The Sellers Exoplanet Environments Collaboration

Phase dependent water vapor and cloud spectra of synchronously rotating aquaplanets in the habitable zones of M-dwarf stars.

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Abstract:

Measurements of variations in thermal emission and reflected stellar energy spectra as a function of orbital phase can provide meaningful constraints on the climate states of terrestrial planets around M-dwarf stars. Here, we explore phase dependent planet spectra based on 3D climate simulations of Earth-size aquaplanets in the habitable zones of M-dwarf stars. Such worlds are expected to be in synchronous rotation with their host star, meaning that the rotational period equals the orbital period, and the same side of the planet always faces the star. Synchronous rotators may present with distinct longitudinal differences in climate (and thus emitted and reflected energy) due to their inherent patterns of stellar insolation, and from altered atmospheric circulation patterns. Icy, temperate, warm, and runaway climate states exhibit different characteristic phase dependent spectral signals, which may allow their characterization by future high-fidelity ground and space based telescopes.

Methods:

Model: Modified version NCAR CAM4 (modifications now available on github!)
https://github.com/storyofthewolf/ExoRT
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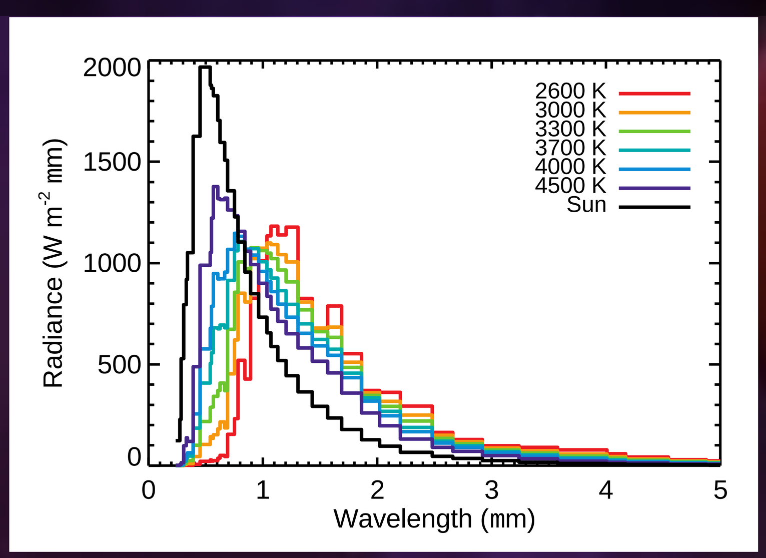
Planet: 1 R_e, 1 M_e, aquaplanet, no OHT
Atmospheric Composition: 1 barN_2 + H_2O

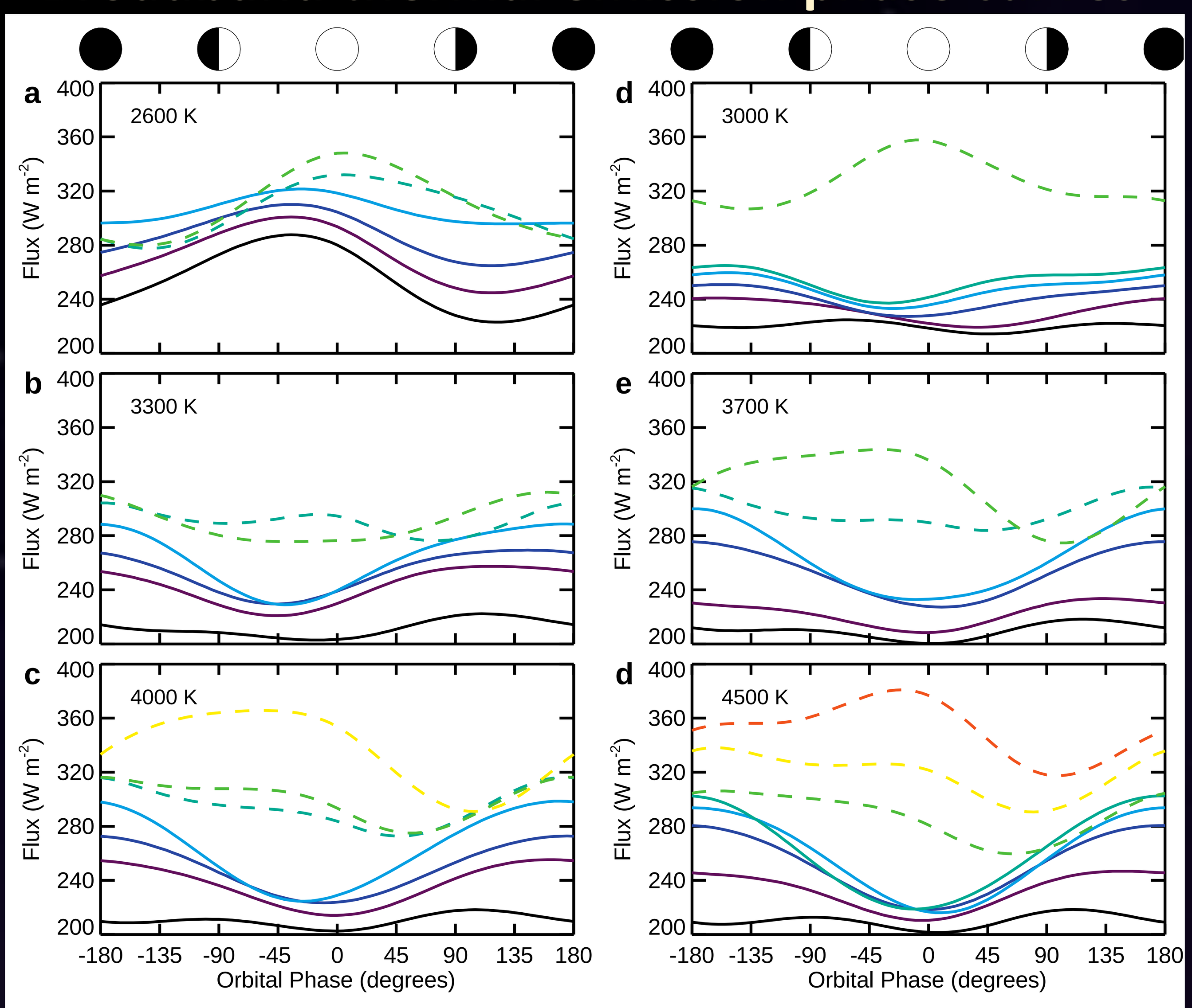
The climates of most models in this study were first described in Kopparapu et al. (2017) ApJ 845:5 (16 pp)

So what's new:
We extract moderate resolution longwave and shortwave phase dependent spectra directly from 3D climate simulations. This required upgrading the radiative transfer from 42 to 68 spectral intervals, then each equilibrated simulation must to rerun for several years. Spectral phase curves are calculated following Koll & Abbot (2016) ApJ 825:99, Appendix A.

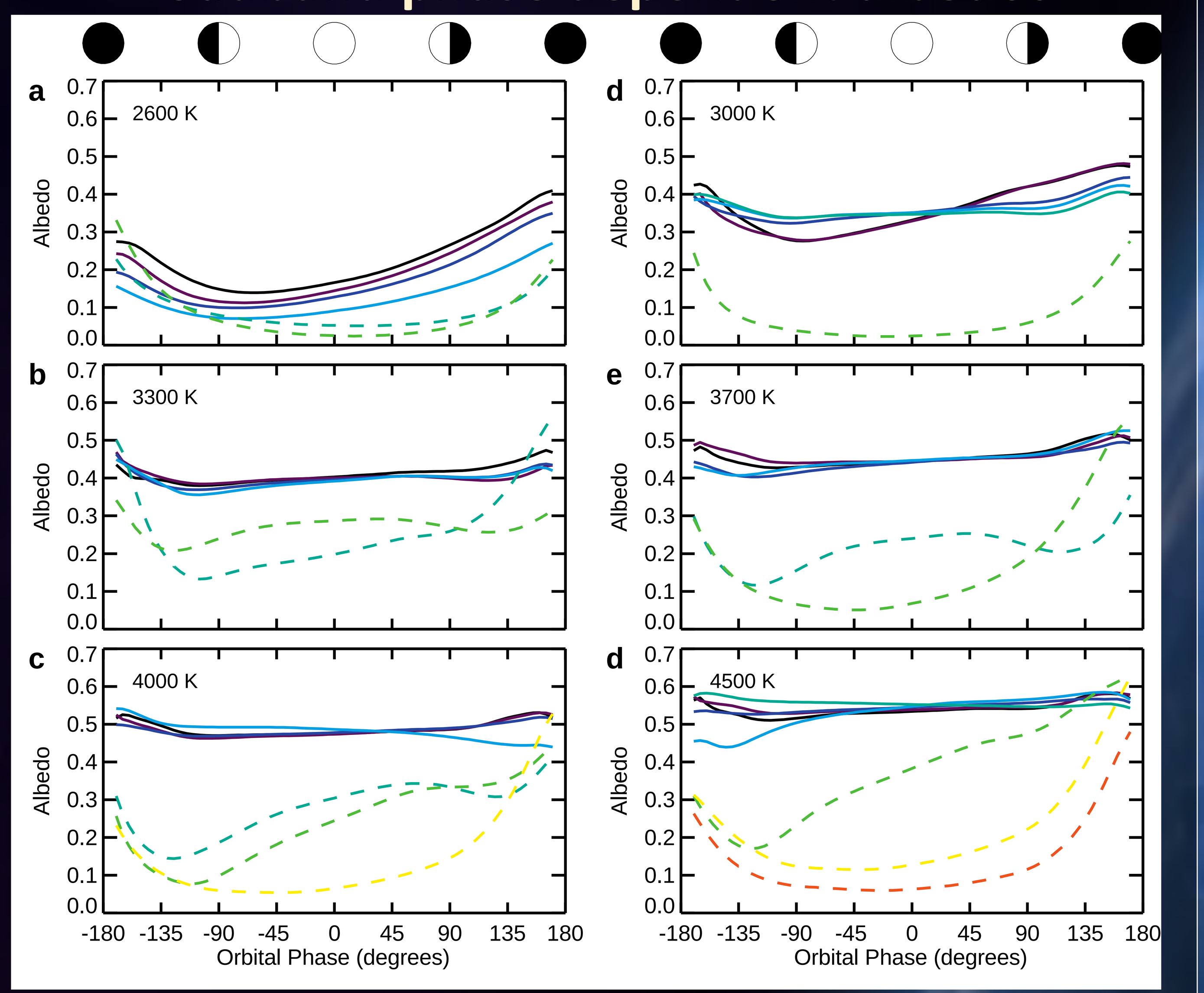


Stellar Spectra: BT-Settl, [Fe/H] = 0, log(g) = 4.5

Broadband thermal emission phase curves



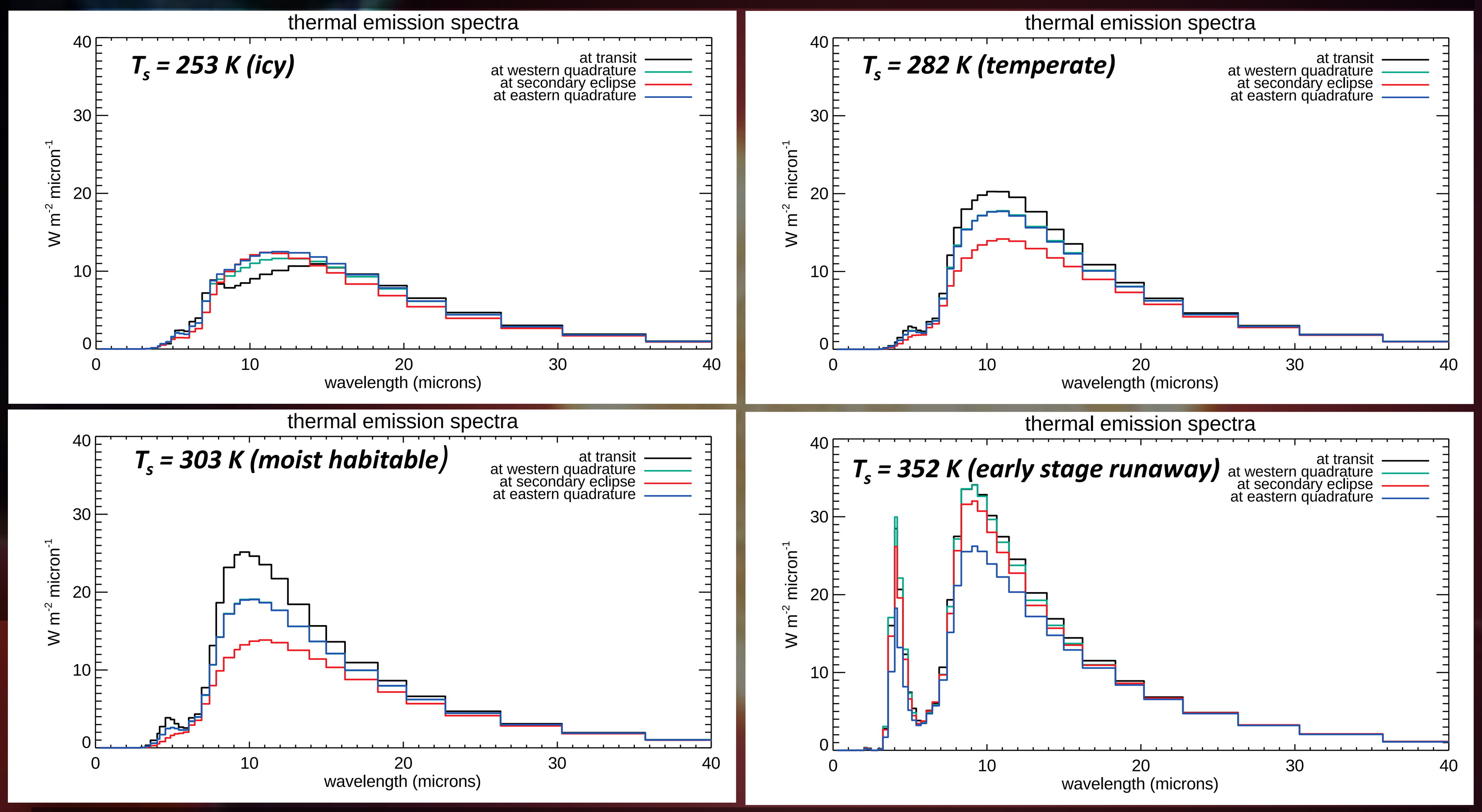
Broadband phase dependent albedos



Broadband thermal emission phase curves (left) and phase dependent albedo (right) calculated for habitable zone aquaplanets around 2600 K, 3000 K, 3300 K, 3700 K, 4000 K , and 4500 K stars (panels labeled). Solid lines indicate habitable planets with stable global mean temperatures between 250 to 310 K. Dashed lines indicate simulations where a runaway greenhouse has been definitively triggered. Generally, a runaway state may be differentiated from habitable states by having higher broadband thermal emission that is strongest at secondary eclipse, and also by having low inferred planetary albedos. However, for planets around 2600 K stars, differences between runaway and stable habitable states are slight, making it more difficult to distinguish between the two. With careful analysis, one may begin to parse between habitable planets of varying temperatures.

Phase dependent thermal emission spectra

planets around a 4500 K star.



Thermal emission spectra measured at the top-of-atmosphere at 4 different phases, and for 4 different climate states. Careful analysis of phase dependent emission spectra can potentially differentiate climate states. The 6μm H_2O band, and ~4 and 8 – 13 μm H_2O windows are of primary interest

Conclusions

- The morphology of the broadband emission and reflected light phase curves can be used to differentiate climate states of terrestrial planets
- We propose to focus spectral observations on the 6 μm H_2O absorption band, and the H_2O window regions located at ~4 μm and between 8 – 13 μm.
- The 8 - 13 μm window will allow us to probe clouds variability. Phase dependent variations hint at atmospheric circulation patterns.
- Significant emission in the 4 μm window indicates moist planets. Planets in runaway should strongly emit near ~4 μm, as their temperatures continue to climb.

Work-Plan:

1. Continue extracting 68 bin radiative spectra from Kopparapu et al. 2017 simulations, thermal and reflected.
2. Conduct new simulations exploring colder simulations, and also the effects of different background N_2 pressures
3. Prepare a paper summarizing our findings, winter 2020.