Living With A Star Science Program
Abstracts of Selected Proposals
(NNH14ZDA001N-LWS)

Below are the abstracts of proposals selected for funding for the LWS program. Principal Investigator (PI) name, institution, and proposal title are also included. 103 Step-2 proposals were received in response to this opportunity. On September 5, 2014, 22 proposals were selected for funding.

William Abbett/University of California, Berkeley
The Transport of Electromagnetic Energy from the Upper Convection-Zone to Outer Corona

To maximize the scientific return from revolutionary new in-situ measurements of the solar corona to be provided by NASA's Solar Probe Plus mission, we propose a focused modeling effort to characterize the transport of electromagnetic energy from the upper convection-zone to the outer corona. Our goals are to (1) self-consistently model the introduction of magnetic energy through footpoint motions and reconnection arising from turbulent granular convection at the Sun's visible surface; and (2) understand how the network of embedded bipolar flux regions, through pseudo-streamers and the main helmet streamer belt, modulates this flow of energy.

We will perform a series of large-scale numerical simulations using a recently-updated version of the radiative-magnetohydrodynamic code RADMHD2S to: (1) Characterize the wave spectra and time series of magnetic field and plasma fluctuations at 5-10Rs in a unipolar open-field region --- one that represents the open field within a coronal hole, and the source of the fast solar wind; (2) Introduce a relatively large-scale bipolar flux system embedded in a unipolar open field to characterize the effects of the closed field region on the transport of material and energy flux, and quantify how the wave spectra and temporal evolution of magnetic field and plasma fluctuations reflect this larger coronal structure; and (3) Extend these simulations to the size of a coronal pseudo-streamer, then to the size of the helmet streamer belt.

This research will, for the first time, allow for a calculation of the energy input and spectrum from an ab-initio, first-principles numerical simulation, rather than making ad-hoc assumptions about how the solar convection zone affects open-field regions. In addition, the construction of synthetic time series of field and plasma quantities, will allow for a comparison to future measurements taken by Solar Probe Plus.

Spiro Antiochos/NASA / Goddard Space Flight Center
Implications of the S-Web for Observing and Understanding the Inner Heliosphere

Objectives: NASA space-based coronagraphs have revealed that the connection of the corona to the inner heliosphere is highly complex and fully dynamic. This connection is clearly due to the Sun's magnetic field. We propose a research program designed to attack this fundamental question in Heliophysics: What are the magnetic topologies and dynamics that produce the observed structure of the inner heliosphere? Answering this question is critical for achieving NASA's goals of understanding the Sun and solar system and for interpreting the wealth of new data that will be obtained by Solar Orbiter and Solar Probe Plus.

Methodology: The proposed work builds on our recently developed S-Web Model for the sources of the slow solar wind and our embedded bipole model for coronal jets. The work consists of a balance of theoretical and numerical studies using state-of-art simulation codes, in particular, our 3D adaptively-refined MHD solver (ARMS). We will employ the methodology that we have used to attack successfully many fundamental Heliophysics problems: first develop insight by investigating idealized models that isolate the key physics of the problem, then apply the understanding gained to calculate signatures that can be compared with observations from the NASA missions.

The Principal Investigator directing this project is Dr. Spiro K. Antiochos of NASA/GSFC. He will be assisted by Drs. Judith T. Karpen and Dr. C. Richard DeVore from GSFC, as well as Dr. Sophie Masson from Catholic U and Ms. Aleida Young, a graduate student from the University of Michigan who will perform part of her thesis research on this project. Dr. Antiochos is an adjunct professor at U. Michigan and is supervising Ms. Young at GSFC.

Relevance to Solar Orbiter/Solar Probe Plus: The physics of the inner heliosphere are almost exclusively determined by the magnetic coupling of the corona to heliosphere. The SO&SPP missions have been designed specifically to measure this coupling for the first time close to the Sun. The proposed research program is essential for understanding the fundamental physical properties of the Sun-heliosphere magnetic field. We will apply our advances in theoretical understanding to the development of detailed models of the inner heliosphere that can be used both to interpret the SO&SPP measurements and to test/refine the theories.

Thomas Broiles/Southwest Research Institute
Understanding Wave-Particle Interactions Between Solar Wind Plasma Waves and Heavy Ions

Solar wind heavy ions are preferentially heated and accelerated by plasma waves in the solar wind. However, very little is known about this wave-particle interaction, and it generally remains poorly understood. For example, it is unknown which types of waves are most responsible.

Our goal is to better understand wave-particle interactions in the solar wind. Our specific objectives are to determine the relative importance of each type of wave, and further constrain the physical conditions when wave-particle interactions occur. We will meet these objectives by identifying the various waves present at the Advanced Composition Explorer (ACE). We will then statistically compare the properties of observed wave modes to sources of free energy in the bulk plasma, and to heavy ion observations. These comparisons will tell us how the waves form, and how they heat and accelerate heavy ions.

We will then repeat this analysis at Ulysses to determine whether the wave-particle interaction changes with heliographic latitude and radial distance. Performing the same analysis at Ulysses' aphelion and perihelion will allow us to study the wave production and heavy ion energization processes as the free energy sources in the bulk plasma become more collisionally aged. Additionally, we will perform this analysis when Ulysses is at high heliolatitude, where the solar wind and IMF conditions are significantly different.

This study will be the first to directly link observations of waves to observations of solar wind plasma and heavy ions. We also point out that the technique proposed in this study is directly applicable to the Solar Orbiter and Solar Probe Plus missions.

Craig DeForest/Southwest Research Institute
Preparing for Solar Probe Plus: Probing the Solar Wind Acceleration Region with Remote Sensing of MHD Waves

We propose to exploit the newly discovered compressive MHD wave field in the outer solar corona to probe the wind acceleration region, Alfvén surface location, and longitudinal structure as preparation for the upcoming Solar Probe Plus mission. In preliminary work, we have measured running waves via careful analysis of synoptic STEREO/COR2 images, and have measured the 2-D projected propagation speed and its variation with altitude. We have further demonstrated that the all important Alfvén surface, where coronal dynamics give way to solar wind dynamics, is significantly above 12 Rs in the coronal hole and at least 15 Rs in the streamer belt at solar minimum. Our science objective is to measure the environment of the accelerating solar wind directly, producing the first direct measurements of: wind speed, Alfvén speed, and sound speed. These measurements will then be used to deduce properties of the solar wind acceleration region and identify the location of the Alfvén surface.

Tim Fuller-Rowell/University of Colorado
Quantifying the Impact of the Neutral Atmosphere on the Topside Ionosphere During Storms

Introduction: The primary goal of this LWS Focused Science Topic (FST) is to elucidate the photochemistry and dynamics governing ion-neutral interactions in the topside ionosphere. This proposal will elucidate the impact of the neutral atmosphere winds, temperature, composition, and the disturbance dynamo on the topside ionosphere, which contributes directly to this FST goal. Improving the ability to predict TEC changes in the topside ionosphere is critical to alleviating the disruptions to communications and navigations from geomagnetic storms. The topside ionosphere during a storm is controlled largely by electrodynamic transport from the expanded magnetospheric convective, penetration, and dynamo electric fields, together with interactions of the ions with the neutral atmosphere, which impact the topside ionospheric plasma in several ways. Equatorward neutral winds raise the plasma in altitude to a region where the O/N2 ratio is greater, thus decreasing the plasma recombination rate. During a storm, the neutral composition changes due to Joule heating at high latitudes creating upwelling and changes in the global circulation. The new circulation changes the O/N2 ratio, and the plasma recombination rate. Changes in the neutral H, He, and O in the topside will alter the rate of O+/H+ charge exchange and He+ concentration in the topside ionosphere.

Goal: Our purpose is to provide the storm-time changes in the neutral atmosphere that are important and relevant for the ion-neutral interactions in the topside ionosphere. These include the changes in neutral winds, O/N2 ratio in the neutral composition, and the neutral hydrogen and helium profiles. The winds are particularly important at mid-latitudes where the geomagnetic field is tilted. The goal is to model the storm-time changes in the neutral species with physics-based models, compare the model estimates with observations to validate the response, and make the information available to ionospheric models. The magnetospheric energy input used to drive the model can be verified by comparing the neutral density response with observations. The changes in the neutral atmosphere following the storm that influence the topside ionosphere can be verified by comparing with mid-latitude winds from ground-based Fabry-Perot interferometers and global distribution of O/N2 ratio from satellite airglow.

Methodology: We will use two mature physics-based models to simulate storm periods with the CTIPe and TIEGCM models when sufficient observations are available to constrain the solar and magnetospheric drivers. During those periods the physics-based models will be combined with available ground and spaced-based observations of winds and neutral composition to determine the impact on ionosphere plasma densities. The proposal will also develop forward models for the neutral atmosphere observables suitable for use in a data assimilation schemes.

Outcome: This proposal will characterize the changes in the neutral atmosphere during geomagnetic storms in order to accurately represent the important ion-neutral interaction responsible for the large changes in electron content in the F-region and topside ionosphere at low, mid, and high latitudes.

Significance: This study addresses the goals of NASA's LWS program of developing the scientific understanding needed for the United States to effectively address those aspects of Heliophysics science that may affect life and society. The proposed investigation will contribute to LWS Strategic Science Area SAA-4 to improve Physics-Based TEC Forecasting Capability. The TR&T program's objectives will be achieved in this proposal by using physics-based modeling and ground and spaced-based observations. The proposed work will contribute importantly and directly to the LWS Focused Science Topic Ion-Neutral Interactions in the Topside Ionosphere. The effort will support the NASA Heliophysics goals of understanding the Sun and its interactions with the Earth.

Larisza Krista/University of Colorado / CIRES
What Is the Origin and Life-Cycle of Transient and Long-Lived Open Solar Magnetic Fields?

Goals and Objectives: Open solar magnetic field primarily consists of long-lived, large open field regions (coronal holes, or CHs) and transient open fields related to solar eruptions (dimming regions). Although these phenomena are well observed, the origin and life-cycle of open magnetic field on the Sun is still highly debated. Open magnetic field may be created during large solar eruptions as magnetic field lines are dragged out into the heliosphere. This open field is briefly observed as a dimming region. Meanwhile, large open magnetic field regions (CHs) form in the quiet Sun and gradually disintegrate, with the cause of the formation and disappearance unclear. It has been suggested that decaying active regions (ARs) may provide a hotbed for CH emergence, but it may or may not be the sole source. Our goal is to investigate the different ways open magnetic field emerges in the Sun: through eruptive processes and gradual accumulation. We will determine its evolution over the solar cycle: is open flux recycled, i.e. concentrated at the poles during solar minimum and redistributed in the quiet Sun afterward, or created by opening closed field near ARs and/or during eruptive events. Methodology: We will carry out our investigation using automated CH and dimming detection algorithms that have already been developed by the PI. These algorithms allow us to determine the properties of CHs and dimmings (area, polarity, location, photospheric magnetic field strength, duration of existence, N/S asymmetry). The algorithms have been developed to be compatible with different satellites and instruments (SDO/AIA, STEREO/EUVI, SOHO/EIT, Hinode/XRT). A CH catalogue (1996-present) has already been created by the PI, and a dimming catalogue is currently being populated. Our dimming tracking algorithm will be further developed to allow for the automated identification of dimmings, allowing us to process the large amount of data available. Our CH and dimming databases have been created using SOHO/EIT and SDO/AIA. We will also use STEREO/EUVI detections to create 360 degree maps of open field regions for the available period and compare them with available PFSS models of the Sun to establish the differences between the observational and theoretical models of open fields. This will be beneficial to CME modeling and forecasting purposes. We have also developed tools to link the observed open field regions with solar wind signatures using ACE data, which will allow us to study the complete Sun-Earth connection and assist improving the accuracy of existing forecasting models. Relevance to the Solar Orbiter/Solar Probe Plus missions: Our proposed research will directly advance our understanding of the connection between coronal and heliospheric structures. Specifically, we will study the connection between short/long lived open magnetic fields (dimmings/CHs) and the corresponding solar wind structures using multiple instruments. Our tools have been thoroughly tested and used in the community (e.g. NOAA/SWPC, Heliophysics Feature Catalogue), making their adaption to Solar Orbiter/Solar Probe Plus straightforward and reliable.

Enrico Landi/University of Michigan

Solar Wind Investigation in Preparation for Solar Orbiter and Solar Probe Plus

Understanding the origin, heating and acceleration of the solar wind is one of the main goals of Solar Orbiter and Solar Probe Plus. This investigation proposes the development of a novel set of tools that allow users to connect remote-sensing and in-situ data from Solar Orbiter and Solar Probe Plus, to identify individual structures as the wind source regions, and to study solar wind acceleration and heating and their response to the variability of the source regions. This tool set will be tested on existing data from ACE, Ulysses, SoHO, Hinode and AIA; these existing data will also be used to develop empirical models that can relate to and interpret the variability of the wind source regions and its effect on wind properties. The tool set, the empirical models, and the enhancement of our understanding of the solar wind provided by this investigation will provide a framework for the analysis of data from Solar Orbiter and Solar Probe Plus.

David Lario/Johns Hopkins University / Applied Physics Laboratory
The Role of Solar Activity in the Longitudinal Broadening of SEP Events

Current Understanding: The fleet of spacecraft distributed through the inner heliosphere (R<~1 AU) offers us the unique opportunity to study solar energetic particle (SEP) events from multiple vantage points. Particles from individual SEP events have been observed to extend over broad ranges of longitude, in some cases nearing a 360° span. Hypotheses that invoke particle injection from inherently broad particle sources, multiple particle injections from distant eruptive sources, and/or spatial dispersion driven by transport processes in interplanetary space have been proposed to explain the wide spread of SEP events. We will study the role that solar activity plays in producing the longitudinal spread of SEP events.

Science Questions and Objectives: We propose a well-delimited and very focused research program aimed at testing the hypotheses proposed to explain the wide spread of SEP events. In particular, we will test those related to solar activity processes; namely: (a) CME-driven shocks accelerate and inject particles over a broad longitudinal range as the shocks expand through the inner heliosphere. (b) Sympathetic solar eruptions that occur in temporal association with, but separated from, the main solar event accelerate and inject particles over a range of longitudes that are well separated from the active region identified as the event origin. (c) Magnetic field configurations close to the Sun allow active regions to connect to a broad range of longitudes in such a way that particles injected from a compact source spread to fill a broad volume of the inner heliosphere. The study of these three hypotheses will allow us to answer the following questions: (1) Is the extension of the coronal EUV waves an indication of the longitudinal spreading of the SEP events? (2) Do sympathetic eruptions play a role in SEP injection at different longitudes? (3) Is the magnetic connection between CME-driven shocks and each spacecraft the dominant factor controlling the arrival of particles at each observer?

Methodology: The proposed methodology is very focused and feasible. We will select SEP events observed by one, two or more spacecraft well separated in longitude. We will combine multi-point remote sensing observations from SDO, SOHO and STEREO A/B with multi-point in-situ solar wind, magnetic field and energetic particle data from ACE, MESSENGER, SOHO, GOES and STEREO A/B to (1) identify the environment where SEP events develop, (2) resolve the solar activity associated with the origin of the SEP events, (3) determine the evolution and extent of EUV waves and CME-driven shocks that track the sources of SEPs, (4) estimate the magnetic connection between each spacecraft and the particle sources by using coronal magnetic field models, and (5) evaluate the release time of the first arriving SEPs at each spacecraft.

Relevance and Contributions to the Focus Team Effort: The proposed study is very timely because of the current configuration of spacecraft and very relevant to the Focus Team Effort (FTE). Our work will determine the solar processes responsible for the observation of SEPs at different points in the heliosphere. Collaborative efforts with other members of the FTE dealing with SEP acceleration and transport processes will allow us to constrain the mechanisms responsible for the longitudinal spread of SEP events. Our experience in both multi-spacecraft analysis of SEP events and solar transient events is a crucial asset for the success of the FTE. We will identify the relative roles played by solar transient phenomena on the formation and development of SEP events as a function of longitude and thus establish the physical association between the first particles arriving at observers well separated in longitude and the longitudinal extent of CMEs in the corona. This work targets several Heliophysics and space weather strategic goals as to how and where solar eruptions accelerate particles that reach Earth.

Noe Lugaz/University of New Hampshire
Evolution of the Magnetic Field in Solar Transients Between the Upper Corona and 1 AU

We propose to investigate the evolution of the interplanetary magnetic field (IMF) in solar transients between the upper corona and 1 AU by a combination of numerical simulations and the analysis of remote-sensing observations and in situ measurements. Coronal mass ejections (CMEs) are the major source of long-duration steady southward Bz, which are the main cause of geomagnetic storms. With recent developments using solar as well as coronagraphic observations, it may be possible to determine the orientation of the magnetic field inside a CME in the corona. However, recent studies have shown that some CMEs rotate as they propagate, modifying the direction of their magnetic field. In fact, a recognized issue in the field of heliophysics is that in situ modeling is often at variance with remote-sensing observations of transients, especially for the CME size and orientation. Other studies have revealed how CME-CME interaction can result in reconnection of the poloidal field of a CME. Last, other sources of steady magnetic fields, such as small transients (STs) have been investigated, but their exact importance to understand and predict the IMF at 1 AU has not yet been determined.

Our objective is to understand how the orientation and magnitude of the magnetic field inside CMEs and STs vary during their heliospheric propagation. To do so, we will address the following science questions:
1- What are the causes of CME heliospheric rotation? How frequent is it and at what distance does it typically stop?
2- How much does the magnetic field inside CMEs and STs decrease during their propagation due to the expansion of the transients?
3- How does the interaction of a CME with other CMEs or with CIRs affect its internal magnetic field?
4- What are other sources of steady periods of southward Bz and can they be predicted from coronagraphic and heliospheric imaging?

To answer these questions, we will conduct self-consistent 3-D MHD simulations in idealized settings as well as simulations of selected real events. We will also analyze in situ measurements of CME-CME interaction and STs for solar cycles 23 and 24, as well as measurements when two or more spacecraft were in conjunction with different analysis techniques. Last, we will analyze remote-sensing observations of solar transients by SECCHI coronagraphs and heliospheric imagers and by LASCO.

This proposal aims at addressing part of the call of Prediction of the Interplanetary Magnetic Field Vector Bz at 1 AU of LWS. Our investigation will focus on "observational and modeling investigations relating to identification of characteristics in the inner heliosphere that affect the magnetic field topology" and "investigations of CMEs to include the embedded magnetic field vector". We propose to contribute to the team efforts in a number of different ways: (i) we will provide our simulations results for possible ``blind" analysis to the rest of the team and (ii) we will provide the link between solar and coronal investigations and in situ measurements by performing numerical simulations of particular events of interest and by studying the causes of the discrepancies between analyses based on in situ measurements and those based on remote-sensing observations.

Pertti Makela/Catholic University of America
A Comparative Study of the Timing and the Radial and Lateral Extent of CME-Driven Shocks Associated with Metric Type II Radio Bursts Relative to the Onset Time and Other Properties of SEP Events in Interplanetary Space

We propose to investigate spatial and temporal correlation of metric type II producing coronal shocks with the solar energetic particle (SEP) events in interplanetary (IP) space with a goal to understand longitudinal particle propagation. We will answer to the following scientific questions: Is the wide longitudinal extent of SEP events due to the propagation of a shock ahead of a coronal mass ejection (CME) or due to some other transverse particle transport mechanisms? How do the timing, spectral index, onset-to-peak time and the peak magnitude of the particle flux depend on spacecraft s connection to the CME-driven shock front? This knowledge is crucial for improving the space weather forecast. In addition, our results will provide necessary constrains for numerical simulations and theoretical modeling of particle propagation.

The proposed work directly addresses the LWS/FST objective "Physics-based methods to predict connectivity of SEP sources to points in the inner heliosphere, tested by location, timing, and longitudinal separation of SEPs", with an aim to advance our "basic understanding of the longitudinal extent of SEP events using observations." Our study will contribute to the FST science objectives by providing detailed measurements of the CME and shock propagation in the low solar corona, especially the shock formation time, the delay between type II onset and solar particle release, along with onset-to-peak time, energy spectrum of SEPs, and classification of SEPs based on correlations of shock location relative to the SEP observing spacecraft, the solar particle release time and the delay of the SEP onset relative to the metric type II onset, the SEP path length, the spectral index, and the maximum particle energy. We will create a website so the science community can have easy access to our results. We will present all the obtained results in national scientific meetings and publish them in peer-reviewed scientific journals.

It is essential to combine the radio, EUV and white-light observations together with SEP observations from multiple spacecraft in order to understand the temporal and spatial evolution of the SEP events in their entirety. We will primarily utilize the imaging and particle data from STEREO and SDO, as well as from SOHO, ACE, GOES and Wind missions; and radio observations at the metric wavelengths from multiple radio observatories located around the globe. The radial and lateral extent of CMEs are studied by forward fitting a spherical model on near-simultaneous EUV and white-light images of the CME. The forward modeling is done by using the IDL code RTCLOUDWIDGET.PRO, which is able to reproduce the image of the 3-D model as seen by the imaging instruments from their respective viewing angles. We determine the solar release time and the path length of the first arriving particles by the velocity dispersion method.

The PI has extensive experience in analyzing the particle, radio and white-light observations of SEP events and CMEs. His scientific background also includes calibration and data analysis of SOHO/ERNE measurements. The CoI has background in instrumentation and analysis of cosmic rays and studies of solar energetic particles. Thus our team has expertise in aspects required for successful completion of the proposed work. Our study will utilize archival data and thus will enhance science return of present science missions. The requested funding provides support for an early-career female researcher.

William Matthaeus/University of Delaware

Trapping, Transport and Dynamic Behavior of Magnetic Connectivity and Energetic Particles in the Inner Heliosphere: Implications for Solar Probe, Solar Orbiter and Heliospheric Prediction

Several challenging problems of great current interest in heliospheric physics and LWS science relate to magnetic field line connectivity and solar energetic particle (SEP) transport. Rapid transport of SEPs in latitude (e.g., seen by Ulysses) and in longitude (seen by STEREO) challenge both theory and prediction. A second (and we argue, related) problem is the broadening of boundaries between fast and slow solar wind due to stochastic interchange of connectivity, allowing energetic particles and plasma of different composition to transport and mix across boundaries. Both cases will be better understood by improved quantitative description of interconnection and exchange of magnetic flux between nearby topological families (flux tubes) due to topological effects in field line transport in space (Seripienlert et al., ApJ 711, 980, 2010), and exchange of field line connectivity in time (Rappazzo et al., ApJ 758, L14, 2012). These processes can have significant consequences considering the complex magnetic environment inferred from observations.

We propose several tasks to further develop these ideas, with the goal of incorporating these anomalous transport effects with focused SEP transport models. We aim to thereby explain existing puzzles in longitudinal transport, and to provide better quantitative description of dropouts. We will determine the variability of the measured SEP flux depending on the observer s location with respect to the turbulence topology (e.g., Ruffolo et al., ApJ 779, 74, 2013). It is intended that improvements in prediction of SEP fluxes will emerge as both intermediate and final products.

Mona Mays/NASA / Goddard Space Flight Center

Observer Global Shock Connectivities Inferred from ENLIL Runs and SEP Measurements

SCIENCE GOALS: Coronal Mass Ejections (CMEs) that drive coronal and interplanetary shocks are known to produce the larger, gradual SEP events. However, understanding these types of events well enough to forecast their properties at a given location requires a realistic picture of the global background solar wind through which the shocks and SEPs propagate. The goal of the proposed work is to use the combination of ENLIL heliospheric modeling and multipoint SEP observations to address the following science questions: (1) What is the importance of observer-shock magnetic connectivity in determining the occurrence of a SEP event, including the time profile and longitudinal extent? (2) Which SEP event characteristics are primarily a consequence of their shock connection and heliospheric field geometries? Are multiple shock connections and/or heliospheric reflections common occurrence? (3) How are SEP anisotropies, including bi-directionality, related to the observer-shock connection(s)? (4) How important is the magnetic cloud in altering a SEP event profile? METHODOLOGY: This study will investigate the above questions and others using a large set of ENLIL models and SEP observations. We will apply a proposed multiple shock detection routine for ENLIL output processing in order to tackle periods with multiple CMEs, a quite common occurrence during active periods. The topology of observer-connected magnetic field lines and plasma and shock properties along the field lines that will be compared against SEP profiles and anisotropies at various observer locations. Starting with the CME parameters and lessons learned from the existing database of short-duration (~6 days) CCMC WSA-ENLIL+Cone runs, we will extend these runs by performing new, long-duration (~month), higher cadence output model runs at CCMC, which also use a larger outer boundary radius (5.5 AU) and employ the proposed necessary multiple shock detection routines. These new simulations will provide a variety of realistic interplanetary field realizations for which the shock geometries relative to any inner heliosphere observer can be examined. The in-situ monitors at STEREO, MESSENGER, near-Earth (ACE, SOHO, GOES), and MAVEN measure SEPs whose behavior will be related to observer shock connections and the global heliospheric setting at the time. Data from these combined multipoint spacecraft observations is essential for studying the longitudinal extension of SEP events. To understand the complexities of these events it is crucial to have an understanding of the heliospheric setting. For example, comparing SEP observations with ENLIL modeling will address the question of how the longitudinal extent is related to single and merged, or multiple shocks in the model. RELEVANCE: This proposal is relevant to NASA's LWS Science goals and specifically addresses Focused Science Topic #2 ("Physics-based methods to predict connectivity of SEP sources to points in the inner heliosphere, tested by location, timing, and longitudinal separation of SEPs") of LWS Targeted Investigations. This individual proposal will provide a global context of magnetic topologies and shock properties from state of the art (ENLIL) heliospheric models, along with necessary SEP profile analysis, including anisotropies and the role of magnetic clouds, in support of potential focused science team collaborations. Our applications of ENLIL runs will also provide additional SEP-related ``model data" products that will be of useful to others in the larger community for SEP event modeling and forecasting tools. This proposed research is of fundamental importance to the focused science team goal of producing "model(s) that predict the longitudinal spread of SEPs, with statistical quantification of the uncertainty."

Zoran Mikic/Predictive Science, Incorporated
Advanced MHD Models and Analysis for Solar Probe Plus and Solar Orbiter

We propose to develop a sophisticated modeling capability to capitalize on the unique measurements expected from Solar Probe Plus (SPP) and Solar Orbiter (SolO). The model will help to integrate these measurements with those from other spacecraft, including STEREO and SDO, and Earth-based observations, into a coherent picture of the inner heliosphere. We will refine an existing 3D MHD model of the corona and solar wind, together with a focused set of tools, so they can be used to interpret observations and to plan observing campaigns for SPP and SolO. We will improve our Wave-Turbulence-Driven (WTD) model to accurately capture the physics of the solar wind. An accurate model will provide a global context to connect in situ and imaging observations, and will allow researchers to investigate the relationship between different observed quantities, and their consistency with solar wind models.

The proposed model will predict the large-scale environment in the vicinity of the spacecraft, to better tailor observing sequences and to optimize instrument pointing for remote sensing. The model will identify expected crossings from slow wind to fast wind (and vice versa), as well as regions with intermediate-speed highly variable solar wind streams. Our model will connect remote images of streamers, pseudostreamers, and coronal holes with in situ solar wind measurements. We propose to develop sophisticated tools based on coronal magnetic field topology to identify particularly interesting regions and to map these out into the solar wind to check their possible intersections with the orbit of SPP or SolO. We also plan to provide a robust 1D model along open magnetic field lines to rapidly scope out the consistency between measured fields and solar wind models.

Our model will be developed to run continuously by specifying time-dependent boundary conditions from measurements of photospheric magnetic fields, to produce an evolving prediction of the solar wind. The parameters in the model will be calibrated by matching with solar observations. The model will be developed to a level of readiness suitable for use during the SPP and SolO missions, and will be shared with the community and SPP and SolO science investigators via NASA's Community Coordinated Modeling Center.

Olga Panasenco/Advanced Heliophysics
Solar Wind from Pseudostreamers and their Immediate Environment:
Observations and Modeling

Beyond the very large-scale relationship of fast solar wind streams to coronal holes, the connection between coronal structures and their solar wind counterparts remains largely mysterious. The traditional view states that slow solar wind arises from the boundaries of coronal holes due to the larger expansion factor. It is hard in this explanation to understand why the slow wind occupies so much space in the heliosphere. Pseudostreamers are multipolar features which develop into fields that are unipolar at greater heights. There is debate as to the speed and nature of the wind from pseudostreamers: it could be fast, slow, or in between. And, in general, they might form a network of slow wind which may or may not connect in the heliosphere to slow wind coming from around the heliospheric current sheet.

Different types of pseudostreamers exist, with a complex inner structure which depends on the number of polarities embedded in the closed regions below. In addition pseudostreamers may also harbor filament channels, often occurring in pairs (twin filament channels). In the latter case, the strongly sheared field of the channel magnetic structures and the skew of the coronal arcade above the channels dictate the way the coronal field expands in the neighborhood of pseudostreamers. We will calculate the expansion factor along the PFSS extrapolated magnetic field lines to investigate relationship between pseudostreamers and wind speed, study how the resulting wind type depends on the global coronal environment, including the height of the pseudostreamer null point, the presence or absence of filament channels, and therefore the expansion of the coronal magnetic field in the neighborhood of the pseudostreamer spine. We will follow formation and evolution of the low-latitude coronal hole from decaying active regions in which pseudostreamers are embedded, study coronal cells and filaments topology at the pseudostreamer bases to determine the direction of the tangential fields and currents in the pseudostreamer bases. We will study the composition and fluctuation of the solar wind from pseudostreamers during the whole period of their evolution from formation to dissipation.

We will also carry out numerical models of the solar wind along field lines chosen from potential field source-surface calculations extrapolated from HMI and MDI magnetograms to better understand the sources of slow and fast solar wind for the Solar Probe Plus mission. The magnetic field extrapolated potentially to 2.5 Solar radii will be used as a skeleton along which both stationary and time-dependent 1D solar wind models will be calculated to understand the solar wind structure in the inner heliosphere. The transverse pressure structure will then be iteratively adjusted (inside 2.5 solar radii) to develop a semi-empirical three dimensional model of the corona and inner solar wind.

Finally, we will also perform local simulations of field point motions in model pseudostreamers to see the type and speed of outflow generated locally by reconnection at the pseudostreamer fan/spine surface. Reconnection at the location occurs due to the accumulation of magnetic stresses from field line stressing due to the random motions at the photosphere. This would release particles from the confined plasma below the pseudostreamer into the solar wind via jets of plasma adding to the solar wind naturally flowing along the open field regions adjacent to the spine.

Jean Perez/University of New Hampshire
Connecting Theory and Simulations of Turbulence in the Inner Heliosphere with Single-Point Measurements by Solar Probe Plus and Solar Orbiter

The primary objective of this project is to develop new methods and tools to better understand the relation between single-point space-craft measurements and the three-dimensional physical properties of the solar wind in the inner heliosphere, which is critical for understanding and interpreting measurements from the upcoming Solar Probe Plus (SPP) and Solar Orbiter (SO) missions. The need for new methods derive in part because in this region, many of the assumptions that are usually made at higher heliocentric distances breakdown, thus requiring novel data-analysis methods in order to obtain meaningful quantitative predictions that can be compared to theoretical and numerical models of the solar wind, as well as other processes that impact life and society here on Earth. In order to achieve the goals of this project, we will produce synthetic data simulating measurements from instruments on board these missions by flying virtual probes in simulations of Alfvenic turbulence. The probe's trajectories will be chosen to simulate planned orbits of the Solar Probe Plus and Solar Orbit missions. We aim to develop new analytical methods to establish meaningful connections between the synthetic measurements and three-dimensional properties of the solar wind. The methods will be validated using the full three-dimensional structure of the underlying fields that are completely known and controlled in the simulations. The simulations will be performed inside a narrow magnetic flux tube that models a coronal hole extending from the solar surface into the solar corona to about 60 solar radii (0.3 AU), using a fully developed spectral element code called IRMHD (Inhomogeneous Reduced Magnetohydrodynamics). The IRMHD code is thus far the only code capable of simulating broad-spectrum non-compressive turbulence while resolving the inhomogeneity of the background profiles, including the outflow velocity, without approximating the nonlinear terms in the governing equations. The outcomes of this project are timely, given that they will be available when SPP and SO become operational, enabling future comparisons with SPP measurements that will contribute significantly to the science return of this pioneering mission.

Pete Riley/Predictive Science, Incorporated
Robust Prediction of the Interplanetary Magnetic Field Using Statistical and Physics-Based Model Approaches

Using a combination of statistical and physics-based models, we will develop a robust scheme for predicting the value of Bz at 1 AU (as well as its associated uncertainties) at least 24 hours in advance. Our diverse team includes the necessary expertise to achieve the goals of the proposed work and our unique, comprehensive approach will provide both a quantitative ground-truth for a variety of techniques as well as a rigorous methodology for improving predictability.

Chadi Salem/University of California, Berkeley
Revisiting In-Situ Helios Data for a Multi-Instrument Investigation of Inner-Heliospheric Plasma Thermalization Processes

We propose to revisit the in-situ Helios data for a multi-instrument investigation of inner-heliospheric plasma heating and thermalization processes.

From 1974 to about 1985, the Helios 1 and 2 spacecraft explored the inner heliosphere between 0.3 and 1 AU and have thereby provided a unique set of in-situ measurements that remains of paramount scientific value. There is however no comprehensive public repository of Helios in-situ data. Currently, most of the highest resolution data can be obtained from a variety of places, although with very little documentation, especially on calibration. Analysis of this data set requires overcoming a number of technical and instrumental issues, knowledge and expertise of which is only possessed by the original PIs of Helios experiments. Therefore there is a sense of urgency to revisiting and reanalyzing this valuable, unique dataset now, before this detailed knowledge is lost, in order to assure its long-term preservation and availability to the community. First, we plan to gather, reprocess and reanalyze all fluxgate and search coil magnetic field measurements, plasma wave data, and ion and electron data (distribution functions and associated moments) from Helios 1 and 2 with the goal of creating a single archive of Helios in-situ data along with documentation and software tools for data analysis, which we will make publicly available.

On its own, this archive will be an asset to the community. However, we will also jointly analyze magnetic fields, plasma wave and particle data to investigate heating and thermalization processes of inner-heliospheric solar wind ions and electrons and their radial evolution as the solar wind expands. Of particular interest is the relative roles of Coulomb collisions, waves and instabilities in influencing the micro-kinetic evolution of the plasma and regulating non-thermal features in solar wind ions and electrons.

We will make systematic fits of the proton and alpha particle distribution functions and determine accurate densities, velocities, temperatures, anisotropies and drifts associated with the core and the beam populations. Similarly, the electron distribution functions will be analyzed to characterize core, halo and strahl populations and determine their respective anisotropies and heat fluxes. The magnetic-field and plasma-wave data will be used to quantitatively characterize the measured electromagnetic wave power and thus relate the ion and electron non-thermal features to the coupled electromagnetic fluctuations. This will allow us to directly search for signatures of instabilities and assess their contribution to the total wave power at kinetic scales.

The proposed work will be a tremendous asset to the the entire heliophysics community but especially to the instrument and science teams of the Solar Probe Plus and Solar Orbiter missions.

Daniel Savin/Columbia University

Analysis of Plumes to Predict Their Signatures in the Inner Heliosphere and Solar Wind: Laying the Groundwork for Solar Orbiter and Solar Probe Plus

A major unsolved problem in solar physics is determining the source regions of the solar wind. We propose to develop new composition diagnostics for in situ solar wind measurements that will enable Solar Orbiter, Solar Probe Plus, and other missions to identify the sources of the fast wind. This work addresses the science element ``Physics of the Inner Heliosphere'' in the Living With a Star program.

The fast solar wind originates in coronal holes. Within coronal holes two major structures are observed: plumes and interplume regions. Whether plumes or interplumes are the source of the fast solar wind is the subject of much debate. Some have argued that plumes are a major contributor to the solar wind, while others question whether plumes are present in the solar wind at all.

In order to resolve this issue, it is necessary to determine the coronal sources of the observed in situ solar wind. Such measurements, mainly by Ulysses, have found structures in fast solar wind streams, notably the microstreams and pressure balanced structures. These might be the remnants of plumes, but their connection remains ambiguous.

One challenge for relating these observations to coronal hole structure is that existing observations were made far from the Sun, where mixing of plume and interplume properties might have occured. Solar Orbiter and Solar Probe Plus are designed to address this problem by going much closer to the Sun.

The other major challenge has been that observations focussed on plasma properties, such as pressure and magnetic field, which are not uniquely related to solar structures. That is, the structures observed in situ could have formed in interplanetary space rather than originating at the Sun. To unambiguously connect observed solar wind material to plumes and interplumes, it is necessary to identify signatures that persist from the corona into the heliosphere.

The objective of our proposed work is to provide definitive composition diagnostics that will identify the coronal sources of the fast solar wind. The solar wind composition is fixed at low heights in the corona and thereby provides a clear link between the solar wind and the source region.

Ion abundances are one such diagnostic. The charge state distribution becomes frozen-in as the plasma flows away from the Sun. Thus, the charge balance reflects the temperature and density structure of the corona. Because plumes and interplumes have substantial differences in temperature, density, and outflow velocity, it is expected that their frozen-in charge states will also differ in solar wind.

We will calculate the time-dependent ionization balance and predict frozen-in ion abundances based on various plume and interplume models and observations. In preparation for analyzing Solar Orbiter and Solar Probe Plus data, we will apply our results to published in situ data from Ulysses and other missions.

Elemental abundances are also fixed at the Sun. In interplume material, the abundances are similar to the photosphere. But in plumes there are indications of a first ionization potential (FIP) effect, in which elements with a low FIP have elemental abundances that are enhanced relative to their photospheric values.

We will infer elemental abundances in plumes and interplumes using largely archival spectroscopic observations. It is likely that the elemental abundances of plumes vary as a function of the age of the plume. We will determine whether there is a time-dependent FIP effect in plumes. Our inferred elemental abundances will be compared with to existing published in situ measurements.

The outcome of this work will be a set of derived ion abundances and measured elemental abundances, which will be available to analyze in situ measurements from Solar Orbiter and Solar Probe Plus, as well as other in situ data. These data will enable determining whether structures seen in the fast wind are due to plumes or not.

Tycho von Rosenvinge/NASA / Goddard Space Flight Center
Multi-Spacecraft Observations and Modeling of Solar Energetic Particle Events

The objectives of this proposal are: (1) To quantify, from multi-spacecraft observations, how solar energetic particles (SEPs) of different types (electrons, protons, heavy ions) spread in longitude following a solar event. Observations from the twin STEREO spacecraft and spacecraft near the Earth will be a foundation of this study, in particular our recently compiled catalog of over 200 SEP events that include 25 MeV protons since the beginning of the STEREO mission (Richardson et al., 2014). Some 40 of these events were detected by both STEREO spacecraft and at the Earth. We have also summarized the longitude-dependence of the electron and proton intensities and delays to onset and peak intensity based on these three-spacecraft events. Both the catalog and these results will provide a starting point for our proposed studies and for co-operative work with other FST members. We also have a database of several hundred similar SEP events since 1967 which will allow us, for example, to infer whether particle transport is unusual in the current solar cycle; (2) We will formulate and construct sophisticated SEP transport models and use them to study the various possible scenarios of populating the inner heliosphere with SEPs over a wide range of longitudes. The simulations will be compared with or constrained by the SEP, solar wind, IMF, solar EUV and CME observations to test their validity. The models will also be used to investigate the radial variation of interplanetary perpendicular transport and to perform careful velocity dispersion analysis to deduce the first particle release time; (3) A newly-developed CME detection algorithm, the "Time Convolution Mapping Method" (TCMM; Thompson & Young, 2014) will be used to provide improved estimates of parameters and trajectories of CMEs associated with SEPs that will help to assess how these influence the spread of SEPs. There is a clear need for more reliable estimates of CME parameters which are crucial for understanding the relationship between CME properties and SEPs. The TCMM algorithm also allows the identification of CME-associated brightenings such as shocks and compression fronts, which are potential acceleration sites. Additionally, we will assess how inner coronal signatures of CMEs (such as EUV waves and dimmings) relate to 3-dimensional transient structures in the corona, with the goal of providing insight into how far SEPs will spread in the heliosphere and improving our ability to predict SEP intensities near 1 AU.

Hong Xie/Catholic University of America
Understanding the Longitudinal Extent and Timing of the SEP Onset

This investigation will focus on large SEP events with energies above 25 MeV that have been observed by both STEREO and near-Earth spacecraft. Recently, Richardson et al. (2014) compiled a catalog of 209 individual greater than 25 MeV solar proton events in cycle 24 and found that there were 25 events observed at all three spacecraft [STEREO and a near-Earth platform] from December 2009 December 2013 when the STEREO spacecraft were separated by greater than ~60 degrees in heliolongitude from Earth. We will combine remote-sensing multi-point observations with forward-modeling using an oblate spheroid shock model to (1) study the longitudinal extent and angular width of the expanding CME-shock and EUV wave for the 25 three-spacecraft SEP events; (2) study the acceleration profiles of the CME-shock and EUV wave in its early evolution, including both radial expansion and lateral expansion; 3) develop the relations between the shock front speed and the shock leading edge speed and the expansion speeds at semi-major and semi-minor axes. By using a full 3D forward-modeling, we can accurately determine the true speed, heliographic distance, angular width, and the location where the magnetic connectivity occurs. Based on the above results, we will study the correlation between the proton peak intensities, the shock speeds and angular widths and derive a formula predicting the SEP intensity. The main objective of this proposal is to investigate whether the wide spread SEP events are in fact a result of the expanding shock and to gain sufficient scientific understanding that will lead to a predictive capability. This proposal is highly relevant to the scientific objectives of the Focused Topic: 3.1.2 Physics-based methods to predict connectivity of SEP sources to points in the inner heliosphere, tested by location, timing, and longitudinal separation of SEPs since the proposed work will focus on models & observations that provide a better understanding of the initial phases of CMEs and how that couples into longitudinal extent and timing for the SEPs. We will contribute data analysis expertise, as well as modeling capabilities that are directly relevant to team objectives. By the end of Year Four we will also provide a three-spacecraft event list with accurate heliographic distances, space speeds, and angular widths of the CME-shock at SEP onset times at each spacecraft. The extensive list developed as part of the proposed investigation will be made available to the modeling efforts and theoretical studies through the CDAW website.

Yongliang Zhang/Johns Hopkins University Applied Physics Laboratory
The Topside Ionosphere and Thermosphere: Dynamics and Coupling During Geomagnetic Storms

(a) Key objectives and their scientific importance

The key objectives of the proposed work are to determine the characteristics of the storm-time topside ionospheric and thermospheric variations, identify the key drivers for these variations and determine their relative contributions so physics based predictive capability of the storm-time TEC can be improved. The topside ionosphere is very dynamic, especially during storm times. However, detailed quantitative (within data and model error limits) understanding of its storm-time behavior remains inadequate, especially regarding changing roles of the competing drivers. The proposed work is to address following scientific questions that are critical to understanding the storm-time topside ionosphere over mid, low and equatorial latitudes.

(1) What are the characteristics of the topside ionosphere and the thermosphere responses to geomagnetic storms under different solar-geophysical conditions?

(2) How do F2-peak region conditions and topside mass flows affect the storm-time topside ionosphere?

(3) What are the impacts of neutral composition and temperature on the storm-time topside ionosphere?
(4) How do storm-time neutral winds and electric fields shape the topside ionosphere?
(5) What are the relative contributions of those drivers listed in (2)-(4) to the topside ionosphere and TEC variations?

(b) Methodology
We will analyze comprehensive global data sets from satellite and ground based measurements over one solar cycle (2002-2013) using a ionospheric assimilation/reanalysis method and will carry out physics based diagnostic simulations using the TIME-GCM (Thermosphere Ionosphere Mesosphere Electrodynamics General Circulation Model) to address these questions. These data sets include (partial list): (a) topside ionosphere density, ion composition, temperature, electric field, plasma drift and topside TEC from satellites (e.g. COSMIC, DMSP, C/NOFS, CHAMP, GRACE, JASON, SACC, Metop-A/B, Demeter, TerraSAR-X/TanDEM), ground based incoherent scatter radars, and ground GNSS receivers and ionosondes; (b) thermosphere neutral density, temperature, composition and wind from TIMED, DMSP, GRACE, CHAMP and ground based FPIs; (c) solar and geomagnetic conditions from TIMED, SDO, WIND, ACE and World Data Center repositories. We will select representative storms (up to 20) and run our existing ionospheric assimilation/reanalysis method to reconstruct global ionospheric density profiles for the selected storms and the quiet times before and after the storms. The physics based TIME-GCM will be updated (extending topside boundary altitude and using topside flux derived from data as topside boundary) and run for the storms. The above five science questions will be addressed through the global data analysis/reanalysis and model runs.

(c) Significance and Relevance to NASA Objectives
The expected results from the proposed work will advance our understanding of the dynamics of the topside ionosphere and thermosphere and their coupling. The proposed work is directly relevant to the 2014 NASA LWS Targeted Research and Technology focused science topic 3.1.3 Ion-neutral interactions in the topside ionosphere . The proposed work also supports the NASA Heliophysics Division Objectives of Understanding the connected Sun-Earth system and Understanding of the Sun and planetary space environments and potentially supports the NASA s new GOLD and ICON missions.

Ming Zhang/Florida Institute of Technology
An Investigation of Solar Energetic Particles from Poorly Connected Solar Events by Propagation Through 3-Dimensional Interplanetary and Coronal Magnetic Fields

We investigate SEP propagation in realistic 3d interplanetary and coronal magnetic fields. It is the first line of investigation for the determination of a connection between an observed SEP event to the timing and location of a source near the Sun. With this investigation, we can separate out the propagation effects from other aspects of the SEPs, such as particle acceleration process, magnetic structures of CME shock and solar flare. Our objectives are exactly the same as what the focus science team needs to achieve: (1) understand the longitudinal spread and timing of SEP enhancements, (2) understand the physics of particle transport in realistic coronal and interplanetary plasma and magnetic field structures, and (3) predict SEP hazards at any point in the inner heliosphere. We solve the 3d focused transport equation for particle propagation and acceleration that essentially includes all physical mechanisms of particle transport. To simulate any SEP event, we start with inputs of magnetic field and plasma configurations, properties of solar events, models of particle transport coefficients and possible calculations of SEP source distribution near the sun. Our product is a prediction of the time profile of SEP flux at any selected energies, pitch angles and locations. The results will be supplies to other team members for comparison with multi-spacecraft observations to determine their connection to SEP sources and to study the underlying physics producing the particles. In this way, we play a central role in the focused science team, because we bring to the team a proven capability of predicting particle intensity with 3d propagation effects included in all SEP data. We will continue our study using our successfully developed model of SEP propagation in the 3d interplanetary magnetic field with newer geometries or scenarios of SEP sources. We will also develop a new model of SEP propagation through the 3d coronal magnetic field from the low corona source sites to the solar wind source surface where our interplanetary propagation model starts. Special attention will be paid to assess the role and the magnitude of perpendicular diffusion and drift in the transport of SEPs in events with a wide longitudinal distribution and the role of lateral expansion of coronal magnetic field in spreading the particles. The model, software tools and gained knowledge from this investigation will eventually become valuable assets for space weather forecasting.