Supporting Information

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Model Spectra with Water Vapor

In the main paper, we consider atmospheres that show spectroscopic signatures of only O_2 and CH_4, a useful set of species to indicate the sort of chemical disequilibrium that might suggest or require life. In reality, however, planetary spectra are most likely far more complicated due to the effects of clouds, hazes, and the presence of other species with spectroscopic signatures. For instance, signatures of H_2O are expected to be present in Earth-like terrestrial exoplanet atmospheres. Here we present the reflection spectra of additional model atmospheres in which the planet shows additional spectroscopic signatures of H_2O in the atmosphere.

The basic properties assumed for the planet and moon are the same as in Table 1. The chemical compositions of the atmospheres in our additional models are summarized in Table S1. Cases 3 and 4 are same as cases 1 and 2, respectively, except that in cases 3 and 4 the planet contains H_2O in addition to O_2 and CH_4. For simplicity, we assume a constant (independent of altitude) H_2O mixing ratio of 0.15% in case 3 and 0.2% in case 4. This leads to a total column density of H_2O in our models, which is roughly equivalent to that of Earth, ~10 kg/m^2. Although we include water vapor in the atmospheres of the planet alone, it could also be present in the atmospheres of the moon or both bodies simultaneously.

Fig. S1 compares cases 3 and 4 in a similar way to Fig. 1. There is now only one absorption band around 1.6 μm that can be uniquely attributed to CH_4. The spectra show strong absorption bands of H_2O around ~1.15 μm and ~1.4 μm. These bands overlap with the CH_4 bands in the wavelength range shown, which could further confuse any attempt of interpretation if we have no prior knowledge of the atmosphere composition.

The spectra of the two cases (planet vs. planet and moon), again, closely resemble each other at lower resolution. In fact, their resemblance is even stronger than in the cases without water vapor. In addition, because strong absorption bands due to the planet and the moon clutter the spectra, it is hard to constrain the continuum level, making it more difficult to measure the absorption depths of oxygen and methane, which complicates one of the possible ways to break the planet/planet + moon degeneracy discussed in the main text.

In summary, the presence of other molecules such as H_2O does not help us to detect a clear biosignature. Instead, additional molecules might contribute to the confusion and could make the problem even more degenerate.

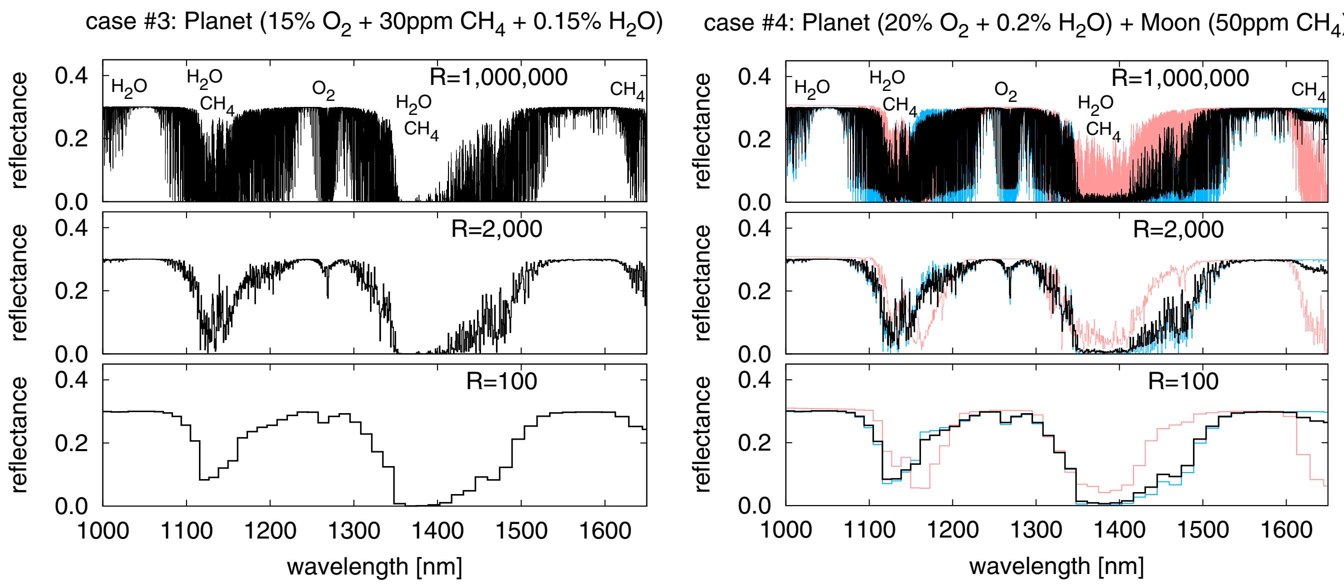

Fig. S1. Model spectra for cases 3 and 4 with varying resolution. (*Left*) Model spectra of a planet with 15% O_2, 30 ppm CH_4, and 0.15% H_2O (case 3). (*Right*) Black lines show combined spectra of a planet with 20% O_2 and 0.2% H_2O and a moon with 50 ppm CH_4 but without H_2O. Blue lines show model spectra of a planet with 20% O_2 and 0.2% H_2O. Red lines show model spectra of a moon with 50 ppm CH_4.

Table S1. Models to compare

Description	Case 3	Case 4	
Target	Planet	Planet	Moon
Composition	15% O_2 + 30 ppm CH_4 + 0.15% H_2O	20% O_2 + 0.2% H_2O	50 ppm CH_4
Normalization	$r_\oplus^2$	$1.16r_\oplus^2$	