Science Mission Directorate TechPort Records for 2019 STI-DAA Release

Total Records: 151
Records Updated: November 2019

TechPort ID*	Project Title*	Project Description*
10575	Advanced Multiplexed TES Arrays	X-ray measurements are critical for the understanding of cycles of matter and energy in the Universe, for understanding the nature of dark matter and dark energy, and for probing gravity in the extreme limit of matter accretion onto a black hole. We propose a program to mature the current x-ray microcalorimeter technology, while developing transformational technology that will enable megapixel arrays. X-ray calorimeters based on superconducting transition-edge sensors achieve the highest ener X-ray measurements are critical for the understanding of cycles of matter and energy in the Universe, for understanding the nature of dark matter and dark energy, and for probing gravity in the extreme limit of matter accretion onto a black hole. We propose a program to mature the current x-ray microcalorimeter technology, while developing transformational technology that will enable megapixel arrays. X-ray calorimeters based on superconducting transition-edge sensors achieve the highest energy resolution of any non-dispersive detector technology. The performance of single x-ray calorimeter pixels has reached that required for many possible future missions such as IXO, RAM, and Generation-X, but further optimization is still useful. In the last years, we have made progress in developing techniques to control and engineer the properties of the superconducting transition. We propose to continue this single-pixel optimization, and to improve both the practical and theoretical understanding of the correlation between alpha, beta, and noise to identify favorable regions of parameter space for different instruments. A greater challenge is the development of mature TES x-ray calorimeter arrays with a very large number of pixels. Advances in the last several years have been significant. We have developed modestly large (256 pixel) x-ray calorimeter arrays with time-division SQUID multiplexing, and demonstrated Walsh code-division SQUID multiplexing, which has the potential to allow scaling to much larger arrays. Here we propose to extend this work, and also to introduce a new code-division SQUID multiplexing circuit with extremely compact, low-power elements. Using this approach, it is possible for the first time to fit all of the detector biasing and multiplexing elements underneath an x-ray absorber, allowing in-focal-plane multiplexing. This approach eliminates the requirement to bring leads from each pixel out of the focal plane, while reducing the power dissipati

10779	Optimization of CZT Detectors with Sub-mm Pixel Pitches	We propose to develop and optimize 0.5 cm thick Cadmium Zinc Telluride (CZT) detectors with very small pixel pitches, i.e. 350 micron and 600 micron. The proposed innovative R&D program is highly relevant for the EXIST (Energetic X-ray Imaging Survey Telescope) mission, the leading candidate for NASA's black hole finder probe. The new EXIST reference design from the recent Advanced Mission Concept Study uses CZT detectors with a pixel pitch of 600 micron. The proposed work focuses on the optimization of the design of the pixel patterns (pad and gap widths), steering grids, guard rings, and bias rings. For the different designs, the detection efficiencies, energy resolutions, charge sharing properties, and minimum achievable energy thresholds will be evaluated. Dedicated measurements with collimated X-ray beams will be performed to evaluate the accuracy with which the depth of the interaction can be reconstructed based on different methods. Measurements with polarized X-ray beams will be used to put estimates of the X-ray polarization sensitivity of EXIST on a solid footing. Last but not least, the experimental results will be used to fine-tune a 3-D model of the detector response. The proposed R&D is exciting and new in that very thick detectors with very small pixel pitches will be studied for the first time in detail. Effects like charge carrier diffusion and charge carrier repulsion are relatively more important for such detectors than for thinner detectors and/or detectors with larger pixel pitches.
10832	High-contrast Nulling Interferometry Techniques	"We are developing rotating-baseline nulling-interferometry techniques and algorithms on the single-aperture Hale and Keck telescopes at near-infrared wavelengths, aimed at the detection of faint emission close to bright stars. Our experiments are aimed at developing simple and robust nulling interferometer systems, that will be useful in the short term for unique observations of faint exozodiacal emission and exoplanets very close to nearby stars, and in the long term for refining and simplifying potential nulling-interferometer-based space missions. Here we propose significant sensitivity, stability, dispersion-reduction and statistical-analysis upgrades to our nulling interferometer systems so as to take our nulling work from the earlier ""basic physics demonstration"" phase to the ""ultimate limiting performance"" stage. Several planned upgrades to our nulling systems will enable forefront nulling capabilities at very low cost. First, we plan to improve the sensitivity of our Palomar Fiber Nuller by two orders of magnitude by replacing our current very modest detector with a much more sensitive IR camera inherited from the Palomar Testbed Interferometer. Second, we plan to improve our fringe stability through a series of upgrades. We will make use of the P3K extreme adaptive optics capability to come on line at Palomar mid-2011 to enable ~ 70 -100 nm stability between subapertures, and also extremely good fiber-coupling stability, together allowing very deep nulls to be measured. We will also upgrade our own post-adaptive optics fringe tracker and implement a novel fluctuation-tolerant fringe tracker algorithm. Third, we will further develop and test novel data reduction algorithms based on the statistics of the null-depth fluctuations to measure accurate astrophysical nulls to levels much deeper than our

		stabilization level would otherwise allow. Finally, we will also implement a number of dispersion reduction techniques to improve broadband operation an
10833	Fabrication of High Resolution Lightweight X-ray Mirrors Using Mono-crystalline Silicon	"Three factors characterize an X-ray optics fabrication technology: angular resolution, effective area per unit mass, and production cost per unit effective area. In general, these three factors are always in conflict with one another. Every telescope that has flown so far represents an astronomically useful compromise of these factors. Of three operating X-ray telescopes, Chandra has been optimized for angular resolution (0.5 arcsecs); Suzaku for effective area per unit mass; and both were optimized in its own way to minimize production cost. We propose an X-ray mirror fabrication method that, when validated and developed, will enable the making of mirror segments with Chandra's angular resolution but with Suzaku's mass per unit area. This method, utilizing an industrial material and commercial polishing techniques, is fast and inexpensive and will enable both small and large X-ray astronomical missions. The method is based on two recent developments. First, revolutionary optical polishing technologies have been developed since the fabrication of the Chandra mirrors. Second, large blocks of mono-crystalline silicon have become readily and inexpensively available. Taking advantage of the grazing incidence geometry of X-ray optics, the new polishing technologies can create mirror segments of high angular resolution on thick silicon blocks fast and at low cost. Given the extremely low internal stress of the nearly perfectly crystalline silicon, these mirrors can then be lightweighted (or sliced off from the silicon block) and still maintain their angular resolution. Instead of the traditional approach of ""lightweight and then polish,"" this method reverses the two steps to ""polish first and then lightweight."" We propose to empirically validate and develop this method in three years. In the first year (FY12) we experiment with making very thin flat mirrors to demonstrate the principle that underpins this method. In the second year (FY13) we extend the experime
10834	Development of a Low Mass, Low Power Deformable Mirror with Integrated Drive Electronics	Deformable mirrors (DM) are key to achieving high contrast for any mission to image expolanets. Currently Northrup Grumman Xinetics is the only viable source for high-contrast capable deformable mirrors. This proposal will help to develop a deformable mirror with integrated driver electronics, eliminating traditional bulky external driver electronics and the associated cabling. The DM will have reduced mass and volume and will consume less power than traditional DMs. "Deformable mirrors (DM) are key to achieving high contrast for any mission to image expolanets. Currently Northrup Grumman Xinetics is the only viable source for high-contrast capable deformable mirrors. This proposal will help to develop a deformable mirror with integrated driver electronics, eliminating traditional bulky external driver electronics and the associated cabling. The DM will have reduced mass and volume and will consume less power than traditional DMs. In addition to the reduced

		mass and volume, the approach incorporates a number of innovations to improve overall DM performance. The actuator uses single crystal giant-piezos offering up to 10 times the energy density of conventional ceramics, and a force-focused and cantilevered configuration to maximize the transducers energy efficiency in generating mirror motions. In addition, it utilizes a bulk micromachining process for DM fabrication in order to create a single crystal architecture at low cost and with a high optical quality surface figure. When fully developed, the DMs are expected to have large stroke (8-um), low-voltage (~40V), low weight, fast rise time (10 microseconds) and low manufacturing cost. Our price/performance goal is 10,000 actuators with a 10 kHz framing rate for $40k. The technology is scalable from hundreds of actuators to millions of actuators. Microscale delivered a first generation DM to JPL under an SBIR grant in early March 2011. This first generation DM driver was delivered with a simple Microchip-based serial interface from the ASIC to a control computer, and detailed documentation on the ASIC interface protocol. JPL will develop an FPGA high-speed ASIC/computer interface, one capable of operating the DM at its full frame rate. Once the high-speed DM driver is complete, JPL will characterize the delivered 32x32 DM in the lab. We will measure the frame rate of the DM, actuator response speed, maximum stroke, go to positioning accuracy, number of dead ac
10843	Dual-Cylinder Laser Reference Cavities for LISA	"Summary: The Laser Interferometer Space Antenna (LISA) mission is under consideration by NASA and ESA as a joint mission to study gravitational wave signals from a number of types of astrophysical sources at frequencies below 1 Hertz. These include mergers of massive black hole binaries out to redshifts of 10 or more and inspirals of stellar mass black holes into galactic center black holes at redshifts out to about 1. Extremely sensitive tests of the predictions of general relativity will be tested under highly relativistic conditions by the measurements. Two dual-cylinder resonant cavities for laser stabilization which are suitable for hard-mounting in spacecraft have been designed and constructed under previous NASA support. Evaluation and testing of these cavities now is being started under NASA Award NNX09AD11G. The cavities have been designed to have substantially reduced sensitivity to vibrations and to temperature variations at frequencies above 1 millihertz. The relative frequencies for the two cavities in their separate small vacuum chambers will tested under a range of different conditions. In addition, a search will be made for occasional small glitches in the phase of lasers locked to the two cavities, which could cause temporary disturbances in the LISA measurements if they occurred too frequently. It now has become clear that the desired range of measurements on the cavities can't be completed by the end of the present funding period. Thus funding is requested under this proposal for two additional semesters of support for a graduate student in order to complete the desired measurements. The category under which this proposal is being submitted is Supporting Technology."

10846	High Energy Laboratory Astrophysics using an X-Ray Microcalorimeter with an Electron Beam Ion Trap	"Since the summer of 2000 we have successfully deployed a high resolution x-ray microcalorimeter spectrometer, based on the spaceflight XRS instrument, at the Electron Beam Ion Trap (EBIT) facility at the Lawrence Livermore National Laboratory. Over the last decade, this highly successful partnership has made fundamental measurements in laboratory astrophysics including the measurements of the absolute cross sections of all the Fe L shell transitions from Fe XVII to Fe XXIV, line ratios in Fe and Ni L shell transitions, measurements of Fe K shell emission over a wide range of electron energies, and direct measurements of charge exchange emission from highly ionized Fe, O, N, and most recently L shell S, using a variety of donor gases. This work has resulted in the publication of over 30 peer-reviewed articles with many more either submitted or in preparation. The newest addition to the facility, the ECS microcalorimeter spectrometer, developed under this program, has performed flawlessly as a facility-class instrument since 2007. We propose here to continue our highly successful partnership and deploy new technology to resolve lines in the important 1/4 keV band that encompasses the M-shell iron emission and the L shell emission, including charge exchange, of many of the lower-Z elements, such as Si, S, Mg, Ne, Ca, and Ar. We thus propose completing a new spectrometer that will bring substantially improved performance to the laboratory astrophysics program at EBIT and will enable fundamentally new measurements. Thus, in addition to maintaining the current spectrometers, which will begin this work, a significant component of this proposal is the completion of a new spectrometer leveraged off of the substantial progress in high-resolution x-ray detectors developed for the International X-ray Observatory mission. The spectrometer will be composed of a detector system with unparalleled spectral resolution: 2 eV resolution across the 0.05-10 keV band. This will allow
10860	New Detector Development for X-ray Astronomy	"We propose to continue our detector development program in X-ray astronomy. Under our current grant we are developing a new type of active pixel detector. The current funding allows us to carry this design through CDR, but will not cover fabrication of the detectors. Here we propose to build and test these innovative detectors, which could potentially be employed in future missions such as IXO, Xenia, Gen-X, and SMEX/MIDEX-class missions. This proposal supports NASA's goals of technical advancement of technologies suitable for future missions and training of graduate students."
10864	Silicon Micromachined Heterodyne Array Receiver at 1.9 THz	We are proposing a new concept of integrated component development technology at submillimeter wavelengths that will dramatically simplify the fabrication, assembly, and integration of large focal plane arrays and imagers. This technology has the potential to significantly increase the pixel count of detector arrays and reduce the mass, volume, and complexity of array receivers for a broad range of applications in astrophysics and earth sciences. We will develop and demonstrate a highly integrated silicon-micromachined array receiver at 1.9 THz based on advanced dual-polarized, sideband-separating, balanced heterodyne mixers. The receiver front-end will be integrated with a novel micro-lens

		antenna array. We will design full-waveguide-band 90-degree quadrature hybrids, orthomode transducers (OMT), polarization twists, in-phase power splitters, and directional couplers at 1.9 THz; fabricate them using deep reactive ion etching (DRIE) based silicon micromachining, integrate them with existing HEB mixers at 1.9 THz; and test and fully characterize them in our laboratory. The scientific importance of high-resolution spectroscopic observations at submillimeter wavelengths is underscored by the key role of heterodyne spectrometers in the ESA cornerstone Herschel Space Observatory as well as the ground-based ALMA and airborne SOFIA. Star formation and key phases of galaxy evolution occur in region enshrouded by dust that obscures them at infrared and optical wavelengths, while the temperature range of the interstellar medium of ten to a few thousand Kelvin in these regions excites a wealth of submillimeter-wave spectral lines. With high-resolution spectroscopy, resolved line profiles reveal the dynamics of star formation, directly revealing details of turbulence, outflows, and core collapse. Observations of emission from ionized species such as C+ at 1900.53690 GHz (158 um), allow one to directly measure the cooling of the diffuse component of the interstellar medium, measure the amount of "dark gas" in which cannot be traced by CO, and analyze large-scale motions of this material from which giant molecular clouds form. The primary motivation to develop multi-pixel array technology arises from the need for future missions to study a wide range of astrophysical topics ranging from planet formation to the large-scale structure of the universe to the monitoring of the earth's atmosphere, this technology effort will also spawn synergistic systems involving other imaging sensors for reconnaissance usage and will help pioneer the emerging uses of the submillimeter-wave spectrum in the homeland security applications. Waveguide circuits have now become a necessity for receivers at terahertz frequencies for their low loss and guided wave properties. However, at frequencies beyond a few hundred gigahertz, the feature sizes of all but the simplest waveguide circuits are too small and the required tolerances are too demanding to be fabricated using conventional machining. In addition, the time-tested technique of building up complex microwave circuits from flanged waveguide components is not suitable for terahertz frequencies due to the losses they incur and reflections they produce. To deal with these issues, a new approach for integrated component development is needed that is compatible with the particular challenges of working at terahertz frequencies. Deep reactive ion etching (DRIE) based silicon micromachined integrated component development is the most promising technology to enable high-performance integrated circuits at terahertz frequencies. Silicon micromachining can achieve small feature sizes with large depths and excellent tolerances, making it ideally suited for fabricating waveguide components which require sharp vertical walls. Moreover, they will allow vertical integration of modular front-end components to a highly sensitive array which will increase pixel counts of heterodyne receivers by many counts.

10876	Magnetically-coupled microcalorimeter arrays for x-ray astrophysics with sub-eV spectral resolution and large format capability	"We propose to develop a revolutionary x-ray camera for astrophysical imaging spectroscopy. High-resolution x-ray spectroscopy is a powerful tool for studying the evolving universe. Emission line ratios (e.g. within the He-like triplet) provide density and temperature diagnostics. Emission and absorption line energies identify ions and determine their velocities, and the shape of the lines can be used to study turbulence or the relativistic effects of a supermassive black hole. The grating spectrometers on the XMM and Chandra satellites demonstrated the power of high-resolution x-ray spectroscopy for astrophysics, but there remains a need for instrumentation that can provide higher spectral resolution with high throughput in the Fe-K band and that can enable spatial/spectral investigations of extended sources, such as supernova remnants and galaxy clusters. The instrumentation needed is a broad-band imaging spectrometer - basically an x-ray camera that can precisely resolve x-ray energies and fluxes over a large field-of-view. While we do not claim that in 3 years we will have developed such detectors, we advocate developing the technology that has the greatest potential for achieving this. Theoretically, magnetically-coupled microcalorimeters are best equipped to achieve sub-eV energy resolution in very large formats. We propose to build upon the work carried out by our group on metallic magnetic calorimeters (MMC) in the antecedent program. The great promise of MMCs for sub-eV energy resolution has been recognized for years. During our current research program, an accident in detector fabrication produced devices that derived their sensitivity from a different operating principle - the temperature dependence of a superconduc
10886	Emission Line Astronomy - Coronagraphic Tunable Narrow Band Imaging and Integral Field Spectroscopy.	We propose to continue our program of emission line astronomy featuring three areas of emphasis: 1) The distribution and nature of high redshift emission line galaxies, using the Lyman alpha and other rest-frame UV lines; and the study of planetary systems in formation in the first 10 Myrs, with the interplay of circumstellar disks and jets; and spectral differencing of transiting planets. 2) We are extending the capability of our Goddard Fabry-Perot Imager by incorporating a Coronagraphic Integral Field Spectrograph (CIFS), and will continue our observations with the improved instrument. We request support for completing the commissioning of the instrument, and for its maintenance and operation. The CIFS, which has been delivered to the Apache Point Observatory's 3.5-m telescope, consists of a custom microlens array and magnifier section, a grating wheel assembly, and a photon-counting electron-multiplying CCD (EMCCD), within the optical train of the Fabry-Perot. The instrument is switchable between Fabry-Perot and IFS modes. It provides observational support to interpret data from the HST, Spitzer, Chandra, Herschel and soon JWST space observatories with capabilities not available on them, and will be used to develop technology for future NASA flight programs such as WFIRST, and NWO, THEIA, ATLAST and other planet-finding missions. In this period we propose to extend the wavelength coverage of the CIFS, by extending the format of the EMCCD.

10888	Exoplanet Direct Imaging	"We propose to develop high contrast coronagraphic techniques for segmented telescopes, providing an integrated solution for wavefront control and starlight suppression on complex aperture geometries. Developing this technology will enable direct imaging of exoplanets from space with significant cost savings relative to monolithic mirrors. Searching for nearby habitable worlds with direct imaging is one of the top scientific priorities established by the Astro2010 Decadal Survey. Achieving this ambitious goal will require 1010 contrast on a telescope large enough to provide angular resolution and sensitivity to planets around a significant sample of nearby stars. Lightweight segmented mirror technology allows larger diameter optics to fit in any given launch vehicle as compared to monolithic mirrors, making it a compelling option for future space telescopes. But until recently, it was believed that internal coronagraphs were incapable of yielding very high contrast on segmented telescopes. Recent developments now show that there is in fact a clear path to high contrast coronagraphy on segmented apertures. The key advances are (1) the demonstration of precision wavefront shaping with amplitude control using multiple deformable mirrors, and (2) improvements in coronagraph mask design that dramatically reduce transmission of segment-gap-scattered light. We propose a plan that will mature these technologies for coronagraphy with on-axis segmented mirror telescopes to TRL 4 by mid-decade with the following elements: 1. Numerical studies for coronagraph optimization and wavefront shaping to yield high-contrast point spread function dark zones. 2. Precision segment phasing concepts and algorithms that will improve the state of the art by one order of magnitude, and will be applicable to any segmented telescope. 3. A system-level demonstration integrating segment precision phasing, wavefront control and shaping, together with advanced coronagraphy. Success
10895	Advancement and New Optimizations of Microcalorimeter Arrays for High-Resolution Imaging X-ray Spectroscopy	"We propose to continue our successful research program in developing x-ray microcalorimeter arrays for astrophysics. This development will directly benefit not only the International X-ray Observatory (IXO), but also other possible mission concepts. We will investigate various array and pixel optimizations such as would be needed for large arrays for surveys, or arrays of fast pixels optimized for neutron star burst spectroscopy. The main emphasis of our research will be the further development of arrays of superconducting transition-edge sensors (TES) for imaging x-ray spectroscopy. We have developed a TES pixel that achieves better than 2.5-eV resolution at 6 keV, and arrays of such pixels that are sufficiently uniform in characteristics as to permit common biasing without significant compromises in the operation of any pixel. We are also making arrays of position sensitive TES pixels that show promise for use on IXO. We propose to advance both the single-pixel and position-sensitive arrays so that we can produce arrays suitable for subsystem-level read-out demonstrations of the IXO X-ray Microcalorimeter Spectrometer focal plane. Additionally, we propose to re-evaluate out successful pixel design which, while certainly suitable for use in developing the architecture of arrays and addressing detector

		systems issues, is not necessarily the final optimization. The performance of a TES depends on the functional form of the current, temperature, and magnetic-field dependence of the resistive transition, and also on the noise at each point on this transition surface. The parameters that describe this transition surface occupy a large phase space, and we have only probed a small portion of it. We propose to fabricate a series of test devices to explore other parts of the phase space and to learn how to engineer the superconducting transition. Recently, our understanding of the physical effects governing the observed resistive transitions has improved, th
10898	Advanced Multiplexed Transition-Edge Sensor Microcalorimeter Arrays	"X-ray measurements are critical for the understanding of cycles of matter and energy in the Universe, for understanding the nature of dark matter and dark energy, and for probing gravity in the extreme limit of matter accretion onto a black hole. We propose a program to mature the current x-ray microcalorimeter technology, while developing transformational technology that will enable megapixel arrays. X-ray calorimeters based on superconducting transition-edge sensors achieve the highest energy resolution of any non-dispersive detector technology. The performance of single x-ray calorimeter pixels has reached that required for many possible future missions such as IXO, RAM, and Generation-X, but further optimization is still useful. In the last years, we have made progress in developing techniques to control and engineer the properties of the superconducting transition. We propose to continue this single-pixel optimization, and to improve both the practical and theoretical understanding of the correlation between alpha, beta, and noise to identify favorable regions of parameter space for different instruments. A greater challenge is the development of mature TES x-ray calorimeter arrays with a very large number of pixels. Advances in the last several years have been significant. We have developed modestly large (256 pixel) x-ray calorimeter arrays with time-division SQUID multiplexing, and demonstrated Walsh code-division SQUID multiplexing, which has the potential to allow scaling to much larger arrays. Here we propose to extend this work, and also to introduce a new code-division SQUID multiplexing circuit with extremely compact, low-power elements. Using this approach, it is possible for the first time to fit all of the detector biasing and multiplexing elements underneath an x-ray absorber, allowing in-focal-plane multiplexing. This approach eliminates the requirement to bring leads from each pixel out of the focal plane, while reducing the power dissipat
10911	Laser frequency stabilization and stray light issues for LISA and other future multi-spacecraft missions	"The Laser Interferometer Space Antenna (LISA) is a joint NASA/ESA project which will use laser interferometry between drag-free proof masses to measure gravitational waves from many galactic and cosmological sources. The same interferometer technology is also the key to future multi-spacecraft missions such as multi-aperture telescope missions. These missions could include several spacecraft all separated by potentially 10s of km, flying in a fixed formation with sub-wavelength variations in their distances. These multi-aperture or distributed aperture telescopes will revolutionize the angular resolution in the

		infrared, optical, and even X-ray band. This proposal addresses two components which are both critical to these missions. The first component introduces a new technique to stabilize the laser frequency to an optical reference cavity. Laser frequency noise will be the limiting factor for most of the distributed aperture telescope missions; in contrast, LISA can trade frequency noise against ranging precision. This new technique is based on heterodyne interferometry which is also used to measure changes in the distances between the spacecraft. Because of this similarity, this technology can easily be integrated into the payload. It requires the same photo detectors and digital signal processing systems that are used for the interferometry. It utilizes to a large degree existing components, reducing R&D time and cost for all interferometric space missions. We have already started initial proof of principle experiments and have reached already a performance remarkably close to the performance of the standard and long time-favored modulation/demodulation technique. Now we propose to study this technique in more detail, study the limiting noise sources experimentally and theoretically, and push it to the limitations of the reference cavity itself. The expected final fractional frequency noise should be better than 0.01ppt for measurement times of a 1000s. This
10920	Development of HEROICs: High-Sensitivity, High-Dynamic Range Detector Systems for Ultraviolet Astronomy	"We propose a four-year program for the fabrication and characterization of high dynamic range, low background photon counting detectors that will support the next generation of UV/optical astronomy missions. These devices will serve as technology pathfinders for large format detectors ideal for space-flight applications. Advanced UV/optical detector systems are essential for addressing NASA's strategic science goals highlighted in the recent Decadal Survey, including a census of the atmospheric properties of extrasolar planets and constraining the physics of reionization in the distant universe. This program will address these goals through the development and testing of imaging High Event rate ReadOut Integrated Circuits (HEROICs), where independent pixel logic allows sustained count rates of order 1 kHz per pixel when coupled with a microchannel plate detector. In addition to directly addressing NASA's strategic science goals, this technology will extend the lifetime of UV detectors by operating at a lower gain and enabling a boot-strapping of primary standard stars to fainter magnitudes, both of which address calibration challenges for future high-sensitivity UV instruments. The proposed program will raise the technology readiness level of these devices from TRL 2 to TRL 4, while developing an architecture that will be compatible with flight applications in NASA's suborbital program. This technology would then be well-placed for use as a primary science detector on future UV/optical Explorer-class missions and ultimately large strategic missions such as ATLAST."

10923	Superconducting Resonator Spectrometer for Millimeter- and Submillimeter-Wave Astrophysics	N.A "We propose to develop a novel ultra-compact spectrograph-on-a-chip for the submillimeter and millimeter waveband. SuperSpec uses planar lithographed superconducting transmission-line filters to sort incident radiation by frequency to an array of direct detectors such as MKIDs. The system is naturally wideband and can be very low loss, enabling background-limited spectroscopy on the ground and in space, as is currently done with a diffraction grating spectrographs. But while moderate-resolution grating systems for the mm and submm bands have sizes measured in tens of centimeters, SuperSpec can have a size measured in millimeters. If successful, SuperSpec will pave the way for a new kind of astronomical instrument for the submm/mm: a 2-D array of hundreds to thousands of individual spectrometers, each simultaneously measuring a separate spectrum. With the possible exception of polarization, such an instrument extracts all available information from the light at a telescope focal plane. SuperSpec thus offers the potential to revolutionize astrophysics in the far-IR through millimeter, an important spectral regime for which the the Astro2010 Decadal Survey made two specific recommendations for this decade: 1) Participate in the Japanese-led SPICA space telescope with a spectrometer instrument such as BLISS, and 2) Construct CCAT and its associated instrumentation. Depending on SPICA's schedule, SuperSpec technology could be injected and would enhance and extend the long-wavelength capability of BLISS or a similar instrument. Whether or not SPICA moves ahead quickly, our demonstration will position SuperSpec to be used in on CCAT and suborbital platforms this decade, paving the way for optimal science return with future NASA-led cryogenic far-IR space missions on the drawing board for the next decade: CALISTO/SAFIR and SPIRIT. SuperSpec is based on propagation on a superconducting transmission line (TL). As radiation propagates along the line, it encounters a seri
10924	Next Generation Microshutter Arrays	We propose to develop the next generation MicroShutter Array (MSA) as a multi-object field selector for missions anticipated in the next two decades. For many applications, this field selector improves instrument efficiency proportionally to the number of shutters opened simultaneously. We have successfully developed and built the JWST microshutter array system, which increases the observing efficiency of the Near Infrared Spectrometer by two orders of magnitude. As a result of this development, there is a significant scientific demand for these devices for space-based and ground based applications. The availability of large format microshutters can significantly increase the scientific reach of spectroscopic survey instrument such as WFIRST and future missions such as ATLAST. The basic design of the JWST MSA cannot be extended to such a large scales due to the design limitations set by the required magnetic actuation. We have recently demonstrated shutter operation using DC plus AC resonant pumping. The breakthrough demonstrates that we are able to eliminate bulky permanent magnets used for JWST MSA actuation, thus opening an avenue to create a very large focal plane field selector that can be built at much lower cost. in this program, we will fabricate electrostatically actuated microshutter

		arrays and demonstrate their performance for use as UV, visible, and infrared field selectors.
10986	Enhancement, Demonstration, and Validation of the Wideband Instrument for Snow Measurements	Advance the utility of a wideband active and passive instrument (8-40 GHz) to support the snow science community. Improve snow measurements through advanced calibration and expanded frequency of active and passive sensors. Demonstrate science utility through airborne retrievals of snow water equivalent (SWE). Advance the technology readiness of broadband current sheet array (CSA) antenna technology for spaceflight applications The Enhancement, Demonstration and Validation of the Wideband Instrument for Snow Measuremetns progect has three key technical objectives. The first is to design, build, and test 8-40 GHz wideband fixed beam feed for an offset reflector. The second objective is to design, build and test multi-function instrument to support SAR and radiometry. The third technical objective is to improve Snow Water Equivalent (SWE) measurement from space by developing new algorithms exploiting wideband antenna/instrument technology.
13641	The Microwave Radiometer Technology Acceleration Cubesat	The science payload on MiRaTA consists of a tri-band microwave radiometer and GPS radio occultation (GPSRO) experiment. The microwave radiometer takes measurements of all-weather temperature (V-band, 52-58 GHz), water vapor (G-band, 175-191 GHz), and cloud ice (G-band, 207 GHz) to provide key observations used to improve weather forecasting. The GPSRO experiment, called the Compact TEC (Total Electron Content) and Atmospheric GPS Sensor (CTAGS) measures profiles of temperature and pressure in the upper neutral atmosphere and electron density in the ionosphere. The MiRaTA mission will validate new technologies in both passive microwave radiometry and GPS radio occultation: (1) new ultra-compact and low-power technology for multi-channel and multi-band passive microwave radiometers, (2) new GPS receiver and patch antenna array technology for both neutral atmosphere and ionospheric GPS radio occultation retrieval on a nanosatellite, and (3) a new approach to spaceborne microwave radiometer calibration using adjacent GPSRO measurements.
13643	A Cubesat Flight Demonstration of a Photon Counting Infrared Detector	Demonstrate that an IR detector with photon sensitivities at 1, 1.5, and 2 microns with linear mode photon counting (LMPC) response can be achieved in a Earth observing orbitwith on-orbit radiation exposure. Demonstrate that the detector can be integrated with its cooler and instrumented with radiation and IR test devices within a 3U CubeSat. Understand the detector dark current and radiation dosage throughout the mission. Determine suitability of detector for future Earth science measurements The objective of this project is to demonstrate in space, a new detector with high quantum efficiency and single photon level response at several important remote sensing wavelength detection bands from 0.9 to 4.0 microns. A key element of this demonstration will include the characterization of the detector's response and dark current levels for specific detection periods as a function of exposure time and

		thus integrated space based radiation dosage. The detector being demonstrated will be a 2 by 8 HgCdTe Avalanche Photo Diode (APD) array developed by DRS -RSTA in Richardson, Texas. The detector will be housed in a small 80K tactical cooler. Currently, there is no space-qualified photon level counting detector at >1-micron which is compatible with long-term space operation. Because a qualified single photon multi-pixel detector was not available at 1 micron, the ICESat-2 mission had to convert its 1-micron laser into the green, which significantly increased the instrument's power and complexity. There are significant NASA needs for photon sensitive IR detector arrays for the ASCENDS, LIST and other planned missions. For this experiment, we will integrate the detector assembly into a 3U cubesat built by the Aerospace Corporation. This will accommodate the DRS device, and will have attitude knowledge and control and ground connectivity similar to the Aerospace cubesats currently operating in space. The experiment only requires the cubesat to point to the ground station and support the detector and cooler operation over short time periods (5 minutes) for multiple missions per week. This mission design significantly simplifies the cubesat hardware design, but provides a long term monitoring of the detector characteristics in a low earth orbit environment. The baseline on-orbit test will use an on-board broad-band optical source integrated with a selectable cubesat flight proven filter mechanism which optically illuminates the detector. We will also endeavor to use the sunlit Earth as another test source and compare the results with multispectral images taken by other Earth observing satellites. A more challenging goal, will involve orienting the cubesat so that it acquires and records laser emissions from our ground station as a one-way lidar to aid in establishing more dynamic operating envelopes for the device compatible with several earth science missions, including LIST, ASCENDS, follow-on ICESat missions, photon-counting laser communications and passive spectrometers in the shortwave to midwave infrared band. To understand radiation exposure details, we will integrate for the first time in a cubesat, the Aerospace dosimeter which was licensed to Teledyne and flew on NASA/LRO, and NASA RBSP-ECT/RPS.
13645	HyperAngular Rainbow Polarimeter HARP-CubeSat	It is the goal to have HARP become a secondary payload on the International Space Station (ISS) in 2016. The desired mission life consists of three months for technology demonstration and an extended science data period of another seven months, which will total almost a year on orbit. The existing Dynamic Ionosphere CubeSat Experiment (DICE) ground station and mission operations center that includes use of the NASA Wallops Flight Facility UHF dish will be used for uplink and downlink communications on HARP. Magnetometers, sun sensors, 3-axis torque coils, and reaction wheels (BCT ADCS system) will be used to maintain 3-axis spacecraft stability and pointing to < 0.5°. Level zero data will then be sent to the science operation center at the University of Maryland, Baltimore County (UMBC) where it will be calibrated, processed, and converted to nal products. The HARP CubeSat mission will be a joint eort between UMBC, the PI institution, who will provide

		the instrument and characterization and scientic analysis; the Space Dynamics Laboratory – Utah State University, who will provide the 3U CubeSat spacecraft and mission operations; and the Science and Technology Corporation, who will lead the science algorithm development and science application funded by NOAA. NASA Wallops will support instrument environmental testing, mission operations, and communications. The program is in support of the NASA Earth Science Technology Oce (ESTO).
13647	Advancing Climate Observation: Radiometer Assessment using Vertically Aligned Nanotubes	Build and flight-qualify a radiometer using Vertically Aligned Carbon Nanotubes (VACNTs) as the absorbing material and fixedpoint gallium blackbody calibration transfer standard. Demonstrate the instrument's effectiveness for measuring the Total Outgoing Radiation (TOR) as a precursor to a CubeSat constellation Earth radiation imbalance measurement system. Verify that VACNT's electrostatic properties do not interfere with spacecraft or instrument electronics. Prototype a representative instrument for a constellation measurement systems concept
13951	New Optimizations of Microcalorimeter Arrays for High-Resolution Imaging X-ray Spectroscopy	We propose to continue our successful research program in developing arrays of superconducting transition-edge sensors (TES) for x-ray astrophysics. Our standard 0.3 mm TES pixel achieves better than 2.5-eV resolution, and we now make 32x32 arrays of such pixels. We have also achieved better than 1-eV resolution in smaller pixels, and promising performance in a range of position-sensitive designs. We propose to continue to advance the designs of both the single-pixel and position-sensitive microcalorimeters so that we can produce arrays suitable for several x-ray spectroscopy observatories presently in formulation. We will also investigate various array and pixel optimizations such as would be needed for large arrays for surveys, large-pixel arrays for diffuse soft x-ray measurements, or sub-arrays of fast pixels optimized for neutron-star burst spectroscopy. In addition, we will develop fabrication processes for integrating sub-arrays with very different pixel designs into a monolithic focal-plane array to simplify the design of the focal-plane assembly and make feasible new detector configurations such as the one currently baselined for AXSIO. Through a series of measurements on test devices, we have improved our understanding of the weak-link physics governing the observed resistive transitions in TES detectors. We propose to build on that work and ultimately use the results to improve the immunity of the detector to environmental magnetic fields, as well as its fundamental performance, in each of the targeted optimizations we are developing.
13962	Inner Shell Atomic Data for Iron Peak Elements	The goal of the proposed research is to assemble a comprehensive and accurate set of atomic data which can be used to model the X-ray spectra from the less abundant iron peak elements. The most abundant of these is are expected to be Cr and Mn, followed by Co and Cu, but our calculations will include all elements with atomic number between 6 and 30 for which such calculations have not been carried out. The major component of this work is to calculate the cross sections for photoionization and photoabsorption. This is a process which is

		important in many astrophysical objects, and for which there have as yet been no calculations using state of the art techniques for these elements. Our group has carried out similar calculations for more abundant elements, and has demonstrated the importance of their astrophysical application. We propose to apply these same techniques to the less abundant iron peak elements.
13965	Exploring the Hard X-ray Polarization of Southern Hemisphere X-ray Sources with a Long Duration Balloon Flight of X-Calibur	We propose a long duration balloon (LDB) flight of the X-ray polarimeter X-Calibur on board of the X-ray telescope InFOCÎ?S. We are currently working on the one-day test-flight of the experiment from Fort Sumner (NM) in Fall 2013. The longer balloon flight from McMurdo (Antarctica) will allow us to measure the energy-resolved 25-60 keV X-ray polarization properties of the supergiant X-ray binaries Vela X-1, GX 301-2, and 4UÂ 1700-377, and the prototypical radio galaxy Centaurus A. Furthermore, we will observe several flaring galactic X-ray binaries and measure their polarization properties with high precision. The X-Calibur experiment is unique in that it combines (i) a sensitivity close to the limiting sensitivity given by the physics of Compton scatterings, (ii) a low background (including neutron initiated events) enabling sensitive observations of X-ray sources with fluxes well below that from the Crab Nebula, (iii) small systematic errors owing to the rotation of the detector assembly. The proposed program includes the modification of a state-of-the art HD3-ASIC to achieve a <2 keV energy threshold. Using this ASIC and a low-Z LiH scattering slab, a satellite borne version of an X-Calibur-like polarimeter can achieve an excellent sensitivity over the broad energy range from ~2 keV to ~100 keV. The proposed program will thus provide NASA with a fully developed broadband polarimeter for future satellite missions. The proposed project combines the strengths of the Washington University (X-Calibur), Goddard (InFOCÎ?S) and Brookhaven (HD3-ASIC) teams to enable cutting edge science at a low price for NASA.
13967	Primordial Inflation Polarization Explorer (Phase 2)	This is the Lead Proposal for the proposed investigation "Primordial Inflation Polarization Explorer (Phase 2)" We propose to fly the Primordial Inflation Polarization Explorer (PIPER) to measure the polarization of the cosmic microwave background (CMB) and search for the imprint of gravitational waves produced during an inflationary epoch in the early universe. Such a signal is expected to exist: the simplest inflation models predict tensor-to-scalar ratio 0.01 < r < 0.16 corresponding to detectable amplitudes in the range 30--100 nK. Detection of the inflationary signal would have profound consequences for both cosmology and high-energy physics. Not only would it establish inflation as a physical reality, it would provide a direct, model-independent determination of the relevant energy scale, shedding light on physics at energies twelve orders of magnitude beyond those accessible to direct experimentation in particle accelerators. PIPER is a balloon-borne instrument optimized to detect the inflationary signal on large angular scales. It consists of two co-aligned telescopes cooled to 1.5 K within a large liquid helium bucket dewar. A variable-delay polarization modulator (VPM) on each telescope chops between linear and circular polarization to isolate the polarized signal while rejecting

		the much brighter unpolarized emission. Four 32 x 40 element detector arrays provide background-limited sensitivity. A series of flights from mid-latitude sites will map the full sky at frequencies 200, 270, 350, and 600 GHz to allow separation of CMB signals from the dominant dust foreground while providing new information on the diffuse dust cirrus. PIPER's innovative architecture combines cryogenic optics with kilo-pixel detector arrays to provide unprecedented sensitivity to CMB polarization. The fast modulation between linear and circular polarization takes advantage of the lack of astrophysical circular polarization to eliminate common sources of systematic error. The sensitivity and control of systematic errors in turn enable measurements over most of the sky from mid-latitude launch sites; long-duration Antarctic flights are not required. With sensitivity r < 0.007 at 95% CL, PIPER will either detect the inflationary signal or rule out nearly all large-field inflation models. PIPER is the only sub-orbital mission capable of probing CMB polarization over the full sky, with sensitivity on angular scales greater than 20 deg where the inflationary signal cleanly separates from the lensing foreground. The PIPER team has exceptional experience in all aspects of the proposed work, including detector development, polarization modulation, instrument integration, and cryogenic ballooning. The team includes the Instrument Integration Lead and Instrument Test Lead for the Wilkinson Microwave Anisotropy Probe (WMAP) as well as the lead authors for the systematic error papers for the ground-breaking COBE-DMR, COBE-FIRAS, and WMAP instruments. The team has demonstrated expertise in data analysis including pipeline development, foreground modeling, and cosmological parameter fitting. The 5-year schedule is ideally suited for graduate student training; the team includes several graduate and post-doctoral students. PIPER began development in 2009 and is nearing completion. With first flight scheduled for 2014, the development schedule compares favorably to other suborbital CMB instruments of similar complexity. PIPER will probe the limits of sensitivity from a suborbital platform while developing instrumentation, observing techniques, and foreground models for an eventual space mission.
14057	Advanced Mirror Technology Development Phase 2	Our objective is to mature to TRL-6 the critical technologies needed to produce 4-m or larger flight-qualified UVOIR mirrors by 2018 so that a viable mission can be considered by the 2020 Decadal Review. As identified by Astro2010, a new, larger UVOIR telescope is needed to help answer fundamental scientific questions, such as whether there is life on Earth-like exoplanets; how galaxies assemble their stellar populations; how baryonic matter interacts with the intergalactic medium; and how solar systems form and evolve. Advanced UVOIR Mirror Technology Development (AMTD-1) was a first step. Thus far, we have achieved all our goals and accomplished all our milestones. We did this by assembling an outstanding team (from academia, industry, and government with extensive expertise in UVOIR astrophysics and exoplanet characterization, and in the design/manufacture of monolithic and segmented space telescopes); by deriving engineering specifications

		for advanced normal incidence mirror systems needed to make the required science measurements; and, by defining and prioritizing the most important technical problems to be solved. We successfully demonstrated a new process for making 400-mm deep-core UVOIR mirrors, by making a 43-cm cut-out of a 150 Hz 4-m mirror and polishing it to <6 nm rms. We have also developed new, fast, and powerful integrated design and modeling capabilities. AMTD Phase 2 (AMTD-2) is the next step towards our goal. We have expanded our team to add expertise. Based on our Phase 1 results and Cosmic Origins Program Office guidance, we are focusing our efforts on three clearly defined next steps: • Fabricate a â…"-scale model of 4-m class 400-mm thick deep-core ULEÂ® mirror. The purpose of this mirror is to demonstrate lateral scaling of the deep-core process to a larger mirror. • Qualify two candidate mirrors (the â…"-scale mirror and a 1.2-m Extreme Lightweight Zerodur Mirror owned by Schott) by characterizing their optical performance from 250 K to ambient, and exposing them to representative vibration and acoustic launch environments. • Continue to add capabilities to our integrated design and modeling tools to predict the thermal, vibration, and acoustic behavior of the candidate mirrors; validate our models; generate Pre-Phase-A point designs; and predict on-orbit optical performance (PSF, Jitter, Encircled Energy, Wavefront Error, MTF, etc.). By the end of this three-year effort, the TRL to design and built 4-m or larger primary mirror assemblies will have advanced by at least a half step by accomplishing specific, quantifiable engineering milestones traceable to science requirements. AMTD-1 demonstrated the ability to make a 400-mm deep mirror, at the 0.5-m scale, traceable to a UVOIR 4-m mirror (<6 nm rms surface figure on a 60 kg/m2 mirror). AMTD-2 will demonstrate that the deep-core process scales to ~1.5-m and will qualify two ~1.5-m class mirrors. AMTD-2 is the next step on the path towards advanced UVOIR telescopes that, once formulated, designed, and built, will extend humanity's insight into many of the fundamental questions NASA has been tasked to answer.
15090	Development of a Compact Solar Spectral Irradiance Monitor with High Radiometric Accuracy and Stability	The objectives and benefits of the proposed instrument development are to produce a compact solar spectral irradiance (SSI) monitor covering 200-2400 nm with the required SI-traceable accuracy and on-orbit stability to meet the solar input measurement requirements defined in the Decadal Survey for establishing benchmark climate records. Building upon our experiences and resources from the Total and Spectral Solar Irradiance Sensor (TSIS) program, the proposed instrument will reduce cost and size of a solar spectral irradiance monitor with SI-traceable absolute calibration at the 0.2% uncertainty level (k=1) while also increasing implementation flexibility for future accommodation opportunities. The 3-year effort will design, analyze, and construct a high-fidelity prototype instrument increasing from entry TRL 3 (design and performance analysis) to exit TRL 6 by validating and quantifying complete spectral and radiometric performance while operating under relevant environmental conditions. The instrument utilizes a straightforward optical design in a compact, folded geometry that

		overcomes the extremely high tolerance and costly fabrication requirements and reduces the overall calibration risks associated with previous designs. The prototype instrument will use a coupled, two-channel design that separates the ultraviolet from the visible-near infrared regions and thus allows each channel to be optimized in performance separately, including the dispersive optical material and reflective coating selection. System level performance characterizations and final end-to-end absolute calibration will be accomplished with the LASP Spectral Radiometer Facility (SRF), a comprehensive LASP-NIST jointly developed spectral irradiance calibration facility utilizing the SIRCUS tunable laser system tied to an SI-traceable cryogenic radiometer. The final high fidelity, calibrated photodiode instrument would serve as an ideal sub-orbital sounding rocket or CubeSat payload for cross-calibration opportunities, with the ultimate future intent to incorporate ESR absolute detectors for full on-orbit calibration maintenance capability.
15093	A Compact Adaptable Microwave Limb Sounder for Atmospheric Composition	The Compact Adaptable Microwave Limb Sounder (CALMS) project will develop the engineering model of a compact, light-weight, low-power CAMLS receiver/spectrometer core system at 340 GHz for observations of composition, humidity, temperature and clouds in Earth's upper troposphere and stratosphere. The CAMLS core system will: consist of only four subsystems, as compared to 46 for Microwave Limb Sounder (MLS) on the Aura satellite, achieve an order of magnitude reductions in size, weight, and power consumption over Aura MLS, and verify the core system's functions and performance in airborne test flights.
15239	Miniature Spatial Heterodyne Time-Resolved Raman Spectrometer (SHRS) for Planetary Surface and Subsurface Boreholes Mineralogy	Objectives: The goal of this project is to develop a miniature time-resolved Raman spectrometer, of unprecedentedly small size, with high spectral resolution, a large spectral range and with high light throughput, and that can be fiber-optic coupled for surface or subsurface planetary measurements. The proposed studies are designed to develop and demonstrate a Raman spectrometer that is 5 mm or less in size, weighing only a few hundred grams, with 5 cm-1 spectral resolution and >3500 cm-1 spectral range, and that can be fiber-optic coupled to a measurement region. The spatial heterodyne Raman spectrometer (SHRS) is a radically different design for a Raman spectrometer and it offers tremendous advantages over dispersive Raman systems, including 10 to 100 times larger acceptance angle and subsequently a much larger field of view, 100 to 10,000 times higher light throughput, very high resolution in a small package, and wide spectral range. The design is amendable to miniaturization because the spectral resolution is not a strong function of device size. The proposed system has no moving parts and is compatible with pulsed laser excitation and gated detection, allowing time-resolved measurements for luminescence rejection. The spectrometer design also inherently allows 1D and 2D imaging and would allow surveying a large area around a planetary lander much faster than current instruments which can only be used for close-up measurements. The small size, weight and spectral performance of this system makes it suitable for orbiting spacecraft and planetary landers

		where power and space are at a premium. Expected Significance: We have already demonstrated the use of a small spatial heterodyne spectrometer that has no moving parts for Raman measurements and have shown that the spectral resolution is as good as theoretically predicted. In this proposal the SHRS will be miniaturized to the millimeter scale without sacrificing spectral performance, and a pulsed laser and gated detector will be added for time-resolved measurements to eliminate sample luminescence interference. The unprecedentedly small size and high sensitivity of the new SHRS will allow multiple spectrometers to be flown on a single spacecraft, greatly expanding the amount of information that can be gathered and increasing analysis throughput. Miniature, high performance, Raman spectrometers of the size described would be a paradigm shifting technology, where a Raman spectrometer can be thought of as a new type of in-situ chemical sensor, that provides multiple dimensions of information, including complete Raman spectral coverage without scanning, as well as spatial, temporal and chemical information. NASA Relevance: The small size of the miniature SHRS would immediately broaden the applicability of Raman for planetary spacecraft and lander applications for planetary geology, water and CO2 ice measurements, and in the broader search for inorganic and organic indicators of past or present life such as water and complex organic molecules. This new technology also has the potential to change the way air-quality monitoring is done on the International Space Station (ISS) or other habitable spacecraft for life-support gases like oxygen, nitrogen, and for potentially hazardous gases such as CO2, CO and combustible gases such as hydrogen and methane, as well as dissolved species for water quality monitoring. Key science objectives include bringing the time-resolved SHRS to between TRL 2 and TRL3, and determining limitations in terms of size and weight and limits of detection for key minerals and organic compounds, and identifying design issues related to miniaturization.
15240	Vital Components of a Planetary Pickup Ion Composition Spectrometer	Newly ionized atoms from planetary sources that are picked up by the solar wind and carried into the heliosphere contain information on the plasma and dust compositions of their origin. These pickup ions (PUIs) are collected by plasma mass spectrometers and analyzed for their density, composition, and distribution in both energy and velocity. In addition to measurements of planetary PUIs, in situ measurements of interstellar gas have been made possible by spectrometers capable of differentiating between heavy ions of solar and interstellar origin. While fascinating research has been done on these often singly charged ions, the instruments that have detected many of them were designed for the energy range and charge states of the solar wind and energized particle populations. To fully characterize these ion species, measurements are made using a triple-coincidence technique (a 'start' and a 'stop' detection to enable a successful time-of-flight measurement, and a total energy measurement). Pickup ions are typically only measured in double coincidence (a successful time-of-flight measurement), as their energy is usually below the energy threshold of solid-state energy detectors. This

		substantially degrades the signal to noise of PUI measurements and affects the mass resolution. For example, besides 3He/4He, isotopic abundance ratios typically cannot be measured in situ, and the mass resolution is insufficient to unambiguously separate the isotopes of elements at mass-per-charge > 20 amu/e. An instrument optimized for the complete energy and time-of-flight characterization of pickup ions will unlock a wealth of data on these hitherto unobserved or unresolved PUI species. The goal of this proposed work is to enable the next generation of pickup ion and isotopic mass composition spectrometers. Three objectives will be accomplished in this work: 1) Develop a large-gap Time-of-Flight–Energy sensor with more collecting power than heritage instruments; 2) Develop a 100-kV power supply for ion acceleration, not only to accelerate PUIs to energies above the energy threshold of solid-state detectors, but also to produce accurate enough time-of-flight measurements that isotopic composition can be determined; and 3) Develop improved electronics for integrated timing and position measurements with minimal electronics noise. Together, these technologies will lead to a new generation of space composition instruments, optimized for measurements of planetary pickup ions, yet applicable to pickup ions in the solar wind as well. These objectives will be accomplished by building on the previous work of the proposing team and by improving on heritage hardware designs. The proposed work is significant in that it will lead to the development of the vital components of a pickup ion composition instrument capable of the isotopic resolution of heavy ions in the solar wind, as well as energy measurements of planetary and cometary PUIs. The measurement of heavy ion isotopes is fundamental to understanding the evolution of matter in the solar system and the universe, as many of the isotopic ratios have steadily changed since the nucleosynthesis of the Big Bang. The technologies developed here will enable these measurements due to their broad applicability to different types of sensors and instruments. For time-of-flight spectrometers, these components will enable low-energy PUIs and isotopes to accelerate within the instrument to energies several times higher than current flight instrument capabilities, dramatically increasing the mass resolution. They also will enable isotopic measurements such as D/H using measurement techniques described in the literature.
15241	MARLI: MARs LIdar for global climate measurements from orbit	We propose to design and demonstrate the key capabilities of a multifunctional atmospheric lidar for Mars orbit. This lidar will simultaneously measure CO2 column density, wind profiles, and atmospheric backscatter and depolarization profiles ideally from polar orbit. These measurements address high priority needs for Mars as summarized in the 2011 Planetary Decadal Survey. Although considerable progress has been made, knowledge of the present Mars atmosphere is limited by a lack of observations in several key areas including diurnal variations of aerosols, water vapor and direct measurements of wind velocity. For example, both MGS and MRO observed only afternoon and early morning local time. Both dust and

		water ice aerosols are pervasive in the Mars atmosphere. Dust interacts strongly with IR radiation causing large changes in the thermal structure and acting as a driver of atmospheric motions at all spatial scales. Water ice clouds play an important role in the water cycle altering the global transport of water vapor. The limited local time coverage of observations to date has shown large changes in the amount and vertical distribution of dust and ice aerosols and water vapor. However, existing observations do not allow the full diurnal cycle of water vapor, dust and ice aerosols to be characterized. Winds on Mars also play a fundamental role, yet basic questions still remain about the 3-D wind structure and how it changes with local time, location, and season. Despite low atmospheric density, the winds are often strong enough to raise large amounts of dust from the surface, and at times the planet can become almost completely enshrouded. The winds transport water vapor, dust and ice aerosols, and mix all atmospheric gaseous constituents. Winds regulate the transfer of water vapor and heat throughout the atmosphere and are a primary player in all surface-atmosphere interactions. Wind velocities provide sensitive input and validation for Global Circulation Models (GCMs), and knowledge of winds is critical for the safety and precision of spacecraft entry, descent and landing (EDL). Despite the importance of winds on Mars, presently there are only a few direct observations of them, and indirect inferences are often imprecise and contain many assumptions. Because the Mars atmospheric dust cycles and CO2 cycles are coupled, and because they both partially drive the wind fields, it is important to measure the dust, wind and CO2 quantities simultaneously. It would be ideal to measure them with the same instrument operating continuously, day and night, from a polar orbit, and this proposed lidar approach is uniquely capable of meeting this need. The targeted lidar is MOLA instrument-sized (a ~80 cm cube) that uses pulsed lasers and the direct detection technique. The transmitter uses small, efficient wavelength tunable lasers that operate on and near a single CO2 line in the 1533 nm CO2 band. The receiver uses a 70 cm diameter receiver telescope and new highly sensitive detectors. This approach allows us to leverage in considerable technology from our ongoing work measuring CO2 in the Earth's atmosphere as supported by the ASCENDS definition and the ESTO IIP and ACT programs. This technology leverage greatly reduces risk, development time and cost. Our goal is developing a strong science investigation and instrument for several Mars opportunities. The highest priority is to prepare for a strong science and instrument proposal for the 2020 Mars launch opportunities. Alternatively this instrument and an optical spectrometer optimized for atmospheric measurements are complementary and are ideally suited as a science payload for a Mars-orbiter based Discovery Mission.

15242	Solving Fundamental Technical Challenges toward a Space-qualified Miniature Absolute Scalar Magnetometer	The magnetic field is a fundamental physical quantity, and its accurate measurement to 1 nT or better is required for many future planetary mission. Future missions targeted here are foremost the Jupiter Europa Orbiter / Europa Clipper, which seeks to resolve induction signals a few nano-Tesla in amplitude during a series of flybys executed over an extended period of time to characterize the Europa sub-surface ocean, and the Uranus Orbiter and Probe, which seeks characterize Uranus' unique offset multi-pole magnetic field. In addition, such an instrument would also support other future missions, such as Enceladus Orbiter and Lunar Geophysical Network, both of which require measurement of small-amplitude magnetic perturbations with good long-term stability. Fluxgate magnetometers alone cannot deliver the required performance because their calibration can drift so that long-term stability is not guaranteed. The proven solution is to partner the high-heritage fluxgate instruments with an absolute reference magnetometer, which serves as an in-flight calibration source. The fact is, however, that the mass and power of existing space-flight absolute magnetometers exceed the capabilities of many planetary missions. To solve the resource problem, The Johns Hopkins University Applied Physics Laboratory (JHU/APL) and the National Institute of Standards and Technology (NIST) have developed a novel miniature absolute scalar magnetometer sensor based on a micro-fabricated alkali-metal vapor cell. In the assembled sensor, the micro-fabricated rubidium vapor cell is illuminated with a vertical-cavity surface-emitting laser (VCSEL), and the resonant response of the atoms, which is related to the ambient magnetic field strength, is detected by a photodiode. The present breadboard experiment has a total mass of ~500 g (sensors and electronics), uses 0.5 W of power, and, operating in Mx mode, achieves a sensitivity of 15 pT/√Hz at 1 Hz, or 0.1 nT rms. The objective of the proposed work is to solve the following fundamental technical challenges toward a space-qualified miniature absolute scalar magnetometer so that maturation of this absolute magnetometer may be proposed in response to the Maturation of Instruments for Solar System Exploration (MatISSE) Program: (a) testing key sensor components for the Europa radiation environment and incorporating mitigation steps in the sensor design; (b) building breadboard electronics for the Mz mode to eliminate the sensor heading error; and (c) quantifying absolute accuracy, sensitivity, and long-term stability of magnetometers based on micro-fabricated vapor cells. These development steps are critical toward achieving and demonstrating the targeted absolute accuracy and sensitivity are 0.1 nT and 0.01 nT, respectively, with a long-term stability of 0.1 nT over 1.5 years, commensurate with the performance and durations required to measure Europa's induction response and to map Uranus' magnetic field. The significance of the miniature scalar magnetometer is that it resolves ambiguities in fluxgate offset and gain drift by providing continual absolute knowledge of the total magnetic field to 0.1 nT and thereby retires performance risks of high-heritage, flight-proven fluxgate

		instruments flown in tandem configuration for future planetary missions.
15243	Spectrometer On a Chip	Millimeter and submillimeter spectrometry is a sensitive and specific probe of gas phase (volatiles) composition and origin. First generation in-situ spectrometers have been built, but are too heavy and power hungry for space applications. This effort will apply new advances in millimeter wave CMOS technology to standard microwave techniques for the first time, with the goal of developing a highly compact, highly sensitive in-situ gas detection system. This simple system will generate the probing radiation inside a cavity resonator, where it interacts with the sample. The design increases sensitivity while simultaneously reducing mass and power. The demonstrated technique will be applicable across the THz spectrum and provide a template design for a multitude of planetary mission profiles.
15244	Microfluidic Life Analyzer (MILA)	We will develop the Microfluidic Life Analyzer (MILA) to characterize organic compounds encountered on NASA missions at parts-per-billion levels. The MILA subsystem could be utilized on planetary in situ probes searching for habitable environments, prebiotic chemistry, and life, on alien worlds. MILA is a microchip-based ultrasensitive chemical analyzer that is capable of determining not only the chemical composition of key organics in samples, but also measuring distributions of key molecular properties that inform us of the processes involved in the formation of these materials. MILA focuses on measurements of amino acids (building blocks of terrestrial proteins) and carboxylic acids (associated with cellular membranes). We choose to analyze these targets not only because they are biomarkers for life as we know it on Earth, but an analysis of their molecular properties could also be used to help identify other truly alien forms of life. But regardless of the outcome in the search for life on planetary missions, there is still an overarching need for understanding of the nature of organic molecules present throughout our solar system. There are a myriad of forms organic molecules can take even in the absence of life. Understanding the nature of abiotic and potentially prebiotic chemistry on bodies such as Europa, Titan, or comets could inform us both of the origin of life on Earth as well as the potential for life elsewhere in the solar system. Hence MILA is relevant to all future in situ missions tasked with characterizing organics in the context of both abiotic and biological chemical pathways (e.g. from primitive bodies like comets with abiotic amino acids to potentially habitable environments like Mars, Europa, and Enceladus). In addition to detecting amino acids and carboxylic acids at parts-per-billion levels or lower, MILA would be capable of determining the identity and chirality of at least 20 different amino acids (simultaneously). MILA would also be capable of determining the distribution of carbon chain lengths of carboxylic acids present in these samples between 1 and 30 carbons. By measuring not only the compositions of these organic compounds, but

		their distributions, we gain valuable insight into the nature of the processes that acted during their formation. For example, life on Earth is based upon just one of the two possible chiral forms of amino acids, whereas abiotic meteoritic material contains approximately equal amounts of both forms. And biological carbon chains are generally built up two atoms at a time, in order to create a host of biological "Lego blocks" including phospholipid fatty acids (PLFAs), which have specific carbon chain lengths, and give cellular membranes their structure. MILA extends a legacy of NASA investment in highly successful R&A and SBIR programs. It utilizes the technique of microchip capillary electrophoresis for sample handling and separation, and laser-induced fluorescence (LIF) for ultrasensitive detection. Our team has considerably extended the state-of-the-art in this area both in microchip automation, chemical analysis, and end-to-end complete system function. Our liquid-based approach overcomes the published shortcomings of gas-phase analysis techniques, particularly when applied to samples containing minerals. To prove MILA's effectiveness in planetary missions, we will validate all our newly developed techniques on Mars-relevant, mineral-rich samples. We will also develop means for storing the fluorescent dyes necessary for our technique, and demonstrate that they are capable of surviving the multiple years required for interplanetary travel. This PICASSO effort will bring the TRL level of MILA from 3 to 5, and lead directly to a follow-on MatISSE-funded effort. MatISSE efforts would be directed towards merging MILA with liquid extraction subsystems to enable end-to-end analysis of powdered samples on planetary missions in the coming decade.
15245	Development of Tensor Superconducting Gravity Gradiometer for Planetary Missions	We propose to develop a compact tensor superconducting gravity gradiometer (SGG) for obtaining accurate gravimetric measurements from planetary orbits. A new and innovative design, based on three decades of development with support from NASA, gives a potential sensitivity better than 10^(-3) E Hz^(-1/2) in the measurement band of 1 mHz to 0.1 Hz for a device miniaturized to a baseline just over 10 cm. Significant advances in the technologies needed for space-based cryogenic instruments have been made in the last decade. These technologies include cryocoolers, spacecraft architectures, and cryogenic amplifiers. The use of a cryocooler will alleviate the previously severe constraint on mission lifetime imposed by the use of liquid helium, enabling mission durations in the 5-10 year range. After the tensor SGG is demonstrated, we plan to submit a follow-on proposal to integrate and test the SGG with a flight-like cryocooler. The original SGG, fully developed in the 1990's, had mechanically suspended test masses, which limited the sensitivity at 1 mHz to ~ 10^(-2) E Hz^(-1/2) with a baseline nearly 20 cm. Magnetic levitation gives a number of advantages. The resulting magnetic spring is much more compliant than a mechanical spring, enabling construction of a more compact tensor SGG with higher sensitivity, as required for planetary missions. Magnetic spring gives two degrees of freedom to each test mass. Hence a tensor gradiometer can be constructed with only six test masses, rather than

		twelve, which further simplifies the design and compactifies the instrument. As a result, the 10^(-3) E Hz^(-1/2) sensitivity can be achieved with a device miniaturized by an order of magnitude in volume and mass from the existing device. With our intended 10^(-3) E Hz^(-1/2) sensitivity of the miniaturized gradiometer, it is anticipated that the present resolution of the global gravity field from decades of Doppler tracking data (L ~ 90 for Mars, where L is the maximum degree of gravity coefficients) could be substantially improved by using SGG data (L ~ 220) from a single spacecraft only within 100 days. It would be even better than the expected resolution of the gravity model (L ~ 180) using satellite-to-satellite tracking (SST) from two co-orbiting spacecraft. The more sensitive measurements from the SGG should also enable mapping the regional scale of seasonal gravity variations every month or every season. Further, the multiple-axis measurement of the gradiometer will give a better east-west resolution of gravity over SST. The development of a single-axis SGG with levitated test masses started in 2012 with a small amount of support from NASA's Earth Science Division. Without provision to measure linear and angular accelerations in the other two axes, the common-mode rejection ratio (CMRR) in this device will be limited to 10^5, which does not permit demonstration of the full sensitivity of the new SGG. Under this PICASSO program, we will expand this instrument to three axes and apply residual balance to improve the CMRR by a factor of 10^3 to 10^8, with a goal to advance the TRL from 3 to 4. Light superconducting test masses will be levitated against Earth's gravity and connected to superconducting circuits to detect all six components of the gradient tensor. We will also study the effect of the cryocooler vibration on the SGG by simulating the same vibration environment in the cryostat as from a cryocooler by use of a shaker. In addition to the hardware development, we will examine scientific applications of time-variable high-resolution global gravity field solutions anticipated from the planetary SGG mission. We will also develop a theoretical error model of the new instrument, which will then be used to define spacecraft control requirements.
15246	A Miniature Electron Probe for In Situ Elemental Microanalysis	We propose to develop a miniature electron probe for in situ elemental microanalysis based on an advanced addressable electron source. This instrument is designed to provide rapid in situ determination of the elemental compositions of solar system rocks, soils, and ices (including the light elements C, N, O, and F) and to map the compositions of planetary materials at sub-millimeter-scale resolution. The effort covered by this proposal is intended to develop the addressable cathode instrument concept from TRL 2 to TRL 4, resulting in a working benchtop demonstration system.
15247	Low-Power Long-Wavelength Infrared Sources for Tunable Laser Spectrometers on New Frontiers	Following the success of the Tunable Laser Spectrometer (TLS) aboard the Mars Science Laboratory Curiosity rover, laser-based spectroscopy instruments are likely to play a vital role in future planetary science missions within the Discovery and New Frontiers programs. By selectively targeting absorption lines of key atmospheric gases and their less abundant isotopologues across the infrared spectrum, next-

	and Discovery Missions	generation TLS instruments can provide valuable information on the composition and origins of bodies throughout the solar system. Lasers emitting in the long-wavelength infrared (LWIR) regime between 7 to 10 µm are required to access absorption lines of several compounds of importance for planetary science; however, such lasers are currently unavailable with the low power consumption required for in situ instrument payloads. We propose to develop single-mode lasers based on semiconductor quantum cascade (QC) structures with emission wavelengths in the 7 to 10 µm spectral range. The laser sources will be designed specifically for module power consumption below 1 W at realistic instrument heat-sink temperatures, while targeting molecular absorption lines of interest for high-priority planetary missions. We will leverage the recent experience of the proposal the team members from JPL in successfully developing low-power mid-infrared QC lasers for portable laser spectrometers and the expertise of the team members from Eos Photonics in designing their proprietary high-efficiency QC active region structures. The proposed LWIR lasers will enable the development of tunable laser spectrometers for New Frontiers and Discovery missions, specifically to study the abundance and isotopic composition of sulfur dioxide for the New Frontiers Venus In Situ Explorer and isotopologues of ammonia and phosphine for the New Frontiers Saturn Probe, both identified as high-priority missions in the 2013-2022 Planetary Science Decadal Survey.
15248	DEVELOPMENT OF A LOW POWER, LOW MASS, SMALL AND EASILY DEPLOYABLE PLANETARY BROADBAND MICRO-SEISMOMETER	Imaging the interior structure and monitoring real-time changes in stresses of solar system objects, including comets, asteroids, and planets, is a critical next step in improving fundamental knowledge of their formation, evolution, and current state. These are key components of both the NRC Planetary Science 2013-2022 Decadal Survey and the NASA SMD 2007-2016 Science Plan. The most direct method for imaging and monitoring interior stresses is through analysis of seismological data. Fundamental new advances in how we image planetary bodies will come only with a major technological advance in a broadband seismometer flight instrument. At present, a robust, low power, low mass, small form factor, and relatively low cost broadband seismometer that can be employed across a broad range of mission types with various deployment scenarios does not yet exist. To achieve this first-order goal, a next generation seismic instrument must be developed. We propose to develop the Integrated Seismic Instrument System (ISIS), a complete broadband micro-seismometer instrument with comprehensive lab and field testing and validation that will be the basis of a flight instrument that can be proposed for a range of solar system missions. ISIS development builds upon our success in developing an innovative new miniaturized seismic sensing element under a current NASA Planetary Instrument Definition and Development Program (PIDDP) grant. We propose to integrate this sensing element with all other components to produce a full assembly of a micro-seismometer instrument prototype. While the sensing element itself is at TRL 4, the integrated instrument TRL is currently between 2 and 3. The other components of ISIS are

		straightforward to develop, based on our preliminary results, but require parallel efforts to complete a fully integrated instrument. These components include: ionic liquid electrolyte, sensor cell package, control electronics, and an instrument housing. With the integration and comprehensive testing, ISIS will be brought to TRL 4 and possibly close to 5 by the end of this three-year project. Development of ISIS will provide a fundamentally improved advancement in the technical state of seismic instrumentation available for flight opportunities. Its design steps far beyond any current flight instrumentation due to its unique and highly desirable combination of characteristics, including low mass, low power usage, high shock tolerance, lack of need to level, broadband sensor, and flexibility of deployment. The system will be available for a broad range of missions, enabling seismology to become a fundamental part of many mission sizes and types such as a lunar network mission or deployment on an asteroid or icy satellite to determine interior structure or current seismic activity. Further, the test of ISIS in multiple-node configuration will provide a concept validation for planetary miniaturized small aperture seismic array (SASA), which may benefit future seismic missions. The work will be performed collaboratively between Arizona State University (ASU) and the Johns Hopkins University Applied Physics Laboratory (APL), while engineering investigators at ASU and APL conduct fundamental instrument development, science investigators at ASU will lead the instrument verification and concept validation on SASA, and science investigators at APL will provide mission instrument related guidance for future exploration missions.
15249	Next-Generation Ground Penetrating Radar for Mars, the Moon, and Asteroids	The exploration of planetary bodies has been dominated by remote sensing of the surface. The martian orbital radars have produced incredibly detailed stratigraphic mapping of the polar caps and have demonstrated that ground penetrating radar (GPR) is a powerful instrument to investigate the subsurface. A high-frequency (500 - 3000 MHz) high-bandwidth Stepped Frequency Continuous Wave (SFCW) GPR called WISDOM will fly on ESA's ExoMars rover mission. The 2013 Science Definition Team for the Mars 2020 rover recognized the benefits of GPR and included subsurface sensing including structural and compositional mapping in its baseline mission, but removed this capability from its threshold (i.e. minimum) mission. Therefore, GPR may get left off as it did on MSL. High-resolution subsurface mapping can also greatly benefit other missions such as: a lunar rover missions to investigate ice in the permanently shadowed terrain, and the Asteroid Retrieval Mission could use radar to investigate the internal properties of the small (<10 m) asteroid before it is captured and possibly destroyed. Our objectives is to construct a GPR that can easily be accommodated into any platform operating in proximity to surfaces, particularly rovers and that possesses a large bandwidth to enable resolution of several centimeters at depths of a few meters and total penetration depths of greater than 10 meters. A large-bandwidth system also enables discrimination of certain mineralogies and rock units based on their frequency-dependent electromagnetic (such as liquid water,

		adsorbed water due to clays or salts, gray hematite, magnetite, palagonite, and ilmenite) or scattering properties. Therefore, we proposed to build a SFCW with a bandwidth of 100 - 1000 MHz with a conformal fractal antenna that will minimally interfere with the primary design of the exploration platform. On a rover these form-fitting antennas would attach directly to the rover belly and protruds less than 10 mm. This is significantly different from the larger WISDOM antennas that must be place in the front or back of the rover. WISDOM antennas would be difficult to attach to a MSL-like rover, because the arm attached to the front and the nuclear power source attached to the back. The SFCW also allows us to minimize Electromagnetic Interference (EMI), by eliminating any radar frequencies that interfere with the avionics or instruments. To accomplish these goals, we will first design and fabricate a set of conformal antennas (Task 1), and then design and fabricate the SFCW GPR electronics that can later be easily adapted for spaceflight (Task 2). Next, we will integrate the flight-like VNA and conformal antennas into our prototype GPR (Task 3), and then field test the GPR (Task 4). Throughout the entire project we use radar-range calculations and full-waveform GPR models to show like results for mission to Mars, Moon, and Asteroids (Task 5). Lastly, we will both assess the system's imaging ability to extract geological structure and stratigraphy, and model our field data to show how different attenuation mechanisms can be measured in the field terrestrially (Task 6). The proposed radar will start at TRL 2 and obtain TRL 4+. We will achieve TRL 4 with the antennas and VNA in the laboratory. Once the radar is integrated, indoor testing becomes problematic without the costly construction of very large test-beds. Therefore, we will conduct our tests at well known field sites (USGS GPR test facility in Lakewood, CO, Great Sand Dunes National Park near Alamosa, CO, and at the Volcanic Tablelands near Bishop, CA), thereby obtaining TRL 4+. Our team has extensive experience in terrestrial GPR, building GPRs, understanding the attenuation mechanisms that a planetary GPR will encounter, and planetary analog investigation with GPR.
15877	Cold Atom Gravity Gradiometer for Geodesy	The Cold Atom Gravity Gradiometer for Geodesy Project objectives are: Design, construct and test a sensitive, low-drift gravity gradiometer instrument aimed at improving satellite geodesy measurements. Develop instrument based on light-pulse atom interferometry using ultra cold atomic samples as ideal proof masses. Resolution goal when extrapolated to microgravity environment is 10-5 Eotvos per measurement at 0.03 Hz repetition rate. Sensitivity better than previous development with acceleration sensitivity at 1.5 x 10-9 m/s2/Hz1/2 Design, construct and test a sensitive, low-drift gravity gradiometer instrument aimed at improving satellite geodesy measurements. Develop instrument based on light-pulse atom interferometry using ultracold atomic samples as ideal proof masses. Resolution goal when extrapolated to microgravity environment is 10-5 Eotvos per measurement at 0.03 Hz repetition rate. Sensitivity better than previous development with acceleration sensitivity at 1.5 x 10-9 m/s2/Hz1/2

17499	A 183 GHz Humidity Sounding Radar Transceiver	We will develop a compact and tunable radar transceiver operating in the underutilized short-millimeter-wave frequency regime to enable high-precision global mapping of humidity inside upper tropospheric (UT) clouds for the first time. This work addresses the Focus Area of Climate Variability and Change because clouds are a leading source of uncertainty in estimating the climate sensitivity from global models, and UT humidity affects radiative feedback and cloud formation. Over three years we will build and validate a radar transceiver to enable humidity sounding inside UT clouds using the technique of Differential Absorption Radar (DAR) operating around the 183 GHz water absorption line. By capitalizing on recently-developed III-V semiconductor Schottky diode and amplifier millimeter-wave devices with state-of-the-art efficiency and power handling capabilities, our approach offers the fastest, lowest cost, and lowest risk route to realizing an active instrument capable of range-resolved water vapor absorption measurements in cirrus clouds. The transceiver will integrate all-solid-state source and detector devices inside a compact (~10x6x2 cm) module with 5% tuning bandwidth. Continuous, 1 W transmit power will be reached in two steps. First, commercially available GaN power amplifiers at 90 GHz will drive a JPL-fabricated GaAs diode frequency doubler with 20% conversion efficiency and 0.5 W output power capacity. Then 1 W will be achieved either through a chip-stack waveguide power-combining geometry or, pending commercial availability in 2016, by 183 GHz power amplifiers. For receiving, an InP low-noise amplifier and a 100 dB isolation quasioptical duplexer will achieve a noise temperature of 500 K even while transmitting. The DAR technique will be validated in ground-based measurements using a custom-built millimeter-wave radar test bench. We anticipate demonstrating DAR sensitivities with few-percent precision, thus enabling a new class of future airborne and orbital measurements for cloud and climate science.
17502	SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES)	Ground deformation measurements obtained with interferometric synthetic aperture radar (InSAR) technologies have the potential to improve short-term forecasting of natural hazards and enable more effective management of natural resources. For maximum impact, InSAR measurements must be precise (sub-cm level) and timely. Frequent acquisitions (sub-weekly) are needed to achieve both requirements. More observations per unit time provide enhanced deformation precision through averaging, and ensure that an event is properly captured and characterized. Yet, single-platform sensors cannot simultaneously achieve frequency and wide-area coverage, and traditional InSAR sensors are too expensive (> $300M) to replicate. We propose to provide high-precision ground deformation measurement capabilities in an affordable package ($1-2M) that can be used to form a constellation of InSAR sensors capable of rapid-repeat (daily) coverage of science targets. Such achievements are made possible through developments in nanosatellite technology, specifically the emergence of the CubeSat standard. We have designed a TRL 2 (TRLin) S-band radar subsystem capable of moderate-resolution (25 m), high-fidelity InSAR

		performance (sub-cm deformation precision, SNR > 14 dB). The radar fits within 1U of a 6U CubeSat and satisfies the power and thermal requirements of the CubeSat environment. We call this subsystem the SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES). In this investigation, we will develop, build, and test the RF and digital electronic subassemblies of SRI-CIRES over a two-year period to achieve a functional prototype at TRL 5 (TRLout). We will ensure that the SRI-CIRES prototype can meet the science objectives and performance requirements of an operational mission (e.g., can correct atmospheric artifacts and ionospheric effects to achieve sub-cm level accuracy). We will also use funds from this award to thoroughly study and model supporting subsystems, such as power, shielding, and thermal support, as well as the high-gain deployable antenna that SRI-CIRES requires to operate as a full instrument.
18526	Primordial Inflation Polarization Explorer (Phase 3)	This is the Lead Proposal for the investigation "Primordial Inflation Polarization Explorer (Phase 3)". We propose to complete and fly the Primordial Inflation Polarization Explorer (PIPER) to measure the polarization of the cosmic microwave background (CMB) and search for the imprint of gravitational waves produced during an inflationary epoch in the early universe. Detection of the inflationary signal would have profound consequences for both cosmology and high-energy physics. Not only would it establish inflation as a physical reality, it would provide a direct, model-independent determination of the relevant energy scale, shedding light on physics at energies twelve orders of magnitude beyond those accessible to direct experimentation in particle accelerators. The recent detection of CMB polarization by the BICEP2 instrument brings new urgency to the field. The BICEP2 detection at degree angular scales is consistent with inflation, but the amplitude is a factor of two higher than upper limits set by unpolarized data. A critical test is the rise in power at large angular scales predicted by inflation. Detecting this rise would confirm the signal's inflationary origin, fulfilling a long quest for cosmology while providing new insight into physics at the highest energies. PIPER is the only suborbital instrument capable of measuring CMB polarization on the large angular scales needed to test an inflationary origin for the BICEP2 detection. PIPER is a balloon-borne instrument, optimized to detect the inflationary signal on large angular scales. It consists of two co-aligned telescopes cooled to 1.5 K within a large liquid helium bucket dewar. A variable-delay polarization modulator (VPM) on each telescope chops between linear and circular polarization to isolate the polarized signal while rejecting the much brighter unpolarized emission. Four 32 x 40 element detector arrays provide background-limited sensitivity. A series of flights from mid-latitude sites will map the full sky at frequencies 200, 270, 350, and 600 GHz to allow separation of CMB signals from the dominant dust foreground while providing new information on the diffuse dust cirrus. PIPER's innovative architecture combines cryogenic optics with kilo-pixel detector arrays to provide unprecedented sensitivity to CMB polarization. The fast modulation between linear and circular

		polarization takes advantage of the lack of astrophysical circular polarization to eliminate common sources of systematic error while enabling mapping on the largest angular scales. The sensitivity and control of systematic errors in turn enable measurements over most of the sky from mid-latitude launch sites; long-duration Antarctic flights are not required. With sensitivity $r < 0.007$ at 95% CL, PIPER will either confirm the inflationary signal or rule out nearly all large-field inflation models. The combination of sensitivity, sky coverage, and systematic error control provides unprecedented sensitivity to CMB polarization on angular scales greater than 20 deg, providing a critical test of the BICEP2 results against inflationary models. PIPER began development in 2009 and is nearly complete. End-to-end testing of detector arrays demonstrates the pixel yield, electrical, and thermal properties required for background-limited sensitivity. Cryogenics, gondola, and flight electronics use components flown on the successful ARCADE mission. The PIPER team has exceptional experience in all aspects of the proposed work, including detector development, polarization modulation, instrument integration, and cryogenic ballooning. The cryogenic optics provide instantaneous sensitivity comparable to a space mission while the full sky coverage tests systematic error control in ways not possible with restricted coverage: PIPER will probe the limits of sensitivity from a suborbital platform while developing instrumentation, observing techniques, and foreground models for an eventual space mission.
18697	Computational Technologies: Feasibility Studies of Quantum Enabled Annealing Algorithms for Estimating Terrestrial Carbon Fluxes from OCO-2 and the LIS Model	The successful launch of the Orbiting Carbon Observatory 2 (OCO-2) on July 2, 2014 should lead to new opportunities to calculate long-term trends in CO_2 fluxes and their regional and global uptake. The sun-synchronous coverage of OCO-2 with its high spatial resolution of 1.29x2.25km at nadir provides the first global dataset of vertical CO_2 concentrations with surface spectral resolutions that can provide accurate CO_2 flux profiles. We propose algorithms that could be significantly enabled by quantum annealing computing (QAC) technologies over the course of the next decade to leverage data products from this mission and other NASA Earth observing satellites to infer regional carbon sources and sinks. ' To evaluate whether quantum computing has the potential to be a disruptive technology in supporting Earth Science missions, we will show that the Dwave QAC housed at NASA Ames can be used to derive value and information from the recently launched OCO-2 satellite. In particular, we propose to explore the use of (QAC) for (i) satellite image registration to detect canopy and vegetation cover changes, and (ii) to perform variational data assimilation. We will apply these schemes to estimate regional net ecosystem exchange (NEE), a challenging and extremely important measurement for climate prediction. Both of these QAC algorithms are very general in that they are applicable to a large number of Earth Science problems. '' We will use QAC to assimilate information from Level 2 vertical profiles from OCO-2 into the Goddard Land Information System at 1° resolution for the following two regions: a high latitude

		region encompassing Barrows Island and a low latitude region encompassing the Amazon. The separate QAC algorithms will be explored to accommodate the two tasks. Image registration will comprise of two QAC algorithms: (i) a binary image thresholding classifier to detect edge-like features will be directly encoded into the Dwave QAC, and (ii) the Dwave Qsage hybrid optimization algorithm will be used to geo-register a time series of OCO-2 images and MODIS images to detect NDVI changes over the two regions. Additionally, A 3D-variational data assimilation algorithm will be directly encoded as a QUBO into the Dwave Chimera graph to perform data assimilation. ' These three QAC algorithms will be tested on a distributed hybrid system consisting of the IBM iDataPlex cluster at UMBC with remote access to the NASA 512 qubit Dwave computer at Ames. After initial development, subsequent tests to assess the scalability of algorithmic solutions will be conducted on 1024 and 2048 qubit QACs provided by Dwave Systems (see attached letter). This dual use of image processing and model data assimilation algorithms will not only contribute to a potential OCO-2 capability to provide an NEE product but may also serve as justification for the continued development of the quantum architecture for remote sensing and climate modeling satellite data assimilation ' including for other remote sensing products related to such things as soil moisture and ocean carbon uptake. 'Clearly, owing to the current state of QAC lacking algorithms to address any of the issues proposed here (or most other Earth Science problems), we consider this project to have an entry TRL of 2. Developing the basic QAC algorithms for image registration and variational data assimilation will raise the TRL to 3, and implementing the full proposed hybrid quantum/classical assimilation OSSE will further raise the TRL to 4. The exit level of this approach will be TRL 4 as we develop a prototype of QAC-enabled data assimilation for Level 3 OCO-2 observations on the Dwave 512, 1024, and 2048 qubit systems.
18867	MISTiC Winds: Midwave Infrared Sounding of Temperature and humidity in a Constellation for Winds	The objective of MISTiC is to advance the readiness of a miniature, high resolution, wide field, thermal emission imaging spectrometer to measure vertically resolved tropospheric profiles of temperature and humidity for deriving global 3-D wind measurements. It will provide ~ 2-3 km spatial resolution temperature and humidity soundings of the troposphere using an AIRS-like (Atmospheric Infra-red Sounding) method. It will enable a LEO constellation approach that provides 3-D Wind field measurements and atmospheric state and transport observations at low system cost. Additionally, it will reduce technology risks with the Infrared Focal Plane Array (IRFPA) and spectrometer technologies critical for significant instrument size, weight and power reduction (15 x 25 x 25 cm, 15 kg, 50 W).
18869	High Power UV Laser Lifetime Demonstrator	Currently, a 40 W, 50-200 Hz, 1 µm supports multiple lidar based Earth Science measurements including next generation measurements of IR, green and UV measurements of next generationcloud and aerosol, winds and ocean color as well as ozone measurements. The current airborne demonstrators meet most requirements for a space-based mission. However, it needs conversion to fully conductively cooled and UV

		lifetime needs to be demonstrated. The High Power UV Laser Lifetime Demonstrator project aims to meet these space laser perforamcne requirements.
18871	Triple-Pulsed 2-Micron Direct Detection Airborne Lidar for Simultaneous and Independent CO2 and H2O Column Measurement Novel Lidar Technologies and Techniques with Path to Space	The project will partner with industry to utilize extensive space-flight laser development expertise to build a unique triple-pulsed 2-µm laser. Project will develop a novel, lightweight, frequecy agile, wavelength turning, and locking system for the triple pulsed IPDA operation. Project will also integrate of the state-of-the-art laser transmitter to the exisiting and upgraded reciever system an strengthen for stable flight operation. Finally, initial ground testing and validation of the IPDA lidar from a mobile lidar trailer will be conducted.
23513	CuSPP Plus - An Enhancement to the Cubesat Mission to Study Solar Particles over the Earth's Poles	Objective: In response to the EM-1 component of NASA solicitation NNH14ZDA001N: Heliophysics-Technology and Instrument Development for Science (H-TIDS), the Southwest Research Institute (SwRI), NASA/Goddard Space Flight Center (GSFC), and the Jet Propulsion Laboratory propose CuSPP Plus, an enhancement of the already-selected CubeSat mission to study Solar Particles over the Earth's Poles: CuSPP. CuSPP is a 4-year project selected in 2014 (NNH13ZDA001N) to design, develop, and integrate a 3U CubeSat with a novel miniaturized sensor to address the primary science objective: 1) study the sources and acceleration mechanisms of solar and interplanetary (IP) particles near-Earth orbit. CuSPP's technical objective is to increase the technological readiness level (TRL) of our novel in situ Suprathermal Ion Spectrograph (SIS) instrument concept so that it can be proposed and flown with significantly reduced risk and cost on future Heliophysics missions. The enhancement is to add back in the de-scoped Energetic Ion Spectrometer (EIS) instrument that measures ~1-50 MeV/nucleon H—Fe ions. In addition, a magnetometer (MAG) from JPL will be added, because particle intensities within the field-of-views of the two instruments depend upon the magnetic field direction and this cannot be determined a priori outside the Earth's magnetosphere. In addition, CuSPP Plus will need an improved telemetry system in order to handle the much larger Earth-spacecraft distances. The addition of the EIS and MAG instruments and enhanced telemetry will increase the size of CuSPP Plus to 6U, as compared to the 3U CuSPP. Scientific Rationale: Over the past two decades (~1992—2012), simultaneous measurements from NASA's Heliophysics System Observatory (HSO) missions like SoHO, ACE, STEREO, and Wind near 1 AU, and SAMPEX in a Low-Earth Orbit (LEO) have revolutionized our understanding of the origin and acceleration of suprathermal (ST) and energetic particles in the inner heliosphere and their impacts on the near-Earth radiation environment. Despite enormous advances, several questions regarding these energetic particle populations are unanswered, largely because high-cadence,

		precise measurements of the suprathermal populations are difficult. CuSPP fills this critical gap by measuring the temporal, spectral, and angular distributions of ~3-70 keV/q ST ions that form the seed particles of the energetic particles. CuSPP Plus also measures the energy spectra and composition of the ~1-50 MeV/nucleon H—Fe ions that evolve from the STs and the interplanetary magnetic field that is closely coupled to the particle distributions. This enhancement to the CuSPP mission provides an orbit that is much better suited to heliospheric science and the two additional instruments greatly increase the scientific return from CuSPP.
23917	Twin Rockets to Investigate Cusp Electrodynamics-2 (TRICE-2)	We propose a re-flight of the Twin Rockets to Investigate Cusp Electrodynamics (TRICE) mission as the TRICE-2 mission. The original mission was quite successful in terms of an excellent range of scientific results presented at meetings, and in papers, but experienced some failures in the particle instruments which limited achievement of all of the science goals. These problems have since been rectified and flight-proven. The science of the mission remains highly relevant to NASA, in particular, to the upcoming MMS satellite mission. The TRICE-2 mission consists of a pair of almost identically instrumented scientific payloads launched from Andoya Rocket Range into the Earth's cusp region during a period when optical and radar data indicate that ionospheric signatures of reconnection are present. The two rockets will fly along very similar ground tracks, but one will fly to an apogee of approximately 500 km and the other will fly to an apogee of >1200 km. By launching the low-flying rocket 2-4 minutes after the high-flying rocket, we will achieve a variety of separations across magnetic field lines between the payloads in both the north-south and east-west directions. The payloads will also cross the same latitudes at different times. Due to the complexity of a two-rocket mission, we are planning for a four-year funding cycle with a launch in the November/December of 2018. The science goals are aimed at distinguishing between signatures of pulsed reconnection verse those of steady reconnection as well as investigating ionospheric cusp electrodynamics. By examining the evolution of stepped cusp ion dispersion along nearly identical field lines at a variety of different times, we will determine if the stepped forms have moved due to convection as predicted by pulsed reconnection models or if the steps are fixed in latitude as predicted by steady reconnection models. The comprehensive suite of measurements will allow a detailed study of the temporal and spatial evolution of the electrodynamics and particle precipitation in the cusp. We will address the physics of current closure, incident Poynting flux, Alfven wave occurrence, and high frequency waves. These measurements will be compared with simultaneous ground-based measurements from radar and imaging detectors to place them in the broader ionospheric context. The proposed pair of well-instrumented rockets will provide a wealth of new information on cusp ionosphere physics. These data will answer outstanding questions about the character of magnetopause reconnection and cusp electrodynamics. The study of magnetic reconnection is a central theme in the

		Heliophysics division. Indeed, the MMS mission to be launched next year will study the microphysics of reconnection making the TRICE-2 science goals of the macroscopic nature of reconnection complimentary to the MMS mission and of high relevance to NASA science.
23922	Development of a Tri-axial Double Probe for DC and AC Vector Electric Field Measurement on Cube-sats and Other Small Spacecraft	The electric field is a fundamental property of the space environment of not only the earth, but of that of other planets. For over 40 years, double probe instruments have been successfully flown on satellite and sounding rocket payloads whose data have established this technique as critical means to accurately measure DC and AC electric fields with high time resolution. Indeed, double probes have flown on a variety of NASA ionospheric and magnetospheric missions, addressing a wide range of science objectives, from ionospheric instabilities to Joule heating to auroral acceleration physics. A key aspect of the double probe experiment is the boom system that must symmetrically extend electric field sensors (typically spheres) from a compactly stowed configuration within a central payload to permit potential difference measurements to be acquired in each of three, orthogonal axes. With the advent of small satellite opportunities (Cubesats and other), there is a need for a tri-axial system that can deploy sensors to separation lengths of several meters, and yet be stowed in a volume scarcely larger than a cube with a side dimension of 10-15 cm. Furthermore, stiff booms are needed to enable such measurements to be carried out on non-spinning (3-axis stabilized) satellites that require a ram front to enable other measurements from other instruments to be gathered. Such long, stiff booms must be thermally stable to avoid any thermal differentials across the booms which could result in thermal pumping of the satellite. Major advances in composite technology provide a new means to compactly stow long elements that, on command, self deploy and extend for several meters each. Such new technologies also enable sensors to be extended with the wires and cables needed to permit the required signals to be gathered. Such composite materials have excellent thermal properties such that no differential heat absorption results across the boom element. Such advances in boom deployment technology, coupled with narrow, stiff composite elements, have been recently developed by Composite Technology Development, Inc., of Colorado. Building on 50 years of double probe research at the NASA/Goddard Space Flight Center, we propose an instrument development initiative to design, build, and test a prototype tri-axial double probe that is suitable to gather DC and AC electric field measurements on a 6-U cubesat. The resulting technology will then be available to the community for wide-ranging applications of DC and AC electric field research in the earth's ionosphere, as well as ejectable planetary probes.
23993	AZURE: Auroral Zone Upwelling Release Experiment	The upwelling or vertical circulation that develops in the high-latitude thermosphere is a critical part of the response of the high-latitude thermosphere to auroral forcing. The large vertical gradients in composition and density make it possible for even small vertical flow velocities to produce large changes in the chemistry and dynamics of the

		region. The vertical flow response is therefore essential to our understanding of the plasma-neutral interactions, energy deposition and redistribution. The limited available measurements, mostly from ground-based Fabry-Perot instruments have consistently shown large vertical winds with magnitudes of 20 to 30 m/s, even in conditions of low to moderate activity. Such large vertical winds typically require large horizontal gradients in the flow to support the circulation, based on the mass continuity equation, but the observed flows also frequently are in the same direction, i.e., either upward or downward, for extended periods of an hour or longer, suggesting that they are large-scale flows rather than narrow features. The combination of the long time scales and large magnitudes makes it difficult to explain the observations. We propose the first set of comprehensive measurements of the vertical winds over the full height range from the lower E region to the F region in the auroral zone during disturbed conditions. Specifically, small lithium cloud releases deployed from rocket-propelled, ejectable canisters will be used as a tracer of the neutral atmospheric motions from which both the horizontal and vertical wind components can be obtained. Specifically, two rockets with apogee near 500 km will be launched from Poker Flat, Alaska, during disturbed conditions near magnetic midnight. Each rocket will carry a total of 12 canister pairs ejected on the upleg. The ejection times and canister detonation sequence will be designed to produce horizontal separations of approximately 50 km between canister pairs and altitude coverage over the range from approximately 110 to 250 km in the general region of the downleg portion of the trajectory. Two-channel photometers on each payload will provide the red and green line altitude profiles. Ionization gauges on each payload will provide neutral density profiles. Time history of the vertical and horizontal winds will be obtained from ground-based Fabry-Perot instruments located at Poker Flat and in the region north of the launch site. The lithium releases require solar illumination for the lithium releases to be visible. Local magnetic midnight occurs near 0230 LT at Poker Flat. In the March time frame suitable twilight conditions can be obtained in the period close to magnetic midnight in the early morning hours when disturbed conditions frequently occur. The proposed experiment will provide the first measurements of the detailed height profiles of the vertical winds across both the E region and F region, as well as the small-scale horizontal variations in both the horizontal and vertical winds. The measurements can thus be used to determine how the vertical flow develops in response to the forcing, how energy, momentum, and atmospheric constituents are transported, and the extent to which the circulation varies horizontally. The research is directly relevant to the strategic goals expressed in the NASA Heliophysics 2009-2030 road map including - RFA H2: Understand changes in the Earths magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects. In particular, furthering our understanding of the processes responsible for the vertical circulations

		has significant implications for the accuracy of operational models of both the neutral and ionized components of the atmosphere. The proposed launch scenario has been discussed with the Sounding Rocket Project Office at Wallops and has been deemed to be practical.
24015	Nature of Interplanetary Low Energy Electrons and Positrons	We propose to explore the source of the negative spectral index of low energy cosmic ray electrons (20-100MeV). To accomplish this objective we will attack the problem from two fronts. First, we propose to measure electrons in the energy range of 20MeV to 300MeV with a new instrument, which we name AESOP-lite, on a high altitude balloon >140kft. This data will provide a clean, calibrated reference at 1AU to be compared with Voyager electron observations from interstellar space. Voyager I and II are currently returning electron spectra roughly within this energy range (<160MeV). Second, we plan to simultaneously measure the positron fraction in the electron flux within this low energy regime using the same instrument. Positron abundances in this energy range should be highly diagnostic of the particle origin. It is important to note these electron energies are not observable by the AMS and Pamela instruments.
24034	Long Duration Daytime Thermospheric Wind Observation Using HIWIND	We propose to fly the balloon-borne Fabry-Perot Interferometer HIWIND (High altitude Interferometer WIND observation) for long duration daytime thermospheric wind observations. The specific scientific questions related to this flight are as follows: 1) how does cusp heating affect the thermospheric winds in the polar region? 2) what are the inter-hemispheric differences in polar cap thermospheric wind patterns? One of the most striking features discovered during the first HIWIND flight in June 2011 is the persistent equatorward wind at all local times just equatorward of the auroral oval [Wu et al, 2012]. The standard NCAR TIEGCM did not reproduce this feature. Instead it showed a strong poleward wind on the dayside. One possible source for the unexpected dayside equatorward winds is strong Joule heating near the cusp region driven by strong east-west IMF conditions [Knipp et al. 2011 and Li et al. 2011]. When the TIEGCM was modified with enhanced cusp heating close to what Knipp et al. [2011] reported, it did reproduce similar equatorward winds. The mystery is that the first HIWIND observation was made during what appears to be modest north, east, and radial IMF conditions. One way to verify the enhanced cusp heating is to make thermospheric wind observations on the poleward side. TIEGCM simulation shows that the enhanced cusp heating can increase the poleward wind on the poleward side of the cusp by ~100 m/s compared to the TIEGCM run with no increased cusp heating. HIWIND is well suited for this kind of observation, because it drifts slowly with the stratospheric winds and scans different geomagnetic latitudes. The proposed HIWIND flight in Antarctica will cover both equatorward and poleward sides of the cusp and provide the necessary data set. Another objective of the HIWIND mission is to understand inter-hemispheric differences in the polar cap thermospheric winds. HIWIND can provide summer time polar cap observations in one hemisphere, while ground

		based Fabry-Perot interferometers simultaneous measure winds in another. The lack of daytime thermospheric wind observation has left many uncertainties in theories and modeling results on the thermosphere-ionosphere coupling in the summer polar cap. The simultaneous winter and summer polar cap wind comparison can shed more light on this topic. Ion drift observations from SuperDARN and ionosondes in the southern hemisphere and incoherent scatter radars in the northern hemisphere and the NCAR TIEGCM model will all be used to understand the thermospheric wind observations. HIWIND has demonstrated that it can provide accurate localized all local time coverage needed for this kind of study. HIWIND will follow the NASA satellite data-sharing rules for public use. This will be a three-year project. We plan to refurbish HIWIND in 2015 and 2016 and to conduct a long duration (~ 30 days) science flight from McMurdo, Antarctica (78S). The proposed new HIWIND observation will directly address questions related to thermosphere-ionosphere interaction. Such efforts belong to the NASA Heliophysics Research program. The program overview states: 'The program also supports investigations of the physics of magnetospheres, including their formation and fundamental interactions with plasmas, fields, and particles and the physics of the terrestrial mesosphere, thermosphere, ionosphere, and auroras, including the coupling of these phenomena to the lower atmosphere and magnetosphere.'
24055	High Angular Resolution Low Energy Neutral Imager (LENI)	Low Energy Neutral Imager (LENI) Technical Objective: Demonstrate high-angular (2) resolution, high-sensitivity (±10-3 cm2 sr/pixel) ENA imaging in the 0.5 - 20 keV range as called for by the Heliophysics Decadal Survey by utilizing ultra-thin foils, 2D collimation, and a novel electron optical design. Supporting the Following Scientific Objectives for Future Missions Heliospheric Science Objective: Understand the spatial and temporal structure of the heliospheric boundary through high-temporal and high-angular resolution imaging over the 0.5 - 20 keV energy range (LENI addresses the more difficult, lower end of that range). Magnetospheric Science Objective: Understand how magnetospheric ions precipitate into and interact with the upper atmosphere by determining the angular and spatial distribution of backscattered energetic neutral atoms (ENAs).
24070	The High-resolution Coronal Imager	We propose to re-launch the Hi-C payload in the summer of 2015 from White Sands Missile Range. The primary science goal of the re-flight is to reveal the mass and energy connection between the chromosphere and corona. A secondary science goal will be to investigate the prevalence of magnetic braiding and wave motions in the corona; evidence of both phenomena was observed in the first Hi-C flight. To image both the chromosphere and corona, we will coat the mirrors with a 174 angstrom passband coating. Additionally, to improve the ability to detect wave motions and fine structure, we will replace the camera from flight 1, which had substantial readout noise, with a new, low-noise camera. By sampling the chromospheric and coronal structures in these

		wavelengths, this flight will also serve as a pathfinder for a possible Solar-C or Explorer mission incorporating Hi-C like imagers.
24114	Marshall Grazing Incidence X-ray Spectrometer (MaGIXS)	The Marshall Grazing Incidence X-ray Spectrometer (MaGIXS) will observe the Sun in the 6-24 Angstrom wavelength range with 6 arcsec resolution along the 8 armin slit. The data will be used to determine the frequency of heating in the solar corona and the FIP bias in different hot coronal structures. This information can be used to discriminate between coronal heating mechanisms and fractionation mechanisms that cause the FIP effect. MaGIXS is composed of three subsystems : an X-ray telescope, a spectrograph, and a detector. The X-ray telescope optic will produce focused images on a slit; a slit jaw imaging system will be used for pointing and data alignment. The spectrograph consists of a collimating and re-focusing pair of corrective X-ray optics and a blazed grating. The detector is a low-noise, fast-readout camera. The alignment of the system will occur in stages, with the final alignment at the Marshall Space Flight Center Stray Light Facility.
24167	Waves and Instabilities from a Neutral Dynamo (WINDY)	This is the lead proposal for project WINDY (waves and instabilities from a neutral dynamo). We propose to study the stability of the postsunset equatorial F region ionosphere and the factors that predispose it to equatorial spread F (ESF), a phenomenon characterized by broadband plasma turbulence which degrades radio and radar signals at low magnetic latitudes. The goal of the investigation is to lay the foundation for a strategy to forecast the disruptive phenomenon. The focus of the investigation will be on the influence of zonal thermospheric winds. It is well established that the neutral wind dynamo in the equatorial F region is imperfectly efficient just after sunset. This implies the existence of significant vertical current. Closure of this current through the lower ionosphere is believed to be the cause of vertical shear in the zonal plasma flow, a feature that is persistently observed in the bottomside. Moreover, recent modeling work suggests that the vertical current contributes significantly to ionospheric instability and also influences the dominant wavelength of the irregularities that emerge. If so, then shear flow should be predictive of ESF occurrence and morphology. Thin scattering layers believed to be driven by zonal neutral winds are also known to emerge in the bottomside where the zonal plasma drifts are retrograde (westward, in opposition to the usual direction of the neutral winds). These layers too should be predictive of ESF if the causality chain implied above holds. We propose to test the chain by evaluating three of its components pertaining to the cause of shear and retrograde flow, the influence of vertical current on ionospheric stability, and the role of the thin scattering layers that often precede ESF. The investigation will be conducted from the Reagan Test Site (RTS) on Kwajalein Atoll in the Marshall Islands in August of 2017. It will involve the launch of one instrumented sounding rocket to measure ionospheric number densities and electric and magnetic fields and another sounding rocket to

		measure thermospheric winds through the release of chemical trails --- TMA in the MLT region and lithium in the thermosphere. Camera sites would be deployed regionally for trail photography and triangulation. The ALTAIR radar will be used to assess launch conditions and to monitor the evolution of the ESF after the launches. A ground-based Fabry Perot interferometer would also be deployed to monitor the evolution of the winds after the launches and to provide context about day-to-day variability. The investigation will lead to a deeper understanding of a complex common natural phenomenon and should ultimately lead to a means of anticipating ESF and the associated effects on communication, navigation, and imaging systems. The research is relevant to the strategic goals expressed in the NASA Heliophysics 2009-2030 roadmap including RFA F3: Understand the creation and variability of magnetic dynamos and how they drive the dynamics of solar, planetary, and stellar environments RFA H2: Understand changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects Both goals are reflected in the 2013 Decadal Survey for Solar and Space Physics in AIMI goal 4, which asks ''how do neutrals and plasmas interact to produce multiscale structures in the AIM system?'' Both support the Heliophysics Science Objective to ''build the knowledge to forecast space weather throughout the helipsphere.''
34765	Multi-channel Combining for airborne flight research using Standard Protocols	The project will achieve goals by conducting software development. They will also develop laboratory testbed for research using RFNEST™ as surrogate for perturbed radio and test and debug chanel bonding. The will also develop an engineering model using iridium modems, develop simulation to characterize existing iridium channels, including both mode and test tools. They will also implement multipath-TCP and multipath-UDP and condlue with flight testing at ARC.
34767	Fiber-based, Trace-gas, Laser Transmitter Technology Development for Space	The project will achieve objectives by usig a fiber-based master oscillator power amplifier (MOPA) architecture for modularity and performance. Seed and pre-amplifier modules will be built in-house at GSFC. Commercial providers will be used to develop the power amplifier. A prototype will be built to meet the key performacne requiremenst. Testing will be performed to achieve TRL-6.
34776	H2O, CH4, and HSRL Airborne Lidar Observations	The project will meet the objectives by extending the LaRC HSRL-2 receiver architecture to enable H2O and CH4 DIAL and HSRL measurements. It will also develop two Fibertek pulsed optical parametric oscillator (OPO) lasres to drive two laser transmitter modules to demonstrate H2O or CH4DIAL measurements. They will also develop a multi-wavelength, frequency agile, and wavelength switched injection seeding soure.Finally the project will demonstrate H2O and CH4DIAL and HSRL measurements from the ground and NASA B200 aircraft.
79594	Heliospheric Hydrogen as a Probe of the Heliopause and Interstellar Magnetic Field	The physical extent of the heliosphere is defined by the interaction between plasma populations in the solar wind and local interstellar medium (LISM), with the size and shape of the boundary region determined locally by the dynamic and magnetic pressures on either side and by the magnitude of the projected relative velocity vectors of

		both media. Neutral hydrogen in the LISM also plays an important role via resonant charge exchange (RCE) with plasma on both sides of the border that acts to increase pressure upstream and decrease it in the heliosphere. The nearest part of the boundary is ~100 AU in the 'upwind' direction defined by the relative motion of the LISM and solar system. Since these distances are difficult to reach with in situ spacecraft, the heliopause has been probed by observing the neutral LISM after it enters the solar system. This entry affects the primary LISM constituents (H and He) differently, with the H velocity distribution being altered via RCE with decelerated LISM protons. Measurements of the Doppler shift of scattered solar Ly-α emission show that RCE decelerates the interplanetary hydrogen (IPH) relative to He (from Ulysses) and the bulk LISM. They also imply a deflection in the H vs He flow directions and an asymmetry in the brightness distribution of the scattered background, which models tie to the strength and alignment of the interstellar magnetic field (IMF). These same models show a deflection from the expected upwind IPH direction that can be mapped spectrally with ~1 km/sec precision. More recently, the IBEX satellite has revolutionized our understanding of the heliopause via detection and mapping of energetic neutrals, including H and He. They find conditions consistent with shifted upstream LISM flow direction and velocities 10-15% slower than those based on earlier measurements. This result is significant for the structure of the boundary, because the implied 25% reduction in plasma pressure will reduce the Mach number of in the upstream direction, potentially eliminating the need for a fast upstream bowshock. Later theoretical work has suggested that a variety of shock conditions are possible, depending on the LISM velocity and the angle of the interstellar magnetic field with respect to the LISM flow direction. The IBEX results were tested using new IPH spectra obtained with HST-STIS in 2012 and 2013. They returned results consistent with the earlier studies showing higher velocities in the LISM, but they are affected by solar maximum conditions, which act to decelerate the flow and by the spectral resolving power that have limiting velocity precision of 1-2 km/sec. They also but lack the spatial sampling to map the upstream deflection, and hence the IMSF. The proposed research program aims to further refine the extent of the discrepancy between the IBEX LISM velocity and STIS. Both aims will be achieved using a sounding rocket experiment built around an all-reflective spatial heterodyne spectrometer (ARSHS). ARSHS is an inteferometric technique that represents a significant advance for high resolving power measurements of diffuse vacuum ultraviolet emission line targets. The étendue (field of view times collecting area) of ARSHS for wide-field sources is more than three orders of magnitude greater than HST-STIS while providing >4x resolving power of R ~120000. As designed, the ARSHS provides limiting velocity of ~0.3 km/sec for spectral line centroiding in a 30 second exposure. We will fly this experiment in 2018 near solar minimum, when the measured IPH velocity is least affected by inner solar system forcing, to obtain 8 spectra along different lines to sight. These will be used to

		provide an improved lower limit to the LISM velocity and to identify the deflection of H and He flow vectors.
79603	A Search for Small-scale Energy Releases in Active Regions and the Quiet Sun with FOXSI-3	The 3rd flight of the Focusing Optics X-ray Solar Imager (FOXSI-3) sounding rocket will perform a high-sensitivity search for small-scale energy release in the quiet and active Sun. Small energy releases in the corona (nanoflares) have the possibility to heat the solar corona to its high observed temperature. Nanoflares can be investigated via direct hard X-ray (HXR) observation of flare-accelerated electrons or by observation of hot, flare-temperature plasma in the otherwise quiescent corona. Unlike previous solar HXR instruments that relied on indirect Fourier imaging, FOXSI uses direct focusing HXR optics. FOXSI has successfully flown twice (Nov. 2, 2012 and Dec. 11, 2014), with a major aim of investigating quiet-Sun HXR emission. However, all FOXSI flights, as well as all NuSTAR solar observations, have been background-limited for quiet Sun nanoflare investigation by single-bounce photons from sources outside the field of view. A major improvement to the FOXSI-3 payload will be a collimating structure that blocks single-bounce flux. Other upgrades will include the replacement of several detectors with improved CdTe detectors provided by ISAS/JAXA and a fuller set of mirrors in each module. With these upgrades, the FOXSI-3 payload will (1) perform a high-sensitivity search for nonthermal electrons in the quiet Sun, (2) measure active region DEMs with better energy coverage than that of NuSTAR (due to deadtime restrictions), and (3) develop a collimation system essential for future direct solar HXR imagers.
79609	VISIONS-2: Quantifying ion outflow in the cusp	The Earth's upper atmosphere is a strong source of ions that ultimately end up in the magnetosphere, strongly affecting a range of processes, including reconnection, ring current development, energetic particle losses, and convection and transport. This flow of ions begins near the exobase, where ions are heated by electrodynamic energy and particle energy inputs, and where wave-particle interactions can begin to resonantly accelerate ions from thermal energies to escape velocities. The relative contributions of these processes remain unknown, and must be better characterized in order to model ion outflows, including their variation in response to changes in their drivers, and their effects on the magnetosphere. The recent VISIONS mission, launched from Poker Flat in February 2013, performed a new type of combined remote sensing / in situ measurements of the drivers of ion outflow associated with an auroral substorm, the characteristics of the ion outflow itself, and the mechanisms by which the ions are accelerated to reach energies greater than 10 eV, at which point they are no longer gravitationally bound. VISIONS focused on the altitude range between 300-1000 km, which is the "first step" in the chain of ion acceleration. VISIONS determined that the majority the low-altitude ion acceleration occurs in regions of intense soft precipitation, and provided important constraints on the overall fluxes and time variation of ion outflow late in the substorm

		expansion phase (30-45 minutes post-onset). We propose a follow-on mission, VISIONS-2, to further examine these important processes, and provide new insight into the mechanisms that drive ion outflow. VISIONS-2 will study ion outflow in Earths' magnetic cusp, a region that is known to produce the most intense ion fluxes in the entire high latitude region. VISIONS-2 will be the first mission to combine ENA imaging of cusp ion outflow with direct measurements of the drivers, including multispectral optical imaging of aurora, corresponding to regions of electron and proton precipitation, as well as direct in situ measurements of fields and particles that provide very strong constraints on the remote sensing inversion and modeling. VISIONS-2 will fly from Ny-Ålesund, Norway, in November 2018, through the magnetic cusp, to an apogee near 800 km. During the flight, it will remotely sense ion outflow and its drivers over a region approximately 1000 km in diameter, providing critical information about the patchiness and burstiness of cusp ion outflow, as well as detailed information about the mechanisms that drive this outflow, leading to a new understanding of the mechanisms that couple the magnetosphere and ionosphere, in support of future missions such as GDC, DYNAMIC, and MEDICI.
79636	Avalanche photodiodes for suprathermal and energetic ion detectors in future Heliophysics missions	Developing a single detector capable of measuring space plasmas from a few keV up to a few MeV/nuc is crucial to understanding many fundamental processes, including particle heating and acceleration, by providing complete spectra of energetic particle populations near the sun, the heliosphere, and in geospace (e.g., solar energetic particles, interplanetary shocks, corotating interaction regions, Van Allen radiation belts, plasma sheet, Earth's bow shock, etc.). However, the current techniques pose serious technical challenges for reasons that the suprathermal (a few keV to 100s keV) region lies between the two most commonly used particle detection techniques that used by thermal or plasma instruments and by Solid-State Detector (SSD)–based energetic particle instruments. This suprathermal range represents the source particle populations which initiate acceleration processes. To reveal the mechanisms hidden in these processes, it is essential that precise and consistent measurements span a wider range and cover suprathermal particles along with energetic particles. Our previous work, funded entirely through SwRI's internal research program, has already demonstrated that a new type of low-noise, low-threshold, SSD – the reach-through Avalanche PhotoDiode (APD) – has a threshold noise level of 1 keV, and can potentially extend the SSD energy coverage into the suprathermal energy range with 0.8 keV intrinsic resolution. In addition, our recent effort identified that fast APD signals triggered by ions are qualified for timing analysis in the Time-Of-Flight (TOF) mass spectrometry system. In preparation for future in-situ instruments, we propose to establish the method to measure ions using this emerging detector technology, including the largely unexplored suprathermal range. The goal of this project is to develop APDs for ions and test them for specific applications and environments expected in future Heliophysics missions. In this project, we will follow the 4 objectives,

		namely, (1) Device Development: Develop and test monolithic, multi-pixel APDs for future applications in energetic ion telescopes, (2) Timing capability and electronics: Develop electronics suitable for existing APDs for simultaneous TOF and energy measurement using off-the-shelf pick-off preamplifiers with a FPGA data handling program. Evaluate the timing resolution and pulse shape with a thinner depletion APD, (3) Dynamic range investigation and electronics: Evaluate APDs for >MeV ions. Develop a read-out method to cover a wider energy range, (4) Radiation hardness: Investigate radiation damage effects for 100s-keV and >MeV protons, and hot electrons. The APD technique satisfies the scientific and technical requirements of suprathermal and energetic particle instruments for NASA HPD's near-term science targets such as the top priority recommendation for Solar Terrestrial Probes (STP) of the Decadal Survey 2012 - STP-5: Interstellar Mapping and Acceleration Probe (IMAP) as well as future science targets that require measurements of plasmas and suprathermal particles. If funded, project would fulfills several of NASA's strategic objectives as outlined in the 2012 Heliophysics Decadal Survey and the 2014 SMD Science Plan.
79709	CuPID Cubesat Observatory	Science Goals and Objectives The Cusp Plasma Imaging Detector (CuPID) cubesat will answer longstanding questions regarding the macroscale properties of magnetic reconnection such as, (i) what is the longitudinal extent of the reconnecting magnetopause; (ii) under what conditions do multiple reconnection sites form; and (iii) under what conditions is reconnection continuous versus bursty? The process of magnetic reconnection changes magnetic topology and permits the flow of energy from the solar wind into the Earth's magnetosphere and ionosphere. This project has great relevance for goal #2 of the NRC Decadal Survey for Solar and Space Physics to "Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs." It can be difficult to determine the global nature of magnetopause reconnection from isolated in-situ spacecraft measurements. Even clusters of spacecraft with inter-spacecraft separations ranging from 10's of kilometers (MMS) or even 1-2 RE (Cluster) cannot determine the extent (and therefore significance) of processes that may span 10's of RE. However, the magnetic field lines on which reconnection occurs converges in the cusps, where observations of cusp ion dispersions provide a rich source of information on the characteristics of reconnection. However inherent ambiguity between spatial and temporal features in in-situ measurements hinders our ability to interpret these observations. The CuPID observatory will overcome the spatial/temporal ambiguity by innovatively imaging ion dispersions in soft X-rays. Soft X-rays are emitted from charge-exchange between high-charge-state solar wind and neutral hydrogen atoms in the Earth's geocorona. By imaging ion dispersions, one can map and understand the full spatial and temporal features of ion injections and therefore the macroscale nature of magnetopause reconnection. Methodology The CuPID mission is designed around an autonomous, magnetorquer-controlled 3U cubesat carrying an X-ray telescope. The wide field-of-view

		soft X-ray telescope will focus 0.1-2keV photons with slumped micropore optics onto a position sensitive anode/microchannel plate assembly. In an inclined, low-Earth orbit, CuPID will look up the throat of the cusp and monitor X-rays emitted from ion injections. The science instrument and much of the flight subsystems come with significant flight heritage. A previous generation of CuPID's X-ray telescope was successfully flown on the DXL sounding rocket in 2012. An identical X-ray telescope to the one planned for CuPID has been developed and will fly on the DXL II launch in December 2015. Many of the flight subsystems such as the flight radio, magnetorquer, power system, and flight computer will be leveraged from the highly successful FireFly cubesat, constructed and operated by team members on proposed project. The communication will implement a UHF radio for both uplink and downlink with the ground station at the NASA Wallops Flight Facility.
88147	EMCCD technology for ultraviolet astronomy and high resolution spectroscopy	This proposal seeks funding to set up a laboratory dedicated to the development, testing, and flight qualification of electron multiplying charge coupled devices (EMCCDs). I propose a focus on detectors for use on ultraviolet (UV) telescopes in particular, but also at visible and near infrared (IR) wavelengths for any photon starved application. Such a lab is uniquely suited to be placed at Caltech. Caltech has unique access to resources at JPL, the expertise at Caltech Optical Observatories on EMCCDs is unparalleled, and the UV telescope expertise provided by Chris Martin's group, the Space Astrophysics Lab, is equally vital. My proposal, to create "The Hamden UV/VIS Detector (HUVD) Lab at Caltech". This lab, and my work in it, will leverage the abilities and technology already present at Caltech, along with substantial institutional support, into an avenue of research that is critical to making the large-scale space-telescopes of the future as effective, inexpensive, and efficient as possible. This lab will be located in a dedicated space provided by Caltech, using a combination of new and existing equipment. Institutional support is provided in the form of my own salary (fully funded through 2020 by the Caltech Prize Millikan fellowship and a National Science Foundation Astronomy and Astrophysics Postdoctoral Fellowship, NSF AAPF), laboratory space, and equip- ment. My proposal includes a plan to mentor a grad student during the development phase, helping to foster a member of the next generation of future instrument builders. I am especially excited by this prospect, as I owe much of my own career to NASA-funded technology initiatives and the emphasis on grad student participation for those programs. The primary goal for this proposal is to produce EMCCD detectors that are flight ready in time for incorporation into Explorer class missions and for use on large scale telescopes likely to be suggested by the 2020 decadal survey. An ancillary benefit is the production of EMCCDs for potential use in ground based instruments, including high resolution spectrographs. The tests necessary for this qualification will take place in a lab setting and in flight on a complementary balloon project. Lab tests include: 1. Accurate measurements of dark current below 0.1 events pix^{-1} hr^{-1} 2. UV quantum efficiency (QE) and quantum yield (QY)

		measurements from 120-900 nm. 3. An exploration of the effect of PCB design and waveform shaping on clock induced charge (CIC) and read noise levels 4. Radiation hardness measurements, both from protons and total ionizing dose 5. Signal to noise measurements, data pipeline, gain burn-in These tests will be conducted on several device sizes and types, including frame transfer and full frame devices [engineering grade and delta-doped ccd97s and ccd201-20s]. High efficiency EMCCD detectors have great potential to increase instrument throughput, lower costs, and increase sensitivity at UV/VIS/near IR wavelengths and can make an immediate, large impact when used at UV wavelengths in particular. The Association of Universities for Research in Astronomy (AURA) recently released a report on a future large scale UV/VIS space telescope (Dalcanton et al., 2015). When identifying essential UV technologies of the future, especially in light of the eventual end of the Hubble Space Telescope (HST), they describe the need for a detector which can achieve the "triple crown...high quantum efficiency, low read noise/photon counting, and low dark current". High efficiency, UV-optimized EMCCD detectors will meet these challenges, and the HUVD lab will provide the tests and results that are needed to put them into space.
88275	Analog Field Deployments of Small Aperture Seismic Arrays on Terrestrial Bodies	The Apollo Missions to the Moon are the only direct experience of humans with exploration of another planetary body, providing us with a critical set of in situ data that has led to a complete revolution in our understanding of lunar geology, the lunar interior, and lunar evolution. To date, the deployment of the geophysical instrumentation packages during the Apollo missions remain our only data points for evaluating the efficacy of human-placed geophysical instrumentation on another world. It is difficult to ascertain what parameters in these astronaut-deployed instrumentation packages could have been modified to improve and increase the scientific return of these geophysical investigations, particularly investigations of subsurface structure in combination with geological information. The effectiveness and success of future missions of human exploration and subsequent habitation of the inner Solar System will depend on characterizing both the practical and scientific value of subsurface materials, including physical properties, geological structures, mineral and ground water resources, hazard assessments, and habitation potential/accessibility. To assess the fidelity of future human-deployed geophysical instrumentation packages and increase the integration of both geological and habitation assessments for planetary targets, we propose a multi year field deployment to evaluate the use of geophysical instrumentation on traverse design during human or robotic missions and different instrument deployment strategies for solving existing science questions about subsurface structure and stratigraphy in the San Francisco Volcanic Field (SFVF), AZ. We will build upon prior investments in the NASA Desert Research and Technology Studies (RATS) to study the human exploration aspects and logistical planning required for deploying geophysical instrumentation concurrently with geological field traverses.

		These studies will also serve as a stepping-stone for using geophysical methods to identify subsurface environments conducive to life, such as aquifers and geothermal sources of heat. The project is relevant to the Planetary Science and Technology Through Analog Research program in that it integrates across field disciplines (geology, volcanology, geophysics) in preparation for future human and robotic mission deployed geophysical instrumentation. The proposed research will deploy instrumentation that is capable of operating on lunar, asteroid, and planetary surfaces in a lava flow environment that is commonplace across terrestrial bodies of the Solar System. The proposed research will result in new science as well as operational and technological capabilities that will enable the next generation of planetary exploration. The proposed activities will include training of graduate students, outreach to the public, and collaboration of academic institutions (UMD, NAU) with a NASA center (GSFC).
88290	Oases for life beneath ice-covered oceans: bio-signature pathways from seafloor ecosystems to the overlying ice-shell	NASA's Mission to Europa plans fly-bys of Europa to investigate its habitability. We seek to support that and future missions through an analog, interdisciplinary field experiment to the Arctic Ocean that will explore for and investigate seafloor chemosynthetic ecosystems, and the fate of any bio-signatures they generate as they are transported up into the water column to the overlying ice. Our field program will include use of an icebreaker, ice-stations and, uniquely, a novel under-ice robot, Nereid Under Ice (NUI) designed specifically for long-range investigations, in both autonomous and remotely operated (human directed) modes, in ice-covered oceans. Shiptime for the project has already been awarded to our international collaborator, Prof. Antje Boetius (Alfred Wegener Institute, Germany) providing essential capabilities for our field program that will explore for and characterize new, isolated, hydrothermal ecosystems on the Arctic seafloor in Year 1. That field program will provide key sample and data sets from which we will derive new scientific and technologic capabilities, essential to planning future space missions. Our science-driven exploration program will be relevant to two key objectives of PSTAR: Science: We will explore for and characterize (geochemically & microbiologically) new sites of seafloor venting at the Karasik Massif which rises from 4700m to 566m at the Gakkel Ridge (87°N, 61°E) and hosts chemosynthetic ecosystems at the seafloor of a permanently ice-covered ocean basin. We will seek to identify biosignatures generated by these chemosynthetic ecosystems and investigate their fate as they are transferred upward into the water column to the overlying ice-cover. We will also assess the potential for such tracers, indicative of chemosynthetic life, to persist and be detectable on the outer shells of other icy moons that host global-scale oceans (e.g. Europa, Enceladus) through remote sensing - using techniques already in use on multiple space missions and as planned for NASA's Mission to Europa. Our field program will use NUI in a range of fully autonomous to real-time human-directed modes for survey and sampling missions: at the seafloor, up through the water column, and at the under side of the overlying ice. Complementary ice-station work will

		allow us to collect a complete continuum of samples, from the ocean floor to the outer surface of the ice. Technology: Beyond NASA's Mission to Europa, follow-on missions to any ocean world will require mobile robotic systems capable of searching for life and life-related chemistry. WHOI has demonstrated robotic exploration for seafloor chemosynthetic ecosystems including using acoustic communications to transmit data to humans, allowing them to intermittently re-task the robot based on information provided within a high-latency telerobotic framework. JPL has flown and demonstrated autonomous operations technologies on Mars Rovers and Earth Orbiters. Here we will forge this relevant experience into a new partnership and develop autonomous systems to perform scientific exploration under engineering constraints (e.g., communications, energy, payload, navigation, vehicle safety). We will develop a balanced autonomy that optimizes operations despite a 2-3h round trip communications delay while still allowing for expert scientific input to on-going high level mission planning. Building from joint participation in Y1 fieldwork that will establish the current terrestrial state of the art, we will (i) identify a viable level of autonomy between the vehicle, shore/ground, and the science/operations team; (ii) develop and implement autonomous operations algorithms and processes suitable for future planetary exploration missions; (iii) test these algorithms using archived field-data coupled with simulated communication and light time delay constraints and (iv) validate the autonomous operations technology we develop, on environmental simulations and in the field.
88340	TubeX: Using GPR, LiDAR, and hXRF to investigate strategies for lava tube exploration	Lava tubes have been studied on Earth since the late 1960's when geologists observed active lava tubes on Hawai'i. Tubes on other planetary bodies, however, have only been studied through remote sensing. In as early as the mid 1970's, it was postulated that these planetary tubes could provide safe havens for human crews and protect their life support equipment from harmful radiation, rapidly fluctuating surface temperatures, and even meteorite impacts. What is not clear, however, is how a human crew will characterize a tube-rich environment in preparation for habitation. The proposed work will address this knowledge gap using a suite of instruments in an analog study. Ground Penetrating Radar (GPR), Light Detection and Ranging (LiDAR), and handheld X-ray fluorescence spectroscopy (hXRF) are all techniques that have been deployed on Earth in a variety of geologic contexts with great success. They have never before been combined in a volcanic setting to investigate lava flow emplacement processes nor have any of them been applied to develop human exploration strategies for the examination of another planetary surface. We propose to both investigate the combination of these field technologies in the development of a strategy for the exploration of lava tube and pit-rich environments as well as to advance GPR processing techniques in an effort to aid in detailed characterization of these subsurface features. In order to develop this concept of operations for tube exploration, we will deploy GPR, LiDAR, and hXRF field instruments at the Lava Beds National Monument (Lava

		Beds NM), California. Lava tubes at Lava Beds NM range in length, depth and complexity. This range of complexity is particularly well-suited to this project as tube geometry present on other planetary surfaces is completely unknown. We will accomplish this work through the completion of five tasks in two PSTAR fidelity areas: 1. Define the instrumentation suite necessary for lava tube exploration and characterization (Science Operations) 2. Develop a GPR library of what different tube and pit geometries will look like (Science Operations) 3. Develop an exploration strategy for how a rover should characterize a tube/pit-rich environment (Science Operations) 4. Identify optimal GPR antenna parameters (Technology) 5. Identify optimal GPR data processing methods (Technology) Together, these Science Operations ("decision-making protocols", "traverse planning", and "navigation unique to science support") and Technology objectives ("the use of mobile science platforms", "intelligent systems and human/robotic interfaces", and "instrument packages") directly apply to the PSTAR call and are therefore relevant to both this program call and to NASA. We also note that caves on other planetary surfaces have been highlighted as a potential place to preserve signatures of life, making this student applicable to NASA's current high priority objective of locating signs of life on other planetary surfaces.
88358	High Broadband Reflectivity Mirror Coatings for the Next Generation ofSpace Observatories	This Development Phase proposal for the 2014 Nancy Grace Roman Technology Fellowship in Astrophysics aims to develop new broadband enhanced lithium fluoride (eLiF) protected aluminum mirror coatings with > 85% reflectivity from the far ultraviolet to the near infrared. We describe the technical and scientific justification for this work, and lay out a four-year development effort plan to raise the Technology Readiness Level of these new coatings to TRL 6, thus qualifying them for future space missions. This RTF will also provide essential measurements of fluoride-protected aluminum coatings to determine their compatibility with high contrast imaging systems for the direct imaging of exoplanets. We present results acquired during the concept study phase that demonstrate a new record reflectivity at O VI in the Lyman UV, and a protected eLiF variant that initial testing indicates is not sensitive to moisture exposure. This proposal will satisfy a priority 1 technology goal of the Cosmic Origins program, and enable a wider bandpass for the next large UV-Optical-IR observatory. This effort fulfills the goals of the RTF program by giving an early career researcher the opportunity to develop a technology with the potential to enable major scientific breakthroughs, and thus develop the skills to become a PI of a future astrophysics mission.
92221	In-Situ Measurements of Neutral and Plasma Dynamics Associated with Earth's Cusp-Region Thermospheric	During the early 2000's, scientists working on satellite accelerometer data discovered two substantial and permanent enhancements of thermospheric mass density, located near the footprints of the north and south geomagnetic cusps, and occurring at around 400 km altitude. These density enhancements increase the weight of the atmosphere in these regions. Because the enhancements are stable, this extra weight must, unavoidably, be supported by local perturbations occurring in one

	Mass Density Anomaly	or more of the other terms that appear in the atmosphere's momentum equation – i.e., either in wind, temperature, or ion velocity. This prediction is confirmed by 3D fluid models. However as of today, more than a decade after the density enhancements were discovered, there are still no observations of any other corresponding atmospheric perturbations to indicate what is supporting the extra weight. It is critical that we resolve this disconnect, because the density enhancements directly affect satellite orbits. Our currently poor understanding of why they occur and what sustains them means we cannot model their behavior. This in turn, means we cannot accurately account for them in orbital predictions used to determine an operational satellite's collision probabilities during its (frequent) near misses with space debris. To reveal how the extra mass is supported, we propose to launch a Black-Brant 12 (or similar) sounding rocket from Andoya Space Center directly into the enhancement region, in an investigation that will measure all relevant terms in the atmospheric momentum equation. Regardless of the root cause of the density enhancements, their most likely support mechanisms involve neutral upwelling and horizontal divergence. The foundation of the investigation will therefore be to obtain absolute neutral wind measurements by following the drift of 20 neutral strontium clouds released from the rocket at altitudes between 200 and 400 km. Drift tracking will be done by photographic triangulation, using cameras located on Svalbard and aboard a NASA aircraft flying along the east coast of Greenland. Strontium tracers provide the only direct and absolute way to measure winds simultaneously within a number of very small sample volumes distributed from 200 to 400 km altitude. Multiply redundant measurements of the density enhancement itself will be obtained from accelerometers aboard the GRACE-FO and SWARM satellites. Existing data strongly suggest that intense narrow sheets of upward ion drag may also be important contributors to supporting the enhanced density. To examine this possibility, we need to measure many additional neutral and electrodynamic quantities. Ion drifts will be measured two ways: by tracking 20 barium ion clouds that will be created along with neutral strontium tracers, and from aboard the rocket with an in-situ Miniature Plasma Imager instrument. Ion density and temperatures will be measured in-situ with a suite of Petite Ion Probes, whereas electron temperatures will be measured in-situ using an Electron Retarding Potential Analyzer. The energy and pitch angle distribution of auroral electron precipitation will be measured in-situ using a stretched top-hat electrostatic analyzer. Neutral temperatures will be measured by remote sensing with an all-sky imaging Fabry-Perot spectrometer at Longyearbyen, which will also give neutral winds over a wider spatial region and temporal interval than that covered by the rocket. Numerous additional ground-based instruments on Svalbard will further characterize the thermospheric, ionospheric, and magnetospheric conditions during the experiment. Scientific closure will be obtained by using a local-scale high spatial-resolution version of the non-hydrostatic GITM model to interpret the observational data. The

		investigation will be a collaboration between five US and four international institutions.
92231	Scintillation Prediction Observations Research Task (SPORT)	The Scintillation Prediction Observations Research Task (SPORT) will make progress on the very compelling but difficult problem of understanding preconditions leading to equatorial plasma bubbles. These ionospheric structures have been observed for decades. They are the primary source of radar reflections in the equatorial F-region ionosphere and cause strong scintillations on radio signals passing through them. The relationships between background ionospheric conditions and the irregularity regions, which may influence their growth to high altitudes are poorly understood. SPORT will address two specific questions about these phenomena: (1) What is the state of the ionosphere that gives rise to the growth of plasma bubbles that extend into and above the F-peak at different longitudes? (2) How are plasma irregularities at satellite altitudes related to the radio scintillations observed passing through these regions? Much has been discovered about what conditions, or state, of the ionosphere typically precedes equatorial plasma bubbles. Signatures in both the density profiles and the plasma drifts are related with some confidence to the resulting formation of plasma bubbles several hours later in the evening. Much of this scientific discovery has come from the Jicamarca Radio Observatory, a single site, within a single longitude sector. What is needed now is a systematic study of the state of the pre-bubble conditions at all longitude sectors. We have developed a focused mission to address our science questions using both in situ and radio occultation sensors on a CubeSat augmented by ground instruments in the Brazilian sector. A satellite in a mid-inclination orbit using both of these types of observations can probe the ionospheric state in a given longitude sector and then examine that same sector later in the evening for the development of plasma bubbles and scintillations. Ground-based observations of both the state of the ionosphere and scintillations of RF signals will complete the dataset required for this study. SPORT's exceptionally capable team will answer these questions by (1) developing and launching a CubeSat observatory to measure key phenomena, (2) leveraging data from existing Brazilian ground observation networks, (3) collecting, analyzing, and distributing resultant geophysical data and analysis tools, (4) integrating relevant data/analysis into scientific presentations addressing the posed science questions. SPORT is an international partnership between NASA, the Brazilian National Institute for Space Research (INPE), and the Technical Aeronautics Institute under the Brazilian Air Force Command Department (DCTA/ITA). SPORT has strong leadership in key positions, clarity in roles and responsibilities, and clean simple interfaces between institutions. NASA is overseeing the flight instruments and the launch to orbit; the Brazilian partners are contributing the spacecraft, observatory

		integration and test, ground observation networks, and mission operations and data management. The science data will be distributed from and archived at the INPE/EMBRACE regional space-weather forecasting center in Brazil, and mirrored at the NASA GSFC Space Physics Data Facility (SPDF).
92237	Plasma Enhancements in The Ionosphere-Thermosphere Satellite (petit Sat)	The mid- and low-latitude ionosphere is home to a variety of plasma density irregularities, including depletions (bubbles), enhancements (blobs), and small-scale scintillation, which result in the distortion of radio wave propagation. Previous studies of plasma density enhancements observed using ROCSAT data have posited that these structures form as the direct result of the formation of bubbles near the geomagnetic equator. However, recent observations from the C/NOFS satellite suggest that multiple mechanisms are responsible for forming plasma enhancements, with wave action in the thermosphere as a significant driver of the enhanced densities. Indeed, statistical analysis of enhancements observed from satellites resembles the statistics of Medium-Scale Traveling Ionosphere Disturbances (MSTIDs) with respect to seasonal variability and solar activity. This study will investigate the link between these two phenomena. In order to investigate the link between these two phenomena, both in situ data of the plasma enhancement and remote data of the MSTID at the magnetic footpoint are required. petitSat is a CubeSat mission designed to provide in situ measurements of the plasma density, 3D ion drift, as well as ion and neutral composition. The instrument suite includes a combined retarding potential analyzer and cross-track drift meter and a neutral mass spectrometer. This instrument suite will provide comprehensive information about the fluctuations in plasma, as well as changes in the neutral profile. petitSat will launch into a 51 deg inclination orbit at 400 km (consistent with an International Space Station deployment), allowing for numerous conjunctions with the Boston University All-Sky Imager network and GPS receivers from the International Global Navigation Satellite Systems (GNSS) Service (IGS) network over the mission lifetime. Through comparative analysis, we will bring closure to our key science question: What is the link between Plasma Enhancements and MSTIDs?
92279	SiC Electronics To Enable Long-Lived Chemical Sensor Measurements at the Venus Surface	This project will develop silicon carbide (SiC) based electronics capable of operation at 500 degrees Celsius to support previously demonstrated high temperature chemical sensors for use in harsh environments such as Venus surface and Gas Giants. The Venus Chemical Microsensor Array (VCMA), which has been separately developed and demonstrated under a NASA Phase II SBIR, consists of highly selective, solid state chemical microsensors (CO, NO, OCS, SOx, O2, H2O, HF, and HCl) that can operate at and above 500 degrees Celsius, but relies on silicon-based support electronics limited to 125 degrees Celsius operation. The development of SiC electronics is the key to enable uncooled long duration operation at the surface of Venus. We will design and fabricate Application Specific Integrated Circuits (ASICS) using NASA demonstrated SiC technology to enable long lived (100s of days) chemical sensor measurements on

		Venus' surface. This project will focus on the development of core SiC electronics for amplification, analog control feedback, and analog to digital data conversion required for sensor operation. Development will be based on previously demonstrated SiC components that have not yet been combined into the high level integrated circuits needed to support many types of instruments, including VCMA. Maturation of high temperature electronics reduces risk to future instrument development, supporting overall mission objectives and providing science relevant to Decadal and Venus Exploration Analysis Group (VEXAG) goals. Makel Engineering, Inc. (MEI) working along with CO-PI's from NASA GRC and NASA JPL will use the NASA GRC Microfabrication facilities for development of the SiC electronics. MEI will provide the expertise on specific circuit designs and ASIC architecture for the microsensors. NASA GRC will provide expertise on circuit implementation in SiC and device fabrication using the NASA GRC Microsystems Fabrication Laboratory. Demonstration and validation of the electronics will be conducted by MEI an JPL by incorporating the SiC electronics with the VCMA into a sensing package for use in JPL's ongoing terrestrial volcanic test program which serves as a hot planetary testbed. The Decadal Survey identifies the Venus In-situ Explorer Mission (VISE) for New Frontiers to, in part, "Understand the properties of Venus's atmosphere down to the surface." Near/on-surface exploration requires high temperature systems and "High-temperature survivability technologies such as…electronics…will enable long-term in situ missions". The Venus Exploration Working Group Technology Plan similarly emphasizes that "Development of high-temperature electronics, sensors… designed for operating in the Venus ambient would be enabling for future missions". However, the technology for such New Frontier exploration is limited and maturation for future missions is needed. This proposal directly addresses VISE's needs for technology operational for extended periods at the surface of Venus. The development of the SiC electronics and the demonstration of the electronics integrated with existing harsh environmental chemical sensors in terrestrial surrogate environments will bring the technology to a high maturity level.
92674	EMCCD technology for ultraviolet astronomy and high resolution spectroscopy	The main object of this proposal is for development phase funding to continue testing in the Hamden UV/VIS Detector lab (HUVD), dedicated to the development, testing, and flight qualification of electron multiplying charge coupled devices (EMCCDs). The concept study proposal was used to purchase hardware, set up the lab space, and begin initial testing of detectors for use on ultraviolet (UV) telescopes in particular. This lab has been successfully set-up using a combination of new and existing hardware and is already generating results in the UV. Future testing funded by the development phase will continue this focus and may also be used for visible and near infrared (IR) wavelengths for any photon-starved, EMCCD application. The HUVD lab takes advantage of unique access to resources at JPL, the expertise at Caltech Optical Observatories, and the UV telescope expertise provided by Chris Martin's group, the Space Astrophysics Lab. Continued funding of the lab

		will leverage the abilities and technology already present at Caltech, along with substantial institutional support, into an avenue of research that is critical to making telescopes of the future as effective, inexpensive, and efficient as possible. Institutional support is provided in the form of my own salary (funded through 2020 by the Caltech Prize Millikan fellowship and a National Science Foundation Astronomy and Astrophysics Postdoctoral Fellowship, NSF AAPF), laboratory space, and equipment. My proposal includes a plan to mentor a grad student during the development phase, helping to foster a member of the next generation of future instrument builders. I am especially excited by this prospect, as I owe much of my own career to NASA-funded technology initiatives and the emphasis on grad student participation for those programs. The primary goal for the development phase is to implement a systematic testing strategy to produce EMCCD detectors that are flight ready in time for incorporation into Explorer class missions and for use on large scale telescopes likely to be recommended by the 2020 decadal survey. An ancillary benefit is the production of EMCCDs for potential use in ground based instruments, including high resolution spectrographs. The tests necessary for this qualification will take place in a lab setting, in flight on a complementary balloon project, and on sky at Palomar Observatory. The work in the near term will focus on ccd201-20s, but the system can easily be modified to test other devices by changing the printed circuit board (PCB). Mike Lesser's lab at the University of Arizona is a good example of a flexible test system which can be used for many different device types. While that lab is focused more on production than just testing, it speaks to the the potential for future growth of a testing focused detector lab at Caltech. High efficiency EMCCD detectors have great potential to increase instrument throughput, lower costs, and increase sensitivity at UV/VIS/near IR wavelengths and can make an immediate, large impact when used at UV wavelengths in particular. The Association of Universities for Research in Astronomy (AURA) recently released a report on a future large scale UV/VIS space telescope. When identifying essential UV technologies of the future, especially in light of the eventual end of the Hubble Space Telescope (HST), they describe the need for a detector which can achieve the "triple crown...high quantum efficiency, low read noise/photon counting, and low dark current". High efficiency, UV-optimized EMCCD detectors will meet these challenges, and the HUVD lab will provide the tests and results that are needed to put them into space.
92675	MgB2 Material Advancements Towards Innovative Astrophysics Technology-Development Phase	Superconducting electronics has become an integral part of NASA's technology portfolio, especially for remote detection across the entire electromagnetic spectrum with unparalleled sensitivity. A particularly important application area includes direct and heterodyne detectors in the submillimeter (terahertz – THz) range for which the low value of the thermal energy in a sensor compared with the quantum energy is required. One major downside of superconducting detectors compared to other technologies is the need to operate at cryogenic temperatures

		(4 K or less). Significant effort was spent in trying to reproduce the state of the art detectors with the cuprate-based high-temperature superconductors (HTS), which could operate at or above 77 K. The success, however, has been very moderate given the difficulties in fabrication of the HTS compound. Besides, the thermal noise at 77 K is too high for most applications. It is recognized that superconducting materials with an intermediate critical temperature may be a better choice. In 2001, the material Magnesium Diboride (MgB2) was discovered to be superconducting with a transition temperature of 39 K, implying devices that can operate at a moderate 20-25 K. This is a very significant advantage to future NASA missions because there already exist high-heritage space cryocoolers that can achieve this temperature range at relatively low cost. This proposal will help NASA to integrate the new superconducting material into its facilities at Jet Propulsion Laboratory in order to develop better superconducting devices and detectors for future NASA missions. The proposal's key objective is to provide a practical source of thin films of superconducting MgB2. There are several applications of this material, which can ultimately help to realize Science Mission Directorate technological goals. MgB2 is poised to be the material of choice for detectors in many next generation THz heterodyne instruments. Some instrument concepts include GUSSTO (balloon-borne), SHASTA (for SOFIA-airborne), and a heterodyne instrument on Origins Space Telescope (OST-Spaceborne). A 20 K heterodyne instrument could also enable new concepts for smaller Explorer missions. Given the great scarcity of the academic and industrial labs where MgB2 can be synthesized, an internal source for such a material would be very important for NASA in order to take full advantage of its capabilities and associated benefits for future missions. During the concept phase, research was carried out to achieve MgB2 thin films by the Atomic Layer Deposition technique using an existing commercial system at JPL. The progress made is described in this proposal substantiating continued work in that direction. The ALD work had an ancillary result in finding suitable alternatives to a hazardous boron source. Additionally during the concept phase, significant advancements have been made externally on a more proven method of growing MgB2 thin films. The hybrid physical-chemical vapor deposition (HPCVD) process is a high temperature high-pressure process, producing the highest quality superconducting films worldwide. The two major drawbacks to this method are the small sample size and the use of highly hazardous Diborane gas. The development phase of this program would be used to design, procure and build a dedicated HPCVD system for large-area films to be grown at JPL using an alternative boron source, opening many doors to advance the state-of-the-art of superconducting electronics and detectors. The PI is Dr. Daniel Cunnane who has strong expertise in the growth of MgB2, particularly by the CVD technique and has matured multiple technologies using these films. He has successfully fabricated and characterized Josephson junctions, circuits,

		superconducting quantum interference devices, Josephson mixers, and THz hot electron bolometer detectors using these films.
92763	SHyRE: Scientific Hybrid Reality Environments	The use of analog environments in preparing for future planetary surface exploration is key in ensuring we both understand the processes shaping other planetary surfaces as well as can develop the technology, systems, and concepts of operations necessary to operate in these geologic environments. While conducting fieldwork and testing technology in relevant terrestrial field environments is crucial in this development, it is often the case that operational testing requires a time-intensive iterative process that is hampered by the rigorous conditions (e.g. terrain, weather, location, etc.) found in most field environments. Additionally, field deployments can be costly and must be scheduled months in advance, therefore limiting the testing opportunities required to investigate and compare science operational concepts to only once or twice per year. To overcome these inherent challenges, SHyRE will develop a scientifically-robust analog environment using a new and innovative hybrid reality (HR) setting that addresses these limitations and enables frequent operational testing and rapid protocol development, addressing the Technology PSTAR fidelity area. By leveraging the HR setting, the SHyRE Science Operations research will elevate the resolution and robustness of insight obtained from planetary analog operations research to an unprecedented level of detail. By conducting analog operations in our HR environment, we can systematically control and vary relevant features (gravitational conditions, availability of scientific instrument data, etc.) of the concepts of operations in a repeatable way, something which has never been done before due to the inability to precisely duplicate test conditions in a traditional field environment. This notion of constructing testable, strictly-controlled environments aligns with and leverages experience from a multitude of established research efforts that examine the impact of new technologies and procedures in similarly complex environments (e.g. air traffic operations, maritime traffic management, and military command). The SHyRE program will be the first NASA analog research program that can leverage and implement the standard practices of human-in-the-loop experimental design to better quantify the demands and identify strategies for executing scientifically-driven exploration. The SHyRE science operations program will execute an operationally- and scientifically-relevant testing campaign to quantify the relationship between information transfer and workload among crewmembers conducting scientifically-driven exploration operations, addressing the PSTAR Science Operations fidelity area. The SHyRE team consists of a unique blend of scientists, engineers, extravehicular activity (EVA) specialists, and operations experts with decades of experience conducting scientific fieldwork, integrated analog testing, and robotic and EVA flight operations. We have the unique capability to develop and

		conduct the proposed Science Operations and Technology objectives and feed them directly into ongoing NASA activities building toward both the Asteroid Redirect Crewed Mission and the Journey to Mars. Our proposed effort will address the Science Operations and Technology fidelity areas of PSTAR. Specifically, in the Science Operations fidelity area, we will address (a) Decision-making protocols; (d) communications and data flow protocols to support science; and (f) Crew scheduling and real-time execution for Intra- and Extravehicular activities, in addition to enabling closure of EVA Systems Maturation Team (SMT) gaps. In the Technology fidelity area, we will address (f) Intelligent systems and human/robotic interfaces as well as develop a new type of analog environment to support future planetary science operations research. SHyRE is relevant to the PSTAR program and to NASA's high-level objectives.
92764	SpaceCubeX: On-board processing for Distributed Measurement and Multi-Satellite Missions	This proposal addresses NASA's Earth Science missions and its underlying needs for high performance, scalable on-board processing. The decadal survey missions stressed higher resolution instruments and persistent measurements, which drove computing needs up by 100-1,000x. Our AIST-14 SpaceCubeX effort developed a framework which supported rapid trade space exploration of on-board heterogeneous computing solutions (Multi-core CPUs coupled with DSP or FPGA co-processors) across a benchmark suite of Earth Science applications, achieving 20-20,000x performance improvements. Today, measurement capabilities emerging from the upcoming 2017 decadal survey such as distributed sensing, data continuity, multi-satellite constellations, and intelligent sensor control will require an additional 10-100x increase in onboard computing performance. For this renewal effort, we propose to extend the SpaceCubeX on-board compute analysis framework and develop a hardware prototype to support the evaluation of these new measurement criteria. Distributed sensing missions require application portability across platform types, however platform constraints lead UAVs and satellites to utilize different processor types (GPUS vs FPGAs). A common framework which supports both FPGAs and GPUs will facilitate migration between these platform types. Multi-satellite missions enable diurnal, and multi-angle measurements, and invoke complex communication and control logic which must be processed on-board. Intelligent sensor control capabilities present complex, ad hoc processing which requires experimentation on prototype hardware. The SpaceCubeX project addresses these challenges by extending the evolvable testbed to include GPU support, model distributed sensors and high bandwidth communication links, develop prototype hardware, and demonstrate the technology. SpaceCubeX provides the following benefits: -Accessible, rapid prototyping of next generation satellite and multi-satellite constellations capabilities by creating virtual satellites in the cloud. -A proto-type heterogeneous on-board computer for experimentation of advanced autonomy and control capabilities required by intelligent instrument control and constellation management. -Accelerate migration of missions from UAV and airborne

		platforms to satellites to support distributed sensing. -Accurate, scalable approach to assessing Multi-Satellite mission performance. -Detailed analysis and initial run-time implementation of FluidCam Structure from Motion, MiDAR, Diurnal Measurements, and Mult-Angle Measurement applications. This project utilizes advanced instruments (FluidCam and MiDAR) currently operational on UAV platforms to drive distributed sensing and intelligent sensor research, and upcoming sensing concepts (Diurnal Measurements and Multi-angle Measurements) to guide multi-satellite constellation platform research. SpaceCubeX leverages substantial research investments from NASA, DARPA, and NRO on revolutionary imaging instruments, space based computing, multi-core and FPGA architectures, and focuses them on NASA Earth science missions and applications. The core team has worked together successfully for 14 years. The University of Southern California's Information Sciences Institute (USC/ISI) will oversee the effort, leading the extension of the framework. NASA Goddard Space Flight Center will develop a prototype science mission processor, and provide multi-satellite applications. NASA Ames Research Center will provide distributed sensing applications. NASA Jet Propulsion Laboratory will advise on application mapping to heterogeneous processors. The team will perform in these areas over a two year period to develop a distributed sensing and multi-satellite framework capabilities in year 1 and to use this framework to characterize end to end performance of candidate processor architectures and create a hardware prototype in year 2, raising the TRL from 3 to 5 in all areas.
92770	Automated protocols for generating very high-resolution commercial validation products with NASA HEC resources	The volume of available remotely sensed data is growing at rates exceeding Petabytes per year. Over the past decade the cost for data storage systems and compute power have both dropped exponentially. This has opened the door for "Big Data" processing systems such as the Google Earth Engine, NASA Earth Exchange, and NASA Center for Climate Simulation (NCCS). At the same time, commercial very high-resolution (VHR) satellites have grown into a constellation with global repeat coverage that can support existing NASA Earth observing missions with stereo and super-spectral capabilities. Through agreements with the National Geospatial-Intelligence Agency NASA-GSFC is acquiring Petabytes of sub-meter to 4 meter resolution imagery from around the globe from WorldView-1,2,3,4 Quickbird-2, GeoEye-1 and IKONOS-2 satellites. Prior to 2008 these data were spatially disparate and were primarily used for evaluation and validation of coarser resolution data products. Current data collections often include repeat coverage in many large regions with contiguous coverage. These data are a valuable no-direct cost resource available for the enhancement of NASA Earth observation science that is currently underutilized. We propose to develop automated protocols for generating VHR products to support NASA earth observing missions. These include two primary foci: 1) On Demand VHR 1/4° Ortho Mosaics - Systematic VHR HEC processing to orthorectify and co-register multi-temporal 2 m multi-spectral imagery compiled as user defined regional mosaics to provide an easily accessible

		evaluation dataset for LCLUC program mapping efforts. We will apply a consistent image normalization approach to minimize the effects of topography, view angle, date and time of day of collection. This work builds on PI Neigh (cad4nasas.gsfc.nasa.gov) prior experience and experience of COI's Carroll and Montesano in processing of VHR data on GSFC's NCCS ADAPT (https://www.nccs.nasa.gov/services/adapt) cluster. We will work with experts in the generation of surface reflectance data to develop a process for normalizing the VHR data which will yield scientifically valid mosaics that can be used to investigate biodiversity, tree canopy closure, surface water fraction, and cropped area for smallholder agriculture. 2) On Demand VHR DEM generation – Systematic VHR HEC processing of available within track and cross track stereo VHR imagery to produce VHR digital elevation models with the NASA Ames stereo pipeline (https://ti.arc.nasa.gov/tech/asr/intelligent-robotics/ngt/stereo/). We will apply a consistent vertical normalization with ICESat to merge and mosaic DEMs systematically to provide products that can support other NASA missions for a number of different programs. These could potentially include earth surface studies on the cryoshpere (glacier mass balance, flow rates and snow depth); hydrology (lake/water body levels, landslides, subsidence) and biosphere (forest structure, canopy height/cover) among others. Successful development of a HEC protocol to process VHR data could foster surmounting prior spatial-temporal limitations found with using these data on an individual PI basis with broad benefits to many NASA programs.
92782	Framework for Mining and Analysis of Petabyte-size Time-series on the NASA Earth Exchange (NEX)	Time-series analysis is key to understanding and uncovering changes in the Earth system. However many currently available geospatial tools only provide easy access to the spatial rather than the temporal component. Therefore the burden is on the researchers to correctly extract the time-series from multiple files for further analysis. While inconvenient, this is often achievable on a small scale, but to search for trends across millions of time-series, quickly becomes a huge undertaking for individual researchers, because apart from scaling the analysis algorithm itself it requires much effort in large-scale data processing, metadata and data management. Additionally, for most researchers in Earth sciences, there are almost no tools that would enable easy time-series access, search and analysis. Finally, there are limited places where algorithms supporting novel time-series approaches can be tested and evaluated at scale. Given the importance of time-series analysis to Earth sciences, we view it as an opportunity to engage and bring together Earth science, machine learning and data mining communities - an important goal of the NASA Earth Exchange (NEX) project. The overall goal of the proposed effort is to develop a platform for fast and efficient analysis of time-series data from NASA's satellite and derived datasets at large scale (billions of time-series from 100's of terabytes to petabytes of data) that would be deployed on NEX and accessible in both supercomputing and cloud environments. While the initial focus will be on deploying the technology to support NEX and NASA users, the overall system will be developed as a flexible framework

		that can easily accommodate any user's time-series data and codes and will be deployable outside NEX using Docker containers. The project will significantly enhance the scale of state-of-the-art in time-series analysis, currently several orders of magnitude below the needs of the Earth science community. To accomplish this goal, we will develop time-series indexing and search components based on the Symbolic Aggregate approXimation (SAX/iSAX) that will be able to extract and index billions of time-series from satellite, model and climate data, giving both science and application users an important analysis tool and lower a major barrier in Earth science research. Finally, as time-series analysis is very active field of research, the platform will be developed as a plug-in framework and will be able to accommodate new improvements in time-series analysis, such as different space reduction methods that are first step in the indexing process. Apart from production use on the NEX system, we will deploy the system as a test-bed for users that will drive advancements in time-series analysis research, while providing unified access to billions of time-series. Because of the symbolic nature of the SAX representation, it is possible to deploy a number of algorithms from text mining, deep learning and bioinformatics that will provide giant leap in our ability to analyze time-series data and are already showing good results in other fields. In terms of the current NRA, this project is proposing to develop a data-centric technology that will significantly reduce development time of Earth science research and increase accessibility and utility of NASA data. In terms of specific technology areas outlined in the NRA, the proposed project will provide new big data analytics capability, as well as tools for scalable data mining and machine learning. Through the use of flexible container-based architecture and building upon existing capabilities of NEX and OpenNEX, the system will be demonstrated in both high-performance computing (HPC) as well as cloud environment on AWS. Period of performance for the proposed project is 2 years. The entry TRL is 3 and exit TRL is 6. While this seems like a big TRL jump in two years, given our understanding of the underlying technologies, we believe it is realistic.
92794	Generalizing Distributed Missions Design Using the Trade-space Analysis Tool for Constellations (TAT-C) and Machine Learning (ML)	A large amount of Earth Science data must be sustained or augmented for scientific and operational purposes under constrained budget requirements. Multipoint measurement missions can provide a significant advancement in science return at a manageable cost. Coupled with recent technological advances, this science interest drives a trend toward distributed architectures for future NASA missions instead of the traditional monolithic ones. As a general definition, Distributed Spacecraft Missions (DSMs) leverage multiple spacecraft to achieve one or more common goals. In particular, a constellation is the most general form of DSM with two or more spacecraft placed into specific orbit(s) for the purpose of serving a common objective. DSMs are gaining momentum in all science domains and in Earth Science they enable new measurements and simultaneous observation sampling increases in spatial, spectral, temporal and angular dimensions. Additionally, DSMs are expected to increase mission flexibility, scalability, evolvability and

		robustness, to facilitate data continuity, and to minimize cost risks associated with launch and operations, thus responding to both data needs and budget constraints. However, distributed architectures also carry a risk of being "robust-yet-fragile," a paradoxical behavior where poorly-understood interdependencies lead to unexpected failures. Considering both the upside potential and downside risk of DSMs requires careful evaluation of operations in a simulated environment. Furthermore, a DSM architectural trade-space includes both monolithic and distributed design variables subject to combinatorial factors. As a result, DSM optimization is a large and complex problem with multiple conflicting objectives. Our proposed solution to these challenges develops an open-access tool which will be available to the scientific community for pre-Phase A constellation mission analysis. Over the last two years, our team has developed the prototype Trade-space Analysis Tool for Constellations (TAT-C). By enumerating and evaluating alternative mission architectures, TAT-C minimizes cost and maximizes performance for pre-defined science goals and helps to quantify and evaluate specific DSM challenges such as data calibration. TAT-C is suitable for missions ranging from smallsats to flagships and is based on existing modeling and analysis capabilities developed at NASA Goddard. TAT-C currently addresses basic capabilities required for pre-Phase A constellation design with a general framework and has already proven valuable in analyzing imaging systems. Its implementation provides improved and integrated capabilities compared to existing solutions; it also enables easy addition of new functionality. This proposal will extend TAT-C to broader Earth Science interests, support additional trades on instruments, spacecraft sizes, launch choices and onboard processing hardware and computations, and extend cost and risk analysis to reconsider requirements of ground operations and mission replanning. The increased number of design variables coupled with combinatorial factors associated with DSMs demand a new Trade-Space Search Iterator driven by machine learning (ML) techniques and working closely with a fully functional and populated knowledge base to efficiently explore and optimize over a tractable design space. The final TAT-C ML software developed under this proposal will provide the Earth Science community a powerful tool to quickly design novel DSMs or augment existing missions to optimize their science return. Without TAT-C, missions would either have sub-optimal performance and science return, or each DSM design team would need to develop an equivalent to TAT-C to enable their mission optimization. Our proposed project responds to the Earth Science Technology Office's AIST Program Operations Technologies Core Topic by designing a tool that will perform mission design trade studies and will enable new types of observations.
92915	High Temperature GaN Microprocessor for Space Applications	Wide bandgap GaN semiconductor has unique material properties that promise high power and high frequency electronics systems. Compared to conventional Si material, GaN has much larger bandgap and lower intrinsic carrier density, which will allow for efficient electronic devices working at high temperatures. Compared to other high temperature

		materials such as SiC, GaN has much higher mobility, which will lead to electronic device with much higher speed and microsystems with higher clock frequency. In this proposal, we plan to demonstrate a GaN-based microprocessor that can work efficiently under high temperature (e.g., > 500°C), which is the first of its kind. Fundamental studies will be performed on the high temperature properties of GaN devices including material defects, electron transports, and thermal stabilities, and their impacts on the performance and reliabilities of GaN microprocessors will be discussed. An interdisciplinary approach is proposed which includes material growth and characterization, TCAD-based device/process simulations, microprocessor chip fabrication, and comprehensive high temperature characterizations. The realization of this microprocessor represents a potentially disruptive technology that will enable electronics system based on wide bandgap GaN devices with greater efficiency, much reduced size and weight, and higher operation temperature, all of which are highly desirable for various NASA and space applications.
92916	High Temperature-resilient And Long-Life (HiTALL) Primary Batteries for Venus and Mercury Surface Missions	Background: Venus, despite being our closest neighboring planet, has not been explored extensively due to its hostile and extreme environment. Its surface temperature is as high as 740 K (467°C) and the pressure is 92 bar. Since the environment is relatively mild at high altitudes, several balloon missions were successfully deployed for moderate durations (up to 46h). Surface missions, landers and probes, e.g., Russian Veneras and Vega 2 Lander, however, continued to be of short duration, lasting <2 hours, due to limited survivability of the batteries (typically primary Li-SO2 batteries), payload and the electronics at these temperatures. Objective: We intend to develop and demonstrate, in two years, new high temperature primary batteries survivable and operational at Venus/Mercury surface temperatures (up to 500oC) for longer durations (30 days). These heat-resilient batteries will be based on similar chemistries and battery designs as the thermal batteries currently being used in planetary missions, e.g., Mars Exploration Rover, Phoenix Lander and Mars Science Laboratory, during Entry Descent and Landing (EDL), but will provide longer operational life (>30 days vs. 2h) and higher energy densities (3-4x over state-of-the-art). These systems will have inherent stability under Venus/Mercury environments, enabled by the use of a modified molten salt electrolyte and Li alloy anode, and will be operational over several days, due to reduced heat dissipation losses in the (hot) ambient conditions. Since battery designs and fabrication methods are identical to the thermal batteries widely used in Department of Defense applications, the proposed battery technology can be rapidly developed and infused into future Venus and Mercury surface missions. Approach: Our approach is based on adapting the proven and heritage chemistry and designs of lithium thermal batteries and modifying both cell designs and components for extended lifetimes in Venus environment. These batteries will be based on new Li alloy anodes, alkali halide molten salt electrolytes and high energy metal sulfide cathodes with high

		temperature stability. In the thermal batteries, the (solid) electrolyte is transformed into a molten and conducting state, with pyrotechnic materials and initiators. These batteries provide high power densities, but only for short durations (of <2h), depending on how long the cell remains hot. Prior to activation, however, these batteries have a long shelf life (>10 years). For the proposed batteries, the high ambient temperatures on Venus will be used to activate them and also enable them to retain heat and operate for longer durations than standard thermal batteries. Specific modifications will include minimizing/eliminating pyrotechnic activation in lieu of in-situ activation from the hot environment, reducing thermal insulation and reducing can thickness. These modifications will result in Gen-1 prototype high temperature batteries with a lifetime of 30 days, specific energy (>100 Wh/kg) and energy density (200 Wh/l). In parallel, we will develop advanced anode/cathode and electrolyte materials and use them in high-energy battery designs to further improve the energy densities to 150 Wh/kg and >200 Wh/l, and to increase the operational life to >30 days at 500oC (in Gen-2 batteries). Benefits: The proposed batteries will enable Venus/Mercury surface missions of >30 days (vs 2 h for current batteries). Their inherent thermal resilience will make the design of the lander/probe less complex and more flexible. Combining the heritage battery designs with our prior experience on the chemistry and manufacturing of high temperature batteries, we anticipate a rapid maturation of the proposed battery to a TRL 4 in two years. These batteries will also be beneficial to several terrestrial applications, e.g., guided missiles, sonobuoys and radar and electronics packages for nuclear weapons.
92917	High Temperature Memory Electronics for Long-Lived Venus Missions	The Hot Operating Temperature Technology Program proposal call seeks to advance "high temperature electrical and electronic systems that could be needed for potentially extended in situ missions…". Electronic systems are a core component of any extended mission affecting, e.g., instruments, communications, and operations. In particular, high temperature electronics are needed in order to "mitigate the risks of mission concepts…and expand the range of science that might be achieved with future missions", esp. those in harsh environments. Decadal notes that technology development is critical "for surface access and survivability, particularly for challenging environments such as the surface of Venus". VEXAG similarly emphasizes "Development of high-temperature electronics, sensors…designed for operating in the Venus ambient would be enabling for future missions". Long-lived high temperature electronics have an identified pathway for potential infusion in a future long-lived Venus mission. A Science Mission Directorate project begun in FY17, Long-Life In-situ Solar System Explorer (LLISSE), is developing a functioning prototype of a low-cost scientific probe capable of providing basic but high-value science measurements from the surface of Venus continuously for months or longer. Activities in this project include demonstration of prototype probes designed to withstand the surface conditions of Venus and

		communicate periodic measurements of temperature, pressure, wind velocity and direction, and chemical composition to an orbiter. These periodic (every 8 hours or better) measurements are over a long duration: a Venus daylight period and the transitions at either end, or approximately 60 Earth days, and provide unique and significant science impact. NASA Glenn Research Center (GRC) has unique capabilities to enable such a mission, and is presently being funded to provide the electronics for LLISSE. This is based on recent breakthroughs in notably expanding electronics capabilities with the world's first microcircuits of moderate complexity that have the potential for sustained operation at 500˚C. Further, operation of these electronics operating for extended periods in-situ in Venus surface atmospheric conditions has also been demonstrated. The electronics for LLISSE includes sensor control and signal processing, power supply management, and communications. The LLISSE approach uses electronics without memory relying on periodic communication of the real-time measured environmental data. This present proposal leverages the electronics development ongoing in LLISSE to address a core capability of broad use, but not part of the LLISSE approach: high temperature memory electronics. The objective is to develop a fully functional 500°C memory packaged circuit operating in-situ for use in long duration Venus missions. The memory is composed of both RAM (Random Access Memory) and ROM (Read Only Memory) chips capable of interfacing with mission control logic and sensors. Both memory types have significant, but different, impact on potential Venus missions. RAM can be written or read as needed for storing and recalling mission data or operations software, while ROM would provide the logic instructions needed for initial power-on or recovery of the mission control logic from serious fault conditions. In particular, this proposed work will develop RAM and ROM technology with supporting electronics with 128 bit and 512 bit capability respectively operable above Venus temperatures (500°C) for at least 3 months, and in Venus surface conditions for 60 days. This work will verify basic compatibility of this memory technology with the system being developed in LLISSE. This work demonstrates for the first time memory electronics operable in Venus surface conditions for extended periods and demonstrates the feasibility of an initial memory "toolbox" for broadening the architecture choices for future missions and decreasing mission risk.
94318	High accuracy laboratory studies of x-ray emission from He-like ions for interpreting spectra from the X-ray Astrophysics Recovery Mission	The launch and successful operation of the Soft X-ray Spectrometer (SXS) calorimeter instrument on the Hitomi X-ray observatory proved transformational. Although only a single high-statistics, high-resolution spectrum was measured, covering the broad energy range between ~ 2 and 10 keV, the resulting advances of our understanding of the physics taking place in the cluster have been profound. During the analysis of the spectrum, however, it was found that many atomic parameters are not known to the accuracy necessitated by the high resolution SXS spectrum. For example, transition energies and line strengths found in the standard models were not adequate to interpret the Perseus spectrum, and in some cases significant differences between standard

		models exist, even in the case of strong lines in the helium-like K alpha complex of Fe24+. Some of the problems were addressed using existing laboratory data, i.e., high accuracy measurements of the K-shell transition energies were required for reliably fitting the SXS Perseus spectrum. However, because of the high quality Perseus spectrum, uncertainties in x-ray line strengths, even those on the 10% level or better, are limiting. Here we propose high accuracy measurements of line emission from helium-like ions of astrophysically relevant ions. The measurements will be made using the Lawrence Livermore National Laboratory's electron beam ion trap EBIT-I coupled with high resolution calorimeter spectrometer built at NASA/GSFC and high resolution crystal spectrometers built at LLNL. These measurements will be made at monoenergetic electron impact energies and also as a function of Maxwellian electron temperature using the EBIT Maxwellian simulator. Particular emphasis will be made on the strength of the forbidden line and in experimentally accounting for polarization effects. These data are particularly important for interpretation of high resolution measurements of a plethora of new sources by the calorimeter instrument to be flown on the X-ray Astrophysics Recovery Mission (XARM), as well as the X-IFU spectrometer to be flown on ATHENA.
94323	Grain Formation Processes in Oxygen-Rich Circumstellar Outflows: Testing the Metastable Eutectic Condensation Hypothesis and Measuring Atom-Grain & Grain-Grain Sticking Coefficients (A Sub-orbital Investigation)	An experimentally-based model of grain formation in oxygen-rich circumstellar outflows that includes vapor-solid nucleation, grain growth, thermal annealing and grain aggregation in sufficient detail to predict the spectral energy distribution (SED) of the shells for comparison with observations of a wide range of stellar sources still lacks critical data. In order to gather this data we propose to conduct a series of laboratory experiments using our proven experimental system and microgravity condensation, growth and grain aggregation experiments on sounding rockets with a flight-proven payload provided by Dr. Yuki Kimura of Hokkaido University. We have proposed that solids from a hydrogen-rich, supersaturated, Fe-Mg-SiO vapor condense at metastable eutectic points in this ternary phase diagram. Because the FeO-MgO system is totally miscible (has no eutectic or metastable eutectic compositions), this predicts that condensates will be pure Mg-silicate or Fe-silicate grains and that no primary condensate will be a mixed Fe-Mg-silicate. We have shown that this observation leads to a logical explanation as to why pure magnesium olivine and enstatite minerals are detected in circumstellar winds rather than the mixed Mg-Fe-silicate grains that might otherwise be expected (Rietmeijer, Nuth & Karner, 1999). This simplifying hypothesis has been built into our models of circumstellar condensation and growth. However, these experimental results require confirmation and testing since they should apply to other, quite similar condensable systems. We propose to test this hypothesis by condensing solids from the Fe-Mg-AlO ternary vapor system. Since FeO-MgO miscibility also applies to this system, the primary condensates from such a vapor should consist of pure amorphous Fe-aluminates and Mg-aluminates. No mixed Fe-Mg-spinels should be detected as primary condensates if this hypothesis is correct, just as none were detected for

		the FeO-MgO-SiO system. Confirmation of this hypothesis would be a major step in establishing a simple, chemical kinetic model for the nucleation, growth and annealing of circumstellar oxide dust. Since strong convective flows in the terrestrial laboratory make it almost impossible to measure the growth and aggregation of freshly condensed, refractory grains, we will conduct experiments in microgravity to eliminate these flows. We propose to measure the efficiency of grain growth from simple SiO, AlO and FeO vapors and the sticking coefficients for dust coagulation via analyses of the grain morphology and size distribution of condensates collected and returned to earth during each rocket experiment. We will discuss the unique experimental systems used to produce our analog samples and the general nature of these materials. We note that these experimental systems were not designed to produce samples at equilibrium like typical petrologic systems. Indeed, they were designed to make samples that will help us to understand the properties of materials produced under highly dynamic conditions, quite far from equilibrium, that are often found in nature wherever steep temperature, pressure and/or compositional gradients result in highly unequilibrated solid systems. This design is an advantage as it presents the chance to compare and contrast samples produced at equilibrium with unequilibrated samples in order to identify distinctive traits that could be used to identify conditions under which natural samples have been formed. We will describe both the laboratory system and the rocket payload. We will present data from previous experiments in these systems and discuss why recovery of the flight payload and analyses of the particles produced is essential to build a rigorous, laboratory-based model of grain formation in astrophysical environments.
94325	Precision Optical Coatings for Large Space Telescope Mirrors	This proposal "Precision Optical Coatings for Large Space Telescope Mirrors" addresses the need to develop and advance the state-of-the-art in optical coating technology. NASA is considering large monolithic mirrors 1 to 8-meters in diameter for future telescopes such as HabEx and LUVOIR. Improved large area coating processes are needed to meet the future requirements of large astronomical mirrors. In this project, we will demonstrate a broadband reflective coating process for achieving high reflectivity from 90-nm to 2500-nm over a 2.3-meter diameter coating area. The coating process is scalable to larger mirrors, 6+ meters in diameter. We will use a battery-driven coating process to make an aluminum reflector, and a motion-controlled coating technology for depositing protective layers. We will advance the state-of-the-art for coating technology and manufacturing infrastructure, to meet the reflectance and wavefront requirements of both HabEx and LUVOIR. Specifically, we will combine the broadband reflective coating designs and processes developed at GSFC and JPL with large area manufacturing technologies developed at ZeCoat Corporation. Our primary objectives are to: •Demonstrate an aluminum coating process to create uniform coatings over large areas with near-theoretical aluminum reflectance •Demonstrate a motion-controlled coating process to apply very precise

		2-nm to 5-nm thick protective/interference layers to large areas, •Demonstrate a broadband coating system (90-nm to 2500-nm) over a 2.3-meter coating area and test it against the current coating specifications for LUVOIR/HabEx. We will perform simulated space-environment testing, and we expect to advance the TRL from 3 to >5 in 3-years.
94335	Development of a Robust, Efficient Process to Produce Scalable, Superconducting kilopixel Far-IR Detector Arrays	We propose to develop and streamline the fabrication processes required to produce background limited large far-infrared arrays with large pixel numbers n ~10^5. We will achieve this goal by combining mature detector and readout technologies from our previous work, to fabricate a robust, close packed high sensitivity bolometer array with reliable high-quantum efficiency absorbers that operates over the entire FIR range and can be efficiently and reliably produced. The simplified process will integrate detector arrays through superconducting bonds to a cold readout multiplexer. It is very versatile in its applications, since it will allow the mating of TES detectors to time domain, frequency domain, microwave and code division multiplexers. The main objectives will be achieved by meeting the following goals: a) Develop a novel BUG architecture in which the superconducting through via proces is separated from the detector production, improving production speed and reducing risk. b) Production of background-limited 5-kilopixel arrays suitable for the FIR spectrometer Super-HIRMES. For the latter we will additionally: c) Refine our AlMn process for quickly and reliably fabricating TES with highly predictable and uniform transition temperatures (better less than 5% variation) across the entire wafer d) Refine a standard process for reliably fabricating impedance- matched and robust absorbers for the entire FIR wavelength range, which are not susceptible to room temperature aging
94339	Correlator Array-Fed Microwave Radiometer Component Technologies	Multiband passive microwave imagery in X to W Bands (e.g., 10, 18 or 19, 22 or 24, 37, 86 or 89 GHz) has a nearly 40-year history of utilization for measurement of multiple geophysical parameters. For example, quantities retrieved include precipitation rate, integrated water vapor, integrated cloud liquid water and ice, ocean surface wind speed, snow water equivalent, sea ice concentration, and land surface temperature (for evapotranspiration). Spatial resolution is limited by aperture size, and although aperture sizes have grown to 1-2 meters, current capability will not meet future science spatial resolution needs. As geophysical models have improved, the need has emerged to improve spatial resolution further to < 5 km. Improved spatial resolution in turn leads to a need to populate the antenna with additional radiometer elements to preserve noise performance (NEDT) and to provide adequate spatial sampling of Earth's surface. We propose to develop key building blocks of a multi-band correlator array that would feed a large reflector antenna to generate multiple radiometer beams on Earth. The envisioned system (relevancy scenario) would image Earth at 36.5 and 89.0 GHz with 2 to 3 km spatial resolution and at 10.65, 18.7 and 23.8 GHz with 5 to 10 km resolution from 700 km altitude with approximately 0.5 to 1 K NEDT. At 36.5 GHz, the proposed spatial resolution is a 10X

		improvement over the legacy polar-orbiting capability SSM/I and SSMIS and a 3X improvement over the modern AMSR2 radiometer. The correlator array feed will also enable a conical scanning radiometer to image with 50% overlap between footprints (complete Nyquist sampling). Today's state-of-the-art radiometers do not provide spatial Nyquist sampling in all of these microwave bands. The key proposed development is a broadband line array covering 10-90 GHz appropriate for illuminating a large deployable reflector and will be developed by industry partner Nuvotronics Inc. A trade-study and design will be performed for integrating calibration noise coupling, frequency multiplexing, and low noise amplification into the beam forming structures. A brassboard sub-scale correlator array-fed radiometer will be developed at 36.5 GHz and elevation scanning of the main beam will be demonstrated. We will enter at TRL 2, mature the technology during a two-year period of performance (Jan. 2018 to Dec. 2019), and exit at TRL 3.
94395	The High-Resolution Coronal Imager (Hi-C) Reflight	One of the most challenging problems in solar physics is understanding the mass and energy balance in the solar atmosphere; "determining how the Sun's magnetism creates its hot, dynamic atmosphere" is identified as a science challenge by the 2012 Decadal Panel. Numerous theories have been introduced to explain the million-degree corona since its discovery in the 1930s; most predict energy release in the corona itself at spatial scales that have been too small to be resolved by previous instrumentation. In the past decade, a new appreciation of the importance of the solar chromosphere has emerged: not only does this region of the solar atmosphere undoubtedly supply the mass to the solar corona and solar wind, it may also be the location of the fine-scale energy release that drives coronal heating. We have a unique opportunity to capture evidence of the small-scale chromosphere-coronal connection by acquiring images with the High-resolution Coronal Imager (Hi-C) co-spatially and co-temporally with chromospheric images and spectra from the Interface Region Imaging Spectrograph (IRIS), all at the sub-arcsecond spatial resolution that recent models indicate is required. Hi-C was selected to complete this science mission in the 2014 LCAS opportunity. During this second flight of Hi-C, the passband of the telescope was changed to be 17.1 nm, considered to be the best match for the science goal. Additionally, the original Hi-C camera, which had roughly 120 electron RMS noise, was replaced with a low-noise camera with 7 electrons RMS noise. The mission flew in July 2016. Unfortunately, the cable controlling the camera shutter was shorted when tightening the connectors before the vibration test at the White Sands Missile Range. Because flight filters were installed (meaning visible light could not easily get through the system), this short was not found during post-vibration testing. The camera shutter did not operate during flight and no science data were captured. The instrument was recovered intact. We propose to fly Hi-C again in the early summer of 2018, roughly four to six months after we receive Authority to Proceed, and capture this rare data set. To facilitate this rapid turn-around, significant

		preparations will occur before ATP. The camera shutter wire will be replaced and a hall effect sensor added to the shutter controller card so that the shutter operation can be verified after flight filter installation. The alignment of the telescope will also be confirmed. After ATP, the avionics and cables will be reintegrated and end-to-end tested. The payload will then be ready for reflight. Often payloads are flown in a series of evolving configurations to refine the instrument concept or to provide calibration data for satellite instruments. Payloads are also launched multiple times if the value of the data for scientific investigations warrants subsequent launches. The first flight of Hi-C, capturing 345 seconds of data in the 19.3 nm passband, was launched on July 11, 2012. Hi-C obtained the highest spatial resolution and highest cadence images of the EUV solar corona ever achieved. Those few minutes of data have thus far generated more than 25 refereed publications, including the first ever observation of coronal braiding and associated energy release (Cirtain et al., 2013). This is arguably one of the most scientifically successful sounding rocket payloads ever launched by NASA and certainly the most valuable for Heliophysics. A Hi-C launch in 2018 in close coordination with IRIS will provide a unique dataset that will lead to breakthrough science. Our data will provide major new insights into the close coupling between heating in the chromosphere and corona that is predicted by recent state-of-the-art numerical models of solar atmospheric heating.
94399	Loss through Auroral Microburst Pulsations (LAMP)	The Loss through Auroral Microburst Pulsations (LAMP) mission will provide the first simultaneous in situ measurements of pulsating auroral and microburst electron flux, in conjunction with extremely high frame rate optical images of the aurora, to determine the spatio-temporal relationship between auroral microbursts and pulsating aurora and to fully characterize the precipitating electron distribution of the auroral microbursts to determine if they contain a relativistic, radiation belt component. Therefore, LAMP is a vital first step in quantifying the auroral contribution to magnetospheric electron loss, and potentially radiation belt loss, through microburst precipitation. This sounding rocket mission is led by Dr. Sarah Jones (Goddard Space Flight Center) with an FY20 launch from Poker Flat Research Range (PFRR, winter 2019/20). LAMP will characterize the distribution of microbursts with respect to pulsating patches, including measurements of scale sizes and temporal variability, as well as determine the precipitating electron energy distribution and measure ionospheric effects associated with microburst precipitation. The LAMP payload will be instrumented with an electrostatic analyzer and two solid-state telescopes, both ion and electron retarding potential analyzers and a fluxgate magnetometer (MAG). A set of ground-based instrumentation also will be deployed, including several ultra-high time resolution, low light level cameras. LAMP directly addresses the stated NASA Heliophysics goal to "Understand the coupling of the Earth's magnetosphere-ionosphere-atmosphere system" and will make a significant contribution to our understanding of electron precipitation to Earth's atmosphere in the

		form of pulsating aurora and auroral microbursts. Identifying the coupling of a key inner magnetosphere loss process (the role of microbursts in depleting Earth's ring current and radiation belt electrons) to perhaps the most ubiquitous type of aurora on Earth (pulsating aurora) is critical to our understanding of Magnetosphere-Ionosphere coupling.
94413	Preparing the next iteration of the Gamma-Ray Imager/Polarimeter for Solar flares (GRIPS)	We request funding to further the maturation of the NASA Gamma-Ray Imager/Polarimeter for Solar flares (GRIPS) concept. GRIPS consists of a spectrometer cryostat equipped with position-sensitive germanium detectors (3D-GeD), and a thick tungsten grid mounted on an eight-meter boom, the Multi-Pitch Rotating Modulator (MPRM). GRIPS's nominal energy range is 30 keV to 10 MeV, imaging down to 12.5" with a 1 degree field-of-view. Though its single monogrid and position-sensitive detector approach is novel, the GRIPS imaging concept borrows heavily from the successful NASA Ramaty High Energy Solar Spectroscopic Imager (RHESSI) satellite. GRIPS's goal is to do imaging spectroscopy of solar flare gamma-ray lines, investigating such questions as "how can accelerated electron-produced and accelerated ion-produced emissions be 20'000 km apart on the Sun?", "are flare electrons accelerated isotropically?"; "how can gamma-ray sources high in the corona be so long-lived?". These questions fall in line with the NASA Heliophysics Research Program's stated goals to "Determine the origins of the Sun's activity and predict the variations in the space environment", and "Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe." As a high altitude balloon payload, GRIPS recently successfully completed its maiden flight from Antarctica. During the flight, two major electron precipitation events, each lasting several hours, were recorded in the 3D-GeD and in the BGO anti-coincidence shields. However, only small to medium solar flares occurred during the flight, and none produced enough counts to be imaged by GRIPS. At the end of the flight, all data vaults were promptly recovered, but the rest of the payload had to spend the Antarctic winter on the ice. In order to finalize the validation of the GRIPS concept, and in preparation for its next iteration and a future spacecraft version, we seek funding to: 1) refurbish the recently returned from Antarctica GRIPS equipment; 2) evaluate the possibility of replacing the current GRIPS GeD ASICs by newer ones recently developed by the Naval Research Laboratory (NRL); 3) complete the validation of GRIPS's X-ray imaging capabilities by exposing the grid and detector assembly to radioactive sources, for both sets of ASICs. This effort will enable us to finalize the maturation of the GRIPS concept, in time for the next solar maximum.
94425	Miniaturized Inductively Coupled Plasma Mass Spectrometer (ICPMS) for Trace Element Analysis	Trace elements, which are defined by abundances of <1000 ppmw in geological materials, serve as extraordinarily sensitive tracers of a variety of planetary processes including (but not limited to): i) biomineralization; ii) meteoritic infall (i.e., source of exogenous organic compounds); iii) hydrothermal activity and/or aqueous alteration; iv) weathering, erosion and sedimentation; and, v) magmatism, which in turn reflects local

		pressure, temperature and redox conditions in planetary interiors. In the commercial realm, trace elements are most commonly measured via inductively coupled plasma mass spectrometry (ICPMS) techniques, where a high-temperature (10,000 K) plasma effectively serves to atomize and ionize both solid (e.g., crystalline minerals or amorphous glasses) and liquid materials (e.g., water samples or chemical extracts). However, traditional modes of in situ chemical analysis available for planetary exploration, such as laser desorption mass spectrometry (LDMS; e.g., the MOMA investigation on the ExoMars rover) and laser-induced breakdown spectroscopy (LIBS; e.g., ChemCam on the Curiosity rover), are challenged to meet the limits-of-detection that enable the accurate quantitation of trace element abundances. Here, we propose to develop a miniaturized ICPMS that integrates a novel, self-sustaining low-pressure plasma source with an advanced prototype quadrupole mass spectrometer (QMS) based on the heritage design of the LADEE NMS and MAVEN NGIMS spaceflight instruments. The low-pressure operation of the plasma will simplify the design of the interface between the source and quadrupole mass analyzer, as well as reduce pumping requirements, thereby circumventing the need for multiple differential pumping regions found in commercial instruments. A laboratory demonstration of the end-to-end system, which will deliver quantitative, ppmw-level measurements of large ion lithophile elements (e.g., Rb and Sr), high-field strength elements (e.g., the lanthanides), and other transition metals (e.g., redox-sensitive V and Cu) in synthetic (NIST reference materials) and natural silicate materials (Clay Mineral Society phyllosilicates and USGS basaltic glasses) will validate this concept as TRL 4 at the end of the period of performance. The low maturity of the innovative ICP, and the unproven interface between this source and a spaceflight QMS system, define an entry TRL 1. The mission-enabling capabilities that will be realized through this effort will support assessments of planetary habitability, provide context for geochronology measurements, and offer insights into the dynamics of planetary surfaces (including atmospheric inputs) and interiors (and potential tectonic activity). Thus, this technology addresses multiple mission focus areas described in the NASA Decadal Survey and Science Plan. As encouraged by the Planetary Science Division, this effort leverages an emerging technology supported by the Small Business Innovative Research (SBIR) program.
94895	Testbed for High-Acuity Imaging and Stable Photometry	This proposal from MIT Lincoln Laboratory (LL) accompanies the NASA/APRA proposal entitled THAI-SPICE: Testbed for High-Acuity Imaging - Stable Photometry and Image-Motion Compensation Experiment (submitted by Eliot Young, Southwest Research Institute). The goal of the THAI-SPICE project is to demonstrate three technologies that will help low-cost balloon-borne telescopes achieve diffraction-limited imaging: stable pointing, passive thermal stabilization and in-flight monitoring of the wave front error. This MIT LL proposal supplies a key element of the pointing stabilization component of THAI-SPICE: an electronic camera based on an orthogonal-transfer charge-coupled

		device (OTCCD). OTCCD cameras have been demonstrated with charge-transfer efficiencies >0.99999, noise of <5 e-, and quantum efficiency > 90%. In addition to supplying a camera with an OTCCD detector, MIT LL will help with integration and testing of the OTCCD with the THAI-SPICE payload's guide camera.
94896	Supernova Remnant Observations and Dark Matter Searches with Micro-X	Micro-X is a sounding rocket payload that combines an X-ray microcalorimeter with an imaging mirror to offer breakthrough science from high spectral resolution observations of extended X-ray sources. The design and development of this complicated payload has been an ongoing NASA APRA effort which is finally complete and undergoing integration in preparation for launch in February 2018. This three-year proposal seeks funding for: (1) Support of our NASA and NIST Co-I's for the first flight and for analysis of the flight 1 data, (2) design and implementation of payload modifications to optimize Micro-X for a dark matter search and the second flight of the payload from Australia in 2019, and (3) flight 2 data analysis. The scientific payload consists of a Transition Edge Sensor (TES) microcalorimeter array at the focus of a flight-proven conical imaging mirror. Micro-X capitalizes on three decades of NASA investment in the development of microcalorimeters and X-ray imaging optics. Micro-X offers a unique combination of bandpass, collecting area, and spectral and angular resolution. The spectral resolution goal across the 0.2-3.0 keV band is 4-8 eV Full-Width at Half Maximum (FWHM). A reconfiguration of the payload optimizing for "grasp" (Effective Area * Field of View) by removing the mirror and increasing the Field of View (FOV) allows this versatile sounding rocket payload to perform dark matter searches with world-leading sensitivity, as well as studies of the soft X-ray background. Our scientific program for this proposal will focus on supernova remnants (SNRs) and sterile neutrino dark matter. For flight 1, we will observe the Bright Eastern Knot (BEK) in the Puppis A SNR. The spatial extent of SNRs has made high-energy resolution observations with grating instruments extremely challenging. X-ray observations of SNRs with microcalorimeters will enable the study of the detailed atomic physics of the plasma; the determination of temperature, turbulence, and elemental abundances; and to look for evidence of charge exchange and clues to gamma-ray emmission from shock regions. We will continue to advance the technology readiness of TES microcalorimeters while enhancing the science capability of the payload by implementing a series of modifications for the second flight. This entails new higher-resolution detectors and modifications of the payload to allow it to fly without the mirror in a large FOV mode appropriate for dark matter searches and studies of the soft-X-ray background. These modifications for flight 2 enable a unique opportunity for a flight collaboration with the XQC sounding rocket team. The X-ray Quantum Calorimeter (XQC) payload is a wide FOV microcalorimeter spectrometer that has flown five times to study the soft diffuse X-ray background. Our two teams will collaborate on a joint observation campaign to take place from Australia in September 2019. The Galactic Center region is the target of Micro-X

		flight 2. This observation looks for an X-ray line from the decay of dark matter in the Milky Way. Sterile neutrinos with keV mass are theoretically well-motivated dark matter candidates with such a signal. In addition to a general search in the 1-10 keV band, Micro-X will investigate the presence of an observed X-ray line of unexplained origin at 3.5 keV from the Galactic Center. If it detects this line, Micro-X will be able to determine if its energy is consistent with that of known atomic lines in that energy range. In addition, its flux in the wider FOV of Micro-X can be compared with the XMM claim to help distinguish between a point-source or extended-source origin for such a line. Although the science goals for Micro-X flight 2 do not require the XQC data, a combined data set with two observations of the Galactic Center region will increase the sensitivity of the analysis and offer a unique collaborative flight experience for our graduate students and postdocs.
94897	Hyperspectral Thermal Imager (HyTI)	Objectives and Benefits: Design, build, assemble, test and fly a 6U CubeSat Low Earth Orbital (LEO) demonstration of HyTI (Hyperspectral Thermal Imager) as a "pathfinder" enabling the next generation of high spatial, spectral and temporal resolution thermal infrared (TIR) imagery acquisition from LEO. Monitoring Global Hydrological Cycles and Water Resources, and developing a detailed understanding of the movement, distribution and availability of water and its variability over time and space is a critical need for NASA's Decadal Strategy for Earth Observation from Space. An associated need is the measurement of land surface dynamics by monitoring the continuous variability of land surface temperature (LST). While LEO hyperspectral TIR observations will enable detailed measurements of both hydrological and LST variability, the focus will be on enabling agricultural remote sensing. HyTI will be designed to investigate the following global food and water security issues: 1. Mapping both irrigated and rainfed cropland areas; 2. Determining crop water use (actual evapotranspiration (ET)) of major world crops 3. Establishing crop water productivity ("crop per drop") of major world crops. Outline of the Proposed Work and Methodology: SaraniaSat Inc. is the HyTI Principal Investigator and lead for the Science/Technology WBS element. The Hawaii Space Flight Laboratory (HSFL) is responsible for Program Management, System Engineering and efforts in all WBS elements:1 through 11. NASA's Jet Propulsion Laboratory (JPL) will supply the Barrier Infrared Detector (BIRD) focal plane array (FPA) under WBS element 5 (Payload). The novel HyTI technologies to be space validated for the first time via LEO flight are: 1. Hyperspectral Imager: The HyTI Hyperspectral Imager instrument will be designed and developed by HSFL and the Hawaii Institute of Geophysics and Planetology (HIGP). Both HSFL and HIGP have a well-established track record of designing and successfully demonstrating state-of-the-art small satellites and imaging payloads ranging from the visible to the IR, including compact hyperspectral imaging for remote-sensing observations. Based on the Fabry-Perot Interferometer principle, the HyTI Hyperspectral Imager is a unique instrument (TRL 5), and will deliver spatial resolution similar to current Landsat-8 performance, but

		with higher spectral resolution. In a 430 km orbit, the HyTI instrument will have ground sampling resolution of 60m for up to 50 spectral samples in the 8.0-10.7 micron wavelength range, with a peak signal-to-noise ratio of ~500:1. HIGP has successfully demonstrated the proposed "no moving parts" hyperspectral imager for a wide range of Department of Defense programs, as well as for a NASA Instrument Incubator Program. 2. TIR Imager Focal Plane: The heart of the HyTI hyperspectral imager is a 2 Dimensional, BIRD FPA designed and developed at JPL. BIRD imagers have high uniformity, low cost, low noise and higher operating temperatures than previously-flown TIR FPAs. JPL will supply the 2D FPA within an Integrated Dewar Cooler Assembly to HSFL. 3. High-Performance Onboard Computing: Onboard computing (OBC) has been the "holy grail" of scientific, remote-sensing missions. The extremely high volume (estimated 3 Petabytes over a nominal 1 year mission life) of raw hyperspectral imagery justifies the implementation of OBC. SaraniaSat Inc. has developed fast, low computational "footprint" algorithms for weak-signal detection, sensor fusion and orthorectification which, when operating on the advanced Unibap e2160 heterogeneous OBC platform, promise to achieve fast turnaround (within 24 hrs of acquisition) of the processed data and information products. Period of Performance Construction of the integrated 6U Cubesat-HyTI Flight model: 24 months. HyTI flight demonstration:12 months. Total project period of performance: 36 months. Entry and planned exit TRL. Entry TRL: TRL5 Exit TRL: TRL6
94898	Compact Total Irradiance Monitor Flight Demonstration	The long-term balance between Earth's absorption of solar radiative energy and emission of radiation to space is a fundamental climate measurement required in the NRC's Decadal Survey report Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. Total solar irradiance (TSI) has been measured from space by a 40-year uninterrupted sequence of instruments. We propose to build and fly a next-generation TSI instrument on a 6U CubeSat, the Compact Total Irradiance Monitor (CTIM). This instrument will meet the measurement requirements of the previous generation instruments while being compact enough to fit on CubeSat platform. In order to accomplish this the CTIM will utilize new technologies, including silicon-based vertically aligned carbon nanotube (VACNT) bolometers. The goal of this program is to demonstrate and raise the TRL of next-generation technology which will permit the measurement of TSI from a CubeSat platform. This compact, lower-mass instrument has shorter fabrication times and lower costs which should provide more flight opportunities, helping reduce the risk of future TSI-measurement data gaps. This program will run from September 17, 2018 through September 17, 2021. We will first rebuild key elements of the CTIM instrument developed during the CTIM Instrument Incubator Program (IIP) program, incorporating lesson learned from the environmental and performance testing of the CTIM. We will then procure and integrate a Blue Canyon Technologies XB1 CubeSat bus. The integrated system will undergo environmental, performance, and end-to-end testing. The target launch

		date of the CTIM-FD is September 2020. The planned one-year mission will test the on-orbit performance of the CTIM-FD directly against Total and Spectral Solar Irradiance Sensor (TSIS) Total Irradiance Monitor (TIM) currently operating on the International Space Station. During this measurement we will test the initial measurement accuracy of the CTIM, and the long-term stability of the measurements over the mission life. The CTIM entry TRL is 5, based on prototype testing work performed on the Carbon Absolute Electrical Substitution Radiometers (CAESR) Advanced Component Technologies (ACT) project and the related Compact Spectral Irradiance Monitor (CSIM) IIP project. The planned exit TRL is 7-9 based on successful on-orbit operations.
94899	SNOOPI: SigNals-Of-Opportunity P-band Investigation	SigNals of Opportunity: P-band Investigation (SNoOPI) will be the first on-orbit demonstration of P-band (240-380 MHz) signals of opportunity (SoOp). SNoOPI will demonstrate an innovative instrument that shows promise for measuring root-zone soil moisture (RZSM) and snow water equivalent (SWE) from space. Accurate measurement of RZSM, identified as a priority target variable for technology development initiatives in ESAS 2017, is of national importance and critical to food production. Microwave observations at P-band are needed to penetrate into the root zone. Snow provides freshwater during spring and summer for a large portion of the world and plays a critical role in hydrology and water management. SoOp measurements of phase-delay are proportional to SWE, whose measurement was recommended as a program element in ESAS 2017. Conventional P-band radar and radiometers are prone to RF spectrum access problems and require very large antennas to obtain sufficient signal-to-noise ratio or spatial resolution. SoOp reuses signals from existing telecommunications satellites and thus does not require a transmitter, as compared to a radar. Such signal efficiency makes SoOp very cost effective. The objective of SNoOPI is in-space validation of the P-band SoOp technique and a prototype instrument. This is a necessary risk-reduction step on the path to a science mission and will verify important assumptions about reflected signal coherence, robustness to the RFI environment, and our ability to capture and process the transmitted signal in space. Our baseline mission design is driven by this objective, which will be met through demonstrating measurement of the complex reflection coefficient over various land surface conditions and showing that statistics of the reflection coefficient magnitude and phase retrieval meet the working requirements for a future RZSM and SWE mission. We are entering the InVEST program with a TRL5 technique and instrument and building upon our team's success on several competitively selected and internally funded projects. Our instrument consists of three subsystems: 1) The low noise front end (LNFE), developed from the SoOp-AD (IIP-13) airborne demonstration instrument and redesigned for a CubeSat form factor under GSFC internal funding; 2) the digital back end (DBE), a modification of the Cion instrument flying on CICERO that capitalizes on the extensive heritage of the Blackjack and TriG GPS receivers; and 3) an array of COTS antennas. LNFE has a patent-pending

		architecture that uses an internal calibration network based upon our experience with the Aquarius and SMAP missions. It also is capable of antenna swapping to suppress the effects of antenna phase and gain imbalances. RF circuits are shielded from out of band signals and spacecraft-generated electromagnetic interference (EMI). DBE employs a combination of off-the-shelf hardware with a custom-designed RF/CLK/Host board and will be modified to accommodate the rad-tolerant Space Micro CubeSat Space Processor (CSP) to make the instrument suitable for a future NASA Class D mission. Four P-band down-converters and a high-performance sampling clock are used to acquire data in two polarizations from the two antennas (zenith and nadir). Success with SNoOPI will retire the critical risks associated with a P-band SoOp satellite mission, and we will exit with a TRL-7 instrument. This instrument will enable direct measurements of RZSM and SWE that are not presently possible and will also be orders of magnitude lower in size weight and power (SWaP) than comparable active radars due to the re-utilization of powerful anthropogenic signals. Coupled with the use of small, wide beam antennas, a P-band SoOp mission is an ideal candidate for a large constellation of micro-satellites or hosted payloads. This constellation could be proposed to a future Earth Venture/Continuity or Earth System Explorer program.
94900	Compact high-resolution trace-gas hyperspectral imagers, with agile on-board processing	Detecting, mapping, and quantifying dilute trace gases via spectral imaging is a capability of enormous value to the earth sciences, from atmospheric science and climate change, to biosphere monitoring, to volcanology. This capability is technologically demanding, however, requiring both high spectral resolution and high sensitivity, traditionally driving investigators to large, complex instruments requiring expensive large-satellite hosts. Furthermore, high-resolution spectral imaging, i.e. hyperspectral imaging (HSI), generates huge volumes of data that must be subjected to detailed analysis to extract and interpret the gas signatures of interest, something traditionally requiring the large downlink bandwidth only available on large satellite platforms. This proposed project seeks to enable a paradigm shift in spaceborne trace gas spectral imaging, from expensive single-platform instruments, to agile constellations of relatively inexpensive instruments on small satellites. Such constellations could be tailored to offer much more favorable combinations of spatial resolution and revisit time, important, e.g., for monitoring low-level volcanic activity or anthropogenic gas emissions, than could be achieved by any single instrument, even given the constraints and limitations of the small-sat platforms. One can even imagine one satellite in the constellation identifying targets of interest and cueing subsequent satellites to investigate in other spectral regions or at higher spatial resolution. Key to this vision is the development of ultra-compact spectral imagers that are competitive in terms of throughput and resolution with their large-satellite-based cousins, and the development of a fast, sensitive, and computationally efficient on-board processing capability so that huge hyperspectral data sets need not be downlinked for analysis. In this project we propose to

		demonstrate and validate on-orbit both of these capabilities. Under internal funding, we have designed, and are in the process of building, an ultra-compact hyperspectral imager designed to mate with LANL's highly successful CubeSat bus. Operating in the 300-500nm spectral region, with f/2 optics, 0.6nm spectral resolution, 320 spectral channels, and 320 across-track spatial pixels, the instrument would target NO2, SO2, ozone, formaldehyde, and other gases, with sufficient spectral resolution to confidently separate the trace gas signatures from the atmosphere. Scientific missions include monitoring and characterizing anthropogenic fossil fuel burning, and monitoring low-level passive SO2 degassing at volcanoes. In terms of spectral resolution and predicted sensitivity, our miniature instrument is comparable to NASA's Ozone Mapping Instrument (OMI) but is aimed at narrow field-of-view targeted observations (roughly 0.5 km spatial resolution from 500 km altitude) rather than OMI's global mapping. The spectrometer package occupies a 1.5 U CubeSat module; coupled with the LANL CubeSat host and payload interposer module, the entire satellite comprises a 3U system. In conjunction with the optical hardware, we have been developing, and testing on our CubeSat's on-board processor, streamlined hyperspectral gas retrieval algorithms that run many times faster than traditional methods. Tests on OMI data demonstrate that these algorithms can achieve sensitivity comparable to more exhaustive standard approaches. Importantly, the LANL CubeSat system allows for on-orbit software uploads, so that on-board retrieval algorithms can be tested and modified throughout the mission. Our project would build and launch our full CubeSat-hosted HSI system, with the aim of validating our ultra-compact optical and cutting-edge on-board retrieval strategies, and demonstrating competitive, scientifically useful trace gas sensitivities, with rapid-turnaround on-board retrievals, on small-sat platforms.
94902	SLUSH: Thermo-Mechanical Deep Drilling System for Ocean Worlds and Mars	SLUSH: Thermo-Mechanical Deep Drilling System for Ocean Worlds and Mars PI: Kris Zacny, Honeybee Robotics Ocean Worlds and Mars are of particular interest to Astrobiology since they could offer clues in the quest to discover life beyond our home planet. Europa has been a primary target in the search for past or present life because it is still geologically active and has a large ocean underneath an ice shell (despite being smaller than our Moon, Europa has more water than Earth). Therefore, we will focus technology development on Europa. However the proposed technology (with various degree of modification) could also be used on other Ocean Worlds and Mars. To advance forward, a probe would need to destroy the formation and move the drilled material behind it. This can be achieved via two primary methods: thermal and mechanical. Each of these two methods has unique advantages and disadvantages but neither is sufficient to reach the ocean. Thermal probes (e.g. melt probes, closed cycle hot water drills - CCHWD, lasers) are very robust penetrators that require just heat to melt through and advance deeper below the surface. Thermal probes, however, are slow (especially in cryogenic ice), require significant amount of power (kW to 10s of kW, depending on the probe's diameter

		and length), and are inefficient, because >90% of the heat is lost into surrounding ice. Mechanical drilling systems, on the other hand, are approximately 100x more efficient and significantly faster. For that reason they are primary methods of making holes and capturing ice cores in Greenland and Antarctica. They can also penetrate materials other than ice (e.g. salts). The major drawback of these drills relates to chips removal. Chips need to be removed by either periodically lifting the drill with chips basket out of the hole (conventional method used in terrestrial ice drilling) or lifting the chips above the probe and re-compacting them to their original density (e.g. inch worm approach). In summary, mechanical systems have very efficient formation breaking approach while thermal systems have very effective chips removal approach. SLUSH is a thermo-mechanical probe that combines the best from these two techniques: mechanical drill to break the formation and melting to remove the cuttings). However, instead of melting an entire volume of ice, SLUSH melts just a fraction of it to form slush. Slush behaves like liquid but is still partially frozen this enables significant reduction in power draw. Since mechanical approach generates higher penetration rates, SLUSH can also reach the ocean in much shorter time. SLUSH looks like a torpedo with a drill bit in front and anti-torque blades on the side (proven system in Antarctic wireline drills). It houses scientific instruments for in-situ analysis. It is connected to a surface lander by an umbilical for data and power. To reduce power draw from the surface energy supply needed for partial melting, SLUSH incorporates General Purpose Heat Source bricks with ~250 Watt thermal power. Once SLUSH passes through the cryogenic lice (a few km thick), it can use just a thermal approach to melt through the warmer ice without the need for mechanical cutting. Thermal probes are significantly more efficient in tempered (warm) ice. Under PICASSO, the TRL of SLUSH will be increased from TRL2 to TRL4. We would focus on two of the most critical technical aspects: drilling/melting and chips transport. To reach TRL4, we propose to: 1. Develop high level designs and thermal models for cryogenic and warm ice to establish power levels needed for partial melting, and constrain probe's diameter and length. 2. Breadboard critical subsystems that will support TRL4 SLUSH design. 3. Design and build TRL 4 SLUSH and test it in our 5 m tall freezer and in our 3.5 m tall thermal vacuum chamber in Europa analog ice. 4. Update high level SLUSH design based on test data.
95082	Holographic designs for the next generation of ultraviolet spectrographs	Ultraviolet Spectroscopy is an essential element in the space astronomy portfolio, and the next ultraviolet spectrograph will need to have enhanced performance in sensitivity, resolution, and multi-object capability. Whether part of a flagship, probe, or explorer class mission, the next generation of ultraviolet spectrographs should be able to take advantage of technological improvements in all aspects of their designs. Work is currently ongoing in the areas of optical coatings and detectors, but the diffraction gratings remain at the same state-of-the-art as those currently employed on HST on STIS and COS. To address the limitations of the current state of-the-art, I propose to develop holographically

		corrected designs utilizing low-order echelle gratings, to demonstrate how future spectrographs could provide the most performance for a future flagship or probe mission. These designs will employ aberration correction in their design (similar to FUSE and COS) to minimize the reflections and enhance their capabilities will providing high efficiency and low scatter. Straw-man holographic designs for HABEX and LUVOIR will be raytraced and published as a proof of concert of what could be achieved. A custom spectrograph design conforming to either a selected decadal UV flagship mission architecture, or a probe architecture, will be developed after the decadal releases the survey results. All work will be published in the proceedings of the SPIE.
95083	Laboratory Studies of Dissociation Recombination with Cold Molecular Ions for Diffuse Cloud Studies by NASA Astrophysics Missions	We propose to advance our understanding of how diffuse atomic clouds transition to diffuse molecular clouds, an important first step in the star formation process. Observing this transition is challenging as H2 lacks a permanent dipole moment, making direct detections extremely difficult. Also, the commonly used H2-surrogate CO is readily photodissociated in diffuse clouds. We will improve the community's ability to use OH+, HCl+, and ArH+ to trace out the astrophysical properties of this transition. These molecules enable us to measure in diffuse clouds the cosmic ray ionization rate of atomic H, to infer the molecular hydrogen fraction, to constrain the far-ultraviolet interstellar radiation field, and to use proxies to trace out the difficult-to-detect H2 molecule and infer H2 column densities and masses. Using OH+, HCl+, and ArH+ to trace out the properties of diffuse clouds requires an accurate understanding of the underlying gas-phase astrochemistry controlling the abundances of these molecules. Key to this are reliable rate coefficients for dissociative recombination (DR) of electrons with OH+, HCl+, and ArH+. Accurate quantum mechanical calculations are lacking due to the theoretical and computational challenges of handling the many-body systems and the infinite number of intermediate states involved. Laboratory measurements are the only reliable means to generate the needed DR data. But previous experimental work is of limited use due to the moderate to high levels of internal excitation of the molecular cations (typically ~300-1000 K), which is much hotter than diffuse cloud temperatures. We will carry out the first DR measurements for OH+, HCl+, and ArH+ with internal excitations of ~10 K, generate DR data suitable for astrochemistry, incorporate these data into diffuse cloud models, and investigate the astrophysical implications of our new chemical data. The DR measurements will be carried out using the recently commissioned heavy ion Cryogenic Storage Ring (CSR) which is located at the Max Planck Institute for Nuclear Physics (MPIK) in Heidelberg, Germany. No other facility in the world is capable of carrying out the proposed DR measurements. Furthermore, we will investigate the astrophysical implications of our new DR data using astrochemical models which we have developed to interpret diffuse cloud observations. For data management, we will publish our findings in refereed journals. The data behind the figures and tables in our papers will be made available electronically through supplementary material

		provided with the published papers. Our research into diffuse clouds addresses NASA's Strategic Goal 1: "Expand the frontiers of knowledge, capability, and opportunity in space". The expected advances in knowledge from our work meets NASA's Strategic Objective 1.6: "Discover how the universe works, explore how it began and evolved, and search for life on planets around other stars". Our findings will thereby enable us to address the Science Goal of NASA's Science Mission Directorate Astrophysics Division, namely "[e]xplore the origin and evolution of galaxies, stars, and planets that make up our universe". Specific NASA missions that our proposal is relevant to include: Herschel Space Observatory, Hubble Space Telescope, Infrared Space Observatory, Kuiper Airborne Observatory, and Stratospheric Observatory for Infrared Astronomy.
95084	Hard X-ray multilayer coatings for HEX-P and other future missions	OBJECTIVES: To enable construction of next-generation hard X-ray telescopes, this project aims to (a) develop Co-, Ni-, and Pt-based X-ray multilayer coatings having high reflectance up to ~200 keV, in order to maximize telescope effective area and extend energy coverage beyond NuSTAR, and (b) develop techniques to mitigate multilayer-coating-stress-induced deformation of thin-shell mirror substrates, in order to achieve hard X-ray telescope angular resolution of 15 arc-seconds or better. METHODS/TECHNIQUES: The proposed project comprises two parallel investigations: one focuses on the development of new hard X-ray multilayers, the other on the development of new deposition techniques that will work with these multilayer coatings to mitigate stress-induced deformations of thin-shell mirror substrates. In support of the first investigation, new multilayers will be designed, fabricated, and tested using established procedures: both depth-graded and aperiodic multilayers will be designed with our IMD software; prototype coatings will be deposited using magnetron sputtering; coating structure and properties will be analyzed using X-ray diffraction, atomic force microscopy, transmission electron microscopy, wafer curvature, and other techniques as required; and "at-wavelength" performance will be measured using our novel hard X-ray reflectometer. Film deposition conditions and techniques that yield optimum performance will be identified, and in particular a new ion source will be used for ion-assisted growth of light metal films in order to realize sputtered Ni- and Co-based multilayers having lower roughness, and thus higher reflectance, than can be otherwise achieved. In support of the second investigation, two complementary techniques will be explored to mitigate substrate deformation resulting from multilayer film stress, extending to hard X-ray multilayer coatings similar techniques that are now being developed for Ir-based coatings operating at lower energies for Lynx. The two mitigation techniques are: 1) stress-balancing using Cr adhesion layers; and 2) double-side coatings acting in opposition. Both techniques will be explored in order to identify the most effective approach. Surface figure of both glass and silicon thin-shell segments, provided by GSFC, will be measured before and after coating using optical interferometry. Two-dimensional control of coating thickness, using novel technology already

		under development, will be used to spatially control film stress and thereby achieve sufficient figure preservation in thin-shell substrates. SIGNIFICANCE: Coating performance drives both effective area and angular resolution in the case of light-weight X-ray telescopes constructed from thin-shell mirror substrates. Without the development of new multilayer coatings having higher X-ray reflectance, and operating at higher X-ray energies, it will not be possible to meet the sensitivity and energy coverage requirements of future missions such as HEX-P. Additionally, without new techniques that sufficiently mitigate coating-stress-induced substrate deformations in thin-shell substrates, it will not be possible to achieve the higher angular resolution required for HEX-P or other future missions enabled by multilayer-coated X-ray telescopes designed to address key science objectives of NASA's Physics of the Cosmos (PCOS) program.
95085	The DEUCE and INFUSE Sounding Rocket Payloads: EUV and Integral Field Spectrographs for Next-generation Space-flight Hardware Development	We propose a four-year suborbital sounding rocket research program to expand the development of next-generation UV instrumentation at the University of Colorado (CU). The aim of this program will be to: 1) complete the ionizing radiation (Extreme-UV (EUV): 650 - 900 angstrom) measurements of nearby B-stars begun as part of our predecessor award to constrain the contribution of hot stars to reionization in the high-z universe, 2) take advantage of the unique southern launch opportunity in 2020 to make the first-ever flux calibrated measurements of low-mass stars in the 500 - 900 angstrom bandpass, 3) develop the first Far-UV (FUV: 1000 - 1600 angstrom) integral field spectrograph (IFS) as a pathfinder for a next-generation NASA mission instrument, 4) fly the IFS to study the impact of massive stars on their galactic environments by quantifying the shock-velocity distribution in a nearby supernova remnant, and 5) provide training for graduate and undergraduate students, and mentorship for NASA's future space mission PIs. We will carry out these aims with two additional launches of the payload developed under the predecessor award, and the development and flight testing of the new IFS instrument. All work will be performed in a university environment with a long history of postdoctoral and student training in UV astrophysics, heliophysics, and planetary science. In the first two years of the proposed work, we will fly the Dual-channel Extreme Ultraviolet Continuum Experiment (DEUCE) payload twice: first to complete the ionizing radiation census of local B stars, and then to obtain the first EUV spectra of the nearest main-sequence stars. Our group recently completed the first flight of DEUCE to observe the ionizing spectrum of one of the only two B-stars with sufficiently low intervening neutral hydrogen column: beta Canis Majoris. A NASA vehicle subsystem failure prevented successful target acquisition on this flight, so in Year 1 of the proposed work we will launch DEUCE to recover the original science mission. In Year 2, we will fly DEUCE from Australia to obtain the first 500 - 900 angstrom spectrum of the potential exoplanet host stars alpha Centauri A and B. The long-term stability of rocky planet atmospheres is driven by EUV radiation from their parent stars, although this quantity is almost completely unconstrained by

		direct observation. DEUCE will constrain the exoplanet climate models used to interpret the first atmospheric spectra of Earth-like planets that will be obtained in the coming decades with JWST, LUVOIR/HabEx, and other forthcoming NASA missions. In parallel with the DEUCE flight schedule, we will leverage recent advances in technology to demonstrate the first FUV IFS: the Integral Field Ultraviolet Spectroscopic Experiment (INFUSE). INFUSE is a 0.5 meter aperture IFS that utilizes an image slicer at the focal plane to spectrally map a 5 x 4.3 arcminute region with ~ 2 arcsecond angular resolution and moderate resolving power (R ~ 6000) in a single pointing. The INFUSE concept is enabled by the recent development of enhanced reflectivity lithium fluoride (eLiF) mirror coatings and large format, high global count-rate cross-strip anode (XS) boro-silicate glass microchannel plate (MCP) detectors - both technologies identified for maturation and flight-testing by the LUVOIR Science and Technology Definition Team (STDT). In Year 4, we will launch INFUSE to provide the first wide-field spectral maps of the shock velocity structure in a region of the Cygnus Loop supernova remnant.
95086	Stellar Infrared Spectra as a Laboratory Source for Identifying Levels of Neutral Iron and Other Elements	Reliable, comprehensive atomic data are needed to quantify the temperature and heavy-element content of the stars and galaxies that give rise to observed fluxes and spectra. Currently, Fe I laboratory measurements of the energies of its high-lying levels are woefully incomplete. The result is a large number of unidentified absorption lines in the UV and the infrared. In the red and infrared, lines of other neutral elements such as calcium and silicon have a significant presence as well. We have made significant progress on Fe I line identification by using high-resolution, high-quality archival ultraviolet and optical spectra of a dozen warm and cool stars as the Fe I laboratory source, relying on the warmer temperatures of these stars to populate higher excitation levels than is possible with the NIST laboratory furnace. We established the identification and energy of 124 previously unknown Fe I levels by demanding an exact match of the positions of at least four Kurucz predicted lines of each unknown level to observed but unidentified stellar absorption features (Peterson & Kurucz 2015; Peterson, Kurucz, & Ayres 2017). For each newly-identified line that was sufficiently strong and unblended, we determined a semi-empirical gf-value by forcing its observed strength to agree with that predicted by the spectral calculations for each relevant star. Level identifications, their energy levels, and these gf-values are all part of each publication, and the complete Fe I line list with theoretical gf-values is made available on the Kurucz web site at the same time. Here we propose to add stellar infrared spectral comparisons to our arsenal, to expand the energy range of the search for lines of an individual level. This should add enough lines to identify a sizable number of otherwise intractable levels, refine the energies of our previous determinations, and contribute reliable gf-values for all sufficiently unblended infrared lines. Our goal is to double the number of our Fe I level identifications, which should add identifications for nearly 2000 features that are potentially detectable in

		spectra from the UV to the mid-IR in the Sun and red giants. We plan to add identifications for other neutral species where feasible. Our program is highly relevant to the Laboratory Astrophysics solicitation of APRA. It is a semi-empirical study designed to improve the quantitative understanding of the Fe I atom by interpreting observed solar and stellar spectra as the "laboratory" source of Fe I features in absorption with theoretical modeling of the Fe I atom and of the spectra themselves, over a panchromatic wavelength range from the ultraviolet to the proposed infrared. Our infrared spectral observations and analysis techniques are already well suited to this task. Fig. 1 of Peterson et al. (2017) showed that our analysis reproduces very well the high-quality, high-resolution spectra in the H band obtained by others for three stars spanning a temperature range of 1500K. It also illustrates how the infrared spectra pinpoint the positions of newly-identified Fe I lines, which more tightly constrains the energies for the corresponding levels. Infrared line identifications are particularly timely for clarifications of flux distributions of infrared sources at virtually all redshifts, such as those to be characterized with spectroscopy from JWST NIRCam, NIRspec, and MIRI and Keck NIRES. In high-resolution echelle spectra such as those from HST STIS and Keck HIRES, our findings will improve substantially the modeling of individual stellar UV spectral features and the definition of the UV continuum, essentials for deriving reliable elemental abundances.
95087	Applying Supervised Machine Learning Approaches to the Reconstruction of High-energy Tracked Compton and Low-energy Pair Events	Combined Compton-scattering and pair-creation telescopes are a key technology for future observations in the gamma-ray energy range. They are the design of choice of two envisioned future satellite missions, ComPair/AMEGO (Moiseev+ 2017) and e-ASTROGAM (De Angelis+ 2017), and will allow us to perform unprecedented measurements of extreme particle accelerators (e.g. GRBs, AGN), study the life cycle of matter generated in stars and supernovae, search for dark matter signatures, and much more. The standard analysis toolset used by both ComPair/AMEGO and eASTROGAM is MEGAlib (e.g. Zoglauer+ 2006). Its default set of algorithms goes back to the development of the MEGA Compton and pair telescope (Zoglauer 2005). However, while the event reconstruction for untracked Compton events has been advanced in the context of COSI (e.g. Kierans+ 2017), the intermediate energy band (2-3 MeV to ~20 MeV), ranging from tracked Compton events to low-energy pair events, has not seen similar advances. This energy range faces several key data science challenges which have to be overcome, such as (1) determining the direction-of-motion of short electron tracks with 2-4 interacting layers, (2) distinguishing single tracks from Compton recoil electrons which perform turn-arounds (e.g. going from upward to downward moving) from low-energy pair events with large opening angles, (3) deciding if the event is a charged particle, shower, pair, or Compton event with a single or multiple tracks, (4) determining energy lost in passive material for electrons going from tracker to calorimeter or in the structure of the tracker and in non-functioning strips/wafers (both are especially important for Compton events which require that the full

		energy is measured for correct reconstruction), (5) distinguishing the hits in the calorimeter caused by electrons moving from tracker to calorimeter from Compton interactions of the scattered gamma ray, (6) determining the full energy of electron and positron from sometimes very nearby interactions in the calorimeter as an uneven energy distribution between electron and positron influence the origin determination, and (7) identifying Bremsstrahlung hits in the detector, especially for Compton events as they need to be distinguished from additional Compton scatters. For COSI, we have recently seen significant improvements in the performance of the event reconstruction approaches for (untracked) Compton events using supervised machine-learning approaches such as random forests of boosted decision trees and neural networks to find the correct path of the gamma rays in the COSI detectors. Here we propose to apply the latest machine learning approaches to the reconstruction of tracked Compton events and low-energy pair events. The approach taken will be similar to what was done for COSI: using simulations, where the event type and path are well known, train a set of different machine learning approaches (random forests, various neural networks), to perform: (1) decision of event type, (2) clustering of hits which belong together e.g. tracks, (3) determining start point of tracks, (4) determination if hits are from Compton interactions or Bremsstrahlung, (5) estimate energy losses in in passive material, (6) determining the Compton path using electron track information, and more. The best metric to determine the performance of the new approaches is the same as the one used for COSI, the angular resolution measure, ARM, as well as the scatter plane deviation for the track direction. All code developments will be available within the publicly available MEGAlib framework. This proposal for "development of new data analysis methods for future satellite missions" will help unlock the full performance of future tracking Compton and pair telescopes in the difficult transition region, and ultimately further NASA's goal to "discover how the universe works".
95088	Submillimeter Spectroscopy of Sublimated Interstellar Ice Analogues	Currently, high-resolution millimeter/sub-millimeter (mm/submm) spectroscopy is the only method used in the remote sensing of trace, gas phase complex species in the interstellar medium (ISM). Many of the observed species are created in ices and then released into the gas phase, but nearly all experimental studies of ice chemistry to date employ spectroscopic detection in the solid phase coupled with mass spectrometry to trace simple species OR samples are analyzed with chromatography after warm-up. Such studies therefore do not fully follow the physical and chemical routes to the formation of trace gas species in the conditions in which they form or with comparable techniques to those used in remote detection. Our team proposes to conduct a 2-year pilot study that includes experiments on processed ices to definitively measure sublimated molecules and photoproducts and demonstrate the utility of this new technique. Proposed Objectives for Work Plan: - Demonstrate the ability to detect molecules during Temperature-Programmed Desorption (TPD) experiments on H2O,

		CH_3OH, and CO samples, and optimize and calibrate the experimental set-up. - Demonstrate the ability to detect photodesorbed species at submm wavelengths during UV photolysis of H_2O and CH_3OH. - Demonstrate the ability to detect products sublimated during the exposure and warm-up of photolyzed CH_3OH samples. - Compare the results of these spectral studies with other techniques. In order to fully understand the chemistry that leads from molecules within an ice to those in the gas phase of the ISM, we have built an experimental system to study the chemistry above the surfaces of laboratory ice samples during heating and/or photoprocessing and is complementary to ice studies conducted in the infrared (IR). This equipment is already in place and functioning at Emory University in the laboratory of co-I Widicus Weaver. The new experimental setup is designed to detect trace species that are sublimated from interstellar ice analogues by employing submm spectroscopy -- the same technique used for remote observations of complex organics in the gas phase of the ISM. Detection is accomplished by in situ spectroscopy measurements of the released gases during photoprocessing or heating of an ice. This technique offers an unprecedented sensitivity that enables the detection of desorbed photoproducts which cannot be easily distinguished using other common laboratory-based methods (e.g., mass spectrometry, or IR and Raman spectroscopies). We have previously established a proof-of-concept demonstration by detecting the sublimation of H_2O from a prepared ice sample. Here, we will apply this technique to ice samples relevant to ISM. In this new effort, we will study the photo- and thermal desorption products in a series of experiments on simple ices, including CH_3OH, H_2O, and CO, at temperatures ranging from ~10 to 100K to simulate environments in the ISM: including dark quiescent clouds, prestellar cores, and hot cores and hot corinos within star-forming regions. This work represents the first effort to probe the desorbed gases from a processed laboratory ice sample at these wavelengths and provides measurements that can be used in future studies to compare directly to remote observations and indirectly to the results of interstellar chemical models. We will focus in this proposal period on detection of photodesorption and photodissociation products from pure ices as the first application of the new experimental technique. We will also establish protocols that will be applied in future proposal periods to examine the gas phase chemistry from more complex ice mixtures. The anticipated number of new molecular detections with future missions and next generation ground-based observatories can only be imagined. Laboratory studies will be necessary for the analysis of future ground- and space-telescopes, such as ALMA, Origins Space Telescope, JWST, and SOFIA.
95089	Overcoming Systematic Effects In Cosmic Microwave Background Missions	Fluctuations in the temperature and polarization of the Cosmic Microwave Background (CMB) encode a wealth of information about the parameters of cosmology and fundamental physics. The challenge for CMB scientists has always been to detect these tiny signals in the face of potentially overwhelming statistical and systematic uncertainties. While

		statistical uncertainties can be reduced by gathering larger and larger data-sets, reducing systematic effects requires both minimizing them in the design of any mission and mitigating them in the analysis of its data. Next-generation missions will attempt to measure the energy scale of inflation from the imprint of primordial gravitational waves in the B-mode polarization of the CMB. As the faintest CMB signal, at the nano-Kelvin level or below, its detection will require both the largest data-sets ever gathered and the tightest control of systematic effects ever achieved. A critical question in the design of such missions is identifying which systematic effects can already be sufficiently mitigated in software, and which require advancements in hardware to meet its goals. Addressing this question proceeds in three steps, and builds on the CMB mission data synthesis and reduction capabilities developed and deployed at scale in our previous APRA project. Firstly we will develop the the algorithms and implementations needed to mitigate the known systematic effects to sufficient precision, with a particular focus on pre-processing the mission time stream data in order to produce the cleanest possible sky maps. Secondly, since their efficacy will depend on the details of the mission survey strategy, we will optimize the survey parameters with respect to the ability to mitigate systematics. Finally, using this mitigation-optimized survey strategy we will identify the sources of systematics residuals that exceed our science threshold and use them to place requirements on instrument performance. Possible reviewers would include Dr Charles Lawrence (Charles.R.Lawrence@jpl.nasa.gov), Dr Brendan Crill (Brendan.P.Crill@jpl.nasa.gov) and Professor Shaul Hanany (hanany@umn.edu).
95090	Glowbug, a Gamma-Ray Telescope for Bursts and Other Transients	We propose to build and rapidly deploy the Glowbug telescope, a scintillator array to detect and localize gamma-ray transients with performance similar to the Fermi Gamma-ray Burst Monitor (GBM). Glowbug will immediately increase the current sky coverage for short Gamma-Ray Bursts (SGRBs) from neutron star (NS) binary (NS-NS or NS-black hole) mergers. With the recent discovery of the SGRB coincident with the gravitational wave transient GW170817, we now know such events occur with reasonable frequency. Expanded sky coverage in gamma rays is essential, as more detections of gravitational waves from such mergers by ground-based interferometers will come in the next few years, and detecting an electromagnetic counterpart is a powerful probe of merger dynamics. To minimize cost and time to first light, Glowbug is based directly on existing detectors and electronics, and we will exploit the Naval Research Laboratory's access to the DoD Space Test Program (STP) for launch and provision of one year of mission operations at no cost to NASA. This proposal seeks funding to build one instrument and argues the need for an expanded network of such sensors that provides all-sky coverage for SGRB detection. Glowbug will complement existing systems such as Fermi GBM and the Swift Burst Area Telescope (BAT), and it will join future systems such as BurstCube in providing low-cost coverage for gamma-ray transients. We will actively work with the

		BurstCube team to streamline software development and standardize user tools and data products.
95091	Advanced vortex phase masks and techniques	The optical vortex coronagraph has shown great performance advances over the last several years, both in the laboratory and on the world's largest telescopes. Our primary objective here is to push the development of optical vortex phase masks in the directions needed by NASA for coronagraphic space missions currently under study - this includes masks capable of deeper contrasts and broader bandwidths for missions such as Habex and LUVOIR, and removing polarization sensitivity and increasing throughput by developing scalar vortices. Our proposed work has several specific goals aligned with individual mission needs. 1) We will extend the high-contrast bandwidth performance of liquid crystal polymer masks; bandwidths of 20-30% would minimize the number of vortex masks that need to be flown on any given mission, and would allow their effective use with spectrometers. 2) We will develop masks capable of reaching 10e-10 contrast. 3) We will develop masks with a reflective central spot conducive to use with low-order wavefront sensors. 4) We will develop scalar vortices without intrinsic polarization sensitivity. These masks will be tested on our existing Infrared Coronagraphic Testbed at JPL and High Contrast Spectroscopic Testbed at Caltech. The ultimate high-performance, broadband visible wavelength masks would be made available for testing in JPL's general purpose coronagraphic testbed (as part of the SAT/TDEM program, if approved). The ability to image faint exoplanets and disks very close to bright stars is key to NASA's strategic goal of creating a census of extrasolar planets and measuring their properties, and calls for the development of very high-contrast coronagraphic techniques, such as the vortex phase mask, which can reach very small angles. Our planned work will allow us to produce high-quality vortex phase masks specifically needed by NASA's high contrast coronagraphic mission concepts such as Exo-C, Habex and LUVOIR. In the near term, our masks will be used with the Picture-C coronagraphic balloon, and various ground-based telescopes.
95092	Megapixel arrays of superconducting UV single-photon detectors	The LUVOIR mission will benefit from detector pixels which are highly efficient in the UV and NIR, are solar-blind, and have high count rates with low dark count rates. By these metrics, superconducting nanowire single-photon detectors (SNSPDs) are a promising detector technology, but at present no architecture exists which can read out thousands or millions of detectors -- to date, the largest demonstrated arrays have consisted of 64 pixels. We propose to advance the LUVOIR mission and the technological state of SNSPDs by implementing a multiplexing architecture capable of reading out megapixel-scale arrays of SNSPDs. In this architecture, each SNSPD pixel communicates photon detection events to a shared readout line by means of a highly localized thermal coupling. This thermally-coupled readout method not only efficiently

		multiplexes the pixels, but also minimizes electrical crosstalk, allowing each SNSPD pixel to operate independently. In order to bring a valuable UV detector technology closer to implementation in future missions, we propose to develop, fabricate, and demonstrate an array architecture which will enable SNSPDs to be multiplexed at the megapixel scale. Such a detector array based on superconducting nanowires would meet and exceed the requirements for future space telescopes such as LUVOIR.
95093	Next-generation feedhorn-coupled kinetic inductance detector arrays	NASA missions in the millimeter, sub-millimeter, and far-infrared part of the electro-magnetic spectrum universally call for larger arrays of low-noise detectors. The microwave kinetic inductance detector is an important low-temperature-detector technology in these applications, and particularly for deployment in space. Dense, highly-multiplexed arrays with few interconnects and low-power consuming electronics lead to lower-cost, more robust satellite missions. We propose to significantly advance the technical maturity of feedhorn-coupled microwave kinetic inductance detectors (FC-KIDs), by tackling the key challenges that have historically limited MKID performance. These challenges include achieving photon-noise-limited sensitivity at detection frequencies below 1 Hz, maintaining high-quality MKIDs when integrated in more complex superconducting integrated circuits, and attaining high yield by avoiding resonator frequency collisions. We propose innovative solutions to overcome each challenge. We will develop 1) ultra-stable (to 1 mHz), low-noise arrays with aluminum sensors; 2) silicon parallel-plate capacitors with reduced size, loss, and TLS noise; 3) multichroic, dual-polarization-sensitive MKIDs scalable from 100-1000~GHz; and 4) highly uniform, >90% yield direct-absorber coupled MKID arrays fabricated on 150 mm substrates. Each of these research directives is backed-up by solid proof-of-principle demonstrations and concrete development plans. Relevant satellite missions for this technology include Origins Space Telescope, Inflation Probe, and Galaxy Evolution Probe.
95094	Superconducting Nanowire Single-Photon Detectors for Exoplanet Spectroscopy in the Mid-Infrared	Superconducting nanowire single-photon detectors (SNSPDs) have emerged as the highest-performing single-photon detectors from the UV to the mid-infrared. These detectors combine very high efficiencies (> 90% in the infrared at 1.55 um), ultralow jitter (~100 ps or less), zero readout noise, and very low dark count rates (< 10-4 Hz) . Recently, we have developed SNSPDs operating in the mid-infrared from 2 - 7 um. Basic models of the physics of the detection process suggest that by reducing the width of the nanowires to ~ 10 - 20 nm, and tuning the composition of the superconducting material, one may be able to demonstrate single-photon detection at wavelengths extending to 60 um. In addition, recently-developed multiplexing techniques should allow the fabrication of small arrays consisting of ~ 1000 pixels or more, which could potentially be useful for spectroscopy and imaging. The primary advantages of using SNSPDs in this wavelength range are high stability of detector gain as a function of temperature and bias current, true single-photon sensitivity, zero readout noise, and extremely low dark count rate. In addition, SNSPDs would not suffer from many of the

		problems inherent with arrays of currently used blocked impurity band (BIB) detectors such as reset anomaly, last-frame effect, droop, drift, multiplexer glow, and latent images. One of the many goals of the Origins Space Telescope (OST) is the study of exoplanets. This study makes up roughly one-third of the science case for OST. In particular, part of OST's mission is the detection of biosignatures such as ozone, nitrous oxide, and methane in the atmospheres of Earth-sized planets transiting the habitable-zones of nearby stars. The spectroscopy of exoplanet atmospheres requires mid-infrared detector arrays combining high stability over time (a few ppm over several hours), high sensitivity (ideally single-photon sensitive), high system efficiency, and low noise. We propose to develop kilopixel-scale arrays consisting of single-photon-sensitive superconducting nanowire detectors that are sensitive in the range of 6 - 20 um wavelengths that would meet the requirements for any future instruments directed towards exoplanet transit spectroscopy, for example the mid-infrared spectrometer and coronagraph (MISC) planned for the Origins Space Telescope. As outlined above, the excellent stability and single-photon sensitivity of these detectors would be ideal for such an application requiring data collection over the course of hundreds of transits of an exoplanet across its parent star, each of which can last several hours or longer.
95096	Development of integrated readout electronics for next generation X-ray CCDs	The Physics of the Cosmos Program Annual Technology Report of 2017 lists "Fast, low-noise, megapixel X-ray imaging arrays with moderate spectral resolution" as one of the fields with the highest priority for technology maturation. The Lynx large mission concept now under study by NASA for presentation to the 2020 Decadal Survey in Astronomy and Astrophysics includes a notional high-definition X-ray imaging instrument (HDXI). This instrument requires a combination of readout rate, noise, spatial resolution and size that cannot be met by currently-mature technologies. One of the most significant challenges is the targeted 300 fold increase in frame rate compared to Chandra, with constrained power and mass budgets. This technological challenge is being addressed from two sides: improvement of the CCD technology and its output stages; and segmentation of the CCD readout architecture with an associated increase in output nodes. Both approaches require concurrent development of the readout electronics to utilize the novel CCD output stages, to provide the (substantial) increase in channel density to match the CCD segmentation, and to mature the required interconnect and integration technology. Building on our experience with Athena and LSST, and utilizing circuit concepts that have been successfully used for both pn-CCDs (JFET outputs) and DEPFETs (buried gate PMOS pixels), we propose to design, manufacture and test a prototype readout ASIC suitable for future X-ray missions. This will be integrated and tested with a high-speed Lynx prototype CCD detector currently in development at MIT-Lincoln Labs. We anticipate that our 16-channel prototype ASIC will be capable of reading the MIT-LL CCDs at an output rate of 5Mpix/sec and with a noise performance as low as 3.2 electrons, in line with the requirements for the notional Lynx HDXI. Our

		test setup will leverage existing X-ray detector facilities at MIT, including a commercial data acquisition system, allowing us to study different CCD outputs and their behaviors, various signal filtering options and specific implementations in an efficient and goal-oriented manner. A key aspect of our study is to investigate the feasibility of using massively parallel Analog-to-Digital Converters and digital shaping techniques for signal filtering. In principle, this offers the potential for substantial gains, providing exquisite control in studies of noise, settling times, clock coupling, amplifier response and crosstalk, allowing us to tune for optimum performance with short turnaround times. In parallel, we will also investigate a more traditional state-of-the-art analog filter approach incorporating dual slope integrators, with the potential addition of zero-suppressed readout to reduce the required analog multiplexing bandwidth. Our study would represent NASA's first comprehensive investigation of architectures and requirements for optimized readout electronics for future large-format X-ray imaging detectors. We will deliver a deeper understanding of the merits and challenges of alternative approaches, and recommend a path toward a scalable readout electronics solution for future missions with high-performance, megapixel X-ray imaging sensors.
95097	X-ray Reflection Gratings: Limitations and Improvements	Recent developments in off-plane diffraction gratings have placed them in the context of future NASA X-ray missions including Explorers, Probes, and the large strategic mission Lynx. Our previous NASA-supported efforts have shown improvements in diffraction efficiency, spectral resolving power, and grating alignment techniques. We recently demonstrated impressive diffraction efficiencies using blazed, large format prototype gratings. We have also demonstrated extremely high spectral resolving power using an unblazed, large format, radial profile prototype grating. However, we have not demonstrated high-performance in both efficiency and resolving power in a single grating. Our fabrication studies have identified methods for achieving the desired custom profile in a single grating. We intend to implement these methods during this project to fabricate novel reflection gratings. These gratings will be tested for diffraction efficiency and spectral resolving power to verify performance. In addition, we have also demonstrated promise for an optical alignment methodology. Using results from recent tests, key improvements have been identified that will enable achievement of grating alignment tolerance requirements. During this project we intend to align the newly fabricated gratings using an advanced optical alignment setup. The alignment will be verified using X-ray performance testing before and after environmental testing.
95098	Modeling of the Air Shower Signals from Cosmic Neutrinos for Space-based Experiments	We propose to develop the first comprehensive, end-to-end simulation package for the measurement of cosmic neutrinos that is applicable to sub-orbital and space-based observations. This development is needed to adequately quantify the neutrino potential of NASA's current and future experimental efforts in cosmic neutrino detection, including, ANITA, EVA, EUSO-SPB2, and the POEMMA Astrophysics Probe. The goal is to provide an efficient and practical cosmic neutrino EAS signal

		generation model that will provide a standard to gauge the neutrino measurement performance of sub-orbital and space-based experiments. Sub-orbital and space-based measurements of both the optical Cherenkov and radio emission signals from upward-moving air showers sourced from tau neutrino interactions within and below the limb of the Earth have the potential to measure the astrophysical and the cosmogenic neutrino flux above one PeV. While the existence of the cosmogenic neutrinos is implied by the baryonic component in cosmic rays, the detection of these neutrinos has remained elusive and is one of the most important measurements in Astroparticle Physics. The details of the cosmogenic neutrino spectrum provide invaluable information to the cosmic ray acceleration process, source distribution, and source evolution. Thus neutrinos are a critical and unique component of multi-messenger astronomy and astrophysics. We propose to develop a simulation package that details all aspects of the processes that lead to the air shower signals, based on different neutrino spectra, that could be used by the community as a tool to determine an instrument's neutrino sensitivity. This includes the modeling the neutrino interactions inside the Earth, propagating the tau leptons into the atmosphere, modeling the decays, forming air showers from the decay products, generating the air fluorescence, Cherenkov, and radio signals, and the propagation through the atmosphere. The atmospheric transmission and scattering effects will be modeled in detail including consideration of the uncertainties, such as those due to propagation through aerosols in the atmosphere for the optical signal and due to propagation through the ionosphere for the radio signal. Relevant atmospheric backgrounds, such as air glow, will also be modeled. The modeling will also be easily adaptable for simulating the detectable signals from UHECR and UHE neutrino air showers. This will allow for the investigation of the potential backgrounds associated with the UHECR air shower signals just over the Earth's limb and the reflection off of clouds and the ground of the downward UHECR air shower signals. The modeling will be performed in such a way to easily be used to generate the fluorescence, Cherenkov, and radio signals delivered to a specific altitude for a given instrumental field-of-view. The results of this modeling effort will allow for the calculation of the sky coverage and the pointing requirements for target of opportunity follow-up observations to extremely energetic transient events. Additionally, the framework will allow for the inclusion of different neutrino interaction cross-sections to allow for the modeling of non-standard physical processes.
95099	Improving the Spectral Resolution of Microwave Kinetic Inductance Detectors for UVOIR Astrophysics	Microwave Kinetic Inductance Detectors, or MKIDs, are a UVOIR photon counting, energy resolving detector technology developed almost wholly under the auspices of the NASA ROSES program. Recent advances include very uniform arrays with 20,000 pixels - the largest superconducting arrays in the world. Despite recent gains in quantum efficiency and yield, the spectral resolution of R=E/dE~10 at 1000 nm remains stubbornly far from the theoretical limit of R>60 at 1000 nm. In this proposal we will focus in on energy resolution, deploying the latest

		techniques and materials developed for superconducting quantum qubits to lower two level system (TLS) noise, and use new traveling wave parametric amplifiers to lower amplifier noise. The combination of these two techniques will allow us to increase spectral resolution towards the theoretical limit, vastly improving the potential scientific return of future space-based MKID missions.
95100	Nano-technology for Advanced X-Ray Microcapillary Plates	The spectacular successes of the Rossi X-ray Timing Explorer (RXTE) and its impending shut down highlight the need for a capable successor mission. A large-area X-ray timing mission with 5-10 times the collecting area of the RXTE Proportional Counter Array (PCA) will be capable of probing the physics of extreme density, temperature, gravitation, and magnetic fields in ways that will have impacts on numerous fields of physics. These including measuring the nuclear matter equation of state and the effects of spin on the gravitational field around black holes. The Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X) is the proposed next generation X-ray timing mission. STROXE-X will probe strong gravity for stellar mass to supermassive black holes and ultra-dense matter with unprecedented effective area, high time-resolution, and good spectral resolution, while providing a powerful time-domain X-ray observatory. Currently, STROBE-X is baselined for glass-based micropore collimators (MPC). MPCs have dramatically less mass and volume than collimator traditional designs, enabling large missions at modest cost. The disadvantage from MCPs is that they are made entirely of glass. Glass has a low X-ray 'stopping power'. We propose to dramatically improve MPC collimator technology by adding metal layers to the inside of the micropore walls. All fabrication techniques can be applied to large area MCP arrays. Prototype will be tested for performance at the MSFC Stray Light Facility and the thermal and mechanical properties that affect its use in a full instrument concept will be studied.
95101	Measuring the cosmological evolution of gas and galaxies with the EXperiment for Cryogenic Large-aperture Intensity Mapping (EXCLAIM)	The EXperiment for Cryogenic Large-aperture Intensity Mapping (EXCLAIM) is a high-altitude balloon spectrometer designed to deepen our understanding of star formation in a cosmological context. It will map the sub-mm emission of redshifted carbon monoxide (CO) and singly-ionized carbon ([Cii]) lines in windows comprising $0 < z < 3.5$. These lines trace the precursors of star formation but have only preliminary characterization beyond the nearby universe, with most previous efforts limited to the brightest objects or galaxies selected in other surveys. Rather than detect individual galaxies, EXCLAIM will measure the statistics of brightness fluctuations of redshifted, cumulative line emission. This approach is known as intensity mapping, and the Enduring Quests Daring Visions Roadmap establishes it as a priority in the Visionary Era, to "completely map the content of selected volumes of space that represent slices through all of cosmic time." EXCLAIM is a pathfinder to future missions that will probe early star formation and reionization. A blind, complete census of redshifted CO and [Cii] addresses New Worlds, New Horizons Decadal Survey priorities to understand baryons in galaxies and the context of their dark matter

		halos. EXCLAIM will address significant outstanding questions: What factors led to the dramatic decline in star formation from z~2 to the present? What is the typical abundance and excitation of the molecular gas which forms stars? How well does CO trace H_2 in our galaxy? Is intensity mapping a viable approach to push to high redshift? We will address these questions by flying six redundant spectrometers configured from 421-540 GHz (lambda/delta_lambda=R=512), permitting cross-correlation of [C ii] 158 um and CO J=6-5, 5-4, and 4-3 emission with galaxies in the Baryon Oscillation Spectroscopic Survey (BOSS). EXCLAIM's strategy is to start with the most feasible intensity mapping demonstration: the brightest emission lines at relatively low redshift in cross-correlation with a rich spectroscopic galaxy catalog. EXCLAIM is the only CO/[C ii] intensity mapping survey specifically designed for corroborated cross-correlation, and takes advantage of overlap with BOSS that is only possible in a conventional flight from the North. Conventional flights simplify logistics and reuse, making this a versatile instrument for testing sub-mm technology in a space-like environment. Due to dramatically reduced column depth and pressure broadening at float, the atmosphere has windows that approach space-like photon backgrounds and are significantly darker than emission from 300 K telescope optics. To exploit these low photon backgrounds, EXCLAIM employs an all-cryogenic telescope (1.5 K) with a 74 cm projected aperture coupled to the microSpec on-chip spectrometer. microSpec implements an on-chip Rowland spectrometer coupled to kinetic inductance detectors. Lithographic construction achieves mass and volume much lower than free-space gratings, making the architecture appealing for future space-borne instruments. Our team has led the field in the development of large, balloon-borne cryogenic apertures, the on-chip Rowland spectrometer, and intensity mapping through cross-correlation. EXCLAIM reuses the design of the Primordial Inflation Polarization ExploreR (PIPER) gondola, housekeeping electronics, software, and 100mK cooling with a continuous adiabatic demagnetization refrigerator. Commissioning (2021) and science (2022) flights are planned. Using data from these flights, we will constrain models of galaxy evolution, and enable new approaches to studying our universe.
95102	On-orbit X-ray telescope figure monitoring and control for adjustable X-ray optics for the Lynx Mission Concept	Adjustable X-ray optics are a potential technology to achieve the difficult requirements (imaging resolution, collecting area, telescope size and mass) of the Lynx mission concept - a potential successor to the Chandra X-ray Observatory. While adjustable optics by themselves have numerous technical advantages over more conventional mirror technologies, on-orbit figure monitoring offers the opportunity to utilize the full potential of adjustable optics by enabling mirror figure correction on-orbit in response to disturbances to mirror figure due to the changing thermal environment resulting from varying spacecraft exposure to the Sun. The ability to correct on-orbit for thermally induced changes represents a capability that is non-existent with any other mirror technology, and could prove critical for the first high angular

		resolution thin mirror x-ray telescope. Development of this capability may: (1) ease telescope thermal control system requirements, (2) ease constraints on telescope pointing with respect to the Sun, and (3) relax constraints on mirror mounting athermalization, simplifying design and building Lynx. Our approach to achieve on-orbit figure monitoring and control is to incorporate semiconductor strain gauges directly in the fabrication of the adjustable X-ray optics, and use the measured change in local strain to determine changes in mirror temperature and shape for subsequent [remote] figure correction. Semiconductor strain gauges are used to measure strains as small as 10 parts per billion, consistent with 0.5 arcsec imaging for some bending spatial wavelengths. In this research program, we will develop the capability to direct deposit semiconductor strain gauges on piezoelectric mirror cells, investigate the limiting accuracy of strain measurements, and understand the separate sensitivity of the strain gauges to temperature changes. We will develop the technology to deposit strain gauges insensitive to mirror in-plane strain, and thereby sensitive only to mirror temperature. We will develop analysis algorithms and incorporate measured mirror temperature data to correct the measured bending strain for thermal effects, and develop suitable control algorithms to use that information to correct mirror figure. We will also investigate the short and long term stability of the strain gauges to assess feasibility for a 5 year planned mission plus telescope assembly and potential continued operation post nominal, and methods of determining and accounting for any strain gauge calibration drift.
95103	Momentum Resolved Charge Exchange Cross Section Measurements and X-ray Spectroscopy	In this proposal to the sub-element Laboratory Astrophysics, we aim to deepen our understanding of X-ray spectra from extrasolar sources of highly charged ions interacting with neutral gases. The most common source of these X-rays is from charge exchange (CX) and is observed in the interstellar medium (ISM), Galactic center, near Supernova, and extrasolar stellar winds. The proposal will introduce a new joint experimental facility for x-ray spectroscopy. The measurements will be augmented with charge exchange cross section and spectral computations. The CX measurements will be conducted at the Clemson Electron Beam Ion Source (EBIS) facility (co-I's Sosolik and Marler) which has the ability to produce a beam of charge state selected ions (up to H- and He-like charge states) from injected neutral targets (e.g. Period 2 and 3 elements) with tunable kinetic energies. The PI Fogle will provide a cold target recoil ion momentum spectrometer (COLTRIMS) system from Auburn University to be mated with a high resolution x-ray calorimeter spectrometer from GSFC, to be operated by co-I's Porter and Leutenegger (GSFC) and Brown (LLNL). In conjunction, these components will allow for complete velocity-dependent measurements of x-ray emission and state-selectivity for CX with HCIs that show predominant lines in the 1/4- and 3/4-keV bands. The COLTRIMS system will produce a neutral beam interaction target that will be crossed by an ion beam. The neutral targets will include but not be limited to He, H2, CO and CO2 to be chosen due to their relevance to astronomical observations. Upon

		CX, electrostatic analyzers collect the ionized target recoils and the charged-changed projectiles on time- and position-sensitive detectors in coincidence. This allows for a precise measurement of momentum transfer that correlates directly to the capture state of the CX electron(s). It also allows for the relative determination of multi-electron processes such as double capture autoionization with respect to single electron capture. An incorporated triggerable x-ray spectrometer will provide the x-ray signature in coincidence with information about the beam and target products from the COLTRIMSs will result in a true triple coincidence measurement. Coupled with the experimental measurements will be complementary computational results. The most relevant and reliable theoretical methods for modeling CX are molecular-orbital close-coupling (MOCC) approaches, which require extensive molecular structure and collision dynamics calculations. For multi-electron targets, such as He or molecules, multi-electron processes can become important but have not been incorporated routinely in models. co-I Stancil and his team will merge current MOCC code with the atomic package AUTOSTRUCTURE to compute single and double electron capture processes which will be incorporated in cascade/X-ray emission models for benchmarking against the measurements.
95104	Dust from supernovae: formation, resilience to sputtering and explosion, and diffusion in the interstellar medium	The evidence of significant reddening in high redshift galaxies calls for the production of dust in massive stars and its effective dissemination into the interstellar medium. However, observations and theoretical predictions disagree on the timing of dust formation and its resilience in the harsh environment of an exploding star. We propose to perform a comprehensive study of the nucleation, growth, agglomeration, and possible crystallization of dust formed in supernova ejecta. The study will be based on both analytical calculations and numerical simulations, and a dedicated code for studying the resilience of grains to grain-grain and grain-particle collisions will be developed, based on the physics of granular materials. Differently to previous efforts, we will perform ab initio calculations of the threshold energies for grain polymerization and crystallization, inhomogeneous conglomerates of different grain species, and study the morphology of grains grown by conglomeration of smaller particles as well as the onset of collisions and UV irradiation. This project will deliver robust prediction of the dust yields from stellar explosion into the interstellar medium, including grain species, fluffiness, crystalline structure, and size distribution.
95105	The Evolution of Galactic Structure: Quantifying the Influence of the Most Massive Stars with the ARTEMIS CubeSat	We propose a four year suborbital-class research program to develop, launch, and operate the Astrophysics Research Testbed and UV Emission Mapping Imaging Spectrograph (ARTEMIS): a 6U CubeSat that will address two key questions in astronomy: How do galaxies provide ionizing radiation to the IGM? The transition from a neutral to an ionized intergalactic medium (IGM) was one of the key milestones in cosmic structure formation. Finding the ionizing sources - galaxies and AGN - is a central goal of the James Webb Space Telescope (JWST), but even this flagship cannot solve one critical aspect of the problem: How much of this radiation actually escapes galaxies to reionize the IGM? Webb

		cannot detect the ionizing radiation itself through the opaque high-z IGM, so users will instead use redshifted UV/optical emission lines as proxies. These proxies must be calibrated with direct measurements of ionizing radiation escape in a sample of galaxies at lower redshift. ARTEMIS will directly measure the ionizing spectrum in 100 $0.15 < z < 0.3$ galaxies and AGN, a sample that will surpass in number and precision all ionizing escape measurements to date and provide critical interpretive tools for core JWST science. What controls the mass, energy and chemical flows within galaxies? OB stars dominate the ionization and kinematic drivers of galactic disks through their intense radiation, fast stellar winds, and metal dispersal in supernovae; but how do these processes interact to drive the evolution of galaxies? ARTEMIS will trace feedback in its earliest stages using unique far-UV diagnostics (FUV: 1000 - 1600 angstroms) and a novel spectral imaging observing mode to create multi-dimensional data cube maps of more than 50 local star forming regions and supernova remnants in the Milky Way and Magellanic Clouds. This survey will quantify the physics of radiative and kinetic energy injection into their host galaxies and provide ground-truth to sub-grid physical models in hydrodynamical simulations. ARTEMIS is designed to carry out these astrophysically compelling spectral surveys while serving as a demonstration testbed for the LUVOIR Surveyor - maturing and flight-qualifying technology identified as Priority One needs in the 2017 NASA Cosmic Origins Program Annual Technology Report. The advanced optical coatings and next-generation photon-counting microchannel plate (MCP) detector in the ARTEMIS design represent a paradigm shift for astronomy in the FUV, enabling more optical elements and exceptionally low on-orbit backgrounds without the crippling throughput losses that would occur with conventional technologies. Our extensive on-orbit calibration program will provide critical in situ measurements of their stability and performance ahead of formal adoption by LUVOIR, HabEx, or other NASA Large-, Probe-, or Explorer-class missions. ARTEMIS will leverage these recent products of the APRA, SAT and Roman Technology Fellowship programs to achieve sensitivities comparable to or exceeding previous FUV Explorer-class missions in a CubeSat envelope. The ARTEMIS instrument is comprised of a rectangular Cassegrain telescope feeding a compact, low resolution ($R \sim 1500$) imaging spectrograph. The science instrument is incorporated into a Blue Canyon Technologies spacecraft bus that provides power, command and data handling, attitude control, and communications. Calibration and testing will occur in existing University of Colorado (CU) UV space-instrument facilities alongside other NASA SMD missions. ARTEMIS will be developed in the framework of CU's student-led space sciences program, where undergraduate, graduate, and postdoctoral training is paramount.

95106	MgB2 HEB based heterodyne array for applications above 2 THz	We will develop terahertz (THz) superconducting scalable heterodyne detector technology, with a focus on building large-array receivers above 2 THz and providing a wide instantaneous spectral bandwidth. High-resolution THz spectroscopy is a vital tool for studying molecular cloud structure and evolution and star formation. Large arrays are needed to study extended fields, and the wide bandwidth is required for the study of objects with high velocity dispersion, such as seen in nearby galaxies as well as the center of our Galaxy. The large bandwidth is also required for future projects that will exploit THz interferometry. Under a previous APRA funded task, we have developed a new type of hot-electron bolometer (HEB) mixer using thin superconducting MgB_2 films (T_c =36-38 K) with a sensitivity close to the state-of-the-art (noise temperature ~ 2,000 K in the range 0.6-4.7 THz). In contrast to the SOA NbN HEB mixer, the new mixer has an intermediate frequency bandwidth of 7 GHz as is required for spectroscopy of 2.7 THz [HD], 3.4 THz [OIII], 4.7 THz [OI], 5.2 THz [NIII], and numerous other high-frequency lines. The mixer also operates at 15-20 K which is beneficial for balloon and space instruments. Our current proposal will continue development of MgB_2 HEB mixer with a focus on improved sensitivity, reduced local oscillator power, and achieving an array receiver. Here we are going to develop waveguide mixer elements using MgB_2 devices on Si membranes. Superconducting MgB_2 films on Si have been achieved for the first time in our recent work and we will build our new approach on these results. This will be a 3-year collaborative work with participation of JPL, Temple University (Philadelphia, PA) and University of California Los Angeles (UCLA).
95107	Collisional processes for astrophysics and mid/far-infrared astronomical spectroscopy	Astronomical observations in the mid/far-infrared wavelengths continue to advance our understanding of the evolution of stars and galaxies. The fine structure emission lines in the mid/far-infrared wavelengths arising from, for example, highly-charged atomic ions (mid-IR) and oxygen atoms (far-IR) are important targets of observations with the NASA Astrophysics missions JWST and/or SOFIA, as well as the archival past missions Herschel, Spitzer, and the Infrared Space Observatory (ISO). In the case of ions, because they are created by high energy phenomena originating in cores and shocks of astronomical objects, their fine structure lines bridge data from these missions to data from, for example, Chandra, as well as to optical data from HST. The fine structure emission lines are highly valued diagnostics of energies and densities in galaxies, planetary nebulae, and stars and as probes of warm gases in circumstellar disks and outflows. Diagnostic values of the fine structure emission lines depend on the ionization potentials of the ions as well as their fine structure transitions (leading to emission lines) in response to collisions with electrons, hydrogen atoms, and other species. We will provide reliable calculations of fine structure changing collisions of [O I] and H, [Ne II] and H, and [Ne III] and H using a fully quantum-mechanical scattering approach. The associated excitation and cooling rate coefficients will be applicable to modeling of astrophysical phenomena observed using mid/far-infrared astronomical spectroscopy and traced

		through gas around active galactic nuclei and irradiated protoplanetary disks, with particular relevance to JWST/MIRI, including several Early Release Science projects. The data will lead to better models of ionic fine structure lines as diagnostics of astrophysical environments using spectroscopic observations from air- and space-borne missions in the mid- and far-infrared wavelengths.
95108	Development of a Photon Detection Module for the Detection of Cosmogenic Neutrinos	The measurement of ultra-high-energy neutrinos is a long-standing quest in astroparticle physics. Neutrinos of these extreme energies are produced inside the sources of cosmic rays (CRs) and when CRs of the highest energies collide with cosmic microwave background photons. They help us identify the origin of CRs and tell us about the CR composition. The elusive nature of neutrinos and their low fluxes require large detector volumes, for example, by observing the atmosphere from balloons and space. We prototype and test the photosensor and signal chain of a camera for a wide-angle Schmidt optics that can be deployed on a balloon or a satellite to detect neutrinos. Such an instrument detects flashes of Cherenkov light in the Atmosphere, which are the remnants of tau neutrinos interacting in the Earth. The signal chain uses siliconphotomultipliers as photosensors and AGET ASICs as readout chips. The siliconphotomultiplier is a relatively new detector concept but, nevertheless, widely used in a vast number of applications. It has features, which are of interest not only for the detection of neutrinos but other space missions as well. It is low mass, compact, and robust. Objectives of this project include a thorough investigation of the signal chain in the lab and in the field. The results of this work help to advance the space readiness of siliconphotomultipliers, which is of interest for several proposed missions beyond the detection of neutrinos.
95109	Development of thin-film polymer actuators for high-resolution X-ray optics	We propose to build and test a novel class of low-voltage thin-film actuators based on electroactive polymers to address the need for adjustable mirror control in future high-resolution X-ray missions. Electroactive polymers can produce high strains at low voltages, being able to correct the deformations that submillimeter-thick mirror shells will experience in future X-ray missions. Fabrication of polymer-based thin films is a low-cost, scalable technology that can be easily translated to production by industrial partners. With processing temperatures below 140 degrees Celsius, electroactive polymer films can be deposited on glass mirror substrates without risk of introducing additional slumping errors. The proposed research has four specific aims: i) produce actuator arrays on 3 x 3 square inch mirror substrates to validate the technology and characterize its figure correction capabilities; ii) explore different fabrication techniques and polymer materials for parameter performance optimization; iii) conduct aging, thermal-vacuum and radiation hardness tests to verify the robustness of the proposed technology in space environment; and iv) optimize the geometry of electrode patterns to produce uniaxial, biaxial, and out-of-plane strains that can reduce the complexity of the figure correction scheme. This research presents a viable avenue to meet the requirement of 0.5 arcsecond image resolution for the optical assembly of the Lynx

		mission, one of four concept studies selected in preparation for the 2020 Decadal Survey. With the high imaging resolution enabled by our proposed mirror correction technology, Lynx will be capable of detecting the first accreting black holes, study the evolution of galaxies and growth of cosmic structure, and verify the existence of a Warm-Hot Intergalactic Medium (WHIM) that could account for the large fraction of missing baryonic matter in the Universe.
95110	Development of High-Density Wiring Capability for Advanced X-Ray Microcalorimeters	Microcalorimeters offer exciting opportunities for X-ray astronomy, with energy resolution that is about a factor of 100 better than the silicon CCDs, which is the current work-horse detector technology being used in current imaging spectrometer satellite missions such as Chandra and XMM. Instruments based on the microcalorimeters can help answer a broad range of important scientific questions as noted in the X-ray mission concepts study reported commissioned by NASA's Program Office for the Physics of the Cosmos. "Lynx" has been listed by NASA as one of the four major mission concepts to be studied in the next Astrophysics Decadal Review. One of the key instruments on such a mission would be a very large format X-ray microcalorimeter array, with an array size of over 100,000 pixels. Currently, one of the main limitations on the achievable microcalorimeter array size is due to the challenge of fabricating high-density, high-yield microstrip superconducting wiring between all the pixels in the array, especially when the pixel pitch becomes very small. In order to realize the large focal plane array envisaged for the Lynx X-ray Microcalorimeter (LXM), with over 100,000 pixels (which is a factor of 100 larger than current state-of-the-art), with pixel pitches as small as 25 microns (corresponding to 0.5 arc-seconds) in some regions, fine-pitch multi-level superconducting wiring with high yield is essential. To achieve this, we propose to demonstrate the viability of this approach by building prototype large-format microcalorimeter arrays as a collaboration between MIT Lincoln Laboratory (MIT/LL) and NASA/GSFC. In this approach, MIT/LL would fabricate the base-layer multi-level superconducting wiring layer, taking advantage of over a decade of investment in infrastructure and process development that makes MIT/LL a leader in this field of development. GSFC would then fabricate and test the microcalorimeter arrays, integrating with the MIT/LL wiring. MIT Lincoln Laboratory recently demonstrated a functional chip with a world record integration of over 800,000 Josephson Junctions, in a process utilizing eight levels of superconducting wiring layers each with submicron resolution. The goal of the proposed effort is to demonstrate the integration of the high-density wiring capability with GSFC's new advanced X-ray microcalorimeters using wiring designs consistent with being able to read out full arrays of the scale needed for the LXM. Since there are currently two leading microcalorimeter technologies under development focused on meeting LXM requirements, transition edge sensors (TES) and metallic magnetic calorimeters (MMC), we will develop separate designs for each, and fabricate these designs together for efficiency. If the proposal is accepted, GSFC will support this

		development as part of an existing work package titled, "Advanced X-ray Microcalorimeters". We will optimize the process and design parameters for both detector technologies, and increase sensitivity for the MMCs by using as thin an insulation layer as possible between the sensor and pick-up coil. We will also generate more advanced wiring designs for hybrid arrays utilizing more layers of wiring, incorporating superconducting ground-plane layers in-between micro-strip wiring to avoid cross-talk, and allowing heat-sinking fabrication as would be needed for a full scale array (MMCs and TESs). Further benefits of high-density wiring, such as miniaturization of components, will be investigated.
95111	Germanium Charge-Coupled Devices for Large-Format, Low-Noise Hard X-Ray Sensors	We are proposing to develop large-format charge-coupled devices (CCDs) on bulk germanium, with sensitivity spanning both soft and hard X-ray bands (0.5 - 50 keV). These devices will demonstrate the characteristics that make silicon CCDs desirable for astronomy -- notably large format, excellent uniformity, low read noise, excellent spectral resolution, and noiseless on-chip charge summation -- in a material that covers a wider energy band than silicon. Compared to the cadmium zinc telluride detectors currently used for hard X-ray sensing, these germanium devices will be larger format, exhibit superior spectral resolution, and not require hybrid integration (bump bonding). The proposed work builds on significant internal research and development in this area at MIT Lincoln Laboratory. To date, we have demonstrated functional 1 kpixel germanium CCDs, fabricated in the same state-of-the-art tool set used to build our silicon CCDs and displaying lower read noise than comparable silicon CCDs. The goals of the proposed effort are to demonstrate a 512 x 512 x 24 micron-pitch germanium CCD with dark noise < 1 e-/pixel/second at an operating temperature of 100 K and < 5 electrons of read noise. These developments could dramatically improve the energy resolution and field of view of future imaging missions in the hard X-ray band.
95112	The Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE): a Next-Generation Experiment for Galaxy Evolution Studies	Understanding the formation and evolution of galaxies over cosmic time is one of the foremost goals of astrophysics and cosmology today. The cosmic star formation rate has undergone a dramatic evolution over the course of the last 14 billion years, and dust-obscured star forming galaxies (DSFGs) are a crucial component of this evolution. A variety of important, bright, and unextincted diagnostic lines are present in the far-infrared (FIR) which can provide crucial insight into the physical conditions of galaxy evolution, including the instantaneous star formation rate, the effect of AGN feedback on star formation, the mass function of the stars, metallicities, and the spectrum of their ionizing radiation. FIR spectroscopy is technically difficult but scientifically crucial. The FIR waveband is impossible to observe from the ground, and spans a crucial gap in the spectroscopic coverage between the Atacama Large Millimeter/submillimeter Array (ALMA) in the sub/mm, and the James Webb Space Telescope (JWST) in the mid-IR. Stratospheric balloons offer a platform which can outperform current instrument sensitivities and are the only way to provide large-area, wide-bandwidth spatial/spectral mapping at FIR wavelengths. We propose an aggressive

		program of instrumentation development and experimental study called the Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE), with the goal of demonstrating the key technical milestones necessary for FIR spectroscopy. STARFIRE will provide a technological stepping stone to the future space-borne instrumentation such as the Origins Space Telescope (OST, formerly the Far-IR Surveyor) or a Probe mission. STARFIRE will address the two key technical issues necessary to achieve this: 1) Low-emissivity, high-throughput telescope and spectrometer optics for the FIR; 2) Background-limited detectors in large format arrays, scalable to >10,000 pixels. We will do this by constructing an integral-field spectrometer from 240 - 420 microns coupled to a 2-meter low-emissivity carbon-fiber telescope. The development of the optics will utilize the capabilities of the Arizona Steward Observatory mirror lab and the unique expertise of our spectroscopic experts to create high-throughput optics. For the detectors, we will leverage the highly advanced development work of the Caltech / JPL group to develop and field kinetic-inductance detectors (KIDs). KIDs represent the most promising route to economical, large format submillimeter detector arrays. In addition to the development and demonstration of crucial technologies for the FIR, STARFIRE will perform groundbreaking science. We will survey two 0.1 square degree fields centered on GOODS-S and the South Pole Telescope Deep Field, both of which have rich ancillary data. Scientifically, we will: 1) Obtain spectroscopic line detections of ~100 galaxies in the atomic fine structure lines [CII](158 microns) (at 0.5
95113	The Development of a Low Energy Compton imager for GRB Polarization Studies	The Gamma Ray Polarimeter Experiment (GRAPE) is designed to investigate one of the most exotic phenomena in the universe -- gamma-ray bursts (GRB). There has been intense observational and theoretical research in recent years, but research in this area has been largely focused on studies of time histories, spectra, and spatial distributions. Theoretical models show that a more complete understanding of the inner structure of GRBs, including the geometry and physical processes close to the central engine, requires the exploitation of gamma-ray polarimetry. Over the past several years, we have developed the GRAPE instrument to measure the polarization of gamma-rays from GRBs over the energy range of 50 to 500 keV. GRAPE is a large FoV instrument with a sensitive energy range covering the peak energy distribution of GRBs. The design is based on an array of independent modules, each of which consists of an array of (high-Z and low-Z) scintillator elements read out by a multi-anode PMT (MAPMT). Our eventual goal is to fly GRAPE on a long duration balloon (LDB) platform or an orbiting platform to collect data on a significant sample of GRBs, allowing us to place constraints on fundmental GRB models. Our experience with two balloon flights (in 2011 and 2014), coupled with further design efforts focused on orbital payloads, has led to an improved polarimeter design. The new design employs a large number of optically-isolated scintillator cubes, with independent silicon photomultiplier readout, arranged in a three-dimensional array. The resulting three-dimensional location data

		provides a moderate level of Compton imaging capability (1 sigma angular resolution of 10-15 degrees). The imaging can not only be used to determine the GRB location (albeit with limited accuracy), it can also be used to significantly reduce the instrumental background by limiting the impact of the cosmic diffuse flux, improving the polarization sensitivity. It is the background reduction that is most important in this case. We have already evaluated some components of this design and are now prepared to embark on an effort to fabricate a prototype to be validated on a high altitude balloon flight. The proposed four year program covers the fabrication of a prototype instrument and an engineering balloon flight Palestine in the summer of 2021.
95114	Development of an Ultra-Stable Mid-Infrared Detector Array for Space-Based Exoplanet Transit Spectroscopy	The discovery of the Trappist-1 system, which consists of an ultra cool M-dwarf star orbited by 7 planets, 3 of which are located in the habitable zone, has demonstrated that these types of plane-tary systems around dwarf stars are very common. Such systems are well suited for the study of exoplanets. In particular the search for bio-signatures in the atmosphere of planets in the habita-ble zone around M-stars will be a high-priority science goal of future space missions. The mid-infrared (mid-IR) band between 6 and 15 microns is probably the best available band for this science, because the band contains spectral lines of methane, ozone, and nitrous oxide. The coexistence of those in a planet's atmosphere would be a very strong indicator for life on the planet. Mid-IR transit spectrometers on future space missions such as Origins Space Telescope (OST) will be the instrument of choice to detect these bio-signatures in exoplanets around M-dwarfs. However, current mid-IR detectors are based on impurity band conduction (IBC) devices such as Si:As detectors, which have significant problems with stability. As a result, those detectors are not expected to provide the required stability of ~ 5 ppm needed for a reliable detection of the aforementioned spectral lines. While efforts are under way to improve IBC detectors, it is un-clear how far the performance can be improved. Here we propose the development of an ultra-stable mid-IR Array Spectrometer demonstration for Exoplanet Transits (MIRASET), which includes a calibration system that, as we show, is needed to achieve the required sensitivity for the detection of atmospheric bio-signatures in habitable-zone planets around M-dwarfs. The spectrometer will be demonstrated with arrays of Transition Edge Sensor detectors (TES). These devices are known to be intrinsically very stable and the required detector parameters (sensitivity, dynamic range) for space based mid-IR transit spectroscopy can be easily met with existing devices. No new detector developments are re-quired. This project will include the development of a high-accuracy calibration system with a stable reference source which itself will be monitored by an out of band (0.5 µm) detector at a wavelength at which the precision of the measurements exceeds that of an in-band calibration. This scheme will allow for real time monitoring of the detector gain, which we anticipate will result in a background limited performance with the required stability of better than 5 ppm for the detection of bio-signatures in a

		designated spectrometer flying e.g. on the OST space tele-scope, and as such will help to answer one of NASA's main questions: "are we alone?"
95116	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.
95117	Frequency-agile and high-power terahertz laser local oscillators	Many molecular species that comprise the interstellar medium have strong spectral features in the 2-5 THz range, and heterodyne spectroscopy is required to obtain ~km/s velocity resolution to resolve their complicated lineshapes and disentangle them from the background. Understanding the kinetics and energetics within the gas clouds of the interstellar medium is critical to understanding star formation processes, validate theories of galactic evolution, and to probe protoplanetary disks. The next frontier for heterodyne spectroscopy is the 2-6 THz region - a spectral range which is well matched to the use of terahertz quantum-cascade (QC) lasers as local oscillators (LOs). This proposal looks beyond the state-of-the-art, to the development of large format heterodyne arrays which contain on the order of 20-200 elements. LO powers on the order of 10-100 mW delivered in a high-quality Gaussian beam will be needed to pump the mixer array - not only because of the mixer power requirement, but to account for large losses in LO coupling and distribution. Large format heterodyne array instruments are attractive for a dramatic speedup of mapping of the interstellar medium, particularly on airborne platforms such as the Stratospheric Observatory for Infrared Astronomy (SOFIA), and on long duration balloon platforms where observation time is limited. In our recent work, we demonstrated a new architecture for terahertz quantum-cascade (QC) lasers capable of delivering scalable output power a near-diffraction limited output beam: the quantum-cascade vertical-external-cavity-surface-emitting-laser (QC-VECSEL). The enabling technology for this proposed laser is an amplifying metasurface reflectarray, which is made up of a sparse array of low-quality-factor antenna-coupled sub-cavities loaded with QC gain material. The sub-cavities on the metasurface radiate coherently into a high-quality-factor external cavity mode, which sets the beam shape and allows for scalable power combining. In previous work, we made two key proof-of-concept demonstrations: (a) a 3.4 THz QC-VECSEL which emitted continuous-wave power of 5 mW in a single-mode and in a high-quality beam at a temperature of 83 K with a wall plug efficiency of approximately 0.13%, and (b) the ability to continuously tune the frequency of QC-VECSEL by changing the cavity length, albeit with inconsistent beam pattern, power levels, and occasional multi-moding. Our overarching research goal in this successor proposal is demonstrate the QC-VECSEL as a credible frequency-agile local-oscillator. In the first theme, we propose to achieve 10x improvement in continuous-wave wall-plug efficiency from ~0.1% to

		1% at 77 K, to allow generation of 10-100 mW with 1-10 W power dissipation at frequencies of 2.7 and 4.7 THz. In the second theme, we propose to demonstrate robust and repeatable tunability of a single mode over 15% of its center frequency near 2.7 THz while maintaining beam quality and power. In the third theme, we will demonstrate frequency-locking of the QC-VECSEL to a microwave reference over its tuning range, which is necessary to stabilize the LO output to resolve complicated lineshapes and allow long receiver integration times. This will be a critical demonstration, as the VECSEL cavity is very different than the monolithic THz QC-lasers that have been frequency/phase locked in the past. Furthermore, demonstration of this level of performance in terms of power, efficiency, beam quality, and tunability will be firsts for any type of stabilized THz QC-laser under consideration for a local oscillator, and would enable new possibilities for frequency-agile heterodyne instruments that could access multiple lines of interest. Additionally, in the course of the program, we will demonstrate the first QC-VECSELs at 4.7 THz which is close to the important OI line 4.745 THz (a major coolant for photo-dissociation regions in molecular clouds).
95118	Advanced on-chip, submm-wavelength spectrometers using superconducting detectors.	This program will develop and characterize ultra-sensitive on-chip spectrometers covering the sub-mm and mm-wavelength observing bands from 3 mm to 230 microns. This builds upon a successful program, SuperSpec, which has demonstrated the basic filterbank operation, a proof of principle that large-format spectrographs for the far-IR and submillimeter can be miniaturized onto silicon chips. Using superconducting mm-wave transmission line components and extremely small-volume kinetic inductance detectors (KIDs), we have constructed and are currently preparing to deploy a ground-based demonstration instrument covering the 1 mm atmospheric band. This is a key enabling technology for the next-generation cryogenically-cooled far-IR flight missions as well as near-future sub-orbital platforms such as balloon-based spectrometers and future SOFIA instruments. However, obtaining full scientific return from these powerful future far-IR missions requires 3 crucial advances in the SuperSpec filerbank technology: (1) improving filterbank loss by a factor of >10; (2) improving the detector sensitivity in order to meet the requirements of the low-background space platforms; (3) extending operation from the mm-wave to 230 microns. In order to meet these goals, we will build on our experience with superspec, as well as advances in dielectric material quality, fabrication techniques, and kinetic-inductance detector (KID) design approaches to accomplish each of these goals. A successful demonstration of these technologies will not only benefit future spectroscopic instruments, but will be immediatly useful for instruments operating in the submm and for KID-based instruments designed for a wide range of science targets. We will begin by adjusting the filterbank electromagnetic design for a silicon inner layer dielectric as this promises factors of up to 50 times lower loss than the current materials. We will build and test silicon-dielectric prototypes, beginning at the current 200--300 GHz band, but then moving up to the 400--700 GHz band. We will explore both deposited

		amorphous silicon (a-Si) using a new low-loss recipe as well as a crystalline silicon (c-Si) ''fliped-SOI" process using silicon-on-oxide (SOI) wafers. Meanwhile we will develop more sensitive KIDs to embed in the spectrometers. In particular, we will adapt our spectrometer design to accommodate very small volume aluminum KIDs, which promises significant improvements in sensitivity required for low-loading applications. Finally, we will explore superconducting transmission lines made from both sputtered and atomic layer deposited (ALD) NbTiN and NbN. These materials have a transition temperature much higher than niobium and should allow us to extend the operation of our basic filterbank architecture to THz frequencies. In addition to a number of test structures sample devices, we will produce a series of four demonstration pixels: [FB-1]: a prototype covering the full 200-300 GHz band with resolving power (R) of at least 1000 and negligible dielectric loss. [FB-2]: a similarly low-loss submm prototype covering the 850-650 micron bands with similar resolving powers. [FB-HR]: a mm-wavelength device designed to achieve the highest possible resolving powers, targeting R~5000. [FB-T]: a sparse filterbank covering regions of the 0.8-1.3 THz filterbank to demonstrate high-frequency operation. The first three of these devices are intended to be field-ready at the conclusion of this program, and the fourth easily adapted for future instruments.
95119	Sensitive Mid and Far-IR Kinetic Inductance Detector Arrays for Space Astronomy	Over the past several years, NASA has been intensively studying future astrophysics missions at mid- and far-infrared wavelengths, including the flagship-class Origins Space Telescope (OST) and the probe-class Galaxy Evolution Probe (GEP). These mission studies follow the broad endorsement of a "Far-Infrared Surveyor" mission in the 2013 30-year roadmap study chartered by NASA, and the 2010 Decadal Survey recommendation for NASA participation in the JAXA/ESA SPICA far-IR mission. Not surprisingly, the OST and GEP studies have identified detector arrays as the highest-priority technology needing development. In this proposal, we offer to address essentially all of the fundamental detector needs for OST and GEP and for sub-orbital precursors, including the full 10-400 micron wavelength range, the varied sensitivity requirements, scalability to the desired array formats, and even to open a path toward highly stable photon-counting detectors needed for mid-IR biosignature characterization of terrestrial exoplanets with OST. We address all of these needs in a timely, integrated, highly efficient program by focusing on a single underlying technology, namely direct-absorption (microwave) kinetic inductance detectors (MKIDs or KIDs) using aluminum as the superconducting material. Our proposal aims squarely at the needs for OST and GEP: 1) sensitivity at or below 1e-19 W/root(Hz); 2) array architecture that enables efficient absorption at wavelengths from 10 to 350 micron, and 3) scalability to focal planes of >10^5 pixels. We will begin by increasing the sensitivity of our existing 350 micron feedhorn-coupled devices (which comfortably meet sub-orbital sensitivity requirements) by 1.5 orders of magnitude with a combination of lower operating temperature, higher quality films, and a reduced volume absorber. We will also push to shorter wavelengths,

		targeting first 30 micron and then 10 micron detectors, through use of new, efficient, and practical absorber geometries illuminated by scalable microlens arrays. This mid-IR capability will substantially reduce the cost and complexity of GEP and provide photon counting capability for high-stability mid-IR spectroscopic characterization of terrestrial exoplanets with OST, extending the initial work with JWST/MIRI. A successful conclusion to our proposed program would represent a substantial reduction of technological risk for future NASA mid- and far-IR missions such as OST and GEP, with demonstration of the sensitivity, wavelength range, and array formats needed for the baseline designs developed by these study teams. It would also open a path to high-stability mid-IR exoplanet characterization with OST via photon counting.
95120	The Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE): a Pathfinder for Next-Generation Extragalactic FIR Spectroscopy -- JPL co-I	This is the JPL Co-I proposal for STARFIRE, the main proposal is led by Joaquin Vieira at University of Illinois. Understanding the formation and evolution of galaxies over cosmic time is one of the foremost goals of astrophysics and cosmology today. The cosmic star formation rate has undergone a dramatic evolution over the course of the last 14 billion years, and dust-obscured star forming galaxies (DSFGs) are a crucial component of this evolution. A variety of important, bright, and unextincted diagnostic lines are present in the far-infrared (FIR) which can provide crucial insight into the physical conditions of galaxy evolution, including the instantaneous star formation rate, the effect of AGN feedback on star formation, the mass function of the stars, metallicities, and the spectrum of their ionizing radiation. FIR spectroscopy is technically difficult but scientifically crucial. The FIR waveband is impossible to observe from the ground, and spans a crucial gap in the spectroscopic coverage between the Atacama Large Millimeter/submillimeter Array (ALMA) in the sub/mm, and the James Webb Space Telescope (JWST) in the mid-IR. Stratospheric balloons offer a platform which can outperform current instrument sensitivities and are the only way to provide large-area, wide-bandwidth spatial/spectral mapping at FIR wavelengths. We propose an aggressive program of instrumentation development and experimental study called the Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE), with the goal of demonstrating the key technical milestones necessary for FIR spectroscopy. STARFIRE will provide a technological stepping stone to the future space-borne instrumentation such as the Origins Space Telescope (OST, formerly the Far-IR Surveyor) or a Probe mission. STARFIRE will address the two key technical issues necessary to achieve this: 1) Low-emissivity, high-throughput telescope and spectrometer optics for the FIR; 2) Background-limited detectors in large format arrays, scalable to >10,000 pixels. We will do this by constructing an integral-field spectrometer from 240 - 420 microns coupled to a 2-meter low-emissivity carbon-fiber telescope. The development of the optics will utilize the capabilities of the Arizona Steward Observatory mirror lab and the unique expertise of our spectroscopic experts to create high-throughput optics. For the detectors, we will leverage the highly advanced development work of the Caltech / JPL group to develop

		and field kinetic-inductance detectors (KIDs). KIDs represent the most promising route to economical, large format submillimeter detector arrays. In addition to the development and demonstration of crucial technologies for the FIR, STARFIRE will perform groundbreaking science. We will survey two 0.1 square degree fields centered on GOODS-S and the South Pole Telescope Deep Field, both of which have rich ancillary data. Scientifically, we will: 1) Obtain spectroscopic line detections of ~100 galaxies in the atomic fine structure lines [CII](158 microns) (at 0.5
95121	Integrating Advanced Wavefront Control and Image Processing for High Contrast Imaging	To image potentially habitable exoplanets and acquire spectra of their atmospheres or surfaces, imaging systems must be capable of operating at high contrast, where 'contrast' is defined as the ratio of stellar brightness to planetary brightness. The amount of starlight diffracted into the science pixels, called stray light, must be minimized by combining coronagraphy and wavefront control techniques. It can be removed by actively controlling the diffraction pattern with a deformable mirror, requiring estimation of its amplitude and phase via a wavefront sensing procedure. The fraction of the stay light that can be removed in this way depends on the efficiency of this wavefront sensing step. Even this procedure for actively removing stray light may not be adequate, so, background subtraction techniques are employed in a post-processing step that identifies and removes some of the remaining stray light. The resulting detection limit contrast (the augmented contrast) must be well below the planet's flux level. At the ~1e10 (star-to-planet) flux-ratio characteristic of potentially habitable exoplanets around Sun-like stars, achieving the required raw and augmented contrast levels is extremely challenging. We will enhance wavefront estimation and integrate it with image post-processing, improving both raw and augmented contrasts. The new framework will deliver well-calibrated science images, utilizing the property that most of the stray light that currently limits detections can be reconstructed from wavefront sensing measurements. Our approach relies on three related techniques: [1] Coherent Differential Imaging (CDI) will identify in the coronagraphic image the coherent (=starlight) and incoherent (=planet light) components. The measurement, relying on coherent mixing with reference starlight, was previously developed for wavefront control. We will optimize it for contrast augmentation and develop the associated processing algorithms. [2] Predictive Control (PC) will optimally combine past wavefront measurements to improve both wavefront correction and stray light estimation. [3] Sensor Fusion (SF) will combine measurements from multiple sensors (such as focal plane images, coronagraphic low-order wavefront sensor, and pupil plane sensors) to estimate the wavefront state and the corresponding residual starlight image component. Together, PC and SF will increase the efficiency, sensitivity and reliability of wavefront sensing for high contrast imaging space missions (technology gaps CG-5, CG-7), and mitigate wavefront control challenges associated with large segmented apertures (CG-6). The CDI approach, together with noise estimation from PC and SF, will provide the real-time image calibration making use of stray light

		information contained in the wavefront sensing telemetry (CG-4). In parallel to numerical development and focused testbed explorations at NASA Ames, University of Arizona, and JPL, we will integrate the approaches in a common framework on the SCExAO high contrast testbed/instrument for both laboratory (daytime) and on-sky validation at moderate contrast levels. The testbed already provides the system-level environment required for maturing and validating multi-sensor algorithms and demonstrating their practical implementation. Wavefront-sensor based post-processing of science images will be exercised on on-sky exoplanet observation datasets for end-to-end validation at moderate contrast. Extrapolation to higher contrast environments will rely on numerical validation of achieved results, supported by testbed calibrations. Our effort will benefit from, and validate, recent advances in detector technologies in visible and near-IR (technology gap GC-9) and machine learning techniques. Our team includes experts in these areas, as well as high contrast imaging and wavefront sensing experts.
95122	Development of Adjustable X-ray Optics with 0.5 Arcsecond Resolution for the Lynx Mission Concept	The overarching goal of the proposed work is to X-ray test a Wolter-I pair of adjustable 0.4 mm thick X-ray optics, fully mounted, aligned and figure corrected, to better than 1 arcsec half power diameter (HPD) at 1 keV. This level of performance will demonstrate the wedding of all three key technologies - mirror mounting, alignment, and figure post-mounting - necessary to achieve the challenging requirements of the Lynx mission concept (the envisioned follow-on to the Chandra X-ray Observatory), and will demonstrate TRL4 for the mirror technology. The major efforts of the program will include: 1. the incorporation of row-column addressing of the [piezoelectric] mirror adjuster cells, reducing mirror electrical connections from ~ 324 to 37, 2. modification and fabrication of the single mirror X-ray test mount to support an aligned primary/secondary mirror pair, 3. final development and demonstration of segment pair alignment via a single pass optical Hartmann test to 0.35 arcsec HPD (residual focus and coma errors), 4. correction of residual fabrication errors (including thin film stress related distortions) and correction of mounting induced distortions, and, 5. an X-ray testing "campaign" using the Stray Light Facility at the NASA Marshall Space Flight Center. At present, no demonstration by any technology has achieved the Lynx imaging performance requirements for the combination of coated, mounted, aligned mirror pair with the ~ 0.5 mm thin mirrors necessary to achieve mission collecting area at suitable spacecraft mass. After much development, we believe adjustable optics technology is at the cusp of breaking out and demonstrating this level of performance, and this program will provide the necessary funding to demonstrate the technical feasibility of Lynx mission critical performance requirements for the most critical of all Lynx mission elements, the X-ray telescope.

95123	Ultra-Stable Structures Development and Characterization Using Spatial Dynamic Metrology	The ability to characterize and demonstrate ultra-stable optical structures and systems is critical to several future science missions. Missions like Habex and LUVOIR require telescope structures and optics with picometer class stability over several minute time scales and missions like LISA and X-ray telescopes can also benefit from these technology improvements. This proposal builds upon the significant progress recently made to develop a new high speed spatial metrology system along with a milli-Kelvin stable chamber. It will advance the measurement methods down to the requirements needed for missions like LUVOIR and Habex and it will also use that facility to characterize simple structures, joints, optical systems and ultra-stable optical and composite materials. The result of this work will mature the technology readiness of ultra stable opto-mechanical systems and will help enable future space missions.
95124	Electron Beam Lithography Ruled Gratings for Future Ultraviolet/Optical Missions: High-Efficiency and Low-Scatter in the Vacuum Ultraviolet	This Strategic Astrophysics Technology proposal will develop to technology readiness level (TRL) 6+ a new method of grating fabrication adapted from X-ray astronomy into high efficiency, low scatter gratings for the far-ultraviolet (FUV; 912 - 2000 Angstroms) and beyond. This effort will directly address a high priority technology gap identified in the 2017 NASA Cosmic Origins Program Annual Technology Report as well as support the NASA large mission concepts LUVOIR and HabEx in preparation for the 2020 Decadal Survey and prior to mission PDR in the mid-2020's. We will adapt an electron beam lithography ruling method that has successfully produced low scatter X-ray gratings with diffraction efficiencies within 90% of the theoretical maximum for the FUV by fabricating four gratings for NASA flight projects that will each progressively push the complexity of the technology. This effort will culminate in the fabrication of a prototype variable line spacing (VLS) grating based on the specifications of the LUVOIR Multi-Object Ultraviolet Spectrograph (LUMOS) to demonstrate directly the benefits for NASA's large mission concepts of the future. This proposal will advance e-beam lithography from TRL 3 to 6 by achieving four principal objectives in a three year program: i. Fabricate gratings that match the specifications of three existing NASA sounding rocket instruments, each adding additional layers of complexity (TRL 4). ii. Characterize the efficiency and scatter profile of each grating (TRL 5). iii. Install each into their respective instrument for end-to-end testing (TRL 6) iv. Fabricate and test a grating that meets the specifications of LUVOIR-LUMOS Flight qualification of this fabrication methodology represents the cross-pollination of NASA technology development by including the PIs of technology projects spanning the Physics of the Cosmos and Cosmic Origins programs. This SAT will directly benefit future NASA missions while synergistically leveraging existing flight projects for maximum scientific impact. Each grating fabricated will be flight tested on a sounding rocket platform after demonstration of performance for no additional cost to further raise the TRL to 7.

95125	Scalable micro-shutter systems for UV, visible, and infrared spectroscopy.	Multi-object spectroscopy (MOS) is a technology development priority of the Cosmic Origins Program. Aperture control methods that are popular in ground-based MOS applications (e.g., robotically configured fibers and punch plates) are not practical options for spaceflight. Microshutter array technology solves this problem. A microshutter array functions as a slit mask that can be programmed to provide any pattern of slits corresponding to sparsely distributed sources on the sky. It can also be programed to provide shaped slits on extended sources. Our first generation micro-shutter technology enabled realization of the James Webb Space Telescope (JWST) Near Infrared Spectrometer (NIRSpec). This prior technology involved a combination of electrostatic and magnetic actuation that results in a heavy complex mechanical assembly that does not scale to larger formats required by strategic mission concepts that are under study for the 2020 Decadal Survey. Our Next Generation MicroShutter Array (NGMSA) technology eliminates the magnetic actuation aspect as well as the mechanical complexity and mass associated with it. The result is a simple low mass shutter array that is scalable to very large formats with no life-limited mechanical components. This major breakthrough has been demonstrated to TRL-4 in small 128 x 64 pixel arrays of 200 x 100 micron shutter pixels under prior APRA and GSFC internal investment funding. A prototype of this small format is in testing for space flight on a sounding rocket that is expected to launch during spring of 2019. This proposal requests support to advance the above NGMSA state of art to a 840 x 420 pixel three side buttable format to support strategic mission applications discussed below. The 840 x 420 format NGMSA is an enabling technology for the Large UltraViolet Optical InfraRed surveyor (LUVOIR), the Habitable Exoplanet surveyor (HabEx) strategic missions, and the Cosmic Evolution Through UV Spectroscopy (CETUS) probe-class mission concept studies that are being developed by the Cosmic Origins Program. Each of these mission concept studies have incorporated large format NGMSAs into their study baseline. Micro-shutters remain the only low complexity option for enabling high (>10^5) contrast MOS for spaceflight applications. The wide range of Decadal Survey mission concept studies that are designing around the NGMSA illustrate the broad science pull for advancing the readiness of this technology to meet National science priorities for astrophysics in the next decade. In this proposal, we request support for a tightly focused three year project to bring the 840 X 420 three side buttable NGMSA array from TRL-3 to TRL-5 and to produce two element mosaic assemblies of these arrays tested to TRL-5, to enable MOS science requirements of the above mission concept studies. This proposal team includes collaborators from each of these mission studies to insure alignment with their respective "pull technology" requirements. In order to lend efficacy to evaluation of the LUVOIR, HabEx, and CETUS mission concept studies by the 2020 Decadal Survey, it is imperative that maturation of the 840 x 420 mosaic building block array be approved on this SAT solicitation cycle.

95126	Microwave SQUID readout technology to enable Lynx and other future Great Observatories	In 2013, NASA's Astrophysics Roadmap "Enduring Quests, Daring Vision" identified as one of its large strategic mission concepts a new X-ray surveyor as critical to the advancement of our knowledge of astrophysics and astronomy. The X-ray surveyor, now known as Lynx, is an X-ray telescope to be considered at NASA's 2020 Astrophysics Large Mission Concept Decadal Survey. The majority of the baryonic matter in the universe is visible in either x-ray emission or absorption, and with its high angular resolution and large field of view Lynx will enable unique astrophysical observations, making it a powerful tool for understanding the origins of the cosmos. In order to provide the greatest scientific capability, the detector package for Lynx has been proposed with an aggressive combination of pixel sensitivity and a large number of pixels. The development of the superconducting detectors and the multiplexing schemes to read them out is critical work to enable Lynx, and will benefit a host of other astronomical applications. The central objective of the proposed work is to prove the hybrid combination of hydra-style transition-edge sensors (from NASA) and microwave SQUID multiplexers (from NIST) before the decadal survey. These devices have never been combined, and while there are no obvious technical obstacles and the components have been demonstrated separately (TRL3), we must demonstrate the combination in order to establish the credibility of the technology (TRL4) for the decadal survey. The need for this work was called out as a technology gap "Large-format, high-spectral-resolution, small-pixel X-ray focal plane arrays" identified in the PCOS Annual Technology Report. We propose to first demonstrate the key features of hydra pixels with microwave SQUID multiplexers, and to subsequently perform a direct demonstration of a hybrid scheme with a Lynx-relevant number of pixels per readout channel. In addition, to simplify the detector array readout and ease the risk of high multiplexing factors we will improve readout algorithms, and to enable the extended array we will attempt to reduce the footprint of the readout circuit.
95127	High Resolution and High Efficiency X-ray Transmission Grating Spectrometer	The MIT Kavli Institute for Astrophysics and Space Research (MKI) intends to submit a proposal to the Research Opportunities in Space and Earth Sciences (ROSES-2017) opportunity (NNH17ZDA001N-SAT) under the Strategic Astrophysics Technology (SAT) program element. With previous NASA support, MIT has developed a revolutionary type of lightweight, high efficiency and high resolution diffraction element called a critical angle x-ray transmission (CAT) grating. Concentrated technology development has produced prototype grating elements with high diffraction efficiency and spectral resolution approaching predicted levels. This technology has advanced to the point where it was selected for the Arcus x-ray spectrometer proposal for a NASA MidEx mission which has won a Phase A award. A series of prototype flight grating spectrometers using CAT gratings have been built and x-ray tested, meeting Arcus mission requirements and passing environmental tests. However, the relatively modest requirements for the Arcus spectrometer are not as challenging as would be necessary for a strategic mission such as Lynx. Further advances in grating diffraction

		efficiency, resolution, element size, manufacturability and assembly accuracy will be necessary in order to meet Lynx scientific and cost goals. MIT proposes to develop new grating fabrication technology leveraging the advanced semiconductor industry tools of the MIT Lincoln Laboratory silicon wafer foundry, essentially transferring fabrication processes developed by MIT students on small wafers using research tools in our on-campus lab to the more precise 200 mm wafer tools in Lincoln's Microelectronics Laboratory facility. The improved process control and patterning accuracy enabled by Lincoln's advanced CMOS fabrication tool set are essential to enable the required improvements in spectrometer performance required by Lynx.
95128	Vortex Coronagraph High Contrast Demonstrations	Our objective is to carry out critical performance demonstrations of the optical vortex coronagraph, by extending our previous work to deeper contrasts, broader bandwidths, and segmented apertures. Our specific goals are demonstrations of broadband pseudo-starlight rejection with a clear aperture at the 10e-10 level (first for 10% bandwidth, and then 20%) on JPL's HCIT-2 testbed, and also to carry out complementary high-contrast demonstrations on a segmented aperture testbed. We plan to carry out initial vortex mask and polarizer/quarter-wave-plate characterization on existing test facilities available to us at JPL and Caltech, including a polarizing microscope, a Muller Matrix Imaging Polarimeter, and cross-polarization spectroscopy in the existing Infrared Coronagraphic Testbed at JPL (which also operates in the visible). Muller matrix imaging and cross-polarization spectroscopy are extremely valuable initial evaluation tools that can immediately characterize a vortex's quality, thereby allowing us to better focus on the best vortices in the HCIT-2 facility. Likewise, the High Contrast Segmented Testbed at Caltech will allow initial testing of apodizers and segmented pupil configurations, prior to final tests in JPL's Decadal Segmented Testbed (DST). The HCIT and DST would thus only be used for final deep coronagraphic testing of already vetted vortex masks and apodizers, thus minimizing chamber time and cost, and maximizing efficiency and chamber sharing. Due to their small inner working angle and high throughput, optical vortex coronagraphs are of great interest to potential NASA coronagraphic missions such as Exo-C, HabEx, and LUVOIR, as well as to forthcoming large ground-based telescopes. Indeed, the vortex coronagraph is the primary coronagraphic mode selected by the Habex design study. Moreover, a broadband vortex coronagraph is also planned for the NASA-funded balloon project Picture-C. The vortex coronagraph thus has a very prominent role in NASA's exoplanet plans.
95129	Electron-beam Generated Plasma to Enhance Performance of Protected Aluminum Mirrors	This proposal addresses the need to develop and advance the state-of-the-art in optical coating technology that will be key to providing improvements that are needed to coat the large astronomical mirrors planned for the advanced NASA mission concepts such as the Large UV/Optical/IR (LUVOIR) Surveyor observatory. The proposed LUVOIR mission is a 8-16 m aperture telescope covering 90 - 2500 nm in spectral range, that will unveil fundamental information related to primary NASA

	for Large Space Telescopes	goals, such as the history of galaxies, both the Milky Way and its neighbors, the origins of stars and planets, the demographics of planetary systems, and the search for life. Importantly, the short-wavelength coverage and performance of the LUVOIR mission will be greatly influenced by the performance of optical coatings. Accordingly, improving optical coating technology has been identified as an "Essential Goal" in the technology needs for the LUVOIR Surveyor. Obtaining broadband coatings with a performance of at least 50-70% reflectance below 120 nm is an immediate, high-priority technology investment area, fundamental to mission feasibility that needs further development. Pure, un-oxidized, aluminum presents high reflectance over the whole LUVOIR target spectral range, however it has to be protected from oxidation with a thin film of a transparent material. While no coatings offer transparency between 91-102 nm, above 102 nm there a few candidate transparent materials (LiF, MgF2, AlF3) that provide efficient coatings. Currently, Al protected with the fluorides LiF or MgF2 is a frequently used solution for far ultra-violet optical systems. Importantly, the reflectance of the fluoride protected Al is limited by the residual absorption of the fluoride layer. This proposal aims to enhance the performance of Al-based reflectors by employing a highly scalable, large area, plasma processing system developed at the Naval Research Laboratory to passivate the surface of aluminum coatings with a fluoride layer. The Large Area Plasma Processing System (LAPPS) at NRL is well suited for this task due to its inherently low ion energy (< 5 eV) which allows essentially damage free plasma processing, a critical attribute for maintaining high quality optical coatings. Previous work at the Naval Research Laboratory has already demonstrated the ability of this system to generate 1 m2, highly uniform, sheet-like, plasma ideally suited for the processing of large optical components. In addition, preliminary studies on the passivation of thin Al films have already demonstrated the feasibility of a plasma process, based on benign pre-cursors, for effectively fluorinating the surface of small Al mirror samples. Further advancement of this initial work will develop a scalable treatment of an aluminum surface on a scale as large as 1+ meter diameter. A successful completion of this task would lead to a Lyman Ultra- Violet (LUV) technology which would ultimately enable new scientific imaging capabilities.
95130	First System-level demonstration of high-contrast for future segmented space telescopes	The search for life is one of the next great challenges in astronomy. NASA's 30-Year Roadmap for Astrophysics envisions a search for signs of life in the atmospheres of Earth-like planets using spectroscopy from a large space telescope. NASA is now pursuing three flagship concept studies that will enable this search (LUVOIR, HabEx, and OST). Estimates for the number of Earth-like planets such a mission can detect and characterize increase as the second power of the aperture, motivating telescopes larger than JWST that must be segmented to fit into anticipated launch fairings. It is certain that a mission capable of directly imaging Earth-like exoplanets will include a coronagraph, even if starshades prove to be effective and feasible. Thus, the technological

		challenges presented by high-performance coronagraphy on segmented telescopes must be solved if we are to mount a statistically robust search for life on other worlds. For three years our group has been at the forefront of developing high-performance coronagraph technology for segmented apertures. We have built a robust, flexible testbed, HiCAT, for our Apodized Pupil Lyot Coronagraph (APLC) approach to segmented apertures. By optimizing individual components, we have matured the technology to TRL 3. But for a segmented telescope aiming to achieve 1e-10 starlight suppression, the stability of the wavefront delivered from the telescope presents special challenges to coronagraph performance. The telescope and coronagraph must be considered together and their technologies advanced as an integrated system. This proposal will support us in taking the next logical step in segmented coronagraph technology, achieving TRL 4 first at the component level, then TRL 4 in a full-system context. Our roadmap intentionally parallels the plan for advancing coronagraphs on monolithic apertures to higher TRLs for WFIRST CGI: Coronagraph designs are first demonstrated in a static environment before integrated tests of the full wavefront control system in dynamic contexts. Maturation of technologies on a flexible ambient testbed sets the stage for advanced demonstrations in vacuum. Our roadmap to raise the system-level TRL for high-contrast coronagraphy on segmented apertures will require the following major technical tasks: 1. Ongoing advancement of the shaped-pupil APLC as an individual component, including refinements to mask designs, hardware optimization and tolerancing, and understanding of the impacts of segment-level aberrations. 2. Advancing the readiness of the integrated system, with the coronagraph and a multi-layered wavefront control system working together to sense and correct for dynamic instabilities on the spatial and temporal frequencies of interest in a segmented observatory. 3. Refining and validating performance models for segmented coronagraphy over a range of spatial and time scales, both to directly support the prior two tasks, and to provide improved modeling capabilities for future vacuum tests and mission design studies. Our roadmap will achieve component-level TRL 4 by the end of 2019, during the deliberations for the 2020 Decadal Survey. System-level TRL 4 is planned for mid-2021. This current stage of our plan focuses on advancing technologies as rapidly as possible in air on our HiCAT testbed. Working in ambient conditions has greater flexibility to make rapid advances, refine models with a wider range of component tests, and quickly respond to new findings. Once we have achieved TRL 4 in air, it will be optimal to move to vacuum for higher TRL demonstrations. Our work will directly mature components and algorithms for tests with the JPL "Decadal Survey Testbed'', which is only now beginning. Our close connections with JPL will make this transfer smooth. In this larger context, the work proposed here will provide a clear path to mature technology and help enable a mid-2020s new start for a mission that will search for life on other worlds.

95131	Linear Wavefront Control for High Contrast Imaging	Summary Direct imaging and spectroscopic characterization of habitable exoplanets requires high contrast imaging capability, which is achieved by combining a coronagraph and a high performance wavefront control system. Wavefront stabilization is the most significant fundamental challenge to this endeavour. An Earth-like planet is approximately 1.5e-10 times as bright as the star it orbits, and at λ=500nm, a pupil plane sine wave aberration of 2 picometer amplitude is sufficient to create an equally bright speckle. The wavefront stabilization challenge is fundamentally a tradeoff between sensing sensitivity and optical stability. Imaging systems operating at high contrast currently use focal-plane wavefront sensing and control: unwanted speckles in the focal plane are probed by a known set of deformable mirror (DM) actuations so that their amplitude and phase can be recovered and then canceled by introducing speckles of opposite complex amplitude. This process, referred to as Electric Field Conjugation (EFC), creates in the image a dark field (DF) suitable for high-contrast imaging. Measurement cycles must be repeated sufficiently frequently to track wavefront changes, and can be time-consuming due to the small amount of light available in the DF. The corresponding images may not be scientifically useful due to the added starlight component. We propose an efficient alternative to this process, locking the DF using bright speckles located outside the dark field, in both spatial and spectral dimensions. Changes in these bright field (BF) regions are highly correlated to the same wavefront changes that spoil the deep halo suppression in the DF. Because the BF images are significantly brighter than the DF images, they can be acquired at higher cadence, and no starlight needs to be directed to the DF during science exposures. By calibrating or computing the linear changes in the BF against wavefront changes, a linear dark field control (LDFC) servo can maintain high-contrast in the DF during science exposures. Recent LDFC laboratory results, together with numerical closed-loop simulations, have demonstrated LDFC's concept and critical functions (TRL3) but not validated LDFC in a relevant dynamical environment. We will further mature the approach through (1) advanced numerical simulations, (2) operation in a relevant high contrast imaging instrument system environment and (3) performance demonstration for dark field stabilization at high contrast. LDFC will be operated in spatial (using a bright light outside the dark hole), spectral (using out-of band light in the dark hole) and spatial+spectral modes. System-level dynamical validations will be conducted off- and on-sky at the Subaru Coronagraphic Extreme-AO Instrument (SCExAO) with an integral field spectrograph and multi-band imaging cameras. High performance will be validated at University of Arizona, NASA Ames and JPL's High Contrast Imaging Testbed (HCIT) to demonstrate, without DM probing, speckle stabilization at the 1e-9 contrast level in a 1e-8 stability test environment. LDFC directly addresses the wavefront stability challenge in high contrast imaging by enabling much-needed continuous wavefront updates that would otherwise only be possible on the brightest targets. The bright speckles signal also provide a sensitive

		measurement of residual variations of the electric field in the dark field during observations, allowing accurate calibration of contrast residuals. The wavefront control approaches we will develop will considerably relax stability requirements for future space telescopes and high contrast imaging hardware (such as DMs). On segmented apertures, LDFC will efficiently track and correct segment cophasing errors, enabling coronagraphic imaging with the large aperture(s) required for spectral characterization of habitable worlds.
95132	Development of High-Resolution Far-Infrared Array Receivers	The far-infrared/submillimeter wavelength (60 to 1000 microns, 0.3 to 5 THz) region in astrophysics is dominated by the continuum emission from warm dust with numerous spectral emission and absorption lines of atomic and molecular gas superimposed. A number of large spatial surveys using the Herschel PACS and SPIRE photometers have determined that the dust and gas emission is filamentary in nature at all scales that have been observed . Although these structures are pervasive, large variations in the rate of star formation are observed. The physical processes that give rise to this structure and facilitate or inhibit the onset of star formation remain the subject of a contentious debate between the effects of turbulence and magnetic fields . Another important open question is the transition between the atomic and molecular phases of the diffuse ISM and how this process determines the characteristics of denser material and how in turn this affects the star formation rate. The velocity structure of atomic and ionized gas associated with dense regions, which can address these problems, remains largely unknown and can only be obtained through high resolution spectroscopy. Separation of components of the ISM requires velocity-resolved atomic, ionic, and molecular line profiles. The 2010 Decadal Survey highlighted questions that will require heterodyne technology to resolve, i.e. how do stars form? [PSF1]; how do circumstellar disks evolve and form planetary systems? [PSF2]; what are the flows of matter and energy in the circumgalactic medium? [GAN 1]; and what controls the mass-energy-chemical cycles within galaxies? [GAN2]. The 2013 NASA Astrophysics Roadmap "Enduring Quests, Daring Visions: NASA Astrophysics in the Next Three Decades" identified one of the "Formative Era" missions to be Far-IR (FIR) Surveyor. Heterodyne spectroscopic instruments are the only technical possibility for obtaining velocity resolved spectra in the far infrared. A previously funded SAT Award (NRA NNH13ZDA001N-SAT, PI Imran Mehdi) led to first ever demonstration of multi-pixel Local Oscillator and Mixer components for 1.9 THz spectroscopic imaging. The proposed investigation builds on the previously funded technology effort and further raises the TRL to 6 by building a high-fidelity 16-pixel receiver using a modular concept that can be directly scaled to a large number of pixels. The TRL of this technology will be raised by demonstrating a concept that is scalable to large arrays, reduces DC power, mass and volume, and reduces the required LO power per pixel. Thus, this approach is required for flight missions such as the FIR Surveyor.