MCMC parameter estimation of CBC inspirals with TaylorF2Amp

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Abstract

We perform MCMC parameter estimation (PE) for compact binary coalescence (CBC) inspirals with TaylorF2Amp, which is a frequency-domain waveform including up to 2.5 pN (post-Newtonian) amplitude corrections and 3.5pN phase corrections. MCMC PE for BH-NS, and BH-BH injections are completed, and here, we present results for non-spinning BH-NS inspirals. We compare 1D posteriors and 2D correlations of a few selected parameters such as orbital phase and polarization angles, varying the pN order of amplitude corrections of templates to be 0pN (Newtonian), 1.5pN, and 2.5pN. Results obtained from 1.5pN and 2.5pN templates are similar, while MCMC computation time with 2.5pN amplitude corrections takes longer than those with 1.5pN corrections by a factor of 1.2-1.7.

Frequency-Domain Waveform

$$\tilde{h}(f) = A f^{-7/6} e^{i\Psi_{\rm SPA}(f)}$$

TaylorF2 ("restricted" waveform)

We include up to 2.5pN amplitude corrections to TaylorF2, in addition to the existing 3.5pN phase corrections [1]. A user can set the order of amplitude corrections.

$$\tilde{h}(f) = \frac{M^2}{d}\sqrt{\frac{5\pi\nu}{48}}\sum_{n=0}^{5}\sum_{k=1}^{7} V_k^{n-\frac{7}{2}} C_k^{(n)} e^{i(k\Psi_{\rm SPA}(f/k)-\pi/4)}$$

TaylorF2Amp

A: amplitude

f/k: orbital frequency at each mode k (Hz)

$\nu = \eta \equiv \frac{m_1 m_2}{(m_1+m_2)^2}$ symmetric mass ratio

$\Psi_{\rm SPA}(f)$:orbital phase (Stationary Phase Approx.)

V_k, C_k : mode coefficients at each pN order n and harmonics k

M: total mass ($M_{\rm sun}$), d : distance to the source (Mpc)

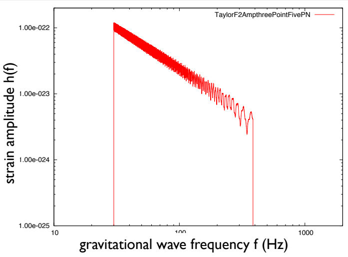

Figure 1a. h(f) of TaylorF2Amp for a BH-NS inspiral. Effects of amplitude corrections are obvious in all frequencies between $f_{\rm low}$(=30Hz) and $f_{\rm ISCO}$(=372Hz).

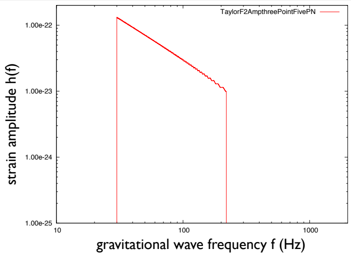

Figure 1b. Same with Figure 1a, but for a BH-BH inspiral. When the mass ratio q is close to one, effects of amplitude corrections are visible only at higher frequencies close to $f_{\rm ISCO}$.

Injections and Computing Resource

Injection: nonspinning BH-NS inspirals

All parameters are fixed, except the distance to source d (Mpc) in order to set the SNR to be ~20

primary mass m_1 =10 $M_{\rm sun}$, secondary mass m_2 =1.4 $M_{\rm sun}$

Computing resource:

All runs are done on KISTI GSDC cluster (3GHz Intel Xeon).

LALSuite is compiled with an Intel C compiler.

injection	M_c ($M_{\rm sun}$)	η	d (Mpc)	inclination i	polarization ψ	orbital phase ϕ_c	time (s)	RA	DEC
BH-NS	2.9943	0.1077	23.1	$\frac{\pi}{4}$	2.606	3.31	894383679	0.645	0.575

Table 1. Injection parameters

MCMC Parameter Estimation

We run lalinference_mcmc with the following settings

- initial LIGO-Virgo network including three detectors with and without Gaussian noise
- S6PE paper priors [2]

Example of a command line: --ifo H1 --ifo L1 --ifo V1 --H1-cache LALLIGO --L1-cache LALLIGO --V1-cache LALVirgo --H1-flow 30 --L1-flow 30 --V1-flow 30 --trigtime 894383679.0 --psdstart 894383379.0 --psdlength 512.0 --srate 4096 --seglen 16 --inj taylorF2Ampinjections.xml --event 3 --inj-fref 100 --inj-spinOrder 0 --inj-tidalOrder 0 --approx TaylorF2AmpthreePointFivePN --fref 100 --spinOrder 0 --tidalOrder 0 --Niter 10000000 --Nskip 100 --Neff 10000 --dataseed 1234 --noSpin --radiation-frame --amporder -1

injection model	approx. chirp length	Network SNR
TaylorF2Amp pN corrections: 2.5pN (amplitude) and 3.5pN (phase)	**12 s**	**19.7**

Table 2. Computation time of different MCMC runs

Results

template	computation time (hr)		Mc ($M_{\rm sun}$)	η	d (Mpc)	cos i	orbital phase	polarization
0pN (amplitude) log $L_{\rm max}$ ~ 181.7	55	std. dev	0.0020	0.001	5.17	0.153	1.81	0.917
1.5pN (amplitude) log $L_{\rm max}$ ~ 191.6	190		0.0018	0.0011	3.89	0.116	0.73	0.281
2.5pN (amplitude) log $L_{\rm max}$ ~ 191.1	240		0.0018	0.0011	3.70	0.114	0.74	0.279

Table 3. Computation time and standard deviations of selected parameters with different templates

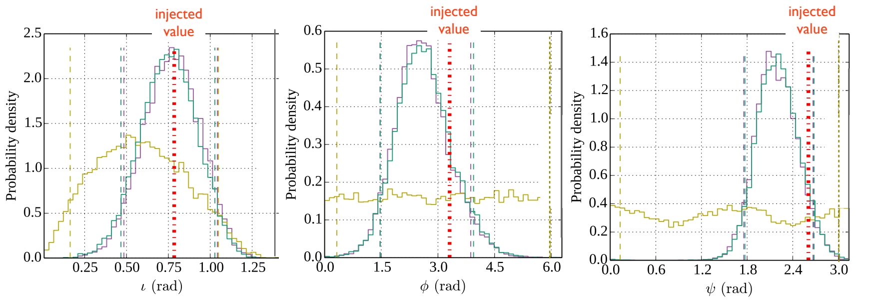

Figure 2. 1D posteriors on parameters related to inclination (left panel), orbital phase (middle panel), and polarization angles (right panel). Injection waveform has 2.5pN amplitude corrections. MCMC PE results from different templates are shown in magenta (2.5pN), green (1.5pN), and yellow (0pN) solid lines. Vertical dashed lines are lower and upper limits at 90% confidence. Templates with amplitude corrections recover the injected parameters much better than a template without amplitude corrections. Note magenta (2.5pN injection vs 2.5pN template) and green lines (2.5pN injection vs 1.5pN template) are barely distinguishable. Phase correction order is fixed to be 3.5pN.

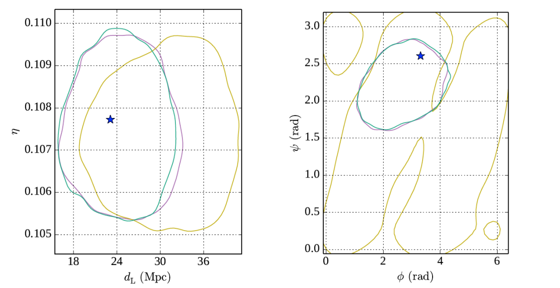

Figure 3. 2D correlation between different parameters. Color codes are the same with Figure 2. Templates including amplitude corrections (1.5pN or higher) are required to constrain orbital phase and polarization. Blue stars are the injected values.

Summary and Future Work

- TaylorF2Amp is available for MCMC parameter estimation with lalinference_mcmc.

  The order of amplitude corrections can be set by --amporder. ex) 0 (0pN), 3 (1.5pN), -1 (max. available: 2.5pN)
- 2.5pN amplitude corrections do not seem to improve accuracy in PE, in comparison to 1.5 pN amplitude corrections
- If an injection is a "full" waveform (2.5pN amplitude + 3.5pN phase), computation time with a template (2.5pN amplitude) takes longer by a factor of 1.2-1.7 than a MCMC run using a template with 1.5pN amplitude corrections

Acknowledgement

This work is supported in part by the National Research Foundation Grant funded by the Korean Government (No. NRF-2011-220-C00029) and the Global Science Experimental Data Hub Center (GSDC) at KISTI. HWL and JK are also supported by NRF-2013R1A1A2060677.

References 1. Arun, Buonanno, Faye, and Ochsner, Phys. Rev. D, 79, 104023 (2009); 2. Aasi et al. Phys. Rev. D, 88, 062001 (2013)