Evidence of Pre-Accretion Irradiation of Cometary Minerals in the Inner Solar System

Cécile Engrand, E Charon, Corentin Le Guillou, Hugues Leroux, J Duprat, Emmanuel Dartois, J Rojas, Sylvain Bernard, L Delauche, I Sansberro, et al.

EVIDENCE OF PRE-ACCRETION IRRADIATION OF COMETARY MINERALS IN THE INNER SOLAR SYSTEM.

C. Engrand[1], E. Charon[2], C. Le Guillou[3], H. Leroux[3] J. Duprat[1], E. Dartois[4], J. Rojas[6], S. Bernard[5], L. Delauche[1], I. Sansberro[7], N. Fray[7], H. Cottin[7], D. Baklouti[8], C. Briois[9], A. Bardyn[9], J. Paquette[10], J. Silèn[11], O. J. Stenzel[12], M. Hilchenbach[12]. [1]IJCLab, Univ. Paris-Saclay, CNRS, 91405 Orsay Cedex, France (cecile.engrand@ijclab.in2p3.fr), [2]Univ. Paris-Saclay, CEA, CNRS, NIMBE 91191 Gif-sur-Yvette, France. [3]UMET Univ. Lille, 59650 Villeneuve d'Ascq, France. [4]ISMO Univ. Paris-Saclay, CNRS, 91405 Orsay, France. [5]IMPMC, CNRS, Sorbonne Université, MNHN, 75005 Paris, France. [6]1EPL, Carnegie Inst. for Science, Washington, DC 20015, USA, [7]Univ. Paris-Est Créteil, Univ. Paris-Cité, LISA, CNRS, 94010 Créteil, France. [8]IAS, Univ. Paris-Saclay, CNRS, 91405 Orsay Cedex, France, [9]LPC2E, CNRS, Orléans, France. [10]NASA-GSFC, Greenbelt, MD 20771, USA, [11]Finnish Meteorological Institute, 00101 Helsinki, Finland, [12]Max Planck for Solar System Research, 37077 Göttingen, Germany.

Introduction: Studies of cometary dust suggest that their constituent crystalline minerals formed at high temperature, close to the early Sun [1, 2]. Although several models can explain their transport to the outer regions of the protoplanetary disk (e.g. [3]), the detailed process(es) and timing of this transport remain unclear. The exposition to the interplanetary environment results in interactions with the solar wind (SW), solar energetic particles (SEP) and galactic cosmic rays (GCR) that can leave signatures in the minerals, such as damaged rims and irradiation tracks, as well as chemical changes. We investigate the evidence for pre-accretion irradiation of single minerals in the early solar system, before their incorporation in the cometary parent bodies.

Samples and results: Samples from comets were returned by the Stardust mission, and analyzed *in situ* by the Rosetta mission. Collected on Earth, chondritic anhydrous interplanetary dust particles (CA-IDPs) and ultracarbonaceous Antarctic micrometeorites (UCAMMs) are thought to be of cometary origin (e.g. [4, 5]). Irradiation features were observed in IDPs (e.g. [6, 7]) and in a UCAMM ([8, 9]), with rim thicknesses of a few tens of nanometers, and irradiation track densities typically around 10^{10} to 10^{11} tracks$\cdot$cm^{-2}. A pyroxene in the UCAMM shows an irradiated rim all around the pyroxene, this pyroxene sitting inside the UCAMM's organic matter. This ~30 nm thick rim shows a significant Mg depletion with regard to the interior of the mineral. Analyses of COSIMA (Rosetta mission) on comet 67P/Churyumov-Gerasimenko show that the compositions of the cometary dust particles are depleted in Mg [10, 11].

Discussion: IDPs have been long known to contain irradiations features, like damaged rims and solar flare tracks (e.g. [6]), that are usually interpreted as resulting from the exposure of the particle to the radiative interplanetary space during its transport to Earth. Keller and Flynn [7] interpret the solar flare densities of several tens of IDPs to constrain the release distance of the dust from the Kuiper belt. The fact that a crystalline pyroxene inside a UCAMM shows an irradiated rim in the interior of the particle, in contact with the organic matter, shows that this mineral was irradiated by the solar wind, prior to its incorporation in a dust particle and in a cometary parent body. The Mg depletion measured in the irradiated rim of this pyroxene is compatible with that observed for lunar grains (e.g. [12]), and could be attributed to the preferential sputtering of Mg atoms in the damaged layer, as observed in laboratory simulations [13].

Analyses of cometary dust by COSIMA/Rosetta revealed a large abundance of carbonaceous matter, and the composition is depleted in Mg with regard to the chondritic composition [10, 11]. Being a time-of-flight SIMS instrument, COSIMA only analyzed the top atomic layers of the samples. In the COSIMA instrument, the cometary particles were disrupted upon collection on the target [14]. The interiors of the dust particles were measured, but they consist in aggregates of units with sizes ranging from ~50 nm to a few µm [15]. The Mg depletion observed by COSIMA could be explained by SW irradiation of the sub-µm units of the dust particles from comet 67P/Churyumov-Gerasimenko, also before their accretion into the dust particle, and to the cometary parent body.

These evidences for pre-accretion irradiation by the solar wind question the interpretation of the track densities in IDPs and UCAMMs. Rims (from the SW) and tracks (from the SEP) can be recorded in the minerals while they were close to the sun, before their accretion into a dust particle. Once agglomerated as a dust particle, the minerals inside the particle are shielded from the SW (which can only penetrate up to a few 100 nm), whereas the SEP can still generate tracks. We will investigate the effect of GCR on the minerals, and compare with that of SEP using laboratory experiments, in order to better understand the evolution of cometary dust particles in the early protoplanetary disk.

Acknowledgments: This work was supported by IPEV-PNRA in Antarctica. Funding from CNRS, PNP, LabEx P2IO, IN2P3, MITI and ANR (COMETOR) are acknowledged.

References: [1] Brownlee D. (2014) *AREPS* **42** 179–205. [2] Wooden D.H. et al. (2000) *Icarus* **143** 126–137. [3] Bockelée-Morvan D. et al. (2002) *A&A* **384** 1107–1118. [4] Bradley J.P. (2003) *Treatise Geochem.* **1** 689–711. [5] Duprat J. et al. (2010) *Science* **328** 742–745. [6] Bradley J.P. (1994) *Science* **265** 925–929. [7] Keller L.P. et al. (2022) *Nat. Astron.* **6** 731–735. [8] Charon E. et al. (2017) *LPSC* **48** #2085. [9] Engrand C. et al. (2019) *MAPS* **54 S2** 6416. [10] Bardyn A. et al. (2017) *MNRAS* **469** S712–S722. [11] Sansberro I. et al. (2022) *COSPAR* **44** 175. [12] Keller L.P. et al. (1997) *GCA* **61** 2331–2341. [13] Demyk K. et al. (2001) *A&A* **368** L38–L41. [14] Hilchenbach M. et al. (2017) *Philos. Trans. R. Soc. A* **375** 20160255. [15] Bentley M.S. et al. (2016) *Nature* **537** 73–75.