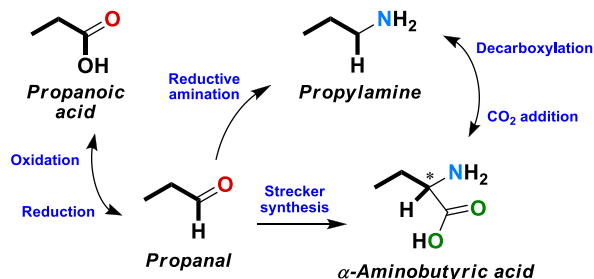


**WHY ARE MONOCARBOXYLIC ACIDS THE MOST ABUNDANT CHONDRITIC ALIPHATIC ORGANIC COMPOUNDS?.** J. C. Aponte<sup>1,2</sup>, J. E. Elsila<sup>2</sup>, D. P. Glavin<sup>2</sup>, and J. P. Dworkin<sup>2</sup>. <sup>1</sup>Solar System Exploration Division, Code 691, NASA Goddard Space Flight Center, Greenbelt, MD 20771, <sup>2</sup>Department of Chemistry, Catholic University of America, Washington, DC 20064. Email: jose.c.aponte@nasa.gov.

**Introduction:** Carbonaceous chondrite meteorites are among the oldest solid materials formed in the Solar System, and contained within their mineral matrix is a rich history dating from the birth of our Solar System [1]. The water-soluble organic compounds present in these extraterrestrial samples constitute a record of pre-solar chemical reactions, including both those that occurred in the early solar system and those resulting from parent body aqueous and thermal processing.

This inventory of organic compounds also represents a potential important source of prebiotic molecules needed for the later origins and development of life [2]. Several types of aliphatic organic compounds have been identified in carbonaceous chondrites, including monocarboxylic acids (MCA), amino acids, aldehydes and ketones, and amines [3,4]. These organic compounds are structurally related (Scheme 1), and therefore, they may share common synthetic origins throughout carbonaceous chondrites.

**Scheme 1.** Simplified synthetic scheme of water soluble meteoritic organics. Reactions may proceed through multiple mechanisms and steps in the pre-solar nebula or during asteroidal stage. (\*) Chiral center.

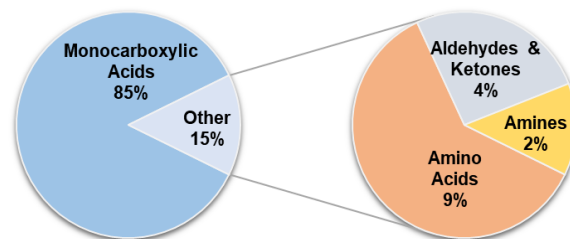


In this work we aim to discuss recent new data regarding the abundance of MCAs in carbonaceous chondrites, its parallel to other carbon-containing meteoritic species such as insoluble organic matter (IOM) and carbonates, the origins of MCAs in meteorites, and their likelihood as end-decomposition products or precursors of other aliphatic organics such as amino acids.

**Abundance and Molecular Distribution of Chondritic MCAs:** The total abundance of MCAs has been recently measured in representative meteorites from multiple carbonaceous chondrite classes, including CM, CR, CO, CV, and CK chondrites [5]. Similar to previous observations of the abundance and molecular distribution of aldehydes, ketones, amines and amino acids [4], the total abundances of MCAs measured

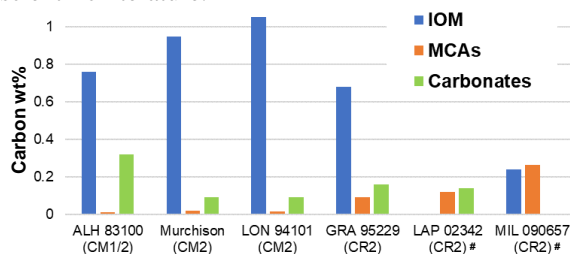
in CM and CR chondrites were a few orders of magnitude higher than those seen in CO, CV, and CK carbonaceous chondrites. In addition, decreasing concentrations of MCAs with increasing aqueous and thermal processing, and low variability in concentration among samples belonging to the same petrologic type were also observed. The most noticeable difference between MCAs and their structurally analogous organic compounds, however, is their overall high concentration in carbonaceous chondrites from CM, CR, CO, CV, and CK groups [5]. Indeed, the abundances of meteoritic MCAs are the highest of the measured water-soluble aliphatic organics, representing over 85% of the total abundances of these organics in the Murchison (CM2) meteorite and other carbonaceous chondrites (Figure 1).

**Figure 1.** Relative abundances of water-soluble meteoritic aliphatic MCAs, amino acids, aldehydes and ketones, and amines in the Murchison meteorite [5-8].



Indeed, the concentration of meteoritic MCAs may be comparable in some cases with that of other carbon-bearing species such as IOM and carbonates. The carbon weight percentages (C wt%) of MCAs were found within the same orders of magnitude to that of IOM and carbonates in CR chondrites, although MCAs were more depleted in CM chondrites (Figure 2).

**Figure 2.** Carbon weight percentages (C wt%) of IOM, MCAs, and carbonates in CM and CR chondrites [9-12]. (#) IOM and carbonates data for LAP 02342 and MIL 090657 respectively, are not available in the scientific literature.

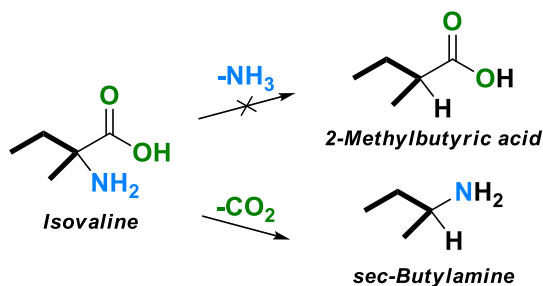


### MCAs Forming from Less Oxidized Species:

The origins of MCAs in the interstellar clouds, the pre-solar nebula, or parent bodies (or a combination of these locations and times) may be linked to the availability of their less oxidized precursor compounds such as alcohols, aldehydes and nitriles. If we assume a homogeneous accretion of these organic species across different parent bodies, it would be expected that less oxidized meteorites would contain lower levels of MCAs relative to the more reduced species. However, CR chondrites are the least oxidized samples analyzed for MCAs and this chondrite group contains higher concentrations of MCAs than CM, CO, CV, and CK chondrites, suggesting that the accretion of aliphatic precursors of MCAs was not homogeneous throughout different parent bodies, or that the abundance of MCAs was mostly influenced by parent body processes.

**Synthetic Relationship Between MCAs and Amino Acids:** Because of the large abundance of MCAs, it could be argued that these compounds may have formed from the decomposition of other meteoritic organic species. From the molecular architecture of MCAs and amino acids, it could be suggested that MCAs formed through the loss of an amino group from the amino acid. However, *ab initio* simulations aimed to determine free energy profiles and decomposition pathways for amino acids suggest that meteoritic aliphatic monocarboxylic acids are not produced from decomposition of meteoritic amino acids (Scheme 2). Under simulated hydrothermal conditions, amino acids may undergo deamination to form  $\alpha,\beta$ -unsaturated MCAs or hydroxy acids; alternatively, amino acids may also undergo decarboxylation to form an aliphatic amine (Scheme 2). However, under the tested conditions, it was unlikely that an amino acid would undergo deamination to yield an aliphatic MCA [13].

**Scheme 2.** The decomposition of amino acids does not result in energetically favorable formation of aliphatic MCAs, but formation of amines is more energetically favorable.



It is likely that MCAs may have been involved in the synthesis of other meteoritic aliphatic organics; indeed, those *ab initio* simulations suggest that

the formation of amino acids through ammonia addition to MCAs may be a well suited synthetic route for the origins of amino acids under hydrothermal asteroid-like conditions [13].

**Conclusions:** MCAs are one of the most abundant water-soluble organic compounds in carbonaceous meteorites. Their high abundances across various chondrite groups may be indicative of a large pre-accretionary concentration of these species, or could indicate that large quantities of their precursor molecules (e.g., aldehydes and nitriles) were incorporated during parent body accretion to be converted into MCAs through alteration processes. The suggestion that MCAs are highly abundant in carbonaceous chondrites because they are oxidized compounds that may represent end-decomposition products of other organic compounds such as amino acids should be reevaluated given that MCAs may in some cases be as abundant as IOM and carbonates and in light of recent computational results indicating that amino acids and hydroxy acids may be generated from MCAs through asteroid-like conditions.

**References:** [1] Anders E. (1989) *Nature* 342, 255-257. [2] Chyba C. and Sagan C. (1992) *Nature* 355, 125-132. [3] Pizzarello S., et al. (2006) *In Meteorites and the Early Solar System II*, pp 625-651. University of Arizona Press: Tucson, AZ. [4] Glavin et al. (2018) *In Primitive Meteorites and Asteroid*, pp 205-271. Elsevier: Amsterdam, Netherlands. [5] Aponte et al. (2018) *Meteorit. & Planet. Sci.* DOI: 10.1111/maps.13216. [6] Glavin et al. (2011) *Meteorit. & Planet. Sci.* 45, 1948-1972. [7] Aponte J. C. et al. (2014) *Geochim. Cosmochim. Acta* 131, 1-12. [8] Simkus et al. (2018) *Meteorit. Planet. Sci.* DOI: 10.1111/maps.13202. [9] Alexander C. M. O'D. et al. (2007) *Geochim. Cosmochim. Acta* 71, 4380-4403. [10] Alexander C. M. O'D. et al. (2012) *Science* 337, 721-723. [11] Alexander C. M. O'D. et al. (2015) *Meteorit. & Planet. Sci.* 50, 810-833. [12] Davidson J. et al. (2015) *LPS XXLVI*, Abstract #1603. [13] Pietrucci F. et al. (2018) *ACS Earth Space Chem.* 2, 588-598.