Laser Interferometers' Calibration Errors In Gravitational Waves From Core Collapse Supernovae

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INTRODUCTION

Laser Interferometers are capable to measure vibrations of space time itself that we call gravitational waves (GWs). GWs, in turn, can be used to produce a number of scientific statements. The precision in the reconstruction of the GWs affect which physics statements we can make. In this poster we quantify the impact of the interferometer calibration errors (between the recorded laser intensity and the strain of space itself).

PROCEDURE

Converting Light Intensity to Strain

$$h(t) = I(t) \star c(t) \qquad c(t): \text{Time Evolving Calibration Filter}$$

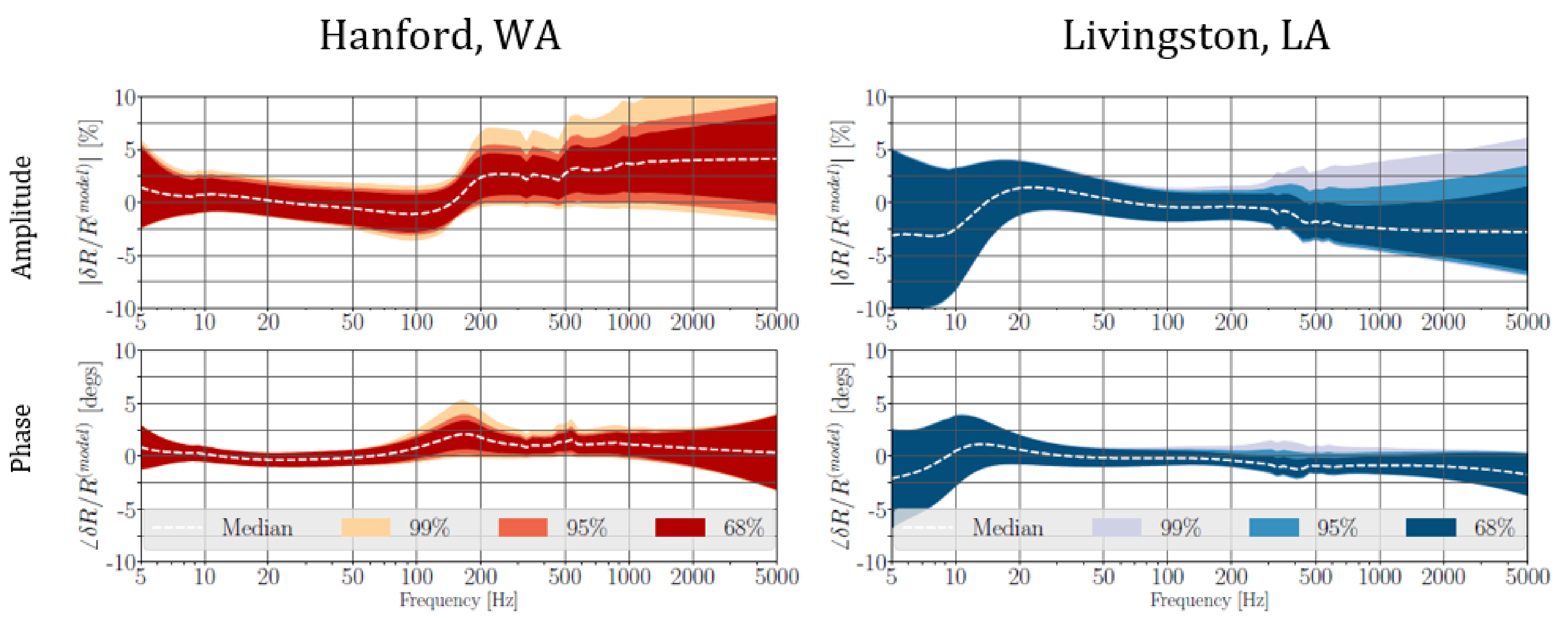
Fourier Transform into the Frequency Space

$$h_c(f) = \int_{-\infty}^{\infty} e^{-2\pi i f t}\, h_c(t)\, dt = A(f)[1 + \epsilon_A(f)]\, e^{i(\phi(f) + \epsilon_\phi(f))}$$

Where:

$\epsilon_A(f)$: Frequency Dependent Calibration error (relative) in the Amplitude

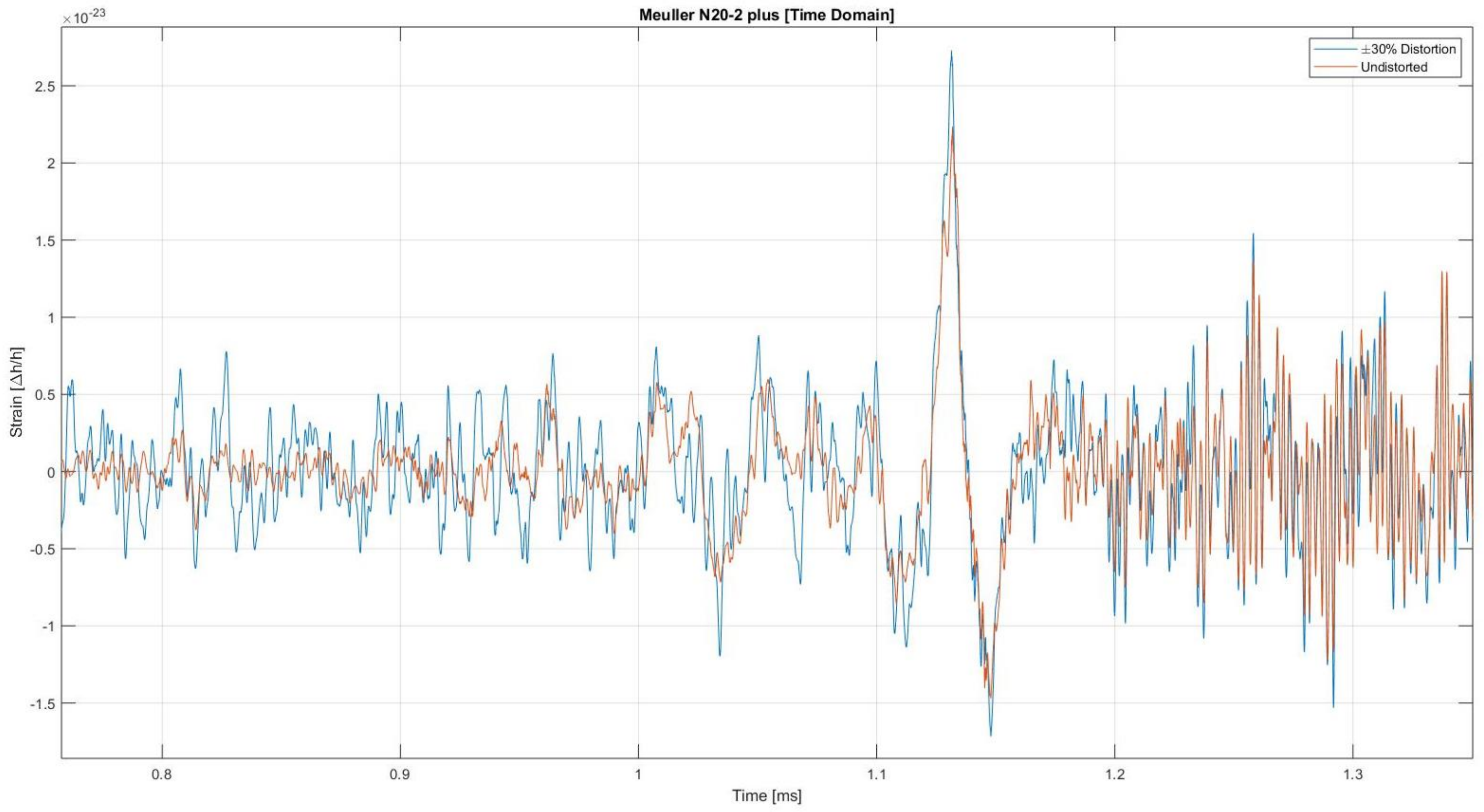
$\epsilon_\phi(f)$: Frequency Dependent Calibration error (relative) in the Phase



Calibration Uncertainties as a function of the frequency [Percentiles for Observing Run Two. The percentiles are created for all of O2 data from November 30, 2016 to August 25th, 2017]

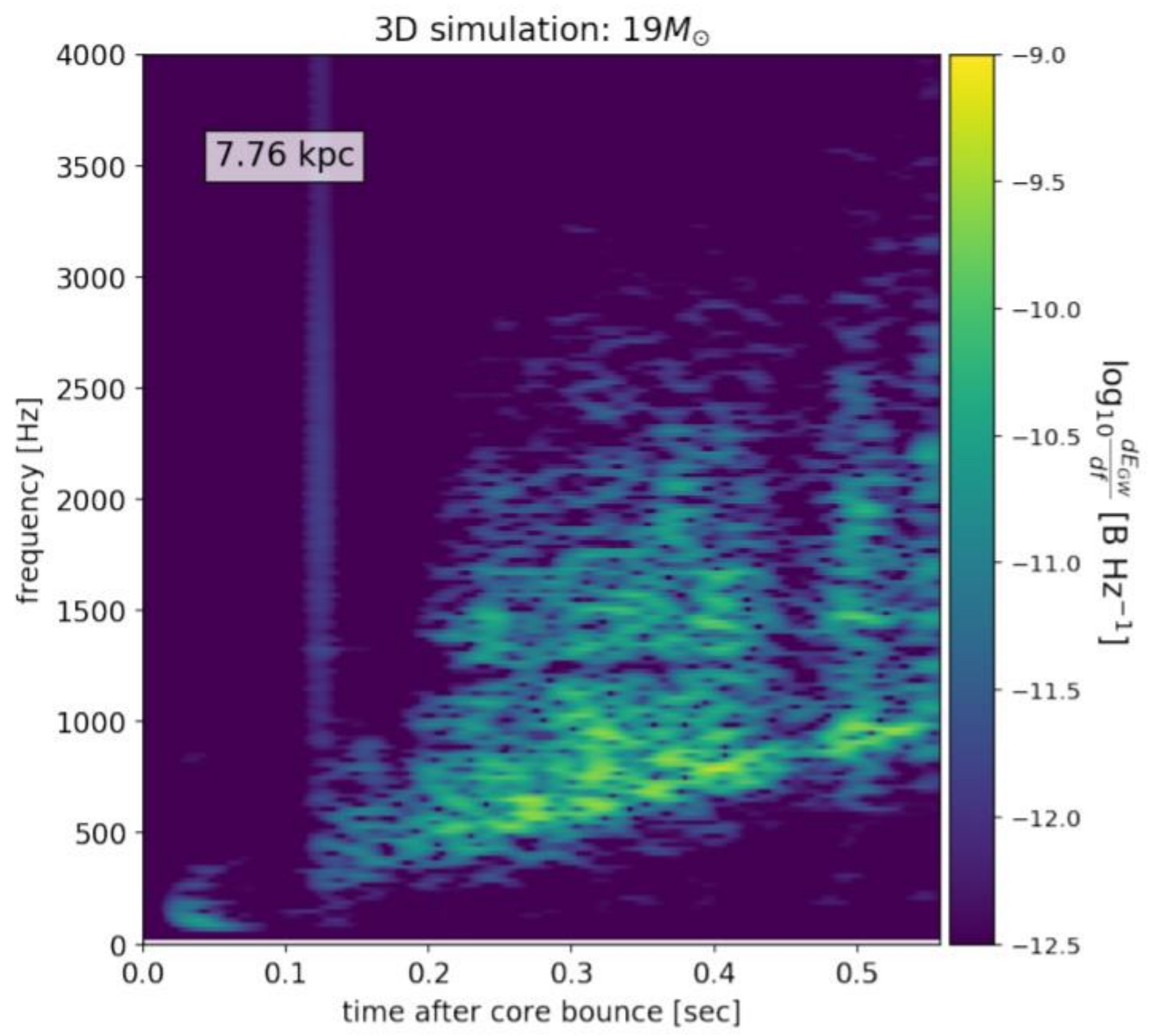
Impact of Phase Calibration Errors

Frequency dependent phase errors can distort the temporal shape of the signal and not just the overall amplitude or arrival time as previously assumed. Below is an example of randomized phase and amplitude errors within a ±30% relative magnitude range.



Supernova Waveforms

Shape distortions like the one above happen when the signals are broadband which is a visible feature in the spectrogram representation



PRELIMINARY RESULTS

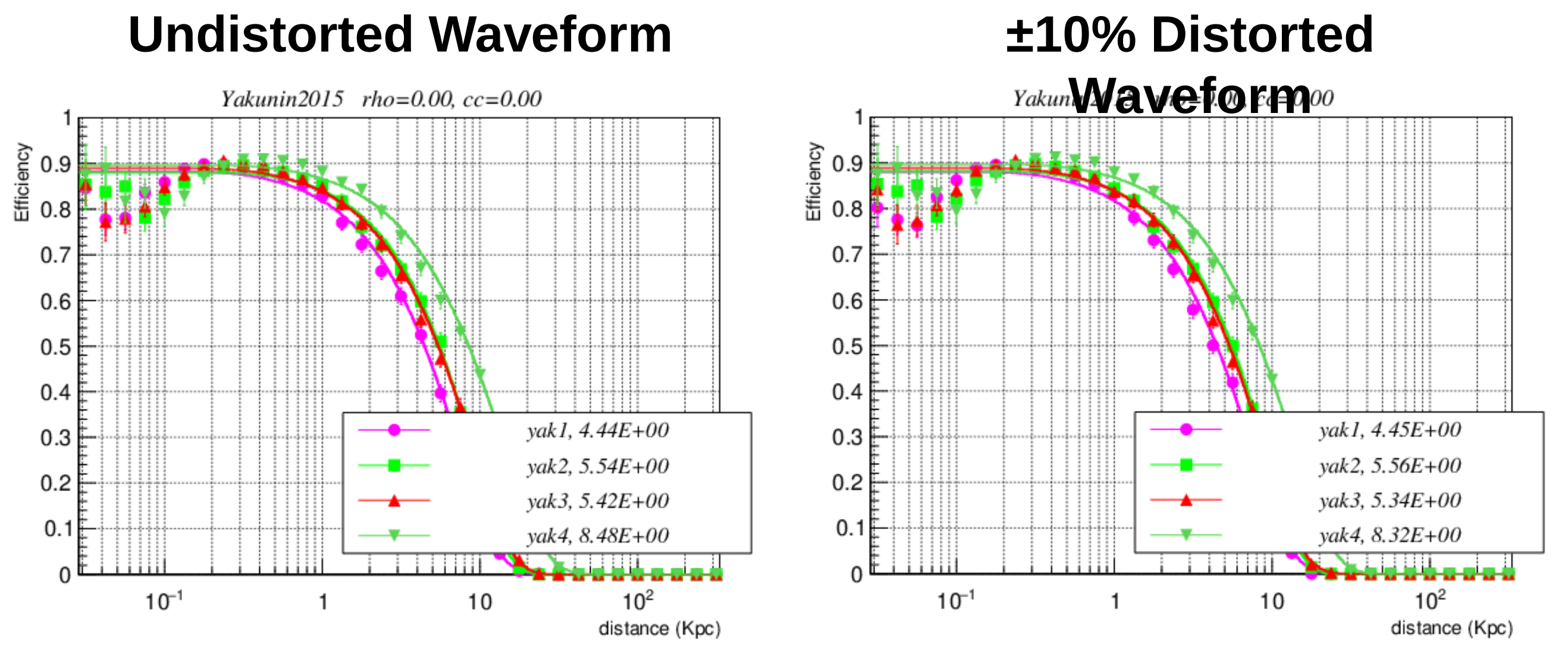
We quantify the impact of calibration errors with three different measures:

1. **CC Coefficient:** Measures similarity of the reconstructed waveform between different interferometers. Calibration errors are expected to reduce the value and also detection efficiency which rely on large values of the cc coefficient

$$cc = \frac{\sum_i^N (x_i - \mu_x)(y_i - \mu_y)}{\sqrt{\sum_i^N (x_i - \mu_x)^2}\sqrt{\sum_i^N (y_i - \mu_y)^2}}$$

Define x_i and y_i to be the two data streams and $i = 1,\ldots,N$ to be the entire set of points

The cc coefficient lies between -1 and 1, inclusive; a value of 1 means that the two series are completely correlated, while a value of -1 means that the series are completely negatively correlated. A value near zero means that the series are uncorrelated.


Undistorted Waveform

±10% Distorted Waveform

Above are preliminary results from the study, the plots denotes detection efficiencies as a function of distance, the first column pertains to a undistorted waveform, whereas in the second column, the same waveform was distorted using the ±10% calibration error model.

2. **Fitting Factor:** Indicates how well an injected waveform matches the reconstructed waveform produced by cWB. Additionally, the fitting factor will also be utilized to compare reconstructed waveforms from undistorted waveforms and those with calibration errors.

$$FF = max \frac{(h_S(f)|\, h_R(f))}{\sqrt{(h_R(f)|\, h_R(f))(h_S(f)|\, h_S(f))}}$$

The FF is a scalar measure ranging from 0 to 1, such a process takes into account spectral noise density.

CONCLUSION

The next steps for the study is to continue the aforementioned analysis of calibration errors for the ongoing optical triggered core collapse supernova search for the so called O3 data set. As follows, the goal is to provide results that take into account the dependent calibration errors found in each of the LIGO sites. Once the study is concluded, a methodology paper can be written further detailing the role of frequency dependent phase errors within gravitational wave signals.