

## COMPARISON OF MOLECULAR COMPLEXITY BETWEEN CHONDRITES, MARTIAN METEORITE AND LUNAR SOILS.

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**Introduction:** Meteorites and comets bear organic molecules ranging in size from one single to an arbitrarily large number of carbon atoms. This contrasts with the limited size of free molecules detected in space environments[1]. Understanding the organic matter cycle in the solar system requires to identify the time and place where the molecules were formed and destroyed.

The High Resolution Mass Spectrometry technique has been used for almost a decade to characterize extraterrestrial material[2]. The technique only accesses the soluble part of the samples and is used both with and without liquid chromatography for molecular identification[3]. Several scenarios have been proposed for the of soluble organic matter in extraterrestrial samples, with for instance aqueous alteration being invoked to explain the growth of N-bearing molecules[4] detected in Murchison.

During the last years, the IPAG group has developed a tool dedicated to the interpretation of the polymerization degree of any kind of organic sample. We highlighted a peculiar pattern in meteorite extracts that can be only reproduced by highly reducing gas phase polymerization experiments[5]. This is interpreted as a piece of evidence for protoplanetary disk origin. The work presented here is a comparison between the typical protosolar pattern and the features found or not in Martian meteorites and lunar soils.

**Method:** We extracted the organic mixtures from 4 lunar soils and from the NWA7533 “black beauty” Martian meteorite[6] by maceration in Toluene and Methanol for 1 week at room temperature. We did the same for several carbonaceous chondrites including Orgueil, Murchison, 4 CR type samples. Laboratory experiment residues produced from ionized gas[7, 8], photon irradiated ices [9, 10] or reactive liquids[11, 12] were also analyzed to provide comparison to well constrained synthesis environments. Mass spectra were acquired with a Thermo LTQ Orbitrap XL at its highest resolving power, coupled with Electrospray ionization (ESI) source. Anions and cations in the following mass range 150 to 800 u were analyzed on a 4 decades dynamic range.

**Results:** The Orbitrap mass spectrometry provides the mass distribution of mixtures with resolution and precision high enough to undoubtedly identify polymeric patterns. In every sample, CH<sub>2</sub> patterns are detected. A CH<sub>2</sub> family has only molecules with R-(CH<sub>2</sub>)<sub>n</sub> formula. From each CH<sub>2</sub> family, the free parameters of the Wesslau model [13] for polymerization can be adjusted to match the distribution. Each sample has from 3 to 15 CH<sub>2</sub> families with up to 30 members. In the synthetic samples, the parameters depend mainly on the precursor mixtures. The meteorites exhibit larger variations of the polymerization parameters than synthetic samples. We discuss the relevance of the various candidates for the emergence of molecular diversity in asteroids. Polymeric patterns in the NWA7533 involve C, H and O. Only CH<sub>2</sub>, C<sub>2</sub>H<sub>2</sub> and C<sub>2</sub>H<sub>4</sub>O patterns seem to be responsible of the molecular complexity. Heteroatomic (O-bearing) pattern is the major difference between chondritic and Martian organics. Another major difference is the absence of nitrogen in any observed cation whereas it was a key feature in Murchison. The patterns in lunar soils are highly variable. Some soils exhibit very little polymerization patterns, if any. One has a pattern comparable to the asteroidal one and one has a peculiar mass distribution that doesn't match any other extraterrestrial sample. The latter is the most exposed to solar wind and the mass range of its mixture is the most extended. We discuss such features in terms of origin and possible evolution of the organic matter delivered to the moon.

**References:** [1]Caselli P. and Ceccarelli C. (2012) *Astron. Astrophys. Rev.*, 20, 1 p. 56.[2]Schmitt-Kopplin P. et al. (2010) *Proc. Natl. Acad. Sci.*, 107, 7 pp. 2763–2768.[3]Yamashita Y. and Naraoka H. (2014) *Geochem. J.*, 48, 6 pp. 519–525.[4]Naraoka H. et al. (2017) *ACS Earth Sp. Chem.*, 1, 9 pp. 540–550.[5]Bekaert D. V. et al. (2018) *Astrophys. J.*, 859, 2 p. 142.[6]Humayun M. et al. (2013) *Nature*, 503, 7477 pp. 513–516.[7]Hörst S. M. and Tolbert M. A. (2013) *Astrophys. J. Lett.*, 770, 1 p. L10.[8]Kuga M. et al. (2015) *Proc. Natl. Acad. Sci.*, 112, 23 pp. 7129–7134.[9]Danger G. et al. (2016) *Geochim. Cosmochim. Acta*, 189 pp. 184–196.[10]Piani L. et al. (2017) *Astrophys. J.*, 837, 1 p. 35.[11]Renard P. et al. (2013) *Atmos. Chem. Phys.*, 13, 13 pp. 6473–6491.[12]Vinogradoff V. et al. (2017) *Icarus*, 305 pp. 358–370.[13]Weßlau V. H. (1956) *Die Makromol. Chemie*, 20, 1 pp. 111–142.