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## Optical indices of organic aerosols for oxidizing atmospheres of Earth-like exoplanets

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### Abstract

Photochemical haze is likely produced in most planetary atmospheres. Optical indices are required to evaluate the haze contribution to the climate of a planet. Unfortunately few experimental data exist and most of them have been measured with laboratory analogs of Titan's haze, which can only be a model scenario for totally reduced atmospheres. In the present work we study the optical indices in the UV-Vis range of analogs of planetary organic haze produced with CO<sub>2</sub>/CH<sub>4</sub> ratios varying between 1 and 4 in order to provide appropriate optical indices for a large range of Earth-like oxidizing atmospheres. Oxidized analogues are found as much as four times better absorbers in the UV than the reduced ones [1].

### 1. Introduction

Depending on their optical properties, hazes could impact planetary habitability via UV shielding and surface cooling [2]. Due to the lack of data, models usually incorporate laboratory optical constants of analogues of hazes produced under Titan's reducing conditions.

The aim of this work is provide optical indices of oxidized organic aerosols better appropriate to provide constraints on climate models of Earth-like exoplanets.

### 2. Method

#### 1.1 Preparation of the analogues

Analogues of photochemical haze are produced using the PAMPRE setup, a 13.56 MHz radiofrequency capacitively coupled plasma reactor [3]. This setup triggers complex organic chemistry mimicking ionospheric chemical conditions at room temperature. The R.F. power source is tuned at 30 W. A low pressure (0.95 mbar) is ensured in the reactor

by a 55 sccm gas flow of the reactive gas mixture. Four different gas mixtures are used to simulate increasing oxidizing atmospheric conditions (Table 1). The plasma is produced within a cylindrical plasma box. Bare silicon substrates are placed on the bottom electrode. The plasma is turned on until a thin film is deposited on the substrates.

Table 1: Thickness of the organic films

N <sub>2</sub> :CO <sub>2</sub> :CH <sub>4</sub>	Thickness (nm)
95:0:5	36.02 ± 0.03
90:5:5	78.80 ± 0.05
95:2.5:2.5	79.04 ± 0.04
90:8:2	26.56 ± 0.38

#### 1.2 Analysis

We obtain the thickness (Table 1) and the optical indices by UV-Visible ellipsometry (Figure 1). The measured ellipsometric parameters result from the interaction between light and both the organic film and the Si substrate. We model a multilayer system consisting of the substrate, the organic material and a roughness layer, combining the optical constants of the organic layer and air. The organic thin film is modeled via a Tauc-Lorentz oscillator, applicable to amorphous organic films. In this model, the imaginary part of the permittivity,  $\epsilon_i$ , is given by:

$$\epsilon_i(E) = \begin{cases} \frac{AE_0C(E-E_g)^2}{E(E^2-E_0^2)^2+C^2E^2}, & \text{for } E > E_g \\ 0, & \text{for } E \leq E_g \end{cases} \quad (1)$$

, where  $E_g$  (eV) is the optical band gap energy,  $E_0$  (eV) is the energy position of the major UV absorption peak,  $A$ (eV) is related to the strength of this peak, and  $C$  (eV) is related to its broadening. The real part of the permittivity,  $\epsilon_r$ , is derived from  $\epsilon_i$  using the Kramers-Kronig relations:

$$\varepsilon_r(E) = \varepsilon_r(\infty) + \frac{2}{\pi} P \int_{E_g}^{\infty} \frac{\xi \times \varepsilon_i(\xi)}{\xi^2 - E^2} d\xi \quad (2)$$

where  $\varepsilon_r(\infty)$  is the high-frequency real permittivity and  $P$  is the Cauchy principal value containing the residues of the integral at the poles on the lower half of the complex plane and along the real axis. And for non-magnetic materials, the complex refractive index is:  $\bar{\varepsilon} = \bar{n}^2 = (n + ik)^2$

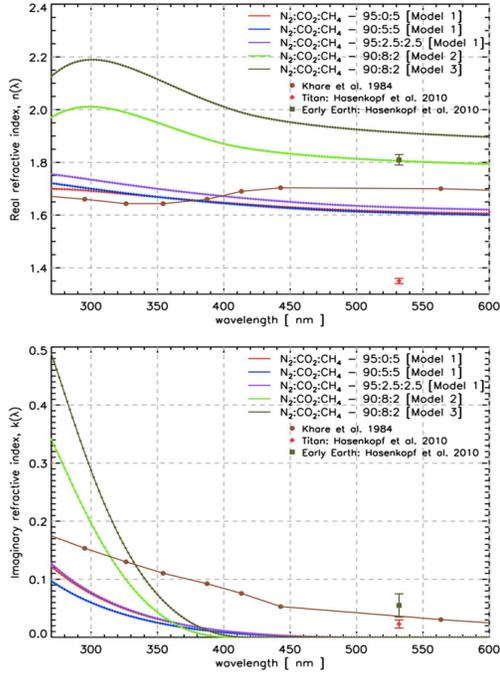


Figure 1: Refractive indices in the UV–visible (270–600 nm) for haze analogues prepared with different mixtures of  $N_2:CO_2:CH_4$ . As  $CO_2/CH_4$  increases, the strength of the major UV absorption is significantly increased [1].

### 3. Summary and Conclusions

This study provides, for the first time, laboratory wavelength-dependent refractive indices of oxidized organic aerosols in the UV–visible range at increasing degrees of oxidation. The analogues produced under oxidizing conditions present a larger band gap than the reduced ones, i.e., their absorption begins in the UV rather than the visible range.

Furthermore, oxidized analogues are as much as four times better absorbers in the UV than the reduced ones, at least up to the measured wavelength of 270 nm.

Such indices can be used to refine radiative transfer models of increasingly oxidizing planetary atmospheres including photochemical hazes [4].

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