KEEP YOUR ION THE NEXT FIVE YEARS: CRATER, A LASER ABLATION ORBITRAP MASS SPECTROMETER FOR FUTURE LUNAR EXPLORATION. L. N. Willhite[1], R. Arévalo Jr.[1], A. E. Southard[2], J. M. Llano[3], A. Bardyn[1], Z. Ni[1], J. D. Graham[4], A. Grubisic[4], R. M. Danell[5], N. Minasola[3], C. Gundersen[3], J. Lee[4], M. E. Fahey[4], A. W. Yu[4], A. Ersahin[6], C. Briois[7], L. Thirkell[7], F. Colin[7], B. A. Cohen[4], and A. A. Makarov[7] [1]University of Maryland, College Park, MD (lnw@umd.edu; rarevalo@umd.edu) [2]Universities Space Research Association, Greenbelt, MD [3]AMU Engineering, Miami, FL [4]NASA Goddard Space Flight Center, Greenbelt, MD [5]Danell Consulting, Inc., Winterville, NC [6]MAE Aerospace, South Glastonbury, CT [7]Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, Université d'Orléans, Orléans, FR [8]Thermo Fisher Scientific, Bremen, DE

Introduction: The CRATER (Characterization of Regolith and Trace Economic Resources) instrument—a laser ablation mass spectrometer—enables rapid *in situ* analyses to determine mineralogy, organic inventory, trace element and isotopic fingerprints of lunar regolith and rock. CRATER includes the *CosmOrbitrap* mass analyzer, a version of the commercial Orbitrap™ adapted for spaceflight by a consortium of French laboratories [1], which provides unprecedented mass resolving power and mass accuracy for chemical analysis of planetary targets.

Support from NASA's Development and Advancement of Lunar Instrumentation (DALI) program and the CNES Research and Technology program will enable the maturation of CRATER technology to reach TRL 6 (i.e., system demonstration in relevant environmental conditions) before the end of 2022. This competitive timeline renders the CRATER instrument ready for deployment on a commercial lunar lander or rover within the next few years [3].

Community-driven science goals: CRATER is suited to critically assess refractory and moderately volatile elemental abundances to provide ground truth constraints on their putative enrichment and depletion in the bulk silicate Moon, respectively. CRATER can detect organic molecules present in lunar surface materials that represent an abiotic inventory delivered by meteorites and comets, thereby providing an astrobiologic "blank". As NASA and other global space agencies continue to look toward the Moon for future space exploration support, endogenous economic resources are important to identify. CRATER is capable of detecting viable economic resources in lunar phases.

Analytical Performance: Analytical strengths of the instrument include mass resolution ($m/\Delta m$ > 100,000, FWHM at m/z 100) and mass accuracy (ppm level) that exceed previous flight capabilities [2], enabling the discrimination of molecular and elemental isobars. Expanded science benefits include fine laser attenuation control and active beam scanning to enable 2D chemical imaging across a 500 micron field of view [4], isotopic abundance precision (<1% 2σ) [5], and dual polarity modes (positive and negative ion detection). The *CosmOrbitrap* analyzer is capable of detecting organic and inorganic species simultaneously, providing inferences of contextual relationships.

Prototype Investigations: Metal alloys containing rock-forming elements have been analyzed for elemental and isotopic abundance accuracy and precision to understand systematic and random sources of error in this novel instrument concept. Through a series of experiments on lunar analog samples of increasing fidelity, the CRATER performance and scientific reach will be established.

Instrument design: CRATER's low mass (8 kg) and power (40 W peak power) requirements make this instrument (**Figure 1**) ideal for spaceflight. A 213 nm, high power laser subsystem ablates/desorbs and ionizes the target. Generated ions are extracted and transmitted through a series of lenses that focus, steer, and inject the ions into the analyzer. The *CosmOrbitrap* employs image current detection of the ions' axial oscillations, which inversely correlate to the square root of m/z.

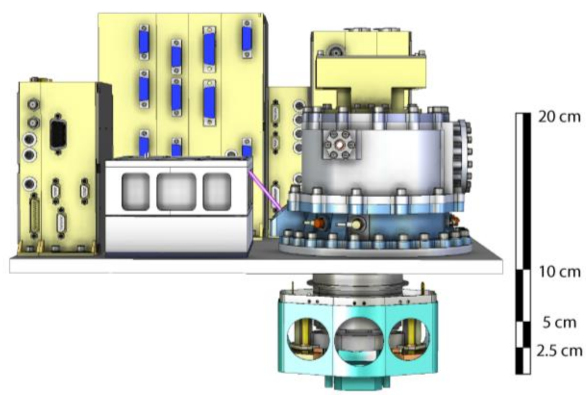

Figure 1. The lightweight and compact CRATER design enables versatile deployment options on an upcoming commercial lunar rover or lander concept.

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