Development of Laser Ablation Time-of-Flight Mass Spectrometer for Future Mission and Planetary Research

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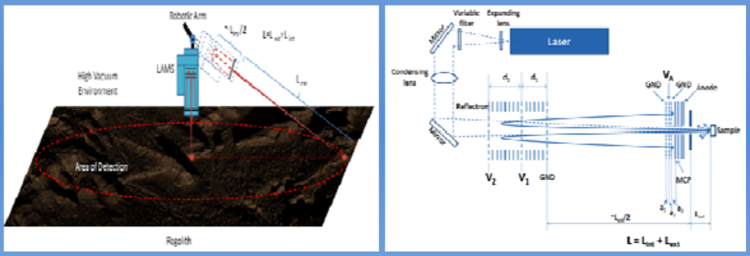
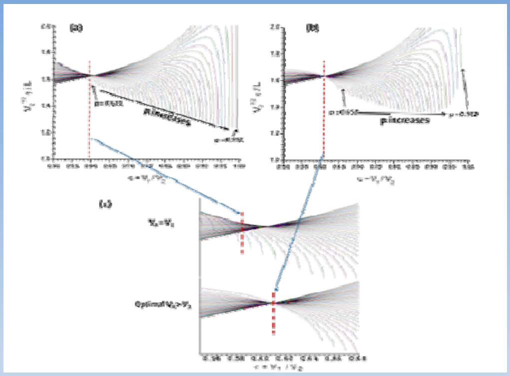
Introduction: Laser ablation time-of-flight mass spectrometry has several attractive features for sample analysis on planetary missions including relative simplicity, wide atomic mass range, high resolution, and compatibility with a variety of sampling and ionization methods. We have designed and developed a miniaturized laser ablation mass spectrometer (LAMS) for use on landed missions to airless bodies such as asteroids, comets, and most planetary satellites including the Moon[1,2]. On such missions, a fixed lander or a rover may be deployed to explore a local region of the surface, where chemical analysis of a variety of regolith materials is expected to be a top priority.

Standoff Elemental Composition Sensor

In LAMS, a high-intensity pulsed laser is directed onto a sample of interest, forming ions that travel across the vacuum gap between the surface and the analyzer inlet, and subsequently focusing them in a reflectron. This technique is in fact compatible with variable L_{ext}. Theoretical modeling results have motivated the application of LAMS for fine-scale *in situ* analysis of samples at variable L_{ext} up to at least several tens of cm, compatible with a robotic arm deployment, for access to many m^2 around a lander or rover [2].

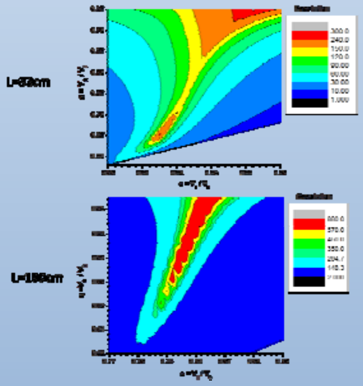


In the instrument, L_{int} =~ 20 cm, $a_1 = a_2$ = 0.4 cm, d_1 = 1.45 cm, d_2 = 2.55 cm.



At L = 33 cm, adjusting the analyzer voltage V_A from (a) the "wide window" case $V_A=V_1$ to (b) an optimal $V_A > V_1$ results in an effectively higher order focus (higher resolution) without having to significantly reduce the ions (represented by the number of trajectory curves) that reach the detector. Optimizing V_A shifts the reflectron focus c slightly as shown in (c).

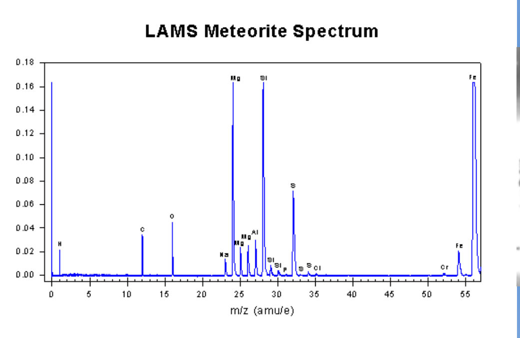
	$V_A = V_1$			Optimal $V_A > V_1$			
L(cm)	$c=V_1/V_2$	Resolution	$V_2^{1/2}$ t/L	$q=V_A/V_2$	$c=V_1/V_2$	Resolution	$V_2^{1/2}$ t/L
33	0.594	39.76	1.626	**0.651**	0.610	**286.43**	1.633
34	0.594	39.68	1.614	**0.660**	0.616	**287.94**	1.618
36	0.604	39.55	1.587	**0.673**	0.626	**304.87**	1.591
38	0.614	39.70	1.558	**0.693**	0.638	**302.60**	1.569
40	0.624	36.96	1.538	**0.702**	0.646	**323.32**	1.545
60	0.684	33.55	1.392	**0.802**	0.718	**483.44**	1.402
80	0.726	33.01	1.314	**0.864**	0.764	**676.48**	1.326
100	0.756	34.87	1.265	**0.903**	0.796	**912.71**	1.278

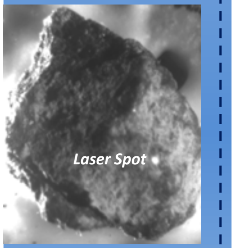


The resolution as a function of detection lengths, c and q. High resolution (R > 250) is achieved at L = 33 cm (a) with a relatively wide window (V_2-V_A) whereas at L = 100 cm (b) with a smaller window.

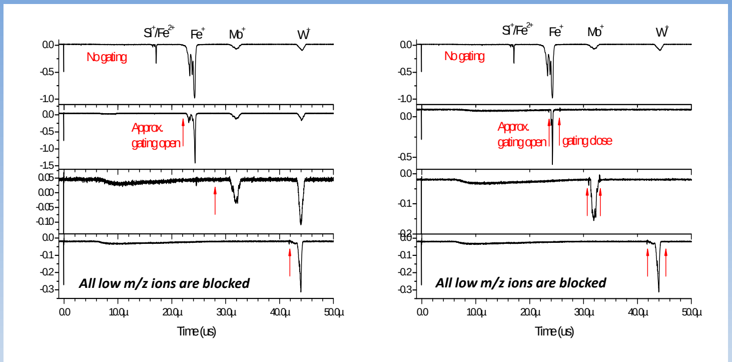
Ion Gating and Trace Element Detection

Pulsed ion gating technique for *in situ* detection of trace elements has great potential diagnostic value in the study of small bodies and moons. Ion gating in LAMS reduces background noise, leading to lower limits of detection, at and below the parts-per-million by weight (ppmw) range for atomic species of high interest, such as some transition metal and rare earth elements, as well as Pb, U and Th.


LAMS Meteorite Spectrum



Allende Sample



The NIST tool steel SRM 1157 contains a wide mass range of elements and also a wide abundance range (<0.01 to > 80%). Gating on V_A grid can select specific peaks of interest in the mass spectrum. Spectra at low mass resolution to demonstrate gate timing.

Solutions for Practical Challenges on Future Missions

➢ The loss of ion density with increasing L_{ext}.

LAMS is able to generate very high ion densities with only modest increases in laser energy in the range of a few mJ per pulse, compensating for signal loss.

➢ Maintaining a small laser spot at different distances.

A combined focusing protocol, where the approximate distance, determined through imaging autofocus, is used to position the laser objective lens.

➢ The uncertainty in the surface morphology of the target sample.

After a "pre-ablation" step (5-20 initial high-energy pulses), irregularities in the sample surface may be removed with ions then emitted toward the LAMS inlet.

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