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Report Title

Quantum Computing Graduate Fellowship

ABSTRACT

A variety of projects are carried out by 2 graduate students under the “Quantum Computing and Graduate Research Fellowship” program. The students are United States citizens, with undergraduate degrees from the California Institute of Technology. The grant complemented award DAAD19-01-1-0648, "Fundamental Studies of Quantum Information Processing with Neutral Atoms" and award W911NF-04-1-0242, "Entanglement and the Power of Quantum Computation".

List of papers submitted or published that acknowledge ARO support during this reporting period. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

1. A. Silberfarb and I. H. Deutsch, "Continuous measurement with traveling-wave probes," Physical Review A 68, 013817 (2003).

2. R. Stock, E. L. Bolda, and I. H. Deutsch, "Quantum state control via trap-induced shape resonance in ultracold atomic collisions," Physical Review Letters 91, 183201 (2003).

3. A. Silberfarb and I. H. Deutsch, "Entanglement generated between a single atom and a laser pulse," Physical Review A 69, 042308 (2004).

4. G. Smith, S. Chaudhury, P. S. Jessen, A. Silberfarb, and I. H. Deutsch, “Continuous Weak Measurement and Nonlinear Dynamics in a Cold Spin Ensemble”, to appear in Physical Review Letters (2004).

5. R. Stock, A. Silberfarb, I. H. Deutsch, and E. L. Bolda, “Generalized pseudo-potentials for higher partial wave scattering”, submitted to Physical Review Letters (2004).

6. T. E. Tessier, C. M. Caves, I. H. Deutsch, D. Bacon, and B. Eastin, "Optimal classical-communication-assisted local model of n-qubit Greenberger-Horne-Zeilinger correlations," Physical Review A 72, 032305 (2005).

7. A. Silberfarb, I. H. Deutsch, and P. S. Jessen, "Quantum-state reconstruction via continuous measurement", Physical Review Letters 95, 030402 (2005).

8. R. Stock, A. Silberfarb, I. H. Deutsch, and E. L. Bolda, "Generalized pseudo-potentials for higher partial wave scattering", Physical Review Letters 94, 023202 (2005).

Number of Papers published in peer-reviewed journals: 8.00

(b) Papers published in non-peer-reviewed journals or in conference proceedings (N/A for none)

Number of Papers published in non peer-reviewed journals: 0.00

(c) Papers presented at meetings, but not published in conference proceedings (N/A for none)

1. Bryan Eastin, Los Alamos Quantum Institute Workshop, 5/2005, "Symmetric Errors and Fault Tolerance",
2. Bryan Eastin, Center for Advandced Studies, UNM, 2005 Workshop, 5/2005, "Fault Tolerant Bounds".
3. Bryan Eastin, ARDA/NSA Quantum Computing Program Review, QuaCGR Talk, 8/2005, "Rules to be Broken".
4. Bryan Eastin, Los Alamos Quantum Lunch Seminar, 11/2005, "Threshold Bounds for Steane Protocols".
5. Andrew Silberfarb, APS DAMOP, 6/2003, "Continuous Measurement and Entanglement with Traveling wave probes"
6. Andrew Silberfarb, Optical Society of America, 10/2003, "Quantum State Reconstruction via Continuous Measurement".
7. Andrew Silberfarb, PRAQSYS Caltech Quantum Control Workshop, 8/2004, "Quantum State Reconstruction via Continuous Measurement".
8. Andrew Silberfarb, Los Alamos Quantum Lunch Seminar, 10/2004, "Quantum State Reconstruction via Continuous Measurement".
9. Andrew Silberfarb, SQuInT Annual Workshop, 10/2004, "Quantum State Reconstruction via Continuous Measurement".
10. Andrew Silberfarb, Caltech Institute for Quantum Information, 3/2005, "Quantum State Reconstruction via Continuous Measurement".
11. Andrew Silberfarb, APS DAMOP, 5/2005, "Quantum State Reconstruction via Continuous Measurement".

Number of Papers not Published: 11.00

(d) Manuscripts

1. J. Barrett, C. M. Caves, B. Eastin, M. B. Elliott, and S. Pironio, "Modelling Pauli measurements on arbitrary graph states via local hidden variables assisted by classical communication," in preparation.

2. B. Eastin, C. M. Caves, and I. H. Deutsch, "Threshold Bounds for Steane Protocols" in preparation.

3. A. Silberfarb, I. H, Deutsch, and P.S. Jessen, "Quantum measurement and dynamics of atomic spins in polarization spectroscopy", in preparation.

4. G. Smith, A. Silberfarb, I. H. Deutsch, and P. S. Jessen, "Non destructive quantum state reconstruction of alkali atom spins via continuous polarization spectroscopy", in preparation.

Number of Manuscripts: 4.00

Number of Inventions:

Graduate Students

Andrew Silberfarb, 50%
Bryan Eastin, 50%

Number of Graduate Students supported: 2.00

Total number of FTE graduate students: 1.00

Names of Post Doctorates

Number of Post Docs supported: 0.00

Total number of FTE Post Doctorates: 0.00

List of faculty supported by the grant that are National Academy Members

Names of Faculty Supported

Ivan H. Deutsch
Carlton M. Caves

Number of Faculty: 2.00

Names of Under Graduate students supported

Number of under graduate students: 0.00

Names of Personnel receiving masters degrees

Number of Masters Awarded: 0.00

Names of personnel receiving PHDs

Number of PHDs awarded: 0.00

Names of other research staff

Sub Contractors (DD882)

Inventions (DD882)

Scientific Accomplishments:

Two students, Andrew Silberfarb and Bryan Eastin, were supported by this QuaCGr fellowship, complementing two ARO grants: award DAAD19-01-1-0648, "Fundamental Studies of Quantum Information Processing with Neutral Atoms" and award W911NF-04-1-0242, "Entanglement and the Power of Quantum Computation". These students have published 8 refereed articles in high ranking journals, have 4 more in preparation, and have delivered 11 invited talks on their work. Andrew should defend his thesis and obtain his PhD in February 2006. Bryan should complete his studies before August 2006.

Andrew performed studies of quantum control, back-action and errors, and quantum state reconstruction. His first accomplishment was to analyze the measurement strength associated with a coherent laser beam interacting with a two-level atom. The measurement strength determined the rate of decoherence (and thus errors in a quantum logic operation) due to the laser mode. The physical origin of the measurement is spontaneous emission by the atom into the paraxial modes that define the beam. While a small fraction of the total spontaneous emission, those of photons emitted into the beam mode are correlated with the state of the atom. Thus, the atom and laser become entangled,. This sets a benchmark for entanglement generation of atoms and photons in free space to which other geometries (e.g. cavity QED) can be compared. The entanglement generation, calculated with our full traveling wave multi-mode formalism, was compared to simplifying models used in previously analyses, showing surprise agreement. This was explained by a deeper understanding of the nature of multipartite entanglement. Using the basic formalism he developed, Andrew turned his attention to the use of continuous measurement of atomic ensembles for real-time quantum state reconstruction. This is his most significant work. Andrew developed a complete new paradigm whereby weak, but continuous, observation of an ensemble can be used to create a measurement history that can be inverted to yield the initial quantum state. In principle this can be accomplished with negligible quantum backaction on the members of the ensemble, and in real-time. Such a protocol is a new tool for quantum feedback control. Andrew has not only worked on the theoretical foundation, but work closely with our experimental collaborators to perform data analysis. We hope to publish the experimental findings in the near future. In addition to his main project, Andrew was a key collaborator in other projects support under the ARO grants. Specifically, he helped to develop the pseudopotential model for ultracold collisions which was a key component of the protocol for quantum logic with neutral atoms in optical traps.

Bryan Eastin's work has focused on error correction. First, he explored fault-tolerant thresholds for particular error models that might arise in a physical implementation. The model for which he has explicit results is one where all errors are assumed to be associated with two-qubit gates, specifically XX, YY, or ZZ errors, and these two-qubit errors occur with equal probability. For this model, he is able to show that the fault-tolerant threshold is about a factor of 10 better than for an error model based on the depolarizing channel. Second, he has developed a general method for calculating upper bounds on the error threshold for the most widely used class of fault-tolerant protocols applied to essentially arbitrary error models. This work was motivated by his first effort, which for the examples investigated, showed that almost all of the improvement in error threshold was due to the restricted error model and not to matching the fault-tolerant protocol to the error model, thus suggesting that the threshold is largely a function of the error model and not of the fault-tolerant protocol. Third, he has worked with graduate student Steve Flammia to explore quantum error-correcting codes based on so-called low-density parity-check classical codes. The goal is to find codes that have good rate and good distance, while at the same time having syndrome detection circuits that are both highly parallelizable and have efficient syndrome decodings. It is not yet clear whether this work will lead to codes with the desired properties or to a series of proofs that they do not exist.