Multiple beam irradiation platform MIRRPLA: origin and evolution of organic matter in the solar system

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"Where do we come from?" is one of the important fascinating open questions of science and philosophy. How did life emerge? What is the origin of organic matter in the universe? Could life also emerge on other worlds than our Earth? Complex organic molecules have indeed been observed in space (comets, meteorites, molecular clouds). In 2023, France launched the *Programmes et équipements prioritaires de recherche* (PEPR) Origins (life and universe), through the program leader the National Centre for Scientific Research, to address these questions [1]. Understanding the origin of primitive organic matter during the formation and evolution of the solar system is fundamental because the contribution of extraterrestrial organic matter via asteroids and comets is one of the possible sources of organic matter available to primitive Earth [2].

In astrophysical environments, icy layers are omnipresent (e.g., micrograins in molecular clouds) and are constantly exposed to multiple radiations (ultraviolet [UV], X-rays, electrons, and ions from solar winds, cosmic rays, and ions trapped in magnetospheres) [3]. Following radiolysis, complex organic molecules can be synthesized [2, 3]. These different types of radiation act simultaneously, but existing laboratory astrophysics experiments are generally performed using a single radiation source and synergistic effects are not studied. It is therefore necessary to carry out simultaneous irradiation with several beams (photons, ions, electrons) to simulate a realistic space radiation field.

Within the PEPR Origins, a unique multibeam irradiation platform (UV photons, keV electrons and keV-GeV ions delivered by the Grand Accélérateur National d'Ions Lourds (GANIL, Caen France) equipped with an infrared spectrometer and a cold head to prepare layers of ices made of mixtures of small molecules will be constructed. Complex organic molecules formed during the irradiation and/or heating of ice layers will be detected using gas phase chromatography and *in-situ* mass spectrometry. This new versatile instrument, the MIRRPLA platform (Multiple-beam IRRadiation PLAtform to investigate the origin and evolution of organic matter of the Solar System), will be open to the various scientific communities (astrophysics, radiobiology,

environmental and materials sciences) as well as to industry via the GANIL–Centre de Recherche sur les Ions, les Materiaux et la Photonique (CIMAP) - Centre for Interdisciplinary Research with Heavy Ions (CIRIL) user platform [4]. Figure 1 shows the involved partners and organizations. Figure 2 the unique principle of MIRRPLA.

The uniqueness of the proposed setup consists in the combination of different types of ionizing radiation (photons, electrons, ions), including the possibility of simultaneous irradiation of samples: for example, GANIL ion beam plus photons or UV electrons to simulate a complex irradiation field, as in space (Figure 2). The modifications induced by the energy treatment will be monitored by Fourier transform infrared absorption spectroscopy. The species emitted to the gaseous phase via a sputtering or desorption mechanism will be monitored by quadrupole mass spectrometry. In addition, a high-resolution mass spectrometer coupled with gas chromatography (CG-Orbitrap) will be connected to the irradiation chamber to study the volatile organic compounds synthesized during the irradiation of ice astrophysical analogs.

In addition to studies of synergistic effects with realistic space radiation fields on icy surfaces, MIRRPLA will also provide organic residues (analogs of primary matter from space) to other PEPR Origins partners for benchmarking chemical analysis techniques or comparison to returned space samples. Beyond the questions related to the origin of complex (prebiotic) organic species in the universe, MIRRPLA also will have an impact in other fields of societal importance. To give some examples, health issues such as fundamental processes in mixed irradiation of biomolecules and deoxyribonucleic acid fragments to develop new cancer treatment protocols can be addressed. Concerning environmental science, polycyclic aromatic hydrocarbons are produced in combustion and are key intermediates in the formation and growth of soot particles. In addition, carbon nanoparticles can be covered with water ice in the upper part of the atmosphere and be exposed to different types of ionizing radiation. For materials sciences, this unique facility makes it possible to study (1) the aging of materials under mixed irradiation environments (nuclear fuel cells, reactor materials, ceramics/glass for the storage of radioactive waste, polymers), and (2) simultaneous multiradiation effects on materials used in spacecraft and space missions (hull, electronics).

The kickoff meetings of MIRRPLA and Origins were held on 26 June 2023 at CIMAP–GANIL, Caen, and on 18–21 September 2023, at Collège de France, Paris, respectively.

Acknowledgment: This work benefits from state aid managed by the French National Research Agency under France 2030 investment plan (reference ANR-22-EXOR-0012).

References

[1] PEPR Origins: https://pepr-origins.fr/

[2] Paola Caselli and Cecilia Ceccarelli, **Our astrochemical heritage**, *The Astronomy and Astrophysics Review* 20 (2012): 1-68.

[3] Guillermo M. Muñoz Caro and Emmanuel Dartois, **Prebiotic chemistry in icy grain mantles in space. An experimental and observational approach**, *Chemical Society Reviews* 42 (2013) 2173-2185.
[4] J. Rangama, C. Grygiel, A. Mery, P. Rousseau, H. Rothard, ***CIRIL: Interdisciplinary Research at GANIL***, *Nucl. Phys. News.* 32, No. 2 (2022) 29-33.

Figure 1. Partners involved in MIRRPLA: CIMAP (Centre de Recherche sur les Ions, les Materiaux et la Photonique, Caen, France) and laboratory PIIM (Physique des Interactions Ioniques et Moléculaires, Marseille, France).

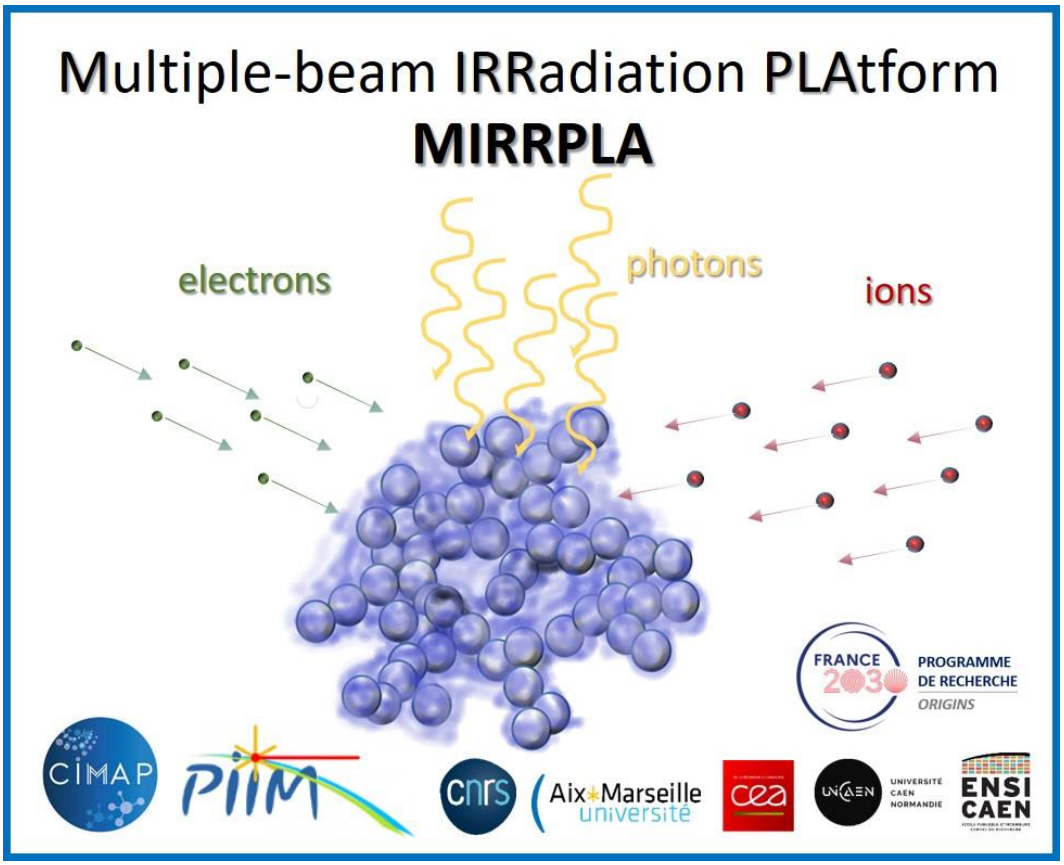

Figure 2. Schematic representaion of the unique principle of MIRRPLA.