Intitulé du Sujet de Thèse : Molecular complexity in astrophysical objects

Laboratoire : Physique des interactions ioniques et moléculaires (PIIM)

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Contexte de l'étude

Interstellar dust grains of the order of 0.1 µm in size are made up of a silicate core. During their transit through the interstellar medium, they may find themselves in certain regions known as dense molecular clouds, where the main elements contained in these clouds (H, O, N, C, etc.) can accrete, then combine to form molecules such as H_2O, CO, CO_2, H_2CO, CH_3OH and NH_3.(1) These molecules gradually cover the surface of the grains, forming so-called "primitive" interstellar ices. The composition of these ices will then evolve under the action of energetic processes (UV, particles, etc.) during the transition from a dense molecular cloud to the formation of a planetary system.(1)

It therefore seems that there is a link between the composition of cometary and asteroidal grains and that of the primitive interstellar grains contained in the molecular cloud. It is this relationship that we wish to establish by following the whole process of evolution of the composition of these grains and especially the role of radicals in the complexification of organic matter in the various environments of the interstellar medium and planetary systems.(2)

Descriptif du projet

We propose to study in the laboratory the evolution and complexification of organic matter in stellar nebulae up to its incorporation into small solar system objects (comets and asteroids). The aim is to understand the origin of the formation of complex nitrogenous molecules (nitriles, amines, amides, cyanopolyynes) in the conditions of the interstellar medium, in small solar system objects (comets and asteroids) and in planetary atmospheres.

At very low temperatures (10 K- 100 K), we will deposit primitive molecules (H_2O, CO_2, CO, NH_3, H_2CO, HCN, etc.) that make up interstellar ices. We will then simulate their evolution by irradiating them with VUV photons (120 nm) and electrons (0.1 – 10 KeV). We have experiments capable of simulating the vacuum (10^{-9} mbar) and temperature (10-300 K) conditions of such environments (AHIIA, RING, RARICI devices). The evolution of ice composition will be measured by infrared spectrometry, mass spectrometry or low-temperature EPR spectrometry. The latter technique (EPR) - rarely used in astrochemistry - will enable us to characterize the radical species formed during irradiation of the ices, and to study their lifetimes at low temperatures (10-100 K), as well as the formation mechanisms of complex organic nitrogen molecules formed in irradiated primitive ices.(2,3) These studies are also intended to provide astrophysicists with new compounds potentially detectable in cometary environments or in star-forming regions. The results obtained will therefore be particularly useful in the interpretation of data collected by missions dedicated to the analysis of cometary nuclei and asteroids, or by observation satellites (JWST). These data will also be useful to astrobiologists studying (among other things) the role of interstellar and cometary organic matter in the emergence of life on Earth.

Références Bibliographiques

(1) Boogert, A. C. A.; Pontoppidan, K. M.; Knez, C.; Lahuis, F.; Kessler-Silacci, J.; van Dishoeck, E. F.; Blake, G. A.; Augereau, J.-C.; Bisschop, S. E.; Bottinelli, S.; et al. The c2d Spitzer Spectroscopic Survey of Ices around Low-Mass Young Stellar Objects. I. H2O and the 5-8 Mm Bands. Astrophys. J. 2008, 678 (2), 985. https://doi.org/10.1086/533425.

(2) Chuang, K.-J.; Fedoseev, G.; Qasim, D.; Ioppolo, S.; van Dishoeck, E. F.; Linnartz, H. Production of Complex Organic Molecules: H-Atom Addition versus UV Irradiation. Mon. Not. R. Astron. Soc. 2017, 467 (3), 2552–2565. https://doi.org/10.1093/mnras/stx222.

(3) Gutierrez A.; Layssac, Y.; Butscher, T. ; Henkel, S.; Tsegaw, YA.; Grote, D.; Sander, W.; Borget, F.; Chiavassa, T. Duvernay, F. iCOM formation from radical chemistry: a mechanistic study from cryogenic matrix coupled with IR and EPR spectroscopies. Mon. Not. R. Astron. Soc. 2021, 506 (3), 3734–3750.