Sub-Neptune atmospheres in response to UV photons

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: When we detect and characterize an exoplanetary atmosphere we are studying the effects left on those atmospheres by the exoplanet's host star. If we are going to go after terrestrial exoplanets in the habitable zones of their host stars, we need to first understand the degree to which stellar high-energy output can drive or alter the planetary atmospheres. While most in-depth terrestrial exoplanet studies lie just out of reach for JWST (in particular for habitable-zone terrestrial worlds), perhaps we can still address questions of photochemistry in the presence of GKM stars by looking at the larger cousins of terrestrial worlds: the volatile-rich sub-Neptunes. These planets represent a large and degenerate parameter space, meaning that we can learn a lot about different kinds of atmospheric chemistry—if we study their atmospheres in the context of their host stars. **We propose an extensive campaign with JWST to observe sub-Neptune atmospheres planets orbiting K and M stars, while *simultaneously* capturing the UV spectra of their host stars with HST**. Learning more about the atmospheres of sub-Neptunes will improve our understanding of atmospheric physics on these worlds, which have pressure and temperatures closer to those of terrestrial planets (as opposed to hot Jupiters, which are much hotter). Getting simultaneous UV observations by the host M dwarf can be used to try to connect the UV output of the star to the photochemical effect it has on the planets atmosphere—i.e., photochemical reaction rates, atmospheric mass loss, disequilibrium processes (especially if a flare is observed in the UV).

Anticipated Science Objectives: Eventually we want to be able to understand how stellar hosts affect the atmospheres of terrestrial exoplanets. Photochemistry plays a key role in Earth's atmosphere, for example in its role in creating ozone. Photochemistry occurs in the upper atmosphere of planets, which is where techniques like transmission spectroscopy are most effective at detecting molecular species. JWST does not have the sensitivity to probe a terrestrial planet atmosphere in a single observation, but it does for sub-Neptune planets (especially if the atmosphere is clear). If we observe a host of sub-Neptune transits (or a smaller number of sub-Neptune phase curves) *simultaneously* with HST UV observations of the host star, then we can develop our understanding of photochemical reactions rates and atmospheric mass loss rates for a population of planets that is closer to terrestrial worlds than, say, hot Jupiters. At the temperatures and pressures of sub-Neptunes (and indeed for HZ terrestrial worlds) we cannot assume that atmospheres are in chemical equilibrium; understanding how much disequilibrium chemistry can come from a host star can eventually help us to rule out false-positive biosignatures, because it may be the star, and not biology, that is driving an atmosphere out of chemical equilibrium [1, 2]. We can learn even more for such a project if a flare is captured in the UV, and we can then measure the atmospheric response of the sub-Neptune atmosphere (e.g., Figure 1). This has been done theoretically [3, 4], however this science lacks empirical information.

Urgency: Simultaneous observations leveraging both JWST and HST's UV capabilities are essential for this program.

Risk/Feasibility: A risk is that even with such a data set, what we learn may be limited if the atmospheric photochemistry response rate is much longer than we are able to observe in transit or phase curve. These observations should be feasible given the sensitivity of JWST to sub-Neptune-like planets [5] and HST's sensitivity to UV photons [6].

Timeliness: Obtaining these observations while HST and JWST are functioning together is critical.

Cannot be accomplished in the normal GO cycle: Scheduling this program would be extremely difficult. Additionally, it would be hard to ask for enough HST time in a joint JWST + HST proposal (or similarly, hard to ask for enough JWST time in a joint HST + JWST proposal).

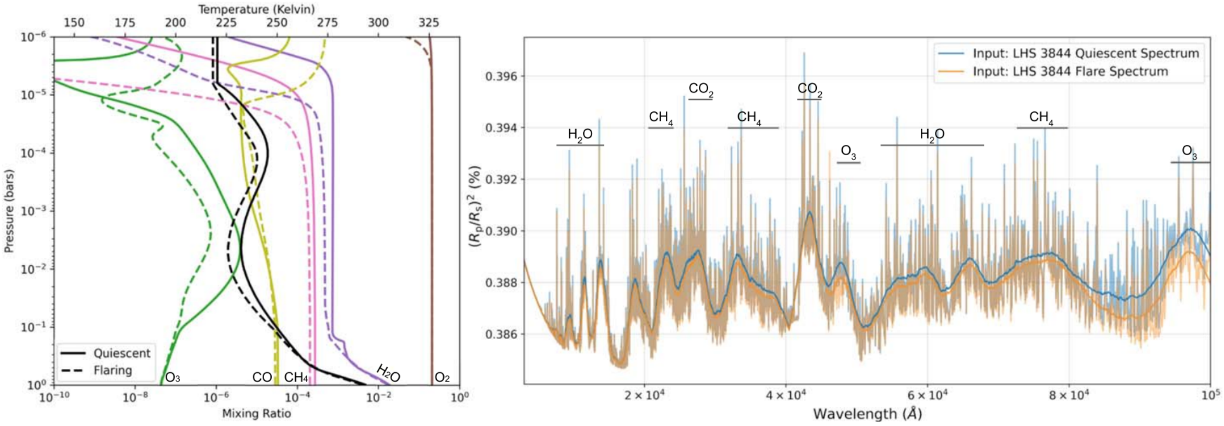

Figure 1: Borrowed from [7], in which a flare was detected in the M dwarf LHS 3844, and theoretical transmission spectra were generated for a hypothetical terrestrial planet. The transmission spectra for a terrestrial planet in the HZ are too difficult for JWST to do in a single observation, but for a warm sub-Neptune such observations could be possible, at the precision necessary to detect features in a single transmission spectrum. Left: T-P profiles for the quiescent and flare cases (black solid and dashed lines, respectively) along with mixing ratios for prominent molecules in Earth's atmosphere. Right: model transmission spectra derived from the photochemical models. The dominant species contributing to various spectral features are labeled.

References

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