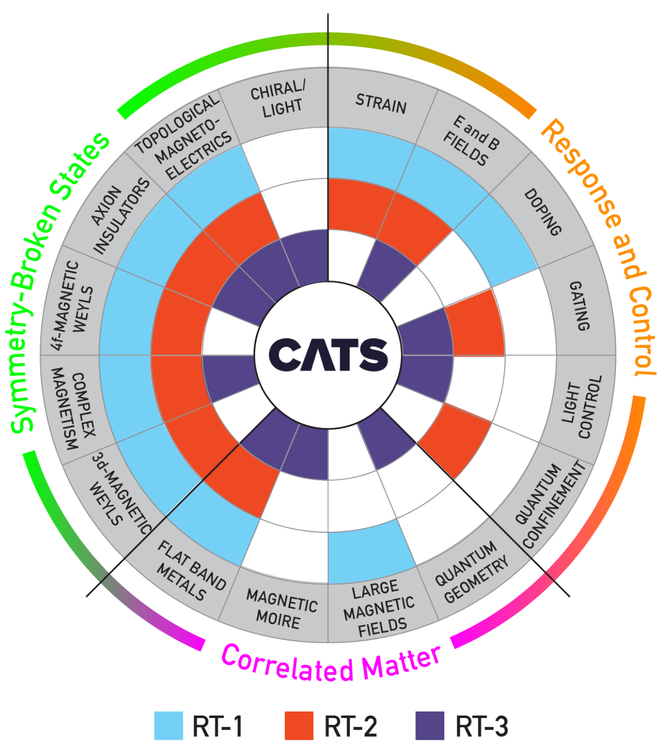
Center for the Advancement of Topological Semimetals (CATS)
EFRC Director: Robert McQueeney
Lead Institution: Ames Laboratory
Class: 2022– 2026

Mission Statement*: To transform how we discover, understand, and harness new topological states of matter.*

The intersection between topology, magnetism, and electronic correlations is one of the most exciting scientific frontiers that promises to profoundly impact fundamental science and future technologies. Topological materials at this frontier can address major challenges in quantum information sciences and microelectronics by enabling new avenues for controlling charge and spin for low energy switching, by delivering dissipationless currents, and providing new ways to manipulate quantum states. These materials also hold great promise for sensing, detection, and energy harvesting via giant nonlinear transport, optical, and photogalvanic responses. The Center for the Advancement of Topological Semimetals (CATS) will achieve its mission through a highly collaborative fundamental research program, with the vision to provide the innovation that is needed to bring the promises of this exciting frontier to fruition.

CATS groundbreaking successes in the discovery, synthesis, theory, and manipulation of magnetic topological materials and their phenomena inform three, highly integrated research goals for the next four years that both build on and expand the scientific directions within CATS' overall mission:

G1. *Harness the unique properties of symmetry-broken topological materials* – Building on our discoveries of novel phenomena that are caused by the coupling of magnetic order and band topology, we seek to significantly expand this frontier to encompass distinctive spin and charge symmetry-broken ground states in topological materials.



CATS integration. CATS goals are in the outer circle and the principal phenomena and capabilities are color-coded by Thrust.

G2. *Discover correlated topological matter* – When combined with topological band structures, strong electronic correlations may give rise to entirely new phases and phenomena. While the discovery of weakly-correlated topological matter has proceeded at an incredible pace, aided by the predictive power of first principles calculations, strongly-correlated topological materials present substantial challenges. CATS' multidisciplinary approach is excellently suited for their theoretical and experimental discovery.

G3. *Control and manipulate the extraordinary responses of topological matter* – Ultimately, the successful adoption of topological matter into future technologies will rely on our ability to control their phenomena, which, in turn, challenges and advances our scientific understanding. CATS aims to develop unique control parameters available via ultra-high-quality single crystals, thin films, and van der Waals (vdW) assemblies that utilize confinement, twist, pressure, strain, and light to design and control symmetry and topology, aided by the development of theoretical methods to predict novel linear and nonlinear responses based on quantum band geometry.

To attain these goals, CATS is organized into three research thrusts (RTs), centered on three distinct–yet highly interconnected–materials platforms: **(RT-1)** ***Discovery and control of magnetic and correlated topological matter*****.** RT-1 emphasizes the prediction and discovery of single-crystals of new magnetic topological materials and understanding their properties and tunability; **(RT-2)** ***Novel topological states in thin films*****.** RT-2 recognizes the importance of epitaxial thin films in delivering controllable quantum transport in topological materials; and **(RT-3)** ***Topological magnetism and magnetoelectricity in 2D materials*****.** RT-3 focuses on highly tunable vdW assemblies of topological materials with special emphasis on nonlinear optical and transport responses. These thrusts share an overarching ambition to deliver superior materials of exceptional quality, spanning from single crystals to epitaxial thin films to monolayers, respectively.

Integration across CATS is achieved by pursuing a common set of materials, the sharing of theoretical and experimental tools, and the collective pursuit of unifying and cross-cutting scientific concepts linked by broad theoretical insight. Along the way, CATS is developing state-of-the art methods in the growth of new materials, the assembly of functional heterostructures, experimental characterization, and new theoretical concepts and methods. CATS utilizes DOE-supported neutron sources, light sources, nanocenters, and leadership computing user facilities. CATS trains young researchers who will, in the future, make their own discoveries of the fundamental properties of matter.

Center for the Advancement of Topological Semimetals (CATS)	
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