

TechPort ID*	Project Title*	Start Date*	End Date*	Project Description*
17594	Super-TIGER2: A Very-Large-Area, High-Resolution, Trans-Iron Cosmic Ray Investigation - Caltech Co-I	Dec 2014	Nov 2018	This is a Co-I proposal from the California Institute of Technology for the proposal entitled "SuperTIGER-2: A Very-Large-Area, High-Resolution Trans-Iron Cosmic Ray Investigation" submitted by Principal Investigator W. R. Binns of Washington University in St. Louis. SuperTIGER is a very-large-area instrument for measuring the composition of galactic cosmic rays on high-altitude balloon flights over Antarctica. Super-TIGER-1 had a highly successful 55-day flight in 2012/2013. The excellent data quality enables us to clearly resolve all nuclei from $Z=10$ to $Z=40$. Additionally, although statistics are low, there appears to be clear resolution of elements with $Z=50-60$. The excellent data from this flight will enable us to achieve the initial goals of the program. The high performance of the instrument, both in charge resolution and collecting power, and the science that can be addressed by measurements of $Z>40$ nuclei, makes a compelling case to conduct additional flights to measure the abundances of individual nuclei up to $Z=60$. This is a 4-year proposal with the primary objective of measuring the abundances of individual nuclei with $41 \leq Z \leq 60$ and to substantially increase the number of $30 \leq Z \leq 40$ nuclei measured. This will be the first time that individual elemental abundances for $41 \leq Z \leq 60$ will be obtained. These new measurements will provide sensitive tests and clarification of the OB-association model of galactic cosmic-ray origins and will test models for atomic processes by which nuclei are selected for acceleration to cosmic-ray energies. They will enable us to determine if the enrichment of refractory elements (those that exist primarily in dust grains in the interstellar medium) over volatile elements (those that exist primarily in the gas phase) extends into the $Z=41-60$ charge range. They will also enable us to unambiguously determine the extent of any r-process enrichment. SuperTIGER provides critical measurements to unravel the mystery of galactic cosmic ray (GCR) origins and complements instruments with different observational aims including AMS, CALET, BESS-Polar, CREAM, TRACER, and PAMELA. This investigation addresses NASA Strategic Goal 2.4—Discover how the universe works, explore how it began and evolved, and search for Earth-like planets. This is a suborbital astrophysics proposal. The proposed work will be performed by a collaboration of scientists from Washington University in St. Louis (PI institution), Goddard Space Flight Center (Co-I institution), the California Institute of Technology (Co-I institution, with JPL participation), and the University of Minnesota (Collaborating institution). SuperTIGER-2 will use the same techniques used in SuperTIGER (dE/dx and Cherenkov measurements combined with trajectory data to measure the charge and energy of cosmic ray nuclei. As in Super-TIGER1, Caltech will be responsible for aerogel radiators in one of the two Cherenkov counters in Super-TIGER-2. Caltech will also participate in integration and test, in monitoring the Antarctic balloon flight, and in data analysis activities.
17614	SuperTIGER-2: A Very-Large-Area, High-Resolution Trans-Iron Cosmic Ray Investigation	Dec 2014	Nov 2018	This is the lead proposal of a multi-institution proposal for the investigation titled "SuperTIGER-2: A Very-Large-Area, High Resolution Trans-Iron Cosmic Ray Investigation". SuperTIGER is a very-large-area instrument for measuring the composition of galactic cosmic rays on high-altitude balloon flights over Antarctica. SuperTIGER-1 had a highly successful 55-day flight in 2012/2013. The data quality is excellent, enabling us to clearly resolve all nuclei from $Z=10$ to $Z=40$. Additionally, although statistics are low, there appears to be clear resolution of elements in the $Z=40-60$ range. The excellent data from this flight will enable us to achieve the initial goals of the program. The high performance of the instrument,

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95116	Development of a novel imaging calorimeter for gamma-ray and cosmic ray studies.	Oct 2018	Sep 2020	We propose to develop an accelerator beam-test instrument to demonstrate the performance of a new type of imaging calorimeter aimed at a future gamma-ray/cosmic-ray mission. The proposal would fund the development, construction and evaluation of a prototype instrument with $150\text{mm} \times 150\text{mm}$ active area and consisting of 4 layers of scintillating fiber x-y trackers, and 4 layers of CsI:Na crystal read out by wavelength shifting (WLS) optical fibers. The prototype would be instrumented with silicon photomultiplier (SiPM) photodetectors and custom electronics, utilizing low power analog pipeline digitizers designed by the U. Hawaii group. Calibrations would be performed using accelerator runs at both tagged photon beam facilities and a heavy ion accelerator. This project is aimed at advancing the technical readiness level of the key detector technologies for a future MDEX (or probe-class) mission concept known as the Advanced Particle-astrophysics Telescope (APT). The instrument design was driven by the requirements of gamma-ray searches for dark matter (requiring a pair telescope with an order of magnitude improvement in geometry factor compared to Fermi LAT) and prompt localization of gamma-ray transients such as the counterparts of gravitational-wave sources/neutron-star mergers (best accomplished by a very large-area Compton telescope). A Sun–Earth Lagrange orbit would remove Earth obscuration providing the largest instantaneous field of view, but would require the use of a relatively thin imaging calorimeter with a depth limited to <6 radiation lengths. The same instrument design would provide multiple differential ionization energy loss (dE/dx) cosmic-ray measurements over a very large area, with a very deep detector. Such an instrument would be a powerful cosmic-ray detector capable of measuring the elemental abundances of very rare, ultra-heavy r-process cosmic ray nuclei for material originating

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				outside our solar system, connecting to the n-star merger science. With the addition of foam radiators, the CsI detectors could detect the transition radiation X-rays from very-high-energy light cosmic rays, specifically Boron and Carbon, needed to differentiate models of cosmic-ray propagation of importance to indirect dark matter detection. The APT detector design would incorporate 20 layers of 5 mm thick CsI:Na with crossed wavelength shifting fiber (WLS fiber) readout, interspersed with 20 x-y scintillating optical fiber tracker (SOFT) layers using interleaved 1.5mm round scintillating fibers. The 3m×3m×2.5m detector volume consisting of passive plastic scintillating fibers and CsI crystals would be read out on the sides with SiPM photodetectors and analog-pipeline waveform digitizers. These electronics would provide adequate look-back time to include signals from the relatively slow CsI detectors in the trigger; achieving this capability within the power budget constitutes another major activity of the proposed research. Ultimately, this work would validate simulation studies that indicate that the APT instrument could achieve 10 times the sensitivity of the Fermi LAT for GeV–TeV gamma-rays, and provide more than an order of magnitude improvement in sensitivity over any other proposed gamma-ray experiment in the MeV energy range with gravitational wave source localization to better than 1 degree uncertainty. Likewise, the cosmic-ray detector would improve statistics on rare heavy elements and high-energy lighter nuclei by orders of magnitude compared to any extant experiment.
95740	Ultra-high Energy Particle Astrophysics with ANITA-V: Ohio State Co-I	Dec 2018	Nov 2021	This is a Co-I proposal for the Antarctic Impulsive Transient Antenna (ANITA) mission (P. Gorham, Hawaii, PI). We propose to fly a significantly improved version of the Antarctic Impulsive Transient Antenna (ANITA) long-duration balloon payload, with a goal of discovering and characterizing ultra-high energy (UHE) neutrinos and cosmic rays in the EeV (Exa-electronvolt) energy range and above. This will be the fifth flight of ANITA payloads, and should achieve the a milestone of 100 days of integrated livetime on orbit, proposed in the earliest flight as a goal for the application of ANITA's novel methodology. Each payload in the series has yielded improved sensitivity, and unexpected results, both in the form of upper limits that excluded long-held predictions for the isotropic neutrino flux from various models, and in the form of serendipitous detections of UHE cosmic rays via radio pulses that were not well understood when ANITA first flew. Moreover, ANITA's ability to perform precision measurements of the pulse shape and polarization properties of the UHE cosmic ray events led to the discovery of candidates for tau-lepton-generated air showers, one in the ANITA-I flight, and most recently, a second candidate in the ANITA-III flight. These events signal the possible appearance of a flux of UHE tau neutrinos, appearing with unexpected properties, in tension with other measurements. ANITA-V will provide an opportunity to elucidate these new potential signals in a compelling way with far-reaching implications for fundamental physics.
95741	Ultra-high Energy Particle Astrophysics with ANITA-V - Washington University - Co-I	Dec 2018	Nov 2021	This is a Co-I proposal that should be cross-referenced to the University of Hawaii proposal titled "Ultra-high Energy Particle Astrophysics with ANITA-V", for which Peter Gorham is the Principal Investigator. We propose to fly a significantly improved version of the Antarctic Impulsive Transient Antenna (ANITA) long-duration balloon payload, with a goal of discovering and characterizing ultra-high energy (UHE) neutrinos and cosmic rays in the EeV (Exa-electron-volt) energy range and above. This will be the fifth flight of ANITA payloads, and should achieve the a milestone of 100 days of integrated livetime on orbit,

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95742	Ultra-high Energy Particle Astrophysics with ANITA-V - University of Kansas Center for Research, Inc. (Co-I)	Dec 2018	Nov 2021	The ANITA-V experiment (PI P. Gorham, U. Hawaii) has observed two events with 'inverted polarity' which does not immediately conform to Standard Model expectations. This may signal some departure from the SM at the extremely high energies to which ANITA is uniquely sensitive. Critical to understanding these events is an understanding of the measurement of the received signal polarity by the ANITA interferometry. The HiCal-3 experiment has, as its science goal, a high-statistics calibration of such a polarity measurement. Following the HiCal-1 and HiCal-2 missions, which demonstrated the principle of the airborne calibration scheme, we now seek to improve on the statistics and fidelity of previous missions. In addition, we seek to provide a calibration source, not only for horizontally-polarized emissions from ultra-high energy cosmic rays (UHECR), but also vertically-polarized emissions from neutrino interactions in-ice.
95743	Ultra-high Energy Particle Astrophysics with ANITA-V California Polytechnic State University Co-I	Dec 2018	Nov 2021	This proposal is in collaboration with Peter Gorham at the University of Hawaii, who is the PI of the lead proposal. Co-I Wissel and her group at California Polytechnic State University (Cal Poly) will be responsible for calibration equipment upgrades, calibration equipment, and deployment of the calibration system and will work in collaboration with Co-I UCLA. The Cal Poly group will provide calibration hardware and support the analysis and interpretation of ANITA-V data in search of ultra high-energy (UHE) neutrinos and cosmic rays. Wissel (now at Cal Poly, a new collaborating institution for ANITA-5) brings significant experience in the detection of high-energy and ultra-high energy particles to the collaboration, leveraging her fifteen years of experience in particle astrophysics and previous work on ANITA-III and ANITA-IV.
95744	Ultra-high Energy Particle Astrophysics with ANITA-V	Dec 2018	Nov 2021	This is the lead proposal on a multi-institutional proposal. We propose to fly a significantly improved version of the Antarctic Impulsive Transient Antenna (ANITA) long-duration balloon payload, with a goal of discovering and characterizing ultra-high energy (UHE) neutrinos and cosmic rays in the EeV (Exa-electron-volt) energy range and above. This will be the fifth flight of ANITA payloads, and should achieve a milestone of 100 days of integrated live-time on orbit, proposed in the earliest flight as a goal for the application of ANITA's novel methodology. Each payload in the series has yielded improved sensitivity, and unexpected results, both in the form of upper limits that excluded long-held predictions for the isotropic neutrino flux from various models, and in the form of serendipitous detections of UHE cosmic

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				rays via radio pulses that were not well understood when ANITA first flew. Moreover, ANITA's ability to perform precision measurements of the pulse shape and polarization properties of the UHE cosmic ray events led to the discovery of candidates for tau-lepton-generated air showers, one in the ANITA-I flight, and most recently, a second candidate in the ANITA-III flight. These events signal the possible appearance of a flux of UHE tau neutrinos, appearing with unexpected properties, in tension with other measurements. In addition to these unexpected anomalous cosmic-ray like events, ANITA-III analysis has yielded one potentially interesting neutrino candidate from a possible in-ice shower, a total of two possible candidates from the 2014-2015 flight of ANITA-III. ANITA-IV analysis is well underway, with about 3 times the expected sensitivity of ANITA-III, but could not be completed prior to this proposal. Depending on ANITA-IV results, ANITA-V will provide an opportunity to elucidate these new potential signals in a compelling way with far-reaching implications for fundamental physics, or to bring to fruition the strongest world limits on cosmogenic neutrino fluxes from the combination of all of the flights, with over 100 days of expected exposure.
95745	Ultra-high Energy Particle Astrophysics with ANITA-V, University of Chicago Co-I	Dec 2018	Nov 2021	This proposal is in collaboration with Peter Gorham at the University of Hawaii, who is the PI of the lead proposal. Co-I Vieregg and her group at the University of Chicago will bear primary responsibility for the analysis of ANITA-V data in search of ultra-high energy (UHE) neutrinos and cosmic rays, and will also be responsible for the development of a prototype drop-down antenna array that will be flown on ANITA-V as a demonstration of a concept for future balloon missions to increase the sensitivity to radio signals from cosmic particles. UChicago will also participate in integration and testing and field work in preparation for the flight of ANITA-V. Vieregg brings significant experience in radio detection of UHE particles to the collaboration, leveraging her thirteen years of experience in ballooning and radio and microwave measurements to support aspects of design, testing, integration, and analysis for ANITA-V.
95747	Enabling imaging astrometry detection and mass measurement of Earth-like planets	Oct 2018	Sep 2021	Accurate measurement of exoplanetary masses is a critical step in addressing key aspects of NASA's science vision. New technologies to implement an astrometric instrument capable of measuring masses of earth-analog planets aboard as a part of NASA's future mission portfolio will be required: this is simply the only viable avenue to attaining these data. Here we propose to advance Diffractive Pupil (DP) technology, capable of performing mass measurements down to 1 Earth mass, to TRL-5. This will immediately empower the possibility for dedicated astrometric missions, and perhaps most enticing, it will enable astrometric observing modes to be added (with relatively low cost and impact) to any mission boasting a sufficiently stable direct imaging platform. Astrometry is the only technique that can unequivocally measure exoplanet masses regardless of the system alignment, and serves to independently confirm direct imaging detections, yielding more precise planet orbits than direct imaging alone. Most critically, detection noise floors make it uniquely suited to habitable zone orbits for Earth-mass objects around sun-like stars: true Earth-analogs. Therefore, this technology can confer unique scientific benefits to future flagship missions. In particular, because these missions are expected to yield one or two dozen exoearths, measurements of mass add very significant value to the science of habitability in the solar neighborhood. The proposed work has three areas that complement each other to develop an efficient and reliable technology: 1) Data reduction and calibration algorithms will be fully

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				developed (including those for a diffractive pupil optimized for single and binary stars). To fully benchmark the methodology, confronting the signal recovery with real data from an optical laboratory testbench is essential. 2) A prototype instrument that performs an end-to-end astrometry demonstration in air and in vacuum will be built and tested. This astrometric instrument will include a star simulator with capability to inject simulated planetary orbital signals, together with a telescope equipped with a diffractive pupil, and laser metrology for detector calibration. 3) A study of implementation aboard the HabEx mission in which the diffractive pupil is implemented at an intermediate location in the optical path (not on the telescope primary mirror) will be performed. Such a scenario calls for calibration of the upstream path by way of the telescope metrology system. During year 1 we will improve existing distortion calibration algorithms (Ames and Sydney) and integrate and test the instrument in air at Ames. In parallel, JPL will build the laser metrology system and calibrate the camera. During year 2 the data reduction pipeline will be tested using real data, and the instrument moved to JPL where the laser metrology will be integrated and the system ready for full vacuum testing. In parallel, the HABEX implementation analysis will be initiated. In year 3, vacuum tests will be undertaken at JPL, while simultaneously the HABEX analysis will be finalized. This proposal leverages successful execution of APRA-09 and TDEM-13 that brought the DP technology to TRL-4. Ames Research Center and JPL will partner for the execution of this proposal utilizing previous investments and expertise in laser metrology from JPL and distortion calibration at Ames.
95771	Vector Interferometry Space Technology using AERO (VISTA)	Feb 2019	Jan 2022	The Vector Interferometry Space Technology using AERO (VISTA) mission is a 90 day CubeSat mission in a polar orbit that will advance our ability to perform radio interferometry using cubesats in space. This mission is a technical pathfinder that leverages the NASA LCAS Auroral Emission Radio Observer (AERO) cubesat project by duplicating that satellite in a build-to-print manner. VISTA will launch at the same time as AERO. The experiment will use the two cubesats in orbit and combine them with ground based beacons and receivers to demonstrate the performance advantages of Vector Sensor Interferometry (VSI) relative to conventional approaches. Controlled experiments will be performed early in the AERO mission lifetime so that the data collected can also contribute to the on orbit AERO calibration and validation effort. Following the initial space interferometry data collection the VISTA satellite will perform primary activities to collect data relevant to risk reduction and planning for future low frequency heliophysics radio constellation missions. These include collection of raw data with the AERO spacecraft over the auroral zone for interferometric analysis and imaging of Auroral Kilometric Radiation (AKR). These measurements can augment both event coverage, the angular resolution, and the time resolution of AERO measurements. They will also provide data to test algorithms for interferometric measurement of auroral radio emissions from orbit. VISTA will additionally implement periodic sampling of the low frequency radio environment in orbit to characterize signals, directions of arrival, and the ability to null strong signals using the vector sensor. The nulling capability is critical for operation of a low frequency satellite constellation near to the Earth as opposed to a more isolated location such as on the Lunar far side. Our technical approach is to use the unique capabilities provided by the electromagnetic vector sensor (EMVS) planned for the AERO mission. This sensor provides the ability to measure angle

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				of arrival and polarization information from a common RF phase center using six orthogonal dipole and loop antennas. The information available from the vector sensor can be used to enable future interferometric constellations with less than half the number of satellites when compared to traditional dipole or tripole antenna based systems. This is due to the increased degrees of freedom available that are inherent in an RF sensor measuring the full information content of an electromagnetic wave. Demonstration of Vector Sensor Interferometry and Imaging is a key next step beyond AERO. The VISTA mission's data acquisition strategy will be similar to the AERO satellite but will focus on obtaining additional raw RF voltage level data. The data that are collected will focus on intervals that enable demonstration of key interferometric measurements. To accomplish the data collection we will double the use of the MSU system and enable the 18m Westford Radio Telescope as an S-band ground station. Ground based assets will also be used to provide a controlled radio beacon and additional interferometric baselines. In particular the use of both space and ground based baselines may enable us to provide closure phase and amplitude calibration for the measurements when ionospheric refraction is properly modeled. From a heliophysics technology perspective, space radio interferometry is necessary for scientific investigation of radio emission from the solar corona, inner heliosphere, and also emissions from other planetary bodies in the solar system such as the Earth, Jupiter, and Saturn.
95772	Low Voltage, Ultra-Compact Plasma Spectrometer: Phase 2	Jul 2019	Jun 2022	Beginning with single spacecraft and progressing to recent multi-spacecraft missions, exploration of near-Earth space has increasingly focused on understanding the energy flow and coupling between different spatial regions through simultaneous measurements of essential plasma parameters, e.g., magnetic field, electric field, density, and temperature, over the relevant spatial scales. The next step in multi-spacecraft missions is to go well beyond missions consisting of a handful of rather large and sophisticated spacecraft to missions comprised of large numbers of more simple spacecraft. For example, the Magnetospheric Constellation mission concept proposes up to one hundred ~10–20 kg spacecraft, each with a power budget of 10 W, deployed in highly elliptical, equatorial orbits. By flying up to 100 small, low-power spacecraft it is possible to resolve the magnetotail as a coupled whole by making dense vector field and plasma measurements over a large region of space. Missions such as Magnetospheric Constellation will revolutionize our view of the magnetosphere by resolving spatial and temporal ambiguities, determining the scale size of processes and regions, and reveal connections between the different regions of the magnetotail. However, plasma instruments small enough to fit on such spacecraft and capable of operating at very low power levels do not yet exist. The first objective of this work is to demonstrate that it is possible to reduce the mass and power of plasma spectrometers by orders of magnitude while maintaining the geometric factor, and thereby the time resolution, to within an order of magnitude of "conventional" instruments. Without such reductions in instrument requirements, it will not be possible to address these core scientific questions. The reductions in mass and power are to be accomplished by lithographically fabricating the essential components of the instrument – using the same state-of-the-art etching processes developed for modern computer chips. The penalty for reduced mass and power is, of course, reduced performance compared to a conventional instrument. However, while addressing the target science questions requires massive numbers of measurements, the individual measurements

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				themselves need not be particularly sophisticated. A second, equally important objective of this work is to demonstrate a significant advancement in the manufacturing methodology of space plasma instruments. By reducing the unit cost for a single plasma spectrometer through mass production, manufacturing defects will be treated as they are in the semiconductor device industry – by simple disposal of the defective unit. Through the support of a previous H-TIDS project, the critical path components needed to realize the proposed plasma spectrometer have been manufactured and successfully tested (the collimator and energy analyzer were successfully tested in a 5 keV electron beam). The prior work also resulted in the identification of significant improvements in the manufacturing process. The work proposed here will employ those improvements to further reduce fabrication costs and enable the assembly of a prototype instrument. The instrument begins at a Technology Readiness Level (TRL) of 3. After integrating a combined collimator and energy analyzer structure with a detector assembly and then testing the prototype instrument in electron and ion beam calibration facilities, this project will terminate with an ultra-compact plasma spectrometer at a TRL of 6.
95773	Extension of the dE/dx-E Technique Using Silicon Detectors to below 1 MeV/nucleon	May 2019	Apr 2022	The "2012 Solar and Space Physics Decadal Survey" and the "2014 Heliophysics Roadmap" acknowledged the importance of better understanding how ions and electrons are accelerated to high energies in the solar corona, the interplanetary medium, and the local galactic medium. Over the past two decades, missions such as ACE and Wind have shown that the existence of a seed population of suprathermal particles plays a central role in the efficient acceleration of high-energy particles. Thus, it is important to understand the mechanisms that produce and maintain the suprathermal particle distribution and accelerate a fraction of it to much higher energies. We propose the development of a sensor that would make possible instruments that can span the ion energy range from <0.5 MeV/nuc to several MeV/nuc with high efficiency and thereby address these objectives. Stacks of silicon solid-state detectors have been widely used since early in the space age for making measurements of energetic particles. By combining the energy loss, Delta-E, from a detector that the particle penetrates with the residual energy, E', in following detectors, the total energy, the nuclear charge, and, in some cases, the mass of the particle can be derived. The lower limit to which this technique can be applied is set by the thickness of the first detector, which the particle must penetrate. Until very recently, silicon detectors with good thickness uniformity have only been available in thicknesses down ~30 microns, which sets a lower energy limit of several MeV/nucleon. Over a number of years, we have developed a new technique for fabricating thin silicon detectors that leads to devices that can be significantly thinner, much more uniform in thickness, and mechanically more robust than earlier detectors. Detectors of this new type are being flown in thicknesses of 12 microns and 25 microns in the EPI-Hi instrument on the Parker Solar Probe mission. We have worked with a commercial detector manufacturer to transition the fabrication process to an industrial setting, thus making this type of detector available to the broader scientific community. The detector fabrication process is thought to be suitable for making devices that are thinner than the 12-micron detectors used in EPI-Hi. We propose the fabrication and testing of prototype detectors with thicknesses down to ~5 microns, which would lower the threshold for the Delta-E vs E' technique using silicon detectors to ~0.4 MeV/nucleon. To optimize the performance of such devices, we will also

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				investigate the use of thinner dead layers, which can be made by low-energy ion implantation, and the use of a novel scheme for coupling the detector to a charge sensitive amplifier that should allow significant improvements in the signal-to-noise ratio in these high-capacitance devices. In addition, we will perform basic environmental tests to establish the suitability of this type of detector for use in spaceflight instruments.
95774	CHIMERA: A hybrid search coil and fluxgate magnetometer for small spacecraft missions	Jan 2019	Jan 2022	This three year proposal will support the development, optimization, and testing of CHIMERA - a hybrid magnetometer that simultaneously operates as both a search coil and a fluxgate. CHIMERA is expected to provide reasonable sensitivity from DC to 10 kHz from a single, compact sensor requiring only one deployable boom. This is particularly useful for small spacecraft and CubeSats, where multiple deployable booms are challenging so even modest sensitivity over this broad range is significant. The hybrid design builds on established fluxgate and search coil technology with decades of heritage operating in extreme and hostile environments. CHIMERA is aligned with the NASA Technology Roadmap in Technology Area 8.3.3 In Situ - Instruments and Sensors and will advance from TRL-3 (technology readiness level) to TRL-6. Science missions have often needed a search coil magnetometer for high frequencies and a fluxgate for the static field and low frequencies. These two instruments interfere with each other - the search coil detecting the drive signal from the fluxgate and the ferromagnetic core providing magnetic gain in a search coil distorting the field measured by the fluxgate. The two resulting deployable booms affect spacecraft control and can impinge the field of view of other instruments. A proof-of-concept laboratory prototype of CHIMERA has demonstrated how to operate a racetrack fluxgate sensor as both a fluxgate and a search coil magnetometer using essentially the same hardware already present in a typical fluxgate instrument. The two sensing techniques can operate simultaneously without interfering in a hybrid sensor engineered to accommodate both effects. The proposed project supports early career development for the PI, David M. Miles, and higher education training for one graduate student and three undergraduate research assistants. A flight-ready hybrid magnetometer enables the investigation of multiple science questions under the NASA Heliophysics overarching science goal to: "Advance our understanding of the connections between the sun, Earth, the planetary space environments, and the outer reaches of our solar system". A hybrid magnetometer is ideally suited for future missions including: a constellation follow-on to the recent funded GTOSat radiation belt CubeSat, daughter payloads deployed from the Geospace Dynamics Constellation (GDC), or small ride along spacecraft that have been suggested for future planetary missions. Magnetic field data from DC – 10 kHz from these missions would be important in addressing, respectively, three science goals identified in Solar and Space Physics: A Science for a Technological Society: SWMI Science Goal 4. Establish How Energetic Particles Are Accelerated, Transported, and Lost; SWMI Science Goal 7. Determine How Magnetosphere-Ionosphere-Thermosphere Coupling Controls System-Level Dynamics; and SWMI Science Goal 8. Identify the Structures, Dynamics, and Linkages in Other Planetary Magnetospheric Systems. We have defined three investigation objectives to ensure that the hybrid magnetometer developed under this proposal is suitable for the broad spectrum of future Heliophysics missions which require magnetic field measurements. 1) Expand the DC – 2 kHz bandwidth of the current hybrid magnetometer prototype to provide magnetic field

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				measurements from DC – 10 kHz from a single magnetometer sensor. 2) Optimize the search coil action of the hybrid magnetometer to achieve noise and sensitivity within a factor of four of that achieved by comparably sized traditional search coil sensors (e.g., RBSP, THEMIS) 3) Scale down the hybrid magnetometer sensor to nanosatellite geometry ($< 10 \times 10 \times 10 \text{ cm}^3$) while preserving scientifically useful sensitivity from DC-10 kHz. CHIMERA will enable high fidelity magnetic field studies on future SmallSat/CubeSat heliophysics missions around the Earth, the moon, and other planetary bodies.
95778	Atmosphere Effects of Precipitation through Energetic X-rays (AEPEX) CubeSat Mission	Nov 2018	Oct 2022	Precipitation into the upper atmosphere is one of the primary sources of loss from the radiation belts. Numerous spacecraft have attempted to measure this Energetic Electron Precipitation (EEP) from Low-Earth Orbit (LEO); however, current instrumentation is not able to resolve the loss cone angle nor measure the pitch angle distribution, and thus the energy deposition in the atmosphere has a large uncertainty. Furthermore, particle detectors on spacecraft provide in-situ detection only, and single-spacecraft missions cannot provide instantaneous spatial information about the precipitation patches. We propose a comprehensive measurement of EEP, by measuring precipitating electron distributions and imaging X-ray photons produced by bremsstrahlung in the atmosphere. This concept is similar to the recent and successful BARREL balloon mission, except we will detect photons from LEO rather than balloon altitudes. Measurements of X-rays at LEO will provide an estimate of energy deposition in the upper atmosphere, will provide spatial information about precipitation regions, will provide global coverage, and will enable longer-term measurements than dedicated balloon campaigns. The proposed AEPEX mission will i) quantify the energy deposition from the radiation belts due to precipitation, during both quiet and active conditions, and ii) provide spatial measurements of precipitation regions. These measurements will improve our understanding of radiation belt precipitation, radiation belt lifetimes, and the effects of radiation belt precipitation on the upper atmosphere, directly addressing the Heliophysics Decadal Survey Key Science Goal 2: "Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs." Methodology: The AEPEX instrument will use an array of 12 RedLen M1770 CZT detectors, which are commercial off-the-shelf X-ray imagers. Each detector is 4 X 4 cm and includes an array of 16 X 16 pixels. These pixels will be binned to provide more limited spatial resolution for the benefit of SNR and data volume. These detectors will measure 50-300 keV photons; shielding will be used to block electrons and protons. As an estimate of moderate precipitating fluxes, modeling calculations show that for a precipitating flux of 3000 electrons/cm²/sec at 1 MeV, we can expect to measure ~150 photons/sec in this instrument. X-ray optics will provide better than 100 km spatial resolution across track and 100 km spatial resolution along track with 10-second time resolution. Additionally, a 0.5U solid-state particle instrument will be included in the payload to measure the precipitating electron spectrum, and will be used to constrain the inversion from X-ray fluxes and spectra to energy deposition in the atmosphere. Spacecraft: The AEPEX CubeSat will adhere to the Tyvak 6U dispenser requirements: mass no greater than 14 kg and volume no greater than 11.6 X 23.9 X 36.6 cm. The C&DH, ADCS, power, communication systems, solar panels, and structure will be provided by the Blue Canyon Technologies (BCT) XB1 bus system. This system reduces the development efforts of the AEPEX team and reduces risk by using established and proven

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				technologies with flight heritage. Mission: We propose a minimum six-month mission to be launched into a circular LEO with altitude near 500 km, and inclination above 70 degrees to enable passes through the radiation belts. The X-ray instrument will look down at the atmosphere by pointing towards the nadir, while the particle instrument points towards the zenith. Data will be downlinked to CU Boulder's S-band ground station at LASP. Mission operations will be controlled from LASP, which has recent experience operating the CSSWE and MinXSS CubeSats.
95779	Laboratory Investigation of Satellite Gas-Surface Interactions for Accurate Construction of Atmospheric Models	Jan 2019	Jan 2022	Accurate estimates of neutral mass densities obtained from satellite drag measurements are vital to NASA science objectives, including the construction of atmospheric models, the understanding of thermospheric dynamics, and the investigation of long-term behavior in the thermosphere. The interpretation of these measurements depends strongly on the assumptions made about atomic or molecular interactions with satellite surfaces which vary with changes in the thermosphere resulting from space-weather (geomagnetic storms) as well long-term (multi-decadal) variations. Such assumptions have been known to introduce errors into the construction of atmospheric models by modifying the aerodynamic coefficients (Ca) that determine scaling factors between observed drag and atmospheric density. We will investigate the interaction of atmospheric gases with spacecraft surfaces under conditions consistent with atmospheric pressures and composition above ~500 km altitude. The main objective of our study is to determine the fundamental gas-surface interaction (GSI) parameters needed to specify spacecraft Ca and atmospheric densities at those altitudes. The largely He atmosphere is expected to result in low surface adsorption probabilities. Characteristics of lower thermal accommodation, such as narrow scattering lobes and minimal energy transfer, should be prevalent in the GSI above ~500 km and the ambient environment is consistent with that of a hypersonic beam facility. However, there is presently no data that provides any quantitative support to the extent of gas-surface accommodation in the He-dominated upper-thermosphere and its dependence on surface roughness or surface cleanliness and GSI models disagree on this parameter by as much as 70% above 500 km. The investigation is divided into the following primary science questions: (1) What are the scattering dynamics of atomic oxygen and He on several representative spacecraft surfaces? (2) How are scattering dynamics affected by surface roughness, and by the presence of adsorbate on the surface? (3) Does aerodynamic data above the O/He transition indicate low, intermediate, or high levels of adsorption? The team will address the science questions using hyperthermal beam-surface scattering techniques developed by T. Minton at Montana State University to measure the scattering dynamics of various incident species scattering from surfaces with different adsorbate coverages and roughness's. Context for the resulting data will be obtained by comparing the aerodynamics predicted by laboratory results with the observed aerodynamics above the He/O transition (~500 km). Specifically, we will observe the ratio of drag measured by a long satellite like GRACE (or GRACE follow on) to the drag measured by a compact spherical satellite and compare it to a ratio modeled using test-particle model techniques and calibrated with the laboratory results. The science enabled by this investigation is relevant to recommendations in the National Research Council Decadal Strategy for Solar and Space Physics including (a) the support of system-science through the development of "computational models that extract the essential physics from

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				measurements made across multiple observing platforms" and can "specify the extended space environment in order to protect society and advance growing aspirations for the use of space", (b) response of the IT system to "magnetospheric forcing over global, regional and local scales" and (c) long-term changes in the planetary environment (thermosphere). A recent NASA LWS institute focused on satellite drag which depends on the accurate determination of aerodynamic coefficients. The proposal team has expertise in hypersonic molecular-beam experiments which simulate the space environment, satellite gas-surface interactions, and the modeling and observations of satellite aerodynamics.
95780	COronal Diagnostic EXperiment (CODEX)	Oct 2018	Sep 2022	NASA Goddard Space Flight Center (GSFC), in collaboration with the Korea Astronomy and Space Science Institute (KASI) plans to develop a coronagraph and to install it on the International Space Station (ISS). The primary goal of CODEX is to Understand the physical conditions in the solar wind acceleration region. Solar wind source and acceleration models are highly under constrained due to current data limitations. CODEX will provide the first global, comprehensive data sets allowing us to provide these crucial constraints on a daily basis, and answer targeted essential questions such as: Are there signatures of hot plasma released into the solar wind from previously closed fields? What are the velocities and temperatures of the density structures that are observed so ubiquitously within streamers and coronal holes? The coronagraph is externally occulted with a field of view from ~3-10 solar radii ($R_{\odot}$), simultaneously covering all latitudes. The observation wavelength is ~400 nm. As demonstrated at total solar eclipse opportunities, photometric filter ratio observations around this band enable the estimation of the 2D electron temperature and electron velocity distribution in the corona. This will be the first time electron density, temperature, and velocity have been measured simultaneously for this field-of-view, and we will do it globally for 6 months! This regular, systematic, comprehensive dataset will test all theories of solar wind acceleration and source region as well as serve to validate and improve space-weather/operational models in the crucial source region of the solar wind. The coronagraph consists of an optical assembly, an external and internal occulter, a polarization camera, command and data handling electronics and a pointing system (gimbals, sun sensor, gyroscopes, drive electronics). The coronagraph itself will have only three mechanisms: an aperture door, filter-wheel rotator, and a launch latch. The polarization camera utilizes a grid directly in front of the detector that eliminates the need for a polarization wheel mechanism and enables obtaining images in close temporal proximity as required for the filter-ratio technique. This proposal will exploit the expertise at GSFC, Wallops Flight Facility, and KASI. The proposal team has extensive experience in coronagraphy, ISS payloads, and solar wind studies and hence is well suited to successfully complete the proposed work. CODEX directly builds upon the Balloon-borne Investigation of the Temperature and Speed of Electrons in the Corona (BITSE), a NASA scientific balloon technology demonstration mission currently under development by the same proposal team and expected to fly for ~8 hours from Ft. Sumner, NM in September 2019. Although BITSE and ground-based eclipses provide some insight, such investigations are too short in duration and limited by sky brightness to obtain all the data needed to achieve CODEX's science objectives. The remote-sensing data from the CODEX mission will augment the in situ and remote sensing measurements from the Parker Solar Probe and Solar Orbiter. The CODEX mission will also exploit the synergy with the currently operating NASA

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				missions such as SOHO, STEREO, and SDO to enhance the science return by combining coronal imagery in overlapping fields of view. Data returned from CODEX will be deposited in the Solar Data Analysis Center web site, a publicly accessible NASA repository. CODEX is highly relevant to the HTIDeS program. The proposed mission is a complete investigation including payload development, instrument calibration, launch, and data analysis. The proposed project offers well-defined technology and science breakthroughs. CODEX's origins of the solar wind investigation will help achieve Strategic Objective 1.1 of the NASA Strategic Plan 2018: "Understand the Sun, Earth, Solar System, and Universe," in particular, the core context of "Discovering the Secrets of the Universe."
95782	Dione: A pathfinder mission for understanding the Ionosphere-Thermosphere responses to magnetospheric forcing	Nov 2018	Dec 2022	Advances toward deploying the highly capable 6U cubesat, along with the culmination of our team's miniaturized particle and field sensor development efforts offers the most efficient, cost-effective approach to addressing one of the most urgent questions in Geospace science today: How, and where is energy transmitted between the magnetosphere and ionosphere? Just like the ancient Greek goddess Dione that presided over the oracle, the mission Dione will demonstrate with a comprehensive sensor package in a low cost, flexible assembly a path for better specification and prediction of Ionosphere-Thermosphere (IT) responses to geomagnetic phenomena. Dione's sensor package includes four instruments: a miniaturized fluxgate magnetometer system that will provide science-grade magnetic field measurements with two sensor heads, GRIDS that will measure vector plasma drifts and deduce the in-situ E-fields, DESA (Dual ElectroStatic Analyser) that will measure precipitating particles as well as upgoing secondary electrons, and NMS (Neutral Mass Spectrometer) measuring total neutral density and composition. Dione will be 3-axis stabilized in a circular LEO, high-inclination orbit, traversing the auroral precipitation and high latitude currents in every orbit. Dione will use the design of the 6U Dellinger bus, which was developed at NASA GSFC, and which is scheduled for flight in August 2017. The primary science objective is to quantify how the ionosphere and thermosphere respond to electromagnetic and kinetic energy inputs from the magnetosphere. This energy input is a key parameter in all physics-based models of the IT system and has long been identified as one of the parameters with the largest uncertainties. Dione will, for the first time since the DE2 mission, provide simultaneous measurements of energy input and IT responses. The energy inputs will be quantified as Poynting flux and electron fluxes, while the IT responses will be quantified as ion drifts and temperatures and neutral density and composition. Dione will provide in situ measurements and through its precession will sample all local times and latitudes and under various geomagnetic conditions. Dione will also establish conjunction passes over key ground instrumentation, specifically auroral imagers and radars, and use conjunction observations to study theories of magnetosphere-ionosphere coupling and IT heating. We will use global MHD models, kinetic models of precipitating electron fluxes, and models of ionospheric conductivity to understand how the incoming electron fluxes and Poynting flux heat the upper atmosphere and result in the observed aurora and neutral heating. Dione targets the community's need to understand how energy is coupled from the magnetosphere down to the ionosphere and thence into the neutral thermosphere, a focus of the 2012 Heliophysics Decadal Survey, and also addresses aspects of the objectives in future NASA strategic missions DYNAMIC and GDC.

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95783	Development of Self-calibrating Science Grade Magnetometer System for Cubesat Platforms	Feb 2019	Jan 2022	Magnetic field measurements are crucial to understanding the fundamental science question in Heliophysics: How do the geospace respond to solar variability? They not only provide the information for mapping the magnetic field and deriving related parameters such as electric currents, but also are essential to organize measurements of thermal plasma and energetic particles. Multi-point measurements are needed to separate spatial and temporal variations in characterizing the dynamics and responses of the geospace; and future Heliophysics missions will require the use of a constellation of smaller nanosatellites (e.g., CubeSats). The Heliophysics community currently lacks a highly accurate, low-resource and low-cost magnetometer system suitable for CubeSat platforms. CubeSats that flew in space in recent years generally carried mass-produced COTS magnetometers or those based on magnetoresistance effects. These magnetometers do not have the necessary accuracy, precision, stability and linearity for science-grade measurements in the ionosphere and magnetosphere. Tri-axial fluxgate magnetometers are reliable and mature technology for vector magnetic field measurements and have been flight-validated in numerous missions as a science payload since the beginning of the space age. Miniaturization of fluxgate magnetometers is generally the approach for the development of science-grade measurement capability. The limitation of fluxgate magnetometers is that the measured baseline can drift, compromising the absolute accuracy of the measurement, and are thus typically flown with scalar magnetometers. We proposed to develop a self-calibrating science grade magnetometer system in a highly miniaturized, boom mountable package for Cubesat platforms. The system is self-calibrating because it includes a miniature fluxgate magnetometer for vector measurements and a chip-scale scalar magnetometer providing important constraints to calibrations of the vector measurements. Such unit consists of a miniaturized tri-axial fluxgate sensor head with embedded microfabricated vapor cell for scalar operation, a miniaturized optics platform, electronics board supporting both vector and scalar operations, a USB computer interface box, the power system, and evaluation software. At project conclusion, we will produce a fully functional, flight-ready unit that has gone through all necessary environmental tests on the ground (TRL-5). The proposed instrument development will help fulfill NASA's Heliophysics strategic objective "to understand the Sun and its interactions with Earth and the solar system, including space weather" and the second Heliophysics Decadal Survey goal to "determine the dynamics and coupling of the Earth's magnetosphere, ionosphere and atmosphere and their response to solar terrestrial inputs" using small satellites. Magnetic field measurements are essential in Heliophysics missions in understanding the fundamental science question: How do the geospace respond to solar variability?
95786	End-to-End Laboratory Validation of a Neutral Wind Detector	Jan 2019	Dec 2019	The purpose of the proposed work is to test a neutral wind sensor in a relevant environment in order to raise its TRL to 6. The sensor measures the ram-component of the neutral wind from an orbiting platform using an energy analysis technique, and incorporates new technology to enable the sensor to be used on a CubeSat platform. Each subsystem within the device has been developed and independently tested under an SBIR grant from the Air Force, but the complete system has never undergone end-to-end testing in a laboratory environment in which a steady-state neutral beam is flowing at orbital speeds. The Naval Research Laboratory has such a facility, so we propose to work with them to perform a series of validation

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				tests on the new sensor. The decadal survey from the National Research Council identifies seven main areas in which focused technology development is required, based on the immediate and projected needs of solar and space physics research. The second and third bullets in this NRC list are: "Developing highly miniaturized spacecraft and advanced spacecraft subsystems for missions involving constellations of multiple spacecraft"; and "Developing highly miniaturized sensors of charged and neutral particles and photons". The sensor we have developed is a miniaturized device that is CubeSat compatible, and therefore a prime candidate for flight on CubeSat constellation missions. At least two NASA-ROSES proposals in the 2018 LCAS cycle involve CubeSat missions in which neutral winds are a critical measurement. The lack of high TRL wind measurement systems for CubeSat platforms is an impediment to such missions, but one that could be mitigated through laboratory testing of new wind sensors such as the one we propose to test. Since the instrument is ready to test and the NRL neutral beam system is operational, we request only a 1-year period of performance with coverage for a single graduate student, plus funding to provide access to the NRL facility.
95787	Broad-band EUV multilayer coatings for high-resolution spectroscopy near 30 nm	Apr 2019	Mar 2022	We propose to develop aperiodic multilayer coatings having high reflectance at normal incidence over a broad spectral band in the extreme ultraviolet (EUV), for spectroscopy of the solar atmosphere. The spectral region from approximately 17 nm to 35 nm contains a number of scientifically important emission lines emanating from the solar corona and transition region. The realization of broad-band EUV multilayer coatings having high reflectance over all or part of this band will enable the construction of high-resolution spectrometers based on normal-incidence gratings, having wide wavelength coverage and sensitivity that is sufficient to support the exposure times and cadences needed for future NASA solar physics and space weather missions. The Hinode/EIS instrument targeted the spectral band from 25 nm to 29 nm using a normal-incidence grating coated with a periodic Si/Mo multilayer. Aperiodic coatings developed in recent years can now be designed to provide high reflectance over a much wider range of wavelengths. Furthermore, newly developed Mg- and Al-based multilayer coatings have been demonstrated to have significantly higher reflectance than Si/Mo multilayers in this spectral region. We thus propose to develop new Mg- and Al-based aperiodic multilayers having nearly flat response over a much wider wavelength band than can be captured using periodic multilayers, thereby enabling significant increases in wavelength coverage in future spectroscopy instruments. The proposed research will focus on several new Mg- and Al-based multilayer material systems that have been developed over the past decade, including the three-material systems Zr/Co/Mg, SiC/Mo/Al and B4C/Mo/Al. Good EUV performance and stability have been demonstrated already with periodic (i.e., narrow-band) coatings comprising each of these material combinations. We will develop aperiodic, broad-band coatings using the same material combinations, following a systematic, experimental work plan. Candidate coatings will be deposited by magnetron sputtering, and coating microstructure, stress, roughness, EUV reflectance, stability and other relevant properties will be fully characterized. The experimental work will be conducted using established facilities and methods, and a systematic, iterative approach will be followed to optimize coating performance. The anticipated outcome of the proposed research is the realization of new broad-band

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				multilayer coatings operating in the 17 – 35 nm band that will enable the construction of high-resolution spectroscopy instruments targeting this region of the EUV, in support of future NASA missions.
95789	Quantum Dot-based Miniaturized Multispectral Imager for Auroral Studies	Feb 2019	Jan 2022	We propose to design, develop and demonstrate an ultra-compact, low mass, high resolution multispectral imager based on an innovative concept of Quantum Dot Array (QDA). QDA acts as an absorptive filter array and replaces prisms and gratings that require long path length to achieve high spectral resolution. We will design this first prototype to image the Auroral emissions at the visible wavelengths. However, we can extend the capability to ultraviolet wavelengths relatively easily to image the Sun in the near future. The proposed instrument technology development effort addresses NASA's Heliophysics Science Strategic Objective: "to understand the Sun and its interactions with Earth and the solar system, including space weather", and the Science Goal: "Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system". Quantum Dots (QD) are semiconductor nanocrystals with a size smaller than twice its exciton Bohr radius, leading to quantum confinement of electric charges, and a unique absorbance spectrum. As the size of QD decreases, the confinement strengthens, increasing the bandgap, and shifting the absorbance spectrum in wavelength. This size dependent bandgap, and thus absorbance, makes it possible to produce a well-defined, continuously tunable, yet distinct, set of absorptive filters, where each pixel is made of QDs of a specific size, shape or composition. Such a filter array can be integrated to a detector array to make a compact imaging instrument. Reducing path length is an advantage also provided by wedged filters; however, QDAs are much cheaper and provides the additional benefit of customizing the wavelength and bandwidth of only the spectral features of interest in order to maximize the signal to noise performance. The sample spectrum can be mathematically reconstructed using the characteristic response of each of the filters and measurements made by the instrument based on wavelength multiplexing principle. The compactness and low resource nature of this potentially revolutionary technique makes it a suitable instrument for small satellite missions such as CubeSats. In this effort, we will leverage our existing collaboration with Professor Bawendi at Massachusetts Institute of Technology, one of the pioneers of quantum dots. We will design and develop the spectrometer to image the key lines of Auroral emissions, including 486.1 nm (proton line), 557.7 nm (brightest Auroral line caused by O(1S)) and 630 nm (O(1D)) with 1 nm target resolution. We will synthesize the quantum dots of the selective size and composition for the target wavelength range; print them on a quartz substrate to fabricate the spectrometer; integrate the spectrometer with a commercial detector array; calibrate each of the pixels to produce their response curves; develop a mathematical algorithm to reconstruct target spectra; and perform night sky measurement of air glow emissions (558 nm is the brightest line) to complete an end-to-end demonstration of the prototype.

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95793	Small UV imager for Heliophysics science investigations	May 2019	Apr 2022	• Many advances in space science have originated with innovations in remote sensing and imaging technologies. Several of these innovations have been implemented by NASA science missions over the years, particularly in Heliophysics. Remote sensing of Earth and its space environment at ultraviolet wavelengths continues to support Heliophysics science missions. • Imaging of Earth's space environment has provided an approach to address specific science questions pertaining to the variability of the space environment and the coupling of energy and momentum between the different plasma regimes around Earth, and to the neutral atmosphere. Advances in these areas are still necessary to develop understanding of our space environment, and provide necessary capability for Space Weather nowcasting and prediction. • HPD's goals, described in the NASA Science Plan, are met by science missions in both the Solar-Terrestrial Physics and Living with a Star Programs that will all likely benefit from and require the implementation of remote UV imaging. Early development work in smaller optics and detectors will give those missions more options to achieve a broader set of science goals, using low-complexity, compact imagers while maintaining good technical margins. • There have been many NASA missions that have implemented UV imagers (TIMED, POLAR, IMAGE, ICON, GOLD). Each of these besides POLAR implemented one or more UV spectrometers to separate specific emissions and create images of the scene, both in nadir viewing tracks and instantaneous 2D snapshots. As described in the 2014 Science Plan, future missions will examine the coupling of the magnetosphere to the ionosphere, atmospheric heating by the aurora, and the regulation of the system by the mass of the atmosphere. These new missions will likely require imagers that provide scientific context over a large field of view with high spatial resolution. Accompanying a spectrograph, this kind of imager relieves the spectrograph from having to provide all of these capabilities. A small UV imager can therefore be a key component in a synergistic payload, providing room to maneuver in the trade space of scientific and technical requirements that require imaging. • This proposal seeks to develop a basic, reference transmissive imager with high spatial resolution and large field of view. The goal is to prove the system with a simple MgF lens focusing UV light on heritage UV sensitive intensifier tube, while implementing first a heritage 1k x 1k imaging capability, and then developing algorithms for spot centroiding that would result in up to 4k effective spatial resolution (i.e. sub pixel resolution). This can be performed within in the H-TIDeS budget for the fact that UCB has recent and extensive capability in building UV hardware and can implement best practices and test programs from recently completed projects. The advancements proposed will also be in reduction of size of the imaging electronics (readout and post-processing). Implementation of a centroiding algorithm will reduce the noise budget to Poisson statistics, obviating sources of noise inherent in most detector schemes. Overall, the expected reductions in mass, power and volume from any previous UV geospace imager will likely support the implementation of multiple cameras on large spacecraft/missions, or single implementations on smallsats, down to possibly a 6U cubesat. • The proposal is supported by 2 scientists at UCB, a technical project lead engineer, and two international Co-Is who will support discussions of traceability and track needs of the European Space Agency for their own mission, looking for opportunities for future collaboration with NASA and ESA missions.

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95795	AGILE: Advanced enerGetic Ion electron tElescope	Feb 2019	Jan 2022	AGILE: Advanced enerGetic Ion electron tElescope Our goal is to develop an innovative instrument to characterize solar, magnetospheric, and, cosmic ray particles. AGILE, will be a compact, low mass, and, low power particle telescope that provides particle identification with unprecedented precision, and cover a wide energy range in multiple differential energy channels to characterize particle spectra. The innovative aspect of AGILE will be to fully digitize the waveform of the charge pulse (i.e., digital signal processing) resulting from energy loss of incident particles in solid-state detectors (SSDs). This technique will enable particle species identification with high accuracy and reliability. AGILE measurements of charged particles advance the broad Heliospheric science goals of: (i) acceleration and transport of charged particles in the inner heliosphere, e.g., solar energetic particles (SEP) (ii) explore processes in the remote heliosphere, viz., the termination shock and the heliosheath, e.g., anomalous cosmic rays (ACR) and, (iii) magnetospheric relativistic electron dynamics, e.g., electron injection into the inner zone. AGILE achieves measurement objectives using: (i) the first space flight application of fast digital signal processing for particle identification, (ii) flight proven solid state detector technology, and (iii) sophisticated onboard software algorithms for particle energy and species identification. AGILE measurements of will cover energy ranges critical to the understanding of SEP and ACR and resolve ion isotopes (e.g. He3 vs. He4) with high accuracy. AGILE uses a new chip, SAMPIC, and associated signal amplifier developed in Orsay, Saclay, and the University of Kansas. SAMPIC provides fast signal sampling of up to 10 GSa/s with low power consumption of ~10 mW per channel, good radiation tolerance, and built-in data reduction. A version of the SAMPIC board has already been tested and used in the high radiation environment of the Large Hadron Collider. These tests at the LHC have shown that the signal properties such as rise-time, S/N ratio are retained after amplification, with improved performance. To begin with, AGILE will comprise of a stack of conventional SSD of varying thicknesses, optimized to measure both electrons and ions. We will then explore novel detectors such as Low Gain Avalanche Detectors (LGAD) and diamond detectors. These detectors show great potential for space instrumentation. During the first year, hardware efforts will focus on using SAMPIC-based front-end electronics to acquire waveforms generated by the passage of a particle. Software algorithms dedicated to particle identification will be developed and tested. During second year these algorithms will be extended to perform on-line data analysis using a low power, space-qualified FPGA. During the third year an engineering model of AGILE will be validated in a test beam with a standard SSD stack as well as a combination of SSD with LGAD or diamond detectors. Our proposed activity falls squarely within one of NASA's strategic objectives, (The 2014 NASA Strategic Plan). Strategic Goal 1 explicitly mentions the need to "develop the new technologies that will open the space frontier". Objective 1.4 lists fundamental questions about Sun-Earth system, "What causes the Sun to vary? How do geospace, planetary space environments, and the heliosphere respond? What are the impacts to humanity?" and notes the importance of understanding "penetrating radiation and energetic particles". AGILE will enable advancing all these stated NASA goals by using state of the art technology to characterize energetic particles addressing not only scientific questions of acceleration, transport and loss of energetic particles but also their space weather aspects. Development of AGILE is therefore

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				directly responsive to the H-TIDeS instrument and technology development (ITD) and the SMD Heliophysics Research Program.
95797	New techniques for Fast Neutron Imaging and Spectroscopy	Mar 2019	Feb 2021	The detection of fast neutrons has important applications in several fields including solar, geospace and planetary physics. The Sun produces neutrons over a wide range of energy during solar flares that provide information on the accelerated particle population. In addition, fast neutrons, produced in the Earth's atmosphere (and other planetary atmospheres) by the interaction of galactic cosmic rays and solar energetic particles, are an important but poorly measured component of the radiation environment in the inner magnetosphere. At Earth, through their decay, they are responsible for populating the inner radiation belt with fast protons. Neutrons are challenging to detect and measurements of them typically suffer from high background rates. High-energy neutrons (>50 MeV) pose even more challenges, because the traditional double-scatter technique based on a time-of-flight (ToF) measurement is limited by short flight paths and small detector sizes characteristic of small satellite platforms. At these high energies, the recoil proton is likely to escape the detector volume, degrading the energy and angular resolution. Long handcuffed by inadequate technology, it is now possible to perform high-energy neutron measurements inside a large monolithic detector by imaging the recoil proton tracks, thus eliminating the need for a time-of-flight measure. The concept is based on a spectrometer assembled from numerous thin hydrogenous scintillating fibers that allow ionization track imaging. The enabling technologies are in the form of (1) new position sensitive, multi-anode, micro-channel plate/photomultipliers (MCP-PMTs) capable of fine grained readout and (2) techniques and procedures for fabricating a space-qualified large detector. Such a Fiber Bundle Neutron Tracker equipped with these sensors can provide high-resolution, fine grained, imaging of fast neutron scatters. We discuss below applications mainly in solar physics but also in radiation-belt physics and planetary physics. Maturing the technology for a possible small satellite mission is important at this time to complement current and upcoming Fermi, Solar Probe Plus, and Solar Orbiter and IMAP missions. This proposed effort builds on optoelectronic technology advancements and experience in fabricating bundles. In addition to the above applications, improved knowledge of atmospheric neutrons themselves, including spatial and temporal variations, are valuable because neutron-induced single event upsets in avionics systems constitute a reliability problem (Leray 2007). Furthermore, neutrons are penetrating, dangerous and abundant, so they pose a health and safety risk to astronauts and aircraft personnel (Dyer 2002). Neutrons also constitute a major background for other NASA assets in LEO (e.g., Wunderer et al. 2006; Ormes et al. 2007). If successful, the proposed work will result in compact, low-mass, low-power neutron detector technology enabling opportunities to detect Heliospheric neutrons on small satellites and/or deep-space probes. We propose a follow-on two-year H-TIDeS Instrument and Technology Development (ITD) program to raise the technical readiness level (TRL) of promising compact, low-power instrumentation for measuring neutrons (between 20-200 MeV) from small satellite (and aircraft) platforms, with the goal of being able to propose such instruments for

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				CubeSat, Explorer, and deep-space (e.g., inner Heliosphere) platforms. We start with experience and equipment acquired from earlier investigations including a currently funded H-Tides grant (FY17-FY19).
95798	Fully-polarimetric Millimeter-wave Spectrometers for Measurement of Earth's Magnetic Field	Jan 2019	Dec 2020	We propose to develop an array of 12 fully-polarimetric millimeter-wave radiometer/spectrometers operating near 118 GHz. The digital spectrometer for these receivers was funded in HTiDS 2017 (PI Dr. Yee/ Johns Hopkins University) and with this proposal we will develop the low cost, low power, low mass polarimetric 118 GHz millimeter-wave array receivers that will not require cooling to meet the sensitivity requirements. As Dr. Yee's digital spectrometer project will be finalized in 2019, we will be able to integrate the complete end-to-end system in 2020. This work will enable a second generation small satellite mission with an off-nadir viewing instrument comprised of 120 such receivers that will globally map the magnetic field in the mesosphere at a horizontal resolution ~50 km with 1-sigma error of 50-90 nT. Earth's ionosphere responds dynamically over a wide range of temporal and spatial scales to changes in the magnetosphere and solar wind from above, and to neutral atmospheric dynamics from below. The atmosphere-ionosphere-magnetosphere (AIM) system is a complex and active element of space weather. The Decadal Survey (DS) prioritized "Determining the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere..." and the DS and the Heliophysics Roadmap both deem vector magnetic field measurements at all altitudes to be essential, as the field plays a major role in controlling the distribution of ionospheric plasma. It is difficult to measure the B-field, either locally or globally, at the altitudes of the upper mesosphere and lower thermosphere (UMLT) where the transfer of energy and momentum between the plasma and neutral components of the system occur. This region is too high for balloons and too low for spacecraft; we need a substitute for in-situ measurements. The 118-GHz imaging magnetometer will measure all four Stokes parameters as a function of frequency about the Zeeman-split center of the 118-GHz molecular oxygen line. From these measurements, the magnitude and direction of the magnetic field imposed upon oxygen molecules near the peak of the receiver's vertical weighting function in the upper mesosphere will be inferred. One potential application of the proposed measurement technique is to provide further understanding of Geomagnetic Induced Currents (GICs) during strong geomagnetic storms. Another important science application is mapping of the horizontal structure and magnitude of magnetic field disturbances associated with the auroral electrojet. High horizontal spatial resolution of the proposed instrument will give a unique opportunity to evaluate spatial variability of storm-time magnetic fields due to variations both in ground conductivity and in the structure of the ionospheric current drivers. Development of this measurement capability will be an important step towards the global monitoring of magnetic field disturbances during strong storms from orbit, which is a potential extension of ground-based networks of extreme-event magnetic observatories. This project will advance the TRL of the large receiver array for the second generation small satellite mission from 4 to 5. The duration of the project is 24 months.

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95799	Ion/Liquid Chromatography for Exploration of Solar System (ILCESS)	Jan 2019	Dec 2021	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.
95800	Water Hunting Advanced Terahertz Spectrometer on a Ultra-small Platform (WHATSUP)	Jan 2019	Dec 2021	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

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				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.
95801	Superconducting Gravity Gradiometer for Planetary Dynamics	Jan 2019	Dec 2021	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

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				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.
95802	Space Exploration Synthetic Aperture Radar (SESAR): A Digital Beamforming Polarimetric Synthetic Aperture	Jan 2019	Dec 2021	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

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	Radar for Subsurface Imaging			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.
95803	WASSR: Water-vapor Sounding Short-range Radar for mapping local atmospheric humidity over the Martian surface from an in situ platform	Jan 2019	Dec 2021	We propose to build a new kind of in situ radar for short-range mapping of near-surface atmospheric water vapor on Mars. Dubbed WASSR (Water Sounding Short-range Radar), the instrument features a highly compact and low-power differential absorption radar that operates near the 557 GHz water absorption line to measure absolute humidity along its beam path with as good as few-ppm accuracy. WASSR takes advantage of a unique and fortuitous condition in the Martian atmosphere wherein water vapor exhibits an extremely strong, identifiable, and narrow molecular rotation absorption feature centered at 557 GHz that will modulate the strength of radar echoes from nearby terrain. The magnitude of beam attenuation depends on the precise frequency of the radar transmission and the water vapor abundance along the radar beam's line of sight. By taking ratios of echo powers between different frequencies along the wing of the water absorption line, and between ground targets at different distances, WASSR can obtain, for the first time ever, range-resolved, absolute humidity estimates. Furthermore, WASSR requires no calibration because its ratio measurements are independent of the ground reflectivity, the radar's transmit power, and its receiver sensitivity – all common mode factors that drop out in a frequency- and range-differential measurement. The central measurement objectives of WASSR are to accurately measure local water vapor mixing ratios over diurnal, seasonal, and yearly time scales; to probe the vertical distribution of water vapor up to 2 km in altitude; and to map ground-level humidity with sufficient range resolution to discern differences in atmospheric water vapor exchange with localized geologic features. Mounted on a two-axis gimbal, WASSR will be able to generate maps of local absolute humidity

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				at ground level by scanning its beam over the terrain at low grazing angles. This functionality may reveal localized regions of higher or lower humidity, perhaps arising from different soil composition, evaporation, or even brine flows. Likewise, beam-scanning up the slopes of nearby topography can validate or constrain models about the variation of humidity with altitude. WASSR can also operate with high accuracy at all times of the day or night in any season, overcoming the limitations of the past relative humidity measurements made by the Curiosity rover. WASSR is thus an excellent candidate for future Mars missions that seek to understand the processes by which water travels in the Martian atmosphere, is exchanged with its soil, and affects astrobiological potential. WASSR's design will be based on low-power millimeter- and submillimeter-wave radar systems that JPL has built over the last decade, especially a 95 GHz Doppler radar prototype for comet jet observations and a 183 GHz humidity-sounding cloud radar for Earth science applications. Special enabling technologies for WASSR include a low-power W-band synthesizer, efficient Schottky diode frequency-multipliers and mixers, and an FPGA-based digital processor. At the conclusion of this MatISSE-18 effort, WASSR will be near TRL 6 and thus well positioned to compete for selection in prime Mars rover or lander missions as soon as the 2020s. The development of WASSR will also open up a whole new class of compact flight instruments for emerging submillimeter-wave radar applications in space, such as water vapor detection from orbit around Mars or on comets or icy moons, and short-range spacecraft navigation for landing or docking.
95804	Swath Mapping Lidar with Fiber Lasers and PN Code Modulation	Jan 2019	Dec 2021	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 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 benefit 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

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				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.
95805	Maturation of a Hypertunable IR Laser Spectrometer for In Situ Planetary Exploration	Jan 2019	Dec 2021	We propose to advance from TRL-4 to TRL-6 an instrument to identify and quantify in situ the abundance of compounds of key chemical and astrobiological significance in planetary gasses and liquids such as icy moon ocean water, the meltwater from planetary ices, and the organic seas and lakes of Titan. The overarching goal is to take an existing, commercial laboratory measurement system (TRL 4) and carry out the necessary trades, design modifications, miniaturization, and environmental testing required to demonstrate a prototype instrument that may be credibly proposed for flight. For the purposes of this proposal, the prototype instrument is designed and constructed around an implementation for a Europa lander. The full instrument concept consists of a front end system that ingests small amounts (mg) of ice, melts the sample in a controlled manner, and analyzes the resulting vapor with a new class of IR laser spectrometer. The major advantage to the proposed system compared to other direct measurement techniques (e.g., GCMS or Raman) is a large saving in resources while simultaneously providing rapid (~ 1 min) and unambiguous spectral identification of volatilized compounds and dissolved gases. It also has significant advantages over reflectance spectroscopy in terms of capabilities, simplicity, resource allocation, and signal-to-noise. For extremely resource constrained missions (e.g., the Europa Lander), such lower resource and high capability instruments may be the only feasible path to obtaining high priority science. The work plan has the following Goals and Objectives: Goal 1: Produce a medium fidelity TRL-5 brassboard and demonstrate overall performance in a simulated operation environment with realistic support elements. Objective 1A: Finalize screening and selection of lasers, electronics, optomechanics and detectors using components with path to flight; conduct radiation testing of key components. Objective 1B: Close miniaturization repackaging trades and finalize mechanical and electrical design into a configuration that is close to the expected form, fit and function of flight instrument. Objective 1C: Fabricate, assemble, integrate and test overall performance and measurement of trace gas spectra under simulated operational conditions. Goal 2: Produce a high fidelity system TRL-6 prototype

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				that adequately addresses all critical scaling issues and is operated in a relevant environment to demonstrate operations under critical environmental conditions. Objective 2A: Complete delta-design trades based on knowledge gained from TRL-5 brassboard. Objective 2B: Assemble, integrate and test laser, optomechanical, electronics, and optical cell subsystems. Objective 2C: Test prototype under relevant conditions and validate against performance design and science-driven measurement requirements. The proposed instrument and development work is in concert with the MATISSE scope and goals. The TRL range is compliant, and the result will be an instrument prototype providing form, fit and function of a flight system that has been tested in the relevant environment.
95806	In-situ Spectroscopic Europa Explorer (iSEE)	Jan 2019	Dec 2021	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]

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				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)."
95807	A high-resolution, large mass range cycloidal sector coded aperture miniature mass spectrometer for planetary exploration	May 2019	May 2022	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 ($\pm 1\%$); 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.
95808	Compact, Robust Spatial Heterodyne Raman Spectrometer for Planetary Exploration	May 2019	Apr 2022	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

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				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.
95809	Electronic Life-detection Instrument for Enceladus/Europa (ELIE)	Jul 2019	Jun 2022	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

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				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 <i>B. subtilis</i> 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.
95810	Terahertz heterodyne spectral imager of planets and comets	May 2019	Apr 2022	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

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				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 cm²/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.
95811	Venus In-Situ Surface Imager	Jul 2019	Jun 2022	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

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				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.
95812	Elastic wave analyzer for icy sub-surfaces (EWAIS) in the solar system	May 2019	Apr 2022	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

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				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.
95813	Radiation Hard and High Temperature Tolerant Thermal Imagers (HOT IR)	Jun 2019	May 2022	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.

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95814	Photonic Integrated Circuit TUned for Reconnaissance and Exploration (PICTURE)	Jul 2019	Jun 2022	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 CO₂, H₂O, CH₄ 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.
95815	DOWSER: Detecting Objects' Water from Spatial Epithermal-neutron Response	May 2019	May 2022	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

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				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 prototype in a sealed cubical physics package of volume 5 cm³ 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.

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95816	A Far-UV Micromirror Integral Field Spectrograph for Planetary Science	Jun 2019	Jun 2022	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.

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95817	In-Situ Organic Extraction, Separation and Detection using Supercritical CO ₂ and Superheated Water	Jun 2019	May 2022	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

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				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
95846	Reflight of the Compton Spectrometer and Imager	Jan 2019	Dec 2020	The Compton Spectrometer and Imager (COSI) is a wide-field gamma-ray (0.2-5 MeV) imager with Germanium detectors, which provide excellent energy resolution. COSI had a successful superpressure balloon flight from New Zealand in 2016, producing results on polarization of Gamma-Ray Bursts (GRBs), positron annihilation emission from the Galactic Center, and detections of other celestial gamma-ray sources. The payload was recovered, and the instrument is in good working order. We propose a reflight of the COSI payload from New Zealand in 2019. Science: COSI will directly map the Galactic positron annihilation emission, shedding more light on the mysterious concentration of this emission uncovered by INTEGRAL. COSI will survey Galactic nucleosynthesis and the role of supernova and other stellar populations in the creation and evolution of the elements. COSI will map 26-Al and positron annihilation with unprecedented sensitivity and uniform exposure, perform the first mapping of 60-Fe, search for young, hidden supernova remnants through 44-Ti emission, and enable a host of other nuclear astrophysics studies. COSI will also study compact objects (in our Galaxy and AGN) and GRBs, providing novel measurements of polarization as well as detailed spectra and light curves. A flight during the 2019 season would occur during the LIGO/Virgo O3 science run, and COSI would provide sky coverage with its Germanium detectors and its active shields for multimessenger astrophysics. Design: COSI is an array of germanium gamma-ray detectors configured in a compact, wide-field Compton telescope configuration. The array is shielded on the sides and bottom by an active anticoincidence shield but is open to the 25% of the sky above for imaging, spectroscopy, and polarization measurements. The instrument is mounted on a zenith-pointed gondola, sweeping out ~50% of the sky each day. This instrument builds off the Compton telescope technique pioneered by COMPTEL on the Compton Gamma Ray Observatory. However, by utilizing modern germanium semiconductor strip detectors in a compact, shielded telescope configuration, COSI achieves two-orders-of-magnitude improvement in detection efficiency, a much wider field-of-view, and high spectral resolution. These capabilities are optimized for a wide-field survey of gamma-ray emission. The wide-field imaging and zenith-pointed mode relaxes requirements on pointing stability. COSI is designed for 100-day ULDB flights, compatible with CSBF's 18 MCF superpressure balloon. Overall Program: For the 2016 flight, we were successful in developing a payload compatible with the superpressure platform by converting our system from liquid Nitrogen-based cooling to a mechanical cryocooler, reducing the weight of our gondola, and developing communication and telemetry systems that allowed for download of the science data in real time. A reflight of COSI will allow us to obtain more science results on transient events (e.g., GRBs and perhaps a black hole transient), to combine the new data with the 2016 data to improve statistics for positron and nucleosynthesis studies, and will provide training for new students and postdocs, which will be critical for the ultimate success of COSI-X.