Programmable Quantum Materials (Pro-QM)
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Mission Statement*: To discover, characterize, and deploy new forms of quantum matter controllable by gating, magnetic proximity and nano-mechanical manipulation.*

Experimentally realizing quantum phases of matter and controlling their properties is a central goal of the physical sciences. In this endeavor, fundamental science is particularly relevant to technological advances. Novel quantum phases with controllable properties are essential for new electronic, photonic, and energy management technologies needed to address the growing societal demands for rapid and energy efficient information processing and transduction. *Quantum materials (QMs*) offer particularly appealing opportunities for the implementation of on-demand quantum phases. QMs host interacting many-body electronic systems featuring an intricate interplay of topology, reduced dimensionality, and strong correlations that leads to the emergence of "quantum matter'' exhibiting macroscopically observable quantum effects over a vast range of length and energy scales.

The unified four-year scientific goals of Pro-QM are organized in two interdependent Research Thrusts (Fig. 1). Thrust-1 will *create, visualize, and utilize intertwined, controllable, and interacting topologically protected states in quantum materials.* Thrust-2 will *create, manipulate, and understand macroscopic coherent states and induce transitions to novel quantum phases.* Both Thrusts explore optically driven effects where light creates new states not present at equilibrium (transient edge states in Thrust 1 and excitonic states in Thrust 2) and examine complementary topological phenomena (mainly electronic in Thrust 1, and mainly excitonic in Thrust 2). The Thrusts harness and rely on two major research Themes, built on the cross-cutting strengths of our team: (A) the creation of new tailored materials and architectures to understand and exploit interfaces, and (B) transformative advances in experimental imaging tools for probing optoelectronic and magnetic properties at their native length- and time-scales. The concerted EFRC effort is therefore imperative to make the desired leaps in progress.

Programmable QMs properties are essential for realizing the promise of quantum technology for disruptive advances in information transfer, processing, sensing, and other currently unimagined functions.

Our team will focus on transition metal dichalcogenides (TMDCs) and 2D-halides: two representative classes of layered van der Waals (vdW) solids combining novel properties with an unprecedented degree of controllability. Realizing the potential for programmable quantum matter requires a three-pronged approach, combining *i)* the unique suite of controls and driving perturbations, with *ii)* a transformative set of synthesis/device fabrication capabilities (Theme A) and *iii)* new nanoscale characterization techniques integrated in a single platform (Theme B). These strategies are particularly well-adapted to vdW materials. Our approach is to combine the three prongs into one cohesive team effort, expanding on already strong collaborations within the Pro-QM team.

Our chief scientific goals and tasks are outlined in Fig. 1 and closely aligned with the DOE Grand Challenges and Basic Research Needs Reports. A common thread underpinning these clear but ambitious goals and tasks is to develop strategies for transforming QMs into a desired state with tailored quantum properties not attainable in common metals or semiconductors. The present knowledge gaps remain immense but can be effectively addressed given the unique combined expertise of the Pro-QM team documented through a track record of breakthrough collaborative research.

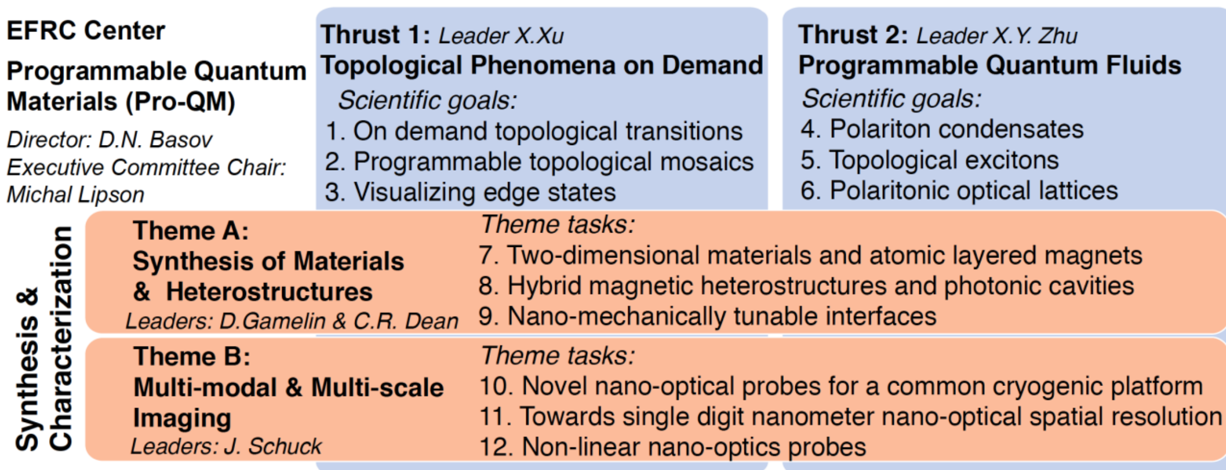

Figure 1: Energy Frontiers Research Center on Programmable Quantum Materials. Center activities are organized into two Thrusts and two cross-cutting Themes.

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