

Investigation of the Surface Composition by Laser Ablation/Ionisation Mass Spectrometry. P. Wurz¹, A. Riedo^{1,2}, M. Tulej¹, V. Grimaudo¹, and N. Thomas¹, ¹Physics Institute, University of Bern, Sidlerstrasse 5, 3012 Bern, Switzerland (peter.wurz@space.unibe.ch), ²Department of Physics, Free University of Berlin, Arnimallee 14, 14195 Germany.

Introduction: We propose to contribute a Laser Ablation Ionization Mass Spectrometer (LIMS) for the analysis of solid matter as an analytical instrument on a landed spacecraft on the Moon in the framework of the ARTEMIS programme of NASA. Our LIMS system is compact, will be portable, features simple and robust operation, and is based on current measurement capabilities of a real-size prototype instrument (chemical analysis within seconds, detection trace elements at the ppm level, no sample preparation is required, minimal sample consumption at the sub- μg level). It will be an ideal tool to support field measurements of astronauts on the surface of the Moon. A fully operational LIMS prototype has been operated for years, and is described in detail in several recent publications. The LIMS system consists of a miniature reflectron-type time-of-flight mass analyser system coupled with a femto-second pulsed fibre laser system. In addition, there is a microscope system to image the samples under investigation.

LIMS measurements would support the future astronauts or could be employed on a rover, for in situ resource utilisation by providing fast and reliable chemical analysis of lunar soils and solids of high quality in situ. The LIMS instrument will also be instrumental in identifying the proper building material on the lunar surface for constructing the planned habitats on Moon by applying e.g., autonomous 3D printing technologies.

Instrument: The LIMS system instrument is a reflectron-type time-of-flight (TOF) mass spectrometer that is coupled to a femtosecond laser system for ablation and ionisation of sample material for mass spectrometric analysis. The mass spectrometer was originally designed for the chemical analysis of solids on the Mercury surface [1] and since then continuously developed further for in situ research on planetary surfaces. Fig. 1 shows the prototype instrument; the principles of operation are discussed in detail in a previous publication (see Fig. 3 in [2]). It has a mass resolution in the range of $m/\Delta m = 500\text{--}900$, with an accuracy of the mass scale better than 1 permille [2], a detection limit around 10 ppb depending on mass [2,3], a dynamic range of 8 decades [2], quantitative measurements of almost all elements in laser ablation mode [3,4,5], and detection of complex molecules in laser desorption mode [3,6]. Measurements conducted with state-of-the-art laboratory-scale LA-ICP-MS and ICP-

MS instruments gave comparable results for composition and their accuracies which demonstrates the performance of our miniature LIMS system [7].

With every laser pulse a limited amount of sample material is removed, atomised, and ionised. Thus, when staying at the same spot the sequence of mass spectra resulting from these laser pulses can be used to derive a depth profile of the atomic composition at the sampled location [7,8,9]. We demonstrated that the obtained depth resolution is better than 1 nm, depending on the applied laser pulse intensity [8]. In case of lunar material, regolith and rocks, penetrating through the weathered surface layer of tens of nanometers will allow to access the true chemical composition of the material. Moreover, even complex molecules could be identified at grain boundaries [6].

Since planetary samples typically are highly heterogeneous it is necessary to perform measurements of the chemical composition on small spots commensurate

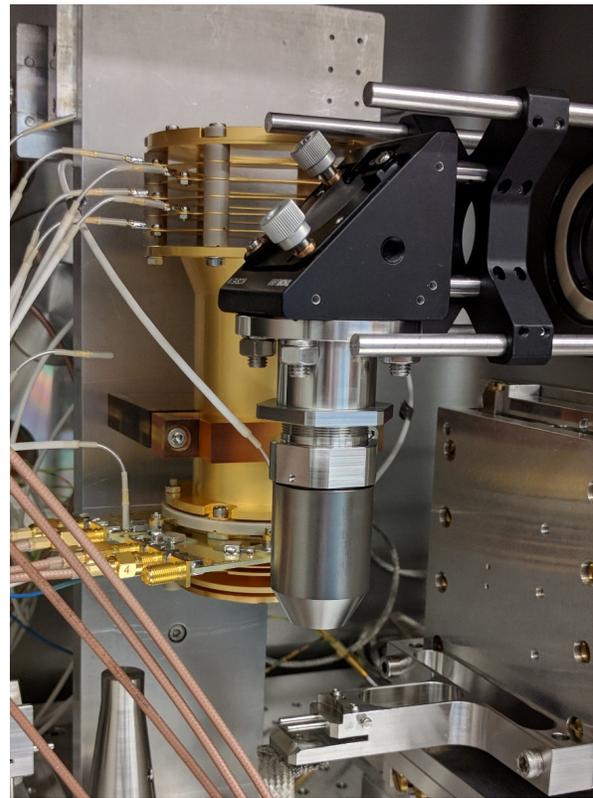


Fig. 1: Prototype LIMS instrument (golden structure in the back) and the microscope imaging system in front [10]. The sample is moved between the two by a translation stage with μm resolution.

with the typical grain size within the object. Typically, a spatial resolution in the range of 10 to 20 μm is adequate, which is given by the size of the laser spot on the sample. In the current instrument setup, the laser is focussed towards the sample surface down to about \varnothing 10 μm , which defines the optimal spatial resolution for investigation on a sample.

We combined our LIMS system with a high-resolution microscopic camera system, which has an optical resolution of 2 μm for detailed optical investigation of the sample [10]. In this way, mass spectrometric analysis and imaging information are available from the exact same location on the sample, allowing to characterise a sample as good as possible (context analysis).

For the demonstration of performance of our miniature LIMS system, we will present exemplary studies from our investigations conducted on suitable sample materials that are relevant for in situ space exploration, that includes e.g., the identification of the mineralogy of heterogeneous samples (minerals and meteorites) to element and isotope studies conducted on lunar and chondritic meteorites, which allows studies of in situ radio-isotope geochronology.

Resources: We have estimated the resources needed to employ such an instrument on an airless body before, for an instrument without the microscope system it is given in [2], for an instrument with the microscope system, the full system it is given in [11]. For the full system we estimate a total weight of about 5.2 kg, an average power consumption of 12 W, and outside dimensions of 320 x 230 x 230 mm^3 (L x W x H). The power consumption is variable, considering standby mode, laser operation and mass spectra collection, or imaging. This can be mitigated by power buffering, to establish a more stable load to the power providing facility. Actually, a battery operation can be realised, for a portable field application.

Acknowledgments: This work was supported by the Swiss National Science Foundation.

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