An AOTF-LDTOF Spectrometer Suite for In Situ Organic Detection and Characterization

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Introduction: On future surface missions to Mars, small bodies, and outer solar system satellites, increasingly robust sample screening and selection may be essential steps to achieve the maximum scientific benefit within limited payload resources. On both in situ and sample return missions, a common central goal will likely be to understand the production and processing of organic molecules in the solar system and their relationship to prebiotic chemistry and habitable environments.

The samples selected for highly sophisticated laboratory analysis or for return to Earth must be carefully vetted by analytical tools that provide the greatest assurance of science value. On the Mars Sample Return mission currently projected at the end of the next decade, one selection criterion might be the presence of certain combinations of reduced complex organic compounds in association with preservational mineral microenvironments from within sedimentary rock. Alternatively, in what will likely be strictly in situ missions for the next decades to icy moon targets such as Europa or Enceladus, robust sample screening will provide the information necessary to select the most interesting targets for further analysis. Subsequent steps could range from conducting more intensive screening to processing and introduction of samples into a sophisticated analytical laboratory with limited sample capacity. One approach to defining such steps for a variety of missions is the identification of key organic functional groups by a spectroscopic prescreening tool, followed by organic compound analysis with one or more mass spectrometric methods of increasing complexity.

We discuss the development of a miniature near-infrared point spectrometer, operating in the 2-4 micron region, based on acousto-optic tunable filter (AOTF) technology. This instrument may be used to screen and corroborate analyses of samples containing organic biomarkers or mineralogical signatures suggestive of extant or extinct organic material collected in situ from planetary surfaces. The AOTF point spectrometer will be paired with a laser desorption time-of-flight (LDTOF) mass spectrometer and will prescreen samples for evidence of volatile or refractory organics before the laser desorption step and subsequent mass spectrometer measurement. The addition of AOTF technology has the potential to enable significant near-IR spectroscopic diagnostic capability without exceeding the resources of a small surface laboratory, and this instrument suite will result in a powerful tool for astrobiological exploration of our solar system.

AOFT and LDTOF Technologies: Acousto-Optic Tunable Filter (AOTF) systems provide great flexibility, being very compact, electronically programmable, with time-averaged power requirements of ∼1 Watt or less. They can provide arbitrary spectral selection over a factor of two tuning range by utilizing a birefringent TeO2 crystal, which acts as a diffraction grating when compressed using RF waves. With broadband light as an input, orthogonally polarized, spectrally narrow beams are diffracted within the crystal and can be separately re-imaged at the output. The AOTF material, TeO2, is inherently radiation hard. Furthermore, these devices have no moving parts, making them an attractive option for space flight.

Our group has a demonstrated history of developing and using AOTF imaging spectrometers for planetary science applications [1, 2, 3, 4, 5, 6]. Several AOTF instruments were developed at NASA/Goddard Space Flight Center and used at ground-based telescopes to observe the giant planets [2] and Venus [5]. These instruments operated both at vis-band (CCD) wavelengths and in the near-infrared to approximately 3 µm. These successes led to the development of a prototype two-channel Acousto-optic Imaging Spectrometer (AlmS) as part of a Mars lander concept [3]. This instrument was used to demonstrate the capability of an IR AOTF camera to spectrally identify minerals similar to those found on Mars’ surface. It was later repackaged for ground-based planetary science applications, including near-IR imaging of Titan [6].

The laser desorption time-of-flight (LDTOF) mass spectrometer provides pulsed-laser desorption and analysis of refractory organic compounds up to >5,000 Da on a spatial scale of 10-30 µm determined by the laser spot size at the target. At higher laser power, it also...
measures major, minor, and trace elements with parts-per-million sensitivity. The compact size and low power requirements of the LDTOF mass spectrometer also make it suitable for mounting on a robotic arm of the type developed for the Phoenix and Mars Science Laboratory (MSL) missions.

**Breadboard Development:** A breadboard version of the AOTF point spectrometer is shown in Fig. 1. Light from a small infrared lamp is sent through the AOTF and the exiting narrowband radiation is coupled to a large-core IR fiber that guides the light to illuminate the sample of interest. The reflected radiation is collected by an off-axis parabolic mirror and directed to a cooled InAs detector. Computer control of the RF frequency sent to the AOTF allows the wavelength of the illuminating light to be quickly scanned to obtain the sample reflectance spectrum. The ability to further modulate the RF drive signal provides improved SNR performance in the presence of background radiation.

The integrated AOTF-LDTOF spectrometer suite is in the design phase. Figure 2 shows a CAD drawing of the current version of the instrument package. The AOTF and LDTOF spectrometers have similar requirements for precise positioning of sensor elements near the sample surface. By combining these into a common optomechanical design, significant savings in instrument mass and complexity are realized. Further, the pairing offers the powerful advantage of cross-checked chemical analyses of individual samples, which can result in less ambiguous science interpretation.

**Future Plans:** The AOTF point spectrometer will be used in Q1 2010 for diagnostic testing of geological samples of known atrobiological importance. An initial mineral and rock sample suite of planetary relevance will be used in the laboratory for baseline testing. To this, we will add a complement of astrobiologically relevant biosignatures from a variety of geomicrobial study sites well characterized in our previous work [7, 8, 9, 10, 11, 12, 13]. These include desert varnish on volcanic, sedimentary, and igneous bedrock, gypsum weathering rind and evaporite communities, travertines and tufas, and a spectrum of biofabrics and biominerals from cave deposits and surfaces.

**Acknowledgements:** This work is supported by NASA’s ASTID and EPSCoR programs through grant numbers NNX08AY44G and NNX08AV85A, respectively.