LIGO ADVANCED SYSTEMS TEST INTERFEROMETER (LASTI)

Program Update:

- Advanced LIGO Isolation & Suspension Research
- Initial LIGO Seismic Remediation Development

12th LIGO PAC Meeting @MIT

M. Zucker

27 June, 2002

LIGO

LASTI Mission

- Test LIGO components & systems at full mechanical scale
- Practice installation & commissioning
- Minimize delays & downtime for advanced LIGO upgrades
- *Qualify design mods & retrofits for initial LIGO*

Specific Advanced LIGO Program Tasks (‘01 - ‘06+):

- Qualify advanced isolation & suspension systems and associated controls at full scale
- Develop detailed SEI/SUS installation & commissioning handbook
- Look for unforeseen interactions & excess displacement noise
- Test LASER and Input Mode Cleaner together at full power

LIGO

LASTI People

Resident MIT Staff

- Students - Jamie Rollins, Keisuke Goda, Meg Goldman
- Engineering - Myron MacInnis, Ken Mason, Ralph Burgess
- Tech support - Fred Miller, Bob LaLiberte
- Scientists - Gregg Harry, Rich Mittleman, Dave Ottaway, David Shoemaker, Mike Zucker

Laboratory and LSC Visitors (to date)

- Initial SEI & SUS- Corey Gray, Hugh Radkins, Gary Traylor, Harry Overmier, Betsy Bland
- Advanced SEI - Joe Giaime, Giles Hammond, Brian Lantz, Wensheng Hua, Tuck Stebbins
- Advanced SUS - Norna Robertson, Calum Torrie, Janeen Romie, Phil Willems, Mark Barton
- CDS/DAQ - Jay Heefner, Rus Wooley, Rick Karwoski, Paul Russel

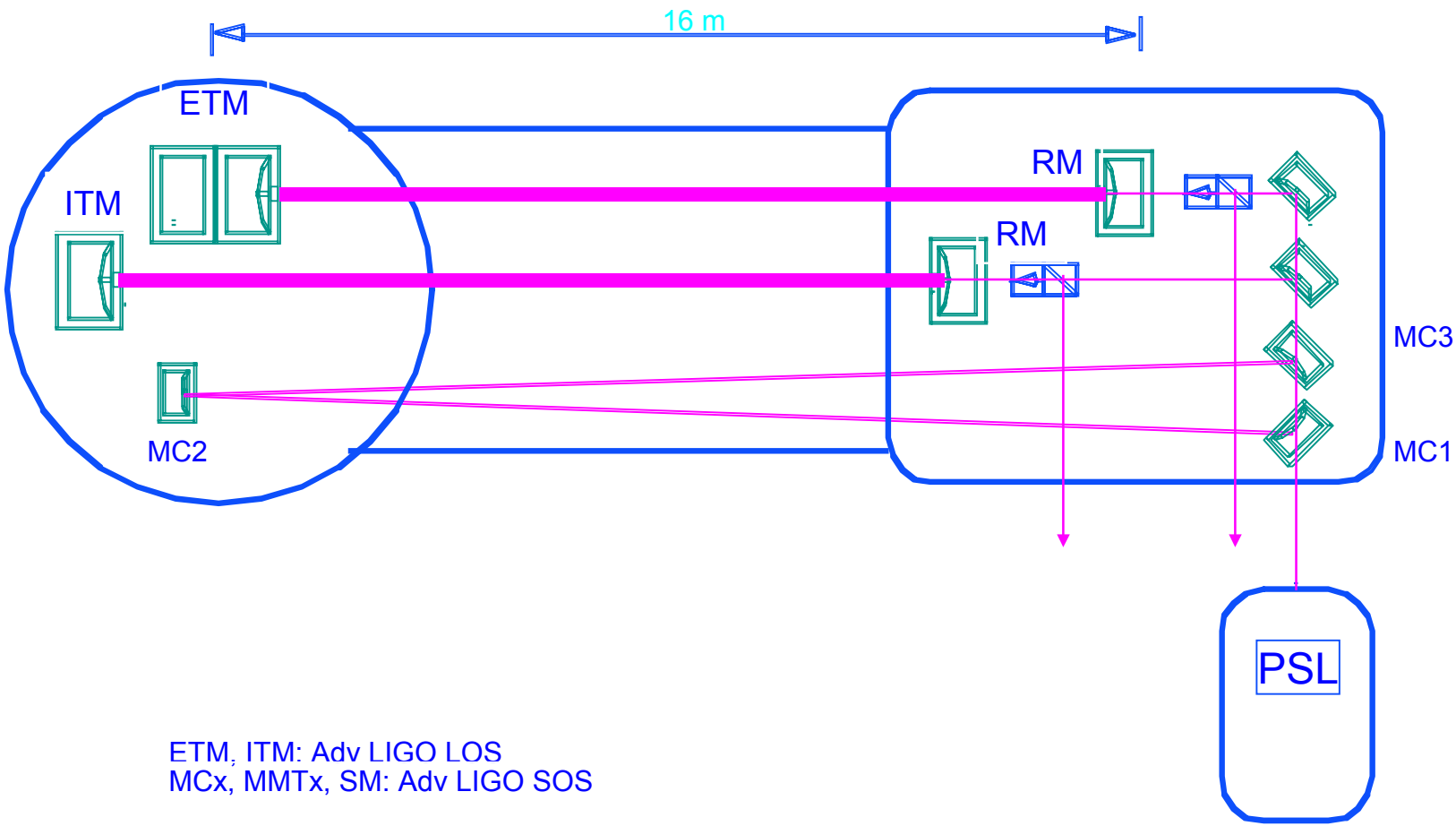
LIGO

LASTI Advanced LIGO R&D Program

- Commission infrastructure (vacuum, cleanrooms, cranes…) ✓
- Commission PSL & controls ✓
- Commission initial seismic stack, suspensions & 1m test cavity in HAM chamber ✓
- 🡻 Develop & test EPI for LLO seismic remediation
- 🡻 Qualification test of early pre-prototype triple pendulum
- Integrate/test active HAM SEI pathfinder
- Integrate/test active BSC SEI pathfinder
- Integrate/test Quad and Triple suspensions
- Integrate/test sapphire & fused silica core optics
- Qualify for low displacement noise with sensitive interferometer system
- Integrate/test AdLIGO 180 Watt PSL & Mode Cleaner

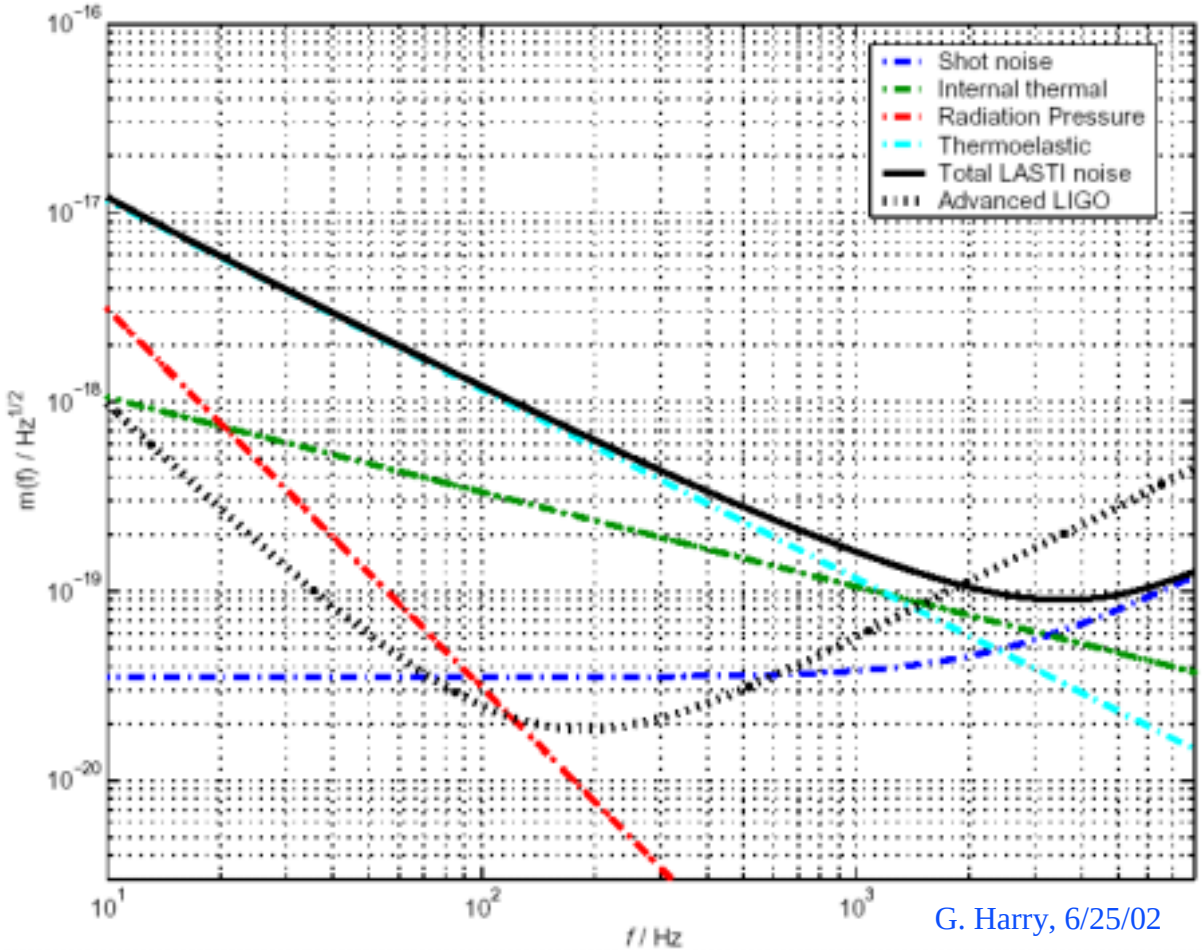
In each step, develop installation & test procedures to optimize LIGO site upgrade

Interferometric Noise Test Configuration



ETM, ITM: Adv LIGO LOS
MCx, MMTx, SM: Adv LIGO SOS

LASTI Interferometer Sensitivity Model

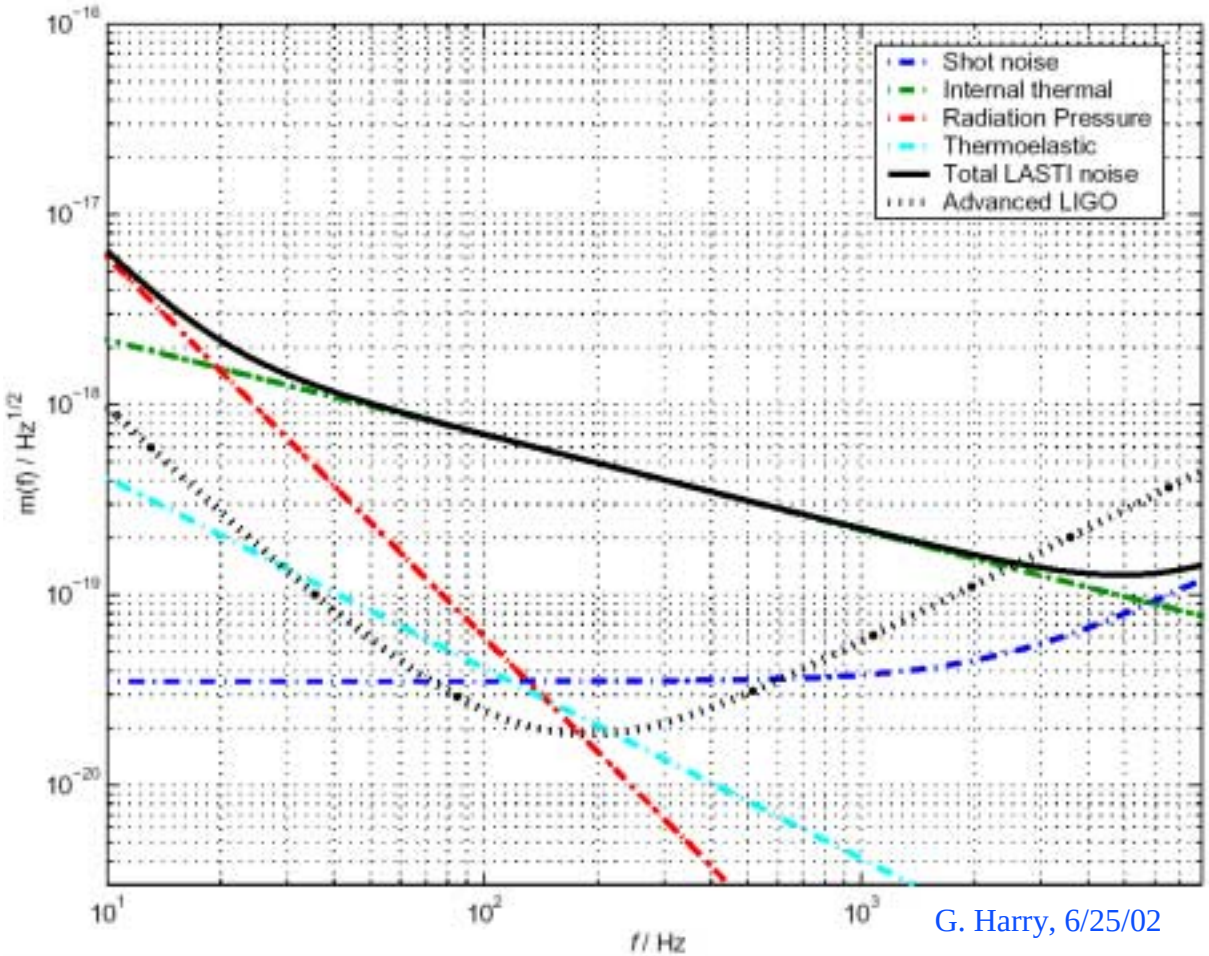


G. Harry, 6/25/02

- For sapphire TM's (baseline plan)
- Q_{TM}= 2e8, $\Phi_{coating}$= 4e-4
- 6W laser power (LIGO I laser)
- Cavity finesse 2000
- 15m cavity length
- 3mm beam radius (max. practical)
- Limited by thermoelastic noise over most of band due to small beam

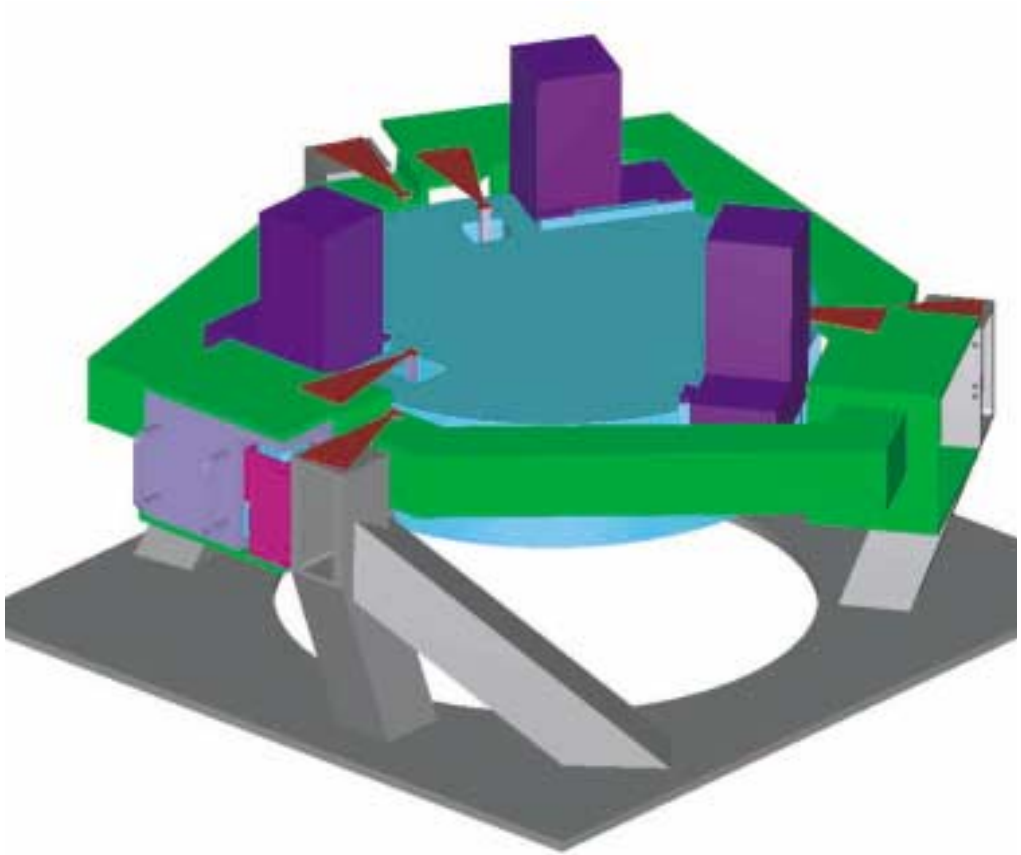
LIGO

(Silica Test Mass Option)



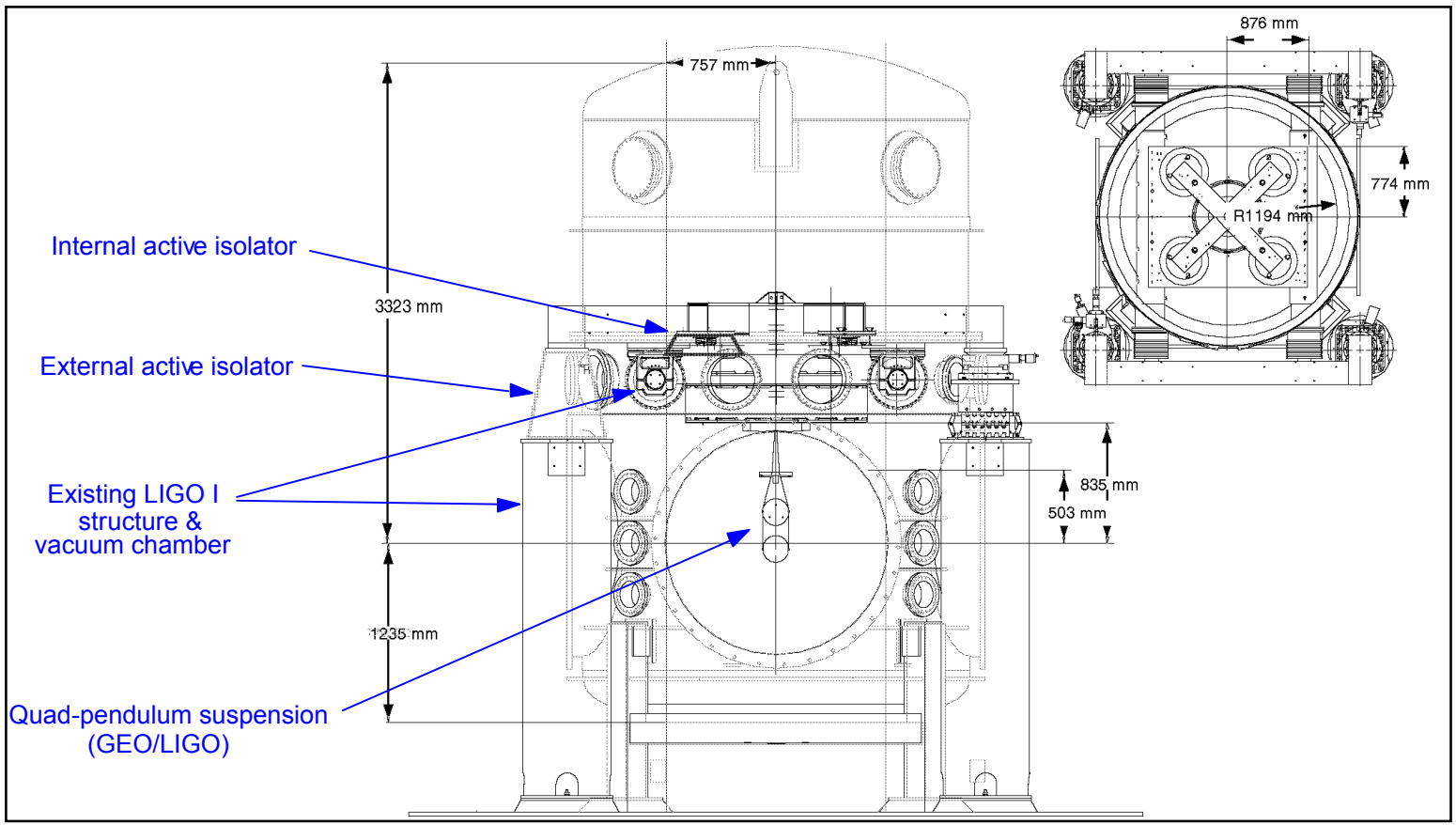
- For silica TM's (backup plan)
- Q_{TM}= 3e7, $\Phi_{coating}$= 4e-4
- 6W laser power (LIGO I laser)
- Cavity finesse 2000
- 15m cavity length
- 2.25mm beam radius
- Limited by internal Brownian noise over most of band due to lower Q

Advanced LIGO Active Seismic Isolation System



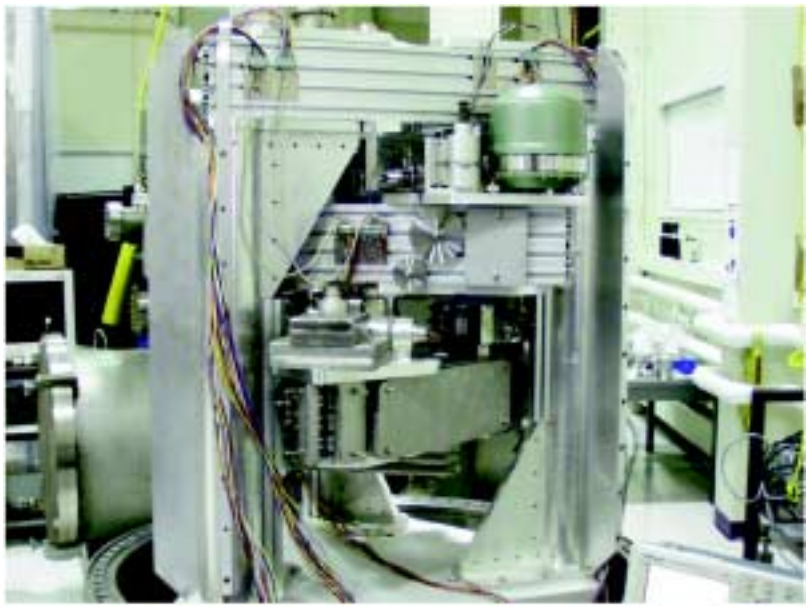
LLO/LSU/Stanford/MIT

Active Seismic Isolation



LIGO

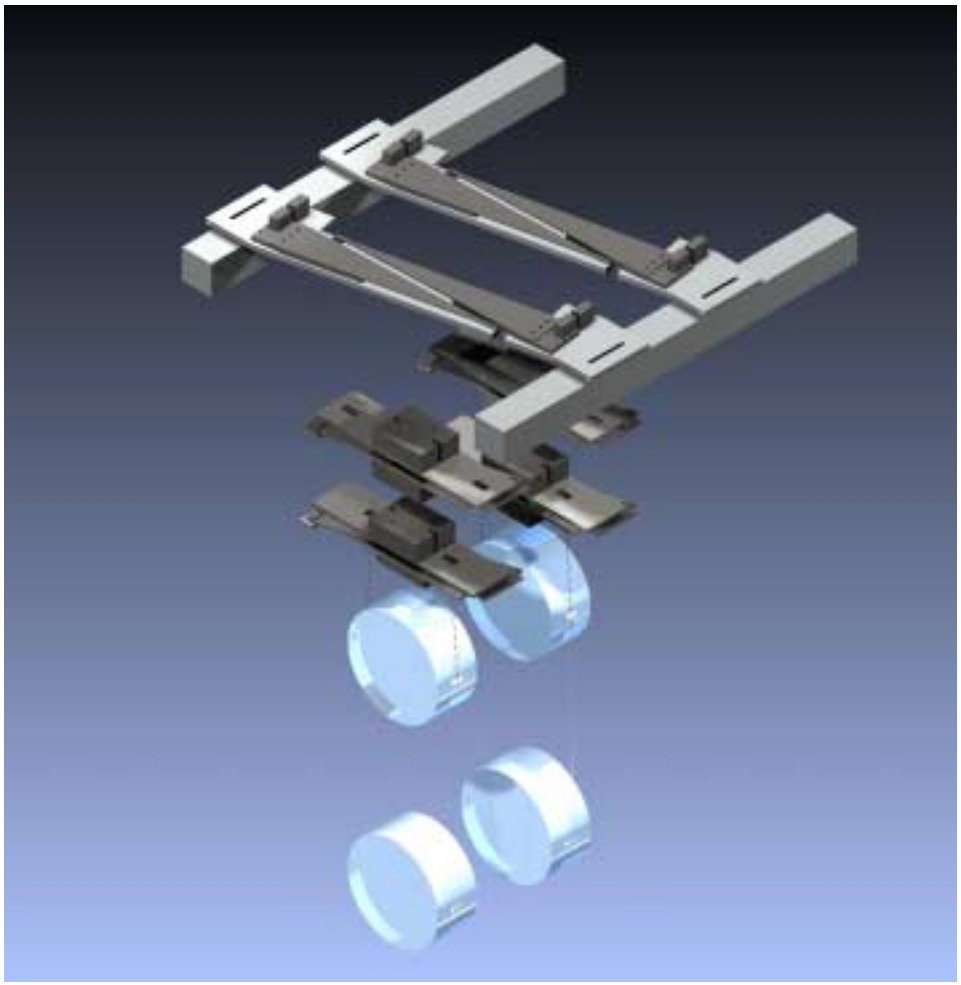
Active Seismic Isolation



Prototype 2-stage active isolator previously developed at MIT (now at Stanford ETF)

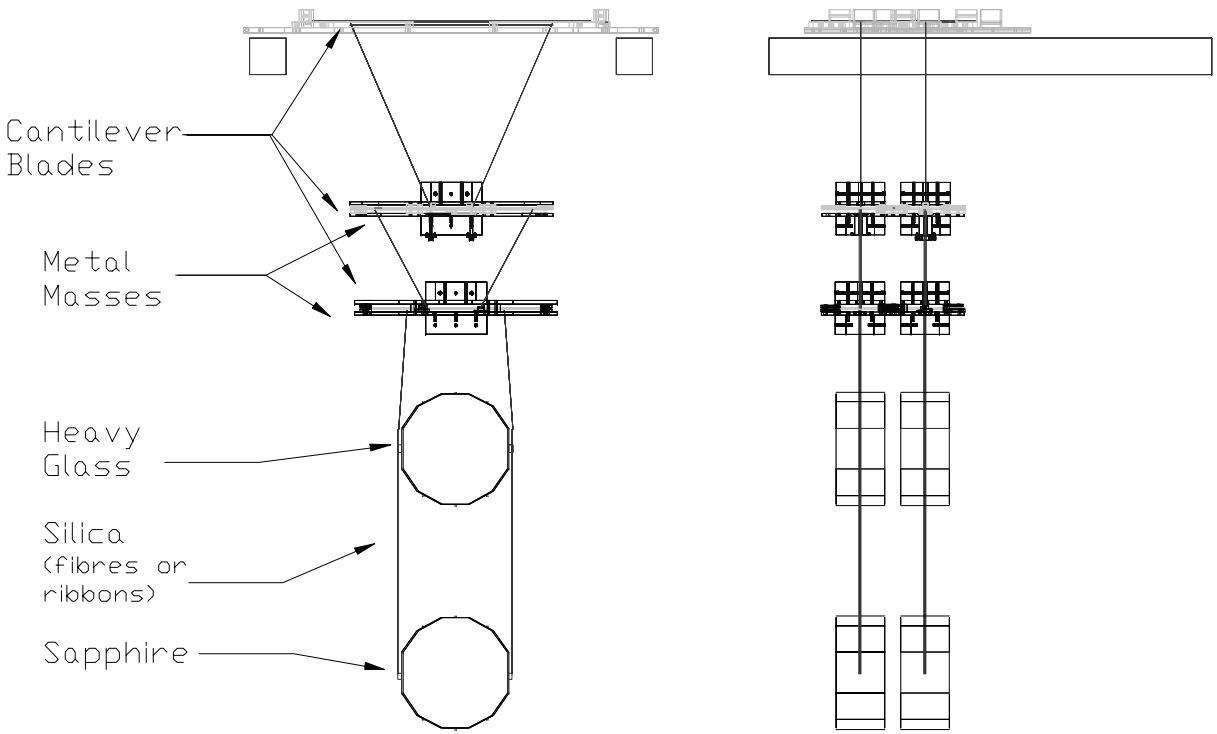
- 2-stage internal active stack w/blade springs & flexures
- 6 degrees of freedom each stage
- Sensors: seismometer, geophone & position sensor encapsulated in airtight ‘pods’
- Magnetic voice coil forcers
- Digital MIMO control system
- External active pre-isolator (EPI) to reduce required stroke & power

Advanced LIGO Suspensions



- Based on successful GEO600 triple pendulum design
- Quad pendula for TM, BS; Triples for input optics
- Blade springs for vertical isolation
- Indirect damping through upper stage recoil
- Electrostatic or photon drive for fast control at final stage; reaction mass for ES recoil

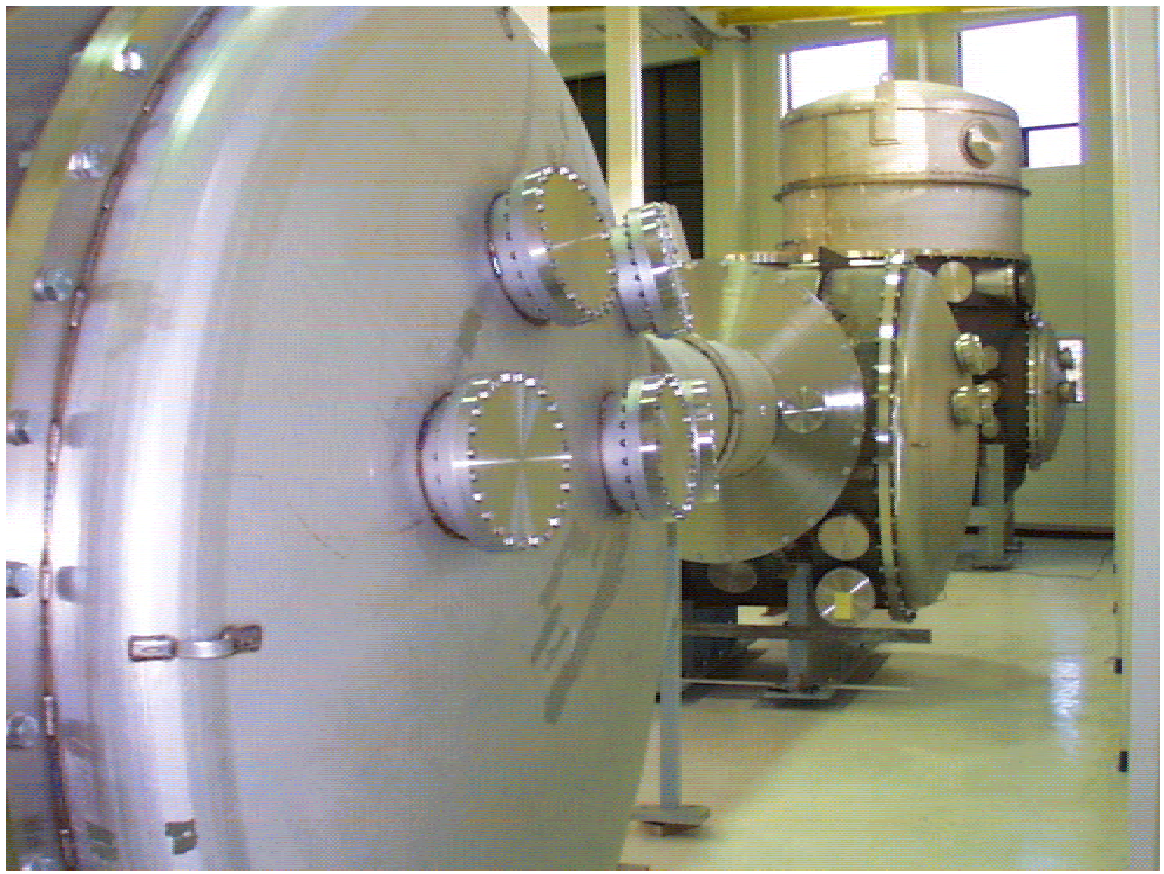
Advanced Suspensions



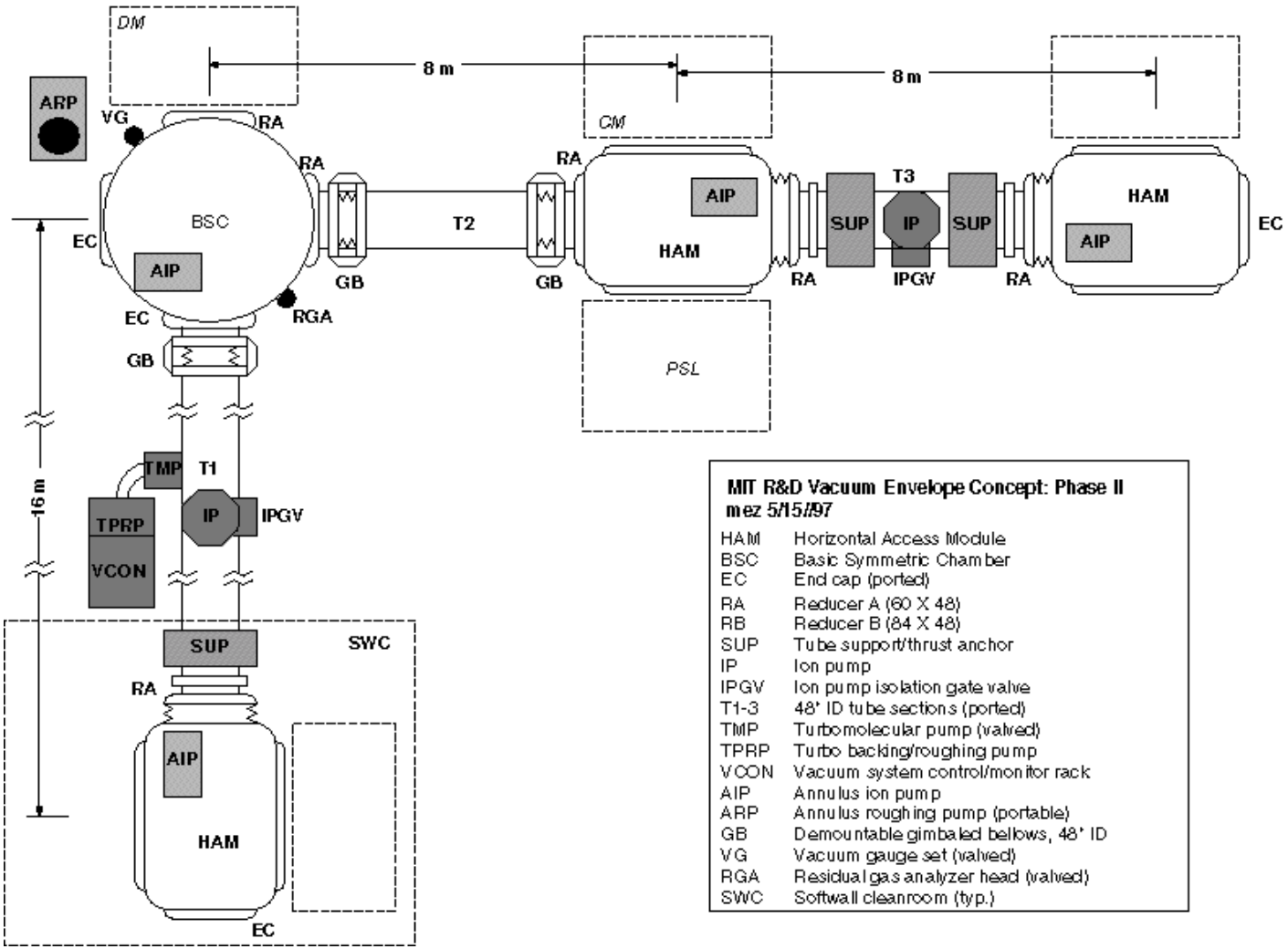
GEO/Caltech

LIGO

Vacuum Envelope



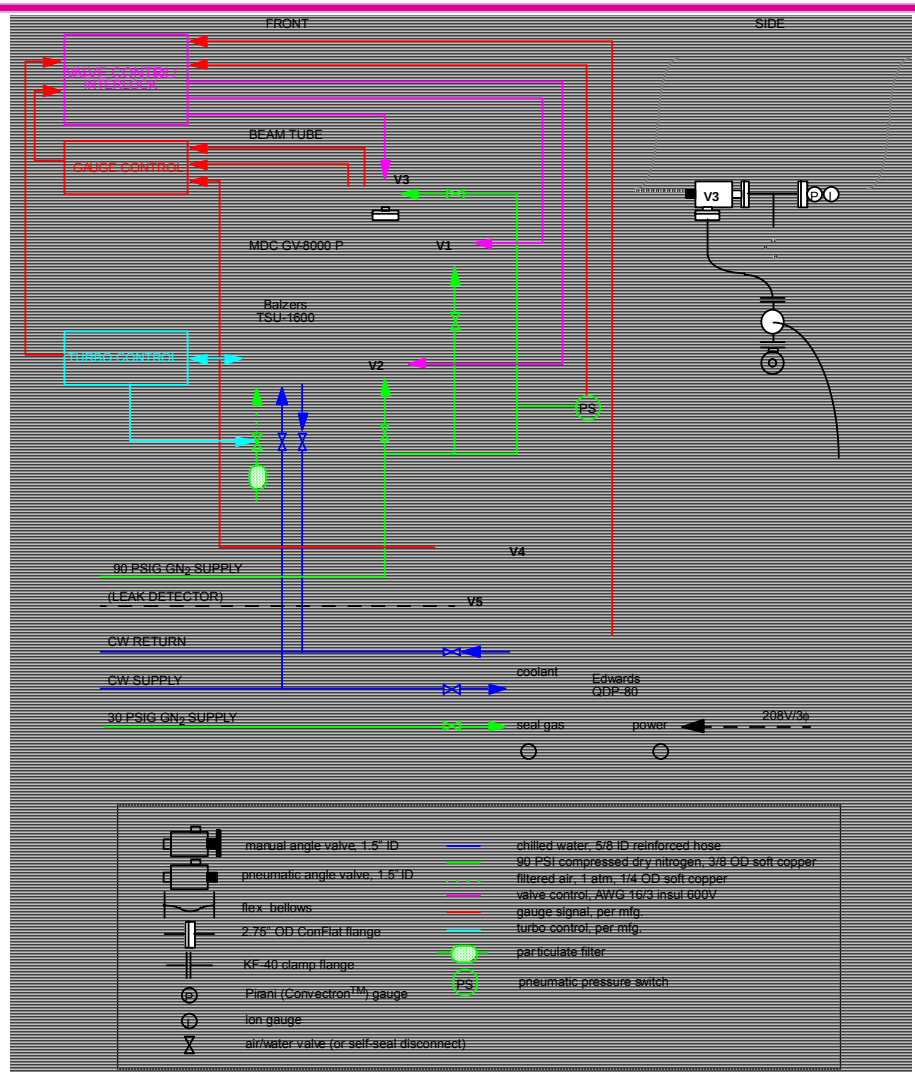
Vacuum System Schematic



MIT R&D Vacuum Envelope Concept: Phase II
mez 5/15/97

HAM	Horizontal Access Module
BSC	Basic Symmetric Chamber
EC	End cap (ported)
RA	Reducer A (60 X 48)
RB	Reducer B (84 X 48)
SUP	Tube support/thrust anchor
IP	Ion pump
IPGV	Ion pump isolation gate valve
T1-3	48" ID tube sections (ported)
TMP	Turbomolecular pump (valved)
TPRP	Turbo backing/roughing pump
VCON	Vacuum system control/monitor rack
AIP	Annulus ion pump
ARP	Annulus roughing pump (portable)
GB	Demountable gimbaled bellows, 48" ID
VG	Vacuum gauge set (valved)
RGA	Residual gas analyzer head (valved)
SWC	Softwall cleanroom (typ.)

Pumping System



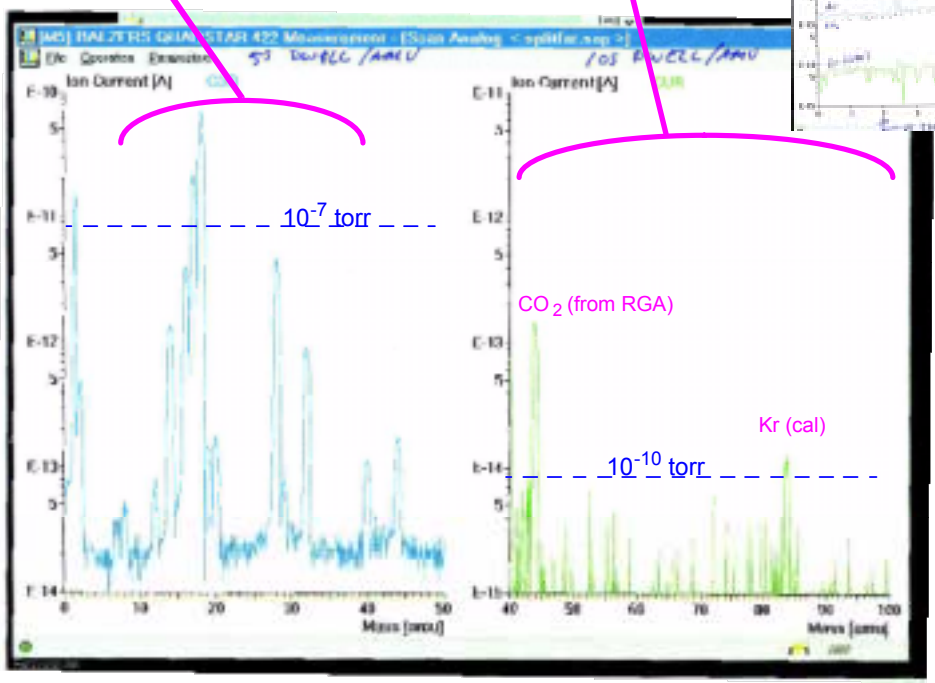
Vacuum Performance

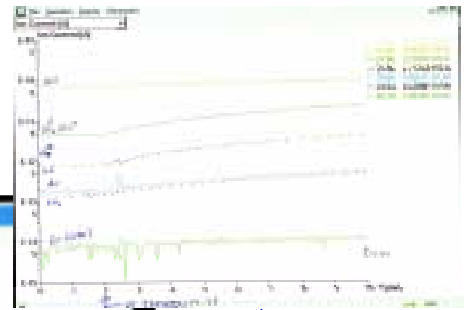
BSC0 stack + 2 SOS + stack + wiring in HAM13

H_20, N_2, O_2, Ar : consistent with degassing of Flourel

$P(H_xC_y)$ < 2e-11 torr

(sensitivity S~ 85 μA/torr)



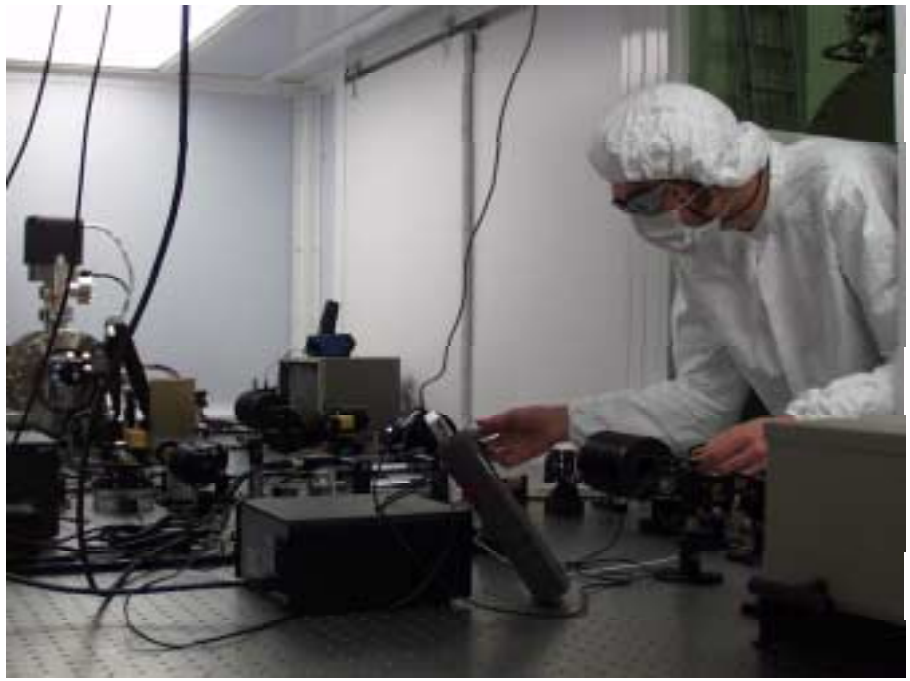


Accumulation test on LASTI volume

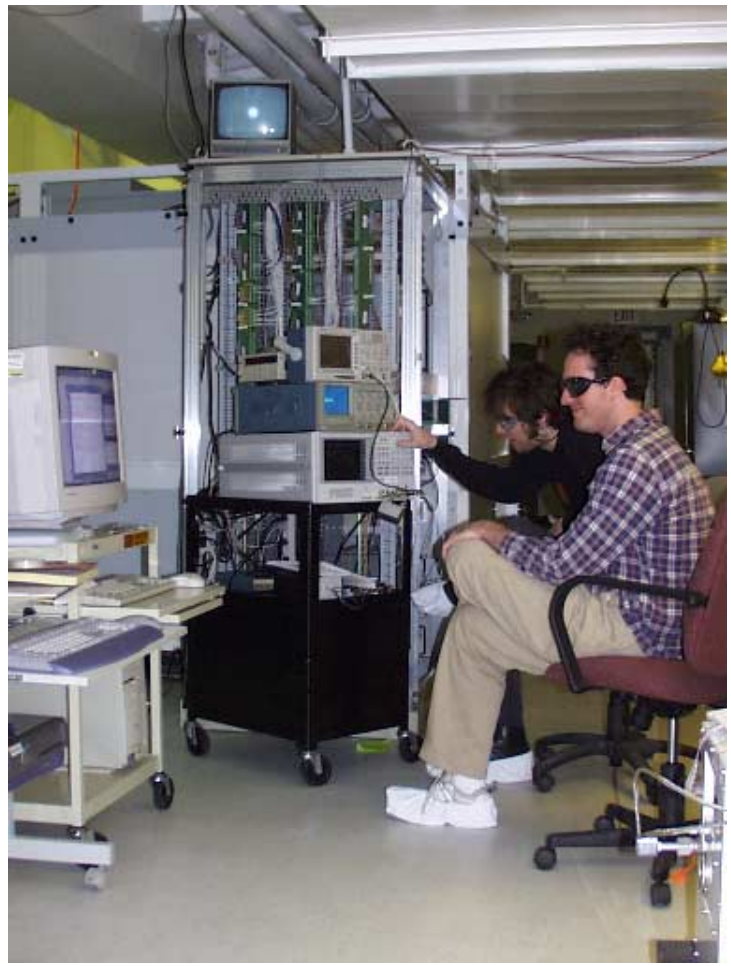
(water diffusion is "interesting!")

LIGO

Prestabilized Laser (PSL)



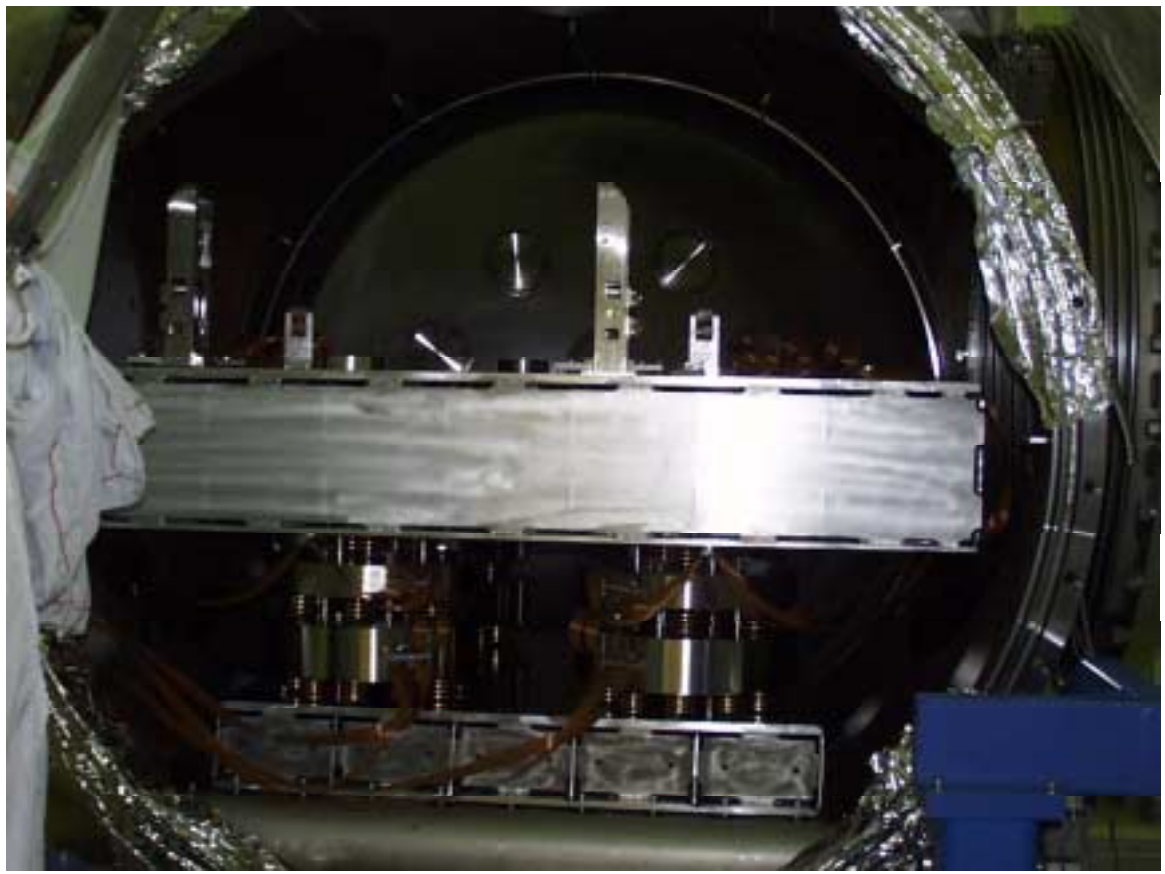
J. Rollins aligning PMC cavity



D. Ottaway (r.) w/ J. Rollins commissioning controls

LIGO

HAM Seismic Stack



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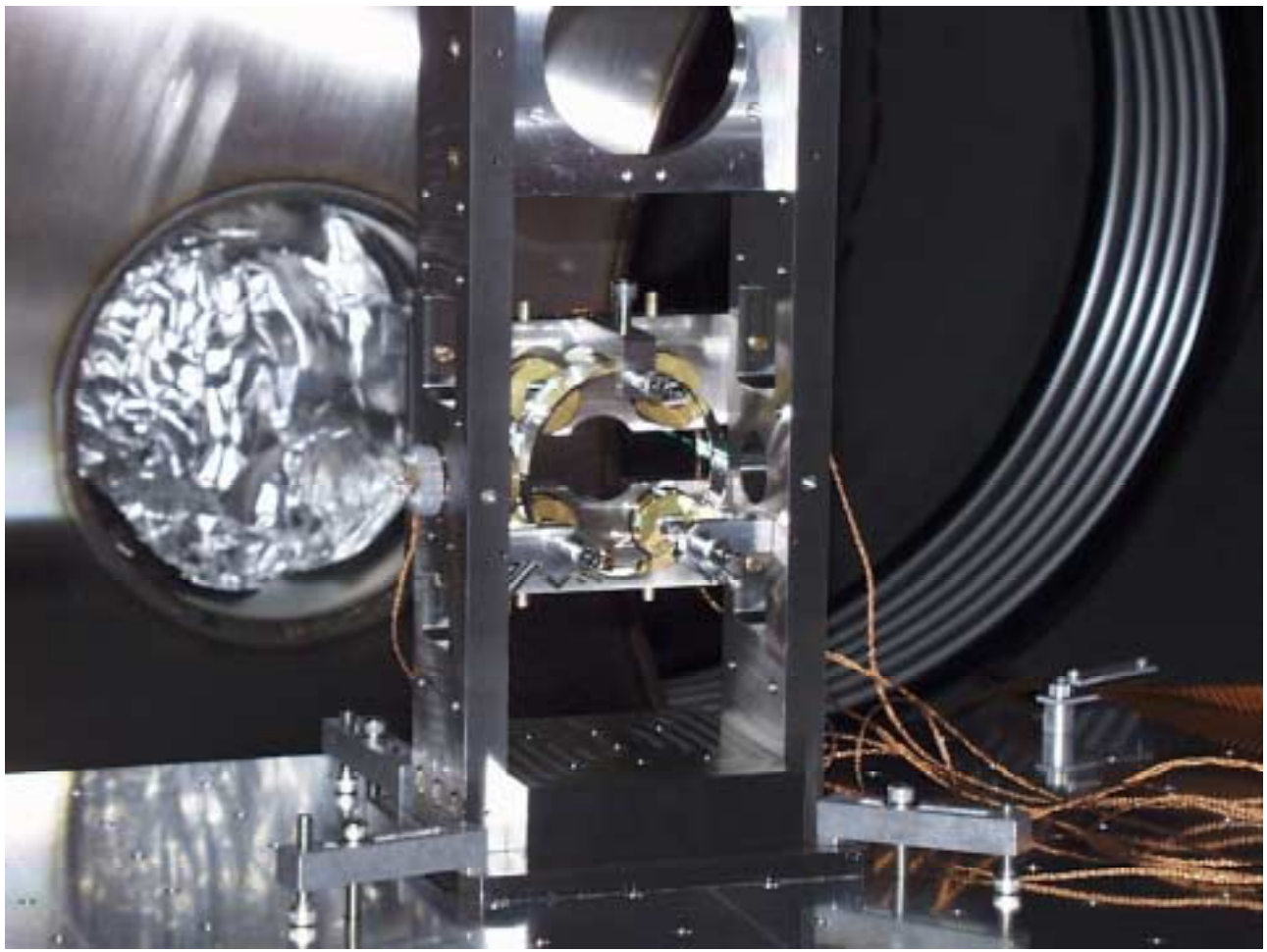
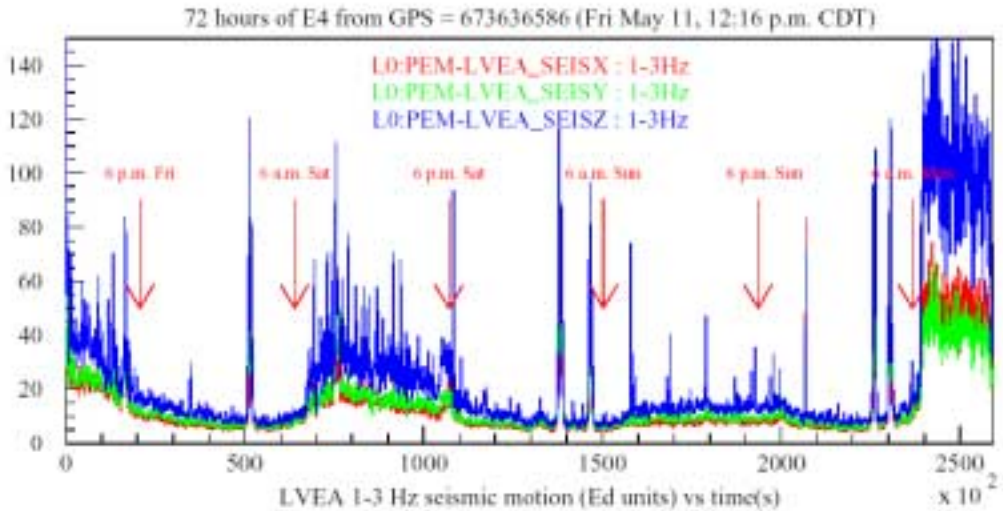
1m Suspended Test Cavity

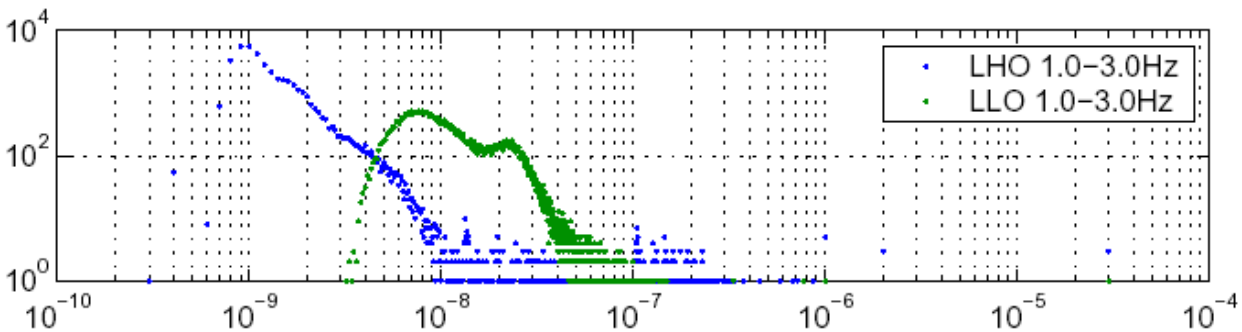


LLO Seismic Remediation



RMS vs. time Ed Daw, LLO/LSU

- Man-made noise impairs ability to lock L4k
- Mainly due to forest logging
- Without some action, LLO limited to night & Sunday operation (or heavy rain)



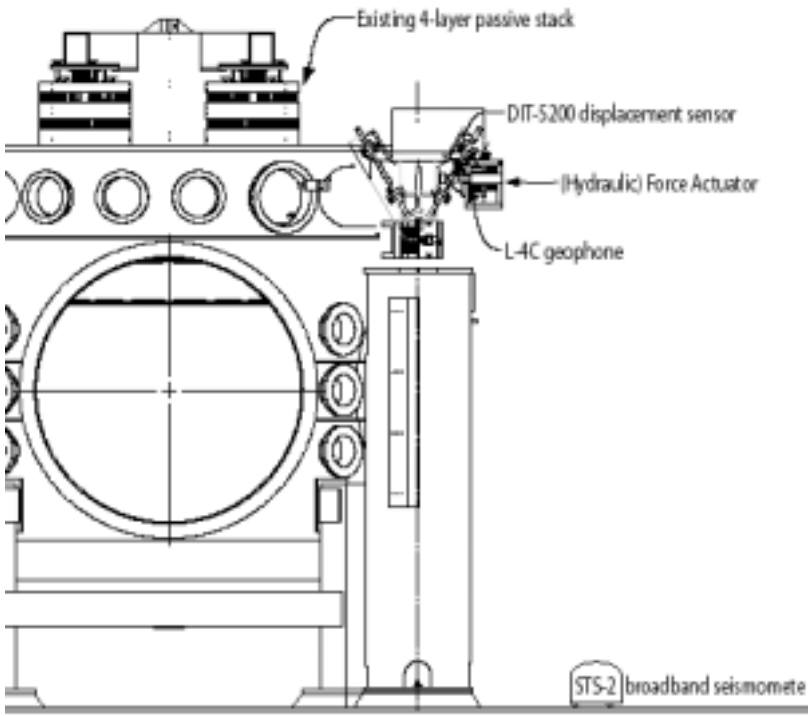
Histogram LHO vs. LLO Ed Daw, LLO/LSU

LIGO

LLO Seismic Remediation Options

- Buy off loggers (we wish)
- Damp existing isolation stacks internally
  - » Principal problem was at stack 1-3 Hz eigenmodes, which are poorly damped; *but*
  - » Passive: compromises noise at higher frequencies, limited damping capacity
  - » Active: internal components complex, tough engineering, long development cycle
  - » Invasive and limited benefit for the downtime
- Add external isolation to augment stacks
  - » Insufficient space/volume for significant passive isolation at $f < 5$ Hz
  - » Active EPI solution already under development for Advanced LIGO using hydraulics (HEPI)
  - » Parallel development also initiated involving 'traditional' magnetic forcers (MEPI)
  - » Both designed to be compatible with existing infrastructure; minimally invasive retrofit
  - » Additional interim opportunities: single-DOF PZT actuators already installed on some chambers, shaker-reaction idea; PEPI and SHREPI respectively)

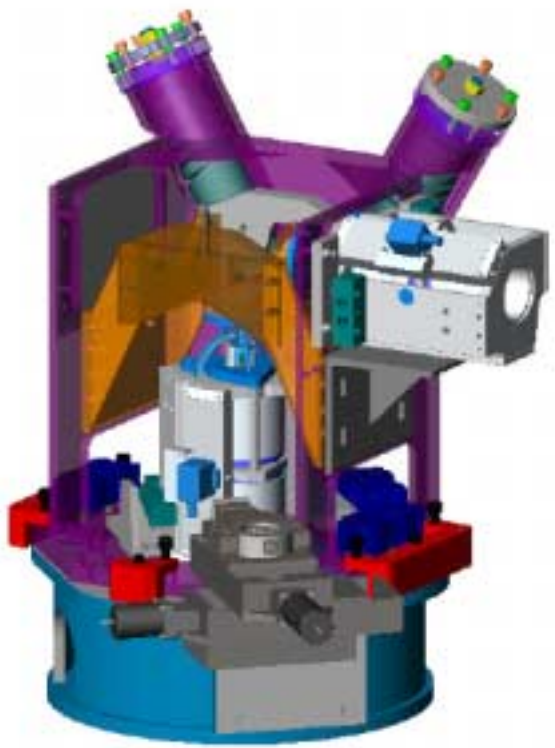
External Pre-Isolators (EPI)



J. Giaime, LLO/LSU

- Active vibration suppression interposed between ground and existing internal seismic isolation
- Main gravitational load is supported by angled coil springs (2 per leg)
- 2 forcers per leg, one vertical and one tangential
- Payload-mounted L-4C geophone + DC position sensor for local feedback
- STS-2 seismometer on floor permits feedforward at low frequencies (μseism)

Hydraulic External Pre-Isolators (HEPI)

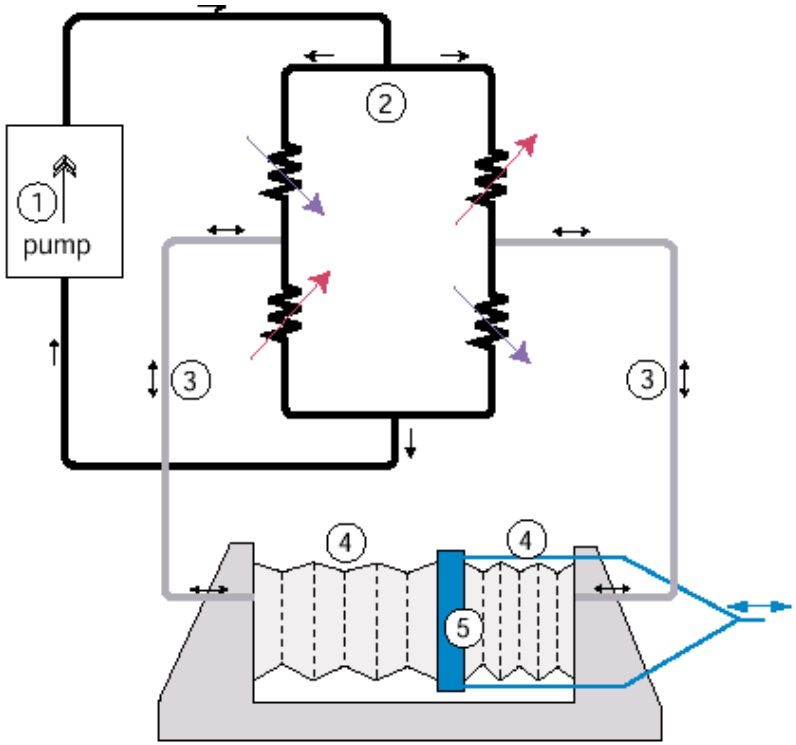


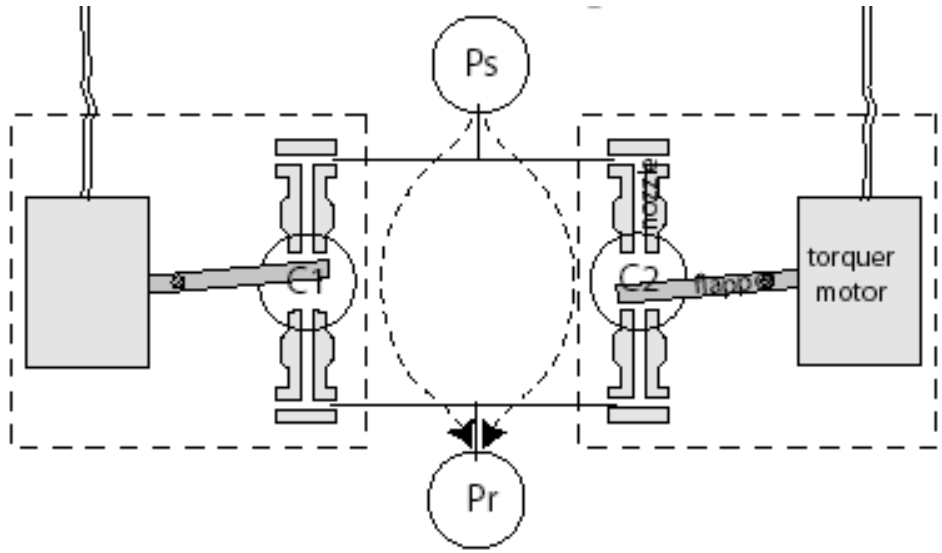
K. Mason, MIT

- Developed by Stanford group
- Working fluid is low-viscosity mineral oil
- Bellows hydraulic pistons apply force without sliding friction, moving seals
- Laminar-flow differential valves control forces
- Stabilized “power supply” is remote hydraulic pump with fluid-equivalent “RC” pressure filtering
- Technology adapted from precision machine tool applications

LIGO

Quiet hydraulic actuator principle



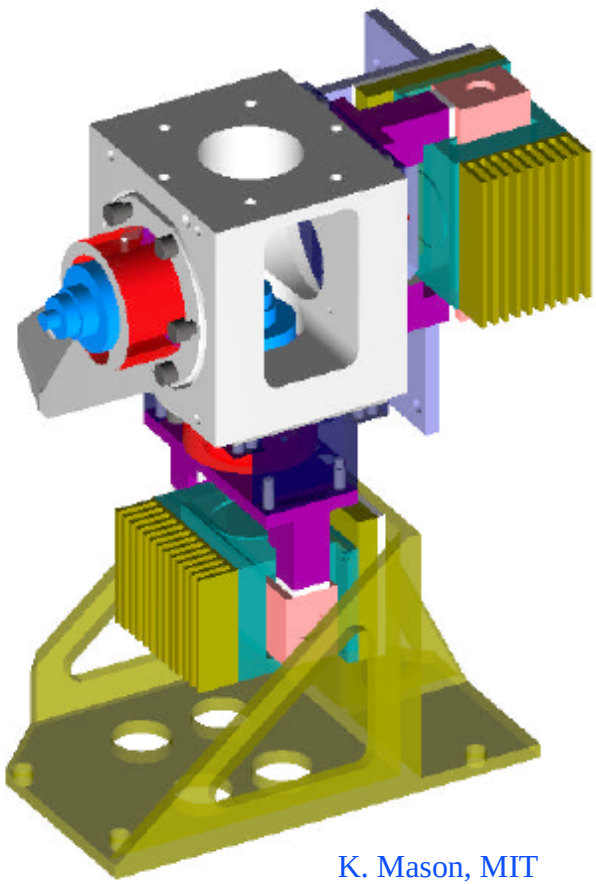


Laminar-flow differential proportioning valve (modified commercial product)

- Fluid analog of Wheatstone bridge w/variable legs
- Differential pair of formed steel bellows as frictionless ‘pistons’
- Tripod thrust articulation to transmit unconstrained linear force

LIGO

Magnetic EPI (MEPI)



K. Mason, MIT

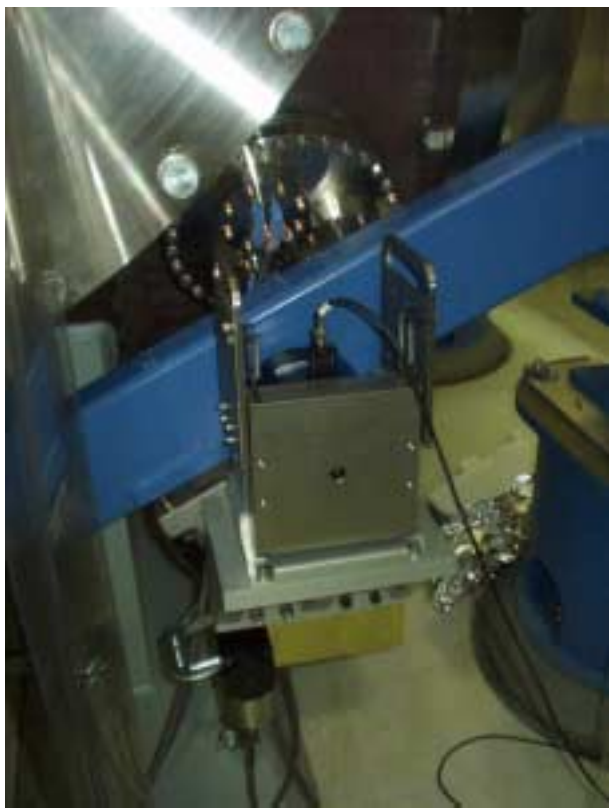
- Developed at MIT
- Uses commercial voice-coil actuator
- ‘Pin-compatible’ mechanically
- Simpler electronics
- ‘Soft’ mechanical back impedance

LIGO

Magnetic Linear Motor

- Commercial actuator (BEI)
- Good field containment, mild shielding probably required for safety margin
- Generous clearances in all but gap direction (alignment noncritical)
- Fits easily in EPI envelope
- Force and magnetic coupling tests underway
- High-current driver designed & built at Caltech, tested at MIT

Interim measure for HAMs: SHaker-Reaction EPI (SHREPI)



- Option to quiet input optics at principal seismic interference frequencies
- Tests at LHO, MIT indicate structure compliance & force adequate to handle excursions
- Low hardware impact (~ off-the-shelf actuators, simple electronics)
- limited performance (low BW, only 2 DOF)
- Tests continuing at MIT

LIGO

Measuring existing BSC stack & pier impedances

Updated milestones:
LLO seismic remediation interleaved with Advanced LIGO development

- 4Q99 (4Q99 act): LASTI vacuum envelope commissioned √
- 1Q00sch (3Q01 act): LASTI SEI external structures installed √
- 2Q00sch (4Q00 act): LASTI infrastructure design review √
- 3Q01sch (1Q02 act): LASTI infrastructure complete (DAQ, SEI, PSL, test cavity) √
- *NEW* 4Q01: Fit LIGO I BSC stack (from spare parts) to support EPI qualification √
- *NEW* 1Q02: External pre-isolator tests for LLO seismic retrofit underway
- *NEW* 4Q02: PSL intensity stabilization experiment underway
- *NEW* 4Q02: HAM triple suspension prototype installed for "controls" pre-test
- 4Q02: HAM SEI pathfinder installed for standalone testing (slips to 2Q03)
- 3Q02: BSC SEI pathfinder installed for standalone testing (slips to 3Q03)
- 2Q04: LASTI noise test begins; SUS prototypes installed
- 1Q05: Interferometric displacement tests
- 2Q05: LASTI SUS/SEI test review
- 3Q05: Adv LIGO PSL/MC tests start

LIGO

Conclusions

- LASTI's mission to pre-qualify Advanced LIGO technology has an unexpected dress rehearsal in the LLO seismic retrofit
- With continued involvement of Lab and LSC visitors, we've been flexible enough to support this initiative without impacting our Advanced LIGO goals
- Enjoy the lab tour