15TH LISA SYMPOSIUM
LISA INSTRUMENTATION
JULY 8 – 12, 2024

APPARENT YIELD MEASUREMENTS USING A LISA-LIKE GRS AND THE UF TORSION PENDULUM

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MOTIVATION

ADDRESSING THE PROBLEM OF CHARGE BUILD-UP

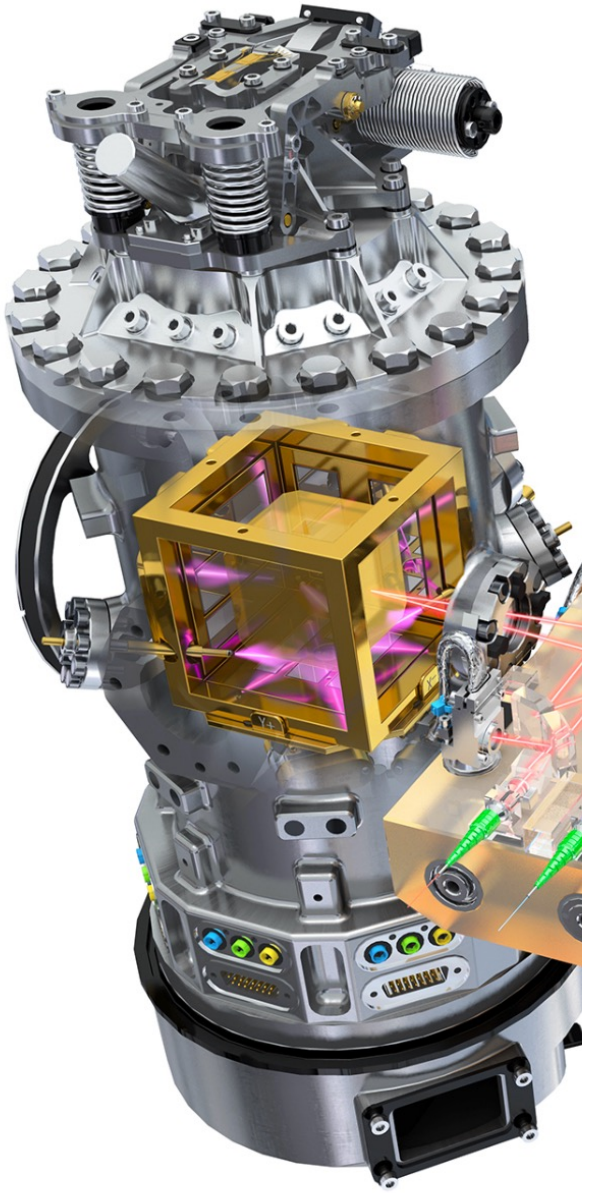
ISSUE OF CHARGE BUILD-UP

Necessity for Charge Management

- Test Mass (TM) accrues charge due to cosmic rays and solar energetic particles
- From LISA Pathfinder (LPF), daily charge rate is $\sim 25\ \mathrm{e/s}$
- LISA requires TM be kept within $\pm 70\ \mathrm{mV}$ (15 million e), roughly 2 weeks of charging from LPF observation
- Causes spurious electrostatic forces that spoil measurements

$$F_x \approx -\frac{q}{C_T}\left|\frac{\partial C_x}{\partial x}\right|\Delta_x$$

- Conclusion: a Charge Management System (CMS) is required

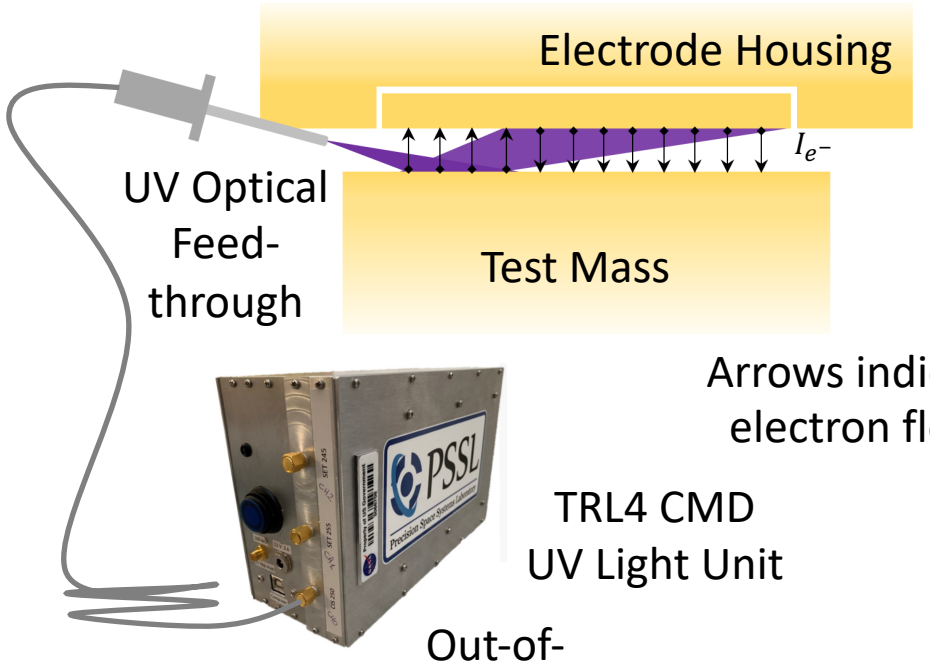


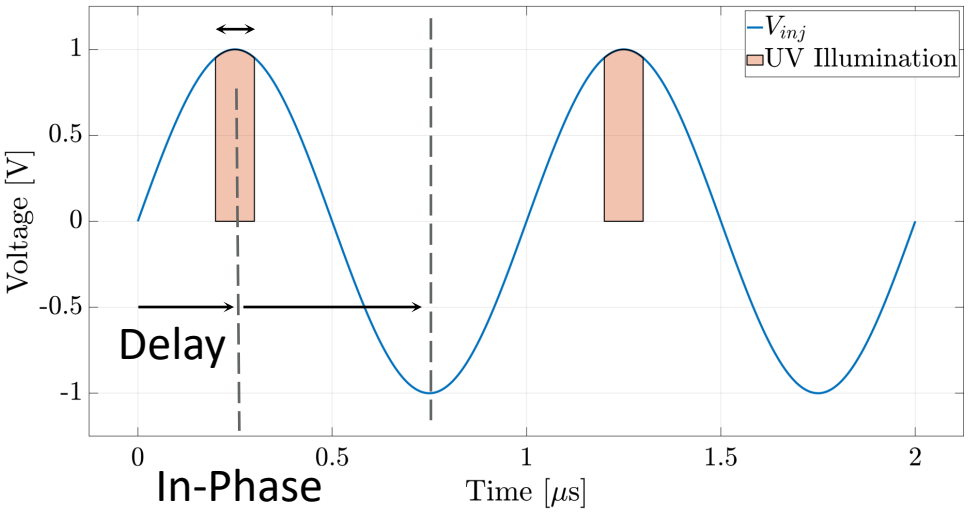
LPF Gravitational Reference Sensor (GRS)

UF CHARGE MANAGEMENT DEVICE

Contactless Charge Control

- Achieved through UV photoemission
- Pulsed UV light can be synchronized with injection signal
- Experimental demonstration of charge control with pulsed light synchronized to GRS capacitive sensing voltages
- LISA has 2 charge control schemes available: (1) ***DC*** and (2) ***pulsed***



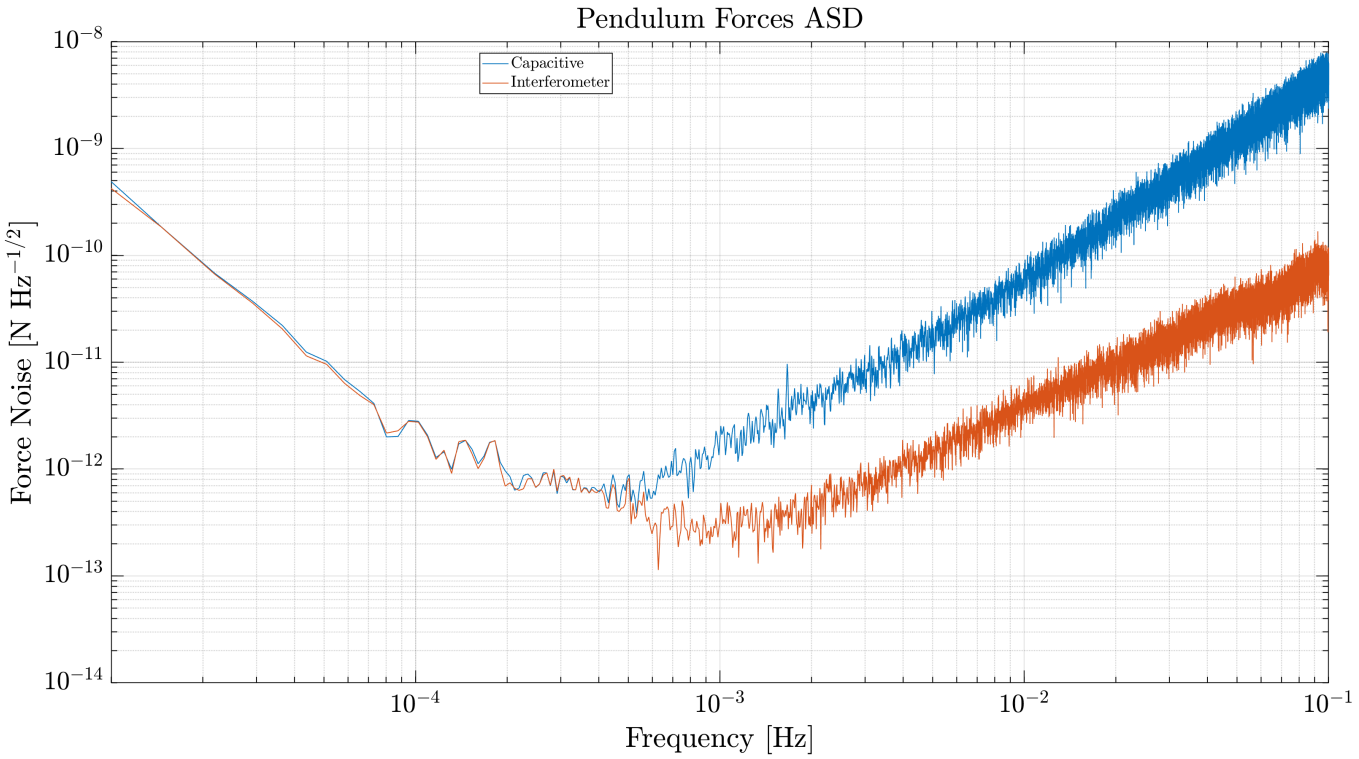


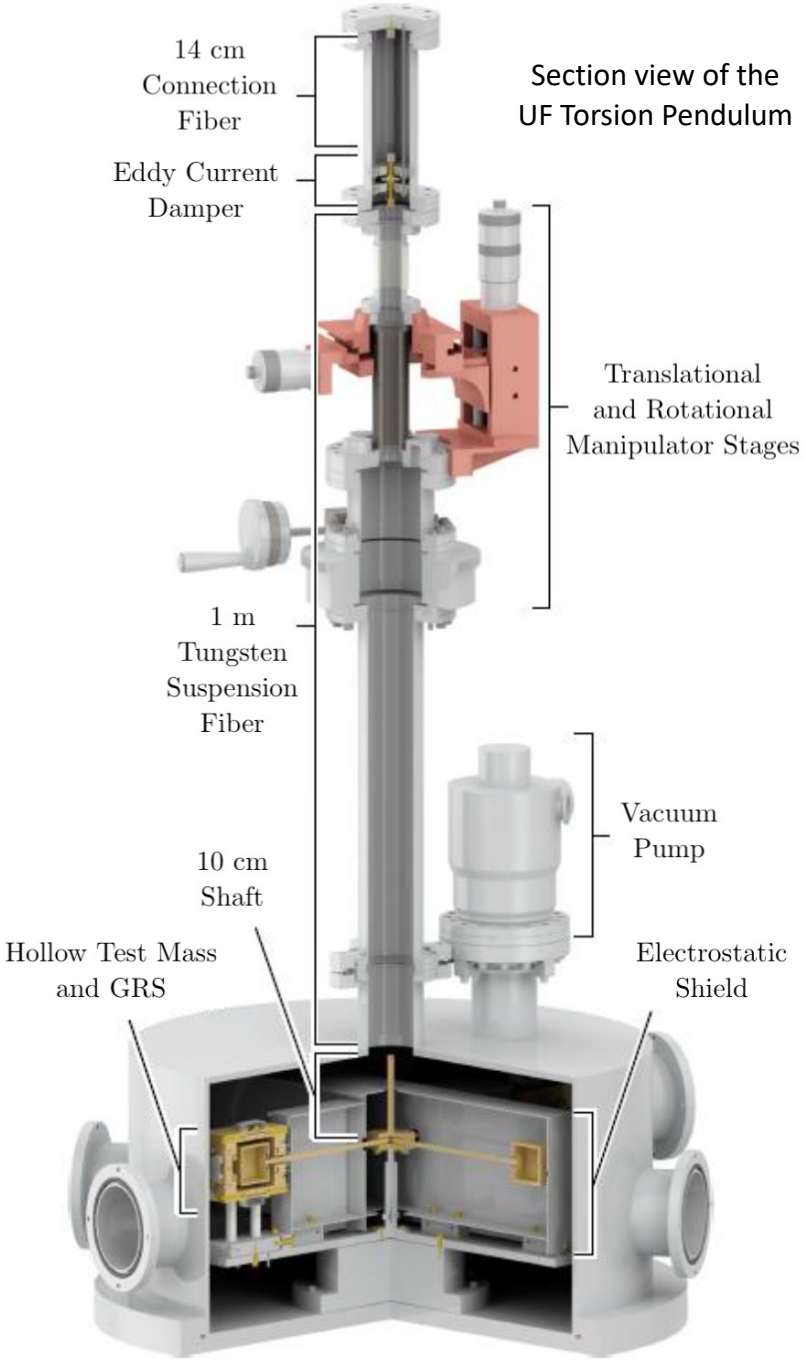
Paper highlight: S. M. Apple et al., *Measurement of stray electric fields in a capacitive inertial sensor using contactless test-mass charge modulation*, Phys. Rev. D **106**, L101101 (2022)

TESTBED BASICS

UF TORSION PENDULUM

- Decouples sensitive suspension rotation axis from Earth's gravity
- Current CMD at TRL6 development; TRL4 is fully integrated with the UF torsion pendulum



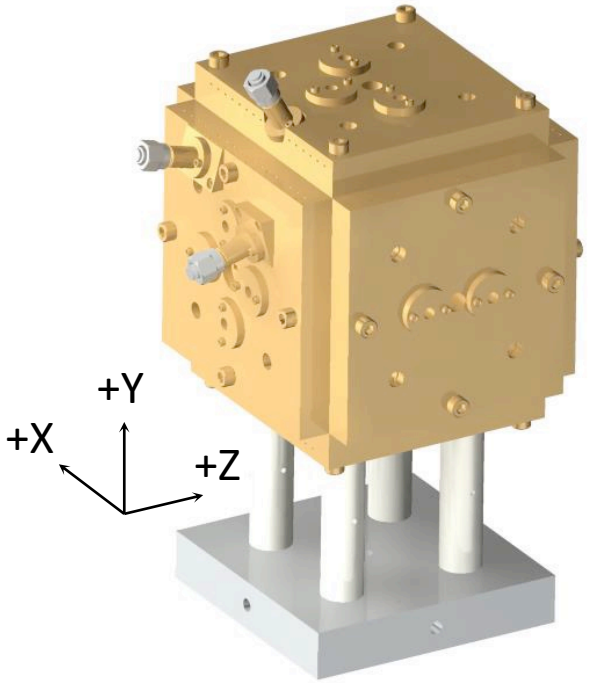


Section view of the UF Torsion Pendulum

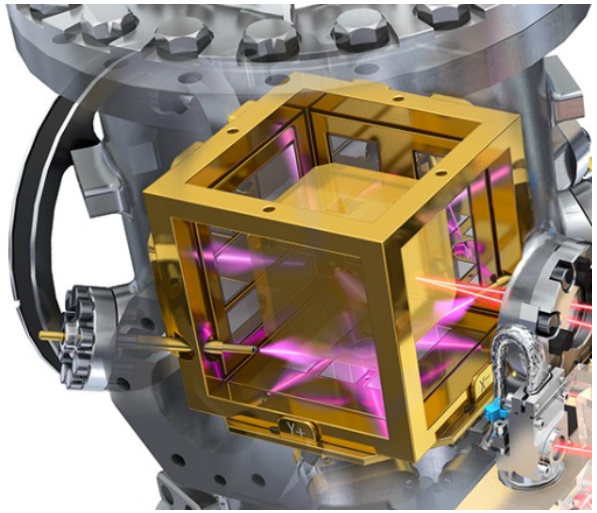
DIFFERENCES IN GRS GEOMETRY

UF GRS is LISA-Like

- Primary differences lie in Optical Feedthrough (OFT) angles and placements with respect to TM
- Light from LISA OFTs incident on TM; light from UF LISA-like OFTs incident on TM *and* electrodes
- Reasons for divergence: to explore pulse synchronization with applied voltages and for easier manufacturing



UF LISA-like GRS



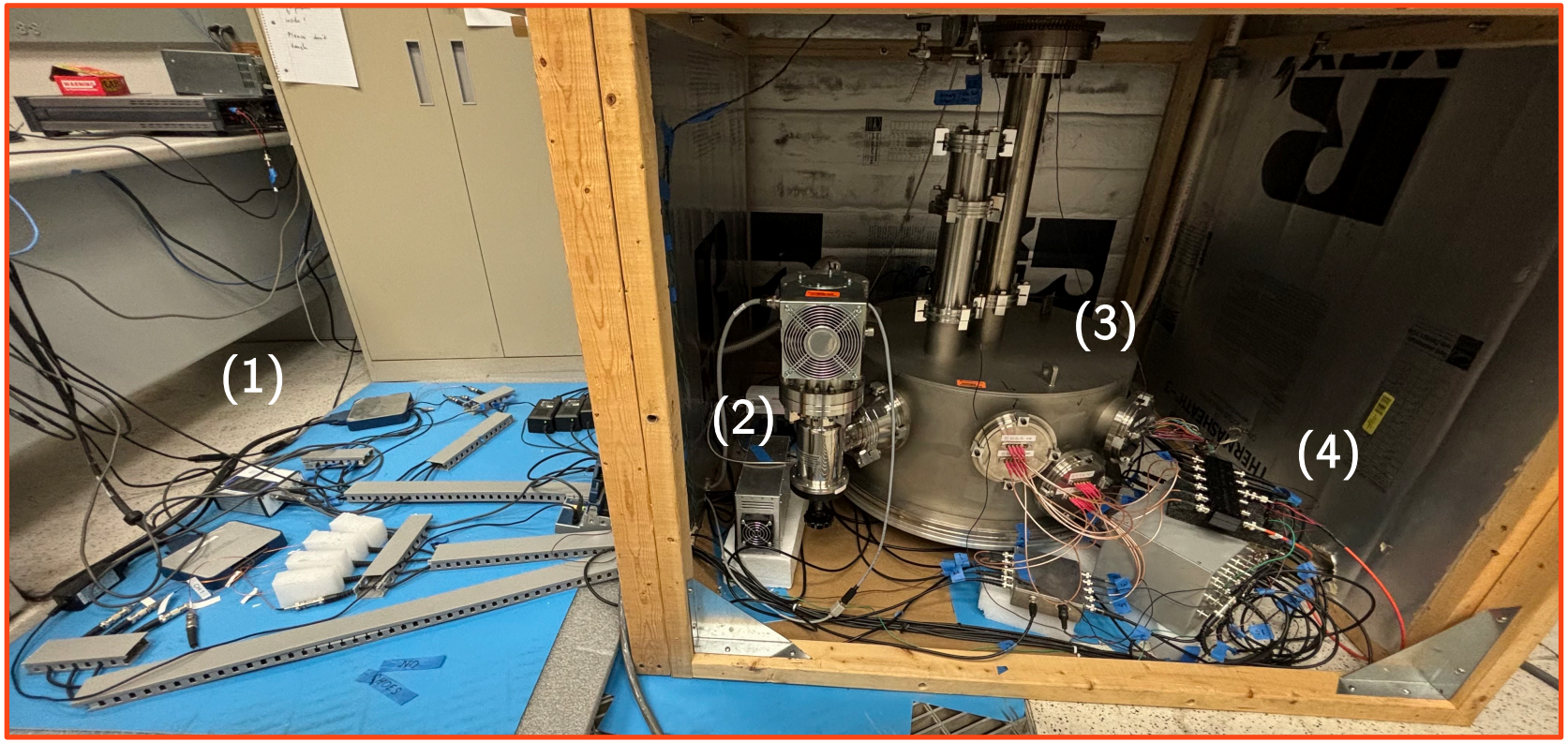
LISA GRS

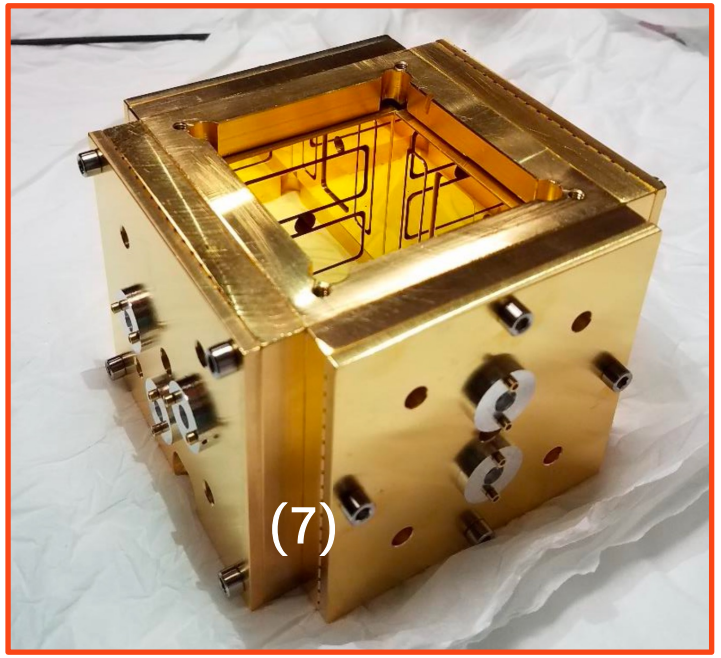
TESTBED HARDWARE

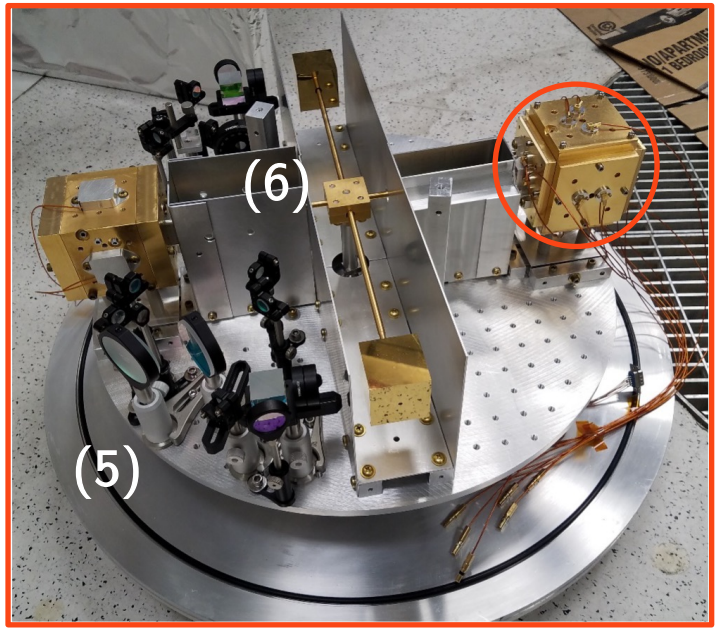
UF TORSION PENDULUM

Capable of full electrostatic actuation authority and capacitive sensing. Also outfitted with interferometric TM position readout.

1) Frontend readout electronics
2) TRL4 CMD ULU
3) Pendulum vacuum chamber
4) Capacitive electronics box
5) Interferometric readout
6) Pendulum crossbar arm
7) UF LISA-like GRS

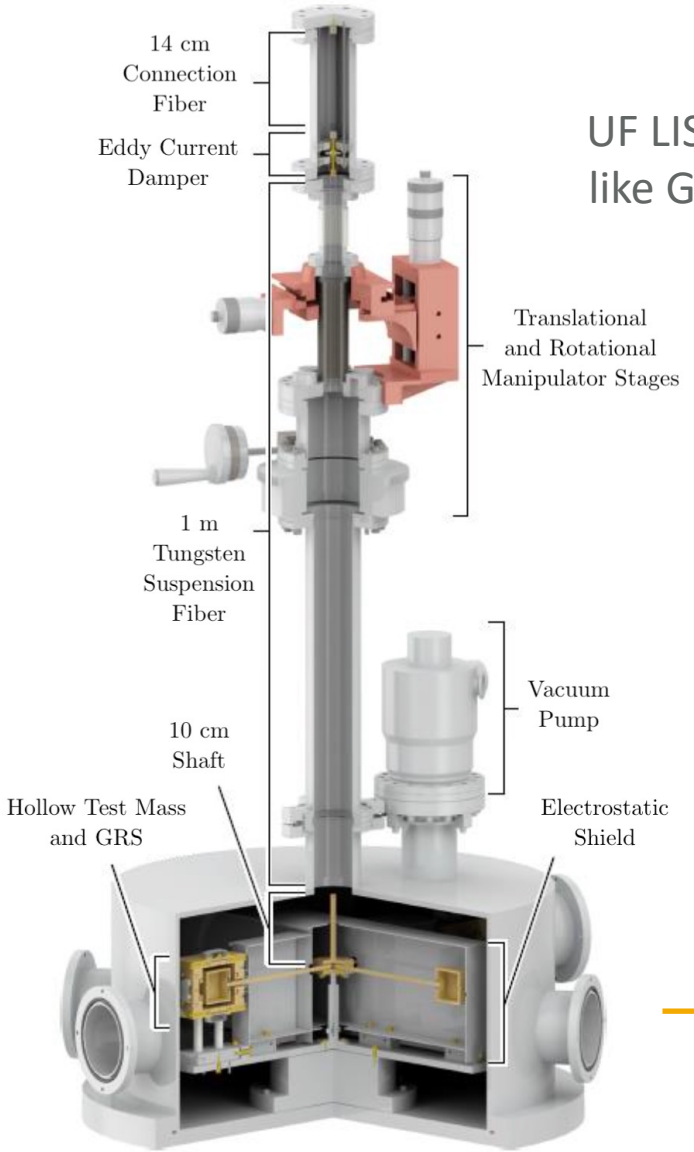




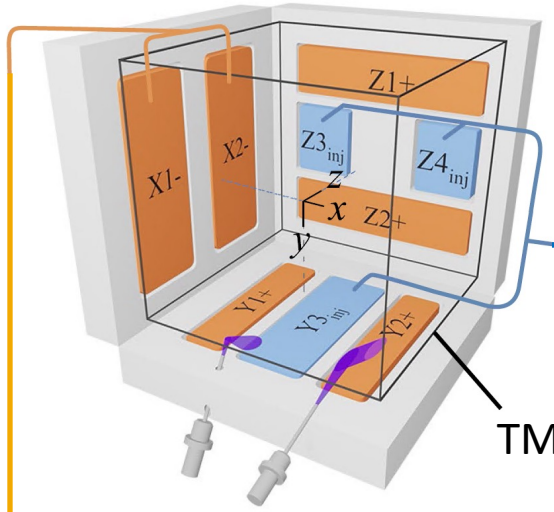


METHODOLOGY

APPARENT YIELD MEASUREMENT PIPELINE



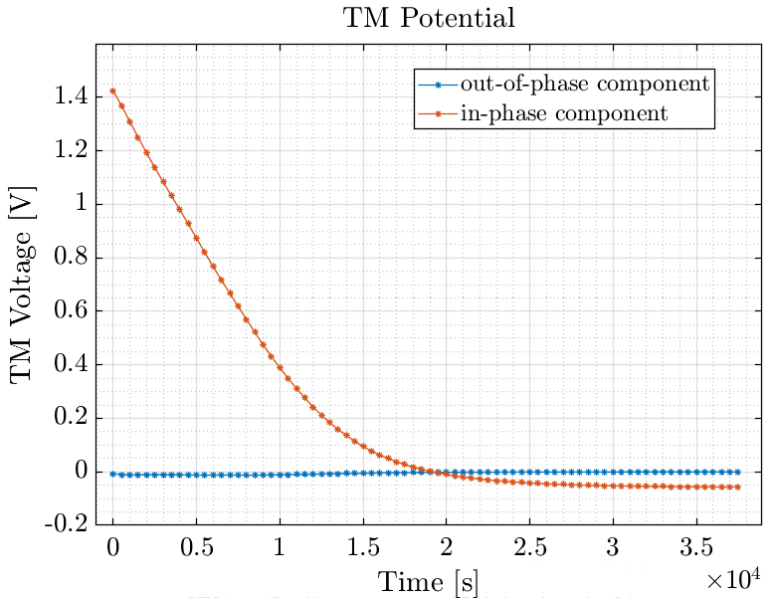
UF LISA-like GRS



$\varphi(t)$

$\varphi_{\mathrm{mod}}(t)$

$$F_{\mathrm{mod}} = 2r_{\mathrm{arm}}\frac{\partial C}{\partial x}V_{\mathrm{mod}}V_{\mathrm{TM}}$$



Charge measurement signal

$$4V_{\mathrm{mod}}\sin(2\pi f_{\mathrm{mod}}t)$$

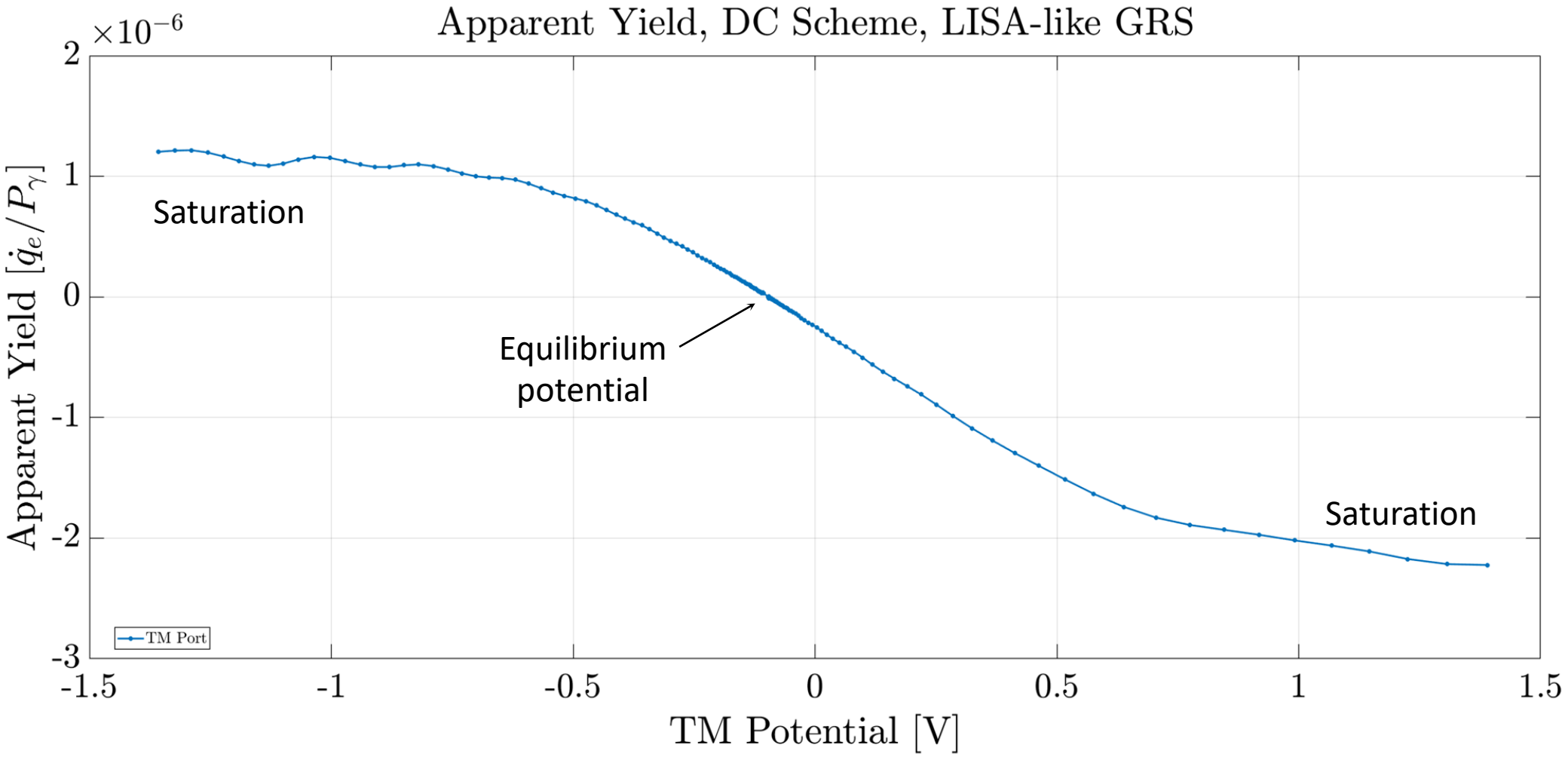
Net discharge rate characterized by the Apparent Yield (AY):

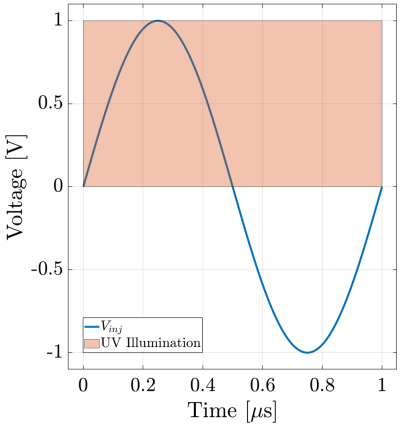
$$AY = \frac{\#\ \mathrm{e\ charges/s}}{\#\ \mathrm{photons/s}} = \frac{\dot{q}_e}{P_\gamma} = \frac{\lambda}{eP_{UV}hc}C_T\dot{V}_{TM}$$

RESULTS
FOR CONTINUOUS AND PULSED CHARGE SCHEMES

APPARENT YIELD MEASUREMENTS

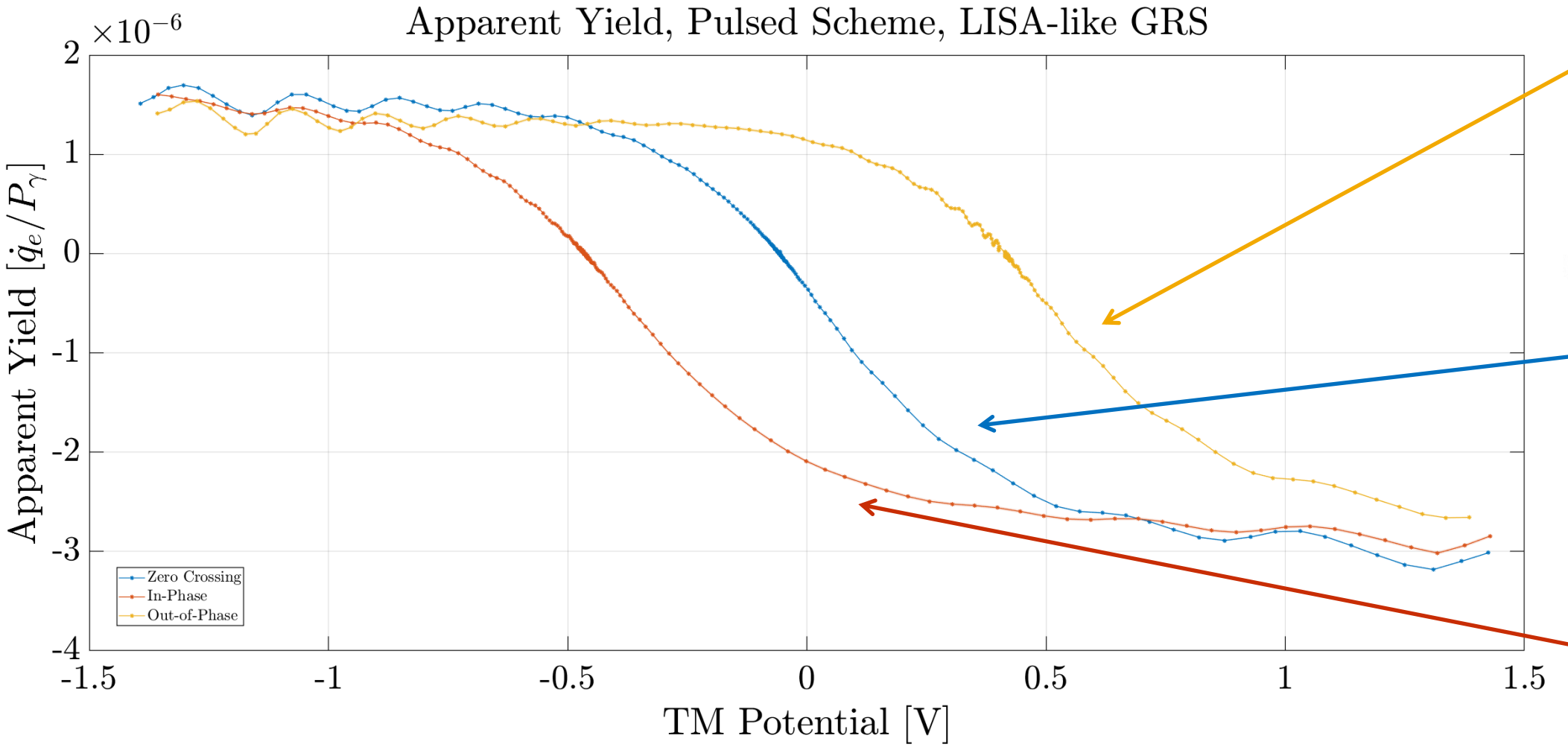
DC SCHEME: TEST MASS OFT

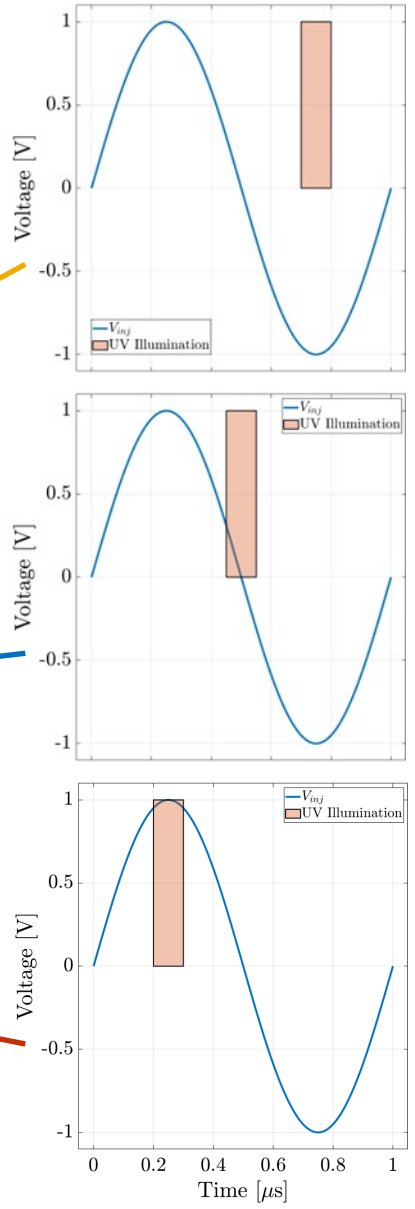




Phase of UV light with respect to injection signal. DC scheme uses 100% duty cycle

PULSED SCHEME: TEST MASS OFT

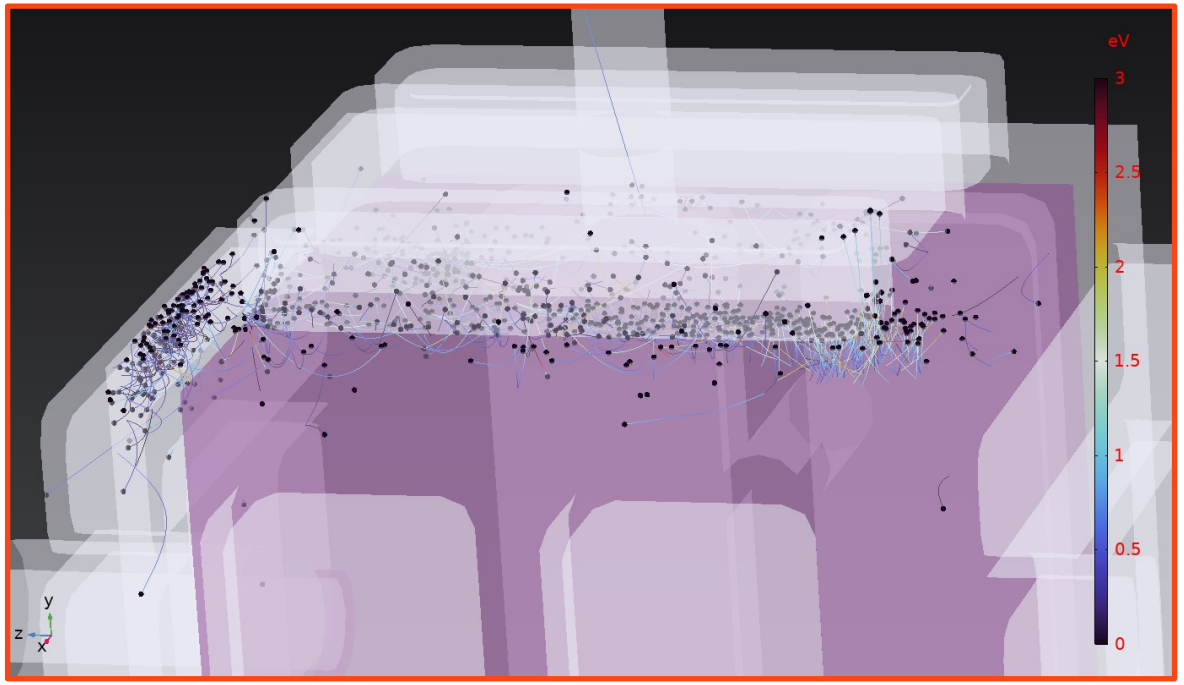




POSTER *140* HIGHLIGHT: BRIJ PATEL

Apparent Yield Curve Modeling

- Model charge management process in its entirety
- Electrostatics computed wit UV light injected and traced inside GRS
- Resulting photoelectron current flow used to calculate AY model
- Model parameters estimated by fitting to experimental data



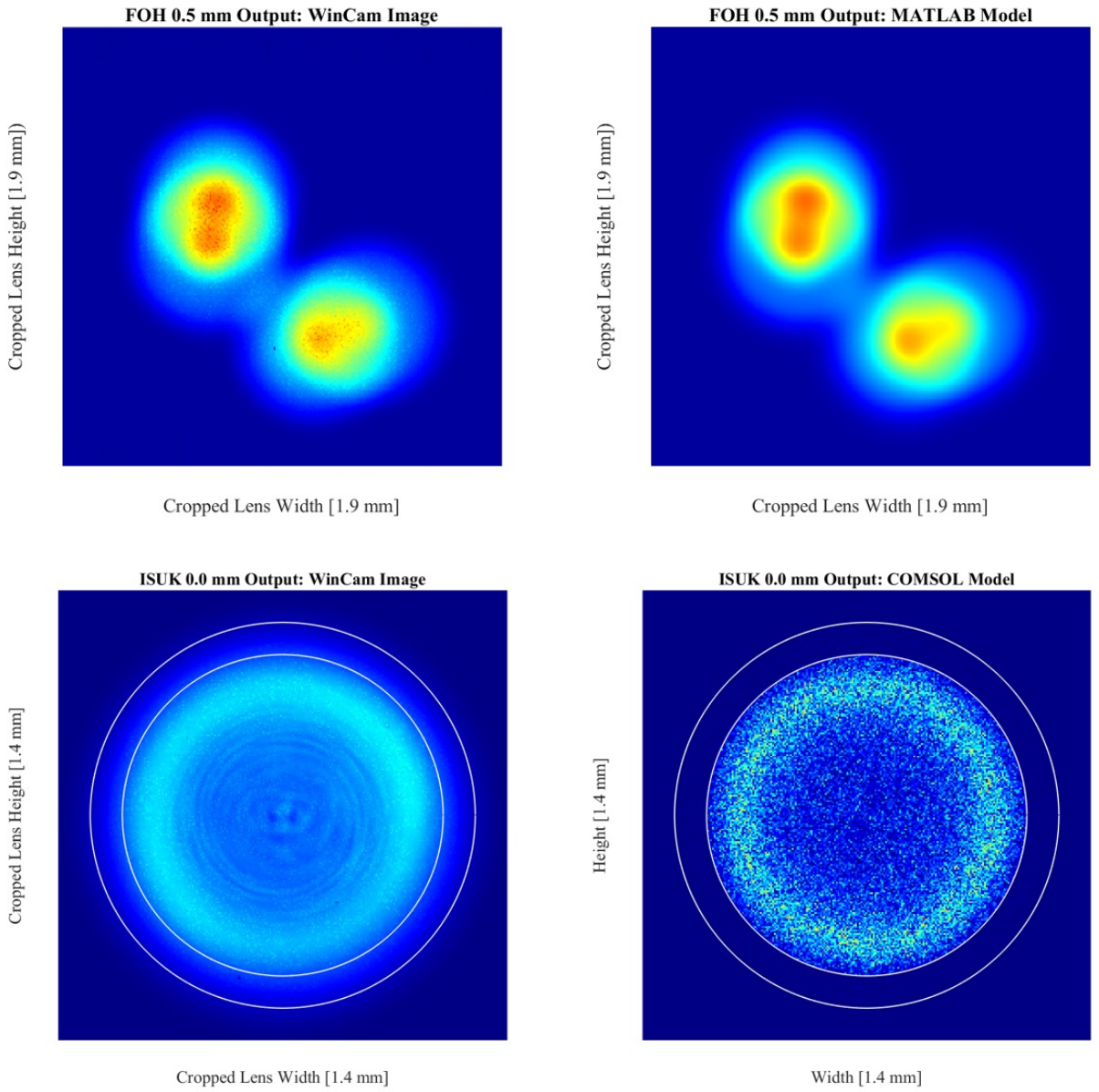
COMSOL simulation of photoelectron trajectories

ADJACENT WORK

POSTER *143* HIGHLIGHT: COREY RICHARDSON

Exit UV Light Characterization

- Simulate UV light beam profile exiting Fiber Optic Harness (FOH) & OFT that interacts with TM
- Light sim output serves as input for photoelectric charge management sim
- MATLAB generates ray distribution, COMSOL propagates model, model then compared with WinCam images of FOH and OFT



WinCam images at FOH and OFT exits

Goal: Characterize UV Light Discharge Behavior

- Apparent yield is ratio of TM charge rate and injected UV power
- UF CMD: non-contact UV photoelectric charge management system
- Demonstrate charge manipulation using only synchronized pulsed light phase variation
- AY curves of different charge schemes allow for better understanding of charge behavior

Adjacent Work: Posters *140* & *143*

- Modeling apparent yield curves: *End-to-end multiphysics simulation of photoelectric charge management for free-falling test masses*
- Simulation and experimental confirmation of exit UV light from OFT and FOH: *Characterization of LISA Fiber Optic Harness*

GRATTIS

- Simplified GRS technology demonstration: *Gravitational Reference Advanced Technology Test in Space (GRATTIS)*
- Combines improved electrostatic GRS performance inspired by the LISA GRS with easier manufactured componentry
- Intended for use in future Earth geodesy missions

QUESTIONS?

THANK YOU FOR YOUR ATTENTION

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