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Thermal Phase Curve Simulations on the Terrestrial Exoplanet TRAPPIST-1 e

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ABSTRACT

In order to better direct future exoplanetary research, we must be able to accurately predict what telescopes like the James Webb Space Telescope (JWST) will be able to detect. I have constructed a data pipeline that takes 3D climate models as inputs, then runs a line by line radiative transfer model called the Planetary Spectrum Generator (PSG) to generate simulated spectra. This pipeline can help determine which features of an exoplanetary atmosphere are observable using JWST. This paper focuses primarily on a strong candidate for a habitable exoplanet, TRAPPIST-1 e, which is assumed to be tidally locked. Recent climate modeling studies indicate that not all tidally locked exoplanets are the same. Exoplanets with long years will have large, substellar clouds, while exoplanets with short years will have a significant Coriolis force, which will result in a smaller substellar cloud and more intense zonal winds. The thermal emission of a planet depends strongly on the spatial distribution of clouds, which would change from the perspective of a distant observer over the exoplanet's year. Observing an exoplanet over its year will produce a thermal phase curve, which may be able to detect features like the size of the substellar cloud or the presence of a runaway greenhouse effect. Although the simulations are done using spectra, observations of thermal phase curves are more well suited for photometry, and would likely need to be characterized relative to simulated thermal phase curves.

1. INTRODUCTION

We have found a number of terrestrial exoplanets which resemble Earth in mass, size, and most crucially, solar irradiance. These terrestrial exoplanets are the most likely candidates in the search for habitable worlds beyond Earth, and by extension, the most likely places to discover extraterrestrial life or a future home for humanity. To date, the list of exoplanets in the classical habitable zone is short, and few are close to Earth, but this will soon change with the recently launched Transiting Exoplanet Survey Satellite (TESS). TESS is expected to discover thousands of exoplanets smaller than Neptune and dozens of Earth sized planets, and was optimized for finding planets that are closer to Earth (Ricker et al. 2014). In conjunction with the James Webb Space Telescope (JWST), we can expect increased quality and quantity of habitable exoplanet observations.

The most easily detectable exoplanets orbit M-dwarfs. These exoplanets are likely tidally locked due to their close orbit to their host star (Turbet et al. 2018).The atmospheres of tidally locked planets behave differently from any atmosphere we are previously familiar with, so the only way to characterize their atmospheres is via global circulation models (GCMs). GCMs were invented to predict weather or climate change, and have proven scientifically valuable for a number of different planets throughout the solar system (Way et al. 2018). Many astronomers have made predictions of what JWST will see on exoplanets, but many of these predictions assume that habitable exoplanet atmospheres will be replicas of Earth (Fortney et al. 2018). However, recent 3D climate modeling experiments demonstrate that exoplanets are typically very different than Earth. For example, Wolf (2018) found that although TRAPPIST-1 d receives approximately the same amount of solar irradiance as Earth, TRAPPIST-1 e makes a better candidate for habitability with only 60% the solar irradiance of Earth.

With the launch of JWST on the horizon, it is essential that we know what to expect from observations, and atmospheric models are the best method for constraining predictions. Simply assuming a tidally locked exoplanet will appear identical to Earth is unreasonable and can lead to inaccurate conclusions. Using GCM simulations for planets in the TRAPPIST-1 system, we can self-consistently predict what the TRAPPIST-1 exoplanets may look like with regards to cloud distributions, precipitation, and temperature. NASA's Planetary Spectrum Generator (PSG) can then be used to generate spectra for these climate models, giving us more accurate predictions of what JWST might be able to see (Villanueva et al. 2018).

The PSG can allow us to measure the thermal emission of the planet as it rotates relative to the Earth over its year. Thermal phase curves measure the change in thermal brightness of an exoplanet as it orbits its star, and can be variable over time. This technique serves as the best method to resolve features like clouds on exoplanets, and by extension, the planet's climate.

Here I will calculate thermal phase curves of several habitable zone exoplanets, but first I will review climate models from Wolf (2017, 2018), focusing on characterizing the surface temperature and the substellar clouds of those models, as well as comparing fast and slow rotators. I will explain the data pipeline around the PSG, which I will use to simulate spectra that will be reduced into thermal phase curves.

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