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# From thermal dissociation to condensation in the atmospheres of ultra hot Jupiters: WASP-121b in context

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## Abstract

Hubble and spitzer space telescope observations of ultra-hot hot Jupiters (Teq>2000K) have revealed a lack of strong molecular features similar to the ones seen in cooler hot Jupiters (Teq<2000K). Many explanations have been proposed for these blackbody-like spectra, including the presence of a quasi-isothermal dayside atmosphere, the presence of a high C/O ratio or the presence of non-solar abundance ratio between water and other molecules such as VO or FeH. Using the case of WASP-121b, we show that at these high temperatures the thermal dissociation of water fundamentally shapes the emission spectra (see Figure 1). Considering the vertical gradient of water and the presence of additional molecules predicted by chemical equilibrium calculations, we show that both the emission and the transmission spectra of WASP-121b can be well reproduced by the outputs of a global circulation model assuming solar abundances and taking into account molecular dissociation and condensation of material at the limb of the planet. Finally, we place WASP-121b into context, and discuss for which planets molecular dissociation is going to play a fundamental role and needs to be incorporated into atmospheric retrieval models [1].

## 1. Introduction

As shown in Figure 2, the currently available set of HST/WFC3 thermal emission measurements for hot Jupiters display a variety of spectral morphology. The presence of a non-inverted thermal structure has been detected with high certainty in the two relatively cool hot Jupiters WASP-43b and HD 209458b, which is consistent with theoretical expectations [4]. For hotter planets, however, there is a surprising prevalence of blackbody-like emission spectra with no clear absorption or emission features (e.g., WASP-12b: WASP-103b; WASP-18b; and HAT-P-7b). Despite the prevalence of blackbody-like spectra among the hottest planets, the spectra for some of these objects have been interpreted as showing emission features (e.g., WASP-33b and WASP-121b), while in one case an absorption feature was reported (Kepler-13Ab).

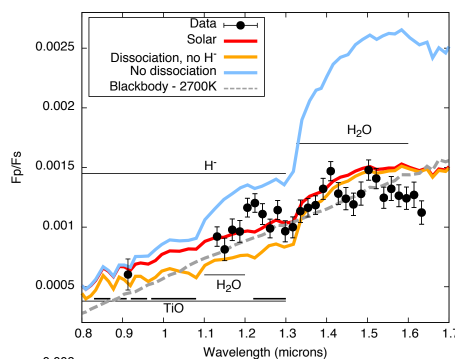


Figure 1: Emission spectrum of WASP-121b. The observations are compared to the dayside spectrum from a SPARC/MITgcm with solar metallicity. Also shown are models with the same thermal structure but with either $H^-$ opacities or water dissociation neglected when calculating the spectrum. Both $H^-$ opacities and water dissociation are responsible for the weak water signature in the WFC3 bandpass.

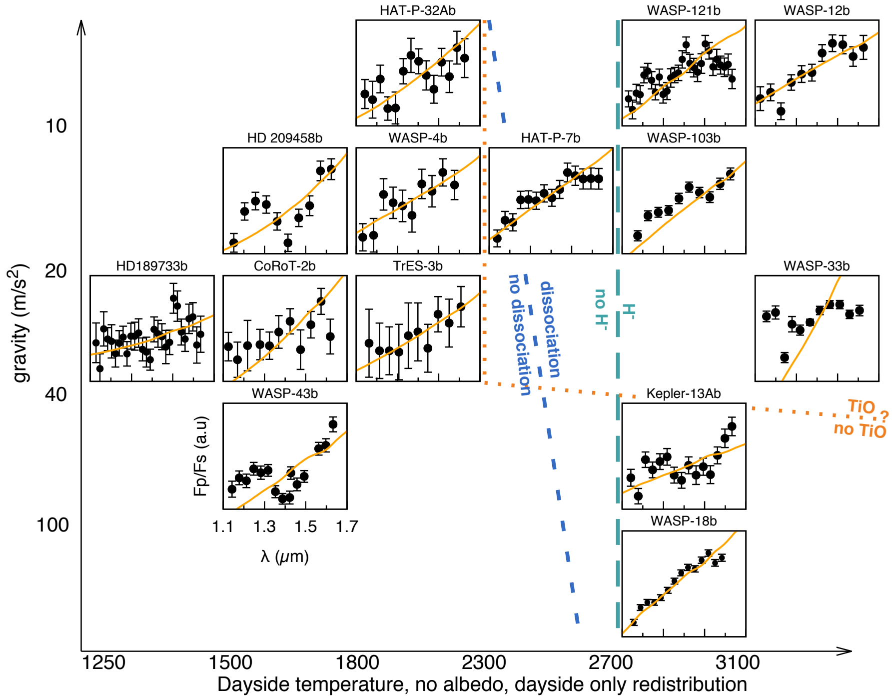


Figure 2: Published secondary eclipse spectra of exoplanets observed by HST/WFC3 with the G141 grism. The spectra have been ordered as a function of gravity and dayside equilibrium temperature. We predict $H_2O$ dissociation to be important for planets right of the short dashed line and $H^-$ opacities should be relevant for planets right of the long dashed line. Both should reduce the spectral features. We additionally show as a dotted line the putative separation between planets with gaseous TiO and planets where TiO is cold trapped Parmentier2013. In each panel the orange line shows the best fit blackbody

## 2. Methods, results, conclusion

We use the SPARC/MITgcm, a global circulation model coupled with a state-of-the-art radiative transfer model assuming chemical equilibrium to study the atmosphere of WASP-121b. We show that the dayside atmosphere of WASP-121b is devoid of $H_2O$ due to thermal dissociation of water molecules. We further show that the vertical gradient of water created by the dissociation significantly flattens out the spectral features expected in the HST/WFC3 bandpass. The presence of hydrogen anions further reduces the water feature strength in this bandpass, leading to a blackbody-like spectrum (see Figure 1).

Using an analytical expression to estimate the depth of the photosphere as a function of temperature and gravity, we further estimate the effect of thermal dissociation of water and $H^-$ opacity across a wide range of parameters. We show that due to their lower gravities, ultra-hot Jupiters are sensitive to water dissociation down to much lower equilibrium temperatures than in M dwarfs.

Finally, in Figure 2 we complete the framework to understand the diversity of hot Jupiter atmospheres by including thermal dissociation and the presence of H- opacity in the well known cold-trapping of titanium oxyde process.

## References

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