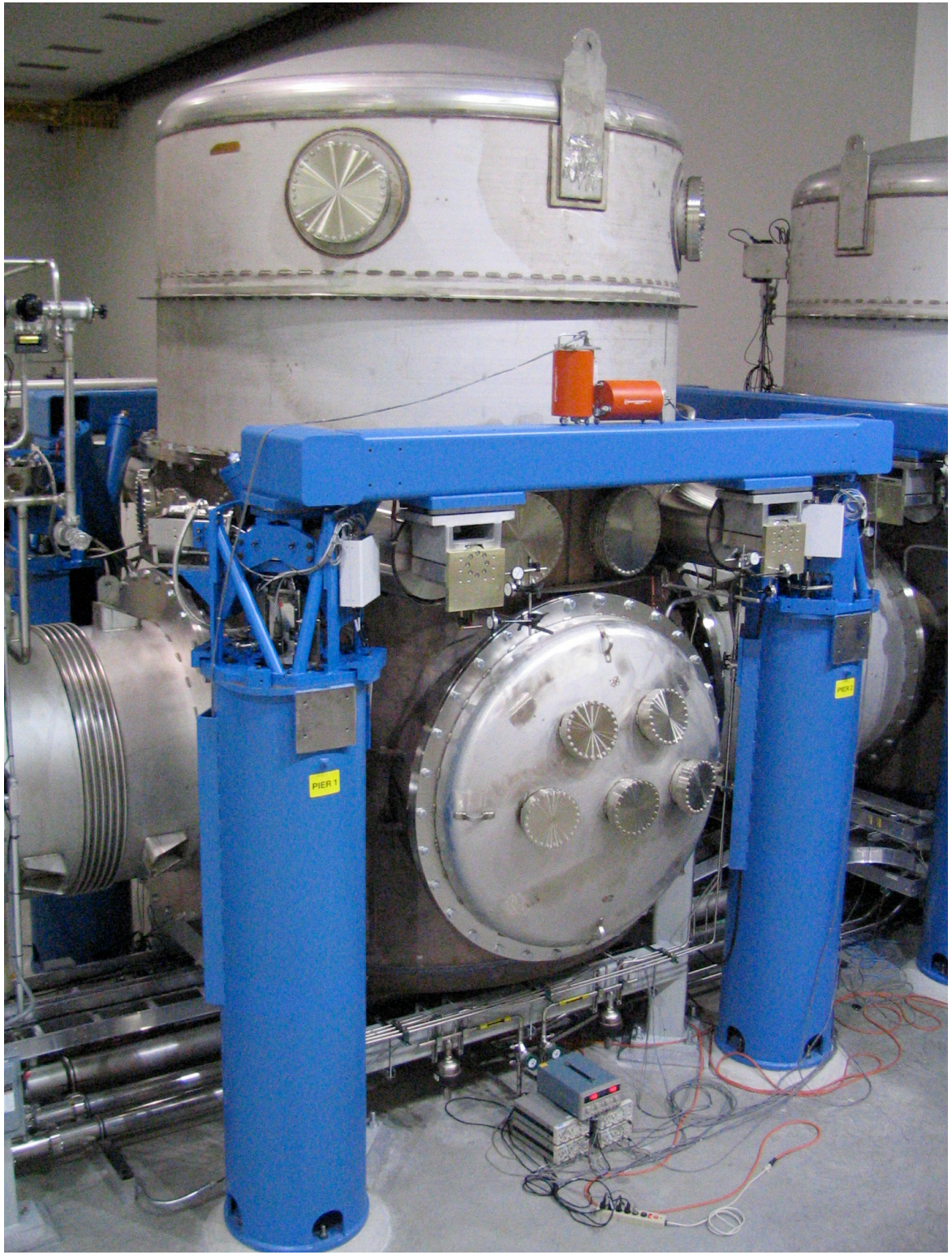
LIGO Commissioning

PAC Meeting, 18 May 2005, LIGO Livingston

Joe Giaime, LSU & LLO,
for the entire commissioning team.

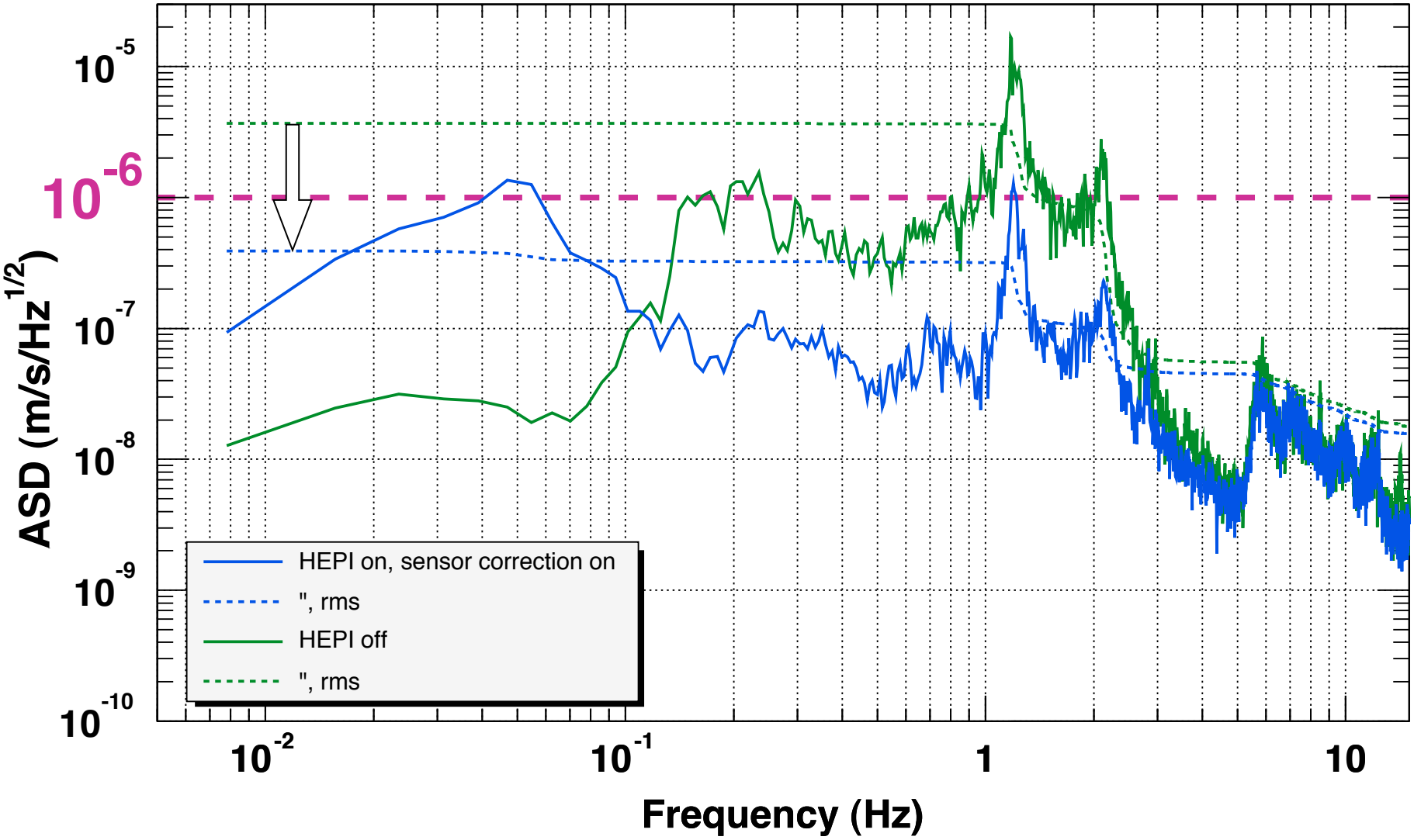
LIGO-G050263-00-D



Hydraulic External Pre-isolation

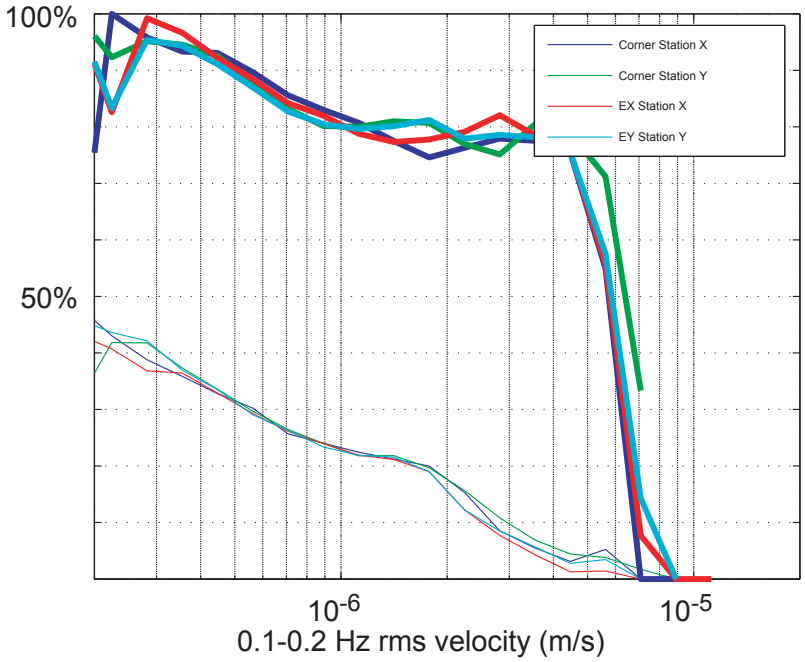
- LIGO Livingston shut down for half a year to install an additional stage of seismic isolation to isolate the detector from our excess ground motion. Work was completed in Fall '04.
- The payload is supported by large coil springs, and actuated by quiet, high force hydraulic bridges.
- Vibration reduction is obtained by actively following inertial sensor signals from payload-mounted seismometers and by canceling floor vibrations.
- Work of LSC at Stanford, MIT, Caltech, LSU, etc.

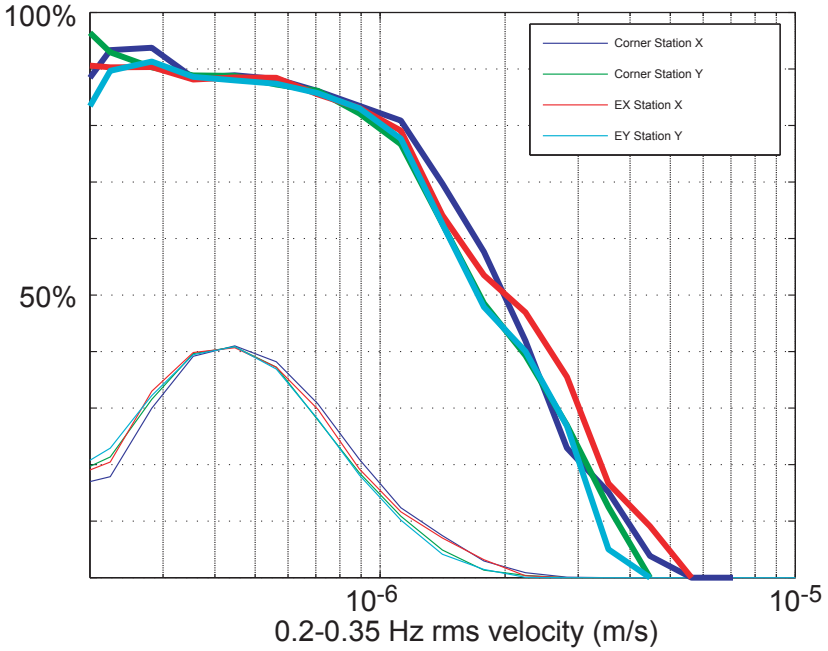
X-arm length disturbance, noisy afternoon

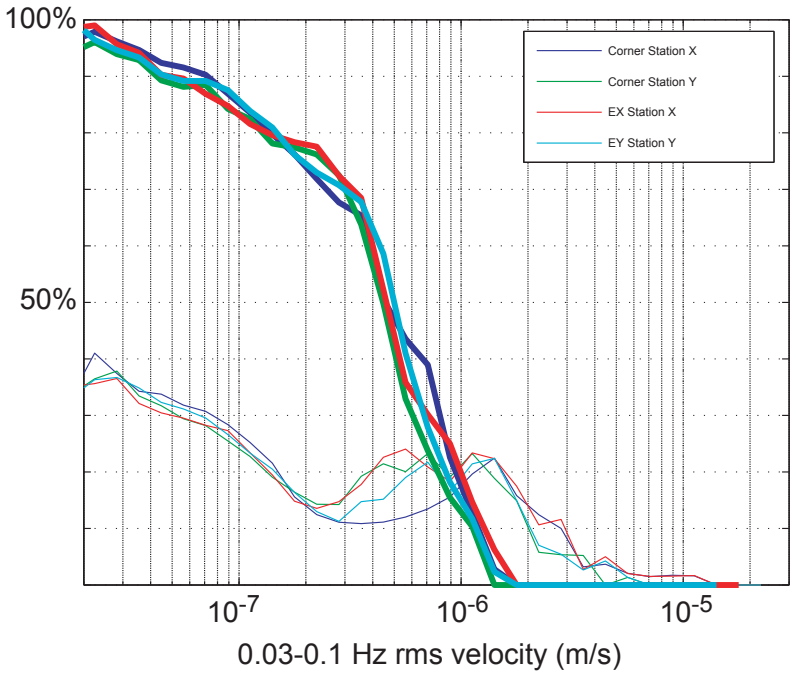


- Noisy afternoon of Aug 10, 2004 had a BLRMS ground velocity 1–3 Hz monitor value between the 90th and 95th percentiles.
- With HEPI in use, we expect the LLO detector to work on such a day, with a factor of 2 headroom.

L1 lock stats versus ground motion



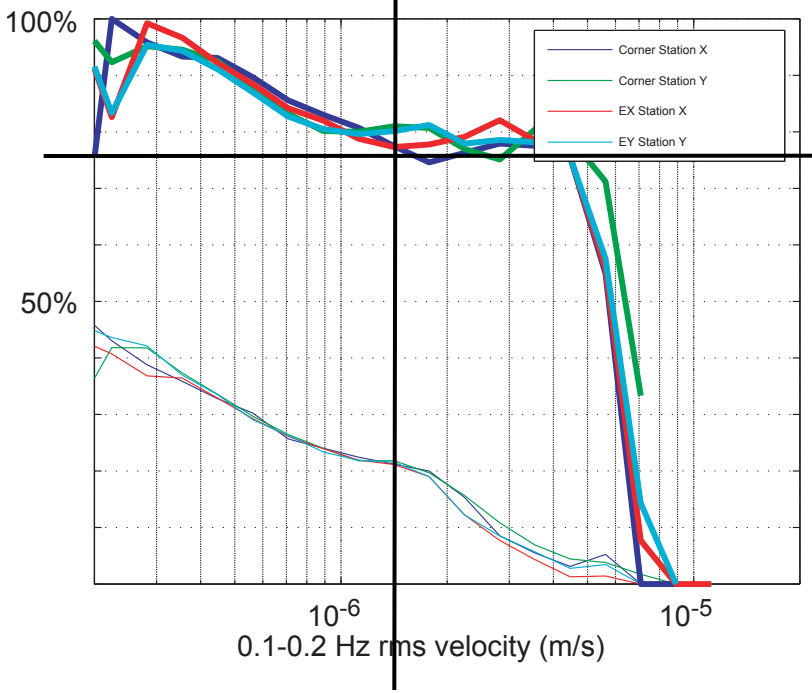


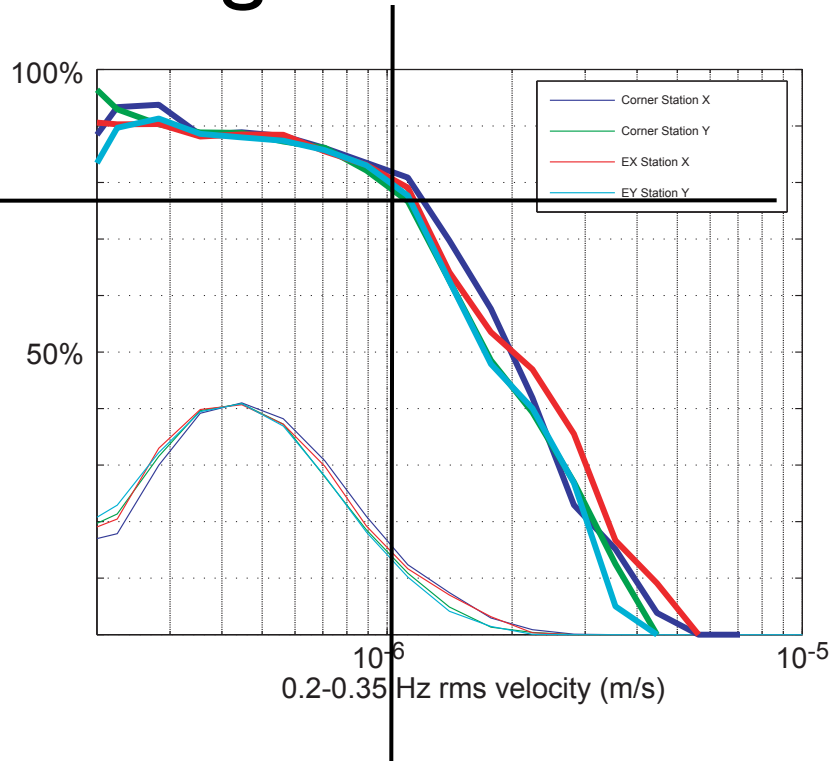


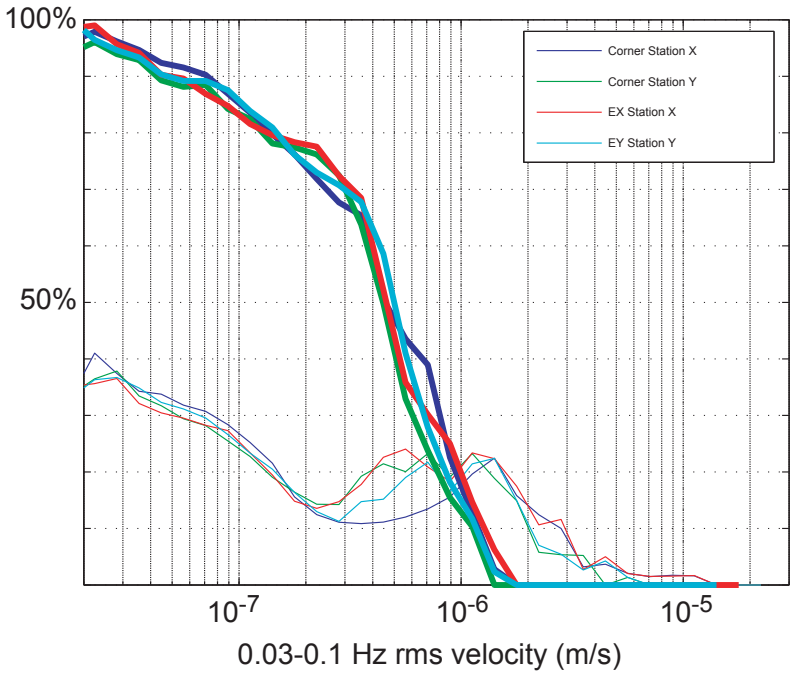
The 95th percentile values from Ed Daw's long-term statistical study are as follows:

f (Hz)	LVEA X	LVEA Y	EX X	EY Y
0.03-0.1	[no stats for 0.03-0.1]			
0.1-0.3	1.7e-6	1.7e-6	1.6e-6	1.7e-6
0.3-1	6.3e-7	6.3e-7	6.5e-7	1.4e-6
1-3	4.0e-7	3.8e-7	4.7e-7	1.7e-7

L1 lock stats versus ground motion







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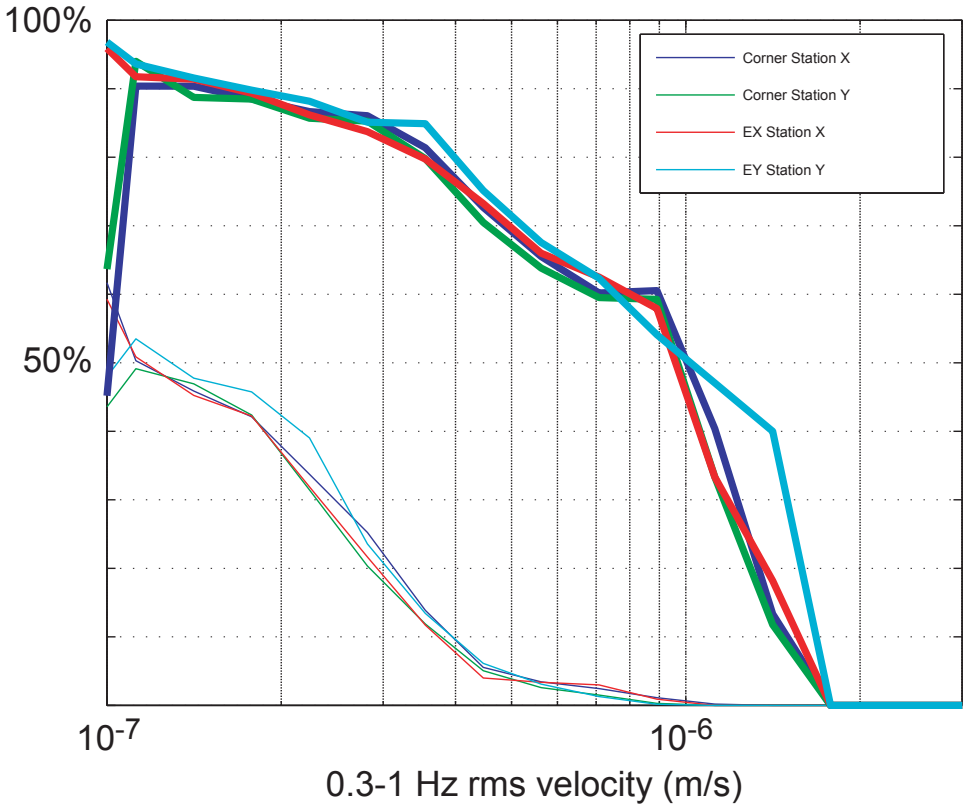
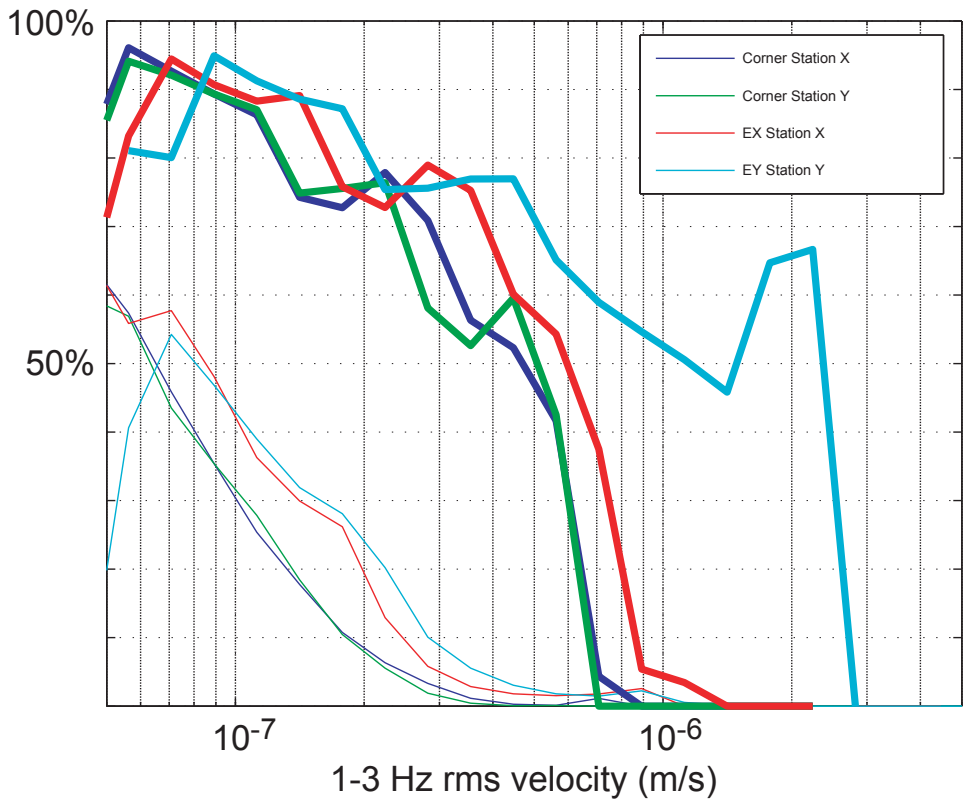
… higher frequencies





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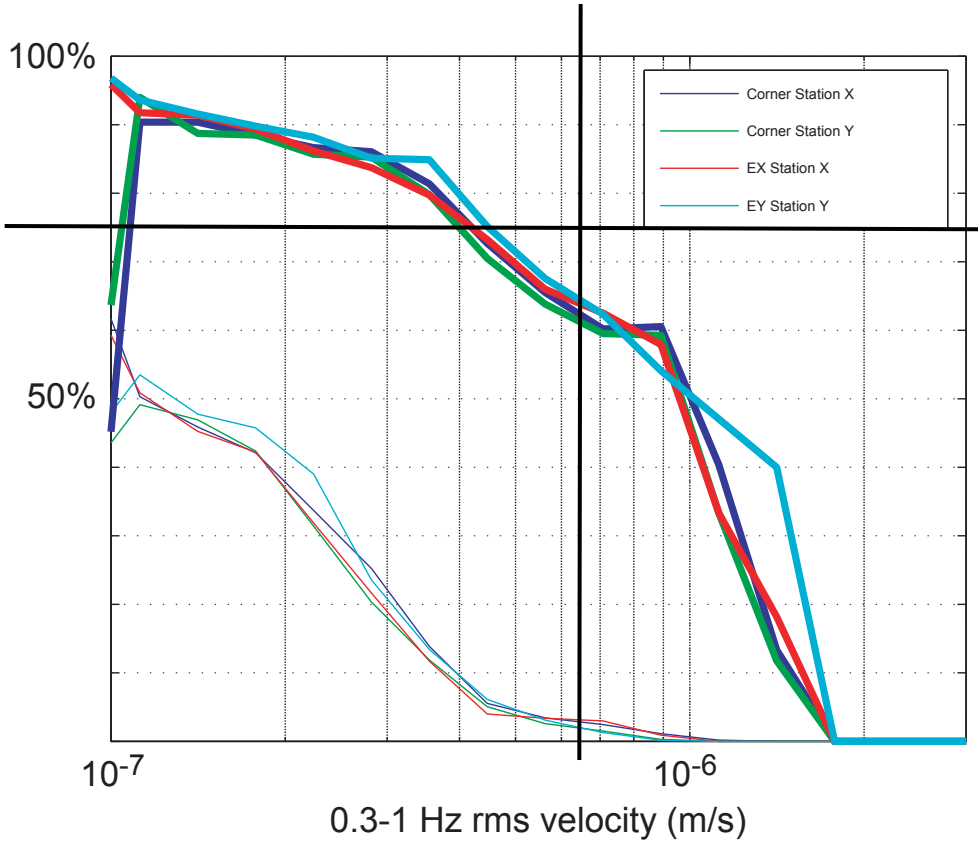
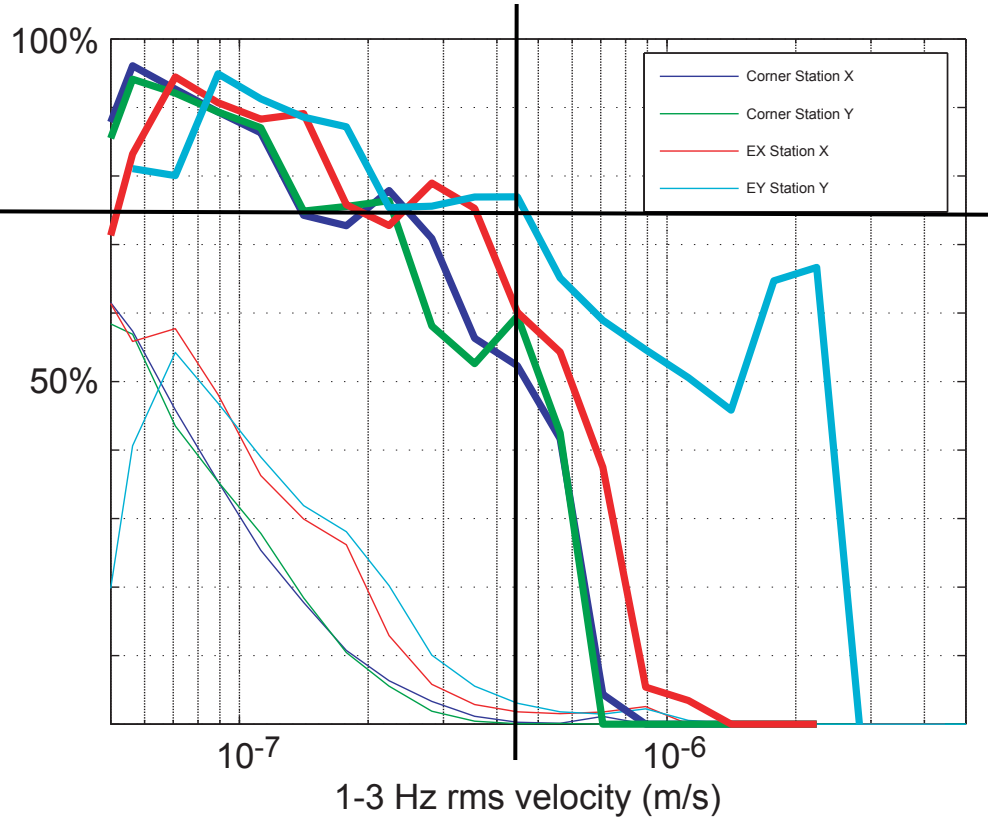
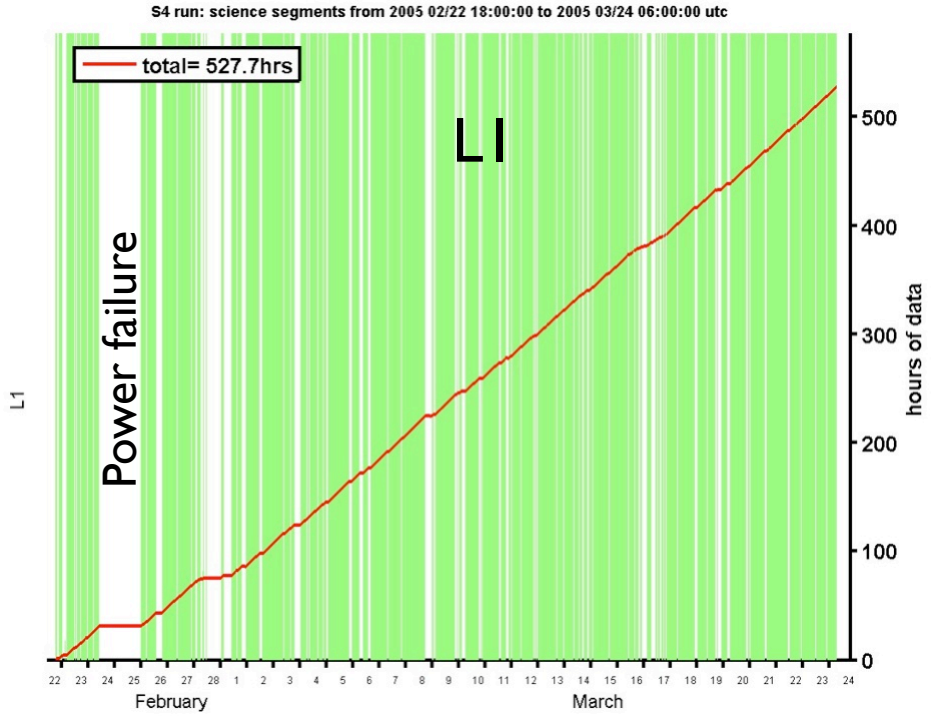
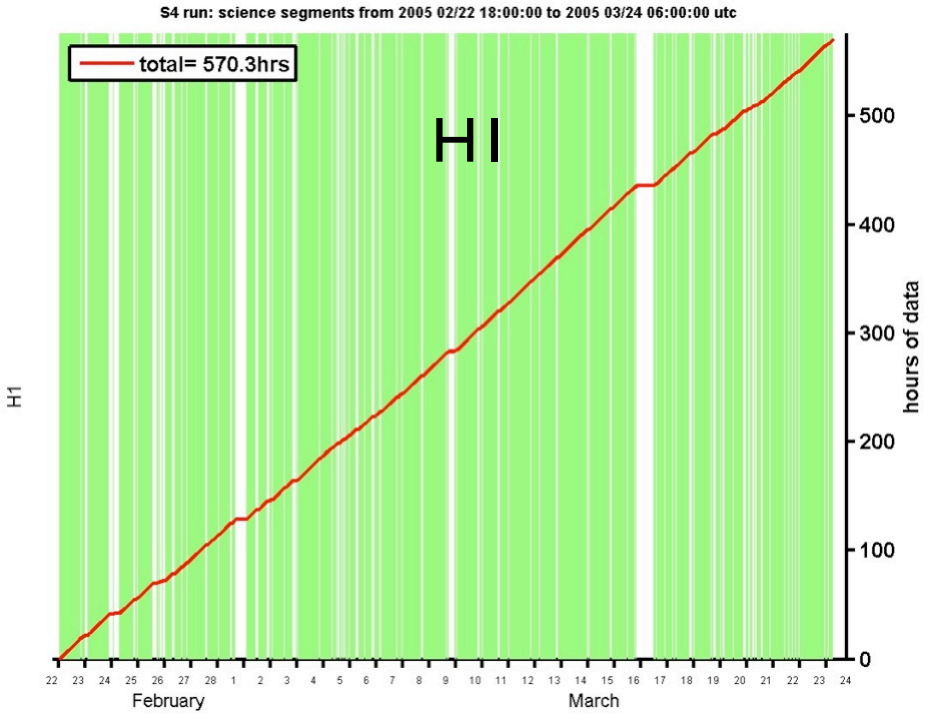


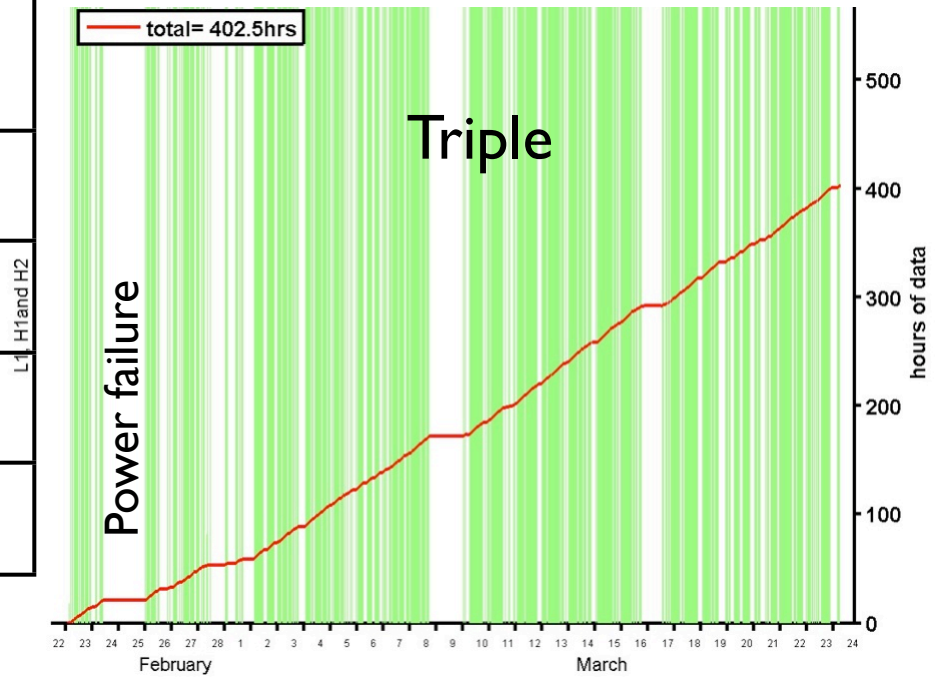


S4 run lock statistics

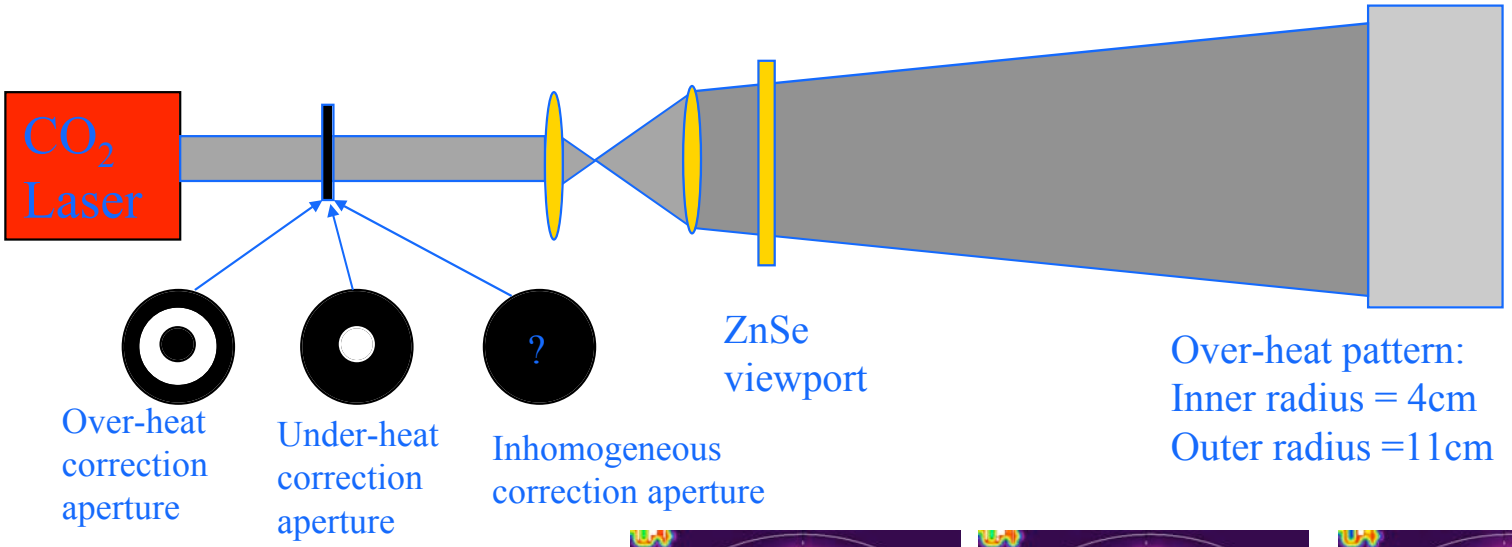


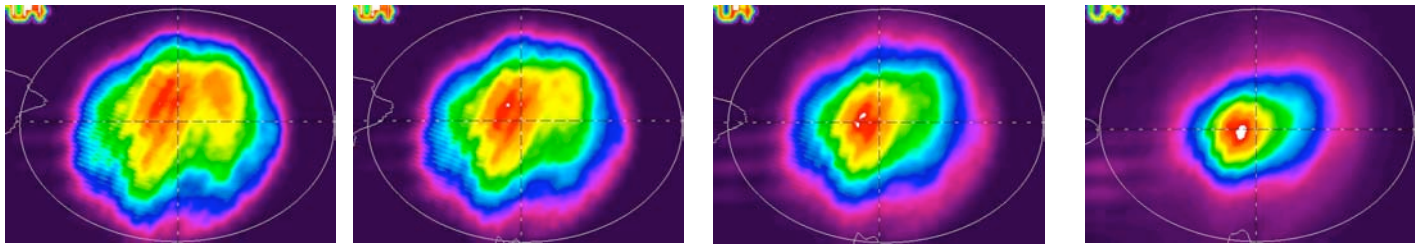


duty cycle	S3	**S4**
L1	22%	**75%**
H1	69%	**81%**
H2	63%	**81%**
Triple	16%	**57%**



Thermal compensation of optics

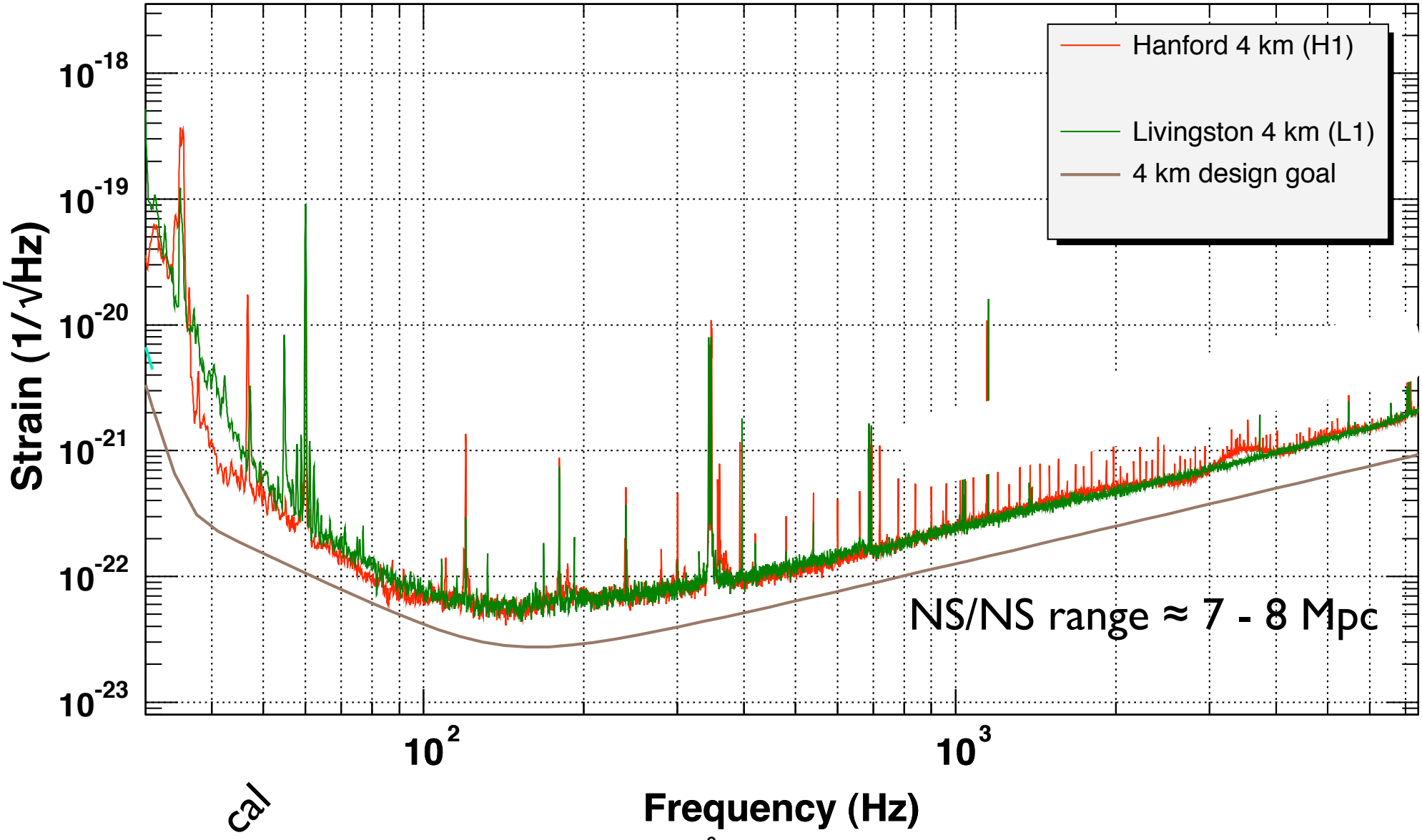




No heat 30 mW 60 mW 90 mW

- Recycling cavity supports a 6 cm beam and is 12 m long, so the *sideband light* mode shape and finesse are strong functions of mirror optical loss through thermal distortions.
- We compensate for this by applying a disk or annulus of 10 μm laser light to increase or decrease the thermal lensing.
- Power levels are adjusted to maximize sideband power and minimize RF phase noise coupling

LIGO noise levels during S4 (March '05)



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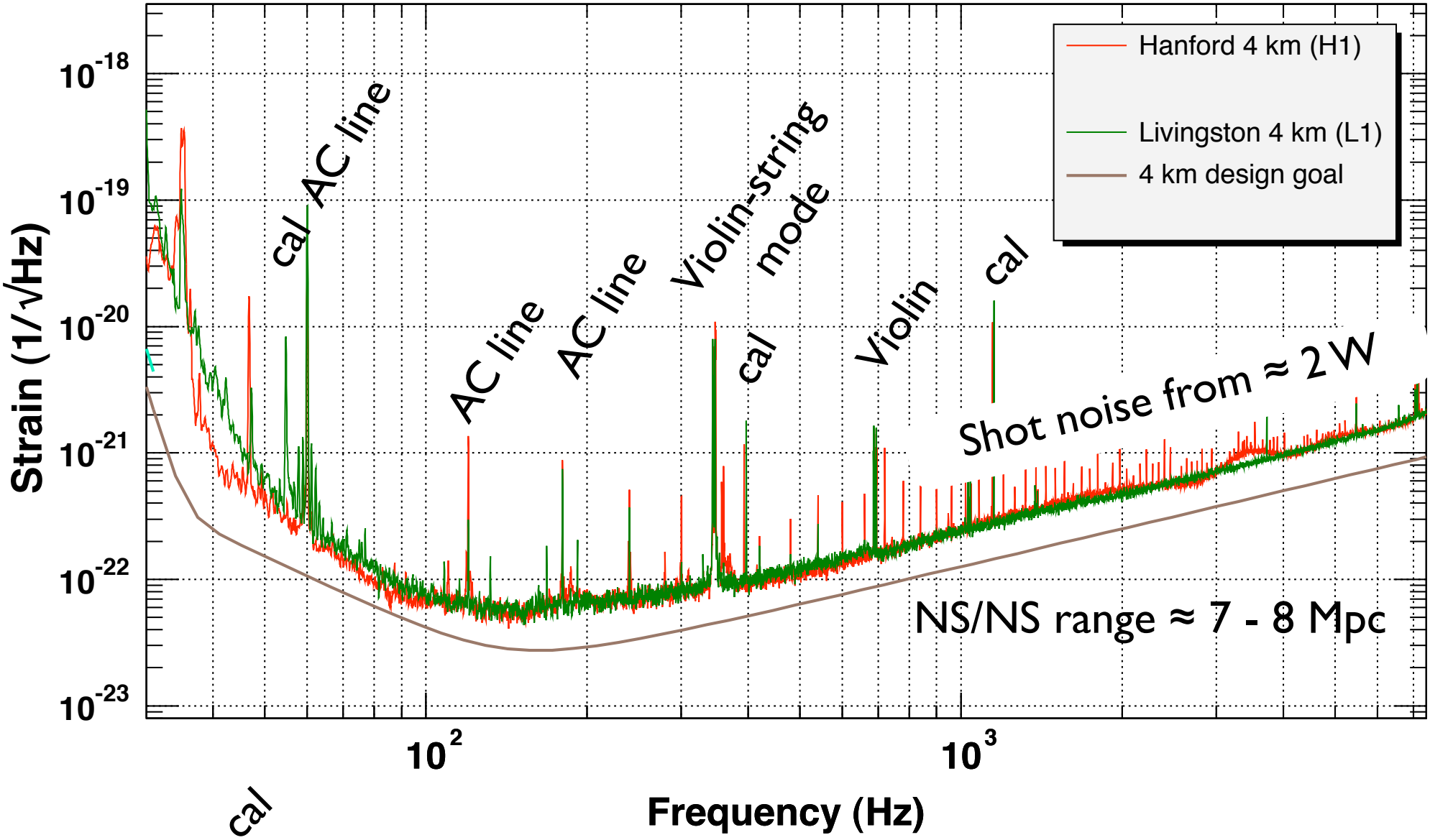

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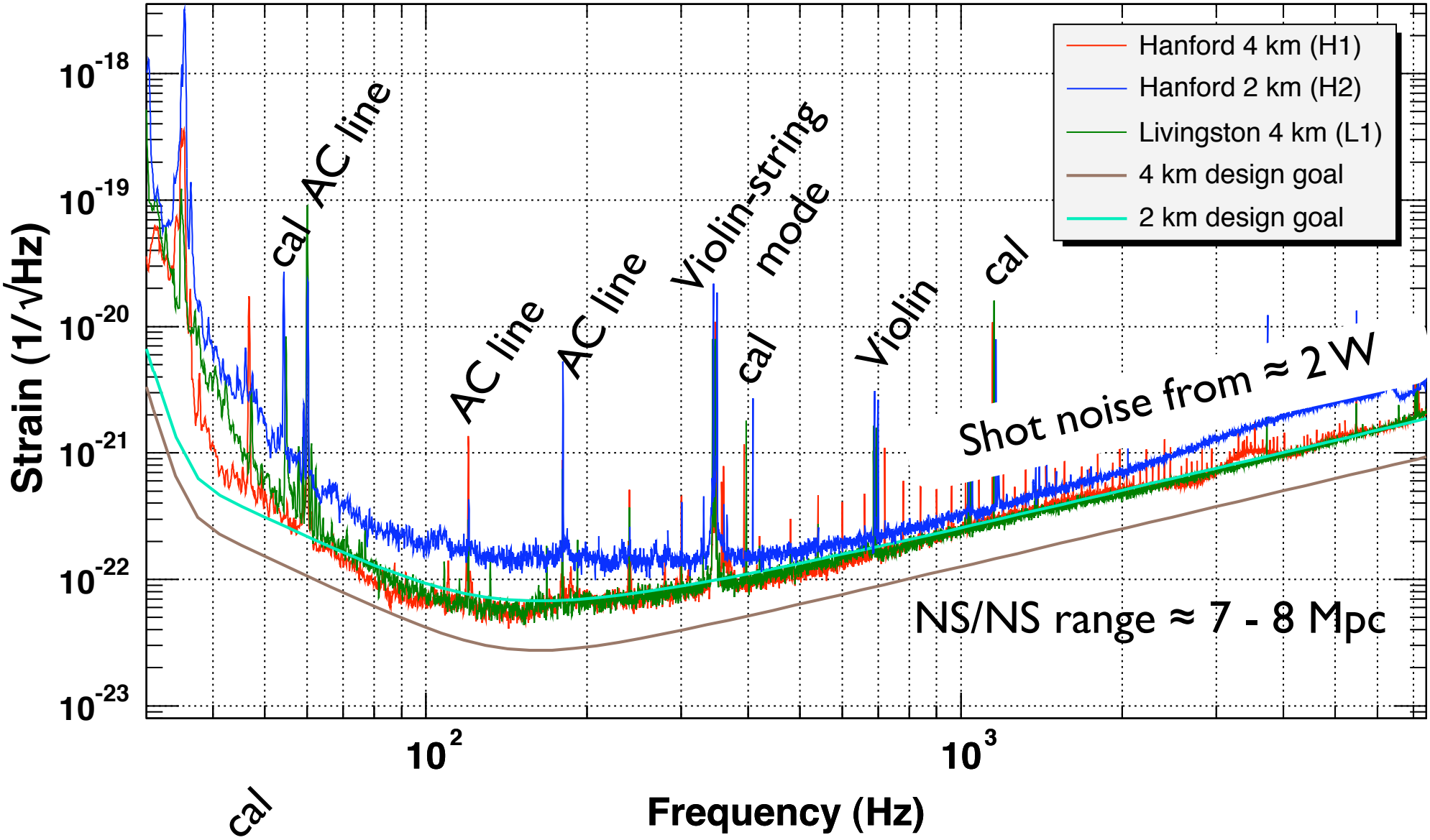
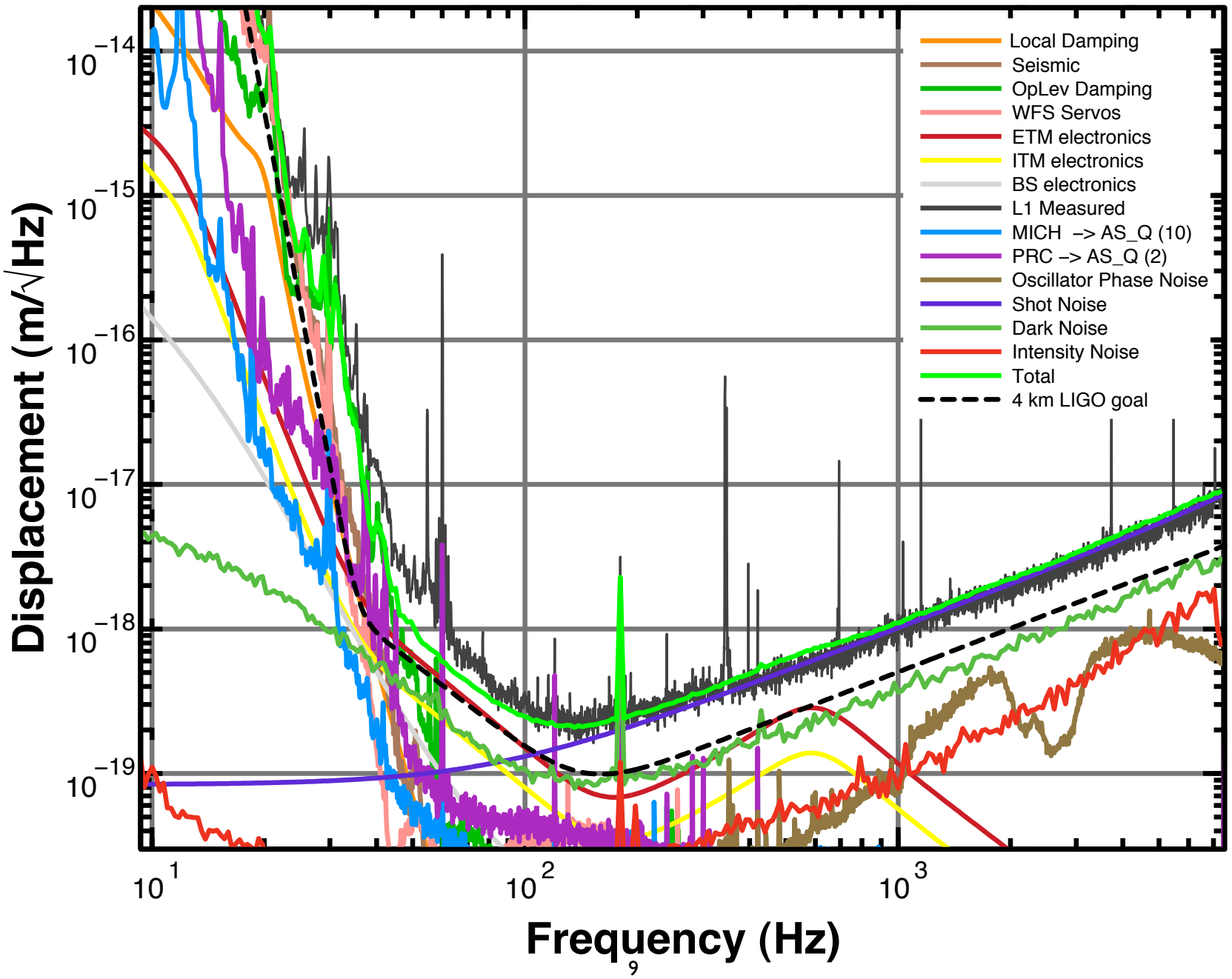


LIGO Livingston S4 noise model



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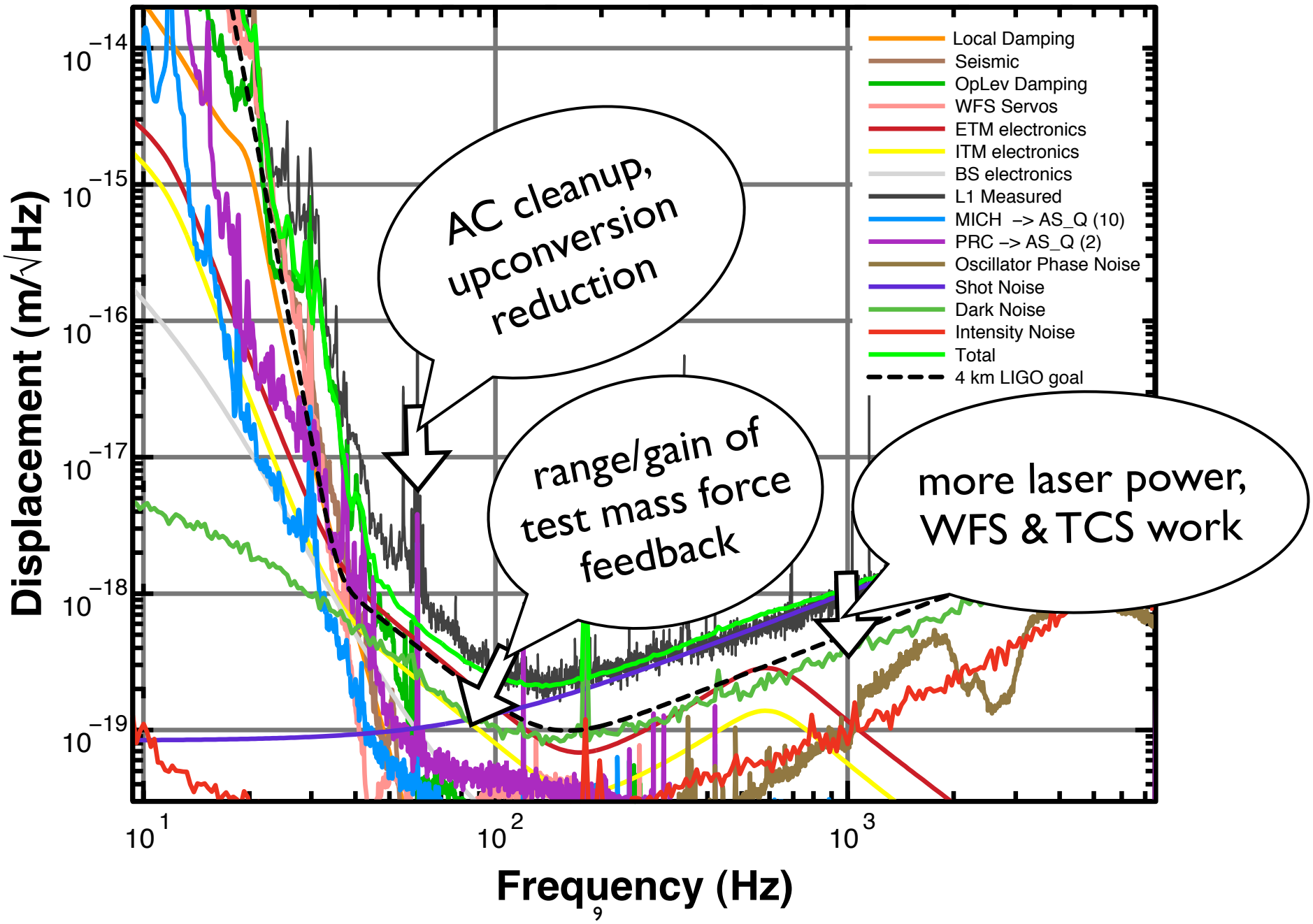
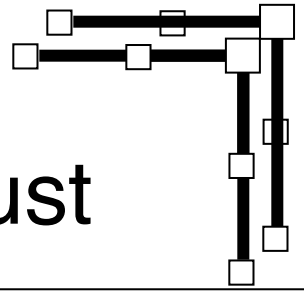
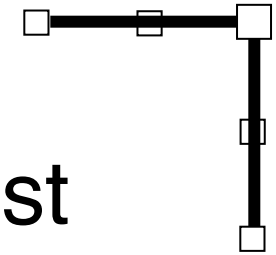


H1 and H2: Accomplished since last August



- New actuation electronics (DAC / Dewhitening / Coil Driver)
- New Table Top FSS (800 kHz bandwidth)
- Installed new MC / CM board (100kHz / 45kHz bandwidth)
  - also for L1 after S4
- WFS head simplified (more RF gain / no oscillation)
- 1-FSR (37kHz) and 100kHz channel readout implemented
- IOT EO shutter replaced with fast shutter
- Equi=Tech balanced power installed (all End's, Mid's and DC power supplies in LVEA)
- New TCS Chillers
- Some front-end code changes:
  - gain ramping (nice!)
  - LSC to ETM SUS timing improved
  - …
- Photon calibrator: Tested on EX

H1:
Accomplished since last August



- New ISS installed (100kHz bandwidth)
- Micro-seismic feed-back system installed
- Mitigation of TCS intensity noise
- Auxiliary loops running on POX + POY (more power)
- Non-Resonant sideband REFL detector running (no improvement)
- 2nd generation OMC testing (Keita) (still beam jitter noise limited)

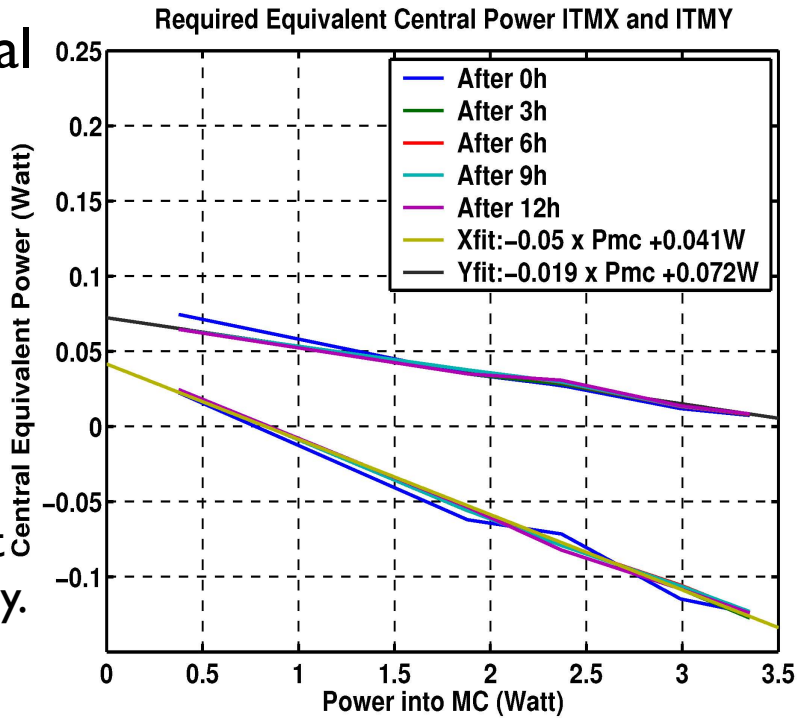
H2:
Accomplished since last August

- All 4 AS photodiodes + electronics installed
- A whole series of small electronics modifications copied from H1.
- Auxiliary loop bandwidth increase
- TCS system installed (but H2 already was close to max recycling gain)
- Moderate power increase (1.4 Watts into the MC)

- But sometimes the biggest sensitivity improvement steps come from eliminating goof-ups…

H1: Test mass replacement

- H1's optics have more loss than those in the other detectors, which results in greater thermal lensing and need for greater annulus TCS heating.
- For S4, 3.3 W of main beam to the mode cleaner, plus 1.6 W TCS power on ITMX (annulus).
  - This gave excellent performance, only 1.8 times SRD, but TCS power and PD count to reach SRD may be unwieldy.
  - TCS intensity stabilization required.
- Many tricky measurements over several months allowed identification of ITMX as the main source of loss.
  - ITMX: 25 mW / W_{MC}, ITMY well behind at 10 mW / W_{MC}.



L1 Progress: TCS, RF oscillator

- For S4, TCS power set to increase sideband recycling gain, without adding too much AS_I, even with its servo. This worked OK, and L1 was shot noise limited for 2 W to the modecleaner.
- After S4, it was discovered that higher power distorted some (non-core) optics enough that one of the WFS sensors was ineffective; the relevant telescope was reworked, the WFS system became effective again, the AS_I servo was no longer required. We expect to need only very small TCS correction for S5.
- Crystal oscillator and improved RF distribution system installed during S4, which eliminated remaining phase noise effect in GW signal. Beat with other RF oscillator sometimes seen in signal, and will be finally eliminated by using fixed rational multiple for other RF, when custom hardware arrives.

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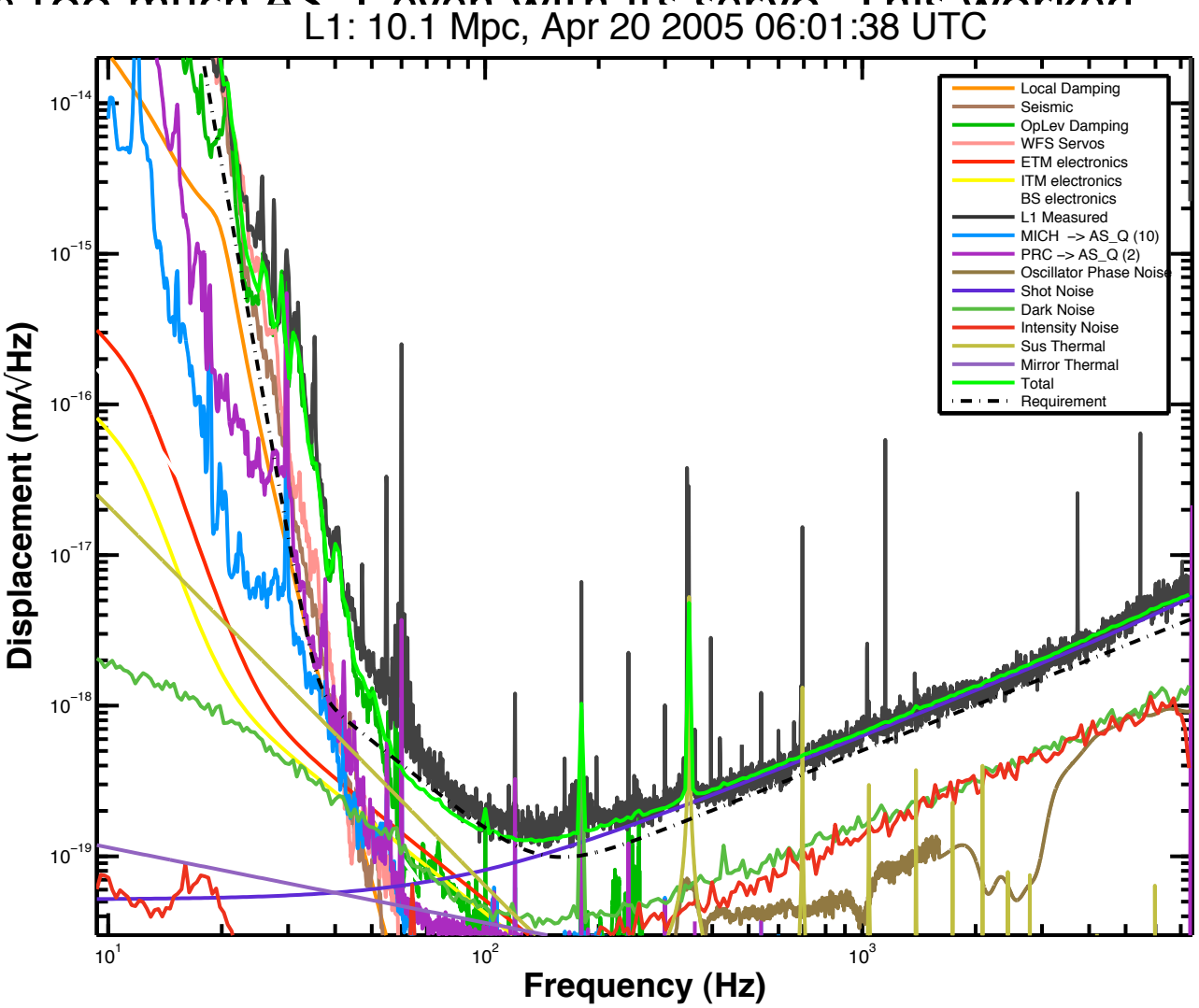

L1 progress: sensing and control

- ITMX pick-off beam now used to sample recycling cavity light. This stronger beam allows higher SNR in auxiliary DOF servos.
- Higher loop gains in WFS loops.
- Higher loop gain 'tidal' servo, overlaps lower end of HEPI band, stabilizes interferometer during sub-tenth-hertz motion.
- Mitigation of scattering from output tables reduced parasitic interferometry that was due to relative velocity between seismically-isolated in-vacuum components and external optics tables.
- Non resonant REFL detection chain.

L1 Progress: Electronics

- Electronics moved to "CDS highbay" in (mostly) RF-tight racks, reducing acoustic coupling and RF interference.
- All CDS equipment runs on "balanced power," which should reduce line harmonic content.
- Modified LSC photodetectors to notch out 2nd harmonic of RF sideband.
- Increased number of Photodiodes from 2 to 4 for S4, then back to 2 after WFS telescope repair was made.
- New AS_I servo electronics for S4, not (always) needed now.

Other post-S4 things

- New laser for L1, then another new laser for L1
  - Two lasers currently at Lightwave for rework, so that work gets done before Lightwave's move to new headquarters. We have one non-optimal spare at the moment.
- Work at Caltech to prepare for test mass swap.
- Work at MIT & LLO on tweaks to HAM HEPI control.
- Production of new photodiodes and other RF electronics
- Optical-fiber timing system (should cure channel hoping), New processor code (should cure mad slider disease).
- Acoustic coupling studies and repair at LHO.