CHES: An astrometry mission searching for nearby habitable planets

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Received: April 19, 2022; Accepted: June 12, 2022; Published Online: June 16, 2022; https://doi.org/10.1016/j.xinn.2022.100270
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Citation: Ji J., Wang S., Li H., Fang L., and Li D. (2022). CHES: An astrometry mission searching for nearby habitable planets. The Innovation 3(4), 100270.

The Closeby Habitable Exoplanet Survey (CHES), a proposed space-borne mission to detect Earth-like planets orbiting 100 nearby solar-type stars (~10 pc or approximately 32 light years from the sun) via micro-arcsecond relative astrometry, is currently being considered by the Chinese Academy of Sciences as a possible space mission for future launch (Figure 1). The discovery of Earth-like planets (or Earth twins, planets with an orbit, mass, and environment similar to Earth) in the habitable zones around nearby solar-type stars will be another “giant leap for mankind” and help us begin to answer essential scientific questions such as “Are we alone in the universe?”, “Is Earth unique?”, and “How do planets become the cradle of life?” Finding such planets could even enable future human visits and identify new habitable places to live.

As of today, more than 5000 exoplanets have been reported since the first planet orbiting a main-sequence star was discovered.1 A statistical study on a large population of exoplanets revealed that their planetary systems are complex and diverse.2 Unlike their siblings in our solar system, these planets are classified into hot Jupiters, warm Neptunes, super Earths, terrestrial planets, and other categories based on their orbits and masses. Among the terrestrial planets, rocky planets in habitable zones orbiting nearby solar analogs are particularly eye catching, both in the field of planetary science and to the public, because a real Earth twin has not been discovered so far. Thus, the major scientific objective of CHES is to detect and characterize habitable-zone Earth-like planets orbiting 100 FGK stars among the solar system’s nearest neighbors (~10 pc).

The Kepler space telescope and the Transiting Exoplanet Survey Satellite hunt for and characterize planets using the transit method, and future programs like the Planetary Transits and Oscillations of Stars are set to do the same. Numerous exoplanets have been discovered using the transit method, the principle of which.
is that when a planet with an edge-on orbit passes in front of stars, the brightness of each host star will be periodically dimmed due to the orbit of the planet. However, the probability of such a scenario is very low (∼0.5% for Kepler mission), and the report of planetary candidates will need extensive confirmation by other approaches (e.g., the radial velocity). Furthermore, the transit method only obtains the radius of planets and cannot directly measure planetary mass.

Compared with transit missions, which can only detect planets that have orbits aligned with the line of sight of the observer, the most distinct advantage of CHES is that astrometry can detect every likely planet around nearby stars, meaning it is capable of carrying out a comprehensive census on planets in neighboring planetary systems with solar analogs (FGK stars). CHES can also directly measure the real mass of a planet, which plays a crucial role in determining whether the planet may resemble Earth. In other words, CHES will be able to detect planets that transit missions (such as Transiting Exoplanet Survey Satellite or Planetary Transits and Oscillations of Stars) can not.

Relative astrometry, an original and innovative technology, will enable CHES to accurately measure micro-arcsecond-level angular separation between one target star and 6–8 reference stars using laser focal planometry, and each target star will be revisited at least 50 times (Figure 1). For an Earth twin orbiting at 1 AU around a solar-type star at a distance of 10 pc, the astrometry wobble from the host star induced by the Earth twin is estimated to be roughly 0.3 μas, so a micro-arcsecond-level measurement (up to 1 μas) will be required during the mission. The subtle change reflects the very tiny wobble of the target star caused by its orbiting planet’s gravitational perturbances and reveals terrestrial planets in the habitable zones of nearby solar-type stars with real masses and three-dimensional orbits.

The scientific payload is a high-quality, low-distortion, high-stability telescope with an optical subsystem, camera subsystem, and on-board calibration subsystem. The optical subsystem is a coaxial three-mirror anastigmat with a 1.2 m aperture, 0.44° × 0.44° field of view, and 500–900 nm waveband. The camera focal plane is composed of 81 MOSAIC scientific CMOS detectors, each with 4 K × 4 K pixels. The on-board calibration subsystem consists of a metrology assembly. Heterodyne laser interferometric calibration technology is employed to ensure micro-arcsecond-level astrometric precision, which is required to detect habitable-zone Earth twins orbiting nearby stars. The mission orbit of the CHES satellite will move about the L2 point of the sun and Earth. The satellite is designed to have a lifespan of 5 years, during which time all target stars will be extensively observed. According to the occurrence rate of rocky planets orbiting solar-type stars, approximately 50 Earth-like planets or super Earths will be detected by observing 100 FGK stars during the mission.

CHES will provide the first direct measurements of the true masses and inclinations of Earth twins and super Earths orbiting our neighboring stars based on micro-arcsecond relative astrometry from space. This mission will begin to help us determine whether there are Earth-like planets in the habitable zones orbiting nearby stars. If, as expected, such planets are found, we will be able to observe how these planets are distributed and estimate the probability of the occurrence of habitable-zone planets in other planetary systems. Furthermore, CHES will partly contribute to studies on cosmology, dark matter, and black holes using ultra-high-precision relative astrometry. CHES will undoubtedly enhance our understanding of the formation of diverse nearby planetary systems and the evolution of our own solar system.

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ACKNOWLEDGMENTS
This work is financially supported by the Strategic Priority Research Program on Space Science of the Chinese Academy of Sciences (grant no. XDA 15020800), the National Natural Science Foundation of China (grant nos. 12033010, 41604152, and U1938111), the Foundation of Minor Planets of the Purple Mountain Observatory, and the Youth Innovation Promotion Association CAS (grant no. 2018178).

DECLARATION OF INTERESTS
The authors declare no competing interests.