Joseph Ajello/Jet Propulsion Laboratory
The Spectroscopy Of Molecular Hydrogen: Cross Sections And Oscillator Strengths For Astrophysics

UV observations of stellar atmospheres and the interstellar medium made by the Hubble Space Telescope (HST), Hopkins Ultraviolet Telescope (HUT), GALEX and Far Ultraviolet Spectroscopic Explorer (FUSE) missions require accurate laboratory measurements of electron collision cross sections, wavelengths, and oscillator strengths of the abundant species (H2 and HD). With the successful FUSE and GALEX missions the entire spectral range from the vacuum ultraviolet (VUV) to near-IR 90-1000 nm has become accessible to astronomers at a resolving-power (lambda/delta-lambda) of greater than 20,000. To closely match with the NASA observations, new laboratory spectroscopic techniques have been developed at JPL to allow expanded wavelength range (40-1200 nm) at high spectral-resolving power (50,000) and with increased sensitivity using array detectors. Lack of cross sections and oscillator strengths for many emissions limits the observed data analysis and modeling accuracy of stellar atmospheres and the interstellar medium. This proposal will provide the much needed molecular parameters for H2 and HD, the most cosmically abundant molecules, by a combination of laboratory measurements and computer modeling techniques. Collision strengths are used in non-LTE (local thermodynamical Equilibrium) statistical equilibrium modeling of molecular clouds and stellar atmospheres, while oscillator strengths are pivotal in abundance determination from absorption line spectra of the ISM. The objectives of the proposed program are: 1) to measure electron impact cross sections (5 eV to 2 keV) and high-resolution optically thin fluorescence spectra (40-1000 nm) of H2 and HD, and 2) to use the measured spectra to verify ab initio oscillator strengths of the n-p-sigma (B, B', B", n=2,3,4), n-p-pi (C, D, D', D", n=2,3,4,5) and n-p-sigma(EG, GK,H, I, J) ungerade and gerade Rydberg series of H2 and HD.

Scott Barthelmy/NASA/Goddard Space Flight Center
GCN: Enabling Real-Time GRB and Transient Research

The GRB Coordinates Network (GCN) is a system of computers which collects all GRB-related information (Positions, lightcurves, spectra, and images) from all space-based and ground-based missions and projects that produces GRB and Transient information. It then distributes that information to all recipients around the world requesting this information via several different methods (internet sockets, email, cellphones/pages).
This is all automated and typically takes no more than a few seconds. It provides a quick, efficient, and cost-saving opportunity to all researchers in the US and the world (many of which are NASA-funded).

**Manuel Bautista/Virginia Polytechnic Institute and State University**  
The coolest iron-peak species in astrophysics

The spectra of low ionization iron-peak (LiFePS) species is arguably the most powerful diagnostic tool in UV, optical, and infrared spectroscopy of gaseous nebulae, e.g. H II regions; PNe; SNe; protostellar disks; AGNs; afterglows of Gamma Ray Bursters, etc. LiFePS are responsible for the so-called iron curtains that dominate the spectra and/or the opacity in many objects, such as supernovae explosions, Eta Carinae, AGN Broad Line Emitters. Therefore, proper modeling of LiFePS is crucial for understanding some of the most important astronomical problems, such as supernovae as cosmological candles, star formation and evolution, galactic evolution and black holes, and the chemical enrichment of the Universe.

The diagnostic power of LiFePS results from their structure that yields many spectral lines throughout the spectrum and their low ionization potentials that allow for several ionization stages to be present in the same nebula. However, for most LiFePS there are no useful spectral models because most of the basic atomic parameters remain unknown. Even for the best studied species, like Fe II, the models remain inadequate. Various models exist for Fe II, yet there is neither consensus among them nor convincing agreement with observations. We propose a systematic study of LiFePS to remedy the current deficiencies and provide a comprehensive theory for their spectra. The calculations will include radiative rates for dipole allowed and forbidden transitions, collision strengths, photoionization cross sections and recombination rates. The calculations will reach the needed level of accuracy thanks to the sum of various factors that include: (a) powerful methods for accurate representations of the atomic species and scattering processes; (b) unprecedented computational power; (c) high quality spectra for comparisons with models. The data and models will be made publicly available and will be incorporated into photoionization modeling codes such as XSTAR and CLOUDY.

**Dominic Benford/NASA Goddard Space Flight Center**  
The ZeptoBolometer: A Background-Limited Far-Infrared Detector Array

Recent mission studies for far-infrared space telescopes such as SPIRIT, SAFIR, and SPECS have each identified a key enabling technology: large arrays of direct detectors for 40µm - 400µm wavelengths for photometry and spectroscopy. Technology development plans for each of these missions seek to produce (1) very low noise, fast (~5 ms) detectors with sensitivities of around 1E-19W/sqrt(Hz) and (2) large array formats of around 10 kilopixels. We propose to pursue both strategic goals. This proposal aims to achieve between two and three orders of magnitude improvement in mapping speed ($n_{pix}/n_{e_{p}}^{2}$ at the required time constant) over the current state of the art - a goal that will demonstrate conclusively that both the sensitivity and array format requirements of
future missions can be met. Spectrometers for SOFIA can provide an early venue for the use of these arrays.

We propose to build on our well-established superconducting transition edge sensor (TES) bolometer technology. Our group has delivered arrays of bolometers spanning 50µm to 3.3mm (90GHz to 6THz) in formats of over a kilopixel. We have also developed planar antennas, low-loss high frequency microstrip, and absorber approaches to enable optical coupling to sensitive TES bolometers.

Our approach centers on the use of electron-phonon decoupling (EPD) to thermally isolate the bolometer. Detailed modeling of the ultrasensitive detector elements will be done using measurements of EPD in a variety of Mo/Au TESs. We will extend our TES fabrication to the smallest limit attainable with optical lithography (<10µm^2 based on our known capabilities). Our design couples the TES to an absorbing antenna termination resistor, which permits a separate optimization of the absorber. A twin-slot antenna provides good optical and DC properties. A bump-bonded wiring wafer allows high-density pixel connections. We will achieve the following: (1) develop the EPD method of fabricating detector with an NEP of ~2E-19W/√(Hz), (2) develop an antenna with an absorber suitable for such a sensitive detector at far-infrared wavelengths from 40µm-400µm+, (3) demonstrate the integration of these elements in a focal plane array scalable to >10 kilopixels, (4) test an optically illuminated 8x8 detector array with phonon-limited performance down to ~2E10-19W/√Hz.

**Walter Binns/Washington University, St. Louis**

**Co-I Proposals: Richard Mewaldt/California Institute of Technology; John Mitchell/NASA Goddard Space Flight Center**

**Super-TIGER: A Very-Large-Area, High-Resolution Trans-Iron Cosmic Ray Investigation**

This is a proposal for Super-TIGER, a new, very-large-area instrument for measurement of the composition of cosmic rays on high-altitude balloon flights over Antarctica. It will measure abundances of elements of atomic number Z in the interval from zinc to molybdenum with an unprecedented combination of individual-element resolution and good statistical precision, and will extend these measurements with good resolution and useful statistical precision through Z = 56. This instrument will also measure with very high statistics the energy spectra of the more abundant elements from silicon to nickel at energies between about 0.8 and 10 GeV/nucleon. Super-TIGER builds on the heritage of the smaller Trans-Iron Galactic Element Recorder (TIGER) which has successfully flown on two stratospheric balloon flights launched from Antarctica, in 2001 and 2003. It will use dE/dx and Cherenkov measurements, combined with trajectory, to measure the charge and energy of cosmic ray nuclei. With these composition measurements we will test and clarify the emerging model of origin of cosmic rays in OB associations, and will extend to higher atomic number than previously models for atomic processes by which nuclei are selected for acceleration. The energy spectra will permit a sensitive test of the hypothesis that microquasars or other phenomena could superpose spectral features on the otherwise smooth power-law energy spectra that have previously been measured with less statistical accuracy.
Webster Cash/University of Colorado
Extended X-ray Off-plane Spectrometer

We propose a program to upgrade an existing, proven, sounding rocket payload and use it in a series of suborbital flights. The science goal is to probe the mystery of the soft x-ray background through diffuse x-ray spectroscopy. The payload uses diffraction gratings and detectors relevant to NASA's science and mission goals. The program emphasizes hands-on training of student scientists.

Timothy Cook/Boston University
Interstellar Medium Absorption Gradient Experiment Rocket

We propose to design, construct, integrate, fly, and analyze the data from an M101 Interstellar Medium Absorption Gradient Experiment Rocket (IMAGER) to measure the ultraviolet (UV) extinction properties of dust in M101. The system is designed to measure the differences in the composition and size distribution of the ultraviolet absorbing dust in the interstellar medium of M101 using four medium band ultraviolet filtered imaging channels. M101 is a face on spiral galaxy that shows a large gradient of metallicity with radial position. As a result we will, in one observation, measure the effects of the galactic environment on dust properties. This work will enable us for the first time to directly probe how the 2175Å bump and far-UV rise vary with metallicity, radiation field hardness, and aromatic features in regions of massive star formation. The existing evidence from Local Group ultraviolet extinction curve and infrared aromatic emission in HII regions indicates that there is significant processing of small dust grains. These new data will be combined with existing SPITZER measurements to probe the connection between the signatures of processing seen in the UV and mid-IR. The results of this investigation will have direct consequences on our understanding of dust itself and our ability to accurately account for the effects of dust on observations of massive star forming regions/galaxies at all redshifts. Determining how the dust features vary physically will make it much easier to model and interpret observations of star forming galaxies. As such, this work will enable the scientific analysis and understanding of observations of galaxies in the ultraviolet and infrared where dust is the dominant mediator of our understanding of the ongoing star formation (including observations with SPITZER, GALEX, HST, JWST, Herschel, etc.).

Mark Devlin/University of Pennsylvania
The Balloon-borne Large Aperture Submillimeter Telescope - BLAST

Understanding the formation and evolution of stars and galaxies is one of the foremost goals of astrophysics and experimental cosmology today. The Balloon-borne Large Aperture Submillimeter Telescope - BLAST, has a comprehensive program in place which has and will continue to make impressive headway in these areas. In the redshift range z = 1-3 massive galaxies go through an evolutionary stage characterized by high rates of star formation. These early, dusty, galaxies are best
characterized in the submillimeter. The story is much the same for dust-enshrowded star-forming regions in our own Galaxy. The study of these two diverse, yet connected, topics was the original primary science motivation for BLAST. Looking ahead, we have begun the next phase by converting BLAST into a polarimeter - BLAST-pol. BLAST-pol will be a unique instrument for studying the hotly debated role of magnetic fields in star formation. With a series of targeted observations in a single flight we will work to answer the question, "Do magnetic fields set the mass scales associated with star formation?" BLAST-pol will have the sensitivity and resolution to sample the magnetic field over the entire volume of a Bok Globule. Obtaining accurate polarization measurements for multiple positions within a globule will allow us to estimate the magnetic field strength.

NASA’s future CMBPol mission will be a very challenging undertaking, with expected signal levels a factor of ten or more below those which can be measured by WMAP. It will require unprecedented control and rejection of systematic effects and foregrounds. Polarized emission from Galactic dust will be one of the most significant sources of foreground contamination and could ultimately limit the sensitivity of CMBPol. It is crucial that experiments like BLAST-pol characterize the dust as fully as possible so that the design of CMBPol can be optimized.

Perry Gerakines/University of Alabama, Birmingham

Time-domain THz spectroscopy of astrophysical dust and ice analogs

We will propose to study the optical properties of astrophysical dust and ice analogs at long wavelength (from about 50 microns to 3 mm) using the technique of time-domain THz spectroscopy. There is a general lack of data in this spectral range for astrophysical materials. This technique is superior to standard FTIR spectroscopy in that the optical constants of the materials will be measured directly, without the need for subsequent analyses. Materials to be studied will include mixtures of ices commonly observed in the interstellar medium and in planetary environments (e.g., H2O, CO, CO2, CH3OH, CH4, et al.), as well as interstellar non-ice solids such as PAHs and silicates. These data will provide valuable physical data for the interpretation of data obtained by missions such as Herschel.

Jonathan Grindlay/Harvard

Detector-Telescope Development for ProtoEXIST: 2nd to 3rd Generation

We propose a 4y investigation to develop the second and third generation ProtoEXIST imaging wide-field hard X-ray telescopes, ProtoEXIST2 and ProtoEXIST3. These follow on our current (year 3 of 3) program that has developed the first successful fully-tiled hard X-ray imaging multi-pixel readout detector. ProtoEXIST1 is undergoing fabrication, testing and integration for Fall 2008 or Spring 2009 first balloon flight with a newly developed gondola. The ProtoEXIST2 detectors are the natural follow-up development as they incorporate a similar, but much more powerful, "DB ASIC" that immediately achieves the 0.6mm pixel size needed for the full EXIST mission. This proposed APRA investigation will develop the needed technology to support the full imaging hard X-ray
detector and wide-field survey telescope required for EXIST. The ProtoEXIST2 sub-telescope would fly in Year 2 along side the two ProtoEXIST1 sub-telescopes now being integrated (providing their second flight test). ProtoEXIST2 is designed to achieve a factor of 4 higher spatial and thus angular resolution and a factor of nearly 2 higher spectral resolution. However it would not be fully tileable, as is ProtoEXIST1, with a lower resolution detector system. To achieve the final imaging detector and telescope required for EXIST, we propose to develop ProtoEXIST3 in years 3 and 4. Having first developed ProtoEXIST2, we can then upgrade the DB ASIC design to slightly reduce pixel size (and further increase spatial resolution) while at same time reducing the ASIC power consumption. The packaging and electronics for the new EX ASIC will be developed to allow a sub-telescope for ProtoEXIST3 to be assembled and flown on a balloon test flight in Year 4. Together with the 3 predecessor sub-telescopes (ProtoEXIST1&2), the full 4-telescope payload will not only test technologies for EXIST but will conduct high spatial resolution studies of cosmic black holes.

Charles Hailey/Columbia University
Co-I Proposals: Steven Boggs/University of California; Rene Ong/University of California, Los Angeles
The General Antiparticle Spectrometer Experiment (GAPS): A Search for Antideuteron-Generated Dark Matter

This is a proposal for the General Antiparticle Spectrometer Experiment (GAPS) is a balloon-borne search for low energy antideuterons. The antideuterons are produced in annihilation of dark matter in the galactic halo. The antideuterons are captured in a target where they create atomic X-rays and pions. This is a unique signature distinguishing the antideuterons from background events. GAPS is complementary to other dark matter search techniques. In many regions of parameter space GAPS is superior to alternative search methods. Detecting and understanding dark matter is an essential ingredient in understanding the unfolding of the Big Bang and galaxy formation, and thus directly addresses NASA strategic goal 3D.

Kent Irwin/National Institute of Standards and Technology
SQUID Multiplexed Transition-Edge Sensor Arrays

We propose to continue our longstanding and highly successful program to develop transition-edge sensors (TES) and multiplexed superconducting quantum interference devices (SQUIDs) for x-ray astrophysics. With support from NASA, our group at NIST demonstrated the first TES x-ray calorimeters in 1995. The performance of TES arrays has advanced dramatically since this first demonstration, and the last three years in particular have seen tremendous progress. The long-standing mystery of excess noise in TES x-ray calorimeters has been resolved by our theoretical calculation of the thermodynamics of nonlinear, nonequilibrium resistive bolometers. The maturity and performance of SQUID multiplexed arrays has increased significantly, with arrays designed for Constellation-X multiplexed now at 16 pixel per column.

We propose to make improvements that enable Constellation-X and build the technological base for future missions such as Generation-X. We will optimize single-
pixel TES calorimeters based on new theoretical understanding, complete the implementation of SQUID multiplexers for the Constellation-X core and extended focal planes, develop future, more powerful multiplexing technologies, and demonstrate practical thermal designs of a TES instrument for Generation-X.

**Timothy Kallman/NASA/Goddard Space Flight Center**  
**Atomic Data for X-ray Photoabsorption**

We propose a program of computations of atomic energy levels, cross sections and transition probabilities applicable to the study of photoionized plasmas in X-ray astrophysics. These divide into five areas: K shells of elements N and Al; Archiving of photoionization data; Streamlined models for use with dynamics codes and other applications; Translation of data into the likely new standard format; and incorporation of data from solids into models. These are all areas in which we have already done significant work, and the proposed research represents a continuation of this work.

**N. Kasdin/Princeton University**  
**Achieving Polychromatic High-Contrast using Hybrid Shaped Pupil and Pupil Remapping Coronagraphs with Multiple Deformable Mirrors**

We propose to develop and experimentally verify an integrated coronagraph design for achieving high-contrast extrasolar planet detection in a moderate sized space mission. We will integrate the diverse set of independent coronagraph designs into a hybrid system that optimizes high contrast science performance, technical feasibility, and optical assembly cost. The final design will blend pupil masks (apodized or shaped), image plane masks, deformable mirrors (DMs), and perhaps polished remapping mirrors. Many of the pieces of such a system have been considered separately (coronagraph design for high-contrast, monochromatic dark hole generation using DMs), but to date, no integrated designs have been proposed. For instance, two DMs in series can be used to achieve amplitude control similar to pupil mappers. How might they be used in combination with polished remapping mirrors to improve wavefront control, relax machining tolerances, or mitigate the alignment constraints? With NASA's increasing interest in a probe class mission for planet detection and characterization, developing an understanding of the integrated coronagraph design, and experimentally verifying the entire assembly, is an essential step towards making convincing proposals that demonstrate the high throughput and low inner working angle critical to the exoplanet detection science program.

**N. Kasdin/Princeton University**  
**Analysis, Control, and Laboratory Verification of Hybrid Occulters for Planet Finding Telescopes**

We propose to design and analyze a hybrid occulter/coronagraph system for imaging exosolar planets. Additionally, we plan to build and test a scaled-down laboratory version of our best design. So-called "external occulters" have been gaining increased interest as a means of removing starlight for imaging planets. They have the advantage
of removing the starlight completely before the telescope, thus allowing conventional optics, and potentially removing the need for wavefront control. On the other hand, manufacture, deployment, control, and stability introduce unique and difficult engineering challenges. For instance, for a large occulter, maintaining the needed pointing may prove difficult. A hybrid occulter shares the challenge of achieving high contrast between an external occulter and a relaxed internal coronagraph. Such a design allows for smaller, closer occulters and relaxes the stability and tolerancing requirements, at the expense of needing more precise internal optics and masks. In the proposed study we will examine various hybrid designs, perform a complete optical analysis, and develop requirements on the integrated system. We will then verify the design by building a scaled-down version and testing it in our laboratory.

Almus Kenter/Smithsonian Astrophysical Observatory
Development of CMOS detectors as Soft X-ray Imaging Spectrometers

The Smithsonian Astrophysical Observatory proposes a four year effort to develop monolithic back-thinned CMOS X-ray imaging spectrometers. We will be joined in this effort, via a subcontract to the Sarnoff Corporation, by Dr. James Janesick. Recent results with preliminary versions of these CMOS detectors have achieved noise performance levels comparable to those of state of the art CCDs. These devices incorporate fully depleted, ultra-high gain (V/e) pixels and have single read noise < 2 electrons rms at a 200k-pixel per second readout rate. The energy resolution is Fano limited for the soft X-ray band. Fowler sampling further reduces noise levels to sub-electron levels. To the best of our knowledge, no other CMOS based imager has achieved a comparable level of performance. The goal of this proposal is to develop CMOS based X-ray imaging spectrometers that, in addition to being Fano limited, will be:

back illuminated;
made from high resistivity silicon (30 kOhm-cm);
back biased (>70 micron depletion depth); and
back surface passivated for good low energy (E<0.5 keV) QE.
The back illumination and passivation will provide 100% fill factor and excellent low energy response. The high resistivity and back biasing will allow depletion depths of >70 microns which will increase high energy quantum efficiency.
CMOS technology offers many benefits over CCDs, including: lower cost, much lower power consumption, higher levels of integration, higher through-put and long-lived radiation tolerance. With this proposal we intend to bring to fruition the promises of CMOS based technology to the next generation of X-ray astronomy missions.

Alan Kogut/NASA/Goddard Space Flight Center
PIPER: The Primordial Inflation Polarization Explorer

We propose to fly PIPER (the Primordial Inflation Polarization ExploreR), a balloon-borne instrument to measure the polarization of the cosmic microwave background in search of the signal from gravity waves generated during an inflationary epoch in the early Universe. PIPER combines fast polarization modulation with large-format Backshort-Under-Grid bolometer arrays and liquid-helium-cooled optics to provide
unprecedented sensitivity to polarization. PIPER develops technologies, observing
methods, and technical solutions for NASA's planned Beyond Einstein Inflation Probe,
while providing an unbiased survey of half the sky to mJy sensitivity in Stokes I, Q, U,
and V parameters at millimeter to sub-mm wavelengths.

Wei Kong/Oregon State University

Far infrared and submillimeter spectroscopy of cationic polycyclic aromatic hydrocarbons

This collaborative project combines the specialties of Wei Kong, a physical chemist from
Oregon State University, and Aigen Li, an astronomer from University of Missouri at
Columbia (who requests no financial support). Our ultimate objective is to use laboratory
spectroscopic data to simulate far infrared (FIR) and submillimeter wave (submm)
emission spectra of different astrophysical environments. This project directly supports
NASA’s strategic goal 3, sub goal 3B.1, 3C.2, and 3D.2. We plan to study cation
vibrational spectroscopy of 18 different polycyclic aromatic hydrocarbons (PAH),
emphasizing the low frequency skeletal modes which are indicative of the size and
geometry of the target species. The 18 PAHs are chosen based on their structural motifs,
avachable presence, and theoretical and experimental tractabilities. In particular, some
of the 18 PAHs have been confirmed to exist in cometary materials and interplanetary
dust particles.
The Kong group will use laser desorption to vaporize the mostly non-volatile PAHs and
use the zero kinetic energy photoelectron spectroscopy (ZEKE) technique to obtain
vibrational information of the cation. Supersonic entrainment will cool the neutral gas
vapor to an internal temperature of less than 30 K. The selection rule of ZEKE results in
detection of even harmonics and fundamental frequencies of some IR forbidden modes.
Consequently, information from this study can also be used for simulations of objects
with different internal temperatures. The ultimate synthesis and utilization of the
spectroscopic information will be realized by the Li group. This project directly supports
a few existing and imminent astrophysical missions, including the Spitzer Space
Observatory, Herschel Space Observatory, and the Stratospheric Observatory for Infrared
Astronomy. Information from this study will help with identifying specific PAH
molecules in space and with solving the problem of unidentified infrared bands. The
outreach activities of both PIs will further the cause of fundamental science among the
public.

Dan McCammon/University of Wisconsin

Sounding Rocket Investigations of Diffuse Cosmic X-ray Physics with Microcalorimeters

The crowning achievement of the last 20 years in astrophysics has been the development
of a highly successful picture of structure formation from the Big Bang up to the point of
producing galaxies. On the other side, we have a highly detailed understanding of the
final phases of star formation and all stages of stellar evolution developed over the last
half of the 20th century. A significant gap between involves the formation of the first
stars, stellar feedback of processed material to the intergalactic medium, the effects of
this on subsequent evolution of the IGM, and the effects of local stellar feedback on star formation rates and galactic evolution. These issues are among the most important contributors to NASA's strategic goal 3D, being central to the science questions on the evolution of the universe and the origin of stars and galaxies, and to the research objective of understanding the origin and destiny of the Universe.

These questions fundamentally involve the hottest phases of the interstellar medium, galactic halos, the IGM, and the connections between them. These areas are all poorly understood, and all are primarily accessible only through X-ray emission and absorption studies. We propose a scientific investigation of the hot phases of the interstellar medium and Galactic halo using suborbital rocket flights of X-ray detectors with very good spectral resolution, coupled with a development program of improving these detectors and associated filters for both our own investigation and for several future NASA X-ray missions. We will collaborate in one or more other investigations as the opportunity arises to most efficiently advance the science and technological goals of this proposal. A significant element of this work is the inspiration and training of a new generation of instrumentalists and potential principal investigators.

Mark McConnell/University of New Hampshire
GRAPE - A Balloon-Borne Polarimeter for Hard X-Ray and Gamma-Ray Astronomy

We have developed a design for a hard X-ray polarimeter operating in the energy range from 50 to 500 keV. This modular design, known as GRAPE (Gamma-Ray Polarimeter Experiment), has been successfully demonstrated in the lab using partially polarized gamma-ray sources, using fully polarized photon beams at Argonne National Laboratory and, in June of 2007, on a high altitude balloon flight. The next step in this program would be to develop a dedicated balloon payload that would provide a significant level of sensitivity for astrophysical sources. We propose a five-year program to fabricate a balloon payload incorporating an array of GRAPE modules and to conduct the first operational balloon flights. For the first flight (a CONUS flight to be launched from Ft. Sumner), GRAPE will be configured in a collimated mode to optimize its sensitivity for measuring polarization from the Crab and other known point sources. Two subsequent LDB balloon flights will be launched from McMurdo Station, with GRAPE configured in an un-collimated mode for optimized exposure to GRBs and solar flares.

Igor Moskalenko/Leland Junior Stanford University
Modeling of cosmic-ray propagation and Galactic diffuse gamma-ray emission in support of current and future NASA missions

A large number of outstanding problems in physics and astrophysics are connected with studies of cosmic rays and the associated diffuse emission (radio, microwave, X-rays, gamma rays) produced during their propagation. The current state-of-the-art cosmic ray propagation code is the GALPROP model which has become a standard analysis tool in cosmic ray and diffuse gamma ray research. 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 to upgrade the
GALPROP model, optimize its code structure, and simplify its installation on different platforms. In particular, we are going to develop and incorporate into the GALPROP model a full 3-dimensional model of the Galactic interstellar medium and a detailed model of our local Galactic environment to study the propagation of very high energy electrons and ultra-heavy nuclei, and construct an improved model of cosmic ray propagation in the Galaxy. Based on the improved model, we will develop a model of the diffuse Galactic gamma-ray emission in a wide energy range from keV to TeV, and search for signatures of neutralino dark matter. We further propose to generalize the GALPROP model to be applicable to other galaxies and other galaxy types to better understand cosmic ray production and propagation in other galactic environments. We will continue to support a dedicated website which hosts different versions of the GALPROP code, results of published models, manuals, a user forum, and other relevant astrophysical information. The improved GALPROP model will become publicly available as was the case with previous versions of the code.

Shouleh Nikzad/California Institute of Technology
Solid State Photon Counting Solar blind Ultraviolet Detector Array for Astronomy Applications

We propose to develop an all solid-state photon counting detector to operate in solar blind ultraviolet range using a new III-N avalanche photodiode (APD) array technology. Compared to the current state-of-the-art in flight-ready microchannel plate (MCP) sealed tubes, this Solar-blind Ultraviolet AVAlanche (SUAV) detector array technology will increase the QE by at least a factor of 5 and significantly enhance both fabrication yield and reliability. Since it is solid state, it does not require high voltage, and it does not require a photocathode that requires cesium or other highly reactive material for activation. Furthermore, due to wide bandgap of the material, the operating temperature of the detector is higher than more conventional silicon detectors and it is more radiation tolerant. These performance improvements and system simplifications will enable a ~4 meter medium class ultraviolet (UV) spectroscopic and imaging mission that is of the highest scientific priority for NASA.

UV astrophysics missions beyond HST and GALEX will require significant detector advances, particularly in quantum efficiency (QE), resolution, and size, in order to produce major new scientific results. Currently, MCP detectors are used extensively in UV instruments. Despite the success of some silicon CCDs in UV response and despite the good response in silicon APDs, MCPs tend to dominate UV instrument field because they possess gain and can be used in photon counting mode, they are solar blind, and they don’t require cooling. With SUAV detector, we will have a solid-state detector that is intrinsically solar blind (wide bandgap of III-N), it can count photons (high efficiency, high gain, low noise design), and can operate at higher temperatures (due to wider bandgap of III-N).

In the proposed effort, we will combine our high quality material (epitaxially grown using nano-engineered templates and compliant substrates), with robust separated Absorption And Multiplication (SAM) avalanche photodiode (APD) design for reduced
noise operation, with our unique III-N processing technology and substrate removal, to achieve high efficiency, high gain, low noise, and uniformity in SUAV arrays. Our proposed effort directly responds to the recommendations of the NASA UV-Visible Detectors Working Group for improving III-N material quality for solid-state detector applications. Our team includes members from JPL, Caltech, and SUNY-Albany with complementary and diverse expertise with unique qualifications to carry out the proposed development. The JPL team has a strong UV detector program with detector design, detector processing, back illumination techniques, readout, and device characterization. Prof. Shahedipour and the SUNY-Albany team have extensive and unique expertise in novel approaches for growth of high quality III-N materials for device applications. Professor Martin’s group at Caltech, in addition to its astrophysics observation expertise and mission heritage, has extensive experience in fabricating UV detectors and building UV instruments of the kind that would directly benefit from the proposed technology. This collaboration also makes a natural and rapid path for validation of the SUAV detector in the FIREBALL (Chris Martin, PI) balloon platform.

Scott Owens/NASA/Goddard Space Flight Center
Phase retrieval metrology of grazing incidence optical systems

We propose to develop phase retrieval metrology for grazing incidence optics. Phase retrieval analysis of off-axis or defocused images of high quality telescope optics has been proven effective in understanding misalignments and optic aberrations for normal incidence, and is being used for integration of the JWST mirror array. The need for a similar metrology tool that does not depend on normal incidence access to each mirror shell surface is a critical step toward integration of future high angular resolution, highly nested x-ray telescope systems. Currently, simulation of optical focal plane images compares well with those seen in the lab, and the x-ray imaging performance agrees well with ray-traced predictions. The target of this research will be to 1) compare the mirror figure determined by phase retrieval analysis with that determined by normal incidence interferometry for 1-D slices of the azimuth of rotation, 2) extend the phase retrieval algorithms to encompass full aperture (2-D) focal plane images, eliminating the need to do scans of the mirror surface, and 3) demonstrate that phase retrieval alone can adequately measure the known mirror segment deformations and misalignments that occur during mirror mounting and alignment.

Joseph Reader/National Institute of Standards and Technology
Expansion of the NIST Atomic Spectra Online Database and New Critical Compilations of Atomic Transition Probabilities, Wavelengths, and Energy Levels

We propose to expand and refine the NIST database on atomic transition probabilities, wavelengths, and energy levels, responding to current and anticipated needs of space astronomy. Several spectral regions of current interest to space astronomers -- the VUV and soft x-ray ranges covered by the HST, FUSE, and Chandra missions and the IR region covered by JWST, Spitzer, SOFIA, and Herschel -- are not well represented in the current database since strong data needs for these regions have arisen only recently. We
plan to create a new online database of normally-forbidden transitions between low levels of neutral atoms (fine-structure lines) that will be of great importance for the new IR telescopes. As with all these spectral regions, the original data are widely scattered in the literature and are difficult for astronomers to access. We will critically compile transition probabilities for C, N, O, Ne, Cl, Ca, Ba, and highly-ionized Fe. We will critically compile spectra and energy levels of the first three stages of ionization of the astrophysically important elements Ti, Cr, Fe, and Ni as well as all stages of H, Ar, Cl, and several heavy elements. Results of these critical compilations will be made available through the online NIST Atomic Spectra Database and in hardcopy publications. The Atomic Spectra Bibliographic Databases on Energy Levels and Spectra and on Transition Probabilities will be integrated with the Atomic Spectra Database to provide transparent linking with original publications.

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**Paul Reid/Smithsonian Astrophysical Observatory**  
**Adjustable grazing incidence X-ray optics with 0.1 arc-second angular resolution**

We seek to develop adjustable grazing incidence optics for X-ray astronomy. The goal of this development is mirrors with angular resolution of one-tenth of an arc-second, nearly 10 times better than the Chandra X-ray Observatory. The new mirror design consists of thin segments of a conventional grazing incidence mirror, with piezo-electric material deposited directly on the back surface of the mirror. By energizing the various piezo cells, it will be possible to correct mirror figure and misalignments to an accuracy previously unachievable.

As part of this investigation we will explore the suitability of various piezo-electric materials, the impact of their deposition on near final figure thin mirrors, measure the influence function of the adjusters and determine optimal shape and size, and develop analytical models of the mirrors. Mirror performance will be demonstrated with x-rays.

Such extremely high resolution X-ray optics will significantly advance X-ray astronomy by enabling detailed investigations such as of the inner regions of the Crab Nebula; exploring the distribution of gas, shocks, and bubbles in clusters of galaxies; and examining details of knots in jets from AGN. These high resolution X-ray optics are consistent with the requirements of potential future NASA missions such as Generation-X.

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**James Ryan/University of New Hampshire**  
**Co-I Proposals: Mark Wallace/Los Alamos National Laboratory**  
**Development of an Advanced Scintillator Compton Telescope**

We propose to investigate the latest scintillator detector technology as a means to design a next generation Compton telescope, one which will greatly improve on the energy resolution, background rejection, and sensitivity of the COMPTEL instrument on the Compton Gamma Ray Observatory. Our goal is to demonstrate that a scintillator-based instrument is the best way to significantly advance the field of medium-energy gamma-ray astronomy in a timely and cost effective manner. Specifically, we propose to 1)
demonstrate, with a laboratory bench model, the performance that underpins a full instrument with much improved sensitivity; 2) study the performance achievable using nanocomposite scintillator materials, which promise to dramatically reduce the cost of high-performance modern scintillators; 3) use detailed Monte Carlo simulations to predict the performance of an Explorer-class mission; and 4) demonstrate, on a piggyback balloon flight making use of NASA's new shared, small-experiment balloon platform, the requisite background-reduction techniques necessary for an order-of-magnitude sensitivity improvement.

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**Daniel Savin/Columbia University**

**Further Measurements of Low Temperature Dielectronic Recombination Rate Coefficients for Photoionized Cosmic Plasmas**

Photoionized plasmas are formed in active galactic nuclei (AGNs), X-ray binaries (XRBs), the intergalactic medium, planetary nebulae, and H II regions. Interpreting the spectra and modeling the properties of these sources requires reliable low temperature dielectronic recombination (DR) which is the dominant electron-ion recombination mechanism for most ions in these sources. We propose to continue our ongoing research program which is designed to provide this needed recombination data. With support from NASA's APRA program, over the past two-plus years we have made substantial progress in this work. These DR data are critically needed to interpret the Fe M-shell unresolved transition arrays (UTAs) seen in Chandra and XMM-Newton observations of AGN warm absorbers. We have published results for Fe XV and XIV and are currently preparing for publication our results for Fe XI, X, IX, and VIII. Our laboratory work has demonstrated that the currently available theoretical DR rate coefficients are not consistently reliable for L- and M-shell ions at temperatures relevant for photoionized gas. For some ions the uncertainties can range up to a factor of two or even orders of magnitude. Laboratory measurements are the only way to generate reliable low temperature DR data for these ions. During the next four years we propose to carry out laboratory measurements of low temperature DR for the M-shell ions Fe XIII, XII, VII, and VI which are needed to further our understanding of AGN warm absorbers. We also propose to carry out low temperature DR measurements for O III, S III, and Ne III. Observations of emission lines by these ions from galactic and extragalactic nebulae are routinely used to infer the properties for a wide range of cosmic objects. These last three ions are particularly important for observations by the Hubble Space Telescope, SOFIA, and the Spitzer Space Telescope.

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**George Seidel/Brown University**

**Development of Magnetic Microcalorimeter Arrays for X-ray Astrophysics**

Microcalorimeters are recognized as being the technology of choice for use as non-dispersive energy resolving x-ray detector arrays in x-ray telescopes. Superconducting transition edge sensors (TES) are at a stage of development where they can be considered for deployment in space instruments. Magnetic microcalorimeters (MMC), while currently not as advanced as superconducting transition edge sensors, offer a number of potential advantages, which may, provide a simpler path to meeting the requirements on
array size that is valuable to x-ray astronomy. Because the read-out of an MMC dissipates no power at the calorimeter, they have the potential of being fabricated into much larger arrays than can be envisioned with TESs, for which cooling may become a limitation. They also have the possibility of providing significantly higher energy resolution than is currently envisioned for microcalorimeters. They would be useful, for instance, for such a broad range of energies that they could remove the need at low energies for a grating instrument.

The technology for using MMC arrays is compatible with that developed for TES focal plane arrays. MMCs are thin film devices that can be read out with SQUID multiplexing. Under a now completed NASA grant, we have developed the technology for producing arrays of sensors of meander geometry with associated x-ray absorber, a design that offers the promise of higher energy resolution than sensors with circular pickup loops, which have demonstrated sensitivity below 3 eV. We have developed an array fabrication process that is scalable to kilopixel array sizes. We propose to build such an array and read out a subset of pixels to demonstrate the array performance. The ultimate goal of the proposed research is to produce sensor arrays with greater than 1 kilopixels and resolution under 1 eV that are robust and reproducible, ready for space applications.

Eun-Suk Seo/University of Maryland
Investigation of Galactic Cosmic Ray Acceleration and Transport

We propose to construct a physical model of acceleration and propagation of cosmic rays in the Galaxy that would extend our thorough knowledge of the processes at energies below $10^{11}$ eV to much higher energies including the possible limit of the contribution of Galactic sources at about $10^{18}$ eV. This work should allow us to explain the overall shape of the cosmic-ray spectrum including its knee structure. The maximum energies and the overall energy spectra of accelerated protons, nuclei, and electrons ejected into the interstellar medium will be found in the investigation of cosmic-ray acceleration in supernova remnants in the presence of strong streaming instability of accelerating particles in the shock precursor. The case of particle acceleration by multiple supernovae and stellar winds shocks will be also considered in this context. The propagation model for cosmic rays in the interstellar medium will include a tensor diffusion coefficient, distributed reacceleration (including the reacceleration of secondary cosmic ray species by strong SNR shocks), and effect of a galactic wind driven by cosmic ray pressure. The statistical variations of cosmic-ray density and anisotropy due to the random distribution of supernova remnants and the effects of nearby supernova remnants, the potential sources of cosmic rays, will be studied for high-energy protons, nuclei and electrons. The work will be in support of several cosmic-ray programs in which NASA is involved.

Oswald Siegmund/University of California, Berkeley
High efficiency microchannel plate detectors for the next generation of UV imaging and spectroscopic missions.

A focus of this program is to develop efficient photocathodes, including Gallium Nitride (GaN) and other NEA materials for detection of UV in the 100nm to 450nm band. A
second area of focus is development of ceramic MCPs (Al2O3) to provide stable substrates for high efficiency photocathodes, and to accomplish high image fidelity amplification. Both of these areas address detector technologies for specific mission concepts submitted for NASAs next generation astronomy missions. GaN work to date has provided good results for opaque UV photocathodes with good stability under vacuum. We intend to build on this work to establish thin film GaN bonded to UV windows, and to develop opaque layers on ceramic MCPs with high detection efficiency. Ceramic, anodic alumina, MCPs are also in development. We intend to work on the enhancement of ceramic MCP performance (gain, lifetime, stability, image fidelity), and their integration with GaN photocathodes.

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**Gordon Stacey/Cornell University**  
**A Miniaturized Cryogenic Scanning Fabry-Perot for Space and Airborne Applications**

We propose to design, construct, and test fully tunable miniature cryogenic Fabry-Perot interferometers (FPI) for use in the mid-IR to submillimeter spectral regime. These Miniature Cryogenic Scanning FPIs (MCSF) enable wide-field spectral line imaging for future space and airborne missions. Our research group has extensive experience with PZT and stepper motor driven cryogenic scanning FPIs. The device proposed here is different: we use novel cryogenic motors of our own design that promise precise (< 50 nm) motion control over relatively large (> 5 mm) travel. Our "PCD motors" are quite compact - fully tunable Fabry-Perots can now fit in filter wheel slots formally reserved for fixed wavelength filters. One filter can replace many, and imaging photometers, such as the FORCAST camera for SOFIA, can be made into imaging spectrometers. The key enabling element for the MCSF is the PCD motor - a miniature, low power, high accuracy, long drive actuator operating at 4 K. No commercially available devices come close to delivering our required performance. Therefore, the major part of the proposed work is to develop the PCD motor. Our motor is based twin piezo-electric transducers - one drives a clutch, and the second turns the screw. Repeated cycles "ratchets" the screw large distances. A miniature cryogenic motor with large travel has many potential applications such as adjusters for optics, slits, or focal plane alignment. A further bonus is that the PCD requires no holding power. When the PCD motor is turned off, the motion stops exactly where the motor left it. The wide-field spectroscopic imaging capabilities of the MCSF are key to many astronomical investigations. We discuss two applications of the MCSF: mid-IR fine-structure line imaging of the Galactic Center with FORCAST/SOFIA, and far-IR fine-structure line imaging of nearby Galaxies with a 10 m class far-IR telescope in space.

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**Phillip Stancil/University of Georgia**  
**Charge Exchange Calculations for Heliospheric and Planetary Exosphere X-ray Emission Modeling**

Many years of all-sky observations in the soft x-ray band (0.1-1.5 keV) have revealed a rich diffuse background produced by a complex combination of x-ray sources. While
much of this emission may be due to sources outside the heliopause, models suggest that roughly half of the background originates from within the heliosphere. The existence of solar system x-rays has been verified by x-ray observations of the Earth's geocorona, of Mars's exosphere, and of comets. The origin of this emission is believed to be the same as that in the heliosphere: charge exchange of solar wind (SW) ions with ambient neutral species. In the SW charge exchange (SWCX) mechanism, a SW ion captures an electron from a heliospheric or atmospheric neutral atom creating a highly excited ion which subsequently emits one or more x-rays in a cascade to the ground state. To improve SWCX x-ray models, we propose to perform advanced quantum-mechanical calculations of charge exchange of the dominant SW ions colliding with H, He, and O. In particular, we will provide absolute final quantum state cross sections, resolved into principal and orbital and spin angular momentum quantum states, as a function of SW speed for C5+, N6+, O6+, O7+, Ne9+, and Mg10+ with H; C5+, N6+, O8+, and Ne9+ with He; and O7+ with O. We primarily focus on heliumlike product ions to obtain accurate cross sections for triplet/singlet ratios. As the calculations will be performed with molecular wave functions, we will also compute the molecular potentials and nonadiabatic coupling matrix elements needed for the scattering calculations. The calculated cross sections will be benchmarked to the limited experimental data, where available. The results of this proposal will then enable accurate modeling of SWCX allowing for investigations of the SW, the heliosphere, and planetary exospheres. It will also have an impact on studies of the Local Hot Bubble and hot extragalactic gas by helping to define the level of heliospheric contamination on such observations, which in the latter case is relevant to searches for missing baryons in the Universe. The results from this project will therefore enhance the scientific return from NASA space astrophysics missions such as ROSAT, EUVE, CXO, XMM-Newton, Suzaku, Constellation-X, and other future x-ray missions.

Joel Ullom/National Institute of Standards and Technology

Solid-state microrefrigerators for cooling low temperature sensors to 100 mK and below

We propose to continue our unique and successful program developing thin-film solid-state refrigerators based on normal-insulator-superconductor (NIS) tunnel junctions. NIS refrigerators can enhance the performance and simplify the design of adiabatic demagnetization refrigerators. NIS refrigerators can also make sub-100 mK temperatures accessible from simple and cheap pumped helium-3 coolers. We have previously demonstrated NIS devices with technologically useful cooling powers (10s of pW/s) and temperature reductions (~130 mK). More recently, we have demonstrated cooling of bulk objects and lithographically integrated transition-edge sensors (TESs) including an X-ray TES with 9.5 eV resolution when operated at a cryostat temperature of 260 mK, 75 mK above its transition temperature. Here, we propose to improve the performance of our NIS refrigerators, including demonstrating cooling from 260 mK to 50 mK and cooling from 30-50 mK to 10 mK. In addition, we propose to demonstrate cooling of complete and separate pieces of user-supplied electronics. Finally, to demonstrate the increasing maturity of NIS refrigerators, we will build a large array of NIS-cooled TES bolometers that can be used to upgrade the MUSTANG millimeter-wave instrument on
the Green Bank Telescope. The use of NIS cooling will allow sky-limited instrument performance even in good weather conditions.

W. Thomas Vestrand/Los Alamos National Laboratory
Key Observations of Gamma-Ray Bursts and Blazars with the RAPTOR Network

We propose a program to study the prompt and early afterglow optical emission from gamma ray bursts (GRBs) and to persistently monitor gamma ray blazars using our network of RAPTOR (RAPid Telescopes for Optical Response) telescopes. Previous RAPTOR observations of GRB optical light curves have revealed the existence of prompt optical emission from GRBs that is correlated with the prompt gamma rays, indicating a linked origin for the optical light and the gamma rays. Within the context of the standard fireball model for GRBs, this new optical component is naturally explained as low frequency emission associated with the internal shocks driven into the burst ejecta by variations of the inner engine. We propose to construct and to operate a ultra-high cadence imager that will allow us to make key observations of the rapid variability of the prompt and very early afterglow emission. To further probe of the physics of this prompt optical component, we also propose to operate our new, more powerful, RAPTOR-T(technicolor) systems. The RAPTOR-T telescope arrays are composed four 0.41-meter telescopes that are co-aligned to make simultaneous 4-color (BVRI) fast cadence photometry of the prompt optical emission starting at 6 seconds after the GRB trigger---measurements that cannot be made by the Swift UVOT. These multi-color optical observations when combined with simultaneous observations of the prompt emission at high energies will allow one to place important constraints on the properties of the ultra-relativistic GRB jet. The RAPTOR-T telescopes will also make important multi-color observations of gamma ray emitting blazars and the early afterglow emission from GRBs. Our recent RAPTOR observations have shown that early afterglow can be understood as a response to the energy input measured by prompt emission. Measurements of the early afterglow response is therefore a new tool for probing the structure of the circumburst environment and the evolution of the jet/environment interaction. Finally we propose to operate the first system capable of sensitive, persistent, monitoring of a significant fraction of the Swift BAT field-of-view in order to search for optical precursors and emission in the 20-second interval before even the fastest response telescopes are on target. This RAPTOR persistent surveillance system employs a primary array that simultaneously monitors 1,000 sq-degrees with a sensitivity of R~16th magnitude in 30 seconds and secondary outrigger arrays that monitor an additional 2,400 sq-degrees with a sensitivity of R~13th magnitude in 30 seconds. Altogether our RAPTOR system will have unprecedented capabilities for observing optical emission from high-energy gamma ray sources and enabling key correlative studies with the GLAST and Swift observatories.
**John Ward/Jet Propulsion Laboratory**

**Tunable Local Oscillators to 2.7 THz for Velocity-Resolved Spectroscopy of Interstellar HD, N+, and O**

We propose to develop tunable, solid state local oscillators in the 2 to 2.7 THz band, and to make them available to a high-altitude balloon-borne observatory, the Stratospheric Terahertz Observatory (STO), for studying species including HD, N+, and O I in the interstellar medium. There is currently no observatory capable of observing in this band. These local oscillators will open a new window into the universe, and will enable new space-borne instruments to observe in this rich region of the spectrum.

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**David Windt/Reflective X-ray Optics, LLC**

**High-performance multilayer coatings for the next generation of astronomical X-ray optics**

This proposal is directed at the continued development of high-performance depth-graded X-ray multilayer technology for use in astronomical X-ray telescopes. Our ongoing research program has made significant progress over the past eight years in the development of this multilayer technology for X-ray astronomy, with a number of noteworthy accomplishments that have had a direct impact on several NASA missions either in development now or planned for future implementation. Over the previous period of performance we achieved most of the stated goals described in our last proposal, including the development a new multilayer deposition technique that allows for simultaneous control of stress and roughness, the development of essential new X-ray multilayer metrology facilities, the development of new a-periodic multilayer designs, and the realization of both low-stress W/B4C multilayer coatings having superior X-ray performance and low-stress, ultra-low-roughness B4C smoothing layers that can be used to significantly reduce the surface roughness of mirror substrates prior to multilayer coating. Over the next four years of research we propose to (a) apply our new reactive sputtering technique and a-periodic coating design approach towards the development of new Co and Ni based coatings in order to produce low-stress multilayers that extend to both higher and lower X-ray energies, (b) develop high-deposition-rate metallic spacer layers made of Mg or Al in order to reduce coating time, and thus reduce mission costs, (c) measure hard X-ray optical constants of the new materials we will investigate, (d) develop new modulated substrate velocity and modulated substrate bias techniques for improved coating uniformity on cylindrical shells, and (e) maintain and enhance our IMD multilayer design and analysis software. Achieving our project goals will significantly advance the state of the art and thereby allow for better performance and reduced costs of NASA missions utilizing X-ray multilayer technology. Reaching these goals may also enable totally new instrument concepts and missions.