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1 Project Description

1.1 Introduction

In sample return missions from comets or asteroids, or from Mars in the sample return mission presently planned for the end of the next decade, robust sample screening and selection will be essential for achieving core goals of the NASA vision. Specifically, sample screening is critical for achieving the goals of understanding the production and processing of organic molecules in the solar system and their relationship to prebiotic chemistry and habitable environments. In what will likely be strictly in situ missions for the next decades to icy moon targets, such as Europa or Enceladus, automated sample screening will provide the information necessary to select the most interesting targets for introduction into analytical laboratories that are restricted to a very limited number of samples due to relatively short battery lifetimes. In these cases, identification of organic functional groups by a prescreening tool followed by organic compound analysis by a mass spectrometer would greatly increase the probability of mission success.

This proposal seeks funds for the development and field testing of a point spectrometer based on acousto-optic tunable filter (AOTF) technology, for “quick look” in situ detection of organic species at millimeter size scales. Although a convincing case could be made for a stand-alone AOTF spectrometer, our intention is to develop an instrument that can be paired with a miniature Time-of-Flight Laser Desorption Mass Spectrometer (TOF-LDMS) (Fig. 1) and demonstrate its ability to prescreen samples for evidence of volatile or refractory organics before the laser desorption step and subsequent mass spectrometer measurement. This instrument development will merge the capabilities of two sensors with significant prior investment by NASA, and will result in a powerful tool for astrobiological exploration of our solar system.

The development of instrumentation for astrobiological investigations will significantly strengthen the research capabilities relevant to NASA’s Science Mission Directorate within the state of New Mexico. Through our partnerships with scientists and engineers at NASA/Goddard Space Flight Center and industry, and with students at NMSU and New Mexico Institute of Mining and Technology, this program will contribute to the science and technology capabilities, higher education, and economic development of New Mexico. We will develop a nationally recognized expertise in astrobiological instrumentation that will be applied to future calls for instrumentation proposals for NASA solar system missions. This capability will expand New Mexico’s participation in NASA research, will develop NASA’s future workforce through student participation, and will enhance the economic viability of the state.

1.2 Technology Background

AOTF systems provide great flexibility, being very compact (a few cm in size), electronically programmable, and requiring low power (~ 1 Watt or less of RF power). They can provide arbitrary spectral selection over a factor of ~ 2 tuning range by utilizing a birefringent TeO_2 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, TeO_2 , is inherently radiation hard, as confirmed by previous testing at GSFC and elsewhere. Furthermore, these devices have no moving parts, making them an attractive option for space flight.

Members of our group have a demonstrated history of developing and using AOTF imaging spectrometers for planetary science applications (Glenar et al. 1994, 1997, 2002; Georgiev et al. 2002; Chanover et al. 1998, 2003). Under NASA Planetary Instrument Definition and Development Program (PIDDP) funding in the mid-late 1990's, several instruments were developed at NASA/Goddard Space Flight Center (GSFC) and used at ground-based telescopes to observe the giant planets (Glenar et al. 1997) and Venus (Chanover et al. 1998). These instruments operated both at vis-band (CCD) wavelengths and in the near-infrared to approximately 3 μm . These successes led to NASA Mars Instrument Development (MIDP) funding for the development of a prototype two-channel Acousto-optic Imaging Spectrometer (AImS) as part of a Mars lander concept (Glenar et al. 2003). The visible channel of this instrument (Fig. 1) was later repackaged for ground-based planetary science applications, including near-IR imaging of Titan (Chanover et al. 2003). Newly available light sources can now allow AOTFs to be used for in situ applications without ambient light. **Thus, the time has come for these instruments to be further developed for a lander mission with an astrobiology focus.**

The Time-of-Flight Laser Desorption Mass Spectrometer (TOF-LDMS) (Fig. 1) provides pulsed-laser desorption and analysis of refractory organic compounds such as Polycyclic Aromatic Hydrocarbons (PAHs) 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 [or lower] sensitivity. The compact size and low power requirements of the LDMS make it highly suitable for mounting on a sample collection arm such as that developed for the Phoenix or Mars Surface Lander (MSL) missions. By raster scanning a TOF-LDMS over a sample surface using a robotic arm, one can obtain detailed chemical maps used to identify sites for collection of high-interest specimens in the case of a sample return mission, or samples for an integral analytical laboratory in the case of fully in situ missions. Within the last several years, the LDMS has been developed to the Technology Readiness Level (TRL) 5 for planetary applications under the leadership of our collaborator, Dr. Will Brinckerhoff (NASA/GSFC).

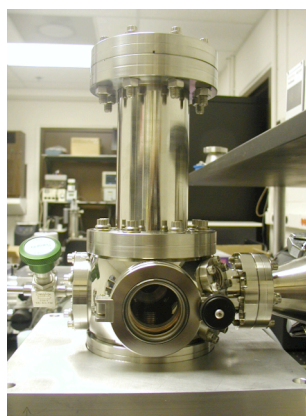
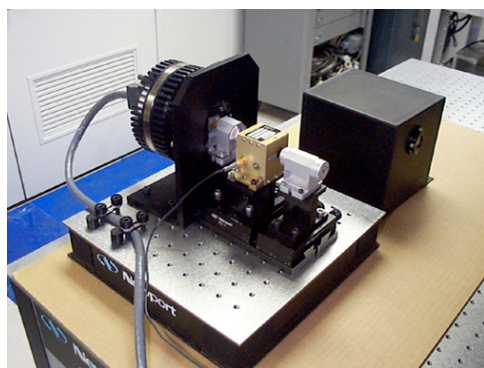


Figure 1. *Left:* Breadboard of VNIR channel of the AImS instrument. The AOTF is in the brass enclosure in the middle and serves as a tunable narrowband filter. *Right:* TOF-LDMS mounted in the vertical tube vacuum section, with sample loaded into base chamber that will be adapted to accommodate optical feedthroughs for the AOTF.

1.3 Research Objectives and Expected Significance

We have adopted two goals for this proposed effort:

1. quantitatively demonstrate that an AOTF-based spectrometer can perform rapid spectral detection of organic species when they are present on the surface of solid samples, and

that a combined sample analysis by both the AOTF and the LDMS produces an unambiguous detection of the organic materials present

2. show that this class of spectrometer can reduce ambiguity and improve the time efficiency of an in-situ LDMS by itself by prescreening samples for the presence of spectral structure arising from organic species.

This significance of work will be the development of an innovative instrument package that can be proposed for future missions of astrobiological interest.

In 2007, NASA commissioned four studies for future flagship missions to the outer solar system, specifically for a Titan Explorer, a Europa Explorer, an Enceladus mission, and a Jupiter System Orbiter. These concept studies outline the unanswered questions and desired measurement objectives for those worlds in the outer solar system, and the work proposed herein fits naturally within that framework. For example, the Titan Explorer Flagship Mission Study (http://www.lpi.usra.edu/opag/Titan_Explorer_Public_Report.pdf) advocates the development of an instrumentation suite that includes a near-IR point spectrometer capable of detecting and characterizing organics. As stated in the Titan report (p. 2-59), “in addition to providing this spectral ground truth for comparison with Orbiter/Balloon datasets, the Lander spectrometer will be used to characterize material prior to ingestion into the chemical analyzer. Thus, the Lander as a whole acts as a spectroscopy calibration laboratory.” The work we propose herein conforms closely to this application.

1.4 Technical Approach and Methodology

1.4.1 Science Case for IR Spectroscopic Sample Screening

Recent spacecraft exploration of Mars, small bodies, and icy satellites, along with supporting laboratory investigations, has generated tremendous interest in these worlds from an astrobiological perspective. Here we review recent results and discuss key measurement objectives that can be achieved with our proposed instrumentation. These objectives can be categorized into three related areas: (i) the detection of organics on planetary surfaces, (ii) the identification of potential spectral biomarkers, and (iii) the detection of mineralogical alteration related to the presence of either extant or extinct organic material.

In parallel with our instrument development efforts, we will propose to observe some of the solar system bodies described below using the Apache Point Observatory 3.5-meter telescope in Sunspot, NM. This will provide us with current characterization data to confirm the spatial distribution of materials of interest in the case of Mars or their global presence or absence in the case of the unresolved bodies.

Outer Solar System Satellites

In its exploration of Europa, the Galileo spacecraft revealed a strong evidence of a subsurface ocean and surface cracks that contain materials of different color and composition. Various compounds in addition to crystalline and amorphous water ice were detected on the surface of Europa using Galileo’s Near-Infrared Mapping Spectrometer (NIMS) instrument, including carbon dioxide, hydrogen peroxide, sulfur dioxide, and molecular oxygen (Carlson et al. 1999; Spencer and Calvin 2002). Understanding Europa’s surface composition will yield information about its subsurface ocean chemistry and very likely the potential of that ocean for supporting

life. Europa's surface chemistry is dominated by radiolysis in the form of energetic particle bombardment of the surface (Carlson et al. 1999), therefore any inferences about the subsurface composition derived from surface measurements must account for these effects. Laboratory work by Moore and Hudson (2000) showed that the infrared signature of H₂O₂ (hydrogen peroxide) was not detectable by proton-irradiating pure water ice at 80 K; rather, it required the inclusion of CO₂ or O₂ in the ice before irradiation. The demonstration phase of our instrument package will include room temperature spectral measurements of organic residues produced in Moore's laboratory at NASA/GSFC by radiolysis of a variety of plausible starting mixtures (see Section 1.3.3). Chyba and Phillips (2001) advocate for a vigorous astrobiology initiative aimed at the exploration of Europa, including a lander mission to inventory the volatiles and search for organics; they deem the latter to be "the highest priority 'biology' experiment to be conducted." A miniature AOTF/LDMS would be an appropriate choice for this task.

The recent discovery by the Cassini spacecraft of energetic plumes and surface stratigraphy (dubbed the "tiger stripes") near the south pole of Saturn's moon Enceladus has changed our perceptions of this small icy satellite. With an internal heat source driving the plume ejection, there is a possibility for subsurface liquid reservoirs, making Enceladus a target for future astrobiology investigations. Near-IR spectra acquired with Cassini's Visible and Infrared Mapping Spectrometer (VIMS) reveal that the surface of Enceladus is dominated by water ice, with amorphous and crystalline ice distinguished by the sharp reststrahlen band at 3.1 μm. Strong signals of complexed CO₂ were seen in the tiger stripes (Brown et al. 2006). Ammonia ice, which was predicted to be present as it is pervasive in the outer solar system, was not detected. Weak features were seen at 3.4 and 3.5 μm, and hydrogen peroxide was subsequently assigned as a plausible explanation for the longer wavelength feature (Newman et al. 2007). For both Europa and Enceladus, the detection of H₂O₂ is significant because it has been postulated to play a role in the evolution of oxygenic photosynthetic organisms on early Earth (Borda et al. 2001).

Saturn's largest moon, Titan, the only satellite with a substantial atmosphere, is regarded as a high priority object for astrobiological investigations. Recent exploration of Titan by the Cassini spacecraft and the Huygens Probe reveals a surface with liquid reservoirs, large quantities of organics, and very few impact craters. Modeling of VIMS spectra indicates that Titan's surface albedo (and variations thereof) is likely due to water ice mixed with a darker material, but no single recipe is consistent with observed spectra in all of Titan's atmospheric windows (McCord et al. 2006). The VIMS data show an anomalously large 2.8/2.7 μm reflectance ratio that cannot be explained by expected H₂O and NH-bearing compounds. This ambiguity in the VIMS data is a strong argument for continued exploration of Titan's surface with an instrument like our proposed AOTF/LDMS package.

Small Bodies

Comets and asteroids also play an important role in astrobiology. Comets are thought to be a main source of water and other volatiles now found in the inner solar system. Although a lander and/or sample return mission to a small body may be developed in the future, there are laboratory analogs that can be studied now in an effort to understand the evolution of organics on these bodies. For C/P/D asteroids and some comets we have carbonaceous meteorites and chondritic interplanetary dust particles, which contain semi-volatile and nonvolatile phases that could be prescreened by an AOTF and detected by an LDMS. For comets and Kuiper Belt Objects, irradiation experiments showed that irradiation of ices readily yields "small" molecules such as CO, CO₂, OCN⁻, CH₃OH, and HCOOH, and a residue that may contain larger organics such as PAHs and polymers (Hudson and Moore 2001). Studies of proton-irradiated amorphous

water ice in the presence of hydrocarbons also show that ethane is produced in sufficient quantities to explain its detection near 3.3 μm in Comets Hyakutake and Hale-Bopp.

Mars

The search for “life on Mars” is arguably the holy grail of astrobiology. It has been one of the primary drivers of NASA’s Mars Program, and has motivated numerous remote sensing, in situ, and laboratory investigations relevant to astrobiology. Despite numerous advances, relatively little Martian surface material has undergone detailed analysis, and the portion of the planet’s surface that has been studied using in situ techniques is still quite small. There remains a need for spectroscopy of surface materials to determine the level and state of organics present; such an investigation is appropriate for an AOTF/LDMS system. Recent laboratory spectroscopy of terrestrial analogs of Mars surface soils indicates that the vis/NIR region, even up to 4.7 μm , is best suited for the detection of nitrate, sulfate, carbonate, and phyllosilicate detection (Sutter et al. 2007). We have demonstrated the capability of an IR AOTF camera to spectrally identify minerals similar to those found on Mars’ surface, as shown in Fig. 2. Through previous funding we obtained samples of oxides, carbonates, sulfates, halides, and sedimentary and igneous rocks relevant to Mars’ surface, which will be used for laboratory demonstration purposes in this work.

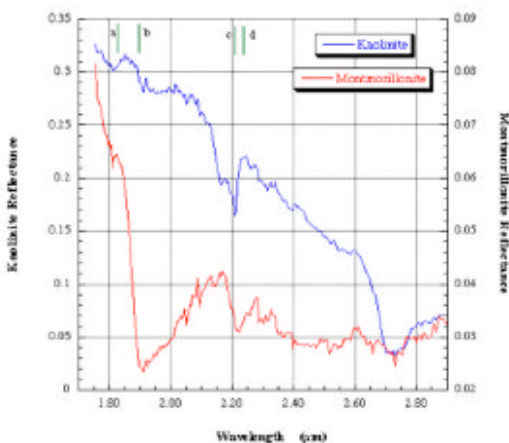


Figure 2. Lab spectra of clay powders relevant to Mars surface studies using an existing IR AOTF camera.

Measurement Objectives

In summary, primary science targets for our proposed compact AOTF/LDMS system would be Mars or small bodies such as comets, asteroids, or icy satellites. In a Mars sample return mission, the AOTF/LDMS could be mounted on the end of a sample acquisition arm such as that under development for the Mars Science Laboratory (MSL). The instrument combination proposed here could also be integrated within a lander or rover body, with samples transported via robot arm. This approach has the advantage of higher stability and less stringent power and mass restrictions.

1.4.2 Spectrometer Design and Implementation

The IR spectrometer will rapidly acquire either a full IR spectrum of the target or reflectance values at a set of pre-programmed target wavelengths. This is accomplished within a time envelope of 1-2 sec, depending on sample reflectance, prior to the laser desorption step. Table 1 shows the basic design objectives, which appear to be fully achievable based on the radiometric modeling discussed below.

Table 1. Spectrometer design objectives.

λ range ^a	Spectral Resolution	SNR ^b	Optics - Physical		Electronics ^c - Physical		Power ^d Requirements
			Mass	Volume	Mass	Volume	
1.8-3.5 μm	7-20 nm	> 100	200 g	150 cm ³	450 g	150-180 cm ³	3.8-4.2 W pk ~ 2.2 W avg

^a Spectral range is limited by the AOTF transducer design and detector cutoff wavelength.

^b Signal to noise ratio (SNR) is based on a 0.1 sec integration time and a Lambertian target with albedo = 0.1 (see Table 2).

^c Dominated by the AOTF, RF synthesizer and power amplifier. See text for specifics.

^d Set by the AOTF, RF unit, estimated at 30-40% efficient, and glower power requirement of ~ 2 W. Detector TE-coolers (not added) are used for breadboard configuration only.

Figure 3 shows a functional diagram of the spectrometer optics, which we divide logically into (i) tunable light source module, (ii) spectrometer head, and (iii) electronics unit (not shown), which will mount tandem under the light source module. Optical components, apertures and ray boundaries are drawn approximately to scale in order to convey the approximate size relative to the GSFC-LDMS unit. Transmitting optics are shown in this configuration for clarity, but we will study a compact, folded all-reflecting configuration for the light source module. The “spot” spectroscopy avoids the stringent image quality requirements typical of an imaging system. The combination of a miniature high intensity light source, all-electronic tuning, and coupling of the source light to the sample via infrared fibers, makes the design simple compared with the active optics required by e.g., Raman methods, and also well suited to the use of multiple sources and detectors. It likewise conforms to the very tight physical constraints imposed by the LDMS assembly, which is shown in profile in Fig. 3.

We will construct two versions of the spectrometer assembly: a “breadboard” version with sufficient flexibility for component-level testing and sample analysis under laboratory conditions, followed by a field-demonstration unit specifically configured for mating to the LDMS. Both versions will use nearly identical copies of the light source module, and the spectrometer head will in both cases operate with the same illumination and light collection geometry. However, the “breadboard” spectrometer head will require its own TE cooling (larger detector package) for operating under ambient conditions. The LDMS spectrometer head will require only temperature stabilization of the detectors since it will operate within the [cooled] LDMS demonstration environment.

Light Source

The acceptance of compact in situ spectrometers has been problematic due to the lack of a sufficiently bright, low-power broadband source, as well as by design difficulties associated with matching the source image to the spectrometer etendue ($A\Omega$). However, the recent development of small-area (~ 0.6 x 1.6 mm) “pulsable” tungsten emitters manufactured by Helioworks, Inc. with an internal parabolic reflector and IR transmitting sapphire window has improved this situation. Radiometric modeling, summarized in Table 2, shows that high SNR spectra should be attainable with short (~ 1 sec) integration times, as a consequence of their very high effective

temperature (~ 1900 K) and optimized glower geometry. We believe this source is an excellent candidate for our point spectrometer instrument.

As shown in Fig. 3 (a), light from the IR source is reimaged at 1:1 magnification onto a 500 μm “pinhole” spatial filter using a short focal length lens, and is then collimated when it enters the AOTF. With RF power applied, the AOTF deflects light of one wavelength but in opposite polarizations symmetrically (approximately ± 6 degrees) at exit from the crystal; the wavelength of this light is selected by changing the frequency of the RF drive source. Narrow-band, orthogonally polarized images of the input pinhole thus appear on either side of the optic axis, and this light is routed to the spectrometer head via large-diameter infrared (“ZBLAN”) fibers, available from IR Fiber Systems in Silver Spring, MD, as well as other suppliers. Either of two U.S suppliers of AOTFs (Brimrose Corp. or NEOS Technologies) can fabricate compact, tellurium dioxide (TeO_2) devices that meet our size, tuning range and spectral resolution requirements as well as the ray guiding properties on which the spectrometer design is based. A separate InAs detector serves as a calibrated monitor of light source stability by sampling the relatively bright undiffracted light at the AOTF output.

Spectrometer Head

Due to the proximity of the LDMS extraction lens assembly, it is necessary to obliquely illuminate and collect light from the target region. Narrow-band light emitted by the fibers is collected using ~5 mm diameter lenses and illuminates a small (~ 2 mm) region of the sample surrounding the laser ablation target. A similar lens configuration is used to reimage the reflected light onto a 1 mm diameter InAs detector, available from Judson Technologies, operating at -65°C . A preamplifier chip and bias circuits will be integrated onto the board at the detector location. Under these conditions, detectivity (D^*) exceeds $10^{11}\text{ cm Hz}^{1/2}\text{ W}^{-1}$ at 3 μm . Built-in thermistors allow these devices to be temperature stabilized, which maintains constant responsivity. As a consequence of oblique illumination, it will be necessary to locate the vertical position of the sample to within ~ 1 mm, which is accomplished by physically contacting the sample with the spectrometer head. In Fig. 3a, we show source and detector in a common plane in order to illustrate the ray guiding geometry. In actuality, the source fibers and detectors will be distributed around the circumference of the spectrometer head as shown in Fig. 3b, with a single, TE-cooled detector used for the breadboard and dual detectors for the LDMS assembly.

Electronics Module

The intent of the breadboard instrument is to evaluate optical performance, and will not require “piggyback” electronics, i.e. all functions will be rack mounted using equipment that is mostly already available at NMSU. The LDMS field spectrometer, on the other hand, will require electronic functions to be integrated into a piggyback module, which synchronously acquires and stores target spectra as commanded by the LDMS unit. This unit will contain: (i) a tunable, 100-180 MHz phase-lock-loop RF synthesizer and power amplifier module (available from Brimrose Corp.), (ii) temperature stabilizing current supply for the IR glower, (iii) bias and temperature stabilization sources for the spectrometer and source-monitor detectors, (iv) buffer-amplifiers and 12-bit ADC, and (v) data memory, all sequenced by a field-programmable gate array (FPGA). External communication could easily be implemented via a serial data interface.

Spectrometer Sensitivity Estimates

Radiometric spreadsheet computations were carried out for the Fig. 3 design concept and show that high signal-to-noise can be achieved with integration times of order 1 msec per spectral point, as required for “quick-look” spectroscopy (Table 2). The largest uncertainty is the source coupling efficiency relative to a perfect 1900 K blackbody, which depends on numerous unknowns (e.g., source emissivity, temperature non-uniformity, and alignment). We estimate this to be ~ 0.07 , based on device far-field measurements at Helioworks.

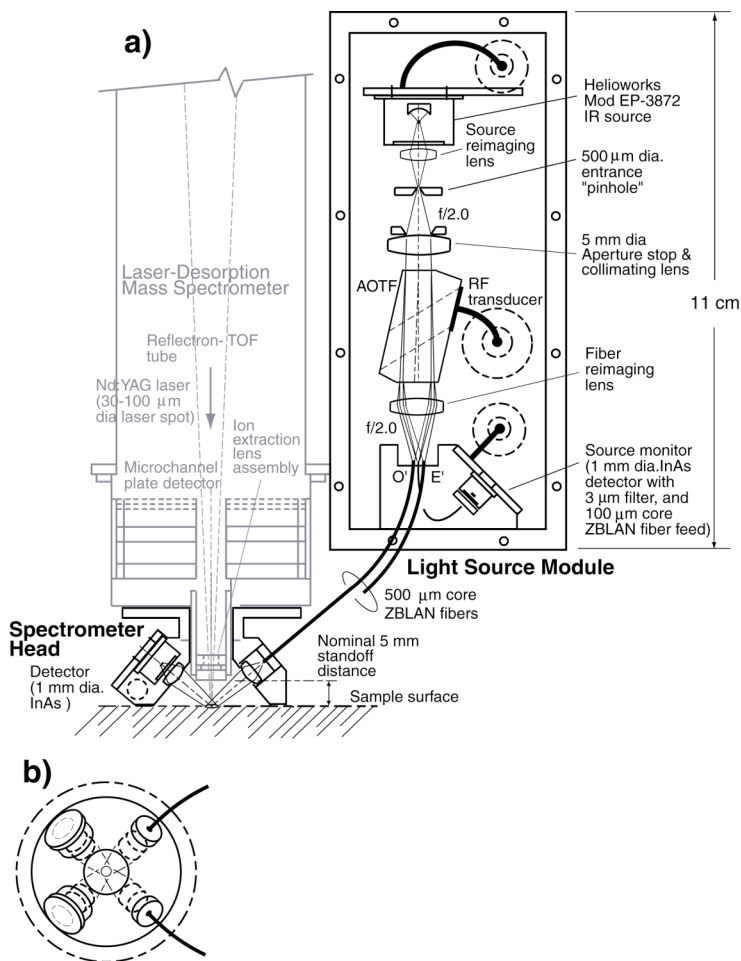


Figure 3. Scale diagram showing the spectrometer components and light guiding ray boundaries. (a) Elevation view of the tunable light source module. The LDMS is included to show its relative size, as well as the scheme for sample illumination and detection. (b) Plan view showing the relative quad source and detector locations in the field configuration, with the spectrometer configured for the LDMS.

Table 2. Spectrometer Radiometric Performance Estimates

Wavelength (μm)	Helioworks ^a W μm ⁻¹	AOTF Δλ (μm)	Sample Irradiance ^b (nW)	Power on detector ^c (nW)	NEP ^d (pW)	SNR/msec
1.8	2.57E-04	0.0054	81.8	1.12	1.11	32
2.2	2.06E-04	0.0081	98.0	1.35	0.68	63
2.6	1.56E-04	0.0113	103.2	1.42	0.44	101
3.0	1.15E-04	0.0150	101.5	1.40	0.43	104
3.4	8.57E-05	0.0193	97.2	1.34	1.27	33
3.5	7.93E-05	0.0204	95.4	1.31	3.54	12

^a Source irradiance into spectrometer AΩ, inferred from bolometric measurements. Overall coupling efficiency relative to ε=1 blackbody is estimated at 0.07.

^b Includes transmittance of AOTF and optics, fresnel losses and fiber coupling factors (overall transmittance ~ 0.18)

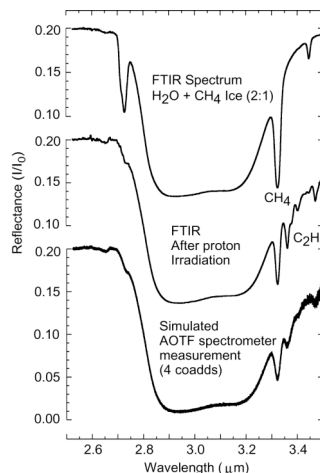
^c Assumes Lambertian sample reflectance with reflectance (albedo) = 0.10, 4 mm diameter collecting lens aperture and 12 mm lens-target distance (~ 0.09 sterad collector).

^d Detector noise equivalent power. Based on spectral detectivity (D^*) estimates from Judson at -65°C , and detector diameter of 1 mm.

Simulations

Figure 4 (bottom trace) shows a simulated AOTF spectrometer result as it views a hypothetical, low-albedo icy surface. The combination of low albedo and narrow spectral features are a difficult challenge for a spectrometer since they demand both high sensitivity and moderate resolution. This simulation was constructed using thin-film FTIR ice absorbance measurements acquired at GSFC, after proton irradiation of a 2:1 H_2O - CH_4 ice mixture. Spectral features in this example are indicative of organic ices that might be found on radiation-processed surfaces in the outer solar system. The data were converted to reflectance, scaled to a peak reflectance of 0.2 to simulate a low-albedo object, and then convolved to our estimated instrument resolution with added detector noise (Table 2). Spectral features from ethane and CH_4 are clearly resolved.

Figure 4. Simulated AOTF spectrum of radiation processed organic ices (bottom trace), based on the instrument performance in Table 2. Source spectra are taken from measurements made by Collaborator Moore of an $\text{H}_2\text{O}/\text{CH}_4$ ice mix before and after proton irradiation. Spectral features from ethane and residual CH_4 are clearly resolved by the AOTF instrument.



1.4.3 Work Plan for Proposed Research

This section summarizes the three main tasks that lead from the present conceptual state for the combined AOTF/LDMS instrument to an integrated working prototype that is capable of characterizing samples in the laboratory. Table 3 shows the 3-year timeline for these activities.

Year 1. Sensor Development and Functional Testing

Significant optical component testing at NMSU will be conducted in the first year, prior to assembling the AOTF breadboard. Performance of the assembled breadboard will be characterized using a combination of calibration sources and targets. In parallel with the AOTF breadboard activities, our GSFC collaborators will conduct staged design and development work in Years 1-2 necessary for integrating the complete TOF-LDMS-AOTF prototype instrument.

Year 2: Measurements of Natural Samples and Analogs

A range of natural samples will be separately analyzed by both the breadboard AOTF and the breadboard TOF-LDMS to demonstrate the effectiveness and complementary information

provided by the two techniques. Samples will be selected from a wide range of Mars and planetary analogs that have already been studied with various techniques in the GSFC laboratory.

Year 3: Integration with the GSFC LDMS and Full-Instrument Operational Tests

The full system will be integrated at GSFC using facility supplies and controllers. Preliminary full-instrument testing will use a small set of pre-calibrated samples from Task 2, with specific criteria for limits of detection of key compounds that will serve as objective measures of performance. The instrument then will be optimized for science relevance on potential missions. This activity includes modifications to the design or the operational protocols of the breadboard hardware necessary to achieve required sensitivity, mass resolution, throughput, limit of detection, and selectivity *of the combined system* using relevant planetary sample materials.

All characterization results will be fully documented, reviewed within the team, and evaluated for presentation at conferences and submission to peer-reviewed journals.

Table 3. Timeline for Completion of Task Elements

	Year 1 10/08-9/09	Year 2 10/09-9/10	Year 3 10/10-9/11
TASK 1: AOTF breadboard;LDMS redesign			
AOTF procurement, Finalize b'board design			
Optical component testing			
Breadboard assembly, characterize, calibrate			
Ion extraction assembly (IEA) redesign/build			
Laser focusing system design mods			
TASK 2: Survey measurements (breadboards)			
Selected smpls (terrestrial analogs, meteorite)			
Survey measurements in Cryo-ice laboratory			
TASK 3: Integration & operational checks			
"Prototype" Opto-mech integration & checkout			
AOTF hardware refinements (learning curve)			
Corroborative sample meas. at GSFC & NM field sites			

1.5 Scientific Impact of Proposed Research

The development of an AOTF/LDMS instrument concept will result in an innovative technique for prescreening surface samples prior to their analysis with a TOF-LDMS. This instrument concept will demonstrate a new application of AOTFs for in situ spectroscopic studies and will fulfill the documented need for sample pre-screening prior to mass spectrometry analysis. We anticipate that the demonstration of a compact, low power, self illuminating, point spectrometer will also lead to new applications in fields such as terrestrial geology, ocean geochemistry, autonomous robotic sensing, and surface inspection.

1.6 Existing Research

Although this proposal represents an important new challenge in the form of establishing the capability for state-of-the-art astrobiological instrumentation development at NMSU, investigators in our team have previously developed extensive expertise with AOTF devices primarily through collaborations with NASA/GSFC. Recent work by investigators Chanover and Voelz focused on the use of an AOTF camera system for ground-based observations of the

giant planets and their moons. Current related projects are the reduction and interpretation of data from recent planetary observations, the resurrection of a NASA/GSFC IR AOTF imaging camera for future planetary studies, and the deconvolution of filter transmission functions from spectral image data.

The New Mexico NASA EPSCoR program was established in May 2007, and there is currently one other investigation in the state being funded through this program. **Our proposed investigation, which is closely linked to NASA’s goals and objectives for its Science Mission Directorate, complements the existing NASA EPSCoR award in New Mexico.** That award, entitled “Structural Health-Monitoring and Self-Healing of Aerospace Structures,” is relevant to NASA’s Exploration Systems Mission Directorate. NASA EPSCoR programs that address both science and aerospace engineering will give the state of New Mexico a broader context within which it can develop capabilities relevant for NASA.

1.7 NASA Alignment and Partnerships

1.7.1 Relevance to NASA and Jurisdiction

Value of Proposed Research to NASA’s Research Priorities

The proposed research is relevant to NASA’s Strategic Goals as outlined in *The Science Plan for NASA’s Science Mission Directorate (2007-2016)*. Specifically, it will address Strategic Goal 3, Sub-goal 3C: **Advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space.** The development of an infrared spectrometer suitable for astrobiology investigations will address NASA’s Research Objective 3C.3: *Identify and investigate past or present habitable environments on Mars and other worlds, and determine if there is or ever has been life elsewhere in the solar system*, as well as the NASA Science Questions *What are the characteristics of the solar system that lead to the origin of life?* and *How did life begin and evolve on Earth and has it evolved elsewhere in the solar system?* By advancing our capabilities to efficiently screen and sample surface materials on astrobiologically interesting targets we will contribute to the advancement of our understanding of the evolution of life in the solar system.

In addition to the relevance of this proposed investigation to the NASA Strategic Goals, our proposed program has direct relevance to NASA’s Astrobiology Roadmap, 2008 Revision. The instrument development proposed herein is directly related to Astrobiology Goal 2: *Determine any past or present habitable environments, prebiotic chemistry and signs of life elsewhere in our Solar System.* To support this goal, Objective 2.1 is *Mars exploration*, and Objective 2.2 is *Outer Solar System exploration.* Both of these objectives require orbital and surface missions “to explore the surface ices and thin atmospheres of these bodies for evidence of subsurface habitable environments, organic chemistry and/or biosignatures.” For both of these objectives, example investigations are given, including the development of instrumentation that can search for signatures of organic materials. The program described herein will do exactly that.

Alignment of Proposed Research with Jurisdiction’s Goals and Priorities

Within the state of New Mexico there is a strong commitment to the strengthening of science, technology, and economic capabilities that are aligned with NASA’s goals and objectives. In 2003, Governor Richardson outlined an economic growth package that included making New

Mexico “a national leader for advanced technology” (Richardson 2003). In 2005, the 21st Century Space and Aerospace Cluster was established as one of five interdisciplinary research clusters on the NMSU campus. The mission of the Aerospace Cluster is to “form a mutually supportive group of educators, researchers, and practitioners to advance 21st century space-related opportunities for research, teaching, and economic development at NMSU and in the region.” The research proposed herein provides an opportunity for the development of new technological capabilities and an educational training program for the development of the future workforce within the state of New Mexico.

Technical Advisory Committee Input

New Mexico NASA EPSCoR received nine pre-proposals for this opportunity. The Technical Advisory Committee (TAC) reviewed the pre-proposals and selected two to go to full proposals, making recommendations for improvement. The TAC then reviewed the full proposals, again providing recommendations for improvement. The involvement of the TAC in the development of this proposal increased the quality of this proposal.

1.7.2 Partnerships/Sustainability

The proposed research represents a collaboration between NMSU and NMT scientists and engineers and NASA/GSFC scientists (Section 1.7.3). In Years 2 and 3 of this program we will solicit participation from other institutions and industries within our jurisdiction as appropriate. There is a group at Los Alamos National Laboratory that has been flying neutron spectrometers in space since 1963 in support of the U.S. nuclear treaty verification program; they were flown most recently on the Lunar Prospector and Mars Odyssey missions. These instruments are used to detect signatures of hydrogen, through which the presence of water ice is inferred. Our proposed point spectrometer complements this technique in that it can be used to prescreen a particular soil sample for evidence of water ice prior to analysis by a neutron spectrometer, and we will explore the possibilities for jointly developing instrumentation for future planetary missions. We will also explore relationships with local physics, geology, and optics industries in New Mexico (e.g. Optometrics, Akamai Physics) to identify potential partnerships relevant to astrobiological instrument development.

National research competitiveness will be achieved through the dissemination of our results and through participation in nationally competed mission opportunities. We will publish the results of our research in nationally recognized journals and will present our findings at nationally attended conferences. Our graduate students will secure future employment at NASA Centers through nationally competed fellowships such as the NASA Postdoctoral Program. Finally, NASA has implemented new requirements for prospective Principal Investigators for small missions. We will explore those requirements and develop the appropriate expertise within our team in order to position ourselves for future science mission opportunities.

1.7.3 NASA Interactions

Previous and Current Interactions

The proposing team has a strong working collaboration with scientists at NASA’s Goddard Space Flight Center (GSFC). Science PI Chanover was in residence at GSFC from 1997-1998 as a National Research Council postdoctoral fellow. In the area of the proposed research, Chanover has continued to collaborate closely with Dr. John Hillman (deceased, 2006), Dr. David Glenar,