Living With a Star Targeted Research and Technology
Abstracts of selected proposals.
(NNH08ZDA001N-LWSTRT)

Below are the abstracts of proposals selected for funding for the Living With a Star Targeted Research and Technology program. Principal Investigator (PI) name, institution, and proposal title are also included. 105 proposals were received in response to this opportunity, and 34 were selected for funding.

Spiro Antiochos/NASA Goddard Space Flight Center
Multiscale Theory and Modeling of Solar Reconnection

We propose a program of fundamental research that is explicitly designed to attack one of the Focused Science Topics identified by the Living With a Star, Targeted Research and Technology Program: "Integrate Non-MHD/Kinetic Effects on Magnetic Reconnection, Particle Energization, and Plasma heating into Global Models". The work builds on the long history and expertise of the proposing team in both kinetic and MHD theory and in modeling reconnection in a variety of space phenomena. We will perform three tightly coupled tasks: extend our physical understanding of kinetic reconnection so that we can develop useful, robust procedures for incorporating kinetic effects in global MHD codes, implement these procedures in the 3D MHD ARMS code, and apply the results to understanding major Heliophysics phenomena, in particular, the initiation of coronal mass ejections, energy release in solar flares, and the acceleration mechanism for coronal jets. All three phenomena are important drivers of space weather and, therefore, have strong relevance for the Living With a Star program.

The Principal Investigator directing this project is Dr. S. K. Antiochos of NASA/GSFC. He will be assisted by Drs. M. Hesse and M. Kuznetsova from GSFC, who are experts on kinetic theory/modeling, and by Drs. C. R. DeVore, J. T. Karpen, and P. J. MacNeice from GSFC and NRL, who are experts in MHD theory/modeling.

Amitava Bhattacharjee/University of New Hampshire
Multiscale Model of the Magnetosphere

Global MHD models of the Earth's magnetosphere have been very successful in simulating large-scale aspects of magnetospheric dynamics. However, a well known deficiency of global MHD models is their inability to model fast magnetic reconnection in the high-Lundquist-number limit. Recent advances in collisionless reconnection theory, governed by a generalized Ohm's law, demonstrate that the Hall current and electron pressure can realize regimes of fast reconnection. The principal objective of this proposal is to develop HallGGCM, an improved global multi-scale model of the Earth's magnetosphere, and to investigate multi-scale dynamics involving collisionless reconnection at the dayside magnetopause and substorm onset in the magnetotail. HallGGCM builds on the foundation of OpenGGCM, which is a global model of Earth's space environment, and is based on the resistive MHD equations. The principal changes are the replacement of the resistive MHD equations by the Hall MHD equations. This will require us to modify the underlying numerical discretization for OpenGGCM. Development of HallGGCM will take the mature framework of an existing global model of the Earth's magnetosphere (OpenGGCM) and take it to the next step where the model will have the ability to couple large-scale magnetospheric dynamics to a more sophisticated and physically realistic description of the smaller scales where non-MHD, collisionless effects play an extremely important role. Using HallGGCM, we will:

- investigate whether Hall-mediated reconnection in the high-Lundquist-number magnetosphere will enable a definitive resolution of the fast reconnection problem in the dayside magnetosphere, enabling the realization of fast reconnection rates that are insensitive to the resistivity of the plasma in the presence of fully 3D dynamics and flows, and
- investigate the role of the coupling of collisionless Hall-mediated reconnection and ballooning instabilities on the problem of substorm onset in the Earth's magnetotail when the high-Lundquist-number 3D magnetosphere is driven by the solar wind.

Dieter Bilitza/George Mason University

A Quantitative Description of Ionospheric Variability for the International Reference Ionosphere: on Average and In Real-Time

We will develop fundamentally important new capabilities for the International Reference Ionosphere (IRI). IRI is a widely used empirical standard for ionospheric environmental parameters. Specifically IRI provides monthly averages of electron density, ion composition, electron temperature, ion temperature and ion drift. Our goal is to add to IRI a description of day-to-day variability both real-time and on average. For many operational applications, IRI users require not only the monthly averages but also the expected range of variation around the monthly mean. The IRI Working Group has given highest priority to the development of such a variability model for IRI. So far, however, most quantitative modeling has been based solely on ionosonde data producing station-specific models for the F-peak density. We will use a large volume of ground and space data including TIMED/GUVI data, ionosonde data, Alouette/ISIS topside sounder data, and insitu data from many older NASA satellites to develop global models for ionospheric variability, not only for F-peak density but for the entire topside and bottomside profile for density as well as temperature and ion composition. Our analysis will help to identify and quantify the contribution of various parameters affecting day-to-day variability including an assessment of solar versus geomagnetic versus 'meteorological' drivers. A real-time description and forecasting of ionospheric variability will be achieved through the use of more appropriate solar proxies than currently applied in IRI and through data assimilation of ionosonde and satellite data.
Our effort will support the LWS TR&T Focused science topic (e) 'Determine and quantify the response of atmospheric/ionospheric composition and temperature to solar XUV spectral variability and energetic particles'. Specifically, it will contribute to the 'development of models that use data assimilation to reproduce past conditions as a test, and then use them to forecast future conditions' that is solicited under this topic.

Aaron Birch/Colorado Research Associates, NWRA, Inc.
Tools for Local Helioseismology

We propose to develop and refine tools for the modeling and interpretation of local helioseismic measurements, in particular for time-distance, holography, and ring-diagram analysis. We will focus on tools for: (1) obtaining approximate solutions of forward problems, and (2) solving inverse problems. We will use numerical simulations of wave propagation and comparisons between different methods using MDI/SOHO and HMI/SDO data to validate these tools. The forward problem is to determine the helioseismic measurements that would be expected to result from known models of physical conditions in the solar interior (e.g., flows or local changes in sound speed). We propose to develop and deliver a code for efficient computation of forward problems in plane-parallel and spherical geometries, following Gizon & Birch (2002) and Birch and Gizon (2007). The inverse problem is to use helioseismic measurements to infer conditions in the solar interior. We will develop and deliver tools for: (1) optimally localized averaging (OLA) inversions of two-point travel times for studying small spatial scales, (2) joint inversions of multiple data types, and (3) inversions in spherical geometry. After validation, these codes will be delivered to the community by making them available in the HMI/SDO pipeline. In order to maximize the benefits of HMI/SDO to the LWS program it is crucial to advance our ability to interpret local helioseismic measurements. Some of the key problems of relevance to LWS which could be addressed using the tools proposed here are: (1) the detection of flows in the deep convection zone, this is centrally important to Focused Science Topic A: ``Measure the properties of the solar dynamo that affect solar irradiance and active region generation" and (2) the detection of subsurface flows or sound-speed variations which may be precursors to active region emergence or evolution.

Friedrich Busse/ University of California, Los Angeles
Using Dynamo Models and Data Assimilation Methods for Modeling and Forecasting Properties of Solar Cycles

Understanding the dynamo mechanism and predicting the cyclic solar activity are among the most important key problems of the LWS program. Recent advances in dynamo modeling and magnetographic and helioseismic observations have provided important insights into the basic mechanism of the solar cycle. However, the physics-based forecasting of the strength and timing of the solar cycles is still not possible because of numerous uncertainties in the parameter values of dynamo models, such as kinetic and magnetic helicities, magnetic field diffusion and the magnetic flux transport by meridional circulation. The observational data provide only weak constraints on the surface magnetic field and on the plasma dynamics of the solar interior where the dynamo operates. We propose to investigate a new approach for modeling and forecasting magnetic properties of the solar cycles by applying data assimilation methods to solar dynamo models. This approach will allow us to determine the importance of various model characteristics for estimating of the physical state of the solar dynamo and for forecasting the future cycle.

The data assimilation methods, such as the Ensemble Kalman Filter (EnKF), have been used successfully for weather and climate modeling forecasting. They provide the best conditional estimates of past, present, and even future states for a given set of measurements, and can do so even when the precise nature of the modeled system is unknown. Our research plan is based on the implementation of data assimilation methods, in particular, the EnKF method, using previously developed 2D and 3D dynamo codes, synoptic magnetic field data for the past three cycles and helioseismology data.

Curt de Koning/NOAA
Single- and Multi-View 3D Localization and Analysis of Coronal Mass Ejections

Single- and multi-view white light imaging of coronal mass ejections (CMEs) in the corona oers exciting possibilities for meeting research and space weather forecasting needs. Since the launch of the dual STEREO (Solar Terrestrial Relations Observatory) spacecraft, we have worked to develop and test the geometric localization technique [Pizzo and Biesecker, 2004], which utilizes a series of lines of sight from the two STEREO/COR2 coronagraphs to determine gross propagation characteristics of CMEs in three-dimensional space. This technique is now mature and can regularly be used for space weather forecasting, using highly-compressed, near-real-time beacon data, and for research purposes, using the standard science quality data. The method enables us to compute the location and velocity, including speed and direction, for any CME observed by STEREO. Therefore, we propose to regularly apply this technique to upcoming STEREO data in the lead-up to solar maximum, and especially at solar maximum. We will catalog our results and make them available to the Living With a Star community to facilitate their use in MHD and other numerical codes that track the progress of CMEs in the inner heliosphere. It is our belief that the future forecasting e cacy of such models requires accurate model boundary conditions, including the parameters of transient disturbances that are launched into the code.
In addition, we also propose to develop a near-real-time tool for use in our space weather forecast center that uses single-view polarimetric imaging from STEREO or SOHO to determine gross CME properties. The polarimetric imaging tool also has important scientific application in analyzing the internal structure of a CME.
The following goals of this proposal are applicable to space weather forecasting and have clear scienti c value:
Create a catalog of gross CME characteristics using geometric localization applied to the STEREO beacon data stream;
Use accurate statistical knowledge of gross CME properties obtained from geometric localization to explore associations among solar surface, coronal, and interplanetary structures and disturbances for Earth-directed geo-eective CMEs;
Develop polarimetric localization tool
{ Use simulations to identify optimal background subtraction for accurate polarization analysis;
{ Compare polarimetric localization results to geometric localization results and other 3D-reconstruction techniques;
Analyze CME internal structure using polarization analysis;
Document combined geometric and polarimetric localization tools and deliver programs

to the IDL SolarSoft library.
These projects, which have compelling space weather and scienti c impact, address LWS TR&T Focused Science Topic B. The proposal also addresses NASA Strategic Goal 3, Subgoal 3B, and Research Objective 3B.3.

Yuhong Fan/University Corporation of Atmospheric Research
Formation of Coronal Flux Ropes and Onset of Coronal Mass Ejections

We propose to carry out 3D MHD simulations of the formation and eruption of magnetic flux ropes in the solar corona as a result of the following photospheric flux transport processes: (1) magnetic flux emergence, (2) shear and twisting motions, and (3) turbulent diffusion. Both analytic and numerical modeling in recent years have shown that a magnetic flux rope containing helical field lines is a promising candidate for the precursor structure for coronal mass ejections, and the eruption can result from an ideal MHD process of loss of stable equilibrium. We will model the formation and evolution of coronal flux rope structures for a wide range of CME source regions, from compact active region filaments to long quiescent filaments in decaying active regions. Through these simulations we will examine the conditions for an ejective eruption of the flux rope and the possible existence of a threshold in terms of the magnetic helcity for the onset of eruption given a normal flux distribution at the lower boundary. We will study the relative importance of the flux rope's self-helicity and the mutual helicity between the flux rope and the surrounding potential field in causing eruptions and explore the possibility where the helicity of the ejected flux rope is of the opposite sign of that of the pre-existing flux rope. Finally we will model specific observed events by carrying out realistic simulations for which the lower boundary driving conditions are derived from the observed vector magnetic field evolution on the photosphere. The resulting evolution of the coronal magnetic field from the simulations will be compared with multi-wavelength coronal observations. Such comparisons will provide crucial insight into the nature of the 3D coronal magnetic field evolution associated with eruptive flares and coronal mass ejections.

Peter Foukal/Heliophysics, Inc.
Facular Studies to Understand Solar Dynamo and Irradiance Behavior.

Digitization of the archival plates at Mt Wilson and Kodaikanal Observatories now provides a continuous record of white light faculae since 1907. We propose to measure facular areas to investigate a relation reported between the (facula/ spot) area ratio at the onset of a solar cycle, and that cycle’s peak amplitude. This relation, if verified, suggests a predictively useful and dynamically interesting connection between the spatial structure of photospheric magnetic fields, and solar dynamo efficiency.

These recent digitizations also provide extended time series of Ca K plage areas. We have used these to reconstruct solar UV flux variation, pointing out that it correlates only weakly with 20th century global temperature, thus calling into question UV driving of global warming. Reconstruction of total solar irradiance (TSI) variation poses a tougher challenge, because the contributions of spots and faculae tend to cancel so they must be known accurately to provide confidence in the calculation of their small difference . We propose to apply the extended plage area record, together with broad band facular contrasts from the balloon - borne Solar Bolometric Imager, to improve TSI reconstruction back to 1907.

We also propose to extend this irradiance reconstruction yet further back in time using recent modeling of active region evolution, which indicates that plage area variations can be reconstructed usefully from spot and white light facular areas. To do this, we will develop a simplified kinematical model to improve irradiance reconstructions to the beginning of the Royal Greenwich Observatory records in 1874.

Finally, we propose to investigate whether the unusually low TSI values measured during the present sunspot minimum might be explained by declining numbers of polar faculae. If not, new TSI variation mechanisms not associated with photospheric magnetism might be required, with profound implications for Sun - climate driving.

Tim Fuller-Rowell/University of Colorado
Modeling the Consequences of Realistic Spatial Structure of Solar Energy Deposition into the Upper Atmosphere

Solar EUV/XUV is the dominant heat source for the thermosphere-ionosphere system except during the rare major storms events. In the interest of computational efficiency, solar heating in thermosphere-ionosphere general circulation models (GCM) is parameterized using a “heating efficiency”. At any given latitude, longitude, and height, the local absorption is calculated based on the incoming solar flux spectrum, the solar zenith angle, and the species absorption cross sections. The absorption is then scaled by a globally-averaged heating efficiency to provide the local solar heating rate. A similar scheme is used for ionization and dissociation rates for a given solar spectrum.

The photochemical models used to derive “heating efficiency” are themselves very sophisticated, and are able to capture the consequences of variation in the efficiency due to zenith angle, ion density structure, photoelectron transport, and neutral composition, which vary greatly with latitude and local time. The GCM coupled thermosphere-ionosphere model in turn are also sophisticated and capture the neutral dynamics, energy budget, plasma processes, and electrodynamics. By using a globally-averaged heating efficiency concept much of the real structure in the photochemical models of the thermosphere-ionosphere system is lost in the GCM numerical models.

The purpose of this proposal is to move beyond the use of heating efficiencies by combining a sophisticated photochemical model with a GCM. The combination will enable the processes that are already known to introduce latitude and local time structure in the heating rates to be treated consistently and appropriately, including the structure in:

> the equatorial ionization anomaly and it latitude and local time dependence,
> the photoelectron heating and its local time and conjugate effects,
> solar zenith angle dependence, and

seasonal/interhemispheric neutral composition.

This proposal addresses the NASA's Strategic Goal 3: Develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human space flight program to focus on exploration: In particular, Strategic Sub-goal 3B which is to understand the Sun and its effects on Earth and the solar system. The proposal will improve our understanding of the impact of solar EUV/XUV energetics on the thermosphere-ionosphere system. This proposal is aimed at LWS TR&T goal e) Determine and quantify the responses of atmospheric/ionospheric composition and temperature to solar XUV spectral variability and energetic particles.

Jay Johnson/Princeton University
Multiscale Gyrokinetics in the Magnetosphere

The importance of kinetic effects on low frequency, global oscillations in the magnetosphere is a grand challenge in space physics. Ion gyroradius, electron inertial, and electron pressure effects can lead to dispersion in global Alfven resonances, while electron trapping and ion Larmor radius effects can significantly affect the stability of the ballooning mode in the magnetotail and field-aligned electron acceleration in Alfven wave pulses and Alfvenic turbulence. We propose to develop a nonlinear gyrokinetic simulation model for low frequency waves and instabilities in the global magnetosphere. The model will be based on a cutting-edge electromagnetic gyrokinetic simulation code developed at Princeton Plasma Physics Laboratory for slab geometry. The model uses a split-weight scheme that accounts separately for the adiabatic and nonadiabatic response of particles in the fluctuating fields, which allows for proper treatment of electron and ion Landau damping over a wide range of plasma beta.

The model will be adapted to realistic global magnetospheric geometry in a systematic manner. First, we will adapt the slab model to magnetospheric parameters typical of the magnetopause where non-MHD effects are important for transport processes. Second, the model will be adapted from slab to cylindrical geometry to include the effects of particle mirroring in a flux tube and the transition from high to low beta along magnetic field lines. Third, the model will be adapted to dipole geometry, and finally, the model will be adapted to a three-dimensional flux coordinate system based on the three-dimensional MAG3D equilibrium developed at Princeton Plasma Physics Laboratory. The code will be systematically used to study the kinetic effects on low frequency, magnetospheric oscillations and ballooning instabilities. Once developed, the code would be useful to examine a wide range of slowly varying (less than the ion gyrofrequency) global magnetospheric phenomena that includes many kinetic effects such as Larmor radius effects, magnetic drifts, and wave-particle interactions.

The proposed project will benefit the goals and objectives of the LWS program. In particular it will address the focused science topic (d) to integrate non-MHD effects into global models because our objective is to adapt a gyrokinetic simulation code (that includes non-MHD effects) to global magnetospheric geometry. The proposal will also further NASA's Strategic Goals 3B: ``Understand the Sun and its effects on Earth and the solar system" in Table 1A of NASA Publication NNH08ZDA001N. In particular it will advance subgoal 3B to understand the sun and its effects on earth and solar system. The proposed work will further research objective 3B.1 to understand fundamental physical processes of the space environment from the Sun to Earth to other planets because the simulations will lead to better understanding of transport of mass, momentum, and energy which to a great extent controls the dynamics of the magnetosphere. It will also further research objective 3B.3 to develop the capability to predict extreme and dynamic conditions because field-line resonances and ballooning instabilities have been linked to auroral acceleration and substorms.

Heejeong Kim/ University of California, Los Angeles
Effect of Fluctuations in the Solar Wind on the Strength of Polar-cap Convection

Convection within the polar caps is fundamental to the transfer of solar wind energy to the magnetosphere-ionosphere system and thus to the LWS goal of obtaining a "physics-based understanding of the integral system linking the Sun to the Solar System both directly and via the heliosphere, planetary magnetospheres, and ionospheres." It has been well known for many years that the interplanetary magnetic field (IMF) is the dominant factor in controlling the strength of this convection, and more recently solar wind dynamic pressure has been found to play a very significant role as well. In addition, radar observations of convection within the dayside polar cap that we have recently examined occasionally show large oscillations with periods of ~15 minutes, the oscillation amplitude being larger than the background convection speed. Several of the examples indicate the possibility that the overall strength of polar-cap convection can be substantially enhanced during periods of large ULF pulsations over that which occurs without the pulsations, particularly for weakly southward and northward IMF. Furthermore, our preliminary analyses suggest that the large amplitude oscillations may occur primarily when there are enhanced pulsations in solar wind parameters, such as in the solar wind dynamic pressure and in the IMF By and Bz, and that these oscillations preferentially occur within high-speed solar wind streams and ICMEs. On the other hand, the direction and magnitude of IMF do not seem to matter in the occurrence and the enhancement of the convection oscillations. These preliminary results suggest that the ULF waves may, at times, be a substantial contributor to large-scale convection and suggest their possible association with solar wind and IMF conditions. We thus believe that it is potentially of fundamental importance to determine how often, and under what conditions, the contribution from ULF waves may be significant. This is the primary goal of the present proposal, and is necessary for determining when such oscillations are likely to be an important aspect of convection, and, ultimately, for determining the cause of the oscillations. We will then consider whether they can appreciably enhance the total cross-polar cap potential drop, whether they are important simultaneously in both hemispheres or is there a hemispherical/seasonal dependence, whether they also appear in the nightside polar cap with the same characteristics as on the dayside, and whether they can lead to the occurrence of substorms (including under northward IMF, as a recent set of observations suggest) and to repetitive poleward boundary intensifications (PBIs). It will be particularly interesting if we find that the pulsations can be associated with enough energy transfer to the magnetosphere to lead to the growth and expansion phase of substorms under conditions when such energy transfer would not otherwise be expected.

For this study, we will use SuperDARN coherent-scatter radar observations to evaluate the ULF waves in convection strength within the polar caps of both the northern and southern hemispheres and the Sondrestrom incoherent scatter radars in the northern hemisphere. Considerable data is available for this purpose from both of these radar systems. To examine solar wind conditions, we will use the data from interplanetary spacecraft as Weimer-mapped to just upstream of the magnetopause nose. We will also analyze ground magnetometer data to examine the wave features within the polar cap. To investigate the possible relation with substorm and PBI occurrence, we will use standard auroral, ground magnetic, and geosynchronous energetic particle signatures.

Alexander Kosovichev/Stanford University
Determination of the Large-Scale and Meridional Flows in the Deep Convection Zone by Time-Distance Helioseismology

We propose a focused investigation with the main goal of detecting the return meridional flow and measuring the properties of deep large-scale flows associated with formation of active regions. Determination of the large-scale and meridional flows in the solar convection zone is crucial for understanding and modeling the solar dynamo and making sort- and long-term predictions of solar activity. There is no doubt that the large-scale and meridional flows play a significant role in the dynamo operation and in the generation of active regions. The local helioseismology inferences have revealed a complicated dynamics associated with the meridional flux transport and evolution of active regions in the upper convection zone. It has been shown that these inferences have a profound effect on the flux-transport mechanism. However, the effects of these flows on the properties of the solar dynamo and active region formation are far from understanding. For this it is particularly important to determine the structure and dynamics of these flows in the deep convection zone including the tachocline where the solar magnetic fields are believed to be generated and organized. This problem is difficult because the deep flows are relatively weak, and their helioseismic signals are difficult to extract from the noisy oscillation data contaminated by the surface magnetism effects. For tuning of the helioseismic measurements and verification and testing of the results we propose to use numerical simulations of stochastically excited acoustic waves in 3D MHD models of the whole Sun, and use the simulation data for developing, the helioseismic techniques. This work includes a thorough investigation of systematic errors and uncertainties, including potential contamination by the surface magnetism effect.

Jakobus le Roux/University of Alabama in Huntsville
Modeling The Radial Dependence Of The Shock Acceleration Of Solar Energetic Particles From The Corona To Earth With A Time-Dependent Focused Transport Model

The proposal fits in with the Targeted Investigations element of the Living With A Star Targeted Research and Technology Program under which it addresses the Focused

Science Topic “Use Inner Heliospheric Observations to better constrain Coronal Mass Ejection (CME) and Solar Energetic Particle (SEP) Event models”. A current time-dependent focused transport shock acceleration model will be further developed so that it can be used to model SEP events due to CME-driven shocks all the way from the corona to Earth using observations of SEP events between 0.3 and 1 AU by to constrain the simulations. A locally available 3D MHD model will be used to simulate the evolution of CME shocks in the corona and beyond to 1 AU. With the extended focused transport model we are going to investigate from first principles the validity of the remarkably successful diffusive shock acceleration model of Tylka and Lee [2006]. This will be done by revisiting SEP injection and shock acceleration at quasi-perpendicular and quasi-parallel CME shock geometries in the corona because the role of magnetic field-line random walk in SEP anomalous diffusive transport is poorly understood. We plan to include the observed ubiquitous non-Gaussian nature of magnetic field-line random walk in the solar wind in the focused transport model to determine the extent that anomalous perpendicular and parallel diffusion processes might become non classical in response, and thereby modify SEP injection and shock acceleration. In addition, the modification of parallel diffusion, and thus of the shock acceleration of SEPs at quasi-parallel CME shocks due to nonlinear wave-wave interaction effects on the SEP generated enhanced wave intensity spectrum upstream, which has not been studied in much detail, will be investigated.

Xinlin Li/University of Colorado at Boulder
Determining the Loss of Outer Radiation Belt Electrons: A High Priority of LWS/RBSP

Energetic electrons in the magnetosphere have been observed to exhibit high variation in flux during geomagnetic storms. The electron flux enhancements are known to be due to acceleration processes within the Earth's magnetosphere, while the largest loss due to precipitation into the atmosphere also occurs during magnetic storms. Thus the acceleration mechanisms that replenish radiation belt electrons during storms must be even more effective than they appear since they act in the face of this enhanced loss. Without a quantitative knowledge of the loss, a quantitative knowledge of the acceleration mechanisms cannot be obtained. A high priority of the NASA/LWS/Radiation Belt Storm Probe program is to differentiate among competing processes affecting the precipitation and loss of radiation belt electrons.

We propose to investigate and quantify the loss rate of radiation belt electrons due to precipitation. We will accomplish this by analyzing SAMPEX data over a solar cycle. SAMPEX circles the Earth 15 times each day in a high inclination orbit and has been providing the measurements of radiation belt electrons at different since its launch in 1992. Because of its low altitude and large geometric factors and the fast time resolution of its detectors, SAMPEX data are ideally suited for determining losses of electrons to the atmosphere. A simple Loss Index Method to calculate the loss rate will be applied to a variety of storm events and over different phases of solar cycle to quantify the electron loss rate as a function of radial distance, magnetic local time, electron energy and relevant geomagnetic indices. We will also adopt the Drift-Diffusion Model that includes the effects of azimuthal drifts and pitch angle diffusion. The detailed Drift-Diffusion Model method will be used to validate the loss rate results from the Loss Index Method. And we will also apply the Drift-Diffusion Model method to obtain complete information about the pitch angle diffusion rate as functions of energy and pitch angle during indvidual storms.

The proposed research has the direct impact to the LWS goals and is closely related to LWS/RBSP mission. RBSP measurements will be taken near the equatorial plane and because of the limited angular resolutions, the pitch angle distribution near and inside the loss cone is difficult to be resolved. SAMPEX still has the best data to address the precipitation loss. Our proposed study will help the mission to ensure full science closure by having a better understanding of the precipitation loss.

Naiguo Lin/University of California, Berkeley
Investigation of Alfvenic Interactions in the Magnetotail and Their Relationships With the Onset of Substorms

The onset of magnetospheric substorm is an explosive increase of dissipation of the energy transmitted into the magnetosphere from the solar wind. The trigger of magnetospheric substorms has been suggested to be due to magnetic reconnection in the mid-magnetotail (~ 20-30 Re) or the disruption of currents in the near-tail (~10 Re). The subsequent development of the substorm is attributed to the propagation of these disturbances out from a single onset region. The models are still controversial, and often inconclusive. An alternative mechanism has been suggested that the substorm onset is a result of Alfvenic interactions in the global current system. The interaction occurs in multiple active regions throughout the tail current sheet. Compressional and shear Alfvén waves play important roles in the transport of energy through the magnetotail. Observations of occurrences and propagation of these disturbances will produce timing relationships between active regions dissimilar from that resulted from single region initiation, and have not been explored before.

We therefore propose to investigate the observational consequences of the Alfvénic interaction mechanism. The tasks include:
(1) Investigate how disturbances in the various regions of the magnetotail are related to each other and to the onset of aurora intensification and the subsequent development of substorms by comparing timing relationships predicted in the Alfvénic interaction mechanism with those resulting from single region initiation. (2) Investigate the properties (phase velocity, propagation direction, intensity, etc) of the waves excited at the onset of substorms. Are the properties consistent with the expectation from the scenarios under examination? (3) Investigate how the external trigger mechanism is related to the observed signatures in the magnetotail and the aurora activity.

We will analyze data from Themis spacecraft and the Themis ground based observatory network, and from the solar wind monitor. This research will advance our understanding of the substorm onset mechanism which will lead to a physical understanding of the integral system linking the Sun and our earth environment. It will provide observational constraints on theoretical study and simulation and modeling of the substorm process. The results of this research are needed for efficient development of global modeling efforts specified in Focused Science Topics d of the LWS TR&T program.

Ward Manchester/University of Michigan
Simulating CME-Driven Shocks and SEP Acceleration

We propose to simulate and predict the propagation of CME-driven shocks in the solar corona, and calculate the acceleration of solar energetic particles at the shocks. We will perform these simulations in a realistic heliosphere using a global magnetohydrodynamic (MHD) model that allows us to perform event studies. The main focus of this study will be the structure and evolution of shocks as they propagate from the low corona to beyond 1 AU and how particles are accelerated at these shock fronts. We will validate our simulations by quantitative comparisons with both remote (coroagraph) observations and in situ observations throughout the heliosphere. The University of Michigan's BATSRUS code and SWMF framework will used to perform the proposed MHD simulations, while the FLAMPA code (Sokolov et al. 2004) will be used for particle calculations. This work builds upon our more recent simulation which demonstrated an unprecedented ability to model real CME events and quantitatively match coronagraph images, including identification of the CME driven shocks (Manchester et al. 2008). This proposal research proceeds as follows: (1) incorporate a realistic MHD model of the inner heliosphere based on the Wang-Sheeley-Argee empirical model, (2) validate coronal density with tomographic reconstructions of coronagaph images (3) investigate pre-eruption active regions and choosse CME initiation by flux rope, shear flows, or breakout mechanism, (4) validate the CME model by quantitative comparisons between synthetic white-light images and stereoscopic SECCHI observations and comparisons with in situ data from IMPACT, PASTIC, ACE, and Messenger (5) identify shock fronts and determine and (6) predict the spectra of particles accelerated at shock fronts. Understanding how CME structures evolve through the heliosphere will enhance the scientific return from numerous NASA instruments (particularly SECCHI and IMPACT) by predicting the white-light appearance of CMEs and predicting SEPs throughout the heliosphere. We will address many scientific issues such as (1) how shocks interact wit the solar wind at different heliocentric distances, (2) show distortions to the shock front affect particle acceleration, (3) what causes some CME to accelerate energetic particles towards Earth while others do not.

Sergei Markovskii/University of New Hampshire
Self-Consistent Kinetic Simulations of the Global Solar Wind Evolution

One of the fundamental problems of solar physics is the origin of the solar wind, which is a key element of the Sun-Earth connection. Because the solar wind becomes collisionless at an early stage of acceleration near the Sun, the acceleration depends on kinetic processes in the coronal plasma. A broad consensus has emerged over the past decade attributing the generation of the fast wind in coronal holes to the dissipation of ion cyclotron waves. However, although a number of investigations of this mechanism have been carried out, two crucial questions remain to be answered: What is the character of the necessary waves? and What is the detailed kinetic response of the plasma?

These questions cannot be answered without understanding how the kinetic processes responsible for the solar wind generation are coupled to its global evolution. The coronal plasma is propelled away from the Sun by a macroscopic force determined by microscopic particle distributions. In turn, the large-scale force shapes the distribution as the particles propagate through the corona. Therefore, analysis of the cross-scale interactions is essential for a working model of the solar wind. This is the goal of the present proposal. Extensive numerical simulations designed to calculate self-consistently the ion distribution, the solar wind acceleration, and the spectrum of waves, which drive the acceleration, will be carried out. This will approach allow the project team to develop a global kinetic description of the fast solar wind. The obtained results will be tested against several types of remote and situ observational data.

The solar wind originating in coronal holes is known to be the dominant heliospheric phenomenon responsible for the geomagnetic activity during the declining phase of the solar cycle. In addition, understanding how and where the solar wind is energized can improve the models of the ambient medium through which solar ejections and their attendant shocks develop and travel from the Sun to the Earth. As a result, the present work can increase the accuracy of space weather forecasting. The expected theoretical findings can further enhance the observational capabilities of future NASA missions relating to the coronal origin of the solar wind, such as Solar Orbiter/Sentinels and Solar Probe Plus.

Chee Ng/NASA Goddard Space Flight Center
Shock Acceleration and Transport of Solar Energetic Particles from the Corona to > 1 AU

This proposal addresses Focused Science Topic 3(b): Use Inner Heliospheric Observations to better constrain Coronal Mass Ejection (CME) and Solar Energetic Particle (SEP) Event Models. We will develop a model to study in detail the interplanetary transport and acceleration of multi-species solar energetic particles (SEPs) at a CME-driven shock that propagates from the solar corona to > 1 AU. The non-linear time-dependent model will include self-consistent interaction between SEPs and Alfvén waves, using a pitch-angle dependent resonance condition. For SEPs, the model will include focusing, convection, adiabatic deceleration, pitch-angle scattering, and momentum diffusion. Treatment of Alfvén waves will include propagation, SEP-driven growth/damping, shock transmission, and cascading.

We will analyze observations of multi-species energetic ions in shock-associated SEP and energetic storm particle (ESP) events by the ACE, GOES, Wind, and STEREO spacecraft to test and constrain the model. The analysis will include time and energy variations of SEP intensities, elemental abundances, and anisotropies. Concurrent observations of SEPs, plasma and magnetic field on multiple spacecraft as well as electromagnetic solar emissions will be used with the model to address issues regarding the importance of evolving shock-normal (BN) angle, shock speed, Alfvén speed, and other shock and plasma parameters, particle scattering, wave amplification, and heavy-ion suprathermal remnants from previous SEP events.

Liying Qian/University Corporation For Atmospheric Research
Thermosphere--Ionosphere Response to Variability of Solar X-ray and EUV Radiation During Solar Flares

We propose to carry out an observational and modeling investigation of characteristics and driving mechanisms of the spatial and temporal responses of the thermosphere and ionosphere to rapid changes of solar X-ray (0.1-10 nm) and EUV (10-120 nm) radiation during solar flares. The primary scientific objectives are:
(1) Understand how locations of flares on the Sun affect their spectral characteristics and hence the neutral density and TEC responses;
(2) Examine whether neutral density and TEC responses scale directly to the intensity of solar flares as classified by their X-ray brightness for flares with the same location on the Sun;
(3) Investigate the timing of the response and recovery of the neutral density and TEC responses and the coupling/decoupling of the two as the flare responses evolve with time;
(4) Study whether the hemispheric asymmetry of the TEC response is coupled to the hemispheric asymmetry of O/N2 and whether there is hemispheric asymmetry in the neutral density response to solar flares.

TIMED Solar EUV Experiment (SEE), GOES X-Ray Sensor (XRS) , SDO EUV Variability Experiment (EVE), and a new flare model (FISM) will be analyzed for solar flares from 2001 to 2007; effects of these flares on the IT system will be investigated using TEC data (CHAMP, ground-based GPS) and neutral density data (CHAMP). These observational studies will result in establishment of characteristics of flare spectra and the IT responses. A modeling effort using the NCAR-TIMEGCM will be carried out in conjunction with these observational studies. The modeling effort will enable us to investigate the flow of physics and chemistry as the flare affects the ionosphere and the thermosphere. These combined observational and modeling studies will bring a better understanding of how the impulsive bursts of X-ray and EUV during solar flares affect the thermosphere and the ionosphere.

Phil Richards/George Mason University
Determination Of The Causes Of Observed Neutral Density Enhancements In The Auroral Cusp

The purpose of this proposed research is to determine the causes of thermosphere neutral density enhancements that have been observed in the auroral cusp region of the Earth's ionosphere on most orbits by the CHAMP satellite. The enhancements are typically a factor of 2 in density and have an average horizontal width of a few hundred kilometers. It has been hypothesized that thermospheric heating due to intense field aligned currents causes the density enhancements, but previous modeling studies do not support this explanation. In this proposal, we investigate an alternative explanation that the enhancements are caused by heating due to soft electron precipitation and magnetospheric heat flows that are ubiquitous in the cusp region. The investigation will be carried out with a reevaluation of the thermospheric heating rate, electron precipitation, and with the aid of a state-of-the-art general circulation model.

The proposed work is important because it will greatly enhance our understanding of the causes of thermosphere variability by quantifying the influence of auroral electron precipitation and magnetospheric heat fluxes on the thermospheric neutral density. In achieving the main goal of determining the cause of the cusp density enhancements, this research will produce two useful products, 1) a better quantification of the auroral electron heating efficiency, and 2) a much improved model of electron precipitation. This proposal addresses some of the fundamental coupling processes and exchanges of plasma between the ionosphere and magnetosphere with far reaching consequences for our understanding of the ionosphere-thermosphere-magnetosphere system

This proposal is aimed at TR&T focused science topic e) Determine and quantify the responses of atmospheric/ionospheric composition and temperature to solar XUV spectral variability and energetic particles.. This work is particularly relevant to NASA's Strategic Goal 3: Develop a balanced overall program of science, exploration, and aeronautics consistent with the redirection of the human space flight program to focus on exploration: In particular, Strategic Sub-goal 3B which is to understand the Sun and its effects on Earth and the solar system.

Aaron Ridley/University of Michigan
Understanding the Thermospheric and Ionospheric Response to Solar Flares

An understanding of both the thermosphere and the ionosphere, two tightly coupled, overlapping regions of the atmosphere, is important for a number of research and space weather applications: (1) examining increased satellite drag due to heating of the atmosphere (2) examining where and when GPS signal degrading caused by strong gradients of electron density will occur; (3) determining when and where high frequency signals will be strongly scattered or lost due to ionospheric scintillation; (4) examining the role of ionospheric and thermospheric dynamics on the climatology of the lower atmosphere; and (5) determining how the ionosphere influences the magnetosphere through ionospheric conductance and outflow.

Energy enters the thermosphere and ionosphere through many different sources, but two of the most important are the solar extreme ultraviolet (EUV) brightness and the high-latitude Joule heating. The solar EUV is present at relative high levels all of the time, while the high-latitude Joule heating primarily occurs during aurorally active time periods. For many years, models have been run assuming that the solar EUV driving is constant, or slowly varying, for long periods of time (e.g., 24 hours), utilizing proxy models of the flux based on single wavelengths in the solar spectrum (i.e., F10.7). Recently, many researchers have realized that significant variations in the solar spectrum may be missed by doing this, and therefore, much of the physical driving of the model was lacking. Because there has been so little research done on the thermospheric and ionospheric response to the variability in the solar EUV spectrum, there is significant uncertainty in how the upper atmosphere behaves during impulsive increases in the EUV brightness (i.e., during flare events). We propose to address the following four questions related to this topic:

- What effect do solar flares have on the thermospheric density, temperature structure and winds?

- How long does the atmospheric effect of solar flares last?

- How does preconditioning of the thermosphere and ionosphere affect the response of the atmosphere to solar flares?

- How does the shape of the temporal behavior of the flare affect the thermospheric and ionospheric reaction to the solar EUV?

- How does the spectral distribution of the flare affect the thermosphere and ionosphere response?

In order to study these topics, we will utilize a global ionosphere thermosphere model (GITM), data from multiple NASA and ESA supported instruments (i.e., GUVI and SEE on the TIMED satellite, EVE data from SDO, when and if available, and data from the CHAMP satellite), a rigorous data analysis program and newly developed data assimilation techniques, which will allow us to better determine whether preconditioning of the thermosphere and ionosphere has an important effect on the response to solar flares.

Peter Schuck/Naval Research Laboratory
Estimating Energy and Helicity Budgets and Monitoring the Evolution of Active Regions by Tracking Vector Magnetograms

We propose a four-year program to develop and test methods for estimating photospheric velocities from a sequence of vector magnetograms. Accurate and precise measurements of photospheric velocities are critical for estimating the coronal energy and helicity budgets and essential for effective use of measurements made by Living With a Star (LWS) satellite missions. Photospheric plasma velocities and energy and helicity fluxes are keys to understanding and predicting eruptions from active regions on the sun, which are a hazard to society, to space-based systems, and to human space-flight.

The proposed techniques determine photospheric velocities by applying the magnetic induction equation and an affine velocity model to a windowed subregion of the magnetogram sequence. This produces an overdetermined system that can be solved directly by standard least squares or total least squares techniques. These subspace methods are inherently statistical. Consequently, the optical flow estimates can be assessed for reliability and for uniqueness (resolution of the aperture problem). The result is a point-by-point optical flow field that is statistically consistent with the magnetic induction equation. Our algorithms have been and will be benchmarked with state-of-the-art MHD simulation codes ANMHD and RADMHD to establish the accuracy of the techniques. We will also participate in a community-wide collaborative effort to compare the accuracy of our methods with optical flow techniques developed by other groups such as local correlation tracking (LCT), inductive local correlation tracking (ILCT), minimum energy fit (MEF), and the inductive method (IM).

Our new techniques will make full use of high-resolution, high-cadence vector magnetogram data for the dual purposes of scientific analysis and augmentation of space-weather prediction through real-time monitoring of photospheric activity and the coronal energy and helicity budgets of active regions. The outputs of this program will be new methods and extensively documented performance characteristics of the algorithms and operational codes for satellite software pipelines. Furthermore, magnetograms will be analyzed and the estimated photospheric velocity, electric fields and associated uncertainties will be available to the solar physics community to (1) assess the energy and helicity budgets of active regions for their forecasting ability, (2) investigate CME initiation, (3) monitor the evolution active regions, and (4) drive realistic MHD simulations. The prime measure of success for this work would be the widespread use of these tools for the determination of photospheric velocities from observational data. Therefore, the library of tools developed under this program will continue to be "open source" and accessible to the solar physics community.

The proposed program addresses the goal of the "Tools and Methods" component of the Living with a Star (LWS) Targeted Research and Technology Program (TR&T). Our program will develop the tools and scientific understanding needed for the United States to effectively address those aspects of the Sun-Earth System that may affect life and society by developing methods for accurately estimating photospheric velocities from magnetogram sequences. Our work will provide the necessary tools to deliver significant new understanding of solar eruptions through the energy and helicity budgets of active regions and resolve persistent controversies concerning the spatial scales and flow structure of solar active region processes and will therefore contribute to advance-warning space environment predictions along the path of robotic and human exploration.

Neil Sheeley/Naval Research Laboratory
Tracking CMEs Through the Inner Heliosphere

Objective: To study the propagation of coronal mass ejections (CMEs) through the inner heliosphere.

Method: We will accomplish this objective by combining remote-sensing observations from the STEREO A/B and SOHO spacecraft with in situ measurements from the Venus Express (VEX), Messenger (MSGR), ACE/WIND, STEREO A/B, and SOHO spacecraft, taking advantage of the favorable spacecraft conjunctions and multipoint viewing opportunities that these spacecraft are providing. Specific activities will include (1) determining the evolution of CME-deflected streamers and their associated shocks; (2) mapping the interaction between co-rotating interaction regions (CIRs) and CMEs; (3)

determining the origin and evolution of very slow wind; (4) comparing CME observations with MHD simulations.

Importance: The study of CME-deflected streamers will provide information about the shocks that accelerate solar energetic particles (SEPs) and constrain models of the resulting heavy ion populations. The study of CIRs and CMEs will reveal how the slow CMEs are swept up by solar wind streams and how the fast CMEs drive shocks through those streams. By determining the origin of the very slow solar wind, we will learn how to interpret HELIOS observations of very slow wind at 0.3 AU and thereby help in planning for the Solar Probe Mission. By comparing CME models with MHD simulations, we will develop an improved capability to predict the occurrence and propagation of CMEs and shocks through the inner heliosphere.

NASA Relevance: These objectives are consistent with NASA's Strategic Goal of understanding the Sun and its effects on Earth and the solar system (as described in Table I and Sections I(a) and IV(e) in the ROSES Summary of Solicitation). Also, they are directly related to the stated goals of the Inner Heliospheric Study of CMEs and SEPs - an objective of NASA's Living With A Star Program of Targeted Research and Technology.

Mikhail Sitnov/The Johns Hopkins Universtiy Applied Physics Laboratory
Parametrization of the Kinetic Processes Responsible for the Onset of Reconnection in the Magnetotail

The mechanism of the onset of magnetic reconnection in the tail of Earth's magnetosphere remains one of the most compelling problems of magnetospheric physics. Missing parametrization of that process is one of the main stumbling blocks in the global MHD modeling of the magnetosphere. In spite of the significant progress in modeling the collisionless reconnection in the simplest antiparallel and guide-field cases, it remains unclear: (1) Where does the reconnection start in the magnetotail? (2) What are the critical plasma and electromagnetic field parameters prior to the onset? (3) How can the kinetic onset conditions be translated into the MHD language? The tools to answer these questions include the new equilibrium models of thin current sheets, nonlocal linear stability analysis codes, and full-particle codes with periodic and open boundaries. They have already been used to demonstrate the possibility of the spontaneous reconnection in the magnetotail, and the theoretical predictions of the destabilizing role of the electron kinetic response have been confirmed by particle simulations with open boundaries, including the effect of different motions of trapped and passing particles. The proposed study is aimed to address the Focused Science Topic D of the NASA LWS TR&T program.

O. St. Cyr/NASA Goddard Space Flight Center
Understanding Interplanetary Shock Dynamics in the Inner Heliosphere with New Observations and Modeling Techniques

Using archival observations and the ENLIL model at the Community Coordinated Modeling Center (CCMC), we propose to evaluate several new methods of predicting interplanetary (IP) shock location and strength throughout the inner heliosphere. Shocks accelerate energetic particles, and coronal mass ejection (CME) driven shocks are the primary cause of severe geomagnetic storms. These new prediction techniques appear to be superior to those presently in use by NASA's Space Radiation Analysis Group (SRAG) and NOAA's Space Weather Prediction Center (SWPC) for predicting shock arrival time at Earth. Our goals are two-fold: to provide observational validation of the ENLIL model in the inner heliosphere and to improve the prediction of shock arrival times at 1 AU .

We have discussed the project with Dr. M. Hesse (CCMC Director), and a letter of support from him is included with this proposal. To insure that the results are immediately useful to SRAG and SWPC we have enlisted Dr. Neal Zapp and Mr. W. Murtagh as collaborators in this work. Although the proposed work is initially based on archival data, the study is timely because the STEREO space weather beacon now provides the real-time coronagraph images as well as the low-frequency radio measurements needed in the new techniques described below.

The first new prediction method is an empirical technique based on the kilometric wavelength interplanetary Type II radio emissions described by Cremades, et al., 2007 (hereafter called "kmTII" technique). The second technique is based on the empirical shock arrival (ESA) model described by Gopalswamy et al. (2005a) based on CME speeds measured in SOHO LASCO. Xie et al. (2006) extended the ESA technique to include a correction for projection effects by a "cone model" (described below). A third technique is an extension of these two, where CME deceleration is included in the corrected ESA model and synthesized with kmTII-derived shock velocities. Promising initial results have been reported recently by Xie et al. (2008).

These empirical techniques will be evaluated against ENLIL driven by a "cone model" of halo CMEs. The ENLIL model developed by Dr. D. Odstrcil (e.g., Odstrcil and Pizzo, 1999) is well-known in the solar-helio community, and ENLIL version 2.3a is currently available to users at the CCMC. Odstrcil is a collaborator on the proposed work. The cone model that is used at the CCMC to drive interplanetary disturbances through the inner heliosphere via ENLIL was developed by a co-investigator to this proposal (Xie et al., 2004).

Space weather forecasters are keen to understand differences between the coronagraphic, the radio and the ENLIL techniques:

-How do these techniques compare to those presently in use at SRAG and SWPC?
-Is one technique superior for all/some CME-driven shocks?

-Are there CME characteristics (e.g., size, speed, mass, event repetition, morphology, etc.) that distinguish when one technique is superior?
-Can the techniques, or aspects of the techniques, such as definition of a more realistic interplanetary density model--be used together to improve the forecast?

The PI, Co-I's, and collaborators are uniquely-qualified to undertake the proposed work, as they have a published track-record of recent, relevant, significant results in this topic. The requested funding resources are modest, and the anticipated gain is significant. The work proposed here directly supports the NASA Strategic Goals. In particular, it supports Subgoal 3B: Understand the Sun and its effects on Earth and the solar system; as well as NASA Research Objectives: 3B.2 Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields, and 3B.3 Develop the capability to predict the extreme and dynamic conditions in space in order to maximize the safety and productivity of human and robotic explorers.

Elsayed Talaat/The Johns Hopkins Universtiy Applied Physics Laboratory
The Effects of Solar Activity on the Middle and Low-Latitude Ionosphere

This proposed work will use existing multi-year satellite observations of ionospheric density, middle and upper atmosphere temperatures and a 3D nonlinear general circulation model to address the following outstanding science questions:

1. What are the relative inter-annual and solar cycle effects on the mid- and low-latitude ionosphere?
2. How far do solar rotational effects penetrate in the mid- and low-latitude ionosphere?
3. What are the quantitative effects of flares on ionospheric heating?

Pavel Travnicek/University of California, Los Angeles
Magnetic Reconnection, Particle Energization, and Plasma Heating in a Global Kinetic Model

Magnetic reconnection, which is a conversion of magnetic energy into plasma wave and kinetic energy, is one of the most important physical processes in geospace. It involves a breaking of the "frozen-in" condition that results from kinetic processes acting on ion and electron scales, yet the release of energy has consequences on meso and global scales. At the Sun, reconnection is believed to be a driver of energetic bursts involved in solar flares and other solar disturbances. As the solar wind with its embedded interplanetary magnetic field (IMF) flows out into the solar system, its interaction with internally magnetized planets creates a magnetosphere in which reconnection is often the dominant form of energy transfer. For the outer planets (i.e., Saturn and Jupiter), corotation dominates the inner magnetospheric region, but for the inner planets, such as Mercury and Earth, magnetic reconnection plays a major role in the configuration of the magnetosphere, its dynamics and the formation of an inner belt of energetic plasma. The goal of this proposal is to apply a global three dimensional (3D) kinetic model of the solar wind interaction with a planetary magnetosphere and examine plasma transport, acceleration and heating that results from reconnection and at shocks. The need for a global kinetic 3D magnetospheric model is urgent and it will have a strong impact on improved space weather forecasting for different solar wind conditions, which is a high priority for the Living with a Star program.

Allan Tylka/US Naval Research Laboratory
Proton Spectra in Ground-Level Enhanced Solar Energetic Particle Events and Implications for Astronaut Radiation Exposure and Storm-Shelter Design

Ground-level events (GLEs) are very large solar energetic particle (SEP) events in which the proton spectrum extends beyond ~400 MeV with sufficient intensity to generate increased signals in terrestrial detectors that count secondary neutrons produced through interactions in the Earth's atmosphere. Although GLEs have been recorded by the world-wide neutron-monitor network for more than 50 years, they remain controversial in terms of how the origin of these very high-energy particles compares with that of particles below ~100 MeV that are typically observed by satellites. Nearly all of the SEP events in the historical record that potentially pose a significant radiation hazard for astronauts have been GLEs. Yet, as highlighted in a recent National Research Council report "Managing Space Radiation Risk in the New Era of Space Exploration" (van Hoften et al., 2008), the radiation-hazards community typically uses exponential spectral forms for these events that are too soft at high energies and inconsistent with the neutron monitor observations. As demonstrated in the NRC report, these erroneous spectral forms can lead to severe under-design of radiation storm shelters meant to protect astronauts during periods of extended SEPs, such as October 1989. The NRC report recommended that NASA re-evaluate these spectra by combining satellite measurements with neutron monitor observations. We have recently developed new data analysis techniques to do this. We propose to apply these new techniques to the entire historical database on GLEs, so as to provide a library of absolutely-normalized proton spectra for ~50 GLEs, thereby providing a new tool to the radiation-hazards community for evaluating the efficacy of radiation-shelter design. This proposal is submitted as an LWS "Independent Investigation." This proposed research directly supports NASA Strategic Sub-goals 3B, 3C, and 3F.

Yi-Ming Wang/US Naval Research Laboratory
The Sun's Polar Fields and the Dynamo

OBJECTIVES AND APPROACH: We will derive constraints on the solar dynamo as follows: (1) Using polar faculae counts since 1906, Greenwich sunspot data, and magnetograph measurements since 1967 as observational constraints, we will carry out surface flux-transport simulations of the photospheric field evolution during cycles 15--23. We will then explore the relationship between cycle amplitude and meridional flow speed (a time-varying parameter in our model), cycle amplitude and the strength of the polar fields, and cycle length and flow speed. In addition, we will determine whether the observed giant poleward surges of flux, and the accompanying fluctuations in the polar fields and faculae numbers near sunspot maximum, require higher flow speeds. (2) As a by-product of these long-term simulations, we will quantify the relationship between total photospheric flux (facular brightness) and total sunspot area, in order to verify our hypothesis that increased diffusive annihilation during high-amplitude cycles causes TSI to saturate. (3) Using MWO, WSO, NSO/Kitt Peak, and MDI photospheric field measurements, MDI 676.7 nm images of polar faculae, and flux transport simulations, we will address the question of why the polar fields ended up so weak in 2008. The flow speeds derived at low latitudes from our simulations will be compared with helioseismic measurements, keeping in mind that the latter may not refer to the same depths that control the magnetic field transport. We will also measure the axial tilts of cycle 23 active regions to see if they are systematically smaller than the cycle 21 tilts analyzed in Wang & Sheeley (1989). (4) We will determine how much leading-polarity flux diffuses across the equator during cycles 20--23 by measuring the steepness of the observed photospheric-field gradients at the equator, and check if the resulting values are consistent with the observed polar field strengths at the end of each cycle. We will ascertain whether these latitudinal gradients were smaller during cycle 23 than during the previous three cycles, which would account for the weak polar fields during the current activity minimum. (5) We will provide a physical explanation for the success of geomagnetic activity precursors in predicting the amplitude of the following solar cycle, by separating the aa index into its constituent parts (mainly solar wind speed and IMF strength). At the same time, we will test our hypothesis that the IMF strength near sunspot minimum provides a better cycle predictor than the aa index itself.

RELEVANCE: The proposed research directly addresses LWS TR&T Focused Science Topic (a): "Measure the properties of the solar dynamo that affect solar irradiance and active region generation." More specifically, it answers the call for analyses revealing how the magnetic characteristics of the solar poles affect the dynamo and the solar activity cycle, and for the "use of observations that discriminate between models that forecast the properties of cycle 24." Our flux transport model will also allow us to investigate how sunspot and plage areas interact to determine the solar irradiance variation.

Daniel Weimer/National Institute of Aerospace
High-Latitude Auroral Heating in the Energy Budget of the Thermosphere

The proposed project will investigate the flow of energy into the thermosphere during geomagnetic storms, and its later dissipation, along with the resulting changes in exospheric temperature and the altitude profile of the neutral density. The solar extreme ultraviolet flux provides a slowly varying background level of heating, while during geomagnetic storms electromagnetic energy deposited in the high-latitude ionosphere produces short-terms variations at a higher level. This heating by the aurora is calculated with empirical models that calculates the ionospheric fields and currents from measurements of the solar wind and interplanetary magnetic field. During the course of this project these empirical models will be improved. The thermosphere's response is observed by means of the neutral density that is derived from measurements of the atmospheric drag on satellites. From these neutral densities are derived the orbit-averaged neutral densities, the average exospheric temperature, and the total energy contained in the thermosphere. By comparing the heat flowing into the thermosphere from different sources with the measured total energy, and combined with the observed cooling rates, a predictive capability will be developed. A tool will be developed for calculating the change in the minimum, nighttime thermospheric temperature during geomagnetic storms. This temperature index can be used in the Jacchia-Bowman 2008 model of thermosphere, and improvements in satellite drag predictions will be evaluated. Another study will determine how quickly the neutral density around the globe responds to auroral heating.

The scientific results from the project will likely help to produce better understanding and prediction of the thermosphere's response, and the resulting anomalous satellite drag, during large geomagnetic storms. The measurements of the thermosphere's cooling rates will be useful for validation of numerical thermosphere-ionosphere coupling models.

This proposed project is submitted under the classification of "Tools and Methods." This work is highly relevant to Focused Science Topic e) "Determine and quantify the responses of atmospheric/ionospheric composition and temperature to solar XUV spectral variability and energetic particles," as well as the on-going Focused Science Topic started in the prior year to "determine the sources of daily variability in the thermosphere and ionosphere." There is relevance to the fourth-listed LWS Strategic Goal in that this project will help "to deliver understanding and predictive models of upper atmospheric and ionospheric responses to changes in solar electromagnetic radiation and and to coupling above and below." The tasks are relevant to NASA's "Strategic Goal 3," under Sub-goal 3B to "Understand the Sun and its effects on Earth."

Martin Woodard/Northwest Research Associates, Inc.
Helioseismology of the Solar Dynamo

We propose to improve current measurements of solar meridional and zonal flows by analyzing the nearly continuous 12-year sequence of Dopplergrams from the SOHO/MDI medium-l helioseismology program. The analysis technique we will use is based on measuring a mode-leakage matrix which is sensitive to the distortion of mode eigenfunctions by flows Significant effort will be devoted to identifying, understanding, and modeling instrumental error.

We are proposing (1) to model and correct for instrumental and radiative transfer effects, (2) to model the theoretical effect of differential rotation and meridional circulation on the leakage matrix, (3) to develop and verify codes to fit the leakage model to helioseismic data, and to run the fitting codes on MDI data and, (4) to invert measurements of the leakage matrix for meridional and zonal flows.

The resulting measurements of deep flows are anticipated to be accurate enough to impact our understanding of the solar dynamo, as meridional flow is a critical component of flux-transport dynamos. In addition, the leakage matrix measurements we will carry out will be useful to other areas of helioseismology.

The goals and measures of success of Focused Science Topic (a) -- "Measure the properties of the solar dynamo that affect solar irradiance and active region generation" -- include "improved measurements of critical subsurface flows, including the expected deep meridional flow." The detection of sub- surface meridional flow promises to facilitate our understanding of, and perhaps predict, the generation, emergence, and evolution of magnetic regions. This research is therefore critical to the TR&T Focused Science Topic and NASA's Strategic Subgoal 3B through Research Objective 3B.1: "Understand the fundamental physical processes of the space environment from the Sun to Earth .. ", which addresses NASA's Science Question, "How and why does the Sun vary?" from Strategic Subgoal 3B.

ChinChun Wu/University of Alabama in Huntsville
A Scheme for Real-Time Forecasting of the Intensity and Timing of Magnetic Storms at Earth based on Observations of Magnetic Clouds at L1

The interplanetary magnetic field (IMF), in addition to electromagnetic and particulate radiation, plays a major role in Sun-Earth connection through a process which is well explained by Dungey's reconnection model. During a prolonged period of a large southward (in GSM) component of the IMF, often associated with magnetic clouds (MCs), a major magnetic storm will usually occur and pose a threat to communications, electric power grids, and Earth's orbiting satellites. In response to NASA's Living With a Star program, which is designed to address this problem as a first priority, we plan to develop a scheme that is able to forecast in real-time the magnetic field structure associated with a magnetic cloud of a N-to-S type and the intensity and timing of a magnetic storm that it drives. N-to-S types, which started around mid 2005, are most common at this time and are expected to continue for about ~seven more years. The proposed investigation will be built upon our knowledge gained from our intensive work on MCs in the past. The scheme contains a series of programs that operate on data from a spacecraft upstream of Earth, at L1 in this case (e.g., ACE): (1) one that automatically identifies a MC-candidate in real time (Program #1), (2) one that does preliminary MC parameter fitting using a variety of boundary trials, guided by those from Program #1 (and a later program that sends pertinent information back to Program #2), primarily to obtain a good estimate of the MC's axis and MC type, (3) one that estimates a refined MC front boundary time (called t_B*) using higher resolution data, (4) one that uses t_B* to carry out a more advanced MC parameter fitting (called the Comprehensive program), including MC expansion and compression, (5) one that finds the "best estimate" of B_z,GSM(MIN) within the MC and its occurrence time, t_MIN, (6) one that calculates the delay time from the observing time at L1 to arrival time at Earth (Delta T_L1-E), and finally (7) one that estimates Dst_min (or other magnetic storm indices) using Bz,GSM(MIN), V_SW, t_MIN, and Delta T_L1-E. Under favorable circumstances for the most common MC durations, say around 18 ± 6 hours, a N-to-S MC will give about a 5.4 ± 1.8 hours warning-time, where Delta T_L1-E is assumed to be about one hour. This is in contrast to the much longer, and therefore more desirable, warning times upon using solar imaging data, where several days are obtained, but usually with quite unreliable or inaccurate results. This is also preferred over current major Dst prediction models which offer only a lead time of ~1 hour. After completion, we will provide the scheme to the community and will set up a designated space weather website to host the predictions, as well as add any new MC information to the presently existing WIND/MFI Website.

Peter Yoon/University of Maryland
Integration of Anomalous Transport Effects by Kinetic Instabilities into Global Models

This proposal in response to the "Living With a Star Targeted Research and Technology" research announcement NNH08ZDA001N-LWSTRT, is aimed at addressing the following outstanding questions that pose limitations on the capability of existing global models to provide accurate representation of magnetospheric dynamics:

(1) What are the kinetic instabilities revealed from observations that may lead to global effects?

(2) How should the effects of localized kinetic instabilities be incorporated into global simulation models?

(3) What differences would the effects of localized kinetic instabilities make on the macroscopic fluid simulation when these effects are incorporated into the code?

We have recently developed a novel theoretical method to extract physical information on the plasma wave characteristics from THEMIS spacecraft data, taken during a dipolarization event. By continuing to employ such a method for other events and for other spacecraft data (e.g., Cluster) we shall establish the true picture of what kinetic instabilities are really operative near the reconnection or current disruption region. We have also recently developed a theoretical formalism to incorporate the effects of kinetic instabilities into the global fluid model by means of anomalous resistivity and turbulent transport coefficients. We shall integrate these coefficients into the Hall-MHD code, and solve the code over model magetotail geometry. We shall demonstrate the differences with simulations without the anomalous transport coefficients. This will serve as an example for other simulation groups that perform existing global simulations of the magnetosphere. In the future, the present method can be further evolved into a more realistic space weather forecasting tool.

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An Improved Self-Consistent Model of the Near-Earth Magnetosphere Magnetic Field

The Earth's radiation belts have received considerable attention recently due to the hazards they pose for spacecraft operating in Earth orbit. A major factor hampering our understanding and prediction of their dynamics is our insufficient knowledge (on an event basis) of the magnetic field in the near-Earth environment. To improve the specification of this field, we propose to develop and test a new approach for self-consistent, realistic three-dimensional magnetic field modeling in the near-Earth magnetosphere. The basis for our approach will be a recent coupling of a bounce-averaged kinetic model of particle evolution (the RAM code) with a 3D plasma equilibrium code with anisotropic pressure. Starting from that coupling, three major proposed improvements will drive our model toward realistic magnetic field computation in the entire near-Earth magnetosphere: 1). a novel Euler potential technique will eliminate the spatial limitations in the preliminary approach, and allow us to treat not only the inner magnetosphere, but also the critical transition region in the near-Earth (6-12 RE) magnetotail; 2). the tilt of the Earth's magnetic axis will be included for the first time in the model, and 3). the electric fields induced by the time change of the magnetic field will be computed and added to the convection field in RAM. Boundary conditions for the coupled model will be either observation-based (from empirical models) or from global model runs at CCMC. Comparisons with Cluster, IMAGE, Polar, THEMIS and geosynchronous plasma and field data will be performed to validate model results, through both in-situ model/data comparison and by employing phase space density analysis. The proposed research will significantly impact NASA LWS program and Heliophysics science in general, as the near-Earth magnetic field is a key element in understanding and predicting radiation belt dynamics. The results will also directly benefit the upcoming NASA mission RBSP.
