Maturation of Instruments for Solar System Exploration Program
Abstracts of selected proposals
(NNH16ZDA001N-MATISSE)

Below are the abstracts of proposals selected for funding for the MatISSE program. Principal Investigator (PI) name, institution, and proposal title are also included. 62 proposals were received in response to this opportunity. On June 22, 2017, 8 proposals were selected for funding.

F. Scott Anderson/Southwest Research Institute
Maturing the TRL of a Complete CDEX Dating Instrument

Science goals

We have developed an instrument to assess and revise the history of the inner solar system, search for organics, and reveal the history of habitability called the Chemistry and Dating EXperiment" (CDEX) instrument. The CDEX instrument is uniquely able to map microscopic chemical and organic context of a sample, while simultaneously determining age. The instrument measures rubidium-strontium (Rb-Sr) isotopes using laser ablation resonance ionization mass spectrometry (LA-RI-MS) for isobar free elemental separation. The RI lasers can be turned off to assess chemistry in LA-MS mode, or organics in two-step laser MS mode. This instrument was the basis for Discovery and Mars 2020 proposals, and planning is underway for future Discovery and New Frontiers opportunities. This proposal specifically addresses instrument TRL deficiencies identified under these earlier flight proposals, and will improve the TRL of the integrated instrument from 4 to 5-6.

Methodology

This proposal focuses on 1) development of a Rb fiber laser, 2) development of a sample gripper and grinder subsystems, and 3) integration and validation of a complete TRL 5-6 CDEX instrument. Specifically, based on our successful development of Sr and ablation lasers under a 2014 NASA MatISSE, we will produce a Rb RI fiber laser subsystem, raising the laser subsystem TRL from 4 to 5-6. The fiber laser design, built in partnership with Aerospace Corporation, improves on the solid-state laser system we built earlier by reducing input power by 50%, increasing output power by 4X, reducing mass by 3X, and reducing optical interfaces by 10X. Reducing the number of optical interfaces is crucial to reducing alignment and contamination requirements. The Rb laser will then be tested and integrated with the existing Sr and ablation lasers subsystems, along with a contributed TRL 6-9 flight spare mass spectrometer from the University of Bern. The integrated CDEX will be lifetime tested in relevant environments at SwRI, and validated by repeating existing benchtop measurements. Sample handling for the instrument will be demonstrated, including development and testing of a sample gripper and grinder, followed by verification measurement on CDEX. The gripper and grinder

development adapts existing high TRL technologies from MDA and HoneyBee Robotics to the CDEX instrument. Finally, we will continue our ongoing sample benchtop measurement campaign, expanding the suite of successful demonstration measurements, thereby raising the maturity of the LARIMS dating method.

Proposal objectives

1) Define flight requirements, environments, and interfaces;

2) Develop, build, environmentally test, and validate a Rb fiber-laser subsystem;

3) Integrate all three lasers (Rb, Sr, and ablation) with a miniature mass spectrometer;

4) Verify and validate instrument performance;

5) Perform lifetime and lunar environmental testing;

6) Validate sample handling, including a gripper, grinder, and docking interface;

7) Build scientific support through ongoing bench-top dating measurements.

Relevance

These measurements are relevant for missions to the Moon, and Mars, as well as other inner solar system targets like Vesta. Specifically, the instrument is relevant to multiple NASA goals, such as:

A) For Mars, the NRC Decadal Survey specifically supports: development of instruments [including] ... in situ geochronology experiments;

B) MEPAG Goals III.A.3-10, but especially 3, specifically call for Constraining the absolute ages of major Martian crustal geologic processes... and the cratering rate. ... with both in situ and returned sample analysis.

C) For the Moon, the NRC DS has a primary goal of: Determining the chronology of basin-forming impacts and constraining the period of late heavy bombardment in the inner solar system, and thus addressing fundamental questions of inner solar system impact processes and chronology.

Richard Mathies/University of California, Berkeley
The Enceladus Organic Analyzer (EOA)

Quantitative compositional and chiral organic molecule analysis is key to understanding an extraterrestrial location including its history, habitability and potential for past or present life.

Few high-TRL instruments exist that can achieve this important goal. The advancement of the Enceladus Organic Analyzer (EOA) to TRL 6 will enable a powerful new approach for characterizing carbon chemistry in our solar system including the non-statistical distribution of organic molecules and optical isomers that tell us about the presence of extant or extinct life. EOA is an innovative microchip capillary electrophoresis (¼CE) system with laser-induced fluorescence (LIF) detection. The µCE electrophoretically separates molecules with high resolution, and is very effective for analysis of organics having a wide range of sizes and complexity from a variety of solid, ice or liquid sources. The integrated Programmable Microfluidic Analyzer (PMA) enables reliable, flexible fluidic processing. LIF is highly sensitive with picomolar concentration limits of detection (the equivalent of only attomoles detected).

EOA SCIENCE OBJECTIVES

Detect and quantify amines, amino acids, carboxylic acids, and polycyclic aromatic hydrocarbons with parts-per-million sensitivity from samples as small as a few micrograms.

Separate multiple (>20) amine-containing species (including amino acids) that differ in isomer or carbon chain-length with baseline resolution. Perform similar analyses on carboxylic acids and polycyclic aromatics.

Separate chiral enantiomers of any observed amino acids.

EOA MISSIONS

Enceladus Plume Fly-By/Orbiter. The organic composition of the Enceladus plume is a high-priority science objective in the NASA Science Plan and the Decadal Survey prioritized an Enceladus orbiter.

Comets. The EOA could be used to sample and analyze organics from comets and their coma that are beyond sample return to answer questions about primordial sources of organic matter and current synthesis.

Icy Moon organic analysis. The core EOA analyzer instrument could also be deployed in orbiters, fly-by or lander missions that acquire solid/ice samples.

TECHNICAL OBJECTIVES

Raise TRL of the PMA. This technology is at a high TRL (5) having been extensively tested in lab and challenging field applications. Our objective is to fully demonstrate the PMA in a relevant environment as an integrated prototype raising TRL to 6.

Raise TRL of LIF. LIF laser and optical detection systems have over a decade of development for space flight beginning with the Urey instrument for the ExoMars rover to the MOA instrument proposed for Mars 2020. This subsystem will be built and tested to elevate its TRL from 5 to 6.

Raise TRL of the Capture Plate System from 3 to 6. When samples for the EOA are acquired from plumes or ejecta, a capture plate collects material during a fly by. An efficient soft impact capture has been developed that obviates the confounding problem of organic contamination found with other soft impact strategies like aerogels.

Raise TRL of the integrated system including all peripheral hardware and control electronics. The TRL of most EOA components and subsystems is as high as 5. We will build and test an integrated technology demonstration unit with flight-like component subsystems raising the TRL of the whole instrument to 6.

RELEVANCE
The proposed work seeks to develop and demonstrate the EOA as a planetary and astrobiology science instrument to the point where it may be proposed in response to future announcements of opportunity without additional extensive technology development (TRL 6).
The EOA is an innovative technology that improves instrument measurement capabilities in a small, low mass, low power package, and is poised to address significant scientific questions relevant to stated NASA goals.

DATA MANAGEMENT PLAN is not required because this proposal is for instrument development only.

Talso Chui/Jet Propulsion Laboratory
A Planetary Broadband Seismometer for the Lunar Geophysical Network and the Ocean Worlds

BACKGROUND AND RELEVANCE:
The NRC decadal survey identified the Lunar Geophysical Network (LGN) as a high-yield New-Frontiers-class mission concept that will place a long-lived and globally distributed network of geophysical instruments on the surface of the Moon to understand the nature and evolution of the lunar interior from the crust to the core. This will allow the examination of the initial stages of planetary differentiation frozen in time some ~3-3.5 billion years ago. The objectives of LGN hinge on the capabilities of an ultra-sensitive, very broad-band (VBB) seismometer. LGN s objectives are designed to discover the interior structure and composition of the Moon that was not possible with the Apollo network. To meet these objectives, a VBB seismometer ~10 times more sensitive than the state of the art (SOA) is required while maintaining the sensitivity over a wide temperature range.
Operating in high-radiation cryogenic environments will also benefit future exploration of Ocean Worlds. Ultra-sensitive seismometers are critical for detecting faint motions deep within the planet that can be used to reconstruct its interior while shedding light on fundamental processes such as plate tectonics, volcanism, ocean waves, ice flow, and geysering.

TECHNOLOGY:
The key PBBS technology is the Electrostatic Frequency Reduction (EFR) technique invented by Co-I Paik in which the mass-suspension natural frequency f0 is reduced to near zero by applying an electrostatic force. This technique broadens the seismometer s response, dramatically increases its sensitivity, and allows remote and fine adjustment of f0 to a level of precision not achievable otherwise. The ability to remotely and autonomously tune f0 is particularly important to operations in cryogenic environments, which cause suspensions to stiffen and result in an increase in f0 and a degradation in the low-frequency sensitivity.
The University of Maryland (UM) and JPL have developed a proof-of-concept Planetary Broad Band Seismometer (PBBS) using EFR (TRL 3). The development was funded through the Planetary Instrument Definition and Development Program, and delivered a proof-of-concept sensor with comparable performance to SOA terrestrial seismometers.

OBJECTIVES AND METHODOLOGY
1: Validate the PBBS performance for the LGN in relevant environment. (TRL 5)
2: Validate the PBBS performance in relevant environment of candidate Ocean Worlds. (TRL 5)

The innovations that make these objectives achievable are: (1) The use of the EFR technology to provide very low resonance frequency, and to compensate for changes in the spring constant with temperature; (2) The use of specialized materials with tailored thermal properties for the springs and the housing; (3) The adaptation of sensitive displacement sensing techniques from the gravitational-wave detection community; (4) The use of advanced digital and analog electronics, including synchronous detection to eliminate 1/f noise that limits the low frequency performance of the InSight seismometer and a force-feedback loop implemented in software and encoded in a Digital Signal Processor (DSP) to allow automatic gain change in the event of a large quake; (5) The use of a commercially available cryogenic motor system for fine leveling and centering of the test mass; (6) The implementation of SOA electronic system; and (7) The use of low-thermal-drift components together with thermal compensation/correction.

The technology advancement methodology is to isolate and track the performance of each subsystem, measuring and improving its performance separately and progressively as an integrated system, first in a laboratory environment and then in cryogenic conditions. A key aspect of this approach is the simultaneous achievement of the mechanical performance requirements in separate biaxial-horizontal and vertical configurations before integrating them into a single mass triaxial system in the fourth year.

Haje Korth/Johns Hopkins University Applied Physics Laboratory
Miniature Absolute Scalar Magnetometer for Resource-Constrained Solar System Body Exploration

The magnetic field is a fundamental physical quantity, and its accurate measurement with absolute stability to better than 1 nT is required for many future solar system exploration missions. Future missions requiring this capability include the Europa Lander, which could resolve induction signals to characterize Europa s sub-surface ocean; the Uranus Orbiter and Probe, which seeks to characterize Uranus unique offset multi-pole magnetic field; an Enceladus Orbiter; and the Lunar Geophysical Network. All of these missions require measurement of small-amplitude magnetic signals with excellent long-term stability. Europa induced magnetic fields are a few nano-Teslas in amplitude and are generated by exposure to periodic magnetic field variations resulting from the rotation of the Jovian tilted magnetic field about the planetary spin axis at a period of ~11 h and from the moon traversing the magnetic environment of its host planet in an eccentric orbit at a period of ~85 h. Magnetic sounding is already an integral investigation of the Europa Multiple Flyby Mission, and it is ideally complemented by lander observations because the induction response is sensitive to altitude so that the induction science return is greatly enhanced by combining the high-altitude flyby observations with those from the surface.

Fluxgate magnetometers alone cannot deliver the required performance because their calibration can drift so that long-term stability is not guaranteed. The proven solution is to partner the high-heritage fluxgate instruments with an absolute reference magnetometer, which serves as a calibration source. The fact is, however, that the mass and power of such instrument combination and of most atomic magnetometers alone exceed the capabilities of many planetary missions, especially those with a lander element.

To solve the resource problem, The Johns Hopkins University Applied Physics Laboratory and the National Institute of Standards and Technology have developed a novel miniature absolute scalar rubidium (Rb) magnetometer within the Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) program. The use of recently developed micro-fabricated Rb vapor cells illuminated with a low-power vertical-cavity surface-emitting laser allows for significant reductions of instrument size and power, while retaining the ability to provide an absolute reference. The present prototype has a total mass of 210 g (sensors and electronics), uses <1 W of power, and operates in both Mx and Mz mode, allowing high measurement speed and absolute accuracy. A sensitivity of 15 pT/ Hz at 1 Hz, or 0.1 nT rms, at a sampling time of 100 ms has been demonstrated in a laboratory environment (TRL 4).

The objective of the proposed work is to leverage our advances toward a low-resource absolute magnetometer within the PICASSO program and develop and demonstrate in a relevant environment a prototype vector instrument for resource-constrained solar system body exploration including ocean worlds and in particular the Europa lander. The development consists of: (a) testing key sensor components for the Europa radiation environment and incorporating mitigation steps in the sensor design; (b) implementing vector measurement capability; (c) designing and fabricating a low thermal resource magnetic field sensor; (d) implementing electronics in flight-equivalent packaging; (e) quantifying instrument performance characteristics; and (f) demonstrating the prototype in relevant thermal and vibration environments.

The result will be a TRL-6 qualified instrument with well-defined resource requirements and performance characteristics. The proposed effort will substantially improve instrument measurement capabilities for planetary science missions in support of the Science Mission Directorate s Planetary Science Division, which is the ultimate goal of the Maturation of Instruments for Solar System Exploration (MatISSE) program.

Walter Harris/University of Arizona
Reflective Spatial Heterodyne Spectrometers for high-resolving-power emission-line characterization from orbital and remote missions.

High-resolution spectroscopy is an important tool for remote sensing of energetic, Doppler, and radiative transfer phenomena in the solar system. However, the technical constraints on the most common spectroscopic instrument designs (e.g. Echelle spectrometers) have limited our ability to deliver high resolving power capabilities to solar system targets via remote probes. This limitation is particularly acute at short wavelengths where the spectrum of solar system targets is dominated by emission lines free from contamination by solar continuum and where high resolving power would be especially effective.

We propose here to continue development of the reflective spatial heterodyne spectrometer (SHS), an instrumental technique that combines high resolving power with exceptional sensitivity in a compact volume that enables their use in remote probes. SHS is a common-path Fourier transform spectrometer that achieves high sensitivity with a large intrinsic field of view that makes it well suited for orbital and flyby observations of planetary/satellite atmospheres, magnetospheric plasmas, and comets comae.

We have constructed 3 demonstration prototypes of reflective SHS instruments under NASA support that have been used successfully at ground based facilities and on a sounding rocket to observe water group emissions from H, O, and OH within narrow bandpasses that collectively cover the wavelength range from 120 to 630 nm. As part of this program we would advance these laboratory instruments from their current TRLs of 3-5. This will be achieved through improved mechanical designs emphasizing thermal tolerance and stability under flight stress in a smaller format, development of automated alignment capabilities, incorporation of an EMCCD photon counting detector system, and enhancement of wavelength coverage through the use of multi-order gratings.

Gordon Chin/NASA/ Goddard Space Flight Center
Picture this SELFI: A Maturation Project for a Submillimeter Enceladus Life Finder Instrument (SELFI)

GOALS AND OBJECTIVES

In this proposal we aim to develop a flexible and power efficient spectrometer for the Submillimeter Enceladus Life Finder Instrument (SELFI). SELFI is a passive remote sensing submillimeter heterodyne receiver, and upgraded version to both the Microwave Instrument for Rosetta Orbiter (MIRO) and the Submillimeter Wave Instrument (SWI), with the latter currently under development for the Jupiter Icy Moon Explorer. We will take advantage of new digital processing capabilities in order to provide a more flexible and power efficient backend processor than those flown on MIRO or planned for SWI. Current digital back-ends for ground-based millimeter-wave astronomy are able to analyze wideband signals, while offering a flexible range of spectral resolutions. These back-ends are based on high-speed analog-to-digital converters (ADCs) and high-density field-programmable gate arrays (FPGA) devices. The present sampling rate of the ADCs and the computing power of the FPGAs make it possible to directly digitize analog signals of a few GHz of instantaneous bandwidth, and later to analyze them at high spectral resolutions up to a few tens of kHz.

METHODOLOGY/DEVELOPMENT

Under this instrument maturation project, we propose to advance the SELFI system design to meet the requirements for a planetary mission to Enceladus in order to 1) investigate the composition, abundance, thermal structure, and transport within the plumes, and 2) characterize the source region and processes from which the plumes emerge. In order to accomplish these mission science objectives, we will design SELFI with high spectral resolving power (>107) and equip the instrument with multiple continuum channels (polarized detectors), enabling detection of thermal emissions as cold as 10K, and providing high dynamical range to allow for Enceladus to be mapped throughout its 30 250K temperature range. Emphasis will be placed on maturing the RF-to-digital electronics by designing and building an engineering model that optimizes spectral sampling and radiometric resolution while minimizing dissipated power. Laboratory characterization and environmental testing will mature key instrument subsystems from TRL 4 to 6.

RELEVANCE

SELFI will be an essential part of any Mission to Enceladus, especially for a plume-sampling fly-by mission and provides numerous compelling science and mission-enabling capabilities. For example, it will provide global observations of Enceladus active regions and plumes Before, During, and After plume encounter, which can then be used as Mission Operational input by an in situ sampling Mass Spectrometer Instrument (MSI). SELFI Plume Science Objectives are highly complementary to an in situ MSI. SELFI can provide definitive identification for molecular species in a global context, even when observing through dust and/or ice, due to its

resolving power >107. SELFI has high sensitivity and will be able to detect many trace molecular species which are biomarkers.

James Abshire/NASA Goddard Space Flight Center
MARLI: MARs LIdar for global climate measurements from orbit

We propose to design, build a brassboard, and demonstrate the key capabilities of a multifunctional atmospheric lidar (MARLI) for Mars orbit. This lidar will simultaneously measure atmospheric backscatter and depolarization profiles, wind profiles, and range from a near-polar circular orbit. These measurements address very high priority needs for Mars as summarized in the 2011 Planetary Decadal Survey.

Knowledge of the present Mars atmosphere is severely limited by a lack of observations in several key areas including diurnal variations of aerosols and direct measurements of wind velocity. Both dust and water ice aerosols are pervasive in the Mars atmosphere. Dust interacts strongly with IR radiation causing large changes in the thermal structure and is a driver of atmospheric motions. Water ice clouds play an important role in the water cycle altering the global transport of water vapor. The limited local time coverage of observations to date has shown large changes in the amount and vertical distribution of dust and ice aerosols. However, existing observations do not allow the vertical distribution of the dust aerosols and ice to be characterized over the full diurnal cycle. Winds on Mars play a fundamental role, yet basic questions still remain about the 3-D wind structure and how it changes with local time, location, and season. Wind velocities provide sensitive input and validation for Global Circulation Models (GCMs), and knowledge of winds is important for the safety and precision of spacecraft entry, descent and landing (EDL). Despite their importance, presently there are only a few direct observations of winds on Mars, and indirect inferences are often imprecise. Because the Mars atmospheric dust cycle partially drive the wind fields, it is important to measure the dust and wind profiles simultaneously. It is ideal to measure them with the same instrument operating continuously, day and night, from a polar orbit.

With support from an award from the Picasso program, we are presently developing a breadboard of a wind profiling lidar (called MARLI) to meet these needs. To date we have made considerable progress by: (a) leveraging the design of a single-frequency pulsed Nd:YAG laser from one now flying on CATS/ISS; (b) using a single solid etalon as a frequency resolver in the direct detection receiver, and (c) utilizing a highly sensitive 16-element HgCdTe APD detector from the ESTO IIP-10 program. We now we are assembling the instrument breadboard for measurement demonstrations. We have also updated our lidar performance/SNR models, which show better measurement performance than originally predicted. We plan to exit the Picasso program with the approach demonstrated from the ground, and accurate instrument performance model. The key components have TRLs from 3-5.

For Mars we now have two approaches: one that measures along a single line of sight, allowing unidirectional measurements, as well as a dual beam/dual telescope approach that allows full vector measurements. Our approach is also flexible in wavelength and allows adding a frequency converter assembly to the laser. By operating at 2030 nm in the Titan atmosphere s

optical transmission window, this also allows measuring wind and aerosol backscatter profiles in the Titan atmosphere from orbit.
Our planned work for MATISSE includes (a) further engineering the breadboard instrument into a brassboard, (b) demonstrating wind measurements (scalable to those from Mars orbit) to thin cirrus clouds from the ground, (c) and taking the key instrument assembly, the laser/telescope/receiver assembly, through vibration and TVAC tests. We will also demonstrate a version at 2030 nm for Titan and make wind measurements from the laboratory. We plan to propose a period of performance of 2 years, starting in April 2017. The component average Entry TRL is 4, and the Exit TRL of the key components will be 6.

Shouleh Nikzad/California Institute of Technology/Jet Propulsion Laboratory
Advancing the TRL of a Compact, High Dynamic Range Ultraviolet Imaging Spectrometer

The UV spectral range has been specifically identified in the Decadal Survey as it is rich with key information that can be employed to study planetary systems. Ultraviolet spectroscopy has previously enabled studies of emission from atmospheres & exospheres, surface activity, and plasma properties related to bodies ranging from planetesimals to satellites to the major planets. The UV spectral range also provides diagnostics of surface characteristics including mineralogy, frost & condensation, and bulk ices. Because of these reasons, UV spectrometers have been included on most planetary missions dating back to the 1960s. We propose to advance the technology readiness level (TRL) of a compact, modular ultraviolet and visible imaging spectrometer that employs advanced detector, optical coatings, and grating. The instrument will enable the elimination of high voltage power requirements as well as a reduction in mass and volume; it will also exhibit reduced sensitivity to radiation and it will have higher dynamic range and greater overall stability. As part of the proposed effort, we will mature the spectrometer by advancing the delta-doped detector camera subsystem. We will evaluate the performance of the camera in CU-Boulder s testbed. University of Arizona will provide science objectives to help guide development, and will evaluate individual components as well as the full instrument in their testbed.