# Ocean Worlds Around Cool Stars: What to ExPECTRA

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## Motivation

Ocean Earths orbiting cool dwarfs pose great interest due to their potential for habitability combined with their system's high signal to noise ratio. Global circulation models (GCMs) simulated by Kopparapu et al. (2017) indicate that although some of these worlds may be in various states of moist or runaway greenhouse, they can still experience livable surface temperatures.

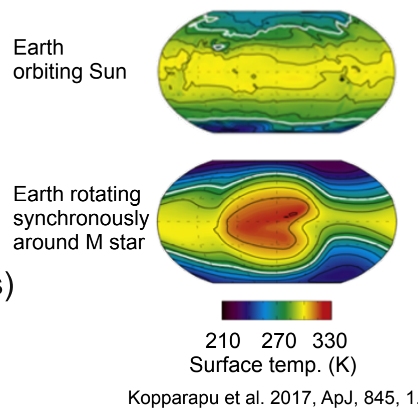


**Fig 1.** These worlds are unique due to the unique circulation dynamics of synchronously rotating planets, which may affect how well we can characterize their atmospheres.

We synthesize what spectra we expect to observe through exoplanet transmission spectroscopy, and how feasible it will be to characterize these worlds with upcoming telescopes.

## Method

The GCMs we use simulate Earth-sized planets orbiting stars of 2600K < $T_{eff}$ < 4500K in the habitable zone. The planets are covered with a 50m slab of ocean. Only H2O and N2 are included in the atmosphere.

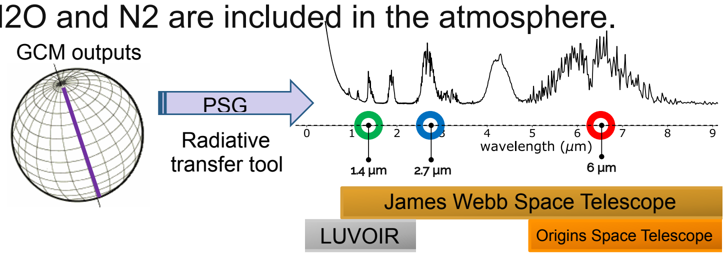


**Fig 2.** We use the Planetary Spectrum Generator, a radiative transfer tool available online, to create spectra from the GCMs. We assign each H2O feature to an upcoming telescope able to characterize it.

## Spectral Analysis

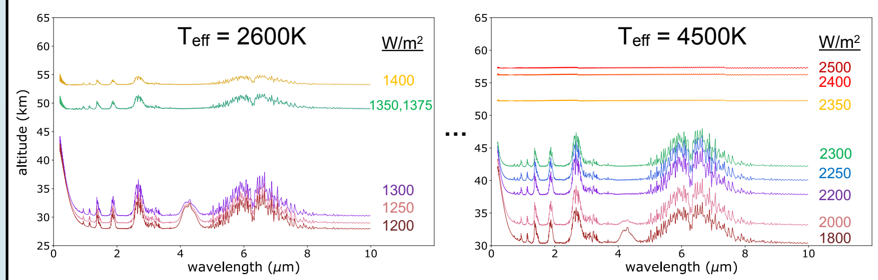


**Fig 3.** Synthesized spectra of ocean Earths orbiting 2600K and 4500K stars at various fluxes. As planets are positioned closer to their star, they approach the runaway greenhouse state, and the water features become completely drowned out by clouds.

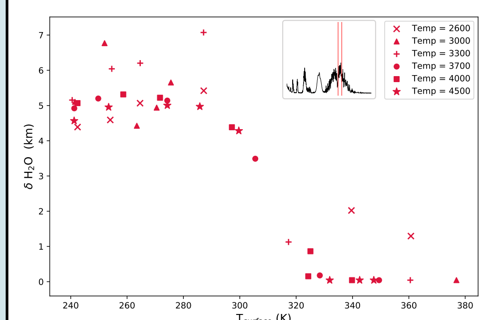


**Fig 4.** Amplitude of the 6μm $H_2O$ spectral feature for all 39 planets against their surface temperature. There are two distinct regions: Runaway planets (flat spectra), and non-runaway planets that share an approximate common amplitude of 5km.

**Runaway planets should not be observed as they have a poor signal.**
**Non-runaway planets share approximately the same value for water feature amplitude.** This trend is true for each $H_2O$ feature in our spectrum.

This common value of water feature amplitude can be applied to real stars in the TESS target catalog. We curate a dataset of 50,248 of the brightest, smallest stars with effective temperature between 2600K and 4500K that TESS will observe. We then calculate the exposure time needed for either JWST, LUVOIR, or OST to resolve water features for a planet orbiting each of these TESS stars.

## Exposure Time Results

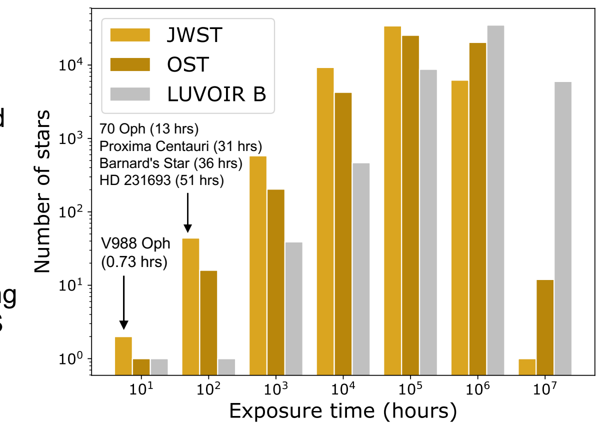


**Fig 5.** Bar graph of exposure times needed for each telescope to resolve its respective feature for Earths orbiting 50,248 TESS stars.

$$\Delta\delta = \frac{(R_p + \Delta R)^2 - R_p^2}{R_*^2} \qquad \mathrm{SNR} = \frac{\Delta\delta \cdot S_{\mathrm{total}}\sqrt{T}}{N_{\mathrm{total}}\sqrt{2}}$$

with $N \approx \sqrt{S}$ and constants $R_p, \Delta R \rightarrow T \propto \frac{R_*^4}{S}$

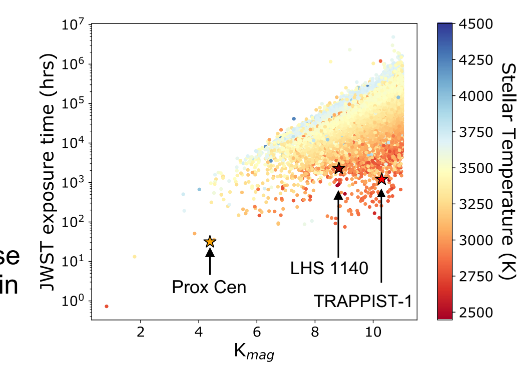


**Fig 6.** JWST exposure times against stellar magnitude and temperature. Stars with the lowest exposure times are brighter and cooler. Noted stars are those with known planets in the habitable zone (pre-TESS).

Exposure times for hypothetical ocean-covered planets orbiting TESS stellar targets average around $10^5$ hours. JWST predicts optimistic results (a few 100 hours in exposure time) for water vapor detection for around 100 stars. We now have a prioritized list of targets for follow-up characterization with future instrumentation.

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## References

Kopparapu, R. k., Wolf, E. T., Arney, G., Batalha, N. E., Haqq-Misra, J., Grimm, S. L., and Heng, K. (2017). ApJ, 845, 5
Villanueva, G. L., Smith, M. D., Protopapa, S., Faggi, S., and Mandell, A. M. (2018). JQSRT, 217, 86.

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