Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) Program
Abstracts of selected proposals
(NNH18ZDA001N)

Below are the abstracts of proposals selected for funding for the Planetary Instrument Concepts for the Advancement of Solar System Observations (PICASSO) Program. Principal Investigator (PI) name, institution, and proposal title are also included. 91 proposals were received in response to this opportunity. On May 3, 2019, 11 proposals were selected for funding.

Jason Amsden/Duke University
A high-resolution, large mass range cycloidal sector coded aperture miniature mass spectrometer for planetary exploration
18-PICASO18_2-0003

Understanding solar system beginnings, searching for the requirements for life, and understanding the workings of solar systems are cross-cutting themes of planetary science research as described in the 2013-2022 Decadal survey. Mass spectrometers have been and continue to be the primary in situ method for analysis of planetary materials to answer priority questions related to the three themes. An ideal mass analyzer for planetary exploration would have: (i) mass range up to at least 500 u; (ii) ability to measure stable isotope ratios with high precision (±1 0); and (iii) Ability to distinguish between various isobaric species at low mass (<60 u). Currently, no flight mass spectrometer has all these capabilities. The proposed SR-CAMMS (super-resolution coded aperture miniature mass spectrometer) instrument described in herein would integrate several unique technologies including cycloidal mass analyzers, the computational sensing techniques of spatially coded apertures and super-resolution, carbon nanotube (CNT) field emission electron ionization sources, and capacitive transimpedance amplifier (CTIA) array detectors. The SR-CAMMS project plan includes demonstration of low TRL technologies followed by combining them with more mature technologies to build a breadboard prototype system reaching TRL 4 by the end of the period of performance. SR-CAMMS is expected to be applicable to a wide range of past and future NASA missions.

Stanley Angel/University of South Carolina
Compact, Robust Spatial Heterodyne Raman Spectrometer for Planetary Exploration
18-PICASO18_2-0013

Objectives: The goal of this project is to advance and mature a new type of miniature interferometer based Raman spectrometer, the spatial heterodyne Raman spectrometer

(SHRS) that we developed with previous PICASSO funding. The SHRS will be brought to TRL 3 by building a proof of concept model using monolithic optical construction techniques to provide miniaturization, robustness and high spectral performance. Raman spectroscopy is potentially a powerful tool for planetary exploration and three instruments are planned for upcoming Mars missions. But conventional Raman systems are large, heavy and fragile and expensive to engineer for planetary applications. The proposed monolithic SHRS (mSHRS) is smaller, lighter, and more robust than conventional Raman spectrometers, and has better sensitivity, larger spectral range, and a much larger field of view making it more sensitive and easier to engineer, expanding planetary applications.

In the proposed project we will build on the SHRS that we previously brought to between TRL 2 and TRL 3.Some of the proposed changes lower the overall TRL to 2, but we will advance this technology to TRL3 at the end of this work. We will advance the technology by moving to a monolithic integrated optic design (mSHRS) where all optical components of the SHRS are directly bonded to each other in a very small solid-state package with no moving parts. Monolithic construction makes the system very robust to vibrations and shock and allows a much smaller spectrometer to be constructed because there are no supporting elements. The unprecedentedly small size and high sensitivity of the mSHRS will allow its use in smaller spacecraft, like CubeSats, and will allow multiple spectrometers to be flown in a single small spacecraft, greatly expanding the amount of information that can be gathered and increasing analysis throughput. The proposed mSHRS Raman spectrometer will be small enough to fit in a 1U Planetary CubeSat for standoff Raman, or in a 25-mm diameter borehole for in-situ mineralogy and high resolution spatial mapping.

Expected Significance: Raman spectra provide a unique fingerprint to identify minerals and organic compounds in complex mixtures. The proposed monolithic Raman spectrometer is not simply a smaller version of existing instruments but a radically new design that allows truly miniature spectrometers with spectral characteristics equal to or better than larger instruments, light throughput for extended sources up to hundreds of times higher than conventional Raman instruments of comparable size, and with features not found in any dispersive Raman spectrometer such as a wide-area measurement and spatial imaging capability.

NASA Relevance: The proposed miniature Raman spectrometer will be small enough for analysis in boreholes of the type that will be used on Mars, Europa and Enceladus to look below the surface and will also be small enough for use in a 1U CubeSat. The monolithic SHRS design is applicable to a broad range of planetary missions and will directly address science questions raised in the 2013 Decadal Survey for Planetary Sciences. This proposal is directly relevant to NASA's Strategic Plan 2018, Goal "Address National Challenges and Catalyze Economic Growth"; Objective 3: "Develop and Transfer Revolutionary Technologies to Enable Exploration Capabilities for NASA and the Nation". The proposed monolithic SHRS is also relevant to the PICASSO Program, "to develop new proof-of-concept instruments or instrument components, including sampling technologies that enable new science by significantly improving instrument measurement capabilities for planetary science missions." Key science objectives include bringing the

time-resolved monolithic SHRS to TRL 3, and determining limitations in terms of size and weight and limits of detection for key minerals and organic compounds, and identifying design issues related to miniaturization.

Jeffrey Balcerski/Ohio Aerospace Institute
Venus In-Situ Surface Imager
18-PICASO18_2-0033

Recent advances in wide-bandgap electronics has resulted in development of electronic circuits capable of operation in the high-temperature, corrosive environment of the Venus surface, leading to possibility of a future mission operating at the ambient temperature of Venus. However, the scientific instrumentation that would fly on such a mission still needs further development. In particular, it is highly desirable that any mission to the surface of Venus would include a camera, but designs for cameras that operate at temperatures of 450°C do not currently exist. We propose to develop an integrated imaging array capable of operating for long periods of time (months) in the ambient Venus surface environment (740K, 92 bars).

All conventional approaches to operating a camera on the surface of Venus have required a sealed vessel to thermally isolate a camera from the environment, most specifically from the external temperature. This requires a protected, insulated, and windowed vessel, and the heat leak from the Venus thermal environment necessarily results in an operational lifetime of at most a few hours before the system undergoes thermal failure. Such systems also incur the significant penalties of increased spacecraft mass (and power, if active cooling is used.) In contrast, our proposed approach is intended to provide an imager with an extended operating lifetime at Venus ambient temperature, consistent with other long-lived lander technologies currently under active development. The combination of high-temperature integrated circuits (consisting of amplifiers, logic gates, and analog-to-digital converters) with small, wavelength-appropriate photovoltaic diodes allows for the construction of a low-mass, low-power imaging photodetector array that is able to function continuously for timescales comparable to a Venus solar day (117 Earth days).

Following the example of the Viking Mars lander cameras, this effort will start with the demonstration of a low-bandwidth, linear array scanning platform capable of gradually building up a high resolution, visible light panorama of a landing site through a simple actuation mechanism. We will leverage significant high-temperature, harsh environment expertise in designing and manufacturing electronic circuits, optical detectors and components, and actuators to enable a mission-enabling advance in imaging for Venus exploration and science.

There is driving science need for such a capability. Of twenty-five missions to land on Venus, only four have resulted in images from the surface, where the most recent images were collected in 1982. Visual imagery at a microscopic and macroscopic scale have been transformational for Mars science, which demonstrates that contextual images of rock and regolith texture at the millimeter scale, and landing site geology/geomorphology

at the kilometer scale, are critical tools for interrogating and understanding the history and current state of a planetary surface.
The high temperature, pressure, and reactivity of Venus near-surface atmosphere make it unfeasible to repurpose and adapt instruments with significant flight heritage for use outside a thermally and chemically protected shell, so this development effort under the PICASSO program is both appropriate and needed. The imaging system produced by this effort would be suitable for deployment on future Venus landers and rovers, with a lifetime long enough to observe transient surface phenomena and over time obtain a suite of microscopic context images that would facilitate small sample analysis of rock grains and minerals. Demonstration of such a proof-of-concept system with photodetectors, electronics, and basic actuation mechanisms will provide the basis for a revolutionary new avenue of Venus exploration.

Yoseph Bar-Cohen/Jet Propulsion Laboratory
Elastic wave analyzer for icy sub-surfaces (EWAIS) in the solar system
18-PICASO18_2-0036

We propose to develop and demonstrate a breadboard of an Elastic Wave Analyzer for Icy Sub-surfaces (EWAIS) instrument suitable for ocean worlds. The EWAIS will provide data for answers to fundamental science questions about the sub-surface structure of water-bearing worlds (e.g., Europa, Enceladus, and Titan) and structure of icy regions on Mars, including critical information about their origin and evolution. These bodies have been identified as high-priority targets of the NRC Planetary Science Decadal Survey, which noted a lack of technology readiness as one impediment to related missions. EWAIS generates and receives elastic waves using array of piezoelectric transducers capable of operating at temperatures as low as 30K. The breadboard will use reflected signals from discontinuities in the materials impedance (the product of wave velocity and density) along the wave path. Analysis of the acquired data will determine the elastic properties, presence of cracks, cavities and other discontinuities, as well as the thickness of ice and liquid layers.

The EWAIS will be developed with a novel dual-frequency transmitters array that will enable reaching distance of kilometers thru ice. This transmitter array will be the first planetary instrument of this kind. It will be driven by piezoelectric transducers with a bouncing constrained mass that impacts a thumper. The mechanism itself has been conceived and implemented as the actuator of the ultrasonic-sonic drilling system developed by members of the proposal team under the PI s leadership. The task development objective is to produce a breadboard that weighs <5 kg, packaged into 0.3 m diameter by 0.2 m height, that uses <5 Watts average power to emit >200 dB. The primary EWAIS drive frequency will be transmitted in the range of 20 to 40 kHz and the secondary converted low frequency (LF) is in the range of 0.1 to 1.0 kHz. These dual frequencies correspond to two depth ranges that can be analyzed, with resolutions of tens of centimeters in the region of tens to hundreds of meters and tens of meters on the kilometers scale, respectively.

Owing to the nature of elastic waves, the waves transmitted by the proposed instrument are not impeded by conducting media such as saline water/ice. Therefore, the EWAIS is applicable to regions in planetary icy bodies that are inaccessible via electromagnetic based Ground Penetrating Radar (GPR), which is currently the mainstay for characterizing the sub-surfaces of planetary bodies.

The proposed EWAIS will allow characterizing the sub-surface of any planetary icy body in the solar system, including Enceladus, which can be as cold as 34K. The analyzer will be applicable for operation from any in-situ platform including surface assets (e.g., lander and rover) and sub-surface assets (e.g., melting probes). The developed breadboard and analytical algorithms will be demonstrated using a 90K ice testbed containing layered structure and simulated discontinuities. The proposed task will advance the TRL from 2 to 4.

Christopher Carr/Massachusetts Institute of Technology
Electronic Life-detection Instrument for Enceladus/Europa (ELIE)
18-PICASO18_2-0027

Background: Widespread synthesis of complex organics, including nucleobases, amino acids, and sugars, occurred early in the history of the solar system, in the solar nebula. These organics were delivered by comets and meteorites to multiple potentially habitable zones (e.g., Earth, Mars, Enceladus, Europa, Titan), which may be targeted by future missions in the search for extant life beyond Earth, e.g., Ocean Worlds. Even in the absence of common ancestry (Panspermia), common building blocks and similar physicochemical environments could have resulted in independent origins of life based on similar biochemistry. We target not only single amino acids (and abundance distribution) but also information-rich biogenic organic molecules: charged linear informational polymers (IPs), enabled by recent advances in solid-state single-molecule nanogap sensors (via quantum electron tunneling, QET).

Science Goals: Our mission is to develop an instrument, the Electronic Life-detection Instrument for Enceladus/Europa (ELIE), capable of detecting prebiotic, ancient, or extant life, and distinguishing forward contamination, through detection of two universal biomarkers: the amino acid abundance distribution and IPs. Our instrument will be quite versatile and suitable for a multitude of missions, including lander, rover, subsea explorer, and plume-fly-through missions to Mars, Enceladus, Europa, and other Ocean Worlds. Furthermore, by quantifying forward contamination, our instrument will be able to identify false positives and support planetary protection.

Objectives: We will validate single molecule nanogap detection and develop a breadboard system to advance ELIE from technology readiness level (TRL) 2 to TRL 4

and a plan to achieve TRL 6 by the Preliminary Design Review of an Ocean World mission such as Europa Lander or a New Frontiers Enceladus mission.

Methodology: An existing nanogap system, already validated on single amino acids, RNA, and DNA, will be used to test first pure solutions, then mixtures of increasing fidelity, such as a protocell and B. subtilis spores in Ocean World analog solutions, prior to validation on environmental analog samples. Comparisons of yield and sensitivity will be made to existing life detection instruments as well as to single molecule sequencing (MinION) and a solid state nanopore, enabled by common low noise amplifier hardware of a proposed TRL 4 system. This system will also integrate a pre-concentration step to target 10 ppt sensitivity for amino acids. Nanogaps have sub-nanometer adjustable gap spacing to accommodate different sizes of molecules. Machine learning methods will be applied to classify biomolecules. The lack of biological reagents supports planetary protection goals by permitting bioburden reduction.

Relevance: Our effort specifically responds to multiple aspects of the PICASSO solicitation including characterize potential biopolymers, detect chemical processes indicative of potential life, and detect ultralow concentrations of microorganisms. We propose a sensitive and information rich approach to detection of life beyond Earth, suitable for future deployment on multiple missions.

Charles Clark/University of Maryland, College Park
DOWSER: Detecting Objects' Water from Spatial Epithermal-neutron Response
18-PICASO18_2-0073

THE GOAL TO BE ADDRESSED is discovery of subsurface water on the Moon and Mars, in both orbital and lander missions.

THE APPROACH AND METHODOLOGY TO BE USED TO ADDRESS THE GOALS is the development of a compact, robust, low-power and low-voltage neutron detector with velocity and energy resolution.
Neutron detection is a proven technique for identifying planetary subsurface water. Due to their 15-minute lifetime, neutrons are absent as background in cosmic rays or solar neutron wind. Any neutron found near a planetary body has been produced by cosmic-ray spallation of planetary matter and thereby carries signatures of its birthplace.
The energy spectrum of planetary neutrons reveals the presence of hydrogen. Spallation neutrons are born at MeV energies; those found with meV energies have been thermalized by hydrogenous planetary matter. Neutrons pass easily through most materials, so subsurface water can be a source of thermal neutrons. Indeed, thermal neutron detection is the only generally applicable technique for finding water within a solid matrix.

Neutron detectors (NDs) have been incorporated in planetary missions for this very purpose. Based on helium-3 proportional counters, these detectors have demanding operational overheads, such as high voltage, high gas pressure, large mass and bulky shielding. They also have limited resolution of neutron energies and directions, which are critical to locating an unknown hydrogenous deposit.

We have brought to TRL 2 a novel ND that overcomes these limitations. It is a network of compact low-overhead detector cells with diverse direction and energy resolution; it replaces the high-voltage proportional-counter electronics of present NDs with modern silicon photomultipliers operating at 28-volts. Optical detection also has a higher intrinsic bandwidth than the electric-discharge detection using proportional counters. The high-pressure helium-3 of present NDs is replaced by a micron-thick boron-10 thin film deposited on a silicon chip, embedded in atmospheric-pressure xenon.

We have demonstrated neutron detection with a protoype in a sealed cubical physics package of volume 5 cm^3 and mass of 10 g. All power, control and readout electronics are contained in a single control module powered by the USB bus. Power consumption in steady operation is about 30 mW. Experimental tests to date, supplemented by detailed modeling, suggest that this detector has neutron detection sensitivity and gamma rejection comparable to that of the LEND instrument, and superior energy and directional resolution.

We propose to bring to TRL 4 a detector based on a cellular network of compact physics packages operated by a single control module. With appropriate moderators and cell alignment, correlation of signals across the network will sample the angular distribution of planetary leakage neutrons.

OUR PROPOSED WORK IS WITHIN THE SCOPE OF THE PLANETARY SCIENCE RESEARCH PROGRAM, because orbital remote sensing and in situ measurement of neutrons have proven to be important tools for planetary geochemistry research. Determining the quantity and vertical distribution of volatile species on and below the surface of planetary bodies is vital for understanding the primordial chemical inventory and subsequent evolution of planets. Due to unavoidable practical limitations, all early lunar mission neutron instruments could only deliver integrated data on detected fluxes, averaged over large energy ranges and escape angles from lunar surface. The first orbital neutron telescope (LEND - CSETN) had a low signal/noise ratio because background ions, electrons, photons, and scattered neutrons triggered neutron detector signals. Our instrument can provide detailed directionality and energy information of planetary leakage neutrons with high detection efficiency and low background signals. Its simple cellular architecture can be adapted to both orbital and lander missions.

Amanda Hendrix/Planetary Science Institute
A Far-UV Micromirror Integral Field Spectrograph for Planetary Science
18-PICASO18_2-0076

Goals and Objectives.
We propose to study an instrument concept to improve upon current capabilities in UV imaging spectroscopy for planetary uses. The concept is a UV micromirror spectrograph with a wide variety of potential applications including Discovery- and New Frontiers-class missions.

The state-of-the-art UV imaging spectrographs, such as the SwRI-built Alice instruments (including Juno UVS, Rosetta Alice and LRO LAMP) and the LASP-built Cassini UVIS and MAVEN IUVS, return useful datasets from their targets and have opened up the field to the next questions to address. Recent technological advances have enabled instrument improvements for the next generation of planetary science missions. Furthermore, a range of possible upcoming missions could successfully utilize such improved UV instrumentation.

The goal of this program is to develop a proof-of-concept instrument for integral field far-UV spectroscopy. By utilizing a pair of digital micromirror arrays, this concept instrument will be capable of dissecting the focal plane and re-forming it into a series of slit-shapes to overcome the limitations of spectral confusion. The TRL of the system is currently estimated at ~2. We expect to advance the TRL to ~4 through this PICASSO program to be ready to propose to MATISSE for follow-on work and further TRL advancement.

Potential science applications of the instrument include atmosphere characterization, in particular using stellar occultations. A highlight of the micromirror concept is that the array allows for the potential to observe several stellar occultations simultaneously, to probe atmospheric composition and density at multiple locations within a planet s atmosphere. Such a capability will be particularly critical in future missions to Venus and Titan, two worlds likely to be the target of orbiters in the future. Furthermore, thin atmosphere and plume characterization will be useful at upcoming comet missions, an Enceladus orbiter, and perhaps even a KBO mission. The UV capabilities of the instrument will also allow for critical surface composition characterization in addition to the study of gases, particularly useful on asteroid (including Ceres) and Trojan missions, for instance. Another area of importance in the Visions and Voyages planetary decadal survey, and likely important in the next decadal survey as well, is an Ice Giants mission to Uranus and/or Neptune. For such a mission, a capable UV instrument will be of extreme value for studying atmospheric composition as well as for addressing questions about the moons of these planets and whether they harbor subsurface oceans.

Methodology

We will construct a testbed telescope and spectrograph to measure performance of commercially available micromirror arrays. The UV-visible integral field spectrograph will include electronics to functionalize and steer the micromirrors. With the testbed we will characterize scatter, mirror surface quality, and imaging/spectroscopic performance.

We will also determine the compatibility of the micromirror arrays with advanced broadband mirror coatings.

We will also perform science trade studies on the instrument architecture as it would be applied to different science targets. We will consider instrument volume and mass, the addition of an internal scan mirror, wavelength coverage, and resolving power. For a range of applications, aperture size will be weighed against field of view and spatial resolution.

Significance and Relevance to the PICASSO Program

This work is relevant to the PICASSO program because it seeks to advance concepts for instrumentation that will directly address science questions relevant to NASA goals. This micromirror array system shows promise for use in future planetary missions.

Boris Karasik/Jet Propulsion Laboratory
Terahertz heterodyne spectral imager of planets and comets
18-PICASO18_2-0031

Science goals and objectives.

The objective of this proposal is the development of a sensitive, frequency-tunable heterodyne sensor for submillimeter/THz molecular line spectroscopy suitable for planetary missions. Such a device could be used for limb sounding the atmospheres of Jupiter, Saturn, Uranus, Neptune, Titan and Triton, observing water vapor plumes on Europa and volcanic plumes on Io, as well as performing spectroscopy of the tenuous atmospheres of icy moons (including Enceladus) and comets. The heterodyne capability allows very high spectral resolution spectroscopy to be carried out and thus individual spectral line shapes and Doppler velocities to be measured. The proposed Tunable Antenna-Coupled Intersubband Terahertz (TACIT) mixer will provide access to the 1-5 THz frequency range, which contains numerous strong spectral lines originating from the rotational transitions of many molecules, including H2O, CO, CO2, CH4, HCl, H2O2, CS, SO and HCN and their isotopologues. Future planetary missions that will benefit from this technology include the Uranus and Enceladus Flagship Orbiters and all New Frontier candidates identified in the current Vision and Voyages Decadal Survey other than the Venus in-situ mission.

The TACIT mixer is expected to have 4 times the sensitivity than that of the state-of-the-art heterodyne sensor on MIRO/Rosetta. The mixer will be able to operate at 60-70 K (passive cooling in space) and will require just a few microwatts of local oscillator (LO) power. The outcome of this work will enable a multi-pixel heterodyne imager (16 pixels or more) which will allow the spatial mapping to be done 16 times faster than with a single pixel.

The proposed R&D task will be a 3-year effort, which will build on the work performed under the previous 2014 PICASSO funding, during which we successfully demonstrated the operation of a single-pixel TACIT mixer at 2.5 THz. It will optimize the design of TACIT devices further, develop the technique for embedding such devices into THz

waveguide which are required for achieving a multipixel imager, and conclude with a demonstration of a lab receiver consisting of a mixer, first-stage low-noise amplifier, and required optics.

Methodology.

The approach to the mixer is to explore a photoconductive mechanism due to the intersubband transition in a 40nm GaAs/AlGaAs quantum well (QW) heterostructure. The mixer device is fabricated from a pure material (electron mobility > 1E6 cm^2/V-s), in order to achieve the high sensitivity of the device resistance to temperature at 50-70 K. Using gate electrodes, the subband separation can be electrically tuned to any frequency in the 1-5 THz range. In order to be imbedded into a waveguide, the mixer QW structure is suspended on a thin Si membrane. The mixer bandwidth is set by the relaxation rate of the two-dimensional electron gas, which can be as large as 10 GHz. TACIT mixer devices fabricated on Si membrane will enable the waveguide-based mixer which will be the starting point for the follow-on 16-pixel imager development effort.

Relevance to the call.

The proposal is relevant to the 2018 PICASSO call, which supports the development of spacecraft-based instrument systems that show promise for use in future planetary missions. We will develop a new component (multipixel heterodyne sensor) that significantly improves submillimeter spectroscopic measurement capabilities for planetary science missions. The entry TRL for this technology is 3 and the exit TRL will be 4. Under this proposal, we will closely interact with an SBIR-funded effort to develop a novel quantum cascade laser THz LO source, which will be required to develop an imaging heterodyne array instrument we expect to pursue under the MatISSE program.

Mina Rais-Zadeh/Jet Propulsion Laboratory
Radiation Hard and High Temperature Tolerant Thermal Imagers (HOT IR)
18-PICASO18_2-0047

Harsh environments are abundant in the Solar System and the ability of current technologies to survive in extreme temperatures is limited. Specifically, Venus is a terrestrial planet with similarities to Earth and exploring how climate and geology work on Venus could potentially provide a deeper understanding of the processes at work in our own environment. Very little is known about surface geochemistry and almost nothing about mineralogy, so spectroscopic information is needed to address such important questions as the formation and rock type of the tessera and the mineralogical changes resulting from weathering caused by surface-atmosphere interactions. As such, there is an increasing interest in exploring such hot planets but so far, the missions to these extreme environments have been very limited in scope and duration. While research exploring active cooling systems for Venus persists, these are still in development, add to mission complexity, and do not operate in other extreme environments with higher

temperatures or radiation. To enable new scientific missions, we propose to develop an instrument capable of taking infrared (IR) images in harsh environments (high radiation, extreme cold or high temperatures up to 500°C) using a sparse array of resonant-based micromechanical devices. In a sparse array, by definition, the number of imaging elements is reduced to save power and cost. The wavelength range of the IR sparse array can be designed to meet the science requirement of the mission. For example, for mission to Venus, the imaging array will be designed to be sensitive to wavelengths of 0.4 to 5 um (to allow collection of surface emissivity measurements over a wide spectral range). Fundamental and unique planetary science questions that can be answered by the proposed instrument concept will thus include observing the current geologic state of the surface and inferring past evolution and the relative importance of surface processes of Venus. In this three year program, we will develop an imaging IR array (that can be used in an imaging spectrometer) capable of operation in high temperature and high radiation environments and will test the instrument at 500C at the existing facility at Stanford University. The starting TRL for this effort is 2 and the target end TRL is 4-5.

Anthony Yu/NASA Goddard Space Flight Center
Photonic Integrated Circuit TUned for Reconnaissance and Exploration (PICTURE)
18-PICASO18_2-0056

Goals and Objectives:
Future planetary science missions require smaller, lighter and lower power instrumentation, while delivering comparable or higher performance than previous generations. The near-infrared (1-5 um) emission of planets, moons, comets and asteroids is rich in information, including gas composition and surface mineralogy. We propose to develop a next-generation near-infrared spectrometer for future planetary missions, based on integrated photonics technology. In this PICASSO, we will build a fully-operational instrument prototype focused on the CO spectral band at 4.6-4.8 um, which is of key importance to cometary science. Successor instruments can be modified straightforwardly for spectroscopy of the nearby bands of CO_2, H_2O, CH_4 for wide applicability in planetary science, by changing the reference laser. This technology development and demonstration will provide an important proof of concept for future flight instruments.

Methodology:
We will design, build and test a compact, high efficiency coherent (heterodyne) optical spectrometer with associated electronics to combine and leverage recent technological breakthroughs by the proposing team and others. Our spectrometer takes advantage of three significant advances in the field of photonics in recent years (a) photonic lantern (PL) technology for astronomy; (b) arrayed waveguide gratings (AWGs); and (c) photonics integrated circuits (PIC) for the telecommunication industry. The PIC allows the complex integration of electro-optics components, including AWGs and local oscillators for heterodyne detection, in a compact form factor that will provide smaller, lighter, and lower-power instrumentation.

We will leverage the significant earlier progress by our team members at NRL and UCSB toward high-performance near-infrared (NIR) laser arrays integrated on a silicon (Si) chip. During the 3-year performance period we will (i) develop key components and subsystems; (ii) integrate sub-systems to build a complete instrument; (iii) demonstrate and validate high sensitivity measurements in conjunction with our existing infrastructure and instrumentation.

The entrance TRL for this instrument is 2, which will be raised to 4 on completion.

Relevance:
Our objective of developing a next-generation near-infrared spectrometer is highly relevant to the PICASSO goal of the development of spacecraft-based instrument components and systems that show promise for use in future planetary missions . After proof of concept under PICASSO, a fully-ready flight instrument could be developed under MatISSE. A PICTURE-like instrument on a cometary mission will be capable of measuring the relative abundances of cometary volatiles, yielding important information on the primitive building blocks of the solar system. Cometary science has been highlighted in the recent Decadal Survey for Planetary Science (Chapter 4, Primitive Bodies) as being of high importance to NASA s strategic scientific goals. More broadly, the scientific capability of the proposed instrument can achieve multiple goals of solar system science, including the measurements of water and trace gases in the atmospheres of Mars, giant planets, and Titan, as well as the spectroscopy of asteroid and moon surface materials.

Fang Zhong/Jet Propulsion Laboratory
In-Situ Organic Extraction, Separation and Detection using Supercritical CO2 and Superheated Water
18-PICASO18_2-0106

Scientific Objectives:
New in situ instruments and strategies are being developed to determine the abundance and distribution of biogenic elements and organic compounds in space and to determine whether indigenous organisms exist (or existed) anywhere on these bodies. While development and maturation of analysis technologies has flourished, front-end sample handling and preparation systems are still underdeveloped. These technologies are crucial for the future of planetary exploration. We aim to address this need by building a breadboard extraction and separation instrument to extract and separate astrobiologically-important organic compounds that uses only supercritical CO2 (scCO2, 40-75 °C) and superheated water (SHW, up to 200 °C).
In our previous ASTID and COLDTECH-funded work, we have demonstrated that scCO2 can extract and separate ppb and ppt-level nonpolar and slightly polar species from complex salty samples at 40-75 °C [1,2]. For polar species, water is a good solvent, but water can also dissolve salt, which can cause issues for detection instruments. No

methodology has yet been developed to eliminate salt while retaining a wide variety of polar compounds. Our proposed integrated instrument will solve this problem by using preconcentration traps and chromatography columns to separate and deliver salt-free analytes to a mass spectrometer. No pyrolysis or harsh organic solvents will be used. Our proposed approach will enable the extraction and analysis of biomarkers of a full range of polarities.

Approach:

The instrument will be operated in two steps for each solvent. 1) Unaltered biomarkers will be extracted (along with salts for SHW, if present) from solid or liquid or mixed samples. The extraction solution will flow through the on-line solid-phase trap column which will trap and preconcentrate the compounds of interest at ambient temperature while rejecting any salt species [3]. 2) Either scCO2 or SHW with a temperature ramp (50-200 °C) will be used to release the preconcentrated compounds from the trap column. The eluted molecules will then be carried into the separation (chromatography) column, where the compounds will be separated using only scCO2 or SHW before being introduced into a detector, in this case an electrospray ionization mass spectrometer. This proposed work will include the selection and testing of off-the-shelf stationary phases, full method development for SHW (including temperature programming and flow optimization), and validation with a variety of sample types and analytes. We will provide quantitative measurements of this instrument s extraction efficiency and detection limits to ensure efficient detection of important biomarkers and that salts do not interfere with the analysis.

Relevance to the PICASSO Program:

The proposed instrument meets the key science requirement to detect and identify low-abundance organic molecules and astrobiologically-relevant species in future planetary missions, for terrestrial-like planets such as Mars, small bodies (comets, asteroids), or icy satellites (Europa, Enceladus, etc.). Our approach, which enables broad mass spectrometric detection of organics without derivatization, is robust and insensitive to salt content. Prior efforts to develop pressurized water extraction (e.g. the Urey instrument developed for Mars) have relied on higher-risk methods with extraction temperatures >200 °C and requiring fluorescent molecular tags to identify specific classes of analytes [4]. Our proposed instrument minimizes risk: it is not analyte-specific, requires no organic solvents or reagents or molecular tags, and uses only the minimum needed temperatures for analysis, thus ensuring preservation and identification of species in their native forms.

1 McCaig, et al. Astrobiol, 2016. 16: 703

2 Menlyadiev, et al. Int J Astrobiol, 2018. 1-10

3 Andrade-Eiroa, A. et al. Trends Anal Chem, 2016. 80: 641-654

4 Amashukeli, et al. Astrobiol, 2008. 8: 597