Discovery of an ideal target for characterizing the atmosphere of temperate Earth-sized planet

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Spectroscopic observations for terrestrial planets enable the characterization of molecular compositions such as CO_2 and H_2O in their atmospheres, providing clues to understand an environment suitable for life. However, the number of known terrestrial planets receiving insolation comparable to Earth (S_E) is still limited, preventing us for characterizing the temperate atmospheres accessible via follow-up spectroscopy. The *TESS* mission has been performing the transit photometry to find planets around nearby stars, among which M-type dwarfs are promising targets to identify small planets due to the small size of M dwarfs. We analyzed the *TESS* light-curve data for the M3-type and 0.24 solar-mass dwarf Gliese 12, discovering a planetary candidate of measured radius nearly equal to that of Earth (R_E) and orbiting the star. To confirm the transit signal, the follow-up photometric observations from the ground were conducted for the candidate with the multi-band imagers MuSCAT2 and MuSCAT3. We also reduced the data of high-contrast imaging performed by NIRI and NIRC2 to clarify whether the photometric measurements in *TESS*, MuSCAT2, and MuSCAT3 are contaminated by objects other than Gliese 12. In addition, the strategic survey of the IRD instrument on the Subaru Telescope independently monitored Gliese 12 since 2019 to search for a planet via the radial velocity (RV) method, allowing us to rule out the presence of a stellar companion around the star. In 2023, we measured the RVs of Gliese 12 using CARMENES on the CAHA 3.5m telescope in Spain. We thus confirmed that the transit signal identified by *TESS* was caused by a planet orbiting Gliese 12. Finally, we carried out a joint analysis to model all the light curves and RVs simultaneously to infer the orbit parameters, radius, and mass of Gliese 12 b. As a result, we found that Gliese 12 b is orbiting the host star at a semi-major axis of 0.067 ±0.002 au. We also constrained the radius and mass of Gliese 12 b to be 0.96 ±0.05 R_E and to be lower than 3.9 Earth mass (3 σ upper limit), respectively. With an insolation from the star of approximately 1.6 S_E, we calculated Gliese 12 b's equilibrium temperature to be nearly 290 K assuming an albedo of 0.3; thus, it can have a temperate climate. Because Gliese 12 is a bright and nearby (12 pc) M-type star, the detected planet is an ideal target for atmospheric characterization via transmission spectroscopy, alongside the planets around TRAPPIST-1. Provided that Gliese 12 is currently less luminous in XUV than TRAPPIST-1, its planet can still maintain a thicker atmosphere than some planets around TRAPPIST-1. Hence, Gliese 12 b is amenable to the follow-up spectroscopy with the space telescope *JWST* to explore atmospheres of terrestrial planets and their molecular compositions.

Keywords: terrestrial planet, Transit photometry, Radial velocity method, Exoplanet atmospheres

