A Distinguish Method of Binary Black Hole and Black Hole Encounter Gravitational Waves Using Machine Learning

Weichangfeng Guo,[1] *Ik Siong Heng,*[2] *Daniel Williams,*[2] *Hunter Gabbard,*[2] *and Zong-Hong Zhu*[1]

[1] Department of Astronomy, Beijing Normal University

[2] SUPA, School of Physics and Astronomy, University of Glasgow

ABSTRACT

High-mass BBH events like GW190521 may appear similar to BH encounters in current detectors. Here we show that, with appropriate injections, the encounter can be inferred to credible posterior using BBH templates. Therefore, this possibility should be considered for future GW events that lack the inspiral portion. Also we give a prospect of a fast machine learning method to point out the indication.

BH ENCOUNTER

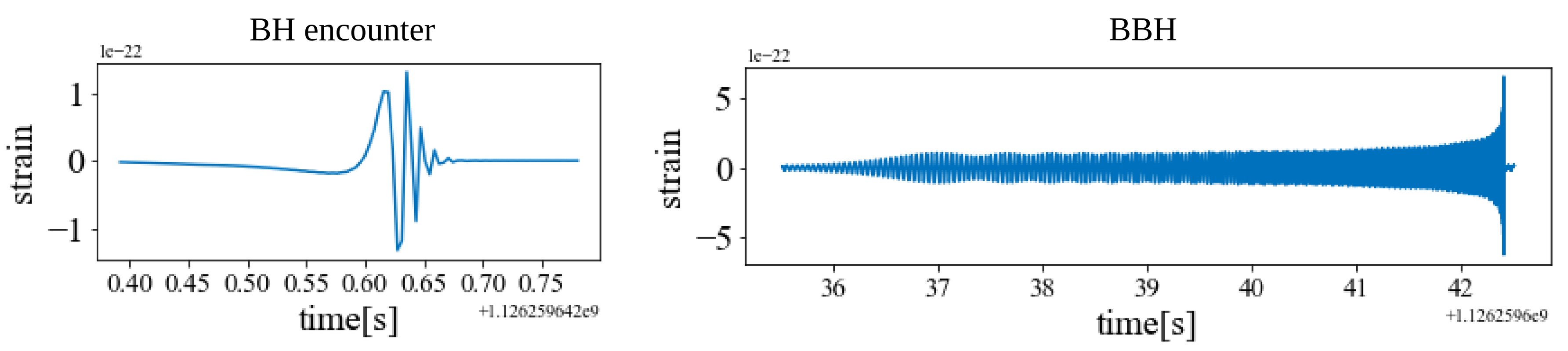

Figure 1: Typical BH encounter and BBH signals. BBH forms from a $10M_{\odot} - 10M_{\odot}$ binary. BH encounter forms from a binary with total mass of 150 $M_{\odot}$, and mass-ratio q of 8. The distances are both 20 Mpc. The orbital of BBH system lost energy during inspiral phase and get circularized before merger, while BH encounter's keeps high eccentricity due to lack of long inspiral phase.

Parameter	min	max	units
m_{total}	150		$M_{\odot}$
d_L	1.5,5,10,15 [a]		Mpc
ra	0	2π	rad.
dec	$-\pi/2$	$\pi/2$	rad.
ψ	0	2π	rad.

Table 1: Injections of the black hole encounter waveform. The merging parabolic waveforms (2017 Yeong-Bok Bae et. al.) are chosen with mass-ratio q of 1,2,4,8,16, each of which has 100 injections. The sky locations are uniformly distributed
a. For $q = 1$, $d_L = 15$; for $q = 2$, $d_L = 10$; for $q = \{4,8\}$, $d_L = 5$; for $q = 16$, $d_L = 1.5$.

VITAMIN SEARCH

VItamin is a neural network pre-trained on BBH signals. We used it to produce Bayesian estimates for large scale BH encounter sets quickly (~20 seconds for one signal, while a typical Bayesian inference takes ~5 hours) and looked for BBH-like posteriors.

For waveforms with mass-ratio q of 1,2,4,8,16, $\frac{n_{BBH-like\ posteriors}}{n_{samples}} = \frac{26}{100}, \frac{14}{100}, \frac{4}{100}, \frac{12}{100}$, and $\frac{17}{100}$ respectively.

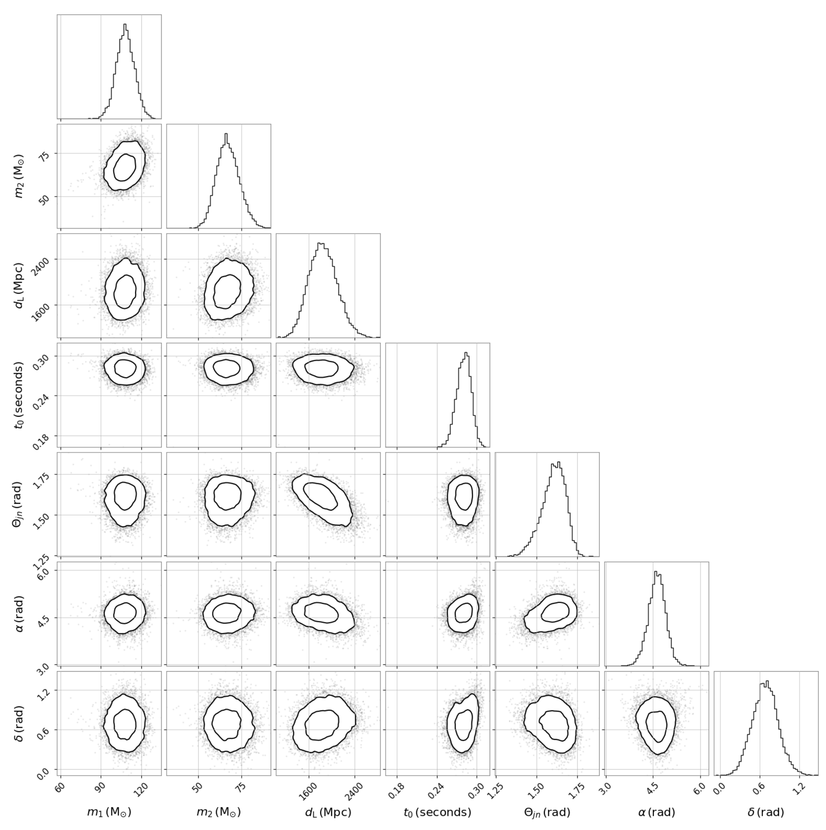

Figure 2:
The BBH-like posterior distributions of parameters for BH encounter Signal given by VItamin. Due to the wrong template, VItamin gets confused about most BH encounter signals and then more likely returns an unstable and meaningless posterior.

Parameter	min	max	units	prior
$m_{1,2}$	30	160	$M_{\odot}$	uniform
d_L	1000	3000	Mpc	uniform
t_0	0.15	0.35	seconds	uniform
ra	0	2π	rad.	uniform
dec	$-\pi/2$	$\pi/2$	rad.	cosine
Θ_{jn}	0	π	rad.	sine
spins	0			-
epoch	1126259642		GPS time	-
detector network			H1, L1, V1	

Table 2: Priors of VItamin. The spins are fixed at zero. ψ and ϕ are both marginalized.

RESULTS

We performed PE run on the encounters with BBH-like posteriors by Bilby, during which non-spinning and spinning BBH templates are adopted. Then we injected BBH using medians of samples to see how BBH mimic BH encounter. Bayes Factor $\frac{H_{spinning}}{H_{non-spinning}}$ shows that spinning BBH template models the data better. We expect that VItamin can quickly give an indication of BH encounter GW event being misclassified as BBH, through the distribution of J-S divergence, while this still needs a large-scale PE run in the future work.

No.	mass-ratio q	$M_{total}(M_{\odot})$	d_L(Mpc)	location(rad.) ra	dec	ψ	ρ_{opt} H1	L1	V1
1	1	150	15	2.94	0.84	0.19	5.29	3.43	14.09
2	1	150	15	0.42	-0.53	0.92	5.15	7.13	12.52
3	2	150	10	5.83	-0.04	0.86	11.29	9.54	11.62
4	4	150	5	5.70	-0.44	1.82	9.44	9.57	15.13
5	8	150	5	0.01	0.41	3.03	13.29	11.07	3.85
6	16	150	5	0.01	0.41	3.03	13.29	11.07	3.85

Table 3: Injections and optimal SNRs of BH encounter signals with a BBH-like posterior. For each waveform we select at least one injection.

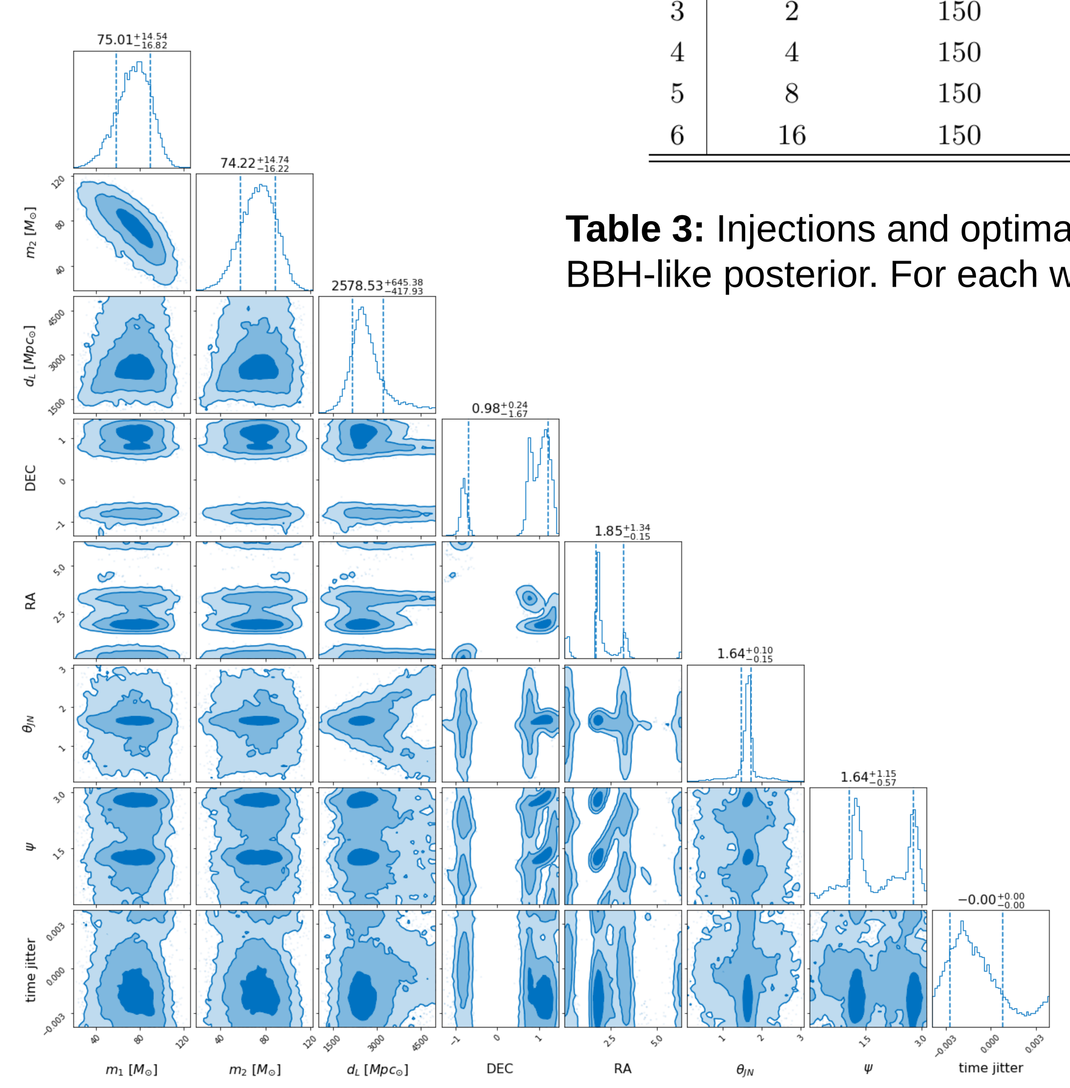

Figure 3:
Posterior distributions of parameters for BH encounter Signal No.1, which looks quite similar to a high-mass BBH. The numbers listed at the top of each 1D marginal distribution are the median and 95% credible interval. The analysis takes a non-spinning BBH model, IMRPhenomPv2, while results from spinning BBH model is more complicated and inconvenient to be displayed here.

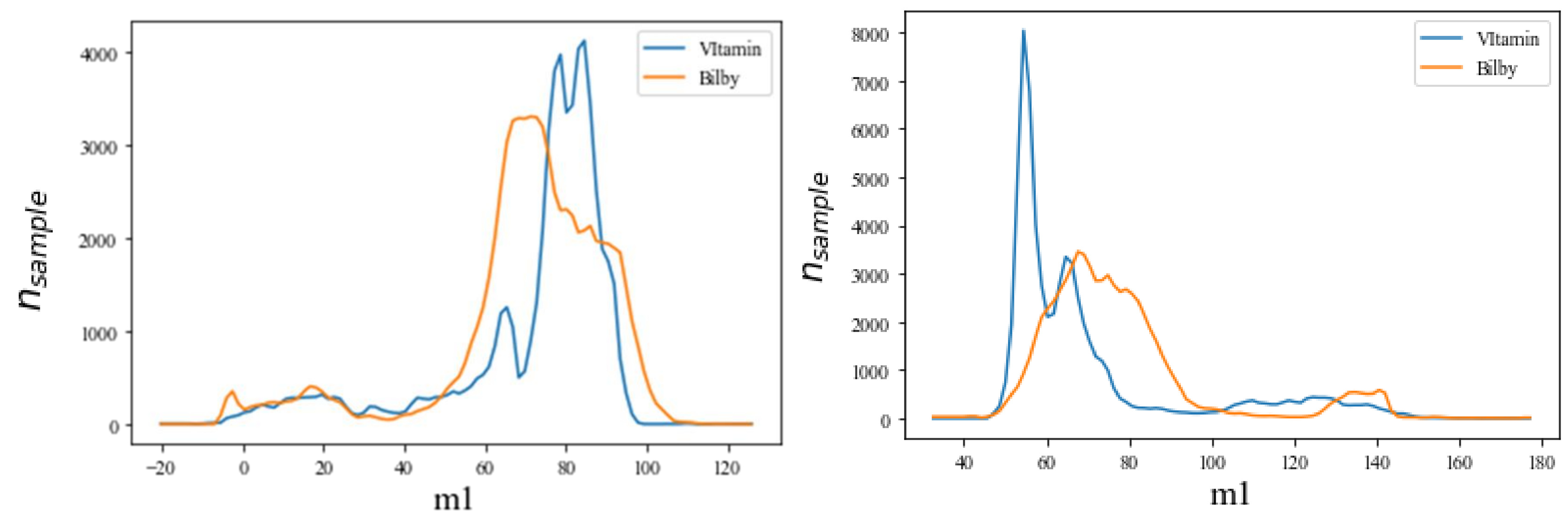

Figure 4:
J-S Divergence for BBH and BH encounter. $JSD_{BBH} = 0.103$, $JSD_{BH\ encounter} = 0.226$.
This may indicate that BH encounters usually have a higher JSD between Bilby and VItamin sampler, which can be an indication to distinguish them from BBHs.

FUTURE WORKS

- Application of IMRPhenomXHM model
- Large scale PE run for full-sky search
- Addition of spins parameter space for VItamin

- Email address
- 201921160007@mail.bnu.edu.cn