Laboratory simulation of plasma-aerosols interaction in Titan's ionosphere

Audrey Chatain, Nathalie Carrasco, Ludovic Vettier, Thomas Gautier, Olivier Guaitella

EPSC Abstracts
Vol. 13, EPSC-DPS2019-1317-1, 2019
EPSC-DPS Joint Meeting 2019

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

Laboratory simulation of plasma-aerosols interaction in Titan's ionosphere

Audrey Chatain (1,2), Nathalie Carrasco (1), Ludovic Vettier (1), Thomas Gautier (1) and Olivier Guaitella (2)
(1) LATMOS/IPSL, UVSQ Université Paris-Saclay, Sorbonne Université, CNRS, Guyancourt, France
(2) LPP, Ecole polytechnique, Sorbonne Université, université Paris-sud, CNRS, Palaiseau, France
audrey.chatain@latmos.ipsl.fr

Abstract

Organic aerosols formed in Titan's upper atmosphere are surrounded by very reactive plasma species. The present work aims to study the potential interactions between aerosols and plasma species.

The exposure of aerosols to plasma is simulated in a cold plasma reactor. IR transmission spectroscopy gives clues about the chemical modifications of the aerosols. Mass spectrometry simultaneously measures the neutral species and positive ions in the gas phase. We observe the formation of HCN and carbocations while ammonia density is decreased by the addition of organic aerosols in the N_2-H_2 plasma.

1. Introduction

Saturn's biggest moon Titan is famous for its orange organic aerosols that spread in all its atmosphere and on its surface. A few information is known about them, especially thanks to the Cassini-Huygens mission. There are complex organic grains of few nanometers formed in the upper atmosphere [1].

The upper atmosphere is then the first place to study to understand how these aerosols are formed. At these altitudes, the major gases N_2, CH_4 and H_2 are partially ionized by energetic photons and particles. This region is a dusty plasma, a mixture of neutrals, ions, electrons and dust. This environment is highly reactive and leads to complex chemical reactions that can form aerosols, but also modify them during their stay in the ionosphere.

To complete the work started by Cassini in Titan's ionosphere, several groups started to gather clues on the formation of these aerosols thanks to cold plasma reactors. They fairly reproduce the ionization conditions in the upper atmosphere of Titan and similarly lead to the formation of complex organic grains, named 'tholins'.

Here our objective is to understand how small grains formed in Titan's ionosphere interact with their surrounding plasma environment

2. Method: laboratory simulation

First, a RF plasma in 95% N_2 and 5% CH_4 gas mixture at 1 mbar is used to produce tholins. These grains have already been studied and have similar IR signature as Titan's aerosols [2].

These grains are spread on a thin stainless steel grid which is inserted in a homogeneous DC plasma reactor. To study the interaction of grains with plasma, without forming new grains, carbon is removed from the gas mixture: only N_2 and H_2 are injected in the reactor, with an H_2 percentage varying from 0 to 5%. Pressure is set between 0.5 and 4 mbar, and the current is varied between 10 and 40mA. These conditions lead to an ionization ratio similar to the one of Titan's ionosphere, around 10^{-8}.

3. Multi-instrumental study

During the exposure of tholins to plasma, simultaneous *in situ* measurements are done to study the evolution of both the solid phase and the gas phase. The objective is to correlate changes seen on the tholins with the formation of new gas species.

A FT-IR spectrometer (ThermoScientific) is used to measure IR transmission spectra through the tholin sample before, during and after its exposure to plasma. Spectra are taken from 1000 to 4000 cm^{-1} with a resolution of 1 cm^{-1}. They give information on the chemical functions of the sample and their evolution during the exposure.

A quadrupole mass spectrometer (Hiden Analyticals) monitors the gas phase composition. Neutrals and positive ions are measured before, during and after the exposure, studying masses from 2 to 100 u with a resolving power of 1 u.

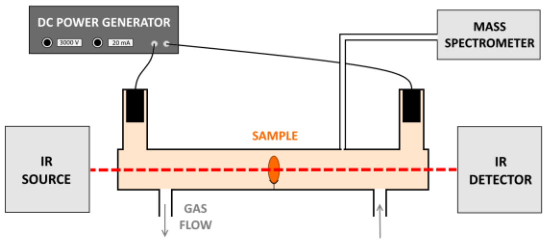

Figure 1: Experimental setup

4. Evolution of the solid phase

Tholin grains are eroded while exposed to plasma, and partly removed from the sample. IR spectra show a strong decrease in absorbance, but also modification of the absorption bands shapes. The more impacted bands are related to C≡N bonds. Depending on plasma parameters, changes can be seen such as the disappearance of isonitriles (2140 cm^{-1}) and the formation of a new unsaturated nitrile band around 2215 cm^{-1}. Similar results on KBr pellets were discussed in [3].

5. Evolution of the gas phase

5.1 Neutral species

The time-evolution of the neutral species is given on Figure 2. Ammonia at m/z 17 is produced when the discharge is on without tholins, and then decreases when tholins are introduced. Tholins seem to absorb ammonia or prevent its formation. On the contrary carbonated species appear at masses such as m/z 27 (HCN), 41 (C_2H_3N) or 52 (C_4H_4).

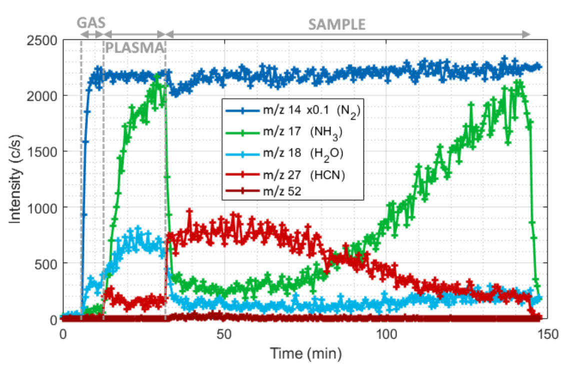

Figure 2: Evolution of some neutral species in a 95% N_2 – 5% H_2 mixture at 1 mbar – 20 mA plasma at 13min and insertion of tholins at 32 min.

5.2 Positive ions

A similar evolution of the positive ions is detected in the presence and in the absence of tholins in the discharge: ammonia ions decrease while organic ions appear, such as C_x^+ (m/z 12, 24, 36), $C_xH_y^+$, CNH_y^+ (m/z 27, 28), and at masses around m/z 53 ($C_xN_yH_z^+$).

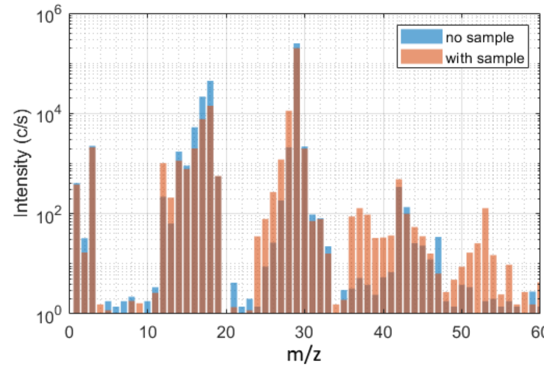

Figure 3: Evolution of positive ions in a 95% N_2 – 5% H_2 plasma at 1mbar and 20 mA

6. Summary and Conclusions

The exposure of tholins to a N_2-H_2 plasma leads to modifications in both the solid and the gas phase. Tests with different amounts of H_2 showed that H_2 is a fundamental reactive molecule to obtain a strong interaction between plasma and tholins, and maybe through the formation of NH_3. We can also guess that the evolution of nitriles in tholins is linked to the formation of HCN in the gas phase.

Acknowledgements

NC acknowledges the financial support of the European Research Council (ERC Starting Grant PRIMCHEM, Grant agreement no. 636829). AC acknowledges ENS Paris-Saclay Doctoral Program.

References

[1] Lavvas, P., Yelle, R. V. et al. Aerosol growth in Titan's ionosphere. Proceedings of the National Academy of Sciences, 110(8), 2729-2734, 2013.

[2] Gautier, T., Carrasco, N. et al. Mid- and far-infrared absorption spectroscopy of Titan's aerosols analogues. Icarus, 221, 320-327, 2012

[3] Chatain, A., Carrasco, N. et al. Evolution of organic aerosols under conditions similar to Titan's ionosphere. European Planetary Science Congress, vol. 12, 2018