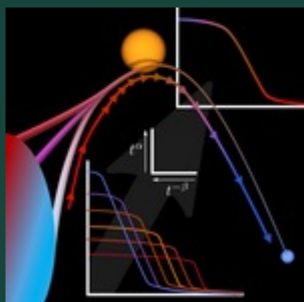
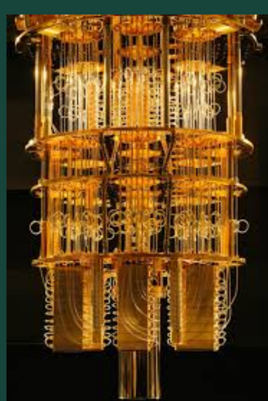
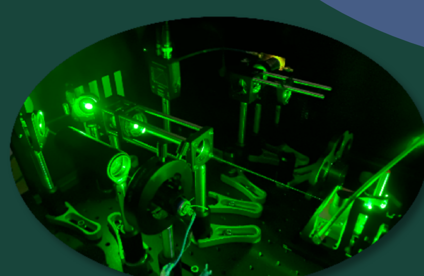
CMP/QIS at MSU

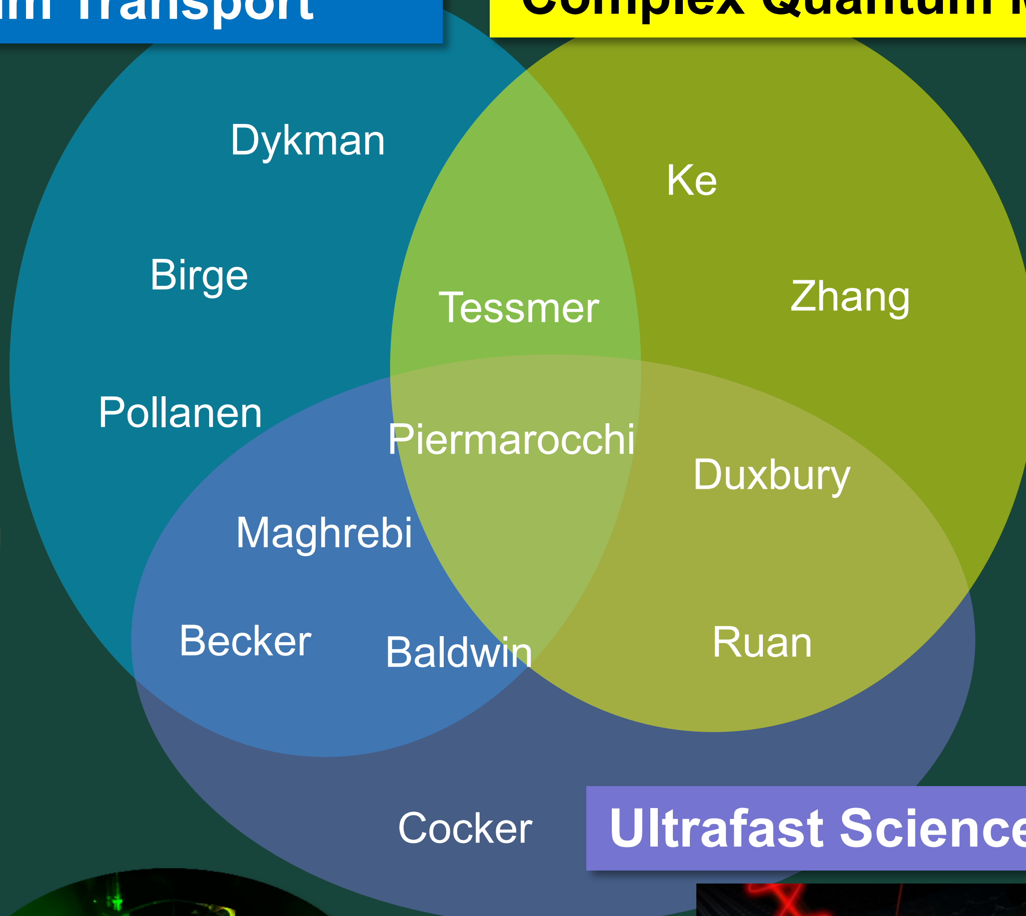
Quantum Information Science & Quantum Transport

Complex Quantum Materials

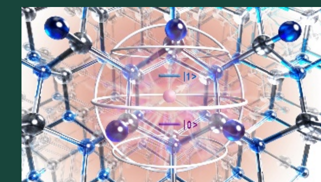


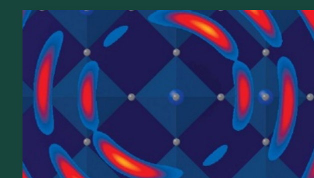


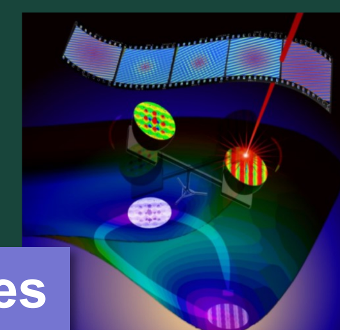


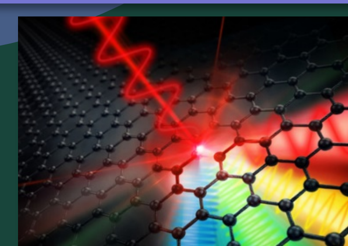


Ultrafast Sciences



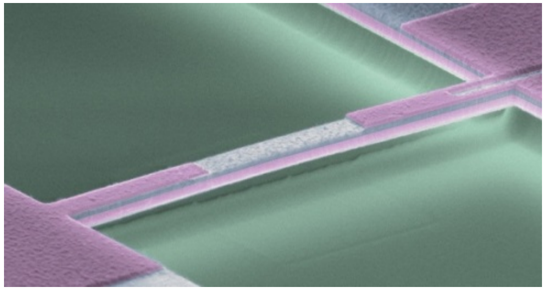




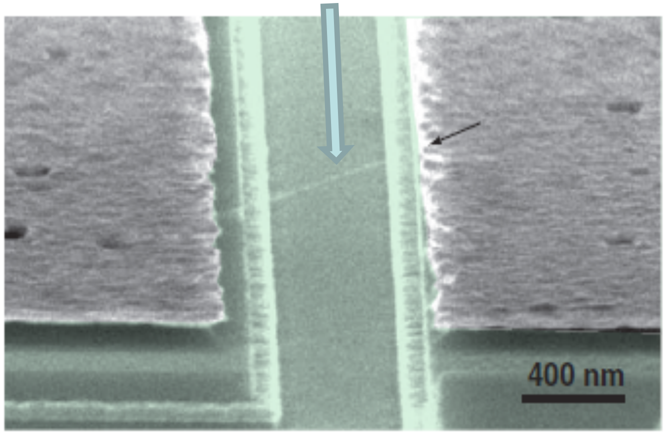


Mesoscopic quantum **oscillators, Floquet phase transitions, quantum computing** PI: Dykman

Vibrational systems that are
- **sufficiently large to be individually accessed**
- **small, so that classical and quantum fluctuations are substantial**



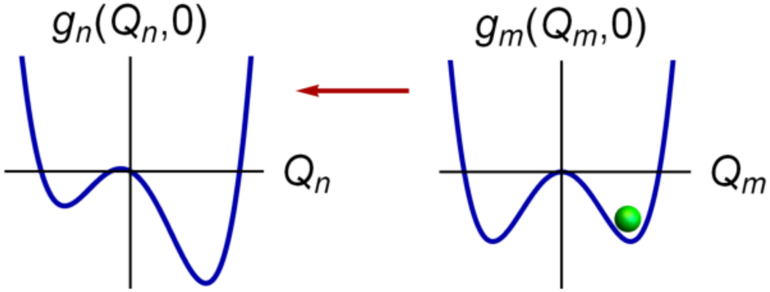
Carbon nanotube



Hamiltonian of a parametric oscillator

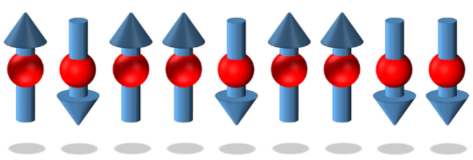
$$H_n(t) = \frac{1}{2}p_n^2 + \frac{1}{2}(\omega_0^2 + F\cos\omega_F t)\,q_n^2 + \frac{1}{4}\gamma q_n^4$$

Coupled parametric oscillators



Mapping on coupled spins: $W_\sigma^{(n)} \propto \exp[-\sigma_n \sum_m J_{nm}\sigma_m/\tilde{\hbar}]$

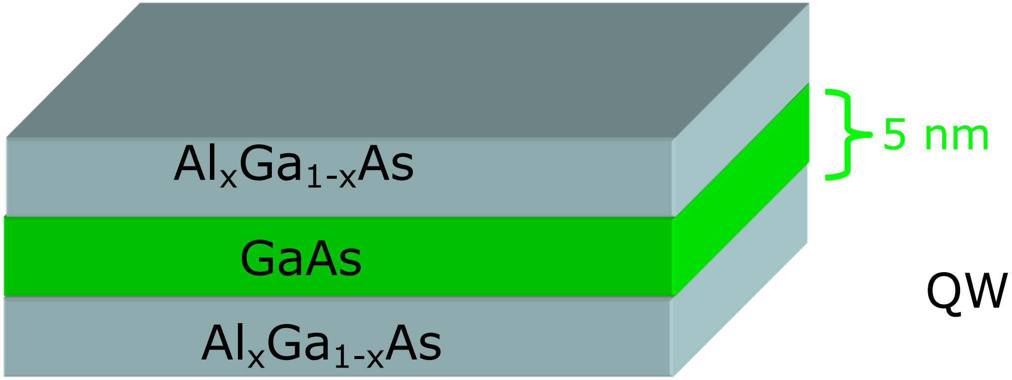
$J_{nm} \neq J_{mn}$

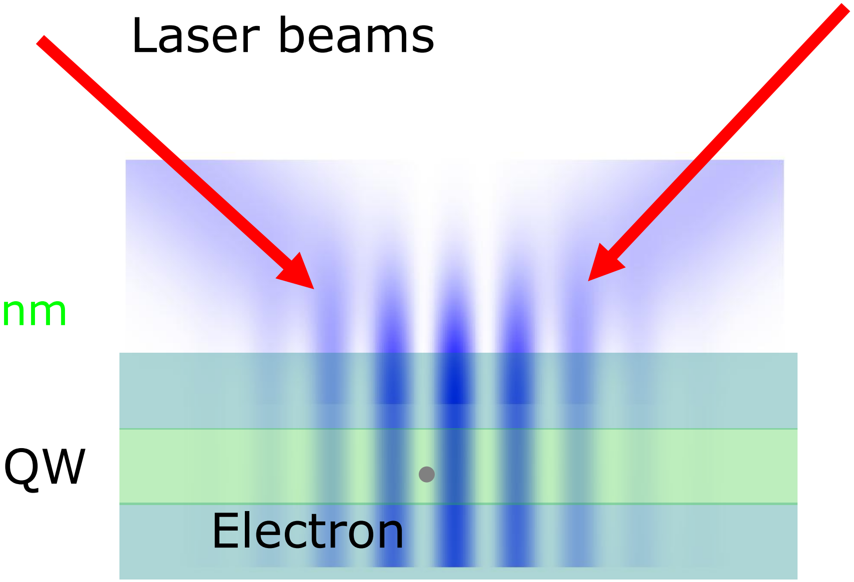


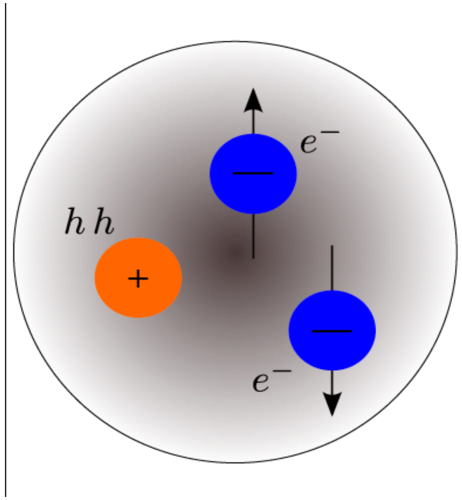
Optical Tweezers for Electrons in Quantum Wells

PI: Piermarocchi

- Semiconductor Quantum Well:
  - 2-dimensional system
  - Electron moves in x-y plane







- Electron Optical Lattice:
  - Electron is trapped due to laser intensity modulation
  - Strong potential due to “trions”

- Trion: two electrons and one hole bound together

PI: Maghrebi

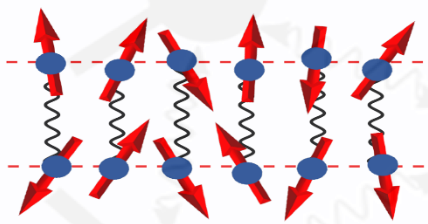
From Quantum many-body physics to Quantum information

Featured in Physics | Editors' Suggestion

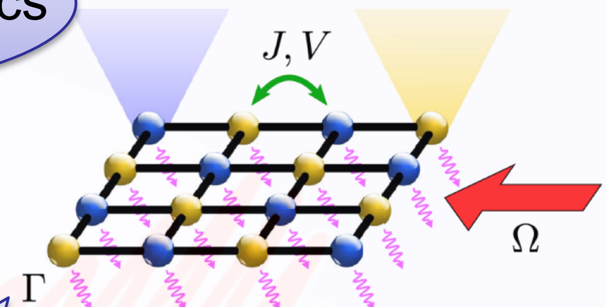
Fluctuation-Induced Torque on a Topological Insulator out of Thermal Equilibrium

M. F. Maghrebi, A. V. Gorshkov, and J. D. Sau
Phys. Rev. Lett. **123**, 055901 – Published 1 August 20

Physics See Synopsis: Topological Insulators Do the Twist

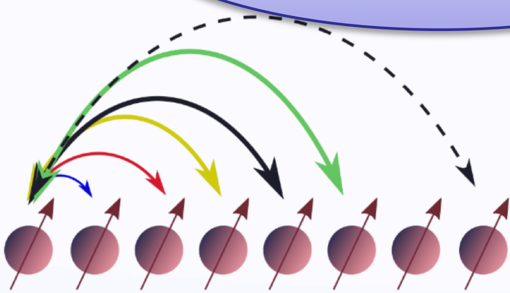


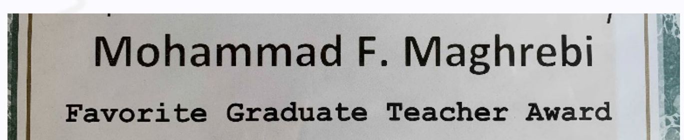
Non-equilibrium dynamics



Many-body physics

Quantum information, computation, simulation, …

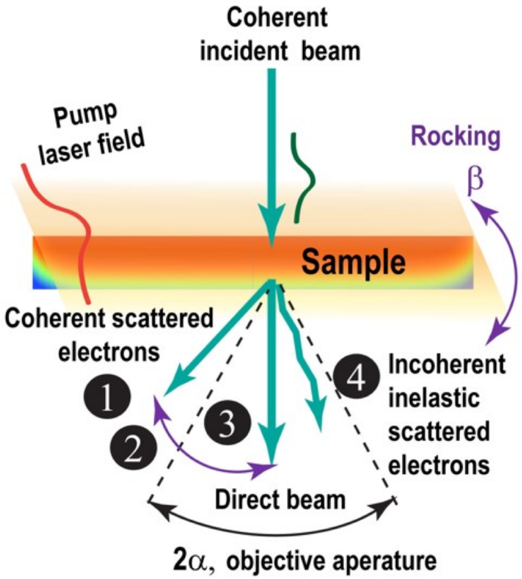


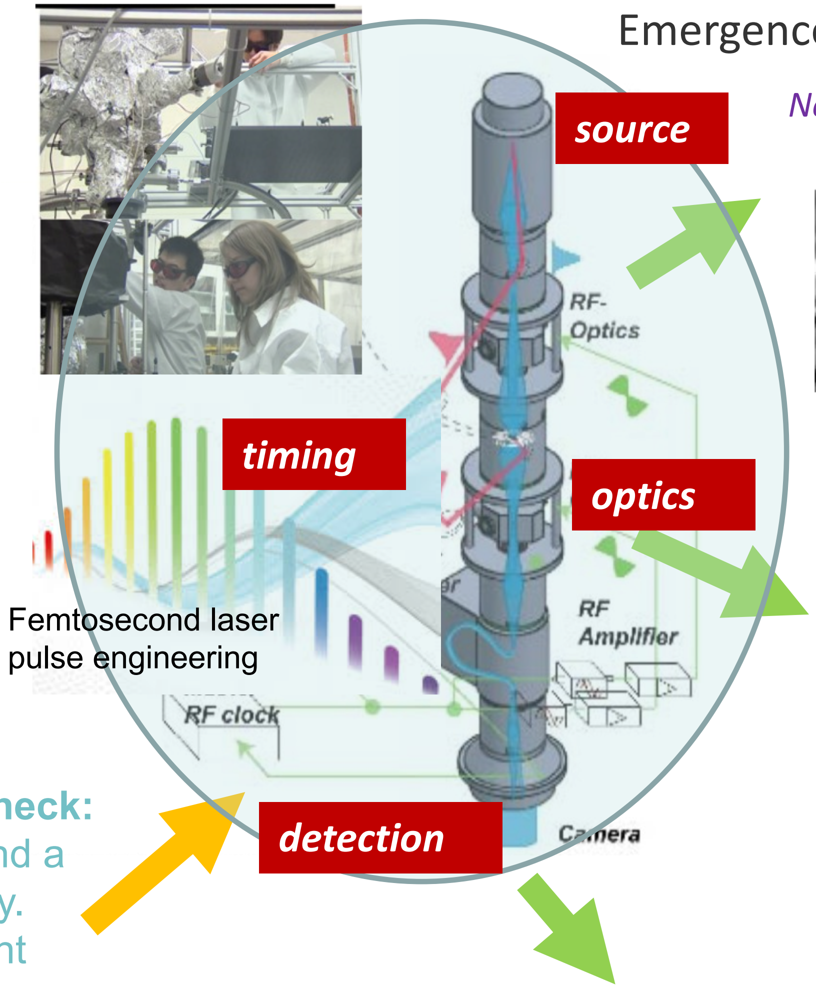


Ultrafast imaging and spectroscopy labs

PI: Ruan

Ultrafast Microscopy concept (TEM + pump-probe)



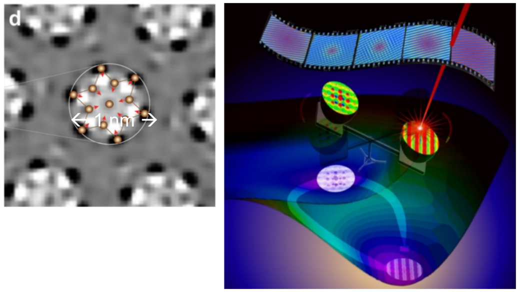


Solving information bottleneck:
Complex dynamics go beyond a single measurement modality. Meshing dynamics at different time and length scales

Ultrafast TEM integrate multimodal capabilities (imaging, diffraction, and spectroscopy) under the same roof.

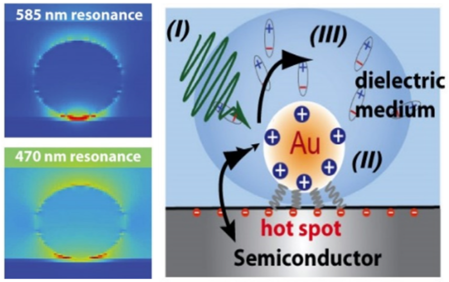
Emergences in Quantum Materials

New phases of matter



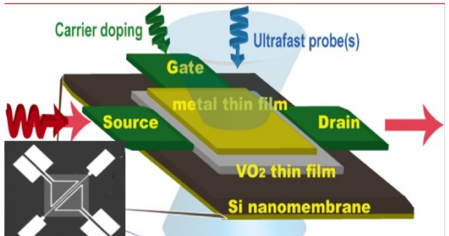
Inter-phase physics

Evolving interfaces, nucleation and transport



Nanoscale devices

visualization of functional materials in operando

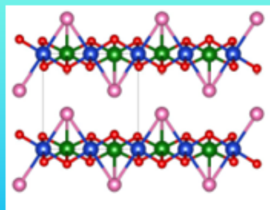


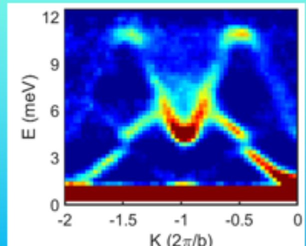
Quantum Materials

PI: Ke

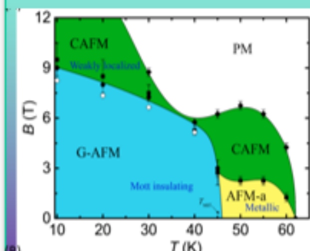
Explore emergent phenomena and understand the underlying mechanisms in quantum materials

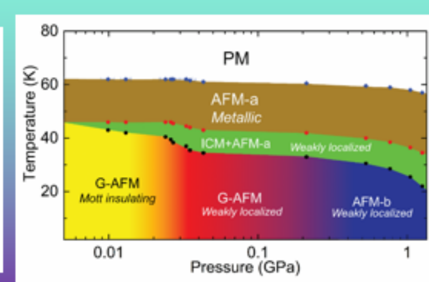
Low dimensional and frustrated quantum magnets



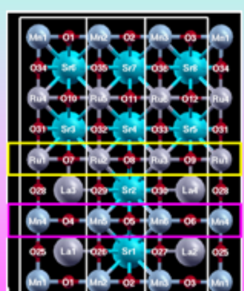


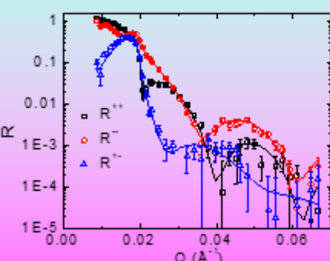
Correlated electronic materials



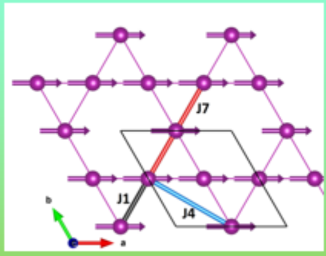


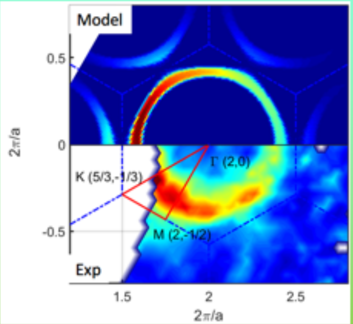
Complex oxide heterostructures





Topological materials





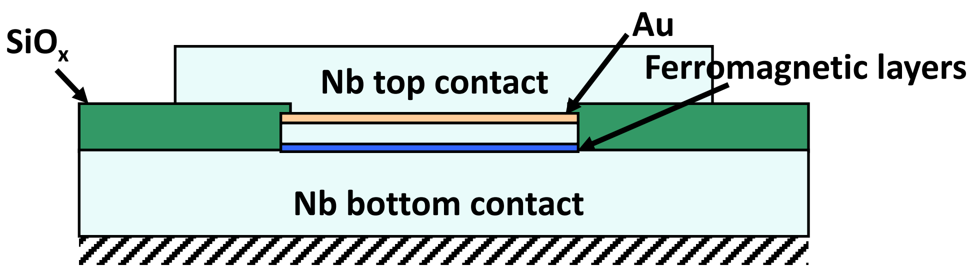
- Crystal growth
- Neutron and x-ray scattering
- Magnetic, electronic, and thermal transport measurements

Superconductor/Ferromagnet Hybrid Systems

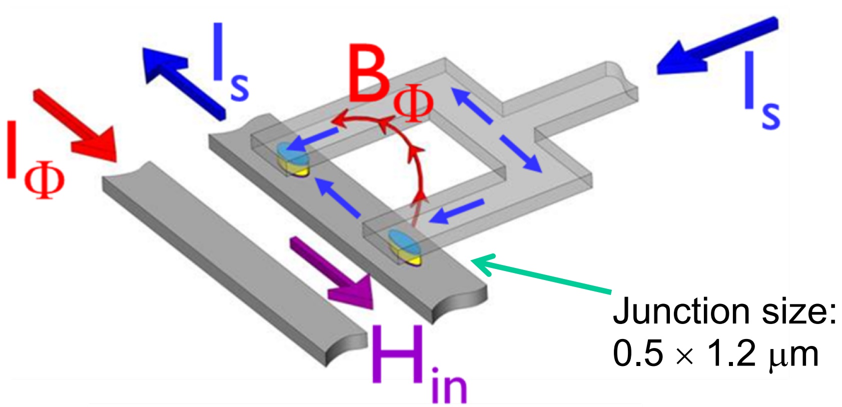
PI: Birge

- Fundamental physics
- Applications in cryogenic memory & superconducting electronics

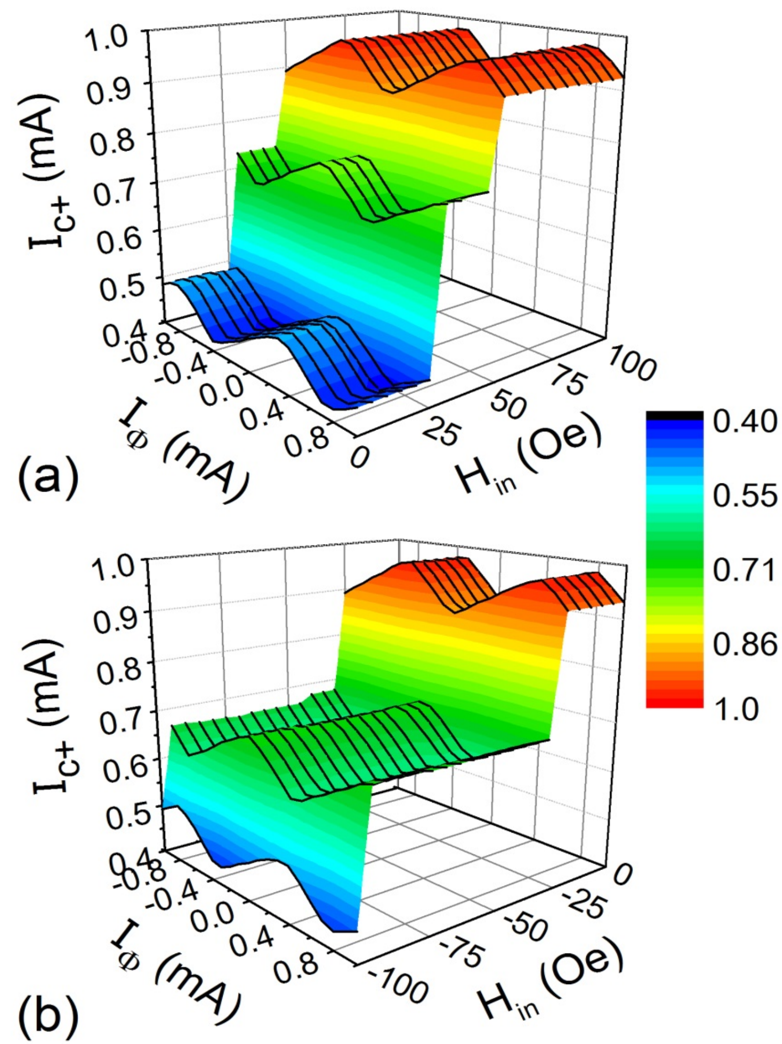
Cartoon of S/F/S Josephson junction:



Cartoon of SQUID for phase-sensitive measurements:

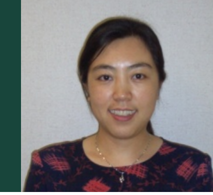


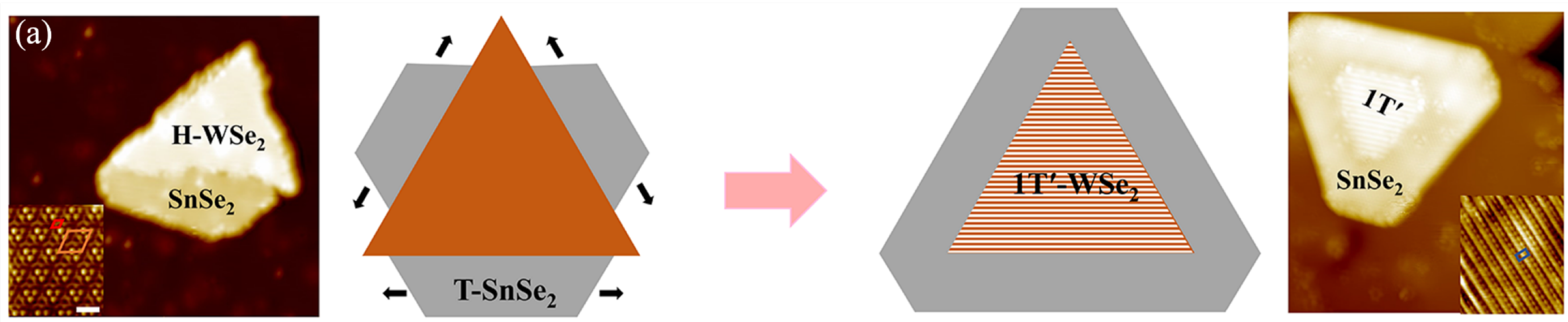
SQUID data showing 0 - π switching of ferromagnetic Josephson junctions:



Heterostructures and Heterointerfaces

PI: Zhang



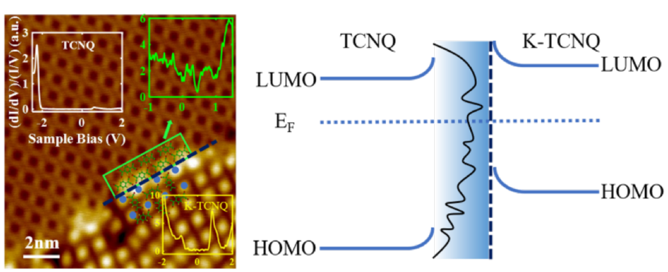


heterostructures and heterointerfaces

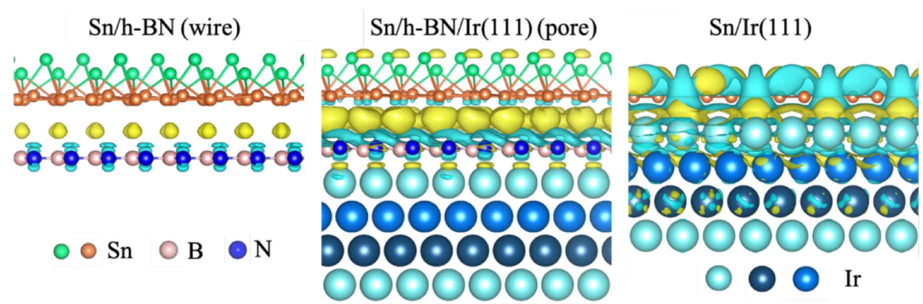
- ✓ Strain
- ✓ Charge transfer
- ✓ Interfacial coupling

- ✓ Moiré physics
- ✓ Spin-orbit coupling
- ✓ Proximity effects

(b)



(c)



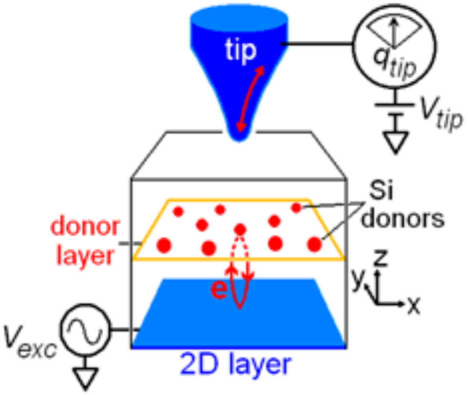
Experimental toolbox (*in-situ* growth and characterization):

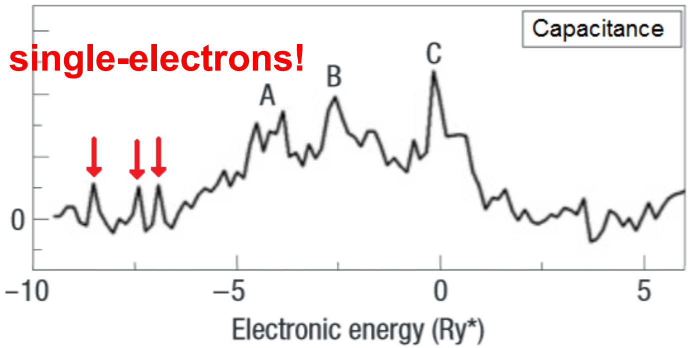
Molecular beam epitaxy, UHV chemical vapor deposition, Scanning tunneling microscopy

Nanoprobe Microscopy

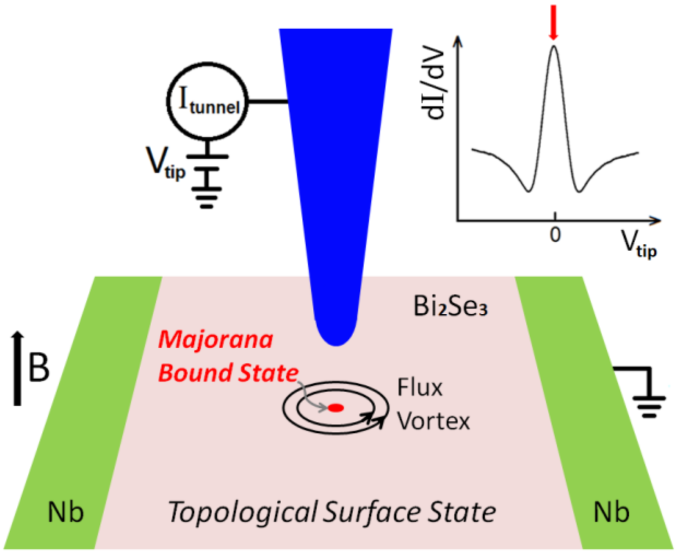
PI: Tessmer

We develop and apply low-temperature scanning probe techniques to study the behavior of charges in nanoscale systems. We are especially interested in the physics of superconductors, topological insulators, and nanoelectronics.



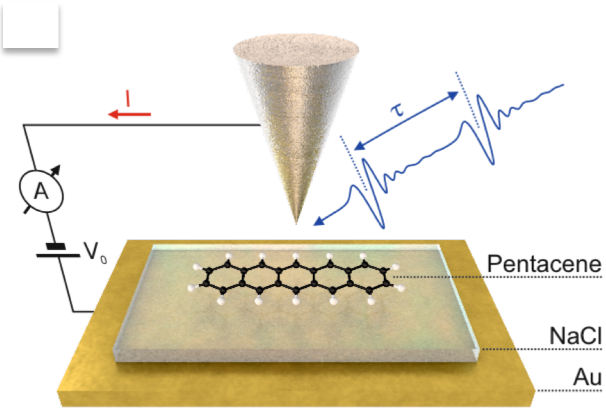


In this experiment we image the electronic structure in the barrier of a topological-insulator Josephson junction in the presence of magnetic field. The goal is to elucidate the interplay between charge, momentum and spin in these fascinating materials. This is a collaborative experiment with Prof. Dale Van Harlingen at the University of Illinois.

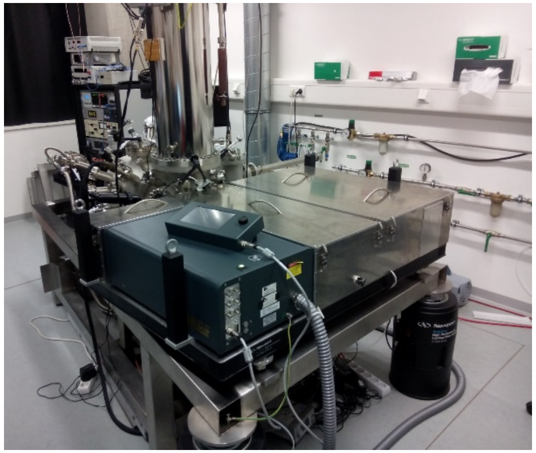


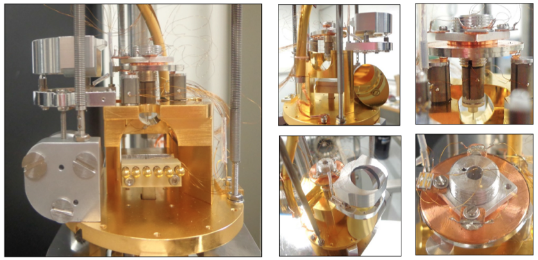
Ultrafast terahertz nanoscopy laboratory

PI: Tyler Cocker

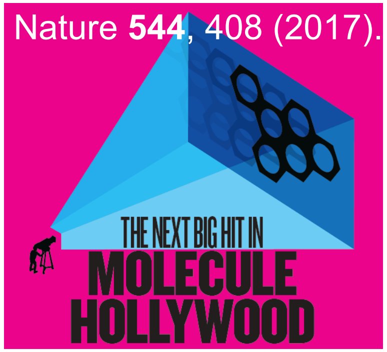


Couple ultrafast **terahertz** pulses to the tip of a scanning tunneling microscope to control electron motion

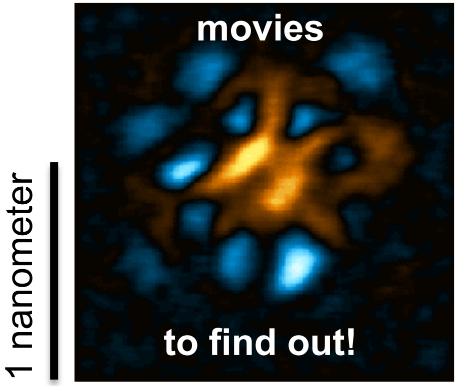


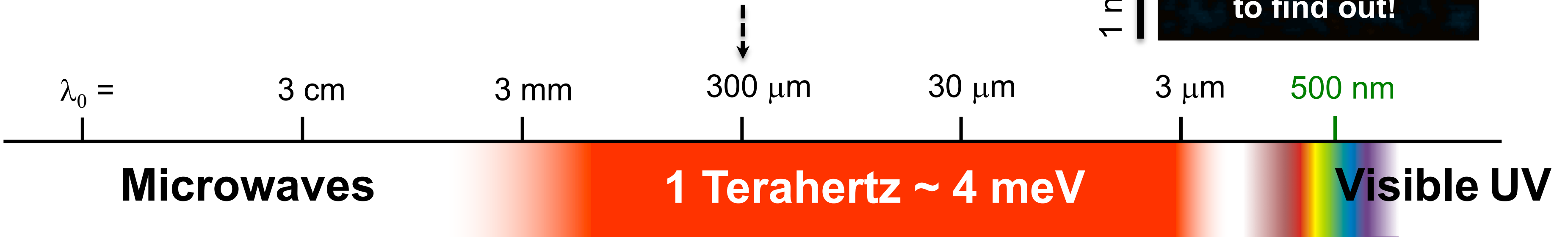


Now under construction at MSU: the **first ultrafast THz-STM in the United States**.
Pictured: Tyler's THz-STM from U. Regensburg
To read more see: Nature **539**, 263 (2016).



How do molecules respond to light on their intrinsic length and time scales…?
…make THz-STM movies to find out!



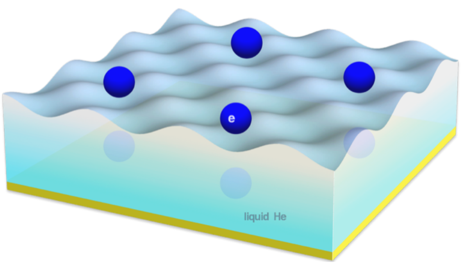


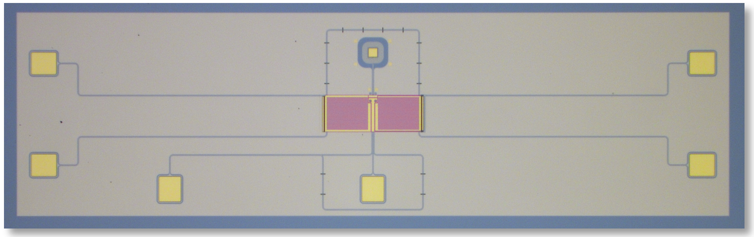
Laboratory for Hybrid Quantum Systems |LHQS⟩

PI: Johannes Pollanen

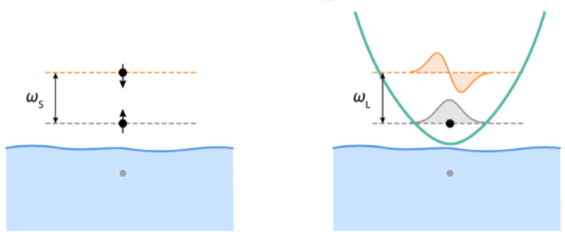
www.hybridquantumlab.com

Electrons on helium





Single electron trapping device



Spin states

$\omega_s/2\pi = 5$ GHz at $B = 0.2$ T

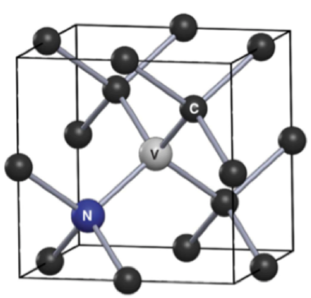
($T_2 \approx 1.5$ s)

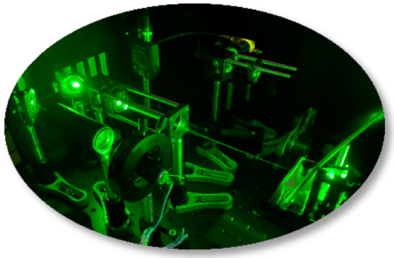
Lateral motional states

$\omega_s/2\pi = 5$ GHz

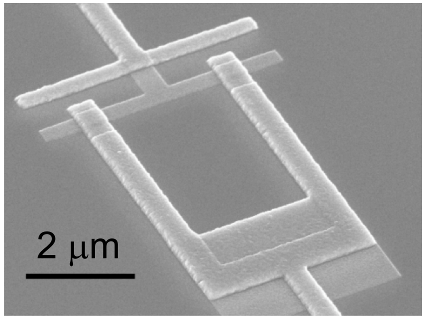
|LHQS⟩

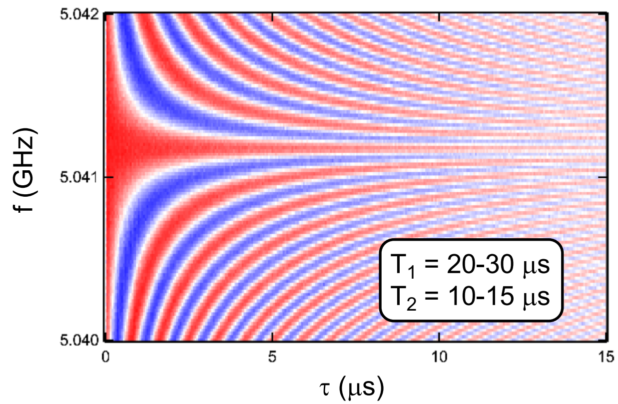
Condensed Matter meets Quantum Information Science (QIS)





optical initialization and readout





Color-centers in diamond

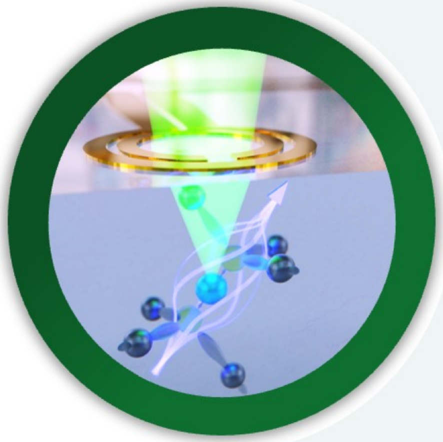
Superconducting qubits

S²QO

Solid-State Quantum Optics Group

PI: Jonas N. Becker

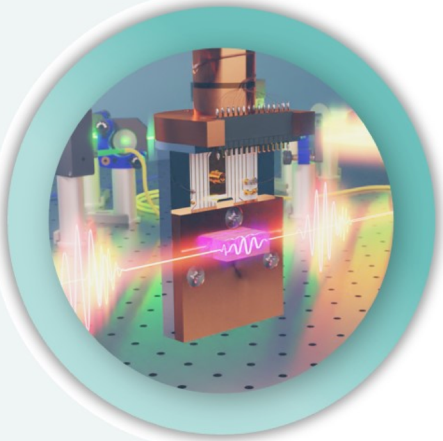
Novel Spin Qubits in Diamond



Can we find the perfect quantum bit?

Our approach: Single crystal defects in synthetic diamond

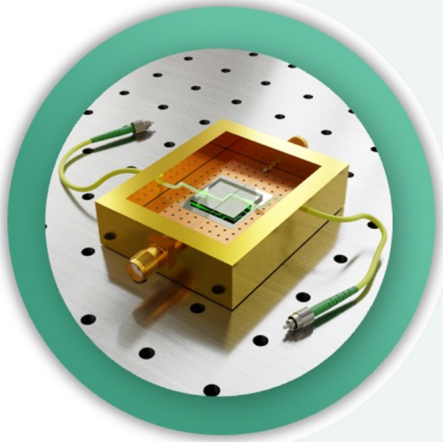
Optical Quantum Memories



How can quantum information be stored?

In ensembles of diamond defects or rare earth ions!

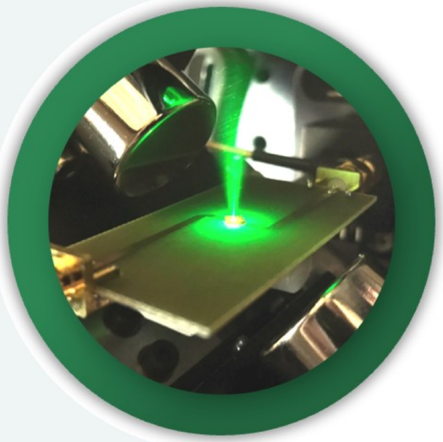
Quantum Interconnects



How do we connect quantum computers?

rare earth crystals to distribute photonic entanglement between microwave qubits

Quantum Thermodynamics



Can quantum physics beat classical engines?

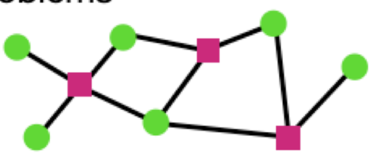
A diamond defect quantum heat engine Can outperform its classical counterpart!

Baldwin Condensed Matter Theory Group

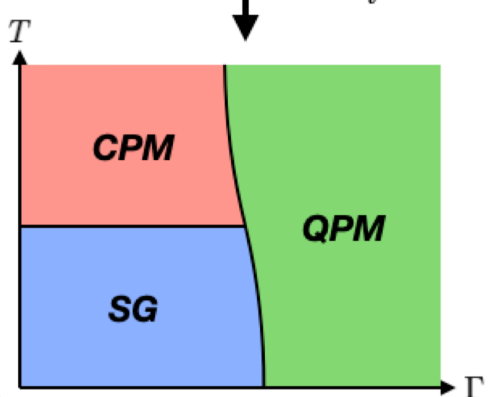
PI: Christopher L. Baldwin

Quantum spin glasses & optimization

- Understanding how quantum fluctuations suppress (or enhance) glassiness
- Motivated by quantum computing & optimization problems

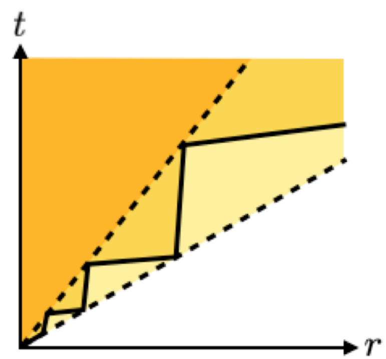


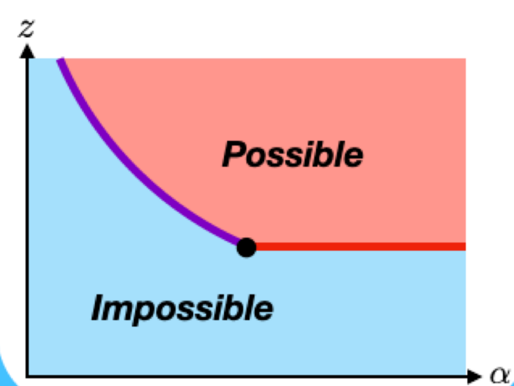
$$H = H_0(\hat{\sigma}^z) - \Gamma \sum_i \hat{\sigma}_i^x$$



Information propagation in disordered systems

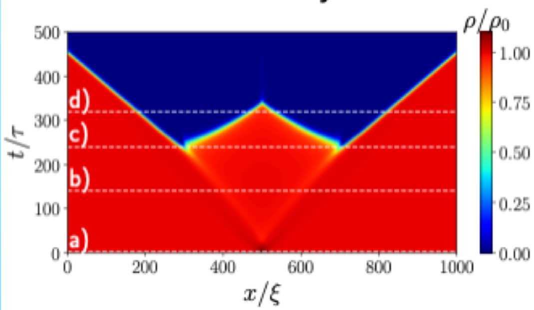
- Constructing mathematical "speed limits" on how quickly quantum information can spread in the presence of disorder

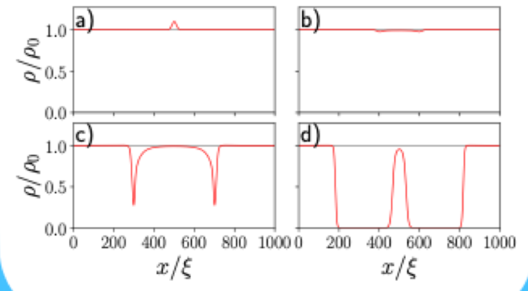




Dynamics of nonlinear waves

- Understanding how the dynamics of nonlinear waves differ from their linear counterparts
- E.g., "optical bistability": existence of many consistent scattering states, analogies with disordered systems





CMP/QIS at MSU

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