SCIENCE CHINA
Physics, Mechanics & Astronomy

• Research Highlight •

November 2023 Vol. 66 No. 11: 119531
https://doi.org/10.1007/s11433-023-2215-4

Perceiving deci-Hertz gravitational waves over the Moon

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Received September 4, 2023; accepted September 5, 2023; published online September 28, 2023

Citation: L. Shao, Perceiving deci-Hertz gravitational waves over the Moon, Sci. China-Phys. Mech. Astron. **66**, 119531 (2023), https://doi.org/10.1007/s11433-023-2215-4

The field of experimental gravitational waves (GWs) started in 1960s with Joseph Weber and his resonant bars which monitor GW-excited vibration of elastic bodies. In 2015, laser-interferometric detectors, as Weber bars' descendant, made the first detection of GWs in the kilo-Hertz band, and opened up a completely new window to observe the gravitational Universe [1]. GWs from coalescing black holes and neutron stars are cataloged. However, like the electromagnetic landscape in astronomy, the GW window is expected to span about 20 decades in the frequency domain. It is therefore of vital importance to extend the current observing frequency bands to unprecedented regimes for new discoveries.

In ref. [2], Li et al. proposed a deci-Hertz GW detecting strategy, using an array of small laser-interferometric seismometers on the Moon. The optimal observing frequency is predicted to be around 0.1-1 Hz. The key concept is to use the entire Moon as a "Weber bar" resonant mass, perceiving the characteristic changes in its shape and position caused by passing GWs. The proposal takes advantage of the considerably quieter seismic environment of the Moon [3], whose annual seismic energy budget is about 4 to 8 orders of magnitude lower than the Earth. In such a lunar GW detector, the thermal noise dominates at the low frequency and the readout noise dominates at the high frequency. Currently, seismometers can achieve an accuracy of $\mathcal{O}(10^{-11})\,\mathrm{m\,Hz^{-1/2}}$, and an improvement by about 2 orders of magnitude is needed in order to detect realistic GWs. With inspiration from studies on laser-interferometric GW detectors, the authors proposed to design optomechanical seismometers to reach the required sensitivity. Besides the instrument design, possible deployment strategies are also envisaged. Lunar seismometers can be pre-fabricated in laboratories on the Earth, and deployed with missions similar to those in the Chang'e project by the China National Space Administration.

A deci-Hertz GW detector on the Moon fills the frequency gap of ground-based kilo-Hertz and space-borne milli-Hertz laser-interferometric detectors. From the perspective of science cases, the deci-Hertz band has its uniqueness with a plenty of astrophysical sources (see e.g., refs. [4,5]). A deci-Hertz GW detector is well suited to confidently observing intermediate-mass black holes, early warning of stellar-mass compact object coalescences, measuring the eccentricity in the early inspiral of binaries, adjudicating progenitors of type Ia supernovae, testing the Standard Model of particle physics and the General Relativity of spacetime and gravitation. It will continue the early success of GW astrophysics and further revolutionize our basic understanding of astronomy, fundamental physics, cosmology, and the Moon itself.

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