Laboratory Calibration Studies in Support of ORGANICS on the International Space Station: Evolution of Organic Matter in Space

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Abstract

This paper describes the scientific overview and current status of ORGANICS an exposure experiment performed on the International Space Station (ISS) to study the evolution of organic matter in space (PI: P. Ehrenfreund), with supporting laboratory experiments performed at NASA Ames. ORGANICS investigates the chemical evolution of samples submitted to long-duration exposure to space environment in near-Earth orbit. This experiment will provide information on the nature, evolution, and survival of carbon species in the interstellar medium (ISM) and in solar system targets.

1. Introduction

Understanding the chemical evolution of organic (carbon-based) matter in space is of great importance for the study of the origin of Life on Earth. Carbon- based molecules form a large fraction of the species detected in the interstellar medium (for recent reviews see Henning & Salama 1998; Ehrenfreund & Charnley 2000). The ORGANICS experiment has been selected by ESA for External Payload on the International Space Station for the study of the effects of near-earth space environment (VUV, vacuum, cosmic rays) on carbonaceous matter. Polycyclic Aromatic Hydrocarbons (PAHs) are observed in reflection and planetary nebulae, HII regions and external galaxies and are thought to be the most abundant free organic molecules and the carriers of some of the visible Diffuse Interstellar Bands (DIBs). PAHs have also been identified in meteorites, interplanetary dust particles (IDPs) and in comet Halley. In the ISM, PAHs can be neutral, ionized, partly dehydrogenated or even fragmented depending on the environment. Fullerenes, could also be important carriers of carbon in our Galaxy. C_{60} and larger fullerenes up to C_{240} have been detected in the Allende meteorite while C_{60}^{+} might be associated with two DIBs in the NIR. Finally, Kerogen is a mixture of complex organic macromolecules. More than 90% of the carbon in meteorites is in the form of insoluble kerogen-type residues (Gardinier *et al.* 2000). By subjecting these molecules to near-earth orbit conditions we simulate the deep space conditions in terms of cosmic rays, space vacuum and ionizing radiation. An extensive laboratory simulation program is now in progress in support of this space experiment (Ruiterkamp *et al.* 2002).

2. Experimental Setup

The ORGANICS experiment is integrated in the multi-user facility EXPOSE that contains 9 experiments dedicated to astrobiology. Selected samples will be exposed to space environment on the outside of the ISS. The samples will remain at least one year onboard the ISS before they are returned to Earth. The radiation dose that is collected by the samples during flight exceeds the limits for simulation in the laboratory and the results will greatly enhance our knowledge of the evolution of large organic molecules in space environment. Due to changes in the ISS external payload program, the mounting site of the EXPOSE experiment on board the ISS is currently not defined.

Sample Carriers: Samples are deposited in thin ($\sim 1\ \mu m$) films by spin coating on MgF_2 windows inside the sample cells (see Figure 1A). Dark samples on the Lower Sample Carrier are shielded from the UV photons and enable us to discriminate between the effects of exposure to photons and cosmic rays. Additional filters will enable us to select specific spectral regions for samples. The 1mm thick MgF_2 windows that hold the sample films are transparent well into the VUV.

Sample Tray: The sample carriers containing the different experiments of the EXPOSE facility are mounted in a sample tray (see Figure 1B). This tray is closed by MgF_2 windows and is equipped with shutters over some of the experiments. Passive and active heating keep the temperature in the 0-25 degree Celsius range. The design of the sample trays allows retrieval of the experiments without transporting the complete EXPOSE support structure. The particle and UV Radiation dose is monitored by the R3D dosimetry experiment situated at the sample level in one experiment tray. Thermocouples are installed at all experiments to monitor the temperature. The ORGANICS experiment will be situated in two compartments of the tray. One compartment will be closed from the external environment and one compartment will be vented to space.

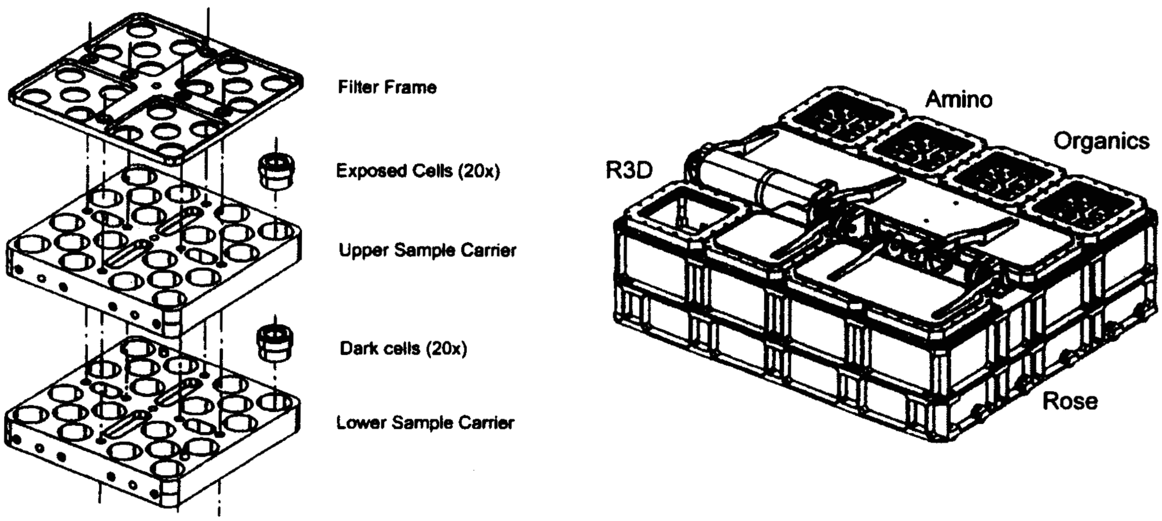


Fig. 1.— A. (left): Layout of the Sample Carriers used in the ORGANICS experiment. Samples are deposited on the inside of the MgF2 pellets that seal the sample cells. B. (right): Sample Tray of EXPOSE. The acronyms of the experiments are located at their assigned positions. The ORGANICS experiment consists of one sealed sample compartment and one vented to space.

3. Experimental Goals

The ORGANICS experiment will investigate the UV photochemistry of complex organic materials and study their evolution in space. It will provide better constraints on the composition and the survival rate of carbonaceous molecules in space (ISM and planetary/cometary surfaces). Matrix isolation spectroscopy of PAHs (Salama 1996) is performed as an integral part of the EXPOSE experiment. The laboratory simulations guides the selection of flight samples and provide an essential tool for the identification of the DIB carriers (Ruiterkamp *et al.* 2002). The results of this experiment will also be of relevance to planetary sciences and could help constrain the cosmic delivery of organics onto planetary surfaces, such as Earth and Mars (ten Kate *et al.* 2002).

4. Approach

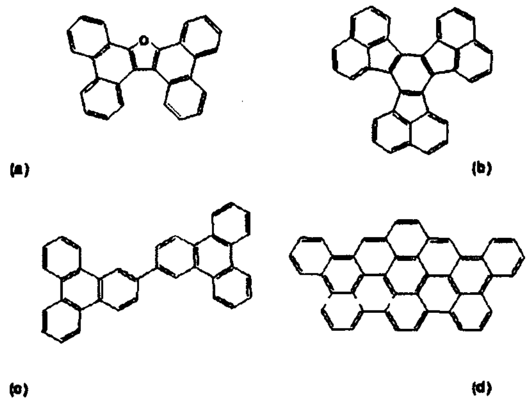
Flight samples will be selected from a set of large PAH molecules, synthesized by the PAH Forschungs Institut. The sample selection will focus on large stable PAHs; aza-, oxo-, thio-PAHs; PAH isomers and potentially reactive PAH species (see Figure 2A).

The selection of large fullerenes depends on sample availability but will include C_{60}, C_{70} and C_{84}. The kerogen samples are of type III that most closely resembles the infrared spectrum of carbonaceous extracts of the Orgueil meteorite (Ehrenfreund *et al.* 1991).

Pre-flight analysis of the samples will consist of a combination of IR spectroscopy, fluorescence spectroscopy, UV/Visible spectroscopy, time-of-flight secondary ion mass spectroscopy, matrix isolation spectroscopy and isotopic analysis by the members of the team. The change in chemical composition resulting from the exposure of the samples on the Space Station Express Pellet will be evaluated with the same methods after retrieval. The EXPOSE platform is equipped with a dosimetry experiment that monitors the flux of radiation striking the sample tray. This will enable us to monitor the total energy input at the samples and to correlate with the spectral information.

5. Preliminary Results and Current Status

The selection and the calibration of the PAH and fullerene samples have been performed through Matrix Isolation Spectroscopy (MIS) studies (Ruiterkamp *et al.* 2002). In MIS, a gas mixture of PAHs highly diluted in Neon is frozen on a cold (5 K) substrate. The inert Ne matrix is transparent to UV. Irradiation with 10.2 eV photons from a hydrogen discharge lamp leads to the formation of PAH ions that are detected through their characteristic electronic spectra in the UV- Visible range (Salama 1996). This method has also been shown to be an effective tool for the preselection of promising species as potential diffuse interstellar band (DIB) carriers (Salama *et al.* 1999). Definitive detection can only be made, however, through free jet expansion (gas-phase) experiments (see e.g. Biennier *et al.* in this volume). In Figure 2B, the spectrum resulting from the 2B convolution of the MIS spectra of 10 PAH ions is compared to a synthetic DIB spectrum in an arbitrary scale. Although no definitive comparison can be made at this preliminary stage, a general overview of the spectral resemblance can be derived. The absence of spectral features toward the infrared of the DIB spectrum is due to the lack of astronomical data and not to a lack of features in this spectral region.



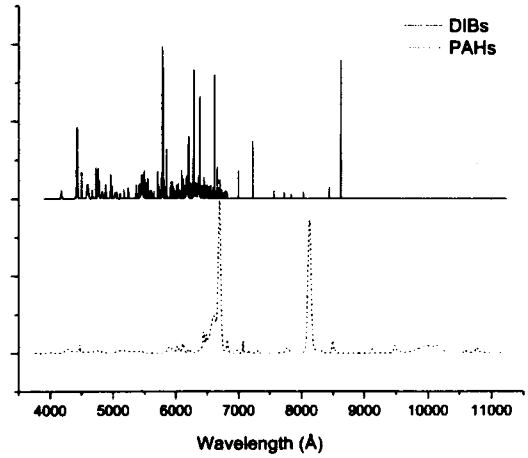


Fig. 2.— A. (left): Examples of Polycyclic Aromatic Hydrocarbons (PAHs) that will be used in the ORGANICS experiment. (a) Diphenanthrofuran, (b) decacyclene, (c) (2,2')-bis-triphenylyl, (d) hexabenzoperopyrene. B. (right): Spectral comparison of a synthetic PAH spectrum composed of the Matrix Isolation spectra of 10 PAH ions and a synthetic DIB spectrum.

In preparation of the ORGANIC experiment on ISS we perform a short duration exposure experiment on BIOPAN. In this experiment the samples will be exposed to near earth orbit conditions for approximately two weeks. The BIOPAN experiment tray will be launched from Russia in October 2002 and the first results will be expected shortly thereafter. The current status of the EXPOSE platform on the ISS allows no definitive prediction of the launch date. In the mean time we will continue the chemical analysis of complex organic molecules and its implications for cosmo-chemistry.

Acknowledgments

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