B.5 HELIOPHYSICS LIVING WITH A STAR SCIENCE

NOTICE: Amended on April 10, 2020. This Amendment presents final text for this program element. Step-1 proposals are due August 27, 2020, and Step-2 proposals are due November 12, 2020.

This program element requires a statement on the NSPIRES cover page regarding the potential contribution to the Focused Science Team effort (see Section 6.3.2).

1. Scope of Program

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. Every year the LWS Program solicits Focused Science Topics (FSTs) that address some part of this goal. This year's FSTs are described in Sections 1.2 and 2-5 below.

This goal 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.

LWS is a component of the Heliophysics Research Program and proposers interested in this program element should read B.1, the Heliophysics Research Program Overview for Heliophysics-specific requirements. Defaults for all ROSES elements are found in the ROSES *Summary of Solicitation* and for all NASA solicitations in the *Guidebook for Proposers* (https://www.hq.nasa.gov/office/procurement/nraguidebook). The order of precedence is the following: This document (B.5) followed by B.1, followed by the ROSES *Summary of Solicitation*, and the *Guidebook for Proposers*. Proposers should review all of these resources to ensure compliance with Program requirements.

1.1 General LWS Goals and Background

The LWS program goals 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 program element. Proposers interested in Strategic Capabilities should see program element B.6 Living With a Star Strategic Capabilities. Cross-Disciplinary Infrastructure Building may be competed in a separate future element.

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 Revised Strategic Science Areas (https://lwstrt.gsfc.nasa.gov/assets/docs/lpag/LPAG_EC_report_2019_12_31.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).

1.2 Solicited Investigations

To be responsive, proposed investigations must have objectives suitable for one of the four following Focused Science Topics (FSTs). Detailed descriptions of each FST are given in Sections 2-5.

The FSTs solicited for proposals this year are as follows:

1) Modeling and Validation of Ionospheric Irregularities and Scintillations (described in Section 2);
2) Understanding and Predicting Radiation Belt Loss in the Coupled Magnetosphere (described in Section 3);
3) The Origin and Consequences of Suprathermal Particles that Seed Solar Energetic Particles (described in Section 4); and
4) Long Term Variability and Predictability of the Sun-Climate System (described in Section 5).

NASA desires a balance of research investigation techniques for each FST, including theory, modeling, data analysis, and simulations. This program element 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. FST teams will be formed from individual proposals that each address an aspect of the FST, and together attack the breadth of the FST (see Section 1.3 below).

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 below (Sections 2.4, 3.4, 4.4, or 5.4), all proposals must address data and model uncertainty. This is mentioned 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." Proposers are free to choose any appropriate method of uncertainty analysis or validation of results, but it must be clearly addressed in the body of the proposal.

1.3 Focused Science Teams

The selected investigators will form a Focused Science Team and coordinate their research programs after selection of proposals. In order to foster the collaborations required to coordinate these team research efforts, one of the Principal Investigators (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 in addition to the required annual progress report for their specific award.

Proposers wishing to serve as a Team Leader must state so in their proposal and must include a separate section immediately following the Science/Technical/Management section describing their qualifications, interest, and approaches to team leadership. Up to one extra page, separate from the Science/Technical/Management section, is allowed for this description. The selection of the Team Leader will be recommended by the LWS staff and made by the Heliophysics selecting official. Guidance for the team development process will be provided by NASA after selection of the Team Leader.

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.

All proposers must include sufficient travel funds in their budgets to cover two team meetings per year. In an effort to leverage travel costs, one meeting per year may 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.

1.4 Data Use in the LWS Program

This program element has policies on the use of data in proposals that expand upon and supersede those given in B.1, The Heliophysics Research Program Overview. Proposals to this program may only require the use of data that is in a publicly available archive at no cost at least 30 days prior to the Step-2 deadline for successful completion of the proposed project. 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 Officer of the element at least 10 days before the Step-1 deadline.

After an award is made, projects may incorporate new data that becomes available at no cost 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 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. Further, the Step-2 evaluation process (see Section 6.3.4) 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. FST #1: Modeling and Validation of Ionospheric Irregularities and Scintillations

2.1 Target Description

Ionospheric scintillations are rapid fluctuations in the amplitude, phase and angle of arrival of received radio signals due to irregularities in the ionospheric plasma that the signals traverse. Scintillations occur at a range of frequencies. L-Band scintillation adversely impacts the continuous tracking of Global Navigation Satellite System (GNSS) signals for position, navigation, and timing services. At UHF and lower frequencies, scintillation leads to intermittent communications outages, sometimes with serious impacts.

Scintillations are most frequent and severe at low- and high-geomagnetic latitudes. There are a number of reasons for this latitudinal dependence. The structure, orientation, and onset of irregularities can be influenced by the latitude-dependent orientation of magnetic field lines. The generation mechanisms can also vary with latitude due to changing conditions in the ionosphere as it responds to latitude-dependent inputs from space above (solar irradiance, solar wind, and magnetosphere) and from the atmosphere below. Further scientific understanding is required to model the latitudinal variation of these phenomena. At low latitudes, this includes the role of ambient ionospheric and thermospheric weather conditions, including electrodynamics and wind, as well as the gradient of bottom-side electron density and rising of the ionospheric F layer. At high latitudes, understanding is needed about the impacts of a host of instability mechanisms that drive severe plasma density, temperature and velocity irregularities imbedded in a time-dependent magnetic field, as well as other processes. At mid latitudes, storm-time drivers become important. The storm-time mid-latitude ionosphere is not well understood, and particularly the generation mechanisms of various types of irregularities that may produce GNSS scintillations during storm-time conditions. Improved ionospheric HF radars now make more measurements of the mid-latitude ionosphere that can support development and validation of new models for mid-latitude irregularities. Some specific candidates are the temperature gradient, gradient drift, and ion frictional heating instabilities.

At all latitudes, the generation mechanisms of ionospheric irregularities have not been investigated to a sufficient degree to understand their role in producing GNSS scintillations, HF radar scatter, and VHF/HF communications disruptions.

Achieving these capabilities will require data analysis and modeling investigations of the conditions, mechanisms and processes leading to the formation of ionospheric irregularities, as well as the dynamics driving their evolution and the impact on radio signals passing through them.

This FST is timely for a number of reasons:

- The upcoming availability of ICON and GOLD observations;
- The growth of the number of high-latitude flights and the opening of the Arctic to shipping and tourism;
- The expansion of technological systems that are vulnerable to disruption due to ionospheric irregularities and scintillations; and
- Increases in observational capabilities as well as models of ionospheric instability that can be tested against these measurements.

This FST is relevant to Decadal Survey Key Science Goal 2 (Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs), and several LWS Strategic Science Areas including SSA-IV (Variability of the Geomagnetic Environment), SSA-V (Dynamics of the Global Ionosphere and Plasmasphere), and SSA-VI (Localized Ionospheric Irregularities).

2.2 Goals, Objectives, and Measures of Success

The main goal of this FST is to understand and model the conditions that lead to the onset and evolution of ionospheric irregularities and resulting scintillation events at low, mid and high latitudes. To address this goal, proposed investigations should include one or more of the following objectives:

- Identify the mechanisms and structures that are responsible for ionospheric irregularities and scintillations at various latitudes (low, mid, and high latitudes) and longitudes;
- Determine growth rates, spectral characteristics, the nonlinear evolution associated with specific generation mechanisms and their role in scintillations;
- Identify the relationship between scintillation at various frequencies; and
- Identify the instability mechanisms responsible for polar F-region irregularities;

Measures of success include, but are not limited to:

- Advance our understanding of the temporal, spatial, and magnitude variability in ionospheric scintillation through data analysis and modeling studies.

2.3 Types of Investigations

An improved theoretical understanding of the initiation and evolution of ionospheric irregularities resulting in scintillation is critical to enabling a physics-based prediction capability of scintillation. Investigations include, but are not limited to, studies that address:

- The properties of instabilities at high-latitude including, but not limited to, irregularities associated with polar cap patches in regions of enhanced

particle precipitation and Interhemispheric aspects of scintillation-inducing irregularities in the polar cap;
- The geometries, scale sizes, and evolution of irregularities;
- Seeding mechanisms by which the instabilities initiate and evolve including comparison between model and observed scintillation data;
- Simulations of the structure and/or motions of plasma density at various latitudes;
- Quantification and simulation of the effects of the longitudinal structure of energy transport (traveling ionospheric disturbances and traveling atmospheric disturbances); and
- Determination of the dynamics and spatial scales of the instability after it grows.

Investigations within this FST may include theoretical, numerical, and data analysis methods. Relevant observational sources for these studies include present-epoch spacecraft and ground-based observations. Details of the data use policy are discussed in Section 1.4.

2.4 Predictability, Interaction with User Communities, and Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

3. FST #2: Understanding and Predicting Radiation Belt Loss in the Coupled Magnetosphere

3.1 Target Description

It is understood that radiation belt dynamics are determined by the changes in multiple plasma particle populations, which inherently involves the interactions that impact particle sources, losses, and their transport. The outer belt can experience variations in the trapped flux by two orders of magnitude over timescales ranging from a few hours to days, but there is also significant variation in where the peak flux location is observed. The Van Allen Probes mission has greatly improved the understanding of individual processes in the relevant regions, but as a whole, the sum of the interactions between different plasma populations has not yet provided a global perspective of the entirety of radiation belt dynamics. This is especially true for understanding and predicting the loss of radiation belt fluxes in this dynamic system.

To date, there are two major loss processes that have been the focus of research, wave-particle interactions that induce pitch-angle scattering into the loss cone or magnetopause shadowing which leads to non-adiabatic dropouts. In the case of wave-particle interactions, particles are pitch-angle scattered into the atmospheric loss cone when multiple plasma populations are co-located in regions such as the plasmasphere, the radiation belts, and the ring current. In the case of magnetopause shadowing, trapped particles reside on drift trajectories that intersect the magnetopause when there is sudden compression of the magnetosphere. Additional radiation belt loss processes that have been considered also include the possibility of rapid deceleration due to nonlinear wave-particle interactions. This focused science topic will address the degree to which various processes are responsible for radiation belt losses.

This FST addresses the Decadal Survey Key Science Goal 2 (Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs), and several LWS Strategic Science Areas including SSA-IV (Variability of the Geomagnetic Environment) and SSA-VIII (Radiation and Particle Environment from Near Earth to Deep Space).

3.2 Goals, Objectives, and Measures of Success

The main goal for this FST is to make significant progress towards understanding and predicting radiation belt loss processes within the inner magnetosphere. To address this goal, proposed investigations should include one or more of the following objectives:

- Provide better understand and ability to predict how the overlapping plasma populations can impact the radiation belt loss processes of electrons which in turn is correlated to the resulting wave particle interactions;
- Improved understanding and ability to predict the radiation loss processes are impacted by non-adiabatic dropout events; and
- Examine other potential loss processes, such as non-linear wave-particle interactions.

Compared to the energization of radiation belt particles and the study of radiation belt transport, the analysis, understanding, and prediction of the loss of radiation belt particles lags in progress. Therefore, this FST specifically focuses on enhancing our understanding of radiation belt loss processes within the framework of LWS needs. Studies to improve the understanding of radiation belt transport or energization are not considered an objective of this FST except where their inclusion is required to address loss processes.

Measures of success include, but are not limited to:

Demonstrate (1) understanding and (2) predictive capability of temporal, spatial, and magnitude of characteristics related to relativistic electron loss by using observations and existing models.

Magnetospheric research has seen a recent boon of observations (e.g., Van Allen Probes, Firebird, BARREL, ARASE, MMS, THEMIS) and historic ones (e.g., SAMPEX) that have greatly expanded the availability of the high quality data. Thus, there is a wide array of data that includes wave characteristics, *in situ* particles, and precipitating particles. During this same windfall era of premium data, radiation belt models have also benefited from this unprecedented wealth of information against which their performance can be measured and improved. Thus, this FST encourages data analysis and modeling studies that focus on the loss of radiation belt electrons from the inner magnetosphere to down to altitudes where atmospheric loss occurs.

3.3 Types of Investigations

In general, studies could include investigations that target a physical understanding of loss processes, improve our empirical understanding of the spatial and temporal characteristics of loss processes, or improve the predictability of relativistic electron loss and the presence (or absence) of conditions amenable to such loss. These investigations include, but are not limited to the following types of studies:

- Analysis of correlated wave and particle measurements that study localized interactions or reveal more about the magnetosphere-to-atmosphere relationships;
- Quantifying electron loss with respect to the spatial overlap between radiation belts and plasmasphere and associated wave phenomena;
- Quantifying the relative roles played by precipitation into the atmosphere versus non-adiabatic loss processes; and
- Modeling non-adiabatic radiation belt drop-out events to understand the underlying physical processes.

Investigations within this FST may include theoretical, numerical, and data analysis methods. Relevant observational sources for these studies include present-epoch spacecraft and ground-based observations, as well as historical records of proxy observations of the electron loss processes. Details of the data use policy are discussed in Section 1.4.

3.4 Predictability, Interaction with User Communities, and Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

4. FST #3: The Origin and Consequences of Suprathermal Particles that Seed Solar Energetic Particles

4.1 Target Description

Substantial improvements in our understanding of the sources and acceleration mechanism(s) of Solar Energetic Particles (SEPs) are essential for development of a predictive capability of potentially hazardous SEP events at Earth and elsewhere in the heliosphere. It is well established that suprathermal ions (ions of a few times the solar wind thermal particle energy up to hundreds of keV per nucleon) play a significant role as the seed population in the acceleration of SEPs by coronal mass ejection (CME) shocks. SEP measurements at ~1 AU from the Sun reveal highly variable intensity–time profiles, spectral shape, and charge-to-mass ratio dependence due to a combination of effects from seed particle acceleration and injection, shock acceleration and SEP transport. In the quest for a reliable prediction of the properties of large SEP events, it is necessary to understand and quantify the sources of variability from each of those processes. Predicting these variations requires refreshed observations and theories for suprathermal ion seed particles and their effects in producing the variability in SEP events. This focused science topic will bring together observers, modelers, and theorists in a collaborative effort.

There does not exist a community consensus to explain the source(s) and acceleration mechanism(s) of suprathermal particles and how exactly the seed particles contribute to large SEP events. The suprathermal particles that contribute to the largest SEP events must be produced close to the Sun, and their production process is likely smeared due to mixing, transport, and other effects by the time that they are observed at 1 AU or beyond. Observations from Parker Solar Probe and Solar Orbiter will fill this gap by providing *in situ* energetic particle measurements close to the Sun. This focused science topic will help with interpreting these data and will help to define science requirements for future measurements of suprathermal particles.

This FST is relevant to the Decadal Survey Key Science Goal 1 (Determine the origins of the Sun's activity and predict the variations in the space environment), Key Science Goal 3 (Determine the interaction of the Sun with the solar system and the interstellar medium), and Key Science Goal 4 (Discover and characterize fundamental processes that occur both within the heliosphere and throughout the Universe). It also addresses several LWS Strategic Science Areas including SSA-II (Solar Eruptive and Transient Heliospheric Phenomena) and SSA-III (Acceleration Transport of Solar Energetic Particles).

4.2 Goals, Objectives, and Measures of Success

The primary goal of this FST is to understand the origin of suprathermal particles and their effects in producing temporal and spatial variations and different spectral properties of SEPs. To address this goal, proposed investigations should include one or more of the following objectives:

- Understand the relative roles of solar flares and CMEs in producing large SEP events;
- Investigate particle acceleration mechanisms for producing suprathermal particles at the Sun and in the heliosphere and for accelerating these particles to high energies; and
- Understand particle transport, mixing, and other effects that result in the observed variability in the properties of SEP events at 1 AU.

Measures of success include, but are not limited to:

- Demonstrate understanding of the origins and acceleration of suprathermal particles and their role as seed particles for SEP events;
- Demonstrate understanding of temporal, spatial, and spectral variations in the properties of SEP events;
- Demonstrate a predictive capability for the properties of SEP events at various locations in the heliosphere.

The outcome from this FST will significantly advance our understanding of variations in large SEP events.

4.3 Types of Investigations

Investigations within this FST may include theoretical, numerical, and data analysis methods to enable a holistic approach to achieve the science goals. Investigations that address the FST's science goals and objectives include, but are not limited to:

- Analysis and modeling of suprathermal particles and SEPs with different species using observations from existing missions, including *in situ* spacecraft measurements as a function of time and location in the heliosphere, as well as remote sensing observations of seed particles in their source regions;

- Modeling and simulations to prepare for analysis of suprathermal particle and SEP measurements from recently launched and upcoming missions;
- Analysis and modeling of the evolution of suprathermal particles and SEP events as a function of time and location in the heliosphere (including the evolution of such events with distance from the Sun); and
- Development of realistic flare and CME models as well as particle acceleration and transport models including suprathermal particles and large-scale shock acceleration, and validation of these models using observations.

Currently available data sources for this FST include spacecraft data from ACE, Wind, SOHO, STEREO, GOES, Parker Solar Probe, and AMS-02. Potential sources of future data include Parker Solar Probe, Solar Orbiter, STPSat-6, and IMAP. Details of the data use policy are discussed in Section 1.4.

4.4 Predictability, Interaction with User Communities, and Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

5. FST #4: Long Term Variability and Predictability of the Sun-Climate System

5.1 Target Description

Variations in the geospace environment are driven by changes in solar inputs and yield a variety of terrestrial responses to this time-varying input. These changes in solar input include both electromagnetic and particle radiation, as well as solar modulation of galactic cosmic rays. They occur over a range of time scales that include short-term events such as solar eruptions, quasi-periodic phenomena such as daily-to-decadal variations in irradiance and high-speed solar wind streams, and longer-term variations such as changes in the sunspot cycle and the associated fluctuations in the magnetic field structure that impact the terrestrial system. This FST will examine the sources and effects of these changes in solar input and how they directly influence the geospace environment. In addition, solar-induced variations in the coupling of various processes throughout geospace give rise to important, second-order effects. Of primary interest are solar-driven impacts on regional and global terrestrial weather and climate, on time scales ranging from weeks (solar rotation) to years (solar cycle) to centuries (solar cycle variation). While shorter-term, impulsive events (flares, CMEs, etc.) are known to produce terrestrial responses, studies of these shorter-term processes will not be considered for this FST.

As with all areas of Heliophysics considered by the LWS program, this FST pursues studies which lead to predictive capabilities that require detailed knowledge of the physical processes related to the solar forcing that impact the Earth's environment. These studies include examinations of historical proxies of both solar activity and the associated terrestrial responses. In addition, the lengthening satellite record provides new opportunities for calibrating these proxies as well as utilizing more recently developed proxies and estimates of the relationship between solar and geophysical activity. Considering these recent and longer-term relationships, proposed studies should emphasize acquiring or refining our understanding of how solar variability and solar-driven geomagnetic variability lead to or alter atmospheric structure and coupling, with the intent of including these processes in global terrestrial climate models. It is expected that proposals submitted in response to this solicitation would focus on specific aspects of this goal. In order to limit the focus of this FST, only studies that primarily examine the solar inputs and/or responses of the terrestrial atmosphere will be included. Studies that focus primarily on ocean variability will not be considered.

Originally, LWS opportunities of this kind were competed under the Sun−Climate theme. This topic is now included as an FST to provide the benefits of a team approach to a specific topic. Despite the complex web of physical processes to be studied, the LWS Science program plays an important role in the overall study of long-term solar and terrestrial variability. In particular, these studies require expertise close to the core of the LWS goals, namely understanding solar and heliospheric activity and the physical processes that couple this activity to the Earth’s climate system. Work accomplished as part of this topic will enable the science community to move beyond simple correlations between solar variability and climate parameters, and instead to define the relevant physical connections.

This FST addresses Decadal Survey Key Science Goal 2 (Determine the dynamics and coupling of Earth’s magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs) and the LWS Strategic Science Area SSA-IX (Solar Impacts on Climate).

5.2 Goals, Objectives, and Measures of Success

The overarching goal of this FST is to provide reliable insight into how longer-term solar variability affects terrestrial variability in the face of natural and anthropogenic changes to the geospace system. To address this goal, this FST will cover two sets of objectives that involve solar or terrestrial studies on time scales ranging from weeks to years to centuries.

The objectives of studies that focus on the solar contributions should include one or more of the following:

- Development and utilization of improved historical proxies or models of changes in solar irradiance, particle, and magnetic inputs to improve the comparison of historical estimates to more recent observations; and
- Transition from proxy-based irradiance prediction to spectrally resolved irradiance that range from the x-ray to the infra-red. This includes the use of models with spectrally resolved irradiance rather than coarse spectral bins, based on either observational or synthetic spectra that vary over time.

The objectives of studies that focus on the impacts of solar variability on the terrestrial climate must examine processes that directly or indirectly amplify the effects on the

Earth of solar variability and solar-driven geomagnetic variability and should address one or more of the following:

- Large-scale structure and dynamics of the magnetosphere-ionosphere-thermosphere-mesosphere system with coupling to the lower atmosphere;
- Variations in atmospheric temperature, winds, and composition;
- Atmospheric waves and circulation;
- Clouds and precipitation;
- Modes of variability (e.g. El Nino-Southern Oscillation (ENSO), North Atlantic Oscillation (NAO), Pacific-North American Oscillation (PNA), Artic Oscillation (AO), Antarctic Oscillation (AAO), Quasi-Biennial Oscillation (QBO)); and
- Radiative process and forcing including the absorption and scattering of total and spectral solar irradiance.

Measures of success include, but are not limited to:

- Show how and to what extent various mechanisms couple and redistribute solar energy at Earth;
- Determine the radiative, magnetic, dynamical, and chemical feedbacks that control weather and climate throughout the atmosphere; and
- Link the regions driven directly by solar influences to tropospheric process where human activities are concentrated.

5.3 Types of Investigations

Investigations that address the goals of this FST will address time scales ranging from weeks (solar rotation) to years (solar cycle) to centuries (solar cycle variation). These investigations include, but are not limited to, the following types of investigations:

- Data analysis, modeling, and prediction of solar inputs such as modulation of irradiance, energetic-particle flux, and solar magnetic field modulation that impact processes in the terrestrial system.
- Data analysis, modeling, and prediction of terrestrial responses, such as: response to variations in the input, coupling, and transport within geospace; and
- Coordinated modelling and data analysis studies that examine the relationship between long-term solar variability and atmospheric and geospace responses including:
  - Predictions of the Earth system response to solar and geomagnetic forcing under future climate scenarios (e.g. the response of current or future terrestrial atmospheres to various possible solar input scenarios);
  - Analysis of the impact on weather and climate of a Maunder-like minimum or an extended period of enhanced solar maxima;
  - Analysis of the effect of long-term solar-driven impacts on large-scale atmospheric circulations; and
  - Analysis of changes in the interactions between different regions of the terrestrial atmosphere under various solar inputs and configurations of atmospheric structure and composition.

Investigations within this FST may include theoretical, numerical, and data analysis methods. Relevant observational sources for these studies include present-epoch spacecraft and ground-based observations, as well as historical records of proxy observations of the varying solar irradiance, particle, and magnetic inputs. Details of the data use policy are discussed in Section 1.4.

5.4 Predictability, Interaction with User Communities, and Uncertainty

In order to improve the usefulness of the results from this FST, all investigations in this FST must consider data and model uncertainty and how sources of error impact the results (see Section 6.3.4).

6. Submission and Evaluation Guidelines

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 at least 20% of their time to the investigation.

In addition to the general requirements and restrictions (e.g., in Table 1 of the *ROSES-2020 Summary of Solicitation* and in B.1 Heliophysics Research Program Overview) this program element has specific compliance constraints for both format (e.g., Sections 6.2.1 and 6.3.1) and content, e.g., involving data (see Sections 1.4 and 6.3.4). These compliance rules ensure fairness and are enforced strictly by the Heliophysics Division. Proposals that are deemed noncompliant may be returned without review or declined following review if violations are found during the evaluation process.

6.1 Two-Step Submission Process

To provide adequate notice to potential reviewers, this program uses a two-step proposal submission process. The overall description of a two-step process can be found in Section IV(b)vii of the ROSES *Summary of Solicitation*.

In the two-step process a Step-1 proposal is required. Because potential reviewers are solicited based on the Step-1 proposal, investigators cannot be changed between the Step-1 and Step-2 proposals, unless prior approval is obtained from the Program Officer of the element. The title and broad science goals of the proposal cannot be changed such that they would significantly affect the scientific or technical expertise required to properly evaluate a proposal.

6.2 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-2020. 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. 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 are eligible to submit a Step-2 (full) proposal.

Submission of a Step-1 proposal does not obligate the offerors to submit a Step-2 (full) proposal.

6.2.1 *Step-1 Proposal Format*

The Step-1 proposal is restricted to a 4,000-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 the relevance of the proposed study to the scientific objectives of the FST, and the potential contributions of the proposed study to the Focused Science Team's effort.

No PDF attachment is required or permitted for Step-1 proposal submission. Proposers will be notified by NSPIRES whether they are invited to submit their Step-2 proposals. Proposers are strongly encouraged to provide names and contact information of up to five experts qualified to review their proposal. These experts must not be from the institutions of the PI or Co-Is. This information can be supplied in response to NSPIRES cover page questions at the time of submission of the Step-1 proposal.

6.2.2 *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 be notified through NSPIRES to this effect.

6.3 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-2020). 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.

Only proposers who submit a Step-1 proposal and who are invited are eligible to submit a Step-2 (full) proposal. Proposers that have received a noncompliance letter in response to their Step-1 proposal are not eligible to submit a Step-2 proposal.

6.3.1 *Step-2 Proposal Format*

All proposals submitted to ROSES must strictly conform to the formatting instructions specified in the *ROSES-2020 Summary of Solicitation* except were superseded by the requirements in this program element. Proposals that violate these instructions may be returned without review or declined following review if violations are found during the evaluation process.

Proposals are restricted to fifteen (15) pages for the Science/Technical/Management section. Proposals for Team Leader additionally may use up to one extra page to describe the proposed team leader activities (see Section 1.3).

6.3.2 *Required Additional Section in Step-2 Proposal Cover 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 web interface cover pages. 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 may 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, Objectives, and Measures of Success) of the FST outlined in Sections 2.2, 3.2, 4.2, or 5.2;
- The potential contributions of the proposed study (Type of Investigation) to the Focused Science Team's effort outlined in Sections 2.3, 3.3, 4.3, or 5.3; 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 2.2, 3.2, 4.2, or 5.2. For proposals that address a Type of Investigation that is listed in Sections 2.3, 3.3, 4.3, or 5.3, 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 FST 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. Proposers must also provide a set of milestones that should indicate the anticipated timing of the major achievements during the course of the proposed study. These metrics and milestones may change once the Focused Science 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 potential contribution of the proposal to the Focused Science Team effort is evaluated (see Section 6.3.4).

6.3.3 *Step-2 Compliance*

Noncompliant Step-2 proposals will be returned without review or may be declined if the noncompliance is found during the evaluation process. Step-2 proposals may be declared noncompliant if:

- The title has substantially changed from that of the Step-1 proposal;
- Investigators have changed since the Step-1 proposal without prior approval of the Program Officer;
- The science goals and objectives have substantially 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;
- The proposal violates the restrictions in Section 1.4 regarding use of data; or
- The proposal violates the formatting instructions in Section 6.3.1.

6.3.4 *Step-2 Evaluation Criteria*

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 Section 1.5 of B.1, the Heliophysics Research Program Overview, will also be evaluated. The Intrinsic Merit and Cost criteria will be evaluated primarily as specified in Section VI of the *ROSES-2020 Summary of Solicitation* and defined in the *NASA Guidebook for Proposers*, but Relevance is handled differently. Clarifications and additions specific to this program element are listed below.

The evaluation of intrinsic merit will include the following:

- Scientific Merit: Compelling nature and scientific priority of the proposed investigation's science goals and objectives, including the importance of the problem within the broad field of Heliophysics; the unique value of the investigation to make scientific progress in the context of current understanding in the field, and the importance of carrying out the investigation now; and
- Technical Merit: Appropriateness and feasibility of the methodology, including the appropriateness of the selected data, models, and analysis for completing the investigation and the feasibility of the methodology for ensuring scientific success.

The treatment of uncertainty will be evaluated as a methodology issue (intrinsic merit) and the review panel will assign a strength or weakness based on the treatment presented in the proposal. Proposals that fail to address uncertainty will be assigned a Major Weakness in the evaluation and may be considered unselectable.

Based on the above two factors (Scientific and Technical Merit), the evaluation will consider the overall potential science impact and probable success of the investigation and an adjectival grade for Intrinsic Merit will be assigned. The evaluation of the potential contribution to the Focused Science Team effort (Section 6.3.2) will serve as the Relevance evaluation and an adjectival grade for Relevance will be assigned. Please note that the review panel will consider only the response to this NSPIRES cover page question (described in Section 6.3.2) in the evaluation of this criterion and will not consider information in the main body of the proposal.

The final adjectival grade assigned to the overall evaluation will be the lower of the two adjectival grades for Intrinsic Merit and Relevance.

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.). The panel will provide feedback to SMD but will not assign a grade and this information will be considered by the Heliophysics selecting official during the selection process.

7. 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-2020 Summary of Solicitation*, Section II a.

8. Available Funds

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 $180K-$250K 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.

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.

9. Summary of Key Information

Expected annual program budget for new awards	~ $5M, see also Section 8, above.
Number of new awards pending adequate proposals of merit	~ 20-28, see also Section 8, above.
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 a separate section for proposals to be Team Leader of a Focused Science Team; see also Table 1 of the *ROSES-2020 Summary of Solicitation* and the *NASA Guidebook for Proposers*.
Relevance	Proposals that are relevant to the FSTs in this program element are, by definition, relevant to NASA. See Section 6.3.4 regarding criteria.
General information and overview of this solicitation	See the *ROSES-2020 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-2020 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-2020 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	NNH20ZDA001N-LWS
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