Staring at habitable-zone terrestrial worlds

Thematic Areas (Check all that apply):

☐ (Theme A) Key science themes that should be prioritized for future JWST and HST observations
☐ (Theme B) Advice on optimal timing for substantive follow-up observations and mechanisms for enabling exoplanet science with HST and/or JWST
☒ (Theme C) The appropriate scale of resources likely required to support exoplanet science with HST and/or JWST
☒ (Theme D) A specific concept for a large-scale (∼500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: Future missions like the Habitable Worlds Observatory will use coronographic instruments to probe the atmospheres of habitable-zone terrestrial worlds around Sun-like stars, but so far we have no sense as to how common atmospheres are on temperate terrestrial worlds. In the Solar System we are effectively at 50-50, with Venus and Earth having substantial atmospheres and Mars and Mercury having little to no atmospheres. While a large JWST program like the Hot Rocks Survey (JWST GO 3730; 115 hours) will probe hot terrestrial exoplanets for the presence of atmospheres, a study investigating the atmospheres of cooler, temperate worlds is beyond the scope of a large or legacy program. **We propose an ambitious, high-risk high-reward program to carry out an in-depth atmospheric characterization of the small sample of nearby, habitable-zone terrestrial worlds we have detected so far**. While the most favorable worlds in this category are TRAPPIST-1e and f, it is feasible to study these planets within the scope of a regular GO program, and indeed preliminary observations are already underway as part of GTOs 1201 and 1331. Solely focusing on the TRAPPIST-1 system carries a lot of risk: while it is highly observable, it is also highly unique in terms of how cool and small the host star is. JWST has already detected flares during transmission spectra of the TRAPPIST-1 planets, raising concerns about atmospheric erosion on the closest-in TRAPPIST-1 planets. In this proposal, we focus on habitable-zone temperate terrestrial worlds orbiting early- to mid-M dwarfs. Possible targets for a survey are LHS 1140b, TOI-700d, TOI-700e, TOI-6251b (not yet confirmed).

Anticipated Science Objectives: Terrestrial exoplanets in the habitable zones of nearby stars are few and far between, and prior to JWST it has not been possible to determine whether or not they have atmospheres. A targeted investigation that stacks ∼20 transits of these worlds is needed to detect atmospheric features (Figure 2), however such a campaign would constitute a large JWST program for any single target. So much time on a single target for an exploratory program is unlikely to get past a standard TAC. Without JWST, this investigation is simply not possible. If such a campaign were to detect an atmosphere on a HZ terrestrial world orbiting an M dwarf, this result would fundamentally make the goal of searching for biosignatures more feasible: we could search HZ planets around even the smallest stars for such signs of life. On the other hand, if the campaign returns a non-detection, this is even more impetus to develop a direct imaging space mission that can characterize the atmospheres of terrestrial planets orbiting in the habitable zones of larger, less active G and K stars. For such a deep dive, a mode such as NIRSpec Prism would be a good choice—it covers a range of common molecular species (e.g., H_2O, CO_2) as well as the regions that are susceptible to stellar activity. If no atmosphere is detected, this deep dive of observations can be used to characterize the stellar surfaces of the host stars to an unprecedented degree [1].

Urgency: **Urgency**: A campaign to probe the possible atmospheres of HZ terrestrial exoplanets will take a long time—many hours over multiple JWST cycles. Getting started on this as soon as possible will inform what JWST will look at in future cycles regarding HZ terrestrial worlds, as well as the development of next-generation observatories.

Risk/Feasibility: This proposal is highly feasible because it will use the well-tested transmission spectroscopy method. The risk is the large time investment for potentially a flat line, which would indicate a bare rock in the habitable zone, or else a cloudy/hazy atmosphere that we cannot penetrate. These results would be degenerate.

Timeliness: JWST is the first observatory capable of probing the atmospheres of temperate terrestrial exoplanets. Though this program is time-consuming, it offers the potential for groundbreaking scientific discoveries.

Cannot be accomplished in the normal GO cycle: It would take a large program to detect the atmosphere of a single HZ terrestrial planet, making such a program a hard sell for a TAC. To do this for multiple HZ terrestrials, as we propose here, would be beyond the scope of a normal GO program.

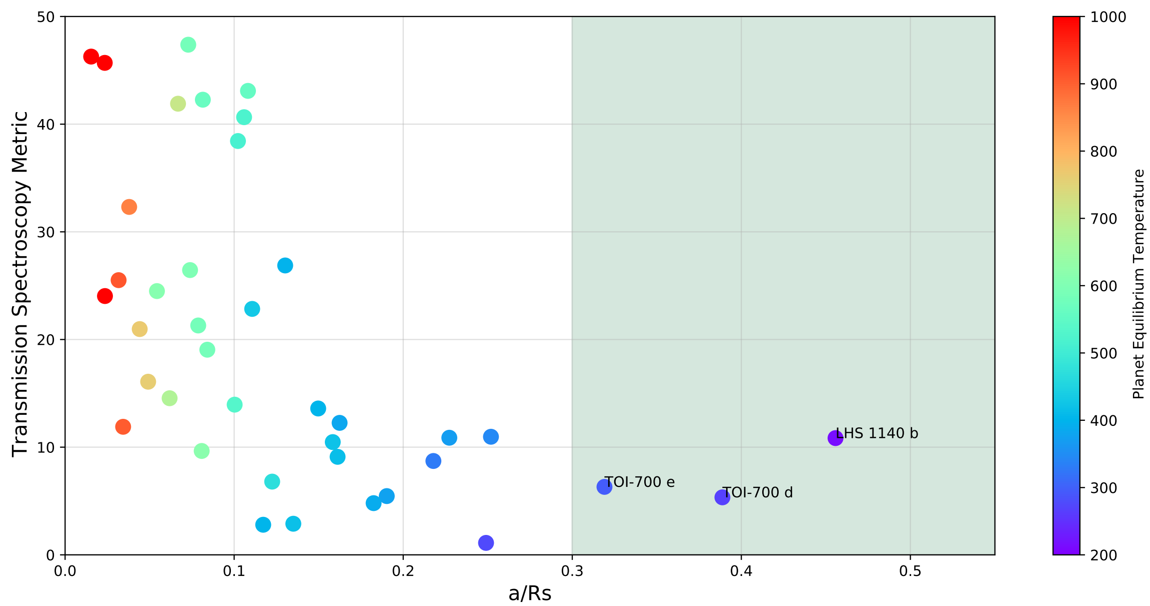

Figure 1: Transmission spectroscopy metric (TSM; [2]) as a function of planetary scaled orbital distance. Marker colors correspond to planet equilibrium temperature. Data points are exoplanets orbiting M dwarfs within 35 pc, excluding the TRAPPIST-1 planets, which can be probed by normal GO programs. The green band represents a rough habitable zone. Cooler planets have much lower TSMs and are therefore more time-consuming to observe, but these are also the worlds most likely to maintain atmospheres in the pressure and temperature ranges of Earth and Venus.

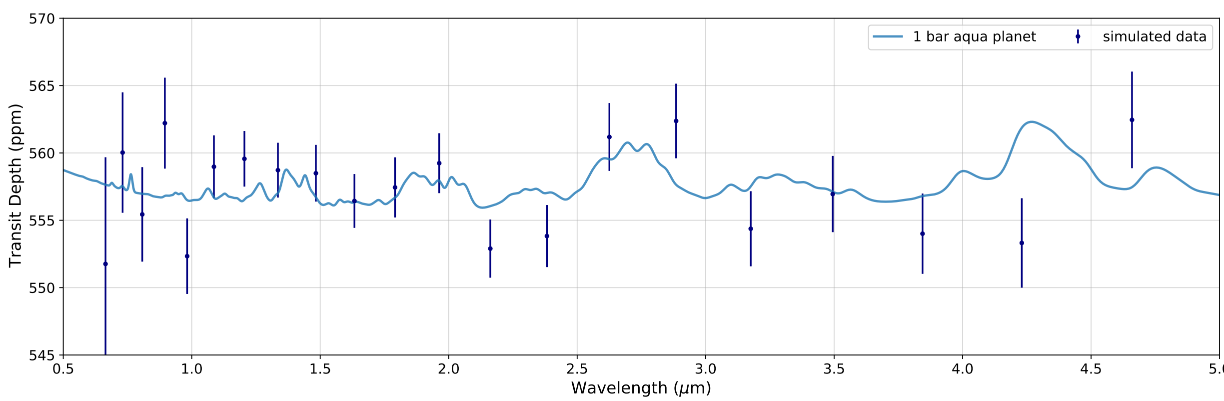

Figure 2: Rough model transmission spectrum of the habitable-zone likely terrestrial planet TOI-700d assuming an aqua planet (ocean surface, no clouds, 1 bar atmosphere containing 80% N_2, 20% O_2, and trace amounts of H_2O, CO_2, SO_2, H_2S, OCS, NO, CH_4) borrowed from [3]. Error bars represent 20 transit observations with JWST/NIRSpec Prism generated by `PandExo` [4]. These observations would cost approximately 160 hours.

References

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[2] Eliza M. -R. Kempton et al. "A Framework for Prioritizing the TESS Planetary Candidates Most Amenable to Atmospheric Characterization". In: PASP 130.993 (Nov. 2018), p. 114401. DOI: 10.1088/1538-3873/aadf6f. arXiv: 1805.03671 [astro-ph.EP].

[3] Andrew P. Lincowski et al. "Evolved Climates and Observational Discriminants for the TRAPPIST-1 Planetary System". In: ApJ 867.1, 76 (Nov. 2018), p. 76. DOI: 10.3847/1538-4357/aae36a. arXiv: 1809.07498 [astro-ph.EP].

[4] N. E. Batalha et al. "PandExo: A Community Tool for Transiting Exoplanet Science with JWST & HST". In: PASP 129.6 (June 2017), p. 064501. DOI: 10.1088/1538-3873/aa65b0. arXiv: 1702.01820 [astro-ph.IM].