Suspensions and Seismic Isolation Working Group Update: US overview

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LIGO-Caltech and University of Glasgow

LSC/Virgo meeting, Hannover
23rd October 2007
G070660-00-R

Suspensions and Seismic Isolation Working Group – SWG

- Research areas: seismic isolation, suspension design and suspension thermal noise
  - » Also charging issues and thermal noise associated with bonding: formally covered in Optics Working Group (OWG) - overlaps with SWG
- Groups involved: ACIGA, Embry-Riddle, Florida, GEO, Hobart/William Smith, LIGO, LSU, Moscow, Southeastern Louisiana, Stanford
  - » equals a large number of people
- Current chair: Norna Robertson
- Current work: focused mainly on Enhanced & Advanced LIGO

Suspensions and Isolation for Advanced LIGO

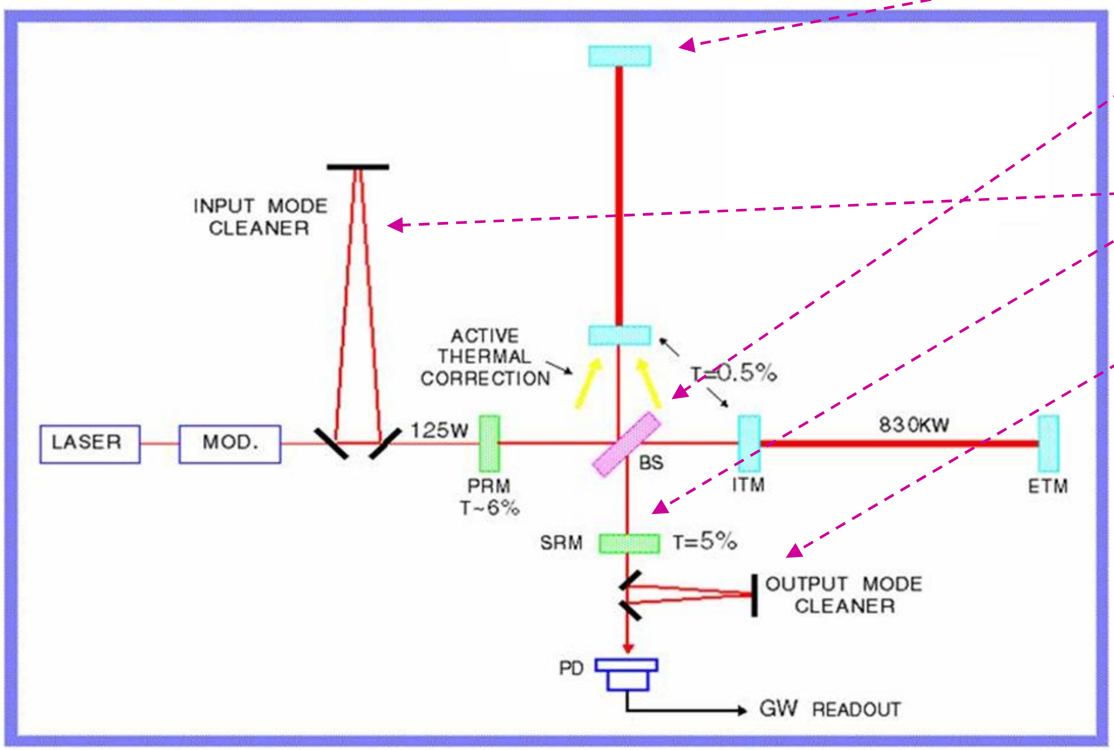
See following plenary talk by Mark Barton

Suspensions

- Most sensitive optics in BSC chambers: UK deliverables
  - » Quadruple pendulum for Test Masses
  - » Triple pendulum for Beamsplitter
- Other optics in HAM chambers: US deliverables
  - » Triple Pendulums for Input Modecleaner Mirrors and Recycling Mirrors
  - » Double Pendulum for Output Modecleaner

Seismic Isolation

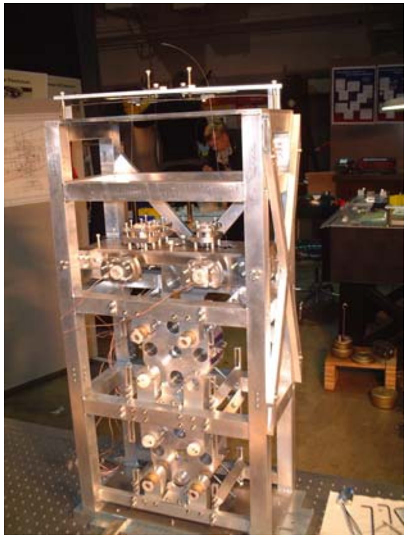
- Two-stage active platform for BSC chambers
- One stage active platform for HAM chambers
- HEPI for both (hydraulic external pre-isolators)

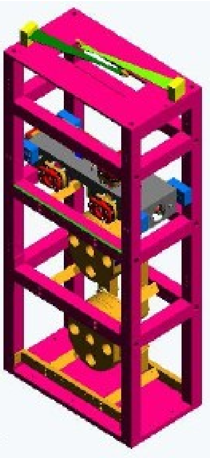


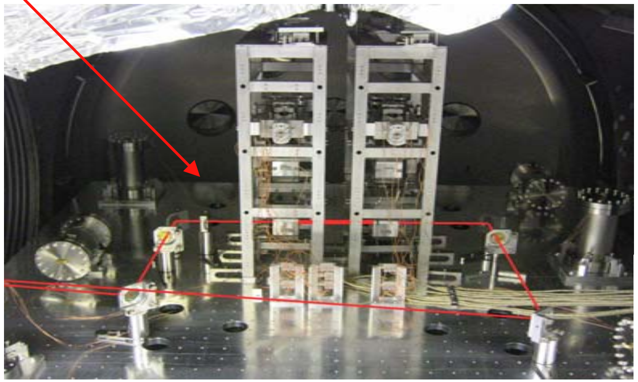
Advanced LIGO optical layout schematic

Input Modecleaner
Triple Pendulum Suspension

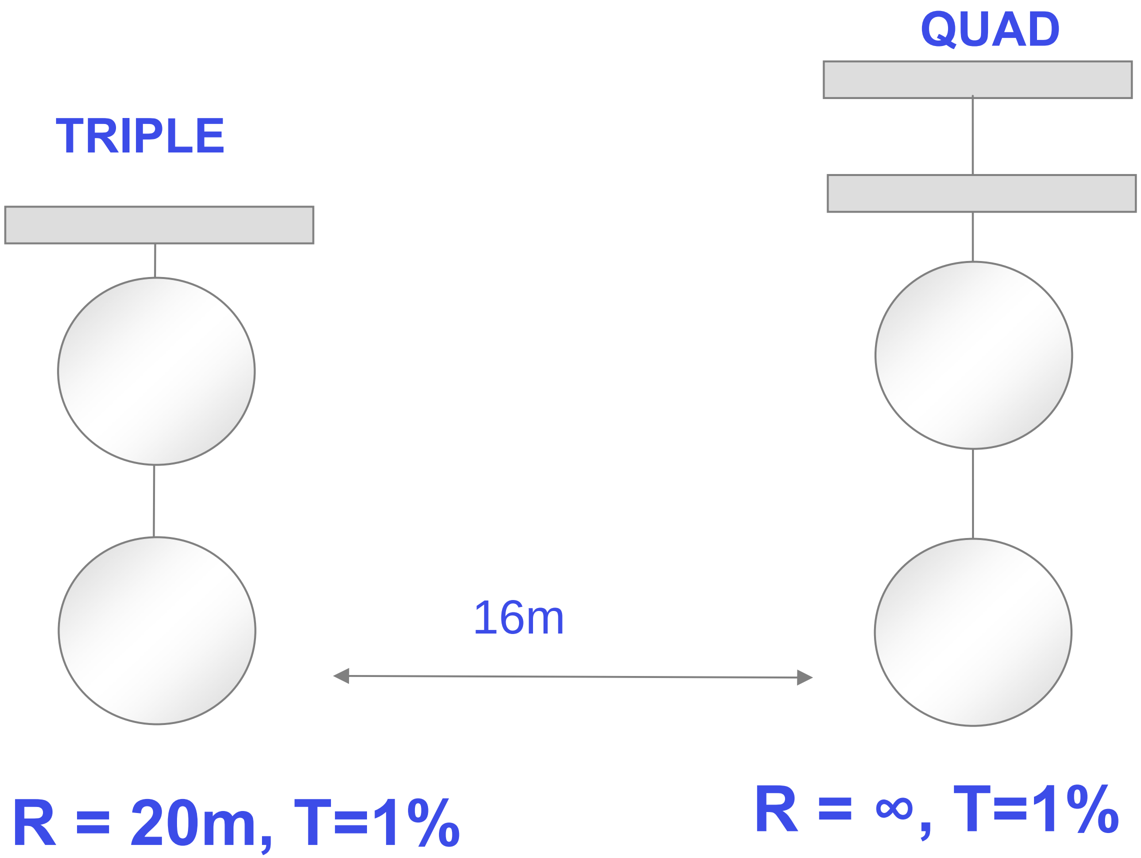
- Design features
  - » Triple pendulum with two stages of blades
  - » Silica mass: 150 mm diam. x 75 mm thick (~3 kg)
  - » Wire suspension
- Experimental investigations
  - » Prototype built at Caltech and fully characterised at LASTI (comparison to MATLAB model)
  - » Test of independent modal control with a state estimator for damping - minimises sensor noise re-injection (L Ruet)
    - – relies on good model
    - – tested using second modecleaner triple pendulum as quiet reference
  - » One modecleaner suspension recently used for cavity tests with quad prototype







One Arm Cavity Tests at LASTI

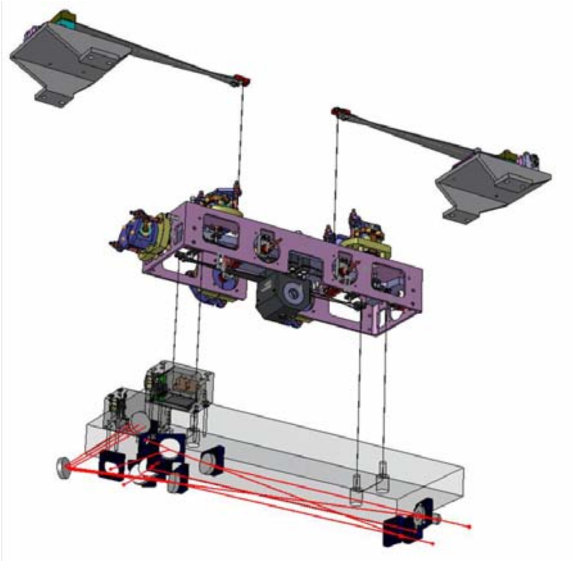


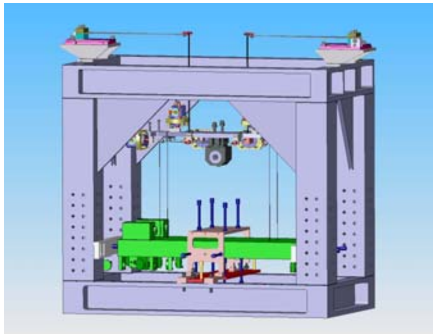
- Cavity set up between input modecleaner triple and test mass quadruple suspensions
- Goals: investigate
  - » Electrostatic Drive (ESD)
  - » Hierarchical Control
  - » Lock Acquisition

See talk by Lisa Barsotti (Wed am)

Output Modecleaner (OMC) Double Pendulum Suspension

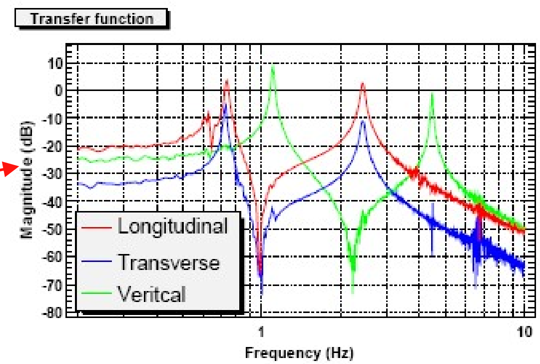
- Design features
  - » Double pendulum with two stages of blades
  - » Silica optical bench 450 mm x 150 mm x 40 mm (~6 kg)
  - » Steel wires
- Requirements
  - » Double pendulum isolation and 6 DOF active damping
  - » Pendulum frequencies 0.8 to 2 Hz (guideline)
- Current status
  - » Prototype with metal bench tested at Caltech, expect to test with glass bench this week
- First Installation
  - » In Enhanced LIGO, end of 2007

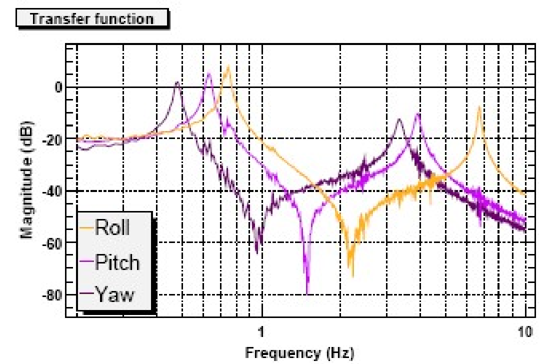


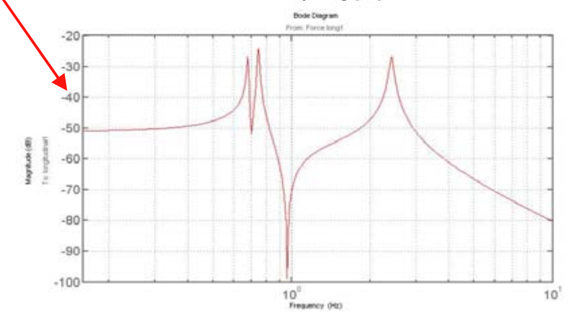


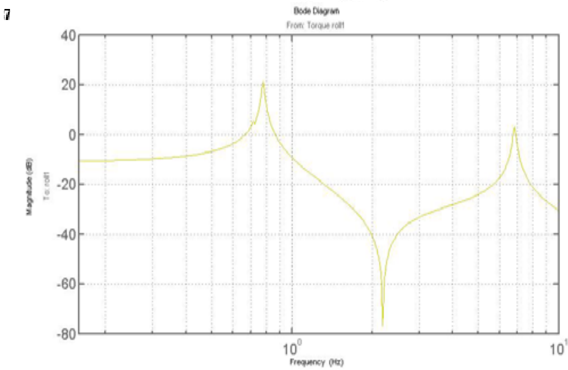
Output Modecleaner Double Pendulum Suspension continued

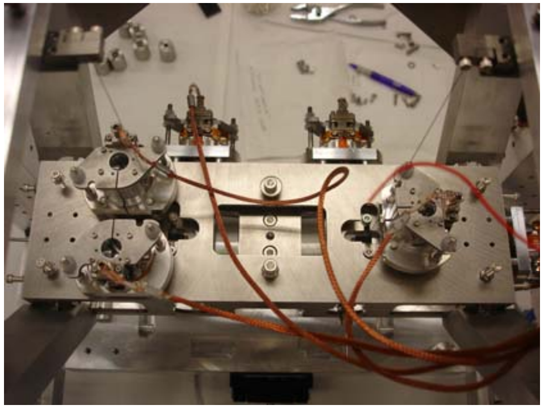
- Characterisation
  - » Mode frequencies: from 0.5 Hz (lowest yaw mode) to 6.7 Hz (highest roll mode)
  - » Transfer functions: measured and modelled (actuating and sensing at top mass)
  - » Damping
- Other tests
  - » Structural resonances
    - – lowest ~148 Hz with ~4 kg non-suspended mass attached
  - » OSEM design from UK
    - – Works well



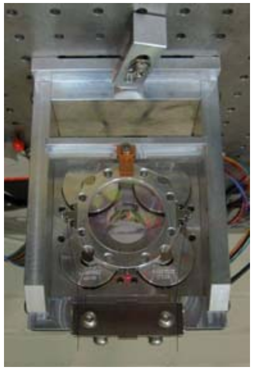






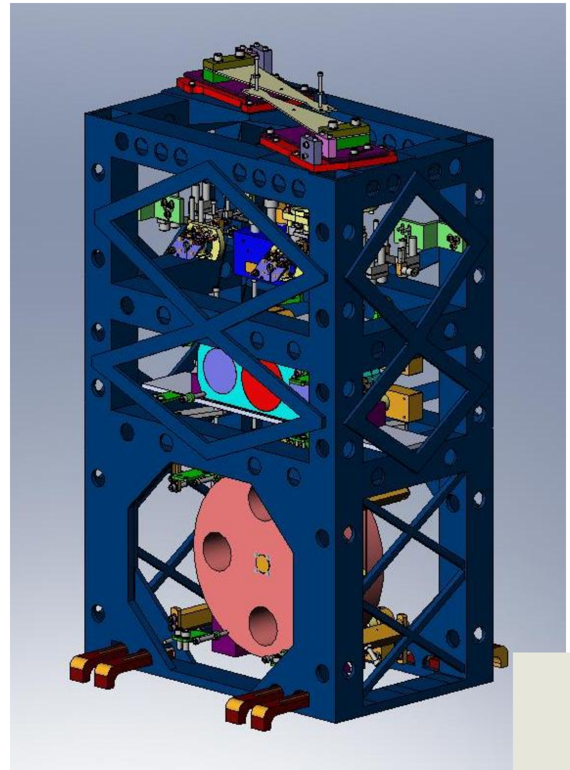


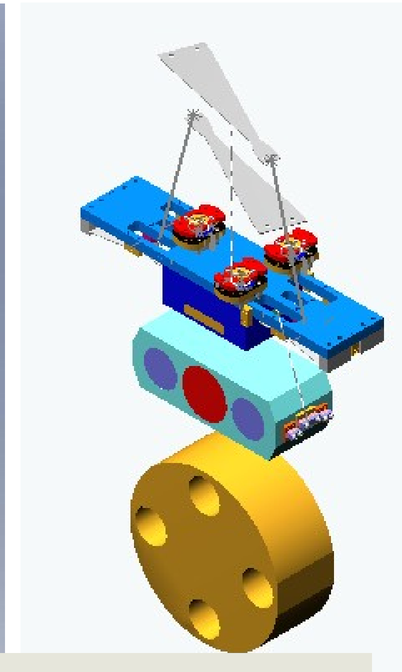
- Associated work: development of tip-tilt mirrors (ANU)
  - » dither beam at high frequencies (>1kHz or even >10kHz) to create error signals for control
  - » under test at Caltech

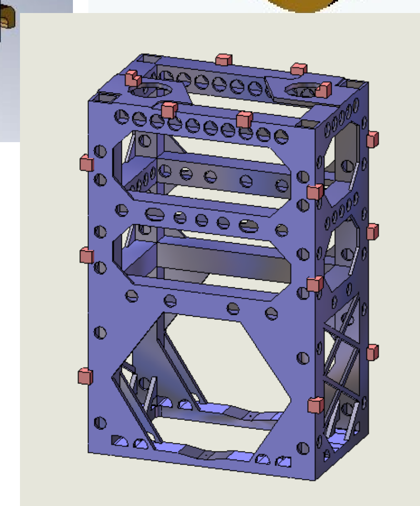


Recycling Mirror (RM) Triple Pendulum Suspension

- Design features
  - Triple pendulum with two stages of blades
  - Silica mass: 265 mm diam. x 100 mm thick (~ 12 kg)
  - Wire suspension
  - Middle mass “squashed” to meet height restriction with large mirror
- Current status
  - detailed design work now underway
  - prototype assembly: early 2008

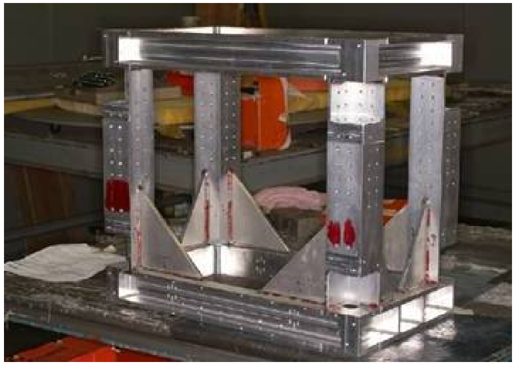




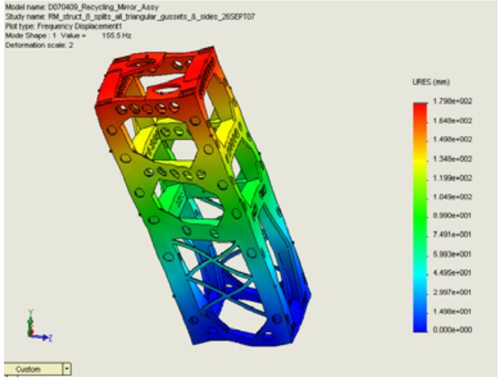


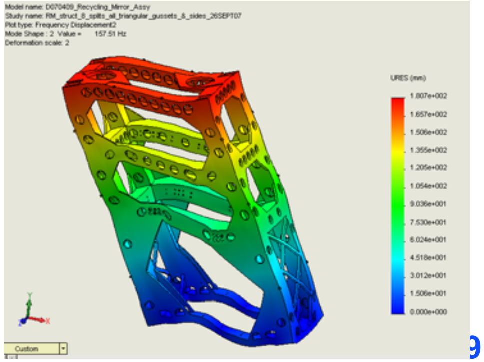
OMC and RM Support Structures

- Design Challenges: OMC
  - » Meeting 150 Hz lowest structural resonance with a design which can be welded in aluminium
  - » Meeting LIGO vacuum requirements with welded aluminium structure



- Design Challenges: RM
  - » Meeting total mass budget (~ 120 kg) and 150 Hz lowest structural resonant frequency with steel structure
    - – Stainless steel structure used to ease welding issues after experiences with OMC structure
  - » Access for assembly and adjustment
    - – Mock-up of suspension used to check



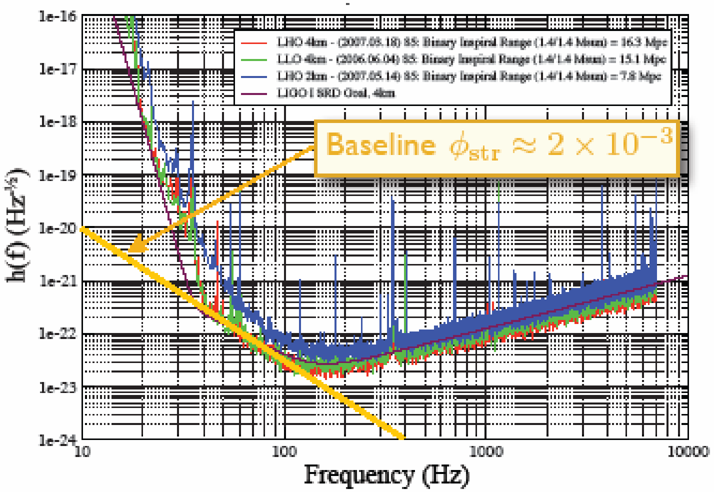


See talk by Calum Torrie (Wed am)

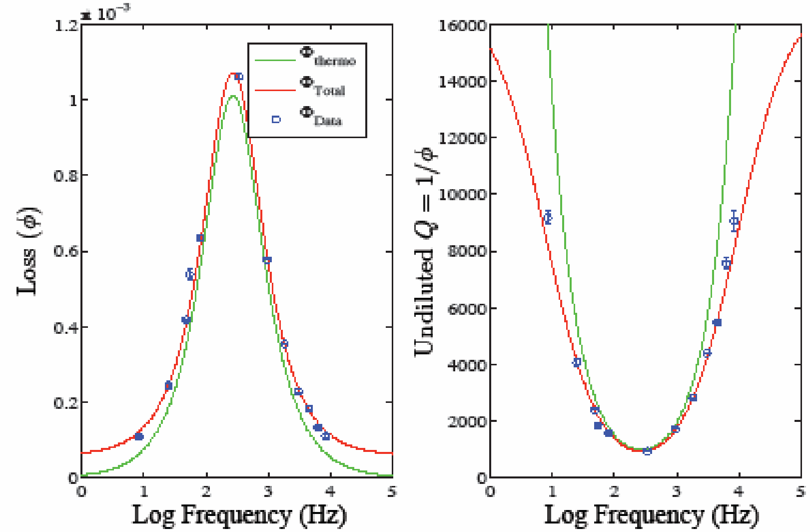
Suspension Thermal Noise for Enhanced LIGO

Steve Penn, Sean Kipperman, Emily Newman, Paul Stephens (HWS), Gregg Harry, David Kelley (MIT), Peter Saulson, David Malling (SU), Andri Gretarsson (ERAU)

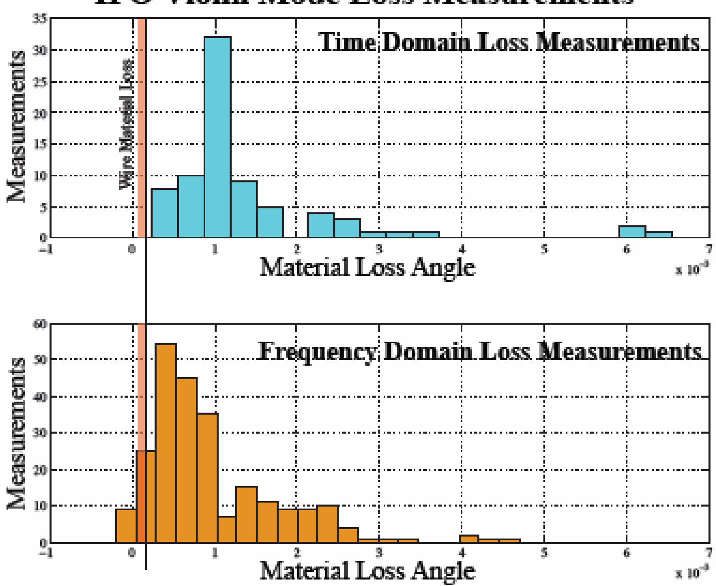
Sensitivity Noise 40–150 Hz has slope of -5/2, similar to suspension thermal noise



Free Wire Structural loss $\phi_{\rm str} = 5.9\times10^{-5}$



IFO Violin Mode Loss Measurements



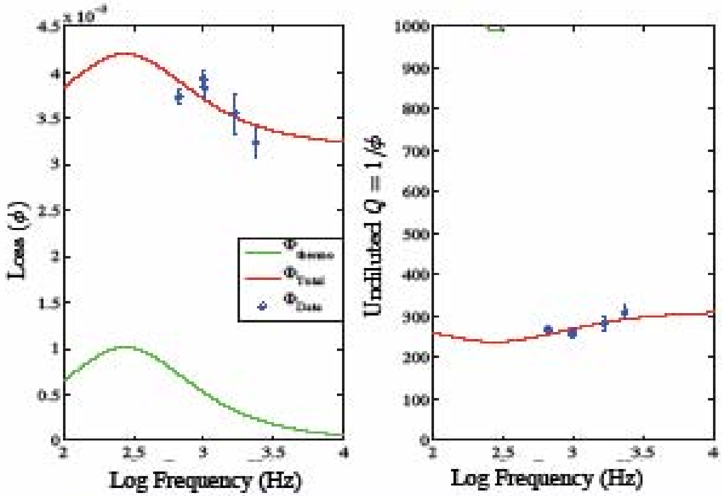
Excess noise in 40–150 Hz region
- Similar dependence to suspension thermal noise
- Implied loss angle 20 x the wire internal loss.

IFO Violin mode measurements of the suspension loss
- Time domain loss from resonant ringdown
- Frequency domain loss from spectral peak width
- Large variability in results for both cases
- Lower amplitude frequency measurements show lower loss, suggests rubbing friction

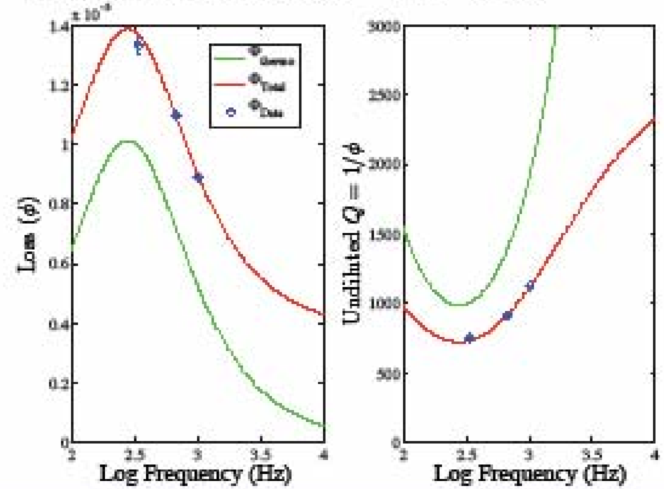
From Steve Penn

Investigating Loss from the Standoff

Silica standoff increases loss to $\phi_0 = 3.19 \times 10^{-3}$



BK7 prism standoff with wire-cut groove decreases loss to $\phi = 3.7 \times 10^{-4}$



Standoff Tests

- Adding silica standoff to test suspension dramatically increases loss.
- Rubbing friction loss will result in variability and amplitude dependence.
- Tested BK7 & sapphire prisms (no groove) and BK7 (saw cut). Losses were less than silica standoff and greater than BK7 w/ wire-cut.

Current Experiments

- BK7 prisms with slots of various depths
- Sapphire prisms with narrow laser-cut wire grooves that slightly pinch wire.
- Steel ribbons with slotted prism standoffs that locate the ribbon twist between the standoff and the optic.
- Sapphire clamps that won't deform wire.

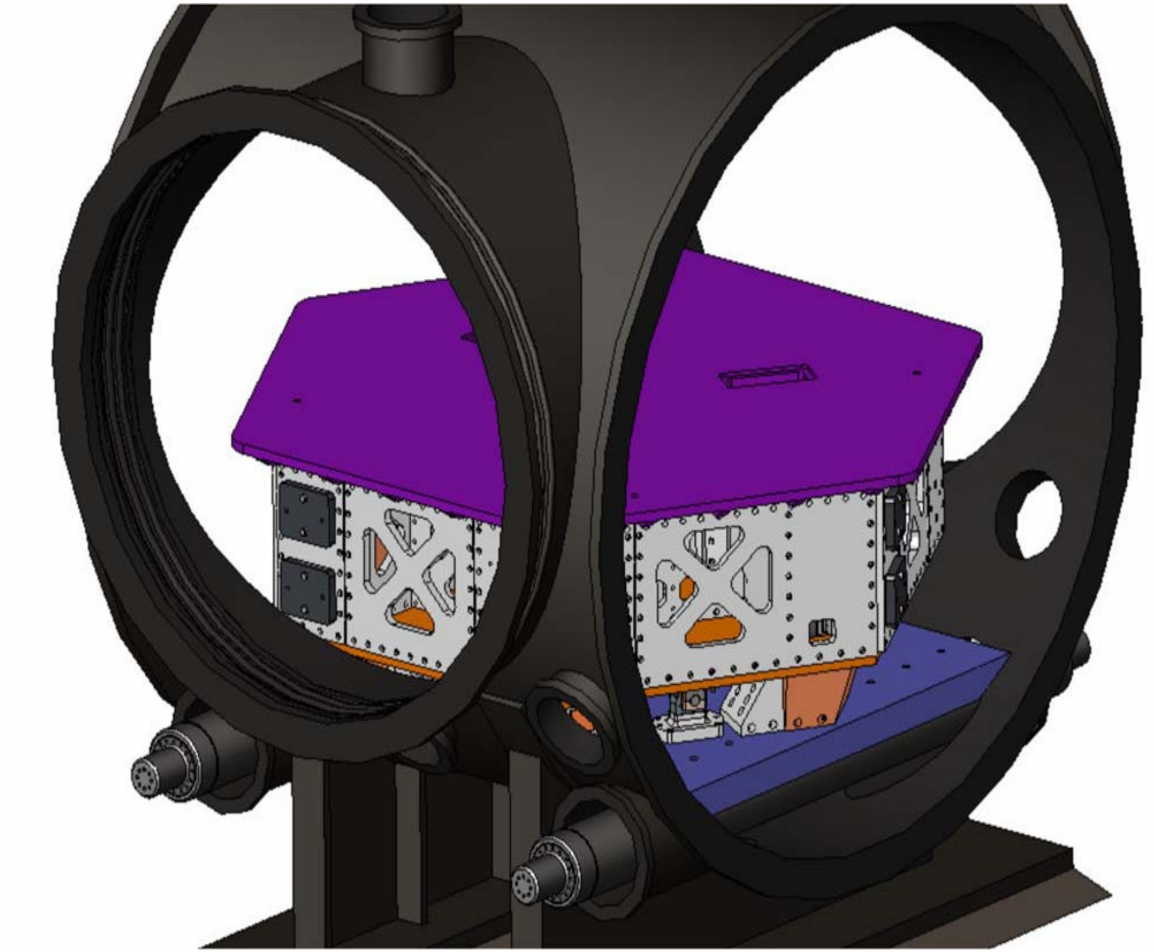
Single Stage HAM Internal Seismic Isolation (ISI) for Enhanced and Advanced LIGO

- Install 2 for Enhanced LIGO
  1 at Hanford, 1 at Livingston in HAM 6.
- Supports the Output Mode Cleaner
- First Articles for Advanced LIGO.
- No HEPI for now.
- Build and air test at HPD in Boulder - Oct-Nov 2007.
  (Brian Lantz and Rich Mittleman both there now,
  and we send our apologies for missing the meeting!)
- First clean installation at LLO in Nov-Dec 2007.
- Second clean installation at LHO in Jan 2008.

From Brian Lantz

HAM ISI

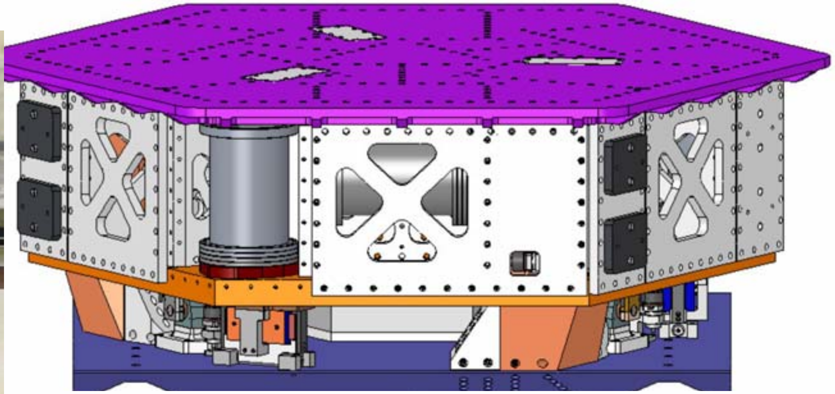
- Bolted aluminum structure
- Suspended by 3 blade springs & wires
- Natural freq's
  x & y: 1.35 Hz
  z: 1.8 Hz
  tip/tilt: 1.07 Hz
  yaw: 0.9 Hz
- mass: stage 1 ~ 1500 kg plus 510 kg of payload
- first bending mode: > 250 Hz
- assume servos with unity gain of 27 Hz

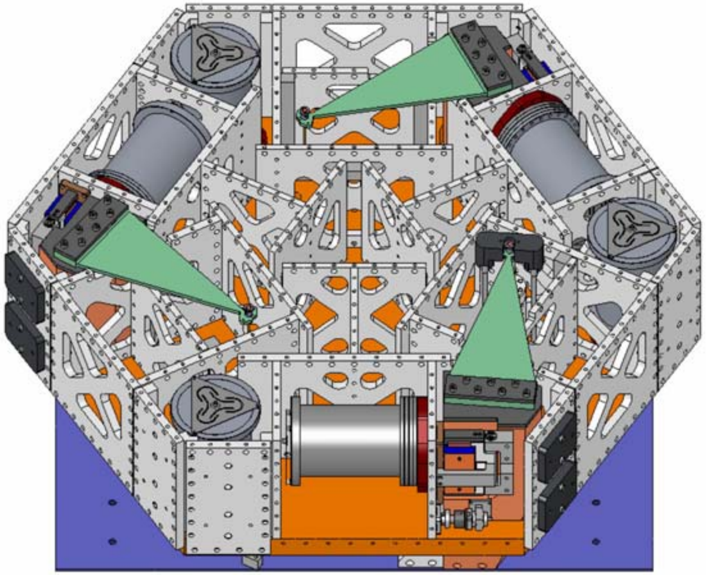


CAD view of isolation platform installed in the HAM chamber (CAD by HPD)

From Brian Lantz

Assembly in progress…





HPD and LIGO staff with the partially assembled table (Oct. 17)

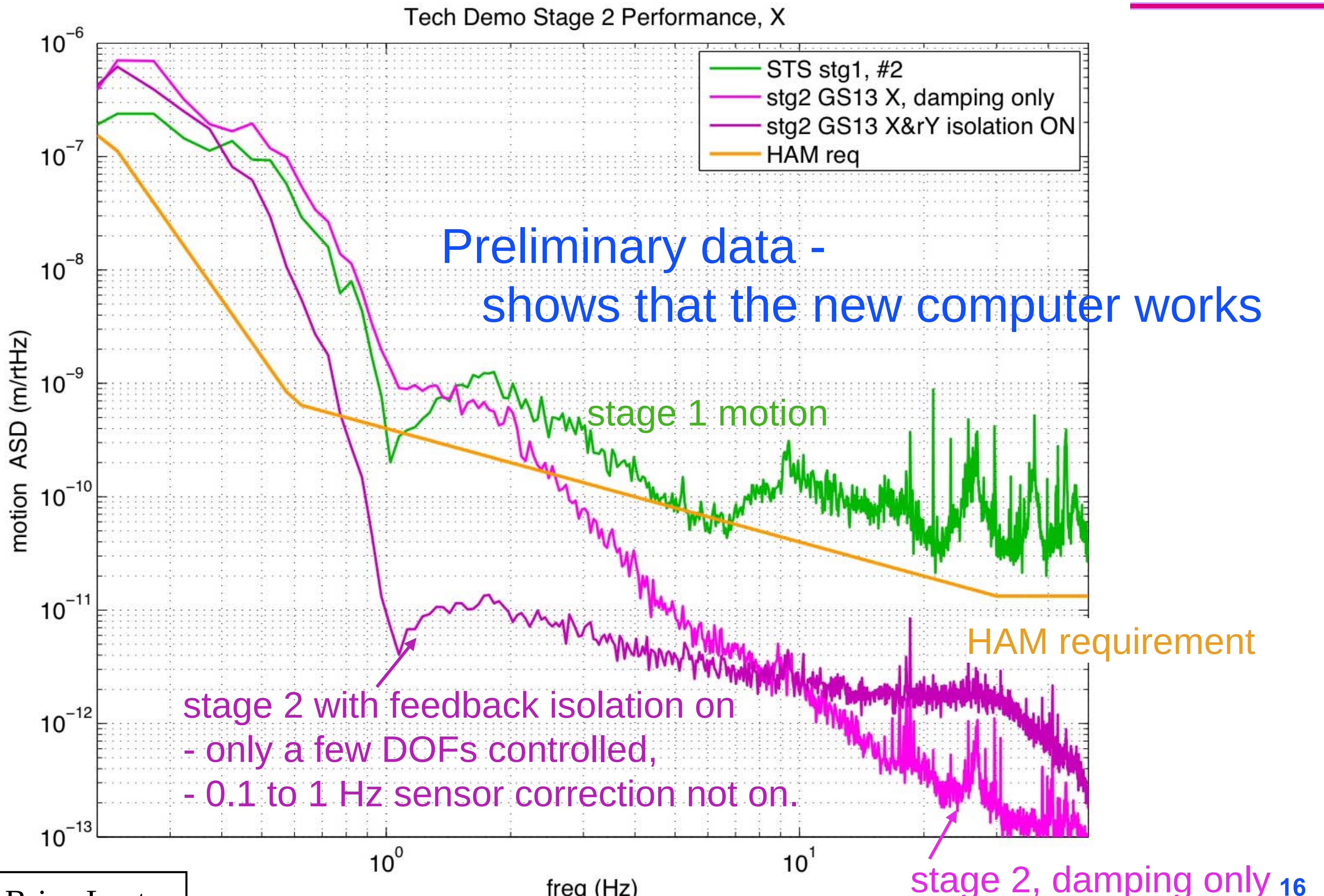
From Brian Lantz

Controls Development at Stanford

- Use the 2-stage tech demo to develop controllers for the Single-Stage HAM
- Make the first stage look (sort of) like the ground at Hanford (using the old control computer)
- Pretend that second stage is a Single-Stage HAM (they have the same sensors and similar dynamics)
- Use the new Advanced LIGO Control Computer to control the second stage.
- Goal: Streamline commissioning at the Observatories

From Brian Lantz

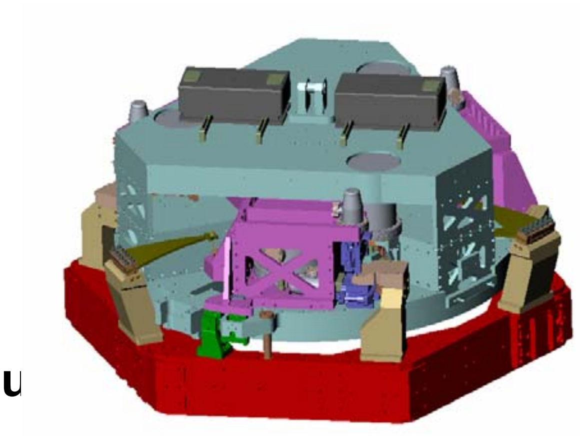
Controls Development at Stanford



From Brian Lantz

BSC ISI at LASTI - update

The BSC ISI is a two stage active internal seismic isolation system, currently being assembled and tested at LASTI

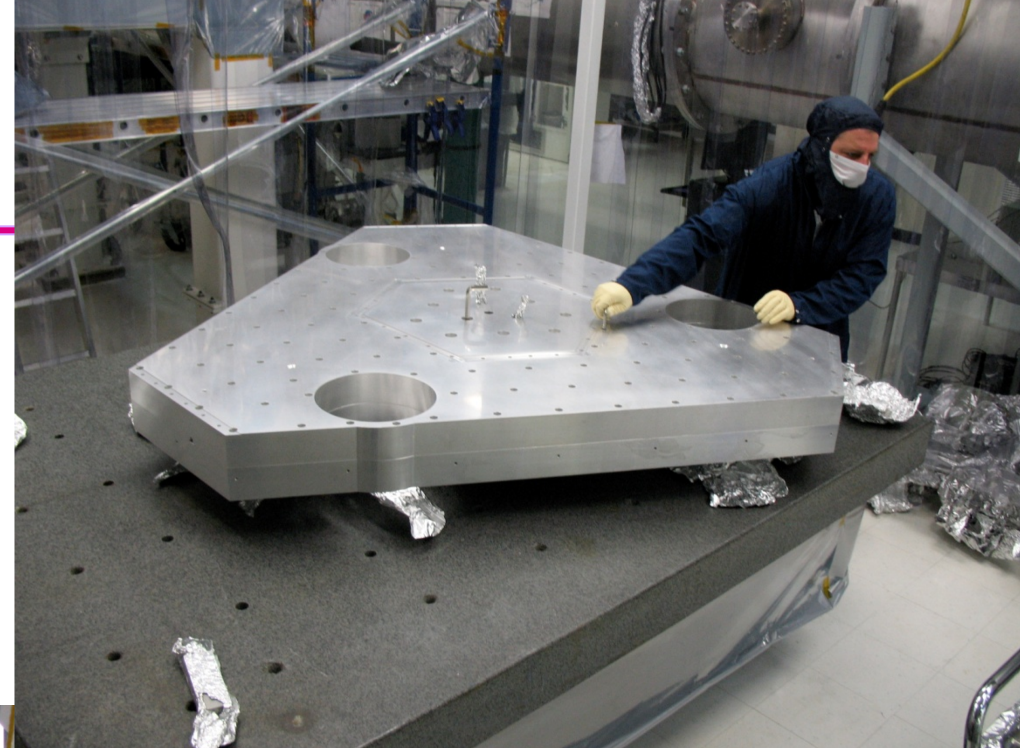


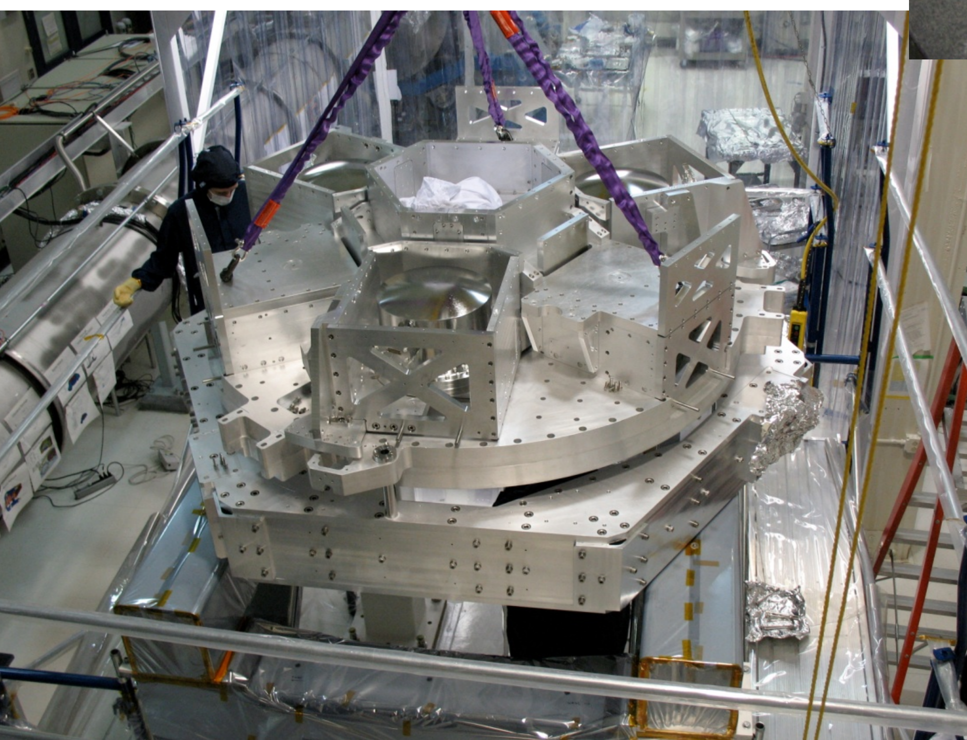
- All of the Hardware has been installed
- All of the sensors are running (one GS13 has a redu gain X10)
- Both platforms are floating and balanced (one corner of stage one has an odd load)
- We should hope to be driving the system by this week (10/22/07)
- The Noise Prototype Quad is on the optics table and free, we hope to have local damping soon
- We have generate a long list of *mostly* minor design changes (http://lhocds.ligo-wa.caltech.edu:8000/advligo/BSC_ISI_Design_Change_List)
- We are planning on inserting into the BSC in early December

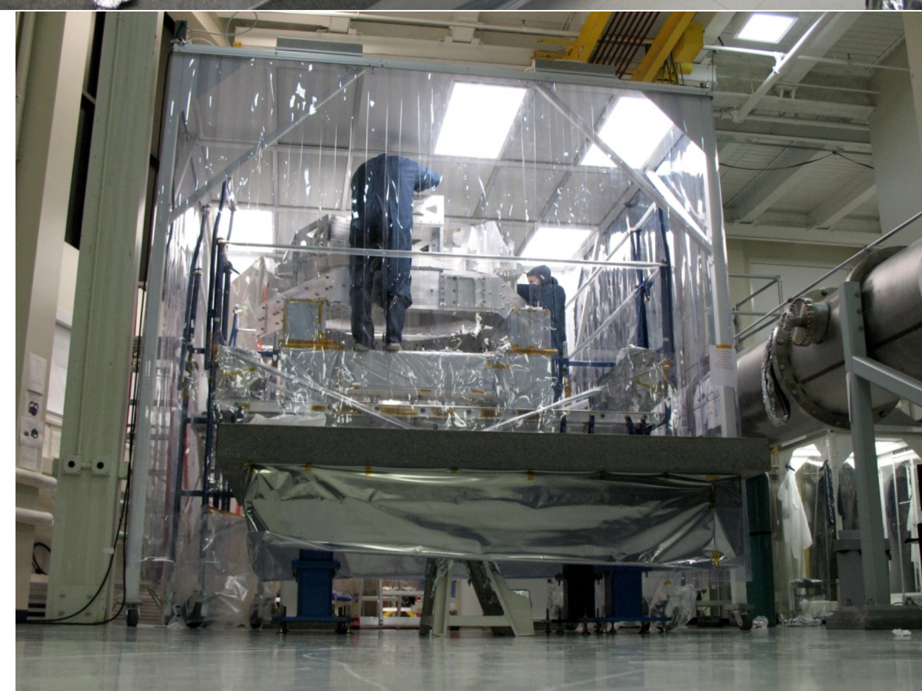
From Rich Mittleman

LIGO advancedligo

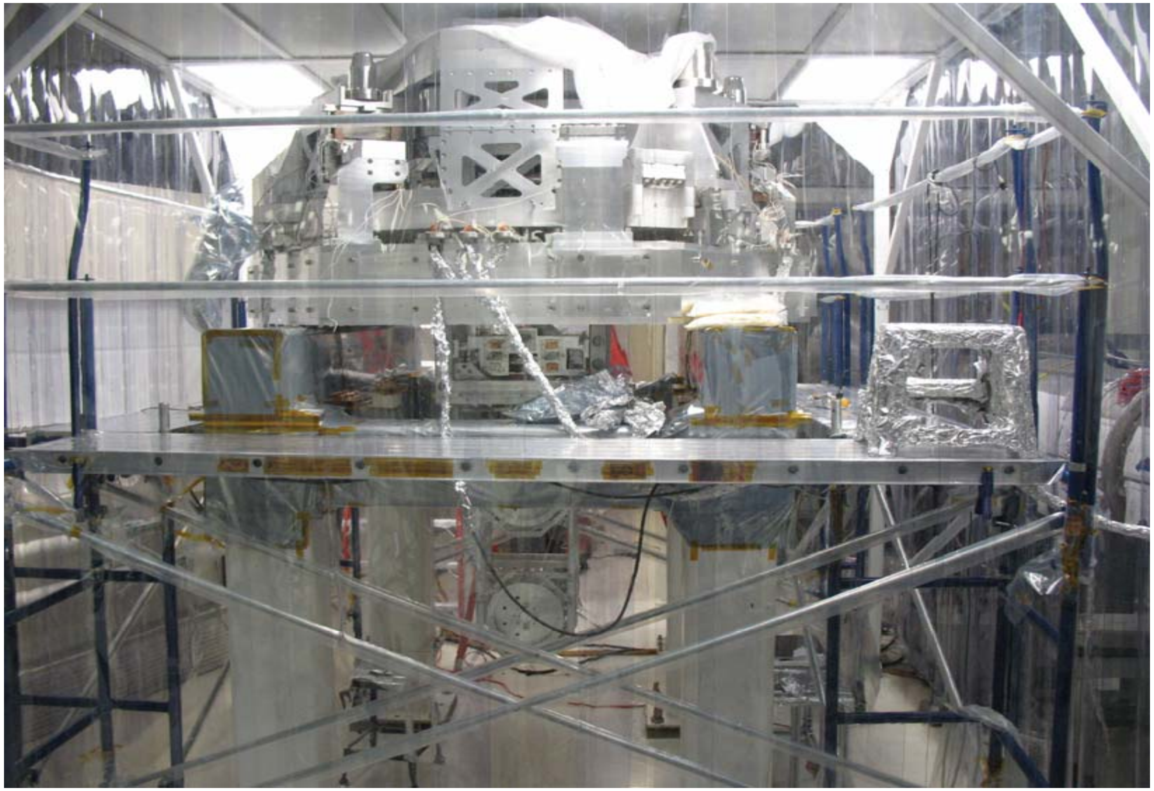
Assembly Pictures



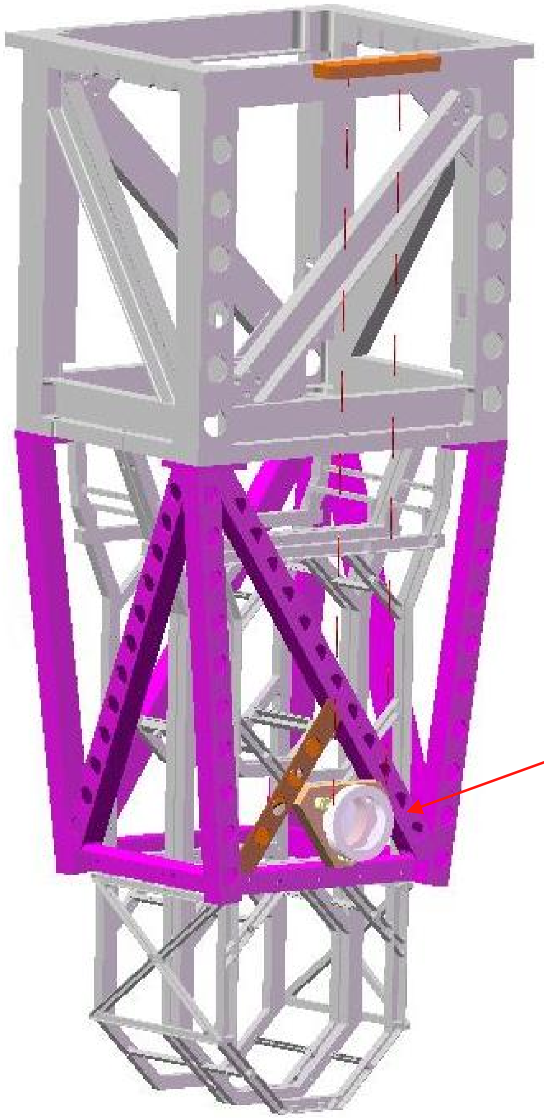




BSC ISI plus Quad at LASTI



Seismic Platform (Suspension Point) Interferometer (SPI)

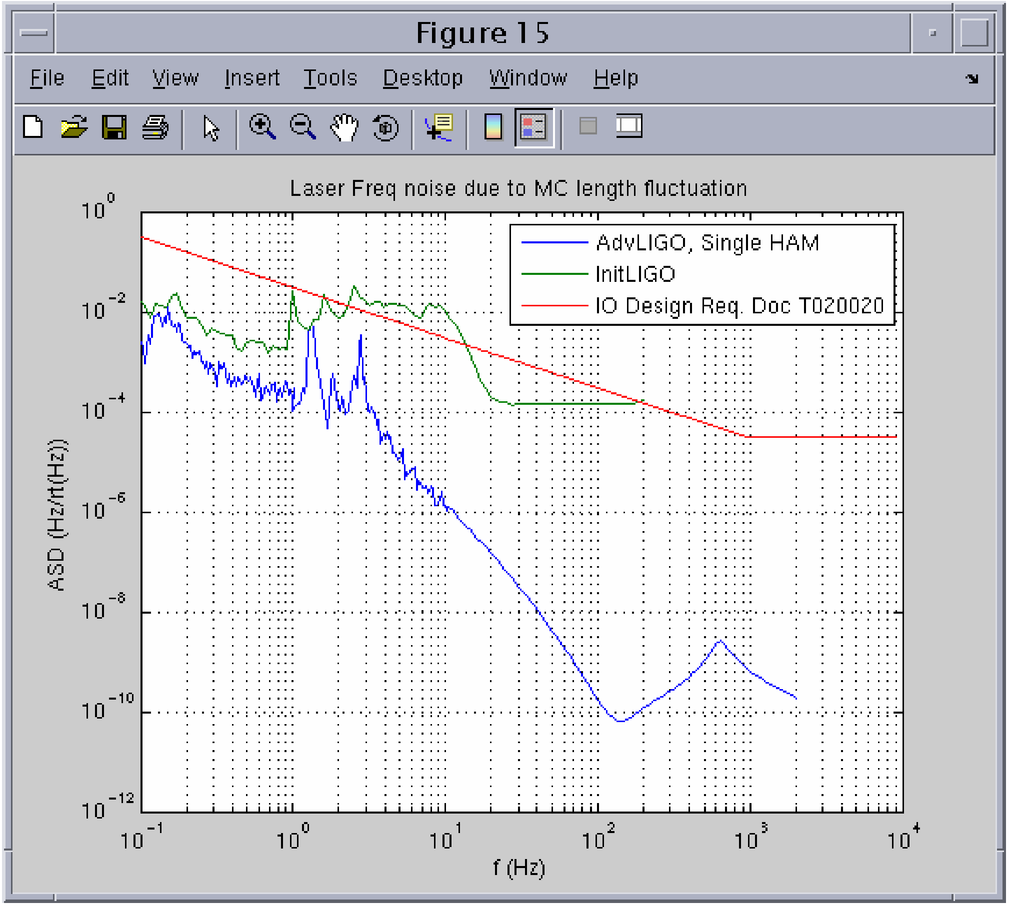


- Purpose: to reduce relative RMS motion of mirrors by a factor of ~ 100 (to ~ 1nm) – will ease locking
- Basic design: interferometer formed by mirrors suspended from the seismic isolation platform, adjacent to quad suspension structure
- Beams run between SPI optics suspended near the penultimate masses above the test masses on each arm
- Feedback to platform, UGF 8 Hz
- Further details on SPI wiki page

http://ilog.ligo-wa.caltech.edu:7285/advligo/SPI_SPI

From Matt Evans

End-to-End (e2e) Modelling



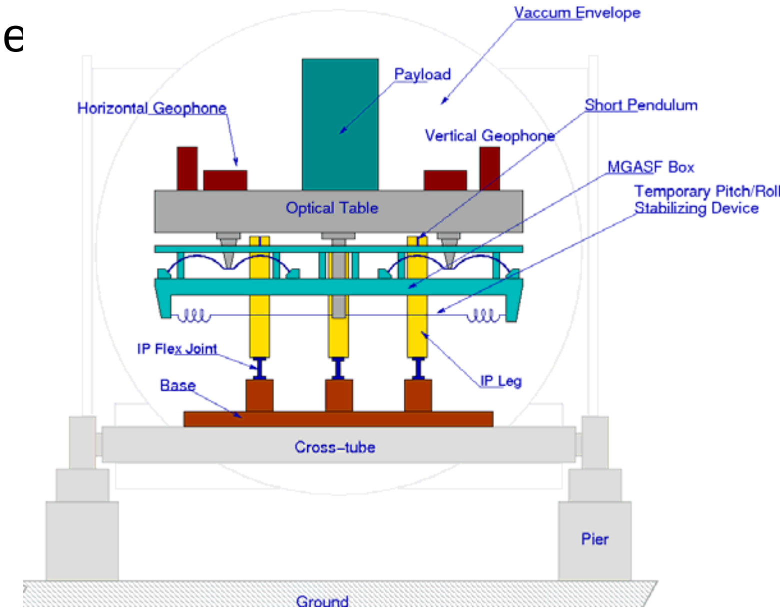
- Time domain simulations of Adv LIGO input optic subsystem
- Integrates seismic isolation and suspension models developed by SEI and SUS groups
- Shown here are optical frequency noise plots for input modecleaner, due to MC length fluctuations from seismic noise
- More details -

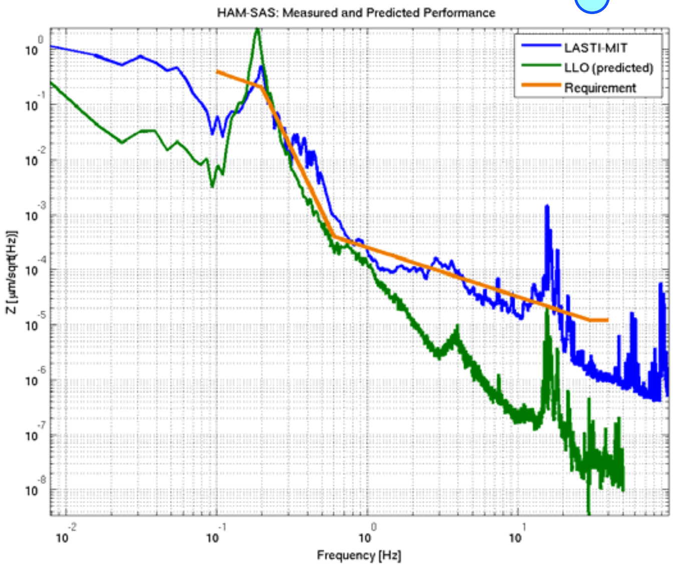
See talk by Sany Yoshida (Wed am)

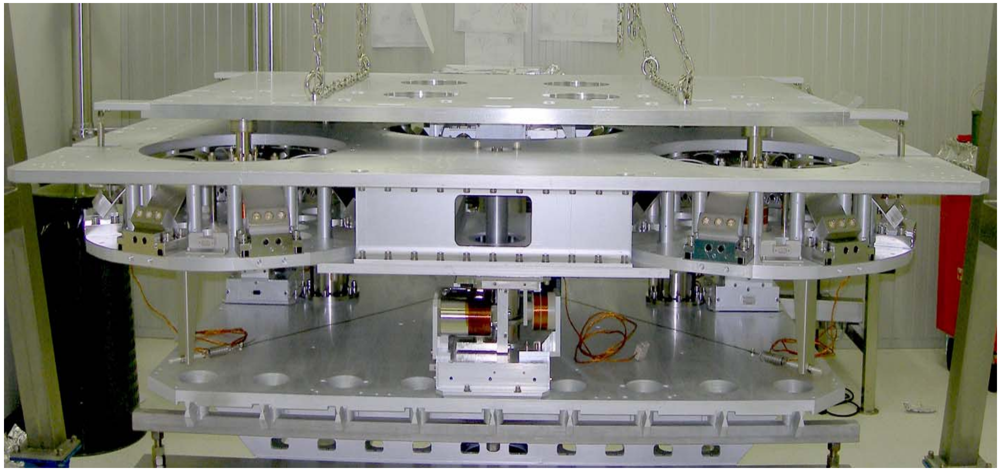
HAM-SAS work

- HAM-SAS was proposed as alternative to the single stage HAM ISI
- It underwent extensive testing at LASTI
- It was not selected: however useful lessons were learnt and experience gained
- For more details -

See talk by Riccardo DeSalvo (Wed am)







Summary: Current and Future Work in the SWG

- Enhanced LIGO:
  - » first application of a single stage active seismic isolation platform + double pendulum suspension for the output modecleaner
  - » possible upgrade to current test mass suspension design with redesigned break-offs
- Advanced LIGO:
  - » continuing development of designs and tests of seismic and suspension prototypes at LASTI
  - » suspension point interferometry development
- Beyond Advanced LIGO:
  - » research into lower loss suspensions, possibly cryogenic
  - » gravity gradient noise measurement/ suppression
  - » advanced seismometers to address tilt/horizontal coupling limitation to isolation system performance