# Simulated Charge Control of LISA Proof-masses

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***Abstract***

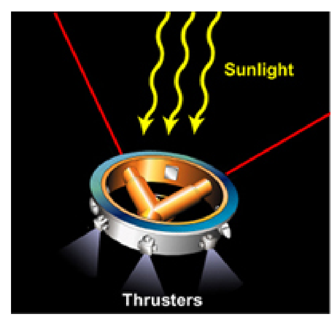
*It has become increasingly important to understand the charge interactions between the proof-masses and proof-mass housing in the LISA spacecraft. In this experiment, UV LEDs are used in an attempt to successfully manage charge between the proof-masses and housing: a system closely simulated by a torsion pendulum*

## Introduction

*About gravitational waves and LISA*

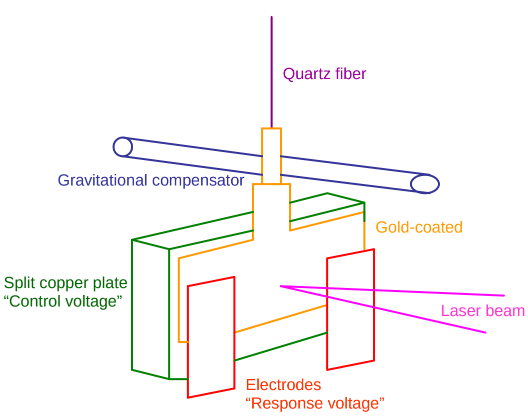
Gravitational waves offer a new way to observe the Universe.[1] These waves, or ripples in space-time, affect all matter they encounter. As a wave passes, massive bodies and the distances between separated objects will oscillate. The consequential movement is tiny, but it's measurable with today's technology.

The Laser Interferometer Space Antenna, or LISA, a joint project of the National Aeronautics and Space Administration and the European Space Agency to observe gravitational waves from space, will detect gravitational waves at low frequencies complementary to earth-based observatories.[1](Appendix, 1) LISA will use laser interferometry (Appendix, 3) to measure the distances between freely floating test masses five million kilometers apart.




A technological challenge of LISA is the charging of the proof-masses by solar rays, which is predicted to be the most significant source of LISA's acceleration noise in lower frequencies.[3] Currently, LISA design includes UV light to discharge the system; therefore it is essential to understand this exchange of charge at small scales.

*About the torsion pendulum*



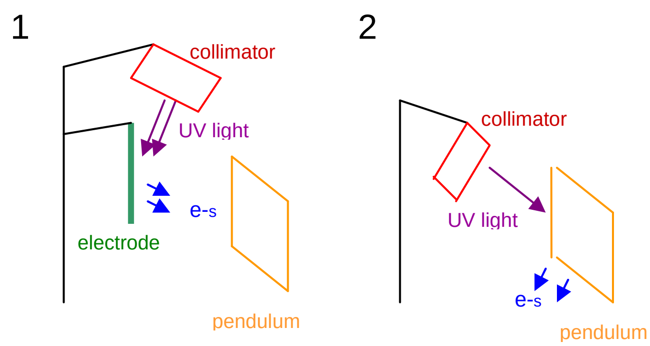

The LISA torsion balance was designed expressly to assess disturbances between conducting surfaces at small distances, similar to interactions in the LISA spacecraft.[3] The LISA torsion pendulum hangs freely from a quartz fiber to keep it electrically isolated. The pendulum itself has a gravitational compensation bar perpendicular to the plane of the pendulum.

The LISA torsion pendulum uses a feedback loop to supply voltages to the response electrodes in order to keep the pendulum at $\theta = 0$ (no torque). Consequently, the most interesting data is the voltage is takes to keep the pendulum in the same plane (referred to as the “response” voltage). The torque on the pendulum is proportional to the response voltage squared.

## Experimental Set-up

The set-up for this experiment was motivated by the basic principals of the photoelectric effect: aim light with the proper wavelength at surface that is to be charged/discharged and knock charge around. However, the design was complex since the light source must not interfere with the laser beam and also extra light must be reflected away from the pendulum and electrodes.

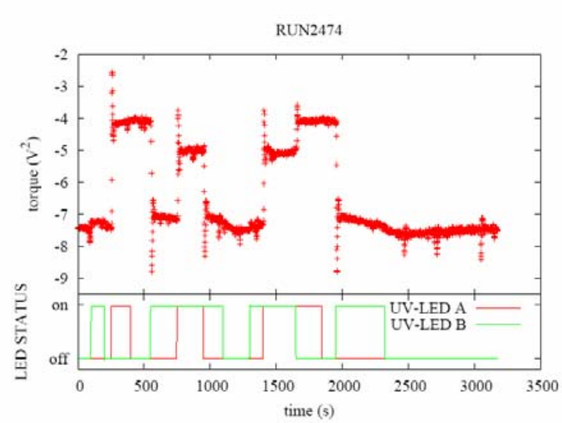
A previous torsion pendulum charge management experiment using a single UV LED aimed at the pendulum demonstrated that the UV light will shift charge off of the gold-coated pendulum.[3] The UV light used has a wavelength (248nm[3, Appendix, 4]) just at the threshold of the work function of gold (5eV)[3].




In order to demonstrate that charge can be controlled our design needed two UV LEDs: one to push electrons off and one to push them on. To do this we mounted a UV LED aimed at the pendulum itself (2, also referred to as “UVA”), and a UV LED aimed at an electrode, which we could vary the voltage on. (1, also referred to as “UVB”) This auxiliary electrode was mounted so that its normal surface faced the pendulum and escaped electrons would charge the pendulum. A collimator, which limited the light’s radius and reduced diffraction, was also used on each LED.

## Results

We clearly demonstrated that charge can be controlled by UV light on surfaces similar to the LISA proof-masses and housing, as seen in the graph to the right. On the y-axis, torque is proportional to the voltage of the response electrode squared. Note that a distinct jump in voltage is seen only when a UV LED is turned on, not off, and that there is an intermediate state around -5 when the two LEDs are on together.



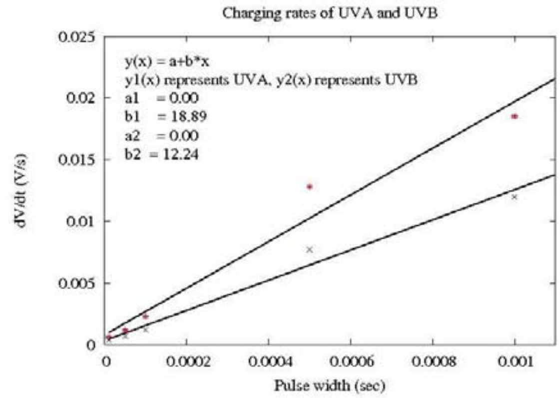

Another quantity important to managing charge is the charging rate of each UV LED on the pendulum. Obvious from the graph above (RUN2474), the UV LEDs charge the pendulum very quickly; in fact, too quickly to determine the rate of charge simply from turning them on. To circumvent this, we charged the pendulum more slowly by pulsing the UV LED light at varying pulse widths (the time the LED is on) at the same frequency. After a rough calculation

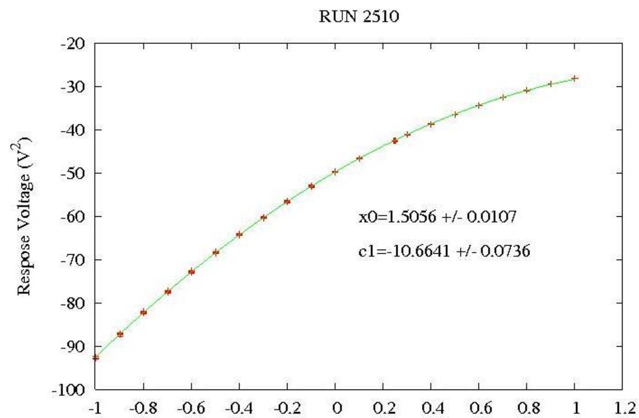
$$dQ/dt = C*dV/dt$$

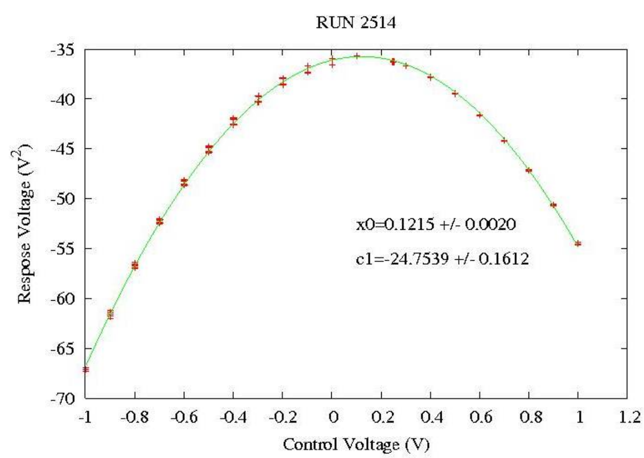
(the exact position of the pendulum and thus the system capacitance was unknown at the time of this paper) the charging rate of UVB is roughly $3.1 \times 10^{-11}$ Coulombs/sec and for UVA, $4.7 \times 10^{-11}$ C/s.

Our next challenge was to measure the charge on the pendulum. This is difficult because the pendulum, hanging from a quartz fiber, is not electrically grounded. Our method of charge measurement was to first measure the voltage on the pendulum. Then Q= C*V and the capacitance of the pendulum-electrode system is about 10 pF when the pendulum is about 2mm away from the electrodes.[3]

Our technique to measure the voltage on the pendulum was to vary the control voltage (the split copper plates) and plot this versus the response voltage squared. The voltage of the pendulum is then the minimum/maximum of the resulting parabola. For example, the graph to the upper right (RUN2510) is a run with UVB off, and the pendulum voltage, x0, is fit to be about 1.5V. In an effort to further understand the complex relationships in pendulum charge, we systematically varied aspects of the experiment to compare the results of each. For example, contrasting RUN2514, in which UVB is turned on, to RUN 2510, we see that the voltage on the pendulum is a great deal more negative. From this we can conclude UVB has a negative effect on the pendulum voltage, which is what we would expect.



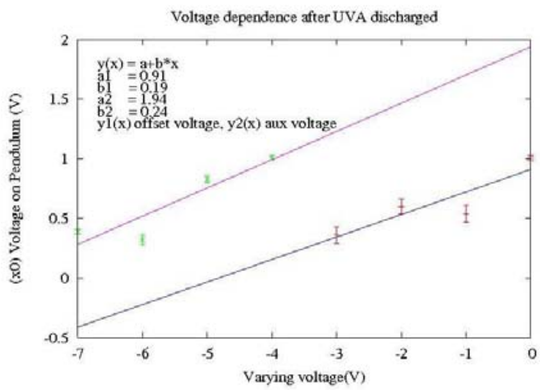

Further results are summarized in the table below, where “off-A” denotes the pendulum discharged by UVA.

Clearly there is a relationship between pendulum voltage (x0) and both the offset and auxiliary voltages and the fit is plotted below. A better understanding of these and similar relationships will eventually yield an accurate indirect measure of charge.

| Offset electrode (V) | Aux electrode (V) | UVB status | x0 (Volts) | | | c1 | | |
|---|---|---|---|---|---|---|---|---|
| -1 | -4 | on | -0.23 | ± | 0.01 | -20.69 | ± | 0.3614 |
| -1 | -4 | off-A | 0.54 | ± | 0.07 | -11.24 | ± | 1.49 |
| 0 | -4 | on | 0.00 | ± | 0.00 | -20.90 | ± | 1.14 |
| 0 | -4 | off-A | 1.01 | ± | 0.02 | -9.15 | ± | 0.16 |
| -2 | -4 | on | -0.31 | ± | 0.01 | -20.48 | ± | 0.49 |
| -2 | -4 | off-A | 0.60 | ± | 0.06 | -10.53 | ± | 1.07 |
| 0 | -5 | on | -0.04 | ± | 0.00 | -20.51 | ± | 1.12 |
| 0 | -5 | off-A | 0.83 | ± | 0.03 | -9.72 | ± | 0.35 |
| 0 | -6 | on | -0.12 | ± | 0.00 | -21.97 | ± | 0.77 |
| 0 | -6 | off-A | 0.32 | ± | 0.04 | -9.98 | ± | 1.15 |
| 0 | -7 | on | -0.22 | ± | 0.01 | -19.76 | ± | 0.91 |
| 0 | -7 | off-A | 0.39 | ± | 0.02 | -7.95 | ± | 0.53 |
| -3 | -4 | on | -0.39 | ± | 0.01 | -20.07 | ± | 0.45 |
| -3 | -4 | off-A | 0.36 | ± | 0.07 | -7.41 | ± | -1.5 |

## Conclusions

We have demonstrated that charge on an electrically isolated gold-coated surface can be managed with UV light. The next step would be developing a method to continuously and precisely charge and apply this to a working charge feedback system. Such a feedback system would have enormous implications for Advanced LIGO and other sensitive experiments where charge noise is limiting factor.




## References

[1] “LISA: Opening a new window on the Universe.” 2007, May 22. NASA. 2008, Aug 21. <lisa.nasa.gov>

[2]”LISA.” ESA: Science and Technology. 2008, Apr 11. ESA. 2008, Aug 21. <lisa.esa.int>

[3]S.E. Pollack. (2008, January 11). Charge Management for Gravitational Wave Observatories using UV LEDs.

¤Image source (LISA thrusters and sunlight): http://lisa.nasa.gov/TECHNOLOGY/spacecraft.html

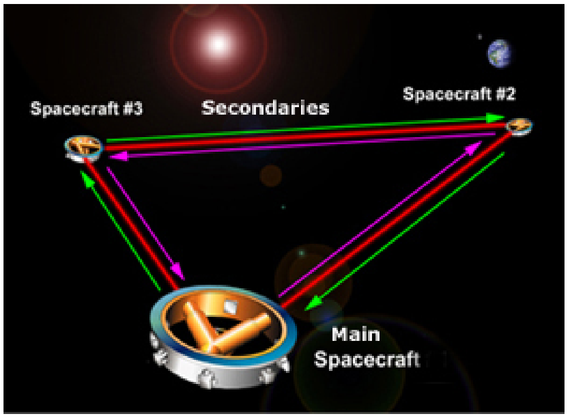
Special thanks to my advisor, Jens Gunlach, members of the Eöt-Wash gravity group, especially Stephan Schlamminger and Charles Hagedorn and the Center of Experimental Nuclear Physics and Astrophysics for their help and support. Thanks to the University of Washington and the Institute for Nulear Theory at UW and the NSF for this opportunity.

## Appendix

*1. Ground based gravitational wave detectors* - Current gravitational wave detectors such as Advanced LIGO, VIRGO and GEO600 are expected to detect a gravitational wave in the near future. These ground-based observatories use laser interferometry to detect subtle variances in the fabric of space-time. In Advanced LIGO, a laser beam is first split and sent down two identical, perpendicular four kilometer long arms (with multiple reflections between mirrors extending the effective optical length even further). If a gravitational wave passes through it will extend the length of one arm and contract the other. Thus, when the laser signal returns to the detector, instead of perfect destructive interference the two signals will be slightly out of phase, generating a light signal. Although laser interferometry in itself is sensitive enough to measure the minuscule perturbations in space-time, seismic noise limits earth-based interferometers to frequencies above 1 Hz[1], which drastically reduces the amount of gravitational wave sources they can observe.

*2. Goals of the project* - LISA aims to investigate a variety of fundamental physical principals including testing Einstein's theory of relativity to a greater accuracy, observing enormous amounts of gravity wave sources, directly detecting merging supermassive black holes, exploring the acceleration of the Universe and shedding light on dark energy's nature.[1] However, detection of gravitational waves from the early Universe would be "the most fundamental discovery that LISA could make."[1] For scale, the Cosmic Microwave Background allows us to observe back to less than 300,000 years after the Big Bang. LISA will have the ability to search for gravitational wave emission from up to one second after the Big Bang. [1]

*3. Laser interferometry of LISA* – The LISA laser interferometry operates on the same general principals as Advanced LIGO (Appendix 1). However, in the LISA design, each spacecraft is the laser source of another, forming three separate interferometers (which will allow the polarity of gravity waves to be determined.) Since the laser signal will be very weak after traveling five million km, the secondary spacecraft will transmit another laser beam in phase with the incoming light rather than reflecting it.[1]




Each identical spacecraft contains a free-falling gravitational reference sensor, used to control the motion of the spacecraft. Inside are freely floating "proof masses". The motion of these cubes relative to their counterparts in different spacecraft is what will detect passing gravitational waves. The cubes are highly polished to enable them to reflect laser light (akin to the end mirrors in LIGO). Image source: http://lisa.nasa.gov/TECHNOLOGY/LISA_interfer2.html.

*4. UV LED specs* – UVTOP -280 (280 being the typical wavelength) made by Sensor Electronic Technology, Inc.

| n | Offset (V) | electro | /B | dulun Volts | |
|---|---|---|---|---|---|
| [illegible] | 0 | -4 | -A | 01 | 2 |
| [illegible] | -1 | -4 | -A | 54 | 7 |
| [illegible] | -2 | -4 | -A | 60 | 6 |
| [illegible] | -3 | -4 | -A | 36 | 7 |
| | | | | | |
| [illegible] | 0 | -4 | n | 00 | 0 |
| [illegible] | -1 | -4 | n | 23 | 1 |
| [illegible] | -2 | -4 | n | 31 | 1 |
| [illegible] | -3 | -4 | n | 39 | 1 |
| | | | | | |
| [illegible] | 0 | -4 | -A | 01 | 2 |
| [illegible] | 0 | -5 | -A | 33 | 3 |
| [illegible] | 0 | -6 | -A | 32 | 4 |
| [illegible] | 0 | -7 | -A | 39 | 2 |
| | | | | | |
| [illegible] | 0 | -4 | n | 00 | 0 |
| [illegible] | 0 | -5 | n | 04 | 0 |
| [illegible] | 0 | -6 | n | 12 | 0 |
| [illegible] | 0 | -7 | n | 22 | 1 |