Heliophysics - Early Career Investigator Program
Abstracts of Selected Proposals
(NNH18ZDA001N-ECIP)

Below are the abstracts of proposals selected for funding for the Heliophysics – Early Career Investigator Program. Principal Investigator (PI) name, institution, and proposal title are also included. **50** proposals were reviewed in response to this opportunity. On April 1, 2019, **11** proposals were selected for funding.

Haihong Che/University of Maryland, College Park
Electron Heating and Plasma Emission in the Solar Corona

Nanoflares heating has been recognized as an important process that contributes to the heating of the solar corona, particularly to electron heating in the lower corona. Similar to solar flares, nanoflares are also a type of impulsive magnetic reconnection (MR), typically with a strong guide field. It is still poorly understood how nearly collisionless MRs efficiently transform magnetic energy into the non-thermal energy of particles with power-law energy distributions and form particle beams. Beams can become unstable to a beam instability and produce coherent plasma emission, manifested as solar radio bursts, and become a part of non-thermal hot plasma in the corona. Three fundamental questions need to be addressed regarding particle heating and acceleration in flares: 1) How are charged particles accelerated in MR with a strong guide field, and what determines the power-law electron energy distribution? 2) How do guide field MR produce particle outflows/beams? 3) How do particle beams produce electron heating and coherent plasma emission?

The PI and collaborators have investigated various aspects of these problems using kinetic theory, numerical modeling, and multi-wavelength observations. The emerging paradigm for particle acceleration in MR is the so-called multi-island MR. The PI and collaborators showed that Fermi acceleration by contraction and merging of magnetic- islands or flux tubes is the primary cause of electron acceleration. Using kinetic theory, Zank and his group have developed a general formulation to describe the power-law energy spectra of energetic particles in a super-Alfvenic flow. We have also developed theoretical models of electron heating in streaming instabilities in strong guide field MR. Benz has discovered a new class of Type III radio bursts associated with ion beams. The PI conducted a comprehensive study of the nonlinear evolution of electron two-stream instability driven by electron beams, and provide a self-consistent model for Type III radio bursts in which coherent plasma emission is continuously generated by cyclic Langmuir collapse.

We will expand our ongoing studies by integrating kinetic theory, Particle-in-cell (PIC) simulations, test particle simulations, and observations. We will extend the Zank acceleration model to sub-Aflvenic flow in the solar corona; use the analytical model and PIC simulations to explore the mechanism of particle acceleration and heating in flares.

We will study the formation of electron beams due to magnetic focusing using test particle simulations in MHD loop-loop and interchange MR configurations. We will extend our successful research on radio bursts, to consider the effects of ion beams. We will investigate the generation of Alfvenic waves and how multi-scale wave-wave interactions lead to Alfvenic wave energy cascade and the subsequent electron heating. We will also study the electron-ion beam coupling and examine how the coupling affects the properties of radio bursts, e.g., how ion beams cause the observed slow drift Type III bursts. We will also study the electron acceleration and Langmuir collapse in magnetopause MR with in situ observations from MMS.

The goal of this proposal will be achieved through a large collaboration among several groups 1) PI and a postdoc; 2) Zank’s group including two graduates; 3) Benz and the SO (STIX) group; 4) Dahlin and Antiochos’ group, and 5) Boardsen and MMS group. We will use two state-of-art PIC codes P3D and VPIC and a numerical code of kinetic transport equation. The proposed research is directly related to the first and fourth science goals of the Heliophysics Decadal survey: 1) Sun's activity and predict the variations in space; 4) fundamental processes within the heliosphere and throughout the universe.

Michael Hartinger/Space Science Institute
Coordinated investigation of the link between ULF waves and geoelectric fields that drive geomagnetically induced currents

Geomagnetic perturbations related to a variety of phenomena in the near-Earth space environment induce electric fields at the Earth s surface. These "geoelectric" fields in turn drive potentially damaging geomagnetically induced currents (GIC) in technological infrastructure such as railroads, pipelines, submarine cables and power grids. The spatio-temporal specification of geoelectric fields is needed to improve forecasts of GIC, and the combination of ground conductivity measurements and the time rate of change of the magnetic field (dB/dt) can be used to estimate the geoelectric field. Pulsations, or waves, at the lower end of the Ultra Low Frequency (ULF) band in the coupled magnetosphere- ionosphere (M-I) generate periodic ground magnetic perturbations and dB/dt that have been linked to geoelectric fields and GIC. A better understanding of the role of ULF waves in generating geoelectric fields is thus needed to improve GIC models and forecasting capabilities.

We propose a coordinated investigation using satellite measurements, coherent scatter radars (SuperDARN), ground magnetometers, magneto-telluric surveys and geoelectric field measurements to address the over-arching science question, "How do ULF waves in the M-I system couple to geoelectric field variations relevant to GIC?" with sub-questions "What are the spatial/temporal scales of dB/dt and geoelectric fields associated with different ULF wave modes? What combinations of ULF wave properties, driving conditions, and local ground conductivities are associated with the largest dB/dt and geoelectric fields?" By examining how ULF waves couple through the M-I system to ground dB/dt, this study addresses the high-level decadal survey Goal 2, "Determine the dynamics and coupling of Earth’s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs," is consistent with the NASA Heliophysics Division strategic objective to "understand the Sun and its interactions with the Earth and the solar system, including space weather" (NASA Heliophysics Roadmap), and complements efforts by the NASA LWS Institute GIC group.

We will address the science questions through a combination of (1) estimates of ULF geolectric fields obtained from a meta-analysis of previous ULF wave studies and magneto-telluric impedance measurements, (2) global measurements of ULF wave properties used to obtain geoelectric fields in detailed case studies, (3) statistical analysis of co-located ground magnetic and geoelectric field measurements. The PI is qualified for this study due to (1) research contributions that demonstrate ULF wave expertise and ability to explore new scientific ideas that will impact the ULF wave and GIC research fields and (2) current leadership activities that demonstrate ability to develop ULF wave themes, lead community in new directions, and mentor junior researchers.

This investigation is timely as it uses several recently available datasets to provide new constraints on ULF wave impacts on geoelectric fields/GIC. Through ULF wave expertise and current leadership activities (e.g., GEM ULF wave focus group), the PI is well-positioned to communicate new results to both the ULF wave and GIC modeling research groups, fostering cross-discussion between these communities and focusing future modeling/observation efforts on ULF wave modes most likely to generate significant GIC.

Seth Dorfman/Space Science Institute
Properties and Dynamics of ULF Waves in the Ion Foreshock

Background:
Waves generated by accelerated particles are important throughout our heliosphere. These particles often gain their energy at shocks via Fermi acceleration. At the Earth's bow shock, this mechanism accelerates ion beams back into the solar wind; the beams can then generate ultra low frequency (ULF) waves when they interact with the backround solar wind plasma. These waves can influence space weather all the way down to the ground and represent a natural laboratory for future turbulence-relevant non- linear studies. Despite a clear connection between the beam and the waves, the mechanisms responsible for the properties and dynamics of the observed ULF waves are still a matter of debate. For example, evolution of the observed frequencies in time and space may be due to a) fast changes in the beam properties or b) a non-linear parametric instability of the ULF waves. We propose to elucidate this and other key physics using a novel combination of ARTEMIS in conjunction with other spacecraft, the Vlasiator global hybrid-Vlasov simulation code, and a new arbitrary distribution function dispersion solver. The results will be applicable to shocks elsewhere in the heliosphere and thus may inform present and future NASA missions. Central Question: What physical processes are responsible for the properties and dynamics of ULF waves in the ion foreshock?

Science Goals:
1) Determine the global structure and local properties of ULF waves in the ion foreshock from the wave source region to the bow shock. Is the general structure seen in Vlasiator runs

consistent with a database of cases from ARTEMIS and other spacecraft or are there significant differences in the key properties and dynamics?
2) Determine how the observed ULF waves are related to the beams of reflected plasma ions which generate the waves. How do changes in the beam properties in time and space influence the growth rate, spectrum, and other wave properties?
3) Examine the role of parametric instabilities in the ion foreshock. Are these processes present and if so do they play a key role in the observed ULF wave dynamics?

Relevance:
The proposed study is relevant to all four decadal survey goals:
Goal 1) Results of this study will help predict variations in the space environment in the ion foreshock and coupled regions of the magnetosphere of both Earth and other planets.
Goal 2) The ion beam and associated ULF waves represent a response of the Earth's magnetosphere to solar input. A more complete understanding of this response will be obtained by carrying out the proposed study.
Goal 3) The proposed research will help us understand similar shocks that determine the interaction of the solar wind with the solar system and the interstellar medium.
Goal 4) Ion beam-wave interactions and parametric instabilities are fundamental processes that occur both within the heliosphere and throughout the universe. We aim to characterize these processes using the Earth's ion foreshock region as our laboratory.

Methodology:
We propose to employ a combination of scientific techniques:
1) Observations: The two ARTEMIS spacecraft, supplemented by data from ACE, Wind, Cluster, and Geotail, provide a unique opportunity to study the local properties and global dynamics of ULF waves starting from the region where they are first generated by the ion beam.
2) Simulations: The Vlasiator hybrid-Vlasov simulation code allows for simulation of the entire near-Earth space including noise-free ion kinetic effects. This allows for detailed space-time resolution of both the ULF waves and the ion distributions in the foreshock that may be compared to observations.
3) Theory: Both a simple Maxwellian dispersion solver and a new arbitrary distribution function dispersion solver will be employed to find wave frequency and growth rates from observed and simulated ion distributions.

McArthur Jones/Naval Research Lab
Teleconnecting climate change: How do changing dynamics in the lower atmosphere impact the upper atmosphere?

Science Goals:
Similar to the troposphere, increases in carbon dioxide are one of the major drivers of anthropogenic climate change in the thermosphere and ionosphere (TI) system. However, because the TI is a driven system, teleconnections with changes in variability in other atmospheric layers should also be considered. Lower atmospheric wave forcing of the TI system is now widely recognized as an important driver of space weather; however, the role of these

wave motions for changing space climate remain unexplored. With the advancement of whole atmosphere modeling and existence of long-duration composition, wind, and temperature measurements, it is possible to investigate the teleconnections between TI climate change and long-term changes in lower atmospheric wave forcing. The objective of this proposal is to uncover and quantify the effects of anthropogenic climate change on the lower atmospheric wave spectrum impinging on the upper atmosphere. The proposed study will answer the following science questions:

1. What long-term changes in lower atmospheric wave activity are produced by increased anthropogenic emission of greenhouse gases?

2. What mechanisms couple the lower atmospheric wave forcing changes to long-term amplitude and phase changes in the mesosphere and lower thermosphere region?

3. To what extent does the changing whole-atmosphere tidal and planetary wave spectrum contribute to long-term changes in the structure, composition, and electrodynamics of the mesosphere, thermosphere, and ionosphere?

Data and Methodology:
The proposed effort will be carried out primarily through model-data comparisons. The models to be employed as part of this study include the NCAR WACCM-X, TIE-GCM, and TIME-GCM. Validation of long-term trends in the lower atmospheric wave spectrum from WACCM-X composition, winds, and temperatures extending up to ~100 km will be performed by comparing model results with the extensive reanalysis, ground- and space- based datasets, including MERRA-2, meteor wind radars, incoherent scatter radars, NASA AURA-MLS, TIMED-SABER and -TIDI; UARS-WINDII, -HRDI, and - HALOE; TOMS; and SBUV. To evaluate the mechanisms responsible for driving long- term changes in lower atmospheric waves numerical experiments with the TIME-GCM will be performed. TIME-GCM lower boundary and middle atmosphere winds, temperature, and composition, will be modified and tuned (i.e., nudged) using WACCM- X to deduce climate driven changes in wave sources compared to climate driven changes in wave filtering by the changing background atmosphere. Estimates of lower atmospheric wave effects associated with anthropogenic climate change will have on the TI dynamics and composition will be analyzed using numerical experiments with WACCM-X following future climate scenarios.

Relevance:
The challenges identified in the proposed study will address the Heliophysics Decadal Survey goal to "Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs." Additionally, the proposed study will address Atmosphere-Ionosphere-Magnetosphere Interactions (AIMI) Science Challenges 3 and 4: "Understand how forcing from the lower atmosphere, via tidal, planetary, and gravity waves influences the ionosphere and thermosphere" and "Determine and identify the causes for long-term (multi-decadal) changes in the AIM system", following AIMI Imperatives 3 and 4: "Integrate data from a diverse set of observations across a range of scales, coordinated with theory and modeling efforts, to develop a comprehensive understanding of plasma-neutral

coupling processes and the theoretical underpinning for space weather prediction", and "Conduct a theory and modeling program that incorporates accumulated understanding and extends the legacy of observations into physics-based models that are utilized for new scientific insight and operational specification and forecast capabilities."

Weichao Tu/West Virginia University
The Effect of Anomalous Magnetic Field Geometries on the Dropout of Radiation Belt Electrons

Relativistic electron flux in the Earth s radiation belt are observed to drop by orders of magnitude on timescales of a few hours. Where do the electrons go? This is one of the most compelling outstanding questions in radiation belt studies. Radiation belt electrons can be lost either by transport across the magnetopause into interplanetary space or by precipitation into the atmosphere. Traditional mechanisms such as magnetopause shadowing and wave-particle interaction induced outward radial diffusion and pitch angle diffusion have been included to model the fast loss of radiation belt electrons. However, in many cases, the observed fast dropouts are still not well explained, calling for the implementation of new physical processes.

Recently, nonadiabatic transport of energetic electrons due to anomalous geometries of magnetic field has been suggested to play a major role in the loss of radiation belt electrons. The mechanisms include magnetic field line curvature (FLC) scattering, drift orbit bifurcation (DOB), and magnetopause shadowing (MPS). Recent studies have shown that these anomalous magnetic field geometries can make significant contribution to the dropout of radiation belt electrons, either by fast pitch angle scattering into the atmosphere or fast radial transport to the magnetopause. However, FLC scattering and DOB have not been well quantified due to the lack of direct test particle simulations of their cumulative effects on electrons. Thus, these two processes have not been physically included in radiation belt models. MPS has been included in radiation belt models by specifying the last closed drift shell (LCDS) of electrons. However, the LCDS defined in previous models usually ignored the bifurcation drift shells between closed and open drift shells, leading to unrealistic representation of MPS.

Here, we propose to perform direct test particle simulations of the cumulative effects of FLC scattering, DOB, and MPS on radiation belt electrons. Based on the simulation results, we will determine physical quantification of these effects and incorporate them into the new DREAM diffusion-advection model. By turning on and off individual loss mechanism in the model and comparing the model results with real-time observations, we will quantify the relative contributions of FLC scattering, DOB, and MPS to radiation belt dropout. The proposal is timely for the unprecedented high-resolution and global electron and wave data from NASA Van Allen Probes, THEMIS, and MMS that cover the entire outer belt all the way to the magnetopause, which will provide an excellent test to our model results. Specifically, we will address the following compelling science questions:

1. When and where do the three different types of anomalous magnetic field geometries cause significant loss of radiation belt electrons? How does the effect vary with solar wind conditions, geomagnetic configurations, electron pitch angle, and energy?

2. Are the FLC scattering and DOB of radiation belt electrons a diffusion or advection process or a mix of both? What are the resulting diffusion and advection rates?

3. What are the relative importance of electron losses due to anomalous magnetic field geometries (FLC scattering, DOB, and MPS) for the dropout of radiation belt electrons compared with other loss mechanisms?

The proposal directly addresses the 2nd science goal of the Heliophysics Decadal survey: Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs . It is also relevant to the 4th goal: Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe since nonadiabatic electron transport due to anomalous magnetic field geometries is a fundamental process that occurs universally. The proposed activities are innovative, and the PI has demonstrated compelling potential for scientific leadership.

Christina Kay/Catholic University of America
Toward Real-Time Modeling of the Propagation and Magnetic Field of Coronal Mass Ejections from the Sun to the Earth

Coronal mass ejections (CMEs) cause the most significant space weather effects near the Earth and throughout the rest of the solar system. These rapid, extreme changes in plasma and magnetic field can cause effects in the atmosphere and on the surface of planetary bodies, as well as threaten any nearby space borne technologies. Mitigating these effects requires knowing if and when a CME may impact, as well as the CME s properties upon impact.

Kay et al. (2013, 2015) developed Forecasting a CME's Altered Trajectory, a model for the nonradial motion of CMEs close to the Sun. ForeCAT simulates both deflection, a change in a CME s latitude or longitude, and rotation, a change in the CME s orientation. Numerous studies have shown that ForeCAT reproduces the deflection and rotation of observed CMEs (e.g. Kay et al. 2016, 2017a, Capannolo et al. 2017).

Building upon the success of ForeCAT, Kay et al. (2017b) introduced the ForeCAT In situ Data Observer (FIDO). FIDO uses the results from ForeCAT to position and orient a magnetic flux rope as it passes over an observer yielding synthetic in situ observations. Kay & Gopalswamy (2017) showed that FIDO can reproduce the magnetic profiles of near-Earth CMEs. We propose to continue developing the ForeCAT and FIDO suite of models as they represent a unique style of model, simple enough to run large numbers of cases, but complex enough to accurately reproduce observations. We will take the remaining steps necessary to yield robust, complete models of the behavior of CMEs between the Sun and Earth, which would then be ready for potential space weather operations.

The proposed work is divided into four major subtasks. First, we will incorporate preexisting models for the arrival time to complete the Sun-to-Earth chain in our models, determining when the impact occurs. Second, we will use the properties of the active region from which a CME erupts to determine the properties of the modeled CME, reducing the number of unknown free parameters in the model. Third, we will compare ForeCAT and FIDO results with in situ observations from satellites at multiple heliocentric distances and longitudes. Finally, we will use the efficient nature of ForeCAT and FIDO to perform ensemble studies of the effects of small changes reflecting the uncertainty in the free parameters.

By completing the proposed work, we will have completed a full model for the behavior of CMEs from the Sun-to-Earth, allowing us to determine if, when, and how a CME may impact on timescales necessary for actual predictions.

Maria Kazachenko/University of Colorado, Boulder
Observationally-Driven Simulations of Flaring Solar Active Regions: Energy Storage & Release

The Solar Dynamics Observatory (SDO) from NASA provides a wealth of data showing simultaneously the magnetic field in the photosphere and the coronal response. Our ultimate goal is to model flares and coronal mass ejections (CMEs) in the corona using observational input of the electric fields derived from the photospheric observations. Making this connection will allow us to understand the physical causes of eruptive events. In particular, it will allow us to identify which photospheric patterns lead to development of coronal currents and turn into the primary driver for eruptions.

We propose to approach this goal through the following process. We will use two advanced coronal MHD models, the Radiative MHD Code (RADMHD, Abbett W.P. 2007, ApJ 665, 1469) and the Magnetic Flux Eruption code (MFE, Fan 2012, ApJ, 758, 60), and tools developed within the Coronal Global Evolutionary Model framework (CGEM, NASA LWS strategic Capability Project, Fisher et al. 2015, SpW, 13, 369) to perform data-driven simulations of two flaring active regions. The advantage of this approach is application of a well-tested PDFI inversion technique to infer the electric fields from sequences of SDO vector magnetograms (Kazachenko et al. 2014, ApJ, 795, 17) that are necessary to drive the models' photospheric layers in a manner that is physically consistent with the observed evolution. We will experiment with different temporal combinations of CGEM and MHD runs and will analyze how differently specified initial and boundary conditions affect the simulations' outcome.

We will perform additional improvements in the electric field inversions that we use to update the model's photospheric magnetic field by using synthetic data from the flux emergence simulation by MURaM radiative MHD code (Voegler et al. 2005, A&A 429, 335, Rempel et al. 2009, ApJ 691, 640), for which the solutions are known and performed AR simulations.

To find the optimum MHD model, we will examine AR and flare properties as a function of time both in the simulations and observations, including but not limited to comparison of AIA observations with synthetic intensities and intensity proxy maps, properties of the eruption (reconnected flux and flux rate, CME dynamics) both in the simulations and the observations. We will then use the most accurate MHD run to calculate magnetic energy fluxes and current densities as a function of space and time, pinpointing the photospheric driving pattern and the current evolution above.

The PI, Dr. Kazachenko, has a unique science expertise and leadership position to make this proposal successful. She is known for her expertise in a wide range of subjects: she is a Co-I on the CGEM project, a co-developer of one of the most advanced methods to implement observations into simulations and has deep understanding of solar observations. She organized multiple conference sessions and meetings on using solar observations to perform data-driven simulations on the Sun. She is a member of the Solar Physics Division Committee and the DKIST Science Working Group. As a new faculty member at CU Boulder, through this grant, she will lead a science program integrating solar observations with simulations. This effort will create one of the most realistic observationally-driven simulations of the flaring solar active region, allowing us to connect the observable photospheric field evolution to the evolution of coronal currents and leading to a deeper understanding of trigger mechanisms for eruptions. Future coupling of such realistic AR-scale models with global models of solar corona will improve prediction capabilities of space weather.

The proposed work addresses KSG1 & KSG4 NASA goals from the Solar & Space Physics Decadal Survey.

Xiangning Chu/University of Colorado, Boulder
Coupling Machine Learning Models of Multi-Instrument Spacecraft Data and Physics-Based Simulations: Applications to Study and Forecast Ultra-Relativistic Electron Flux

The main goal of the proposed project is to develop a coupled model that combines a first-principles physics-based Fokker-Planck (FP) simulation with a series of machine- learning-based predictive models that supply the initial, boundary and driving conditions for the FP model, to accurately model the dynamics of the energetic electron fluxes in the Earth s magnetosphere. Especially interesting are the predictions of the ultra-relativistic electrons, or killer electrons, which are responsible for damaging satellite systems and posing a serious hazard to astronauts. The main objective of our project is to answer the overarching science question: what are the key physical processes that control the dynamics of the energetic electron fluxes in the Earth s inner magnetosphere, ranging from plasma sheet (~tens of keV) to ultra-relativistic (~several MeV) energies. In addition to our main scientific goal, a number of supporting models will be developed which have intrinsic scientific merit in and of themselves and will produce a three-dimensional near real-time description of the state of the inner magnetosphere, including the cold plasma distribution, a variety of naturally-occurring plasma waves, and energetic particle fluxes.

The approach of combining physics-based and machine-learned environmental models of the inner magnetosphere is novel, and (to the best of our knowledge) represents a completely unique application of BIG DATA in the space sciences. Machine learning models alone cannot be used to specify the extremely hazardous ultra-relativistic electron fluxes (~5-10 MeV) because the observations represent a data-starved environment, so a physics-based Fokker-Planck (FP) simulation is the only way to model the dynamics of the ultra-relativistic electrons. One limitation of the FP simulation is that it is sensitive to the initial and boundary conditions, which should be global and time-dependent since the electron acceleration occurs throughout the drift trajectory around the Earth. Therefore, a series of machine-learned environmental models of the plasma, wave, or energetic particle environment will be developed to provide global and time-dependent conditions as simulation input, which cannot be achieved using either statistical models or in-situ measurements. This combined model will be a boon for space weather prediction and will aid in insight discovery for scientific research purposes, of the key driving parameters that control the hazardous near-Earth radiation environment. Each of the machine-learned environmental models of the plasma, wave, or energetic particle environments is very useful in its own right.

Our proposed project directly addresses the most important questions in the radiation belt physics, which is currently one of NASA's highest priorities. The proposed research is highly relevant to Goal 2 from the Heliophysics Decadal Survey, which is to determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs. Our proposed project addresses the timely and urgent needs of Space Weather prediction, articulated in a set of recent documents including a White House Executive order issued in October 2016 entitled Coordinating Efforts to Prepare the Nation for Space Weather Events, which states Government must have the capability to predict and detect a space weather event, the Space Weather Action Plan (SWAP) issued by the Office of Science and Technology Policy (OSTP) in October 2015 and the Space Weather Research and Forecasting Act introduced as Senate Bill 2817 in April 2016.

Kristopher Klein/University of Arizona
Improved Characterization of Solar Wind Dissipation, Energization, and Stability

The heliosphere is a complex system in which the transport of mass, momentum, and energy from large to small scales and the eventual dissipation of energy as plasma heat shapes the global evolution. As modeling the physical process involved at all scales is not yet tractable, we study in this project the mechanisms that act to transfer energy between electromagnetic fields and charged particles using a combination of theoretical modeling and in situ solar wind observations. A number of different processes have been proposed which may mediate this energy transfer, but there is no clear scientific consensus as to which of these mechanisms operate in the solar wind. Each mechanism preferentially transfers energy to or from particles with unique characteristic velocities, and may dominate the energization under different solar wind and plasma conditions. In order to observationally differentiate between these proposed mechanisms, we will search for distinct velocity-space signatures in particle distributions and associated electric and magnetic fields. The nature of these signatures will be motivated by analytic models and numerical simulations, which combined with solar wind observations will allow us to associate particular plasma and solar wind parameter regimes with the occurrence of particular energization mechanisms.

The proposed project is divided into four tasks:
1) Identify instances of particular energization mechanisms operating in the solar wind from in

situ observations using correlations between velocity-space particle distributions and electromagnetic fields.

2) Characterize the plasma and solar wind parameters for which different energization mechanisms dominate.

3) Apply an alternative stability determination method to solar wind observations to ascertain how unstable the solar wind is when considering multiple sources of free energy.

4) Improve existing parameterized models for solar wind stability using the alternative stability determination method.

Characterizing which mechanisms act under what solar wind and/or plasma conditions will improve our understanding of the heliosphere, and enable global models of this system to incorporate more physically motivated small scale physics.

Raluca Ilie/University of Illinois, Urbana-Champaign
Impact of energetic heavy ions on the magnetosphere dynamics

This project will quantify the relative contribution of N+ ions to the total heavy ion population of the near-Earth environment. There has been much interest in the transport and energization of O+ through the ionosphere-magnetosphere system since it was first reported. However, relatively little has been done with N+ even though past observations have established that N+ is a significant ion species in the ionosphere, the second most dominant in the F2 region, and its presence in the magnetosphere is significant. The transport and energization of N+, in addition to that of O+, have not been considered by most studies, simply because the observational record of its existence and significance has been overlooked. Most past missions lacked the possibility to reliably distinguish the N+ from O+ owing to their very close masses and therefore, we lack knowledge of the relative contribution of N+ to the near-Earth plasma population. In spite of only 12% mass difference, N+ and O+ have different ionization potentials, scale heights and charge exchange cross sections. The latter, together with the geocoronal density distribution, plays a key role in the formation of ENAs, which in turn controls the energy budget of the inner magnetosphere and the decay of the ring current. Therefore, knowledge of their separate behavior through the ionosphere-magnetosphere system can be used as a tracer for the altitude-dependent transport and energization of ionospheric plasma. The main task of this effort is to provide answers to the following questions:

1. How does the N+/O+ ratio of the magnetospheric plasma changes in response to the solar, geomagnetic and inter-planetary variability?

2. What determines the spatial and temporal variations in heavy ion composition on timescales comparable to the ion drift periods?

3. What role does the neutral dynamics play in the transport and losses of the ring current heavy ions and how does it alter the local ion composition?
Knowledge of the contributions of N+ to the near-Earth plasma population will provide a unique and necessary view into the differential transport of heavy ions throughout the magnetosphere. Their presence in the near-Earth environment has a profound impact on the global magnetosphere-ionosphere dynamics, especially during times of increased geomagnetic activity. They affect the global structure and properties of the current sheet, the reconnection rate and the local properties of the plasma, and can influence the waves propagation and frequency, which depends on the mass composition.

The proposed work will build a detailed understanding of self-consistent transport and energization of heavy ions in the terrestrial magnetosphere. This makes it directly relevant to NASA s high-level science goals from the Heliophysics Decadal survey: 1) Determine the origins of the Sun’s activity and predict the variations in the space environment; 2) Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs; 3) Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.

This project will use simulations with the Space Weather Modeling Framework together with observations from the MMS, Van Allen Probes and THEMIS NASA missions. We will conduct simulations with SWMF in various model configurations and compare model output with the observations in order to assess the near-Earth nonlinear feedback processes on the spatial and temporal structure of inner magnetospheric ion composition. Direct data-model comparisons will grant an in-depth understanding of the physical processes that control the transport and losses of these heavy ions throughout the ionosphere-magnetosphere system, allowing to quantify their distribution and the location their energization takes place.

Reka Winslow/University of New Hampshire, Durham
Evolution and interaction of transients in the inner heliosphere and their effects on galactic cosmic rays
The proposed research investigates the evolution and interaction of transients as well as their effects on galactic cosmic rays (GCRs) in the inner heliosphere. We leverage many years of spacecraft observations from NASA missions at different heliocentric distances from Mercury to Mars to study the evolution of interplanetary coronal mass ejections (ICMEs) and small flux ropes (SFRs), and their interaction with each other, with corotating interaction regions (CIRs), and with the heliospheric current sheet (HCS)/plasma sheet (HPS). We use observations from MESSENGER at Mercury, Venus Express (VEx) at Venus, Wind/ACE/STEREO/LRO near 1 AU, and MAVEN/MSL at Mars, spanning heliocentric distances from 0.3 to 1.7 AU.

The key science questions (SQs) addressed are:
1) Does ICME complexity increase with distance from the Sun? How is ICME complexity affected by interaction with other transients? Is change in complexity an inherent consequence of ICME propagation?

2) Is there evidence from in situ measurements, in particular from their evolution within and past 1 AU, that small flux ropes are of coronal or heliospheric origin?
3) How is the modulation of GCRs affected by ICME evolution and interaction between transients? Can reconnection of the ICME flux rope with other transients weaken its modulation of GCRs?

The objective of our proposed work is to develop our physical understanding of the evolution and interaction of transients in the inner heliosphere, in preparation for Parker Solar Probe and Solar Orbiter. A complete understanding of the changes in the properties of transients as they propagate is required to understand their space weather impact at different planets and on the modulation of GCRs. The proposed research makes novel use of disparate (in terms of time and type of) datasets over large heliocentric distances from eight spacecraft missions to glean valuable insights into these currently unresolved topics that have unique relevance for all of Heliophysics, but also for planetary science and astrophysics (astrospheres and stellar activity). This work is positioned for significant unanticipated discoveries and has valuable deliverables to the community: databases of 1) ICMEs observed in conjunction at the different spacecraft, 2) SFRs (along with flux rope parameters), and 3) Forbush decreases (Fds) associated with ICMEs will be made publicly available.

To answer our science questions, we will use a combination of solar wind, magnetic field, and GCR observations in conjunction with ENLIL model simulations of the steady state solar wind. We will use well-known techniques to determine changes in the global structure of transients during propagation and their effects on GCRs, including performing superposed epoch analyses, shock normal analyses, and flux ropes fits.

The proposed work investigates transient propagation/interaction in the inner heliosphere, leading to better understanding of ICME evolution and interaction with the solar wind and transients. It thus directly addresses the third Heliophysics Decadal Survey goal to: Determine the interaction of the Sun with the solar system and the interstellar medium.