

LASER INTERFEROMETER GRAVITATIONAL WAVE OBSERVATORY
- LIGO -
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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 interferometers during Science Run 3, 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.

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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 1.4-1.4 M_{\odot} 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 report on the performance of the LIGO interferometers during Science Run 3 (S3), covering the period 2003 Oct 31 08:00 PST to 2004 Jan 09 08:00 PST. The data presented was gathered from online running of SenseMonitor at the observatories, and also from offline running over some of the early S3 Livingston data for the to take advantage of corrected calibration information for that interferometer which became available during S3.

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 LIGO detectors during the S3 run as measured by SenseMonitor.

All data presented in this report comes from science mode segments, as listed at

<http://www.phys.lsu.edu/faculty/gonzalez/S3LockStats/>

Copies of the scripts, plots, and data used in this report are available from the author.¹

2 Executive Summary

Table 1 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

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shows the total space-time volume 4V scanned by each interferometer since the start of S3, in units of Mpc^3yr :

$${}^4V = \sum_i^N \frac{4\pi}{3} R_i^3 \Delta t \quad (1)$$

where the data length used for each range estimate R_i is $\Delta t = 60\text{sec}$. The ‘‘mean range’’ column is the effective range over the entire run:

$$R_{\text{eff}} = \left[\frac{3}{4\pi} \frac{{}^4V}{\sum_i^N \Delta t} \right]^{1/3} \quad (2)$$

$$= \left[\frac{1}{N} \sum_i^N R_i^3 \right]^{1/3} . \quad (3)$$

IFO	4-volume 4V (Mpc^3yr)	mean range R_{eff} (Mpc)	quartile ranges (Mpc)				
			0%	25%	50%	75%	100%
H1	19.88	3.37	0.07	2.30	2.93	3.78	5.98
H2	0.32	0.88	0.04	0.81	0.88	0.93	1.19
L1	0.25	1.15	0.00	0.89	1.04	1.22	2.06

Table 1: Summary of the performance of each of the LIGO interferometers during Science Run 3, 2003/10/31 08:00 PDT - 2004/01/09 08:00 PDT.

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 homepage² (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.³ Assuming that the detector

²<http://blue.ligo-wa.caltech.edu/mainPage.html>

³The 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.

noise is Gaussian with one-sided noise power spectrum $S_h(f)$, this distance is

$$r = \left(\frac{5\mathcal{M}^{5/3}\theta^2}{96\pi^{4/3}\rho_0^2} \int_{30\text{Hz}}^{1400\text{Hz}} df \frac{f^{-7/3}}{S_h(f)} \right)^{1/2}. \quad (4)$$

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

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

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.

The upper limit of integration in (4) is the approximate frequency at which the inspiral terminates for 1.4-1.4 M_o binary system. In practice, the contribution to the range from frequencies above 1000Hz is negligible. The lower limit is chosen sufficiently low so that the contribution to the integral is again negligible. Hence, the range estimated using (4) is insensitive to the precise choice of the limits of integration.

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

$$x_h(f) = \frac{1 + G(f)}{C(f)} x_{AS-Q}(f) \quad (6)$$

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 (6) then becomes

$$x_h(f) = \frac{1 + \alpha(t)\beta(t)G(f)}{\alpha(t)C(f)} x_{AS-Q}(f) \quad (7)$$

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 IFO 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.

At LIGO Livingston valid reference calibrations were not available until Nov 21. As a result, the L1 results from before this date which are shown in this report have been taken from offline runs of SenseMonitor performed at CIT.

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).

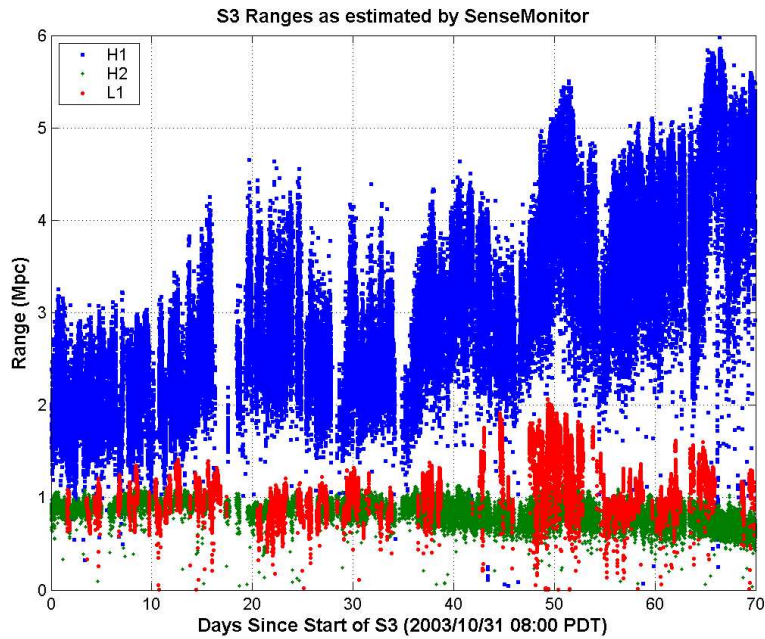


Figure 1: Effective range to which the LIGO interferometers could detect a binary neutron star inspiral versus time during S3.

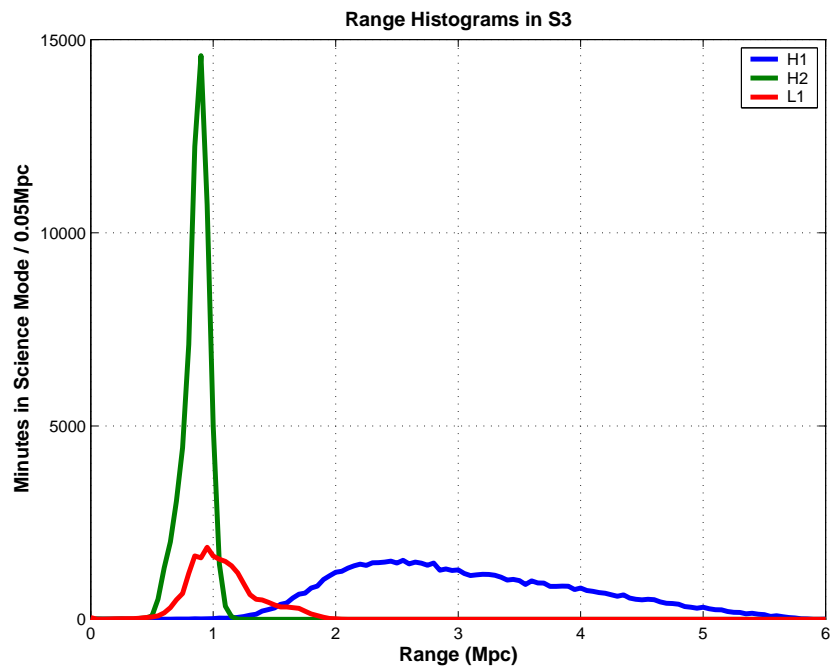


Figure 2: Histogram of effective range to which the LIGO interferometers could detect a binary neutron star inspiral versus time during S3.

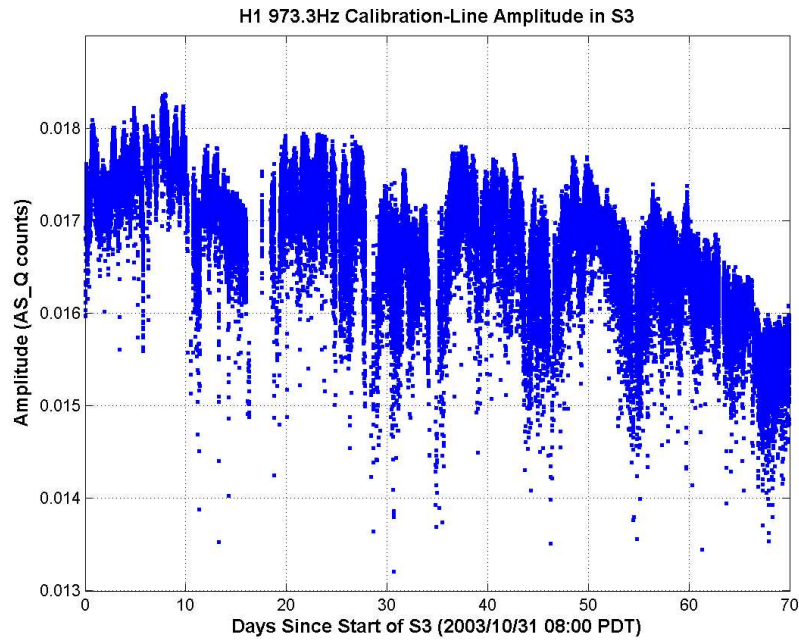


Figure 3: Amplitude of the 973.3Hz calibration line in H1 during S3. Larger values indicate greater sensitivity.

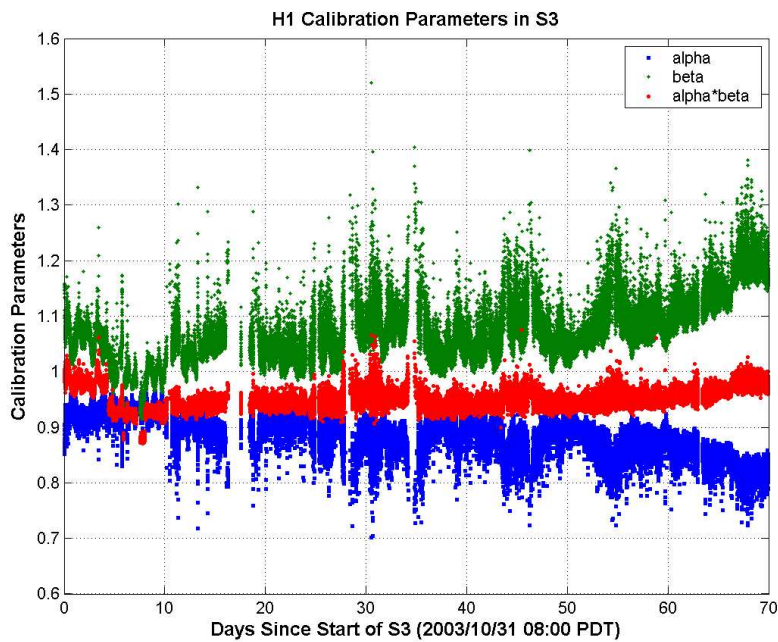


Figure 4: The calibration parameters α , β , $\alpha\beta$ for H1 during S3. Ideally $\alpha\beta$ is constant during any particular lock.

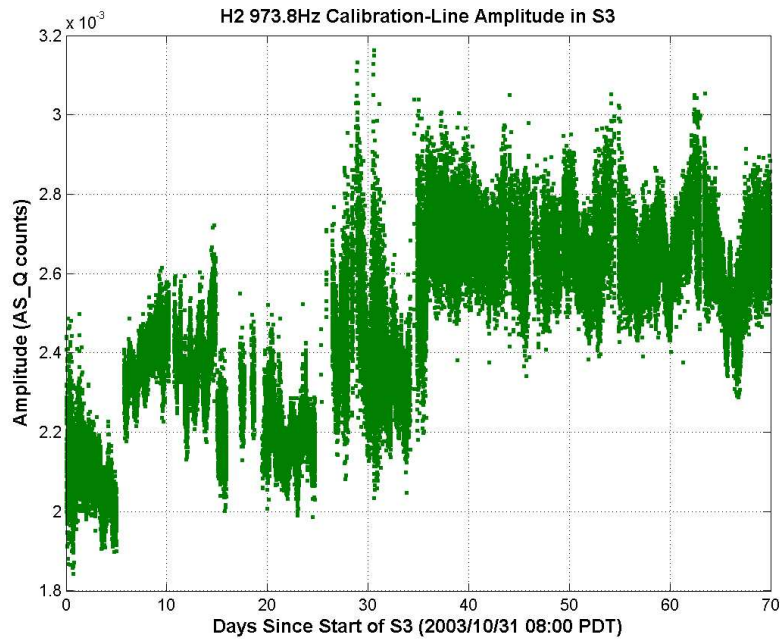


Figure 5: Amplitude of the 973.8Hz calibration line in H2 during S3. Larger values indicate greater sensitivity.

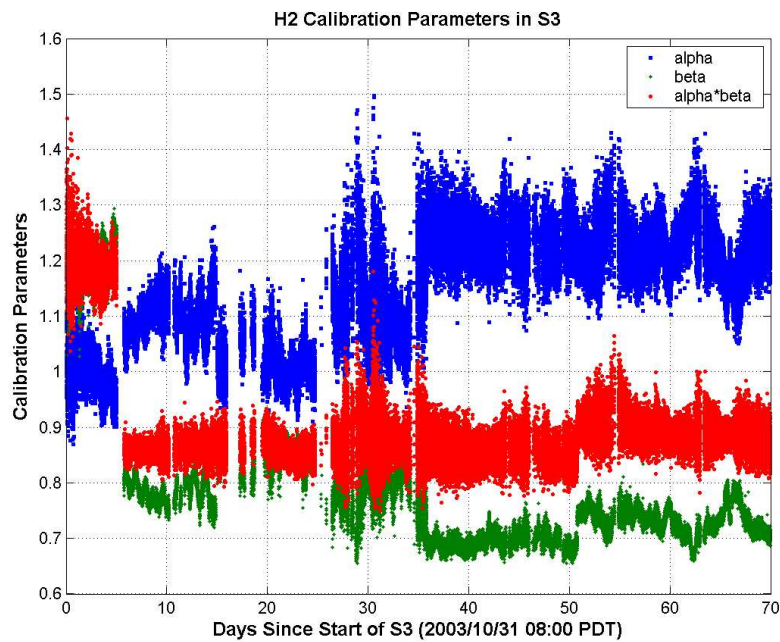


Figure 6: The calibration parameters α , β , $\alpha\beta$ for H2 during S3. Ideally $\alpha\beta$ is constant during any particular lock.

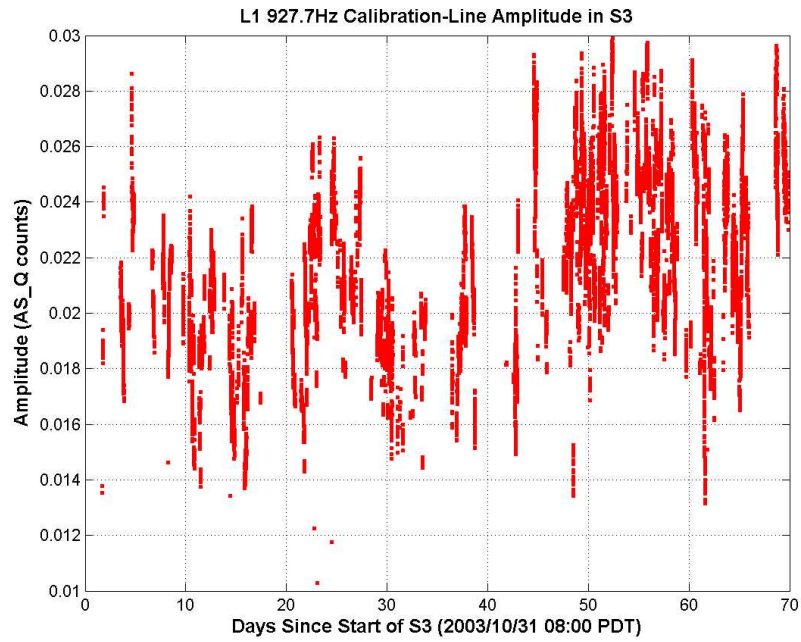


Figure 7: Amplitude of the 927.7Hz calibration line in L1 during S3. Larger values indicate greater sensitivity.

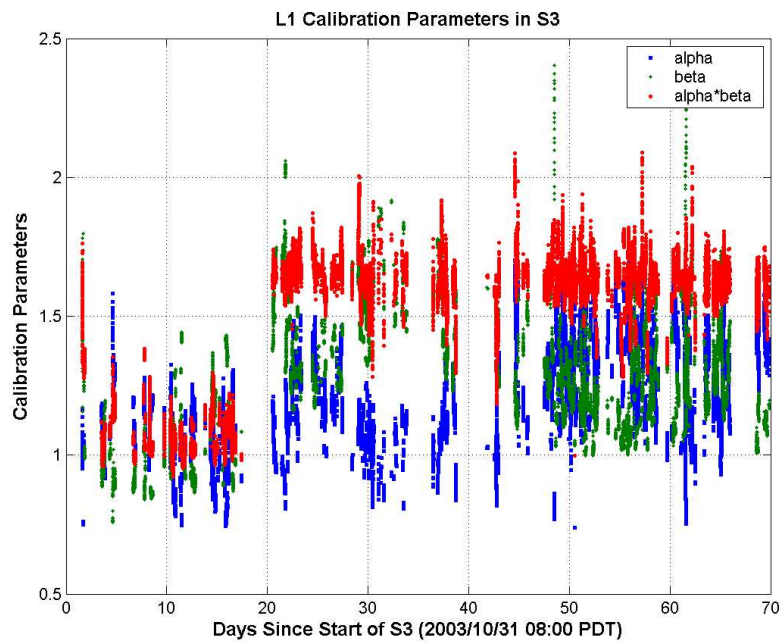


Figure 8: The calibration parameters α , β , $\alpha\beta$ for L1 during S3. Ideally $\alpha\beta$ is constant during any particular lock.

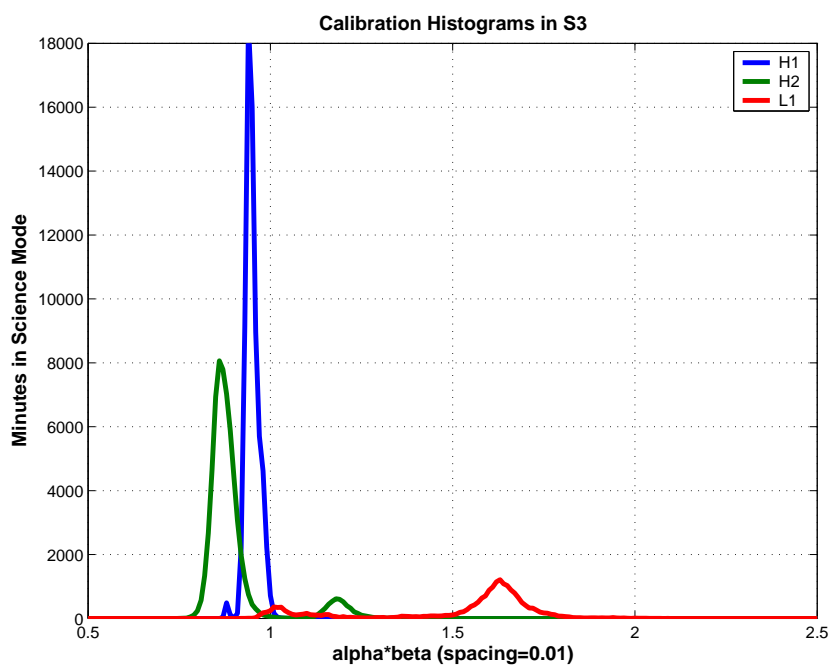


Figure 9: Histogram of $\alpha\beta$ values for the LIGO interferometers during S3.