Solar and Heliospheric Physics
Abstracts of selected proposals.
(NNH06ZDA001N-SHP)

Below are the abstracts of proposals selected for funding for the Solar and Heliospheric Physics program. Principal Investigator (PI) name, institution, and proposal title are also included. 118 proposals were received in response to this opportunity, and 33 were selected for funding.

David Alexander/Rice University
Fokker-Planck modeling of solar flare particle kinematics in realistic magnetic field geometries

Spatially resolved hard X-ray data from solar flares obtained from RHESSI are providing new observational constraints on the mechanisms of flare energy release and particle acceleration. A critical component in understanding flare initiation and the role played by the various characteristics of the solar magnetic field (e.g. evolution, topology, currents) is the ability to categorize the particle distribution functions generated during the energy release process in flares and responsible for the bulk of the observed photon emissions. While Type III bursts can provide direct evidence of flare-accelerated particles on open field lines, inferring the accelerated particle properties back at the Sun requires the inversion of or the forward-fitting to the observed hard X-ray photon properties (energy spectrum, time history, spatial structure). The relationship between the observed photon distributions and their parent particles is further complicated by the effects of magnetic geometry, energy losses and pitch angle scattering in the corona, photon production assumptions in the forward fitting (bremsstrahlung cross-section, injected pitch-angle distribution, power-law energy spectra, etc.), and time integration in the image reconstruction process. Using RHESSI and other relevant coronal observations, we propose to explore these issues and to develop key diagnostics of the injected particle distribution functions in solar flares. We will perform a forward fitting approach using a Fokker-Planck kinetic code to model the particle transport and characterize the particle distribution function in phase-space (space, time, energy, and pitch-angle) in realistic magnetic loop geometries where the magnetic field is allowed to converge independently at each of the footpoints. By employing this approach in conjunction with topological information from magnetic field data and TRACE coronal and chromospheric observations, we aim to determine the role played by the particles in flares and place constraints on where they are produced and what acceleration and reconnection physics is required to reproduce the observed flare behavior.

Stuart Bale/University of California
Wave-particle physics in solar wind reconnection

We propose to study plasma wave characteristics and generation in reconnecting current sheets in the solar wind using instruments from the Wind, ACE and Cluster spacecraft, as well as experiments on the recently launched STEREO twin observatory. Solar wind reconnection sites are ideal for the study of reconnection microphysics as they appear to be very stable over spacecraft crossing times. In addition, the formation and evolution of reconnecting current sheets in the solar wind may give rise to large-scale evolution of the solar wind topology. Hence understanding this process is not only important in the context of reconnection physics, but also potentially the evolution of the heliospheric magnetic field, both major goals of the Heliophysics program.

The work will be divided into two phases: First, a statistical study by Huttunen et al., [2007] of high frequency plasma waves (Langmuir, electron phase space holes, and ion acoustic-like) in solar wind reconnection regions will be extended into the low frequency range (lower hybrid, whistler, and ion-cyclotron waves). Second, particles distributions and current signatures in reconnection sites will be computed and related to wave observations in order to study instabilities responsible for the generation of different wave modes.

To support this work, we ask for a total of 16.5 months of salary support over two years: 2 months of summer salary for the PI (Prof. Stuart D. Bale) and 14.5 months of support for Co-I Dr. Emilia Huttunen. In addition, we request publication page charges and travel expenses to AGU meetings. We expect to obtain significant results on a short time scale and will present our results at scientific conferences and publish in the appropriate journals.

Simon Bandler/University of Maryland
High Spectral Resolution, High Cadence, Imaging X-ray Microcalorimeters for Solar Physics

A microcalorimeter x-ray spectrometer is a non-dispersive, high spectral resolution, imaging instrument that has been in development and use for x-ray astrophysics for more than 20 years and has successfully flown on both orbital and suborbital missions since 1995. We propose here to adapt this highly successful technology for solar physics by developing a high cadence, high spatial and spectral resolution instrument for observations of high energy processes in the sun. This instrument would, for example, be perfectly suited to detailed observations of reconnection events and the associated particle acceleration in active solar regions.

We believe that development of this detector system is straightforward as a logical extension of our detector development efforts for the Constellation-X observatory. However, we believe that a dedicated development effort is required before a tractable solar sub-orbital or orbital program could be proposed. We realize that cryogenic x-ray spectrometers have been proposed by other groups for the sub-orbital program in the past, and we strongly believe that there are enormous benefits in utilizing this technology for high performance sub-orbital instruments. We feel, however, that it is more appropriate at this stage to perform the dedicated research necessary to produce a high-cadence imaging microcalorimeter specifically engineered for solar physics. We propose here to develop an instrument for the unique requirements of a solar sub-orbital program that is also suitable for deployment on an Explorer-class mission and for the Reconnection and Microscale (RAM) Solar-Terrestrial Probe.

Benjamin Chandran/University of New Hampshire
Wave-particle kinetic code for coronal heating

We will develop a new numerical tool, the Wave-Particle Kinetic (WPK) code, that will advance our understanding of coronal heating to a new level. The WPK code will: (1) use rigorous weak-turbulence theory to describe wave-wave interactions in the weakly-turbulent part of wavenumber space; (2) use strong-turbulence phenomenology to account for the wave-wave interactions among strongly turbulent low-frequency Alfven waves; (3) use quasilinear theory to describe the effects of wave-particle interactions on both waves and particles; and (4) move beyond all previous studies of coronal heating by including the full range of wave-vector directions and solving for the anisotropic evolution of both waves in wavenumber space and particles in velocity space. By employing the powerful analytical tools of weak turbulence theory and quasilinear theory within their respective domains of validity, the WPK code will achieve a combination of spatial resolution and velocity-space resolution that is far beyond the reach of particle-in-cell codes or hybrid codes. The WPK code will thereby provide definitive answers to key, long-standing questions regarding the role of high-frequency waves in the heating of the corona, and help us to take a major step towards a first-principles theory of the origin of the solar wind. The proposed research will have an important impact in other areas as well. It will lay the groundwork for future predictions of the ambient energy spectra of superthermal particles and waves in the inner heliosphere, both of which are important for understanding the acceleration of solar energetic particles by coronal-mass-ejection shocks. In addition, the WPK code will be a valuable tool for future studies of stochastic particle acceleration in solar flares. The proposed research will support numerous NASA missions that investigate the solar wind, including WIND, SOHO, ACE, Ulysses, and STEREO, as well as future missions including SENTINELS and SOLAR PROBE.

Bart De Pontieu/Lockheed Martin Solar & Astrophysics Lab
Connecting Chromospheric and Transition Region Dynamics

Recently, we have been able to make significant progress in understanding dynamic jets (spicules) in the magnetized chromosphere, where over 90% of the non-radiative energy needed to drive solar activity and space weather going into the outer atmosphere of the Sun is deposited. Comparing MHD simulations and high-resolution observations show that there are two types of spicules that have very different dynamic properties. Type I spicules are driven by shock waves that form when global oscillations and convective flows leak into the atmosphere along magnetic field lines on 3-5 minute timescales. Type

II spicules are much more dynamic with lifetimes of 10-60 seconds and seem to be rapidly heated to (at least) TR temperatures.

We aim to capitalize on these exciting advances and unequivocally connect the dynamics of the chromosphere and transition region. We propose to compare multi-instrument observations with advanced numerical simulations to determine the prevalence and dominant formation mechanism of both spicule types. We will apply an extensive suite of tools to analyze previously obtained data from TRACE, SUMER and the SST, and acquire new observations with the SST, TRACE and Hinode/SOT-EIS-XRT. Ultimately, this hybrid analysis will help determine how the transport and dissipation of the magneto-convective energy in the photosphere heats the transition region and corona.

This issue is of crucial importance for several NASA missions such as TRACE, SDO, STEREO and especially Hinode, which is focused on how the Sun's magnetism influences its atmosphere. Our work is directly relevant to the strategic subgoal 3B of NASA's Science Mission Directorate: to understand the Sun and its effects on Earth and the solar system. We will also further the NASA Science outcomes 3B.1 and 3B.2, by leading to progress in understanding the fundamental physical process of the space environment of the Sun, and understanding of solar variability.

Craig DeForest/Southwest Research Institute
Very High Resolution Studies of the Small-Scale Solar Dynamo: The Stereoscopic High-Speed Zeeman Magnetograph

We propose to produce the world's highest resolution quantitative magnetograms of the Sun's photosphere, and to use them to study the small-scale solar dynamo and magnetoconvection at the fundamental physical scale of solar flux tubes. Generation, evolution, and convection of the solar magnetic field under the influence of photospheric convection are fundamental to most of the phenomena of the solar atmosphere, including the presence of the solar corona and the origin of the solar wind. The background "quiet Sun" processes dominate the overall magnetic energy balance. Yet analysis of existing magnetograph data shows that the most advanced current instruments are not capable of completely characterizing the fundamental processes by which the Sun's "salt-and-pepper" magnetic carpet evolves. In particular, no existing or under-construction instrument has both sufficient spatial resolution and sensitivity to identify the origin, collection, and dispersal of the flux that gives rise to the ~70km diameter kilogauss flux tubes under g-band bright points.

Using a new technique, stereoscopic spectroscopy, we will build up a portable magnetograph instrument that is capable of producing a line-of-sight photospheric magnetogram with ~10 G RMS noise, with a single exposure of ~100 milliseconds at or near the host telescope's diffraction limit. By acquiring each magnetogram with a single exposure, our instrument (SHAZAM) defeats noise induced by solar and atmospheric motion and improves photon efficiency by more than an order of magnitude compared to any other quantitative imaging magnetograph in existence. This allows us to use frame selection and other data intensive techniques to produce evolution studies of the magnetic field on the scale of the smallest currently resolvable features on the Sun.

We will deploy SHAZAM on four (total) observing runs: two at the 76-cm DST and two at the 110-cm Swedish Solar Telescope (SST). Our observing plan includes straightforward incremental improvement of the technique. We will produce calibrated magnetogram sequences at spatial scales between 140km (0.2") and 70km (0.1"), sensitivity of ~10 Gauss, and 0.1-3 second temporal resolution using two suitable magnetograph lines: the Fe I lines at 6173.4\AA and 3937.3\AA .Using these image sequences we will probe the fundamental length scale of the small scale solar dynamo, and use an existing computer vision code (SWAMIS) to interpret the data and gain insight into the fundamental processes of solar magnetoconvection and energy transport.

After deployment, SHAZAM will be stored at NSO. It and its reduction software will be made available for use by interested observers.

Brian Dennis/NASA Goddard Space Flight Center
Imaging X-ray Polarimeter for Solar Flares

This proposal describes a novel imaging X-ray polarimeter for solar flares that would be sensitive enough to measure flare polarization in the 20 to 50 keV energy range during a short-duration balloon flight. The objective of such observations is to determine the directivity of the high-energy electrons producing solar X-rays, and hence to learn about the particle acceleration and energy release processes in solar flares. Secondary objectives include the separation of the thermal and nonthermal components of the flare X-ray emissions and the separation of the photospheric albedo flux from the direct emissions.

We recently demonstrated a Time Projection Chamber (TPC) for photoelectric polarimetry that has unprecedented sensitivity around 6 keV. The technique is both broadband and tunable to higher energies. An imaging polarimeter can be constructed by placing such a device behind a Rotating Modulation Collimator (RMC).

The purpose of the proposed work is to demonstrate a larger device optimized at 20-50 keV for solar flare observations. We anticipate leveraging this demonstration in a future balloon proposal to launch an instrument around the next solar maximum. The key technical demonstration occurs at the end of the first year of our proposed work plan, enabling a credible follow-on proposal before the end of this effort.

This work supports the NASA Strategic Objective to “explore the Sun-Earth system to understand the Sun and its effects on Earth, the Solar System, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational Earth observation systems.”

Mihir Desai/Southwest Research Institute
An Advanced Mass and Ionic Charge Composition Experiment (AMICCE) for Heliophysics Missions

We propose to undertake a proof-of-concept study for an innovative instrument that can simultaneously measure the ionic charge state, isotopic, and elemental composition of the largely unexplored suprathermal ion population between ~8-100 keV/nucleon and that of energetic charged particle populations in the ~0.1-5 MeV/nucleon energy range present in the heliosphere. The new instrument - Advanced Mass and Ionic Charge Composition Experiment (AMICCE) - combines a highly promising, novel concept for an electrostatic analyzer (ESA) with a proven design for measuring the time-of-flight (TOF) and residual energy (E) of the incident ions to uniquely determine their elemental, isotopic, and ionic charge composition. AMICCE will be designed to measure the ionic charge states of various heavy ions from He-Fe in the ~10-500 keV/q energy range with a charge state resolution of dq/q<0.2. The novel concept for the ESA uses only four voltage steps to cover the entire E/q range which decreases the duty cycle and yields nearly a factor of ~20 improvement in the collecting power when compared with current suprathermal ion instruments. AMICCE has a mass resolution dm/m<0.15 in order to separate rare isotopes like 3He from the more abundant 4He. AMICCE has a separate high-energy channel that measures the isotopic and elemental composition of H-Fe ions between ~0.1-5 MeV/nucleon.
The main goals of this project are:
1. Optimize the design of the ESA, the collimator, the TOF/E, and the high-energy channel, and refine our existing 3D Simion model of AMICCE.
2. Complete the mechanical design and fabricate the laboratory prototype of the ESA and the collimator.
3. Test and fully characterize the laboratory prototype of the ESA/collimator assembly in SwRI's vacuum chamber.

AMICCE can be easily tailored to satisfy the scientific and technical requirements of suprathermal and energetic particle instruments for a variety of NASA's future heliophysics missions like the Inner Heliospheric Sentinels and the Solar Probe, and ESA's Solar Orbiter. AMICCE will provide unique measurements that will revolutionize our understanding of the previously unexplored suprathermal particle population and therefore of the physical processes responsible for accelerating particles in the heliosphere. This proposal fulfills several of NASA's strategic objectives as outlined in the Sun Solar System Connection 2005 Roadmap, e.g., "by developing innovative techniques, knowledge, and infrastructure to explore the destination for human exploration, and by designing, building, and validating the next generation of S3C instrumentation."

C DeVore/Naval Research Laboratory
Coronal Mass Ejection Initiation in Complex Source Regions

Solar coronal mass ejections (CMEs) and eruptive flares are critically important contributors to the Sun-Earth connection and to space weather. Their associated fluxes of radiation and particles pose substantial hazards to space hardware and to human explorers beyond low Earth orbit. Consequently, understanding the origin of CMEs is a high-priority objective of solar and heliospheric physics and of NASA's science and exploration activities.

The Naval Research Laboratory proposes a three-year program of research applying our expertise with physically robust theories of CME initiation and state-of-the-art numerical simulation models to advance our understanding of these events. In previous work, we have shown that fast CMEs can be initiated by the onset of magnetic 'breakout' reconnection in simple multipolar coronal topologies, followed the evolution of their ejecta into interplanetary space, and quantified the magnetic source of the energy powering these eruptions. One of our recent achievements is a demonstration of breakout initiation of homologous, confined eruptions with prompt filament reformation in an active-region geometry. We propose to build upon these successes by extending our numerical simulations of breakout CMEs to more complex and realistic configurations of the source region. Our research plan is to perform and analyze simulated eruptions from active-region topologies in four increasingly challenging scenarios, all of which have been cited as responsible for well-observed solar events. We will determine the plasma and magnetic signatures of our simulated eruptions for comparison with those observed. Our research promises to provide crucial new insights into the physics of CMEs, a timely development in light of the recent launch of NASA's STEREO mission to obtain unprecedented 3D stereoscopic views of solar eruptions.

This project will be carried out by Drs. C. Richard DeVore and Spiro K. Antiochos, recognized experts in numerical magnetohydrodynamics and theories of solar CMEs and eruptive flares.

Terry Forbes/University of New Hampshire
3D Magnetic Reconnection in Solar Active Regions

We propose a program of coordinated analytical and numerical calculations to determine the properties of three-dimensional (3D) magnetic reconnection in solar active regions. The analytical work will involve calculating the evolution of a 3D line-tied flux rope model that we will use to estimate an upper limit on the reconnection electric field in the approximation of rapid reconnection. Numerical simulations will incorporate the formation of reconnecting current sheets and will lead to more accurate evaluation of the magnitude and spatial structure of the electric field. We will use the results of the magnetic field modeling to identify the locations of reconnection regions (null points, current sheets, and quasi-separatrix layers) and to quantify the rate of magnetic reconnection in the solar corona. We will use the information on the structure and evolution of the electric field to compute particle fluxes into the reconnection region and the number of particles that can be accelerated in a powerful flare. We will use the requirement to produce the observed particle flux (the so-called number problem) to constrain the geometry and dynamics of 3D reconnection in eruptive flares. The proposed work will incorporate a realistic 3D magnetic geometry, which will lead to a significant improvement in the accuracy of model predictions. The ultimate goal of the project is to quantify the efficiency of conversion of the coronal magnetic energy into heat and the kinetic energy of accelerated particles in solar flares. We will make specific predictions for the locations and intensity of high-energy emissions in flares, which can be tested using the available and future data obtained with instruments on board RHESSI and Hinode.

Thomas Gorczyca/Western Michigan University
Accurate Treatment of Electron-Ion Recombination Rate Coefficients for Solar Physics

With support from NASA's Solar and Heliospheric SR&T program, we have continued our program, first funded as a joint experimental/theoretical project for three years (00-03), and then maturing into an essentially theoretical project for three more years (03-06). We have established and developed a state-of-the-art, methodological program to calculate the total and state-selective high temperature dielectronic recombination (DR) rate coefficients needed for solar physics. Accurate DR data are needed in order to interpret reliably spectra from the solar transition region, chromosphere, and corona (i.e., the solar upper atmosphere).

The goal of our research program is to provide reliable DR data that supercedes the (non-existent, inferred, or extremely unreliable) currently-used DR databases for ions important in the solar environement. We are doing this by carrying out state-of-the-art theoretical DR calculations. Laboratory measurements cannot provide the massive amount of required DR data, and therefore theoretical calculations are the only viable solution.

During the course of our previous grants, we have made substantial progress in producing the needed DR data for all L-shell ions of all elements up to and including Zn and we have since begun tackling the extremely-complicated M-shell sequence: Al-like through Ar-like. Over the next three years, we will extend our work for these ions, beginning with the iron-peak elements, but also providing data for entire isoelectronic sequences in these M-shell sequences.

This work will be relevant to the interpretation of spectroscopic data from a range of past, present, and future solar observatory missions including OSO, Skylab, Hinotori, P78-1, SMM, Yohkoh, SOHO, TRACE, STEREO, Solar-B, and SDO.

Eberhard Gruen/University of Colorado
Interstellar Dust Instrumentation

The solar system is currently passing through a region of low density weakly ionized interstellar medium of our galaxy. Interstellar dust that is part of the interstellar medium has formed as stardust in the cool atmospheres of giant stars and in nova and super-nova explosions. The interface between interstellar space and the heliosphere is currently located about 100 AU from the sun. Nevertheless, interstellar phenomena including interstellar dust grains cross this boundary and enter the heliosphere.

About fifteen years ago the Ulysses dust detector has positively identified interstellar dust grains at Jupiter's distance. Since that time Ulysses found a variation of the total flux correlated with the heliospheric magnetic field configuration which changes every solar cycle. The effect is size dependent: small interstellar grains displayed the biggest effect of heliospheric interaction. In the mean time both Cassini and Galileo recorded interstellar grains in interplanetary space down to 0.7 AU from the Sun. The Stardust mission made the first attempt to collect such particles and deliver them to the Earth for detailed analysis.

This instrument development proposal aims at an innovative next step of interstellar dust research to be undertaken by NASA in the foreseeable future: the development of a dust telescope and an active dust collector. A dust telescope characterizes simultaneously the trajectory and chemical composition of individual dust grains in space. The dust telescope is optimized for (1) large area (0.1 square meter) impact detection and accurate trajectory analysis of submicron-sized and larger dust grains, (2) the determination of physical properties of sub micron sized grains, such as flux, mass, speed, electrical charge, and (3) high resolution chemical analysis (M/delta M > 100) of cosmic dust. In a future advanced Stardust-type mission interstellar grains are collected by an “active dust collector” and returned to Earth. An active dust collector is a combination of a trajectory sensor with aerogel or metal film collectors behind it. The trajectory sensor provides for each collected grain the impact position and the incoming trajectory and hence its origin.

In a previous PIDDP project "Development of Critical Elements of a Dust telescope" concepts of the most risky components of a dust telescope, namely, a large-area mass analyzer, LAMA, and a dust trajectory sensor, DTS, were developed and individually verified in laboratory tests. The specific tasks of this proposal are the development, fabrication, and first tests of lab versions of an integrated dust telescope and an active dust collector for interstellar dust.

Heliophysics Program Element: Outer heliosphere/Development of instrument concepts

---

Walter Harris/University of Washington
Spectro-polarimetric study of the dynamics and distribution of interplanetary hydrogen as a probe of the heliosphere-ISM interface.

The physical extent of the Sun’s influence is bounded by the interaction with between the outflowing solar wind and ions in the interstellar medium (ISM) through which the solar system is moving. At an estimated distance of 100 AU, the actual boundary is past the edge of the explored solar system. In the absence of in situ measurement, this interface is studied with observations of the neutral ISM after it crosses the plasma boundary. Interplanetary Hydrogen (IPH) that has crossed this boundary is altered in its velocity distribution via charge exchange (CE) reactions with decelerating plasma near the heliopause. From the line-shape and polarization of scattered solar radiation from the IPH it is possible to use the CE processing of the IPH to constrain the dimensions of the heliosphere.

We propose continuation of our NASA-SHP program to study the IPH with a sounding rocket (the Hydrogen Polarimetric Explorer-HYPE) experiment. HYPE is equipped with a new type of spectro-polarimeter consisting of an all-reflective spatial heterodyne spectrometer (SHS) and a LiF waveplate-diamond Brewster polarimeter. SHS offers a significant advance for high spectral resolving power measurements of diffuse emission line targets with a design combining large étendue (field of view times sensitivity) with high-resolving power in a compact format. The HYPE polarimetric sensor provides an advance in UV polarimetry that will enable the study several important emissions such as the Hydrogen Ly-alpha line. HYPE therefore represents a significant improvement in performance, size, and weight relative to the current state of the art that will be broadly applicable to a host of missions where line-shape and scattering polarimetry are useful to a spectroscopic investigation. We are currently meeting the primary goals of our existing program, which are to assemble, test, and integrate a flight payload for a first sounding rocket flight in mid 2008. The continuation of this program will support field operations for the 2008 mission to observe the upwind IPH, along with refurbishment and field operations for follow-up flights to observe the sidewind and downwind flow directions.

In addition to the sounding rocket, our continued program aims to advance our understanding of the IPH with a combination of flight/archival data and model simulations. The sounding rocket data will be compared with archived spectral data and will be modeled using an enhanced version of a kinetic simulation for describing heliopause-crossing hydrogen. Our enhancements to this code will include polarization and opacity effects, as well as the physical effects of ionization, radiation pressure, and gravity that modify the IPH as it enters the inner solar system. Our aim is to use the simulation to predictively model IPH emission along any line of sight and, through a comparison with flight data, to constrain the properties of the heliosphere boundary.

Donald Hassler/Southwest Research Institute
Rapid Acquisition Imaging Spectograph (RAISE)

The Rapid Acquisition Imaging Spectrograph Experiment (RAISE) sounding rocket payload is an extremely high speed scanning-slit imaging spectrograph designed to observe the dynamics and heating of the solar chromosphere and corona on time scales as short as 100 ms, with 1 arcsec spatial resolution and a velocity sensitivity of 1-2 km/s. The first flight of RAISE is scheduled for Spring 2008 (Flight 36.219 US) and will focus on the study of high frequency, small-scale dynamics of active region structure, connection between constantly emerging and evolving magnetic structures, and intensity fluctuations measured in the higher atmosphere in coordination with the recently launched Hinode spacecraft.

In F.Y. 2008-2010, we propose to: 1) launch the first flight of the RAISE sounding rocket experiment, 2) analyze and publish the scientific data from this first flight and, 3) re-fly RAISE again in 2010 with a dual slit design to increase temporal resolution, and modify the optical design to incorporate a new TVLS grating optimized to study transient brightenings in the quiet Sun network and coronal holes.

Scientific motivation for the development of RAISE has stemmed, in part, from the fact that high speed imaging from TRACE has shown that rapid motions and reconnection are central to the physics of the transition region and corona, yet TRACE imaging cannot resolve the differences between propagating phenomena and bulk motion! Previous/existing spectrographs such as SoHO CDS and SoHO SUMER have yielded intriguing measurements of motion and heating in the solar atmosphere, but their time resolution is on the order of minutes to hours. HINODE/EIS and EUNIS will capture EUV spectra of the high temperature corona and flares in progress, but with spotty coverage of the chromosphere and transition region. No existing instrument, other than RAISE, can capture spectral information in the chromosphere, transition region, and corona on the ~1-10 Hz time scale required for few-second cadence spectral imaging or rapid wave motion studies. For these reasons, RAISE was developed to uniquely explore this hard-to-reach domain.

J. Hoeksema/Stanford University
Large-Scale Solar and Heliospheric Magnetic Fields Early in Cycle 24

As we near the activity minimum between Solar Cycles 23 and 24, the Wilcox Solar Observatory (WSO) at Stanford observes that the polar fields are 50% weaker than during the last three minima. The polar field strength is an important forecaster of the new cycle magnitude that together with the large-scale field patterns indicates how the flux that emerged during Cycle 23 has been redistributed over the surface. The computed heliospheric current sheet is also much less flat at this minimum, perhaps because the polar field is much weaker. Ulysses' traversal of the ecliptic will test the modeling. With STEREO now moving away from the longitude of Earth, we will finally be able to thoroughly test predictions of the location of the heliospheric current sheet at multiple points in the ecliptic. WSO data are widely used by the solar physics community in analysis of data from NASA space missions and by forecasters of solar wind conditions. WSO has a unique capability to measure the large-scale magnetic field with high precision, accuracy, and stability. We propose to continue the 31-year record of the dynamic large-scale solar magnetic field until we can adequately cross calibrate the large-scale measurements with HMI (planned for commissioning in late 2008), MDI, and SOLIS.

Qiang Hu/University of California, Riverside
Non-force free extrapolation of coronal magnetic field from vector magnetograms

We propose to develop and apply a new and realistic approach to deriving the three-dimensional non-force free solar active region magnetic field structure from vector magnetograms. The local structure in approximate magnetohydrodynamic equilibrium above the photosphere is to be reconstructed, utilizing high-quality vector magnetograms which provide boundary conditions within certain field-of-view.

In our approach, the coronal structures are considered to be in force-balanced equilibrium through plasma relaxation. Based on the Principle of Minimum Dissipation Rate for such relaxation process, an equation for magnetic field is derived, allowing the presence of finite plasma pressure gradient. An exact solution to this equation can be expressed as the superposition of two linear (constant-α) force free field solutions and one potential field solution. The parameter, α, for each of the two linear force free field, can be determined by optimizing the requirement that the recovered transverse magnetic field components as the superposition of the corresponding components of the two linear force free fields and the potential field agree with the observed ones at the photospheric level. Therefore, an optimal solution without the common force-free assumption is obtained by solving three linear force free extrapolation problems (one is potential), in which only the normal component of the magnetic field at the bottom boundary is known.

The proposed research has significant relevance to Heliophysics research. It addresses the important problem of solar active region magnetic field structure, which is closely related to the origin, pre-eruption conditions, and properties of coronal mass ejections. At the present time, new high-quality and high-resolution magnetograph data from both ground-based and space-borne instrumentations are becoming available. It is imperative to develop such a tool to meet the community demands for quantitative analysis of solar coronal magnetic field.

Devrie Intriligator/Carmel Research Center
From the Sun to the Outer Heliosphere: Analyses and Comparisons with 3D MHD Modeling

Objectives: The CRC/EXPI/GI team proposes a major time-dependent 3D modeling study of the outer heliosphere and heliosheath to be tightly constrained by spacecraft observations and data analysis from ACE, Ulysses, STEREO, Cassini, Voyagers 1 and 2. Our overall objective is to significantly increase knowledge of the 3D structure and variability of the outer heliosphere and its interaction with the local interstellar medium (LISM). The 3D numerical magnetohydrodynamic (MHD) Heliospheric Hybrid Model System (HHMS) will be extended to 100 AU and expanded to include the effects of pickup protons from interstellar neutral hydrogen entering the heliosphere. Solar wind in the outer heliosphere is significantly altered by mass loading, slowing, and heating due to pickup protons. Beginning with simple distributions of neutral hydrogen for testing and sensitivity analyses, the team will progress to a realistic directed flow from the LISM. We will compare the 3D HHMS results with spacecraft data for benchmark comparisons. The 3D quiescent solar wind will be analyzed in terms of its density, vector velocity, temperature, entropy, magnetic field magnitude/direction, latitude asymmetries, and longitude asymmetries; and the effects of pickup protons. Similar studies will be performed for the 3D “disturbed” solar wind associated with the propagation of solar events through the outer heliosphere. The quiescent and disturbed interplanetary parameters and energetic particle data will be sorted into temporal and spatial “buckets” for statistical analyses. Statistical results will be compared to 3D model predictions not only to estimate latitude/longitude asymmetries, gradients, and turbulence, but also to delineate outer heliospheric structures and boundaries. The results will help determine the

important underlying physical mechanisms (e.g., for heating, acceleration, and energy loss) in the outer heliosphere and heliosheath.
Technical Approach/Methodology: We will be combining the continuous 3D MHD HHMS with data returned from various spacecraft to increase our knowledge of the 3D structure and dynamics of the outer heliosphere and its interaction with the interstellar medium. The time dependent continuous feature of the 3D MHD HHMS allows it to input solar data without interruptions so as to model the dynamic nature of the Sun. Each year of this 3-year study we will submit papers to scientific journals. In the first 18 months, we will categorize the quiescent/disturbed solar wind cases in the Voyager data. We will include pickup ion effects in the 3D MHD model, extend its outer boundary and compare the results with Voyager data.
In the second 18 months, we will perform comprehensive statistical analyses, develop contour maps of parameters, quantify the magnitude of the asymmetries, and delineate outer heliospheric and heliosheath structures. Our proposal is unique since we combine in-depth analysis of the Voyager data with continuous 3D MHD modeling of the quiescent/disturbed solar wind in the outer heliosphere and heliosheath on a daily basis, thus simulating isolated as well as multiple interacting events. Our CRC/EXPI/GI team has successfully worked together in combining data analysis with 3D modeling from the Sun to Voyager 1.
Significance: This work directly relates to the NASA goals - F2 - fundamental processes of particle acceleration and transport (also F2.1, F2.2, F2.3); F3 - the role of plasma and neutral interactions (also F3.1, F3.4); J1 - characterizing the variability, extremes, and boundary conditions of the space environment; J3 - develop the capability to predict the propagation and evolution of solar disturbances to enable safe travel for human and robotic explorers. Our project will directly impact future NASA missions and the interpretation of the data returned from them, particularly Voyager, other heliospheric (such as Ulysses, STEREO), planetary, interstellar (e.g. IBEX), and cometary missions.

J. Jokipii/University of Arizona
Theory of Energetic Particle Transport and Acceleration in the Sun and Heliosphere

This proposal seeks three years of continued support for a program of fundamental theoretical studies and associated computer simulation and modeling, of energetic particles and their interactions in the heliosphere. The objective is to extend our fundamental understanding of energetic particles in solar and heliospheric plasmas, and concomitantly, to extend our knowledge of the plasmas and their magnetic fields. A goal will be to understand better the physics of the Sun and the interaction of the Sun with the local interstellar medium. A wide range of techniques will be utilized in our work, ranging from large numerical simulations through analytic work. Quantitative comparison with a variety of observations will be an important part of the work.

We propose the specific following areas of work during the proposal period:
1. Improve, using advanced numerical methods and basic heory, our understanding of the physics of energetic-particle acceleration and transport in a turbulent medium, including shocks.

2. Work on the important problem of how turbulent luctuations in the Sun's atmosphere are carried out to form the turbulent fluctuaionsobserved in the solar wind and hence the transport of energetic particles.
3. Study the acceleration of superthermal particles in the interplanetary medium with emphasis on understanding both low-rigidity electrons and the observed v^(-5) ion energy spectrum.
4. Determine the effects of large-scale structure of the solar wind termination shock, heliosheath and interplanetary turbulence on the acceleration and transport of charged particles.
5. Improve our understanding of the effects of CME structure on solar energetic-particle acceleration and transport.

We will utilize the analytical expertise and computational tools which we have developed in the past, and which have led to significant progress and closure between observation and theory.

Judy Karpen/Naval Research Laboratory
Structure and Dynamics of Solar Prominences

This proposal describes a 3-year plan to investigate the formation and evolution of solar prominences, using analytic theory and numerical simulations with our well-tested, state-of-the-art, 1D hydrodynamic and 3D MHD codes. Explaining prominence formation and dynamics has long been a core problem in Heliophysics, and is a major objective of current and future SEC missions (NASA Strategic Sub-goal 3B). In addition, because prominence ejections always are associated with large eruptive events, prominences play a key role in space weather.

Over the past decade, we have developed the sheared 3D arcade model to explain key properties of the magnetic structure, and the thermal nonequilibrium model to explain the plasma structure and dynamics. Building upon the successful application of these models thus far, we will calculate the evolving mass distribution within our merged-arcade magnetic structure, and investigate the role of flux cancellation in creating filament channels.

Our prior studies were focused separately on the magnetic structure and the plasma behavior. Although it is not presently feasible to simulate the full system self-consistently, we will formulate a comprehensive model as follows. First we will automate the characterization of a large number of flux tubes from our latest 3D MHD model of the filament-channel magnetic structure. From these parameters, 1D simulations will be performed to predict the plasma evolution in the selected flux tubes. We will combine these results to construct a first-ever composite picture of the entire filament channel. Second, we will investigate the poorly understood process of flux cancellation, beginning with the simplest possible configuration to develop physical insight and continuing with cancellation of a sheared arcade, as has been proposed to create filament channels from emerged bipoles. These pioneering calculations will reveal how flux cancellation operates on the Sun and determine its role in generating the conditions leading to eruptive solar activity. Throughout this effort, we will compare the simulation results with available data from NASA missions, in particular Hinode and STEREO, to test how well our models reproduce the observed behavior.

The PI, Dr. Judy Karpen (SSD/NRL) will manage the program and perform the proposed simulations. The PI and Co-Is, Drs. Spiro Antiochos (SSD/NRL) and C. Richard DeVore (LCP&FD/NRL), will collaborate on code modifications, interpretation of the simulation results, comparison with observations, and development of theoretical insights. We have a long record of fruitful collaboration on understanding prominences, and are recognized experts in the application of large-scale computing to fundamental solar-physics problems. Relevant publications: Antiochos et al. 2000, ApJ 536, 494; DeVore & Antiochos & Aulanier 2005, ApJ 646, 1349; Karpen et al. 2005, ApJ 635, 1319.

Vasili Kharchenko/The Smithsonian Institution Astrophysical Observatory
X-ray Diagnostics of Interactions between the Solar Wind and Heliospheric Gas

We propose to develop X-ray/EUV diagnostics of the Solar Wind (SW) plasma and interstellar gas and to employ it to analyze the observational data of the heliospheric X-ray and EUV emissions. The new diagnostic is based on analysis of the extreme ultraviolet (EUV) and X-ray emission spectra induced by heavy SW ions in the charge-exchange collisions with the neutral interstellar gas. Charge-exchange EUV and X-ray emission is a major source of the diffuse background X-rays with photon energies below 1 keV. Intensities and spectra of the charge-exchange EUV and X-rays depend on the parameters of the solar wind plasma and heliospheric gas. Heliospheric X-ray and EUV emission spectra, that have been already observed with the X-ray and EUV satellite telescopes, will be used for a determination of the heliospheric plasma and gas distributions. We will compute the intensity and spectral composition of the charge-exchange X-ray and EUV emissions induced in interaction between the solar wind and interstellar gas. Anisotropy parameters of the diffuse X-ray and EUV emission will be computed for the total spectra and for selected spectral X-ray emission lines. Theoretical spectra will be employed to analyze data on the soft X-ray emission observed with the ROSAT, Chandra, XMM-Newton, and Suzaku X-ray telescopes and data on the background EUV spectra from CHIPS and FUSE observations. Directional maps of EUV and X-ray emissions will be computed with different models of the heliospheric plasma/neutral gas distributions and compared with observations. The heliospheric gas and plasma distributions will be determined by fitting EUV and X-ray data form satellite observations with theoretical spectra. X-ray flux induced by the solar wind from the helium focusing cone will be computed and compared with observational data. X-ray and EUV spectra will be investigated for different solar activities. The spatial distributions in the helium focusing cone will be determined from the Chandra and XMM-Newton data on the EUV and X-ray background emission. X-ray diagnostics of the solar wind have been successfully interpreted for the charge-exchange X-rays from the cometary and planetary atmospheres and we propose to employ the same procedures for the heliosphere.

Michael Knoelker/University Corporation for Atmospheric Research
The Sunrise Balloon Investigation: Arctic Mission Support

Sunrise is an international program for the quantitative exploration of physical processes in the solar atmosphere at extremely high angular resolution. The objective is to obtain measurements of the magnetic field, dynamics, and thermal properties of the solar photosphere and chromosphere at a spatial resolution down to approximately 35 km on the Sun. Sunrise will meet these objectives by flying a series of long-duration balloon (LDB) missions, carrying a 1-m diameter solar telescope with instrumentation for highly quantitative vector magnetic field measurements in the visible and near infrared, plus imaging in the UV between 225 and 400 nm.

The original NASA grant under the sub-orbital program funded the gondola and instrument development up to and including a test flight in the Continental U.S., but deferred costs related to the science flight to a future proposal. A one-day gondola system test flight is now scheduled from the Ft. Sumner, NM Balloon Facility in August 2007. With this current proposal, we are requesting funds to complete the hardware phase of the US contribution to Sunrise up to and including Sunrise Arctic flight in 2009. Specifically, we request funds to: 1.) refurbish the gondola after the 2007 gondola system test flight, 2.) acquire and integrate the solar power system, and 3.) support the U.S. contribution to the integration, testing, and calibration of the flight science instrumentation to the gondola. The requested funding of $245,473 over two years will allow the Sunrise program to continue on track for the Arctic flight planned for 2009, thereby permitting Sunrise to contribute its unique high-resolution observations that are of greatest importance to the science targeted by space missions such as HINODE and SDO.

Dietmar Krauss-Varban/UC Berkeley
Solar Flare Ion and Electron Acceleration Associated with low-beta Reconnection

X-ray and gamma-ray observations show that electrons and ions are accelerated in solar flares to very large energies. Also, a large number of electrons is affected, pointing to a process resembling bulk heating rather than acceleration of a small or localized population. It is generally accepted that solar flares occur in conjunction with magnetic field line reconnection. However, since the reconnection site makes up an insignificant volume compared to flare loop dimensions, the problem of efficient acceleration has remained unresolved. Recently, we described a new model in which the initial acceleration/ heating takes place along the discontinuities that bound the reconnection inflow/ outflow in a Petschek-type geometry. Self-consistently generated turbulence and the collapsing magnetic field lines provide secondary acceleration. The objective of the proposed research is to further investigate this new, promising model with a combination of simulations, modeling, and comparison to observations. A detailed plan is laid out that allows stepwise study of this problem despite the large differences between flare loop and kinetic scales. Given the role of wave-particle interactions in energization and transport, and the non-adiabatic behavior at the attached discontinuities, it is clear that the problem can only be addressed kinetically. To properly describe the essential kinetic physics, large-scale two-dimensional hybrid and full-particle simulations will be performed. Our goals are quantitative results for the particle spectra, fluxes, and characteristic temporal and spatial scales. Observational data will be used to determine the simulation parameters, and the results and predictions will be parameterized and compared to observations. Understanding the processes that lead to particle acceleration in solar flares and quantifying the resulting fluxes and parameter dependence is a task that fits squarely within the objectives of NASA's Solar & Heliospheric program, and uses existing and upcoming spacecraft observations such as provided by RHESSI and STEREO.

Samuel Krucker/University of California Berkeley
The Focusing Optics Solar X-ray Imager (FOXSI)

We propose to apply newly available hard X-ray (HXR) focusing optics together with pixelized solid state detectors to solar observations. The proposed telescope, the Foscusing Optics X-ray Solar Imager (FOXSI), will provide imaging spectroscopy with high sensitivity and dynamic range up to 15 keV. For the first time, it will be possible to search for HXR emission of thermal network flares occurring in the quiet corona. Detection of HXR counterparts would strongly suggest that network flares are small versions of regular flares, while the absence would indicate that a different emission mechanism is heating network flares. Additionally, FOXSI will extend the flare distribution in active regions down to two orders of magnitude smaller events. With the sensitivity of FOXSI, it will also be possible to detect HXR emission from energetic electrons producing coherent radio bursts such as radio type I noise storms providing the first quantitative measurements of energy content in non-thermal electrons in these events. Furthermore, FOXSI will be a pathfinder for a future generation of solar HXR spectroscopic imagers that will make it possible to trace electron beams in the corona, outline where they are accelerated, along which path they travel away from the acceleration site, where they lose their energy, and how some escape into interplanetary space.

Enrico Landi/Artep, Inc.
Spectroscopic diagnostics of solar plasmas with CHIANTI

The goal of the CHIANTI atomic database is to provide a well-developed set of atomic data, transition probabilities and software to help understand the basic physics of the solar atmosphere through the analysis of data from high resolution spectrometers and imagers. CHIANTI is used worldwide for the analysis of data from all the current NASA solar missions (SOHO, TRACE, RHESSI, STEREO, Solar-B) and will be part of the standard analysis and calibration software of the future NASA missions (SDO). Analyses from SOHO, TRACE, and RHESSI data have demonstrated that the solar atmosphere is variable and dynamic at all scales, so that data are needed to model transient ionization. Here we propose a three-year investigation aimed at expanding and improving the CHIANTI database, by including ionization and recombination data necessary to model states of transient ionization typical of solar activity at all scales, as well as new data to predict a large number of lines in the soft X-ray, EUV and UV wavelength ranges. We will use the ionization and recombination data also to calculate ionization equilibrium for finite density plasmas. The new version of CHIANTI that will result from the present investigation will allow solar physicists to study observations of all regions and all phenomena taking place in the solar atmosphere (coronal hole, solar wind, active regions, flares, CMEs, explosive events, irradiance) from all current and future NASA missions, and will therefore be an essential tool for any study aimed at addressing NASA's strategic objectives of exploring the Sun-Earth system to understand the Sun and its effects on Earth.

Roberto Lionello/Science Applications International Corporation
THE SPATIAL AND TEMPORAL
VARIABILITY OF THE SOLAR WIND: AN MHD INVESTIGATION

The solar wind is not a homogeneous stream as it was originally thought. It is well known that it is made of
of a fast and a slow component. Although it is the slow component that exhibits by far the greater time variability, pressure balance structures are present in the fast wind.

We intend to study four aspects of the spatial and temporal variability of the solar wind using our 3D MHD model in spherical coordinates. We will

- Model the plume-interplume spatial structure in the fast solar wind from the solar surface to 1AU.

- Validate the Fisk mechanism for the generation of the solar wind, which naturally explains the temporal variability of the slow solar wind, using a sequence of high-resolution MDI magnetograms of the quiet Sun.

- Investigate whether the thermally driven pressure imbalance in the loops under the streamer may cause disruption and contribute to the variability of the slow solar wind.

- Study the instabilities in the heliospheric current sheet above the streamer and their possible influence on the time profile of the slow solar wind.

The study of the solar wind is very relevant to NASA's objective to understand the effects of the Sun on the other bodies of the Solar System.

Chung-Sang Ng/Univeristy of New Hampshire
Heating and Acceleration of the Solar Wind and Corona by Anisotropic MHD and Hall MHD Turbulence

Observations by the Ultraviolet Coronagraph Spectrometer (UVCS) on the Solar and Heliospheric Observatory (SOHO) show that heavy ions are heated to hundreds of times the temperatures of protons and electrons, with highly anisotropic velocity distributions.

This indicates the importance of the heating and particle acceleration action by waves in the ion cyclotron range of frequencies, generated by magnetohydrodynamic (MHD) turbulence, in the solar corona and solar wind. A major challenge of this approach is that these waves are supposed to have a much larger parallel component of wave vector ($k_\parallel$) than the perpendicular component ($k_\perp$), but MHD turbulence is highly anisotropic and mainly cascade energy to the $k_\perp$ direction. One novel way to overcome this difficulty is by   extending MHD turbulence to include Hall MHD waves and turbulence in the large $k_\perp$ regime, which can then support a branch of waves below the ion cyclotron frequency with $k_\perp >> k_\parallel$. One of the principal objectives of the present proposal is to carry out a comprehensive study of this process. The resolution of this process requires, on the one hand, an improved understanding of the extension of anisotropic MHD to Hall MHD turbulence, and the application of that knowledge to the problem of ion heating and acceleration. In particular, by means of high-resolution simulations and analysis, we will:

* investigate anisotropic spectra and dissipation in MHD/Hall MHD turbulence and the coupling and transition between the two in the inertial range;
* demonstrate how waves in the ion cyclotron range of frequencies can be generated through the Hall MHD turbulence; and
* study the heating and particle acceleration mechanism by such waves and deduce empirical laws that are consistent with observations of the solar corona.

Our computational tools include a suite of MHD as well as two-fluid (or Hall MHD) codes (based on spectral or finite-difference methods) for direct numerical simulations, and relevant experience with data analysis . Results of analysis and simulation will be compared in detail with data from NASA-supported missions.

The objective of the proposed research is highly relevant to current and future NASA missions, such as Solar-B, Solar TErrestrial RElations Observatory (STEREO), and Magnetospheric Multiscale (MMS), as well as turbulence in other astrophysical systems, such as the interstellar medium. The proposed research includes significant interactions between theory and observation and is consistent with Goal 3 of the 2006 NASA Strategic Plan, especially Objectives 3B.1 and 3B.3.

Aimee Norton/National Solar Observaotry
3-D Magnetic Fields: The Dynamic Scaffold of the Solar Atmosphere

The magnetic fields in the solar atmosphere act as a dynamic scaffold - a raised, 3-D framework supporting the energetic processes of our Sun's tenuous, outer layers. We propose to utilize the capabilities of the Synoptic Optical Long-term Investigations of the Sun (SOLIS) Vector Spectromagnetograph (VSM) to investigate the dynamic connectivity of the 3-D magnetic scaffold. We will use VSM data alone and in conjunction with data from NASA missions. Specifically, we plan to begin a new program to operate SOLIS in a fast-cadence scan mode to provide photospheric Stokes profiles of flaring regions to support the scientific investigations of STEREO, TRACE, Hinode, SOHO, RHESSI, and SDO. Subsequent data analysis will illustrate how photospheric magnetic field configurations change during flares. In addition, VSM data will be used to study the polar fields to correlate the lifetime of polar plumes to their flux element footpoints. Simultaneous STEREO EUV and VSM vector, photospheric data will be a unique source of information on the non-linear, current-carrying fields believed to be responsible for flares and CMEs. We propose to use VSM chromospheric magnetograms to characterize the unique environment of the canopy and, in conjunction with SDO AIA (or TRACE) images, understand how often the canopy horizontal magnetic fields suppress energy from the underlying shock-related bright points. Lastly, VSM vector data can provide an inversion initialization for HMI whose high-cadence filtergram vector data requires an inversion capacity not yet developed. This proposal seeks financial support for post-doctoral scientists. With post-doctoral assistance in achieving the scientific potential of VSM, the SOLIS base-supported staff will have the freedom to acquire the pre/post-flare scans and make the data publicly available. The science that can be achieved by combining data from VSM and NASA missions is science that cannot be achieved with a single instrument.

Jiong Qiu/Montana State University
An Observational Study of Loop Oscillations in the Active Corona

{\bf Energetic explosions from the Sun, which have significant impact on the space environment, take place in the Sun's corona. Therefore, a better understanding of the active corona is an important science objective for NASA's strategic goals.} We propose to conduct observational research on the dynamics of active region corona through comprehensive and extensive analyses of coordinated EUV and X-ray observations of coronal loop oscillations by a variety of solar telescopes. Using observations from SUMER on-board SoHO, as well as EIS on Hinode and AIA on SDO, we will search for loop oscillation events, categorize them, and identify the oscillation modes from Doppler-shift measurements in multiple EUV and X-ray lines at different temperatures.
We will analyze coordinated imaging and spectroscopic observations by instruments including TRACE, RHESSI, SXT/Yohkoh, and EIT/SoHO. The goal is to better understand the mechanisms of wave excitation by looking for observational signatures of impulsive heating events and plasma flows before or at the onset of the oscillation. Furthermore, we will measure the mean magnetic field in coronal loops from the theoretical relationship between the loop oscillation properties and coronal plasma properties obtained from spectroscopic analyses of coordinated observations by SUMER, RHESSI and SXT. A large sample of loop oscillation events will be analyzed to achieve statistically significant results. The observationally obtained physical properties of coronal loops and oscillations will provide critical inputs to theoretical models investigating physical mechanisms of heating and dynamics of the active region corona.

Alysha Reinard/CIRES
Probing the Three Dimensional Structure of Coronal Mass Ejections: Multi-point Data Analysis and Modeling

This project will tackle a difficult and important topic in Solar and Heliospheric Physics, namely Coronal Mass Ejections. The underlying causes of CMEs are not well understood, nor are the precise details of their internal magnetic and plasma structure. To fully understand the initiation and propagation of CME ejecta it is necessary to examine the full three-dimensional structure of ICME ejecta and to relate those in-situ structures to conditions at the solar source region. The specific scientific questions that will be addressed in this investigation are as follows: A) What is the detailed spatial structure of ICME ejecta and what substructures can be identified? B) What are the spatial scales of ICME substructures and the ICME itself? C) Is it possible to reliably identify in-situ structures with specific source region material?

We propose an investigation using in-situ and remote data sets from STEREO, SOHO, and ACE in combination with modeling results to determine the overall heliospheric ICME structure and the spatial scales of coherence for the various magnetic field, plasma, and composition signatures that characterize ICME material. We will then relate those structures to the CME source region. A non-cylindrical, non-force-free model has been developed and is able to capture significant distortions from the minimum-energy LFF state and will be fit to the ICME magnetic field data sets simultaneously to more accurately determine the in-situ three-dimensional magnetic structure. This model will be extended using flow deflection techniques to allow the examination of both magnetic cloud and non-cloud ICMEs and will provide a structured three-dimensional context for the plasma and composition data.

With high-cadence in-situ measurements by multiple spacecraft, for the first time, we will be able to examine ICME plasma and composition structure, not only in the spatial cross-section that a single spacecraft traverses, but also the variation along the central ICME axis. This proposal directly addresses NASA's Strategic Sub-goal 3B by its focus on the detailed understanding of CME structures in the heliosphere and the relationship of those structures to specific solar features. In particular, this proposal is relevant to NASA Science Outcome 3B.1 and 3B.3. CMEs are one of the main solar phenomena that directly affect the Earth and other heliospheric bodies and this study will provide a detailed understanding of the fundamental CME physical processes. In addition, a better understanding of ICME structures and their relationship to solar source region structures will increase the ability to predict the initiation of these events and the resulting trajectory and structure in the heliosphere.

Valentin Shevchenko/University of California, San Diego
Study of Acceleration and Heating Processes in the Solar Wind

The main goal of the proposed research is study of mechanisms of energization of heavy ions and protons due to their interaction with MHD fluctuations in the solar wind.

A self-consistent nonlinear model describing simultaneous resonant cyclotron interaction of heavy ions with two Alfven wave packets (i) with the packet propagating in outward direction from the sun and (ii) and the one propagating in inward direction will be constructed. Since lines of the ion diffusion in the velocity space due to interaction with oppositely propagating waves intersect, ions can jump from one shell distribution to another and vice versa. This will result not only in their diffusion over pitch angle but in their energization as well (second-order Fermi acceleration). First, the ion heating process will be studied in local approximation. The dynamics of the ion distribution function will be studied by solving the Fokker-Planck equations self-consistently with equations for Alfven fluctuations as well as by numerical simulations. Second study will address the problem of radial evolution of the ion heating in the divergent solar wind. This problem will also be studied using the quasi-linear approach as well as by numerical simulations.

The solar wind proton acceleration resulted from a distortion of a distribution function of resonant protons due to cyclotron interaction with MHD fluctuations of both left and right polarizations propagating in the outward direction in the divergent solar wind will be studied. Three problems will be solved. First one is the numerical simulation of the interaction in test particle approximation. The problem of the bridging the gap between maximum proton resonant velocity for left-handed waves and minimum resonant velocity for right-handed waves will be addressed. Second task is a self-consistent dynamics of resonant protons due to their interaction with MHD fluctuations in the divergent solar wind. A bulk proton velocity acquired due to distortion of the resonant proton distribution via their cyclotron interaction will be found as function of distance. And finally, the problem, that includes both (i) heavy ion and (ii) resonant proton interactions with left-hand and right-hand polarized waves in the divergent solar wind, will be addressed self-consistently. The heavy ion-proton differential speed will be found as function of the distance from the Sun.

Statement of the methods/techniques proposed to accomplish the stated research objectives: Codes and models already developed by our team as well as methods of nonlinear plasma theory and computational physics (spectral method, method of resonant numerical simulation, etc.) will be used in this study

Statement of the perceived significance of the proposed work to the objectives of the solicitation and to NASA interests and programs in general: As a result of the work microscopic and macroscopic picture heating processes of heavy ions due to cyclotron interaction with MHD waves in the solar wind will be created. An improved understanding of heavy ion-proton mutual dynamics due to their interaction with outward electromagnetic fluctuations in the solar wind will be achieved. So the proposed study is significant to the objectives of the solicitation that include “the development of theoretical models and numerical simulation techniques pertinent to solar and heliospheric physics”. Results of the proposed study will explain observations made by space missions SOHO and Ylysses supported by NASA.

Robert Stein/Michigan State University
Solar Surface Magneto-Dynamics

GOAL: The goal of this research is to understand the magneto-dynamics of the solar surface, on scales from granules to multiple supergranules, in quiet and active regions of the Sun. We will analyze the simulation results to discover the physical processes that determine the solar surface magneto dynamics. We will: investigate the interaction of convection, radiation and magnetic fields; study the nature of supergranulation; probe the creation, emergence, dispersion and disappearance of magnetic flux in the quiet Sun; examine the origin and maintenance of the magnetic network; improve our ability to probe the internal structure of the Sun via helioseismology; calibrate local helioseismic inversion methods, and reanalyze the solar oxygen abundance. These investigations are important for interpreting the results from NASA missions (SOHO, Hinode, SDO), for validating local helioseismic methods, and for understanding the surface behavior that controls the corona and ultimately space weather.

METHODOLOGY: Our code solves the conservation equations for mass, momentum and internal energy and the induction equation for the magnetic field, in three-dimensions, on a staggered grid, with a realistic equation of state including ionization and excitation of the abundant elements and with LTE, non-gray radiation transfer heating and cooling. Spatial derivatives are calculated by sixth-order, centered, finite differences. Time advance is by explicit, third-order, Runge-Kutta with variable time steps. The code is parallelized using either MPI or OpenMP (with the entire calculation in a single parallel region).

PROJECTS: We will simulate: (1) the behavior of an active region in a domain 96 Mm wide and 20 Mm deep; (2) flux emergence and the magnetic network in supergranulation scale magneto-convection in the quiet Sun in a domain 48 Mm wide by 20 Mm deep; (3) rise of a magnetic flux tube through the upper convection zone and emergence through the surface in a domain 48 Mm wide by 20 Mm deep; (4) granule scale magneto-convection at very high resolution in a domain 6 Mm wide by 3 Mm deep. (5) We will use the simulations to reanalyze the solar oxygen abundance.

SIGNIFICANCE: Magneto-convection drives solar atmospheric dynamics and space weather via the magnetic flux that emerges through the solar surface and is moved about by convective motions. Turbulent magneto-convection near the solar surface also impacts local helioseismic determinations of subsurface flows and magnetic fields. This forward modeling is essential to accurately determine subsurface temperatures, flows and magnetic fields using time-distance, ring diagram and holographic techniques. It is also needed to properly interpret observations from the Swedish 1m Solar Telescope, SOHO/MDI, Hinode, and eventually SDO and ATST. Comparison with these observations will be used to verify both the simulation results and the observational anaylsis procedures.

Alphonse Sterling/NASA/MSFC/NSSTC

Initiation of Solar Eruptions: Magnetic Setting, Eruption Onset, and Coronal Dimming

We propose a three-year program to study the initiation of solar eruptions resulting in flares and Coronal Mass Ejections (CMEs), and the magnetic source regions of CMEs. Using new analysis approaches, we will address two main questions: (A) What leads to the initial disruption and energy release of the erupting flux system, and (B) How do the localized flare-site eruptions relate to the CMEs, which typically have much larger extent than the flare site? We will analyze primarily EUV, soft X-ray (SXR), white-light coronagraph, and magnetic-field data. These will primarily be from SOHO/EIT, Yohkoh/SXT, SOHO/LASCO, and SOHO/MDI, although we will consider other data sets in a supplementary role. We will examine events with clearly-trackable filament eruptions, and use the filament motions around the time of violent eruption as tracers of the motion of the exploding coronal magnetic field that carries the filament. From work from our previous grants, we have observed that erupting filaments often display slow-rising motions prior to fast eruption, and the slow-rise phase can be accompanied by other phenomena, such as subtle pre-flare intensity dimmings and brightenings, that give an indication of the full extent of the region involved in the eruption; stronger dimmings and bright flaring accompany the fast eruption. Building on these previous studies, our new work will have three main parts. Part I: A quantitative statistical investigation of the rise trajectories for approximately 50 erupting filaments. Part II: Detailed analysis of a more restricted set of the events investigating various aspects, including dimming and brightening variations during the slow-rise and start of the fast-rise of the filament; evidence for magnetic connections between the main eruption site and more remote locations; the inter-relationship and relative timings of phenomena in EUV, SXRs, and HXRs; and the role of newly-emerging flux in initial disruption of the field, and its subsequent violent eruption. Part III: A study of CME source regions at the Sun, investigating why the angular extent of CMEs is commonly much larger than the angular extent of the associated flare. We will consider implications of our findings for various eruption models. This work supports the objectives of NASA's strategic goals, in that it will produce basic new knowledge and understanding of solar eruptions, laying the foundation for short-term (minutes to hours) forecasting of CME onsets; CMEs can affect the Earth and its environment, and can be dangerous to astronauts in space. Our requested funding includes support of a post-doctoral-level researcher.

Gary Zank/University of California
The Transmission and Amplification of Turbulence at Shock Waves

Shock waves are ubiquitous in the interplanetary medium being launched in the solar corona, driven by coronal mass ejections, diverting the solar wind about planets and comets, and the heliospheric termination shock. Multi-point measurements made of shock structure and characteristics indicate existing theory is deficient. These environments are inevitably composed of smaller scale fluctuations, including structures, and magnetohydrodynamic turbulence. The purpose of this project is to develop models, both quasi-analytic and computational, to investigate the interaction of turbulence with shock waves, focusing on the transmission and amplification of fluctuations at the shock and the back-reaction of turbulence on the shock jump conditions. We have begun several investigations in this direction (Zank et al., 2003; Sjoegreen & Yee, 2004). (1) Analytically, we have developed a closure scheme that goes beyond the simpler linear wave analysis developed by McKenzie & Westphal, 1968. This approach will be extended to MHD shocks in a collisionless space plasma environment. (2) To address the role of computational models, we have invested significant effort in constructing a new and robust approach. Recently developed high-order filter schemes (Sjoegreen & Yee, 2004) are highly parallel and have been shown to exhibit higher accuracy, efficiency and stability than commonly used shock-capturing schemes for typical shock/turbulence fluid dynamics and MHD simulations. Unlike the hybrid approach of switching between schemes, our filter schemes consist of very high order non-dissipative spatial base schemes in conjunction with adaptive numerical dissipation control as the filter. We propose to use and improve the Sjogreen-Yee and Yee-Sjogreen adaptive numerical dissipation control in spatially high order filter schemes to accurately simulate the interaction of shocks and turbulence. We furthermore propose to use hybrid simulations to explore the short-time interaction of turbulence with shocks to investigate on smaller scales the modification to shock structure.