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Evolution of Titan's atmospheric aerosol under high-altitude ultraviolet irradiation

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Abstract

The Cassini-Huygens space mission revealed that the chemistry initiating Titan's aerosols formation starts in the upper layers of the atmosphere (~1000 km). The grains then sediment until deposition at the surface. Despite all the data collected, the photochemical evolution of the aerosols between 1000 and 600 km is still unknown, especially regarding their optical properties. The aim of this work is to investigate the photochemical aging processes of those aerosols and how they interact with the VUV solar radiations. We put our results in perspective with the Cassini data for different atmospheric altitudes.

1. Introduction

Titan is the biggest satellite of Saturn whose atmosphere is mainly composed of molecular nitrogen (N₂) and methane (CH₄) with an average ratio of 98/2 %. [1]

The Cassini/Huygens mission revealed that the interaction between those neutral molecules and the UV solar light leads to a complex photochemistry that produces heavy organic molecules. When those molecules condense, they will then become the solid aerosols, which are responsible for the brownish haze surrounding Titan. [2, 3]

Between 1000 and 600km, the VUV solar radiations are still significant and will continue to modify the physical, chemical and optical properties of those grains. A change in these parameters can impact the radiative budget of Titan's atmosphere.

Then, the aim is to identify and understand the photochemical evolution of the aerosols. In order to compare our data to the ones of Cassini's instruments such as CIRS or VIMS, we will focus on their infrared signatures and how they can be modified after being exposed to VUV radiations.

2. Method

To do so, we irradiate thin films of Titan's atmospheric aerosols analogues with VUV synchrotron radiations provided by the DESIRS beamline at the SOLEIL synchrotron facility. The analogues are produced by submitting a 95-5% N₂-CH₄ molecular mixture to a radio-frequency electron discharge.[4]

In Titan's ionosphere, the aerosols are exposed to the full VUV-solar spectrum so the experiment needs to reproduce those conditions in terms of wavelength and flux. The effect on the aerosols may vary according to the wavelength. This is why we chose three typical wavelengths representative of irradiation effects according to the altitude:

1. 95 nm to test possible ionizing effects
2. 121.6 nm (Ly- α), as an important solar contribution
3. 190 nm, to probe the soft VUV irradiations

The solar VUV-UV photon flux reaching the top of Titan's atmosphere is about 10¹⁴ photons/s/cm² [5] while the DESIRS line provides a monochromatic flux of 10¹⁶ photons/s/cm².

Nevertheless, our irradiation time is of few hours and it has been calculated that the residence time of the

aerosols in the thermosphere (between 1000 and 600 km) is about the duration of one Titanian day (10^6 s). [6] So we counterbalance our higher photon flux by a shorter irradiation time.

The diagnostic of the irradiated films is then performed using infrared absorption spectroscopy (ATR technique).

2. Results

Figure 1 describes the evolution of the infrared absorption signature of the tholins films as a function of the irradiation wavelength. It seems that the main difference happens at 95 nm. The N-H amine signature (3250 cm^{-1}) decreases while the saturated-hydrocarbon ones increases (2920 and 2850 cm^{-1}), which is consistent with a transfer of H from N to C. This leads us to think that VUV irradiation, firstly, dishydrogenates the amines functions and, secondly, increases hydrogenation of olefinic structures in the aerosols.

Implications for Titan's aerosols

Because of absorption, the atmospheric penetration depth varies from one wavelength to the other. For Titan, the 95 nm radiations are more likely to occur above 1000 km of altitude, while the 121.6 and 190 nm ones will be more absorbed in lower parts. Our results imply then a chemical evolution of the aerosols right after their appearance in the thermosphere. The growth process in the ionosphere will enrich the nanoparticles with N-bearing groups, which will be simultaneously affected by the short VUV radiations, as in our experimental conditions, in order to favor the aliphatic groups. Those results are in agreement with the Cassini-VIMS[7] and CIRS[8] measurements in the stratosphere, showing a main saturated-hydrocarbon signature of Titan's aerosols in the mid-IR range.

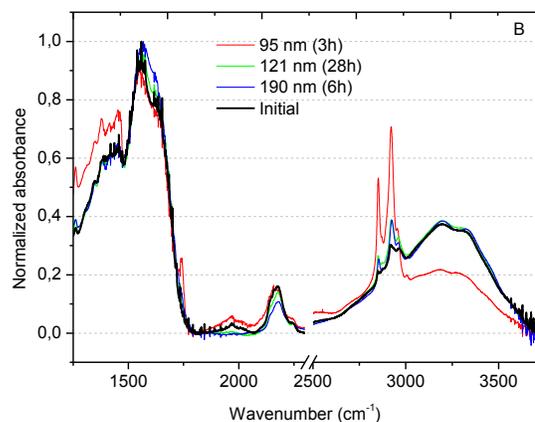


Figure 1: Infrared absorption spectra recorded from samples irradiated by photons for 3h (95 nm), 28h (121.6 nm), and 6h (190 nm). The thick black spectrum is the mean of the non-irradiated spectra.

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