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Photo-thermo-chemistry of hot Jupiters : application to HD 209458b

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Abstract

We have developed a new model to study the atmospheres of exoplanets, adapted to the high temperature and conditions of the atmospheres of hot Jupiters. Such a model appears essential to interpret recent and future observations, predict the composition and understand the formation and evolution of these planetary bodies. Results of a 1D thermo-photochemical model for HD 209458b are presented. An important problem of photochemical model is the lack of high temperature photochemical data. In order to improve this situation, we have begun a campaign of measurement of VUV absorption cross section at high temperature for H_2O, CO_2, CH_4 and CO. We will present the influence of these new experimental data on the thermo-photochemical model.

1. Introduction

In hot Jupiters' atmospheres, high temperatures (typically 500 K - 2500 K), very high UV fluxes (10,000 times the flux received at the top of Jupiter's atmosphere) and strong circulation dynamics coexist. There are observational constraints of few hot Jupiters (HD 209458b and HD 189733b for instance). Traditional equilibium models fail to reproduce these observations because they lack mixing and photolyses. Photochemical models fail because of their incomplete reaction network which lacks endothermic processes and because their reaction rate are inadapted to the high temperature [6].

2. Numerical Modelling

We have developed a new photo-thermo-chemical model adapted to the study of hot Jupiters. The chemical scheme comes from an industrial model developed to study car engines combustion [1]. Consequently, it includes endothermic reactions that are usually neglected when dealing with cooler atmospheres and high temperature kinetics. This original chemical network has been developed to satisfy many prescribed thermodynamical constraints as well as a large set of time-dependent experimental measurements covering a broad range of pressure, temperature and elemental compositions, comparable to the conditions found in both car engines and hot Jupiters. The completeness of this scheme allows the kinetic model to reach the thermodynamical equilibrium with a very good accuracy (Figure 1). Moreover, we favor the kinetic evolution rather than the thermodynamical equilibrium. Indeed, this scheme is not completely reversed by the thermodynamic principle of microscopic reversibility. For some reaction, we use experimental measurements for both the forward and the reverse reactions that fit better flame experiment. Thus, the kinetic evolution of this scheme is different than a 100% reversed scheme and has been validated by several experimental data. Our 1D model uses this chemical scheme, in addition with vertical transport and photodissociations coming from a model of Titan's atmosphere [2, 3]. We will show the results of our 1D model apply to HD 209458b (Figure 2), and compare them with previous models [9][4][5] and observations [7]. This will be also presented in a forthcoming paper [8].

3. Experimental measurement

An important source of uncertainty in photochemical models is the temperature-dependency of their parameters : IR absorption coefficients $k_\lambda(T)$, UV absorption cross-sections $\sigma(T)$ and chemical kinetics reaction rates k(T). Usually, data available are measure-

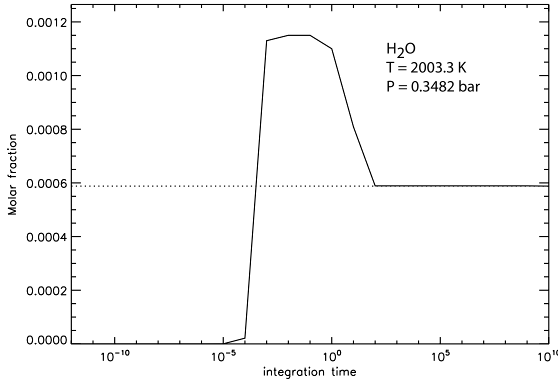

Figure 1: Comparison between the results from a thermodynamical equilibrium model (dotted line) and a kinetic 0D model (solid line), for H_2O.

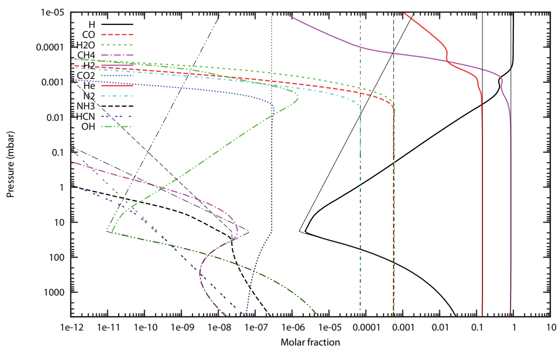

Figure 2: Steady-state of HD 209458b atmosphere (colors) compared to the thermodynamical equilibrium (black and white).

ment at ambiant temperature, which is problematic for high temperature modelling. In order to improve this situation, we have begun a campaign of experimental measurement of VUV absorption cross sections at high temperature, for some important species of transiting exoplanets atmospheres : water H_2O, carbone dioxyde CO_2, methane CH_4 and carbone monoxyde CO. This experimental work is done using the BESSY synchrotron facilities (Berlin, Germany). We will show the results of these measurements and their effect on the 1D model.

4. Summary and Conclusions

Thanks to an original chemical scheme, coming from an industrial combustion car engine model, we have a thermo-photochemical model which reproduces the atmosphere of hot Jupiters. The deviation from the thermodynamical equilibrium strongly depends on the temperature profile, the efficiency of the vertical mixing and the intensity of UV irradiation. We will present some results and see how it affects transmission and emission spectra. The experimental measurements we are doing for the absorption cross section of some important species of the atmosphere, improve the reliability of our results. They will be of prime interest when confronted to the future insights the James Webb Space Telescope will provide us into these high temperatures photothermochemical laboratories on a planetary scale.

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