Journal of Physics: Conference Series **716** (2016) 012033 doi:10.1088/1742-6596/716/1/012033

Parameter estimation for compact binary inspirals with a simple noise realization

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Abstract. In the context of parameter estimation of gravitational waves (GWs), detector noise is assumed to be Gaussian and stationary. In reality, many electric glitches, which are neither Gaussian nor stationary, were observed and reported in publications by the LSC-Virgo collabotation. Proper noise reduction is important in GW data analysis, as these glitches would limit, if not downgrade, the quality of parameter estimation. In this work, we investigate the accuracy of results obtained by Markov Chain Monte Carlo (MCMC) parameter estimation for compact binary inspirals with the LIGO-Virgo network when non-Gaussian, stationary noise is remained in data of each interferometer. Spiky, delta function-like glitches, which are stationary, do not affect correlations between parameters. However, most likely values of chirp mass and distance seem to be shifted by the specific frequencies and amplitudes of glitches.

1. Introduction

When developing a parameter estimation (PE) library for gravitational-wave (GW) signals, detector noise is assumed to be Gaussian and stationary. However, non-Gaussian noise features (e.g. electric glitches) have been observed in engineering and science runs of the GW detector network. Many works studied appropriate treatments of detector noise existing in GW data [1, 2, 3, 4, 5, 6, 7]. In this work, we perform Markov Chain Monte Carlo (MCMC) PE for non-spinning black hole (BH) - neutron star (NS) binary inspirals with a simple model for non-Gaussian noise "glitches" at given frequencies. For a simple exercise, we adapt the frequencies of glitches found during the *blind injection challenge*[1] [8] assuming they are stationary glitches. We compare MCMC PE results with and without glitches.

Table 1. Selected source parameters for the BH-NS inspiral injection used in this work.

Parameter	$M_{\rm chirp}$ ($M_{\rm sun}$)	m_1 ($M_{\rm sun}$)	m_2 ($M_{\rm sun}$)	symmetric mass ratio	m_1/m_2	R.A. (rad)	dec. (rad)	distance (Mpc)	SNR
Value	2.994	10.0	1.4	0.108	7.1	6.485	5.747	310	19.9

[1] This corresponds to the LIGO's fifth science run and Virgo's first science run.

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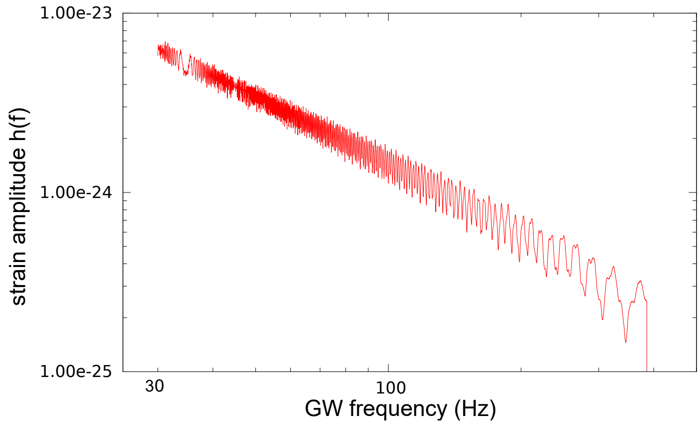

Figure 1. The injection GW signal is a full waveform generated for BH-NS inspiral in the frequency domain. We use `TaylorF2` with amplitude corrections implemented in a local branch of `LALSuite`. Note the amplitude modulations are strong due to the mass difference between BH and NS ($m_2/m_1 = 0.14$). Considering the initial LIGO-Virgo network, the injection signal is generated between the low cut-off frequency (30Hz) and ISCO frequency for a BH-NS binary (372Hz).

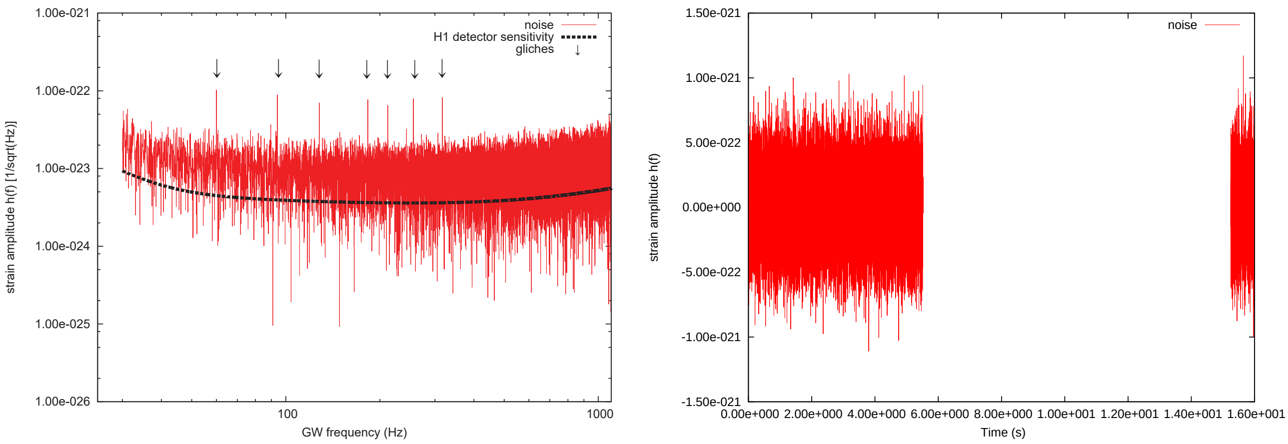

Figure 2. (a) Simulated noise (in red) for the LIGO Hanford (H1), where seven delta function-like glitches are injected to the Gaussian noise realization. We overlay the strain amplitude spectral density for H1 in a dotted black line for comparison. Black arrows indicate frequencies of artificial glitches. Noises for the Livingston (L1) and Virgo (V1) detectors are similar to that of H1. (b) We present the inverse Fourier transformed noise (from the left panel) in the time domain.

2. Generating a data

For this work, we use the `LIGO Algorithm Library (LALSuite)` in order to create a mock data, i.e. data(f) = signal(f) + noise(f) and use `LALInference` to perform MCMC PE. We consider a BH-NS inspiral as an injection, assuming a signal-to-noise ratio of 19.9. The inspiral length is roughly 12 s, between the low cut-off frequency of 30 Hz and the innermost stable circular orbit (ISCO) frequency of 372 Hz. The strain of the injection signal h(f) is shown in Fig. 1. The injection and template waveforms are generated by the frequency-domain waveform model (called TaylorF2) based on the post-Newtonian (pN) formalism. The model takes into account up to 3.5 pN order corrections for phase and 2.5 pN corrections for amplitude of a GW signal. Selected source parameters for an injection is listed in Table 1. In addition to the Gaussian noise realization for each detector, we add seven delta function-like glitches. For simplicity, we assume the frequencies of glitches are the same at all three detectors in the LIGO-Virgo network (labeled as L1, H1, and V1), where $f_{\rm glitch}$ = 60, 94, 128, 183, 212, 256, and 317 Hz. The values of glitch

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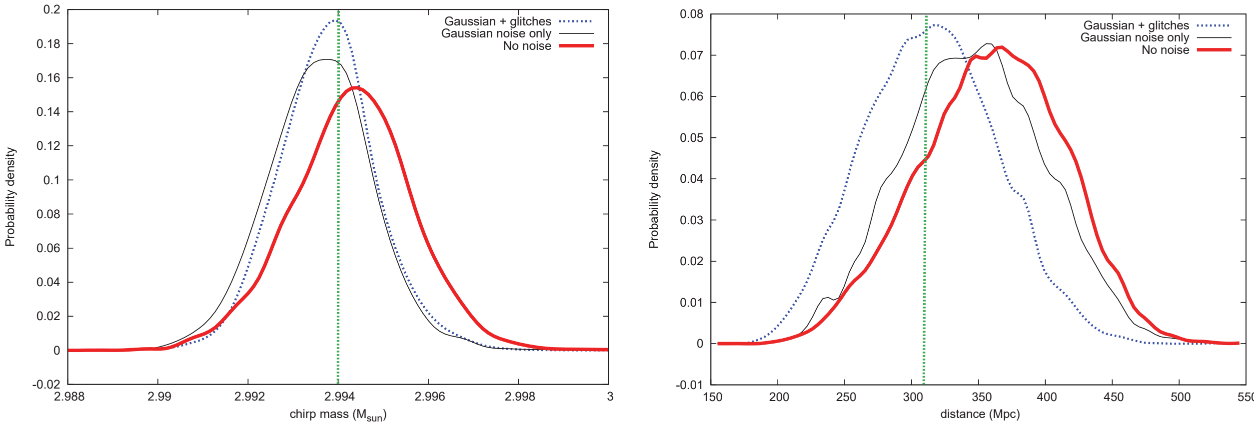

Figure 3. Posterior probability density functions (PDFs) of (a) chirp mass ($M_{\rm chirp}$) and (b) distance.y. We present results from three noise models: no noise (red thick solid lines), Gaussian noise only (thin solid lines), Gaussian + glitches (blue dotted lines). The green dotted vertical lines indicate the injection parameters.

frequencies are directly read by eyes among strongest glitches appeared in [8] (the LIGO blind injection experiment). A glitch amplitude is chosen by amplitude $= 10 \times \frac{1}{2}[PSD(f)]^{\frac{1}{2}}$, where PSD stands for a power spectral density (see Fig. 2 for the generated Gaussian with glitches for the initial LIGO Hanford noise curve). All glitches are assumed to be stationary.

3. Results

In Figs. 3 and 4, we compare PE results obtained from three noise models: (a) no noise (red thick solid lines), (b) Gaussian noise only (black thick solid ines), and (c) Gaussian + glitches (blue dotted lines). We present standard deviations of source parametes obtained from our reference MCMC run in Table 2. As one can see from these results, starionary, spiky glitches affect the most likely values and overall shape (width) of the posterior probability density function (PDF). However, standard deviations are not changed significantly.

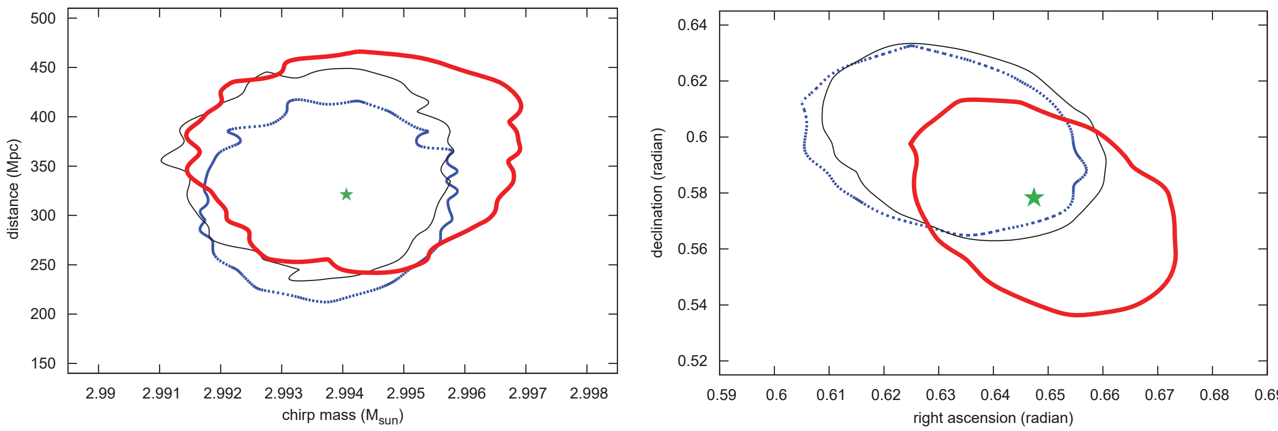

Figure 4. 2-D correlation plot of (a) chirp mass - distance and (b) right ascension - declination of the source in the Equatorial coordinate. Line color and style are the same with Fig. 3. Green stars indicate the injection values. The correlations are roughly consistent with all models, although the no noise model is least biased with respect to the injection parameters.

4. Conclusion

We examine effects of non-Gaussian glitches on PE for inspiral GW signals, assuming one of the simplest glitch model, i.e. stationary glitches with fixed frequencies like sine waves. We perform MCMC PE for non-spinning BH-NS inspirals with glitches embedded in Gaussian noise realizations. We find the medians and most likely values of individual parameters are affected by the existence of these delta function-like glitches. However, the overall widths of individual PDFs or correlations between two parameters are not significantly affected. In this work, we assume seven delta function-like glitches at given frequencies for simplicity. Realistic glitches observed from laser interferometers, however, have complicated feature in both frequency and amplitude. Moreover, many of them are not stationary. In this work, we show even the most simple form of glitches should be removed as a prerequisite of PE. We now have the machinery to inject glitches to Gaussian noise realizations for each detector using `LALsuite`.

Table 2. Standard deviations of selected source parameters obtained from different noise realizations.

	no noise	Gaussian noise only	Gaussian+glitches
chirp mass (M_{sun})	0.0014	0.0012	0.0011
distance (Mpc)	53.5833	52.8344	49.3058
right ascension (rad)	0.0114	0.0123	0.0122
declination (rad)	0.0191	0.0180	0.0170

Acknowledgments

This work is partially supported by NRF, No.NRF-2013R1A1A2060677 and by collaborative research program through KISTI/GSDC. CK is grateful for support from KASI-Yonsei DRC program of Korea Research Council of Fundamental Science and Technology (DRC-12-2-KASI).

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[9] URL `http://www.ligo.org/news/blind-injection.php`