Initial Electric Field Meter Results for Advanced LIGO and Beyond

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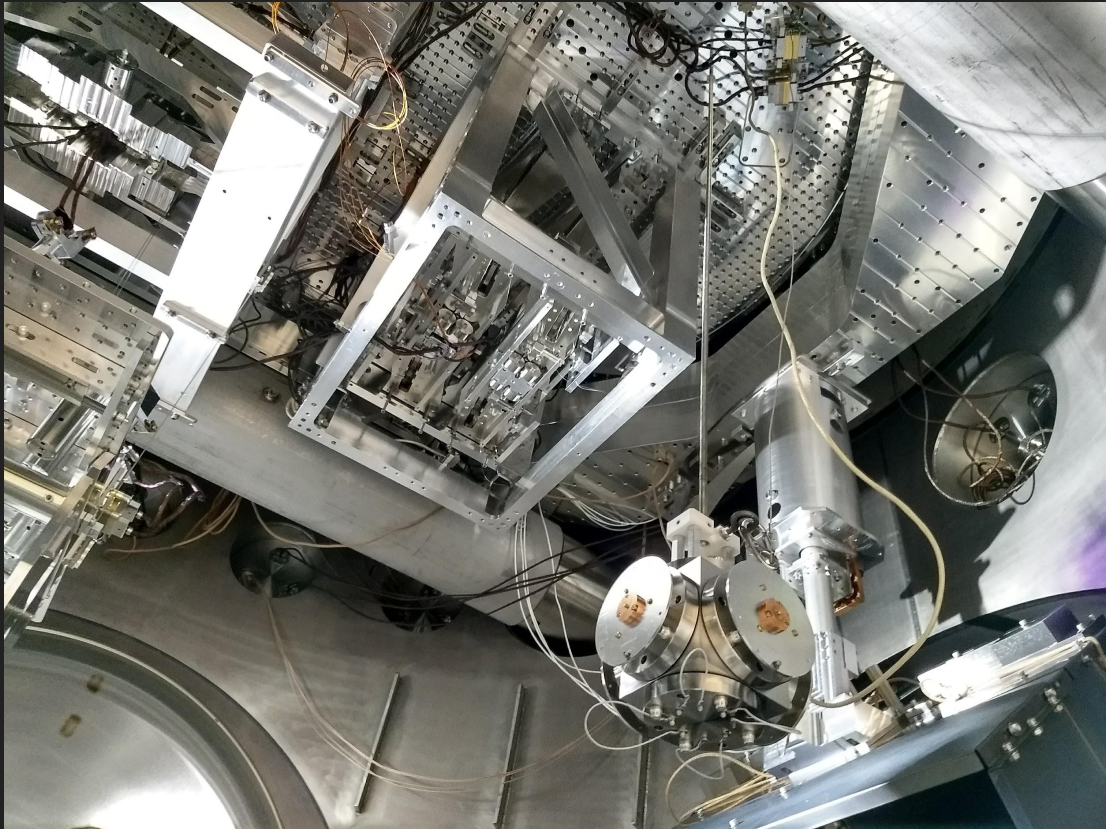
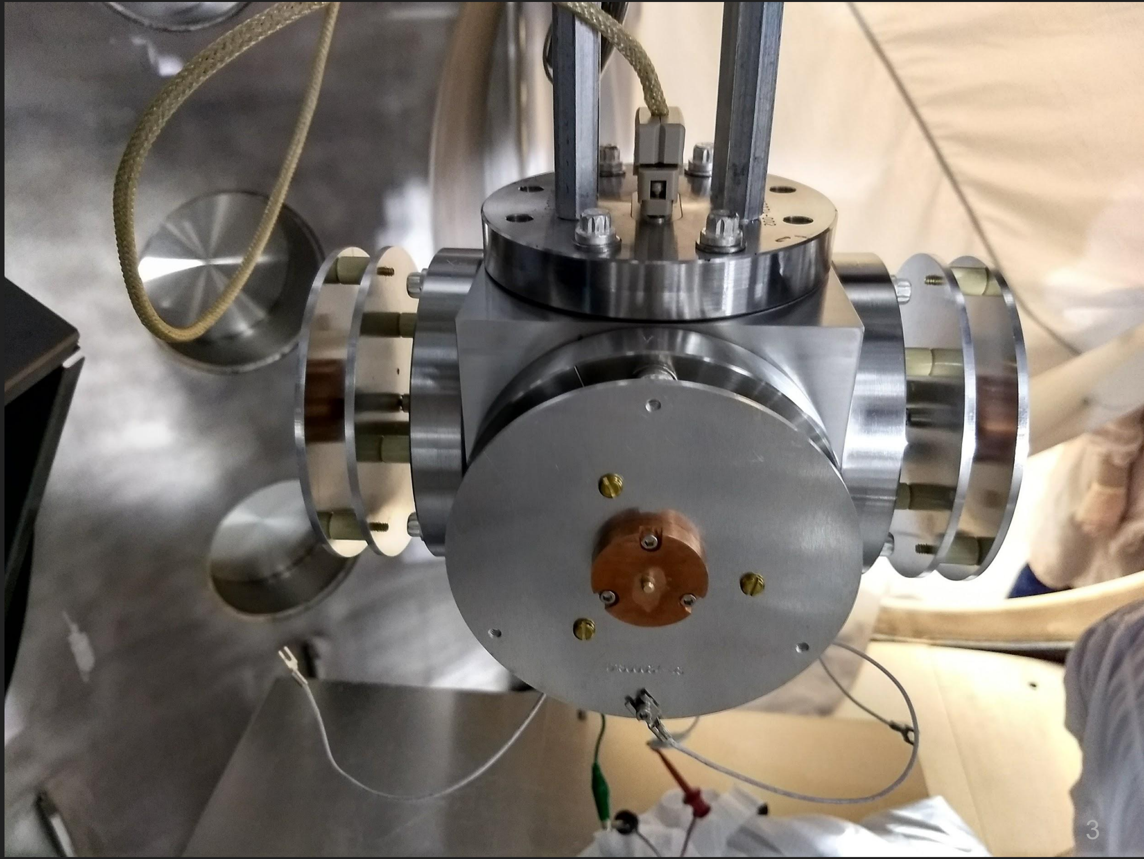


What is the Electric Field Meter?

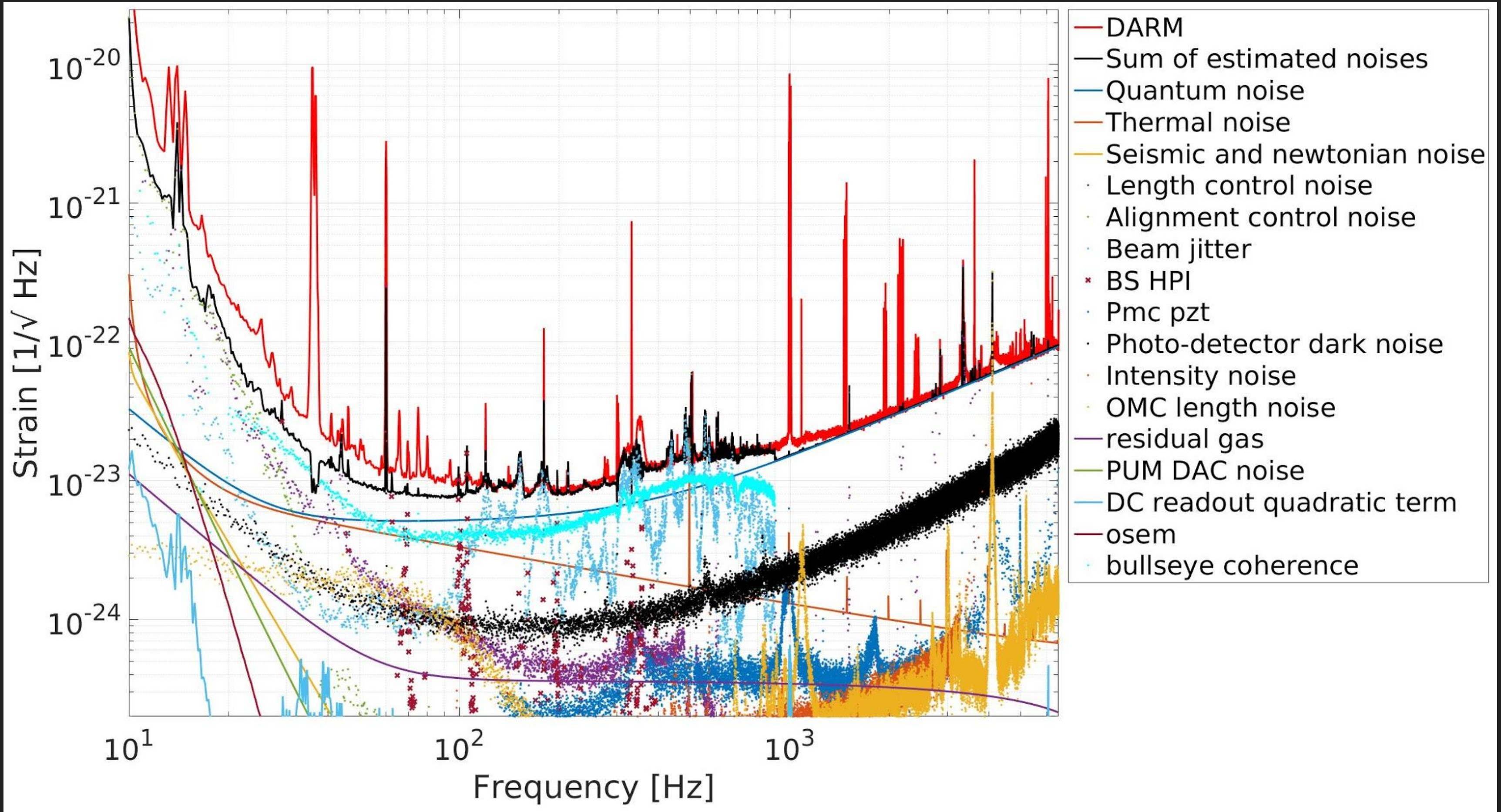
The Electric Field Meter measures ambient electric fields in its environment.

Four sensor plates, pointed in the +X, -X, +Y, and -Y directions, have electric fields pass through them and induce a voltage on the plate.

These induced voltages pass through a differential op-amp to report overall electric field.



Motivation for the Electric Field Meter

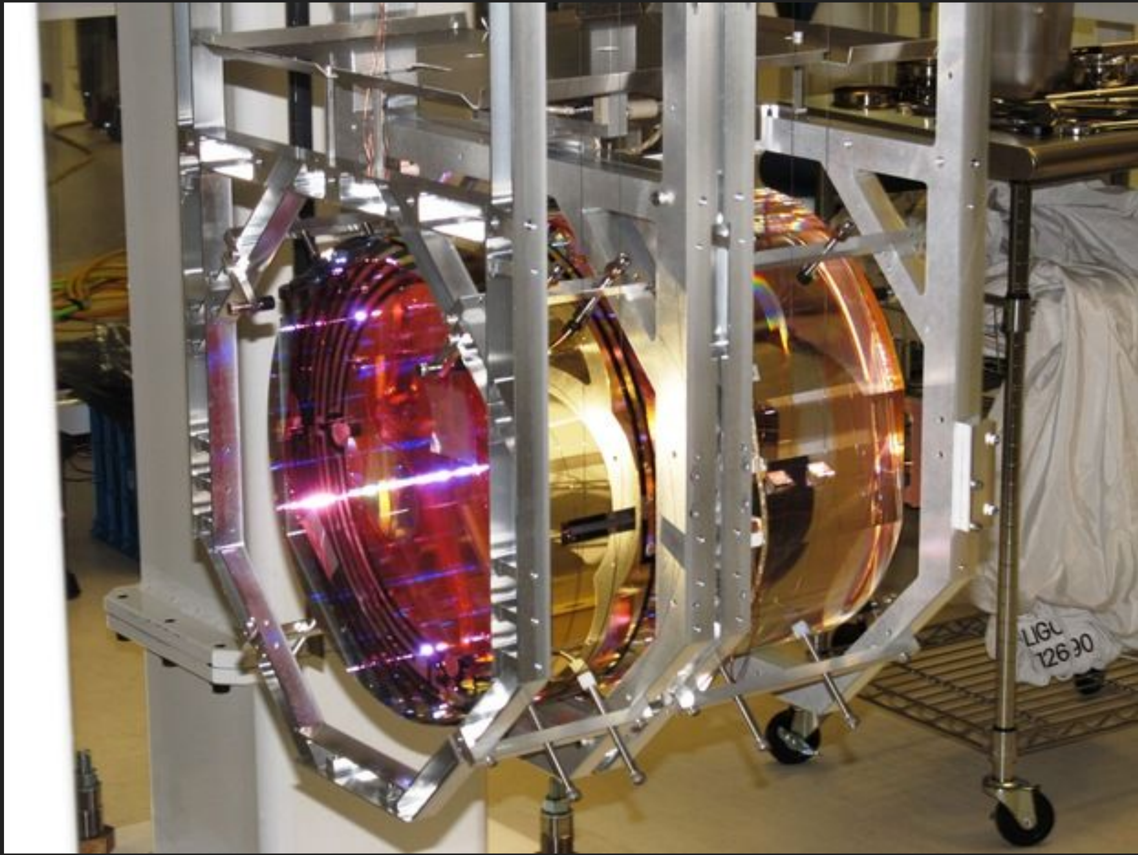


Charge and The Electrostatic Drive (ESD)

The Electrostatic Drive (ESD) polarizes the optic in order to actuate upon it, creating a small surface charge density.

Optics made of fused silica, an insulator. Difficult for charges to move around, makes discharging optics hard.

Ion pumps produce UV/X-rays which ionize test mass directly. First Contact, earthquake stops also sources of charge.

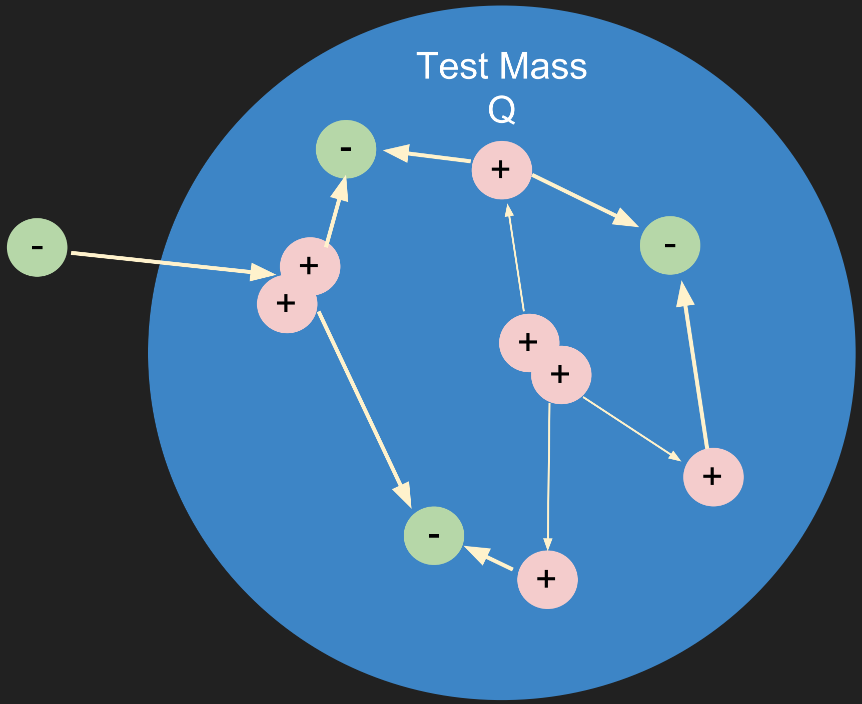


Three ways Electric Fields interact with the ETM

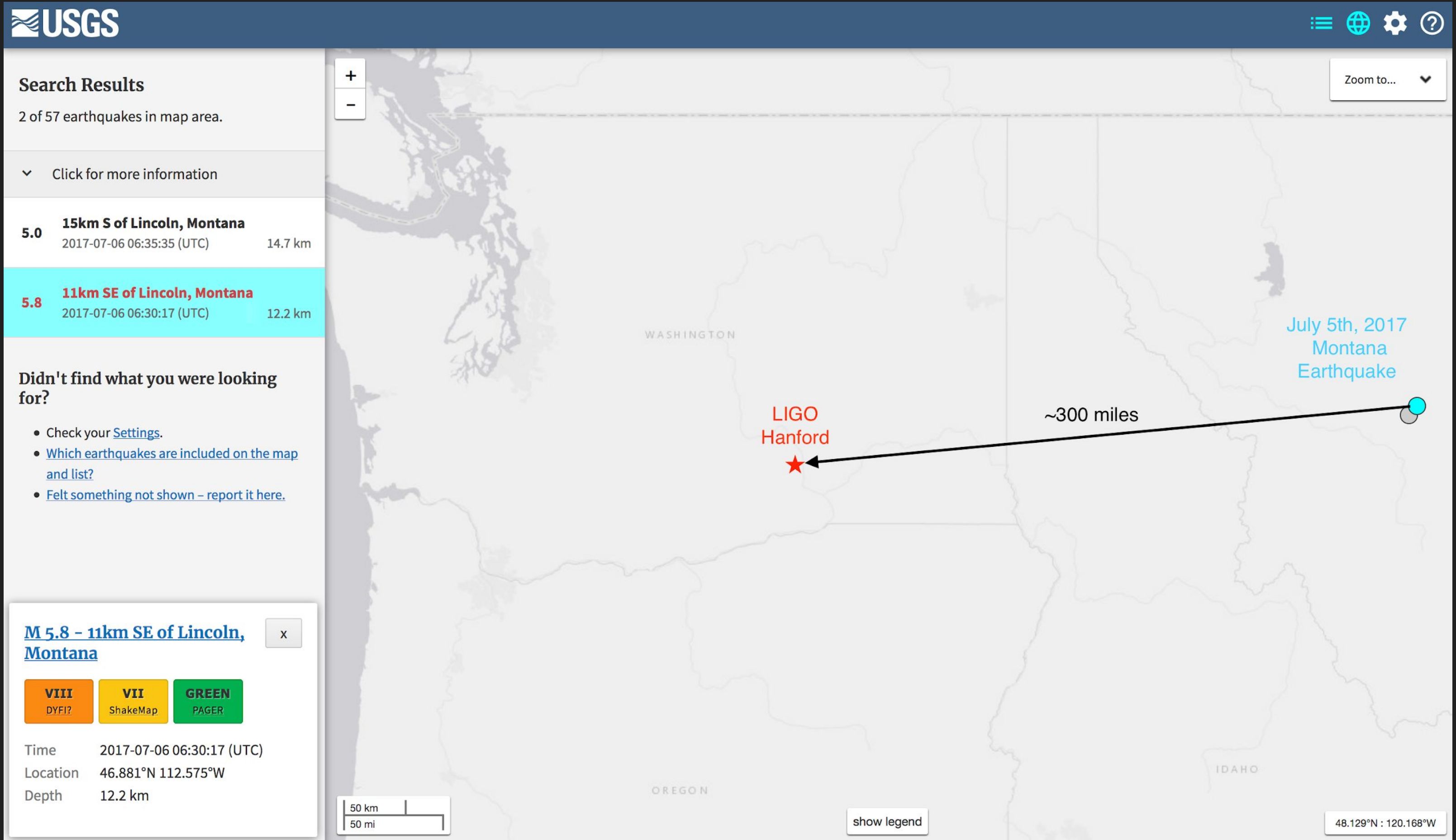
Net Charge ($F \sim Q*E \sim f^{-2}$)

Dielectric Polarization ($F \sim E^2 \sim f^{-2}$)

Space Charge Polarization (aka charge hopping or charge fluctuations) ($F \sim f^{-3}$)

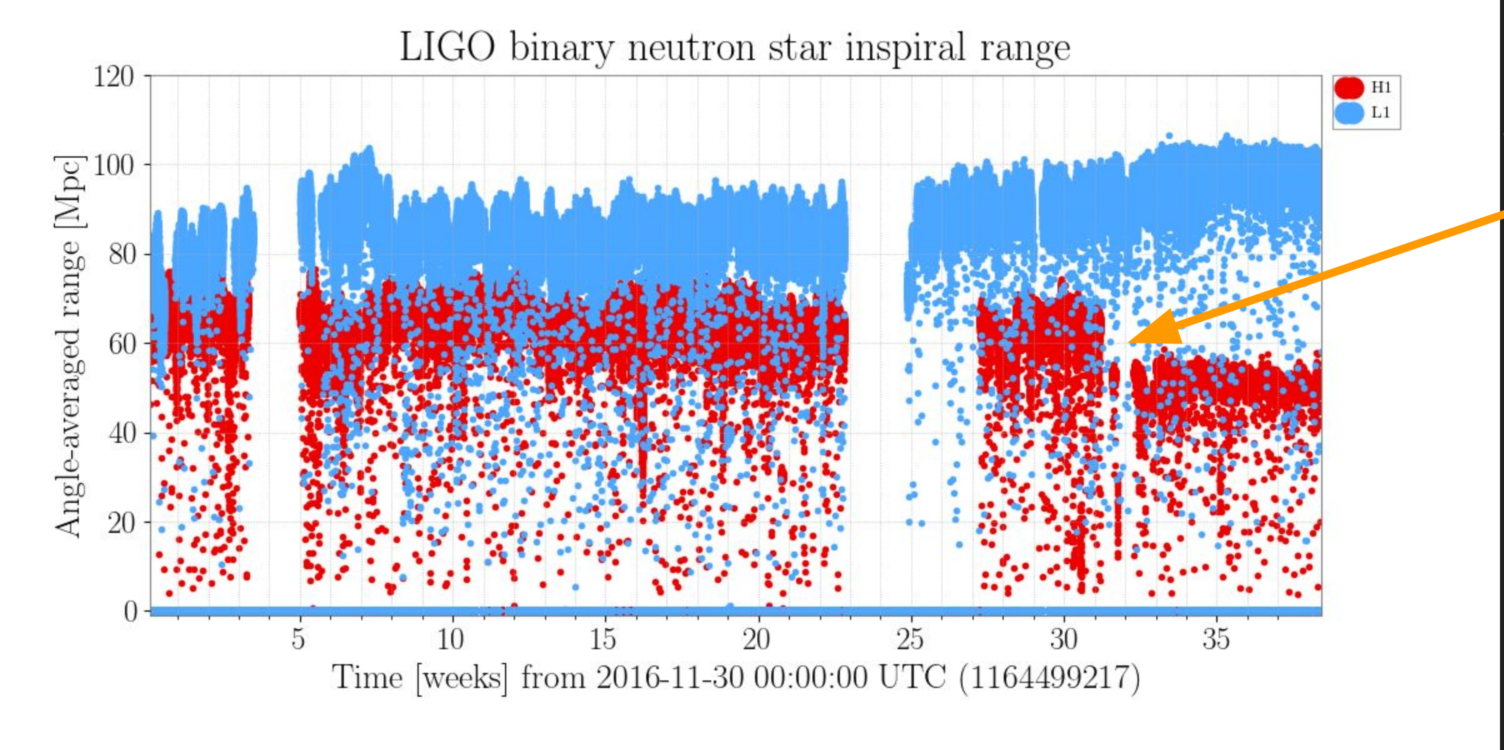


July 5th, 2017 Earthquake at LHO



July 5th, 2017 Earthquake

A 5.8 magnitude earthquake hit western Montana, around 300 miles from Hanford, during O2. This caused a 25% loss in sensitive range at Hanford.



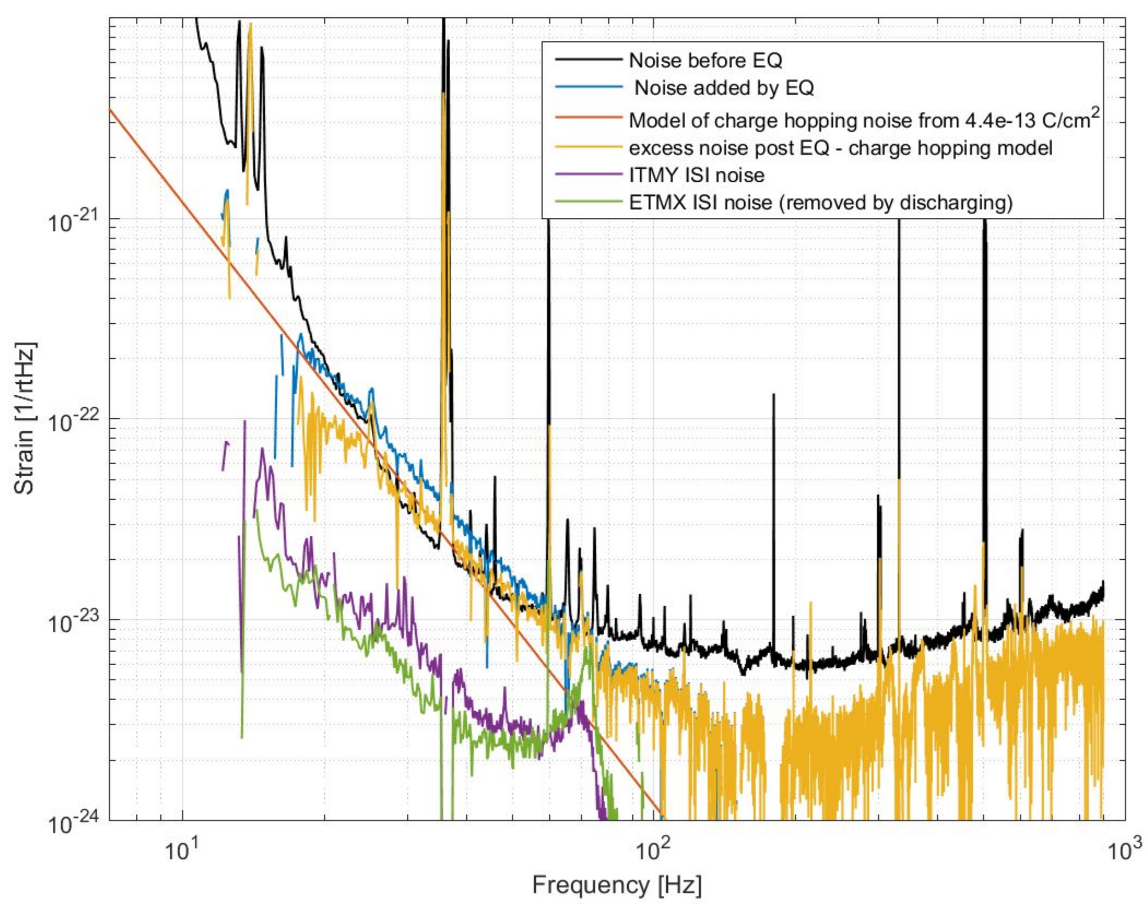
July 5th Earthquake

July 5th, 2017 Earthquake

A 5.8 magnitude earthquake hit western Montana, around 300 miles from Hanford, during O2.

The core optics hit the earthquake stops, which transferred charge from the stops to the optics.

Discharging reduced noise, but could not eliminate all noise.



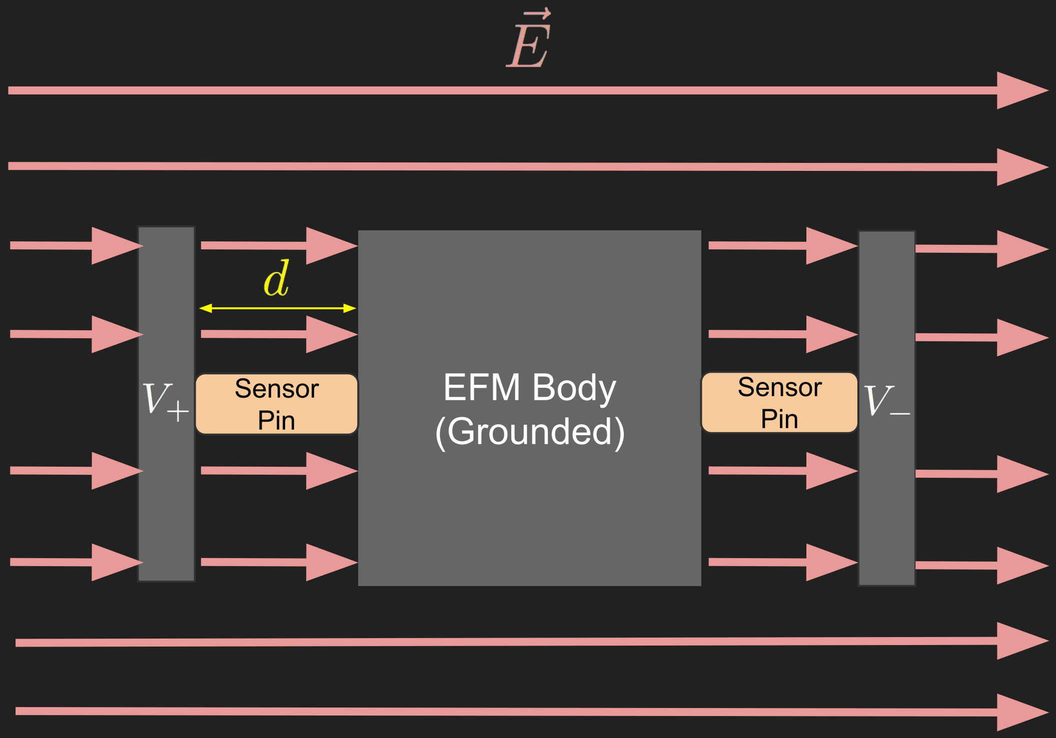
How does the Electric Field Meter work?

Some electric field $\vec{E}$ is incident on the EFM.

The $\vec{E}$ field terminates on the grounded body, and passes through the floating sensor plates, inducing voltage $V = |\vec{E}|d$

Inside the EFM is a differential op-amp circuit, so the EFM output is

$$V_{\text{out}} = V_+ - V_-$$



Calibrating the Electric Field Meter

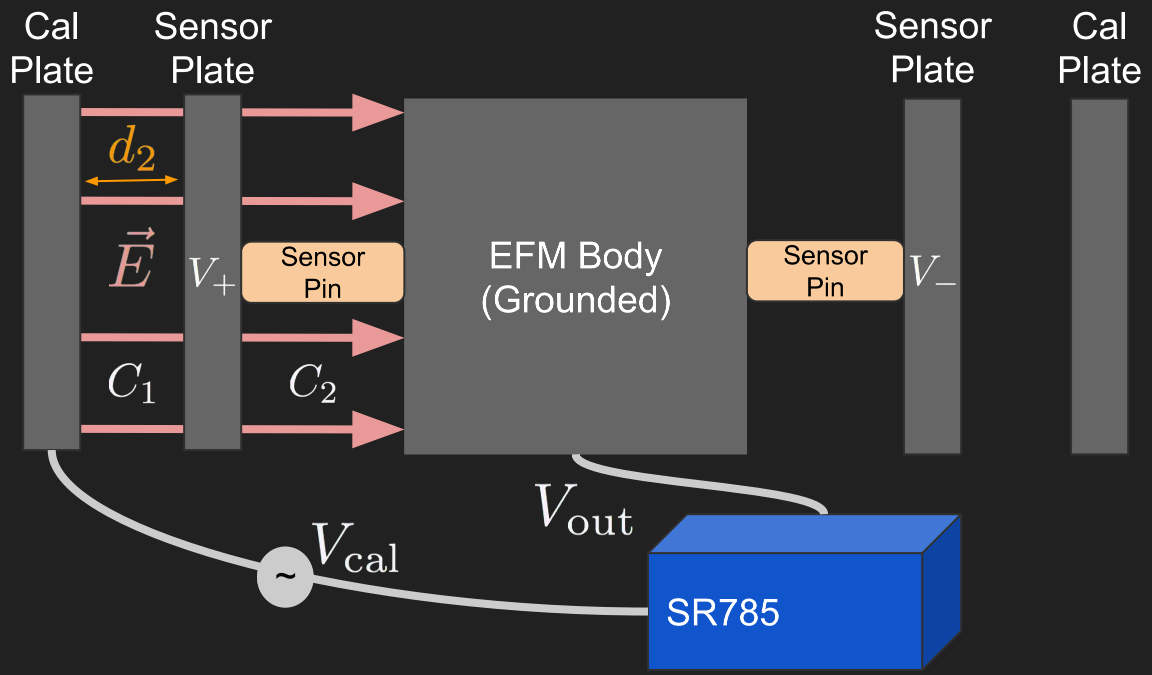
Attach a floating calibration plate and drive it using an SR785.

Measure transfer function from driven to output voltage. $\frac{V_{\text{out}}}{V_{\text{cal}}}$

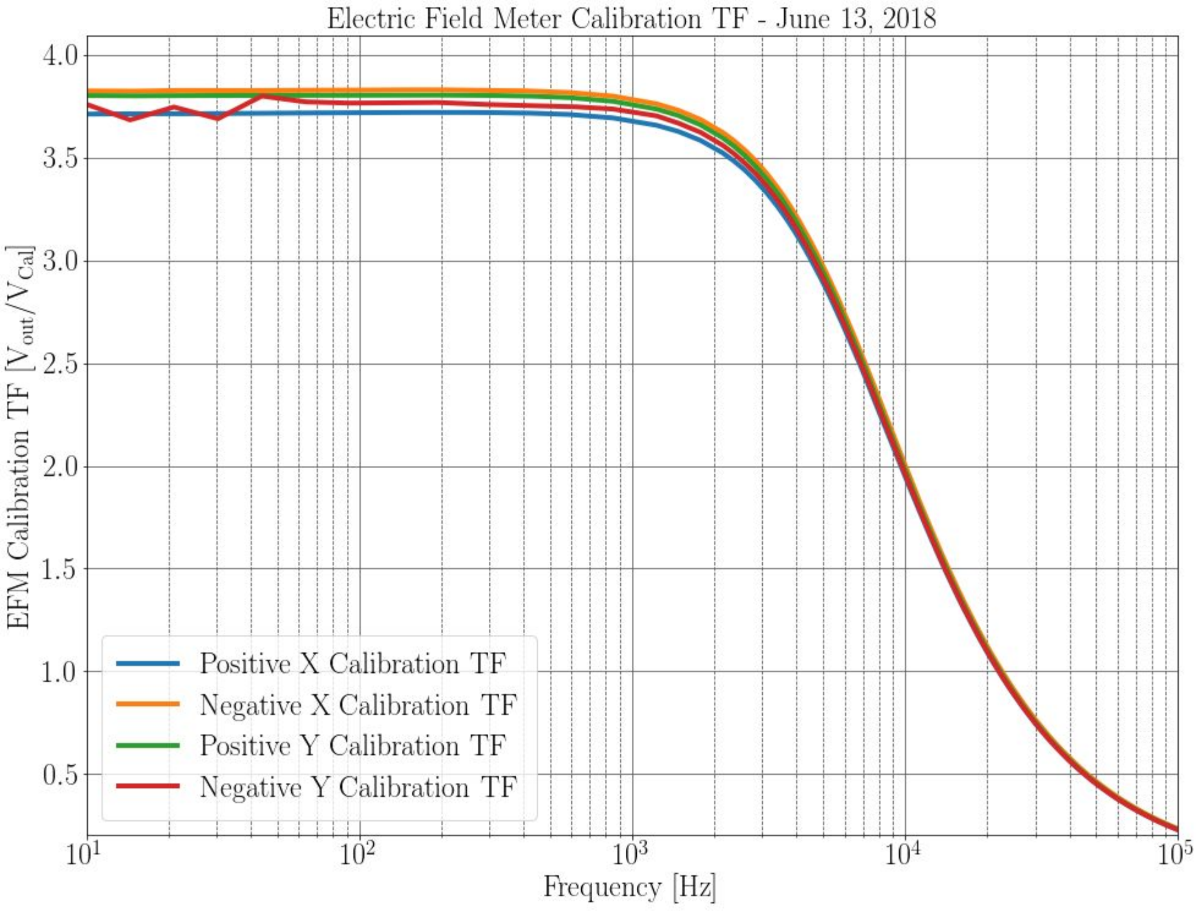
Measure the capacitances between the cal and sensor plates C_1 and the sensor plate and the EFM body C_2

Estimate calibration volts to electric field transfer function

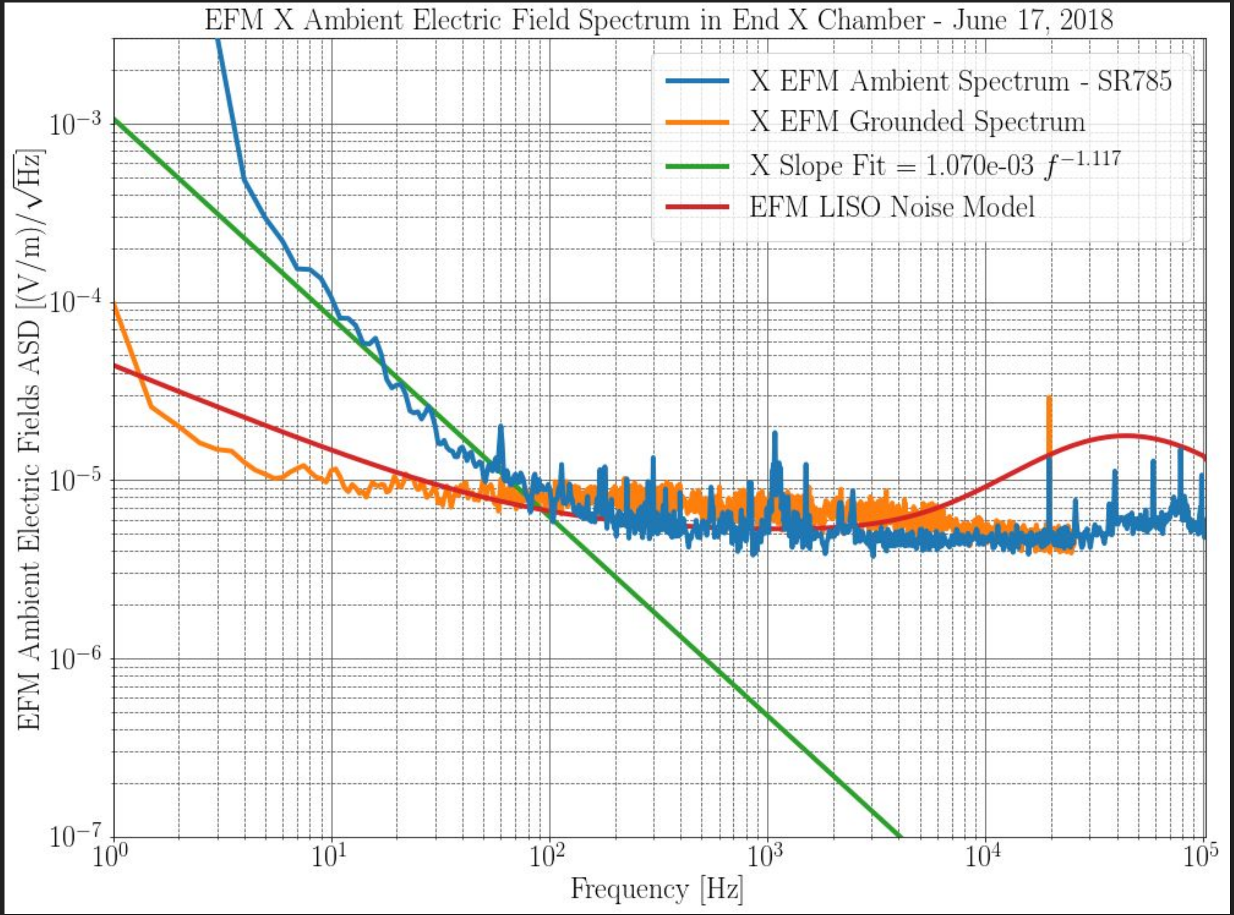
$$\frac{|E|}{V_{\text{cal}}} = \frac{C_1}{d_2\,(C_1 + C_2)} \approx 37.3\,\frac{\mathrm{V/m}}{\mathrm{V_{cal}}}$$



Calibrating the Electric Field Meter



LHO X-end Electric Field Meter Noise ASD



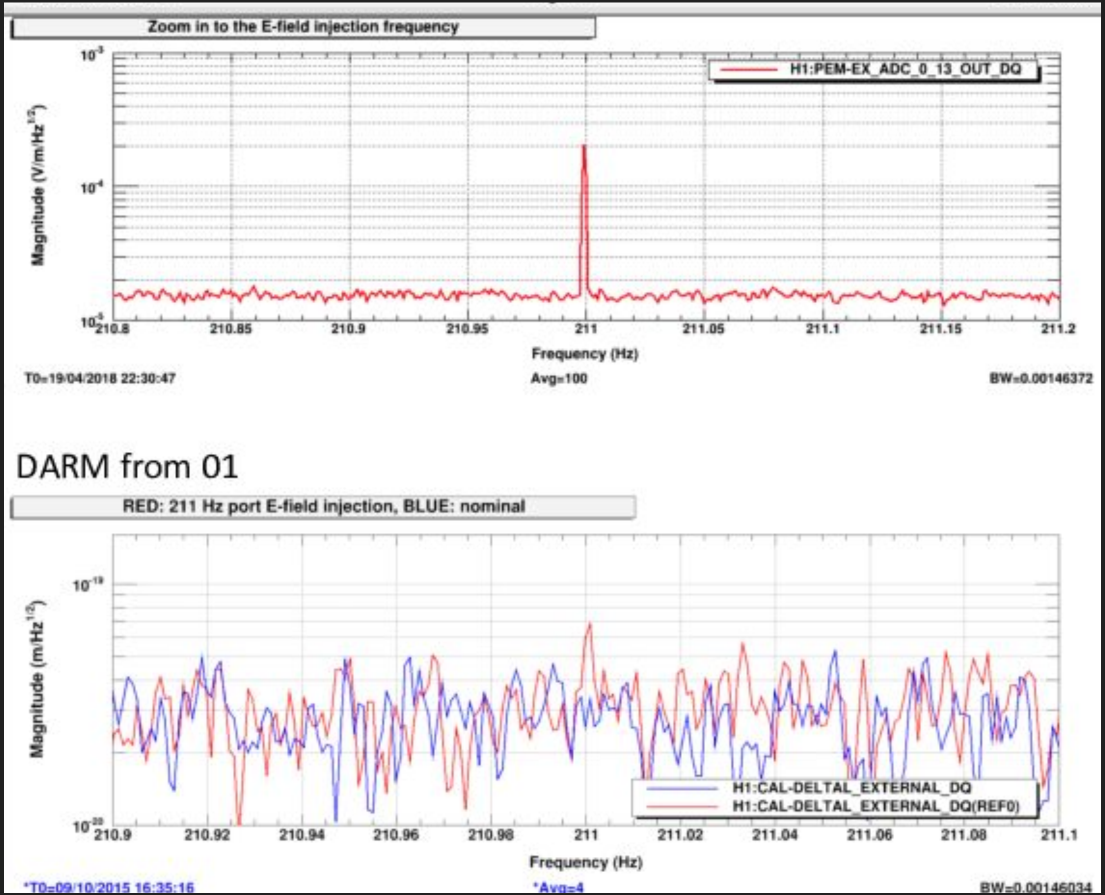
X-end Viewport Electric Field Injection

During O1, Robert Schofield injected an electric field at 211 Hz through an X-end viewport to measure the coupling to DARM.

After installing the 2nd EFM prototype, Robert and Georgia repeated the measurement.

SNR for the EFM is greater.
For O3 we'll be sensitive to electric fields coupling into DARM

$$\frac{L_{\mathrm{DARM}}}{E_{\mathrm{EFM}}} = 1.6 \times 10^{-16} \frac{\mathrm{m}}{\mathrm{V/m}}$$



What's Next

1) Install EFMs at LHO Y-end and LLO.
2) Figure out whether the EFM is sensitive enough to tell us interesting info about electric fields.
3) Better estimate of electric field to length coupling.
4) Think about potential sources of excess in-chamber electric fields.
5) Estimate the EFM electric field to ETM electric field transfer function. (Hard)
6) If it is, we can answer big questions:
   a) How much do stray E fields couple to DARM?
   b) Can we do something to limit the stray E field levels?
   c) Are ESDs with fused silica ETMs viable actuators for the future of low-noise interferometry?

EFM Team

Rai Weiss, Peter Fritschel

Rich Abbott, Calum Torrie, Luis Sanchez

Georgia Mansell, Jeff Kissel, Robert Schofield, Craig Cahillane

Carl Adams, Carl Blair

Bibliography

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[3] Martynov, D. "Lock Acquisition and Sensitivity Analysis of Advanced LIGO Interferometers." Thesis. https://dcc.ligo.org/P1500087

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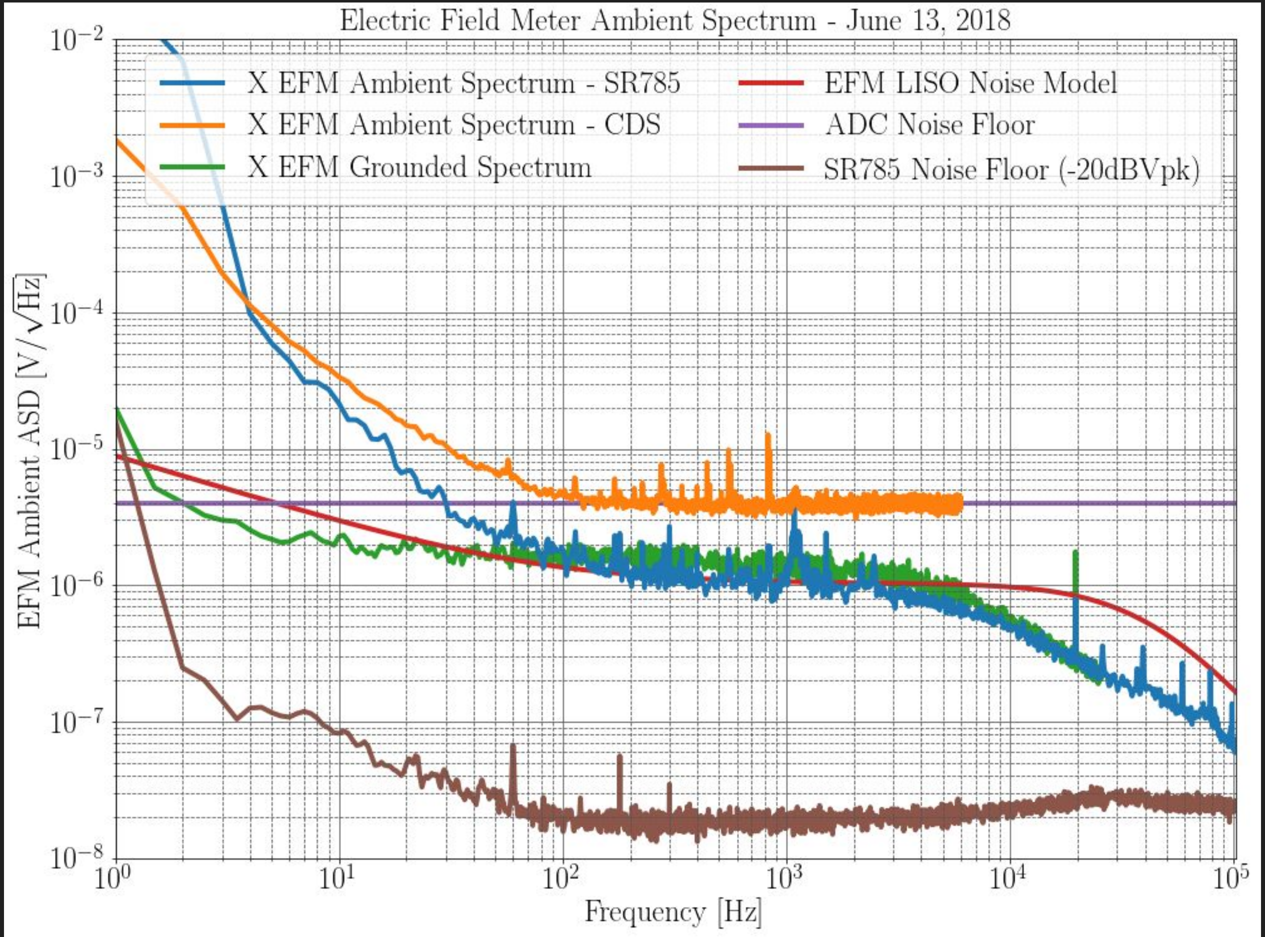
[8] Sorazu, B. "Charging issues at the sites" https://dcc.ligo.org/G1401033

[9] Lantz, B. and Mason, K. "Overview for the Advanced LIGO HAM ISI Preliminary Design Review" https://dcc.ligo.org/T080236

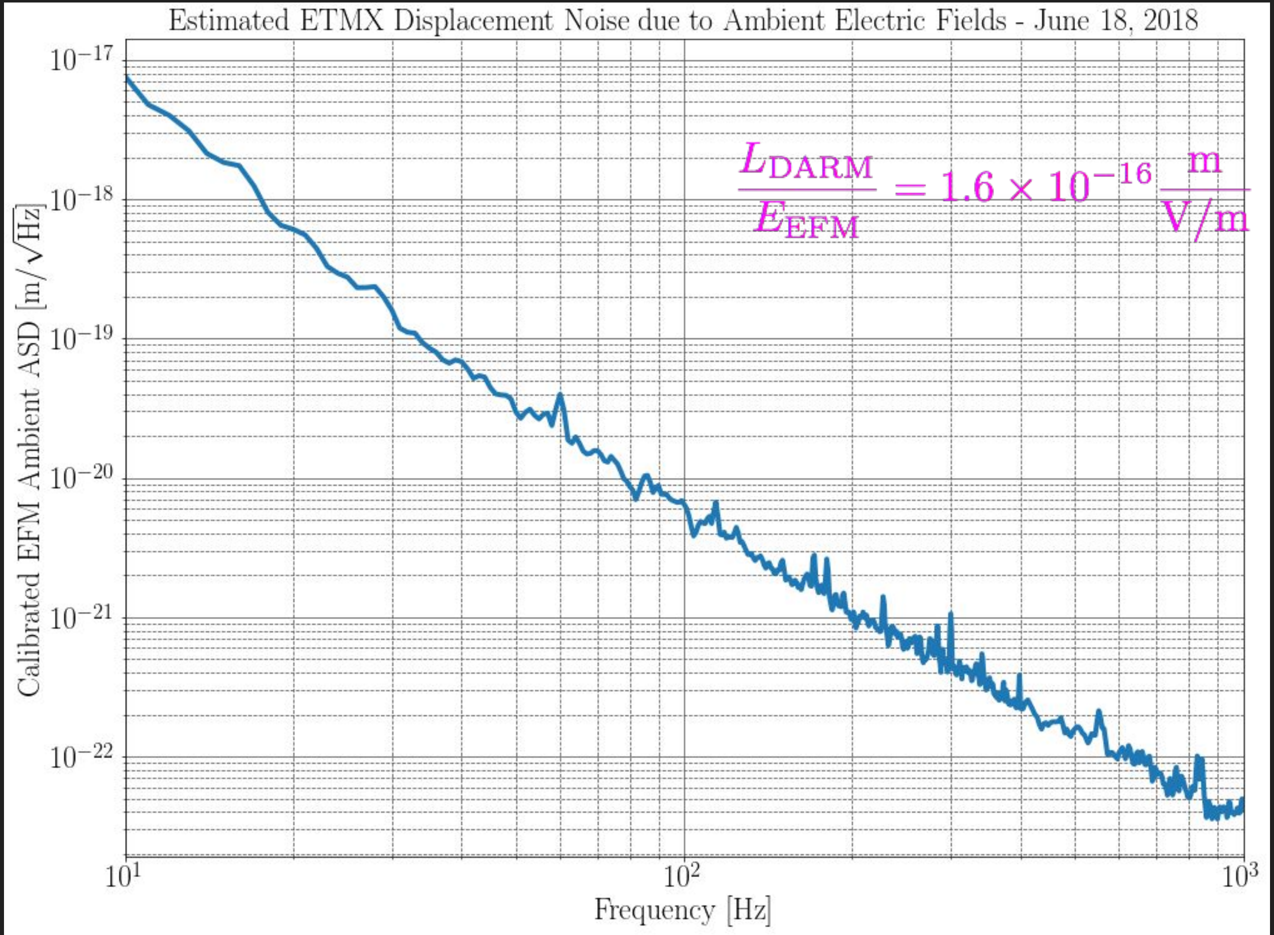
[10] aLIGO Quad Assembly. https://dcc.ligo.org/LIGO-D060454

Extra Slides

EFM Volts ASD



Electric Field Displacement Noise Estimate



EFM LHO aLOGs

Characterization and EF Injection for 1st EFM Prototype: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=40878
Initial Calibration of 1st EFM Prototype: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=40949
Optics Lab Characterization of 2nd Prototype EFM: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41374
EFM CDS Channels added to PEM: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41393
Installation of 2nd Prototype: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41427
Characterization of 2nd Prototype: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41483
Further Characterization of 2nd Prototype: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41532
Electric Field Injection with 2nd Prototype: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41559
Electric Field Injection Results: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=41589
Installation of EFM1: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=42245
Characterization of EFM1: https://alog.ligo-wa.caltech.edu/aLOG/index.php?callRep=42250

Note: 1st EFM Prototype is Rai Weiss's 3rd version which was sent to LHO for initial tests.
The 2nd EFM Prototype is the first version build by Rich Abbott, Calum Torrie, and Luis Sanchez at Caltech.
EFM1 is the permanently installed version at LHO X-end)

Initial Prototype Electric Field Meter

Rai Weiss's Prototype, installed briefly at LHO by Georgia Mansell and Jeff Kissel

Was put in chamber, characterized, and detected the ISI drive electric fields.

Results were deemed promising enough to have Rich Abbott and Calum Torrie design a more permanent EFM for use during O3.