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Update on a busy year for LIGO

Stan Whitcomb, LIGO-Caltech, on behalf of the LIGO Scientific Collaboration
whitcomb_s@ligo.caltech.edu

2003 marks another important year for LIGO as it continues the transition from construction and commissioning to full science data-taking. The first papers describing searches for gravitational waves using data from the first Science Run between the LIGO and GEO detectors are being submitted, a second Science Run has been accomplished with an order of magnitude improvement in sensitivity, commissioning activities to bring the detectors to their design performance are making good progress, and planning for an even more sensitive set of detectors (``Advanced LIGO") is well underway.

Results from LIGO's first Science Run

The first LIGO science run [1], S1, spanned a period of 17 days in August and September 2002; the GEO-600 interferometer also operated during S1. The three LIGO detectors were operating with a noise level about a factor of 100 above the design level, so the probability of detecting any gravitational waves, particularly in such a short run were extremely small. However, the upper limits which could be set from these observations on different types of gravitational waves are typically as good or better than previous direct observational limits.

The LIGO Scientific Collaboration has taken the leadership in analyzing the S1 data, forming four data analysis working groups, each aimed at a particular type of gravitational wave signal. One working group focused on searching for gravitational waves from the inspiral of binary neutron stars. A second one searched for the nearly sinusoidal waves from a millisecond pulsar (J1939+2134). The third one searched for a stochastic background of gravitational waves, while the fourth looked for poorly modeled burst-type sources such as supernovae or GRBs.

In the previous issue of MOG [2], Gary Sanders gave a description of preliminary results from S1, using both LIGO and GEO-600 data. These results have been refined, and four papers, one for each analysis, are in the final stages of preparation prior to submission. The performance parameters of the LIGO and GEO-600 detectors during S1, including their configurations, plots of sensitivity, and tables giving the fraction of time that each detector was operational, are given in a fifth paper. Preprints of these papers are being made available [links at reference 3] as they are approved by the LIGO Scientific Collaboration. The publication of these papers marks a real milestone in LIGO's evolution.

The second Science Run

S1 was the first in a series of progressively more sensitive science runs, interleaved with interferometer commissioning. The second Science Run, S2, took place from February 14 to April 14, 2003. The interferometers showed good reliability for this stage in their development. The duty cycle for the interferometers, defined as the fraction of the total run time when the interferometer was locked and in its low noise configuration, ranged between 37% (for the

Livingston interferometer) and 74% (for the Hanford 4 km interferometer). Building on the lessons learned from S1, procedures were put in place to better monitor the performance and the result was better stability of the performance.

Most important, S2 sensitivity was improved by more than an order of magnitude over S1. Typical noise levels for S2 were about a factor of 10 better than in S1 with the 4km interferometer at Livingston having the greatest sensitivity, followed by the 4 km interferometer at Hanford. The increase sensitivity represents the first time the LIGO detectors have had the sensitivity to see potential sources in other galaxies, most notably the Andromeda galaxy. Once again, LIGO would not be expected to see gravitational waves at this level, but it still represents a significant step toward design sensitivity.

The S2 run also involved coincident running with the TAMA-300 detector, following the signing of a new LIGO-TAMA Memorandum of Understanding.

Commissioning progress

Since the end of S2, the commissioning team has been hard at work to complete an ambitious set of improvements and ``fixes" to the interferometers at both sites.

At both sites, there have been changes inside the vacuum system. Minor changes to the positions of optics have been made to made to adjust cavity lengths closer to their design values. At Hanford, the input test mass on one arm was replaced because of a lossy AR coating. Baffles have been installed to prevent errant high power laser beams from damaging suspension wires on the input optics.

A number of changes have been made to reduce the coupling of acoustic noise to the interferometers. Steps have been taken to reduce the amount of acoustic noise generated by the air conditioning system and by fans in the electronics racks. Acoustic enclosures have been purchased to surround the most sensitive optical tables. Larger aperture optics and mounts have been installed on the optical tables at the outputs of the interferometer.

The commissioning of the wavefront-sensing alignment systems have been a high priority at both sites. This system was operating to control 8 of 10 angular degrees of freedom on the 4km interferometer at Hanford during S2, and demonstrated how much more stability could be achieved. Good progress has been made on both all interferometers.

As a result of the various changes, the 4 km interferometer at Hanford has achieved its highest sensitivity yet, a range for binary neutron star inspirals of 1.5 Mpc.

Future plans

Two major activities loom on the near-term horizon for LIGO: the third Science Run (S3) and an upgrade to the Seismic Isolation System at the LIGO Livingston Observatory (LLO).

S3 is scheduled for approximately two months in November and December 2003. The commissioning progress described in the previous section should provide a significant sensitivity improvement over S2, though perhaps not as great as the jump between S1 and S2. The more complete implementation of the wavefront-sensing alignment system should give better stability and move the analysis closer to what is expected in full operation.

Immediately after S3, we plan to install an upgrade to the Seismic Isolation System at LLO. Since the beginning of commissioning, the interferometer at LLO has suffered from higher than expected seismic noise due to anthropogenic sources. These large motions occur at low frequencies and often exceeded the ability of the control systems to cope with them. As a result, the duty cycle of the LLO interferometer has been lower than specified. The upgrade consists of active vibration isolation systems installed outside the vacuum system to cope with ground motions in the 0.1-10 Hz range. It has been under development for the past 18 months, initially aimed at Advanced LIGO, but once it was determined that it could help the situation at LLO, its development was accelerated. Hardware is expected to be ready for installation in very early 2004.

Advanced LIGO

The LIGO Laboratory, with strong support from the LIGO Scientific Collaboration, submitted its proposal to the NSF in March, 2003 for Advanced LIGO. The proposed system consists of three nominally identical interferometers - two 4km systems at Hanford, and one at Livingston, and each are tunable through variations of the input power and the signal recycling mirror position. The increase in sensitivity is greater than a factor of 10 over initial LIGO, and also the potential for observation a factor of 4 lower in frequency. The result is that it is anticipated that one will be able to see e.g., 1.4 solar mass neutron star binary inspiral signals to roughly 350 Mpc (for the 3 interferometer detector system), or greater than a factor of 15 further than initial LIGO for this source. This new detector, to be installed at the LIGO Observatories, will replace the present detector once it has reached its goal of a year of observation, with the planning date for first observations presently at 2010. The improvement of sensitivity will allow the one-year planned observation time of initial LIGO to be equaled in just several hours.

The new design involves a complete replacement of the initial detector. The laser power is increased from 10 W to 180 W, to improve the shot-noise limited sensitivity of the instrument - this will be a contribution from the Hannover GEO colleagues. Prototypes have demonstrated over 100 W to date. The input optics, under the leadership of the University of Florida LIGO group, will resemble the initial LIGO design but improved to handle the higher power. The test masses will be made of sapphire, 40 kg in mass to resist the photon pressure fluctuations, and with coatings which must be low optical loss and low mechanical loss (to keep thermal noise low). Sapphire 'pathfinder' pieces of the final size have been fabricated, and show excellent mechanical properties. The test mass suspensions, contributed by our Glasgow GEO colleagues, resemble the GEO 600 design with a final stage using fused silica fibers, again for low thermal noise. The seismic isolation design comes from LSU and Stanford, and uses high-gain servo systems to deliver very low motion in as well as below the gravitational wave band - the low-frequency noise of the interferometer at low power will be limited by the Newtonian background from gravitational gradients. Aspects of the design have been tested in various prototypes, and a complete prototype is in test at Stanford at this time. These mechanical aspects of the design will be tested together at the MIT LASTI full-scale test facility. The gravitational readout system will use a form of DC sensing, moving slightly away from the dark fringe of the interferometer output port, and will make use of the innovations from table-top and suspended signal-recycled interferometer tests made in Australia, Florida, Glasgow, Garching, and Caltech; a complete engineering test of the readout and control system is in development at the 40m Lab at Caltech.

A review of the proposal was held by the NSF in June, and the feedback was quite positive. The materials for the review can be found at http://www.ligo.caltech.edu/advLIGO/, and can serve as a resource for further information. We are excited by the kind of leap forward this instrument should give to the field, and hope that it will be observing in concert with other instruments that can be operating at that time - a second generation VIRGO, and a cryogenically-cooled underground system in Japan as examples. When will it be another ordinary day when a few more gravitational waves sources are logged? We hope around 2010!

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More information about LIGO can be found at: http://www.ligo.caltech.edu.

References:

[1] MOG article describing S1 performance:

http://www.phys.lsu.edu/mog/mog20/node10.html

[2] MOG article describing S1 results:

http://www.phys.lsu.edu/mog/mog21/node10.html

[3] S1 paper links:

http://www.ligo.caltech.edu/LIGO_web/s1/