EPSC Abstracts
Vol. 6, EPSC-DPS2011-645, 2011
EPSC-DPS Joint Meeting 2011

Chemical composition of extrasolar giant planets

P. Lavvas (1,2), T. Koskinen (1) and R.V. Yelle (1)
(1) Lunar & Planetary Laboratory, University of Arizona, USA, (2) GSMA, Université de Reims, France
(lavvas@lpl.arizona.edu)

Abstract

We have developed detailed photochemical models to characterize the atmospheric composition of extrasolar giant planets and applied them to the planets HD 209458 b, HD 189733 b and GJ 436 b. The first two planets are gas giants orbiting G and K type stars, respectively, while GJ436 b is a Neptune-type planet orbiting an M dwarf. Our models are able to simulate the chemical processes from deep inside the planet's troposphere, where thermochemical equilibrium prevails, up to the thermosphere where the impacts of stellar radiation and atmospheric escape have an important contribution. We present results for the impact of the stellar type spectrum in the resulting composition of each planet and discuss the role of the stellar Ly-a emission in the overall photochemistry.

1. Introduction

It is commonly assumed that Ly-alpha emission, being the most intense stellar line, will have the strongest impact on the atmospheric photochemistry, as is the case in the solar system atmospheres. Nevertheless, the large H abundance in the upper atmospheres of these planets can effectively screen the underlying atmosphere from the impact of Ly-α, rendering photochemistry at this wavelength inactive [3]. In that case the stellar flux at longer wavelengths will have a dominant role in the resulting chemical composition, with the latter varying strongly with the spectral type of the host star.

2. Model Description

The major input parameters required for the calculations are the photon fluxes for each parent star, the vertical temperature profile in the atmosphere, and the equilibrium chemical composition deep in the atmosphere. HD209458 is of similar spectral type as the Sun, thus, we used the solar spectrum for this star. For the other stars we used composite spectra based on stars of similar spectral type and available observations (for GJ 436). Fig.1 presents the Ly-α fluxes for the three host stars. For the thermal structure we assumed vertical temperature profiles in the lower atmosphere based on GCM simulations [4,5]. In the upper atmosphere we used the temperature profiles derived from our escape calculations. Fig.2 presents the vertical temperature profile for the case of HD189733 b. The chemical composition at the lower boundary was derived from thermochemical equilibrium, assuming solar elemental abundances [2]. The model then follows kinetically the thermochemical equilibrium, which is perturbed at higher altitudes due to atmospheric mixing and photochemistry. All reactions in the calculations are reversed based on the principle of microscopic reversibility with data from the NASA Thermodynamic Polynomial Database [1]. In total, there are 1700 reactions describing the evolution of 110 species of H, C, N, and O composition. Along with molecular diffusion and atmospheric mixing, we include in the calculations a vertical advection velocity that is provided by the hydrodynamic escape calculations. The latter parameter controls the escape of species from the top of our simulated atmospheres.

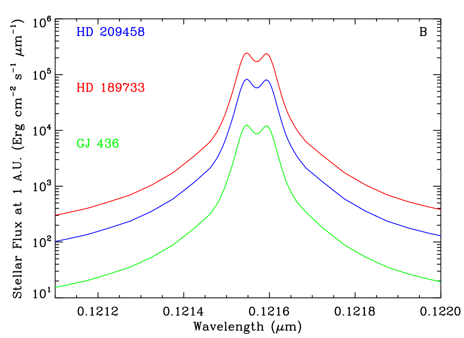

Figure 1: Ly-α fluxes for the 3 parent stars.

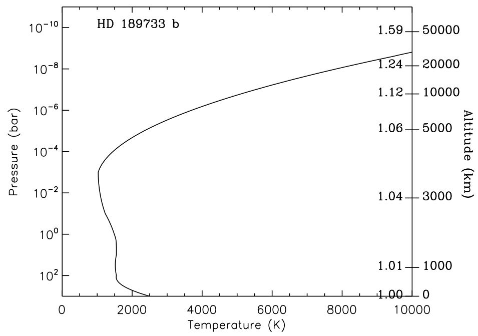

Figure 2: Assumed vertical temperature profile in the atmosphere of exoplanet HD 189733 b.

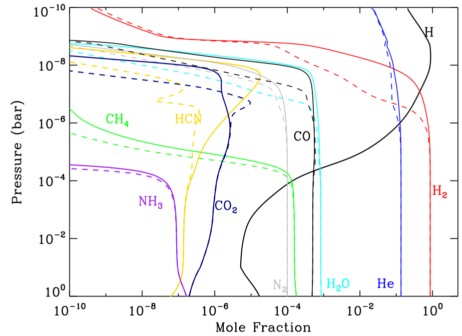

Figure 3: Calculated chemical composition of exoplanet HD189458 b. Solid and dashed lines present the sensitivity of the model results on the inclusion of Ly-α photolysis (dashed) or not (solid).

3. Results

The resulting chemical composition of the three exoplanet atmospheres investigated has a variable dependence on the Ly-α photon deposition. For the case of HD209458b the inclusion or not of Ly-α absorption by atomic hydrogen has a small effect in the resulting composition because the high temperature conditions in this atmosphere make the thermochemical processes more efficient than the photochemical. The same holds for GJ436b, which although characterized by a cooler temperature profile is also impacted by a weaker Ly-α flux. For HD189733 b on the other hand, the results demonstrate (Fig. 3) a large dependence in the Ly-α radiation, due to the large flux emitted by the parent star. The inclusion of the vertical advection velocity in the simulations provides a smooth transition from molecules to atoms in the upper atmosphere, and allows for a rapid escape of light species.

4. Summary and Conclusions

The resulting chemical composition of each simulated atmosphere depends on the thermochemical equilibrium abundances assumed deep in the atmosphere, the temperature profile that controls the chemical kinetics, the assumed eddy mixing profile, and the stellar fluxes at different regions of the atmosphere. The large abundance of atomic H in the thermospheres of these planets can efficiently absorb all Ly-α radiation and null the photochemistry at lower altitudes for this wavelength. Thus, the photochemistry in these atmospheres is mainly controlled photons at longer wavelengths. Nevertheless, the impact of the H screening of Ly-α radiation depends on the atmospheric thermal profile. The higher the temperature (and lower the stellar Ly-α flux) the lower the impact of photochemistry in the resulting chemical composition.

Acknowledgements

This work was supported through NASA grants NNX09AP14G and NNX09AB58G and NASA's Astrobiology Initiative through JPL subcontract 1372177 to the University of Arizona.

References

[1] Burcat A. and Ruscic, B.: New NASA Thermodynamic Polynomials Database with Active Thermochemical Tables updates. Report ANL 05/20 TAE 960.

[2] Burrows, A. and Sharp, C.M.: Chemical equilibrium abundances in brown dwarf and extrasolar giant planet atmospheres. Astrophys. J., Vol. 512, pp. 843-863. 1999.

[3] Koskinen,T. et al.: Characterizing the thermosphere of HD209458b with UV transit observations. Astrophys. J., Vol. 723, pp. 116-128.

[4] Lewis, N.K. et al.: Atmospheric circulation of eccentric hot Neptune GJ436b, Astrophys. J., Vol. 720, pp.344-356, 2010.

[5] Showman, A.P. et al.: Atmospheric circulation of hot Jupiters: Coupled radiative-dynamical general circulation model simulations of HD 189733b and HD 209458b, Astrophys. J., Vol. 699, pp. 564-584, 2009.