EPSC Abstracts
Vol. 8, EPSC2013-361-1, 2013
European Planetary Science Congress 2013
© Author(s) 2013

Longitudinal chemical gradients in hot Jupiter atmospheres

M. Agúndez (1,2), V. Parmentier (3), O. Venot (4), F. Selsis (1,2)
(1) Univ. Bordeaux, LAB, UMR 5804, F-33270, Floirac, France, (2) CNRS, LAB, UMR 5804, F-33270, Floirac, France, (3) University of Nice-Sophia Antipolis, CNRS, Observatoire de la Côte d'Azur, Laboratoire LAGRANGE, B.P. 4229, 06304 Nice Cedex 4, France (4) Instituut voor Sterrenkunde, KU Leuven, Celestijnenlaan 200D 2401, 3001 Leuven, Belgium

Abstract

We have built a pseudo two–dimensional (altitude and longitude) model to study the chemistry in the atmosphere of hot Jupiters. Our model considers a vertical column of atmosphere that rotates along the equator, mimicking a superrotating wind. We have applied it to the well known exoplanets HD 209458b and HD 189733b. We find that below a certain pressure level, which may be located somewhere between 10 bar and 10 mbar depending on the molecule, the chemical composition is given by thermochemical equilibrium, while about such level, the dynamical time scales for vertical and horizontal mixing compete producing a complex abundance distribution with altitude and longitude. A main conclusion of our study is that some molecules such as CO, H_2O, and N_2 maintain rather constant abundances with altitude and longitude while others such as CO_2, CH_4, NH_3, and HCN show important abundance gradients as a function of longitude.

1. Introduction

Hot Jupiters (gas giant planets orbiting close to their star) stand out among the rich variety of exoplanets because they are nearly the only ones for which constraints on their atmospheric composition has been obtained from observations. The identification of a handful of molecules and the derivation of their abundances, through transmission and emission spectra acquired during transits [1, 2] has motivated the development of one–dimensional vertical models including thermochemical kinetics, vertical transport, and photochemistry [3, 4]. Global circulation models (GCMs) predict the presence of strong winds, with velocities of up to a few km s^{-1}, which move material in the horizontal direction and could eventually lead to chemical gradients with longitude and latitude [5]. Pursuing our previous work in which we investigated the different influence of horizontal and vertical transport on the distribution of the main atmospheric constituents in hot Jupiters [6], we have now improved our model to take into account simultaneously horizontal and vertical transport as well as photochemistry.

2. Pseudo 2D atmosphere model

We consider a planet in synchronous rotation whose atmosphere rotates as a solid body with respect to the synchronously rotating frame. We aim at studying the equatorial region of the atmosphere, where the superrotating wind structure is present according to GCM models. We therefore adopt the temperature structure in the equatorial region from a GCM model [7] and built–up a pseudo two–dimensional model in which a vertical column of atmosphere rotates along the equator. Our model includes thermochemical kinetics, vertical transport, and photochemistry. The horizontal transport is taken into account by considering the movement of the vertical column with longitude, mimicking an equatorial superroting wind structure. In summary, we model the three–dimensional circulation patterns by an horizontal advection, for which we adopt the average wind speed around the equator, and a vertical diffusion, the strength of which is calculated from a GCM model [7].

3. Results and conclusions

We have applied our model to the hot Jupiters HD 209458b and HD189733b. We find that below a certain altitude, which may be located between 10 bar and 10 mbar depending on the molecule, molecular abundances are given by thermochemical equilibrium. Above such layers, the situation gets more complex as the dynamical time scales for horizontal and vertical transport compete resulting in a complex abundance distribution of the main atmospheric constituents with altitude and longitude. As illustrated in Figure 1, some molecules such as CO, H_2O, and N_2 maintain rather constant abundances with altitude and longitude while others such as CO_2, CH_4, NH_3, and HCN show impor-

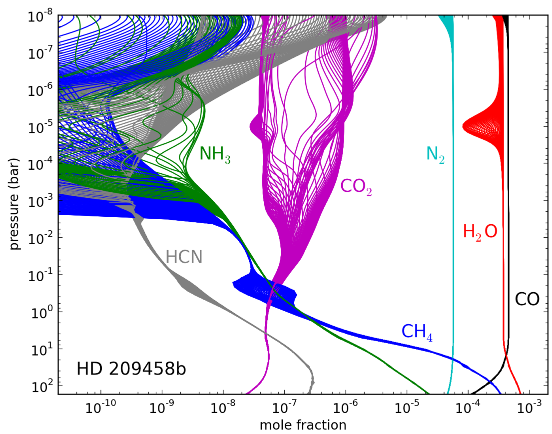

Figure 1: Calculated vertical abundance profiles for some of the most abundant molecules along the equator of HD 209458b's atmosphere. Note how some molecules maintain rather constant abundances while for some others the abundance spread over a wide range of values at different longitudes.

tant abundance gradients as a function of longitude.

This work emphasizes the need to account for dimensions additional to the vertical one in chemical models of exoplanet atmospheres, since the distribution of some atmospheric constituents which are very active in producing spectral features in the infrared, is expected to be far from uniform in the horizontal direction. These results may have consequences for the interpretation of transmission and emission spectra of hot Jupiters, especially if the emission spectrum at different phases can be observed in the near future with incoming missions such as the James Webb Space Telescope and EChO.

Acknowledgements

M. A. and F. S. acknowledge support from the European Research Council (ERC Grant 209622: E3ARTHs).

References

[1] Swain, M. R., Tinetti, G., Vasisht, G., et al.: Water, methane, and carbon dioxide present in the dayside spectrum of the exoplanet HD 209458b, ApJ, 704, 1616-1621, 2009.

[2] Tinetti, G., Vidal-Madjar, A., Liang, M.-C., et al.: Water vapour in the atmosphere of a transiting extrasolar planet, Nature, 448, 169-171, 2007.

[3] Moses, J. I., Visscher, C., Fortney, J. J., et al.: Disequilibrium carbon, oxygen, and nitrogen chemistry in the atmospheres of HD 189733b and 209458b, ApJ, 737, 15, 2011.

[4] Venot, O., Hébrard, E., Agúndez, M., et al.: A chemical model for the atmosphere of hot Jupiters, A&A, 546, A43, 2012.

[5] Showman, A. P., Cooper, C. S., Fortney, J. J., and Marley, M. S.: Atmospheric circulation of hot Jupiters: three-dimensional circulation models of HD 209458b and HD 189733b with simplified forcing, ApJ, 682, 559-576, 2008.

[6] Agúndez, M., Venot, O., Iro, N., et al.: The impact of atmospheric circulation on the chemistry of the hot Jupiter HD 209458b, A&A, 548, A73, 2012.

[7] Parmentier, V., Showman, A. P., & Lian, Y.: 3D mixing in hot Jupiter atmospheres I: application to the day/night cold trap in HD 209458b, arXiv1301.4522P, 2013.