Irradiation of cometary surfaces, application to the origin of the organic matter in ultra-carbonaceous micrometeorites

Micrometeorites are submillimeter extraterrestrial particles that represent the major source of interplanetary material accreted by the Earth each year. The analysis of micrometeorites allows to study the diversity of small bodies of the solar system (asteroids and comets). This thesis is about the study of micrometeorites from the Concordia collection, developed over the last 20 years thanks to a program carried out at the Dome C station (Antarctica). The first part of the work presented concerns a quantitative study of the flow of interplanetary matter arriving on Earth. The study based on more than 2000 micrometeorites from the Concordia collection shows that the flux of micrometeorites is ~10 μg/m²/year, which corresponds to a global annual flux of 5200 ± 1500 tons on our planet. The obtained results allow to better constrain the mass distributions of the particles in the size range below 300 μm and their comparison with the theoretical predictions indicate that the majority of the particles have most probably a cometary origin.

The second part of the presented work concerns the study of a rare type of micrometeorites, rich in organic matter: the Ultra-Carbonaceous Antarctic MicroMeteorites (UCAMM). Isotopic analysis of UCAMMs by nanoscale secondary ion mass spectrometry (NanoSIMS) reveals isotopic heterogeneities in H, N and C of the organic matter of UCAMMs at the scale of several microns.

The third part presents experiments of ice irradiations by heavy ions, carried out with the IGLIAS device during three experimental sessions at the Large Heavy Ion National Accelerator (GANIL). These experiments have simulated the interaction of the Galactic cosmic rays on mixtures of nitrogen- and carbon-rich ices at low temperature (10K). A solid organic residue is obtained after sublimation of the volatile species at the end of the irradiation of the ice film. The results obtained show that isotopic heterogeneities present in initially adjacent layers of irradiated ice can be transmitted to the organic residue produced. NanoSIMS ion imaging analysis of the organic residue shows the formation of isotopic heterogeneities in the organic residue, which are comparable to those observed in UCAMMs. These isotopic heterogeneities depend on the chemical nature of the irradiated ice mixture.

All the results obtained on UCAMMs and the irradiation experiments carried out at GANIL are put in perspective and compared to data on other interplanetary materials of asteroidal and cometary origin. The work carried out confirms that these exceptional interplanetary particles most probably come from the surface of icy bodies, rich in nitrogen, having evolved in the outer regions of the solar system. They confirm that the isotopic signatures in light elements (H, N and C) of UCAMMs can, in part, be inherited from gaseous parent reservoirs present in the protoplanetary disk. Finally, I will present possible future studies on UCAMMs to better constrain the surface composition of icy bodies present at large heliocentric distances.