Heliophysics Living With a Star Science
Abstracts of selected proposals
(NNH19ZDA001N-ROSES)

Below are the abstracts of proposals selected for funding for the Heliophysics Living With a Star Science 2019 program. Principal Investigator (PI) name, institution, and proposal title are also included. Sixty-five proposals were received in response to this opportunity and 30 were selected for funding. Twenty–six proposals were initially selected on July 31, 2020. Two more proposals were selected on September 2, 2020, and an additional two were selected on September 23, 2020.

Veronica Bindi/University of Hawaii
Forecasting of galactic cosmic rays in the Heliosphere over different solar cycles and Forbush decreases

Science Goals and Objectives.
Galactic cosmic rays (GCRs) constitute a major radiation hazard for deep-space human exploration to Moon and Mars. GCRs vary on different time scales: from a few days, driven by short-term solar wind disturbances, to the well known 11- and 22-year solar cycles, to even longer periodicities. Studying the time dependence of GCRs is paramount to a better understanding of the origin of the Sun activity and to predicting variations in space environment.
The goal of the proposed research is to make accurate physics-based forecasting of the deep-space GCR spectra on various time scales, by combining numerical models for GCR transport in the heliosphere with multi-point observations of GCRs in a wide energy range, spanning several solar cycles.

Methodology.
We will use a 3D steady-state model to analyze the long-term variations of GCRs, and a 2D time-dependent model to study Forbush decreases.
Monthly averaged GCR data collected by ACE, Voyager 1 & 2, Ulysses, PAMELA, AMS-02, and other spacecraft will be fit to spectra obtained from the 3D numerical model, using a Markov Chain Monte Carlo (MCMC) technique to estimate a posterior probability density function (PDF) over the free parameters of the model. We propose to speed up the MCMC inference by training a deep neural network (DNN) that approximates the numerical model output, using a coarse grid of known solutions as training data to predict the GCR spectra from model parameters. Furthermore, DNN gradients enable the use of faster sampling algorithms in the MCMC.
We will model, with linear and neural network regressions, the relation between the inferred parameters and common features of the solar cycle, e.g. sunspot number (SSN), open magnetic flux, and F10.7 index. This will enable us to predict GCR spectra at any location in the heliosphere as a function of observable quantities, and to estimate the

spectra uncertainties from the PDFs of the model parameters. The predictions will be validated on monthly averaged neutron monitor (NM) count rates collected since the 1950s, propagating the modeled GCR fluxes through the Earth atmosphere with the NM yield function by Mishev et al (2013).
We will investigate the effect of a Dalton-like minimum on the GCR intensity by reproducing the abundances of 10Be in ice cores and 14C in tree rings between 1600 and 2000 with the modeled GCR fluxes predicted by the historical SSN time series. For this, we will rely on the 10Be and 14C production, transport, and deposition model by Poluianov et al (2016).
Interplanetary coronal mass ejections (ICMEs) will be modeled as propagating diffusion barriers, and hourly averaged data from NM and ACE during Forbush decreases will be fit to the output of the 2D time-dependent code, using the DNN-accelerated MCMC approach previously developed. Similar to the long-term analysis, we will relate the inferred parameters with ICMEs properties, e.g. maximum solar wind speed, magnetic field, and temperature in the ICME cloud. This will provide an estimation, with corresponding uncertainty, of the GCR shielding effect of ICMEs.

Proposed Contributions to the Focused Science Team Effort
The proposed investigation directly addresses Goal 1 of LWS "Deliver the understanding and modeling required for useful prediction of the variable solar particulate and radiative environment at the Earth, Moon, Mars and throughout the solar system", by improving two numerical models of GCR modulation in the heliosphere and Forbush decreases induced by extreme CME events.
The simulated GCR spectra will be compared with spacecraft and Earth-bound measurements, so that the models can be validated in a wide range of physical conditions. Particular care will be devoted to quantify the uncertainties on the various predictions by propagating the uncertainties of the models parameters to the GCR spectra.

Yun-Ju Chen/University of Texas at Dallas
Hemispheric asymmetries of the electrodynamic environment in the middle and high-latitude ionosphere

Hemispheric asymmetries in the ionosphere arise naturally from seasonal differences in the behavior of the plasma and neutral gases and from the offset between the geomagnetic and geographic poles in each hemisphere. Hemispheric asymmetries also arise from the interaction of the geomagnetic field with the solar wind, which is dependent on the orientation of the interplanetary magnetic field with respect to the geomagnetic field. These hemispheric asymmetries appear in the plasma density and electrodynamic environment of the high and middle latitude ionosphere either directly due to changes in the ionospheric conductance and neutral winds that are dependent on solar zenith angle, or indirectly by mapping of electric potentials, modified by field-aligned potential drops, between the ionosphere and the magnetosphere.
We propose to investigate hemispheric asymmetries in the middle and high-latitude ionosphere by focusing on three main questions

1) How are hemispheric differences in the electric field and associated plasma motions in the auroral zones related to hemispheric differences in the energetic particle precipitation that influence the ionospheric conductance and indicate the presence of field-aligned potential drops?

2) How do hemispheric differences in the ionospheric conductance at middle latitudes affect the current closure associated with penetration electric fields equatorward of the auroral zone?

3) How do interhemispheric differences in the plasma convection pattern and geographical offsets in the magnetic poles combine to produce interhemispheric differences in the plasma density distribution?

Addressing these questions will require the identification of hemispheric differences in the ionosphere with respect to their connection to the equatorial plane of the magnetosphere and the condition of the external drivers and ionospheric conductance. Publicly available data from the Defense Meteorological Satellite Program will be used in this study to describe the plasma motion, the particle precipitation, and the field-aligned current density in each hemisphere. Regional measurements of total electron content (TEC) from sites distributed in mid-latitude and high-latitude regions in each hemisphere, will be utilized to illustrate the differences in the plasma density distribution. An open source magnetic field model, including nominal magnetospheric current systems, will be utilized to collocate observations along the same magnetic flux tube in the ionosphere and the equatorial plane of the magnetosphere.

Our investigation will focus on identifying systematic variations in the ionospheric potential distribution across the auroral zone in each hemisphere that are related to systematic variations in the average energy and energy flux of the precipitating particles. This will establish the degree to which interhemispheric differences in ionospheric potential distributions may be accounted for by field-aligned potential drops. We will also examine the sub-auroral penetration electric field and the TEC in each hemisphere associated with storm time evolution of the high latitude convection pattern in order to examine the influence of ionospheric conductance on the region-1 and region-2 field-aligned current systems. In addition, comparing TEC measurements in the northern and southern polar, auroral and mid-latitude regions will quantify changes in the ionospheric plasma density attributable to transport and geographical offsets with respect to the magnetic poles.

This work will provide observational insights that will advance our understanding of interhemispheric asymmetries in ionospheric electrodynamics. However, we expect that our results will be integrated with other focus team activities to provide a complete link between ionospheric asymmetries and the dynamics of the ionospheric-magnetosphere-solar wind interaction.

Richard Collins/Univeristy of Alaska Fairbanks

Wave-Driven Asymmetries in the Ionosphere-Thermosphere due to Asymmetries in the Northern and Southern Polar Vortices

The goal of this project is to understand how hemispheric asymmetries in the polar vortices create hemispheric asymmetries in the ionosphere-thermosphere through coupling by gravity waves (GW). The polar vortices have significant hemispheric asymmetry, where there is the stark contrast in the strength, stability, persistence, and breakdown timing of the polar vortices in the two hemispheres. The northern vortex is buffeted by stronger planetary wave activity is weaker than the southern vortex. The higher level of planetary wave activity in the northern hemisphere results in major Sudden Stratospheric Warmings (SSWs) where breaking planetary waves disrupt the vortex and reverse the wintertime circulation of the middle atmosphere. These wind reversals change the propagation paths for different populations of gravity waves through the middle atmosphere. Low wind speeds block the propagation of orographic GWs while the wind reversal also changes the population of non-orographic GWs that pass into the ionosphere-thermosphere thus reversing their forcing of the ionosphere-thermosphere when they finally break. Major SSWs are rare in the Antarctic with only one occurring in the last half-century. Thus through the action of SSWs on the polar vortices there is a systematic hemispheric asymmetry in the propagation of GWs into the wintertime polar ionosphere-thermosphere.

The direct impact of GWs on the ionosphere-thermosphere has only recently been appreciated. Model studies show that GWs breaking in the ionosphere-thermosphere can drive wind perturbations in the E- and F-regions that are comparable to the background winds. Lidar observations and model studies have shown that breaking gravity waves produce secondary waves that propagate further into the thermosphere extending the reach of wave coupling to higher altitudes. These effects are not currently included in circulation models though the magnitude of these effects is similar to the reported discrepancies between current space weather models and observations.

This project will employ both satellite- and ground-based observations to characterize the wintertime GW activity and reanalysis data to characterize the circulation of the polar vortices.. The project will combine new data sets from AIM/CIPS, with established satellite data sets (e.g., TIMED/SABER, Aqua/AIRS, Aura/MLS) to characterize the GW activity in the vicinity of the polar vortices. Lidars at McMurdo, Antarctica and Chatanika, Alaska have accumulated multi-year observations over a wide range of altitudes (stratosphere to thermosphere) and variables (density, temperature and/or wind) that characterize waves and their environment. These lidar measurements will support investigations of the propagation and generation of GWs, and extend the interpretation of the satellite measurements. The different instruments are sensitive to different parts of the wave spectrum and the combination of instruments will provide a more complete view of GW activity. SuperDARN radar measurements characterize GWs in the ionosphere-thermosphere through measurements of medium-scale ionospheric disturbances and provide observations across the polar regions. These SuperDARN measurements have shown that the occurrence of ionospheric disturbances in the Arctic is correlated with the meteorology of the polar vortex consistent with variations in the propagation of GWs. The project will establish the observational basis for a hemispheric asymmetry in GW activity in the middle and upper atmosphere driven by the meteorology of the polar vortices. This project will be integrated into modeling studies of the ionosphere-thermosphere associated with the comprehensive effort of the Focused Science Topic (FST).

Anthea Coster/Massachusetts Institute of Technology
Model-Data Exploration of Hemispherical Asymmetries in the Magnetosphere/Ionosphere System

Science Goals and Objectives: We are proposing a comprehensive effort to explore several salient hemispherical asymmetries in the coupled magnetosphere-ionosphere (MI) system that are related to or driven by specific asymmetries and variability of solar wind/IMF field, higher-order moments and dipole tilt in the intrinsic geomagnetic field, and the resulting dynamical processes in plasma behavior. The project will focus on these unexplained phenomena:
(1) What is the nature of the observed dynamics and spatial distribution (specifically the longitudinal variations) of the sub-auroral polarization stream (SAPS) electric field structures and the storm enhanced density (SED) feature during geomagnetic storms at subauroral and middle latitudes?
(2) What are the drivers and mechanisms causing the observed tongue of ionization (TOI) and related density structures over the polar caps, and the patterns of ExB ionospheric convection pattern, and their observed hemispheric asymmetries?
(3) What processes control the hemispheric asymmetry in both the location and strength of the equatorial anomaly structures as observed during both quiet and disturbed conditions?
An accompanying goal will be further development of the coupled first-principles ionosphere-inner magnetosphere numerical model SAMI3-RCM.
Methodology: The goals will be accomplished by combining theoretical and empirical modeling efforts with a comprehensive observational program. The phenomena to be studied will be characterized (in event studies and statistically) with data analysis at the MIT Haystack Observatory utilizing their extensive GNSS TEC database, their access to SuperDARN observations, solar wind data from ACE, and the new GOLD data. Specific time periods for further analysis will be selected and additional data will be gathered for team analysis from incoherent scatter radars, SuperMAG, Iridium/AMPERE, DMSP, and TIMED GUVI. The simulations part of the project (Rice University and Syntek Technologies) will use the previously developed model SAMI3-RCM. Both components of the model and the coupling will be updated to use the most recent version of the international geomagnetic reference field (IGRF, 2015) model. Currently, the coupled SAMI3-RCM model utilizes an offset dipole geomagnetic model, and although it does a good job of predicting the ionospheric conditions during storm periods in the Northern hemisphere, it does not do as well at predicting conditions in the Southern hemisphere. The goal is by incorporating a more realistic geomagnetic field, the new comprehensive model of the SAMI3-RCM plasmasphere-ionosphere system will capture the observed asymmetries. Model-data comparisons will be an integral part of the model development. As an outcome, we hope to unveil the hemispheric asymmetries that are due to electro-dynamical coupling in the MI system and, in doing so, shed more light on those processes that are driven by other forces.

Contributions to the FST: By improving the geomagnetic field model in the RCM and SAMI3 models, this project will directly address the 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." The updated RCM-SAMI3 model will also addresses SSA-4: Physics-based Total Electron Content (TEC) Forecasting Capability and the Decadal Survey s Atmosphere Ionosphere Magnetosphere (AIM) Interactions Science Goal 4: Plasma-Neutral Coupling in a Magnetic Field. The coupled RCM and SAMI3 model, both in its current and final configuration, will be available for team evaluation. This project will also gather data from select time periods for further analysis, and for model verification and data input. Data analysis routines will be developed and provided to the team. At the end of the project the SAMI3-RCM model will be delivered to NASA's CCMC.

Yue Deng/University of Texas at Arlington
Advances in numerical simulations for resolving multi-scale geomagnetic disturbances

Geomagnetically induced currents (GICs), which are strongly related to the change rate of geomagnetic field, pose a large hazard to the important infrastructures, such as powerlines and pipelines, especially during geomagnetic super storms. It is essential to understand the magne- tospheric and ionospheric processes responsible for the geomagnetic disturbances (GMD) during space weather events in order to improve the preparedness of society to the space weather impact. Recently significant progresses have been made in both observations and simulations to improve the description and understanding of GICs. A wide range of spacecraft and ground datasets has been utilized to analyze GICs and their correlation with drivers. Meanwhile, both first-principles physical models (MHD model coupled with ionosopheric electrodynamic model) and empirical models have been applied to the calculation of the geomagnetic perturbations. The ground con- ductivity model, which plays a crucial role to estimate the geoelectric field from geomagnetic disturbance (GMD), has been improved from 1-D to 3-D. However, a comprehensive understand- ing of the impact of different processes on the multi-scale geomagnetic disturbances is lacking, yet it remains fundamental to correctly interpret and specify GICs. Further, it is clear that small spa- tial scale magnetic perturbations with large amplitudes are a contributor to the GIC problem, but the underlying physics of these localized effects remains unclear [Ngwira and Pulkkinen, 2019]. The goal of this project is to examine the relative significance of different forcing terms in driving the multi-scale variations of geomagnetic disturbances through magnetosphere-ionosphere coupled simulations. Specifically, we will address the following three science questions (SQ):

(1) What is the role of the ionospheric and thermospheric processes in producing geo- magnetic disturbances on the ground? Proposed study: use MHD-GCM numerical models with expanded coupling that includes thermospheric processes such as the neutral dynamo to examine disturbance generation and to compare with observations.

(2) How does the combined M-I system produce geomagnetic disturbances of different spa- tial and temporal scales? Proposed study: With high resolution MHD-GCM coupled model, explore processes leading to different scales of disturbances, including solar wind conditions, con- ductance and neutral-wind perturbations driven by atmospheric waves.
(3) How do magnetic perturbations manifest as geoelectric fields, and how much does the Earth conductivity model affect this conversion? Proposed study: examine the frequency depen- dence of geoelectric field conversion, decompose the geoelectric field by its contributions from different geospace regions, and convolve numerical results with 1D and 3D models of Earth s conductivity.

This investigation will make significant contributions to the scientific objectives of the NASA LWS Focus Science Topic 3: Magnetospheric and ionospheric processes responsible for rapid geomagnetic changes. Specifically, it will improve modeling of geomagnetic disturbances and geoelectric field during disturbed periods and to improve understanding of the role of solar wind, magnetosphere, ionosphere and thermosphere in driving geomagnetic variation and geoelectric field. Furthermore, this investigation will make important contributions to science questions from the Heliophysics Roadmap and Decadal Survey. We would intend to interact with space physicists in the team to work on problems of overlapping interest that may be identified.

Mihir Desai/Southwest Research Institute
A Multi-spacecraft Approach to Understand the Spectral and Temporal Evolution in Large Solar Energetic Particle Events

Current Understanding: Large gradual Solar Energetic Particle (SEP) events are thought to be produced by diffusive shock acceleration (DSA) processes at coronal and interplanetary (IP) shocks driven by fast coronal mass ejections (CMEs) as they plough through the solar corona and IP space. These SEPs are routinely transported to distant locations in the heliosphere, including near-Earth orbit. They are often associated with large increases in particulate radiation that can pose serious hazards to humans and technological assets in space. SEPs are thus a key driver of Space Weather and one major hurdle for human deep space exploration. The behavior of the energy spectra in SEP events is directly indicative of their intrinsic radiation threat and has been the subject of numerous studies. Studying SEP spectral properties; particularly understanding the physical mechanisms responsible for producing their variable spectral slopes and roll-over or break energies (Eo) is critical for developing a complete picture of DSA, how ICME shocks accelerate SEPs near the Sun and in IP space, and how SEPs are transported.
Objective: Our over-arching goal is to develop a physics-based understanding of the temporal and spectral properties of H Fe ions observed in large gradual solar energetic particle (SEP) events at 1 AU, and relate them to physical conditions (e.g. turbulence levels, shock properties, seed population) at their near-Sun source using existing theories, models, and available observations.

Science Questions: We achieve our objective by combining multi-spacecraft observations of >200 SEP events with targeted modeling of selected events to answer the following three questions:
SQ1. What physical processes determine the spectral shape of SEP events; acceleration or interplanetary transport?
SQ2. What are the relative contributions of acceleration and transport to SEP spectra during different interplanetary conditions?
SQ3. What do acceleration, transport signatures tell us about IP conditions, SEPs, & shock properties?
Methodology: To achieve our objective, we will perform the following prime tasks: (1) Survey SEPs detected at ACE, Wind, STEREO-A & -B, and PSP during 1998-present. (2) For each event, derive the associated shock, ICME, and SEP spectral and abundance properties. (3) Examine the H-Fe spectral Eo and their temporal behavior to identify the effects of acceleration and transport. (4). Perform extensive correlation analysis to reveal the processes that dominate SEP properties during different conditions (SQ1 closure). (5) Examine the spectral evolution of SEPs for different shock properties (geometry, strength, speed, pre-event conditions) to determine how the charge-to-mass dependence of Eo evolves throughout the event. (6). Perform detailed analysis on ~3 SEP events measured at multi-spacecraft to determine how the pre-event conditions and shock parameters affect the observed temporal and spectral profiles at 1 AU. Finally, we will model the 3 events using a physics-based model with constraining input from the observations. This will enable us to interpret the influence of different input parameters (SQ2, SQ3 closure).
Relevance and Contributions to the Focused Team Effort: Our project responds directly to the first Focused Science Topic (FST), The Variable Radiation Environment in the Dynamical Solar and Heliospheric System, by focusing on the production and acceleration mechanisms of SEPs, often associated with extreme particulate radiation. We contribute to the FST goals by providing physics-based understanding of acceleration and transport effects of SEPs, and critical modeling of SEP constraints. Our team has extensive experience in SEP analyses from multi-spacecraft and modeling SEP acceleration & transport effects. The project also responds to the first Strategic Science Area (SSA-0) determined by the LWS TR&T steering committee and to 2 key science goals of the 2012 Heliophysics Decadal survey (1&4).

Gary Egbert/Oregon State University
Interdisciplinary Study of Ionospheric Currents and Associated Geoelectric Fields

Polar field-aligned currents (FAC) mainly close via horizontal ionospheric currents, causing rapid measurable changes in the ground magnetic field. We propose an interdisciplinary study of these ionospheric current systems in order to model and predict induced geoelectric fields, which are the primary input for calculating geomagnetically induced currents (GICs) in human technological infrastructure. The proposed activities will combine analysis of ground-based and satellite data, physics-based modeling with the Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIE-GCM),

and 3D modeling of induced geoelectric fields. Data and models will be combined in a data assimilation scheme to map ionospheric current systems for geomagnetic storms of varying intensity. The principal research objective will be to improve characterization of the temporal evolution and spatial structure of rapid geomagnetic variations and associated geoelectric fields. Measurable outcomes of this work will include 1) a data-constrained representation of storm-time ionospheric current systems; 2) an improved characterization of storm-time magnetic and geoelectric disturbances; 3) characterization of errors inherent to geoelectric fields derived from empirical magnetotelluric impedances and/or a national impedance map of the United States, and 4) a natural framework for estimating optimal spacing and location of ground-based observatories. The work will build on an ongoing collaboration between researchers in geomagnetic induction, satellite magnetometry and ionospheric physics (funded by NASA-ESI). In this current project we are developing empirical models for diurnal variation (DV) fields, with the goal of imaging deep Earth electrical conductivity. Our approach involves principal components analysis (PCA) of ground- and space based magnetometer data to express variations via a modest number of temporal/spatial mode products by using basis functions for 3D ionospheric source fields derived from PCA TIEGCM.
A similar approach is proposed here using higher frequencies for data and model analyses, to derive models of storm-time variations relevant to GICs. Statistical analysis will be based on a large number of storm events, but geoelectric field solutions for individual events will be derived. Ground-based data analysis will involve both global and higher-density regional magnetometer arrays to better resolve spatial structure. The TIEGCM will be driven by AMPERE FAC, assimilative mapping of ionospheric electrocdynamics (AMIE) ion convection, and magnetospheric model output. While our study by itself will not constrain magnetosphere processes, e.g., tail or ring currents, drivers of FAC, we will be able to provide a detailed data-constrained characterization of horizontal ionospheric currents in the auroral region and at middle latitudes, including the continental United States. We will model geoelectric fields resulting from these current systems using 3D induction codes, and best available models for 3D Earth conductivity. We will contribute to the Focused Science Topic (FST) #3 by providing the ionospheric current for events constrained by ground-based and satellite data, together with the resulting geoelectric fields. Our models can be linked with those of other FST members to better connect these to the ground response. In this collaborative way we can contribute to "discovering any preconditions necessary for extreme GICs", and investigation of "correlations between GIC and various solar wind parameters". Our study will contribute more directly to other listed FST #3 science goals, including improvements in modeling geoelectric fields" going beyond the 3D plane-wave assumption by driving the models with modeled current sources, and "new and improved indicators of GIC activity" -- indeed the ground-based temporal modes that are key to our modeling approach provide a rich set of "indices" that can be explored.

Banafsheh Ferdousi/University of New Hampshire, Durham
Modelling the GIC Response from the Solar Wind to the Ground

Objectives
Magnetic storms can cause critical hazardous for our technologies with imposing geomagnetic induced current (GIC) through our infrastructure like power grids, railways, and pipelines. In this project, we aim to address the following issues:

- What are the GIC variations under different geomagnetic conditions. For example, during quiet times, can BBFs (Bursty Bulk Flows) generate substantial GICs; how much GIC can be generated during substorms, and how are they related to substorm strength; how do different types of storms (CME, CIR) generating GICs.
- We extent the studies to extreme storms, such as Carrington-class events or the STEREO-A event.
- We will examine if there are any specific ways in which GICs are pre-conditioned. For example, does a sequence of storms (such as during the Halloween storms) lead to more intense GICs?
- Do GICs generated by different drivers have different GIC distributions and extents. For example, is the GIC from a substorms more spatially confined than that generated by a SSC or a storm?

Methodology:

In this project, we use global MHD magnetosphere, inner magnetosphere, and ionosphere coupled model, OpenGGCM-RCM-CTIM. The model computes many key electric currents in the magnetosphere and ionosphere (MI) system. In particular, magnetopause and tail currents in the magnetosphere, ring current, field aligned current (FAC) between magnetosphere and ionosphere, and ionosphere currents on 2D shell at 110 km. The latter are represented on a 0.5 (lat) by 3.0 (lon) degree mesh. From the currents, dB/dt on the ground can be calculated in different ways, like Biot-Savart (B-S) integration over equivalent currents or full B-S integration over all MI current systems. Practical time resolution can be as little as 1 second. The models are tested to various degrees separately. Using the models in unison will allow to test the entire chain of processes that lead to GIC. With proper ground data the validity of the approach can be tested. It is important to introduce statistical errors associated with the model. Data assimilation technique will be used to determine these errors in the model. We also use available data such as the ground magnetometers, DMSP, THEMIS/MMS for substorms, IMAGE and ASI cameras for aurora, and more importantly AMPERE which provides direct global and large scale structures of FAC.

Contributions to the FST effort
We will particularly address LWS topic numerical simulations using solar wind MI coupling models with the goal of investigating the role of solar wind in driving GICs as

well as analysis of current and historic satellite and ground data sources during extreme GIC times with the goal of discovering any preconditions necessary for extreme GICs.

Federico Fraschetti/University Of Arizona
Tracking mechanisms efficiently accelerating charged particles at shocks at multiple heliospheric distances out to ~1.5 AU

The solar energetic particles (SEPs) are regarded as a major component of space weather forecast and modelling. A primary goal of the upcoming Interstellar Mapping and Acceleration Probe (IMAP) mission is to connect SEPs measured at 1 AU with those over the entire heliosphere. This proposal focuses on such an unchartered domain and will benefit of the currently available Parker Solar Probe (PSP) data. A first step toward predicting the observations of SEP detectors onboard IMAP is the modelling of the evolution of properties of shock-accelerated particles (ions and electrons) between the closest possible approach to the Sun of PSP and Mars. In particular, we propose a targeted investigation to determine the time evolution of time profiles and momentum spectra at shocks at various distances from the Sun (between 10-15 Sun radii and 1.5 AU, i.e., Sun-Mars distance). The proposed study will combine a balance of: 1) data analysis and interpretation of interplanetary shocks by using publicly available high time resolution data collected by SEP detectors and magnetometers onboard PSP, ACE (Advanced Composition Explorer) and STEREO (Solar TErrestrial RElations Observatory) and MAVEN (Mars Atmosphere and Volatile EvolutioN); 2) theory and hybrid/test-particle numerical simulations at shocks to interpret the data.
Science goals   The theory of diffusive shock acceleration (DSA) assumes a population of energetic particles (EPs) with a nearly isotropic pitch-angle distribution in the local plasma rest frame; the DSA theory cannot be applied to particle speed comparable to the flow speed. Using spacecraft measurements obtained at different locations in the inner heliosphere, we will investigate how the time profiles change and how spectra harden or soften at distinct distances from the Sun. This goal meets all three LWS program objectives.
Methodology - For the proposed investigation we will make use of publicly available high-time resolution SEP and magnetic field measurements at PSP (EPI-Lo, EPI-Hi, MAG), at 1 AU from ACE (EPAM, MAG) and STEREO A/B (LET, HET, SEPT, SIT, MAG) and at 1.5 AU from MAVEN (SEP, MAG). We will identify a number of shock events observed in two distinct locations (or only at a single location) and extract at various distances from the shock, both upstream and downstream, particle intensity and pitch-angle distribution. We will perform comparative test-particle and hybrid simulations of the intensity profiles, pitch-angle and momentum distribution at the shock and far downstream and compare with observations.
Feasibility The assembled team has already a series of publication on: 1) the data analysis and interpretation at 1 AU (e.g., Zhou et al., RNAAS, 2,145, 2018, Giacalone, 2015, ApJ. 799,80) and 1.5 AU (Lee et al., JGR, 122, 2017); 2) numerical simulations for particle acceleration at shocks (Giacalone, 2005, ApJ, 628, L37; Fraschetti & Giacalone, MNRAS, 448, 3555, 2015).

Proposed Contributions to the Focused Science Team (FST) Effort - The comparison of SEP observations at multiple distances from the Sun will provide unprecedented constraints on the underlying acceleration mechanism. This project will complement modelling efforts between the Sun and Mars within the same FST team to cover, for instance, the physics of the coronal mass ejections driving the shocks. This project will contribute to the LWS types of investigation Studies of the temporal and spectral properties of large SEP events and Simulations of high-energy particle dynamics and comparison with spacecraft measurements . Milestones: 1) extract from data profiles, spectra and pitch-angle distribution from ~10-15 Sun radii out to 1.5 AU; 2) investigate effects of large-scale geometry and spacecraft angular/radial separation in the interpretation of the data; 3) numerical simulations for the interpretation of data. We will make available some of the numerical codes used. The PI volunteers to serve as FST team-leader.

Jennifer Gannon/Computational Physics, Inc.
Conductivity model evolution from the practical to the ideal

The goal of this project is to evaluate the techniques for using magnetotelluric data in both practical and ideal settings. System modeling tools, and the needs of the power utility end user, may differ from those of the researcher working at the cutting edge of GIC research. This work will evaluate techniques such as smoothing, averaging, grid spacing, and the algorithms used in magnetotellurics to determine the level of improvement gained by increases in dimensionality, complexity, and local accuracy. If successful, this work will advance the practical solutions needed by power operators towards the eventual scientific-level ideal in ground response to geomagnetic storm conditions.

Fan Guo/Los Alamos National Laboratory
High-energy Particle Acceleration by Extreme Coronal Shocks

Science Goals and Objectives
The primary objective of this proposal is to understand the acceleration of high-energy solar energetic particles (SEPs) by extremely fast shocks driven by coronal mass ejections (CMEs). These most extreme SEP acceleration gives rise to ground level enhancement events with an increase of energetic particle flux at hundreds of MeV. Our theoretical and numerical investigations will address the physics involved the most intense and highest energy SEP events which can have important effects on Earth and spacecraft hardware.

Methodology
We will model low-energy proton injection at shocks using hybrid simulations (kinetic protons and fluid electrons) of coronal shocks, with different magnetic field orientation in

the upstream region. This is to determine the injection process from a pool of thermal solar wind or pre-accelerated superthermal particles. High-energy proton acceleration by diffusive shock acceleration with injection constraint by outcome of the hybrid simulations. Again consider the importance of upstream magnetic field configuration.

Proposed Contributions to the Focused Science Team Effort
The project directly addresses Science Goal #1 of the 2012 NAS Heliophysics Decadal Survey: Determine the origins of the Sun's activity and predict the variation in the space environment. It also fits well with the LWS program objective: Understand how the Sun varies and what drives solar variability. We will provide to the Team new models and understandings of high-energy particle acceleration. We will clarify for the Team the roles of fast CMEs in producing most energetic particles. Our proposed work is essential for determining the variability and predictability of the SEP environment. We will combine our first-principles based studies with the observational studies of the Team to make substantial progress on achieving the FST goal of understanding the acceleration and transport of SEPs.

Michael Henderson/Los Alamos National Laboratory
Physics-Based Modeling of Geomagnetically Induced Currents (GICs)

For the GIC problem, propagation of geoelectric fields from the ionosphere to ground is typically performed using Biot-Savart integrals. This approximation ignores the localized complexity of lithosphere electrical conductivity and the relative high conductivity of ocean water compared to lithosphere. Three-dimensional models of Earth conductivity with mesoscale spatial resolution are being developed, but a new approach is needed to incorporate this information into the space weather forecast modeling chain. In response to these short comings, we have developed a Finite Difference Time Domain (FDTD) electrodynamic model (called GeoRad) that solves Maxwell's equations on a vertically-stack 2D unstructured Voronoi tessellation. We propose to apply this new capability to provide more realistic simulations of the dB/dt generating at ground level during a variety of space weather disturbances including storms, substorms, and SMCs. We will utilize existing and new simulations of the geomagnetic disturbances computed with the SHIELDS framework (SWMF + RAM/SCB). It is expected that the results will substantially deviate from the currently used Biot-Savart methodology and we wil quantify these differences. The work is directly relevant to the Focused Science Topic #3 (Magnetospheric and Ionospheric Processes Responsible for Rapid Geomagnetic Changes) and has extensive important applications in space weather prediction and protection of ground-based long-conductor technological systems (e.g. Power distribution systems, etc.)

Qiang Hu/University Of Alabama, Huntsville

Magnetic Reconnection Rate and its Implications for Fast Reconnection Onset in Solar Flares and Magnetopause

The science objectives of this investigation are to characterize, quantitatively, the magnetic reconnection rate in various plasma regimes at the reconnection sites, i.e., current sheets. Specifically these reconnection processes are usually preceded by fast onset in the solar corona and at the Earth s magnetopause, where the primary current sheets form and evolve, as manifested by energetic solar flares on the Sun and significant energy transfer at the magnetopause due to magnetic reconnection. The associated evolution of magnetic topology and plasma dynamics will be investigated. The goal is to elucidate the relation between reconnection rate and fast reconnection onset across disciplines.

The methodology to be employed is a combined approach of observational analysis and numerical simulations. For the magnetic reconnection rate in the solar corona, we will utilize the well-established quantitative analysis based on remote-sensing observations of flare-associated energy release processes. Specifically, the separation of flare ribbons seen in the low solar atmosphere manifests the magnetic reconnection progressively higher in the corona, as two regions are magnetically connected. This enables a quantification of the magnetic reconnection rate by combining flare ribbon motion seen in H-alpha/UV wavelengths with longitudinal photospheric magnetic field measurement. For the Earth s magnetopause, we will measure the reconnection rate using ground-based radars, which involves identifying the ionospheric projection of the reconnection X-line and measuring the electric field tangential to it in its rest frame. By performing the measurement at a longitude conjugate to spacecraft that are positioned at the magnetopause, we can obtain the relation between the reconnection rate and the current sheet. All these measurements are readily available for our investigations. The numerical simulations involve both large-scale MHD and fully kinetic Particle-in-Cell simulations. The former aims at the formation and disruption of current sheets, leading to large-scale topological change, which can be compared with flare ribbon evolutions. The latter simulation at kinetic scales is more tailored toward fundamental reconnection physics in terms of the roles of guide field, the plasma asymmetry across the current sheet and the amount of magnetic shear and flow shear in fast reconnection onset, with implications for the aforementioned studies in the different space plasma regimes.

The proposed study is highly relevant to the FST #2: Fast Reconnection Onset . This investigation addresses the identified primary goals by examining the reconnection rate in various regimes relevant for heliophysics in order to understand the global- and local-scale processes . Specifically, we aim to address one of the listed Measures of success : Determining the reconnection rate, and in particular the criteria for fast reconnection to occur in various physical environments within the heliosphere and across size scales . We will contribute to the FST team effort by providing the expertise and necessary tools in the observational analysis of flare-ribbon morphology and probing the reconnection processes at the magnetopause via multiple observations and simulation runs. In anticipation of the development and utilization of large event sets from multiple observations, the detailed analysis results will be made available to the whole team. In addition, numerical simulation runs will be performed in coordination with the entire team to optimize the pursuit of common goals and allocation of resources.

Hyomin Kim/New Jersey Institute Of Technology
Investigation of Interhemispheric Asymmetries in High-Latitude Magnetosphere-Ionosphere Coupling Processes

1. Science Goals and Objectives
The main goal of this study is to understand the causes and effects of asymmetries in the Magnetosphere-Ionosphere coupling processes. This proposal is motivated by the recent studies conducted by the team members, in which the observational and modeling work built upon hypotheses that the interhemispheric differences in temporal response, spatial extent and intensity of magnetic field variations, current systems, and convection patterns may occur due to external drivers and their complex interactions with each other. We propose to further test these hypotheses by systematically applying them to more extensive and integrated sets of data and simulations available today. The specific science questions are as follows:
1) How do the spatiotemporal characteristics, and magnitudes of interhemispheric asymmetries at high latitudes as observed in magnetic field variations, current systems and convection patterns change with different drivers?
2) What are the relative contributions of the external drivers to the asymmetric MIC processes?
3) How much electromagnetic energy is transferred by each of these MIC processes to the Thermosphere system?

2. Technical Approach and Methodology
The proposed work will utilize data from spacecraft and ground-based instruments that cover high latitudes in both hemispheres, which include field and particle data from spacecraft in the solar wind and magnetosphere and over polar regions in low earth orbits, magnetic field data from the ground magnetometers and SuperDARN radars at interhemispheric conjugate locations. These data sets will be used to characterize asymmetries in magnetic field perturbations, current systems and convection patterns and their coupling dynamics with the thermosphere. To model the solar wind interaction with the coupled M-I-T system and analyze the global response to different drivers, we will use the BATS-R-US and RIM models. These models will return the global plasma flow and pressure profiles in the magnetosphere, FACs, particle flux, characteristic energies, electric potentials on top of the ionosphere, and ground magnetic perturbations. The convection and auroral precipitation obtained from the global MHD modeling will be used to drive GITM to obtain plasma and neutral densities, temperature and velocity. In addition, idealized simulations will be conducted to analyze the effects of different solar wind and IMF drivers.

3. Relevance and Perceived Significance

The proposed study will advance the understanding of origin and propagation of interhemispheric asymmetries and associated magnetosphere-ionosphere-thermosphere (M-I-T) coupling processes employing a system-wide approach. Unlike other studies, this work aims to quantitatively analyze the effects of asymmetries across three different domains in the near-Earth environment. The proposal team will make use of newly deployed ground magnetometers, therefore will employ unprecedented measurement data to analyze asymmetries and guide the modeling approach. The proposed research will have important implications for understanding M-I-T coupling processes and space weather forecasting by extensively investigating the role of external drivers. This proposal directly addresses the Focused Science Topic #4 of the LWS program: "Causes and Consequences of Hemispherical Asymmetries in the Magnetosphere - Ionosphere - Thermosphere System". In addition, the majority of the proposed work is related to studies on M-I-T coupling processes due to transient phenomena related to the solar wind, one of the major external drivers. Therefore, this proposal also addresses the Focused Science Topic #3: "Magnetospheric and Ionospheric Processes Responsible for Rapid Geomagnetic Changes".

James Klimchuk/NASA Goddard Space Flight Center
Onset of Magnetic Reconnection and Solar Applications

Magnetic reconnection is a fundamental physical process that is at the heart of many important drivers of space weather. A crucial property of reconnection is its switch on nature. Reconnection must remain dormant to allow magnetic stresses to build, then suddenly activate to release the stored energy. If it were to occur too soon, phenomena like coronal mass ejections, solar flares, and magnetospheric substorms would be much weaker than observed, and nanoflares would be unable to heat the corona to its multi-million degree temperatures. Our overarching goals are to identify and understand (1) the onset conditions for fast reconnection and (2) the conditions necessary to sustain the reconnection to allow a large release of energy. We will concentrate on physical environments similar to those found on the Sun and other stars. Reconnection occurs at current sheets, and our specific objectives are to determine the dependence of reconnection on current sheet width, shear angle, length, and any other physical parameters that we may find to be important, including an investigation of the effects of line-tying and atmospheric stratification. We will study both equilibrium configurations and configurations that are evolving, e.g. in response to footpoint driving. An ultimate goal is to develop a numerical technique for incorporating these critical conditions into large-scale numerical simulations that are unable to resolve individual current sheets.

In some environments, such as the magnetosphere, reconnection onset appears to require that the thickness of the sheet be comparable to kinetic scales (ion gyroradius, ion skin depth). This is not the case in the solar corona. The tearing instability, which is how reconnection usually begins, is very fast even for sheets that are much fatter. Thus, a resistive MHD treatment is appropriate. We will use well-resolved numerical MHD simulations to study the linear onset and nonlinear growth of reconnection, expanding upon our recent initial results. As an observational test of our simulations, we will construct synthetic EUV spectral line profiles of very hot (> 5 MK) emission lines and compare them with data from EIS/Hinode, IRIS, and the EUNIS rocket. The shapes of the line profiles provide valuable information on spatially-unresolved flows and should reveal whether the reconnection is laminar, turbulent, or plasmoid dominated. In some cases there may be spatially-resolved signatures of reconnection (e.g., large plasmoids in eruptive flare current sheets). For these, we will compare with imaging observations such as those from AIA/SDO. We will also relate our results to general observational constraints, such as the famous Parker angle for coronal heating, which is the characteristic misalignment angle between adjacent magnetic strands in the tangled coronal magnetic field.

We will share our results and ideas freely with the entire Focused Science Team. It is highly likely that other team members will emphasize reconnection at kinetic scales. While solar reconnection is initiated by processes at fluid scales, the actual breaking of field lines occurs at kinetic scales. We treat this with electrical resistivity, but other kinetic effects are potentially important. Interacting closely with the team on this and other aspects of mutual interest is vital to progress. We will help other team members with comparisons to solar observations where appropriate.

San Lu/University of California, Los Angeles
Current sheet configurations and their control of fast reconnection onset

1. Background
Magnetic reconnection, a process that converts magnetic energy to plasma energy via topological changes in magnetic field lines, occurs in current sheets throughout the universe. Reconnection in the current sheets observed in the heliosphere is usually fast, leading to explosive energy conversion and particle acceleration, such as solar flares, coronal mass ejection, and geomagnetic storms/substorms. Although fast reconnection occurs ubiquitously in these current sheets (solar corona, solar wind, and magnetospheres of Earth and planets), the configurations of these current sheets differ from one heliospheric system to another. Moreover, even in one specific heliospheric system, there are various types of current sheets. Configurations of these current sheets control whether and how reconnection initiates. However, the current sheet configurations are not well documented, and how do they control fast reconnection onset is not well understood.

2. Science Goals
(1) Perform a systematic survey of current sheet configurations for Earth s magnetotail and solar wind.
(2) Investigate how the configurations of these current sheets control fast reconnection onset.

3. Methodology
(1) To achieve science goal 1, we will analyze in-situ current sheet crossings in the solar wind and Earth s magnetosphere by the spacecraft of MMS, THEMIS, ARTEMIS, and Parker Solar Probe. These events will be classified into several different categories based

on their structures of magnetic and electric fields and distributions of density and temperature. For each category of the current sheet, we will perform statistical studies to give parameter ranges for a more quantitative description.
(2) To achieve science goal 2, we will perform particle-in-cell (PIC) simulations using different current sheet configurations as initial conditions to see whether and how these quiescent current sheets evolve into fast reconnection. For each current sheet categories, we will perform series of simulations with different parameters that are guided by the aforementioned statistics of spacecraft observations. These PIC simulations will give critical values of these parameters for fast reconnection onset in every current sheet configurations.

4. Proposed Contributions to the Focused Science Team Effort
This proposed research aims to contribute to the Focused Science Team #2, Fast Reconnection Onset in the following four aspects. (1) A systematic survey of current sheet using in-situ spacecraft observations in various heliospheric environments will provide pre-conditions for fast reconnection onset in throughout the heliosphere. (2) The PIC simulations with observation-motivated current sheet configurations will answer how these current sheet configurations control fast reconnection onset in the observed heliospheric environments. (3) Further analyses of the simulation results help better understand the mechanisms and dynamics of fast reconnection onset, which have also been controversial for decades. (4) Although the in-situ observations and the observation-motivated simulations are for the current sheets and reconnection in the solar wind and Earth s magnetosphere, the results of this research can be generalized to other heliospheric systems, such as the solar corona and planetary magnetospheres.

Naomi Maruyama/University Of Colorado, Boulder
The impact of the hemispheric asymmetry on the thermal structure and airglow in the Magnetosphere-Ionosphere-Thermosphere (MIT) system

MOTIVATION:
Remote sensing observations of airglow emission have been used to infer the dynamics and chemistry of the upper atmosphere and ionosphere. Airglow observations tend to pose challenges in their interpretation mainly because it is difficult to identify the various sources of airglow emission associated with photoelectrons, aurora precipitation, various excitation, production and loss mechanisms. To overcome these challenges, GLOW model has widely been used to reproduce the observed airglow. In spite of many successful previous studies owing to the availability of the model to the community, however, a considerable degree of uncertainty still exists because of the presence of the hemispheric asymmetry. One of the major cause of the uncertainty could be atributed to superthermal electrons (SE) originating from the conjugate hemisphere and the overall SE dynamics in the coupled MIT system generated by asymetric conditions of background atmosphere in the conjugate hemispheres. Very few studies have quantified the role of conjugate SEs in observations primarily due to lack of observations.

Furthermore, even fewer studies have addressed the impact of conjugate SEs on airglow emission and the thermal structure of the MIT system.

SCIENCE GOALS AND OBJECTIVES:
The main objectives of this proposal are to quantify the impact of the hemispheric asymmetry of SEs in the coupled MIT system on airglow emission and thermal structure of the upper atmosphere, with a focus on elucidating the causes and the consequences of the hemispherical asymmetries. The proposal will address the following three specific science questions: (1) What is the role of the hemispheric asymmetry in the formation of SE fluxes in the MIT system?; (2) How much of the observed airglow can be attributed to the SE originating from the conjugate hemisphere and how MIT SE coupling impact on the overall airglow sources in both magnetically conjugate regions?; (3) To what degree do SE originating from the conjugate hemisphere play a role in the energetics of the ionosphere and plasmasphere and how much their energy can be lost in the magnetosphere and redistributed back to the IT system?

METHODOLOGY:
We will simulate MIT coupling effects by taken into account of hemispherical asymmetries in the MIT system based of the rigorous coupling of the two well documented codes: IPE and STET. The Ionosphere-Plasmasphere-Electrodynamics (IPE) model is a time dependent, three-dimensional, global model of the ionosphere and plasmasphere. Super Thermal Electron Transport (STET) model includes the full solution of the Boltzmann-Landau kinetic equation for SEs in the energy range of 1 eV to 50 KeV along the magnetic field line from the 90 km in the Northern hemisphere to the 90 km to magnetically conjugate region. STET code will be moved to the architecture of the IPE model with the adjustment of all input parameters of the IPE code including the realistic configuration of the magnetic field (IGRF) and statistical electron precipitation pattern based on NOAA measurements. The neutral and plasma densities structure that simulated by IPE code will be two way coupled with the STET simulations. The electron distribution function obtained from the coupled IPE-STET code will be used to calculate the thermal structure of ionosphere and plasmasphere and airglow emissions. Furthermore, we will compare model simulations with various NASA missions (e.g., FAST, GOLD) and supplementary ground-based observations with the focus on causes and the consequences of the hemispherical asymmetries.

Proposed Contributions to the Focused Science Team Effort:
We will plan to provide to the team such parameters including plasma densities and temperatures, energy flux, energy spectrum with emphasis on the low energy tail, as well as any improvements we will have made to the GLOW code obtained from our project in improving the emission calculation.

Astrid Maute/University Corporation For Atmospheric Research (UCAR)
Causes of interhemispheric asymmetries in the ionosphere

SCIENCE GOALS AND OBJECTIVES

Knowing the ionospheric plasma condition is important for space weather applications such as predicting the occurrence of plasma depletions and associated irregularities affecting communication and navigation systems. The ionospheric plasma distribution strongly depend on the neutral winds, electric fields and thermospheric composition changes driven by magnetosphere-ionosphere-thermosphere coupling, by upward propagating planetary waves and tides, and is also modulated by Earth s magnetic field. Interhemispheric asymmetries in the plasma distribution exist which cannot be explained by the seasonal variation of solar radiation. Similarly, hemispheric asymmetries are evident in many observed quantities of the magnetosphere and ionosphere even after taking account of the interplanetary magnetic field (IMF) orientations and seasonal effects. Furthermore, the lower atmosphere has inherent interhemispheric differences due to the non-uniform excitation and propagation condition of waves and tides, which impact the ionosphere and thermosphere from below. So far, what causes the interhemispheric asymmetries in the ionosphere remains largely elusive. Disentangling the important drivers and mechanisms leading to interhemispheric asymmetric plasma distribution is the focus of the proposed investigation.

The proposed investigation will advance our understanding of the response and interaction of the ionosphere to interhemispheric asymmetries in the MI coupling and in the lower atmospheric tidal and planetary wave forcing. It focuses on three science questions that are central to Focused Science Topic #4 Causes and consequences of hemispherical asymmetries in the Magnetosphere-Ionosphere-Thermosphere System :

(1) How can the interhemispheric asymmetries in the field-aligned currents and Joule heating be characterized during quiescent and disturbed conditions?

(2) What are the important processes through which the ionosphere responds to and interacts with the asymmetric magnetospheric forcing?

(3) How large is the contribution from the asymmetric lower atmospheric dynamics to the overall ionospheric asymmetry and what are the important pathways?

METHODOLOGY

This investigation will combine data analysis with the state-of-the-art Whole Atmosphere Community Climate Model-eXtended (WACCM-X). WACCM-X with specified dynamics by reanalysis data will be employed to simulate the coupling between the lower atmosphere and the thermosphere-ionosphere system. Numerical experiments will be conducted to delineate the effects from the lower atmosphere. The interhemispheric asymmetries in field-aligned currents (FAC) will be characterized by analyzing the AMPERE magnetometer data. To describe the interhemispheric asymmetries in the Joule heating we will use the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure and the AMPERE FAC forcing in WACCM-X with different auroral conductance descriptions, e.g., DMSP/SSUSI observations, and empirical aurora models. The interhemispheric asymmetry in the ionosphere will be characterized by analyzing GPS-TEC, COSMIC and evening GOLD electron density, and once available COSMIC-2 and ICON data. WACCM-X simulations will be conducted to investigate the ionospheric response and interaction of the lower atmosphere and the MI coupling. The simulated interhemispheric asymmetries in the ionosphere via dynamics, composition and electrodynamic changes will be evaluated by model-data intercomparison of e.g., O/N2 from TIMED/GUVI, GOLD and the upcoming ICON, ion drifts from DMSP, CNOF/S, and the upcoming COSMIC-2 and ICON.

PROPOSED CONTRIBUTION TO THE FOCUSED SCIENCE TEAM
This investigation supports the LWS program goal of understanding which drivers generate the observed asymmetries and improve physics-based understanding of time-evolving structural changes in ionospheric electron density between hemispheres . We will share the AMIE, WACCM-X and data analysis results.

Mark Moldwin/University of Michigan
Space weather electromagnetic pulse impacts on modern smart cities and Internet of Things technologies: Observations and modeling of fast and small-scale induced currents in the context of GICs

We combine ground and space-based magnetometer observations with the University of Michigan s Space Weather Modeling Framework (SWMF) and the University of Utah s time-domain, full-vector Maxwell s equations geomagnetic field-ionosphere model to characterize the properties of fast (< a minute) geomagnetic disturbances that often precede and accompany the slower (5-10 minute) Ground-Induced Current (GIC) disturbances. We frame our work within the context of nuclear explosion (anthropogenic space weather) generated electromagnetic pulses (EMP) to highlight the similarities with geomagnetic disturbances. An EMP has three components. The early-time (E1) EMP reaches field of 50 kV/m up to 1 microsecond, the intermediate-time (E2) EMP reaches 100 V/m between 1 microsecond and a few seconds, and the late-time (E3) EMP reaches 40 V/km between 1 and several hundred seconds. E3 EMP hazards are analogous to geomagnetic storm GICs. E2 EMP have similarities with lightning and therefore most electric grid systems are protected. However, with the advent of smart grids that depend on low-voltage electronic devices, modern electronic infrastructure becomes more susceptible to faster (E1 and E2-type) disturbances that are not well studied in the context of geomagnetic disturbances. One significant difference between the faster EMP effects compared to E3/GIC is that E1/E2 electric fields couple to electronic systems directly and not through ground currents and therefore ground-conductivity plays no role in their potential impact.
The objective is to identify in 1-second ground-magnetometer data large dB/dt intervals, place them into solar wind and geomagnetic context (storm and substorm correlation) and characterize the spectral properties of the events at previously under-studied high-frequency (on the order of Hz) signatures. We will analyze decades of magnetometer data from scores of stations. Our recent studies have found: (1) that a significant fraction (40%) of the largest dB/dt events are not associated with substorms and (2) many of the largest dB/dt within the E3/GIC time domain are preceded and/or accompanied by large and more rapid fluctuations (E2). From this list, we will identify events that have both LEO (e.g., Swarm, FAST) and magnetospheric satellite (e.g., Van Allen Probes, MMS, THEMIS) observations. Though mapping uncertainties and the need to have broad conjunction criteria will make it difficult to find the same event on the ground and in

space, we will characterize the field signatures (e.g., dipolarizations, compressions) and wave properties of the space-based observations to place the events into global context. We will then model select intervals with both models to understand the current and ionospheric electric field structures responsible for the fast and GIC signatures.
We will address all three primary objectives ((1) determine the space context of dB/dt, (2) characterize their temporal and spatial scales, and (3) using observations and models estimate the ideal spacing of ground-based observations) of the Magnetospheric and Ionospheric Processes Responsible for Rapid Geomagnetic Changes FST.
We contribute to five of the seven types of listed investigations: (1) Observational and numerical approaches for determining variations of GIC; (2) Numerical simulations to investigate drivers of GICs, (3) New indicators of GIC activity, (4) Analysis of satellite and ground data during GIC times; and (5) Modeling of conditions related to GICs.
Our Metrics and Milestones include developing a complete list and statistics of large dB/dt including a large number that occur outside of traditional GIC storm events, their corresponding space weather conditions, and a set of modeled events using both the UM and Utah models to examine the full-range of scales. We will work closely with the TST that overlap with our objectives to provide opportunities for reproducibility as well as unique data-model comparisons.

Christopher Mouikis/University of New Hampshire
The role of O+ on reconnection onset in the Earth's magnetotail

The goal of this proposal is to address the effects of multi-scales on the onset of collisionless magnetic reconnection in the earth s magnetotail, introduced by the presence of O+ of ionospheric origin, using a tandem of state-of-the-art kinetic simulations and in-situ observations from MMS and CLUSTER. The proposed work will contribute understanding of the following issues : i) effects of ionospheric outflows of O+ in the tail pressure build-up and reconnection onset in the magnetotail; ii) the role of O+ ions in the formation of multiple islands in the magnetotail, and in the structure of magnetic separatrices; iii) the influence of O+ on the reconnection rate.

For the first time 3D multi-species global hybrid simulations will be used to simulate the effects of the ionospheric outflows to the global magnetosphere and in particular how those affect reconnection in the earth's magnetotail. The proposed simulation model/experimnts should be viewed as a kinetic model that will capture the most important aspects of global ion dynamics correctly and will enable the analysis of global-local coupling and the influence of O+ on the processes of current sheet formation and reconnection onset with a degree of realism that goes far beyond the previous (notably MHD) simulations of similar effects.

This work will provide for the first time insight how the global and local multi-scales interact in the earth's plasma sheet and how this interaction affects the dynamics of the magnetotail.

Shin-ichi Ohtani/Johns Hopkins University
Magnetospheric and solar wind conditions for potentially hazardous geomagnetic disturbances

PROJECT GOAL:
The goal of this project is to understand magnetospheric and solar wind conditions for rapid and intense geomagnetic changes, extreme dB/dt events , and to identify responsible processes in the magnetosphere-ionosphere (M-I) system.

SCIENCE QUESTIONS
We will achieve this goal by addressing the following questions:

SQ1.Under what magnetospheric and solar wind conditions do extreme dB/dt events take place?
1a. How are the probability distribution functions (PDFs) of dB/dt characterized in terms of global geomagnetic activity and location, such as magnetic latitude (MLat) and magnetic local time (MLT)?
1b. What ionospheric current system is associated with extreme dB/dt, and to what solar wind condition, if any, is it related?
1c. What plasma sheet processes are associated with extreme dB/dt, and how are they characterized?

SQ2. How are storm-time shock-preceding substorms characterized as a cause of extreme dB/dt events?
2a. Where (MLT and MLat) and when (relative to the shock arrival) does ground dB/dt become large during storm-time shock-preceding substorms? How are such spatio-temporal structures characterized (compared with other types of intense geomagnetic activity)?
2b. How are ionospheric currents distributed and how do they develop? How are they characterized?
2c. How do basic plasma sheet processes (e.g., dipolarizations, convection enhancements, and reconnection) develop in time and space? How are they characterized?

APPROACH:
Those two sets of SQs reflect our bi-directional approach to the project goal: data-oriented search for conditions for extreme dB/dt events (SQ1) and hypothesis-based investigation of relevant processes (SQ2).

For SQ1 we will calculate the PDFs of dB/dt on different time scales using magnetic field data from various stations. We will then address 1a-1c:

1a: We will examine how the PDFs change with geomagnetic indices, and will identify the state of the M-I system (i.e., storms, substorms) under which dB/dt becomes large. By comparing PDFs at different locations, we will identify where (MLT and MLat) dB/dt most likely become hazardous.
1b: We will select extreme dB/dt events based on the PDFs. By examining polar plots of equivalent currents, along with global auroral images if available, we will identify the responsible ionospheric current system and process, and will address if its intensification can be associated with any solar wind structure.
1c: For the extreme events we will examine the timing and location of dipolarizations and convection enhancements, and will address their characteristics.

For SQ2 we will test the hypothesis that storm-time shock-preceding substorms (Group 1) are a significant cause of extreme dB/dt events, and will compare their characteristics with other types of intense geomagnetic activity (Group 2: storm-time shock-preceding convection bays; Group 3: storm-time non-shock-preceding substorms and convection bays; and Group 4: non-storm-time supersubstorms).
2a: We will examine the polar distribution of dB/dt and its evolution, and will address how Group 1 is characterized.
2b: By examining polar plots of equivalent currents, along with global auroral images if available, we will identify how ionospheric currents develop for Group 1, and how it is characterized compared with Groups 2-4.
2c: By examining dipolarizations and convection enhancements in the plasma sheet, we will address how magnetospheric processes develop for Group 1, and how they are characterized compared with Groups 2-4.

We will use (i) the SuperMAG database for geomagnetic disturbances, (ii) the OMNI database for solar wind conditions, (iii) magnetic field and plasma data from current and past NASA missions as well as other available satellites for plasma sheet processes, and (iv) Polar and IMAGE auroral images for spatio-temporal structures of auroral activity.

Kevin Pham/University Corporation For Atmospheric Research (UCAR)
Impact of Thermospheric Asymmetry On Geospace Coupling

Ionospheric outflow consists of ions that have escaped the upper atmosphere and flow into the magnetosphere where they impact the global magnetosphere dynamics that feedback into the upper atmosphere. The amount of ion outflow is determined by the energization sources from the magnetosphere above and the underlying thermospheric state, but the northern and southern thermospheric states have drastically different seasonal dependencies that will influence the resulting ion outflow characteristics. A comprehensive understanding of the ion outflow response to the asymmetries in the thermosphere continues to prove challenging because it requires characterization of the thermosphere and outflow for each hemisphere simultaneously (of the whole geospace coupled system). Sources of asymmetry can come from any of the geospace components and characterizing their importance and influence requires a complex coupled geospace model. Previously modeling efforts have only electrodynamically coupling the thermosphere to the magnetosphere, limiting the types of asymmetries that can propagate. Recent development of a coupled geospace model provides additional pathways for asymmetry to propagate. Specifically, this project aims to address the following scientific issues through numerical modeling and model-data comparison:

1) Characterization of the degree in which ion outflow is hemispherically asymmetric under different seasonal and solar activity.

2) Role and relative contribution of various asymmetric drivers to asymmetric outflow.

3) Impact of asymmetric outflow on geospace coupling and feedback loops.

4) Determine the relative contribution of each asymmetric driver on the whole coupled geospace model.

We will employ a coupled geospace model that includes the Lyon-Fedder-Mobarry global MHD magnetosphere model, the Ionosphere-Polar Wind Model of the polar wind and ion outflow, and the Thermosphere-Ionosphere-Electrodynamic General Circulation Model of the global thermosphere and ionosphere in combination with observations (particularly NASA FAST, NASA THEMIS, AMPERE, and DMSP) to carry out numerical experiments to simulate asymmetry within the whole geospace system and to address these scientific issues.

The proposed work is directly relevant to the goals of the NASA LWS Focus Science Topic #4: Causes and Consequences of Hemispherical Asymmetries in the Magnetosphere, Ionosphere, Thermosphere System, as the proposed work carries out numerical simulation using a coupled geospace model that captures the asymmetries from both external and internal asymmetric drivers for all three systems and is capable of propagating their asymmetries to the other systems.

Tai Phan/University of California

In-situ investigations of the controlling factors for the onset of magnetic reconnection in solar wind, magnetosheath, and magnetospheric current sheets

Science Goals and Objectives:
Magnetic reconnection in current sheets is a universal plasma process that converts magnetic energy into plasma jetting and heating, and is important in many laboratory, space, solar, and astrophysical contexts. While past in-situ observations in the magnetosphere and solar wind have provided convincing evidence for the occurrence of reconnection, the conditions necessary for the onset of reconnection have not been firmly established. In-situ observations reveal that reconnection occurs in only a fraction of

current sheets detected in the Earth s magnetosphere and in the solar wind. For example, the occurrence rate of reconnection in the near-Earth magnetotail is less than 10%, while reconnection signatures are seen in a smaller fraction of solar wind current sheets at 1AU. Observations in the magnetotail have revealed that the onset of reconnection occurs only when the thickness of the magnetotail current sheet is of the order of an ion skin depth or smaller. However, Earth s dayside magnetopause is usually a thin current sheet due to the constant compression of the solar wind against the magnetosphere, but the reconnection occurrence rate there is no more than 50% even when the magnetic shear across the magnetopause is large. This indicates that a thin current sheet is a necessary but not sufficient condition for reconnection. In order words, other conditions need to be satisfied for reconnection to occur, but what are they?

Using in-situ observation in the solar wind, Earth s magnetopause and magnetosheath, we propose to address the following key question about reconnection onset:

What are the controlling factors for the onset and suppression of reconnection in solar wind, magnetosheath, and magnetospheric current sheets?

Methodology:
We propose to use publicly available data from the Parker Solar Probe and Magnetospheric Multiscale missions, collected in the near-Sun solar wind, in the solar wind at 1 AU, and in the Earth s magnetopause and magnetosheath regions. We will examine a large number (hundreds) of current sheets in each of these regions to (a) determine whether reconnection occurs or not in the current sheets, and (b) determine the properties, plasma regime, and boundary conditions of the current sheets. This investigation will reveal the key controlling factors for the onset and suppression of reconnection over a wide range of plasma parameter space.

Relevance of the proposed work to the objectives of the solicitation and to NASA:
The proposed work directly addresses FST #2 Fast Reconnection Onset and is therefore relevant to the objectives of the LWS solicitation. As stated in the AO this proposal is therefore relevant to several LWS Strategic Science Areas (SSAs): SSA-0: Physics-based Understanding to Enable Forecasting of Solar Electromagnetic, Energetic Particle, and Plasma Outputs Driving the Solar System Environment and Inputs to Earth s Atmosphere; SSA-1: Physics-based Geomagnetic Forecasting Capability; SSA-3: Physics-based Solar Energetic Particle Forecasting Capability; and SSA-6: Physics-based Radiation Environment Forecasting Capability. Also, due to the inherent cross-disciplinary nature of this Focused Science Topic and its direct correspondence with space weather as a driver of energy release, this topic is ultimately relevant to all LWS SSAs 0-6.

The proposed study will be relevant to key aspects of the Decadal Survey questions: What is the role of magnetic reconnection in energy release in coronal mass ejections and flares? What are the interactions and feedbacks that connect the magnetosphere, solar wind, and ionosphere? and How does the Sun s magnetic field shape the dynamic heliosphere?

Ian Richardson/NASA Goddard Space Flight Center
The Influence of Solar Wind Structures on Energetic Particles in the Heliosphere Over a Wide Energy Range

Science Goals and Objectives: We propose to study the effects of solar wind structures (SWS) on energetic particle populations at multiple points in the heliosphere extending from suprathermal ions to Galactic cosmic rays (GCRs), building on studies by proposal team members that include investigations of solar energetic particle (SEP) and GCR modulations by SWS (shocks/interplanetary coronal mass ejections (ICMEs) and corotating high-speed streams). These studies will be extended to solar cycle 24 and the rise of cycle 25, providing a survey of the influence of SWS on energetic particles over 5 solar cycles. A catalog of ICMEs at Ulysses (Richardson, 2014) will be used to examine the radial/latitudinal variation of the associated short-term GCR depressions (Forbush decreases, Fds). We will also study SWS effects on particles at Helios at 0.3-1 AU, Parker Solar Probe (PSP), and at Mars, together providing a global picture of the impact of SWS on particles from near the Sun to Jupiter s orbit. We will also investigate small-scale SWS associated with energetic particle modulation, for example, whether discontinuities, planar magnetic structures, magnetic islands and mini flux ropes could contribute to modulation in shock sheaths in addition to turbulence. We will use analytical Fd models accounting for the effects of the shock-sheath and ICME, and statistical methods, to relate Fd characteristics to SWS properties. Multi-point solar and heliospheric observations will be used to determine whether mid-term (< solar cycle) GCR modulations are driven primarily by solar magnetic flux variations or by merged interaction regions. Another focus is the influence of SWS on high-energy SEP transport, including on the magnetic connectivity between the SEP source and observer, and SEP event temporal evolution and energy spectra. In particular, we will investigate how SWS influence the transport of high-energy SEP events, including the most energetic that produce Ground-Level Enhancements (GLEs) recorded by ground-based instruments (e.g., neutron monitors).

Methodology: We will use in situ measurements from spacecraft including ACE, Wind, SOHO, STEREO, Helios, IMP 8, Ulysses, GOES (including a recalibrated SEP data set), PAMELA and PSP, and MSL/RAD on the surface of Mars. Particle measurements will be used to characterize SWS effects on particle intensity, anisotropy and spectra. Field and plasma measurements will characterize large and small scale SWS such as shocks, sheaths and ICMEs. Observations of solar phenomena and solar wind models (e.g., WSA-ENIL+cone) will be used to provide context.

Proposed contributions to the Team effort: This proposal is relevant to the FST goals to determine the influence of solar and heliospheric plasma dynamics on high-energy particle radiation environments within the heliosphere , and of major solar eruption events on the high-energy particle environment near Earth and in interplanetary space . We will provide a comprehensive analysis of the radiation environment and its solar wind context. We will correlate neutron monitor and spacecraft data to determine how high-energy particle events contribute to the radiation environment in the heliosphere, and how SWS influence SEP temporal evolution and spectra. Products will include a global synopsis of the effect of SWS on particles including GCRs, catalogs of Fds at Helios, PSP, Mars and Ulysses, and a normalized GCR counting rate database that will link observations from Helios, IMP 8 and Ulysses with current observations e.g., from SOHO/EPHIN and planetary missions.

Mikhail Sitnov/JHU/APL
Magnetotail reconnection: Understanding and quantifying onset conditions using kinetic theory, simulations and data mining

Science goals and objectives: Magnetotail reconnection is inherently unsteady. Its onset, which is thought to be the cause of substorms, critically depends on the strength of the northward magnetic field Bz and its distribution along the tail. Onset may be permitted by demagnetization of electrons or ions in that field. It is preceded by the formation of ion-scale thin current sheets (TCS) embedded into a thicker plasma sheet. Unsteady regimes and mechanisms of reconnection depend on the tail geometry and the solar wind driving strength and are poorly constrained by observations because of extreme data paucity. The goal of this project is to understand the mechanisms of magnetotail reconnection onset during magnetospheric substorms. The objective is to quantify the onset conditions, regimes and their uncertainties using a combination of kinetic particle-in-cell (PIC) and magnetohydrodynamic (MHD) models, as well as data-mining (DM) algorithms to address the following Science Questions:
1) What are the critical conditions for reconnection onsets, enabled by demagnetization of electrons and ions, taking the observed pre-onset geometry of the tail, realistic external driving conditions and 3-D non-reconnection motions into account?
2) How does the magnetotail stability picture based on isotropic plasma equilibria change in the presence of TCS?
3) How unsteady is the magnetotail reconnection and what is the distribution of the reconnection electric field?
Methodology: To reproduce unsteady reconnection regimes it is proposed to use 3-D particle-in-cell (PIC) simulations covering ~10 earth radii (RE) along the tail and a few RE across the tail. Initialization of PIC runs will be done using new classes of weakly anisotropic 2-D TCS equilibria that describe embedded TCS with the observed aspect ratios and Bz profiles. To describe the global configuration of the tail prior to the onset we employ DM processing of space magnetometer data. The DM approach enables visualizing the global geometry of the tail at the moment of interest by mining big historical data. It resolves tailward Bz gradients, critical for the ion-demagnetization mediated onset, and embedded TCSs. It allows one to assess the unsteady component of

the reconnection electric field, while its steady component will be assessed independently from the solar wind and interplanetary magnetic field data using a global MHD model. Proposed Contributions to the Focused Science Team Effort: This study will determine the roles of global and local features of the magnetotail in reconnection onset: TCS, Bz profiles, ion and electron demagnetization processes as well as ideal MHD regimes. It will extend existing tearing stability picture going beyond isotropic current sheet models and single-scale TCS. It will help better understand not only the magnetotail onset physics but also similar processes in other space plasmas, where in situ observations are more limited or impossible. The potential contributions to the FST s team effort will be DM-enabled models of the magnetotail reconnection onset, its quantitative criteria and their observational constraints. Reconnection electric field distributions will help define the reconnection rate. Metrics of the proposed study will include predictive onset parameters, such as the critical TCS thickness and aspect ratio, tailward Bz gradient, strength of the driving electric field, roles of non-reconnection motions, electron and ion demagnetization parameters. The milestones will be determined by different classes of DM tail reconstructions and driving field strength. Error measures will include validation results for individual events and statistical bias of the DM data bins, estimates of impact of artificial parameters used in PIC codes, simulation and observation constraints in the assessment of ion and electron demagnetization parameters.

Kareem Sorathia/JHU/APL
Mesoscale Ionospheric Electrodynamics as a Driver of Rapid Geomagnetic Variability

Science Goals and Objectives.
Ongoing work has identified the critical role of complex and localized geomagnetic disturbances (GMDs), and their interaction with the Earth's 3D conductivity distribution, in driving geoelectric fields (GEFs). These localized and rapid GMDs are not only a key space weather target but also a manifestation of fundamental magnetospheric processes and their auroral ionospheric counterparts at mesoscales. The overarching goal of the proposed project is to "Understand the physical processes responsible for the generation of localized and rapid GIC variability by characterizing magnetospheric drivers and ground effects of mesoscale ionospheric electrodynamics."

Predicting GICs is a grand challenge of geospace modeling, ground effects are the end result of a causal chain of processes ultimately driven by the interaction of solar disturbances with the magnetosphere. To accomplish our goal we will utilize a combination of cutting-edge first-principles models and a collection of heterogeneous data sets spanning geospace: in the magnetosphere, ionosphere, and on the ground. We will address the following science questions:

SQ#1: What is the role of magnetotail bursty bulk flows in driving localized (<500 km), rapid surface geomagnetic disturbances? How does it depend on the level of geomagnetic activity?

SQ#2: What is the relationship between the intensity and spatiotemporal scale of geomagnetic surface disturbances? Do spatially localized disturbances consistently (statistically) produce larger surface magnetic field temporal variations (dB/dt)?

SQ#3: How do rapid ground geomagnetic disturbances interact with global and mesoscale structure in the Earth's ground conductivity to create hazardous geoelectric field magnitudes?

Methodology.
Our investigation will proceed along three major thrusts:
Multi-scale and multi-domain modeling: We will deploy a physics-based model pipeline combining a global magnetosphere model with an electromagnetic induction model incorporating global or regional realistic 3D conductivities. Each of the models has a demonstrated capability of resolving GIC-critical scales, hundreds of km on the ground.

Cross-domain and cross-scale validation: We will isolate and quantify model errors at each stage between the solar wind and ground by using "bracketing" data sets: THEMIS and GEOTAIL (magnetotail), AMPERE (ionosphere), and SuperMAG, augmented by POLAR and IMAGE (ground). We will formulate our validation strategy to focus on the ability of the models to reproduce statistical relationships seen in data at all pertinent scales.

Community access and stakeholder engagement: The modeling we propose to undertake is timely as it will respond directly to the need for improved characterization of extreme GEFs to inform ongoing work to update GMD standards. We will work with stakeholders to transition new research-based understanding to inform evolving standards.

Relevance and contributions to Focused Science Topic (FST).
This work contributes to all three primary goals of FST#3: high-resolution modeling will connect solar wind driving to ground GMDs at GIC-critical scales (FST Goal #1); using surface GMDs as an input to 3D conductivity models will predict GEFs and their characteristic scales (FST Goal #2); and finally, by combining the previous two efforts, we will identify the critical ground-scales for situational awareness and hazard mitigation and informing spacing and location of ground-based observatories (FST Goal #3). Beyond direct contribution to the FST primary goals, this work will also complement the broader FST team effort by providing high-resolution model predictions of GMDs and GEFs.

Marc Swisdak/University of Maryland
The Onset of Reconnection and Associated Turbulence in Solar Eruptions

One of the most important outstanding problems in space science has been to understand the mechanisms responsible for the onset of explosive energy release during magnetic reconnection. Simulations dating back to the GEM Challenge have demonstrated that in an idealized case -- two-dimensional, laminar, symmetric, anti-parallel reconnection in a collisionless electron-proton plasma – reconnection is mediated by the physics of whistler waves so that onset occurs when the width of the current layer becomes thinner than the ion inertial length. When these constraints are relaxed, however, the criteria for onset become less clear. In the solar corona, for example, collisions can be important during onset (i.e., the reconnection is not super-Dreicer). In addition, turbulence can oftentimes both trigger and disrupt reconnecting current layers to a sufficient degree (particularly when three-dimensional dynamics are allowed) that the two processes cannot be independently considered.

In this proposal we will focus on the onset of reconnection and triggering of flares in the solar corona. The corona represents a particularly challenging case because of the wide disparity in scales -- more than ten orders of magnitude lie between kinetic length scales and the dimensions of flare regions. Moreover, physical processes on these scales are interconnected since, for example, the compression of a coronal current sheet by forcing flows at large scales can lead to turbulence and the onset of reconnection at small scales.

We propose to examine the microscale aspects of this problem through a mixture of theory and simulation studies, but plan as well to take advantage of the expertise offered by a Focused Science Team to connect with the macroscales. We will examine such important questions as: Does the onset of reconnection in coronal environments necessarily involve turbulence? How important is the plasma collisionality? Are there significant differences between two-dimensional and three-dimensional systems with regards to reconnection and the associated turbulence? Our simulations will primarily use particle-in-cell and hybrid codes which will include collisions self-consistently. The reconnection rate will provide a key diagnostic to determine if onset occurs and what factors significantly affect it. The role of turbulence will be studied by analyzing systems with and without turbulence and noting key differences. In addition, the statistical properties of the turbulence generated in the system (e.g., spectra, structure functions) will be determined with an eye for how they vary between systems and how this may affect reconnection onset. In addition, the role of secondary reconnection sites generated by turbulence and how they impact the global process will be addressed.

This proposal would address a critical portion of the Focused Science Team's effort by providing theoretical and simulation studies of reconnection onset criteria and the associated turbulence in the solar corona. It is anticipated that this proposal will particularly help the Focused Science Team address the primary goal of ``Establish[ing] an understanding of what the critical conditions are for the onset of fast reconnection at a current sheet in the various regimes relevant for heliophysics", although the work will also contribute to the other primary goals.

The PI of the proposal is Dr. Marc Swisdak, who will be responsible for the overall direction and its integration into a Focused Science Team. Prof. Drake will be a co-Investigator and will collaborate on all aspects of the theoretical analysis and particle-in-cell simulations. Prof. Shay and Prof. Matthaeus will be co-Investigators based at the University of Delaware. They will collaborate on all aspects of the theoretical analysis and will be primarily responsible for the turbulence portions of the proposal.

Valeriy Tenishev/University of Michigan
Integrated Model for the Solar Energetic Particles, Galactic Cosmic Rays, and Alfven Wave Turbulence in the Inner Heliosphere

The aim of the proposed investigation is to characterize the radiation environment due to solar energetic particles (SEPs) and galactic cosmic rays (GCRs), and the variability of this environment affected by the Sun. The two principle science objectives of this study are 1) quantification of the relationship between extreme SEP events and Forbush decrease, and anisotropy of the CGRs observed at Earth, and 2) identification of the mechanism of SEP acceleration and their energy spectrum and anisotropy.

In this investigation, we will analyze energetic proton spacecraft observations, and use them for the model validation. Modeling that will be performed as a part of the study includes three major components: 1) kinetic modeling of SEPs in the inner heliosphere accounting for their stochastic acceleration, 2) kinetic modeling of GCRs starting at 5 AU as they propagate toward the inner heliosphere, and 3) MHD modeling of solar wind including the quantification of turbulence. The novel feature of our approach is concurrent modeling of the turbulent solar wind, SEPs, and GCRs in the same simulation.

To address the diffuse shock acceleration driven by the Coronal Mass Ejection (CME), we will employ the Eruptive Event Generator using the Gibson-Low flux rope (EEGGL) to simulate the CME and accompanying shock.

To model the SEP transport through a wide range of heliocentric distances from 1 Rs to about 5 AU. We will use the Field-Line-Advection Model for Solar Particle Acceleration (M-FLAMPA) model, recently implemented to work with multiple lines.

The realistic three-dimensional magnetic field governing the particle motion will be simulated using the Alfven Wave turbulence based Solar atmosphere Model (AWSOM) with the capability of faster than Real-time simulation (AWSOM-R). In the latter, the Alfven wave turbulence both heats the solar corona and powers and accelerates the fast and slow solar wind. Following a system approach, we will employ the turbulence as simulated in the AWSOM-R as the agent controlling the energetic particle transport and determining the particle spatial diffusion coefficient or pitch-angle scattering.

With an assumed (or based on observations) spectra of GCRs at 5AU, we will study their transport to the inner heliosphere as well as the SEP population propagating from the Sun. The highest-energy particle trajectories will be traced with the Adaptive Mesh Particle Simulator (AMPS) code available at the University of Michigan. Electric and magnetic fields that are needed for calculating these trajectories, as well as the level of turbulence, will be derived from the expanded AWSOM model.

The model of the SEP fluxes and spectra will be validated against the spacecraft observations (ACE, STEREO, and GOES).

The proposed project will contribute to the Focused Team Effort by characterizing the radiation environment due to SEPs and GCRs in the heliosphere up to 5 AU. One of the outcomes of the project will be improved the models of the solar wind, SEPs, and GCRs models that were developed and maintained by the proposing team. That serves improving the numerical models of cosmic ray modulation in the heliosphere, high-energy particles from major solar eruptions, and the Forbush decrease by extreme CME events, which is a measure of success of FST #1. All the relevant models are available to the heliophysics community via the Community Coordinated Modeling Center (CCMC). Therefore, this work will have a broader impact that goes beyond the science goals of this investigation by providing better modeling tools to the heliophysics community.

The proposed work will also directly contribute to Understanding the influence of major solar eruption events on the high energy radiation environment near-Earth and interplanetary space, and Studies of the temporal and spectral properties of large SEP events that are the science goals of FST #1.

Ming Zhang/Florida Institute Of Technology
Determining the radiation level of galactic cosmic rays and solar energetic particles in the heliospheric magnetic field based on magnetogram measurements of the solar photosphere

Background: Galactic cosmic rays (GCRs) and solar energetic particles (SEPs) are two major sources of energetic radiations that affect the space weather. GCRs are modulated by the solar wind mainly in the 11-year solar cycle and to some small magnitude (Forbush decreases) by interplanetary disturbances. The most reduction of GCR intensity occurs in the heliosheath. The intensity of SEPs is highly variable, and the occurrence appears random. The majority of SEPs are produced by solar flares, or coronal mass ejection (CME) shocks deep in the solar corona or near the surface where seed particle density is high. Solar flares and CME shocks cover limited ranges of longitude and latitude, so a direct connection by magnetic field lines between SEP source and observer is not always guaranteed. Yet, it is quite surprising that SEPs are often detected over wide ranges of longitude even for those events with characteristics of impulsive events. To understand or predict GCR and SEP radiation hazards, we need to look at how energetic particles propagate through coronal and interplanetary magnetic fields. With this understanding, we can connect the particle source to the observed properties, such as the boundary condition, the timing, location, spectrum, anisotropy, and composition.

Objectives: We will investigate the effects of energetic particle transport in data-driven MHD corona and heliosphere models. Since SEPs and GCRs share the same particle transport mechanisms and magnetic field media, we intend to treat the GCR modulation and SEP propagation problems consistently and systematically. Our research consists of three parts: (1) Improve our GCR modulation and SEP propagation investigations with a more realistic combined data-driven MHD-based MAS, CORHEL, and MS-FLUCKSS heliosphere models to understand how particle radiation varies with solar wind condition and solar eruptions; (2) Apply our model calculation results and our expertise to the team effort in analyzing specific SEP events and GCR modulation phenomena; (3) Obtain understanding of the physics of particle acceleration and transport through comparison between observations and model simulations.

Methodology: We will rigorously solve the transport equations for particle propagation (also acceleration) in 3-D coronal and heliospheric magnetic fields. We will use a data-driven model from time-dependent MHD simulations constrained with measurements of the solar wind and photospheric magnetic field. The transport equation contains all the relevant mechanisms of particle transport: pitch angle scattering, perpendicular diffusion, magnetic focusing, anisotropic adiabatic energy loss or gain, streaming along the magnetic field, and convection with the solar wind, and gradient/curvature drift. It is solved using corresponding stochastic differential equations using both time-forward and time-backward approaches. Using the results of SEP source acceleration, we will produce predictions of particle flux at any specified location in the heliosphere. Our product will be the time profile of GCR and SEP flux at all energies, which can then be directly compared with observations.

Contribution to the Focus Science Team Effort: We bring the focus science team an indispensable, unique, state-of-art, and proven capability of calculating GCR modulation and SEP propagation through data-driven 3-D magnetic fields with essentially all particle transport mechanisms including perpendicular diffusion. We will provide team members with model calculations and expertise in data analysis, and, more specifically, the interpretation and prediction of SEP and GCR fluxes under various coronal and heliospheric configurations. When combined with simulations of CME-driven shocks or solar flares by other members of the team, we can also make further contributions to the understanding of particle acceleration and transport processes.

Lingling Zhao/University of Alabama, Huntsville
Diffusive Particle Acceleration and Extreme Solar Energetic Particle Gradual Events

Objective: Gradual solar energetic particle (SEP) events are associated generally with interplanetary shocks driven by coronal mass ejections (CME), where energetic ions are thought to be accelerated via diffusive shock acceleration (DSA). Close to the Sun, strong shocks can occasionally accelerate particles to GeV energies. Most typical CME-driven shocks tend to accelerate charged particles to quite modest energies, and the total energy contained within the accelerated SEPs is typically a small fraction (< 10%) of the kinetic energy of the shock. However, a number of extreme CME-driven shock events have been observed with energetic particle pressures not only dominating the downstream thermal and magnetic field pressures but being a significant fraction of the ram energy of the shock wave itself. These extreme shocks are fast, very broad, and do not satisfy the standard Rankine-Hugoniot conditions. For these extreme events, not only the backreaction of the energetic particles on shock structure has to be properly considered, but the turbulence generated by the SEP component streaming in the solar wind plasma needs also be taken into account as they affect the scattering and transport properties of the SEPs. Therefore, to build a complete picture of extreme SEP events, one should consider shock structure, turbulence, and energetic particles as an integrated system. The science goal of this project is to (1) model the time-dependent, multi-D mediation of shock structure by the DSA of SEPs for extreme SEP events, and (2) describe quantitatively the 2D interplanetary transport of SEPs that escape a mediated shock, stream and generate turbulence that affects the transport of the SEPs themselves.

Methodology: For Goal #1, we propose to develop a theoretical model of SEP mediated shock propagation in the inner heliosphere. The shock model will treat SEPs as a separate component from the bulk solar wind, using a diffusive transport equation formulation. To describe the scattering of particles, we will couple modern scattering theories for the spatial diffusion tensor to modern theories of turbulence transport. The PI and Co-Is have previously developed models for the structure of energetic particle mediated shock waves, charged particle scattering theories, and turbulence transport models. These models will serve as the starting point of our investigation. To accommodate the realistic solar wind, we will develop numerical solutions for 2D time-dependent shocks and solve the SEP transport equation. For Goal #2, we will solve the gyrophase-averaged particle transport equation for SEPs in the solar wind away from the shock to obtain their energy and pitch-angle distribution. The PI and Co-Is have developed numerical codes previously that solve the focused transport equation for energetic particles using a stochastic simulation method, and these will be the basis for modeling extreme SEP events. To validate our theoretical and numerical models, we will compare them against in-situ observations of plasma, magnetic fields, and SEPs from Parker Solar Probe, Helios, ACE, Wind, Ulysses, and the upcoming Solar Orbit and IMAP missions during extreme SEP events. Our existing iPATH (improved Particle Acceleration and Transport in the Heliosphere) code has successfully simulated some selected normal SEP events. However, it does not apply to extreme SEP events. We will compare the new model results i.e., the SEP-mediated extreme events, with the non-feedback (normal) models (using iPATH) to contrast the differences.

Contributions to the Focused Science Team: Our proposed investigation will contribute directly to FST #1 by focusing on the acceleration and transport of extreme SEP events, which contribute to the interplanetary radiation environment. As these extreme SEP events are often associated with CME-driven interplanetary shocks, this work may provide insight into the prediction of extreme SEP events.