1. Science aim/goal

This program will characterize the atmospheres of nearby, transiting terrestrial exoplanets using the transmission and emission spectroscopy techniques. The goal is to detect atmospheric biosignatures in multiple systems and assign probabilities to their origins.

2. (i) Scientific Importance:

One of the primary goals of the astrobiology community in particular, and the broader astrophysical and planetary science communities in general, is the detection of biosignatures on inhabited worlds. Habitability is typically defined as the ability of a planet to sustain liquid water on its surface. It is primarily a function of incident radiation, but can also depend on other factors such as UV flux, atmospheric composition, etc. Spectroscopic characterization of terrestrial atmospheres will provide constraints for climate models to assess the potential for habitability. Furthermore, the detection of specific combinations of molecules would provide evidence of biosignatures, which suggests biological interactions between atmospheric and surface processes.

In the mid-infrared, the main observable is a planet's dayside emission spectrum, as measured using the secondary eclipse technique. For terrestrial exoplanets orbiting within the habitable zones of mid-to-late M-dwarf stars, the planet-to-star flux contrast ratio becomes favorable at wavelengths > 8 μm (see Figure 1). Accounting for the decrease in photon count rate at longer wavelengths, the signal-to-noise ratio is favorable out to ~30 microns. Within this wavelength range, there are prominent absorption features due to CH_4, CO_2, O_3, NH_3, N_2O, and SO_2, as well as the H_2O vapor continuum. These features can readily distinguish a wet Earth-like planet from a dry, Venus-like planet with a dense CO_2 atmosphere and a Mars-like planet with a thin CO_2 atmosphere (see Figure 2). The strong ozone band at 9.7 μm allows for the inference of molecular oxygen, which is a powerful biosignature when combined with other out-of-equilibrium molecular species (such as CH_4 at 7.7 μm and/or N_2O at 17 μm). Additionally, emission spectroscopy uniquely probes a planet's thermal structure, which is critical towards assessing its habitability.

In addition to measuring planetary emission, mid-infrared observations can take full advantage of a planet's transmission spectrum, as measured during primary transit. Transit observations place additional atmospheric constraints on the above-mentioned molecules at the planet's terminator. Furthermore, spectra from 5 – 28 μm are less sensitive to high-altitude aerosols that tend to obscure transmission spectra at shorter wavelengths.

Emission and transmission spectroscopy data are highly complementary because they probe different longitudes and pressure levels of a planet's atmosphere. Their combination can help resolve degeneracies such as the atmospheric scale height, thus constraining a terrestrial atmosphere's mean molecular weight.

(ii) Measurements Required:

The simultaneous detection of ozone with methane and/or nitrous oxide in a terrestrial atmosphere is a strong indicator of biosignatures. Transmission and emission feature strengths vary from system-to-system, but are nominally ~10 ppm for an Earth-like planet transiting an M5V star. For these molecules, the instrument shall be capable of reaching a precision of < 3 ppm (noise floor). The detection of water's rotational bands requires a minimum resolving power of 300.

Biosignature detection will require multiple visits to build up sufficient signal. Thus, to maximize observing efficiency and minimize the effects of variability, the full wavelength coverage shall be acquired in a single visit. Additionally, the instrument shall be capable of observing the nearest M dwarf, Proxima Cen (K = 4.4), without reaching saturation.

Time series observations require uninterrupted monitoring before, during, and after each transit/eclipse event. Thus, the telescope shall make no movements during these observations outside of pointing corrections. Furthermore, the telescope shall have stable pointing to within 0.1 pixels over the duration of a transit/eclipse observation (~6 hours).

(iii) Uniqueness to 10μm to few mm wavelength facility:

Current and near-term facilities are limited in their ability to characterize exoplanet atmospheres in the mid-infrared. These wavelengths provide a direct measure of planetary emission from temperate worlds that are potentially habitable and access to biosignature indicators (such as N_2O) that may otherwise be undetectable.

(iv) Longevity/Durability:

The OST would provide high-precision follow-up observations of targets discovered by TESS. The Transiting Exoplanet Survey Satellite (TESS) mission is scheduled to launch in early 2018, will survey approximately 500,000 nearby stars, and is expected to detect transits from about 3,000 systems. Approximately 10 rocky exoplanets (<1.6 Earth radii in size) are expected to be found orbiting mid-to-late M dwarfs. These objects will be ideal targets for an in-depth atmospheric characterization study in search of biosignatures. Additional targets, similar to TRAPPIST-1 and LHS 1140, will be found using ground-based techniques.

The JWST is scheduled to launch in October 2018. It will obtain high-quality transmission spectra of giant planets, and, with a large investment in observing time, can provide relatively low signal-to-noise spectra of a few super-Earths. JWST spectroscopy is limited to infrared wavelengths below 12 μm, which does not allow for the efficient dayside characterization of temperate (~300 K) planets or the detection of N_2O at 17 μm. Given its larger aperture than JWST, broader wavelength coverage, and next generation instruments, OST will be capable of efficiently characterizing a statistically significant sample of rocky planets, some of which will be in their host stars' habitable zones.

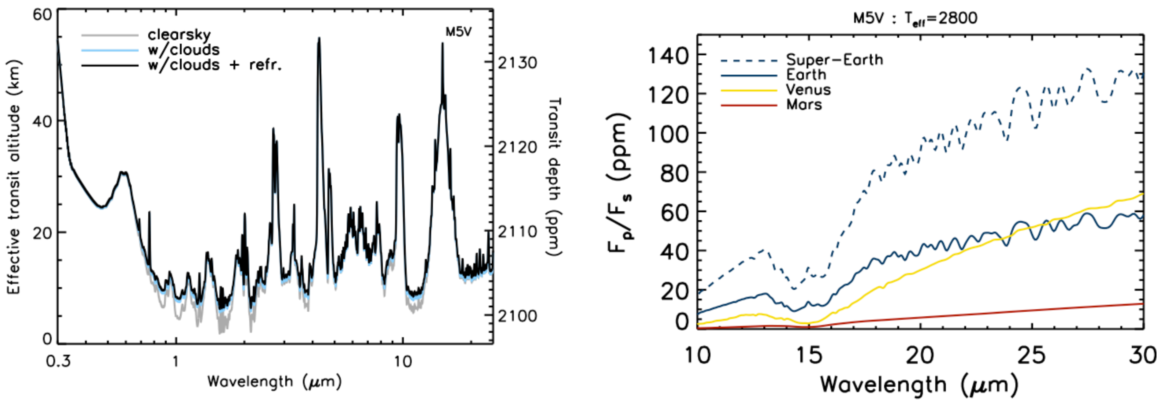

Figure 1: Transmission (left) and emission (right) spectrum models of terrestrial planets orbiting a theoretical M5V star (Robinson, 2017). The transmission models assume a one Earth-radii planet. Compared to a clear sky, the presence of clouds (black line, left panel) has less relative impact on the transmission spectrum in the mid-infrared. In the right panel, the rapid increase in planet-star contrast ratio at > 10 μm highlights the advantages of utilizing a mid-infrared observatory to obtain emission spectra from temperate exoplanets.

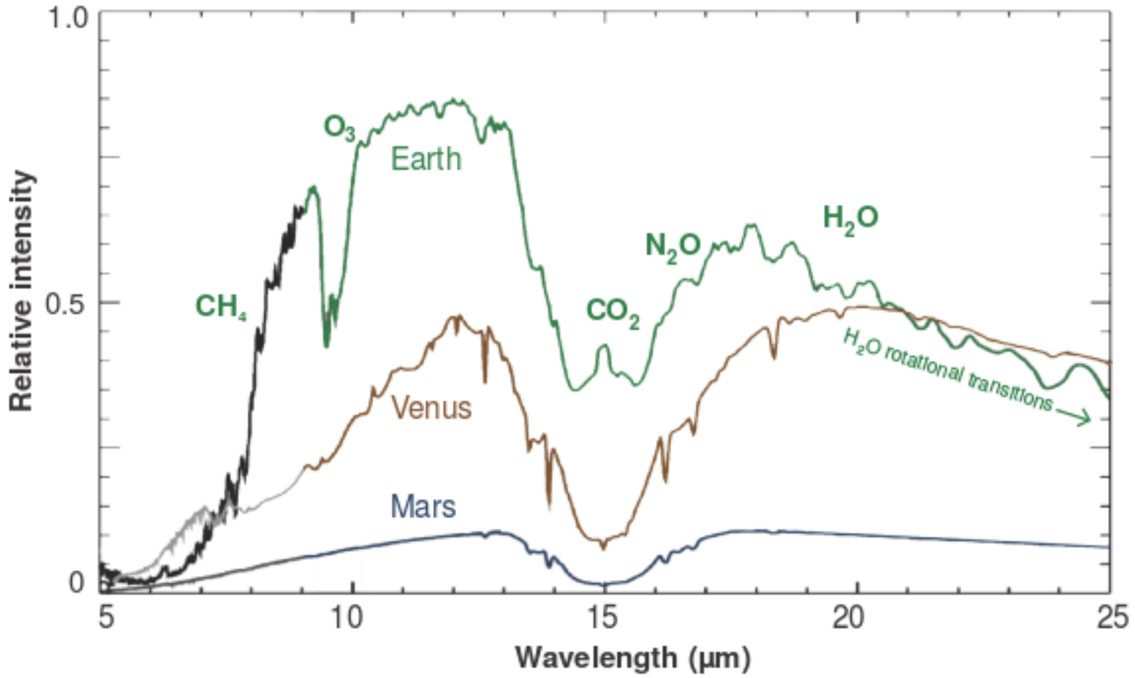

Figure 2: Relative intensity of planetary emission as a function wavelength for three terrestrial planet models. Bands for ozone, carbon dioxide, nitrous oxide, and water vapor can all be readily observed at > 8 μm. Depending on the planet-star contrast ratio, methane may or may not be detectable in emission at 7.7 μm. However, methane can still be detected in transmission.

Table:

Parameter	Unit	Required value	Desired Value	Comments
Wavelength/band	μm	6 - 25 μm	4 - 28 μm	The required value range allows for the detection of CH_4, O_3, CO_2, NH_3, N_2O, and H_2O.
Number of targets		10	30	The required value is based on the expected number of temperate rocky planets to be detected by TESS alone.
Angular resolution	arcsec	-	-	Transit spectroscopy is not limited by angular resolution
Spectral resolution	$\Delta\lambda/\lambda$	300	500	At ~20 μm
Bandwidth		19 μm	23 μm	Must acquire full range in one observation.
Continuum Sensitivity (1 σ)	μJy	-	-	
Spectral line sensitivity (1 σ)	W m^{-2}	-	-	
Signal –to-noise		5	>10	On isolated planetary emission spectra. Desired value allows characterization of terrestrial planets orbiting M dwarfs
Cadence	minute	< 1	-	
Photometric Precision	ppm	3	1	JWST ~ 25

Key references:

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