EPSC Abstracts
Vol. 7 EPSC2012-688-4 2012
European Planetary Science Congress 2012

Temperature effects on exoplanetary atmospheric (bio)markers

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Abstract

We have developed a photo-thermo-chemical model adapted to the study of the hot terrestrial atmospheres. Such a model is essential to interpret future observations and to predict the composition of hot extrasolar terrestrial planets. It is also important to understand the formation and the evolution of some of their key atmospheric species. We investigate here the effect of an increase of the temperature on the predicted abundances of some of these key species, such as ozone O_3 and carbon dioxide CO_2.

1. Introduction

The search for extrasolar terrestrial planets raises currently a considerable scientific interest. The first one to be discovered are on close-in orbits around their parent stars. Known terrestrial exoplanets can therefore be as hot as a few thousand K, such as Corot-7b [7] and Kepler-10b [1]. The detectability of any spectral features in exoplanetary atmospheres depends mainly on two main parameters: their chemical composition and their temperature profile. However, the competition between photochemical kinetics and thermochemistry susceptible to exist in hot terrestrial atmospheres prevents us from generalizing the processes occurring in Earth's atmosphere and initiating potential departures from equilibrium. It requires therefore detailed modelling in order to estimate the risk of false-positive and/or false-negative occurrences when seeking spectroscopic evidence of habitable conditions and life. One-dimensional models coupling photochemical and thermochemical kinetics and vertical diffusion already exist to study the effects of disequilibrium chemistry on the atmospheric composition of "hot-Jupiter" exoplanets [10, 11, 12, 13, 8]. We apply here such method to the modelling of hot terrestrial exoplanets.

2. Photothermochemical modelling

Our photo-thermo-chemical model is pertinent to the study of hot terrestrial atmospheres. It is adapted from a numerical code that has been used lately to simulate the photochemistry of a wide range of planetary atmospheres: primitive Earth, Titan [5], Neptune [3], hot Jupiters [8]. We have modelled some isothermal terrestrial-like atmospheres, composed initially of N_2, O_2, CO_2 and H_2O, at different temperatures. These atmospheres were allowed to evolve, according to UV irradiation, photochemical/thermochemical kinetics [6] and vertical diffusion, until steady state is achieved. The results obtained are shown in Fig. 1. High atmospheric temperatures seem to inhibit very efficiently the production of an ozone O_3 layer when considering thermochemical kinetics and when fully reversing reaction rates. In the Earth's atmosphere, the destruction of ozone O_3 occurs through a large number of reactions, among which are some catalytic cycles involving mainly hydrogenous compounds (H, OH, HO_2) and competiting efficiently with the regular Chapman cycle [4]. Globally, the higher the atmospheric temperatures, the larger the increase in some of these active compounds abundances over equilibrium predictions.

3. Experimental measurement

An important source of uncertainty in photo-thermo-chemical 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, available data have been measured at ambient temperature, which is problematic for modelling hot atmospheres. 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 such as water H_2O and carbone dioxyde CO_2. This experimental work has been done using the BESSY syn-

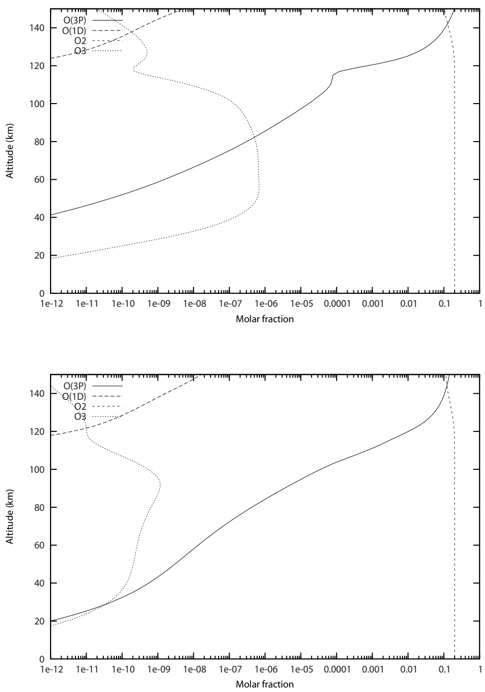

Figure 1: Abundances of O^3P, O^1D, O_2 and O_3 in an atmosphere with a uniform 300 K thermal profile (up) and a uniform 700 K thermal profile (bottom).

chrotron facilities (Berlin, Germany). We will show the results of these measurements and their effect on a 1D model of terrestrial atmospheres at different temperatures.

4. Summary and conclusions

We have developed a photo-thermo-chemical model which is appropriate to study hot terrestrial exoplanets. We have shown that the ozone abundance is very sensitive to the temperature profile and is consequently a source of notable uncertainties. The experimental measurements we are doing for the absorption cross section of some key species of the atmosphere is a prerequisite for reproducing correctly the atmospheres of hot terrestrial exoplanets.

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