Living With A Star
Abstracts of selected proposals
(NNH15ZDA001N-LWS)

Below are the abstracts of proposals selected for funding for the Living With A Star program. Principal Investigator (PI) name, institution, and proposal title are also included. Ninety two proposals were received in response to this opportunity. On August 28, 2015, twenty proposals were selected for funding.

Meg Austin/University Corporation For Atmospheric Research (UCAR)
Heliophysics: Integrating knowledge across disciplines

One of the major challenges facing the Living With a Star Program (LWS) is the development of a research community that crosses traditional discipline boundaries to attack system-wide problems central to understanding and modeling the Sun-Solar System connection. The Visiting Scientist Programs office (VSP) of the University Corporation for Atmospheric Research (UCAR) has partnered with the university community to develop a focused Heliophysics Summer School (held yearly since 2007) and a successful postdoctoral fellowship program (since 2009) to address this challenge. This proposal seeks to establish a five-year Cooperative Agreement with NASA for the continuation of VSP s successful efforts to facilitate the training and education of a new generation of scientists and support interactions within the heliophysics community.

VSP s Mission: To help prepare the next generation of scientific leaders and workforce by supporting effective and collaborative fellowship, visitor, and workshop programs that meet emerging training and research needs.

In support of the NASA Heliophysics division s long-term goal of developing the scientific understanding needed for the United States to effectively address those aspects of the connected Sun-Earth system that may affect life and society, the Visiting Scientist Programs office helps Earth systems scientists develop a new research community and build productive, collaborative, working relationships. To reach this goal, VSP:

Organizes, hosts, and administers the annual Heliophysics Summer Schools to foster learning and development of Heliophysics as a broad, coherent discipline. This includes support in developing additional teaching tools that may include textbooks, problems sets, labs, and distance learning modules. Every year VSP provides project leadership for the Heliophysics Summer School. While the content of the Summer School is designed by and for the scientists involved, VSP contributes planning and logistical support, efficient on-line registration mechanisms, creation and publication of agendas and schedules, and on-site support while the summer school is in session.

Established and administers the Jack Eddy Postdoctoral Fellowship Program, which matches early career PhDs with hosting mentors in order to build a new generation of scientists. Each year VSP will recruit candidates from around the world for three or more Jack Eddy fellowships. A UCAR-appointed steering committee will review candidate applications in the spring, and recommend the most highly-qualified candidates for two-year appointments. Fellows are matched with experienced host scientists at U.S. academic institutions or research labs to conduct independent research projects.

Established a Communications Plan and Team to broaden the reach of Heliophysics science to a larger audience. As with all communication in the social and mobile age, a key objective of updating heliophysics communication is not simply reaching a modern-day audience, but also promoting active exchange among the heliophysics community researchers, writers, educators, and even space weather forecasters.
Hosts and administers Educational and Collaborative Workshops for the benefit of VSP fellows and the larger Earth system science community. Workshops and seminars foster the exchange of ideas in an informal setting, and help the attending scientists form and nurture productive, ongoing scientific relationships. VSP provides efficient online registration mechanisms for workshop participants, and provides administrative and logistical support when the workshops are in session.

Hosts and administers the Living With a Star Institute that is designed to facilitate a bridge between cutting-edge heliophysics research and a societally relevant technology area that is affected by space weather. Competitively selected working groups will define and scope new research that will make a critical difference to this technology.

Joseph Borovsky/Space Science Institute
Analyzing the Web of Correlations and Time Lags between the Solar Wind and the Inner Magnetosphere: Systems Science with CCA

The overarching objective of this LWS Investigation is to use a systems-science approach to increase understanding of the connections, time lags, feedback loops, and hysteresis in the reaction of the inner-magnetosphere system to the solar wind. The mathematical technique of canonical correlation analysis (CCA) will be used to simultaneously analyze a global data set (millions of points) comprised of multiple measures of the solar wind and multiple measures of the inner magnetosphere. Specific objectives are (1) To determine and assess the dominant correlations and time lags between the multiple variables of the solar wind and the multiple measures of the inner magnetosphere, (2) To determine the important hysteresis terms in the reaction of the inner magnetosphere to driving by the solar wind, (3) To identify correlations with known physical processes and to highlight unexplained correlations, (4) To exploit CCA methods to gain information about causality and information flow in the web of correlations, and (5) To interact with the VarSITI SPeCIMEN community to attain its goals.

Canonical correlation analysis is an ideal tool when causes and effects cannot be described or measured by a single variable, which is the case for the solar wind driving the highly coupled inner magnetosphere. CCA has a demonstrated ability to uncover patterns in the reaction of the magnetosphere-ionosphere system to the solar wind. In this NASA LWS Investigation, CCA will be applied to the inner magnetosphere driven by the solar wind. A multiyear Grand Inner-Magnetosphere Data Set will be assembled from multiple time-dependent variables measuring the plasmasphere, the plasma cloak, the ion plasma sheet (ring current), the electron plasma sheet, substorm-injected electrons, the electron radiation belt, the ion radiation belt, ULF amplitudes, magnetospheric convection, magnetic-field morphology, particle anisotropies, plus other measures that become available from the SPeCIMEN community. The solar wind data set will be the multiyear OMNI2 data plus a new solar-source categorization of the solar wind.

CCA techniques have been developed to identify and quantify hysteresis in the reaction of the Earth to the solar wind and to identify feedback processes. Techniques will be developed in this Investigation to study time lags and the flow of information between the solar wind and the inner magnetosphere. CCA methodologies will be exploited that can provide information about which correlations are causal and which are spurious.

This proposed investigation directly supports Key Science Goal 2 of the Decadal Survey: Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs . This investigation supports the NASA Heliophysics Division Science Goal 2 Advance our understanding of the connections that link the Sun, the Earth and planetary space environments, and the outer reaches of our solar system . This proposed Investigation supports the NASA Strategic Subgoal 2.2 Understand the Sun and its interactions with Earth and the solar system from the 2011 NASA Strategic Plan and it directly supports the Heliophysics Science Question How do the Earth and planetary systems respond? . This Investigation supports the LWS Program Objective Understand solar variability and its effects on the space and Earth environments with an ultimate goal of a reliable predictive capability of solar variability and response . This investigation uses a systems science approach to directly address the VarSITI SPeCIMEN overarching question How does the inner magnetosphere respond as a coupled system to Sun/solar-wind driving? and this investigation will help to achieve the SPeCIMEN stated anticipated outcome A better understanding of the physical processes leading to a series of coupled, related models that quantitatively predict the dynamical evolution of the inner magnetospheric state.

Benjamin Brown/University Of Colorado, Boulder
Stellar Insights into Solar Magnetism: Exploring Fundamental Dynamo Physics Across the Lower Main Sequence

Magnetism is a ubiquitous feature of stars like our Sun. Stars on the lower main sequence generate their magnetic fields by dynamo action in their sub-photospheric convection zones. When stars like the Sun are young, they rotate much more rapidly and are much more magnetically active. High coronal X-ray emission in young stars, cyclic magnetism, and frequent large stellar flares must profoundly affect these potential abodes of exosolar life. Likewise, solar magnetic activity and space weather affect life here on Earth. In this proposed research, we will probe the fundamental physics of dynamo action across the lower main-sequence of sun-like stars. The proposed work involves numerical and theoretical studies of global-scale stellar dynamo action, seeking to understand the fundamental physics that drive stellar dynamos in solar-like stars. This effort includes global-scale 3-D MHD simulations on supercomputers, mean field models, and significant work to understand the underlying fundamental physical processes occurring in stellar dynamos.

Our proposed work fits naturally into Focus Team Effort 2: The Solar-Stellar Connection of Living With a Star science. This work addresses the Heliophysics Science Question ``What causes the Sun to vary?". Our work will provide theoretical underpinnings for the current missions STEREO and IRIS, and especially for the HMI and AIA instruments on the SDO mission. All are concerned with evolving solar magnetism, as are our proposed theoretical efforts. Our work on stellar dynamos and magnetism will aid in interpretations of results from Kepler and TESS, where stellar spots and white light flares are major observational features. By studying stellar dynamo properties across the lower main sequence, we can learn what is specific to the Sun and what is common to all solar-like stars. Our work will position the Sun and its dynamo in a broader context.

Derek Buzasi/Florida Gulf Coast University
Exploring the Solar-Stellar Connection Using K2

The proposed project involves using data from NASA's K2 mission to identify and characterize solar analogs in the K2 fields. We will make use of both primary targets (those specifically proposed by others) as well as secondary targets which serendipitously appear in the K2 "postage stamps"; we anticipate more than 1000 solar analogs in the latter category alone.

For each analog, we will determine rotation period, activity level, and spot and flare characteristics, as well as determine if the star is a Maunder Minimum candidate. In addition, for the brighter stars we will perform basic asteroseismology to better characterize physical characteristics. All results will be supplied to the focus team for follow-up and more detailed investigation.

The result of the proposed effort will be a well-defined, well-characterized, and statistically significant set of solar analogs which will be key to improving our understanding of the solar-stellar connection.

Ofer Cohen/Smithsonian Institution/Smithsonian Astrophysical Observatory
The Heliosphere in Time: Scaling Heliospheric Parameters with Stellar Evolution of Solar Analogs and Studying Heliospheric Consequences of Young Active Suns

We propose to use the Space Weather Modeling Framework (SWMF) to study the state of the heliosphere and the interplanetary environment for different stages of the Sun through its evolution. The study will include: simulating the stellar winds of solar analogs at different ages, driven by low-resolution magnetograms now available for significant number of stars; studying young and active, fast-rotating suns, and examining their flares and superflares by simulating their Coronal Mass Ejections (CMEs); using both optical and X-ray observations of stars to constrain flaring rates; investigating other possible dynamic mechanisms to trigger superflares (such as the azimuthal stretching of coronal loops as the result of the fast rotation); studying the role of CMEs in the solar mass loss rate over time (potentially important for the faint young Sun paradox); and investigating the cosmic ray/SEP generation, transport, and modulation for different ages of the Sun in quiescent and superflare conditions. The end result of the project will be a complete, physics-based description of the heliosphere through time and a general scaling of the interplanetary environment, in which the Earth and the other planets were formed.

Marc DeRosa/Lockheed Martin Inc.
Evolving Models of Stellar Photospheric and Coronal Magnetic Fields

Magnetic fields in the atmospheres of Sun-like stars are the bridge between the dynamo activity occurring in stellar interiors and their observable characteristics. Observational evidence of magnetic fields and magnetic proxies show that Sun-like stars span the gamut of activity levels, ranging from extremely quiet stars to highly variable stars possessing starspots or starspot groups covering a large fraction of the stellar surface. Furthermore, comparative studies show the Sun is far from a typical star.

In this project, we aim to answer the following science questions:

" What constraints can measurements of magnetic spots, differential rotation, and flares on other stars teach us about the solar dynamo?

" What are the limits of observational inference of magnetic fields and differential rotation on other stars?

" What are the coronal magnetic configurations associated with superflare events (as observed, for example, in white light photometric data in Kepler)?

" What is the importance of well-known physical processes on the Sun (including flux emergence, differential rotation, turbulent diffusion) for magnetic activity on other stars?

We propose a forward modeling framework to address these questions. First, we will run a series of surface-flux transport (SFT) models of starspot evolution. A number of these models will then be used as lower boundary conditions to drive time-evolving force- free models of the global stellar coronal field. The coronal magnetic fields are evolved by magnetofriction (MF), which has been applied successfully for modeling a variety of solar coronal field configurations, including active regions and filaments. This type of time-dependent modeling will allow us to construct force-free coronal fields evolving in response to starspot evolution.

The combined SFT/MF simulations will be used to produce synthetic spectropolarimetric measurements, which then will serve as input constraints for Zeeman Doppler Imaging (ZDI) inversions. The aim is to determine the validity of the inversions, and to examine the correspondence between such inferred magnetic properties with the input SFT parameters governing flux emergence, differential rotation and turbulent dispersal. Properties that appear important for the solar case but are not well constrained for other stars, such as latitudinal flows, will also be considered. The buildup of free magnetic energy in the MF simulation domain will also be evaluated, and used to determine whether evolution associated with interacting starspots (which presumably may be much larger than the biggest sunspots) may build up sufficient free magnetic energy to power so-called superflares (such as those observed in Kepler white light time series data).

This project is expected to complement other participating projects in the LWS Solar-Stellar Connection Focus Team by enabling outputs of dynamo models, in particular those that produce time-varying surface flux patterns throughout successive stellar activity cycles, to be used for ZDI inversions and coronal MF simulations described above. The resulting Stokes spectral profiles and model coronal fields can then be analyzed as if they were observed, and compared with actual observations of cool stars.)

Francis Eparvier/University Of Colorado, Boulder
Improving Solar EUV Spectral Irradiance Models with Multi Vantage Point Observations

Solar EUV irradiance is a primary source of energy for the upper atmospheres of terrestrial planets. First-principles-based thermo/ionosphere models (e.g. TIE-GCM for Earth and MGITM for Mars) require solar EUV spectra as input. Simple F10.7-based proxy models are often used, but TIMED-SEE and SDO-EVE data have shown that models using four proxies from distinct temperature regions of the Sun better estimate the solar EUV. In addition, photoelectron models require 0.1 nm resolution spectra between 0-6 nm to properly account for Auger electrons that further ionize by electron impact in the planet s atmosphere.
The MAVEN mission to Mars is the first planetary probe to directly measure solar EUV in-situ with its EUVM instrument, providing an unprecedented opportunity to develop and validate new methods to estimate the solar EUV input at other planets, addressing the objectives of Focused Science Topic (FST) 1, Space Weather at Terrestrial Planets: Comparative Climatology. We propose to use MAVEN and Earth-based solar observations to meet the following three objectives: (1) Improve models of daily solar EUV irradiance at other planets; (2) Improve models of flaring solar EUV irradiance at other planets; (3) Develop a 0.1 nm resolution model of flaring irradiance in the 0-6 nm band validated by photoelectron measurements.
Objective 1 is met by developing a model using a variety of Earth-based proxies to produce daily irradiance values elsewhere in the solar system and validating the model against MAVEN-EUVM measurements made at different heliospheric longitudes. The EUVM measures transition-region, hot and cool corona emissions and hence covers a variety of solar irradiance variability. Earth-based proxies to be considered include linear interpolating standard proxies via Carrington Rotation, flux transport models (e.g. Air Force Data Assimilative Photospheric-flux Transport (ADAPT)), and helioseismology-derived far-side imagery such as those derived by SDO HMI and GONG. The comparison of the Earth-based proxies to EUVM measurements will help advance the understanding of center-to-limb variations (CLV) for EUV wavelengths and to improve the ability to forecast the effects of active region evolution as related to behind-the-limb active regions from Earth s view but visible to Mars.
Objective 2 is met by using simultaneous flare observations from Earth and Mars to characterize CLV effects, and updating flare irradiance models with recent advances to accurately capture the EUV gradual phase. Simultaneous measurements from Earth and Mars of both optically thick and thin emissions, a variety of which have already been made, provide an unprecedented opportunity to validate our capability of estimating solar flare irradiance elsewhere in the solar system. Flare irradiance models for Mars driven with Earth proxies will be validated with MAVEN measurements, and models for Earth driven with Mars proxies will be compared against Earth asset measurements.
Objective 3 is met by developing a model that uses the EUVM bands (as simulated using Earth measurements) as proxies and SXR reference spectra from the TIMED-SEE XPS model, spectral rocket measurements, and new SXR spectral measurements from the NASA MinXSS cubesat that is expected to be launched in June 2015. Validations will

include using the new spectra in photoelectron models and comparing the results to photoelectron observations at both Mars and Earth.
This proposal meets the FST 1 goals by advancing the understanding&of various planets&to solar forcing at various time-scales as well as providing improved solar EUV spectral models catered to planets other than Earth which will improve modeling and characterization of response of various terrestrial environments to varying solar output by using current observations to validate and calibrate models and allow these models to explore historical and climatological trends .

Jay Johnson/Princeton University
Identifying Causal Relationships in Stellar Activity Cycle Dynamics

Science Goals and Objectives: Magnetic activity similar to the sun is observed on a variety of cool stars with convection envelopes. Stellar rotation coupled with convective motions give rise to the development of strong magnetic fields. High precision spectroscopy and photometry measurements have detected cycles in the magnetic activity of stars similar to the 11 year solar cycle. The goal of this project is to discover causal relationships that govern stellar cycle dynamics utilizing spectroscopy and photometry measurements from sun-like stars. In particular, our investigation will relate basic observables, such as mass, metallicity, radius, rotation rate, depth of convection zone, and differential rotation rates with total solar irradiance and starspot properties including: total spottedness and switching of dominant activity between longitudes (flip-flop cycles). We will focus on determining which factors control the periodicity of starspots, how stellar cycles evolve with the age of stars, and which factors determine deep global minima in stellar cycle dynamics.

Methodology: We will utilize a set of information-theoretical tools that have been recently developed to examine cause and effect relationships in observational datasets. Transfer entropy and mutual redundancy are entropy-based measures of dependency (e.g. mutual information) that are based on conditional probabilities and can be used to measure the directed information transfer between two variables. The conditional redundancy will be used to systematically isolate controlling variables from a set of input measurements. Once causal variables are identified, we will construct coupling functions to describe the dependence of stellar cycle dynamics on the causal variables using the principle of maximization of information.

Proposed Contribution to the Focus Team Effort and Relevance to NASA: This investigation will contribute to the focus team effort 3.1.2 ``The Solar-Stellar Connection." The proposed techniques will be used to identify processes (variables) that control total solar irradiance and starspot cycles, including periodicity and deep global minima, and to construct nonlinear maps that capture the activity cycle dynamics and have predictive value. The proposed project relies heavily on collaborations with observers and modelers on the LWS team. Our plan is to work with observers on the team to compile a database of variables that characterize the magnetic activity cycle dynamics and to identify causal variables that control the dynamics. We will work with team modelers to evaluate the output from predictive models to ensure that they adequately capture the system dynamics, and we will use the principle of maximization of information to construct predictive models for starspot dynamics. Identification of observables and model parameters that control solar cycle dynamics will also advance Goal 1 from the Heliophysics Decadal survey ``Determine the origins of the Sun's activity and predict the variations in the space environment."

Han-Li Liu/University Corporation For Atmospheric Research (UCAR)
The Effects of Solar Minimum Irradiance Variability on Whole Atmosphere Climate

Using a state-of-the-art solar radiation MHD model, we will estimate the photospheric total solar irradiance (TSI) and chromospheric ultra-violet (UV) emissions under extreme quiet solar conditions. The proposed simulation employs very high spatial resolution to calculate changes in TSI from photospheric variations with different magnetic field configurations, and solar spectral irradiance (SSI) by performing radiative transfer in a few frequency bands. The total chromospheric variation will be estimated from these models by using the upward directed Poynting flux above the photosphere as a proxy, and can be related to the variation of photospheric TSI variation. These physically self-consistent estimates will then be used to drive the National Center for Atmospheric Research (NCAR) Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) to study the implications for the climate of the whole atmosphere system, including the bottom-up and top-down interactions of the ionosphere, thermosphere, mesosphere, stratosphere and troposphere. This will enable us to quantify the atmospheric climate state under extreme quiet solar conditions using physically-based minimum irradiance estimates, and will provide insights into the solar-climate connection. The solar TSI and SSI estimates will first be validated against existing observations under nominal solar minimum conditions, and these observed solar spectra be used to drive WACCM-X baseline simulations. The WACCM-X baseline simulations will be compared to the Chemistry-Climate Model Initiative (CCMI) results for validating the stratosphere, and to measurements of the mesosphere and lower thermosphere by the SABER instrument on the TIMED satellite. We will then perform WACCM-X simulations under extreme quiet solar conditions, using estimates obtained from the solar radiation MHD simulation. The WACCM-X simulations will be compared with the baseline simulations, to analyze the differences in the lower, middle and upper atmosphere. The unique capability of WACCM-X will enable us to investigate the mechanisms responsible for these changes, including direct radiative impact, and upward and downward coupling processes.

The purpose of this work is to constrain the lower limits of solar irradiance and create a grand minimum scenario based on a well-characterized photospheric magnetic field distribution using a small-scale dynamo MHD simulation, and to apply these constraints on the irradiance to study the whole atmosphere climate state. We will elucidate the mechanisms by which the middle and upper atmosphere influence tropospheric climate, and estimate the global and regional climate response to Grand Minimum conditions. Although it is not yet possible to accurately calculate actual solar irradiance under these conditions, it is feasible and timely to attempt to constrain the problem. Therefore, we will address basic questions concerning solar forcing and the response of the whole-atmosphere climate system:

(1) What lower limit constraint on TSI and SSI during Grand Minimum can be provided through solar modeling?

(2) How would the terrestrial atmosphere respond to this reduced irradiance, and what are the solar signals in space and terrestrial climate?

(3) What are the mechanisms of interaction between the upper and lower atmosphere, and between the atmosphere and ocean, that could amplify or reduce the terrestrial response to solar forcing?

The proposed study addresses strategic objectives of the Living With a Star (LWS) Sun-climate theme, and will contribute to the international Role Of the Sun and Middle-atmosphere-thermosphere-ionosphere In Climate (ROSMIC) project of SCOSTEP/VarSITI.

Ward Manchester/University Of Michigan, Ann Arbor
Solar Wind Interaction with the Mars Upper Atmosphere: The Impact of ICME Events

The study of the solar wind interaction with Mars upper atmosphere/ionosphere has recently received a great deal of attention, especially the investigation of ion escape fluxes due to its potential impact on the long-term evolution of the Mars atmosphere (e.g., loss of water) over its history. However, accurate estimations of ion escape fluxes from spacecraft data are difficult due to the complex geometry of the loss regions around Mars. This limitation necessitates global simulations, which couple the thermosphere/ionosphere and solar wind interaction regions for Mars. Such models can accommodate upstream solar wind conditions, solar EUV/UV irradiance conditions, and Mars planetary conditions self-consistently.

The major science goal of this current project is to investigate the responses of the Mars upper atmosphere/ionosphere to historical ICME events. Specific science goals include: (1) Investigate the 2-way coupled model (SWMF system) responses to specific ICME events. Simulate ICME upstream solar wind conditions for ICME events that have previously been observed and studied at Earth. Compare the Mars system model responses to available Mars datasets (e.g. MGS, Mars Express). (2) Contrast the Earth and Mars responses (both observed and modeled) to the same ICME events. Identify and quantify the role of the most important processes that drive major differences between the two planets. Determine how these processes that regulate ion losses are dependent on specific features of ICMEs.

We will simulate the space weather at Mars by coupling together four multi-fluid MHD models whose domains combine to encompass the solar atmosphere from the chromosphere to interplanetary space extending to Mars where the solar wind will be coupled to the Mars upper atmosphere. Specific tasks include the following: (1) We will modify the SWMF framework to provide a 2-way coupling to interactively link the Mars GITM code and the Mars multi-fluid MHD code. (2) Test the SWMF coupled system in a 1-way linked configuration (upward then downward) to establish two baselines against which 2-way coupling can be compared. (3) Finalize a fully 2-way coupled system, activating both upward and downward coupling capabilities. Compare the SWMF model outputs from this coupled configuration with each of the 1-way coupled configurations above for the same upstream solar wind conditions. This will be accomplished making use of both available Mars spacecraft datasets and coupled global model simulations to produce self-consistent interaction of the solar wind environment with the Mars upper atmosphere/ionosphere. For specific ICME events, simulated solar wind conditions will be used to drive the coupled model system. Model data comparisons will then be used to validate the models. The solar corona will be simulated with AWSoM, which describes the solar wind as a two-temperature plasma (electrons and protons) driven by Alfven wave turbulence. This model is coupled to an inner heliosphere model, which propagates the solar wind to Mars.

This project will make the following contributions to the focused science team: (1) Quantitatively link the extremes of solar wind variability during ICMES events the corresponding TI responses for the first time, which will benefit disparate Mars upper atmosphere communities. (2) Modeling will provide a context for ICME signatures in the Mars upper atmosphere densities and temperatures for events observed by MAVEN, which will be most useful for Mars data interpretations studies making use of models. (3) The modeling will permit both Earth and Mars scientist to contrast the relative responses by Earth and Mars to ICME events, thereby uncovering physical reasons for the difference responses. (4) Predicted particle fluxes will be available for use by other modelers, which provides a way to compare model responses to the same forcing. This is needed in Aeronomy studies if possible.

Naomi Maruyama/University Of Colorado, Boulder
What are the plasma sources for the long-lived plasmaspheric drainage plumes?

Central objectives: This project is focused on understanding the source of plasma to sustain the long-lived plasmaspheric drainage plumes observed during long-lived high-speed-stream-driven magnetic storms.

Motivation: The long-lived plumes occur during long-lived high-speed-stream-driven storms with durations up to 11 days [Borovsky et al., 2014]. The plasmaspheric drainage plumes can cause energetic particle precipitation via electromagnetic ion cyclotron (EMIC) waves in the magnetosphere [Spasojevic et al., 2004]. Furthermore, the plumes influence the rate of dayside magnetic reconnection [Borovsky and Denton, 2006; Borovsky, 2014], which controls the amount of solar wind-magnetosphere-ionosphere coupling. The previous studies have suggested several mechanisms to explain the plasma source for the long-lived plumes, such as including substorm disruption of the nightside plasmasphere, radial transport of plasmaspheric plasma in velocity-shear-driven instabilities near the plasmapause, or high upflux of cold ionospheric plasma from tongue of ionization (TOI). However, none of these mechanisms have succeeded in explaining the observed plumes in a satisfactory manner. Theoretical models of ionosphere and plasmasphere used in previous studies substantially underestimate the observed fast refilling rates [Denton et al., 2014].

Science Questions: The overall objectives of the project are to elucidate the source of plasma to sustain the long-lived plasmaspheric drainage plumes. The specific questions are as follows:(1) What are the possible mechanisms to explain the observed fast refilling rates, and what is their relative importance?; (2) What is the role of the mass coupling between ionosphere and plasmasphere within the SED/TOI in the long-lived plumes?; (3) What is the role of the magnetospheric electric field in eroding the plasma at first and later sustaining the plumes during long-lived high-speed-stream-driven storms?

Methodology: The Ionosphere-Plasmasphere-Electrodynamics (IPE) model [Maruyama et al., 2015; Sun et al., 2015] will mainly be used to address the science questions as well as the fully updated 2014 version of the Sheffield University Plasmasphere-Ionosphere Model (SUPIM-14). A kinetic plasmasphere model [Pierrard and Stegen., 2008] will be used to evaluate the kinetic process in the plume formation. The coupled CTIP/RCM will provide a storm time neutral atmosphere to drive IPE. OpenGGCM will provide the electric field in the outer magnetosphere during long-lived high-speed-stream-driven storms to drive IPE. Refilling rates from the model simulations will be validated comprehensively against the observations from the topside ionosphere by DMSP and from the plasmasphere by NASA Van Allen Probes and THEMIS, and by LANL spacecraft in geosynchronous orbit. Numerical experiments will be performed with a suite of state-of-the-art physics-based models to test and verify the various possible hypotheses proposed for explaining the long-lived plumes.

Perceived Significance: This proposal will target the LWS support for the Scientific Committee on Solar Terrestrial Physics (SCOSTEP) Variability of the Sun and Its

Terrestrial Impact (VarSITI) International Program. In particular, it will address the goals of the Specification and Prediction of the Coupled Inner-Magnetospheric Environment (SPeCIMEN) project. The outcome of this work addresses quantitative prediction and specification of the Earth s inner magnetospheric environment based on Sun/solar wind driving inputs.

Viacheslav Merkin/Johns Hopkins University
Storm-time magnetosphere: Specification and prediction using a global MHD model with empirical ring current pressure

Goals and objectives
A rich set of magnetic field measurements made by historic and current NASA missions goes largely unused by first-principles predictive global models of the geospace environment. These data have been intelligently mined and integrated into empirical magnetic field models of the Tsyganenko family with the most recent incarnation (TS07D) providing unprecedented spatial resolution. This empirical model gives access to the wealth of observational information that is critical in supplying the missing physics to global magnetospheric models. In particular, the hot pressure in the inner magnetosphere is created by physical processes that are beyond the magnetohydrodynamic (MHD) approach commonly used. In this project we propose to extract the equilibrium magnetic pressure from the empirical TS07D model and use it to augment our global MHD model thus yielding a predictive global model of the storm-time geospace environment. The specific tasks include: (i) Derive the equilibrium pressure from TS07D model for a number of selected storm events during the Van Allen Probe (VAP) era and compare with VAP data; (ii) Modify the equation of state in the global MHD model using the empirical plasma pressure; (iii) Perform coupled empirical pressure-global MHD simulations for the previously selected storm events; (iv) Validate the simulations with VAP data.

These transformative modeling capabilities will lead to resolution of fundamental outstanding issues of magnetospheric physics. In particular, our science investigation will address the following questions: What are the global effects of the inner magnetosphere hot plasma pressure in the storm-time evolution of the magnetosphere? How does the distribution of plasma in the plasma sheet influence the formation and evolution of ring current? Due to the limited scale of the project, we will restrict our detailed investigation to global effects in the night-side magnetosphere. However, the effects of the inclusion of hot plasma pressures will be much more far going and may include the magnetosphere-ionosphere coupling, saturation of the polar cap potential, boundary instabilities, and global magnetospheric properties such as the magnetopause standoff distance.

Methodology
We will use the TS07D empirical model of the magnetospheric magnetic field to derive equilibrium pressures in the inner magnetosphere. These will be used to modify the

equation of state in the Lyon-Fedder-Mobarry (LFM) global MHD model of the magnetosphere. The resulting global MHD model with empirical pressure corrections will be used to perform simulations of geomagnetic storms, which will be validated with Van Allen Probes data, and used to address the science questions posed.

Relevance to SCOSTEP/VarSITI
This project is an ideal fit for the SPeCIMEN theme of the VarSITI program. In particular, it addresses directly all four aspects emphasized in ROSES B.6 as it elaborates and attacks the following science targets: (i) help understand the response of the inner magnetosphere as a coupled system to solar wind and interplanetary magnetic field forcing; (ii) improve predictive capabilities with specific emphasis on model integration; (iii) couple different magnetospheric regions affecting the state of the inner magnetosphere; (iv) fuse empirical and first-principles approaches. Model development will constitute only a minor part of the proposed effort with emphasis placed on storm-time magnetosphere simulations and addressing the science questions in concert with VAP observations.

Andres Munoz-Jaramillo/Georgia State University Research Foundation, Inc.
Geophysically Relevant Prediction of Solar Cycle 25

Solar cycle prediction has been traditionally limited to an estimation of the number of visible sunspots; a quantity that from a practical point of view is of little to no use. Part of the reason is a strong disconnection between the study of the dynamo mechanisms that cause the solar cycle, and studies of the impact of the solar cycle on the heliosphere. However, understanding the Sun-Earth connection and the impact of solar activity on the Earth's magnetosphere, atmosphere and climate requires much more than the compartmental study of heliospheric scientific domains.

The primary objective of this proposal is to couple 3D kinematic dynamo, solar wind, and cosmic ray transport models, with aims to predict solar wind conditions and cosmic ray flux inside the heliosphere for the oncoming solar cycle 25. This goal will be achieved by: 1. Carefully integrating the three models so that they match observations, 2. Assessing the sensitivity of the integrated system to degradation of the input data, and 3. Testing the viability of synthetic input data for predicting solar wind properties and cosmic ray flux at 1AU.

This proposal represents a clear effort to break traditional scientific boundaries by coupling 3D kinematic dynamo, MHD solar wind, and cosmic ray transport models; effectively creating a mega-computational domain spanning all the way from the tachocline into the outer edge of the heliosphere and laying down the foundation that will lead to a new generation of solar cycle predictions, which will not be limited to a simple number of sunspots in the photosphere. Instead, it builds the necessary framework to provide agencies and industry with geophysically relevant quantities such as solar wind properties and galactic cosmic ray flux at 1AU.

By developing the framework necessary to predict solar wind properties and GCR flux, the research in this proposal represents a directed effort at making solar cycle predictions accessible and useful to agency and industry planners. This is of critical importance for the planning and operation of long-term missions, especially manned missions such as long-term astronaut visits to the international space station and the intended visit of humans to an asteroid by 2025 and Mars in the 2030s -- goals outlined in the bipartisan NASA

Aaron Ridley/University Of Michigan, Ann Arbor
Understanding the effects of solar flares on the upper atmospheres of Mars and Venus

The upper atmospheric reaction to solar flares and solar extreme ultraviolet (EUV) radiance has been studied extensively at Earth using both data and models. At Mars and Venus, the reaction has not been studied nearly as much. While the slowly varying solar cycle variations in the solar EUV are known to cause changes in temperature, winds and densities, it is unclear how rapid variations in the solar EUV will cause changes at Mars and Venus.

These planets are somewhat similar to each other and Earth in that they each have both thermospheres and ionospheres. While the Earth has a strong magnetic field, Mars's magnetic field is quite weak and localized and Venus has no magnetic field. Prior studies showed that the magnetic field plays a role in the ionospheric response to solar flares at Earth, but it is not clear whether this would be true at Mars.

Both Earth and Mars have a rotation period that is similar, which allows a relatively weak day-to-night temperature gradient, and therefore a weak change in the speed of propagation from the dayside to the nightside for the traveling atmospheric disturbance (TAD) from the flare. At Venus, however, the rotation rate is quite small, and a strong terminator exists. This would cause a large change in the wave speed from day to night, and may alter the propagation characteristics of the TAD.

We plan to quantify the role that traveling atmospheric disturbances play in shaping the upper atmospheres of Venus and Mars through the use of a Global Ionosphere Thermosphere Model (GITM) that has been adapted for use at both Venus and Mars as well as Earth. We will focus on disturbances that are launched as a result of solar flare activity and investigate the behavior of these waves and how they depend on the differences in the temperature and density of the upper atmosphere as well as look at the role of Mar's small-scale magnetic fields plays in the global transfer of energy and momentum.

Finally, we will perform data-model comparisons using a variety of datasets, including observations from MAVEN (IUVS, NGIMS, ACCEL), MGS (RS, ACCEL), Mars Express (MARSIS), and Venus Express, in order to better understand the physical processes that shape the upper atmospheres of each planet.

While we will not study TADs and flares at Earth, we will compare the results of the studies at Mars and Venus to the published results at Earth, in order to put the results into context.

Steven Saar/Smithsonian Institution/Smithsonian Astrophysical Observatory
Observational Constraints and Tests for Dynamos in Solar-like Stars

Data from other stars can help solar dynamo models, putting more on constraints on the models, and then testing them over a wide range of properties. A surprising amount of information can be gleaned with careful analysis of a variety of stellar data. Starting with existing databases and published values, and later using data generated by other FST and the growing VSSO database, we propose to: 1) Generate cycle periods, amplitudes, secondary periods, rotational periods, surface differential rotation, diffusivity and meridional flow estimates, identify activity belts, and see how all these vary with mass and age. 2) Explore mass and age dependence of stars which may be in magnetic grand minima, and improve Ca II HK calibration, 3) Determine how the rates of large flares and CMEs vary with mass and age, and 4) explore new dynamo cycle proxies. These will be generated from existing data and datasets initially and sent to the dynamo modeling teams and the VSSO; later improvements and additional constraints will be derived from new data coming into the VSSO and from other sources. These results will lay a crucial foundation for improving our physical understanding of the dynamos of solar-type stars and how they evolve in time.

Gavin Schmidt/NASA Goddard Space Flight Center
Consistent simulations of radiative and particulate impacts of solar activity on climate

Our investigations will focus on answering the question of whether we can understand the processes producing solar-related variance in climate observations using our best simulations of the physical drivers, and what the relative importance of the different mechanisms are on a variety of timescales. We propose to utilize the Goddard Institute for Space Studies (GISS) ModelE to examine the impact of quasi-decadal and longer-term changes in solar activity in the historical context of the 20th and early 21st Century climate. ModelE is uniquely appropriate for this task since it has well-tested whole-atmosphere chemistry (up to the mesosphere) that produces a good match to solar-cycle variability in atmospheric composition and surface regional climate responses. Additionally, new versions of the model with higher vertical resolution (and/or a model top near the mesopause) are able to self-generate a quasi-biennial oscillation (QBO), which has been hypothesized to be a key modulating factor in coupling upper and lower atmospheric impacts of solar change. Furthermore, using the MATRIX aerosol microphysical scheme we have the capacity to simultaneously assess the impact of changes in ionization (via the solar modulation of Galactic Cosmic Rays (GCR)) on fine aerosols and the subsequent growth into cloud condensation nuclei.

We will develop a set of coherent solar-related drivers that can be used simultaneously or separately consisting of time-series of total solar irradiance (derived from the SORCE-based reconstruction), with full variations in the relevant spectral bands and time and space variations in ionization. We propose to perform an ensemble of historical (1850-2014) coupled ocean-atmosphere simulations using (at minimum) four subsets of forcings: an all-forcing case (including GHGs, ozone depleting substances, aerosols, volcanoes, land use/land cover change, short-lived reactive gases and all solar factors), an all-forcing case only including radiative solar effects, and two solar-only cases with purely radiative, and with radiative and ionization changes. These simulations and input datasets will be publicly archived with complementary simulations performed under the auspices of the Coupled Model Intercomparison Project (CMIP6).

Simulations will be compared to solar cycle variance inferred from SABER O3 and temperature in the upper atmosphere, Modern-Era Atmospheric Reanalyses (MERRA), and SAGE, MLS and SBUV retrievals. In addition, we will compare the output to the HALOE water vapor and MSU/AMSU/SSU temperatures where they are coherent with the solar cycle. We will be particularly focused on transient impacts on stratospheric sudden warmings, tropospheric annular modes (impacting regional climate and ocean circulation), and changes in tropical precipitation in order to improve attribution and forecasts of solar-related climate change and assess the relative importance of irradiance vs. energetic particle impacts.

Mikhail Sitnov/Johns Hopkins University
Empirical specification and forecasting of the inner magnetosphere magnetic field

Science goals and objectives: The objective of this project is to investigate the influence of solar wind and IMF parameters on the structure and evolution of the magnetic field in the inner magnetosphere. This knowledge will be used to develop capabilities for quantitative prediction and specification of the inner magnetosphere environment. A distinctive feature of this study is the use of a new generation of empirical geomagnetic field models that (i) are free from ad hoc distortions characteristic of the past custom-tailored models; (ii) have the spatial resolution capable of resolving the key morphological features of the inner magnetosphere; (iii) respond to multiform variations of solar wind driving, including its trends and memory effects. Earlier empirical models (e.g., TS05) used global indices or pre-defined functions of the solar wind/IMF parameters as their input, as well as custom-tailored modules for the major current systems (e.g., partial and symmetric ring currents). A new approach, suitable for retrieving from data the actual shape of magnetospheric currents and taking consistently into account trends and integral effects of the solar wind driving was implemented in the new TS07D model. We propose another major advance in this direction with the main goal to 1) provide a high accuracy specification of the inner magnetosphere magnetic field and 2) determine key factors of the solar wind driving, which control the storm-time magnetic field.

Methodology: To achieve these goals we first propose to fit TS07D with modern Van Allen Probes and THEMIS data as well as historical data from the Polar mission to determine the number of basis functions describing the equatorial currents, which resolve the structure of the storm-time inner magnetosphere, including radial and local time current distributions around the pressure peak. Second, we will investigate the flexibility of the new system of field-aligned currents, assuming their variation in latitude and local time to match the present equatorial current expansion. The new system reproduces the Harang discontinuity effect. Third, we will investigate the sensitivity of the new empirical magnetic field specification to various factors of the solar wind driving. So far it was determined by the solar wind electric field parameter vBz, Sym-H index and its time derivative. In this project we investigate magnetospheric response to inputs using the preceding solar wind/IMF parameters only and thus providing empirical forecasting capability. We will also investigate the effects of the extension of the input state due to the IMF clock angle, solar wind density, velocity, and turbulence amplitude. Since all key elements of the model have already been designed and tested its further development will constitute only a minor part of the proposed effort.

Relevance: The project s objective is consistent with the overarching goal of the LWS SCOSTEP/VarSITI Program element SPeCIMEN to provide quantitative prediction and specification of the Earth s inner magnetospheric environment based on Sun/solar wind driving inputs . The geomagnetic field is one of the main parameters that determine the state of the inner magnetosphere. It plays a key role in coupling the inner magnetosphere processes, because it determines the shape and evolution of radiation belts, provides the mapping between the inner magnetosphere and the ionosphere, allows one to reconstruct the global current systems, their 3D structure and closure paths, and even to assess the plasma pressure distribution from the quasi-static force balance equation. Thus, this project directly addresses SPeCIMEN s goal to understand how the inner magnetosphere responds as a coupled system to Sun/solar-wind driving . Moreover, since the proposed empirical specifications are driven by data rather than by an ad hoc model structure, they are particularly suitable for integration with other models, both empirical and first-principles ones.

James Slavin/University Of Michigan, Ann Arbor

Space weather at Mercury: The effect of interplanetary coronal mass ejections on Mercury s atmosphere and magnetosphere

The MESSENGER mission has found that Mercury has a magnetic field strong enough to stand off the solar wind from the surface under average solar wind conditions. However, the degree to which the surface is shielded under extreme conditions, especially interplanetary coronal mass ejection (ICME) impacts, is not known. The high subsolar pressure and intense reconnection accompanying these events will tend to expose the surface to direct solar wind impact. However, Mercury has a very large electrically conducting core, which is expected to decrease the compressibility of the magnetosphere due to solar wind-driven induction currents. Mercury s tenuous atmosphere is maintained by photo-desorption, micrometeorite impact vaporization, and sputtering from the surface. In this manner the solar wind in the inner solar system, Mercury s magnetosphere, atmosphere, and the planet itself are all coupled and believed to respond strongly to solar activity. The primary goal of this investigation is to discover response of Mercury s atmosphere and magnetosphere to ICMEs. Our investigation will use numerical simulations and MESSENGER observations of Mercury s atmosphere and magnetosphere to: 1) understand and characterize the structure of ICMEs at Mercury s orbit (0.3 0.5 AU); 2) discover the changes in the magnetosphere during ICME impact especially changes in configuration and internal dynamics that will affect the flux of solar wind and magnetospheric charged particle flux to the surface and produce sputtered neutrals; and 3) determine the average and maximum effect of ICME impact on Mercury s atmosphere. The propagation and modeling of ICMEs to Mercury in the MESSENGER observations will be carried out using WSA-ENLIL and the Alfven Wave Solar Model (AWSoM) MHD simulations. These models will also be used to reconstruct historical events, such as the Bastille Day 2001 and Halloween 2003 ICMEs, but as they would have appeared at Mercury s orbit. The magnetosphere will be modeled with the BATSRUS global MHD model with embedded and two-way coupled Particle-in-Cell (PIC) domains using the iPIC3D code. The use of Hall MHD in combination with embedded regional PIC (MHD-EPIC) allows a proper representation of the fast reconnection. This is necessary because of the very high reconnection rates measured by MESSENGER. The interior of Mercury will be modeled as a layered finite resistivity body that allows for induction currents. The response of Mercury s neutral exosphere, including sources/losses and transport of neutrals and photo-ions, will be investigated with the Adaptive Mesh Simulator (AMPS). The BATSRUS, iPIC3D and AMPS models are integrated into the Space Weather Modeling Framework (SWMF) and coupled together. This sophisticated coupled model can capture the response of the exospheric neutral and ion species to ICMEs by accounting for the variation of the sputtering source. The results of these simulations will be compared, validated, and used to guide analysis of the observations returned by the MESSENGER mission. Our contribution to the Space Weather at the Terrestrial Planets Focused Science Topic will be the improved understanding, characterization and modeling of the effects of ICME impact on surface bounded exospheres (Mercury and Moon) and intrinsic field magnetospheres of terrestrial-type bodies (Mercury and Earth).

Pavel Travnicek/University of California, Berkeley
Space Weather at Mercury and its Effect on the Exosphere

In this proposal, space weather at Mercury and its effects on the exosphere will be studied. It is now well established that Mercury has an intrinsic magnetic field and as such joins the Earth as the other inner planet in our solar system to have a magnetosphere. Because the strength of Mercury s magnetic dipole is relatively weak, its magnetosphere is considered in some sense to be like a miniature version of Earth s magnetosphere. There are, however, some important differences between the two magnetospheres. One is that at Mercury the planet occupies a much larger volume of the inner magnetosphere compared to the Earth, and another is that Mercury has a much weaker atmosphere and ionosphere. Also, due to its proximity to the Sun, Mercury is buffeted by a much stronger, highly variable solar wind and by virtue of its relatively small magnetic moment, it has a much more dynamic magnetosphere with global reconfigurations occurring on the time scales of a few minutes or less, compared to 10 s of minutes to hours at the Earth. Thus space weather at Mercury is likely to be more extreme and volatile than at Earth, which can strongly affect its thin atmosphere. Understanding Mercury s atmosphere, strictly speaking a surface-bounded exosphere, is vitally important for understanding the composition of the surface, the loading of the magnetosphere with heavy ions, and the identification of the putative volatile substances that may be sequestered in partially permanently shadowed craters near the poles. Mercury s tenuous, collisionless, neutral exosphere with Na, K, and Ca was originally observed spectroscopically and this has been confirmed by direct measurements made by instruments mounted onboard the MESSENGER spacecraft, which has been in orbit around Mercury since March 2011. MESSENGER has also shown that ionized versions of these and other heavy atoms are also present around Mercury.

Shuhui Wang/Jet Propulsion Laboratory
Solar Forcing Impacts on Middle atmospheric Ozone-controlling HOx and NOx chemistry and the climate

Solar cycles (e.g., 11-year cycle) and the associated UV variability cause quasi-periodic signals in atmospheric temperature and composition, which has to be accurately quantified in order to better understand the complex changes in the O3 layer and climate. However, large discrepancies between observations and models as well as disagreements among various observations remain unresolved. The large uncertainties in solar spectral irradiance (SSI) variabilities adopted by climate models results in different or even contradictory predictions of atmospheric O3 responses to solar forcing, but all models find agreement with observations from certain locations and/or selected parts of the middle atmosphere, making it puzzling to quantify natural O3 variability on decadal scale.

While O3 solar cycle variabilities are complex, involving direct photolysis and many indirect effects, the catalytic HOx (OH and HO2) and NOx (NO and NO2) chemistry that largely controls middle atmospheric O3 loss plays a major factor. Previous work reveals that HOx chemistry variability likely dominate O3 solar cycle responses above ~40 km. However, models significantly underestimate OH variability during the solar 11-year cycle even when using the largest observed SSI variability. At lower altitudes where NOx catalytic cycles take over the role of HOx in controlling O3 loss, surprisingly large discrepancies between models and observations were also reported. Therefore, in addition to SSI, uncertainties in our current understanding of the HOx-NOx-O3 chemical system could be another major source of discrepancy. This is echoed by recent studies on OH responses to solar 27-day cycles: Models underestimate observed OH variability although short-term SSI variability uncertainties are small. Given these puzzles, understanding solar-induced variabilities in O3-controlling HOx and NOx chemistry and quantifying the uncertainties could be the key to help resolve current discrepancies in middle atmospheric responses to solar forcing and to provide insights for the resulting climate impacts.

We propose to use various observations and targeted modeling work to examine the mechanisms that control middle atmospheric variability in the HOx-NOx-O3 system. We will use HOx data from Aura/MLS, long-term ground-based OH measurements, NO2 data from NDACC stations and various satellites, and the ~30 year O3 composite from GOZCARDS. Our modeling work will involve a 1-D chemical-transport model and the 3-D WACCM model. We focus on: (1) Establishing and quantifying the correlations of solar-induced variabilities in the involved key species; (2) Understanding the spatial distribution of variabilities and investigating disagreements among observations and between models and observations; (3) Validating chemical modules by quantifying uncertainties in the involved chemical kinetics and adjusting it within recommended uncertainty ranges to compare with observations; (4) Provide insights for SSI debates and implications for climate models.

By quantifying uncertainties in chemistry and comparing model variability with observational signals over short time scale when SSI uncertainty is small, an optimized state of chemical module will be proposed, which can be used to study longer time scale (11-year cycle) variability when SSI uncertainty is large. This will provide new insights to help explain the unresolved discrepancies of O3 variabilities and important implications for models studying Sun-climate interaction.