Quantum Testbed Stakeholder Workshop

Hosted by the Advanced Scientific Computing Research Program

Los Alamos National Laboratory

Quantum Computing Capabilities and Interests

February 14 – 16, 2016

U.S. DEPARTMENT OF ENERGY | Office of Science

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LANL Capabilities & Interests Summary

Primary Expertise & Interest Areas

- Broad capabilities in complex and quantum materials; making-measuring-modeling to devices
- Algorithm development for novel architectures
- Testbed exploration, including with partners

Most Differentiating Factor

- "Culture" of co-design has a decade+ history
  - algorithms and architectures
  - Experiment-Theory-Simulation
- Deep history in quantum physics: correlated materials to quantum information science

Main Contribution/Role

- Balanced integration of materials and computing expertise
  - Greater focus on far future, especially quantum, than next-gen CMOS
- User facilities, Centers & Institutes, Testbeds provide venues for partnership/collaboration (academic, industrial, other Labs)

LANL Self Assessment of Capability Areas

- Quantum computing hardware capabilities
- Quantum computer science capabilities
- Fabrication and characterization capabilities
- Capabilities in engineering and support technologies
- Domain science communities at the lab that stand to benefit from quantum computing
- Directly relevant LDRD investments and lessons learned
- Experience with various facility management models that could be adapted to a quantum testbed facility
- Relevant external partnerships with industry or universities; experience in working with industry, IP protection and technology transition

High

Medium

Low

Los Alamos has a long history in Quantum Science

- **We possess a broad quantum capability**

  "Quantum Complexity" a focus since ~ 1980

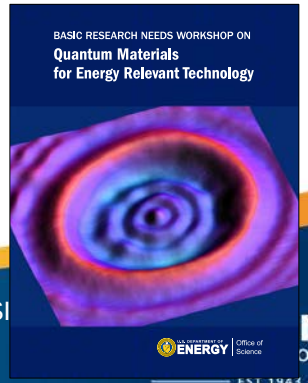
  – Quantum Information/Quantum Measurement (e.g., QKD)
  – Quantum Computing
  – Quantum Materials

  –continuous activity in each area with evolving emphasis

- **Quantum Institute is a vehicle for community coordination**
  – Span internal capabilities & window to the world
  – Distinguished alumni network
  – "Quantum Lunch" still ongoing

    http://quantum.lanl.gov/qlunch/2017_qlunch/index.html

- **A quantum renaissance is upon us**



Co-design, broadly defined, is required for success, and LANL has significant expertise and breadth

- Partnerships and external engagement are important
  - User facilities, Centers & Institutes, industrial relationships a strength
  - Beyond Moore is a problem well-suited to an ecosystem of Labs
- LANL has significant co-design expertise and breadth
  - Our materials strategy emphasizes controlled functionality
    - With a particular focus on integrated nanomaterials and complex functional materials
  - We have experience in translation and scaling
    - Superconductivity Technology Center, Fuel Cells, Quantum Dots, Perovskite solar cells
  - We are active in non-general-purpose algorithms and systems
    - Probabilistic computing, resiliency, quantum algorithms, performance emulation
  - Testbeds and technology exploration are central to our strategy
    - Roadrunner, D-wave, Darwin, Trinity …

Bridging the continuum is challenging and an opportunity for this effort

The Center for Integrated Nanotechnologies (CINT) emphasizes integration

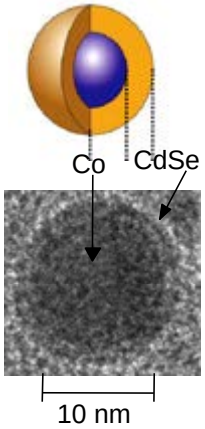
Core Facility at Sandia
96,000 sq ft total
30,000 sq ft lab space
9,000 sq ft clean room

Los Alamos NATIONAL LABORATORY EST.1943 | Sandia National Laboratories | U.S. DEPARTMENT OF ENERGY | Office of Science

Gateway Facility at Los Alamos
36,500 sq ft total
11,000 sq ft lab space

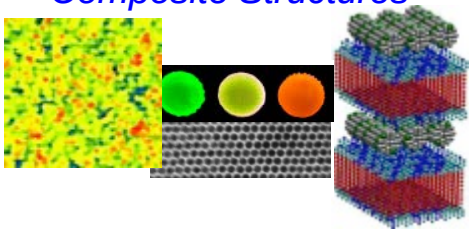
Nanoscience Integration:

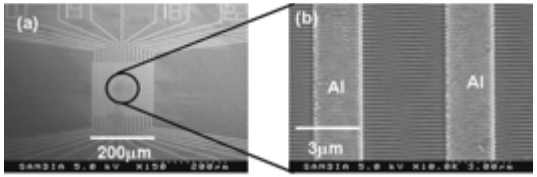
Functional Nanomaterials



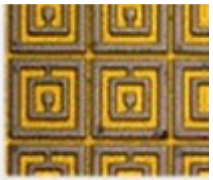
nanometer

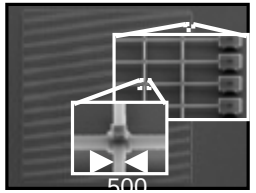
Composite Structures





Active, Functional Systems



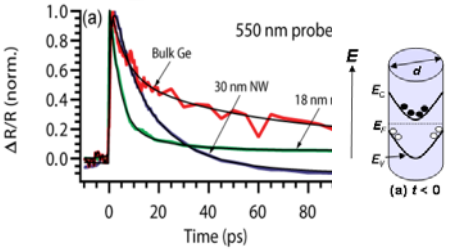


micron

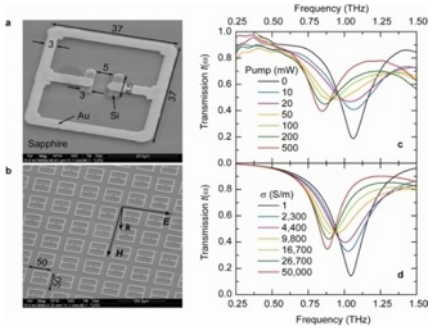
CINT differentiating strengths include…

Ultrafast photonics

Carrier Dynamics

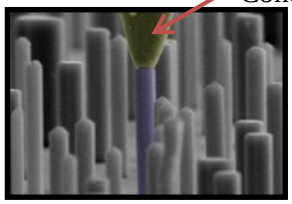


THz Metamaterials

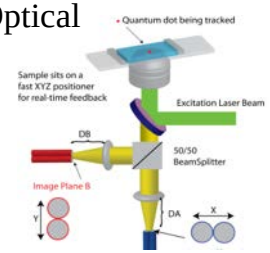


Nano-manipulation & scanning probes

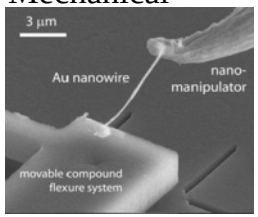
Electrical



Optical



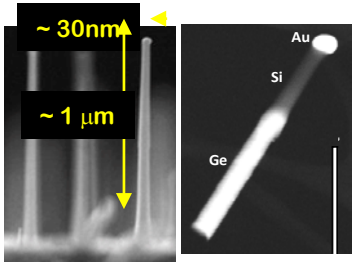
Mechanical



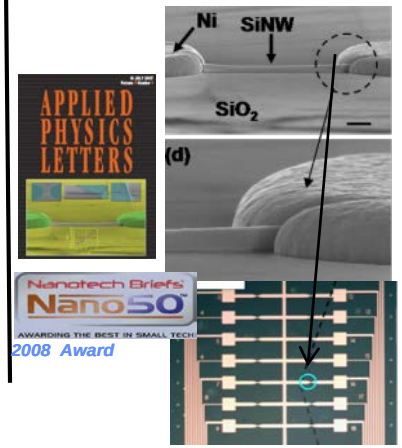
CINT user C. Volkert project

Nanofabrication

Synthesis

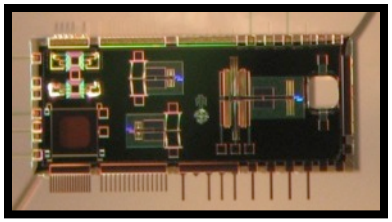


Directed Assembly

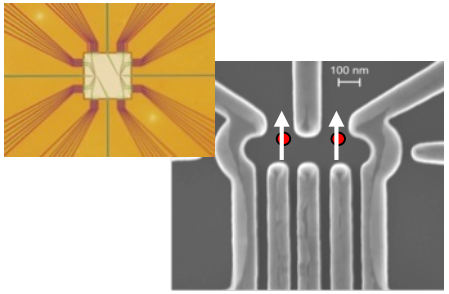


Discovery Platforms™

Nanomechanics & Thermal Transport



Quantum Computing & Electrical Transport



Diverse materials synthesis, fabrication, and characterization capabilities in a user facility mode: CINT scientists are a key differentiator

LANL possesses broad complex materials and device modeling capabilities

Electronic, magnetic, optical properties of complex functional materials

Spin detection: Spin noise, Nonequilibrium dynamics

Nanomaterials, Metamaterials, Casimir physics

Organic electronics and spintronics; device physics

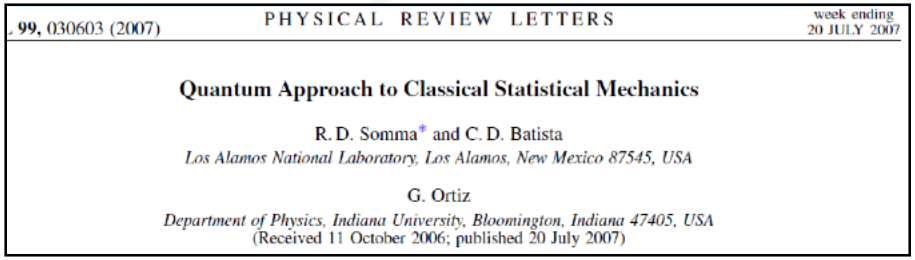
Techniques: QMC, DFT, Quantum Annealing, etc.

Condensates: BEC, ultra-cold gases

Quantum communication, cryptography, algorithms

CINT is an entry point to theory capability

One element of our algorithms strategy : Mixing Classical & Quantum Approaches to Solve Real World Problems



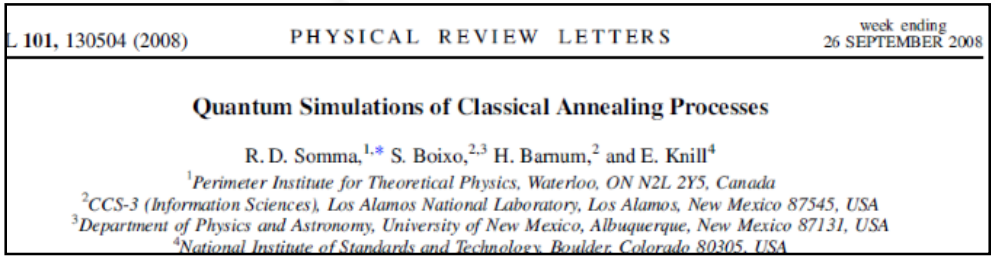
99, 030603 (2007) PHYSICAL REVIEW LETTERS week ending 20 JULY 2007

Quantum Approach to Classical Statistical Mechanics

R. D. Somma* and C. D. Batista
Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

G. Ortiz
Department of Physics, Indiana University, Bloomington, Indiana 47405, USA
(Received 11 October 2006; published 20 July 2007)

Quantum Algorithms for Classical Physics

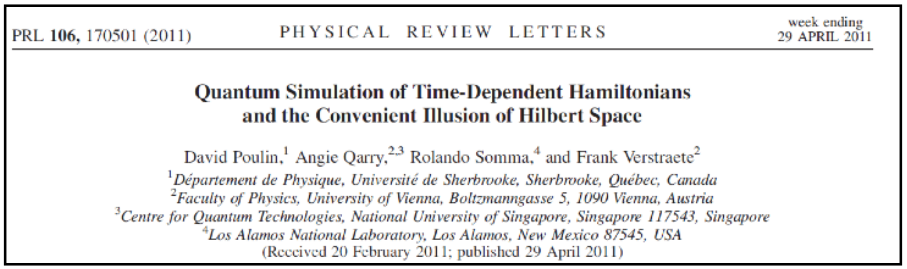


101, 130504 (2008) PHYSICAL REVIEW LETTERS week ending 26 SEPTEMBER 2008

Quantum Simulations of Classical Annealing Processes

R. D. Somma,[1,*] S. Boixo,[2,3] H. Barnum,[2] and E. Knill[4]
[1]*Perimeter Institute for Theoretical Physics, Waterloo, ON N2L 2Y5, Canada*
[2]*CCS-3 (Information Sciences), Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[3]*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico 87131, USA*
[4]*National Institute of Standards and Technology, Boulder, Colorado 80305, USA*

Quantum Algorithms for Classical Physics

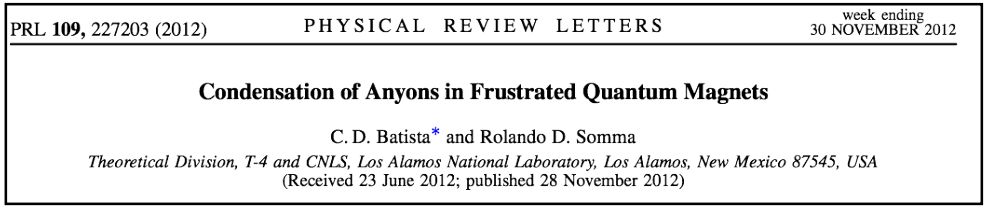


PRL 106, 170501 (2011) PHYSICAL REVIEW LETTERS week ending 29 APRIL 2011

Quantum Simulation of Time-Dependent Hamiltonians and the Convenient Illusion of Hilbert Space

David Poulin,[1] Angie Qarry,[2,3] Rolando Somma,[4] and Frank Verstraete[2]
[1]*Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, Canada*
[2]*Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria*
[3]*Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore*
[4]*Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
(Received 20 February 2011; published 29 April 2011)

Quantum Algorithms for Quantum Chemistry



PRL 109, 227203 (2012) PHYSICAL REVIEW LETTERS week ending 30 NOVEMBER 2012

Condensation of Anyons in Frustrated Quantum Magnets

C. D. Batista* and Rolando D. Somma
Theoretical Division, T-4 and CNLS, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA
(Received 23 June 2012; published 28 November 2012)

Quantum-Motivated Algorithms for CMP

Historic strength in quantum foundations (e.g., Zurek et al.)

Focus on condensed matter and chemistry challenges (e.g., Somma et al.)

Emerging strength in optimization, machine learning, related areas

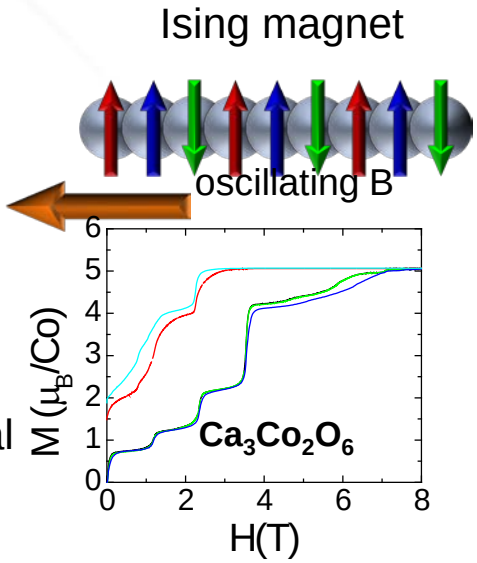
-Marcus Daniels, Stephan Eidenbenz, Scott Pakin

Ongoing LDRD-DR: Hybrid Quantum-Classical Computing

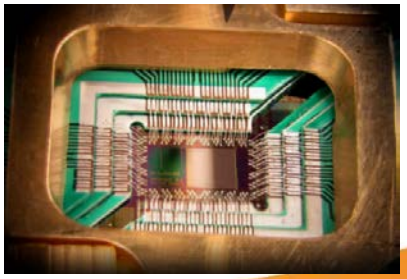
Breakthroughs in quantum technologies have yielded “quantum annealers.” They hold promise in optimization challenges, but do not behave ideally, are not fault-tolerant, and are poorly characterized.

Technical Approach

- Develop new algorithms for challenging optimization problems
- Develop methods for benchmarking quantum annealers based on the dynamics of phase transitions
- Develop a quantum programming compiler
- Conduct laboratory experiments of quantum annealing on physical systems that are ubiquitous in optimization



Scott Pakin will discuss co-design grounded in theoretical physics



Various smaller-scale efforts (current and past).

Team-scale activities (~$1.5M/yr best enable co-design/synergy)

Los Alamos hosts a D-Wave 2X system: “Ising”

- D-Wave 2X system (1000+ qubits)
  - Quantum annealing and related applications
  - Co-design of future technologies
  - Workforce development emphasis
- Shared resource usage model on open network
- Focus is to develop collaborative network of people and ideas
  - Users/collaborators welcome

Stephan Eidenbenz will discuss our efforts to stimulate usage and grow community

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