Living With A Star Program (LWS20)
Abstracts of Selected Proposals
(NNH20ZDA001N-LWS)

Below are the abstracts of proposals selected for funding for the Living With A Star Program (LWS20). Principal Investigator (PI) name, institution, and proposal title are also included. Sixty (60) proposals were received in response to this opportunity. On May 24, 2021, twenty-seven (27) proposals were selected for funding.

Lauren Blum/University Of Colorado, Boulder
The Contribution of Atmospheric Precipitation to Radiation Belt Loss: When, Where, and How

While NASA's Van Allen Probes mission has greatly enhanced our understanding of electron acceleration mechanisms in Earth s radiation belts over the past decade, quantitative physics-based understanding of loss mechanisms remains elusive. In particular, improved understanding of the timing, location, and drivers of energetic electron precipitation into Earth s atmosphere is needed. Losses to the magnetopause often cannot fully account for depletions observed across the outer radiation belt during dropout events and while diffusion models can now reproduce observed acceleration events quite accurately, radiation belt depletions are less well-captured. A more complete picture of global precipitation rates and drivers is an essential step towards understanding radiation belt dynamics and ultimately predicting relativistic electron variations.

This proposal aims to address the following questions:
1. When and where does MeV electron precipitation into Earth s atmosphere occur?
2. How much loss does precipitation contribute during dropout events as compared to other times?
3. What drives MeV electron precipitation and how does this vary across L shell, magnetic local time (MLT), and storm phase?

To address the questions above, we propose to examine the temporal profiles and global distributions of energetic electron precipitation in relation to trapped radiation belt evolution. To do this we will utilize observations of both precipitation from low Earth orbit (LEO) (utilizing the currently operating CALorimetric Electron Telescope (CALET) instrument onboard the International Space Station (ISS), as well as the historical ~20 year database from the SAMPEX satellite) in addition to equatorial measurements of the trapped electron population and fields and waves (from the Van Allen Probes and THEMIS spacecraft). The simultaneous precipitation observations from low altitude complement equatorial measurements of trapped particles and wave distributions to provide a more complete picture of trapped and precipitating electrons variations, wave drivers, and magnetospheric dynamics. Using these data, we plan to perform the following specific tasks:

1. Identify and characterize precipitation features in CALET and SAMPEX - classify by precipitation type/time profile, spectral hardness, and location (MLT, L)
2. Perform superposed epoch studies of precipitation during radiation belt dropouts and quantify the relative losses across different storm phases and locations (MLT, L)
3. Investigate the wave drivers of different precipitation types through magnetically conjugate observations from CALET and RBSP (2015-2019) and SAMPEX and THEMIS (2007-2012)

Through these coordinated studies, this work will determine the contribution of precipitation to overall radiation belt dynamics and loss, and identify when and where various precipitation drivers are occurring. These aims are directly relevant to the Focus Science Topic Understanding and predicting radiation belt loss in the coupled magnetosphere and can inform radiation belt modeling efforts to more accurately capture energetic electron precipitation loss.

Jacob Bortnik/University of California, Los Angeles
Developing the scientific understanding and prediction capability of enhanced radiation levels at aviation altitudes due to energetic electron precipitation

The goal of our proposed project is to develop a comprehensive scientific understanding and a prediction capability of recently discovered enhanced radiation level events that were observed in measurements taken on commercial altitude (above 9 km) aircraft. These events are thought to result from the precipitation of >2 MeV electrons, which drive gamma-ray beams due to Bremsstrahlung. The measurements are made using the operational Automated Radiation Measurements for Aerospace Safety (ARMAS) system flown on agency-sponsored flights (NASA, NOAA, NSF, FAA, DOE) in automated radiation collection mode, as well by commercial space transportation companies and airliners. By late 2019, ARMAS obtained real-time radiation measurements from the ground to 89 km altitude for >700 flights consisting of >200,000 science quality one-minute measured absorbed dose (silicon) and derived effective dose rate records.

For decades, galactic cosmic rays (GCRs) and solar energetic particles (SEPs) were believed to be the two major sources of atmospheric radiation occurring at aviation altitudes. However, a case study using a subset of ARMAS data revealed a dynamic and variable radiation environment, occurring in a narrow magnetic latitude band (corresponding to L-shells of $2 < L < 7$) caused by other radiation sources during times when no SEP event is reported. Additionally, comparison with NASA's Nowcast of Atmospheric Ionizing Radiation for Aviation Safety (NAIRAS) model shows that the mean effective dose rate during the events is nearly double that for the background GCR level. Even during quiet geomagnetic conditions, the effective dose rate can be up to 32% higher than from GCRs alone. Observed correlations between ARMAS radiation events and coincident measurements of >2 MeV electrons on Van Allen Probes suggest that 5Ä-ray beams may be produced at mesospheric altitudes by precipitating relativistic electrons from the radiation belts, likely precipitated by electromagnetic ion cyclotron (EMIC) waves.

In response to Focused Science Topic 2 Understanding and Predicting Radiation Belt Loss in the Coupled Magnetosphere , which addresses Decadal Survey Key Science Goal 2 (Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs), and several LWS Strategic Science Areas including SSA-IV (Variability of the Geomagnetic Environment) and SSA-VIII (Radiation and Particle Environment from Near Earth to Deep Space), we propose a 4-year project whose main goals and objectives are:

1. Understand the spatial and temporal distribution, and variability of Aviation Altitude Radiation Events (AAREs), and their correlation to geomagnetic conditions
2. Understand the relationship of AAREs to the waves observed simultaneously near the geomagnetic equator through coincident observations and physics-based diffusion modeling
3. Predict the occurrence of AAREs using machine learning techniques based on their relationship to geomagnetic driving and coincident wave observations
4. Quantify the total loss of energetic electrons that results in AARE s and compare to radiation belt dropout events to determine their fraction of total electron loss

The methodology we will employ involves a statistical examination of the ARMAS database, comparison to Van Allen Probes wave observations, both for conjunction events, and in a global statistical sense, diffusion-based modeling of radiation belt precipitation, and machine-learning based prediction of the occurrence location, time, and magnitude of AARE events.

This proposal is highly timely due to the availability of the ARMAS database, and contributes to the FST effort by providing real measurements at aviation altitudes of the end result of energetic electron precipitation, which exemplifies the LWS overall purpose of & to understand those aspects of the Sun and Earth's space environment that affect life and society .

Radoslav Bucik/Southwest Research Institute
Understanding the role of flare-accelerated suprathermal ions on spectral and abundance variations in large gradual solar energetic particle events

Science: The overarching objectives of this study are to (i) identify the pathways by which coronal mass ejection (CME)-driven shocks gain access to suprathermal ions from solar flares and (ii) determine how these suprathermal ions influence the energy spectral and abundance variations of H and heavy ions in large gradual solar energetic particle (SEP) events. To achieve these objectives, we answer the following three science questions:

Q1) What is the relative role of simultaneous versus preceding solar flare activity in driving the event-to-event spectral and abundance variations in large gradual SEP events?

Q2) How does the simultaneous activity in parent source regions or other sites in the corona affect the spectral and abundance variations in large gradual SEP events?

Q3) What is the relationship between remnant flare suprathermal ions and the spectral and abundance variations in large gradual SEP events?

Motivation: Large CME-driven shocks-associated gradual SEP events that are hazardous for human and robotic space exploration often exhibit extreme enhancements in the abundances of 3He and heavy-ion species. Since such enrichments are typical of the smaller impulsive flare-related SEP events, it is now accepted that flare suprathermal ions are an essential component of the seed population for CME-driven shocks. However, the mechanisms through which CME-shocks gain access to these flare suprathermals and produce large gradual SEP events remain largely unexplored. Two competing ideas are: 1) CME-driven shocks are launched into heliospheric reservoirs that are populated by residual material created during preceding flare activity   the so-called remnant flare suprathermals, and 2) CME-driven shocks gain access to suprathermal material produced in the parent source region or by simultaneous flares from other sites in the corona.

Methodology: We bring closure to the proposed science questions using comprehensive in situ and remote-sensing analyses from five active Heliophysics missions, namely, ACE, SDO, STEREO, Wind at 1 au, and PSP at ~0.1 1.0 au. The remnant population is probed with the suprathermal ion measurements on azimuthally and radially separated ACE, STEREO, and PSP. Closer to the Sun, PSP can detect suprathermals from weaker flare-related events and simultaneously, the azimuthally separated spacecraft at 1 au can measure flare suprathermals distributed over a wide range of heliolongitudes. We determine residency times of flare suprathermals in the reservoir from prior occurrences of type-III radio bursts that are associated with impulsive SEP events. We investigate simultaneous activity in the parent flare using high-resolution observations on SDO. Rapidly changing structures with a size of ~1000 km can be resolved with SDO. These observations can reveal minor and short-lived jets that have been associated with solar sources of impulsive SEP events. Large-scale waves or shocks ejected from the parent source region can traverse jets at other sites in the corona. To examine the magnetic connection in the corona and to determine whether coronal structures are open or closed, we numerically model magnetic fields using PFSS (Potential Field Source Surface) and NLFF (Non-Linear Force Free) models.

Relevance: The proposed study is highly relevant to the scientific objectives of the Focused Science Topic (FST) #3: The Origin and Consequences of Suprathermal Particles that Seed Solar Energetic Particles. Specifically, it is relevant to two out of the three FST objectives: Understand the relative roles of solar flares and CMEs in producing large SEP events; Understand particle transport, mixing, and other effects that result in the observed variability in the properties of SEP events at 1 au. We contribute to the

Focused Science Team s effort by providing new insights into the role of flare suprathermals on the spectral and abundance variations in large SEP events.

John Dombeck/University Of Minnesota
Determining the net solar and magnetospheric electron energy contributions to Earth's atmosphere by precipitation mechanism

Electron precipitation is a primary component of Magnetospheric-Ionospheric-Thermospheric-Mesospheric (M-ITM) coupling and therefore one of the primary means through which solar input affects the atmosphere. The mechanisms resulting in this precipitation, mainly direct solar input, wave scattering and acceleration by quasi-static potential structures (QSPS, inverted-v) or Alfvén waves, cause dramatic differences in the electron energies and isotropies precipitating. This causes different atmospheric results and can vary by solar rotation period, season and solar cycle. Determining the relative contributions of the various mechanisms has been a crucial but elusive goal. Further, FAST spectra analysis, Dombeck et al. [2018], found that multiple mechanisms occur in the same event 65-70% of the time.

We propose to determine the amount of energy flux contributable to each of the primary mechanisms in most cases, including multiple mechanism events, for intense events and for a significant amount of the weak ones and how they vary over solar rotation, season and an entire solar cycle. We will also investigate the number flux contributable to each mechanism and investigate the trends of mechanisms for weak precipitation.

Specifically, our science goals are:
1) Determine the amount of net energy flux contributable to direct solar input, electron wave-scattering, quasi-static and Alfvénic acceleration and weak precipitation by solar rotation period, season and dependence on solar cycle;
2) Determine the trends in energy contributions by mechanism under different conditions by intensity to infer relative importance of the different mechanisms in weak precipitation;
3) Investigate the net number flux contributions by mechanism by solar rotation period, season and dependence on solar cycle.

The study directly relates to the goals of FST #4 Long Term Variability and Predictability of the Sun-Climate System in that it characterizes one of the primary sources of solar input into the atmosphere on the scale of weeks to years. It improves our understanding of how solar variability and solar-driven geomagnetic variability lead to or alter atmospheric structure and coupling by providing an understanding of one of the key atmospheric inputs, directly investigates the dynamics of the M-ITM system which affects inputs to the lower atmosphere, and determines how the different precipitation mechanisms couple solar energy to Earth. It is critical for the FST as they provide inputs for models of how upper atmospheric input affects lower levels.

To address these goals, the full 2d electron distributions (2dED), not just spectra, of the entire ~13 year FAST mission (> a full solar cycle) will be analyzed to determine which mechanism(s) are occurring, the temperature and density of the source (solar direct or wave scattered) population, and the potential drop of any QSPS. With this information several interrelated models for electron precipitation and backscatter will be used to determine the amount of net energy flux contributable to the sources and QSPS. The Alfvénic contribution is then the remainder. The 2dED provide the ability to more accurately identify the precipitation mechanisms and for weaker events than the spectral methods and can be used to determine their characteristics. The energy flux attributable to the different mechanisms will then be analyzed for variability by solar rotation period, season and solar cycle.

The models to be extended and then used include: an empirical model for backscatter spectra; two partially-coupled ensemble partial tracing models for the magnetosphere and a thick ionosphere that produce 2dED that can be directly compared with the FAST data; and a physics-based model for the effects of reflection of the backscatter by QSPS.

The number flux contributions highly depend on the differential fluxes of low energy electrons which are less accurately modeled results in higher uncertainty.

Scot Elkington/University Of Colorado, Boulder
Quantitative Assessment of Loss Processes in the Radiation Belts

OBJECTIVES: Understanding the physical processes and timescales for energetic particle loss are crucial to understanding the overall dynamics of the radiation belts. Here we address the overarching science question: "What are the relative effects of particle loss due to wave-particle interactions and magnetopause loss?" In particular,

1) How do different loss mechanisms vary with solar wind drivers and geomagnetic activity? We will examine loss processes as a function of location in the inner magnetosphere, and will use event-specific solar wind conditions and diffusion models to contrast particle loss during CME- and CIR-driven storms.

2) What are the effects of differing ULF and VLF wave distributions on the resulting radiation belt phase-space density profiles? Our method of developing event-specific diffusion models will provide insight into the relative effects of these waves on radiation belt losses.

3) What are the relative effects of atmospheric precipitation as compared to nonadiabatic loss to the magnetopause? Our method allows us to selectively remove or accentuate certain effects and wave modes, allowing us to examine the impact of each separately.

METHODOLOGY: This study will combine state-of-art global simulations of the coupled solar wind/magnetosphere system with comprehensive observations of the inner magnetosphere via the Van Allen Probes, THEMIS, BARREL, geosynchronous, and other available observational platforms.

Simulations will be undertaken using the K2 modeling framework. This model combines global, 3d MHD simulations of Earth's inner magnetosphere with energetic test particle simulations, augmented by Stochastic Differential Equation (SDE) methods, to allow simulation of wave-particle interactions with high-frequency waves not described within the MHD appproximation. This framework can self-consistently model radial transport due to interactions with global ULF waves, impulses in the solar wind, and substorm activity; accurately describes the location and evolution of the magnetopause under varying solar wind condtitions; and captures the effect of precipitation losses due to high-frequency wave-particle scattering.

CONTRIBUTIONS: This proposal addresses Focus Science Topic #2, "Understanding and predicting radiation belt loss in the coupled magnetosphere". This work will directly address all three of the major goals and objectives under this Science Topic, as described in Section 3.2 of the AO. Specifically, our work will (1) provide better understanding and ability to predict how overlapping plasma populations can impact the radiation belt loss processes of electrons, by using comprehensive, coupled simulations of the inner magnetosphere, including the plasmasphere, ring current, plasma trough, and magnetopause, to examine in detail the losses due to wave-particle-induced precipitation. (2) Provide improved understanding and prediction of radiation losses by non-adiabatic dropout events. Our simulation framework will self-consistently model both outward radial transport and the time-evolving location and shape of the magnetopause and associated losses, as well as precipitation due to wave-particle interactions, to elucidate factors controlling the non-adiabatic loss of particles from the radiation belts and identify physical parameters predicting such losses. And (3) examine other potential loss processes, such as non-linear wave-particle interactions and effects of Shabanksy orbits on precipitation and magnetopause loss of electrons.

Rachael Filwett/University of Iowa
Suprathermal Property Scaling and Acceleration Processes from the Near-Sun Environment to 1AU

The overarching goal of this investigation is to develop a physics-based understanding of the acceleration and sources of the suprathermal (ST) ion population in the inner heliosphere. The ST population is thought to be the primary source of seed particles that feed large solar energetic particles (SEPs), the main driver of space weather. We will achieve this by addressing the following scientific questions:

1. How do acceleration and transport processes sculpt the radial variations of suprathermal particle properties (spectra, composition, etc.) from ~0.1-1.0 AU?

2. What suprathermal particle acceleration mechanisms predominate in the quiet solar wind, energetic storm particles (ESPs), corotating interaction regions (CIRs), and SEP events at 1 AU?
3. How do shock parameters and event properties, such as size, peak flux, and integrated spectrum affect suprathermal acceleration in ESP, SEPs, and CIRs at 1 AU?

We will use the publicly available Parker Solar Probe and Solar Orbiter observations to examine the near-Sun ST environment. STEREO, ACE, and Wind data will be analyzed to understand the ST and energetic particle environment near 1 AU. These missions will provide a wide range of particle measurements enabling the examination of the radial evolution, transport effects, and longitudinal effects from the near-Sun to 1 AU. The observed ST properties will then be used in the iPATH model to understand how the initial seed particle parameters affect the accelerated particle properties at 1 AU.

These three science questions approach the Focused Science Team (FST) stated goal of understanding the origin of ST particles as seed particles in new and meaningful ways. First, characterizing the ST population near the Sun, and determining how it scales out to 1 AU gives new insights into how the seed population mixes and evolves. Seed particles are key ingredients to large SEP events, associated with strong interplanetary shocks. Injection into the shock is a continuous process from the Sun to 1 AU; proper modeling of large SEP events requires knowing the radial variation of the seed population. One outcome of the proposed study is the radial scaling of seed population, which will be incorporated to the iPATH model to examine how different seed populations (and their radial variation) can affect the accelerated particle spectrum. Second, studying a wide variety of solar transient events, focusing on the A/Q distribution of the seed population and that of the accelerated population, will provide a better understanding of the underlying acceleration mechanisms. Third, we will investigate how the shock properties (e.g., geometry, strength, and size in both radial and longitudinal components) contribute to the wide range of SEP properties observed at 1 AU. In achieving this goal, we will use the iPATH model. Input parameters of iPATH include plasma parameters, plus the seed particle distribution, which has NOT been tested much in the past. This proposal will investigate the mechanisms responsible for accelerating these particles to high energies and work to understand particle transport, mixing, and other effects that result in the observed variability in the properties of SEP events at 1 AU.

This proposal will contribute to the FST by providing an understanding of the linkage between the ST population near the Sun to the mechanisms that contribute to their acceleration to energetic particle events observed in solar transient events near Earth. This proposal utilizes both data analysis and modeling to further contextualize the observations and help understand the significance of various parameters to the transport and mixing of ST particles from near Sun to 1 AU. 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).

Lon Hood/University Of Arizona
Top-Down Solar Influence on the Madden-Julian Short-Term Climate Oscillation

OBJECTIVES: The objective is to evaluate the significance of solar variability in influencing tropical deep convection, the 30-60 day Madden-Julian Oscillation (MJO), and resulting effects on subseasonal to decadal weather and climate at northern midlatitudes in winter-spring.

METHODS/TECHNIQUES:
In year 1, new 27-day solar multiple linear regression (MLR) analyses will be carried out for tropical lower stratospheric static stability and several quantities that are more directly diagnostic of the intensity of deep tropical convection (outgoing longwave radiation, divergent winds). This will test and extend previous evidence that solar-induced changes in upwelling and static stability in the tropical lower stratosphere are the initiators of solar influences on tropical deep convection and the MJO.

In year 2, the dependence of the 27-day solar modulation of the MJO on MJO phase will be investigated. In particular, efforts will focus on testing previously reported evidence that 27-day solar UV minima are associated with enhanced eastward propagation of the MJO past the Maritime Continent barrier. In addition, analyses of WACCM6 model data will determine whether this advanced GCM is able to simulate the observed 27-day solar modulation of the MJO.

In year 3, further analyses of WACCM6 model data will determine whether this model is able to simulate an 11-yr solar modulation of the MJO. Any obvious deficiencies in WACCM6 that might preclude simulation of the 27-day and 11-yr modulations will be identified. Work will also begin on compositing of filtered climate variables to determine whether lagged effects on intraseasonal climate of the 27-day and 11-yr solar modulations of the MJO can be detected. at northern midlatitudes in boreal winter-spring.

In year 4, the intraseasonal climate analyses will be completed. Also, a comprehensive investigation will be conducted of whether modulation of the MJO by the solar cycle and by the quasi-biennial oscillation (QBO) can assist in understanding observed influences of both the QBO and the 11-yr solar cycle on the occurrence of sudden stratospheric warmings (SSWs) at high northern latitudes in winter (known as the Holton-Tan and Labitzke-van Loon effects). SSWs have significant tropospheric weather consequences.

SIGNIFICANCE/RELEVANCE: The MJO is the strongest of the intraseasonal oscillations, which have important derivative effects on extratropical circulation and weather, including impacts on storminess and temperature in the United States (e.g., http://www.cpc.ncep.noaa.gov/products/intraseasonal). The main significance of the proposed work is that it will lead to a better evaluation of the role of solar variability on both the 27-day and 11-year time scales for influencing the tropical MJO and its derivative effects on intraseasonal and decadal climate variability. It will also test whether a state-of-the-art coupled climate model with daily solar forcing can simulate this influence. The proposed work will directly contribute to Focused Science Topic #4:

Long-Term Variability and Predictability of the Sun-Climate System as described in para. 5.2 of Appendix B.5 (Heliophysics Living With a Star Science) of the ROSES 2020 solicitation. It focuses on ``the impacts of solar variability on the terrestrial climate", specifically investigating how the upper stratospheric region driven directly by solar influences is linked, via the MJO, to tropospheric processes where human activities are concentrated. It incorporates space-based observations, both directly in satellite outgoing longwave radiation data, which are a measure of tropical convection, and indirectly as essential inputs to meteorological reanalyses, which are the main climate data source for the proposed work.

Xianglei Huang/University Of Michigan, Ann Arbor
Understand the effect of solar spectral irradiance partition between the visible and near-IR on high-latitude surface climate through a bottom-up mechanism

The importance of total solar irradiance (TSI) on Earth's climate has been long recognized and studied. What has not been equally studied is how the solar spectral irradiance (SSI) over the different spectral regions affect our climate. Absorption and scattering of solar radiation by Earth s atmosphere and surface are spectrally dependent. Thus, how the climate responds to the SSI variation might not be simply scaled with TSI variation.

So far, most SSI-climate connection studies have been focused on the UV. Visible and near-IR consist of about 48% and 45% of the TSI, respectively; thus, a small fractional change in the visible and near-IR SSI can still matter for our climate. The partition of SSI between the visible and near-IR (hereafter referred to as VIS-NIR partition for brevity) is especially relevant to Earth's climate because both water vapor absorption and sea ice reflectance vary significantly from the visible to near-IR. As a result, a different VIS-NIR partition of the same TSI value can lead to different amounts of solar absorption and reflection by the climate system.

NASA TSIS-1 mission launched in 2017 has provided more accurate SSI measurements than ever before. Compared to the SSI used in the recent IPCC climate model simulations, the TSIS-1 SSI for a given VIS or NIR band can differ as much as 4 W/m^2. Such VIS-NIR partition differences can cause statistically significant differences in the simulated polar climate, as shown by our recent study using the NCAR new flagship climate model, CESM2. Such change is caused by the response of surface energy budget to the VIS-NIR partition difference and a variety of atmospheric radiative feedbacks, which we termed as a bottom-up mechanism for the SSI to influence our climate. Such findings motivate us to propose a series of studies to address the following questions:

1. When the actual TSIS-1 SSI is used in the simulations with prescribed sea surface temperature and sea ice, how does the simulation compare to the simulation done with the default SSI used by the climate modeling community? How do model simulations compare to the observations over the same period? The answer will help us understand the fast atmospheric responses to the VIS-NIR partition difference.

2. How does the fully coupled CESM2 simulation over multiple decades respond to the SSI VIS-NIR partition difference between the TSIS-1 observation and the data used by the IPCC community? Can we quantify the strengths and spatial distributions of radiative feedbacks caused by such VIS-NIR partition difference?
3. Based on the TSIS-1 measurement uncertainty, what would be the uncertainty in the TSIS-1 VIS-NIR partition? How can such uncertainty be propagated to the uncertainty in the simulated climate? Can we express such propagation as a Jacobian sensitivity matrix?
4. Based on #2 and #3, using CESM2 time slice run, can we estimate the impact of VIS-NIR SSI partition on the IPCC historical and future simulations? This will elucidate to what extent the bottom-up mechanism can affect the simulated climate change.

We propose to carry out a series of CESM2 simulations with different SSI configurations to address the above questions. CU-Boulder team specializes in SSI observation, uncertainty quantification, and reconstruction, and the Michigan team specializes in climate model simulations and solar physics. The proposed study aims for FST #4. It addresses two specific topics, "radiative process and forcing including the absorption and scattering of total and spectral solar irradiance" and "variations in atmospheric temperature." The goal is to understand the physics behind how the climate system responds to the variations of SSI VIS-NIR partition. Doing so will advance our physical understanding of the SSI-climate connection and help improve the predictability of the earth system models. It will pave a road to further integrate NASA SSI observations into the climate modeling community.

Yi-Min Huang/Princeton University
Investigating the roles of turbulence and reconnection in generating suprathermal seed populations for SEP events

Scientific Objectives

Solar energetic particles (SEPs), which have energies ranging from a few tens of keV to several GeV, pose severe hazards to astronauts and spacecraft components beyond the protection of Earth s magnetic field. A fundamental goal of space weather forecasts is the capability to predict SEP events reliably.

Suprathermal particles play a crucial role as the seed population that can be further accelerated by other mechanisms to produce SEPs. However, the mechanisms that generate the suprathermal particles and ultimately determine their energy distribution remain elusive. An in-depth understanding of these mechanisms is essential for predicting SEP events and determining their energy spectrum under various circumstances.

To address this question, we propose a research project based on recent first-principles simulations performed by the proposing team. These simulations indicated that the omnipresent small-scale reconnection sites in a magnetized turbulent plasma play a crucial role in generating the seed particle population, even though the reconnection sites do not account for the majority of particle energization. Observational evidence indicates that the solar corona is turbulent. We conceive that small-scale reconnection in turbulence may be the source of the suprathermal particles that seed SEP events. The ongoing Parker Solar Probe (PSP) mission may be able to probe these small-scale reconnection sites.

The primary objective of the proposed research is to investigate the roles of turbulence and magnetic reconnection as the cause of suprathermal particles with state-of-the-art numerical simulations, theoretical analysis, and comparison with PSP observations.

Methodology

The numerical simulations will involve multiple models, including MHD, five and ten-moment multi-fluid models, test-particle simulation, and fully kinetic particle-in-cell (PIC) simulation. Among the fluid models, the five and ten-moment multi-fluid models have been demonstrated to capture essential kinetic physics beyond MHD. Fully kinetic PIC simulation resolves the smallest scales and will be employed to produce the seed population. This step provides first-principles input of the seed populations that will be injected as test particles in fluid simulations to investigate the further acceleration of SEPs under various large-scale circumstances, including solar flares, coronal mass ejections (CMEs), and CME-driven shocks. In situ measurement of SEPs from PSP will be employed to test and validate theories and numerical simulations.

Proposed Contributions to the Focused Science Team Effort

This project is fully in line with the Focused Science Topic #3   The Origin and Consequences of Suprathermal Particles that Seed Solar Energetic Particles. We propose the following investigations:
 Determine the distribution of suprathermal particles. By performing PIC simulations, test particle simulations, and theoretical analysis, we will determine how the distribution of suprathermal particles depends on plasma parameters and the charge-to-mass ratio of different elements and isotopes. The distribution of each species will directly impact its relative abundance in SEPs. The prediction will be tested against in situ observations of the Parker Solar Probe during quiet periods.
Investigate the effects of suprathermal particles on SEPs under various circumstances. To test whether the physics-based suprathermal seed particles generated by turbulence can lead to the high energy and intensity of observed SEP events, we will inject the seed population into fluid simulations of solar flares and CME-driven shocks to be further accelerated, corresponding to impulsive and gradual SEP events.

Joseph Huba/Syntek Technologies Inc.
Global Modeling of Equatorial Spread F

Science Goals and Objectives:
Post-sunset ionospheric irregularities in the equatorial F region were first observed by Booker and Wells in 1938 using ionosondes. This phenomenon eventually became known as equatorial spread F (ESF). It is now known that during ESF the equatorial ionosphere becomes unstable because of a Rayleigh-Taylor-like instability: large scale (10s km) electron density `bubbles' can develop and rise to high altitudes (1000 km or greater at times). Given the complexity and non-linear development of equatorial plasma bubbles, computational models are needed to tackle this problem. We propose a 4 year program to investigate the causes and nonlinear consequences of equatorial spread F. The objectives of the proposed research program are to (1) identify the causes of day-to-day and longitudinal variability associated with equatorial spread F, (2) investigate the nonlinear evolution of equatorial plasma bubbles, and (3) calculate the linear growth rate of the instability to help identify the underlying driving mechanism(s).

Methodology:
We will use the first-principles whole atmosphere model WACCM-X and the ionosphere model SAMI3 to investigate the onset and evolution of equatorial spread F on a global scale. These models provide a unique capability to address this problem. The WACCM-X model not only provides the large-scale variations of the neutral densities, temperature, and winds as inputs to SAMI3, but also self-consistently generated atmospheric gravity waves that can act as seeds to trigger equatorial spread F. The SAMI3 model, using WACCM-X inputs, is capable of resolving the onset and evolution of equatorial plasma bubbles. Moreover, SAMI3 use a high-order flux-correction transport scheme that reduces numerical diffusion and allows steep density gradients to develop that is necessary to model ESF. To our knowledge this is the only global model with this capability. We will compare and validate our simulation studies to available data such as TEC, radio occultation, radar, and ionosonde experiments. An emphasis will be on coordinating and comparing model results to GOLD and ICON observations. Working with rest of our LWS team, we will seek additional collaborative opportunities to analyze relevant data and further validate our results.

Proposed Contributions to Focused Science Team Effort:
The proposed program is directly relevant to this focused science topic. Two of the goals of the program are (1) to ``identify the mechanisms and structures that are responsible for ionospheric irregularities and scintillations at various latitudes (low, mid, and high latitudes) and longitudes" and (2) to ``determine the growth rates, spectral characteristics, the nonlinear evolution associated with specific generation mechanisms and their role in scintillations." The milestones are to (1) perform simulation studies of equatorial spread F under different geophysical conditions, (2) identify the causes of day-to-day and longitudinal variability, and (3) calculate the linear growth rate of the instability to help identify the underlying driving mechanism(s). The proposed effort also directly addresses a key objective of the LWS program SSA-4 (Physics-based Total Electron Content (TEC)

Forecasting Capability) as well as goals set forth in the Decadal Survey regarding plasma-neutral coupling.

Anthony Jull/University Of Arizona
Internal decadal anomalies in atmospheric 14C quantified with tree-ring proxies and implications for long-term variability of the sun-climate system

We propose to quantify long-term dynamics of the sun-climate system with annual 14C series from tree rings over the Holocene, as part of FST #4: Long Term Variability and Predictability of the Sun-Climate System. We hypothesize that abrupt spikes in 14C production (internal decadal anomalies, IDA sometimes called Miyake events) precede the onset of longer solar minima and impact the solar forcing of global climate via shifting irradiance wavelets and ionization. Our objective is to develop IDA 14C records to improve the use of historical proxies for changes in solar forcing and validate climate models. The annual rate of 14C production in the low stratosphere-troposphere reflects the variance of electromagnetic radiation over time due to changes in galactic cosmic rays and solar energetic particles. This important feature of atmospheric chemistry can be used to identify changes in solar activity, particularly intensity of the Schwabe cycle during solar minima and solar maxima. 14C records will explore the interaction of the IDA signal with known and uncharacterized Grand Solar Minima (showing the irregular variability of solar activity), and the regular state of 14C behavior using wavelet analysis and dynamic time-warping methods. Changes in the Schwabe cycle at the beginning of the Spoerer and Maunder minima have been extensively studied (e.g. Eastoe et al. 2019, Moriya et al. 2019, and earlier references). However, the lack of highly-resolved 14C records obscures the impact of solar activity on climate during other solar minima. Our initial studies report different types of solar minima around 5480 BC and 835-778 BC that have no associations with specific climatic anomalies. Simulations of PMIP4-CMIP6 paleoclimate models have identified the broad range of solar irradiance variations, especially the transition from solar minima to regular solar activity (Jungclaus et al. 2017, Otto-Bliesner et al. 2017). Modeling of climate forcing across transitional climatic events (e.g. Little Ice Age) gives great insight into externally-forced variability and multidecadal climate dynamics (e.g. Fernández-Donado et al. 2013, Ortega et al. 2015, Zanchettin et al. 2015, Luterbacher et al. 2016). Yet, attribution of solar minima to cold-temperature regimes for many other Holocene abrupt events like 8.2ka, 6.3ka, 4.7ka, 2.7ka, 1550 BP, 550 BP is neither clear nor ambiguous (Wanner et al 2011). Temperature characteristics of other abrupt climate events recognized by regional climate proxies have not been well-defined. Our analysis will examine the relationship between irregular long-term solar variability, quantified with annual delta 14C (3-box model parameterization) and ranging multiproxy climate reconstructions. Recent simulations of Chemistry-Climate Models (CCM) show high-amplitude variations of total solar irradiance that are essential to reproduce the cooling events of global climate (Solanki et al. 2010, Calisto et al. 2011, Semeniuk et al. 2011, Shapiro et al. 2011, Rozanov et al. 2012, Anet et al. 2013). Regular changes of solar irradiance are well studied by climate forcing models. A typical increase over the 11-year solar cycle of ~0.1 % is welldocumented by instrumental observations (ca. 1978) and sunspot number records (ca. 1610). Other changes (e.g. IDA) are irregular and manifest on a longer timescale. These changes are studied much less and their impact on the climatic system is debatable. These random solar events introduce additional volatility to the climate-forcing system that may last from several decades to centuries. For example, rapid solar-irradiance variations with larger amplitude during Grand Solar Minima or Grand Solar Maxima are superimposed on the 11 year cycle and offset the intensity and duration of the Schwabe solar cycle. The new 14C signal can be an indicator of climate forcing: new characteristics of solar activity and atmospheric chemistry: irradiance and atmospheric ionization.

Jeffrey Klenzing/NASA Goddard Space Flight Center

Driving the Ionosphere from Below: Effects of Planetary Waves and Ion-Neutral Coupling on Low-latitude Plasma Density Irregularities

We intend to systematically examine the effect of multi-day planetary waves on the mid- and low-latitude Ionosphere-Thermosphere (IT) system, including the enhancement and suppression of plasma irregularity formation, which have a devastating effect on communication and navigation signals. Because the terrestrial IT system is driven through multiple energy paths (including direct solar EUV forcing, high-latitude geomagnetic inputs, and forcing from the lower atmosphere), forecasting of both the large-scale structure of the ionosphere and smaller-scale irregularities such as scintillation remains a challenge for the space weather community. At low-latitudes, this scintillation is attributed to turbulence around meso-scale plasma depletions formed through a Rayleigh-Taylor Instability (RTI) seeded by waves in the bottomside ionosphere. Two factors are needed to form the depletion: background conditions to sustain a positive growth rate and the existence of a seed. This growth rate varies with longitude as a function of magnetic field line geometry. In certain regions, the seeds occur far more often than the depletions, and yet significant variability within the system is still seen when comparing consecutive days with similar solar or geomagnetic inputs. While coupling with the lower atmosphere is typically invoked as a potential cause of this day-to-day variability, this has not been systematically investigated.

The proposed work will incorporate analysis of the planetary waves using data from TIMED/SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) and the Microwave Limb Sounder (MLS), as well as global ionospheric structure including background density, meso-scale plasma bubbles, and scintillation through data from the Coupled Ion-Neutral Dynamics Investigation (CINDI), the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC), and ground-based GPS observations. These results will be compared to simulation results from coupled runs of the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) and the SAMI3 ionosphere model. Data comparisons with the model will be performed at every stage of analysis, including validating the WACCM-X planetary waves driving the ionosphere and the background SAMI3 ionospheric plasma distribution. The likelihood of plasma bubbles and scintillation will be determined by calculating the RTI growth rate integrated along the SAMI3 flux tubes as a function of longitude and season throughout long-term runs of the IT models. This study will be the first systematic zonal analysis of the variation and variability of the RTI growth in conjunction with detailed bubble statistics.

This work directly addresses the first and second goals of the Focus Science Topic -- "Identify the mechanisms and structures that are responsible for ionospheric irregularities and scintillations at various latitudes (low, mid, and high latitudes) and longitudes and Determine growth rates, spectral characteristics, the nonlinear evolution associated with specific generation mechanisms and their role in scintillations -- as well as connecting LWS strategic Science Goals SSA-VI Ionospheric Irregularities and SSA-VII Composition and Energetics of the Upper Neutral Atmosphere. As part of the larger Focus Science Topic, this work will contribute simulations of the structure and/or motions of the plasma density at various latitudes, establishing a quiet-time baseline for the variation and variability of the mid- and low-latitude IT system that can enhance or suppress the growth of low-latitude instabilities at various longitudes. The proposal team will work with the full FST team to quantify the relative contributions of other ionospheric drivers on the Rayleigh-Taylor Instability growth rate. This work uses a comprehensive set of publicly available data, including that from NASA (CINDI, GOLD, ICON, TIMED, MLS).

Jakobus le Roux/University Of Alabama, Huntsville
Generation of Suprathermal Seed Particle Populations by Dynamic Small-scale Flux Ropes in the Vicinity of Traveling Shocks.

1. Science Goals and Objectives. The main goals of this project are: (i) Investigation of the fundamental physics of how, and to what extent, dynamic small-scale magnetic flux ropes (SMFRs), observed to occur in the vicinity of shocks driven by coronal mass ejections (CMEs) and their interplanetary counterparts (ICMEs), produce suprathermal particle populations through efficient SMFR acceleration. (ii) Gain an understanding of how these populations act as seed particles for the diffusive shock acceleration (DSA) of solar energetic particles (SEPs) at CME/ICME-driven shocks between the solar corona and Earth orbit. This involves the following main science objectives: (1) Determination of the relative efficiency of various theoretically identified competing 1st and 2nd order Fermi acceleration SFMR mechanisms in producing suprathermal ion and electron populations. (2) Estimation of the probability of these suprathermal particle populations in forming a significant seed population for injection into DSA of SEPs at CME/ICME-driven shocks. (3) Study the existence of a competition between SMFR acceleration and DSA above a threshold energy which might modify the spectral features and time profiles of SEPs undergoing DSA. (4) Deduction of the background suprathermal spectrum in the corona.

2. Methodology. Transport theory based simulations of SMFR acceleration of suprathermals and DSA of SEPs near CME/ICME shocks, constrained by spacecraft data

analysis results, will be performed for both ions and electrons between the solar corona and 1 AU. Existing focused and SMFR transport theories for suprathermal SMFR acceleration in the solar wind will be used to update available focused transport numerical models of energetic ion and electron transport and DSA at traveling shocks to include SMFR acceleration. Analysis of available data from ACE, Wind, STEREO A & B, Helios 1 & 2, and current and future data from the Parker Solar Probe will be used to estimate detailed SMFR characteristics with the aid of Grad-Shrafranov and wavelet data analysis methods and determine the associated SMFR accelerated energetic particle characteristics in the vicinity of CME/ICME-driven shocks to constrain simulations of SMFR acceleration. Data analysis will also address CME/ICME driven shock characteristics and relevant features of SEPs undergoing DSA at these shocks to constrain DSA simulations.

3. Relevance and Contribution to Team Effort. This project addresses Focused Science Topic (FST) 3: "The Origin and Consequences of Suprathermal Particles that Seed Solar Energetic Particles". Numerical focused transport models combining SMFR acceleration with DSA at CME/ICME-driven shocks will be developed. Simulations of SMFR acceleration to form suprathermal populations near CME/ICME driven shocks, DSA of SEPs, and injection of SMFR-accelerated into DSA of SEPs at these shocks, will be simulated for both ions and electrons between the solar corona and 1 AU. Conclusions about the dominant SMFR acceleration mechanisms for both ions and electrons, the injection efficiency of SMFR-accelerated suprathermals into DSA of SEPs, competition between SMFR acceleration and DSA above a threshold energy, and the background spectra of suprathermals in the corona will be drawn. This will be accomplished by validating the simulations with (i) observed time and spectral profiles of enhanced fluxes of suprathermals accelerated by SMFRs in the vicinity of CME/ICME-driven shocks and of SEPs undergoing DSA at these shocks, and (ii) with observed SMFR parameters estimated with the aid of Grad-Shrafranov and wavelet data analysis methods. Our theoretical, numerical, and data analysis results will be published in scientific journals.

Christina Lee/University of California, Berkeley
The Role of Magnetic Connectivity and SEP Event History in Determining Seed Populations and Large SEP Events

Forecasting large SEP events continues to be an outstanding challenge in solar and heliospheric physics. We do not directly observe the timing/location of particle acceleration regions, the transport of SEPs along magnetic field lines, or properties of the pre-event seed populations. Multipoint observations have shown that enhanced SEP fluxes can be detected at widely separated locations in the inner heliosphere, especially during active times, when multiple interplanetary shocks are present. Using data-driven modeling of shock evolution, we will determine the connectivity to the observing spacecraft and the spatial relationship between the shock(s) and observer(s). Results will be compared with multipoint measurements to determine the contribution of cross-field transport by evaluating how far away from the shock-connected regions SEPs are still detected.

Hypotheses for the origin of the seed populations associated with large SEP events include: (a) variations in the suprathermal tail of the nominal solar wind distribution at the Sun or in the heliosphere; (b) suprathermal ions from prior or current solar flares; and (c) previously shock-energized particles as a heliospheric source. We propose a combined data analysis and modeling approach to quantify the potential contribution of each of these by investigating the spatiotemporal extent and variability of:

1. SEP (shock) origin in the heliosphere: We will use Wang-Sheeley-Arge (WSA)-Enlil with SEPMOD to examine the field line connectivity and determine how much cross-field transport is necessary to explain the spatial extent of SEP events observed at multiple locations (e.g., L1, STA, PSP). Can the connectivity to CME-driven shock fronts explain the entire longitudinal extent of SEP events?

2. Magnetic geometry near the Sun: We will examine topological structures like pseudostreamers, S-web arcs, and narrow open-field channels into or near the flare site/CME source. Each of these regions has a large squashing factor, i.e., a small angular difference at 1Rs but a large angular difference at the source surface or 21.5Rs. As a result, any flare or CME dynamics could greatly enhance the longitudinal extent available to SEPs.

3. Pre-event conditions and remnant seed particles in the heliosphere: We will use WSA-Enlil+Cone with SEPMOD to investigate how often the observer field lines intersect multiple shocks. The modeled shock parameters will be used as input for detailed shock acceleration calculations with the resulting seed population(s) injected onto WSA-Enlil field lines. As the shock evolves, different field lines will encounter different suprathermal properties.

4. CME-driven shocks near the Sun: We will examine the shock structure in the low corona (<21.5Rs) from MHD simulations of CME eruptions and couple the field line connectivity information to that from WSA-Enlil to investigate the coronal source of the seed population. Additionally, we will examine open field lines that have reconnected in the eruption process, the evolution of the magnetic topology disturbed by the eruption, and the longitudinal extent at 21.5Rs of flare/shock-connected field lines.

The results of our project will build a better understanding of multipoint observations of large SEP events. Without a first-order knowledge of magnetic connectivity to interplanetary shocks, it is difficult to evaluate the importance of perpendicular transport in the context of real events. Our project will make significant progress towards the LWS FST objectives to understand the relative roles of solar flares and CMEs in producing large SEP events and understand particle transport, mixing, and other effects that result in the observed variability in the properties of SEP events at 1AU. Our project is highly relevant to the LWS Strategic Science Areas SSA-II (Solar Eruptive and Transient

Heliospheric Phenomena) and SSA-III (Acceleration Transport of Solar Energetic Particles).

Xiaocan Li/Dartmouth College
The Acceleration of Energetic Particles in Solar Flares and Their Transport in Solar Eruption Regions

Science goals and objectives:
This proposal's overarching goal is to understand how the flare-accelerated particles contribute to the seed population of large Solar Energetic Particle (SEP) events. While magnetic reconnection is believed to be the driving process for the solar eruption and associated release of magnetic energy, how suprathermal particles get accelerated in the flare region is still not well understood. The accelerated particles travel through complex magnetic fields in the eruption region, get released into heliospheric space, and may actively contribute to large solar energetic particle (SEP) events as a seed population. How this happens is also poorly known and holds the key to further understanding of SEP events. Our proposed research will connect physics understanding of particle acceleration in flare reconnection and large-scale magnetic field evolution and particle release and transport process in the eruption region, including coronal mass ejection (CME) initiation in the very early stage of SEP events. With this study, we will unravel the role of solar flares in large SEP events. The work will provide critical information about how flare related "seed" particles are generated and contribute to large SEP events.

Methodology:
We will achieve the science goals through several well-defined and inter-connected investigations with various theoretical and numerical modeling efforts, including carrying out self-consistent kinetic simulations of local reconnection regions, performing sophisticated magnetohydrodynamic (MHD) simulations of the solar eruption region, and calculating the evolution of high-energy particle distributions in electromagnetic fields obtained from the MHD simulations. With these efforts, we will obtain the spatiotemporal distribution of flare-accelerated particles in the corona region during large-scale solar eruption and quantify how they can further feed into the CME-shock system and contribute to the interplanetary seed particle population.

Relevance and potential contributions:
This proposal directly addresses the scientific objectives of the focused science topic (FST) #3: The origin and consequences of suprathermal particles that seed solar energetic particles by studying the roles of solar flares in large SEP events and investigating particle acceleration mechanisms for producing suprathermal particles in solar flares. In the focused science team, our unique suite of numerical tools will allow us to interact and collaborate closely with team members on observation, theory, and other numerical modeling components to study energetic particle acceleration and transport in a systematic approach. We will provide the team with new models for flare energetic particle production and release and the evolution of SEP composition in space and time.

We will clarify the origin and distribution of seed particles and their roles in producing large SEP events.

Wei Liu/Bay Area Environmental Research Institute, Inc.
Suprathermal Seeds for Solar Energetic Particles: Two-stage Acceleration from Flares to CME-Shocks

(I) Science Goal and Objectives:

We propose a cross-disciplinary, paradigm-shifting investigation of the mechanisms of particle acceleration and transport in solar eruptive events, including particle acceleration and transport at the flare site on the Sun and at the CME-driven shock in the heliosphere. We will focus on the coupling between these processes, which were traditionally treated separately, but can play a crucial role in providing the seed population for solar energetic particles (SEPs), with flare-produced suprathermal particles to be re-accelerated by the CME-driven shock.

Specifically, we aim to address: (1) the mechanism(s) of particle acceleration at the coronal flare site, most likely via stochastic acceleration (SA) by plasma turbulence; (2) the processes that govern the escape and transport of flare-accelerated suprathermal particles to the CME-driven shock; (3) diffusive shock acceleration (DSA) of particles at the CME-driven shock, using the escaping flare particles as seeds; (4) the escape of particles from the CME-driven shock, upstream to 1 AU as SEPs and downstream to the Sun as gamma-ray producers, especially in those long-duration and behind-the-limb flares detected by Fermi.

(II) Methodology:

We will adopt a novel, systems approach consisting of balanced, mutually supporting elements of theoretical development, numerical modeling, and data analysis.

(1) This will be pursued in the framework of a hybrid model involving kinetic treatment of particles on microscopic scales and fluid (magnetohydrodynamic, MHD) treatment of the macroscopic development of the CME and shock evolution. The kinetic treatment involves SA and DSA of charged particles, as well as their two-way transport between the flare site, the CME-driven shock, and the in-situ instruments. We will perform data-driven simulations of well-observed events, where the MHD modeling will provide shock parameters for modeling DSA and magnetic connectivity for modeling particle transport.

(2) The modeling results will be rigorously compared and validated with remote-sensing and in-situ observations. Special attention will be paid to (i) nonthermal flare radiation, at X-rays from RHESSI, gamma-rays from Fermi, and radio from ground based telescopes and (ii) accelerated electron to proton ratios and isotopic enrichments of ions, such as 3He, that are sensitive to the underlying acceleration mechanisms.

(III) Relevance, Impact and Contribution:

Relevance: The proposed investigation directly addresses two of the three objectives of this LWS FST regarding (i) "the relative roles of solar flares and CMEs in producing large SEP events", and (ii) "particle acceleration mechanisms for producing suprathermal particles at the Sun and in the heliosphere and for accelerating these particles to high energies". It is also relevant to the third objective regarding "particle transport ... and other effects that result in the observed variability in the properties of SEP events at 1 AU."

Impact and Contribution: (1) The proposed study, when fully executed, will have the potential to revolutionize our understanding of SEP production in solar flares and CMEs as a coupled system. (2) To the best of our knowledge, no previous studies have tackled this important aspect of SEP production by self-consistently including flare-accelerated particles as the seed population. We will be able to fill this gap and contribute to the FST with a fully-developed modeling suite that can track particle acceleration at the flare site and at the CME-driven shock, as well as particle transport in between. (3) With an over-arching systems approach, it can also potentially contribute to the FST by tying together works by individual teams that focus on different aspects of the problem and by performing end-to-end validation of modeling results with observations.

Andres Munoz-Jaramillo/Southwest Research Institute
The missing link: Relating decades of solar and cosmic ray observations to Lightning and extreme weather patterns on Earth

Motivation and Science Objective:
While the impact of solar variability on the upper atmosphere and geospace is well established and understood, solar impact on terrestrial weather and climate is much harder to assess. The main solar variables with potential links to terrestrial weather are Galactic Cosmic Rays (GCRs) and total (TSI) and spectral (SSI) solar irradiance.
We propose to make a detailed, quantitative measure of the non-linear causal connection, sensitivity, and significance between water precipitation, cloud coverage, lightning, cyclonic storm strength and frequency, and GCRs and TSI.

To accomplish our objective, we address the following questions:
SQ1. How do solar and cosmic ray variability affect tropospheric weather parameters as functions of latitude and longitude?
SQ2. What are the temporal lagging times between solar and cosmic ray variability, and multi-scale (days to years) changes in tropospheric weather parameters?
SQ3. How do solar and cosmic ray variability affect terrestrial extreme weather events on different time scales (e.g., Hurricanes, droughts, extreme precipitation, enhanced/extreme lightning activity)?

Data and Methodology:
We use public data from multiple resources: Plasma and energetic particle data from space-based platforms (ACE/CRIS and OMNI), ground-based neutron monitors, and major ground-based and space-based meteorological data sets (e.g., Global Lightning Monitor, MODIS cloud coverage, CCMP wind vector, NCEP/DOE water precipitation among others). Our team comprises experienced scientists who worked on and are very familiar with these multidisciplinary datasets.
We carefully assemble a comprehensive unified database that comprises temporal and spatial binning on different scales (e.g., days to years, seasons, geographic coordinates). We perform lagged cross-correlation, linear causality, and transfer entropy analysis on this data to determine and quantify (i; SQ1) solar and cosmic ray correlations with spatial weather parameters; (ii; Q2) their temporal correlation; and (iii; Q3) How solar and cosmic ray variations affect extreme weather events. We take advantage of rigorous significance analysis to account for uncertainty in our data

Relevance:
This project responds to Strategic Science Area (SSA-IX) determined by the LWS TR&T steering committee, 2 key science goals of the 2012 Heliophysics Decadal survey (2&4), and this LWS Focused Science Team (FST) program elements. It is a data analysis study that examines the relationship between long-term solar variability and atmospheric responses , which focuses on variations in atmospheric temperature, winds, and composition and clouds and precipitation . Additionally, by taking advantage of novel information theory causality analyses, we move beyond simple correlations and enable a proper quantification of causality and its significance.

Contribution to the FST:
Our project will collate a set of diverse space and terrestrial tropospheric data in standardized cubes that we will share with the FST team to further probe their intertwined physical connections. Our results will include a relevance score to different space-related quantities, when determining their causal connections to tropospheric weather. This will provide new physical insights into the mechanisms that connect space phenomena with weather variations on Earth.

Yukitoshi Nishimura/Boston University
Identifying driving mechanisms of GPS scintillation in the high-latitude ionosphere

Science goal and objectives:
Our goal is to determine the relation between GPS radio signal scintillation and plasma conditions in three key regions in the high-latitude ionosphere (cusp, nightside auroral oval, and polar cap). The goal will be achieved by addressing three science questions:
(1) How are scintillation occurrence and strength related to ionosphere conditions?
(2) What types of auroral and airglow forms are related to scintillation?
(3) What are the wavenumber spectra of F-region ionosphere density irregularities during scintillation?

Methodology:
The scintillation will be identified using the Canadian high arctic ionospheric network (CHAIN) GPS receiver data. The ionosphere density will be obtained from TEC given by individual receiver-satellite combinations. The flow velocity will be obtained from the SuperDARN radars and Swarm satellites. THEMIS and REGO all-sky imagers will be used to determine auroral intensity and structure. The density irregularity spectra will be provided from the Swarm satellites.
Case studies and linear correlation analyses will be performed for determining the relation among scintillation, TEC, flow velocity, auroral intensity, and their gradients. Nonlinear correlations and causality will be identified through the application of information theory. For nightside and polar cap scintillation, the imager data will be used to find the types of auroral and airglow forms for identifying what auroral forms and airglow structures are related to scintillation occurrence. When the Swarm satellites are in conjunction with the CHAIN network, the slope of the density wavenumber spectra will be calculated to find what cascading processes contribute to formation of density irregularities. The findings from these works will be used to identify what type of instability (e.g, gradient drift instability and Kelvin-Helmholtz instability) is consistent with the observation.

Proposed contributions to the FST effort and relevance to the FST:
The proposed study will provide observational specification of the occurrence conditions of the scintillation in the high-latitude ionosphere. The relation between scintillation and ionospheric structures (TEC, flow, precipitation and in-situ density structure) will observationally show what types of forcing to the ionosphere are important for creating scintillation, and what instability mechanisms explain the scintillation occurrence. These expected findings will directly address the goal of the FST "understand and model the conditions that lead to the onset and evolution of ionospheric irregularities and resulting scintillation events at low, mid and high latitudes.", and two of the FST objectives "Identify the mechanisms and structures that are responsible for ionospheric irregularities and scintillations&" and "Identify the instability mechanisms responsible for polar F-region irregularities".
The observational work is complementary to proposals that will conduct numerical simulations of scintillation. Our work will provide observational constraints of the simulation setup of ionosphere conditions, and will assist interpretation of the physical

mechanisms of simulated density irregularities and scintillation. Information theory can also provide a novel approach to model verifications and validations. The traditional model-data comparison methodology of comparing simulation with data at a particular point in space and time can be supplemented with comparing information flow from input to intermediate and to output variables in the simulation and observational data. Our work on high-latitude scintillation in North America is complementary to studies of scintillation at low/mid-latitudes and other longitudes/hemispheres, and will contribute for comparing similarities and differences in scintillation at various regions.

Meers Oppenheim/Boston University
Simulating radio wave propagation and scintillations through the turbulent ionosphere

Science Goals: Disturbances in the Earth s ionosphere frequently disrupt radio waves transmitted through it in a process called scintillation. These disruptions often cause a loss or degradation of GPS and Earth-space communication, a major space-weather problem. The goal of this project is to model the propagation of radio waves through simulated ionospheric irregularities with the objective of learning how to mitigate these effects. Specifically, this research will perform massively parallel simulations of plasma density irregularities generated by the high latitude gradient-drift instability (GDI). The output of these simulations will then be used in another set of high-resolution simulations to obtain quantitative information about how radio waves propagate and scintillate through a disturbed ionosphere. These modeled impacts will then be compared to observations, both previously archived and those generated by other members of the Focused Science Team. In order to reduce the effects of scintillation we will analyze the high latitude irregularity spectra driven by the GDI, and examine the relationship between scintillation at various frequencies.
Methodology: The main product of this research is to develop and validate a massively parallel Finite Difference Time Domain (FDTD) simulation for propagating radio waves through a turbulent plasma. The FDTD method simulates realistic wave forms and will enable a study of the scintillation effects on different transmitted frequencies with realistic bandwidths. The inputs for the FDTD simulation will be density perturbations from kinetic and hybrid GDI simulations using the Electrostatic Parallel Particle-in-Cell (EPPIC) code. EPPIC is a robust, mature simulator that has been used extensively to study the nonlinear evolution of electrostatic instabilities, including the GDI and Farley-Buneman instabilities. Recently a 2D hybrid version of EPPIC simulated the secondary Farley-Buneman instability occurring within a larger gradient drift instability. This research will develop a 3D solver for the hybrid version of EPPIC, allowing it to simulate the evolution of the plasma along the vertical magnetic field direction. The coupled FDTD and EPPIC code will provide a unique and realistic simulation of radio and microwave propagation and scintillation through the high latitude GDI in both the E and F regions. The FDTD simulation will calculate scintillation indices, allowing for comparisons to ground based data and other model outputs.

Relevance to NASA Objectives: The FDTD simulations will enable quantitative modeling of radio wave propagation at a range of frequencies, directly addressing the objective to identify the relationship between scintillation at various frequencies. The FDTD code will also be designed to couple with other plasma simulation models to investigate scintillation from other instabilities. The hybrid simulations in this research will improve the community s understanding of the gradient-drift instability at the smallest relevant scales, where current measurements of the irregularity spectra are difficult to make. The hybrid simulations combined with a theoretical analysis will help to determine the growth rates, spectral characteristics, and nonlinear evolution of the GDI and its role in scintillation, as well as to help identify the instability mechanisms responsible for polar F-region irregularities. The gradient-drift instability is inherently a space weather effect, so studying the scintillation it causes directly advances the NASA Living with a Star objective to obtain scientific knowledge relevant to mitigation or accommodation of undesirable effects of space weather effects on humans and human technology on the ground and in space.

Gareth Perry/New Jersey Institute Of Technology
Characteristics of High Frequency Radio Propagation and Scintillation in the Polar-Cap Ionosphere

The topic of the proposed work is ionospheric scintillation in the polar-cap ionosphere, more specifically, scintillation measured in the high frequency (HF; 3-30 MHz) portion of the radio spectrum. The overarching objective of the is to advance our understanding of ionospheric scintillation in the northern polar-cap ionosphere through the analysis of radio science data from an HF receiver in low Earth orbit, and modeling studies. The proposed work is guided by three science questions: do diffractive effects contribute significantly to HF scintillation in the polar cap; what geophysical phenomena are responsible for HF scintillation; and, what is the relationship between HF scintillation and radar scattering in the polar-cap ionosphere?

To accomplish this, we will analyze 7 years of spaceborne HF receiver measurements (over 350) of well known and characterized HF radar systems located in the high-latitude region for signatures of ionospheric scintillation. Ionospheric and HF ray trace modeling will be used to synthesize magnetoionic, instrumental, and other expected contributors of fluctuations in amplitude and phase measured by the receive, to help identify scintillation contributions from refractive and diffractive effects created by ionospheric irregularities. The modeling will incorporate data sets from other geospace sensors, including incoherent and coherent scatter radar systems, to help constrain and validate the modelling work and interpret the HF receiver data. Ionospheric scintillation signatures caused by refraction and diffraction will be identified and correlated with the occurrence of geophysical phenomena in the region, such as large scale plasma density irregularities and particle precipitation, as well as regional geomagnetic conditions to identify scintillation generation mechanisms and sources.

The HF receiver measurements at the heart of this work are unique in that provide signal amplitude, phase, and polarization parameters of the received signal in the polar cap at a sub-second temporal resolution - a capability that is virtually unprecedented in polar-cap radio science. As such, the proposed work has the potential to dramatically transform our knowledge of ionospheric scintillation and plasma dynamics in the region by providing the necessary data and analysis that can be used to advance modeling and other theoretical work targeting the complex plasma processes generating plasma density irregularities and scintillation in the region.

The proposed work is timely and directly responds to the Heliophysics LWS solicitation. It will undertake "modeling and validation of ionospheric irregularities and scintillation" (FST # 1). Its objectives and science questions address each of the combined objectives of the 2014 Science Plan and the 2013 National Research Council Decadal Strategy for Solar and Space Physics report, outlined on page B.1-1 of the NASA ROSES 2020 document. The work will provide the critical information required to study and characterize the ionospheric scintillation in the space environment; advance the understanding of the connection between these phenomena and its space weather drivers; and produce results from which scintillation detection and forecasting methodologies can be developed to mitigate their negative effects.

Weichao Tu/West Virginia University
Quantifying the Global Precipitation of Energetic Electrons and Its Relative Contribution to Radiation Belt Dropout

Energetic 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? Radiation belt electrons can be lost either by transport across the magnetopause into interplanetary space or by precipitation into the atmosphere. Therefore, quantifying the precipitation loss of energetic electrons and its relative contribution to fast radiation belt dropout is one of the most compelling science objectives in radiation belt studies. However, the global picture of precipitation has not been quantified at high spatial and temporal resolution due to the lack of physical models that directly simulate the precipitating electrons observed at low altitude. Furthermore, the relative importance of precipitation to radiation belt dropout is not yet understood due to the lack of models that link low-altitude precipitation with high-altitude electron dropout.

Here, we propose to use the newly developed Drift-Diffusion model, which includes the effects of pitch angle diffusion, azimuthal drift, and atmospheric backscatter, to simulate the distributions of drift-loss-cone (DLC) and bounce-loss-cone (BLC) electrons observed by multiple NOAA/POES satellites at low altitude during selected dropout events. The model will quantify electron precipitation over all longitudes with high temporal and spatial resolution. Physical forms of pitch angle diffusion coefficients derived from quasi-linear theory of wave-particle interactions will be used in the model to resolve the waves that are responsible for pitch angle diffusion and the magnetic local time and L distribution of the waves. The derived wave intensity will be further compared with wave data from Van Allen Probes to seek direct evidence of wave-particle interactions. Additionally, since the DLC and BLC electrons at low altitude show distinct longitude distribution at different levels of pitch angle diffusion, we will develop a new proxy model for precipitation based on easily calculated characteristic indices of the count rate vs. longitude distribution observed by POES satellites. The proxy model will be validated against detailed event simulations and serve as an efficient method to quantify the precipitation of radiation belt electrons. Finally, the predicted electron loss at high altitude due to precipitation from our model will be compared with the observed electron dropout by Van Allen Probes to quantify the relative contribution of precipitation to the overall loss. This will be done both in event studies using the Drift-Diffusion model and statistically using the proxy model, to resolve the relative importance of precipitation to radiation belt dropout at various electron energies, locations, and geomagnetic conditions.

To sum, we will address the following compelling science objectives:

" Quantify the global picture of energetic electron precipitation with high temporal and spatial resolution and resolve the wave-particle interaction processes that are responsible for the observed precipitation;

" Develop a new proxy model for precipitation based on the longitude distribution of electron count rates observed at low altitude;

" Resolve the relative contribution of precipitation to observed radiation belt dropout at various electron energies, locations, and geomagnetic conditions.

These objectives are highly relevant to the 2nd science objective of the FST that is Improved understanding and ability to predict the radiation loss processes are impacted by non-adiabatic dropout event . The proposed work also directly addresses two types of investigations targeted by the FST, which are Quantifying the relative roles played by precipitation into the atmosphere versus non-adiabatic loss processes and Modeling non-adiabatic radiation belt drop-out events to understand the underlying physical processes .

Wenbin Wang/University Corporation for Atmospheric Research
Solar Driven Upper Atmosphere Climatology Under the Influence of the Secular Change of Earth s Magnetic Field and Anthropogenic Forcing

The Earth s upper atmosphere is governed by solar inputs via complicated chemical and physical processes. Variations in solar radiation and geomagnetic activity are coupled with Earth s internal processes to shape the upper atmosphere climate and its variability. These processes include, in particular, the increasing anthropogenic greenhouse gas concentrations that impact the upper atmosphere thermal structure and the secular changes of the Earth s magnetic field that is expected to regulate ion-neutral coupling and the redistribution of energy and momentum both locally and globally. These processes are especially important on time scales from the 27-day solar rotation, season to solar cycle and beyond. However, the physical processes by which anthropogenic forcing and secular magnetic field change affect the solar-driven upper atmospheric climate, and the quantitative extent of these effects, have not been adequately studied and fully understood. It is not clear how much the changing greenhouse gas concentrations and the magnetic field impact the solar-driven upper atmospheric climate, and very importantly, how they impact the way that solar energy input governs the upper atmosphere climate Here we propose to study how solar and magnetic activity determine the upper atmospheric climatology in the presence of the changing greenhouse gas concentrations and magnetic field. Specifically, we propose to undertake following studies:
1) How is the solar driven upper atmospheric climate modulated by the secular change of Earth s magnetic field, regionally and globally?
2) How is the solar driven upper atmospheric climate modulated by the increasing anthropogenic greenhouse gas concentrations?
3) How do solar activity, and the secular changes of the Earth s magnetic field and greenhouse gas concentrations contribute to upper atmosphere climate separately and collectively?
4) How deep do the atmospheric climate effects of solar-terrestrial magnetic forcing penetrate to the mesosphere?
Diagnostic analysis of model simulations and model-data comparison will be performed to address these questions and obtain new insight into solar driven upper atmosphere climate and its change. The model used is the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X), which treats the Earth s atmosphere as an integrated system. WACCM-X can simulate upper atmospheric energetics and dynamics driven by solar and magnetic activity, taking into account anthropogenic greenhouse forcing and magnetic field change. We will analyze long-term space and ground-based data in this work. These data include: thermosphere composition from TIMED/GUVI, mesosphere temperature from TIMED/SABER, ionospheric peak density from ionosondes, plasma density and temperature from incoherent scatter radars. Data uncertainty will be assessed and analyzed. Model-data comparisons and ensemble model runs will be performed to assess and characterize model uncertainty.

This proposed work is highly supportive of the LWS Program goal by providing an understanding of the solar-climate system with realistic Earth s internal forcing. It is directly relevant to the 2020 LWS FST #4 Long Term Variability and Predictability of the Sun-Climate System . The proposed study also addresses science goals of the Heliophysics Decadal Survey, such as to Determine the dynamics and coupling of Earth s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs .

Our project will characterizes the upper atmospheric climate determined by solar and geomagnetic activity and gain new insight into the dynamics and chemical processes through which the anthropogenic forcing and magnetic field secular change affect this climate. The data collected, model simulations and diagnostic analysis results will be made available to other team members. We will also run the model for team-identified events as part of the team efforts.

Dong Wu/NASA Goddard Space Flight Center
Investigations of the solar cycle variations in D/E-region electron density

The objective of the proposed study is to develop an accurate representation of electron density (Ne) and variability in the D/E-region from the Global Navigation Satellite System (GNSS) Radio Occultation (RO) observations, so as to better understand its roles in atmospheric ozone loss and global electric circuit. We will characterize the Ne uncertainty through validations against other data sets. We will develop empirical Ne models as a function of latitude, height and local time, as well as a parameterized function with solar forcing and magnetic activity proxies. We will study and evaluate the connection between the polar nitric oxide (NO), ozone (O3) and Ne from auroral and radiation belt electron precipitation, to quantify the role and potential contribution of Ne in NO enhancement and O3 reduction. The improved understanding and characterization of the D/E-region Ne will yield an important contribution to 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 .

The proposed study responds directly to FST #4: Long Term Variability and Predictability of the Sun-Climate System, in particular, impacts of solar variability and solar-driven geomagnetic variability on atmospheric composition (i.e., NO, O3). As a primary goal, the proposed investigation will address the hypothesized process that polar auroral and radiation belt electron precipitation would enhance HOx and NOx concentration and cause more ozone loss. Atmospheric ozone is an important climate variable. However, it remains uncertain about the extent to which polar auroral and radiation belt electron precipitation may affect the ozone chemistry through additional HOx and NOx production. The short-lived HOx tends to produce direct and localized effects on the ozone loss, while the long-lived NOx can be transported down to the stratosphere producing indirect effects on the ozone loss. Our investigation will provide a key observational constraint to the modeled concentrations of polar electron precipitation and quantify its impacts on NO and O3 variations.

The secondary goal of the proposed study will address an electrical coupling process of the Sun-climate system by characterizing global D/E-region Ne and variability for the upper boundary potential of the global electric circuit (GEC) system. This has an important implication on how effectively the electrified clouds in the troposphere can couple to the ionosphere under GEC. Thunderstorms and electrified clouds are the GEC driver that maintains a potential difference between the ground and the lower ionosphere, and the lower-ionospheric conductivity is directly affected by the distribution and variations of the D/E-region Ne. Our investigation will characterize the D/E-region Ne (i.e., the GEC upper boundary potential) with unprecedented spatiotemporal coverage and greatly reduce the current uncertainties about electron concentration and variations in the lower ionosphere. The proposed development of Ne empirical models will serve as a valuable tool to validate model inputs and improve model predictability.

The schedule and milestones reflect key project accomplishments. In addition to the peer-reviewed papers planned at these milestones, we will make the validated D/E-region Ne data available to the science community, as well as the associated empirical models developed from this project. The proposed project activities will include algorithm development and improvement (Year 1), characterization of Ne morphology and variations (Years 1-2), Ne validation (Years 2-3), development of Ne empirical models (Years 2-3), and investigations of Ne connections to NO and O3 variations (Years 3-4).

Zhiyang Xia/University Of Texas, Dallas
Investigating the contribution of microbursts to radiation belt losses

Chorus waves have been suspected for some time now to be the dominant cause of relativistic microbursts, which represent an important source of electron loss from the outer radiation belt. Due to a prior scarcity of temporally- and spatially-connected observations of the waves causing the scattering (in the magnetosphere) and the resulting precipitation (observable at low Earth orbit), details of the scattering process are largely unknown. To address this scarcity, in recent years the FIREBIRD CubeSat and Van Allen Probes Electric Fields and Waves teams have worked closely to produce a novel conjunction dataset that now consists of more than 150 days of conjunctions with >100 hours of simultaneous high time resolution burst waveform and high time and energy resolution electron flux measurements. This combined dataset is the first of its kind that will allow a strongly constrained intercomparison of the microburst creation process. Because the scattering likely occurs away from the chorus observations, available conjunction observations alone are unable to fully characterize this scattering process. We will fill this observational gap by applying our recently developed sophisticated chorus wave model and test particle simulation tool to the conjunction dataset. Specifically, we will achieve the following objectives:

O1. Characterization of the observed microbursts and their association with chorus wave properties.

O2. Investigation of the dependence of microbursts on the properties of chorus waves and the properties of ambient thermal and suprathermal plasmas.
O3. Assessment of how well the chorus waves can account for the microbursts during conjugation events.
O4. Parameterization of electron precipitation loss due to chorus waves.

For O1, we will go through the established dataset of FIREBIRD/Van Allen Probes conjunctions to identify the events containing chorus waves and without other potential waves around, and to determine microburst and chorus wave properties for these events. We will sort peak flux and duration as a function of energy. The obtained chorus wave properties and microburst properties will be compared to see any observable dependence.

For O2, we will use the established ray-tracing chorus model and test particle simulation to examine the dependence of microburst creation. We will simulate electron precipitation as a function of energy and time by varying chorus wave parameters and by varying chorus source location and plasma density. We will investigate the effect of these parameters by varying each parameter while holding the others fixed.

For O3, we will select a few of the closest conjunctions of chorus/microbursts to run event-specific modeling. For each event, we will extract the observed chorus properties from Van Allen Probes data and microburst precipitation from FIREBIRD data. Observed chorus properties will be input to our ray-tracing simulation to constrain model chorus sources. The obtained precipitation flux from the test particle simulation in the modeled chorus waves will be compared directly against FIREBIRD data.

For O4, we will obtain chorus wave statistic properties parameterized by Kp, L, and MLT, and perform test particle simulation to simulate microbursts for statistic properties of chorus waves. We will build and publish a parameterization of precipitation loss time scale due to chorus waves as a function of L, MLT and Kp, and work with FST team to implement this effect.

This research is relevant to the overall objective of Van Allen Probes mission, Goal #2 of the Heliospheric Decadal Survey, and Objective H2 of the 2009-2030 Heliophysics roadmap. This proposed research of discovering electron losses due to microbursts directly contributes to FST #2 Understanding and Predicting Radiation Belt Loss in the Coupled Magnetosphere .

Matthew Zettergren/Embry-Riddle Aeronautical University
Contributions of auroral electron precipitation and plasma fluid instabilities to the formation of high-latitude ionospheric density structures and scintillation.

Intermediate scale ionospheric density irregularities can lead to fluctuations in amplitude and phase, i.e. scintillation, of trans-ionospheric radio signals, potentially resulting in degradation of GPS accuracy, scattering of HF radio signals, and other effects.

Scintillation is common in high-latitude regions including the cusps, where it has been associated with flow shears and density gradients, and the polar cap, where it has been associated with high-density plasma patches. Background inhomogeneities in the plasma in these regions (strong gradients and flow shears) have led to identification of ionospheric gradient-drift and Kelvin-Helmholtz instability as processes involved in irregularity generation. By contrast, scintillation in the auroral zone is often associated with visible auroral arc structures, suggesting an important role for energetic electron precipitation along with density gradients and complicated flow structures. Due to a confluence of many different processes that could, in principle, contribute to irregularity generation, processes leading to auroral scintillation events are relatively poorly understood compared to their cusp and polar cap counterparts.

The proposed work plans to investigate the role of electron precipitation in producing auroral scintillation by addressing a single top-level science question concerning specific physical mechanisms which lead to scintillation, and the conditions under which auroral scintillation occurs: (SQ) What are the features of density structuring and scintillation produced by electron precipitation (a) directly via impact ionization and (b) indirectly through seeding of ionospheric fluid instabilities triggered from inhomogeneous background conditions?

Comprehensive modeling and data analysis efforts for this project will leverage ionospheric and radio propagation models combined with in situ and remote sensing data from Poker Flat, Alaska. Our ionospheric model, GEMINI, self-consistently describes effects of electron precipitation (i.e. impact ionization, heating, and optical emissions), and fluid-electrodynamic processes responsible for plasma interchange instabilities. GEMINI is coupled to a radio propagation model, SIGMA, to simulate scintillation from a modeled field of density irregularities - creating a full physics based pathway for simulating synthetic scintillation data from hypothetical auroral configurations. These models will be used for physics-based investigations of density irregularities and attendant scintillation produced by precipitation directly (structured impact ionization) and indirectly (seeding of instabilities). High-rate fluctuation data (50 Hz) from the SAGA L-band array at PFRR will be used to directly monitor scintillation during auroral events. Conjunctions between SAGA and other data sources will establish connections between different plasma state parameters and suggest physical mechanisms responsible for structures. Swarm fine-scale measurements of density and drift above the ionosphere, will characterize irregularities and seed structures, while the background state of the ionosphere will be monitored via the Poker Flat Incoherent Scatter Radar. Finally, precipitation will be monitored via inversion of filtered allsky camera measurements which will provide images of structured precipitating electron flux and energy. Data analysis activities will both serve to provide much-improved characterizations of auroral scintillation and to guide selection of parameters for modeling hypotheticals and case studies.

This project directly addresses FST 1 in the B.5 solicitation concerning modeling and validation of irregularities and scintillation and is relevant to LWS program goals 2 and 3 and Heliophysics Decadal survey key science goal 2. The likely role of this project within the FST group is to provide theoretical guidance on sources of auroral small--scale density struc-tures and their connection with scintillation.

Shun-Rong Zhang/Massachusetts Institute of Technology
The Influence of Traveling Ionospheric Disturbances on Ionospheric Irregularities

This project will study traveling ionospheric disturbances (TIDs) and their connection to ionospheric irregularities. Ionospheric irregularities are small-scale plasma density structures that exist nearly universally in the Earth's upper atmosphere and which exhibit diverse characteristics. They are believed to be initiated through plasma nonlinear instability processes. Frontier community topics of relevance include how, where, when, and exactly which instabilities are in action for a given condition. Furthermore, TIDs are, very much like irregularities, a ubiquitous and permanent feature of ionospheric variability. Depending on spatial scale and propagation properties, TIDs are excited by forcing from high latitudes and from below. A joint TID and irregularity relationship has been reported in the literature, but there still exists a lack of comprehensive knowledge to establish a connection between conditions for TID excitation, TID propagation, and irregularity onset. We will address some of these fundamental irregularity questions from a TID perspective:,

Q1.1. What is the global climatology and variability of the medium-scale TID (MSTID) activity during quiet times?

Q1.2. What climatological features are common to global MSTIDs and specific irregularities? Can this information be used to gauge irregularity behavior through global TID monitoring?

Q2. What physical mechanisms drive storm-time MSTID excitation at subauroral and mid- latitudes? Do these MSTIDs and associated instabilities trigger plasma irregularities at lower latitudes?

Q3. What are the characteristics of bubble-like ionospheric super-depletion structures observed at mid- and low latitudes during storms? Are they locally generated irregularities under MSTID influences, part of the poleward extension of an equatorial bubble, or an inherent plasmasphere structure?

This project will analyze satellite in situ and ground-based ionospheric remote sensing data. It involves significant statistical work for MSTID global climatology and irregularity characteristics (Q1) as well as case studies (Q2-Q3) utilizing multi-datasets. These include (1) extensive GNSS TEC with global coverage, allowing TID calculation on a daily basis and statistics on a monthly basis for a solar cycle; (2) GOLD observations of nighttime ionospheric bubbles/irregularities with direct comparison to GNSS data; (3) ionosonde data at midlatitude stations (e.g., Austin, TX and Eglin AFB, FL), used to examine Spread-F occurrence at mid-latitudes during storm and quiet times; and (4) in-situ LEO Swarm and DMSP plasma irregularity observations.

Our project addresses the irregularity onset mechanisms associated with MSTIDs during both quiet and storm times, which are directly relevant to the FST goals in the understanding of "the conditions that lead to the onset and evolution of ionospheric irregularities", in particular, to "identify the mechanisms and structures that are responsible for ionospheric irregularities". We will

1- Produce an improved understanding of irregularity onset and global distribution from a MSTID perspective for both quiet and storm conditions. By elaborating MSTID roles, we will contribute to the overall FST science goal on the irregularity phenomenology and mechanisms.

2- Provide unique and comprehensive global MSTID information to the team from GNSS TEC observations. The baseline data used to calculate MSTIDs are available through the MIT Madrigal database. In addition to daily MSTID maps, we will also provide monthly statistics of MSTID global distribution.

3- Provide MSTID-irregularity analysis results and subsequent questions to modeling members of the team and will assist with theoretical understanding and model-data comparison activities.

This project is within Decadal Survey Key Science Goal 2 and LWS Strategic Science Areas SSA-IV (Variability of the Geomagnetic Environment) and SSA-VI (Localized Ionospheric Irregularities).

Andreas Zoglauer/University of California, Berkeley
Analyzing the first all-sky images of DREP events measured with COSI

Science goals and objectives:
Electron precipitation into the atmosphere can significantly drain the radiation belts during geomagnetic storms. Loss to the magnetopause may also be significant, but the relative importance of magnetopause versus atmospheric loss is so far not well quantified. Quantifying the electron loss rate is crucial for incorporating accurate loss estimates into radiation belt models. Wave-particle interactions are thought to be responsible for pitch-angle scattering of electrons into the atmospheric loss cone. Based on observations, atmospheric precipitation has been classified into at least two main types, believed to be caused by different wave-particle interactions: duskside relativistic electron precipitation (DREP) and microburst precipitation.
Both event types have been observed with the Compton spectrometer and imager. COSI is a balloon-borne Compton telescope operating in the energy range from 150 keV up to 5 MeV. In spring 2016, COSI was launched from Wanaka, New Zealand, for a 46-day flight at ~110,000 feet altitude. Its observation of DREP and microburst events marks the

first time these events have been observed with an all-sky imaging gamma-ray detector combining an angular resolution of a few degrees with millisecond time resolution, a few keV energy resolution, and the capability to measure gamma-ray polarization.
As a consequence, COSI provides the first direct images of these events and thus enables the determination of the spatial scale and structure of the precipitation along with any potential drifts of the emission region with time. This will enable a much more accurate determination of the loss rate of the electrons and ultimately help to verify or refine the radiation belt models. In addition, the knowledge of the spatial scale of the emission will give us a better understanding of the electron scattering mechanism (e.g. the efficiency of the interaction with EMIC waves). An exploratory analysis of the data of the strongest observed event (160530A) shows clear indications for spatial variability between the individual sub-peaks of the event. Finally, the COSI data will for the first time constrain the polarization levels of the gamma-ray emission. The emitted Bremsstrahlung is expected to be polarized, and therefore the observed level and angle of polarization (after taking into account polarization loss due to electron scattering in the atmosphere) can help inferring the pitch angle distribution of the precipitating electrons and distinguish between strong diffusion, weak diffusion, and non-linear scattering mechanisms.

Methodology:
The first goal of this proposal is to generate all-sky maps of the incoming gamma-ray flux (including uncertainties) as a function of energy and time at the balloon altitude, and to constrain the polarization level and angle. For the analysis we can rely on existing simulation models, responses, and analysis tools developed for the analysis of COSI s astrophysical targets. However, the tools need to be adapted to determine polarization from extended sources and then evaluated with realistic simulations.
The second goal is to evaluate existing models of how the electron precipitation is generated with the COSI results and constrain the spatial scale and the pitch angle distribution of the precipitating electrons. This will be achieved via Monte-Carlo simulations of the expected precipitation emission and the atmosphere, followed by a comparison of the simulation results and COSI observations.

Connection to the Science Objectives of the Focus Science Team efforts:
This proposal is relevant for FST #2: Understanding and predicting radiation belt loss in the coupled magnetosphere (B.5-6). By determining the spatial and temporal emission variations during electron precipitation events, it will further our understanding and the predictability of radiation belt losses in the inner atmosphere due to precipitation.