start

Torsion Balance Measurement of Forces Between Closely-Spaced Surfaces

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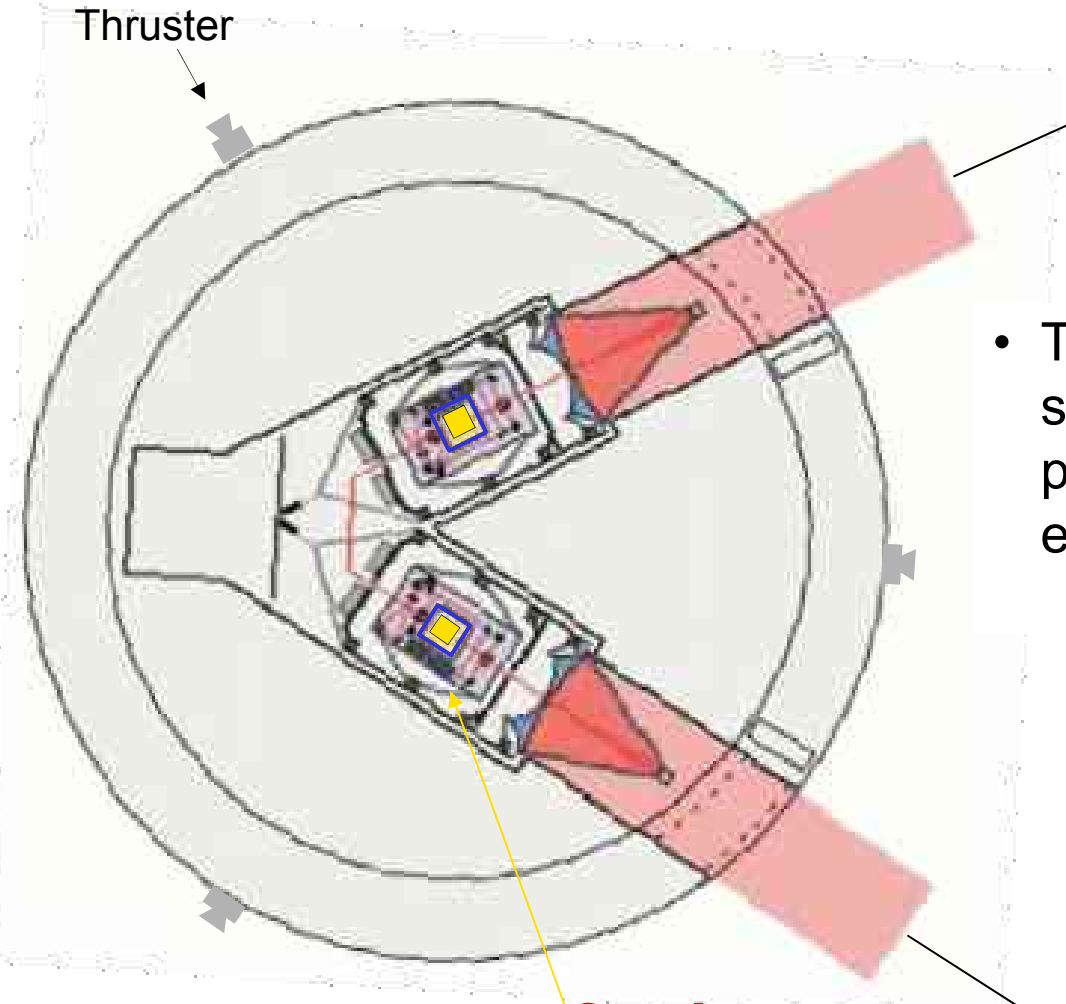
- Motivation
- Apparatus
- Measurements
  - Noise measurements
  - Electrostatic measurements
- Instrumental improvements

The EötWash-team in Seattle

Eric Adelberger	Professor
Ki-Young Choi	Graduate student
Ted Cook	Graduate student
Jens Gundlach	Professor
Suzanne Hayward	Undergrad
Blayne Heckel	Professor
Seth Hoedel	Post Doc.
CD Hoyle	Post Doc.
Dan Kapner	Graduate student
Frank Marcoline	Graduate student
Michael Nickerson	Undergrad
Braxton Osting	Undergrad
Stephan Schlamminger	Post Doc.
Erik Swanson	Res. Engineer

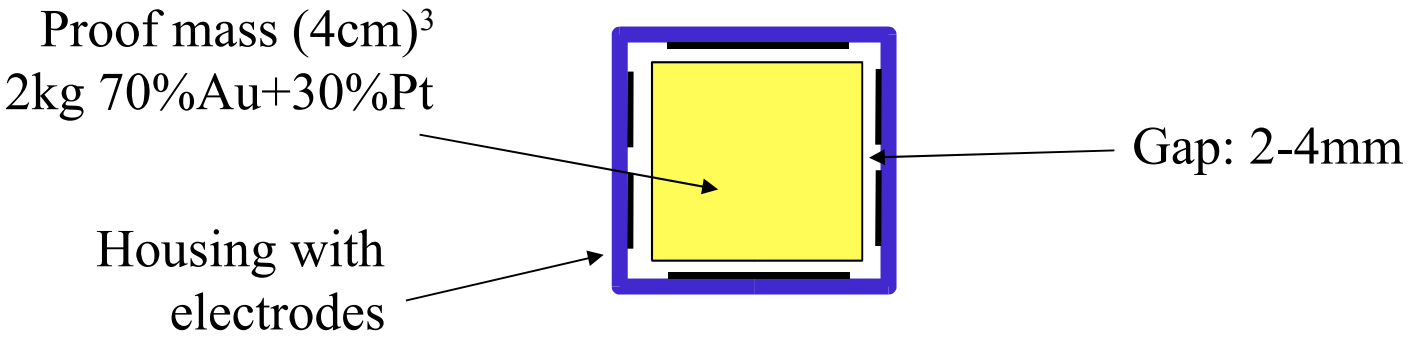
- 4 torsion balances instruments are operating simultaneously, one of them dedicated to LISA tests.

The LISA gravitational wave observatory space crafts



- Thrusters move the space craft to keep the proof masses “free” of external forces

Gravitational Reference Sensor (LISA-GRS):



acceleration noise requirement:

This is extremely small

$$S_a^{1/2} < 3 \times 10^{-15}\ \mathrm{m/s^2/\sqrt{Hz}}\ @\ \mathrm{mHz}$$

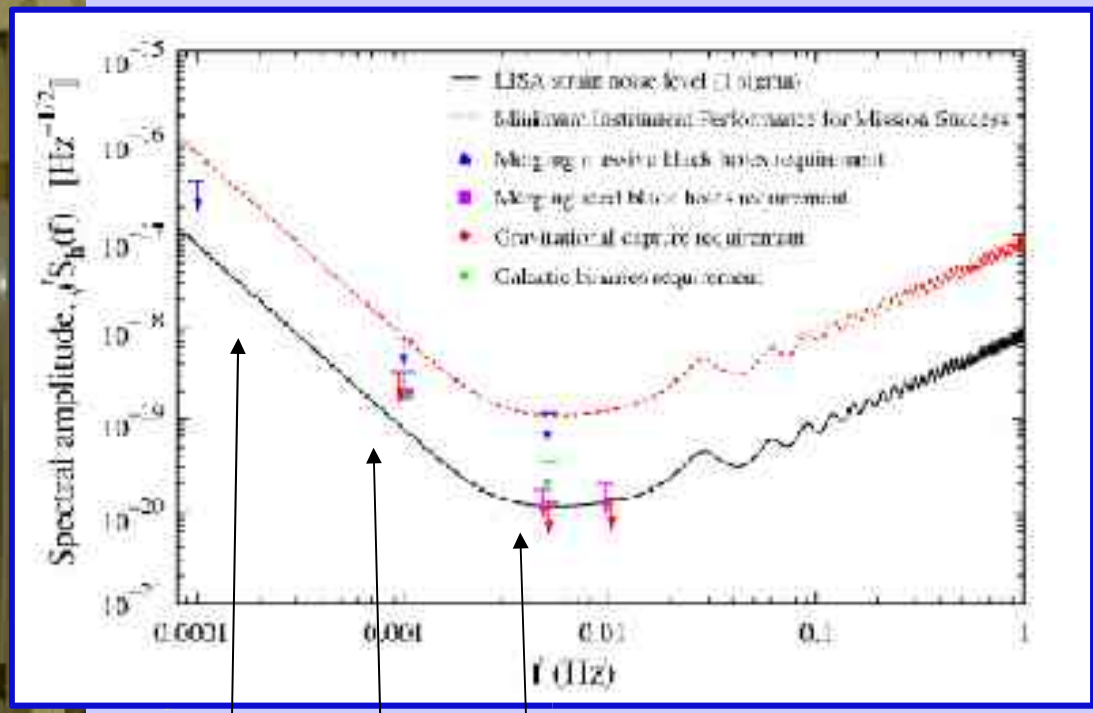
Concerns: Very subtle forces must be understood precisely, e.g.:

- Patch effects
- Outgassing
- Charge accumulation
- Magnetic impurities
- Radiometer effect
- Gravitational forces
- Actuation cross talk
- Hereto unknown or underestimated effects?
- ….

UW's small force tests for LISA

Stephan Schlamminger
(post doc)

Erik Swanson
(research scientist)



Weak interactions of the proof mass with the spacecraft ?

Torsion balance tests are ideally suited in frequency and sensitivity for these LISA small force tests.

Our apparatus to test for forces between closely space surfaces

ion pump, 10^{-5} Pa

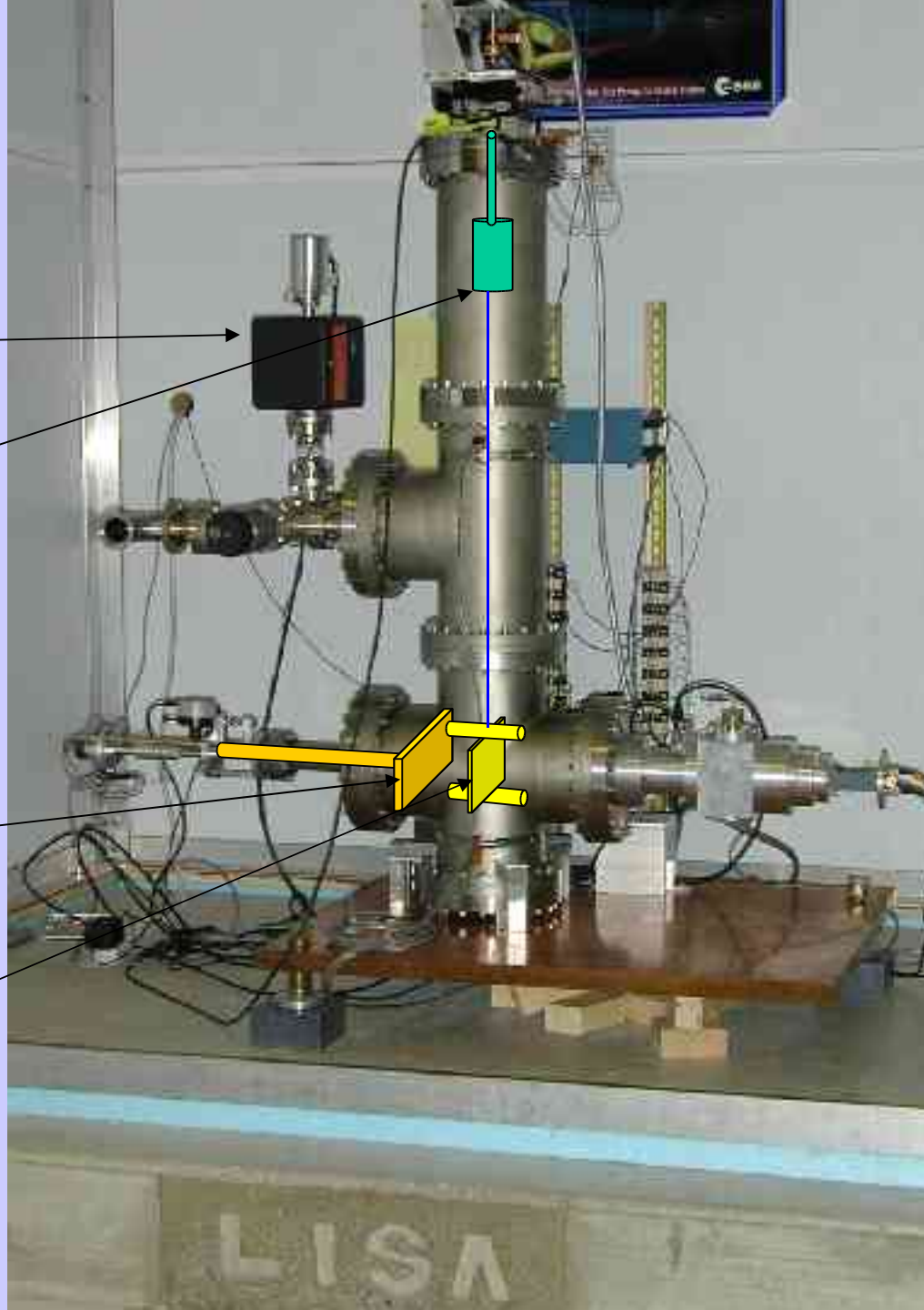
swing- and vertical motion damper

gravity compensators

adjacent surface

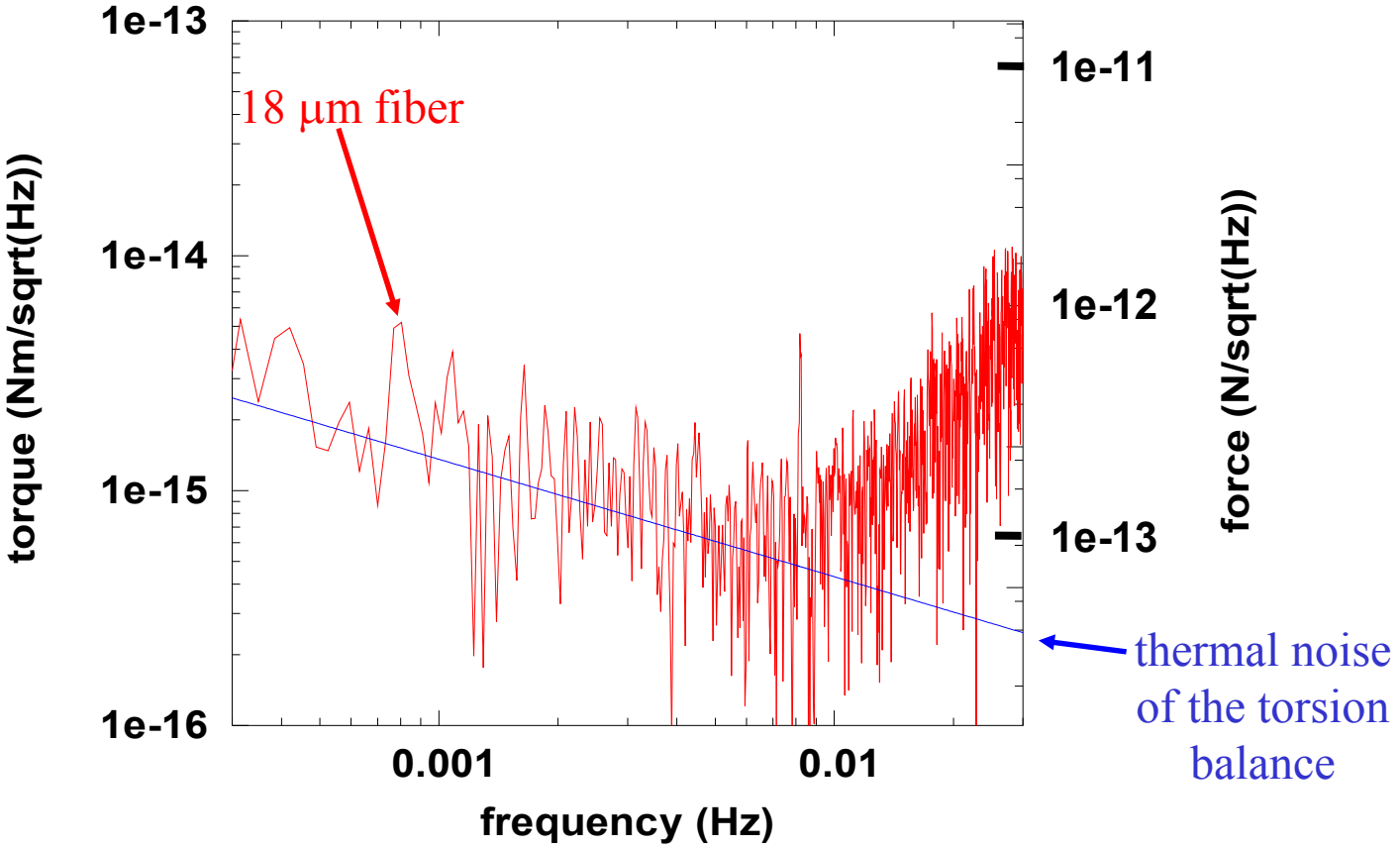
test pendulum
Au-coated glass plate
4cm 4cm

mass:10g



Torque / Force Sensitivity

i.e. opposing plate far away



Torque / Force Sensitivity

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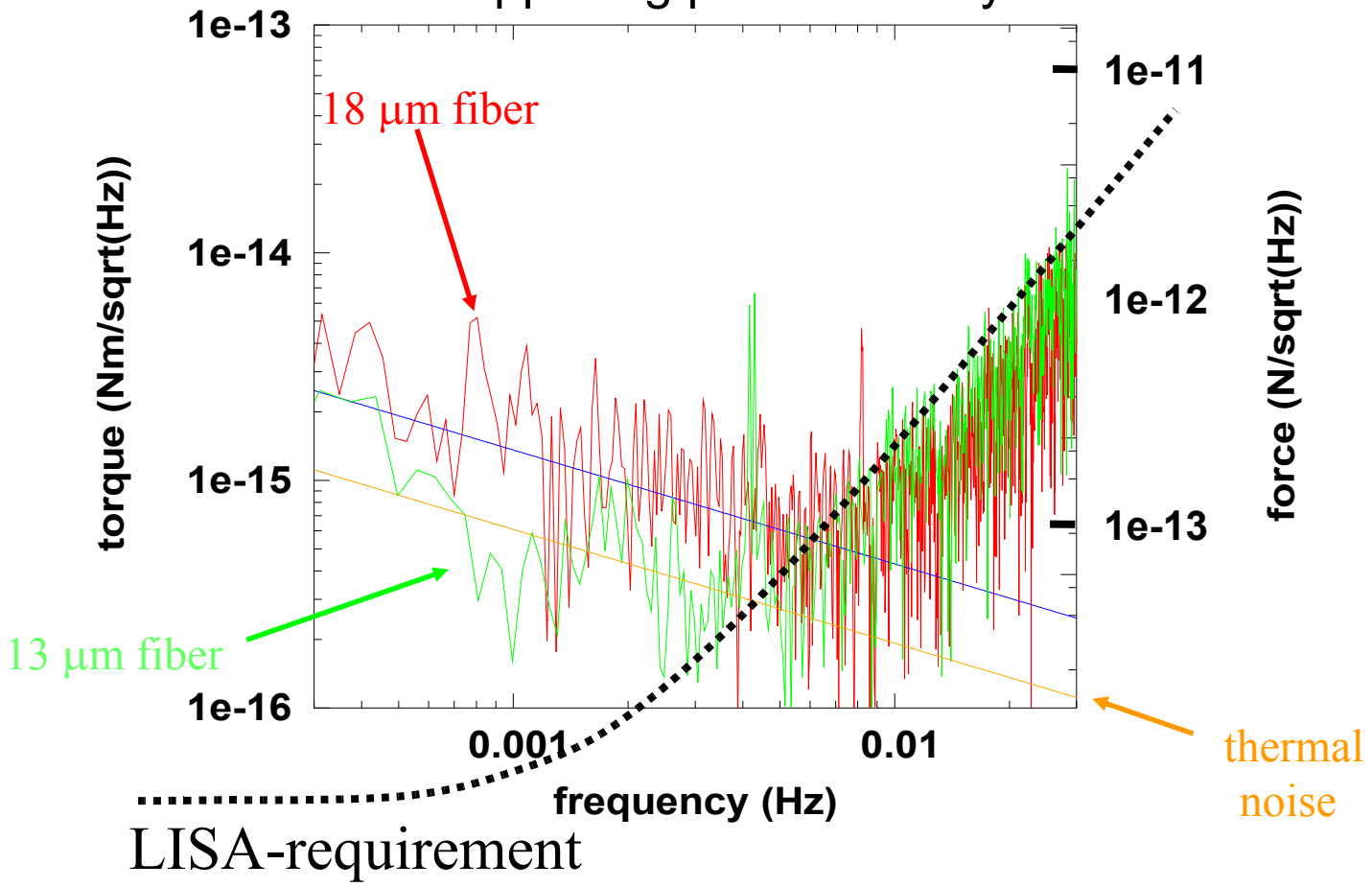
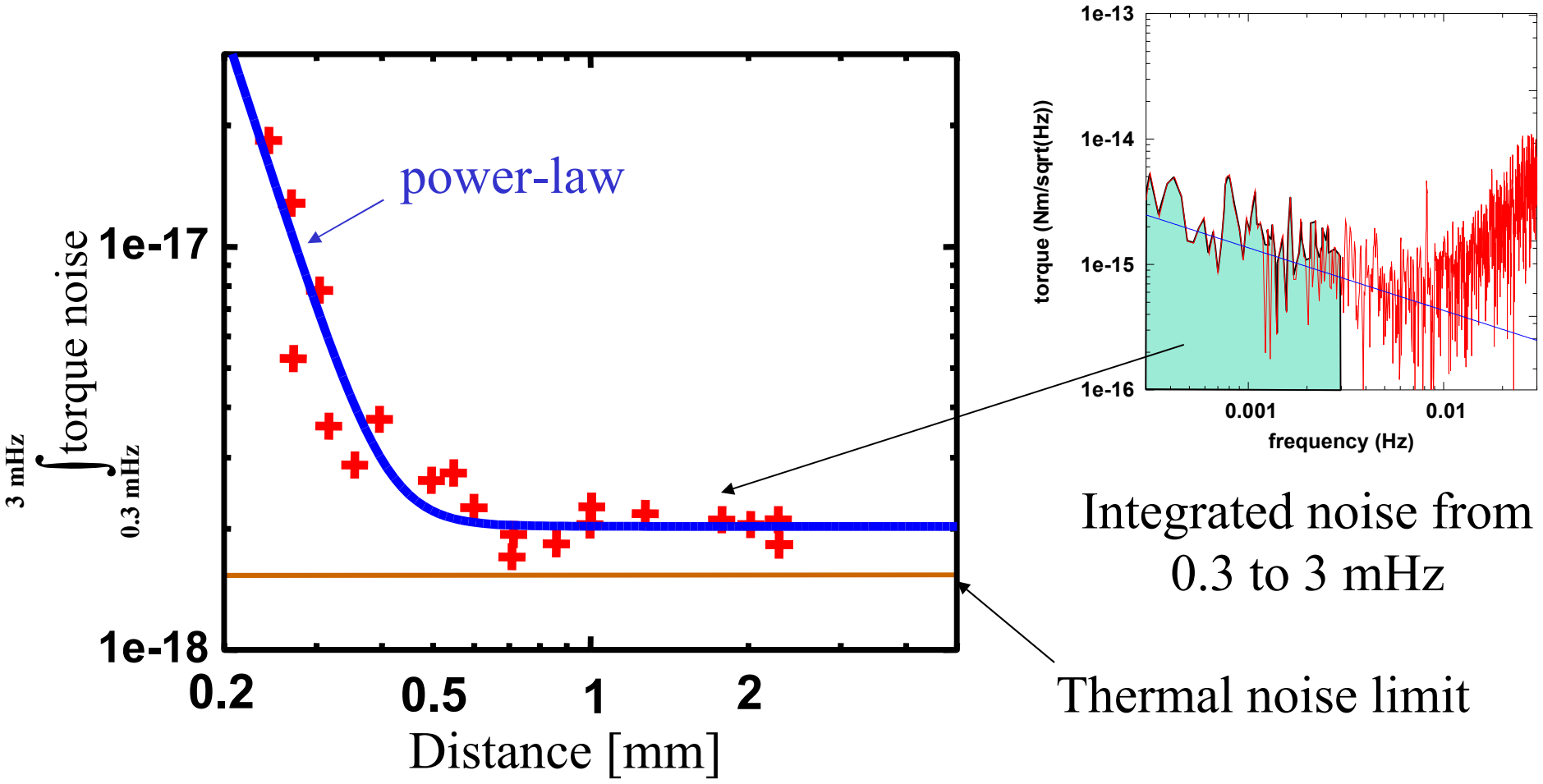


⇒ to match the LISA requirement we need to:

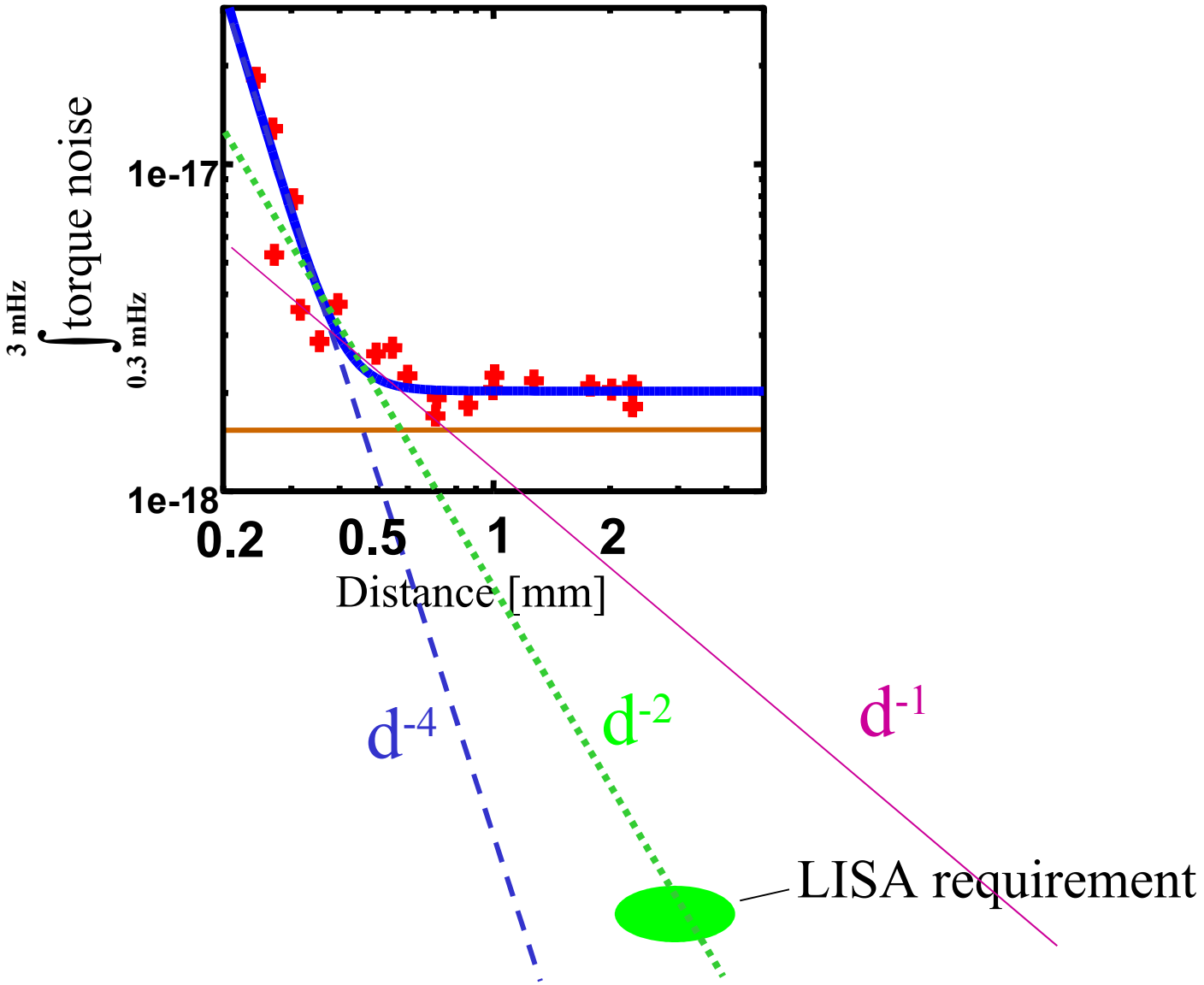
- extrapolate from closely spaced surfaces
- need to improve sensitivity

Torque noise as a function of plate separation



These data are preliminary

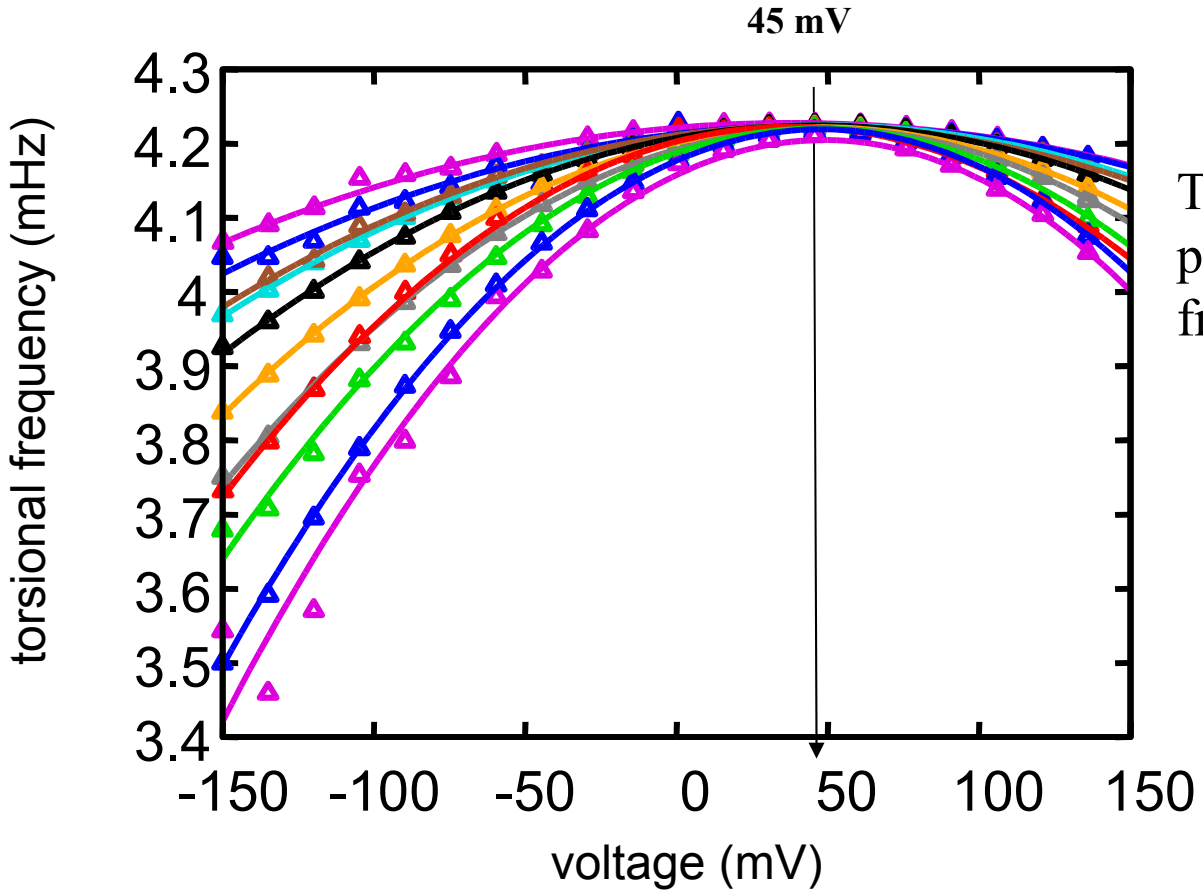
data and conclusions are preliminary



The observed d^{-4} behavior is probably due to a pendulum artifact (more later….)

Electrostatic Experiments

(1) Oscillation frequency vs. voltage applied to the pendulum and plate

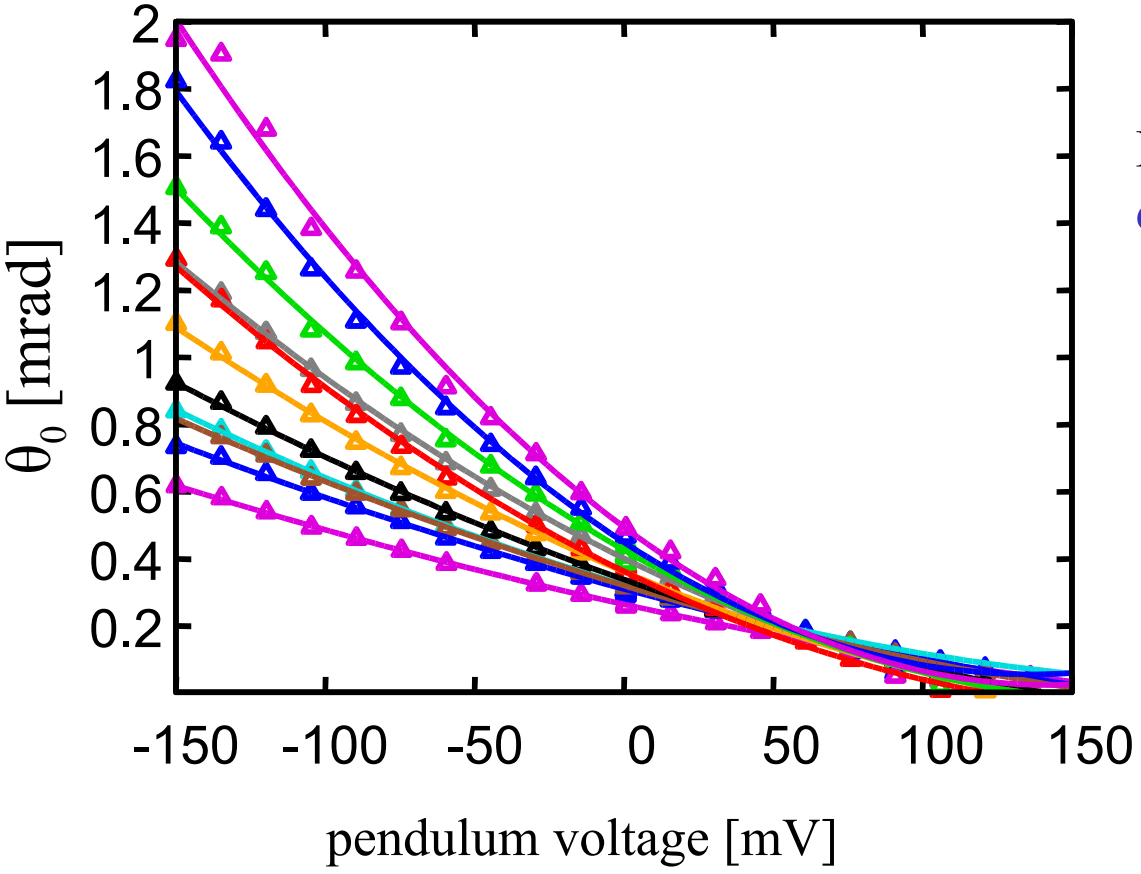


The different curves are for plate-pendulum separations, d, from d = 0.4 mm to 0.75 mm

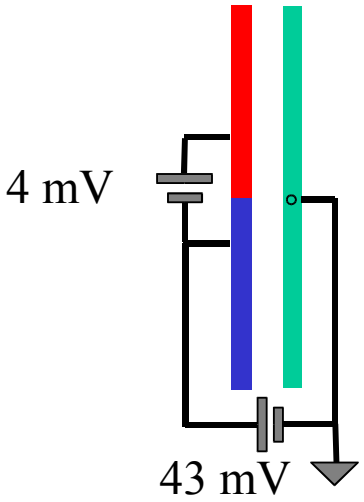
- 45 mV offset voltage between plate and pendulum
  the origin of this voltage is under investigation
- Prediction: curvature $\sim 1/d^3 \Rightarrow$ can be used to calibrate d

Electrostatic Experiments

(2) Equilibrium angle vs. voltage between pendulum and plate



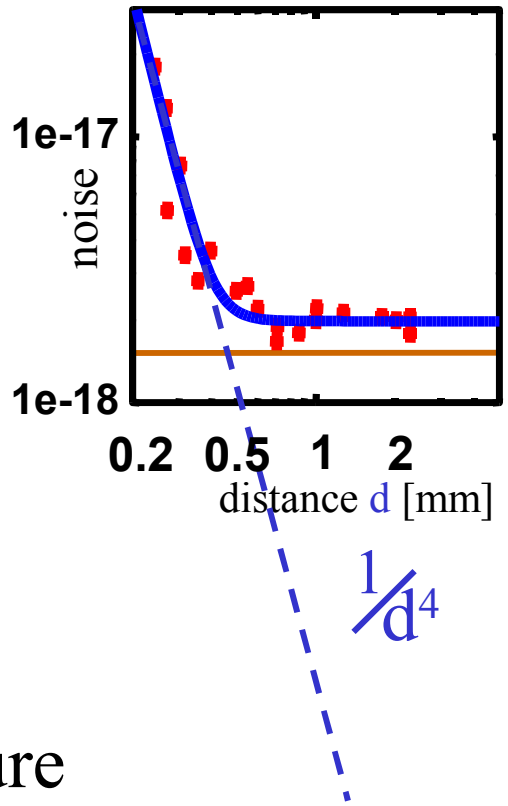
Data are for separations of
d = 0.4 mm to 0.75 mm

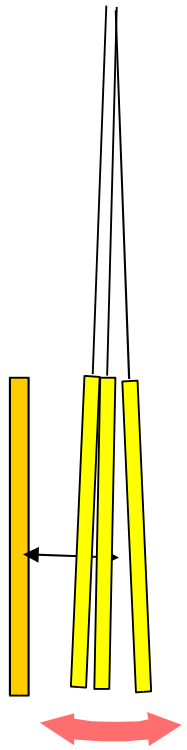


- slope at V= 0 ~ (spatial asymmetry)/d^2
- consistent with right-left voltage difference ≅ 4 mV

d^{-4} - noise?

- Pendulum swing mode (0.6Hz) is excited by ground vibrations to a few µrad amplitude.
- A small electrostatic asymmetry converts the swing into a twist angle:
  - ~ (average d)$^{-4}$
  - ~ (swing amplitude)^2
  - Timescale ~ swing damping time (mHz)

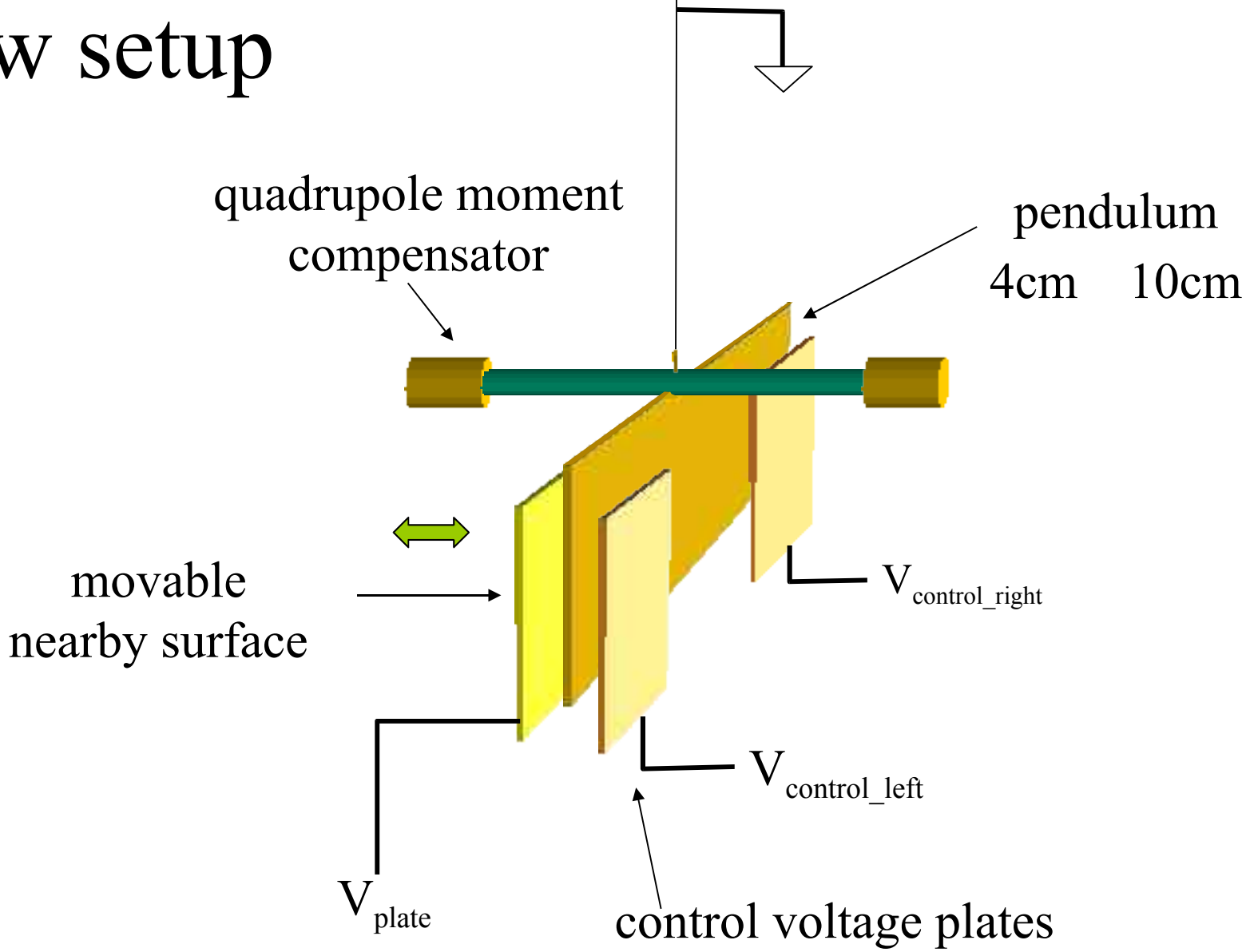




⇒ d^{-4}-noise is likely an experimental artifact

⇒ We need to avoid and/or measure swing mode and/or compensate the asymmetry.

New setup



→ more signal

→ reduced noise

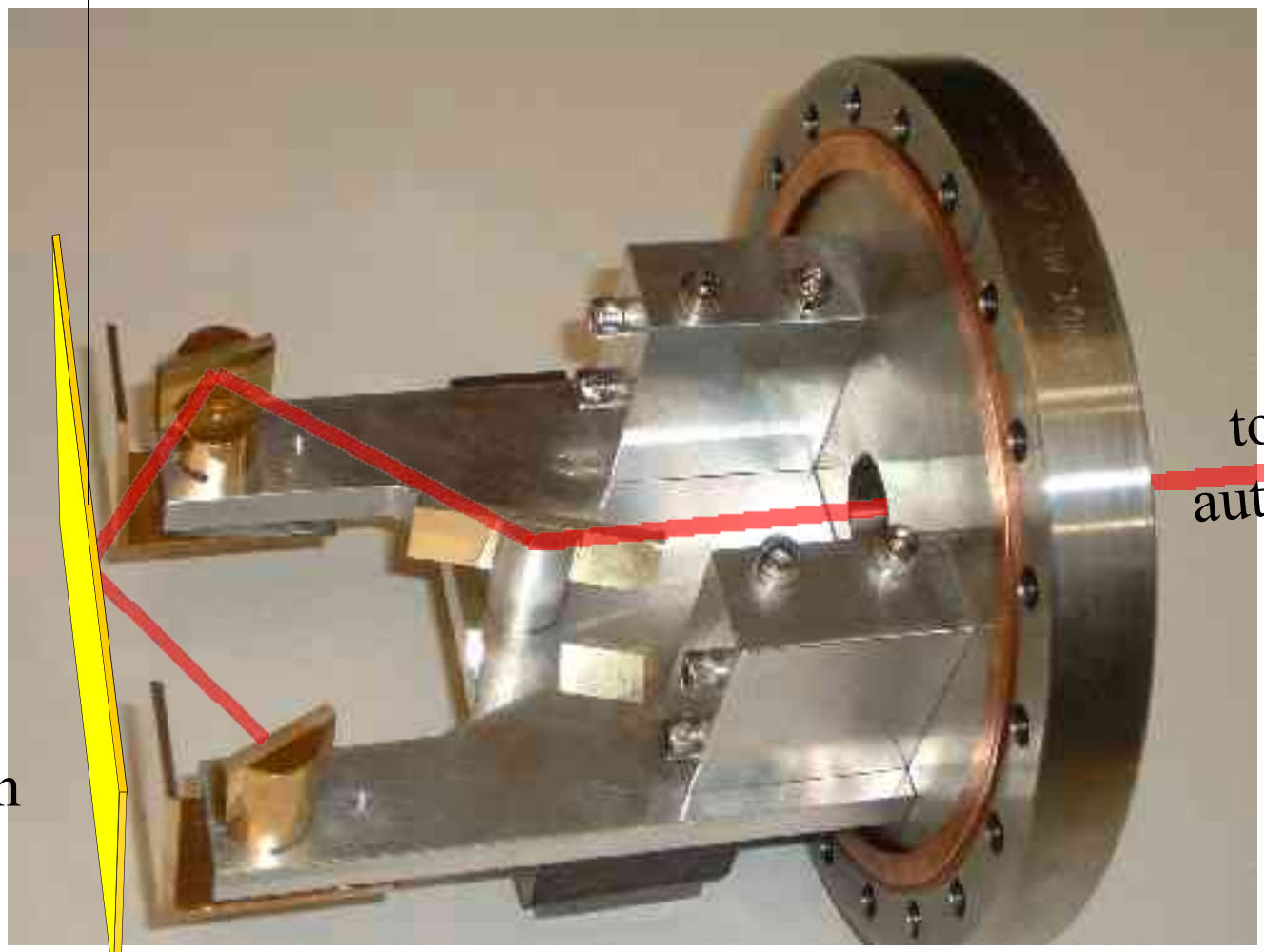
Pendulum

- Pyrex plate
  39 100 0.75mm^3
- sputter coated with Au
- total weight: 15g
- torsion fiber: 13μm W,
  ~40% breaking strength

Compared to our previous pendulum:

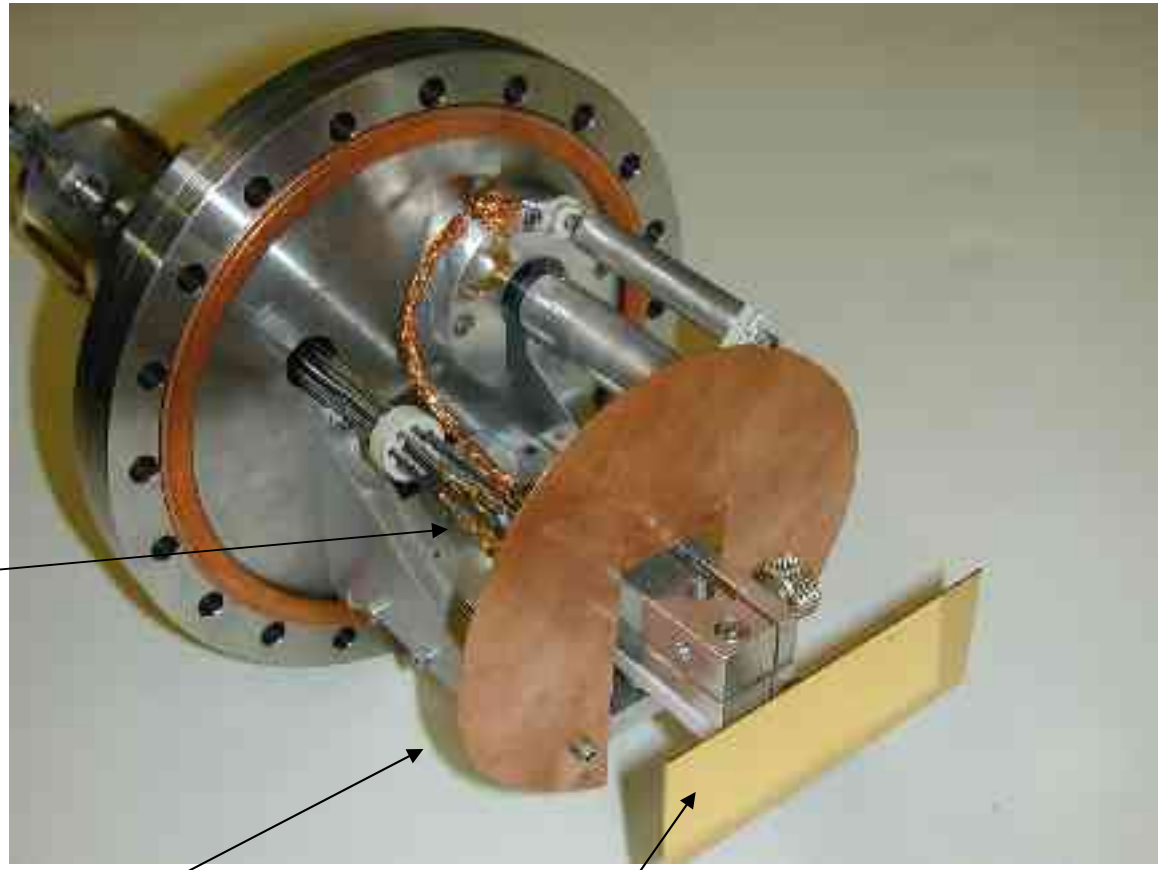
- 2.5 area
- 2.5 moment arm

Double Reflection Autocollimator



optical angle = 4 pendulum angle

Nearby plate manipulator



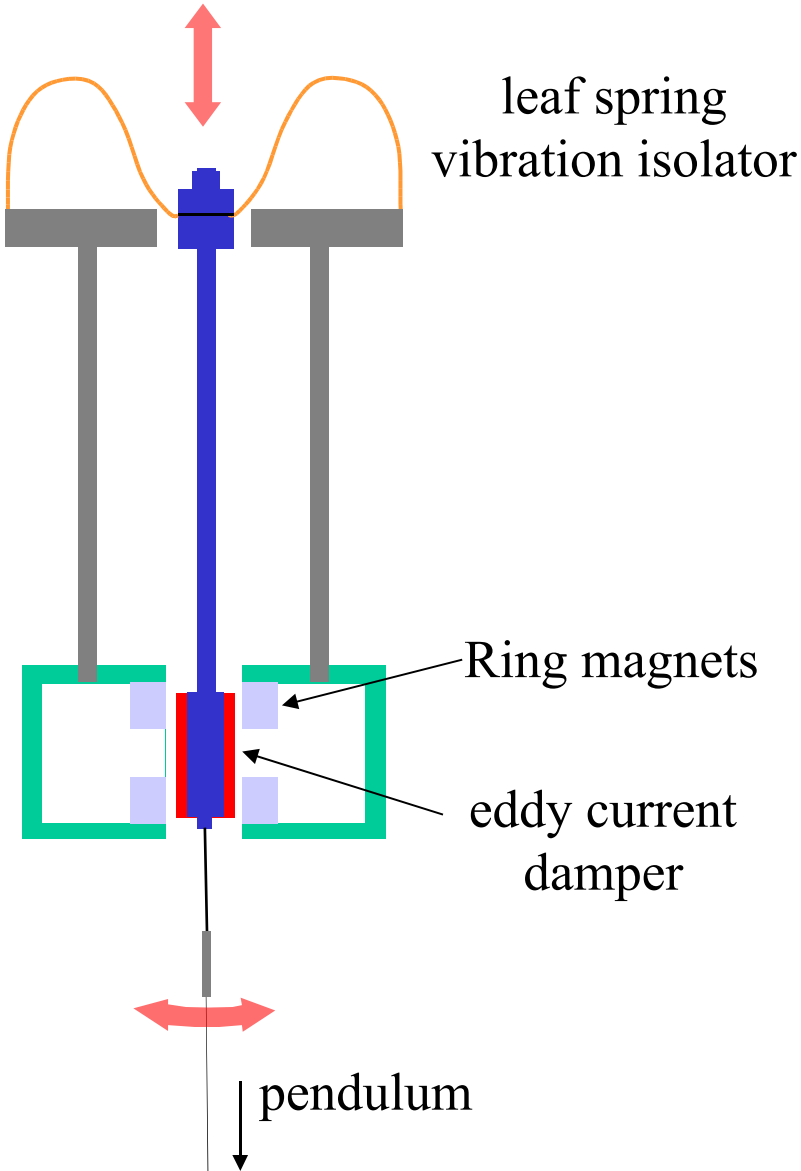
translation stage

electrostatic shield

“nearby plate”

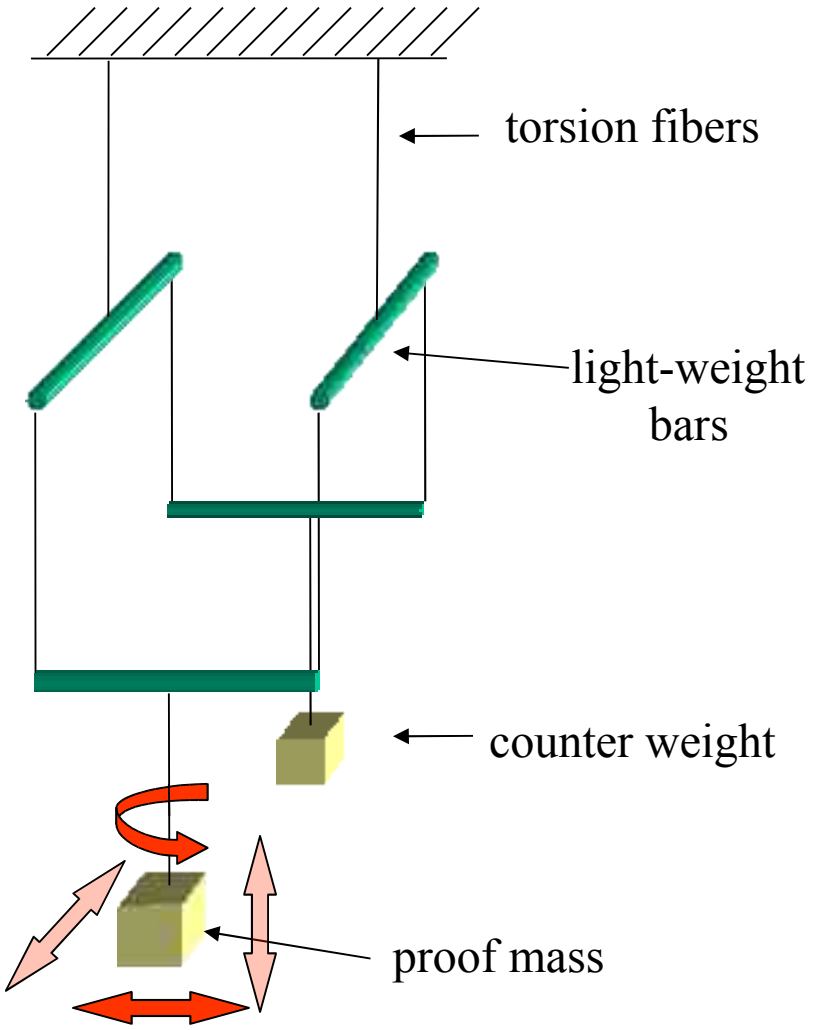
Vibration isolation / damper

Vertical motion corner frequency
≅ 1.5Hz



New torsion balance system for LISA tests:

two^{+} degrees of freedom are "free" and decoupled:



- not as impractical as it may seem…(I have built a 0th order prototype)
- more degrees of freedom: system can be staged
- is very compliant in the vertical direction
- translational frequency <2mHz
- can be made insensitive to gravitational gradients

$\Rightarrow$ test cross coupling

$\Rightarrow$ test forcing

$\Rightarrow$ test uncaging

Conclusions

- Preliminary results of force/torque noise between closely spaced surfaces.
- Improved instrument with highly improved sensitivity has been built and ~~will be used shortly~~ is being used right now.

Acknowledgements

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