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Advanced LIGO status

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Abstract. Advanced LIGO is currently in the final stages of installation and early commissioning. In the design of Advanced LIGO a key goal was the ability to detect gravitational waves from compact object binary inspirals, as these are thought to be the most likely candidates for early detections with ground based interferometers. Special emphasis has been placed on improving the low frequency sensitivity relative to the first generations of LIGO, in addition to improving the high frequency sensitivity by increasing the laser power. The interferometer in Livingston Louisiana has been locked (continuously held within the linear operating range) and noise investigations have begun, and the major installation activities for the interferometer at Hanford, Washington are completed.

1. Features of Advanced LIGO

During the successful science observation runs of Initial and Enhanced LIGO, several changes to the LIGO instruments were identified which were needed to build instruments with a high probability of detecting gravitational waves. A new interferometer, called Advanced LIGO, has been designed and built in the LIGO infrastructure based on these lessons learned during Initial LIGO. A major improvement in Advanced LIGO is in the reduction of seismic noise. The design calls for 10 orders of magnitude attenuation of ground motion at 10 Hz. Advanced LIGO relies on seven stages of isolation to achieve this: an external stage which relies on inertial sensors and hydraulic actuators for active control of large low frequency drifts, two internal stages which employ a combination of passive isolation and active isolation [2, 3, 4], and four pendulum stages used to suspend the test masses which provide passive isolation above the pendulum resonances from 0.5-2 Hz [5, 6]. These seven stages together are designed to improve the sensitivity at 30 Hz by 4 orders of magnitude compared to initial LIGO and to extend the low frequency limit of LIGO's observation band down to 10 Hz, as shown in the noise budget in Figure 1. This low frequency sensitivity will be critical for the detection of gravitational waves from compact binary inspirals.

In the intermediate frequency range, Brownian motion of the suspensions and the optical coatings are the dominant noise sources. To reduce mechanical dissipation in the suspensions, and therefore thermal motion of the test mass, the final suspension stage is one continuous assembly of fused silica elements. This creates a resonator with low mechanical losses and a quality factor estimated to be around 1 billion for the violin modes of the suspension fibers [7]. The beam size on the highly reflective end test masses has also been increased in Advanced LIGO compared to initial LIGO to reduce the impact of Brownian noise from optical coatings by averaging over a larger area of the coating surface.

At high frequencies, shot noise will be the dominant noise source. Advanced LIGO aims to improve the shot noise limited sensitivity by using up to 125 W of input power [8, 9], along with power and signal recycling [10]. With 125 W of input power, the arm cavity circulating power

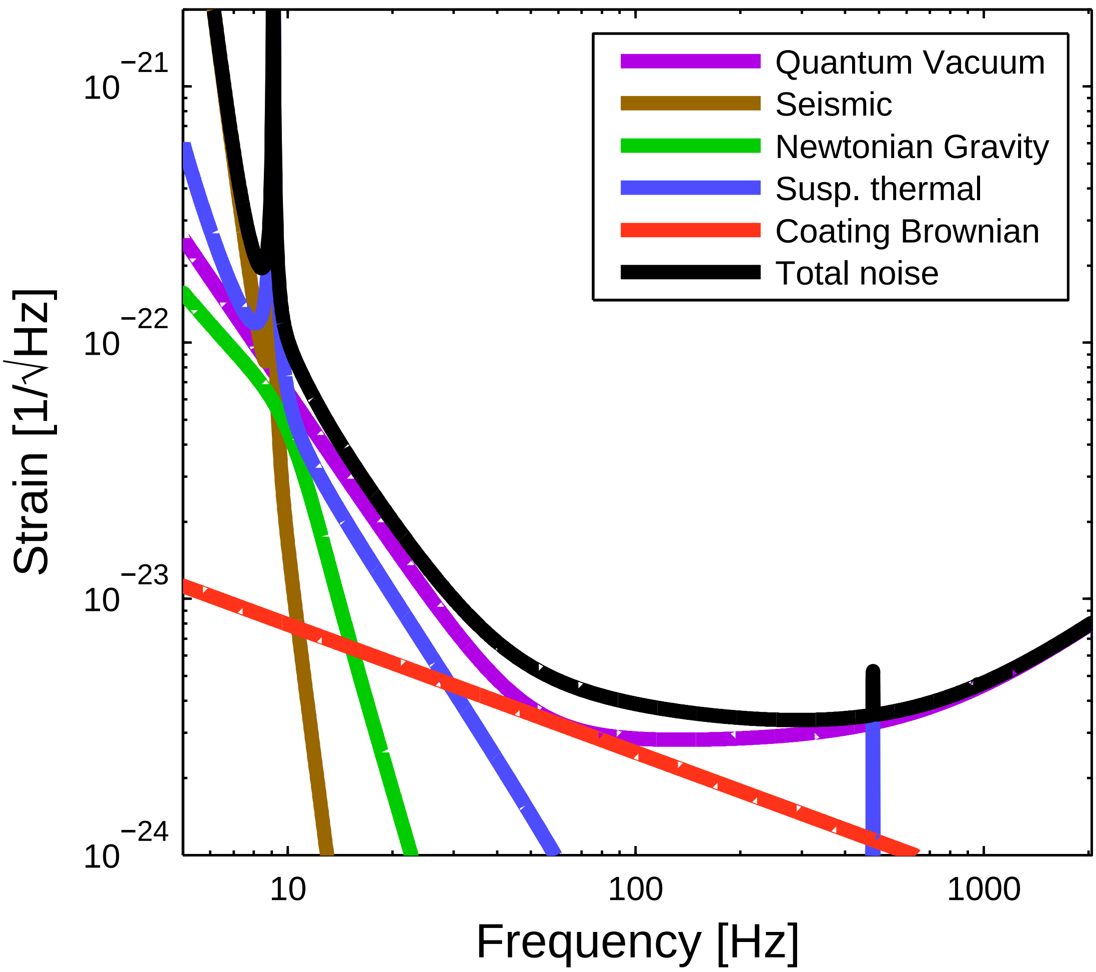

Figure 1. Noise sources for Advanced LIGO design sensitivity. Additional technical noise sources will make contributions to the noise performance, by design at the level of approximately 10 % [1]

is expected to be 800 kW, increased from 40 kW in Enhanced LIGO [11]. This high circulating power will pose several challenges, one of which is thermal lensing of optics due to absorption. A thermal compensation system has been designed to cancel the thermal lensing using a CO_2 laser projected onto a compensation plate and a heating element on the outer radius of the test masses. Hartmann sensors have been installed to sense the thermal lensing of each optic individually[12], which allows the possibility of locally controlling the curvature of each optic independently. A second challenge posed by high power operation is the increased radiation pressure force on the optics. The mass of the test masses in Advanced LIGO has been increased to 40 kg to reduce the displacement caused by this radiation pressure force.

Advanced LIGO will use a signal recycling mirror for broadband resonant sideband extraction. In this scheme the signal sidebands created by a gravitational wave in the arm cavities are extracted towards the interferometer dark port, so that the number of round trips the signal sidebands make in the arms is reduced [13]. For the next several years this will be used with no detuning, allowing for a broadband sensitivity and simplified operation. The reduction of shot noise with squeezed light injection has been demonstrated in Enhanced LIGO and at GEO [14, 15], and if implemented as anticipated in Advanced LIGO will further improve the shot noise limited sensitivity.

2. Lock Acquisition

The sensors used to measure the length degrees of freedom in ground based interferometers have very narrow linear operating ranges. This means that lock acquisition can be a difficult challenge for ground based interferometers, where five length degrees of freedom and many angular degrees of freedom must all be within a narrow range before the signals used to control them become available [17]. Each of these degrees of freedom are also coupled, so that vertex degrees of freedom disturb the sensors used to control the arm degrees of freedom and vice versa. Advanced LIGO has employed a new technique using a second frequency of laser light (doubled Yag, 532 nm green light) to stabilize the arm degrees of freedom and continue to stabilize them while holding them off resonance from the main laser [18, 19]. The vertex degrees of freedom are then stabilized using sensors that are relatively insensitive to the arm degrees of freedom. Once all degrees of freedom are controlled by these decoupled sensors, which have relatively poor noise performance, the arm cavities are brought on resonance and controls switched in a controlled way to the highly coupled, low noise sensors used for gravitational wave detection. This system was designed to speed up the lock acquisition process and improve the duty cycle by making the locking sequence more robust. The performance of this lock acquisition sequence has now been demonstrated in both Advanced LIGO interferometers [20].

The Advanced LIGO detector in Livingston, LA was fully locked for the first time in June 2014, a significant milestone for advanced gravitational wave detectors. These first locks have been followed by rapid progress in noise reduction. The last major installation activities for the interferometer at Hanford, WA are being completed in July 2014 with the first attempts at locking the full interferometer expected to take place starting in September.

3. Outlook

Now that Advanced LIGO has achieved the first locks of one full interferometer, the focus will be on improving noise performance in preparation for the first observing runs. In the coming years the schedule will be designed to increase the likelyhood of making an early detection of gravitational waves. While the chances of detection increase with the cube of improved detector performance, time spent commissioning the instruments must be balanced against time spent collecting data, especially in light of uncertainty in the estimates of event rates [21]. An early short observing run is planned for late 2015, when the range for binary neutron star inspirals is significantly better than Enhanced LIGO's range, between 40-80 Mpc [22]. This run will be followed by a series of longer observing runs at improved sensitivities with the goal of making a first direct detection of gravitational waves.

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