Research Agenda Statement

Research Vision

My research is driven by a fundamental question: **how can we understand the ways complex systems process, transmit, and interpret signals?** My long-term research agenda is to develop signal-processing and data-analytic approaches that reveal meaningful structure within complex systems and use that structure to understand the processes responsible for their observable behavior. Rather than treating complexity as a problem to be removed from data, I am interested in identifying the features, interactions, and organizational structures that make complex behavior interpretable.

My research has approached this question through different scientific measurement problems, from extracting chemical information from high-dimensional measurements to identifying structured interference in spacecraft magnetometer data. In the future, I plan to extend this foundation toward broader questions of information processing and emergence in complex systems, with particular interest in cognitive and neural systems. Through this research, I aim to develop interpretable computational methods that help explain not only what patterns exist within complex data, but how interactions among underlying components give rise to those patterns.

Building a Foundation in Complex Signal Analysis

My early research established the signal-processing foundation for this agenda through the analysis of complex chemical measurements. During my master's research, I investigated two-dimensional gas chromatography time-of-flight mass spectrometry (GC×GC-ToF-MS) data to identify unknown persistent organic pollutants. I used signal comparison, principal component analysis, clustering, and related data-analysis methods to extract relevant chemical information from high-dimensional measurements containing overlapping features and substantial variability.

That work introduced a research problem that has continued across my subsequent work: meaningful information is often embedded within measurements produced by many interacting processes. Extracting a feature is therefore only part of the problem. Understanding what produces the feature, how it relates to other components of the measurement, and whether it reliably represents the underlying system are equally important.

Current Research: Understanding Structure in Spacecraft Measurements

My doctoral research extends these questions to spacecraft magnetometer measurements. Scientific magnetometers measure naturally occurring magnetic fields in space, but they simultaneously measure fields generated by the spacecraft itself. Electrical systems, scientific instruments, currents, and mechanical systems such as reaction wheels can all contribute to the observed measurement. The resulting data therefore represents the combined behavior of multiple natural and engineered processes.

Traditional interference-mitigation techniques rely heavily on physical assumptions about spacecraft magnetic fields and sensor geometry. More recent statistical and machine-learning approaches can relax these requirements but introduce different assumptions concerning statistical independence, sparsity, training data, spacecraft telemetry, or signal structure. My dissertation investigates an alternative question: **what physical and mathematical structure within the signals themselves provides information about their sources?**

I focus particularly on reaction-wheel magnetic interference and investigate how harmonic behavior, phase relationships, spatial differences between sensors, and time-frequency structure can distinguish spacecraft-generated signals from ambient magnetic phenomena. Using operational spacecraft measurements and controlled laboratory data, I evaluate how these relationships appear across sensors and magnetic-field components and how they can inform interference identification.

This work moves beyond treating interference mitigation exclusively as a noise-removal problem. Reliable scientific processing must suppress unwanted contributions while preserving the physical information scientists intend to measure. My research therefore emphasizes interpretable and reconstructable signal representations that allow both the removed and retained information to be examined. This approach provides a foundation for developing methods that use knowledge of signal structure without requiring complete prior knowledge of every source contributing to a measurement.

Future Research: Information Processing in Complex Systems

My future research will expand from separating sources within complex measurements toward understanding how information is organized and transformed within complex systems. A central direction will be the development of **interpretable signal-processing and data-analytic methods that connect observable patterns to interactions among underlying components**. Signal processing, statistical modeling, and machine learning provide powerful tools for identifying structure, but identifying a pattern does not necessarily explain why that pattern exists. I am interested in integrating computational methods with domain knowledge so that extracted features can be interpreted in terms of the processes that generate them.

In the near term, I plan to continue developing and validating structure-aware signal-processing approaches across complex sensing environments. Questions arising from my doctoral work—including how features persist across measurement conditions, how interacting sources can be separated, how information is represented across temporal and spatial scales, and how uncertainty propagates through reconstruction—provide a foundation for investigating other physical and biological systems.

A longer-term direction of this agenda is the study of **cognitive and neural information processing**. Cognitive systems present a particularly compelling complex-systems problem: interactions among many components across multiple spatial and temporal scales produce learning, memory, perception, and behavior. I am interested in investigating how measurable neural and behavioral signals encode these interactions and how computational approaches can

help connect lower-level signal dynamics with higher-level emergent behavior. This direction would build upon my expertise in signal analysis while extending the underlying research question from using signals to understand complex systems toward understanding how complex systems themselves process information.

These directions are united by a common methodological challenge: complex systems cannot always be understood by examining their components independently. My long-term goal is therefore to develop computational frameworks that identify meaningful building blocks within complex signals while also characterizing the relationships among those components that produce system-level behavior. Such methods could contribute to scientific instrumentation, biological and neural signal analysis, and other environments in which meaningful information emerges from interactions among many underlying processes.

Developing an Independent Research Program

My research trajectory has provided experience working across disciplinary boundaries while maintaining a consistent focus on extracting and interpreting information from complex signals. My current work in spacecraft instrumentation provides a rigorous environment for developing these methods because successful processing requires both quantitative performance and preservation of physically meaningful measurements. My future research will use that foundation to pursue broader questions concerning signal structure, information processing, and emergence.

This agenda creates opportunities for collaboration and external support across signal processing, complex systems, scientific instrumentation, and computational neuroscience. As the program develops, I will pursue funding aligned with both the methodological development of interpretable computational approaches and their application to complex physical and biological systems. My ultimate goal is to establish a research program that uses signals not simply as data to be processed, but as observations through which the organization and behavior of complex systems can be understood.