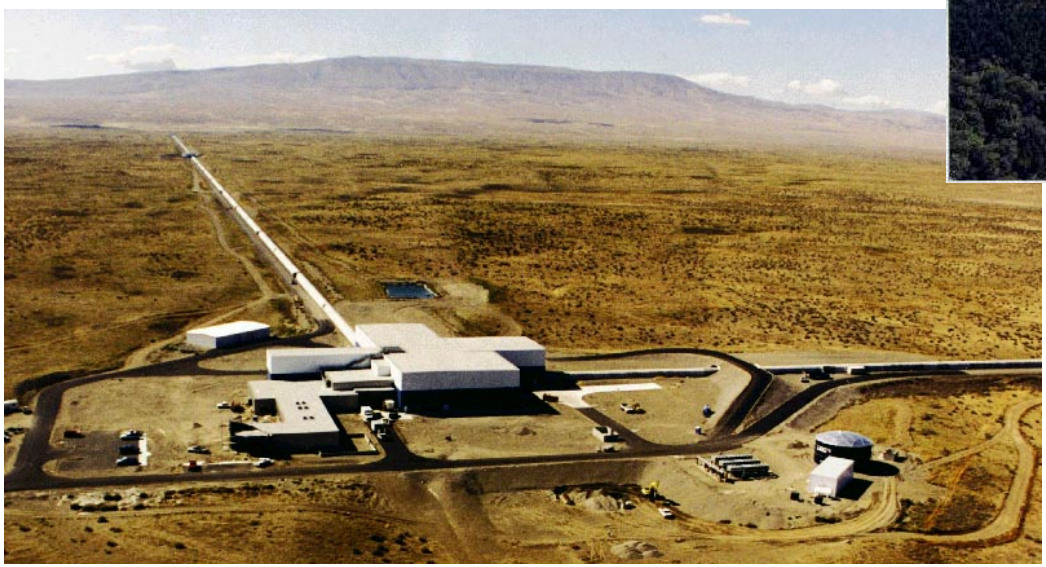
LIGO

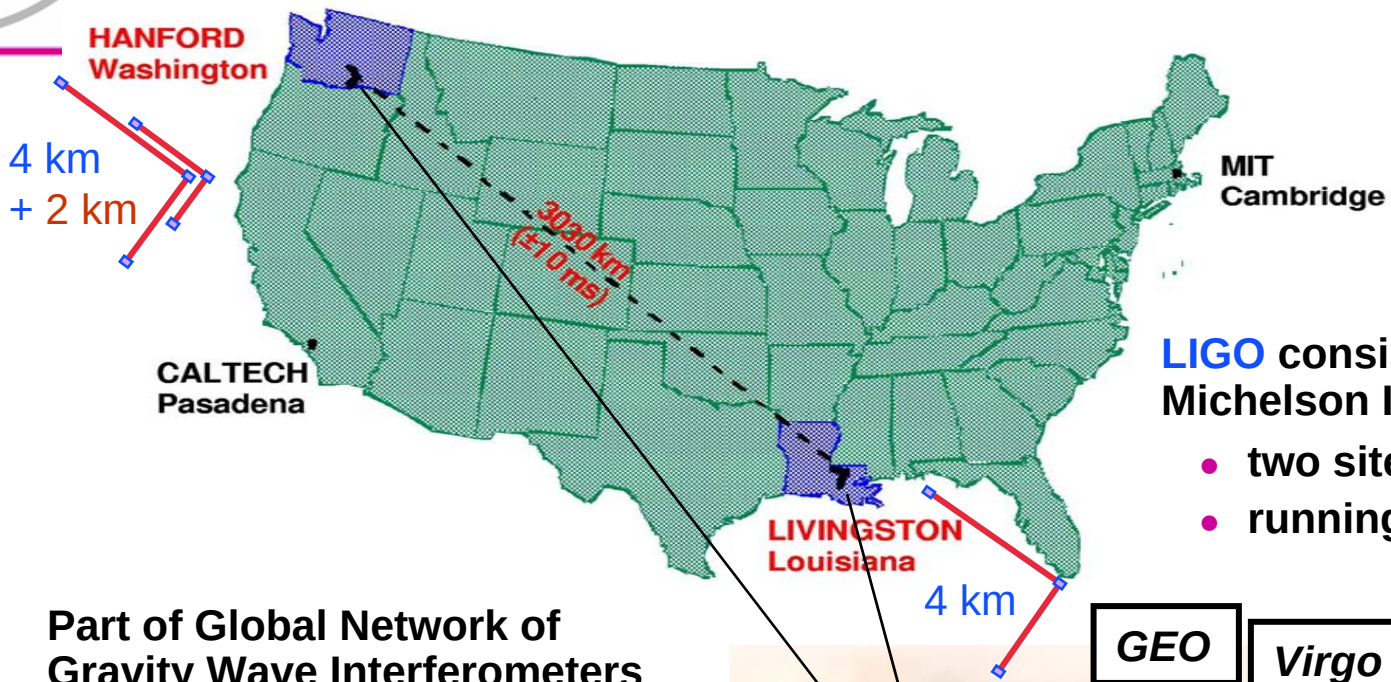
Plans for Advanced LIGO Instruments

Amaldi Meeting, July 12, 2007



Carol Wilkinson
LIGO Hanford Observatory

LIGO and Global GW Interferometer Network

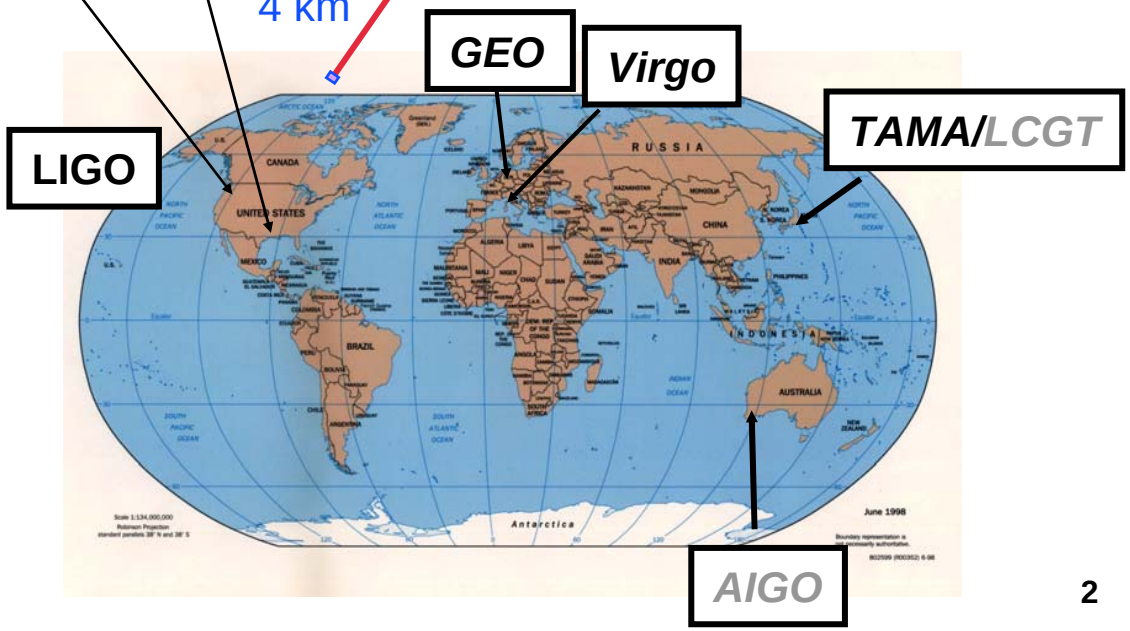


LIGO consists of 3 Fabry-Perot Michelson Interferometers

- **two sites 3030 km apart**
- **running in coincidence**

Part of Global Network of Gravity Wave Interferometers

- **VIRGO (Italy/France) - 3km arm length**
- **GEO 600 (UK/Germany) - 600m arm length**
- **TAMA 300 (Japan) - 300m arm length**
- **AIGO (Australia) – 80m R&D facility**



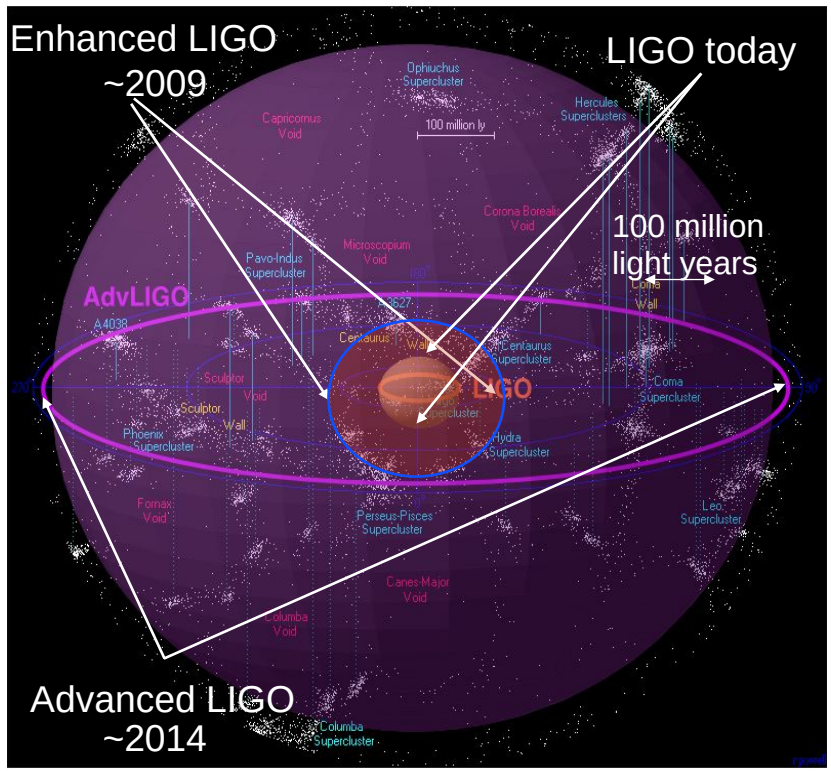
Phased Plan for LIGO Interferometers

Extend sensitivity and range of interferometers in steps

- **Initial LIGO**
  - Initial phase to establish science with low probability of observation
  - Equivalent year of data at full LIGO design sensitivity (S5) of 10^{-21} in 100 Hz bandwidth
  - Ending Sept 2007
- **Enhanced LIGO**
  - Factor of 2 improvement in sensitivity (factor of 8 in event rate)
  - Early tests of Advanced LIGO hardware and techniques
  - Install in 2008: Online in 2009 for 1 year
- **Advanced LIGO**
  - Factor of 10 improvement in sensitivity (factor of 1000 event rate)
  - Frequent observation; gravitational wave astrophysics
  - Install starting in 2011: Online in 2014

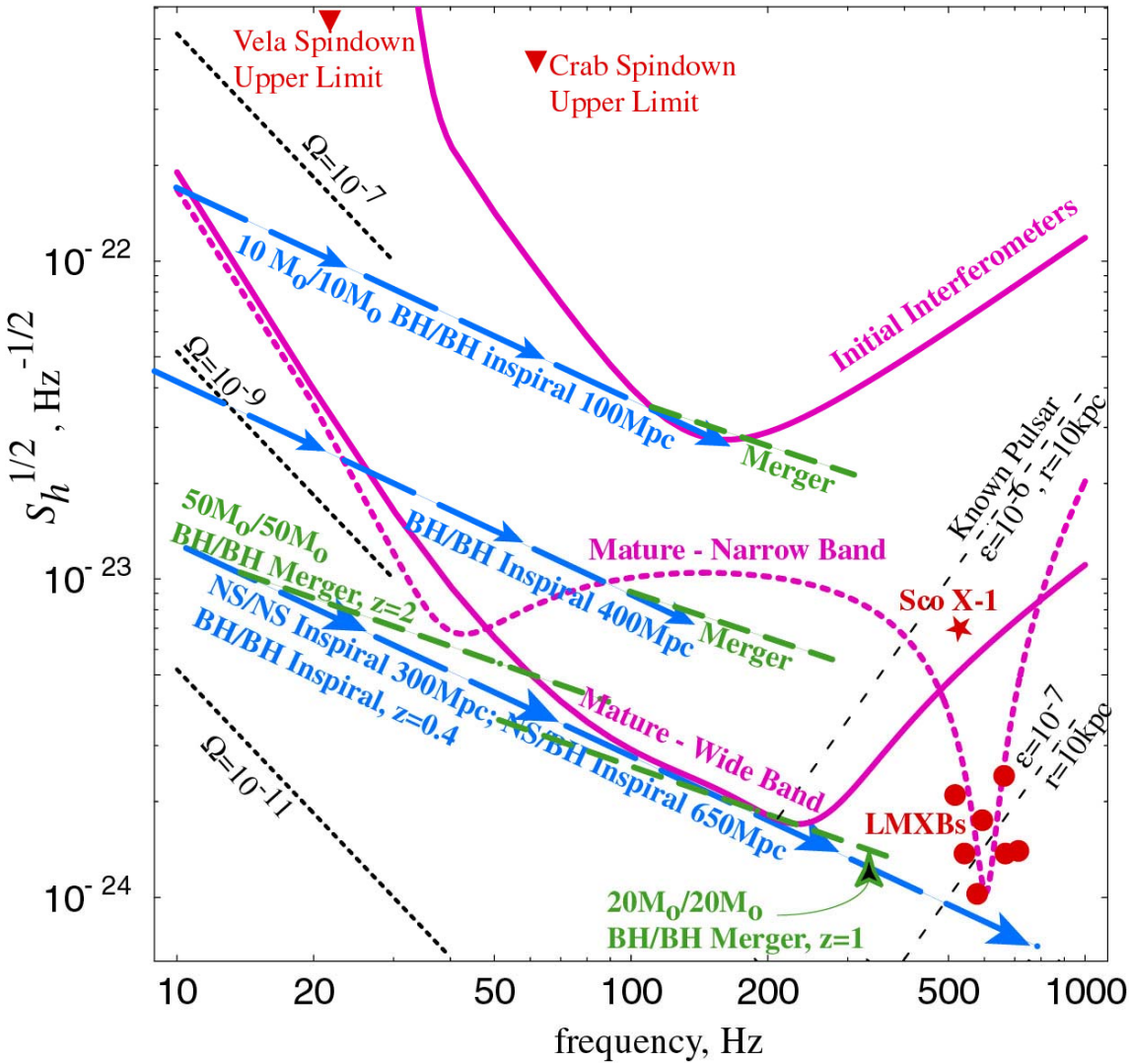
LIGO range for 1.4 Mo NS-NS binaries:

- Initial LIGO – Hundreds of galaxies
- Enhanced LIGO – Thousands of galaxies
- Advanced LIGO – Millions of galaxies



Advanced vs. Initial LIGO Astrophysical Reach

- Neutron star & black hole binaries
  - » inspiral
  - » merger
- Spinning neutron stars
  - » LMXBs
  - » known pulsars
  - » previously unknown
- Supernovae
- Stochastic background
  - » Cosmological
  - » Early universe



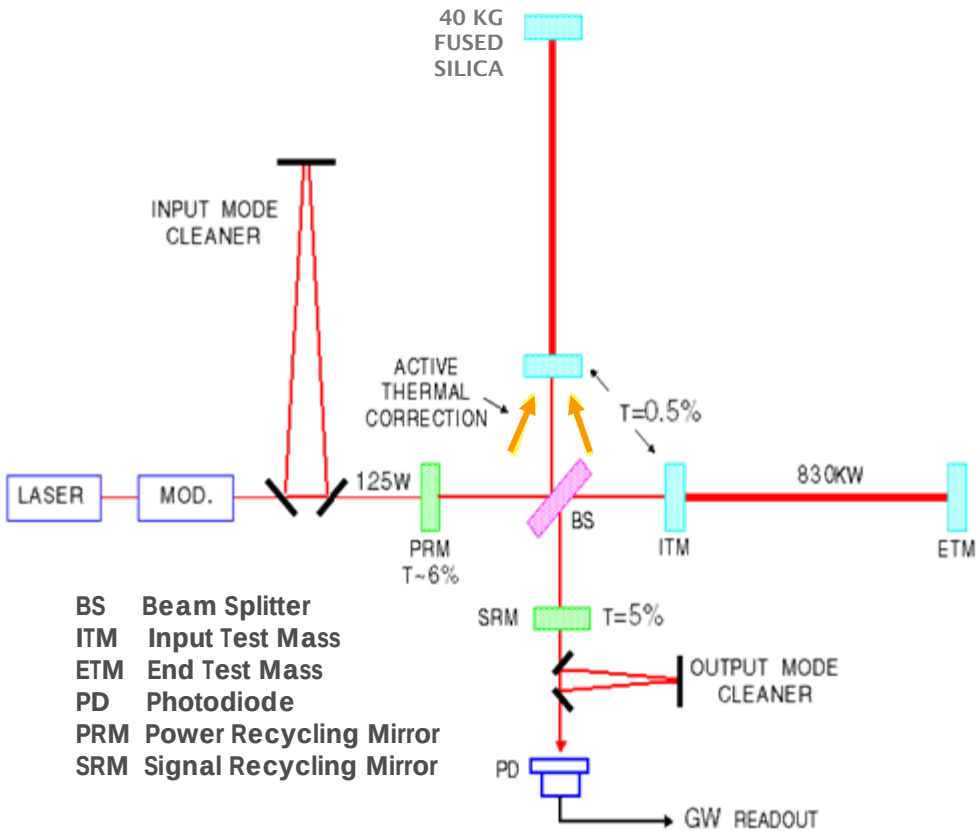
Advanced LIGO Detector Improvements

Upgrade instrument components to increase sensitivity and move seismic wall to lower frequencies

- 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.

ADVANCED LIGO LAYOUT

3 Fabry-Perot Michelson Interferometers with 4K arms



Advanced LIGO Parameters

Parameter	*LIGO*	*Advanced LIGO*
Input Laser Power	10 W	180 W
Mirror Mass	10 kg	40 kg
Interferometer Topology	Power-recycled Fabry-Perot arm cavity Michelson	Dual-recycled Fabry-Perot arm cavity Michelson
GW Readout Method	RF heterodyne	DC homodyne
Optimal Strain Sensitivity	3×10^{-23} / rHz	Tunable, better than 5×10^{-24} / rHz in broadband
Seismic Isolation Performance	f_{low} ~ 50 Hz	f_{low} ~ 10 Hz
Mirror Suspensions	Single Pendulum	Quadruple pendulum

Advanced LIGO in Context

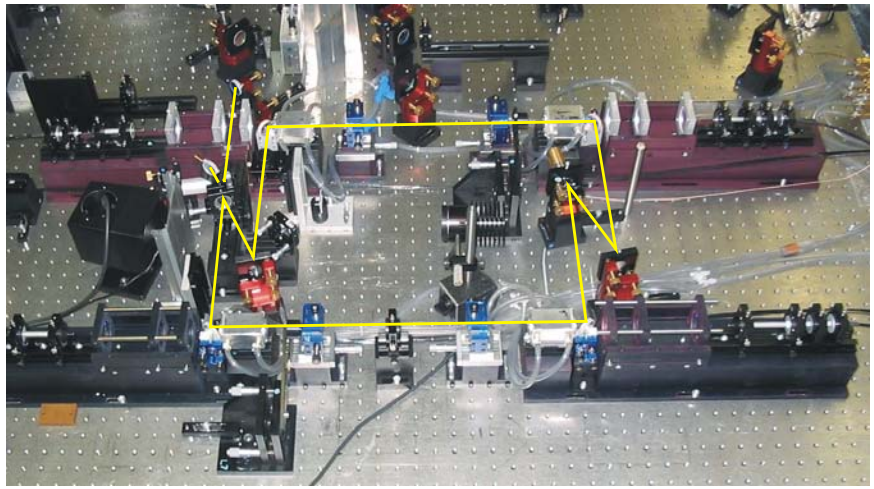
Black: Enhanced LIGO; Blue: Project

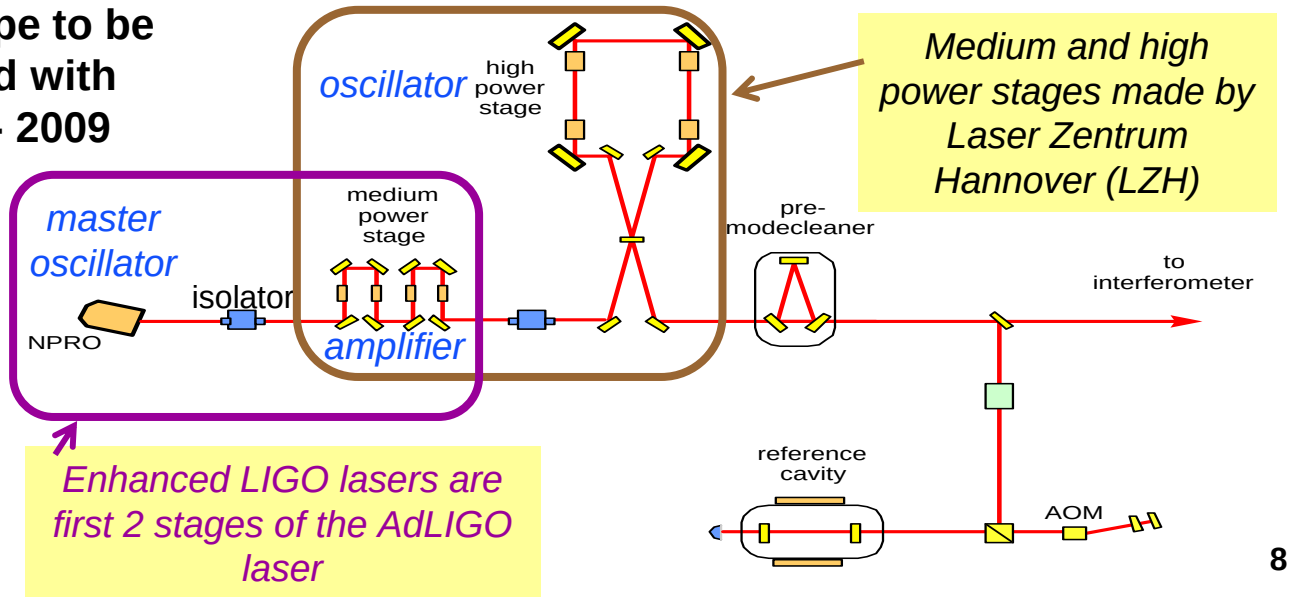
- **Enhanced LIGO install starts Oct 2008 at Hanford and Livingston**
  - **Initial LIGO S5 reaches goal 1 year of integrated data Sept 2007**
- **Advanced LIGO expected funding start Oct 2007**
  - **Procurements of optics, seismic pre-isolator (HEPI), and TM suspensions in 2008**
- **Complete prototype testing and final designs of remaining AdL systems in 2008 and early 2009**
  - **LIGO test beds and Enhanced LIGO integration**
- **Fabrication, assembly, and stand-alone testing of remaining detector components starts in 2009**
- **Enhanced LIGO science runs early 2009 to late 2010**
- **Advanced LIGO starts installing detector components in 2011**
- **First Advanced LIGO interferometer accepted (2-hour locked stretches) in 2013, second and third in 2014**
- **Engineering and coincident science runs starting in 2014**

Pre-Stabilized Laser (180W) Highlights

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

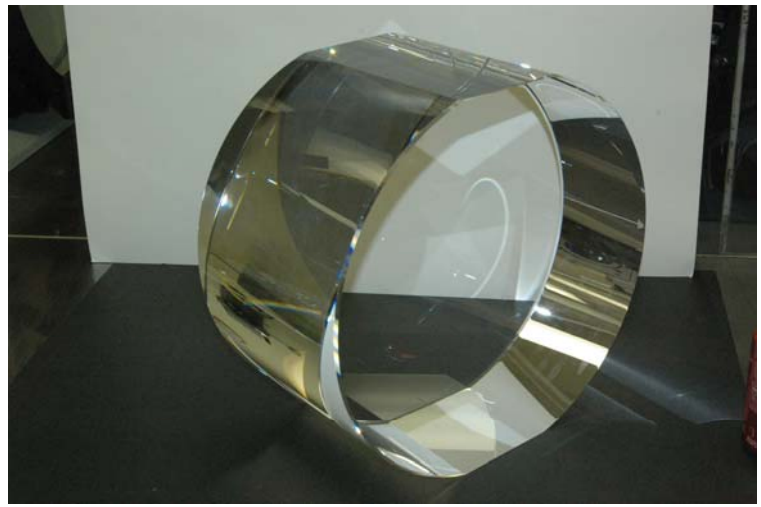
- **Injection locking of the 200 W Laser (LZH, AEI) demonstrated**
  - » **150W, 85% TEM00 mode, 8-10 hours**
- **New Front-End (medium power stage) changed from oscillator to amplifier**
  - » **First 35W FE delivered to LIGO**
  - » **2 more will be used in Enhanced LIGO**
- **Engineering prototype to be integrated and tested with LIGO controls 2008 - 2009**





Core Optics Highlights

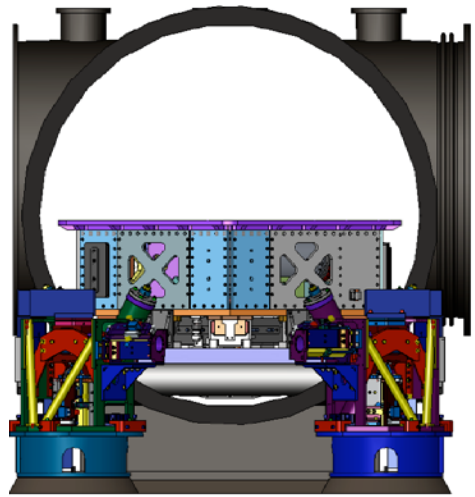
- **Selected low absorption, fused silica for Beam Splitters and Test Masses for procurement in 2008**
- **Acceptable silica/titania-doped tantalum coating recipe and vendor**
  - » **Continue R&D for low mechanical loss and absorption: will coat Test Masses with best possible coating in September 2009**
- **Pathfinder optics evaluate polishing and coating vendors; finalize specs mid to late 2008**
- **Exploring understanding and mitigation schemes for electrostatic discharge and parametric instability**



Seismic Isolation Highlights

- **Hydraulic External Pre-Isolator (HEPI):**
  - Deployed successfully at LLO, performance understood; procure in 2008
- **Internal Seismic Isolation (ISI) selected:**
  - Results from Technology Demonstrator at ETF/Stanford
  - Designed, built, tested, and rejected a prototype of alternative HAM Seismic Attenuation System (SAS)
- **Two stage ISI for the BSC chamber:**
  - In-air prototype testing complete; proceeding to in vacuum testing at LASTI
  - Start procurement early 2009
- **Single stage ISI for the HAM chamber:**
  - Started fabrication of 2 units for Enhanced LIGO
  - Complete integrated testing with Enhanced LIGO and start procurement in mid 2009

BSC-ISI Assembly at LASTI

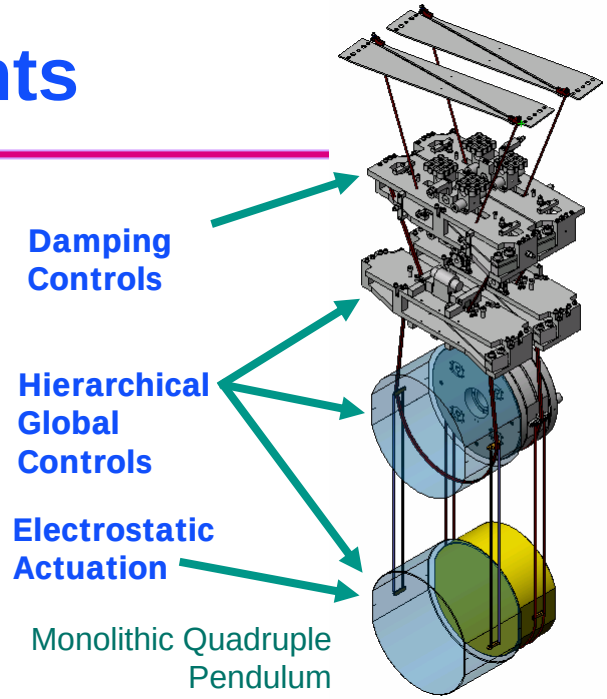


HAM-ISI CAD Model

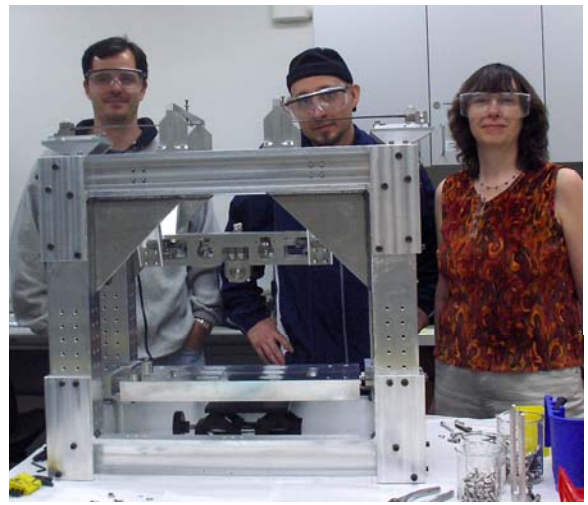
Suspensions Highlights

- **Test Mass (Quad) Suspension**
  - GEO-like monolithic design with fused silica fibers
  - ‘Controls’ prototype tested at LASTI
  - ‘Noise’ prototype being cleaned for integrated testing with ISI at LASTI
  - Production slated for early 2008
- **Mode Cleaner Suspension**
  - ’Controls’ triple prototype demonstrated at LASTI
  - Recycling mirror noise prototype testing at LASTI in 2008
  - Production starting in early 2009
- **Output Mode Cleaner**
  - Bench testing of prototype completed
  - Enhanced LIGO fabrication Aug 2007
  - Complete integrated testing in Enhanced LIGO and start production late 2008

ETM/ITM Quadruple Pendulum Noise Prototype Assembly at RAL



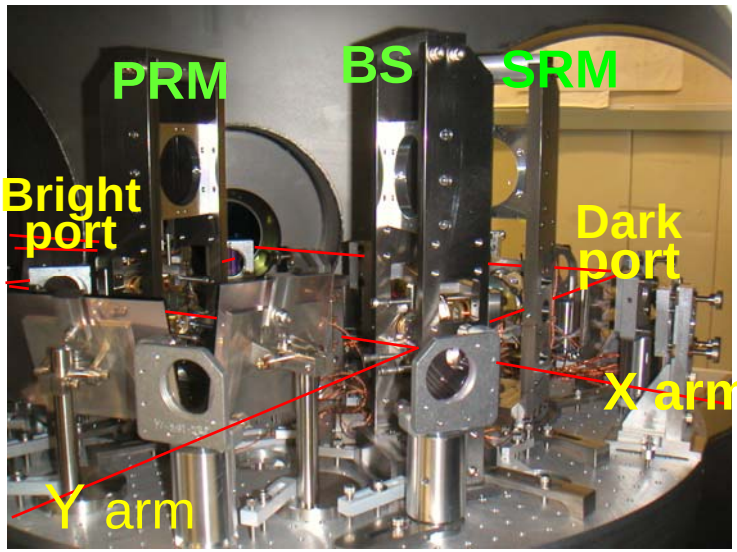
Monolithic Quadruple Pendulum



Output Mode Cleaner Suspension

Integrated Systems and Controls Highlights

- **DC readout design is well-advanced**
  - » Output Mode Cleaner and DC readout elements in fabrication for Enhanced LIGO
  - » Tip-tilt mirror development for OMC alignment: prototype built at Australia National University
- **Lock Acquisition**
  - » Locking test of a quad+triple suspension cavity in progress at LASTI
  - » Investigation of Seismic platform interferometer to stabilize low-frequency fluctuations of the long arms by Australia National University



40M beam splitter chamber

- **Alignment sensing and control**
  - » New modulation scheme with lower modulation frequency & more flexible interferometer tuning
  - » New InGaAs quadrant photodiodes identified and tested
- **Project fabrication schedule to start mid 2009**

Input Optics and Thermal Compensation Highlights

INPUT Optics

- **Mode cleaner optical design complete; procure optics in 2008**
  - » **Active beam jitter suppression dropped from design; PSL beam stability plus MC filtering good enough**
  - » **Controllable mode matching changed from CO2 beam directed on a MMT mirror to a resistive ring heater around an FI element**
- **Faraday isolators & RTP modulators being prepared for Enhanced LIGO**
- **Final design and procurement of other elements in 2008**

Modulator for EnLIGO

Isolator for EnLIGO

Thermal Compensation System

- **Full sensor-compensator test planned for LASTI in 2008-2009**
- **Production starting early 2010**

Advanced LIGO Status Summary

- R&D proceeding well
  - No significant technical issues
  - Matched to and keeping up with project schedule
- Enhanced LIGO is an early test of many Advanced LIGO subsystems
  - Will retire a lot of technical/implementation risk
- Passed baseline review in June at NSF – confirmation of cost, schedule
- Strong support from Congress for the NSF allowed budget for 2008
- Review in Fall after Congress allocates budget – one last check of situation (theirs and ours)
- ….Funding in ~October 2007…
- Start turning off ELI in 2010, start turning on AdL in 2013