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Recent Status of Taiji Program in China*

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Abstract The Taiji-1 satellite is a pilot satellite mission of Taiji program, which is used to verify Taiji's key technology and also to testify the feasibility of Taiji roadmap. Taiji-1 was launched on 31 August 2019 and its designed mission was successfully completed. The in-orbit scientific achievements of Taiji-1 satellite in the first stage have been published and now it has entered the extended task phase. Taiji-2 will prepare all the technology needed by Taiji-3, and remove all the technical obstacles faced by Taiji-3.

Key words Gravitational wave, Taiji program, Global gravity field model

Classified index V47, P35

Taiji is a Chinese space-borne Gravitational Wave (GW) detection mission led by Chinese Academy of Sciences[1−3]. Taiji will be launched in 2030 s[2,3] in order to have at least 1-year overlap with LISA to form a LISA-Taiji network[4]. To ensure the launching date, a three-step plan has been established. The first step has been accomplished by launching a pilot study satellite known as Taiji-1 in 2019[5]. The second step is to launch the Taiji pathfinder (also called Taiji-2) no later than 2025. The final step is to launch Taiji (also called Taiji-3), which is similar to the LISA constellation, in 2030 s.

During Taiji-1's operating time, the working principle of the optical metrology system and drag-free control system were verified properly (see Fig.1[5]). Since these two technologies were the most essential for Taiji-2, the success of Taiji-1 laid a solid foundation for Taiji-2.

On 20 July 2021, Taiji scientific collaboration team released the scientific achievements of Taiji-1 satellite in the first stage. The results of the first-stage in-orbit test and data analysis show that the Taiji-1 has achieved the highest precision of space laser interferometry in China. The accuracy of displacement measurement of the laser interferometer on Taiji-1 reached 100 $\mathrm{pm \cdot Hz^{-1/2}}$, 25 $\mathrm{pm \cdot Hz^{-1/2}}$ in some frequency bands. The accuracy of the gravitational reference sensor on the satellite reached 10^{-10} $\mathrm{ms^{-2} \cdot Hz^{-1/2}}$, and the sensing accuracy and range ratio reach the best level of 2×10^{-6} $\mathrm{Hz^{-1/2}}$ in China. For the first time in the world, the on-orbit verification of the micro-thruster Radio-Frequency (RF) and dual-mode Hall electric propulsion technology has been realized. The micro-propulsion system achieves 0.15 $\mathrm{\mu N \cdot Hz^{-1/2}}$ noise level, and the thrust measurement accuracy is better than 0.02 $\mathrm{\mu N \cdot Hz^{-1/2}}$. The first in-orbit experiment of drag-free control of satellite was carried out in China, and the residual acceleration is better than 10^{-8} $\mathrm{ms^{-2} \cdot Hz^{-1/2}}$. The temperature control of the satellite platform reaches ± 2.6 mK. The above results of these in-orbit tests have been published in *Communications Physics*[5].

Meanwhile, *International Journal of Modern Physics A* of the World Scientific Press has published

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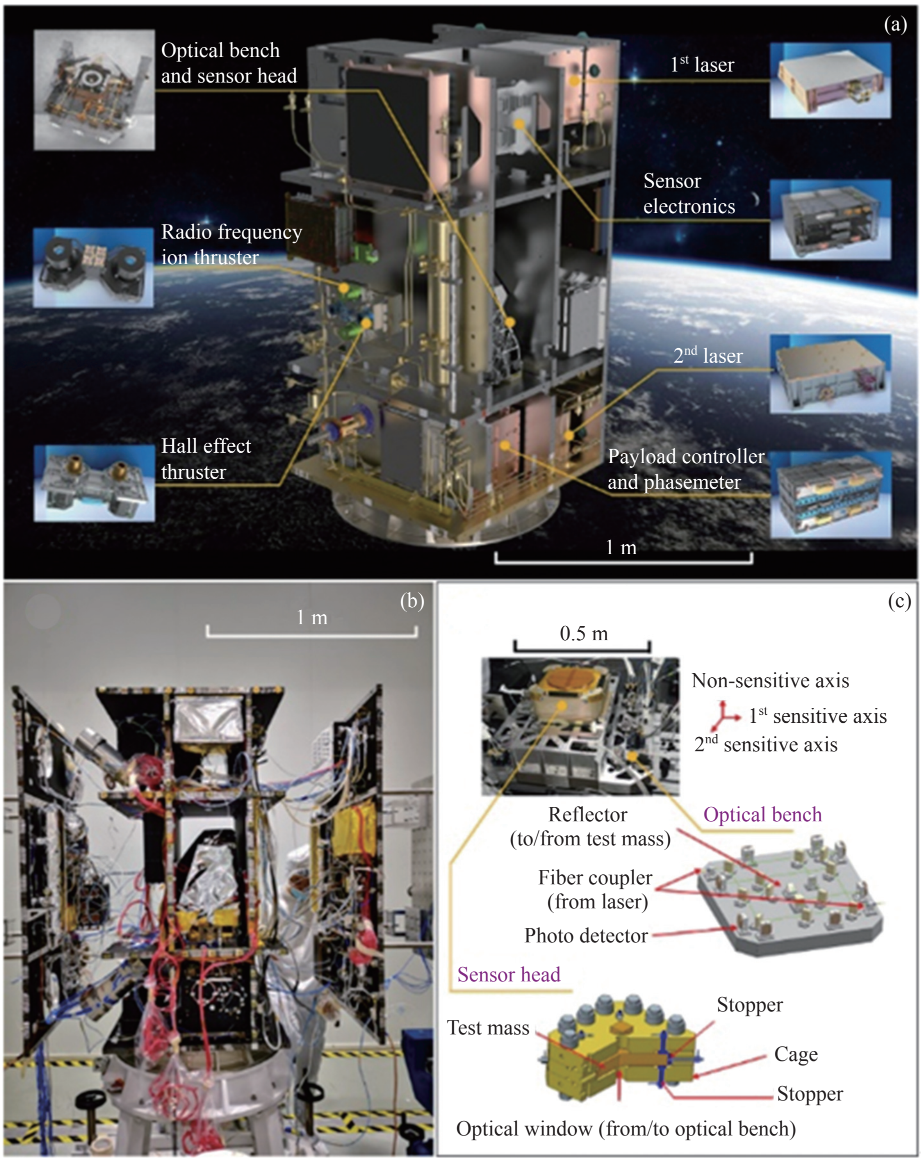

Fig. 1 Anatomy of Taiji-1 and its payloads. (a) The distribution of the payloads in Taiji-1. (b) Taiji-1 satellite before assembly. (c) The core measurement unit, which contains an optical bench and a sensor head

more detailed experimental results of Taiji-1 in the form of an album[6], including 26 papers, from more than 180 researchers, and more than 30 cooperative institutions. This album covers the interferometer system, gravitational reference sensor, micro-thruster system, drag-free control, ultra-stable and ultra-static satellite technology, and introduces the data processing process of Taiji-1 in detail.

After finishing its planned tasks, Taiji-1 has entered the extended task phase since 2021. Taiji-1 continues collecting the data of the precision orbit determinations, the satellite attitudes, and the non-conservative forces exerted on the S/C. Therefore, during its free-fall, Taiji-1 can be viewed as operating in the high-low satellite-to-satellite tracking mode of a gravity recovery mission. By using the data from both the Beidou navigation system and the inertial sensor, a China's first domestically developed global gravity field model (monthly averaged) is produced (see Fig.2) and as the approved extended free-falling phase with minimal disruptions and disturbances, Taiji-1 will provide us the independent measurement of both the static and the monthly variable global gravity field.

Since Taiji-1's launch, the research and develop-

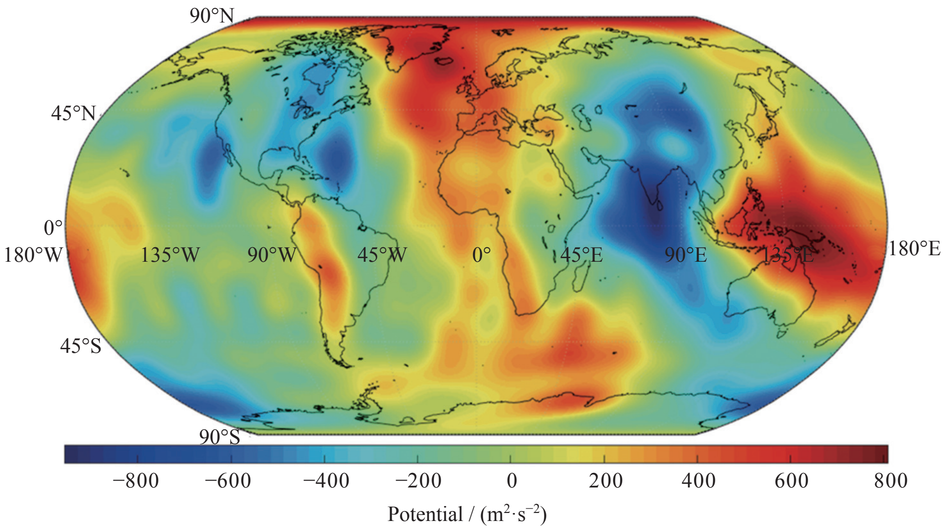

Fig. 2 Global gravity field model represented by spheroidal harmonics up to degree and order (d/o) 20

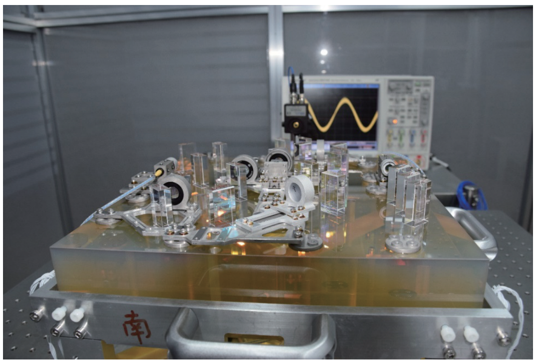

Fig. 3 Principle prototype of Taiji-2's laser metrology system

ment of Taiji-2's key technologies have been carried out in an orderly manner. According to interface and function, Taiji-2's key technologies are divided into five categories, such as laser metrology system, inter-satellite laser link maintaining system, gravitational reference sensor system, drag-free and micro-thruster system and hyper-stable and hyper-static satellite platform. The principle prototypes of Taiji-2's key technologies have been developed and the prototype of the laser metrology system is shown in Fig.3. The ground verifications of Taiji-2's key technologies have been completed and all the test items and performances meet Taiji-2's requirements.

The other important issue for Taiji-2 is to verify the algorithm of time delay interferometry. In the other satellite of Taiji-2, an optical fiber interferometer is set up to simulate a short arm of tens of kilometers. By using this optical fiber interferometer, together with the ranging data and clock synchronization data, the techniques of time delay interferometry can be applied. Despite of the path length noise of the fiber interferometer, the feasibility of the algorithm of time delay interferometry can be verified.

Once Taiji-2 is launched, the technologies could be verified by flight demonstration. It will remove all the technical obstacles faced by Taiji-3.

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