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S3 Performance of the LIGO Interferometers as Measured by SenseMonitor
Preliminary Report

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Abstract

I report on the performance of the LIGO Hanford interferometers during the first three weeks of S3, as measured by SenseMonitor. Included are the effective ranges to which each interferometer was sensitive to binary neutron star inspirals, and information on the calibration stability.

Contents

1 Introduction

SenseMonitor is a binary inspiral sensitivity monitor for the LIGO interferometers. It computes the average distance to which a LIGO interferometer is capable of detecting the inspiral of a 1.4-1.4M_o neutron-star binary with a signal-to-noise ratio greater than 8. It runs continuously at both LIGO observatories, providing a real-time measure of each interferometer's ability to detect this standard candle source.

In this document I briefly report on the performance of the LIGO Hanford interferometers during the first three weeks of the S3 run, covering the period 2003 Oct 31 08:00 PST to 2003 Nov 21 08:00 PST. The LIGO Livingston interferometer is not included due to the lack of accurate calibration information for that instrument during the period in question.

Section 2 gives an executive summary of the performance of each interferometer. Section 3 provides some basic information on SenseMonitor and the data it reports. Section 4 contains plots of the performance of the H1 and H2 detectors during the S3 run as measured by SenseMonitor.

Copies of the scripts, plots, and data used in this report are available from the author.

2 Executive Summary

The following table shows the percentile range estimates for each interferometer, with 0% (100%) denoting the lowest (highest) range reported. All ranges are in megaparsecs (Mpc). The "4-volume" column shows the total space-time volume scanned by each interferometer since the start of S3, in units of $\mathrm{Mpc}^3\mathrm{yr}$.

IFO	4-volume	0%	25%	50%	75%	100%
H1	1.8	0.32	1.87	2.18	2.54	4.66
H2	0.098	0.04	0.87	0.91	0.96	1.11

3 SenseMonitor

SenseMonitor evaluates the effective range by estimating the calibration of the detector and using that information to compute the strain noise power spectrum of the gravitational-wave data channel. SenseMonitor then reports: the current range estimate; current calibration information, calibrated noise power spectrum, and range integrand. Output is sent to summary web pages available through the CDS homepage[1] (complete monitor documentation is also available there), the DMTViewer, and trend files.

3.1 Range Definition

SenseMonitor estimates the distance to which an interferometer can detect an inspiral, averaged over all possible sky positions and orientations of the binary system.[2] Assuming that the detector noise is Gaussian with one-sided noise power spectrum $S_h(f)$, this distance is

$$r = \left(\frac{5\mathcal{M}^{5/3}\theta^2}{96\pi^{4/3}\rho_0^2} \int_0^\infty df \, \frac{f^{-7/3}}{S_h(f)} \right)^{1/2} . \tag{1}$$

Here ρ_0 is the minimum signal-to-noise ratio required for detection, $\theta = 1.77$ [3] accounts for the averaging over the binary positions and orientations, and $\mathcal{M}$ is the binary chirp mass, defined as

$$\mathcal{M} = \frac{(M_1 M_2)^{3/5}}{(M_1 + M_2)^{1/5}} . \tag{2}$$

Here M_1, M_2 are the masses of the components of the binary. SenseMonitor calculates ranges for $M_1 = M_2 = 1.4M_o$, for which $\mathcal{M} = 1.2M_o$, and a minimum signal-to-noise ratio of 8.

3.2 Calibration

SenseMonitor estimates the strain noise spectrum from the AS_Q data following the calibration technique described by Adhikari *et al.* [1]. In this approach a set of reference calibration data are measured for each interferometer at a given time. These consist of the open loop gain $G(f)$ (dimensionless), which describes the feedback of the interferometer's control system, and the sensing function $C(f)$ (AS_Q counts/strain), which describes the interferometer's response to a differential arm motion (eg a gravitational-wave) in the absence of feedback. The relationship between the AS_Q data and strain is given in the frequency domain by

$$x_h(f) = \frac{1 + G(f)}{C(f)} \, x_{AS\_Q}(f) \tag{3}$$

[1] http://blue.ligo-wa.caltech.edu/mainPage.html

[2] The range convention used by the Inspiral Analysis Group is the *maximum* distance to which an optimally positioned and oriented binary can be detected. To convert to this range multiply the SenseMonitor estimate by 2.26.

According to the interferometer model used, the calibration functions C and G change over time only by overall re-scalings. A change in the optical gain of the interferometer cavity appears as a time-dependent rescaling $\alpha(t)$ of the sensing function. Changes in the gain of the control feedback are denoted by $\beta(t)$. Equation (3) then becomes

$$x_h(f) = \frac{1 + \alpha(t)\beta(t)G(f)}{\alpha(t)C(f)}\, x_{AS\_Q}(f) \tag{4}$$

A value $\alpha > 1$ indicates an increase in the sensitivity of the instrument compared to the reference time, while $\alpha < 1$ indicates a decrease in the sensitivity. During S3 the control system for each interferometer modifies β to keep the quantity $\alpha\beta$ constant over time (or attempts to do so).

The parameter β is easily tracked, as it is determined by known changes in the interferometer control system. The parameter α is determined by monitoring the amplitude of an injected calibration line, which is a sinusoidal excitation of fixed amplitude and frequency added to the feedback signal.

4 H1 and H2 Performance During S3

SenseMonitor was running continuously at LIGO Hanford since the beginning of S3. The reference calibration data was provided by the calibration team [2] and measured during E10.

The following plots show for each interferometer the range versus time, a histogram of the ranges, the calibration-line amplitude versus time, the calibration parameters α, β, and $\alpha\beta$ versus time, and histograms of the values of $\alpha\beta$.

References

[1] Rana Adhikari, Peter Fritschel, Gabriela Gonzalez, Mike Landry, Luca Matone, Hugh Radkins, Akiteru Takamori, and Brian O'Reilly, *Calibration of the LIGO detectors for the First LIGO Scientific Run*, T030097-00-D (2003).

[2] http://blue.ligo-wa.caltech.edu/engrun/Calib_Home/

[3] Lee Samuel Finn and David F. Chernoff, *Observing binary inspiral in gravitational radiation: One interferometer*, PRD **47** 2198 (1993).

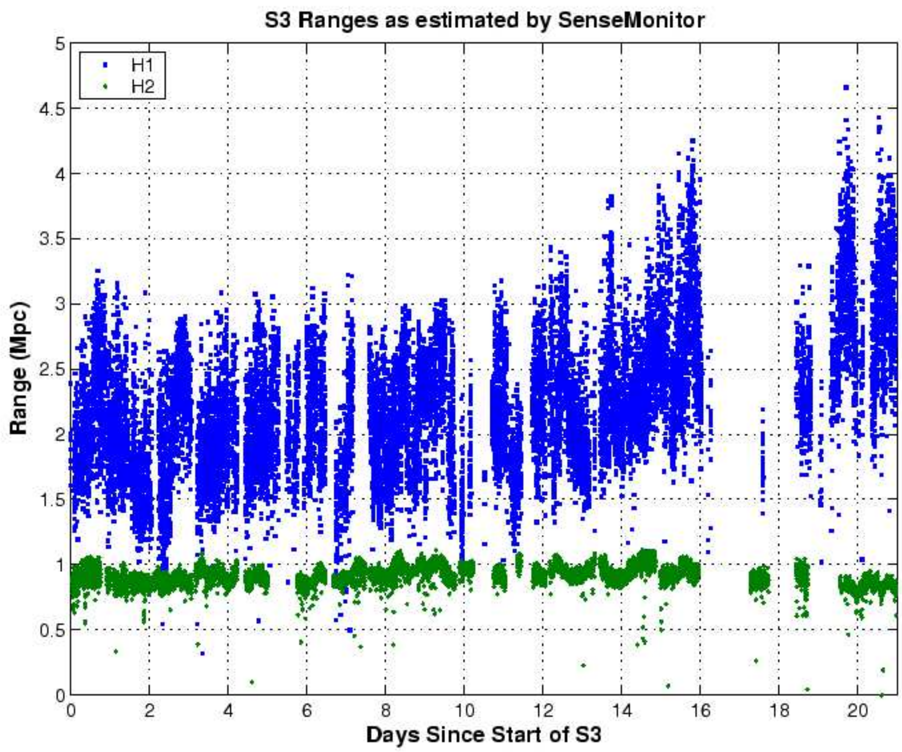

Figure 1: Effective range to which the LHO interferometers could detect a binary neutron star inspiral versus time during the first three weeks of S3.

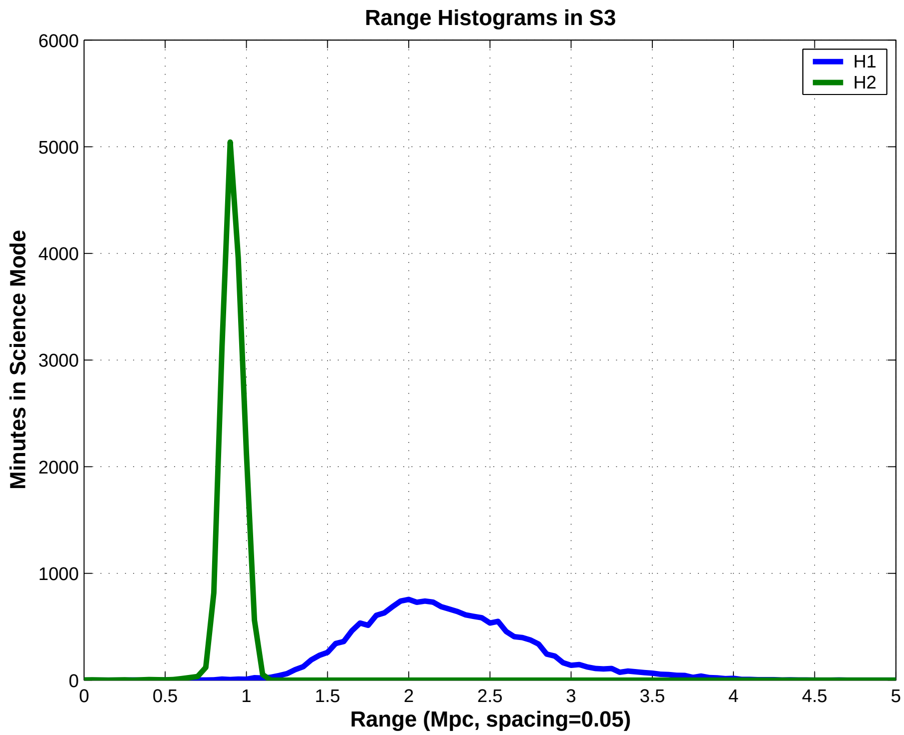

Figure 2: Histograms of the effective range to which the LHO interferometers could detect a binary neutron star inspiral versus time during the first three weeks of S3.

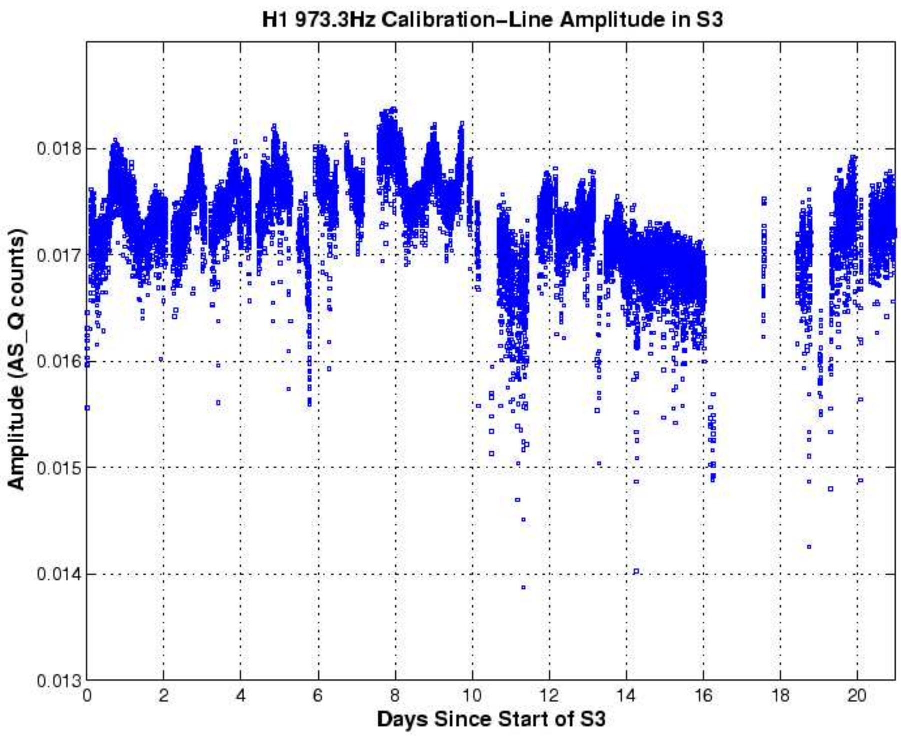

Figure 3: Amplitude of the 973.3Hz calibration line in H1 during the first three weeks of S3. Larger values indicate greater sensitivity.

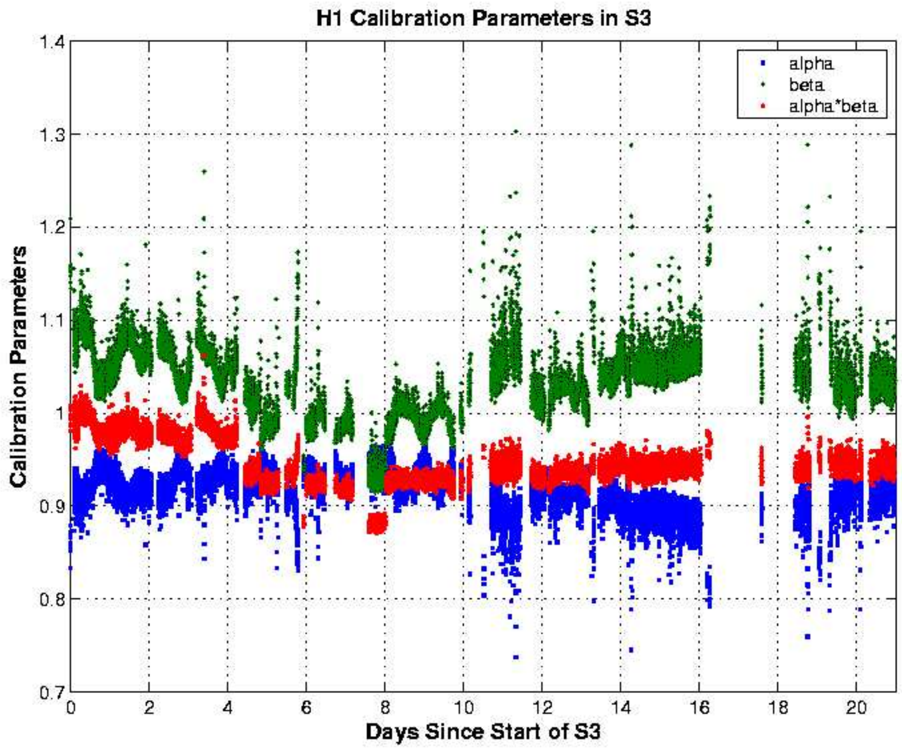

Figure 4: The calibration parameters α, β, $\alpha\beta$ for H1 during the first three weeks of S3. Ideally $\alpha\beta$ is constant during any particular lock.

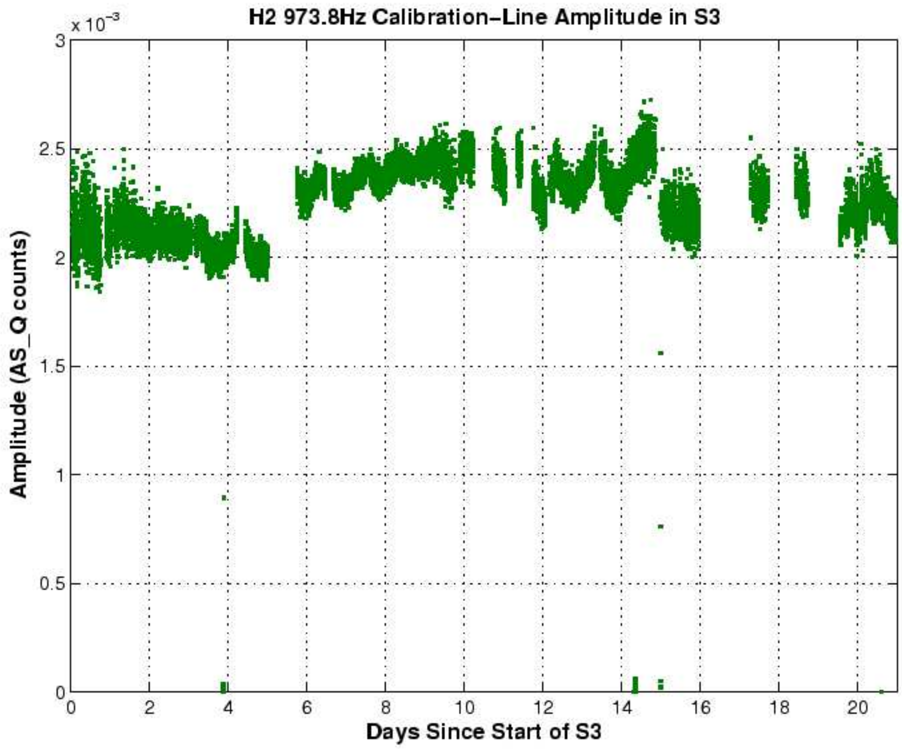

Figure 5: Amplitude of the 973.8Hz calibration line in H2 during the first three weeks of S3. Larger values indicate greater sensitivity.

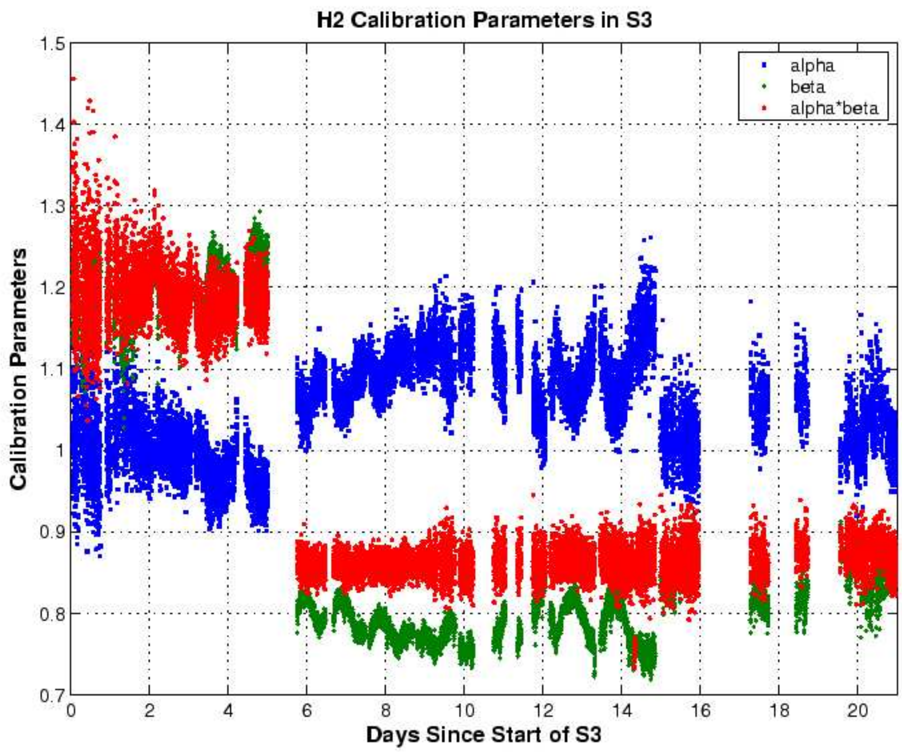

Figure 6: The calibration parameters α, β, $\alpha\beta$ for H2 during the first three weeks of S3. Ideally $\alpha\beta$ is constant during any particular lock.

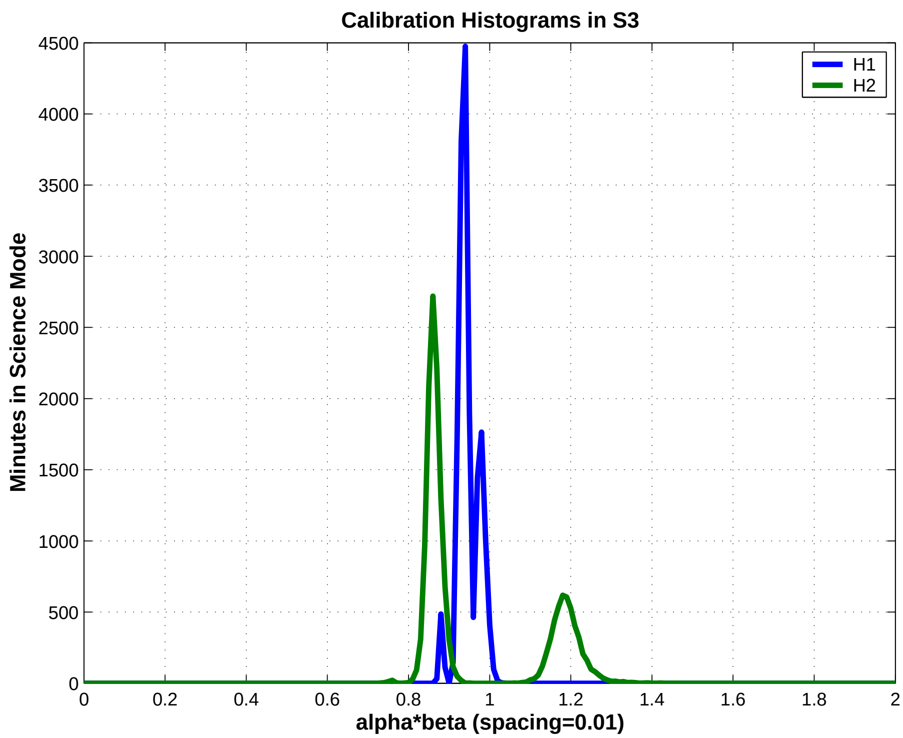

Figure 7: Histogram of $\alpha\beta$ values for the LHO interferometers during the first three weeks of S3.