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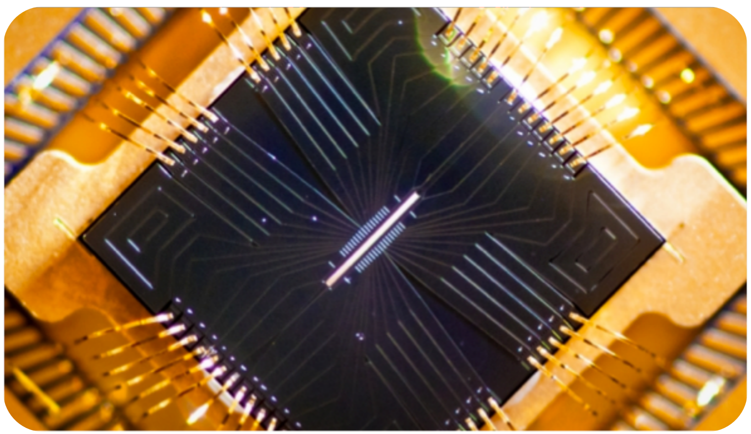

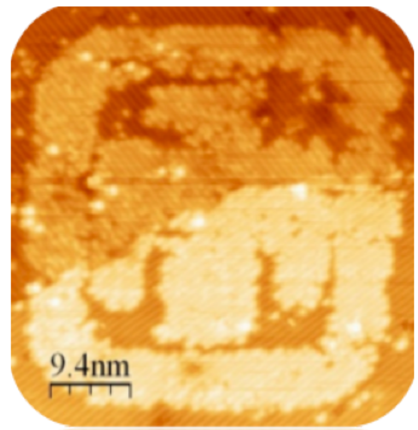

Robust quantum simulation for near-term realizable quantum hardware

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Near-term promise of quantum

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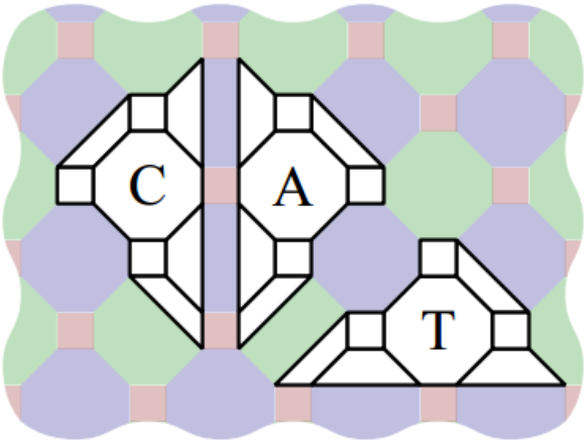
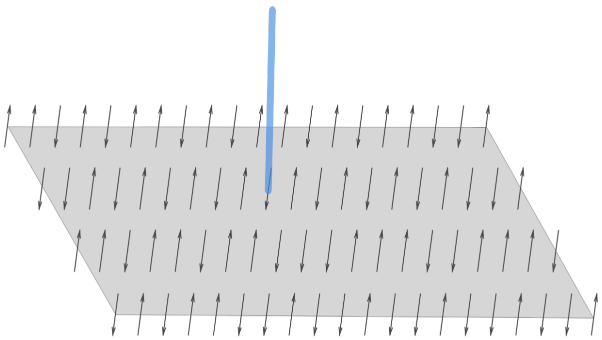
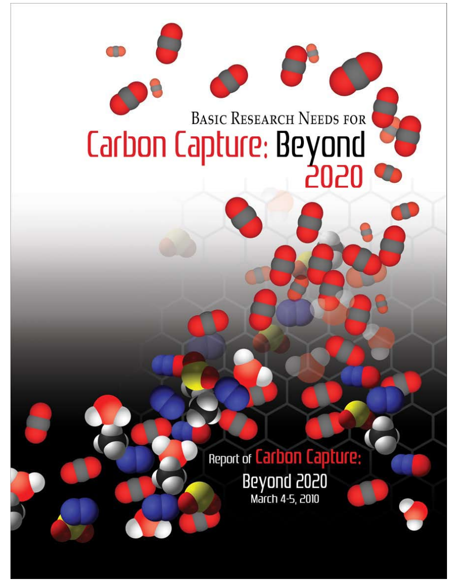
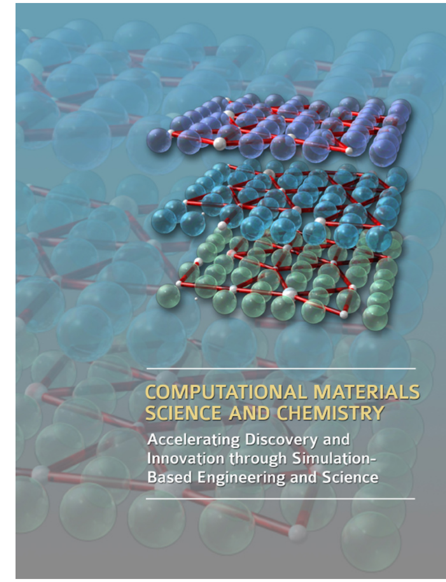
- Long-term promise of quantum is well-known
  - FT-QEC enabling large circuits simulating factoring, unstructured search, etc.
  - DOE-relevant problems: optimization, graph properties, quantum simulation
- What can we do in the near term (10 years)?
  - It is likely we will have some special purpose quantum hardware that can establish and manipulate quantum states in this time frame.
  - Probably not enough qubits to perform QEC **and** an algorithm
  - What algorithms can we identify?

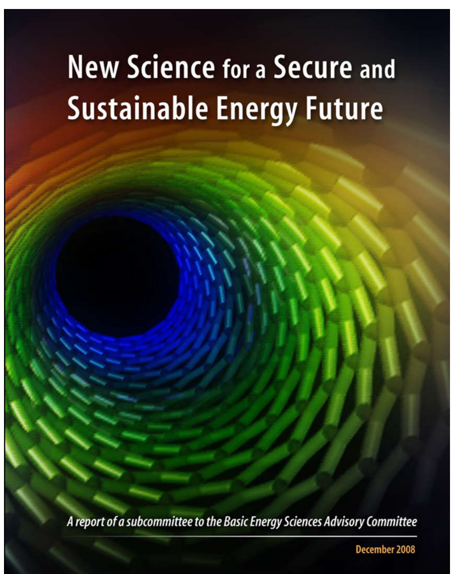


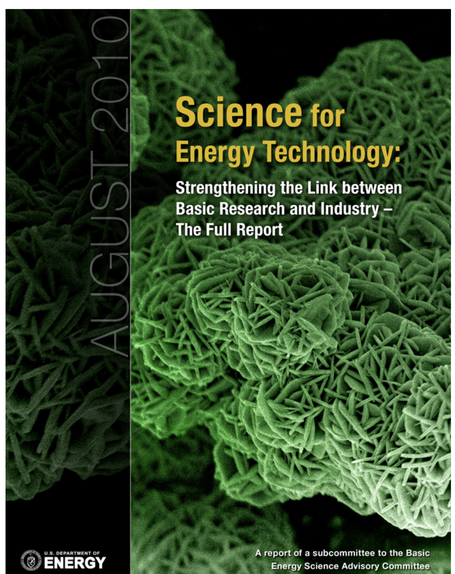


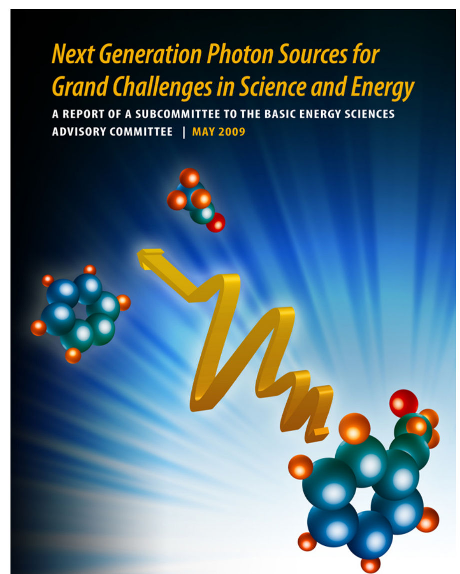
Simulation is Central to ASCR & DOE

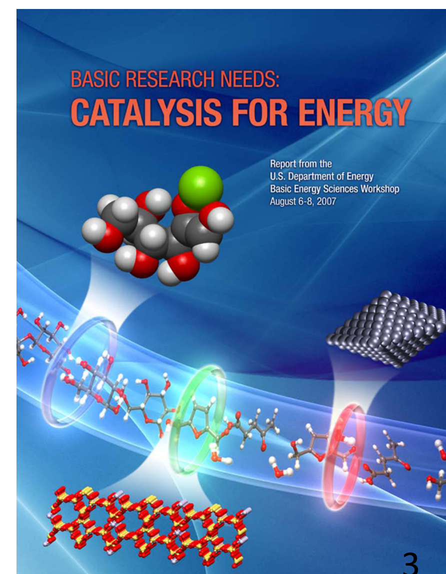












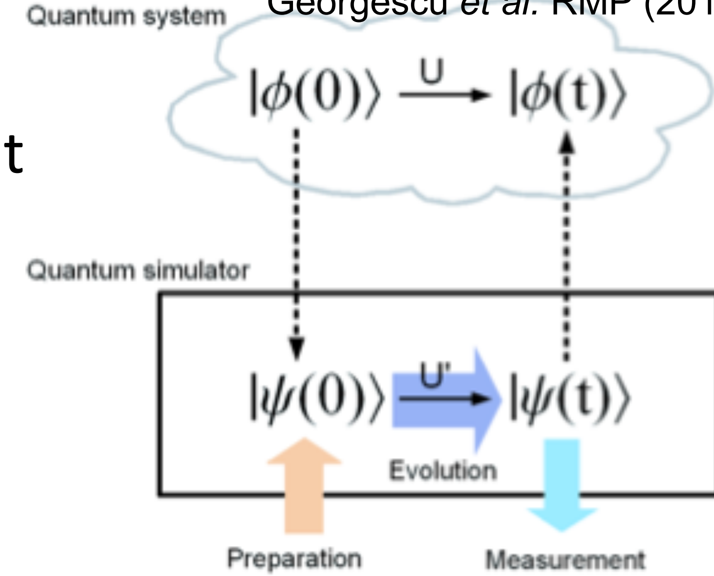
Robust quantum simulations

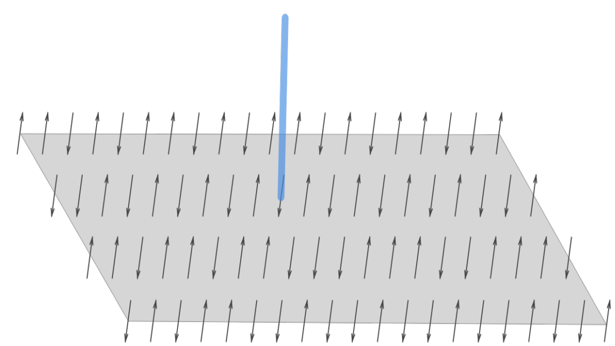
- Robustness
  - Since we can't afford FT-QEC, we need algorithms that are somehow robust to noise, disorder, decoherence.
- Potential robust algorithms
  - Analogue simulation of quantum systems
    - Device noise mimics simulation noise
  - Shallow quantum oracles
    - Variational eigensolver by Peruzzo et al from quantum chemistry
    - Minimize the build-up of noise with shallow circuits
  - Dissipative quantum processes
    - Perform operations with stable fixed points that are insensitive to noise in the distant past

Analogue simulation of quantum systems

Georgescu *et al.* RMP (2014)

- Arrange qubits so that their Hamiltonian closely approximates that of the quantum system of interest.
- Useful for lattice properties of materials
  - e.g. Does Fermi-Hubbard model with X parameters superconduct?
- Robust because of assumed similarity between device noise and system noise
  - Need to understand how well noise models map between analogues





I. Georgescu, S. Ashhab, and F. Nori, "Quantum simulation", Rev. Mod. Phys. **86**, 153 (2014).

Variational quantum eigensolver

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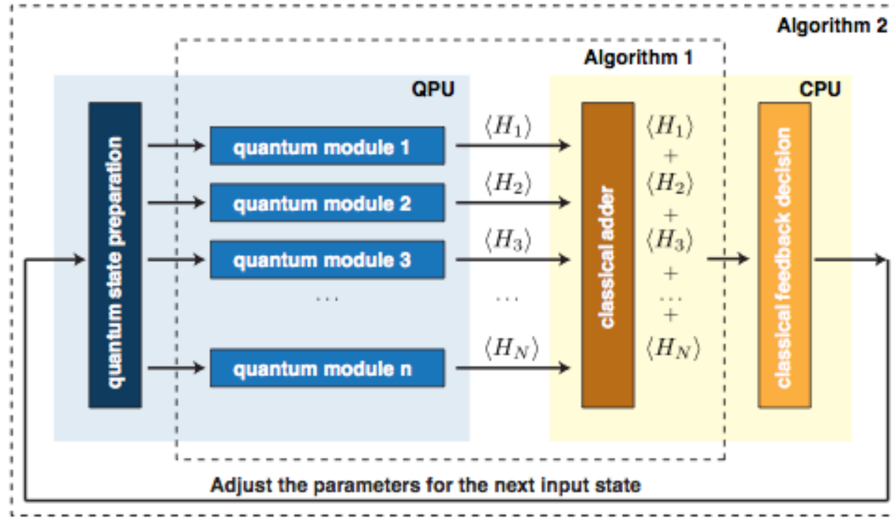
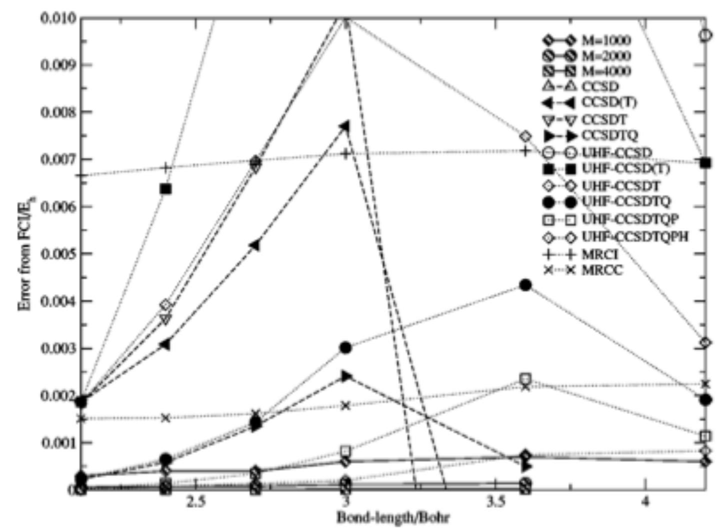
- Example of shallow oracle
- Prepare and measure quantum states based on few classical parameters that are varied and optimized using classical means
- Need to identify wave functions where polynomial optimization results in something computationally useful
- UCC very promising
  - Size consistency and variational are not exclusive, and may both be required for materials design
  - Is UCC unique?



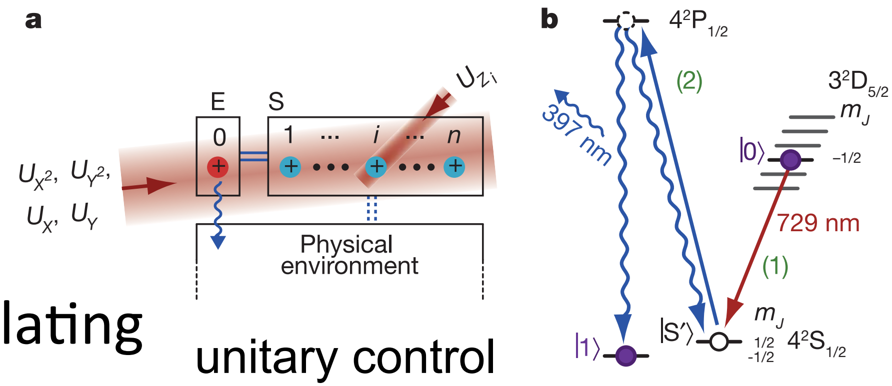


Chan et al., JCP (2004)

A. Peruzzo et al, "A variational eigenvalue solver on a quantum processor", Nat. Comm. **5**, 4213 (2014)

Dissipative quantum processes

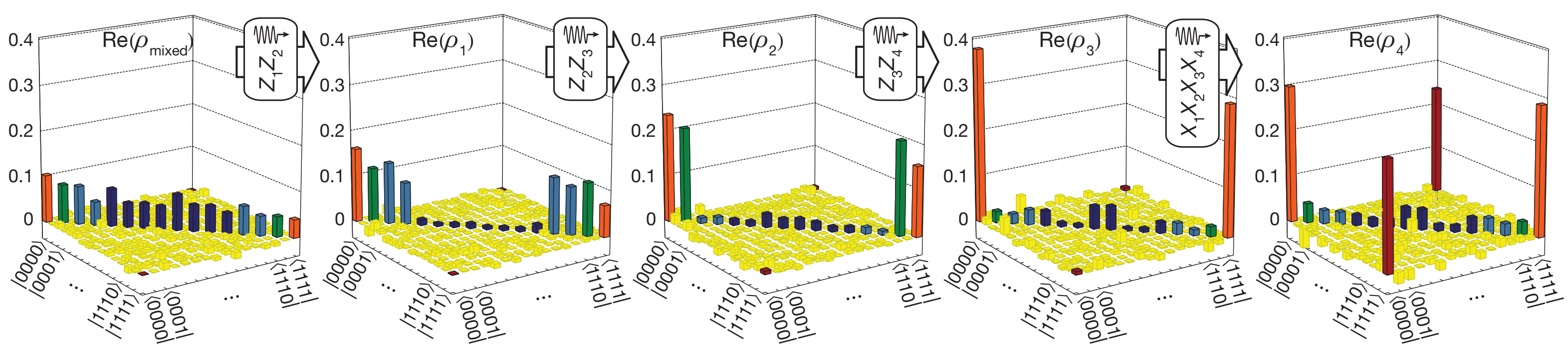
- Overwhelm unintentional loss with engineered loss
- Noise *perturbs* the steady state from the ideal instead of accumulating *drift over time* of a state from the ideal
- Natural platform for open system dynamics
- “Easy” to engineer quantum correlations, hard to protect quantum information:



unitary control

dissipative control

Barreiro et al., Nature (2011)



F. Verstraete et al, "Quantum computation and quantum-state engineering driven by dissipation", Nat. Phys. **5**, 633 (2009)

Path forward

- Office of Science mission to a large degree involves materials simulation
- Robust simulation promises
  - Quantum speedup without overhead of QEC
  - Clearest application to DOE-relevant problems
- Some of this problem space may be explored in the very near term via quantum emulation
  - Direct simulation of quantum vector states possible for small numbers of qubits
  - Use noise models extracted from GST studies of existing systems (e.g. arXiv 1310.4492)
  - Establish how device space and simulation space noise models map for different types of simulation.
- In-depth partnership with experiment is necessary for validation and continued progress.