Laboratory Astrophysics Studies of the Evolution of Organic Matter with the COSmIC Facility.

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1. Introduction

Understanding the origin of organic matter in astrophysical environments ranging from circumstellar (CS) outflows to diffuse and dense interstellar (IS) clouds to protoplanetary disks and planetary bodies has become a central objective in astrophysics. Experimental facilities dedicated to the formation and characterization of laboratory analogs generated under conditions relevant to the targeted environments have been developed in the past recent years. Recent advances achieved in laboratory astrophysics using COSmIC's laboratory data in synergy with observational data will be presented. These results include the use of laboratory spectra to search for IS organic molecules and ions in astronomical spectra, the formation of laboratory analogs of CS and IS dust grains and planetary atmospheres aerosols from molecular precursors.

2. The Cosmic Simulation Chamber (COSmIC)

The COSmIC facility is a versatile facility (cf. Fig. 1) that was developed to study the formation and the evolution of organic matter in CS, IS, and planetary environments in the laboratory[1]. COSmIC is dedicated to the study of neutral and ionized molecules, nanoparticles and sub-µm solid grains under the low temperature and density conditions that are required to simulate space environments. It is composed of a Pulsed Discharge Nozzle (PDN) that generates a plasma in a free supersonic jet expansion, coupled to high-sensitivity, complementary *in situ* tools used for the detection and characterization of the neutral and ionized gaseous species present in the expansion: Cavity Ring Down absorption Spectroscopy (CRDS) and fluorescence spectroscopy systems for photonic detection and a Reflectron Time-Of-Flight Mass Spectrometer (ReTOF-MS) for mass detection[1]. Solid phase products resulting from the plasma-induced chemistry can be collected on various substrates and analyzed using different *ex situ* techniques (SEM, IR). The chemistry is

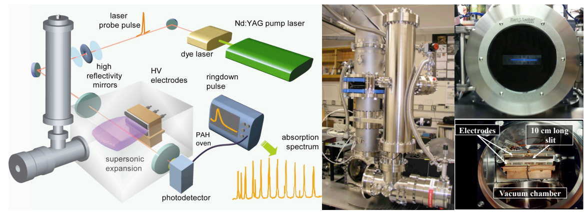

Figure 1. Schematics and photo of COSmIC.

simulated by plasma in the stream of a pulsed, supersonic jet-cooled expansion. The nature of the seeded carrier gas is adjusted to the environment that is simulated in the experiment, e.g., inert gases such as Ar for interstellar and circumstellar experiments and nitrogen for Titan atmosphere experiments. The unique characteristic of the COSmIC facility is that it cools down the seeded carrier gas to circumstellar outflow temperature or Titan-like temperature (150 K) *before* inducing the chemistry by plasma[1], and that the pulsed nature of the plasma allows for a controlled chemistry that can be used to study the early stages of grains and/or aerosol production, which has not been readily accomplished so far using other production methods. Different Ar-Hydrocarbon (CH_4, C_2H_2, PAH)-based gas mixtures can be injected in the plasma for the circumstellar outflow simulation experiments while N_2-CH_4-based gas mixtures can be injected in the plasma, with or without the addition of trace elements (C_2H_2, C_6H_6, etc) present on Titan for the Titan Haze Simulation (THS) experiments. The *in situ* and *ex situ* analyses of both the gas[1] and solid phase[1] products resulting from the plasma-induced chemistry can be used to interpret astronomical observations and Cassini's return data.

3. Gas Phase Studies

3.1. Signature of neutral and ionized interstellar aromatic molecules and ions:

CRDS spectra of neutral and ionized PAH molecules isolated in a free cold jet expansion with Ar buffer gas have been measured in COSmIC, and compared to the spectra of reddened stars along lines of sight probing IS clouds[1]. Upper limits for the column densities were derived for IS PAH molecules.

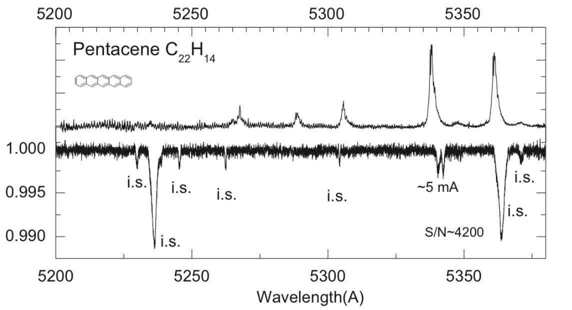

Figure 2: Absorption spectrum of a prototype PAH along lines of sight probing translucent IS clouds [8].

3.2. Formation of organic aerosols in Titan's Haze:

in situ TOF mass spectrometry analyses of the gas phase[1] and modelling studies[1], have demonstrated the advantage of the COSmIC/THS to probe the first and intermediate steps of the N_2-CH_4 chemistry and the chemical pathways in Titan's atmosphere.

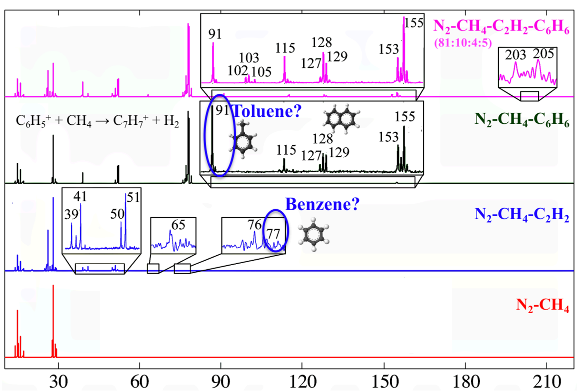

Figure 3: ReTOF THS mass spectra for N_2-based mixtures demonstrating that a controlled chemistry can be achieved in the COSMIC/THS experiment[1].

Due to the short residence time of the gas in the pulsed plasma discharge, only the first steps of the chemistry occur in a N_2-CH_4 discharge. By adding heavier hydrocarbon trace elements to the initial N_2-CH_4 mixture (C_2H_2, C_6H_6…), we observe a chemical growth evolution and study the intermediate steps of Titan's atmospheric chemistry as well as specific chemical pathways. The results of this gas phase study have been compared to data from the Cassini CAPS-IBS instrument and have provided encouraging results that illustrate the unique power of the COSmIC/THS laboratory approach to help analyse and understand return data from Cassini.

4. Solid Phase Studies

In COSmIC, simple hydrocarbons (CH_4, C_2H_2) and PAHs seeded in either Ar or N_2 gas can be used as precursors to generate and study IS, CS and planetary grain formation, respectively in the gas phase. IS grain- and Titan aerosol analogs produced in gas mixtures of various chemical complexity were analyzed *ex situ* using Scanning Electron Microscopy (SEM), X-Ray Absorption Spectroscopy, mass spectrometry, and visible and IR spectroscopy in order to investigate the effect of the initial gas mixture on the morphology and composition of these solid grains. SEM images have shown that the grains produced from heavier precursors are much larger, consistent with a more complex chemistry occurring when adding heavier precursors, as observed in the gas phase.

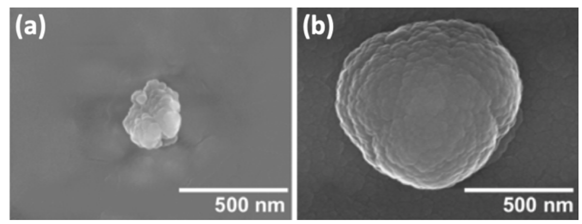

Figure 4: SEM images of grain produced in (a) N_2/CH_4 (95:5) and (b) $N_2/CH_4/C_2H_2$ (90:5:5).

Acknowledgements

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References

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