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Impact of circulation winds on the atmospheric chemistry of the hot Jupiter HD 209458b

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Abstract

We investigate the effects of circulation winds on the atmospheric chemistry of the hot Jupiter HD 209458b. We identify the existence of a pressure level of transition between two regimes, whose location depend on each molecule. Below this transition layer, chemical equilibrium holds, while above it, winds tend to homogenize the chemical composition of the atmosphere, bringing molecular abundances in the nightside close to those prevailing in the dayside. We find moderate abundance variations for some molecules such as CO_2 between the morning and evening limbs, which would have consequences for transmission spectra that sample the planet's terminator of hot Jupiters.

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 [4, 5] has motivated the development of one dimensional photochemical models including vertical transport [2, 6].

Hot Jupiters are generally thought to be tidally locked because of their proximity to the star, implying a extremely high temperature contrast between the dayside and the nightside in the absence of atmospheric winds. Three dimensional circulation models, however, predict the presence of strong winds, with velocities of up to a few km s^{-1}, that would efficiently redistribute the energy from the dayside to the nightside in such planets [3]. We investigate here the effects of such circulation winds on the chemical composition of the atmosphere of the hot Jupiter HD 209458b.

2. The model

We consider a planet in synchronous rotation whose atmosphere rotates as a solid body, i.e. with a constant angular velocity with respect to the synchronously rotating frame. A time dependent radiative code is used to compute the temperature structure for the atmosphere of HD 209458b, adopting an equatorial wind velocity of 1 km s^{-1} at the 1 bar pressure level [1]. The resulting longitudinal temperature profiles (see Figure 1) are then used to compute the evolution in the chemical composition of the atmospheric gas as it circulates along the equator at various pressure levels.

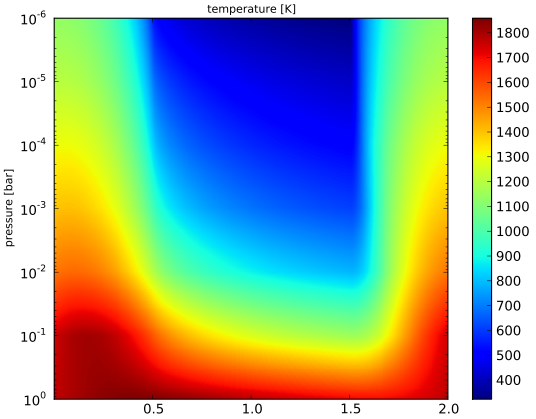

Figure 1: Temperature structure calculated at the equator for the atmosphere of HD 209458b. The longitudes 0 and π correspond to the substellar and antistellar points, respectively.

The chemical kinetics network used, with ∼100 species linked by ∼2000 gas phase chemical reactions, has been validated in the area of combustion chemistry and has been found suitable to model the atmosphere of hot Jupiters [6].

3. Results

The impact of circulation winds on the atmospheric chemistry may be understood in terms of time scales. On one side the chemical time scale of the different chemical transformations that take place as the wind moves gas between the hot dayside and the cooler nightside, and on the other side the dynamical time scale related to the gas flow.

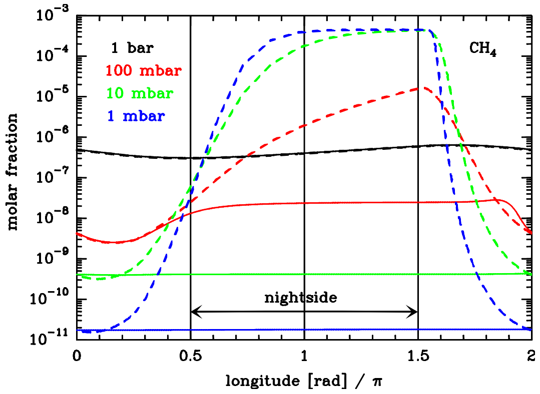

Figure 2: Molar fraction of CH_4 as a function of longitude for various pressure levels, as given by chemical kinetics (solid lines) and by chemical equilibrium (dashed lines).

A good example is the system CO/CH_4. At chemical equilibrium most of carbon is in the form of CO at high temperatures and as CH_4 at temperatures below $\sim$ 1000 K. This is illustrated in Figure 2, where it is seen that the chemical equilibrium abundance of CH_4 (dashed lines) remains low in the dayside, where most of carbon is in the form of CO, but becomes very high in the cool upper altitudes of the nightside. The presence of the circulation wind, however, produces significant departures from equilibrium (solid lines). In the hot and dense bottom layers of the atmosphere chemical time scales are short and chemical equilibrium is attained (see e.g. at 1 bar). At higher altitudes, however, temperatures and pressures decrease and chemical time scales become longer than the dynamical time scale, producing a "quenching" effect in the abundances (see e.g. at 10 and 1 mbar). The circulation wind, therefore, tends to homogenize the chemical composition of the atmosphere, bringing molecular abundances in the nightside close to those prevailing in the dayside.

The "quenching" level, above which chemical equilibrium does not hold anymore and abundances are "quenched" to dayside values, is different for each molecule ($\sim$100 mbar for CH_4 and $\sim$100 μbar for CO_2; see Figure 3). Below this "quenching" level, abundances can vary significantly with longitude for certain molecules. An interesting effect is that the abundance can be quite different in the two equatorial points of the planet's terminator (e.g. the molar fraction of CO_2 at the 100 mbar level is 2-3 times larger in the morning limb than in the evening one; see Figure 3), with consequences for transmission spectra.

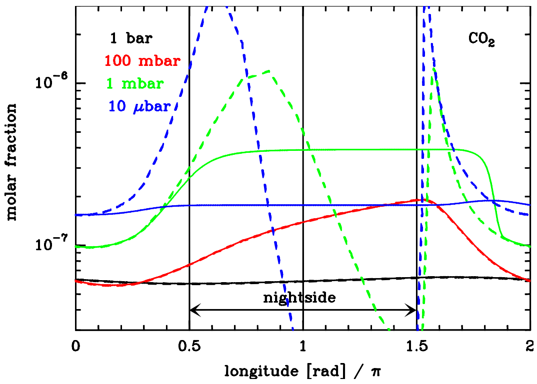

Figure 3: Same as Figure 2, but for CO_2.

References

[1] Iro, N., Bézard, B., and Guillot, T.: A time-dependent radiative model of HD 209458b, A&A, 436, 719-727, 2005.

[2] 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.

[3] 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.

[4] 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.

[5] 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.

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