

LIGO Is ON!
The Laser Interferometer Gravitational-Wave Observatory

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These are exciting times for LIGO, for the LIGO Scientific Collaboration, and for the international community of gravitational-wave interferometric detectors. As we present this status report, the initial LIGO detectors are midway through a two-month science run at sensitivity levels within a factor of ten of requirements and are already yielding data that will establish new upper limits on the gravitational-wave flux. Additional commissioning is required. This will be followed in 2004 by operation at the target threshold levels. Our goal is to record at least one full integrated year of data through 2006. In 2007 we will begin installation of Advanced LIGO detectors. The sensitivity of LIGO detectors is improving rapidly as we install the final interferometer systems and resolve remaining technical challenges. To date, commissioning progress has been so successful that we are already performing the most sensitive searches ever undertaken for gravitational waves.

1 LIGO Status

The total funding provided by the US National Science Foundation (NSF) for LIGO construction and initial operations was \$360,728,000 (US). Of this, we have expended all but approximately \$2 million, which will be used over the next few months to procure additional computers for data analysis and materials required to complete the facilities. LIGO is over 99 percent complete. All of the major construction project milestones have been completed.

2 A Picture Tour of LIGO



Figure 1: The LIGO Hanford Observatory (left), located 26 kilometers north of Richland in Washington State includes a two-kilometer interferometer and a four-kilometer interferometer in the same vacuum envelope. The LIGO Livingston Observatory (right), located 42 kilometers east of Baton Rouge, Louisiana, is a single four-kilometer interferometer.



Figure 2: The beam tube and enclosure under construction in 1998. The beam tube is 1.2 meters in diameter and the wall is 3 mm stainless steel. The tube was constructed in 65-foot spiral welded sections that were girth welded together in place in portable clean rooms. The beam tube was baked in situ at 160 C. The volume of the vacuum system is 20,000 m³ at 10⁻⁸ to 10⁻⁹ torr. There are over 50 kilometers of weld, and this was accomplished with no leaks.

3 Commissioning and Operations

Our commissioning strategy intersperses periods of intense activity with quiet operation. Initially the operational periods were termed “Engineering Runs,” since the primary focus was to collect data for the subsequent tuning activity and also to test software under development for data analysis.

The seventh engineering run started December 28, 2001 and continued through January 14, 2002, a total of 402 hours. This was an important project milestone for LIGO because it was our



Figure 3: Process Systems International provided the vacuum chambers in the corner and end-stations.

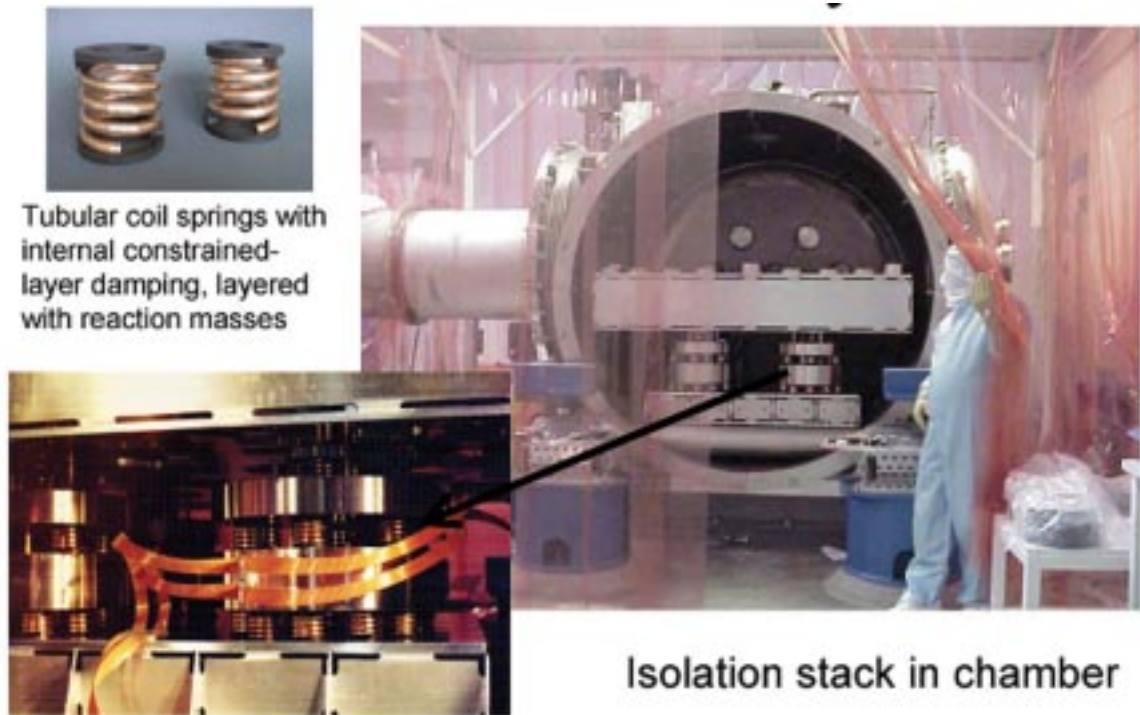


Figure 4: An isolation stack is shown in one of the horizontal access module vacuum chambers. All installation was performed in portable clean rooms.

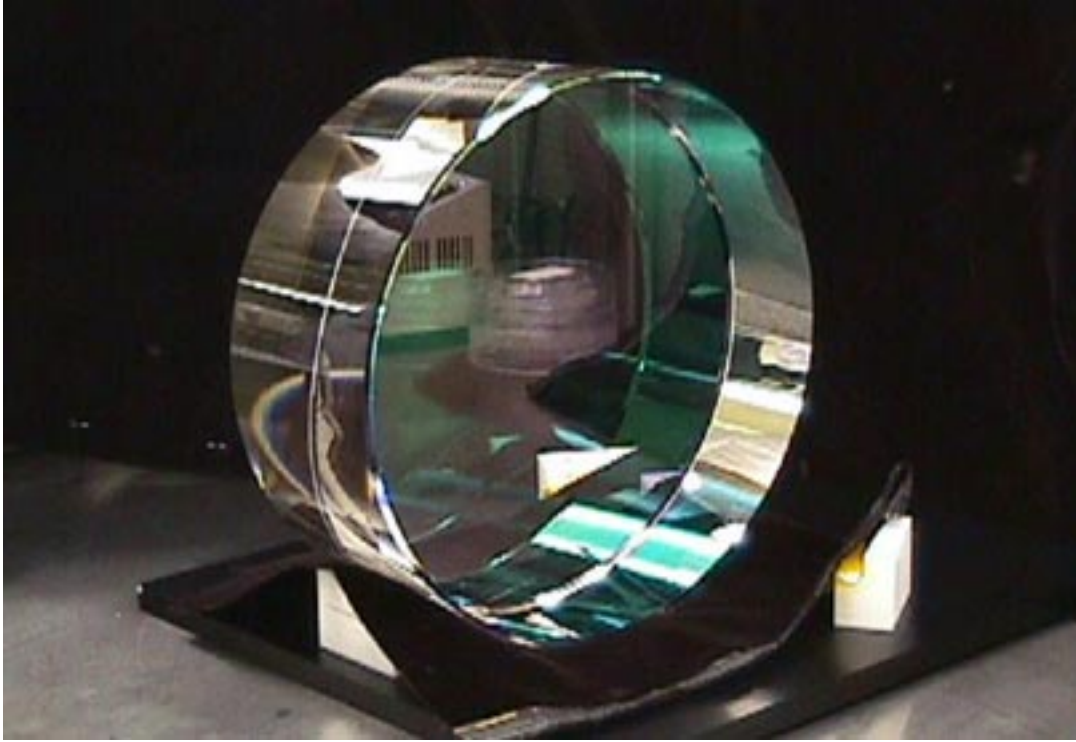


Figure 5: The LIGO test masses are SiO₂, 25 centimeters in diameter and 10 centimeters thick. Homogeneity is less than 5×10^{-7} and the internal mode Q's are greater than 2×10^6 . The optics are polished to a surface uniformity of less than 1 nm rms and the radii of curvature are matched to less than 3 percent. The coating scatter is less than 50 ppm, absorption is less than 2 ppm, and the uniformity is less than 10^{-3} .



Figure 6: A suspension and optic mounted on an optical table. In the initial LIGO configuration the suspensions are all single stage.

first attempt to operate all three LIGO interferometers in coincidence. This was also the final reporting milestone for the cooperative agreement with the NSF for the construction portion of the project. GEO, a joint United Kingdom/German interferometer^a was also operated in coincidence during this run.

Table 1 summarizes some of the statistics for E7. For example, the Livingston four-kilometer interferometer (L1) accumulated a total of 231 hours in clean segments longer than 15 minutes for a total availability of 53 percent. The longest clean segment was 3 hours and 58 minutes. All three LIGO interferometers operated in coincidence for 46 hours (11 percent availability) with the longest segment being one hour and 18 minutes. The three LIGO interferometers were operated in coincidence with the GEO interferometer a total of 26 hours (7.8 percent availability). The strain sensitivity of the Hanford two-kilometer interferometer approached 10^{-20} ($1/\sqrt{\text{Hz}}$) at 1000 Hz. This experience demonstrated that large duty cycles were attainable.

Table 1: E7 Engineering Run Statistics

<i>Configuration</i>	<i>Total clean segments longer than 15 minutes</i>	<i>Availability (percent)</i>	<i>Longest clean segment (hrs:min)</i>
Livingston four-kilometer (L1)	231 hours	53	3:58
Hanford four-kilometer (H1)	206 hours	48	4:04
Hanford two-kilometer (H2)	125 hours	28	7:24
L1, H2 in coincidence	70 hours	16	1:50
L1, H1, H2 in triple coincidence	46 hours	11	1:18
L1, H1, H2, and GEO in coincidence	26 hours	7.8	

LIGO initiated its first science run (S1) August 23, 2002. Data was recorded over 17 days (408 hours) some of it in coincidence with GEO. During S1, the most sensitive detector (the Livingston four-kilometer interferometer) approached a strain sensitivity of 10^{-21} ($1/\sqrt{\text{Hz}}$). The “in-lock” statistics for S1 are summarized in Figure 7 and Table 2.

This was our first opportunity to record data specifically targeting the search for gravitational waves. The sensitivity of the detectors, though short of our ultimate goal, was still better than any previous attempts with multiple interferometers in coincidence. We did not really expect to find gravitational waves, but we did “reach” a bit further into the universe. New “upper limits” on the gravitational-wave flux were established, and preliminary results will be presented during this conference^{b,c} and are being prepared for publication.

The LIGO Scientific Collaboration (LSC) is performing these analyses. The LSC is divided into four working groups, one each for: inspiral sources (e.g., compact binary inspiral), burst sources (e.g., supernovae, gamma ray bursts), periodic sources (e.g., pulsars), and cosmological signals (e.g., the stochastic background). Draft pre-prints were sent to the collaboration in January 2003, and released for internal comment and for selected presentations in March.

Since S1, the commissioning team has made even more impressive advances, as illustrated in Figure 8. This plot shows the evolution of the sensitivity of the four-kilometer detector in

^a<http://www.geo600.uni-hannover.de/>

^b“Results from LSC Known Periodic Sources Upper Limit Group,” A. Sintes (Palma)

^c“Results from LSC Coalescing Binaries Upper Limit Group,” G. Gonzalez (Baton Rouge)

H1: 235 hours
Verticle Bars (with dark bands): “in-lock” segments

Lines: integrated “in-lock” segments

H2: 298 hours

L1: 170 hours

Triple
Coincidence:
95.7 hours

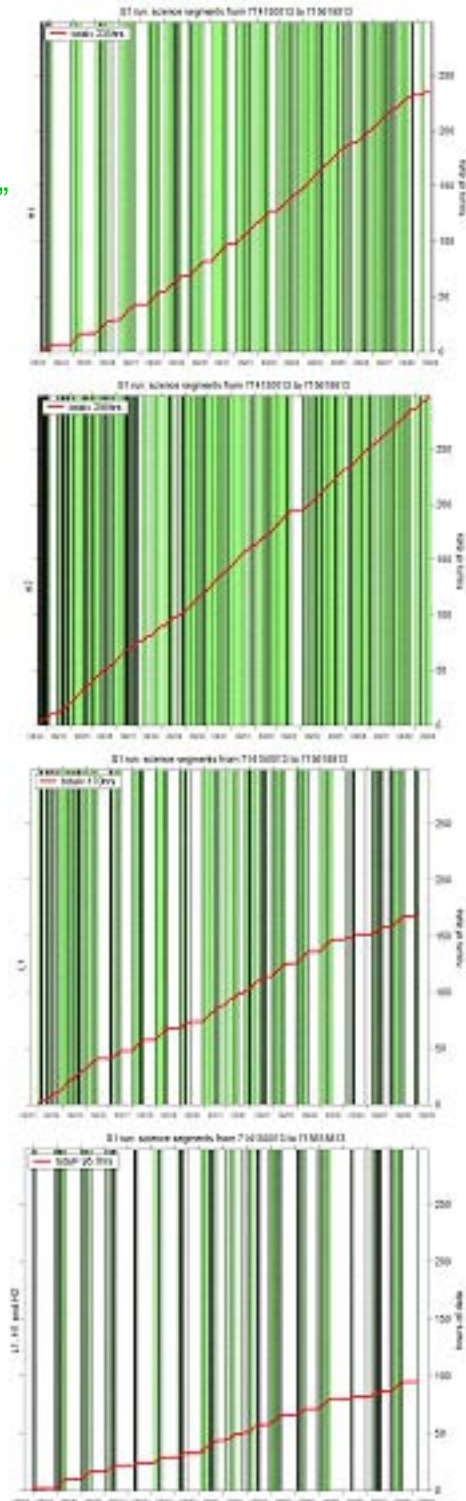


Figure 7: “In-lock” Durations for the First Science Run (S1)

Table 2: Summary of “In-lock” Statistics for the first Science Run (S1)

	Duty Cycle (percent)	Total Locked Time (hours)
H1 (4km)	57.6	235
H2 (2km)	73.1	298
L1 (4km)	41.7	170
L1 & H1	28.4	116
L1 & H2	32.1	131
H1 & H2	46.1	188
Triple Coincidence	23.4	95.7

the observatory at Livingston, Louisiana. The curve represents the smallest signal that we could reliably discern as a function of the frequency. The Sept 2002 (dashed) curve shows the sensitivity during S1. A factor of ten improvement by the beginning of 2003 set the stage for a second Science Run (S2), which started February 14. S2 will run through April 15 and provides the first opportunity to see potential sources in other galaxies, most notably the Andromeda galaxy. The duty cycles to date are comparable to those experienced in S1 (67 percent for H1, 60 percent for H2, and 40 percent for L1). The longest “science” segment so far in a single interferometer is a record 66 hours (H1). The Livingston availability is limited by daytime seismic noise sources caused by human activities. However, the Livingston reach while locked has varied between 0.8 and 1.2 Megaparsecs. We still do not expect to catch a gravitational wave, but we have extended the “science reach.” Five interferometers are collaborating internationally during this run including GEO (UK/Germany) and TAMA in Japan.

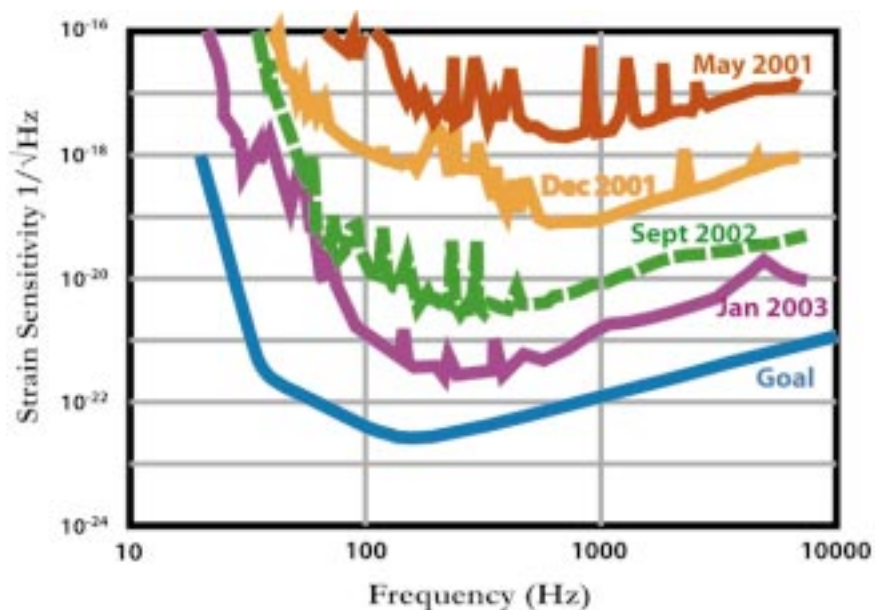


Figure 8: Sensitivity History for the Livingston, Louisiana four-kilometer Interferometer. Impressive improvements in the noise floor have been achieved over the past two years. Similar improvements are being realized in the other LIGO interferometers as hardware and techniques tested and proved on one are incorporated into the others.

4 Advanced LIGO

What next? Current operations are planned and funded through 2006. In February we submitted a proposal for an Advanced LIGO¹ to the National Science Foundation. The instrument proposed is ten times more sensitive over a broader frequency band than initial LIGO, will see a volume of space greater than one thousand times that seen with initial LIGO, and extends the range of compact masses that can be observed by a factor of four or more. We plan to begin installation in 2007 with operations starting in 2009. Advanced LIGO is described in a separate presentation².

5 Conclusion

LIGO commissioning is underway, and we have made very good progress towards the design sensitivity. Initial results are being prepared for publication, and even better data is being recorded that should improve results by more than a factor of ten. Our plan is to initiate operations at the design sensitivity early next year and to accumulate at least one integrated year of data before the end of 2006. A proposal for an Advanced LIGO Detector that would dramatically improve sensitivity even further has been submitted to the National Science Foundation and our schedule for beginning installation of the new hardware is 2007.

Acknowledgments

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