Three Years of Charging Research at Trinity University

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MIT LIGO Seminar
June 27, 2008

The Surface Charge Problem

- Surface charge may build up on test masses
- Sources of charge buildup
  - » Mechanical contact with other materials (earthquake stops)
  - » Cosmic rays – Braginsky *et al.,* Phys. Lett. **A350**, 1-4 (2006)
  - » Friction with dust molecules during pumpdown (not yet measured)
- Potential concerns
  - » Electric fields can interfere with positioning control
  - » Motion can be source of low-frequency suspension noise
  - » Dust may be attracted/held to optic surface, increasing absorption

What We Know/Don't Know

What we know:

- Optics experience drifts of ~10^5 e^-/cm^2/month
  - » Mitrofanov *et al., Phys. Lett.* **A300**, 370 (2002).
- Negligible effects on mechanical Q
  - » Mortonson *et al., Rev. Sci. Inst.* **74**, 4840 (2003).

What we don't know:

- The correlation time for charge mobility, which affects force as:

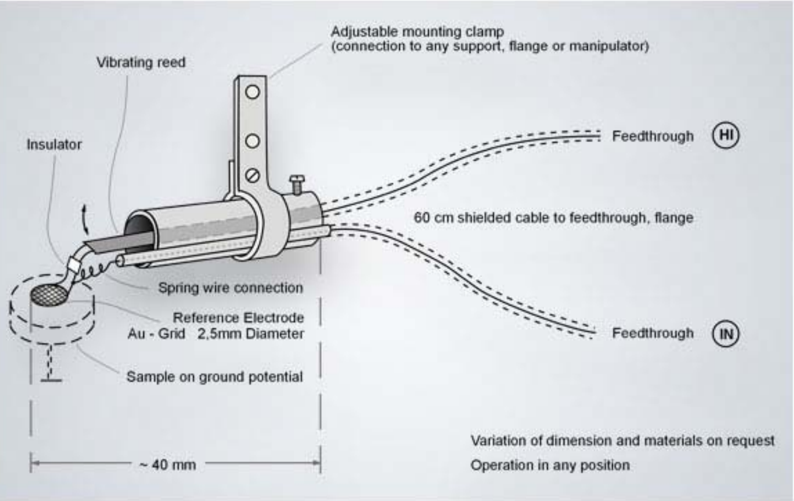
$$F^2(f) = \frac{2\langle F^2 \rangle}{\pi\tau_0\left[\frac{1}{\tau_0^2} + (2\pi f)^2\right]} \approx \frac{2\langle F^2 \rangle}{\pi\tau_0 (2\pi f)^2}$$

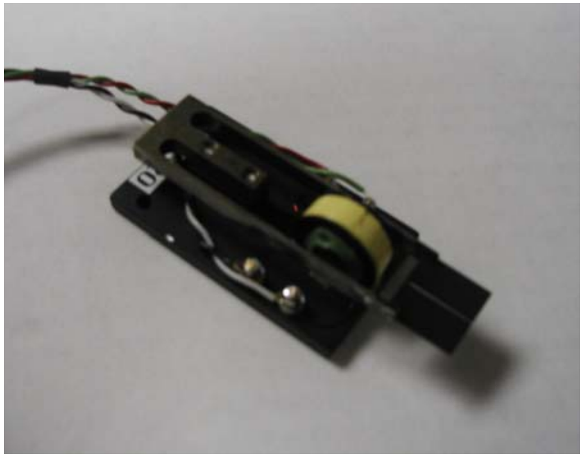
(R. Weiss, LIGO-T960137-00-E)

- The effectiveness of charge reduction techniques
  - Conducting ionic coating
  - UV light
  - Conducting test mass shield
  - Electron/positive ion gun

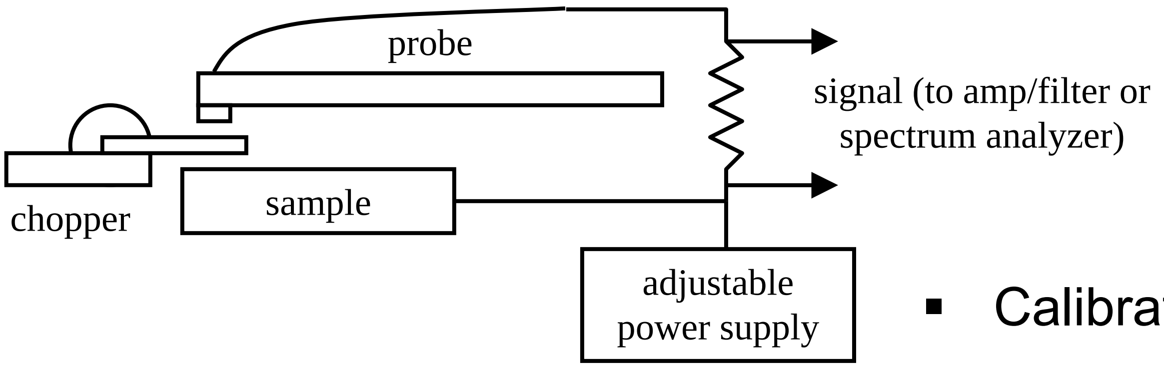
The Kelvin Probe

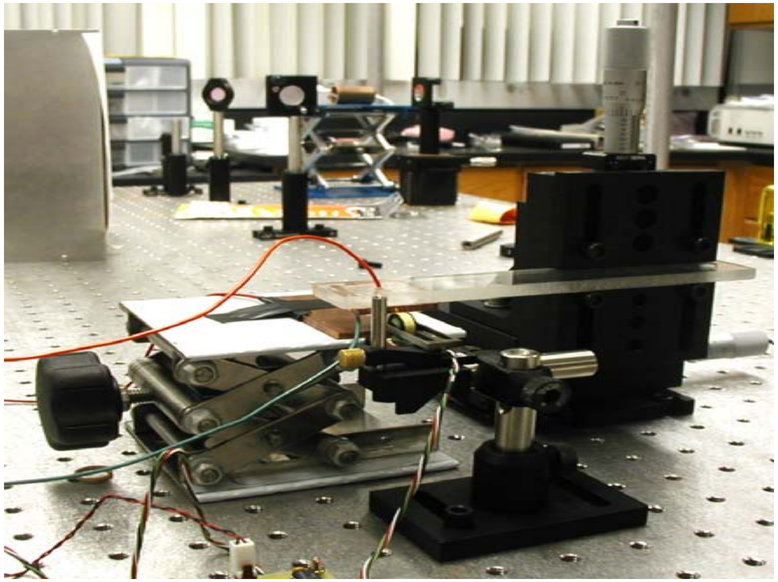
- We need a charge sensor that is small, vacuum-compatible, and inexpensive
- The Kelvin probe measures the contact potential difference between the probe and sample
- Commercial probes modulate the difference by vibrating the probe tip by PZT or voice coil -- expensive
- Instead, modulate difference with optical chopper





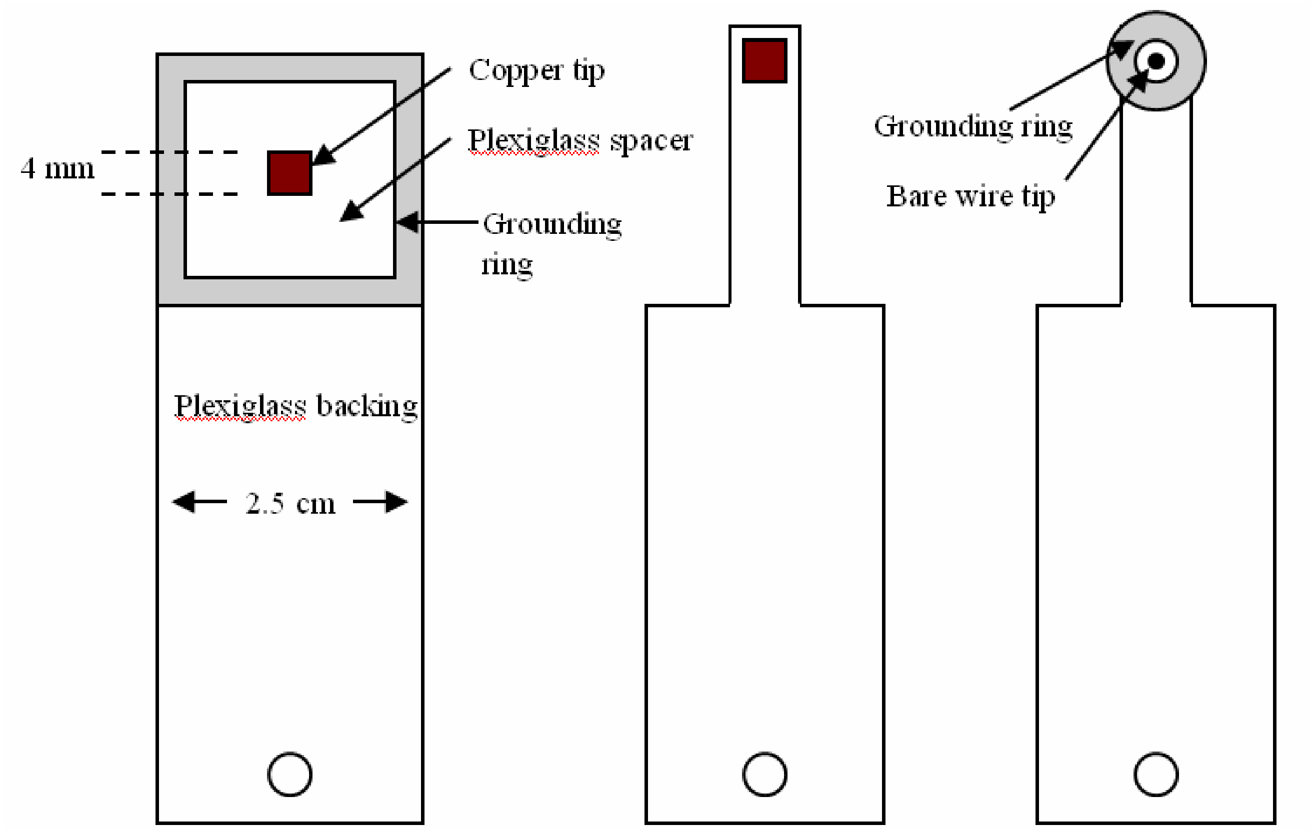
Experimental Setup





- Calibrate with conducting sample
- Measure response vs. separation
- Move to vacuum
- Measure time constant for charged test mass

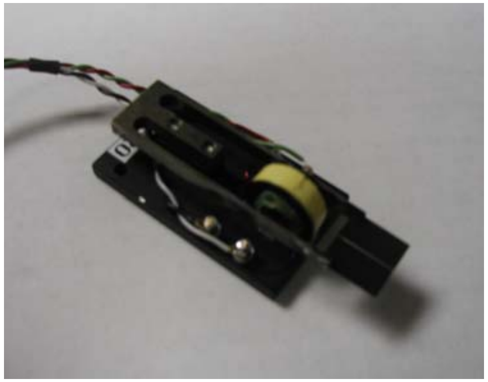
Probe Designs



First -- area around tip too wide, collides with chopper

Second– lots of noise without grounding ring

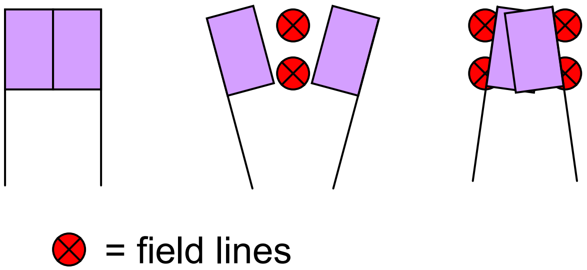
Final version



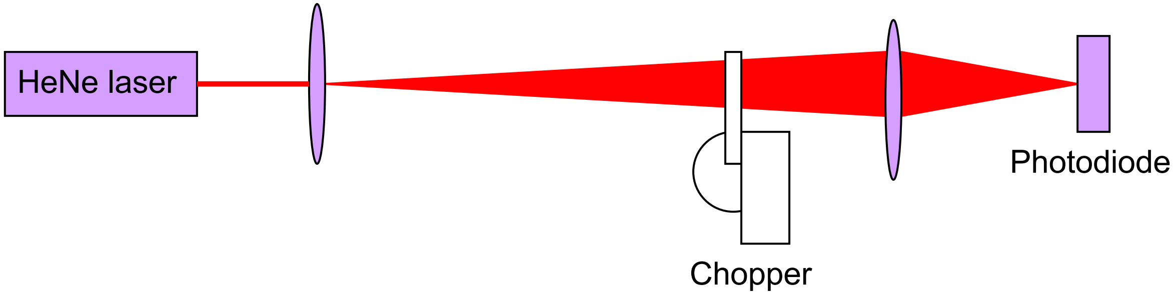
In-vacuum model

Dealing with Noise at the Chopping Frequency

We found a nearly noise-free signal at twice the chopping frequency, due to the chopper's 50% duty cycle. When the chopper blades overlap, electric field lines can pass outside of the blades.



We used the optical setup shown below to verify this effect. The beam is broadened to be slightly wider than the chopper blades.



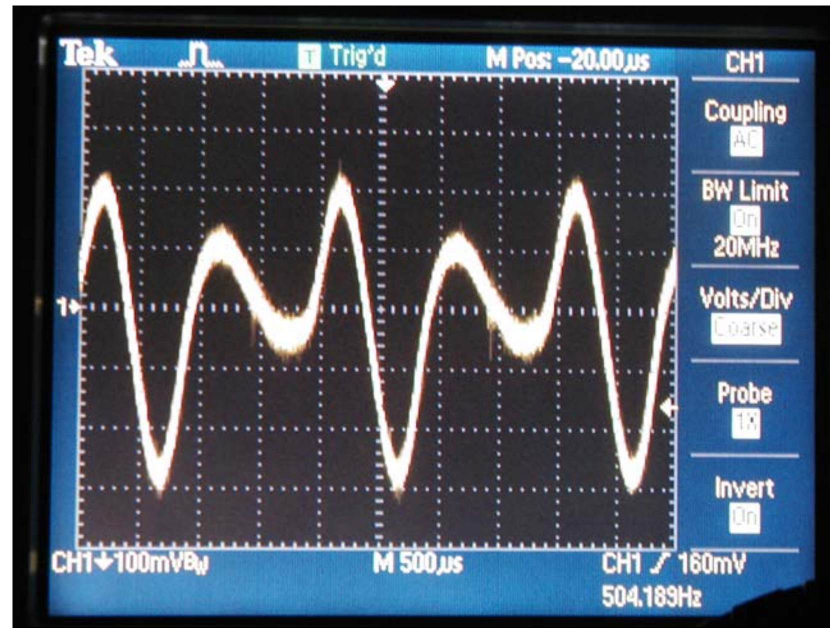
Signal at 2x Chop Freq.

Photodiode signal from optical setup

Blades open

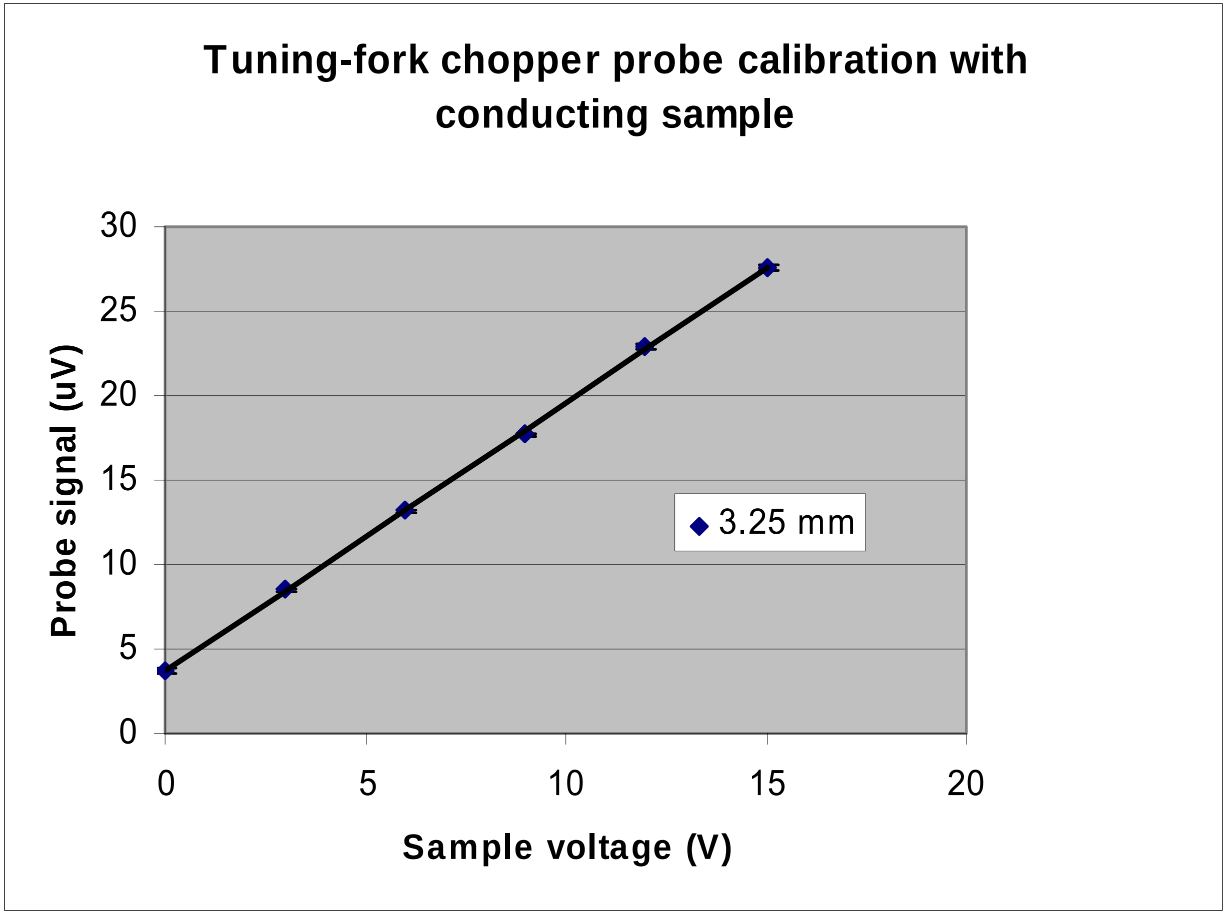
Blades closed

Capacitive probe output



The probe trace (right) looks very much like the derivative of the optical trace (left).

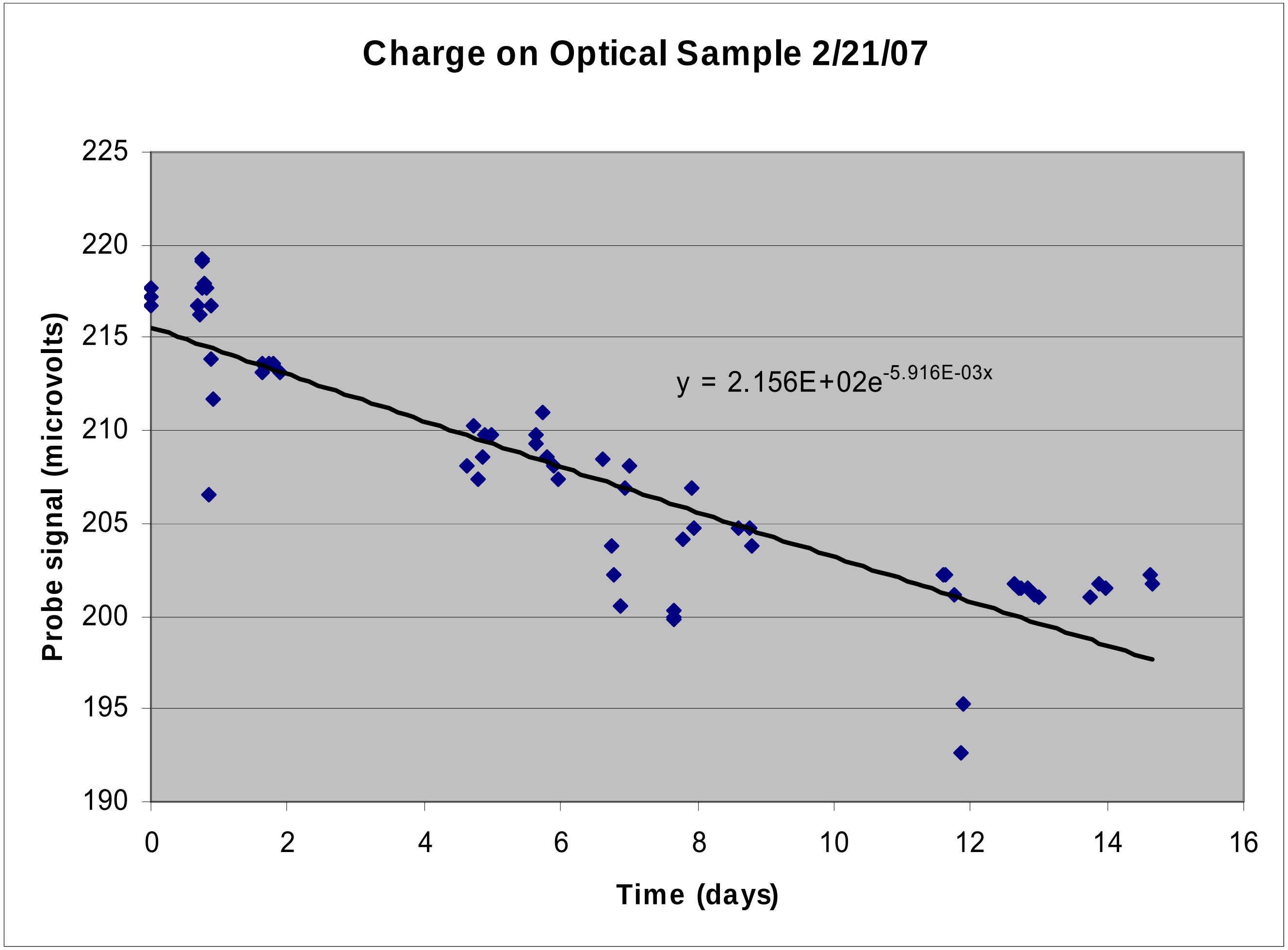
Probe Calibration



Signal fluctuation of ~0.1 μV corresponds to a sensitivity of 2.7×10^5 *e/cm²* at 3.25 mm separation.

Sensitivity improves with inverse square of separation, but chopper is in the way.

16-Day τ_0 Measurement



Corresponds to time constant of (170 +/- 30) days, or ~4000 hours.

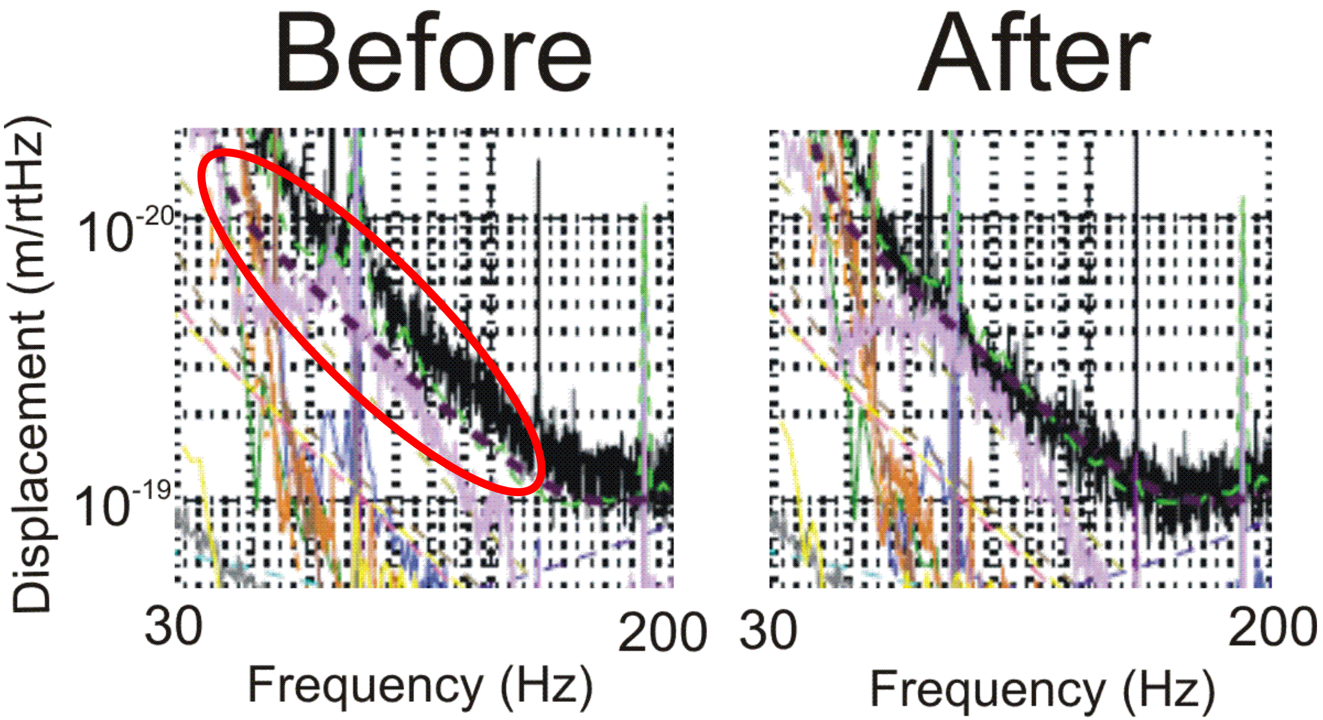
Moscow State measures much larger times, except once.

A sample not cleaned by ultrasound bath gives comparable time constant.

The LLO ITMY Incident

In May 2006, an earthquake causes ITMY at LLO to wedge against its limit stops.

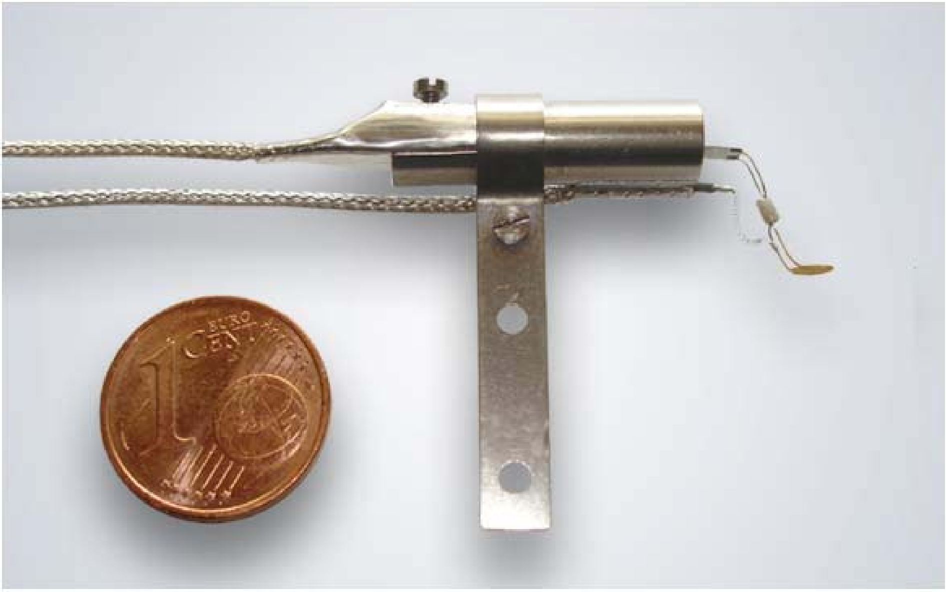
Venting frees the optic, but once running resumes, a low frequency noise contribution is gone.

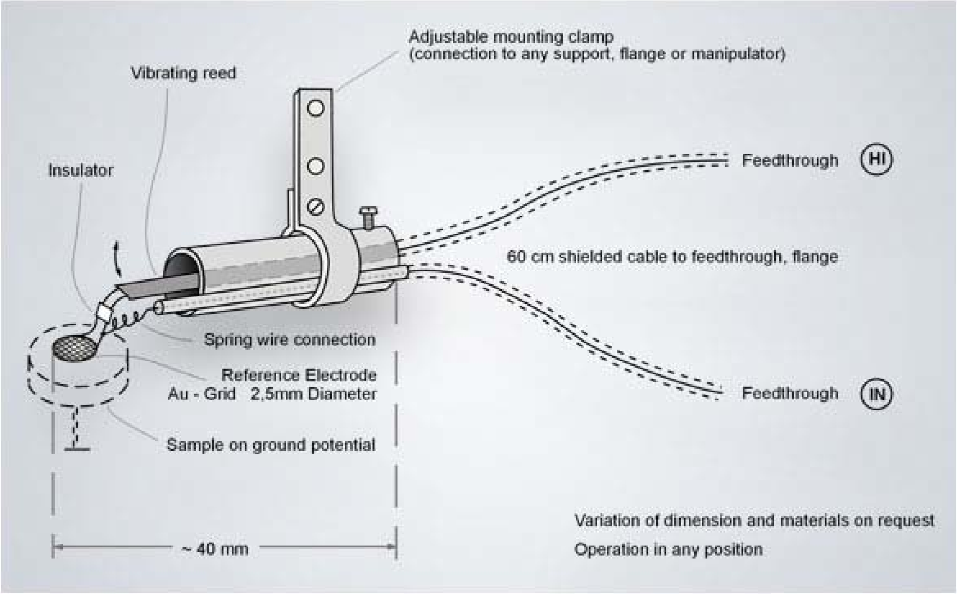


Priorities change:

- Concentrate on charging solutions, such as UV light
- Funding for better probe now readily available
- Does wavelength of UV matter?

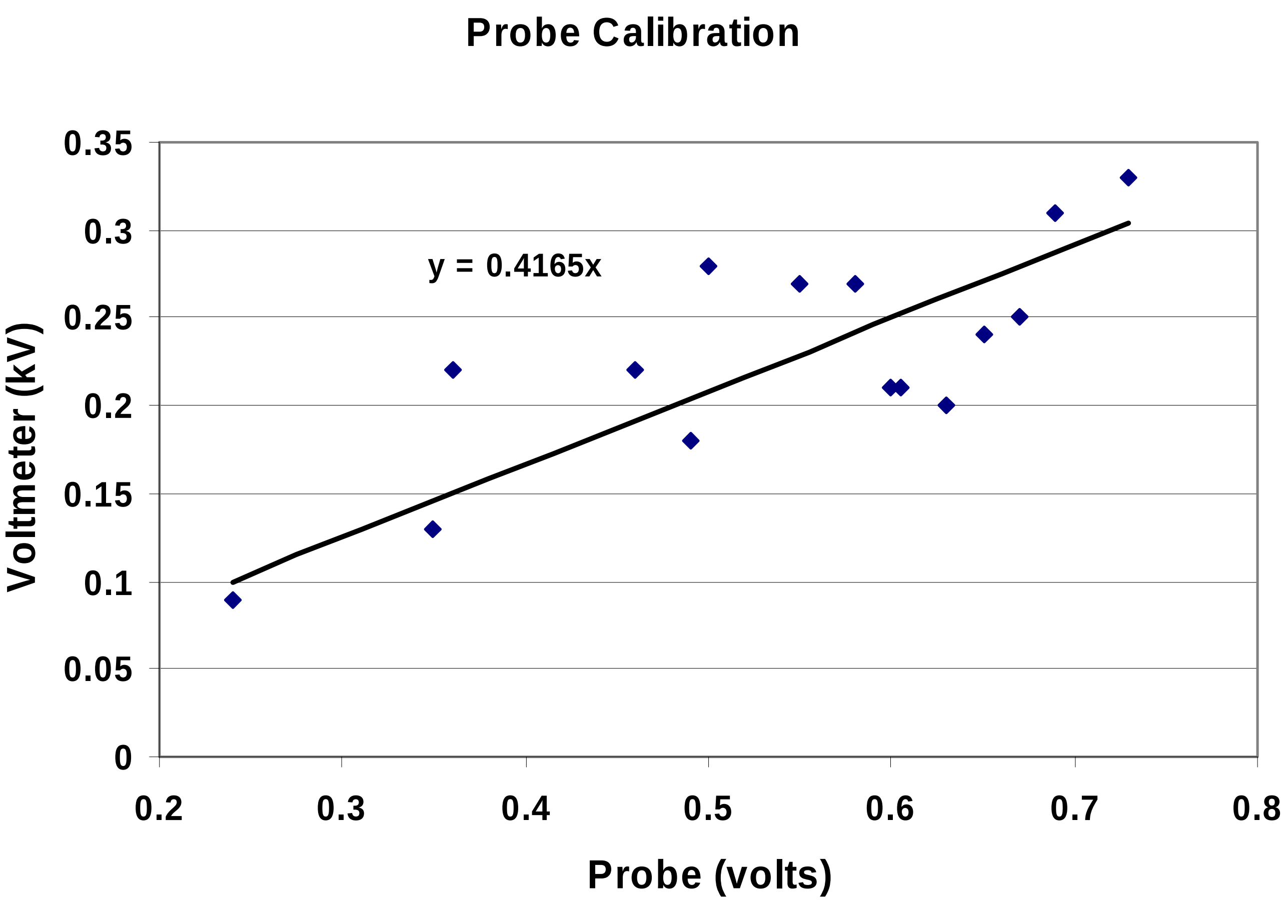
Besocke Kelvin Probe





- Vacuum-compatible probe from Besocke delta phi GmbH
- Probe + preamplifier = $7,100
- Modulates probe electrode position with PZT
- Reported sensitivity of 0.1 mV

Calibration Results



For the fit shown, a probe signal of 1 volt

= 10^{-7} C/m^2

= 8×10^7 e$^-$/cm^2

Since the probe noise level is measured to be +/- 0.1 mV, sensitivity

= 10^{-11} C/m^2

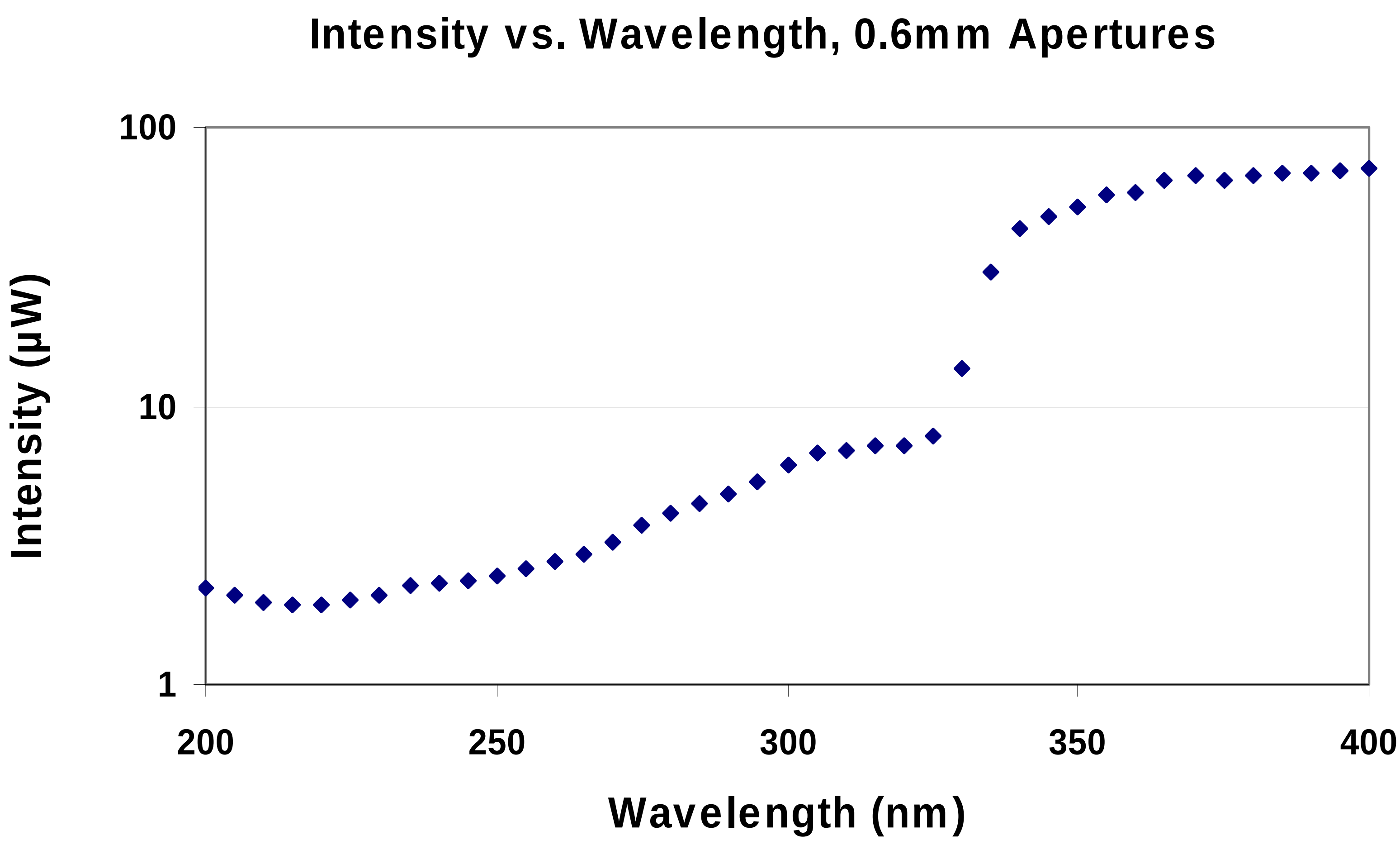
= 8×10^3 e$^-$/cm^2

Sensitive to probe-to-sample separation

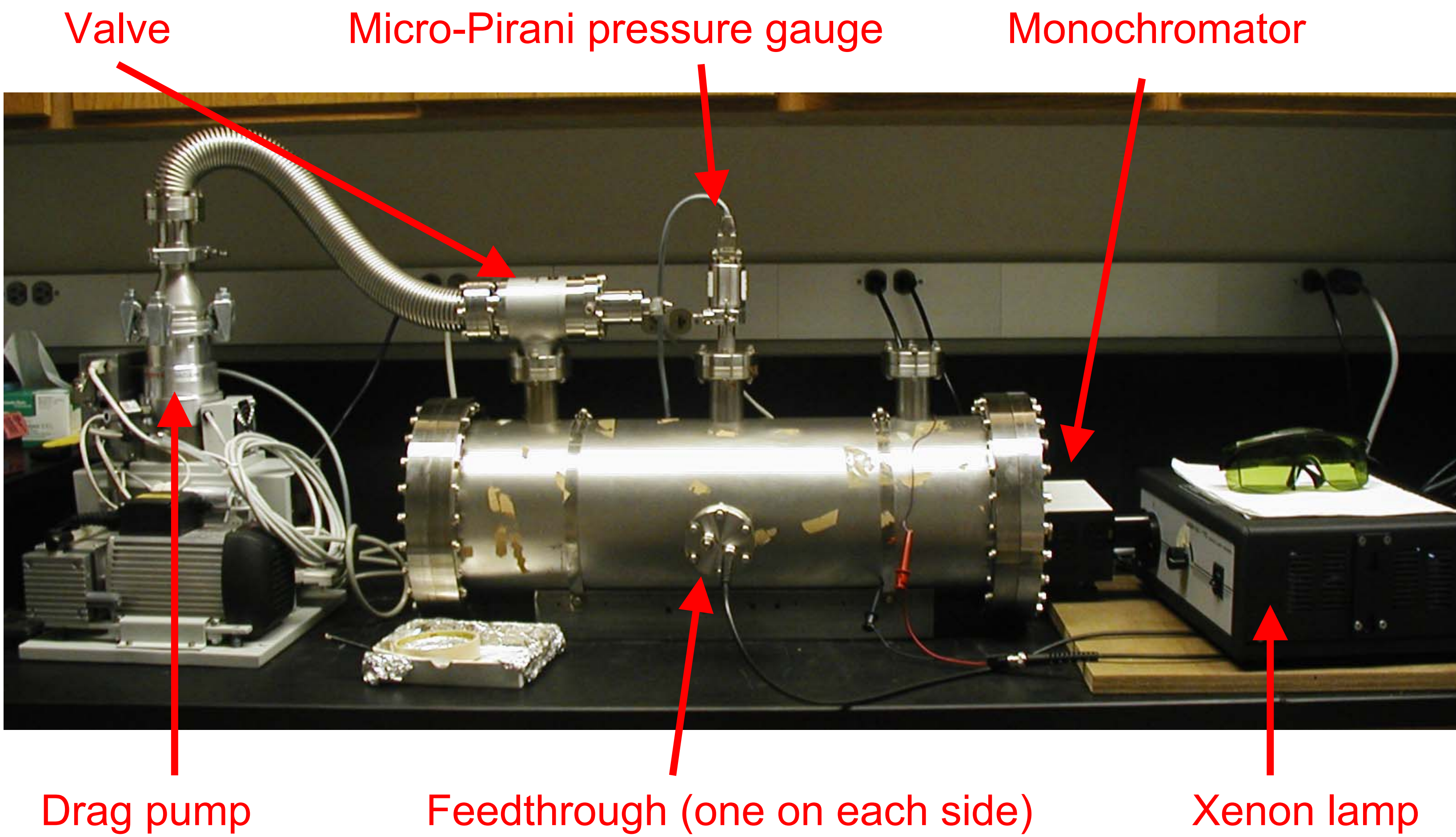
UV Light Source

- 175W broadband Xenon lamp, 200nm – 2,200nm
- 2400 lines/mm monochromator grating, 180nm-680nm range
- Intensity control through lamp knob, monochromator aperture

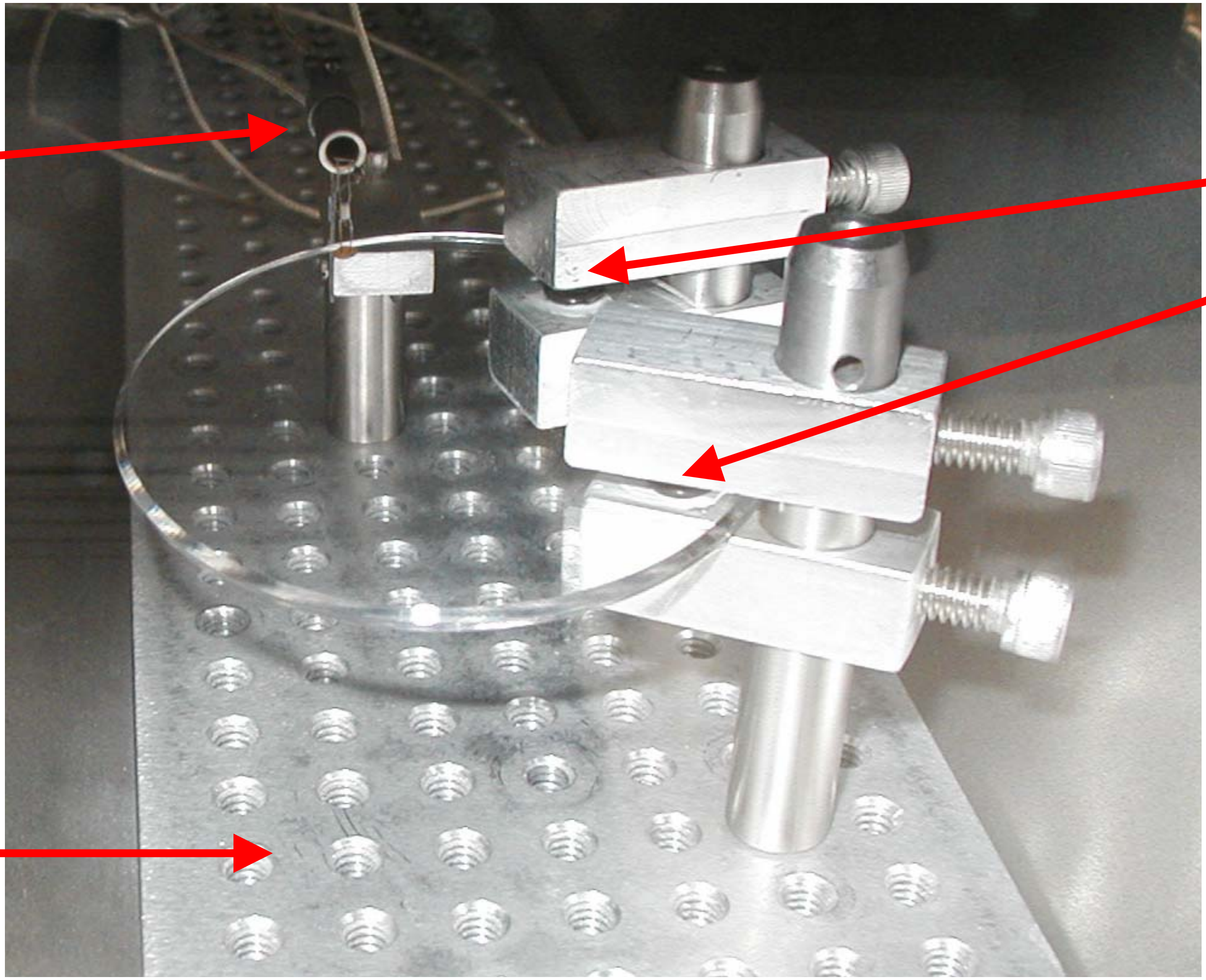
UV Intensity Spectrum



Experimental Setup



Experimental Setup (cont.)

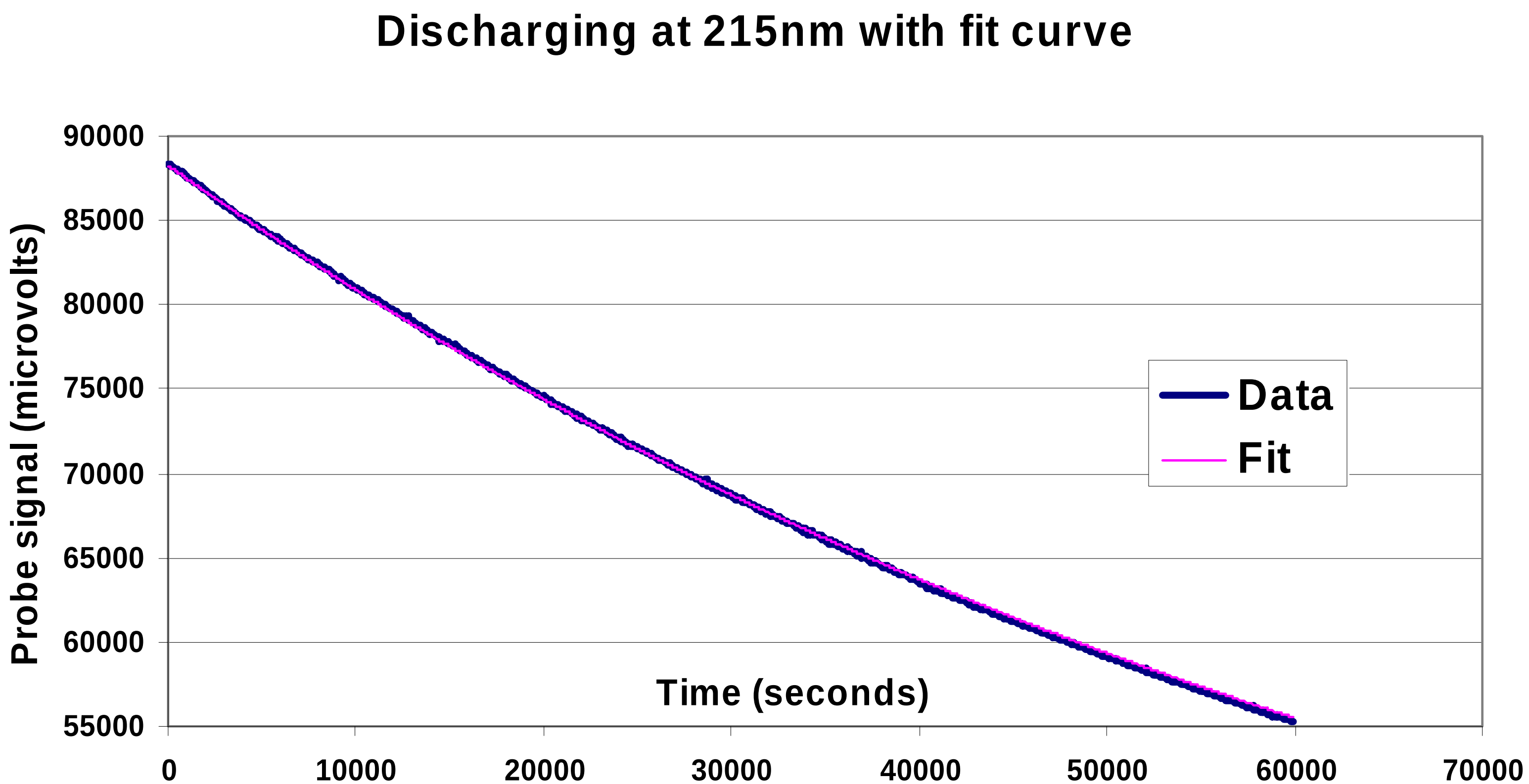


Besocke probe

Clamps (with viton O-rings)

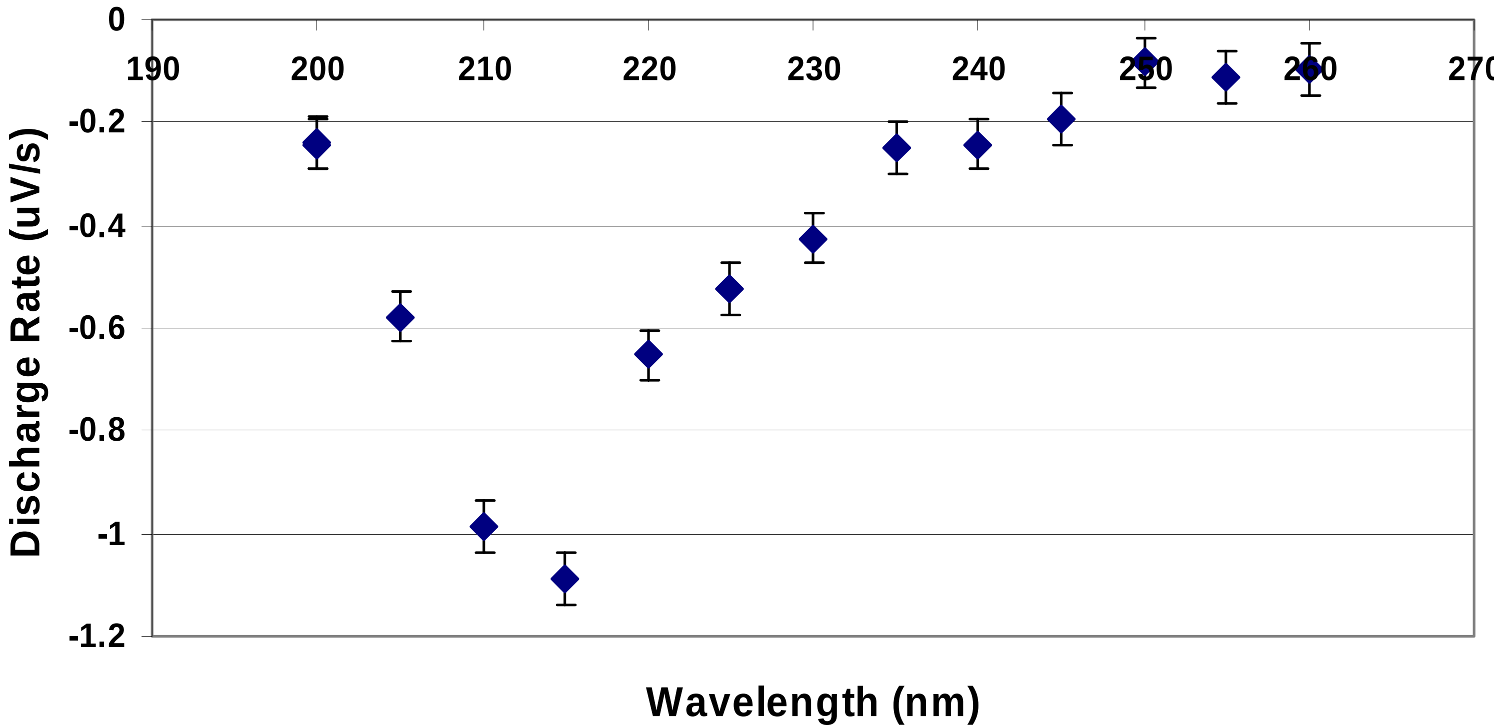
Removable table

UV Discharge



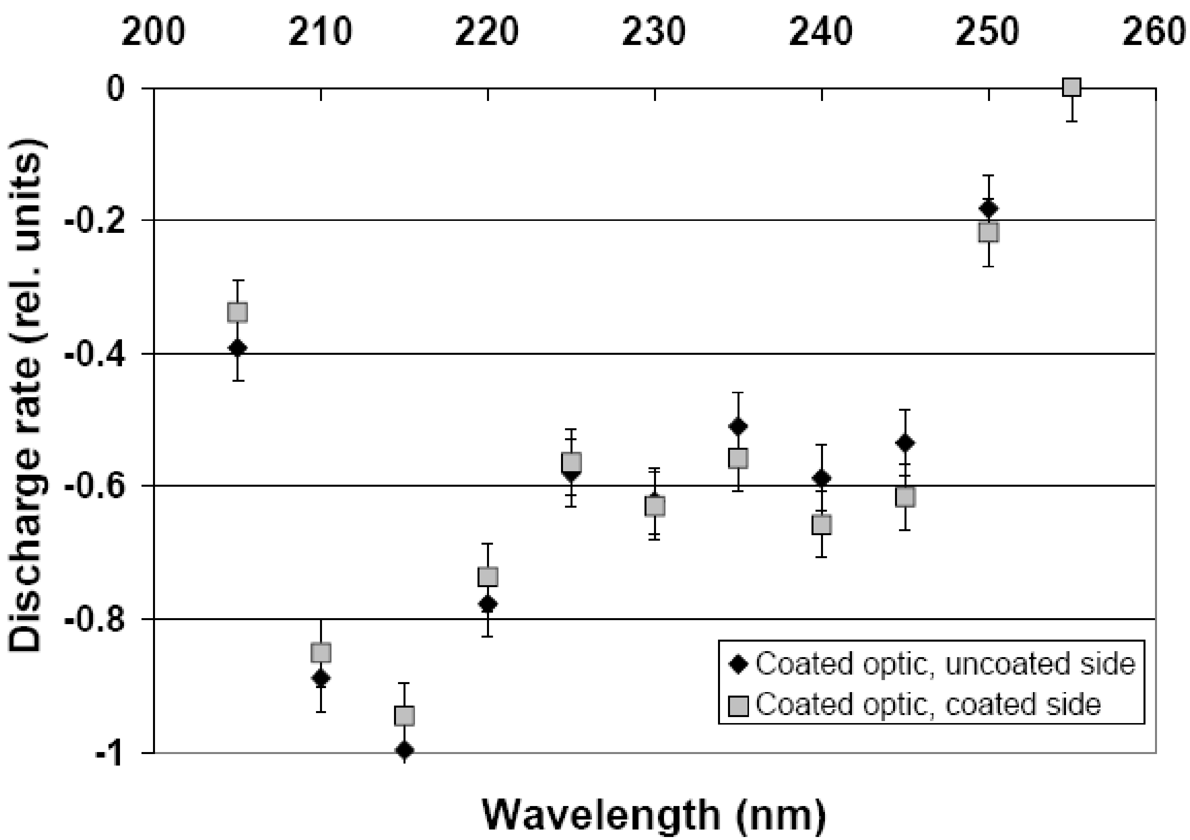
- Exp. fit implies linear relationship between charge level and discharge rate
- Gives correction for measurements taken at different charge levels

Discharge vs. λ, Uncoated



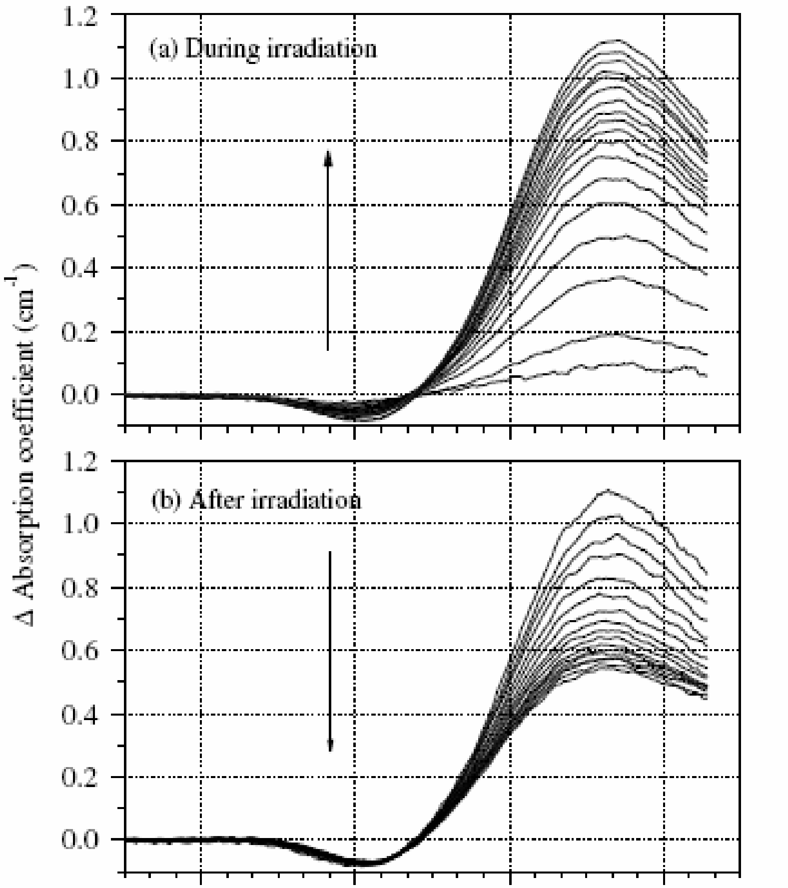
- Corrected for charge level, source intensity, viewport transmission
- Peak response at 215nm, surprisingly low at 255nm
- Not a “shelf” (photoelectric effect) – charge is positive

Discharge vs. λ, Coated



- Relative units – absolute rate varies by x2 from one measurement to next
- Wavelength dependence is determined by substrate, not coating

Paramagnetic E’ Centers



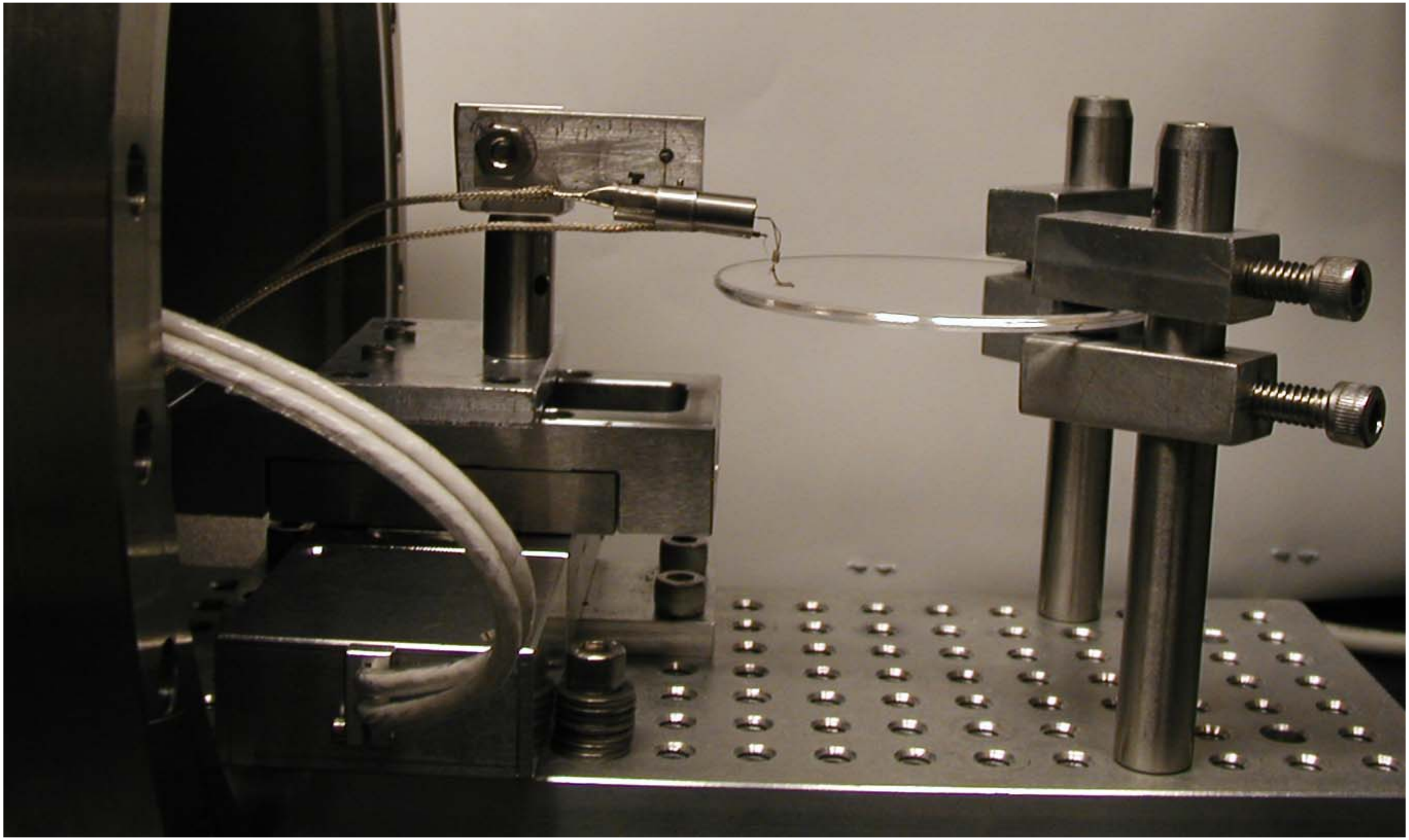
- Bond defect common to many types of fused silica
- Optical absorption band centered at 5.83 eV (213 nm)
- Can be induced by UV illumination at 265 nm, removed by exposure to molecular hydrogen

F. Messina and M. Cannas, J. Phys: Condens. Matter **17**, 3837 (2005).

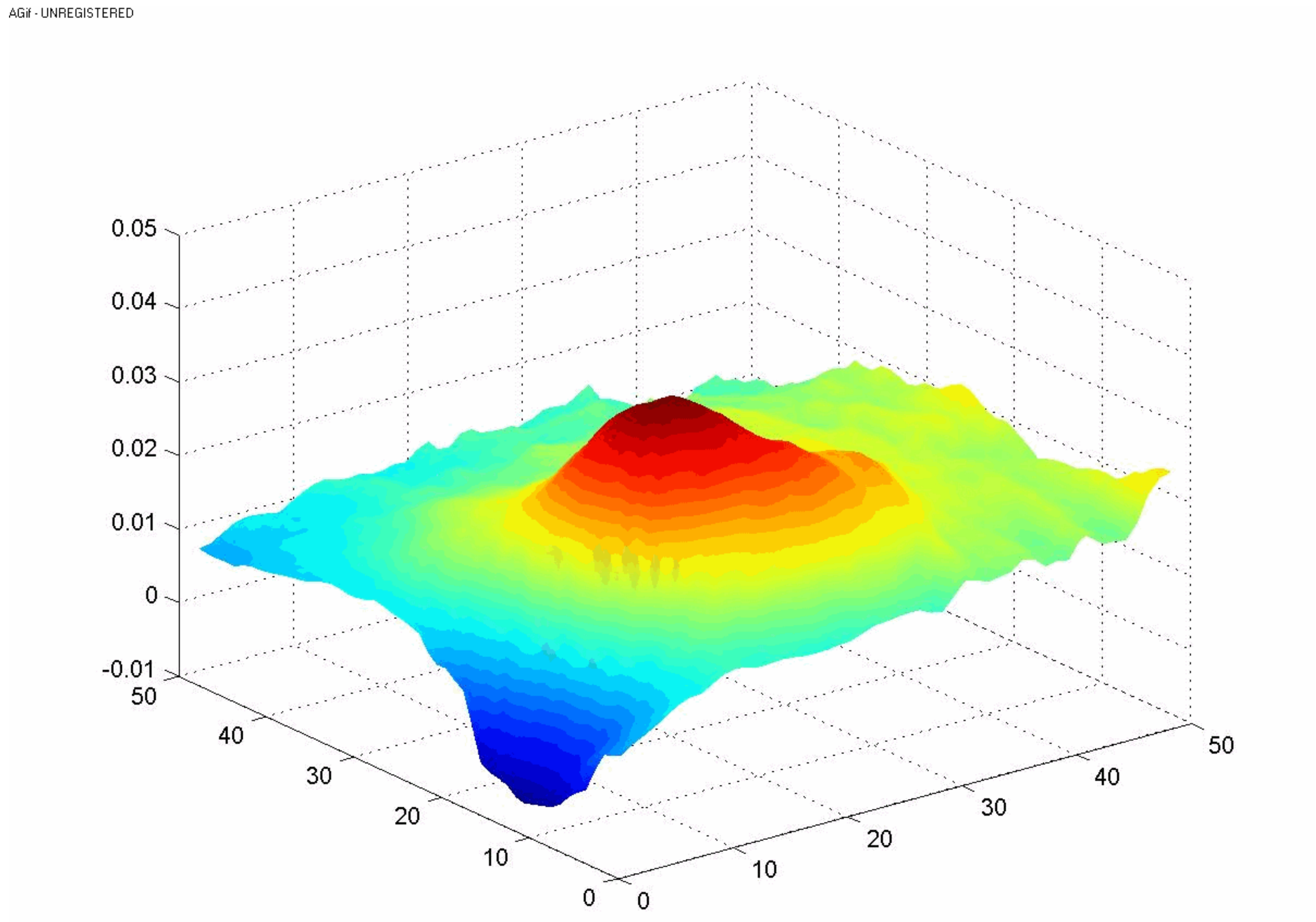
2D Motor Control

- Two big, unanswered questions:
  - » How does the charge move on the sample surface?
  - » When we illuminate with UV, is charge removed proportional to area or charge density? In other words, do “patches” of charge disappear over time?
- Solution – introduce motor control to map spatial distribution of charge on sample

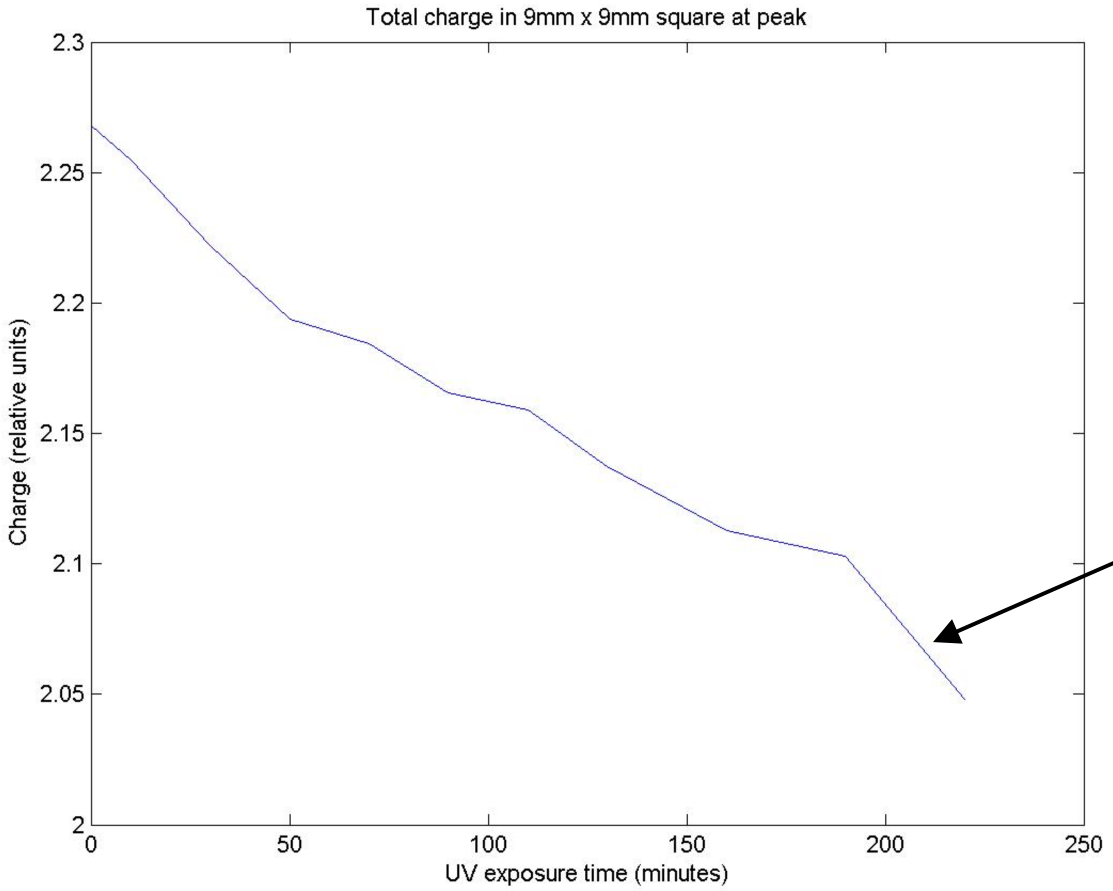
Experimental Setup



Behavior Over Time



UV Discharge of Peak

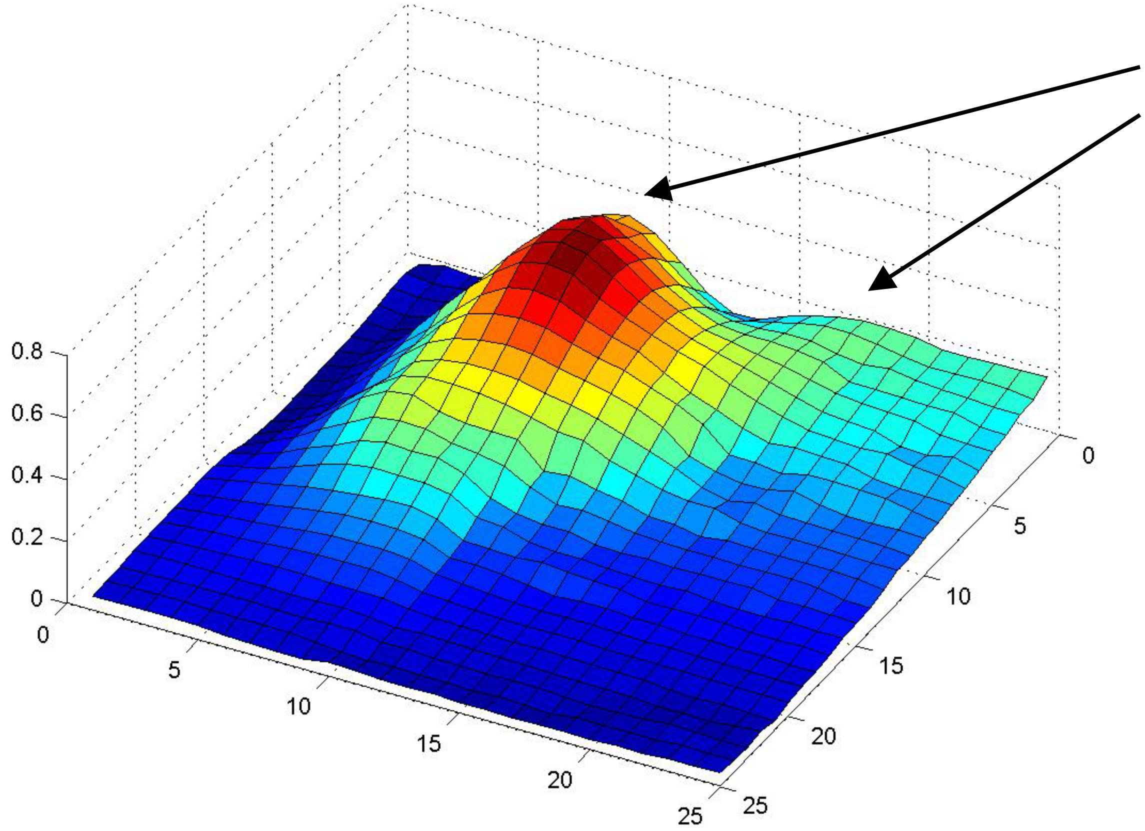


Total charge in 9mm x 9mm square centered at charge peak, versus UV exposure time.

Last exposure made after 30 minutes of illumination at 265 nm to induce E' centers.

Have not reproduced at single point on sample.

Surface Feature?

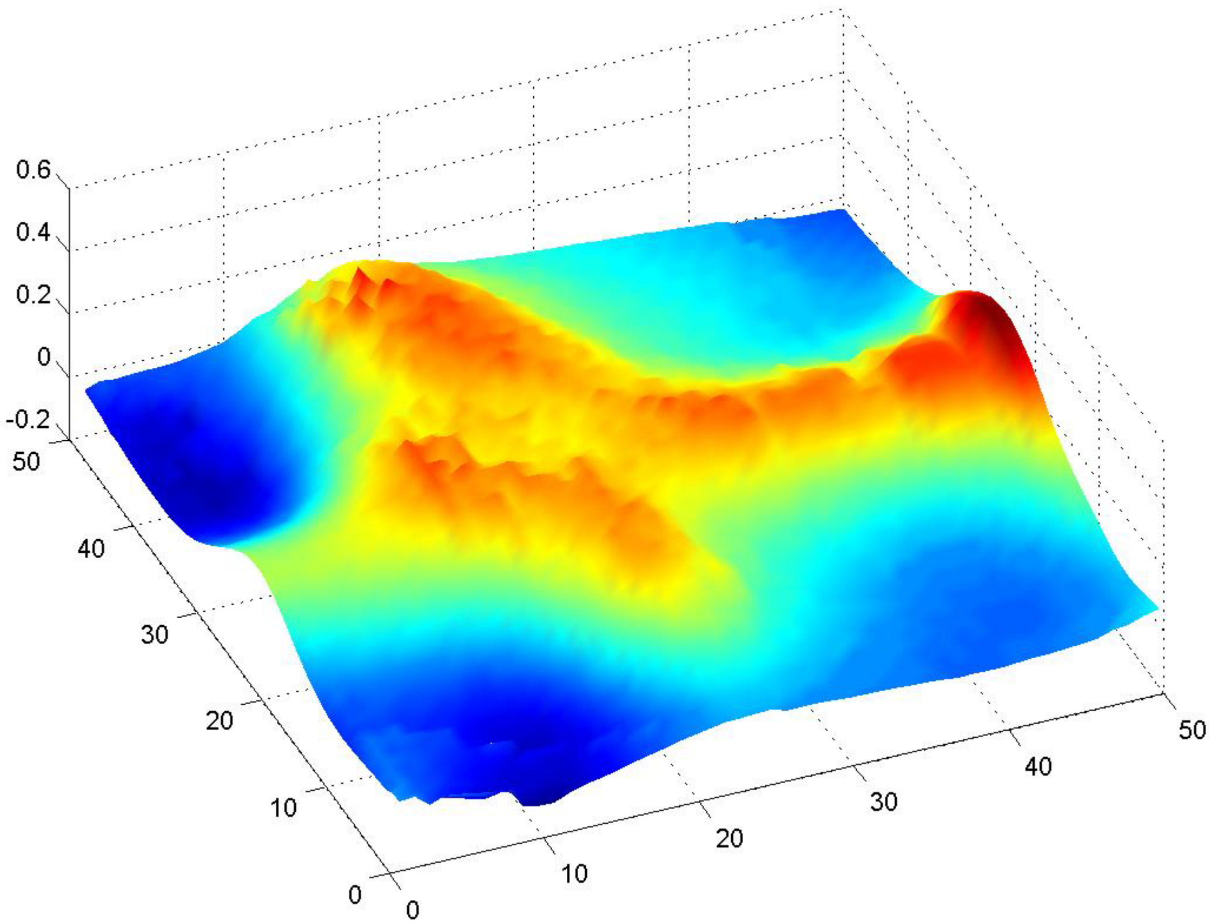


Tried to deposit charge in two vertical lines.

Charge is either accumulating at or preferentially hanging onto this particular spot.

No surface feature visible to the naked eye.

Most Recent Scan



Rotated surface defect out of scan range.

Cleaning surface with ethanol generated negative charge.

Viton o-ring was then dragged across surface in cross pattern.

Summary

- Many advances in experimental setup in three years
  - » Highly sensitive commercial Kelvin probe with 2D motor control
  - » Vacuum down to 2×10^{-6} torr
  - » Positive and negative charging mechanisms
  - » Tunable UV illumination source
- Several interesting measurements on horizon
  - » Motion of charge over time for variety of sample preparations
  - » Effect of UV on spatial distribution
  - » First Contact reformulation
- Testbed available for whatever else comes along