NASA Heliophysics Division
Strategic Space Flight Programs
Structures and Implementations

1. Introduction

NASA Heliophysics Division has three strategic space flight programs: Solar Terrestrial Probes (STP), Living With a Star (LWS), and NASA Space Weather (NSWx). (The fourth space flight program, the Explorers program, is not a strategic program. That program solicits only mission concepts where the science objectives and mission implementation details are defined by the proposer.)

STP and LWS missions have been primarily defined by the solar and space physics decadal surveys (published by the National Academies of Sciences, Engineering, and Medicine [“National Academies”]). NSWx was formulated after the 2013 Decadal Survey and has supported mission development outside of the decadal survey process.

This document summarizes the historical structures of the STP and LWS programs, discusses the structural characteristics that enable a healthy and robust program, and defines a new structure for these three strategic programs.

1.1 Decadal Surveys, 2003 and 2013

The first two solar and space physics decadal surveys, *The Sun to the Earth – and Beyond: A Decadal Research Strategy in Solar and Space Physics* (henceforth 2003 Decadal Survey) and *Solar and Space Physics: A Science for a Technological Society* (henceforth 2013 Decadal Survey), recommended missions for the STP and LWS programs. Each mission was based on broad science goals that it could address (and included a “reference mission” that would address those goals).

The 2003 Decadal Survey prioritized missions of three types (based on the cost to NASA): large (>$400M FY2002), moderate ($250-400M FY2002), and small (<$250M FY2002). It assigned moderate missions to STP and a combination of all three types to LWS.

In the following decade, STP began and/or completed development of two NASA-led missions that addressed prioritized science goals (STEREO, MMS) and one NASA contribution to a partner mission (HINODE). LWS began and/or completed development of five NASA-led missions (SDO, RBSP, BARREL, PSP, SET) and one prioritized NASA contribution to a partner mission (Solar Orbiter). Of the NASA-led missions, only one was PI-led (BARREL).

When the 2013 Decadal Survey was released, it contained a recommendation to restructure the STP program and identified a method for distinguishing the STP and LWS programs from one another.

The STP restructuring would shift the program from supporting moderate-scale, NASA-led ("directed") missions to a "moderate-scale, competed, principal-investigator-led (PI-led) mission line that is cost-capped at $520 million per mission in fiscal year 2012 dollars including full life-cycle costs." [R3.0]. Following from this recommendation, three specific mission implementations were prioritized [R3.1-3.3].

With this restructuring, the 2013 Decadal Survey distinguished the STP and LWS programs primarily on project management and cost cap. The links to expected science results and LWS' stated focus on life and society were secondary to the programmatics and anticipated project complexity:

> A very important distinction is made by the survey committee between the restructured STP program and the Living with a Star (LWS) mission. Certain scientific problems can be addressed only by missions that are relatively complex and costly. […] As research evolves naturally from the discovery-based mode to one focused increasingly on quantification and prediction, missions benefit strongly from an integrative approach, whereby the knowledge obtained from prior research can be combined with new, innovative measurements for the development of understanding of the global machinery of the system. This effort may naturally require a larger mission, and it also accords with the societal-relevance theme of the LWS program. In the survey committee's plan, major missions are thus appropriately undertaken via NASA's LWS program and would continue to be executed by NASA centers, whereas the STP program should be considered a community program, like the Explorer program. [p. 106]

Although the 2013 Decadal Survey's program distinction does include references to science motivation and results, other parts of the decadal survey demonstrated how difficult that difference is to maintain when the recommendations are primarily based around mission implementations, specific instruments/measurements, and programmatics. As examples:

1. The recommendation for IMAP specifically references its serving as a real-time L1 monitor for space weather observations [p. 99].
2. The Atmosphere-Ionosphere-Magnetosphere Interactions (AIMI) panel repeatedly referenced the value of DYNAMIC to space weather in its prioritization discussion. (This was done for all mission concepts, including those not recommended.)
    - "It is the AIMI panel's view that the Heliophysics Systems Observatory should be continued with a mission that determines how solar energy drives ionosphere-thermosphere variability, and that *lays the foundation for a space weather prediction capability*. There are two complementary notional missions that are put forth as the panel's highest-priority imperatives to satisfy this need: GDC and DYNAMIC." [Section 8.5.1; emphasis added]
    - Relevance to space weather by the ability to "enable prediction" and "develop the basis for forecasting" of ionosphere-thermosphere phenomena [Table 8.4]
3. The Solar Wind-Magnetosphere Interactions panel, the source of the MEDICI reference mission, considered in its prioritization the broader impact of a mission, with a given example being "the development of a forecasting system for space weather".

1.2 Post-2013 Implementation Issues

In the decade after the 2013 Decadal Survey was published, it was recognized that there were unintended consequences of the recommended STP/LWS distinction. The National Academies documented some of these concerns in their report *Progress Toward Implementation of the 2013 Decadal Survey for Solar and Space Physics: A Midterm Assessment* (henceforth 2020 Decadal Survey Midterm).

In Section 6.2, “Considerations for Next Decadal Survey Process”, the 2020 Decadal Survey Midterm stated:

> Separation of strategic missions into the STP and LWS programs by their cost, instead of by their science focus, is not an effective long-term scenario to maintain two distinct programs, nor for planning a regular cadence for strategic missions that comparably advance the different heliophysics sub-disciplines. Lessons learned from implementing the PI-led IMAP (Interstellar Mapping and Acceleration Probe) mission under STP and from implementing the Parker Solar Probe and planning the GDC-like (Geospace Dynamics Constellation) mission under LWS will provide valuable guidance in defining future NASA strategic missions. Furthermore, elucidation of the overarching and unique science goals for the distinct STP and LWS programs are important as guidance for the next decadal survey studies. [p. 6-4]

It followed this discussion with one Finding and one Recommendation for NASA:

> *Finding 6.5:* The next decadal survey committee may want to consider how to best distinguish the NASA Heliophysics LWS and STP strategic mission lines, both in terms of critical science goals and implementation strategies. Without distinct goals for these two programs, there is a risk to limit effective planning for larger strategic missions.
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> *Recommendation 6.3:* [...] To address the evolving needs for science-driven strategic plans, the agency sponsors should ensure the following items are included as tasks for the next decadal survey committee:
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> > Definition of distinct science goals and implementation strategies for NASA’s Solar Terrestrial Probes and Living With a Star programs[.]

In its formal response to the National Academies, NASA addressed each recommendation. For Recommendation 6.3’s note on the STP and LWS programs, NASA responded:

> NASA agrees that it is important for programs to have distinct science goals and implementation plans, and is currently conducting internal discussions to distinguish the scopes and boundaries of the Solar Terrestrial Probes and Living With a Star programs. These discussions are based upon the referenced need for a scientific basis that is able to evolve with the Heliophysics Division’s, the Agency’s, and the Nation’s needs. NASA's intention is to produce a plan for those programs, after which NASA would seek comments and input from the science community. A final plan for the two programs would then be published in time for the next decadal survey.

This document describes the plan for distinguishing the STP and LWS programs. It additionally addresses the NSWx program, which was not referenced in the midterm recommendation, with finer details deferred to a document focusing on NSWx and LWS.

2. Program Structures

2.1 Background

The primary bases upon which mission programs can be distinguished from one another are programmatic or scientific.

The 2013 Decadal Survey's method was programmatic (e.g. cost cap, project management paradigm). Beyond the subsequent midterm assessment's acknowledged long-term concerns, the decadal survey's programmatic basis that the midterm did not discuss also will not lead to a sustainable long-term solution.

The decadal survey motivated the distinction, in part, by saying that larger missions were necessary to make progress on space weather quantification and prediction with innovative measurements of a global system. However, the report itself stated that the recommended STP missions would produce those results and the next ten years showed that advances in small-spacecraft technologies could enable Explorer-class missions to do the same.

That leaves distinguishing the programs based on science alone. This can be interpreted in three different ways: 1) broad science goals, 2) focused science objectives, and 3) science measurements.

The 2013 Decadal Survey's recommendations for mission science used (1) and (3). However, this was not sufficient to fully distinguish missions or mark when science progress had negated the need for a new project.

In the 2013 Decadal Survey, the recommended science goals and science measurements for DYNAMIC (STP) and GDC (LWS) had a significant amount of overlap. The 2020 Decadal Survey Midterm discussed how the GOLD, ICON, and AWE missions (selected competitively in the Explorers program) overlapped with the DYNAMIC science goals but would not provide all of the recommended measurements or complete all of the recommended science goals [Finding 3.27].

It is important to note that recommendations that do not include focused science objectives will always encounter this ambiguity. Science goals are not expected to be completed by a small number of missions, so the Midterm Assessment's Finding (cited above) will always be true. With just a set of measurements and a mission implementation, it will be a perpetual challenge to determine when a set of other missions have significantly reduced the priority of the recommended mission.

2.2 Effective Program Structures

Program structures that are effective and sustainable in the long-term have a set of characteristics:

- Clear definitions that…
    - …flow from and to program goals and objectives;

    - …do not overlap with one another;
    - …are objectively distinguishable; and
    - …permit immediate, exclusive assignment of missions to a mission line.
- Programmatic structure that is…
    - …mature (e.g., well documented, follows set processes, provides accountability);
    - …agile and responsive; and
    - …accessible to stakeholders (both inside and outside of the government).
- Programmatic content that has…
    - …a basis in science goals and objectives, and not particular mission implementations;
    - …a clear role in larger Agency activities; and
    - …a clear link to a multi-decadal science strategy.

Although community discussions on the difference between STP and LWS have revolved around programmatic bases and specific mission implementations, they have also included the scientific motivation and narrative. Those key concepts, as discussed in previous documents, can be formalized to form an implementation strategy that addresses the 2020 Decadal Survey Midterm's conclusions.

These program structures are based around project objectives. Objectives are those narrowly scoped tasks that will be completed by the project. They are clear steps in a strategy to address science goals (where science goals are sometimes phrased as science questions that cannot be completely answered by a single mission), and lead to science requirements. Those science requirements then would flow down into mission implementation details (e.g. measurements, orbits, lifetime).

[It should be noted that these objectives are only the tasks that a mission is prioritized, designed, and flown to complete. It is understood that every science mission will return data that would (alone or with other missions' data) enable other science tasks to be completed. This point will be discussed in Section 3.]

2.3 Defining Program Structures

In the following sub-sections, the science focus and implementation strategy for the NSWx, LWS, and STP programs are each discussed. The distinction between these programs expands on and refines the existing program narratives.

The Living With a Star program's focus has always been the science "necessary to understand those aspects of the space environment that affect life and society" and that "enable[s] robotic and human exploration" [2005 Heliophysics Roadmap, 2009 Heliophysics Roadmap]. Although the previous documents' focus tended to be on impacts to Earth and the terrestrial space environment, these foundational concepts are inherently and explicitly generalizable to all targets of NASA space science investigations. The Roadmaps and the decadal surveys repeatedly called out the application of Living With a Star-responsive science to other subjects, including exploration (e.g. 2013 Decadal Survey, pp. 69-70) and planetary habitability (e.g. 2005 Roadmap, p. 24).

The Solar Terrestrial Probes program's focus has been described as either "understanding the fundamental physical processes that determine the mass, momentum, and energy flow" or "target[ing] the 'weakest links' in the chain of understanding" of the solar and space environments [2005 Roadmap, 2009 Roadmap]. Although the application of Solar Terrestrial Probes-responsive science outside of the heliosphere was not as explicitly stated as for Living With a Star, the theme of the universality of those physical processes was clearly made in the 2013 Decadal Survey's Key Science Goal 4, *Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe,* and related discussions.

These imply a distinction based on proximity to a predictive capability (whether for space weather or specific impacts on life; this distinction is sometimes referred to as the "maturity" of a science topic). That difference can be used to build a clearer programmatic distinction between the STP and LWS. In addition, the NSWx program fits into this distinction by its explicit link to the transition between science and operational activities.

2.3.1 NASA Space Weather (NSWx)

The NASA Space Weather program expands NASA's role in National space weather activities and formalizes it within a single program. Its scope focuses on the effective transition of space weather relevant scientific knowledge, capabilities, technology, and techniques to operational and application environments. These activities are supported for the purpose of improving existing operational capabilities and developing applications to support space weather end users through the Research-to-Operations-to-Research loop.

This program supports work that includes, but is not limited to,

1) decreasing uncertainty or measures of error in current operational predictions and forecasts,
2) demonstrating new technologies' and techniques' suitability for transition from research to operations and applications, and
3) supporting radiation measurement and validation for NASA human and robotic exploration activities (e.g. Artemis Program).

NSWx activities are more guided by Agency and National needs than the LWS and STP programs, specifically in its work within NASA's areas of responsibility, as articulated in the 2019 National Space Weather Strategy and Action Plan and the 2020 Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow (PROSWIFT) Act. External input (e.g. decadal survey, advisory committees) is incorporated as appropriate and as permitted within program resources.

Many of these are addressed by the program's Research and Analysis component, but certain tasks can only be met in the space flight component. It is expected that these space flight missions will be formulated primarily as hosted payloads (on NASA and non-NASA platforms) and small missions or medium-sized missions.

Although space environment measurements are a necessary component of most NSWx projects, the program (like all NASA Heliophysics programs) does not support long-term monitoring for non-NASA operational uses. In instances where a NASA capability is desired for another Agency's operational use, it is expected that continued operations would be supported by the other Agency or the asset would be transitioned to the other Agency.

NSWx program objectives are defined in terms of specific science, technology, and/or exploration objectives that are clearly within the scope described above and that can be completed by a space flight mission.

2.3.2 Living With a Star (LWS)

The Living With a Star program is responsible for completing science objectives necessary to achieve quantified, measurable advances in understanding those aspects of the Sun and the space environment that affect life and society. The goal of this 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. This program is the primary method through which the Heliophysics Division contributes its scientific expertise to

1. developing new heliophysics system science capabilities intended and expected to have a path to operational space weather prediction and forecasting,
2. supporting preparation for human and robotic exploration of the heliosphere, and
3. understanding the space environment's impact on life (whether terrestrial or not).

For space weather-relevant topics, LWS investigations produce the new scientific understanding and capabilities. After the investigation is completed, the NSWx program assumes responsibility for transitioning the new capabilities to operational uses.

For exploration-relevant topics, LWS investigations produce scientific understanding that is intended to be leveraged in the design and development of future exploration projects.

For impacts on life, LWS investigations study the Sun and other stars (alone or in combination) and Earth and other planets (alone or in combination) to produce scientific understanding that informs the effects of the space environment on the development and persistence of life. This includes planetary habitability and other astrobiological topics that benefit from heliophysics expertise.

The implementation strategy for formulating LWS missions uses a structure that is analogous to the Focused Science Topics (FSTs) used for LWS Targeted Research and Technology (TR&T), also referred to as LWS Science activities.

The LWS Strategic Science Areas (SSAs) are very broad and long-term themes. LWS TR&T has FSTs that are moderately broad and short-term endeavors. Each FST breaks down into a defined set of objectives that investigations can demonstrate the completion of through clear measures of success. LWS supports one or more narrowly focused, short-term investigations that produce quantified new knowledge and/or capabilities.

The LWS program has Focused Mission Topics (FMTs) that are the mission equivalent of FSTs. These FMTs addressed targeted scientific needs for one of the above three areas. Each FMT is composed of specific, completable scientific objectives that have clear metrics for success.

These FMTs are developed through external input (e.g. decadal survey) with modifications and/or additions based on programmatic concerns. These concerns may be due to emerging Agency interests (e.g. exoplanets, habitability, human exploration efforts) or National needs (e.g. pre-operational space weather).

The mirroring of the LWS TR&T and the LWS space flight missions structure provides a clear framework that is accessible to stakeholders, provides flexibility in implementing supported activities, and enhances the complementary nature of the two sides of the LWS program. This programmatic focus also allows Heliophysics Division to maintain a long-term strategy that is aligned with Agency and National interests informed by the scientific community's expertise.

The LWS program does not prioritize specific space flight missions or specific measurement capabilities, but rather the FMTs (and their objectives). LWS space flight investigations are then formulated in order to complete one or more of those objectives, with the scope of each investigation determined by the resources available.

2.3.3 Solar Terrestrial Probes (STP)

The Solar Terrestrial Probes (STP) program focuses on significant, broad-based scientific progress for the heliophysics field as a whole. It supports space flight investigations that address short-, medium-, and long-term strategic scientific needs, interdisciplinary science, and cross-mission synergies.

While documents (e.g. 2009 Heliophysics Roadmap) have previously discussed STP in terms of fundamental processes, that framing weakens the focus on broad scientific advance. As a strategic program, STP investigations are formulated based on the identification of long-term advances and the necessary steps towards achieving them.

A successful STP investigation closes a general knowledge gap that is inhibiting advancement of the scientific field as a whole. An investigation that addresses a narrowly focused objective without opening up a scientifically broader field of scientific inquiry is not strongly responsive to the STP program.

For science topics potentially relevant to the LWS program, STP investigations are responsible for the scientific understanding of the physical that is necessary to identify the path to developing predictive capabilities, constraining the processes that could affect or be leveraged by exploration projects, or quantifying impacts of the space environment on life and society. If the STP investigation's completion produces a clear path to quantification/application, then the LWS program is responsible for any subsequent investigation that would execute that applied-science investigation. (This later investigation would likely be executed with a new LWS mission, as continued operation of the STP mission would be based on additional STP science investigations.)

The STP program has strategic science objectives that flow down into investigation science objectives that STP missions are formulated to complete. These strategic objectives are defined at a level between investigation goals and investigations objectives. They are more narrowly focused than investigation science goals such that there is a clear path to specific science objectives, but not so focused that they pre-define the exact scope of an investigation (i.e. the objectives).

These strategic science objectives are developed through external input (e.g. decadal survey) with modifications and/or additions based on programmatic concerns. These concerns may be due to emerging Agency interests (e.g. exoplanets, habitability, human exploration efforts) or National needs (e.g. physical processes common across different space environments).

3. Project Prioritization

Each program supports the formulation of projects whose objectives represent significant progress on the program objectives, as described in the previous section. Programs do not support the formulation of projects to complete objectives not relevant to the program objectives.

By these definitions, there is no overlap between NSWx, LWS, and STP missions in terms of project objectives.

However, it is possible for a project, alone or in combination with other projects, to produce data sufficient to complete science investigations outside the scope of its own objectives. This is true for complementary projects within the Heliophysics System Observatory, projects operated by other organizations, or ground-based observatories.

That reality of scientific impact beyond the project objectives is understood and expected. However, that potential impact is not relevant to the determination of which program supports a project.

The formulation of a project within a program depends only on the project objectives' ability to make progress on the program objectives. The prioritization of a project within a program depends only project objectives' amount of progress on the program objectives.

In the situation where two programs have separate program objectives that could be addressed by similar (or the same) mission implementations, each program would prioritize a project separately. The program that would support the development and operation of that mission would be the one that assigned a higher priority to the respective project objectives.

Assuming that the first program's project was successfully implemented, the other program would be expected to *not* develop a highly similar mission but rather formulate the project next in its priority list.

4. References

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