Astrophysics Research and Analysis Program
Abstracts of Selected Proposals
(NNH15ZDA001N-APRA)

Below are the abstracts of proposals selected for funding for the APRA program. Principal Investigator (PI) name, institution, and proposal title are also included. 159 proposals were received in response to this opportunity. On September 16, 2016, 54 proposals were selected for funding. On Jan 30, 2017, and additional 6 selections were made. Abstracts for those proposals are at the bottom of this list.

James Aguirre/Trustees of the University Of Pennsylvania
The Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE): A Next-Generation Experiment for Galaxy Evolution Studies

This is the lead proposal for the Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE).

Understanding the formation and evolution of galaxies is one of the foremost goals of astrophysics and cosmology today. The cosmic star formation rate has undergone a dramatic evolution of the course of the last seven billion years. Dust-obscured star forming galaxies (DSFGs) offer the perfect tracers of this evolution as they contain much of the star-forming activity. By their very nature, DSFGs are difficult to study and have, until recently, been poorly understood. A variety of unextincted diagnostic lines are present in the far-infrared (FIR) which can provide insight into the conditions of star formation, including the instantaneous star formation rate, the effect of AGN feedback on star formation, the mass function of the stars, and the spectrum of their ionizing radiation. Spectroscopy in the far-infrared is technically difficult but scientifically crucial. 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 short wavelengths. STARFIRE will provide a technological stepping stone to the future space-borne instrumentation such as the Far-IR Surveyor or a Probe mission. Key to this science is the development of a telescope using low-emissivity, high-throughput optics onto a dispersive spectrometer, and having high-sensitivity, large-format detector arrays.

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 balloon-borne FIR spectroscopy limited by the photon noise from the atmosphere. STARFIRE will address the two key technical issues necessary to achieve this:

1) Low-emissivity, high-throughput telescope and spectrometer optics
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 2.5 meter low-emissivity carbon-fiber telescope. 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. The development of the optics will utilized the capabilities of the Arizona Steward Observatory mirror lab and the unique expertise of our spectroscopic experts to create high throughput optics.

Scientifically, we will

1) Obtain spectra of ~100 galaxies in the fine structure lines CII(158 micron) ($0.5 < z < 1.5$), OI(63 micron) and OIII(88 micron) ($2 < z < 4$), and establish their correlation with other galaxies via stacking
2) Demonstrate deep tomographic maps capable of detecting the aggregate shot-noise and clustering power spectra of CII from galaxies across the peak of cosmic star formation.

Dmitri Babikov/Marquette University

Computational Studies of Inelastic Scattering using Mixed Quantum/Classical Theory

Molecules are an important component of the universe that dominates the cooling process and determines the degree of ionization of interstellar gas clouds and, hence, regulates star and planet formation. The exploration of paths toward chemical complexity in space has direct bearing on the origin and evolution of life. Moreover, molecular transitions provide a sensitive probe of the dynamics and the physical and chemical conditions in a wide range of objects at scales ranging from newly forming planetary systems to galactic and extragalactic sizes.

In the vast majority of the conditions present in the interstellar/circumstellar/cometary media, the so-called collisional de-excitation rate coefficients are indispensable to convert an observed signal into a species column density and, therefore, abundance, and to constrain the density and temperature of the emitting or absorbing gas. However, a significant part of this information is still missing and there is no simple way of determining it from the laboratory experiments.

In order to fill this serious gap, we will approach the problem by employing a mixture of quantum and classical mechanics in a state-of-the-art theoretical approach to the dynamics of molecule + quencher collision. We showed that it is feasible to simplify the physical model and gain a significant computational advantage by treating selected degrees of freedom classically, while the most important internal degrees of freedom are still treated quantum mechanically. In this project we propose to carry out:

i) Benchmark MQCT calculations of rotational quenching of H_2O (including deuterated forms) by H_2 at lower temperatures first, to compare against the existing full-quantum scattering calculations, but then at higher temperatures where no accurate data exists, up to, typical to hot cores and corinos, outflow shocks, and the innermost regions of protoplanetary discs.

ii) Conceptually new calculations of ro-vibrational quenching and excitation of the most astronomically relevant excited bending mode of H2O, first by atomic quencher, He, and then by molecular quencher, H2, using MQCT, in a broad range of temperatures, up to when these processes become important (typical to red supergiant stars).

iii) First detailed calculations for H2O + H2O rotational quenching and excitation within MQCT framework in the temperature range relevant to warm star-forming regions or cometary environment. Deuterated forms of ortho/para-water can all be studied.

Peter Beiersdorfer/Energy Livermore Office, United States Department Of Energy
X-ray Line Formation by Charge Exchange

Existing X-ray telescopes have revealed charge exchange to be a key astrophysical process leading to X-ray emission when highly charged ions from such diverse sources as stellar winds, supernova remnants, or galactic super-winds interact with comets, planetary atmospheres, or the interstellar neutral gas. Charge exchange with bare sulfur ions, for example, was proposed as an alternative explanation of the 3.5 keV X-ray feature in the emission of galactic clusters that had been associated with the possible decay of sterile neutrinos. Fe XVII dominates the spectral emission of a large number of astrophysical X-ray sources and, thus, is of prime diagnostic importance, as illustrated in numerous measurements by Chandra and XMM-Newton. Although immense progress has been made in laboratory measurements and spectral calculations of collisional plasmas since the launch of these X-ray observatories, model calculations of the Fe XVII X-ray spectrum still do not yield agreement with astrophysical observations that is completely satisfactory. As a result, charge exchange has been invoked as an alternative explanation for the poor agreement between models and observations. Theoretically, line formation by charge exchange, however, is still only poorly understood both in the case of the rather ‘simple’ K-shell spectra of hydrogenlike or heliumlike ions, such as Fe XXV and Fe XXVI, and the more complex L-shell spectra of neonlike ions such as Fe XVII. Experimentally, there is only a small set of laboratory measurements involving X-rays from K-shell ions, and almost no measurements of the charge exchange produced X-ray emission involving L-shell ions. Moreover, the existing laboratory measurements have focused mostly on charge exchange processes pertaining to the solar wind interacting with complex (molecular) gases in cometary and planetary atmospheres. By contrast, we propose here to perform X-ray measurements pertaining to astrophysical exchange processes dominated by atomic hydrogen, molecular hydrogen, and helium. Our measurements will answer the question whether charge exchange can indeed produce the pattern of emission observed near 3.5 keV in the galactic x-ray spectra. It will also identify the signature of line formation by charge exchange in the L-shell X-ray spectra, notably in Fe XVII. Our measurements are very timely not only because of the controversies surrounding current CCD-resolution X-ray observations, but also because of the recent launch of the Hitomi X-ray Observatory. The Soft X-ray Spectrometer

(SXS) calorimeter aboard Hitomi will change the way the community will study the X-ray emission from extended sources. For the first time, astronomers have the spectral resolution and the effective area to see individual X-ray lines from diffuse objects. Our proposed measurements will utilize the Livermore electron beam ion trap (EBIT), a newly commissioned atomic hydrogen source, and the EBIT Calorimeter Spectrometer (ECS), which resides at the Livermore EBIT facility and has the same performance specifications as those of Hitomi's SXS. In addition, we will make the first modeling calculations of charge exchange produced X-ray emission of L-shell iron using a model we had developed earlier for studying K-shell X rays. The proposed work will, thus, provide the tools needed to identify and quantify charge exchange as a line formation mechanism in extended astrophysical objects observed both with current CCD resolution and with the high resolution of the Hitomi X-ray Observatory.

Pietro Bernasconi/Johns Hopkins University
STO-2: Support for 4th Year Operations, Recovery, and Science JHU/APL Co-I

This is a collaboration Co-I Institution proposal for the proposal "STO-2: Support for 4th Year Operations, Recovery, and Science" whose lead proposal is submitted by the University of Arizona with Dr. Christofer Walker as PI.

STO-2 was flight-ready in the 2015-2016 austral summer. However, due to the late establishment of the stratospheric anti-cyclone and poor surface conditions, STO-2 was unable to launch. The decision was made to winter-over the STO-2 payload in its hangar for launch during the 2016-2017 Antarctic campaign. Funds to cover preparations and deployment of key members of the instrument team in support of the campaign are being provided by NASA under the existing grant. However, these funds are only sufficient to cover expenses up to approximately December 31st. Here we request supplemental funds to cover costs associated with STO-2 operations and recovery beyond this date.

STO-2 will address a key problem in modern astrophysics, understanding the Life Cycle of the Interstellar Medium (ISM). STO-2 will survey approximately 1/4 of the Southern Galactic Plane in the dominant interstellar cooling line [CII] (158 Î¼m) and the important star formation tracer [NII] (205 Î¼m). In addition, STO-2 will perform path finding observations of the 63 Î¼m [OI] line toward selected regions. With ~1 arcminute angular resolution, STO-2 will spatially resolve atomic, ionic and molecular clouds out to 10 kpc. The STO-2 survey will be conducted at unparalleled sensitivity levels. STO-2 will uniquely probe the pivotal formative and disruptive stages in the life cycle of interstellar clouds and the relationship between global star formation rates and the properties of the ISM. Combined with previous HI and CO surveys, STO-2 will create 3-dimensional maps of the structure, dynamics, turbulence, energy balance, and pressure of the Milky Way's ISM, as well as the star formation rate. Once we gain an understanding of the relationship between ISM properties and star formation in the Milky Way, we can better interpret observations of nearby galaxies and the distant universe. The mission goals for these surveys are to: 1) Determine the life cycle of Galactic interstellar gas. 2) Study the creation and disruption of star-forming clouds in the Galaxy. 3) Determine the parameters that affect the star formation rate in the galaxy. 4) Provide templates for star formation and stellar/interstellar feedback in other galaxies.

STO-2 reuses the 80 cm telescope and many subsystems from STO-1. It also reuses the gondola developed by APL for the BOPPS and BRISSON comet missions. For the STO-2 flight, STO-1's high spectral resolution (<1 km/s) heterodyne receiver system was upgraded for extended cryogenic lifetime, enhanced sensitivity, and greater reliability. The flight receiver has five, cryogenic HEB mixers; two optimized for the 158 Î¼m [CII] line, two for the 205 Î¼m [NII] line, and one for the 63 Î¼m [OI] line. STO is capable of detecting every giant molecular cloud, every HII region of significance, and every diffuse HI cloud with (AV >= 0.4) within its survey region.

Peter Bloser/University System Of New Hampshire
Continued Development of a Soft Gamma-Ray Concentrator

We propose to continue our development of a concept for a soft gamma-ray (E > 100 keV) concentrator using thin-film multilayer structures. Alternating layers of low- and high-density materials will channel soft gamma-ray photons via total external reflection. A suitable arrangement of bent structures will then concentrate the incident radiation to a point. Gamma-ray optics made in this way offer the potential for soft gamma-ray telescopes with focal lengths of less than 10 m, removing the need for formation flying spacecraft and opening the field up to balloon-borne instruments. Under previous APRA funding we have been investigating methods for efficiently producing such multilayer structures and modeling their performance. We now propose to pursue magnetron sputtering (MS) techniques to quickly produce structures with the required smoothness and thickness, to measure their channeling efficiency and compare with calculations, and to design a "lens" with optimized bandpass and throughput and predict its scientific performance. If successful, this work will confirm that this innovative optics concept is suitable for a balloon-born soft gamma-ray telescope with unprecedented sensitivity.

Steven Boggs/Regents Of The University Of California
The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons. University of California, Berkeley Co-I.

This is a Co-I proposal in support of the PI lead proposal entitled "The GAPS experiment: a search for dark matter using low energy antiprotons and antideuterons" submitted by Prof. Charles Hailey, Columbia University. Our proposed program would support the UC Berkeley tasks on the GAPS experiment as detailed in our task statement. The primary focus of this work in on the development and testing of the Si(Li) readout electronics and support of the flight program and scientific analysis.

Charles Bradford/California Institute Of Technology

The Spectroscopic Terahertz Airborne Receiver for Far-InfraRed Exploration (STARFIRE): A Pathfinder for Next-Generation Extragalactic FIR Spectroscopy -- JPL Co-I

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Understanding the formation and evolution of galaxies is one of the foremost goals of astrophysics and cosmology today. The cosmic star formation rate has undergone a dramatic evolution of the course of the last seven billion years. Dust-obscured star forming galaxies (DSFGs) offer the perfect tracers of this evolution as they contain much of the star-forming activity. By their very nature, DSFGs are difficult to study and have, until recently, been poorly understood. A variety of unextincted diagnostic lines are present in the far-infrared (FIR) which can provide insight into the conditions of star formation, including the instantaneous star formation rate, the effect of AGN feedback on star formation, the mass function of the stars, and the spectrum of their ionizing radiation. Spectroscopy in the far-infrared is technically difficult but scientifically crucial. 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 short wavelengths. STARFIRE will provide a technological stepping stone to the future space-borne instrumentation such as the Far-IR Surveyor or a Probe mission. Key to this science is the development of a telescope using low-emissivity, high-throughput optics onto a dispersive spectrometer, and having high-sensitivity, large-format detector arrays.

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Steven Christe/NASA Goddard Space Flight Center
Developing fine-pixel CdTe detectors for the next generation of high-resolution hard x-ray telescopes

Over the past decade, the NASA Marshall Space Flight Center (MSFC) has been improving the angular resolution of hard X-ray (HXR; ~20 “70 keV) optics to the point that we now routinely manufacture optics modules with an angular resolution of 20 arcsec Half Power Diameter (HDP), almost three times the performance of NuSTAR optics (Ramsey et al. 2013; Gubarev et al. 2013a; Atkins et al. 2013). New techniques are currently being developed to provide even higher angular resolution.

High angular resolution HXR optics require detectors with a large number of fine pixels in order to adequately sample the telescope point spread function (PSF) over the entire field of view. Excessively over-sampling the PSF will increase readout noise and require more processing with no appreciable increase in image quality. An appropriate level of over-sampling is to have 3 pixels within the HPD. For the HERO mirrors, where the HPD is 26 arcsec over a 6-m focal length converts to 750 Âµm, the optimum pixel size is around 250 Âµm. At a 10-m focal length these detectors can support a 16 arcsec HPD. Of course, the detectors must also have high efficiency in the HXR region, good energy resolution, low background, low power requirements, and low sensitivity to radiation damage (Ramsey 2001). The ability to handle high counting rates is also desirable for efficient calibration.

A collaboration between Goddard Space Flight Center (GSFC), MSFC, and Rutherford Appleton Laboratory (RAL) in the UK is developing precisely such detectors under an ongoing, funded APRA program (FY2015 to FY2017). The detectors use the RAL-developed Application Specific Integrated Circuit (ASIC) dubbed HEXITEC, for High Energy X-Ray Imaging Technology. These HEXITEC ASICs can be bonded to 1- or 2-mm-thick Cadmium Telluride (CdTe) or Cadmium-Zinc-Telluride (CZT) to create a fine (250 Âµm pitch) HXR detector (Jones et al. 2009; Seller et al. 2011). The objectives of this funded effort are to develop and test a HEXITEC-based detector system through the (1) design, manufacture, and test of front-end electronics instrument boards and (2) calibration of the detectors to assess their performance and (3) vibration and environmental testing. By the end of this program, multiple detector assemblies will be built and characterized, and can be used as part of future instruments.

We propose to augment the existing effort with the development of an anti-coincidence shield for these HEXITEC-based detector assemblies to maximize sensitivity. Designing the anti-coincidence shield is enabled by the addition of a new team member, Wayne Baumgartner, who has recently and fortuitously joined the existing effort. Dr.

Baumgartner has valuable and relevant past experience with a similar shield systems developed for NuSTAR and the InFOCÂµS x-ray telescope.

We are asking for a modest amount of additional funding in this proposal year, as it coincides with a key time in the characterization and environmental testing of the detector assemblies. Characterization and environmental testing of the bare assemblies is already funded under the current effort. The addition of this active shield will allow for a more complete detector module vibration and environment test at the end of the existing development program so that this project results in a detector system with a demonstrated TRL of 6: "System/subsystem model or prototype demonstration in a relevant environment. "

Stephane Coutu/Pennsylvania State University
Cosmic Ray Energetics and Mass (CREAM) Launch and Operations, PSU Co-I

This proposal covers the activities of the Penn State group on the BACCUS high-altitude balloon experiment in Antarctica and on the CREAM mission to the ISS. These projects together will achieve definitive measurements of the cosmic-ray elemental spectra into the PeV range (nuclei) and of cosmic-ray electrons into the TeV range, as well as detailed studies of secondary nuclei (such as B or the sub-Fe elements). These are the experimental measurements needed to sort out the details of cosmic-ray acceleration and propagation in the Galaxy, a long standing puzzle in particle astrophysics.

Abe Falcone/Pennsylvania State University
Novel Hybrid CMOS X-ray Detector Developments for Future Large Area and High Resolution X-ray Astronomy Missions

In the coming years, X-ray astronomy will require new soft X-ray detectors that can be read very quickly with low noise and can achieve small pixel sizes over a moderately large focal plane area. These requirements will be present for a variety of X-ray missions that will attempt to address science that was highly ranked by the 2010 Decadal Survey, including missions with science that overlaps with that of IXO and Athena, as well as other missions addressing science topics beyond those of IXO and Athena. An X-ray Surveyor mission was recently chosen by NASA for study by a Science & Technology Definition Team (STDT) so it can be considered as an option for an upcom-ing flagship mission. A mission such as this was endorsed by the NASA long term planning docu-ment entitled "Enduring Quests, Daring Visions," and a detailed description of one possible reali-zation of such a mission has been referred to as SMART-X, which was described in a recent NASA RFI response. This provides an example of a future mission concept with these requirements since it has high X-ray throughput and excellent spatial resolution. We propose to continue to modify current active pixel sensor designs, in particular the hybrid CMOS detectors that we have been working with for several years, and implement new in-pixel technologies that will allow us to achieve these ambitious and realistic requirements on a timeline that will make them available to upcoming X-ray missions. This proposal is a continuation of our program that has been work-ing on these developments for the past several years. The first 3 years of the program led to the development of a new circuit design for each pixel, which has now been shown to be suitable for a larger detector array. The proposed activity for the next four years will be to incorporate this pixel design into a new design of a full detector array (2kÃ—2k pixels with digital output) and to fabricate this full-sized device so it can be thoroughly tested and characterized.

Ryan Fortenberry/Georgia Southern University Research and Service Foundation, Inc.

Development of a Reparametrized Semi-Empirical Force Field to Compute the Rovibrational Structure of Large PAHs

The Spitzer Space Telescope observation of spectra most likely attributable to diverse and abundant populations of polycyclic aromatic hydrocarbons (PAHs) in space has led to tremendous interest in these molecules as tracers of the physical conditions in different astrophysical regions. A major challenge in using PAHs as molecular tracers is the complexity of the spectral features in the 3-20 Î¼m region. The large number and vibrational similarity of the putative PAHs responsible for these spectra necessitate determination for the most accurate basis spectra possible for comparison. It is essential that these spectra be established in order for the regions explored with the newest generation of observatories such as SOFIA and JWST to be understood.

Current strategies to develop these spectra for individual PAHs involve either matrix-isolation IR measurements or quantum chemical calculations of harmonic vibrational frequencies. These strategies have been employed to develop the successful PAH IR spectral database as a repository of basis functions used to fit astronomically observed spectra, but they are limited in important ways.

Both techniques provide an adequate description of the molecules in their electronic, vibrational, and rotational ground state, but these conditions do not represent energetically hot regions for PAHs near strong radiation fields of stars and are not direct representations of the gas phase. Some non-negligible matrix effects are known in condensed-phase studies, and the inclusion of anharmonicity in quantum chemical calculations is essential to generate physically-relevant results especially for hot bands. While scaling factors in either case can be useful, they are agnostic to the system studied and are not robustly predictive.

One strategy that has emerged to calculate the molecular vibrational structure uses vibrational perturbation theory along with a quartic force field (QFF) to account for higher-order derivatives of the potential energy surface. QFFs can regularly predict the fundamental vibrational frequencies to within 5 cm-1 of experimentally measured values. This level of accuracy represents a reduction in discrepancies by an order of magnitude compared with harmonic frequencies calculated with density functional theory (DFT). The major limitation of the QFF strategy is that the level of electronic-structure theory required to develop a predictive force field is prohibitively time consuming for molecular systems larger than 5 atoms. Recent advances in QFF techniques utilizing informed DFT approaches have pushed the size of the systems studied up to 24 heavy atoms, but relevant PAHs can have up to hundreds of atoms.

We have developed alternative electronic-structure methods that maintain the accuracy of the coupled-cluster calculations extrapolated to the complete basis set limit with relativistic and core correlation corrections applied: the CcCR QFF. These alternative methods are based on simplifications of Hartree—Fock theory in which the computationally intensive two-electron integrals are approximated using empirical parameters. These methods reduce computational time to orders of magnitude less than the CcCR calculations.

We have derived a set of optimized empirical parameters to minimize the difference between the CcCR QFF energies for the geometries used to build the force field for two molecular ions of astrochemical significance. We have shown that it is possible to derive a set of empirical parameters that will produce RMS energy differences of less than 2 cm-1 for our test systems.

We are proposing to adopt this reparameterization strategy and some of the lessons learned from the informed DFT studies to create a semi-empirical method whose tremendous speed will allow us to study the rovibrational structure of large PAHs with up to 100s of carbon atoms.

Javier Garcia/Smithsonian Institution
Atomic Data for Modeling X-rays in High-Density Plasmas

Iron K-shell lines emitted by gas closely orbiting black holes are observed to be grossly broadened and skewed by Doppler effects and gravitational redshift. The accuracy of these spin estimates is called into question because fitting the data requires very high iron abundances, several times the solar value. Meanwhile, no plausible physical explanation has been proffered for why these black hole systems should be so iron rich. The most likely explanation for the super-solar iron abundances is a deficiency in the models, and the leading candidate cause is that current models are inapplicable at densities above 10^18 cm^-3. These models neglect stimulated processes, while simple estimates indicate that the radiation intensities in relativistic line emitting gas are sufficiently high that such processes as stimulated recombination, bound-bound decay, and Compton scattering are likely to be important. Furthermore, at high gas densities rates for atomic processes that allow the survival of iron ions against total ionization are affected by mechanisms related to interactions with nearby ions and electrons. Given iron's relevance as a diagnostic tool in astrophysical plasmas, we will start our development of high-density models by focusing on the Fe K-shell atomic data. The products of this work will be: (i) Rate coefficients for atomic processes affecting iron line formation at a range of densities up to those appropriate for relativistic lines; (ii) ionization balance curves and X-ray emissivities and opacities that are appropriate for high densities and radiation intensities; and (iii) publicly available codes and tables of calculated spectra and emissivities for use in modeling and fitting observed spectra of relativistic iron lines. These new atomic data are required for the detailed modeling of spectra with ~5 eV resolution that will soon be provided by the calorimeter spectrometer aboard the recently launched X-ray mission Hitomi (Astro-H).

Jonathan Grindlay/President And Fellows Of Harvard College
HREXI prototype for 4piXIO

We propose to complete our development of the High Resolution Energetic X-ray Imager (HREXI) and to build and test a full Engineering Model of a detector and telescope system for a 12U Cubesat that will be proposed for a test flight. This will enable a future SMEX (or MIDEX) proposal for a 4piXIO mission: a constellation of Cubesats (or Smallsats) that would dramatically increase the sensitivity, source location precision and especially number of Gamma Ray Bursts (GRBs) to explore the Early Universe. Over the past two years of our current APRA grant, we have developed the world's first (to our knowledge) readout of a high-level imaging detector that is entirely three dimensional so that imaging detectors can then be tiled in close-packed arrays of arbitrary total area. This important new technology is achieved by replacing the external lateral readout of an ASIC, which reads out data from (for example) a 2 x 2 cm imaging detector through "wire bonds" to external circuits in the same plane but beyond the detector, with a vertical readout through the ASIC itself to external circuits directly below. This new technology greatly simplifies the assembly of the large area, tiled arrays of such detectors and their readout ASICs used for coded aperture wide-field telescopes that are uniquely able to discover and study X-ray (and low energy gamma-ray) transients and bursts that are key to understanding the physics and evolution of black holes. The first actual fabrication of such 3D-readout of close-tiled HREXI imaging detectors is underway and will be demonstrated in this third and final year of the current APRA grant. This proposal takes the HREXI detector concept a major step further. By incorporating this technology into the design and fabrication of a complete Engineering Model of a HREXI detector and coded aperture telescope that would fit, with comfortable margins, in a 12U Cubesat, it opens the way for a future low-cost constellation of ~25 such 12U Cubesats to achieve the first full-sky, full-time imaging survey for Gamma-ray Bursts (GRBs) and transients. The full-sky/time coverage immediately increases GRB detections by factors of 6, a significant increase in the search for GRBs from the Early Universe. The proposal will also extend the development of smaller pixel size for the required ASIC chips which will significantly improve angular resolution and make the low-cost Cubesat mission even more compelling. The science goals that a multi-satellite mission enabled by HREXI detectors for high resolution imaging over the full sky include using GRBs to trace star formation back to the very first (Pop III) stars and using flares from quasars to track the growth and evolution of supermassive black holes. Both are key NASA and PCOS science objectives. This is achieved by combining coordinated optical and IR data from a 4piXIO mission with LSST ground-based optical data as well as optical/IR spectra from a future optical-IR spectroscopy telescope in space, such as the proposed TSO probe-class mission.

Christopher Groppi/Arizona State University
STO-2: Support for 4th Year Operations, Recovery, and Science ASU Co-I

This is a Co-Investigator proposal for "STO-2: Support for 4th Year Operations, Recovery, and Science" with Prof. Christopher K. Walker (University of Arizona) as PI. As a participant in the STO-2 mission, ASU will participate in instrument design and construction, mission I&T, flight operations and data analysis. ASU has unique capabilities in the field of direct metal micromachining, which it will bring to bear on the STO-2 cold optical assembly, flight mixers and LO hardware. In addition, our extensive experience with receiver integration and test will supplement the capabilities of the PI institution during the I&T phase at the University of Arizona, CSBF (Palestine, TX) and in Antarctica. Both the ASU PI and student will also participate in data analysis and publication after the flight.

J Eric Grove/Naval Research Laboratory
CsI Calorimeter for a Compton-Pair Telescope

We propose to build and test a hodoscopic CsI(Tl) scintillating-crystal calorimeter for a medium-energy Î³-ray Compton and pair telescope. The design and technical approach for this calorimeter relies deeply on heritage from the Fermi LAT CsI Calorimeter, but it dramatically improves the low-energy performance of that design by reading out the scintillation light with silicon photomultipliers (SiPMs), making the technology developed for Fermi applicable in the Compton regime.

While such a hodoscopic calorimeter is useful for an entire class of medium-energy γ-ray telescope designs, we propose to build it explicitly to support beam tests and balloon flight of the Proto-ComPair telescope, the development and construction of which was funded in a four-year APRA program beginning in 2015 ("ComPair: Steps to a Medium Energy γ-ray Mission" with PI J. McEnery of GSFC). That award did not include funding for its CsI calorimeter subsystem, and this proposal is intended to cover that gap.

ComPair is a MIDEX-class instrument concept to perform a high-sensitivity survey of the γ-ray sky from ~0.5 MeV to ~500 MeV. ComPair is designed to provide a dramatic increase in sensitivity relative to previous instruments in this energy range (predominantly INTEGRAL/SPI and Compton COMPTEL), with the same transformative sensitivity increase – and corresponding scientific return– that the Fermi Large Area Telescope provided relative to Compton EGRET. To enable transformative science over a broad range of MeV energies and with a wide field of view, ComPair is a combined Compton telescope and pair telescope employing a silicon-strip tracker (for Compton scattering and pair conversion and tracking) and a solid-state CdZnTe calorimeter (for Compton absorption) and CsI calorimeter (for pair calorimetry), surrounded by a plastic scintillator anti-coincidence detector.

Under the current proposal, we will complete the detailed design, assembly, and test of the CsI calorimeter for the risk-reduction prototype telescope, Proto-ComPair. We will:

1. Purchase CsI(Tl) crystals, Silicon Photomultipliers (SiPMs), and components for the analog and digital readout of the SiPMs;
2. Assemble and test Crystal Detector Elements (CDEs) from crystals, SiPMs and optical wrap;
3. Assemble and test analog and digital front-end and readout control boards;
4. Fabricate the mechanical structure that supports and contains the CDEs and electronics boards; and

5. Assemble and test the CsI calorimeter, and integrate it with the remainder of the Proto-ComPair subsystems.

The PI team for this proposal conceived, designed, developed, assembled, tested, and currently operates the LAT calorimeter and is uniquely qualified to leverage the experience gained from that effort for ComPair.

Mikhail Gubarev/NASA George C Marshall Space Flight Center
Technology Development for Direct Fabrication of Light-Weight High-Resolution Full-Shell X-Ray Optics

The next generation X-ray telescopes will require the availability of technologies to fabricate high resolution, very low mass, x-ray optics. To increase the throughput of the telescopes by nesting, the mirrors need to be relatively thin, yet stiff enough to ensure the mechanical stability and high angular resolution required. A full-shell approach takes advantage of the natural stiffness of the closed geometry, so potentially very-thin-wall x-ray mirrors can be employed. Also the full-shell approach permits simpler alignment and integration, compared to segmented x-ray optics, and less massive telescope structure.

We intend to develop the capability (polishing techniques, fixturing, metrology methods) for direct and efficient fabrication of Chandra-like full-shell x-ray optics, yet with over an order of magnitude lighter mirrors using a Zeeko computer-controlled 7-axis polishing machine. The techniques that will be developed will be applicable to full-shell mirrors, but can be equally applied to segmented optics. This effort will build on work done to date on fixturing, software and metrology, funded internally at MSFC. Fixturing, already designed, will be tested and used to support the thin shells in a very-low-stress manner during all aspects of fabrication. In-situ metrology will be incorporated, specifically tailored for use in conjunction with the deterministic surface figuring machine. The goal of the 3-year program is to demonstrate capability through the fabrication and x-ray testing of thin (~ 1.5mm), light-weight, full mirror shells with few-arcsec angular resolution and describe a path forward to sub-arcsecond resolution.

Charles Hailey/Trustees of Columbia University in the City of New York
The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons

This is the lead proposal for a multi-institutional proposal which includes UCLA, UCB, University of Hawaii, and M.I.T.

The general antiparticle spectrometer experiment (GAPS) is a balloon-based search for dark matter. It uses a Lithium-drifted Silicon tracking telescope to detect X-rays and particles emitted when antimatter, produced by dark matter annihilation and decay, is stopped in the instrument. A flight from Antarctica can significantly constrain or detect dark matter.

Donald Hall/University Of Hawaii Systems
A 1.5k x 1.5k class photon counting HgCdTe Linear Avalanche Photo-Diode Array for Low Background Space Astronomy in the 1 – 5 Micron Infrared.

Under a current award, NASA NNX 13AC13G "EXTENDING THE ASTRONOMICAL APPLICATION OF PHOTON COUNTING HgCdTe LINEAR AVALANCHE PHOTO-DIODE ARRAYS TO LOW BACKGROUND SPACE OBSERVATIONS" UH has used Selex SAPHIRA 320 x 256 MOVPE L-APD HgCdTe arrays developed for Adaptive Optics (AO) wavefront (WF) sensing to investigate the potential of this technology for low background space astronomy applications. After suppressing readout integrated circuit (ROIC) glow, we have placed upper limits on gain normalized dark current of 0.01 e-/sec at up to 8 volts avalanche bias, corresponding to avalanche gain of 5, and have operated with avalanche gains of up to several hundred at higher bias. We have also demonstrated detection of individual photon events.

The proposed investigation would scale the format to 1536 x 1536 at 12um (the largest achievable in a standard reticule without requiring stitching) while incorporating reference pixels required at these low dark current levels. The primary objective is to develop, produce and characterize a 1.5k x 1.5k at 12um pitch MOVPE HgCdTe L-APD array, with nearly 30 times the pixel count of the 320 x 256 SAPHIRA, optimized for low background space astronomy. This will involve: 1) Selex design of a 1.5k x 1.5k at 12um pitch ROIC optimized for low background operation, silicon wafer fabrication at the German XFab foundry in 0.35 um 3V3 process and dicing/test at Selex, 2) provision by GL Scientific of a 3-side close-buttable carrier building from the heritage of the HAWAII xRG family, 3) Selex development and fabrication of 1.5k x 1.5k at 12 um pitch MOVPE HgCdTe L-APD detector arrays optimized for low background applications, 4) hybridization, packaging into a sensor chip assembly (SCA) with initial characterization by Selex and, 5) comprehensive characterization of low background performance, both in the laboratory and at ground based telescopes, by UH. The ultimate goal is to produce and eventually market a large format array, the L-APD equivalent of the Teledyne H1RG and H2RG, able to achieve sub-electron read noise and count 1 – 5 um photons with high quantum efficiency and low dark count rate while preserving their Poisson statistics and noise.

Nils Halverson/Regents Of The University Of Colorado
Planar Silicon Metamaterial Lenslet Arrays for Spaceborne Millimeter-wavelength Imaging

Large imaging arrays of detectors at millimeter and submillimeter wavelengths have spaceborne applications that include measurements of the faint polarization signal in the Cosmic Microwave Background (CMB), and submillimeter astrophysics. Precision spaceborne measurements of the faint CMB polarization signal have the potential to probe physics at GUT energy scales, when the universe was thought to have undergone a rapid period of exponential expansion called inflation. Future spaceborne submillimeter and far-infrared missions will reveal information about the first stars and the early history of galaxy evolution.

One challenge in making large focal plane arrays is how to couple the detectors to the intrument optics in a way that is scalable, easily fabricable, broadband, and robust during launch and in the space environment. Here we propose to develop planar lenslet arrays using metamaterials fabricated using silicon wafers. Instead of curved optical surfaces, the lenslets consist of a stack of silicon wafers each patterned with a periodic array of subwavelength features. We will develop two approaches based on our previous work: gradient-index (GRIN) lenslets produced by etching radially varying holes in the wafers, and metal-mesh lenslets produced by depositing a radially varying metal mesh grid that acts as a series of transmission line (TL) lumped element filters to control the wavefront phase delay across the lenslet. The advantage of these techniques is that they can be fabricated in only a few steps; they are precise, repeatable, scalable, mechanically robust, and the flat optical surface lends itself to a variety of broadband anti-reflection (AR) coating techniques, including impedance matching to free space using metamaterial itself.

Shaul Hanany/Regents of the University Of Minnesota
EBEX-IDS: A Balloon-Borne Experiment to Observe and Separate Galactic Dust from Cosmic Inflation Signals

Measurements of the imprint of inflationary gravity waves on the cosmic microwave background radiation are currently limited by uncertainty in the properties of polarized galactic dust. A balloon-borne platform probing frequency bands that are not accessible from the ground is uniquely suited to drastically reduce this uncertainty.

We propose EBEX-IDS, a long-duration balloon-borne experiment that will measure the polarization of galactic dust at 360~GHz with 36 times lower power spectrum noise, compared to the Planck satellite. With 20,562 detectors, spread over 7 frequency bands between 150 and 360~GHz, including bands at 280, 320, and 360~GHz, EBEX-IDS will determine the spectral index of polarized dust emission and its B-mode power spectrum at 150~GHz with an unprecedented accuracy of 0.04% and signal-to-noise ratio (SNR) of 42, respectively.

The multitude of independent bands will precisely determine the shape of the dust spectral energy distribution at the frequency bands that are most relevant for the extraction of the inflationary signal. By combining observations and sharing data with the ground-based BICEP/Keck Array and Polarbear/Simons Array instruments the three experiments will give a map depth in the BICEP2 region of less than 1 microK arcmin, the deepest map yet produced compared to any other sky region. With this depth and using the the EBEX-IDS data to provide the crucial leverage on the properties of dust emission, the combined data will place a 2 sigma upper limit of $r<0.003$ on the telltale signature of inflation after accounting for dust separation. This limit is a factor of 30 more stringent than current limits using CMB data. The limit using the EBEX-IDS data alone will be $r<0.008$.

With resolution higher than other balloon payloads EBEX-IDS will map the CMB lensing deflection angle, improve the determination the lensing power spectrum by a factor of 8, and will constrain the sum of neutrino mass by nearly a factor of 2 compared to current limits. At 360~GHz EBEX-IDS is six times more sensitive than Planck to the signals due to the cosmic infrared background and it adds comparable sensitivity in 4 additional bands that Planck does not have.

EBEX-IDS will advance the state of readiness of satellite-worthy technologies by pioneering a balloon-borne focal plane consisting of sinuous antenna multichroic pixels (SAMPs). This focal plane leverages the already-funded development of focal planes with SAMPs for STP3G, Polarbear-2, and Simons Array, but EBEX-IDS will implement pixels at higher frequencies and optimized for a space-like environment. We will use a new readout system that multiplexes 64 readout channels onto two wires, a factor of 4 larger than has been used to date. EBEX-IDS is the only balloon platform proposed to elevate the readiness level of these technologies, which are baselined for LiteBIRD, a CMB satellite mission that is now in Phase-A study both by NASA and JAXA.

Investing in EBEX-IDS mitigates balloon-flight risks, and is cost-effective for NASA, because it will re-use flight-tested hardware, designs, and techniques from a predecessor experiment, EBEX2013. The experiment will be fielded by the team that in 2009 pioneered the use of TES bolometers read out with SQUID amplifiers on a balloon flight, and in 2012 was the first to conduct balloon-borne cosmological observations with a kilo-pixel array using this technology. The EBEX team was the first to implement a digital frequency-domain readout system that has now been adopted by several ground-based experiments, and we pioneered and demonstrated a successful implementation of a superconducting magnetic bearing for astrophysical polarimetry. The proposed effort will be carried out primarily by graduate students overseen by postdoctoral scholars, thereby contributing to NASA educational STEM goals.

Reggie Hudson/NASA Goddard Space Flight Center
Abundances and Reactions of Sulfur-Containing Molecules in Interstellar Ices – Spectroscopic and Radiation-Chemical Investigations

Infrared (IR) telescopes, such as ISO, Spitzer, KAO, Keck, VLT, and IRTF, have revealed a rich variety of molecules trapped in interstellar ices. However, quantifying the abundances of these molecules has been difficult because reference IR data, such as band strengths and optical constants, often are poorly known. This scarcity of data has severe implications for the study of sulfur-containing molecules, such as OCS and SO2, since accurate molecular abundances are needed to address the missing-sulfur problem in interstellar space. The expected abundances of sulfur-containing species in dense molecular clouds are much higher than reported from telescopic observations, although the latter are based on laboratory data of questionable relevance, such as with liquids at room temperature compared to the 10 K ices of some interstellar regions. Exacerbating the problem is that few sulfur-containing molecules of any type have been examined in the laboratory under the necessary, relevant icy conditions.

We propose to address and correct the problems associated with abundance determinations of interstellar sulfur-containing ices. We will combine several recent successful efforts from our laboratory and measure near- and mid-IR spectral intensities for ices containing SO_2, OCS, H_2S, CS_2, CH_3SH, and C_2H_5SH both in the presence and absence of H_2O-ice. This work will be done at multiple temperatures and ice phases to generate reference IR spectra and band strengths, accompanied by refractive indices, and optical constants. Moreover, we will study the radiation chemistry of these molecules to determine their radiolytic half-lives (stabilities) and uncover product molecules that can become candidates for future searches and perhaps help better understand the missing-sulfur problem. This proposal is a convergence of three lines of work in our laboratory: recent successes in deriving IR optical constants of interstellar molecular ices (Hudson et al. 2014a, 2014b), measurements of radiolytic stabilities of interstellar and planetary molecules (Gerakines & Hudson 2013, 2015), and our long history of working with sulfur-containing molecules and ions (Moore et al. 1988; Loeffler & Hudson 2010, 2012). Our collaborators were selected specifically for their interest in this proposal's focus and for their expertise in interstellar chemistry.

William Jones/Trustees of Princeton University
Spider: Probing the Early Universe with a Large-Scale CMB Polarization Survey

The standard dark-matter and dark-energy dominated cosmological model (LCDM) has proven to be remarkably successful in describing the current state and past evolution of the Universe. However, there remain significant uncertainties regarding the physical mechanisms that established the initial conditions upon which the LCDM predictions rely. Theories of cosmic genesis - the extremely high energy mechanisms that established these conditions - should be expected to provide a natural description of the nearly flat geometry of the Universe, the existence of super-horizon density correlations, and the adiabatic, Gaussian and nearly scale-invariant nature of the observed primordial density perturbations.

The primary objective of Spider is to subject models of the early Universe to observational test, probing fundamental physics at energy scales far beyond the reach of terrestrial particle accelerators. The main scientific result will be to characterize, or place stringent upper limits on the level of the odd-parity polarization of the CMB. In the context of the inflationary paradigm, Spider will confirm or exclude the predictions of the simplest single-field inflationary models near the Lyth bound, characterized by tensor to scalar ratios $r \sim 0.03$. While viable alternatives to the inflationary paradigm are an active and important area of investigation, including string cosmologies and cyclic models, early Universe models described by inflationary periods are now widely accepted as the underlying cause behind much of what we observe in cosmology today. Nevertheless, we know very little about the mechanism that would drive inflation or the energy scale at which it occurred, and the paradigm faces significant questions about the viability of the framework as a scientific theory.

Fortunately, inflationary paradigms and alternative theories offer distinct predictions regarding the statistical properties of the Cosmic Microwave Background radiation. Spider will use measurements of the polarization of the CMB to search for the signature of primordial gravitational waves that are predicted within the currently favored theories of inflation. A definitive detection of this signal would provide the first direct insight into the underlying physics of inflation as well as a measurement of its energy scale. A stringent limit on the amplitude of this signal would exclude the currently favored class of inflationary models, bolstering the case for alternative theories.

Spider is a suborbital Long-Duration Balloon payload housing six cryogenic small-aperture (half-degree resolution) millimeter-wave polarimeters. The frequency bands of the individual polarimeters are chosen to optimize overall sensitivity to the inflationary CMB polarization signal in the presence of Galactic foregrounds. By making extremely deep, high fidelity measurements of the entire portion of the southern sky that is relatively free of Galactic emission, the Spider data complement those of Planck (in sensitivity and control of systematics) PIPER (in frequency coverage) and EBEX (in sky coverage and angular scale). The data from Spider's inaugural flight in 2015 has resulted in high signal-to-noise maps of the southern Galactic hemisphere covering 10% of the full sky at each of 94 and 150 GHz.

The payload is now being fabricated and fitted with a suite of 285 GHz cameras to extend our frequency coverage, improving our ability to disentangle the Galactic and cosmological signals. If its signature is present in the CMB, Spider's frequency coverage and fidelity to a broad range of angular scales enable the experiment to take a step beyond detection, toward the characterization of the gravitational wave induced signature in the CMB. Additionally Spider serves as a training ground for young scientists, including 16 graduate students (9 female, 7 male).

Mary Elizabeth Kaiser/Johns Hopkins University
ACCESS - Absolute Color Calibration Experiment for Standard Stars

Establishing improved spectrophotometric standards is important for a broad range of missions and is relevant to many astrophysical problems. ACCESS, “Absolute Color Calibration Experiment for Standard Stars”, is a series of rocket-borne sub-orbital missions and ground-based experiments designed to enable improvements in the precision of the astrophysical flux scale through the transfer of absolute laboratory detector standards from the National Institute of Standards and Technology (NIST) to a network of stellar standards with a calibration accuracy of 1% and a spectral resolving power of 500 across the 0.35 âˆ’ 1.7 micron bandpass.

Jonathan Kawamura/California Institute Of Technology
STO-2: Support for 4th Year Operations, Recovery, and Science (JPL co-I)

Here we propose “STO-2: Support for 4th Year Operations, Recovery, and Science,” a project being led by Dr. Christopher Walker of the University of Arizona. The Stratospheric TeraHertz Observatory was ready for its second Antarctic flight (STO-2) in the 2015-2016 austral summer. However, due to the late establishment of the stratospheric anti-cyclone and poor surface conditions, STO-2 was unable to launch. The decision was made to winter-over the STO-2 payload in its hangar for launch during the 2016-2017 Antarctic campaign. Funds to cover preparations and deployment of key members of the instrument team in support of the campaign are being provided by NASA under the existing grant. However, these funds are only sufficient to cover expenses up to December 31st, 2016. Here, we request resources for calendar year 2017 to support mission operations, payload recovery, and science operations. These elements will enable the team to deliver fully on STO-2's science mission, and maximize NASA's demonstrated investment in STO-2's success.

STO-2 addresses a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). STO-2 will survey approximately Â¼ of the Southern Galactic Plane in the dominant interstellar cooling line [CII] (158 Âµm) and the important star formation tracer [NII] (205 Âµm). In addition, STO-2 will perform path finding observations of the 63 Âµm [OI] line toward selected regions. With 1 arcminute angular resolution, STO-2 will spatially resolve atomic, ionic and molecular clouds out to 10 kpc. The STO-2 survey will be conducted at unparalleled sensitivity levels. STO-2 will uniquely probe the pivotal formative and disruptive stages in the life cycle of interstellar clouds and the relationship between global star formation rates and the properties of the ISM. Combined with previous HI and CO surveys, STO-2 will create 3-dimensional maps of the structure, dynamics, turbulence, energy balance, and pressure of the Milky Way's ISM, as well as the star formation rate. Once we gain an understanding of the relationship between ISM properties and star formation in the Milky Way, we can better interpret observations of nearby galaxies and the distant universe. The mission goals for these surveys are to:

- Determine the life cycle of Galactic interstellar gas.
- Study the creation and disruption of star-forming clouds in the Galaxy.
- Determine the parameters that affect the star formation rate in the galaxy.
- Provide templates for star formation and stellar/interstellar feedback in other galaxies.

STO-2 reuses the 80cm telescope and many subsystems from STO-1. It also reuses the gondola developed by APL for the BOPPS and BRRISON comet missions. For the STO-2 flight, STO-1’s high spectral resolution (<1 km/s) heterodyne receiver system was upgraded for extended cryogenic lifetime, enhanced sensitivity, and greater reliability. The flight receiver has five, cryogenic HEB mixers; two optimized for the 158 Âµm [CII] line, two for the 205 Âµm [NII] line, and one for the 63 Âµm [OI] line. STO is capable of detecting every giant molecular cloud, every HII region of significance, and every diffuse HI cloud with (AV â‰¥ 0.4) within its survey region.

Almus Kenter/Smithsonian Institution
Advancing the Technology of Monolithic CMOS detectors for their use as X-ray Imaging Spectrometers

The Smithsonian Astrophysical Observatory (SAO) proposes a two year program to further advance the scientific capabilities of monolithic CMOS detectors for use as x-ray imaging spectrometers. This proposal will build upon the progress achieved with funding from a previous APRA proposal that ended in 2013. As part of that previous proposal, x-ray optimized, highly versatile, monolithic CMOS imaging detectors and technology were developed and tested. The performance and capabilities of these devices were then demonstrated, with an emphasis on the performance advantages these devices have over CCDs and other technologies.

The developed SAO/SRI-Sarnoff CMOS devices incorporate: Low noise, high sensitivity (“gain”) pixels; Highly parallel on-chip signal chains; Standard and very high resistivity (30,000Ohm-cm) Si; Back-Side thinning and passivation. SAO demonstrated the performance benefits of each of these features in these devices. This new proposal high-lights the performance of this previous generation of devices, and segues into new technology and capability.

The high sensitivity (~135uV/e) 6 Transistor (6T) Pinned Photo Diode (PPD) pixels provided a large charge to voltage conversion gain to the detect and resolve even small numbers of photo electrons produced by x-rays. The on-chip, parallel signal chain processed an entire row of pixels in the same time that a CCD requires to processes a single pixel. The resulting high speed operation (~1000 times faster than CCD) provide temporal resolution while mitigating dark current and allowed room temperature operation. The high resistivity Si provided full (over) depletion for thicker devices which increased QE for higher energy x-rays.

In this proposal, SAO will investigate existing NMOS and existing PMOS devices as x-ray imaging spectrometers. Conventional CMOS imagers are NMOS. NMOS devices collect and measure photo-electrons. In contrast, PMOS devices collect and measure photo-holes. PMOS devices have various attributes that would make them superior for use in X-ray astronomy. In particular, PMOS has: “no” photo-charge recombination; “no” Random Telegraph Signal noise (RTS); and lower read noise. The existing SRI/Sarnoff PMOS devices are small and have been developed for non-intensified night vision applications, however, no x-ray evaluation of a monolithic PMOS device has ever been made. In addition to these PMOS devices, SAO will also evaluate existing NMOS scale-able format devices that can be fabricated in any rectangular size/shape using stitch-able reticles. These “Mk by Nk” devices would be ideal for large X-ray focal planes or long grating readouts. The Sarnoff/SRI Mk by Nk format devices have been designed, with foresight, so that they can be fabricated in either PMOS or NMOS by changing a single fabrication reticle and by changing the type of Si substrate. If X-ray performance results are expected, this proposal will lead the way to future fabrication of Mk by Nk PMOS devices that would be ideal for X-ray astronomy missions such as “X-ray Surveyor”.

SAO will also investigate the interaction of directly deposited Optical Blocking Filters (OBFs) on various back side passivated devices, and their resultant effects on very “soft” x-ray response. The latest CMOS processes and very fast on-chip, and off-chip digital readout signal chains and camera systems will be demonstrated.

Adrian Lee/Regents of the University of California
Hierarchical Phased Array Antenna Focal Plane for Cosmic Microwave Background Polarization and Sub-mm Observations

We propose to develop planar-antenna-coupled superconducting bolometer arrays for observations at sub-millimeter to millimeter wavelengths. Our pixel architecture features a dual-polarization, log-periodic antenna with a 5:1 bandwidth ratio, followed by a filter bank that divides the total bandwidth into several broad photometric bands. We propose to develop an hierarchical phased array of our basic pixel type that gives optimal mapping speed (sensitivity) over a much broader range of frequencies. The advantage of this combination of an intrinsically broadband pixel with hierarchical phase arraying include a combination of greatly reduced focal-plane mass, higher array sensitivity, and a larger number of spectral bands compared to focal-plane designs using conventional single-color pixels.

These advantages have the potential to greatly reduce cost and/or increase performance of NASA missions in the sub-millimeter to millimeter bands. For CMB polarization, a wide frequency range of about 30 to 400 GHz is required to subtract galactic foregrounds. As an example, the multichroic architecture we propose could reduce the focal plane mass of the EPIC-IM CMB polarization mission study concept by a factor of 4, with great savings in required cryocooler performance and therefore cost.

We have demonstrated the lens-coupled antenna concept in the POLARBEAR ground-based CMB polarization experiment which is now operating in Chile. That experiment uses a single-band planar antenna that gives excellent beam properties and optical efficiency. POLARBEAR recently succeeded in detecting gravitational lensing B-modes in the CMB polarization. In the laboratory, we have measured two octaves of total bandwidth in the log-periodic sinuous antenna. We have built filter banks of 2, 3, and 7 bands with 4, 6, and 14 bolometers per pixel for two linear polarizations. Pixels of this type are slated to be deployed on the ground in POLARBEAR and SPT-3G and proposed to be used on a balloon by EBEX-IDS and in space on the LiteBIRD CMB polarization mission.

The deliverables for the proposed work include:

*Fabrication and test of a sinuous-antenna-based pixel with a 5:1 total bandwidth. Separate pixels will be built that are sensitive down to 30 GHz and others that are sensitive up to 400 GHz to cover the full range required for CMB measurements and to push into the sub-mm wavelength range. The efficiency of these pixels will be maximized by introducing a low loss silicon nitride insulator layer in all of the transmission lines.

*Hierarchical phased arrays that use up to five levels of arraying will be fabricated and tested. The hierarchical phased array approaches the optimal mapping speed (sensitivity) at all frequencies by adjusting the beam size of the array with frequency.

*We will develop 3 and 5 layer anti-reflection coatings using a new ``thermal spray'' technique that we have developed which heats ceramics and plastics to melting temperature an then sprays them on optical surfaces with excellent uniformity and thickness control.

The dielectric constant of each layer can be adjusted by choosing mixing ratios of high and low dielectric constant materials. Prioritization committees including the Astro2010 decadal, Quarks to Cosmos, and Weiss Committee have strongly advocated for prioritizing Cosmic Microwave Background polarization measurements and other science goals in the mm and sub-mm wavelength regime. The technology we propose to develop has the potential to greatly increase the cost effectiveness of potential missions in this frequency range. We have assembled an experienced team that includes expertise in antenna design, RF superconducting circuits, microfabrication, and CMB observations. Our team includes detector and/or CMB observation experts Bill Holzapfel, Adrian Lee, Akito Kusaka, and Aritoki Suzuki.

Tyson Littenberg/Universities Space Research Association
Data Analysis Technologies to Reduce Risk in Future Gravitational-Wave Missions

The existence of gravitational waves has at last been confirmed by the LIGO/Virgo discovery of a binary black hole merger, heralding the beginning of a new fields of research in observational astronomy, astrophysics, and relativity research. the LISA Pathfinder mission has begun collecting science data, paving the way for space-based gravitational wave measurement. Gravitational wave science will reach its full potential with a space-based observatory able to access mHz frequencies. The proposed work will investigate how develop crucial data analysis infrastructure for a future space mission. The three key themes of the proposal are (i) to incorporate lessons learned from LISA Pathfinder into our understanding of a GW observatories performance, (ii) develop data analysis methods for inter-spacecraft ranging critical to achieving the measurement precision needed for GW detection, and (iii) explore how known sources in the mHz band can be used as calibration sources.

Herman Marshall/Massachusetts Institute of Technology
Rocket Experiment Demonstration of a Soft X-ray Polarimeter

This proposal is the lead proposal. Boston University will submit, via NSPIRES, a Co-I proposal, per instructions for Suborbital proposals for multiple-award. Our scientific goal of the Rocket Experiment Demonstration of a Soft X-ray Polarimeter (REDSoX Polarimeter) is to make the first measurement of the linear X-ray polarization of an extragalactic source in the 0.2-0.8 keV band. The first flight of the REDSoX Polarimeter would target Mk 421, which is commonly modeled as a highly relativistic jet aimed nearly along the line of sight. Such sources are likely to be polarized at a level of 30-60%, so the goal is to obtain a significant detection even if it is as low as 10%. Significant revisions to the models of jets emanating from black holes at the cores of active galaxies would be required if the polarization fraction lower than 10%.

We employ multilayer-coated mirrors as Bragg reflectors at the Brewster angle. By matching to the dispersion of a spectrometer, one may take advantage of high multilayer reï¬,ectivities and achieve polarization modulation factors over 90%. Using replicated foil mirrors from MSFC and gratings made at MIT, we construct a spectrometer that disperses to three laterally graded multilayer mirrors (LGMLs). The lateral grading changes the wavelength of the Bragg peak for 45 degree reflections linearly across the mirror, matching the dispersion of the spectrometer. By dividing the entrance aperture into six equal sectors, pairs of blazed gratings from opposite sectors are oriented to disperse to the same LGML. The position angles for the LGMLs are 120 degrees to each other. CCD detectors then measure the intensities of the dispersed spectra after reflection and polarizing by the LGMLs, giving the three Stokes parameters needed to determine the source polarization.

We will rely on components whose performance has been verified in the laboratory or in space. The CCD detectors are based on Chandra and Suzaku heritage. The mirror fabrication team at MSFC has significant experience with flight systems and five mandrels to be used already exist and the team will fabricate more for this project in order to increase the area of the flight optics. LGMLs have been in development under NASA APRA funding for the past few years and are sufficient for this project. A current APRA grant is funding further development to improve the LGMLs. Prototype gratings for the project have been fabricated at MIT and the development team continues to improve them under separate funding.

We have constructed a source of polarized X-rays that operates at a wide range of energies with a selectable polarization angle in the lab for testing prototype components of our proposed instrument. In 2013, we demonstrated that the polarimetry beam-line provides 100% polarized X-rays at 0.525 keV. In 2014, we upgraded the source by installing a mirror with a laterally graded multilayer (LGML) coating, providing a wide energy range. In 2015, we tested new LGMLs with two more material combinations (C/CrCo and La/B4C) in order to obtain higher efficiencies in different soft X-ray bands than our early LGML made of W and B4C.

The REDSoX Polarimeter would rotate by 120 degrees about the optical axis in flight in order to assess and remove possible systematic effects. Our technological approach has significant promise for future missions that would operate in the 0.1 to 1.0 keV band. This sounding rocket program would provide a demonstration that a multilayer-based polarimetry approach can work, providing a basis for an orbital mission.

Christopher Martin/California Institute Of Technology
FIREBall-2: Trailblazing observations of the space UV circumgalactic medium.

The Faint Intergalactic-medium Redshifted Emission Balloon (FIREBall-2) is designed to discover and map faint emission from the circumgalactic medium of low redshift galaxies ($0.3<z<1.0$). This balloon is a modification of FIREBall-1 (FB-1), a path-finding mission built by our team with two successful flights (2007 Engineering, 2009 Science).

FB-1 provided the strongest constrains on intergalactic and circumgalactic (IGM, CGM) emission available from any instrument at the time.

FIREBall-2 has been significantly upgraded compared to FB-1, and is in the final stages of integration for a September 2016 flight from Ft. Sumner, New Mexico. The spectrograph has been redesigned with a wider field of view and greater efficiency. An upgraded detector system including a groundbreaking high QE, low-noise, UV optimized CCD detector is under final dark current and noise testing and will improve instrument performance by more than an order of magnitude. CNES is providing the spectrograph, gondola, and gondola flight support team, with construction of all components complete and final alignment and testing ongoing. We propose three additional years of funding to support the FIREBall-2 team in one additional flight in 2018 to fully utilize the upgraded spectrograph. This second flight, along with the funded 2016 flight, will conduct an initial blind CGM survey of dense fields at z~0.7, conduct a targeted search of circumquasar (CQM) media for selected targets, and conduct follow up on likely tar-gets selected via GALEX and a pilot survey conducted by our group. We will also conduct a statistical search for the faint IGM via statistical stacking of our data. The FIREBall-2 team includes two female graduate students in key roles (both of whom are finishing their PhDs in 2016) and is overseen by a female Postdoctoral scholar (supported by NSF AAPF and Caltech Millikan Fellowships, in addition to a recent Roman Technology Fellowship award). Additional funding is necessary to keep this highly qualified balloon team together for a second flight.

FIREBall-2 will test key technologies and science strategies for a future space mission to map emission from CGM and IGM baryons. Its flights will continue to provide important training for the next generation of space astrophysicists working in UV and other wavelength instrumentation. Most importantly, FIREBall-2 will detect emission from the CGM of nearby galaxies, providing the first census of the density and kinematics of this material for low z galaxies and open-ing a new field of CGM science.

Stephan McCandliss/Johns Hopkins University
Rocket and Laboratory Experiments in Astrophysics -- Validation and Verification of the Next Generation FORTIS

We submit herein a proposal describing plans for further development of a Next Generation Far-UV Off Rowland-circle Telescope for Imaging and Spectroscopy (FORTIS). The goal of the proposal is to demonstrate the scientific utility of multi-object spectroscopy over wide angular fields in the far-UV with investigations of: the blue straggler population in the Globular Cluster M10; low metallicity star formation in the Magellanic Bridge; shock structures Cygnus Loop supernova remnant; a search for unidentified emissions in star-forming galaxies; and potentially an, as yet, unnamed comet as a target of opportunity.

FORTIS is a pathfinder for developing the technologies necessary to enable far-UV spectroscopic surveys. Such surveys will allow us to probe problems relevant to the formation of large scale structures, the origin and evolution of galaxies, and the formation and evolution of stars from interstellar gas. In combination with existing and future spectroscopic surveys, they will provide a complete and compelling panchromatic picture of the observable universe.

Next generation FORTIS will fly as a sounding rocket borne instrument and incorporate a number of unique technologies, including the Next Generation MicroShutter Array (NGMSA), which provides for the simultaneous acquisition of spectra from multiple objects within a wide angular field. The NGMSA will be controlled by an autonomous targeting system capable of identifying multiple objects on-the-fly for further spectral analysis in the short time afforded to far-UV observations from a sounding rocket ~ 400 seconds. We will also incorporate long life microchannel plate (MCP) detectors that have have high open area ratios, providing for increased quantum efficiency, and improved resistance to gain sag, allowing operation at higher count rate.

Recent flight experience with the first generation FORTIS has provided guidance to improving the science return of the next generation FORTIS. Our plans for a rigorous validation and verification of the science and technology is detailed.

This program will serve as the basis of doctoral theses for several graduate students in addition to providing hands-on experience with space science missions to a number of undergraduates. It will enable new science thrusts, enabled by new technologies while cultivating new skillsets in the next generation of space scientists.

Randall McEntaffer/Pennsylvania State University
X-ray Rocket Payloads for Key Technologies and Core Science

The goal of this project is to fly two suborbital rockets for X-ray astronomical observations. The first flight will use an existing payload and replace the GEM detectors with state-of-the-art hybrid CMOS detectors, a key technology for future NASA missions. Concurrently, this payload will be the first science flight for the key water recovery technologies that are currently being developed by NASA's Sounding Rocket Program Office. We will fly from Kwajalein launch range and recover the payload from the water. This will be the first flight for both the X-ray hybrid CMOS detectors and the water recovery technologies. The latitude of Kwajalein allows for southern hemisphere exposure which is a large benefit for astronomical rockets. Given the large field of view for this payload, we will be observing a large portion of the Vela supernova remnant that has not been fully observed or characterized by current X-ray Observatories. We will detect key lines that indicate the temperature and ionization state of this plasma.

The second payload has a science goal of concurrently observing with the Chandra X-ray Observatory to provide cross-calibration of the low energy spectral response. Such an observation will enable a new update to the response and contamination models that are critical to the Chandra Calibration Database. A detailed calibration of our payload will take place at the MPE PANTER X-ray facility. The throughput and spectral resolving power is designed so that the duration of a rocket flight will provide an adequate spectrum for cross-calibration with Chandra, the preeminent X-ray observatory.

Igor Moskalenko/Leland Stanford Junior University
Modeling of Cosmic-Ray Propagation and Galactic Diffuse Gamma-Ray Emission in Support of Current and Future NASA Missions, Phase 3

This is a "Phase 3" successor proposal that is a continuation of work funded by the Astrophysics Research and Analysis (APRA) Program through the sub-topic "Particle Astrophysics": Considerable advances in astrophysics of cosmic rays in recent years have become possible due to superior instrumentation launched into space and to the top of the atmosphere. The ACE-CRIS, AMS-02, Fermi-LAT, HAWC, PAMELA, SuperTIGER, Voyager 1,2, WMAP, and many other missions made a lot of breakthroughs and more is expected in the following years. Other high-expectations missions are recently launched (CALET) or are awaiting for launch (ISS-CREAM). The claimed precision of the AMS-02 data reaches 1-3%. Taking full advantage of the high quality data requires numerical models of comparable accuracy. The current state-of-the-art cosmic ray propagation model is GALPROP, which has become a standard analysis tool in astrophysics of cosmic rays, studies of the diffuse emissions, and related fields. It provides a unified framework for the interpretation of data collected by many different kinds of experiments and emphasizes the inter-relationship between different types of data. We are proposing considerable improvements of the GALPROP model and tool that include generalization of the description of the components of the Galactic interstellar medium to the full 3D and extensive application of the Bayesian tools in building such data-sets, development of a heliospheric propagation tool fully compatible with GALPROP, development of a reliable diffuse emission model in the keV-TeV energy range, generalization of the nuclear reaction network and cross section routines to include trans-iron nuclides, improvements in the description of the production of secondary particles in cosmic ray interactions, various speed and memory optimizations. We will continue to support a dedicated website which hosts GALPROP WebRun, a user-friendly interface for running the GALPROP code on a dedicated cluster, together with the source code, results of published models, manuals, a user forum, and other relevant astrophysical information. The improved GALPROP model will be publicly available as was the case with previous versions of the code.

Scott Nutter/Northern Kentucky University Research Foundation, Inc.
Cosmic Ray Energetics And Mass (CREAM) launch and operation, NKU Co-I

This is the Northern Kentucky University Co-I proposal to request continued NASA support for the on-going Cosmic Ray Energetics And Mass (CREAM) project. The balloon-borne CREAM instrument was flown for ~161 days in six flights over Antarctica, the longest known exposure for a single balloon project. Building on the success of those balloon missions, one of the two balloon payloads was successfully transformed for exposure on the International Space Station (ISS) Japanese Experiment Module Exposed Facility (JEM EF). Following completion of its system-level qualification and verification, this ISS-CREAM payload was delivered to the NASA Kennedy Space Center in August 2015 to await its launch to the ISS. The ISS-CREAM mission would achieve the primary science objectives of the Advanced Cosmic-ray

Composition Experiment for the Space Station (ACCESS), which was given high priority in the 2001 NRC Decadal Study Report. Its nuclei composition data between 10^12 and 10^15 eV would enable detailed study of the spectral hardening first reported by the CREAM balloon project and recently confirmed for protons and helium by the PAMELA and AMS-02 space missions using permanent magnet spectrometers. In addition, multi-TeV energy electron data allow searches for local sources and the signature of darkmatter, etc.

The ISS-CREAM instrument is configured with redundant and complementary particle detectors capable of precise measurements of elemental spectra for Z = 1 - 26 nuclei, as well as electrons. The four layers of its finely segmented Silicon Charge Detector provide charge measurements, and its ionization calorimeter provides energy measurements. Its segmented scintillator-based Top and Bottom Counting Detectors separate electrons from nuclei using shower profile differences. Its Boronated Scintillator Detector distinguishes electrons from nuclei by detecting thermal neutrons that are dominant in nuclei induced showers. An order of magnitude increase in data collecting power is possible by utilizing the ISS to reach the highest energies practical with direct measurements. The ISS-CREAM launch is currently manifested on SpaceX-12, which is scheduled for April 2017. It is expected to accumulate a total of > 4.5 years exposure during the grant period.

The study of cosmic accelerators supports the Science Mission Directorate's Goal for Astrophysics in NASA's 2010 Science Plan, "Discover how the universe works, explore how the universe began and evolved, and search for Earth-like planets." It specifically addresses the Science Question, "How do matter, energy, space and time behave under the extraordinarily diverse conditions of the cosmos?"

Rene Ong/University of California, Los Angeles
The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons [UCLA Co-I]

This is a Co-I proposal in support of the PI lead proposal entitled "The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons" submitted by Prof. Charles Hailey, Columbia University. Our proposed program would support the UCLA tasks on the GAPS experiment as detailed in our task statement. The primary focus of this work is on the development, construction and testing of the time-of-flight (TOF) system, the master GAPS trigger and support of the simulation and analysis tasks.

Frederick Porter/NASA Goddard Space Flight Center
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 15 years, 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 40 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 ¼ 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 IXO and now Athena large-scale observatories. 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 us to disentangle line blends for nearly every high energy emission line over the entire astrophysical spectrum using the non-dispersive, highly efficient microcalorimeter instrument alone and in concert with the high resolution but narrow band dispersive spectrometers at the LLNL EBIT facility.

This work is highly relevant to NASA objectives as it allows for the unambiguous connection between spectroscopic observations with Chandra, XMM, Astro-H, and future spectrometers aboard missions like Athena, and the physics occurring in the cosmological source. Our program aids these measurements by benchmarking the spectroscopic synthesis models used to interpret all x-ray observations. Without laboratory measurements to support these models, it is not a priori certain that the models are correct, and the observational data correctly interpreted. This is especially true for charge exchange measurements, where there are substantially differences between theory and measurement in K shell emission, and no useful theory at all in L shell emission.

Alessandra Ricca/SETI Institute
PAH Infrared Spectroscopy in the JWST Era

The extraordinary infrared instruments on the James Webb Space Telescope (JWST) will transform the field of cosmic spectroscopy. We propose to supply the astronomical community with theoretical and experimental spectra of a wide range of Polycyclic Aromatic Hydrocarbons (PAHs) and PAH clusters and to use our IR absorption spectra to calculate emission spectra that will be crucial in interpreting the new observational data.
The Infrared Space Observatory and Spitzer Space Telescopes have shown that the mid-IR emission spectrum of the interstellar medium is dominated by strong bands at 3.3, 6.2,

7.7, 8.6, 11.3 and 12.7 microns superimposed upon broad underlying plateaus generally attributed to PAHs, PAH clusters and very small grains. Despite the limited spectral and spatial resolution of these data, detailed analysis has revealed that each band is, in fact, a blend of multiple emission features. Subtle variations in the band blending can be detected even for spectra measured at different positions within a single astronomical source. These variations can be seen to arise from multiple PAH and PAH-related carriers that are each responding differently to the local physical conditions. The James Webb Space Telescope has near-IR and mid-IR instruments, NIRSpec and MIRI, with an extremely high spectral resolution, spatial resolution, and sensitivity that will revolutionize infrared astronomy. These instruments will provide spatial maps on a sub-arcsecond scale with an unprecedented level of spectral detail, allowing detailed study of the interrelationship of the individual components within each emission band. This will provide a critical insight into the molecular characteristics of the emitting species and their (photo)chemical evolution in space.

Exploitation of these astronomical spectra requires fundamental data on potential emitting species that fully account for all astrophysically relevant materials. Over the last two decades, spectra of neutral and charged PAHs have been calculated using quantum theory. Due to computational limitations, this data set is biased towards smaller or highly symmetric species. In addition, continued analysis of the mid-IR emission bands by several recent Spitzer studies, has demonstrated that PAHs and PAH clusters with less symmetric structures containing “bay regions”□ are more important for understanding the IR emission bands than had previously been realized. The currently available infrared data set on less symmetric PAHs and PAH clusters is insufficient to exploit the astronomical data.

Advances in computing power now allow spectra for a much wider range of species to be calculated. In support of the analysis of Spitzer data and the upcoming JWST mission, we therefore propose to calculate the 3-20 micron spectra of isolated as well as clustered neutral and charged PAHs containing up to 150 carbon atoms and with a wide range of compact structures and eroded structures with irregular shapes containing “bay regions”, “coves”, and “fjords”. These theoretical data will be validated by a dedicated laboratory study of PAH species and their clusters. These IR absorption spectra will be used to calculate emission spectra that can be directly compared to existing astronomical observations and that will be used to guide our quantum chemical and experimental studies on relevant species for support of Early Release Science proposals for JWST.

Matthew Richter/University of California, Davis

A Compact Igh-Resolution Grating Spectrograph for Spaceborne Infrared Astronomy

The primary research area for this investigation is space-based astronomical observations of the infrared universe; specifically, in the areas of star and planet formation, astro-chemistry, evolved stars, solar system atmospheres, and probing the atmospheres of extra-solar planets. This proposed work's primary objective is to increase the technology readiness level of a high-resolution infrared spectrograph that employs a Germanium immersion grating as the primary diffractive optical element. This spectrograph's optical pathway would be designed to fit within a compact volume consistent with a low overall instrument mass, potentially enabling novel high-resolution spectroscopy on a small-format spacecraft. Additionally, maturing this capability now makes possible a high-spectral resolution mid-IR spectroscopy mode for 2020 Decadal Candidate missions such as the Far Infrared Surveyor or the Large Ultraviolet, Optical, and Infrared Surveyor. The investigation would deliver performance data from an optical-bench test version of a Germanium-immersion-grating-equipped instrument. This preliminary design and performance data will next be used to support a proposal for further technical readiness level advancement such as building a spectrograph for a ground-based, balloon-based, or sounding rocket telescope observations.

Stephen Rinehart/NASA Goddard Space Flight Center
BETTII: The Balloon Experimental Twin Telescope for Infrared Interferometry (Phase 2a) - High Angular Resolution Astronomy at Far-Infrared Wavelengths

The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) is an eight-meter baseline far-infrared interferometer to fly on a high altitude balloon. The combination of the long baseline with a double-Fourier instrument allows BETTII to simultaneously gain both spatial and spectral information; BETTII is designed for spatially-resolved spectroscopy. The unique data obtained with BETTII will be valuable for understanding how stars form within dense clusters, by isolating individual objects that are unresolved by previous space telescopes and my measuring their spectral energy distributions. BETTII will be also used in future flights to understand the processes in the cores of Active Galactic Nuclei. In addition to these scientific goals, BETTII serves as a major step towards achieving the vision of space-based interferometry.

BETTII was first funded through the 2010 APRA program; last year, the proposal also fared well in the APRA review, but for programmatic reasons was only awarded one year of funding. With the current funding, we will complete the BETTII experiment and conduct a Commissioning Flight in August/September 2016. The effort proposed includes full analysis of data from the Commissioning Flight, which will help us determine the technical and scientific capabilities of the experiment. It also includes two science flights, one in each 2017 and 2018, with full data analysis being completed in 2019.

Karwan Rostem/Johns Hopkins University
Ultra-Low-Noise Sub-mm/Far-IR Detectors for Space-Based Telescopes

The sub-mm and Far-IR spectrum is rich with information from a wide range of astrophysical sources, including exoplanet atmospheres and galaxies at the peak star formation. In the 10-400 Î¼m range, the spectral lines of important chemical species such H2O, HD, and [OI] can be used to map the formation and evolution of planetary systems. Dust emission in this spectral range is also an important tool for characterizing the morphology of debris disks and interstellar magnetic fields. At larger scales, accessing the formation and distribution of luminous Far-IR and sub-mm galaxies is essential to understanding star formation triggers, as well as the last stages of reionization at z~6.

Detector technology is essential to realizing the full science potential of a next-generation Far-IR space telescope (Far-IR Surveyor). The technology gap in large-format, low-noise and ultra-low-noise Far-IR direct detectors is specifically highlighted by NASA's Cosmic Origins Program, and prioritized for development now to enable a flagship mission such as the Far-IR Surveyor that will address the key Cosmic Origins science questions of the next two decades.

The detector requirements for a mid-resolution spectrometer are as follows: (1) Highly sensitive detectors with performance approaching 10^-19 - 10^-20 WHz 1/2 for background- limited operation in telescopes with cold optics. (2) Detector time constant in the sub- millisecond range. (3) Scalable architecture to a kilo pixel array with uniform detector characteristics. (4) Compatibility with space operation in the presence of particle radiation.

We propose phononic crystals to meet the requirements of ultra-low-noise thermal detectors. By design, a phononic crystal exhibits phonon bandgaps where heat transport is forbidden. The size and location of the bandgaps depend on the elastic properties of the dielectric and the geometry of the phononic unit cell. A wide-bandwidth low-pass thermal filter with a cut-off frequency of ~1.5 GHz and extending to 10 GHz can be realized with quasi-periodic phononic structures. A few 10^-19 WHz-1/2 detector sensitivity is readily accessible with phononic filter thermal isolation. Phononic filters are naturally compact, <20 Î¼m in longest dimension, and contribute negligible heat capacity to a thermal sensor.

We propose a three-year effort to fabricate and test phononic-isolated Transition- Edge Sensor arrays suitable for background-limited operation in a Far-IR Sur- veyor. We emphasize that phononic thermal isolation offers a viable path towards detector sensitivities an order of magnitude above that achieved with current state-of-the-art thermal detector technologies. Our effort addresses the APRA solicitation for advancing detector design and operation towards highly sensitive, compact, and robust characteristics.

Mark Schattenburg/Massachusetts Institute of Technology
Development of High Resolution X-ray Telescope Optics

We propose to develop novel high-precision x-ray telescope mirror fabrication and figure correction technology which will lead to thin-shell mirrors rivaling Chandra's mirrors in angular resolution but with 10-100X larger area' all with significantly reduced weight and cost. The proposed effort builds on previous research at MIT and complements NASA-supported research at other institutions.

Thin shell mirrors with resolution in the sub-5 arc-sec domain require significant advances in mirror shaping and correction technology. The best thin-shell mirrors fabricated to date allow a mission-level angular resolution of only ~10 arc sec. For slumped glass mirrors the PSF is currently dominated by surface errors in the mid-range spatial frequency domain which are difficult to remove by any of the proposed post-fabrication correction schemes.

MIT is developing novel glass slumping technology which supports hot mirrors on a thin film of air, thus eliminating mid-range errors due to mandrel surface contamination and anti-stick coatings. We are also developing a surface-stress mirror correction technique utilizing a scanning MeV ion beam to remove mid- and long-range spatial frequency errors from mirrors. Surprising recent results from our lab show that MeV ions are capable of applying the full stress tensor to surfaces, unlike competing methods such as piezoelectric films which can apply only equi-biaxial film stresses. Computer models show that access to the full stress tensor is essential in order to correct kinematically-mounted mirrors into the sub-1 arc-sec domain. We propose a research program which builds on these new tools to help accelerate progress in x-ray mirror figure quality while reducing the cost of both glass and silicon mirrors.

David Schiminovich/Trustees of Columbia University in the City of New York
FIREBall-2: Trailblazing observations of the space UV circumgalactic medium (Columbia University, Co-I Proposal)

Columbia University is a Co-I institution in a collaborative research program with Caltech, the Lead Institution (PI: Christopher Martin).

The Faint Intergalactic-medium Redshifted Emission Balloon (FIREBall-2) is designed to discover and map faint emission from the circumgalactic medium of low redshift galaxies ($0.3<z<1.0$). This balloon is a modification of FIREBall-1 (FB-1), a path-finding mission built by our team with two successful flights (2007 Engineering, 2009 Science). FB-1 provided the strongest constrains on intergalactic and circumgalactic (IGM, CGM) emission available from any instrument at the time.

FIREBall-2 has been significantly upgraded compared to FB-1, and is in the final stages of integration for a September 2016 flight from Ft. Sumner, New Mexico. The spectrograph has been redesigned with a wider field of view and greater efficiency. An upgraded detector system including a groundbreaking high QE, low-noise, UV optimized CCD detector is under final dark current and noise testing and will improve instrument performance by more than an order of magnitude. CNES is providing the spectrograph, gondola, and gondola flight support team, with construction of all components complete and final alignment and testing ongoing. We propose three additional years of funding to support the FIREBall-2 team in one additional flight in 2018 to fully utilize the upgraded spectrograph. This second flight, along with the funded 2016 flight, will conduct an initial blind CGM survey of dense fields at $z\sim0.7$, conduct a targeted search of circumquasar (CQM) media for selected targets, and conduct follow up on likely tar-gets selected via GALEX and a pilot survey conducted by our group. We will also conduct a statistical search for the faint IGM via statistical stacking of our data. The FIREBall-2 team includes two female graduate students in key roles (both of whom are finishing their

PhDs in 2016) and is overseen by a female Postdoctoral scholar (supported by NSF AAPF and Caltech Millikan Fellowships, in addition to a recent Roman Technology Fellowship award). Additional funding is necessary to keep this highly qualified balloon team together for a second flight.

FIREBall-2 will test key technologies and science strategies for a future space mission to map emission from CGM and IGM baryons. Its flights will continue to provide important training for the next generation of space astrophysicists working in UV and other wavelength instrumentation. Most importantly, FIREBall-2 will detect emission from the CGM of nearby galaxies, providing the first census of the density and kinematics of this material for low z galaxies and open-ing a new field of CGM science.

Eun-Suk Seo/University of Maryland
Cosmic Ray Energetics and Mass (CREAM) Launch and Operations

We request continued NASA support for the on-going Cosmic Ray Energetics And Mass (CREAM) project. The balloon-borne CREAM instrument was flown for ~161 days in six flights over Antarctica, the longest known exposure for a single balloon project. Building on the success of those balloon missions, one of the two balloon payloads was successfully transformed for exposure on the International Space Station (ISS) Japanese Experiment Module Exposed Facility (JEM EF). Following completion of its system-level qualification and verification, this ISS-CREAM payload was delivered to the NASA Kennedy Space Center in August 2015 to await its launch to the ISS. The ISS-CREAM mission would achieve the primary science objectives of the Advanced Cosmic-ray Composition Experiment for the Space Station (ACCESS), which was given high priority in the 2001 NRC Decadal Study Report. Its nuclei composition data between 10^12 and 10^15 eV would enable detailed study of the spectral hardening first reported by the CREAM balloon project and recently confirmed for protons and helium by the PAMELA and AMS-02 space missions using permanent magnet spectrometers. In addition, multi-TeV energy electron data allow searches for local sources and the signature of darkmatter, etc.

The ISS-CREAM instrument is configured with redundant and complementary particle detectors capable of precise measurements of elemental spectra for Z = 1 - 26 nuclei, as well as electrons. The four layers of its finely segmented Silicon Charge Detector provide charge measurements, and its ionization calorimeter provides energy measurements. Its segmented scintillator-based Top and Bottom Counting Detectors separate electrons from nuclei using shower profile differences. Its Boronated Scintillator Detector distinguishes electrons from nuclei by detecting thermal neutrons that are dominant in nuclei induced showers. An order of magnitude increase in data collecting power is possible by utilizing the ISS to reach the highest energies practical with direct measurements. The ISS-CREAM launch is currently manifested on SpaceX-12, which is scheduled for April 2017. It is expected to accumulate a total of > 4.5 years exposure during the grant period.

The study of cosmic accelerators supports the Science Mission Directorate's Goal for Astrophysics in NASA's 2010 Science Plan, “Discover how the universe works, explore how the universe began and evolved, and search for Earth-like planets." It specifically addresses the Science Question, "How do matter, energy, space and time behave under the extraordinarily diverse conditions of the cosmos?"

Antony Stark/Smithsonian Institution
STO-2: Support for 4th Year Operations, Recovery, and Science: Smithsonian Astrophysical Observatory Co-I

The Lead Proposal for this investigation originates from the University of Arizona, Steward Observatory under Principal Investigator Dr. Christopher K. Walker. The Smithsonian Astrophysical Observatory (SAO) is pleased to submit this subsidiary proposal for engineering and scientific collaboration on the reflight of the Stratospheric TeraHertz Observatory (STO-2). This proposal covers Support for 4th Year Operations, Recovery, and Science as a result of the failure to launch due to weather in the 2015-2016 season. The Institutional Principal Investigator for the SAO effort is Antony A. Stark, and scientific Co-Investigators Gary Melnick, Volker Tolls, and Matthew Ashby. SAO will provide pre-flight engineering and flight monitoring support for the second Long Duration Flight (LDF) from McMurdo Sound in Antarctica. Subsequent to the flight, SAO Co-Is will contribute to data management and analysis, scientific interpretation, publication of results, and public distribution of data.

David Thompson/NASA Goddard Space Flight Center
Development of a Drift-bar CZT Calorimeter with Good Energy Resolution for Gamma-ray Spectroscopy

We propose to develop, fabricate and test a three-dimensional, high-energy-resolution, high-efficiency calorimeter for photon energies 0.2 – 10 MeV, based on novel drift (Frisch-grid) bar CdZnTe (CZT) detectors recently developed at Brookhaven National Laboratory (BNL). This calorimeter will have a position resolution of n of 0.1 – 0.5 mm alon along each of 3 axes depending on the incident photon energy, energy resolution of âˆ¼1%, and capability of operating in ambient conditions. The drift-bar approach will allow the use of CZT detectors with poorer quality, which can significantly increase the yield of acceptable detectors and consequently reduce the cost. This technology represents a breakthrough, because it promises excellent performance with large area detectors at a reasonable cost. The proposed efforts will combine the strong expertise of the BNL team in CZT detectors with that of the GSFC team in the design of space instrumentation.

The immediate application of this technology is in medium-energy gamma-ray telescopes (e.g. ComPair or ASTROGAM), whose high scientific potential has been emphasized by results at lower energies (Swift, NuSTAR) and higher energies (Fermi Large Area Telescope). In particular, the drift-grid CZT detector will enable a medium-energy gamma-ray instrument to: (1) provide incident photon energy measurement with high resolution, including the capability to measure cosmic nuclear lines; and (2) serve as a focal plane detector for Compton-scattered events to determine the direction and polarization of incident photons.

Susan Trolier-McKinstry/Pennsylvania State University
High Resolution Adjustable Mirror Control for X-ray Astronomy

We propose to build and test thin film transistor control circuitry for a new high-resolution adjustable X-ray mirror technology. This control circuitry will greatly simplify the wiring scheme to address individual actuator cells. The result will be a transformative improvement for the X-ray Surveyor mission concept: mathematical models, which fit the experimental data quite well, indicate that 0.5 arcsecond imaging is feasible through this technique utilizing thin slumped glass substrates with uncorrected angular resolution of order 5-10 arcseconds.

In order to correct for figures errors in a telescope with several square meters of collecting area, millions of actuator cells must be set and held at specific voltages. It is clearly not feasible to do this via millions of wires, each one connected to an actuator. Instead, we propose to develop and test thin-film technology that operates on the same principle as megapixel computer screens. We will develop the technologies needed to build thin film piezoelectric actuators, controlled by thin film ZnO transistors, on flexible polyimide films, and to connect those films to the back surfaces of X-ray mirrors on thin glass substrates without deforming the surface. These technologies represent a promising avenue of the development of mirrors for the X-Ray Surveyor mission concept.

Such a telescope will make possible detailed studies of a wide variety of astrophysical sources. One example is the Warm-Hot Intergalactic Medium (WHIM), which is thought to account for a large fraction of the normal matter in the universe but which has not been detected unambiguously to date. Another is the growth of supermassive black holes in the early universe.

This proposal supports NASA's goals of technical advancement of technologies suitable for future missions, and training of graduate students.

Joel Ullom/National Institute of Standards & Technology
Advanced Microcalorimeter Arrays for Next-Generation X-Ray Missions

We will develop several technologies to enable significantly larger arrays of x-ray microcalorimeter sensors for future NASA missions such as the X-ray Surveyor. In particular, we will develop sensor fabrication and readout strategies compatible with arrays of 10^5 or more sensors. Our readout strategies rely, in part, on a novel switching element recently developed at NIST that has not previously been used with microcalorimeter sensors. Our work will enable in-focal plane multiplexing in which the sensors and readout circuitry are co-located. The scalability of this approach is highly favorable for large sensor arrays. We will also develop x-ray microcalorimeters using novel materials consisting of doped AlMn alloys. These materials allow precise control of the transition temperature over 150 mm wafer area. This wafer scale is necessary for arrays of 10^5 to 10^6 sensors.

Joel Ullom/National Institute of Standards & Technology
Large-scale Polarimeter Array with Integrated Tunnel Junction Cooling

Normal-Insulator-Superconductor (NIS) tunnel junctions are solid-state devices capable of cooling thin film or bulk payloads at sub-Kelvin temperatures. The performance of NIS refrigerators has improved steadily in recent years and we will leverage this progress to build an array of microwave polarimeters with integrated NIS cooling. The use of NIS refrigerators will improve pixel sensitivity, size, and mechanical robustness. By design, the polarimeter array will be well matched to a future suborbital mission to study polarization in the cosmic microwave background. The array will also demonstrate the suitability of NIS refrigerators for a future NASA satellite mission.

Melville Ulmer/Northwestern University
Correcting and Coating Thin Walled X-ray Optics via a Combination of Controlled Film Deposition and Magnetic Smart Materials

The project goal is to demonstrate that thin walled (<400 micron thick) X-ray optics can be controllably shaped to produce high quality (~1" or better) X-ray optics at an affordable price. Since the desired surface area for the next generation X-ray telescope is >10x that of Chandra, the >10x requirement is then for >200 m^2 of surface area with a surface finish of better than 0.5 nm. Therefore, replication of some sort is called for. Because no replication technology has been shown to achieve ≤1" angular resolution, post fabrication figure corrections are likely going to be necessar. Some have proposed to do this in orbit and others prelaunch including us. Our prelaunch approach is to apply in-plane stresses to the thin walled mirror shells via a magnetic field. The field will be held in by some magnetically hard material such as NiCo. By use of a so called magnetic smart material (MSM) such as Terfenol-D, we already shown that strong enough stresses can be generated. Preliminary work has also shown that the magnetic field can be held in well enough to apply the figure correcting stresses pre-launch. What we call "set-it and forget-it." However, what is unique about our approach is that at the cost of complexity and some areal coverage, our concept will also accommodate in-orbit adjustments. Furthermore, to the best of our knowledge ours is one of two known stress modification processes that are bi-axial. Our plan is first to validate set-it and forget-it first on cantilevers and then to expand this to working on 5 cm x 5 cm pieces. We will work both with NiCo and glass or Si coated with Terfenol-D. Except for the NiCo, substrates we will also coat the samples with NiCo in order to have a film that will hold in the magnetic field. As part of the coating process, we will control the stress of the film by varying the voltage bias while coating. The bias stress control can be used to apply films with minimal stress such as Terfenol-D and X-ray reflecting coatings such as Ir. Ir is a highly desirable coating for soft X-ray astronomy mirrors that can have significant built in stress unless some technique like our is used to apply the coating. An alternative use for the bias stress control coating process is to improve the initially fabricated mirror by applying spatially dependent stresses with a Cr film. We will also expand upon the work we have done that shows this method has promise to reduce the amount of corrections needed by the MSM plus the magnetic field process.

Philip von Doetinchem/University Of Hawaii Systems
The GAPS Experiment: A Search for Dark Matter Using Low Energy Antiprotons and Antideuterons [University of Hawaii Co-I]

This is a Co-I proposal in support of the PI lead proposal entitled “The GAPS experiment: a search for dark matter using low energy antiprotons and antideuterons” submitted by Prof. Charles Hailey, Columbia University. Our proposed program would support the Umiversity of Hawaii at Manoa tasks on the GAPS experiment as detailed in our task statement. The primary focus of this work is the calibration and test of the Si(Li) detector modules, instrument simulation and support of the flight program and scientific analysis.

Christopher Walker/University of Arizona
STO-2: Support for 4th Year Operations, Recovery, and Science

The Stratospheric TeraHertz Observatory was ready for its second Antarctic flight (STO-2) in the 2015-2016 austral summer. However, due to the late establishment of the stratospheric anti-cyclone and poor surface conditions, STO-2 was unable to launch. The decision was made to winter-over the STO-2 payload in its hangar for launch during the 2016-2017 Antarctic campaign. Funds to cover preparations and deployment of key members of the instrument team in support of the campaign are being provided by NASA under the existing grant. However, these funds are only sufficient to cover expenses up to December 31st, 2016. Here, we request resources for calendar year 2017 to support mission operations, payload recovery, and science operations. These elements will enable the team to deliver fully on STO-2's science mission, and maximize NASA's demonstrated investment in STO-2's success.

STO-2 addresses a key problem in modern astrophysics: understanding the Life Cycle of the Interstellar Medium (ISM). STO-2 will survey approximately Â¼ of the Southern Galactic Plane in the dominant interstellar cooling line [CII] (158 Âµm) and the important star formation tracer [NII] (205 Âµm). In addition, STO-2 will perform path finding observations of the 63 Âµm [OI] line toward selected regions. With 1 arcminute angular resolution, STO-2 will spatially resolve atomic, ionic and molecular clouds out to 10 kpc. The STO-2 survey will be conducted at unparalleled sensitivity levels. STO-2 will uniquely probe the pivotal formative and disruptive stages in the life cycle of interstellar clouds and the relationship between global star formation rates and the properties of the ISM. Combined with previous HI and CO surveys, STO-2 will create 3-dimensional maps of the structure, dynamics, turbulence, energy balance, and pressure of the Milky Way's ISM, as well as the star formation rate. Once we gain an understanding of the relationship between ISM properties and star formation in the Milky Way, we can better interpret observations of nearby galaxies and the distant universe. The mission goals for these surveys are to:

- Determine the life cycle of Galactic interstellar gas.
- Study the creation and disruption of star-forming clouds in the Galaxy.

- Determine the parameters that affect the star formation rate in the galaxy.
- Provide templates for star formation and stellar/interstellar feedback in other galaxies.

STO-2 reuses the 80cm telescope and many subsystems from STO-1. It also reuses the gondola developed by APL for the BOPPS and BRRISON comet missions. For the STO-2 flight, STO-1’s high spectral resolution (<1 km/s) heterodyne receiver system was upgraded for extended cryogenic lifetime, enhanced sensitivity, and greater reliability. The flight receiver has five cryogenic HEB mixers; two optimized for the 158 Âµm [CII] line, two for the 205 Âµm [NII] line, and one for the 63 Âµm [OI] line. STO is capable of detecting every giant molecular cloud, every HII region of significance, and every diffuse HI cloud with (AV â‰¥ 0.4) within its survey region.

Susanna Widicus Weaver/Emory University
Harnessing the Efficiency of O(1D) Insertion Reactions for Prebiotic Astrochemistry

We propose a THz spectroscopic study of the small prebiotic molecules aminomethanol, methanediol, and methoxymethanol. These target molecules are predicted as the dominant products of photo-driven grain surface chemistry in interstellar environments, and are precursors to important prebiotic molecules like sugars and amino acids. These molecules are also expected to be major contributors to the spectral line density in the submillimeter spectral surveys from the Herschel and SOFIA observatories. We will use our custom mixing source to produce these molecules through O(1D) insertion reactions with the precursor molecules methyl amine, methanol, and dimethyl ether, respectively. We will then record their rotational spectra across the THz frequency range using our existing submillimeter spectrometer.

This research will increase the science return from NASA missions because the target molecules serve as tracers of the simplest organic chemistry that can occur in star-forming regions. This chemistry begins with methanol, which is the predominant organic molecule observed in interstellar ices. Methanol photodissociation leads to small organic radicals such as CH3O, CH2OH, and CH3. These radicals can undergo combination reactions on interstellar ices to form many of the complex organic molecules that are routinely observed in star-forming regions. Our target molecules aminomethanol, methanediol, and methoxymethanol are some of the simplest molecules that can form from this type of chemistry, and serve as tracers of ice mantle liberation in star-forming regions. These molecules also participate in gas-phase reactions that lead to amino acids and sugars, and as such are fundamentally important prebiotic molecules in interstellar environments. These types of small organic molecules also have high spectral line density, and are major contributors to line confusion in observational spectral surveys such as those conducted by Herschel and SOFIA. Therefore, the proposed research will aid in full data interpretation from Herschel and SOFIA observations.

Currently there is no spectral information available for these molecules to guide observational studies, despite their importance in astrochemistry. This is because these molecules are difficult to study in laboratory settings due to their instability and reactivity. We are using highly exothermic O(1D) insertion reactions to produce these molecules in a supersonic expansion, and investigating the products using THz spectroscopy. This work builds on the work involved in our previous APRA award (Grant NNX11AI07G) "New THz Tools to Support Herschel Observations: Integrative Studies in Laboratory Spectroscopy, Observational Astronomy, and Chemical Modeling". In this previous award, we laid the groundwork for these experiments by constructing and benchmarking the spectrometer, designing and testing the molecular source used for the O(1D) reactions, and studying the proposed formation reactions for the laboratory work through computational studies. We have confirmed production of methanol from O(1D) insertion into methane, and then applied this chemistry to produce vinyl alcohol from ethylene. We have now also obtained preliminary spectra of aminomethanol. Here we propose to extend this work by finishing the aminomethanol characterization as well as examining methanediol and methoxymethanol during the next proposal period.

David Windt/Reflective X-Ray Optics, LLC
Two-Dimensional Differential Deposition and Erosion for Thin-Shell Figure Correction, and Non-Distorting, High-Energy X-ray Multilayers

We propose to continue our development of two-dimensional differential deposition and erosion, a novel methods for high-throughput surface height error correction in thin-shell cylindrical mirror substrates. We also propose to develop non-distorting X-ray reflective multilayer coatings for use above 80 keV. Our specific research objectives are: (a) develop two-dimensional control of film deposition and erosion to correct both low- and mid-frequency surface height errors in cylindrical, thin-shell mirror substrates, and (b) develop high-efficiency, non-distorting, zero net-stress, and stress balanced, reflective multilayer coatings for use above 80 keV.

Andreas Zoglauer/Regents of the University of California
Advanced Source Deconvolution Methods for Compton Telescopes

The next generation of space telescopes utilizing Compton scattering for astrophysical observations is destined to one day unravel the mysteries behind Galactic nucleosynthesis, to determine the origin of the positron annihilation excess near the Galactic center, and to uncover the hidden emission mechanisms behind gamma-ray bursts. Besides astrophysics, Compton telescopes are establishing themselves in heliophysics, planetary sciences, medical imaging, accelerator physics, and environmental monitoring.

Since the COMPTEL days, great advances in the achievable energy and position resolution were possible, creating an extremely vast, but also extremely sparsely sampled data space. Unfortunately, the optimum way to analyze the data from the next generation of Compton telescopes has not yet been found, which can retrieve all source parameters (location, spectrum, polarization, flux) and achieves the best possible resolution and sensitivity at the same time. This is especially important for all sciences objectives looking at the inner Galaxy: the large amount of expected sources, the high background (internal and Galactic diffuse emission), and the limited angular resolution, make it the most taxing case for data analysis. In general, two key challenges exist: First, what are the best data space representations to answer the specific science questions? Second, what is the best way to deconvolve the data to fully retrieve the source parameters?

For modern Compton telescopes, the existing data space representations can either correctly reconstruct the absolute flux (binned mode) or achieve the best possible resolution (list-mode), both together were not possible up to now. Here we propose to develop a two-stage hybrid reconstruction method which combines the best aspects of both. Using a proof-of-concept implementation we can for the first time show that it is possible to alternate during each deconvolution step between a binned-mode approach to get the flux right and a list-mode approach to get the best angular resolution, to get achieve both at the same time!

The second open question concerns the best deconvolution algorithm. For example, several algorithms have been investigated for the famous COMPTEL 26Al map which resulted in significantly different images. There is no clear answer as to which approach provides the most accurate result, largely due to the fact that detailed simulations to test and verify the approaches and their limitations were not possible at that time. This has changed, and therefore we propose to evaluate several deconvolution algorithms (e.g. Richardson-Lucy, Maximum-Entropy, MREM, and stochastic origin ensembles) with simulations of typical observations to find the best algorithm for each application and for each stage of the hybrid reconstruction approach.

We will adapt, implement, and fully evaluate the hybrid source reconstruction approach as well as the various deconvolution algorithms with simulations of synthetic benchmarks and simulations of key science objectives such as diffuse nuclear line science and continuum science of point sources, as well as with calibrations/observations of the COSI balloon telescope.

This proposal for “development of new data analysis methods for future satellite missions” will significantly improve the source deconvolution techniques for modern Compton telescopes and will allow unlocking the full potential of envisioned satellite missions using Compton-scatter technology in astrophysics, heliophysics and planetary sciences, and ultimately help them to “discover how the universe works” and to better “understand the sun”. Ultimately it will also benefit ground based applications such as nuclear medicine and environmental monitoring as all developed algorithms will be made publicly available within the open-source Compton telescope analysis framework MEGAlib.

Kevin France, University of Colorado Boulder.

Colorado Ultraviolet Transit Experiment:
Mass-loss and Magnetic Fields in Exoplanetary Systems

We propose a four year suborbital-class research program to develop, launch, and operate a cubesat mission to study the atmospheric properties of planets orbiting other stars. Exoplanets in short-period orbits (Prot = 1-5 days) provide a unique opportunity to observe phenomena critical to the development and evolution of our own solar system writ large, including atmospheric mass-loss, interaction with the host star, and possibly even planetary magnetism. Hot Jupiters and Hot Neptunes are laboratories for studying the physics of atmospheric escape. Owing to their large sizes and short-periods, the physics of atmospheric mass-loss can be studied at with a dedicated small instrument. Observations of short-period planets have found them to be greatly inflated, extended to several planetary radii in some cases. Systems with light curves showing late-egress relative to their optical transit have been modeled as comet-like tails that form as the planet's extended atmosphere extends beyond the Roche lobe and escapes into interplanetary space. Early-ingress observations may also indicate rapid mass-loss, but have been alternatively interpreted as evidence for a magnetically-supported bow shock ahead of the planet's orbital motion. These processes cannot be observed in broad-band optical light curves (e.g., with Kepler). The Colorado Ultraviolet Transit Experiment (CUTE) is designed to spectrally isolate diagnostic atomic and molecular transitions arising within these atmospheres to study the physics of atmospheric mass-loss and possibly detect the presence of magnetic fields on exoplanets.

Sarah Horst, Johns Hopkins University

Laboratory Exploration of Exoplanet Hazes in Preparation for JWST

Science Goals and Objectives
Although it has long been postulated that clouds and hazes were important components of exoplanet atmospheres, it is only recently that observations have substantiated their existence. Clouds and/or hazes have been detected at high significance in the atmospheres of the super-Earth GJ1214b (Teq~600 K), Neptune-mass GJ436b (Teq~800 K), and hot-Jupiter Kepler-7b (Teq~1700 K). In the case of Kepler-7b in the high temperature regime, equilibrium silicate clouds provide an adequate match to the observe variations in the planetary albedo as a function of orbital phase. The nature of the clouds/hazes in the atmospheres of GJ1214b and GJ436b are more uncertain, as thick equilibrium cloud species are not expected to form this temperature regime. Thus far there are no observational indications that photochemistry (either haze formation or disequilbrium chemistry) strongly affects planets hotter than 1200 K. It is expected that photochemistry will play a much greater role in the atmospheres of planets with average temperatures below 1000 K, especially those planets that may have enhanced atmospheric metallicity and/or C/O ratios such as super-Earths and Neptune-mass planets. The Kepler mission has shown that the most populous type of planets are those for which we have no solar system analogs, super-earths (1.25 Rearth < Rp <2.0 Rearth) and mini-Neptunes (2.0 Rearth < Rp < 4.0 Rearth). The TESS mission will substantially increase the number of super-Earths and mini-Neptunes on which atmospheric characterization studies can be conducted. However, these studies will require improved experimental constraints on photochemical processes in these cooler metal-rich planetary

atmospheres. Although models of atmospheric photochemistry and haze optical properties provide good first estimates, they are incomplete and biased by available solar system data. There are no solar system analogues in both size (mass and radius) and equilibrium temperature that could serve as an initial guide to haze formation in this important new sample of exoplanet atmospheres. We propose to determine the optical and solid state properties of experimentally produced exoplanet haze analogs in regimes relevant to the astrophysics missions TESS, JWST, and WFIRST. We will address the following ques- tions: What are the densities of haze particles in exoplanet atmospheres and what are their optical properties over a broad, observable wavelength region?

Methodology
Here we propose to investigate photochemical processes cooler metal-rich exoplanetary atmospheres in a state-of-art laboratory facility specifically designed to investigate a range of planetary atmospheres. Our laboratory experiments will produce photochemical hazes whose optical properties will be studied from the UV through the IR. Additionally, we will measure particle density to provide constraints for haze microphysics models. We will investigate the effect of gas composition, temperature, and energy source on the physical/chemical properties of haze.

Relevance
The proposed investigations are directly relevant to the objectives of the Astrophysics Research and Analysis Program. The experimental exploration of this atmospheric phase space will enable interpretation of current and future observations and improve our understanding of the physics and chemistry occurring in planetary atmospheres. Specifically the proposed measurements will determine solid-state parameters that are essential for analyzing and interpreting the data from NASA Astrophysics missions by exploring the spectroscopic properties of...particulate matter, as well as their chemical, physical, and dynamical properties under astrophysical conditions.The proposed investigations were specifically designed to enable analysis and interpretation of observations from JWST.

Peter Ryan, Boston Micromachines Corporation

Compact, scalable deformable mirror systems for space-based imaging of exo-earths

In the proposed project, Boston Micromachines Corporation (BMC) plans to demonstrate a new architecture and integration approach for compact, robust large-format deformable mirrors (LFDM) and to show a feasible path for scaling up that demonstration platform and manufacturing integration approach to larger formats with up to 10,000 actuators. These LFDMs will take advantage of BMCs proven and scalable microelectromechanical (MEMS) silicon processing technology while substantially reducing the required size and weight of the driver system and eliminating the need for high-density cables. NASAs Exoplanet Exploration Program (EEP) recently identified LFDMs as a critical technology gap for the high-resolution coronagraph instruments that are at the core of EEPs technology plan. This proposal specifically addresses EEPs request for technology development efforts that redesign the electronic interconnectors to the actuators and miniaturize the drive electronics, thereby making LFDM systems more technologically ready for space missions.

In this project, BMC will demonstrate feasibility of low-stress, high-reliability bonding of MEMS arrays to interposers. Also, BMC will demonstrate complete integration of a MEMS system based on the new LDFM design. The integrated system will feature 32×32 actuator MEMS arrays capable of up to 1.5 μm of stroke, 1 kHz frame update rate, and 14 bit precision. It will consume no more than 8 Watts of power, and will be contained within a cubic volume measuring 100 mm on a side. Finally, BMC will develop a technology plan and design for scale-up of the approach to LFDMs with up to 96×96 actuators.

Jeff McMahon, University of Michigan, Ann Arbor

Horn Coupled Multichroic Polarimeters with Comprehensive Frequency Coverage and Integrated Readout for Future CMB Missions

Precision measurements of the cosmic microwave background (CMB) have the potential to transform our understanding of cosmology and fundamental physics. A detection of B-mode polarization on large angular scales can reveal the existence of gravitational waves produced in the earliest moments of the universe, during the epoch of inflation. If detected, this signal would probe physics near the Grand Unification energy scale. The detection of the B-mode signal requires not only high-sensitivity and control of instrument systematics but also requires astrophysical foreground characterization and separation. Measurements with broad frequency coverage subdivided into many bands offer the best solution to this challenge.

We propose to develop novel arrays of feedhorn-coupled, multichroic polarimeters that maximize sensitivity, control systematic effects, and provide comprehensive frequency coverage (25-650 GHz) to characterize and remove foregrounds to enable measurement of the faint inflationary signatures in the CMB. We further propose to demonstrate a transformative wafer-level integration of bolometric sensors and multiplexed readout that drastically reduces focal plane complexity, cost, and mass.

We will achieve these goals by scaling existing 2:1 ratio bandwidth designs to different frequency bands, increasing the number of spectral bands per spatial pixel, and exploring a new detector architecture, based on quadrupole-ridge waveguide coupling that achieves 3:1 ratio bandwidth. Power sensing is achieved with sensitivity and low-frequency stability proven superconducting transition-edge sensors (TES) bolometers, and these sensors are read out with an on-wafer integrated microwave SQUID multiplexer. This aspect of the proposed work enables TES detectors to acquire the same straightforward multiplexing architecture as microwave kinetic inductance detectors (MKIDs) while retaining the sensor qualities that have made TESs the workhorse of CMB science.

The proposed work will boost sensitivity, increase spectral resolution, reduce focal plane mass, and vastly simplify focal plane integration for future satellite missions. This detector architecture represent a logical technology for a definitive all-sky CMB polarization satellite experiment.

Peter Day, Jet Propulsion Lab

Superconducting Traveling-Wave Kinetic Inductance Amplifiers for Detector Readout and Other Applications

We propose to continue work to develop the Traveling-wave Kinetic Inductance Parametric (TKIP) amplifier, a versatile new superconducting amplifier with properties enabling a
number of new instruments for astronomy that would be used in NASA missions. The main characteristics of this amplifier are exceptional sensitivity, closely approaching the limits imposed by quantum mechanics, and very broadband operation. Versions of this concept may be implemented for operation at frequencies throughout the microwave and millimeter wave bands to potentially above 1 THz with octave bandwidth. Additionally the amplifier would have a high saturation power, while dissipating very little power itself. These properties make the TKIP well suited for a number of applications in the area of detectors and detector arrays for astronomy. In the microwave band, the application we target is the multiplexed readout of detector arrays. For example, the TKIP is an ideal readout amplifier for arrays of Microwave Kinetic Inductance Detectors (MKIDs), a technology that is being vigorously pursued for large detector arrays for wavelengths from the millimeter band to X-rays. The sensitivity of these detectors is ultimately limited by the noise of the readout transistor amplifier, which is a factor of 20 above what is achievable with the quantum-limited amplifier that we propose. The sensitivity of the TKIP amplifier would also be sufficient for a direct frequency-domain multiplexed readout for Transition Edge Sensor (TES) arrays, which could significantly improve the multiplexing factor for these detectors beyond what is achievable with current SQUID systems. For this project, we will concentrate on developing a practical microwave band version of TKIP that could be supplied to astronomical instrument builders for improving the sensitivity of MKID arrays or for TES multiplexing. We will explore the TES readout application using sensors embedded in microwave frequency resonators. Finally, we will begin to explore higher frequency operation of the TKIP by developing a W-band version of the device.

Manuel Quijada, NASA Goddard Space Flight Center

Improved Lyman Ultraviolet Astronomy Capabilities through Enhanced Coatings

The proposed mission Large UV/Optical/IR (LUVOIR) Surveyor observatory, a 8-16 m aperture telescope covering 91 nm - 10 µm spectral range, will greatly contribute to unveil fundamental information, related with the primary NASA goals, such as the history of galaxies, the Milky Way and its neighbors, the origins of stars and planets, demographics of planetary systems, the search for life. However, the short-wavelength coverage and performance will be greatly determined by the performance of coatings. In fact, to achieve high-reflectance broadband coatings has been identified as an "Essential Goal" in the technology needs for the LUVOIR Surveyor. Moreover, according to the report "From Cosmic Birth to Living Earths, the Future of UVOIR Space Astronomy", AURA, (2015), obtaining broadband coatings with a performance of >5070% reflectance below 120 nm is an immediate, high-priority technology investment area, fundamental to mission feasibility, that needs further development.

Pure Aluminum presents high reflectance over the whole LUVOIR target spectral range, although it has to be protected from oxidation with a thin film of a transparent material. Above 102 nm there are still some transparent materials (LiF, MgF2, AlF3) that are fundamental to obtain relatively efficient coatings; Al protected with fluorides among LiF or MgF2 have been the most used solutions. But below 102 nm down to 91 nm, no transparent material is available to protect Al and coating mirror reflectance stays below 40%. But even above 102 nm, the reflectance of protected Al is limited by the residual absorption of the fluoride.

This proposal aims to enhance the LUV reflectivity of standard Al coatings by either depositing a denser and less absorbent fluoride films onto Al, through techniques such as Ion Assisted Physical Vapor Deposition (IAPVD), or by protecting Al either with a very thin film such as a fluoride film prepared by Atomic Layer Deposition (ALD). If any of the aforementioned methods work satisfactorily, this would lead to a LUV technology which would ultimately enable new scientific imaging capabilities.