Project Details

ROSES ID: NNH13ZDA001N
Selection Year: 2013
Program Element: Targeted Science Team

Topic: Connection between Solar Interplanetary Structures and the response of Earth's radiation belts

Project Title:
Competing Pathways of Radiation Belt Response to Solar Interplanetary Structures

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Summary:
Goals and Objectives: The response of the outer radiation belt to solar interplanetary structures is notoriously unpredictable. Such unpredictability is likely due to the numerous competing pathways through which Coronal Mass Ejections (CMEs), Corotating Interaction Regions (CIRs), and other structures can influence radiation belt sources and losses. It is the overarching goal of this proposal to understand what are the factors associated with interplanetary structures that affect the radiation belts, and to understand the pathways by which those factors exert their influences. Specifically, we will focus on the following objectives:

1) Identify the features of solar interplanetary structures associated with radiation belt sources and losses, and characterize how specific solar wind structures affect the radiation belt fluxes

2) Characterize and explain the pathways through which solar interplanetary structures regulate the wave environment, by:

a. Exploring the response of the plasmasphere, which is vitally important in understanding the propagation of waves, to these structures

b. Quantifying the response of the ring current electrons and ions, which provide the free energy for many of the important waves in the inner magnetosphere.

c. Characterizing how the magnetospheric composition changes in response to solar interplanetary structures. Knowledge of composition is vital to understanding wave generation and propogation.

d. Understanding the resulting generation and propagation of ULF, EMIC, Chorus and other waves in the magnetosphere

3) Identify how magnetospheric boundaries change in response to interplanetary structures and the consequences for sources and losses of radiation belt fluxes.

4) Translate the impact of solar interplanetary structures on the wave-environment and magnetospheric boundaries and plasma parameters to radiation belt fluxes.

5) Explain why and when pathways of influence dominate over competing ones.

Methodology: To achieve our objectives we propose a tightly integrated and well-coordinated Targeted Science Team (TST) to carry out a four-year study. Our TST will include observational studies correlating and characterizing the detailed space-time structures of interplanetary features impinging on the Earth s magnetosphere with observations of the response of the radiation belts, global simulations (fully coupled magnetosphere, ring current, radiation belt, plasmasphere) of the magnetospheric response to these structures, and studies of wave generation and damping and the impact on radiation belt electrons. The core

numerical models to be used include resistive, anisotropic and multi-fluid versions of the BATS-R-US magnetosphere code, the Comprehensive Ring Current Model (CRCM), the Radiation Belt Environment (RBE) model, and the SAMI3 model for the plasmaphere. Data for the observational aspects of the study will be drawn from various satellites including ACE, WIND, CLUSTER, THEMIS, SAMPEX, GOES, and the recently launched Van Allen Probes.

This work is directly related to LWS strategic goal number 3 which seeks to "...deliver the understanding and modeling required for effective forecasting/specification of magnetospheric radiation and plasma environments" to mitigate the effects of space weather on valuable space based assets.

Publication References:

Summary: This study focuses on the radiation belt dropouts as a result of EMIC waves as compared to shadowing. It advances the LWS goal to understand the variation of radiation belt environment in response to solar interplanetary structures.

Reference: Kang S.-B.; Fok M.-C.; Glocer A.; Min K.-W.; Choi C.-R.; Choi E.; Hwang J.; (2016). Simulation of a rapid dropout event for highly relativistic electrons with the RBE model. Journal of Geophysical Research (Space Physics), 121, 4092-4102, doi: 10.1002/2015JA021966

- **Investigation Type:** Theory and Model Development
- **Existing theories/models/datasets which the study is based:** Modeling study is based on the CIMI code
- **Domains:** Magnetosphere

Summary: This work improves our understanding of the dayside magnetosphere-solar wind interaction, a major driver of space weather which LWS goals seek to understand, predict, and mitigate .

Reference: Glocer A.; Dorelli J.; Toth G.; Komar C. M.; Cassak P. A.; (2016). Separator reconnection at the magnetopause for predominantly northward and southward IMF: Techniques and results. Journal of Geophysical Research (Space Physics), 121, 140-156, doi: 10.1002/2015JA021417

- **Investigation Type:** Theory and Model Development
- **Existing theories/models/datasets which the study is based:** The modeling work was done with the BATSRUS code and the development of a new technique for extracting magnetic separators and nulls from 3D simulations.
- **Domains:** Magnetosphere

Summary: This study sought to understand puzzling dropouts in Van Allen Probe data. Glocer's involvement in the study was supported by this LWS project providing the modeling of the dropouts. This supports LWS goals to understand the variation of the radiation environment by looking at what causes radiation belt dropouts and moreover assess the performance of first principles models.

Reference: Dixon P.; MacDonald E. A.; Funsten H. O.; Glocer A.; Grande M.; Kletzing C.; Larsen B. A.; Reeves G.; Skoug R. M.; Spence H.; Thomsen M. F.; (2015). Multipoint observations of the open-closed field line boundary as observed by the Van Allen Probes and geostationary satellites during the 14 November 2012 geomagnetic storm. Journal of Geophysical Research (Space Physics), 120, 6596-6613, doi: 10.1002/2014JA020883

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** BATSRUS, CIMI
- **Datasources:** Van Allen Probes:RBSPICE

Summary: This work looks at the interplay of energy between the ionosphere and magnetosphere in the region of the diffuse aurora. This has impact for conductances and circulation in the magnetosphere and thus advances the LWS goal to improve first principles predictive capabilities.

Reference: Khazanov G. V.; Tripathi A. K.; Singhal R. P.; Himwich E. W.; Glocer A.; Sibeck D. G.; (2015). Superthermal electron magnetosphere-ionosphere coupling in the diffuse aurora in the presence of ECH waves. Journal of Geophysical Research (Space Physics), 120, 445-459, doi: 10.1002/2014JA020641

- **Investigation Type:** Simulations
- **Domains:** Magnetosphere Ionosphere
- **Model Types:** Kinetic

Summary: The development of a new model of the radiation environment of near-Earth space (CIMI) advances the LWS goal to support the development of first principles models of the space weather environment.

Reference: Fok M.-C.; Buzulukova N. Y.; Chen S.-H.; Glocer A.; Nagai T.; Valek P.; Perez J. D.; (2014). The Comprehensive Inner Magnetosphere-Ionosphere Model. Journal of Geophysical Research (Space Physics), 119, 7522-7540, doi: 10.1002/2014JA020239

- **Investigation Type:** Theory and Model Development
- **Existing theories/models/datasets which the study is based:** This paper describes the development of the Comprehensive Inner Magnetosphere Ionosphere (CIMI) model.
- **Domains:** Magnetosphere

Summary: This work looks at the interplay of energy between the ionosphere and magnetosphere in the region of the diffuse aurora. This has impact for conductance and circulation in the magnetosphere and thus advances the LWS goal to improve first principles predictive capabilities.

Reference: Khazanov G. V.; Glocer A.; Himwich E. W.; (2014). Magnetosphere-ionosphere energy interchange in the electron diffuse aurora. Journal of Geophysical Research (Space Physics), 119, 171-184, doi: 10.1002/2013JA019325

- **Investigation Type:** Simulations
- **Domains:** Magnetosphere Ionosphere
- **Model Types:** Kinetic

Summary: Plasmasphere response and refilling is a critical aspect of radiation belt dynamics as it affect the wave environment. This study therefore addresses the LWS objective to characterize the radiation environment.

Reference: Denton M. H.; Borovsky J. E.; (2014). Observations and modeling of magnetic flux tube refilling of the plasmasphere at geosynchronous orbit. Journal of Geophysical Research (Space Physics), 119, 9246-9255, doi: 10.1002/2014JA020491

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** SUPIM
- **Datasources:** LANL:MPA

Summary: A major goal of the LWS program is to deliver the understanding and modeling required for effective forecasting specification of magnetospheric radiation and plasma environments. This research does exactly this by developing a new neural network model of the plasmasphere as a specific example of a more generic predictive approach. The plasmasphere is an important mediator of the radiation belt environment and predicting its variation is important to delivering on the goal of effective forecasting specification.

Reference: Bortnik J.; Li W.; Thorne R. M.; Angelopoulos V.; (2016). A unified approach to inner magnetospheric state prediction. Journal of Geophysical Research (Space Physics), 121, 2423-2430, doi: 10.1002/2015JA021733

- **Investigation Type:** Theory and Model Development
- **Existing theories/models/datasets which the study is based:** A new neural network model for inner magnetosphere plasma specification.
- **Domains:** Magnetosphere

Summary: This reserach advances the goal to deliver the understanding and modeling required for effective forecasting specification of magnetospheric radiation and plasma environments. It does this by using superposed epoch analysis to look at the response of the radiation belt to solar wind structures. This type of analysis improves our knowledge of radiation belt dynamics and drivers of source and loss.

Reference: Li W.; Thorne R. M.; Bortnik J.; Baker D. N.; Reeves G. D.; Kanekal S. G.; Spence H. E.; Green J. C.; (2015). Solar wind conditions leading to efficient radiation belt electron acceleration: A superposed epoch analysis. Geophysics Research Letters, 42, 6906-6915, doi: 10.1002/2015GL065342

- **Investigation Type:** Data Analysis
- **Data Sources:** Van Allen Probes:ECT Van Allen Probes:EMFISIS Van Allen Probes:EFW Van Allen Probes:RBSPICE Van Allen Probes:RPS

Summary: Sources and losses of radiation belt electrons are critical to understanding the evolution of trapped radiation belt electrons. As such, understanding pitch angle scattering of electrons via EMIC waves is important to being able to predict the variation of the radiation belt environment. This work therefore advances the LWS goal to deliver the understanding and modeling required for effective forecasting specification of magnetospheric radiation and plasma environments.

Reference: Ni B.; Cao X.; Zou Z.; Zhou C.; Gu X.; Bortnik J.; Zhang J.; Fu S.; Zhao Z.; Shi R.; Xie L.; (2015). Resonant scattering of outer zone relativistic electrons by multiband EMIC waves and resultant electron loss time scales. Journal of Geophysical Research (Space Physics), 120, 7357-7373, doi: 10.1002/2015JA021466

- **Investigation Type:** Theory and Model Development
- **Existing theories/models/datasets which the study is based:** EMIC wave induced pitch angle scattering of trapped radiation belt electrons.
- **Domains:** Magnetosphere

Summary: This work addresses the formation of butterfly distributions in response do to interactions with magnetosonic waves. Understanding the evolution of the electron populations in the radiation belts is critical to understanding the radiation environment in the inner magnetosphere. As wave-particle interactions are critical to this evolution, this work goes towards advancing our basic understanding needed to make better space weather predictions. Thus the work advances the LWS goal to deliver the understanding and modeling required for effective forecasting specification of magnetospheric radiation and plasma. environments.

Reference: Li J.; Ni B.; Ma Q.; Xie L.; Pu Z.; Fu S.; Thorne R. M.; Bortnik J.; Chen L.; Li W.; Baker D. N.; Kletzing C. A.; Kurth W. S.; Hospodarsky G. B.; Fennell J. F.; Reeves G. D.; Spence H. E.; Funsten H. O.; Summers D.; (2016). Formation of energetic electron butterfly distributions by magnetosonic waves via Landau resonance. Geophysics Research Letters, 43, 3009-3016, doi: 10.1002/2016GL067853

- **Investigation Type:** Simulations
- **Domains:** Magnetosphere
- **Model Types:** Kinetic

Summary: Understanding the dayside solar wind-magnetosphere interaction is a major issue in improving our understanding and space weather.

Reference: Borovsky J. E.; Denton M. H.; (2016). Compressional perturbations of the dayside magnetosphere during high-speed-stream-driven geomagnetic storms. Journal of Geophysical Research (Space Physics), 121, 4569-4589, doi: 10.1002/2015JA022136

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** LFM
- **Datasources:** GOES:X-RAY LANL:MPA

Summary: Characterizing the upstream solar wind conditions into meaningful categories is essential to determining the response of the radiation environment, and ultimately the space weather hazard, to the solar interplanetary structures.

Reference: Xu F.; Borovsky J. E.; (2015). A new four-plasma categorization scheme for the solar wind. Journal of Geophysical Research (Space Physics), 120, 70-100, doi: 10.1002/2014JA020412

- **Investigation Type:** Theory and Model Development
- **Existing theories/models/datasets which the study is based:** 1963–2013 OMNI2 data set spanning four solar cycles and to the 1998–2008 ACE data set.
- **Domains:** Interplanetary space or solar wind

Summary: This work examines how the radiation belt environment evolves in response to high speed streams. This advances the LWS goal to provide a detailed characterization of radiation environments.

Reference: Borovsky J. E.; Cayton T. E.; Denton M. H.; Belian R. D.; Christensen R. A.; Ingraham J. C.; (2016). The proton and electron radiation belts at geosynchronous orbit: Statistics and behavior during high-speed stream-driven storms. Journal of Geophysical Research (Space Physics), 121, 5449-5488, doi: 10.1002/2016JA022520

- **Investigation Type:** Data Analysis
- **Data Sources:** SDO:HMI SDO:HMI SDO:HMI

Summary: Understanding the energy conversion at the dayside magnetopause and its potential impact geoeffectiveness

Reference: Cassak P. A; Genestreti K. J.; Burch J. L; Phan T.-D.; Shay M. A.; Swisdak M.; Drake J. F.; Price L.; Eriksson S.; Ergun R. E; Anderson B. J.; Merkin V. G.; Komar C. M.; (undefined). The Effect of a Guide Field on Local Energy Conversion During Asymmetric Magnetic Reconnection: Particle-in-Cell Simulations. Journal of Geophysical Research: Space Physics, n/a--n/a, doi: 10.1002/2017JA024555

- **Investigation Type:** Data Model Comparison
- **Names of models being tested or validated:** BATS-R-US
- **Datasources:** MMS:EIS AMPERE:IONOSPHERIC POTENTIAL

Summary: Capturing the drift-resonant response of electrons in the Inner Magnetosphere. Important for understanding the dynamics of the Earth's radiation belts.

Reference: Komar C. M.; Glocer A.; Hartinger M. D.; Murphy K. R.; Fok M.-C.; Kang S.-B.; (undefined). Electron Drift Resonance in the MHD-Coupled Comprehensive Inner Magnetosphere-Ionosphere Model. Journal of Geophysical Research: Space Physics, n/a--n/a, doi: 10.1002/2017JA024163

- **Investigation Type:** Simulations
- **Domains:** Magnetosphere
- **Model Types:** Kinetic Physics-based MHD