B.6 HELIOPHYSICS LIVING WITH A STAR SCIENCE

NOTICE: Amended June 19, 2019. This Amendment releases the final text for this program element. Step-1 proposals are due December 5, 2019 and Step-2 proposals are due by February 27, 2020.

1. Introduction

The Living With a Star (LWS) Program emphasizes the science necessary to understand those aspects of the Sun and Earth's space environment that affect life and society. The ultimate goal of the LWS Program is to provide a scientific understanding of the system that leads to predictive capability of the space environment conditions at Earth, other planetary systems, and in the interplanetary medium.

The LWS program objectives are as follows:

1. Understand how the Sun varies and what drives solar variability.
2. Understand how the Earth and planetary systems respond to dynamic external and internal drivers.
3. Understand how and in what ways dynamic space environments affect human and robotic exploration activities.

The LWS Program seeks to make progress in understanding the complex Heliophysics system, focusing on the fundamental science of the most critical interconnections. Further information on the LWS Program can be found at the LWS website (http://lwstrt.gsfc.nasa.gov/). The LWS Science program maintains a strategy with three components, namely, Strategic Capabilities, Targeted Investigations, and Cross-Disciplinary Infrastructure Building programs. Only the Targeted Investigations will be competed in this announcement. Proposers interested in Strategic Capabilities should see Program Element B.10 Living With a Star Strategic Capabilities. Cross-Disciplinary Infrastructure Building may be competed in ROSES-2020.

Further background material concerning relevant research objectives can be found on the LWS website, and in the following documents:

- The LWS TR&T SDT Report (https://lwstrt.gsfc.nasa.gov/images/pdf/TRT_SDT_Report.pdf)
- The LWS *10-Year Vision Beyond 2015 Report* (http://lwstrt.gsfc.nasa.gov/images/pdf/LWS_10YrVision_Oct2015_Final.pdf)

The National Research Council Decadal Survey Report *Solar and Space Physics: A Science for a Technological Society* (http://www.nap.edu/openbook.php?record_id=13060).

1.1 Data Use in the Living With a Star Program

This program element has policies on the use of data in proposals that expand upon and supersede those given in B.1 Heliophysics Research Program Overview.

For successful completion of the proposed project, proposals to this program may only use data that is in a publicly available archive at least 30 days prior to the Step-2 deadline. This applies to both space-based and ground-based observations, as well as any data products derived from them. This latter point does not exclude data products to be developed as part of a proposed study, only those existing in advance of Step-2 submission. Any questions about whether a data set or data product qualifies as publicly available must be submitted to the program element's point of contact at least 10 days before the Step-1 deadline.

After an award is made, projects may incorporate new data that becomes available in a public archive, provided that their use does not alter the goals and objectives of the selected proposal. Any planned changes in the data used must be described in the annual progress report submitted by the Principal Investigator (PI) and approved by the LWS Program Scientist.

While the inclusion of useful ground-based observations is allowed, proposals are expected to incorporate space-based observations so collaboration between space-based and ground-based observers are permitted. Further, the Step-2 evaluation process (see Section 7.2.3) will include the consideration of the presence and importance of space-based or ground-based observations in the proposals. Regardless of the type of data that would be utilized in the proposed study, space-based, ground-based, or some combination, the proposal must clearly demonstrate why the proposed data set or data sets are sufficient to address the proposed goals and objectives.

2. Scope of Program Element - Targeted Investigations

The stated goal of LWS, that of achieving an understanding of those aspects of the Sun and Earth's space environment that affect life and society, poses two great challenges for the LWS program. First, the program seeks to address large-scale problems that cross discipline and technique boundaries (e.g., data analysis, theory, modeling, etc.); and second, the program will identify how this new understanding has a direct impact on life and society. Over time, the Targeted Investigations have provided advances in scientific understanding that address these challenges.

The Targeted Investigations component this year consists of four Focused Science Topics (FSTs). Detailed descriptions of each FST are given below.

2.1 Focused Science Topics

The FSTs permitted as the objectives for proposals this year are as follows:

1) The Variable Radiation Environment in the Dynamical Solar and Heliospheric System (described in Section 3);
2) Fast Reconnection Onset (described in Section 4);
3) Magnetospheric and Ionospheric Processes Responsible for Rapid Geomagnetic Changes (described in Section 5);
4) Causes and Consequences of Hemispherical Asymmetries in the Magnetosphere – Ionosphere – Thermosphere System (described in Section 6).

NASA desires a balance of research investigation techniques for each FST, including theory, modeling, data analysis, observations, and simulations. In previous ROSES calls, proposals could be individual proposals that would form part of a team or Targeted Science Teams (TSTs) that form prior to submission under a single PI and submit a single TST proposal that attacks the entire breadth of the FST. However, such

TSTs will not be permitted this year and the FST teams will be formed from the selected individual proposals based on panel evaluations and programmatic considerations.

Given the strategic nature of LWS, and the fact that strategically feasible tasks require sufficient investment, it is anticipated that FST proposals will have annual budgets in the range of $190K - $235K per year. (This includes fully encumbered Civil Servant labor, where appropriate.) It is left to individual PIs to decide whether a strategically feasible award size could be achieved by increased collaborative efforts, greater time commitment of investigators, or a mix of the two. PIs should be cognizant, however, that verification of the level of effort versus the actual work proposed will be part of the review panel process. Given the submission of proposals of adequate number, merit, and range of investigative techniques, NASA anticipates forming teams of ~5 – 7 selections for each of the four FST topics.

Past experience has shown that Focused Science Teams usually need a year to get organized since team members may not have worked together before, followed by another three years to make significant progress on the FST. Thus, the expected duration of FST awards is four years. While proposals with shorter duration are allowed, proposers are encouraged to propose up to four years to ensure maximum overlap between individual contributions to the team efforts.

2.2 Focused Science Teams

Once selected, these investigators will form a team and coordinate their research programs. In order to foster the collaborations required to coordinate these team research efforts, one of the PIs will serve as the Team Leader for the FST for which he/she proposed. The Team Leader will organize team meetings, and will be responsible for producing a yearly report to NASA Headquarters describing team activities and progress. Proposers wishing to serve as a Team Leader must state so in their proposal, and must include a separate Appendix at the end of their proposal describing their qualifications, interest, and approaches to team leadership. Up to one extra page of the proposal is allowed for this Appendix. Team Leader activities should not be included in the proposal budget. The Team Leader will receive up to an additional $25,000 per year to support his/her leader activities, and the Team Leader’s budget will be revised during final award negotiations. The selection of the Team Leader will be made by the LWS Staff and the Heliophysics Selecting Official. Guidance for the team development process will be provided by NASA after selection of the Team Leader.

All proposers should include sufficient travel funds in their budgets to cover two team meetings per year to be held on the U.S. coast farthest from their home institutions. This assumes that one meeting per year will be held in conjunction with a major U.S. scientific meeting. Successful teams will participate in a Kickoff Workshop where the selected team members will meet and develop work plans for the anticipated period of performance, generally 4 years, based on the requirements of the FST and the composition of the selected team.

3. FST #1: The Variable Radiation Environment in the Dynamical Solar and Heliospheric System

3.1 Target Description

Galactic cosmic rays (GCRs) and solar energetic particles (SEPs) propagate in the heliosphere, forming the energetic particle radiation environment close to Earth and elsewhere in the interplanetary space. Because of the low plasma density of the interplanetary medium, the dynamics of energetic particles are primarily influenced by electric and magnetic fields. GCRs and SEPs constitute a major threat to satellites and astronauts in space. This threat is difficult to mitigate using current technologies.

The energetic particle radiation environment varies at different temporal and spatial scales. The high-energy component of energetic charged particles (>500 MeV) at Earth is registered by ground-based neutron monitors. The deep solar minimum in cycle 23 and relatively weak cycle 24 have led to record increases in the flux of GCRs. Based on Voyager 1's *in situ* measurement of GCRs in the interstellar medium, 75% of the cosmic rays with energies ~1 GeV are filtered out by the heliosphere. The incoming cosmic ray flux is affected by a variety of physical processes internal to our heliosphere. The changes in the solar wind associated with the recent weak solar cycle have provided important clues for the underlying physics. If solar activity were to descend into a Dalton minimum condition, the level of the GCR flux would surge and needs to be quantitatively determined. The radiation environment is variable also because of solar transient events such as solar flares and coronal mass ejections (CMEs). The most extreme SEP acceleration gives rise to ground level enhancement events with an increase of energetic particle flux at hundreds of MeV. Fast CMEs lead to decreases of the high-energy particle flux for days termed a Forbush decrease. These effects are known to be observable in the whole heliosphere. A primary goal of the upcoming Interstellar Mapping and Acceleration Probe (IMAP) mission will be connecting energetic particles measured at 1 AU with those over the whole heliosphere. It is important to monitor and understand the variability of energetic particle radiation in the dynamical solar corona and heliosphere.

This FST is timely with the availability of measurements of the dynamical heliosphere and its boundaries from the Interstellar Boundary EXplorer (IBEX) mission, and in preparation for the upcoming IMAP mission, which will offer unprecedented measurements of energetic particles throughout the heliosphere. Work done under this FST will provide additional insights on the coupling between Earth's space environment and its interstellar surroundings. Meanwhile, the Parker Solar Probe (PSP) and the future Solar Orbiter missions will provide *in situ* measurements of high-energy particles created close to the Sun.

The FST is relevant to LWS Strategic Science Areas (SSAs): SSA-0: Physics-based Understanding to Enable Forecasting of Solar Electromagnetic, Energetic Particle, and Plasma Outputs Driving the Solar System Environment and Inputs to Earth's Atmosphere; SSA-3: Physics-based Solar Energetic Particle Forecasting Capability; and SSA-6: Physics-based Radiation Environment Forecasting Capability.

3.2 Goals and Measures of Success

The primary goals of this FST are:

- Determine the influence of solar and heliospheric plasma dynamics on high-energy particle radiation environments within the heliosphere;
- Determine the influence of major solar eruption events on the high energy particle environment near Earth and in interplanetary space.

In addition, this FST has the goals of improving the numerical models of cosmic ray modulation in the heliosphere, high-energy particles from major solar eruptions, and the Forbush decrease by extreme CME events.

Measures of success include, but are not limited to:

- Improved models of the variability of the energetic particle radiation environment in the heliosphere over the solar cycle;
- Improved models of the acceleration and transport of high energy SEPs by CMEs in the solar corona and in the heliosphere;
- Understanding the relationship between observed CME properties and Forbush decreases;
- Validation of models, and quantification of intrinsic uncertainties over a range of physical conditions.

3.3 Types of Investigations

Investigations that address this FST's science goals include, but are not limited to:

- Studies of the effect of variations in solar wind dynamic pressure on the cosmic ray flux change;
- Correlation analyses between neutron monitor data and spacecraft data to understand change of high-energy charged particles such as Forbush decrease;
- Understanding the influence of major solar eruption events on the high energy radiation environment near Earth and interplanetary space;
- Studies of the temporal and spectral properties of large SEP events;
- Simulations of high-energy particle dynamics and comparison with spacecraft measurements.

Investigations within this FST may include theoretical, numerical, and observational methods. Available data sources include measurements of solar wind parameters at 1 AU and energetic particle observations from past and present missions, including ACE, GOES, IBEX, Voyager, Parker Solar Probe, AMS-02 and neutron monitors.

3.4 Predictability, Interaction with User Communities, and Uncertainty

Given the potential relevance of this FST with the Parker Solar Probe and upcoming Solar Orbiter and IMAP missions, proposers may consider potential overlap of the FST and the anticipated observations of those missions. However, proposals must not require the use of data from these missions that do not meet the data policy in Section 1.1 to address their science questions. Rather, the impact of the potential future observations from these missions may be considered as a possible source of future data.

All investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 7.2.3).

4. FST #2: Fast Reconnection Onset

4.1 Target Description

Magnetic reconnection is one of the most fundamentally important physical processes that impacts heliophysics and space science more broadly. Reconnection spans energy scales, from nanoflares that contribute to coronal heating to solar flares, which are the largest explosions in the solar system. It is the mechanism by which stored magnetic energy is suddenly converted into kinetic and thermal energy, radiation, and accelerated particles and is therefore a fundamental source of the most energetic space weather phenomena, including flares, coronal mass ejections, and geomagnetic storms. Although ubiquitous, reconnection is a process that requires critical conditions to be fulfilled in order to occur, making it an excellent probe of magnetic field topology and dynamics throughout the heliosphere.

One criterion for fast magnetic-field-line reconnection to occur is that a current sheet must thin to a critical width. As examples, many fast reconnection investigations in the collisionless regime require that ions and/or electrons become demagnetized to allow the magnetic field to slip through the collisionless plasma. Another commonly invoked criterion requires the excitation of the tearing instability, which in turn relies on the current sheet reaching a critical aspect ratio. In partially ionized collisional plasmas, reconnection studies have shown that fast reconnection is achievable if the ion–electron recombination rate exceeds a critical threshold, and that this can also be related to the current sheet thinning down below the ion-neutral coupling scale. Thinning of current sheets may be caused by, for example, (non-uniform) compression of the plasma, shocking of the plasma, and stressing the large-scale magnetic configuration in which the current sheet is imbedded. The critical thickness for fast reconnection onset has been related to ion gyro-radii, to ion inertial lengths, to electron gyro-radii, to ion–neutral coupling scales, and to tearing mode criteria. The criteria for the onset of fast reconnection may depend on such variables as the magnetic field topology, the amount of magnetic shear, the amount of velocity shear, ion composition, ion plasma beta, or plasma asymmetry across the current sheet.

Throughout the heliosphere, numerous observations are now available of current-sheet conditions related to the onset of reconnection: it has been observed via remote imaging in the onset and evolution of coronal mass ejections and flares and for the evolution of coronal helmet streamers; it has been observed via *in situ* measurements for the heliospheric current sheet (e.g., from ACE and Wind, and it is expected that observations from Parker Solar Probe will soon be added to this list), for solar-wind directional discontinuities, for the Earth’s magnetosheath, for solar-wind/magnetosphere coupling at the dayside magnetopause, for substorms in the Earth’s magnetotail, and even in other planetary magnetospheres. Combining these regimes is a necessary way to make cross-disciplinary progress on this critical topic.

The FST is relevant to several LWS Strategic Science Areas (SSAs): SSA-0: Physics-based Understanding to Enable Forecasting of Solar Electromagnetic, Energetic

Particle, and Plasma Outputs Driving the Solar System Environment and Inputs to Earth's Atmosphere; SSA-1: Physics-based Geomagnetic Forecasting Capability; SSA-3: Physics-based Solar Energetic Particle Forecasting Capability; and SSA-6: Physics-based Radiation Environment Forecasting Capability. However, due to the inherent cross-disciplinary nature of this Focused Science Topic and its direct correspondence with space weather as a driver of energy release, this topic is ultimately relevant to all LWS SSAs 0 – 6.

This FST, by addressing reconnection onset throughout the heliosphere, will address key aspects of the Decadal Survey questions: "What is the role of magnetic reconnection in energy release in coronal mass ejections and flares?" "What are the interactions and feedbacks that connect the magnetosphere, solar wind, and ionosphere?" and "How does the Sun's magnetic field shape the dynamic heliosphere?"

4.2 Goals and Measures of Success

The primary goals of this FST are:

- Establish an understanding of what the critical conditions are for the onset of fast reconnection at a current sheet in the various regimes relevant for heliophysics;
- Determine what the onset criterion is and how the reconnection speed depends on these various regimes;
- Understand the global- and local-scale processes that bring a current sheet to the critical state required for reconnection for the various reconnection phenomena active in the solar corona, solar wind, and the Earth's magnetosphere;
- Establish predictive parameters for the onset of reconnection that can be implemented in large-scale MHD simulation codes for the corona, solar wind, and the Earth's magnetosphere.

This FST targets the onset of fast reconnection in a variety of environments by combining the expertise from different heliophysics subfields (i.e., observations in different contexts [remote sensing and *in situ* measurements], MHD and kinetic theory and modeling, and laboratory experimentation).

Measures of success include, but are not limited to:

- Understanding when, where, and how fast reconnection commences, and what circumstances prevent or inhibit its occurrence, in a variety of physical environments within the heliosphere;
- Determining the reconnection rate, and in particular the criteria for fast reconnection to occur in various physical environments within the heliosphere and across size scales;
- Validation of models, and quantification of intrinsic uncertainties over a range of physical conditions.

4.3 Types of Investigations

Investigations that address this FST's science goals include, but are not limited to:

- Theory and simulation studies of reconnection onset criteria for plasma regimes and magnetic field configurations relevant to heliophysics, including particle-incell, hybrid, multi-fluid magnetohydrodynamic, and Hall magnetohydrodynamic investigations;

- Observational studies (remote sensing and *in situ*) of current sheet evolution and reconnection onset in the outer corona, solar wind, magnetosphere, and laboratory experiments;
- Theory and modeling studies of global and local phenomena which bring current sheets into fast reconnection states in magnetic field configurations important for heliophysics phenomena, including both kinetic physics and global magnetohydrodynamic investigations;
- Statistical analysis of observed reconnection events and detailed analysis of prime reconnection events;
- Development of predictive parameters for implementation into large-scale magnetohydrodynamic simulations of heliophysics reconnection phenomena.

4.4 Predictability, Interaction with User Communities, and Uncertainty

All investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 7.2.3).

5. FST #3: Magnetospheric and Ionospheric Processes Responsible for Rapid Geomagnetic Changes

5.1 Target Description

Geomagnetically induced currents (GICs) are a hazardous space weather phenomenon, which can cause serious damage to critical infrastructures such as electric power transmission systems and pipeline networks. Although the observation of GICs is limited, they are closely correlated with geomagnetic disturbances, and qualified geomagnetic field data have been collected for several decades. Major GIC events take place during extremely intense storms, and it is generally known that the intensity of the GICs depends on the rate of the change of ground geomagnetic disturbances. It still remains to be understood under what conditions the rate of the change of geomagnetic disturbances becomes extraordinarily large, what magnetospheric and ionospheric processes are responsible, and if there are any preconditions for such processes to take place and grow to extreme levels. The answers are probably different at different latitudes, and they may also depend on solar wind drivers. For tackling these issues, systematic studies including both satellite and ground observations, with the aid of global modeling are highly required.

This topic can benefit from a wide range of current and past spacecraft and ground data sets. The Heliophysics community now has unprecedented coverage of spacecraft data from the solar wind to the inner magnetosphere including data from NASA missions such as ACE, THEMIS, Van Allen Probes, and MMS. NSF’s AMPERE project provides global and large-scale ionospheric field aligned electric currents using data from the Iridium satellite constellation. Considering that qualified spacecraft and ground data have been accumulated for several decades, we can also revisit historical data sets including, for example, global auroral images taken by satellites such as Polar and IMAGE.

One of the most pressing needs is specification of the geoelectric field under disturbed space weather conditions. The geoelectric field is the space weather quantity of most interest to the operational and forecasting communities because it is the primary input for calculating GICs. Estimating the geoelectric field from the geomagnetic field generated in global models requires ground conductivity models, which range from 1D models, depending only on depth, to 2D or 3D models that depend both on depth and horizontal variations. These later models are needed to represent ground conductivity structures. NSF's EarthScope project, which was supplemented by NASA space weather funding, has recently developed, and made available for use, conductivity models on the basis of their magnetotelluric measurements over large regions in the United States. Surveys like this are also being carried out by other countries around the globe. Conductivity models, which represent conductivity structures, are needed in progressing from global to local predictions of the severity of GIC effects.

The suggested topic is the central issue of SSA-1: Physics-based Geomagnetic Forecasting Capability, and is also related to SSA-0: Physics-based Understanding to Enable Forecasting of Solar Electromagnetic, Energetic Particle, and Plasma Outputs Driving the Solar System Environment and Inputs to Earth's Atmosphere.

This FST also addresses the Decadal Survey Key Science Goal to "determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs", and the Decadal Survey Solar Wind – Magnetosphere Interactions (SWMI) Science Challenge 3 to "determine how coupling and feedback between the magnetosphere, ionosphere, and thermosphere govern the dynamics of the coupled system in its response to the variable solar wind".

5.2 Goals and Measures of Success

The primary goals of this FST are:

- Determine the solar wind parameters, magnetospheric conditions, and ionospheric properties that affect the rate of the change of geomagnetic field;
- Estimate the corresponding temporal evolution of ground geoelectric fields and their spatial scales, research products, which are the primary input to operational and engineering models of GICs and of most use to these communities;
- As a potential valuable output from global models and estimations of spatial scales in this FST, provide an initial estimate of the spacing and location of magnetospheric ground-based observatories that are required to provide adequate spatial coverage for situational awareness and for triggering mitigation strategies.

5.3 Types of Investigations

This is an FST that will benefit from joint investigations of global modeling and data analysis techniques. Datasets to be included span from ground-based (magnetometers, etc.) for identification of ionospheric conditions and geomagnetic field disturbances, to space-based magnetospheric data (THEMIS, Van Allen Probes, MMS, Polar, IMAGE, NSF's AMPERE project, etc.) for identification of the magnetospheric conditions, and solar wind data: ACE, DSCOVR, OMNI.

Investigations that address this FST's science goals include but are not limited to:

- Observational and numerical approaches for determining latitudinal variations of GIC sources and effects;
- Investigation of improvements in modeling geoelectric fields associated with moving from 1D to 2D to 3D ground conductivity models during different levels of geomagnetic activity;
- Numerical simulations using solar wind – magnetosphere – ionosphere coupled models with the goal of investigating the role of solar wind in driving GICs, and accompanying observational studies of correlations between GIC and various solar wind parameters;
- Exploring improvements in the lead time and accuracy of predictive GIC modeling (for example, by focusing on specific types of interplanetary drivers or linkages to particular geospace source processes, etc.);
- New and improved indicators of GIC activity (beyond Kp, dB/dt, etc.);
- Analysis of current and historic satellite and ground data sources during extreme GIC times with the goal of discovering any preconditions necessary for extreme GICs, and of any magnetosphere–ionosphere coupling processes involved;
- Modeling of associated conditions related to GICs that cover a broad range of intensity.

5.4 Predictability, Interaction with User Communities, and Uncertainty

The formulation of this FST is based on a strong interaction between Heliophysics researchers and the user communities, as well as inputs from the Heliophysics community. The open research questions that were summarized in the 2015 LWS Institute Geomagnetically Induced Currents Working Group Report are relevant to this FST. This report is available on the LWS website (http://lwstrt.gsfc.nasa.gov/). The list of open questions in this report deal specifically with research issues constructed using inputs from Heliophysics researchers, the electric power transmission industry, the National Oceanic and Atmospheric Administration (NOAA), the US Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), and insurance industry representatives. Proposers are encouraged to consider this report as a resource for interactions with the user communities.

All investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 7.2.3).

6. FST #4: Causes and Consequences of Hemispherical Asymmetries in the Magnetosphere – Ionosphere – Thermosphere System

6.1 Target Description

While both northern and southern polar upper atmospheric regions are closely linked through the magnetosphere, the coupling is often not symmetrical. The reasons for this are not fully understood, and certainly cannot yet be predicted. Fundamentally, these asymmetries evolve from geographic and/or geomagnetic aspects of Earth, as well as possible effects that arise directly from the solar wind. Examples of this asymmetrical coupling include magnetic pulsations, ion outflows, field-aligned currents, electromagnetic energy (Poynting) flux, auroral particle precipitation, high-latitude ionospheric convection, currents and conductance, ionospheric electron densities and thermospheric winds and mass densities. One interhemispheric area that deserved more attention is the polar cleft during extreme northward interplanetary magnetic field (IMF) magnetospheric driving: anomalous large drag is experienced by low altitude satellites as they pass over the polar cusp during some IMF Bz northward periods. It is also known that asymmetric ion outflows may be related to some of the low temperature ions observed in the magnetosphere. Many of these hemispheric asymmetries can be traced back to a handful of fundamental causes including interplanetary magnetic fields, solar illumination, Earth's magnetic field (e.g., different offsets between magnetic and geographical poles, differences in field strength at conjugate regions, displacement of the magnetic equator from the geographic equator) as well as land−sea distribution. There are also hemispherical differences at the mid and low latitudes, and associated coupling processes between the hemispheres (e.g. magnetic lines of force, winds, and electrodynamics), that lead to differences in the neutral atmosphere and plasma. This FST calls for observational and modeling studies that will establish relationships between the many types of hemispheric asymmetries, their fundamental causes, and their effects on geospace structures and the coupled geospacer system responses.

Understanding the origin and evolution of asymmetry is an important aspect of this FST as is how these asymmetries are affected by the external environment (in this case, the solar wind, solar irradiance, the offset between the geomagnetic and geographic poles, asymmetric inputs from the lower atmosphere, etc.). The challenge is to understand how asymmetric structures emerge and incorporate this information into predictive models. Hemispheric asymmetries are often investigated through statistical averaging of individual variables and/or idealized simulations focused on one causal effect. Even though such investigations are valuable, the underlying physical processes are dynamic and complex, resulting from multiple asymmetric coupling mechanisms that are operating simultaneously. Consequently, it is important to avoid treating hemispheric asymmetries in isolation.

This FST addresses LWS SSAs: SSA-2: Physics Based Satellite Drag Forecasting Capability and SSA-4: Physics-based Total Electron Content (TEC) Forecasting Capability. It also addresses the Decadal Survey's Atmosphere Ionosphere Magnetosphere (AIM) Interactions Science Goal 4: Plasma-Neutral Coupling in a Magnetic Field – How do neutrals and plasma interact to produce multiscale structures in the AIM system? This FST also addresses Key Science Goal 2 of the Decadal Survey: "Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs." In this case, the FST is focused specifically on the effects of hemispheric asymmetries in solar and terrestrial inputs.

This research is timely in preparation for the upcoming ICON mission and benefits greatly from the global views of the ionosphere – thermosphere – mesosphere (ITM) system provided by the newly launched GOLD mission. In addition, this FST is complementary to the 4-year NSF Geospace Environment Modeling (GEM) focus group on "Interhemispheric Approaches to Understand M-I Coupling (IHMIC)", that began in the summer of 2018.

6.2 Goals and Measures of Success

The efforts described above show that interhemispheric differences in coupling are ubiquitous. The topics addressed, while not coordinated, span a wide range and include a number of fundamentally important concepts, ideas that are essential for the development of successful modeling efforts. These ideas also feed directly into LWS goals, including understanding thermospheric effects and better modeling of total electron content and neutral atmospheric densities.

The primary goals of this FST are:

- To unveil the fundamental causes of hemispheric asymmetries in magnetosphere – ionosphere – thermosphere coupling. In the process it is expected that new information on magnetosphere – ionosphere coupling processes and plasma-neutral coupling will be revealed that would not be apparent under symmetrical driving conditions;
- Develop an improved physics-based understanding of, for example, time-evolving structural changes in thermospheric mass density and ionospheric electron density (TEC) between the hemispheres;
- Determine which drivers, e.g. the solar wind, the offset between the geographic and geomagnetic sources, generate the observed asymmetries and how these drivers interact with each other.

6.3 Types of Investigations

Potential approaches to hemispheric asymmetry studies might depend on the region being addressed. Investigations that address this FST's science goals include, but are not limited to:

- Comparison of differences between the Arctic and Antarctic polar vortices and the associated asymmetries that develop in the ionosphere – thermosphere system due to upward propagating effects;
- Measuring hemispheric differences in the magnetic local time (MLT) location of aurora, the relationship to IMF, and consequences for thermospheric circulation and ionospheric current systems;
- Comparing differences in high latitude convection, cross polar cap potentials, and Joule heating under a variety of asymmetric driving conditions;
- Identifying drivers that caused hemispheric asymmetries using for example coupled numerical models. These studies could incorporate data from a number of recent ground-based and space- based conjugate observations (e.g., ground-based: magnetometer chains, GPS TEC, SuperDARN, and all-sky imagers; and satellite-based: Iridium/AMPERE, DMSP, TIMED/SABER, TIMED/GUVI, GOLD). These same data sets could also be used to validate the models.

Investigating the processes that drive *low, mid, and high-latitude* hemispherical differences by employing numerical modeling and analysis of observed ionospheric plasma and neutral densities. For example, both observational and modeling techniques might be used to study how general thermospheric circulation features drive hemispheric differences in winds, and composition and to investigate the processes responsible for hemispheric differences in ionospheric structures like storm-enhanced density plumes and equatorial ionosphere anomalies.

6.4 Predictability, Interaction with User Communities, and Uncertainty

All investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 7.2.3).

7. Proposal Submission and Evaluation Process

To streamline the proposal process (submission, evaluation, and administration), this program uses a two-step proposal submission process (see the overall description of a two-step process in the *ROSES-2019 Summary of Solicitation* Section IV(b)vii).

Each PI, or the Science PI if applicable, is allowed to submit one and only one proposal to this program element. The expectation is that the PI (or Science PI) will invest a substantial portion of their time, at least 20%, to the investigation.

In addition to the general requirements and restrictions (e.g., in Table 1 of the *ROSES-2019 Summary of Solicitation* and in B.1 Heliophysics Research Program Overview) this program element has specific compliance constraints for both format (e.g., Sections 7.1.1 and 7.2.1) and content, e.g., involving data (see Sections 1.1 and 7.2.3). These compliance rules ensure fairness and are enforced strictly by the Heliophysics Division. Proposals that are deemed noncompliant will be returned without review or declined following review if violations are found during the evaluation process.

7.1 Step-1 Proposals

A Step-1 proposal is required and must be submitted electronically by the Step-1 due date given in Tables 2 and 3 of ROSES-2019. The Step-1 proposal must be submitted by an Authorized Organizational Representative (AOR) from the PI institution. No budget or other uploaded files are required. Only proposers who submit a Step-1 proposal are eligible to submit a Step-2 proposal. Step-1 proposals will be checked for compliance, but they will not be evaluated. Only proposers who submit a Step-1 proposal and who are invited can submit a Step-2 (full) proposal.

The Step-2 proposal title, science goals and objectives, must be the same as those in the Step-1 proposal. No additional investigators (Principal Investigator, Co-Investigators, Collaborators, Consultants, and Other Professionals) are allowed in the Step-2 proposal. Submission of a Step-1 proposal does not obligate the offerors to submit a Step-2 (full) proposal.

7.1.1 *Step-1 Proposal Format*

The Step-1 proposal is restricted to the 4000-character Proposal Summary text box on the NSPIRES web interface cover pages. It must include the following information:

- A description of the science goals and objectives to be addressed by the proposal;
- A brief description of the methodology to be used to address the goals and objectives; and
- A brief description of "Proposed Contributions to the Focused Science Team Effort" (see Section 7.2.2 for the material to be summarized).

The NSPIRES system for proposal submission requires that Step-1 proposals include a summary (i.e., abstract) describing the proposed work as outlined above. The proposal summary is entered directly into a text field in NSPIRES. No PDF attachment is required or permitted for Step-1 proposal submission. All information for the proposal summary will be entered within the 4000-character Proposal Summary text box on the NSPIRES web interface cover pages. Proposers will be notified by NSPIRES whether they are invited to submit their Step-2 proposals.

7.1.2 *Step-1 Compliance Criteria*

Step-1 proposals may be declared noncompliant if they fail to meet the submission guidelines or if they are outside the scope of the LWS Science program. PIs of noncompliant proposals will not be invited through NSPIRES to submit the associated Step-2 proposal and will receive a letter to this effect.

7.2 Step-2 Proposals

A Step-2 (full) proposal must be submitted electronically by the Step-2 due date (see below and Tables 2 and 3 of ROSES-2019). The Step-2 proposal must be submitted by an Authorized Organizational Representative (AOR) from the PI institution. A budget and other specified information is required. The Step-2 proposal title, science goals and objectives, must be the same as those in the Step-1 proposal. No additional investigators (Principal Investigator, Co-Investigators, Collaborators, Consultants, and Other Professionals) are allowed in the Step-2 proposal.

Proposers must have submitted a Step-1 proposal to be eligible to submit a Step-2 proposal. Proposers that have received a noncompliance letter are not eligible to submit a Step-2 proposal.

7.2.1 *Step-2 Proposal Format*

All proposals submitted to ROSES must strictly conform to the formatting instructions specified in the *ROSES-2019 Summary of Solicitation*. Proposals that violate these instructions may be returned without review or declined following review if violations are found during the evaluation process.

General agency guidelines for proposals are specified in the *NASA Guidebook for Proposers* but the requirements in this program element supersede those found in the Guidebook (see Section I(g) of the *ROSES-2019 Summary of Solicitation*).

7.2.2 *Required Additional Section in Step-2 Proposal Front Pages: Proposed Contribution to the Focused Science Team Effort*

Proposals to this program element must address the proposed contribution to the Focused Science Team effort in a 4,000-character plain text box on the NSPIRES cover pages and this will be peer reviewed as part of the evaluation of relevance (see Section 8.2.3). Since it is no longer included in the main body of the proposal, this text does not count against the 15-page limit for the Scientific/Technical/Management section. Proposals that fail to address the proposed contribution to the Focused Science Team effort will be declared noncompliant and will typically be returned without review or declined following review if violations are found during the evaluation process.

This section must summarize the following three topics:

- The relevance of the proposed study to the scientific objectives (Goals and Measures of Success) of the Focused Science Topic outlined in Sections 3.2, 4.2, 5.2, or 6.2;
- The potential contributions of the proposed study (Type of Investigation) to the Focused Science Team's effort outlined in Sections 3.3, 4.3, 5.3, or 6.3; and
- Metrics and milestones for determining the successful progress and outcome of the proposed research.

This summary must describe the goals of the proposed project and why they are aligned with the FST goals outlined in Sections 3.2, 4.2, 5.2, or 6.2. For proposals that address a Type of Investigation that is listed in Sections 3.3, 4.3, 5.3, or 6.3, this summary must also describe briefly how the proposed investigation addresses one or several of those investigations. For proposals that address a Type of Investigation that is NOT listed in the FST description, the summary must briefly describe the proposed Type of Investigation and how the proposed investigation will meet the Focused Science Topic Goals and Measures of Success. In addition, all proposers are expected to provide a set of metrics that they will use to identify progress toward their proposed goals. Finally, a set of milestones should indicate the anticipated timing of the major achievements during the course of the proposed study. These metrics and milestones may change once the FST Team is formed so the proposed metrics and milestones should be based on the proposed study as a stand-alone effort. The review panel will only consider material in this section when the "Proposed Contribution to the Focused Science Team Effort" portion of the proposal is evaluated.

7.2.3 *Step-2 Compliance and Evaluation Criteria*

Noncompliant Step-2 proposals will be returned without review. Step-2 proposals may be declared noncompliant if:

- The title has changed from that of the Step-1 proposal;
- Investigators have been added since the Step-1 proposal;
- The science goals and objectives have changed from that of the Step-1 proposal;
- The proposal has the same (or essentially the same) team and objectives as a Step-2 (full) proposal submitted to another Heliophysics program; or
- The proposal violates the restrictions in Section 1.1 regarding use of data. If possible, proposers should include a link or links to the data set(s) to be used in the proposed study.

Compliant proposals will be evaluated according to three main criteria: (1) Intrinsic Merit, (2) Potential Contribution to the Focused Science Team Effort (Relevance), and (3) Cost Reasonableness. The data management plan, described in ROSES, will also be evaluated. The Intrinsic Merit and Cost criteria will be evaluated primarily as specified in the *ROSES-2019 Summary of Solicitation* and the *NASA Guidebook for Proposers*, but Relevance is handled differently (see below).

The evaluation of Intrinsic Merit will consider information contained within the 15-page main body of the proposal (the Scientific/Technical/Management section). Most proposals are expected to describe a complete scientific study (i.e., clearly identified science questions and a project that makes significant progress on those questions in the context of current understanding. However, this program element also accepts proposals that lack a complete scientific study but instead describe a project that would enable or enhance the FST's activities (e.g. develop a data set or implement a model for use by the FST Team). Regardless of the project, all proposals must identify science questions responsive to the FST's goals that are addressed by the proposed work.

A critical element in enhancing understanding and developing predictive capabilities is the determination of whether the model or data products being developed, and any associated simulations, are accurate and reliable. Consequently, a methodology for verification and validation of results, and quantification of uncertainty, is required as a key component of the proposed research. As mentioned above (Sections 3.4, 4.4, 5.4, or 6.4), all proposals must address data and model uncertainty. This is described in Section 3.13 of the *NASA Guidebook for Proposers* which indicates that all proposals must address "sources of error and uncertainties and what effect they may have on the robustness of potential results and conclusions." The treatment of uncertainty will be evaluated by the review panel as a methodology issue (intrinsic merit) and will be assigned a strength or weakness based on the treatment presented in the proposal. Proposers are free to choose any appropriate method of uncertainty analysis but it must be clearly addressed in the body of the proposal. Proposals that fail to address uncertainty will be assigned a Major Weakness in the evaluation and may be considered unselectable.

The evaluation of the Potential Contribution to the Focused Science Team (Section 7.2.2) will serve as the Relevance evaluation. Please note that the review panel will consider only the response to this NSPIRES cover page question (described in Section 7.2.2) in the evaluation of this criterion and will not consider information in the main body of the proposal.

Evaluation of Cost Reasonableness will include a comparison of the scope of the proposed study to the proposed resources (personnel-time allocated, necessary computer resources, etc.).

8. Award Types

The Heliophysics LWS Science program will only award funds through three vehicles: (1) grants, (2) interagency transfers, and (3) awards to NASA centers. This call will not award contracts, as it is not appropriate for the nature of the work. Please also see the *ROSES-2019 Summary of Solicitation*, Section II a.

9. Summary of Key Information

Expected annual program budget for new awards	~ $4.9M
Number of new awards pending adequate proposals of merit	~ 21 – 26
Maximum duration of awards	4 years
Due date for Step-1 proposals	See Tables 2 and 3 of this ROSES NRA
Due date for Step-2 proposals	See Tables 2 and 3 of this ROSES NRA

Planning date for start of investigation	No earlier than 6 months after the Step-2 proposal due date.
Page limit for the central Science-Technical-Management section of proposal	15 pages; one extra page permitted for proposals to be Team Leader of a Focused Science Topic; see also Table 1 of the *ROSES-2019 Summary of Solicitation* and the *NASA Guidebook for Proposers*.
Relevance	Proposals relevant to the FSTs in this program element are, by definition, relevant to NASA. See Section 7.2.3 regarding evaluation criteria.
General information and overview of this solicitation	See the *ROSES-2019 Summary of Solicitation*.
General requirements for content of proposals	See Section 3 of the *NASA Guidebook for Proposers* and Section IV and Table 1 of *the ROSES-2019 Summary of Solicitation*.
Detailed instructions for the submission of proposals	See https://nspires.nasaprs.com/tutorials/ Sections 3.22-4.4 of the *NASA Guidebook for Proposers* and Section IV(b) of *the ROSES-2019 Summary of Solicitation*.
Submission medium	Electronic proposal submission is required; no hard copy is permitted.
Web site for submission of proposals via NSPIRES	http://nspires.nasaprs.com/ (help desk available at nspires-help@nasaprs.com or (202) 479-9376)
Web site for submission of proposals via Grants.gov	http://grants.gov (help desk available at support@grants.gov or (800) 518-4726)
Funding opportunity number for downloading an application package from Grants.gov	NNH19ZDA001N-LWS
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