PHYSICS

Special Topic: Gravitational Wave Astronomy

The Taiji Program in Space for gravitational wave physics and the nature of gravity

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The discovery of gravitational waves (GWs) by the LIGO collaboration [1] in 2016 has provided a direct test on the prediction made by Albert Einstein a century ago based on his general theory of relativity [2]. It has caused a significant influence worldwide on the basic research in science.

Space-based GW detection has become the next interesting target for the further study on the gravitational universe as space-based GW detection would reach a wider range of gravitational radiation sources than the ground-based GW detection can [3]. After the LISA/eLISA strategic plan [4] on space-based GW detection was put forward in the 1990s, Chinese scientists also showed their interest and began to make proposals for space-based GW detection in the 2000s. Recently, the Chinese Academy of Sciences (CAS) has set up a strategic priority research program that includes the pre-study of space-based GW detection referred to as the 'Taiji Program in Space' [5].

GWs are expected to provide a new window to explore the evolution of early universe and the nature of gravity. Though space- and ground-based GW detectors adopt the same detecting principle of a Michelson interferometer, the required critical technology is quite different. Space-based GW detection needs to make use of gravitational reference sensors and a low-noise micro-thruster to implement drag-free performance as well as non-contacting discharging of test masses for free-flying test mass. It requires picometer optical assemblies for resolution ranging between the test masses and the spacecraft and high-stability monolithic precision ranging of test mass and spacecraft. The high-stability telescope, precision attitude control, a high-accuracy phase-meter and frequency stabilization are all needed for the precision ranging from spacecraft to spacecraft. To reach high thermomechanical stability, it is necessary to orbit the Sun.

The Taiji program is proposed to detect GWs with frequencies covering the range of 0.1 mHz to 1.0 Hz with higher sensitivity around 0.01–1 Hz than eLISA (see Table 1). The Taiji program proposes to use a triangle of three spacecrafts in orbit around the Sun (see Fig. 1). Laser beams are sent both ways between each pair of spacecrafts, and the differences in the phase changes between the transmitted and received laser beams at each spacecraft are measured. The preliminary design for the Taiji mission is based on 3-million-kilometer separations between the spacecrafts, and the expected launch date is about 2033. The purpose of the Taiji program is to study the most challenging issues concerning massive black holes, such as how the intermediate mass seed black holes were formed in the early universe, whether dark matter could form a black hole, how seed black hole grows into a large or extremely large black holes and what is the nature of gravity.

Table 1. Baseline design parameters of the Taiji preliminary mission proposal in comparison with the LISA/eLISA mission proposal.

	Preliminary mission proposal of Taiji	LISA	eLISA
Arm length	$3 \times 10^9\ m$	$5 \times 10^9\ m$	$1 \times 10^9\ m$
1-way position noise budget	$5 \sim 10$ pm Hz$^{-\frac{1}{2}}$	18 pm Hz$^{-\frac{1}{2}}$	11 pm Hz$^{-\frac{1}{2}}$
Laser power	2 W	2 W	2 W
Telescope diameter	~ 50 cm	40 cm	20 cm

Gravity was the first recognized basic force in the universe, while its nature is not as clear as for the three other basic forces. Single gravitons are far from being observable, although GWs are thought to be composed of gravitons. Understanding the nature of gravity and the unification of all basic forces are the most challenging problems in basic sciences in the twenty-first century. Dark matter and dark energy observed via gravitational effects are regarded as two big 'puzzling clouds' in the twenty-first century in physics and astronomy. Solving those problems requires us to develop quantum gravity and build a unification theory for all basic forces. As the early universe was filled with elementary particles at very high energy and temperature, exploring the intrinsic correlation between the very small elementary particles and the extremely large universe has been regarded as the frontier of particle physics and cosmology in basic sciences.

The establishment of quantum gravity [6] is a necessity to understand the origin and evolution of the universe.

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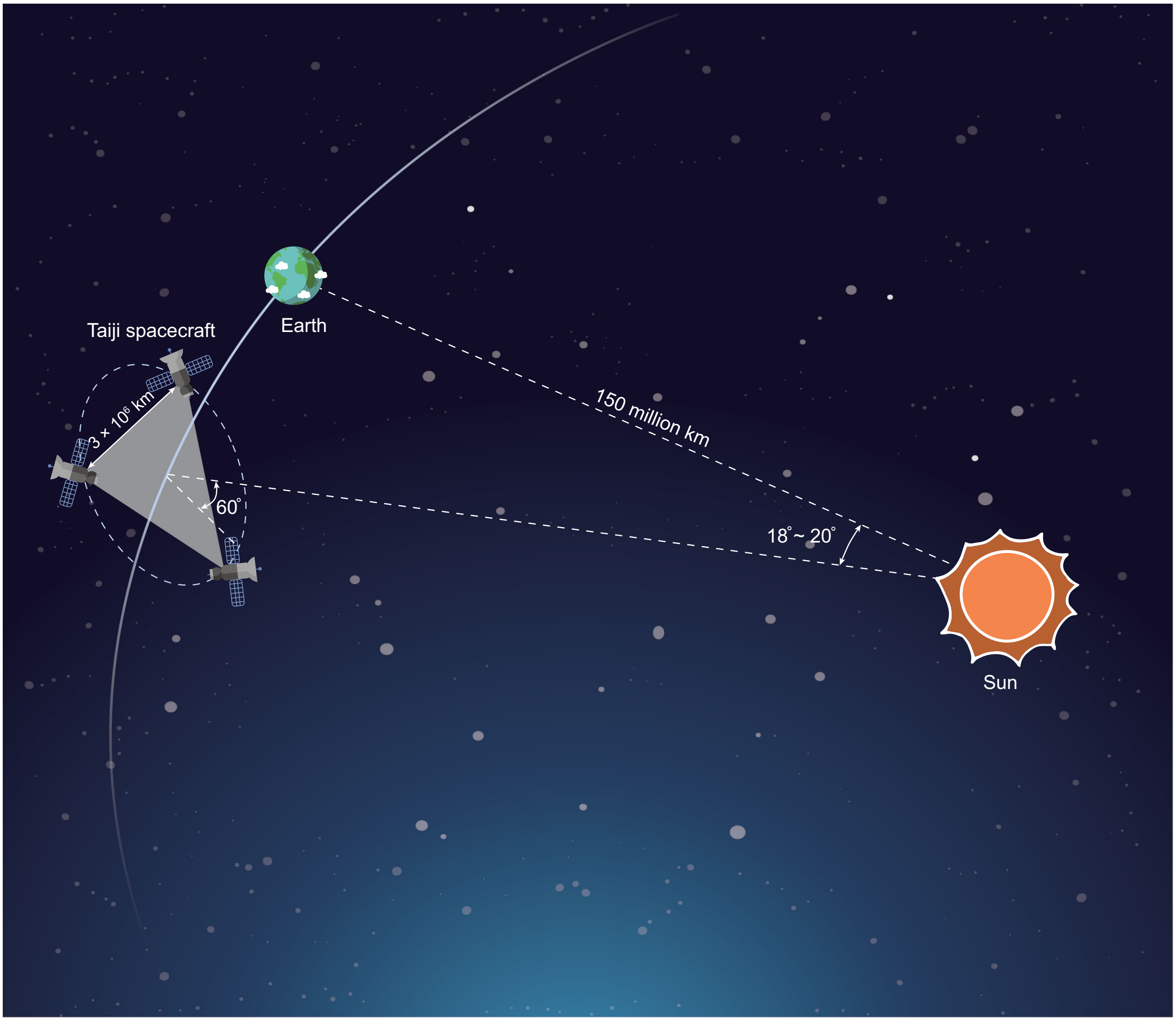

Figure 1. Taiji spacecraft in orbit around the Sun.

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