Gravitational reference sensor technology development for LISA

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LISA Gravitational Reference Sensor

*F. Antonucci et al (2011)
UF Torsion Pendulum

- Follows 4TM Trento pendulum
  - Fiber supports cross bar with 4 hollow TMs (rotation $\rightarrow$ translation)
  - Light weight (0.46 kg) Al structure reduces needed fiber diameter
  - Measures surface forces
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![Image of UF Torsion Pendulum]

**Graph:**
- Acceleration noise for LISA TM [m s^{-2} Hz^{-1/2}]
  - Fiber thermal noise
  - Capacitive readout (40 nm/Hz^{1/2})
  - Interferometer readout (1 nm/Hz^{1/2})
  - LISA requirement
UF Torsion Pendulum

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Inside the Chamber

Simplified Electrode Housing

\[ \varphi = \frac{x_1 - x_2}{22.2 \text{ cm}} \]

\[ X = \frac{x_1 + x_2}{2} \]

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AC Capacitive Readout & DC Actuation

- Typical Sensitivity: 30 nm/Hz$^{1/2}$

![Diagram of AC Capacitive Readout & DC Actuation](image)

- **Demod/processing**
- **ADC**
- **DAC**
- **Diff. amp**
- **Preamp**
- **DC Amp (10/250 V)**
- **DC actuation**
- **100 kHz injection**
- **FPGA-side**
- **Host-side**
- **NCO: 100 kHz**
- **φ + π/2**
- **φ**
- **To DAC**
- **From ADC**
- **R(θ)**
- **Q**
- **I**
- **Q’**
- **I’**
- **Output**

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Interferometer Readout

- Polarization multiplexed Mach-Zehnder interferometer measures differential displacement of two test masses
- Light delivered by fiber feedthrough
- Recombined beam sensed outside chamber (free-space)
- Typical sensitivity: 0.5 nm/Hz$^{1/2}$
Pendulum Angle Time-series
ϕ Spectrum

2016-05-13 PHI LPSD

LTPDA 2.9.4 (R2014a), 2016-08-30 17:45:19.364 UTC, ltpda: 967b0ee, lplot
Torque Impulses in $\varphi$
Torque Impulses

![Graph showing torque impulses over time. The graph compares capacitive and interferometric measurements.](image-url)
Pendulum Performance vs. LISA

\[
S_a^{1/2} [m \cdot s^{-2} \cdot Hz^{-1/2}]
\]

- LISA requirements
- Capacitive, full weekend
- Interferometer, no spikes

Frequency [Hz]
LISA Pathfinder-like GRS

- Internal geometry equivalent to Pathfinder
- 3 UV light injection ports
- Prototype: Aluminum + PEEK
- Integrated into pendulum in summer

UV injector
(Ti ferrule + UV fiber + SMA connector)
UV LED-based Charge Control

- TM charges due to release after launch & cosmic rays (~50 e/s)
- Charge increases electrostatic stiffness & interacts with $E$ fields
- TM Charge control via UV photoemission demoed by GP-B
- UV LEDs are attractive alternate to Hg lamps
  - 240 ± 10 nm UV LED < Au work function 243 nm
  - ~10x reduction in SWaP (~150 mW in → 25 µW out)
  - Enables AC charge control

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UV LED-based Charge Management System

- **Electronics driver**
  - DC, AC, PWM current source with external reference
  - Thermo-electric cooler (TEC) driver

- **Fiber coupler houses**
  - UV LED (240 nm)
  - Mode-matching optics
  - TEC

- 0.6 mm diam UV fiber

- UV light injector

![UV LED driver & fiber coupler, v1.0](image-url)
DC Charge Control on Pendulum

- Applied AC field drives pendulum with amplitude $\propto q$
- Illuminating the housing drives electrons to the TM
- Illuminating the TM drives electrons to the housing
- Bi-polar charge control demoed, but not well balanced ($-2 \text{ V} < q < 1 \text{ V}$)

![Graph showing the change in TM potential over time with marked time intervals and LED states.](Image)
QE Measurements

- # liberated electrons / # incident photons (typ. $\sim 10^{-5}$ for Au)
- Drives charge control performance (want $R < \text{QE}_1/\text{QE}_2 < R^{-1}$)
- Measurement technique:
  - Fiber-coupled UV LEDs illuminate coated sample
  - Samples (-9 V), sphere (+9 V)
  - Picoammeter measures current flow from sample to sphere
  - Vacuum: $< 10^{-5}$ Torr
Improved Consistency with Bake-out

Thanks to discussions with ICL

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**Graph**

- **Blue dotted line**: with bakeout at 130deg C
- **Red dotted line**: Measurement after turning the heater off from previous measurement
- **Green dotted line**: Measurement with vacuum vented and pumped down again
- **Yellow dotted line**: Measurement before bake-out
- **Magenta dotted line**: Measurement after the heater is mistakenly turned off from night before

**Axes**

- **Y-axis**: Quantum efficiency (QE) x 10^-5
- **X-axis**: Time (hours)

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Plans

- **April-May**: Test AC charge control with v2.0 electronics
- **May-August**: Integrate LPF-like GRS
- **May-August**: v3.0 driver electronics
- **Fall 2017**: Test AC charge control with LPF-like GRS
- **Down the road**: Continuous charge control tests