

# Space Weather: Complexity science, convergence research, and a risk and resiliency framework

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Objective

Respond to the grand challenges that confront the Earth and Space Sciences by embracing methods from the field of complexity and systems science that can adapt our thinking and our science to be more inter- and cross-disciplinary and enable broader connection across individuals, teams, communities, and sciences.

What is complexity science?

Complexity science is the study of phenomena that emerge from a collection of interacting objects. The methods of complexity science are multitudinous. It has transformed various domains of science, including biology, ecology, and cognitive science

“

The 21st century will be the age of complexity.

”

-Stephen Hawking

Background

In an age of growing reliance on technology and physical expansion into space, what does a science of space weather look like for a more resilient society? We suggest that future progress in understanding Heliophysics and space weather depends on a complexity science paradigm. We take space weather as a demonstrable ‘wicked problem’ around which to outline the complexity paradigm, which then applies across domains and problems

## How to read this poster

- Read ‘The Complexity Paradigm’ then visit the quadrants to learn more about each component and see an example of the paradigm in action
- Visit the ‘Resource Exchange’ to learn more, find references, and share your resources
- Contribute to the living conversation

## In Practice

An example

### Vision:

Addressing wicked problems by merging innovative ideas, approaches, and technologies from a wide and diverse range of sectors



### Problem:

Electrical power grids, on which we all depend, comprise numerous interconnected components, including generators, transformers, and transmission and distribution lines, among others, as well as the operating processes required to keep these components functioning. These massive and truly complex systems function at the whim of myriad natural forces (including space weather) and the vicissitudes of human behavior that can reduce grid reliability or knock out operation altogether. Creating a power grid that is resilient to these forces is a national-scale societal challenge, one that cannot be addressed by a single sector or discipline.

### Solution: An Open Knowledge Network

Creates a more cohesive community, crossing the domains involved • Supports effective data sharing, coordination, and analysis (e.g., data science) • Enables systems analysis that encompass the diversity of physically dominant processes in each part of the space weather environment

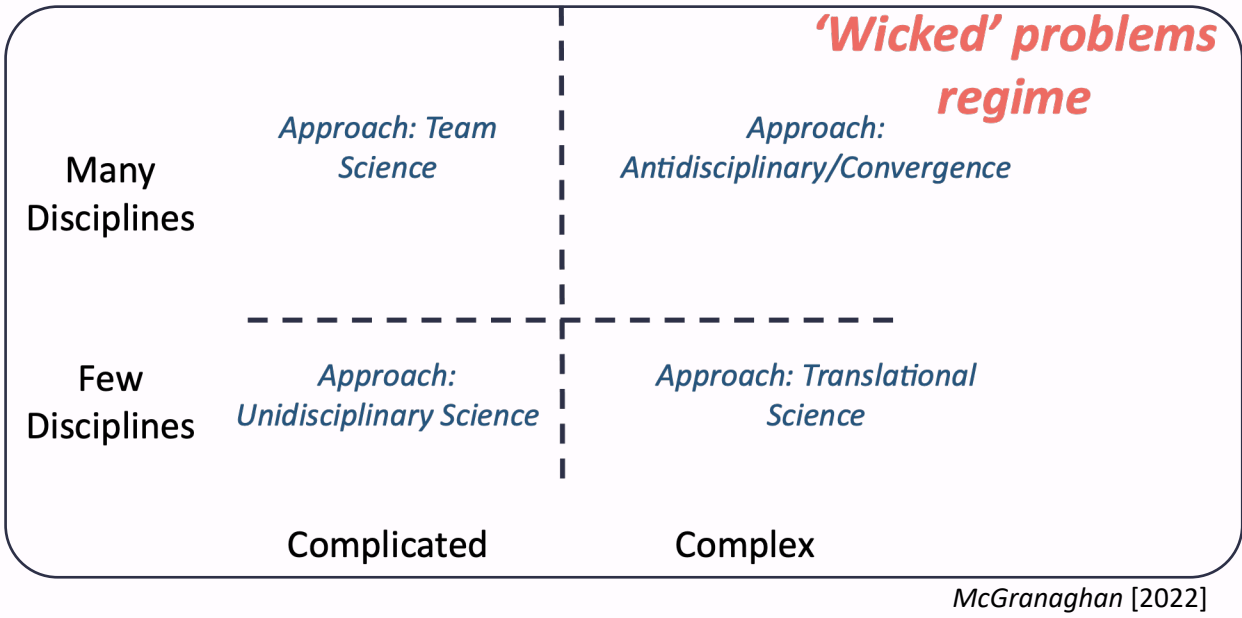
## Exploring Convergence:

A community-wide “simulation game”

## The Complexity Paradigm

complexity science, convergence research, and a risk and resiliency framework together provide a vision and path for the future of Heliophysics and space weather research and other ‘wicked problems’

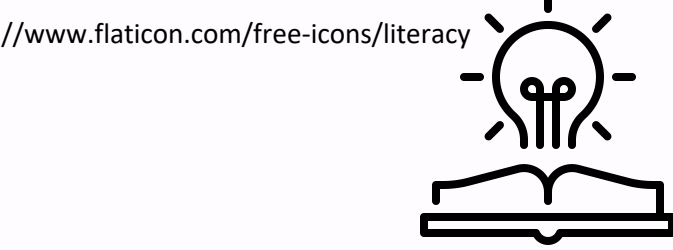
“ We have reached a stage where the pace of discovery and the nature of shared knowledge bring the whole venerable exercise of disciplinary fads into question ... The cost of [disciplinarity] is that it restricts the scope of our inquiries and causes us to lose sight of the numerous extradisciplinary ideas and methods that have contributed to (and will be required to further) our progress through the thorny branches of science. ”



-David Krakauer (*Worlds Hidden in Plain Sight*)

To respond to the wicked problems in the Earth and Space Sciences requires methods from the field of complexity science, a new *paradigm* [Kuhn, 1962]

<https://www.flaticon.com/free-icons/literacy>



Convergence and complexity illuminate new literacies that we need to develop as individuals and incentivize as a community

### Complexity Science

Complexity science is the study of phenomena that emerge from a collection of interacting objects. To understand a complex system requires a plurality of frameworks and we must be able to move between levels (e.g., micro and macro). Complexity science is a paradigm that suggests ways of reconciling the micro and macro scales. It is the collection of methods to understand a system across scales, the smaller scale behavior in connection with the larger-scale phenomena that emerge from it. The complex systems paradigm transcends the concepts of scale and discipline, providing methods to connect across them.

### Convergence Research

Meeting grand sociotechnical challenges requires convergence, the merging of innovative ideas, approaches, and technologies from a wide range of sectors and expertise. With convergence comes a new spectrum of challenges involving how we work across disciplinary lines, collaborate meaningfully in large groups, and develop healthy—meaning open, participatory, and resilient—connections among diverse stakeholders. Indeed, tackling the problems we face as a society, whether global pandemics or climate change or complex systems, requires new levels of cooperation, facilitation, and synthesis.

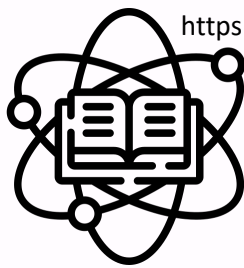
### Risk & Resilience Framework

Within this framework, a system is treated as a complex entity that can be defined by whether or not it can accommodate changes and reorganize itself while maintaining its unique characteristics (Scheffer et al., 2001). The framework is built on two important principles: 1) Consideration of the holistic Sun-to-society system, and 2) Quantification of the uncertainty that arises from coarse-graining and statistical simplification (McGranaghan, 2022). If space weather is approached through the lens of risk and resiliency, the domain could share a common framework with other risks such as terrestrial weather (e.g., hurricanes).



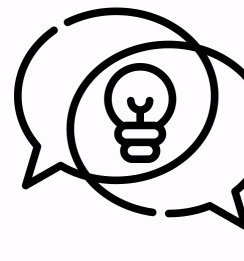
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To cultivate new literacies requires rethinking the visible quantities that our community uses to drive resources, particularly our most precious one: attention



<https://www.flaticon.com/free-icons/science>

These literacies can coalesce into a new curriculum—a more information-literate Heliophysics community. This must be done together through co-creation; open science is an ethos under which we can join these literacies.



<https://www.flaticon.com/free-icons/common>

To build the complexity paradigm and a healthier community we need a *knowledge commons*

### Connect to other ‘risk’ domains

Recognize that space weather does not happen in isolation, indicating a need to be able to overlay various hazard maps to better visualize and assess compound risk • develop data integration systems (e.g., knowledge graphs) that allow research and information about multiple hazards—space weather, floods, and wildfires, for example—to be integrated and overlain • A compound risk *Open Knowledge Network*

### Value new research skills

The role of facilitation—too often underappreciated—in solving complex challenges is becoming ever more essential • scientific and engineering communities must learn, apply, and value facilitation skills

### Develop literacies, curriculum, and metrics for Complexity Heliophysics

Complexity Heliophysics requires our community to develop new literacies and the curriculum that encompasses them

A curriculum for complexity heliophysics and a more healthy community: knowledge commons & open science

### Complexity in Heliophysics:

Heliophysics processes span at least 15 orders of magnitude in space and another 15 in time. The reaches of our science go well beyond our own solar system and Earth’s space environment to touch planetary, exoplanetary, and astrophysical domains. The history of Heliophysics has, like many sciences, been one of specialization--categorizing and separating domains and building understanding within those ever smaller systems.

### Heliophysics in the 21<sup>st</sup> century:

Our sensing capabilities are revealing cross-scale behavior • Data analysis and computational tools are enabling cross-system and multi-scale research • The demands on our science are growing exponentially

<https://tinyurl.com/McGranaghan-Complexity>



## Moving forward

### Create a Community of Practice

Create a Community of Practice of ‘Complexity Heliophysics and Space Weather’ • bring this community into conversation with complexity science communities

### Open new research vistas

Complexity science and convergence research suggest new areas of research relevant to space weather • how we represent our knowledge and data science systems that can integrate it • how we organize our teams and facilitate interactions • and how we incorporate human behavior in our models