Understanding Initial LIGO and Possible Influences on Enhanced LIGO

Sam Waldman and Rai Weiss

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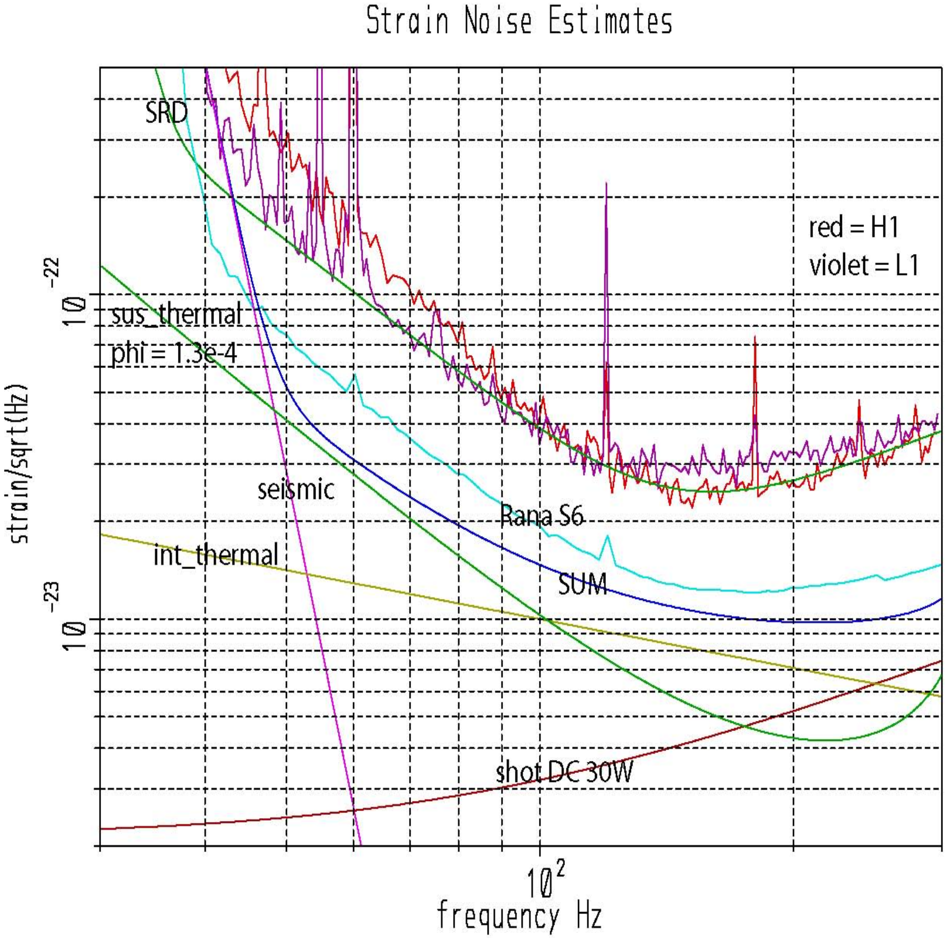
Outline

- Motivations
  - Improve understanding of initial LIGO, f < 200Hz
  - Improve chance of detections in enhanced LIGO
  - Reduce probability of surprises in advanced LIGO
  - Reduce commissioning time in advanced LIGO
- Known and suspected noise contributions
  - Evidence for the noise sources and their effect on the enhanced LIGO spectrum in the low frequency band. Noise sources considered in the original enhanced LIGO plan included.
  - Concepts to reduce the noise

Noise sources

- Sufficient understanding to propose fix
  - Charge fluctuations on the dielectrics
  - Up-conversion: magnetic moment fluctuations in control magnets driven by control current
  - Broad band noise in bias and coil driver electronics: Johnson and excess noise
- Insufficient understanding to propose fix
  - Auxiliary length and angular control noise coupling to main interferometer
  - Excess dissipation in the test mass suspensions leading to increased thermal noise



Estimates by Ilya Mandel, Richard Shaughnessy, Vicky Kalogera Jan 2008

Horizon Distance Mpc

curve	NS/NS	10/10BH	30/30BH	60/60BH
H1 S5	32	160	169	57
L1 S5	31	157	215	83
SRD	34	170	219	127
Rana S6	71	349	443	208
SUM	92	450	638	209

Detection Rate relative to SRD

curve	NS/NS	10/10BH	30/30BH	60/60BH
H1 S5	0.84	0.83	0.46	0.09
L1 S5	0.79	0.79	0.94	0.28
Rana S6	9.1	8.7	8.2	4.4
SUM	20	19	23	4.5

NS/NS detection rates using 100 NS/NS mergers per Myr in MWEG and 0.01 MWEG/Mpc^3

H1 S5 => 0.012/year

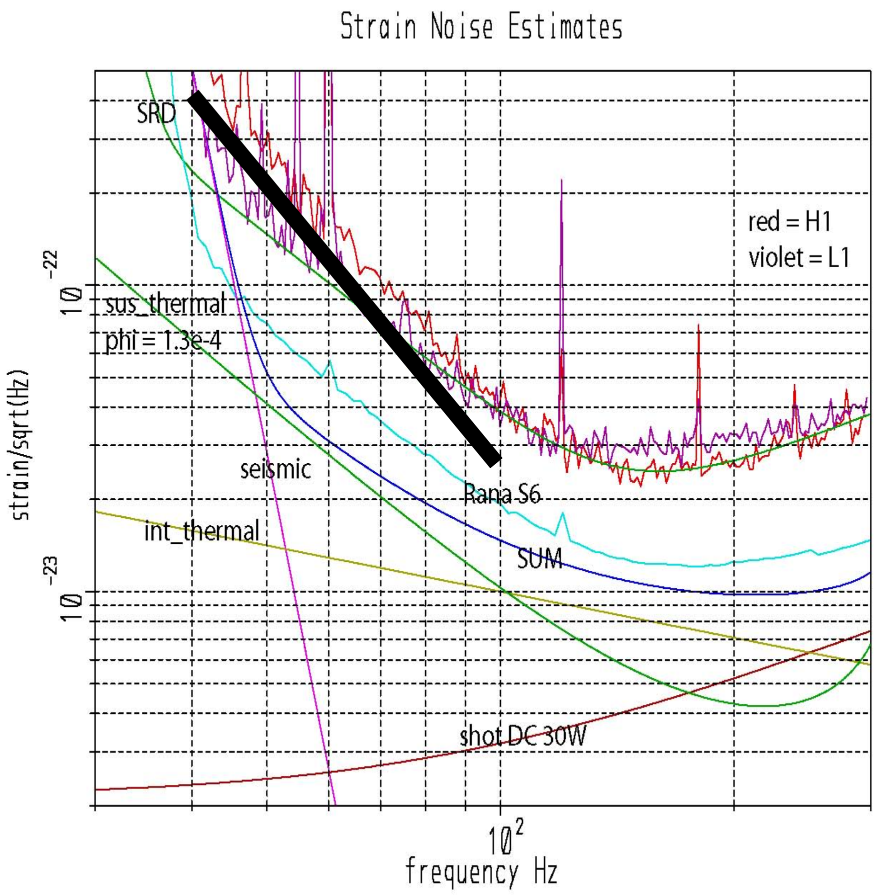
L1 S5 => 0.011/year

SRD => 0.014/year

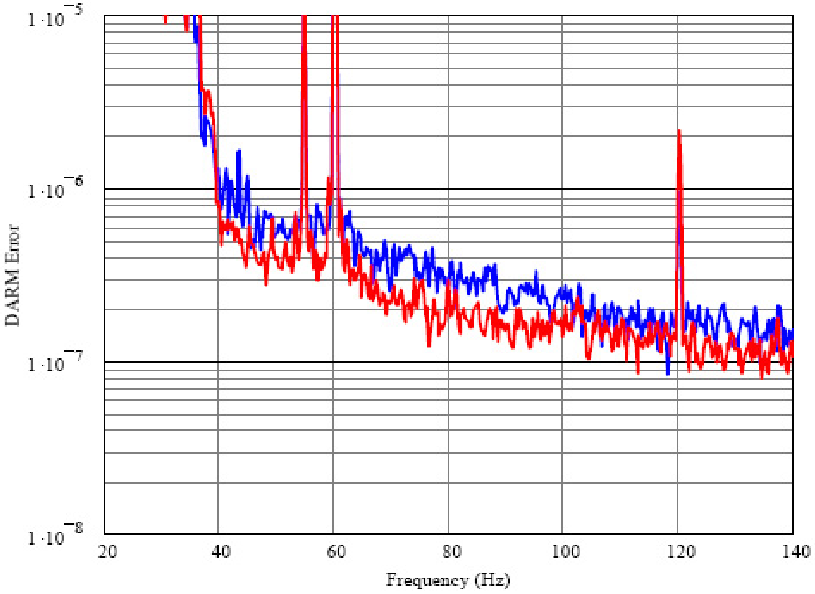
Rana S6 => 0.13/year

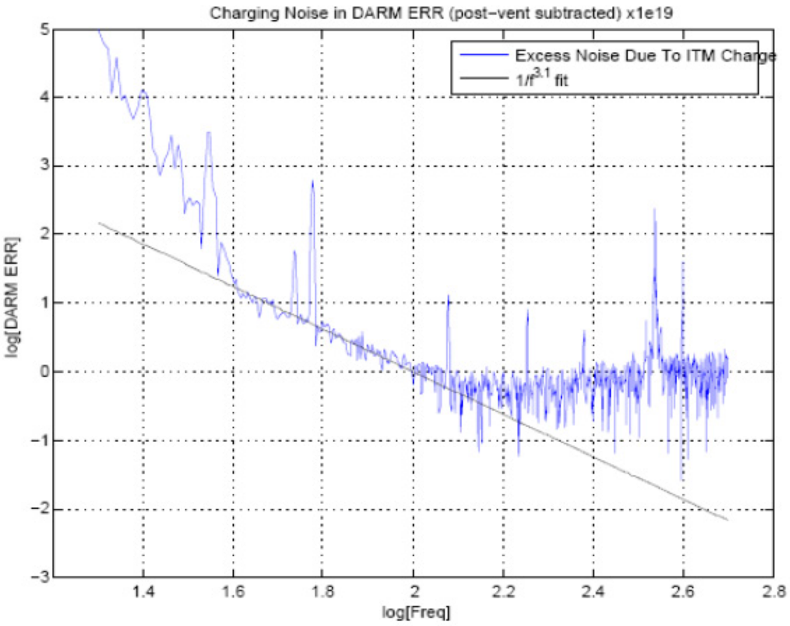
SUM => 0.28/year

Charging Noise



Charging event from earthquake stop Viton contacting test mass. Figure bottom right shows fit of difference in displacement spectra (top right) to $1/f^3$ spectrum. Charge transfer measurements between Viton and fused silica are 100 times larger than by silica against silica, Moscow State University measurements. **Fix:** new earthquake stops



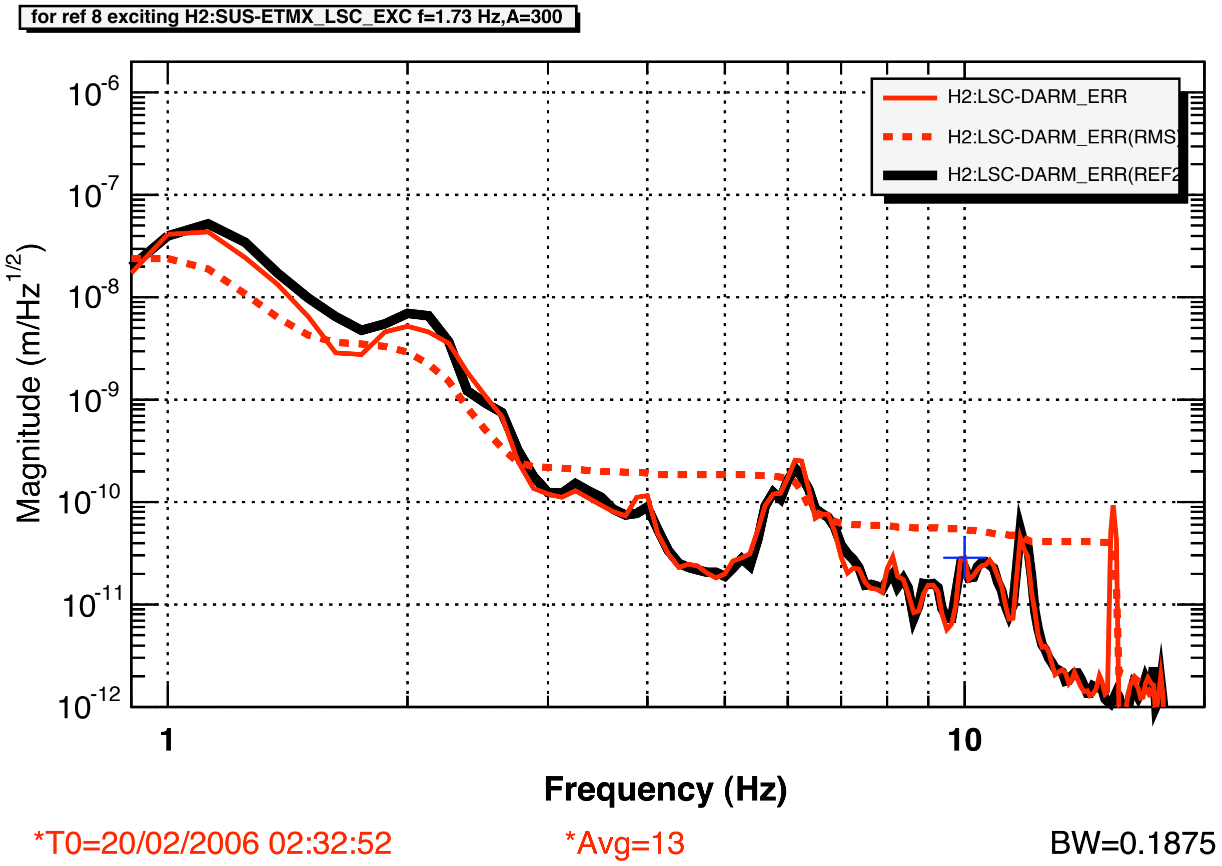


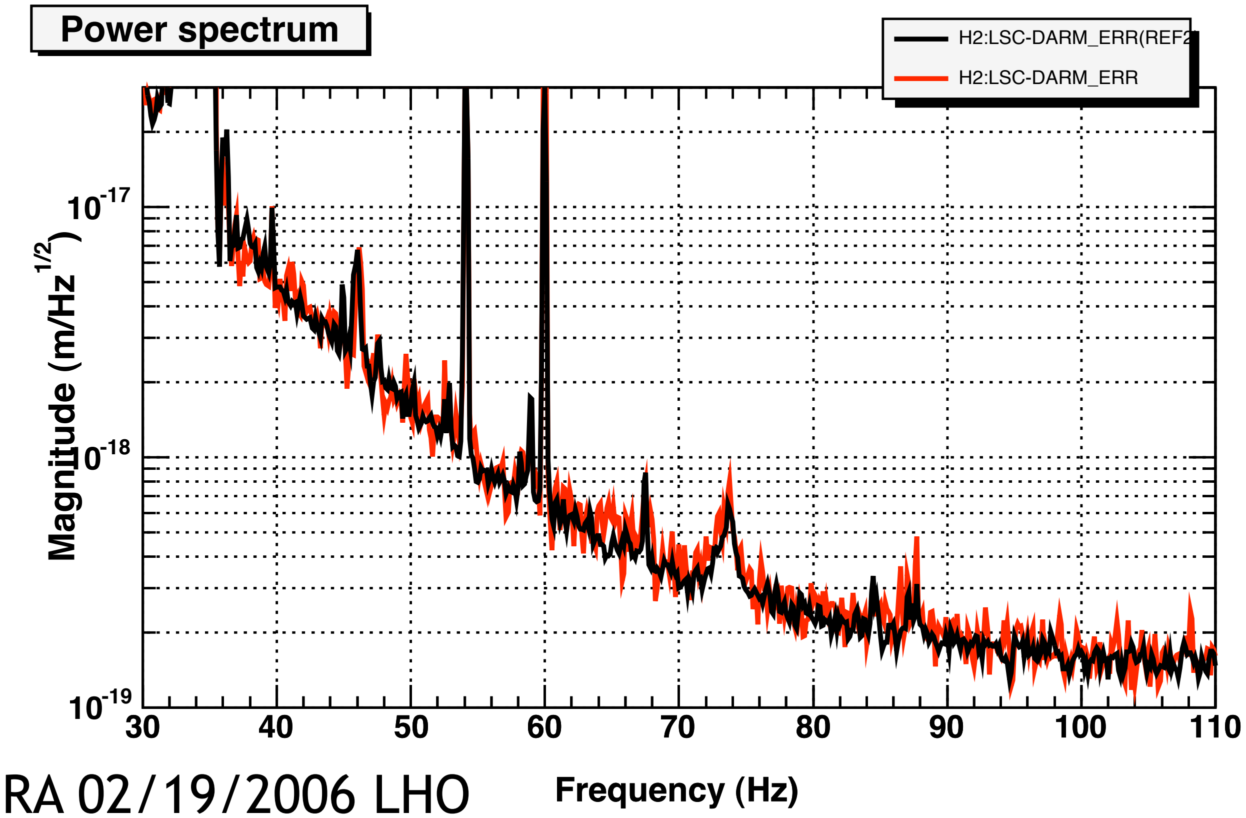
Rupal Amin

Up-Conversion

- Observation of reduction in NS/NS range and increased noise below 100Hz with increase in low frequency (f < 10Hz) noise.
- Investigation into causes of up-conversion
  - RF saturation
  - Coil driver saturation and non-linearity
  - relation to test mass displacement
  - Positive correlation with coil current
- Mitigation
  - Reduction in coil current by redistribution of control
  - Feed forward technique for low frequency contribution (proposal)
- Source of the up-conversion is magnetization noise in the magnets
  - Barkhausen noise test rig results
  - In-situ direct measurements of the up-conversion
  - Projection for the residual noise under quiescent conditions
- Proposal to replace noisy NdFeB by quiet SmCo magnets of equal strength and geometry

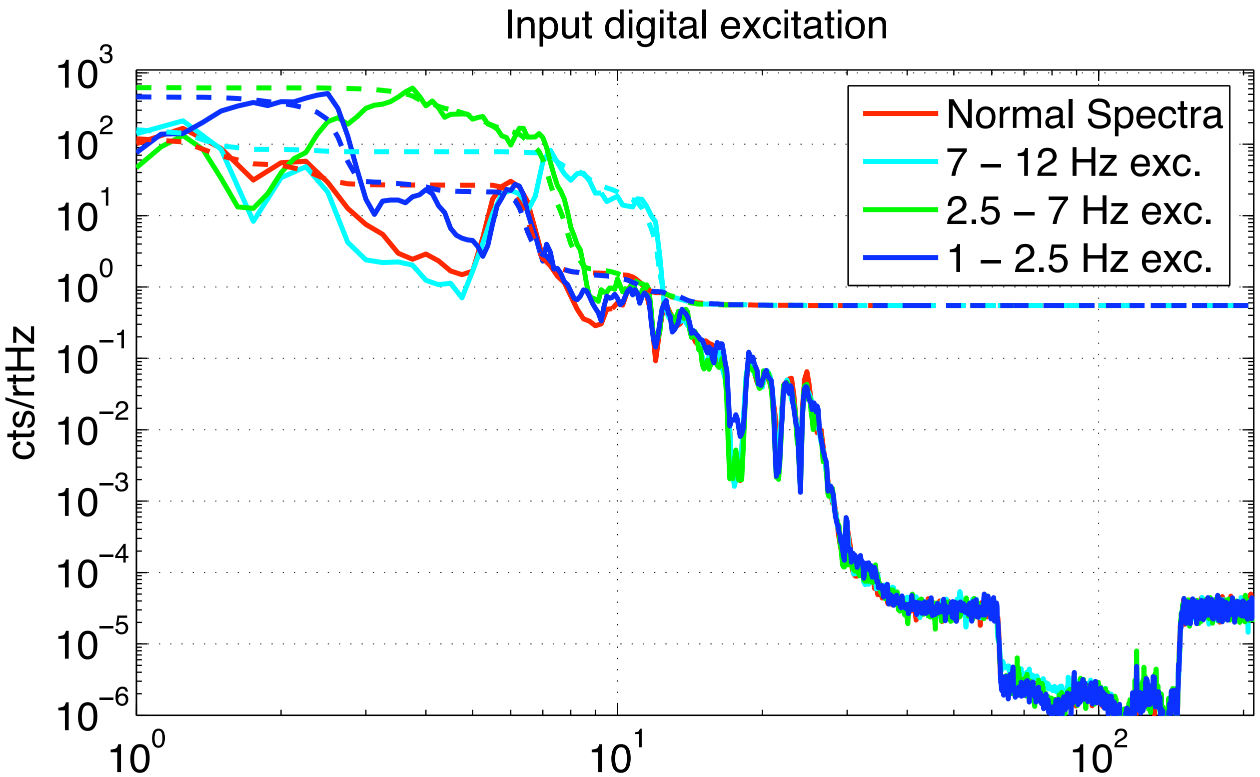
null RF saturation measurement

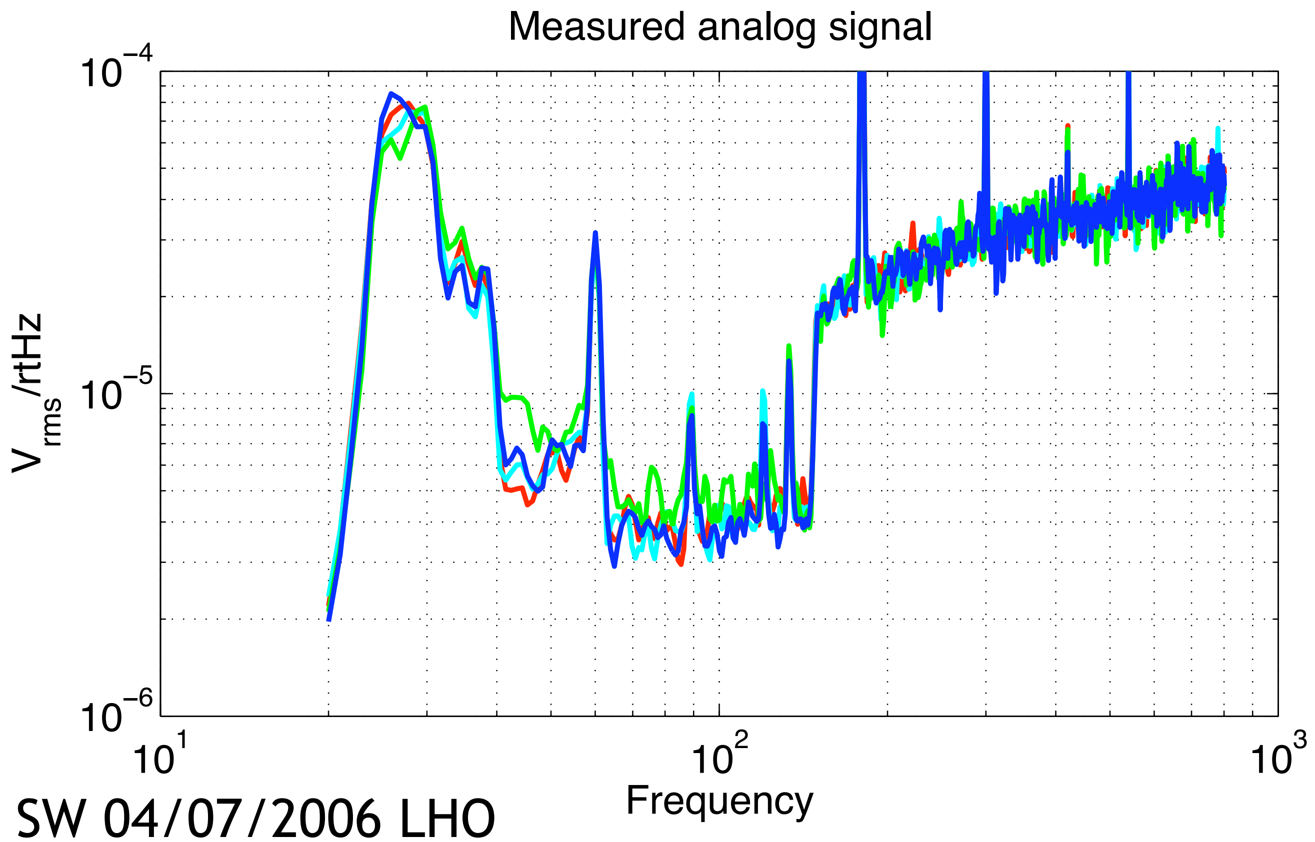




RA 02/19/2006 LHO

null coil driver measurement

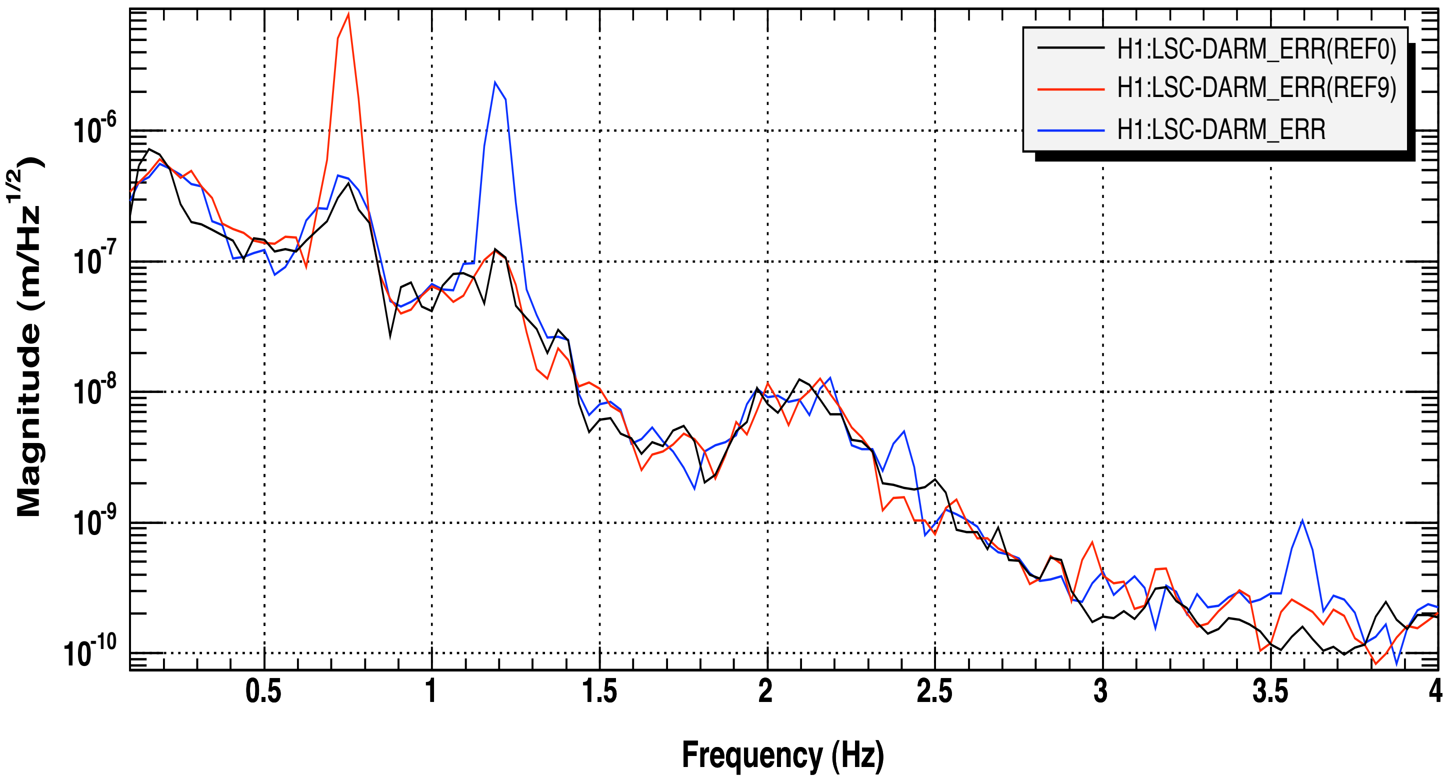




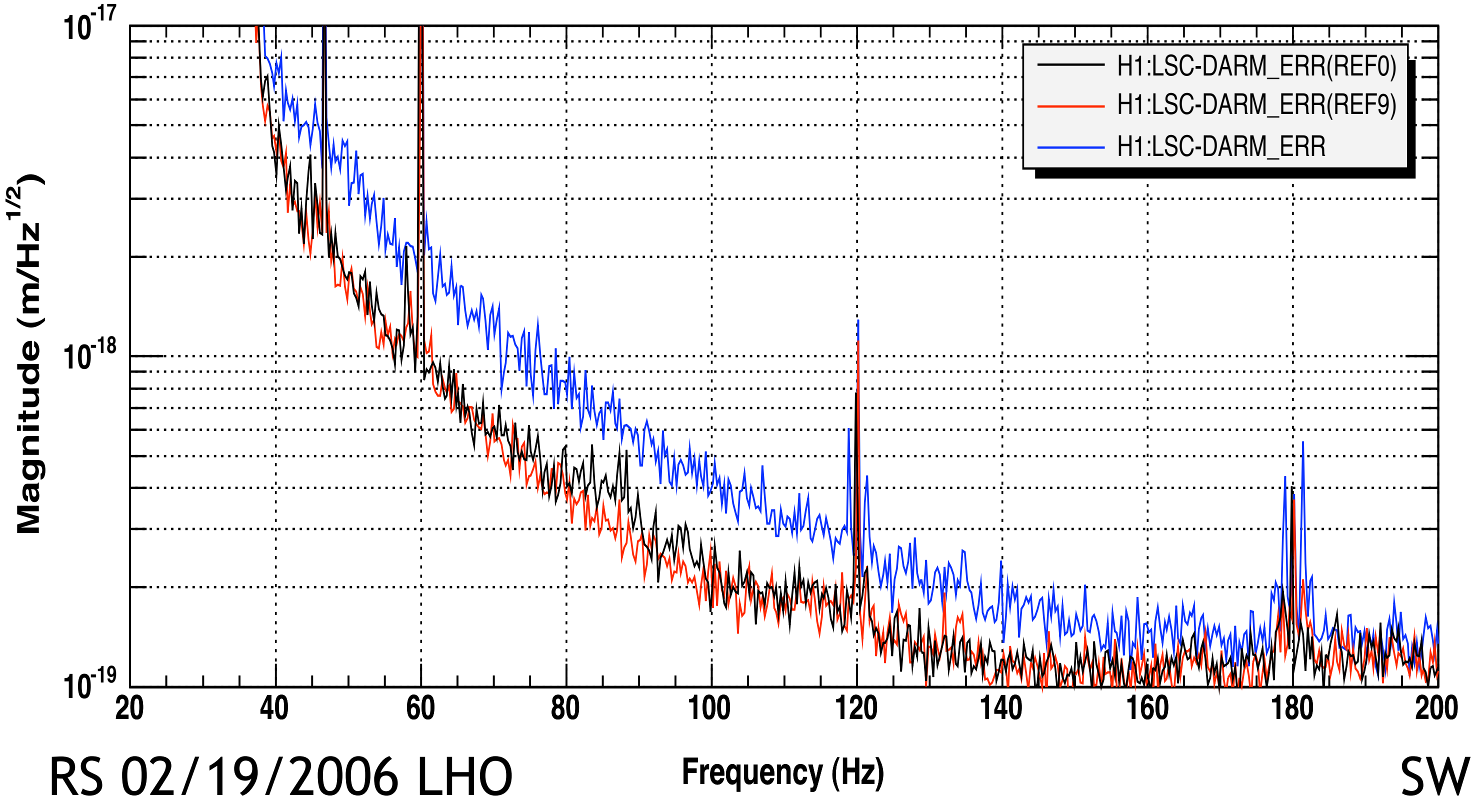
SW 04/07/2006 LHO

noise independent of DARM motion

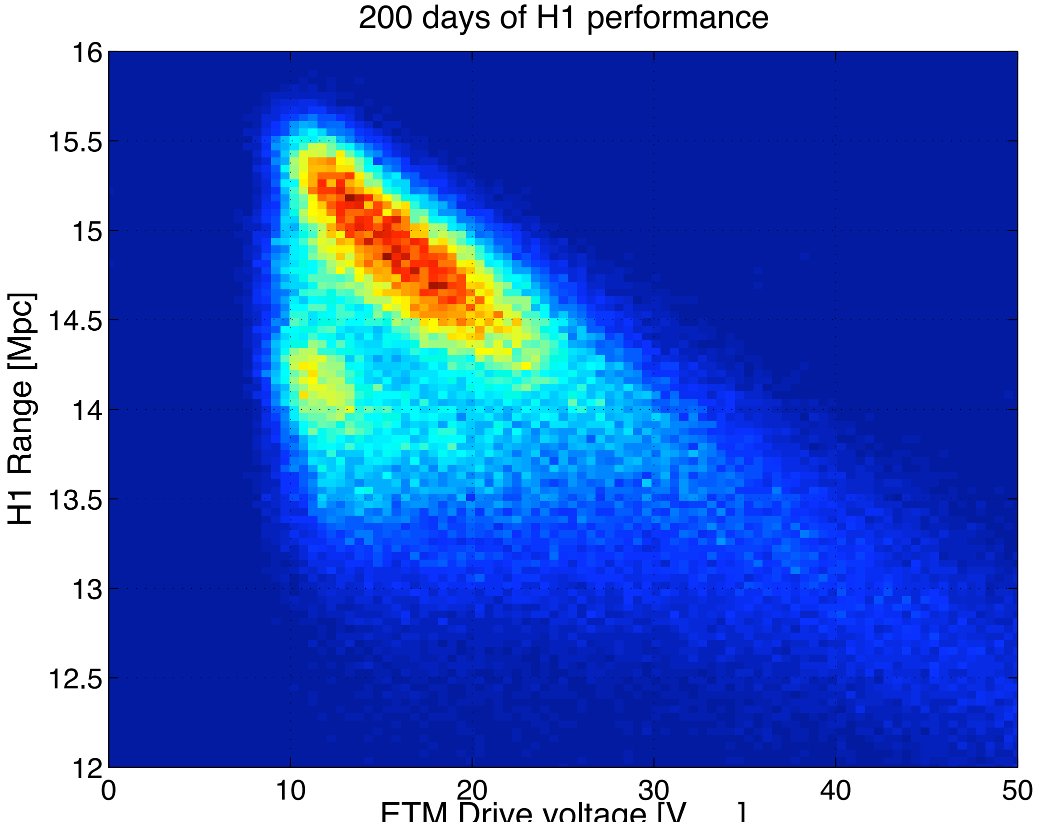
Mid-Y ground injections: Black: none, Red: 0.75 Hz, Blue: 1.2 Hz

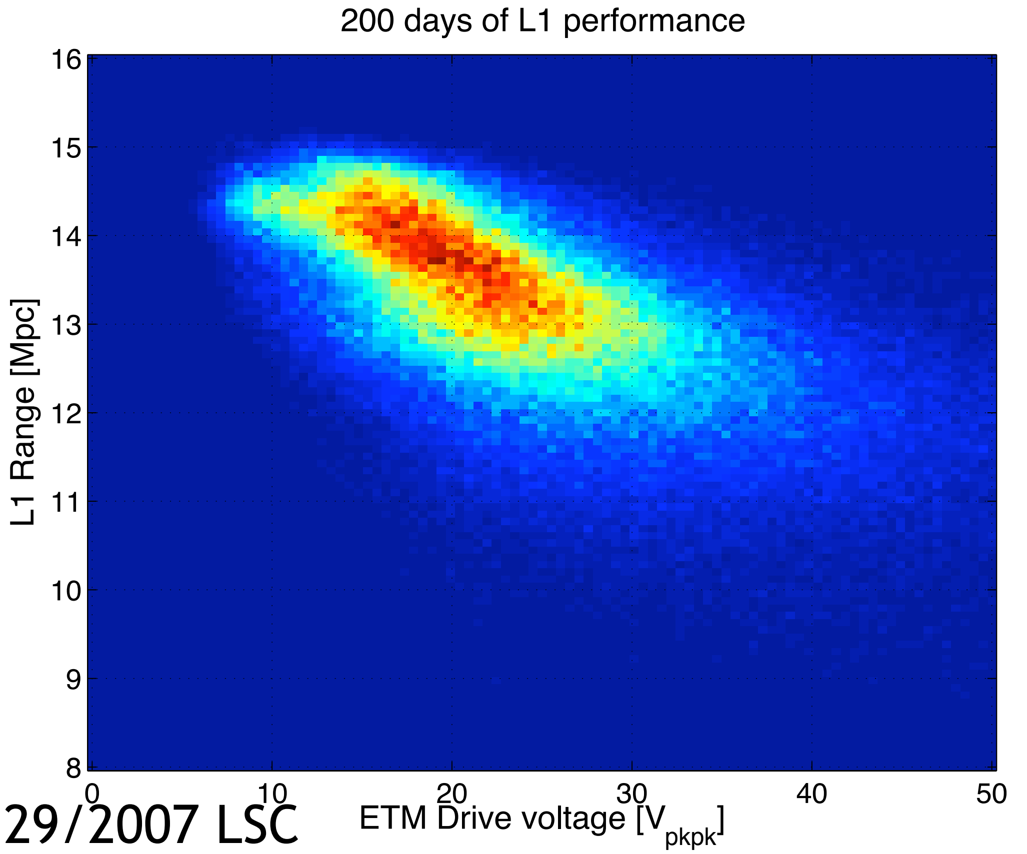


Same color scheme



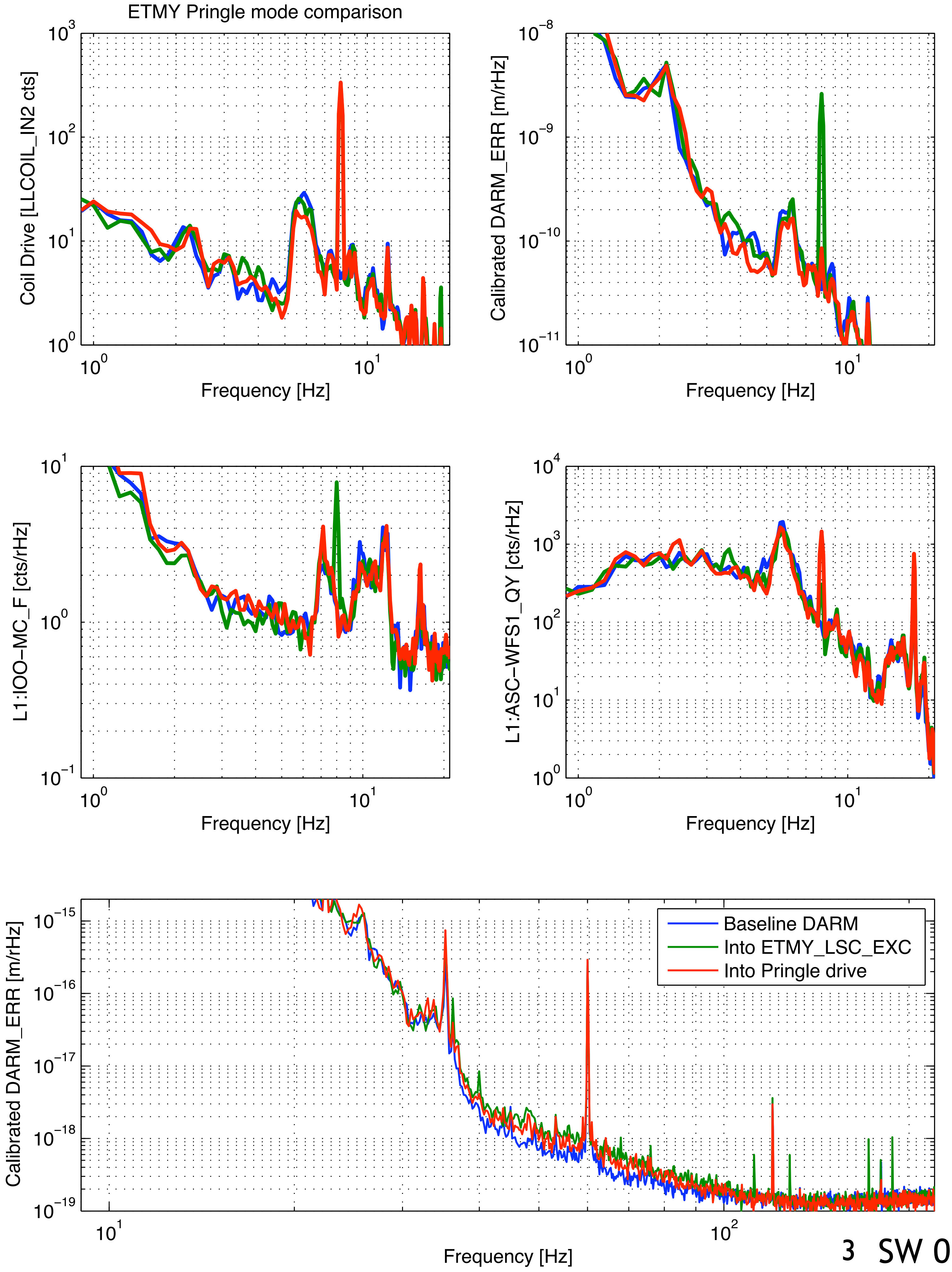
noise correlate to coils





RS 02/19/2006 LHO

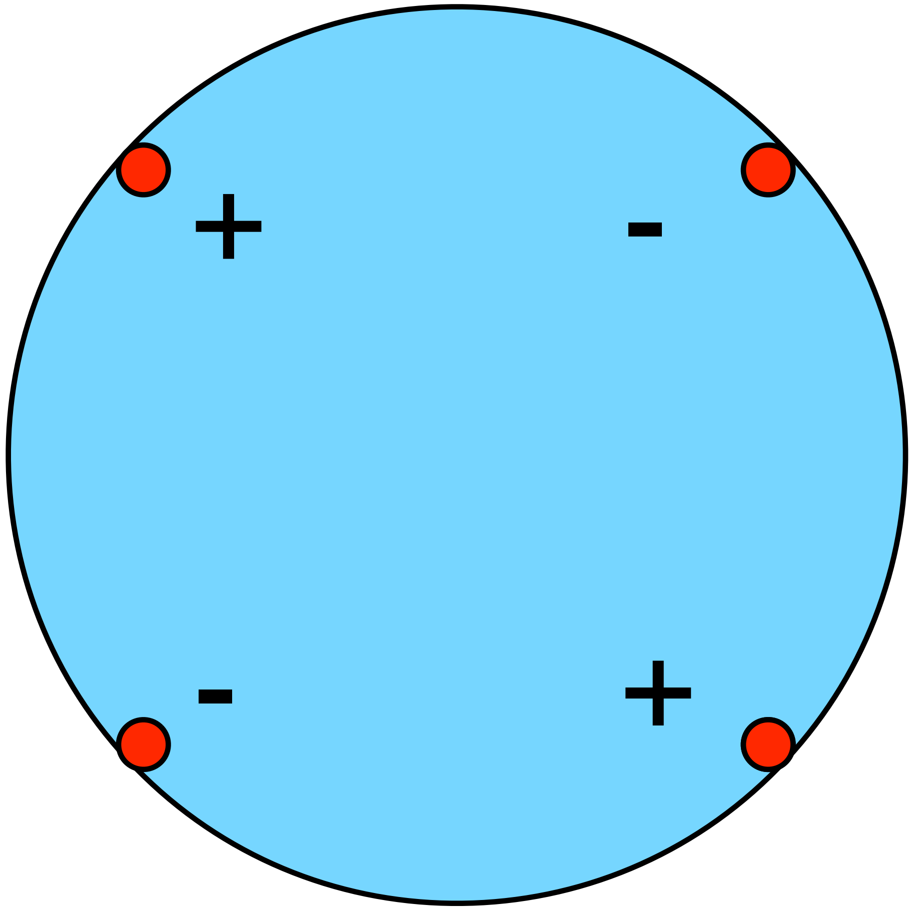
SW 03/29/2007 LSC



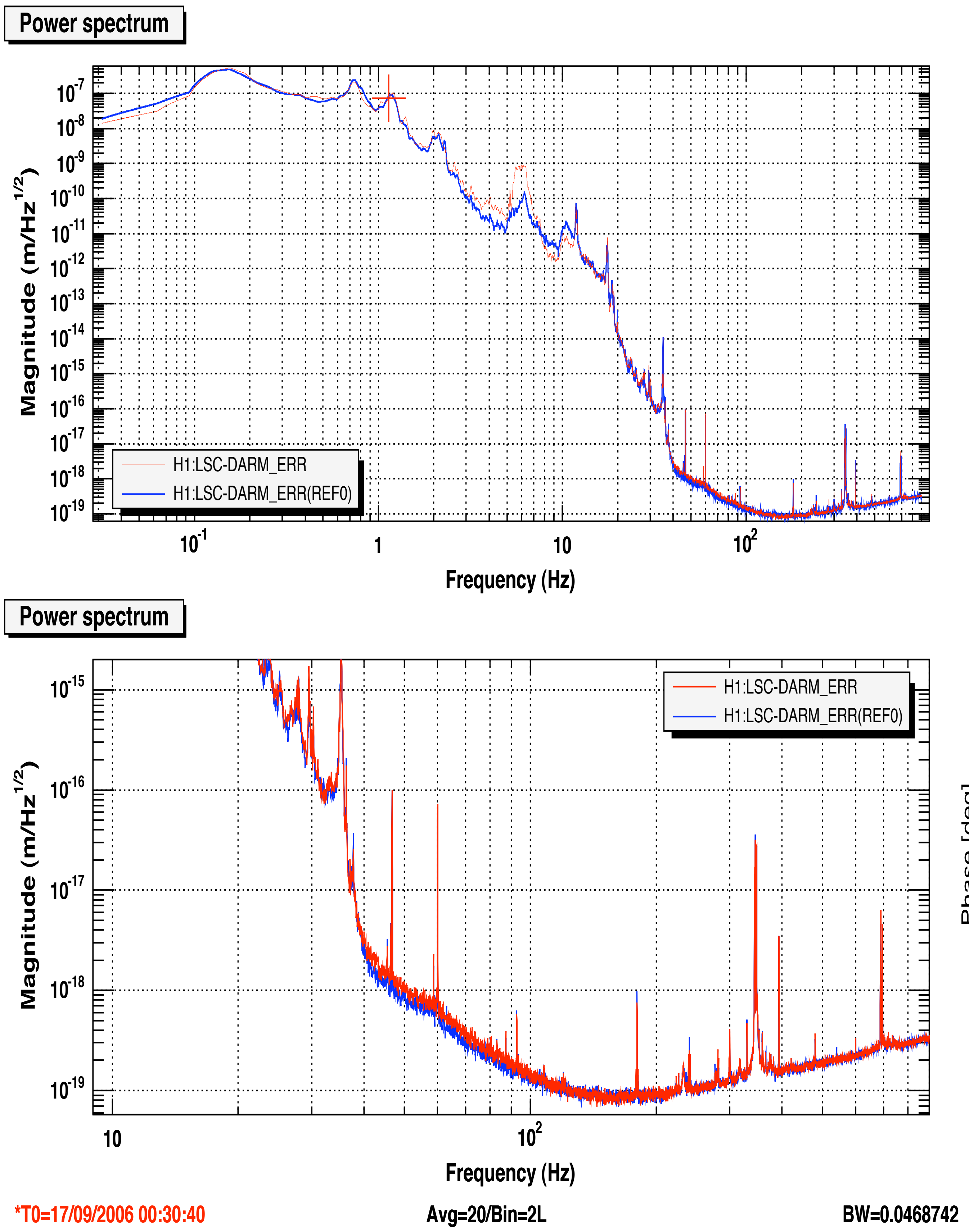
Pringle mode excitations show noise without optic motion dependent on coil drive

Induced noise spectrum similar to drive with pos and microseism

Noise spectra consistent with 70-100 Hz excess.

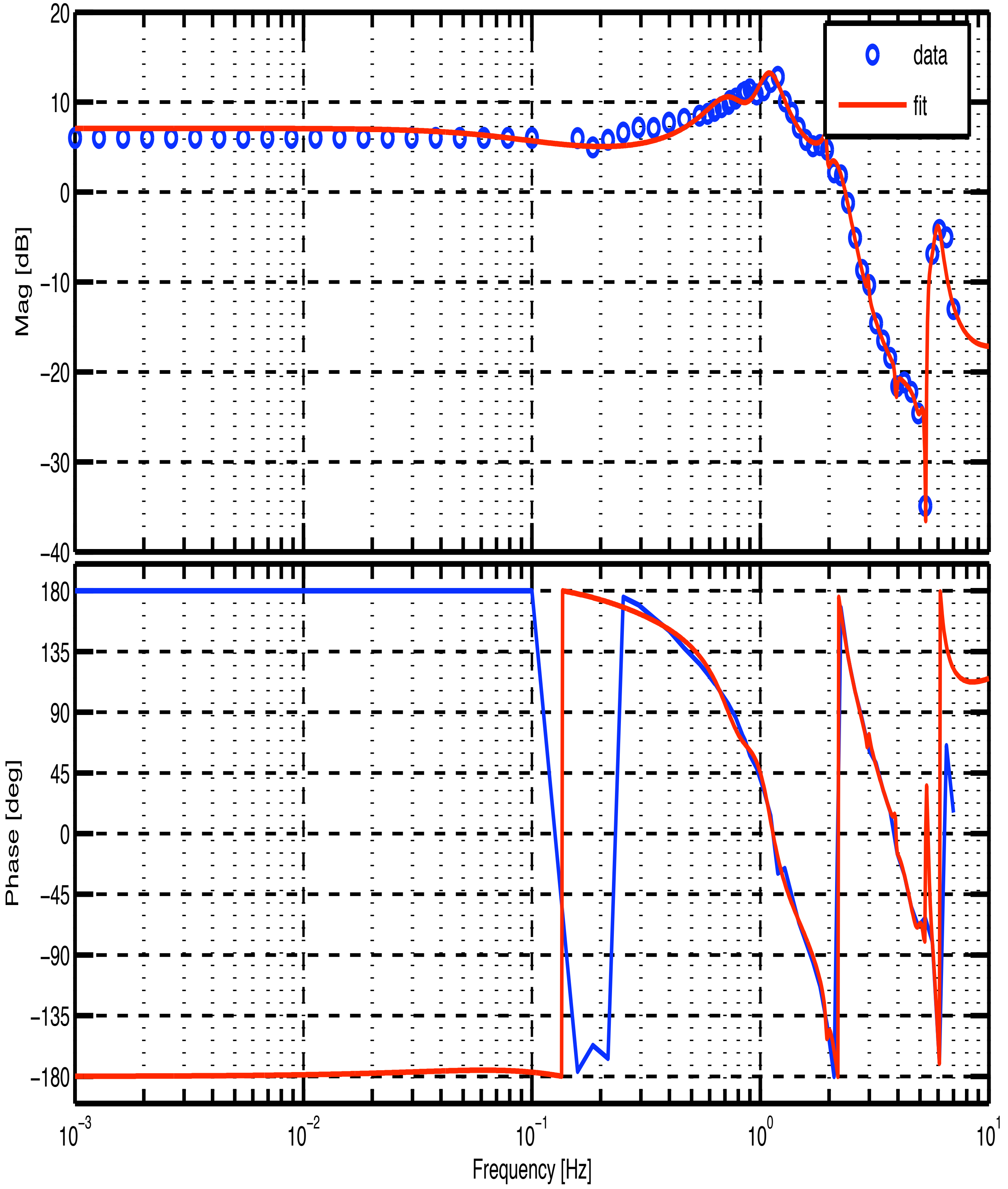


Coil reduction w/ damping filters



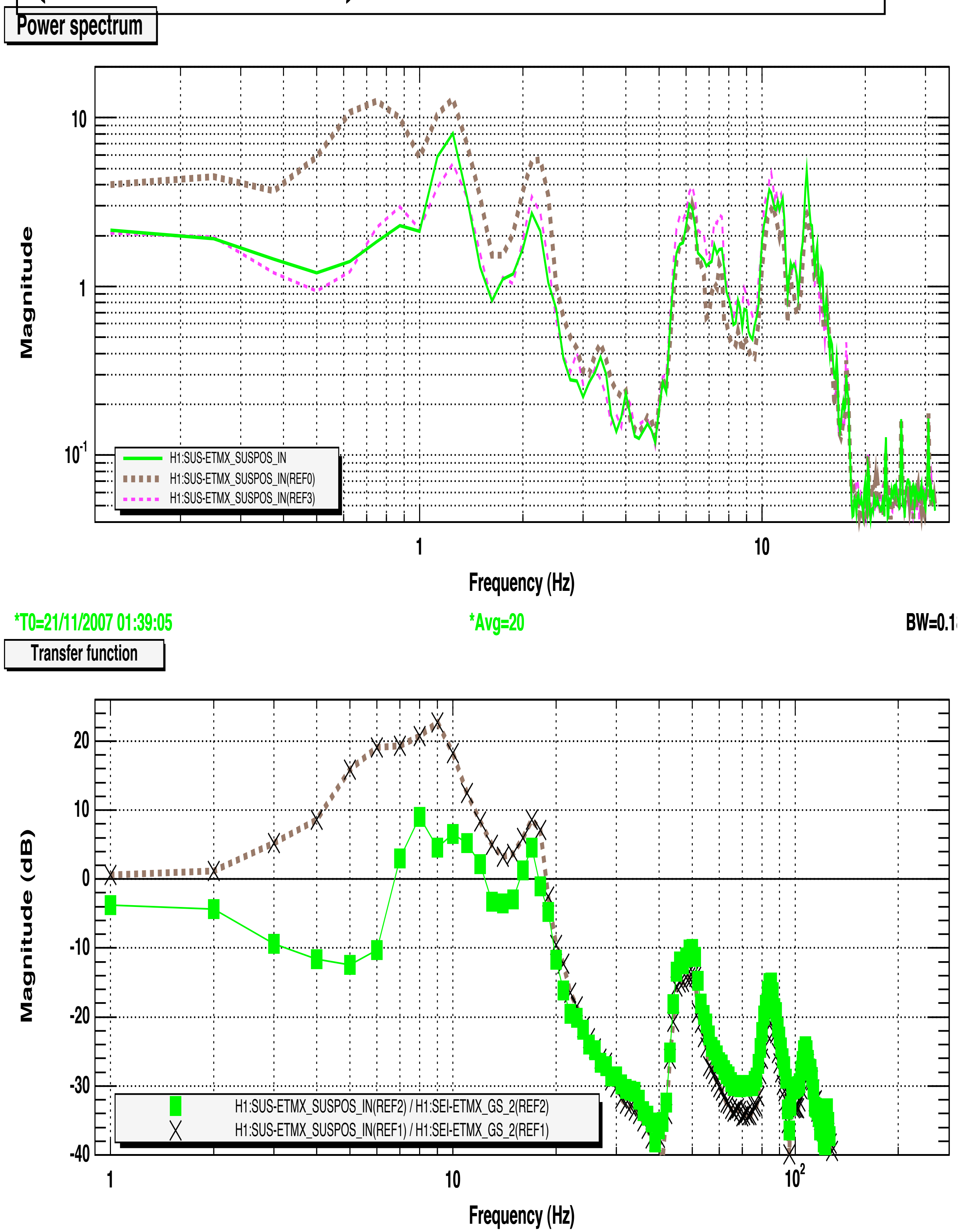
SW 09/17/2006 LHO

Coil reduction w/ tidal feedback



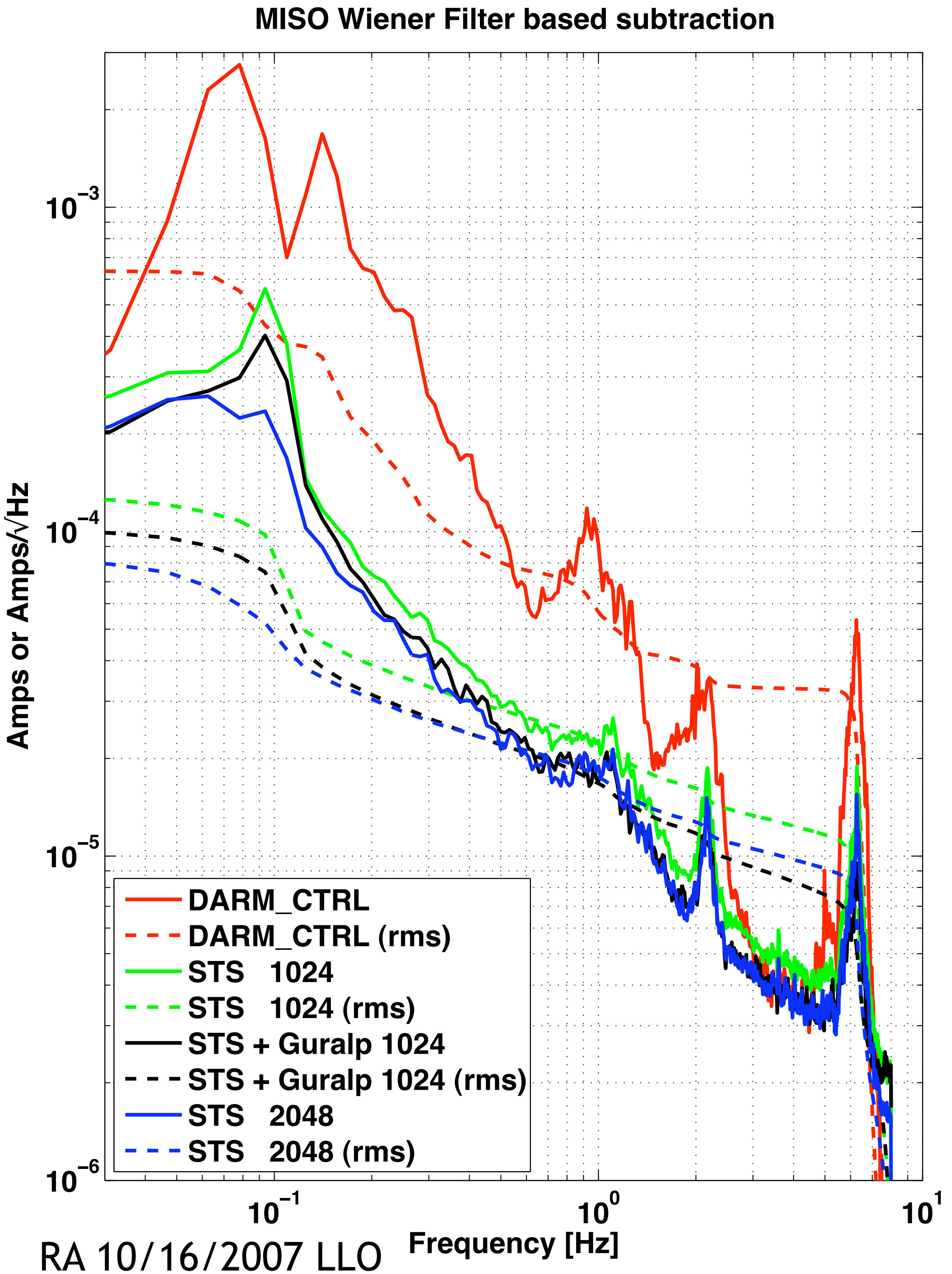
irish 01/30/2007 LLO

reduction w/ feedforward (first effort)



RA 11/21/2007 LHO

reduction w/ adaptive feedforward (predictive)



RA 10/16/2007 LLO

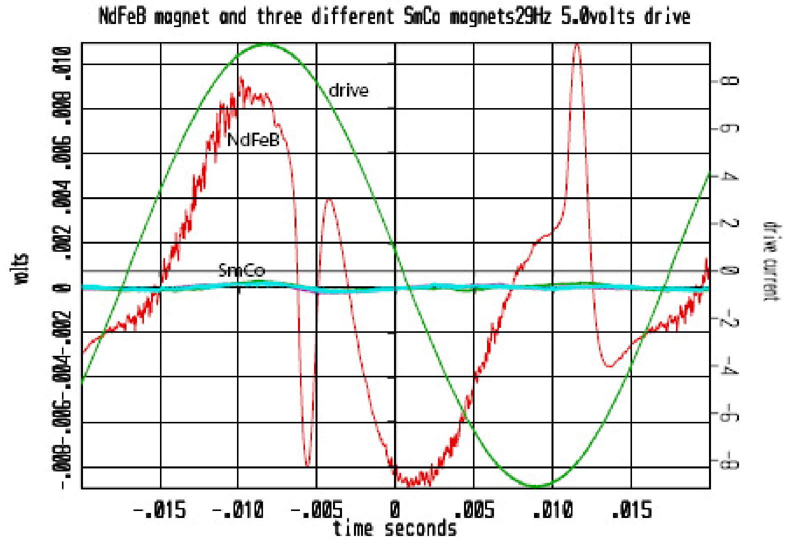
Barkhausen Noise

- Fluctuations in the magnetization of ferromagnetic materials due to internal friction of domain rotations when driven by time varying magnetization currents.
- Occurs in permanent magnets that are not saturated
- Fluctuating force

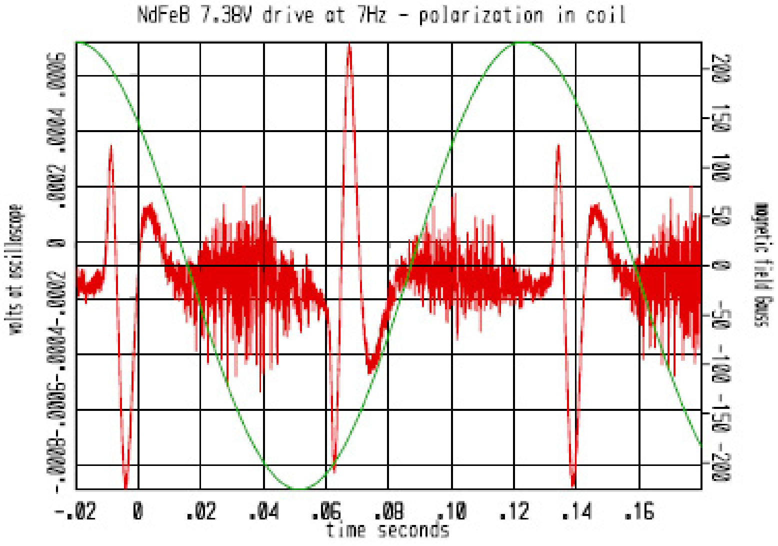
$$F(f) = \mu(f)\frac{dB}{dz}$$

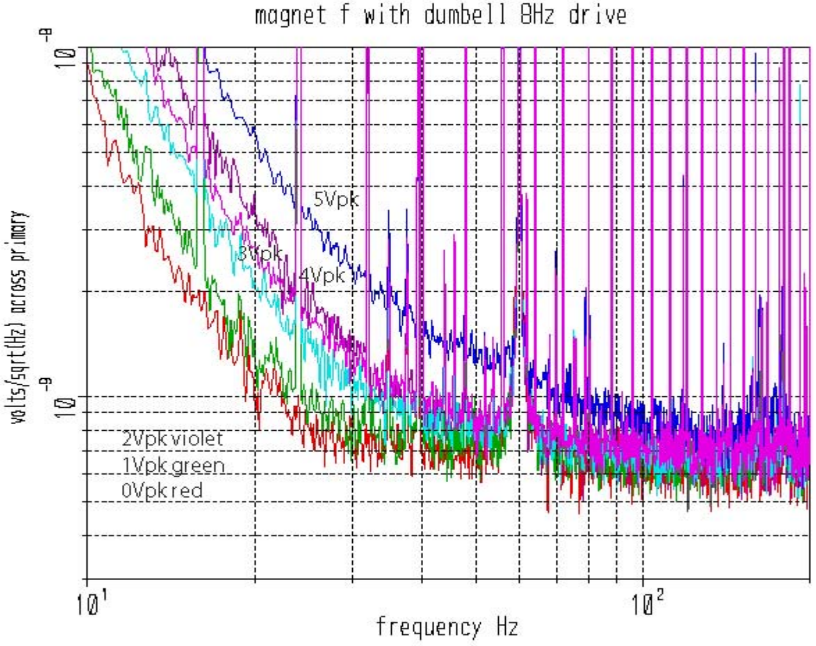
Fluctuating magnetic moment of control magnet varying as the $I^{3/2}$. Has both coherent (repeatable) and incoherent components.

Gradient of the magnetic field acting on the control magnet. The gradient comes primarily from the PAM magnets with a small part from the bias current in the coil

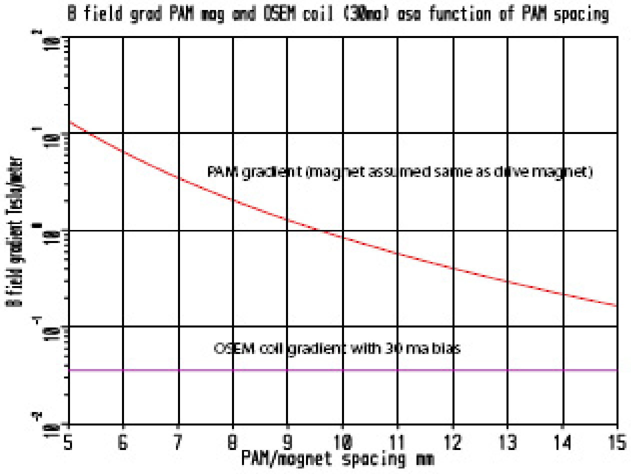


Upper figure: Repeatable component of the Barkhausen noise near H = 0 and the magnetization discontinuity at H extremum. Measured in bridge test rig in NdBFe magnets. The repeatable part depends on the direction of the exciting current and the magnetic moment. SmCo does not exhibit this behaviour because the magnetization is saturated. Lower figure: Both incoherent and coherent components

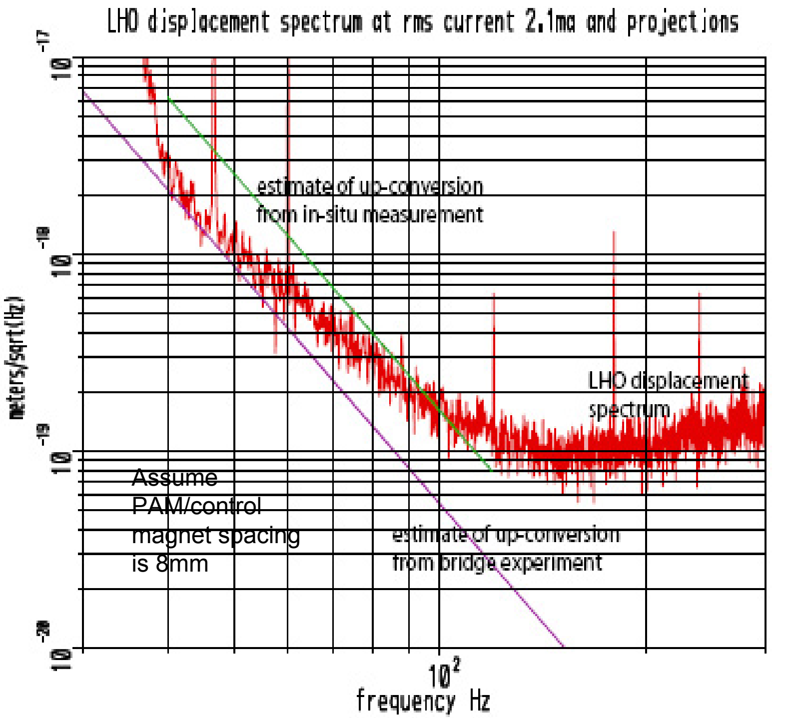


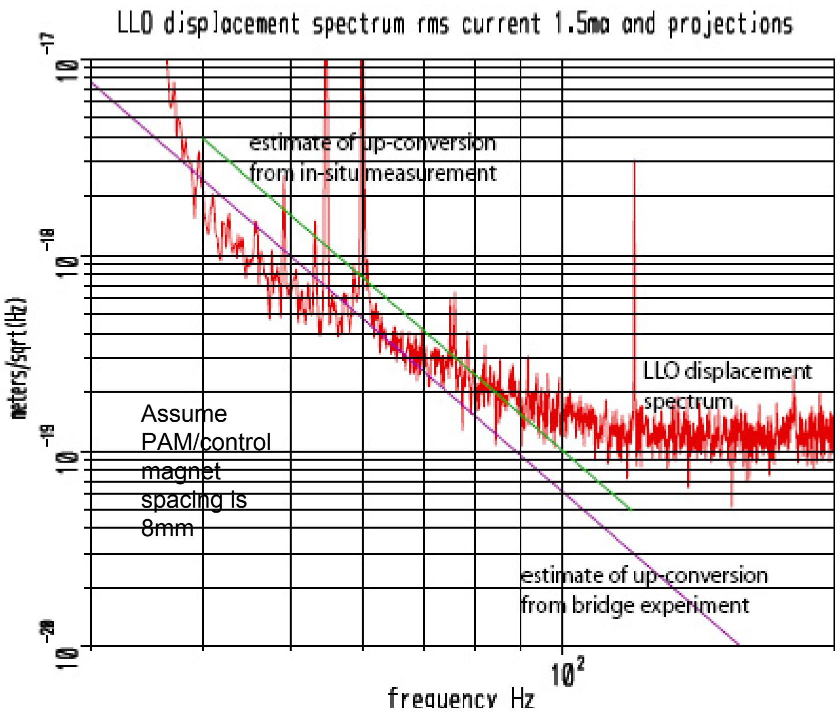


Spectrum in test rig varies as 1/(f-fo). This spectrum corresponds after conversion to B field (1/f) and displacement (1/f2) to the up-conversion spectrum



B field gradients from the PAM magnets as a function of magnet separation





Note: Estimate from bridge experiment underestimates Barkhausen noise due to assumption of 8mm magnet spacing. Estimate from in situ measurments most likely overestimates due to simplicity in convolution with quiescent current spectrum.

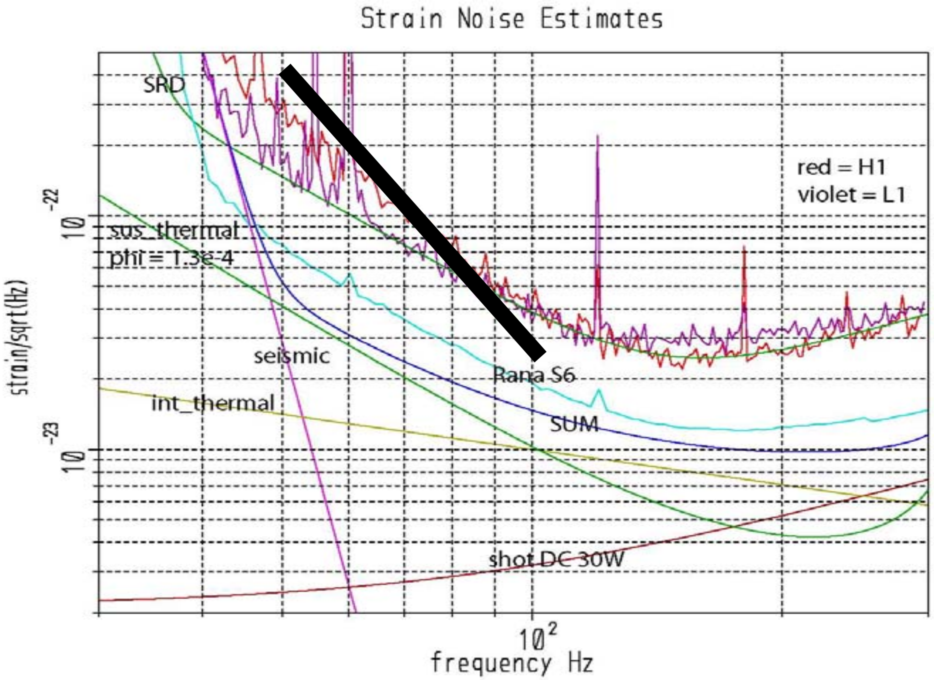
Barkhausen noise scaling

Drive current: $I^{3/2}$

Spectrum: convolution with $1/(f-fo)f^3$

fo = drive frequency

Fix: reduce current, increase PAM/control magnet spacing, change NdFeB to SmCo magnets

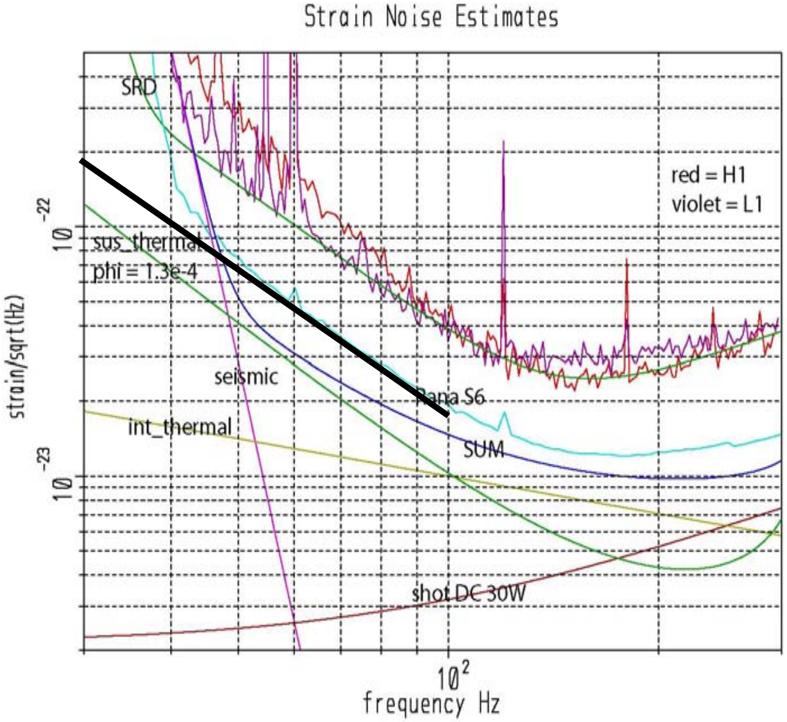


Broadband noise in bias and coil driver electronics

- Considered in the original plan for enhanced LIGO
- Both bias modules and coil drivers to include filters to remove excess noise
- Johnson noise could become dominant noise

Variety of ideas and mitigation strategies:

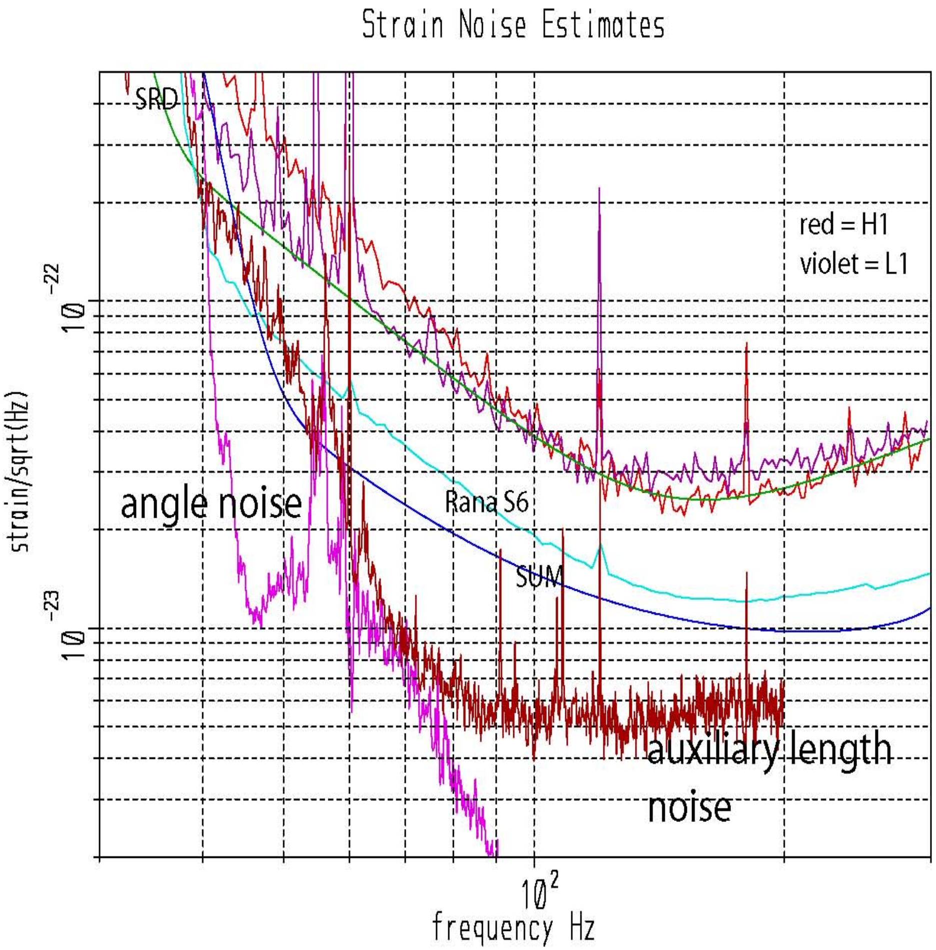
- Use larger series resistors, may require new bias module and will require higher voltage coil drivers
- Operate series resistors at 30K using cryogenics acquired for beamtube bakeout. Place cryogenics in maintenance area.
- Use an inductor as the series impedance for the bias
- Use electronic cooling with low noise FET



Less urgency, external to the instrument and can be modified during S6

The noise estimated in the figure comes from Johnson noise in the series resistors, 7.5K ohms in the bias modules and 4K ohms in the coil drivers using a coil drive of $1.6\mathrm{x}10^{-2}$ Newtons/Amp. Excess electronics noise is typically larger by 1.5.

Auxiliary Length and Angle Noise



A mixture of technical noise sources in the **initial** LIGO detector has been grouped as auxiliary length noise and angle noise, shown in figure at left.

Auxiliary length noise is the coupling of differential Michelson (BS) and common mode Michelson (RM) sensing noise into the darm error signal. This noise is expected to reduce with increased injected laser power.

The angle noise is the coupling of the WFS sense and control signals into the darm error signal. The best guess is that this noise will not change for enhanced :LIGO. In either group,there is significant work expected to make any changes in these contributions.

Consult Rana Adhikari and Peter Fritschel for estimates of the intransigence of these noise terms.

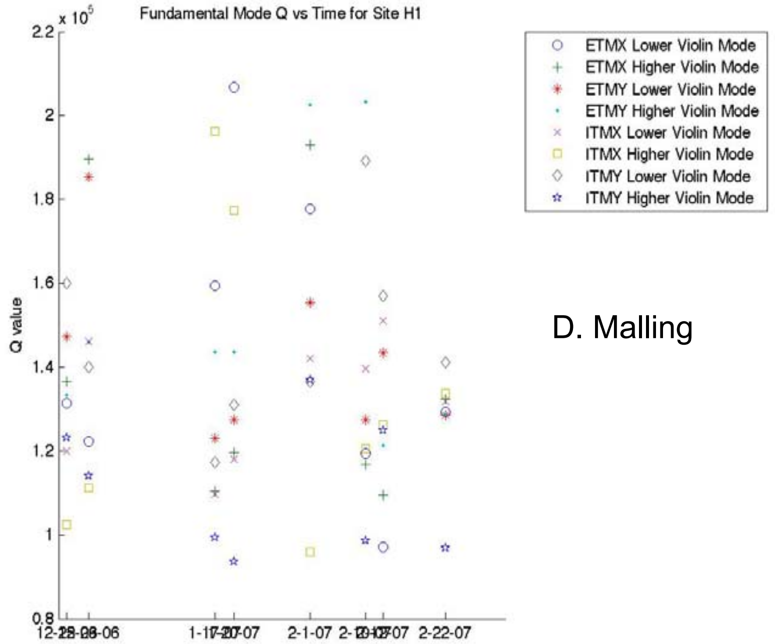
EXCESS DISSIPATION IN TEST MASS WIRE SUSPENSIONS

- Evidence for the excess loss
  - Inconstant and low values of wire violin mode Q in all three interferometers
  - Direct measurements in the suspension test rig give similar inconstant and low violin mode Q
- Needs resolution
  - May significantly limit enhanced LIGO spectrum
  - Needs to be understood (and fixed) for Advanced LIGO signal recycling mirror suspension
- Do not currently have a reliable fix

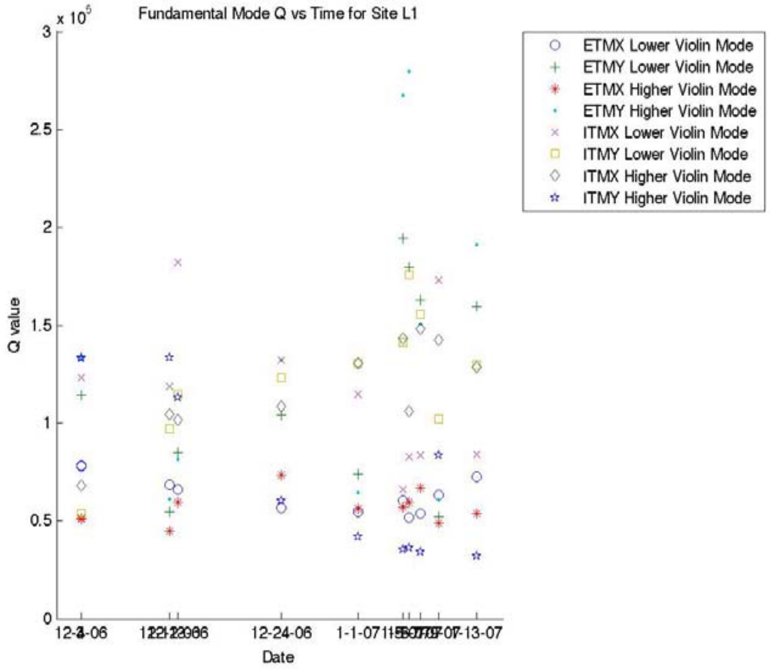
What is "known"

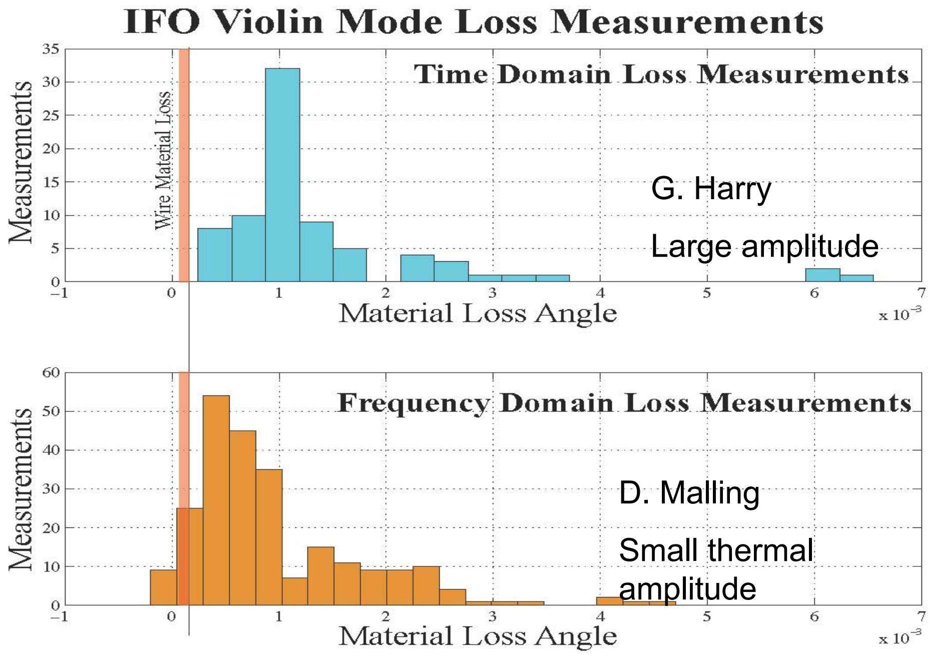
- Wire structure damping loss is low, $\phi = 6$ x 10^{-5} (S. Penn free wire measurement) $\phi < 1$ x 10^{-4} (S. Penn guitar measurement). BASIS FOR SUM CURVE IN ENHANCED LIGO PROJECTIONS
- Upper wire clamp is most likely not implicated.
- Lower grooved cylindrical wire standoff is most likely cause.
  - sharp edged prism gives factor ~10 increase in Q (guitar)
  - prism improves Q in suspension test rig but not consistently
- Wire vibration polarizations experience different loss in the LIGO suspension, FB > RL.
- "Guess" that wire below the standoff vibrates due to slope coupling across standoff and rubs on the test mass in FB motions.
- More consistent results replacing standoff with a small hardened steel clamp.

Test mass wire suspension dissipation



D. Malling





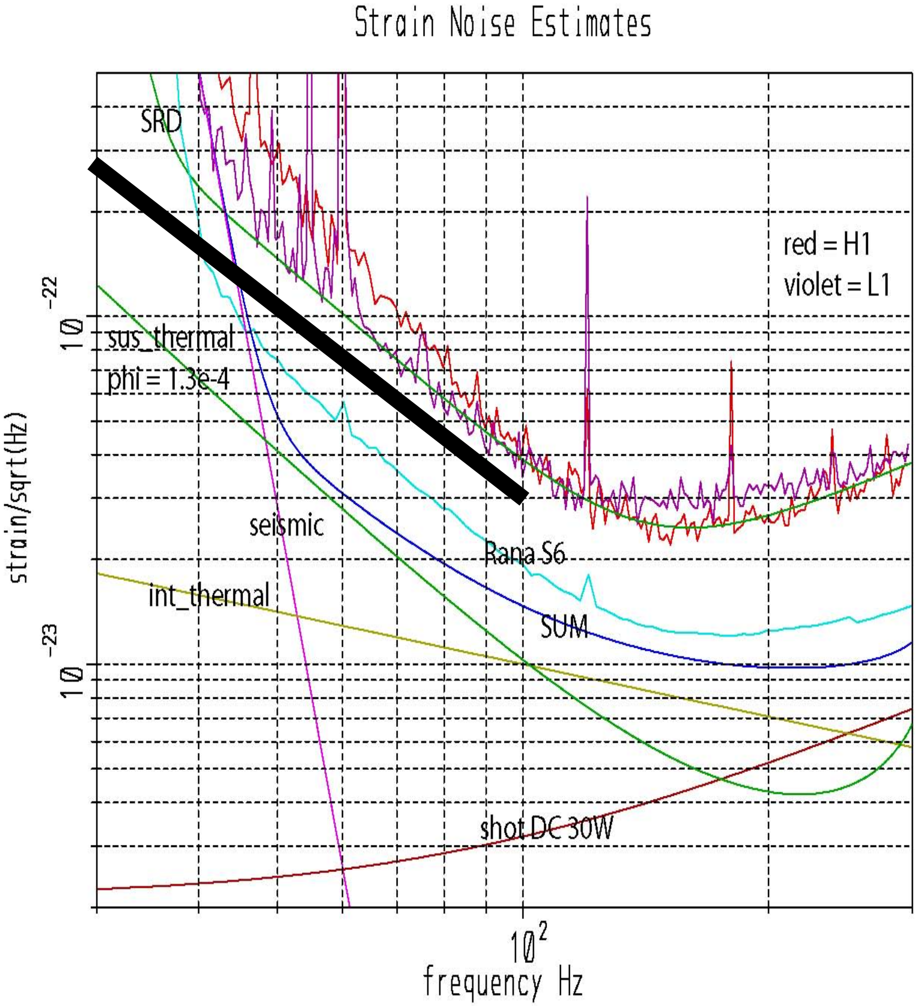
G. Harry

Large amplitude

D. Malling

Small thermal amplitude

Test mass wire suspension violin modes have significantly lower Q than expected from knowledge of the material properties and the Q vary from measurement tp measurement



Fix: Establish a well defined boundary condition at the standoff in the suspension test rig.

Program:

- Need to do more research
- Need to be ready with a tested solution when (if) enhanced LIGO gets stuck at this noise.

Thermal noise line drawn for wire structural loss 1 x 10^{-3}, the average of the frequency domain in situ wire loss measurements