Advanced LIGO Update

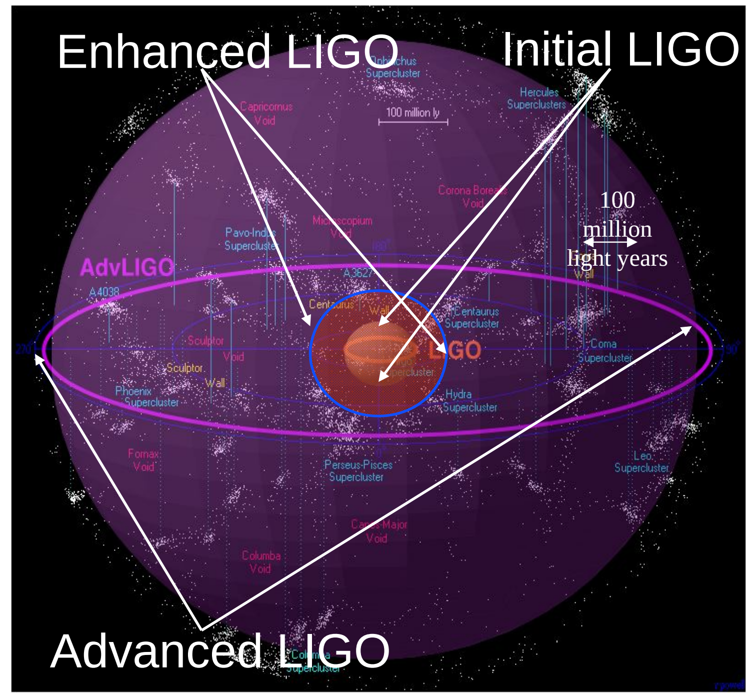
LIGO-Virgo Collaboration Meeting

26 September 2011

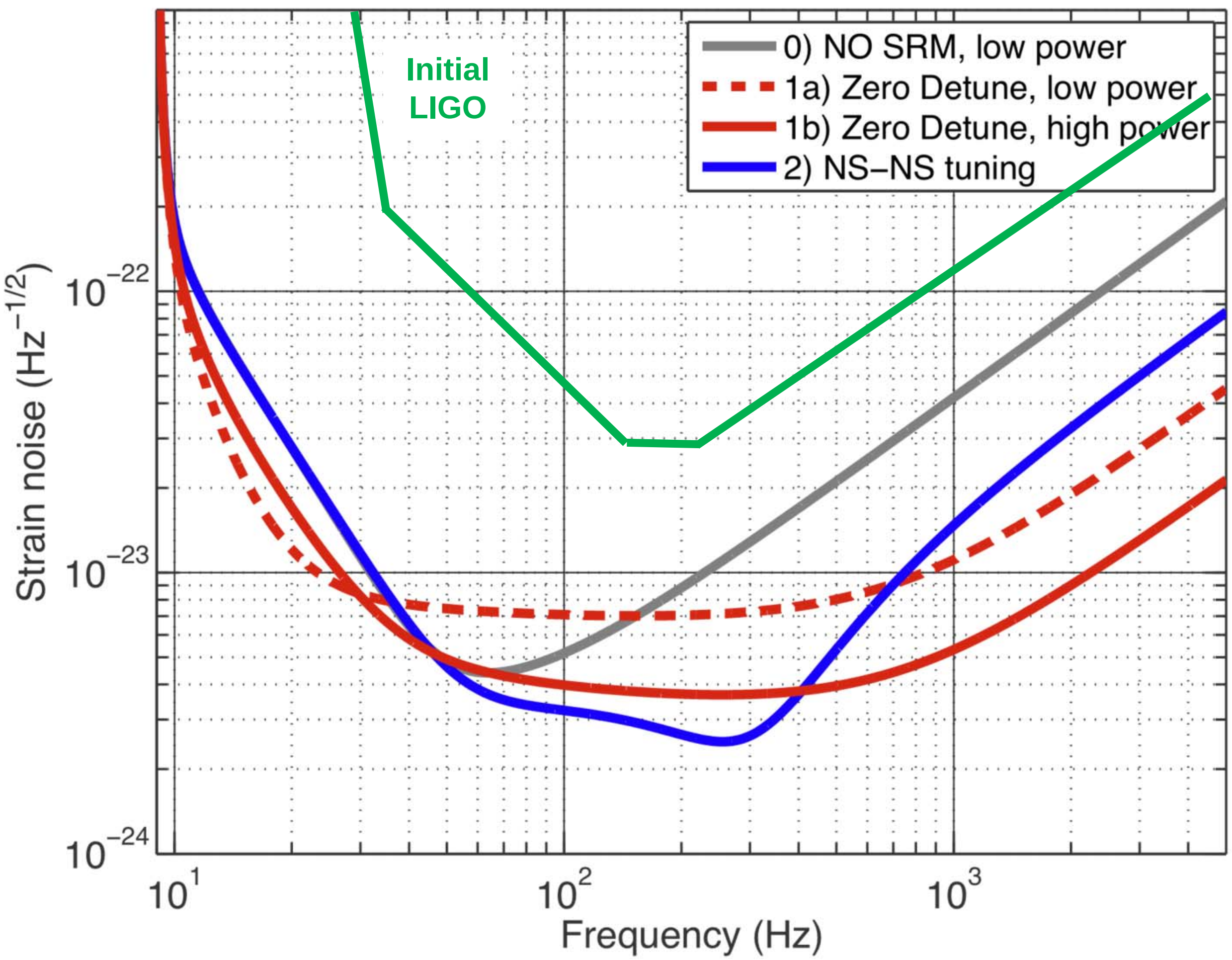
David Shoemaker

Advanced LIGO, viewed from 10,000 meters

- Factor of 10 greater sensitivity than initial LIGO
- Factor 4 lower start to sensitive frequency range
  - » ~10 Hz instead of ~40 Hz
  - » More massive astrophysical systems, greater reach, longer observation of inspirals
- Intended to start gravitational-wave astronomy
- Frequent detections expected – exact rates to be determined, of course
  - » Best guess: NS-NS inspirals 1/week – 1/month



Interferometer Performance – no anticipated change

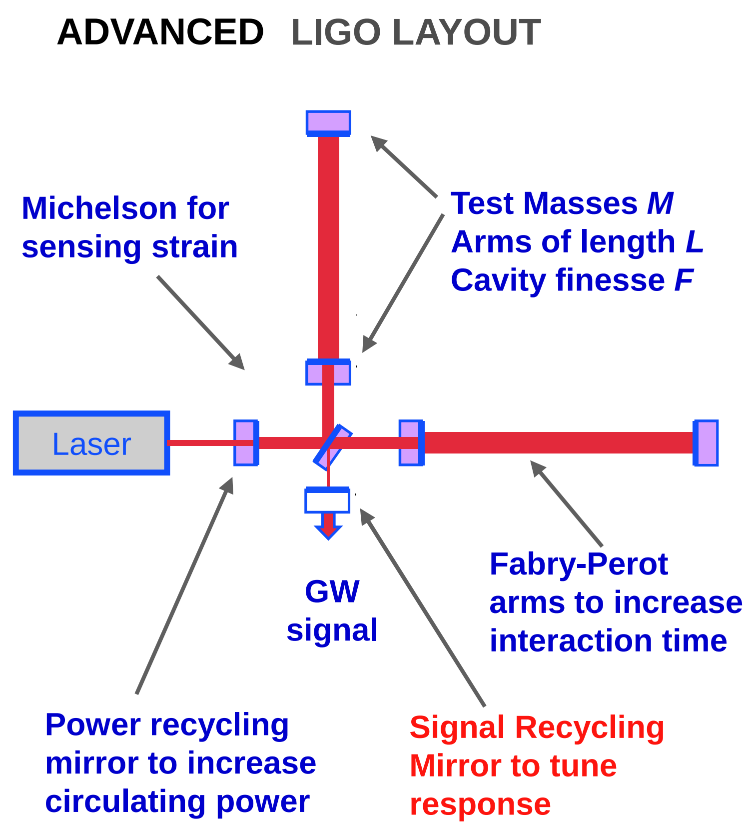


Detection range for binary inspirals

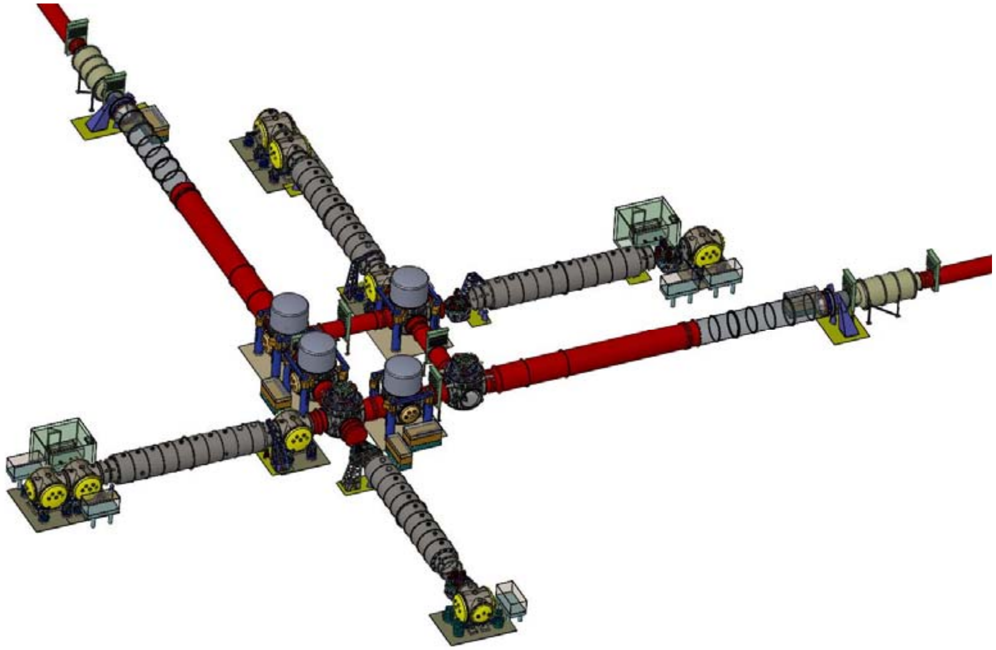
case	NS-NS	BH-BH (30 $M_{\odot}$)
0	150 Mpc	1.60 Gpc
1a	145 Mpc	1.65 Gpc
1b	190 Mpc	1.85 Gpc
2	200 Mpc	1.65 Gpc

Design Outline

- Recombined Fabry-Perot Michelson with
  - Signal recycling (increase sensitivity, add tunability)
  - DC readout, Output Mode Cleaner (better use of photons)
  - Mode-stable recycling cavities (more robust against thermal, etc. effects)
- ~20x higher input power (lower shot noise)
- 40 kg test masses (smaller motion due to photon pressure fluctuations)
- Larger test mass surfaces, low-mechanical-loss optical coatings (decreased mid-band thermal noise)
- Fused Silica Suspension (decreased low-frequency thermal noise)
- Active seismic isolation, quadruple pendulum suspensions (seismic noise wall moves from 40Hz → 10 Hz, control forces on test masses much reduced)



Advanced LIGO Scope



- Re-use of 99% of vacuum system, buildings, technical infrastructure
- Replacement of virtually all initial LIGO detector components
  - » Re-use of a small quantity of technical components – some eLIGO 'prototypes' promoted

- Three interferometers, as for Initial LIGO
  - » Can be all identical, or may choose to make one narrow-band at startup – requires exchange of one mirror
- All three interferometers 4km in length
  - » For initial LIGO, one of the two instruments at Hanford is 2km

Progress last 6 months, viewed from 10,000 meters

- Removal of initial LIGO complete for two interferometers
- Squeezing continuing on the third
- Almost all Advanced LIGO equipment contracted for production
- A lot of equipment – almost all Seismic and Suspension parts – made; DAQ installed and running; 2km test mass chambers moved 4km
- The first equipment being readied for installation in-vacuum

- Some delays due to fabrication difficulties – vacuum equipment, suspension parts, optics
- Some delays due to puzzles in testing, assembly, chamber cleaning

- We are bit over half-way done with the Project
- Now 5 months ahead of NSF schedule instead of 7 months
- Currently plan interferometers accepted (2 hour lock) July 2014

LIGO

View from 10 meters

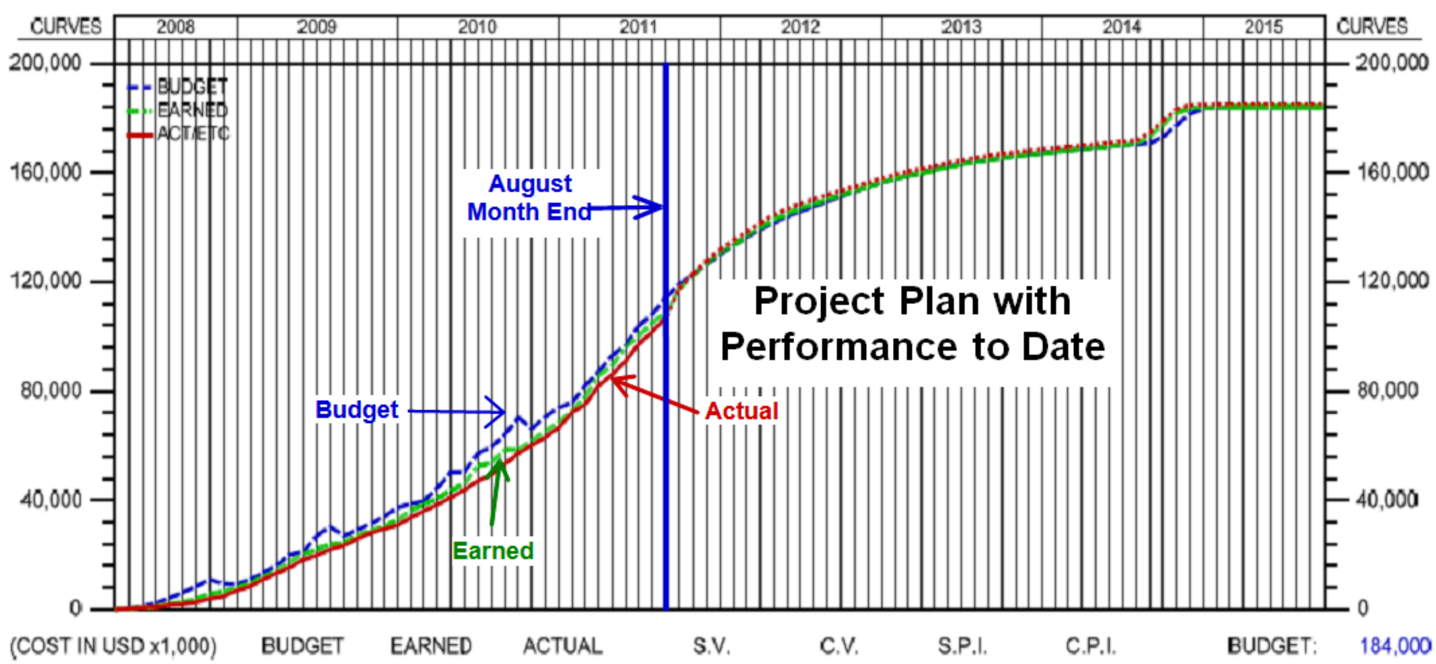
Advanced LIGO chronology

- 1999: Conceptual Design established, detailed design starts
  - » All development supported on Lab Operations, LSC funds – no Project funds
- April 2008: Project start
  - » All activities past Final Design Review on Project funds
- October 2010: Hand-off of Observatories to Advanced LIGO, de-install of Initial LIGO
- **Now: Installation seriously underway**
- Integrated testing of 4km arm, near-mirror Michelson in 2012
- August (was June) 2013: First Interferometer accepted (internal date)
- January 2014: 2nd, and July (was April) 2014 3rd, interferometers accepted (internal dates)
- March 2015: Computer procurement, planned Project end

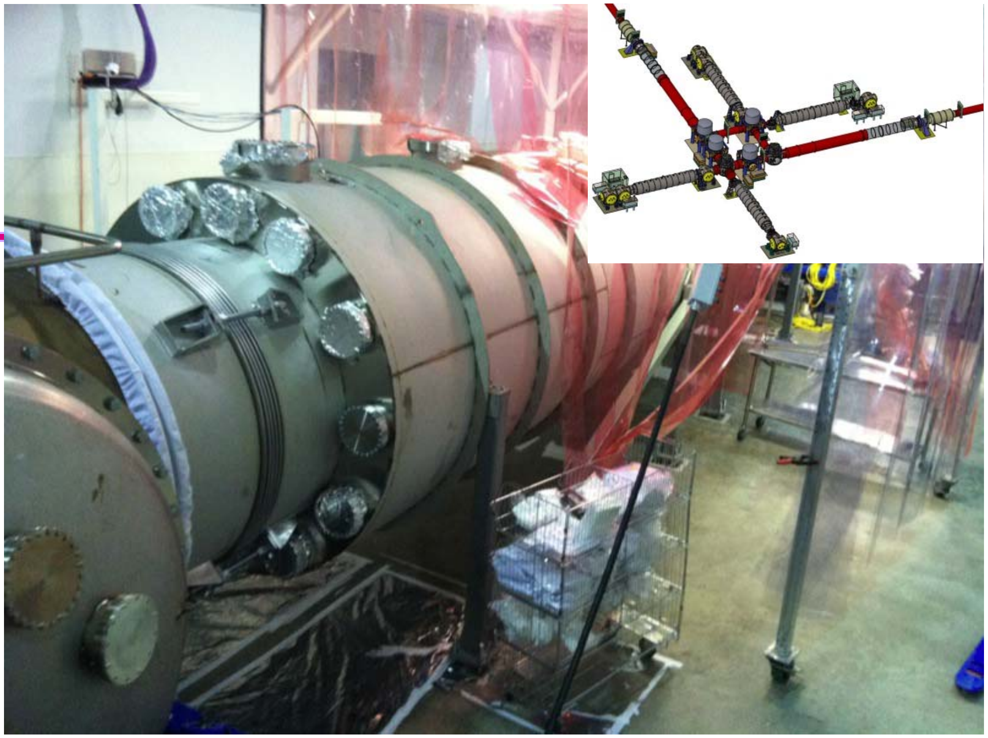
- By the way: LIGO-India (as was for LIGO-Australia) is not an element in our planning or execution at this time; will take that detour if it happens
  - » Expect it to be roughly break-even in schedule and cost if we do it

Metrics

- We have our full funding from the NSF to the close of FY2011 ($154M of $205)
  - Current markups indicate also full funding for 2012
  - Thank You NSF!
- The project is 60% complete
- The cost contingency is at about 25% of the remaining cost to complete
- We have used schedule contingency in the last half-year – 2 (of 7 initial) months at Livingston (L1) and one instrument at Hanford (H1)



Facility Modifications & Preparations (FMP)



- Modifications to the vacuum equipment: additions to enable the move of the chambers from 2k to 4k at LHO, larger Input and Output optics tubes
  - First tubes installed at LLO; second pair received; further units in fabrication
- In-chamber cleaning is now routine; requires constant flow of degreased pneumatic tools, but appears to be feasible
- Design and execution of Laser Area Enclosures: done for LLO and H1
- Fabrication and support of installation tooling

Seismic Isolation (SEI)

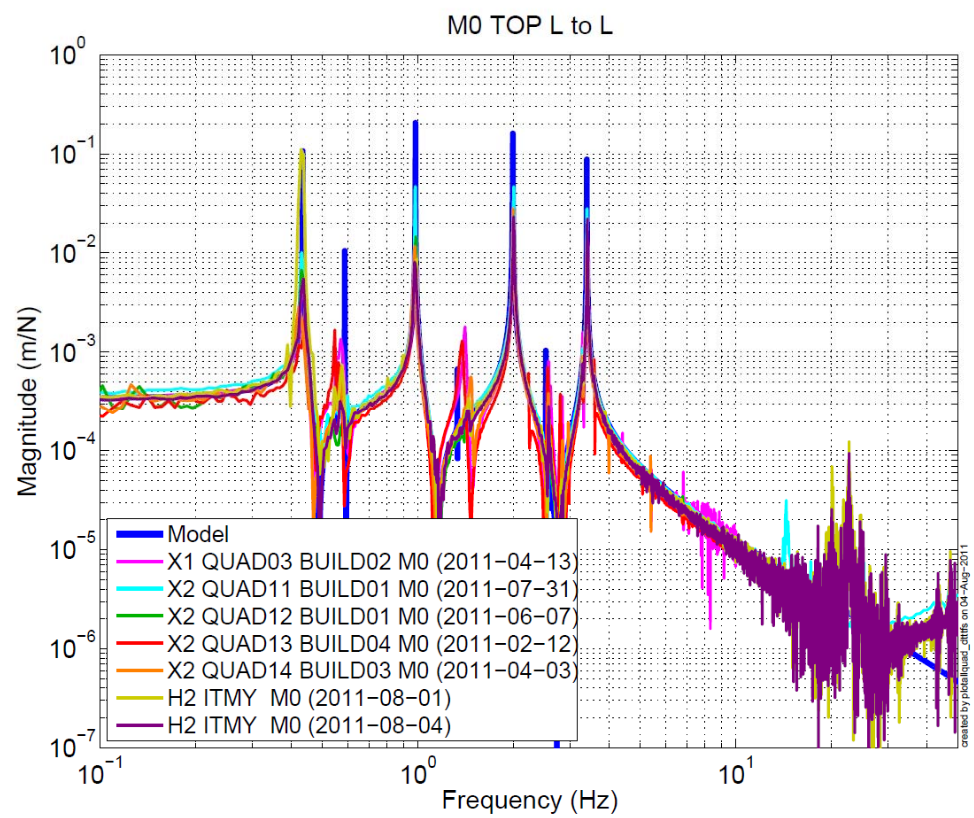
- Testing of the **last** of the HAM chamber internal seismic isolation platforms for LLO is underway, and assembly of LLO BSC units has started.
- At LHO, the first BSC isolator is tested, a second in testing, and a third BSC isolator is in assembly.

- Hydraulic pre-isolators are installed at both observatories, and plumbing is nearing completion.
- Some waiting for instruments – infant mortality complicated by vacuum issues
- Overall, great progress on this ‘foundational’ subsystem.
- A poster-child for testing as well

Suspensions (SUS) – UK Scope

- The UK consortium contributed the Test Mass Quadruple Suspensions
- Many of the quad systems are now assembled, with metal masses and wires

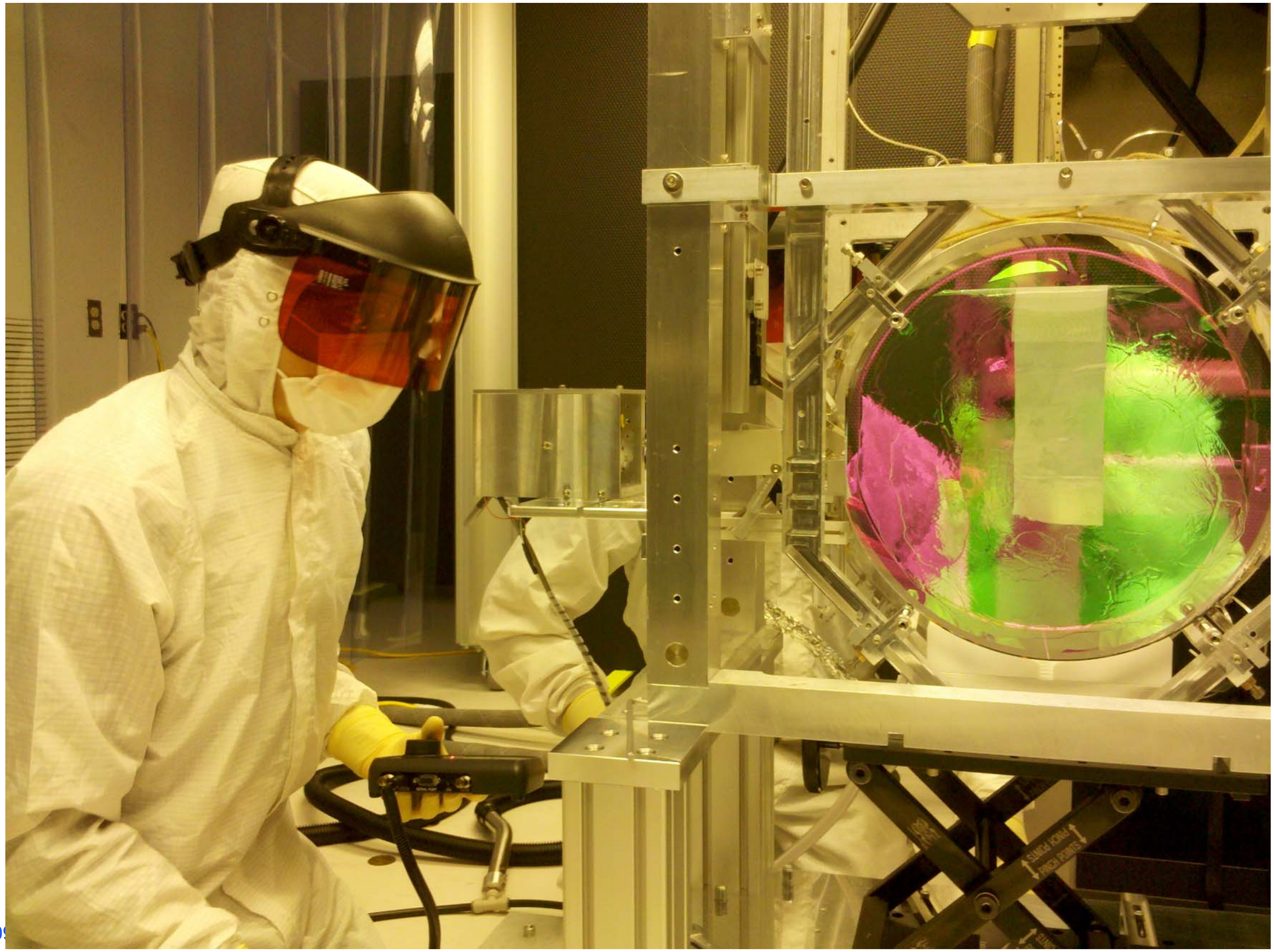
- A focus this last half-year has been on testing:
  - » Assembling a testing team
  - » Determining a successful test program
  - » Pushing through with a production environment of testing



Test mass suspensions

- The first suspension has been 'mated' to the first seismic isolator, and…

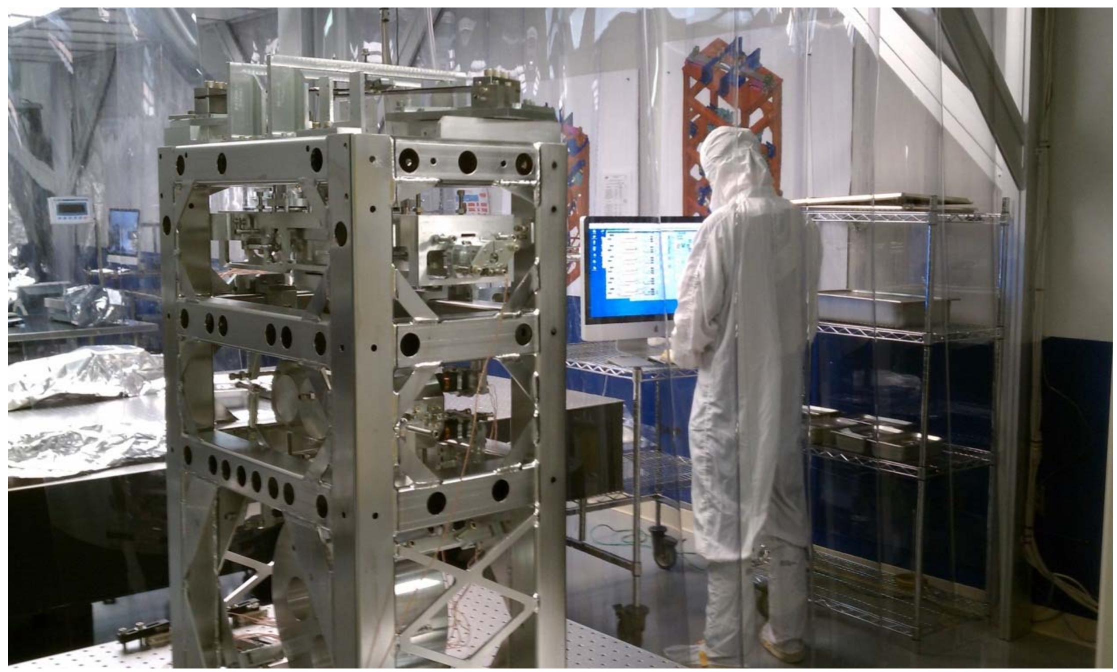
First production all-fused-silica suspension completed!



Suspensions (SUS) – US Scope

- US producing smaller suspensions for smaller optics, based on the same principle of multiple pendulum suspensions
- Procurement and fabrication of the Large and Small Triple Suspensions (HLTS, HSTS) parts has continued to be the focus for the team
- Difficulties with the spring production – oxidation of the Maraging steel between the fabricators and the protective nickel plating vendor
- Difficulties with the structure fabrication – welding, ordinary machining
- Believe we are over the 'hump'

- Now have all the structures for the Large triple suspensions, most all machined parts, and the first of the Large suspensions is now going together
- First small suspension frames almost ready, different vendor for remaining parts



Pre-stabilized laser (PSL)

- The core of the subsystem is being contributed by the Max Planck Albert Einstein Institute (AEI), using German funds; US provides interfaces, infrastructure, and computing
- The first Observatory Laser, at LLO, is installed, tested, and accepted for this phase of installation
- The second is at LHO and will be processed in October

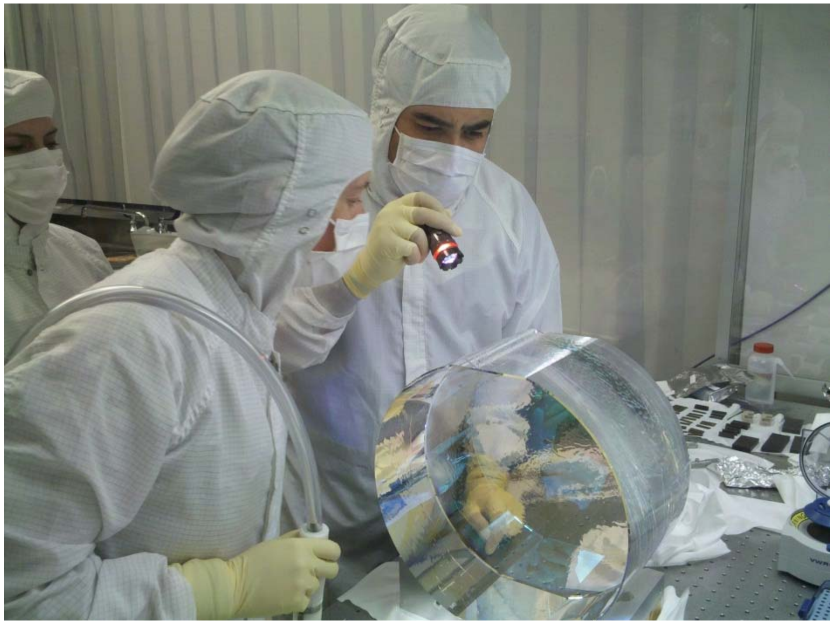
Input Optics (IO)

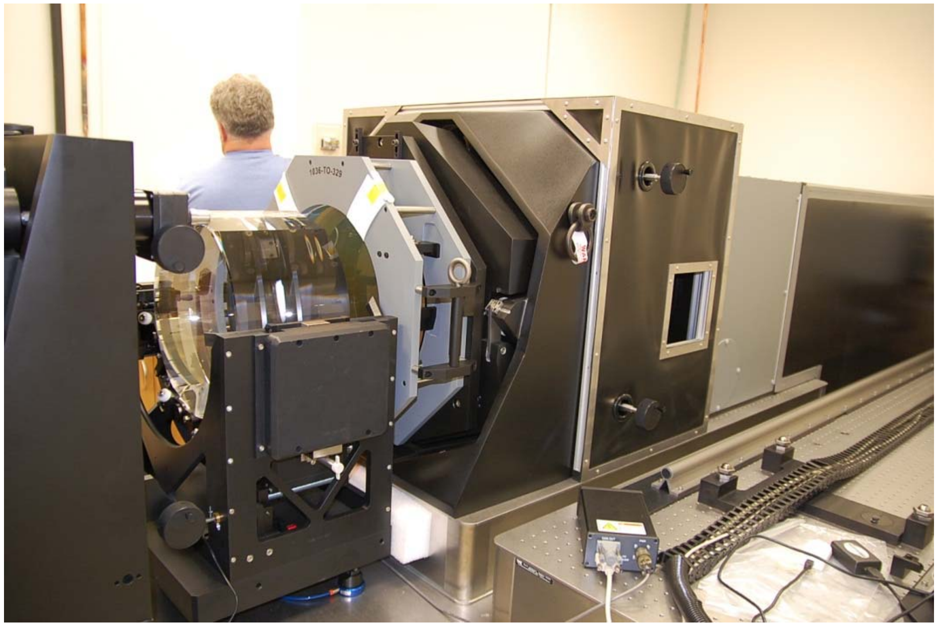
- The University of Florida (UFl) carries the responsibility for this subsystem under subcontract (as it did for initial LIGO).
- Optics largely procured, fabricated, characterized
- LLO out-of-vacuum components mounted on shared table with the Laser, in testing

- UFl group picked up additional scope for small suspensions, and playing key role in triple SUS assembly and test

Core Optics Components (COC)

- All originally planned COC substrates received and polished
- Making some more (initial material for end test masses not satisfactory)
- Coatings (temporary…) on end and input test masses for 4km one-arm test
- Will swap out later, but can get the value from the integration test with presently available optics
- It is *hard* to make optics to our specifications!





Auxiliary Optics Subsystem (AOS)

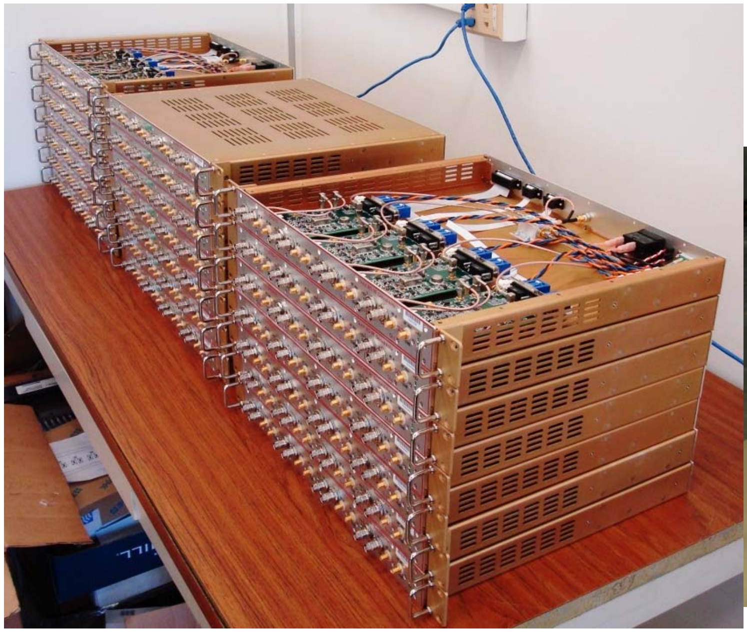
- The unifying theme for the AOS work is in-vacuum optical layout and beam transport:
  - » transport of interferometer output beams, suspended telescopes -- first such suspension being readied for one-arm test
  - » stray light control – baffles, some also suspended – went through cycle with porcelain coatings, back to stainless steel
  - » thermal compensation (including diagnostic wave front sensing) – CO_2 laser now identified
  - » optical levers for alignment reference – first pylons shipped
  - » initial alignment procedure and equipment, underway
  - » the photon calibration/excitation system
- The only subsystem with significant remaining development – has been necessary to replan into smaller ‘chunks’ to meet early needs
- It is now on a good path, although many of the deliveries will be just-in-time

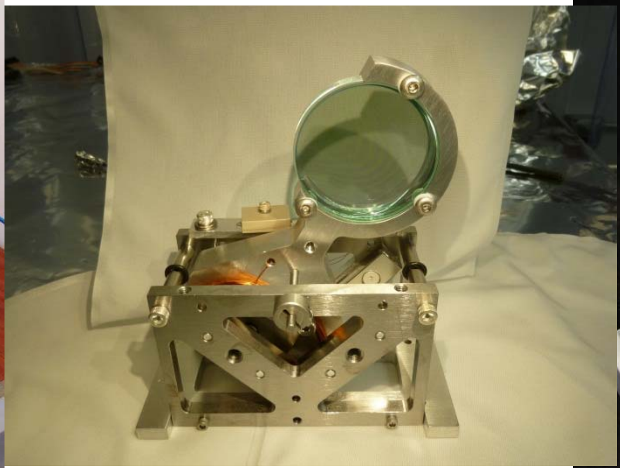
Interferometer Sensing & Control (ISC)

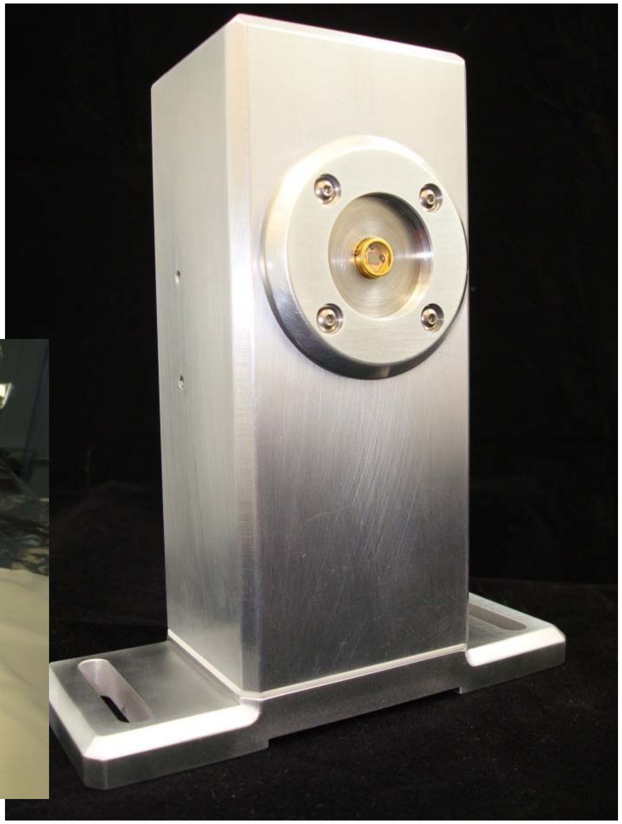
- Australia contributing the pre-lock Arm Length Stabilization system – being assembled now for the one-arm test

- Laser, optics, and electronics to arm-length stabilization light in and out of interferometer end mass coming together

- In-vacuum photodiode, beam diverter first articles ready





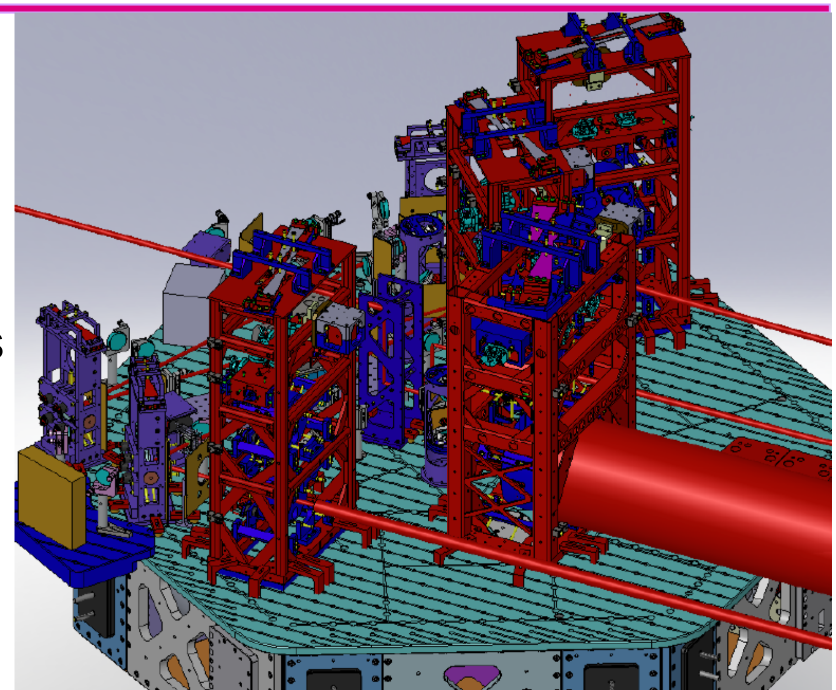


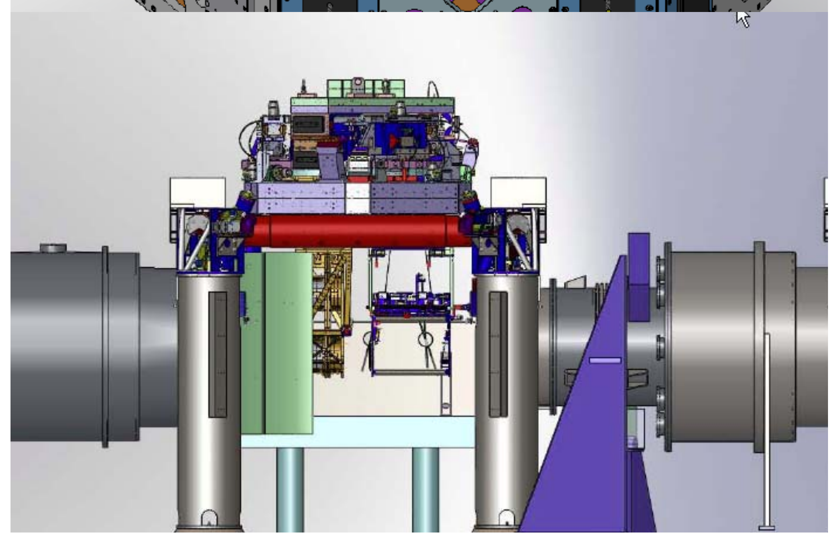
Data Acquisition, Supervisory Controls, Networking Subsystem (DAQ)

- Network and core DAQ system in place at both observatories
- Test stations using standard hardware and software in intensive use for subsystem assembly, alignment, testing
- Software well tested in the process
- Constructive users group leads to good bandwidth with software folks, but also some restraint on changes on-the-spot initiated by either software folk or scientists

Systems Engineering (SYS)

- Defines, establishes, and control individual subsystem requirements and interface requirements between subsystems
- SYS also maintains the opto-mechanical layout, maintains the mass budgets, performs trade studies as needed, and reviews technical compliance with requirements and standards by the subsystems
- A lot of the sophisticated mechanical engineering – FEA, thermal, etc. – is done by this group
- Integration in virtual space to ensure space, and order of assembly, works
- Cable design and routing
- Oversight of testing





Installation

- The Install leaders are central players in interfacing subsystems to the project management, coordinating and distributing resources, making peace, etc.
- Very significant progress on many fronts; often in conjunction with subsystems (so some common threads).
  A sampling:

- The Electronics building at LHO was placed on its foundation, and services installed. Additional cooling at LLO was installed to handle electronics heat loads.
- The PSL enclosure was finished up at LLO, and the H1 enclosure is well underway
- In-chamber cleaning: the first chamber took 7 weeks; most recent, 7 days

Installation

- The Hanford mid-station test mass (BSC) chambers were uninstalled and transported to the end station; the replacement spool pieces were installed and leak checked, and the system is again at vacuum

Installation

- Removal of one of the initial LIGO Input Optics beam tubes; the replacement tube is larger in diameter, allowing a more flexible optical layout of beams in the mode cleaner.

- HAM chambers were moved at both LHO and LLO to their new Advanced LIGO positions.

Challenges

- Maintaining schedule, for which the scariest parts for me are
  - Vacuum equipment updates fabricated and installed
  - Vacuum cleanliness tempo – Clean/Bake, in-chamber cleaning
  - Suspensions parts in house, assembled, and tested
  - Optics delivered in time, and meeting requirements
  - AOS parts into production
  - Finding that the difficult-to-detail-plan integration fits in our ‘struts’
- Working around the squeezing experiment on H1
- Keeping people happy and healthy – everyone on the aLIGO team is *very* invested in what’s going on

The Last Page

- Things have really moved along in the last 6 months
- We have now made significant material progress on all ‘phases’ of the project except integration
- We have used some schedule and cost contingency to get here
  - » Some lessons learned (read: mistakes made!) along the way
  - » Should allow some future potholes to be avoided
- …Integration is the remaining unexplored territory
  - » We have prepared well (read: better than for initial LIGO) by extensive, thorough, documented component and sub-assembly pre-testing
  - » Will be really underway in by the next LVC meeting with the one-arm work at LHO, the and the Mode Cleaner – Laser work at LLO

- Very busy year coming up
- I am confident that we’ll make some more mistakes, and that we will again make some really good progress –
- We live in exciting times.