The ET mission to search for earth 2.0s
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“Are we alone in the universe?” This fundamental question is as old as human-kind itself. Since the dawn of civilization, humanity has wondered whether there is life elsewhere in the universe and, if so, whether it is hosted on a second Earth. The discovery of the first extrasolar planet (also called an exoplanet), 51 Pegasi b, around a sun-like star in 1995 dramatically changed our understanding of the extrasolar planet worlds and challenged the uniqueness of our solar system. Mayor and Queloz were awarded the Nobel Prize in physics in 2019 for this major achievement.

To date, over 5000 new exoplanets have been detected mainly by the high-precision space photometric transit method and the ground-based radial velocity method (https://exoplanets.nasa.gov/discovery/exoplanet-catalog/). In particular, NASA’s Kepler space mission with a 0.95-m space telescope identified over 2000 new exoplanets with ultra-high photometric precision of around 30 parts per million (ppm) using the transit method. Kepler revealed diverse planetary worlds, including two new types of planets that are difficult or impossible to detect from ground-based transit observations: planets with sizes between that of Earth and Neptune, also known as super-Earths (1.25R₄ ≤ Rplanet ≤ 2R₄) and sub-Neptunes (2R₄ ≤ Rplanet ≤ 4Rₑ).

However, Kepler failed at its primary scientific goal of finding and characterizing Earth 2.0s, which are Earth-sized planets (0.8Rₑ ≤ Rplanet ≤ 1.25Rₑ) in the habitable zone of a solar-type star (F8V–K2V). The unexpected high stellar noise³ for solar-type stars and the high readout noise of Kepler’s charge coupled-device (CCD) detectors were major issues that prevented it from achieving the critical photometric precision for detecting Earth 2.0s. The failure of two of Kepler’s reaction wheels further reduced its chance of detecting Earth 2.0s around quiet and bright stars. Given the limited observation time and the small number of suitable target stars, Kepler’s failure to detect Earth 2.0s was unsurprising. Earth 2.0s remain elusive and pursued by astronomers. The upcoming ESA’s Planetary Transits and Oscillation of Stars (PLATO) mission, planned for launch in 2026, has some chance of detecting Earth 2.0s. However, since it was designed for detecting transiting planets around bright stars (4–11 mag) and bulk planet characterization, its short staring time even in the long-pointing mode (2–3 years) limits its ability to detect Earth 2.0s robustly. Note that to detect an Earth analog, a transit is only detectable about once per year!

We propose the ET (Earth 2.0) mission to pick up where Kepler left off and detect Earth 2.0s and other Earth-sized planets orbiting other suns. ET consists of seven telescopes, of which six are 30-cm wide-field transit telescopes and one is a 35-cm microlensing telescope (Figure 1). The transit telescopes feature a larger field of view (FoV) and higher precision photometry than Kepler, properties that significantly increase the chance of detecting Earth 2.0s. ET adopts a

![Figure 1. The design of the ET scientific payload, which includes six 30-cm diameter transit telescopes and one 35-cm diameter microlensing telescope ET’s 500-square degrees of field of view (encompassing the original Kepler field) will be monitored continuously by the ET’s transit telescopes over 4 years to search for transit signals from Earth 2.0s. To date, all the potentially habitable Earth-size planets were detected around M dwarfs. ET plans to find the first Earth 2.0 within the habitable zone of solar-type stars.](image-url)
small-size (30 cm) telescope design with refractive optics to achieve a much larger FoV (500 deg²) than Kepler (105 deg²) and will combine photometry data from six of these 30-cm telescopes to achieve a photon-collecting power equal to a 73.5-cm diameter single-aperture telescope. Additionally, the use of state-of-the-art cutting-edge complementary metal–oxide–semiconductor (CMOS) detectors with a readout noise of 4e⁻/pixel (over 20 times smaller than Kepler’s CCDs) will be used to achieve ultra-high-precision photometry for the first time in space. Moreover, instrumental errors associated with telescope temperature fluctuations, being over 10°C for Kepler, that led to image drifts and star size changes, will be minimized with advanced temperature control, providing a long-term stability of ±0.3°C. For example, ET will have an error budget of about 7 ppm compared with Kepler’s instrument error of about 13 ppm for a 12th magnitude solar-type star. ET photometry simulations, including photon and instrument noise, show that the current design can reach a photometric precision of 34 ppm for a G = 13.4 solar-type star with a 6.5-h integration on the target. The high photometric precision allows transit planet detection even for faint stars in ET’s large FoV, greatly increasing the number of suitable target stars.

ET transit telescopes will monitor over 1.2 million FGKM dwarfs, 7 times the number of targets monitored by Kepler, leading to 10 to 15 times the capability of Kepler in searching for terrestrial planets, including Earth 2.0s. ET yield simulations show that the ET transit survey will be able to detect ~29 000 new planets, including ~4900 Earth-sized planets and 10 to 20 Earth 2.0s, assuming an Earth 2.0 occurrence rate of 10%.” When combined with the Kepler legacy data, ET can detect transits of exoplanets with periods of up to 4 years. The ET microlensing telescope will further increase the sample of long-period planets and free-floating planets. The microlensing survey will be able to detect ~400 cold planets and 600 free-floating planets down to the mass of Mars; ~300 of these planets will have mass measurements.

In short, ET will provide the first detections of true Earth 2.0s, allowing for follow-up characterizations of the planet density, internal structure, and atmospheric composition to assess these candidates’ habitability. ET can significantly extend the current exoplanet demography and shine a light on planetary formation and planetary system evolution. ET’s detailed specifications and other scientific merits, e.g., asteroseismology, galactic archeology and time domain sciences, are summarized in the ET white paper.²

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DECLARATION OF INTERESTS
The authors declare no competing interests.