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# From Astrochemistry to Astrobiology: a methodological approach

**L. Le Sergeant d'Hendecourt** (1), G. Danger (2)

(1) Institut d'Astrophysique Spatiale, CNRS-UPS, Campus d'Orsay, 91400 Orsay, France, ldh@ias.u-psud.fr

(2) Aix-Marseille Univ, PIIM UMR 7345, 13397, Marseille, France, gregoire.danger@univ-amu.fr

## Abstract

Astrochemistry is a well-established discipline of astrophysics devoted mainly to the chemistry that is observed in the interstellar medium. Complex organic molecules are found in many different environments, mainly in molecular clouds in star forming regions. However, it is not clear if these molecules, often presented as prebiotic, are indeed involved in the process leading to life emergence on a planet. Based on astronomical arguments and on different laboratory experiments aiming at the simulation of interstellar ices, we examine the possible connection between astrochemistry and astrobiology.

## 1. Introduction

Solid state matter in astrophysical environments evolve in a cyclic manner. Heavy elements are produced in the nucleosynthetic processes within stars. They are ejected in space by the explosions of supernovae of massive stars. The interstellar medium is thus enriched in these elements and this astration process will lead to the universal (at least in our local interstellar medium) consequence that the relative abundances of the elements are described by the so-called cosmic abundances, well measured in the atmosphere of the Sun or in primitive chondrites. These cosmic abundances represent a very strong constraint for astrochemistry.

### 1.1 Grain formation processes

Solid state materials such as interstellar grains are observed to be formed in the atmospheres of late type stars, red supergiants in their AGB phases. These grains are of a mineral nature (eg silicates) or pure carbon, depending on the O/C ratio of the envelope where they are formed. Although nucleation and condensation are processes that are difficult to fully apprehend, the composition of these grains are usually correctly described, to the first order, by a condensation sequence at equilibrium that considers the formation of different minerals according to their thermodynamic properties (their enthalpy of formation).

### 1.2 Observed depletion of the elements

As is well known, cosmic abundances of the elements are not observed on lines of sight to distant stars: some elements are depleted. They are missing from the gas phase essentially because these elements, the more refractory ones, are blocked in the interstellar grains. Some elements are not depleted at all (N, S, P), others only mildly (O, C) while minerals-constituting elements (Si, Al, Fe, Mg, Ca) are heavily depleted (2 to 3 orders of magnitude).

### 1.3 Astrochemical evolution

The first obvious consequence of this grain formation process is that, since H,O,C,N, S (and P?) are abundant and present in the gas phase, these elements will display essentially an organic chemistry that is largely observed through radio-astronomy in the sub-mm and mm ranges. Furthermore, as noted very early by Oort and van de Hulst [1], gaseous elements that are cosmically abundant and remain in the gas phase of the interstellar medium will, together with hydrogen atoms, form simple hydrides ($H_2O$, $CH_4$, $NH_3$) and, in the presence of cold surfaces, vast amounts of ices will result. These ices are indeed observed by infrared spectroscopy; they are well documented and reflect the interplay between gas phase chemistry (ion-molecule reactions for example) and cold solid surfaces where ices can form, stabilize and offer the possibility to develop more chemical complexity.

## 1.4 Natural evolution of the ices

Astrophysical ices will follow a complex pathway that is related to the evolution of the molecular cloud leading to the formation of protoplanetary disks. Ices will get photo- and thermo-chemically processed and, because of the natural protection offered by the presence of the grain surfaces and their shielding, molecular complexity and the formation of very complex molecules is expected. This evolution is difficult to follow from observations essentially because infrared spectroscopic features are hidden by the most abundant species ($H_2O$). However, laboratory simulations are possible and present a global view to this molecular complexity.

## 1.5 Laboratory simulations

Laboratory simulations of the photo/thermo-chemical evolution of ices are relatively easy to perform in the laboratory using classical methods inherited from *Matrix Isolation Spectroscopy*. A gas mixture made of the most abundant observed IS molecules is deposited onto a cold (10 to 77 K) window and irradiated (in our case by UV photons). Heating the sample to room temperature always leads to the formation of a very complex organic residue that can be analysed by different methods from analytical chemistry techniques (gas chromatography coupled to mass spectrometry and/or Very High Resolution Mass Spectrometry techniques such as Orbitrap). The first method reveals the presence of many specific compounds such as amino-acids [2] and sugars [3] that may be related to prebiotic chemistry although the direct connection is not yet firmly established. The second method shows the obtained complexity: thousands of molecules are detected starting with a mixture containing only three simple ones [4]

## 1.6 The methodological approach

The extreme complexity of the organic residues produced by the simulations shows that a classical approach involving a full reductionist understanding of the formation of these species is clearly impossible. Non-directed experiments performed in the laboratory do represent the only possible solution to this problem. Tentative comparisons between this obtained complexity and the one observed in meteorites are underway and show that our approach, considering these organic residues as templates for this complex extraterrestrial chemistry offers some validity that needs to be seriously taken into account.

## 2. Summary and Conclusions

Astrochemical evolution, following the evolution of our Galaxy, clearly favours the emergence of a complex organic chemistry. The role of cosmic ices in this evolution toward complex organic matter can be simulated in non-directed laboratory experiments. However, the prebiotic nature of this matter and its role in prebiotic chemistry at the surface of a planet is far from being understood. Other non-directed experiments should be performed considering the interaction of these materials with the primitive environments offered by planets such as the Earth.

## References

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