TechPort ID*	Project Title*	Project Description*
96614	Development of compact Superconducting On-chip Fourier Transform Spectrometers arrays for sub-millimeter astronomy and cosmology.	Utilizing tunable superconducting mm-wave planar circuits, we plan to fabricate and characterize on-chip Fourier Transform Spectrometers (FTSs) for mm and submm wavelength astronomy and cosmology. This novel technique uses the non-linear current dependent inductance of high kinetic inductance (Lk) thin-film materials to replace meter-scale mechanical FTSs and grating spectrometers with cm-scale devices. Such devices can be easily arrayed into wide-band imaging/spectral integral field unit (IFU) focal planes, enabling a new class of powerful orbital and sub-orbital instruments for measuring spectral distortions of the cosmic microwave background (CMB), studying the epoch of reionization and star formation histories. Submm telescopes, with a limited number of detectors and readout channels, must balance the number of spatial-pixels and the number of simultaneous observing bands. State-of-the-art wide-band spectrometers with moderate/high resolution employ a hand-full of pixels. Broadband cameras for CMB and submm-wavelength astronomy include thousands of pixels but a limited number of bands. Additional bands improve foreground sensitivity in CMB cameras, and a reduction in detector count per mm-wavelength channel enable spectrometers with a large number of spatial pixels. Thus a technology that enables instruments to increase the spatial or frequency-resolution of each detector channel would have immediate benefit for CMB instruments, submm-wavelength cameras, and spectrometers used for both pointed observations and intensity mapping applications. We intend to develop a novel IFU with broadband spectroscopy per pixel; each pixel being an on-chip FTSs. Our scheme is entirely solid-state, avoiding the issues which complicate mechanical FTSs whilst having the continuum broadband scanning advantage of an FTS on individual pixels. These devices drastically reduces the size of the FTS by using high kinetic inductance (L_k) superconductors as the phase delay path. We use non-linear L_k response to DC currents to dynamically tune the inductance and thus phase delay with current biasing. Tiling many such FTS-pixels on a focal plane a broadband spectrometric

		imager with good spatial resolution can be realized. Our high Lk material is Titanium Nitride deposited in nanometer thick layers using Atomic Layer Deposition. We have successfully tested resonators with thicknesses as small as 3nm and Lk as high as 8 nH/square. We have designed and operated a series of dark prototype devices including a DC current-biasing mechanism and transmission lines to characterize the phase-delay and phase-noise of these films. These results show that such compact and flexible FTSs are indeed feasible. This proposal will support device fabrication at the Pritzker Nanofabrication Facility at U. Chicago, support for the co-I who will lead the electromagnetic design, and a postdoc or student effort to complete the design, fabrication, and testing. Device testing will make use of existing cryogenic testbeds. At the conclusion of this two year program, we will produce a fully characterized prototype detector array consisting of several antenna-coupled pixels, each measuring continuous broadband mm and submm wavelength spectra.
96623	Development of an On-Chip Integrated Spectrometer for Far-IR Astrophysics	Far-infrared (IR) astronomy is one of the main tools astrophysicists use to understand the universe around us. Such observations probe objects and processes that are often invisible at other wavelengths, such as young stars and their formation; the birth and growth of supermassive black holes; and the nature and properties of dust in the interstellar medium (ISM) in local and distant galaxies. The far-IR hosts a rich and diverse set of atomic and molecular transition lines that are diagnostic of heating and cooling processes that trace the physical state of matter and radiation in the cosmos. Molecular transitions in protoplanetary disks trace the temperature, density, and composition of nascent solar systems outside our own. Observations of far-IR line emission and absorption from atomic gas including [OI], [NII], [CI], and [CII] yield insights into the processes responsible for the formation of stars at all epochs, ranging from clouds within our own galaxy all the way back to the first galaxies. Many other examples exist, which all point to the fact that spectral measurements in the far-IR are a crucial probe of the formation of structure in the cosmos at all distances and times. At far-IR wavelengths, the Earth's atmosphere is both absorptive of astrophysical photons,

but also emissive, contributing both large Poisson noise and time-varying emission to observations at ground-based sites. The best solution to this problem is to perform measurements in space, but opportunities to do so are rare and resource-constrained. In general, space instruments be designed around the physical limitations of the platform, many of which make standard spectral dispersion technologies challenging to implement. Recent advances in semiconductor fabrication offer the potential for new, integrated devices that use quasi-photonic methods to disperse and sense the light. This kind of technology offers large scalability, ease of manufacture, size, weight, and power envelopes, and performance advantages that would allow us to envision instruments that are able to meet the demands of astrophysics in the next two decades. Here we propose a short, focussed investigation whose primary objective is the production of an integrated on-chip spectrometer prototype operable at wavelengths between 100 and 200 microns. The spectrometer will be integrated with a butted kinetic inductance device (KID) detector array, integrating the light dispersion and detection on a single compact device. We target a spectral resolution of R>100, and plan to demonstrate 10 bands over the wavelength range. Spectral dispersion will be provided by waveguide etched into the Si coupled to harmonic resonators, similar to existing technologies operating at longer wavelengths. The spectrometer will be designed and fabricated by members of our team at the University of Illinois, and the detectors will be designed and fabricated at the University of Chicago. The Rochester Institute of Technology will build a spectral calibration apparatus, and all three institutions will be involved in the integration and test of the device. Though this technology has applications across the entire range of astrophysics, to provide a concrete mission context we baseline the requirements of a sounding rocket platform concept that will search for axion-two photon decay in local dark matter halos. This challenging scientific goal will ensure the technology is robust, sensitive, and deployable on a small budget and constrained time scale. By the end of the 18-month investigation, we will deliver a TRL 3 prototype, and will

		be well-placed to design, fabricate, and fly a 2,000 detector device in the next 5 years. Beyond the reference sounding rocket mission, we expect this technology to have applications to a wide range of NASA strategic interests, including SOFIA, the Origins Space Telescope, possible Probe-Class missions, and elsewhere.
96511	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier - KUCR Co-I	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI of the lead proposal. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-

		capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected; lower energy neutrino measurements by the IceCube detector are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which currently challenge fundamental particle physics. PUEO, at a small fraction of the cost of a large ground-based facility like the IceCube observatory, will establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.
96516	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI of the lead proposal. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics

	the Cosmic High Energy Frontier (Ohio State University Co-I)	detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near

		200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected; lower energy neutrino measurements by the IceCube detector are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which currently challenge fundamental particle physics. PUEO, at a small fraction of the cost of a large ground-based facility like the IceCube observatory, will establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.
96518	Probing Exoplanet Atmospheric Physics with the EXoplanet Climate Infrared TElescope (EXCITE)	We propose to build and fly the EXoplanet Infrared Climate TElescope (EXCITE). EXCITE is a low resolution 1-4 micron spectrograph that will measure spectroscopic phase curves of bright, short-period extrasolar giant planets, or hot Jupiters, over their full orbits. These spectral measurements probe varying depths in exoplanets atmospheres thus contributing to our understanding of general circulation models, which will provide key insights into atmospheric physics and chemistry. Hot Jupiters provide an ideal laboratory for understanding atmospheric dynamics, which is a stepping stone to understanding the foundation of models which will be needed to search for potentially habitable planets. With its long observation times and special purpose design to characterize exoplanet

		atmospheres, EXCITE can deliver science that the James Webb Space Telescope (JWST) is unlikely to carry out, as well as complement the science which JWST will deliver. EXCITE uses a commercially available 0.5 m diameter telescope pointed with high accuracy and stability using the successful Balloon Imaging Testbed (BIT) pointing platform. The telescope is coupled to a cooled spectrometer made from commercially available components. EXCITE will flight test detector readout technology that will be used on the Wide Field Infrared Survey Telescope (WFIRST). The combination of these elements results in a unique instrument for exoplanet atmospheric characterization. EXCITE's initial science will result from an Antarctic long duration balloon flight.
96519	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier Jet Propulsion Laboratory Co-I	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI of the lead proposal. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload

itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected; lower energy neutrino measurements by the IceCube detector are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which currently challenge fundamental particle physics. PUEO, at a small fraction of the cost of a large ground-based facility like the IceCube observatory, will

		establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.
96520	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier	This is the lead proposal for the Payload for Ultrahigh Energy Observations (PUEO). KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray

		extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected; lower energy neutrino measurements by the IceCube detector are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which currently challenge fundamental particle physics. PUEO, at a small fraction of the cost of a large ground-based facility like the IceCube observatory, will establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.
96526	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier - Washington University Co-I	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI of the lead proposal. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights

searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200MHz. We propose to move the low-end cutoff frequency to 300MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important

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96527	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier (Penn State)	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI of the lead proposal. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four longduration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radiofrequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current

limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected; lower energy neutrino measurements by the IceCube detector are of great

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96533	Development of a novel imaging calorimeter for gamma-ray and cosmic ray studies.	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 150mm×150mm 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 MIDEX (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 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.
96534	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier -- University of Hawaii Co-I	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI of the lead proposal. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic

Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues,

		and allowing us to increase the number of antennas by more than a factor of two. An even more important improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected; lower energy neutrino measurements by the IceCube detector are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which currently challenge fundamental particle physics. PUEO, at a small fraction of the cost of a large ground-based facility like the IceCube observatory, will establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.
96538	The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons. University of California, Berkeley Co-I.	This is a Co-I proposal in support of the PI lead proposal entitled "The GAPS experiment: a search for dark matter using low energy antiprotons and antideuterons" submitted by Prof. Charles Hailey, Columbia University. Our proposed program would support the UC Berkeley tasks on the GAPS experiment as detailed in our task statement. The primary focus of this work in on the development and testing of the Si(Li) readout electronics and support of the flight program and scientific analysis.
96542	Particle Astrophysics with the Payload for Ultrahigh Energy Observations (PUEO): A Next Generation Long-duration Balloon-borne Instrument for the Cosmic High Energy Frontier [University of Delaware] Co-I	This proposal is in collaboration with Abigail Vieregg at the University of Chicago, who is the PI. KEY OBJECTIVES: We propose a next generation ultra-high energy particle astrophysics detector, the Payload for Ultrahigh Energy Observations (PUEO), based on the highly successful Antarctic Impulsive Transient Antenna (ANITA) payload. ANITA has completed four long-

duration balloon flights searching for signatures of ultra-high energy neutrinos interacting in the Antarctic ice sheets, producing radio-frequency impulses via the Askaryan effect, coherent radio Cherenkov emission from electromagnetic cascades. Gurgen Askaryan's theoretical work on this process in the 1960s has engendered a host of particle astrophysics techniques for detection of both neutrinos and cosmic rays at the highest energies, both before and after its confirmation in 2001 at the Stanford Linear Accelerator. Over the last decade, ANITA has produced among the best current limits on cosmogenic neutrinos -- those ultra-high energy cosmic neutrinos that result from interaction of the 2.7K cosmic microwave background with ultra-high energy cosmic rays throughout the universe. ANITA's constraints have eliminated a host of theoretical flux models for cosmogenic neutrinos, but the impetus to determine and characterize this so-called 'guaranteed' flux of neutrinos remains as strong as ever. ANITA has also seen a handful of anomalous cosmic-ray like events which could be a hint of beyond-standard model physics. ANITA's methodology is sound and the payload itself is mature, but the sensitivity is lacking to conclusively demonstrate the nature of these anomalies and to reach the elusive cosmogenic flux. We propose major augmentations that will increase the acceptance by an order of magnitude, while building carefully on the existing gondola and its infrastructure, to enable a smooth transition to a significantly more science-capable payload in PUEO. METHODS AND TECHNIQUES: The most critical parameter in the sensitivity of instruments that exploit the Askaryan effect, and related radio-impulse generation in cosmic-ray extensive air showers, is the energy threshold, and this scales almost directly with the total antenna collecting area. ANITA flew up to 48 quad-ridged horn antennas, each with effective areas (or gains) that were nearly optimized for the constraints of the payload launch envelope. However, radio-frequency interference reduced the usefulness of the lowest frequencies near 200 MHz. We propose to move the low-end cutoff frequency to 300 MHz, avoiding the interference issues, and allowing us to increase the number of antennas by more than a factor of two. An even more important

		improvement will come from coherent phased-array approaches to triggering the system, substantially improving the threshold compared to the previous incoherent trigger. The combination of these effects will improve the reach by an order of magnitude in terms of event rate compared to the most recent ANITA-IV payload, a major advance in sensitivity, that warrants the new payload designation of PUEO. PERCEIVED SIGNIFICANCE: The cosmogenic neutrino flux has not yet been detected in any form; lower energy neutrino measurements by the IceCube detector are of great interest, but are unrelated to cosmogenic neutrinos. PUEO's detection of, or stringent constraints on, this flux will have immediate and important consequences on our understanding of the origin and evolution of the universe, specifically our understanding of the nature of the ultra-high energy accelerators throughout the universe. In addition, PUEO will be able to conclusively resolve the nature of the anomalous events seen by ANITA, which currently challenge fundamental particle physics. PUEO, at a small fraction of the cost of a large ground-based facility like the IceCube observatory, will establish an observatory class suborbital instrument for measurements of the highest energy particles in the universe.
96546	The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons	This is the lead proposal for a multi-institutional proposal which includes UCLA, UCB, University of Hawaii, and M.I.T. The general antiparticle spectrometer experiment (GAPS) is a balloon-based search for dark matter. It uses a Lithium-drifted Silicon tracking telescope to detect X-rays and particles emitted when antimatter, produced by dark matter annihilation and decay, is stopped in the instrument. A flight from Antarctica can significantly constrain or detect dark matter.
96547	The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons [UCLA Co-I]	This is a Co-I proposal in support of the PI lead proposal entitled "The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons" submitted by Prof. Charles Hailey, Columbia University. Our proposed program would support the UCLA tasks on the GAPS experiment as detailed in our task statement. The primary focus of this work is on the development, construction and testing of

		the time-of-flight (TOF) system, the master GAPS trigger and support of the simulation and analysis tasks.
96492	Seismometer for a Lunar Network (SLN)	Seismic studies provide definitive knowledge of internal planetary structure. Reexamination of seismic data from the Moon has provided an important glimpse of its mantle and core structure, which has bearing on its thermal, petrological, and rotational history. Data suggest the presence of a fluid-like transition layer between the lunar core and mantle. The Moon may therefore still be undergoing chemical segregation and thermal layering. The seismologist's challenge is substantiating this view. Further investigation of internal structure hinges on innovative development of a Lunar Geophysical Network (LGN) that includes advanced seismic sensors and deployment methods. This network will need to overcome the limitations of an initially sparse grid and improve upon the quality of Apollo-era seismograms. The best design for such instruments, considering they will likely be delivered by a new class of small commercial landers, is currently underdeveloped. We propose to raise the TRL of a Silicon Audio commercial-off-the-shelf geophone from 4 to 6. This instrument is a novel combination of a classic seismic geophone and a laser interferometer. Micron-scale movements of an internal mass are recorded as induced current, while submicron-scale motions are recorded by the laser system. This allows for a small (<300gm), sensitive (1x10-8 m/s2/Hz1/2) broadband (0.01-100Hz) seismic instrument that is competitive with state of the art planetary seismometers. The 3-axis instrument is insensitive to tilt over 180º. Here we pursue a redesign of this system to partition the electronics, replace commercial parts with flight-worthy parts and perform environmental tests to demonstrate a sensor suitable for deployment on the Moon. In partnership with Honeybee Robotics, we will also pursue subsurface deployment using a pneumatic drilling technique, which is enabled by the small size of the Silicon Audio device. Drilling is accomplished by compressed gas jetting through a cylindrical, 3-axis, seismic probe, stirring up the soil underneath and lofting the regolith out of the hole. Burial will enable

		lower mass and power by automatically creating an isothermal environment, will improve seismic coupling, and reduce noise from the lander. This approach was successfully demonstrated in a previous SBIR project in a vacuum chamber with compacted (1.9 g/cc) lunar soil simulant. In the proposed effort, the deployment system will demonstrate seismic sensor implantation to 50 cm depth in compacted lunar soil simulant under vacuum, advanced from its current TRL 4 to TRL 5. Goals: 1) Raise the TRL of a redesigned Silicon Audio optical three-axis seismometer from 4 to 6. 2) Demonstrate burial with the Honeybee system raising the TRL from 4 to 5. Methodology. 1) Redesign the existing seismic instrument by partitioning electronics from the sensor-head. Replace the laser and photodiode with parts suitable for deployment on the Moon. Redesign the remaining electronics to be housed in a support electronics box. Test the sensor prototype in a relevant environment. 2) Demonstrate burial of the seismic sensor with the gas jet system in a simulated lunar regolith, in vacuum. Relevance: The objectives of the DALI program are to "develop new technologies that significantly improve instrument measurement capabilities for lunar science missions." LGN is identified as a priority New Frontiers mission in the Planetary Decadal Survey. Demonstration of the combined sensor and deployment system will position us for rapid response to upcoming commercial launch and landing opportunities, expected as early as 2019. An early landed commercial payload could test three deployment scenarios: buried in the regolith, sitting on the surface, and integrated into the body of the lander. Comparing the quality of data from each scenario will allow us to assess the level of science that can be achieved, which is directly relevant to future LGN-level instrumentation.
96493	The Lunar Environment Monitoring Station (LEMS)	Past missions have shown that the lunar exosphere is very sensitive to small changes that affect the plasma environment, the surface, or the interior of the Moon. Volatiles in the exosphere provide global tracers of changes in the lunar environment, and their driving processes (whether they are geophysical or manmade in nature). Though previous missions were successful at identifying short-term changes, they did not last long

		enough and/or did not have the capability to conduct long-term monitoring of the exosphere. Our proposal aims to mature the concept of a long duration surface station that monitors the lunar exosphere. This compact monitoring station will be designed to autonomously collect and relay measurements of changes in exospheric composition over a nominal 2 years period. These exospheric measurements will be acquired using a neutral mass spectrometer with a long heritage of flight implementation. Additionally, this autonomous station will accommodate a low power seismometer and provides the building blocks of a larger seismographic and geodesic network. This instrument development effort fully addresses the DALI Program objective of "spacecraft-based instruments that show promise for use in future lunar missions including expected commercial ventures". Specifically, this proposal focuses on maturing the packaging of key three subsystems (from TRL 4 to 6), along with characterizing the instrument's end-to-end performance and concept of operations using a high-fidelity prototype. When the proposed development is complete, the Lunar Environment Monitoring Station will be proposed for deployment on all relevant lunar landing missions (manned, robotic scientific missions, or commercial missions).
96494	CRATER: Characterization of Regolith And Trace Economic Resources	In situ laser ablation sampling enables spatially-resolved measurements (on the scale of <100 microns) of inorganic and organic composition via bond-breaking and mass removal of mineralogical matrices, and desorption/ionization of embedded organic content, respectively. High-resolution mass spectrometry empowers the separation of isobaric interferences (chemical compounds sharing the same nominal mass), including atomic (e.g., 54Cr+ versus 54Fe+), molecular (e.g., 28Si16O+ versus 12C16O2+), and organic signals (e.g., protonated phenylalanine C9H12NO2+ versus protonated triaminopurine C5H8N7+). In combination, these two analytical capabilities offer unparalleled potential to probe the chemistry of the lunar surface and subsurface. Here, we propose to develop CRATER (Characterization of Rock and Trace Economic Resources), a 7.9 kg, 47 W (active power) Orbitrap-based laser ablation mass spectrometer offering

ultrahigh mass resolution (m/dm > 100,000, FWHM at mass 100) and enhanced photon-substrate coupling via deep ultraviolet (213 nm) radiation. Specifically, we will advance the following critical subsystems: 1. a dual-polarity Orbitrap mass analyzer, originally developed for commercial applications by Thermo Fisher, ruggedized for spaceflight by a consortium of French laboratories, and capable of measuring both positively- and negatively-charged ions across a range in molecular weight (20 – 1000 amu), volatility, and ionization potential; 2. a high power solid-state (Nd:Cr:YAG) laser system with continuously variable output energy (1 – 100% attenuation in 1% increments) capable of generating ≥1 mJ of deep UV light (213 nm) by quintupling the frequency of the heritage oscillator/amplifier flown on the Mercury Laser Altimeter (MLA); and, 3. an ion inlet subsystem that supports laser sampling of lunar materials (including regolith fines) under ambient conditions, and acceleration/energization/delivery of discrete ion packets into the Orbitrap analyzer. The science objectives of the CRATER investigation fall into three distinct, but related, categories: DYNAMICS OF THE MOON-FORMING EVENT: The CRATER investigation will critically assess the purported enrichment in refractory elements (e.g., Al) and depletion in volatile metals (e.g., K) in lunar surface materials relative to the cogenetic silicate Earth, and characterize chemical distinctions between regolith and subsurface samples. DEFINITION OF A "LIFE DETECTION BLANK": The highly capable CRATER instrument will quantitatively measure prebiotic organic compounds, including amino acids and nucleobases derived primarily from the infall of cometary and/or asteroidal materials, down to pmol/mm2 concentrations, enabling provenance recognition based on diagnostic abundance patterns and the definition of an abiotic baseline for future astrobiology missions. RESOURCE EXPLORATION: The CRATER instrument will also enable resource prospecting through the generation of 2D chemical maps of economically important transition metals (e.g., Ti, Cr, Fe, and Cu) in positive ion mode, and sulfur (S) and halogens that serve as proxies for liquid water and/or solar implantation (e.g., F, Cl, and Br) in negative

		ion mode. Through these initiatives, the CRATER investigation addresses key science questions from all three crosscutting themes defined in the NASA Planetary Decadal Survey, as well as the evolving priorities of the Lunar Exploration Assessment Group (LEAG), as outlined in the Lunar Exploration Roadmap (2016). The activities proposed through this study support the objectives of the DALI Program, specifically: development of spacecraft-based instruments that show promise for use in future Lunar missions including expected commercial ventures; advancement of new technologies that significantly improve instrument measurement capabilities; and, demonstration of instruments for small stationary landers.
96495	Maturation of the Potassium-Argon Laser Experiment (KArLE)	Maturation of KArLE (Potassium-Argon Laser Experiment) for in situ planetary geochronology Barbara A. Cohen, NASA MSFC 1) Description of the science goals and objectives to be addressed by the proposal: The proposed Potassium (K) - Argon (Ar) Laser Experiment (KArLE) is intended to provide the capability for in situ dating in planetary missions. KArLE will simultaneously measure K and Ar on a given sample to achieve a precise age, while also performing additional analyses of common interest such as elemental analysis and imaging on rocks of interest to lander and rover missions. Previous development work under a PIDDP grant has proved the KArLE concept in a laboratory environment, both at the component level and through end-to-end tests, to achieve TRL 4. We seek to mature the KArLE architecture to TRL 6, suitable for proposing to future flight missions. 2) Brief description of the methodology to be used to address the science goals and objectives: The KArLE-unique hardware consists of a small vacuum chamber, a focusing lens set, partner instrument interfaces, and a sample handling system. The stationary KArLE hardware is intended to interface with flight-heritage instruments: a Laser-Induced Breakdown Spectroscopy (LIBS), mass spectrometry (MS), optical imaging instruments, and lander/rover drill or sample handling system. The KArLE design to interface with existing, flight-proven instruments offers a low cost, low risk approach to accomplish additional and highly-desirable science measurements with minimal extra hardware. In this proposal, we will

		mature both the KArLE hardware and techniques. We will build engineering prototypes of a KArLE chamber and lens set, sample-introduction hardware and a resealable vacuum flange that will mate to the KArLE chamber, and a small mass-range quadrupole mass spectrometer. We will integrate these into a brassboard along with LIBS and camera optical interfaces. The brassboard KArLE suite will be subjected to environmental (thermal vac, vibration) testing and end-to-end sample analysis on appropriate lunar analog and meteorite samples. 3) Relevance of the proposed research to this call: Absolute ages are the backbone of understanding lunar thermal and impact history, and by extension, the historical framework for the solar system. A geochronology capability will be crucial for investigating lunar formation, bombardment, and magmatic history, because we cannot possibly bring back samples from everywhere on the Moon. In situ geochronology has been proposed for inclusion in Discovery missions in the 2014 call and will be again to the 2019 call, but thus far has not advanced to TRL 6. For a first-time use of in situ geochronology, it is critical to advance the maturity of the approach before a mission risks including it. We mature the KArLE concept for Discovery, but will also develop envelopes to understand how commercial lander capabilities would be able to carry all or parts of KArLE. This project will mature both components of the KArLE system and the overall KArLE architecture to TRL 6.
96496	Adapting the Compact Integrated Raman Spectrometer (CIRS) for Lunar Exploration	During DALI we will adapt and mature the Compact Integrated Raman Spectrometer (CIRS) from Lunar TRL 4 to TRL 6. This effort will enable CIRS to perform in situ characterization of lunar minerals and screening of ISRU raw materials vital for future mining and processing efforts. In-situ Raman analysis of the Moon can provide definitive mineralogy, especially mineral chemistry of major lunar minerals, such as Mg/(Mg+Fe) ratio of olivine, Mg/(Mg+Fe+Ca) ratio of pyroxene, end members (Or-Ab-An) and intermediate solid solutions of plagioclase, Fe-Ti-Cr ratio information in lunar opaque minerals, as well as ID the minor and trace minerals of the lunar surface. Raman analysis is also capable to characterize adsorbed H2O, structural H2O in minerals, and H2O ice. A fully functional prototype of the CIRS

instrument has been developed under the MatISSE program. The laser, optical, optical-mechanical, and detector electronics of the instrument were the major focus of the MatISSE effort, maturing these subsystems to TRL 5 for landed missions to Mars, Venus, and Europa. During the next two years CIRS will be re-designed into smaller, rad-hard instrument (273mmx136mmx72mm) including an internal sample containment system allowing drill cuttings of icy samples to be analyzed in their solid, melted, and desiccated states. Under MatISSE, the electronic control of the instrument relies exclusively on commercial off-the-shelf (COTS) parts. This approach allows us to rapidly test and validate the performance of CIRS as well to develop the autonomy and image processing functionality necessary for it to operate without Earth-in-the Loop (e.g. Venus, Europa). Development of flight electronics and firmware with equivalent functionality must necessarily occur after this, a phase for which CIRS is currently ready to undertake under DALI. Accordingly, under DALI, we will leverage on the efforts above, and focus our efforts on: (1) designing the CIRS instrument such that it can tolerate the extreme thermal environment presented on the Moon while the instrument is immersed in sunlight and shadow regions and (2) developing CIRS flight electronics and flight firmware using a Vertex-5 processor to execute the suite of functions previously validated using COTS electronics/software), (3) combining these efforts with lunar specific architectural modifications necessary to reach Lunar TRL 6 for the entire instrument, and (4) finally verifying and validating that CIRS is truly Lunar 6 by exposing CIRS to simulated launch and lunar operating conditions using JPL Flight Instrument Testing labs and testing protocols (HALT, TVAC, etc). This effort, if funded, will provide a mature Raman instrument that can be interfaced with a lunar rover or spacecraft in the timely and cost-efficient manner necessary to support early robotic mission opportunities for NASA's new thrust in establishing a permanent presence on the Moon.

96497	LASVEGAS on the Moon: A Hypertunable IR laser Spectrometer for the Analysis of Volatiles	This proposal seeks to adapt the novel, low resource, high capability Laser Absorption Spectrometer for Volatiles and Evolved Gas (LASVEGAS) to the lunar surface environment. Regolith volatiles underpin many high priority lunar science goals identified by NASA (2014, 2016), the NRC (2007, 2012), and LEAG (2016, 2017a,b), and are also of critical importance for in situ resource utilization (Jawin et al., 2018; Fassett, 2019; Sanders, 2018). The volatile measurements required to achieve these goals are obtainable with the lunar-specific LASVEGAS accommodated on any of the landed spacecraft currently under consideration, including Commercial Lunar Payload Services (CLPS) spacecrafts. With the arrival of NASA's Artemis architecture, now is the ideal time to bring this low risk, low resource instrument to TRL-6 flight maturity. The instrument fits in a resource envelope far lower than GCMS or Raman spectrometers with unambiguous species determination. Capabilities enabled by LASVEGAS broadly include: • Fast, high precision, unambiguous measurement and detection of both anticipated and perhaps unexpected volatiles (H2O, CO2, CO, CH4, H2S, SO2, NOx, HCN, OCS, CxHy…) within the regolith. • Isotopic measurements of 13C /12C, 18O /16O, and D/H from one or more molecular species. • Downstream analysis of gases from a GCMS or other instrument(s) for complementary or independent measurement corroboration. The traceability of the proposal science objectives from NASA Goals down to measurement requirements and LASVEGAS performance are detailed in a fully developed Science Traceability Matrix. LASVEGAS is a laboratory-proven (TRL-4) infrared laser spectrometer originally developed for icy worlds (Europa, Enceladus, Titan, etc.) and requires specific and necessary modifications and additions in order to achieve science and exploration measurement requirements within the relevant lunar environment. The samples and sample handling are different. The dust environment is critically different. The thermal environment is different. The payload resource allocations and accommodation requirements are different. The Goal of this proposal is to refine, implement, and validate a lunar LASVEGAS instrument for use on the lunar surface starting from the BIM

		design. The proposal Objectives are tied to specific instrument subsystems and lunar-specific measurement requirements: 1) Implement a novel, more compact, lower optical noise, more dust resistant, and higher throughput laser multiplexing subsystem. 2) Address head-on the challenges of lunar dust contamination with the addition of a high heritage dust mitigation system. 3) Perform a structural, thermal, and optical analysis driven by the lunar environment and implement design changes, as necessary. 4) Refine, assemble, and interface a sample acceptance subsystem to existing TRL-5+, sample handling subsystems. 5) Perform relevant environmental testing and qualification to bring the instrument to TRL-6. 6) Initiate a spectroscopic library used to perform retrievals of lunar LASVEGAS spectra. The proposed investigation is highly relevant to the DALI Program solicitation. LASVEGAS is a TRL-4 instrument to be matured to TRL-6 specifically under relevant lunar conditions. The science goals and objectives are directly traceable to NASA lunar science and human exploration, including ISRU. DALI is specifically interested in small payloads for small lander spacecraft, and LASVEGAS fills this niche with its high capability yet low mass, volume, and power/energy requirements. The maturation and implementation program is low risk and detailed with many milestones along backed by strong program oversight and guided by a fully load resource schedule. The team has the experience and qualifications to carry out the proposed work.
96498	XTRA: An eXTraterrestrial Regolith Analyzer for Lunar Soil	The mineralogical composition of lunar soil or regolith can be used to elucidate its petrogenesis and that of its parental lithologies (e.g., igneous rocks, impact breccias), as well as subsequent diagenetic or metamorphic events. In addition to its value to landed lunar science and as ground truth for orbital missions, in-situ mineralogical analysis of the lunar regolith can be used to evaluate potential ISRU processes such as the production of water or oxygen, production of metallic Fe or Al, ceramic building materials, or ore deposits useful for Rare Earth Element extraction. The eXtraTerrestrial Regolith Analyzer (XTRA) is an XRD/XRF instrument capable of quantitative analysis of as-received lunar regolith when deployed from a small

lander or rover. XRD is the only in-situ technique able to definitively identify, quantify and determine the elemental composition of minerals present in lunar regolith. XRD can also determine the quantity of amorphous material present in a regolith sample, and when combined with XRF, the elemental composition of the amorphous component(s). Taken together, XRD/XRF provides a comprehensive analysis of lunar regolith mineralogy that can only be improved upon by sample return. XTRA is a CheMin-inspired XRD/XRF instrument with enhanced XRF capabilities (11<30) due to its reflection geometry and operation in vacuum at the lunar surface. XTRA will be integrated with a sample collection/delivery system developed by Honeybee Robotics. As-received regolith samples are delivered to the XTRA instrument and placed in a vibrated, reflection geometry cell. Collimated X-rays from a Co anode X-ray tube intersect the sample surface at an acute angle. Diffracted photons between 15 – 60° 2θ are detected by an energy-discriminating, single photon counting CCD. These are identified by their energy and summed into a 2D array that constitutes the diffraction pattern of the sample. A histogram of all photons detected by the CCD constitutes an X-ray fluorescence spectrum of the sample. Rietveld refinement and full pattern fitting are used to determine the abundance and chemistry of the crystalline material and the relative amount of amorphous material. Fundamental parameter calculations are used to determine the quantitative elemental composition of the sample from the XRF spectrum. We have used a CheMin-derived commercial instrument to quantify mineral abundances in 110 lunar regolith samples. XTRA addresses DALI program goals of "instruments that support NASA's broader lunar exploration goals, including human exploration and ISRU, as well as fundamental lunar science, and missions to other planetary surfaces." XTRA is suitable for stationary landers, rovers and future laboratories on the lunar surface. Data from XTRA directly address concepts outlined in the 2007 NRC study "The Scientific Context for the Exploration of the Moon" as updated by the LEAG Specific Action Team in 2018, "Advancing Science of the Moon," including Concept 2 (structure and composition of the lunar interior), Concept 3

		(planetary processes recorded in the diversity of lunar crustal rocks), Concept 4 (lunar poles as special environments), Concept 5 (lunar volcanism as a window into the thermal and compositional evolution of the Moon), and Concept 7 (moon as natural laboratory for understanding regolith processes). XTRA, a follow-on instrument to the CheMin XRD/XRF on Mars Science Laboratory, benefits from previous NASA technology programs, and shares high-maturity components with MapX, a currently funded MatISSE effort. The XTRA geometry has been validated by commercial portable reflection XRD/XRF instruments developed for non-destructive identification of pigments in works of art and archeological materials. XTRA is currently TRL-4 and will be at TRL-6 at the end of DALI funding, at which time it will be proposed for flight.
96499	Lunar Heat Flow Radiometer	Motivation: The Lunar Heat Flux Radiometer (HFR) will peer into the lunar subsurface using microwave wavelengths (~10-200cm, 300MHz to 6GHz and a 90Ghz surface radiometer), providing a measurement of geothermal heat flux without need for drilling. Though this is primarily aimed to be a landed instrument for DALI, this instrument can equally be used as an orbital measurement. We place its current state of development at TRL 4, but we can quickly bring it to TRL 6+ by leveraging our team's experience with Earth-orbiting radiometer instruments. The upwelling surface emission at microwave wavelengths is a function of the sub-surface temperature profile and dielectric material properties. For solid planetary bodies, surface transparency in microwave wavelengths varies mainly due to changes in minerology (dominated on the Moon by the dielectric properties of the mineral ilmenite) and density (i.e., subsurface rocks). Physical temperatures vary mainly with regolith thermal inertia (influenced by the presence of subsurface rocks or ice) and, at depth, geothermal heat. By observing radiation from multiple frequencies between 300MHz and 6GHz, our instrument will measure: 1) dielectric properties, 2) depth of bedrock, buried rocks and ground ice, and 3) subsurface temperatures that constrain geothermal heat flux. China's Chang'E 1 and 2 orbiter missions carried two 4-channel (3.0, 7.8, 19.35, and 37 GHz) microwave instruments into lunar orbit. These

		measurements have been used to reconstruct regolith layer thickness, dielectric properties, subsurface temperatures, and geothermal heat flow. Although it has given tantalizing information and provide an excellent proof of concept as to the possibilities of a microwave instrument, it used off-the-shelf frequencies not specifically optimized for subsurface observations. Our goal is to design a purpose-built instrument to measure near surface density, dielectric properties, and geothermal heat flux. We will develop and test a prototype instrument for remote lunar heat flow. This includes developing the ultra-wideband antenna, radiometer front-end with embedded calibration sources and the spectrometer backend. The instrument will capable of measuring calibrated upwelling brightness in the range of 300 MHz to 6 GHz. The instrument will leverage technology developed for Earth and planetary instruments, including ultra-low power CMOS spectrometer chips. We will first perform a study to refine the instrument performance parameters and create a set of key and driving requirements. Design studies for each sub-system will lead to sub-system prototyping efforts and finally a fully functional engineering model that will undergo testing to raise the TRL to 6. Relevance: The proposed effort is relevant to the DALI call in the following ways: 1. By enabling new measurements of regolith stratigraphy and heat flow we answer central objectives of "The Scientific Context for the Exploration of the Moon", specifically Characterizing the thermal state of the interior heat engine, and determining the physical properties and the vertical extent and structure of the regolith. 2. In addition to surface lunar investigations, the HFR could be used as an orbital instrument. 3. The TRL of the proposed instrument is raised from 4 to 6 by retiring technology risks and allowing insertion into future lunar mission instrument calls. 4. The effort continues to drastically lower the weight and power of the key instrument technology.
96500	Submillimeter Solar Observation Lunar Volatiles Experiment (SSOLVE)	SSOLVE (Submillimeter Solar Observation Lunar Volatiles Experiment) will use submillimeter and terahertz receivers to investigate water in the lunar exosphere by observing strong transitions of H2O, OH, and HDO against the Sun as a backlight source. Submm-

THz systems provide the high sensitivity needed to resolve the fundamental uncertainties of water vapor in the lunar exosphere: how much is there, where does it come from, how is it lost, does it exist primarily as water molecules or as hydroxyl radicals. SSOLVE will be developed for a landed platform to access the sky over the lander and to measure the variability of exospheric water with time of day. If an orbital platform is available instead, the identical design could be deployed for nadir viewing of gas transitions against thermal emission from the lunar surface to map water in the exosphere at all latitudes and local times. The total column abundance of water and free hydroxyl radicals over the Moon's surface addresses the highly uncertain quantity of water group species in the atmosphere and its chemical form. The relative enrichment of deuterium is an important constraint on the delivery mechanism for water to the lunar surface, particularly if the column abundance is greater than the exobase limit, which would imply an indigenous source. Identifying or ruling out significant indigenous water in the current atmosphere will provide important insight into whether the lunar formation process incorporated significant primordial water. Measuring the abundance of water in the lunar atmosphere and determining whether it is indigenous or exogenous is essential to assessing the likely availability of water for in situ resource utilization (ISRU) of limited lunar water supplies. The development program for SSOLVE will leverage existing capabilities and designs at Goddard Space Flight Center, derived from extensive heritage in microwave systems for Earth atmosphere investigations, including the successful Earth-orbital IceCube cubesat to measure ice clouds in Earth's atmosphere. SSOLVE will use a heliostat to track the Sun regardless of lander orientation or leveling. Designs have already been developed for antenna and telescope assemblies, the mechanism, and internal calibration. Suitable receiver designs are available at TRL4-5 to serve as the front end for the 557 GHz H2O, 509 GHz HDO, and 2.5 THz OH receivers, with suitable digital spectrometer back-end designs already at high TRL. SSOLVE is a low-risk, high sensitivity, high reliability concept with potential for high scientific payoff.

96501	Lunar CubeSat Mass Spectrometer with LETS Radiation Sensor	JPL and JSC propose a single suite with two payloads sharing power and C&DH electronics to be advanced from TRL-4 to TRL-6 for prolonged operation on the Lunar Surface. JPL's Lunar CubeSat Mass Spectrometer (LCMS) will detect trace abundance volatiles including the first measurements of Xe and Kr at 20-100× higher sensitivity than the LACE experiment on Apollo 17 (the only previous lunar surface mass spectrometer investigation). LCMS will retire a longstanding lunar science goal, documented in a series of Planetary Decadal Survey, LEAG, and NRC reports, to understand the composition of Volatile Chemical Compounds (VCC) at the surface. JSC's Linear Energy Transfer Spectrometer (LETS) will make the first radiation measurements on the Lunar Surface, addressing important Lunar Human Exploration Strategic Knowledge Gaps (SKGs) and helping pave the way for long-term human exploration. Both the LCMS and LETS require thermal/radhard adaptations and testing to be integration with a Lunar Commercial Lander platform by the September 2022 time-frame. LCMS is a proven Quadrupole Ion Trap (QIT) Mass Spectrometer (MS) design that operated successfully on the International Space Station from 2010 to 2012. It provides up to two orders of magnitude higher sensitivity and mass resolution than GSFC's Neutral Mass Spectrometer, with ≤1% precision isotope ratios from both atmospheric and solid samples. It can additionally perform tandem MS studies of complex organic species (capability not used for the DALI program). The LCMS's rugged 8U design, 7 kg mass, and 22 W peak power are ~2-3× lower than current high performance flight MS designs, making it compatible with CubeSat and SmallSat mission platforms. Its low cost, modular design leverages ~15 years of QITMS maturation history at JPL, and decades of flight-proven MS electronics built by the University of Michigan. LETS is a flight spare radiation sensor built by JSC for NASA's BioSentinel CubeSat, scheduled for launch in 2020. Its Timepix detector technology is currently operating successfully on the ISS as part of the REM and MPT instruments. The knowledge of the ISS radiation environment gained from these data sets is adding to our understanding of the radiation risks faced by astronauts in low earth orbital environments. The

		LETS investigation will provide further knowledge required for human exploration. LETS' software is already fully compatible with the LCMS's C&DH electronics, and it can be integrated with the LCMS for a very modest cost. It is only 200g in mass, and requires 2 W operating power (plus shared 7 W for power and C&DH from the LCMS). Its low mass and low power consumption make it an attractive solution for detailed sampling of the radiation field on any lunar lander. Our science goal is to use LCMS to determine which volatile species are present at the lunar surface at abundances ≥50 mol/cm3. The LCMS requires an unobstructed view of the Lunar surface to minimize the effects of Lander out-gassing. Its 30 deg field of view enables measuring exospheric atoms as they bounce across the lunar surface. LCMS's QITMS sensor is designed to meet all performance requirements in an ultra-high vacuum environment where ion-ion and ion-neutral interactions are rare. We have already validated its performance for sensor/sample temperatures up to 300°C and show that no helium buffer gas is required. The LCMS/LETS suite will make substantial progress on addressing a broad set of NASA's strategic goals, and can fully address them on future lunar lander missions. Beyond NASA's lunar exploration program, successful operation of the LCMS/LETS on the lunar surface will provide NASA with a flight-proven MS and LETS suite that can enable low cost, high performance mass spectrometry and/or radiation sensing on a wide variety of future planetary platforms including CubeSats, SmallSats, mini descent or drop probes, mini rovers and small landers, quadcopters, small balloons and ultralight aircraft.
96502	Maturation of the Bulk Elemental Composition Analyzer (BECA) for Surface and Sub-surface Lunar Studies	The Bulk Elemental Composition Analyzer (BECA) is ideally suited to making high precision in situ measurements of the bulk elemental composition of the near-surface of the Moon. With no moving parts, BECA will provide bulk elemental composition information over a volume roughly 1m radius and 20 cm depth beneath the lunar surface without the need to touch the surface regolith. This powerful new BECA instrument will therefore be a highly useful tool for answering fundamental lunar science questions. BECA fills a special niche in that it measures the bulk composition of materials beneath the lunar surface and

is thus less sensitive to effects of space weathering and other surface processes. BECA is especially versatile in application, with its ability to produce scientifically important information in both static lander and lunar rover configurations. BECA's measurement of the local concentrations of both major and minor rock-forming elements such as H, O, Na, Mg, Al, Si, P, S, Cl, Ca, Ti, and Fe and the naturally radioactive elements (K, U and Th) will provide important geochemical constraints on the thermal and compositional evolution of the Moon. BECA can also answer outstanding science questions about lunar formation through its measurements of the distribution of lunar volatile elements at both polar and middle latitudes. In addition to these scientific contributions, BECA will also provide in situ ground truth validation for orbital composition maps obtained by multiple missions. Finally, BECA will also provide extremely useful information about near-surface resources important for future lunar exploration. BECA consists of a Pulsed Neutron Generator (PNG) which emits high energy neutrons that penetrate into the lunar subsurface and cause the materials to emit gamma rays with energies characteristic of the elements that produced them. BECA's Gamma Ray Spectrometer (GRS) measures these gamma rays' energies to identify the elements and the gamma ray line intensities to determine the quantity of the elements present. Low energy neutrons are also emitted by the lunar surface and measurements by BECA's Neutron Detectors (NDs) allow for a more sensitive and deeper measurement of hydrogen than available from the gamma rays alone. BECA offers important science and resource detection capability for both static landers and rovers. Although the inclusion of the PNG dramatically increases its capabilities, BECA would provide important measurements on a static lander even without the PNG. The full BECA instrument is especially powerful for small rovers where it can make scientifically important elemental composition measurements for some elements in 15 minutes and complete composition measurements in about 2 hours. The BECA instrument currently contains components ranging from TRL 4 to TRL 9, thus its entering system TRL is 4. We propose to bring the individual

		components to TRL 6 and then test BECA in both a static lander and rover configuration to verify the maturation of the entire BECA instrument system to TRL 6 so that it is ready for both static lander and rover applications. We will verify BECA's performance in both the static lander and small rover configurations at the Gamma ray Neutron Test (GNT) facility at NASA/GSFC. The static lander configuration will be tested by placing the BECA components on top of large, previously-assayed basalt and granite monuments and measuring their composition. The rover configuration will be tested by mounting the BECA components onto a small APL-developed rover. The rover would then drive over buried materials at the test site to demonstrate its capabilities for measuring variations in subsurface composition. This rover experiment will also allow us to develop operations procedures and quick turn-around analysis software so that the bulk elemental composition results from BECA can be used as part of the decision-making process for future lunar missions.
96503	Lunar Super Low-Frequency Atomic Seismometer	We propose to develop a super low-frequency atomic seismometer for lunar landers and network applications. The seismometer instrument employs using atomic test masses as the inertial reference frame and atom interferometry for displacement measurements. The baseline technology has been investigated and demonstrated as a quantum gravity gradiometer for earth gravity measurements and an orbiter atomic drag-free reference instrument for planetary gravity measurements. Due to its reliance on the atomic system, the measurement system can be more stable over longer time period than its mechanical counter parts. Therefore, the atomic seismometer will provide unprecedented seismic sensitivity at frequency ranges from Hz down to μHz. Seismology has been a key technique for understanding a planet and its interior. Seismic measurements have extensively provided unique and valuable information about the interior structure and dynamics of the Earth. Indeed, almost all first lander mission of a planet carried seismometers, including on the moon. The need and benefit of broadband planetary seismometers with low-frequency sensitivity are exemplified by the VBB instrument on the InSight mission. The potential for the atomic

		seismometer to achieve extremely high sensitivity and low noise at very low frequencies (sub-μHz) is vital for science on the moon, which is very quiet in comparison with Earth or even the activity levels predicted for Mars. In particular, the low-frequency sensitivity of the instrument enables science beyond that achieved with the instruments from the Apollo missions, including long-period surface waves and normal modes at frequencies down to sub-mHz range and tide measurements in the sub-μHz range. The atomic seismometer instrument is based on the principle of quantum matter-wave interferometry. It utilizes the interference of atom waves, with atoms laser cooled to microKelvin temperatures without cryogenics. One major difference of the atomic seismometer from traditional mechanical ones is the use of totally free-fall test masses without any spring mechanism or measurement back-action. This allows for high acceleration sensitivity and extreme measurement stability without the need for on-board calibrations. Through NASA ROSES programs, we have demonstrated a transportable atomic gravity gradiometer and subsequently miniaturized it into a shoebox-sized accelerometer sensor system. The objective of the DALI effort is to develop and mature an integrated instrument system of atomic seismometer specifically for moon deployment, perform full characterizations and evaluations, and make it ready to be infused into for a lunar lander mission.
96504	An Ultra-Compact Imaging Spectrometer for the Lunar Surface: Enabling Volatile Mapping and Unraveling the Moon's Geologic History	Goals & objectives: The proposed project will advance an ultra-compact shortwave infrared imaging spectrometer (UCIS) for use on future lunar surface missions, including expected commercial lander ventures. UCIS will be developed to address science knowledge gaps about the abundance and sources and sinks of lunar volatiles and provide key knowledge about possible in situ resources for future human exploration. UCIS is currently TRL4 for these objectives on a landed lunar mission based on its (1) spectral range, (2) lunar surface environments, and (3) onboard processing to maximize return of surface information to Earth. We will develop these three areas, raising UCIS-Moon to TRL6 so that it may be proposed in response to future announcement of a landed lunar flight

opportunity. We will maintain its low volume, mass and power requirements to be suitable for diverse landed platforms. Approach & methodology: UCIS is currently capable of collecting spectra to 2600 nm. For this work, we will upgrade the spectrometer detector and thermal system to extend the spectral range to 3600 nm. The extension to 3600 nm is critical to detect, attribute, and map lunar water resources -- specifically, the form, abundance, spatial distribution, and temporal variability of lunar OH species, molecular H2O, and water ice – as well as organics. In addition to volatiles, the extended wavelength range to 3600nm will enable UCIS to detect organic material that may be present, delivered to the moon via impact of external, organic-rich solar system objects. UCIS will maintain its capability to map the mineralogical composition and geologic context of the lunar surface, unraveling the geological history at unprecedented spatial scales (meters to microns depending on optics). We will also develop new on-board analysis to enable return of high value spectra while reducing the volume of transmitted data. We will adapt existing algorithms based on (1) endmember detection and (2) fitting continuum-removed absorptions. These can identify unanticipated materials and detect known high-value target signatures, respectively. Prioritized downlink of key spectra and derived maps will ensure fast, efficient landed operations. Onboard analysis will enable investigation lifetimes as short as one lunar day while still obtaining full maps of the landing site. Finally, we will develop the UCIS instrument to operate in the challenging thermal lunar surface environment. Temperatures on the surface of the moon can range from approximately 100 – 400 K, and reach even lower temperatures of ~30 K on permanently-shadowed lunar ice deposits. We will mature the UCIS thermal design to operate in this wide temperature range while maintaining excellent signal-to-noise-ratio and sensitivity. A high precision mode will be included to allow useful measurements from terrain scattered light in permanently shadowed regions. Reasons proposed work is within scope of program element & why program is most appropriate: This work is within the scope of the DALI program because it seeks to mature lunar science instruments that support

		NASA's broader lunar exploration goals, including human exploration and in situ resource utilization (ISRU) as well as lunar science. We will mature the UCIS instrument from a TRL4 to TRL6 to operate in the lunar environment, extend its wavelength range to answer high priority lunar science and ISRU questions, and add onboard analysis to support high yield during short-lifespan missions. The full range spectroscopy of UCIS-Moon is required to identify and quantify the surface abundance of lunar surface volatiles and their geologic context for future in situ resource utilization objectives. DALI is the most appropriate program element because the work proposed is specific to advancing lunar science via an instrument suitable for a lunar lander, including those of commercial providers.
96505	Electrostatic Dust Analyzer (EDA) for Exploring Dust Transport Processes on the Lunar Surface	This proposal is to develop and advance the flight readiness of the Electrostatic Dust Analyzer (EDA) for exploring electrostatic dust transport phenomena on the lunar surface in order to understand its role in shaping the properties of the lunar regolith. The in-situ measurements enabled by EDA will answer one long-standing science question: What is the efficacy of electrostatic dust mobilization and transport as one of the fundamental physical processes shaping the lunar surface? This investigation will advance our understanding of the formation and evolution of the Moon and therefore the history of the solar system, which is a high-priority goal in the Planetary Science Decadal Survey 2013 – 2022 and in the NASA Science Plan 2014. This investigation will also provide enhanced knowledge about potential hazards posed by electrostatically lofted dust and critical inputs for developing the mitigation strategies for future lunar robotic and human exploration, as described in the lunar human exploration Strategic Knowledge Gap (SKG). The science objectives are: 1) Detect individual dust particles that are lofted due to electrostatic effects on the lunar surface; 2) Characterize the charge, velocity, and mass distributions of lofted dust particles; and 3) Characterize the electrostatically transported dust flux and its variability as function of local time, solar activity, and orbital phase around the Earth. EDA consists of a dust analyzer module and an auxiliary operating system (AOS). The dust analyzer module is a

		miniaturized version of the Electrostatic Lunar Dust Analyzer (ELDA) that has been previously developed to Technology Readiness Level (TRL) 4 through NASA's Planetary Instrument Definition and Development Program (PIDDP) at the University of Colorado. The dust analyzer module consists of two Dust Trajectory Sensor (DTS) units with a Deflection Field Electrodes (DFE) unit between them. Wire-electrodes inside DTS measure the charge and velocity of a dust particle passing through them. The dust particle is deflected in the DFE region in which its mass is determined from the deflection trajectory. EDA's AOS operates the instrument on the surface for an optimized field-of-view (FOV) for dust collection and for preventing solar wind plasma and solar ultraviolet (UV) radiation from entering the dust analyzer. To minimize the effect of local plasma environment around lander on the dynamics of lofted dust particles and consequently their collection, EDA is designed for being deployed on the lunar surface by a small stationary lander that also provides power and communication. The volume, mass and power of EDA are estimated to be 23x20x19.5 cubic cm, 4.9 kg, and 5.3 W, respectively. The current development of EDA is at TRL 4 and will be raised to TRL 6 after the proposed work is completed. Beyond the Moon, the exploration of electrostatic dust transport phenomena enabled by the proposed development of EDA is also important for understanding regolith processes on other airless bodies (e.g., asteroids and comets) in the solar system. This instrument is therefore applicable to multiple future planetary science missions. It is of high interest to the planetary science communities as well as NASA's robotic and human exploration program.
96506	Development of the SUBLIME seismometer for future Lunar missions	Constraining the details of the Moon's internal structure and seismic activity is required to understand its origin, history, and evolution. Further, characterization of moonquake magnitude and distribution is an essential element of providing safety to human-driven exploration of the Lunar surface. These observations and constraints are primarily enabled via monitoring of seismic and bolide activity on the Moon. Data from seismometers therefore provide a critical approach to enable a detailed mapping of the interior of the Moon from regolith to core, to constrain physics of internal

lunar dynamics, and to catalog and characterize moonquakes and bolide impacts. The key technological challenge is to produce a modern, high-performance seismometer that can provide the range of seismic data necessary to achieve the aforementioned objectives. Here we propose to mature a pathfinder planetary seismometer, the SUBsurface Lunar Investigation and Monitoring Experiment (SUBLIME) instrument. This seismometer is based on an innovative Molecular Electronic Transducers (MET) technological design, which is rugged, simple to deploy, allowing flexible incorporation on a broad range of future commercial lander missions and long term monitoring stations. We propose to further develop our instrument concept to retire technical risks associated with the instrument design. Specifically, our team has identified the following risks: Risk-1) maturing the seismic package and control electronics to ensure they can operate in the Lunar environment, Risk-2) minimizing resources to accommodate SUBLIME within a reasonable mass, volume, power and data volume, and Risk-3) document the requirements associated with the deployment of SUBLIME to ensure it is well coupled to the surface for science operations. To address these risks our team will (1) fabricate a high fidelity engineering model to demonstrate operation in the relevant environment and provide precise constraints on mass, volume and power requirements (addresses Risk and Risk-2) and (2) conduct field tests in an appropriate Lunar analog to define deployment requirements (addresses Risk-3). This proposal is relevant to the DALI program in that the work proposed here will aid the SUBLIME concept in reaching TRL 6 in the 2021/2022 timeframe. Moreover, this proposal will develop subsystems of the SUBLIME instrument in order to verify performance of the complete system and will mitigate risks associated with its development and accommodation on future Lunar missions. The ASU/GSFC/UMD partnership has successfully worked to develop the seismic sensor technology under a NASA COLDTech award and has tested key components of the sensor subsystem in relevant environments. This partnership has a proven record of achievement and is well suited to continue development of the SUBLIME instrument.

96509	Soil Properties Assessment Resistance and Thermal Analysis (SPARTA)	Proposal Summary: The proposed effort seeks to develop a proof-of-concept, highly versatile, miniature instrument that will provide NASA with a new capability for in-situ measurements of the physical properties of regoliths (soil-like material, dry and ice-rich permafrost) for future surface landed missions. Our proposed instrument, the Soil shear Properties Assessment, Resistance, Thermal, Analysis multiTool – (SPARTA) will characterize the principal physical and chemical properties of regoliths, including thermal/electrical properties and chemical potentials of water and ice, through the integration of specialized tools into a small, portable instrument. Methodology: Each of the components is based on classical terrestrial geotechnical instruments and none of the instruments or measurements has been deployed previously on any planetary surface (except Earth-Note: a double probe TECP was flown on Phoenix with mixed results, for SPARTA we are proposing a single probe instrument). The proposed research will bring each component up to a NASA Technology Readiness Level (TRL) 3 for future integration into SPARTA. Instrument development will occur in two stages: Stage 1 is a three-year proposed effort (PICASSO) to design, fabricate, characterize, and demonstrate proof of concept in a controlled set of soil samples, for a soil probe capable of measuring: 1) Dielectric Spectroscopy (DS-measures water content and other physical properties using relative permittivity and soil relaxation times), 2) Thermal Conductivity/Soil Moisture Probe (TSP), 3) Vane Shear-Strength and Cone Penetration Measurements (VCT), and 4) Relative Humidity Probe (RHP). At the end of Stage 1 development, we will deliver a prototype of the SPARTA instrument that can be used for Phase 2 testing. In Phase 2 of SPARTA development (MatISSE), we will integrate the components into a breadboard for laboratory and field-testing with a surrogate robotic arm under varying environmental conditions. Relevance: The proposed research will adapt several classical terrestrial geotechnical and chemical measurements to spaceflight operations to enable in-situ interrogation of extraterrestrial regoliths. Miniaturization will allow placement on a robotic arm, and subsets of components might also be placed on

		sample gathering apparatus, and lander footpads. The instrument's simplicity, miniature size, as well as minimal sample and power handling requirements, are synergistic with existing spacecraft hardware (including CubeSats). This benefit enables use without taxing strict power, payload, communications and operational constraints of future surface and sub-surface explorer missions, making it ideal for in-situ surveys.
96510	Micro-Sampling System for Mineralogical Instruments	The CheMin X-ray diffraction (XRD) instrument, successfully deployed on Mars Science Laboratory (MSL) for more than 7 years, established the quantitative mineralogy of the Mars soil, characterized the first habitable environment on another planet, revealed in-situ evidence of Martian silicic volcanism, documented the dessication and oxidation of the environment in Gale Crater during Hesperian time, established an upper limit for CO2 in the early Mars atmosphere, and provided ground truth for orbital measurements. CheMin as-designed is restricted to Flagship-class missions due to its size, mass and power, as well as its reliance on a heavy and mechanically complex sample collection system. Deployment of XRD on smaller rovers (MER type) requires instrument miniaturization and a light weight sampling system. We propose a Micro-Sampling System for in-situ analysis of rocks and soils, focusing on weight-saving solutions for smaller landers and rovers. This research will cover all aspects of sample management from powdered sample collection to XRD analysis, exclusive of the transport assumed to be provided by a robotic arm. We will focus this research on XRD analysis, but other analytical techniques could benefit from this sampling system, individually or as part of a suite of instruments analyzing the same sample. The Micro-Sampling System will be divided into two major subsystems: a Powder Collection and Delivery (PCD) system fitted to a rover/lander arm, and an Instrument Sample Manipulator (ISM) internal to the XRD unit. The PCD will be designed for low power and load requirement, precise sampling, and preservation of mineral species. Methods for the collection of powder from rocks will be the subject of an initial trade study leading to a PCD breadboard development. This engineering effort will be conducted by Honeybee Robotics. The ISM will rely on one-time use sample cells

		loaded on a single tuning fork design utilizing the same vibrated cell method used in CheMin. A new cell will be pushed in place prior to each analysis, with new pristine cells stored in a cartridge. Mechanism studies and breadboard development will done by Honeybee Robotics engineering staff under the lead of the PI. A field-deployable XRD instrument will be built by the PI around the ISM breadboard to allow its evaluation in a complete analytical system, and verification of XRD performance. Extensive tests will be conducted by CoI Lafuente with this instrument. Higher fidelity prototypes of the PCD and the ISM will be developed by Honeybee Robotics and tested jointly in their Mars chamber, under critical conditions of vacuum and heavy dust contamination. By the end of this 3-year effort, we will demonstrate a full "rock to data" system and make it available for field campaigns. This PICASSO addresses critical improvements in technology for the deployment of next generation XRD instruments for definitive mineralogical analysis. This work targets Discovery class missions and MER size rovers in particular. The sampling system and associated XRD instrument will enable the determination of quantitative mineralogy from rocks and soils on Mars, the Moon, or other rocky planetary bodies. The combined expertise in Mars rover operation of CoIs Yen (MER and MSL), Bristow (MSL) and Blake (MSL) will be leveraged through this research to provide technologies that answer real operational needs of remote planetary science. This work leverages 20+ years of development of advanced XRD systems for planetary and commercial applications by the PI and his collaborators, a number of SBIR, MIDP, PIDP, ASTID, PICASSO, MatISSE and DALI grants for the development of planetary X-ray instruments and associated sample handling, and the expertise of Honeybee Robotics in planetary sample handling.
96514	Small Lidar for Profiling Water Vapor and Winds from Planetary Landers	The planetary boundary layer (PBL) is the lowest layer of the atmosphere that interacts directly with the surface. For Mars and Titan, processes within the PBL are very important scientifically because they control the transfer of heat, momentum, dust, water, and other constituents between surface and atmospheric reservoirs. For Mars understanding these processes is critical for understanding the modern climate, including

how the regolith exchanges with the atmosphere, how wind shapes the landscape, how dust is lifted and transported, and for being able to improve general circulation models. The PBL is also critical for operations since it is the environment in which landed missions must operate. The PBL is difficult to observe from orbit, and so detailed observations of it have been mostly limited to those from landers. The lack of PBL observations has led to significant gaps of understanding in several key areas. These include diurnal variations of aerosols, water vapor and direct measurements of winds, the combination of which provides information on the horizontal and vertical transport of water, dust, and other trace species and their exchange with the surface. The Mars atmosphere has complex interactions between its dust, water and CO2 cycles. Because these quantities are interrelated it is important to them simultaneously, ideally with the same instrument. Here we propose to develop and demonstrate a small, highly capable atmospheric lidar to address these needs for a future lander on Mars or Titan. The lidar will measure vertically-resolved profiles of water vapor by using a single frequency laser. The laser will be tuned onto and off strong isolated water vapor lines near 1911 nm. The vertical distribution of water vapor will be determined from the on- and off-line backscatter profiles via the differential absorption lidar (DIAL) technique. The same laser is used for measuring aerosol and wind profiles via the Doppler shift in the backscatter. It emits two beams that are offset 30 deg from zenith and perpendicular to one another in azimuth, allowing directional wind profiles to be resolved. Both lidar measurement channels are otherwise identical and use common lens-type receiver telescopes. These lidar measurements address important science needs that are directly traceable to MEPAG science goals relating to climate, surface-atmosphere interactions, and preparing for human exploration. Our lidar will measure vertical profiles of water vapor, and dust and water ice aerosols and winds with km-scale vertical resolution from the surface to > 15 km altitude. These measurements will directly profile the full planetary boundary layer, which is key for understanding how water, dust, CO2 and trace species

		exchange between surface and atmosphere. The lidar will uniquely providing observations of all quantities simultaneously. The lidar on the Phoenix Mars lander mission previously measured aerosol backscatter profiles at 1064 nm and 532 nm as a function of altitude and time. Our team's approach to remotely profiling atmospheric water vapor and winds via lidar at 1911 nm is new. Our team though has directly relevant experience since we previously developed a tunable single-frequency lidar to measure atmospheric column CO2 and backscatter profiles near 1572 nm. Measuring vector wind profiles from a small surface lidar is also new, but our team has previously demonstrated a similar Doppler wind lidar approach at 1064 nm. A key component of the receiver, the highly sensitive avalanche photodiode detector, is already available. Over the project's 3-year duration we will develop the remaining lidar components from TRL 2 to 4, and develop a breadboard of the lidar. The laser part of the breadboard will be used to measure water vapor in a laboratory cell, and the breadboard lidar will be used to demonstrate measurement profiles of water vapor and wind from the Mauna Kea astronomy site.
96521	Ultra-Violet Detector Innovation for Raman Exploration and CharacTerization (UV-DIRECT) of Ocean Worlds	Ultra-Violet Detector Innovation for Raman Exploration and CharacTerization (UV-DIRECT) enables the identification of minerals, volatiles, organic molecules, biopolymers, water, and other hydrous phases in planetary materials with the added bonus of Raman spectroscopic imaging. UV-DIRECT accomplishes this by utilizing time-gated SiC avalanche photodiode (APD) detector technology. Our goal is to develop a compact, energy efficient, ruggedized linear detector array for UV-NUV (266 nm-340 nm) - Raman spectroscopy and spectroscopic imaging. The development of UV-DIRECT will be guided by recent efforts by Army Research Laboratory to design a compact and wavelength-specific SiC Avalanche Photodiode (APD) detector for the identification of chem-bio compounds in the field. SiC APD detectors have advantages over the Si Single Photon Avalanche Diodes (SPADs) that have been developed for time resolved Raman spectroscopy in recent years. SiC substrates are more tolerant to radiation and temperature extremes and do not require cooling, moreover these detectors provide a higher

signal-to-noise than their Si based detector counterparts in the UV region. Yet, the benefits of SiC detectors have not been taken advantage of in planetary science. The successful demonstration of our novel approach on fabricating a single 35 µm square pixel device using e-beam lithography to reduce the sidewall widths from ~ 10 microns for beveled mesa to ~2 microns, will lay the groundwork for developing large format, high fill factor SiC APD arrays in the future. Our team will build on our wealth of experience in spectroscopic science and detector technology to develop a SiC APD specifically targeted for the identification of ocean world-relevant compounds utilizing UV/NUV-Raman spectroscopy. We will develop our UV focal plane with an entry level maturity of TRL-2 to an exit of TRL-3. In this PICASSO we will fabricate a two-pixel array with a single pixel as the fallback depending on the first-year progress. Task phasing has been selected to first extend the UV response of a single SiC APD to the performance levels comparable to single Si APD (SPAD) response. This involves 1) Modifications to the sensor structure to accommodate the 266-340 nm spectral window, and the fabrication process commensurate with the 35 micron pixel size with a 20 micron spacing for a future array; 2) E-beam lithographic techniques to reduce the sidewall thickness from 10 microns to 2 microns permitting the higher fill factors; 3) Characterization of dark current, gain uniformity, impact of dislocation densities, single photon detection efficiency using a single photon counting set-up in the laboratory; 4) Evaluation of the single pixel device with the fast-pulsed 340 nm LED source; 5) Integration with laboratory optical bench breadboard assembly; 6) Testing the breadboard system in time-gated mode using ocean worlds-relevant samples. We have identified a selected development and characterization work effort appropriate for the PICASSO time scale. This proposal is directly relevant to the Planetary Science Division's strategic goals "to develop new technologies that significantly improve measurement capabilities for planetary science missions". We will be leveraging technologies in use by the military to detect chemical and biological agents that have not yet been proven for a planetary science

		context, satisfying the PICASSO requirement of low TRL instruments, "developing new proof-of-concept instruments or instrument components, including sampling technologies, that enable new science by significantly improving measurement capabilities for planetary science missions…". UV-DIRECT addresses the needs of the NASA Astrobiology Strategy, including "…process samples from their native solid and liquid matrices, characterize potential biopolymers, detect ultralow concentrations of microorganisms, and detect chemical processes indicative of potential life".
96530	Deep Atmosphere Microwave Radiometer for Ice-Giant Exploration	The Juno microwave radiometer (MWR) demonstrated new type of instrument that provided a major breakthrough and paradigm shift in our understanding of giant planet atmospheres. MWR was originally designed based on theories of Jupiter's atmospheric structure that assumed homogeneity at depth. An MWR uniquely interrogates atmospheric composition and structure (down to >1000 bars pressure). Results revealed that Jupiter's deep atmosphere is not globally uniform below the meteorological layer (see Figure 1-1). This discovery is likely a fundamental characteristic of giant planets atmospheres. Based on Juno results we identified two key technologies to develop for advancing the next generation MWR to address the expected deep variability in an ice giant's deep atmosphere. The technologies proposed would be equally important to an investigation of Saturn or even a return to Jupiter. As described below, the questions that an MWR can address at ice giants align with the fundamental questions regarding ice giant deep atmospheres and planetary formation reflected in the last National Academy's Decadal Report (V&V, 2011). Ice giants are an essential part of understanding planetary origin and evolution within and outside of our solar system. Ice giants present the most serious gap in understanding planetary atmospheres (p 81, Visions and Voyages). An MWR can provide insights into the dynamics, structure and variability of NH3, H2S and H2O. These constrain heat flux in a giant planet connecting the interior to the atmosphere. Juno demonstrated that its high spatial resolution, signal to noise and a simultaneous set of observations covering a wide range of frequencies (corresponding to different

atmospheric depths) are essential to understanding giant planet deep atmospheres. Measurements of the ice giants at sufficient spatial resolution are not possible from ground based telescopes (i.e. ALMA or VLA). The Juno MWR comprises six independent radiometer channels from 0.6 to 22 GHz. Each radiometer has a separate antenna that produces a single beam. It takes advantage of spacecraft rotation to acquire observations of the atmosphere at range of emission angles along the sub-spacecraft track to probe the depth of processes and composition. Observing the emission angle dependence is a powerful approach to separate temperature and opacity information contained in the microwave spectrum (Janssen et al., 2005). Juno also demonstrated a second powerful observation mode enabled by spinning orthogonal to the trajectory. This mode scans the antenna beams longitudinally mapping the deep atmosphere in three dimensions, but gives up the limb darkening information since each observation is at a single incidence angle. The goal of this proposal is to mature the technology for a next generation MWR instrument with the following innovations: • Combine multiple channels into a single wideband, flexible, spectrometer instrument, and increasing the number of observed frequencies channels • Electronically form multiple antenna beams in two principal planes to replicate the along-track and cross-track scanning modes without the need to spin the spacecraft Achieving these innovations requires development of a broadband array antenna capable of covering multiple MWR channels and a digital processor that separates the broadband single into multiple spectral bands and digitally forms simultaneous beams. This proposal builds upon the immensely successful Juno MWR instrument with two key contributions, (1) The proposed wide-band antenna will be designed to match the performance of the Juno MWR A1 and A2 receivers (600MHz and 1.2GHz) with the added capability of measuring the full spectra from 500 MHz to 1.5 GHz, and (2) the ability to electronically form multiple along-track and across-track beams from a single stationary antenna.

96531	Bubble-based Ocean-worlds Organics Sample Trap (BOOST)	Background: Estimated energetic limits for life in Ocean Worlds such as Enceladus and Europa suggest that many current life detection technologies will require pre-concentration of ice or liquid (brine, ocean) samples on the order of 1000X to facilitate detection. Science Goal: We propose to develop an organic concentrator, BOOST, which could be utilized to process samples from a plume, ice, brine pocket, or liquid, such as from a subsurface ocean. Objectives: (1) Conduct lab experiments to determine optimal system design. (2) Develop a prototype and evaluate performance on a set of Ocean World analogs. (3) Advance technology readiness level (TRL) from TRL 2 to TRL 4 and characterize steps required to advance BOOST, with further funding, to TRL 6. Methodology: Our approach is inspired by observations that bubbles can scrub organic material from liquids, that organics concentrate in a sea-surface microlayer, and that bursting bubbles can generate enrichment of organic materials relative to the bulk aqueous phase. Lab experiments will be used to study the impact of device and sample parameters on bubble size, lifetime, number, and other characteristics and related to enrichment of organics across a 10^10 size range, from amino acids to whole cells. Prior work demonstrates how tuning of parameters affects enrichment, and factors of 10^2 to 10^4 have previously been achieved. Temperature gradients can be used to move bubbles even in the absence of buoyancy (e.g., in weightlessness), and can also be used to promote enrichment through bubble thinning and via convective flow. These lab experiments will be used to optimize the design of BOOST devices, with the boundary conditions represented by a milli-fluidic, single bubble, device up to a one-liter sample capacity device. BOOST would be anti-fouling as it achieves concentration without a physical filter. It is amenable to batch or continuous flow applications. We will utilize both synthetic analogs, representing Ocean World end-members for Europa and Enceladus, as well as evaluating a range of relevant samples, such as NaCl, MgSO4, and MgCl2 brines from environmental terrestrial analogs being studied under related work by Carr. The ability to concentrate organics (amino acids, protein, nucleic acids, whole cells) will be compared to

		other methods being utilized to study these samples, and the expected limit of detection (LOD) improvements demonstrated in full-scale life detection tests. Relevance: Our work is specifically relevant to the solicitation in that it would help provide a critical pathway to enabling life detection for future Ocean Worlds missions (such as at Enceladus, Europa, Titan, or at Mars, a relic Ocean World), as described in the Planetary Science Research Program and the NASA Science Plan. Our work would "substantially improve instrument measurement capabilities" and will include "explicit comparisons to the current state-of-the-art." BOOST will bridge the gap between life detection instrument LODs and the LODs required to detect life as part of Ocean Worlds missions.
96532	RAMS: RAman-Mass Spectrometer for planetary exploration	RAMS will enable comprehensive analysis of the surface chemistry of astrobiologically-relevant planetary bodies by characterizing organic and inorganic inventories as well as their spatial distribution in rocky or icy planetary sample materials via fine spatial resolution (geo)chemical imaging enabled by a combination of laser desorption ionization imaging mass spectrometry and Raman microspectroscopy. The unprecedented level of integrated analytical capabilities promises to shed light on the provenance and distribution of organic as well as inorganic material in planetary surfaces samples and inform on dominant chemical processes leading to their formation and evolution during planetary body evolution. Science Goals and Objectives. To achieve their main objectives, future landed missions to solar system destinations of high astrobiological/astrochemical interest will require science instrumentation capable of accomplishing comprehensive and highly sensitive in situ analyses of surface samples in order to (i) assess habitability, as in the case of Ocean Worlds, or (ii) infer the role of small airless bodies in seeding organic material on early Earth and other solar system bodies, as in the case of comets and asteroids. RAMS enables such a detailed in situ characterization of the planetary surface samples through acquisition of spatially resolved maps of (i) overall organic content, including macromolecular carbon reservoirs, (ii) astrobiologically-relevant molecules, such as nucleobases, amino acids, amines

and carboxylic acids, as well as (iii) mineral phases in the delivered samples. The combination of trace level sensitivity and specificity to organic species and ability to reveal organic-inorganic material associations provides an important dataset to understand the provenance of the organic material and help inform on the evolution of the sampled planetary surface. Methodology. RAMS is a highly capable analytical instrument that offers the complementary strengths of laser desorption/ionization mass spectrometry (LDMS) and Raman spectroscopy (RS) in a streamlined, hybrid instrument package expected to offer size, weight and power (SWaP) savings over two separate instruments and thus conform to the resource constraints of future Discovery- and New Frontiers-class missions. Building on our team's interdisciplinary experience in miniaturized instrument technology development, we will integrate a fiber-coupled dual-wavelength Raman spectrograph with a laser desorption/ionization mass spectrometer utilizing a raster-scanning capable, narrow spectral bandwidth, two-wavelength solid state laser source compatible with, both, LDMS and RS, to enable acquisition of co-localized information on mineral (mainly via RS) and organic (mainly via LDMS) fractions in planetary surface samples. Relevance. RAMS is a hybrid LDMS/RS instrument that will provide comprehensive sample analysis capabilities transcending those of either technique alone by providing organic molecular and mineralogical composition maps of the sample on a sub-100 micron spatial scale, thus directly responding to the PICASSO program objective to "…develop new proof-of-concept instruments that enable new science by significantly improving instrument measurement capabilities for planetary science missions". The proposed work draws significantly from our team's expertise in space-flight laser, spectrograph, and prototype LDMS developments, as well as our in-depth experience in LDMS and RS analytical techniques. The outcome of the proposed work will be a RAMS breadboard instrument prototype capable of sensitive detection and identification of molecular organics via LDMS and detailed characterization of mineralogical context via RS

		to provide a thorough understanding of the chemistry of the planetary surface samples.
96535	An ultra-compact midwave hyperspectral framing camera	Mapping spectrometers, or hyperspectral imagers, enable remote identification of minerals, biomarkers, and the composition of atmospheres; such tools have been successfully employed in several NASA applications. Traditionally, imaging spectroscopy systems are extremely complex instruments, often with significant Size, Weight, and Power (SWaP) requirements. Under a NASA STTR program, Nanohmics and the University of Maryland demonstrated a VIS/NIR chip-scale hyperspectral framing camera technology based on computational speckle-based spectroscopy techniques—this PICASSO proposal seeks to extend this technology to the midwave infrared (MWIR, about 3-5 microns) where many important molecular vibrational bands and mineral spectral signatures are present. Instruments operating in the MWIR spectral region face several challenges that are mitigated by our chip-scale spectroscopy technique: because the entire spectroscopic element is 1 mm thick and sits less than 1 mm from the image sensor, it will be integrated into the same dewar as the image sensor, adding only a small passive thermal load to the system. This simplification will result in cascading savings in SWaP and cost, allowing it to be integrated even with CubeSats and rovers. The program goal is the development and subsequent demonstration of a MWIR hyperspectral framing camera with a chip-scale spectral element. To achieve this goal, we will: (1) Refine the needed spectral resolving power, spatial resolution, etendue, integration times, and other optics design parameters required to accomplish high priority measurements derived from the Planetary Decadal Survey (PDS), including comet and small body flyby and sample return, in situ Lunar resource prospecting, determining the habitability of Mars and Ocean Worlds, or a Uranus probe. (2) Determine the optimized spectroscopic element design parameters required to achieve the desired spectral and imaging performance for selected candidate missions through simulation and modeling. (3) Design, fabricate, and assemble a functioning chip-scale MWIR spectral

		imaging element using microfabrication facilities. (4) Integrate the chip with an existing sensor and characterize spectral, radiometric, and imaging performance. The MWIR hyperspectral framing camera is currently TRL 2+. PICASSO funds will mature the hyperspectral technology to TRL 4 for infusion into the MatISSE program. Successful maturation through MatISSE funding will strategically position this technology for integration onto payloads on multiple planned planetary missions, including CubeSats, rovers, and larger missions. Our team from academia and industry has extensive NASA ties and will leverage prior NASA STTR investments to enable new science by significantly improving instrument measurement capabilities for planetary science missions including Discovery, New Frontiers, Mars Exploration opportunities. Several elements of NASA's PSD will be addressed by our technology: 1) Understand the processes that determine habitability in the solar system: enables characterization of geothermal activity through multi-frame hyperspectral movies; determines chemical composition of deposits on planets, moons, and small bodies; and help determine water and hydrate abundance and cycles. 2) Identify and investigate past or present habitable environments and determine if there is/has been life elsewhere in the solar system: spectral mapping of organics and biomarkers at either reconnaissance distances or rover distances provides candidate sites for further investigation. 3) Explore the space environment to identify hazards and resources for human presence: spectral signatures of hydrates and ice provide information about where water and other in situ resources can be acquired. 4) Sample return missions from moon, small bodies, and Mars: Spectral imaging of prospective sample collection regions can optimize choices to ensure best collection choices.
96536	Development of a Rugged Seismometer for Venus Surface Deployment	Goals & Objectives Understanding the seismicity and interior structure of Venus have been long-standing objectives of the scientific community. Venus Express observations of recently emplaced basalt on the surface and injected SO2 in the atmosphere—alongside new studies of plume-induced subduction at coronae—indicate that Venus likely hosts magmatic and tectonic

activity. While seismological investigation from orbit or floating atmospheric platforms have been conceptualized for Venus, only a surface station can measure all three dimensions of ground motion as required to achieve high-priority science goals. The objective of this proposal is to develop a miniature seismometer that could be deployed on the surface which has sufficient sensitivity, frequency response, and environmental tolerance to address seismological activity for a timescale of 60 Earth-days or longer. The instrument will be compatible with the harsh surface environment of Venus and will have a low vertical profile which ensures that wind-induced noise is kept low enough to minimize interference with possible seismic signals from the crust and depths below. The goal of the work is to increase the TRL of individual components and the assembled seismometer from its current entry TRL 1 to exit TRL 4. Approach & Methodology The proposed miniature seismometer is based on a liquid sensing body using a molecular electronic transducer (MET) mechanism. It has the advantages of high shock tolerance, arbitrary installation angle, high sensitivity and wide dynamic range, and high ability to withstand any strenuous environmental conditions. The high shock tolerance and arbitrary installation angle of the MET sensor provide advantages over conventional seismometers on sensor deployment and also the possibility of creating a seismic array via a single landing on a planet's surface. In this proposal, we will build upon our success of developing MET based seismometers supported by NASA COLDTECH, and gear them towards Venus applications. The proposed specific tasks include: 1) development of MET senor components for Venus surface applications; 2) development of readout circuit; 3) sensor assembly, performance validation and pier testing. Relevance to PICASSO The proposed work is within the scope of the PICASSO program since our seismometer has significant advantages over the traditional ones and shows promise for application in future Venus missions. The team, composed of scientists and engineers from Arizona State University and Wayne State University, anticipates demonstrating science objectives/instrumental capability relationships and the

		exit TRL 4. Our traceability between high-level goals from the decadal survey and the physical parameters measurable by one or more rugged seismometers demonstrates that our proposed instrument achieves the goal of the PICASSO program from the solicitation to "develop new proof-of concept instruments that enable new science by significantly improving instrument measurement capabilities for planetary science missions" and is responsive also to the additional selection criterion regarding "the extent to which [a rugged seismometer] addressees a priority science goal of the mission or missions for which it would be candidate for flight."
96537	UV/Visible Photon Counting and Imaging Silicon Detectors for Planetary Science Instruments	We propose to develop photon-counting detectors--including detectors for the ultraviolet spectral range. Planetary science instruments being developed for upcoming New Frontiers, Discovery, SIMPLEx, and flagship missions require photon counting detectors for studying the atmosphere and surface of planetary bodies. Recent silicon-based photon counting detectors have the potential to enable more compact, higher capability instruments. Quanta Image Sensors (QIS), recently invented at Dartmouth college and currently under development through NASA-SBIR Phase II and other sources by Gigajot offers a new category of solid-state detectors capable of room temperature photon counting. Unlike other solid-state photon counting detectors such as avalanche photodiode arrays (APDs), single photon avalanche photodiode (SPAD) array, and electron multiplying charge coupled devices (EMCCDs) that rely on impact-ionization (avalanche) gain to produce high signal to noise ratio, QIS achieves photon counting at room temperature by having an ultralow noise readout. This structure achieves photon counting with less than five volts. QIS has zero dead time, low dark count, low power, low operating voltage. Because it is fabricated in the latest 3D CMOS image sensor processing, it is easily extendable to various formats and image processing capabilities for planetary cameras, subsystems, and instruments. We will procure QIS wafers and process ultraviolet photon counting silicon detectors and fully characterize them for photon counting, quantum efficiency, dark current, operating temperature, time-resolved measurements, and read

		noise. We will evaluate their performance in a side by side comparison with other photon counting ultraviolet detectors such as microchannel plates (MCPs) and EMCCDs in our existing testbeds at JPL and University of Arizona. We will evaluate the radiation tolerance of the QIS architecture by testing them before and after exposure to protons, electrons and gamma rays for total ionization dose and displacement damage. We will rank QIS performance and radiation tolerance and will recommend their further development roadmap and potential use for various environment and applications accordingly. This technology development will be enabling for planetary instruments by replacing lower QE, high voltage image tube-based detectors and will allow planetary instrument designers, including the proposing team, to select the most suitable detectors from a cadre of high-performance arrays for the space environment and science requirements.
96540	Detection of Organics by Gas Chromatography/Gas Phase Fluorescence (GC/GPF)	The GC-GPF (Gas Chromatography-Gas Phase Fluorescence) system will take a detection method capable of very high sensitivity (fluorescence) and combine it with a separation system, (GC), that has been used successfully on mission. This will produce a compact, light, and low power detector that provides high sensitivity. The instrument would be designed to detect fatty acids in extracts of planetary samples produced by the Extractor for Chemical Analysis of Lipid Biomarkers in Regolith (ExCALiBR) for in-situ life detection. ExCALiBR integrates traditional lipid analysis techniques into a microfluidic platform that uses minimal reagent volumes and concentrates organics for analysis, thereby increasing signal-to-noise ratios by orders of magnitude. Functional groups of interest, in this case the carboxylic acid groups on fatty acids, are derivatized before separation. Such a derivatization is necessary for GC analysis of many types of compounds, including fatty acids, in order to provide sufficient volatility. Here, in addition to imparting a chemical selectivity, this derivatization attaches a fluorescence chromophore for sensitive detection. After derivatization, compounds are separated by GC and their fluorescence is detected as the gas stream passes through the GPF detector. Fluorescence is generally accepted as one of the most sensitive detection

		techniques available for analytical separation applications at this time. Our project would: 1) Identify a derivatization procedure for fluorescently tagging carboxylic acids compatible with the thermal cycling and long-term stability requirements for planetary surface instruments. 2) Identify fluorescent tags that will allow suitable separation and detection. 3) Develop and demonstrate GC-GPF detection to a functional system based on laboratory-scale components. 4) Test the system with ExCALiBR extracts. We rate the initial TRL as 2. The final TRL as 4. The detection of the molecular biosignatures of life is an important science goal for NASA's mission. This technology would contribute to such detection on missions to Europa, Enceladus and Mars. More generally, the detection of organics would be relevant indicators of early solar system chemistry (comets, asteroids, and KBOs) and prebiotic chemistry (on Titan, Mars, and Europa/Enceladus). The detector will be designed to work with the ExCALiBR system for biomarker detection, but would also be readily adaptable to detection of other organics and/or other extraction systems. This program is, as the solicitation states, "development of spacecraft-based instrument systems that show promise for use in future planetary missions". The detection of organics would be applicable to a variety of missions (the search for life, detection of prebiotic chemistry, and geochemical and solar system processes) and worlds (e.g. Mars, Europa, Titan, Asteroids, and Comets). Its size/eight would make it suitable for any class of missions. The solicitation gives as a criteria "the extent to which the proposed instrument system or subsystem is applicable to multiple Planetary Science missions". It could also contribute to missions in planetary geology, geochemistry, and astrobiology and meets the solicitation's interest in "planetary and astrobiology science". Its low power/cost/weight makes it responsive to the solicitation emphasis on "small, low-mass, and low power consumption instruments".
96541	A feasibility study of Raman optical activity for the detection and discrimination of chiral biological	Amino acids and carbohydrates, as individual compounds, can be formed abiotically and have been identified in a variety of extraterrestrial materials. Therefore, in these cases, it is not merely the presence,

compounds for planetary science instrumentation

but rather the chirality of these molecules that is indicative of biological origin. Biological materials on Earth are composed exclusively of L enantiomer amino acids and D enantiomer carbohydrates. To date, no spacecraft-based Raman spectrometer has the capability to distinguish between enantiomers of these compounds. While there is only one commercial-off-the-shelf (cots) Raman optical activity (ROA) spectrometer available, TRL 3, surprisingly to date however, no research using this technology as an innovative analytical technique for biosignature detection in astrobiology and planetary science has been undertaken. Therefore, for the first time, this work would carry out a feasibility study to establish if ROA would afford the discrimination of the chirality of amino acids and carbohydrates in astrobiologically relevant simulant samples. This feasibility study is not about building a ROA instrument, but rather, undertaking experiments to report and observe basic principles of ROA of chiral biological compounds in astrobiologically relevant simulant samples, entry TRL 1, and demonstrating the feasibility of this proof-of-concept, exit TRL 3. This in turn, would provide invaluable information and baseline data that would feed forward into instrument design and implementation of a miniaturized ROA system. A substance is optically active if it shows a difference with the interaction of left circularly polarized and right circularly polarized light. ROA is based on the phenomenon of inelastic scattering of circularly polarized light by chiral molecules. It is measured as the difference in intensity of the right and left circularly scattered Raman light. Funding is requested to purchase the cots ROA spectrometer to conduct the proposed work. Firstly, the proposal would investigate if ROA can distinguish between the D and L enantiomers of a collection of amino acids and carbohydrates most commonly found in biology and meteorites. Common amino acids that most frequently occur in abiotic and biotic samples include glycine, alanine, glutamic acids, aspartic acid, leucine, serine, and valine, and likewise, common carbohydrates include glucose and fructose. These compounds would be purchased in their D and L enantiomers from Sigma-Aldrich and Alfa Aesar. ROA spectra would be collected

		and chirality between D and L enantiomers would be elucidated. Subsequently, a database of amino acid and carbohydrate chirality relevant for astrobiology would be constructed. Then, the limit of detection would be determined by serial dilution of the D and L enantiomers of the above compounds in water, then likewise for saline solutions relevant for Europa, such as, NaCl, KCl, MgCl, MgSO4, and Na2Mg(SO4)2. To further test the feasibility of this technique, mixtures of Raman active substances, amino acids, and carbohydrates would be analyzed to determine the strength of chiral signatures. To facilitate this, statistical methods such as chemometrics would be employed to discriminate characteristic chirality signals and further determine enantiomeric ratios. The proposed work is highly relevant to the PICASSO goals of supporting planetary and astrobiology science instrument feasibility studies, concept formation, proof-of-concept instruments, and advanced component technology development. With the discovery of water-ice and a subsurface liquid ocean on Europa and Enceladeus, measurement of chirality is becoming a highly desirable capability for search for life centric missions. To this end, NASA is currently investigating a potential Europa lander mission, and instrument and technologies relevant to such a mission are also especially of interest. Goal 1 of this mission, which ranks the highest, is to search for evidence of extant life.
96522	Development and Demonstration of an All Solid-State 4.7 THz spectrometer Enabling Measurements of Thermospheric Winds, Temperature, and O Density	TeraHz Limb Sounder (TLS) is a low-mass, low-power, high spectral resolution heterodyne spectro-polarimeter operating in the TeraHz (THz) frequency regime designed to remotely measure thermospheric wind, temperature and atomic oxygen density profiles from a low-earth orbit platform. It resolves the Doppler line shapes of the atomic oxygen emissions at 2.06 THz (145 micron) and 4.7 THz (63 micron) and uses their polarimetric properties to improve its measurement precisions. Under the support of previous G/IDES program (2/2013-1/2016) and H-TIDS program (3/2016-2/2019), we have designed and fabricated a receiver prototype for the 2 THz channel of TLS and successfully demonstrated its technology feasibility and performance. While the 2 THz channel of TLS is optimized to provide lower thermospheric

measurements, we propose here to develop the 4 THz channel and demonstrate its measurement capability at higher thermospheric altitudes using the same innovative low-size, mass and power receiver design approach. The 4 THz channel of the THz Limb Sounder (TLS) instrument will be developed and performance demonstrated under this proposed Heliophysics Technology and Instrument Development for Science Program (H-TIDeS) investigation. It can, for the first time, measure neutral wind profiles globally during both day and night in an altitude region where most of the ion-neutral energy/momentum coupling takes place and the neutral atmosphere responds to external energy inputs. These measurements provide critical observational constraints to the complex dynamics in the coupled lower atmosphere/thermosphere/ionosphere/magnetosphere system, as highlighted in the 2012 HDS and 2014 Heliophysics Science and Technology Roadmap for 2014-2033. This H-TIDeS instrument unequivocally supports the science objectives of DYNAMIC (Dynamical Atmosphere Ionosphere Coupling), a 2014 Roadmap recommended a Solar Terrestrial Probes (STP) mission, which directly benefits future Heliophysics mission planning and implementation. In addition, TLS is compact, small, light-weight, low power and ideal to support future cost-effective science missions in implementing the Decadal Survey DRIVE (Diversify Realize, Integrate, Venture, Educate) initiative. This proposed H-TIDeS ITD effort is a joint project between The Johns Hopkins University, Applied Physics Laboratory (JHU/APL) and NASA Jet Propulsion Laboratory (JPL). The TLS development leverages on the chip fabrication capability and recent advances in our 2 THz mixer technology made at JPL. Because scientific payloads on future NASA Heliophysics missions, including DYNAMIC, is likely resource-limited and cost-constrained, in this proposal we seek characterization and demonstration of a compact, low mass and low risk THz instrument that fits within Explorer-class mission constraints. Under the proposed 36-month HTIDeS project (3/1/20 to 2/28/23), we will mature and optimize a compact, low-mass, low-power, and low-noise 4.7 THz receiver concept to meet both

		Heliophysics science and programmatic requirements. We will design, build and integrate a single-element TLS receiver system at 4.75 THz with the sensitivity and stability required for wind measurements. This THz receiver system will be operated at 120-150 K ambient temperature, which is achievable with passive radiators in space. This HTIDeS project, focuses on the THz receiver system integration, optimization, and demonstration of two key subsystems developed under our currently funded efforts: (1) high-yield local oscillator chain and (2) low-noise THz mixer. The successful completion of this proposed HTIDeS project will not only reduce implementation risk/cost for future DYNAMIC-like mission, but also shorten instrument development time.
96523	Development of the Alaska Cubesat Auroral Plasma Spectrometer (ACAPS)	SCIENCE GOALS AND OBJECTIVES Observations illustrate that the fundamental processes that drive and modulate the auroral emissions are occurring on a wide range of spatial and temporal scales. Complete understanding of auroral dynamics cannot be achieved without simultaneous multi-point in situ observations of the particle dynamics at the spatial and temporal scales on which they occur. While satellite missions have provided excellent field and particle measurements, knowledge of the critical scale lengths remains ambiguous due to the limitations of single spacecraft observations. However, with the promise of constellations of small spacecraft and fast primary electron precipitation analyzers, such an array of satellites can separate and directly link the observed energized electron spectra to the associated spatial and temporal scales, thus providing critical insight into the processes driving and modulating the auroral emissions. One of the premier instruments for aurora particle observations ever deployed, the Fast Auroral SnapshoT (FAST) ESAs provided 78 ms time resolution (up to 1.6 ms in burst mode with limited energy sampling). Our goal is to develop primary elements of a high time resolution auroral electron spectrometer (ACAPS) for CubeSats. ACAPS will provide high time resolution, non-distorting sensitivity control, and modest energy/angle resolution, for now. Accordingly, we cite four objectives, to be achieved within a 1U CubeSat resource envelope: 1. Design, build and perform beam testing

and vibration testing on a prototype ESA mechanical model that meets specified performance and environmental requirements. 2. Demonstrate function of a non-distorting MCP sensitivity control for position sensitive counting instruments. 3. Design, build and perform beam testing and vibration testing on a prototype MCP detector and front end electronics for a 1D imaging system that meets specified requirements. 4. Integrate the ESA/Detector and perform end-to-end beam test to verify performance. Achieving these objectives increases the ESA and Detector subsystems from TRL-2 to TRL-6 and enables observations necessary to answer our science questions. METHODOLOGY AND INSTRUMENT CONCEPT The goal is to implement ACAPS within resources for a 1U CubeSat instrument, with its entrance aperture viewing 360º x 10º from a stabilized 1U CubeSat unit (or 1U within a larger CubeSat). An important development aspect is a non-distorting count rate control feature in the Micro Channel Plate (MCP) stack that extends dynamic range by up to a factor of 100. This is accomplished by a Retarding Potential Analyzer (RPA) upstream of the last MCP stage. Resource minimization is a primary focus. We apply additive manufacturing (AM) techniques and the use of AM metals and plastics to minimize mass. The UAF GI and engineering departments have extensive machine shops with decades of experience in space flight instrument design and in both additive and subtractive manufacturing. Further, we use high resistance (lower max count rate) and custom shaped MCPs (minimize active area) to minimize HV current/power and mass/volume. This is enabled by our MCP/RPA sensitivity control approach. IMPORTANCE AND RELEVANCE TO NASA This proposal addresses Key Science Question 2 from the most recent Heliophysics Decadal Survey: "Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs" and follows the recommendation in the "Diversify" element of that document's DRIVE initiative, in "targeting the development of very-small-satellite flight opportunities as a key growth area for both NASA and NSF". This research also addresses Research Focus Area H3 from the most recent Heliophysics Roadmap, to "understand

		the coupling of the Earth's magnetosphere-ionosphere-atmosphere system, and its response to external and internal forcing".
96544	Medium Energy Electron Telescope	We propose to develop a miniaturized electron telescope, the Medium Energy Electron Tele-scope (MEET), to fit into a 1U (10x10x10 cm3) of a CubeSat to measure 30-400 keV electrons in the inner radiation belt (L<3) in a highly inclined low Earth orbit (LEO). Such an orbit has the unique advantage of separating electron measurements from trapped energetic protons based on location since trapped energetic protons are relatively stable and are seen by LEO spacecraft only in the South Atlantic Anomaly (SAA). In contrast, the Van Allen Probes, in low inclination geo-transfer orbits, have shown again that instruments in the inner radiation belt are subject to penetrat-ing energetic protons (10s of MeV to GeV). The Relativistic Electron Proton Telescope (REPT) and the Magnetic Electron and Ion Spectrometer (MagEIS) on the Van Allen Probes are heavily shielded but still experience proton contamination and despite sophisticated procedures to remove this background uncertainties remain. The inner belt electrons have recently been shown to be more interesting than previously be-lieved. For instance, measurements from the Relativistic Electron Proton Telescope integrated little experiment (REPTile, a simplified and miniaturized version of REPT) on board the Colorado Stu-dent Space Weather Experiment (CSSWE), a 3U CubeSat in a highly inclined (65o) LEO revealed that galactic cosmic-ray albedo neutron decay (CRAND) is a significant source of energetic elec-trons in the inner belt. (In CRAND, cosmic rays interact with the upper atmosphere to produce al-bedo neutrons which β-decay to produce energetic electrons.) This discovery was made possible by a highly inclined LEO where all three populations of electrons could be measured. REPTile was able to measure stably-trapped, quasi-trapped (electrons that are lost before completing a complete drift around the Earth), and precipitating electrons thanks to the asymmetry of the Earth's magnetic field. However, REPTile had only three energy channels: 0.50 – 1.63, 1.63-3.8 and >3.8 MeV. Even more interesting is the dynamic behavior of lower energy electrons (<300 keV) in the in-ner belt. They

		respond to storms and substorms implying the penetration of convection electric fields deep into the inner magnetosphere that is not well understood. Electron measurements by DEMETER, another satellite in a highly inclined LEO, revealed an excessive number of <300 keV electrons in the inner belt that cannot be explained by CRAND. A recent study has shown that measurements of <200 keV electrons by DEMETER in the inner belt were severely saturated dur-ing active times showing that accurate measurements of 30-400 keV electrons in the inner belt are still lacking. These advancements beg for a deeper understanding of these energetic electrons in the inner belt: their source, loss, intensity, and cause of their dynamic variation. We propose to develop MEET to address these issues. Methodology. MEET differs from our previous REPTile in that it will measure lower energy (30-400keV) electrons and by incorporating pulse height analysis (PHA) will have much finer energy resolution (>40 energy channels instead of three) and by applying anti-coincidence to veto events from side and back penetrating protons will make cleaner measurements. There are two main tech-nical challenges: (1) avoiding saturation from the higher electron fluxes at lower energies and (2) measuring the smaller energy depositions of these lower electrons in the detector. To overcome (1), we will use a smaller geometric factor (a smaller detector area and a longer collimator to restrict the field of view) and a front foil to block <30 keV electrons. As for (2), we propose to use a thinner and smaller silicon detector to increase the detector's response time and reduce the detector's noise. Detailed GEANT4 simulations will be conducted throughout the design, building, and testing phases to guide our designs and validate the results.
96508	Laboratory Studies of OH(v) + O Multi-quantum Vibrational Relaxation Required for TIMED/SABER Observations	SRI International proposes laboratory measurements investigating key mechanistic pathways and rate constants for the interaction of highly vibrationally excited hydroxyl, OH(v), with ground state oxygen atoms, O(3P) or O. These measurements are essential for the analysis and interpretation of mesospheric OH(v) Meinel band emissions and the determination of the chemical heating rate from measurements obtained by NASA's Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument aboard the

Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite. Our previous studies provided the first laboratory measurements on the interaction of OH(v = 9) with O atoms at room temperature and most recently demonstrated a new mechanism for vibrational relaxation of OH(v) by O that also leads to an enhancement of other nightglow emissions. According to this mechanism, the deactivation of OH(high v) by O involves a fast, spin-allowed, multi-quantum vibration-to-electronic energy transfer process generating excited O(1D). The excited O(1D) atoms produced can then rapidly transfer energy to other species. The new mechanism helped resolve the long-standing problem of unacceptably large discrepancies between model calculations and observations of the nighttime CO_2 4.3-micrometer emission in the mesosphere and was shown to represent a significant, previously unrecognized source of the O_2 Atmospheric band nightglow emission. The proposed laboratory studies will investigate the recently discovered multi-quantum OH(v) + O vibrational relaxation process for levels v = 5-9, for which this energy transfer pathway is energetically allowed. The experiments will determine the relevant vibrational-level-specific rate constants at mesospheric temperatures, so that the results can be directly applicable to the OH emission altitudes and the SABER instrument data. We will use laser-based experimental approaches previously developed in our laboratory. The proposed measurements are required for a reliable analysis of TIMED/SABER observational data. More specifically, the results of the proposed measurements are critical for modeling the SABER instrument's channels #7 (4.3 micrometer, CO_2), #8 (2.0 micrometer, OH high v), and #9 (1.6 micrometer, OH low v). Currently, the only relevant laboratory result available is our most recent demonstration of the new mechanism for OH(v = 9) + O at room temperature. There are no laboratory measurements at the low temperatures relevant to the mesosphere and no information at all on the OH(v) vibrational level dependence for the new energy transfer mechanism. The proposed studies represent major advances by addressing upper atmospheric science problems that have remained open

		for decades. The research goals are well aligned with the objectives of NASA Heliophysics and its Laboratory, Nuclear, Atomic, and Plasma Physics (LNAPP) element. Knowledge of the mechanistic pathways involved and accurate rate constants for the deactivation of the high-v states of OH at mesospheric temperatures are necessary to model TIMED/SABER data and determine the heating efficiency of the H + O3 reaction, an important factor in photochemical models of the upper atmosphere. The results of the proposed research are also needed for reliable modeling of the OH emission in planetary atmospheres in general, including extrasolar planets. Finally, the proposed measurements advance our understanding of fundamental physical processes in support of NASA's Strategic Objective for Heliophysics Research to understand the Sun and its interactions with the Earth and the Solar System.
96517	Technology Development of High Speed CMOS Detectors and Multilayer Mirrors for Dynamic Solar Soft X-ray Spectral Imaging	We propose to the H-TiDS ITDS 2019 call to further enhance capabilities for soft X-ray and EUV dynamic imaging. We will develop high speed readout back-illuminated CMOS soft X-ray (sxr) detectors to 1) mitigate saturation and blooming of solar flare images, 2) study high time cadence (0.05 second variations) phenomena, and 3) generate spectral images of active regions (ARs), coronal bright points (CBPs), small flares (A - B GOES class) and aspects of the quiet Sun (QS). The high speed read out detectors alone can provide course low time cadence (minutes) moderate spectral resolution (resolving powers, E/dE of 10 – 40) spectra. To enable narrowband (resolving powers, E/dE of 50 – 100) spectral images, we will also design, deposit, and measure reflectivity of sxr narrowband multi-layer mirrors (MLM) as a proof of concept. This work will setup a future proposal for spaceflight demonstrations on future sounding rocket launches, CubeSats, and large satellite missions. Our proposed work directly addresses the NASA Heliophysics DIvision and NRC decadal survey fundamental science question "What causes the Sun to vary?", and addresses the NASA Heliophysics Science Goal of "Explore the physical processes in the space environment from the Sun to the Earth and throughout the solar system". Question 1 is, do solar flares vary on sub-second timescales and if so what does this tell us about the magnetic field? Sxr filters can be used to

modify the spectral bandpass and intensity range of high speed readout (40 Hz - 1,000 Hz, speed varies as a function of readout region size) CMOS detectors, which can be used to study the brightness evolution of solar flares on sub-second timescales. Furthermore, charge blooming, which commonly occurs with CCDs and has hindered Hinode X-ray Telescope large flare images, can be minimized with CMOS detectors. Each CMOS pixel is uniquely addressable with separate preamplifier and readout capabilities, and architecture to prevent charge from "spilling" to adjacent pixels. This can greatly increase sxr flare image quality. Intensity variations of ARs, CBPs and the QS can also be determined on sub-second timescales depending on the instrumentation that is coupled to the detector. Question 2 is, how are heating processes and plasma transport different for ARs, CBPs, small flares and the QS? Fast readout rates allow the detection of single photon events in the CMOS detector. The number of electron-hole pairs liberated is directly proportional to the energy of the incident photon. Thus, low resolving power spectroscopy can be performed on timescales of minutes for ARs, CBPs, small flares and longer timescales for the QS. These spectrally separated images can be used to investigate the temperature structure, which is vital for constraining heating processes and variations in the elemental abundances of Mg, Si, O and Fe which are enhanced in the corona, to constrain plasma transport. The narrowband multilayer mirrors can be tuned to sxr energies below 2.0 keV for spectral line and/or continuum measurements at high time cadence during solar flares. We will expand the initial testing in Kenter et al. 2014 on new 16 micrometer (um) pitch 1k x 1k CMOS detectors that are already at SAO. The current architecture allows for 10 - 20 us readout time per column. We will characterize the actual readout rates vs. number of columns, readout noise, dark noise, fixed pattern noise, and other noise along the data chain as a function of operating temperature. We will determine and model the spectral resolution and charge splitting as a function of energy using the onsite Chandra High Resolution Camera (HRC) calibration facility with manson and Fe 55 sources from 0.5 - 6.4 keV. We will

		also test linearity, which is vital for the integrating mode (dynamic range). We will use MLM resources from Marshall et al. 2018 for deposition and reflectivity measurements.
96525	ACSEPT: A Compact Solar Energetic Particle Telescope	The process through which particles are energized and transported within the heliosphere remains a major outstanding question in heliophysics. A number of acceleration mechanics have been proposed such as shock acceleration and acceleration in the lower solar atmosphere, and each has characteristic time-scales, energy spectra, as well as implications for mass-dependence acceleration. In order to separate the relative effect of these acceleration and transport mechanisms, energetic particle measurements are needed over a wide range of energy and over a variety of ion species, including heavy ions. ACSEPT: A Compact Solar Energetic Particle Telescope (pronounced "accept"), leverages high heritage energetic particle telescope elements while also providing innovative front-end electronics development to enable particle detection over a large energy range and ion species. The front-end electronics advancement proposed here includes the development of a new multichannel Boston Extended Amplitude Range (BEAR) ASIC chip with an innovative charge-sensitive preamplifier (CSA) that will enable broad extended-range energy measurements. Although the BEAR chip will be developed as part of the ACSEPT instrument, the chip will also demonstrate this promising and novel CSA technology that could be used for a variety of energetic particle detectors in many space science environments. Additionally, the chip will be available for other instruments for the community as well. Although a number of groups and institutes in the community are developing energetic particle detectors, very few are advancing the necessary front-end electronics proposed to be developed here. ACSEPT is a standalone instrument that will measure ~0.5-100 MeV/nuc ions from H to Fe from a 1.5U form factor with low power and mass requirements. ACSEPT offers an expansion in energy range by two orders of magnitude over other particle detectors developed for small satellite and CubeSat platforms. Although the innovative front-end electronics provides the ability to detect a broad

		extended energy range, ACSEPT will occupy a similar volume and have similar power consumption and mass to previous compact energetic particle telescopes. A low resource, large energy range, energetic particle telescope such as ACSEPT will enable multipoint energetic particle measurements within the heliosphere. Such a measurement would be transformative for our scientific understanding but is cost-prohibitive from a large spacecraft platform.
96529	MICRO - A Magnetograph using Interfermetric and Computational Imaging for Remote Observations	One of the top questions for NASA Heliophysic's is: "What causes the Sun to vary?". The solar magnetic field plays a fundamental role in this variation and hence its measurement, made with magnetographs, is essential. Traditional magnetographs are large optical systems that require elaborate designs and exquisite engineering and, as a result, are heavy and expensive -- both of which place limits on their use in space. We propose to develop a novel magnetograph that leverages advances in Photonics Integrated Circuits (PICs) and low-noise lasers that are being developed by the evolving telecommunications industry. These compact and relatively inexpensive instruments can enable greater and more cost-effective coverage of the solar fields to support research in solar physics and to improve space weather forecasts. In our design, a single PIC replaces traditional optical components by exploiting the interferometric imaging techniques developed as part of the Lockheed Martin led SPIDER project. The PIC processes incoming near infrared signals via two, independent waveguide circuits for the two circular polarizations. Narrow band spectroscopy is achieved by heterodyning the signals with a common local oscillator provided by a tunable laser. The resulting signal is then processed using standard techniques from radio astronomy and solar magnetometry. The optics package for our prototype system observes the full disk of the sun, achieving 30 arc second resolution with a square, 2cm wafer. The technology is scalable to sub-arc second resolution using larger wafers, resulting in 100x reductions in volume and mass when compared to traditional designs. The cost of these wafers leads to a comparable reduction in the cost since they are printed on silicon wafers using lithographic methods developed for microelectronics rather than by precise manual

		assembly. Small, solid wafers also do not need expensive structures to maintain precise optical alignments during launch or on orbit, which further reduced size and cost. The penalty for this compactness is an increase in computational and data management requirements. The associated electronics required for our breadboard prototype are challenging but are manageable in the laboratory using open-source hardware and software. The objectives of this proposal are threefold: Produce a set of PICs to capture the infrared solar signal and transform it into the RF domain where it can be processed using standard radio astronomy and helioseismology methods. Assess the performance of the system and explore alternative processing strategies. Develop the next generation PIC design and RF processing concept based on our results in preparation for a future flight opportunity. Our team combines the expertise in optical interferometric imaging, advanced photonic circuit development, solar image processing, and magnetogram creation. By the end of this three-year project, we will have validated our laboratory system, raising the TRL from 3 to 4, and be positioned to develop a flight instrument. Our single wafer magnetographs can easily be deployed throughout the heliosphere to form cost effective small-sat constellations with resolutions comparable to existing space-borne instruments. Planar magnetographs with resolutions meeting or exceeding current ground-based observatories can also be deployed using arrays of these wafers. The technology developed and the lessons learned from our project can ultimately drive new concepts for imaging spectropolarimeters for other applications across NASA domains.
96513	Fast, Multi-spectral, Polarization-Sensitive IR Detectors for Solar Astronomy from 5 to 100 Microns	The emission of the Sun at wavelengths from 3 to 100 um is a relatively unexplored region of the solar spectrum, but one that has raised some intriguing questions. We propose to develop a new class of high-cadence imaging detectors in this wavelength range that has novel polarization and spectral properties that can address these questions and characterize the layer of the solar atmosphere that is sensitive to these wavelengths. We propose to push the state-of-the-art in infrared (IR) imaging to a) extend the spectral range

of focal plane arrays (FPAs) out to 100 um, b) provide multi-spectral imaging at these wavelengths, c) provide polarization sensitive imaging, and d) do so at high cadence. The detectors discussed in this proposal can provide imaging to further explore these questions and in particular at multiple mid/far-IR wavelengths to measure the spectrum of solar irradiance and flare emission at high cadence. Additionally, they provide a crucial capability missing from all previous mid/far-IR observations: the ability to measure polarization. Measurement of polarization is the key to studying magnetic fields and the ability to do so at mid/far-IR wavelengths routinely would help us to understand the evolution of magnetic fields with height in the lower solar atmosphere and the role of chromospheric magnetic fields in solar flares. The capabilities of the detectors we're developing have never before been available for spectral irradiance measurements or for flares of any class. This proposed project will focus on detecting infrared (IR) electromagnetic (EM) radiation at wavelengths between about 3 um and 100 um using novel dipole nanoantennas developed at UND. These unique devices are capable of multi-spectral, high-cadence, polarization-sensitive detection across a wide range of wavelengths and are uncooled and inexpensive to fabricate. Nanowire antennas resonantly absorb EM waves; the radiation-induced antenna currents heat the center of the antenna where the hot junction of the antenna-coupled nanothermocouple (ACNTC) is located. The resulting temperature difference between the hot and cold junctions of the NTC results in a measurable open-circuit voltage. The antenna plus wires determine the resonant frequency and polarization characteristics. UND has already demonstrated that ACNTCs suspended over cavities offer high gain compared with other nanoantenna configurations. The cavity eliminates most of the thermal losses to the Si (leaving only heat conduction through the lead lines and air) as well as reflects the EM waves and causes positive interference at the antenna. The capabilities of ACNTCs have already been demonstrated: high gain by being suspended over an air-filled cavity; capable of high cadence (beyond 160 kHz) due to their nano-size; polarization sensitivity due

		to the nature of half-wave dipole antennas; fabricated in thermopiles of multiple antennas whose output scales with the number of antenna components. In this work, antenna performance will be improved, and Sun-as-a-star imaging will be performed to test at various wavelengths. Here, the full sensor will be one pixel at one wavelength. High cadence will also be possible yielding time-dependent flux at selected wavelengths. Laser measurements will be used to develop imagers in the 60 to 100 um range in preparation for later space missions. Multi-polarization and multi-spectral FPAs will be fabricated and tested. As proof of concept, the proposed FPAs will provide a resolution of up to 16 x 16 pixels for one imaging wavelength or fewer pixels split amongst various wavelengths and/or polarization angles. The goals are to improve the sensor fabrication process; improve the sensitivity across the spectrum; perform Sun-as-a-star measurements on single-pixel sensors; integrate multiple pixels into FPAs; demonstrate multi-spectral and multi-polarization imaging at high-cadence, and validate operation using a high-quality amateur telescope.
96545	Development of a COmpact Rapid Electron (CORE) Instrument	Turbulence is a ubiquitous process in plasma physics. It is responsible for cascading energy injected at fluid scales, down to smaller kinetic scales, where it can be more efficiently transferred to charged particles. Turbulence therefore provides a fundamental mechanism for heating in collisionless plasmas throughout the universe. The underlying physics of this cascade and subsequent particle heating processes are still hotly debated, as measurements of the detailed plasma properties at electron scales have been difficult to obtain. Even the state-of-the-art plasma measurements from NASA's Magnetospheric Multiscale (MMS) mission are not sensitive enough to fully resolve key features in the solar wind electron distribution function. The science objectives discussed here directly address the NASA Heliophysics Science Goal: "Explore the physical processes in the space environment from the Sun to the Earth and throughout the Solar System" as defined in the NASA 2014 Science Plan. We propose to develop a COmpact Rapid Electron (CORE) instrument capable of providing high temporal resolution and high sensitivity measurements of solar

		wind electrons. CORE will unlock unprecedented observations of electron-scale plasma physics, providing faster-than-MMS particle data in a CubeSat form-factor. CORE is a microchannel-plate-based (MCP) Faraday cup, where a single MCP plate is added ahead of a solid anode to achieve orders of magnitude increase in sensitivity over existing sensors. Building upon recent successful lab measurements of a single MCP plate, we propose to develop a form-fit-and-function prototype instrument (TRL 6) capable of being proposed for future heliophysics missions.
96515	Excitation of whistler-mode chorus waves in a laboratory plasma	1. Introduction Naturally-generated whistler-mode chorus emissions are coherent electromagnetic plasma waves found widely in the near-space region of the Earth and other magnetized planets. Recent observations made by NASA's Van Allen Probes and THEMIS missions have demonstrated that chorus waves are able to efficiently accelerate keV electrons up to MeV energies and precipitate electrons from tens of keV to a few MeV into the dense upper atmosphere, leading to phenomena such as diffuse aurora, pulsating aurora and relativistic electron microbursts. The chorus-induced electron precipitation affects the ionospheric conductivity and thus controls the global electric field distribution. As such, understanding the excitation of whistler-mode waves is an important physical problem in its own right, but also has bearing on the various magnetospheric processes that the whistler waves affect downstream. Despite its recognized importance, the exact generation mechanism of chorus waves is still poorly understood. The basic nonlinear wave-excitation theory has been proposed and certain scaling laws have been developed based on the theory. However, experimental testing is difficult to perform in space, due to the lack of precise control and the sparse measurements of the wave excitation process. For this reason, we believe that a laboratory-based study of the whistler wave excitation problem is the most compelling avenue for making progress in this important field. 2. Science goals and objectives The overarching goal of the proposed project is to understand the mechanisms that control the excitation and the basic characteristics of whistler-mode chorus waves using a set of controlled laboratory experiments.

The specific goal of the proposed project is to: (G1) Build a controlled laboratory experiment to generate chorus emissions using anisotropic electron distributions in the Large Plasma Device (LAPD). (G2) Supplement the laboratory experiments with comprehensive theoretical analysis and particle-in-cell (PIC) simulations. (G3) Test the understanding gained from the laboratory experiments against in-situ observations in space. 3. Methodology We will excite chorus waves in the LAPD using hot electrons with a pitch-angle anisotropy in a magnetic mirror geometry. The hot electrons will be generated using microwaves via Electron Cyclotron Resonance Heating (ECRH) in the LAPD. The ~20 m long plasma column in the LAPD allows sufficient interaction length and thus enough phase-trapping time for efficent electron interactions with chorus waves. We have the PIC code OSIRIS to support the design and data analysis of the laboratory experiments. We will use the full set of measurements from the Van Allen Probes, THEMIS, MMS and ERG/Arase missions to test the insights gleaned from our laboratory experiments. 4. Perceived significance The immediate impact of our proposed project is to help us understand the origin and excitation of chorus waves, which is a fundamental physical problem in the Earth's magnetosphere and the magnetospheres of other planets, and a key ingredient in space weather. The proposed project will put the nonlinear theory of chorus excitation on a solid basis by testing its key predictions for the first time in a controlled laboratory experiments. More broadly, our proposed project will improve the understanding and prediction of space weather. It is known that the chorus waves play an important role in the radiation belt physics. The laboratory experiments are able to determine what plasma parameters control the various characteristics (e.g., the lower and upper frequency limits, the frequency sweep rate, the saturation amplitude and the wave normal angle distribution) of chorus waves by performing detailed parameter scans. This will ultimately help us construct a wave model that can be used in the quasi-linear modeling of the radiation belt.