Environmental Noise-Related Lessons from S6

Robert Schofield, University of Oregon

March 2011 **LIGO-G1100330**

1) Output Mode Cleaner increased sensitivity to beam jitter
2) aLIGO active ISI system isolates less at hi-f than iLIGO passive
3) Active suspension damping is better than passive damping
4) We need in-vacuum structural damping
5) Smaller permanent magnets are better where beam jitter hurts
6) Commercial electronics were the source of inter-site correlated lines
7) Piezo systems caused severe long term glitching in S6
8) Turbulence in HVAC air and chiller water can be worse than motors
9) Repaving 240 reduced seismic signal by >2
10) Upconversion: 303 steel becomes ferromagnetic when cold-worked

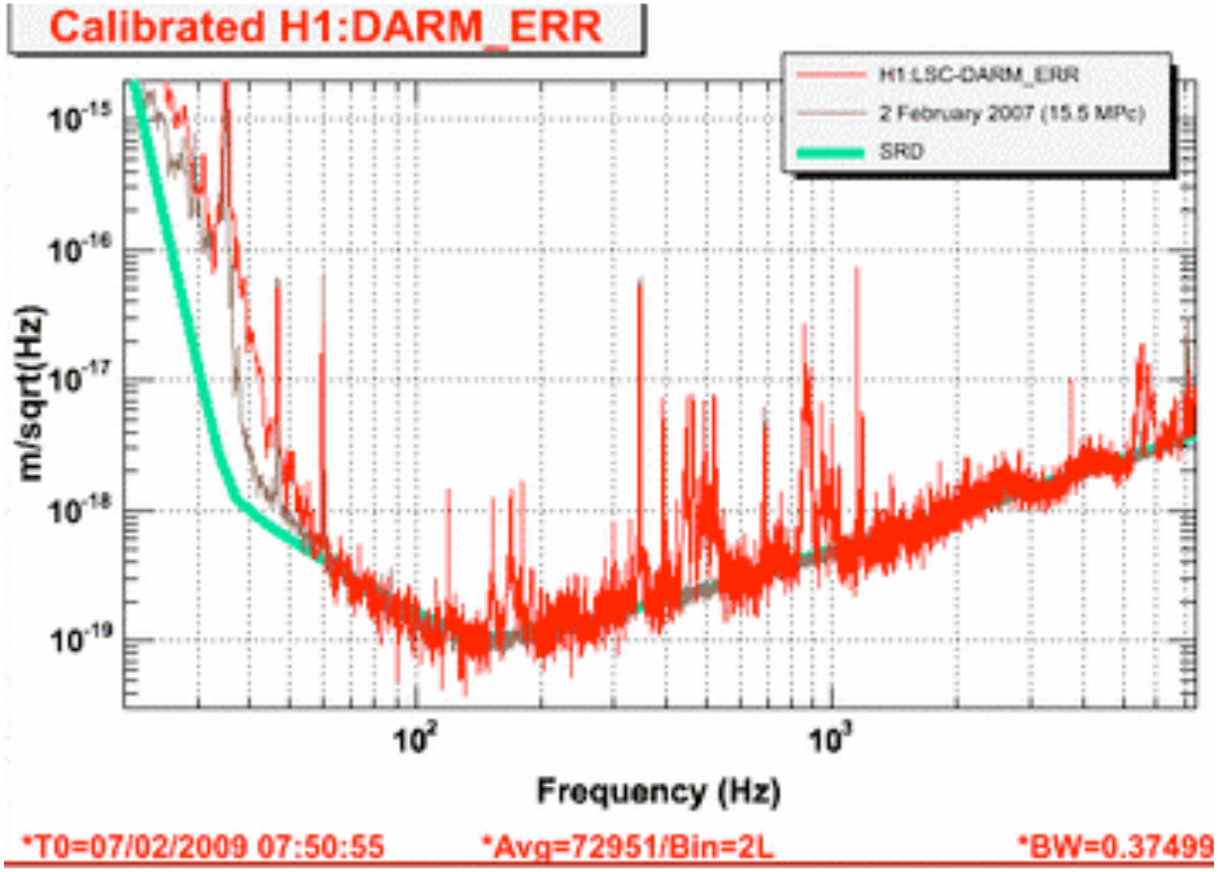
Photo: A. Johannesen.

Output mode cleaner increased jitter coupling

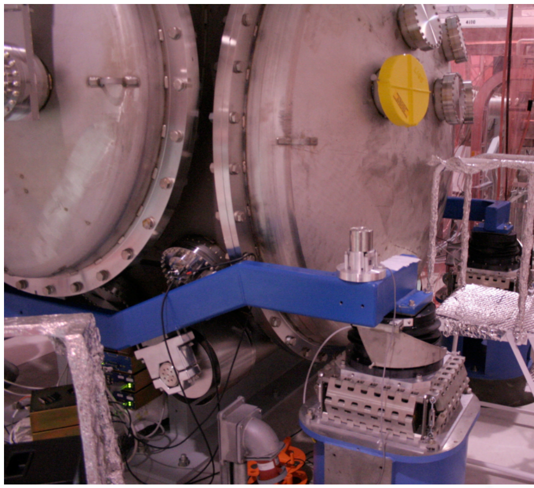
aLIGO active internal seismic isolation less than iLIGO passive at high frequencies

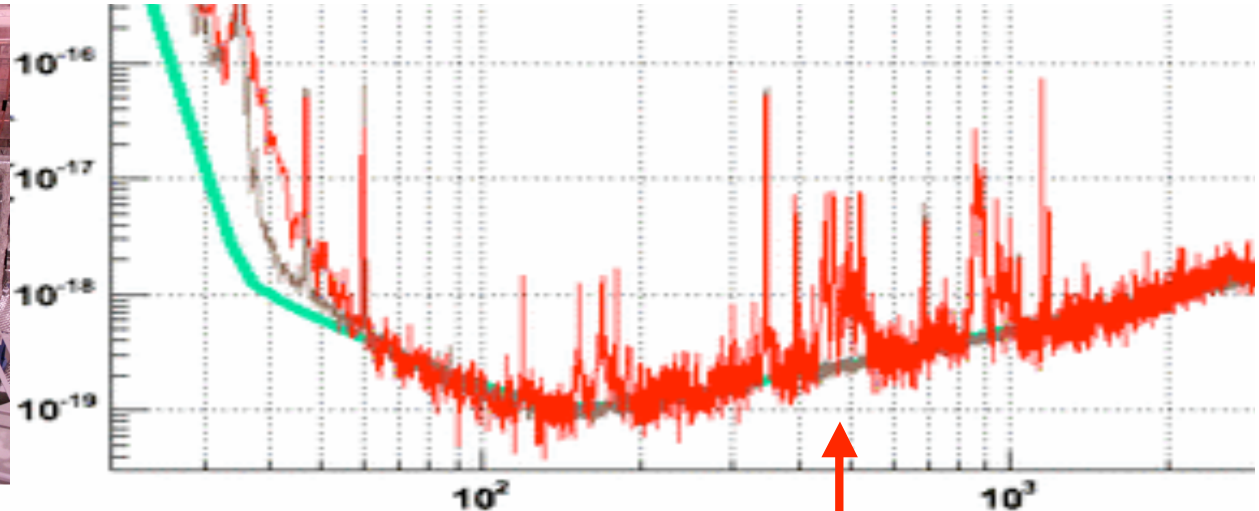
eLIGO began with huge acoustic peaks

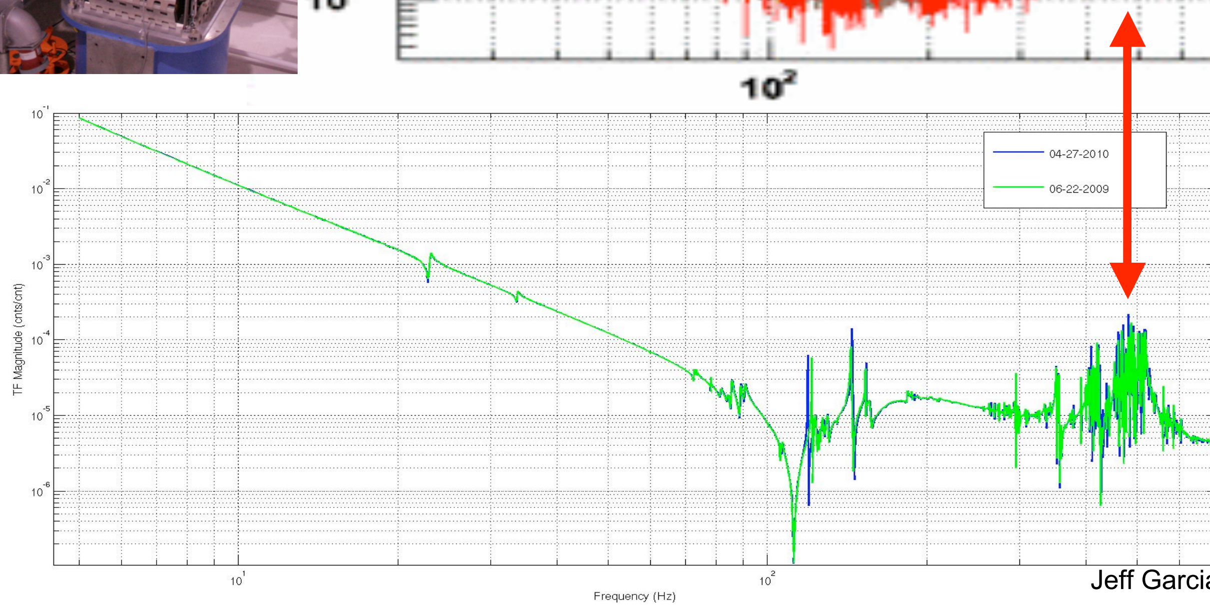
Counterintuitively, when the dark port was moved into vacuum, acoustic coupling increased by roughly a factor of ten due to higher beam jitter coupling and less hi-f seismic isolation than passive stacks



Peaks lined up with HAM6 ISI driven transfer function

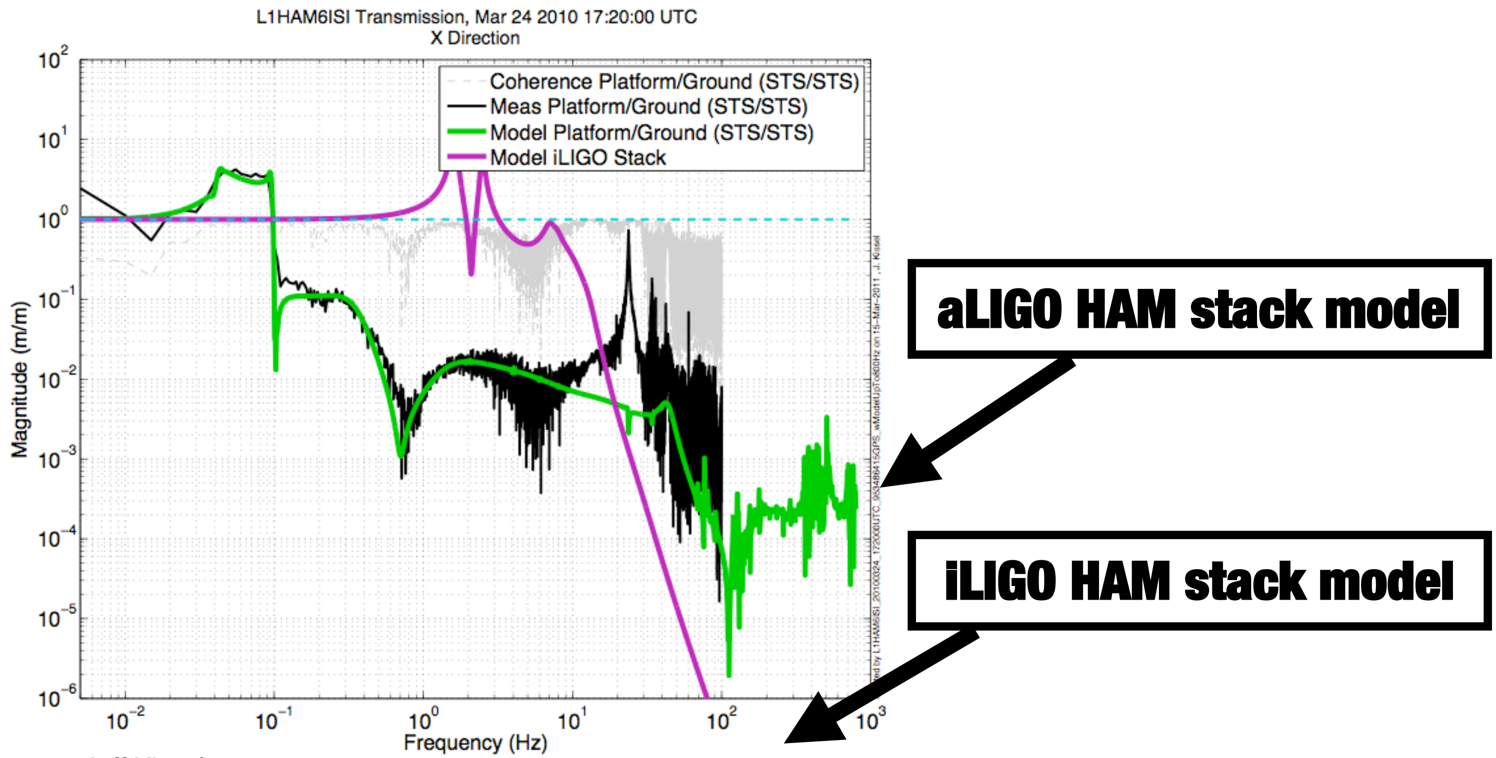






Jeff Garcia

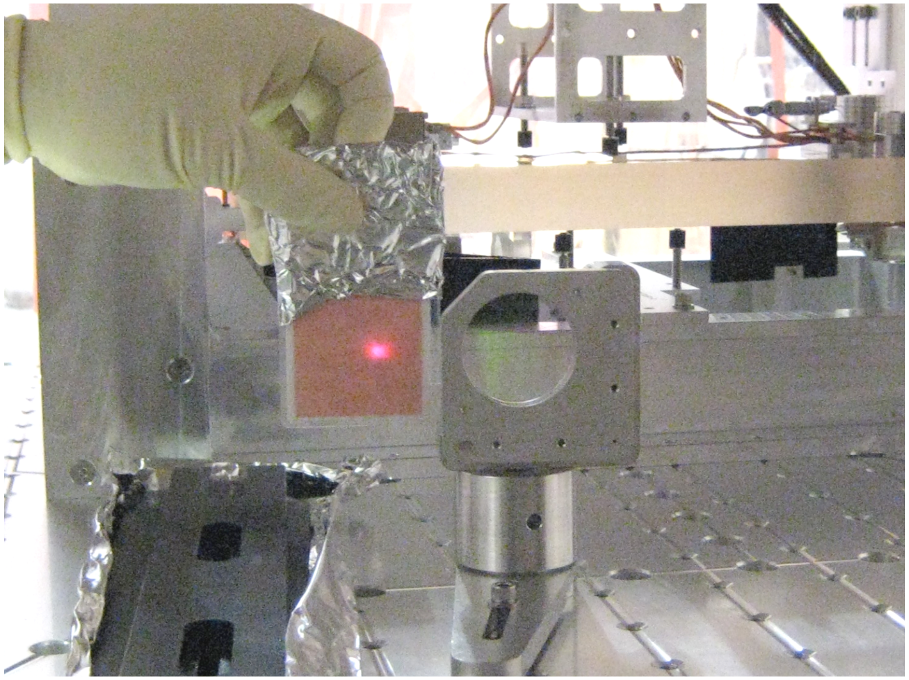
aLIGO Vacuum tables have less high-f isolation

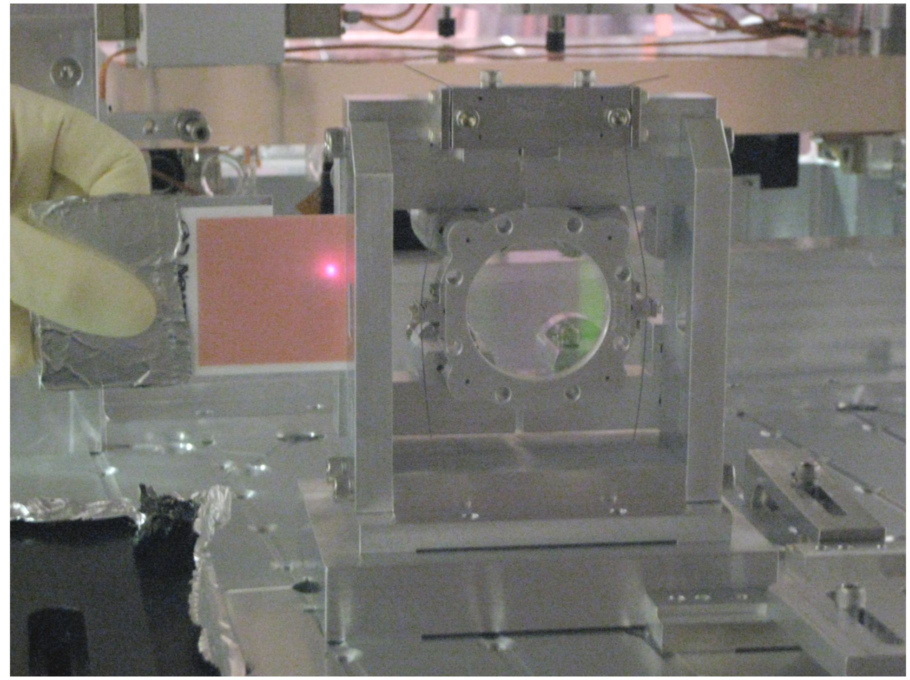


Jeff Kissel

aLIGO ISI meets specifications, its just that Hi-f isolation is to be provided by suspensions

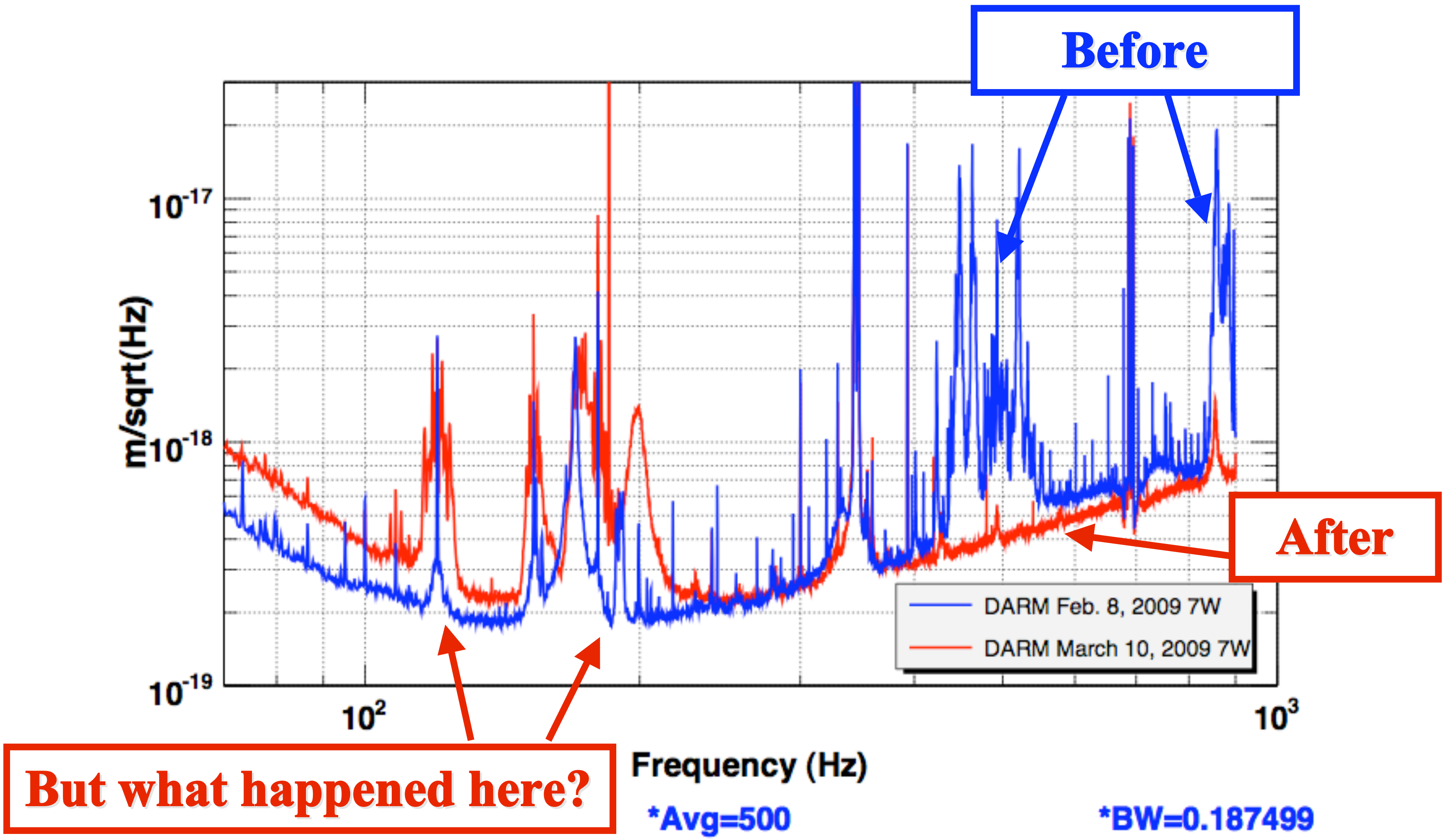
Rigid mount replaced with suspended mount





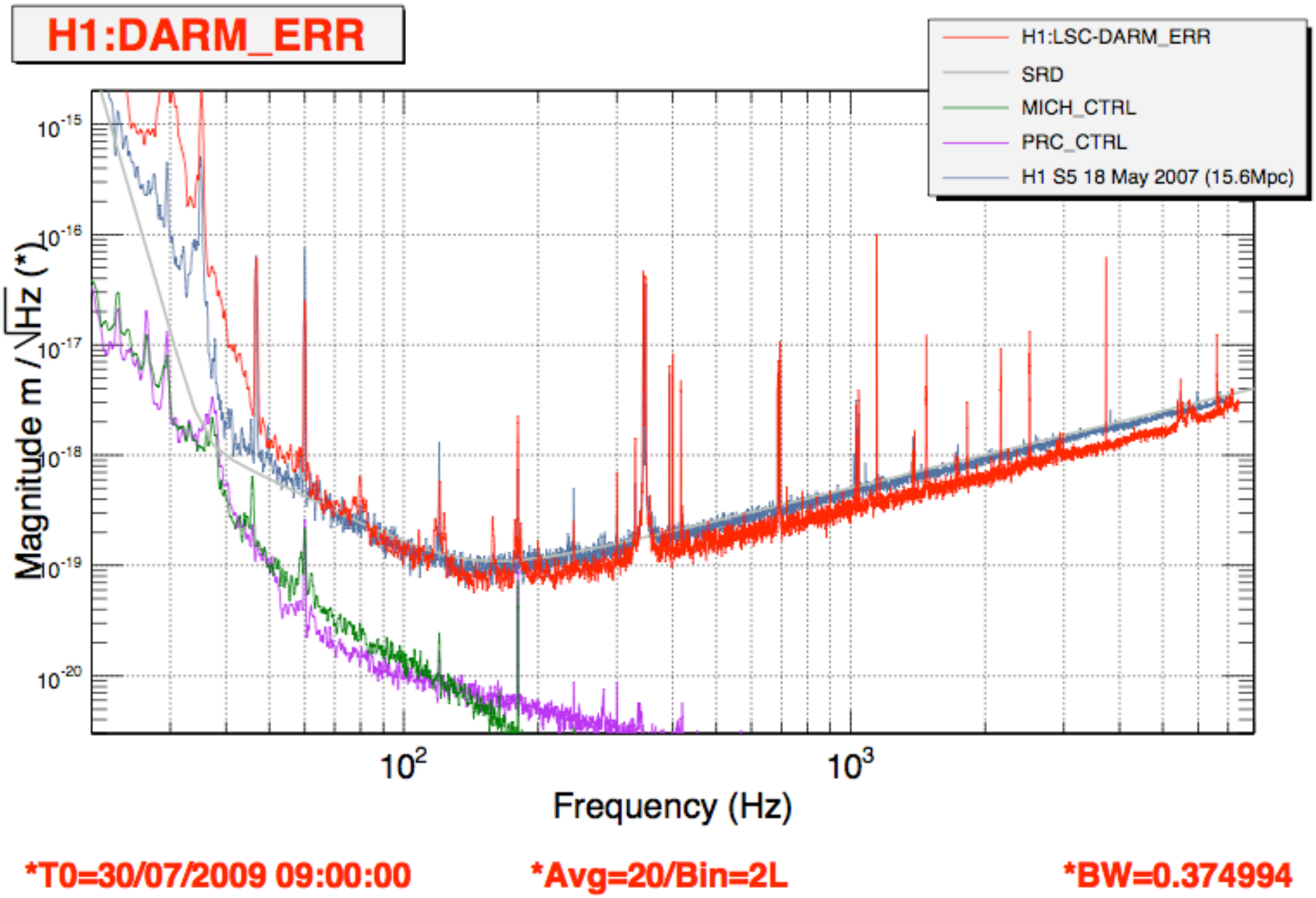
adLIGO tables have only 1 (HAM) or 2 (BSC) stages of isolation in the audio band, while iLIGO had 3 or 4. We will have to avoid rigid mounts and worry more about scattering from tables and cages.

Most peaks gone, LHO & LLO

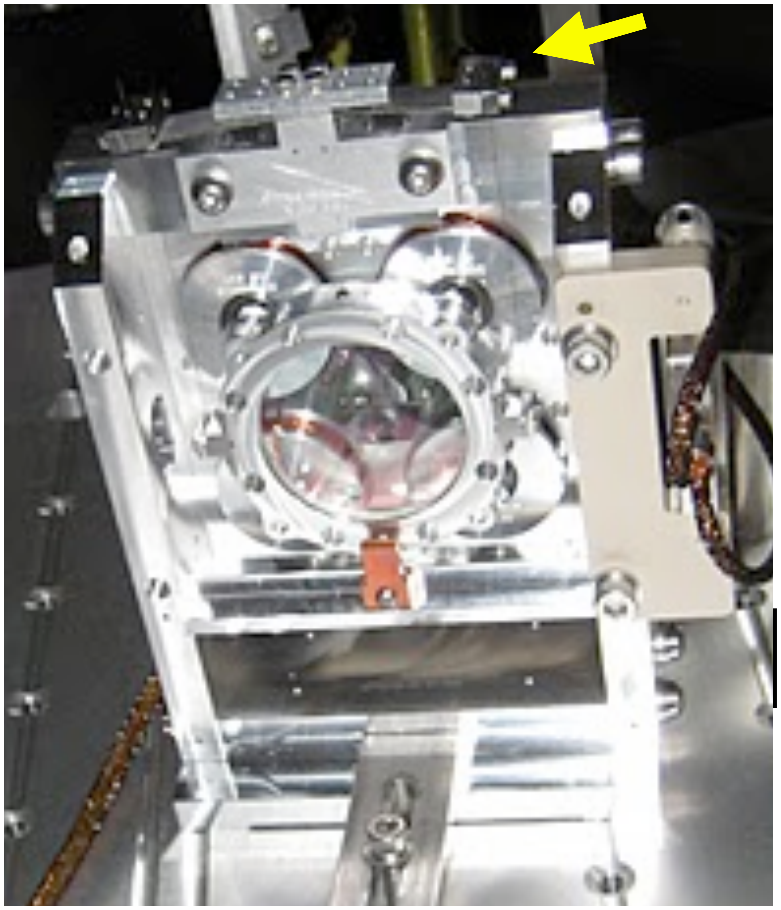


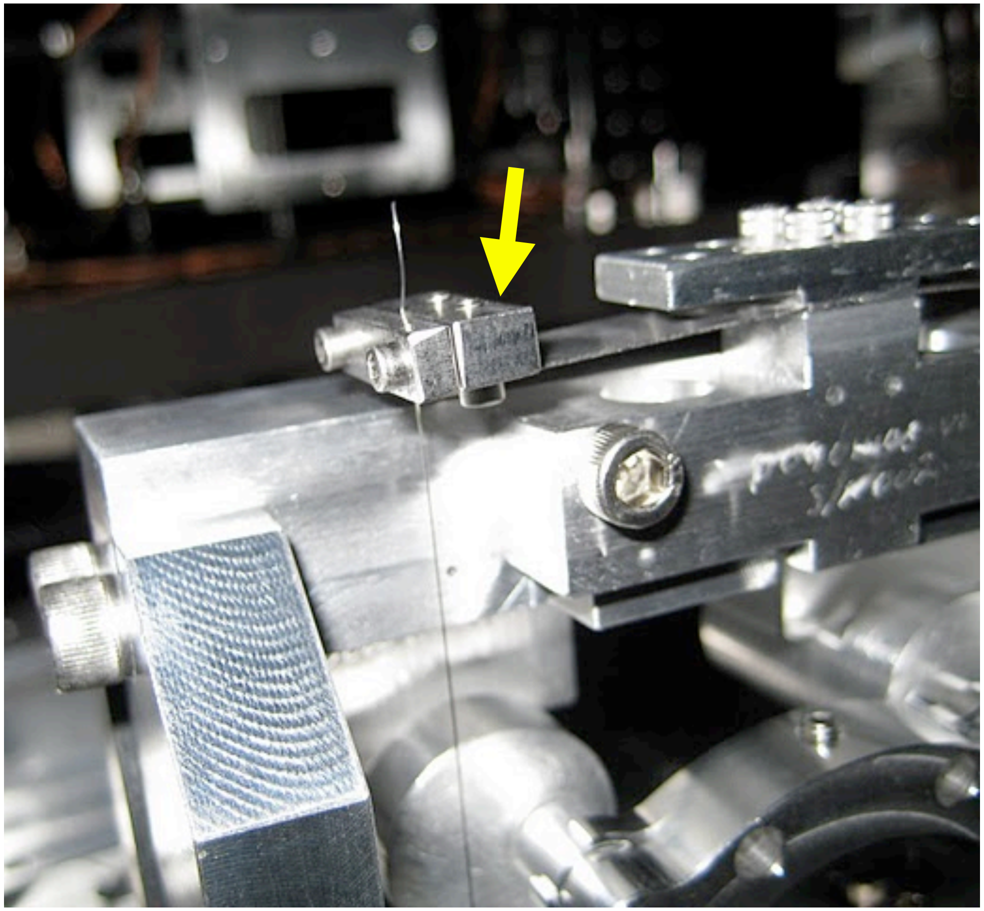
Replacing wires with thin wires

reduced bounce mode frequency, moving peaks to where they were mostly below background



Version with blade springs reduced bounce modes further

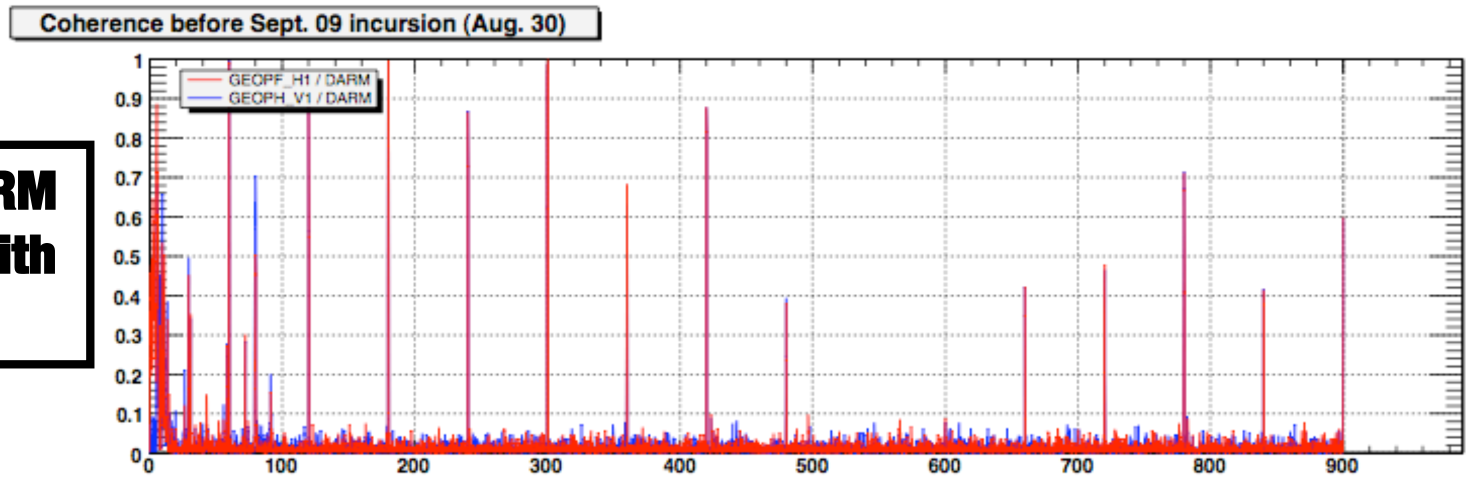




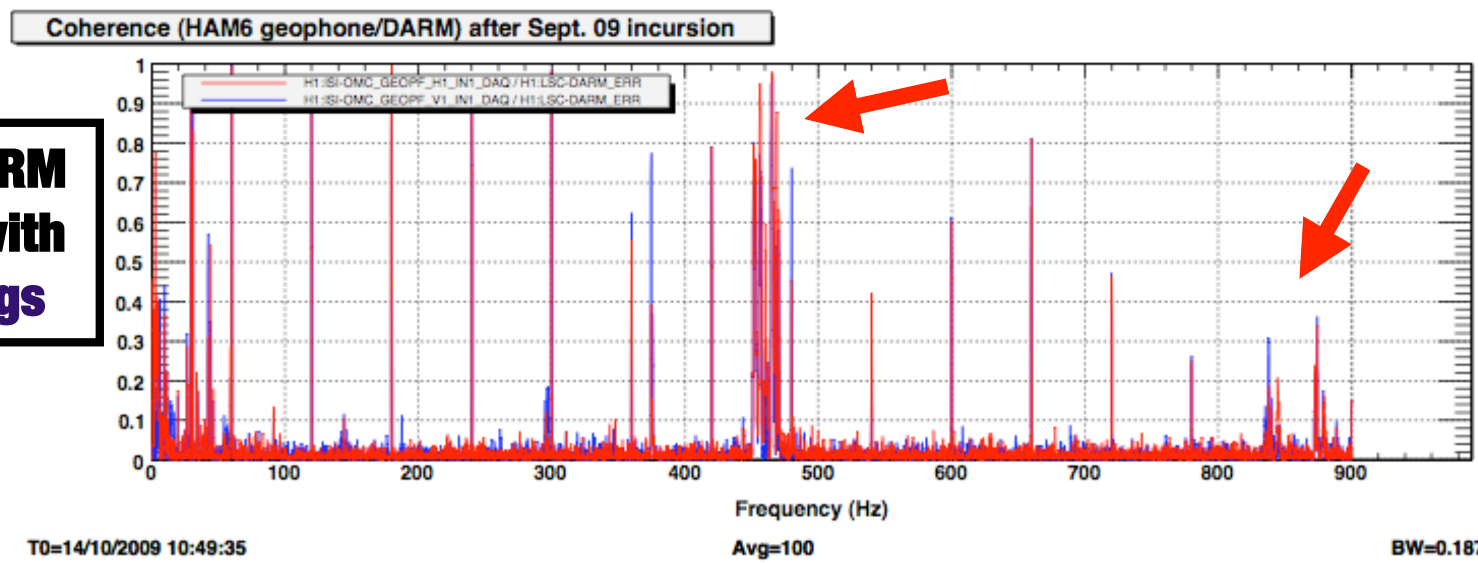
Photos: Rana A.

But high frequency coupling increased with blade spring TTs

Geophone/DARM coherence with thin wires



Geophone/DARM coherence with blade springs



Cause: passive damping?

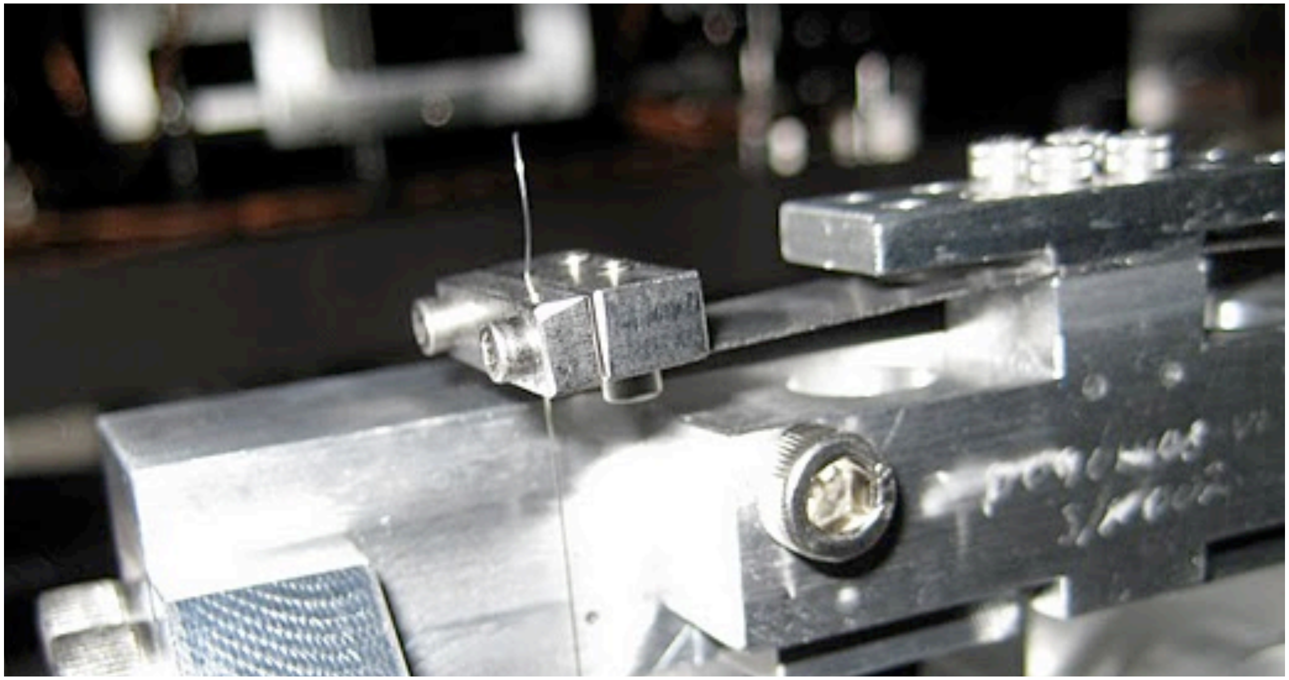
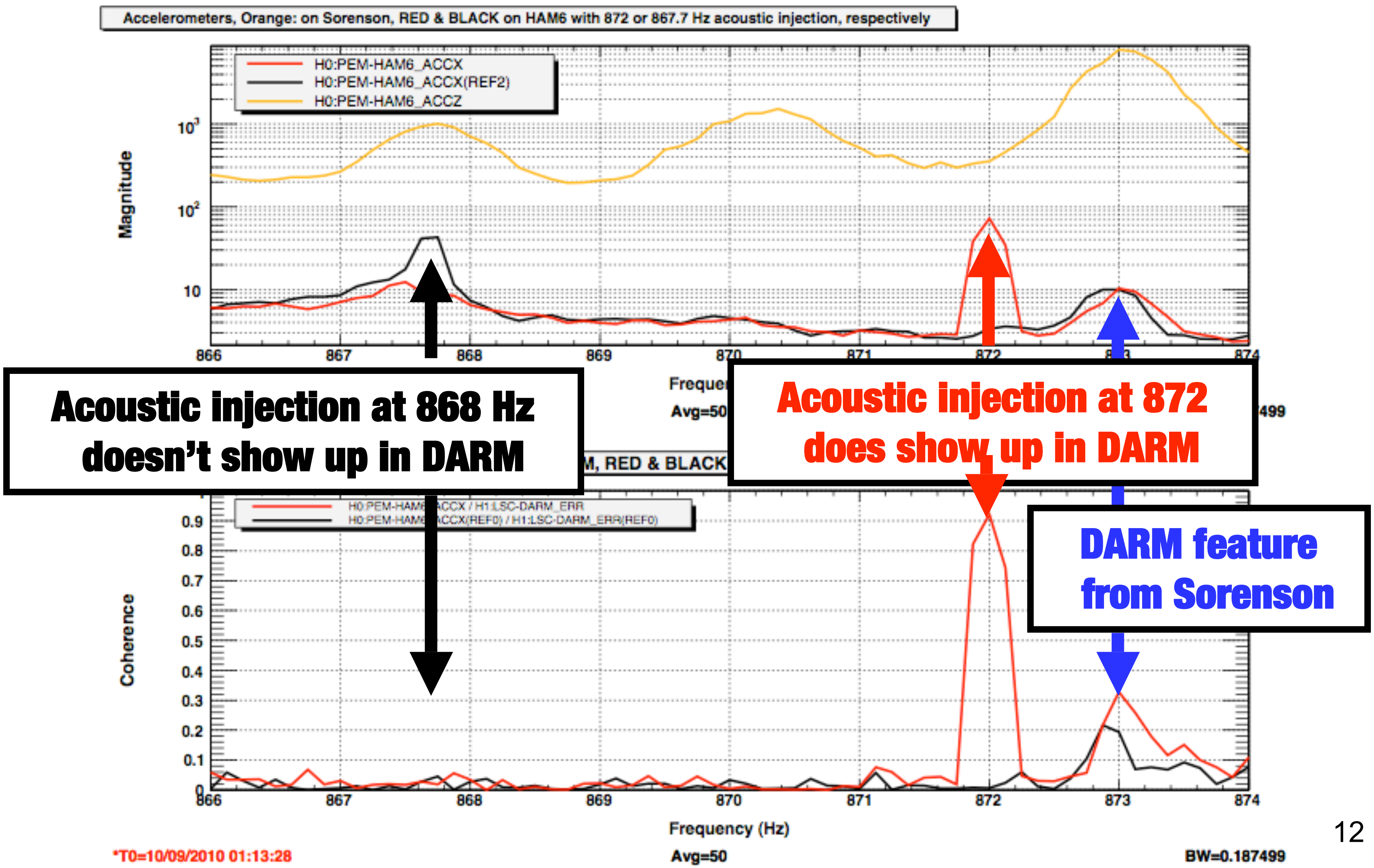


Photo: Rana A.

Active damping best because it can be varied from outside and it provides better hi-f isolation.

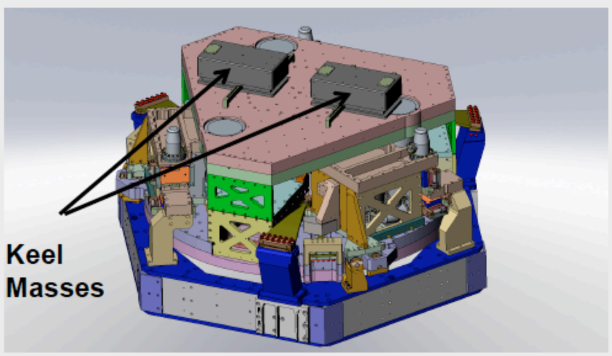
Sharp resonances around 900 Hz lead to highly variable coupling

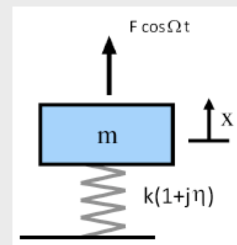


We need in-vacuum damping reaching high frequency

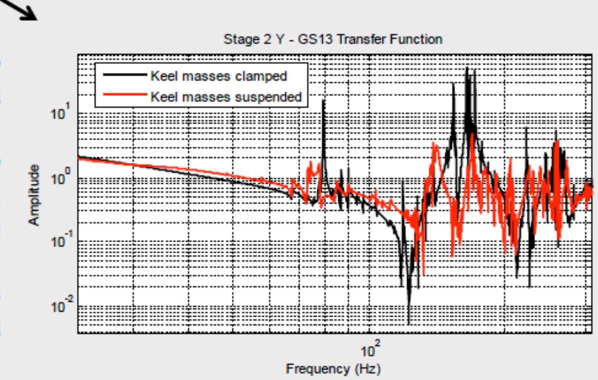
Poster from Sebastien Biscans & Fabrice Matichard suggesting mass/viton damping system. Something similar needed to damp at 450 and 850 Hz on HAM6 and possibly others.

Keel Mass Dampers on Stage 2



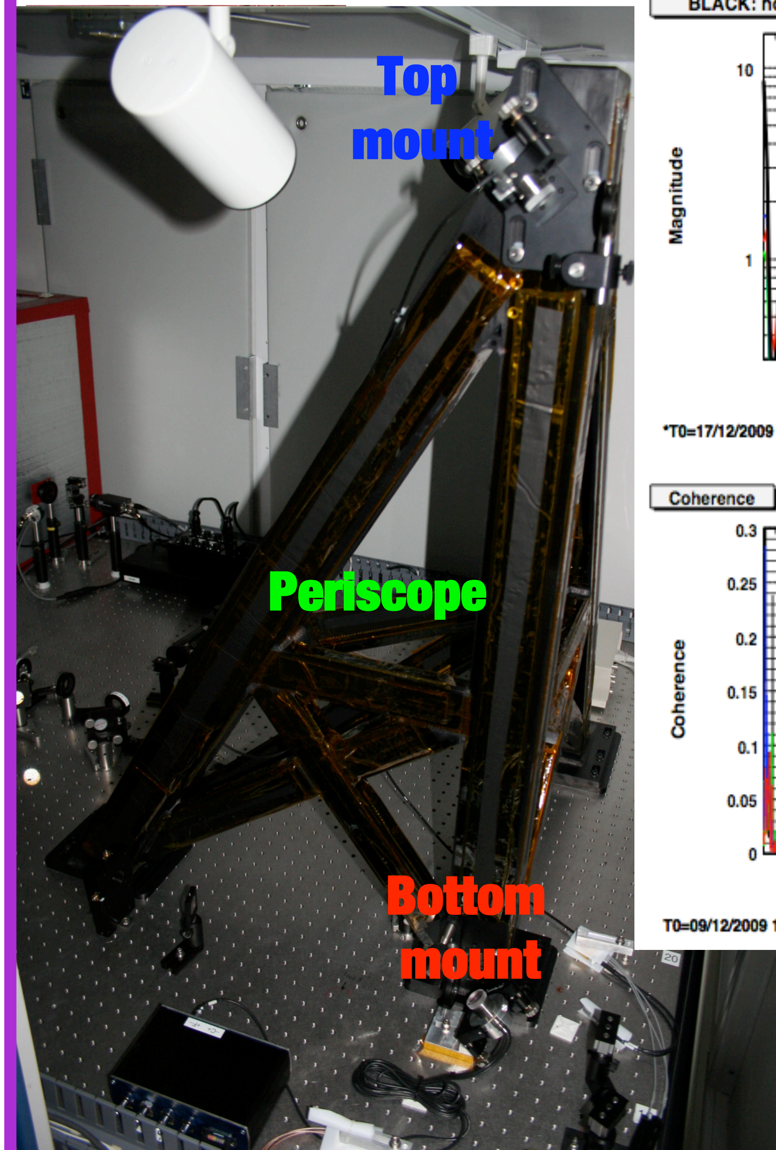


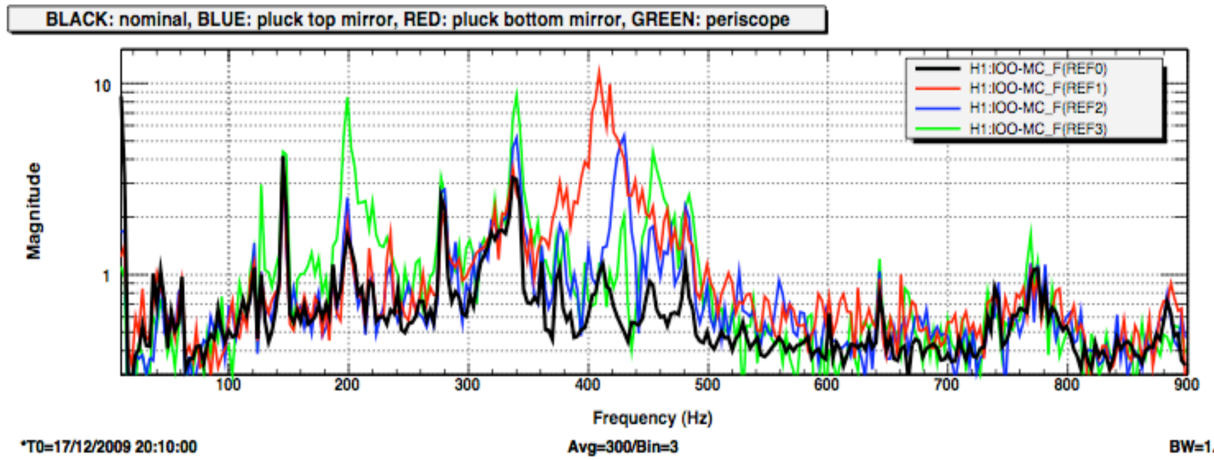
Model of the keel mass damper. The Viton pad provides both the spring and the damping.

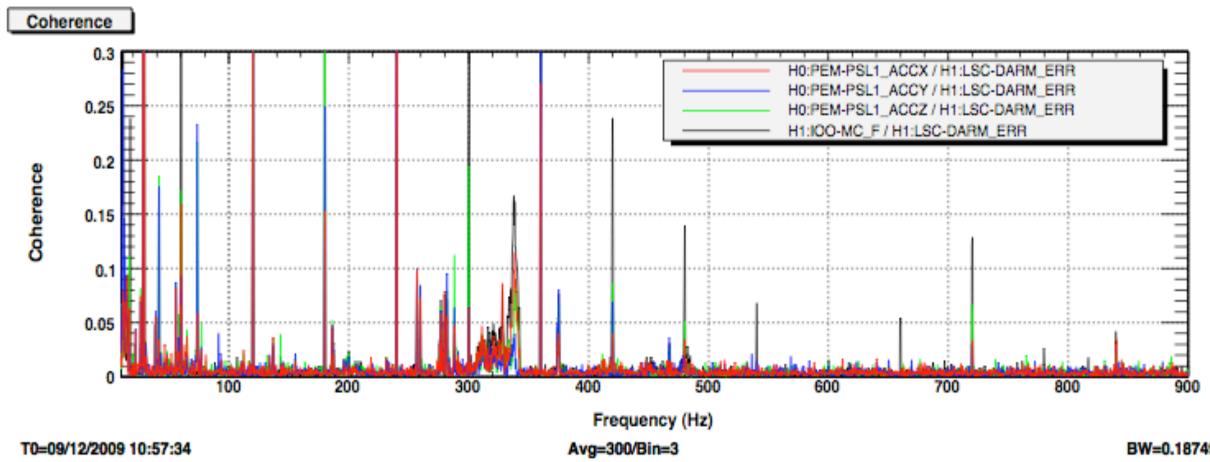


The BSC-ISI design includes two keel masses necessary to balance the system. These 400 lbs masses are used as a counterweight to the optical payloads.
The idea presented here is to use these keel masses to make spring mass dampers. The masses are mounted on Viton pads, whose dimensions have been tuned to set the mass-spring frequency around 60 Hz.
This approach damps many resonances under 200 Hz as shown in the graph on the right where the Qs are reduced by a factor of 10.

PSL periscope peaks in DARM







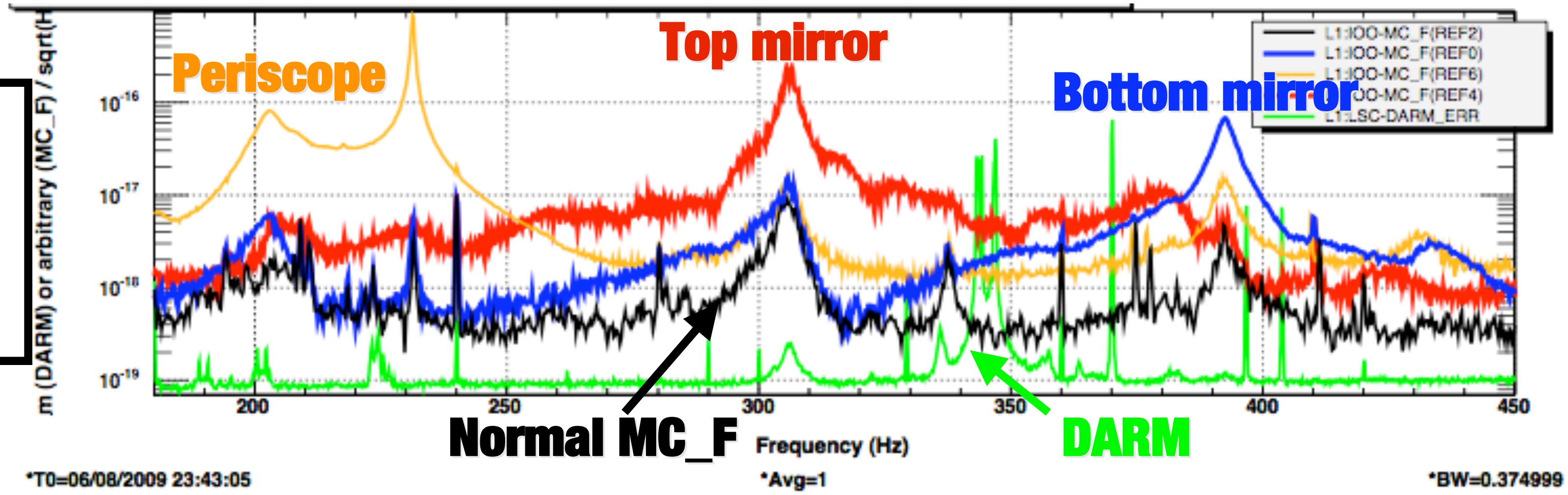
Periscope body: 200, 340, 450 Hz

Bottom mirror mount: 410-420 Hz

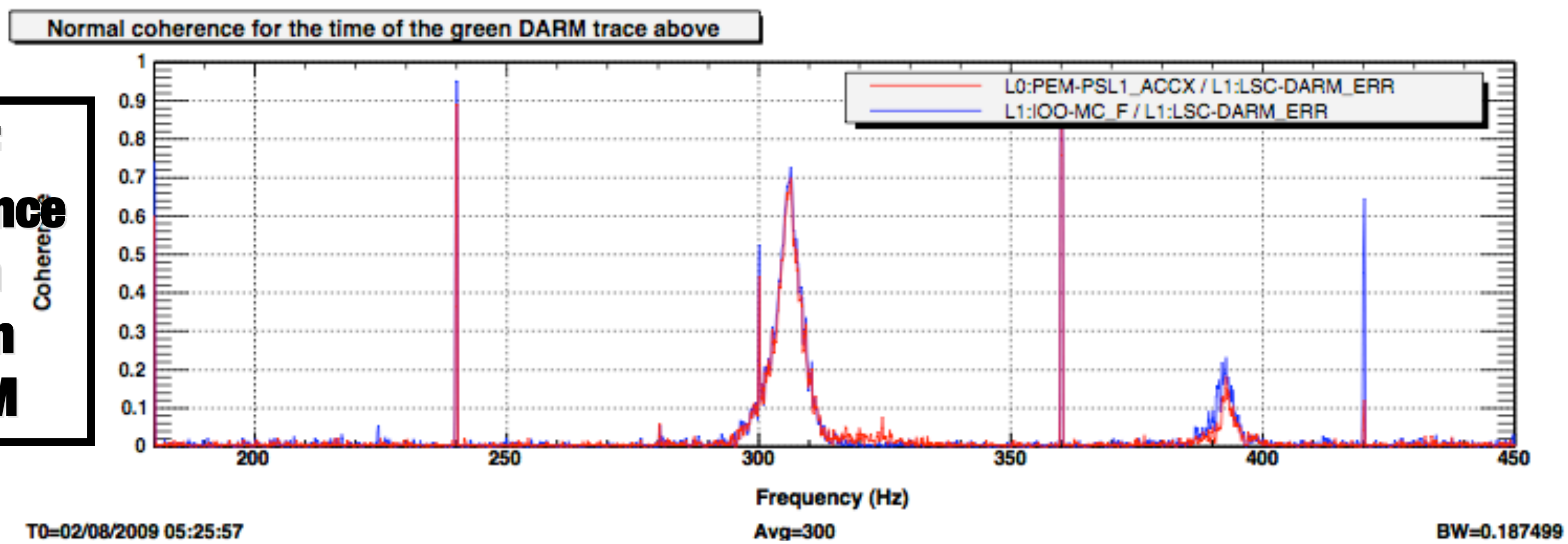
Top mirror mount: 420-430 Hz

ID of acoustic peaks in DARM from plucking LLO PSL structures

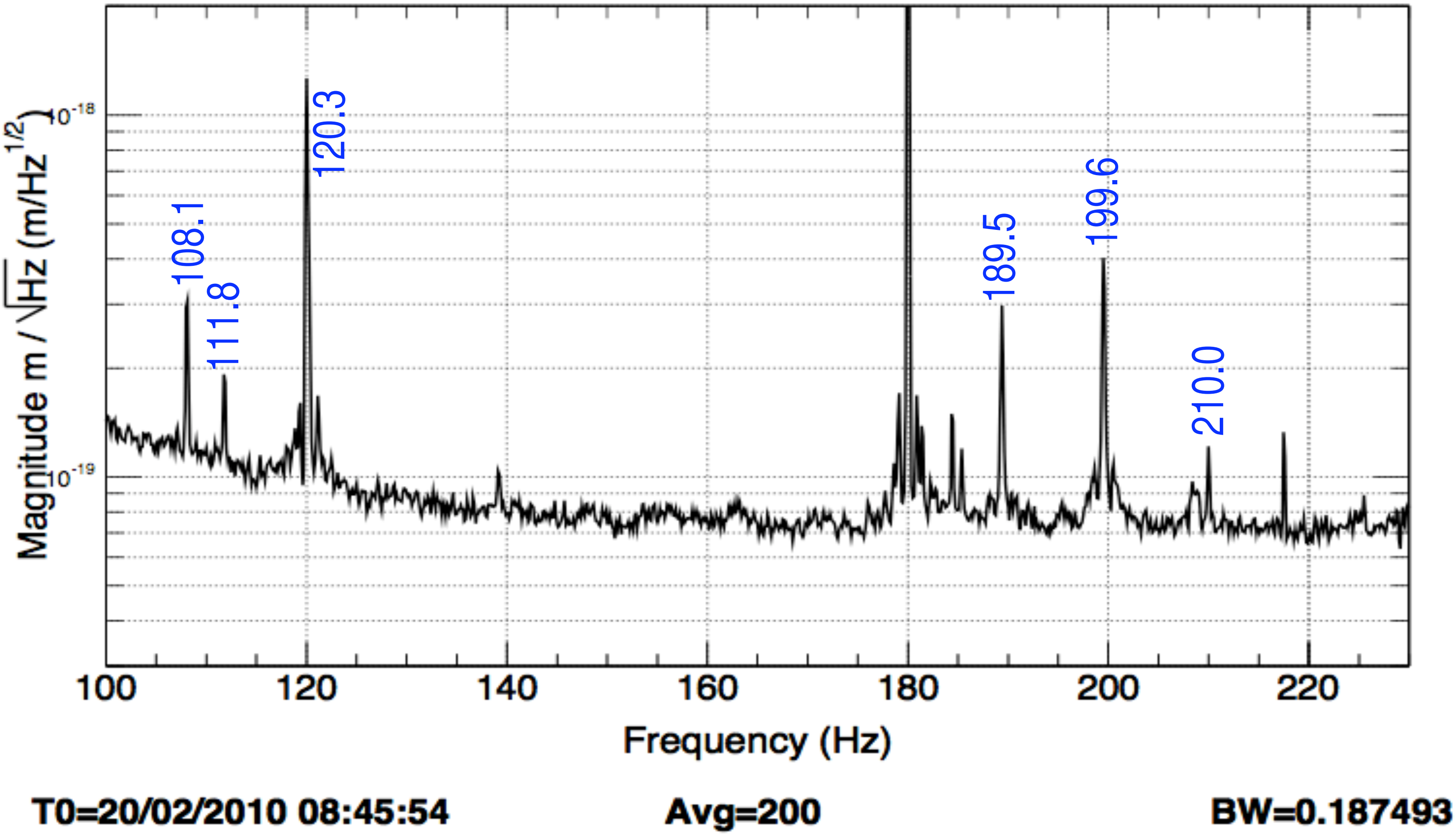
DARM: green, MC_F: others



MC_F coherence with green DARM



UNIDENTIFIED: JITTER PEAKS



Very non-stationary:

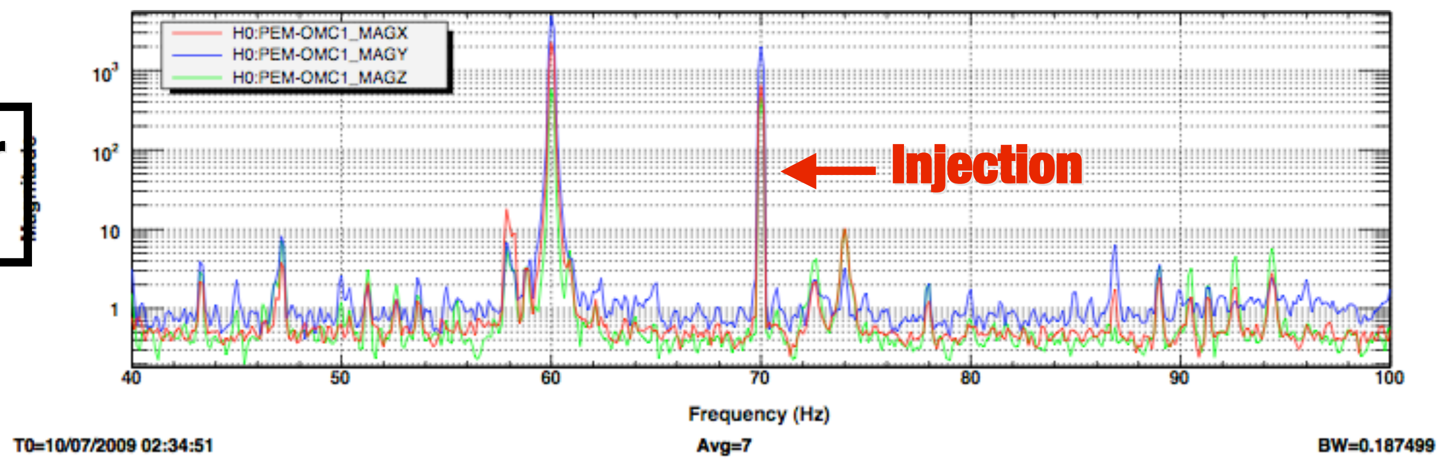
probably should be notched from burst search

Smaller permanent magnets are desireable on jitter-sensitive optics

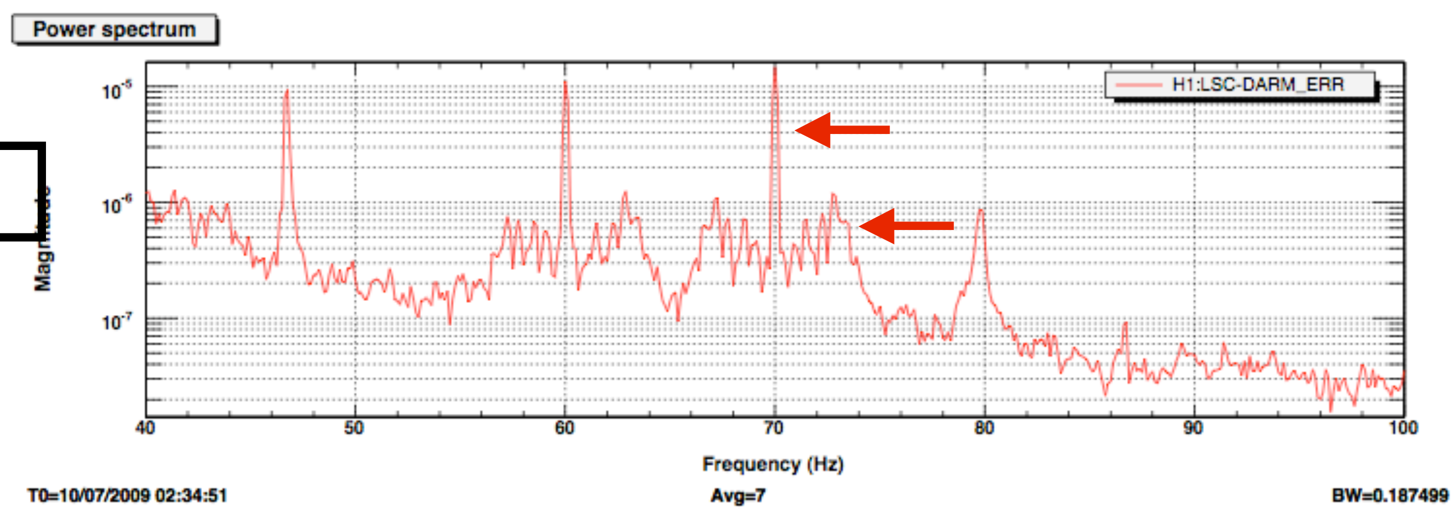
Source of 60 Hz sidebands

70 Hz magnetic field produced near OMC with amplitude matched to ambient 60 Hz, produced similar feature in DARM

magnetometer By HAM6

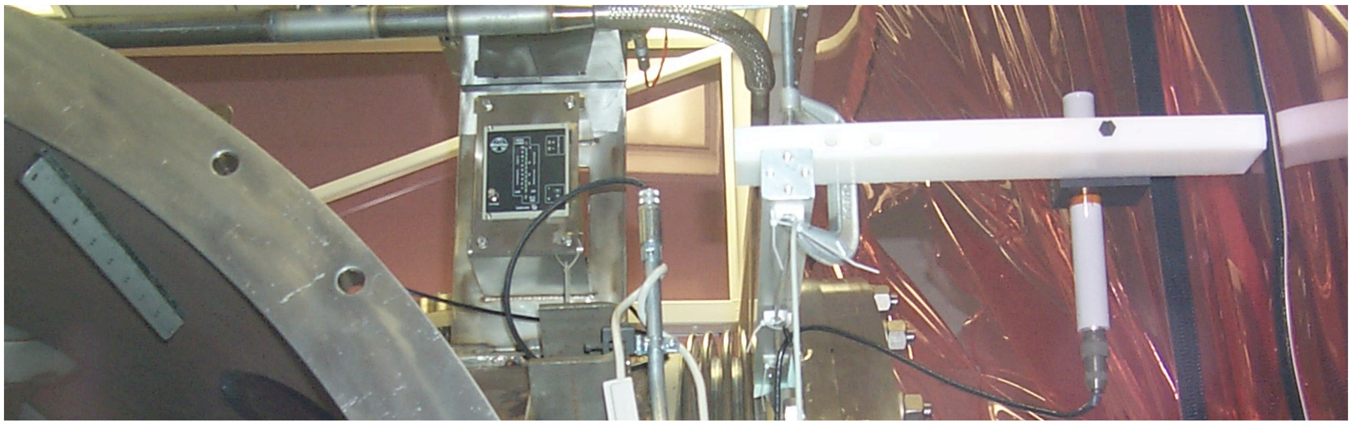


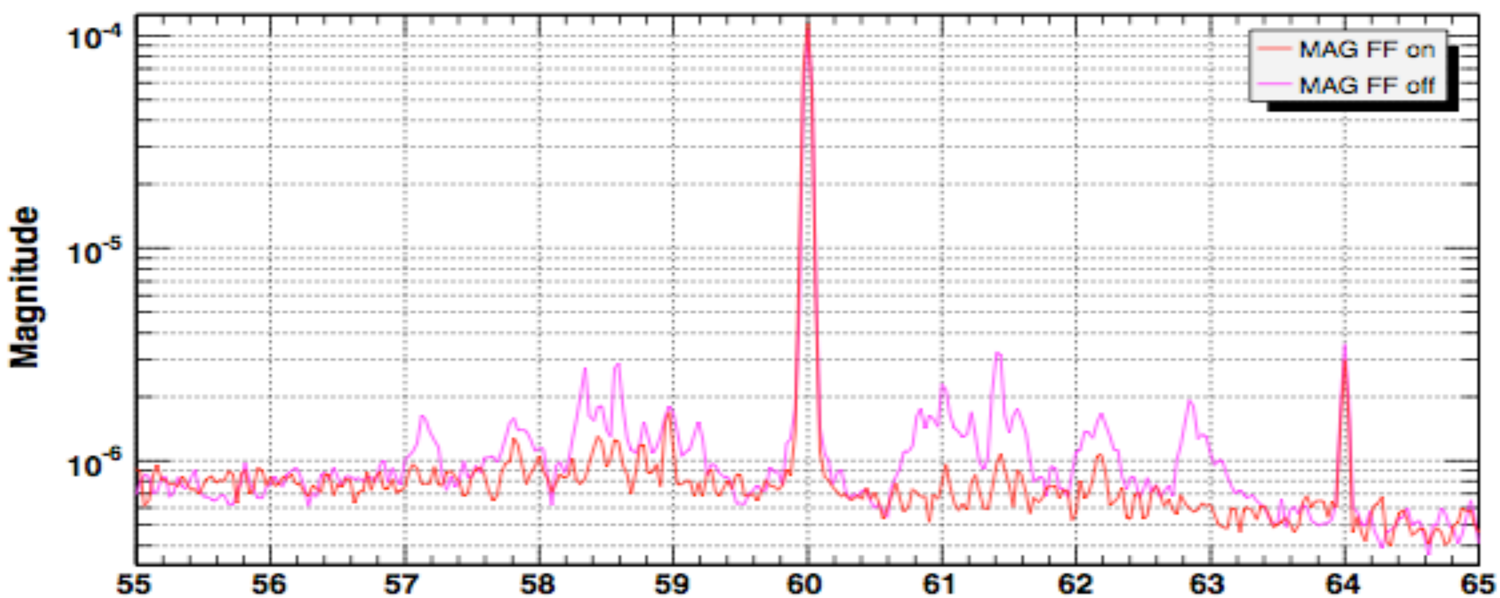
DARM



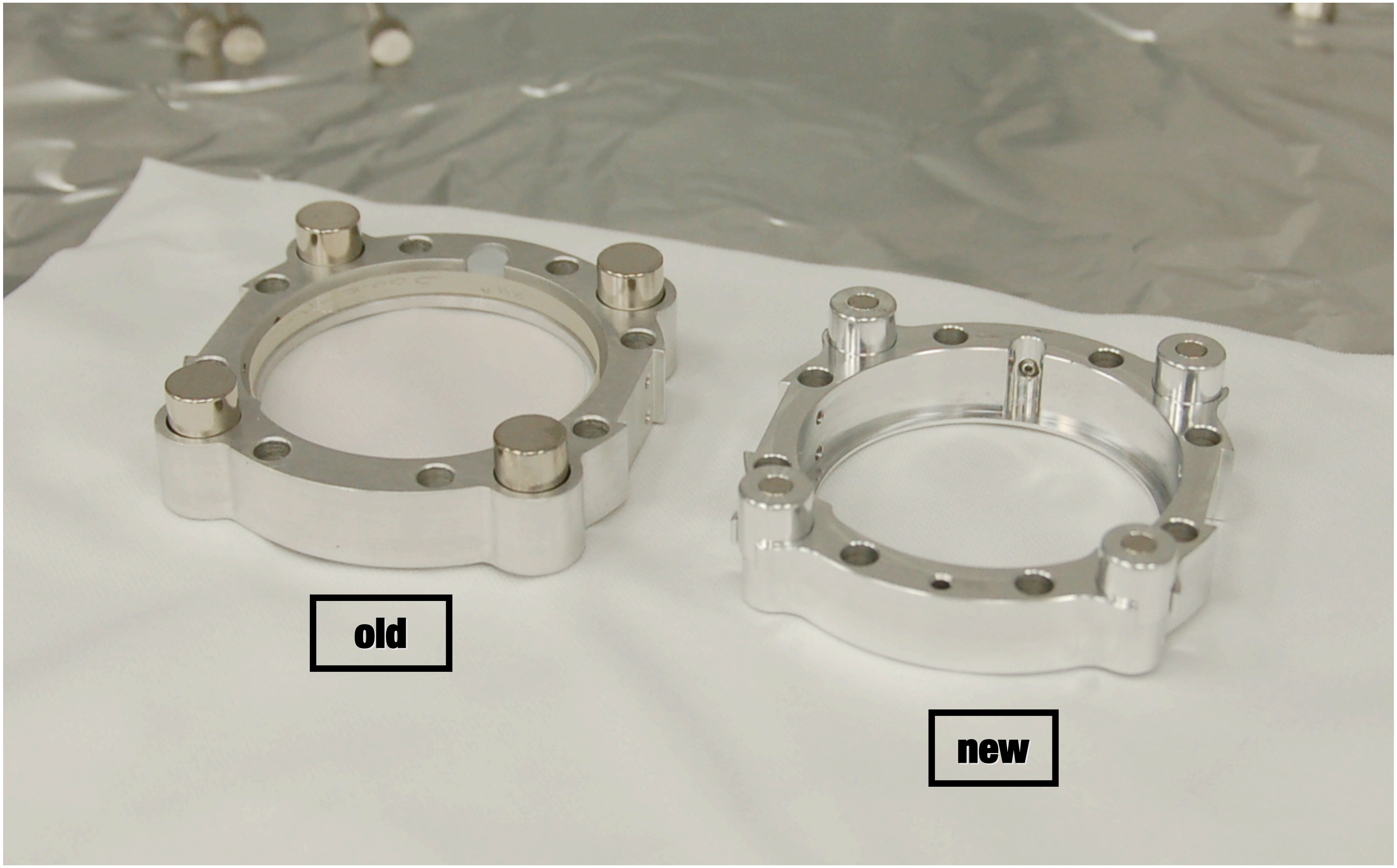
Magnetometer feed-forward system

Servo by Nic Smith





Smaller magnets helped

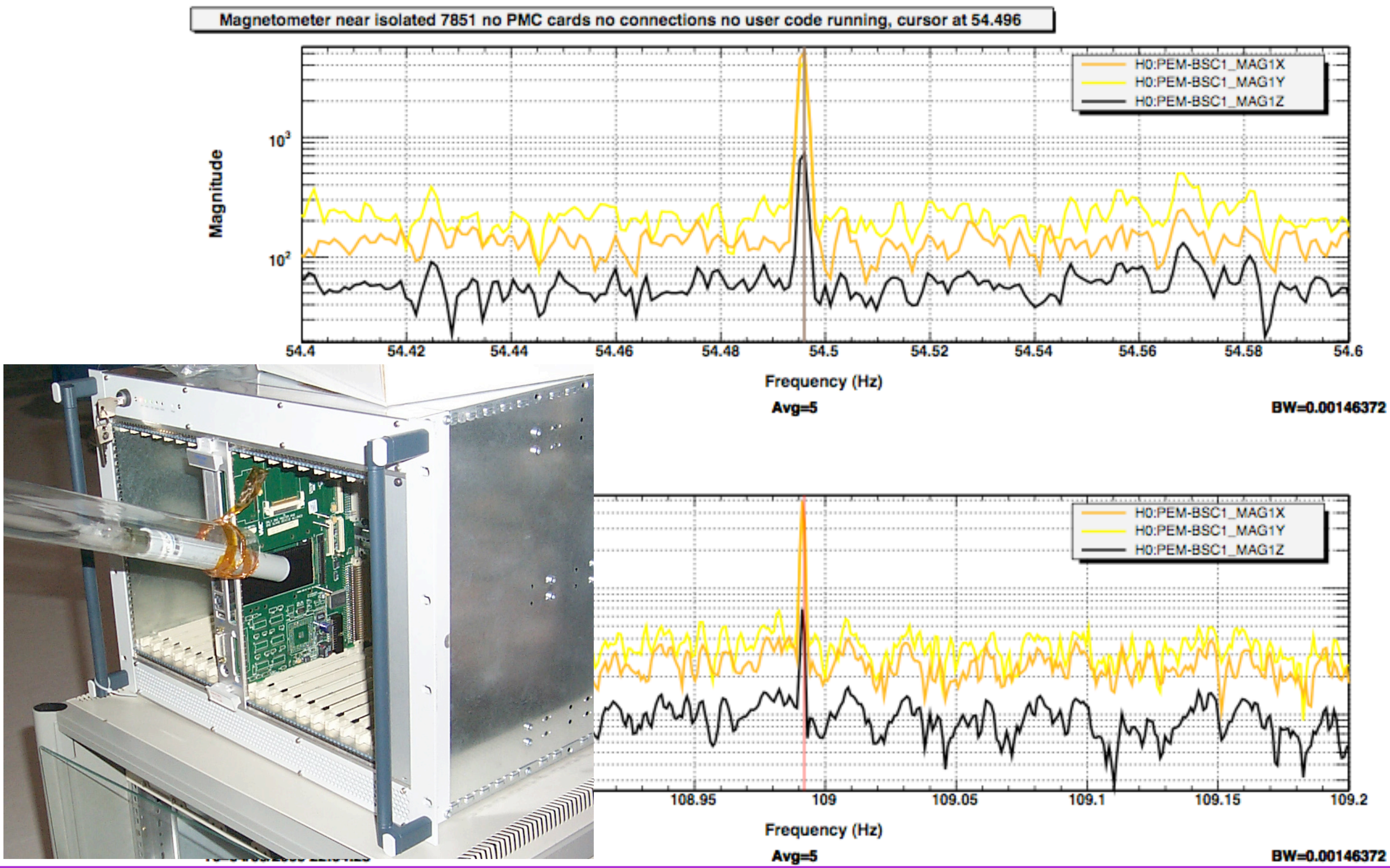


Lines from commercial electronics can be correlated between sites

Intersite coincident lines from VME CPUs

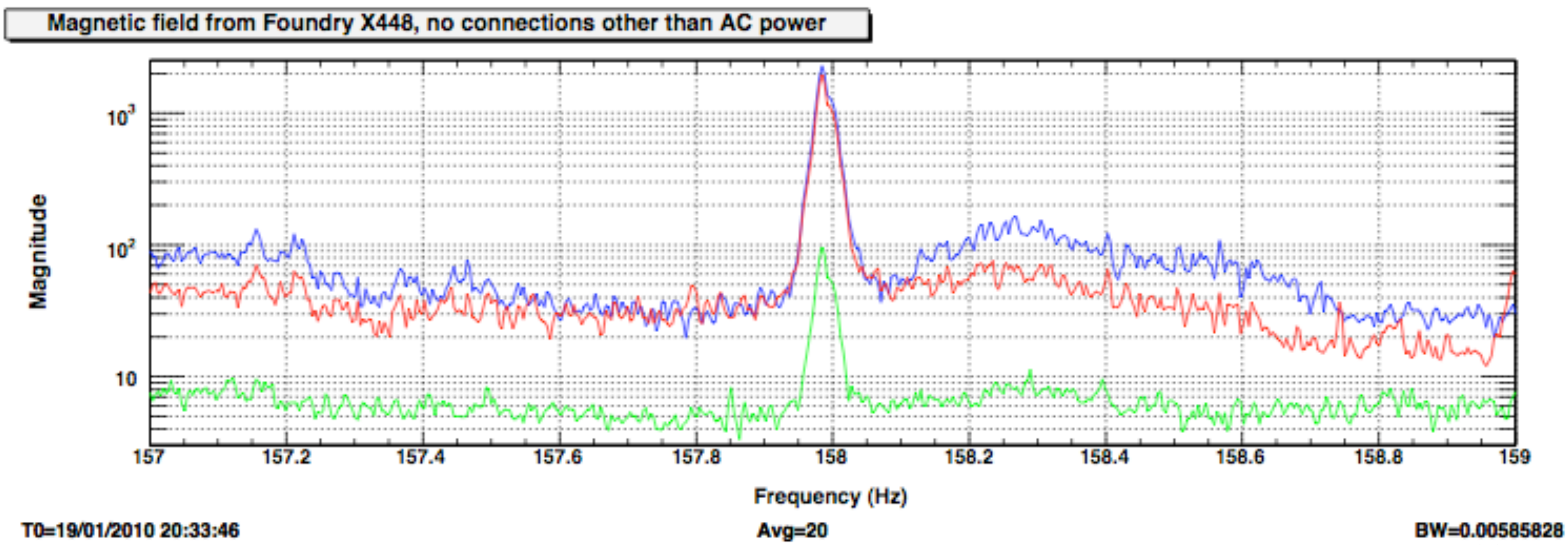
Lines at 54.496 and 108.922 from isolated 7851

Jonathan Leong, Richard M., Dave B, Robert S.



158 Hz Peak from isolated Foundry ethernet switch

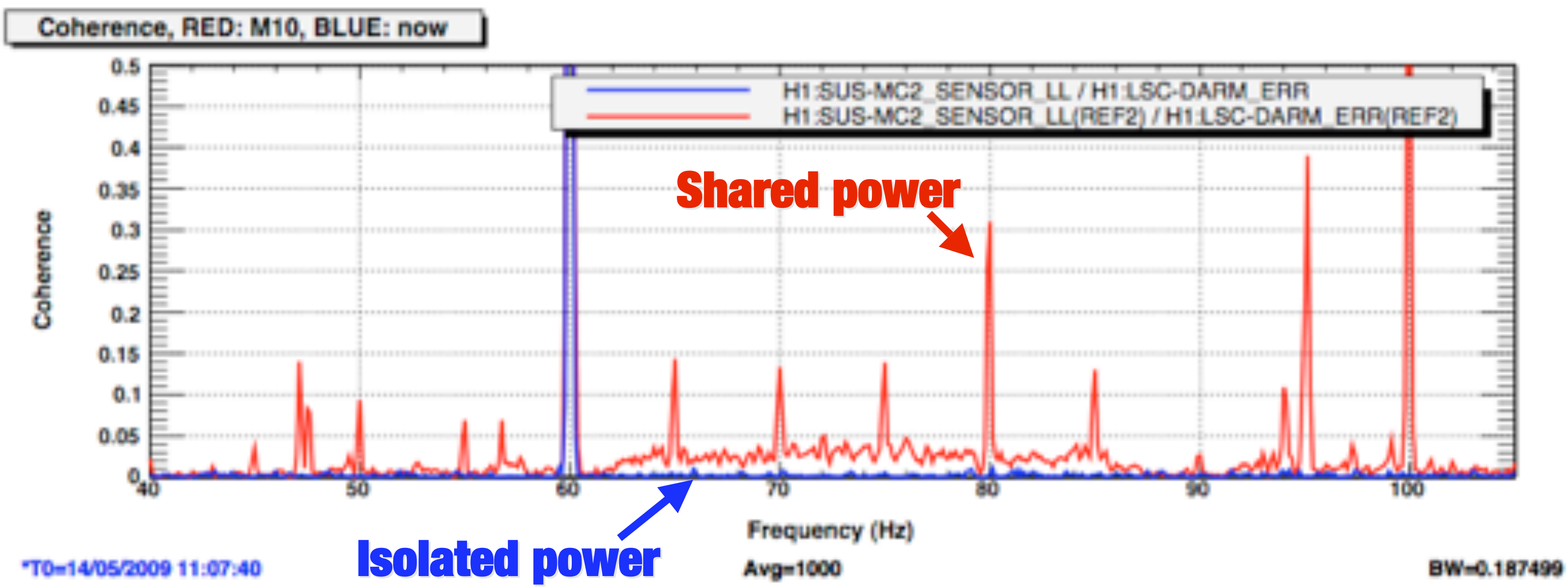
Ian Simpson, Vladimir Dergachev, Robert Schofield



5 Hz comb from PSL laser controller

Refresh of Beckhoff display screen - solved by powering with separate power supply

Rick S., Christian Veltkamp, Richard M., Robert S.



Piezo systems caused severe S6 glitches

1) **Gremlin**: preceded by 600 Hz oscillation visible only on PD1&2, no longer seen after 600 Hz notch added to OMC length control.

2) **ISCT1**: eliminated by shutting down power supply to RBS mirror piezo actuator.

3) **Grid**: eliminated by resoldering connections in piezo power supply for OMC.

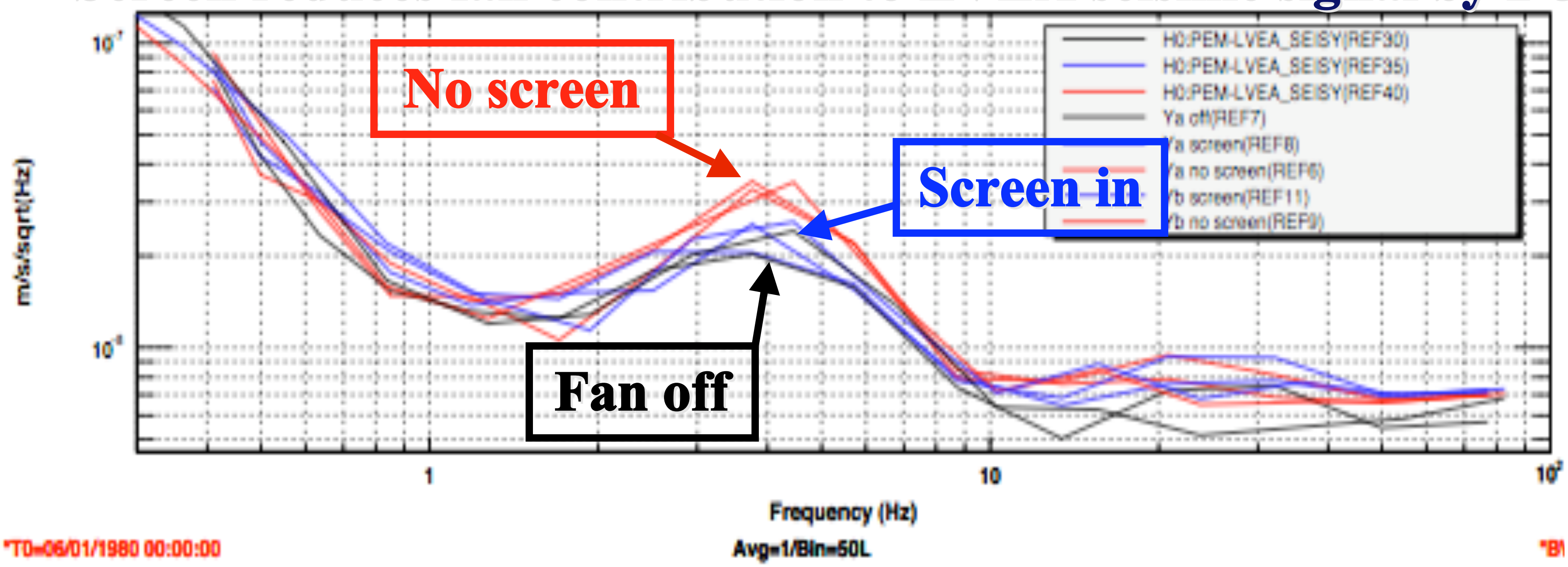
HVAC and Chilled water hurt most through turbulence, not motors

Screen reduces low-f noise from HVAC fans

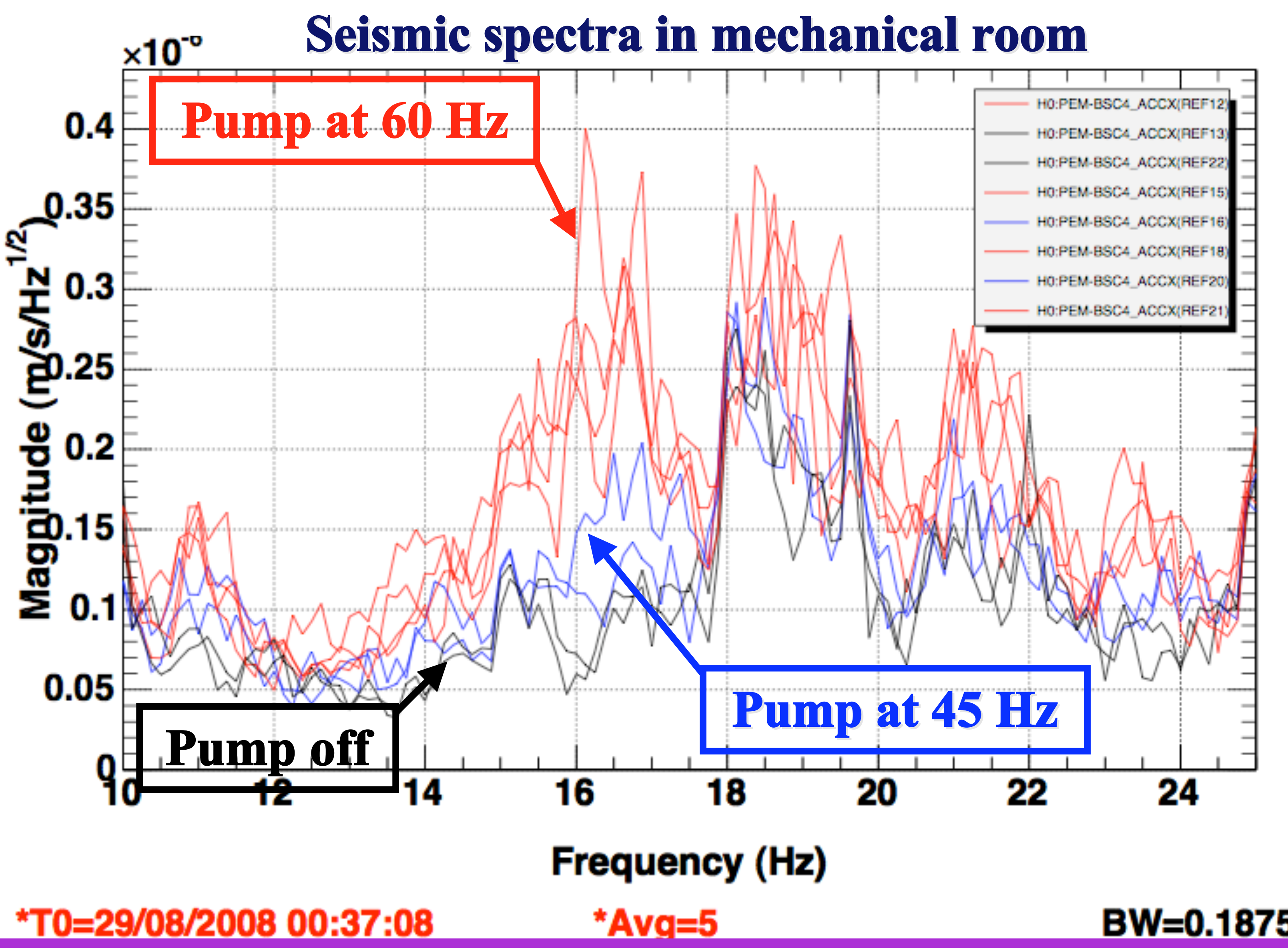
Low frequency noise from large eddies.

Reduce eddy size with screen

Screen reduces fan contribution to LVEA seismic signal by 2-3



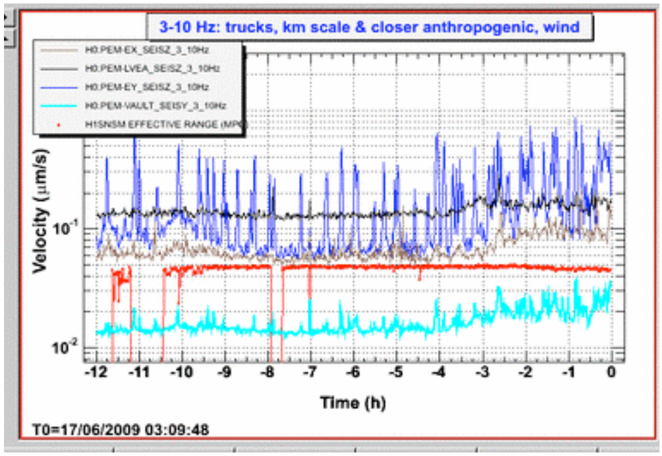
Reducing seismic noise by running chilled water pumps at 45 Hz instead of 60 Hz



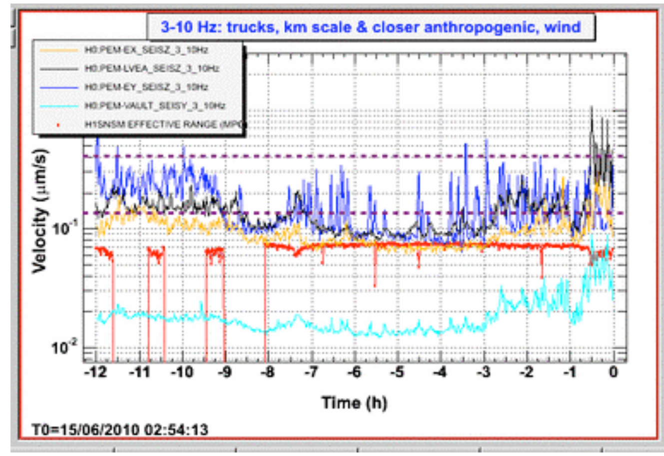
Road repaving reduced worst 3-15 Hz sesimic signals by 2 to 3

3-10 Hz PEAK SEISMIC NOISE DOWN BY >2 WITH RESURFACING OF HIGHWAY 240

Before



After



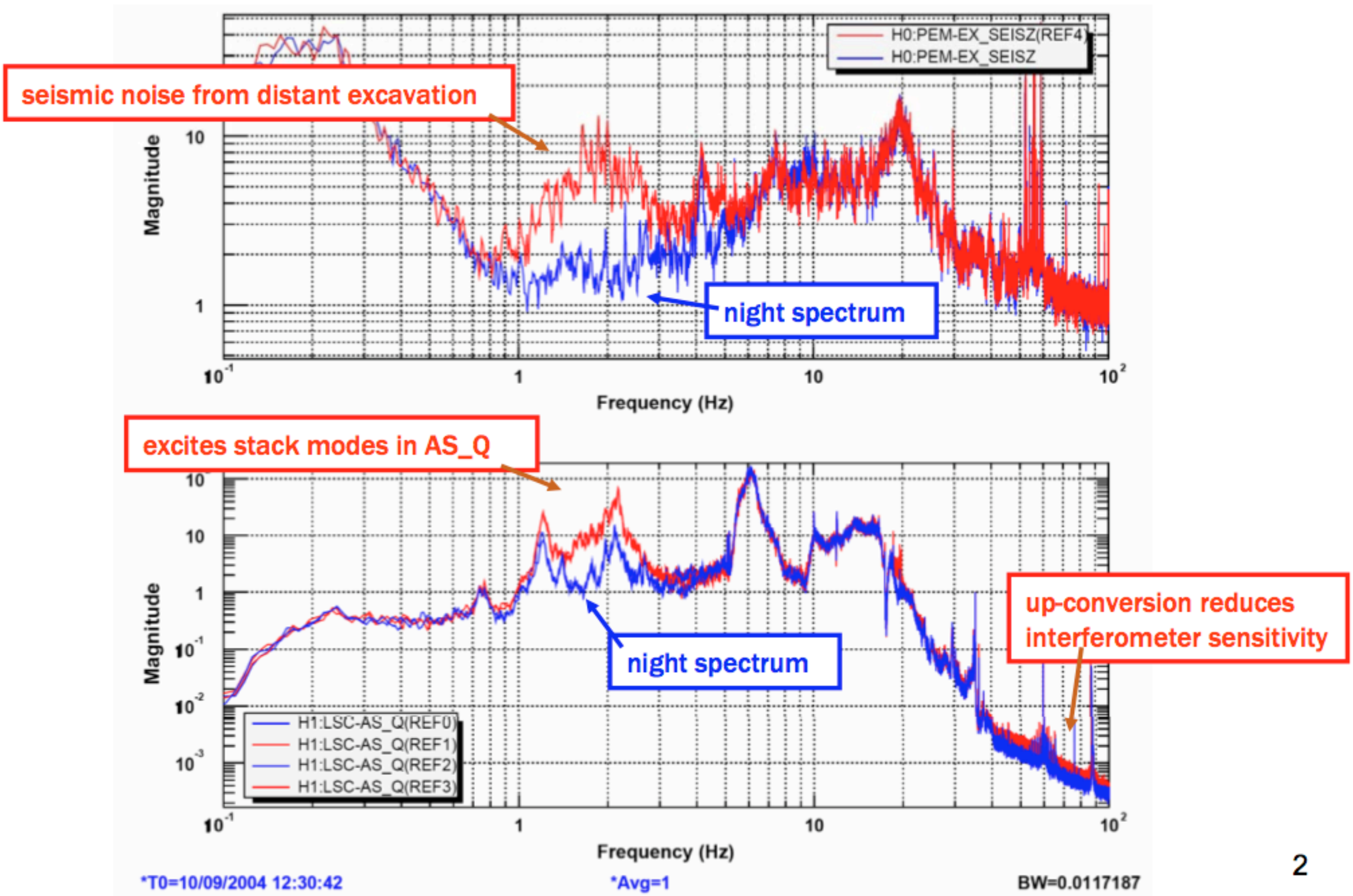
Percentiles from sorted 1 minute trend values (maxima) of H0:PEM-EY_SEISZ_3_10Hz for 150 days starting Nov. 2

Percentile	Amplitude 2008-2009	Amplitude 2009-2010	After paving/ before paving
99.9	23982	8637	0.36
99	5560	2582	0.46
95	2630	1205	0.46
90	1633	769	0.47
75	575	309	0.54
50	251	152	0.61

Maximum 10 Hz Newtonian noise estimates down by >2 for aLIGO

Upconversion: 300 series steel can become magnetic when cold worked

Seismic upconversion began limiting range in 2004



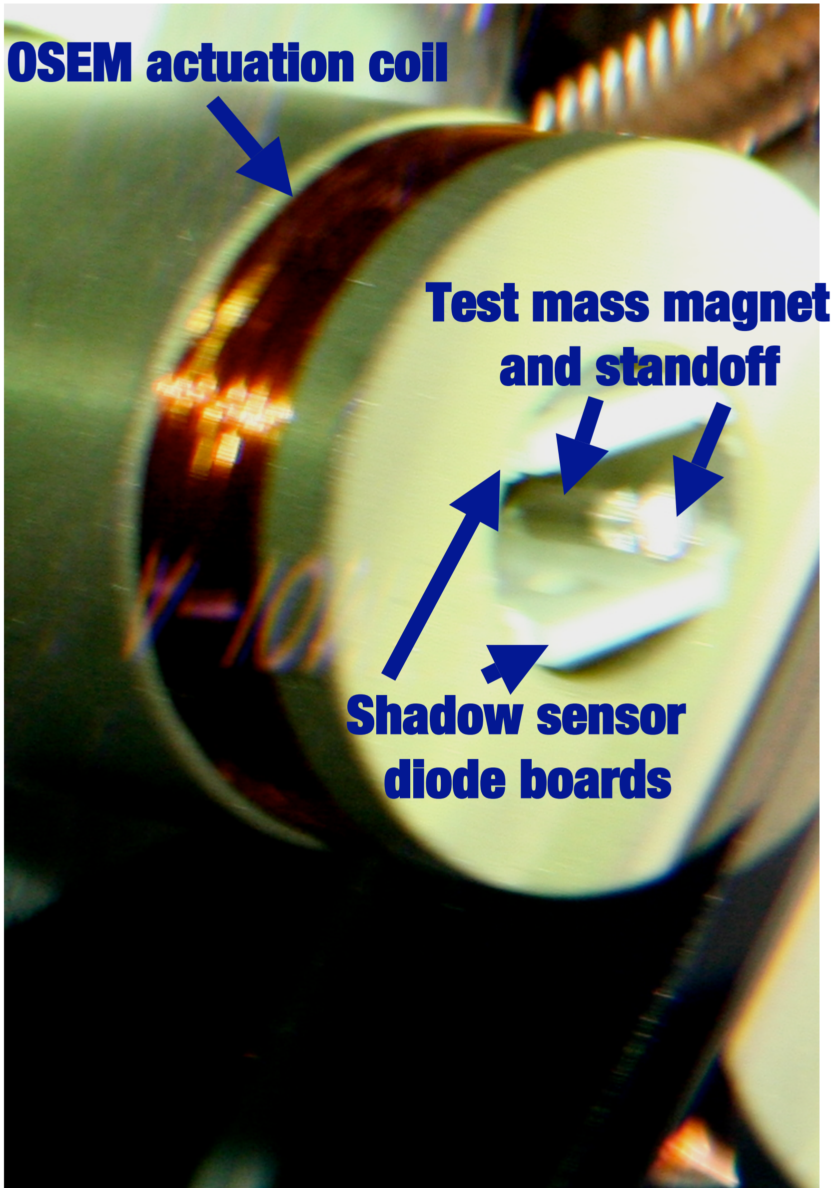
LHO upconversion before and after test mass magnet swap
and predicted PAM magnet forces

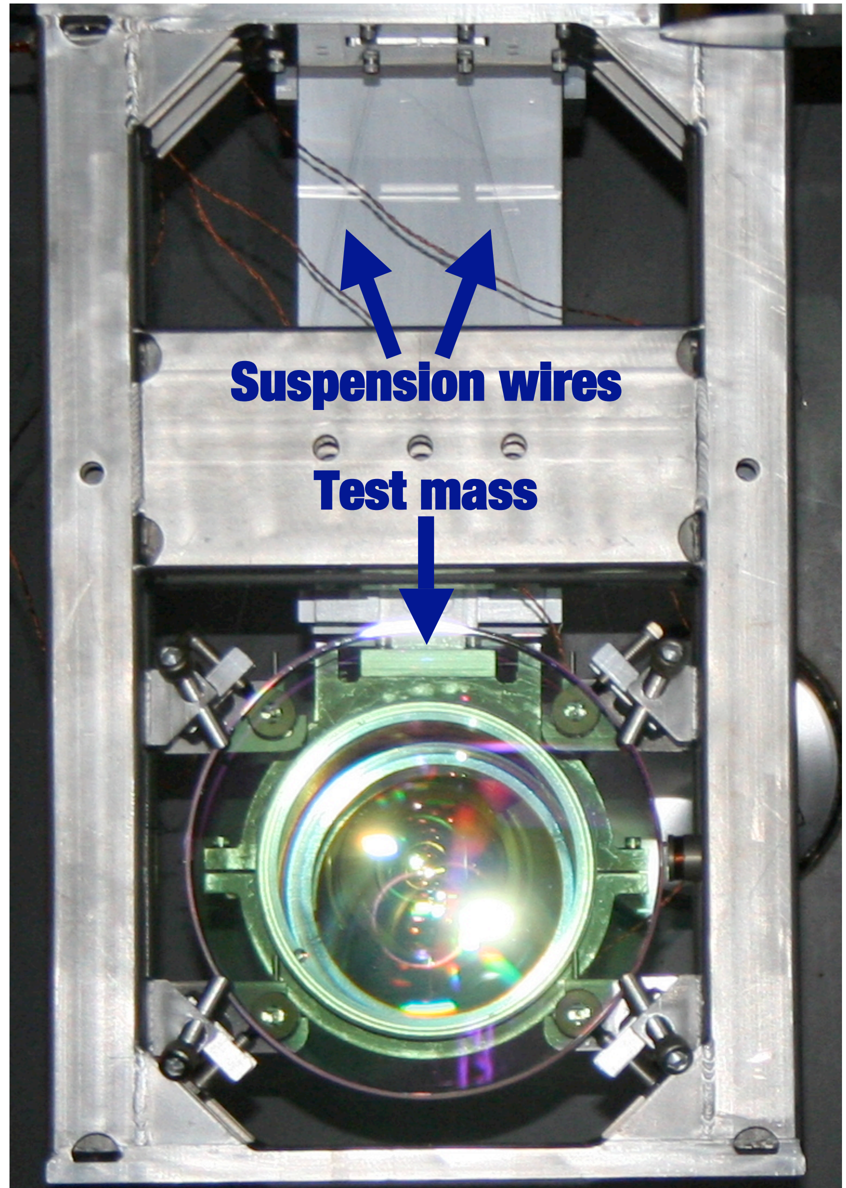
Test mass	Upconversion noise fit to A/f^4: pre-swap A	recent A	ratio	Predicted PAM magnet forces: before	after	ratio
ETMX	3.8e-12	b 5.6e-12	1.48	12	8.2	0.7
ETMX		a 6.5e-12	1.72			
ETMY	1.2e-11	c 1.2e-11	1.01	14	8.4	0.6
ETMY		b 1.1e-11	0.90			
ETMY		a 1.3e-11	1.06			
ITMX	3.5e-12	6.2e-12	1.76	24	4.4	0.2
ITMY	7.1e-12	5.3e-12	0.74	49	26	0.5

To test upconversion from individual test masses, directed LSC control to each test mass using Rana's resonant gain technique.

Take home message: TM magnet swap didn't reduce upconversion and no evidence that switching PAM magnets would have helped.

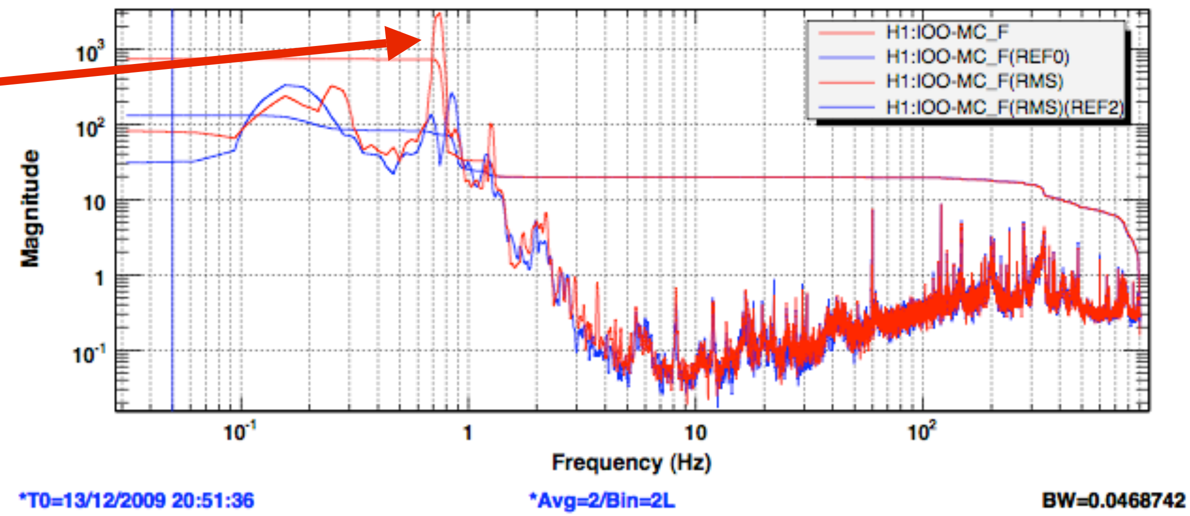
Mechanisms other than Barkhausen?



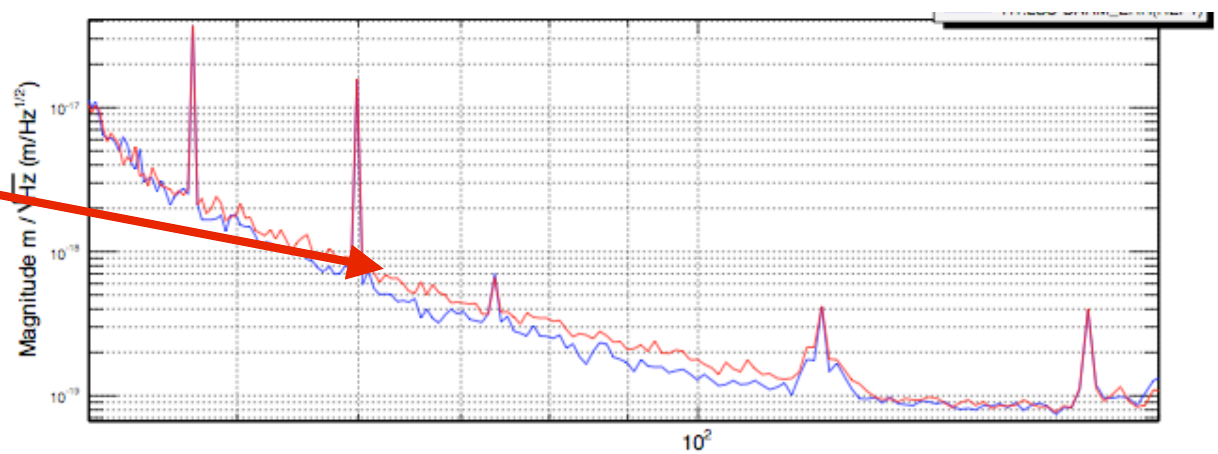


Upconversion goes with coil current not test mass motion

100 fold increase in common mode motion of test masses



Leads to small increase in upconversion predicted from small increase in coil current due to angular damping

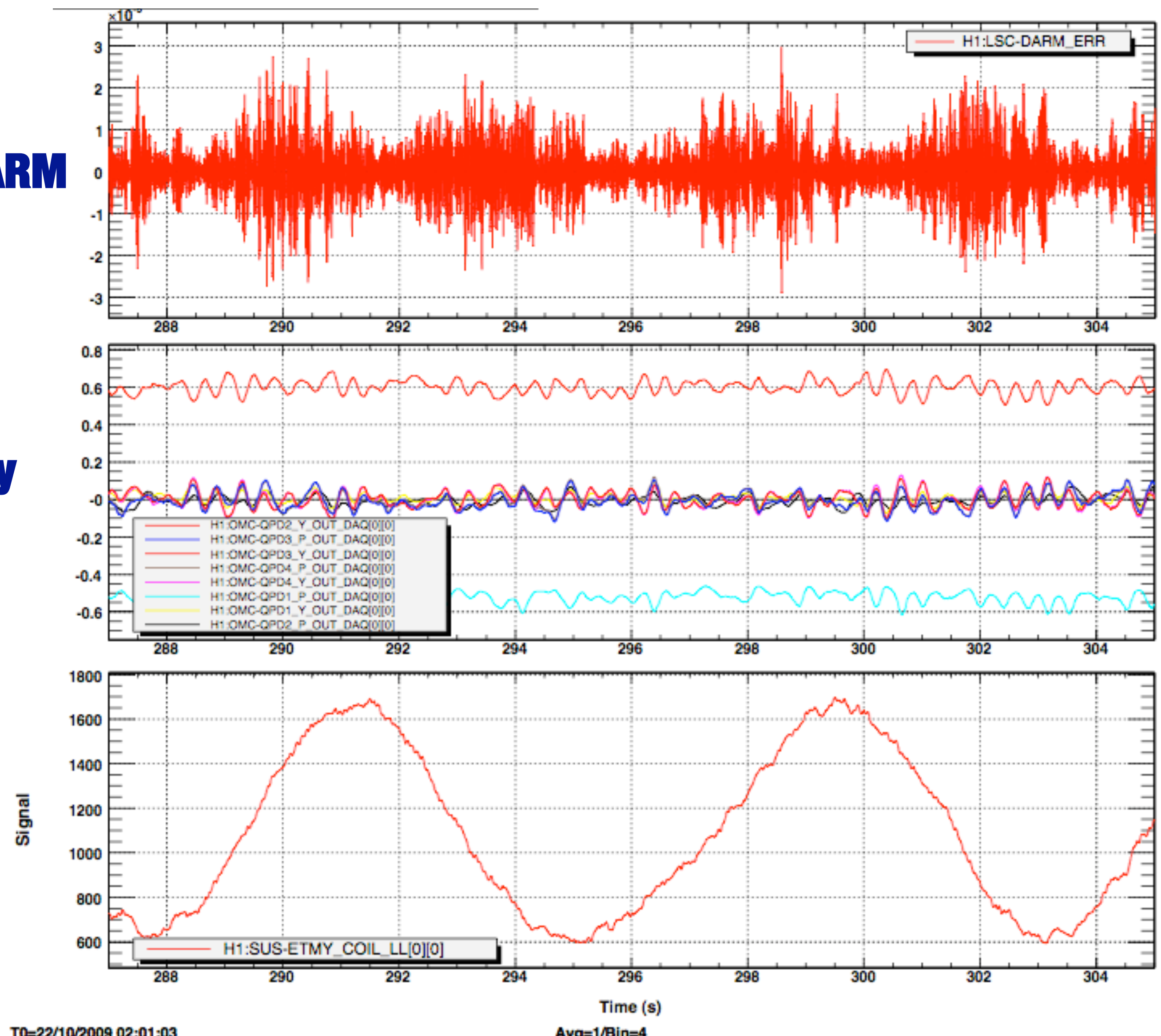


Upconversion bursts go with coil current not beam jitter

70 - 110 band of DARM

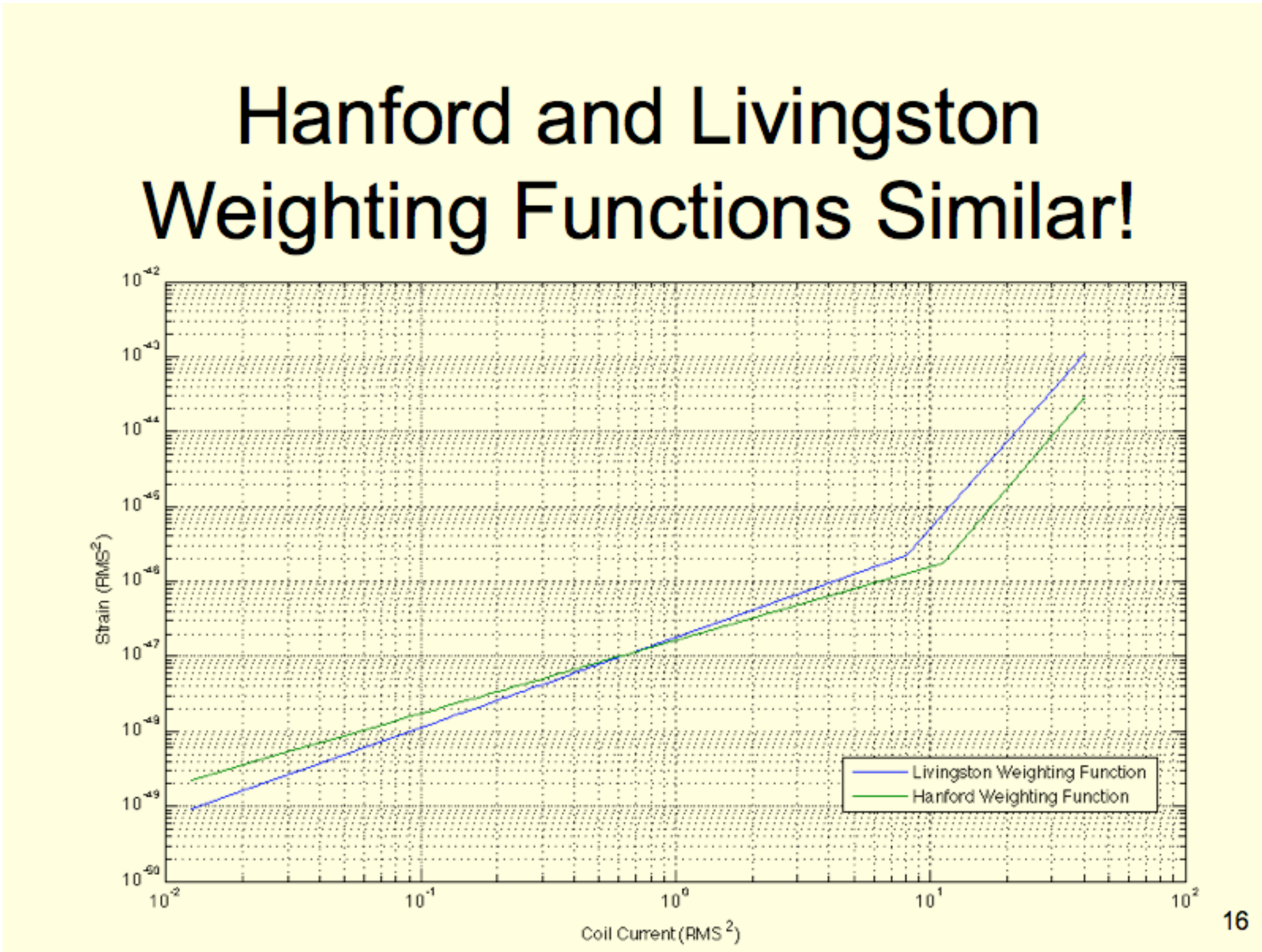
Beam jitter as seen by OMC quad diodes

Actuation coil current

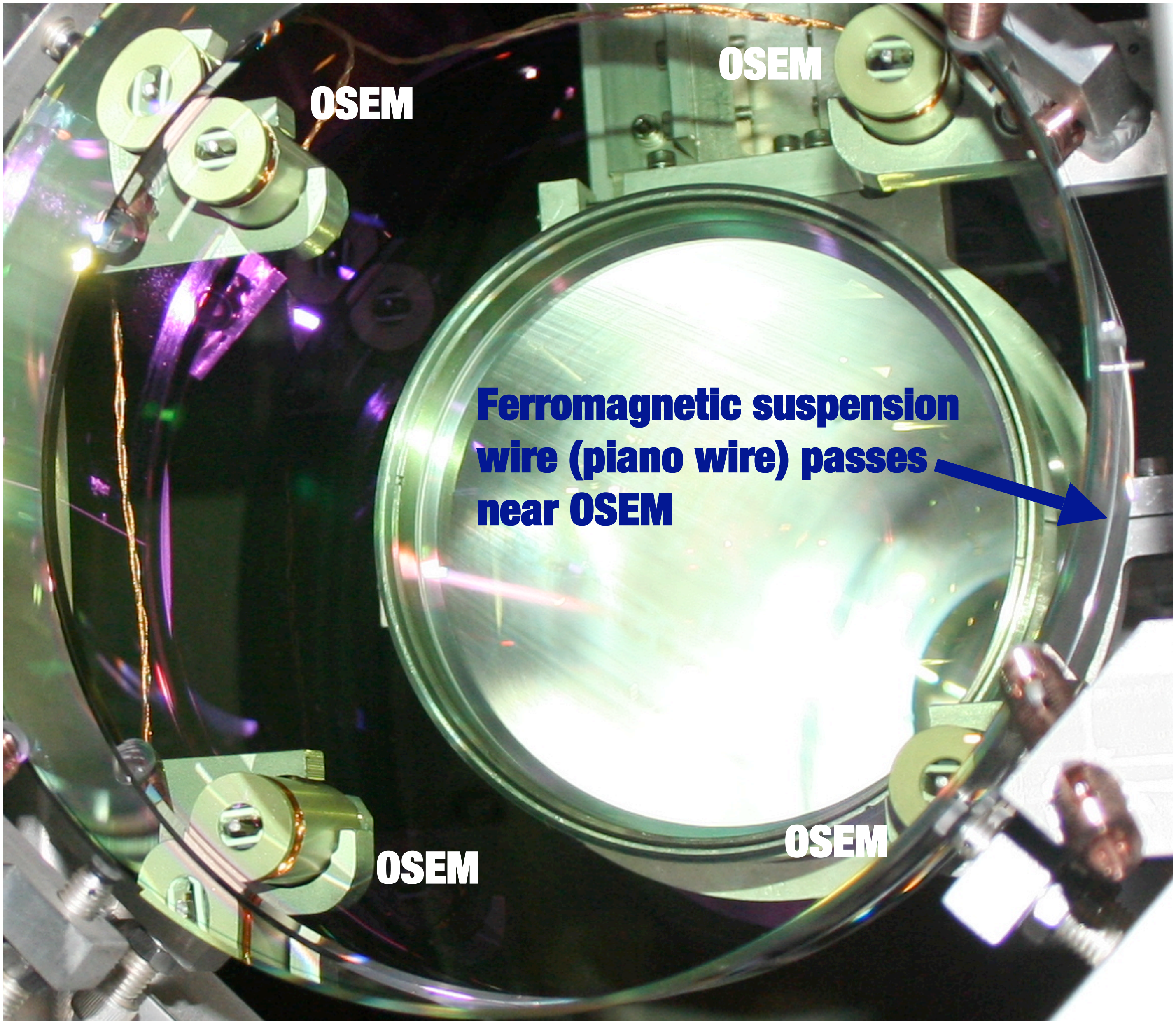


LHO and LLO similar

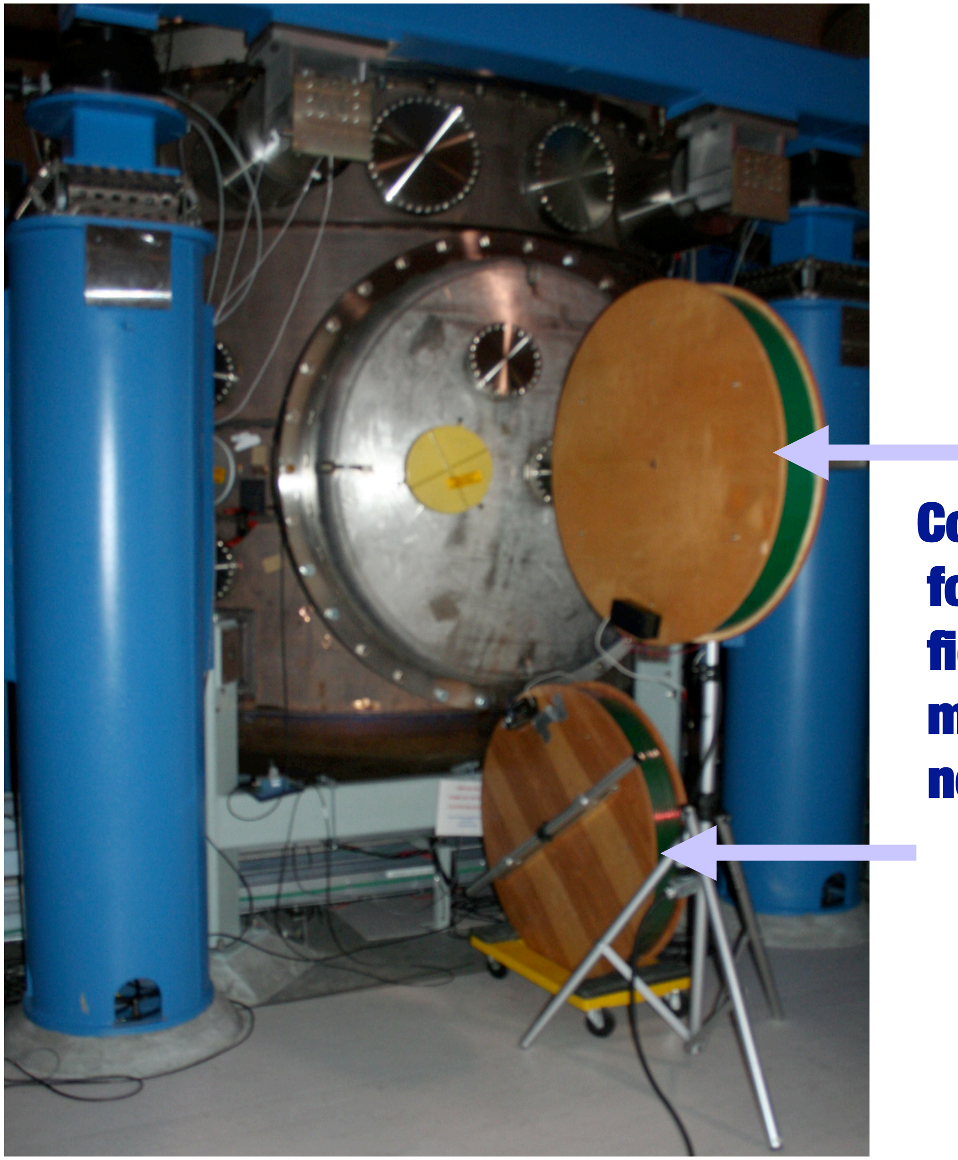
S6 seismic upconversion flags from Ryan Quitzow-James (University of Oregon) use similar weighting functions for coil currents.



Barkhausen noise from suspension wire ?

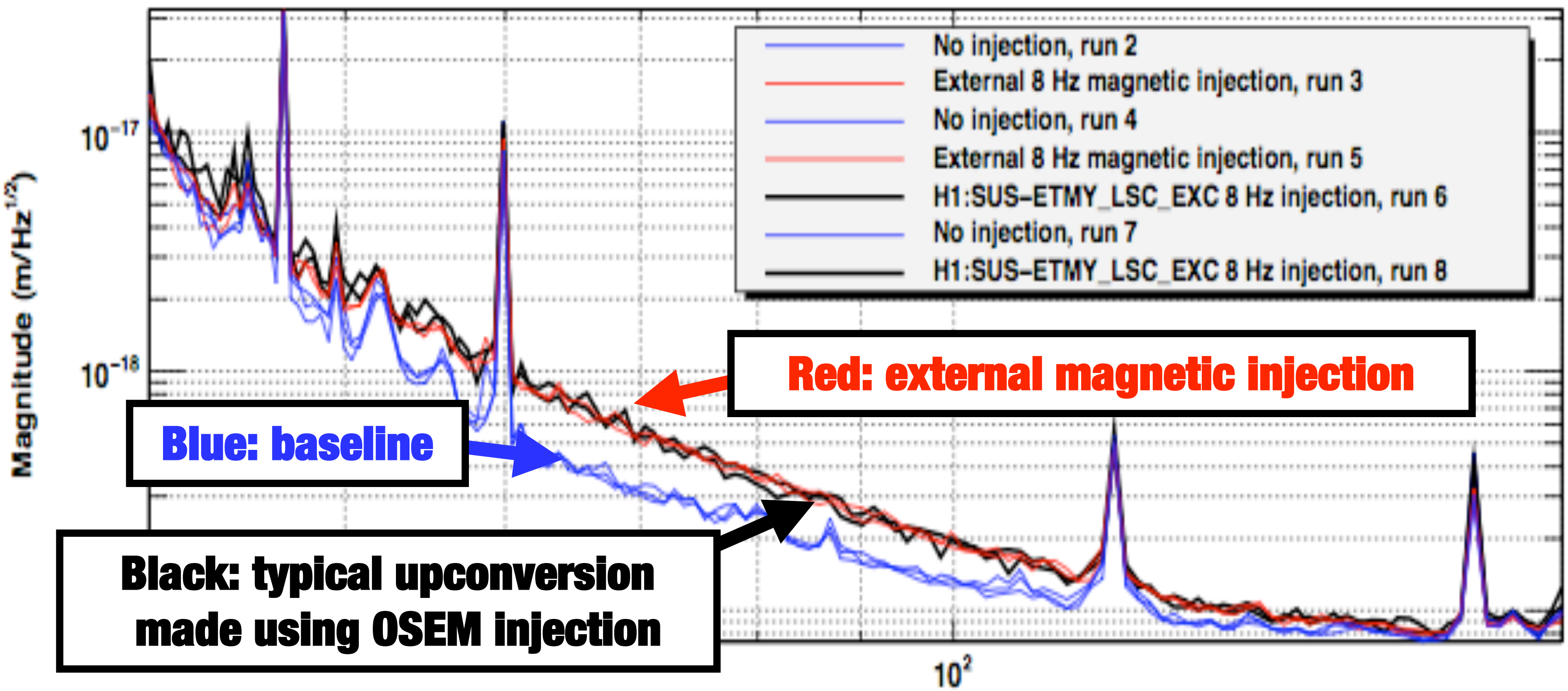


Can magnetic fields reproduce seismic upconversion ?



Coils in position at ITMY for injecting magnetic fields to test Barkhausen magnetic domain change noise hypothesis

Upconversion from external 8 Hz magnetic injection



Reproduces spectral shape of seismic upconversion

Similar plot for 2 test masses, 3 injection frequencies

Location of Barkhausen noise source

Source is assumed to be located where magnetic fields from external and OSEM injections are equal, for equal upconversion

- **Not suspension wires, because externally generated field at wires was >100 times larger than OSEM field for same upconversion level**

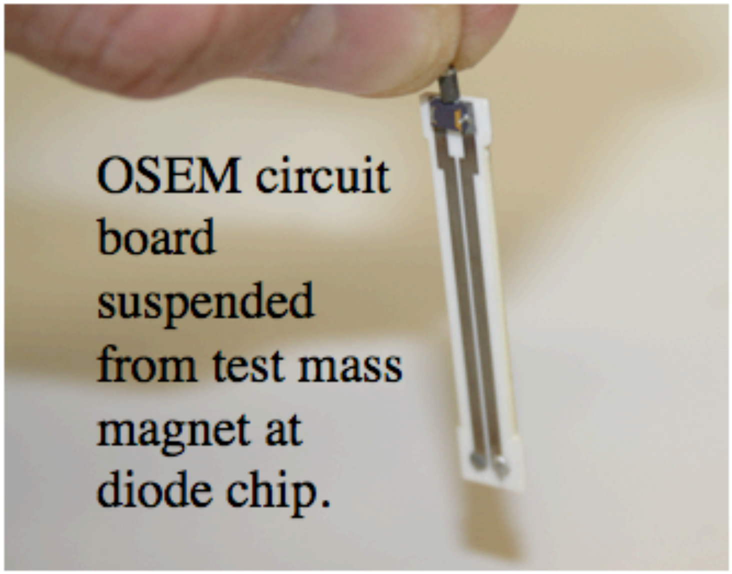
- **Not other locations distant from OSEM (e.g. earthquake stops)**

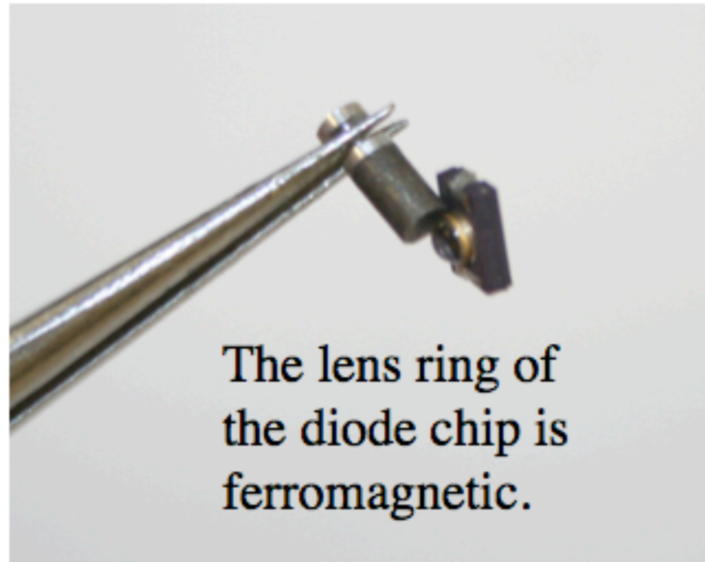
External and OSEM fields match at OSEM center
for equal levels of upconversion

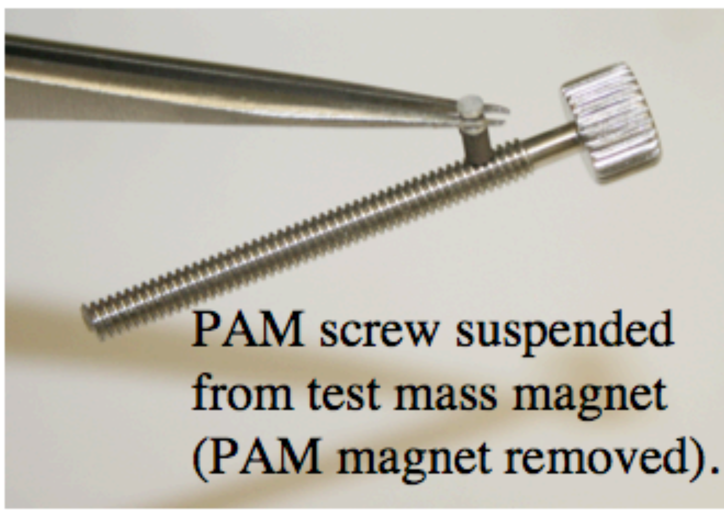
Estimated magnetic fields at center of OSEM coil

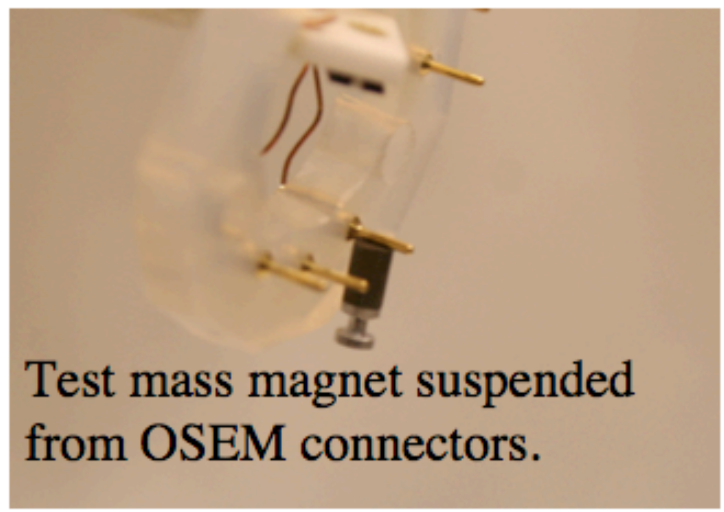
Location and frequency	From external coil	From OSEM coil	OSEM/external coil
ITMY 8 Hz	9.8 e-6 T	8.94e-6 T	0.91
ETMY 8 Hz	5.86e-6 T	5.50e-6 T	0.94
ETMY 4 Hz	1.06e-5 T	7.20e-6 T	0.68
ETMY 2.5 Hz	9.33e-6 T	1.11e-5 T	1.19

Ferromagnetic materials found near OSEM center

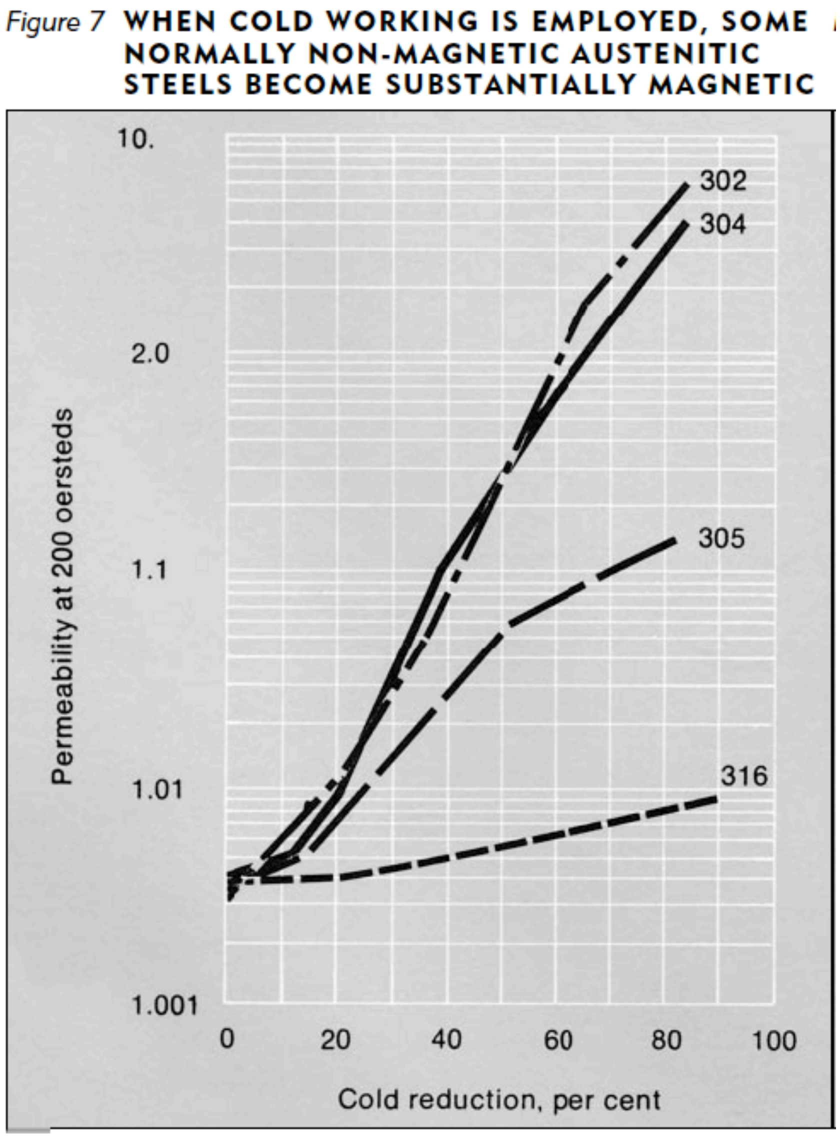








Fasteners can become magnetic when cold worked



What about advanced LIGO?

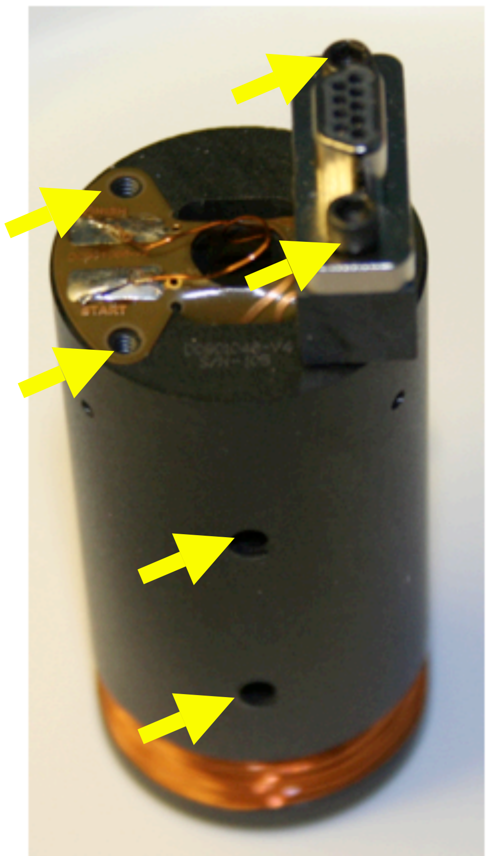
Electrostatic control of test mass, magnetic control of penultimate mass, so noise will be filtered by test mass pendulum

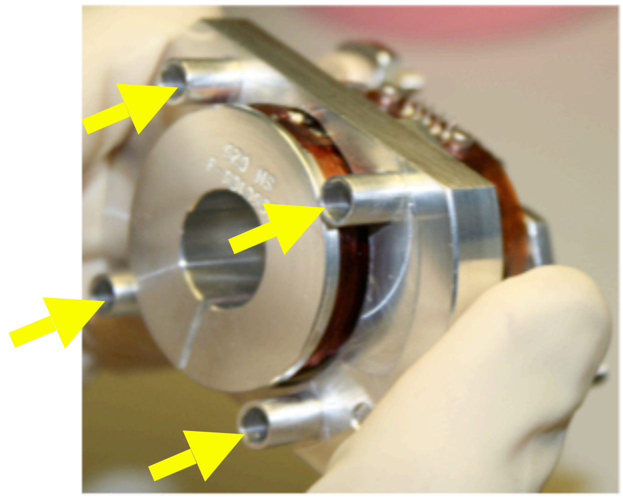
Barkhausen upconversion should not limit adLIGO if:

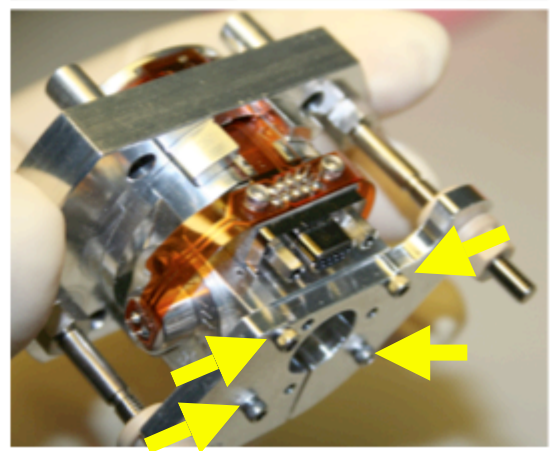
- Displacement noise at penultimate test mass is no more than for iLIGO
- Noise is not greater at low frequencies than predicted from spectral shape at 100 Hz

Risk reduction plan for adLIGO

- Use 316ss at indicated locations in all AOSEMs
- Replace the indicated fasteners in BS and FM BOSEMs







Summary

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2) aLIGO active ISI system isolates less at hi-f than iLIGO passive
3) Active suspension damping is better than passive
4) We need in-vacuum structural damping
5) Smaller permanent magnets are better where beam jitter hurts
6) Commercial electronics were the source of inter-site correlated lines
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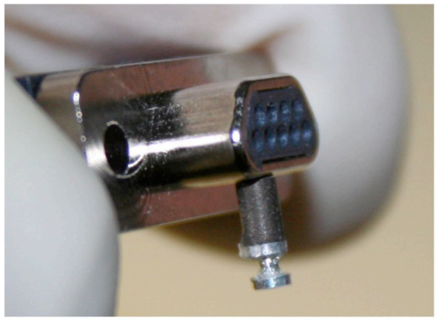
8) Turbulence in HVAC air and chiller water can be worse than motors
9) Repaving 240 reduced seismic signal by >2
10) Upconversion: 303 steel becomes ferromagnetic when cold-worked

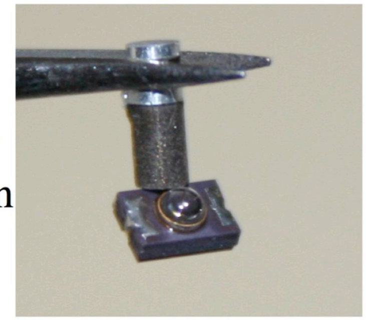
Photo: A. Johannesen.

Ferromagnetic components in AOSEMs

Connector (with suspended test mass magnet)

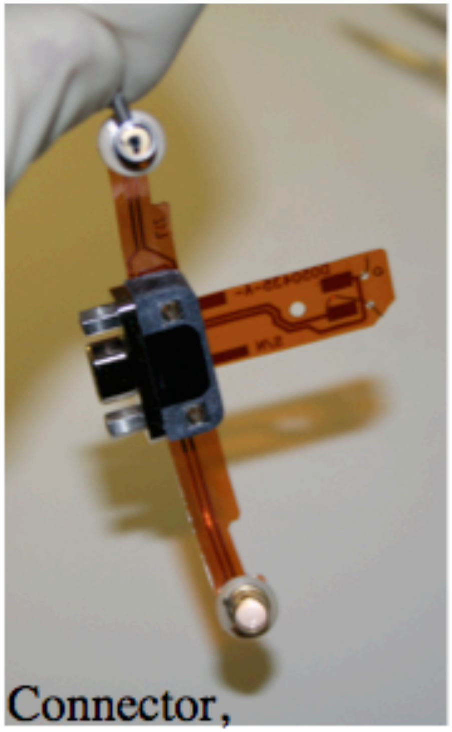


Diode chips, both transmitter and receiver, can be suspended from magnet



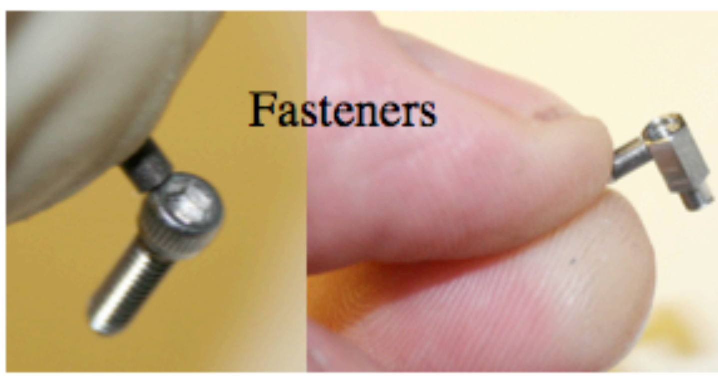
Fasteners

Ferromagnetic components in BOSEMs

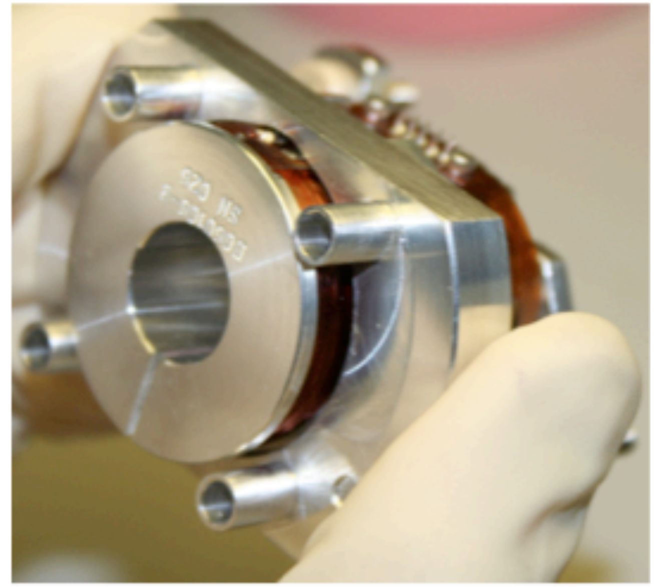


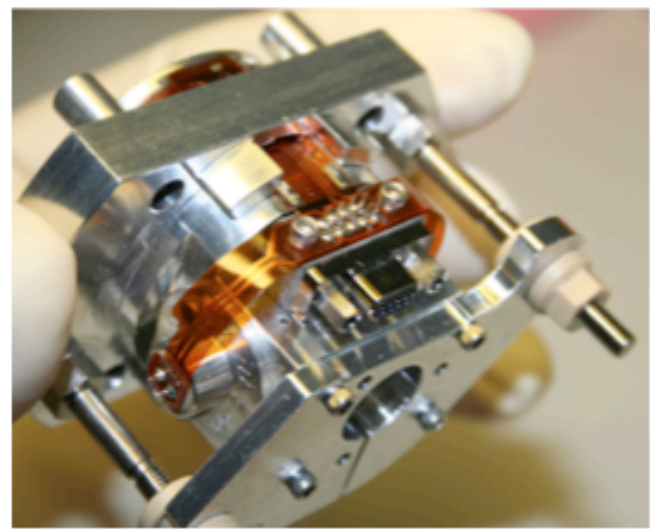
Connector, flexicircuit, LED and photodiode assembly suspended from test mass magnet

Connector (with suspended test mass magnet)



Fasteners



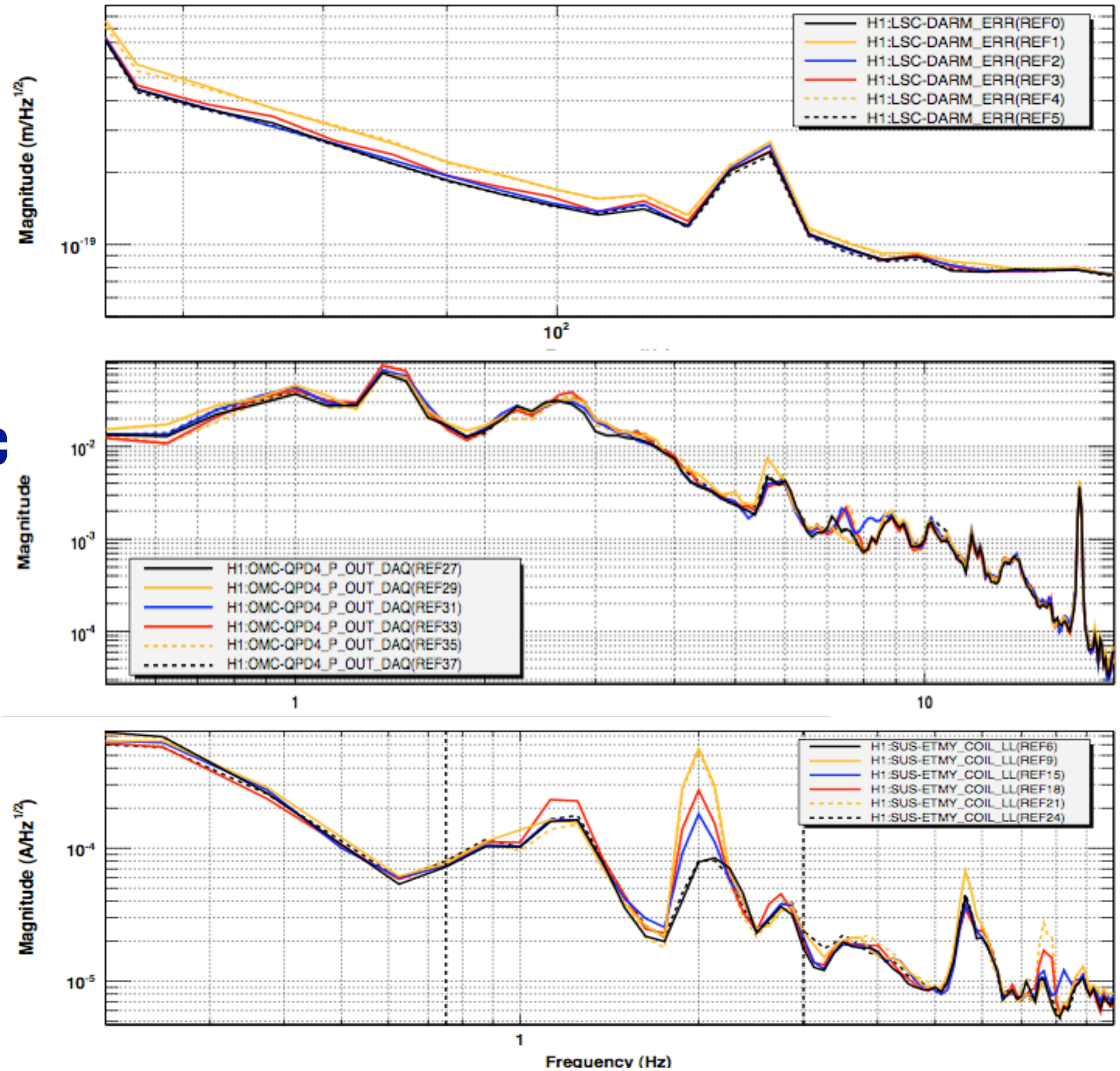


Upconversion goes with coil current not beam jitter

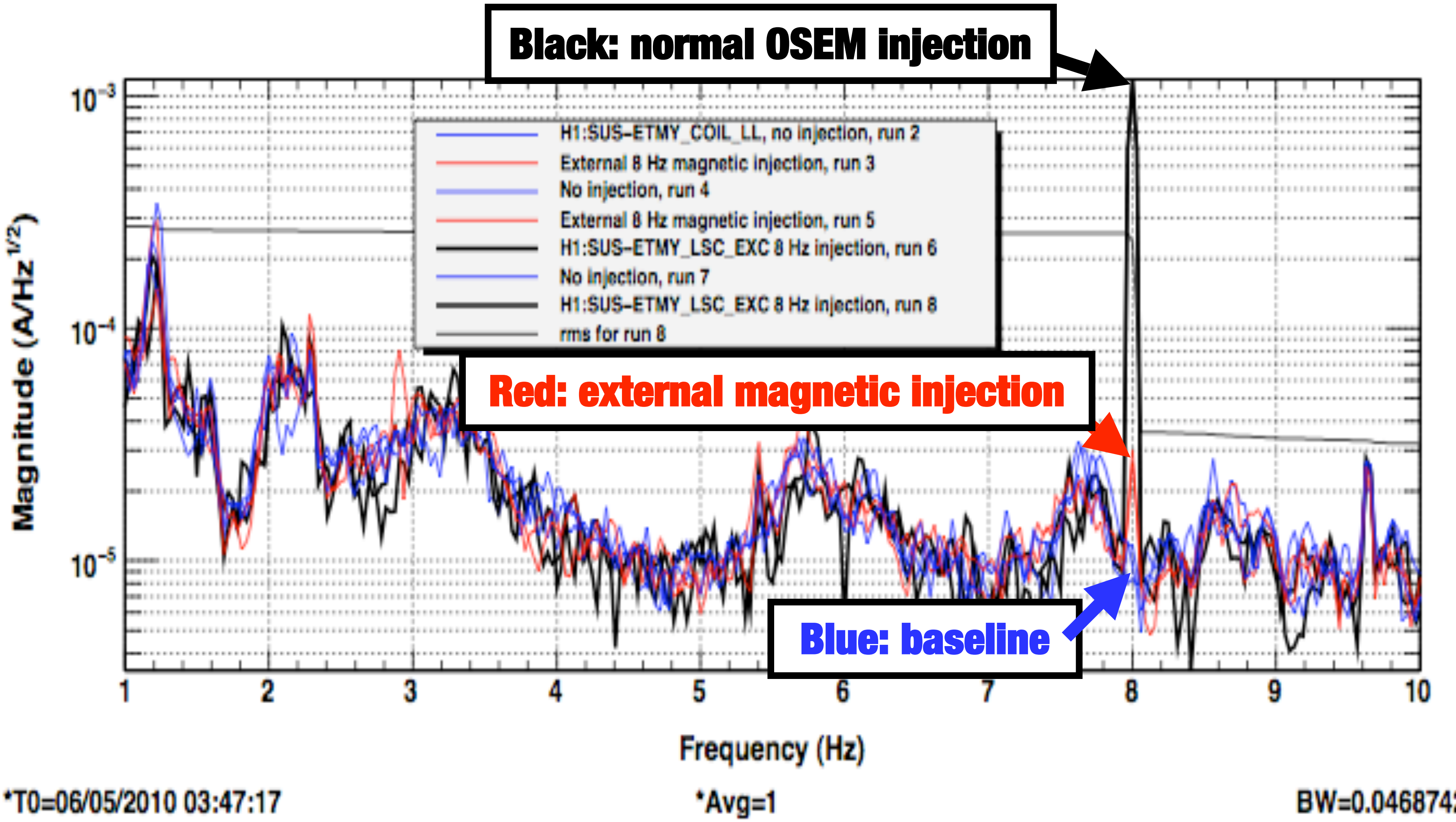
DARM upconversion region

Low f beam jitter from OMC quad diodes (pitch)

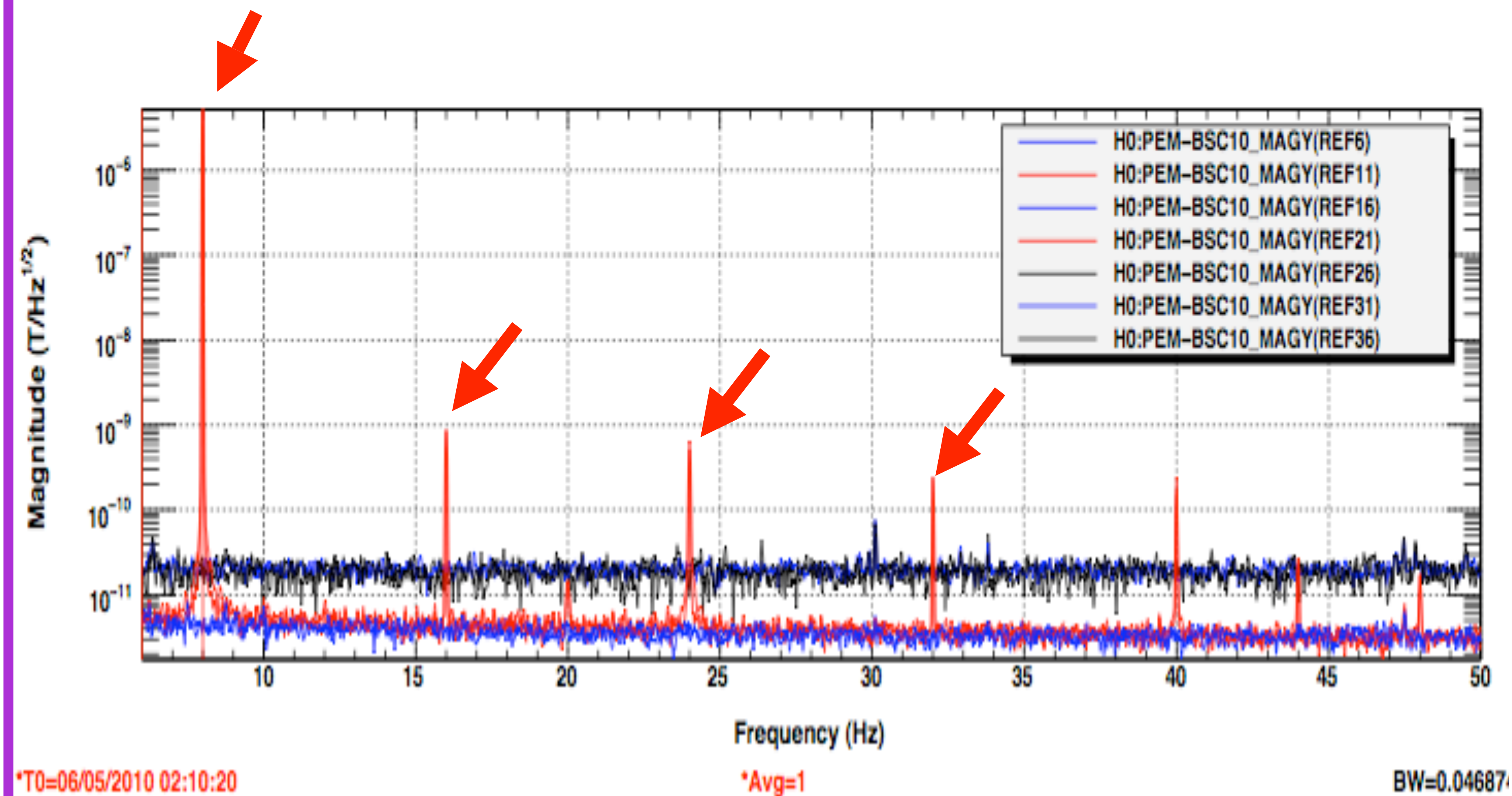
Low f coil current



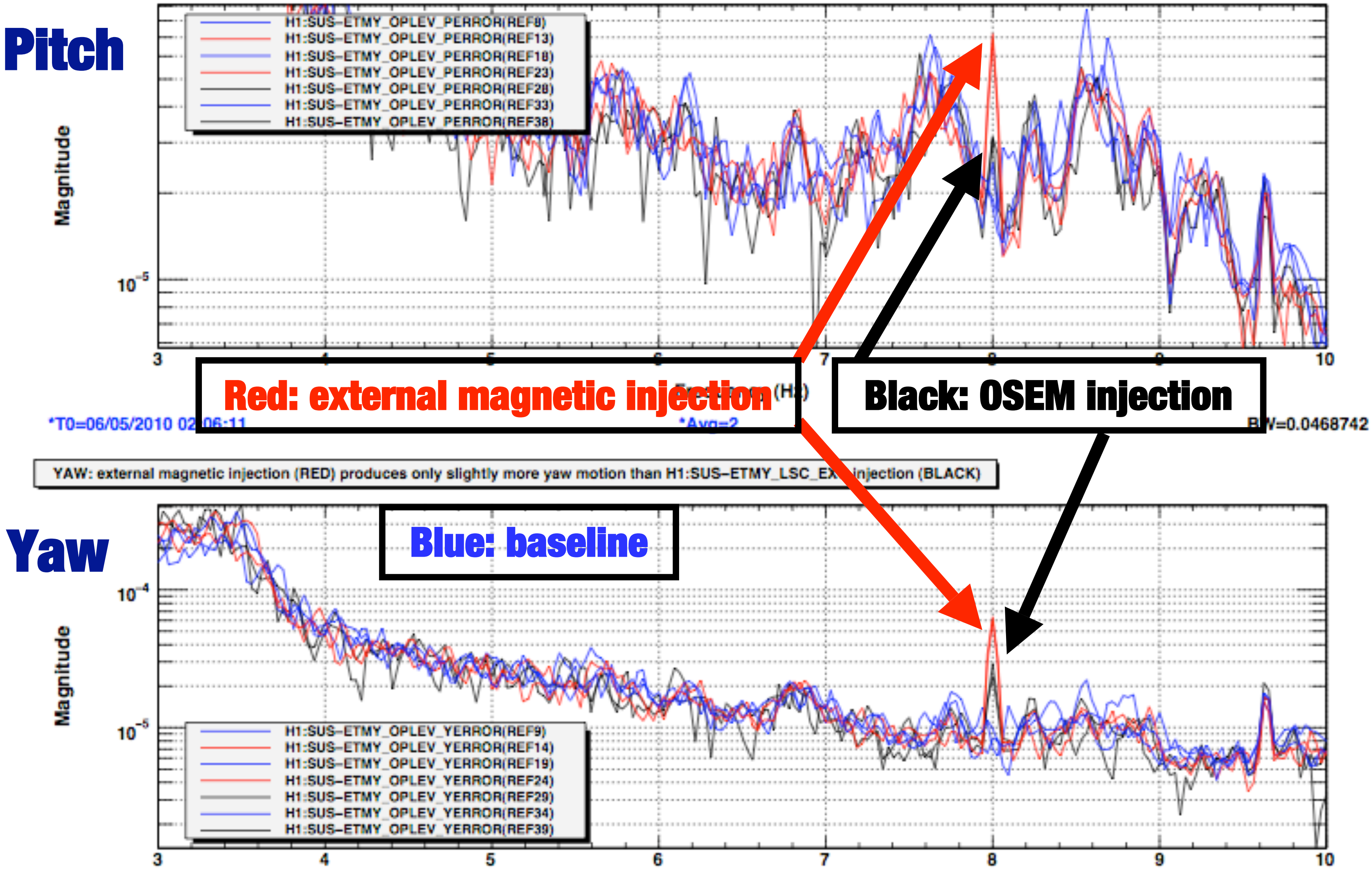
Check: coil current much smaller for external injection



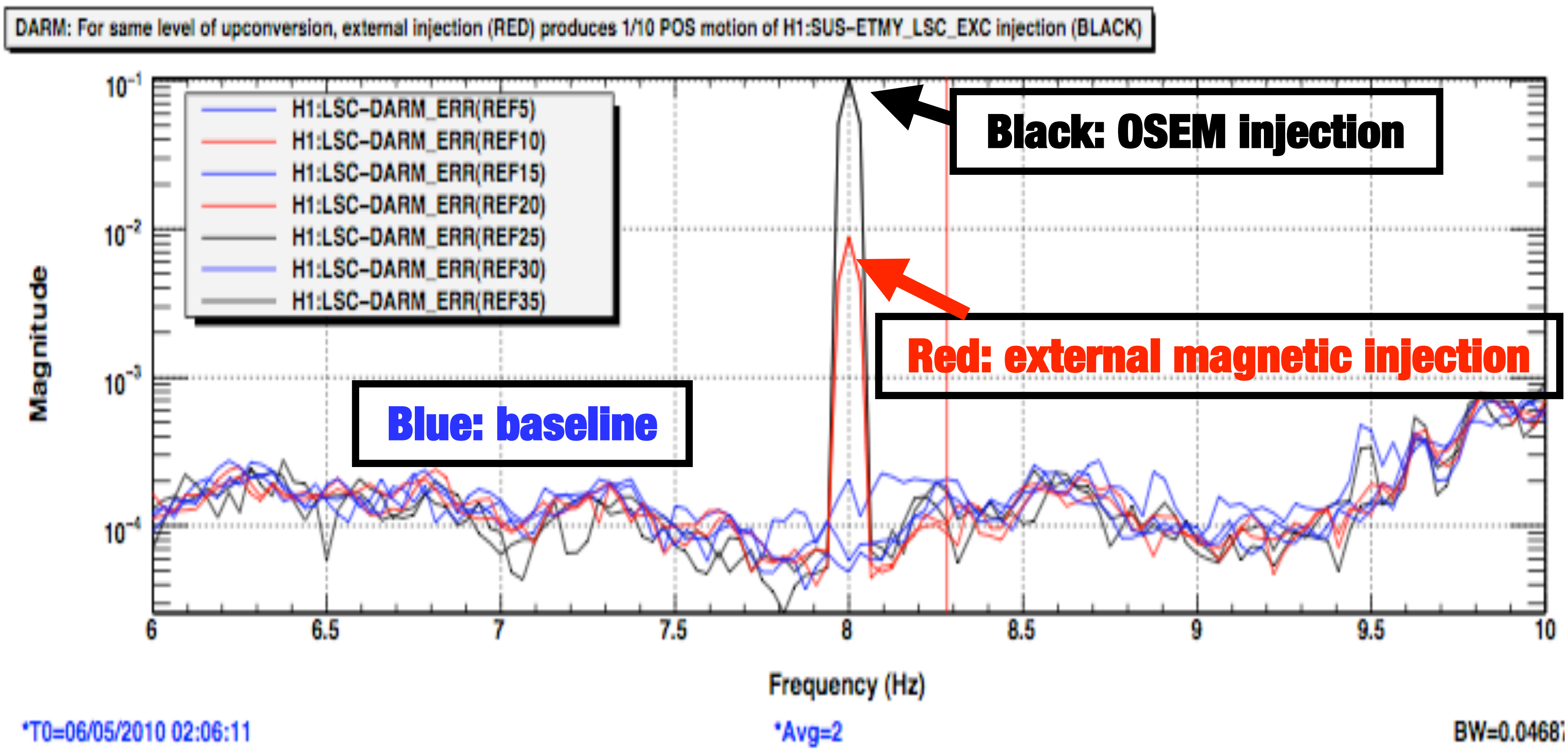
Check: only small magnetic fields at harmonics



CHECK: PITCH AND YAW MOTION FOR EXTERNAL INJECTION IS MINIMAL



Check: beam line motion was 10x less than for OSEM injection



Determining fields to narrow location of noise source

Predicting fields inside BSC chamber from external coil

- Fields assumed to drop off as $1/r^3$
- Small correction for eddy current shielding (knee ~20 Hz)
- Measured at 6 external locations to test prediction (including opposite side of chamber)
- Magnetometer calibrated at 2.5, 4, 8 Hz
- Standard deviation of predicted/measured was 0.34, n=6

Determining fields to narrow location of noise source

Predicting fields from OSEM coil

B_{center} = 4pi x 1×10^{-7} N I / sqrt(L^2 + $4R^2$)

N = number of turns in OSEM coil, 400 (unraveled and counted)
I = current through OSEM coil, from COIL channel, calibration: 6.67e-6 A/count
L = length of OSEM coil, 0.0047 (checked by measuring)
R = radius of OSEM coil, 0.01m (measured)

Summary

1) External magnetic injections were used to test the hypothesis that seismic upconversion is mainly Barkhausen magnetic domain noise.

2) External magnetic injections did produce upconversion and the spectral shape matched that of seismic upconversion.

3) For matched levels of upconversion, the OSEM and externally injected magnetic fields were estimated to be equal at the OSEM, suggesting that the source of the Barkhausen noise is in the OSEM.

4) Ferromagnetic parts were found inside the OSEMs, the largest was the PAM magnet screw.

5) A measurement of the Barkhausen noise from this screw should be made to confirm that it was the source of seismic upconversion.

6) Barkhausen noise is unlikely to limit adLIGO (test mass actuation is electrostatic) but to reduce risk, some screws in the penultimate mass magnetic actuators will be replaced with 316ss.