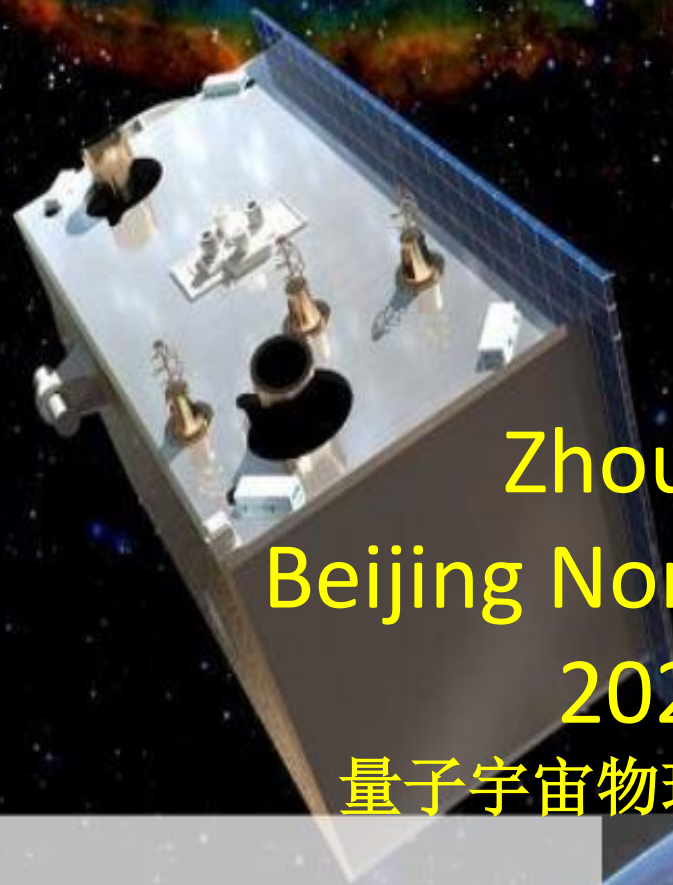
太极模拟数据集简介

TAIJI

PROGRAMME

IN SPACE



Zhoujian Cao
Beijing Normal University

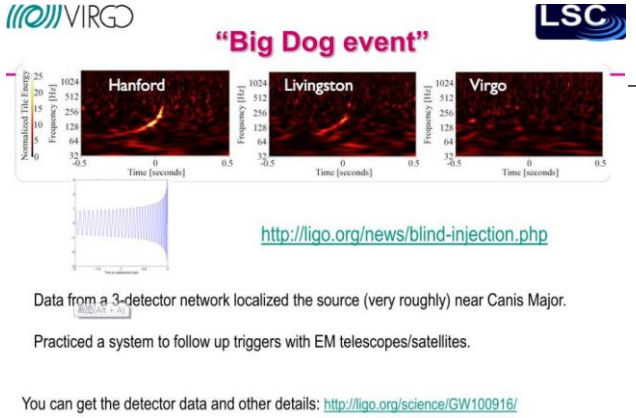
2023-5-11

量子宇宙物理论坛（千岛湖）

Taiji Data Challenge

没有模拟的观测则罔, 没有观测的模拟则殆

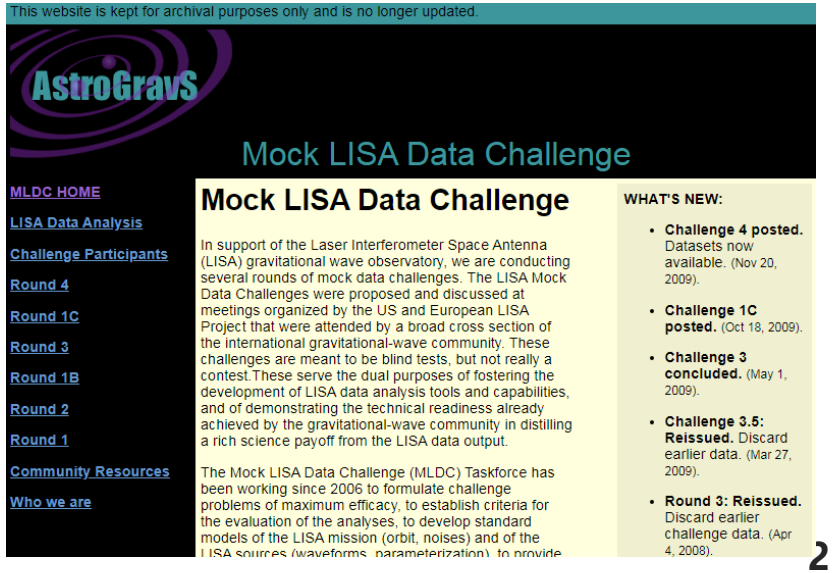
若为仪器故,两者皆可抛



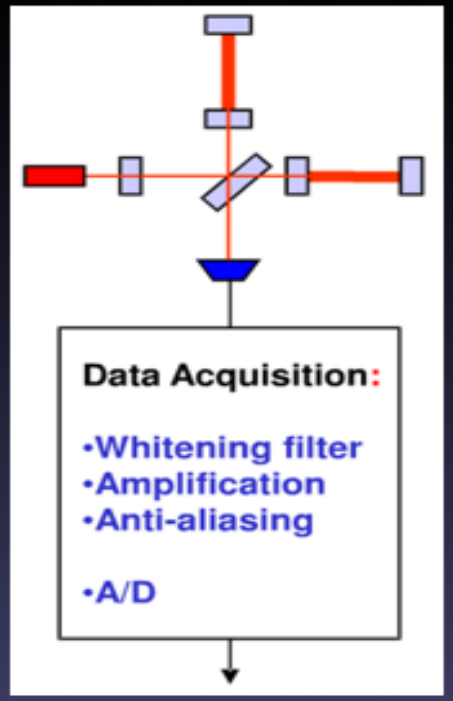
PHYSICAL REVIEW D **107,** 023021 (2023)

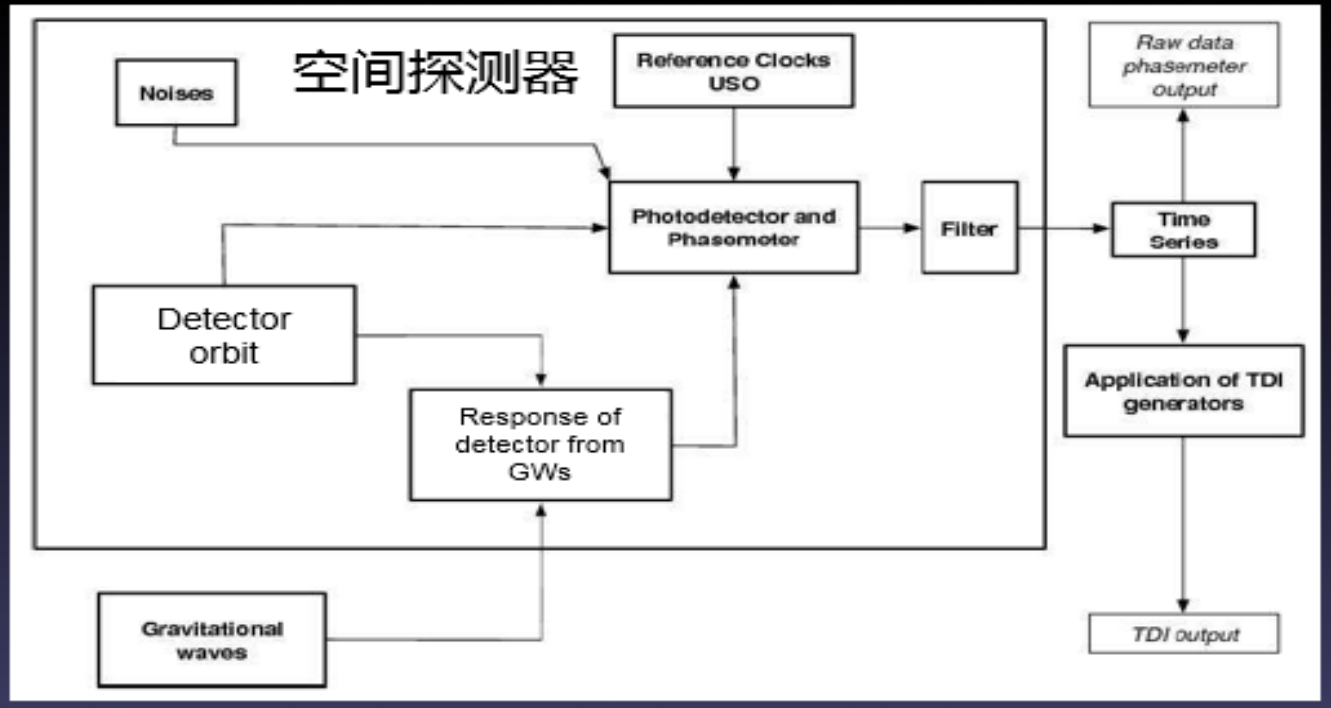
First machine learning gravitational-wave search mock data challenge

Marlin B. Schäfer,[1,2] Ondřej Zelenka,[3,4] Alexander H. Nitz,[1,2] He Wang,[5] Shichao Wu,[1,2] Zong-Kuan Guo,[5] Zhoujian Cao,[6] Zhixiang Ren,[7] Paraskevi Nousi,[8] Nikolaos Stergioulas,[9] Panagiotis Iosif,[10,9] Alexandra E. Koloniari,[9] Anastasios Tefas,[8] Nikolaos Passalis,[8] Francesco Salemi,[11,12] Gabriele Vedovato,[13] Sergey Klimenko,[14] Tanmaya Mishra,[14] Bernd Brügmann,[3,4] Elena Cuoco,[15,16,17] E. A. Huerta,[18,19] Chris Messenger,[20] and Frank Ohme[1,2]



地面 vs 空间





$$y_{slr} = (\nu_r - \nu_s)/\nu$$

$$h(t) = F^{+}h_{+}(t) + F^{\times}h_{\times}(t)$$
$$h(f) = F^{+}h_{+}(f) + F^{\times}h_{\times}(f)$$

$$y_{slr} = \frac{1}{2}\frac{n_l \otimes n_l}{1 - k \cdot n_l} : [H(t - L - k \cdot p_s) - H(t - k \cdot p_r)]$$

$$X = y_{31} + y_{13,L} + (y_{21} + y_{12,L})_{,2L} - (y_{21} + y_{12,L}) - (y_{31} + y_{13,L})_{,2L}$$

$$y_{slr,nL} = y_{slr}(t - nL)$$

a = 1AU $\alpha = L/2a \quad \phi = \pi/3 + 5\alpha/8 \qquad \lambda_k = \lambda_1 + 2\pi(k-1)/3$

$$e = \left(1 + \frac{4}{\sqrt{3}}\alpha\cos\phi + \frac{4}{3}\alpha^2\right)^{1/2} - 1 \qquad \tan\iota = \frac{2}{\sqrt{3}}\frac{\alpha\sin\phi}{\left(1 + \frac{2}{\sqrt{3}}\alpha\cos\phi\right)}$$

PHYSICAL REVIEW D **100,** 122001 (2019)

Analytical analysis on the orbits of Taiji spacecrafts

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$e \approx 5.789 \times 10^{-3}$

TDC,LDC2b	<LDC2b
$O(e^3) \rightarrow O(e^2)$	$O(e)$

TDC: $$\mathrm{LTT} = \mathrm{LTT}^{(0)} + \mathrm{LTT}^{(1)} + \underline{\mathrm{LTT}^{(2)} + \mathrm{LTT}^{(\mathrm{Sh})}}$$

LDC1 LDC2a LDC2b

$$\mathrm{LTT}^{(0)}(t) = \frac{1}{c}|\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t)|$$

$$\mathrm{LTT}^{(1)}(t) = \frac{\vec{v}_{\mathrm{recv}}(t)}{c^2} \cdot (\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t))$$

$$\mathrm{LTT}^{(2)}(t) = \frac{|\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t)|}{c^3} \left[\vec{v}^2_{\mathrm{recv}}(t) - \vec{a}_{\mathrm{recv}}(t) \cdot (\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t)) + \left(\frac{\vec{v}_{\mathrm{recv}}(t) \cdot (\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t))}{|\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t)|} \right)^2 \right],$$

$$\mathrm{LTT}^{(\mathrm{Sh})} = \frac{R_S}{c} \cdot \ln \frac{|\vec{x}_{\mathrm{send}}(t)| + |\vec{x}_{\mathrm{recv}}(t)| + |\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t)|}{|\vec{x}_{\mathrm{send}}(t)| + |\vec{x}_{\mathrm{recv}}(t)| - |\vec{x}_{\mathrm{recv}}(t) - \vec{x}_{\mathrm{send}}(t)|}$$

$$H(t) = h_+^{\mathrm{SSB}}(t)\xi_+(\hat{\theta}, \hat{\phi}, \vec{n}(t)) + h_\times^{\mathrm{SSB}}(t)\xi_\times(\hat{\theta}, \hat{\phi}, \vec{n}(t))$$

$$\xi_+ = (\hat{\theta} \cdot \vec{n})^2 - (\hat{\phi} \cdot \vec{n})^2$$

$$\xi_\times = 2(\hat{\theta} \cdot \vec{n})(\hat{\phi} \cdot \vec{n})$$

$(\hat{\theta}, \hat{\phi})$: GW source localization

$\vec{n}$: unit vector from sender spacecraft to receiver spacecraft

$$y(t_{\mathrm{recv}}) = \frac{1}{2(1 - \vec{k} \cdot \vec{n}(t_{\mathrm{recv}}))} \left[H\left(t_{\mathrm{recv}} - \frac{\vec{k} \cdot \vec{x}_{\mathrm{send}}(t_{\mathrm{recv}})}{c} - \mathrm{LTT}(t_{\mathrm{recv}}) \right) - H\left(t_{\mathrm{recv}} - \frac{\vec{k} \cdot \vec{x}_{\mathrm{recv}}(t_{\mathrm{recv}})}{c} \right) \right]$$

$\vec{k}$: unit vector from GW source to solar system
$\vec{x}_{\mathrm{send}}$: location of sender spacecraft
$\vec{x}_{\mathrm{recv}}$: location of receiver spacecraft

<LDC2b

1st generation TDI

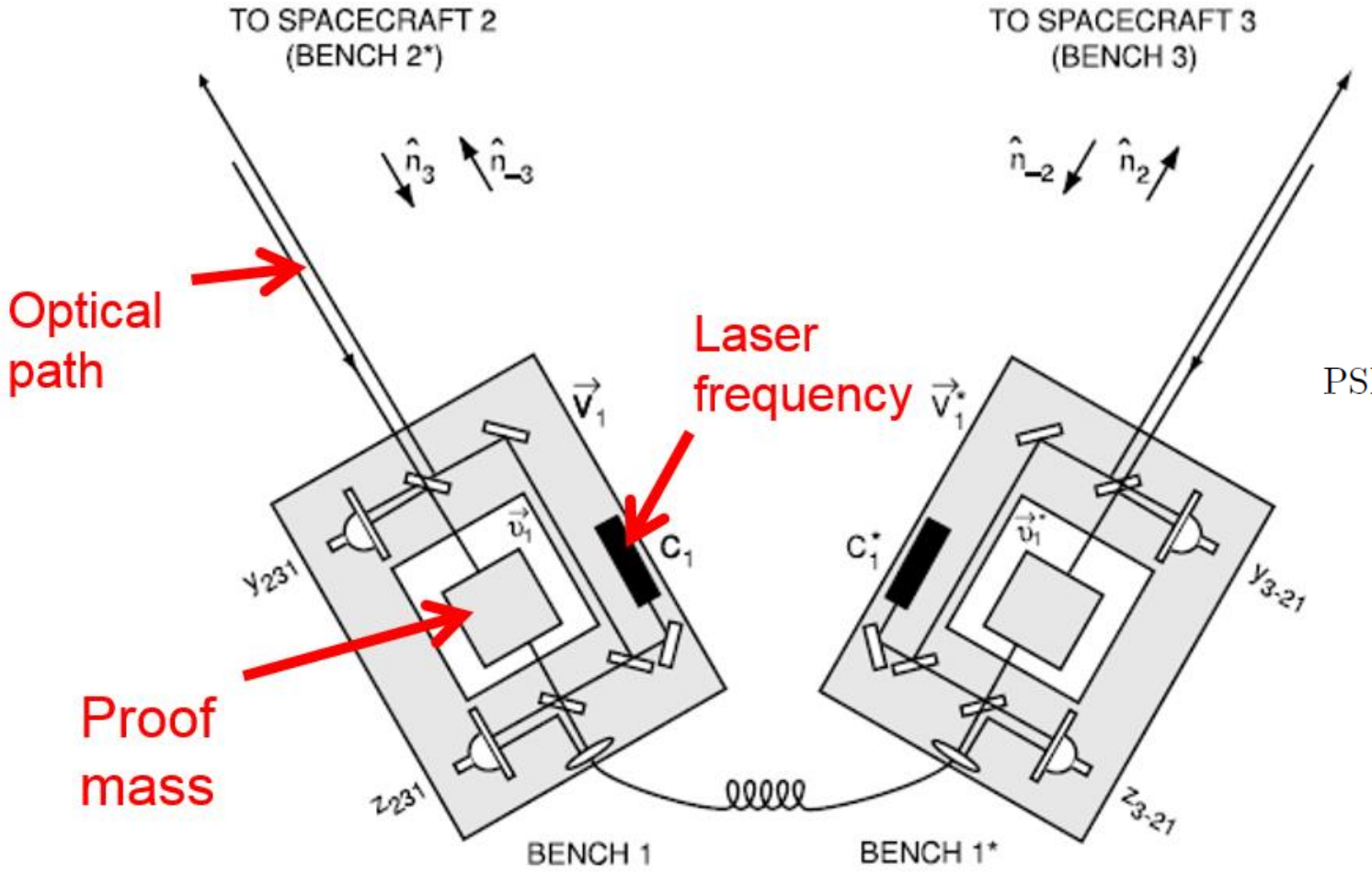
$$X_1(t) = (y_{2':322'} + y_{1:22'} + y_{3:2'} + y_{1'}) - (y_{3:2'3'3} + y_{1':3'3} + y_{2':3} + y_1)$$

TDC, LDC2b

2nd generation TDI

$$X_2(t) = y_{1'} + y_{3,2'} + y_{1,22'} + y_{2',322'} + y_{1,3'322'} + y_{2',33'322'}$$
$$+ y_{1',3'33'322'} + y_{3,2'3'33'322'} - y_1 - y_{2',3} - y_{1',3'3} - y_{3;2'3'3}$$
$$- y_{1',22'3'3} - y_{3,2'22'3'3} - y_{1;22'22'3'3} - y_{2',322'22'3'3}.$$

The variables Y and Z could be obtained by cyclic permutation of the indices



$$\omega = 2\pi f / c$$

$$\mathrm{PSD}_{X_1} = 16 \sin^2(\omega L) \left(P_{\mathrm{oms}} + (3 + \cos(2\omega L)) P_{\mathrm{acc}}\right),$$

$$\mathrm{PSD}_{X_2} = 64 \sin^2(\omega L) \sin^2(2\omega L) \left(P_{\mathrm{oms}} + (3 + \cos(2\omega L)) P_{\mathrm{acc}}\right)$$

$$P_{\mathrm{oms}}(f) = 64 \times 10^{-24} \frac{1}{\mathrm{Hz}} \left[1 + \left(\frac{2\mathrm{mHz}}{f}\right)^4\right] \left(\frac{2\pi f}{c}\right)^2,$$

$$P_{\mathrm{acc}}(f) = 9 \times 10^{-30} \frac{1}{\mathrm{Hz}} \left[1 + \left(\frac{0.4\mathrm{mHz}}{f}\right)^2\right] \left[1 + \left(\frac{f}{8\mathrm{mHz}}\right)^4\right] \left(\frac{1}{2\pi f c}\right)^2$$

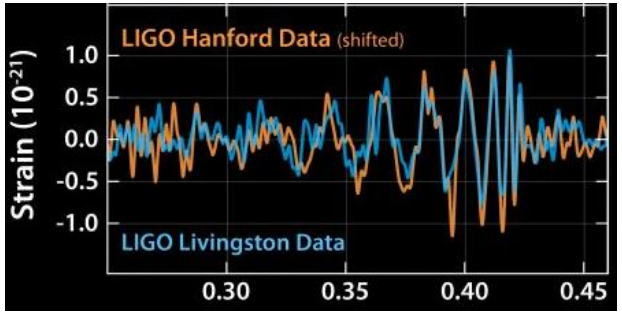
TDC data = TDI Response(h_{ij}) + TDI simulated noise

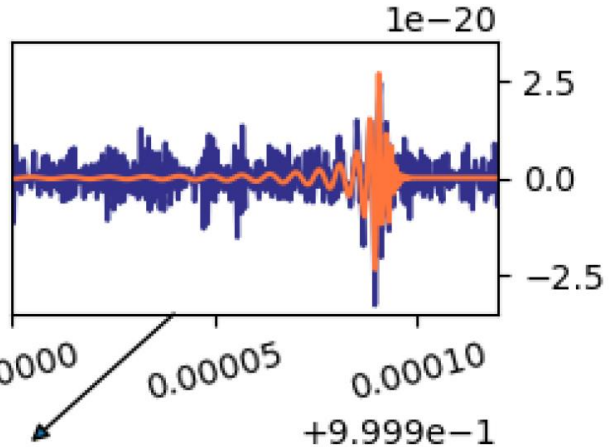
Methods: GW signal waveform

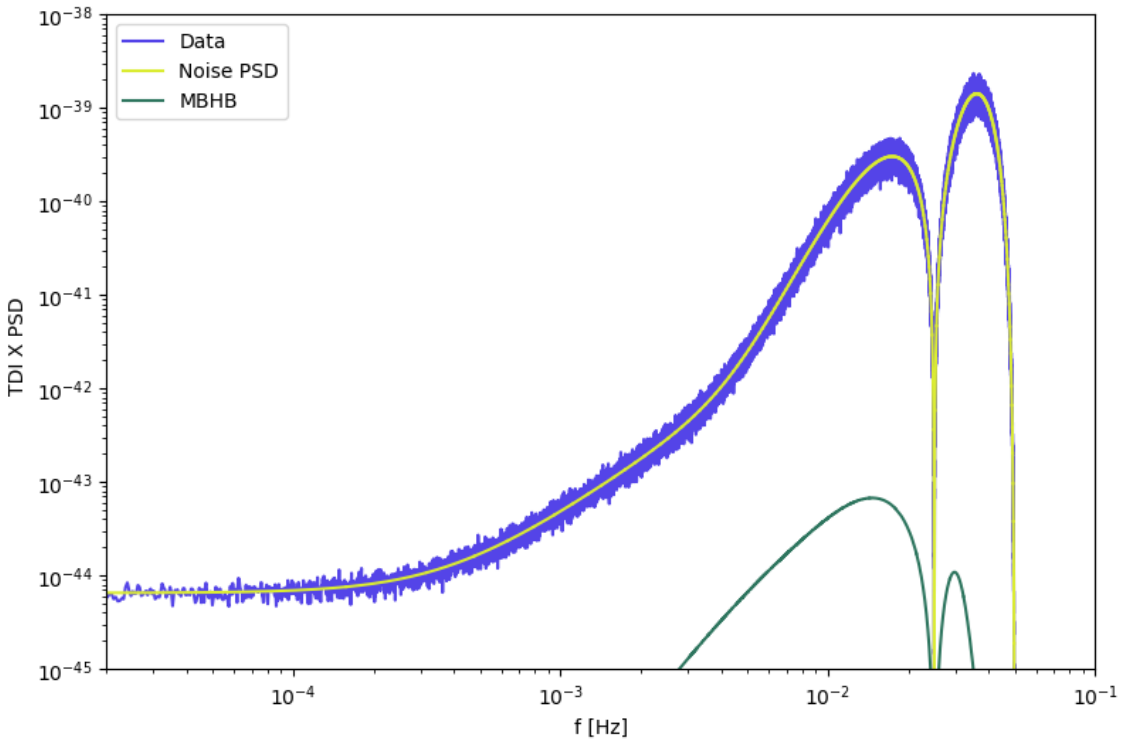
Signal Type	LDC		TDC	
	Waveform Template	Response (TDI) Config	Waveform Template	Response (TDI) Config
EMRI	**AK**	TDI **1.0** in TD	**PN5AAK / XSPEG**	TDI **2.0** in TD
MBHB	**IMRPhenomD**	TDI **1.0** in **FD**	**SEOBNRv4_opt**	TDI **2.0** in **TD**
GB	Sinusoidal	TDI **1.0** in **FD**	Sinusoidal	TDI **2.0** in **TD**
SOBBH	IMRPhenomD	TDI **1.0** in **FD**	IMRPhenomD	TDI **2.0** in **TD**
SGWB	Power law PSD	TDI 1.0 in FD	Power law PSD / **Non-Gaussian curvature perturbation**	TDI **2.0** in FD

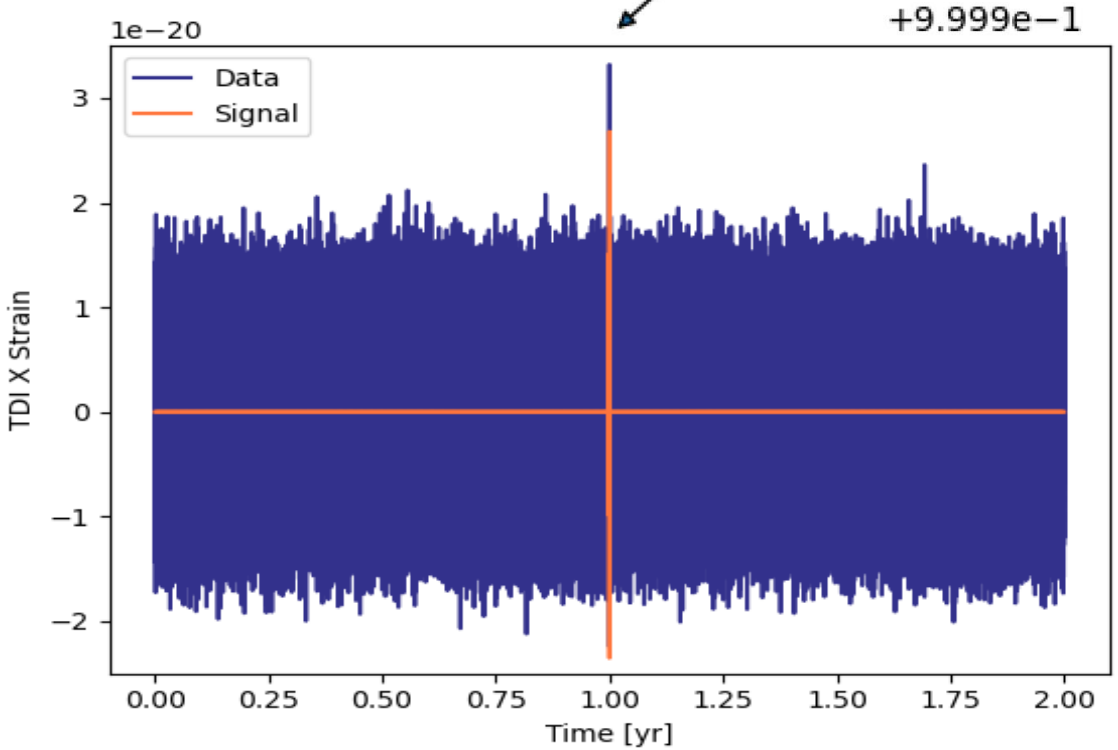
Dataset 1: MBHB signal

① Time domain MBHB data
② Frequency domain MBHB data

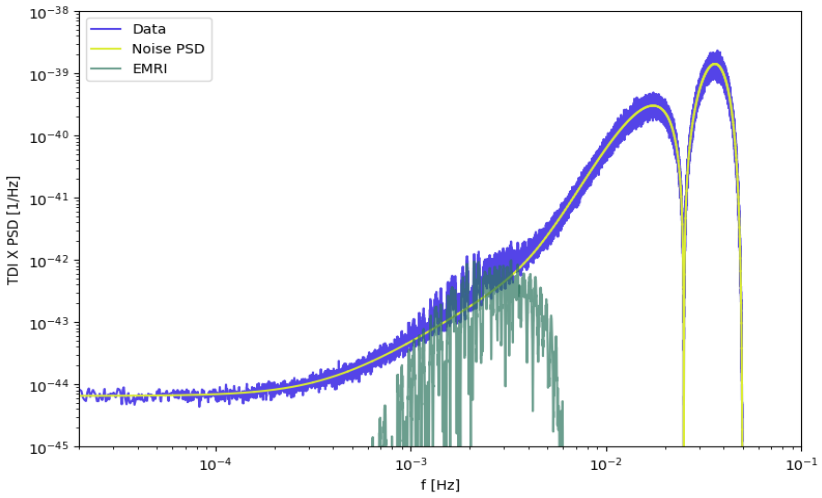


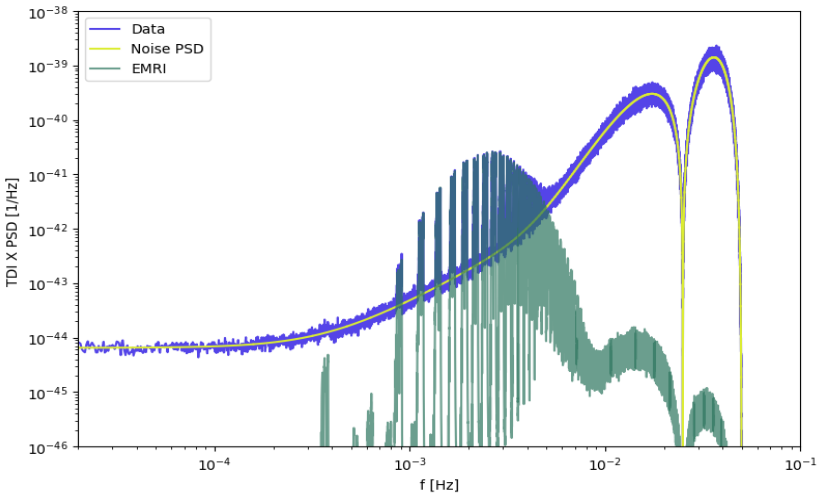


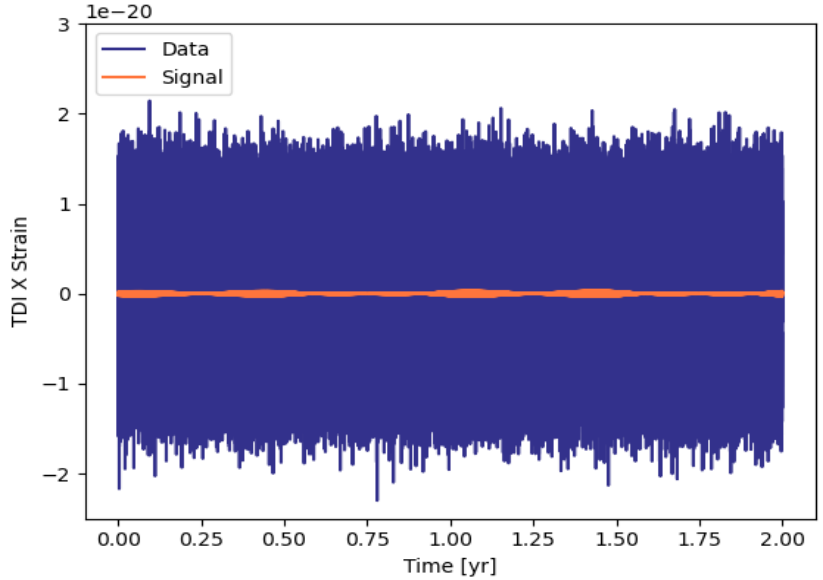


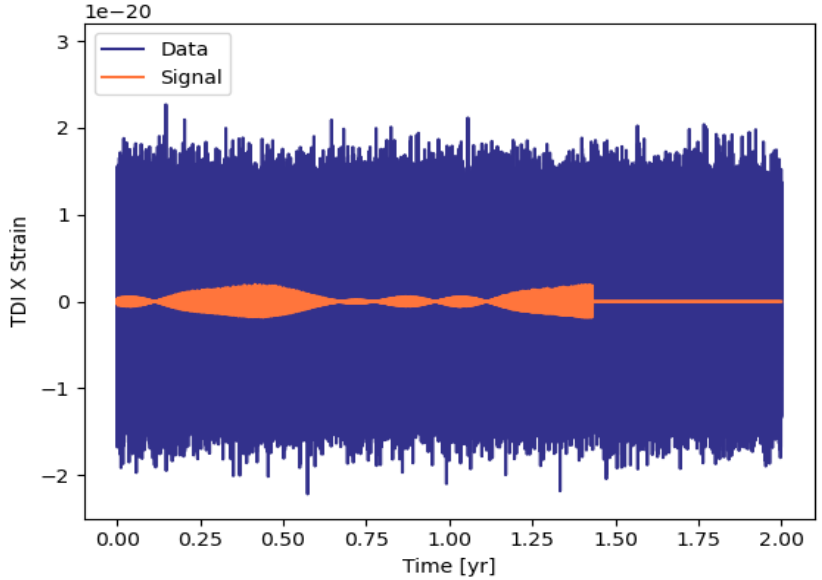


Dataset 2: EMRI signal







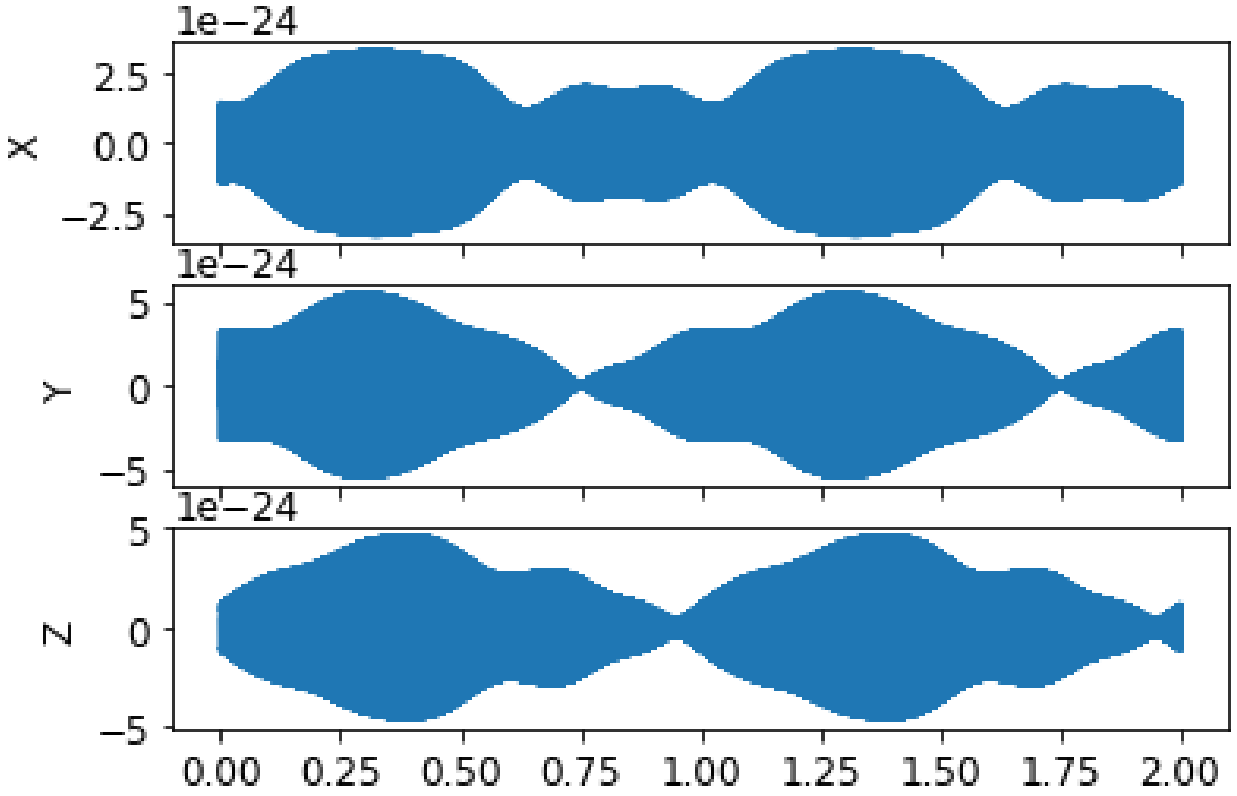


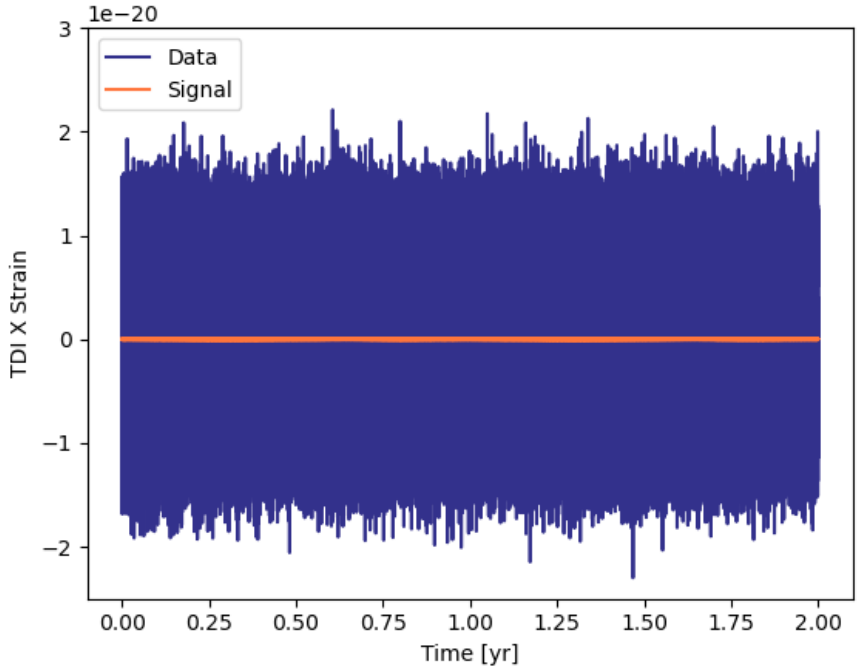
PN5AAK

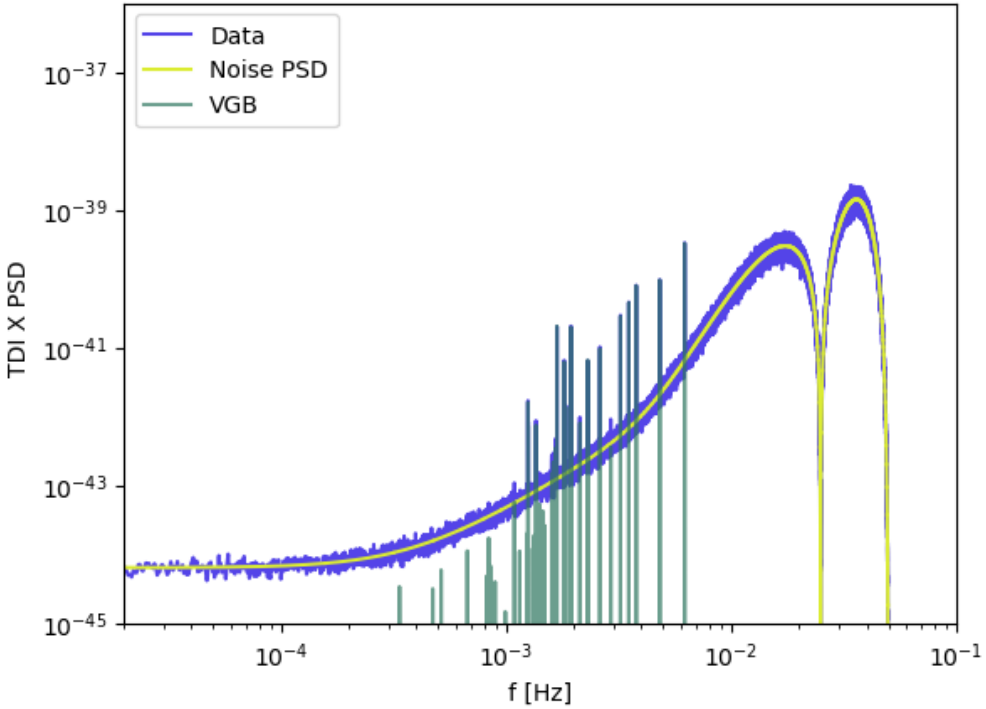
XSPEG

Dataset 3: VGB signals

① Time domain VGB data
② Frequency domain 43 VGB data
③ Single LISA Verification Galaxy binary in 3 TDI channels

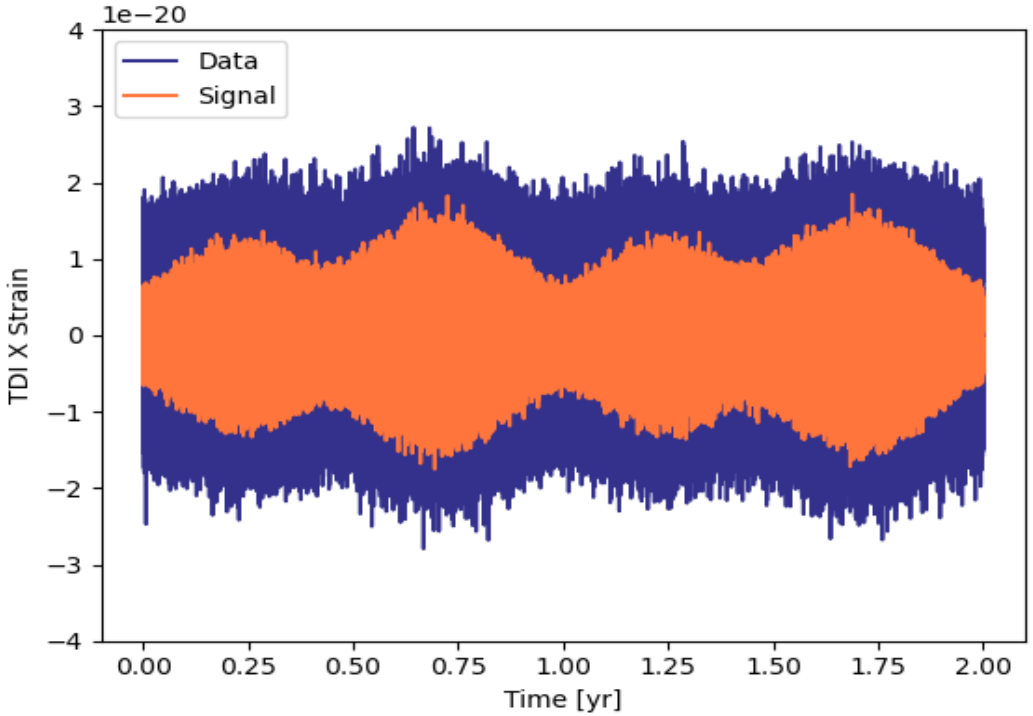


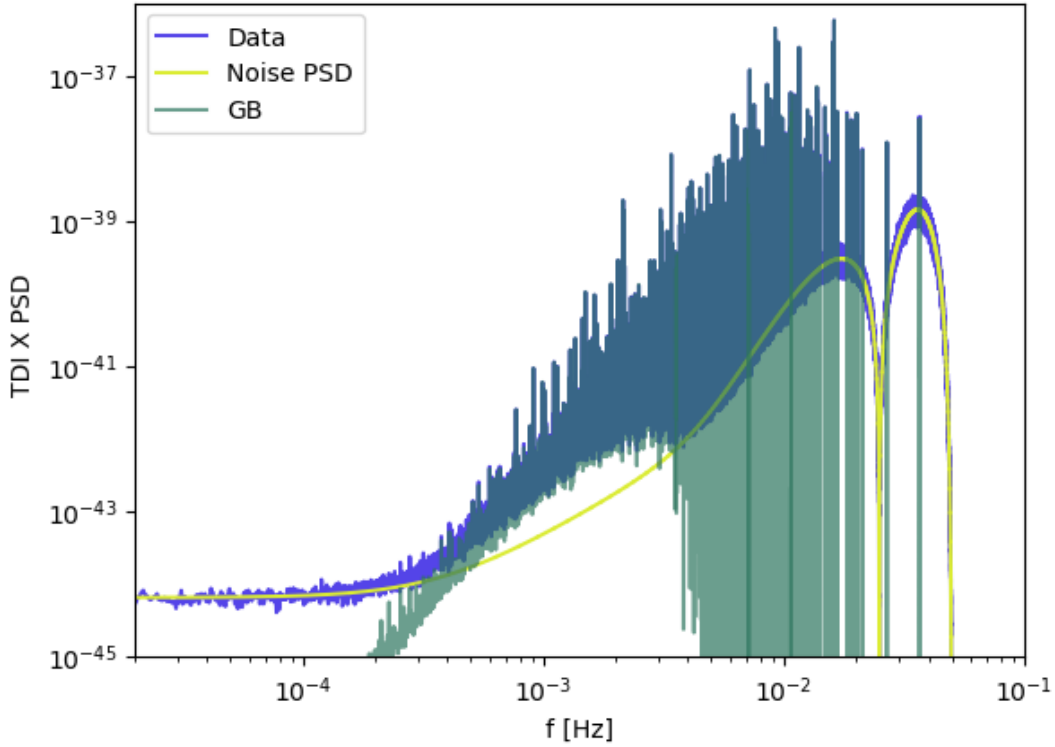




Dataset 4: GB signals

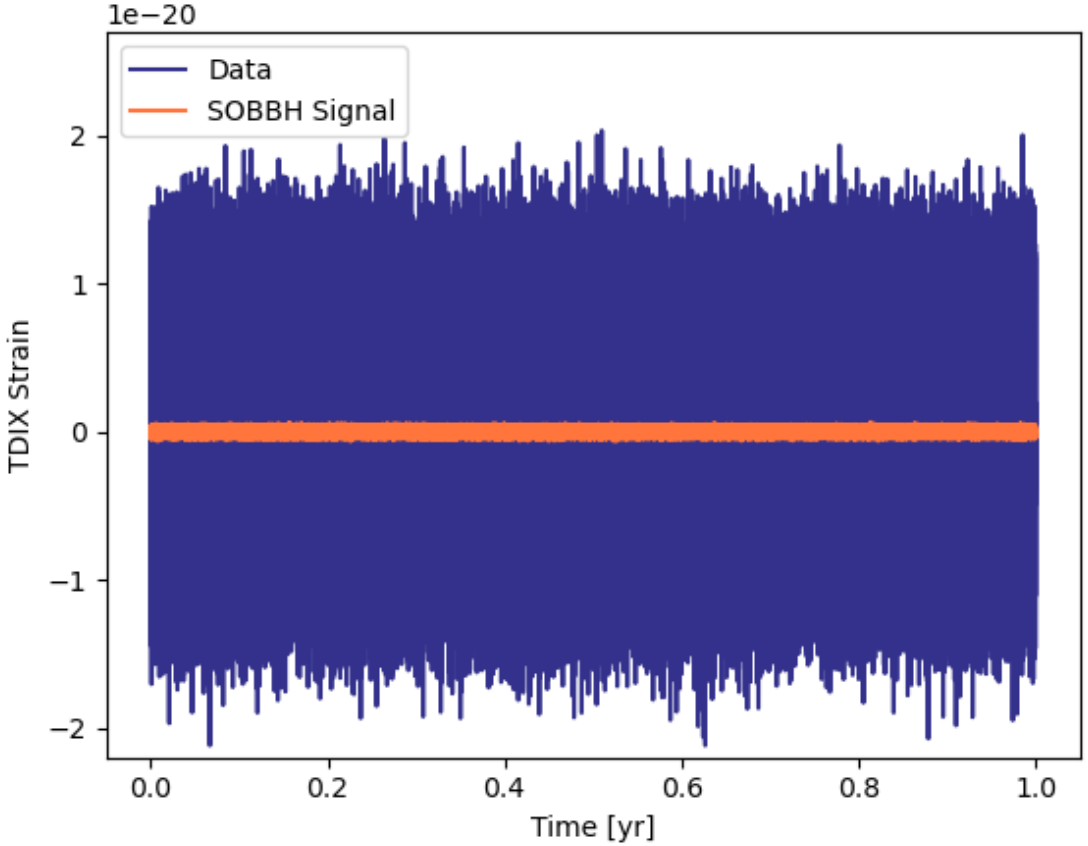
① Time domain GB data
② Frequency domain GB data

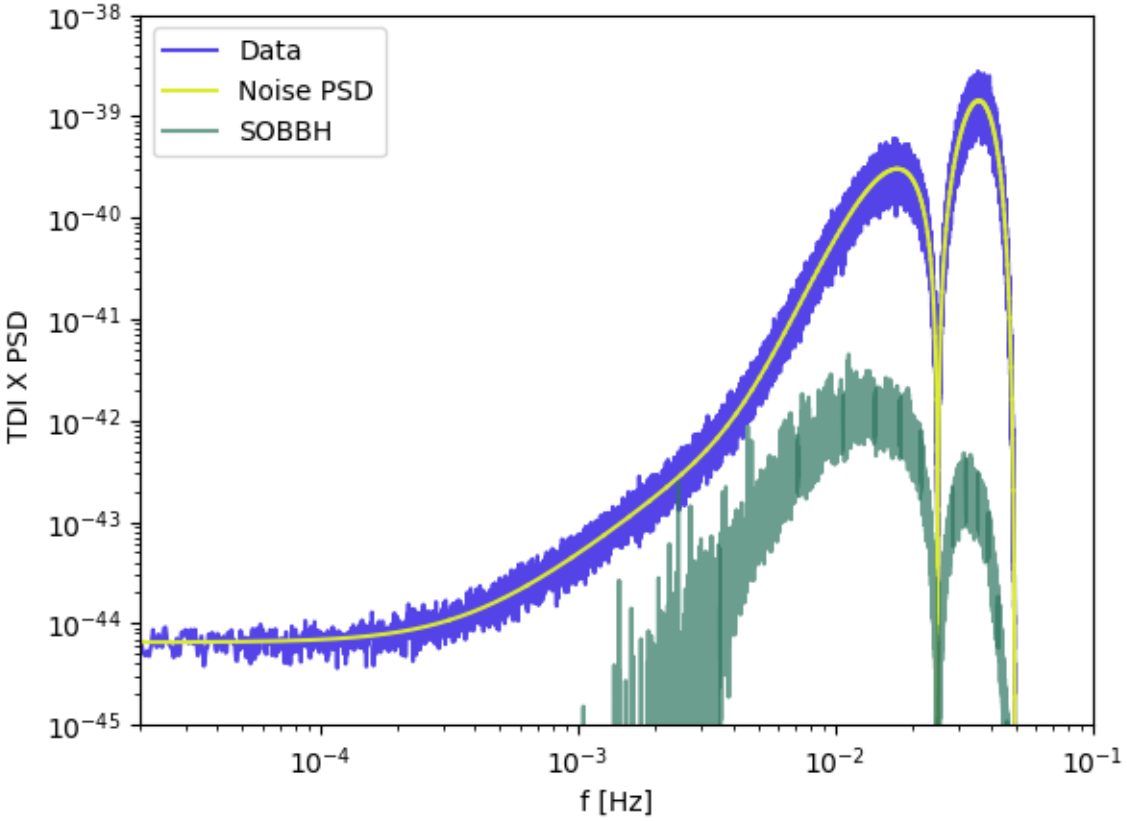




Dataset 5: SOBBH signals

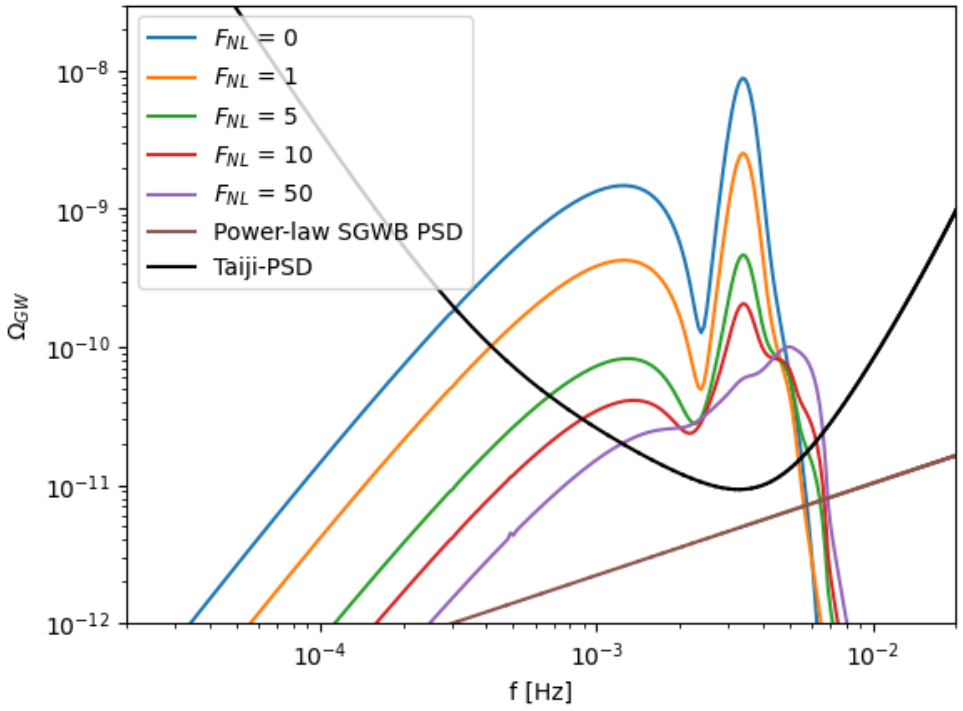
① Time domain SOBBH data
② Frequency domain SOBBH data

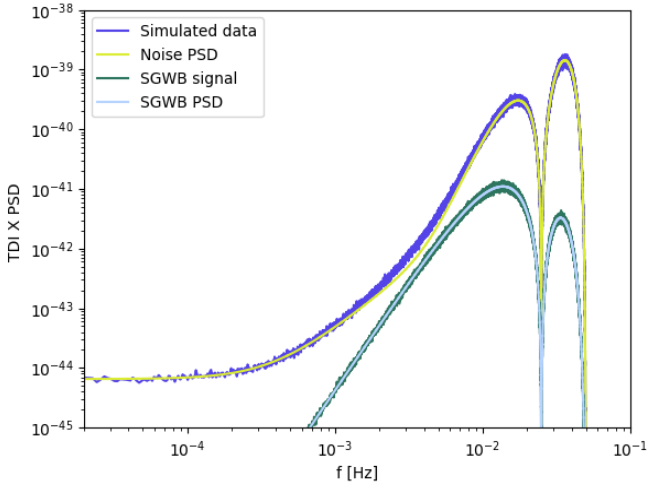


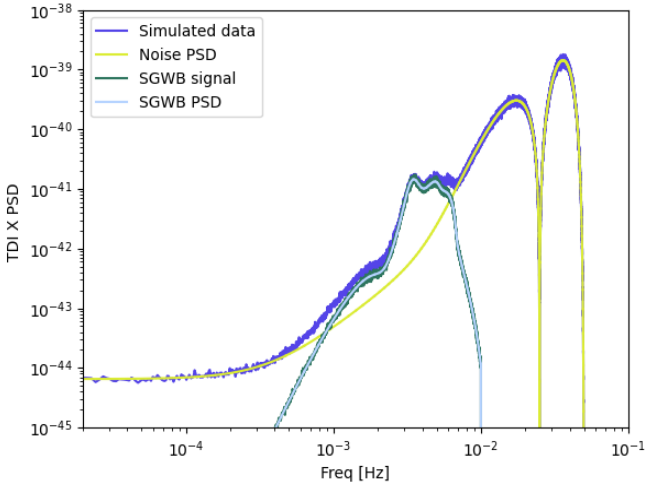


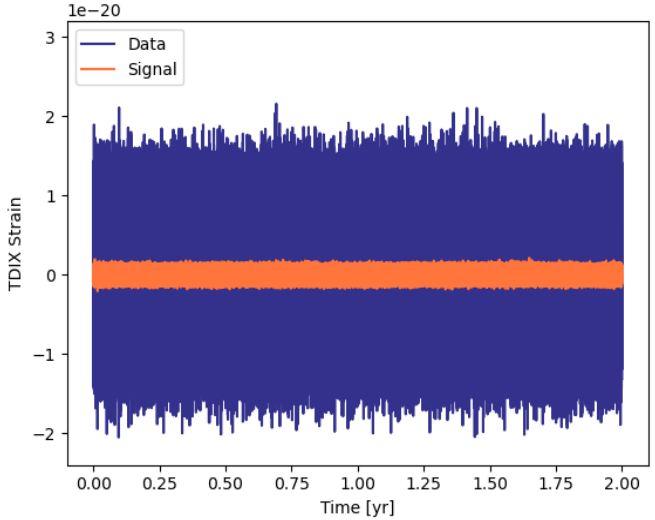
Dataset 6: SGWB signals

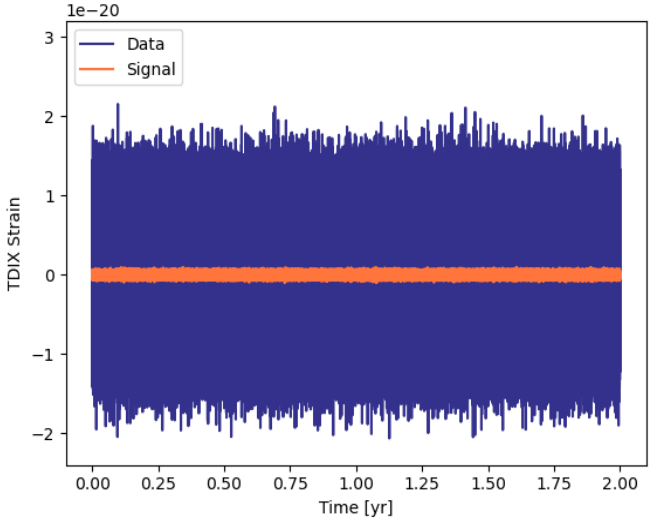
① Time domain SGWB data
② Frequency domain VGB data





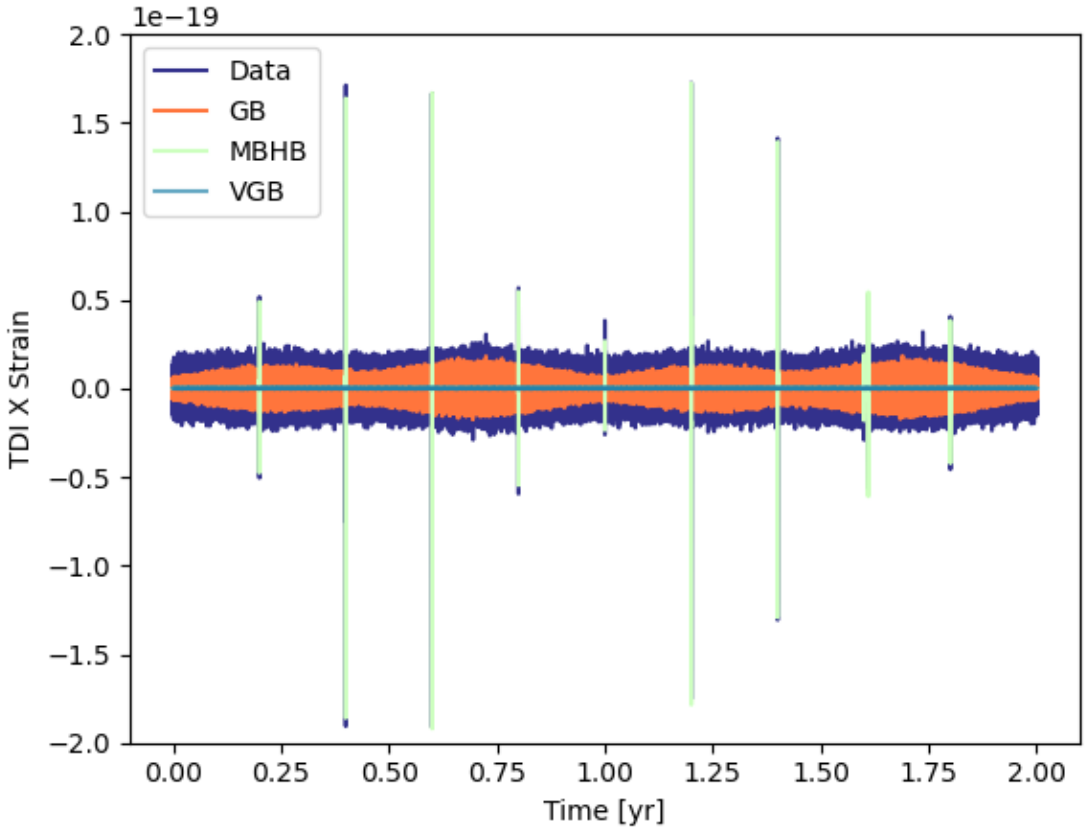


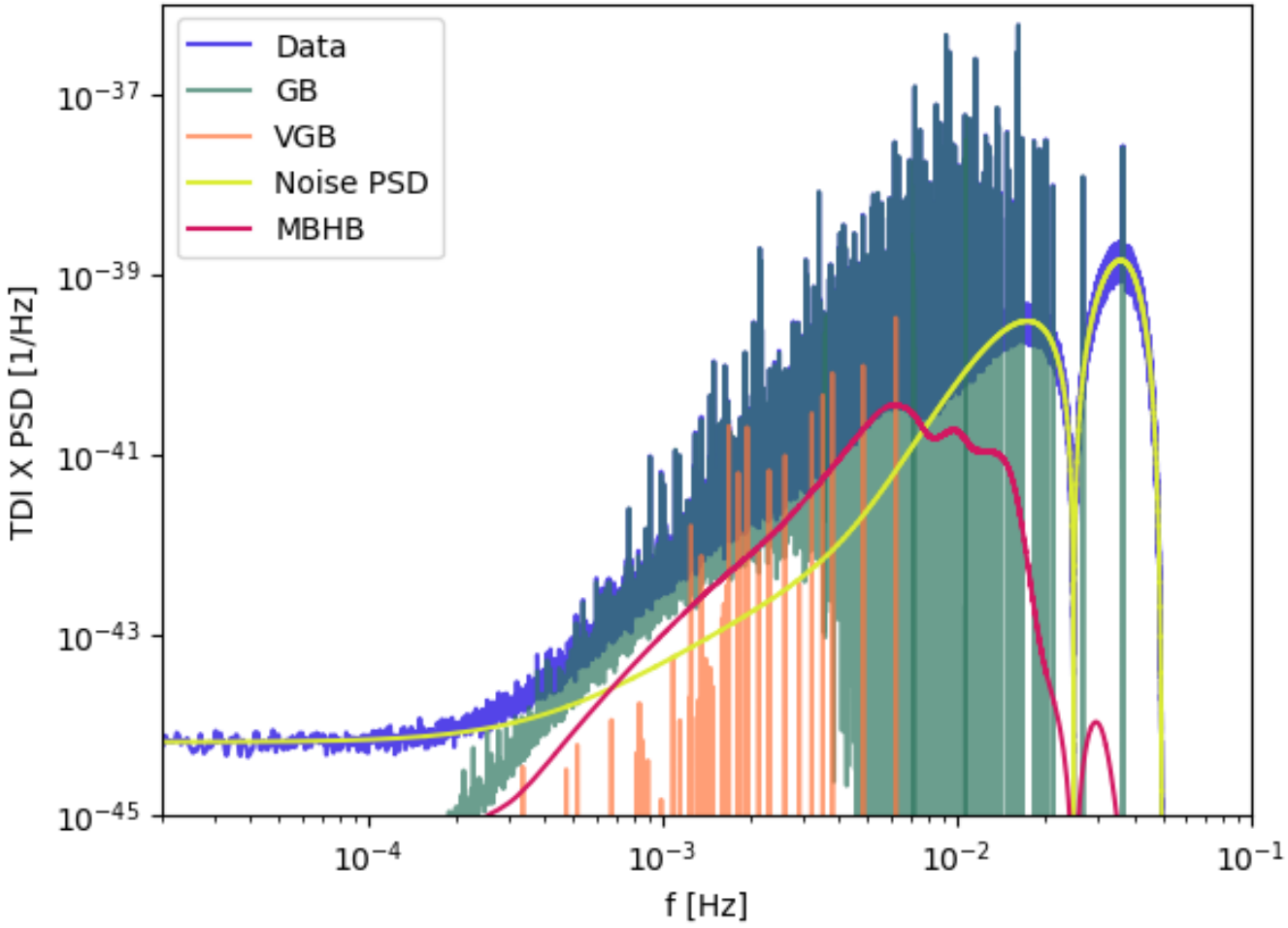




Dataset 7: Mix signals

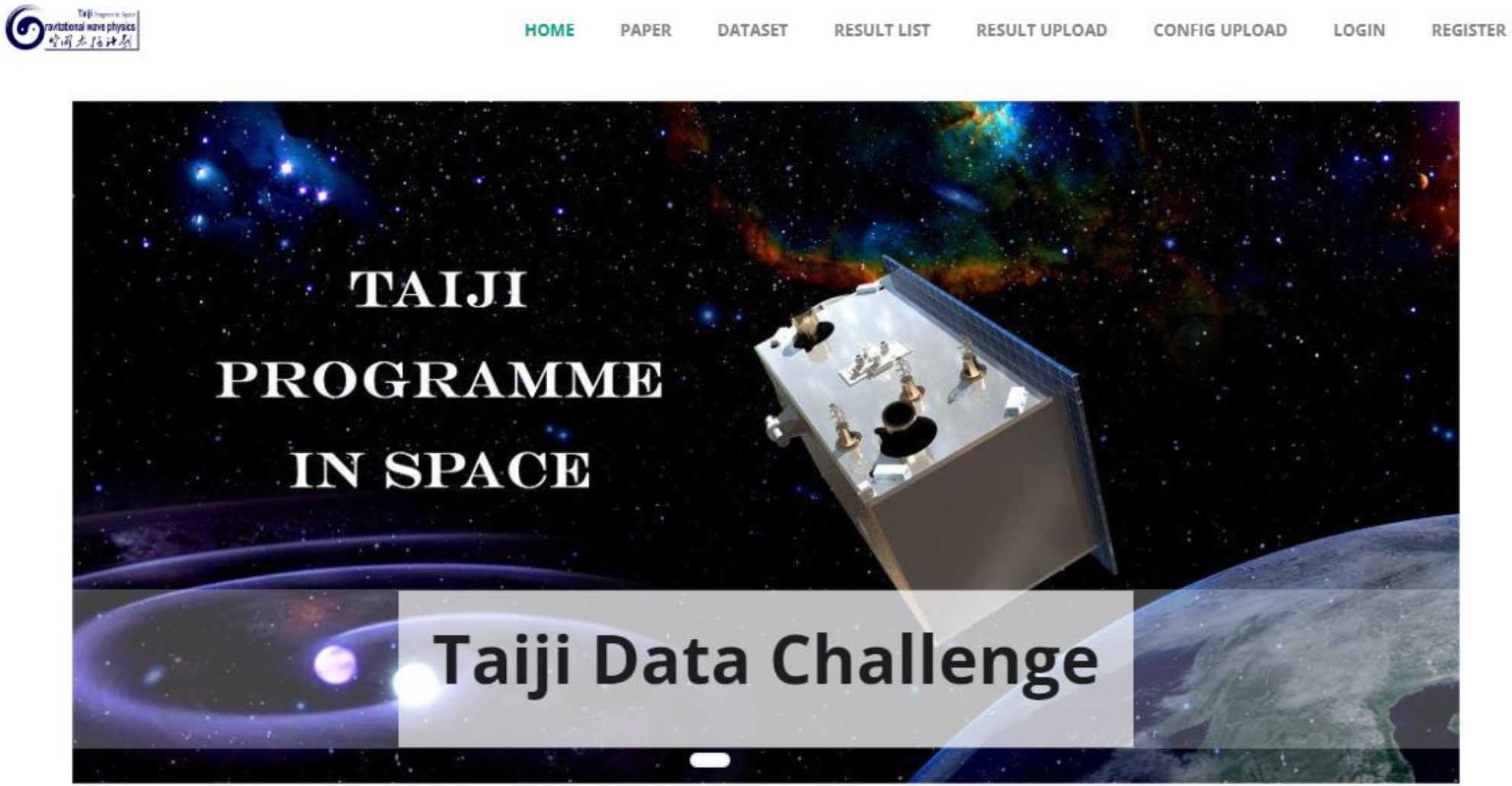
① Time domain data
② Frequency domain data





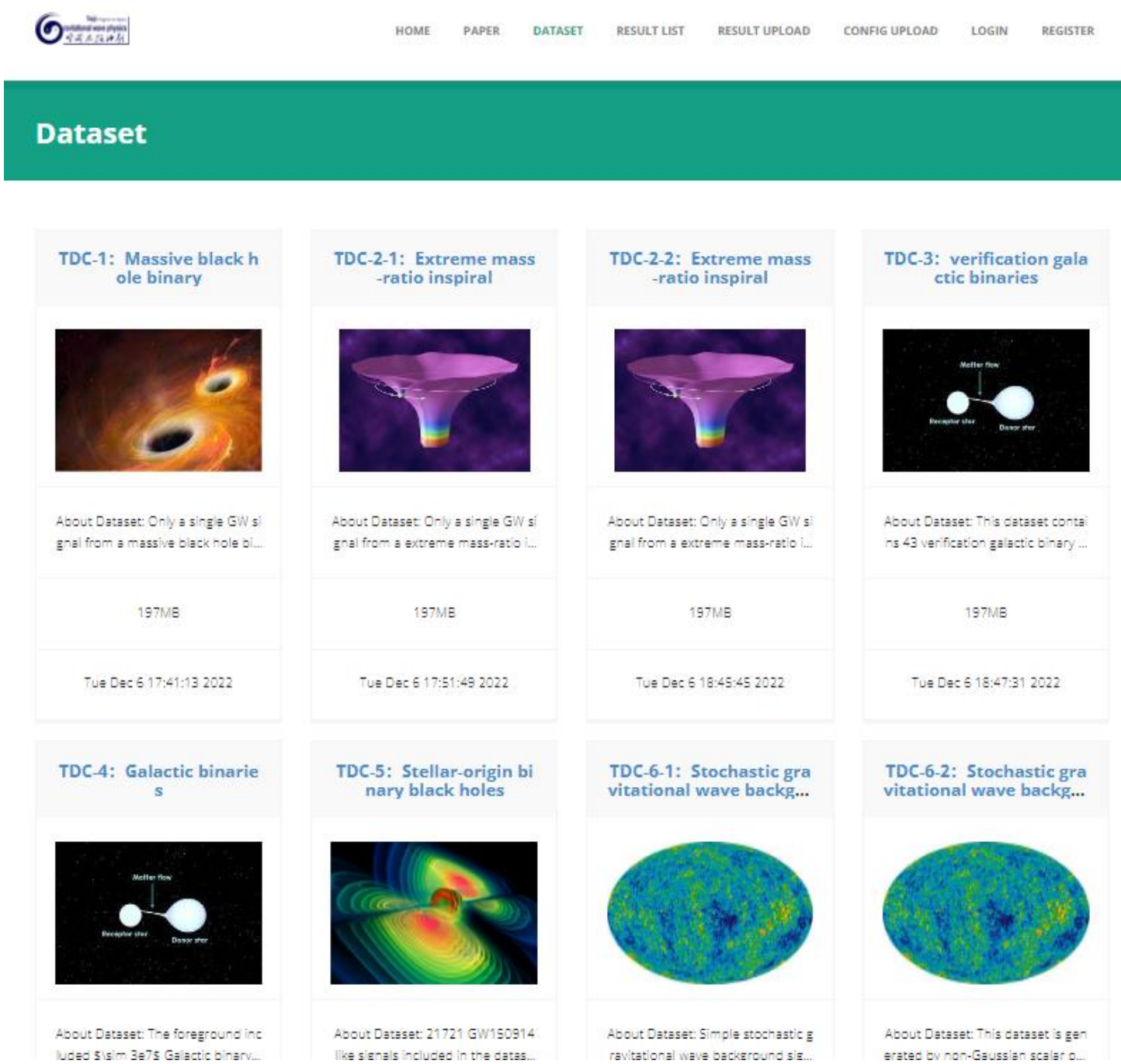
Website

http://taiji-tdc.ictp-ap.org/



Website

Core Features	Description
TDC overview	Introduction to Taiji Data Challenges
User register	Register with edu emails
Dataset download	Introduction to each dataset and challenge task information with download link
Configuration file upload	For user customize dataset configuration file upload
Result submit	Submit challenge results
Result list	A list of submitted results for each challenge dataset



Summary

1、Taiji mock data is ready, most advanced mock data to date compared to LDC

2、Benchmark for template check

3、Benchmark for science data analysis development