Detection of BH Encounter GWs Using BBH Template

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Outline

BH Encounter

Minke and VItamin Search

PE Run Using spining/non-spining BBH template

Black Hole Encounter

GR capture

Place: globular clusters and the centres of galaxies

The energy radiated by GWs > The initial orbital energy

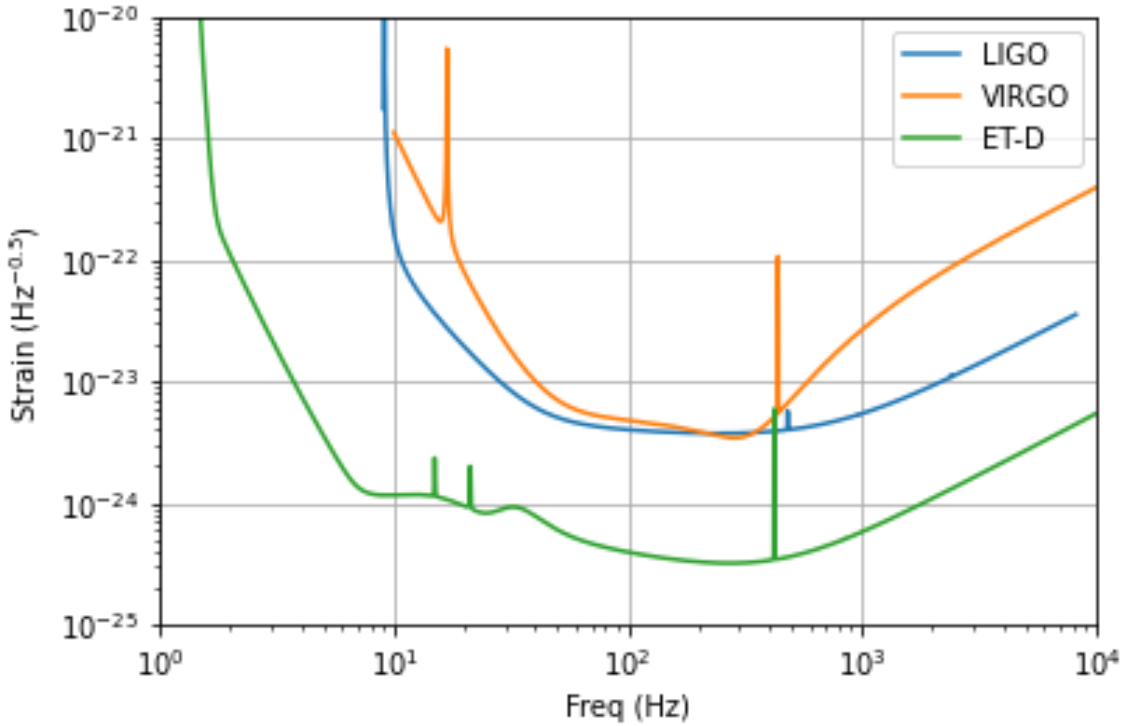


Fig.1 The ASDs of detectors

BH Encounter

lack of a long inspiral phase → High eccentricity

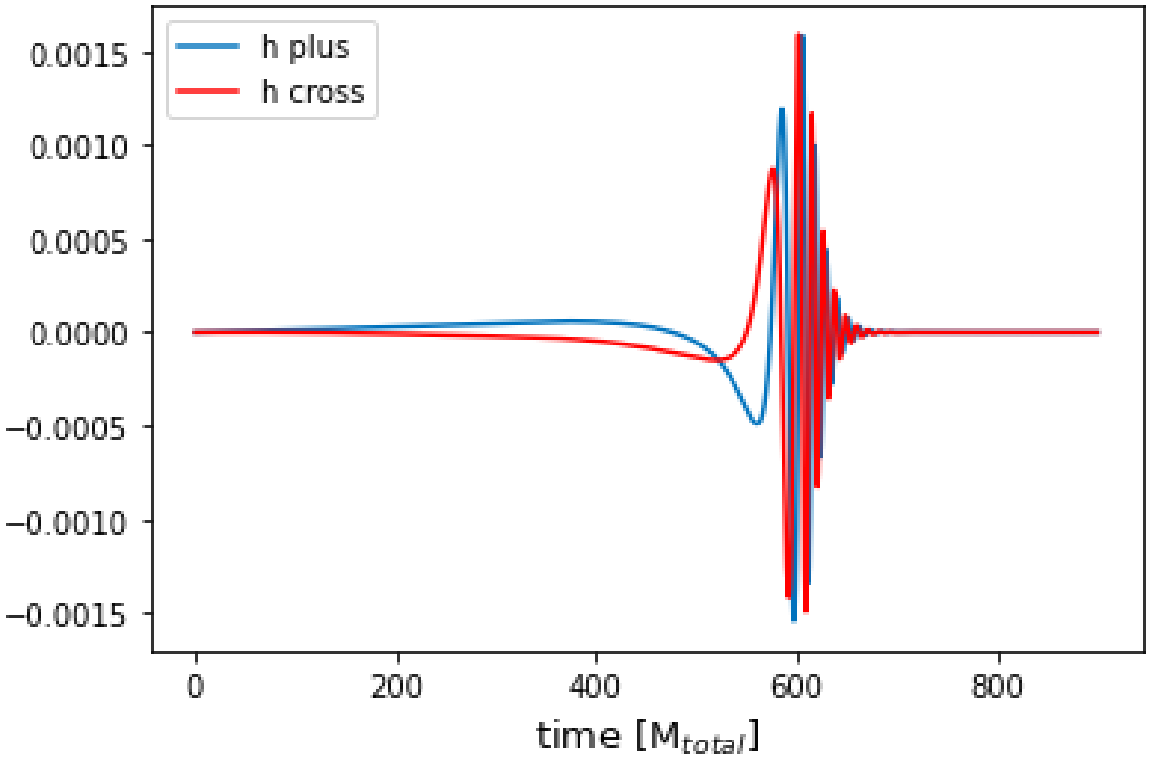


Fig.2 Encounter waveform with mass ratio q = 1

BBH

inspiral — merger — ringdown

loss of the orbital energies

circularized

4

Inject BH encounter

Waveforms (2017 Yeong-Bok Bae et. al.)

— Parabolic approximation

— non-spinning pairs of BHs

— relative velocity up to 10 ~ 20 % of c

We pick up the merger ones to mimic BBH.

5 x 100 = 500 !!

The injection parameters

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

The distributions of locations can be specified by Minke.

The code to inject BH encounter is provided by D.Williams

VItamin Search

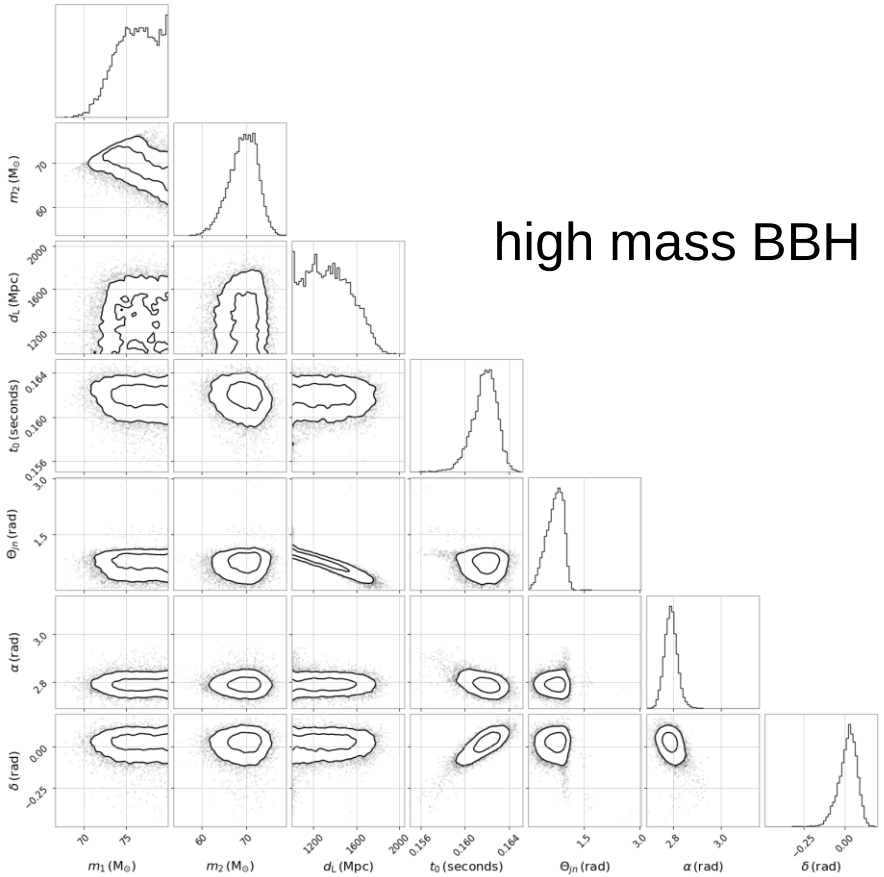
The prior of VItamin

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			

The network training is made by H.Gabbard

VItamin Search

Find the encounters whose posteriors appear similar to high mass BBH’s.



high mass BBH

Fig.3 High mass BBH on VItamin

non-BBH like posteriors

— No peak or hump

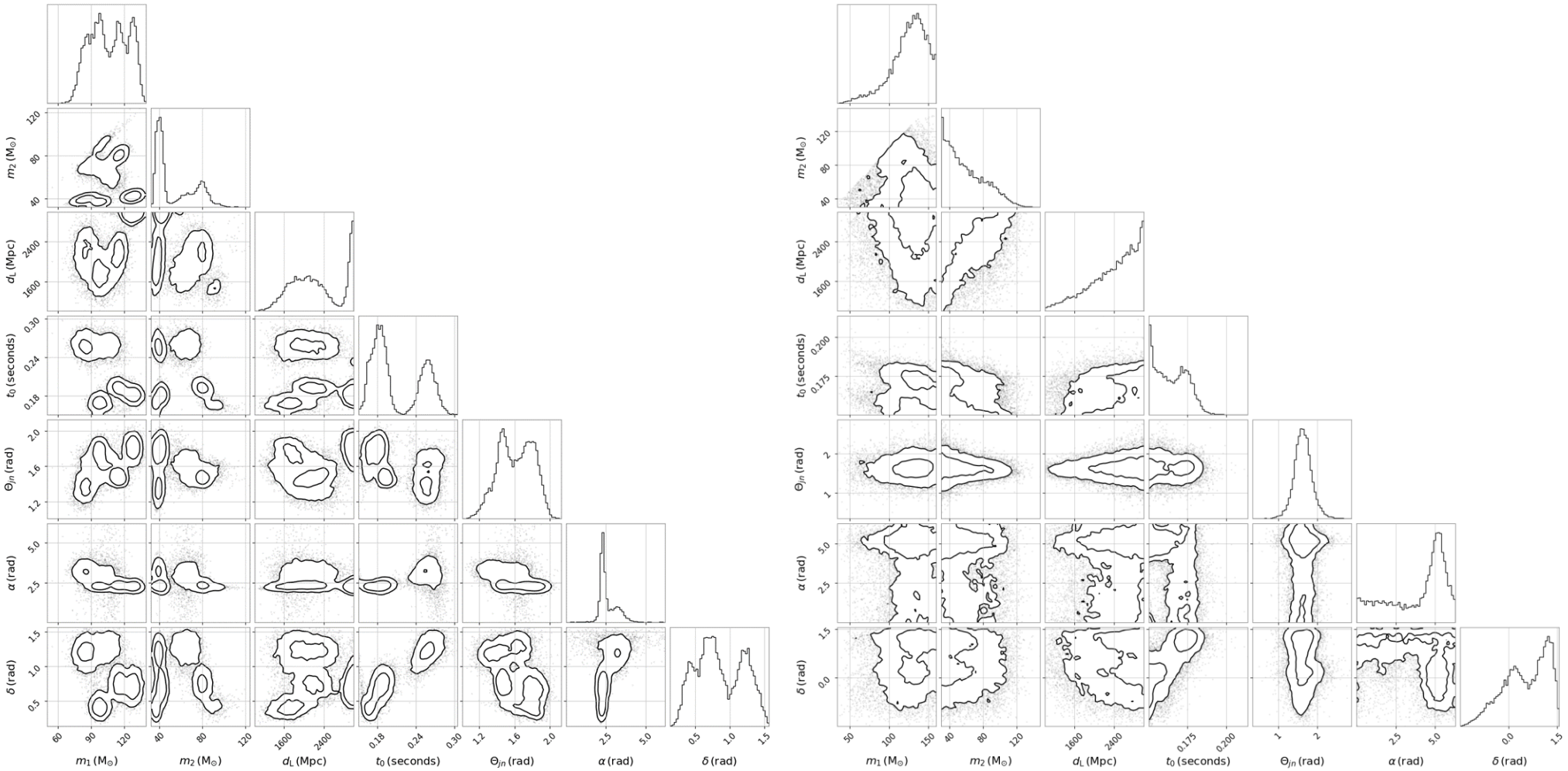


Fig.4 Non-BBH like signal on VItamin

BBH like posteriors

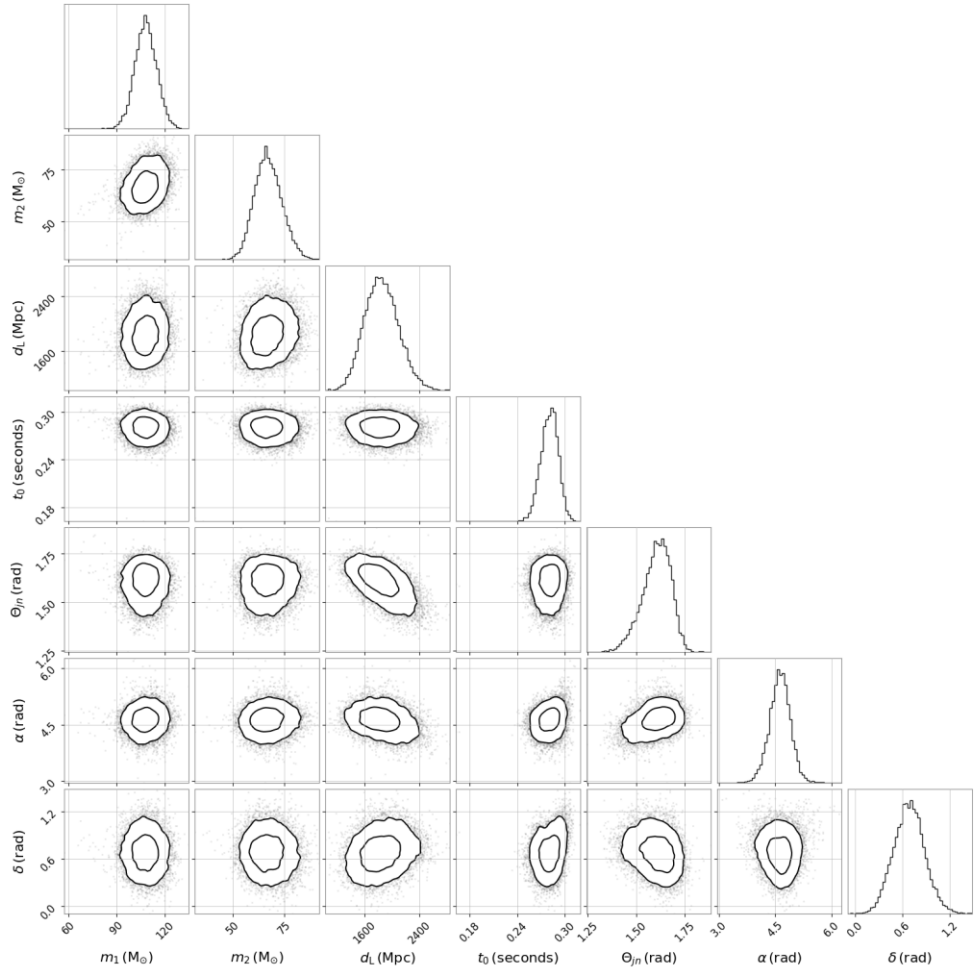


Fig.5 BBH like signal on VItamin

$$\frac{\text{BBH like signals}}{\text{Samples}}$$

Mass ratio q = 1 $\frac{26}{100}$

Mass ratio q = 2 $\frac{14}{100}$

Mass ratio q = 4 $\frac{4}{100}$

Mass ratio q = 8 $\frac{12}{100}$

Mass ratio q = 16 $\frac{17}{100}$

Parameters and optimal SNRs of BBH like signals

No.	mass-ratio q	$M_{total}(\mathrm{M}_\odot)$	$d_L(\mathrm{Mpc})$	location(rad.)			ρ_{opt}		
				ra	dec	ψ	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

Fig.6
Typical BBH posterior using BBH non-spinning model, with time and phase marginalization

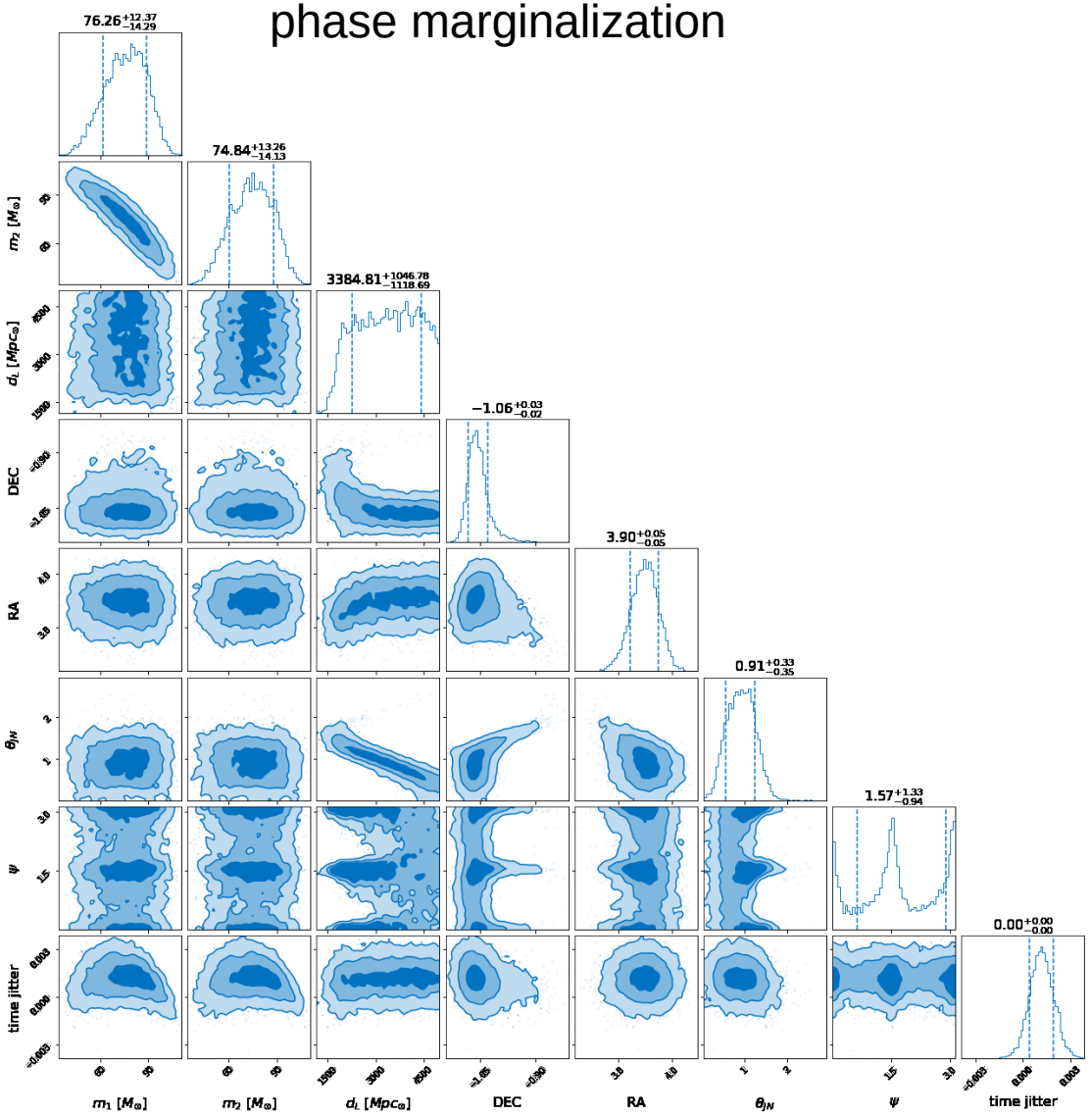
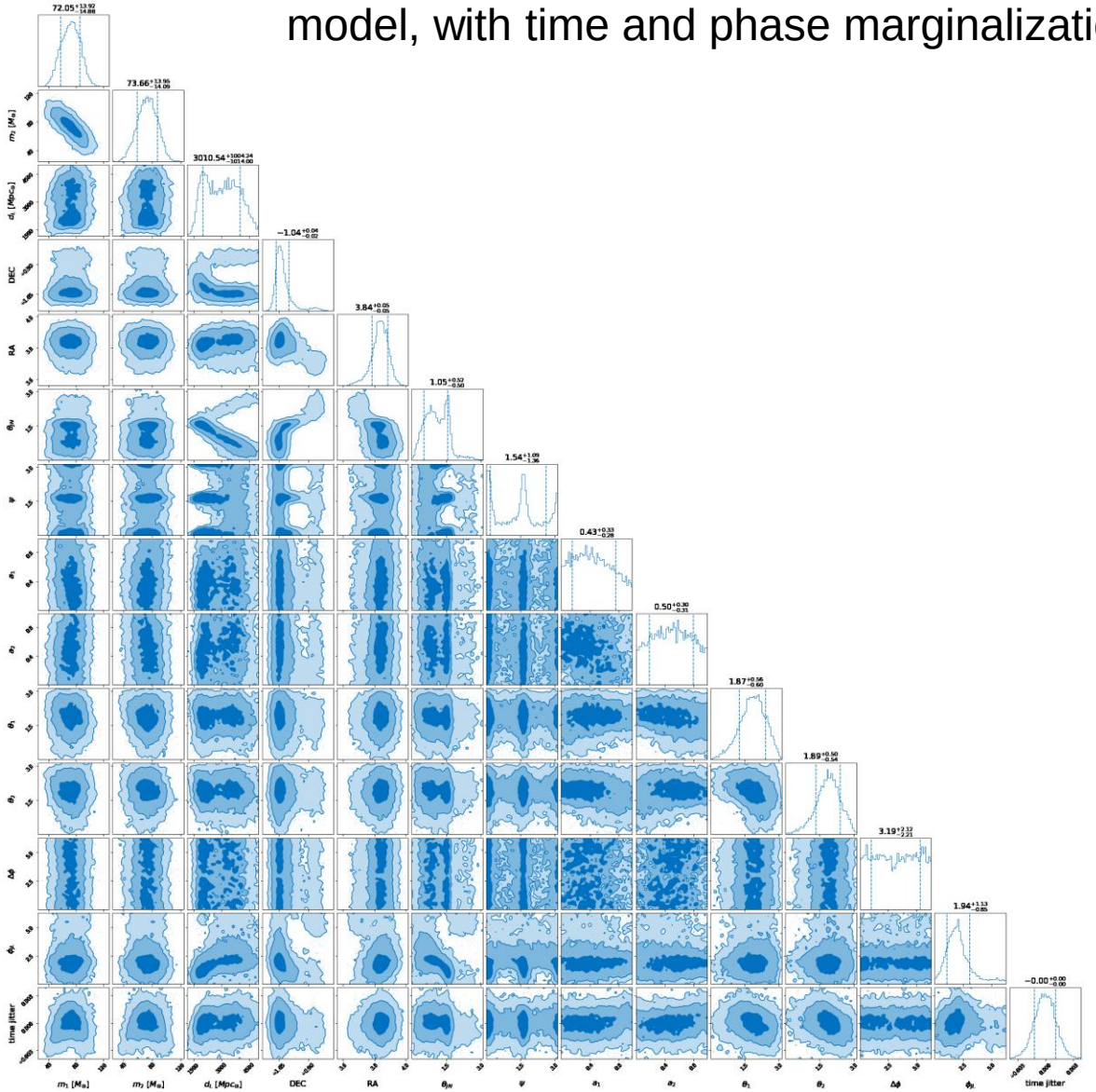


Fig.7
Typical BBH posterior using BBH spinning model, with time and phase marginalization



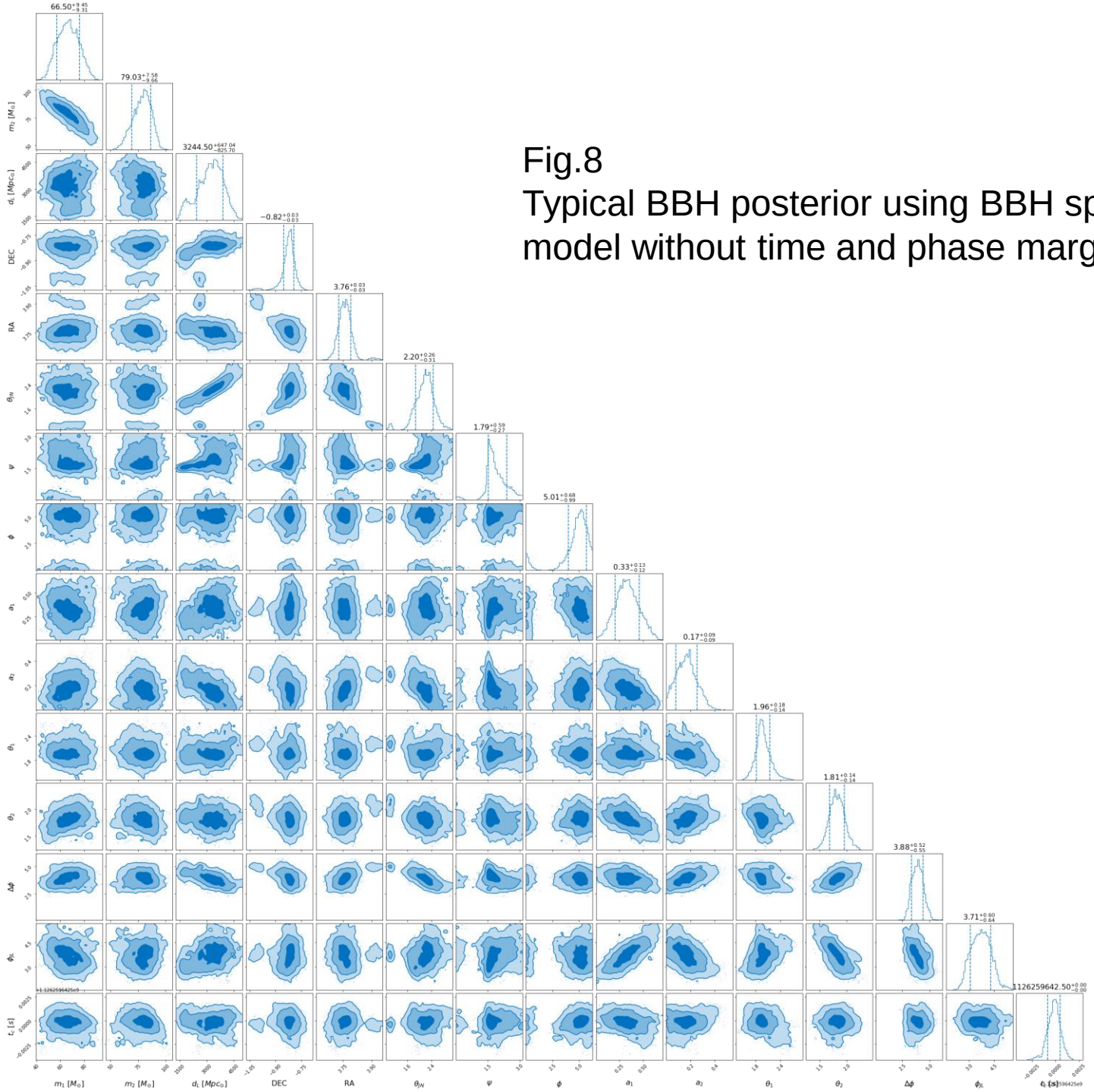


Fig.8
Typical BBH posterior using BBH spinning model without time and phase marginalization

Let’s see how BH encounter performs on Bilby !

Signal No.2 (q = 1)

IMRPheonomPv2, non-spining

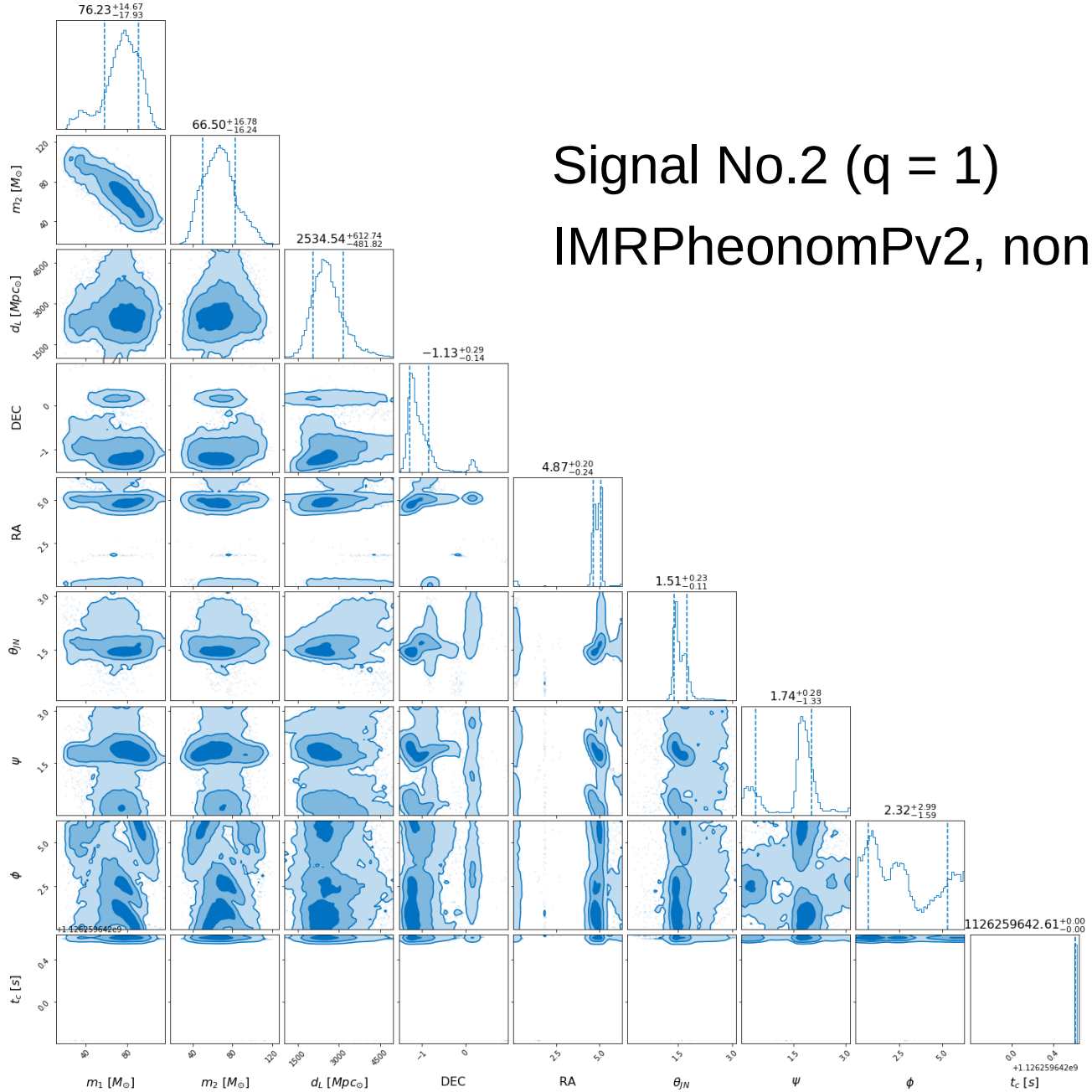
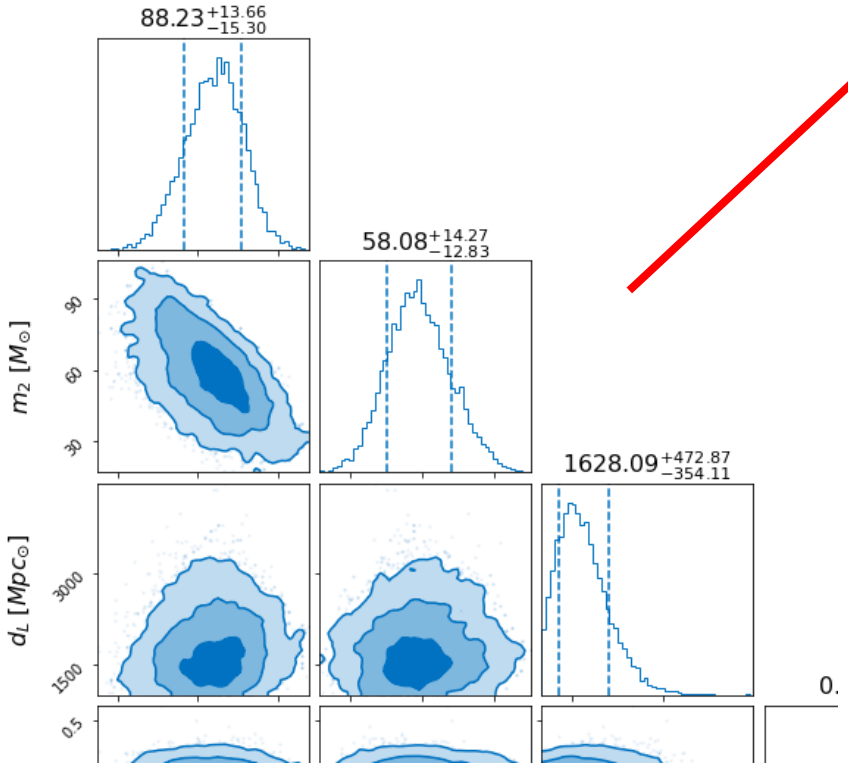


Fig.9 encounter on Bilby with non-spinning model

Signal No.2 (q = 1)

IMRPheonomPv2, spining



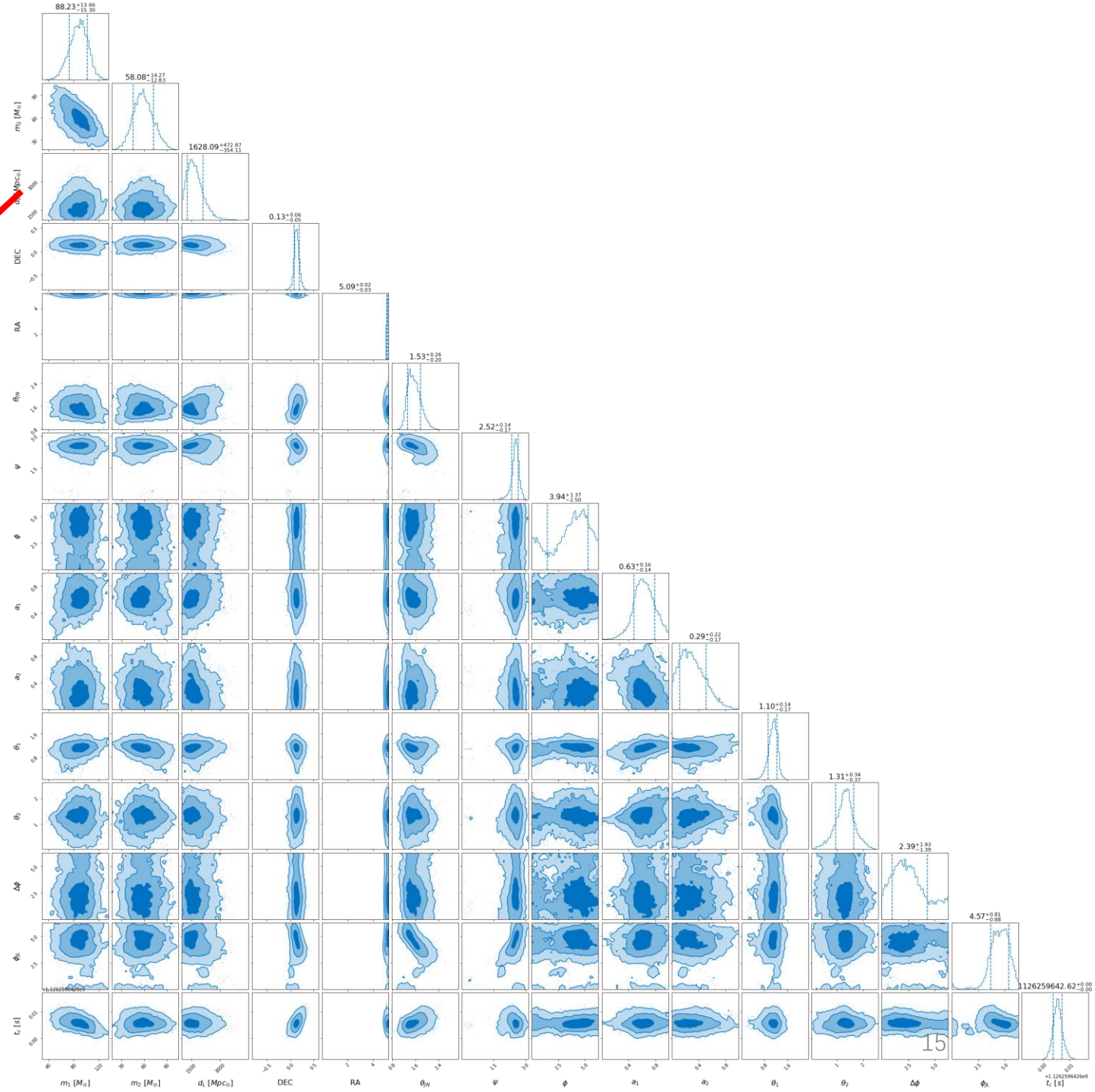


Fig.10 encounter on Bilby with spinning model

Bias of BH encounter's parameters using BBH model for Bayesian Inference.

No.	$m_1(\mathrm{M}_\odot)$			$m_2(\mathrm{M}_\odot)$			$d_\mathrm{L}(\mathrm{Mpc})$		
1	75	75.01	75.60	75	74.22	73.30	15	2579	2622
2	75	71.88	72.63	75	70.91	69.12	15	2633	2847
3	100	79.56	98.60	50	76.88	68.48	10	3963	3162
4	120	84.39	79.69	30	84.18	78.57	5	2523	2187
5	133.33	91.90	91.16	16.67	90.91	79.83	5	4332	3413
6	141.18			8.82					

Bayes factors

No.	Bayes factor K		
	non-spinning	spinning	ratio
1	$24.34^{\pm 0.17}$	$24.98^{\pm 0.16}$	1.03
2	$20.81^{\pm 0.17}$	$21.68^{\pm 0.18}$	1.04
3	$38.08^{\pm 0.17}$	$120.16^{\pm 0.20}$	3.16
4	$53.77^{\pm 0.18}$	$62.59^{\pm 0.20}$	1.16
5	$38.33^{\pm 0.16}$	$46.03^{\pm 0.17}$	1.20
6			

Inject BBH using maximums of encounter's posterior

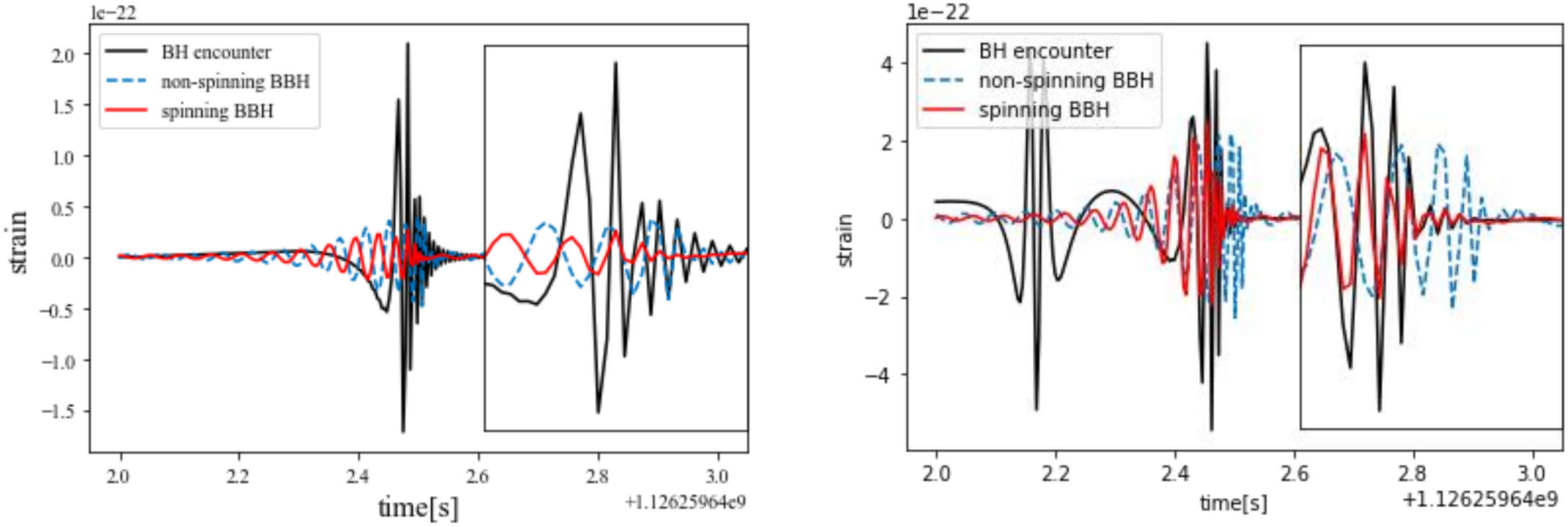


Fig.11 Signal No.2 and No.3 (q = 1, 2)

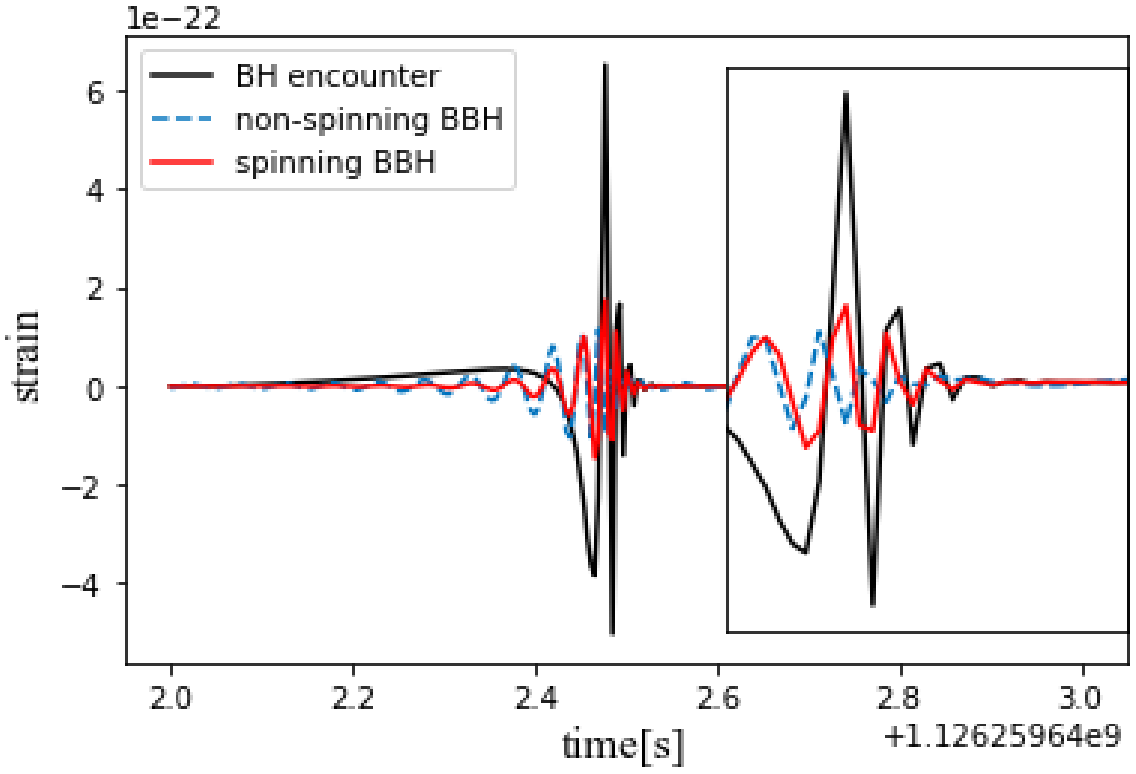


Fig.12 Signal No.6 (q = 16)

In the future…

IMRPhenomXHM model

Appendix

Bayesian inference

- Sampler: Dynesty
- Nsamples ~ 25000
- Npoints: 1000

Bilby prior

Parameter	min	max	units	prior
$m_{1,2}$	5	160	$M_\odot$	uniform
d_L	1000	5000	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
ψ	0	π	rad.	uniform
ϕ	0	2π	rad.	uniform
spins	0		-	-
epoch	1126259642		GPS time	-
detector network	H1, L1, V1			

Parameter	min	max	units	prior
$m_{1,2}$	5	160	$M_\odot$	uniform
d_L	1000	5000	Mpc	uniform
t_0	-1	1	seconds	uniform
ra	0	2π	rad.	uniform
dec	$-\pi/2$	$\pi/2$	rad.	cosine
Θ_{jn}	0	π	rad.	sine
ψ	0	π	rad.	uniform
ϕ	0	2π	rad.	uniform
$a_{1,2}$	0	0.99	rad.	uniform
$\theta_{1,2}$	0	π	rad.	sine
$\Delta\phi$	0	2π	rad.	uniform
ϕ_{JL}	0	2π	rad.	uniform
epoch	1126259642		GPS time	-
detector network	H1, L1, V1			

Signal No.3 (q = 2)

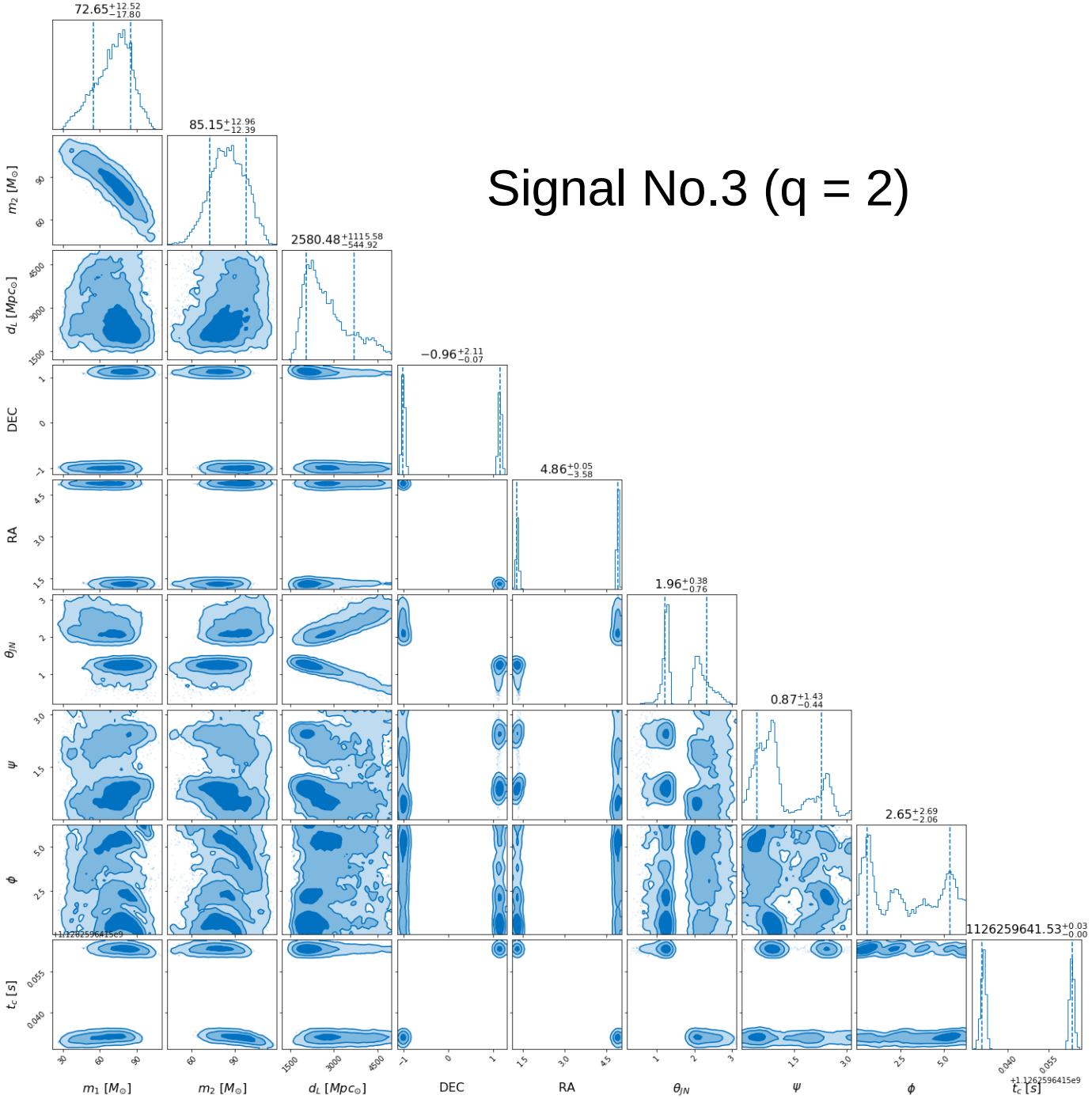
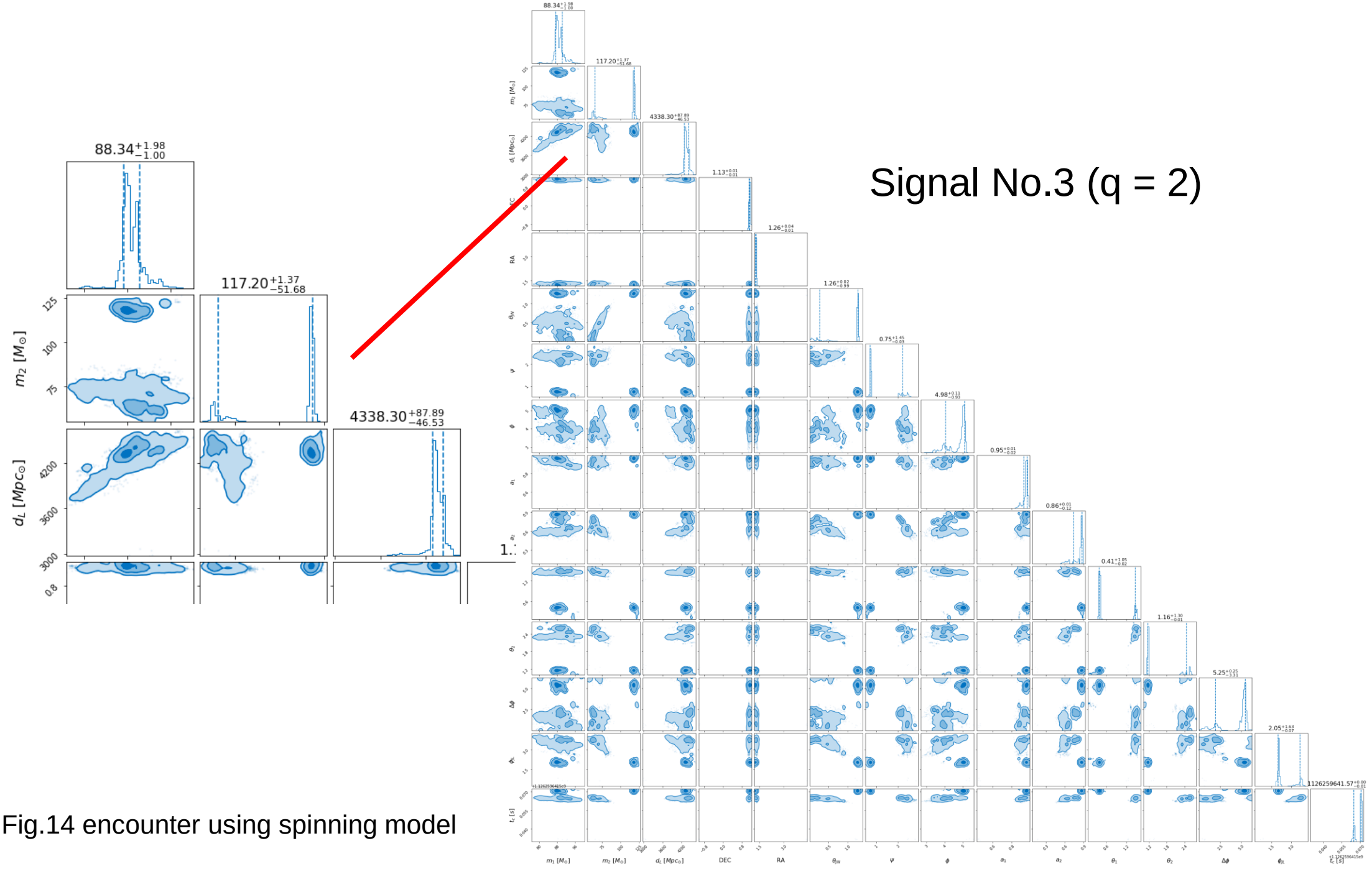


Fig.13 encounter using non-spinning model



Signal No.3 (q = 2)

Fig.14 encounter using spinning model

Signal No.6 (q = 16)

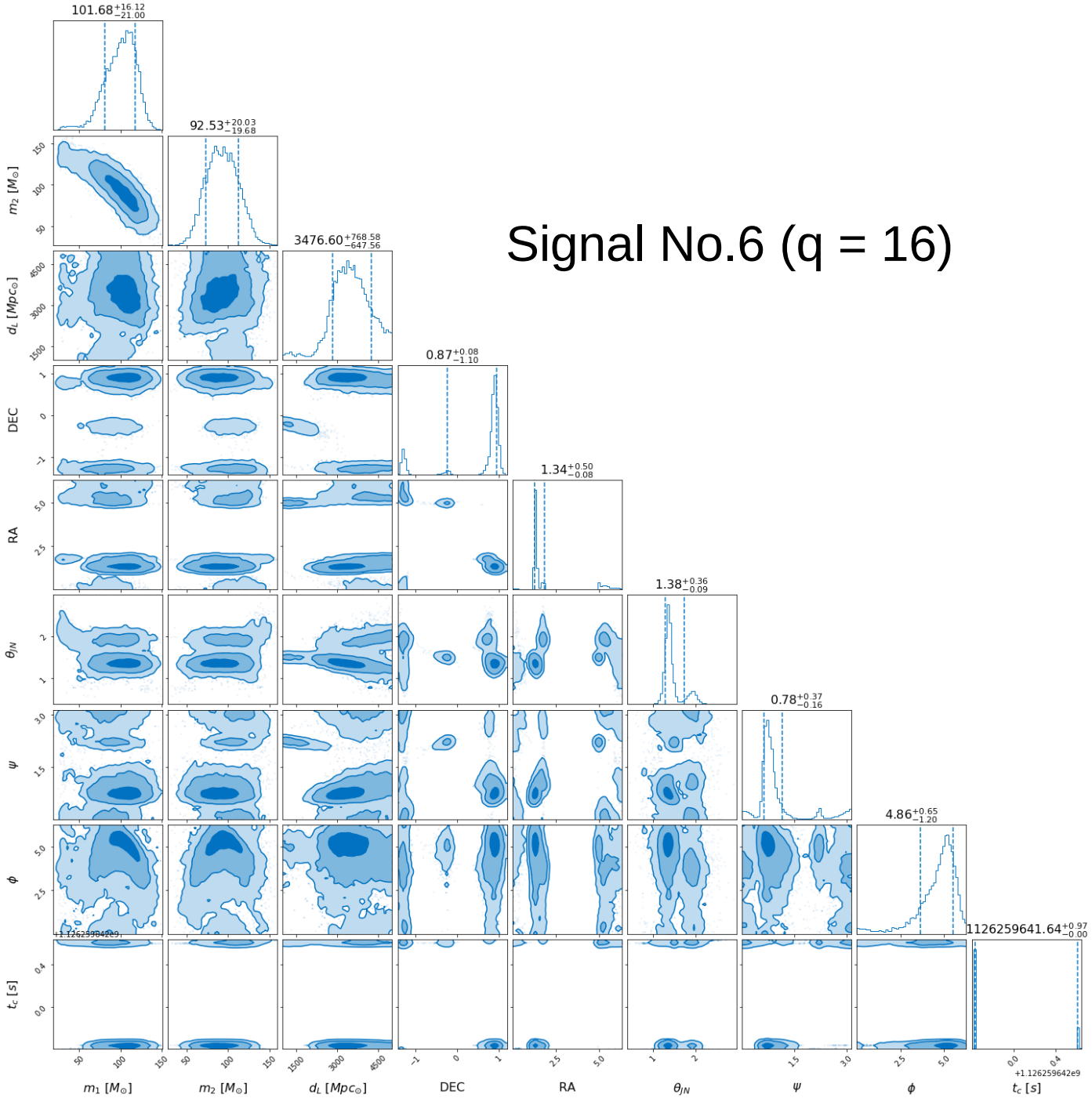
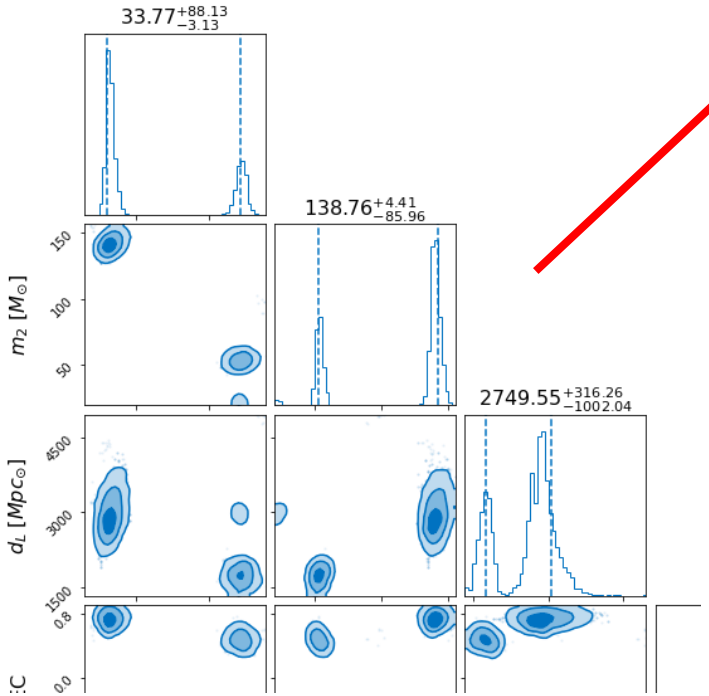


Fig.15 encounter using non-spinning model



Signal No.6 (q = 16)

Fig.16 encounter using spinning model