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Seismic Isolation

Requirements and Design Breakout Presentation

NSF Review of Advanced LIGO Project

Joseph Giaime
Louisiana State University

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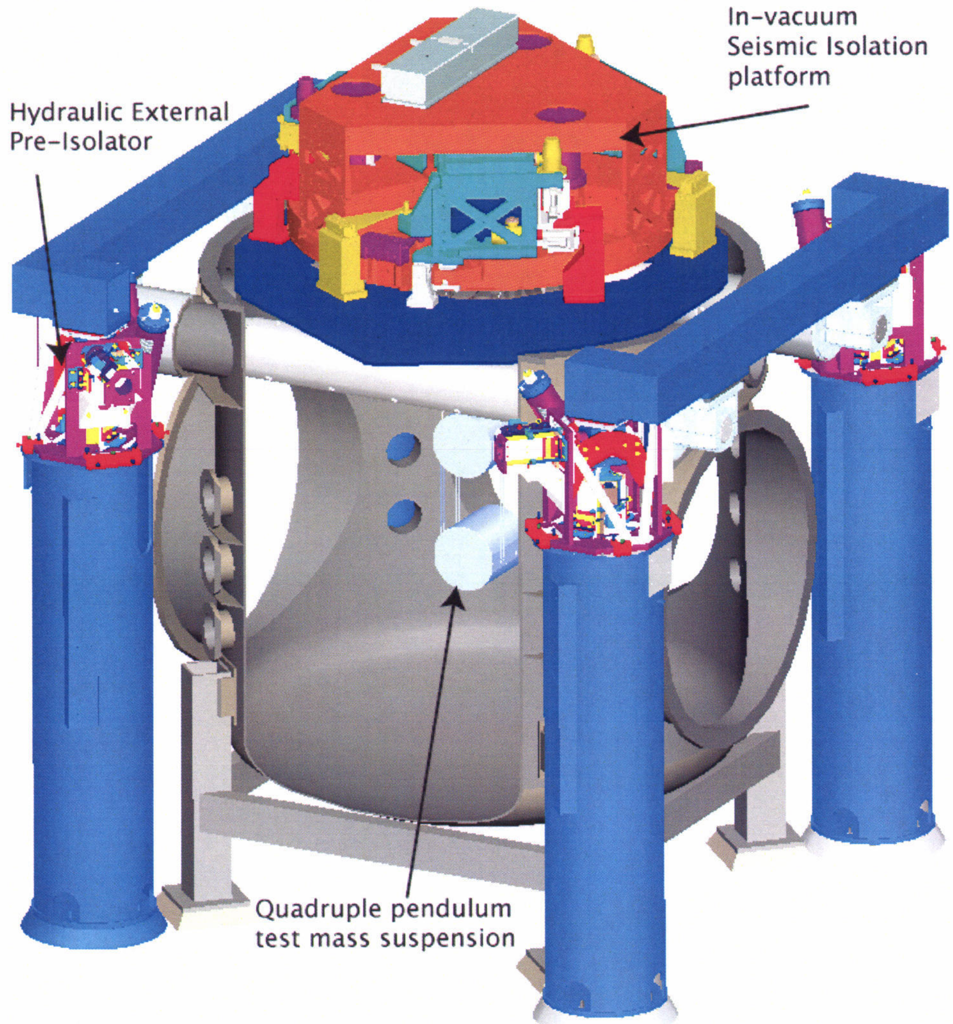
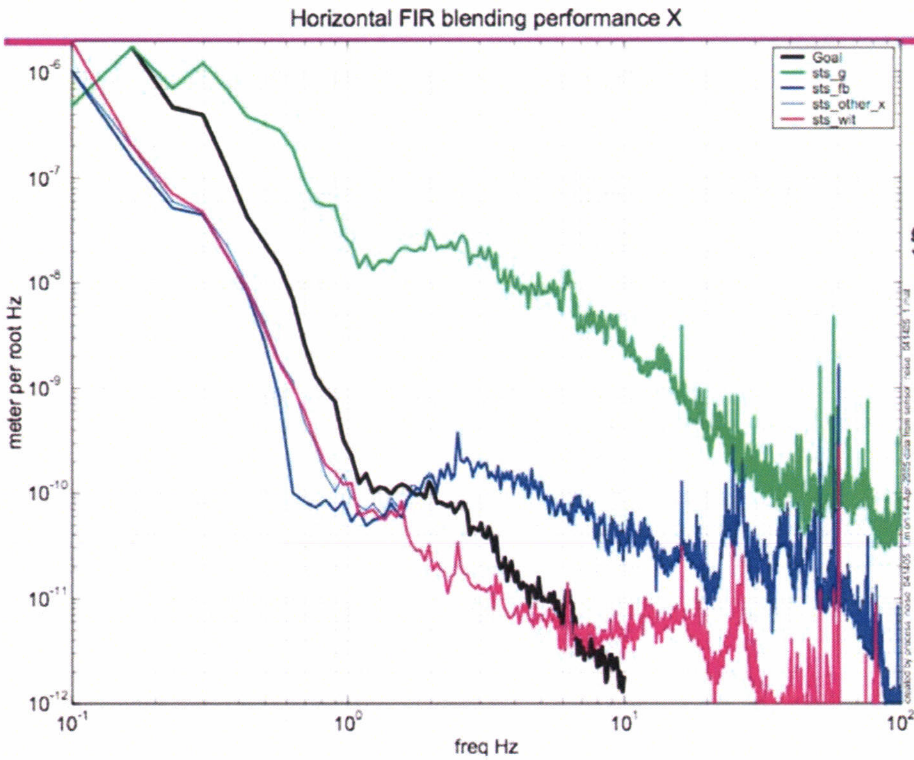
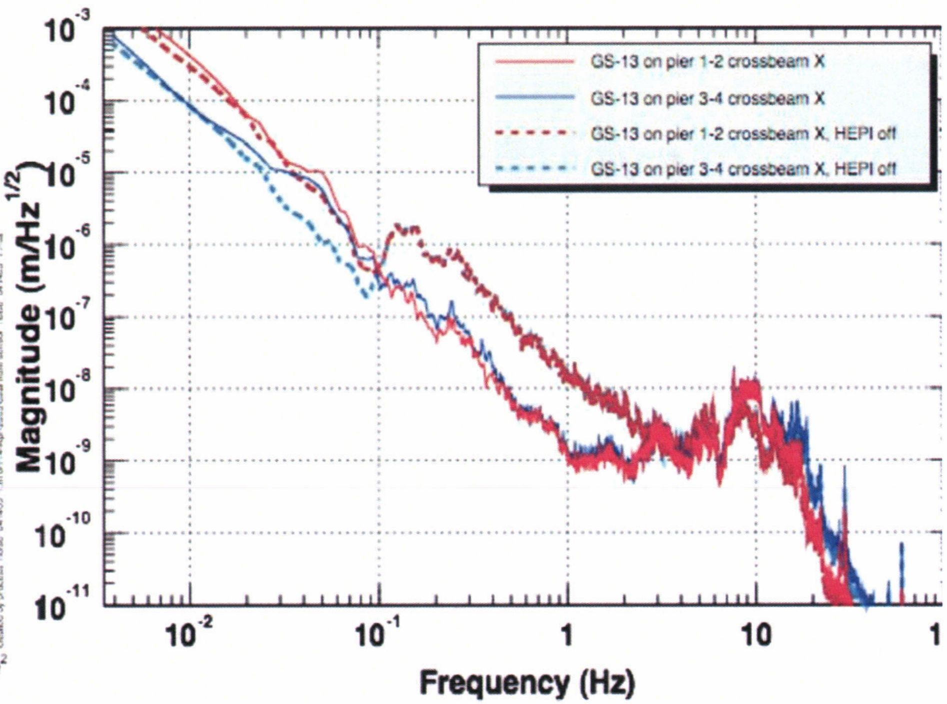
Seismic Isolation Functions

- The test mass is isolated from mechanical vibration in three cascaded stages:
  - » Hydraulic External Pre-Isolator (HEPI), which tracks Earth tides and reduces vibration in the 0.15–2 Hz band. The technique is mostly **feedforward**, based on signals from a floor-mounted seismometer. $8.6 M
  - » A two-stage Internal Seismic Isolation (ISI) platform, which is responsible for isolation in the 1–10 Hz band, to greatly reduce RMS motion. The technique is **active seismic isolation,** which employs force **feedback** based on signals from inertial sensors on the payload. $13.5 M + $21.4 M
  - » A quadruple pendulum suspension; transmitted vibration falls with 8 powers of *f* above several hertz. Isolation is **passive.**
- The seismic isolation system provides physical support of a matrix-drilled optics table for suspension and other components, allows global alignment and positioning, and carries electrical signals.



advancedligo Demonstrated Performance





- 2-stage in-vacuum "Technology Demonstrator" platform in Stanford's Engineering Test Facility (ETF) validated critical sensor noise floor, design robustness to reactive load, and allowed refinement of design parameters.
- HEPI already deployed in LIGO Livingston detector (before S4 run), and has met isolation performance expectations and increased Livingston duty cycle.

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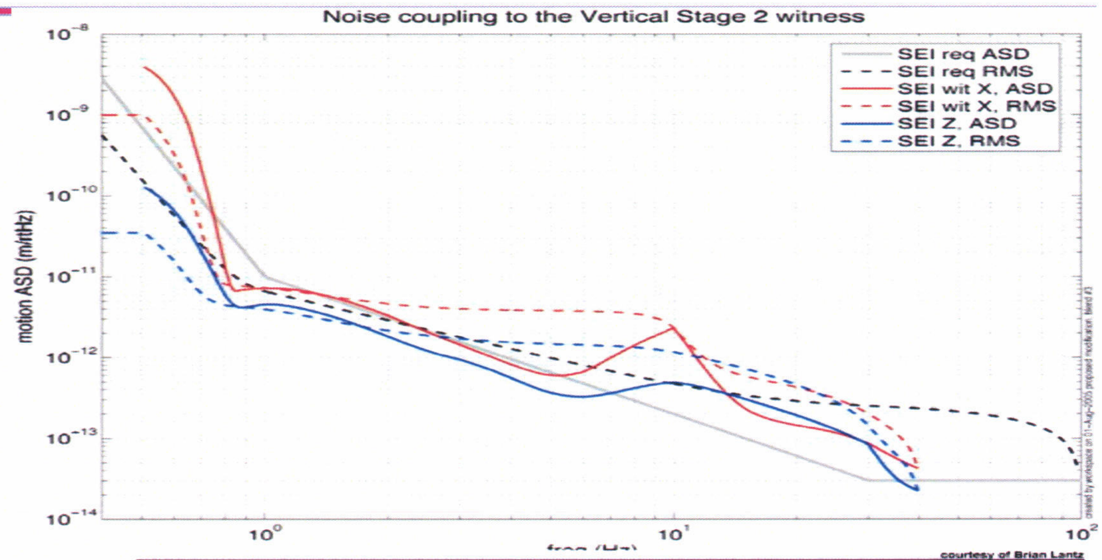
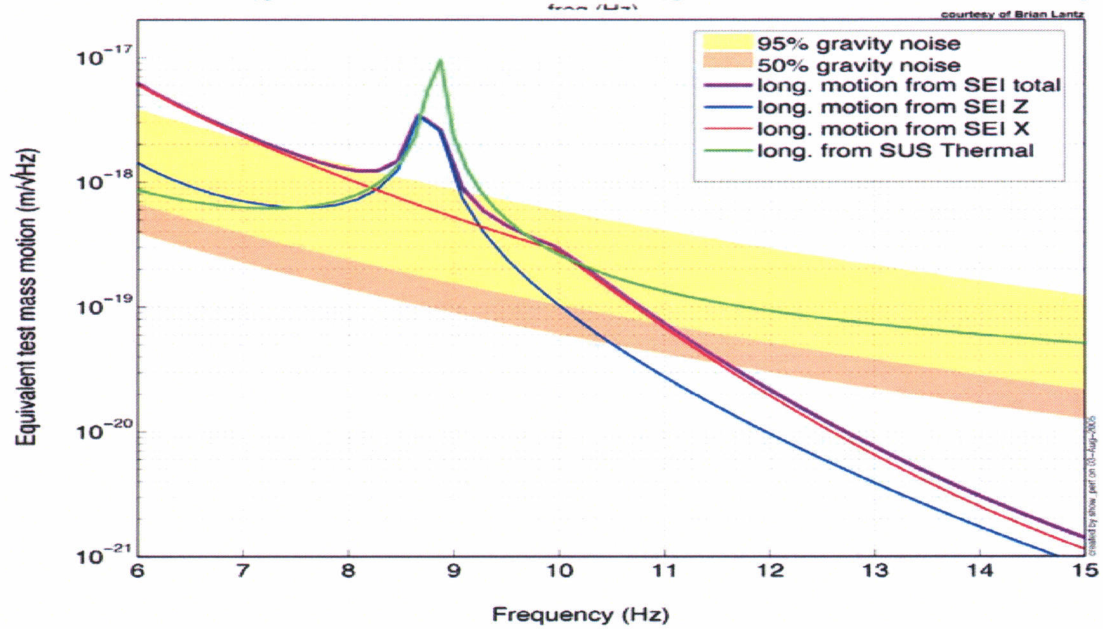
BSC Requirements (HEPI & ISI)

Requirement	Value
Payload mass	800 kg
Range	± 1 mm, ± 0.5 mrad
Optics table noise	few x 10^{-13} m/√Hz (at 10 Hz)
Angular noise	1×10^{-8} rad RMS

BSC Isolation Requirements

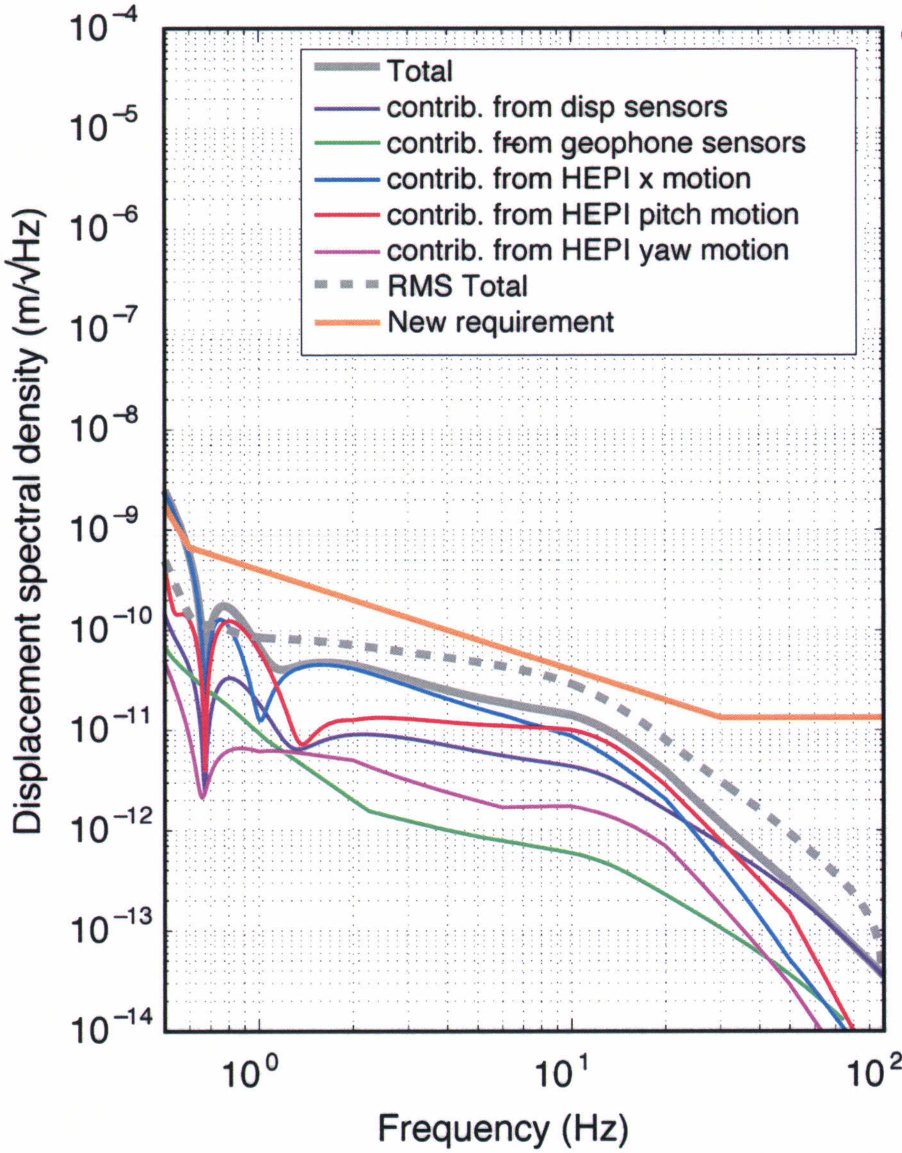
- **HEPI isolates by factor of 10 over “double-frequency microseism” band up to about 2 Hz.**
- **ISI Isolation requirement is approximately a factor of 100 at 1 Hz and 1000 at 10 Hz**
- **Passive isolation in Quad pendulum provides bulk of isolation in GW band.**
- **Noise due to transmitted vibration below gravity gradient and/or suspension thermal noise over most frequencies.**
- **ISI presently not meeting strict requirement at 10 Hz due to vacuum tank resonance; Critical review held last year approved variance, though MIT experiments suggest new technique to recover difference.**
- **Payload: 800 kg**
- **Range:** ± 1mm, ± 0.5 mrad
- Angular: < 10^{-8} rad, 1–30 Hz.





HAM Requirements

- Recently revised in light of better understanding of interferometer design.
- Single stage design chosen as baseline.
  - » Omitted second stage served to reduce 1–10 Hz noise; not needed for HAM payloads
- Payload 510 kg.
- Optics table motion: < 4 x 10^{-11} m/√ Hz at 10 Hz.
- Yaw < 10^{-8} above approx 0.5 Hz, factor of 10 higher when lower f's included. Pitch < 10^{-8} rad



Seismic development status

- HEPI deployed successfully at Livingston, costs & performance understood.
  - » Study underway to determine ideal configuration for LHO.
- Results from Tech. Demo. at Stanford:
  - » 12-DOF controllers.
  - » Measured instrument noise floors at required level.
  - » Active isolation factor at required level.
  - » Accommodation of reactive load (prototype SUS cage).
- Prototype of BSC (tall tank, for test masses) for MIT Lab:
  - » Mechanical procurement complete, assembly underway.
  - » New design of motion-limiting stops ensures safety of humans and sensors during assembly and operation.
  - » Electronics and data systems designed, fabrication underway.
- Prototype of HAM (short tank, for aux. optics) for MIT Lab:
  - » Fabrication to begin in one year.
- Dynamic modeling carried out in 6 DOFs for HEPI and for ISI, tested against prototypes.
  - » Joined ISI-Suspension model with full back-reaction is next step.

Development work plan with risks

- Testing at LASTI of BSC ISI, mounted on HEPI system:
  - Work plan:
    - ‘dirty’ assembly & testing, 2Q ’06.
    - Cleaning for ultra-high vacuum, 3Q, ’06.
    - Assembly and test, 4Q, ’06.
    - Cartridge installation and testing with suspension system follows.
  - Risks, *plans for risk reduction*:
    - Value-engineered blade spring design; minimal but new risk.
    - we are prototyping in a noisy environment and will have to extrapolate to observatory performance.
    - *electronics self-diagnostics.*
    - *installation in ‘real’ LIGO tank.*
    - *Test of long-term operation and assessment of reliability.*
- Single stage HAM development:
  - Work plan:
    - Conceptual design engineering (aided by contractor Mech. E.), 1+2Q ’06.
    - Prototype detailed design, 3+4Q, ’06.
    - Possible early deployment of Adv LIGO HAM at LLO for post-S5 upgrade.
  - Risks, *plans for risk reduction*:
    - Sub hertz motion of suspension points dominated by HEPI angular motion; some improvement here is desired. *Addressed by HEPI improvements under study at LLO.*
    - *Post S5 deployment in LIGO-1 may retire all design performance risk.*

Development work plan with risks, cont'd.

- Study of alternate suppliers for sensors can reduce risk from supply interruptions or business plan changes. (ongoing)
- Development of rapid sys-id and controller design techniques will aid in commissioning speed.
  - Stanford group building experience with rapid sys-id techniques: rapid turn-around seen in combined seismic platform - suspension cage test earlier this year.
  - Tests at LASTI of adaptive feedforward may lead to faster and better filter design.
- Study of the incorporation of the seismic system with LIGO's global control scheme will aid in development of both.
  - Current Livingston detector uses control reallocation from suspension electromagnets to HEPI, the "tidal" servos.
  - Adv LIGO may include seismic platform interferometer, which would feed back to HEPI (see P. Fritschel's presentation) and more complete control reallocation to HEPI from other degrees of freedom.