Testing new GRS technologies and configurations with the UF torsion pendulum

John W. Conklin*, Ryan Shelley, Andrew Chilton, Taiwo Olatunde, Giacomo Ciani, Guido Mueller

University of Florida

*jwconklin@ufl.edu
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 Europe
- Develop
- 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.

Acknowledgement:
U. Trento

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UF Torsion Pendulum

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

![Graph showing noise levels](image)
Simplified GRS

- Six electrodes, 40 nm/Hz\(^{1/2}\) sensitivity, translation only
- Al housing, Al electrodes, ceramic spacers, Au coated
- 3 UV injection ports
AC Capacitive Readout & DC Actuation

Poster: A. Chilton

Diagram:

- **PC**
  - Demod/processing
  - ADC
  - DAC

- **Preamp**
  - Diff. amp
  - dc Amp (250 V)

- **TM**
  - DC actuation
  - 100 kHz injection

- **FPGA-side**
  - NCO: 100 kHz
    - $\phi + \pi/2$
    - $\phi$
  - To DAC

- **Host-side**
  - $Q$, $I$ from ADC
  - $Q'$, $I'$
  - $R(\theta)$
  - Output

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First Oscillations

[Graph showing oscillations with displacement and angle over time]
Rotational mode: 1/48 min

Swinging mode: 1/2.3 sec
First Acceleration Noise Curve

- Fiber thermal noise
- Capacitive readout (40 nm/Hz\(^{1/2}\))
- IFO readout (10 pm/Hz\(^{1/2}\))
- Measured

Warning! Preliminary Results
Charge Control

- UV LEDs are attractive alternate to Hg lamps
  - \(240 \pm 10\) nm UV LED
    < Au work function 243 nm
  - Enables ac charge control
  - \(\sim 10x\) reduction in SWaP

![Fiber coupled UV LEDs (SETi)](image)

![Diagram](image)

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UV LED Testing & Qualification

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

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Quantum Efficiency (QE) for samples coated at different times

- 240 nm
- 250 nm

Sample 1
- Quantum efficiency $\approx 3 \times 10^{-6}$

Sample 2
- Quantum efficiency $\approx 2.5 \times 10^{-6}$

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Reference:
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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
  - $\pm 10 \text{ V across sensitive axis } @ \ 20 \text{ mHz } \rightarrow \text{ oscillating field}$
  - Coherent response of the pendulum $\propto \text{ TM charge}$

- Bi-polar charge control demoed:
  - LTP scheme
  - UV light directed to TM or housing
  - 240 nm, 3.6 $\mu$W, dc

![Graph showing frequency response with oscillating field on and off]
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

Limit from interferometry, antenna pattern

Limit from GRS acceleration noise

Inspirals
- BH binary
- EMRI

Galactic binaries
- resolved
- verification
- confusion

Characteristic strain amplitude

$M_{\text{tot}} = 10^7 M_\odot$

$M_{\text{tot}} = 10^6 M_\odot$

$M = 10^6 M_\odot + 10 M_\odot$

Frequency (Hz)

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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

- LISA Pathfinder
  - ESA LISA Technology Package will test the GRS in space
  - Launch: July 2015
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\(^{-1/2}\)

*Measured Trento pendulum sensitivity*

*UF pendulum design sensitivity*

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