Advanced LIGO Research and Development Status

LIGO PAC19
December 12, 2005

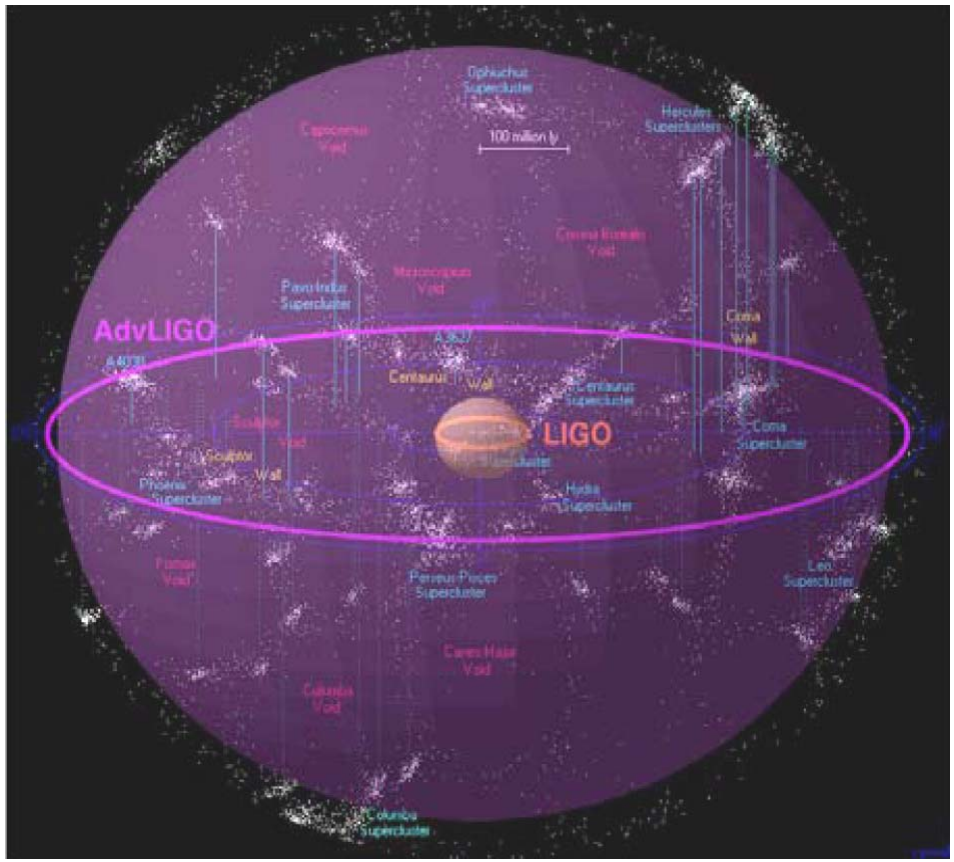
Carol Wilkinson
LIGO Hanford Observatory

Advanced LIGO Proposal

➔ **Reminder:**

Upgrade all 3 Interferometers and convert Hanford 2K to 4K Interferometer

- Factor of 10 better amplitude sensitivity
- Factor of 4 lower frequency bound
- Factor of ~1000 greater volume and thus event rate
- Potential for tunable, narrow band searches

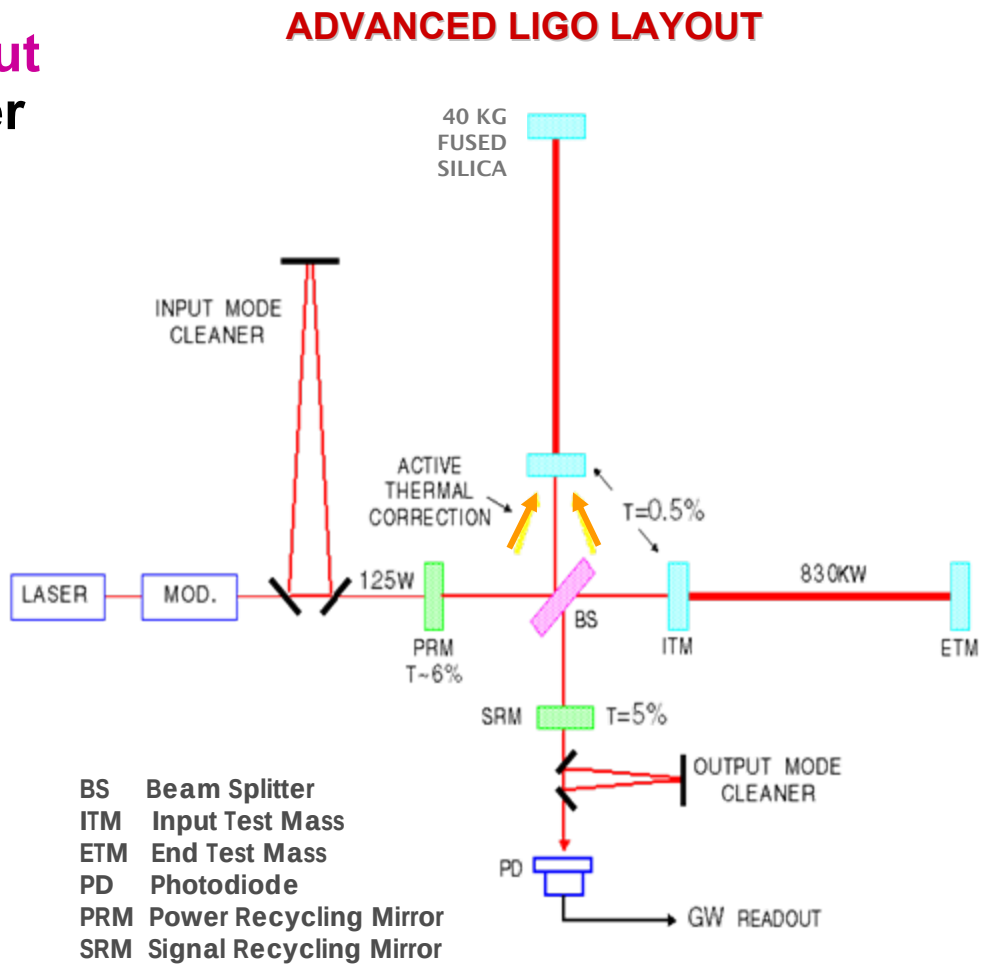


Sky map showing locations of superclusters, walls, and voids of galaxies within about 500 million light years. Superimposed circles show the range of LIGO (orange inner circle) and the 10 times larger range of AdvLIGO (purple outer circle). The milky way is at the center in this representation. *Credit: the underlying black and white image with names of clusters and voids is by Richard Powell; the superimposed color circles were added by Beverly Berger, Division of Physics, NSF.*

Advanced LIGO Detector Improvements

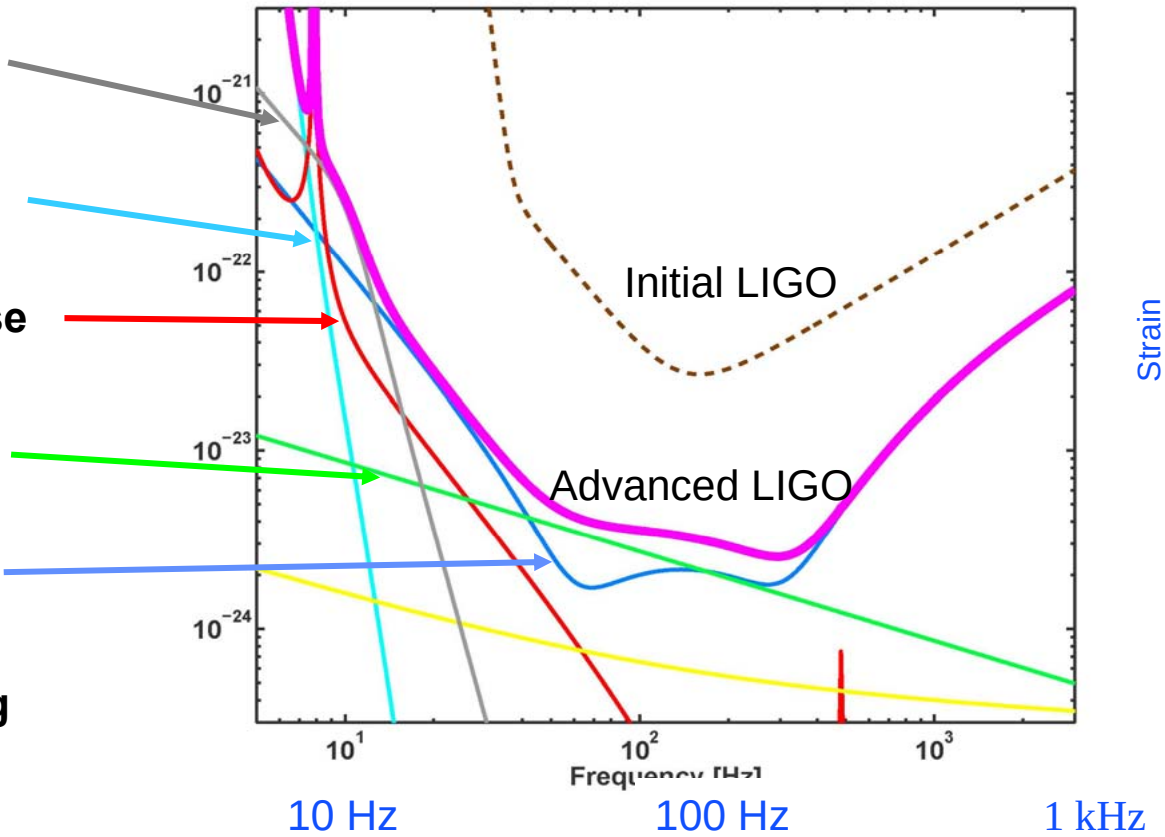
Retain infrastructure, vacuum chambers, and initial LIGO layout of power recycled interferometer

- Replace passive seismic isolation with multi-staged system with inertial sensing and feedback control
- Increase number of passive suspension isolation steps and use lower noise actuation
- Use lower mechanical-loss materials and construction in suspensions and optical coatings to reduce thermal noise
- Increase laser power ~20x and reduce optical losses to improve shot noise limits and signal strength
- Add GW signal recycling at output to increase sensitivity and allow narrow band frequency tuning.



Projected Adv LIGO Detector Performance

- Newtonian background, estimate for LIGO sites
- Seismic 'cutoff' at 10 Hz
- Suspension thermal noise
- Coating thermal noise
- Unified quantum noise dominates at most frequencies for full power, broadband tuning



Principal noise sources and selected technical noise sources for Advanced LIGO

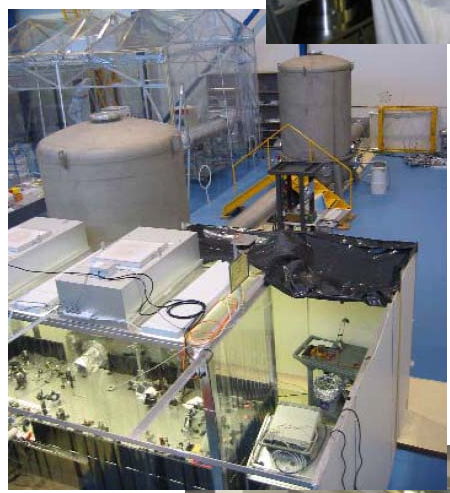
Construction Project Funding Status

- **NSF and Presidential Out-Year budget includes $185M with proposed FY08 start** (one of 3 proposed new starts)
- **International Partner Contributions of ~$25M already funded**
  - United Kingdom (PPARC): UK Team (U of Glasgow, U of Birmingham, Rutherford Appleton Lab.) plans approved and funded through construction
  - Germany (MPG): AEI contributions approved and funded through construction
  - Australia (ARC + others): ACIGA (ANU, UWA, U of Adelaide) continuing to pursue funding options
- **Detailed baseline review of project scope, schedule and costs in mid-2006**
- **Preliminary Construction Schedule (for NSF FY08 funding start)**
  - Start fabrication in FY08
  - Schedule installation work to minimize downtime and effectively use “experts”
  - Shutdown Livingston in FY10 while continuing Hanford operations
  - Shutdown Hanford in FY11
  - Resume operations at end of FY13

Research & Development Status

- **Research, design, and development phase aimed at FY2008 MREFC start**
- **Most major subsystems are in preliminary design stage**
  - » Design, fabrication, and testing of accurate, full scale prototypes
- **A few systems are further along**
  - » HEPI installed and operating at Livingston
  - » Quad suspension in final design
- **Many testbeds around LSC provide testing of processes and hardware performance**
  - » LIGO Advanced System Test Interferometer (LASTI) @MIT
  - » 40m Interferometer @CIT
  - » Gingin Facility @Gingin, Australia
  - » Engineering Test Facility (ETF) @Stanford
  - » 10m Interferometer @U of Glasgow
  - » Thermal Noise Interferometer @CIT
  - » GEO600 @Hannover, Germany
  - » Initial LIGO @Hanford, Livingston

LASTI



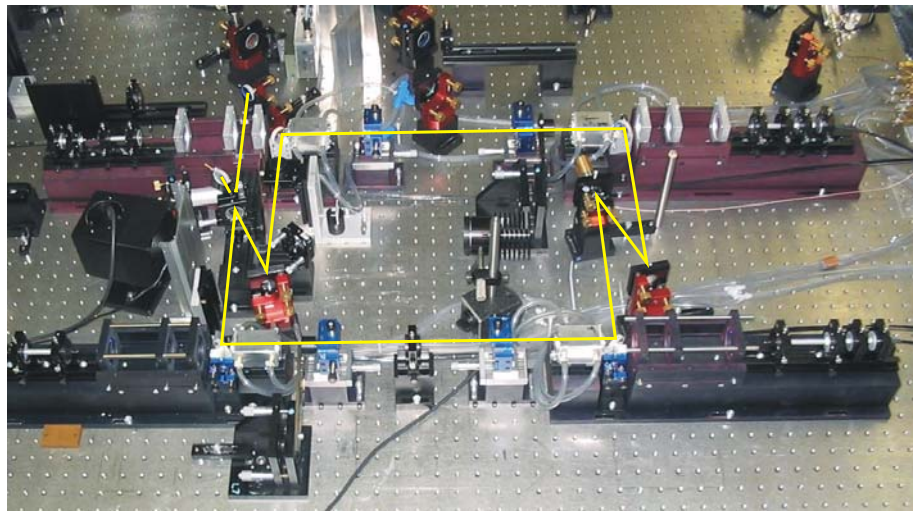
Gingin Facility

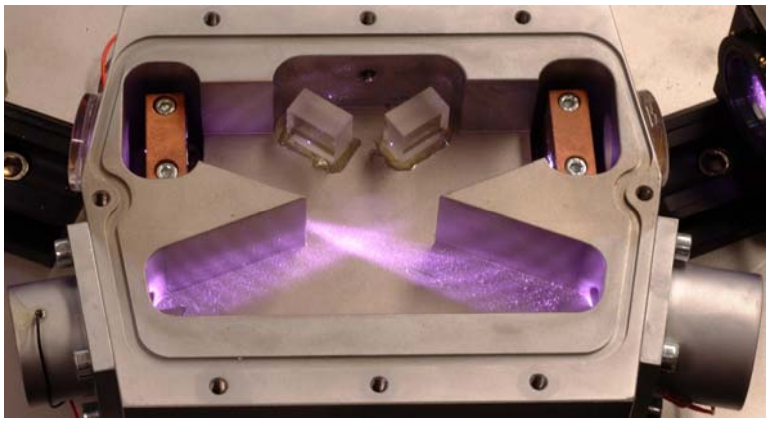
40 M Lab

Pre-Stabilized Laser

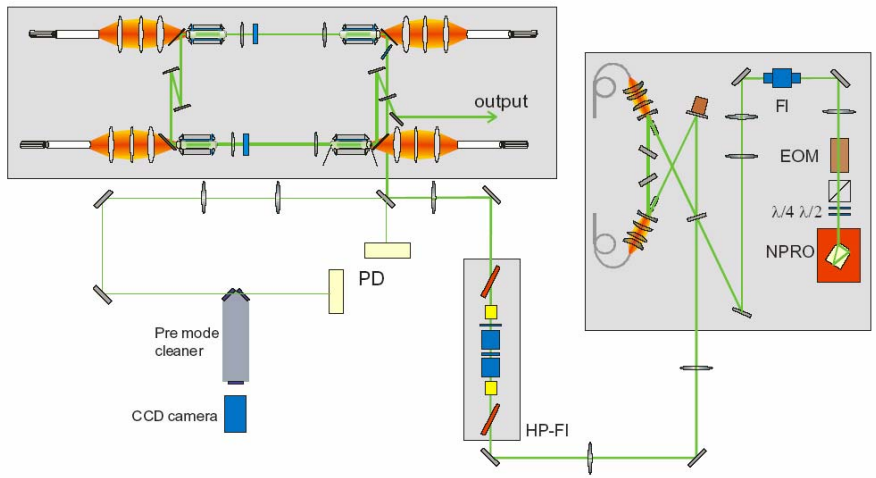
Max-Planck Institute, Hannover leads the PSL development, working with Laser Zentrum Hannover and CIT

- **Injection locking of the 200 W Laser (LZH, AEI)**
  - » Demonstrated
- **Characterization of spatial and temporal behavior is underway**
  - » Developed diagnostic LIGO-like Pre-Mode Cleaner (PMC)



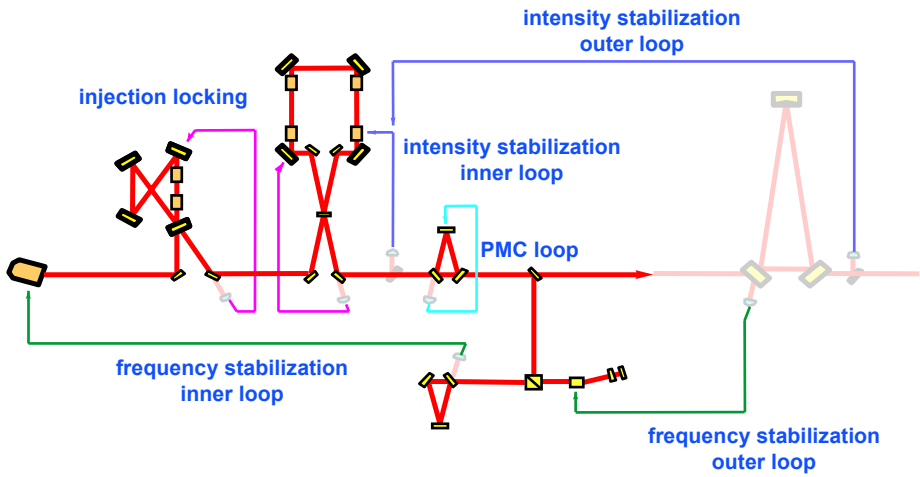


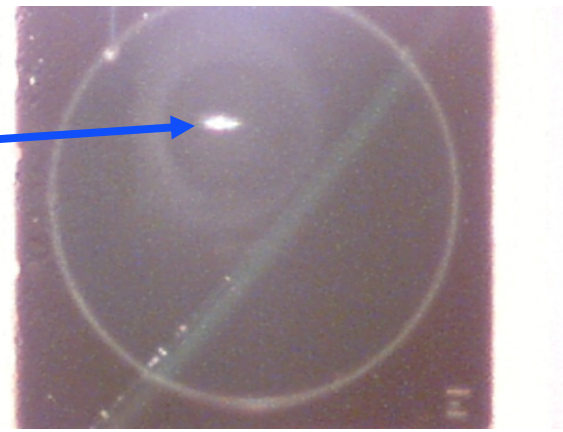
12 W Laser



Pre-Stabilized Laser

- **Improved intensity stabilization at Hannover**
  - » Power noise reduced to within factor of 2 of req's
- **Studies of Relative Intensity Noise (RIN) Stabilization at GEO600 Interferometer**
- **Successful Requirements and Conceptual Design Review, March 2005**
- **Stress testing of photodiodes for intensity stabilization at Caltech**
  - » Damage threshold is above 600 mA for one minute
- **Max Planck Group has granted funds for delivery of all PSL's**

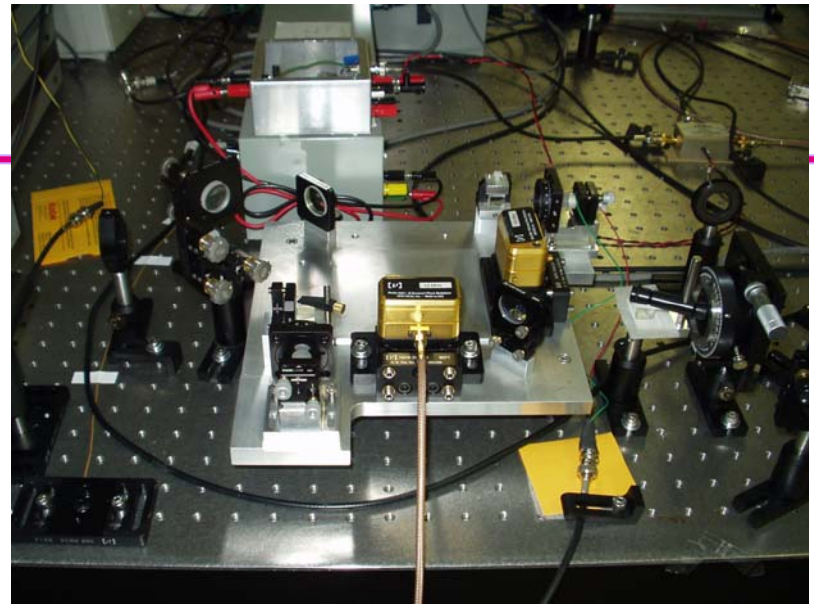




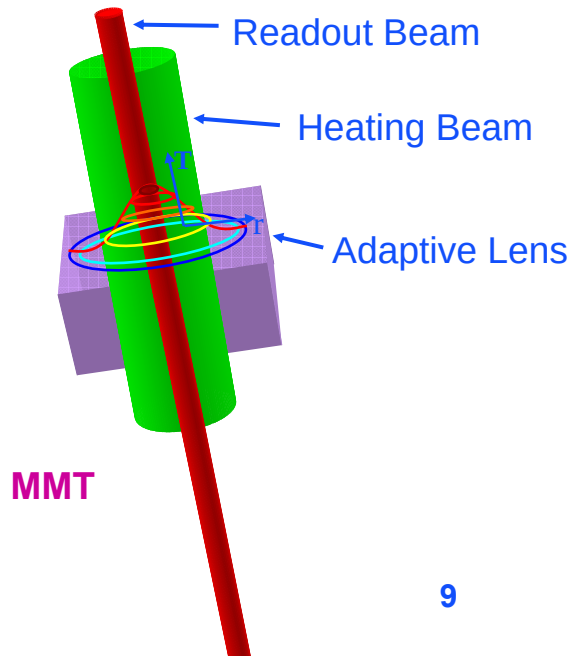
Input Optics

Lead by University of Florida, Gainesville

- **Faraday Isolators**
  - » Prototype Faraday isolators tested up to 100W
  - » Good isolation and passive thermal lens compensation
- **Mach-Zehnder modulation system**
  - » Analysis of noise couplings nearly complete
  - » Prototype MZ electro-optical modulator (EOM) locked and undergoing characterization
- **High power electro-optic modulators**
  - » Characterizing excess phase and amplitude noise
  - » No damage at 85 W for > 400 hrs at irradiances greater than for AdL
- **Adaptive mode matching telescope (MMT)**
  - » First generation MMT at UFL provides "Proof of principle" for dynamic focusing
  - » No measurable higher order mode contamination
  - » Implementing CO_2 laser as heating beam



Mach-Zehnder Modulation



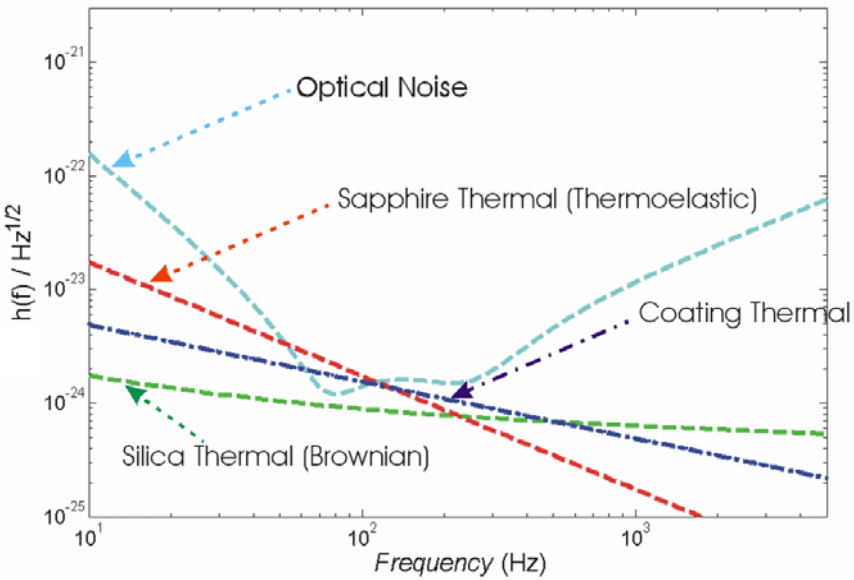
MMT

Core Optics

Combined CIT, MIT, Stanford, Glasgow efforts

- **Substrate selection = Fused Silica**
  - » Recommendation based on a comparative study
  - » Either material could work, but more risks for sapphire
- **Continuing Fused Silica studies:**
  - » Annealing
  - » Cleaning procedures and required particulate cleanliness levels
  - » Electrostatic charging
  - » Parametric instability
- **"Pathfinder process" studies**
  - » Polishing and coating for LASTI noise prototype and UK funded first article test masses
- **Thermal compensation development**
  - » Gaining experience with initial LIGO implementation

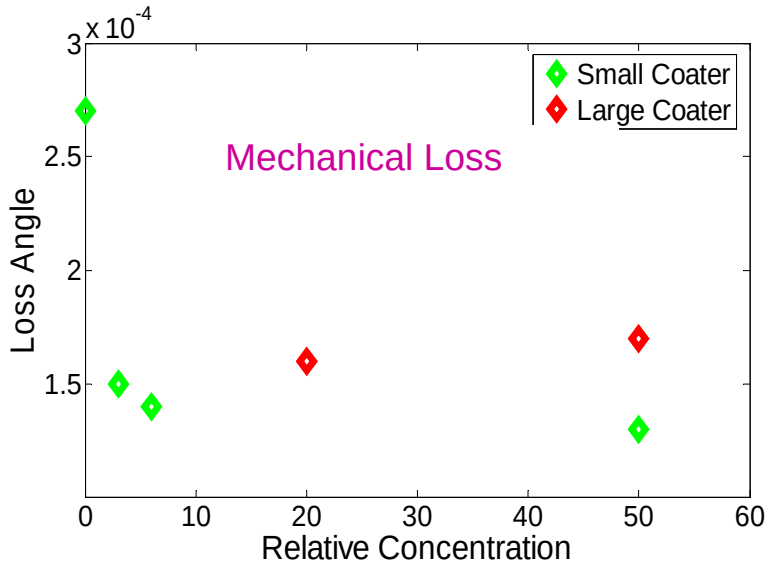
	Sapphire	Silica
NS-NS 1.4 Ms	191 Mpc	191 Mpc
BH-BH 10 Ms	920 Mpc	1050 Mpc
Pulsar h/√Hz	7×10^{-24}	12×10^{-24}
Omega	4.8×10^{-9}	2.6×10^{-9}



Core Optics: Optical Coatings

(CIT, MIT, Lyon LMA, CSIRO, UG, Stanford Efforts)

Goal: Reduce initial LIGO loss angle, bringing coating thermal noise below optical noise

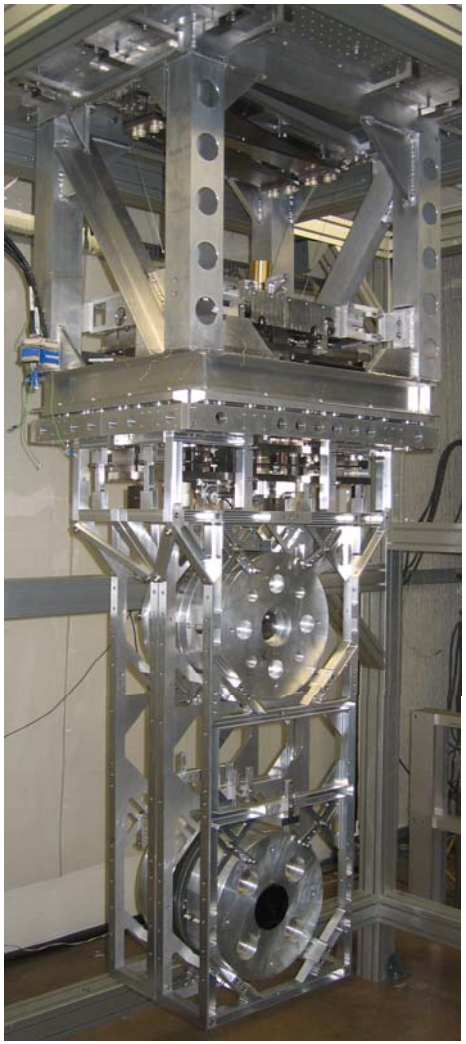


Concentration of TiO_2 in Ta_2O_5

- **Thermal Noise Interferometer (TNI) verifies reduction in thermal noise from TiO_2 doped Ta_2O_5**
  - » Broad optimum concentration
  - » Results in good agreement with Q measurements.
- **Studying absorption and scatter to ensure all requirements met simultaneously**
- **Could build 'good enough' interferometer with tweaking of present materials and process**
  - » Pursuing potential improvements and understanding

"Improvements lead to expanded range"

Suspensions



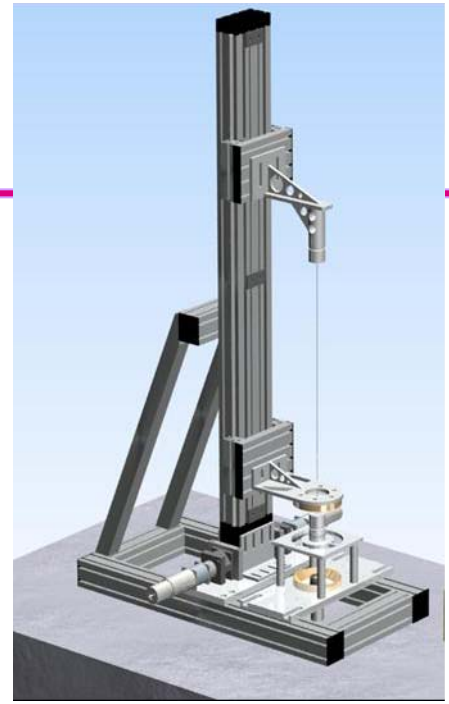
Combined US/UK Effort

- **Mode Cleaner (Triple) Suspension**
  - » LASTI testing of 'controls' prototype showed performance as expected
  - » Noise prototype will be built in 2006
- **Test Mass (Quad) Suspension**
  - » Joint design effort by US and UK
  - » 'Controls' prototype bench tested at CIT
  - » Being prepped for shipping to LASTI for testing
  - » 'Noise' prototype and final design led by UK (U. Glasgow, U. Birmingham; Rutherford Lab; concurrent with 'controls' prototype testing
- **Electronics preliminary design review in progress**

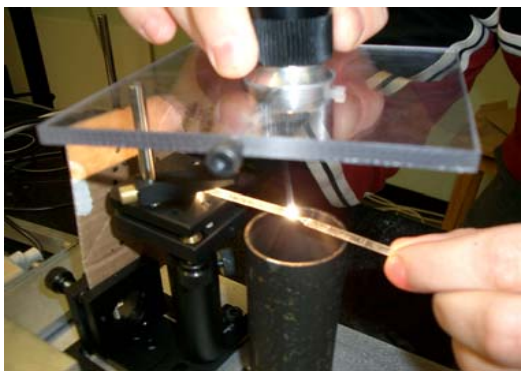
'Controls' Triple Installation at LASTI

Suspensions: Silica Fibers

- **Silica Fiber/Ribbon Pulling**
  - » R&D on CO_2 laser system proceeding well
  - » Assembling final stage prototype of fiber fabrication machine
- **Fiber/Ribbon Welding**
  - » Fiber & ribbon welding demonstrated
  - » Laser welding being further developed
- **Ears and Silica Bonding**
  - » Adapting designs used in GEO600 interferometer for Advanced LIGO application

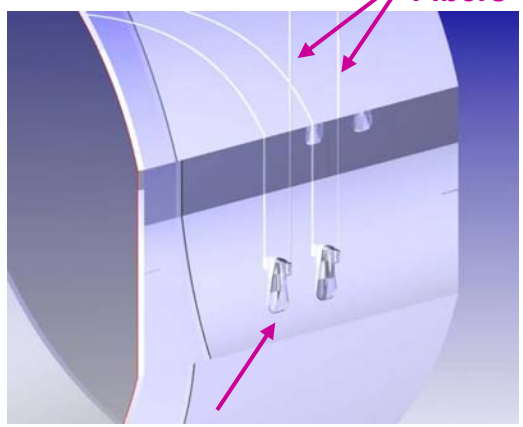


Fiber pulling fixture



Welding silica rod with 9W CO_2 laser

- **Fiber/Ears/Bonding PDR held in October, 2005**
  - » Waiting for panel report before proceeding with final designs

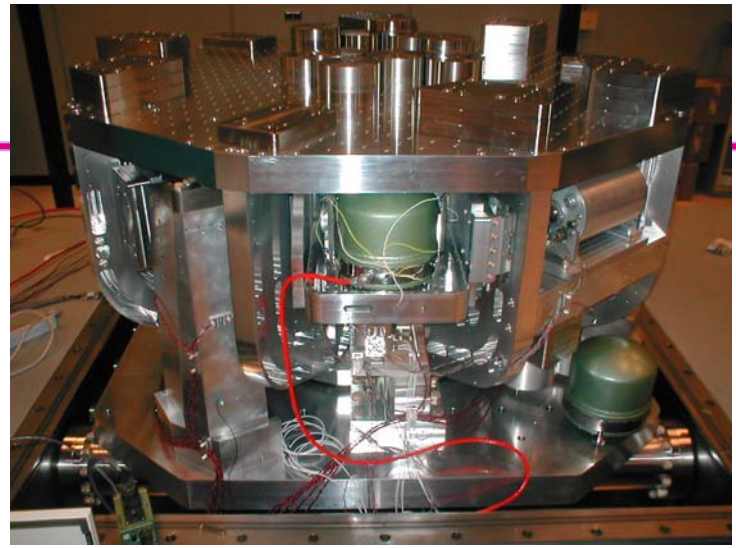


Ears bonded to fused silica substrate

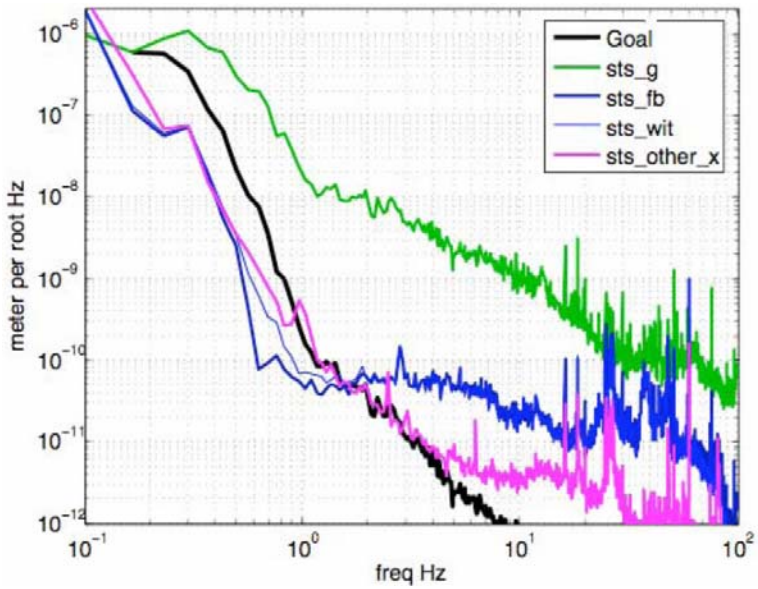
Seismic Isolation

Combined effort: LSU, Stanford, CIT, and MIT

- **Full scale seismic isolation prototype for the test mass chambers (BSC) in production**
  - » Significant progress in performance and understanding of Stanford prototype
  - » Analysis of coupled SEI-SUS dynamics indicates effect is manageable
  - » Tuning design to meet requirements
  - » Critical design review recommends proceeding with fabrication of prototype
- **Installation and testing at LASTI in ~1 year**



SEI Technology Demonstrator @
Stanford Engineering Test Facility (ETF)



Seismic Isolation

- **Next focus is on the auxiliary optics chamber (HAM) seismic isolation design**
  - » Have a preliminary layout design in baseline
- **Reviewing the requirements**
  - » Present requirements equal to those of test mass chamber, but
  - » Instruments less sensitive to motion in the auxiliary chambers, leaving room for relaxed requirements
  - » May allow a design with lower cost and complexity
- **Comparing several design approaches**
  - » Current realization (ETF) or a design more similar to the BSC Single-stage system with lower cost and complexity
  - » Passive isolation similar to VIRGO interferometer technology
- **HAM prototype fabrication start expected for late FY06**

Two stage, 'stiff' Technology Demonstrator @ Stanford's ETF

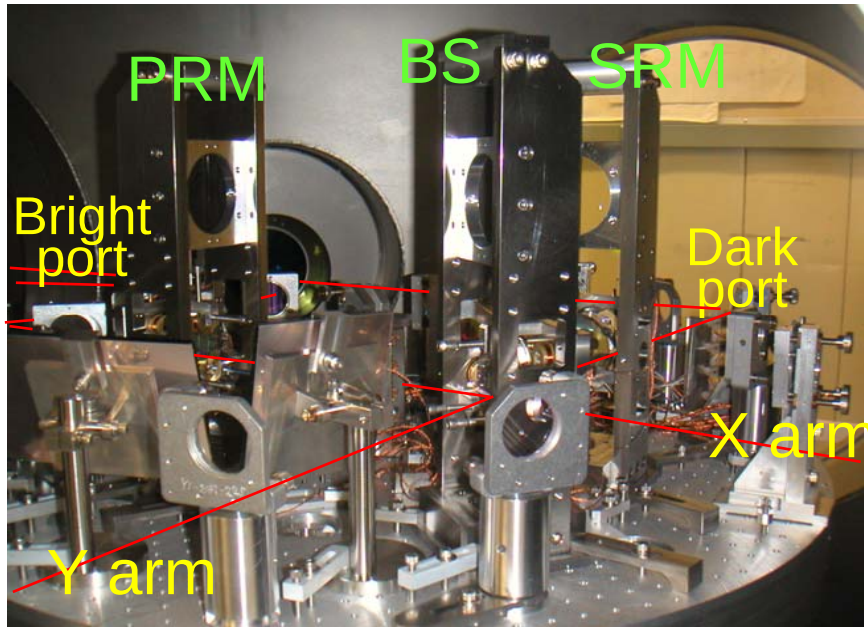
Geometric Anti-Spring (GAS)

Passive, 'inverted pendulum' and GAS demonstration at CIT

Integrated Systems and Controls

Combined effort: CIT and MIT

- **Systems Engineering**
  - » Starting an integrated 3D opto-mechanical layout
  - » E2E Adv. LIGO modeling well underway
  - » Systems trades & Requirements/Interface definition proceeding
- **Controls and Diagnostic Systems**
  - » Development and implementation of control systems for LASTI suspension and seismic isolation testing



40M beam splitter chamber

- **40M Tests of Controls**
  - » Lock acquisition of dual recycled interferometer
  - » Length sensing and control scheme for resonant sideband extraction
  - » DC gravity wave readout scheme
  - » Verify optical spring and optical resonances
  - » Test simulations for extrapolation to advanced LIGO
  - » Explore modulation techniques such as Mach-Zehnder design

Projected Activity Highlights for 2006

- **Seismic isolation**
  - Assemble multi-stage BSC seismic isolation prototype at LASTI
  - Determine HAM seismic requirements and optimize design. Start LASTI prototype fabrication
- **Suspensions**
  - Test dynamics/controls prototype of quadruple pendulum suspension at LASTI
  - Finish final design and build test mass ‘noise’ suspension for integrated LASTI testing
  - Start final design of triple suspension
- **Core optics**
  - Continue coating R&D for lower mechanical and optical loss
  - Pursue ‘pathfinder’ polishing and coating for LAST ‘noise’ suspension
- **Control and Data Systems**
  - Install prototype systems at LASTI for seismic and suspension testing
  - Finish Electronics Infrastructure Conceptual Design
- **Pre-stabilized Laser**
  - Finish preliminary design and start bench prototypes
- **Integrated Sensing and Controls**
  - Continue 40M work on lock acquisition schemes and gravity wave readout systems
- **Project Baseline**
  - NSF Review of cost and schedule in May

On track for FY2008 construction start