Tracking of calibration lines in the S1 run

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During the S1 LIGO run there was a set of calibration lines at frequencies:

H1:LSC-AS_Q	37.25 Hz	973.3 Hz
H2:LSC-AS_Q	37.75 Hz	973.8 Hz
L1:LSC-AS_Q	51.3 Hz	972.8 Hz

The parameters (amplitude and phase) of these lines were measured in real time using the LineMonitor, which is a DMT tool to track narrow lines. The method of the line tracking is described elsewhere [1]. Since the calibration lines have stable and known frequencies (monochromatic lines), they were monitored in the mode with fixed frequencies. When the line frequency is known, the detector output (IFO:LSC-AS_Q) is re-sampled at new sampling rate

$$f_{new} = f \cdot (\text{int}(f_{old} / f) + 1)$$

Then one line period contains an integer number of the data samples L. It means that the line coincides with one of the Fourier functions. Therefore applying the discrete Fourier transform with rectangular window, the line energy will be accumulated in only one bin at the line frequency (no sinc leakage). Dividing the data on the sections of L samples long and averaging them, the line interference signal can be found. It has the length of *1/f* (one period of the frequency *f*) and includes contribution from all line harmonics. The FFT of the line interference signal gives the complex amplitudes a_n, which correspond to different line harmonics n. To avoid the energy leakage from the low frequency harmonics, where the detector signal is usually large, the Hann window is used.

The lines should be measured on the top of the detector noise, which is the source of uncertainty in the measurement of the line's parameters. To take the noise into account, the LineMonitor estimates the noise power spectral density (N) in the vicinity of the line. Using the PSD measured at the line frequency S, the LineMonitor filter parameters can be found

$$F(nf) = 1 - \frac{N(nf)}{S(nf)},$$

where n is the harmonic number. The line complex amplitude is then $a'_n = a_n \cdot F(nf)$. The signal to noise ratio is defined as the ratio of the line and noise intensity in the output of the LineFilter

$$SNR = F\frac{S}{N}.$$

The uncertainty of the line amplitude, arising from the detector noise, can be roughly estimated as

$$\frac{\delta a'_n}{a'_n} \approx \frac{1}{\sqrt{SNR(nf)}},$$

assuming that the detector noise fluctuations in a single frequency bin are 100%.
Figures 1,2 show the calibration line peaks on the top of the detector noise for 60 sec of the H2:LSC-AS_Q data. The vertical axis is in the units of the root square of the power spectral density. For typical SNR of 100-200 the expected uncertainty for the line amplitude is approximately 10%, which is confirmed by the plots.

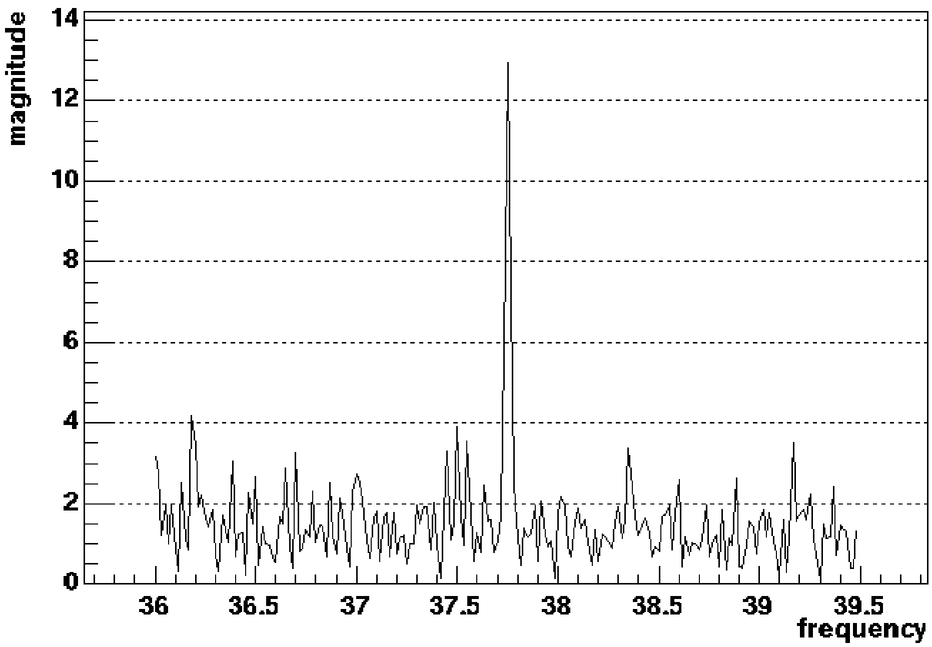

Figure 1. Magnitude of 37.75 Hz calibration line in the H2:LSC-AS_Q channel.

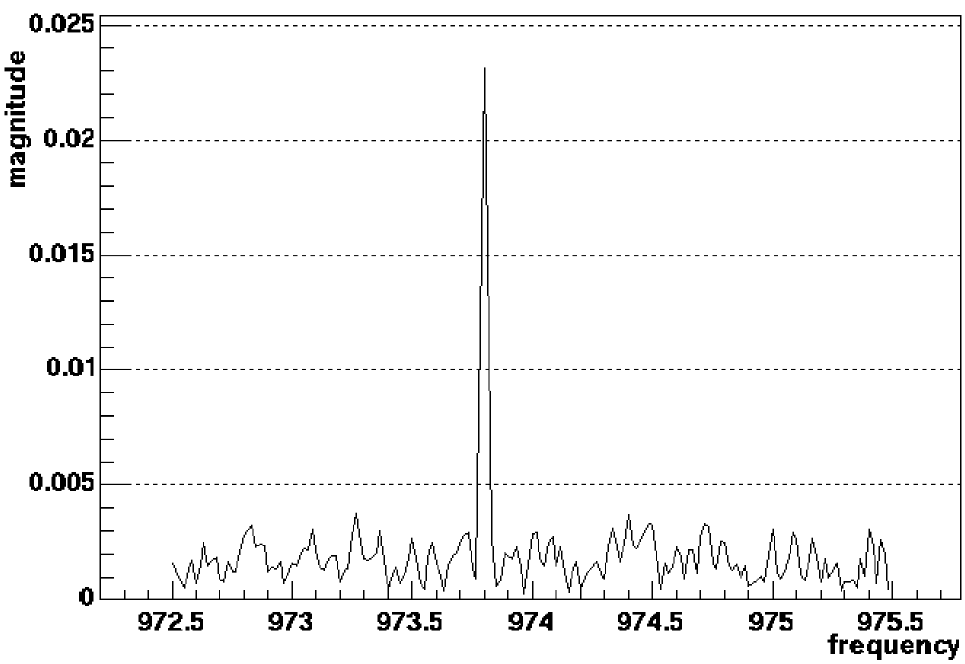

Figure 2. Magnitude of 973.8 Hz calibration line in the H2:LSC-AS_Q channel.

The Figures 3-6 show the calibration line amplitudes for all tree interferometers. The gps time on the top of each plot is the start time.

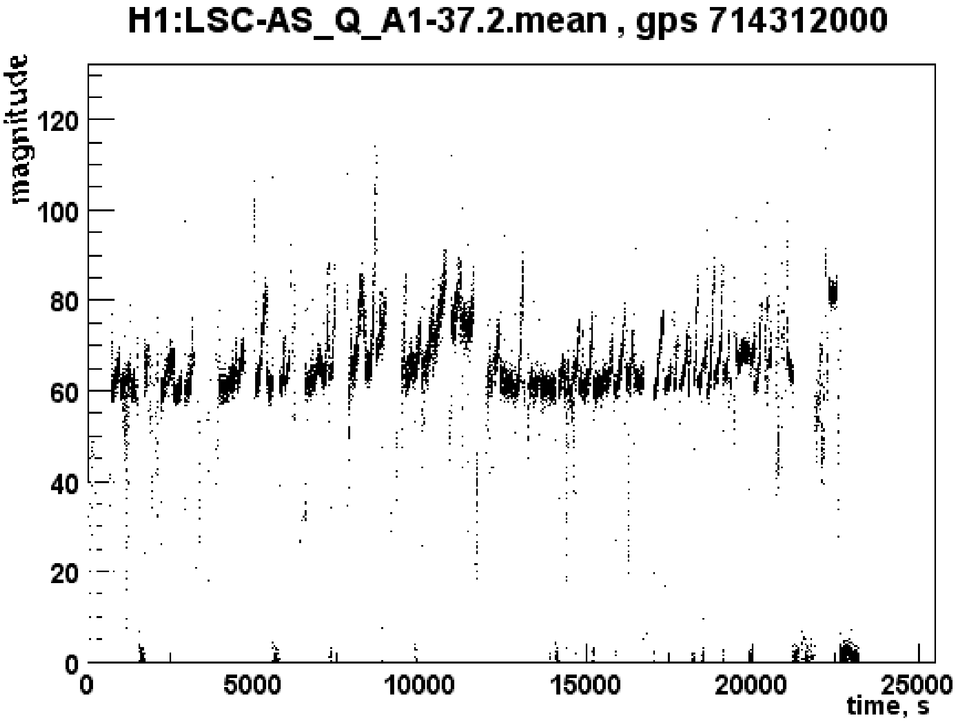

Figure 3. Amplitude of the 37.25 Hz calibration line for the S1 run data.

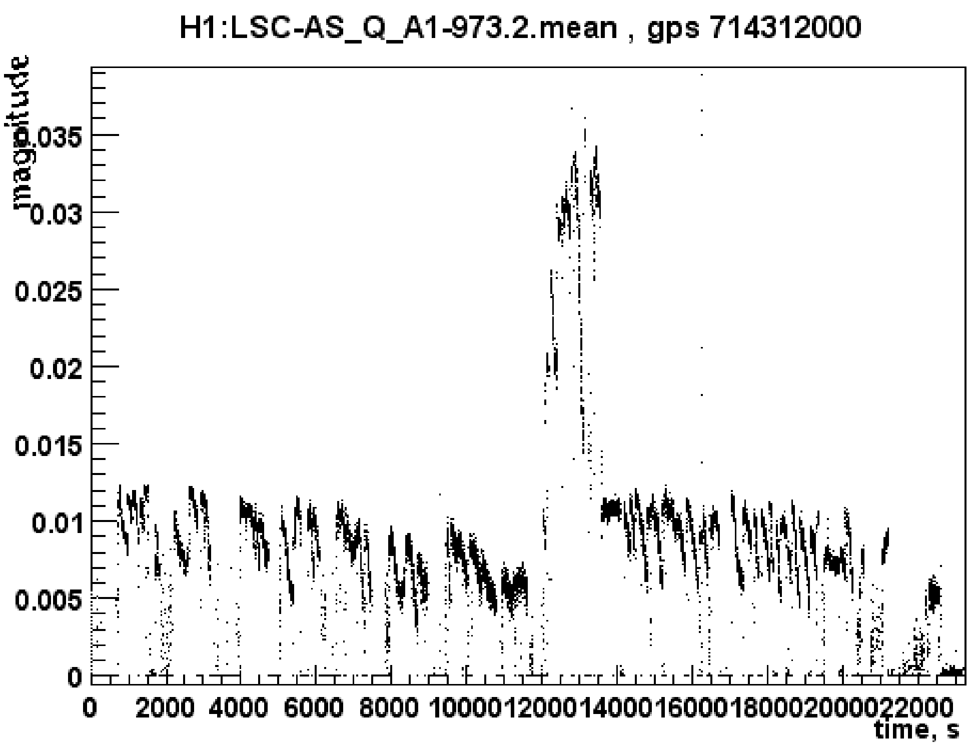

Figure 4. Amplitude of the 973.3 Hz calibration line for the S1 run data.

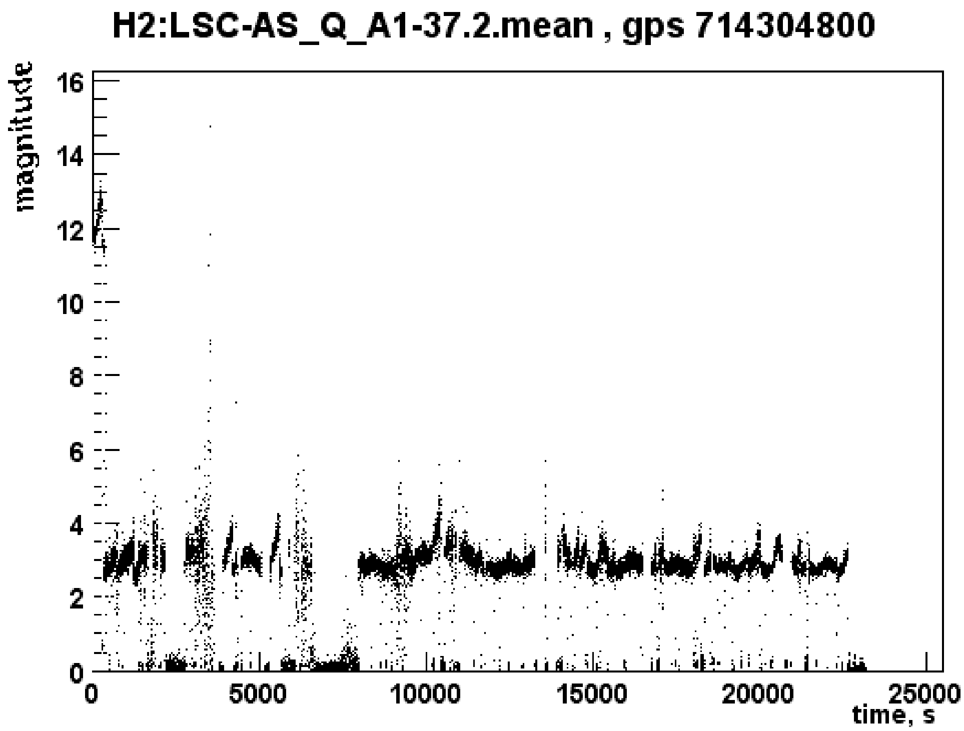

Figure 5. Amplitude of the 37.75 Hz calibration line for the S1 run data.

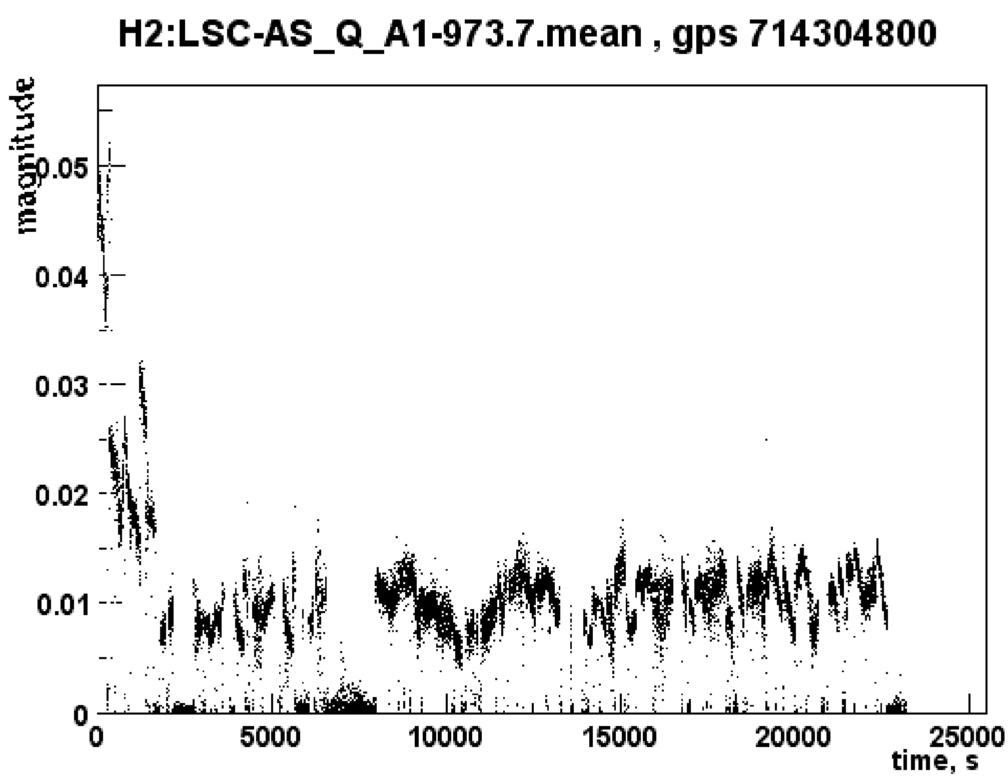

Figure 6. Amplitude of the 973.8 Hz calibration line for the S1 run data.

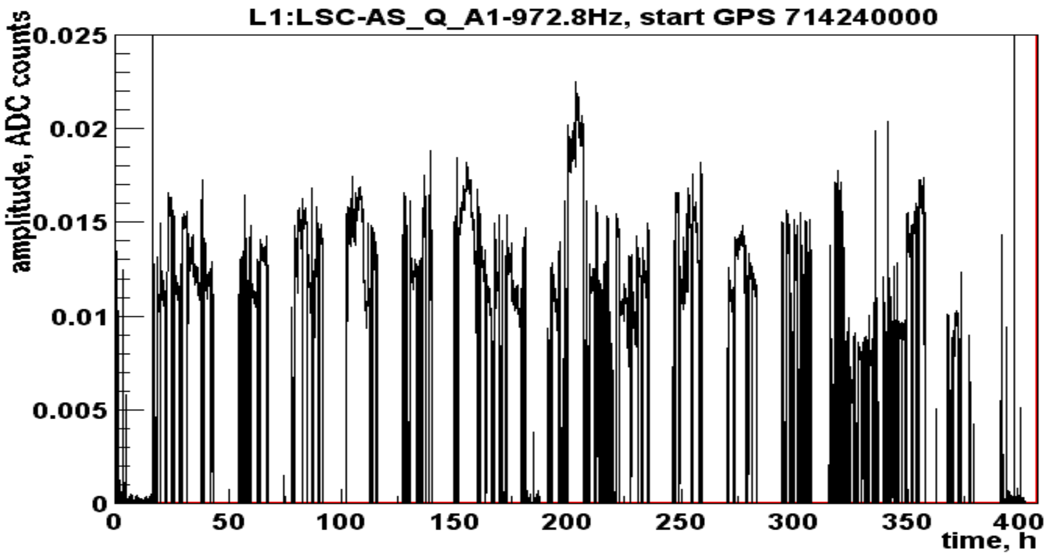

Figure 7. Amplitude of the 972.8 Hz calibration line for the S1 run data.

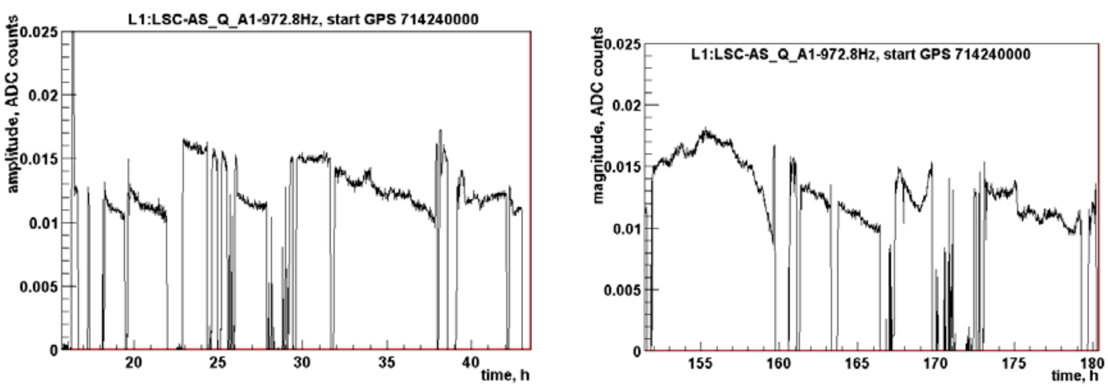

Figure 8. Two expanded sections of the S1 data showing the amplitude of the 972.8 Hz calibration line. The uncertainty of the line amplitude is few percents, which is consistent with the SNR plot below

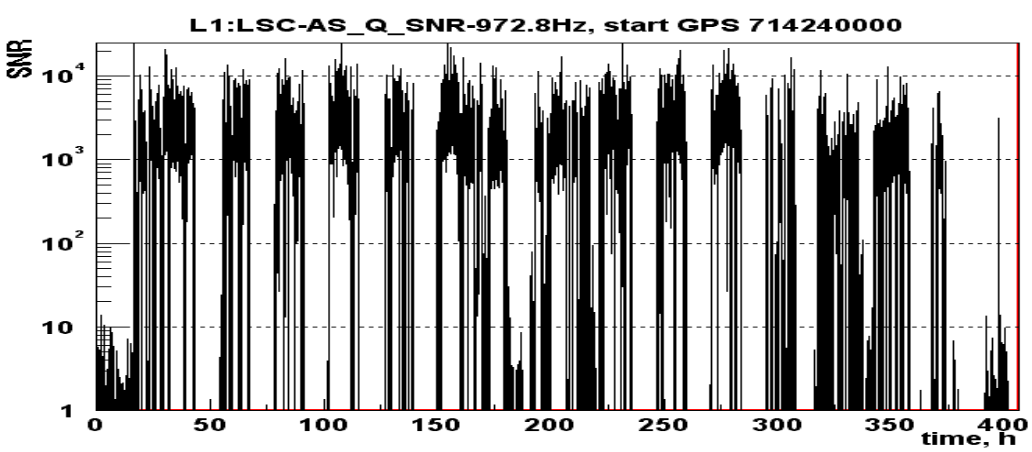

Figure 9. Signal to noise ratio for the S1 972.8 Hz calibration line.

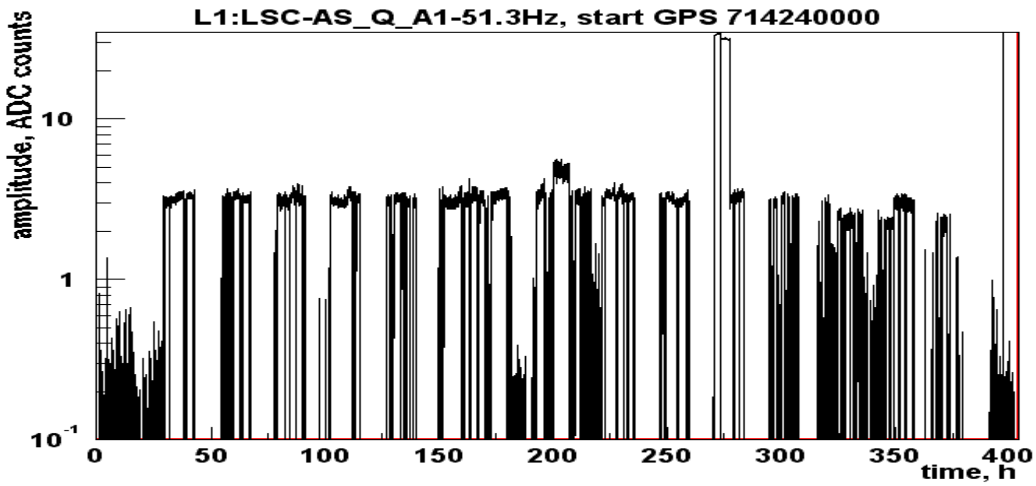

Figure 10. Amplitude of the 51.3 Hz calibration line for the S1 run data.

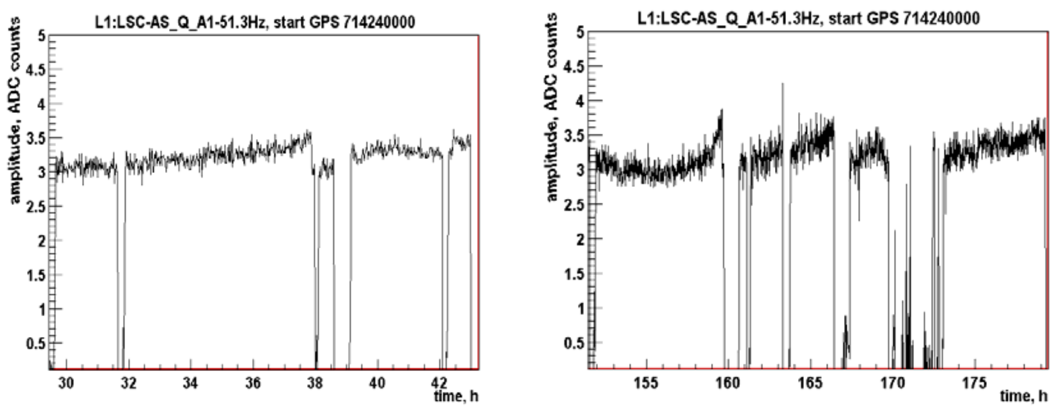

Figure 11. Two expanded sections of the S1 data for the 51.3 Hz calibration line. Although the amplitude of the line is approximately the same, the uncertainty of the line amplitude is different due to different interferometer noise.

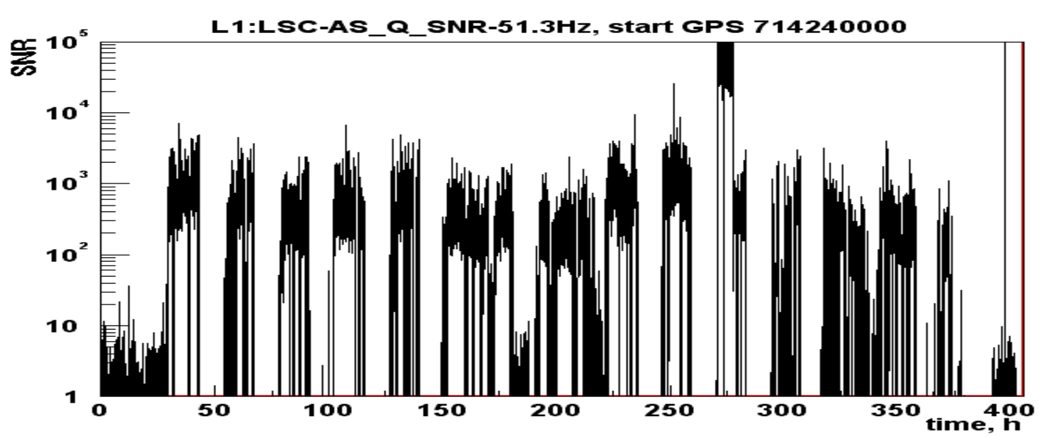

Figure 12. Signal to noise ratio for the 51.3 Hz calibration line.