Seismic isolation and suspension systems for Advanced LIGO

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Institutions

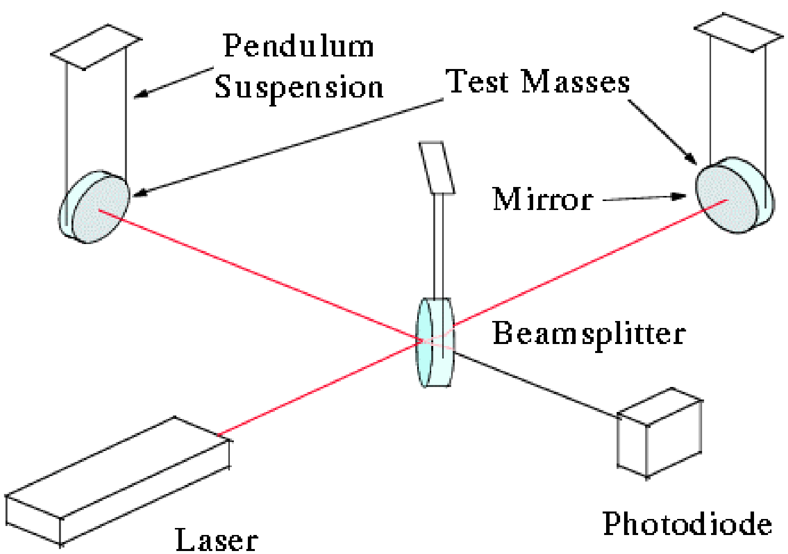
- Edward L Ginzton Laboratory, Stanford University
- Institute for Gravitational Research, University of Glasgow
- LIGO Laboratory, California Institute of Technology
- LIGO Livingston Observatory, Livingston
- LIGO Laboratory, Massachusetts Institute of Technology
- School of Physics and Astronomy, University of Birmingham
- LIGO Hanford Observatory, Richland, WA,
- Universitat Hannover, Institut für Atom und Molekülphysik
- Department of Physics and Astronomy, Louisiana State University
- Department of Aeronautics and Astronautics, Stanford University
- Engineering Department, Rutherford Appleton Laboratory
- Department of Physics and Applied Physics, University of Strathclyde

Outline

- Introduction: from LIGO to Advanced LIGO
  - isolation, alignment and suspension
- HEPI (Hydraulic External Pre-Isolator)
- Two stage Active Isolation Platform
- Quadruple Pendulum Suspension
- Conclusions and Future Work

Introduction: from LIGO to Advanced LIGO

LIGO Hanford Observatory

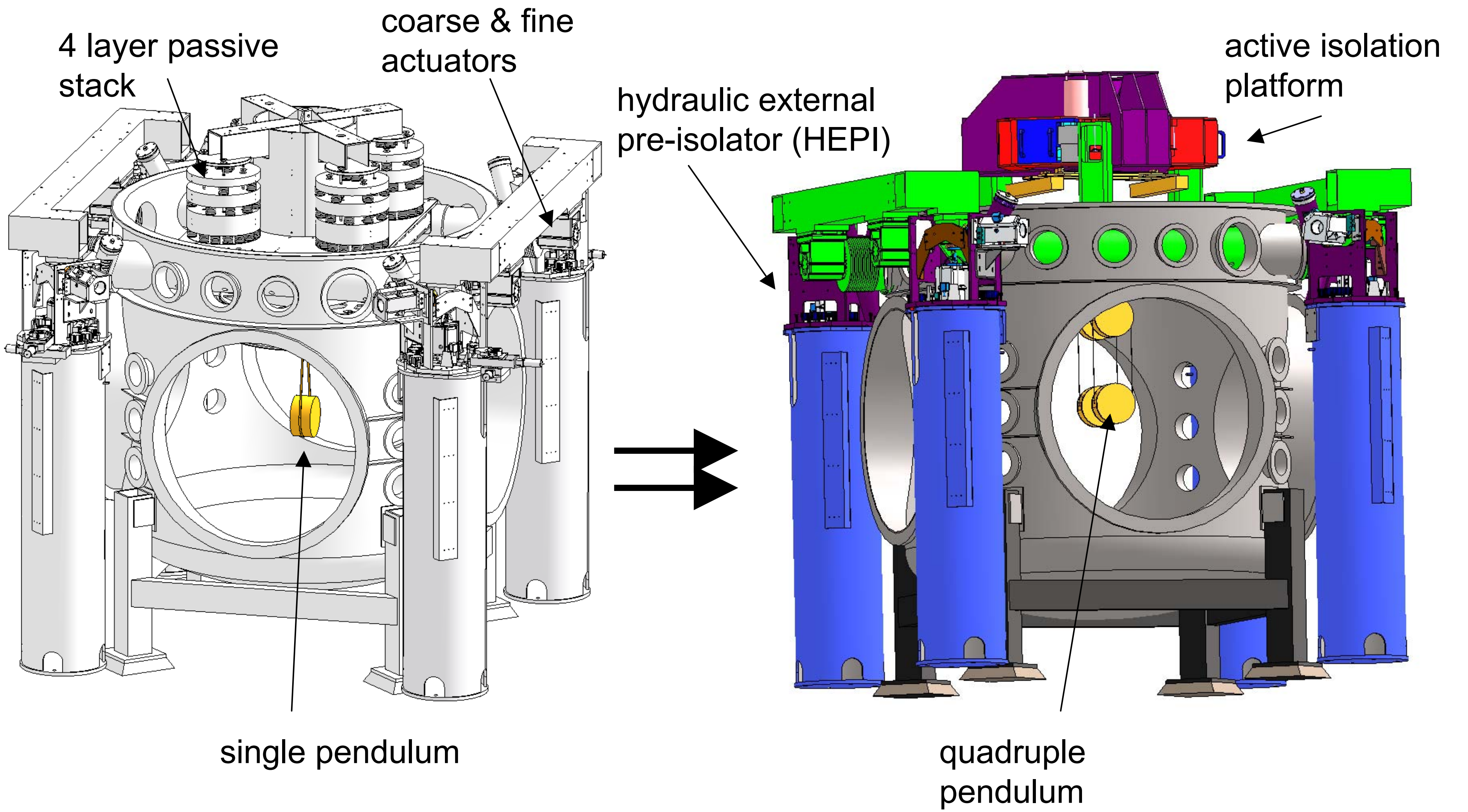


- Sensitivity of initial LIGO detectors is expected to be limited by:
  - suspension thermal noise in the region ~40 Hz to ~150 Hz
  - residual seismic noise below 40 Hz
- To improve the sensitivity in Advanced LIGO and extend working range down to ~10 Hz requires
  - reduction of suspension thermal noise
  - improvement in seismic isolation.

Advanced LIGO: Isolation, Alignment and Suspension

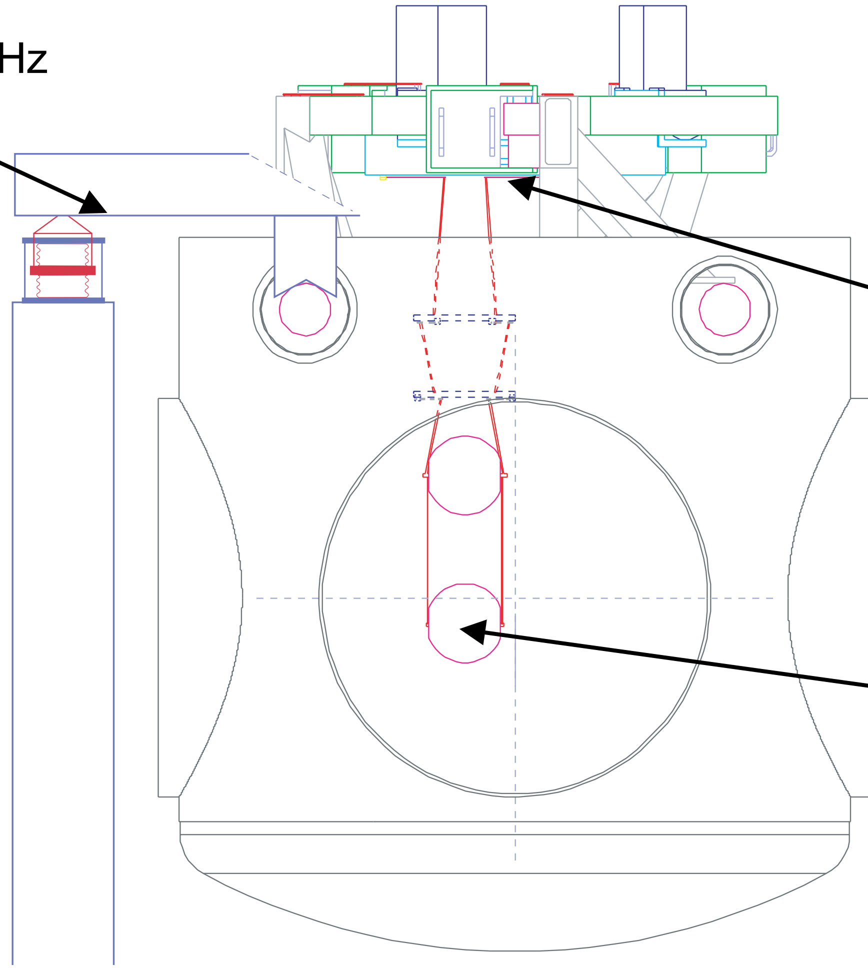
- To achieve the overall isolation, alignment and suspension requirements for Advanced LIGO, we are developing three sub-systems:
  - a hydraulic external pre-isolator system (HEPI) for low frequency alignment and control, outside the vacuum system
  - a two-stage in-vacuum active isolation platform designed to give a factor of ~1000 attenuation at 10 Hz
  - a quadruple pendulum suspension system that provides passive isolation above a few hertz, and minimizes suspension thermal noise by using silica ribbons in the final stage.

From Initial to Advanced LIGO



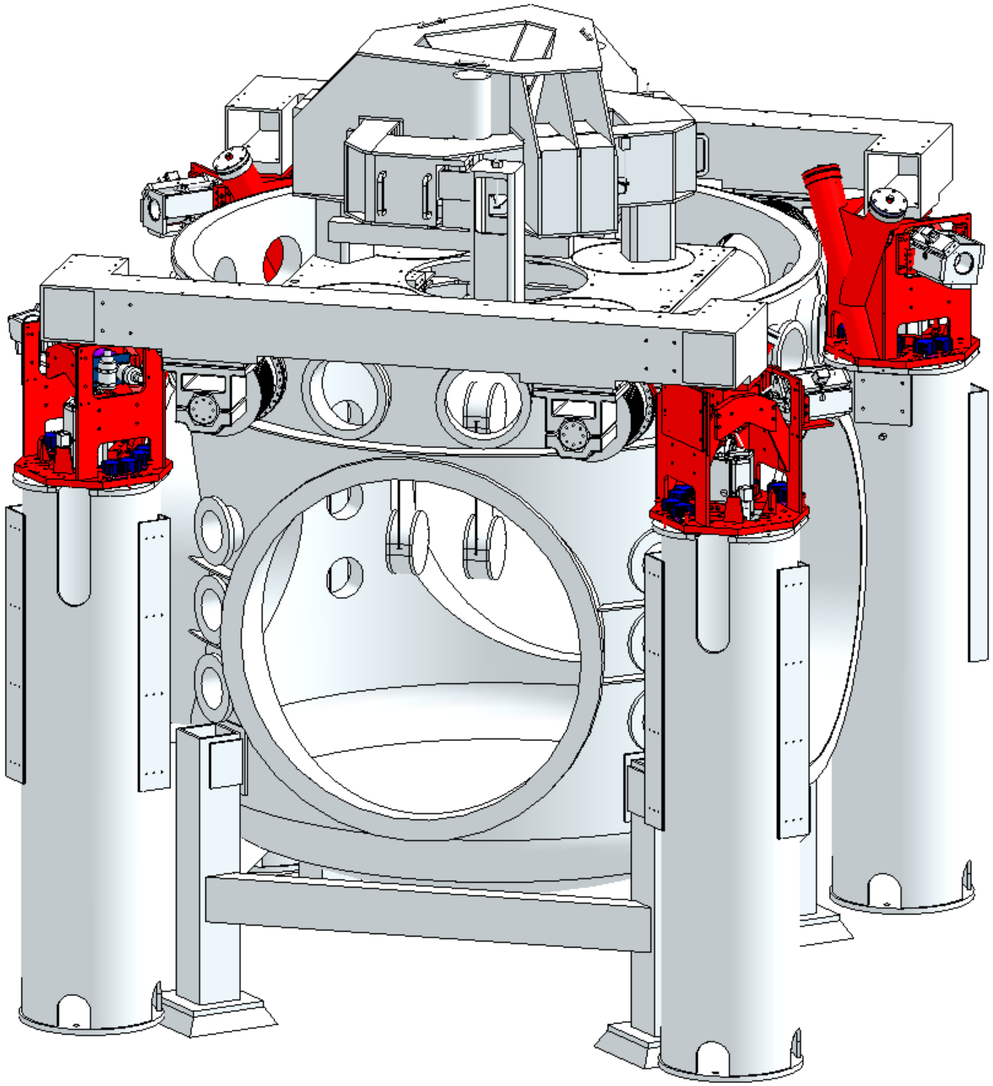
Corwin Hardham

Requirements for Advanced LIGO

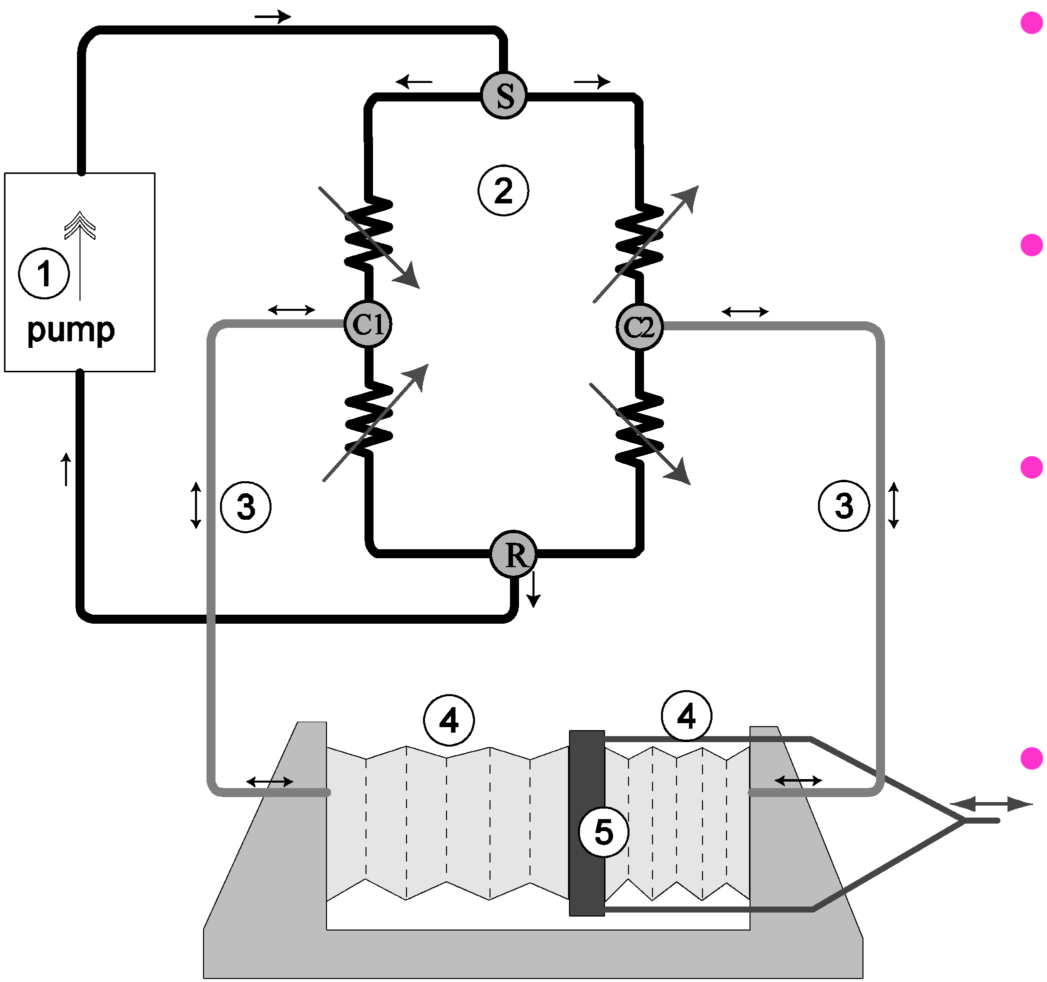


Seismic noise at sites:
a few x 10^{-6} m/ √ Hz at microseismic frequency (~0.15 Hz)
~4 x 10^{-10} m/ √ Hz at 10 Hz

Hydraulic External Pre-Isolator (HEPI)

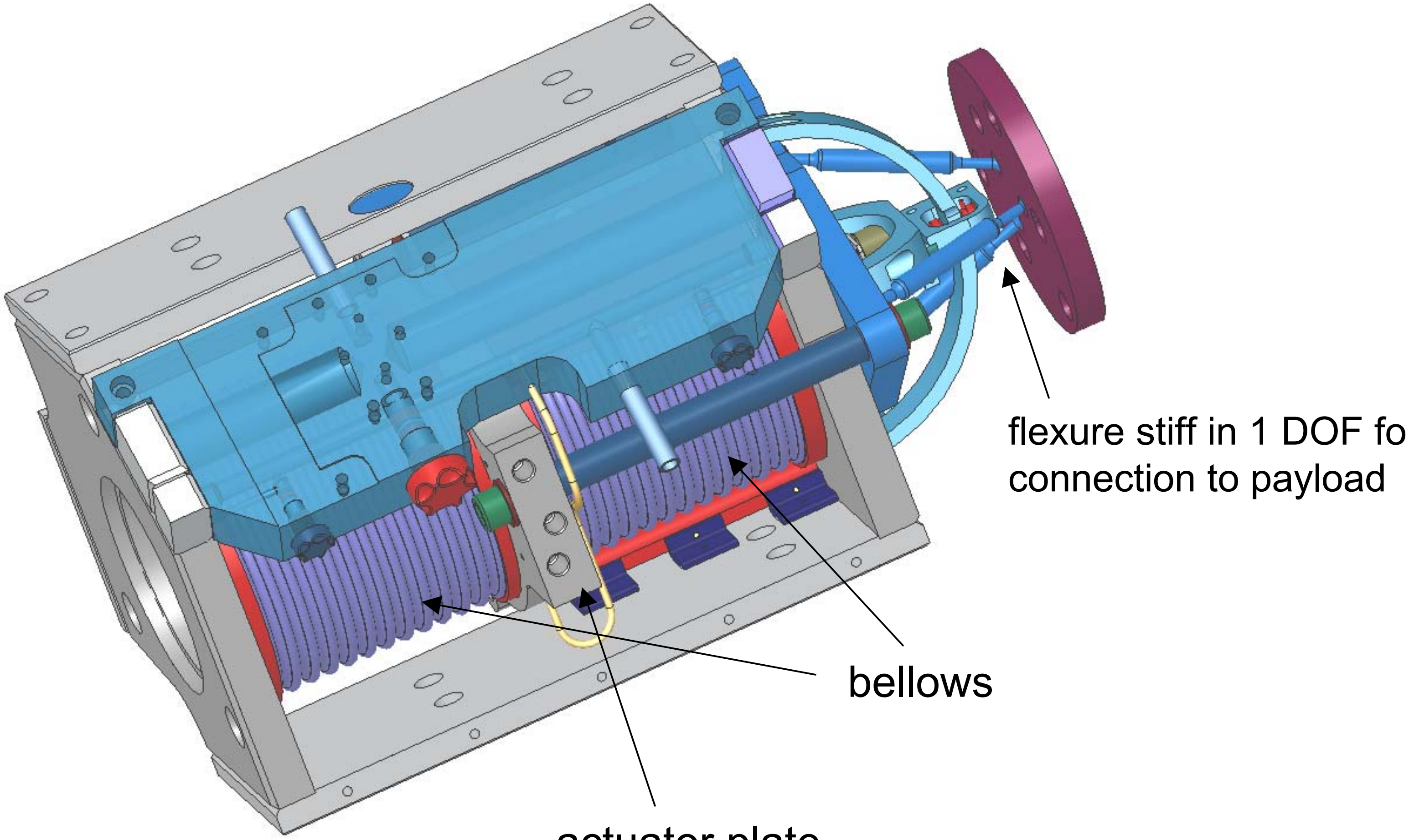


HEPI – principle of operation

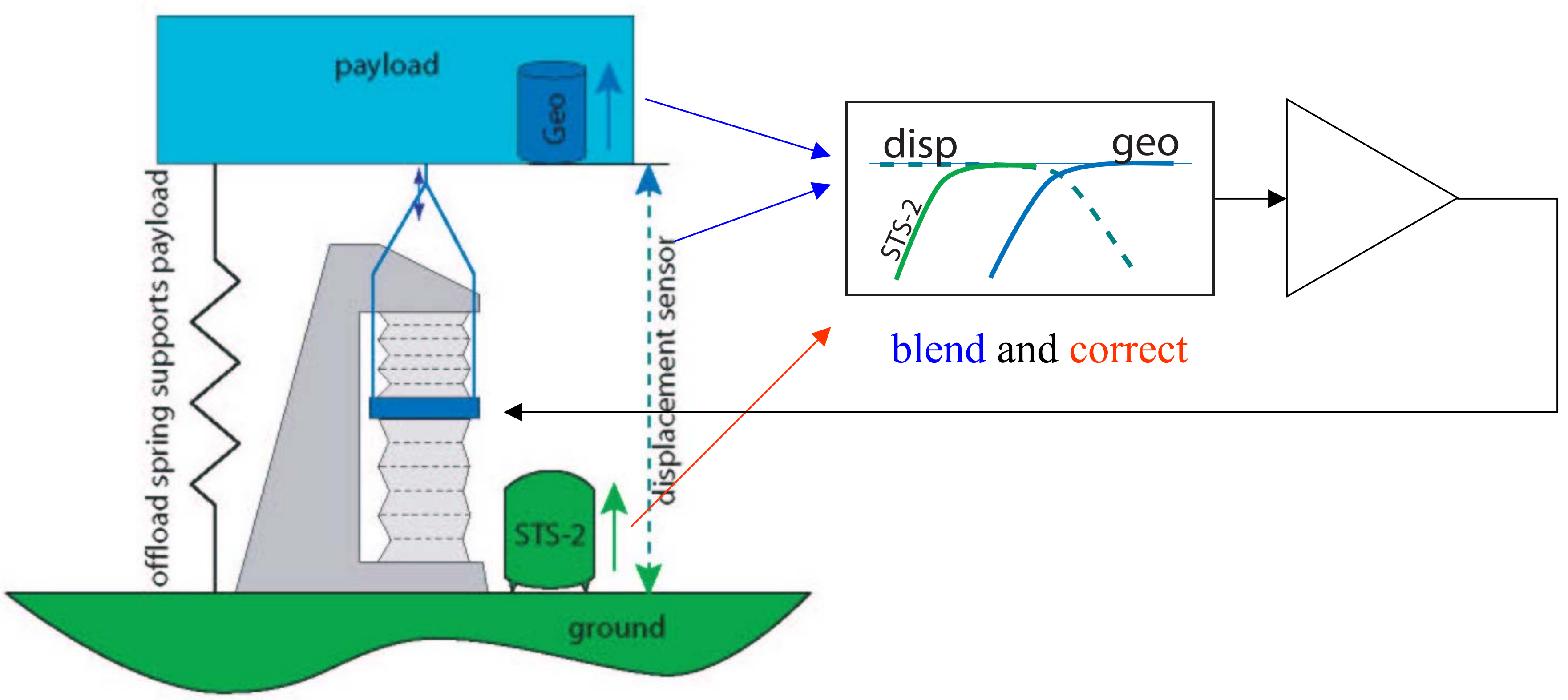


- The pump, (1), supplies a constant flow of fluid through the actuator.
- This fluid flows through the hydraulic equivalent of a Wheatstone bridge (2).
- Differential pressure is generated across the bridge, which modifies the flow, (3), to the bellows (4).
- The bellows act as a piston which moves the actuator plate, (5), connected to the payload.

Schematic of HEPI unit



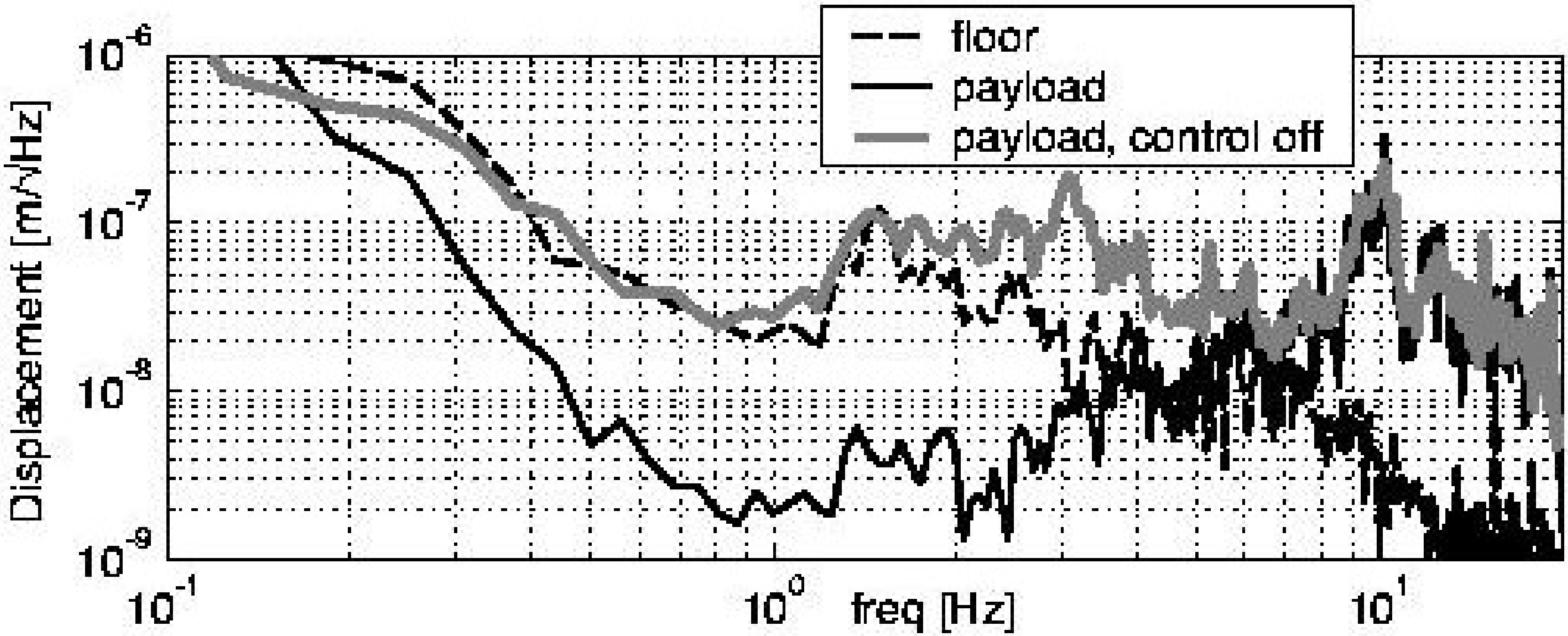
HEPI – principle of operation contd.



Sensor blending - "supersensor" from blending relative displacement sensor + "Geo" seismometer -> control position at low frequency and gain isolation at higher frequencies

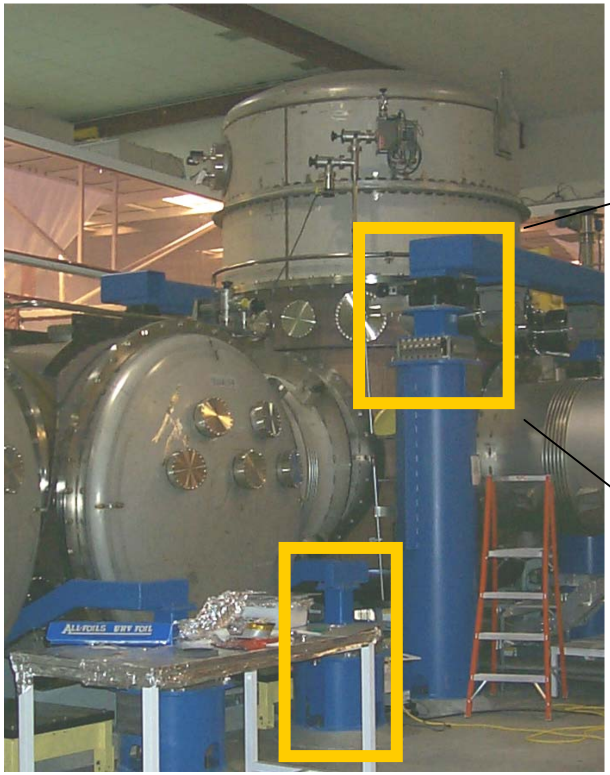
Sensor correction - add signal from ground-mounted seismometer (STS-2) to displacement sensor signal and gain lower frequency isolation

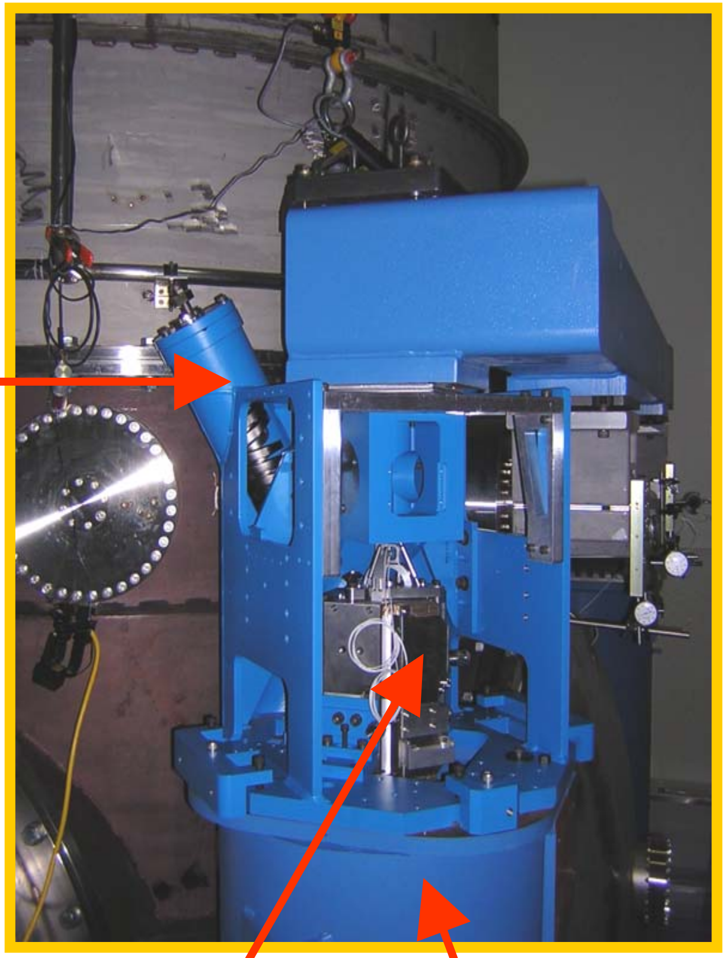
Performance of the prototype HEPI system



- Horizontal (beam direction) motion at the payload, with and without the noise-reduction system.
- A factor of approximately 10 noise reduction is seen over the band 0.5 – 2 Hz (performance measured at MIT test facility)

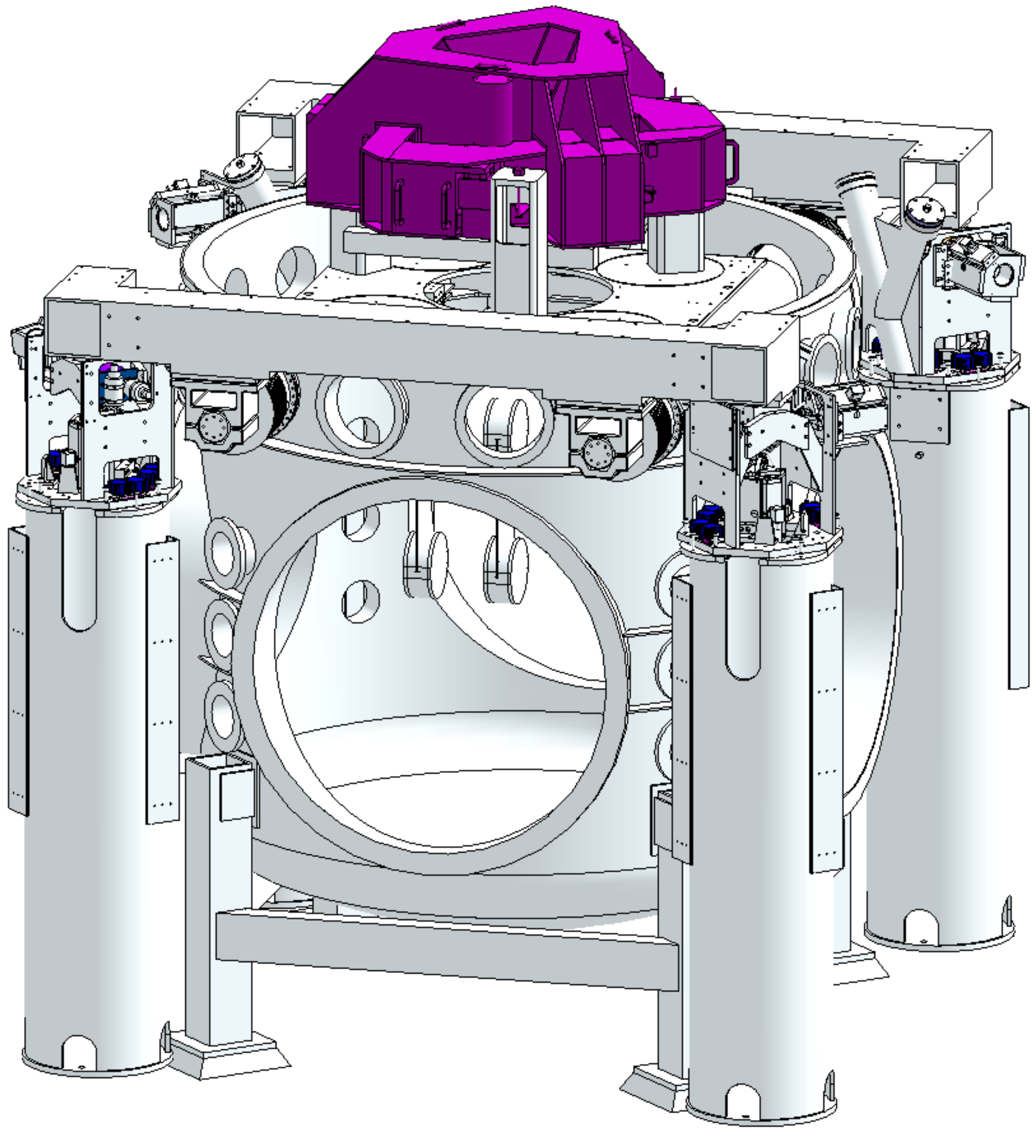
HEPI Installation at LIGO Livingston



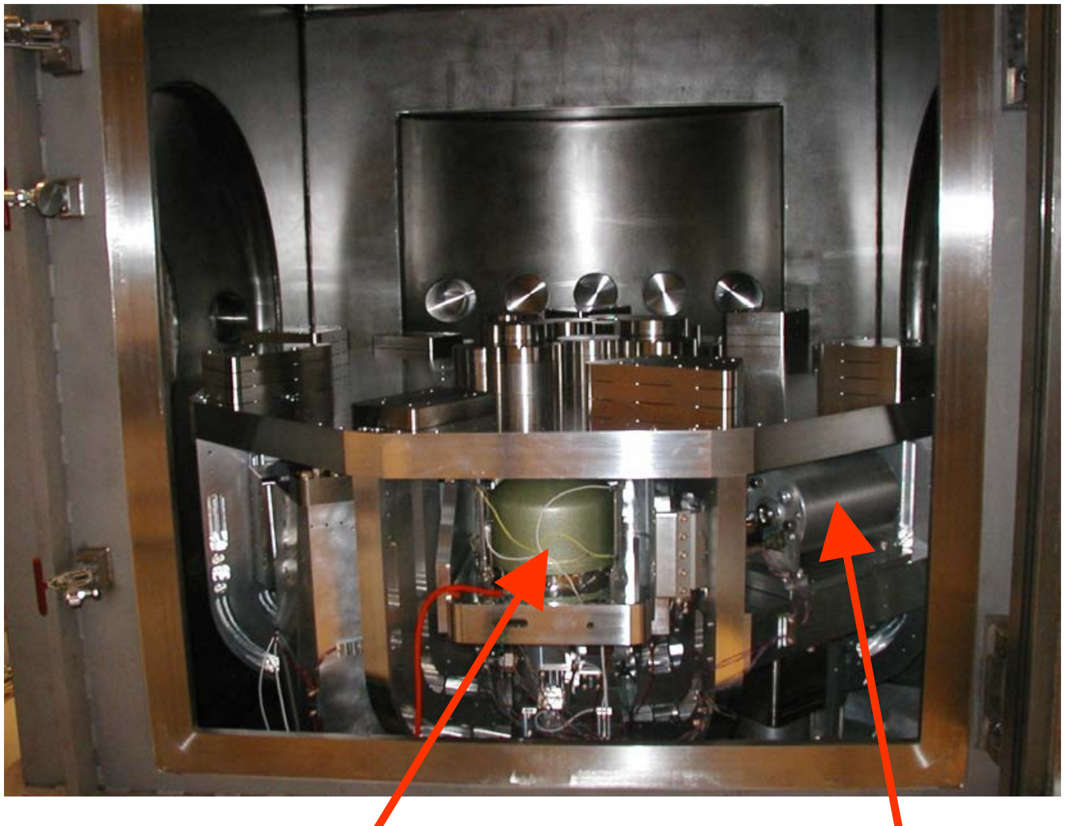


- Retrofit at LIGO Livingston to allow reliable operation during high-noise periods of excess ground motion due to human activity
- Replacement of the coarse and fine actuators (indicated in yellow above) with HEPI units
- Installation *without* opening the chambers.

2-Stage Active Isolation Platform



2-stage Active Platform Development: Technology Demonstrator at Stanford

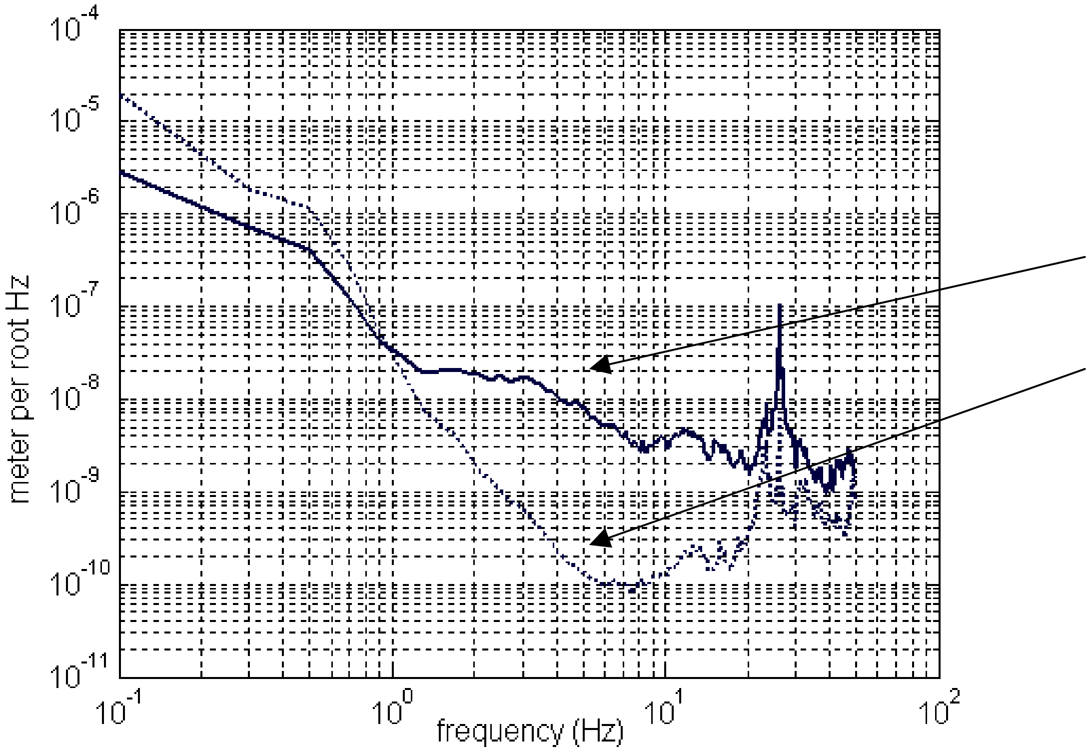


STS-2 seismometer on stage 1

GS-13 geophone on stage 2

- Two cascaded stages, suspended through stiff blade springs and short pendulum links: natural frequencies in range 2-10 Hz
- Active isolation by sensing motion in 6 degrees of freedom (DOF) and applying suitable forces via feedback loops using sensor blending and correction (27 for full control)
- First stage feedback signal derived by blending signals from three sensors for each DOF
  - long-period broadband seismometer (Streckeisen STS-2)
  - short-period geophone
  - relative position sensor.
- Second stage uses a GS-13 (Geotech Instruments) low-noise geophone and relative position sensor for each DOF.
- Actuators are electromagnetic non-contacting forcers, which apply forces between adjacent stages

Preliminary results from technology demonstrator



noise level on the ground in a horizontal direction

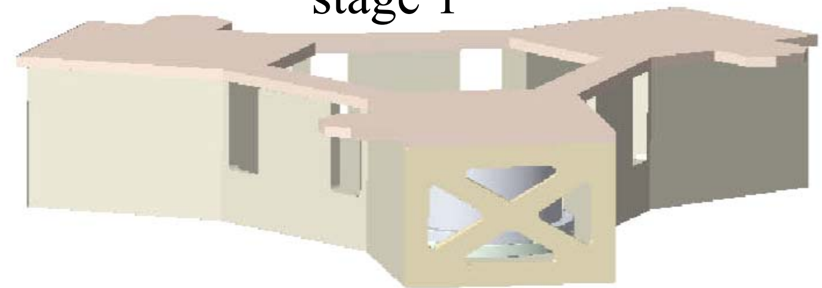
residual noise on stage 1 of the platform.

(The blend frequency used was 0.5 Hz)

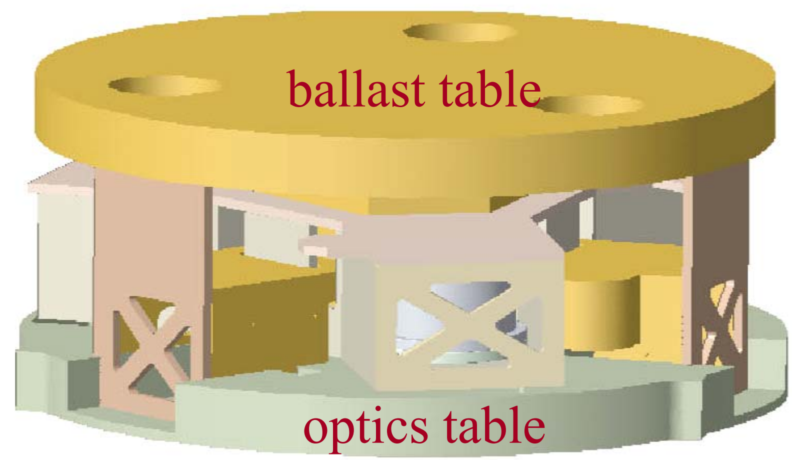
- Result shown for one horizontal direction on stage 1- other horizontal direction and vertical direction are similar
- Isolation is obtained above 1 Hz (sensor correction not yet implemented)
- At ~10 Hz there is an isolation factor of approximately 30

New prototype for MIT test facility

stage 1



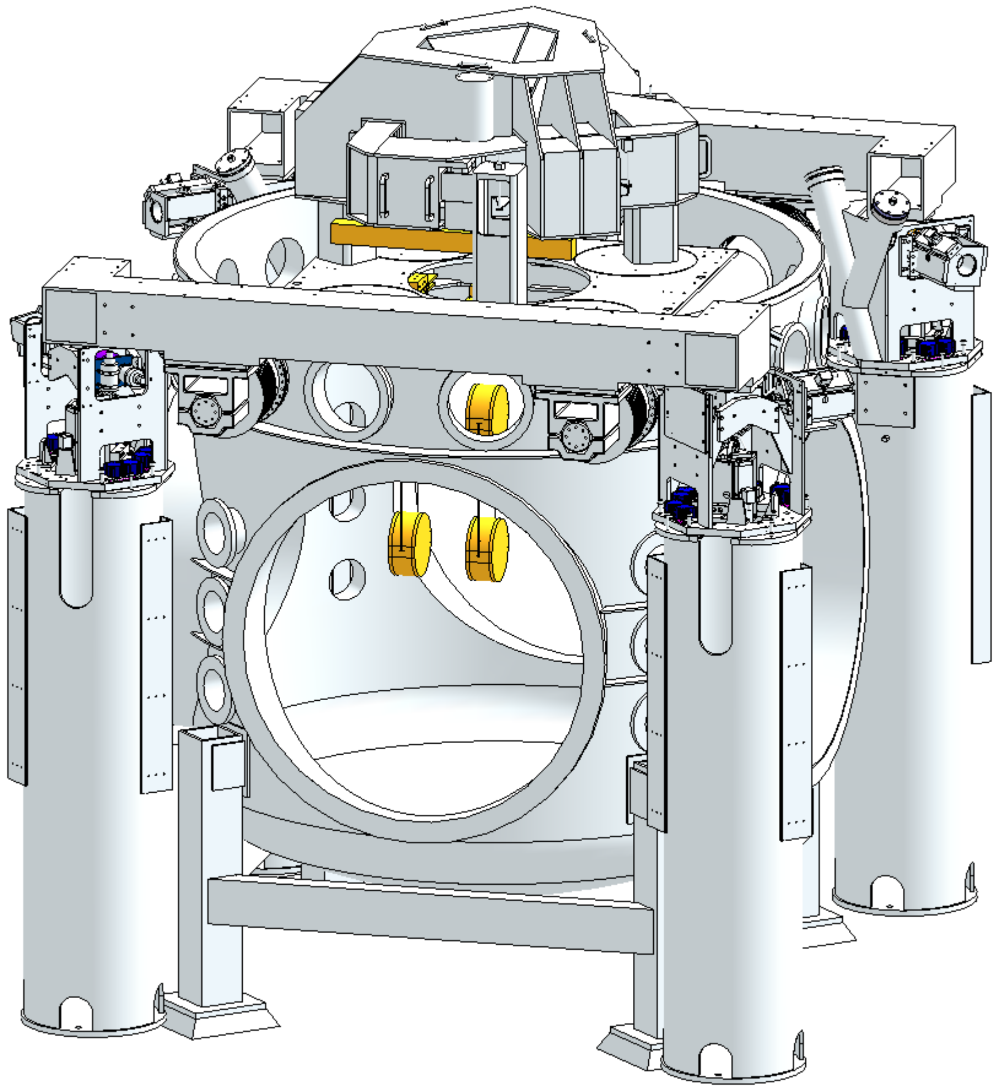
stage 1 and stage 2



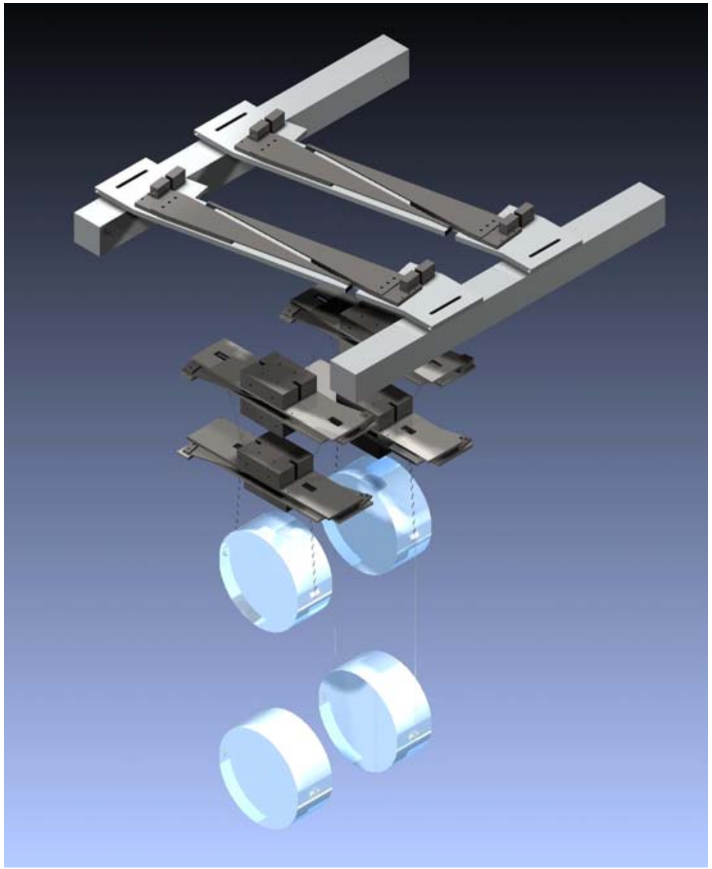
design by
Alliance Space-systems Inc. (ASI)

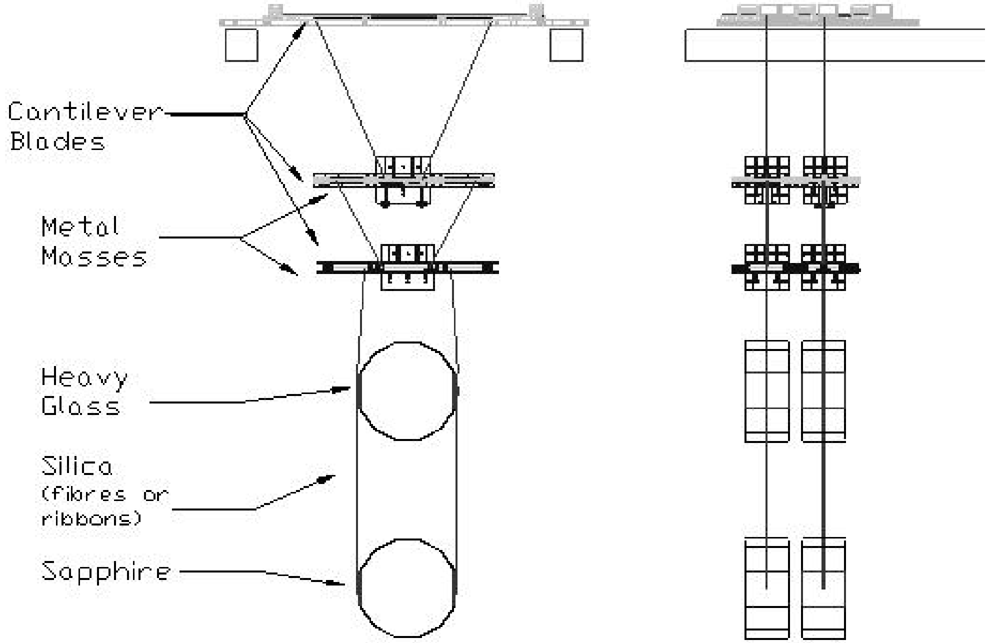
pictures are views from ASI e-drawing bsc_configuration_v1.easm.exe

Quadruple Pendulum Suspension



Quadruple Pendulum Suspension

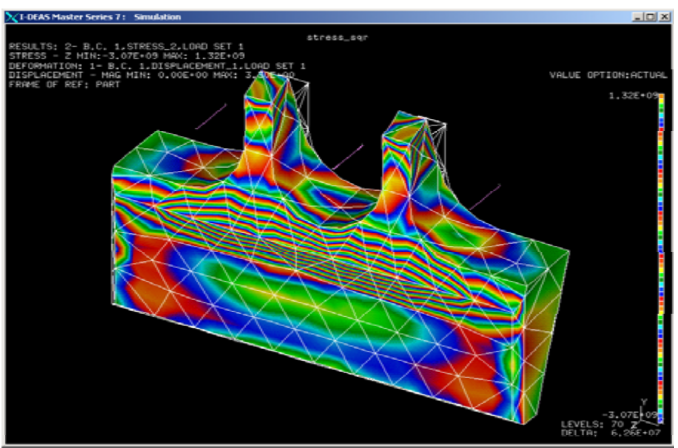




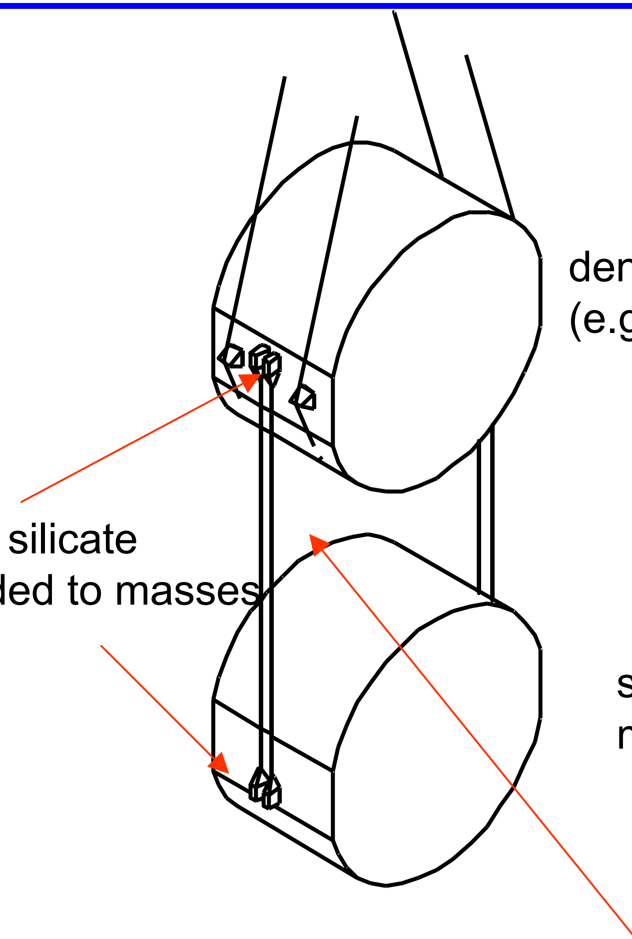
- 4 stages for passive isolation, 3 with cantilever blade springs for enhanced vertical isolation
- Final stage on silica suspension (see overleaf)
- Damping of low frequency modes using 6 co-located sensors and actuators at highest mass, may be supplemented by eddy current damping. Development of low-noise sensor design and control strategy underway
- Global longitudinal forces applied via a quiet reaction pendulum

Final stage suspension design

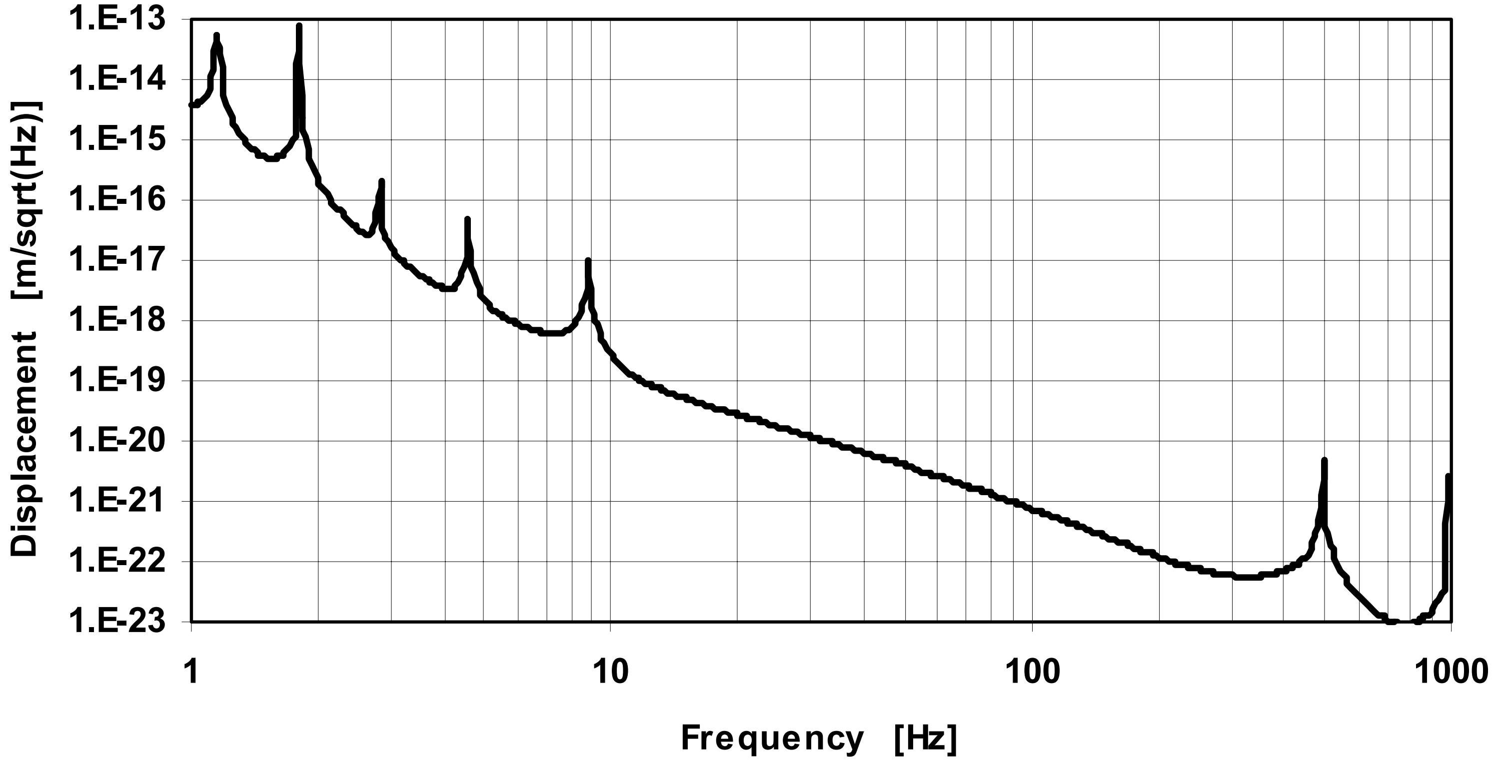
- Developed from GEO 600 triple suspension design
- Research on quality factors of ribbons: currently Q~1.4x10^8 measured at Glasgow for pendulum and violin modes
- Research on ear design (see below) for required mechanical strength while minimising thermal noise associated with bond



Stress in a finite element model of a GEO ear under load. Closely spaced contours show rapidly varying stress which typically occurs at regions of high stress.



Suspension Thermal Noise Spectrum

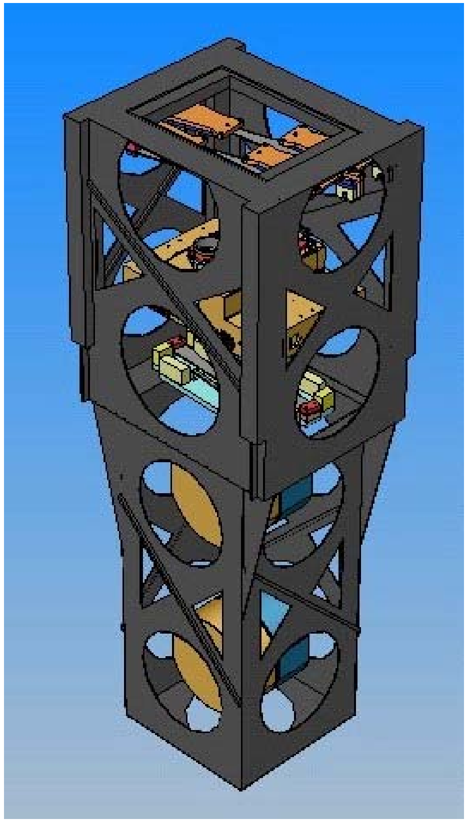


Estimate of suspension thermal noise for quadruple pendulum suspension

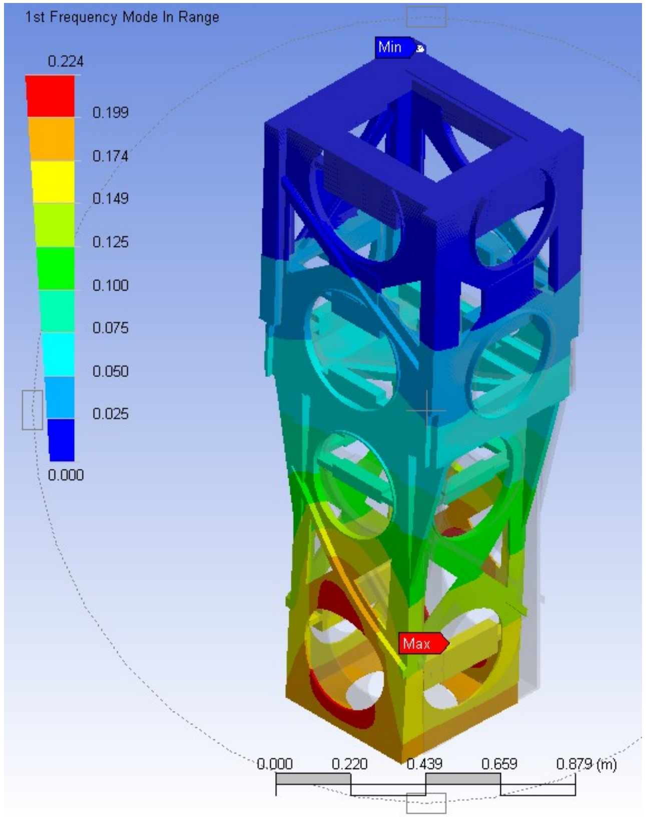
Masses: 22 kg, 22 kg, 40 kg, 40 kg (top to bottom).
Suspension: four 60 cm silica ribbons of dimensions 1.1 mm x 0.11 mm.

G Cagnoli

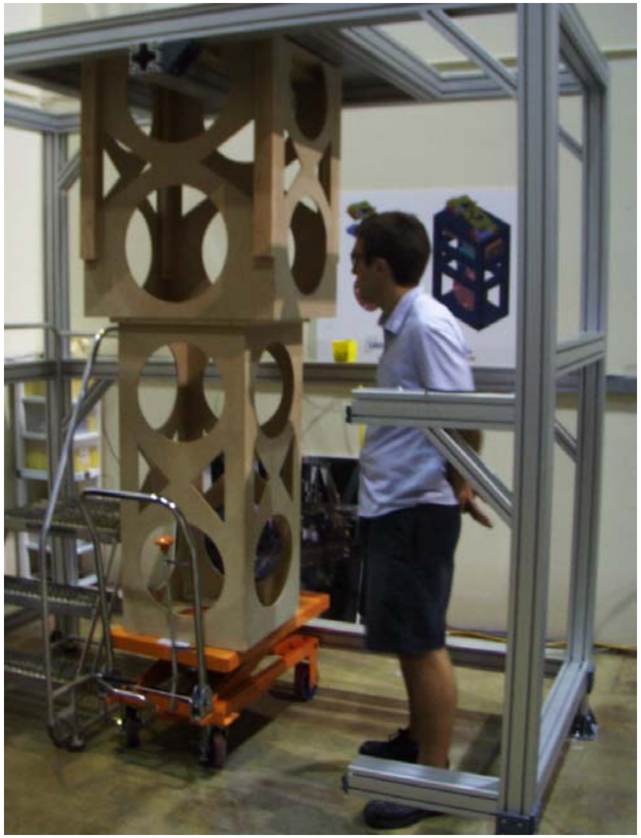
Quad Support Structure



Conceptual design for supporting structure around quad pendulum



Study of resonances of structure:
1st mode 120 Hz



Lightweight prototype of structure

Manipulation of 40 kg masses

Dummy steel/aluminium mass, held by vacuum, being manoeuvred by ergonomic arm

Prototype of penultimate and test mass being assembled at Caltech

Conclusions and Future Work

- Prototypes of all sub-systems already constructed or underway and initial results obtained. R and D continuing at many institutions in USA and UK, funded by NSF, PPARC and local institutions.
- HEPI system currently being installed at the LIGO Livingston site - expected to be in operation later this year. Another is being fitted into a LIGO-sized test chamber at MIT.
- Technology demonstrator active isolation platform currently under development and testing at Stanford. A new prototype, essentially the Advanced LIGO design, is currently under construction: delivery to MIT due ~end of 2004.
- All metal quadruple pendulum prototype under construction at Caltech - to be installed at MIT early 2005.
- Thereafter testing of overall alignment, isolation and suspension system and continuing development work