Living With A Star TR&T NASA/NSF Partnership for Collaborative Space Weather Modeling
Abstracts of selected proposals
(NNH11ZDA001N-LWSCSW)

Below are the abstracts of proposals selected for funding for the Living With A Star TR&T NASA/NSF Partnership for Collaborative Space Weather Modeling program. Principal Investigator (PI) name, institution, and proposal title are also included. Fifty-one (51) proposals were received in response to this opportunity. On February 22, 2013, 8 proposals were selected for funding.

Spiro Antiochos/NASA Goddard Space Flight Center
A Modular Capability for Community Modeling of Flares, CMEs and their Interplanetary Impacts

NASA Goddard Space Flight Center and the University of Michigan propose a collaborative research program that attacks one of the most important problems in space weather: understanding the giant explosions of solar magnetic field and plasma known as eruptive flares/coronal mass ejections (CMEs). Our strategy is to develop a second-generation Strategic Capability that will enable both our Team and, more importantly, the outside community to test theories of solar eruptions against observed events, and to work towards a predictive capability. The distinguishing feature of our program is that it is modeled after a NASA instrument or NSF facility program in that it will enable the whole community to attack the solar eruptions problem with state-of-art modeling and analysis, just as NASA space and NSF ground-based instruments provide the community with state-of-art observations. As with a hardware program, we will use the Capability to perform a Team science program, but the bulk of the science results ultimately will be obtained by the outside community. Furthermore, our science modeling capability will serve as a prototype for the eventual development of first-principles based operational tools.

The Capability that we will build, the Modular Solar Eruptions Capability (MSEC), is a bold but logical next step in the NASA/NSF Strategic Capability Program. MSEC will consist of a set of interchangeable modules and libraries, including a Training Library, that will enable the user to model a complete solar eruption event, from energy buildup by flux emergence to space weather impact at Earth. All the MSEC components will be delivered to the CCMC and the source code will be made publicly available. We will use MSEC to attack the four central problems in the science of solar eruptions: (1) energy buildup and eruption onset, (2) explosive energy release, (3) the nature of fast coronal reconnection, and (4) Heliospheric impacts.

The proposing team consists of internationally recognized experts in basic solar/heliospheric theory, in the modeling and data analysis of observed events, and in computational physics. The proposed work builds on our recent advances in understanding the physics of flares and CMEs and in modeling space weather. Our team has developed some of the leading theories for solar activity and has delivered some of the most widely used space weather models to the CCMC.

In addition, the proposed collaboration builds on and greatly strengthens the long partnership between NASA/GSFC and U Michigan. It will provide the opportunity for students of U Michigan to work with leading NASA scientists and have access to the unique resources at GSFC, a national facility.

Amitava Bhattacharjee/University of New Hampshire

Integration of Extended MHD and Kinetic Effects in Global Magnetosphere Models

The primary science focus of the proposed Strategic Capability (SC) is the integration of extended magnetohydrodynamics (XMHD) and kinetic effects in global models. While our application is geared to the Earth s magnetosphere where, thanks to in situ observations, a rich database exists for the verification and validation of the predictions of such a SC, the core science module of the model has much broader applicability, and has potentially transformative implications for our ability to understand and predict a broad range of heliospheric space weather events that involve magnetic reconnection, instabilities of current sheets, and turbulence. Over the last 15 years, there has been significant progress in our theoretical understanding of these processes in collisionless systems. It has become clear from these studies and comparison with observations that it is essential (i) to study plasma dynamics in the high-Lundquist-number regime, and (ii) to go beyond the standard framework of the resistive MHD model to include multi-fluid physics (referred to here as XMHD), including a generalized Ohms law, enhanced equations of state (EOS) for electrons and ions that incorporate kinetic effects, and multiple charged particle species. The proposed SC will be in the form of a state-of-the-art version of OpenGGCM, a traditional version of which is presently used extensively in the community and the NASA-CCMC for space weather predictions.

Intrinsic Merit: The present SC will assimilate and represent nearly 15 years of remarkable advances in our understanding of extended MHD and kinetic effects within the framework of a global magnetosphere code. These advancements have been brought about for two principal reasons: (1) sophisticated computer simulation codes that are based upon novel algorithms and software, developed in partnership with applied mathematicians and computer scientists that exploit the power of advances in high-performance computing technologies, and (2) the availability of multi-satellite observations. The present multi-institutional team of investigators have played leading roles in several of these advancements, especially in the area of magnetic reconnection and associated plasma instabilities, and have in hand a suite of mature physics-based modules, based on high-Lundquist-number MHD, Hall MHD, hybrid, multi species, and fully kinetic particle-in-cell codes, as well as a global magnetosphere code, OpenGGCM. In this SC, we address foundational issues in multi-fluid science that impact our ability to predict accurately space weather events within the context of global magnetosphere simulations, and show a pathway to use this foundational science to improve significantly the accuracy of space weather predictions.

Relevance and Broader Impact: These enhanced capabilities will enable our global magnetosphere code to accurately model the kinetic scale processes (e.g., magnetic reconnection) responsible for extreme space weather events with direct impact on human society. While our application is geared to the Earth s magnetosphere, the core science module of the model has much broader applicability, and has potentially transformative implications for our ability to understand and predict a broad range of heliospheric space weather events that involve magnetic reconnection, instabilities of current sheets, and turbulence. The team, which is a partnership between academia and national laboratories, consists of several junior scientists, postdoctoral fellows, and graduate students who will be educated in this broadly interdisciplinary subject, involving theoretical as well as experimental space plasma physics, applied mathematics, and high-performance computing. The PI as well as other institutional PI s have a strong track record of mentoring postdoctoral fellows and graduate students (including women, one of whom is identified as a leader of this project).

George Fisher/University of California
The Coronal Global Evolutionary Model (CGEM)

Coronal mass ejections (CMEs) and large solar flares produce the strongest space weather disturbances, and are driven by the release of stored magnetic energy low in the solar corona. Since the build up of coronal magnetic energy is induced by magnetic evolution at the photosphere, the ability to use observations of the evolving photospheric magnetic field to drive a time-dependent model of the coronal magnetic field has long been a goal of both NASA's Living With a Star (LWS) Program and the multi-agency National Space Weather Program (NSWP), with the aims of both understanding how CMEs and flares work and predicting such events. Here, we --- a collaborative team from UC Berkeley, Stanford, and Lockheed-Martin --- demonstrate precisely this ability, using sequences of vector magnetograms and Dopplergrams from the Helioseismic and Magnetic Imager (HMI) instrument aboard the LWS program's Solar Dynamics Observatory to drive a magnetofrictional (MF) model of the coronal magnetic field in AR 11158, which produced an X2.2 flare. During a three-day simulation run, magnetic energy in the model field increased steadily, and the model field erupted at a time in the data sequence coincident with the actual flare. We propose to implement this MF model in spherical coordinates, to enable real-time, long-term modeling of the non-potential coronal magnetic field, both globally and for active region (ARs). The model's Earth-facing hemisphere will be driven using electric fields derived from the observed evolution of photospheric line-of-sight magnetic fields and electric currents. Far-side data inputs will be from an existing flux transport code, combined with HMI far-side observations of new active regions, with empirical parametrizations of orientation and flux. Because this model includes large-scale coronal electric currents, it is a substantial improvement over existing real-time global coronal models, which assume potential fields. Data products available from the model include: 1) the evolving photospheric electric field, Poynting flux, and helicity flux; 2) estimates of coronal free energy and non-potential geometry and topology; 3) initial and time-dependent boundary conditions for MHD modeling of active regions; and 4) time-dependent boundary conditions and flux tube expansion factors for MHD and empirical solar wind models. Unstable configurations found from MF models will be dynamically evolved with local and global MHD codes. Modules used to derive surface electric fields from magnetic evolution will be incorporated into the HMI data pipeline, and data products will be distributed through the JSOC and directly to space weather forecasters and users. The electric field and MF codes will be delivered to the CCMC for science analysis and use with other models.

Intellectual Merit: By including electric currents in modeling long-term coronal evolution driven by photospheric evolution, our magnetofrictional model will improve our capability to study both how the coronal magnetic field responds to conditions at the solar surface, and how and where magnetic energy is stored in the corona.

Broader Impacts: This model will represent an improved fidelity over existing potential-field global solar models, and will result in an improved ability to model and predict space-weather events and conditions, and thereby lead to better space-weather forecasting.

Anthony Mannucci/Jet Propulsion Laboratory

Medium Range Thermosphere Ionosphere Storm Forecasts

We are on the threshold of a new era of scientific understanding of the connected Sun-Earth system, ushered in by the development of first-principles coupled models spanning the solar corona to the Earth's upper atmosphere (thermosphere and ionosphere). The community is now ready to develop a space weather forecasting system for the upper atmosphere. We propose to develop the first system to forecase storm conditions in the upper atmosphere caused by solar high speed events up to 4 days in advance. Our objectives are to:

1) Develop space weather forecasts for adverse conditions that arise in the upper atmosphere (thermosphere and ionosphere) resulting from coronal mass ejections (CMEs) and high speed streams (HSS), using the most advanced first-principles models, combined with ensemble-based forecasting methods that have proven their value in terrestrial weather forecasting;
2) Perform system science investigations using the first principles model chain from the solar corona to the Earth's upper atmosphere;
3) Deliver advanced models of the heliosphere and upper atmosphere to the Community Coordinated Model Center (CCMC) for their use in Heliophysics scientific investigations and to improve space weather forecasting; and
4) Deliver the forecast capability to the community via CCMC to establish space weather forecasting as a new science;

Our approach is to assemble an inter-disciplinary team of space physicists, modelers, applied mathematicians and numerical weather prediction experts who have the knowledge needed to create an effective forecasting system. We will use the proven ensemble forecasting method to create forecasts with uncertainties, rigorously based on careful comparisons of forecasts with measurements spanning Sun to Earth. It is widely known that attaching realistic uncertainties to forecasts is important to create useful forecasts. Upon completion of this project, the full capability of the forecasting system will be delivered to CCMC for community use.

To increase forecasting accuracy and for science investigations, we will deliver first-principles models to CCMC. The Space Weather Modeling Framework (SWMF) two-temperature heliosphere model will be upgraded with a module that tracks CME propagation. The Global Ionosphere Thermosphere Model (GITM) will be upgraded with a plasmaspheric component, and adapted to run in real-time for CCMC.

Our effort is directly aligned with Living With a Star objectives to develop first principles models as tools for science investigations and as prototypes for predictive capabilities. The inter-disciplinary nature of our team will make progress that transforms the field.

We cannot over-emphasize that new scientific results will emerge from our effort. We will use first-principles models and observations to study the Sun-to-Earth as an integrated system. The expertise of our team spans the entire physical domain from Sun to upper atmosphere. In the proposal, we outline how we will address systems science questions that are directly relevant to the LWS program. The observationalists on our team will provide the necessary measurements to conduct our scientific investigations, and also to ensure that the forecast system is rigorously calibrated against all relevant observations.

Two graduate students will be trained as part of this effort. This is an important aspect of our broader impacts, because these young individuals may forge pioneering careers in space weather and Heliophysics science.

Now is the time for an effort such as ours. The first principles models exist now, the scientific understanding is sufficiently advanced, and the need has never been greater. We are supplying the needed ingredient: an inter-disciplinary team with the necessary skills to advance Heliophysics science and create a new science of space weather forecasting.

Nagi Mansour/NASA Ames Research Center
Integrated Global-Sun Model of Magnetic Flux Emergence and Transport

The Sun lies at the center of space weather and is the source of its variability. The primary input to coronal and solar wind models is the activity of the magnetic field in the solar photosphere. We propose to develop physics-based models for the dynamics of the magnetic field from the deep convection zone of the Sun to the corona with the goal of providing robust near real-time boundary conditions at the base of space weather forecast models. The proposal addresses new strategic capabilities that enable characterizing and predicting the magnetic field structure and flow dynamics of the Sun by assimilating data from helioseismology and magnetic field observations into physics-based realistic magnetohydrodynamics (MHD) simulations.

The proposed integration of first-principle modeling of solar magnetism and flow dynamics with real-time observational data via advanced data assimilation methods is a new, transformative step in space weather research and prediction. The primary deliverables will be three analysis tools that produce: (i) enhanced solar synoptic maps at the photosphere, (ii) first-principles-based models for the rise of magnetic structures from the deep interior to the corona, and (iii) local maps forecasting the location and emergence of active regions. The tools will result in substantial improvement in modeling and prediction of space weather.

The effort includes a substantial enhancement to an existing model of magnetic flux distribution and transport developed by the Air Force. The Air Force Photospheric Flux Transport, ADAPT, model is expected to be incorporated, during fall 2012, by the National Weather Service (NWS) Space Weather Prediction Center (SWPC) to approximate the magnetic flux at the base of the solar wind model (WSA-Enlil). We will develop an enhanced model under this proposal that will enable data assimilation of near-surface flow dynamics from helioseismology and vector magnetic data from the Solar Dynamics Observatory - Helioseismic and Magnetic Imager (HMI).

In addition to enhancing the data input and global magnetic modeling of ADAPT, we will use the Space Weather Modeling Framework (SWMF) to develop Coupled Models for Emerging flux Simulations (CMES) that couples three existing models: (1) an MHD formulation with the anelastic approximation to simulate the deep convection zone (FSAM code), (2) an MHD formulation with full compressible Navier-Stokes equations and a detailed description of radiative transfer and thermodynamics to simulate near-surface convection and the photosphere (Stagger code), and (3) an MHD formulation with full, compressible Navier-Stokes equations and an approximate description of radiative transfer and heating to simulate the corona (Module in BATS-R-US). CMES will enable simulations of the emergence of magnetic structures from the deep convection zone to the corona.

Finally, we will develop Flux Emergence Prediction Tool (FEPT) in which helioseismology-derived data and vector magnetic maps are assimilated into CMES that couples the dynamics of magnetic flux from the deep interior to the corona. This new simulation tool will be implemented within the SWMF, and we expect it to become part of the CCMC toolset of available community software.

Dusan Odstrcil/NASA Goddard Space Flight Center

Integrated Real-Time Modeling System for Heliospheric Space Weather Forecasting

Heliospheric space weather forecasting is lagging behind the atmospheric one and until recently there was no physically based model able to predict arrivals of coronal mass ejections (CMEs) faster than real time. This is caused by huge spatial domain, lack of suitable observations needed to initialize models, and computational challenges posed by number of coupled processes at various spatial/temporal scales. Heliospheric forecasting is in infancy and requires basic research to increase understanding. Urgent societal needs are expressed in National Space Weather Program. Until recently these needs were satisfied only by a real time monitor, ACE spacecraft at L1-point which provides 20-40 min warnings of CMEs approaching geospace. Desired lead time of 1-3 days can only be achieved by following their propagation from Sun though heliosphere. Due to various dynamic interactions, numerical simulation is needed.

Within our previous AFOSR/MURI, NASA/LWS and NSF/CISM projects we developed the WSA-ENLIL-Cone modeling system that met above needs by proper combination of available observations with analytic, empirical, and numerical models. This “hybrid” system does not simulate CMEs origin but uses appearance in coronagraphs, fits geometric/kinematic parameters and launches a CME-like structure into the solar wind computed using WSA coronal model. This system was validated at NSF Center for Integrated Space Weather Modeling and implemented at NASA based multi-agency Community Coordinated Modeling Center (CCMC). Run-on-Request service at CCMC exposed the modeling system to community (>50 users, <1500 runs) and resulted in numerous presentations, papers, thesis, and educational materials. This together with validation by CCMC, contributed to selection of WSA-ENLIL-Cone as the first numerical model to be transitioned into operation at NOAA/Space Weather Prediction Center (SWPC) and NASA Space Weather Center (SWC). Recent operational results show that improvement in predicting the CMEs arrival has been achieved.

However as these results begin to accumulate, it also shows that accurate predictions are achieved mostly if the solar wind is stable and if multi-spacecraft observations of CME onset obtained by STEREO are used. Since operational STEREO-like system is not yet planned, space weather forecasting is facing a serious problem. Further this system as incorporated at NOAA and NASA does not cover other phenomena important to heliospheric research and forecasting, and does not take full advantage of available observations.

We propose to develop an integrated real-time modeling system for heliospheric space weather forecasting that will significantly improve current operational capabilities and will provide valuable tool to research and education community. Our five-year project will (1) Develop the critical but missing components for real-time prediction of the southward IMF component at geospace and solar-energetic particle fluxes at planets and spacecraft; (2) Improve the semi-automatic CME parametrization, ensemble modeling, and probabilistic forecasting; (3) Increase the predictive accuracy by “on-the-fly” comparison of simulated scenarios with remote and in-situ observations. This system when transitioned to SWC will provide operational support to NASA missions. Simulations of all CMEs observed during STEREO era will support research community. While these objectives look very ambitious, many elements are already working in a preliminary state. Proposed project improves them and brings together, and produces new system that will exercise their collective capabilities in both research and operational settings. Project brings together model developers, experienced observers, users familiar with validation and operational use, graduate students, and domestic/foreign collaborators. Most of team members are at NASA/GSFC which will facilitate collaborative development and smooth transition to NASA/SWC and ultimately to NOAA/SWPC.

Robert Schunk/Utah State University

Physical Processes Governing Energy and Momentum Flows on Multiple Scales in Near-Earth Space Using a First-Principles-Based Data Assimilation System for the Global Ionosphere-Thermosphere-Electrodynamics

The Earth s Ionosphere-Thermosphere-Electrodynamics (I-T-E) system varies markedly on a range of spatial and temporal scales that can have adverse effects on human operations and systems, and consequently, there is a need to both mitigate and forecast near-Earth space weather. Following the meteorologists, we propose to specify and forecast the global I-T-E system with data assimilation (DA) models, because this is reliable, feasible, and models are already available. Currently, we have first-principles-based DA models for the ionosphere, ionosphere-plasmasphere, thermosphere, high-latitude ionosphere-electrodynamics, and mid-low latitude ionosphere-electrodynamics. These models assimilate a myriad of different ground- and space-based observations and have been used for operational purposes and science studies. Specifically, we propose to use these models as the building blocks for a first-principles-based Data Assimilation System (DAS) for the Global Ionosphere-Thermosphere- Electrodynamics.

First Objective: Science Focus

- Elucidate the fundamental physical, chemical, and coupling processes that operate in the I-T-E system for a range of actual, global-scale, space weather events that include plasma and neutral structures generated, for example, during storms and substorms.
- Identify the spatial and temporal scales over which mass, momentum, and energy flow in the system.
- Determine the effect of plasma and neutral gas structures (100-1000 km) on global-scale flows.

Second Objective: Model Development

- Construct a Data Assimilation System for the Global Ionosphere-Thermosphere-Electrodynamics based on first-principles-based models that we already have. DAS will use an ensemble Kalman filter for the coupled, global, I-T-E system to provide self-consistent specifications and forecasts for the global system.

- Construct a Multimodel Ensemble Prediction System (MEPS) for the I-T-E system that will incorporate our existing data assimilation models with different physics, numerics and initial conditions. MEPS will allow ensemble modeling with different data assimilation models for specific applications.

Third Objective: Deliveries to CCMC

- Deliver the Data Assimilation System for the Global Ionosphere-Thermosphere-Electrodynamics and MEPS, (with component data assimilation models; ionosphere, ionosphere-plasmasphere, thermosphere, high-latitude ionosphere-electrodynamics, and mid-low latitude ionosphere-electrodynamics) to the CCMC.

Relevance: Our team includes theorists, modelers, computational scientists, and data experts. Our team possesses all of the expertise and experience needed to successfully complete the proposed research. The research is relevant to the NSF CEDAR, GEM, and Facilities programs, and the NASA LWS, Theory, and various satellite programs.

Expected Significance: DAS will be modular so that it can be coupled to lower atmosphere (weather) models and to first-principles-based magnetosphere models. Hence, DAS can take account of upward propagating tides, planetary waves, and gravity waves. Since DAS reconstructions will be consistent with the available I-T-E measurements, self-consistent ion outflows, convection E-fields, precipitation, currents, etc., can be provided to magnetosphere models for inputs and/or validation. The modular architecture also means that individual components of DAS (ionosphere, thermosphere, electrodynamics) can be replaced if better models become available. Also, MEPS will incorporate different data assimilation models for specific parts of the near-Earth space domain, which will allow ensemble modeling with several different DA models. The DAS and MEPS data assimilation models will be made available to the scientific community so that others can study the I-T-E system with state-of-the-art data assimilation models. The use of these models will lead to a paradigm shift in how basic physical processes are studied in near-Earth space.

Nathan Schwadron/University of New Hampshire
Corona-Solar Wind Energetic Particle Acceleration (C-SWEPA) Modules

The 3-D Coronal-Solar Wind Energetic Particle Acceleration (C-SWEPA) modules provide tools for taking the critical next step in understanding Solar Energetic Particle (SEP) events and characterizing their hazards through physics-based modeling from the low corona through the inner heliosphere. C-SWEPA s central objective is to develop and validate a numerical framework of physics-based modules that couple the low corona and CMEs with solar wind, shocks, acceleration and composition of energetic particles, and the fluctuations and turbulence within solar wind that buffet terrestrial and planetary magnetospheres. Using pre-existing EMMREM modules, we characterize time-dependent radiation exposure in interplanetary space environments. Simulated observers (e.g., spacecraft near L1, Earth, moon, Mars, etc.) provide basis for comparison with spacecraft and tools to explore simulated mission datasets (e.g., Solar Probe Plus, SPP, and Solar Orbiter, SolO).

C-SWEPA fulfills the need for a transformative synthesis of LWS capabilities by bringing together an exceptional team of leading experts from five institutions in solar, heliospheric and magnetospheric physics and two successful LWS strategic capabilities: the Earth-Moon-Mars Radiation Environment Modules (EMMREM), and the Next Generation Model for the Corona and Solar Wind. C-SWEPA leverages new advancements in High Performance Computing (HPC) through the use of heterogeneous architectures (Graphical Processing Units; GPUs) and develops an innovative approach to delivering complex models that enables the CCMC to use dedicated GPU-enabled and massively parallelized systems for C-SWEPA simulations.

C-SWEPA is a transformational project providing: an integration between observationally-driven modeling of CMEs, solar wind, shocks and energetic particles from the low corona through the heliosphere; incorporation of seed populations and associated compositional dependencies; new fundamental information via highly-resolved inertial node-lines vital to studies of the magnetosphere (e.g., by the upcoming Radiation Belt Storm Probes mission, RBSP), other planetary magnetospheres and the microstates and turbulence within solar wind; and detailed models that probe the steady and disturbed corona thus paving the way for Solo and SPP studies.

C-SWEPA deliverables include: two numerical systems (one at the CCMC and one at UNH) that run C-SWEPA; documentation; and an intuitive interface. These systems provide: on-line availability and event scenarios from Sun-to-Earth; runs that include solar wind, CMEs and associated shock(s), SEP flux time series, dose & dose-equivalent rates, integrated doses behind various layers of shielding; and results of runs made for specific campaign events of interest to the science community at large. Both EMMREM and CORHEL run at the CCMC and the associated teams have a strong history of partnering with the CCMC.

C-SWEPA answers fundamental scientific questions via four science subgroups that study the corona, solar wind, CME initiation, shocks, solar energetic particle acceleration and propagation, and solar wind waves and turbulence. Core team members have experience working together and leverage developments from CISM, EMMREM, CORHEL, NSF s FESD Sun-to-Ice project, and existing Focus Science Teams (FSTs) of NASA's Living With a Star (LWS) Program.

C-SWEPA provides broad impacts by advancing discovery and understanding while also promoting teaching, training of graduate students, undergraduate involvement, and participation of under-represented groups. C-SWEPA enhances the infrastructure for research and education through development of computing capabilities for the science community. By advancing tools for understanding and predicting space weather, C-SWEPA provides important societal benefits enabling expansion of space technologies.