Constraining the effect of stellar activity on exoplanet transmission spectra

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 ($\sim$500 hours) Director's Discretionary exoplanet program to start implementation by JWST Cycle 3.

Summary: We advocate for observations of exoplanet atmospheres at different levels of stellar activity using highly active stars of stellar types G, K, and M with the goal of constraining the amount of stellar activity that influences our conclusions about the observed atmospheres of exoplanets. Observations using HST UVIS Grism (G280) and JWST NIRISS SOSS (or NIRSpec PRISM if faint enough) over their host star stellar cycle and through a broad diversity of host star types and activity levels will show how stellar activity is masking and influencing our inferences from transmission spectroscopy. Signatures of stellar contamination are expected to be most obvious in the UV-optical, but the smaller signatures predicted in the near-IR can be nefarious as we begin our in-depth observations with JWST, as they are more difficult to identify and disentangle (see Fig. 2). Therefore, observations of active stars with these two telescopes in these two wavelength ranges will allow us to definitively detect the presence of active regions using the shorter wavelengths, and diagnose the associated signatures in the near-IR. Without knowing our host stars, it is impossible to be confident in our conclusions of their atmospheres with transmission spectroscopy.

Anticipated Science Objectives:

Every aspect we can learn about exoplanets through their transit events is inherently linked to the host star, hence we can only ever know our planets as well as we know our stars. Recent studies with JWST [1] and ground-based telescopes [e.g. 2, 3] have shown that single transit observations of exoplanet systems can be affected by the host star (also known as the Transit Light Source Effect, Fig. 1); most importantly, whether they included stellar heterogeneities in their model impacted their atmospheric conclusions drawn from the observed transmission spectrum.

Models predict that GK stars can impart detectable offsets on transmission spectra in the UV-optical wavelength ranges [e.g. 4], even more so if they are particularly active. M dwarfs, which are clearly of high interest to the exoplanet community both as small-planet [i.e. 5, 6] and large-planet [i.e. 7, 8] hosts, are the most problematic: they are expected to significantly influence and even potentially inject false molecular signatures into the observed exoplanet transmission spectra, even in the near-infrared wavelength ranges targeted by JWST [9]. Thus we advocate for observing a sample of GKM host stars to 1) test these predictions where signals are largest in the UV-optical with HST and 2) use the presence of detected activity from HST to determine the less obvious level of contamination present in near-IR observations with JWST (Fig. 2).

Urgency: Observations of exoplanet atmospheres in the UV-optical are critical to distinguishing between stellar and planetary signals (Fig. 2), therefore acquiring these observations while HST is operational is imperative.

Risk/Feasibility: Some stars are more active than others, and especially M dwarfs show a large range of variability. A relatively large sample is needed to statistically derive a relationship between stellar heterogeneities and features in the transmission spectrum.

Timeliness: To fully take advantage of JWST's precision and accurately characterize exoplanets atmospheres — including their potential habitability — we need to understand the stellar effects affecting our observations. Additionally, determining if stellar contamination in transmission spectroscopy is a barrier we can overcome with more data is imperative to decide on the optimal strategy to try to observe potentially habitable worlds in the future.

Cannot be accomplished in the normal GO cycle: The investment of hundreds of hours for observing transmission spectra at different stages of their rotational phase and evolutionary cycle is beyond the scope of what can be accomplished through the normal GO opportunities, even as a Large Treasury program.

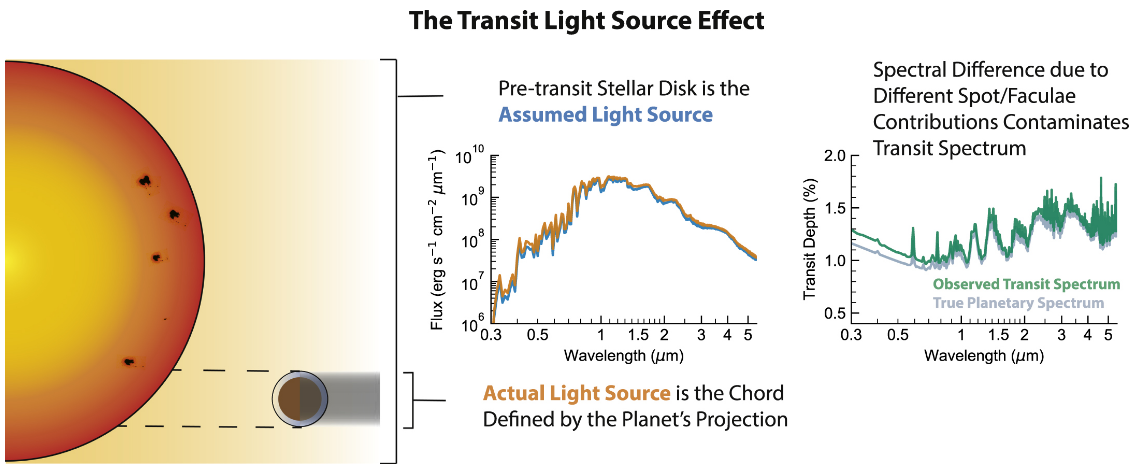

Figure 1: The Transit Light Source Effect, Figure from [9], demonstrating the effect of changes in the stellar spectrum (center) due to heterogeneities on the stellar surface (left) which in turn affects the observed exoplanet transmission spectrum (right).

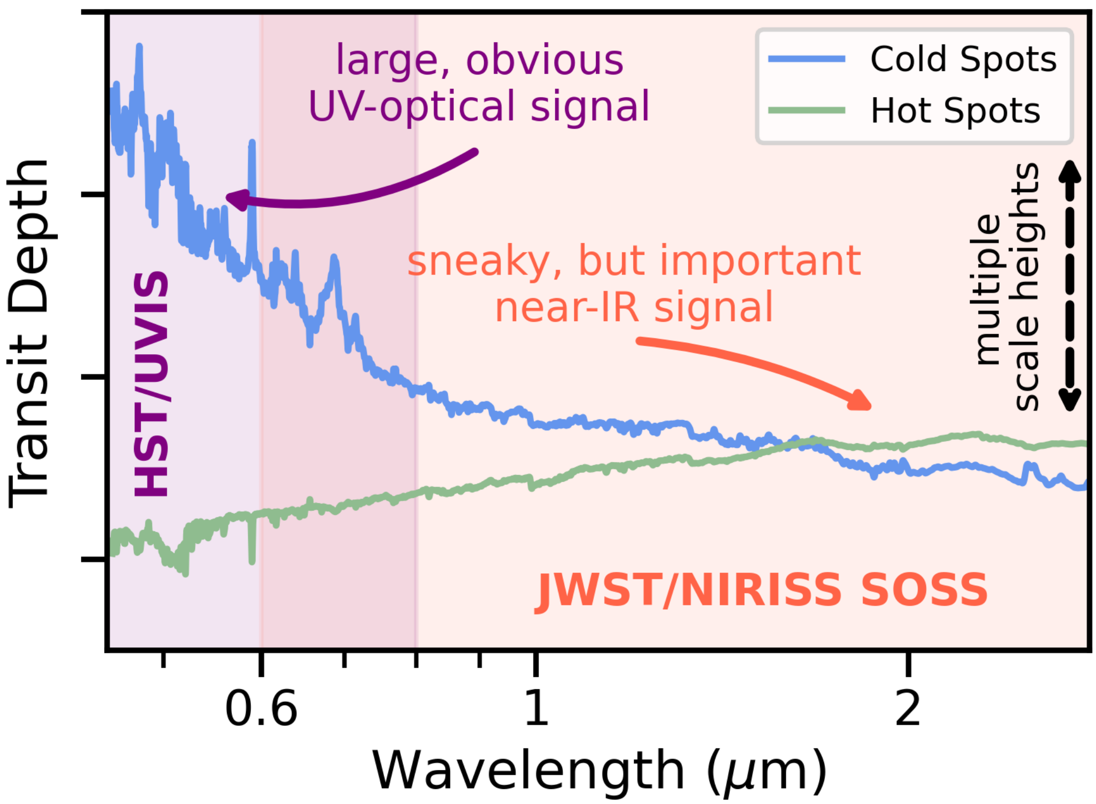

Figure 2: Potential effect of stellar contamination in transmission spectroscopy from either cold or hot unocculted spots, and our suggested observations to diagnose 1) the obvious, large signal in the UV-optical and 2) the smaller, more difficult to identify resulting signal in the near-IR.

References

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