LIGO-T030021-00-M

LIGO's First Preliminary Science Results

Gary Sanders, sanders@ligo.caltech.edu , on behalf of the LIGO Scientific Collaboration

In the previous report in MOG, I described the completion of the first LIGO science run, S1. The strain spectral sensitivity of LIGO in that run, and the duration of the run, is described in that article. S1 was the first in a series of progressively more sensitive science runs, interleaved with interferometer commissioning and improvement periods. S1 has now yielded preliminary science results. These are being presented, as this article is written, at the AAAS meeting in Denver. The talks from this symposium will be posted shortly on the LIGO Laboratory website, and the LSC website. This article follows closely the content of Albert Lazzarini's talk in that symposium. Final results from S1 are in preparation and should appear as preprints in the next several weeks with formal publication after the March LSC meeting.

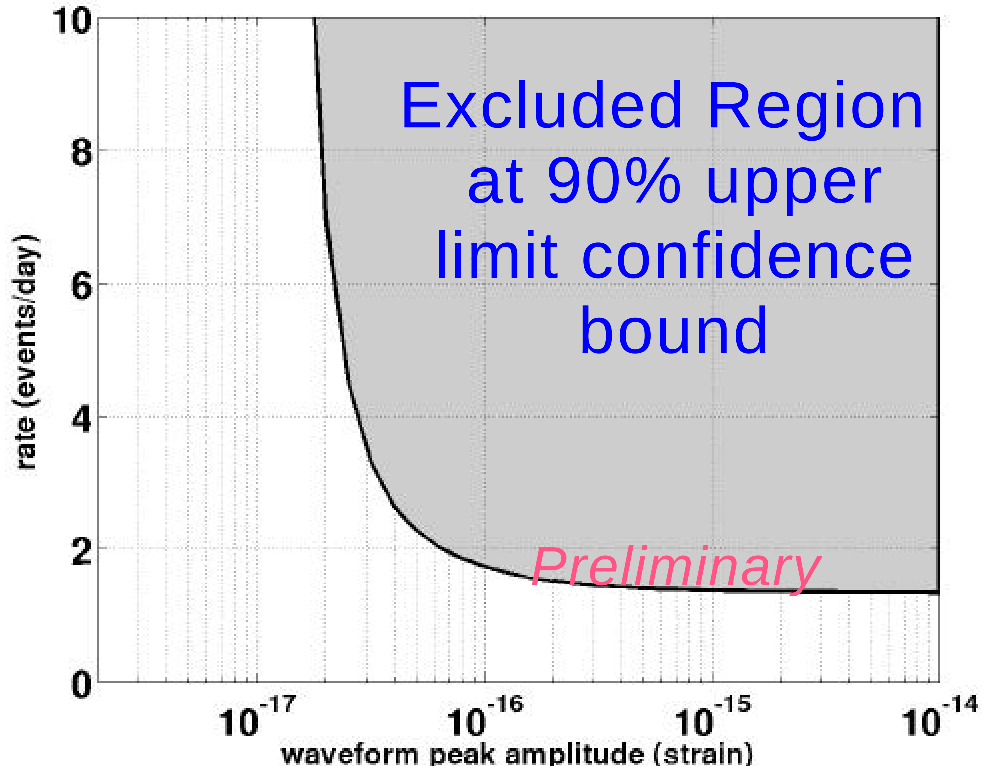
The results below mark the first from LIGO, a milestone in the program. The physics impact of these results is not very significant, but the lessons learned about the interferometer data streams and the analysis algorithms lay the foundation for more meaningful future work as LIGO's sensitivity increases and as the science runs extend over longer periods. In that sense, the analysis methods that will be published are at least as significant as the results themselves.

The GEO-600 interferometer also operated during S1, as we previously reported, and results are quoted below from the joint GEO-LIGO effort. Coincident running with the TAMA-300 interferometer is the subject of analysis by a separate working group and is not reported here.

For the analysis of this data, the LIGO Scientific Collaboration has divided itself into four Upper Limits Working Groups. The terminology clearly reflects the expectation that the early running is most useful to set upper limits on the various gravitational wave fluxes and/or source populations. These working groups are focused on burst, inspiral, periodic and stochastic sources.

The data analysis techniques adapt to the source characteristics. Deterministic signals from inspiral and periodic sources can be parameterized by amplitude and frequency evolution. Template sets can be selected to cover the parameter space covered by the data. Statistical signals, such as stochastic gravitational wave backgrounds, are sought by cross-correlating pairs of interferometers, seeking correlations and statistical variations. Unmodeled signals such as supernovae, gamma ray bursts or entirely new transient sources cannot be addressed by parametric techniques. For these, very basic data trends are sought such as power excesses in the frequency-time domain, or notable amplitude changes in time. In all of these studies, use is made of the coincidence between multiple detectors, a most powerful filter.

The LIGO Burst Sources Working Group has taken on one of the most challenging search topics. In the absence of a waveform model, they have searched for frequency vs. time domain power excesses and time varying amplitude departures, setting a bound on unmodeled bursts of rate vs. strength. The analysis serves as a prototype for any searches for discrete events. Diagnostic triggers from the detectors indicating instrumental or environmental data artifacts confront event triggers from the interferometers. Requiring three-interferometer coincidence further filters event triggers that are not vetoed by this process. Bursts of peak strain amplitude above a given rate have been excluded in this search as shown in Figure 1. The displayed limit is not yet the best achieved as resonant



mass detectors have published superior limits [1,2].

The Inspiral Sources Working Group is searching for 1- 3 solar mass neutron star binaries, black hole binaries heavier than 3 solar masses, and MACHO binaries in the 0.5 – 1 solar mass range. They have completed the neutron star search at this time. The analysis employs template based matched filtering. During the S1 run, the LIGO interferometers were individually sensitive to 1.4 solar mass binaries out to 38 kpc to 210 kpc, for optimal orientation and signal to noise ration (SNR) of 8. With appropriate treatment of the expected population in the Milky Way galaxy, and the Large and Small Magellanic Clouds, and using triggers from the Hanford and Livingston 4 km interferometers, the resulting limit is:

$R_{90\%}$ (Milky Way) < 1.7×10^2 /yr

The best previously published observational limit was obtained using data from the 40 Meter Interferometer at Caltech[3] ($R_{90\%}$ (Milky Way) < 4.4×10^3 /yr).

The Periodic Sources Working Group is searching for gravitational waves radiated by periodic sources such as rotating prolate neutron stars with ellipticity in the range 10^{-3} – 10^{-4}. These would be of best interest in a LIGO search if all of the observed spin-down were attributable to gravitational wave emissions. The search can be carried out in the frequency domain by cross-correlating the data stream with templates, seeking power correlations. A complementary approach uses a time domain search, removing motion of the Earth, and comparing the result with what would be expected from noise in the absence of a signal. The analyses are still in progress. However, no signals are seen. Preliminary limits, with 95% confidence, on periodic sources are set on maximum strain amplitudes individually for the GEO interferometer and the three LIGO interferometers ranging from 3×10^{-21} to 2×10^{-22}, the latter limit set by the Livingston 4 km interferometer.

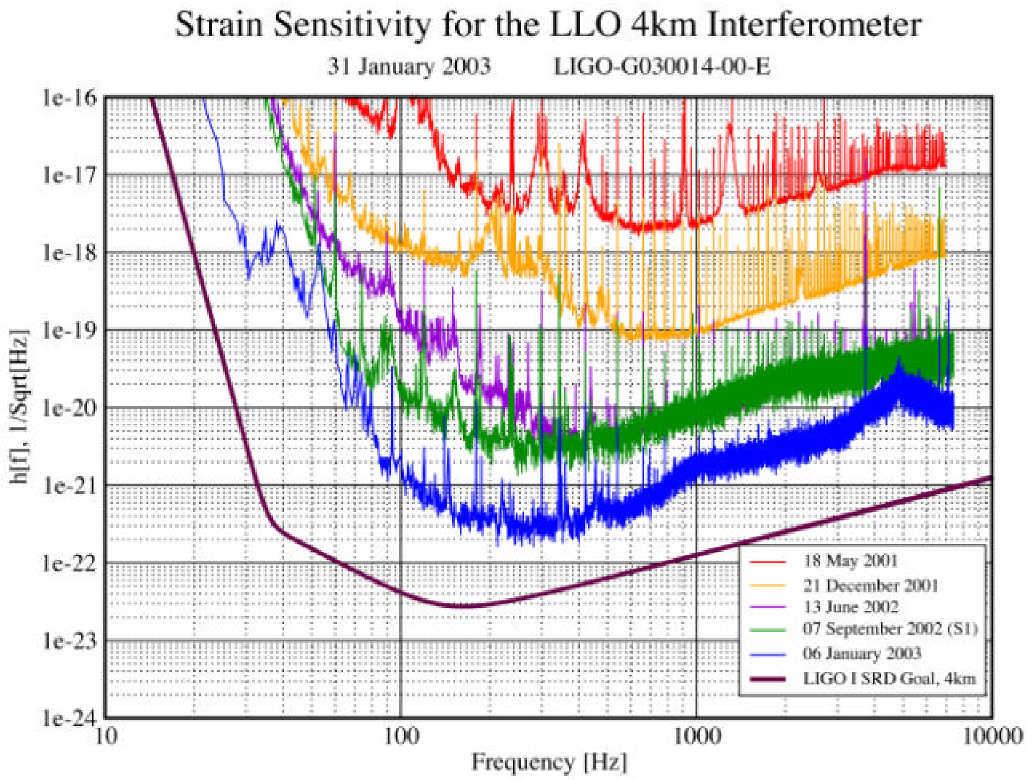
The Stochastic Sources Working Group is searching for these remnant signals by cross-correlating interferometer outputs in pairs, using the long baseline Livingston-Hanford 4 km interferometers and the short baseline co-located Hanford 2 km and 4 km interferometers. The full initial LIGO science run should be able to reach sensitivity of $\approx \Omega_{GW} < 10^{-5}$, comparable to upper limits inferred from Big Bang nucleosynthesis[4]. The best detector-based limit is $\Omega_{GW}(907\text{ Hz}) < 60$ from resonant mass detector results[5]. Based upon analysis of only 7.5 hours of data from the S1 run, the Stochastic Sources Working Group estimates the limits from the full S1 run as shown in Table 1.

Interferometer Pair	Measurement Bandwidth	**Extrapolated Upper Limit for S1 (by scaling 7.5 hrs to 150 hrs)**	T_{obs}
H2km - H4km	40 Hz < f < 300 Hz	W_{GW} **< 5 (90% C.L.)**	**150 hr**
H4km - L4km	40 Hz < f < 314 Hz	W_{GW} **< 70 (90% C.L.)**	**100 hr**
H2km - L4km	40 Hz < f < 314 Hz	W_{GW} **< 50 (90% C.L.)**	**100 hr**

This is only an estimate of the S1 result, as stated. Actual results from the full data set will be represented in preprints to be released prior to the LSC meeting in March.

As this S1 analysis matures, LIGO has already begun the S2 run, on February 14. An 8-week run is planned, four times longer than the S1 run. Most important, LIGO sensitivity is more than an order of magnitude better now, across the sensitive spectrum. Figure 2 displays the progression in sensitivity for the Livingston 4 km interferometer, illustrating the improvement since S1.

The S2 run will involve coincident running with the LSC partner GEO-600 instrument, and with the TAMA-300 detector, following the signing of a new LIGO-TAMA Memorandum of Understanding. 2003 promises to be a propitious year for ground-based gravitational wave interferometry!



LIGO is funded by the US National Science Foundation under Cooperative Agreement PHY-0107417. This work is a collaborative effort of the Laser Interferometer Gravitational-wave Observatory and the institutions of the LIGO Scientific Collaboration.

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

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[1] Int.J.Mod.Phys. D9 (2000) 237
[2] Class.Quant.Grav. 19 (2002) 5449
[3] Allen et al., Phys.Rev.Lett. 83 (1999) 1498
[4] Kolb et al., 1990.
[5] Astone et al., 1999.