The Isotopic Composition of Ultra-Carbonaceous Antarctic Micrometeorites Organics, Ion-Irradiation of Isotopically Heterogeneous Ices.

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Introduction: Ultra Carbonaceous Antarctic MicroMeteorites (UCAMMs) are sub-millimeter extraterrestrial particles with high abundance of organic matter and low abundance of minerals ($C/Si \approx 10 - 10^3$), identified independently in the French and Japanese micrometeorite collections [1-6]. The organic matter in UCAMMs present high N/C ratios ranging from 0.02 to 0.2 [2, 7] and can present extreme D/H ratio. The characteristics of UCAMMs suggest that they were formed by irradiation by Galactic Cosmic Rays (GCRs) of nitrogen-rich ice mantles at the surface of small icy bodies [4, 8]. We investigated the isotopic signature of light elements in the organic matter of UCAMMs to study their links with organic matter from carbonaceous chondrites and interplanetary dust particles (IDPs). We present here a summary of our recent results, including sample analyses and ice irradiation experiments that aim at synthesizing analogs of the organic matter in UCAMMs.

NanoSIMS analyses of UCAMMs: the H, C and N isotopic compositions of the 4 UCAMMs DC06-05-94 (DC94), DC06-07-18 (DC18), DC06-14-309 (DC309) and DC06-04-43 (DC43) were analyzed by nanoscale secondary ion mass spectrometry (NanoSIMS) at the Carnegie Earth and Planets Laboratory, the Museum National d'Histoire Naturelle and the Institut Curie [9]. The 4 UCAMMs do not exhibit similar isotopic compositions, with δD bulk values ranging from 1000‰ to 9000‰, $\delta^{13}C$ from -90‰ to 30‰ and $\delta^{15}N$ from -120‰ to 270‰. Each UCAMM is characterized by isotopic heterogeneities, typically at scales of a few µm [9].

Ice irradiation experiments: We performed ice irradiation experiments during 3 sessions in 2019, 2020 and 2021 at GANIL (Caen, France) [10], using the IGLIAS experimental setup connected to the IRRSUD ion beam (0.5-1 MeV/u). We formed 10µm – thick ice films by gas condensation on IR-transparent windows cooled down to 10K [8, 11]. The ice films consisted in one layer of isotopically labeled ice (with D, ^{15}N and/or ^{13}C-rich ice) between 2 layers of isotopically unlabeled ice ($^{14}N_2$-$^{12}CH_4$ or $^{14}NH_3$-$^{12}CH_4$), forming an ice sandwich. The labeled layer accounted for 1% to 4% of the total thickness. Ice sandwiches were subsequently irradiated by heavy ions and slowly warmed up to the room temperature to obtain refractory organic residues. The residues, exhibiting an IR signature comparable to that of the organic matter in UCAMMs [8], were subsequently analyzed by NanoSIMS at the Institut Curie, to map the H, C and N isotopic heterogeneities. This study shows that the ion-processing of ice sandwiches made of N_2-CH_4 form an organic refractory residue that keeps the large isotopic heterogeneities of the initial ice sandwich, while that of NH_3-CH_4 ice sandwiches appears less favorable to the formation of isotopic heterogeneities. Extreme isotopic heterogeneities at low scale were observed in organic residues, indicating that local preservation of the initial ice sandwich composition can occur, maybe related to sporadic events during the annealing of the ice films.

Results and discussion: These irradiation experiments demonstrate the possibility to form large micron-scale isotopic heterogeneities in organic residues from multilayer, isotopically heterogeneous, ice precursors. The organic matter of UCAMMs can thus have formed by irradiation by GCRs of isotopically heterogeneous ice mantles. Numerical models of the evolution of the early solar system predict the existence of gaseous reservoirs isotopically fractionated in H, C and N at different locations in the protoplanetary disk [12, 13]. The parent body/bodies of UCAMMs may have inherited from these fractionated reservoirs, condensed on its/their surface under the form of ice mantles. The diversity of isotopic signatures from one UCAMM to another also suggest that UCAMMs do not have anomalies inherited from one single parent gaseous reservoir. Further investigations on the correlation of elemental and isotopic ratios in the organic matter of UCAMMs will bring new insights to better constrain the characteristics of the parent reservoirs of UCAMMs.

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