The APSIS EXPERIMENT: Simulating the VUV Photochemistry of the Upper Atmosphere of Titan

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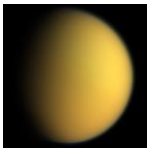


Figure 1 & 2: Titan seen by the Cassini's imager

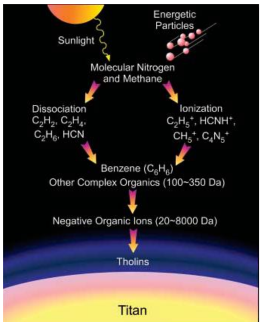


Figure 3: Aerosols' formation in Titan's upper atmosphere

Titan, the largest moon of Saturn, has a **dense atmosphere** whose **upper layers** are mainly composed of **methane (CH_4) and molecular nitrogen (N_2)**. The **Cassini mission** revealed that the **interaction** between those **molecules** and the **solar VUV radiation**, as well as the electrons from Saturn's magnetosphere, leads to a **complex chemistry above an altitude of 800km** [1].

This **naturally ionized environment** contains **heavy organic molecule**s like benzene (C_6H_6) even at altitudes higher than 900 km [2]. This is consistent with an **initiation of the aerosols in Titan's upper atmosphere**. Moreover, some **N-bearing molecules of pre-biotic interest** such as NH_3 have been detected by the instruments; but in quantities that do not match the theoretical models [3] .

The presence of those molecules **makes Titan a natural laboratory** to witness and understand **prebiotic-like chemistry** but despite all the data collected, **all the possible chemical processes in such a hydrocarbon-nitrogen-rich environment are not precisely understood.**

→ High interest of **Titan's ionospheric chemistry experiments** with **pure-photochemistry simulations**

The APSIS Experiment

Atmospheric Photochemistry SImulated by Surfatron

In order to reproduce the efficient photochemistry occurring in this **kind of upper atmospheres**, we designed **a gas reactor named APSIS.** This reactor is to be **coupled with a VUV photon source (figure 5)** as **N_2 needs wavelengths shorter than 100 nm** in order to be dissociated.
The APSIS reactor is described in details in [4]. Briefly, it is a stainless steel chamber of dimensions 500 mm x 114 mm x 92 mm where the reactive **95:5 N_2:CH_4 mixture** is introduced via a gas inlet (figure 4)

The VUV Source

At the LATMOS laboratory, a **surfatron source** has been developed **using noble gases in a micro-wave discharge**. For example, **neon has two resonance lines at 73.5 and 74.3 nm** which allow us to dissociate and/or ionize both CH_4 and N_2.
The photon flux of the source depends on the neon pressure and the micro-wave power delivered. We calculated it for the 73.5-nm neon line: it varies between a maximum of $4{\times}10^{14}$ ph.s^{-1}.cm^{-2} (1.7 mbar and 100W) and a minimum of $2{\times}10^{13}$ ph.s^{-1}.cm^{-2} (0.4 mbar and 40W) (figure 6).

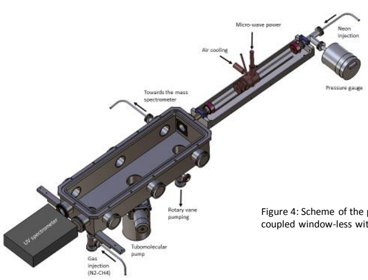
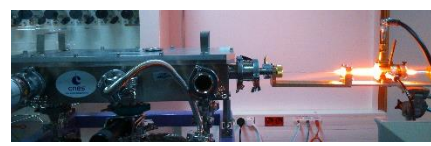


Figure 4: Scheme of the photochemical reactor coupled window-less with the VUV source.

Figure 5: Picture of the APSIS reactor coupled window-less with the VUV neon source.



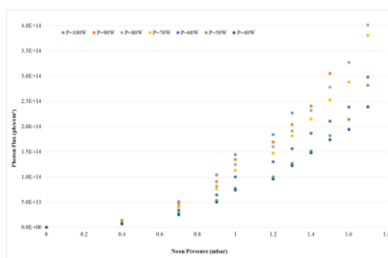


Figure 6: Photon flux of the VUV source versus the neon pressure and the micro-wave power

RESULTS

P_{APSIS}= 0.5 mbar
P_{neon}= 1 mbar
P_w=80W
Diagnosis by mass spectrometry: HIDEN HPR-20 QIC mass spectrometer

Figure 7 shows **analogue mass spectra prior** (black curve) **and after** (red curve) **irradiation** of the reactive medium with the VUV surfatron-based source. It shows **clear productions of C2 compounds**, but also **C3 and C4**. This is confirmed by **time-monitored spectra** of the **masses m/z=27** (figure 9) **and 52** (figure 10) (possible molecules: HCN and C_2N_2 respectively) which reveal **a sharp rise of the signals when the VUV source is turned ON** (red lines).
The consumption of methane is moreover followed versus time (figure 8), showing a **decrease of nearly 5% in 25 minutes**.
All the results are reproductible.

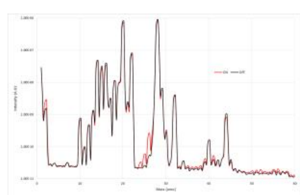
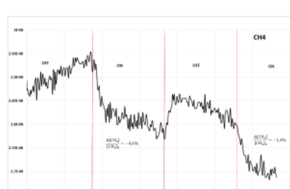
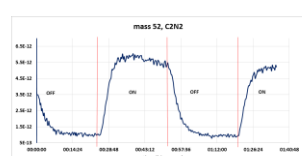


Figure 7 (top): analogue mass spectra before (black curve) and after (red curve) irradiation with the VUV source
Figure 8 (bottom): CH_4 consumption monitored with time. The red lines show the moments the VUV source is turned ON.

Figure 9 (top): time-monitored productions of HCN (m/z=27) showing reproductibility. The red lines show the moments the VUV source is turned ON.
Figure 10 (bottom): Same but for C_2N_2 (m/z=52)





PERSPECTIVES

The high flexibility of our VUV source will allow us to change the rare gas and thus the wavelength used to irradiate the reactive mixture. For example, helium provides 58-nm radiations and argon 104-nm ones.
Inside APSIS, the pressures can also vary as well as the CH_4 ratio.
Testing all those conditions will give us more information on the photochemical processes occuring in Titan's upper atmosphere and shed some light on prebiotic-like chemistry.

References:

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4. Carrasco N, et al. VUV photochemistry simulation of planetary upper atmosphere using synchrotron radiation. J Synchrotron Radiat. 2013;20(4):587–9.