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An observation-based classification scheme for irradiated gaseous planets

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Abstract

Despite the confirmation of thousands of planets, a global picture regarding their atmospheric characteristics is yet to be established. This has been mainly due to the lack of dedicated instruments, designed specifically to study exoplanetary atmospheres. However, E-ELT, JWST, and ARIEL will likely change this status in the near future by providing the community with high quality atmospheric data. But even then, our resources will not be unlimited; hence all targets must undergo through a rigorous selection process. We present a new classification scheme for irradiated planets to help with the identification of potential targets with predicted desired atmospheric characteristics. The classification is shaped in three steps: First, we study the synthetic spectra of 28,224 self-consistent cloud-free atmospheric models with petitCODE; assuming effective temperature, surface gravity, metallicity, C/O ratio of the planet, and host star's stellar type as free parameters. In the next step, we explore the fingerprints of disequilibrium chemistry on this classification by performing 84,672 full chemical network kinetic simulations with `ChemKM`. We further present the results of 38,500 self-consistent cloudy models to investigate how this picture changes when the radiative feedback of clouds are included in the models. Our three-step strategy allow for a disentanglement of the effects of different physics on the atmospheric spectra of planets.

1. Introduction

Characterization of planets have always been a challenge. Even the composition of the outer planets in the solar system was under dispute until half a century ago. The challenge has become even more severe after the discovery of exoplanets. Despite the confirmation of thousands of planets, only a small portion of them could meet the classic planetary classification in the solar system. Thus, new classifications were proposed

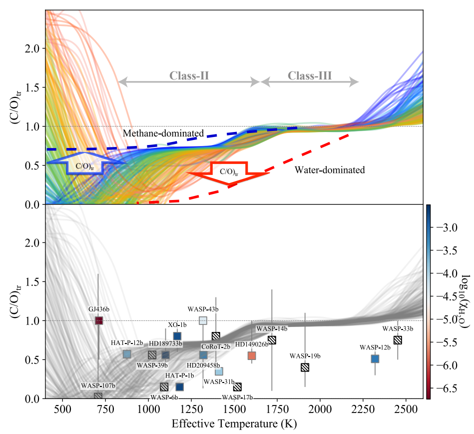

Figure 1: **Top)** Transition C/O ratios in self-consistent cloud-free thermochemical equilibrium setup. Two classes and the Methane Valley are shown. **Bottom)** The location of a handful of exoplanets on the thermochemical equilibrium map with estimated T_{eff} and C/O; color-coded by inferred water abundances from their HST transmission spectra.

to include the new exotic worlds and to provide a platform for the future predictions.

Large scale simulations could assist us to predict the diversity of the exoplanetary atmospheres, and where on the parameter space we have a higher chance to find our target with desired properties. Therefore, we aim to understand the fingerprints of physics and chemistry of exoplanets on their atmospheric spectra through a series of large scale simulations.

2. Method

We conduct our study in three steps. In the first step [1] we consider self-consistent solutions of cloud-free atmospheres at thermochemical equilib-

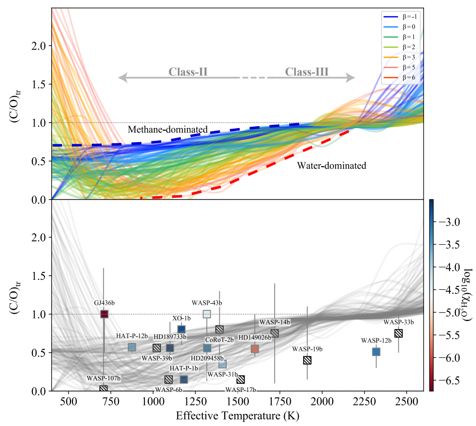

Figure 2: **Top)** Transition C/O ratios from chemical kinetic models. **Bottom)** The location of exoplanets on the chemical kinetic map. The vertical mixing makes the transition from methane- to water-dominated atmosphere to occur at lower C/O ratios on average for Class-II and III planets. Higher β values (a linear combination of surface gravity and metallicity) represent deeper photospheres, which are more prone to the vertical mixing. Planets at the boundary of class-II and III are affected by diffusion the most. Vertical mixing seems to merge Class-II and III to one extended class as well.

rium. Our study covers a broad range of parameter space: 400 K<T_{eff}<2600 K, 2.0<log(g)<5.0, -1.0<[Fe/H]<2.0, 0.25<C/O<1.25, and stellar types from M to F. It has been shown that the composition, and subsequently the spectrum, of a planet would change if the carbon-to-oxygen (C/O) ratio is changed. Water is expected to be the dominant species at the photospheric level of warm-hot gaseous exoplanets with solar or sub-solar C/O ratios. Increasing the C/O ratio enhances the methane production in general, although its production is more favorable in low temperatures. Hence a transition C/O ratio exists at which the atmospheric spectra transforms from a water-dominated to a methane-dominated one. We quantitatively find these transition C/O ratios by using the "spectral decomposition technique" and propose a new classification scheme based on the transition C/O ratios' general trends.

In the second step [2], we use our recently developed Chemical Kinetic Model (`ChemKM`) to study the effect of disequilibrium chemistry on the atmospheric spectra. We perform 84,672 full chemical network simulations and find how our classification scheme is affected by the additional physics.

Finally, we explore clouds' fingerprints on the temperature structure and planetary spectra by conducting 38,500 self-consistent cloudy simulations [3]. We present the parameter space at which clouds have the most prominent effects on the composition and TP structures, accessible to the future facilities such as JWST and ARIEL.

3. Results and Conclusion

By analysing our self-consistent cloud-free models, we find that the transition C/O ratio depends on all atmospheric parameters. By mapping all the transition C/O ratios we propose a "four-class" classification scheme for irradiated planets between 400 K and 2600 K. We also find a parameter space, "Methane valley", where a greater chance of CH_4 detection is expected, see Fig. 1.

In the second series of simulations, where we investigate the effects of disequilibrium chemistry, we find that our proposed classification holds its general shape, although two classes (II and III) may merge to one extended class under severe vertical mixing, see Fig. 2. We find that the Methane Valley remains unchanged by vertical diffusion. The first robust CH_4 detection on an irradiated planet (HD 102195b) places within this region; supporting our prediction.

Finally, we present our results on the effects of clouds' radiative feedback on this classification. We also present synthetic Spitzer IRAC's color-maps and discuss how any deviation of observational points from these color-maps are likely to be due to the presence of clouds and not disequilibrium chemistry processes.

References

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