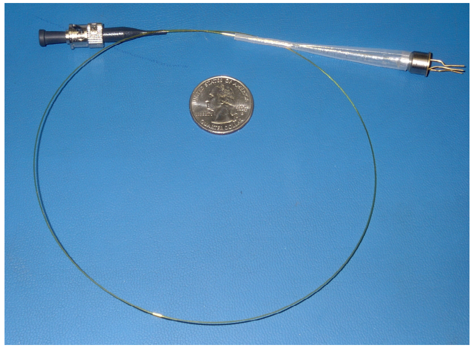
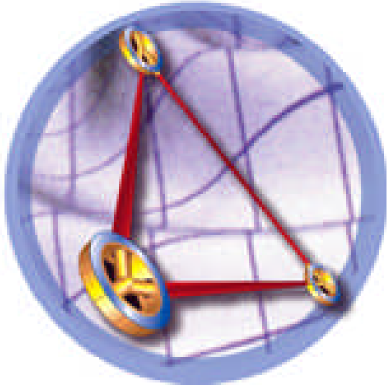
# LIGO Test Mass Charging Mitigation Using Modulated LED Deep UV Light

LIGO-G060172-00-Z





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Saps Buchman, and Robert Byer
Stanford University

LIGO Science Collaboration (LSC), OWG & SWG Joint Meeting
LIGO Hanford Observatory, March 22, 2006

K. Sun, B. Allard, S. Williams, S. Buchman, and R. L. Byer, "LED Deep UV Source for Charge Management for Gravitational Reference Sensors," presented at Amaldi 6 Conferences on Gravitational Waves, June 2005, Okinawa, Japan. Accepted for publication at Classical Quantum Gravity, as a highlight of the Amaldi 6th conference.

# Outline

- LIGO test mass charging is a growing concern for LIGO
  - Charging mechanism
  - Consequences
- Deep UV LED based AC charge management is expected to be an effective mitigation
  - Heritage from GP-B precision flight
  - High frequency AC modulation to reduce disturbances
  - Out of GW signal band modulation (10 kHz)
  - New dimensions of measurements and calibrations
- Stanford ongoing experimental efforts

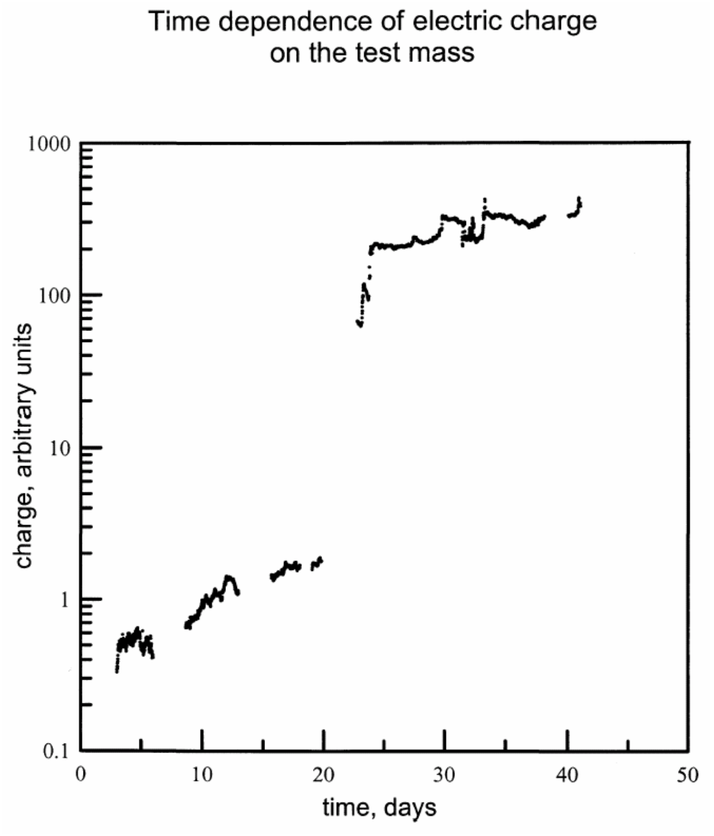
# LIGO Test Mass Charging

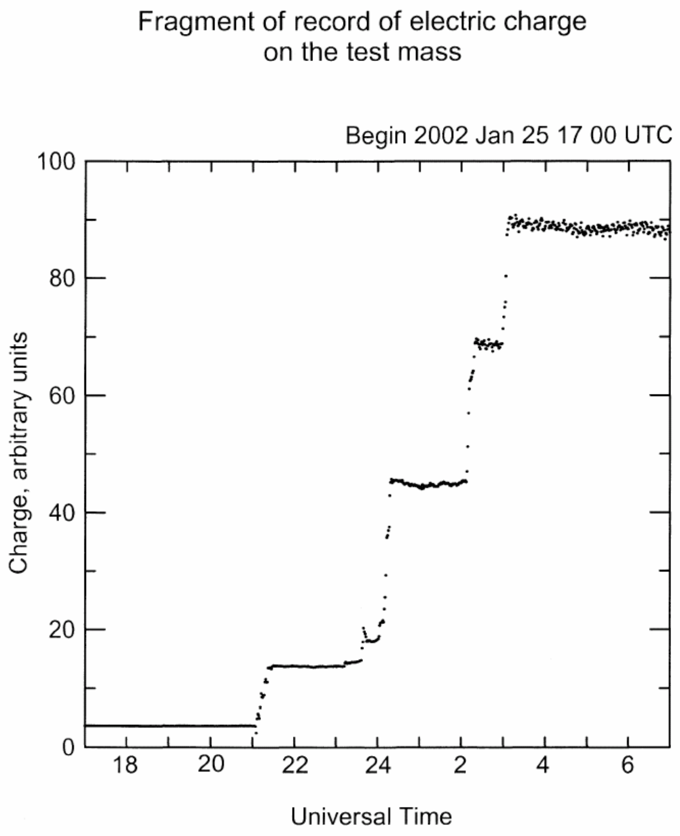
- Test mass charging due to:
  - Cosmic ray ionization (Braginsky G020033)
  - Pumping system transportation (Rowan CQG **14** 1537)
  - Dust rubbing transfer (Harry, G040063)
- Test mass charging consequences:
  - Reduction of suspension Q (Rowan, Harry)
  - Non-Gaussian noise due to charge hopping (Weiss)
  - Possible noisy forces due to other charged bodies

# LIGO Test Mass Charges Accumulation

Charges can accumulate on LIGO test mass for several months

Charge Control Necessary


Time dependence of electric charge on the test mass

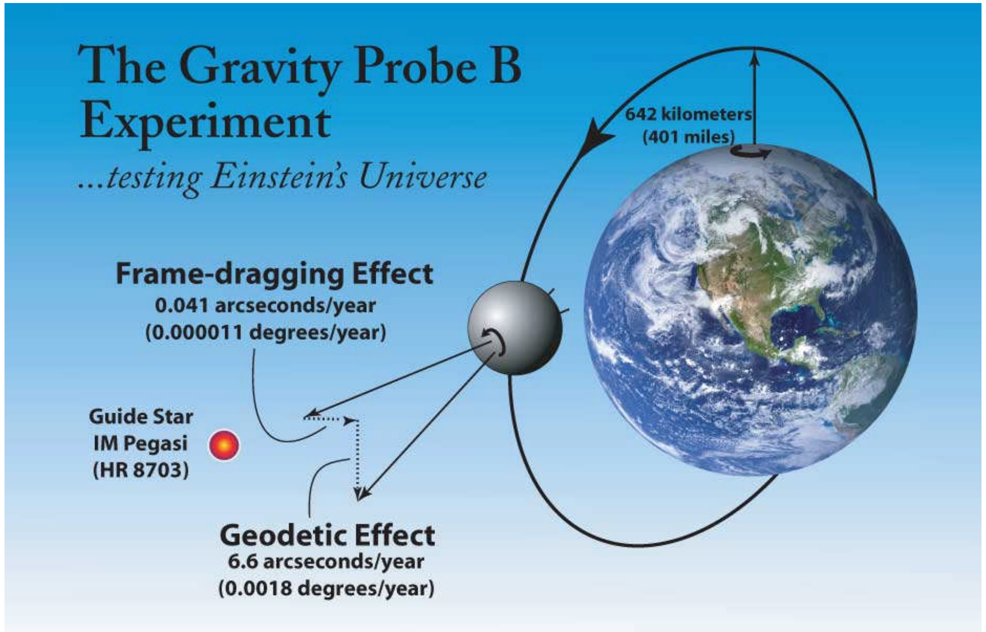

Fragment of record of electric charge on the test mass

*From Braginsky LIGO-G020033

# Gravity Probe-B

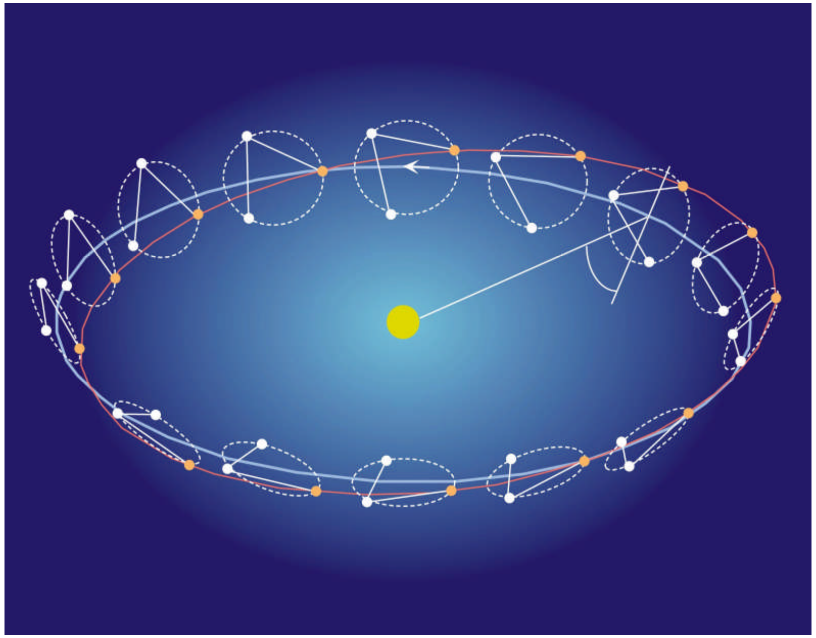
## A Stanford-Marshal-Lockheed Satellite Program

## A Precision Space Flight Required *Charge Management*



GP-B selected UV over cathode discharge

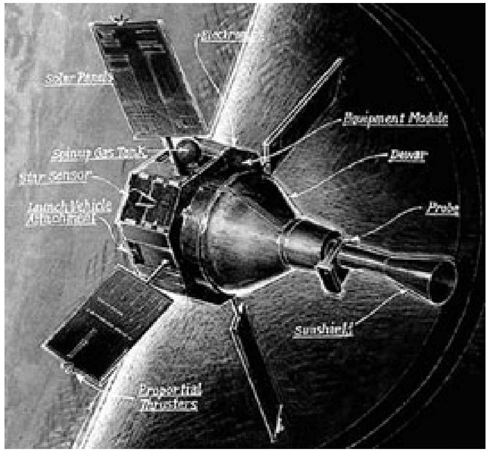
LISA selected GP-B technology as the charge management baseline

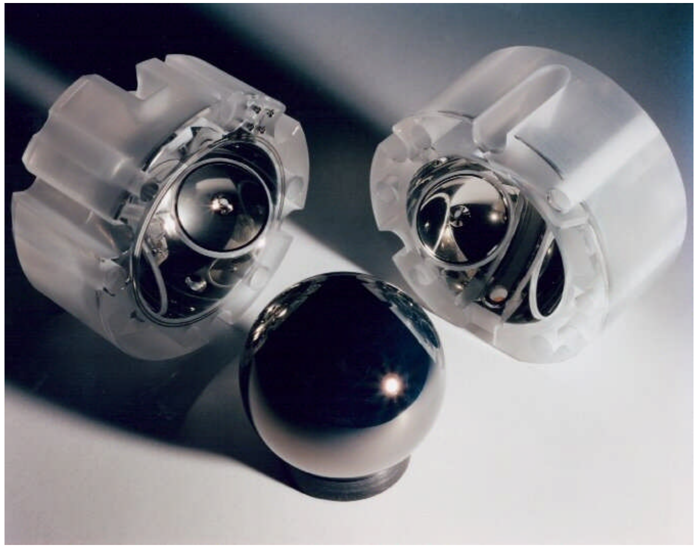


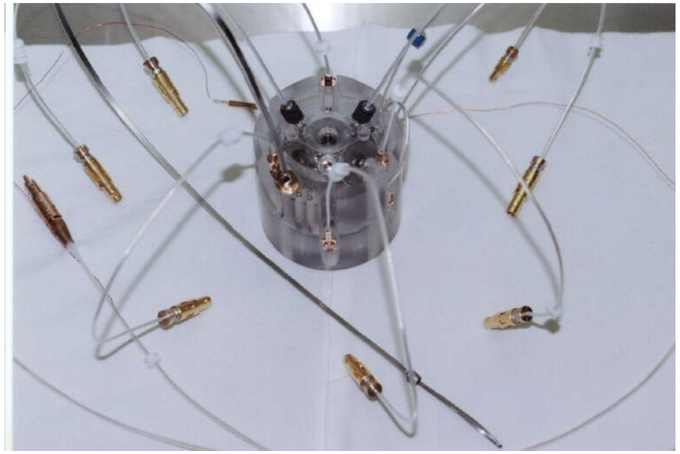
# GP-B Charge Management R&D Heritage at Stanford

## GP-B charge management (Buchman 1993)

- R&D since 1990’s
- Non-contact charge transfer by UV light
- Critical to GP-B mission success
    - Initial gyro lifting-off
    - Continuous charge management during science measurement







[Buchman 1993] Saps Buchman, Theodore Quinn, G. M. Keiser, and Dale Gill, “*Gravity Probe B Gyroscope charge control using field-emission cathodes,*” J. Vac. Sci. Technol. B **11** (2) 407-411 (1993)

# UV Photon Source Requirements for LIGO Test Mass Charge Management

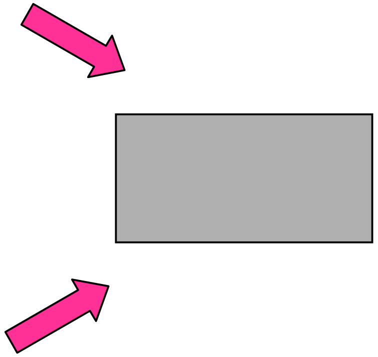
- $Q_c \sim 10^{-7}$ C/m$^2$ commonly cited
- Charging rate $Q_c \sim 10^{-7}$C/day
- $N_e \sim 10^{12}$ electrons/day
- Photoelectric “Q. E.”: $\eta \sim 10^{-5}$
- UV photons required: $N = 10^{17}$
- $P_{UV} = Nhc/\lambda\, T = 8.9\text{x}10^{-7}$ W
- $P_{UV} \sim 1$ μW (average power over a day)
- Dynamic Range ~ 1000,

$P_{UV} \sim 1$ mW (Peak power)

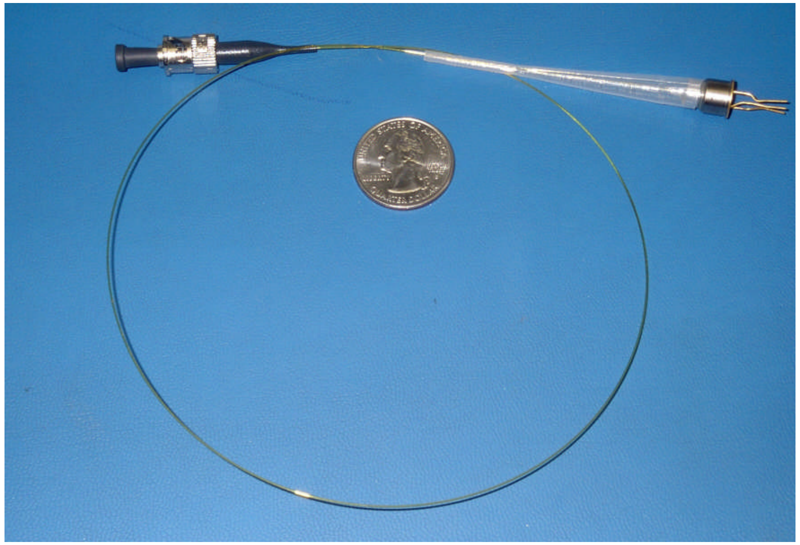
# UV Illumination Schemes

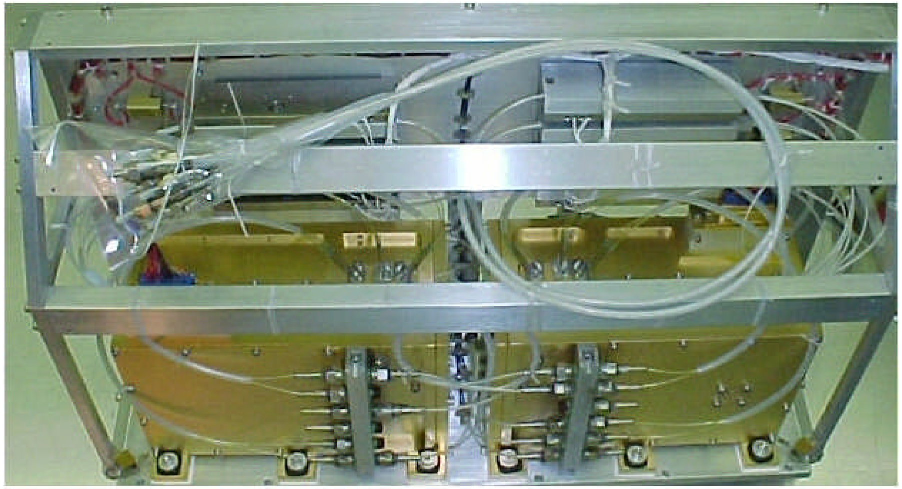
- Direct illumination
  - UV mercury lamp is routinely used for attachment removal
  - UV LED has sufficient power for cw direct illumination
  - Possibly works

- Illumination on coatings
  - Au coating on non-critical portions of test mass and suspension structure
  - Photoelectric effect on Au surface has been utilized in GP-B and ST-7
  - Higher throughput in charge control



# UV LED vs. Mercury Lamp





UV LED

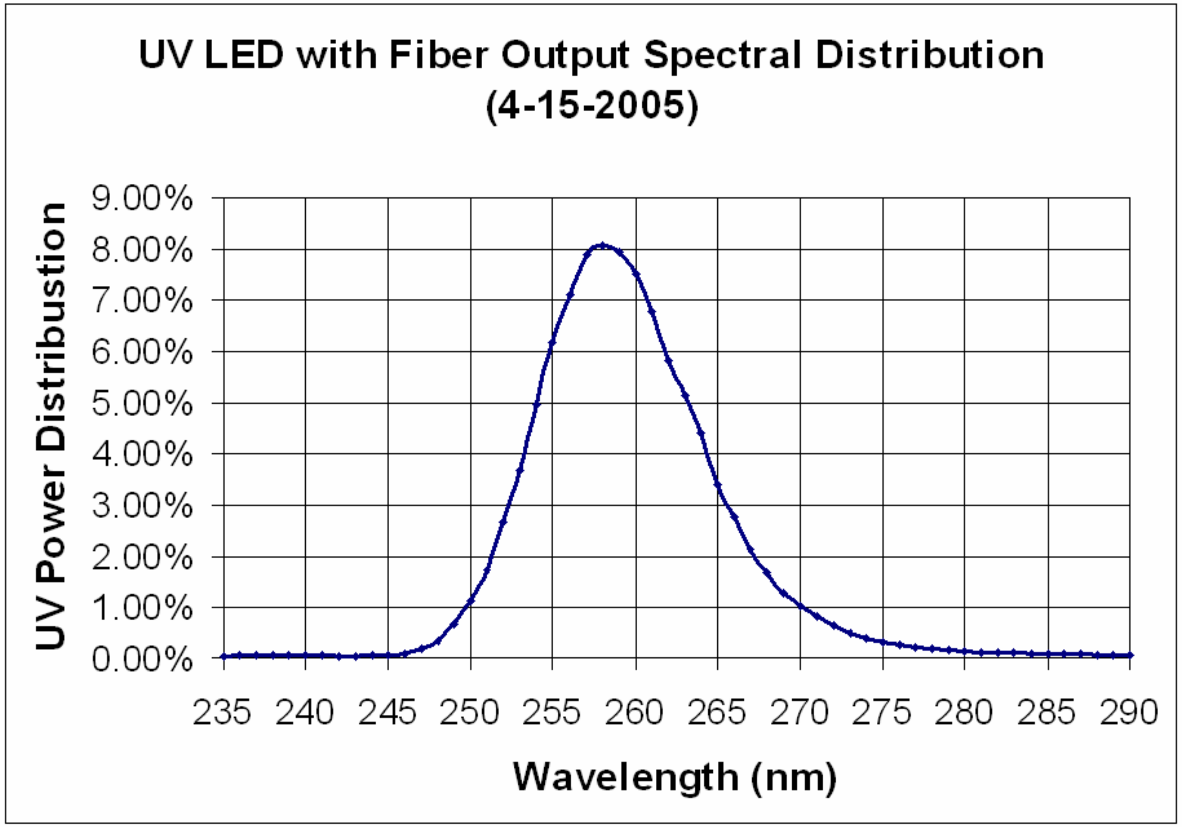
- TO-39 can packaging
- Fiber output with ST connector
- Reduced weight
- Power saving
- Reduced heat generation, easy thermal management near GRS

**GP-B CMS in Flight**

- **2 Hg Lamps**
- **Weight: 3.5 kg**
- **Electrical Power 7~12 W (1 lamp on, 5 W for lamp, 5 W TEC cooler)**

# UV LED Spectrum Measured at Stanford

- Peak wavelength: 257.2 nm, comparable to Hg line 254 nm
- FWHM: 12.5 nm, good photoemission for Au coatings
- Total UV power: 0.144 mW, sufficient for charge management

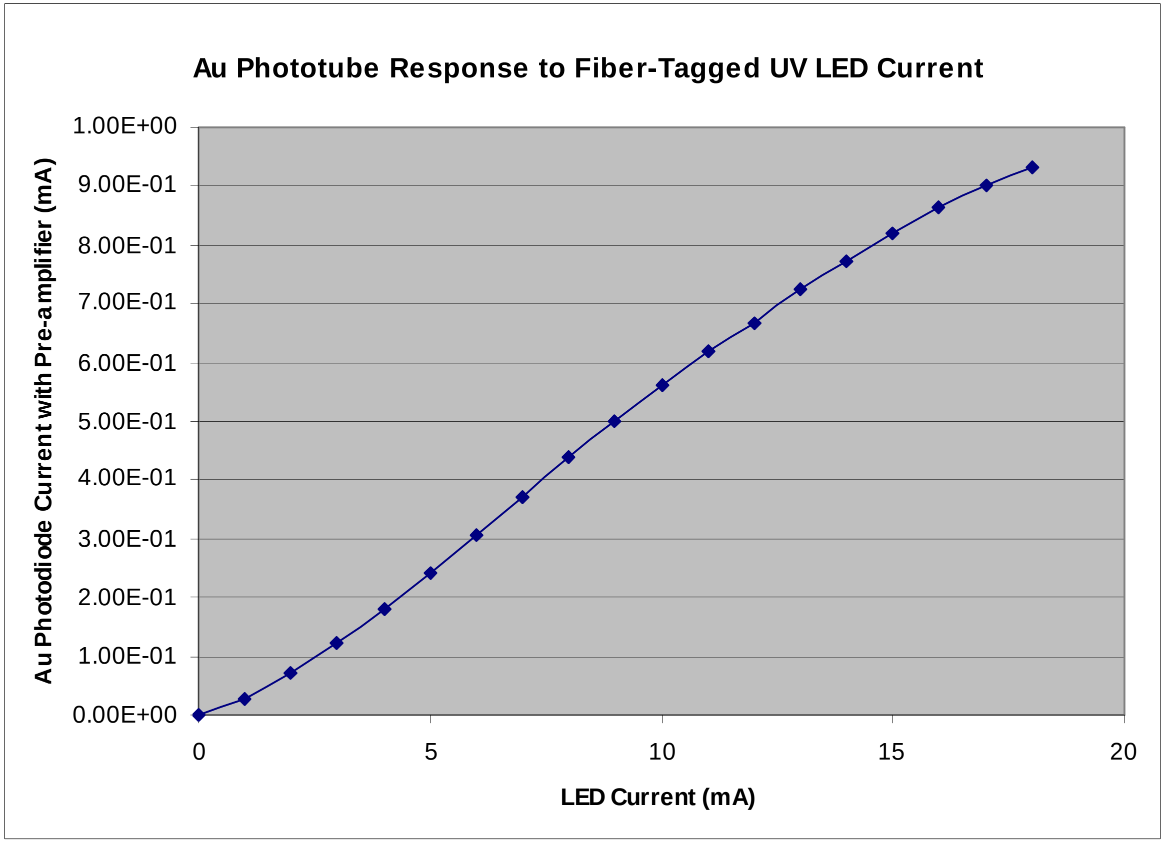


# Au Photodiode Photocurrent Response vs. Fiber-Tagged UV LED Current

## Efficient Photoelectron Emission Observed

Advantages of direct replacement of mercury lamp with UV LED:

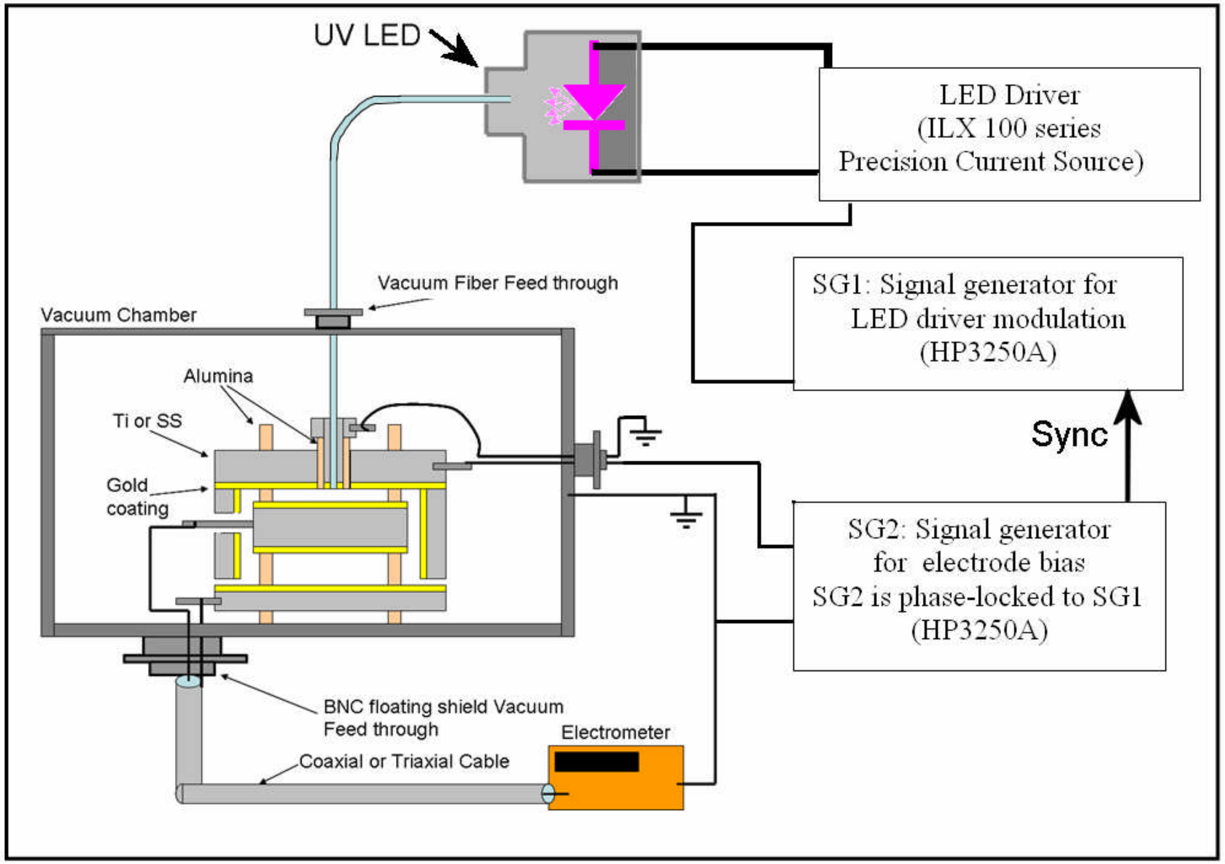
- Significant power saving
  - 1 W for UV LED CMS (including all control electronics)
  - 15 W for Hg lamp CMS
- Significant weight reduction
  - 4~5 kg per spacecraft
  - 12~15 kg for launch
- Easy environmental management:
  - Less heat generation near GRS module
  - Much less EMI



*(Au phototube UV power calibration ~16μW/mA)*

# UV LED Charge Management

## Experimental Setup



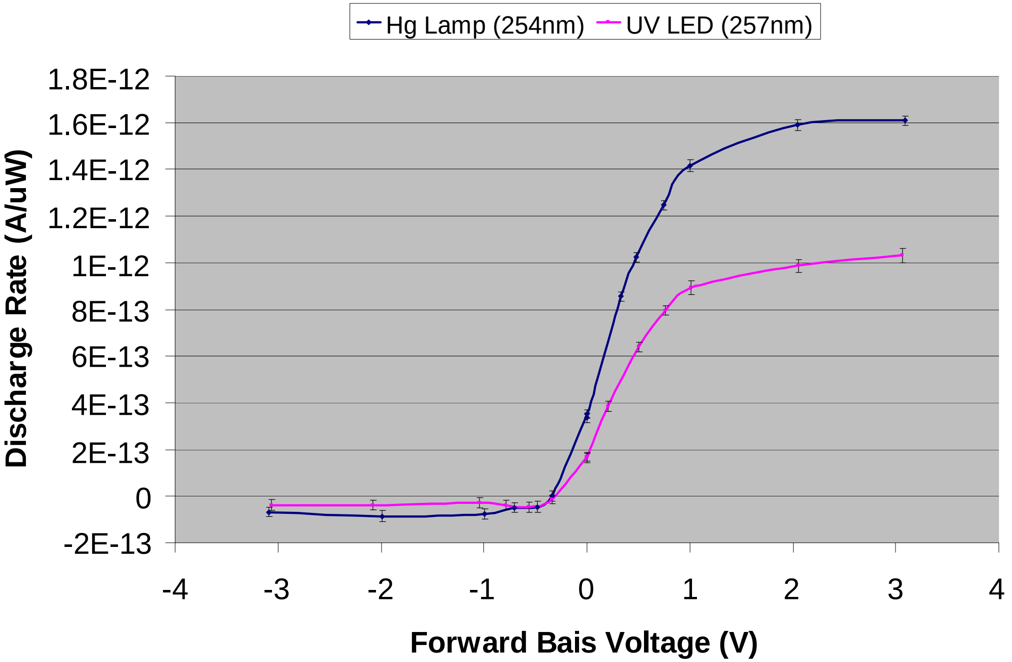
- GP-B heritage
- Au coating on proof mass and housing to simulate LISA GRS
- Fiber connected UV LED driven by modulated current source
- Housing electrode modulation phase-locked to UV modulation
- UV light shining on proof mass and reflected onto housing electrode
- Sensitive electrometer to measure the proof mass potential

# UV LED Charge Management System Has Potential Significant Scientific Pay Off

Direct Replacement of Mercury Lamp with UV LED ---

Save electrical power --- ~15 W per spacecraft

- The power can be used to double the laser power ---
  - Enhance sensitivity by 41%,
  - Increase event rate and detection volume by a factor of 282%.
  - Significant astrophysical observational pay off

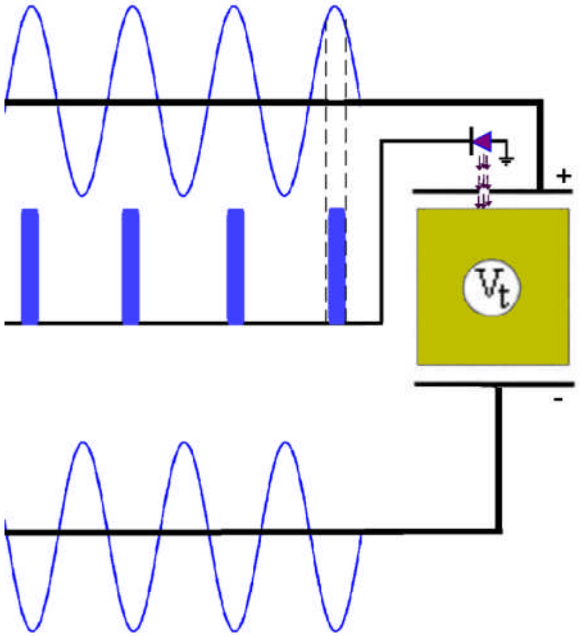


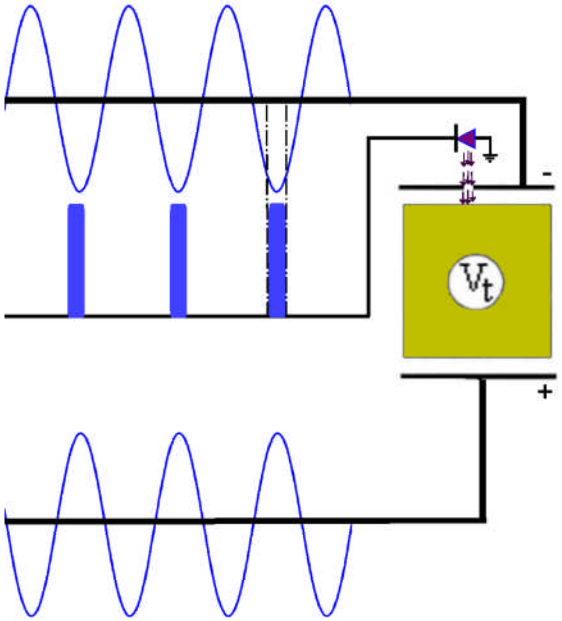
**Comparable Discharge Rates For First UV LED Experiment**

# AC Charge Management

## Enabled by Fast Direct Modulation of UV LED

- No need for dedicated DC bias, simplified structure
- Any AC electrical field such as capacitive readout or electrostatic forcing voltages can be used
- UV modulation can be out-of signal band high frequency, minimizing disturbances



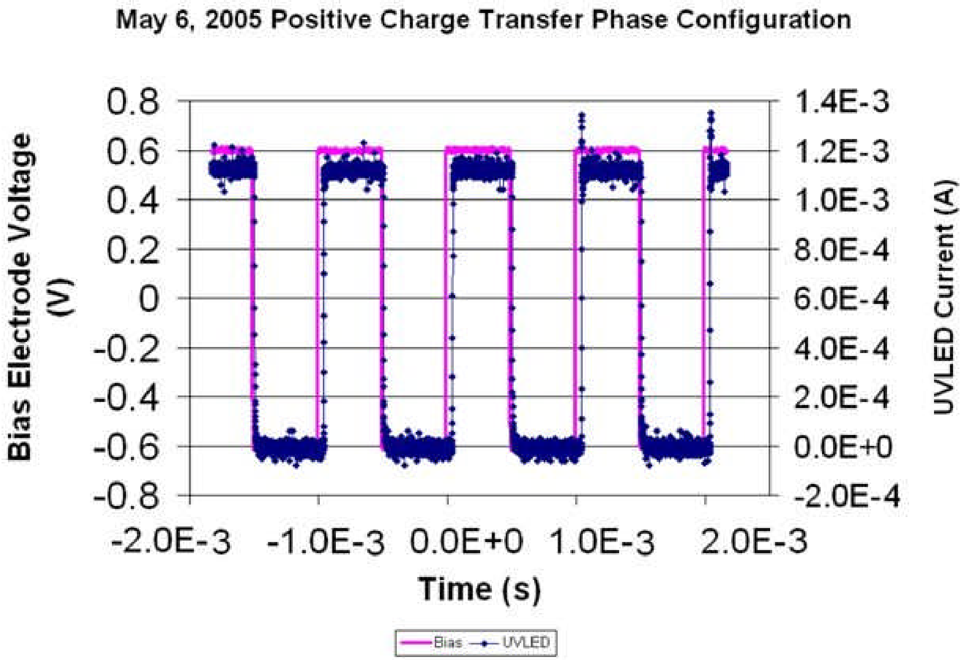


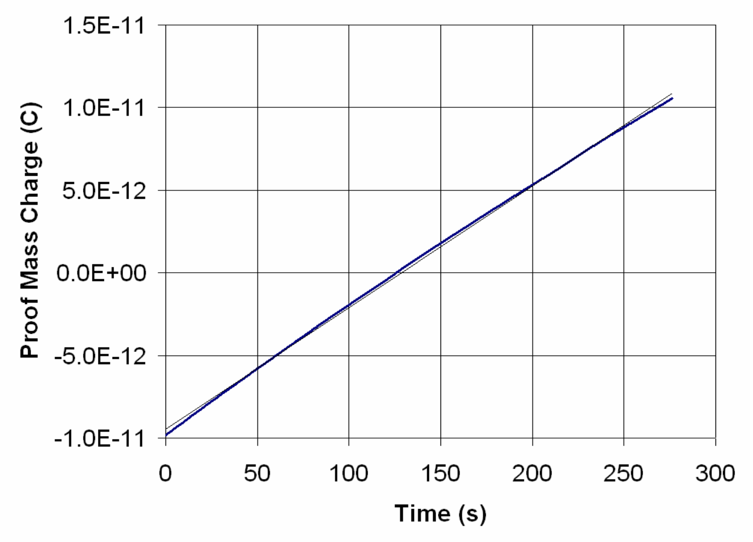
UV modulation is in phase with the *positive* AC ½ cycle: Photoelectrons only produced during positive bias, and transported to housing electrodes

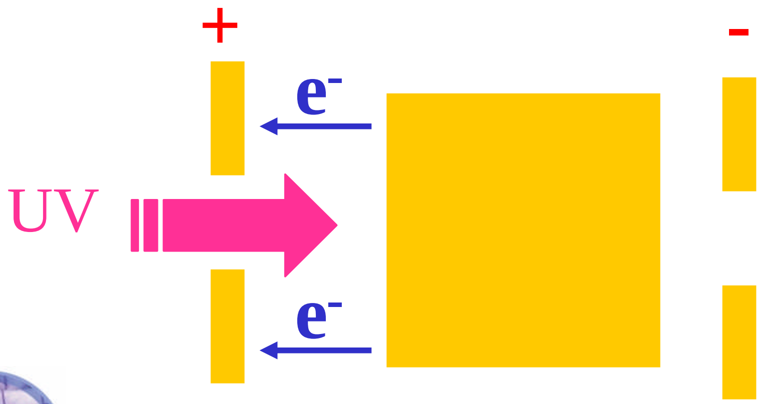
UV modulation is in phase with the *negative* AC ½ Cycle: Photoelectrons only produced during negative bias, and transported to proof mass

# Positive Charge Transfer

## UV LED and bias voltage modulated at 1 kHz







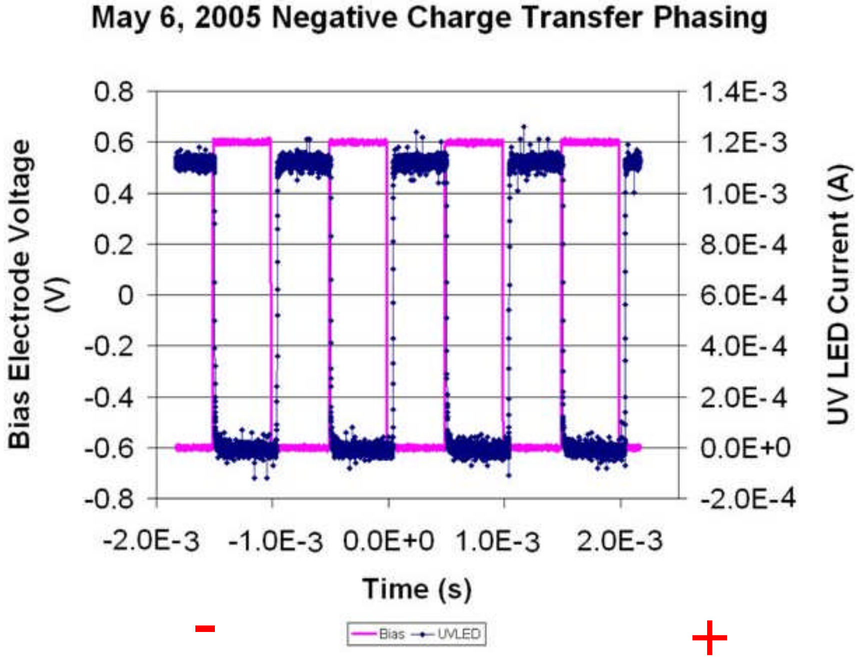
UV phased to positive AC ½ cycle

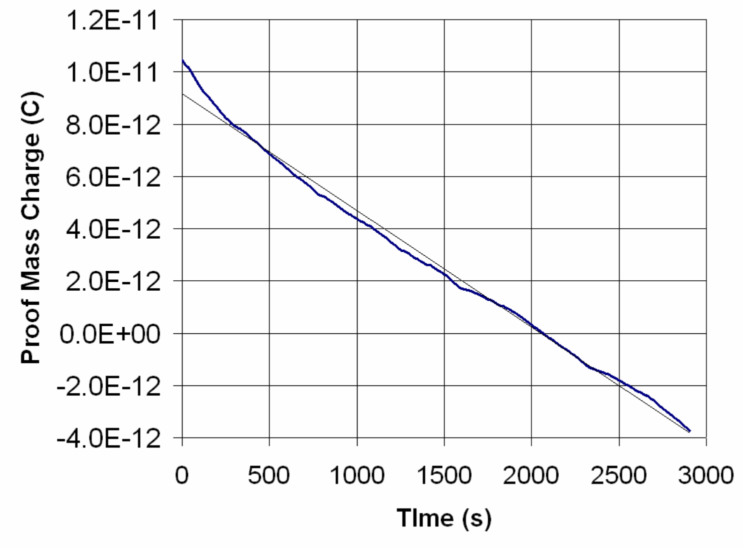
Electrons fly to housing electrode

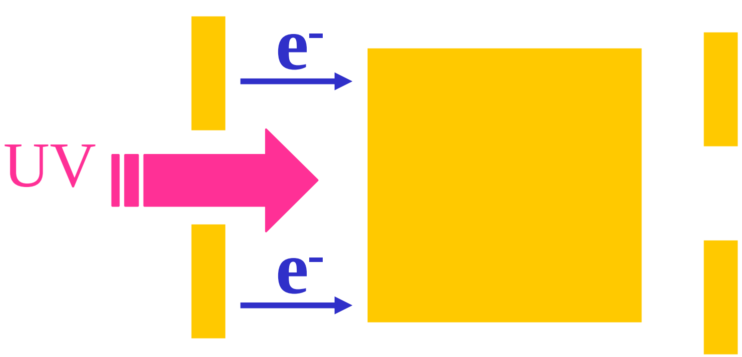
Proof mass potential increase

# Negative Charge Transfer

## UV LED and bias voltage modulated at 1 kHz





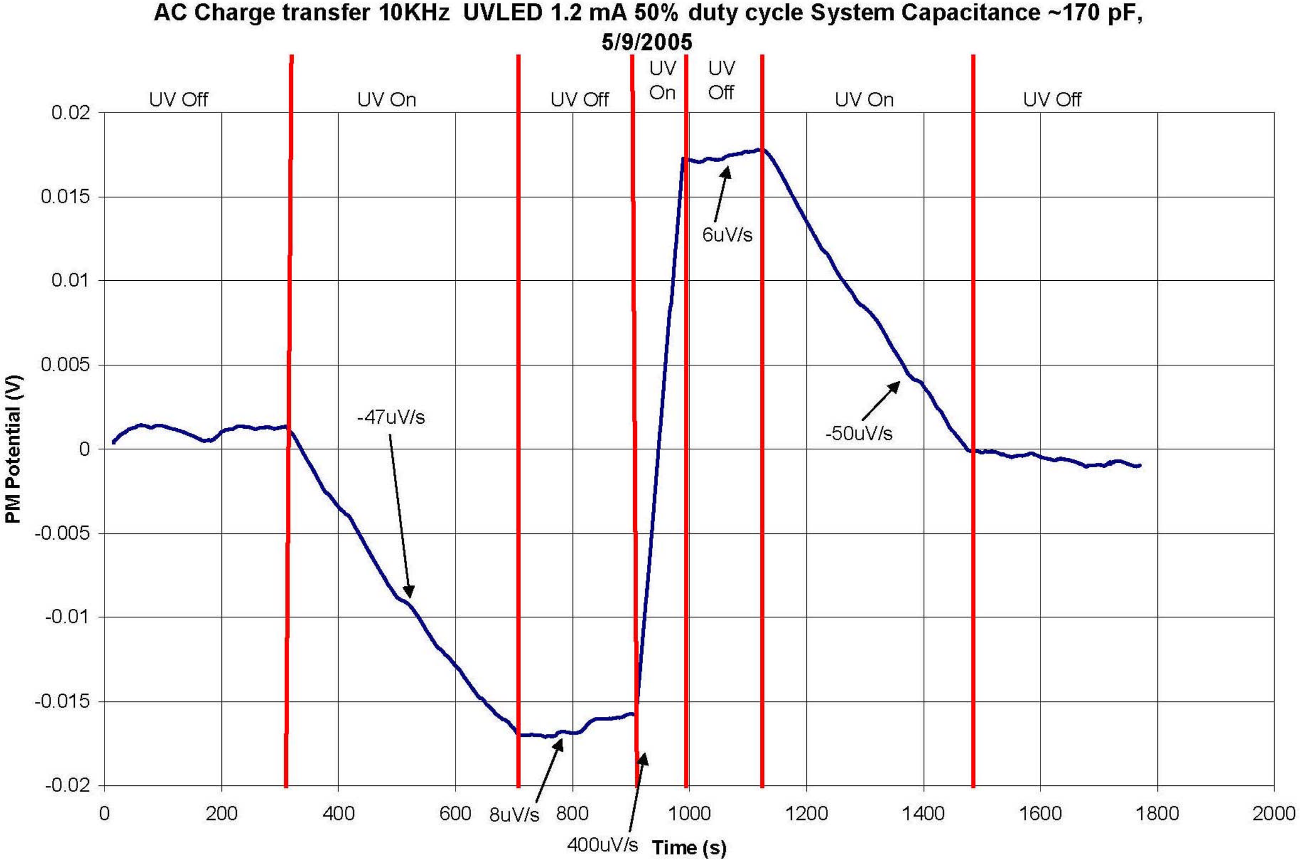


UV phased to negative AC ½ cycle

Electrons fly to proof mass

Proof mass potential decreases

# UV LED Based AC Charge Management



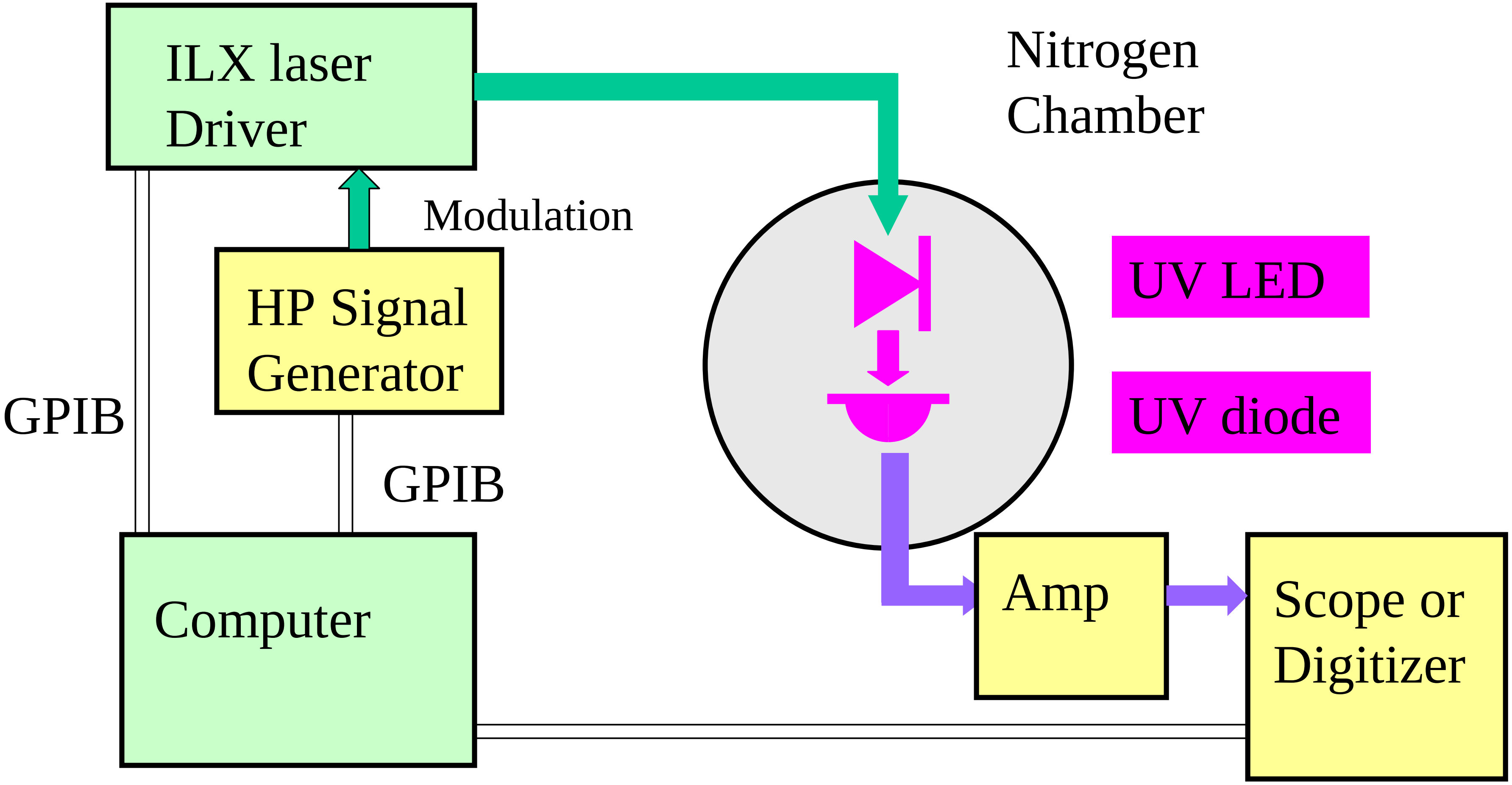
AC Charge transfer 10KHz UVLED 1.2 mA 50% duty cycle System Capacitance ~170 pF, 5/9/2005

Results for AC charge transfer studies using a UV LED with observed power or ~11 **m**W at a center wavelength of 257.2 nm. The image on the left shows the UV test facility. The figure shows both charging and discharging over a proof mass potential of +/- 20 mV.

# UV LED vs. Mercury Lamp Based Charge Management System

| *Category* | *UV LED CMS* | *Mercury Lamp CMS* |
|---|---|---|
| Electrical Power Consumption | 1 W | 15 W |
| EMI | Minimal | Large due to RF excitation |
| Weight | 0.3 kg | 3.5 kg |
| Dimension of the CMS system | 10 cm x 8 cm x 3 cm | 17 cm x 13 cm x 17 cm |
| UV emission power | ~120 μW | ~100 μW |
| UV Power at the fiber tip | ~16 μW | ~11 μW |
| UV Wavelength, central | 257 nm | 194 nm & 254 nm |
| UV Wavelength, spread | 12.5 nm | Doppler Broadening |
| Fast modulation capability | Yes – Intensity, pulse train frequency and phase, etc. | No |
| Charge management method | AC & DC | DC only |
| Charge management frequency | Out-of signal band | In signal band |
| Equivalent dynamic range | 100,000 | 100 |
| Charge management resolution | high | low |
| Charge management speed | high | low |

# UV LED Lifetime Experiment



ILX laser Driver

Nitrogen Chamber

Modulation

HP Signal Generator

UV LED

UV diode

GPIB

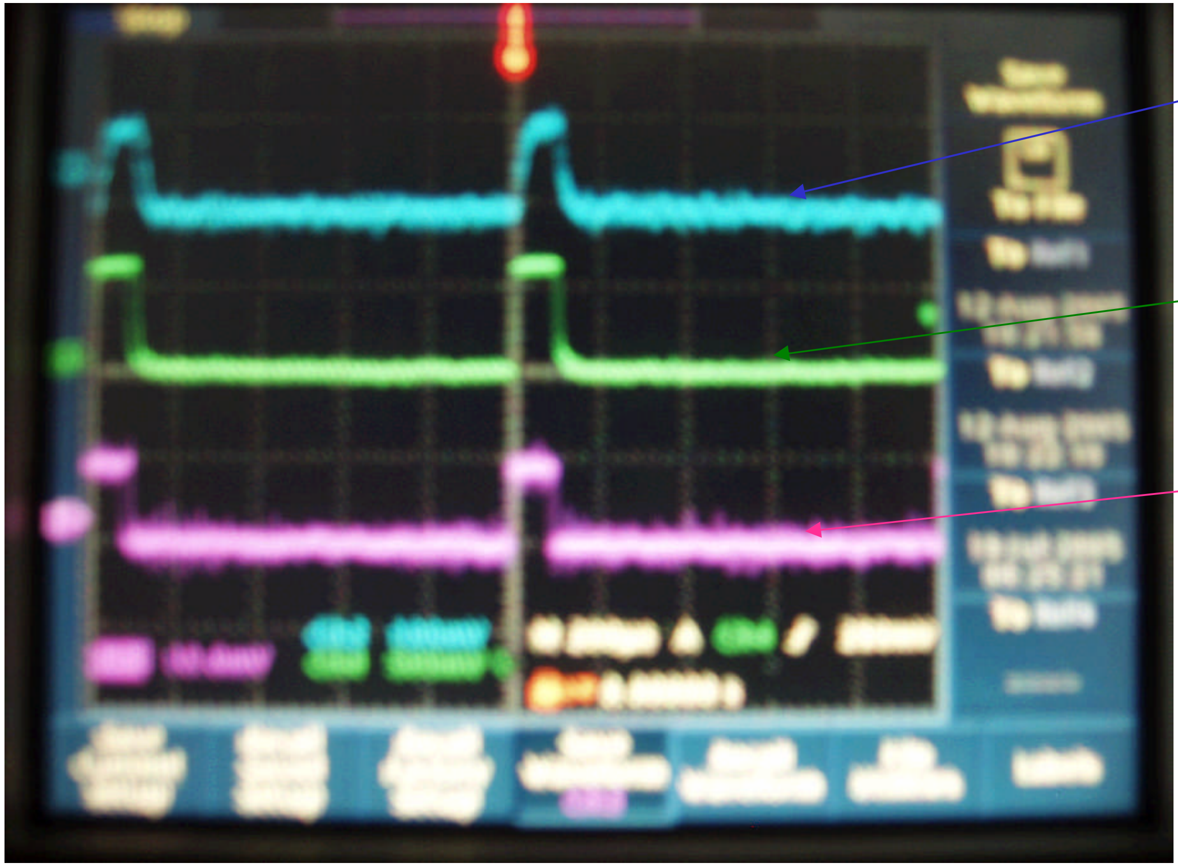
GPIB

Computer

Amp

Scope or Digitizer

# UV LED Modulation Direct Readout



Signal from UV Photodiode

UV LED driver voltage

Driving signal

# Continued Experiments at Stanford

- **UV LED lifetime measurement**
  - GaN is an intrinsically better radiation-hard material
  - Operate UV LED under realistic working conditions for AC charge management
  - Measure the output power level of UV LED over time
  - First step of space qualification

- **UV Photoelectron energy measurement**
  - Measure the kinetic energy of the photoelectrons
  - Deduce work function distribution on the proof mass surface
  - Provide surface analysis for contamination patches
  - Correlation to surface reflectivity for calibration of optical sensing

- **Science outreach students involvement**
  - Research opportunities provided to local high school students