THE LIGO DETECTORS CONTROLS

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Abstract

All three LIGO detectors have reached their design sensitivities. A sky-averaged detection range (SNR > 8) of more than 15 Mpc for inspiral binary neutron stars with masses of 1.4 Msol has been achieved with the two 4 km instruments. The fifth LIGO science started in November 2005 and ended September 2007. About 365 days of coincidence data have been collected. The feedback controls system is a major component to make LIGO work and its performance has been crucial to achieve the present sensitivity.

INTRODUCTION

Interferometric gravitational wave antennas are based on Michelson interferometers whose sensitivity to small differential length changes has been enhanced by adding multiple coupled optical resonators. The use of optical cavities is essential for reaching the required sensitivity, but sets challenges for the control system which must maintain the cavities near resonance. The goal for the strain sensitivity of the Laser Interferometer Gravitational-wave Observatory is 10^{-21} rms, integrated over a 100 Hz bandwidth centered at 150 Hz [1,2].

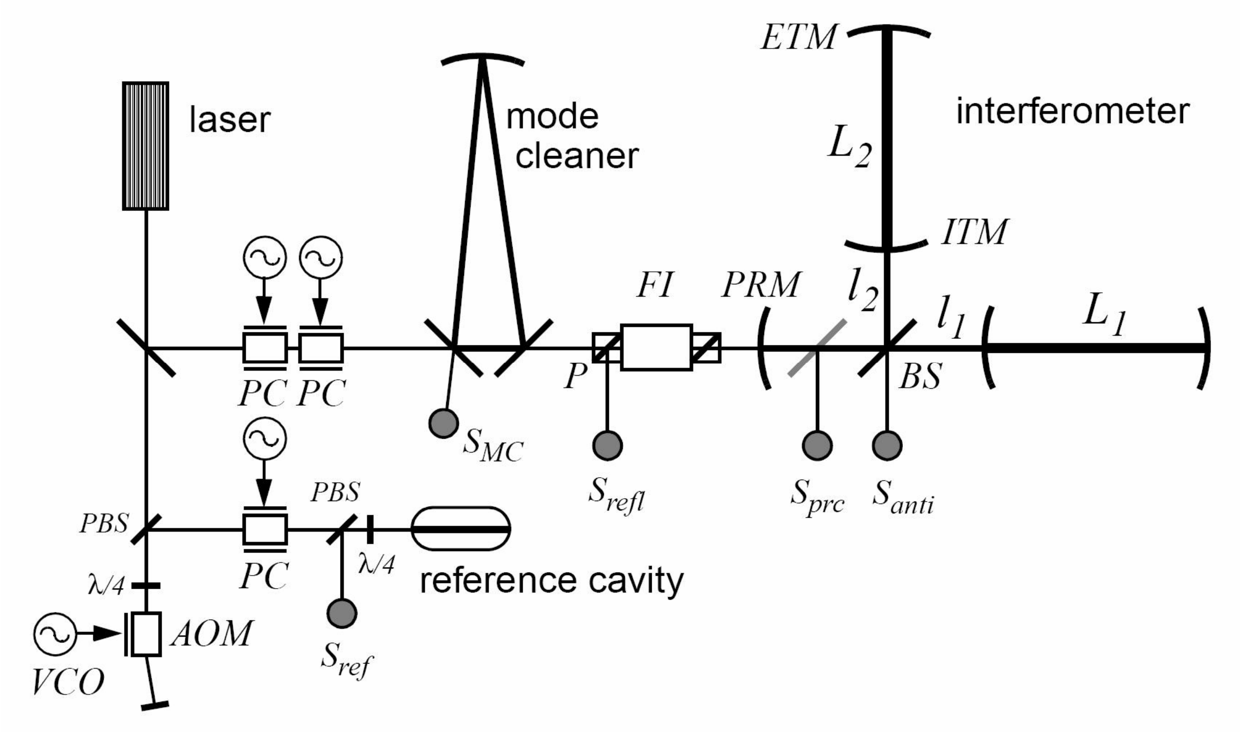

Figure 1: Schematic view of the optical path in LIGO. The light of a frequency stabilized Nd:YAG laser is passed through a triangular mode cleaner cavity before it is launched into a Michelson interferometer. To stabilize the laser frequency a small fraction of the light is sampled, doubly passed through an acousto-optic modulator (AOM) which serves as a frequency shifter, passed through a Pockels cell and sent to a reference cavity. Using a polarizing beamsplitter (PBS) and quarter-wave plate (λ/4) the light reflected from the reference cavity is measured by a photodetector to obtain the error signal, S_{ref}, which in turn is used to adjust the laser frequency. The main laser light is passed through a pre-modecleaner (not shown) and a series of Pockels cells which impose the phase-modulated rf sidebands used to lock the mode cleaner and the Michelson interferometer. The mode cleaner locking signal, S_{MC}, is measured by a photodetector in reflection of the mode cleaner cavity. The light which passes through the mode cleaner is sent through a Faraday isolator (FI) which also serves the purpose, together with a polarizer (P), to separate out the reflected light signal, S_{refl}. The main interferometer consists of a beamsplitter (BS), two arm cavities each of them formed by an input test mass (ITM) and an end test mass (ETM), and the power recycling mirror (PRM). Additional locking signals are obtained at the antisymmetric port, S_{anti}, and by sampling a small amount of light from inside the power recycling cavity, S_{prc}.

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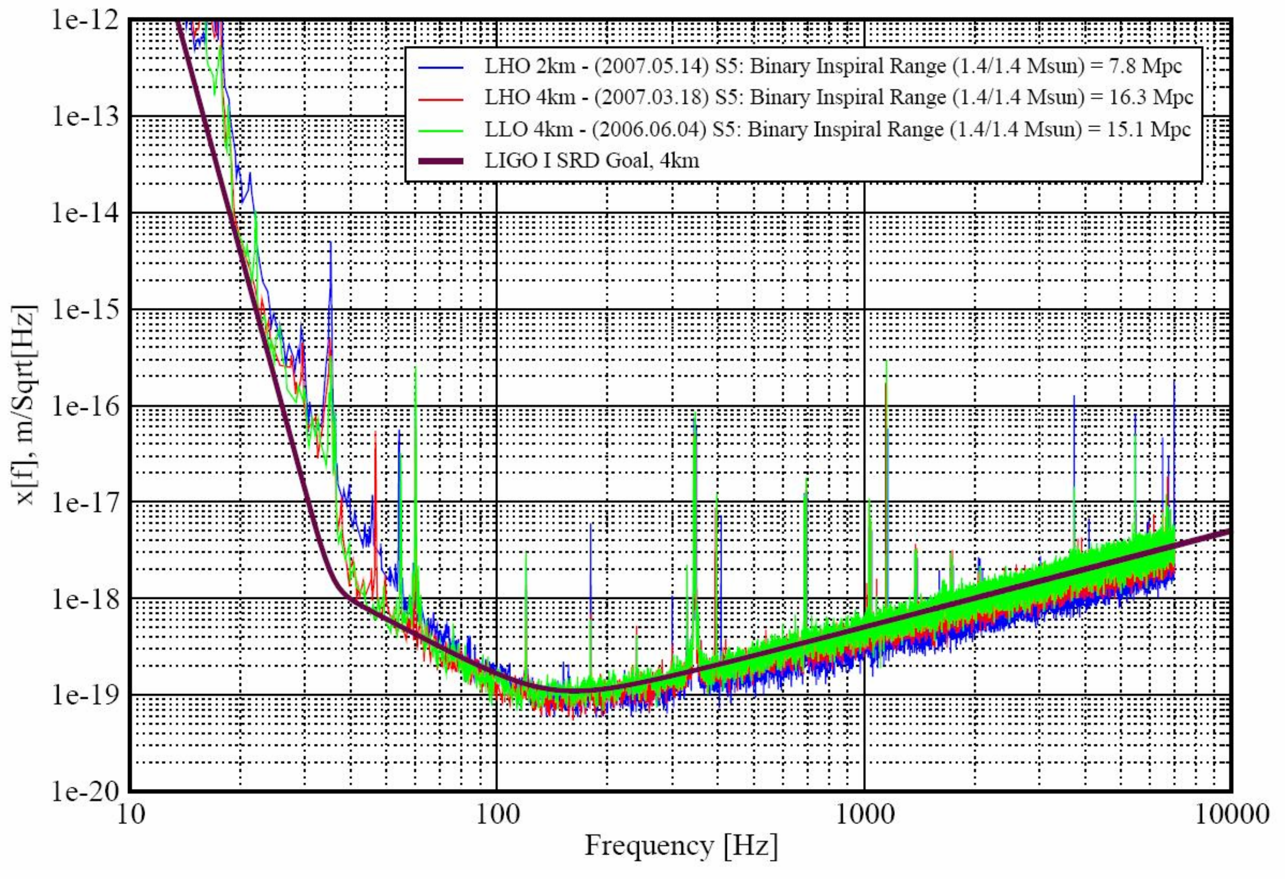

Figure 2: LIGO sensitivity during the 5th science run. The three spectral curves represent the displacement sensitivity of the three LIGO detectors. The smooth curve represents the original goal as outlined in the LIGO proposal. Also, indicated is the sky-averaged range to detect the inspiral of two standard 1.4 Msol mass neutron stars with a signal-to-noise of 8.

LIGO implements a power-recycled Michelson interferometer with Fabry-Perot arm cavities (see Fig. 1). Using optical cavities is essential in reaching the ultimate sensitivity goal but it requires an active electronic feedback system to keep them ‘on resonance’. The control system must keep the round-trip length of a cavity near an integer multiple of the laser wavelength so that light newly introduced into the cavity interferes constructively with light from previous round-trips. Under these conditions the light inside the cavity builds up and the cavity is said to be on resonance [3]. Attaining high power buildup in the arm cavities also requires that minimal light is allowed to leave the system through the antisymmetric port, so that all the light is sent back in the direction of the laser where it is reflected back into the system by the power recycling mirror. Hence, an additional feedback loop is needed to control the Michelson phase so that the antisymmetric port is set on a dark fringe.

SENSITIVITY

The current displacement sensitivities of the three LIGO detectors are shown in Fig. 2. The sensitivity above approximately 200 Hz is limited by shot noise of the laser light. Below about 40 Hz the sensitivity is limited by anthropogenic and seismic activities. The noise in the intermediate frequency band is not completely understood. Thermal noise, electronics noise, back scattering of stray beams and upconversion of low frequency excitations may all contribute.

THE 5TH SCIENCE RUN

The LIGO observatories consist of three detectors at two different sites. At the Hanford Observatory in Washington a 4 km and a 2 km long interferometer share the same vacuum envelop. A single 4 km long interferometer is implemented at Livingston site in Louisiana.

The 5th LIGO science run started on November 4, 2005 and ended on September 30, 2007. Just over 365 days of triple coincidence data have been acquired. A little more than 400 days of two site coincident data have been archived. The duty factor for the 4 km interferometer at Hanford was around 78%, it was about 79% for the 2 km interferometer at Hanford and it was about 66% for the Livingston interferometer. The triple coincidence duty factor was 53%, whereas the two site coincidence duty factor was 60%.

RESULTS AND CONCLUSIONS

The data of the 5th science run are still being analyzed. Results from earlier runs are available in Refs. 4-26.

Initial LIGO has achieved its major goals. Plans for the next generation advanced LIGO detectors are well underway.

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