Chemical evolution and release of molecular mantles at the surface of interstellar grains

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The atoms of which we are composed (H, C, O, N...), have passed multiple times through the cycle of formation and destruction of stars. Our molecular universe was born well before the formation of the Earth. Water (H_2O) is a very abundant molecule in the Universe, but the way it was delivered on Earth is still debated. More than 200 other molecules are observed in space. Some relatively complex (alcohols, acids, peptides ...) can serve as a basis for prebiotic chemistry, which some locate the beginning in the cold environments of molecular clouds that precede the birth of stars. What is certain is that molecular diversity develops in these dense environments (for space: density $>10^4$ particles/cm^3), protected from UV radiation, where temperature drops around 10K. In these regimes, molecules and atoms stick on the surface of interstellar dust (condensates of silicates or carbonaceous soot of submicron sizes) and undergo a very deep chemical transformation before they return in the gas phase.
Our team studies experimentally the transformation of atoms (O, H...) and molecules that they generate on the surface of interstellar dust grains (H_2, H_2O...), and this without any external energy input (photons, electrons...). We are interested in accretion or sticking, surface diffusion and return to the gas phase, as well as in reaction pathways. In dedicated UHV devices [1], we expose cold surfaces (10-100K) to atomic (H,O,N..) or molecular (CO, H_2O...) gases, following the surface composition by infrared spectroscopy, and the exchanges with the gas phase by mass spectroscopy,. We are particularly interested in surface mechanisms at the molecular layer (or sub-layer) scale.
During my presentation, after having resituated the astrophysical context, I will present our experimental devices[1] by illustrating the methods to obtain the adsorption[2] and diffusion energies of species, even reactive ones (such as O or H)[3], demonstrate that the chemical activity is dominated by surface effects, and give some general examples of the molecular evolution at the surface of interstellar grains.

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[1] Congiu, E., A. Sow, T. Nguyen, S. Baouche, and F. Dulieu. 2020. "A New Multi-Beam Apparatus for the Study of Surface Chemistry Routes to Formation of Complex Organic Molecules in Space." *Review of Scientific Instruments* 91 (12): 124504. https://doi.org/10.1063/5.0018926

[2] Minissale, Marco, Yuri Aikawa, Edwin Bergin, Mathieu Bertin, Wendy A. Brown, Stephanie Cazaux, Steven B. Charnley, et al. 2022. "Thermal Desorption of Interstellar Ices: A Review on the Controlling Parameters and Their Implications from Snowlines to Chemical Complexity." *ACS Earth and Space Chemistry*, February, acsearthspacechem.1c00357. https://doi.org/10.1021/ACSEARTHSPACECHEM.1C00357.

[3] Minissale, M., E. Congiu, and F. Dulieu. 2016. "Direct Measurement of Desorption and Diffusion Energies of O and N Atoms Physisorbed on Amorphous Surfaces." *Astronomy & Astrophysics* 585 (January): A146. https://doi.org/10.1051/0004-6361/201526702