RESULTS FROM LIGO OBSERVATIONS: STOCHASTIC BACKGROUND AND CONTINUOUS WAVE SIGNALS

NELSON CHRISTENSEN, FOR THE LIGO SCIENTIFIC COLLABORATION

Physics and Astronomy,
Carleton College, Northfield, Minnesota, 55057 USA
nchriste@carleton.edu

The search for gravitational radiation has entered a new era as the Laser Interferometer Gravitational Wave Observatory (LIGO) has reached its initial target sensitivity. Other similar interferometric detectors are also approaching their design goals. There is presently vigorous activity in the gravitational radiation community in the search for signals. Here we review the status of the LIGO search for a stochastic background, and continuous wave signals.

1. Introduction

The Laser Interferometer Gravitational Wave Observatory (LIGO)[1,2] has achieved its initial target sensitivity, and the detection of an event could come at any time. The expected gravitational wave (GW) sources include supernovae, pulsars, the inspiral of binary systems with neutron stars and/or black holes followed by merger and black hole ringdown phases, or even the stochastic background from the Big Bang. Members of the LIGO Scientific Collaboration (LSC) are enthusiastically working to make gravitational radiation detection a reality. LIGO and the LSC have gone through a number of *science runs* where data was collected and analyzed. So far, LIGO has completed four science runs (S1-S4) and is now in its fifth science run, S5. Between these runs the interferometer performance was improved through commissioning work. LIGO has more than met its design goal with a strain sensitivity of $h(f) < 3 \times 10^{-23}\mathrm{Hz}^{-1/2}$ at 200 Hz, and $h_{\mathrm{rms}} \approx 10^{-21}$ within a bandwidth of 100 Hz. In S5 the LIGO 4 km interferometers have a sensitivity range for optimally oriented $1.4M_{\odot}$-$1.4M_{\odot}$ neutron star binary inspirals out to a distance of 33 Mpc for an SNR of 8. Here we summarize the LIGO results for searches for a stochastic background, and for continuous wave signals.

2. The Stochastic Background Search

Various mechanisms during the Big Bang and in the early universe will produce a stochastic background of GWs, analogous to the electromagnetic cosmic microwave background. This would seem to be a background noise in each detector, but the signal could be extracted through a correlation of the outputs of two detectors.[4,5]

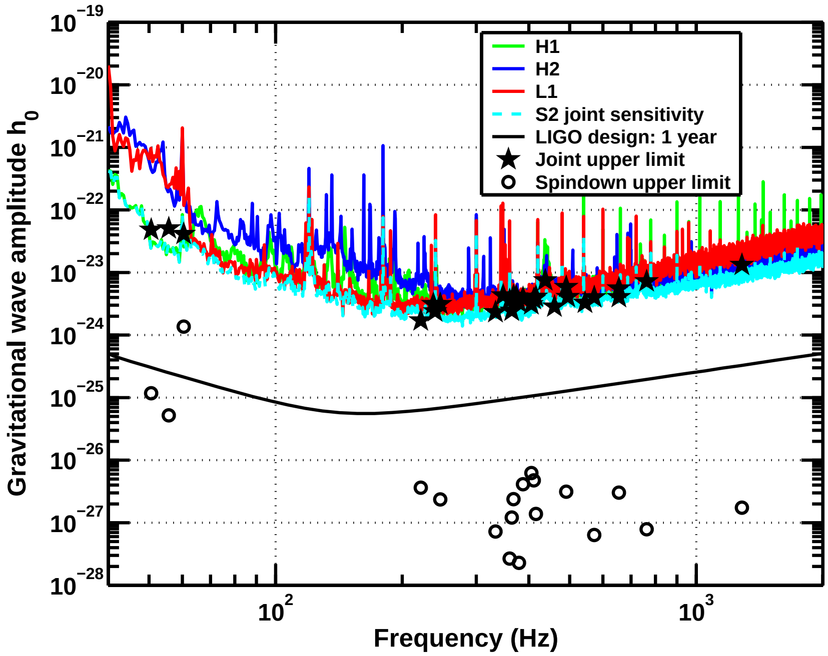

Fig. 1. As presented in Ref. 11, the upper curves are the h_0 amplitudes detectable from a known generic source with a 1% false alarm rate and 10% false dismissal rate for single detector analyses and for a joint detector analysis. All the curves use typical S2 sensitivities and observation times. H1 and H2 are the 4 and 2 km detectors located in Hanford WA. L1 is the 4 km detector situated in Livingston LA. Lower curve: LIGO design sensitivity for 1 yr of data. Stars: upper limits for 28 known pulsars. Circles: spindown upper limits for the pulsars with frequency derivative values if all the measured rotational energy loss were due to GWs (for a moment of inertia of 10^{45} g cm^2).

A background could also be produced after the Big Bang, e.g. through the addition of signals from binary systems or supernovae throughout the universe. LIGO is actively searching for the stochastic background,[6–8] and setting limits on its strength. The magnitude of the stochastic background is usually described by the GW energy density per unit logarithmic frequency, divided by the critical energy density to close the universe, $\Omega_{\rm gw}(f)$. Using the S4 data LIGO was able to set a limit on the stochastic GW energy density of $\Omega_{\rm gw}(f) < 6.5 \times 10^{-5}$ in the frequency band from 51 Hz to 150 Hz for a frequency independent GW spectrum.[8] An important benchmark in stochastic background sensitivity is the indirect bound set by nucleosynthesis.[9] If the energy density of GWs at the time of nucleosynthesis were too large it would affect the ratio of light nuclei production. LIGO's S5 sensitivity and data could allow it to set a limit below the nucleosynthesis level.

3. Continuous Wave Signal Searches

Rapidly spinning neutron stars, or pulsars, could be sources of GWs. In order for radiation to be produced the neutron star would need to be non-axisymmetric in shape. This type of gravitational radiation would be a nearly perfect sinusoidal signal. One must still account for Doppler shifts due to the motion of the Earth, and changes in the interferometers' response as the Earth rotates and orbits about the sun. Radio observations can help the search as this provides sky location, rotation frequency and spindown rate. Typically, GWs will be emitted at twice the rotation frequency. In the absence of a signal it is still possible to produce meaningful astrophysical results. An upper limit on the strength of a GW corresponds to an upper limit on the ellipticity of the neutron star; an indirect limit can be set from the star's spindown rate, and this is used as a benchmark of the sensitivities of the direct limits. LIGO has published a series of results on the upper limits of signal strength for various known pulsar signals.[10–12] Using the S2 data 28 pulsars were studied, and limits on the strain signal strength as low as 1.7×10^{-24} were achieved, along with limits on pulsar ellipticity as low as 4.5×10^{-6}.[11] The pulsar gravity wave signal limits set by LIGO with its S2 data are displayed in fig. 1. LIGO all-sky searches can detect unknown periodic sources due to any emission mechanism; for the S2 search[12] the overall best upper limit on the GW amplitude at the detector was 4.43×10^{-23} for the 200-400 Hz band. For upcoming analyses the detector sensitivity has increased by a factor of 20, we have looked for many more known pulsars, and the frequency band of some of our unknown searches has increased to 50-1500 Hz.

4. Acknowledgments

The authors gratefully acknowledge the support of the U.S. National Science Foundation for the construction and operation of the LIGO Laboratory and the Particle Physics and Astronomy Research Council of the United Kingdom, the Max-Planck-Society and the State of Niedersachsen/Germany for support of the construction and operation of the GEO600 detector. The authors also gratefully acknowledge the support of the research by these agencies and by the Australian Research Council, the Natural Sciences and Engineering Research Council of Canada, the Council of Scientific and Industrial Research of India, the Department of Science and Technology of India, the Spanish Ministerio de Educacion y Ciencia, The National Aeronautics and Space Administration, the John Simon Guggenheim Foundation, the Alexander von Humboldt Foundation, the Leverhulme Trust, the David and Lucile Packard Foundation, the Research Corporation, and the Alfred P. Sloan Foundation.

References

1. B. Barish and R. Weiss, Phys. Today **52**, 44 (1999).
2. B. Abbott *et al*, Nucl. Instrum. and Methods A, **517**, 154 (2004).
3. B. Abbott et al., Phys. Rev. D **69** 082004 (2004)
4. N. Christensen, Phys. Rev. D **46**, 5250 (1992).
5. B. Allen and J. Romano, Phys. Rev D **59**, 102001 (1999).
6. B. Abbott *et al*, Phys. Rev. D **69**, 122004 (2004).
7. B. Abbott *et al*, Phys. Rev. Lett. **95**, 221101 (2005).
8. The LIGO Scientific Collaboration, astro-ph/0608606, Ap. J. in-press (2006)
9. M. Maggiore, Phys. Rep. **331**, 283 (2000).
10. B. Abbott *et al*, Phys. Rev. D **69**, 082004, (2004).
11. B. Abbott *et al*, M. Kramer, A.G. Lyne, Phys. Rev. Lett. **94**, 181103 (2005).
12. B. Abbott *et al*, Phys. Rev. D **72**, 102004 (2005).