

Guiding Heliophysics Toward an Enhanced Transdisciplinary Framework

White paper for the Heliophysics 2050 workshop

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Introduction. Heliophysics is an inherently interdisciplinary field that overlaps multiple academic specialties to understand how the Sun drives the surrounding space environment. But to truly grasp the fundamental nature of the physical processes that govern the heliosphere¹, we must push the boundaries of the traditional scientific workflow. The walls that currently exist between heliophysics subdisciplines—especially walls between heliophysics and outside disciplines—stymie creativity and hinder the major scientific discoveries required to accelerate NASA's Heliophysics Program. Once these walls are razed, scientists will be more free to figuratively (and literally) think outside the box. One mechanism for breaking down these barriers is to deliberately leverage outside disciplines (such as applied mathematics, statistics, data science, electronics, etc) for the challenging heliophysics problems of the 21st century. We outline steps for moving heliophysics toward this transdisciplinary framework by 2050.

Motivation. Underpinning every aspect of the NASA Heliophysics program is a myriad of tools and methods that enable development of instruments, analysis of mission data, and the simulation of heliospheric systems. To characterize kinetic instabilities in the solar wind that govern wave-particle energy transfer, fitting algorithms applied to particle velocity distribution functions must be reliable as input to plasma dispersion solvers. To develop appropriate instrumentation capable of addressing mission-specific science objectives, statistical models must be employed to identify noise floors. To robustly predict space weather phenomena and increase the related data discoverability, the application of state-of-the-art machine learning techniques and advancement of the data cyberinfrastructure are required. However, there is no formal mechanism or support by which to leverage the expertise of non-heliophysicists to create, and improve upon, these tools and techniques. Whether it is an applied mathematician researching spectral analysis for more efficient signal processing algorithms, or a computer scientist whose insights could boost the performance of modeling codes, there are vast opportunities to advance not only our understanding of the heliosphere, but the means by which we advance our understanding. Consequently, ***we must incentivize a more holistic approach to scientific research which rewards the improvement of tools and techniques.*** This requires reimagining our definition of a heliophysicist and rewarding new avenues of research beyond the current funding infrastructure and traditional career paths.

¹A current high-level Heliophysics Decadal Survey Goal.

The Current Landscape. NASA funding for investigations into developing and improving methods, whether for data analysis or modeling, is highly limited². NASA proposals typically favor low-risk projects that rely on pre-established tools and methodologies. This strategy usually leads to incremental progress, utilizing proven and available tools. However, it strongly limits the development of new methodologies. Therefore, scientific progress may be stifled to solely incremental improvements in our understanding, with no possibility for sweeping scientific breakthroughs or the emergence of hybrid disciplines³. The call for the Heliophysics DRIVE centers specifies NASA's intent for more interdisciplinarity, stating that "many of the most exciting questions at the very edge of current understanding are strongly interdisciplinary in scope and require the merging of perspectives from different parts of the heliophysics community and *possibly* other discipline areas." We call on NASA to *definitely* include outside disciplines on the quest for solving the long-standing mysteries permeating the heliosphere.

Funding agencies such as the Department of Energy (DOE) and the National Science Foundation (NSF) already have mechanisms to fund diverse teams with broad objectives through programs such as Scientific Discovery through Advanced Computing (SciDAC) in DOE and Cyberinfrastructure through Sustained Scientific Innovation in NSF. However, the NASA Heliophysics program currently offers insubstantial support for concentrated research into improving the techniques and tools at a heliophysicists' disposal. Furthermore, while an individual from an outside field can engage in a high-risk/high-impact project for the heliophysics community, it comes with an attendant risk to their career advancement. Consequently, ***the expertise from these key personnel is under-valued***. We outline steps to change this.

Specific Recommendations. The ideal heliophysics landscape would enable individuals to immerse themselves in multiple fields, both outside and inside the traditional realms of heliophysics. These transdisciplinary teams would push those outside fields towards practicality for heliophysics, with the intent that those new ideas would be leveraged in heliophysics.

Short Term. Within the next 5 years, we recommend that the NASA heliophysics program supplies separate dedicated funding to transdisciplinary teams (applied math, computer science, space sciences, etc). This new funding avenue would solicit projects to investigate new methods or tools that would pave the way toward answering science questions, without needing to answer those questions within the proposed effort. The goal of the dedicated grants would be to improve tools to facilitate better science. Advancing this pathway is only possible by incentivizing personnel with diverse backgrounds and subsequently valuing their unique expertise. These grants would require appropriate funding and duration on par with other 2-4 year ROSES solicitations. A successful program also needs improved panel reviewer literacy; for example, if a transdisciplinary team proposes to use Machine Learning (ML) to predict space

² These funding sources are short-lived with limited budgets, such as ROSES: Heliospheric Data Environment Enhancements.

³ In 1884, Svante Arrhenius faced disapproval from his physics PhD dissertation committee. Other thought leaders in Europe, who were developing the new field of physical chemistry, valued his work. Consequently, an extension of his dissertation, detailing the process of electrolyte solutions, won the 1903 Nobel prize in chemistry. His work brought the concept of a cation into chemistry only a few years after Michael Faraday named the charged particles "ions."

weather patterns, NASA must include an ML consultant on the review panel. The societal impact of the proposed program could provide an avenue to reach out to a community broader than heliophysics as the problems we solve become more technical.

Medium Term. While it is natural for scientific exploration to grow continuously from a single question, transdisciplinary collaborations to develop methodologies may reach natural endpoints. ***It is therefore essential to establish a pipeline enabling the career stability of researchers who lead these transdisciplinary developments.*** This may necessitate different funding models that allow researchers to support projects at one or multiple institutions without the economic uncertainty of relying on individual grant awards. In the next 15 years, we therefore recommend the establishment of dedicated funding for transdisciplinary faculty development at universities, in addition to full time positions at NASA centers, to coordinate specific transdisciplinary work. Although NASA centers employ personnel to help with code development, optimization, visualization, and other computing matters, these personnel should be expanded to include expertise in statistics, machine learning, data cyberinfrastructure development, and others. The ambitious, high-impact scientific problems these individuals would aim to solve should be tackled by diverse teams to promote creative collaboration. These transdisciplinary scientists would also serve as liaisons between the multiple silos within heliophysics.

Long Term. We recommend establishing support for the aforementioned team members to serve as mentors by training and financially sustaining the next generation of transdisciplinary scientists. Avenues such as apprenticeships, internships, bootcamps, and REUs would be a ***pathway for sustainable development of high-impact scientific progress.*** Successful transdisciplinary programs at universities may follow suit. At both the undergraduate and graduate level, we envision flexible programs with hybrid degrees, without the burden on students to motivate siloed professors to engage in a transdisciplinary venture. Once transdisciplinarity itself is a valued and sustainable scientific avenue, these projects would be reclassified as low-risk, and the pace of major scientific discoveries would vastly improve.

Current Landscape	Short/Medium Goal	2050 Goal	Outcome
Inadequate support for outside disciplines to assist with tools applied to heliophysics	Dedicated NASA funding for transdisciplinary teams to explore optimal trajectories to facilitate heliospheric research	Establish infrastructure for transdisciplinary scientists to support mentees through REU programs and/ or internships	Train/support the next generation of transdisciplinary scientists
Poor career stability for individuals engaging in transdisciplinary work to assist heliophysicists	Dedicated full-time positions at universities and/or NASA centers to establish a network of transdisciplinary teams to tackle complex problems	Facilitate organic transdisciplinary efforts at universities, including more flexibility with hybrid majors/PhD programs	The expertise of individuals outside the field of heliophysics is valued and utilized
Insufficient diversity of thought within the broad field of heliophysics	Train personnel to serve as liaisons between heliospheric subdisciplines	Scientists from outside fields are immersed in heliophysics, and vice versa	Holistic, sustainable approach to heliophysics
Incremental scientific progress in heliophysics	Expand NASA review panel process	High-risk/high-impact projects reclassified as low-risk/high-impact	Increase rate of scientific breakthroughs