Testing new GRS technologies and configurations with the UF torsion pendulum

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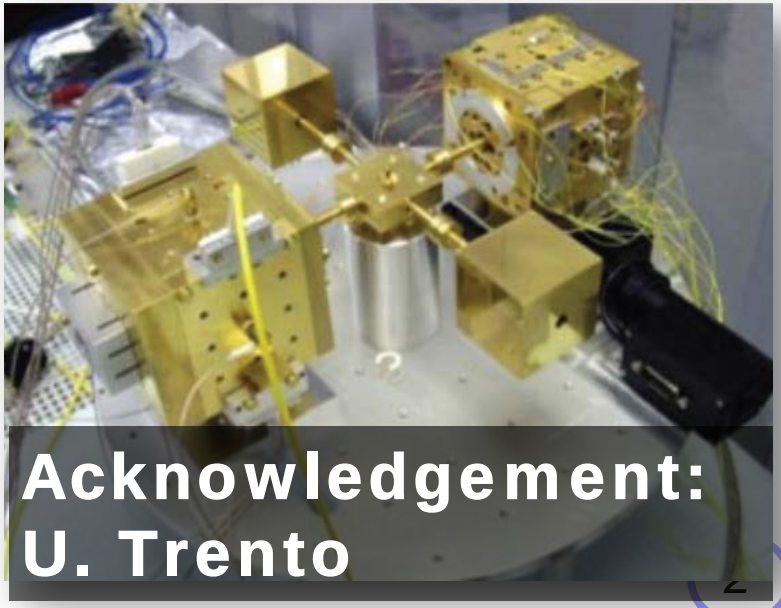
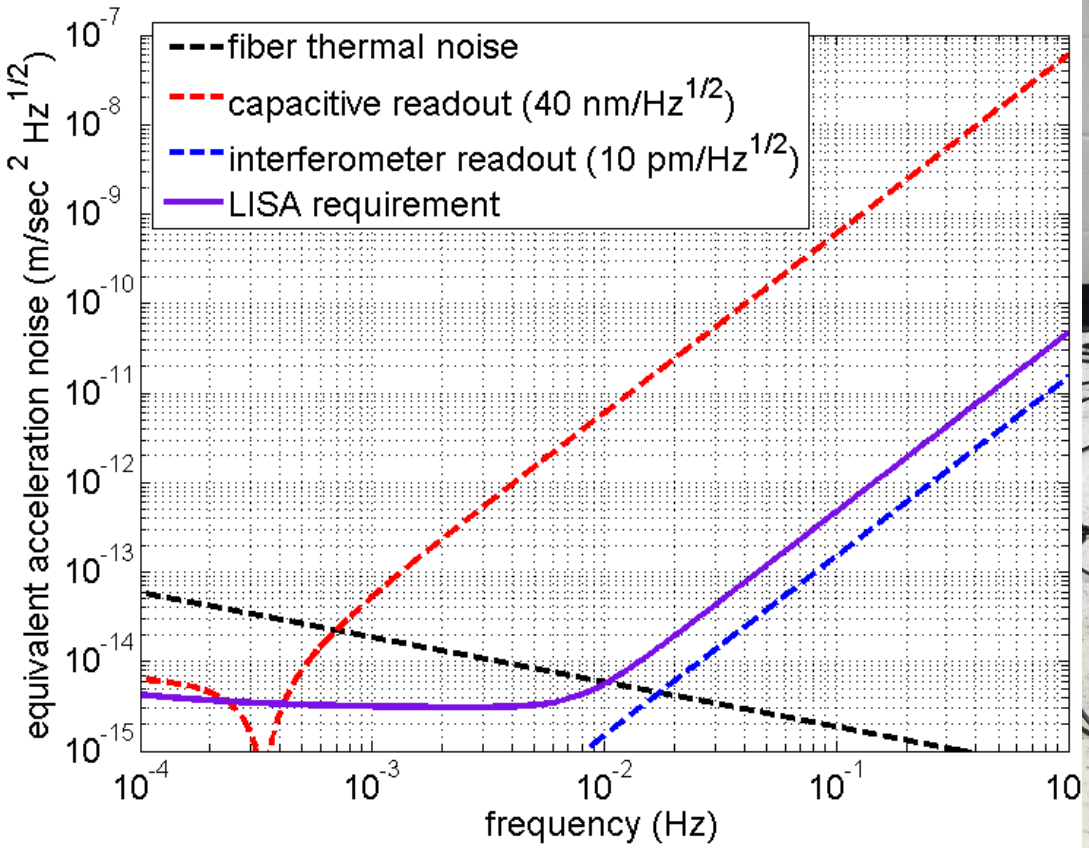
Motivation for the UF Pendulum

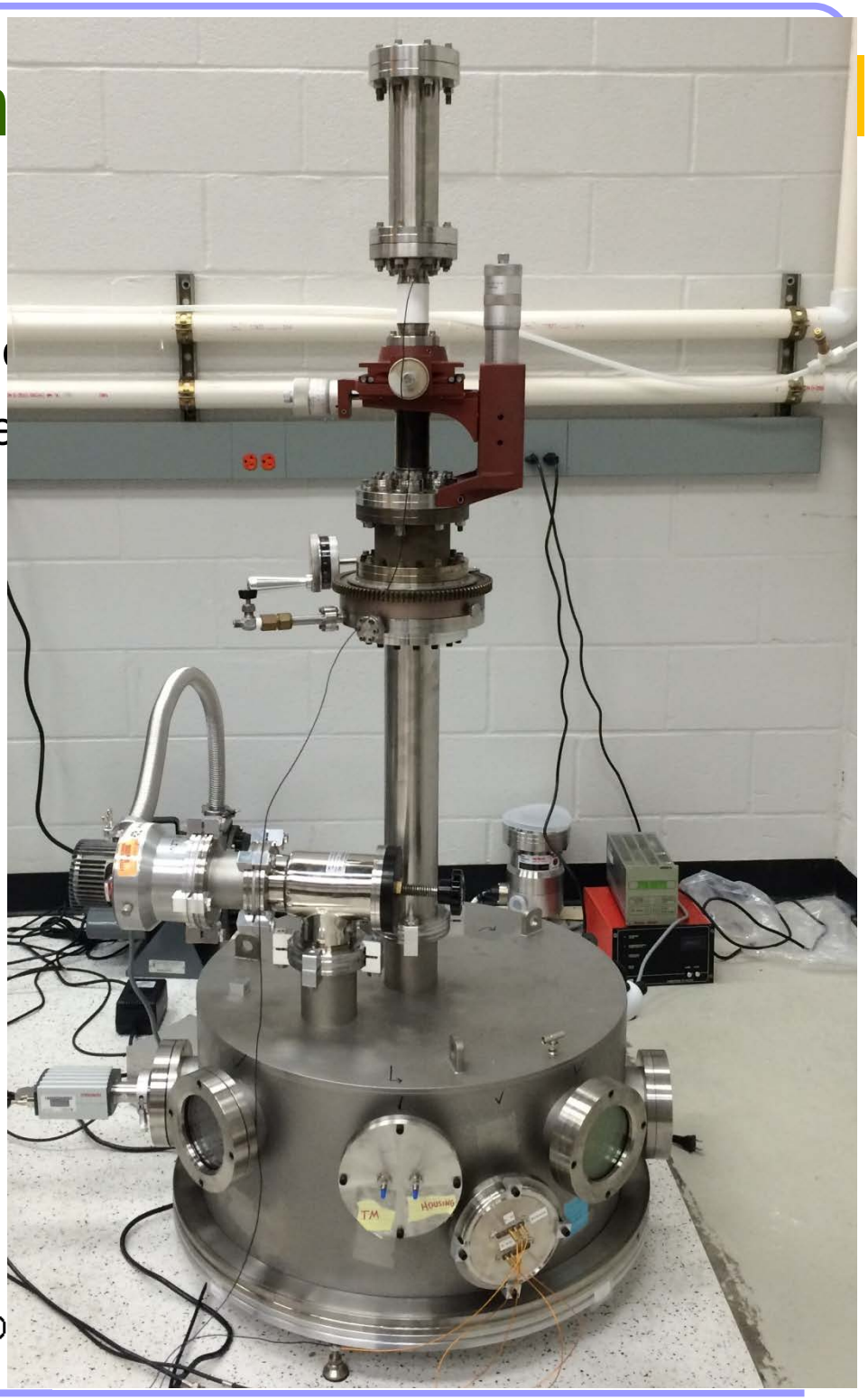
- R & D of new inertial sensor technologies for GW observatories, geodesy, fundamental physics, ...
  - Charge management: New UV sources (LEDs) & discharging modes
  - 6 degree-of-freedom IFO readout (pm and nrad)
  - Alternate geometries and actuation modes (drift-mode)
- Independent confirmation of results from EuropeDevelop
- U.S. expertise in ultra-precise inertial sensors
  - Needed for U.S.-led GW mission
  - or for meaningful partnership
- It seems we have time to catch up.



UF Torsion Pendulum

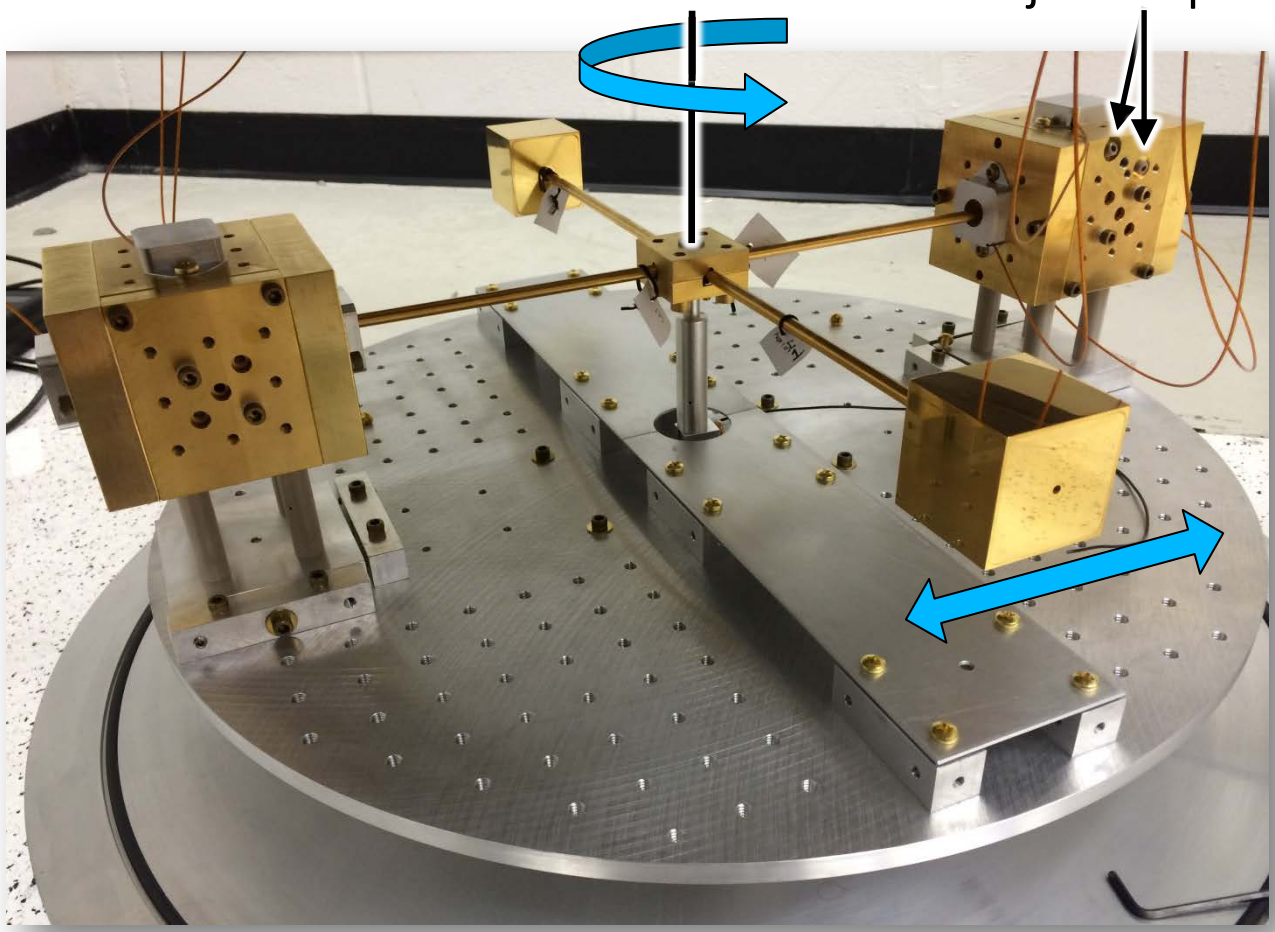
- Based on Trento pendulum
  - Fiber supports cross bar with 4 hollow TMs (rotation → translati
  - Light weight (0.46 kg) al structure reduces needed fiber diameter
  - Measures surface forces

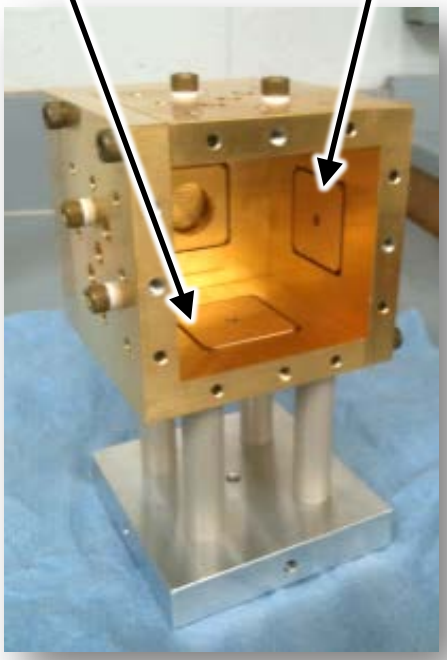




Simplified GRS

- Six electrodes, 40 nm/Hz$^{1/2}$ sensitivity, translation only
- Al housing, Al electrodes, ceramic spacers, Au coated
- 3 UV injection ports

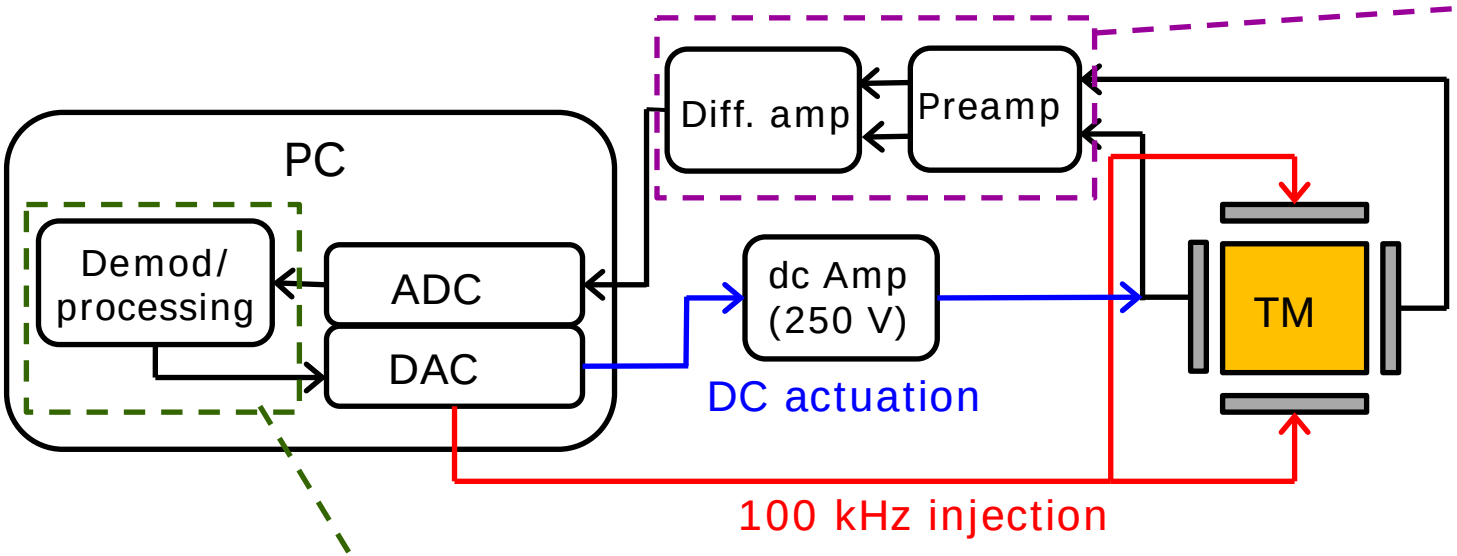


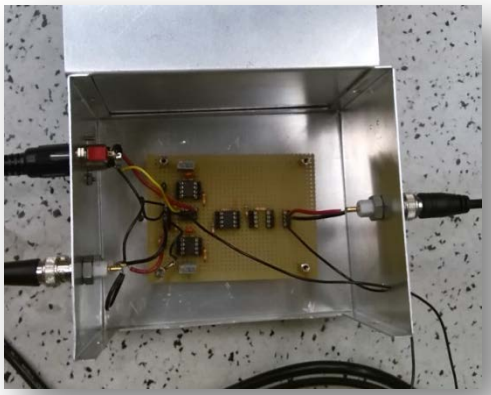


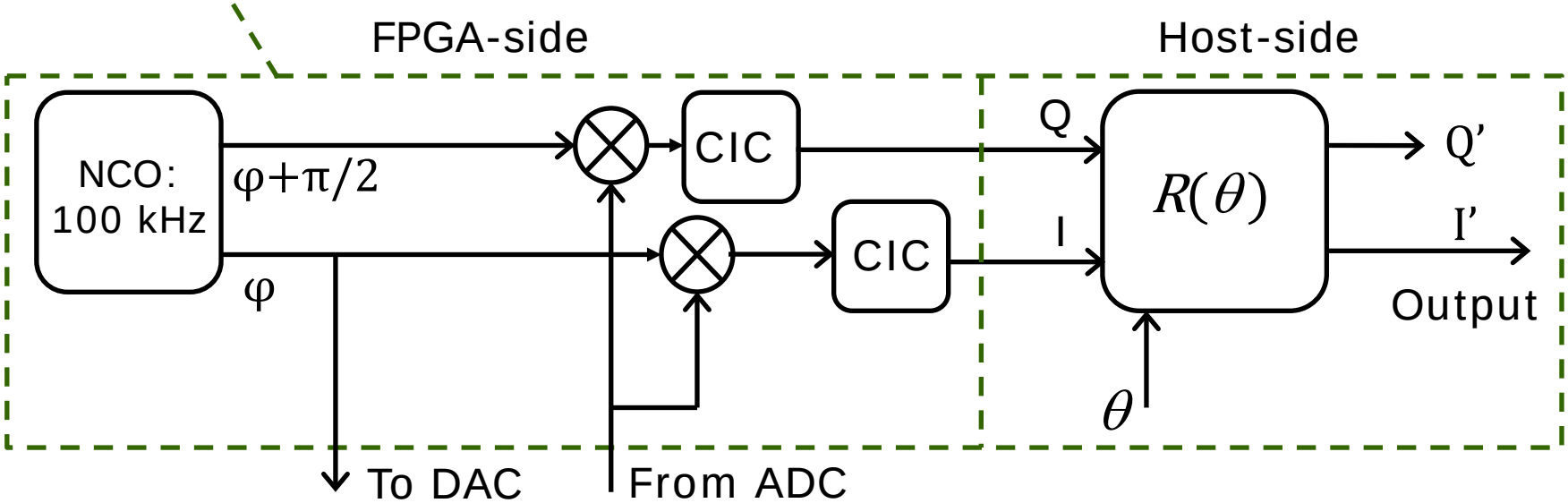
Simplified 6-electrode inertial sensor

AC Capacitive Readout & DC Actuation

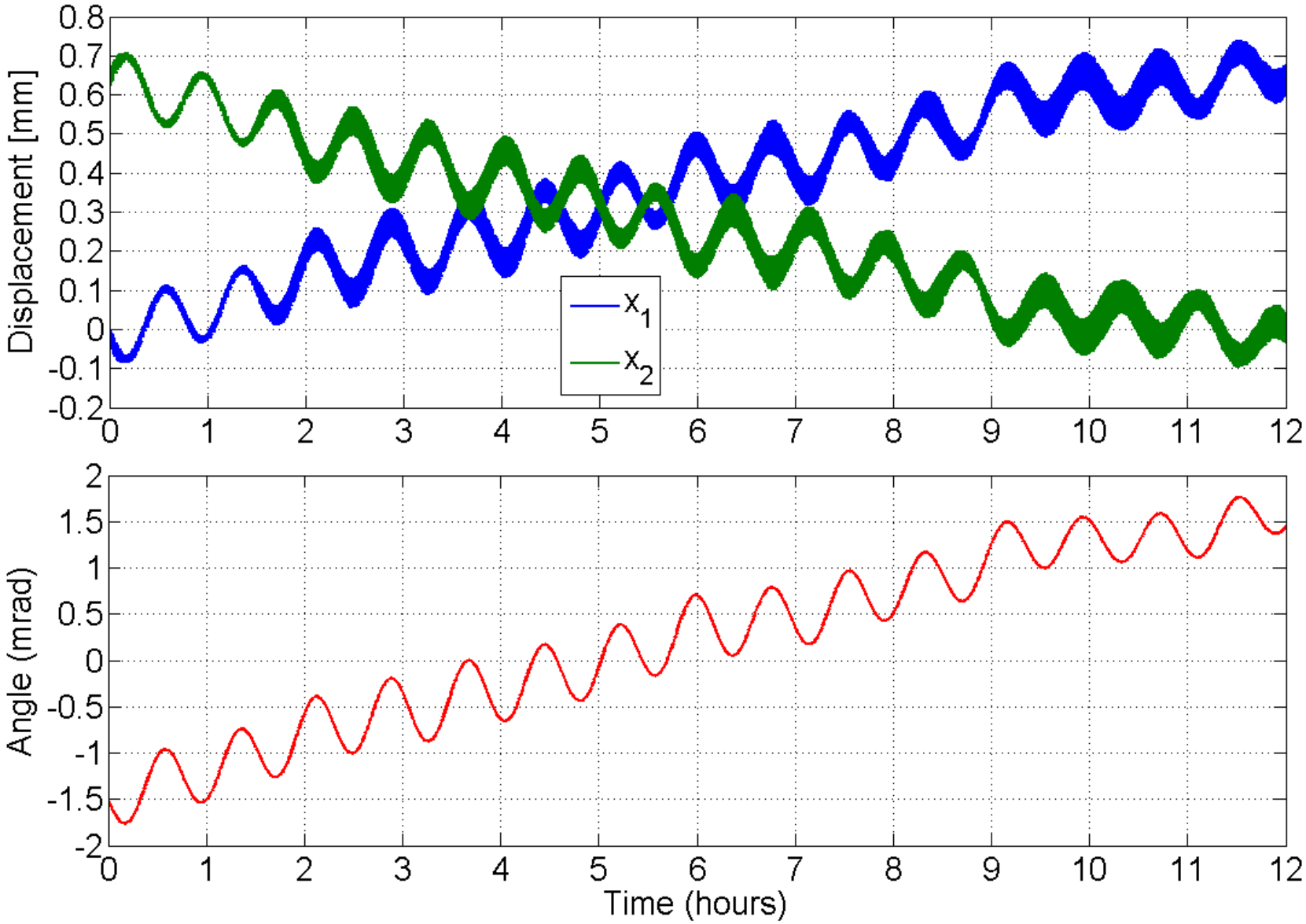
Poster: *A. Chilton*



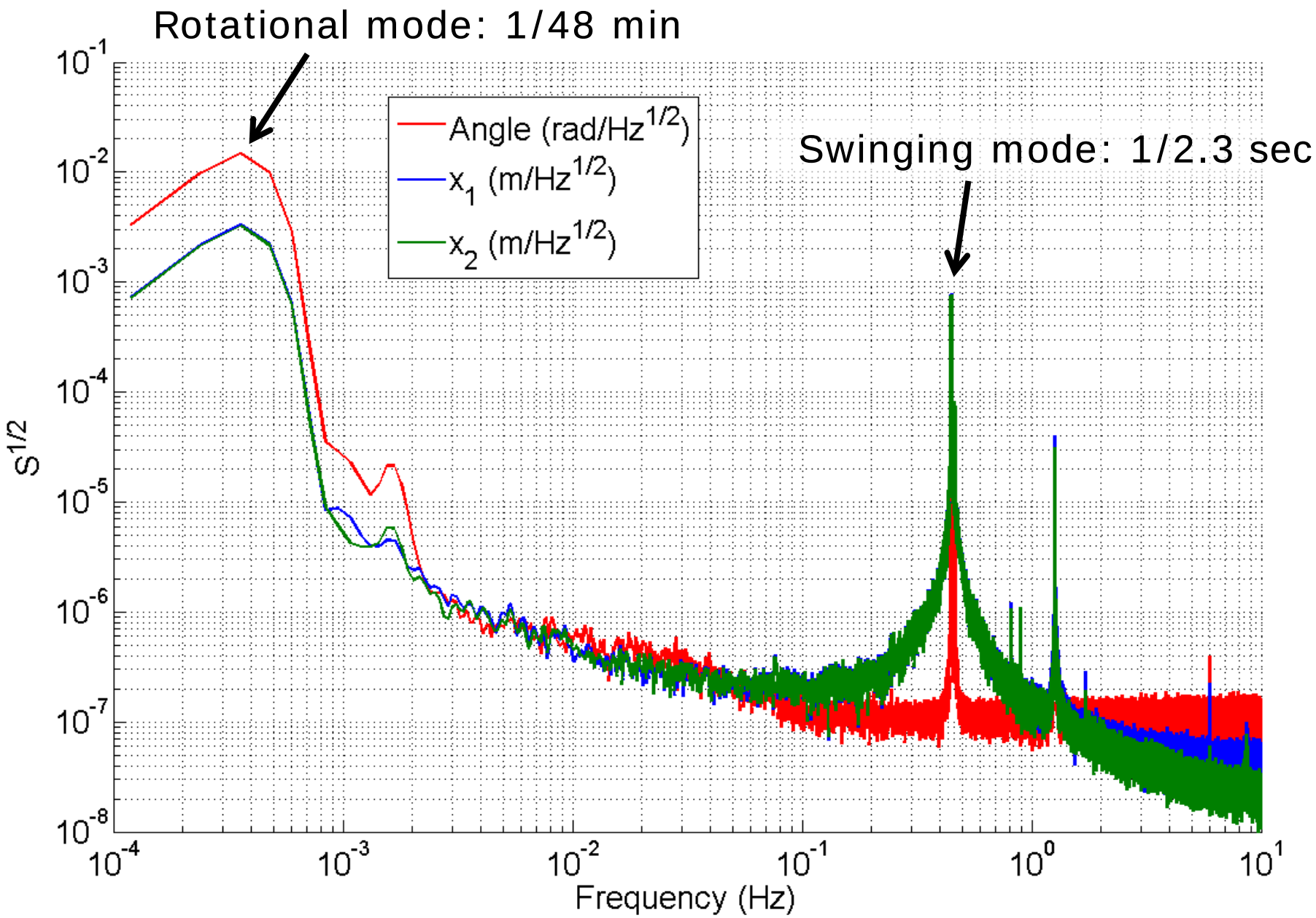




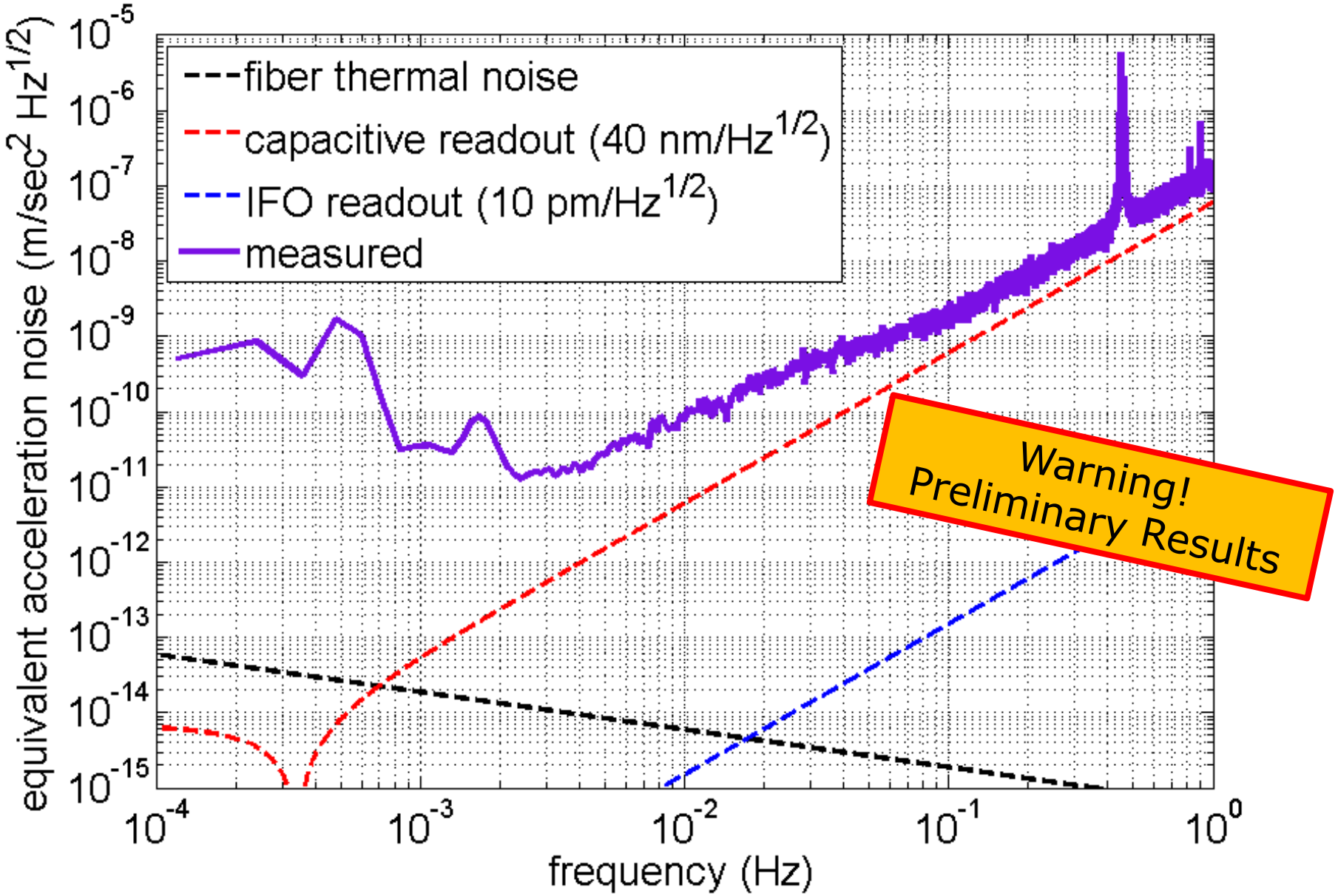
First Oscillations



Spectrum


Rotational mode: 1/48 min
Swinging mode: 1/2.3 sec
Angle (rad/Hz^1/2)
x1 (m/Hz^1/2)
x2 (m/Hz^1/2)
S^1/2
Frequency (Hz)
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-4
10^-3
10^-2
10^-1
10^0
10^1

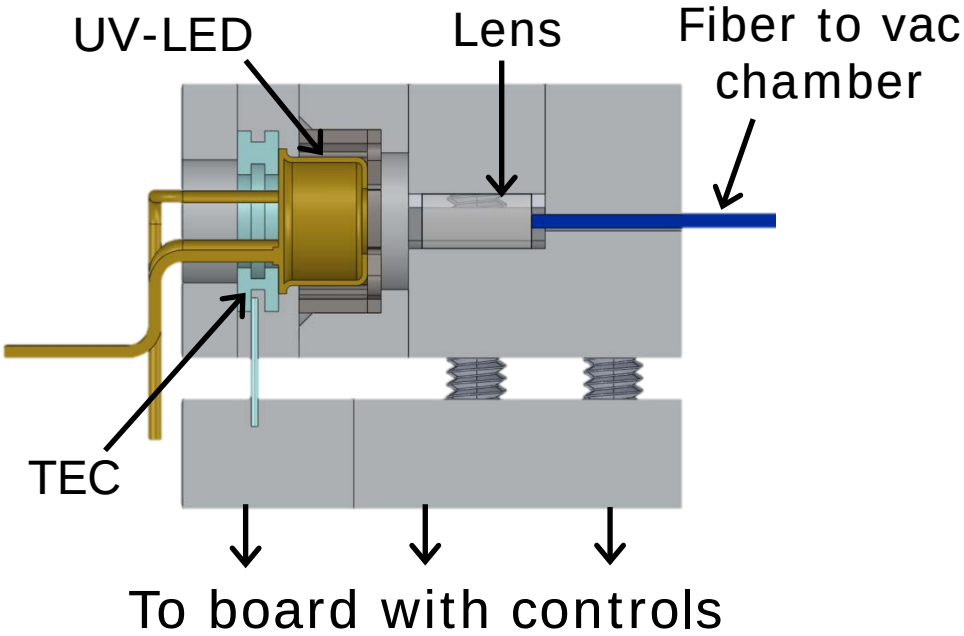
First Acceleration Noise Curve

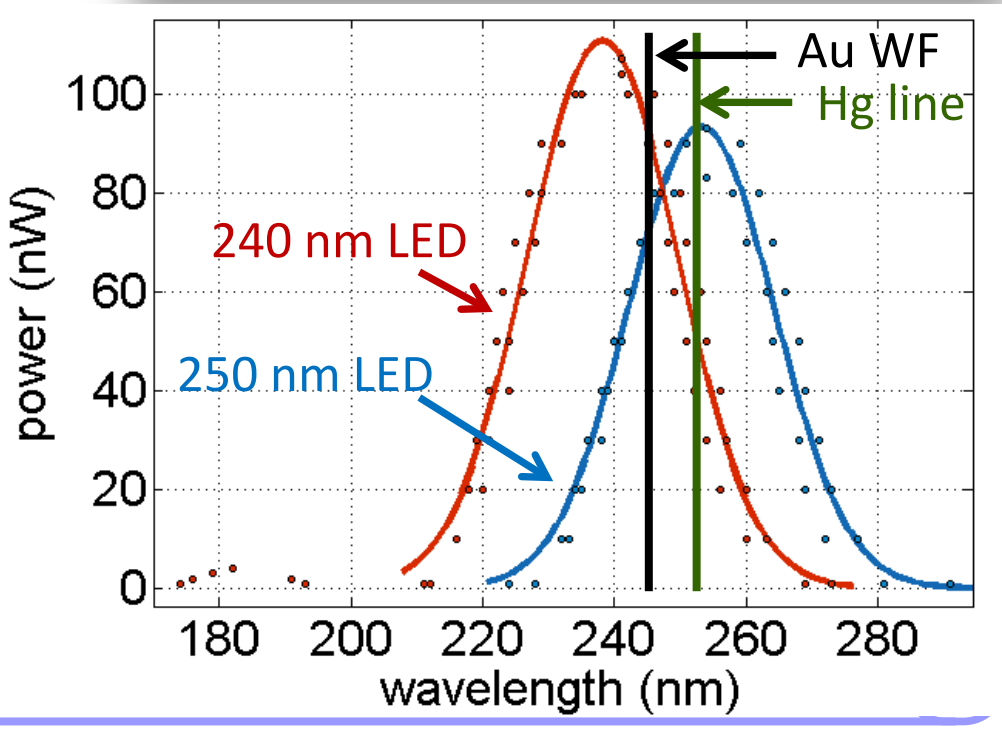


Charge Control

- UV LEDs are attractive alternate to Hg lamps
  - 240 ± 10 nm UV LED
    < Au work function 243 nm
  - Enables ac charge control
  - ~10x reduction in SWaP

Fiber coupled UV LEDs (SETi)

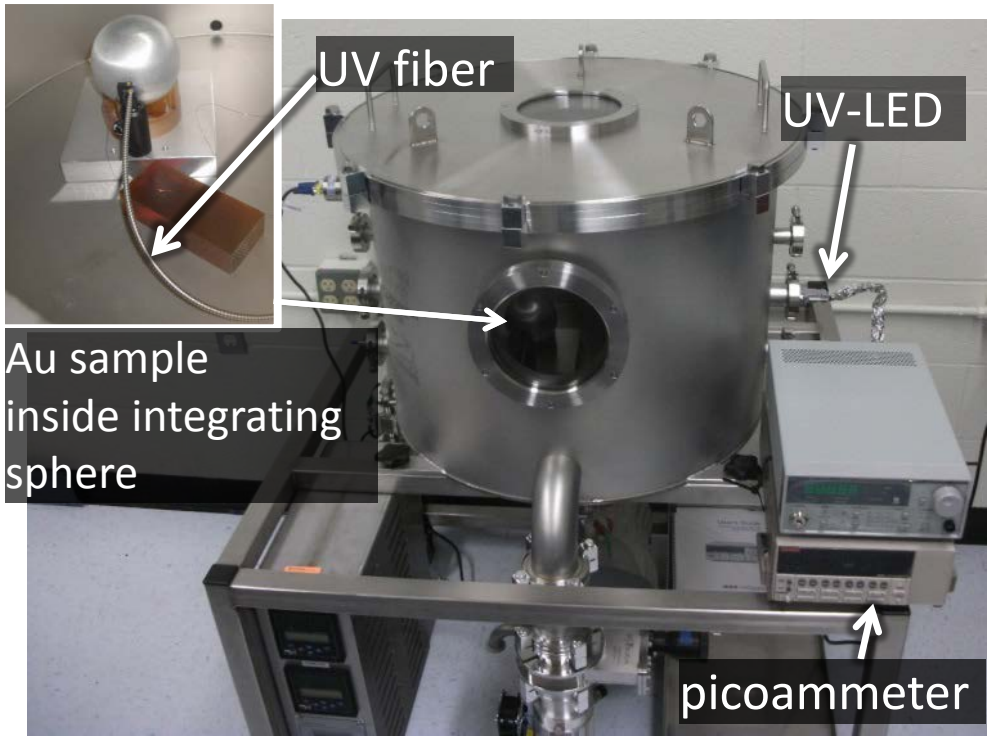


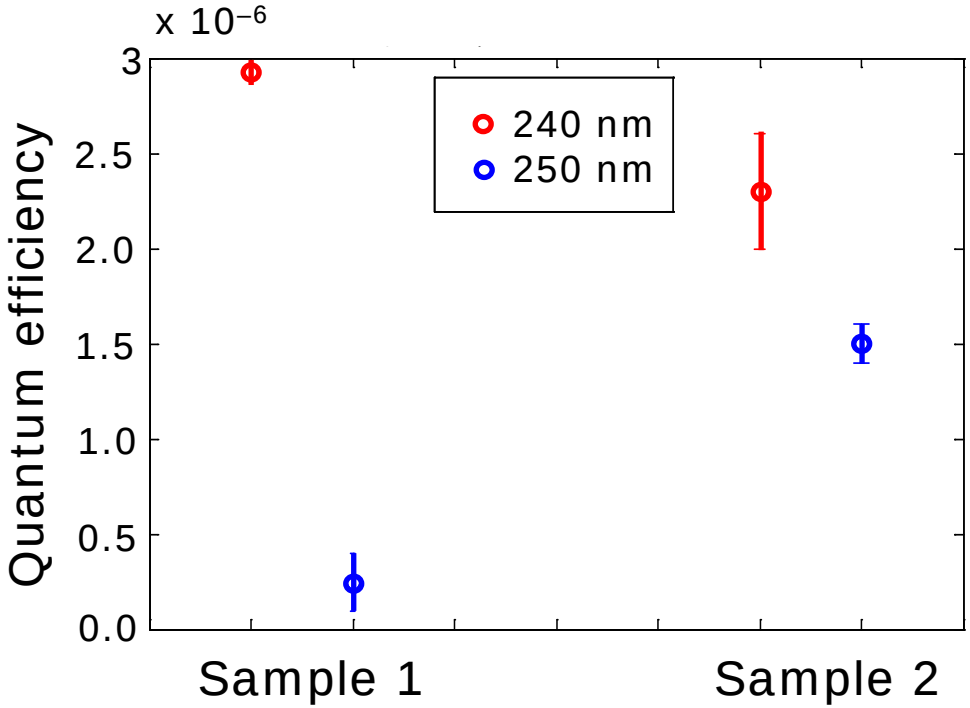


UV LED Testing & Qualification

Poster: *T. Olatunde*

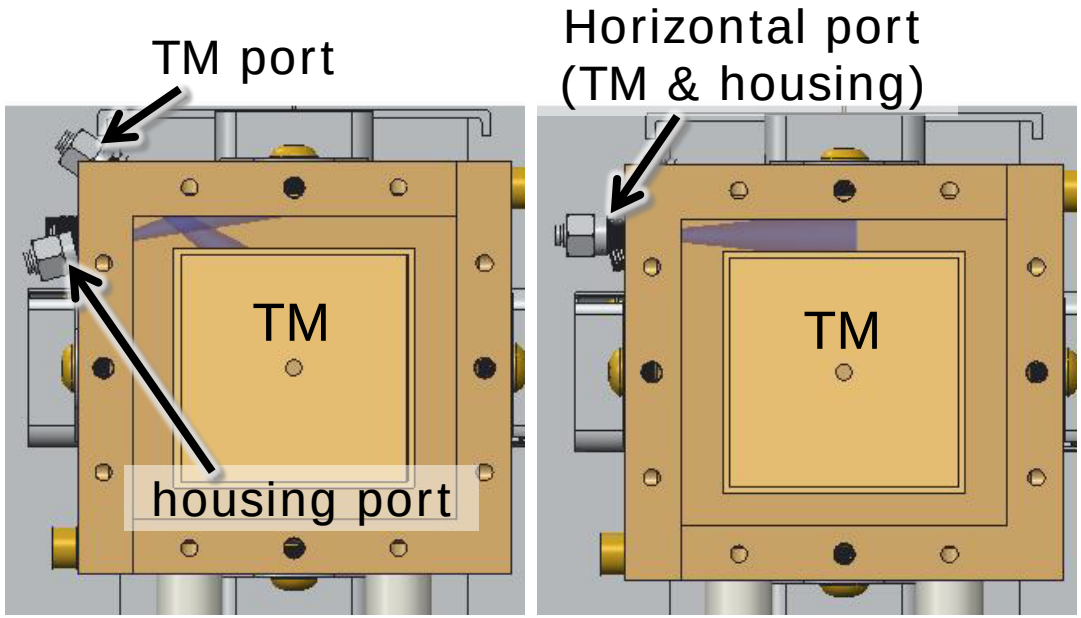
- Tracking variations in QE, reflectivity of Au surfaces
  - QE varies widely with surface preparation, contamination
  - QE (240 nm) ≈ 2-10 x QE (250 nm)
- UV LED Small Sat launch next month:

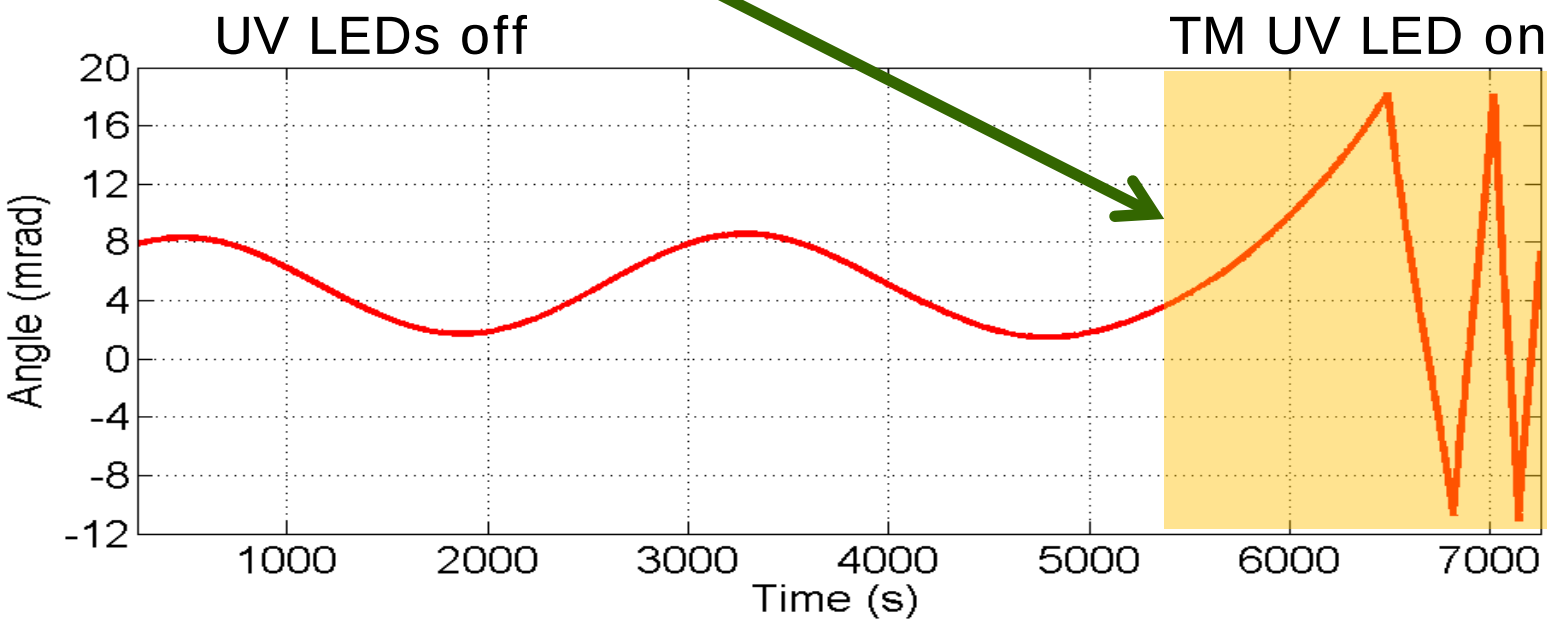




Initial Test Mass Charging Test

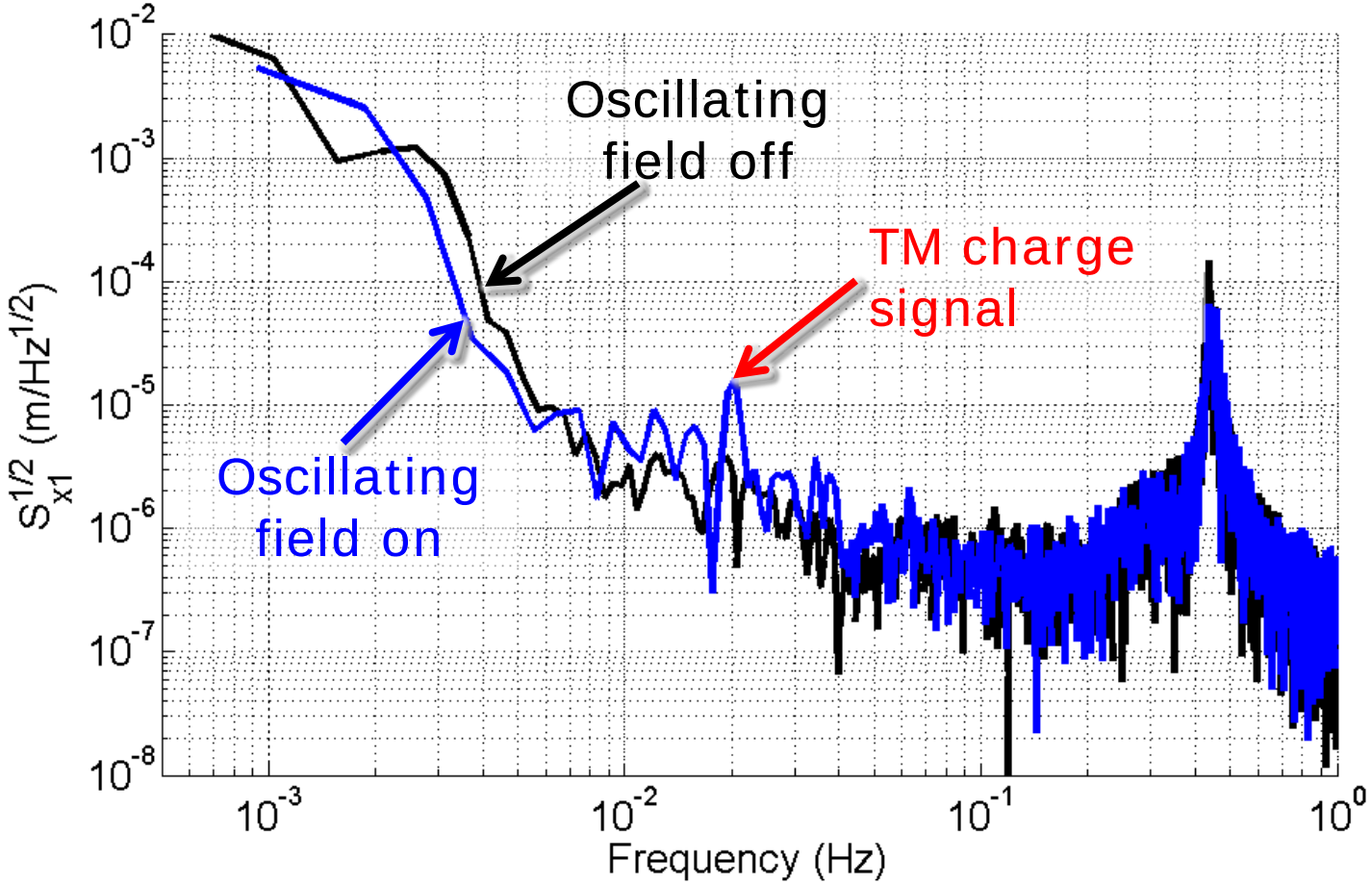
- Each GRS has 3 UV ports
- TM UV LED switched on
  - 240 nm LED, 3.6 µW dc
- After ~5 minutes pendulum destabilized





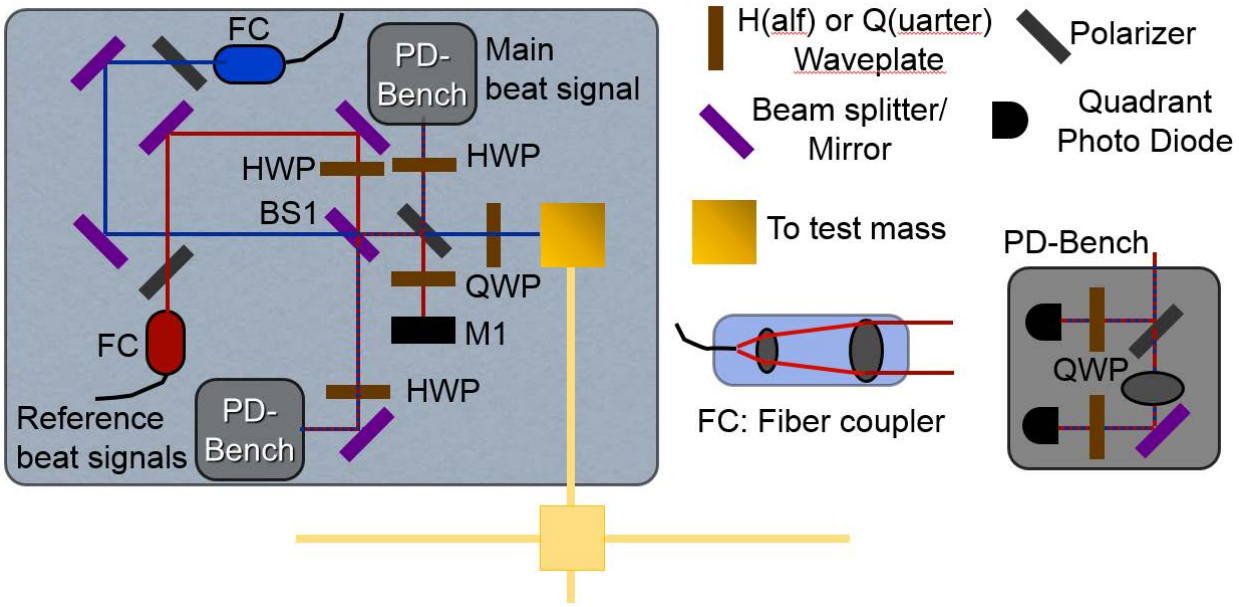
Bi-polar Charge Control

- Initial charge measurement scheme implemented
  - ±10 V across sensitive axis @ 20 mHz → oscillating field
  - Coherent response of the pendulum ∝ TM charge
- Bi-polar charge control demoed:
  - LTP scheme
  - UV light directed to TM or housing
  - 240 nm, 3.6 µW, dc



Future Plans

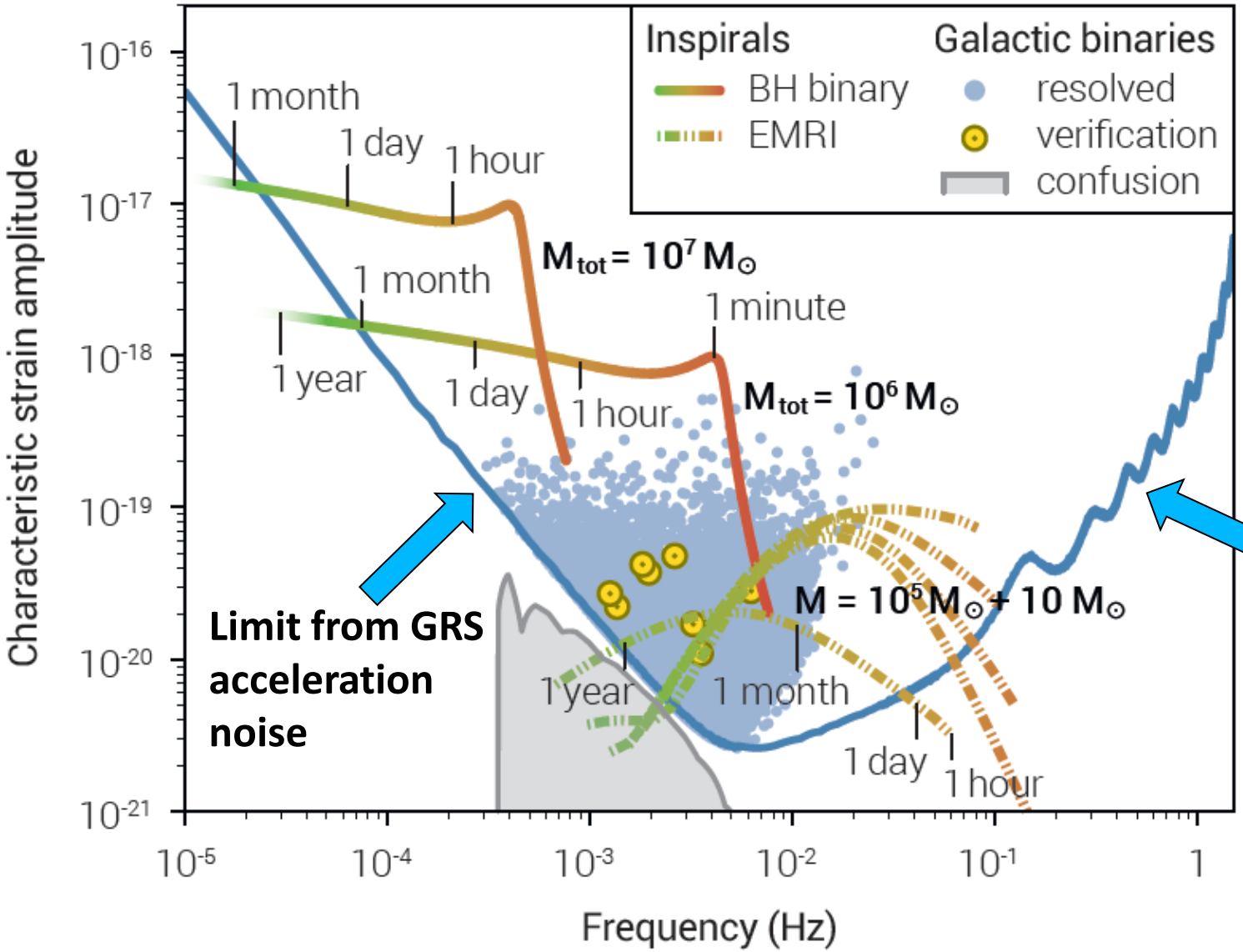
- Many things on our to do list:
- Noise hunting and noise reduction
- Develop and construct more flight-like GRS (requires funding)
- Integrate LISA-like short arm IFO (pm)
- DC, AC and/or continuous charge control
- Drift mode operation
- Six DOF optical sensing
- ...

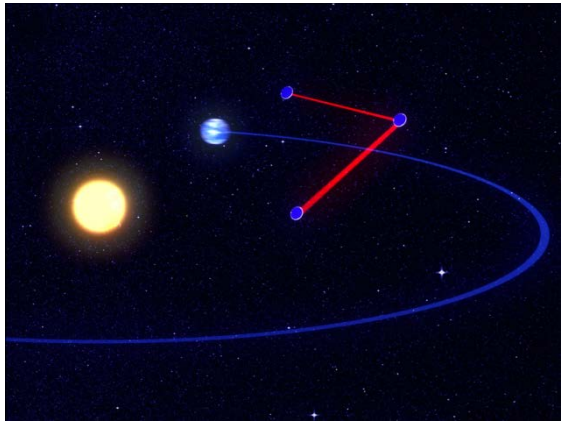


Backup slides …

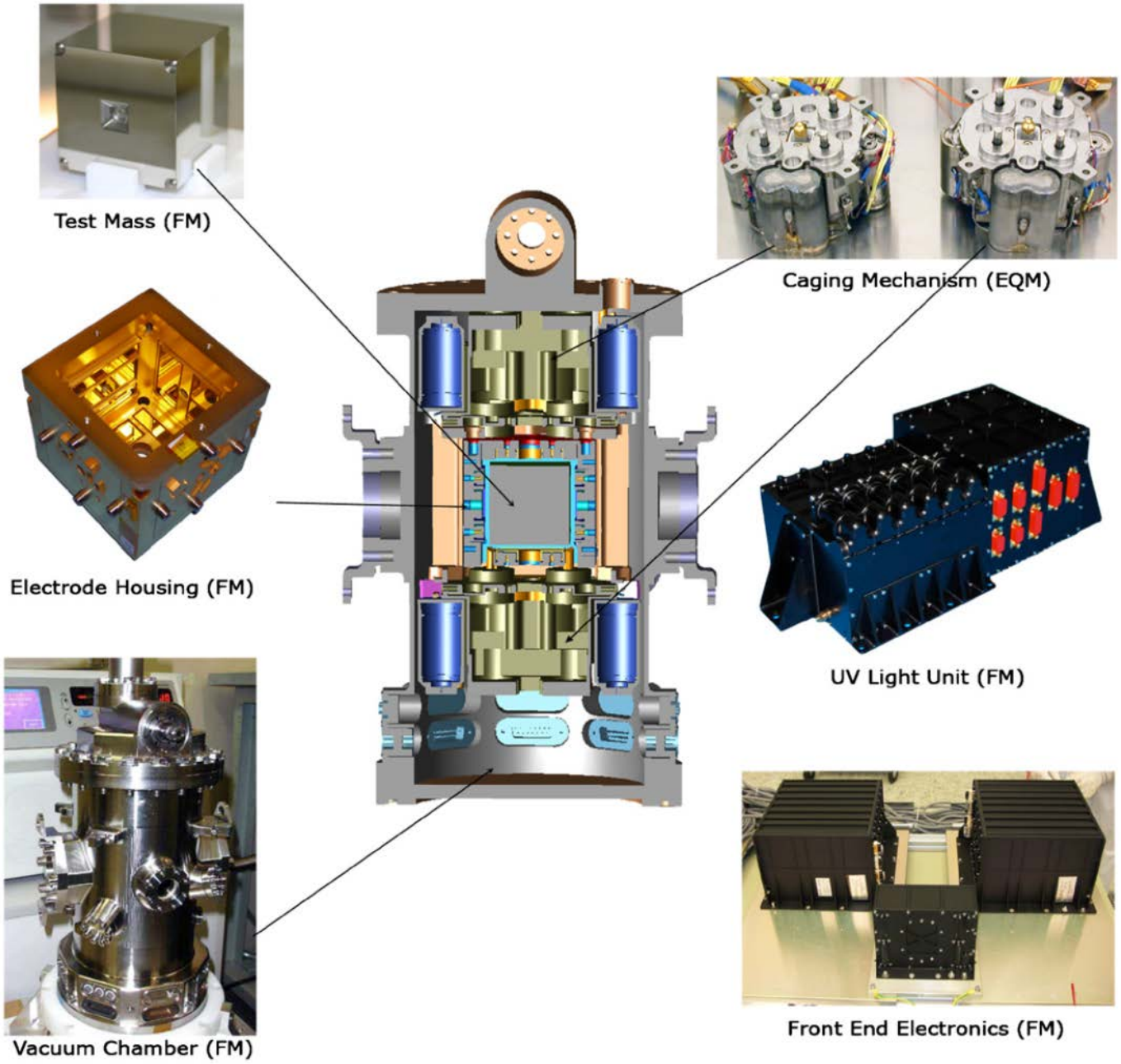
The Gravitational Universe

A science theme addressed by the *eLISA* mission observing the entire Universe





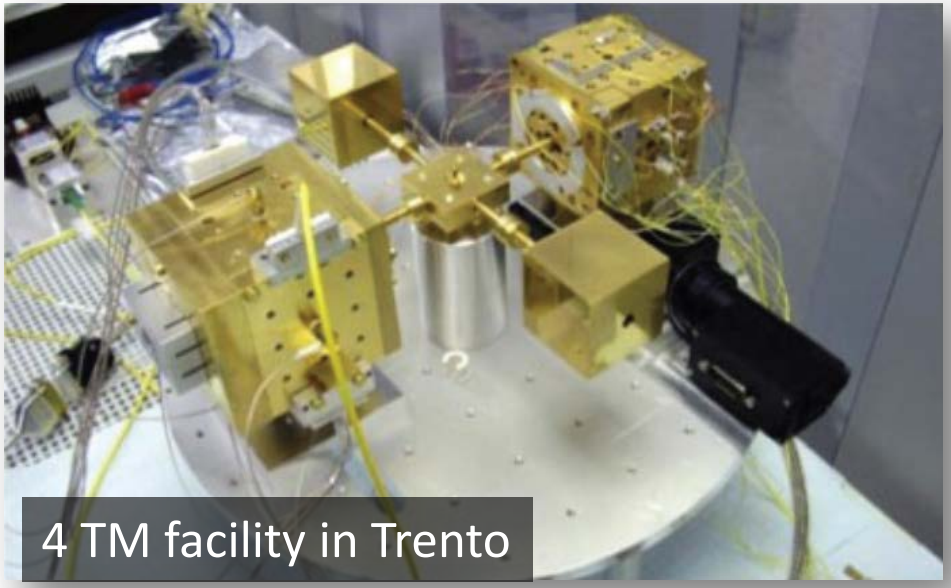
LISA Gravitational Reference Sensor



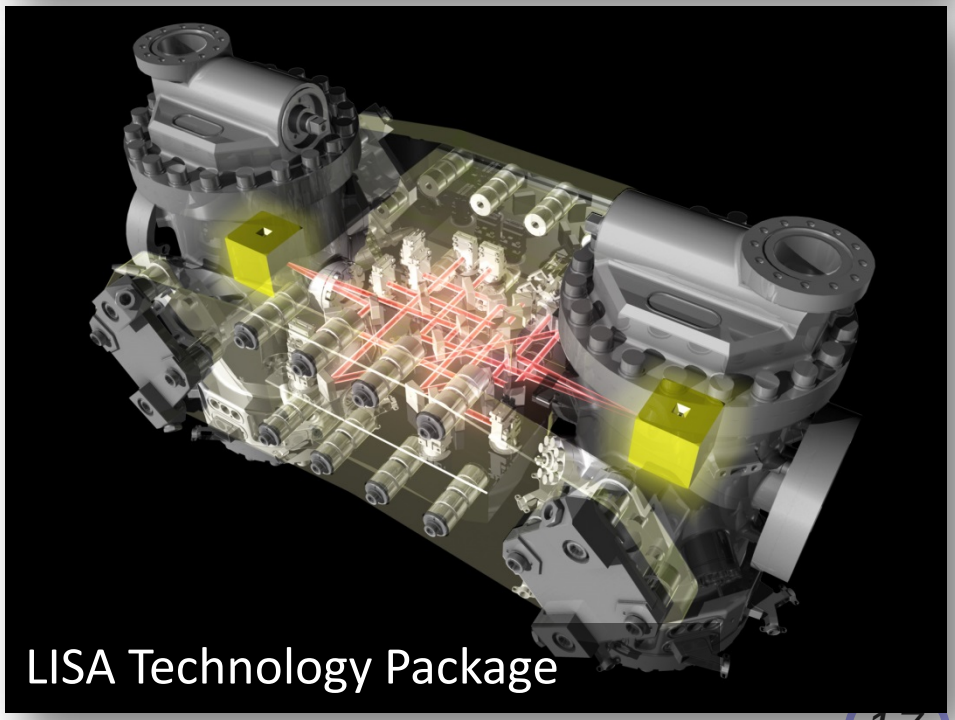
*F. Antonucci et al (2011)

GRS Testing

- Torsion pendula
  - Provides one (or more) DOF decoupled from local gravity
  - U. Trento leading the development of the GRS, with two torsion pendula


4 TM facility in Trento

- LISA Pathfinder
  - ESA LISA Technology Package will test the GRS in space
  - Launch: July 2015


LISA Technology Package

Zoo of Test Mass Surface Force Noise

Stiffness:
Sensing bias
TM charge
DC voltages
Any force gradient…

Thermal effects:
Radiometer effect
Radiation pressure
Differential out-gassing

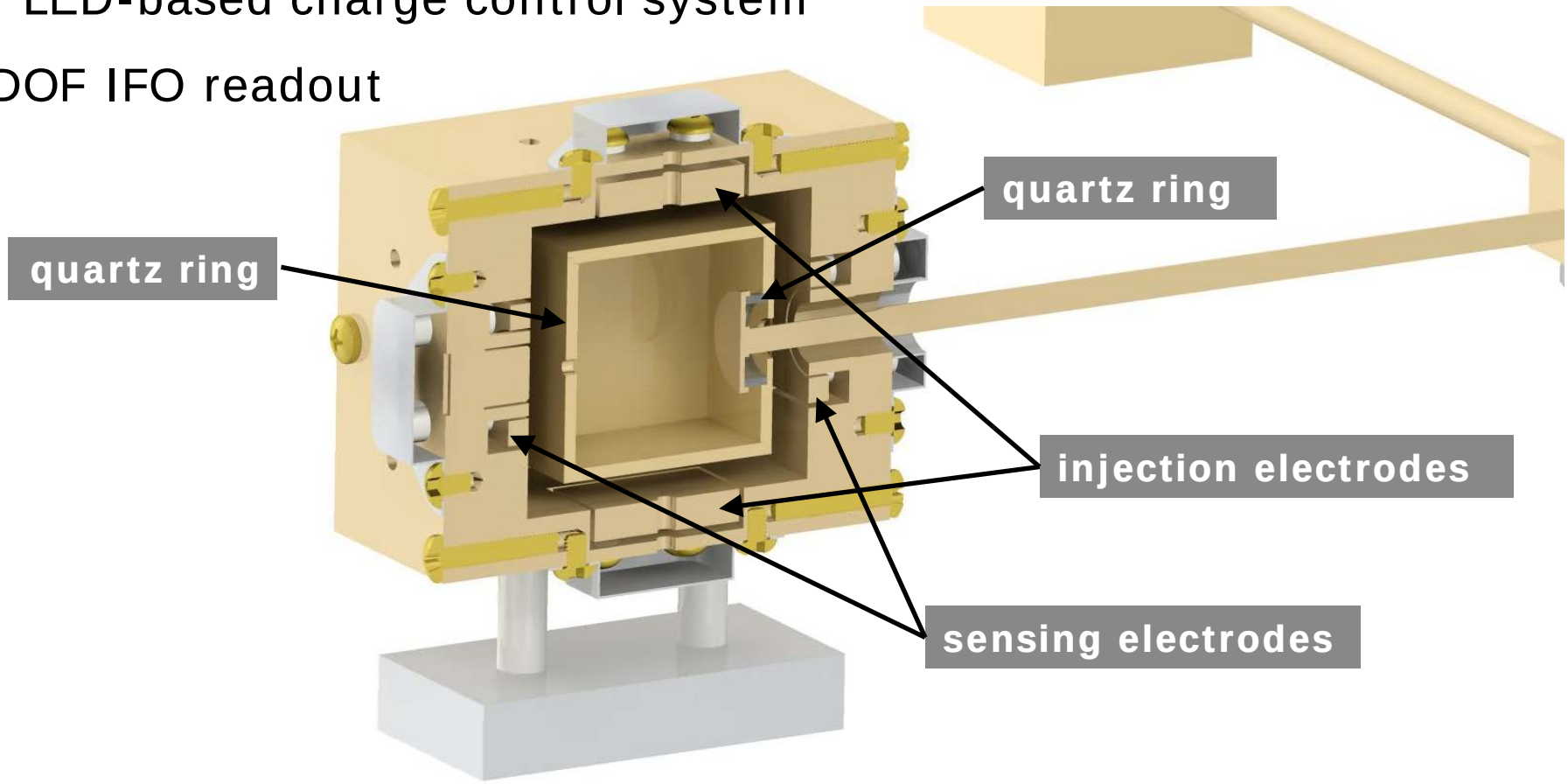
Electrostatics:
TM random charging
Stray DC voltages
Electronics back-action

Residual gas damping

Unknown effects

UF Torsion Pendulum Design

- Based on Trento design + modifications
  - Longer arm for more real-estate & separation of forces & torques
  - Underground facility for improved thermal, seismic isolation
  - UV LED-based charge control system
  - 6 DOF IFO readout



Predicted Noise Limit

- Thermal torque noise: W fiber, ~1 m length, 50 μm diam
- Arm length: 22 cm
- Pendulum mass: ~0.5 kg
- ϕ measurement: Differential interferometer ~ 10 prad $Hz^{-1/2}$