LIGO Status and Plans

Barry Barish
March 13, 2000
LIGO Plans

(schedule)

1996 Construction Underway (mostly civil)
1997 Facility Construction (vacuum system)
1998 Interferometer Construction (complete facilities)
1999 Construction Complete (interferometers in vacuum)
2000 Detector Installation (commissioning subsystems)
2001 Commission Interferometers (first coincidences)
2002 Sensitivity studies (initiate LIGO I Science Run)
2003+ LIGO I data run (one year integrated data at h ~ 10^{-21})
2005 Begin LIGO II installation
LIGO Sites

Hanford Observatory

Livingston Observatory

3030 km (+/- 10 ms)
LIGO Facilities

Beam Tube Enclosure

• minimal enclosure
• reinforced concrete
• no services

Figure 2.1-1 -- Cross Section of Design Baseline at Hanford
LIGO Beam Tube

- LIGO beam tube under construction in January 1998
- 65 ft spiral welded sections
- Girth welded in portable clean room in the field
LIGO

vacuum equipment
Vacuum Chambers

HAM Chambers

BSC Chambers
Seismic Isolation

Constrained layer damped Springs
Seismic Isolation Systems

**Progress**

» production and delivery of components almost complete

» early quality problems have mostly disappeared

» the coarse actuation system for the BSC seismic isolation systems has been installed and tested successfully in the LVEA at both Observatories

» Hanford 2km & Livingston seismic isolation system installation has been completed, with the exception of the tidal compensation (fine actuation) system

» Hanford 4km seismic isolation installation is ~75% complete
Seismic Isolation Systems

Support Tube Installation

Stack Installation

Coarse Actuation System
LIGO I

interferometer

- LIGO I configuration
- Science run begins in 2002
Optics

mirrors, coating and polishing

- All optics polished & coated
  - Microroughness within spec. (<10 ppm scatter)
  - Radius of curvature within spec. (δR/R < 5%)
  - Coating defects within spec. (pt. defects < 2 ppm, 10 optics tested)
  - Coating absorption within spec. (<1 ppm, 40 optics tested)
The 2km Input Optics subsystem installation has been completed

- The Mode Cleaner routinely holds length servo-control lock for days
- Mode cleaner parameters are close to design specs, including the length, cavity linewidth and visibility
- Further characterization is underway
Input Optics

Hanford 2 km

Control System Racks

Input Optics Section
Recycling Cavity Alignment

- Alignment of the mode match telescope to the recycling cavity was accomplished by aligning the PSL beam to the projected reticule pattern & then by retroreflection from the recycling mirror.
Recycling Cavity Alignment

Adjusting the Fold Mirror Alignment
Initial Alignment System

Optical Levers

- Optical levers have been installed, aligned & are operational for all core optics in the 2km interferometer

Input Test Mass Optical Lever

Transmit & Receive modules visible with spool piece removed for input test mass alignment
Commissioning Configurations

- Mode cleaner and Pre-Stabilized Laser
- Michelson interferometer
- 2km one-arm cavity

- At present, activity focussed on Hanford Observatory
- Mode cleaner locking imminent at Livingston
Schematic of system
Commissioning

Pre-Stabilized Laser-Mode Cleaner

- Suspension characterization
  - actuation / diagonalization
  - sensitivity of local controls to stray Nd:YAG light
  - Qs of elements measured, $3 \times 10^{-5} - 1 \times 10^{-6}$

- Laser - Mode Cleaner control system shakedown

- Laser frequency noise measurement
Wavefront sensing

Mode Cleaner cavity

- Alignment system function verified
Michelson Interferometer

- Interference quality of recombined beams (>0.99)
- Measurements of Qs of Test Masses

Table 1. Internal Resonance Measurement Data

<table>
<thead>
<tr>
<th>Optic Name</th>
<th>Resonant Frequency (f_0) (kHz)</th>
<th>Mode Name</th>
<th>(Q) Measured</th>
<th>(Q) Theoretical</th>
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<tr>
<td>ITMx</td>
<td>6.1475</td>
<td>Butterfly</td>
<td>1.40x10^6</td>
<td>1.3x10^6</td>
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<td>ITMx</td>
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<td>Drum Head</td>
<td>6.16x10^5</td>
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<td>ITMx</td>
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<td>Breathing</td>
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</table>

* A rough estimate compared to other values in table (data analysis method for this value was different). Betsy Weaver 1/19/00
2km Fabry-Perot cavity

- Includes all interferometer subsystems
  - many in definitive form; analog servo on cavity length for test configuration
- confirmation of initial alignment
  - ~100 microrad errors; beams easily found in both arms
- ability to lock cavity improves with understanding
  - 0 sec 12/1 flashes of light
    - 0.2 sec 12/9
    - 2 min 1/14
    - 60 sec 1/19
    - 5 min 1/21 (and on a different arm)
    - 18 min 2/12
    - 1.5 hrs 3/4 (temperature stabilize pre modecleaner)
2km Fabry-Perot cavity

- **models of environment**
  - temperature changes on laser frequency
  - tidal forces changing baselines
  - seismometer/tilt correlations with microseismic peak

- **mirror characterization**
  - losses: ~6% dip, excess probably due to poor centering
  - scatter: appears to be better than requirements
  - figure 12/03 beam profile
2km Fabry-Perot cavity
15 minute locked stretch
Schedule

commissioning and testing

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<thead>
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<th>ID</th>
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12/22 7/18
12/20 7/17
## Significant Events

| **Hanford 2km interferometer** | Single arm test complete installation complete interferometer locked | 6/00  
|                               |                                                                      | 8/00  
|                               |                                                                      | 12/00 |
| **Livingston 4km interferometer** | Input Optics completed interferometer installed interferometer locked | 7/00  
|                                |                                                                      | 10/00 |
|                                |                                                                      | 2/01  |
| **Coincidence Engineering Run (Hanford 2km & Livingston 4km)** | Initiate Complete | 7/01  
|                                      |                                                                      | 7/02  |
| **Hanford 4km interferometer** | All in-vacuum components installed interferometer installed interferometer locked | 10/00  
|                                |                                                                      | 6/01  |
|                                |                                                                      | 8/01  |
| **LIGO I Science Run (3 interferometers)** | Initiate Complete (obtain 1 yr @ h ~ $10^{-21}$) | 7/02  
|                                            |                                                                      | 1/05  |
LIGO

*astrophysical sources*

Sensitivity of LIGO to coalescing binaries

- **LIGO I** (2002-2005)
- **LIGO II** (2007- )
- Advanced LIGO
Phase Noise

splitting the fringe

• spectral sensitivity of MIT phase noise interferometer

• above 500 Hz shot noise limited near LIGO I goal

• additional features are from 60 Hz powerline harmonics, wire resonances (600 Hz), mount resonances, etc
Noise Floor

40 m prototype

- displacement sensitivity in 40 m prototype.
- comparison to predicted contributions from various noise sources
Detection Strategy

Coincidences

Two Sites - Three Interferometers

- Single Interferometer: non-gaussian level ~50/hr
- Hanford (Doubles): correlated rate (x1000) ~1/day
- Hanford + Livingston: uncorrelated (x5000) <0.1/yr

- Data Recording (time series)
  - gravitational wave signal (0.2 MB/sec)
  - total data (16 MB/s)
  - on-line filters, diagnostics, data compression
  - off line data analysis, archive etc

- Signal Extraction
  - signal from noise (vetoes, noise analysis)
  - templates, wavelets, etc
Real interferometer data is UGLY!!!
(Gliches - known and unknown)
The Problem

How much does real data degrade complicate the data analysis and degrade the sensitivity??

Test with real data by setting an upper limit on galactic neutron star inspiral rate using 40 m data
"Clean up" data stream

Effect of removing sinusoidal artifacts using multi-taper methods

Non-stationary noise
Non-gaussian tails
**Inspiral ‘Chirp’ Signal**

**Template Waveforms**

“matched filtering”
687 filters

44.8 hrs of data
39.9 hrs arms locked
25.0 hrs good data

sensitivity to our galaxy
$h \sim 3.5 \times 10^{-19} \text{ mHz}^{-1/2}$
expected rate $\sim 10^{-6}$/yr
Detection Efficiency

- Simulated inspiral events provide end to end test of analysis and simulation code for reconstruction efficiency
- Errors in distance measurements from presence of noise are consistent with SNR fluctuations
Setting a limit

Upper limit on event rate can be determined from SNR of ‘loudest’ event

Limit on rate:
\[ R < 0.5/\text{hour with } 90\% \text{ CL} \]
\[ \varepsilon = 0.33 = \text{detection efficiency} \]

An ideal detector would set a limit:
\[ R < 0.16/\text{hour} \]
Conclusions

- LIGO I construction complete
- LIGO I commissioning and testing ‘on track’
- Interferometer characterization underway
- Data analysis schemes are being developed, including tests with 40 m data