# Supplementary Material

## 1 Importance of the 50 to 300 Hz band in LIGO

Quite generally, the signal-to-noise ratio (SNR) for a source with Fourier-transformed strain signal $h_{source}(f)$ and a detector with noise power spectral density $S_h(f)$, assuming optimal filtering, is given by:

$$\left(\frac{S}{N}\right)^2 \propto \int_0^\infty \frac{|h_{source}(f)|^2}{S_h(f)} \mathrm{d}f \tag{S-1}$$

We see that the SNR for a given broadband gravitational-wave source is dominated at frequencies where the detector noise power (given for the LIGO H1 detector by the square of the amplitude spectral density shown in Figure S-1), has a minimum.

Some of the most promising sources of gravitational waves are compact binary inspirals. Two neutron stars, two black holes or a neutron star and black hole that are bound in a binary system will lose energy through gravitational radiation. The closer the two compact objects circle around each other the more efficient this process becomes and more energy is emitted. The resulting gravitational wave signal chirps up in frequency as the system accelerates. Earth-based detectors will be able to detect inspiraling compact binary systems in the last few seconds to minutes prior to coalescence. For the inspiral phase of binary neutron star systems, the Newtonian quadrupole approximation gives $|h_{source}(f)|^2 \propto f^{-7/3}$. We see that the accelerated chirp waveform of the emitted gravitational waves heavily weights the SNR for neutron star inspirals toward low frequencies.

The sensitivity of earth-based detectors is limited at the low frequency end by a combination of seismic motion, Newtonian gravity gradient noise and thermal noise. In initial LIGO, these noise sources begin to rise steeply below about 150 Hz (Figure S-1). For Advanced LIGO, a major effort has been to lower these noise sources so that they are not significant above 50 Hz, thus making the region between 50 and 300 Hz the most critical frequency band for detecting these sources on Earth.

## 2 Limits of the net improvement in the 150 to 300 Hz band

The reason for the small net improvement in the 150 to 300 Hz region is evident from Figure S-1: shot noise is not the only significant noise source in that region, and other technical noise sources (which cannot be reduced by squeezing) contribute to the total noise.

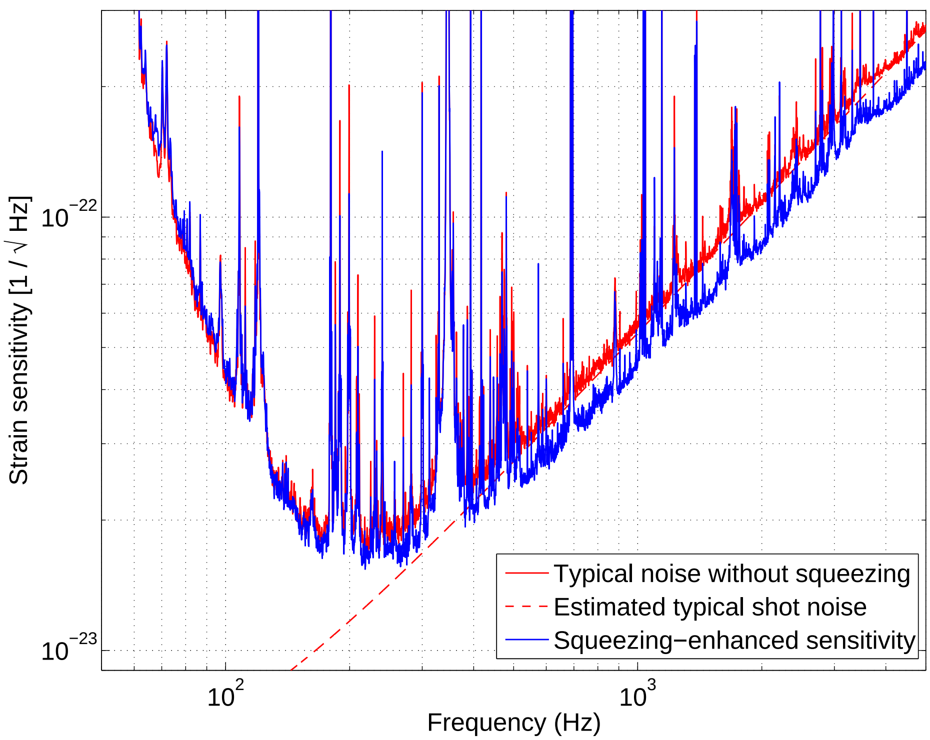


Figure S-1: Shot noise contribution to the typical noise. Shot noise does not account for all the noise, especially below a few hundred Hz.

In Figure S-2, we show the LIGO noise performance zoomed in between 100 to 500 Hz. The observed spectrum without squeezing (red curve) is a combination of shot noise (dashed red curve) and other (technical) noise sources (black curve). Squeezing can only reduce the shot noise, and will not affect the various technical noise sources. The predicted noise we expect with 2.15 dB of squeezing combined with the technical noise is shown in the green trace, and it is in very good agreement with our measured curve with

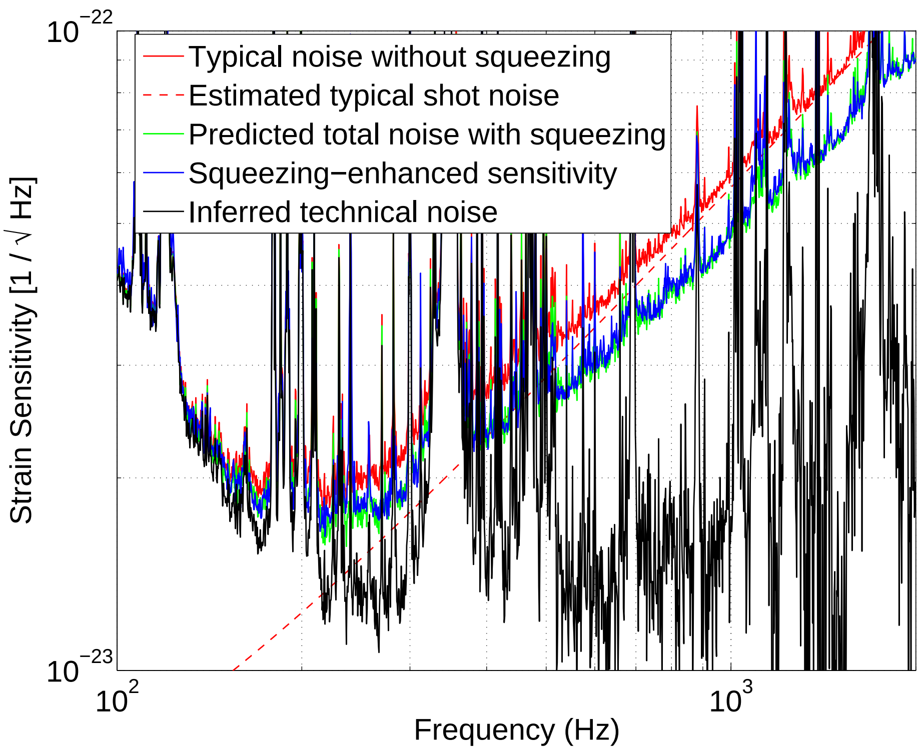


Figure S-2: Prediction for the sensitivity with squeezing (green) compared to the actual measured curve (blue) in the mid-frequency region. The black curve is the sum of the other technical noises.

squeezing (in blue).

Figure S-3 shows the ratio of the typical LIGO sensitivity and the sensitivity with squeezing. The effects of squeezing are visible even below 150 Hz, although at a reduced level when other sources of noise begin to dominate shot noise.

In addition to the low frequency region, technical noise sources dominate over shot noise in a number of line features which are visible in the sensitivity curve. The catalog of lines includes the 60 Hz AC line harmonics, the violin modes of the suspended test masses at about 345 Hz, 690 Hz and 1035 Hz, the narrow test mass resonances above 3 kHz, the transverse mode arm cavity resonances of the RF sidebands between 1 kHz and 2 kHz, some features due to laser frequency noise coupling above 5 kHz, and a few other lines due to electronics artifacts. These narrow line features in the noise

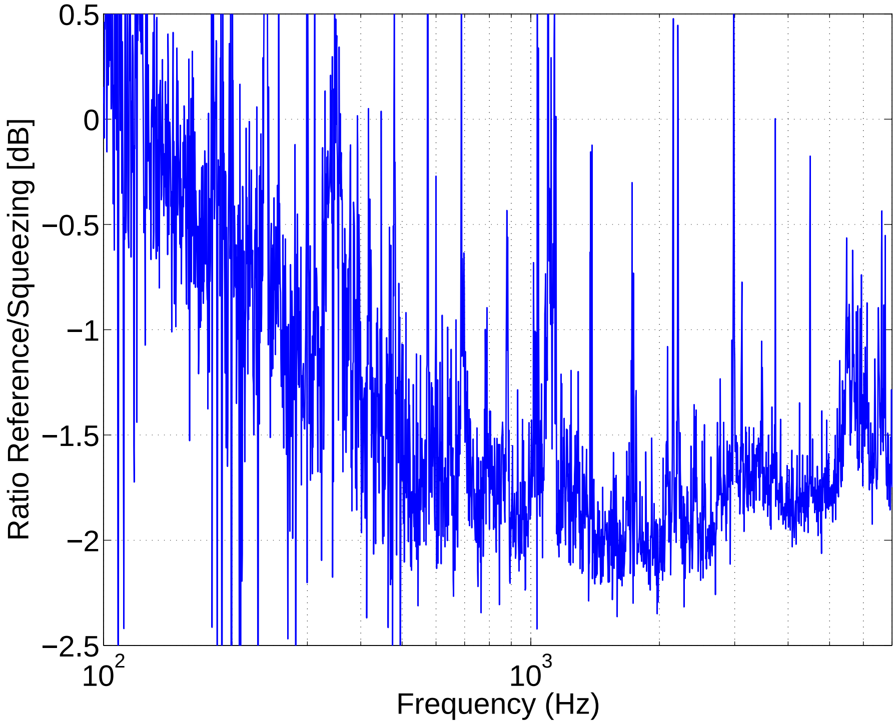


Figure S-3: Ratio of LIGO sensitivities without and with squeezing. Some squeezing is visible down to 150 Hz. If shot noise were the only noise source contributing to the total noise, this ratio would be 2.15 dB at all frequencies.

spectra in Figures S-1 and S-2 increase the denominator in equation S-1, effectively eliminating any contribution to the SNR from those lines. Line features appear to the eye as quite significant because of their amplitude, but in fact they reduce the useful bandwidth by only a few percent and cause a correspondingly small decrease in sensitivity (for broadband sources). This is true whether squeezing is applied or not.

## 3 Comparison between LIGO and GEO600

A squeezed light source must be carefully engineered so as to enhance the performance of the gravitational wave detector in those bands where quantum noise dominates. In the frequency band below 300 Hz, several noise coupling mechanisms between the squeezed light source and the interferom-

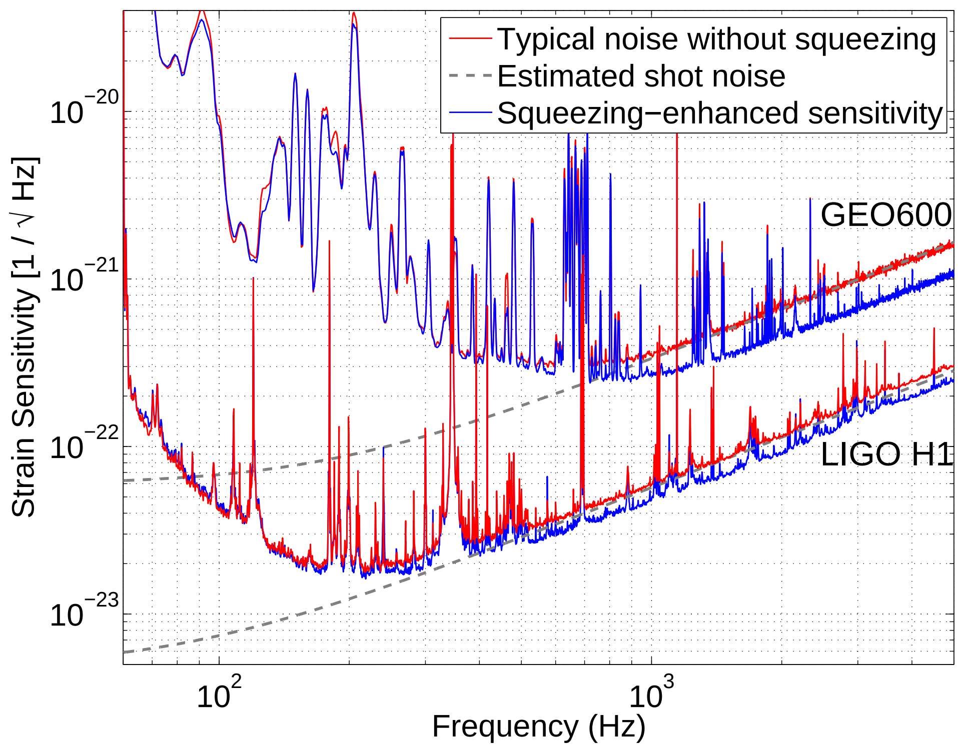


Figure S-3: GEO and LIGO performance with and without squeezing. GEO600 data are courtesy of H. Grote.

eter could potentially not only limit the effectiveness of squeezing, but also degrade the sensitivity. However, if technical noises largely dominate over quantum noise in a given frequency band, the performance of the squeezed light source cannot be tested.

LIGO is substantially more sensitive to gravitational wave strain than GEO600, as shown in Figure S-4. In the frequency band around 200 Hz, shot noise is a limiting noise source for the LIGO H1 detector, while for GEO600 shot noise is a factor of 10 to 100 below the total noise. Consequently, the performance of squeezing cannot be demonstrated by GEO600 in this astrophysically important frequency band.

# 4 Amplitude vs. Power

As gravitational wave detectors measure the *amplitude* of gravitational radiation, their sensitivity is expressed in amplitude spectral density. This fact generates a common misunderstanding when quantifying squeezing enhancement in the context of gravitational wave detectors.

With a squeezing source producing 10 dB of squeezing (or $V_{sqz} = 0.1$ in power) and 10% of losses (or detection efficiency $\eta = 0.9$), one can calculate that the quantum noise is reduced by $\eta V_{sqz} + (1 - \eta) = 0.2$, roughly. That is, a factor of $1/0.2 \sim 5$ reduction in the detector noise. However, this is factor of 5 reduction in power, and it corresponds to an improvement in the detector sensitivity of a factor of $1/\sqrt{0.2} \sim 2$.