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Laser-Based Mass Spectrometry for the Chemical Analysis of Precious Planetary Samples

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Laser-based analytical techniques, such as laser desorption mass spectrometry (LDMS) and laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS), enable the untargeted characterization of solid sample composition ([1] and references therein). The spatial resolution of such methods ranges from the nm- (e.g., ablation depth per laser shot) to the µm- (e.g., typical focused beam diameters) to the mm-scale (e.g., 2D chemical imaging via active beam scanning or sample manipulation). Collocated observations of mineralogy, elemental/isotopic composition, and organic molecule inventory enable insights into sourcing/provenance, reconstructions of local environmental conditions, and geological context for putative biosignatures. Laser-based mass spectrometry techniques are thus well adapted for the comprehensive chemical analysis of precious planetary materials, as supported by the inclusion of instrumentation on several upcoming planetary missions (e.g., ExoMars/MOMA; [2]) as well as modern-day workflows for ground-based investigations into asteroidal return samples (e.g., Bennu [3]).

Miniaturized, field-deployable hardware facilitates in situ investigations by enabling transportation of analytical instrumentation to the curation facility rather than requiring that the samples be shipped to/from multiple organizations, reducing the risk for contamination from additional handling requirements and/or disparate institutional capabilities/processes. Miniaturized laser-based instruments are particularly valuable when considering the containment protocols and biosafety measures associated with returning planetary materials that could harbor extant life [4], such as subsurface samples from Mars. Miniaturized instruments could be installed semi-permanently into Biosafety Level 4 spaces, like the Mars Sample-Return Receiving Facility (MSRRF), circumventing the risk of backwards contamination without needing to sterilize (and potentially alter) the samples.

In the M-CLASS Laboratory, we have developed several low-mass (< 20 kg), low-power (< 100 W peak) laser-based instruments that can be deployed in the field or relocated to curation facilities. Here, we demonstrate the value of: deriving 2D chemical images to map sample heterogeneities; quantifying elemental abundances to establish lithology and track geochemical proxies; determining mineral modal proportions; and, characterizing the diversity, distribution, and molecular complexity of insoluble organic matter.

References:

[1] Farcy and Arevalo (2025) *Treatise on Geochemistry (3rd Edition)*
[2] Goesmann et al. (2017) *Astrobiology*
[3] Glavin et al. (2025) *Nature Astronomy*
[4] Teece et al. (2025) *Astrobiology*