# On the Need for a Coronal and Inner Heliospheric Panel for the 2024 Heliophysics Decadal Survey

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**Synopsis**

The unique recommendation of this White Paper is that the 2024 Decadal Survey has a panel specifically dedicated to the Physics of the Upper Corona and Inner Heliosphere, separate from a panel on Solar Physics.

The organization of the decadal survey in panels is a key component that greatly affects the overall results and recommendations. In past cycles, the Solar and Space Physics (Heliophysics) decadal survey was organized along three main scientific panels, merging together all solar–heliospheric research, while separating magnetosphere–ionosphere–thermosphere–meososphere (M-ITM) processes into the solar wind–magnetosphere panel and the atmosphere–ionosphere–magnetosphere interactions panel. We argue that this organization does not reflect the current focus of NASA Heliophysics and overall space physics research, and is unfair to researchers focusing on the Sun and heliosphere, since they comprise about 50% of researchers in heliophysics. Inner heliospheric instrumentation combines instrumentation typically used for solar research (remote sensing) and for geospace research (plasma and field and energetic neutral atoms). This results in a wide range of expertise needed to judge mission concepts for inner heliospheric research. The requirement of launching to interplanetary space for most inner heliospheric missions makes this community unique within Heliophysics and closer to the planetary community in the complexity of developing explorer-class mission concepts. Therefore, a split of the solar–heliosphere research area into solar physics and the physics of the heliosphere is needed, especially if magnetosphere and ITM are separated. The place of outer heliosphere within these is also discussed.

## 1 Introduction

• **Panel Organization in Past Heliophysics Decadal Surveys**

In past decadal cycles, the Solar and Space Physics (Heliophysics) decadal survey was organized along three main scientific panels, merging together all solar–heliospheric research, while separating magnetosphere–ionosphere–thermosphere–meososphere (M-ITM) processes into the solar wind–magnetosphere panel and the atmosphere–ionosphere–magnetosphere interactions panel. Hereafter, we do not focus on the possibility for other panels or working groups, for example focusing on applied research (space weather), specific techniques (theory, modeling) or the state of the profession. The focus of this white paper is fully on the organization of the basic research panels in the 2024 Decadal Survey for Solar and Space Physics.

## 2 Inner Heliosphere Research

• **Relative Importance of Inner Heliospheric Research: NASA Awards**

The NASA/Heliophysics Supported Research (HSR) program is the most open call for proposals and provides a way to judge the relative importance of the different categories. For selections in 2020–2021 (the most recent year for which data are available), 50% (35/70) of the proposals selected for funding through the NASA/HSR were in the domain of Sun–heliosphere with a near 50–50 balance in both years. For selections in 2018–2019, NASA separated the selections into four regimes: Sun, heliosphere, magnetosphere, ITM. Over these two years, there were 37 proposals selected in the magnetosphere domain (34%), 33 for Sun (31%), 26 for heliosphere (24%), and 12 for ITM (11%). As such, heliospheric research represents about one quarter of Heliophysics research (and Sun–heliosphere more than half). The exact weight of inner heliospheric research depends on where upper coronal research is put (for example, are PSP and PUNCH solar or heliospheric missions?), but as is argued below, the difference between solar and inner heliospheric research and instrumentation, in many respects, requires a separate panel.

We note that the two communities are represented by the American Astronomical Society (AAS) Solar Physics Division (SPD) for solar and coronal research and the Solar, and by Heliospheric and INterplanetary Environment (SHINE) for coronal and inner heliospheric research. Both organizations have yearly meetings in the summer. There is clear overlap (in terms of themes and personnel) between the two communities, but they remain very distinct. Over 300 researchers have been attending the SHINE workshop yearly in the past few years, a similar number that attends the SPD meeting, with only limited overlap.

• **Heliophysics 2050 Workshop Organization**

The Heliophysics 2050 workshop was supported by NASA, NSF, and NOAA ahead of the Solar and Space Physics Decadal Survey. The goal was to enable conversations that would provide a common basis in preparation for the Decadal process. This community-led workshop was held virtually from May 3 to May 7, 2021. White papers were requested in advance of the meeting. The Science Organizing Committee (SOC) worked together to identify themes contained within and complementary to the white papers submitted for the workshop, and then constructed the program around those themes. As such, and after internal discussion, the Heliophysics 2050 workshop was organized as follows:

1. Solar: Dynamo/Cycle/Global Surface Properties
2. Corona and Inner Heliosphere
3. Magnetosphere
4. Ionosphere, Thermosphere, Mesosphere
5. Space Weather: Basic and Applied Research, Operations, and Human Exploration
6. Outer Heliosphere and Interstellar

7. Expanding the Frontiers: Planetary Magnetospheres / Habitability / Exoplanets / Sun-as-a-Star
8. Heliophysics as a Community in 2050
9. Fundamental Physics Processes [5 themes: Wave–Particle Interactions, Magnetic Reconnection, Turbulence, Plasma–Neutral Interactions, Shock Physics]

This organization represented, approximately, the same division as for NASA ROSES Heliophysics for the first four themes, as well as three additional science themes and two sessions on overarching physical processes and community. During discussions, the SOC decided to separate inner and outer heliosphere, and to join interstellar physics with outer heliosphere (instead of expanding the frontiers) and to join corona with inner heliosphere (where research on coronal processes has a more appropriate place than in solar physics).

The preceedings from the workshop includes the following write-up regarding the coronal–heliospheric research. “Key science questions include the 1) force balance of eruptive magnetic structures at different distances, 2) the locations where the evolution of the solar wind and of eruptions transitions from magnetically dominated to primarily hydrodynamical, and 3) the partition of energy between its thermal, kinetic, and magnetic components, including energy carried out by energetic ions and electrons. Further out, interactions between coronal and interplanetary structures mediate the mass and energy transfer and the transport of energetic particles. The peak CME speed is typically reached close to the boundary between the corona and the heliosphere, as defined by the region where the solar wind becomes super-Alfvénic. While some progress has been made towards understanding the large-scale evolution and variation of transients in general, the moderate-scale is still largely unexplored and the physical causes and drivers of event-to-event variability are still unknown. In addition, the formation and properties of CME-driven shocks and sheath regions is an area where progress remains relatively elusive.” These are some of the science questions driving research in the middle and upper corona, inner heliosphere and interplanetary space.

While white papers submitted to the 2050 Heliophysics workshop only represent a snapshot of the community and the different level of preparation of sub-disciplines did affect the numbers, this however, provides a quantitative estimate of the heliophysics community. The list of white papers submitted to the 2050 Heliophysics decadal survey can be found here: https://www.hou.usra.edu/meetings/helio2050/pdf/helio2050whitepapers_program.htm. It includes 37 white papers on solar physics, 20 on heliospheric science, 13 on magnetospheric science, 21 on ITM science, 16 on space weather, 4 on interstellar/exoplanet science, 15 on programmatic topics, and 4 on technology. Physics of the heliosphere carries the same weight as ITM science and more than magnetospheric science based on these numbers.

Once organized by the SOC, there were 53 posters on the Sun, corona, and inner heliosphere, 43 posters on the Near-Earth environment, and 31 posters on space weather, outer heliosphere, and Local Instellar Medium (LISM). Once again, this shows that solar–heliospheric physics represent about 50% of Heliophysics and that the number of researchers working in the upper corona and inner heliosphere is approximately equal to the number of those working in the solar interior, surface, and low corona.

• **NASA ROSES Heliophysics Organization**

The Heliophysics program overview as published by NASA (for example the 2022 ROSES B.1 Heliophsyics Research Overview) lists five overarching "research regimes": **Sun, Heliosphere, Magnetosphere, Ionosphere–Thermosphere–Mesosphere (ITM) and System-Interdisciplinary**. These research regimes are further divided into 18 science topics:

1. Solar Interior
2. Photosphere

3. Solar Transient Events
4. Solar Atmosphere – Corona
5. Particle Acceleration, Transport, Modulation
6. Turbulence, Waves, Composition
7. Interplanetary CMEs / Magnetic Clouds
8. Outer Heliosphere – Interstellar Boundary
9. Dayside Magnetosphere
10. Inner Magnetosphere
11. Magnetotail
12. Ionosphere – Atmosphere Coupling
13. Neutral Atmosphere
14. Solar – Heliosphere Coupling
15. Solar Wind – Magnetosphere Coupling
16. Magnetosphere – Ionosphere Coupling
17. Solar – Ionosphere/Atmosphere Coupling
18. Multi-disciplinary

It is clear that topics 1–3 belong to solar physics, topics 6–8 to heliospheric physics, while topics 4–5 are coronal and are shared between both (in particular, particle transport is clearly heliospheric) and topic 14 corresponds to the coupling between these two regions. Topics 9 and 15 belong to solar wind–magnetosphere and topics 12, 13, 16 to atmosphere–ionosphere–magnetosphere interactions, while topics 10 and 11 can be considered as belonging to both solar wind–magnetosphere and magnetosphere–ionosphere–atmosphere interactions. Topics 17 and 18 can be considered interdisciplinary. As such, heliospheric physics represent $\sim$ 22%—26% of topics (3 full, two partially out of 17 topics, excluding the multi-disciplinary one).

## 3 The Need for a Panel on the Physics of the Upper Corona and Inner Heliosphere

• **Physics of the Upper Corona and Inner Heliosphere**

**We argue that having a panel on the physics of the corona and inner heliosphere is necessary**, as reflected both in NASA ROSES discussion and through the Heliophyics 2050 workshop. Our definition of the inner heliosphere consists of the heliosphere between the Alfvén surface (the boundary with the corona) and Mars, following the language of inner/outer planets. In terms of processes, this is the space where individual structures and transients dominate, i.e. before the formation of merged interaction regions at Jupiter's distance. The physics of the upper corona and inner heliosphere consists of a number of topics: The evolution of solar wind streams, such as the formation of corotating interaction regions (CIRs) and stream interaction regions (SIRs), including the formation and structure of shock pairs associated with the interaction, the structure of the heliospheric current sheet and heliospheric plasma sheet, the evolution and properties of interplanetary transients, such as magnetic clouds/coronal mass ejections (CMEs), including the formation and properties of their sheath regions, the formation, evolution, and properties of interplanetary shocks, as well as particle transport and local acceleration, including the ubiquitous suprathermal population. In addition, key processes such as the evolution from magnetically dominated to hydrodynamical occur within this region. Several other white papers certainly describe the science questions associated with this research regime, hence we shall not dive into details here. Turbulence in interplanetary plasma, including CME sheaths and ejecta and the compositional signature of various solar wind streams, including magnetic clouds, also clearly belong to this category.

• **Unique Launch Constraints for Inner Heliospheric Research**

Inner heliospheric research relies heavily on *in situ* measurements. While remote observations are possible from the ground (interplanetary scintillation, radio observations) or low-Earth orbit (wide-angle coronagraphs and heliospheric imagers, e.g. see SMEI and PUNCH), all direct measurements require to actually reach interplanetary space. **The lack of adequate launch opportunities for Explorers to reach beyond the geospace has resulted in a lack of Explorers dedicated to inner heliospheric research**. This places the inner heliospheric research in a unique position as compared to **all** other Heliophysics research areas. Solar physics relies on remote observations that can be done from the ground or from Earth orbits, magnetospheric and ITM research rely on *in situ* measurements, but launches to the magnetosphere or the ITM regions are generally simpler and can be done within the constraints of Explorer-class missions. In that sense, inner heliospheric research is closest to planetary research, for which remote observations can be made from the ground or from Earth orbits but precise measurements needed for breakthroughs require *in situ* measurements from the studied planets.

The Advanced Composition Explorer (ACE), a middle-class explorer (MIDEX) launched in 1997 (25 years ago) is the only Heliophysics Explorer mission that has reached beyond the Moon to date. This was made possible by a launch on Delta II rocket (same rocket that launched MESSENGER, Dawn, or STEREO). THEMIS, also launched on a Delta II, had two of its five spacecraft going to the Moon during the extended mission Phase. Finally, IBEX, launched on a Pegasus XL, reached about 45 $R_E$ (still within the Moon orbit) by holding its own flight segment. This is the farthest a Heliophysics SMEX has reached to date and probably the farthest a Pegasus XL (the typical SMEX launch option until 2022) may launch a spacecraft.

The 2022 SMEX call initially offered launches to low-Earth orbit (LEO) and geostationary transfer orbit (GTO). Upon comments from the community, an option to launch to cislunar space was added, highlighting the possibility to design inner heliospheric SMEX mission concepts if a launch to interplanetary space is possible.

- **Unique Instrumentation Requirements for Inner Heliospheric Research**

In terms of instrumentation, solar physics is almost exclusively studied through remote sensing, whereas the physics of the inner heliosphere is typically investigated through a combination of unique remote sensing observations (wide-angle coronagraph, heliospheric imagers, radio emissions, interplanetary scintillation), and *in situ* measurements to measure plasma and magnetic fields, including composition, charge state for both thermal, suprathermal, and energetic ion population, as well as thermal, suprathermal, and energetic electrons. Outer heliospheric research is not significantly different from inner heliospheric research in terms of instrumentation with *in situ* measurements combined with energetic neutral atoms (ENAs) that are often based on plasma instruments.

We note that heliospheric research truly connects solar and geospace research in terms of instrumentation. One striking example is the ability of two of the five THEMIS spacecraft to go from a geospace mission to a lunar and interplanetary mission, highlighting that the instrumentation (and hardware expertise) is the same. For other missions, like PUNCH, the focus is on the coronal–heliospheric connection and the heliospheric measurements most closely resemble the remote observations common for solar research. Lastly, we note that numerous core team members of IMAP (the PS, Joe Wesltake, the two DPS, Drew Turner and Ian Cohen, the IMAP-Ultra, Matina Gkioulidou) have their main expertise in geospace research. As such, merging solar and inner heliosphere into a single panel brings the risk of having a lack of expertise in the specific measurements required for inner heliospheric research.

## 4 Inadequacy of Other Categories

- **Call for Nominations for the 2024 Decadal Survey Committee and Panels**

This white paper came in response to the call for nomination for the 2024 Decadal Survey

committees. It invited researchers to select one of ten categories (plus “other”). The text is copied below:
Broad area(s) of expertise for the candidate
The panel structure has not yet been determined. This list represents a broad spectrum of possible areas for the committee and panels. Please add additional areas as appropriate.

1. Solar Physics
2. Physics of the Outer Heliosphere
3. Space and Laboratory Plasma Physics
4. Solar Wind–Magnetosphere Interactions
5. Atmosphere–Ionosphere–Magnetosphere Interactions
6. "Sun as a Star”: Astrospheres, Exoplanets, and Planetary Habitability
7. Space Weather and Applications
8. Space Platforms, Technologies/Instrumentation, and Systems Engineering
9. Data Science
10. State of the Profession

As such, (a) it forces researchers working in the inner heliosphere to choose from categories 1, 3, 4, 7, or Other when being nominated, potentially diluting their weights when forming the panels and steering committee, but in any case making the formation and balancing of the panels more complex, (b) if a similar range of expertise is used for the panel structures or white paper allocations, it would force one of the five core areas of heliophysics to be split over multiple panels, potentially diluting its importance for fundamental research, (c) in addition to the traditional solar(–heliosphere) and magnetosphere–ITM disciplines, it highlights four other scientific areas (outer heliosphere, plasma physics, Sun as star, and space weather) but leaves out an essential foundational area in heliophysics. This does send a potential message to all the applicants on the relative importance of specific topics and brings a potential bias to the entire process.

- **Inadequacy of Other Research Categories: Solar Physics, Space Weather, and Outer Heliosphere**

Here, we focus on the areas listed in the call for nomination for the 2024 Decadal Survey committee and panels.
Researchers focusing on interplanetary and inner heliospheric research (as well as upper corona) are not represented within the area of “solar physics” nor within the “physics of the outer heliosphere”. While many of these topics have applicability to space weather, the primary focus of research on the inner heliosphere is often fundamental and is not driven directly by its applicability to space weather. As such, such topics are not best fit within the area of “space weather and applications”. The same argument of applicability to space weather can be made for many of the research areas within the geospace realm (for example ionospheric disturbances, outer radiation belts), but these research areas also exist in their own right without a direct connection to space weather.

- **Inadequacy of Other Research Categories: Fundamental Plasma Physics, Solar Wind – Magnetosphere Interaction**

While some processes occurring in the inner heliosphere are often thought as belonging to “space and laboratory plasma physics” (for example, reconnection and turbulence), others such as particle transport, the formation of ICME sheath regions, or the magnetic configuration of magnetic clouds are not. A topic of “space plasma physics” is also overall inadequate as most of heliophysics is “space plasma physics”. While reconnection is central to the dayside and nightside magnetosphere, magnetospheric research also stands on its own, without a direct connection to fundamental space plasma physics.

While the panel focusing on “solar wind–magnetosphere interaction (SWMI)” has the word "solar wind" in its name, the focus is clearly on magnetospheric processes. This can be seen, for example, from the seven SWMI science goals from the 2012 Decadal Survey, or by the first sentence of the report of the Panel on solar wind–magnetosphere interaction (chapter 9): "The magnetosphere is a central part of the solar and space physics system. Its various regions interact globally in complex, nonlinear ways with each other, with the solar wind, and with the upper atmosphere." As such, this panel's focus was on the magnetosphere and how it responds to the solar wind, not the solar wind itself.

## 5 Consequences on Past and Current Decadal Surveys

• **Consequences of the Lack of Heliosphere Panel During the 2012 Decadal Survey**
**The four key science goals from the Solar and Heliospheric Panel (SHP) of the 2012 Decadal Survey focused primarily on solar and outer heliospheric physics**. These goals were:

SHP1. Determine how the Sun generates the quasi-cyclical variable magnetic field that extends throughout the heliosphere.

SHP2. Determine how the Sun's magnetism creates its dynamic atmosphere.

SHP3. Determine how magnetic energy is stored and explosively released.

SHP4. Discover how the Sun interacts with the local galactic medium and protects Earth.

There were 15 subgoals listed in the SHP. Only two of these goals were relevant to inner heliospheric physics (SHP2d "Discover the origin of the solar wind's dynamics and structure." and SHP3c "Determine the origin and variability of suprathermal electrons, protons, and heavy ions on timescales of minutes to hours."). Goal SHP3d was clearly space weather-focused ("Develop advanced methods for forecasting and nowcasting of solar eruptive events and space weather") and we do not consider it covers the need for fundamental research on coronal mass ejections. While the entire SHP4 was dedicated to the outer heliosphere, there was no parallel goal for the inner heliosphere. We note that the only Figures out of 20 showing *in situ* measurements in Chapter 10 (Solar and Heliospheric Panel) were Figure 10.14 showing heliosheath measurements (i.e. outer heliosphere) from Voyager and Figure 10.17 showing solar cycle variations in galactic cosmic rays, magnetic field strength, and solar wind dynamic pressure. In addition, there were no figures showing remote observations in the upper corona or inner heliosphere. In short, **the 2012 Decadal survey highlighted no figure showing results from the inner heliosphere**. This is the case even though STEREO (launched in 2006) was a mission dedicated to the upper corona and inner heliosphere, and provided both the first stereoscopic views of solar wind structures and transients and, with heliospheric imagers, the first clear views of CMEs and CIRs propagating past the orbit of Mercury and Venus. Those could have been striking images to highlight research in the decade finishing in early 2010s.

We emphasize that this is true through all chapters of the Decadal Survey report, with Figures 1.3 showing the solar disk, 1.5 showing the outer heliosphere, Figure 2.1 showing an eclipse and the low coronal magnetic field, Figure 2.2 showing a sunspot, Figure 2.3 the IBEX ribbon, Figure 2.8 the simulation of a CME at approximately 3 solar radii.

We also note that there were certainly results to highlight. For example, within the ten most cited papers published in *JGR: Space Physics* from 2000 to 2010, four articles focused on the outer corona and interplanetary space, namely: (a) A catalog of white-light coronal mass ejections observed by the SOHO spacecraft, (b) Solar wind spatial scales in and comparisons of hourly Wind and ACE plasma and magnetic field data, (c) Interplanetary coronal mass ejections in the near-Earth solar wind during 1996–2002, and (d) Solar and interplanetary sources of major geomagnetic storms (Dst <= -100 nT) during 1996-2005.

Lastly, the previous Decadal survey (2003), in its Sun and Heliospheric Physics panel report highlighted five main “research themes” for the upcoming decade (i.e. for the decade of 2003-2012):

1- Exploring the solar interior
2- Understanding the quiet Sun
3- Exploring the inner heliosphere
4- Understanding the active Sun and heliosphere
5- Exploring the outer heliosphere and the local interstellar medium.

Themes 3 and 4 were clearly dedicated to inner heliospheric research, providing a better balance as compared to the 2012 Decadal survey. There were also two Figures out of 13 (1.6 and 1.7) highlighting the coronal and heliospheric propagation of CMEs.

• **2024 Decadal Survey Steering Committee**

The initial composition of the Steering Committee was announced on 22 July 2022 with two co-chairs and 16 members. Only one steering committee member, Gary Zank, has a primary expertise in heliospheric physics (both inner and outer). Another member, Tim Bastian, has primary expertise in radio bursts, which include both solar, corona, and interplanetary space. There are no members with expertise in numerous inner heliospheric (and upper coronal) research, including CME evolution, sheath formation, SIR formation, interplanetary shocks and associated particle acceleration, and particle transport. This issue was compounded by the fact that only four out of the 18 members had primary expertise in solar–heliospheric physics.

At this time, we do not know the results of numerous comments from the solar–heliospheric community on the composition of the steering committee. However, even if more members with expertise in solar–heliospheric physics are added, the imbalance will still be there, especially for heliospheric physics. As such, one of the main ways to ensure that heliospheric physics white papers are adequately read and judged is to have a dedicated panel.

• **Place of Outer Heliosphere**

Inner and outer heliosphere research share common topics (particle acceleration, shocks, turbulence) but also differ in many fundamental aspects, where the outer heliosphere more closely resembles magnetospheric studies, with the interaction between a magnetized “sphere” (the heliosphere) with a magnetized wind (the LISM flow with respect to the heliosphere). Overall, outer heliosphere might be well served by a separate working group or could be kept merged with inner heliosphere. However, in that case, the relative weight of inner and outer heliosphere research should represent approximately the weights of the community (taking into consideration the probable growth of the outer heliosphere community following the launch of IMAP in 2025).

## 6 Recommendation

**Our unique recommendation is that the 2024 Decadal Survey has a panel specifically dedicated to the Physics of the (Upper) Corona and Heliosphere, separate from a panel on Solar Physics.**

In light of similar instrumentation and overlap between researchers, outer heliosphere would have a natural home within such a panel. The panel composition, however, should reflect, as much as possible, the relative number of researchers currently working in inner vs. outer heliospheric research. If the decadal survey is organized into a larger number of science-based panels (for example, seven based on the first six categories of the call for nomination plus inner heliosphere), then inner and outer heliosphere would be best kept separate as both topics have differences in required orbits as well as science (while there is overlap in the energetic particles, some aspects of outer heliosphere are closer to the study of Earth’s magnetosphere than interplanetary physics).

We believe there is risk that the solar–heliospheric part of the decadal survey would be considered as bias if a foundational field such as coronal, interplanetary, and inner heliospheric physics is not properly represented. Having a dedicated panel would ensure that the community of heliospheric researchers feels that the decadal process properly represent them at their existing weights.