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# Overview of Charging Research

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On behalf of charging subgroup

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Two recent events stimulated more intensive research in the field of charging problems.

- May 2006 Livingston charging event when the noise decreased after freeing of the sticking ITMY,
- GEO case of December 2006 when the big charge built up on the test mass as a result of a power cut and of a possible contact between the test and the reaction masses.

These cases have also shown that whatever mechanism is responsible for the test mass charging and generation of noise associated with charging, it is necessary to provide minimal charge on the test masses.

# Earthquake stops replacement

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The practical step has been done recently by Enhanced LIGO team at both LIGO detectors: viton tipped earthquake stops were replaced by fused silica tipped stops.

What can we expect from this operation?

The result of Gregg Harry analysis is presented on the next slide.

The analysis is based on one of possible mechanisms of generation of Gaussian noise associated with test mass charging (R.Weiss model): charge relaxation is treated as a random Markov process with a single correlation time  $\tau$ .

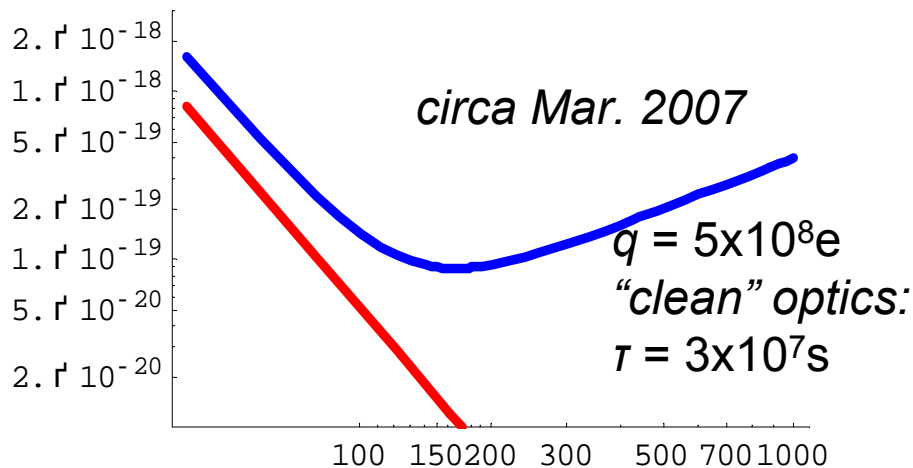
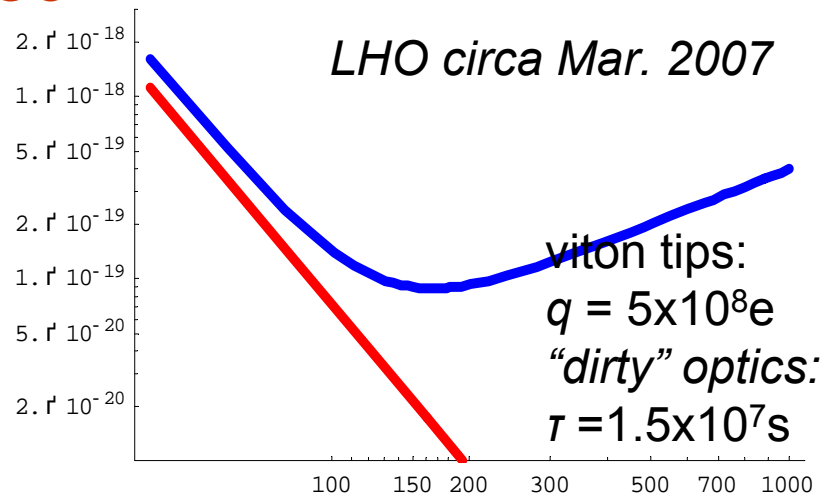
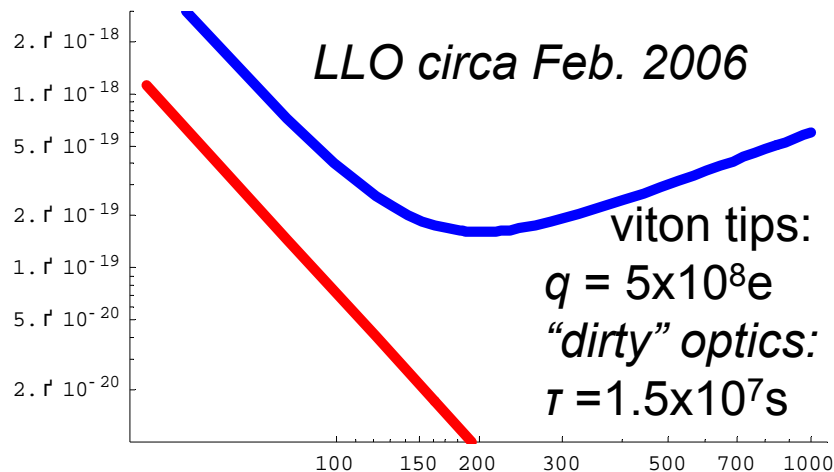
Key parameters that determine this noise:

- ◆  $q$  – amount of charge transferred to the optic by contact with earthquake stop,
- ◆  $\tau$  - charge relaxation time.

Their values were measured in Moscow Univ. and in Trinity Univ.&MIT (they may differ from real test mass values, but we have no opportunity to measure them *in situ*)

- Also Moscow group has demonstrated dependence of charge relaxation time on cleanness of the sample surface. The recent result: the measured charge relaxation time was found to be more than 5 years (the sample was cleaned in ultrasound bath but this procedure may damage to LIGO optics).
- At present, it is supposed to use First contact™ polymer solution to clean and protect LIGO optics. The nearest goal of LSC charging group is to search “charging outcome” from this procedure.

### Initial LIGO



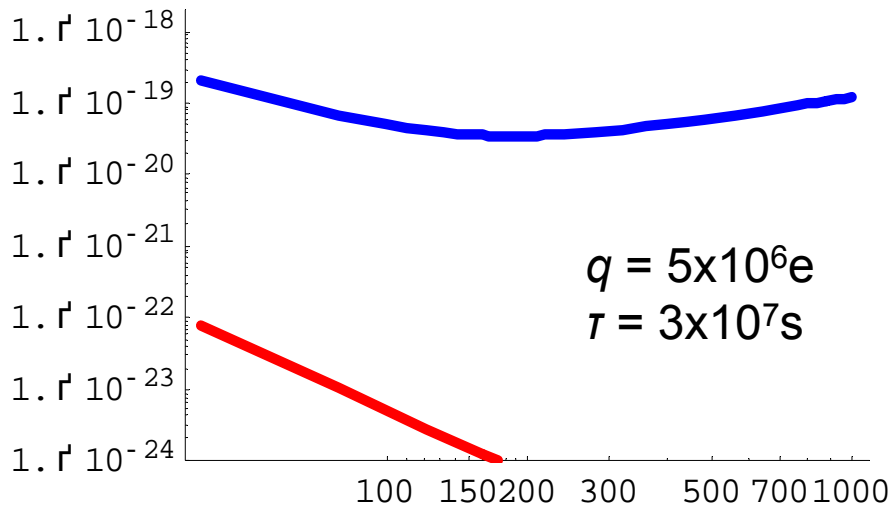
**Red** curves – calculated noise due to charge,  
**Blue** curves – actual or planned total noise.

Uncertainty in  $q$  and  $\tau$  allowed to explain observed noise.

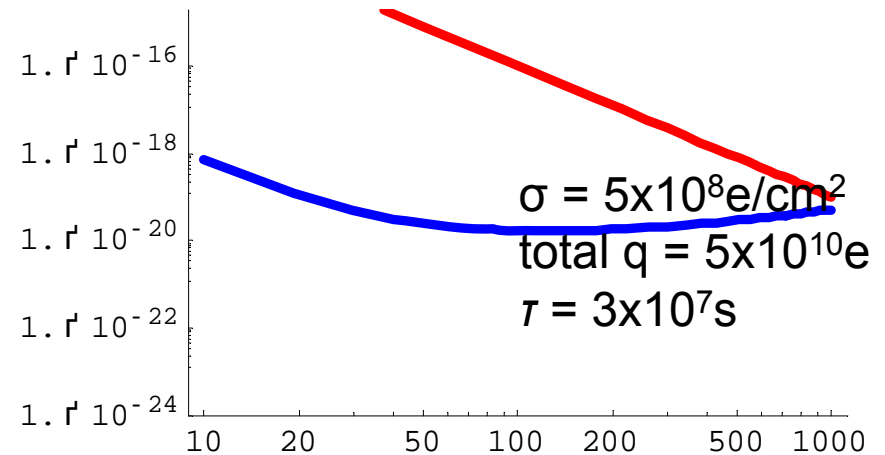
# Estimate of noise from charging

## G.Harry (LIGO-T080019-00-R)

Good result may be expected for Enhanced LIGO with “clean” optics



Adv. LIGO with “clean” optics, charged from contact with ESD (similarly to GEO case)



## Estimates of noise - comments(2)

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- Other mechanisms of generation of noise associated with test mass charging (e.g. cosmic rays (V.B.Braginsky, O.G.Ryazhskaya,S.P.Vyatchanin, PLA 2006) were not taken into account by this analysis.
- Red graph on the last Fig. of Gregg's slide relates to the case of large charge (total charge is  $\sim 5 \times 10^{10} e$  spread evenly over TM) if some event analogues to GEO case will occur in Adv.LIGO in the presence of close placed reactive mass with ESD.

After the case of December 2006 GEO group had successfully realized the charge mitigation by UV illumination of the optics (M.Hewitson et. al., CQG 2007), but some questions remained.

# Some questions about charge mitigation by UV illumination of the test mass

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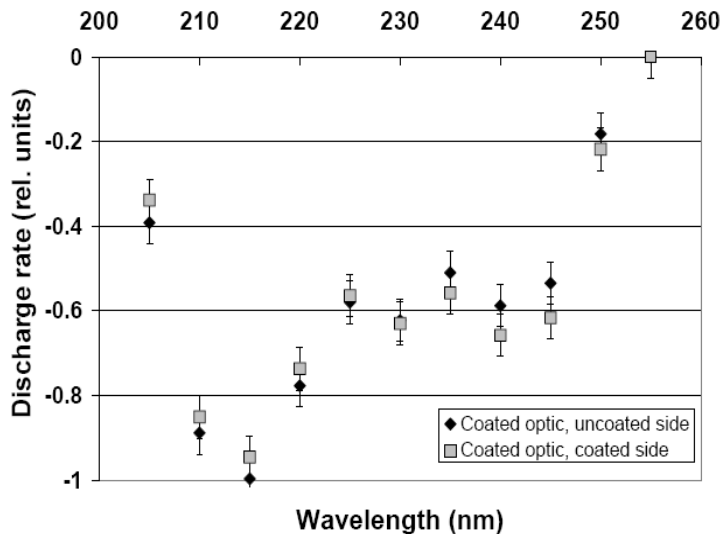
- What mechanisms determine the UV charge mitigation of positive and negative charges? Quantitative characteristics of the process?
- What effect does UV light on uneven positional distributions of charges? What minimal charge value on the test mass may be achieved?
- Does UV light cause damage of test mass coating and excess optical and mechanical losses?



Discharging of positively charged TM by Xenon lamp with monochromator.

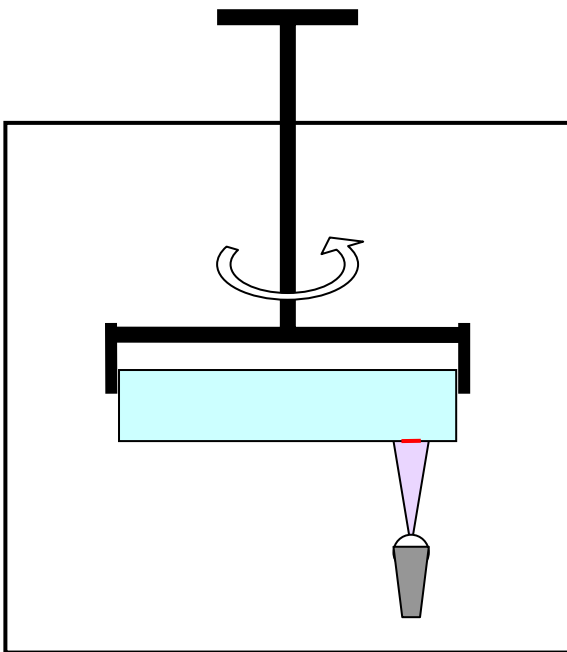
- Discharge rate is:
  - √ a linear function of charge magnitude and UV intensity;
  - √ a function of UV wavelength, maximum at 215 nm (5.8eV)  
(corresponds to absorption peak, measured elsewhere);

To discharge TM by 90% deposited energy of  $\sim 0.1 \text{ J/cm}^2$  is required.



( D.Ugolini, et.al., submitted to PLA)

Mitigation of charge locally deposited on the SiO<sub>2</sub> sample by UV LED with a ball lens ( $\lambda = 265 \text{ nm}$ , illumination intensity of  $20 \mu\text{W}/\text{cm}^2$ ) placed inside the vacuum chamber.



- Charged area < the light spot diameter.
- Positive and negative charges.
- Two operation modes:
  - ◆ static (sample is immovable),
  - ◆ scanning (sample rotates).

(V.P.Mitrofanov, L.G.Prokhorov, to be published).

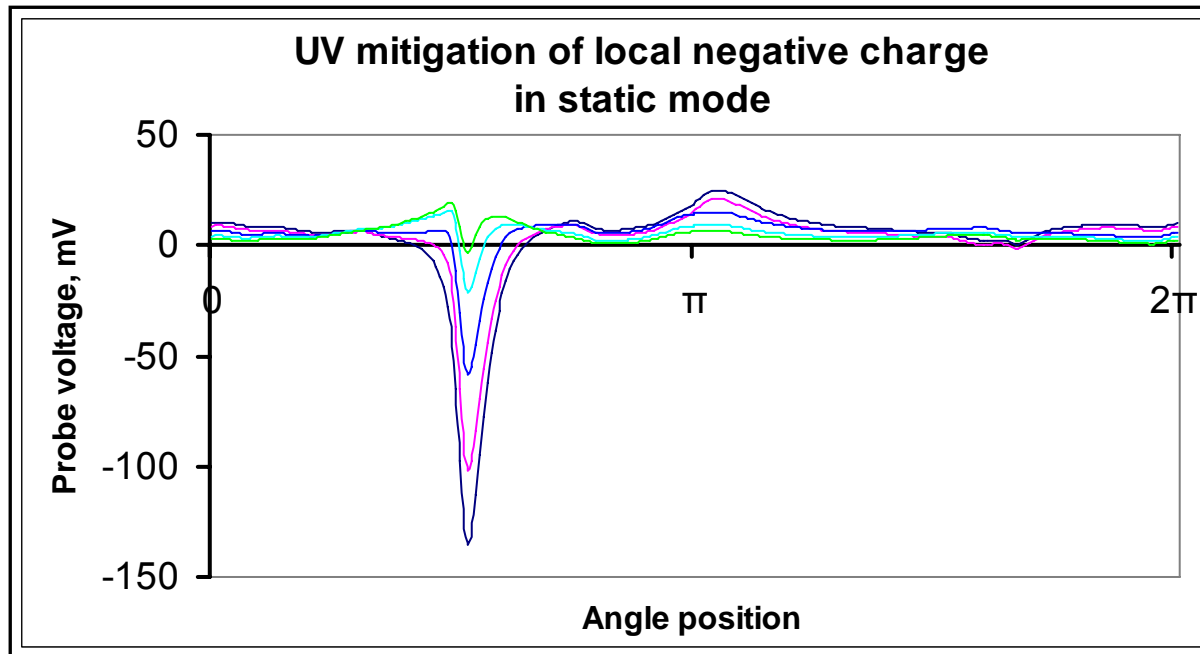
# UV charge mitigation measurements (Moscow University)

Deposited charge	Static mode		Scanning mode	
	Decay time, hours	Residual uneven charge, e	Decay time, hours	Residual uneven charge, e
Positive	8	$+10^6$	16	$< 10^5$
Negative	4	$+10^6$	60	$< 10^5$
Close to zero		$+10^6$		$< 10^5$

- At static mode charges of both signs are mitigated with relaxation time of less than 10 hours but residual charge  $\sim +10^6$  e remains on illuminated area of the sample.
- At scanning mode negative charge is mitigated much slowly than positive one and charge distribution evens out.

# UV charge mitigation measurements (Moscow University)

An example of evolution of charge distribution when UV illuminated negative charge at static mode: negative charge decreased, positively charged area arose around it.



Such charge behavior may be a result of photoelectron emission together with positive ion emission from  $\text{SiO}_2$ .

- The electron emission did not arise from excitation of valence band electrons, but arose from defect states in the bandgap  $\approx 9$  eV. Several types of point defects are present in the bulk and on the surface: oxygen vacancy with a trapped hole ( $E'$ -center), nonbridging oxygen (NBO-center), twofold-coordinated silicon with a trapped hydrogen atom (H-center), etc.
- Positive ion emission during UV irradiation may be attributed to electrostatic mechanism, where ions adsorbed at or near surface electron traps are ejected when the underlying electron trap is photoionized by UV.
  - Photolysis (UV induced bond dissociation) may likely cause the ion emission from the surface of  $\text{SiO}_2$  as well.



# UV impact on mirror absorption

(measurement of Stanford Univ. group)

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See talk by Ke-Xun Sun at this session.

# Conclusion

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- We learned a lot of things about TM discharging with UV light. Though there are a lot of things we do not know. Likely, the UV method has the serious disadvantage - additional optical absorption.

Other methods of charge mitigation (venting of the chamber with subsequent neutralization by ions or via surface conductivity of adsorbed water; the glow-discharge ignition at low pressure; coating of TM and suspension fiber by very thin conductive film) has disadvantages as well.

- So it is better to avoid the necessity of charge mitigation after chamber pumping. It is reasonable to control and maximally mitigate charge on TMs at every step of suspension and preparation before the pumping of the chamber as well as to exclude building up large charge in process of operation (contact electrification, electrical discharge).
- Study of UV charge mitigation have shown that the surface of fused silica TM is very complicated structure. Can processes on the surface of TM produce additional noise?

- Further investigation of charge behavior and mechanisms of noise generation associated with charging of the test masses (e.g. Trinity are adding motion control to their Kelvin probe so that to make two-dimensional charging map of optics).
- Testing of elements of Adv.LIGO construction and new technologies from point of view of charging effects (e.g. using of the First Contact™ polymer solution, gold coating of the test mass barrel for TCS, gold coating for ESD).
- Study of different charge mitigation techniques and their impact on optical absorption and mechanical losses.