EPSC Abstracts
Vol. 13, EPSC-DPS2019-160-1, 2019
EPSC-DPS Joint Meeting 2019


EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

# Photochemistry and Aerosols Formation in Hot-Jupiter Exoplanet Atmospheres

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## Abstract

Photochemistry can substantially affect the gas-phase composition of warm exoplanet atmospheres and lead to the formation of aerosols with consequences on the radiative transfer, thermal structure, and dynamics of the atmospheres. In this work, we investigated experimentally the photochemistry and the formation of photochemical aerosols in 'carbon-rich' Hot Jupiter atmospheres.

## 1. Introduction

Atmospheres of hot (800-3000 K) giant planets with short orbital periods and correspondingly small semimajor axis values [1] are exposed to high temperature and intense UV flux. These harsh conditions without equivalent in our solar system represent a new frontier for the study of photochemistry and aerosol formation.

For exoplanets with T < ~2000 K, photochemistry can seriously affect the atmospheric gas-phase composition [2]. Moreover, recent observations suggest that aerosols are present in a large variety of exoplanet atmospheres such as the super-Earth GJ 1214b [3], the hot-Neptune GJ 436b [4], and several hot Jupiters [5]. However, whether the observed aerosols are mainly condensate clouds or photochemical aerosols remains largely unknown. Although higher-temperature condensate clouds are expected to dominate the hotter atmospheres, some of these observations were made at altitude where the pressure is too low to allow the formation of these clouds [5], leaving the question of the formation of photochemical aerosols open.

We will present the results of a first experimental study of the photochemistry and formation of aerosol in Hot Jupiter exoplanets atmospheres [6]. We investigated the chemistry and formation of aerosols in hot-Jupiter-type exoplanet atmospheres with T > 1000 K and a C/O ratio of 1, representing C enhancement relative to solar value of 0.54.

## 2. Material and Methods

To simulate the photochemistry and the formation of aerosols in Hot Jupiter exoplanet atmospheres, we used the Cell for Atmospheric and Aerosol Photochemistry Simulations of Exoplanets (CAAPSE) experimental setup. A scheme of the setup is presented in Figure 1.

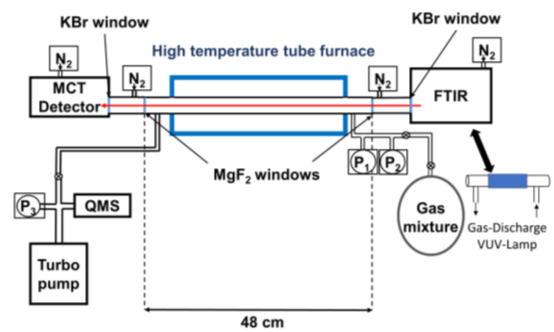


Figure 1: Scheme of the CAAPSE experimental setup at the Jet Propulsion Laboratory.

The cell was filled at room temperature with 15 mbar of $H_2$:$^{13}CO$ gas mixture (99.7%:0.3%). $H_2$ and CO are the two most abundant molecules in hot-Jupiter exoplanet atmospheres (excluding He) and represent the simplest plausible atmospheric composition. The gases were heated at 5 K minute$^{-1}$ to oven temperatures ranging from room temperature (~295 K) to 1473 K. After attaining the desired temperature, the gas mixture was irradiated with UV photons at 121.6 nm ($Ly_{\alpha}$) and 140-160 nm using a hydrogen microwave discharge lamp separated from the cell by a $MgF_2$ window.

The evolution of the gas mixture composition was monitored using infrared spectroscopy and mass spectrometry. Sapphire windows were placed inside CAAPSE to collect any aerosols produced during the irradiation and aerosol composition was determined using infrared spectroscopy.

## 3. Results

We conducted a series of experiments by heating a $H_2$:CO gas mixture to various temperatures and then irradiating it with UV photons. We found that both thermochemistry and photochemistry lead to the modification of the gas-phase composition. Thermochemistry leads to the formation of carbon dioxide at each studied temperature, and occasionally to the formation of methane. Further, subsequent irradiation of these gas mixtures was found to enhance the formation of $CO_2$ and leads to the formation of water at the highest studied temperature.

We have also observed the formation of solid organic thin films after irradiation of the gas mixture at 1473 K. Analysis of these thin films with infrared spectroscopy confirmed that they are non-volatile hydrocarbon aerosols with HCO functionality involving aromatic and aliphatic hydrocarbons.

## 4. Summary and Conclusions

This work presents a first experimental simulation of the chemistry in hot Jupiter exoplanet atmospheres, where UV photochemistry should play a key role. We found that $H_2$/CO gas compositions can change significantly from thermal equilibria when irradiated with UV photons and that photochemistry efficiency is strongly correlated with increasing temperature. Finally, the formation of a solid organic condensate at 1500 K and under $Ly_\alpha$ UV radiation observed in our experiments, confirmed the possibility of forming photochemical hazes in Hot Jupiter exoplanet atmospheres.

## Acknowledgements

The research work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. 

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