Maturation of Instruments for Solar System Exploration 2018
Abstracts of selected proposals
(NNH18ZDA001N-MATISSE)

Below are the abstracts of proposals selected for funding for the Maturation of Instruments for Solar System Exploration 2018 program. Principal Investigator (PI) name, institution, and proposal title are also included. 55 proposals were received in response to this opportunity. On November 20, 2018, 6 proposals were selected for funding.

Dasgupta, Purnendu/University of Texas at Arlington
Ion/Liquid Chromatography for Exploration of Solar System (ILCESS)

Goals and Objectives
We propose to develop a spacecraft-based TRL5 system for in-situ measurement of soluble organic and inorganic anions on planetary missions. The system will detect compounds that contain key elements of life (i.e., CHNOPS) or that bear on the habitability potential of a given environment (i.e., salts), in a broad range of planetary materials at levels significantly lower than previously flown instruments. The proposed development leverages a front-end solvent extraction system and a back-end Open Tabular Liquid Ion Chromatograph (OTLIC) system, developed under the PICASSO program. Both subsystems have been tested under critical environmental conditions, making the entry system TRL 4. We will integrate all subsystems into a fully functional prototype that will be tested under relevant space conditions, so the exit TRL is estimated at 5.

Methodology
Brassboards of the OTLIC and extractor subsystems will be built and tested separately to validate key performance parameters traceable to specific instrument requirements. Next we will define interfaces, integrate both subsystems into a system brassboard, and perform interface tests. We will then conduct end-to-end operational and performance validation tests of the integrated system brassboard both prior and after environmental testing in chambers (thermal/vacuum and shock/vibration), using a combination of laboratory and natural samples relevant to other planetary bodies.

Relevance
Ion chromatography is the standard laboratory method to separate and detect dissolved organic and inorganic ions in a sample. However, ion chromatography has not been implemented in any planetary mission to date. Our team has developed two key solutions to bridge this technology gap: (1) a solvent extraction system that mixes samples and water to bring soluble ions into an aqueous solution; and (2) an open tubular ion chromatography (OTIC) system where the stationary phase is a coating on the wall of a narrow bore capillary, thereby eliminating the sensitive handling requirements of the separation column and paving the way for a compact, robust flight instrument. We now want to integrate both subsystems into a prototype that will significantly improve the capability of planetary missions to characterize water-soluble compounds, both organic and inorganic, in a broad range of samples, including sediments, rocks, regolith, water and ices. The proposed development directly addresses strategic goals and objectives relevant to the Planetary Science Division by enabling investigations of the chemistry

and soluble ion composition of samples collected on the surface and subsurface of Mars and Europa; in ocean materials in the Enceladus plume; or in comets, meteorites, and asteroids.

Chattopadhyay, Goutam/Jet Propulsion Laboratory
Water Hunting Advanced Terahertz Spectrometer on a Ultra-small Platform (WHATSUP)

Science Goals and Objectives: What s up with Water? Water is the key component of our planet s biosphere. All life uses water as its chemical medium. Water is also the linchpin molecule in the search for habitable worlds. Nevertheless, the origin of Earth s water, and more broadly solar system water, remains uncertain. We will develop Water Hunting Advanced Terahertz Spectrometer on a Ultra-small Platform (WHATSUP) to address this key question. WHATSUP, implemented on ultra-small platforms such as CubeSat and SmallSat, will measure the D/H and 17O/18O isotope distribution of water sublimating from comets and is responsive to the Decadal Survey s goal of deciphering the record in primitive bodies of epochs and processes not obtainable elsewhere. The origin of D:H and oxygen isotope anomalies in meteorites has long been a matter of debate, and WHATSUP observations will provide unique information as to whether isotopic ratio gradients are present in the solar system. This would shed light on the origin of the mass-independent isotopic anomaly, and would moreover reliably provide new isotopic constraints on important reservoirs that might have supplied water to the Earth.

Methodology: WHATSUP features a low-mass and low-power 500-600 GHz molecular spectrometer capable of remotely measuring water isotopes based on their unique rotational molecular spectra at sub-millimeter wavelengths. The D/H and 17/18O relative abundance of comets will be measured to a precision better than a few percent in a few hours of observation from <15,000 km distance by pointing the spectrometer just above the comet s limbs. This performance estimate comes from a combination of the receiver sensitivity of JPL s well-characterized 560 GHz Schottky diode-based room temperature mixer, combined with some assumptions about water column distribution of typical comets. The spectrometer includes a heterodyne sensor that is a direct descendant of the 560 GHz MIRO receivers flying on Rosetta; low mass/power silicon integrated circuits that have been developed and demonstrated as part of previous MATISSE effort (a synthesizer and a Fourier transform spectrometer); and an integrated low-loss waveguide switch for differential radiometric calibration. The novel calibration switch uses a low-loss waveguide structure with a large deflection microelectromechanical systems (MEMS) actuator to mechanically alter the waveguide dimension to create the switching function. This integrated calibration switch is a big step forward in these spectrometer instruments as it will make the use of power-hungry flip-mirror assembly unnecessary for instrument calibration. The spectrometer s ~18 cm aperture diameter achieves a ~3 mrad beam footprint for remote sensing. We have developed a spiral leaky-wave planar metasurface antenna with a circular waveguide feed that can be easily integrated to the calibration switch and the spectrometer front-end. The mass and power of the instrument are below 2.0 kg and 5 W, making it ideal for implementation on ultra-small platforms such as CubeSat and SmallSat.

Relevance to MatISSE Goals: The proposed instrument is relevant to NASA s goal to explore and observe objects in the solar system to understand how they form and evolve and improve our understanding of the origin and evolution of life on Earth through an investigation of the processes involved in the formation of cometary water and the oxygen isotopic fingerprint. This

work addresses several objectives of the MatISSE program element as listed in the NRA. Technology developed for WHATSUP can be applied to future submillimeter-wave radiometer/spectrometers to cometary bodies. The instrument developed under this program can also be used to missions to Mars, Europa, Enceladus, Venus, and Titan. Under this program, we will mature instrument technology to TRL 6 (currently at TRL 4) and demonstrate the working instrument in the laboratory and validate TRL 6 for most critical components.

Paik, Ho Jung/University of Maryland
Superconducting Gravity Gradiometer for Planetary Dynamics

Proposed Research. We propose to mature a superconducting gravity gradiometer (SGG) that measures all six components of the gravity gradient tensor for future planetary missions. A new and innovative design, based on three decades of development (mainly funded by NASA), gives a potential sensitivity of 0.1 mE Hz^(1/2) in the frequency band of 0.1 mHz to 0.1 Hz (1 E = 10^(-9) s^(-2)). The measurement band and sensitivity can be optimally tuned in-flight during the mission by changing the resonance frequency of the SGG, which allows measurements of both high-resolution static gravity field for geological and geophysical investigations and time-variable fields for atmospheric and climate studies from the same mission.
Relevance to NASA. The present study would help advance several goals and questions stated in the Planetary Science Decadal Survey 2013-2022, including (1) Characterization of planetary interiors to understand how they differentiate and dynamically evolve from their initial state, (2) Determination of the nature and evolution of the geologic processes that have created and modified the Martian crust over time. Key parameters of atmospheric mass transport dynamics on Mars and Venus can be constrained via accurate monitoring of temporal changes in their gravity fields. The internal structure and dynamics of Mars and Venus can also be better characterized by measuring static gravity fields much more accurately than at present. In sample return missions to small bodies (like OSIRIS-Rex and CAESAR), the body s gravity field must be surveyed from a relatively high orbit to enable a surface landing. Even from a high orbit, the SGG could greatly reduce gravity errors near the surface of the body.
The SGG is a viable solution to reducing the cost, size and complexity of future planetary gravity missions, and thus accomplishing major programmatic goals of the Planetary Science Division. The SGG has a precision two orders of magnitude better than the electrostatic gravity gradiometer that was used on the GOCE mission and the atom-interferometer gravity gradiometers under development. The SGG requires only a single spacecraft and measures all components of the gravity gradient tensor and is more sensitive to short-wavelength gravity signatures compared to satellite-to-satellite tracking (SST). With its resonance frequency tuned to a lower frequency, the SGG is also competitive with the SST for long-wavelength signals.
Proposed Methodology. The new SGG will employ three pairs of superconducting test masses, with their sensitive axes oriented orthogonal to each other. Each such pair is levitated on two precisely aligned superconducting tubes. By measuring differences in the motions of these test masses, using superconducting circuits, all six components of the gravity gradient tensor are simultaneously measured. Under PICASSO, a prototype single-axis SGG was constructed and demonstrated. Under MatISSE, we will develop a full-tensor SGG, and implement an in-situ axis alignment system by using persistent currents, which will enable common-mode rejection to 10^(8).
The SGG requires cooling to <6 K, and the goal for a space mission is to use a cryocooler to enable a mission lifetime of 5-10 years. The most significant issue for such a mission has been

the potential for vibration from the cryocooler to couple into the SGG. There are two candidate cryocoolers for a future SGG mission that have successfully mitigated vibration: Northrop-Grumman s MIRI cryocooler and Creare s turbo-Brayton cryocooler.
TRL. In PICASSO, we constructed and tested a prototype single-axis SGG in the laboratory. The proposed tensor SGG for MatISSE is a combination of three single-axis SGGs with in-situ sensitive axis alignment capability. The entry TRL of this instrument for MatISSE is 4. We will advance the tensor SGG to TRL 5 by the end of the project, by demonstrating adequate performance while testing it under simulated cryocooler vibrations.

Carter, Lynn/University of Arizona
Space Exploration Synthetic Aperture Radar (SESAR): A Digital Beamforming Polarimetric Synthetic Aperture Radar for Subsurface Imaging

We propose to build and test a prototype P-band (70 cm wavelength) beamforming P-band synthetic aperture radar(SAR) called Space Exploration SAR (SESAR). Many key science objectives require the ability to penetrate through meters of dust and regolith to expose buried terrain. Our science objectives are focused on the Moon and Mars, but the radar could be used for Discovery or New Frontiers missions to Venus, Mercury, asteroids, or other objects where several meters of surface penetration are required. SESAR will be able to detect and map buried ice deposits including using a sounding mode to measure the depths to such deposits. It will be able to resolve the Recurring Slope Linea on Mars to search for evidence of salts or brines. SESAR will penetrate through dust to reveal buried fluvial channels and lake deposits on Mars, and it will also provide the capability for detailed morphological studies of volcanic deposits. SESAR will also be able to search for lava tubes and caves.

SESAR is fully-polarimetric with meter-scale spatial resolutions and has modes for altimetry, scatterometry and nadir sounding. The beamforming capability also allows the look angle to be changed without rolling the spacecraft to acquire optimum data on sloped surfaces and for polarimetry modeling. The prototype will leverage proven advanced radar technologies and techniques developed at NASA/Goddard Space Flight Center through PICASSO, IIP, SBIR, and GSFC Internal Research and Development program investments. These advancements include digital beamforming, broadband/light-weight antenna arrays, digital multi-channel radar waveform generator/data processors, onboard radar processing, low-power RF electronics, and radar system demonstrations with aircraft-based radar architectures. SESAR employs a modular approach that allows the antenna and radar electronics to be scaled to work for multiple planetary targets.

Building and testing the SESAR prototype will provide development of innovative technologies that improve instrument measurement capabilities, as described in the MATISSE solicitation. No other planetary radar missions have operated at P-band or have the capabilities (resolution, full polarimetry, flexibility) of the SESAR instrument. NASA s investment in this technology will therefore be key in making future planetary radar missions feasible and in addressing the large number of Decadal Survey and Exploration Analysis Group science goals that require imaging of the subsurface. We will help achieve these goals by bringing the SESAR instrument flight readiness to a TRL 6 by the end of the project.

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Sun, Xiaoli/NASA Goddard Space Flight Center
Swath Mapping Lidar with Fiber Lasers and PN Code Modulation

We propose to develop a swath mapping lidar with a fiber laser operated from telecommunication industry and pseudo noise (PN) code modulation and correlation detection technique. We will use a recently developed 2x8 pixel HgCdTe avalanche photodiode (APD) array detector to achieve a near quantum limited receiver sensitivity and, thus the longest possible range. The proposed lidar is especially suitable to map small bodies, such as asteroids or comet cores where there is a greater uncertainty in their orbit and and shape. There can also be potential hazard objects near the asteroid. Investigations of asteroids including near Earth objects (NEOs) will provide us with greater insight into the solar system formation and evolution, the physical forces acting on the objects, and their orbit and potential encounters with Earth. Lidar measurements can determine the body s shape and orbit dynamics of the asteroid with high geodetic accuracy. A lidar investigation at asteroids can benefits from the versatility of the proposed lidar, which can operate in a long-distance survey mode, a precision global mapping mode, a high-resolution 3-D targeted area-mapping mode, and a real-time multi-pixel proximity ranging mode to assist landing and sample collection. Current planetary lidar cannot cover such a wide span of ranges. Additionally, conventional planetary lidar are usually too expensive to be considered for typical asteroid missions.

We propose to demonstrate a low-cost multifunction lidar based on our patented return-to-zero pseudo-noise (RZPN) laser modulation and correlation detection technique. The receiver detects the laser pulse pattern instead of individual laser pulses by correlating the received signal with the original RZPN pattern. The technique has already been widely used in radio frequency (RF) ranging and the Global Position System (GPS). This approach enables the use of low peak-power lasers at high pulse rate for very long-distance range measurement without aliasing. The newly available HgCdTe APD array detectors give high quantum efficiency over a broad spectral range in the infrared which allows us to use existing fiber lasers from the terrestrial laser communication industries. The new HgCdTe APD array detector has single photon sensitivity which makes it possible to achieve a multi-pixel flash lidar type measurement from 10 s to 100 s of kilometer altitude orbits.

The proposed lidar can be reconfigured in space. The individual pixel output from the multi-pixel detector can be combined to improve sensitivity. The receiver signal integration time can be continuously adjusted to allow a trade-off between the receiver sensitivity and the measurement rates for intermediate range measurements. The laser power can be continuously adjusted according to target distance. In addition to range measurements, the lidar can also measure the surface reflectance from the number of received photons and effectively image the asteroid with the laser illumination without the need for sunlight.

For this MatISSE program, we plan to build a prototype instrument and perform environmental tests of the key subsystems. Our work will mature the instrument from TRL-4 to TRL-6 at the end of the program. The proposed lidar is directly relevant to the MatISSE program by providing a new instrument for near Earth object and asteroid studies called for by the recent Planetary Science Decadal Survey. Our approach provides multiple measurement capabilities with a single cost-effective instrument. It also provides a low-cost alternative to the existing planetary and landing lidar.

Sobron, Pablo/SETI Institute
In-situ Spectroscopic Europa Explorer (iSEE)

Objectives:

We propose to build and critically test a TRL6 in-situ Spectroscopic Europa Explorer (iSEE), a next-generation ultra-compact Raman Spectrometer with superior performance that meets the top-level scientific requirements of multiple planetary missions to the inner and outer Solar System. Our motivation is to build a small, versatile instrument that can address priority science goals in missions to several targets and with different spacecraft configurations (orbiters, fly-throughs, landers, rovers).

iSEE integrates, for the first time, a digital micromirror device/photomultiplier assembly (DMD/PMT) and a microchip diode laser into a miniature Raman spectrometer that enables unprecedented measurements: in-situ chemical identification and quantitation of complex organic compounds, including pre-biotic compounds (e.g. amino acids); biomolecules (organic biomarkers including proteins, lipids, and nucleic acid polymers); minerals/salts; and volatiles. iSEE also provides sample context, including ice composition, crystallinity, and ice phase distribution.

Approach:

The overarching goal of this project is to reduce risks (technical, scientific, operational, and programmatic) for development, delivery, and deployment of a future planetary exploration instrument. For any given planetary mission, iSEE would address the following Science Objectives:

1. Detect and quantitate organic compounds;
2. Search for specific biomolecules that can serve as biosignatures;
3. Determine fine-scale mineralogy;
4. Search for sources of chemical energy (e.g. redox couples);
5. Characterize ice crystallinity and ice phase distribution.

iSEE informs these five science objectives by performing high-resolution, high-sensitivity, quantitative analyses of samples via an innovative approach to Raman spectroscopy. Raman is probably the most powerful tool available for in-situ, non-invasive molecular and mineralogical characterizations. Based on the inelastic scattering of light, the Raman technique identifies molecular species and their chemical and structural nature. iSEE changes paradigm in in-situ planetary exploration: it significantly improves science instrument measurement capabilities for landed and fly-through missions and has potential to become a key new instrument in NASA s exploration toolbox that can replace flown and to-be-flown in-situ sensing technologies in future mission opportunities

Relevance:

Our instrument significantly improves instrument measurement capabilities for planetary science missions such as Discovery, New Frontiers, Mars Exploration, and other planetary programs. It

has potential to become a critical new instrument in NASA s exploration toolbox that can replace already-flown in-situ sensing technologies in future mission opportunities.

iSEE will enable in-situ chemical classification and quantitation of complex organic compounds, minerals/ices, and volatiles. Therefore, iSEE will enable measurements responsive to three of the five science objectives of the SMD s PSD, as stated in the NASA Science Plan: [2] Understand how the Sun s family of planets, satellites, and minor bodies originated and evolved; [3] Understand the processes that determine the history and future of habitability of environments on Mars and other Solar System bodies; [4] Understand the origin and evolution of Earth life and the biosphere to determine if there is or ever has been life elsewhere in the universe.

Specifically, iSEE will enable all three investigations required to understand the habitability of Europa s ocean through composition and chemistry, the priority objective of the proposed Europa lander concept, as developed by a NASA-commissioned Science Definition Team.

This MatISSE project builds on NASA STTR (innovative spectrometer architecture) and SBIR (auto-focusing system)-funded R&D. Thus, this project leverage[s] technology investments [from] NASA Small Business Innovation Research (SBIR).