Living With A Star Science
Abstracts of Selected Proposals
(NNH22ZDA001N-LWS)

Below are the abstracts of proposals selected for funding for the Living With A Star Science program. Principal Investigator (PI) name, institution, and proposal title are also included. Thirty-nine proposals were received in response to this opportunity. On April 11, 2023, fourteen proposals were selected for funding.

Laura Balmaceda/George Mason University
Investigating the Forecast Capabilities of the Modeling of the Solar Spectral Irradiance from the Solar Surface Magnetic Flux

Science goals and objectives
This proposal addresses the Focused Science Topic (FST) #1: Beyond F10.7: Quantifying Solar EUV Flux and its Impact on the Ionosphere Thermosphere Mesosphere System" via the modeling of the Solar Spectral Irradiance (SSI) from the evolution of the surface magnetic flux of the Sun.
Goals
We aim to further develop and test solar spectral models to quantify the solar EUV flux and help evaluate its impact on the Ionosphere, Thermosphere, and Mesosphere (ITM) system. Depending on the direction of the FST team we can also contribute to the development of retrospective analysis of the SSI.

Objectives
We will accomplish our goals by investigating the following scientific questions:
What is the contribution of the different magnetic features on the Sun's surface (active regions, ephemeral regions, quiet sun) to the variability of the SSI in different regions of the spectrum?
How does the SSI vary at different timescales, i.e. from short (hours, days) to long (solar rotation, solar cycle) periods?

Methodology
We will use the COronal DEnsity and Temperature (CODET) physics-based model to recover the Solar Spectral Irradiance variability in specific wavelengths in the EUV. The CODET model uses a flux transport model that assimilates line-of-sight magnetic field data from available magnetograms (SOHO/MDI, SDO/HMI, ground-based observations). This project will include the ADAPT (Air Force Data Assimilative Photospheric Flux Transport) model. To model the electron density and temperature in the solar corona, the CODET model uses: i) the potential field source surface (PFSS) extrapolations of the coronal magnetic field; and ii) an emission model based on the CHIANTI atomic database. The modeled irradiance is then compared to the irradiance measurements, from

e.g., SOHO/SEM, TIMED/SEE, SDO/EVE, as well as disk integrated intensities from STEREO A and B, AIA/SDO EUV images.
First, through the comparison of the implementation of different flux-transport models (different approaches and/or input data) we will quantify the effect of observational limitations (duty cycle restrictions, foreshortening, different resolution, center-to-limb variation, reduced sensitivity, and low signal) on the estimation of the SSI .
Secondly, we will evaluate the forecast capabilities of the SSI model. To take into account the magnetic flux emerging on the far-side of the Sun we will use different approaches such as incorporating helioseismology-based far-side imaging or EUV observations from the STEREO spacecraft.
Proposed Contributions to the FST Team Effort
Relevance: The proposal addresses three of the FST science objectives: (1) identifying new and/or improved EUV indices for driving model predictions of ITM structure; 2) improved understanding of how particular portions of the EUV spectrum influence specific aspects of ITM structure; and 3) exploring new EUV observations characterizing the interactions between the ionosphere and thermosphere". Furthermore, our study is relevant to the LWS program goal #1 Understand how the Sun varies and what drives solar variability" and one of four main goals of the LWS Targeted Research and Analysis program (TR&T), now known as LWS Science: Deliver the understanding of how variations in solar radiation, particles and magnetic fields contribute to global and regional climate change" as stated in the LWS 10-Year Vision Beyond 2015 Report.
Contributions to the Team: We will provide time series of SSI in specific wavelengths and/or spectral bands, and for specific time intervals as discussed with the team: i) to be used as input in ITM models, ii) to be compared with other solar indices and/or proxies from other teams, iii) to be tested in the specification and prediction of ITM parameters.

Thomas Berger/University Of Colorado, Boulder
Using Helioseismic Far-side Imaging to improve Solar EUV Irradiance Prediction

We propose to develop a supervised non-linear Machine Learning (ML) regression model of far-side AR helioseismic signal to EUV irradiance measures using SDO/HMI far-side maps and SECCHI EUV images as training data. Front-side EUV image data from SDO/AIA will be correlated to both SECCHI EUV images and to F10.7 cm flux to create a chained regression from far-side helioseismic signal to EUV image characteristic to proxy irradiance values that can be used in current thermospheric satellite drag forecasting models. We will also investigate the impact of large ARs rotating onto the disk on thermospheric temperature and composition, correlating EUV signal increases with measurements from the NASA/Global Observations of the Limb and Disk (GOLD) mission, enabling the development of direct thermospheric impact predictions from far-side AR measurements.

The investigation directly addresses the LWS program goal to understand how the Earth responds to dynamic external drivers, specifically connecting observed and predicted solar EUV irradiance variations to ITM system responses. As a member of the F10.7

FST team, we will bring far-side AR detection and correlation to EUV irradiance to the effort as a standard tool for use in building other irradiance models or conducting IT impact studies.

Joseph Borovsky/Space Science Institute
Advanced Statistical Analysis of the Solar Wind Control of Magnetospheric Activity and Magnetospheric Particle Populations

OBJECTIVES
The objectives of this LWS FST Investigtion are (1) To determine what solar-wind variables (and their time history) control geomagnetic activity and various magnetospheric particle populations and their response lag times. (2) To explore the upstream-turbulence effect and determine if it has a causal explanation or if the upstream-turbulence amplitude is acting as a statistical proxy for another physical variable. (3) To explore the possibility that polar-cap-potential saturation is not a post-reconnection coupling phenomena but rather is caused by an inadequate description of the true solar wind driving of the magnetosphere. (4) To work with other Focus Science Teams to develop statistical analysis methods for simulation outputs that can be used to statistically test codes against real solar-wind/magnetosphere data. In previous works the investigators have identified many correlations between solar wind properties (v, B, n, fluctuation amplitude, Mach number, strahl intensity) and magnetospheric properties (convection, auroral activity, polar-cap currents, substorm occurrence, plasma sheet, substorm-injected electrons, radiation belt electrons), and now will further explore the causality (rather than coincidence) of these and other statistical connections.

METHODS
Two main statistical tools used will be canonical correlations analysis (CCA, vector-vector correlations) and information transfer. This will extend existing statistical methodologies to gain more information about causality rather than simple correlations. CCA work in the past has been focused on examining the modes of reaction of the magnetosphere to the solar wind, here we will use CCA to focus on the solar wind properties that drive Earth. Information transfer goes beyond the standard correlations to examine liner and nonlinear cause and effect statistical connections. We will exploit this specifically for Objective 2. We will merge CCA and information transfer to create a vector-vector analysis methodology based on transfer entropy or mutual information rather than on Pearson linear correlations. The merged technique will be used to determine the causal relationships and response modes and time scale. To determine time lags, an evolutionary (genetic) algorithm will be used that runs the vector-vector analysis tool. Further, the new dynamic canonical correlation tool will be introduced to heliophysics.

SIGNIFICANCE
This LWS FST Investigation will deliver extensive knowledge of solar-wind/magnetosphere coupling informed by collaboration with other groups. This FST

Investigation directly supports all five FST#2 objectives: (1) identifying the parameters controlling the transfer of energy through dayside magnetopause reconnection, (2) establishing the role of ionospheric and magnetospheric plasmas in solar wind magnetosphere coupling, (3) investigating the physical processes controlling non-reconnection coupling, (4) understanding the role of solar wind fluctuations in the coupling of the solar wind to the Earth, and (5) understanding the post-reconnection reconfiguration of the magnetosphere and ionosphere system in response to extreme solar wind magnetosphere coupling. Outstanding questions about the upstream-turbulence effect and about polar-cap potential saturation will be addressed. The system-science tools that will utilized are quite general and can be applied to datasets from other FST subteams. This could be the glue of the FST Team. One desire of this FST subteam is to develop and test a system-science methodology to gauge simulation codes by statistically analyzing simulation outputs and comparing with statistical analysis of actual system measurements. With collaborations with other subteams, we will compare the information flow in the simulated system and with the information flow in the real M-I-T system.

Phillip Chamberlin/University Of Colorado, Boulder
The Next Generation of Flare Irradiance Spectral Models: FISM-3 and FISM-AI

Version 2 of the Flare Irradiance Spectral Model (FISM2; Chamberlin et al., 2020) was released in Dec 2020, and has quickly replaced the original FISM model as the most accurate solar ultraviolet spectral irradiance model over all time scales from solar flares (seconds to hours), active region emergence (hours to days), solar rotation (days to weeks), and solar cycle (months to years). FISM's accuracy and cadence are attributed to moving beyond using solely the F10.7 cm radio flux to more representative proxies for each wavelength, such as the H I Lyman Alpha 121 nm, Mg II core-to-wing ratio (c/w), and He II 30.4 nm measurements. Additionally, including higher temporal cadence proxies, such as those from GOES-XRS, allows for significant improvements in FISM's ability to model variations due to solar flares.

Science Goal: Improve the accuracy of solar UV spectral irradiance modeling on all time scales from seconds to decades. Despite significant improvements from FISM to FISM2, discrepancies remain between FISM2 estimates and the measurements for which it is based. This proposal will add additional capabilities in the next versions, FISM-3 and FISM-AI. The specific objectives of this proposal for FISM-3 are to (1) incorporate the Lumped Element Thermal Model (LETM; Thiemann et al., 2017a) for the delay in flare peak emissions for different wavelengths, (2) incorporate new MinXSS-1/-2/DAXSS soft X-ray spectral measurements, (3) add the additional daily proxies of plasma Temperature and Emissions measures (Schwab, PhD thesis, 2022), (4) improve the center-to-limb variation correction, (5) incorporate the new routine proxies that are now available from the GOES/EUVS instrument and (6) incorporate the ADAPT full-Sun magnetic field model, as well as relations of the photospheric magnetic field to irradiance, to drive a 'daily average' forecast of the UV solar spectral irradiance. Furthermore, for Objective

(7), FISM-AI will employ an artificial intelligence (AI) model to determine if this method can improve upon the accuracy of the traditional UV spectral irradiance empirical model results from FISM-3.

Methodology: Objective (1) will use the approach described in Thiemann et al. (2017a), using available emissions to estimate the required cooling time constant. Objectives (2 and 4-6) will determine regression coefficients between irradiance measurements and proxies, detrended according to fundamental timescale (solar cycle, solar rotation, etc.), following the approach of Chamberlin (2007; 2008; 2020). Objective (3) will use OSPEX modeling software to calculate coronal plasma temperatures and emission measures and correlate these to GOES XRS irradiance as a proxy measurement. Objective (7) will employ state-of-the-art multi-dimensional time-series learning algorithms to develop an independent deep-learning powered empirical model.

Relevance: This proposal is for the Beyond F10.7" Focused Science Team and the proposed significant improvements to FISM will directly address this FST Objective #1, identifying new and/or improved EUV indices for driving model predictions of ITM structure". We expect through collaboration with other teams, who will presumably bring a wealth of ITM expertise, these improved irradiances will be used to address the other two FST objectives.

Yuxi Chen/Princeton University
Quantifying global mass and energy transfer rates from solar wind to magnetosphere by magnetopause reconnection

Magnetic reconnection is widely considered as the most important mechanism for the solar wind plasma transferring into the magnetosphere. The local properties of magnetic reconnection, such as the local reconnection rate and the plasma flow around the reconnection site, have been extensively studied with both local simulations and satellite observations. However, it is difficult to measure the global consequences of the magnetopause reconnection with in situ satellite data, and such investigation largely depends on global numerical simulations. Ideal and resistive MHD models have been widely used to simulate solar wind-magnetosphere coupling. These models usually produce well-defined steady separatrices at the magnetopause, and the global reconnection rate, which is closely related to the efficiency of solar wind plasma transferring into the magnetosphere, can be calculated as the integral of the electric field along a separator line. In recent years, however, both beyond-MHD simulations and satellite data indicate that the magnetopause X-lines are usually patchy and unsteady, and the products of multiple X-line reconnection, flux transfer events (FTEs), occur frequently. Such complex reconnection structures imply the global solar wind-magnetosphere coupling efficiency needs to be revisited. However, it is difficult to apply the electric field integral method to calculate the global reconnection rate for such beyond-MHD simulations, because 1) it is not trivial to find and trace the patchy and unsteady magnetopause X-lines, and 2) it is not clear how the contribution of FTEs should be evaluated. On the other hand, traditional MHD simulations do not contain kinetic phenomena that are produced by the bow shock, and they may have a significant influence on magnetopause reconnection.

We propose to study the solar wind-magnetosphere coupling efficiency under different solar wind conditions and evaluate the influence of bow shock by simulating the solar wind-magnetosphere interaction with the MHD with Adaptively Embedded Particle-In-Cell (MHD-AEPIC) model, measuring the global solar wind-magnetosphere coupling efficiency with a test particle module that is coupled to the MHD-AEPIC model, and validating the global simulation results with MMS data and high-resolution one- and two-dimensional local shock simulations. Specifically, our proposed investigation will answer the following three fundamental science questions:
1. What are the global mass and energy transferring rates by magnetopause reconnection under different solar wind conditions?
2. What are the paths for the solar wind particles entering the magnetosphere? What is the role of FTEs in transferring plasma?
3. How will the kinetic phenomena produced near the bow shock change the global magnetopause reconnection and plasma coupling efficiency?

The proposed investigation is highly relevant to the LWS FST #2: Coupling of the Solar Wind Plasma and Energy to the Geospace System", and it focuses on the FST #2 science goals of identifying the parameters controlling the transfer of energy through dayside magnetopause reconnection" and understanding the role of solar wind fluctuations in the coupling of the solar wind to the Earth".

Gonzalo Cucho Padin/Catholic University Of America
Specifying Properties of Dayside Magnetopause Reconnection from a Machine-Learning Model for the Earth s Cusps

This proposal quantifies the properties of dayside magnetopause reconnection via a novel machine-learning-based analysis of in-situ measurements of ion fluxes within the terrestrial cusps. It addresses the following science questions:

How do solar wind plasma and magnetic field conditions control the spatiotemporal variability of the high/mid-altitude cusps?
How do solar wind plasma and magnetic field conditions control the spatiotemporal variability of the low-altitude cusps?
What can we infer about the location(s) of reconnection on the magnetopause from cusp properties?
What can we infer about the time dependence of reconnection on the magnetopause from cusp properties?

Magnetic reconnection on the dayside magnetopause represents the primary mechanism for transporting mass, momentum, and energy from the solar wind into the terrestrial magnetosphere. Despite its crucial role, accurate information regarding the location, extent, and time dependence of reconnection remains difficult to obtain. Several studies have demonstrated that the spatiotemporal dynamics of the dayside magnetic reconnection can be inferred remotely from the time-energy dispersion of ions in the cusps; however, it is still difficult to infer the overall cusp behavior from intermittent snapshots of isolated in-situ measurements.

This project aims to use novel machine learning techniques to leverage the immense amount of ion flux observations available from the cusps, provide reliable models for cusp dynamics, and, through these, improve our understanding of magnetic reconnection on the dayside magnetopause. First, we will implement regression models for the high/mid-altitude Northern cusp (beyond <2 Earth Radii) using artificial neural networks (ANNs) as well as solar wind/IMF data and ion flux spectra from the Cluster/CODIF instruments. This data-based model will yield a 3-D distribution of ion flux within the cusp region for each energetic channel in the CODIF instrument. Uncertainties of the model will be estimated through a robust statistical analysis of modeling results and observations. We will assess the modeled cusp features by comparing them with cusp simulations from the physics-based model Auburn global hybrid simulation code in 3D (ANGIE3D) and in-situ observations of the Polar/TIMAS instrument. Then, we will identify the relative role of each input solar wind parameter on the cusp structure using the DeepSHAP algorithm. Second, following a similar procedure, we will generate regression models for the low-altitude cusp using data from the SSJ5 ion spectrometers on board the DMSP-F17/F18 missions. Then, we will estimate their corresponding uncertainties and will assess the modeling results by comparing them with ANGIE3D model simulations and observations of the SSJ5 instrument onboard the DSMP-F16/F19 spacecrafts. Also, we will use DeepSHAP to evaluate the relationship between the low-altitude cusp ion structures and each input solar wind parameter. Third, we will conduct a correlation study between the spatial distribution of dayside magnetopause reconnection sites and the 3-D ion flux distributions in the cusp under steady solar wind conditions. For this, we will run ANGIE3D simulations of the dayside solar wind-magnetospheric interaction region and support the results with in-situ plasma observations of the MMS mission. Then, for a number of cases, we will analyze the relationship between the location and extent of reconnection entry points and the 3-D structure of the cusp. Finally, we will leverage the time-varying property of the data-based cusp models to investigate the relationship between the spatiotemporal properties of reconnection entry points estimated by ANGIE3D and the spatiotemporal ion flux distributions in the cusp during transient events such as solar wind tangential discontinuities (TD) and rotational discontinuities (RD).

Chih-Ting Hsu/National Central of Atmospheric Research
Effect of the uncertainty and variability of solar irradiance on the thermospheric and the ionospheric weather predictability

The goal of this project is to advance our understanding of how solar irradiance variability drives the variability of Earth's thermosphere and ionosphere and improve our capability to represent this driver-response relationship in physics-based models using data. The upper atmosphere absorbs solar radiation in the ultraviolet range and generates plasma through photon ionization and dissociation processes, so the thermosphere and the ionosphere are very sensitive to changes in solar irradiance. The solar ultraviolet spectrum in most current numerical models is parameterized by the daily 10.7 cm solar ux. However, solar ultraviolet radiation is highly variable on time scales shorter than a day, and the changes in different wavelengths are not perfectly correlated. Some recent modeling efforts incorporate a more realistic solar spectrum model. Yet, the uncertainty in spectrum models is not quantified and considered in any numerical models of the thermosphere-ionosphere. It is critical to investigate the sensitivity of the thermosphere and ionosphere to short-term solar ultraviolet variability and uncertainty in the solar spectrum.

Building on our past work with the National Center for Atmospheric Research Whole Atmosphere Community Climate Model with thermosphere and ionosphere eXtension (WACCM-X) and the Data Assimilation Research Testbed (DART) Ensemble Adjustment Kalman Filter, this project will develop a new ensemble forecasting and data assimilation modeling framework that is interoperable with the solar ultraviolet spectrum model, Flare Irradiance Spectral Model-Version 2 (FISM2). The FISM2 model doesn't provide information of uncertainty regarding the solar irradiance data. Therefore, the solar irradiance data will first be analyzed statistically to evaluate the spectral variability and uncertainty of solar irradiance ranging from 0.1 to 180 nm. Next, WACCM-X ensemble forecasting driven by FISM2 and associated spectral variability and uncertainty will be performed to understand the sensitivity of the thermosphere and the ionosphere to both the short-term variability and the uncertainty of solar radiation. Data assimilation experiments will also be performed to examine the capability of the new method for thermospheric and ionospheric weather prediction. With the help of DART, NASA-GOLD, NASA-ICON, and COSMIC-II data will be assimilated into the WACCM-X driven in the same way as ensemble forecasting experiments. Observing system simulation experiments will be launched to help quantify the new method's impact on thermospheric and ionospheric weather prediction. Observing system experiments will further improve our scientific understanding of how solar irradiance affects the variability of the thermosphere and ionosphere.

This project will answer the following science questions:

1. How does the uncertainty in the solar spectral irradiance of different wavelengths, explicitly ranging from 0.1 to 180 nm, impact the uncertainty in thermosphere-ionosphere simulations at different altitude regions?

2. What are the relative contributions of the uncertainty of the thermosphere and ionosphere associated with uncertainties of the solar spectral irradiance during different solar activity levels and different seasons?
3. Does improved specification of the solar irradiance enhance thermosphere-ionosphere predictability?

The proposed project is highly aligned with the scientific objectives of this year's Living With a Star Focused Science Topic #1 to develop the ability to reliably specify and predict the effects of solar variability on the ITM system. We primarily focus on identifying the improved solar spectrum model for driving model predictions of IT structure. The project will advance our understanding of the connection between the short-term variability of solar irradiance and the Earth's thermosphere and ionosphere, and improve our capability to numerically predict the weather of the thermosphere and ionosphere.

Jiang Liu/University of California, Los Angeles
Foreshock Transients Impact on Magnetospheric Perturbations and Plasma Population

When the interplanetary magnetic field (IMF) is approximately parallel to the normal direction of Earth's bow shock, a foreshock forms with many dynamic structures in the upstream solar wind. Foreshock transients are ion kinetic structures commonly observed in the foreshock, characterized by dynamic pressure disturbances. Of these transients, hot flow anomalies (HFAs) and foreshock bubbles (FBs) have the most significant dynamic pressure perturbations. The perturbations can induce oscillations in the bow shock and magnetopause, driving ultra-low frequency (ULF) perturbations in the magnetosphere. During this process, the transients have transferred solar wind energy into the magnetosphere in the form of the perturbations. When foreshock transient disturbances propagate tailward along the magnetopause surface, they can continue inducing perturbations in the magnetosphere. Because ULF perturbations can modulate particle flux non-adiabatically and cause radial diffusion, foreshock transients are potentially important for redistributing the magnetospheric plasma population. This redistribution is key to deciphering magnetic storms and space weather phenomena. Knowledge about the transients' impact on the magnetosphere is crucial for understanding how solar wind energy control magnetospheric processes and increasing the predictive abilities of them. We thus propose to determine whether and how foreshock transients impact the magnetosphere and its plasma population, especially for electrons of the inner magnetosphere. We will investigate the whole chain of the solar wind-magnetosphere coupling related to fore-shock transients: from the significance of the transients' perturbations in the solar wind to how and how much of the perturbations enter the magnetosphere; from whether the perturbations interact with magnetospheric particles in the small scale to whether the particle population varies in the macroscale due to conditions favoring transients-related perturbations. Specifically, we will answer the following questions:

- How significant is the contribution of foreshock transients to those caused by magnetic storm-causing interplanetary shocks? The answer to this question will reveal the geo-effectiveness of the transients, such as a first-order modification to the existing storm models.

- How do the perturbations triggered by HFAs and FBs cross the magnetopause into the magnetosphere? How much of the perturbation can be transmitted to the magnetosphere? The answer to these questions will inform us to what extent the transient-driven perturbations can effectively drive perturbations in the magnetosphere.

- Can the perturbations triggered by HFAs and FBs modulate magnetospheric electron flux nonadiabatically? The answer to this question will tell us whether and how the energy from foreshock transients controls magnetospheric electron flux.

- Does the IMF cone angle control the radial diffusion during magnetic storms? When the solar wind cone angle is smaller, the foreshock, and thus the transients, are closer to Earth. The perturbations caused by the transients are less damped when arriving at the magnetosphere, so they can cause stronger radial diffusion. The answers to this question determine whether the cone angle must be considered in next-gen prediction models of the storm-time particle population.

To answer these questions, we will employ a global 3D hybrid simulation (note that this simulation will not be used to investigate any electron scale physics) and spacecraft data from NASA's THEMIS, MMS, and Van Alen Probes missions and OMNI datasets. The results of the proposed study will significantly advance the understanding of FST #2 of the LWS call by providing insight into non-reconnection coupling between solar wind fluctuations and the magnetosphere. The budget of the proposal will support young researchers and a graduate student.

Katariina Nykyri/Embry-Riddle Aeronautical University, Inc.
Role of Solar Wind Fluctuations on Solar Wind- Magnetosphere - Ionosphere Coupling Processes and Magnetotail Energetics

Title: Role of solar wind fluctuations on solar wind -magnetosphere-ionosphere coupling processes and magnetotail energetics.

Science Goals and Objectives:
The overarching science goal of the project is to address the role of solar wind fluctuations driven by solar wind transients and solar wind substructure on the dynamics and energetics of the tail flank region and magnetotail and their corresponding ionospheric signatures and properties.

Our objective is to answer the following science questions (SQs)

SQ1. What are the effects of enhanced SW and IMF fluctuations on tail flank magnetopause fluctuations?

SQ2. What is the role of SW, IMF and tail magnetopause fluctuations on tail dynamics and energetic particle fluxes?

SQ3. How do enhanced SW, IMF and magnetopause fluctuations affect Magnetosphere-Ionosphere (M-I) coupling?

Methodology:

Our study uses a
1) statistical, empirical Solar wind And Magnetosphere Unification (SAMU) model (developed by PIs group) that currently has 15+ year of data from THEMIS and ARTEMIS thermal and suprathermal plasma and magnetic field instruments
2) spacecraft case studies using THEMIS, ARTEMIS, MMS, DMSP, and AMPERE spacecraft.
3) machine learning and information theory to establish linear and nonlinear causal relationships and response time scales from solar wind to the magnetopause to the magnetosphere and to the ionosphere.
4) global, 3-D MHD simulations (OpenGGCM) on solar wind-magnetosphere-ionosphere system. E.g., For global simulation, we can add pressure perturbation or magnetic field fluctuation in the solar wind with certain frequency and see the responding response of the magnetosphere and ionosphere.
6) existing list of CMEs, SIRs, Substorms and Kelvin-Helmholtz waves.
7) geomagnetic activity indices (e.g., AE and Dst)

Relevance:
The proposed study is directly relevant to the Decadal Survey Goal 2: ``Determine the dynamics and coupling of Earth's MSP, ionosphere, and atmosphere and their response to solar and terrestrial inputs'' and LWS FST$\#$2 topic 4) ``understanding the role of solar wind fluctuations in the coupling of the solar wind to the Earth''. Our previous works (Nykyri et al., 2017, JGR) have shown that KHWs growth, and properties (e.g., size) depends on the nature of seed fluctuations in the shocked solar wind. Enhanced flank fluctuations during Geoeffective SW drivers may 1) help trigger tail reconnection, initiate substorms and affect energetic particle acceleration, transport and loss via interaction with radiation belts, 2) as well as help transport energetic particles from large-scale diamagnetic cavities further into the magnetotail.

David Sibeck/NASA Goddard Space Flight Center
Pressure Pulse Interactions with the Earth's Magnetosphere

Solar wind pressure pulses drive a unique mode of solar wind-magnetosphere interaction. We propose a closely-linked combined observational and hybrid code numerical simulation study of this interaction mode. We begin by determining and distinguishing between the characteristics of pressure pulses intrinsic to the solar wind and those generated by kinetic processes within the Earth's foreshock, with an emphasis on the properties that determine their significance to the overall interaction, namely their extent, amplitude, and occurrence patterns. Observations from L1 monitors and spacecraft immediately upstream from the Earth's bow shock are used for this task. Next we consider how the properties of pressure pulses change as they interact with the bow shock and transit the magnetosheath. Simultaneous observations from spacecraft upstream and downstream from the bow shock are used for this task. Once they reach the magnetopause, pressure pulses drive magnetopause motion and may trigger magnetic reconnection. Observations from spacecraft at and upstream from the magnetopause are used for this task. Finally, both pressure pulses, and the bursty reconnection that they may trigger, launch Alfvén mode waves that propagate down to the ionospheric footprints of magnetic field lines that lead to the magnetopause and fast mode waves that propagate across the magnetic field to locations deeper within the dayside magnetosphere. We survey the corresponding perturbations that occur in high-latitude ground-based magnetograms and in the magnetic field measurements of spacecraft at various locations throughout the dayside magnetosphere to determine the contribution of the pressure pulses to ionospheric convection and diffusion within the radiation belts as a function of solar wind conditions. At each step, we compare hybrid code model predictions with the in situ observations. The significance of the proposed work lies in the fundamental nature of the interaction, its importance to triggering reconnection, and its potential importance to ring current and radiation belt processes. Finally, we propose to lead the focus group team comprising all the proposals selected for this opportunity, establish connections between and beyond the team members selected, and maintain even more regular communication demonstrating progress with NASA HQ staff than the required annual individual and team reports.

The proposed research is relevant to the focus science team because it addresses the following AO-stated tasks (1) identifies the parameters controlling the transfer of energy through dayside magnetopause reconnection, (2) investigates the physical processes controlling non-reconnection coupling, and (3) defines the role of solar wind fluctuations in the coupling of the solar wind to the Earth. The proposed study returns (1) a survey of solar wind fluctuation amplitudes and occurrence patterns, (2) specifies how fluctuations are transmitted through the magnetosheath, (3) quantifies their impact on magnetopause motion and reconnection, and (4) defines the properties of the transient ionospheric convection and ring current and radiation belt diffusion that they drive. Finally, the proposal provides experienced leadership to the proposal team.

Sergio Vidal-Luengo/Laboratory for Atmopsheric and Space Physics
Interplanetary Disturbances Obliquity Effects in the Generation of db/dt Events

Ground Induced Currents (GICs) are a current concern in modern society as they flow through conductors and can damage power grids and oil pipelines. Interplanetary disturbances in the solar wind and substorms have been already identified as the main sources of geomagnetic disturbances responsible of GICs. However, the determination of the spatio-temporal distribution GICs during geomagnetic disturbances remains as an unsolved issue as the drivers that control transfer of energy between interplanetary disturbances and the inner magnetosphere and the ionosphere stay elusive. This becomes a challenge for forecasting of GICs and their potential impact on infrastructure. A more accurate characterization of both interplanetary disturbances and the resulting geomagnetic disturbance are essential to identify the drivers of GICs. This proposal aims to address the following questions:

1. What are the most common characteristics present interplanetary disturbances during large dB/dt events?
2. How does the interplanetary disturbance front inclination angle affect global spatio-temporal of dB/dt events?
3. What is the spatio-temporal of dB/dt events to substorms during an asymmetrically compressed magnetosphere?

To answer the preceding queries, we propose to examine particle and magnetic field data from the spacecraft that constitute the Heliophysics System Observatory (HSO) to study interplanetary disturbances and magnetic field from ground-based magnetometers from the year 2007 onwards to study the geomagnetic response. We will create independent catalogs of interplanetary disturbances and dB/dt events. This systematic combination of space and ground observations will allow the study of solar wind disturbances inducing geomagnetic disturbances generating GICs. Simultaneously, we will run MHD simulations to study the theoretical geomagnetic response to highly inclined disturbance fronts as well as the geomagnetic response to substorms during asymmetrical compression of the magnetosphere. The simulations will provide flexibility of controlling the initial conditions and evaluate idealized extreme cases as well as realistic cases.

This project will investigate the relevance of multiple characteristics of ICMEs, CIRs, the pre-existing conditions when they occur, and identify their contribution to the generation of GICs. Some of these characteristics are the front inclination of the disturbance, the occurrence of ICMEs after CIRs, and ICMEs structure complexity. This project follows the goal of the LWS Focus Group #2 of investigate processes by which the solar wind drives the magnetosphere - ionosphere - thermosphere system" and is particularly compelling for specific objectives (3) investigating the physical processes controlling non-reconnection coupling," and (4) understanding the role of solar wind fluctuations in the coupling of the solar wind to the Earth."

Shaosui Xu/University of California, Berkeley
Characterization and Validation of Solar EUV and Soft X-Ray Spectral Irradiance Models Using Photoelectron Spectra as an Absolute Irradiance Reference

Science Goals and Objectives: Solar extreme ultraviolet (EUV) and X-ray photons are a primary source of energy for the upper atmospheres of terrestrial planets. To best characterize how the solar EUV flux impacts Earth's Ionosphere-Thermosphere-Mesosphere system, more accurate models of the solar EUV spectrum are needed. Simple F10.7-based proxy models are often used, but studies have shown that models using four proxies from distinct temperature regions of the Sun better estimate the solar EUV. Meanwhile, photoelectrons are a product of solar EUV photoionizing the neutral atmosphere, whose energy spectra preserve distinctive features of the solar EUV spectra and can be used to validate solar irradiance models. In this project, we utilize a unique combination of observations and models available at Mars, the quality of which are unparalleled by measurements at any other planet including Earth, to best validate the solar irradiance modeling for both Mars and Earth, which addresses FST#1: Beyond F10.7: Quantifying solar EUV flux and its impact on the IMT system. Our proposed objectives are: (1) characterize and validate a solar irradiance model, Synthetic Reference Spectra (SynRef) Model, using a combination of MAVEN (Mars Atmosphere and Volatile EvolutioN) observations and photoelectron modeling with the SuperTheraml Electron Transport (STET) model; (2) compare validated SynRef irradiances with those measured by the TIMED and SORCE X-ray Photometer System (XPS) Level 4 modeled irradiances; (3) develop a soft X-ray proxy based on the Auger electron fluxes (photoelectrons produced by soft X-rays < ~2.5 nm); and (4) provide a flare catalog from 1999 to 2006 and 2014 to 2022 at the vantage point of Mars with observations from Mars Global Surveyor (MGS) and MAVEN.

Methodology: To achieve Objective 1, the SynRef model provides the solar irradiance spectrum for 0.1 190 nm, which is fed into the STET model to simulate photoelectron energy spectra. The modeled photoelectron energy spectra can then be compared with observed photoelectron energy spectra by MAVEN. The free parameters of Synref are the reference spectra and the instrument response function (within its known uncertainty range). We will conduct data-model comparisons over a range of solar activity to best calibrate the SynRef model. We will then compare the improved SynRef model with irradiance observations made at Earth by SORCE and TIMED XPS and quantify any differences (Objective 2). We will make the comparison when the Sun-Mars-Earth angle is small, as well as compare 27-day smoothed values to minimize differences due to different vantage points. For Objectives 3 and 4, we utilize the linear correlation between the photon flux and the photoelectron flux to develop a proxy for soft X-rays. We will find the linear regression relationship between the Auger electron fluxes observed by MAVEN and the best-fit band-passes predicted by the SynRef irradiance model (Objective 3). This linear regression relation will be then applied to Auger electron observations by both MAVEN and MGS to generate a soft X-ray proxy and then a catalog of solar flare events for 1999-2006 (MGS) and 2014-2022 (MAVEN) (Objective 4).

Relevance and Impacts: Our Objectives of improving the solar irradiance modeling directly address FST #1: Beyond F10.7: Quantifying solar EUV flux and its impact on the IMT system" by identifying new and/or improved EUV indices for driving model predictions of ITM structure." In addition, our Objectives 3 and 4 provide a long-term proxy for soft X-rays at an additional vantage away from Earth. This additional catalog of flares observed at Mars is of particular interest for studying over-the-limb and far-side flare effects on near-side disk radiance and radiative transport in the solar corona, which improves our general understanding of the solar flare generation and thus also helps a better quantification of solar EUV fluxes.

Sijie Yu/New Jersey Institute Of Technology
Behind F10.7: Understanding The Physical Origin Of Solar F10.7 Index With Microwave Imaging Spectroscopy

Solar EUV flux is a dominant source of heating and ionization processes in the ionosphere-thermosphere-mesosphere (ITM) system but cannot be observed from the ground. Solar F10.7 index has been used as a proxy for EUV flux since then. Solar F10.7 index comprises a mix of contributions from mainly three emission processes: thermal emission from the upper chromosphere; ubiquitous thermal bremsstrahlung; and thermal gyroresonance from strong magnetic fields. While the first two emissions are closely related to solar EUV emission, the gyroresonance component in F10.7 index does not directly correlate with EUV flux. Moreover, gyroresonance contribution is dominated by the large active region, its partition in F10.7 could be significant when the solar is active. However, the relationship between them has not been well characterized so far. The reliability of using F10.7 as an EUV proxy is therefore limited. One solution is to image the Sun at 2.8 GHz routinely with sufficient angular resolution (< 60 arcsec) and quantify the contributions from these emission processes in different regions. Such diagnostic power was not available until the recent commissioning of the Expanded Owens Valley Solar Array (EOVSA). Daily microwave images at multifrequencies over 1-18 GHz have been available during the period from 2017 to 2022, covering the deep solar minimum in late 2019 to the present when the Sun has become increasingly active. With microwave imaging spectroscopy and multi-wavelength observations from space-based instruments, it is possible to characterize F10.7 that is not related to EUV flux and potentially remove their contributions from solar F10.7 index.

Science Objectives:
The overarching goal of the project is to gain a comprehensive understanding of the origin of solar F10.7 radio flux.
We will guide our investigations using the following specific science questions:
1. What are the sources of solar F10.7 flux and how F10.7 is partitioned over different sources?
2. How does solar F10.7 index and its partition evolve in different solar activity levels?
3. What is the relationship between solar F10.7 index and EUV irradiance?

Methodology:
To achieve the science objectives above, we propose the following investigations:
1) optimize EOVSA full-disk imaging procedure and create high fidelity images at multifrequency (1-18 GHz) from 2017. It will allow us to obtain the spatially resolved radio spectra of the Sun, perform spectral analysis to identify the emission mechanism(s) for different regions over the Sun and quantify the contributions of individual components.
2) study in detail the time-dependent variations of spatially resolved F10.7 and its index partition in different regions. Explore how the gyroresonance component and its fraction in F10.7 index vary in active regions of different sizes, magnetic field strength, activity levels, etc.
3) Calculate the prediction of bremsstrahlung emission with DEM (differential emission measures) results derived from EUV images of SDO/AIA. It will allow a quantitative comparison between the microwave observations and the bremsstrahlung prediction, in particular for the active region fluxes, whose discrepancy is largely due to gyroresonance contribution. We will explore the relation between gyroresonance emission and the physical properties of the active region towards a better estimation of the fraction of F10.7 flux contributed by gyroresonance.

Relevance:
Our proposal is highly relevant to the scope of FST#1, Beyond F10.7: Quantifying Solar EUV Flux and its Impact on the ITM", as this proposed research will advance our understanding of the physical origin of solar F10.7 index and consequently provide a modified F10.7, that is exclusively related to the coronal plasma responsible for EUV irradiance, as a better EUV proxy.

Ying Zou/University Of Alabama, Huntsville
Effects of Foreshock and Magnetosheath Kinetic Structures on the Global Magnetosphere

Science Goals and Objectives:
It is well established that the Bz and By components of the IMF are geoeffective, and many study have exclusively focused on them when studying the variance of geomagnetic indices. However, these two IMF components are not always dominant, and the radial component has been recognized to play an increasingly important role in the solar wind-magnetosphere interaction. A radial IMF displaces the foreshock region from the dawn side to cover almost the dayside region, favors the generation of foreshock waves and foreshock cavities, and causes a highly fluctuating magnetosheath. While these fluctuations have been shown to cause magnetopause boundary indentations, trigger magnetopause reconnection, and excite ultra-low frequency waves, whether and how they affect the macroscale dynamics of the magnetosphere is poorly understood. The overarching goal of the proposal is to understand how foreshock and magnetosheath kinetic structures affect macroscale magnetosphere-level dynamics. This will be accomplished through addressing the following questions:

1. How do foreshock and magnetosheath kinetic structures incident upon the magnetosphere impact measures of global dynamics such as polar cap index, auroral electrojet indices, and Kp?
2. What disturbances in the magnetosphere do the kinetic structures drive that contribute to the variances of the measures of global dynamics?
3. How do varying solar wind conditions (e.g., IMF Bz, IMF By, speed, Mach number) support or suppress the geoeffectiveness of the kinetic structures?

Methodology:
The project will employ a comprehensive set of observations of the solar wind-magnetosphere-ionosphere system, and a state-of-art MHD-AEPIC model that two-way couples the Hall-MHD model BATS-R-US and the semi-implicit PIC code FLEKS through the Space Weather Modeling Framework (SWMF). For the observations, the project will conduct both statistics and case study analysis. The statistical analysis will assess the statistical similarities and differences in the measures of global dynamics when foreshock and magnetosheath kinetic structures are present versus absent. The case study analysis will focus on events with multi-point observations that can validate the model results and illuminate the sequence of events that lead to changes in the global state of the magnetosphere. For example, we will use ACE, WIND, and Geotail for the pristine solar wind, MMS, THEMIS, CLUSTER, Van Allen Probes, and GOES for the dayside (including the shock and magnetosheath), nightside, and inner magnetosphere, and ground-based radars and magnetometers for plasma convection and magnetic perturbations. For the simulation, the domain covered by the PIC code will be varied to cover (exclude) the foreshock and magnetosheath so that the kinetic effects of the upstream will be assessed for a given pristine solar wind. BATS-R-US coupled with RCM handles the rest of the simulation domain and simulates the dynamics of the magnetosphere.

Significance and Relevance:
The proposed study directly addresses the scientific objectives of the Focused Science Topics (FST) #2 of the NASA Living with a Star (LWS) Program, which is to identify the parameters controlling the transfer of energy through dayside magnetopause reconnection and to understand the role of solar wind fluctuations in the coupling of the solar wind to the Earth. It is also directly relevant to the LWS program goal #2, which is to understand how the Earth and planetary systems respond to dynamic external and internal drivers. The proposing team has expertise in numerical simulation and observations of the coupled solar wind-magnetosphere-ionosphere system, and the collaborative efforts are expected to contribute substantially to the FST team efforts.