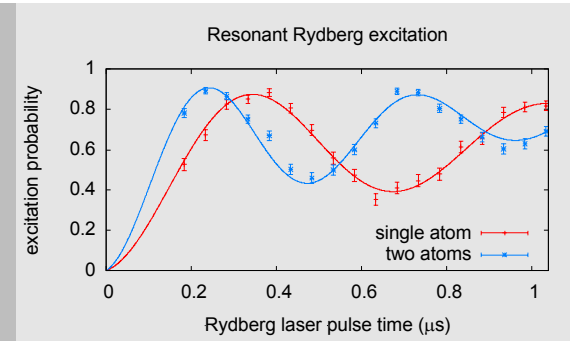
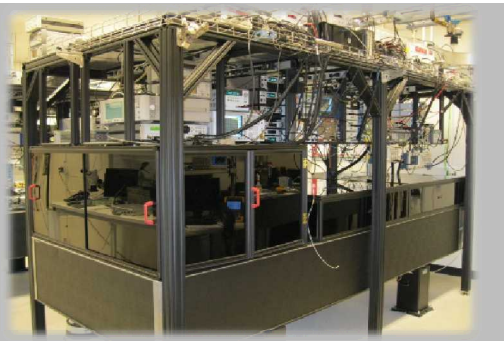
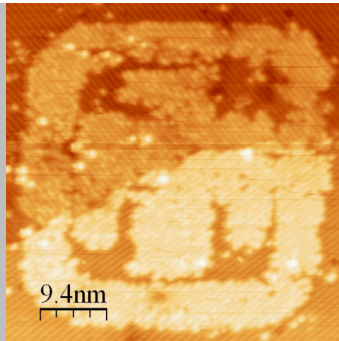
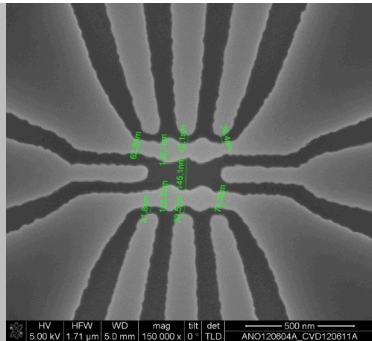


*Exceptional service in the national interest*



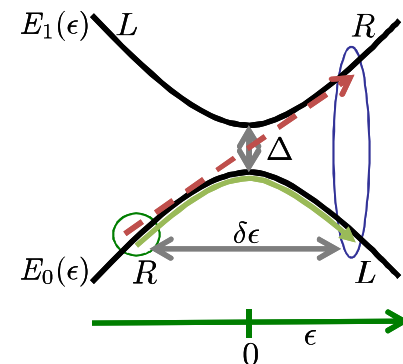
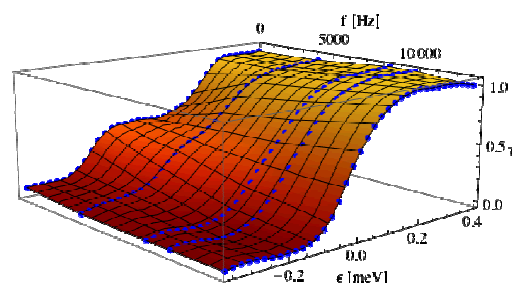
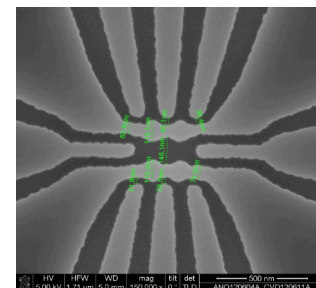
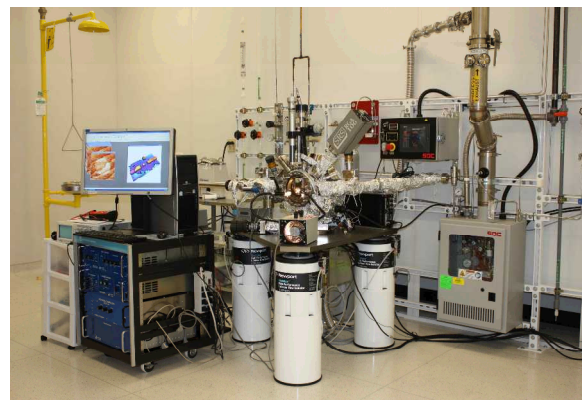
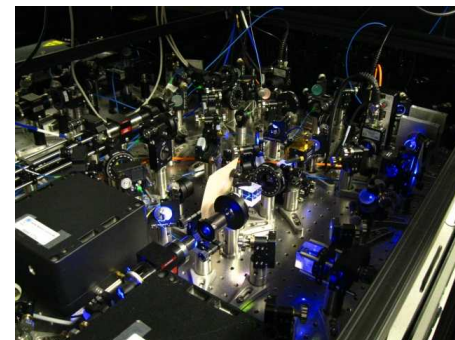
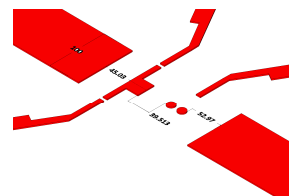
# AQUARIUS

## Programmatic Overview

Steven M. Rinaldi  
Program Manager

April 17, 2013

- Vision and Objectives
- Programmatic Review
  - Milestones
  - Financial Report
  - Staffing
  - AQC Workshop
  - Outreach
  - Intellectual Property Strategy
  - Risks
- Future Vision and Plans
- Questions

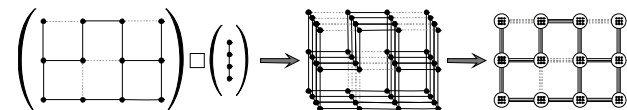
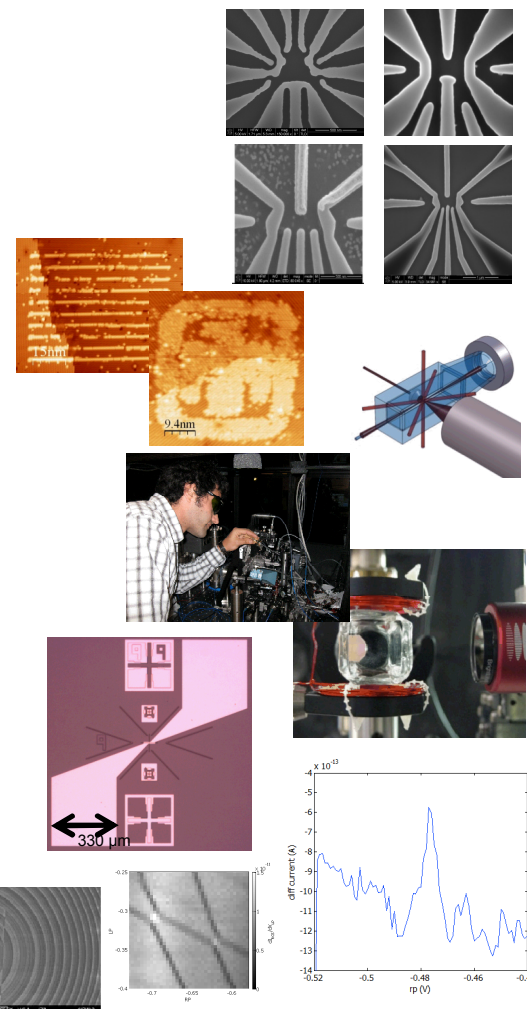


# Vision and objectives

**VISION:** Develop a quantum-computing architecture whose resource requirements are more achievable than conventional approaches due to the intrinsic noise immunity offered by adiabatic physics

## OBJECTIVES:

- Demonstrate two-qubit *special-purpose* adiabatic quantum optimization algorithms in:
  1. Neutral atoms trapped by a nanofabricated optical-trap array
  2. Electrons trapped by semiconductor nanostructures
- And for these technologies to:
  3. Evaluate the potential for fault-tolerant general-purpose adiabatic quantum computation architectures through design & simulation



# Milestones – last EAB

- **Year 1:**
  - Establish AQUARIUS EAB (Oct 2010)
  - Market and external environment report (Dec 2010)
  - EAB Meeting #1 (Feb 2011)
  - Management assurance review for Chief Technology Officer (CTO) (Mar 2011)
  - Hire staff, postdocs (ongoing throughout FY)
  - Establish contracts (ongoing throughout FY)
  - CTO Management Assurance Review (Sep 2011)
  - Year 1 final report (LDRD requirement) (Sep 2011)
- **Year 2:**
  - EAB Meeting #2 (Oct 2011)
  - Workshop #1 (Mar 2012)
  - CTO Management Assurance Review (Mar 2012)
  - Report on EAB #2 Recommendations (Jun 2012)
  - EAB Meeting #3 (Jun 2012)
  - Quarterly tracking and benchmarking reports (Jun 2013, Sep 2013)
  - FY13 renewal process (Jul 2012)
  - CTO Management Assurance Review (Sep 2012)
  - Develop/implement intellectual property strategy (Sep 2012)
  - Report on EAB #3 Recommendations (Sep 2012)
  - Year 2 final report (LDRD requirement) (Sep 2012)
- **Year 3:**
  - Quarterly tracking and benchmarking reports (Dec 2012, Mar 2013, Jun 2013)
  - Second International AQC Workshop (Mar 2013)
  - CTO Management Assurance Review (Mar, Sep 2013)
  - EAB Meeting #4 (Apr 2013)
  - Report on EAB #4 Recommendations (Jun 2013)
  - Year 3 final report (LDRD requirement) (Sep 2013)

Green – satisfactory  
Yellow – in progress  
Red – pending

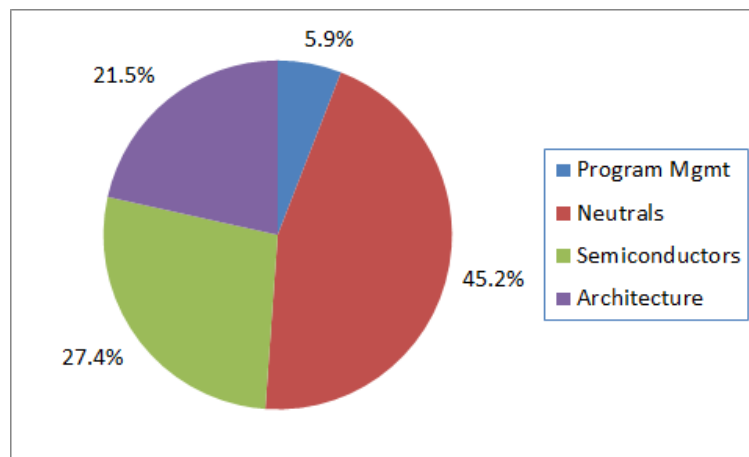
# Milestones – current status

- **Year 1:**
  - Establish AQUARIUS EAB (Oct 2010)
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  - CTO Management Assurance Review (Sep 2012)
  - Develop/implement intellectual property strategy (Sep 2012)
  - Report on EAB #3 Recommendations (slipped to Apr 2013)
  - Year 2 final report (LDRD requirement) (Sep 2012)
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  - Quarterly tracking and benchmarking reports (Dec 2012, Mar 2013, Jun 2013)
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Green – satisfactory  
Yellow – in progress  
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# Financial report

- FY13 budget: \$6,043K
  - \$228K cut in late FY12 during renewal phase
  - Restored Nov 2012
- Tracking well vs spend plan
- Will scrub budget by end of April
  - Determine if any funds shifts are necessary
  - Support EAB recommendations
- Ongoing issue: dil fridge



# Staffing

- Changes:

- Kevin Young  
Architecture Lead



- New team members:

- Jonathan Rivera  
Technologist, STM



- Losses:

- Rajib Rahman (research professorship, Purdue University)
- James Chin-Wen Chou (in 2 weeks)

- Overall staff development, lifetime of AQUARIUS

- 5 new staff hires
- 9 postdocs supported (3 converted to staff)
- UNM: 6 students and 2 postdocs supported
- University of Wisconsin: 1 student and 1 postdoc supported



- Highly successful second workshop – March 6-8, 2013
  - Hosted by University College London and Institute of Physics, co-sponsored by Sandia, Lockheed-Martin, and D-Wave Systems
  - Over 70 participants – up from last year
    - 30 papers (5 from AQUARIUS)
  - Excellent international participation
  - Broad spectrum of research reported – theory, experiments, algorithms, tests of D-Wave machine
  - General community sense that “this workshop is timely and needed”
- AQC 2014 set for March, 2014
  - Hosted by Bob Lucas, USC Information Sciences Institute
  - Steering Committee Chair – Paul Warburton
  - Local Organizing Committee Chair – Daniel Lidar
  - Sandia will co-sponsor (along with Google, D-Wave Systems)

- Publications

- Publications since beginning:

- 10 papers (+20 in preparation)
    - 33 presentations
    - 11 posters
    - 9 seminars/lectures/other outreach talks

EAB: We encourage Sandia to maintain an ambitious publication strategy, and to present its results at major conferences such as the American Physical Society (APS) March meeting.

- Will continue to publish results in major conferences and journals

- More detail in technical presentations
    - AQC 2013 was excellent venue for disseminating results; will participate in AQC 2014

- New academic connections

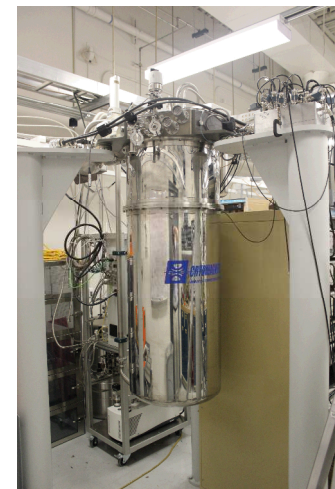


- Purdue University

- Now under contract following successful Summer 2012 internship
    - Examining application of QUBO to solving partial differential equations
    - Visiting researcher – Rishabh Chandra
    - Mentor – Toby Jacobson

- Grand Challenge LDRDs directed to develop IP strategies
  - IP protection issues are particularly critical given:
    - Changes in patent laws
    - Potential for AQUARIUS patents based on research results to date
- Developed strategy in close consultation with Sandia Legal
  - Held discussions with Legal throughout FY12
  - General principles:
    1. Obtain “defensive” patents as service to the Nation and scientific community
    2. Ensure USG doesn’t pay twice
    3. Publish or patent? Consider levels of protection each provide and weigh against principles 1 and 2
- Provisional patent filed (1/28/13): “Semiconductor Qubits for Adiabatic Quantum Annealing and Quantum Computing”

- Dilution refrigerator
  - Problems uncovered during installation
    - First temperature stage did not reach target of 70K – only achieved 84K
    - Limits 12T magnet current to low current or no current
    - Required installation of new first stage heat exchanger
  - Returned to Cryomagnetics for rework;
    - Temporary solution:
      - Minor rework of heat exchanger
      - Reinstalled at SNL in Dec 2012 with limited B-field range ( $\sim 3$ T)
    - Permanent solution:
      - Cryomagnetics proposes to design/build/install prototype 12T system (new heat exchange system); target date July 12
      - SNL views this as high risk - untested design & poor history
  - Fridge is operational now
  - Still having issues
    - Problems with the wiring inside the fridge
    - SNL team rewired DC feed through after finding problem (time lost troubleshooting)
  - Examining budget contingencies for final payment



- Objectives
  1. Continue technology development through sponsored and internally funded research
  2. Insert technologies into sponsored and internally funded projects
  3. Build upon the partnerships developed under AQUARIUS
- Gameplan
  - Get the word out – publications, AQC workshops, sponsor interactions are critical
  - Follow the leads – Perspectives' reports, BAAs, SNL-sponsor interactions
    - Growing interest in near-term, novel applications – particularly apparent at AQC 2013
    - Growing interest in STM
    - Following potential contacts with DARPA, AFOSR, others
  - Transfer technologies internally
- Potential areas of high interest
  - Quantum computing with neutral atoms – circuit model
  - Atomic precision fabrication (STM-based approach) for nano-scale devices
  - Universal AQC with STM-based devices

# *QUESTIONS?*

# EAB Charge (1)

## Overall Performance

Thinking back to the beginnings of AQUARIUS and the R&D accomplishments achieved over 2.5 years of the project's 3 year duration, please help us assess what we have achieved

- Strategy
  - What is your view of the execution of the AQUARIUS research strategy, strategic goals, focused research areas, awareness of external competition, and measures of success?
  - Have we addressed past EAB feedback?
- Relevance
  - Has the work provided benefit to the nation?
  - Which technical challenges addressed in AQUARIUS are relevant to the Quantum Information Science community?
- Quality
  - What is your view of the research quality? Is the research of high quality and at the leading edge?
- Workforce / Capabilities
  - How has the research enabled the attraction / retention / development of Sandia's technical staff, as well as the development of differentiating capabilities?
- Impact
  - What is AQUARIUS' likely long-term S&T legacy?
  - Has AQUARIUS effectively disseminated its results, deployed its developed technology, and protected / leveraged its intellectual property?

# EAB Charge (2)

## Technical:

- Are our key experiments and theoretical analyses in alignment to achieve our most important technical goals? What are we missing?
- In the remaining 5 months, what are the most important things we should focus on to maximize technical achievement and the overall future impact of AQUARIUS on the broader QIS community?

## Programmatic:

- We are developing our post-LDRD vision and exploring opportunities to continue this research in FY14 and beyond. Internal funding for AQUARIUS R&D stops at the end of FY13
  - For which AQUARIUS capabilities should we solicit continued external R&D funding?
  - What are the most important capabilities we have developed, and how should we best leverage them beyond AQUARIUS to maximize our opportunities for follow-on programs and/or impact to the QIS community?