0254-6124/2024/44(4)-0674-03 *Chin. J. Space Sci.* 空间科学学报

LUO Ziren, ZHANG Min, WANG Jianyu, WU Yueliang. Progress of Taiji-2 Project. *Chinese Journal of Space Science*, 2024, **44**(4): 674–676. DOI:10.11728/cjss2024.04.2024–yg14

Progress of Taiji-2 Project*

LUO Ziren[1,2,3] ZHANG Min[1,2,4] WANG Jianyu[2,5] WU Yueliang[1,2,4]

1(*Taiji Laboratory for Gravitational Universe*, *University of Chinese Academy of Sciences*, *Beijing* 100049)

2(*Hangzhou Institute for Advanced Study*, *University of Chinese Academy of Sciences*, *Hangzhou* 310024)

3(*Institute of Mechanics*, *Chinese Academy of Sciences*, *Beijing* 100190)

4(*International Center for Theoretical Physics Asia-Pacific*, *University of Chinese Academy of Sciences*, *Beijing* 100190)

5(*Shanghai Institute of Technical Physics*, *Chinese Academy of Sciences*, *Shanghai* 200083)

Abstract Taiji-2 project is the second step of Taiji program, which is to verify the required technology for Taiji-3 mission. The feasibility study of Taiji-2 is successfully finished, and some of the main progress is introduced here.

Key words Gravitational wave, Taiji program, Taiji-2 project

Classified index V474

Taiji is a Chinese space-borne Gravitational Wave (GW) detection program led by Chinese Academy of Sciences[1,2,3] and planned to be launched in 2030 s. Taiji-1 satellite mission is the first step of Taiji program which was launched in 2019[4]. The second step is to launch the Taiji pathfinder (also called Taiji-2) no later than 2030. The final step is to launch Taiji (also called Taiji-3), which is similar to the LISA constellation (see Figure 1). The purpose of Taiji-2 project is to verify thoroughly the required technology for Taiji-3 and may also produce limited scientific outcomes.

Taiji-2 is initially proposed to build a pair of satellites to test the whole key technology. These two satellites will be deployed in the heliocentric orbit, as same as Taiji-3. The architecture of the platform and the design of the payload of Taiji-2 satellite will be made to be the same to Taiji-3 satellite for inheritance (see Figure 2). On the other hand, if there could be a second party that can contribute another satellite, Taiji-2 would have the potential to form a 3-satellite-constellation as a mini Taiji-3. In that case, Taiji-2 could possess the capability to detect some supermassive black hole mergers, although it is designed to have a relaxed requirement of sensitivity.

The feasibility study of Taiji-2 was begun in

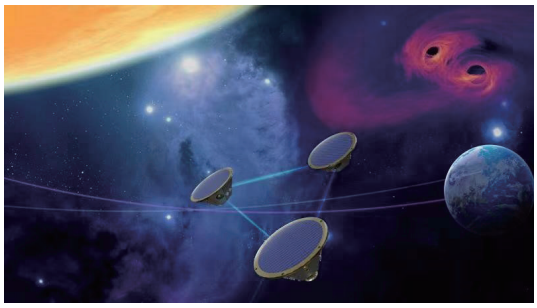

Fig. 1 Taiji-3 constellation. Taiji-3 consists of 3 identical satellites which form a gigantic equilateral triangle. Each of the satellites takes an Earth-like heliocentric orbit. The constellation will be leading or trailing Earth for about 18°. Taiji-3 has the ability to detect the GW from intermediate or supermassive black hole mergers

* Supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA15021100), the National Natural Science Foundation of China (12147103) and the Fundamental Research Funds for the Central Universities

Received June 20, 2024

©The Author(s) 2024. This is an open access article under the CC-BY 4.0 License (https://creativecommons.org/licenses/by/4.0/)

2020 and it was successfully completed in 2022. Taiji-2 now is ready to be approved for engineering phase. Some results of this feasibility study were gradually being published.

One of the significant progress of Taiji-2 feasibility study is parameter estimation of GW sources for space-borne gravitational wave detection missions such as LISA[5], Taiji[1,2,3] and Tianqin[6]. The team of Taiji data analysis has for the first time demonstrated the application of machine learning techniques, specifically the normalizing flows, in parameter estimation of massive black hole binary events[7]. Compared to traditional techniques, this method has remarkable speed that could be several orders faster (see Table 1). Notably, this approach remains resilient against challenges such as confusion noise and the intricacies of varying reference times, underscoring its reliability and potential for broader applications.

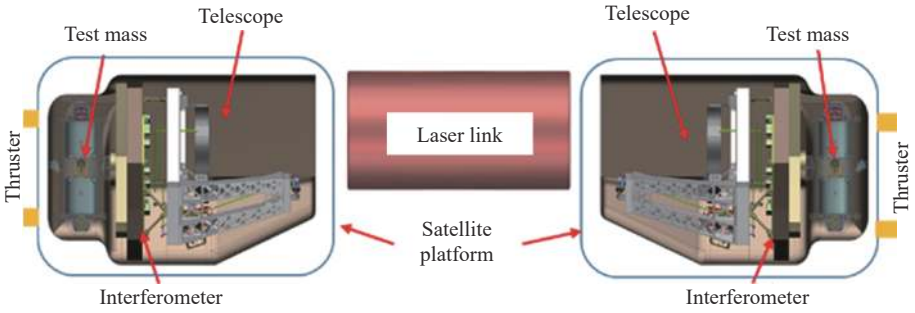

Fig. 2 Taiji-2 satellites. The payload configuration of Taiji-2 satellite is designed to be as same as Taiji-3 in order to expand to 3-satellite constellation when there is second party to contribute additional satellite

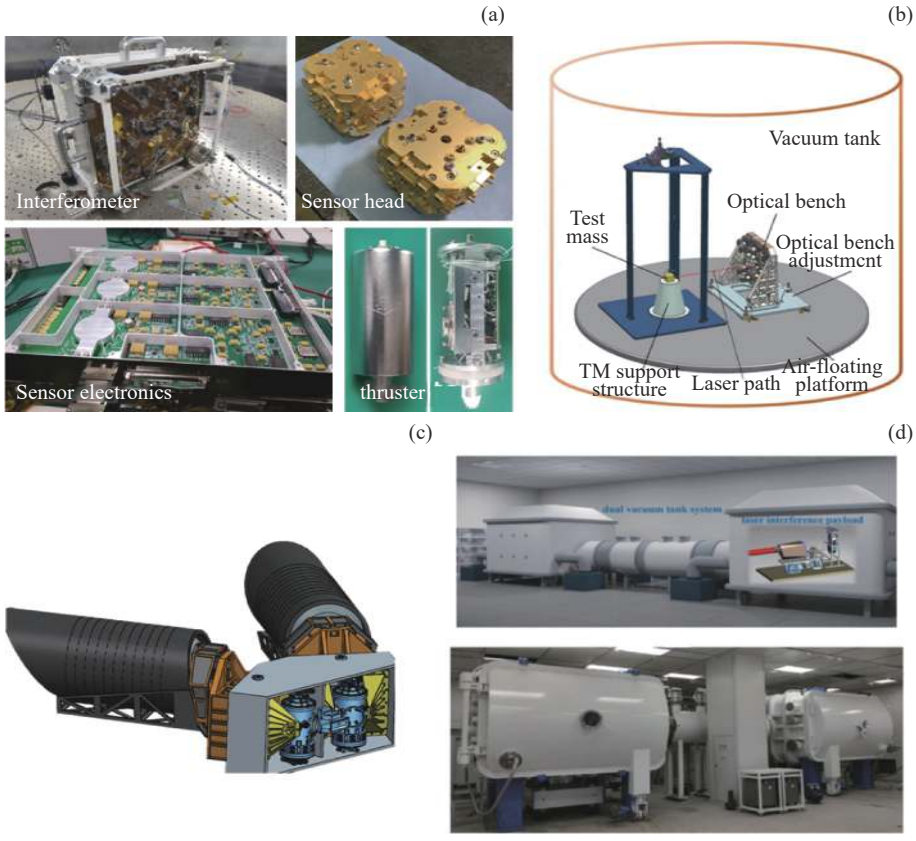

Fig. 3 (a) Taiji-2 payload prototypes. (b) The torsion balance with DWS technique. (c) Payload integration scheme. (d) Test bed for Taiji-2 inter-satellite laser interferometric ranging

Table 1 Comparison of computational time required by different posterior sampling approaches to generate their respective samples

Sampling method	Numbers of samples	Run time /s	Time per sample/s
Nest sampling	11215	3000	0.26750
Normalization flow	10000	2.7	0.00027

The second progress is Taiji-2 payload integration scheme and its verification. During the feasibility study project, the team of Taiji-2 payload research had built and tested the prototype of laser interferometer, inter-satellite laser acquisition sub-system, inertial sensor, stable structure of satellite platform, micro-thruster and drag-free control unit (some of the prototypes were shown in Figure 3). One of the most challenging tasks is to evaluate the performance of inertial sensor due to its extreme sensitivity and complex disturbances on ground. To tackle this problem, a novel design of torsion balance with differential wave front sensing (DWS for short, see Figure 3b) was proposed[8] which can measure the test mass's acceleration to 3×10^{-13} $\mathrm{m\cdot s^{-2}\cdot Hz^{-1/2}}$. Besides, an integration scheme for Taiji-2 payload was also studied (see Figure 3c). In order to test the integrate payload, a test bed was built and put into use in 2023[9]. It consists of two vacuum tanks that can fully test the inter-satellite interferometric ranging for Taiji-2 laser interferometer (see Figure 3d) with displacement and laser pointing jitter measurement ability to 100 $\mathrm{pm\cdot Hz^{-1/2}}$ and 100 $\mathrm{nrad\cdot Hz^{-1/2}}$ respectively.

References

[1] HU W R, WU Y L. The Taiji Program in Space for gravitational wave physics and the nature of gravity[J]. *National Science Review*, 2017, **4**(5): 685-686

[2] LUO Z R, GUO Z K, JIN G, *et al*. A brief analysis to Taiji: science and technology[J]. *Results in Physics*, 2020, **16**: 102918

[3] LUO Z R, WANG Y, WU Y L, *et al*. The Taiji program: a concise overview[J]. *Progress of Theoretical and Experimental Physics*, 2021, **2021**(5): 05A108.

[4] The Taiji Scientific Collaboration. China's first step towards probing the expanding universe and the nature of gravity using a space borne gravitational wave antenna[J]. *Communications Physics*, 2021, **4**(1): 34

[5] AMARO-SEOANE P, AUDLEY H, BABAK S, *et al*. Laser interferometer space antenna[OL]. arXiv preprint arXiv: 1702.00786, 2017

[6] LUO J, CHEN L S, DUAN H Z, *et al*. TianQin: a space-borne gravitational wave detector[J]. *Classical and Quantum Gravity*, 2016, **33**(3): 035010.

[7] DU M H, LIANG B, WANG H, *et al*. Advancing space-based gravitational wave astronomy: rapid parameter estimation via normalizing flows[J]. *Science China Physics, Mechanics & Astronomy*, 2024, **67**(3): 230412

[8] WANG S X, LIU H S, DAI L, *et al*. Using DWS optical readout to improve the sensitivity of torsion pendulum[J]. *Sensors*, 2023, **23**(19): 8087

[9] WANG Y K, MENG L Q, XU X S, *et al*. Research on semi-physical simulation testing of inter-satellite laser interference in the China Taiji space gravitational wave detection program[J]. *Applied Sciences*, 2021, **11**(17): 7872

Author Biography

LUO Ziren Male, born in August 1980 in Yongzhou, Hunan Province, is currently a professor researcher and doctoral supervisor at Institute of Mechanics, Chinese Academy of Sciences. His major research area includes space-borne gravitational wave detection, laser metrology, precise measurement, theoretical and experimental relativity

E-mail: luoziren@imech.ac.cn