Charging Overview

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Charging Working Group

LSC/Virgo Meeting
Amsterdam
September 25, 2008

G080448-00-R

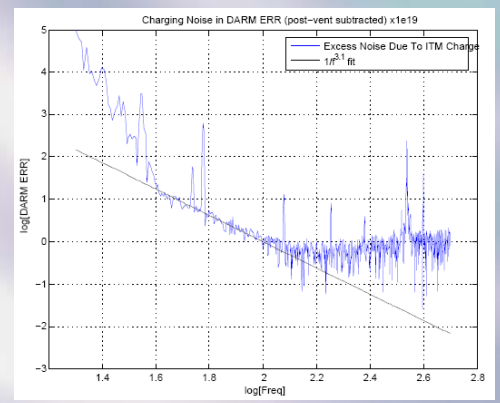
Markov Theory of Gaussian Noise

$$S_F(f) \approx 2 \langle F^2 \rangle / (\pi \tau (1/\tau^2 + (2 \pi f)^2)$$

$$\langle F^2 \rangle = Q^2/(4 d^2)$$

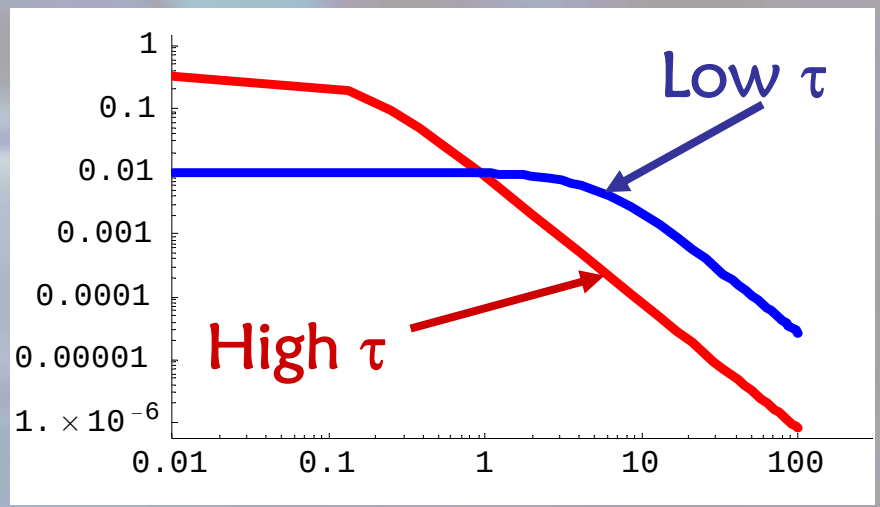
February 2006 LLO Event

- ITMy hits earthquake stop
- Low frequency noise $\sim f^{-3}$



Charge Noise Observed at LLO

Force Noise Level



For $f > 1/(2 \pi \tau)$

amplitude noise $\sim f^3$

Possible Mitigation Strategies

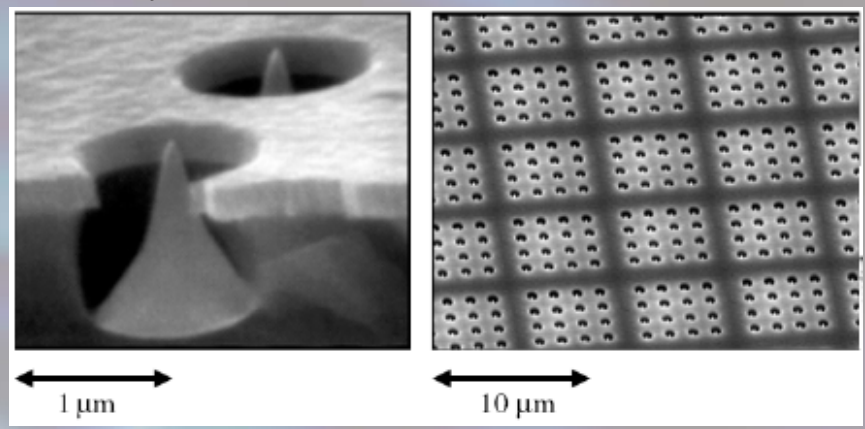
Ultraviolet Light

- Directly applied to optic
- Indirectly used to liberate charge from nearby surfaces

Ion Gun

- Shoot low energy ions near optic

Spindt Cathode Ion Source



Viton Tipped Earthquake Stop

Choice of Materials

- Silica-tipped earthquake stops
- Carbon nanotube First Contact
- Conducting coatings/surfaces

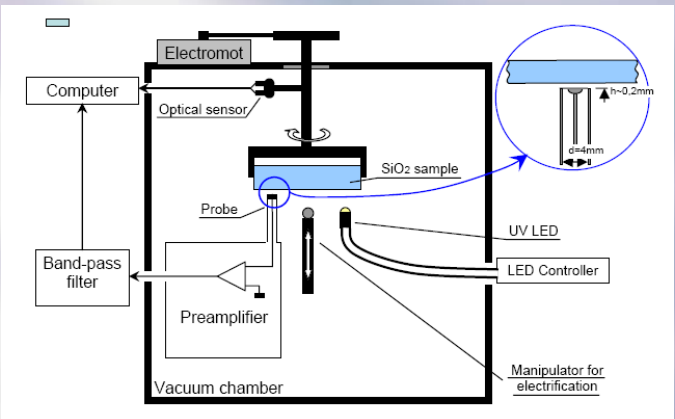
Progress on Parameter Measuring

Correlation Time τ

- Dirty Optic – Trinity
  170 days (1.5 10^6 s)
- Clean Optic - MSU
  at least 8000 hours (2.9 10^7 s)

Distance d

- ESD – 3 mm?
- Earthquake Stop Shaft – 4 mm
- Earthquake Stop Tip – 0.5 mm

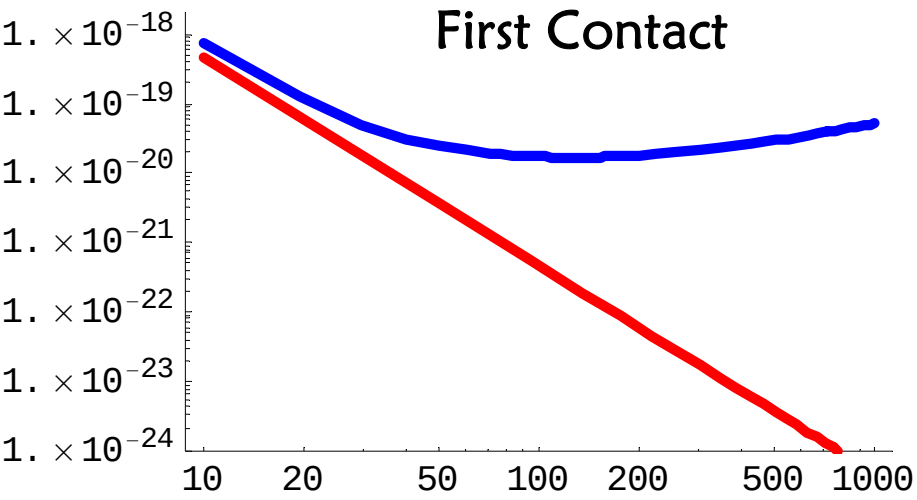


Charging Q

- Viton contact – MSU
  at least 5 10^8 e^- in 5 mm contact circle
- Silica contact – MSU
  5 10^6 e^- in 5 mm contact circle
- Dust friction – MSU
  ~ 10^5 e^-/cm^2 (10^{-14} C/cm^2)
- First Contact – MSU, Trinity
  Regular: at least 10^9 e^-/cm^2
  Carbon Nanotube: 10^8–10^9 e^-/cm^2

Moscow Experiment

Adv LIGO Noise from First Contact

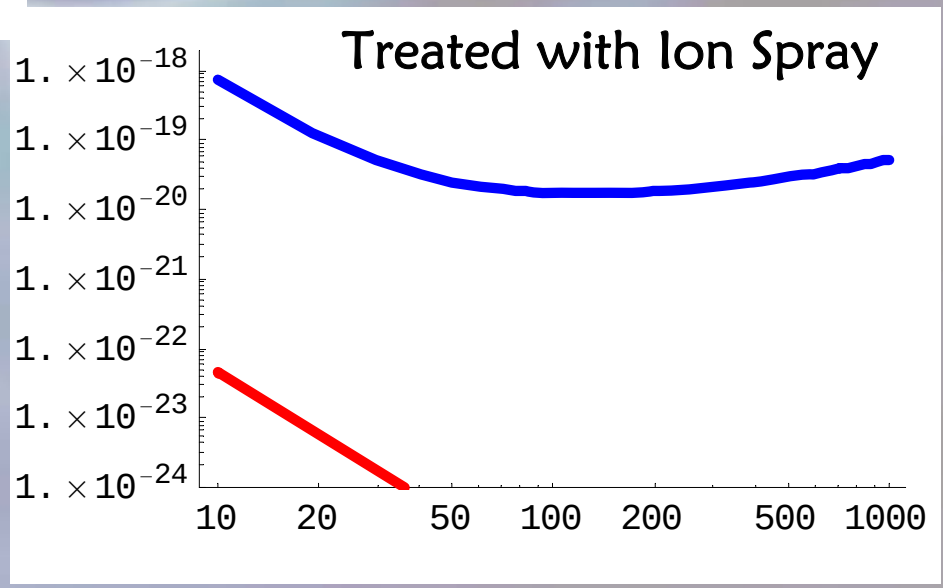


Carbon Nanotubes

- Q/A = 10^{-11} C/cm^2
- d =4 mm
- $\tau = 2.9\ 10^7$ s

After Ion Spray

- Q/A = 10^{-14} C/cm^2
- d =4 mm
- $\tau = 2.9\ 10^7$ s



AdvLIGO Noise Scenarios

Contact with Silica Earthquake Stop

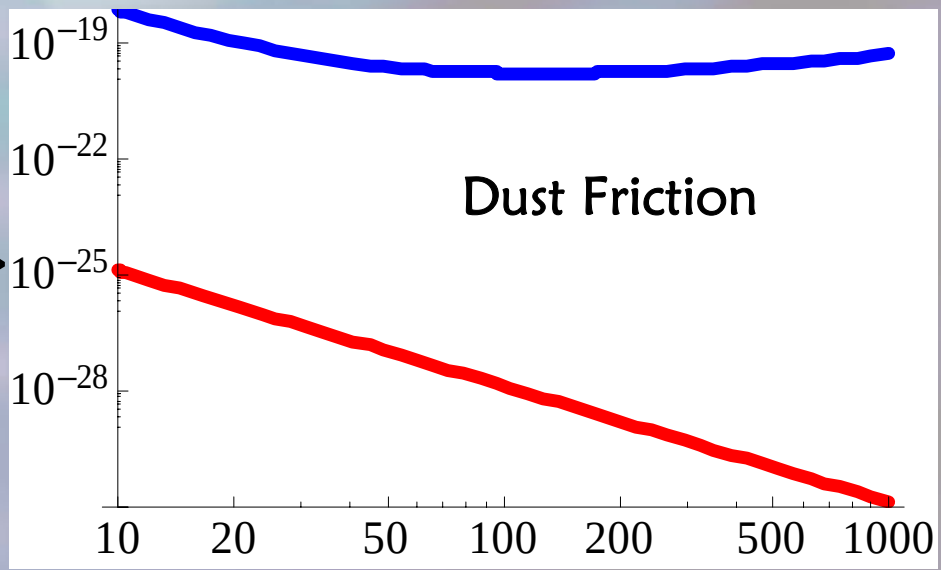
10^4 below expected sensitivity at 100 Hz

Charging from Cosmic Rays

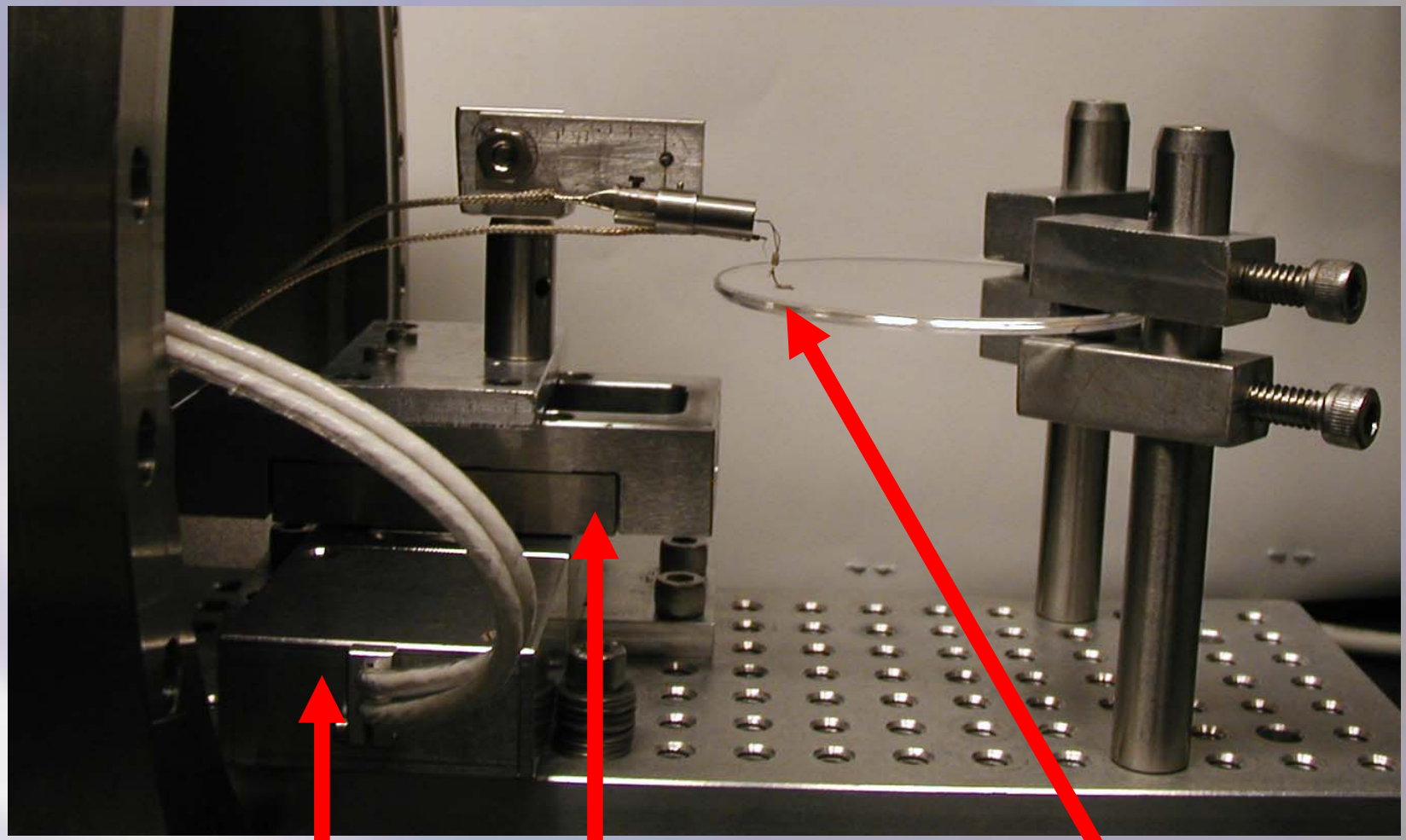
10^{16} below expected sensitivity at 100 Hz

Friction with Dust

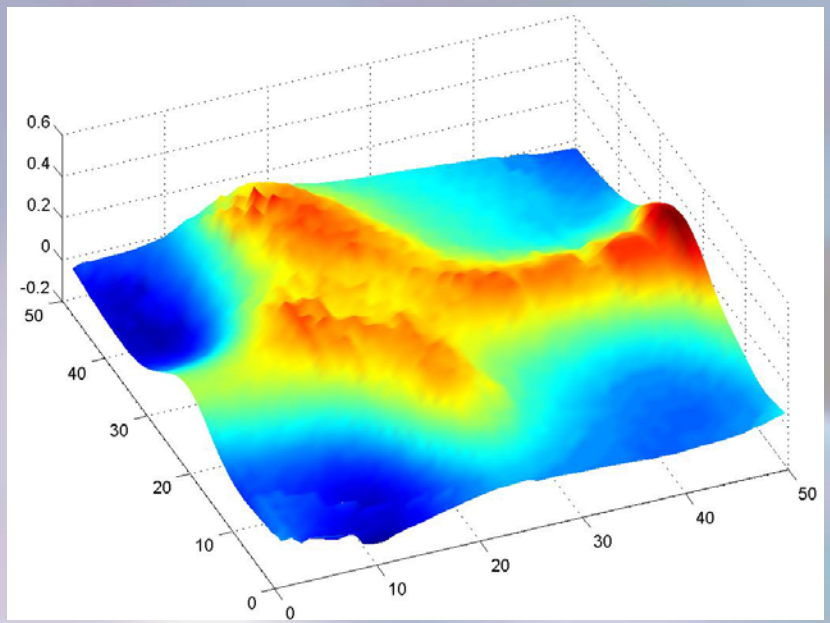
- $Q/A = 10^{-14}$ C/cm^2
- d= 4 mm
- t =1.5 10^6 s



Two-Dimensional Charge Mapping Setup at Trinity



Recent Results from Trinity



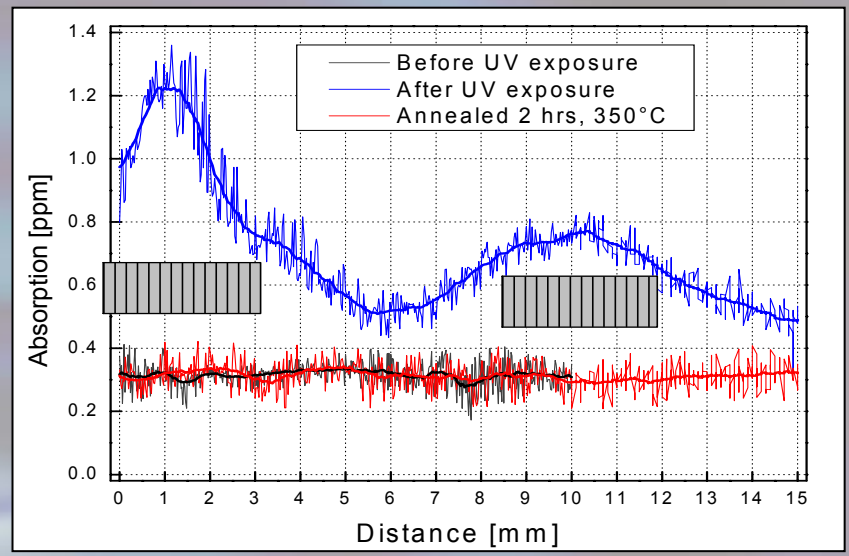
Positive Charging
From Viton

- Positive and negative charge on same sample
  - Ethanol wash - negative
  - Viton - positive "cross"
- UV removes only positive
- Successive applications of viton $\Rightarrow$ smaller time constants
  - Conductive film left?
- Carbon Nanotube First Contact leaves $\sim 2 \times 10^8$ e^-/cm^2
  - Improvement; still troubling
- Plan to investigate τ vs surface conditions

Stanford Status and Plans

Mitigation with UV

- Annealing repairs UV damage to coating (2 hours /350° C)
- First Contact partially shields coating from UV



Seismic noise coupling through charged stop

- Must be < 10^{-6} C/m^2 on stop tip to avoid excess noise
- Plans to investigate conductive coating

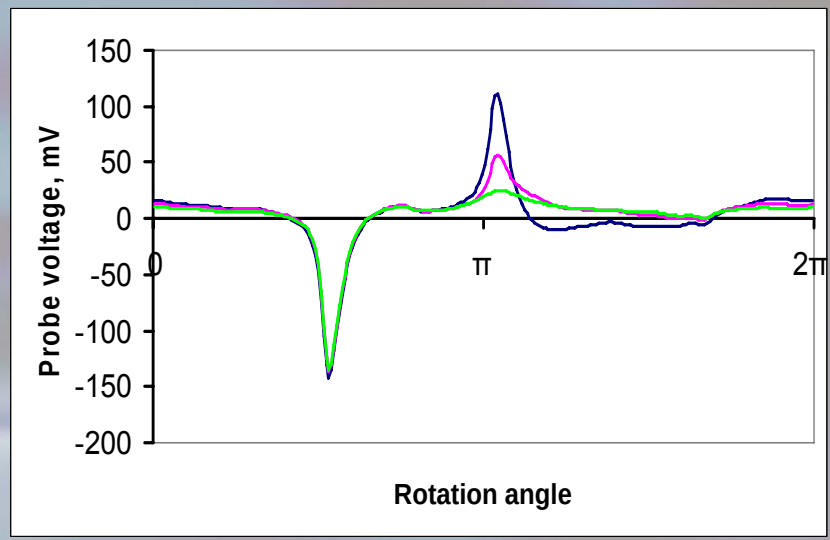
Conductive Coating

- ~ GΩ/sq sufficient
- Could move charge away from coating to allow UV to act
- Plan to study materials

Recent Results at Moscow

- UV mitigation of positive charge
  - $\lambda = 265$ nm
  - Intensity ~ 20 μW/cm^2
  - Negative charge responds but nearby positive increases
  - $|Q| < 10^6$ e^-/cm^2, charge increases with UV
- Friction charge from pumpdown dust
  - No more than 10^5 e^-/cm^2
  - Outgassing may play a role

UV Mitigation of Positive Charge

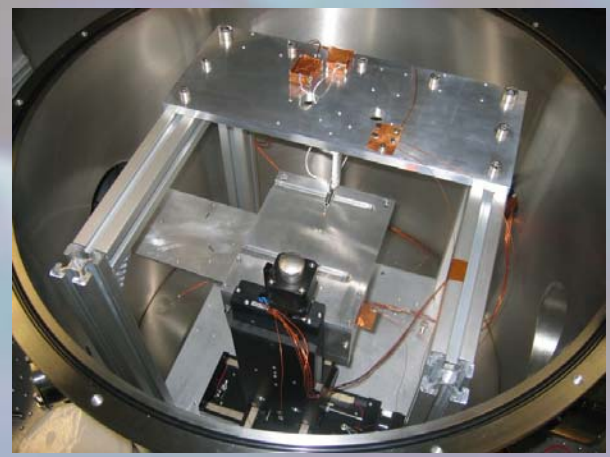


- Carbon Nanotube First Contact received
  - Check Trinity result
  - Some question of First Contact type at Trinity

Glasgow Status

A Kelvin probe experimental chamber has been commissioned, including:

- a 3-axis manipulation stage with +/-50mm travel
- a Besocke Delta Phi Kelvin probe (identical to Trinity University)
- a sample loading chamber to minimise pumping downtime
- the possibility of UV discharge and electron irradiation

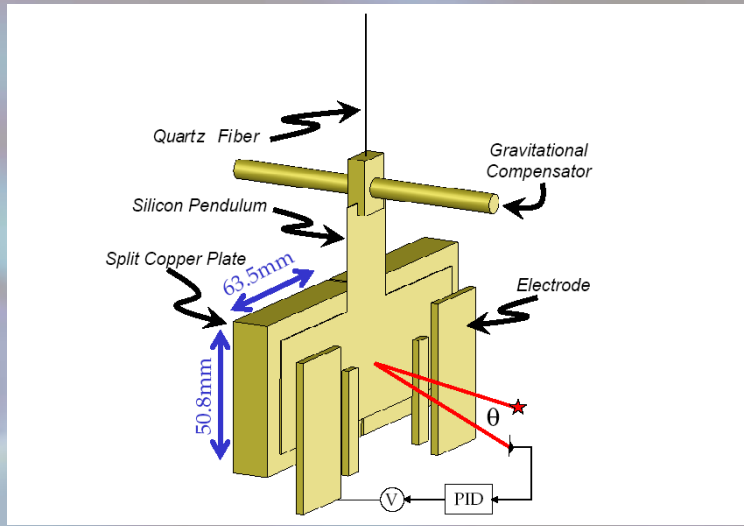


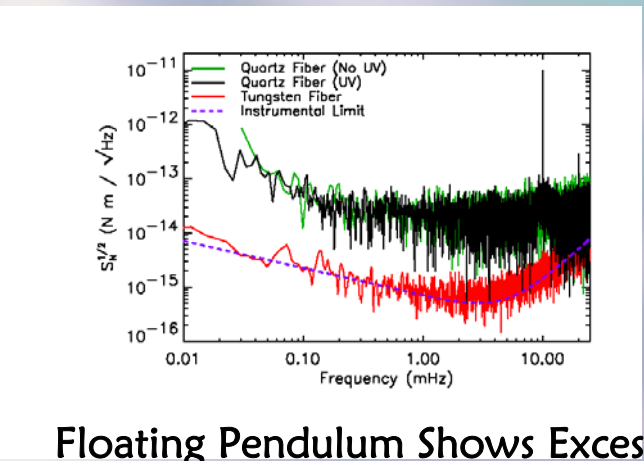
- we plan to study the effect of τ on sample cleanliness
- the surface conductivity of different varieties of FirstContact
- the force noise due to charge distributions using a torsion balance in the same vacuum tank

Plans for Direct Measurement

- UWashington torsional pendulum to directly measure charge noise
- Noise vs earthquake stop separation
  - vs charge amount
  - vs silica cleanliness
- Observe in vacuum noise improvement with UV

Torsional Pendulum



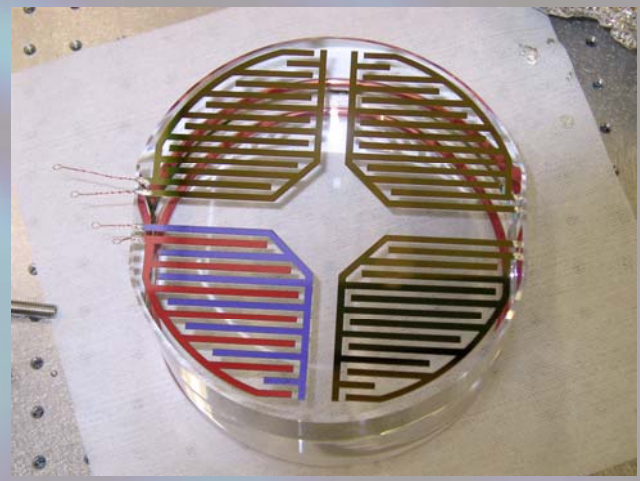


Floating Pendulum Shows Excess Noise

- Build on LISA experience
- Minimal changes needed to apparatus
- UWashington plans to apply for LSC membership in December

Modeling and Theory Needs

- Modeling: Finite Element and Analytical
  - Electro-static drive
    - actuation, gold coating, calibration, dynamic range, etc.
  - GEO ESD charging event
  - DC forces, engineering concerns
  - Cosmic ray charging – GEANT?

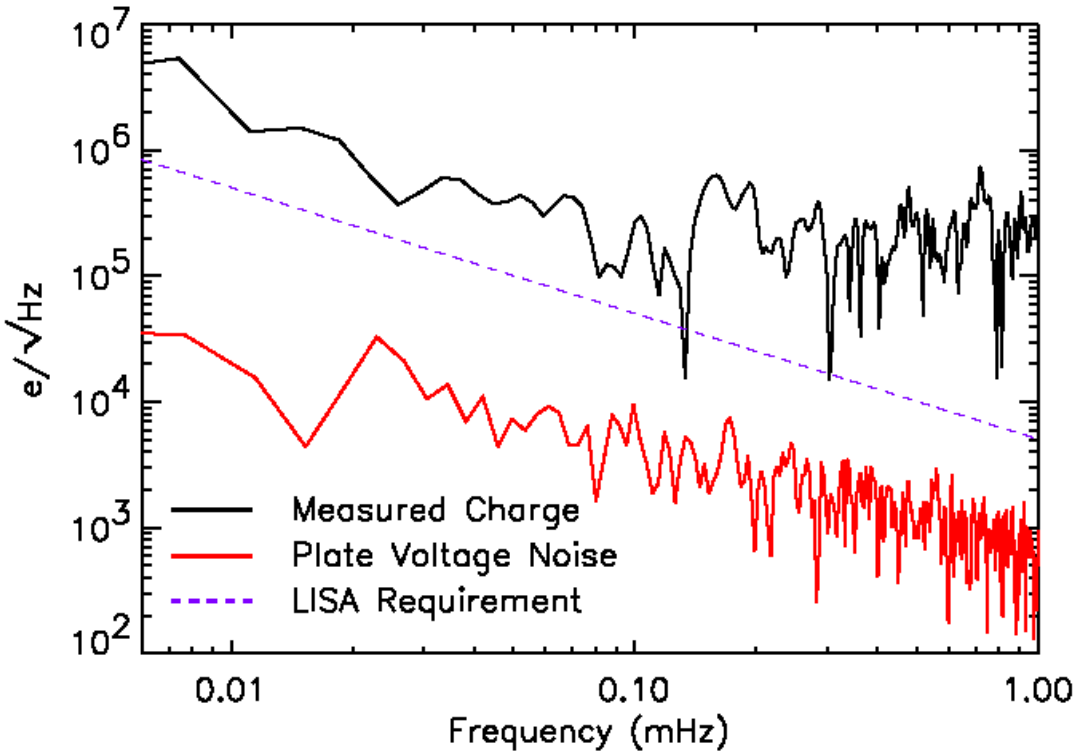


- Theoretical work – under consideration at UTexas Brownsville (Rakhmanov)
  - Two charged dielectrics in Markov model
  - Moving ground planes in Markov model
  - Noise from dipole charges
  - Color centers effects on charging and discharging

Future Experimental Plans

- Further study of parameters
  - Charging from dust friction
  - Charging from removal of First Contact
  - Charging from contact with ESD (as happened in GEO)
  - Relationship of cleanliness with correlation time
- Measurement of noise from charging
  - UWash, ANU?, TNI?, LASTI?
- Cleanliness studies
  - Can First Contact charge be removed in a clean way?
- Further Development of mitigation techniques
  - Indirect UV
  - Conductive coatings
  - Ion gun
- Study non-Gaussian noise including cosmic rays

Backup

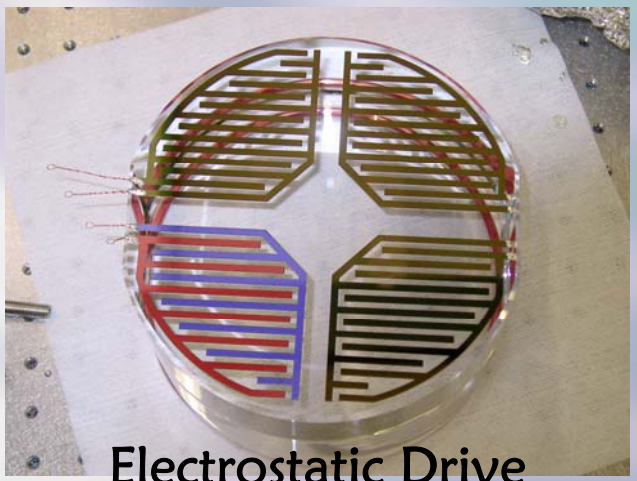

10^7
10^6
10^5
10^4
10^3
10^2
e/√Hz
Measured Charge
Plate Voltage Noise
LISA Requirement
0.01
0.10
1.00
Frequency (mHz)

Other Charging Issues

Potential Problems

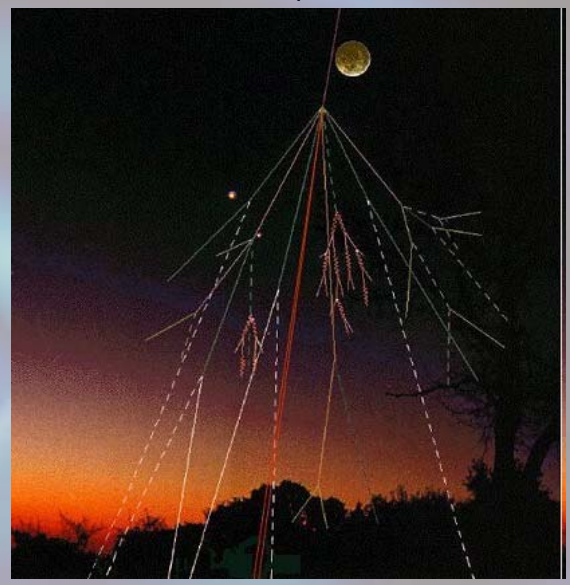
Direct coupling to noisy environment
- SUS Support Structure
- Environmental electric fields

Non-Gaussian Noise
- Cosmic Rays
- Other Charging Events
- Charge Motions



Electrostatic Drive

Cosmic Ray Shower



Interactions with Electrostatic Drive
- Noise
- Effects on Actuation

More Complexity in Gaussian Noise
- Dipoles
- Two Dielectric Surfaces