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Detectability of Habitability Signatures on TRAPPIST-1e with Current and Future Ground- and Space-Based Observatories

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Abstract

1. Introduction

The work completed in this project aims to quantify the detectability of selected habitability "signatures" such as methane, water, ozone, oxygen, and carbon dioxide on TRAPPIST-1e. To do this, we simulated the atmosphere of TRAPPIST-1e with a global climate model (GCM), a photochemical model to simulate atmospheric configurations, and a spectrum generator to calculate synthetic spectra. This commission of tools allowed us to calculate the number of transits required to detect various absorption features. We made this calculation for both current and future ground- and space-based observatories.

Decades of exoplanet searches have led to surprising discoveries, from giant planets close to their stars, to planets orbiting two stars, to small ultra-cool dwarf stars (T < 2700K) harboring rocky exoplanets within close orbits. Amidst the hundreds of planets discovered in recent years, one particular system stands out amongst the rest. Located 12 parsec away, the TRAPPIST-1 system contains seven known planets and is one of the most promising rocky-planet systems for near-term characterization. It is favorable for characterization efforts due to the relatively strong depths of its transit signals (and the relative proximity of the star). Three of the planets in the system are located within the Habitable Zone (HZ) of the host star (TRAPPIST-1e, f, and g) where surface temperatures would allow liquid water to exist. While all three of these planets will be prime targets for atmospheric characterization with future observatories, the most likely to be habitable is TRAPPIST-1e, which receives the right amount of stellar flux to allow liquid water on the surface across a large range of atmospheric configurations. Because it has been deemed the worthiest of further studies with regards to habitability, this work focuses on future observations of TRAPPIST-1e (along with similar exoplanets) and the feasibility of atmospheric characterization and biosignature detection. As the era of exoplanet detection continues to flourish, it is now important that we move forward and begin developing the tools necessary for the characterization of these new systems. In this context, the simulation of transmission spectra obtained from future (and current) facilities is crucial to predict the observational constraints to characterize nearby rocky exoplanet atmospheres and eventually detect biosignatures.

2. Methods

This work employs the use of the LMD-G GCM to simulate a modern Earth atmospheric configuration for TRAPPIST-1e. To represent a large set of gas species, photochemistry is simulated at the terminator via the ATMOS model using the GCM profiles as input. Finally, synthetic transit spectra are calculated using the Planetary Spectrum Generator (PSG) web interface.

3. Results

We first evaluate the strength of each spectral line across the 0.2-20 μm wavelength range that will be relevant for any atmospheric characterization of rocky exoplanets assuming a modern Earth-like atmosphere. After the identification of each significant spectral line, the signal-to-noise ratio (S/N) and the number of transits required for 5σ detection is then determined for various absorption lines for current/future ground and space-based observatories such as JWST, HabEx, LUVOIR, OST, and ELT's. Preliminary results address the weaknesses of JWST's ability to characterize exoplanets in the habitable zone. Advances required beyond JWST to detect the atmosphere of a habitable exoplanet are discussed in reference to the status of future observatories and their proposed design strategies, highlighting the importance of instrument stability rather than aperture size or wavelength range. Synergies between ground- and space-based observatories are also included in this study.

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