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# Planetary Applications For In Situ Laser Ablation Processing Coupled With Mass Spectrometry

Ricardo Arevalo (1), Benjamin Farcy (1), Mehdi Benna (2), Mazdak Taghioskoui (3), William McDonough (1), William Brinckerhoff (4), Christelle Briois (5), Laurent Thirkell (5), Fabrice Colin (5), Laura Selliez (5), Alexander Makarov (6), Anthony Yu (4), Molly Fahey (4), Adrian Southard (7), Andrej Grubisic (4), Ryan Danell (8), and Cynthia Gundersen (9)

(1) University of Maryland, Department of Geology, College Park, MD, US (rarevalo@umd.edu), (2) University of Maryland, Baltimore County, MD, US, (3) Trace Matters Scientific, Somerville, MA, US, (4) NASA Goddard Space Flight Center, Greenbelt, MD, US, (5) Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E), Orléans, FR, (6) Thermo Fisher Scientific GmbH, Bremen, DE, (7) Universities Space Research Association, Columbia, MD, US, (8) Danell Consulting, Inc., Winterville, NC, US, (9) AMU Engineering, Inc., Miami, FL, US

Over the next few decades, top-level planetary mission objectives will pivot towards the in situ chemical analysis of silicate- and/or ice-rich bodies in order to augment our understanding of: i) planetary geology, informing on processes such as protracted accretion, internal differentiation, and interior dynamics; ii) prospects for habitability and biosignature preservation potential of surface and subsurface environments; and ultimately, iii) the detection of organic matter and identification of alien biological systems (if present). Lander and rover platforms continue to become more enabling, offering expanded payload capacities (i.e. more mass, volume, and energy resources for instruments), drills capable of acquiring materials from depths at the km-scale, and precision sample manipulation with advanced robotic systems.

Mission concepts that incorporate elements of both fundamental geology and astrobiology are highly prioritized by the scientific community, NASA Science Mission Directorate, and ESA Cosmic Vision Program; viable mission candidates include comet, asteroid, and/or lunar sample return, and the progressive exploration of Mars and its moons. The addition of "Ocean Worlds" to the New Frontiers 4 Announcement of Opportunity served to underscore the critical need for in situ chemical analyzers capable of characterizing solid planetary materials, such as salts, ices, and sublimated residues (in addition to more traditional silicate minerals and accessory phases).

The M-CLASS (Measurement of Composition via Laser Ablation Sampling and Spectrometry) Laboratory, a joint venture between the University of Maryland, NASA GSFC, and international partners, is advancing a number of pioneering technologies geared specifically towards analyzing elemental composition, isotopic abundances, and organic content of solid planetary materials via in situ laser ablation mass spectrometry. For geological investigations, a miniaturized inductively coupled plasma mass spectrometer (ICPMS) equipped with a heritage quadrupole mass analyzer (a la the SAM QMS) is in development. The innovative plasma source, which was designed originally through the NASA SBIR Program, requires as little as 1 W of power (tunable per science requirements) but provides access to trace element signals. Because trace elements (defined by abundances at ppmw levels or below) are too depleted to form accessory phases, they can vary by more than three orders of magnitude in geological samples and serve as sensitive tracers to a host of planetary processes (global differentiation, weathering/erosion, biomineralization, etc.).

For astrobiological investigations, we are building and qualifying for spaceflight an engineering model of a laser-enabled Orbitrap mass analyzer capable of detecting organic compounds and contextual mineralogical indicators via high sensitivity and active beam scanning, resulting in 2D chemical imaging without extensive sample handling requirements. A prototype version of this instrument has been shown to distinguish organic molecules as potential biomarkers with ultrahigh mass resolution ($m/\Delta m \geq 120{,}000$, FWHM at m/z 100) and highly accurate peak assignments within 3 ppm of absolute values. The quantification of isotopic abundances with $\leq$1.0% ($2\sigma$) precision, and the detection of a variety of amino acids at concentrations as low as $\leq$1 pmol/mm2, were also demonstrated.