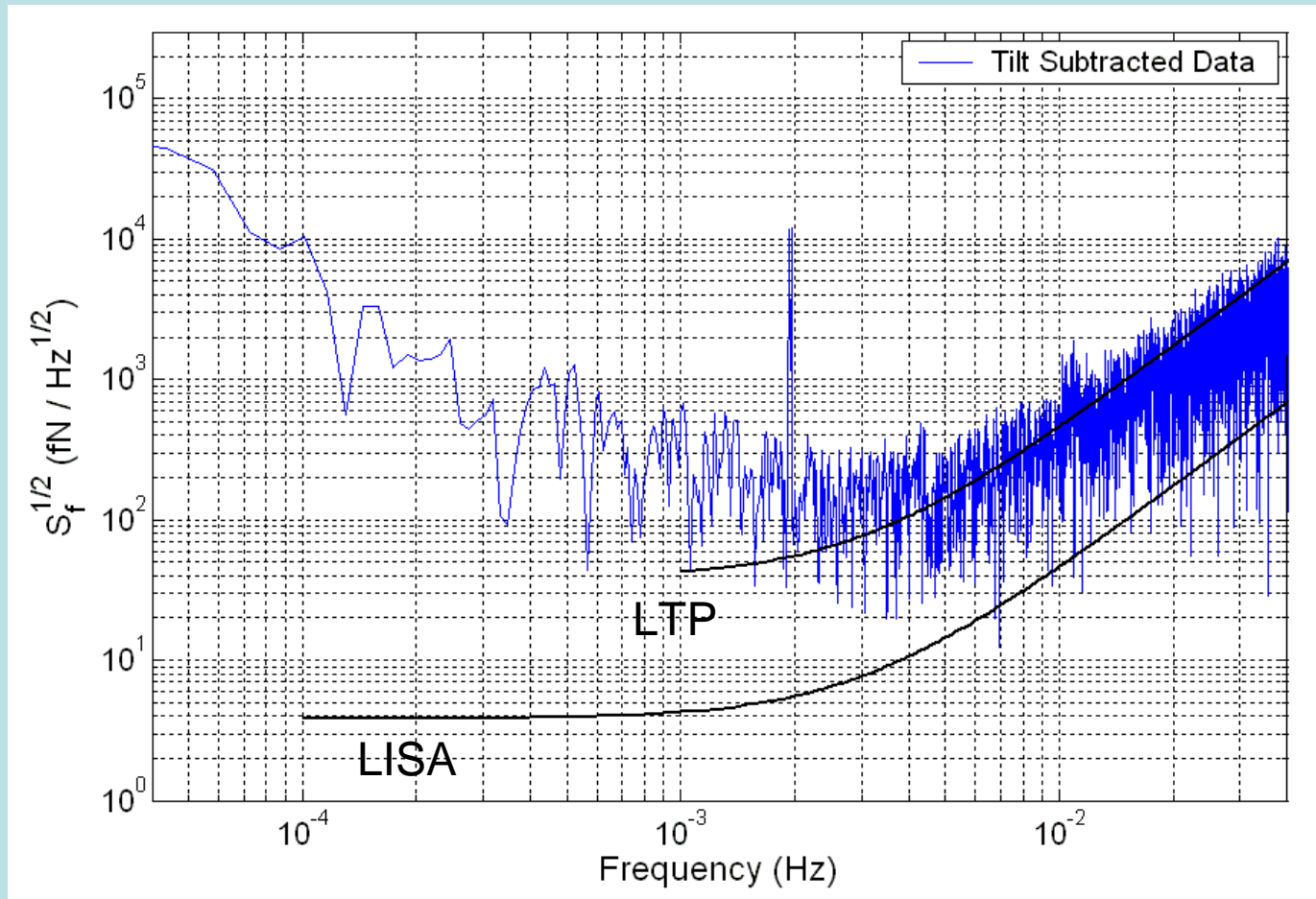
Random forces upper limit



Conversion from torque noise to differential force noise:

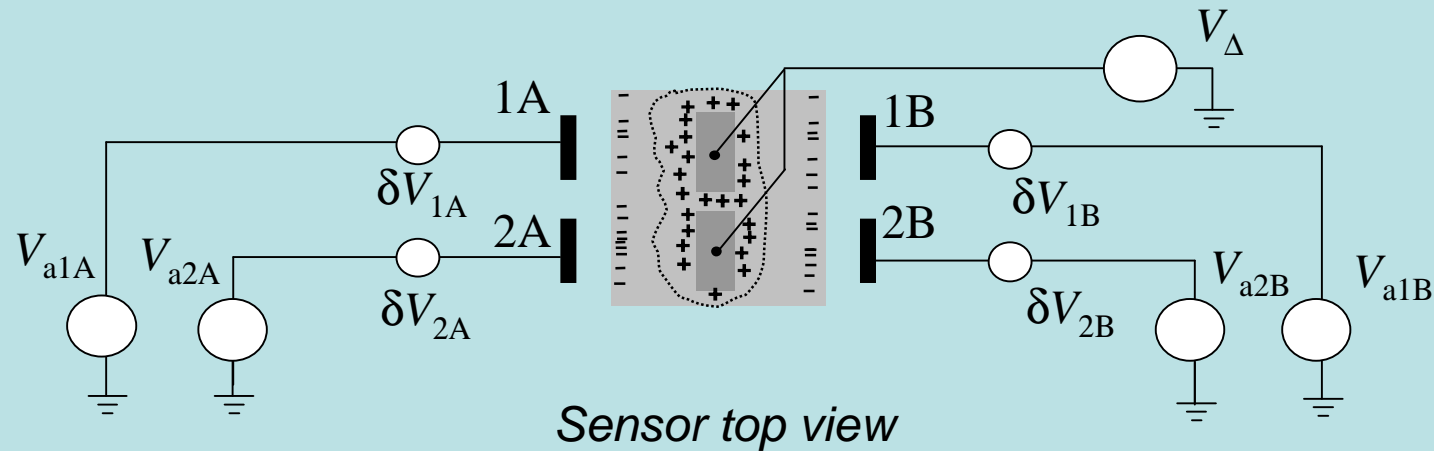
- Sensor **back-action**: arm length $L = R_\phi \approx 10$ mm
- Randomly **distributed surface effects**: $L \approx 20$ mm

Impact for LISA



- Upper limit on **random surface forces**:
molecular collisions, homogeneously distributed patch charges
- Relatively **insensitive to bulk** gravitational/magnetic disturbances
and to net forces

Electrostatic torque measurements: modulated DC biases



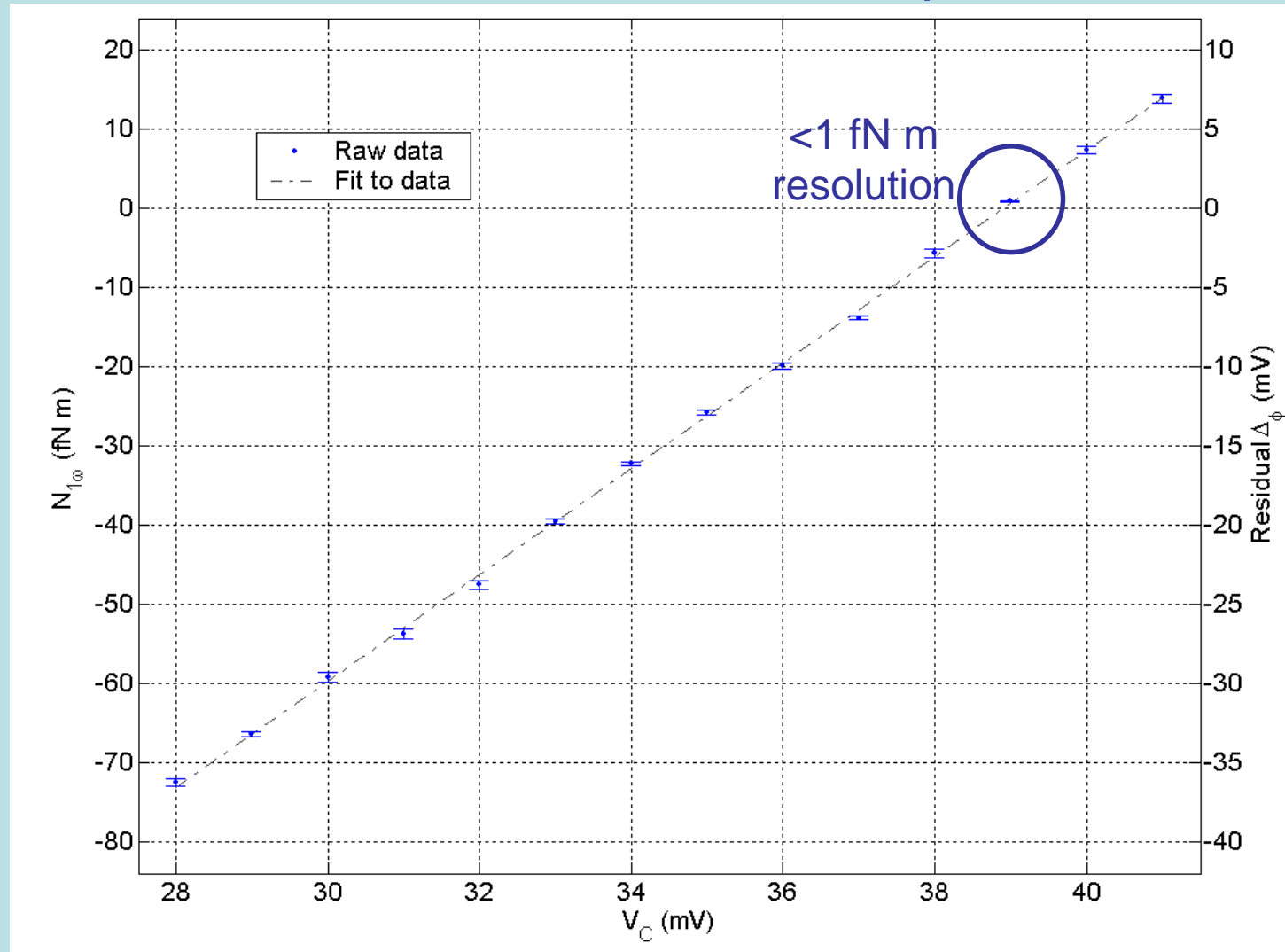
- Modulate test mass voltage with $V_{\Delta} = 3V$ amp at $f_0 = 5$ mHz on injection electrodes
- Charge and DC biases produce torques at voltage driving frequency
- Measured $1\omega_0$ torque sensitive to “diagonal” DC bias imbalance

$$\Delta_{\phi} = \delta V_{1A} + \delta V_{2B} - \delta V_{1B} - \delta V_{2A}$$

- Compensate with applied voltages:

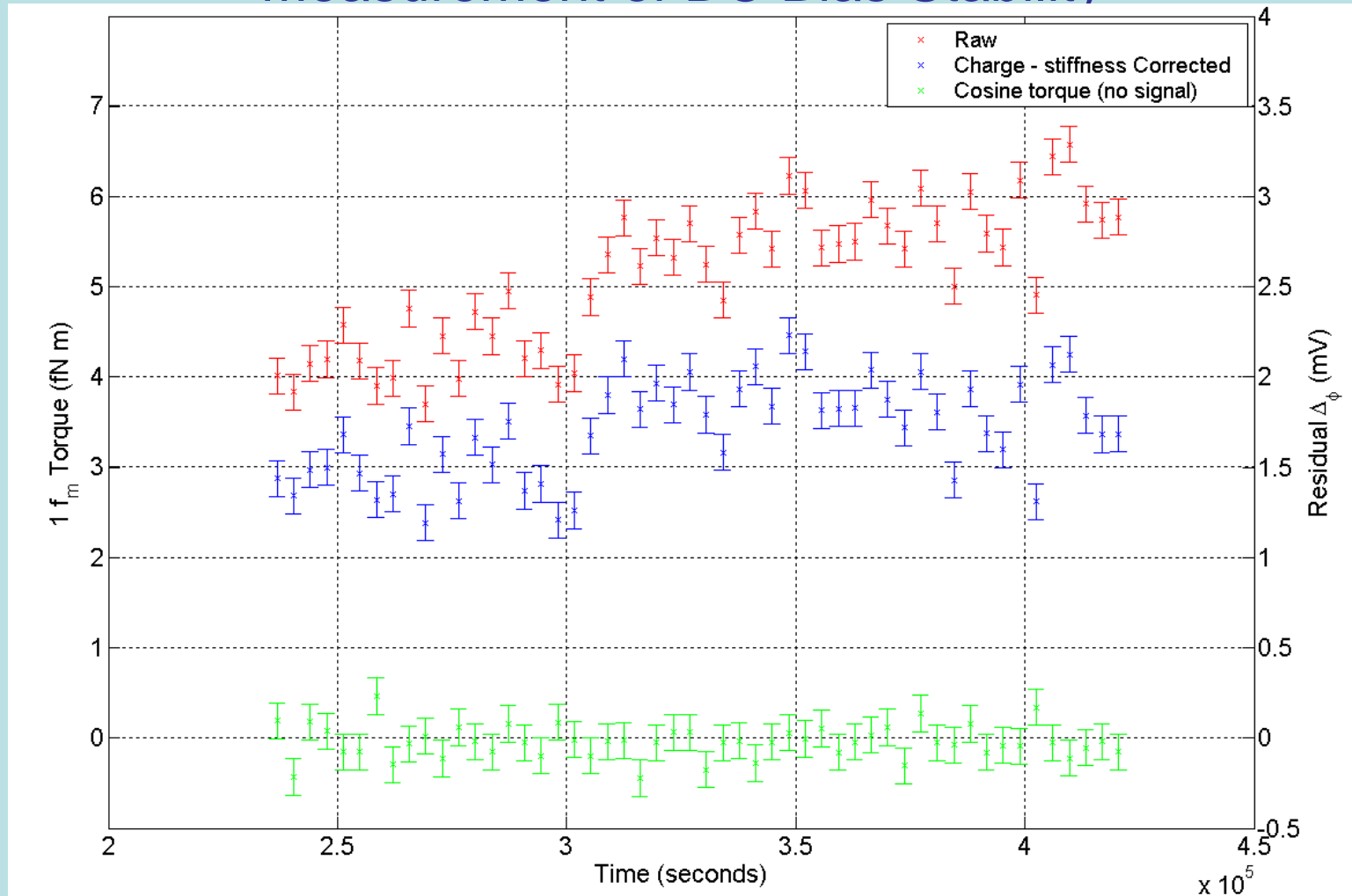
$$V_{a1A} = V_{a2B} = -V_{a1B} = -V_{a2A} \equiv V_{COMP} = -\Delta_{\phi}/4$$

DC Bias measurement and compensation



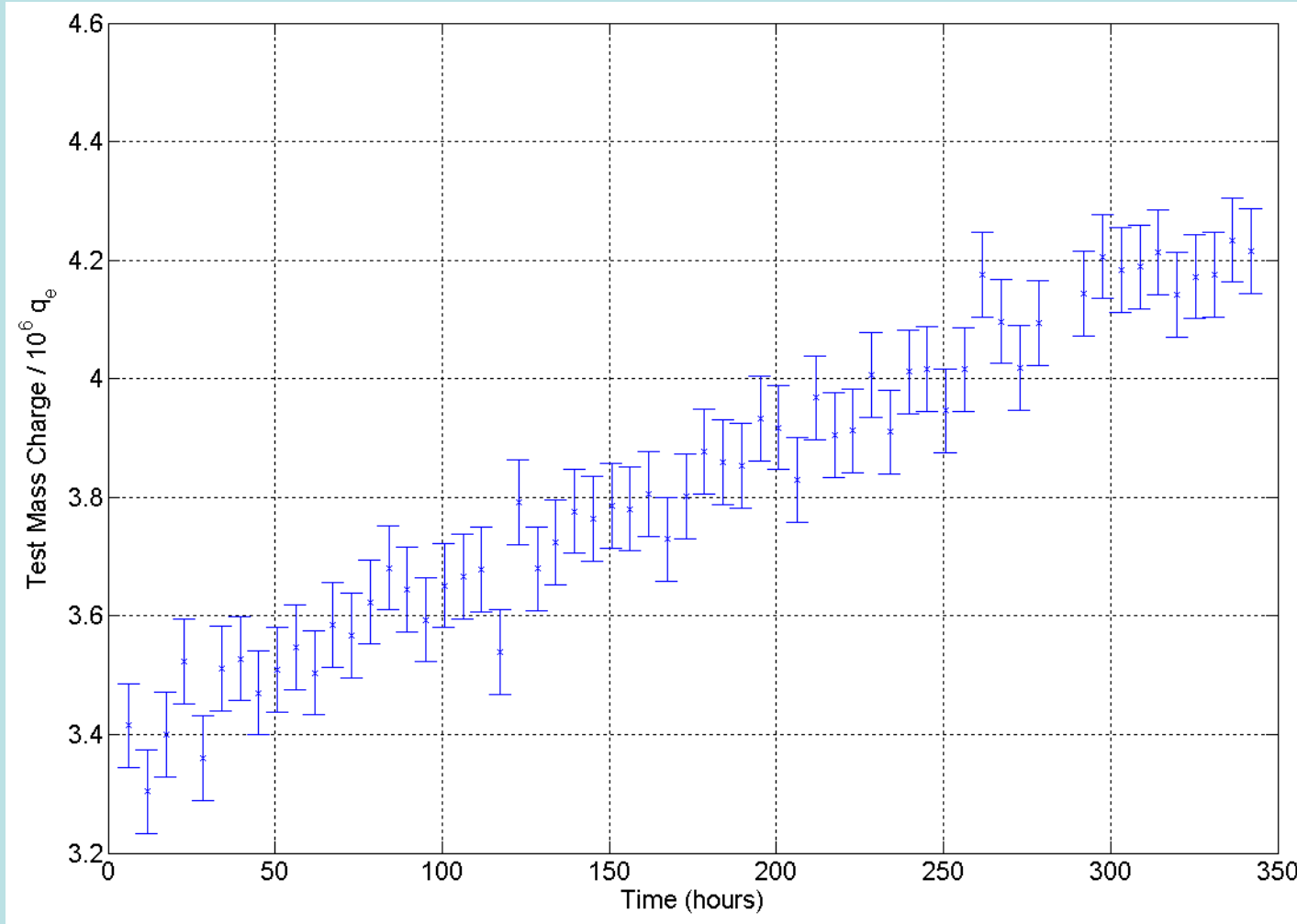
- DC Bias imbalance measured and compensated within 1 mV
- Problem for LISA: 10 mV level

Measurement of DC Bias Stability



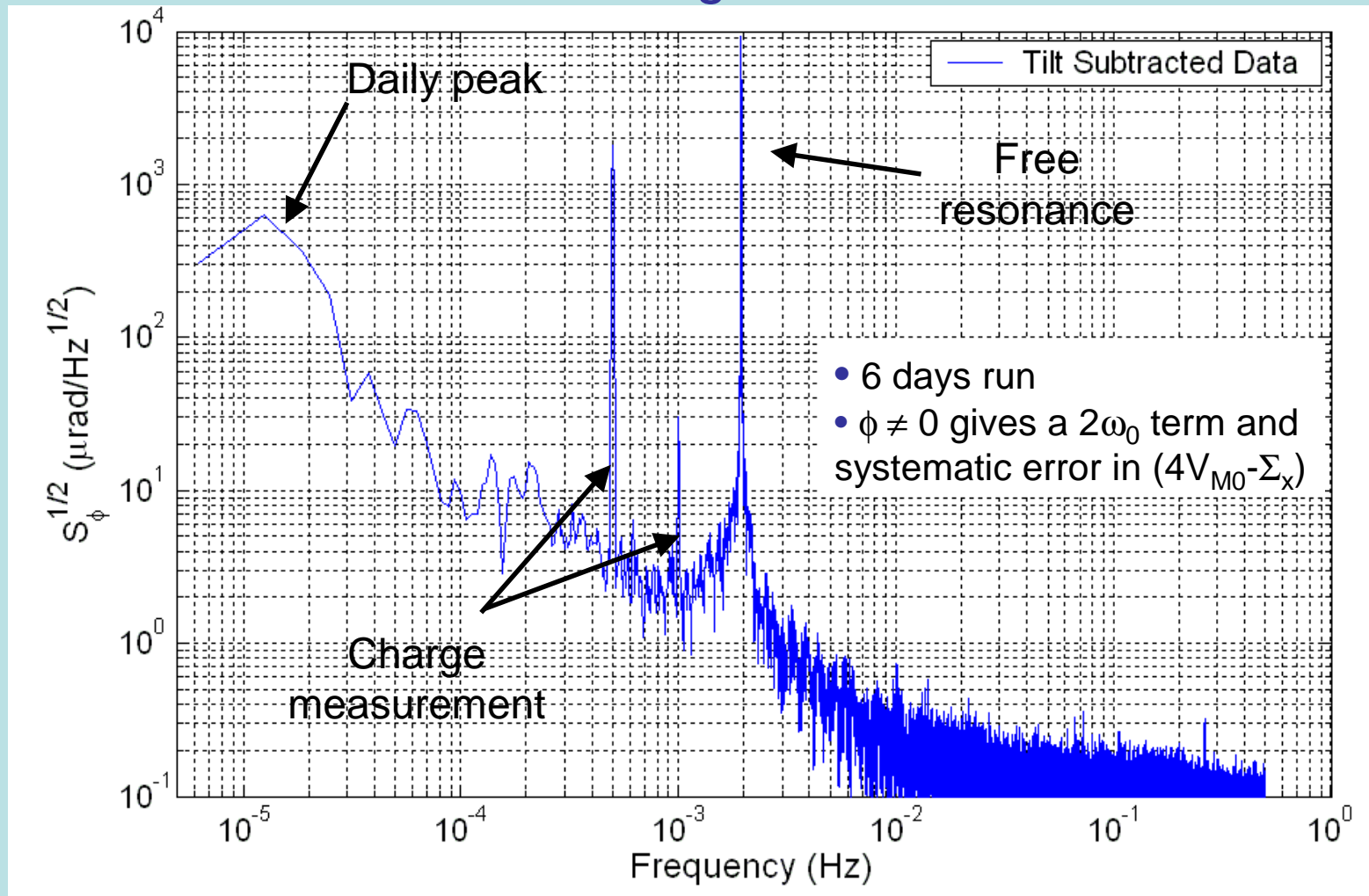
- DC bias imbalance stable to within 1 mV over 50 hour run
- Measurement noise (cosine phase) is below the observed scatter in the electrostatic signal

Long term charge measurement



- Roughly +1 e/s charging
- Measurement error of $5 \cdot 10^4$ charges in a 6 hour measurement with 50 mV measurement bias

Test mass charge measurement



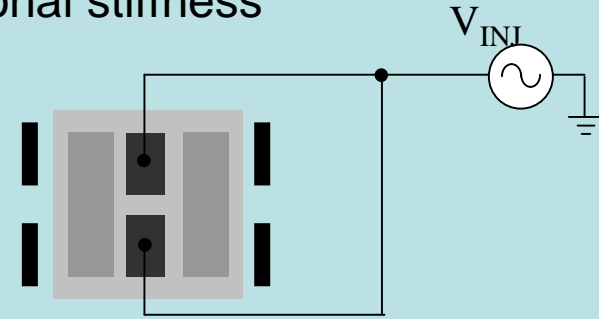
Ground-based demonstration of the technique to be used in flight for:

- Stray DC fields
- Test mass charge

Measurement of electrostatic sensing stiffness

- Sensor bias voltage produces electrostatic rotational stiffness

$$N_0 = \frac{1}{4} \left(V_{in0} \frac{C_{in}}{C_{TOT}} \right)^2 \sum \frac{\partial^2 C}{\partial \phi^2} (\phi - \phi_0) = -\Gamma_{sens} (\phi - \phi_0)$$

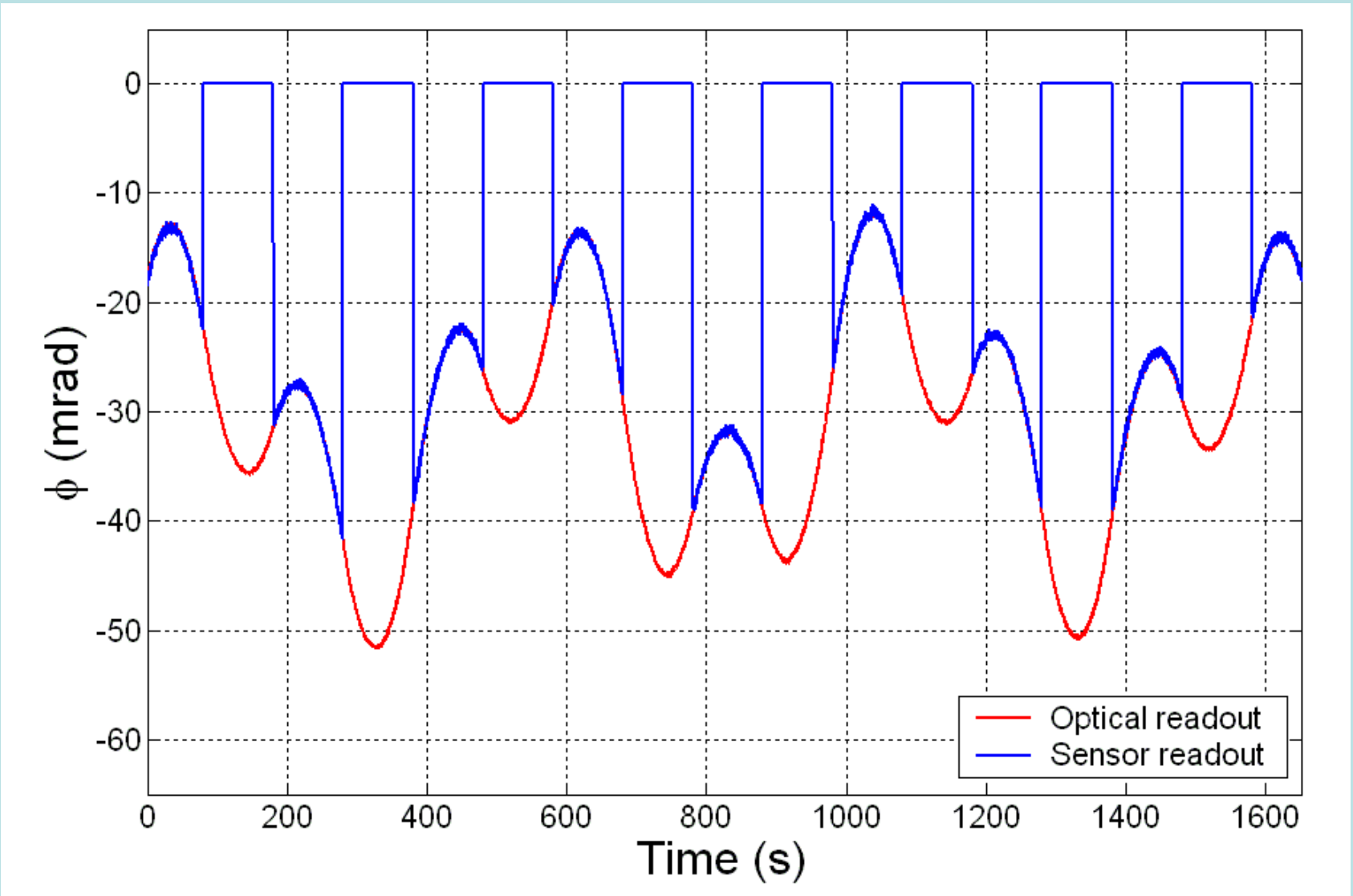


- Squarewave modulation of 100 kHz sensor bias amplitude produces squarewave torque $N(t)$

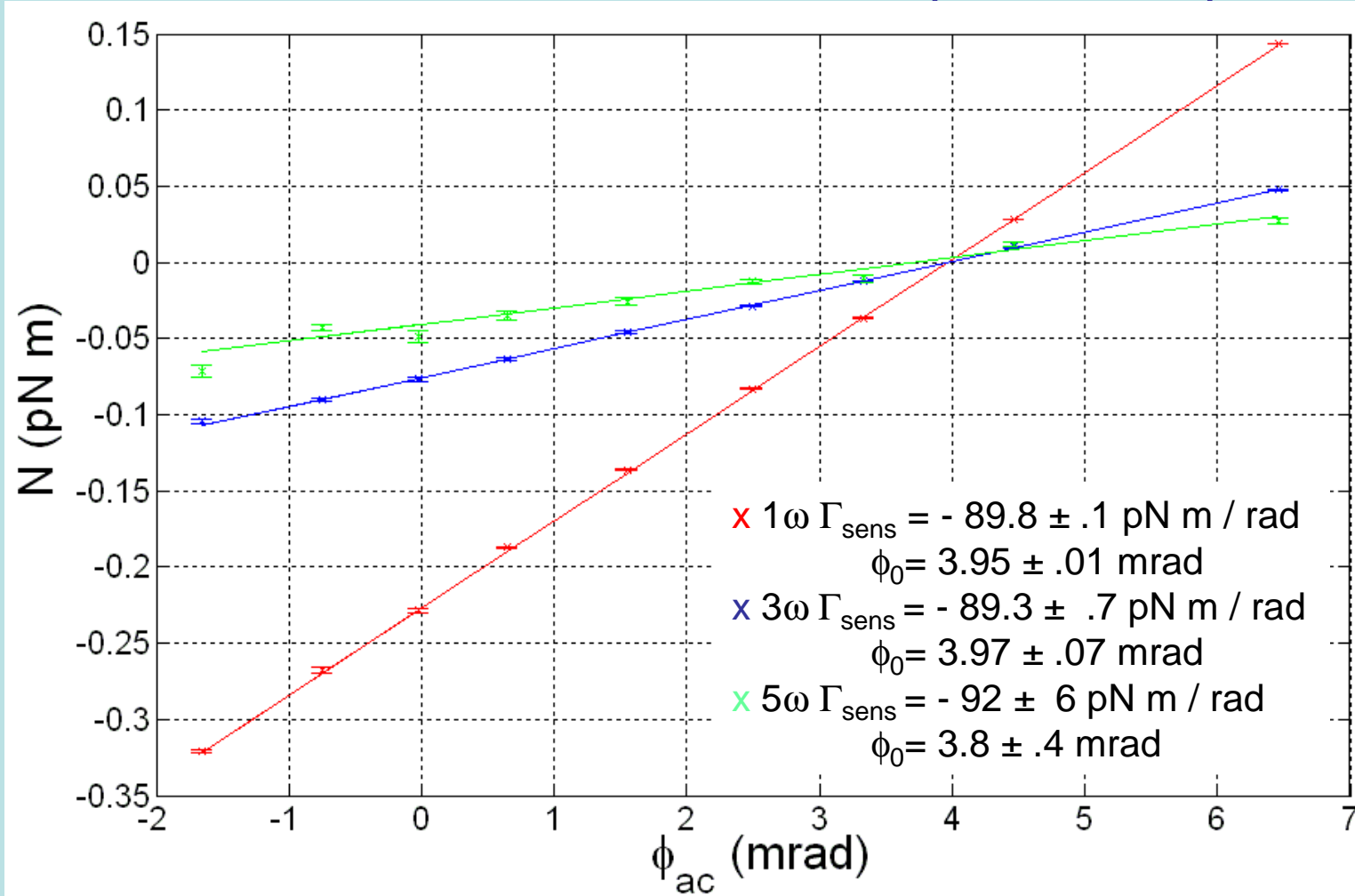
$$N(t) = N_0 \times \left\{ \frac{1}{2} + \frac{2}{\pi} \sin \omega_0 t + \frac{2}{3\pi} \sin 3\omega_0 t + \frac{2}{5\pi} \sin 5\omega_0 t + \dots \right\}$$

- Coherent detection of $1\omega_0$, $3\omega_0$ torques ... each give independent estimate of squarewave torque amplitude
- Measure torque $N(\phi)$ as function of position to get the torque gradient or angular stiffness: $\Gamma_{sens} = -\partial N_0 / \partial \phi$

Electrostatic stiffness measurements: coherent torque scheme



Electrostatic stiffness measurements: position dependence



Infinite wedge capacitor: $\Gamma_{sens} = -\frac{1}{4} \left(V_{in0} \frac{C_{in}}{C_{TOT}} \right)^2 \sum \frac{\partial^2 C}{\partial \phi^2} \approx -96 \text{ pN m / rad}$

For LISA: known with **5%** (or better) precision

Status of the facility:

- “natural end” of the experiment due to fiber detaching from pendulum
- 6 months continuous operation

Next future:

- mirror and inertial member Au coating to reduce charging effects
- automated micropositioning system for sensor ϕ for total stiffness measurement
- charge management system device for LTP (breadboard)

Future:

- multiple mass configuration to study translational forces
- improved tilt immunity
- ...

Experimental results in submitted paper, on line at:

http://xxx.lanl.gov/PS_cache/gr-qc/pdf/0307/0307008.pdf