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Parameter Estimation of Stellar Mass Binary Black Holes under the Network of TianQin and LISA

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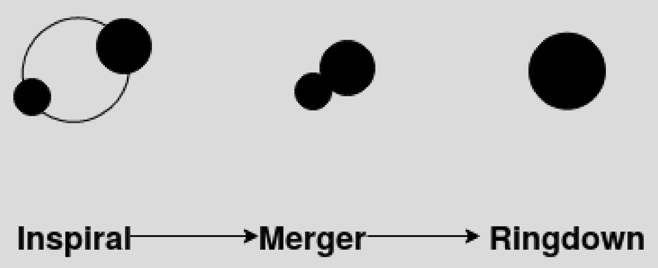
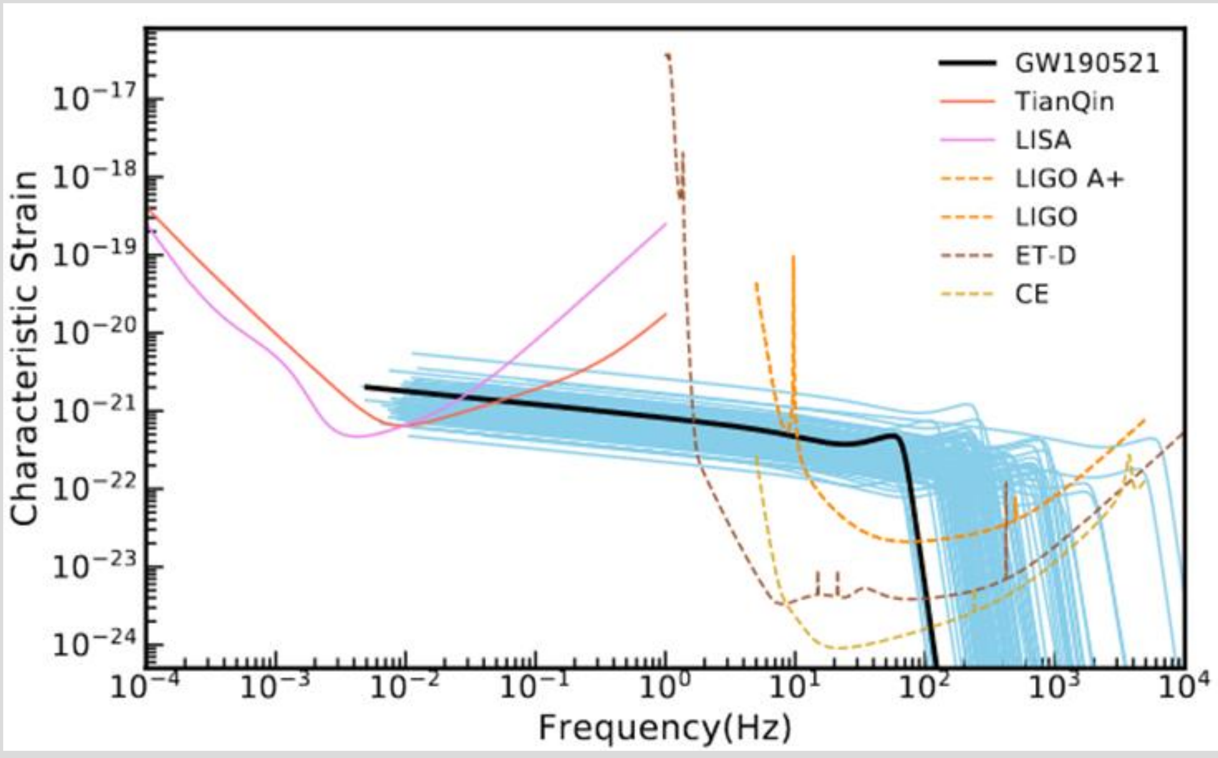
The observation of the stellar-mass binary black holes (sBBHs) system plays an crucial role in understanding the stellar evolution and formation mechanism of binary black holes. Currently, LIGO-VIRGO-KAGRA have successfully detected more than 80 sBBHs merger events[1], which means that gravitational waves (GWs) have become a useful tool for studying sBBH systems.

sBBH systems



According to the stages of GW evolution, their waveform can be divided into inspiral, merger, and ringdown phases, with frequencies ranging from milli-hertz to hundred-hertz.

sBBH GWs & Space-borne GW detectors[4]



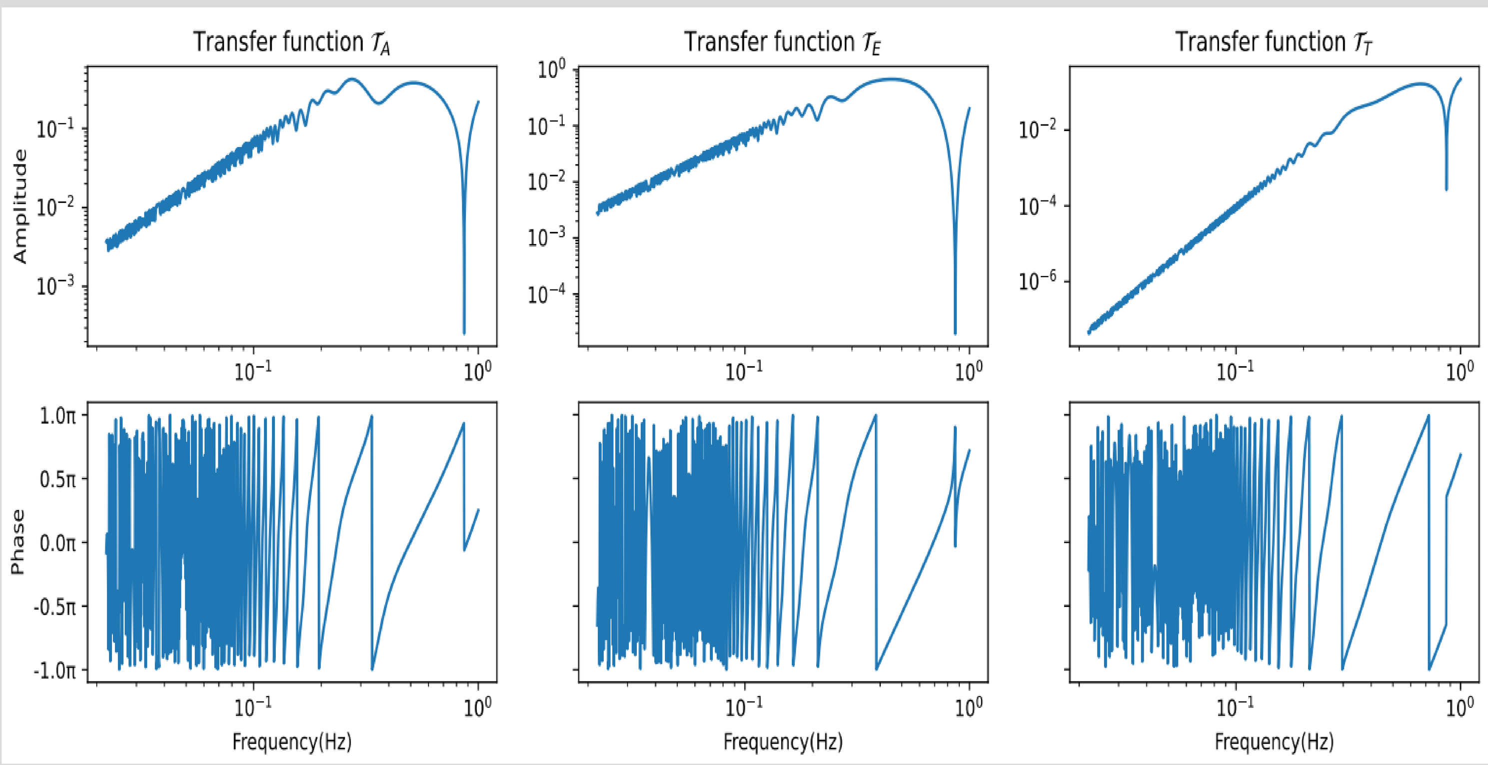
During the inspiral phase, sBBH can be observed simultaneously by space-based gravitational wave detectors such as TianQin[2] and LISA[3], making this source suitable for multi-detector observations.

GW full-frequency response

In frequency domain, GW observables $\tilde{y}_{sr}$ can be explained by the GW $\tilde{h}(f)$ and transfer function T_{sr}[7].

$$\tilde{y}_{sr} = T_{sr}\tilde{h}(f)$$

In our work, we complished the **full-frequency** response[8] for TianQin under the TDI channels: A, E, T [9].



Bayesian inference

According to Bayesian inference, the posterior probability distribution $P(\boldsymbol{\theta}|D)$ of the source parameters $\boldsymbol{\theta}$ can be expressed as:

$$P(\boldsymbol{\theta}|D) \propto L \times P(\theta),$$

$L = P(D|\theta)$ is the likelihood and $P(\theta)$ is the prior of parameter. Assuming the Gaussian stationary noise n in GW data D, $D = h + n$.

$$\boldsymbol{P(D|\theta) = e^{-\frac{1}{2}(D-h|D-h)}}$$

where $(a|b)$ are inner-product of $a(t)$ and $b(t)$.

sBBH for parameter estimation(PE) results

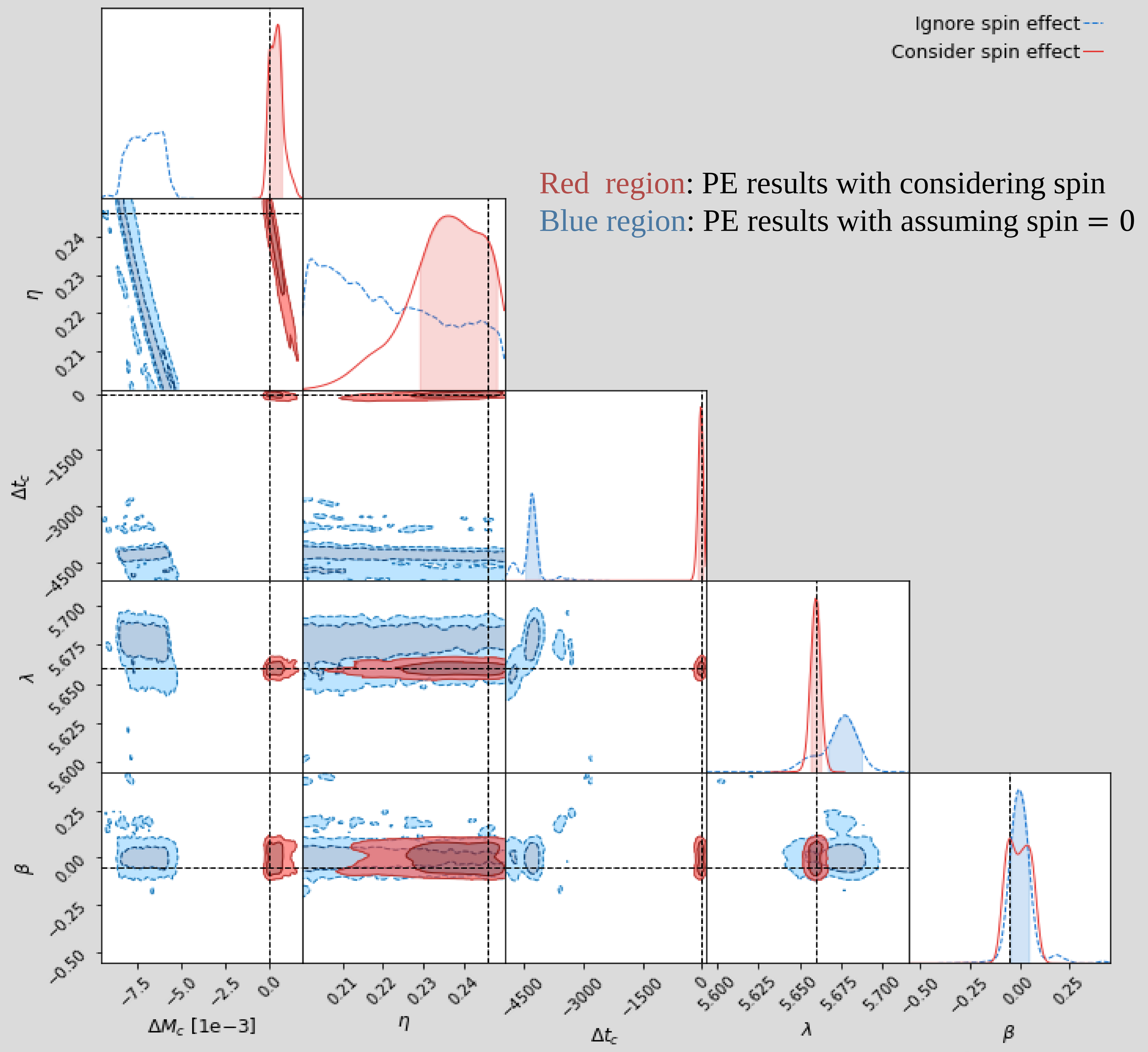
This work uses **Bayesian inference** framework-based PE method, selects two GW events - **GW150914** and **GW190521** - as simulated signal sources, and analyzes TianQin's, LISA's, and combined TianQin and LISA's PE abilities through **full-frequency response**.

Parameters	TianQin	LISA	Joint
$M_c(M_\odot)$	$65.10^{+8.087e-4}_{-6.077e-4}$	$65.10^{+7.43e-4}_{-4.53e-4}$	$65.10^{+3.47e-4}_{-3.48e-4}$
η	$0.228^{+0.014}_{-0.017}$	$0.224^{+0.017}_{-0.016}$	$0.238^{+0.0085}_{-0.0010}$
χ_a	$0.60^{+0.098}_{-0.16}$	$0.61^{+0.090}_{-0.17}$	$0.67^{+0.051}_{-0.089}$
χ_l	$0.15^{+0.26}_{-0.30}$	$0.17^{+0.28}_{-0.26}$	$0.082^{+0.24}_{-0.22}$
ι(rad)	$0.48^{+0.40}_{-0.34}$	$0.55^{+0.38}_{-0.38}$	$0.44^{+0.38}_{-0.31}$
D_L(Mpc)	$972.18^{+178.50}_{-222.44}$	$962.05^{+205.49}_{-221.23}$	$972.18^{+143.45}_{-202.52}$
$t_c - 6.31e7(s)$	-154^{+197}_{-210}	$-59.9^{+53.5}_{-69.7}$	$-22.1^{+51.2}_{-22.8}$
λ(rad)	$5.66^{+0.0061}_{-0.0064}$	$5.66^{+0.0049}_{-0.0049}$	$5.66^{+0.0029}_{-0.0030}$
β(rad)	$-0.0093^{+0.090}_{-0.074}$	$-0.014^{+0.067}_{-0.058}$	$-0.0046^{+0.062}_{-0.060}$
ψ(rad)	$1.51^{+1.089}_{-1.015}$	$1.55^{+1.092}_{-1.075}$	$1.67^{+0.97}_{-1.093}$
ϕ_c(rad)	$0.0067^{+2.057}_{-2.20}$	$0.16^{+2.033}_{-2.17}$	$-0.18^{+2.23}_{-2.15}$

The 1σ regions and the center values of PE for GW190521 are provided.

Spin-mismodeling effect

Spin mismodeling involves estimating the parameters of an sBBH source based on the assumption of no spin, despite the source having a non-zero spin.



The result shows that **spin-mismodeling** can cause **significant deviations** from PE results and the true value of waveform parameters.

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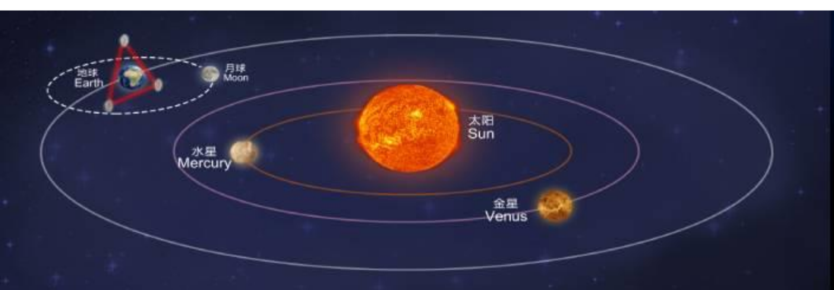

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