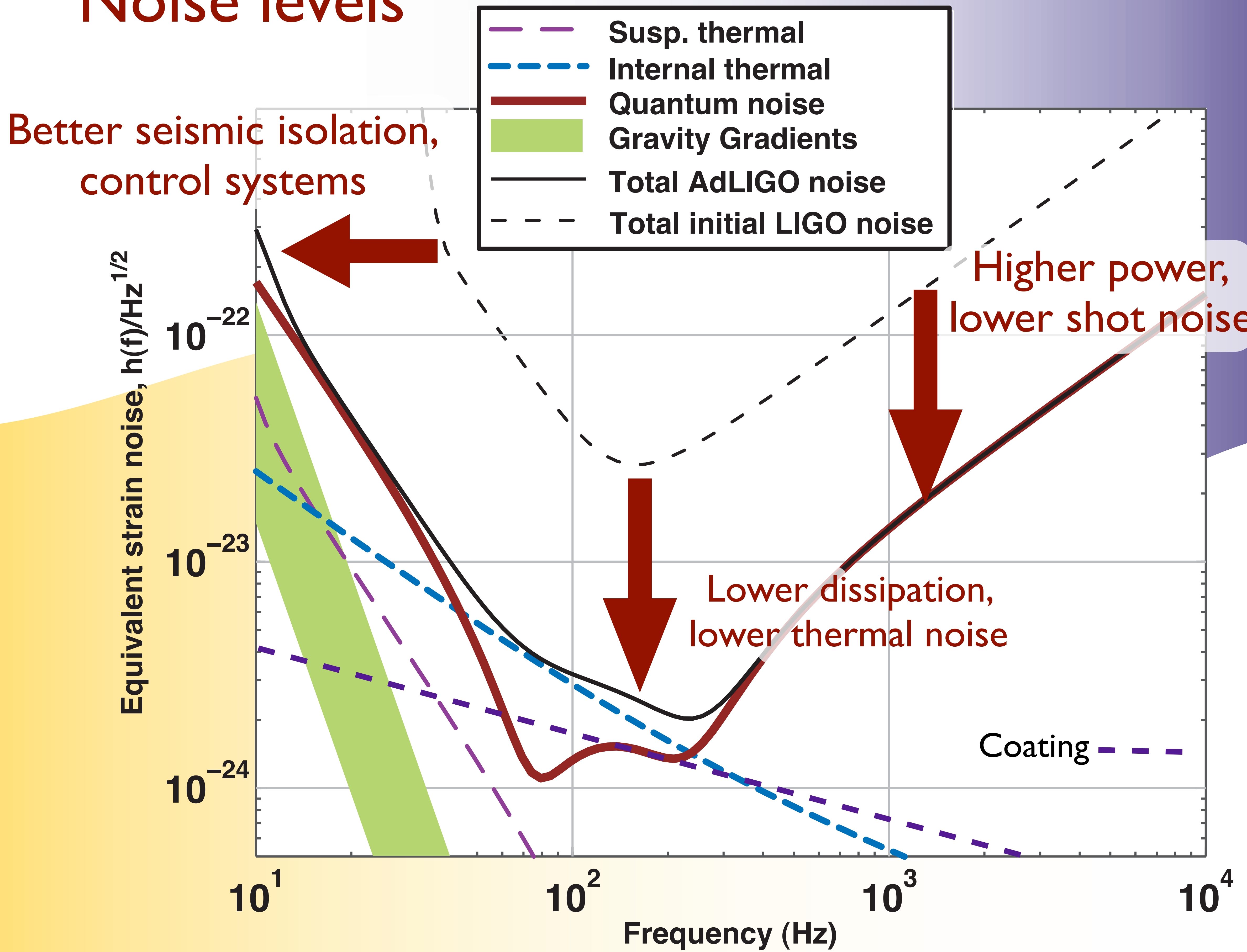
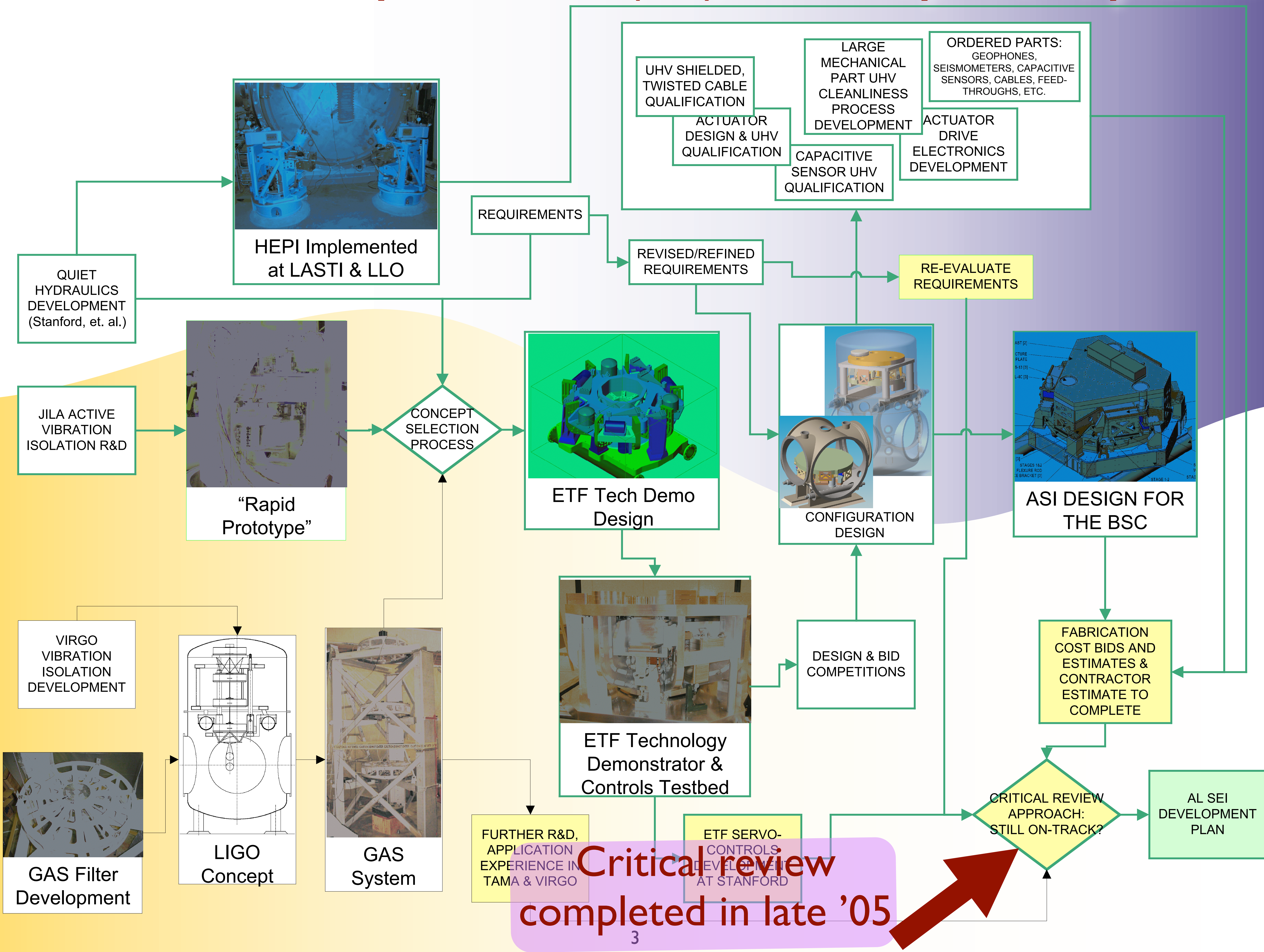
Seismic isolation development

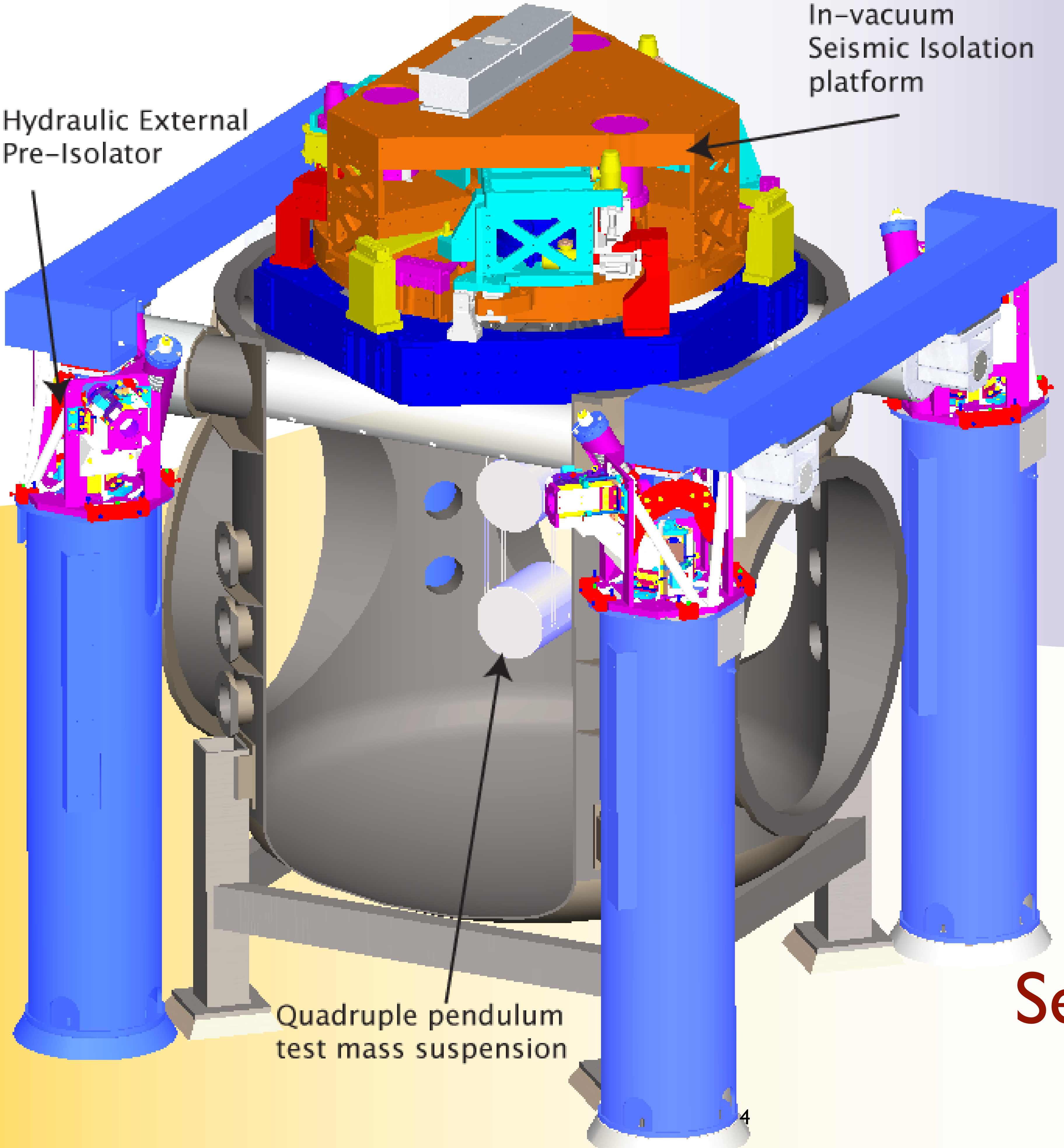
J. Giaime, for the Advanced LIGO seismic isolation team.
Mar 2006 LSC meeting.
G060119-00-D

Noise levels



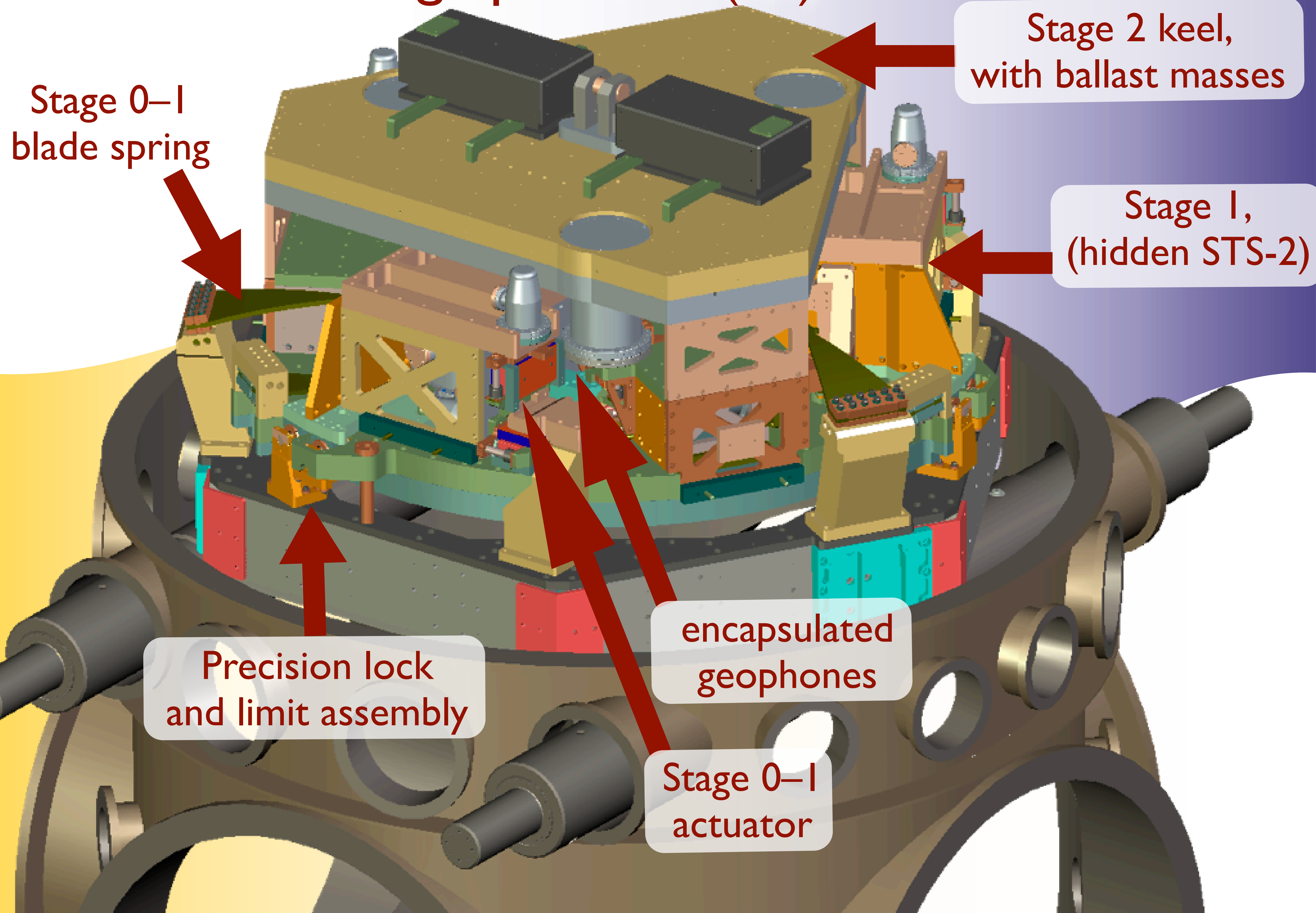
BSC in-vacuum platform (ISI) development plan…





Seismic Isolation for BSC

In-vacuum 2-stage platform (ISI)

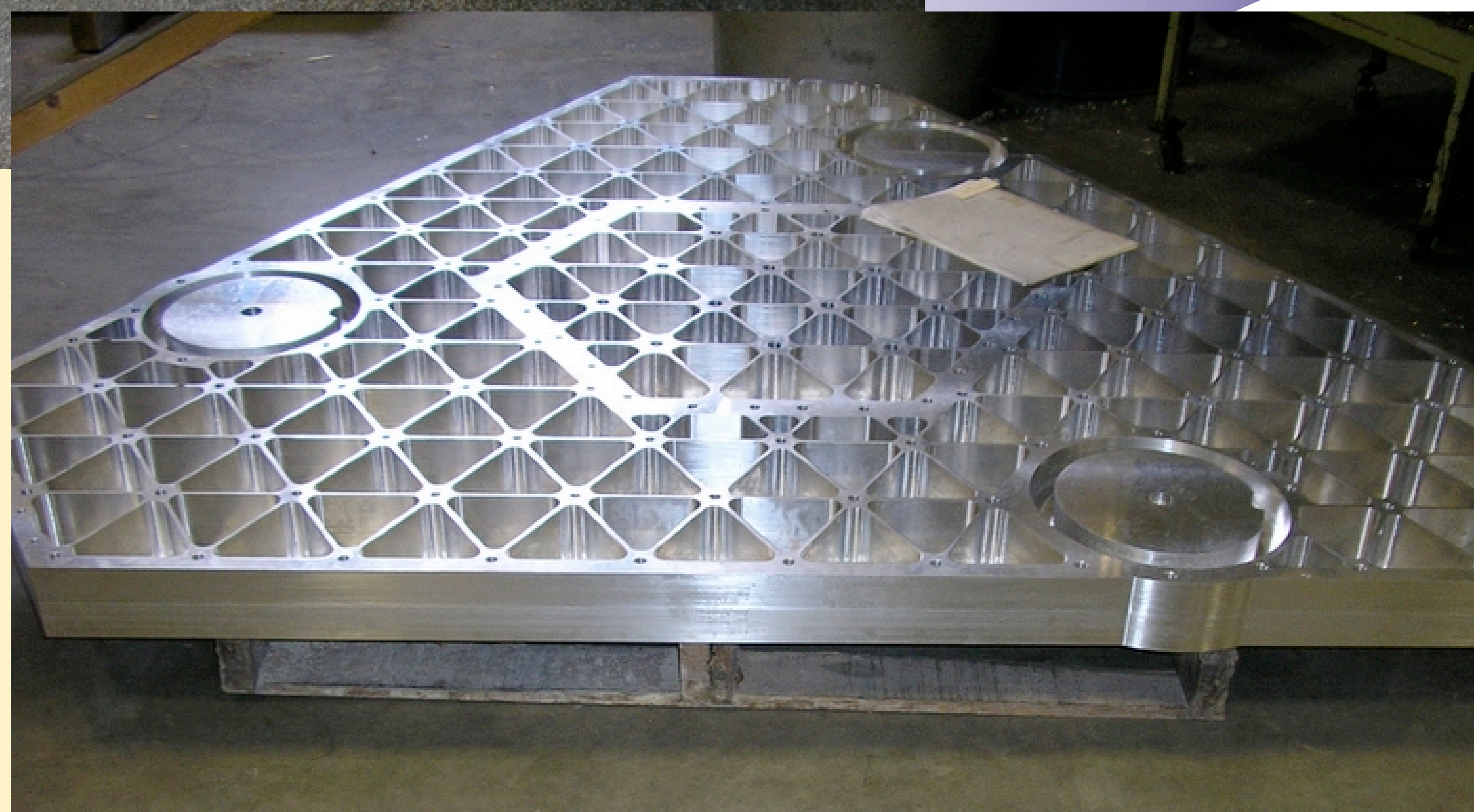


Development

- True prototype design is being fabricated for installation in LASTI (at MIT) for full scale, UHV, tests with suspension systems.
  - finite-element modeling of structural and rigid-body modes. we require modal frequencies to be > 150 Hz to accomodate ≈ 50 Hz servo unity-gain point.
  - strict requirements on 6 x 6 DOF stiffness at low frequencies. For example, we require horizontal-tilt cross coupling < 1/500 m.
  - new design for rigid and strong stops, to exactly position stages and restrict motion during earthquakes.
  - can accommodate ≈ 1 ton payload. Servo and mechanical design need to tolerate mechanically reactive massive payload.
- Technology demonstrator extensively tested at Stanford vacuum system.
  - mechanical system designed for approximately LIGO size platform, with approx half-size payload capacity.
  - most sensors and actuators as in final design.

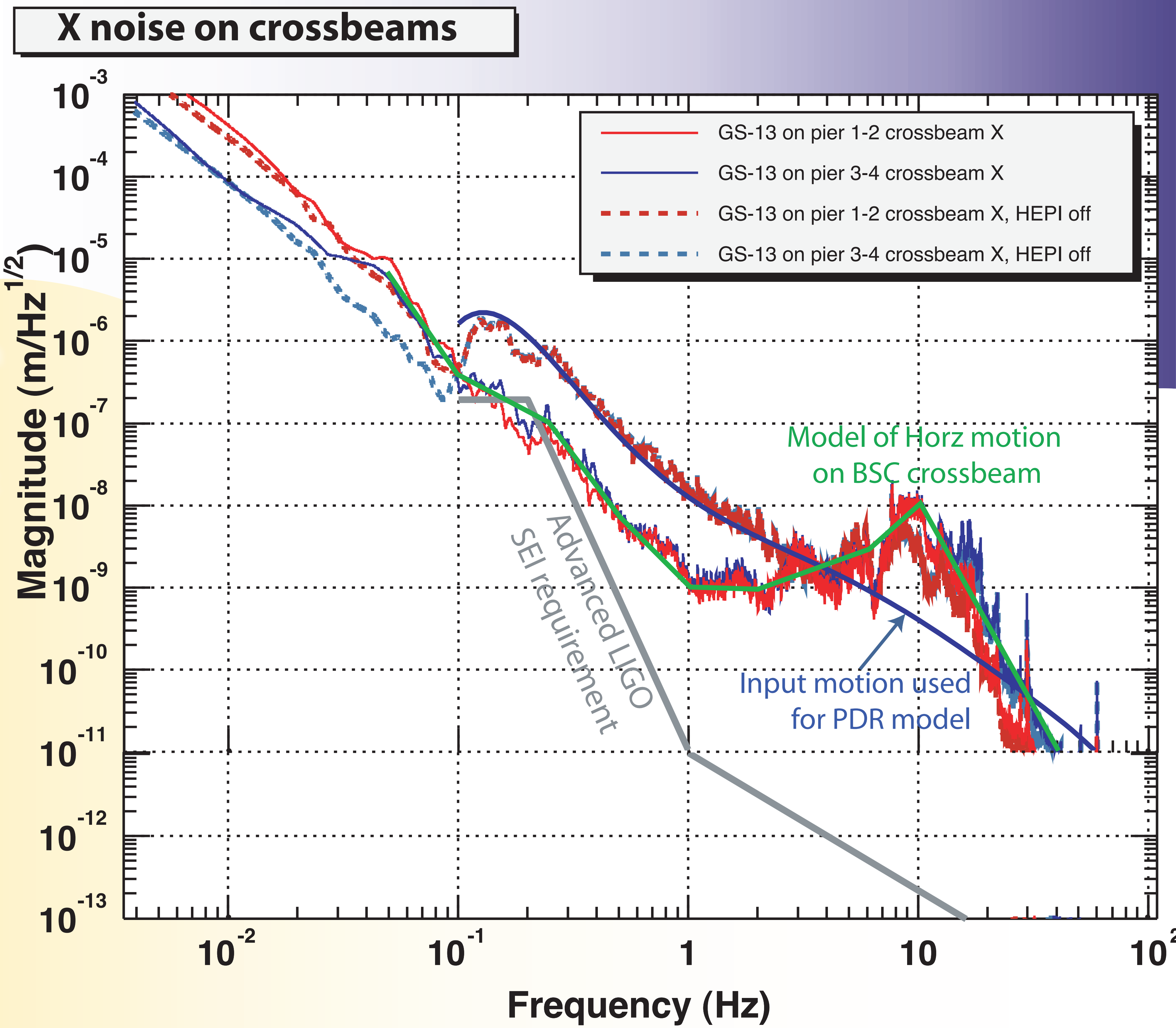
Prototype schedule for BSC @ LASTI

- April ’06, Dirty assembly of prototype on granite table.
- May ’06, Complete assembly on short test stand.
  - some instrumentation installed, some dummy masses.
  - alignment, modal, and stiffness matrix tests.
- June–August ’06, Disassemble, send parts out for UHV cleaning.
- August–September ’06, assemble on tall test stand in LASTI highbay, fully instrumented.
  - Simple functionality tests: all sensors, actuators, and damping servos.
  - Reliability and noise floor measurements of instrumentation channels, commissioning and testing of watchdog electronics layer.
- Not before last bullet fulfilled, move SEI into vacuum chamber.
  - Dummy payload or locked-down SUS, to minimize collateral damage.
  - Complete SYS-ID, servo design, function & performance tests.
- Joint tests with SUS noise prototype.



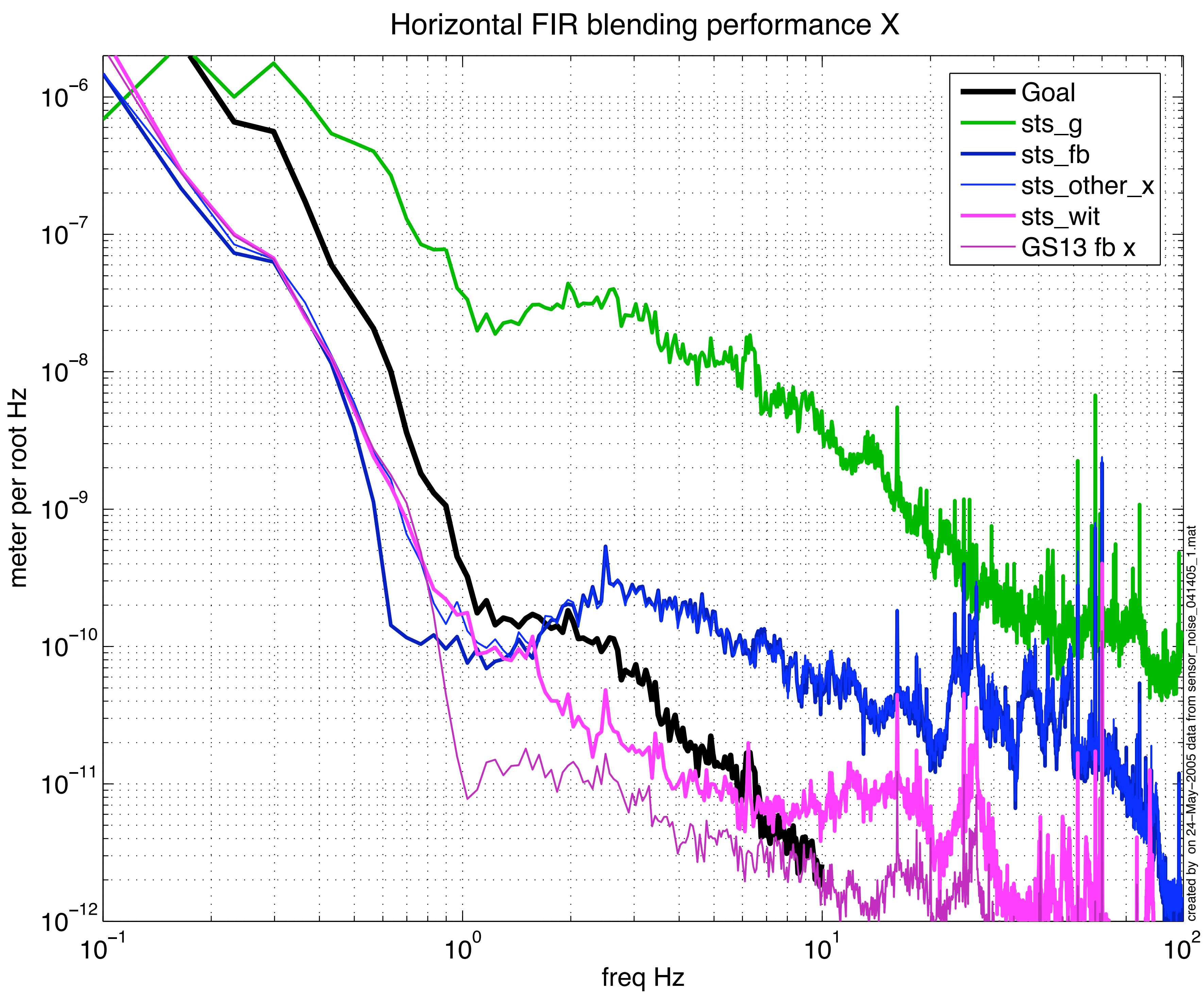
BSC noise requirements

- HEPI already in use at LLO, so noise at base of ISI is already known.
- Planned for active noise reduction of ≈1000, 1–10 Hz, based on source noise on VEA floor. However…
- HEPI noise reduction at 1 Hz relaxes ISI requirements.
- Excess noise on HEPI platform seen near 10 Hz, due to coupling to large vacuum tank vibrational noise. Feedforward technique under development to deal with this.

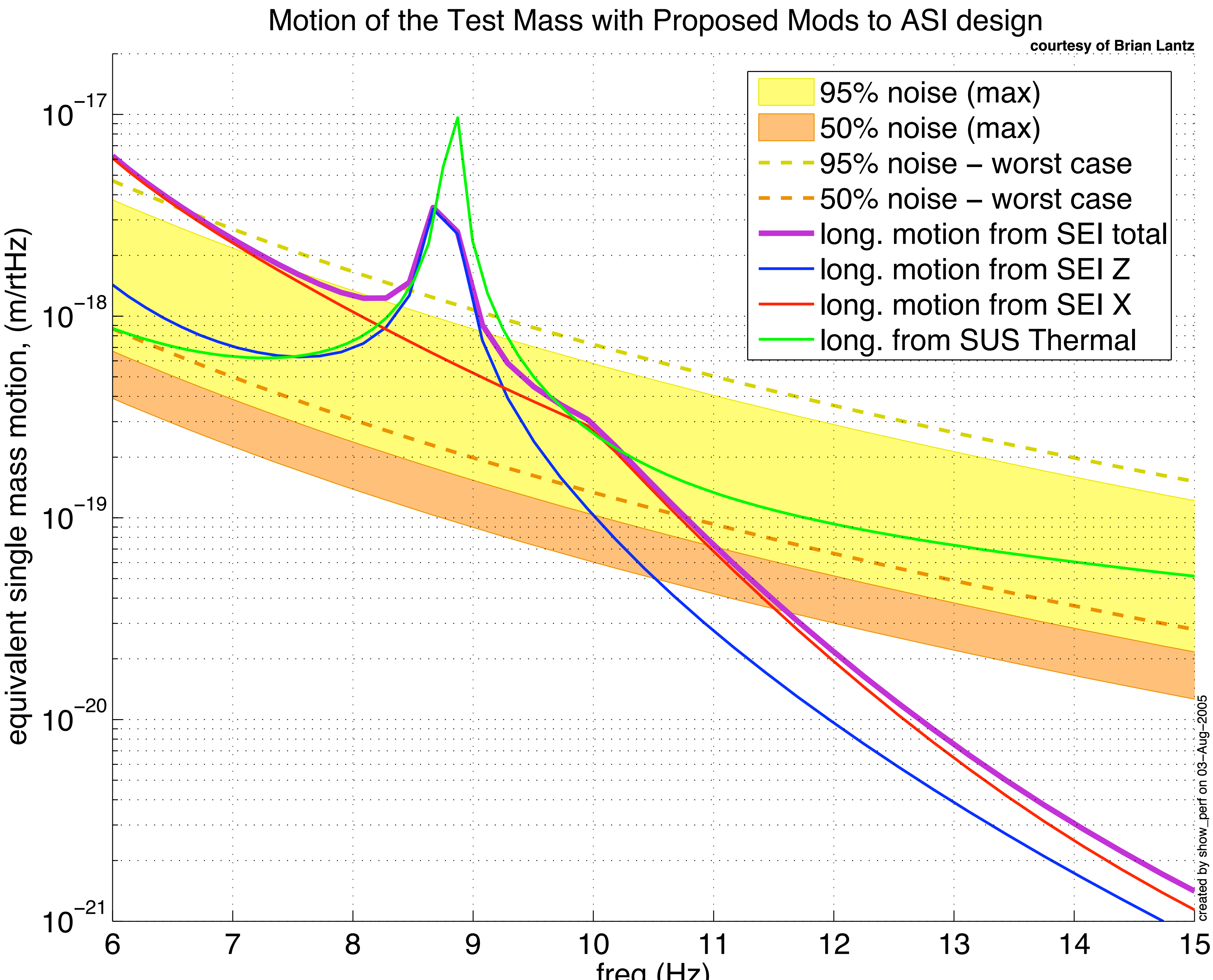


Technology demonstrator at Stanford results, part 1.
Working groups highly parallel, so I am stealing Brian's thunder...

- 12-DOF servos demonstrated at required gain and bandwidth; 10 Hz (BSC-tank bump problem not included)
- Noise transmission dominated by tilt coupling at some frequencies.
- GS-13 stage-2 geophone factory-supplied pre-amp noisier than in brochure!
- **Outcome:**
  - **GS-13 pre-amps redesigned and successfully tested.**
  - **LASTI Prototype blade springs lengthened to lower pitch/roll coupling.**

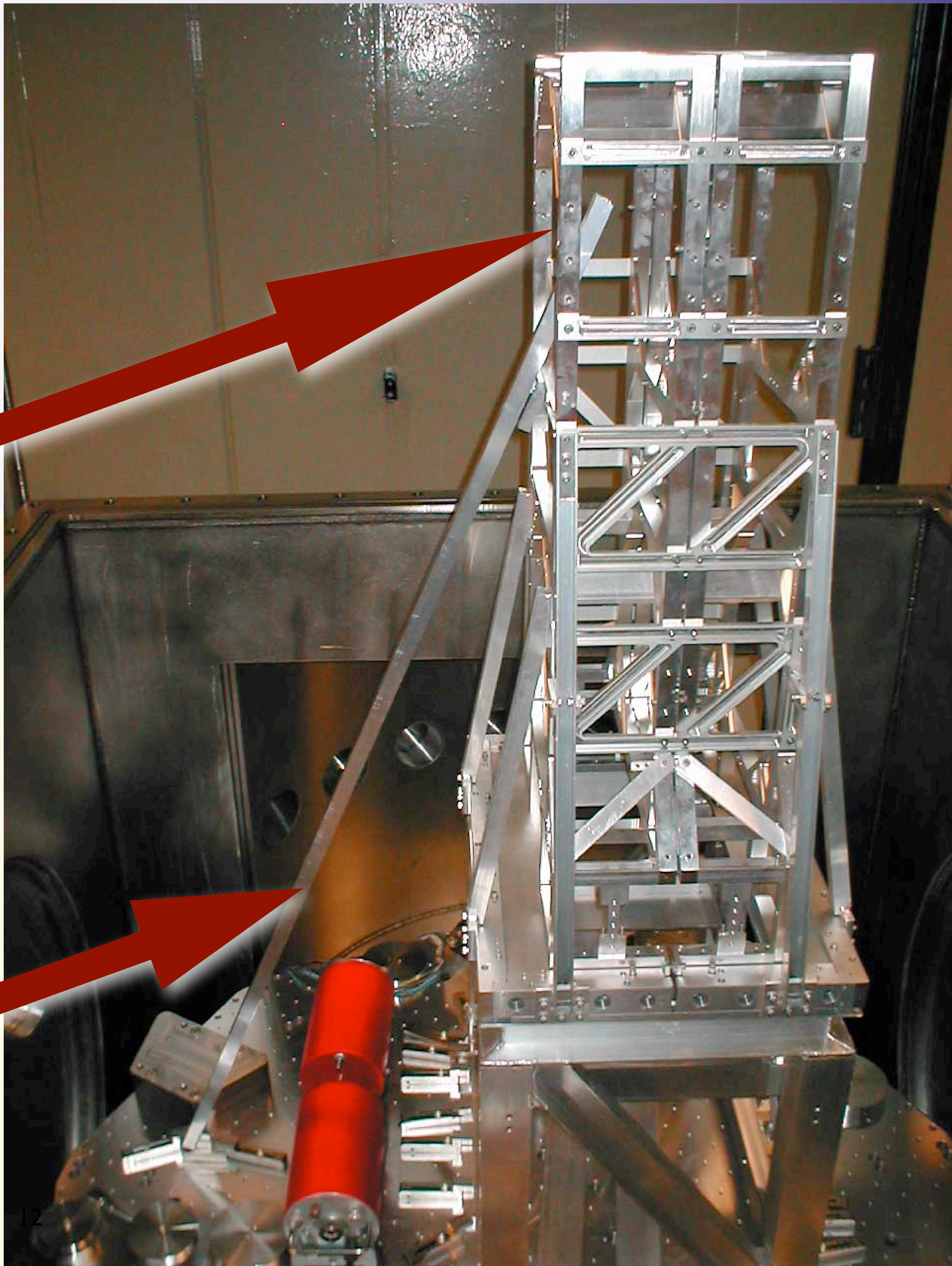


Predicted Performance w/ Pendulum



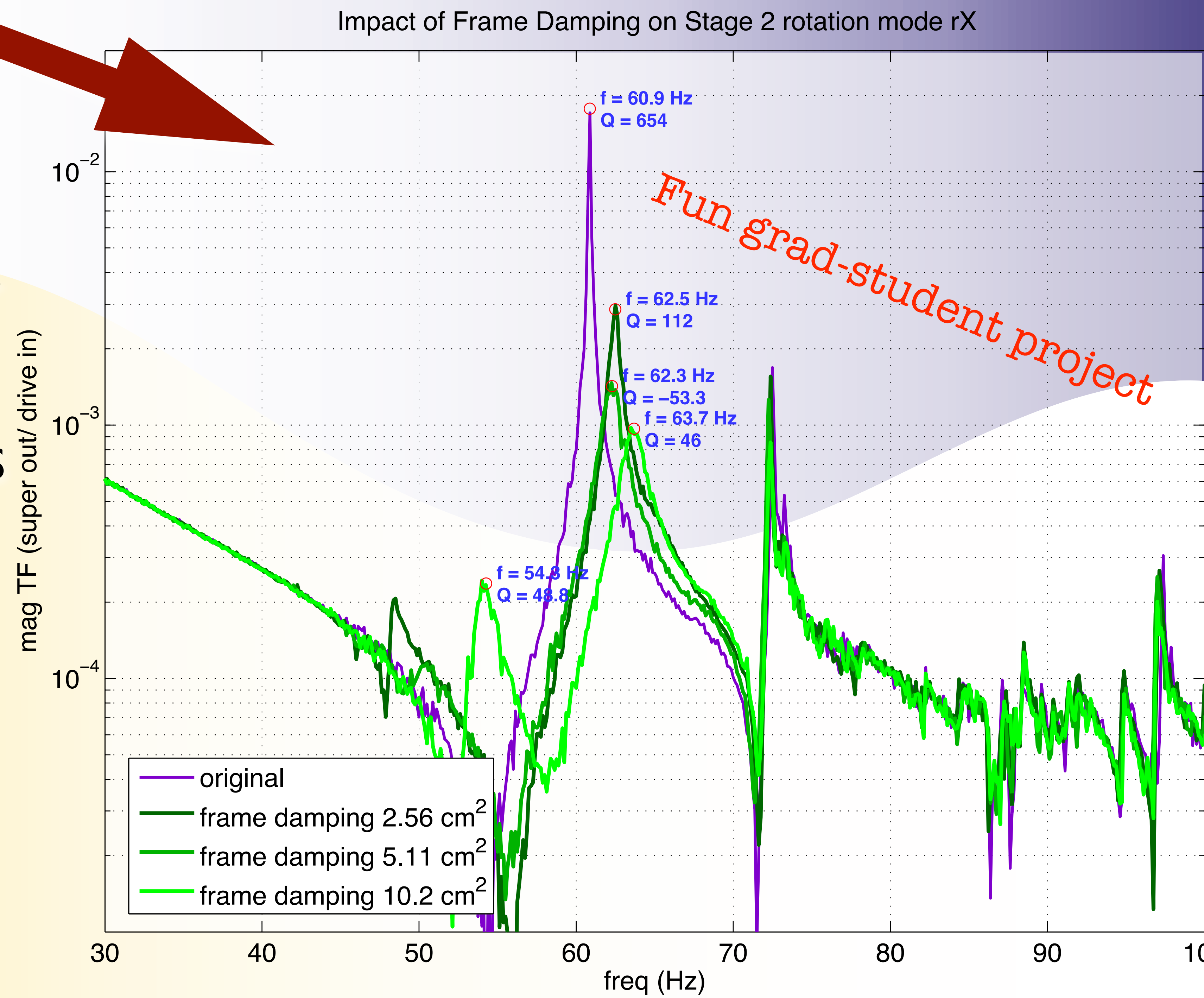
Technology demonstrator at Stanford results, part 2.

- Analysis last year by D. Coyne indicated possible loop destabilization from mechanical resonances.
- Enormous, early prototype SUS cage bolted to stage-2 optics table.
- B. Lantz was able to close seismic loops **with** resonances present, and …
    - **lowest cage mode (in each direction) successfully damped electronically using SEI loops.**
    - **lowest cage mode also damped using constrained-layer damping strut.**



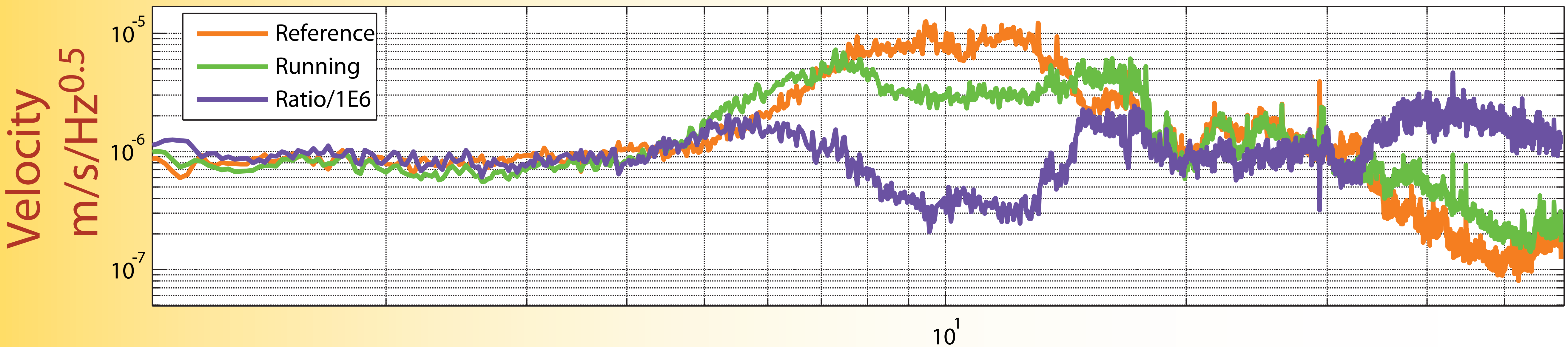
Technology demonstrator, complexity

- constrained-layer damping strut technique explored by T. Casebolt, indicating > 10 Q reduction.
- Critical review in ’05 identified **complexity** as cause for concern, given small but finite chance that any instrumentation channel will fail in commissioning or operation.
  - Self-diagnostics programs currently in use at LIGO for SUS and HEPI. HEPI diag. script part of operators’ procedures.
  - M. DeGree developing auto-diagnostic routine for 2-stage platform.
- Critical review also identified **thermal management** as concern.
  - W. East’s measurements of this indicate wide safety margin.

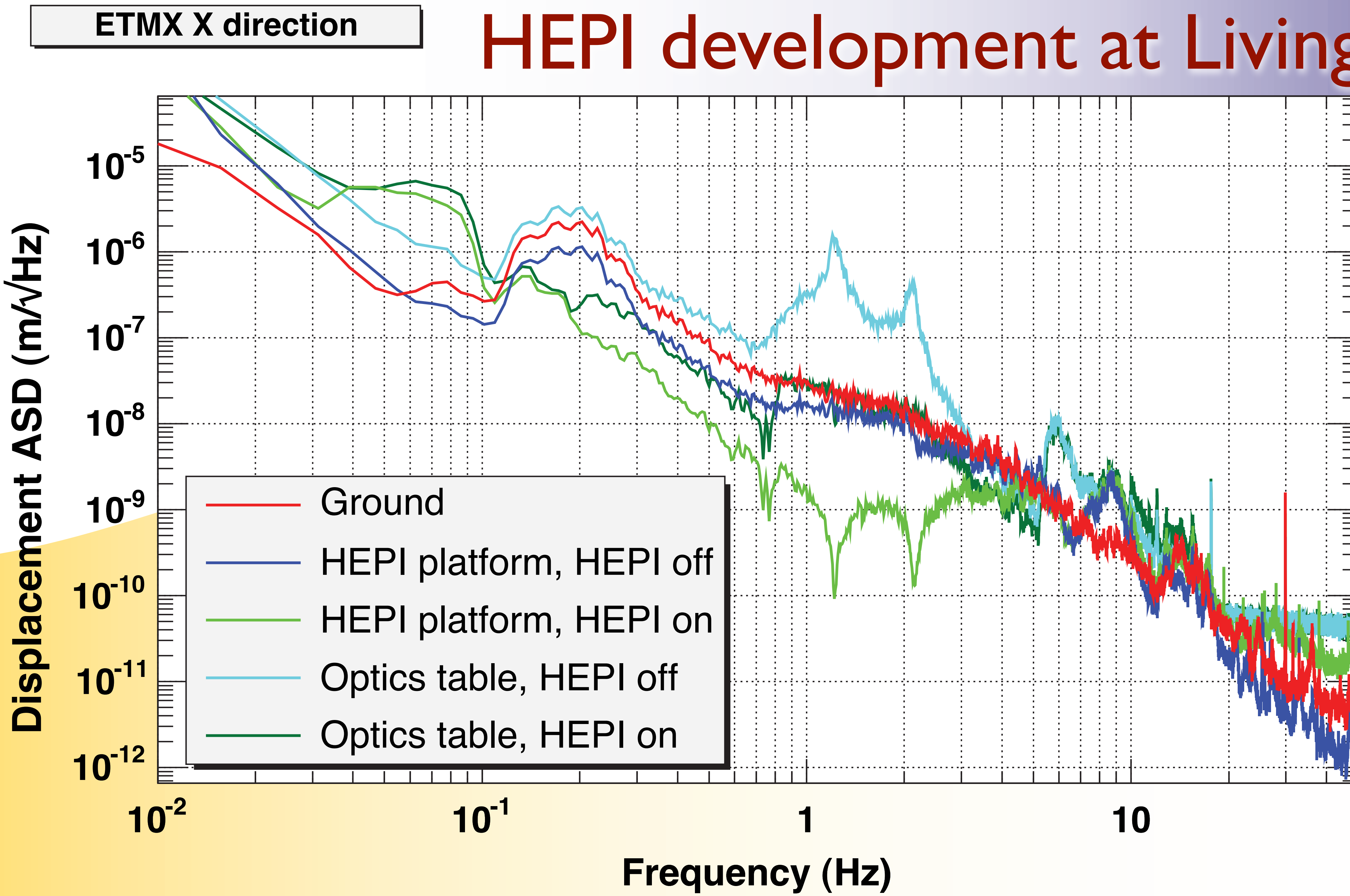


HEPI development: LASTI

- Excess 10–20 Hz noise on BSC HEPI crossbeam long observed at both LIGO and LASTI systems.
- Studied in detail by R. Mittleman at LASTI and found to be resonance of the massive BSC tank, coupling to the payload through the concrete slab compliance.
- Mittleman instrumented BSC with geophone, and tested adaptive feedforward in this band. The geophone signal passes through a continually-adjusted filter and is applied to HEPI actuators.
- The technique is considered very promising, and may solve the excess 10 Hz bump in the Adv LIGO system, and may even be considered for inclusion at LLO before Adv LIGO.

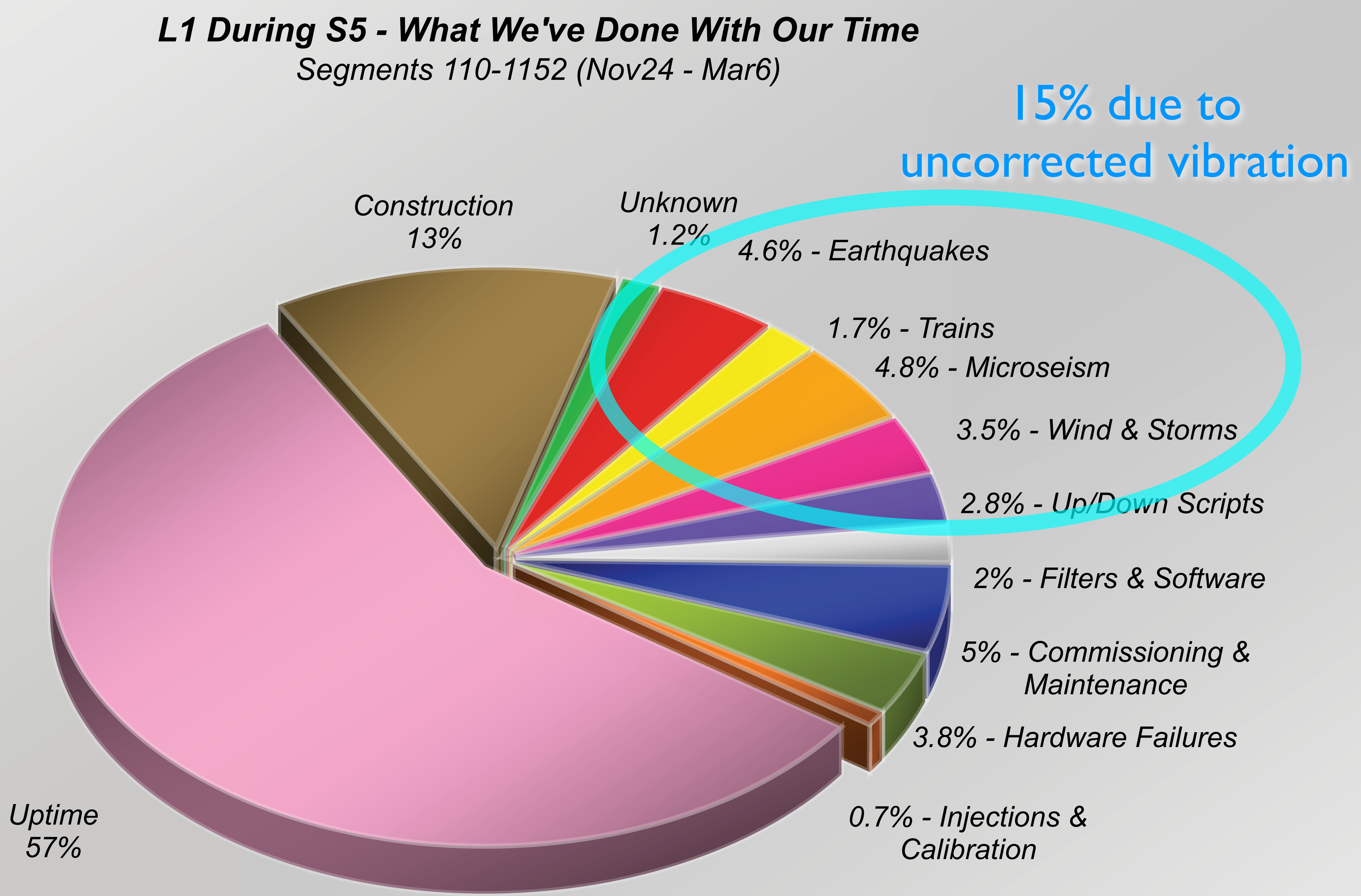


HEPI development at Livingston



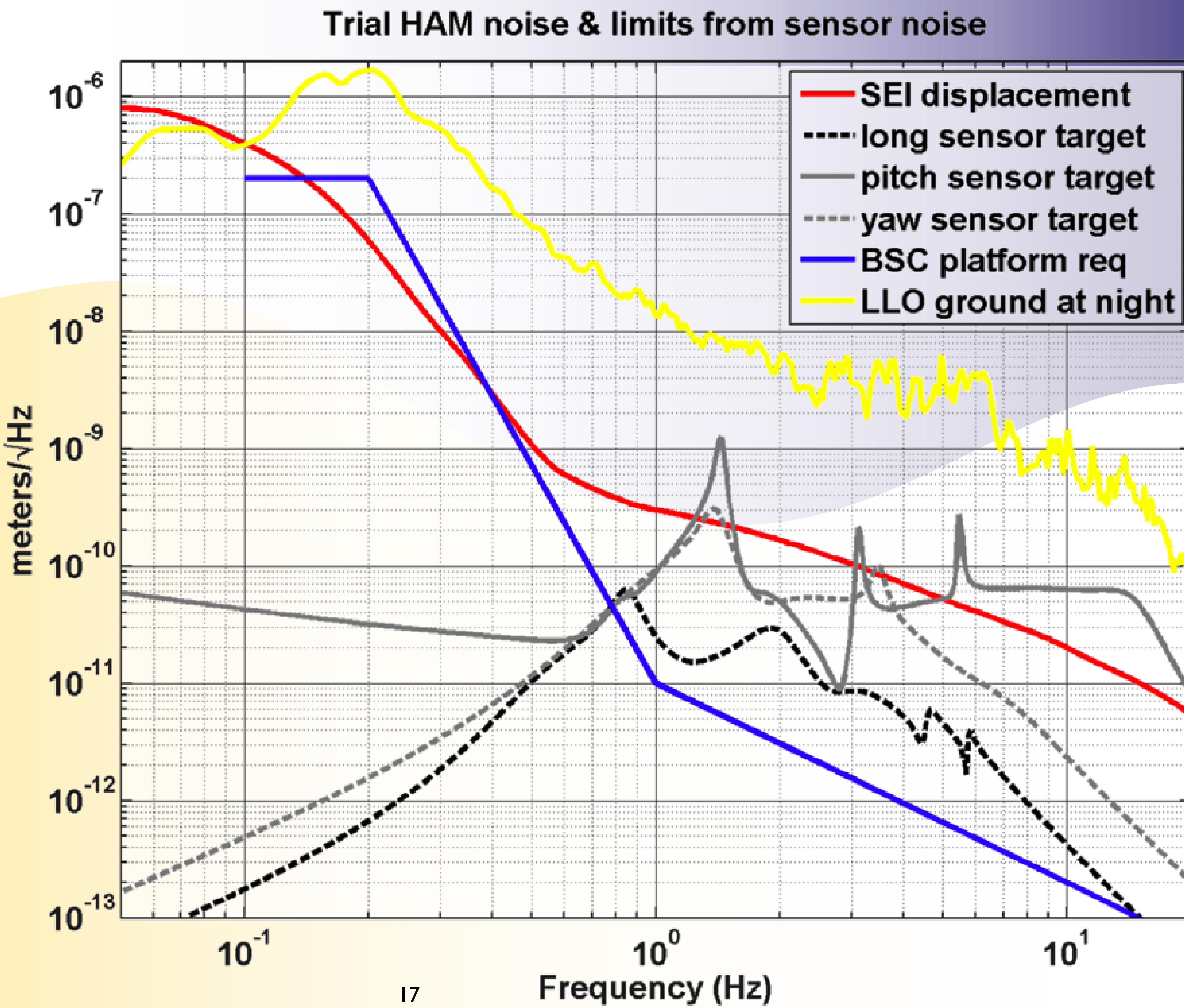
- S. Wen incorporated resonant gains at stack and pendulum bounce modes included in BSC HEPI.
- Skinny HEM gull-wing crossbeams bend when forces are applied; Mittleman's technique for correcting for this has been implemented at LLO by Wen.
- New projects: optimize sensor correction for X and rY HAM DOFs, ultra-low-frequency optimization (S. Wen & B. O'Reilly)

Vibration "contribution" at LLO in early S5



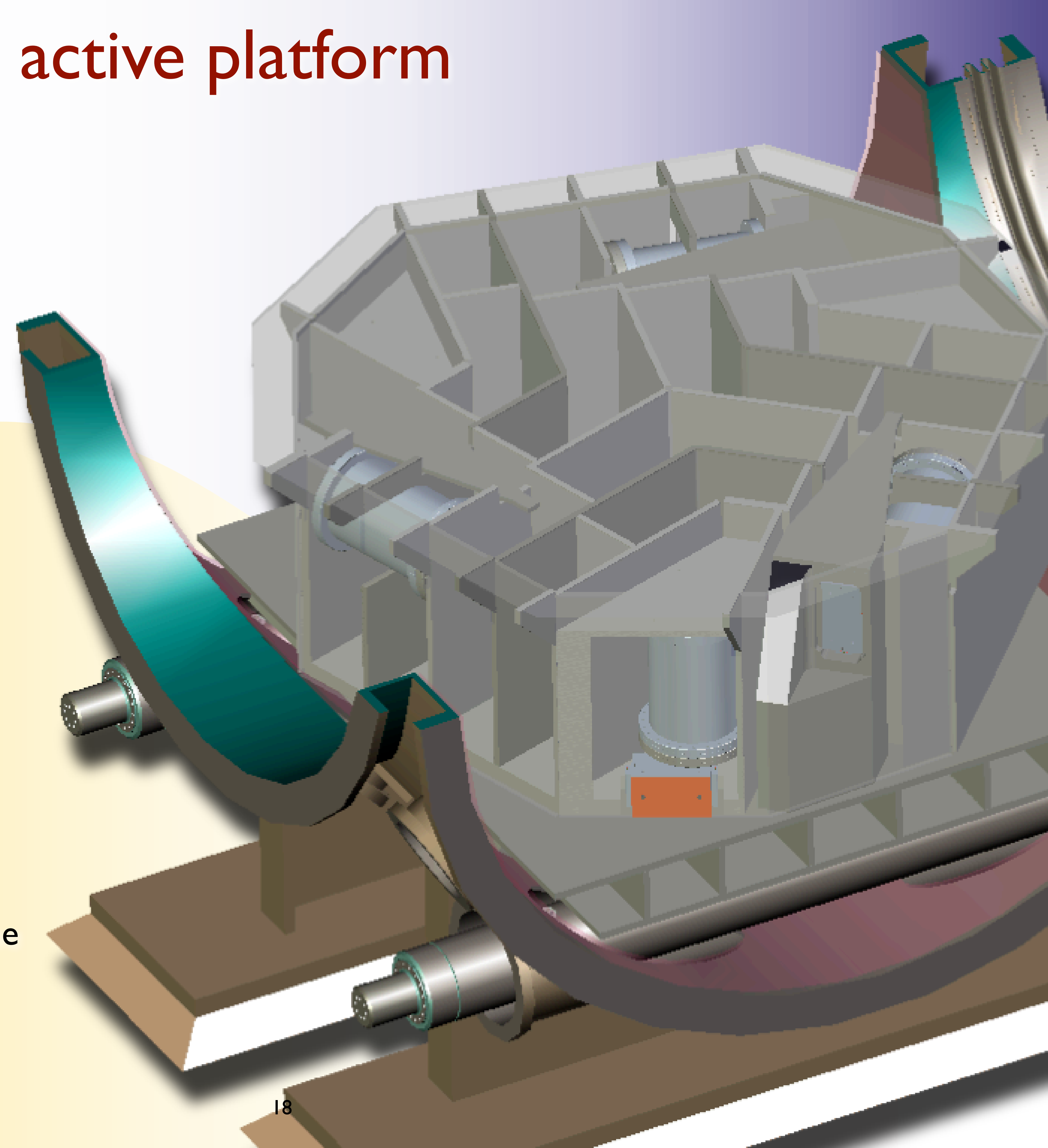
P. Fritschel's *tentative draft proposed* HAM SEI requirements

- Other competing noise sources considered, including SUS local sensors.
- Requirements on RMS motion.
- Tentative MC controller sketched out to compare residual MC length noise with those requirements.

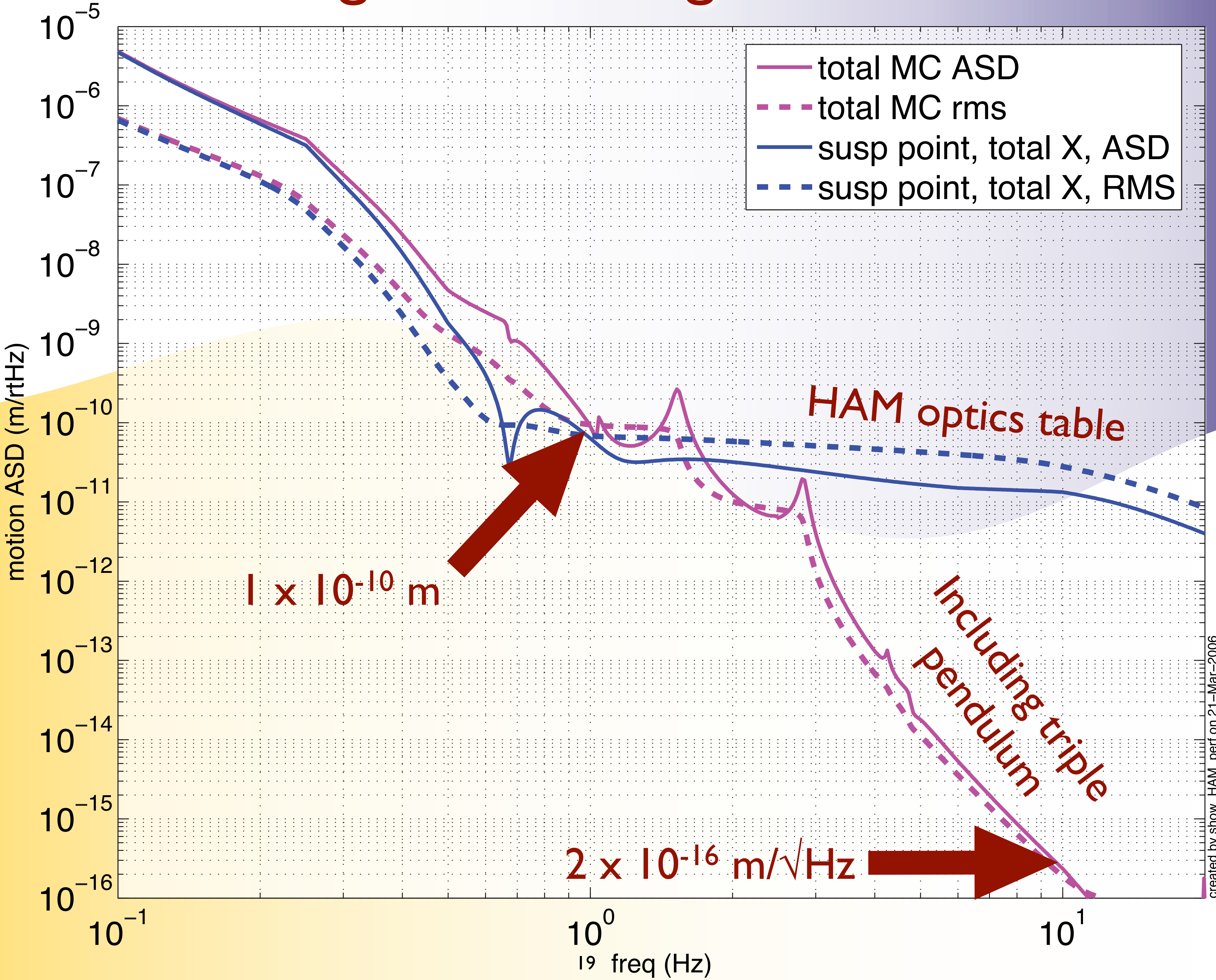


Single-stage active platform

- Motivations: Simplicity, **Economy**, Commissioning speed.
- B. Lantz has developed a 6-DOF dynamic model, using realistic input vibration and instrument noise levels.
- meets P. Fritschel's *draft* modified Adv LIGO HAM requirements.
- C. Hardham (Stanford grad, now LIGO consultant) has developed straw-man mechanical design.
  - Simple geometry allows much higher stiffness.
  - Single stage allows easier balance and alignment.
  - high-reliability GS-13 is the only inertial instrument.
- Next step is to develop detailed cost estimate.

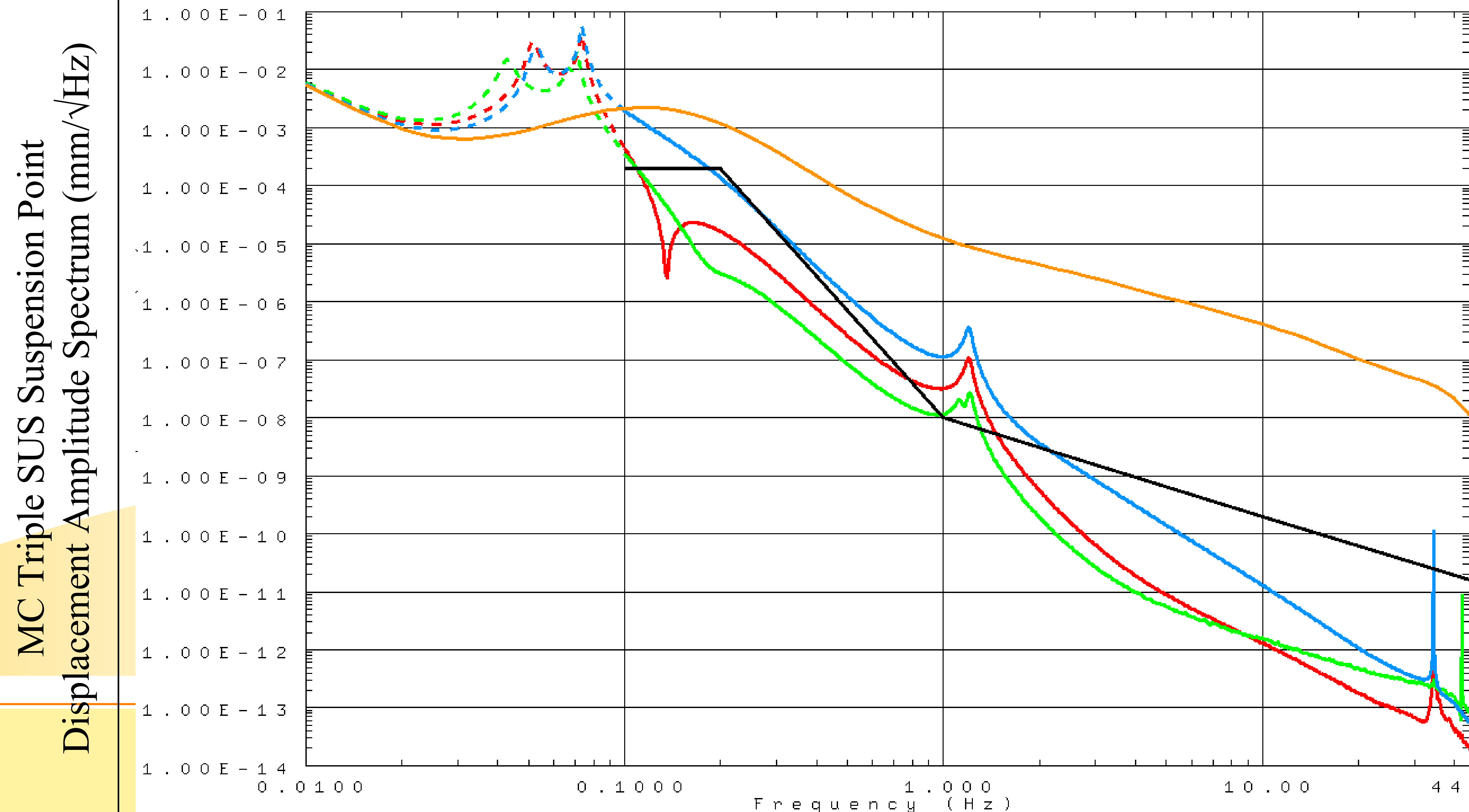


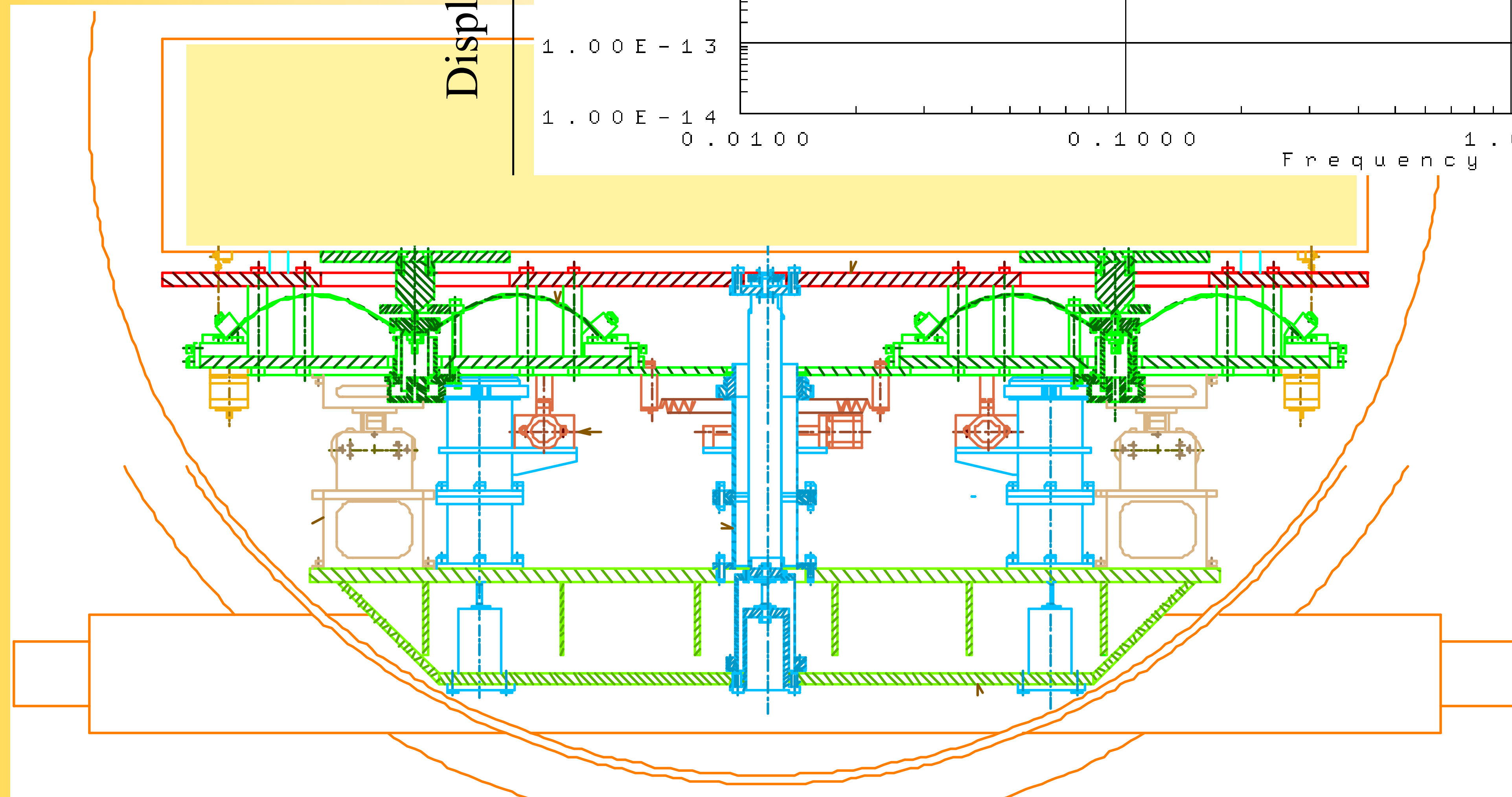
Single active stage noise model



HAM SAS experiment at LASTI

- Motivation: simplicity, economy, need for detailed careful test of main alternative to baseline design. R. DeSalvo's team has been improving the technology since the seismic down-select.
  - In about March 2007, LIGO will consider replacing baseline HAM design with HAM SAS or variant if warranted.
- New geometry of ultra-low-frequency passive isolation stage.
  - Short inverted pendulum (IP) mounted on existing support tubes.
  - Four GAS springs support optics table from top of inverted pendulum
- Both IP and GAS spring stages to have natural frequencies at some tens of millihertz, in order to passively isolate the microseismic peak.
  - small vacuum-compatible motor-driven bias springs to set DC position.
- 6 DOF control, to maintain DC position.
- Damping needed for ca. 1 Hz horizontal blade spring modes.
- Measurements planned of displacement and tilt noise down to 10 mHz, to observe isolation, noise floor, and rms motion.


MC Triple SUS Suspension Point
Displacement Amplitude Spectrum (mm/√Hz)
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
0.0100
0.1000
1.000
10.00
44
Frequency (Hz)



15:50	0:25	Calum Torrie/Caroline Cantley	AdL suspension development	
		AIC - Conference Room, Staging Building	OWG - Lg. Conf. Rm - Secondary (OSB) Bldg	SWG - Main Building Auditorium (rm 124
16:15	0:15	Stable Recycling Workshop	AdLIGO Optics Processing Session	Coyne, Optical and mechanical layout
16:30	0:15	Phil Willems - TCS noise couplings Muzammil Arain - Mode matching considerations	Helena A - overview of cleaning procedures	Torrie, Controls Prototype Progress
16:45	0:15		DeSalvo - strategies for installation; Vendor perspectives	Aston, Electronics requirements and development overview
17:00	0:15		Bill Kells (by phone) - ITM postmortem analysis	Greenhalgh, Observed and predicted performance of blade springs
17:15	0:15			Barton, Suspension mechanical modeling
17:30	0:15		K.-X. Sun - Progress in Grating Optical Sensors	Heptonstall, fiber and ribbon design and welding
17:45	0:15		K.-X. Sun - Test Mass Charging Mitigation Using Modulated LED UV Light	Greg Harry / Steve Penn suspension resonance experiment

WEDNESDAY March 22

		AIC - Main Building Auditorium (rm 124)	OWG - Lg. Conf. Rm - Secondary (OSB) Bldg	SEI (SWG) - Conference Room, Staging Building
8:00	0:15			LASTI REVIEW
8:15	0:15			
8:30	0:15			
8:45	0:15			break
9:00	0:15	ADvLIGO ISC Workshop	Gregg Harry - AdvLIGO optical coating research status	Lantz, ETF seismic isolation experimental results, SUS cage damping
9:15	0:15	Peter F. - Overview Rana - Consideration in picking a LSC/ASC scheme	Steve Penn - Silica Loss	DeSalvo, Overview of HAM SAS at LASTI project.
9:30	0:15	Kentaro - Low F sensing scheme	Jesper Munch - Off axis Hartmann sensing	Yoshida, E2E modeling of Adv LIGO SEI
9:45	0:15	Osamu - SNR evaluation of sensing schemes	DeSalvo - Mesa Beam update	Sannibale &/or Boschi, HAM SAS mechanical & controls model results
10:00	0:10	Ke-Xun - High power diode development (LSC/ASC)		Ottaway, HAM SAS tests planned at LASTI
10:10	0:15			Mittleman, HEPI adaptive feedforward
10:25	0:15			Wen, LLO HEPI development
10:40	0:15		Break	
10:55	0:15		Joint SWG/OWG session - Conference Room, Staging Building	
11:10	0:15	LIGO Enhancements Dicussion	Mitrafonov - Experimental search for charging of the test mass	
11:25	0:15	Guido M - Implications for IO	Dennis Ugolini - Optics Charging Research	
11:40	0:15			
11:55	0:15			