# *IN SITU* LASER TIME-OF-FLIGHT MASS SPECTROMETRY ON PLANETS AND SMALL BODIES.

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**Introduction:** The in-depth landed exploration of planets, moons, and small bodies represents an enormously exciting and challenging next step for planetary science. Such missions will require increasingly sophisticated and miniaturized robotic analytical tools for *in situ* sampling and composition studies [1]. These tools must work as an efficient suite to provide complementary and cross-calibrated data. As a potential member of such a suite, we are developing miniature time-of-flight mass spectrometers (TOF-MS) for microanalysis of minimally-prepared samples. TOF-MS instruments may enable chemical analyses of individual minerals in surface samples, detection of organics on Mars and comets, and direct sampling of ice composition on Europa. While isotopic precision in these highly-miniaturized instruments is not sufficient for *in situ* geochronology, TOF-MS probes may enable efficient selection of optimal samples to be returned to Earth for such analysis.

TOF-MS naturally couples to direct, pulsed ionization methods such as laser ablation (LA). An adjustable-energy pulsed laser volatilizes and ionizes material from a small region on the sample. Ions enter the instrument and are detected at a sequence of times proportional to the square root of their mass-to-charge ratios. Thus, each laser pulse produces a complete mass spectrum (in less than 50 µs). These instruments can be significantly miniaturized while maintaining high performance.

**Laser TOF-MS Instruments:** Prototypes at JHU/APL include the following features pertinent to *in situ* analysis:

1. The laser spot diameter is adjustable between 10 µm and 500 µm, for nested microprobing.
2. Sample preparation is usually not required. Rock, fine, and ice matrix samples may be directly analyzed.
3. A micro-imager with a few-mm FOV permits the preselection of the laser analysis position.
4. Repeated laser pulses analyze layer-by-layer (and can access unweathered material via depth profiling).
5. TOF-MS has an unbounded mass range: elements through large organic molecules ($10^2$ - $10^5$ amu).
6. Detection limits are 0.1-10 ppmw for many elements.
7. Mass resolution up to 1000 (FWHM) can be achieved.
8. Precision of rock-forming element abundance ratios, such as Mg/Si, Al/Si, Mg/(Mg+Fe), (Na+K)/Si, Fe/Si, and Fe/Mn, is sufficient to distinguish general classes.
9. Organic molecules may be analyzed with a range of samples and inlet systems, including use of direct and matrix assisted laser desorption methods
10. Mass (< 2 kg) and power (few W peak) are very low.

**Laser Ablation TOF-MS:** Work with a laser ablation mass spectrometer (LAMS) [2] has shown that analyses of rocks, ice, and fines can be obtained with a laser focused to $10^9$ W cm$^{-2}$, in a TOF-MS < 20 cm long. Such high irradiance produces a large flux of atomic ions (and essentially no molecules). Precision of Mg, Al, S, Ca, and Fe ratios to Si permitted differentiation between chondrite classes [3]. On an airless body, no sample contact is required.

**Laser Desorption TOF-MS:** While LAMS is very useful for bulk or microprobe elemental analyses, and for depth profiling, the lower-irradiance range termed laser desorption (LD) is ideal for organic/molecular analysis and some trace element studies. Miniature LDMS instruments can detect organics up to thousands of amu with high mass resolutions.

**Combined LA/LD on a Small Body Lander:** A new prototype TOF-MS at JHU/APL combines LA and LD in one instrument (Fig. 1). This is an important direction for extremely-constrained missions such as small body or Europa landers. Using a simple, coaxial geometry and novel, monolithic reflectron designs [4], this TOF-MS may be able to correlate elemental and organic/molecular composition in sequences of spectra from a co-imaged field of view (Fig. 2).

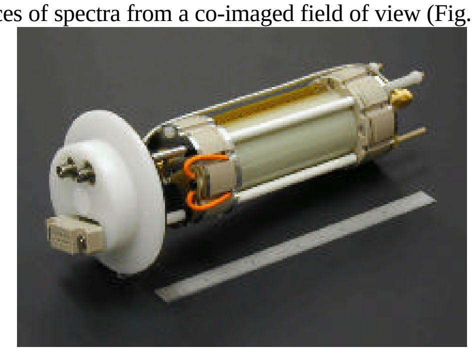

**Figure 1** JHU/APL "Plastic TOF-MS." Rule is 15 cm.

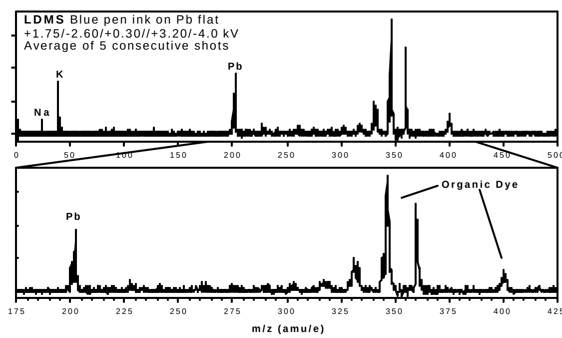


**Figure 2** LD TOF-MS data showing simultaneous detection of elemental (Pb) and organic (ink) composition.

Current *in situ* TOF-MS instrument enhancement efforts include: (1) a complementary evolved-gas capability for volatiles; (2) incorporation of miniature turbopumps; (3) automated sample manipulation systems; (4) laser systems for post-ionization; and (5) operating modes for coupling micro-imaging with (inferred) mineral identification.

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[1] Meyer C. et al., eds. (1996) *Planetary Surface Instruments Workshop,* LPI Tech. Rpt. 95-05. [2] Brinckerhoff W. et al. (2000) *Rev. Sci. Instrum., 71,* 536. [3] Brinckerhoff W. et al. (1998) *LPS XXIX*, 1789; [4] Cornish T. et al. (2000) *Rapid Commun. Mass Spectrom., 14*, 2408.