Project Details

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Selection Year: 2021
Program Element: Strategic Capability

Topic: A global model of the magnetosphere

Project Title:
Beyond MHD: Flexible fluid-kinetic global geospace model

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Summary:
The objective of the proposed work is to develop a new capability that will enable new investigations aimed at answering a fundamental and yet so far unanswered question:
What is the role of microscopic/kinetic effects on the large-scale dynamics of the Earth's magnetosphere?
In general, the new capability will enable investigations of many pressing questions in magnetospheric science. Specifically, we target questions centered around the physics of magnetic reconnection onset in the magnetotail, which is essential for better understanding and modeling of magnetospheric substorms, some of the most energetic phenomena that are key to space weather science. With minimal modifications, our new capability will also enable significant progress on understanding the processes controlling dayside solar wind/magnetosphere coupling.

The Earth's magnetosphere is a complex system comprising diverse particle populations interacting via processes characterized by several orders of magnitudes in scale separation between the kinetic and system scales. Despite remarkable progress over the past decade, all existing methods that attempt to go beyond a magnetohydrodynamics (MHD) description of the magnetosphere have significant limitations. The method proposed here promises to overcome the limitations of existing approaches by coupling a highly-accurate modeling framework built on MHD and leveraging decades of development, GAMERA, with a unique approach to solve the kinetic equations, called SPS, by means of a spectral expansion. The project involves including anisotropic pressure and Hall MHD physics in GAMERA, developing improved preconditioning and adaptive capabilities in SPS, and developing a coupled GAMERA-SPS framework that will be delivered to the Community Coordinated Modeling Center. Several verification and validation efforts will document the accuracy and efficiency of the new algorithm and its ability to reproduce observational data.

The proposal is strongly aligned with the solicitation and incorporates many of the requested Targeted Objectives. It achieves 'Improved modeling of reconnection and electron scale physics in general' by embedding the SPS kinetic solver into the large-scale global MHD model GAMERA. It develops 'Inclusion of Hall MHD physics' in GAMERA. It uses 'New approaches to solving the Vlasov-Maxwell equations such as moment expansion or spectral transform methods' and achieves 'Improvements to computational stability and efficiency, novel approaches to reduce computation demand without impacting the physics' through the SPS spectral approach that allows one to dial-up kinetic physics as necessary and hence reduce the computational load relative to a fully kinetic approach. It also performs 'Extensive validation of codes   metrics on code diffusivity, energy and momentum conservation, accuracy in solving equations, deviation from pure MHD, etc'. The proposal is also strongly aligned with the overall NASA Heliophysics Science Objectives. By developing new capabilities that include kinetic/microscopic physics in large-scale magnetospheric modeling, we enable investigations that 'Explore and characterize the physical processes in the space environment from the Sun to the heliopause and throughout the universe', 'Advance our understanding of the connections between solar variability and Earth and planetary space environments' and support 'Develop the knowledge and capability to detect and predict extreme conditions in space to protect life and society and to safeguard human and robotic explorers beyond Earth'.

Publication References:

no references