Standard siren cosmology with the LISA-Taiji network

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Gravitational waves (GWs) are a marvelous prediction of general relativity. The GW waveform from a compact binary coalescence is theoretically predictable, and different binary systems emit GWs in different frequency bands. The frequencies of GWs emitted by stellar-mass binaries fall within the detection band of ground-based detectors ($10\text{--}10^4$ Hz). GWs at lower frequencies ($10^{-4}\text{--}1$ Hz) emitted by massive black hole binaries (MBHBs) have wavelengths larger than the earth itself. Deploying a GW detector large enough to efficiently detect them requires going to space. To achieve this goal, several space-based GW detection projects, such as LISA, Taiji, and TianQin, are proposed, planning to launch spacecraft to space in the early 2030s.

LISA and Taiji have three identical drag-free spacecrafts that form an equilateral triangle orbiting the Sun, with arm lengths of 2.5×10^6 and 3×10^6 km, respectively. The location of LISA is proposed to be 20° behind the Earth, while the Taiji constellation orbits the Sun ahead of the Earth by 20° . TianQin plans to operate in the Earth orbit with arm lengths of 1.7×10^5 km. The space-based GW observatories could provide key information about the astrophysical history of galaxies and black holes, the dynamics of compact clusters and galactic nuclei, the nature of gravity, and the expansion history of the Universe.

GWs have an advantage over electromagnetic (EM) waves in exploring the expansion history of the Universe because

they rely only on gravitational physics and provide absolute luminosity distances without the distance ladder, which is usually referred to as “standard siren” [1]. If the EM counterparts of GW events are detected, the distance-redshift relation can be used to constrain cosmological parameters. Till now, GW170817, the only one GW event having EM counterparts, gives a $\sim 14\%$ precision for the measurement of the Hubble constant H_0 . The space-based GW observatories may improve the constraint precision of cosmological parameters by providing the standard siren data at higher redshifts and increasing the number of data points. For example, the standard siren mock data from LISA’s 5-year observation could give a $\sim 2\%$ precision for the H_0 measurement [2], and Taiji has the similar capability [3].

Ruan et al. [4] proposed for the first time the conception of the LISA-Taiji network for greatly improving the detection capability, and found that once LISA and Taiji form a detector network, the location precision of GW sources could be improved by almost four orders of magnitude [4–6]. This helps identify the host galaxies of MBHBs and increase the detection rate of EM counterparts, thus greatly optimizing the detections of standard sirens compared to the single GW observatory. The LISA-Taiji network is able to constrain the Hubble constant within 1% accuracy via GW dark sirens [7].

Zhang’s group [8] investigated the capability of the LISA-Taiji network in cosmological parameter estimation using

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GW standard sirens. They forecasted the detection rate of MBHB merger events with EM counterparts based on three MBHB population models, assuming a configuration angle of 40° between LISA and Taiji, and then used the mock data from five-year observation of the LISA-Taiji network to constrain several typical cosmological models.

In ref. [8], it is found that: (1) Compared with LISA or Taiji alone, the number of EM-GW events doubles due to the improvement of the location precision of GW sources. (2) The constraint precision of the Hubble constant could reach $\sim 1\%$ by using the LISA-Taiji network, which meets the criterion of precise cosmology. (3) Combined with the observation of the cosmic microwave background, the constraint precision of the equation of state of dark energy could reach $\sim 4\%$, which is comparable to the current best results of CMB+BAO+SN. The standard siren observation of the

LISA-Taiji network will become a precise probe of the late Universe.

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